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BAMS

Bulletin of the American Meteorological Society

YEAR OF TROPICAL CONVECTION

CONVEYING HURRICANE RISK

AFRICAN PRECIPITATION DATASET

VORTEX2

THE HUNT FOR
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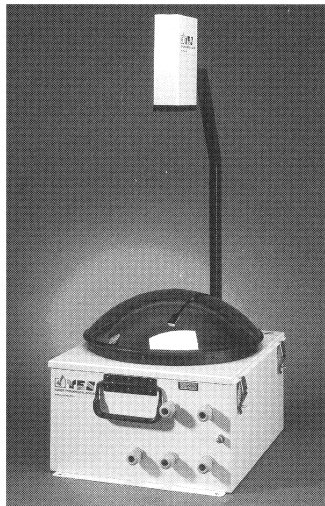
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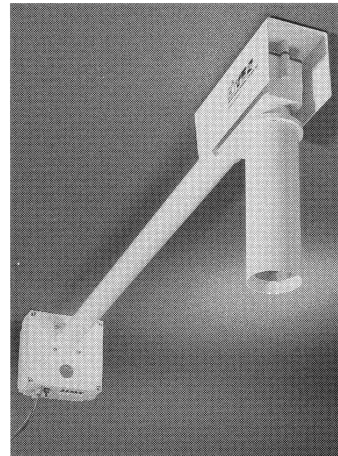
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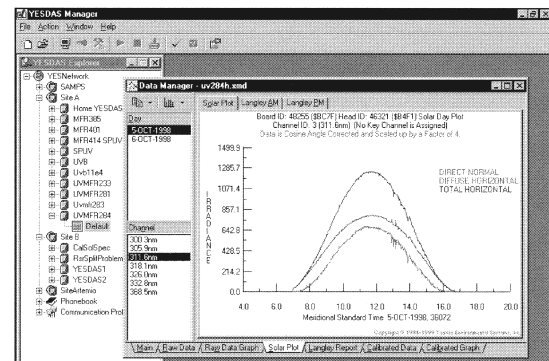
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ON THE COVER

Lindsay Bennett and Tim Marshall deploy a Tornado Pod in Goshen County, Wyoming, on 5 June 2009. The pod, one of 12 deployed ahead of this tornado by the Center for Severe Weather Research, weighs about 50 kg, holds blade and ultrasonic anemometers, a temperature/humidity sensor inside a radiation shield, and video cameras, as well as a data logger inside a steel waterproof box. For more on VORTEX2, see Wurman et al., page 1147. (PHOTO: Ryan McGinniss)

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The *Bulletin of the American Meteorological Society* is the official organ of the Society, devoted to editorials, articles of interest to a large segment of the membership, professional and membership news, announcements, and Society activities. Editing and publishing are under the direction of Keith L. Seitter, executive director. Contributors are encouraged to send proposals to be considered for publication. For guidance on preparation and style, see the Authors' Resource Center online at www.ametsoc.org/pubs/arcindex.html.

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LETTER FROM THE EDITOR: THE BEST LAID PLANS

How do you surround a dangerous, moving target that you can't always see at first? Very carefully.

In VORTEX2, the goal was to find rotation in its infancy and follow it as it grew—all the way to a full-blown tornado, if possible. Some 50 vehicles carried diverse meteorological instruments for quick deployment (and redeployment!) at strategic spots near enough to good roads and far enough from each other to set up temporary, nested storm- and meso-scale observing networks. The various radars needed to be positioned at proper distances, without obstacles, to penetrate the anticipated rotation aloft at appropriate altitude and resolution. In addition, because of the time required for setup and transport, they needed to be spaced properly ahead of the storm track so that the rotation could be continuously monitored for more than an hour.

Planning, however, does not mean rigidity. In essence, as Wurman et al. (p. 1147) put it, VORTEX2 was a nomadic meteorological network, wandering afresh each day in search of scientific payoff somewhere over a million-square-kilometer domain. If the logistical problem of taking observations wasn't trial enough, try orchestrating pit stops, meals, and overnight accommodations for 100 participants in the one-light towns that dot the Plains.

The key to success in field programs is to plan, plan, plan—and then to know when to improvise. It was even more true for a program like VORTEX2, in which the observing network follows the weather. Project leaders strategized to the hilt, but they also knew to decentralize ultimate deployment decision-making, assigning this responsibility to a set of field coordinators who could respond to immediate hazards and opportunities on the road.

If a few weeks of multiscale, regional observational study seems formidable, then extend the logistical challenge from microphysics to mesoscale organization to global dynamics, over the course of two years. It's no wonder the Year of Tropical Convection described by Moncrieff et al. and Waliser et al. (pp. 1171 and 1189) created a *virtual* field campaign to get necessary results. Real observing—from space and on location—is involved of course; project leaders take advantage of existing resources. But the “backbone” of the global study of sub-model grid processes is a high-resolution modeling database amassed for a single scientific purpose. Virtual or not, it took tremendous foresight and coordination to create this fertile basis for breaking the deadlock in researching, modeling, and predicting tropical convection. Furthermore, YOTC not only addresses current research questions but also anticipated needs of next-generation climate modeling.

Indeed, YOTC is a collaborative product of the same critical sense of timing and foresight—yes, the ability to plan!—that drove VORTEX2 across the Plains. The only difference is scale. On an even longer time-scale, the timing and foresight of nineteenth-century pioneers enabled Nicholson et al. (p. 1219) to construct a two-century precipitation database for all of Africa. It is an inspiring reminder that data today could have unimaginable benefits in the future. In fact, you can almost plan on it.

—Jeff Rosenfeld, EDITOR-IN-CHIEF

CREATION AND COMMUNICATION OF HURRICANE RISK INFORMATION

Reducing loss of life and harm when a hurricane threatens depends on people receiving hurricane risk information that they can interpret and use in protective decisions. To understand and improve hurricane risk communication, this article examines how National Weather Service (NWS) forecasters at the National Hurricane Center and local weather forecast offices, local emergency managers, and local television and radio media create and convey hurricane risk information. Data from in-depth interviews and observational sessions with members of these groups from Greater Miami were analyzed to examine their roles, goals, and interactions, and to identify strengths and challenges in how they communicate with each other and with the public. Together, these groups succeed in partnering with each other to make information about approaching hurricane threats widely available. Yet NWS forecasters sometimes find that the information they provide is not used as they intended; media personnel want streamlined information from NWS and emergency managers that emphasizes the timing of hazards and the recommended response and protective actions; and emergency managers need forecast uncertainty information that can help them plan for different scenarios. Thus, we recommend that warning system partners 1) build understanding of each other's needs and constraints; 2) ensure formalized, yet flexible mechanisms exist for exchanging critical information; 3) improve hurricane risk communication by integrating social science

knowledge to design and test messages with intended audiences; and 4) evaluate, test, and improve the NWS hurricane-related product suite in collaboration with social scientists. (Page 1133)

THE SECOND VERIFICATION OF THE ORIGINS OF ROTATION IN TORNADOES EXPERIMENT: VORTEX2

The second Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2), which had its field phases in May and June of 2009 and 2010, was designed to explore i) the physical processes of tornadogenesis, maintenance, and demise; ii) the relationships among tornadoes, tornadic storms, and the larger-scale environment; iii) numerical weather prediction and forecasting of supercell thunderstorms and tornadoes; and iv) the wind field near the ground in tornadoes. VORTEX2 is by far the largest and most ambitious observational and modeling study of tornadoes and tornadic storms ever undertaken. It employed 13 mobile mesonet-instrumented vehicles, 11 ground-based mobile radars (several of which had dual-polarization capability and two of which were phased-array rapid scan), a mobile Doppler lidar, four mobile balloon sounding systems, 42 deployable in situ observational weather stations, an unmanned aerial system, video and photogrammetric teams, damage survey teams, deployable disdrometers, and other experimental instrumentation as well as extensive modeling studies of tornadic storms. Participants were drawn from more than 15 universities and laboratories and at least five nations, with over 80 students participating in field activities. The VORTEX2 field phases spanned 2 yr in order to increase the prob-

ability of intercepting significant tornadoes, which are rare events. The field phase of VORTEX2 collected data in over three dozen tornadic and nontornadic supercell thunderstorms with unprecedented detail and diversity of measurements. Some preliminary data and analyses from the ongoing analysis phase of VORTEX2 are shown. (Page 1147)

MULTISCALE CONVECTIVE ORGANIZATION AND THE YOTC VIRTUAL GLOBAL FIELD CAMPAIGN

The Year of Tropical Convection (YOTC) project recognizes that major improvements are needed in how the tropics are represented in climate models. Tropical convection is organized into multiscale precipitation systems with an underlying chaotic order. These organized systems act as building blocks for meteorological events at the intersection of weather and climate (time scales up to seasonal). These events affect a large percentage of the world's population. Much of the uncertainty associated with weather and climate derives from incomplete understanding of how meteorological systems on the mesoscale (~1–100 km), synoptic scale (~1,000 km), and planetary scale (~10,000 km) interact with each other. This uncertainty complicates attempts to predict high-impact phenomena associated with the tropical atmosphere, such as tropical cyclones, the Madden-Julian oscillation, convectively coupled tropical waves, and the monsoons. These and other phenomena influence the extratropics by migrating out of the tropics and by the remote effects of planetary waves, including those generated by the MJO. The diurnal and seasonal cycles

modulate all of the above. It will be impossible to accurately predict climate on regional scales or to comprehend the variability of the global water cycle in a warmer world without comprehensively addressing tropical convection and its interactions across space and time scales. (Page 1171)

THE “YEAR” OF TROPICAL CONVECTION (MAY 2008–APRIL 2010): CLIMATE VARIABILITY AND WEATHER HIGHLIGHTS

The representation of tropical convection remains a serious challenge to the skillfulness of our weather and climate prediction systems. To address this challenge, the World Climate Research Programme (WCRP) and The Observing System Research and Predictability Experiment (THORPEX) of the World Weather Research Programme (WWRP) are conducting a joint research activity consisting of a focus period approach

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ABSTRACTS

along with an integrated research framework tailored to exploit the vast amounts of existing observations, expanding computational resources, and the development of new, high-resolution modeling frameworks. The objective of the Year of Tropical Convection (YOTC) is to use these constructs to advance the characterization, modeling, parameterization, and prediction of multiscale tropical convection, including relevant two-way interactions between tropical and extratropical systems. This article highlights the diverse array of scientifically interesting and socially important weather and climate events associated with the WCRP-WWRP/THORPEX YOTC period of interest: May 2008–April 2010. Notable during this 2-yr period was the change from cool to warm El Niño–

Southern Oscillation (ENSO) states and the associated modulation of a wide range of smaller time- and space-scale tropical convection features. This period included a near-record-setting wet North American monsoon in 2008 and a very severe monsoon drought in India in 2009. There was also a plethora of tropical wave activity, including easterly waves, the Madden–Julian oscillation, and convectively coupled equatorial wave interactions. Numerous cases of high-impact rainfall events occurred along with notable features in the tropical cyclone record. The intent of this article is to highlight these features and phenomena, and in turn promote their interrogation via theory, observations, and models in concert with the YOTC program so that improved understanding and pre-

dictions of tropical convection can be afforded. (Page 1189)

A TWO-CENTURY PRECIPITATION DATASET FOR THE CONTINENT OF AFRICA

A wealth of historical information on climate and weather exists for the African continent. Documentary information, hydrologic indicators, and rain gauge records have been compiled and combined into a semiquantitative precipitation dataset that extends from 1801 to 1900. That dataset describes “wetness” for 90 regions of Africa, using a seven-category index. A regional gauge dataset for 1901–2000 has been converted to the seven-class system, extending coverage to two centuries. These datasets are available through the Paleoclimate Data Center. (Page 1219)

NEW FROM AMS BOOKS!

“Professor Lackmann has prepared an excellent synthesis of quintessential modern midlatitude synoptic-dynamic meteorology.”

—LANCE BOSART, *Distinguished Professor, Department of Atmospheric and Environmental Sciences, The University of Albany, State University of New York*

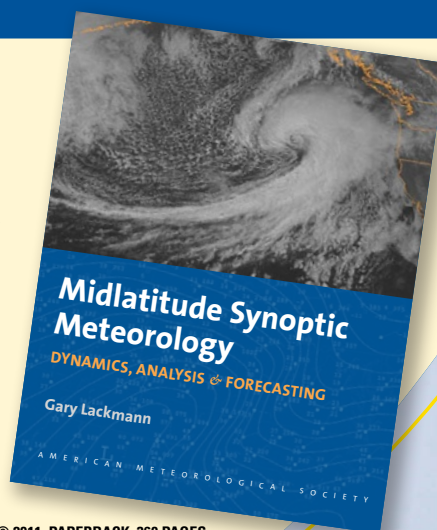
Midlatitude Synoptic Meteorology: *Dynamics, Analysis, and Forecasting*

GARY LACKMANN

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NEWS AND NOTES

COMMERCIAL SHIPS COULD AID IN TSUNAMI WARNINGS

When the 2010 Chilean earthquake occurred, it generated a tsunami wave that a geodetic GPS system on a University of Hawaii–Manoa (UHM) vessel detected on the open ocean. Although the wave was small—only about four inches high—what the researchers discovered was big. The data detecting changes in sea surface height almost matched that of NOAA’s Pacific Tsunami Warning Center.

Given that tsunamis have small amplitudes in deep water, this came as a surprise to the scientists, led by James Foster, assistant researcher at the UHM School of Ocean and Earth Science and Technology. It also gave them the idea of using commercial ships to help collect data. “If we could equip some fraction of the shipping fleet with high-accuracy GPS and satellite communications, we could construct a dense, low-cost tsunami sensing network that would improve our detection and predictions of tsunamis—saving lives and money,” Foster comments.

Currently, details about earthquake-generated tsunamis are provided by NOAA’s Deep-Ocean Assessment and Reporting of Tsunami (DART) systems, which consist of tide gauges and deep ocean pressure sensors. The data are needed to accurately predict how big the tsunami will be for specific locations. However, DART

systems are expensive and difficult to maintain, and in the case of the 2010 Chilean earthquake the sensor closest to Hawaii was out of order.

Shipping lines crisscross the Pacific basin and provide coverage globally around tsunamigenic regions. Foster and his colleagues plan to deploy a demonstration system that will stream GPS data from one or two ships, generating accurate real-time heights. He

‘RAPID REFRESH’ OF NEAR-TERM FORECASTS

In May, NOAA began using an updated, short-term weather forecast computer model to improve predictions of quickly developing severe weather. Rapid Refresh (RAP) is a replacement model of the Rapid Update Cycle (RUC) that, according to its users, has proved more skillful. “Overall, RAP provides equal or better forecasts than its predecessor for all variables, from winds to precipitation,” comments Stan Benjamin, lead developer of the new model and a research meteorologist at the Earth System Research Laboratory.

The model updates every hour, with a new forecast extending out 18 hours for North America. The developers point out that these forecasts are particularly important in aviation, where fast-developing weather conditions can affect safety and efficiency. One of the key upgrades of the model is the extended geographical coverage of NOAA’s weather situational awareness information to include

added that the same processing system will concurrently determine precipitable water over the ocean, identified by the delay in the GPS signal through Earth’s atmosphere, which meteorologists can use to improve weather model forecasts.

The research was published in a May issue of *Geophysical Research Letters*. (SOURCE: Hawaii Institute of Geophysics and Planetology)

all of North America. The addition of Alaska is particularly relevant when it comes to aviation. “The majority of Alaska is not connected to a road network, so the only means of transportation to many locations is by air,” says Gene Petrescu, science and technology transfer meteorologist at the NWS in Anchorage, Alaska. “We are hearing from our forecast offices that they see value in these hourly forecasts.”

The model is proving to be equally important for severe weather and energy-related forecasting. It is based on the Weather Research and Forecasting model, a significantly more advanced numerical weather prediction model than RUC. It also uses an innovative technique for assimilating current observations used to initialize the forecast model.

The new model was tested extensively, running experimentally for 22 months at NCEP before being put to use. (SOURCE: NOAA)

CORALS GET COOL RELIEF IN EQUATORIAL PACIFIC

Rising ocean temperatures are a primary cause of coral bleaching, which occurs when coral ecosystems lose the nutrient-providing protozoa that give coral their color. With some global climate models predicting an increase in sea surface temperatures of almost 3°C in the central tropical Pacific Ocean by the end of the century, many coral reefs could be damaged or destroyed. But according to new research published in *Nature Climate Change*, an ocean current that runs right along the Equator could curtail the warming of the water and help to preserve the threatened corals in that region.

Scientists studying satellite maps of the equatorial Pacific

noticed higher levels of ocean chlorophyll near the Equator—specifically, around the Gilbert Islands, a chain of atolls and coral islands northeast of Australia that

are a part of the nation of Kiribati. The maps also showed that sea surface temperatures off the western coasts of the islands were cooler than in nearby waters.

ROYAL'S FORECAST REIGNS

In May, news viewers in Scotland got a royal spin on their weather report. Prince Charles—who has expressed an interest in climate change and environmental issues—took over the forecast on a visit to mark the 60th anniversary of the BBC. He was introduced live on air by lunchtime news presenter Sally Magnusson with the words, “Over to you, Your Royal Highness.” While the forecast itself was dour—rain, rain, and more rain—the prince was relaxed and even a bit feisty. Reading a bulletin that included special references to royal residences in Scotland, he exclaimed: “There’s potential for a few flurries over Balmoral—who the hell wrote this script?!—as the afternoon goes on.” It wasn’t the prince’s first venture into weather-related broadcasting. He is the narrator of *Harmony*, a documentary about climate change, which held its worldwide premiere in London in April. (SOURCE: The Associated Press)

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“I’ve been studying the tropical Pacific Ocean for most of my career, and I had never noticed that,” says study coauthor Kristopher Karnauskas of the Woods Hole Oceanographic Institution (WHOI). “It jumped out at me immediately, and I thought, ‘there’s probably a story there.’”

In an attempt to understand the observations, Karnauskas and coauthor Anne Cohen of WHOI combined high-resolution satellite measurements, an ensemble of global climate models, and an eddy-resolving regional ocean circulation model to study the areas around the islands. Their results showed that the rate of warming of the water around the islands will be reduced by about 0.7°C per century, which “may allow corals and their symbiotic algae a better chance to adapt and survive,” according to Karnauskas.

The cooling of the water in the area stems from a negative climate feedback on the Equatorial Undercurrent (EUC), a fast-moving flow of cool water that travels eastward—counter to surface currents pushed by equatorial trade winds—about 100–200 meters below the ocean’s surface. When the EUC runs into land, it pushes the cooler water and nutrients up to the surface, creating small areas of favorable conditions for plants and corals. According to the researchers, rising air temperatures that weaken the trade winds will lead to a weaker Pacific surface current, which in turn will reduce the friction and drag on the EUC. As a result, they determined that the EUC will get stronger—by about 14%—and upwelling around the western edges of the islands will increase by about 50%, subsequently cooling the waters in those areas.

“These little islands in the middle of the ocean can counteract global trends and have a big effect on their own future,” Karnauskas says, “which I think is a beautiful concept.” (SOURCE: National Science Foundation)

WHAT LIGHTNING CAN TELL US ABOUT PLANETARY ATMOSPHERES

Lightning discharges in Earth’s atmosphere give off electromagnetic pulses that collectively resonate around the globe as extremely low-frequency (ELF) waves. Known as Schumann resonances—named after physicist Winfried Otto Schumann, who mathematically predicted them in 1952—these

this finding could lead to a better understanding of the atmospheric dynamics of other planets.

Venus, Mars, Jupiter, and Saturn also have conditions conducive to the electrical activity needed to excite and maintain Schumann resonances; but the frequency of the waves is related to the size of the planet as well as the makeup of atoms and molecules in its atmosphere. As a result, certain chemical elements and compounds known as “volatiles”—such as water, methane, and ammonia—that played an important role in the formation and growth of our solar system can be measured in planetary atmospheres by remotely monitoring the frequency of Schumann resonances

ECHOES

““ I’m glad we had storm chasers. We need storm chasers. We don’t need 200 of them.”

—Woodward County, Oklahoma, Sheriff GARY STANLEY on the good and bad rise in the number of people chasing tornadoes. He credits a storm chaser from an Oklahoma City TV station with spotting a tornado after dark in mid-April and warning Woodward before the twister hit. It killed six people that early Sunday, but Stanley says the chaser likely saved lives.

Chasers converged on tornadic storms the day before in Kansas and Oklahoma, causing fender-bender accidents and miles-long traffic jams. Emergency officials say the influx of so many chasers is beginning to cause real problems. They not only get in each other’s way, they clog roads, the officials complain, slowing emergency vehicles and sometimes keeping them from getting through. Sheriff Glen Kochanowski of Saline County, Kansas, described the surge of chasers that weekend as “a million-and-one gawkers. Just citizens trying to get that one shot that is going to get them their five minutes of fame.” (SOURCE: *The Wall Street Journal*)

resonating waves travel in the cavity between Earth’s surface and the inner edge of the ionosphere, about 55 kilometers up in the atmosphere. In the past, Schumann resonances in Earth’s atmosphere were only studied from land, but last year they were also detected by NASA’s Vector Electric Field Instrument on board a U.S. Air Force satellite. A new study suggests that

around a particular planet. Such information can provide valuable evidence on how that planet formed. Additionally, more accurate data on the composition of our planets’ atmospheres could help scientists understand why certain planets have more volatiles than others—information that could provide insight into the formation and evolution of our solar system.

"[I]f we can get a better sense of the abundance of these kinds of atoms in the outer planets, we would know more about the abundance in the original nebula from which the solar system evolved," explains Fernando Simoes of NASA's Goddard Space Flight

Center, lead author of a recent paper on the topic published in *The Astrophysical Journal*.

Satellite detection of a planet's resonance would require close observation, from several hundred miles above the surface. But, because the Schumann resonances

occur throughout a planet's atmosphere, the new technique would provide more complete data than current methods of measuring the composition of planetary atmospheres that are only able to focus on specific areas. (SOURCE: NASA/Goddard Space Flight Center)

GATHERING NEWS

PANEL DISCUSSION: OBSERVATIONS AND MODELING OF LANDFALLING TROPICAL CYCLONES

With significant progress being made in observing and modeling landfalling tropical cyclones (TCs), new insights are emerging. Advances in data-assimilation technology and numerical models have improved TC forecasts before, during, and after landfall. These developments were discussed during a panel discussion at the Tenth Symposium on the Coastal Environment, held in conjunction with the 92nd Annual Meeting of the AMS in January 2012. The

goals of the panel discussion were to promote discussion of the new way the complicated processes involved with TC landfall (e.g., high winds, heavy precipitation, storm surge, flooding, and even tornadoes) are understood and to develop new strategies for designing the next generation prediction system for landfalling TCs.

The panel members were Peter Black, Science Applications International Corporation (SAIC); Mark DeMaria, NOAA National Environmental Satellite, Data, and Information Service (NESDIS); Frank Marks, NOAA Hurricane Research Division (HRD); Melinda

Peng, Naval Research Laboratory; Mark Powell, NOAA HRD; and Fuqing Zhang, Pennsylvania State University. Each of the panelists made a short presentation, followed by questions from the audience. The panelist's presentations can be broadly grouped into three categories: 1) societal impacts; 2) observational assets and initialization; and 3) targeted observations and predictability. They can be viewed online at <http://ams.confex.com/ams/92Annual/webprogram/Session29746.html>.

Accurate predictions of winds and precipitation in and around landfalling TCs are of vital importance for hurricane preparation and damage mitigation; yet they remain a challenge for hurricane research and NWP communities. Marks and several other panel members were coauthors of a publication appearing in *BAMS* in 1998 that discussed the state-of-the-science regarding landfalling TCs at that time. Now, 15 years later, it seemed appropriate to re-examine some of the issues raised by that report, especially in the context of NOAA's recently announced "Weather-Ready Nation" initiative. The panel discussion was organized to this end. For example, the forecast performance of Hurricane Irene (2011) was discussed to highlight the progress made in TC prediction

ECHOES

“It's like a game with loaded dice. A six can appear every now and then, and you never know when it happens. But now it appears much more often, because we have changed the dice.”

—DIM COUMOU, a scientist at the Potsdam Institute for Climate Impact Research (PIK) in Germany, on a new study he led that establishes a connection between human-caused climate change and some extreme weather events. The study combined elementary physics, statistical analysis, and computer simulations to verify a link between recent increases in global temperatures and extreme rainfall and heat-wave events that occurred since 2000. The research notes that there has been three times the number of record hot months observed at different points around the globe as there would have been in a climate that was not changing. "The question is whether these weather extremes are coincidental or a result of climate change," says Coumou. "Global warming can generally not be proven to cause individual extreme events—but in the sum of events the link to climate change becomes clear. It is not a question of yes or no, but a question of probabilities." The research was recently published in *Nature Climate Change*. (SOURCE: Potsdam Institute for Climate Impact Research)

and also to illustrate the challenges still facing the research and operational community.

As Irene approached the U.S. East Coast, important questions regarding which path northward Irene would take, how strong it would be at landfall, and at what time it would make landfall had far-reaching implications for civil and military preparedness. The official track forecast captured the general path of the storm, especially during the time leading up to and during Irene's landfall (24–28 August),

with the National Hurricane Center reporting mean track errors considerably lower than the previous 5-year average through 96 hours. Observations made by the NOAA G-IV jet aircraft surveillance missions on 23 August benefited the operational model track forecasts. These data were assimilated into the operational forecast models. During the same period, however, the official intensity forecast errors exceeded the previous 5-year average with a high bias persisting for more than four days, from 24

to 29 August. The forecast storm intensity at times was two categories higher than what was observed, which indicates that TC intensity prediction remains a challenging issue. It should also be noted that the track forecast errors were quite large during the early stage of Irene's life, especially before 24 August. Further improvement in track forecasts is thus required.

—WILLIAM T. THOMPSON
AND YI JIN
*Naval Research Laboratory,
Monterey, California*

TECHNOLOGY

FLOOD INUNDATION SOFTWARE GETS FASTER

The Department of Homeland Security's Science and Technology Directorate has developed new computer software that models flood inundation. Aimed at dam and levee owners and emergency planners, the software tool provides something that is critical in the event of a flood: speed.

In modeling floods, specialists calculate how water will move around physical objects using complex equations that can take a lot of time and resources. With the new software, a flood that would take 24 hours to inundate downstream areas can be modeled by the software tool in less than 24 minutes.

The developers explain that a key component is the Decision Support System for Water Infrastructural Security (DSS-WISE) with its underlying flood simulator, CCHE2D-FLOOD, which provides the speed. The DSS-WISE first prioritizes the affected regions then processes the model's framework, or "skeleton," applying the "skin" afterward. The next step is dividing

the flood-path model into tens of millions of geometric cells, using parallel processing to parcel them out to separate processors.

The other part of the software is the Dams Sector Analysis Tool (DSAT). This web-based tool provides algorithms for dam owners and operators to identify and prior-

itize the most critical dams. DSAT also uses a geospatial viewer that provides query capabilities as well as access to real-time information such as weather and earthquakes.

The DSS-Wise module was launched in February and by March was delivering results to dam owners, safety officials, and



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ECHOES

“ **Severe heat is the big hammer.**”

—NOAH DIFFENBAUGH, assistant professor of environmental Earth system science at Stanford's School of Earth Sciences, on the effect of rising global temperatures on corn crops. Researchers from Stanford and Purdue found that higher temperatures outweighed both changing oil prices and government energy policies on corn-price volatility. The researchers were surprised that climate had the largest effect of these three influences on spikes in the price of corn. (SOURCE: *Nature Climate Change*)

emergency managers in seven states. The developers hope that the combined science and technology involved on a local level can have a national impact in the response time to floods. (SOURCE: Newswise)

CONNECTING ICE MELT TO SEA LEVELS

The contribution of rapidly melting ice sheets to the rise of global sea levels has largely been ignored in scientific studies, which tend to measure average sea level changes on a global scale. But a new study published in the *Proceedings of the National Academy of Sciences* is utilizing unique statistical and data analysis techniques to better understand how much these individual ice sheets contribute to rising sea levels. The method may help distinguish ice-melt contributions to sea level changes from other possible influences, such

as tides, waves, and variations in ocean circulation.

Every melting ice sheet has its own distinct influence on sea levels, which is known as its sea level fingerprint. In the new research, scientists outlined a mathematical formulation utilizing both a Kalman smoother and a Kalman filter on tide gauge observations to estimate individual sources of global sea level change. The researchers contend that the Kalman smoother naturally accommodates measurements with data gaps, such as those inherent in tide gauge records from the nineteenth and twentieth centuries. Using the smoother, they were able to overlook any issues with data continuity, which enabled them to work with a larger selection of observations to determine the most likely maximum contribution to sea level rise from the melting Greenland

and West Antarctic ice sheets. It also allowed for the estimation of nonlinear trends. Additionally, the scientists used the Kalman filter and dozens of glacial-rebound models to separate the melting signal from the other contributors to sea level change.

The researchers tested their method using synthetic datasets—which have the same amount of noise as real data, but with known melting signals—and the success of those tests led to using the method on actual data.

“We are now applying our methodology to historical sea level records to provide a new estimate of total sea level rise and the melt rates of the Greenland and West Antarctic ice sheets over the twentieth century,” says the lead author of the study, Carling Hay of the University of Toronto.

According to Hay, preliminary findings suggest an acceleration of globally averaged sea level rise in the second half of the twentieth century that corresponds with increasing global air temperatures. After completing the analysis of the historical records, the researchers plan to apply their unique method to satellite-based measurements of sea level changes. (SOURCE: University of Toronto)

PRODUCTS

METPAK COMPACT WEATHER STATION

The MetPak Pro is a compact, lightweight, multisensor weather station that measures wind speed and direction, relative humidity (RH), air temperature, barometric pressure, and dew point. The integral sonic anemometer by MetPak's maker, Gill Instruments, requires no maintenance

or calibration and is good for wind speeds up to 134 mph, but is especially good for very slow wind movement (as low as 0.02 mph). The RH and temperature sensors are industry standard and housed in a radiation shield. The MetPak has a serial data output and can be easily connected to most data loggers to create a complete research-grade weather station.

The MetPak Pro is similar to the original MetPak weather station but includes a junction box for adding other sensors, such as a pyranometer for measuring sunlight, a rain gauge, or soil moisture sensor. The system also has MODBUS output options available.

The station was used at the British Open golf tournament last year and will be used again

this year. Real-time wind speeds and weather data from several locations around the course were displayed and made available to

golfers and viewers alike. Met-View software is included with the MetPak Pro for graphical display of all the weather pa-

rameters as well as for recording the data.

For more information, see www.gill.co.uk.

PAPERS OF NOTE

DEPENDENCE OF SNOW GAUGE COLLECTION EFFICIENCY ON SNOWFLAKE CHARACTERISTICS

Large uncertainties are often observed in precipitation measurements especially for solid precipitation. An accurate measure of snowfall amount is critical because it is directly linked to a better understanding of the global water cycle. Discrepancies in snowfall measurement may lead to uncertainties in the analysis of climate variability and the verification of climate models. Over a shorter time scale, the amount of snow falling on the ground has an impact on surface and air transportation. It has been recognized that systematic errors in snowfall measurements are often observed due to gauge geometry and weather conditions. Previous studies have shown that the higher the wind speed, the lower the precipitation rate recorded by the gauge, due to snowflakes blowing over or around the gauge—making wind the most important contributor to the uncertainties. Measuring snowfall amount is also complicated because it is common to observe many different types of snowflakes simultaneously. Given the importance of accurately measuring snowfall amount, we investigated the effect of snowflake characteristics on gauge collection efficiency. Our goal was to better understand the scatter in the collection efficiency of a Geonor precipitation gauge surrounded by a single Alter wind

shield for a variety of snowflakes falling in a given wind speed. This gauge–shield configuration was chosen because it is the most commonly used.

To address the issue, we conducted numerical simulations and field observations at the NCAR testbed in Boulder, Colorado. First, we employed a theoretical study using finite element modeling to simulate the flow around the gauge. We used a Lagrangian model to investigate snowflake trajectories and the derived flow field to compute theoretical collection efficiency for different types of snowflakes. Secondly, we made field observations to determine how different types, shapes, and sizes of snowflakes collect inside a Geonor gauge.

Our results show that the types of snowflakes as well as their size distribution influence the gauge collection efficiency. Different types of snowflakes, which fall at different terminal velocities, interact differently with the airflow around the gauge. Fast-falling snowflakes are associated with a higher gauge collection efficiency than slow-falling ones. The correction factor used to adjust the data for the wind-speed in-

fluence is improved by adding a parameter for each type of snowflake. Further studies should be conducted to correlate measured terminal velocity and gauge collection efficiency, however. Also, the impact of turbulence should be studied in greater detail.

Overall, the results show that an accurate measure of snow depends on the wind speed as well as the type of snowflakes observed during a snowstorm. It shows the strong impact of crystal types on the gauge collection efficiency and helps explain the large scatter in the data. These key findings could have an impact on, for instance, long-term snowfall measurements. In particular, warm regions experiencing wet snow could receive more

ECHOES

“**Hunting a tornado can feel like swimming with a shark in dark waters. You know it's there. You just can't find it.**”

—BILL PAXTON, narrator of the film, *Tornado Alley*, playing in IMAX theaters through September. In the film, Paxton—a lead in the movie, *Twister*, and real-life severe weather enthusiast—notes the difficulty of collecting tornado data. While the main focus of *Tornado Alley* is on the tornadoes themselves, the secondary storyline is the work of VORTEX 2. The final scene involves Sean Casey, the cameraman and creator of the Tornado Intercept Vehicle (TIV), finally succeeding in his quest to drive into a tornado, capturing the intercept on film. This same tornado, which roared through Goshen County, Wyoming, on June 5, 2009, also provided the most data ever on a tornado's complete life cycle for VORTEX 2. (SOURCE: Capital Weather Gang)

snow than cold regions as a result of higher collection efficiency of wet snow compared to dry snow. Finally, this study has improved our understanding of the factors re-

sponsible for the difficulty in measuring snow.—JULIE M. THÉRIAULT (CURRENT AFFILIATION: UNIVERSITÉ DU QUÉBEC À MONTRÉAL), R. RASMUSSEN, K. IKEDA, AND

S. LANDOLT. “Dependence of Snow Gauge Collection Efficiency on Snowflake Characteristics,” in the April Journal of Applied Meteorology and Climatology.

CONFERENCE NOTEBOOK

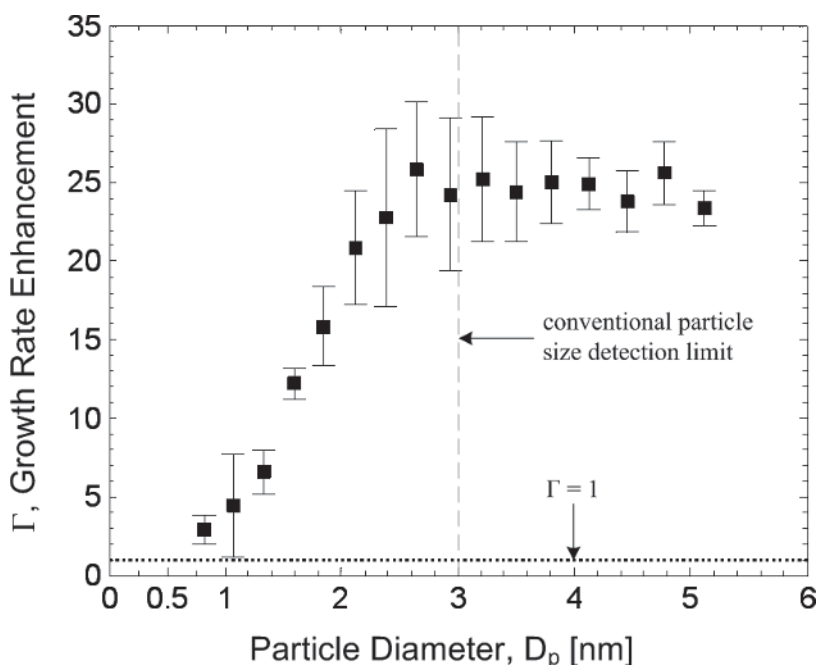
FIRST GROWTH RATE MEASUREMENTS TAKEN OF ATMOSPHERIC NUCLEI AS SMALL AS 1 NM

Atmospheric particles influence climate and climate change on local to global scales by affecting the atmospheric radiation balance, both directly through scattering and absorbing incoming solar radiation and indirectly as cloud condensation nuclei (CCN). New particle formation (NPF) occurs when trace gases react photochemically in the atmosphere to produce stable “nano-condensation nuclei” (nano-CN) around 1 nm in diameter, which then grow to a detectable size (3 nm) through the uptake of various gases, often including sulfuric acid. NPF greatly increases the number concentration of atmospheric particles, up to a factor of 100, and is often followed by rapid particle growth to a size that can serve as a CCN, around 100 nm. This rapid growth, up to 50 times that of the growth assuming the uptake of sulfuric acid alone, is neither well understood nor represented in regional and global climate models. Adequate understanding and model representation of growth rates is especially lacking at sizes below 3 nm, a knowledge deficit our study sought to address.

In our study we obtained for the first time size- and time-resolved growth rates for newly formed particles down to 1 nm,

along with the size-resolved contribution of sulfuric acid uptake to that measured growth. This was accomplished by measuring sulfuric acid concentrations and size distributions of freshly formed particles during two intensive field campaigns; size distributions were obtained using a newly developed particle detection and sizing in-

strument capable of bridging the size range from large gas molecules and molecular clusters (< 1 nm) to nano-CN and beyond. Previously, the particle size detection limit was 3 nm. By fitting these measured size distributions to a model for particle size evolution, we obtained particle growth rates as functions of time and size



Values of the growth rate enhancement Γ (ratio of the measured growth rate to the sulfuric acid-limited growth rate) and their corresponding uncertainties (one standard error) are plotted as a function of particle diameter D_p for a strong new particle-formation event observed on 19 Sep 2010 in Boulder, Colorado. A dotted horizontal line indicating $\Gamma = 1$ (sulfuric acid-limited growth) and a dashed vertical line indicating the conventional particle-size detection limit (3 nm) are shown for reference. During the event, Γ is greater than 1 and increases with D_p , which directly indicates the increasing contribution of species other than sulfuric acid to particle growth with increasing particle size.

for particles from 1 to 5 nm. Measured growth rates were found to increase linearly with particle size, with sulfuric acid uptake accounting for a decreasing fraction of the growth with increasing size, providing direct evidence that species other than sulfuric acid contribute significantly to initial particle growth.

Using these measured particle growth rates and compositions improves model NPF rates by orders of magnitude over earlier model results assuming sulfuric acid limited growth. These results for initial particle growth and composition enable a more accurate assessment of the impact of NPF on CCN formation and subsequent climate impacts by providing needed observational constraints and motivating the development of more realistic models for initial particle growth.—CHONGAI KUANG (BROOKHAVEN NATIONAL LABORATORY), M. CHEN, J. ZHAO, J. SMITH, P. H. McMURRY, AND J. WANG. “*First Size-Dependent Growth Rate Measurements of 1- to 5-Nanometer Freshly Formed Atmospheric Nuclei*,” presented at the *Fourth Symposium on Aerosol-Cloud-Climate Interactions*, 22–26 January 2012, New Orleans, Louisiana.

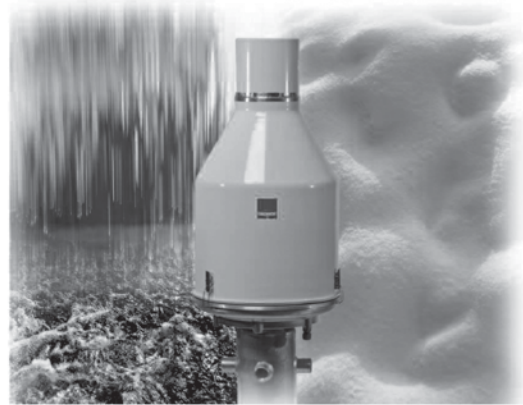
ECHOES

“ I think their silence is deafening, and I’m embarrassed for them—terribly embarrassed for them.”

—RUSS FINE of the Injury Control Research Center (ICRC) at the University of Alabama in Birmingham, speaking about the Centers for Disease Control and Prevention (CDC), which has failed to recommend that people wear helmets during tornadoes. The ICRC recently released a report that “propos[ed] the use of ‘safety helmets’ by individuals at risk for being in the path of a tornado,” with safety helmets defined as any sort of headgear made of a hard material that is designed to minimize anatomical damage caused by high-velocity impacts. However, the CDC recommends that people use their hands or “anything available” to protect their heads, but does not specifically mention helmets. In some areas, wearing helmets is being actively encouraged; for example, at a recent Birmingham (Alabama) Barons baseball game, bicycle helmets were given out to attendees to promote tornado preparedness. “Will it 100 percent absolutely, positively save your life? Probably not,” Fine states. “But it’s a whole lot better than having no helmet on, and that’s a no-brainer.” The ICRC report can be found at www.uab.edu/icrc/tornado_helmet_com.html. (SOURCE: National Public Radio)



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Radar and Atmospheric Science: A Collection of Essays in Honor of David Atlas

Edited by Roger M. Wakimoto and Ramesh Srivastava



This monograph pays tribute to one of the leading scientists in meteorology, Dr. David Atlas. In addition to profiling the life and work of the acknowledged “Father of Radar Meteorology,”

this collection highlights many of the unique contributions he made to the understanding of the forcing and organization of convective systems, observation and modeling of atmospheric turbulence and waves, and cloud microphysical properties, among many other topics. It is hoped that this text will inspire the next generation of radar meteorologists, provide an excellent resource for scientists and educators, and serve as a historical record of the gathering of scholarly contributions honoring one of the most important meteorologists of our time.

Radar and Atmospheric Science: A Collection of Essays in Honor of David Atlas

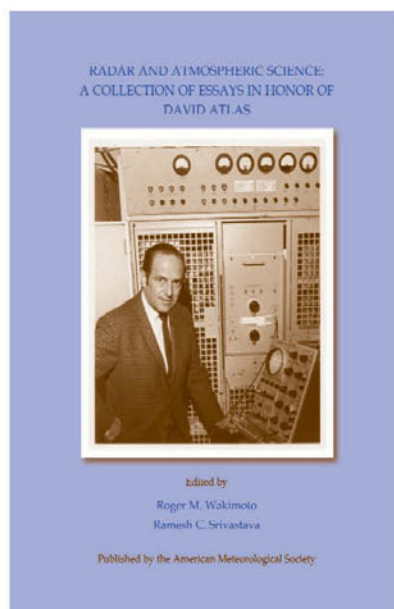
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Weak Pressure Gradient over the Iberian Peninsula and African Dust Outbreaks

A New Dust Long-Transport Scenario

BY LUIS NEGRAL, STELLA MORENO-GRAU, XAVIER QUEROL, JOSÉ MORENO, MAR VIANA, ANTONIO GARCÍA-SÁNCHEZ, ANDRÉS ALASTUEY, AND JOAQUÍN MORENO-CLAVEL

African dust outbreaks over the Iberian Peninsula have been related to four synoptic patterns responsible for the advection of dust:

- 1) *A North African high located at surface level.* African dust penetrates Iberia via an Atlantic arch due to an anticyclone located over southern Iberia, North Africa, the western Mediterranean, or off the Atlantic coast. The reference system of the northern Atlantic high at these latitudes, the Azores high, does not appear or it is displaced to show the same strength over Iberia as in its typical position, so convex plumes reach Iberia after covering the Atlantic coasts of the peninsula. The transport of desert dust happens at lower atmospheric levels (< 1,000 m). Figures 1a and 1b present an example of this synoptic pattern on 31 December 2006.
- 2) *An Atlantic depression centered over northwestern Africa, western Iberia, or the southwest of the Portuguese coast with an associated high or ridge over the Mediterranean Sea.* African dust reaches Iberia due to a northward flow from Africa that

transports the dust in lower and upper levels. Figures 1c and 1d present an example of this synoptic pattern on 1 November 2006.

- 3) *A North African depression.* A system of three centers of pressure controls the flows affecting southern Europe and the Mediterranean basin: a trough placed over northern Africa, the western Mediterranean, or even the Iberian Peninsula; the Azores high located to the west of the trough; and a frequent high or ridge over eastern Europe or the eastern Mediterranean basin. This scenario could be considered a rotation of the former pattern, with the depression in an eastern position. In this case, the transport of African dust toward Iberia is across the Mediterranean and is limited to the lower levels. Figures 1e and 1f present an example of this synoptic pattern on 16 June 2006.
- 4) *A North African high located at upper levels.* This scenario is associated with thermal lows over northern Africa, or even the Iberian Peninsula, due to the intense heating in summer. Once the convective system has injected the dust in the midtroposphere (up to 5,000 m), a massive transport of dust covers the western Mediterranean basin and Iberia, forming a wide plume toward the north. Figures 1g and 1h present an example of this synoptic pattern on 17 May 2006.

Consequently, particulate matter (PM) levels in Iberia are expected to rise when any of these atmospheric synoptic scenarios prevail. Nevertheless, PM levels might not increase due to wet deposition, as Spain receives the most African-derived dust rain events of any European country. A temporal revision of these African dust outbreaks confirmed the linkage between these meteorological conditions (cause) and the worsening in air quality (consequence).

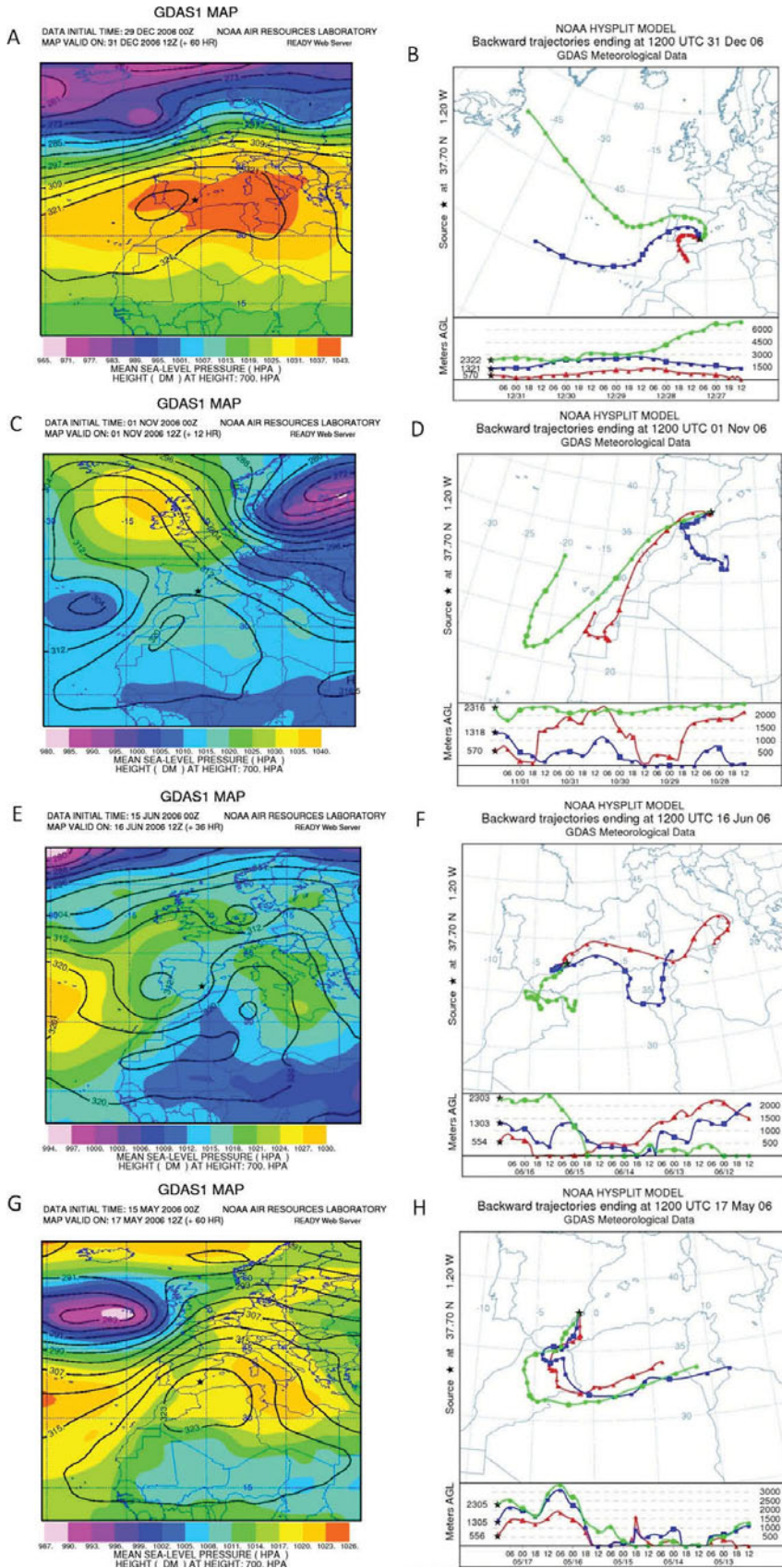
In this study, a meteorological scenario different than the above situations is evaluated. An in-

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crease in African dust in the southeast Iberian Peninsula is caused by a scenario not previously defined. African dust was detected at surface levels in southeastern Iberia during 562 of 1,613 days between January 2004 and May 2008. During this period, 117 of these African dust days were associated with the new synoptic pattern presented here. This newly identified pattern exemplifies how transition and/or stagnation conditions between strong synoptic systems can also result in augmentation of PM levels with a north African origin. This is appealing, as current European legislation allows air pollution managers to account for natural contributions when assessing legal accomplishments anytime there is solid proof of such natural contributions. As a consequence, a solid knowledge of the circumstances causing these events is necessary. Pursuing this further, an example of this newly identified scenario

FIG. 1. Examples of four synoptic patterns conducive to African dust outbreaks over the Iberian Peninsula. Mean sea level pressure is colored, and 700-hPa heights are solid black lines (left pictures); five-day air mass isentropic back trajectories arriving in the southeastern Iberian plateau are indicated at 750 (red), 1,500 (blue) and 2,500 (green) m above sea level for a point in the Iberian southeast (right pictures). (a) and (b): 31 Dec 2006; (c) and (d): 1 Nov 2006; (e) and (f): 16 Jun 2006; (g) and (h): 17 May 2006.

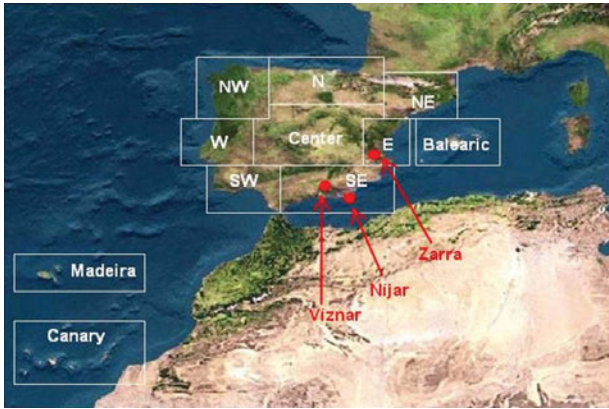


FIG. 2. Geographical distribution of sectors of the network of regional background stations of Portugal and Spain with the three regional background stations considered in this study: Nijar, Viznar, and Zarra. Figure modified from Querol et al. (2010), background image courtesy of Google Earth.

that occurred during October 2006 will be discussed in the subsequent paragraphs.

Two regional background stations in southeastern Iberia (Nijar and Viznar) registered the occurrence of African dust on 8–11 October 2006. Another regional background station in the eastern sector of Iberia (Zarra) observed the African dust on 9–11 October 2006. This geographical distribution of sectors (Fig. 2) is based on the network of regional background stations that the Portuguese authorities and the Spanish Ministry of Environment and Rural and Marine Affairs use for monitoring background air pollution. Although Zarra is considered to be in the eastern sector of Iberia, it is also utilized to study the synoptic patterns during the elevated PM level events in the southeast. The proximity of Zarra to the southeast sector and the additional data the location provides help illustrate the evolution of an African dust outbreak.

An African dust outbreak is identified at a station when the level of PM₁₀ (particulate matter $\leq 10 \mu\text{m}$) in a day exceeds the monthly (30 days) moving 40th-percentile value, excluding outbreak days. This 40th-percentile value is assumed to be the theoretical concentration of PM at the regional background station during a day without a dust outbreak. The benefit of taking the values of percentiles between 5th and 50th has been discussed in literature, with results indicating that using the 30th and 40th percentiles are the most advisable in Spain. As a result, Spanish legislation currently establishes the 40th percentile as the value to consider. The subtraction of this 40th-percentile value from the daily PM₁₀ will yield the net African dust. To illustrate this, Table 1 depicts the registered PM₁₀ and the net African dust at Nijar, Viznar, and Zarra during the 8–11 October 2006 dust outbreak, as well as one day before and one day after the outbreak.

Synoptic patterns at mean sea level pressure and at 700 hPa are presented in Fig. 3. Five-day air mass isentropic back trajectories arriving in the south-

TABLE 1. Concentration of PM₁₀ and estimated net African dust in $\mu\text{gPM}_{10}\text{m}^{-3}$ at Nijar, Viznar, and Zarra during the African dust outbreak on 8–11 Oct 2006 and one day before and after.

Day	$\mu\text{gPM}_{10}\text{m}^{-3}$	Nijar	Viznar	Zarra
7	Concentration	16	22	18
	Estimated net African dust	No dust outbreak	No dust outbreak	No dust outbreak
8	Concentration	19	26	18
	Estimated net African dust	3	14	No dust outbreak
9	Concentration	19	95	10
	Estimated net African dust	3	83	3
10	Concentration	16	63	18
	Estimated net African dust	<1	51	10
11	Concentration	28	19	18
	Estimated net African dust	12	7	10
12	Concentration	23	18	7
	Estimated net African dust	No dust outbreak	No dust outbreak	No dust outbreak

eastern Iberian plateau at 750, 1,500, and 2,500 m above sea level on 7–12 October 2006 are displayed

in Fig. 4. These back trajectories were computed with the Hybrid Single-Particle Lagrangian Integrated

Trajectory (HYSPLIT) model via the Real-time Environmental Applications and Display System (READY), a world network of data managed by the Air Resources Laboratory at NOAA. Aerosol maps of the Navy Aerosol Analysis and Prediction System (NAAPS) for those days are presented in Fig. 5.

On 7 October 2006, the Iberian plateau was affected by a high over the Bay of Biscay at mean sea level pressure (Fig. 3a). The Azores High remained with weak influence over Spain and Portugal at 700 hPa. The origin of the southeastern Iberia back trajectories was the northwestern Atlantic (Fig. 4a). These humid air masses were discharging the moisture as wet deposition over the northern Spanish territories until they reached the Iberian southeast based on the database of the State Meteorological Agency of Spain (AEMET, not shown). No wet deposition was recorded over the southeastern territories during the period of the dust outbreak. The NAAPS map presents minimum optical depth for dust over the Spanish plateau at this time (Fig. 5a).

On 8 October 2006, high pressure became more accentuated over central Europe at mean sea level (Fig. 3b). Conversely, southwestern territories of Europe, the western Mediterranean, and northern Africa remained under barometric stagnation at 700 hPa. The back trajectories of the upper levels penetrate the peninsula through the western Atlantic respect to Iberia; they even originate from the occidental coasts of Africa (Fig. 4b). Moreover, a slowdown of the back trajectories

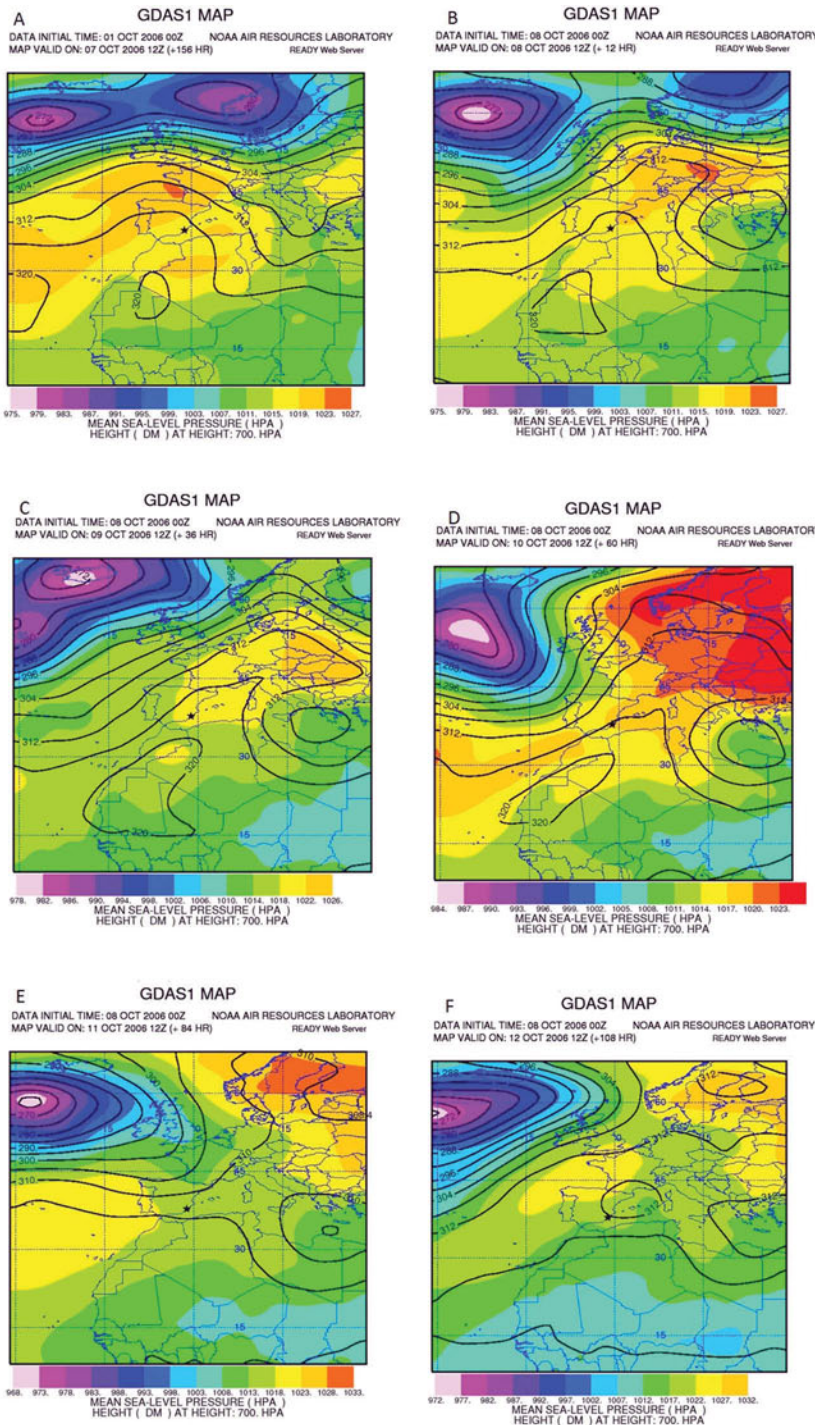


FIG. 3. Forecast charts for the African dust outbreak over the Iberian southeast on 8–11 Oct 2006. One day before and after the event are also provided. Mean sea level pressure is colored and 700-hPa heights are solid black lines. (a) 7 Oct; (b) 8 Oct; (c) 9 Oct; (d) 10 Oct; (e) 11 Oct; and (f) 12 Oct.

is observed on their way to southeastern Iberia. This slowdown is depicted as a circular trajectory during the latter portions of the trajectory period. This feature may be related to the presence of African dust over the Iberian southeast, as this zone is only about 200 km from Africa. The vicinity of the Iberian southeast to Africa implies that once the air masses have left the African continent, they are able to reach Spain with only a simple recirculation over the area. The NAAPS analyses (Fig. 5b) indicate a ridge that extends over Iberia from Africa with optical depths for dust between 0.4 and 0.8 and concentrations of dust up to $80\text{--}160\ \mu\text{gPM}_{10}\text{m}^{-3}$.

On 9 October 2006, the system of high pressure at mean sea level continues over Central Europe, with scarce influence over Spain (Fig. 3c). The western Mediterranean basin remains as the day before at 700 hPa, far away from relevant systems of pressure. The circular back trajectories (Fig. 4c) convert into loops when they reach their destiny over southeastern Iberia. These loops, especially in the case of the highest back trajectory, penetrate the north of Morocco about 100 km. The NAAPS maps present optical depths for dust between 0.8 and 1.6 over the southeast of the Iberian Peninsula and the stain of dust covers the Iberian plateau with peaks up to $80\text{--}160\ \mu\text{gPM}_{10}\text{m}^{-3}$ (Fig. 5c). The notably high levels of PM10 (Table 1) observed at Víznar [1,071 m above sea level (asl)] in comparison to Níjar (353 m asl) and Zarra (523 m asl) are explained by the differences in altitude.

On 10 October 2006, the high pressure extended from central Europe to Scandinavia at mean sea level, so the influence

over Spain is further diminished (Fig. 3d). The plateau is constrained under stagnant conditions. At the same time, a system of high pressure is located over Morocco and Sahara at 700 hPa. This description of a

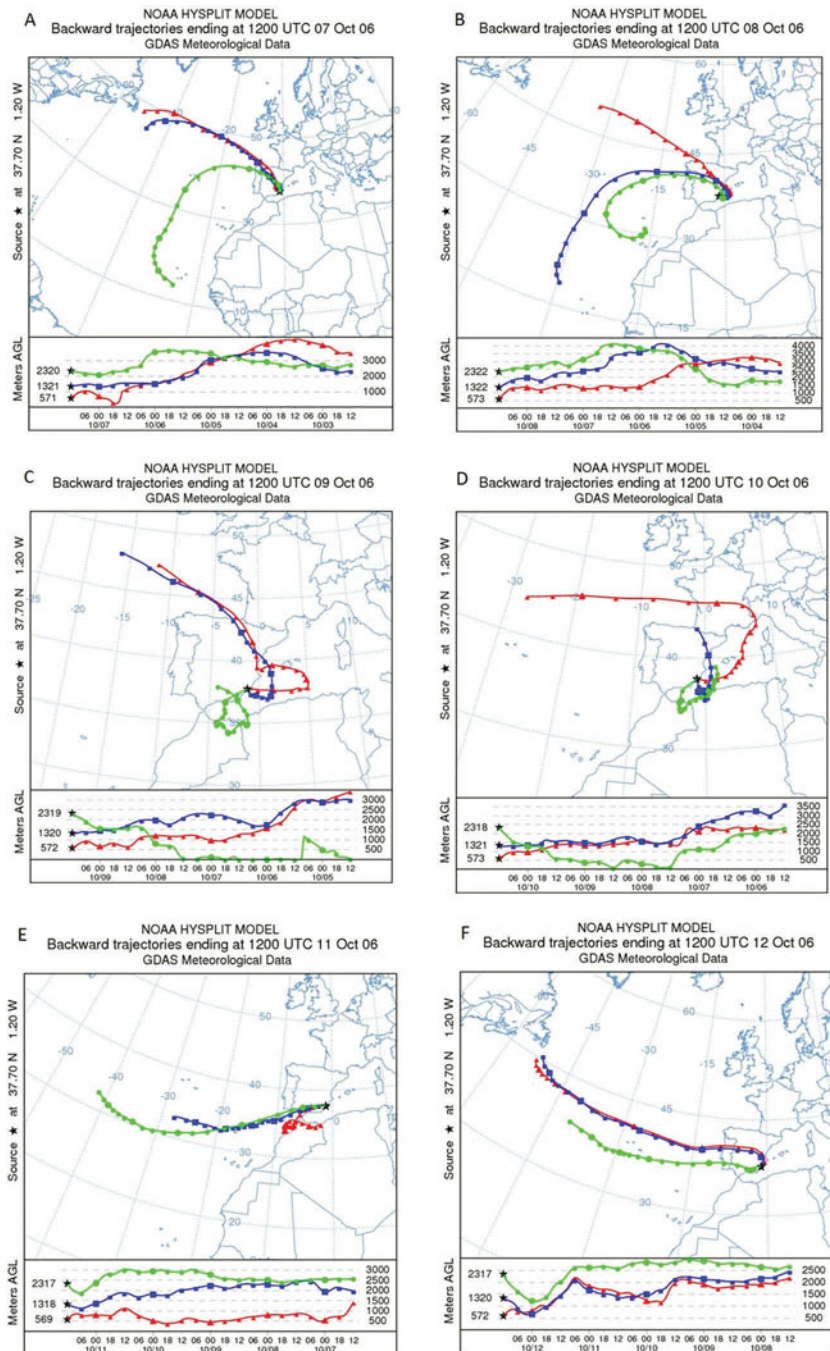
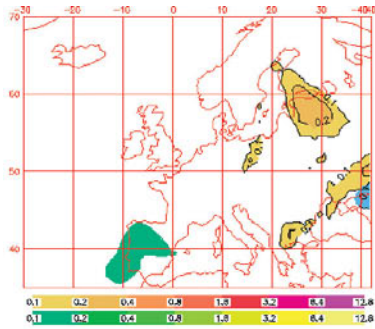
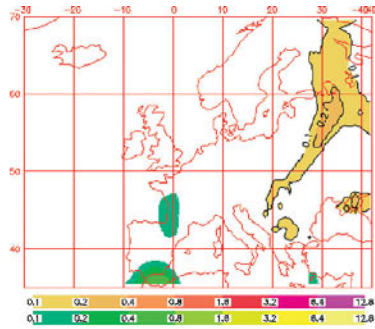


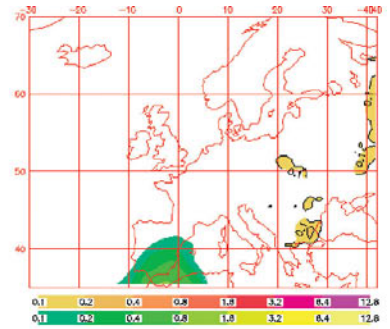
FIG. 4. Five-day air mass isentropic back trajectories arriving in the southeastern Iberian plateau at 750 (red), 1,500 (blue) and 2,500 (green) m above sea level for a point in the Iberian southeast during the African dust outbreak from 8 until 11 Oct 2006. One day before and after the event are also provided. (a) 7 Oct; (b) 8 Oct; (c) 9 Oct; (d) 10 Oct; (e) 11 Oct; (f) 12 Oct.



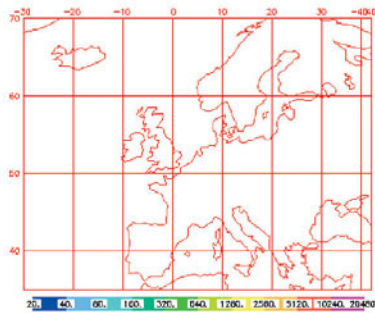
A NAAPS Optical Depth for 12:00 of 07 Oct 2006
Sulfate: Orange/Red, Dust: Green/Yellow Smoke Blue



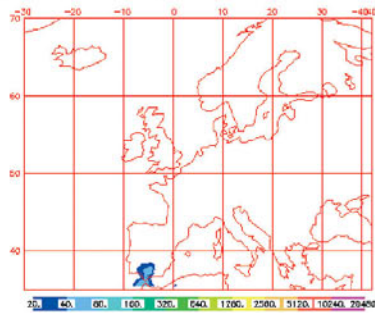
B NAAPS Optical Depth for 12:00 of 08 Oct 2006
Sulfate: Orange/Red, Dust: Green/Yellow Smoke Blue



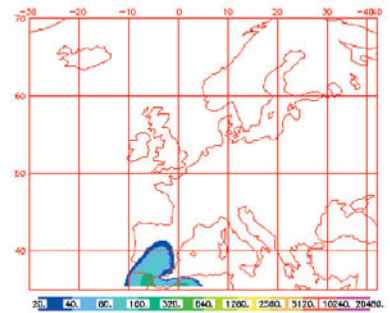
C NAAPS Optical Depth for 12:00 of 09 Oct 2006
Sulfate: Orange/Red, Dust: Green/Yellow Smoke Blue



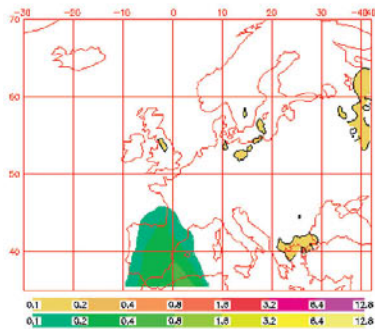
NAAPS Surface concentration (ug / m³)
for 12:00 of 07 Oct 2006 Dust



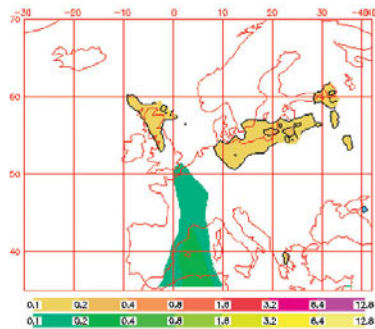
NAAPS Surface concentration (ug / m³)
for 12:00 of 08 Oct 2006 Dust



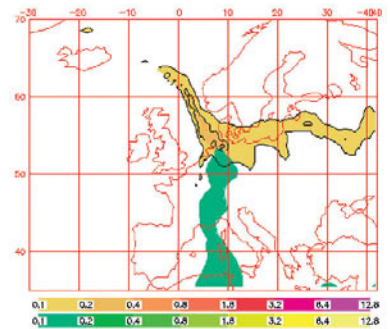
NAAPS Surface concentration (ug / m³)
for 12:00 of 09 Oct 2006 Dust



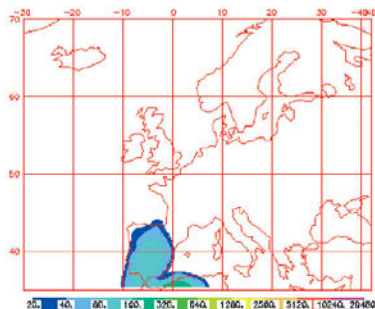
D NAAPS Optical Depth for 12:00 of 10 Oct 2006
Sulfate: Orange/Red, Dust: Green/Yellow Smoke Blue



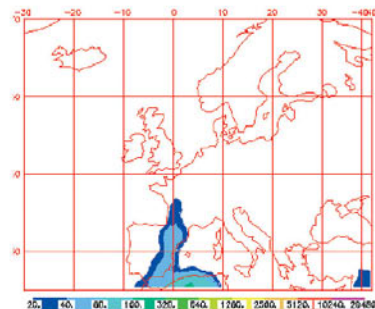
E NAAPS Optical Depth for 12:00 of 11 Oct 2006
Sulfate: Orange/Red, Dust: Green/Yellow Smoke Blue



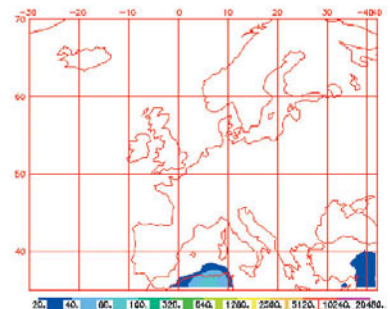
F NAAPS Optical Depth for 12:00 of 12 Oct 2006
Sulfate: Orange/Red, Dust: Green/Yellow Smoke Blue



NAAPS Surface concentration (ug / m³)
for 12:00 of 10 Oct 2006 Dust



NAAPS Surface concentration (ug / m³)
for 12:00 of 11 Oct 2006 Dust



NAAPS Surface concentration (ug / m³)
for 12:00 of 12 Oct 2006 Dust

FIG. 5. NAAPS analysis of the (top) optical depth and (bottom) surface concentration of aerosol during the African dust outbreak over the Iberian southeast on 8–11 Oct 2006. One day before and after the event are also provided. (a) 7 Oct; (b) 8 Oct; (c) 9 Oct; (d) 10 Oct; (e) 11 Oct; and (f) 12 Oct.

high centered over the north of Africa at upper levels of the atmosphere accompanied by lows at mean sea level corresponds to one of the scenarios described previously in literature (Escudero et al. 2005). The loops of the back trajectories (Fig. 4d) are notable. The highest air-parcel trajectories originate in air masses relatively close to their endpoints over southeastern Iberia. The lowest air parcels slow down considerably over the western Mediterranean during the latter stages of their trajectories. To summarize, the highest air masses remain within a radius of around 800 km during the five days, when substantial levels of African dust are detected. The signal for the optical depth for dust from the NAAPS analysis (Fig. 5d) covers Iberia and the western Mediterranean basin, whereas the stain of dust extends over most of Iberia, peaking with 80–160 $\mu\text{gPM}_{10}\text{m}^{-3}$.

The African dust outbreak over southeastern Iberia ends during 11 October 2006. The high pressure at mean sea level continues to move away through Scandinavia, and the Azores High is not strong enough to cause important advections over the Spanish southeast (Fig. 3e). The western Mediterranean basin remains under a very light flow at 700 hPa. The back trajectory of the lowest air masses runs through the Gibraltar Strait with loops (Fig. 4e). Simultaneously, the highest air masses start to change their origin. Although they still penetrate through the Iberian southwest, sweeping along the dust in front of the African coasts, they originate thousands of kilometers west over the Atlantic Ocean. As a consequence of the barometric valley over the western Mediterranean basin, the NAAPS analysis of optical depth for dust (Fig. 5e) presents a narrowing and a lengthening of the covered area, including the whole Spanish east coast up to the English Channel. The values of optical depth for dust account for 0.1–0.2 in most of the area. This geographical distribution is similar to that shown by the NAAPS map for dust, with levels peaking up to 40–80 $\mu\text{gPM}_{10}\text{m}^{-3}$.

By 12 October 2006, the dust event has ended (Table 1). The Iberian plateau is again affected by a high over the Bay of Biscay and residual systems of pressure over the Mediterranean basin at mean sea level (Fig. 3f). The back trajectories originate in the Atlantic, thousands of kilometers away from western Iberia [i.e., in the case of the lowest back trajectories close to the Canadian coasts (Fig. 4f)].

As this case illustrates, by examining the levels of PM every day and the models of the origin and trajectory of the air masses, it can be concluded that

synoptic patterns without strong systems can be responsible for peaks in atmospheric pollution across parts of Iberia. These peaks are due to a natural source hundreds of kilometers from the affected area. The authors believe this scenario could be extended to other places with increases in pollution and no dispersive conditions. Similarly, Yu and Pielke (1986) observed how slow-moving high pressure conditions were associated with stagnant conditions causing a worsening of atmospheric pollution in the Lake Powell Area (southern Utah/northern Arizona), and Kallos et al. (1993) noticed some of the worst pollution episodes in Athens, Greece, caused by weak pressure gradients associated with transport of warm air masses from northern Africa. Although only three regional background stations have been assessed in this document, the interaction between natural and anthropogenic pollutants might be expected to increase the levels of secondary pollutants where the human factor is more prominent.

Finally, the scenario presented here is different than the associations established by Escudero et al. (2005) between synoptic patterns and the occurrence of African dust over the Iberian plateau. As with the four synoptic scenarios described by Escudero et al. (2005), the pattern described here does not necessarily indicate the detection of African dust in the Iberian southeast. In other words, the measure of African dust can be related to stagnation conditions, but it does not imply that every time stagnation conditions appear there is an advection of African dust toward the Iberian southeast. During the 53 studied months, this stagnant regime appeared 60 times accounting for 117 days in total. The duration of the events under this regime was 1 day (33 times), 2 days (19 times), 3 days (once), 4 days (3 times), 6 days (twice), 7 days (once), and 12 days (once). Nevertheless, on just four occasions (7 days in total) this regime appeared separated in time by more than 24 hours from any of the synoptic patterns responsible for the transport of dust over the Iberian Peninsula, as described by Escudero et al. (2005). This regime, along with the other types of synoptic patterns, suggests that the presence of dust in the Iberian southeast under the new scenario has mainly either a residual, transitional, or incipient character of any other dust-transporting synoptic patterns. Back trajectories showing many loops can be considered as a signal for the new scenario. The four times when the new scenario did not appear in the vicinity of the others would correspond to the beginning of any

other scenario that did not develop. In summary, this stagnant system would be joined to the presence of African dust over the Iberian southeast if any of the other synoptic patterns is somehow (either in time or generation) associated with it.

ACKNOWLEDGMENTS. The authors gratefully acknowledge the State Meteorological Agency of Spain (AEMET) for permission to use their resources, the Navy Aerosol Analysis and Prediction System (NAAPS), and the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and/or READY website (www.arl.noaa.gov/ready.php) used in this publication. We also thank two anonymous reviewers and the editor for their comments on the presentation of the new scenario.

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CREATION AND COMMUNICATION OF HURRICANE RISK INFORMATION

BY JULIE L. DEMUTH, REBECCA E. MORSS, BETTY HEARN MORROW, AND JEFFREY K. LAZO

Working together and in collaboration with social scientists, NWS forecasters, emergency managers, and the media can improve the hurricane risk information that they convey to aid protective decision making.

Katrina, Rita, Ike, Irene—These and other hurricanes have caused substantial damage and loss of life in the United States during the past decade. In response to hurricane threats, some people who should evacuate their homes or take other protective action do not, often placing themselves at unnecessary risk, while others who are not at significant risk do evacuate, creating unnecessary congestion on roads and in shelters (Gladwin et al. 2009). Meteorologists and others often wonder why this happens. Hurricane forecasts have improved significantly in recent years; the average error in hurricane

track forecasts has been reduced by 60% since 1990 (NOAA 2011b), and improving hurricane intensity forecasts is currently a major priority (Toepfer et al. 2011). Information about geographical areas at high risk from hurricanes is also improving, for example, through updated mapping, advances in storm surge modeling, and more precise determination of evacuation zones (Rappaport et al. 2009; Florida Division of Emergency Management 2011). Moreover, social science research is developing a growing understanding of the factors that contribute to people's hurricane preparation and evacuation decision making (Dow and Cutter 1998; Dash and Morrow 2001; Gladwin et al. 2001; Gladwin and Morrow 2005; Dash and Gladwin 2007; Zhang et al. 2007; Taylor et al. 2009; Lazo et al. 2010; Morss and Hayden 2010). Here we complement these efforts by examining the starting point of the warning and response process—that is, how information about forecasts, warnings, and recommended protective actions is created and communicated when a hurricane threatens. This understanding is critical because people's responses to hurricane risks are interconnected with the risk messages they receive. Yet few researchers have investigated this component of the process.

Although the hurricane forecast, warning, and response process involves many factors, we focus

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on three major groups that strongly influence how hurricane risk messages are created and conveyed: National Weather Service (NWS) forecasters at the National Hurricane Center (NHC) and local weather forecast offices (WFOs), local emergency managers (EMs), and local television and radio personnel. Together, we refer to these groups as the *hurricane warning system*. Our findings are based largely on an in-depth study of these groups in the Miami, Florida, area. This work is part of a larger project examining hurricane warning communication from several theoretical and methodological perspectives, including a parallel study in the Houston, Texas, area (Anthony et al. 2012) and work examining perceptions and responses to different hurricane risk messages by members of the public, including vulnerable populations (Lazrus et al. 2012).

By examining forecasters', emergency managers', and the media's roles, goals, and interactions, we aim to understand the processes that shape the messages underlying how people interpret and respond to hurricane risk. Building on this understanding, we identify strengths and challenges in how the hurricane warning system functions and how it serves the U.S. public in providing useful hurricane risk information, and we discuss opportunities for improving on current successes. Our goal is to help participants in the hurricane warning system improve how they interact with each other and how they generate and convey information, ultimately contributing to the broader goal of increasing societal resilience to hurricanes and related weather hazards (e.g., Subcommittee on Disaster Reduction 2005).

STUDY METHODOLOGY. This study employed a mixed-method, empirical approach. The primary source of data was in-depth, semistructured interviews with members of the three groups. The interviews included questions about interviewees' job roles and partnerships; their sources, uses, creation, and communication of information; their audiences; their views on the hurricane forecast and warning process; and related topics. Data were collected between April and September 2009 from three NHC forecasters, two Miami WFO forecasters, two Miami-area emergency managers, and nine meteorologists and other personnel from four television and four radio stations in the Miami area (including non-English language). The interviews were supplemented by observational sessions involving development of mock hurricane forecast products by a subset of

participants. The mock product development was based on a hypothetical hurricane threatening the Miami area, using a scenario provided by the NHC beginning four days prior to "landfall." Further information about the study methodology and data collection is available from the authors.

All observation sessions and interviews were digitally recorded and transcribed. The data were analyzed inductively to identify key themes, presented in this article. In developing the findings and recommendations, we also incorporated the authors' knowledge about NWS forecasters, emergency managers, the media, and the hurricane warning and response process from related work, as well as information from discussions with members of the project's Expert Advisory Group (which includes members of all of the groups studied). Based on this broader knowledge, we emphasize findings that we believe are broadly applicable. Nevertheless, because of the purposive sampling approach and geographic focus of the data collection, our results are not truly generalizable. To preserve anonymity, participants' quotations are identified only by their group type.

THE HURRICANE WARNING SYSTEM.

Hurricane risk information is generated, communicated, and interpreted through complex interactions among a variety of actors, including NWS forecasters, private sector forecasters and vendors, multiple types of media and government agencies, nongovernment organizations, businesses, and members of the public. Within this larger process, we focus on three groups that have a primary influence on what risk information is created and communicated when a hurricane approaches the United States: NWS forecasters, local emergency managers, and local television and radio personnel. We selected these groups because they are key actors in the hydrometeorological¹ forecasting, public sector decision making, and media communication processes associated with landfalling hurricanes, respectively. Although each of these groups has a variety of concerns and responsibilities in general, here we analyze their roles within the hurricane warning system when a hurricane threatens.

Analysis of our data revealed that the three groups have different job roles and specialties (Figs. 1, 2). They also work in organizations with different priorities, constraints, and broader roles. Despite these differences, the groups interact within the hurricane warning system context to further overarching,

¹ In this article, we use the term *hydrometeorological* to refer to meteorological and hydrological fields.

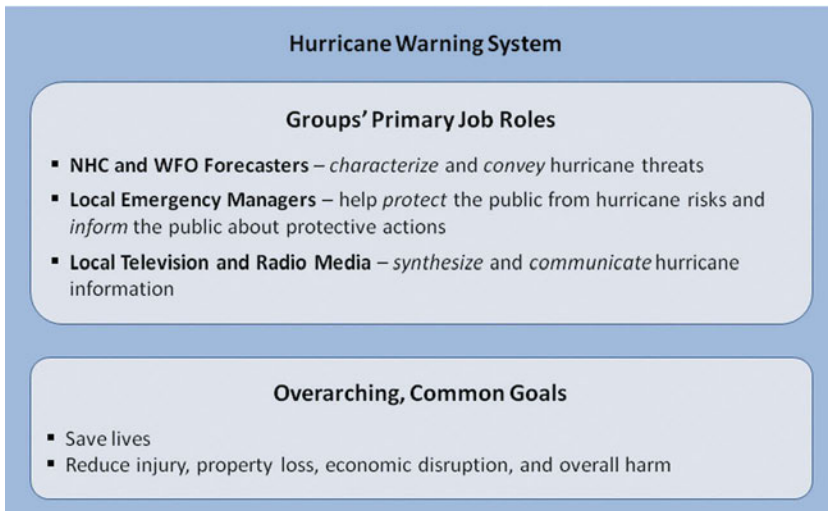


FIG. 1. Primary job roles of the three major groups in the hurricane warning system and their common goals.

common goals of saving lives and reducing harm when a hurricane threatens (Fig. 1). The groups' roles and interactions are guided by organizational procedures and public policy, but the hurricane warning system is largely informal. Many aspects of the structure in its current incarnation developed (and continue to develop) in an ad hoc manner over time, with each group's roles evolving in ways that complement the others' roles while maintaining its own specialty (Fig. 2) and orientation toward the overarching goals.

National Weather Service forecasters. The NHC is the national-level center in the NWS that specializes in tropical cyclones, including hurricanes. When a hurricane has formed or is forming, NHC forecasters' primary role is to characterize and convey the hydrometeorological threat that the storm poses at regional and larger scales (Fig. 2). They characterize the threat by applying their expertise to analyze and synthesize information from multiple sources (Lindell et al. 2007; Morss and Ralph 2007; Heinselman et al. 2012). They then convey this threat by regularly generating and issuing a suite of products, including textual forecasts,

track forecast cone graphics, wind speed probabilities, and tropical storm and hurricane watches and warnings. NHC forecasters described their role as the "quarterback . . . calling the signals based on the meteorology of what's going on." They "tell everybody where the storm is going to go, how strong it will be, how big it will be." In this way, NHC products serve as a starting point for the other groups in the hurricane warning system to do their jobs.

NWS forecasters at local WFO offices also characterize and convey hurricane threats

but with an emphasis at regional and local scales² (Figs. 1, 2). When a hurricane threatens their area of responsibility, Miami WFO forecasters described their primary role as "taking the information [NHC puts] together and downscaling it to be digestible"

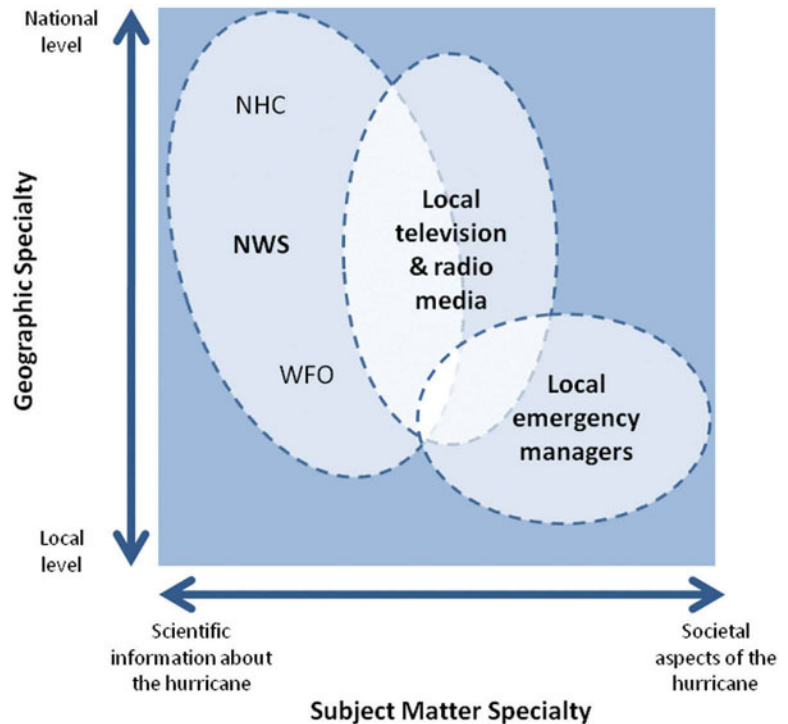


FIG. 2. Conceptual representation of the primary geographic and subject matter specialties of the groups in the hurricane warning system. Areas of overlap represent overlap in specialties, not necessarily interactions among the groups.

² The Miami WFO's area of responsibility, for example, includes seven counties covering south Florida (excluding the Florida Keys).

for their users. They do so by assessing the hydrometeorological situation for their area of responsibility and the anticipated hydrometeorological and societal impacts. They convey this information through products such as textual hurricane local statements, hazard impact graphics, and warnings for hurricane-related hazards, such as inland winds, tornadoes, and flooding.

In deciding how to characterize and convey threats, NHC and WFO forecasters coordinate with each other and with other NWS entities (e.g., Hydrometeorological Prediction Center, Storm Prediction Center) through a regularly scheduled “hotline” call and other mechanisms. They provide forecast and warning information to emergency managers, the media, the public, and others through NWS products that are disseminated via multiple automated mechanisms as well as through formal briefings and informal discussions.

As a governmental agency, the NWS has a public service orientation; its mission is to provide forecasts and warnings for the protection of life and property and enhancement of the economy (NOAA 2011c). Thus, NHC and WFO forecasters characterize and convey hurricane threats with this broader goal in mind (Fig. 1). However, they cannot directly accomplish this broader goal on their own for several reasons. First, their primary emphasis is generating and providing forecast information that, at best, can only inform and promote the protective actions needed to save lives and reduce harm. Second, many audiences, excepting the media and emergency managers, do not directly receive information from NWS forecasters; much of the NWS information received by others (e.g., the public) is filtered through the private sector, especially radio and television, or through interpersonal sources (e.g., Taylor et al. 2009; Morss and Hayden 2010). Third, NWS forecasters’ primary training is in meteorology, not in forecast communication or use, so the primary expertise they contribute is in the physical sciences. NHC and WFO forecasters must also work within their organizational constraints and policies, including guidelines on the allocation of responsibilities within the NWS, on the generation of forecast and warning products, and on their role relative to the private sector (NRC 2003; NOAA 2011a). Thus, NHC and WFO forecasters must partner with each other and with other groups in the hurricane warning system to fulfill their job roles in ways that support the overarching goals.

Local emergency managers. Local emergency managers described their primary role when a hurricane

threatens as being “to protect the public” by informing people at risk and helping keep them out of harm’s way (Fig. 1). This includes recommending, coordinating, and implementing preparedness and public safety activities (such as evacuations, sheltering, and closures) for their area of responsibility. It also includes working to “advise [people] what they should be doing and what the consequences are if they fail to do that,” for instance, by recommending such activities as shuttering, gathering emergency supplies, and finding safe shelter. In other words, within the hurricane warning system, emergency managers work to translate hurricane threats into risk-reduction actions based on their assessment of a hurricane’s potential societal impacts (Fig. 2). In doing so, they incorporate a variety of considerations beyond the hydrometeorological threat. Decisions about risk-reduction actions are made by several actors; for example, evacuation decisions typically are made by elected officials, and most protective actions are implemented by members of the public, businesses, and other governmental and nongovernmental actors. Emergency managers play a critical role by serving as primary translators of hydrometeorological information for these groups.

Like the NWS, local emergency managers are employed by governmental agencies and thus have a public service orientation. Emergency managers’ role connects them more directly than the NWS’s role to the broader goals of saving lives and reducing harm (Fig. 1). However, like NWS forecasters, they cannot accomplish their job role in support of these overarching goals without partnering with other groups. Emergency managers rely on the NWS to provide scientific expertise about the hydrometeorological threat posed by a hurricane and, in many cases, on private sector forecast services to amalgamate and provide enhanced forecast information. They also rely on the media to communicate information about the hurricane threat and recommended actions to the public and other audiences. And, again, emergency managers typically only recommend or facilitate protective action, so they must work to achieve their job role and goals within the constraints of their organizational and political environments.

Local television and radio personnel. When a hurricane threatens, television and radio are the most common sources of hurricane information for the public (Piotrowski and Armstrong 1998; Zhang et al. 2007; Morss and Hayden 2010). In the context of the hurricane warning system, media personnel described their primary role as “storytellers” who synthesize hurricane forecast, preparedness, and response

information, and communicate it to their audiences (Figs. 1, 2). Although most television meteorologists use their own meteorological knowledge, they typically do not develop their own hurricane forecasts or warning products from raw meteorological data. Rather, they and radio broadcasters rely on their warning system partners—NWS forecasters and emergency managers—to provide them with hurricane risk information. The media also rely on private sector weather vendors to transmit and postprocess NWS data, produce value-added forecast information, and provide a platform for creating camera-ready graphics for television. The media say they then take the hurricane risk information they receive and focus on “boil[ing] it down into bullet points, into facts, into useful information” for their audiences. As one television meteorologist described, “Most people today . . . still get their information from TV and still rely on us to explain it to them, decipher the information, and communicate it.”

NWS forecasters and emergency managers do provide information directly to the public, and venues such as the Internet are a growing source of hurricane risk information (Lee et al. 2009; Sherman-Morris et al. 2011). However, television and radio broadcasters remain the everyday faces and voices that serve as a primary conduit for weather warning information to the public (Sherman-Morris 2005; Demuth et al. 2009). Unlike the NWS and emergency managers, media organizations are in the private sector and thus have goals such as maintaining market share and generating profit. In pursuit of these goals, media producers and managers can influence aspects of hurricane coverage. The media aim to effectively communicate impending weather threats in part because doing so helps them retain audience trust and therefore market share. In addition, the media personnel we interviewed felt that, within the context of the hurricane warning system, they communicate threats in support of the altruistic goal of protecting their viewers and listeners (Fig. 1). As one television meteorologist said, “I don’t care if somebody’s watching me or . . . another station, as long as they’re getting the message and preparing. To me, it’s not about me, it’s about safety and the message.” Although the media personnel we interviewed indicated they often have flexibility in deciding when and how they communicate hurricane risks, they nevertheless face constraints from the media environment in which they work. They also cannot accomplish their roles or goals without their NWS and emergency management partners.

Groups in partnership: Beyond borders. Our analysis indicated that the partnerships within the hurricane warning system are generally successful, in that each group plays a unique and critical role and that, together, the groups make information about hurricane threats widely available (Taylor et al. 2009; Morss and Hayden 2010). As one NHC forecaster noted, “It’s amazing when you sit down and look at everything that could go wrong, and yet 99-point-some percent of the time, the forecasts go out on time. The public is able to get it.” Another NHC forecaster added, “The TV stations get it, the word goes out. It gets widely disseminated. That’s something that’s the biggest strength, the ability to rapidly disseminate that critical information.” This information is then used by many public officials, members of the public, and others to make protective decisions.

One reason for these successes is the complementarity of roles within the hurricane warning system. The expertise and job functions required within the system are extensive; there is sufficient overlap to allow the groups to support each other’s roles but enough differentiation that groups typically avoid unproductive duplication of effort. For example, NHC forecasters do not order people to evacuate, but they do aim to provide emergency managers and members of the public with the scientific information they need to make evacuation decisions because “they can’t interpret the science like we can.” Meanwhile, emergency managers know that “our mission is not to tell the world about the dynamics of the hurricane.”

Another factor underlying the hurricane warning system’s successes is that group members generally recognize and appreciate their interdependency and the importance of their partnerships. A member of the media explained, “I couldn’t do my job without [the NHC and WFO] . . . With the hurricane, I don’t have the tools, the data, and the knowledge that they do . . . so I rely on them almost 100% for info that I’m getting . . . I’m an extension of them to get out their hard work.”

And, according to an NHC forecaster, “I think there’s been a big push in the media lately, too, to take our information but expand on it and actually provide additional information that they can with either fancy graphics or things that we don’t produce here. I think that’s great. If they can find ways of getting people thinking and getting them to take action beyond what we can do, I think that’s a good thing.”

The emergency managers we interviewed spoke about their strong relationships with specific NWS and media partners, including personal connections that helped them contact WFO forecasters, in

particular, for specific information or clarification about the forecasts when needed. As one emergency manager noted, “If we’re unclear, we’ll call them up and talk to them . . . [I’m] not even kidding about having [WFO forecaster] on speed dial.” In return, one WFO forecaster indicated, “As far as emergency managers, I’m becoming increasingly convinced that, more than users, they’re really our partners.” The partnerships are not flawless, and below we discuss challenges pertaining to certain aspects of the partnerships. Nevertheless, an important component of the partnerships’ successes is the confidence that members of the groups have in each other based on the organizational trust and personal relationships they have built over time.

The hurricane warning system’s effectiveness is also enhanced by its flexibility. When a critical opportunity or need arises in a specific hurricane situation, individuals can go beyond their typical roles to serve the overarching goal. For example, although NHC forecasters’ specialty is the science of tropical cyclone and hurricane forecasting, over time they have also become a trusted face in communicating about hurricane risk with the public (NOAA 2011d). Reflecting this, the media sometimes turn to the NHC as an on-camera source for hurricane information, including information about the local hurricane forecast and impacts generated by WFOs. As credible voices with the public, NHC forecasters and television meteorologists also aid emergency managers by advising protective actions. Similarly, leading up to Hurricanes Katrina and Ike, WFO forecasters concerned about life-threatening situations included in their hurricane local statements dramatic language warning of catastrophic damage and urging people at risk to take protective action (Morss and Hayden 2010). Although such extensions of roles can create tensions among warning system partners, in most cases they seem to be accepted by other groups in the hurricane warning system because of the overall sense of partnership in service of a common goal. Such role extensions can also allow groups to evolve and renegotiate their roles over time, as needs for information and opportunities change.

CHALLENGES IN COMMUNICATING HURRICANE RISK. Despite many successful aspects of partnerships within the hurricane warning system, our analysis revealed some issues. These can lead to challenges for NHC and WFO forecasters, emergency managers, and media in fulfilling their job roles and, more generally, in effectively

communicating hurricane risk to achieve the broader goals of saving lives and reducing harm. The types of challenges we observe are common in interorganizational settings (e.g., Brown and Duguid 2001). Thus, our goal is not to be critical of the actors involved, but rather to identify opportunities for improvement.

NWS forecast products: Volume, complexity, content. Hurricane forecast information provided by the NWS is indispensable. However, it could be improved in several ways. One issue is the volume of information produced by the NWS—including the number of products, their length, and the detail included. For example, a member of the media noted that NHC and WFO forecast products can be so long that they’re “unwieldy;” he has “to ferret through all of [the] stuff that gets mixed in together” to find out what information applies to which geographical areas. This problem is exacerbated when a hurricane is near or makes landfall and the NWS issues additional products for different associated hazards. Another member of the media observed, “As the hurricane’s getting closer, we get advisories after advisories after advisories . . . So a hurricane watch becomes a hurricane warning. Then a flood watch is issued. Then a tornado watch is issued. Then an inland high wind watch is issued. It’s a little bit too much, I think, sometimes.”

This raises challenges for time-constrained emergency managers and media personnel who must sift through this detailed information and sort out what they and the public need to know. As a member of the media explained, “It gets to the point where it’s like, all these watches, all these warnings, all this stuff . . . We know all of that is or likely is going to happen with a hurricane. So instead of getting bogged down in all of that stuff, the most important thing to do . . . [is] really giving people specific information on when this stuff might occur, when the worst of it could be. That’s the kind of stuff we try to communicate.”

Another issue with NHC and WFO information is that it can have an NWS-specific meaning that may confuse audiences outside the NWS. According to a member of the media, “A good example of what the problem is, and I don’t know if it’s political boundaries or Weather Service or what, but a hurricane warning only affects the coast, and then there’s an inland hurricane wind warning. So all of a sudden you’ve got this demarcation, and people are like, is it a hurricane or not?”

Even an NHC forecaster, a producer of the information, noted that users can have difficulty interpreting their forecast products:

I think the biggest obstacle in communicating is, I don't think people really understand what [NWS products] mean. People, as in the public, and even sometimes the emergency managers, I'm not sure really understand when we put up a warning, what does that really mean? Because it doesn't mean that every place along the coast that's under the warning is going to experience hurricane-force winds. What it means is that hurricane-force winds will be experienced by someone within the warning area within 24 hours.

A related issue is the level of scientific and technical content of many NWS products. Because NHC and WFO forecasters' primary emphasis is on scientific accuracy and thorough characterization of hurricane threats from a hydrometeorological perspective, they tend to use technical language and provide meteorological detail. This can frustrate warning system partners who need more accessible information to fulfill their roles. As one member of the media explained:

Sometimes scientists speak like scientists and not like people. You know, some people don't know what low pressure means, what high pressure means, and some people don't know and don't care what millibars are. They don't care about all of the meteorological terms. They want to know three things: what does it mean to them, what does it mean to their family, and what do they need to do right now. And so don't speak like a meteorologist. Tell me what we need to know . . . I can't tell you in the middle of an emergency how many times we've looked at each other in the news room and said, "Well, that was no help whatsoever," because we couldn't get numbers, specifics, what the public needed to know at that moment.

One reason this occurs is that NWS forecasters' primary expertise and training is as physical scientists. Moreover, they work in an organization that focuses on precise scientific information and that evaluates forecasters' performance based on specific metrics that are often scientifically based. As a result, they do not want to omit important details about hydrometeorological threats, and they sometimes have difficulty explaining those threats in layperson's terms. Further, NWS forecasters work within an organizational structure that emphasizes timely issuance of a consistent, structured suite of products. This emphasis is beneficial because it helps product recipients know what to expect and design

their systems accordingly, and it helps the NWS serve audiences with limited communication technologies (e.g., mariners at sea). However, this structure creates inertia, leading the NWS to retain outdated or redundant forecast products and formats and to be slow to adopt new techniques and technologies for conveying information. An NHC forecaster explained:

I think by us latching onto these legacy text products so much, we're kind of limiting ourselves in what we can do . . . People are very visual, and they need more graphical-type products . . . I think we're very slow to react to changes in the population and the population's needs. I think right now, the structure of the forecast process doesn't really quickly allow for these types of things to be incorporated . . . [However], the process has worked now for decades, and there is some good stuff that has been instituted that needs to be kept, needs to be followed. It's just trying to find that balance for moving ahead in the modern age but keeping the legacy things that are good and have worked well.

Another challenge is that the NHC and WFO have multiple, diverse audiences; even with the suite of products NWS forecasters provide, it is not possible for them to serve all of their users' needs all of the time. Moreover, despite the partnerships described earlier, the NWS does not receive much direct feedback from many of the people who receive and use its information. Thus, NWS forecasters sometimes do not have a clear sense of who their audiences are for specific products and what information these audiences need and can use. Based on the limited feedback they do receive, however, NWS forecasters recognize some of the issues with their forecast information. As a WFO forecaster described:

From the insider in the agency, I consider [the NWS hurricane forecast and warning process] to be probably convoluted and complex, more than it needs to be. There's too much emphasis on products instead of thinking, what is essentially what we need to get out and finding the most efficient way to get it out . . . The media complains about this constantly, "Why do you guys have to issue so many different types of products?" All you have to do is look at our website in a tropical cyclone situation event. Oh, my God! I mean, it's unbelievable.

The NHC and WFO forecasters we interviewed want to do a better job of communicating hurricane risk to their warning system partners and to members

of the public, but they struggle with how to best do so given their knowledge, training, and institutional constraints.

Media information needs: Sooner, more, better. Given their role as communicators, the media want to present timely, aesthetically pleasing, and useful information to their audiences. Yet the media personnel we interviewed identified several ways in which the information they receive from NWS forecasters and emergency managers does not always meet their needs. One issue, discussed earlier, is that NWS products are sometimes too long and complex and contain content that is too technical for the media to easily translate into what members of the public need to know. This, along with the timing of NWS product issuance relative to television newscast timelines, squeezes the time broadcast meteorologists have to learn the latest forecast information and put together their weathercast.

Further, as a hurricane approaches, the media significantly increase the amount of time they devote to hurricane coverage, with television often covering the threat continuously (going “wall to wall”). During such times, media personnel crave updated information so they can tell an evolving story. They also want useful information so they can meet the needs of their listeners and viewers. An NHC forecaster noted:

[The media] always want the data sooner, quicker, they want insights. Can you whisper it in my ear? type of thing . . . They typically want more details, more specifics. They want more content. We tend to be very conservative, maybe rightfully so, on content, given the uncertainty. We don't want to hype things up, so they often want more content, more detail, more specifics, prettier pictures, things they can show on air, maybe things that are not appropriate to show on air.

This creates a tension between the media's pull for more updated, usable information sooner and the NWS's capabilities and desire to provide that information.

Television meteorologists want to use high-resolution visuals that convey key information simply and clearly to their audiences. Although the NHC and WFOs have started to generate more graphical products, these must still be adapted, often significantly, by the media before they can be used to communicate with the public. Some of the graphics produced by the NWS were critiqued by media personnel as being not very useful because they are too difficult

to understand, are of insufficient quality, or do not convey needed information. Although media outlets will always want to modify NWS graphics somewhat to differentiate themselves from other sources, having more useable graphics and graphics-ready data from the NWS and from the vendors that supply NWS information to the media nevertheless would help television meteorologists communicate updated hurricane information in a more timely manner.

The media also want to provide useful information on preparedness and response. Yet the media personnel we interviewed sometimes had difficulty obtaining accurate, updated information from local emergency managers as a hurricane threat evolved. To obtain this information, some members of the media expressed interest in getting a formal product from emergency managers at regular time intervals, similar to those issued by the NHC and WFOs. One said he “think(s) emergency managers should create their own HLS [Hurricane Local Statement] product.” Another requested a “fact sheet” or “public information statement”: “You know, just bullet points . . . It'd be nice if I could just go to an email and print off, 'this is what people need to do. . .' Because right now, that message is getting buried in press conferences. I have to dig for it. I have to go to their website, and sometimes it's not updated.”

As one member of the media explained, it is also important for public officials, including emergency managers, to go on air at critical times during a hurricane event and communicate directly with the public. “You don't want the meteorologist, even the chief meteorologist at the TV station, to tell people when to evacuate. It's not their call.”

As a hurricane approaches landfall, NWS forecasters and emergency managers are extremely busy and are working under their own organizational and political constraints. Nevertheless, since the media are a key disseminator of hurricane information to the public, it is important for them to have information from NWS forecasters and emergency managers that is as accurate, updated, and accessible as possible given situational uncertainty, competing demands, and other constraints.

Information for emergency management decisions: Time sensitive under uncertainty. As a hurricane approaches, emergency managers make protective decisions using criteria partly based on the hydrometeorological threat, but not necessarily the specific information provided by NWS forecasters. This can lead to potential gaps when emergency managers must map the NWS information they receive onto what they

need for their decisions, often under significant time pressure and uncertainty. For example, NHC and WFO forecasters consider watches and warnings to be one of their most important products for triggering protective decisions. The emergency managers we interviewed, however, said that “we don’t use watches and warnings as any of our triggers” because they must start preparations much earlier. The emergency managers do like to know in advance if and when watches and warnings will be issued, but primarily so they can anticipate decisions by businesses and other groups who do use watches and warnings as decision criteria.

Emergency managers interviewed instead emphasized their need to know when tropical-storm-force winds will arrive because they do not want major preparation activities to be occurring during those potentially dangerous conditions. Working backward from the expected arrival of tropical-storm-force winds, emergency managers use timelines to implement preparation measures. Currently, this key criterion must be calculated from other hurricane forecast information using software tools such as HURREVAC (2012). Thus, it would be useful for the NHC or WFOs to explicitly “include [the arrival] as another milestone,” say emergency managers. Some forecasters know how important the arrival information is to emergency managers’ decision making and try to provide it. However, it has yet to be formally included in NWS products.

Another area of mismatch is the provision and use of uncertainty information. NWS forecasters convey uncertainty as part of scientifically characterizing the hurricane threat, and they view this information as being useful to particular audiences in certain ways. For example, an NHC forecaster explained:

This [wind speed probability product] is mainly meant for EMs, I think, because a lot of the general public won’t really know—let’s say their area is under a 10% chance of extreme hurricane force winds—they may not really know what that means, what they should do with that information. So it’s really up to the EMs to take that information, give it to their public officials, and then they can say, “Based on this information, this is what we recommend that you do.”

Emergency managers account for hurricane forecast uncertainty in their decisions—but not necessarily in the way NWS forecasters expect. Instead, given their focus on protecting the public, they often take a conservative approach to ensure they

are ready for a worst-case scenario (Morss 2010). As described by one emergency manager, “We say, ‘When [the hurricane] comes straight nonstop and it intensifies,’ that’s how we plan for the uncertainty.” The other emergency manager explained, “The arrival for me is more important than probabilities because I have to assume the worst-case scenario.”

When emergency managers do not use the scientific uncertainty information conveyed in specific forecast products, forecasters sometimes misconstrue this as emergency managers not wanting any uncertainty information or not understanding forecast uncertainty. This view was expressed, for example, by an NHC forecaster: “[Emergency managers] typically don’t like probabilistic. They usually get frustrated and don’t want to mess with it.” Yet planning for the worst-case scenario is a way of considering uncertainty. Thus, the primary issue appears to be a disconnect between how emergency managers currently account for uncertainty in their decisions and what uncertainty information the NWS provides. Underlying this mismatch are differences in how scientists and practitioners think about and treat uncertainty (e.g., Morss et al. 2005; Demeritt et al. 2007). Given the influence of emergency management recommendations on lives and life safety, addressing these information gaps is an important challenge.

FINDINGS AND RECOMMENDATIONS.

Based on our analysis, we identified several opportunities for improving how NWS forecasters, local emergency managers, and local television and radio personnel interact with each other to create and communicate hurricane risk information.

- Strengthen warning system partnerships through regular interactions to improve understanding of each other’s priorities, constraints, and information capabilities and needs.

The success of the hurricane warning system relies on successful partnerships among NWS forecasters, emergency managers, and the media. Each group has its own job role and specialty, and no group can accomplish its role or achieve its goals without its partners. Members of each group are familiar with their own priorities, pressures, capabilities, and policies, but they typically only have a partial appreciation of others’ priorities. Improving understanding of each other’s work environments, needs, and goals can help the groups work together better to improve communication of hurricane risk information. We hope that this analysis is one step in that direction. Another

important step is for groups to regularly meet in person to discuss opportunities and needs for improved interactions and information exchange. We enthusiastically support current efforts that bring together diverse actors (e.g., the annual National Hurricane Conference), but we recommend that the groups also pursue locally oriented approaches. These could follow the Integrated Warning Team workshop model that brings together NWS forecasters, emergency managers, media, other warning system partners, and social science researchers within a geographic area (Dix and Fieux 2011; Rogers and Frazier 2011).

- Ensure that mechanisms for exchanging critical information are formalized, yet retain opportunities for flexibility in interactions.

During hurricane events, partners need information from each other, but everyone is busy and dealing with competing demands. Strong partnerships and personal relationships among group members can facilitate exchange of key information in these situations. However, relying on these informal mechanisms for information exchange is insufficient if some partners do not receive important information in a timely manner. For example, media personnel identified a need for more regular, updated information from emergency managers during hurricane threats. Thus, we recommend that the groups institutionalize formal mechanisms for exchanging critical information, following the examples of the hotline calls among NWS personnel and the briefings between NWS forecasters and emergency managers. In doing so, we recognize the importance of maintaining flexibility in intergroup interactions, given that each hurricane presents a unique situation.

- Focus on improving communication to audiences by using knowledge from risk communication and other social sciences to develop and test hurricane risk messages.

Given their specialties and job roles within the larger hurricane warning and response process, the groups we studied have limited direct ability to achieve their broader goal of saving lives and reducing harm. NWS forecasters, in particular, often feel frustrated and disheartened when they provide accurate hurricane forecasts and people nevertheless suffer harm. Meteorologists have a tendency to address such communication gaps by trying to educate their audiences about the scientific meaning of information. But often two-way interactions among information

providers and recipients are needed, to learn what information people want and can use in the decisions that matter to them (Fischhoff 1994; Vogel et al. 2007; Morss et al. 2008). In other words, although providing scientifically accurate information is important, communicating *the science* of hurricane threats is not the same as communicating *what people need to know* to effectively respond to hurricane risks (e.g., Weigold 2001). Thus, we recommend that NWS forecasters and warning system partners not dwell on what they cannot do and focus instead on what they can do: improve how they communicate about weather threats to enhance understanding of risks and motivate action to the extent possible.

NWS forecasters, emergency managers, and media personnel can improve how they convey hurricane risk messages through awareness and application of risk communication knowledge and best practices (Fischhoff 1995; Bier 2001; Lundgren and McMakin 2009; Heath and O'Hair 2009). More specifically, most NWS products are based on incomplete perceptions of audience needs rather than on sufficient research and user-oriented product development (e.g., Broad et al. 2007). Thus, to improve communication of hurricane threats, we recommend that the NWS and warning system partners collaborate with social scientists, including experts in communication, psychology, sociology, economics, anthropology, human geography, and other relevant areas, to 1) improve knowledge about how audiences interpret and use hurricane forecast and warning information and 2) apply this knowledge to rigorously design and test hurricane risk messages with intended audiences.

- Evaluate, test, and improve the NWS product suite through collaborations among warning system partners and with social scientists.

We identified several challenges with the volume, complexity, and content of NWS products that are important to address. If the media, emergency managers, and others do not get or cannot easily extract needed information from the suite of NWS products, then they cannot effectively communicate or respond to impending hurricane threats. Examples of this include 1) the need identified by the emergency managers interviewed for information about the timing of arrival of tropical-storm-force winds and 2) the challenge encountered by media personnel interviewed to quickly find updated information about the threat for a given area. Two-way dialogues through meetings between NWS personnel and their partners, as recommended above, can help bridge

these gaps. Yet such conversations are not sufficient; more formal mechanisms are also needed to help emergency managers and media personnel articulate their information needs and to connect these to what NWS forecasters can reasonably provide. Thus, we recommend that the NWS systematically evaluate its full hurricane-related product suite, especially before adding more products or more information to existing products.

Such evaluations should apply formal methods to examine the usability of current NWS products, identify opportunities for streamlining NWS products, and investigate ways to provide hurricane risk information that NWS's primary partners want and is appropriate given the NWS's roles relative to private sector forecasting entities. Doing so will require NWS working with emergency managers, the media, the private sector, and other warning system partners as well as with social scientists. Because the hurricane warning system environment is continually evolving, the NWS will need to implement such evaluations at regular intervals. We also recommend that the NWS work with the media and its vendors to provide graphics or data that can more readily be translated into visuals for communicating with the public.

This research focuses on hurricanes and is based largely on data from a specific geographic region. The specifics of the partnerships and the challenges of communicating hurricane risk may vary in different geographic areas based on, for instance, hurricane experience, governmental structure, demographics, and culture. Nevertheless, we believe our findings and recommendations can serve as a starting point for improving the creation and communication of hurricane messages in all areas and about weather risks more broadly. Addressing these types of issues is particularly important given that changes in technology and communication channels—especially the explosion in the use of the Internet, smartphones, and social media—are rapidly changing how people access and interpret hazardous weather information. NWS forecasters, emergency managers, and media personnel who create and communicate weather risk information must be proactive in adapting to this increasingly fragmented communication environment. To do so, we recommend that meteorologists and others interested in communicating weather-related risk reframe concerns that “people don’t understand our information” into action to address the question, “how can we work together to best communicate in a way that people understand and can use?” Doing so is essential to achieving the overarching goals of saving lives and reducing harm.

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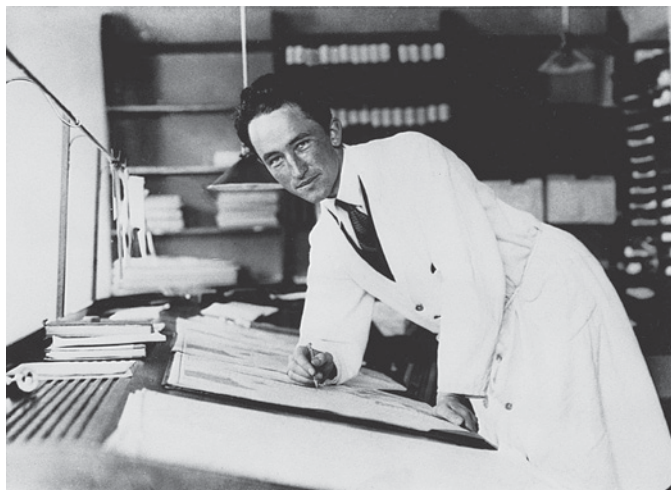
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THE LIFE CYCLES OF EXTRATROPICAL CYCLONES



Edited by Melvyn A. Shapiro and Sigbjørn Grønås

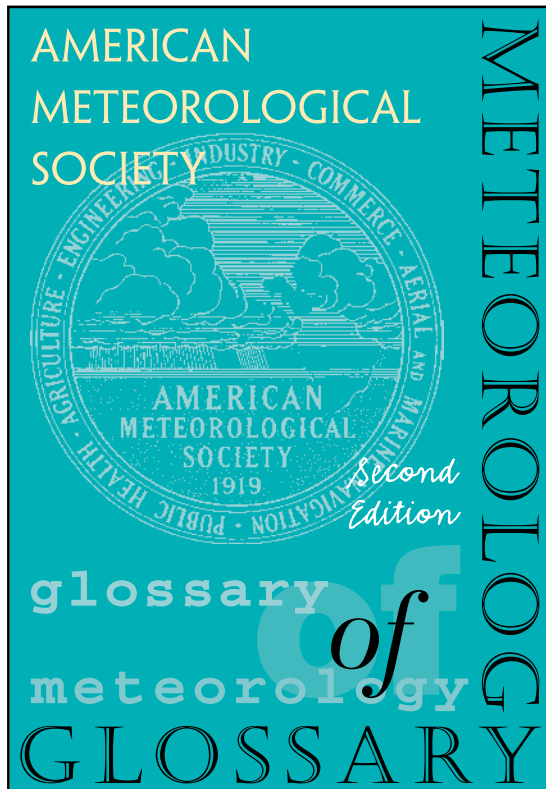
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THE SECOND VERIFICATION OF THE ORIGINS OF ROTATION IN TORNADOES EXPERIMENT

VORTEX2

BY JOSHUA WURMAN, DAVID DOWELL, YVETTE RICHARDSON, PAUL MARKOWSKI, ERIK RASMUSSEN, DONALD BURGESS, LOUIS WICKER, AND HOWARD B. BLUESTEIN

VORTEX2 is the largest, most ambitious study focused on improving our understanding of tornadoes, including tornadogenesis, tornado structure, and improving forecasts.

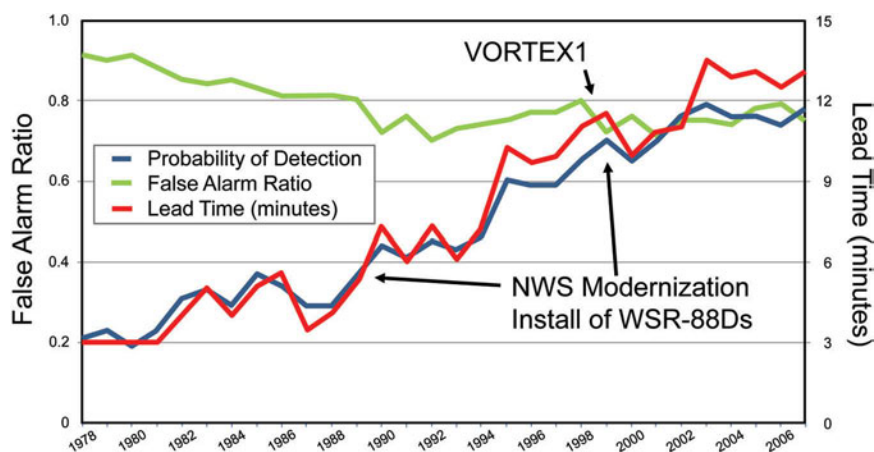


FIG. 1. History of lead times, probability of detection, and false-alarm rates for tornado warnings. Improvements in warning performance are related to introductions of new technology and forecasting methods.

Nearly all of the most intense tornadoes, those capable of causing the most widespread damage and largest number of fatalities, are spawned by supercell thunderstorms. Recently, computer models and observing technology used to study supercells have become more accessible and increasingly sophisticated, enabling detailed scientific exploration of supercells and tornadoes. Improvements to tornado forecasts and warnings in recent decades may be linked to improvements in observing technology and understanding of processes related to tornado formation (Fig. 1). Although these advances have led to an increase in knowledge and improvements to conceptual models of the processes governing tornadic storms, they also have illuminated gaps in our understanding of tornadogenesis and evolution, particularly those aspects of the problem that require contemporaneous knowledge of ►

the wind, thermodynamic, and precipitation fields in and around supercells.

These gaps in our knowledge, and improvements in observing capabilities, motivated the second Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2) as a successor to the original VORTEX (VORTEX1) and other smaller follow-on programs. Using the latest developments in quickly deployable observing technology, the primary objectives of VORTEX2 were to obtain simultaneous wind, precipitation (p), and thermodynamic data to i) better understand and document the processes underlying tornadogenesis, intensification, maintenance, and demise; ii) identify properties of the local environment that are influential in the tornado life cycle; iii) improve computer modeling and prediction of supercell thunderstorms and tornadoes; and iv) improve our understanding of the near-surface structure of tornadoes and the relationship between tornadic winds and damage.

The overarching goal of VORTEX2 was to improve the understanding of the processes thought essential to improving the accuracy, lead time, and false-alarm rates of tornado warnings. Delineating the subtle, poorly understood, and/or difficult-to-observe differences among nontornadic supercells, weakly tornadic supercells, and violently tornadic supercells would further this improvement. Additional objectives of VORTEX2, thought to be important for improving forecast skill, were to determine how storms interact with each other and with their local environment and how these interactions

affect tornado genesis, maintenance, and demise. Data collected by VORTEX2 also will be used for the development of storm-scale numerical weather prediction (NWP) systems. Finally, because many of the details concerning tornado structure are not well understood, such as the vertical distribution of winds and the intensity and variability of winds near the surface, VORTEX2 sought detailed documentation of tornado structure and its relationship to damage.

RECENT OBSERVATIONAL STUDIES OF SUPERCELLS AND TORNADOES.

Our knowledge of tornadoes and supercell storms progressed substantially during the latter portion of the previous century (e.g., Ludlam 1963; Lemon and Doswell 1979; Doswell and Burgess 1993; Davies-Jones et al. 2001; Markowski and Richardson 2009). However, until the mid-1990s, much of this understanding arose from theoretical, laboratory, and numerical models as well as from low-resolution observational studies. Major portions of the conceptual understanding of tornadogenesis were unverified by actual observations.

VORTEX1: 1994–95. A pivotal moment occurred in 1994–95, when VORTEX1 established a new experimental paradigm and pioneered a decade of targeted, mobile experiments that focused on tornadic storms and greatly enhanced our understanding of supercell thunderstorms (Rasmussen et al. 1994). Potentially tornadic storms were targeted by an array of instrumentation, including a quickly scanning mobile Doppler radar (Wurman et al. 1997; Wurman 2001, 2008), FM-CW and W-band radars (Bluestein et al. 1995, 1997), an array of instrumented vehicles (the mobile mesonet; Straka et al. 1996), several mobile balloon sounding systems (Rust et al. 1990), several mobile photogrammetric teams, deployable in situ instrumentation (Winn et al. 1999), and an aircraft fitted with a pseudo-dual-Doppler radar system (Wakimoto and Atkins 1996). This targetable array of cutting-edge instrumentation permitted the study of tornadoes and supercells with a degree of detail and breadth never before achieved. VORTEX1 established the viability of employing a large, fully adaptable array of land- and air-based instrumentation to sample short-lived, rare, and nonstationary phenomena such as tornadoes. Data, techniques, and knowledge from VORTEX1 were used by many researchers (e.g., Wakimoto and Atkins 1996; Wurman et al. 1996a,b, 1997; Dowell and Bluestein 1997, 2002a,b; Markowski et al. 1998a,b,c, 2002, 2003, 2008; Wakimoto et al. 1998; Wakimoto and

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Liu 1998; Trapp 1999; Rasmussen et al. 2000, 2006; Wurman and Gill 2000; Ziegler et al. 2001; Gilmore and Wicker 2002; Fierro et al. 2006; Richardson et al. 2007; Straka et al. 2007) to advance our knowledge of tornadic storms.

VORTEX1 resulted in a qualitative change in our understanding of tornadic storms. Observations revealed striking kinematic similarities between tornadic and nontornadic supercells at scales just larger than the tornado, suggesting that tornadogenesis is a perhaps fragile process that may depend on subtle, unobserved differences in morphologies and processes within supercells and their ambient environments. As such, it is now known that both tornadic and nontornadic supercell storms can contain strong low-level mesocyclones (Trapp 1999; Markowski et al. 2011). Though the importance of downdrafts in tornadogenesis was hypothesized before VORTEX1 (e.g., Ludlam 1963; Davies-Jones 1982a,b), VORTEX1 field observations and recent idealized simulations suggest that the thermodynamic properties of the downdraft may play an important role in modulating tornado formation and intensity (Markowski et al. 2002, 2003). Our awareness of the prevalence of mesoscale heterogeneities, such as those associated with outflow boundaries and anvil shadows in the supercell environment, has been heightened, leading to numerical simulations to study their effects on the evolution of convective storms (Atkins et al. 1999; Gilmore and Wicker 2002; Fierro et al. 2006; Richardson et al. 2007; Frame and Markowski 2010). Strong and violent tornadoes often were found to be associated with preexisting mesoscale boundaries (Markowski et al. 1998c).

Additionally, finescale observations of tornado structure and evolution were first obtained during VORTEX1. The first detailed three-dimensional maps of the winds in tornadoes were obtained by the prototype Doppler on Wheels (DOW) mobile radar. These three-dimensional maps of the core flow and surrounding regions with fine temporal and spatial resolution permitted the documentation of the horizontal (H) and vertical (V) distribution of intense winds and their evolution, central downdrafts, rapid changes in tornado structure, and the vertical and horizontal distribution of debris (Wurman et al. 1996a,b; Wurman and Gill 2000; Rasmussen and Straka 2007).

Post-VORTEX1 field projects. Building on the adaptive, targeted experimental design of VORTEX1, several smaller field programs focusing on tornadoes and supercell thunderstorms were undertaken

during the 1996–2008 period. Several programs, such as sub-VORTEX with rear-flank downdraft (RFD; (Markowski et al. 2002; Shabbott and Markowski 2006) and Analysis of the Near-Surface Wind and Environment along the Rear-Flank of Supercells (ANSWERS) concentrated on thermodynamic observations, primarily using mobile mesonet vehicles to study the properties of downdrafts and their relationship to tornadogenesis (e.g., Lee et al. 2004; Lee et al. 2011). Other field projects including the Radar Observation of Thunderstorms and Tornadoes Experiment (ROTATE; Wurman 1998, 1999, 2003, 2008), utilized mobile or quickly deployable high-resolution radars to study tornadogenesis and maintenance (Dowell et al. 2002; Bluestein et al. 2003a; Wurman et al. 2007b,c; Marquis et al. 2008; Wurman et al. 2010; Marquis et al. 2012); tornado structure (Wurman 2002; Bluestein et al. 2003b, 2004; Alexander and Wurman 2005; Lee and Wurman 2005; Bluestein et al. 2007a,b; Tanamachi et al. 2007; Kosiba et al. 2008; Kosiba and Wurman 2010); storm-scale processes coincident with tornadogenesis (Wurman et al. 2007c; Biggerstaff et al. 2008; Byko et al. 2009); the relationship between tornadic winds, debris, and damage (Burgess et al. 2002; Wurman and Alexander 2005; Dowell et al. 2005; Wurman et al. 2007a); and supercells that did not produce tornadoes (Beck et al. 2006; Frame et al. 2009; Markowski et al. 2011). ROTATE operated 12 of the 13 post-VORTEX2 years (1996–2001 and 2003–08) and utilized up to three DOWs, including a rapid-scan DOW (Wurman et al. 2008), mobile mesonet vehicles, and 12 instrumented in situ tornado pods. It collected single- and/or dual-Doppler data in approximately 140 different tornadoes and in many nontornadic supercells, allowing for the construction of a radar-based climatology of tornado characteristics and kinematics (Alexander and Wurman 2008; Alexander 2010).

MAJOR OUTSTANDING QUESTIONS IN TORNADO SCIENCE.

Although the aforementioned studies have continued to advance our understanding of tornadoes and supercell storms, the lack of contemporaneous thermodynamic data and high-resolution, radar-derived wind fields has limited the ability of these studies to fully diagnose the processes involved with tornadogenesis, evolution, and structure, because the development of low-level rotation is likely to depend on both the vorticity present in the environment as well as that developed baroclinically within the storm's cold pool. Evaluating the contributions of each of these requires knowledge of both the wind and thermodynamic

fields over multiple spatial scales and over temporal periods extending far enough before tornadogenesis that parcels participating in the genesis process can be traced back through the storm, revealing the source of rotation. Recently, several data assimilation techniques for convective-scale models have been utilized to retrieve the three-dimensional thermodynamic and hydrometeor fields from single-Doppler data (e.g., Dowell et al. 2004; Marquis et al. 2012) but, without observations to verify or refute model-generated output, the veracity of these computer-generated fields remains largely untested. Several key focus areas requiring additional study were identified.

Tornadogenesis. The most pressing problems in tornado science are centered on predicting the occurrence of significant tornadoes [i.e., tornadoes capable of inflicting damage corresponding to an enhanced Fujita (EF) scale rating of 2 or higher]. Identifying those storms that will produce significant tornadoes is critical because most fatalities and catastrophic damage are associated with the small fraction of tornadoes that exhibit the most intense wind speeds (a fraction that may be larger than previously thought; (Alexander and Wurman 2008; Alexander 2010) and the even smaller fraction that impacts densely populated areas (Brooks and Doswell 2001; Wurman et al.

2007a). However, this identification is complicated by the following observations:

- although most significant tornadoes are spawned from supercell thunderstorms, most supercell thunderstorms do not produce tornadoes and an even smaller fraction produce significant tornadoes (Trapp et al. 2005);
- if a tornado does occur, it only occurs during a small portion of the lifetime of the supercell thunderstorm; and
- most tornadic supercell thunderstorms, even when producing tornadoes, do not produce significant tornadoes (Verbout et al. 2006).

A brief review of our current knowledge of tornadogenesis is presented here. The reader is referred to Davies-Jones et al. (2001) and Markowski and Richardson (2009) for more detailed reviews. In the absence of preexisting environmental vertical vorticity, supercell thunderstorms acquire midlevel rotation through the tilting of environmental horizontal vorticity by an updraft and the subsequent stretching of this now vertical vorticity by the horizontal convergence associated with the updraft (Rotunno 1981; Lilly 1982; Davies-Jones 1984). Although the tilting of horizontal vorticity solely by an updraft can produce

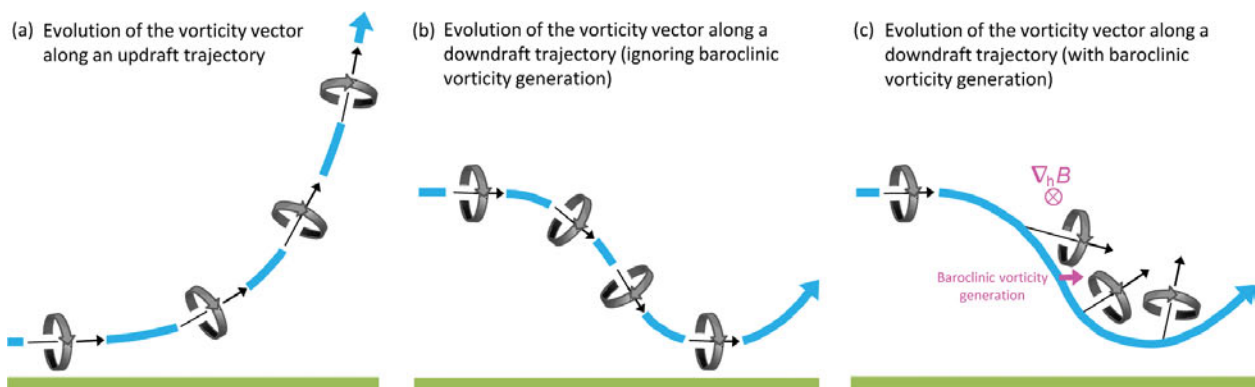


FIG. 2. Evolution of the vorticity vector (thin black arrows; the sense of rotation is indicated by the broad, curled black arrows) along trajectories (blue) in three situations. The upstream vorticity is streamwise in each case. (a) In the case of air rising through updraft, tilting of horizontal vorticity by the updraft alone cannot produce vertical vorticity at the surface because air is rising away from the surface as vertical vorticity is acquired. (b) In the case of air subsiding through a downdraft in which baroclinic vorticity generation is neglected, the horizontal vorticity is tilted downward during descent and returns to a horizontal orientation at the surface. (c) In the case of air subsiding through a downdraft in which horizontal vorticity is generated baroclinically by a horizontal buoyancy (B) gradient, such that warm air is into the page (the direction of vorticity generation is toward the right and indicated by the magenta arrow), the baroclinic vorticity generation introduces, in the words of Davies-Jones and Brooks (1993, p. 113), a “slippage between the descending fluid and vortex lines.” Subsequent tilting of the vorticity vector allows air parcels to reach the surface having cyclonic vorticity. Intense stretching can further amplify the vertical vorticity near the surface (such stretching probably requires that the downdraft parcels not be too negatively buoyant, lest they cannot ascend and be associated with large dw/dz). Here, (c) is adapted from Davies-Jones and Brooks (1993).

intense rotation at midlevels, no near-surface rotation is generated because vertical vorticity only develops as parcels rise away from the surface (Fig. 2). Therefore, downdrafts are critical in transporting and/or generating (through baroclinic effects and subsequent tilting) low-level vertical vorticity (e.g., Davies-Jones 1982a,b; Rotunno and Klemp 1985; Walko 1993; Davies-Jones and Brooks 1993; Straka et al. 2007). Indeed, dual-Doppler analyses (e.g., Brandes 1978; Dowell and Bluestein 1997; Wakimoto and Cai 2000; Dowell and Bluestein 2002a) and numerical simulations indicate that at least some air parcels pass through the RFD before entering the tornado (Wicker and Wilhelmson 1995).

Downdrafts have long been observed in the rear flanks of both tornadic and nontornadic supercells (e.g., Ludlam 1963; Fujita 1975; Burgess et al. 1977; Lemon and Doswell 1979). Surface observations of the RFD suggest that different combinations of microphysical and dynamical processes may be important in different supercells, at different locations within individual RFDs, and at different times in the same supercell (Markowski et al. 2002; Grzych et al. 2007; Hirth et al. 2008). Some tornadic supercells contain multiple rear-flank gust fronts (RFGFs; Wurman et al. 2007c; Marquis et al. 2008; Wurman et al. 2010; Marquis et al. 2012), suggesting that some forcing mechanisms may be transient and that RFD air reaching the ground nearly contemporaneously within the same supercell may reach the ground with substantially different thermodynamic properties (Finley and Lee 2004, 2008; Grzych et al. 2007). The relative importance of these processes in tornadogenesis is poorly understood.

Supercells and their environments. Understanding how the environments of supercell thunderstorms affect their propensity to cause tornadoes is critical to our ability to forecast tornadogenesis. Studies have shown that environmental variability and surface boundaries can affect storm structure and may instigate tornadogenesis (e.g., Maddox et al. 1980; Marwitz and Burgess 1994; Brooks et al. 1994, 1996; Weckwerth et al. 1996; Markowski et al. 1998c; Rasmussen et al. 2000; Richardson et al. 2007). Although many numerical studies have been conducted on isolated supercell thunderstorms (e.g., Rotunno and Klemp 1985), supercells in nature are rarely isolated and their environments are frequently complex (e.g., Ziegler et al. 2001). Supercells can develop from multiple smaller cells (Bluestein and Parker 1993), and rapid changes can occur after interaction with another cell (e.g., Lemon 1976; Lee et al. 2000; Bluestein and

Gaddy 2001; Hastings and Richardson 2010). Tornadogenesis may occur after storm mergers (Lee et al. 2000; Houston and Wilhelmson 2011; Dowell and Bluestein 2002a,b; Magsig and Dowell 2004). Wurman et al. (2007c) hypothesized that tornadoes resulting from cell mergers might tend to be weak and short lived. It is not clear which interactions promote tornadogenesis and which are detrimental.

Low-level winds in tornadoes. Computer, laboratory, and conceptual models of tornado vortices [for a more detailed review, see Davies-Jones et al. (2001)] remain largely unsubstantiated by reliable quantitative observations of actual tornadoes. In order to have confidence in conceptual models and theories developed from laboratory and numerical experiments, quantitative observations are needed in a variety of actual tornadoes having a variety of observed structures.

Although observational studies of the low-level and core-flow regions are challenging, observations by radar and in situ instruments occasionally have been obtained. The most frequent observations have been by mobile radars at close range to tornadoes (e.g., Wurman et al. 1996a,b, 1997; Wurman and Gill 2000; Bluestein and Pazmany 2000; Wurman 2002; Lee and Wurman 2005; Bluestein et al. 2004; Wurman and Alexander 2005; Alexander and Wurman 2005; Bluestein et al. 2007a; Tanamachi et al. 2007; Kosiba et al. 2008) and occasional in situ observations (Winn et al. 1999; Lee et al. 2004; Wurman and Samaras 2004; Wurman et al. 2007a). In a limited number of cases, some basic predictions of the conceptual and computational models have been confirmed, including the quasi-linear relationship between wind speed and distance to the axis of rotation in the core-flow region. Sub-tornado-scale vortices within large tornadoes also have been mapped (Wurman 2002; Alexander and Wurman 2005), as have the vertical distribution of wind speeds (Wurman et al. 1996a; Wurman and Gill 2000; Bluestein et al. 2004; Wurman and Samaras 2004; Alexander and Wurman 2005; Bluestein et al. 2007a; Wurman et al. 2007a), with suggestions of convergent inflow at the lowest levels (Alexander and Wurman 2005; Wurman et al. 2007a; Kosiba et al. 2008).

Model simulations with a wind engineering focus, such as those conducted by Fouts (2003), Sengupta et al. (2003), and Selvam and Millet (2003), have sought to modify traditional, straight-line wind engineering studies, including those based on wind tunnel experimentation. Preliminary results suggest that changing winds produce more damage than static wind conditions. McDonald (2001) and Marshall

(2002, 2004) have suggested that the wind speed–damage relationships implied in the original Fujita scale overestimate the peak winds in tornadoes. Based on comparisons of direct radar observations and observed damage, Wurman and Alexander (2005) proposed that changing wind speeds and directions and/or the integrated effect of wind-speed moments are correlated with damage just as well as peak-wind-gust Fujita-scale-type metrics. Except for this single case, there exists no extensive field validation of measured winds compared to a diverse range of damage. Consequently, until the actual nature of the tornado low-level wind threat can be better quantified, building codes cannot be intelligently designed to mitigate this threat.

Storm-scale NWP. During VORTEX2 field operations, the forecasting and field coordination team incorporated experimental real-time convection-allowing NWP models (Clark et al. 2011) into the process of selecting target regions and anticipating convective-storm evolution. Supporting the development of the next generation of high-resolution NWP systems (Stensrud et al. 2010; Xue et al. 2000), VORTEX2 NWP research is focusing on analysis and prediction of supercells, mesocyclones, and tornadoes; assessment of parameterization errors for storm-scale models; optimal use of observations; and analysis and prediction of the prestorm mesoscale environment. Unprecedented multisensor and multiscale observations obtained in the field are available for model initialization and forecast verification, enabling one to determine the optimal mix of observations, adaptive observing strategies, data assimilation methods, and forecast models needed for successful storm-scale NWP.

THE VORTEX2 FIELD EXPERIMENT.

Although VORTEX1 and other projects have increased substantially our knowledge of tornadogenesis, evolution, and structure, key questions remain and appear not to be fully addressable using only the observations provided by these efforts. Specifically, there is a need to observe supercell evolution prior to and during tornadogenesis as well as during the entire life cycle of the tornado. At minimum, these observations need to span periods of 1000–2000 s in order to capture key evolutionary processes. In addition, simultaneous radar observations must be obtained at multiple scales, including the storm scale, covering substantial portions of the supercell up to well above the melting layer; the mesocyclone scale, resolving the kilometer-scale flow surrounding the

tornado throughout the rear-flank region; and the tornado scale, resolving the tornadic circulation itself. Storm- and mesocyclone-scale radar observations should allow for dual-Doppler synthesis to reconstruct important kinematic fields (e.g., vorticity and divergence) within and around the storm. Critically, contemporaneous thermodynamic data are required in various regions of the storms, particularly in the inflow, across gust fronts, and within the rear- and forward-flank downdraft regions.

VORTEX2, managed by a steering committee comprising the authors of this report, was designed to address these questions. Documentation related to VORTEX2, including the scientific program overview (SPO), experimental design overview (EDO), and operations plan, as well as lists of principal investigators, instrumentation, and other information, can be found at the VORTEX2 website (www.vortex2.org). A field catalog is maintained by the National Center for Atmospheric Research (NCAR; at http://catalog.eol.ucar.edu/vortex2_2010 and http://catalog.eol.ucar.edu/vortex2_2009).

Project domain and nomadic plan. In order to maximize the number of tornadic supercells intercepted, VORTEX2 operations followed the ROTATE nomadic model and were conducted in a substantially larger area of the Great Plains than was done in VORTEX1, extending from the Dakotas to southwestern Texas and from Colorado/Wyoming to Iowa/Missouri, covering more than 1.2×10^6 km² (Fig. 3). Operations in urban areas, in hilly and/or forested terrain, and in areas with few roads were avoided when possible.

Data collection phase. Tornadoes are of short duration, and they occur relatively infrequently, irregularly, and in different geographical locations each year. Planning an experiment that targeted such a fickle phenomenon posed unique challenges. Ideally, one would conduct a many-year study and operate throughout the entire peak tornado season, which extends from March until July (Brooks and Doswell 2001) but, because of limitations of funding and staffing, it was impractical to do so. The ROTATE project, which intercepted approximately 140 tornadoes over 12 field seasons, provided a statistical basis for choosing the optimal field operation period and for estimating the level of success that could be reasonably anticipated by VORTEX2.

Operating over various spatial domains and time periods, sometimes shorter and smaller than planned for VORTEX2, ROTATE observed tornadoes on an average of 4.9 days per season and

significant tornadoes (F2/EF2 or greater), which were of the greatest interest to VORTEX2, on 1.3 days per season. Data were collected in zero significant tornadoes during 4 of the 12 seasons, yielding an F2+ “failure” rate of 33%. However, these failure seasons were uncorrelated and occurred during consecutive years only once, or 1 out of 11 possible seasons (9%). Thus, it was decided to spread the VORTEX2 field operations over two years, focusing on the most likely time for tornado occurrence in the Great Plains. Operations were planned for 10 May–15 June 2009 and 1 May–15 June 2010.

Observational strategies. One of the central and most ambitious goals of VORTEX2 was to obtain contemporaneous radar data at multiple scales (storm scale, mesocyclone scale, and tornado scale) in tandem with in situ thermodynamic and microphysical data collected by a combination of mobile mesonets, arrays of deployable weather stations (StickNet and pods), an unmanned aerial system (UAS), rawinsondes, and disdrometers. These integrated, multiplatform observations, at the surface and aloft, for long durations and at frequent intervals, were critical to testing many of the hypotheses related to tornadogenesis, evolution, and structure. VORTEX2 employed approximately 50 vehicles and was staffed by approximately 110 participants (Table 1), more than half of whom were students.

NESTING OF STORM-SCALE AND MESOCYCLONE-SCALE RADAR ARRAYS. The multiscale radar observations were accomplished by deploying nested groups of radars (Fig. 4). Storm-scale coverage was provided by two University of Oklahoma (OU) C-band (5.5 GHz) Shared Mobile Atmospheric Research and Teaching (SMART) radars (Biggerstaff et al. 2005) deployed approximately 20–30 km to the south of the forecast track of a supercell thunderstorm, with a baseline of ~35 km, resulting in a dual-Doppler surveillance area of ~1,500 km² and extending lengthwise for approximately 50 km along the storm’s path. Ideally, assuming a typical storm motion of 10 m s⁻¹, dual-Doppler observations through the entire depth of the storms could be obtained in this configuration for ~1.5 h. (Table 2)

An array of four X-band (9.4 GHz) radars from the Center for Severe Weather Research (CSWR) (DOW6 and DOW7), the National Severe Storms Laboratory (NSSL) (NOXP; Palmer et al. 2009), and the University of Massachusetts (UMASS) (UMASS XPOL; Kramar et al. 2005) ideally deployed in a line ~10 km to the south of the path of the hook of

the supercell, spaced 10–20 km apart, establishing an elongated region of fine-spatial-resolution dual-Doppler coverage along the path of the mesocyclone. As soon as the mesocyclone passed the rearmost X-band radar, that radar would move forward to the head of the X-band line, thereby ensuring continuous dual-Doppler coverage at the mesocyclone scale. The Mobile Weather Radar 2005 X-band Phased Array (MWR-05XP) (Bluestein et al. 2010a) would

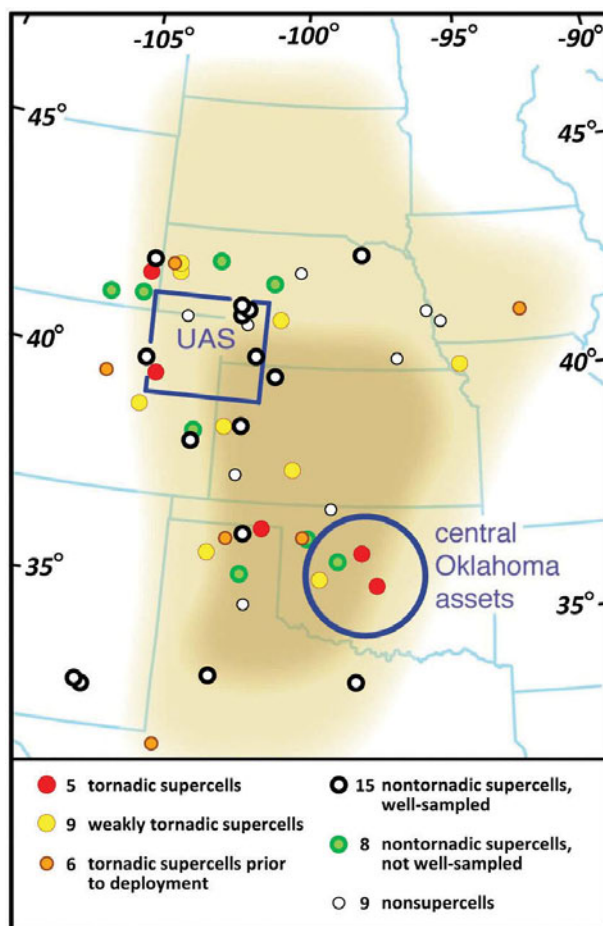


FIG. 3. The VORTEX2 operational domain. VORTEX2 operated in a nomadic fashion throughout a large portion of the high plains and surrounding area. Operations near certain fixed (Oklahoma) and restricted (UAS) assets were sometimes prioritized. Operations in the central portion of the domain (dark shade) were preferred because of superior terrain (fewer hills, trees, and urban areas) and road networks. Locations of VORTEX2 intercepts of various types of storms are indicated. During 2009–10, about 40 supercell thunderstorms were sampled, as summarized in the following: 5 tornadic supercells; 9 weakly tornadic supercells; 6 tornadic supercells prior to deployment; 15 nontornadic supercells well sampled; and 8 nontornadic supercells not well sampled. Nine nonsupercell storms are indicated.

TABLE 1. List of major instruments and operating institutions.

Instrument name	Operating institution	Description
SMART-RI	OU	C band (5 cm)
SMART-R2	OU	C band (5 cm), dual polarization
DOW6	CSWR	X band (3 cm), dual polarization, dual frequency, 18 m T, RH, Wind
DOW7	CSWR	X band (3 cm), dual polarization, dual frequency, 18 m T, RH, Wind
Rapid-scan DOW	CSWR	X band (3 cm), 6 simultaneous beam rapid scan, 14 m AGL, R, RH, Wind
NOXP	NSSL	X band (3 cm), dual polarization
UMASS XPOL	UMASS	X band (3 cm), dual polarization
TTUKa1	TTU	Ka band (1 cm)
TTUKa2	TTU	Ka band (1 cm)
UMASS-WV	UMASS	W band (3 mm)
MWR-05XP	NPS/CIRPAS	X band (3 cm), phased-array rapid scan
FC	NSSL	Communications and SASSI control center
Tornado pods (18 platforms)	CSWR (16), CU (2)	1-m wind, T, RH; hardened for in situ tornado measurements
StickNet (24 platforms)	TTU	2-m wind, T, RH; tripods
UAS	CU	Airborne T, RH
MGAUS	NSSL (2), NCAR (2), SUNY(1)	Mobile, van based, upsonde systems
Mobile mesonets	PSU/NSSL (6), CSWR (4)	3-m wind, T, RH, ρ ; vehicle mounted
Laser disdrometers	CU (2), UF (6), NSSL (1), NSSL/UI/NCAR (2)	Parsivel laser disdrometers
Photogrammetry	LSC, OU, NCAR	Cameras, some with integrated GPS navigation

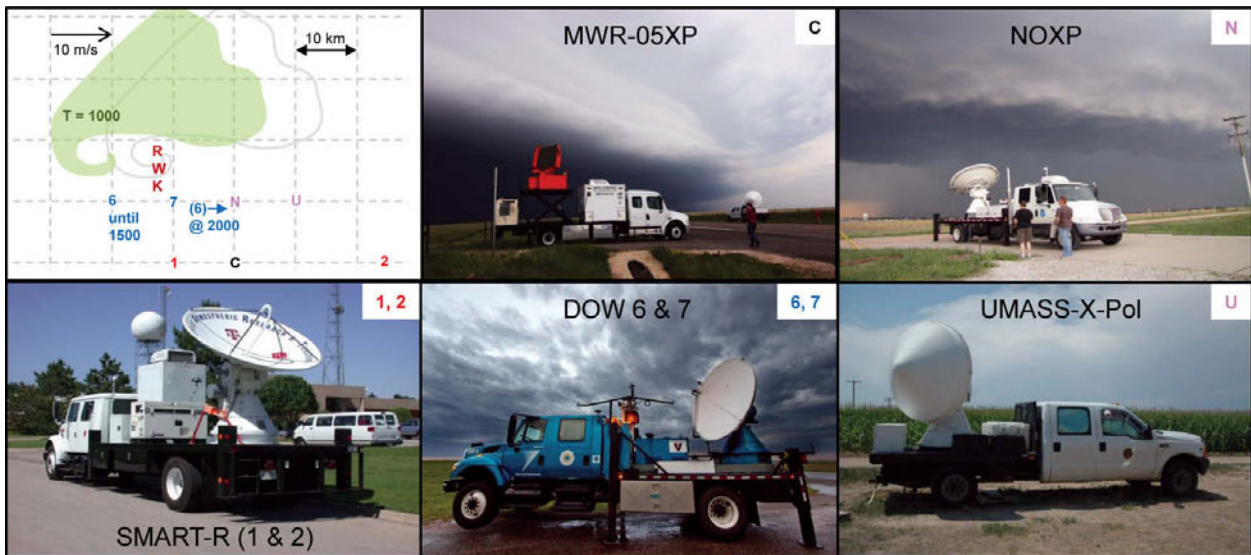


FIG. 4. VORTEX2 radars and deployment schematic: Storm- and mesocyclone-scale radars and a schematic of a typical deployment on a supercell. Storm-scale radars SMART-I (1), SMART-2 (2), and MWR-05XP (C) deploy well to the south of the storm, establishing long-duration, dual-Doppler coverage. Mesocyclone-scale radars DOW6 (6), DOW7 (7), NOXP (N), and UMASS XPOL (U) establish transient dual-Doppler baselines just to the south of the hook, leapfrogging in order to maintain continuous coverage. Tornado-scale radars (no photos shown) rapid-scan DOW (R), UMW (W), and TTUKa1, and TTUKa2 (K) deploy near to developing or existing tornadoes.

TABLE 2. Radar characteristics of VORTEX2 radars and lidar.

Radar name	Wavelength	Transmitter	Polarization	Volume time	Beam width, range resolution
SMART-R1	5 cm	mag 250 kW	H	180 s	1.5°, 63 m
SMART-R2	5 cm	mag 250 kW	Dual polarization	180 s	1.5°, 63 m
DOW6	2 × 3 cm	mag 2 × 250 kW	Dual polarization Dual frequency	120 s deep 60 s shallow	0.9°, 30–60 m
DOW7	2 × 3 cm	mag 2 × 250 kW	Dual polarization Dual frequency	120 s deep 60 s shallow	0.9°, 30–60 m
Rapid-scan DOW	3 cm	TWT 40 kW	H	7 s (rapid scan)	0.8°, 25–50 m
NOXP	3 cm	mag 250 kW	Dual polarization	120–180 s	1.0°, 75 m
UMASS XPOL	3 cm	mag 20 kW	Dual polarization	120–180 s	1.2°, 60–150 m
TTUKa1	1 cm	mag 10 kW	H		0.5°, 30 m
TTUKa2	1 cm	mag 10 kW	H		0.5°, 30 m
UMASS-W	3 mm	mag 1 kW	V		0.2°, 30–60 m
MWR-05XP	3 cm	TWT 15 kW	H	12 s (rapid scan)	2.0°, 75–150 m
TWO-LF	2 μm				

deploy to observe at the mesoscale and storm scale, providing deep volume updates at 7–14-s intervals.

A lidar system, the Truck-Mounted Wind Observing Lidar Facility (TWOLF), was attached to this platform (Bluestein et al. 2010b).

This was an idealized deployment strategy that was only approximately achieved in real-world conditions. However, on several occasions, nested storm-scale/mesocyclone-scale arrays were established successfully, such as on 9 June 2009 (Fig. 5).¹



FIG. 5. Snapshot of actual deployment of various radars. Storm and mesocyclone-scale radars are deployed in real-world road and terrain conditions in Kansas on 9 Jun 2009 on a marginally tornadic supercell to establish multiple-Doppler coverage.

SURFACE AND AIRBORNE IN SITU OBSERVATIONS INTEGRATED INSIDE DUAL-DOPPLER AREAS. Temperature (*t*), relative humidity (RH), wind, and pressure measurements at the surface and aloft are needed to characterize the thermodynamic and kinematic properties of the air in and around supercells. Several platforms were used to collect these data within the radar

¹ These idealized deployment strategies were rarely realized in practice, because of complications related to real road networks, storm motion/morphology, and other logistics. Radars would sometimes experience delays; have difficulty finding deployment sites unblocked by trees, terrain, or buildings; malfunction; or be unable to redeploy owing to intense intervening precipitation, traffic, poor road networks, or even low clearance overpasses. In general, an attempt was made to have the rearmost radars move to the front of the array so that multiple-Doppler radar coverage was maintained as continuously as possible.

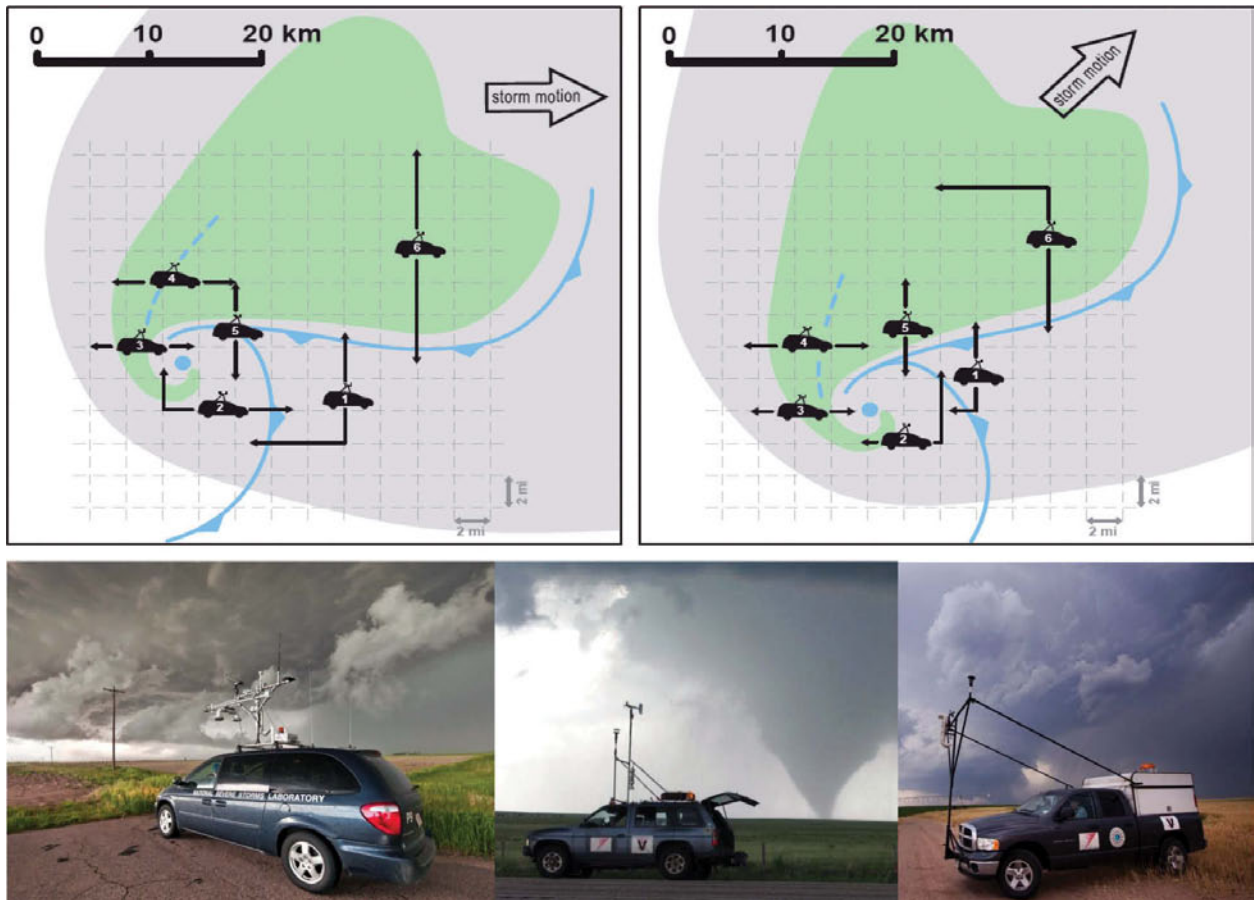


Fig. 6. Mobile mesonets used in VORTEX2 and schematic deployment routes through a slow-moving supercell.

coverage area. Mobile mesonets were tasked with conducting elaborate transects in various portions of the supercell, with a particular focus on the RFD, the forward-flank gust front (FFGF) and RFGF, and the primary inflow (Fig. 6). There were up to 11 mobile mesonet vehicles: 6 provided by NSSL [operated by The Pennsylvania State University (PSU) and NSSL], 1 provided by the Canadian Meteorological Service, and 4 combination pod/mesonet vehicles provided by CSWR.

The StickNet array, operated by Texas Tech University (TTU), consisted of 24 portable weather stations designed for deployment over large areas (Weiss and Schroeder 2008). Each StickNet probe consists of a tripod with weather instruments mounted at a height of approximately 1.5 m AGL (Fig. 7). The StickNet probes were deployed with a spacing of 1–5 km in lines ~20 km in length, ideally on several consecutive roads, in advance of the approaching supercell. StickNet deployments were designed to cover the span of a supercell, with an enhanced concentration near the forward-flank and rear-flank gust fronts.

During 2010, a UAS, operated by the University of Colorado (CU) and the University of Nebraska (UNL), provided information about the immediate storm environment aloft (Fig. 8). The UAS was launched near supercells and flew patterns outside the storms, but operations were limited by regulatory restrictions to airspace. Operations were permitted over only a small portion of the VORTEX2 domain (Fig. 3), so on many days when VORTEX2 intercepted supercells there were no UAS deployments.

TORNADO-SCALE OBSERVATIONS. Four (2009) and then six (2010) CSWR vehicles were equipped to carry a total of 16 pods (Fig. 9). Each pod contained an ultrasonic anemometer, a propeller anemometer, and a shielded temperature/relative humidity (T/RH) sensor at a height of 1 m (Wurman 2008). A data logger was housed in an armored waterproof box at the base. The entire package weighed approximately 50 kg and was designed to retain data in the event of high winds and/or debris damage. The pods were deployed in arrays to maximize the chance of achieving multiple transects through the

StickNet Deployment Strategy Slow-moving Storm (Default)

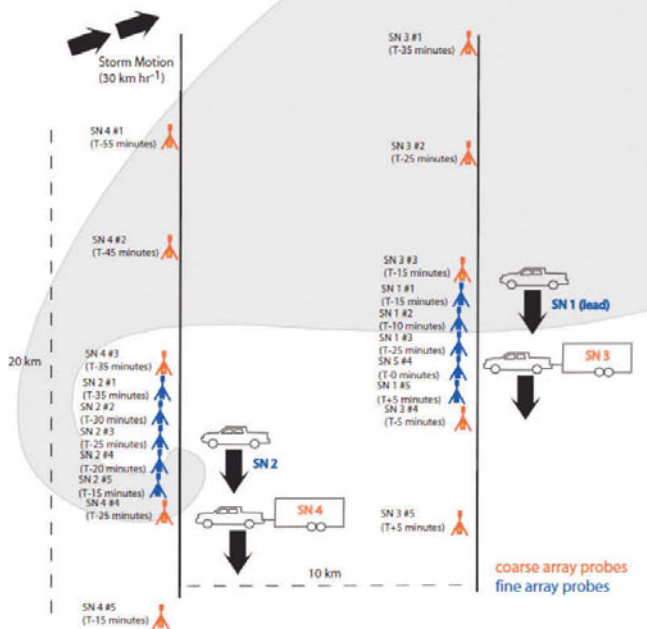


FIG. 7. A StickNet weather station and schematic deployment pattern.

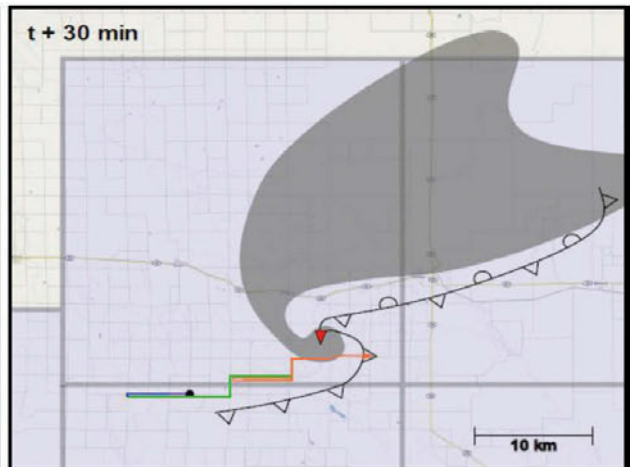


FIG. 8. UAS and schematic of flight pattern.

core and surrounding flow of a tornado. Pods also could supplement StickNet observations well away from the tornado, bringing the total possible number of deployable weather stations to 40.

The rapid-scan DOW (DOW5), the TTU Ka-band radars (TTUKa1 and TTUKa2) (Weiss et al. 2009), and UMASS W-band radar (UMW), having half-power beam widths of 0.8°, 0.5°, and 0.19°, respectively, provided data with very finescale

spatial resolution. These radars were deployed near to and south of the tornado track, scanning over the pod array, in order to provide 2D and 3D wind measurements from 15 to 1,000 m AGL (Fig. 10). The rapid-scan DOW provided fine temporal-spatial-scale volumetric updates at 7-s intervals. A pulsed Doppler lidar (TWOLF) on the MWR-05XP was used in 2010 for clear-air detection at ultra-high azimuthal resolution.

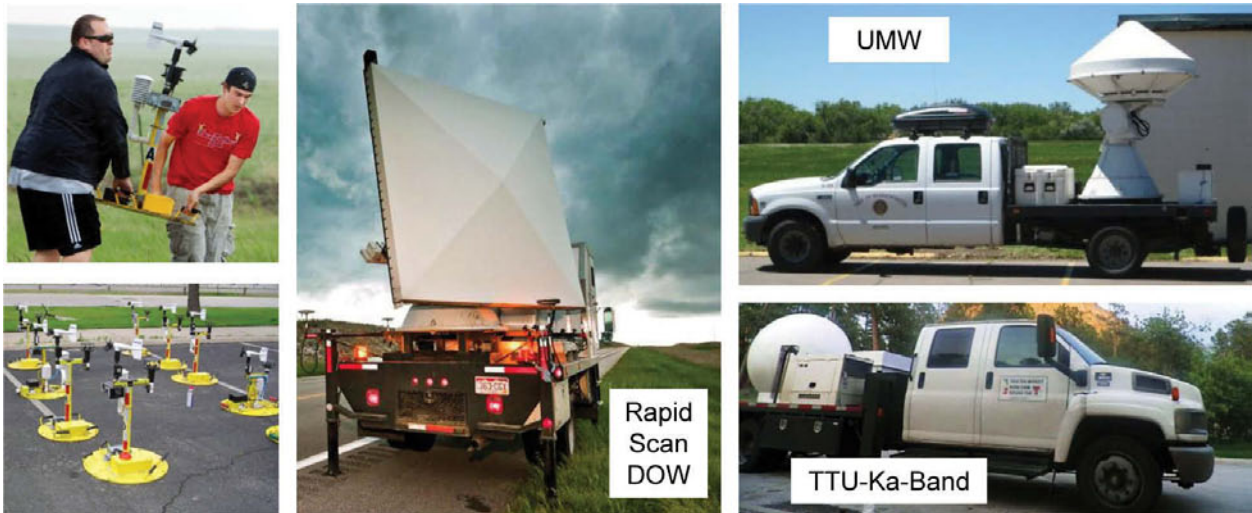


FIG. 9. A tornado pod and tornado-scale radars.

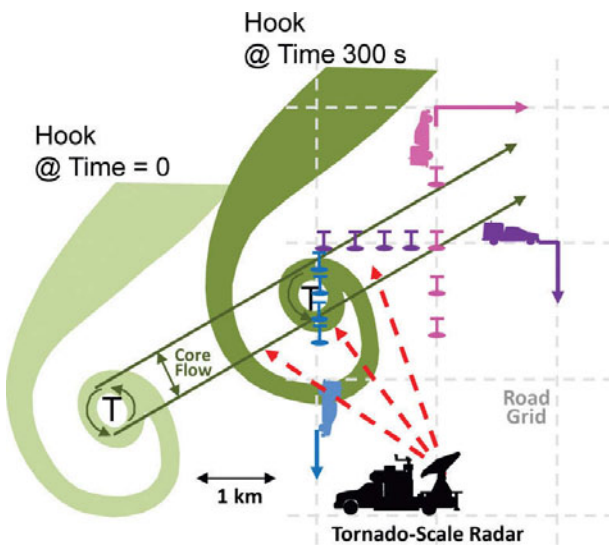


FIG. 10. Schematic diagram of deployment of tornado pod array with a tornado-scale radar scanning over the pods.

MICROPHYSICAL MEASUREMENTS USING RADARS AND DISDROMETERS. Testing of several hypotheses related to tornadogenesis requires knowledge of the microphysical properties of the precipitation in various portions of supercells. Several of the mobile radars had dual-polarization capability, including a SMART radar, UMASS XPOL, and NOXP. The DOW6 and DOW7 radars were upgraded for the 2010 season to dual-frequency, dual-polarization capability and could conduct quick-scanning dual-polarization measurements. All the dual-polarization radars had two missions because they were critical components of the nested dual-Doppler arrays described above. On each mission day, scanning was optimized either

for dual-polarization objectives (scanning through a deeper layer in the storm with slower updates) or for dual-Doppler objectives (shallower scanning with more rapid updates).

Several rapidly deployable disdrometers (Fig. 11), provided by the University of Colorado, the University of Florida (UF), the University of Illinois (UI), NCAR, and NSSL, were deployed in areas of the storm that had dual-polarization radar coverage in order to relate microphysical observations aloft to those at the surface.

STORM ENVIRONMENT MEASUREMENTS WITH SOUNDING SYSTEMS. In order to characterize the local environment in which supercells form and are maintained, Mobile GPS Advanced Upper-Air Sounding Systems (MGAUSSs), operated by NCAR, NSSL, and the State University of New York at Oswego (SUNY), launched instrumented balloons at frequent intervals near storms (Fig. 12). Sondes were launched prior to convective initiation in order to assist forecasting decisions and to capture changes in the local environment thought to be conducive to supercell formation. Once the supercell had formed, the environment surrounding the storm was sampled.

PHOTOGRAMMETRY AT TORNADO AND STORM SCALE. Photogrammetry teams from NCAR, Lyndon State College (LSC), and OU deployed at various locations near the storms (Fig. 12). Some of these teams were collocated with mesocyclone-scale radars, usually DOW6 and DOW7, or tornado-scale radars in order to conduct an integrated photographic-radar analysis of storm and tornado structure. These teams were also available for damage surveys. Other teams documented the evolution of various other portions of the supercell, such as the RFD.

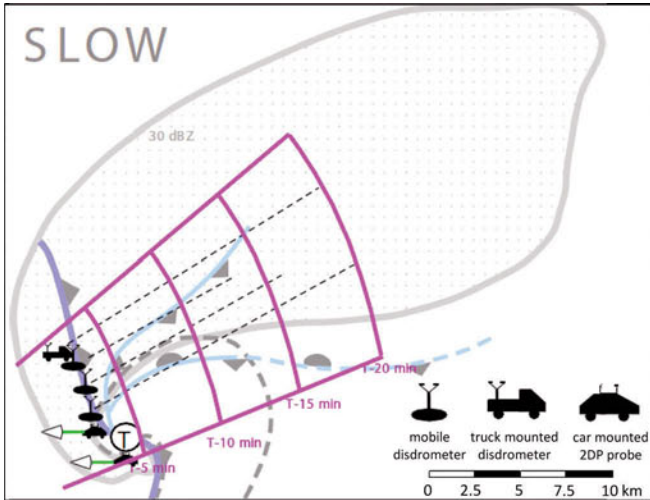


FIG. 11. Disdrometers and schematic deployment strategy.

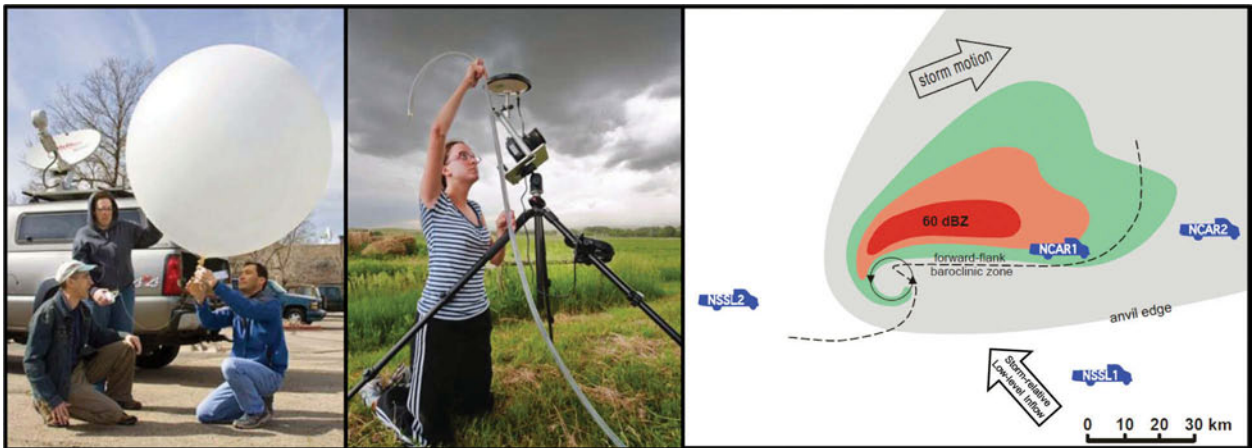


FIG. 12. (left) Mobile balloon launching team. (middle) Photogrammetry equipment. (right) Schematic of deployment pattern.

Field logistics. The size and mobility of VORTEX2 posed unique challenges to achieving both safe and efficient field operations.

FORECASTING. Forecasting of target regions a day in advance of, on the morning of, and during the day of a mission was critical. Members of the VORTEX2 steering committee rotated through the morning forecast duties in 2009, whereas in 2010 members of a dedicated field forecast team led these discussions. During missions, forecasting was led by the field coordination team. VORTEX2 used imagery (ranging from environmental data to experimental numerical model guidance) obtained from the internet with mobile broadband systems, real-time Weather Surveillance Radar-1988 Doppler (WSR-88D) data, and real-time environmental and storm-scale data collected by VORTEX2 in the field (e.g., soundings, mobile-mesonet observations,

and radar data) to assess the rapidly evolving weather situations. Participants at the National Weather Center’s Hazardous Weather Testbed facility assisted with forecasting, nowcasting, and facilitating communication with the National Weather Service, the Storm Prediction Center, and public safety officials with real-time information from the field.

COMMUNICATIONS AND COORDINATION. One of the most challenging aspects of VORTEX2 was the coordination of nearly 50 scientific vehicles. Deployment strategies were complex and fluid in rapidly changing weather scenarios. Supercell thunderstorms posed a risk to crew and vehicle safety, producing large hail; hazardous winds; frequent lightning; flash flooding; low visibility; hydroplaning hazards; and, of course, tornadoes with the attendant hazards associated with extremely high winds and airborne debris.

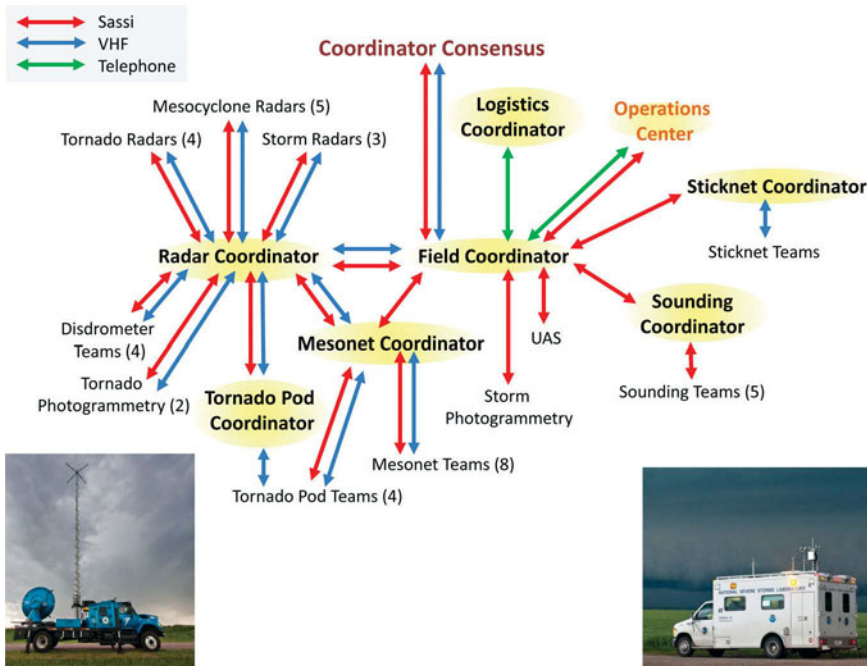


FIG. 13. Schematic of decentralized communications flow in VORTEX2. (right) FC managed SASSI, provided nowcasting and coordination for the VORTEX2 fleet, and provided communications with nonfield forecasters. (left) DOWs and other vehicles with masts could communicate and relay messages using VHF over long ranges.

Based on experiences from VORTEX1, ROTATE, sub-VORTEX-RFD, and other tornado studies, it was decided that decentralized coordination was critical because of the number and variety of vehicles, platforms, and missions. Thus, control of deployments was split among several coordinators: mobile mesonet, radar, field, UAS, balloon, etc. Overall targeting, forecasting, and logistical decisions were made through a consensus of these coordinators (Fig. 13). Initial mission and targeting decisions were made at morning meetings by consensus of the principal investigators, with a mission scientist (member of the VORTEX2 steering committee, according to a predetermined schedule) leading mission discussions and breaking ties, when needed.

To facilitate this decentralized control model, a high level of situational awareness among all the participants was needed. The Situational Awareness for Severe Storm Intercepts software (SASSI) was designed with this in mind, providing real-time vehicle tracking, weather display, and chat capabilities through cellular internet (Fig. 14). Participants and coordinators could communicate via chat with their team leaders and others. Coordinators could annotate maps to provide awareness of the forecast location of the mesocyclone, future multiple-Doppler lobes, and hazards such as washed out roads. SASSI

was controlled through a field coordination vehicle (FC), which provided nowcasting and strategic guidance.

Several teams operated very high-frequency (VHF) radios, some with power up to 200 W. Several platforms had pneumatic masts that could be raised (e.g., DOWs to 18 m AGL, the FC and a SMART radar to 13 m AGL) to achieve VHF ranges up to a few tens of kilometers. Intra-team communication among several of the radars, mobile mesonets, StickNet, and tornado pod teams was often conducted via VHF radio, particularly when an internet connection was not possible.

LODGING, FOOD, AND FUEL.

VORTEX2 had unique logistical challenges due to its fully nomadic nature, requiring lodging (~100 hotel rooms) for up to 160 participants and observers in different small cities every evening, with little notice. Each afternoon, a consensus decision was made concerning the overnight location for VORTEX2, even though the current day's mission often was far from complete. At times, fueling of over 50 vehicles and obtaining food and restroom services could overwhelm local facilities. We know of no precedent in any science project for billeting a group this large in different locations, on such repeatedly short notice.

PRELIMINARY RESULTS AND SUMMARY.

During the 2009 and 2010 field phases of VORTEX2, data were collected in about 40 supercells, about 14 of which produced tornadoes observed by at least some VORTEX2 instruments (Fig. 3). The year 2009 was very challenging for studying tornadic supercells. May 2009 was particularly quiescent and, consequently, many objectives of the VORTEX2 project were not achieved during this period. However, weather conditions became more propitious for scientific study in June 2009. In particular, a long-lived, strong tornado, which occurred in Wyoming on 5 June 2009, became the best-sampled tornadic supercell to date. Several other days in 2009, including 7, 9, and 11 June, yielded

data in nontornadic and weakly tornadic supercell thunderstorms. During 2010, data were obtained in over a dozen tornadic supercells. Particular events of interest include 10, 12, 19, and 25 May and 7 and 13 June. With the exception of 10 May 2010, most of these tornadoes were weak and/or short lived. A summary of the most interesting cases as identified by VORTEX2 PIs is provided in Table 3.

The integration of diverse datasets into coherent analyses is a complex process. In nearly all of the cases, combined multiple-Doppler and thermodynamic analysis are being conducted through collaborations among multiple groups. In addition to the listed cases, more specialized analyses, often focusing on data from unique or experimental instruments (i.e., TWOLF/MWR-05XP data and photogrammetry) also are being conducted. Analyses of these cases are ongoing and the final results will be published elsewhere. Some very preliminary results were presented at the American Meteorological Society's Severe Local Storms Conference in Denver, Colorado,

in October 2010 and at the Radar Meteorology Conference in Pittsburgh in 2011. An unofficial count revealed 46 individual presentations at the Denver meeting and 21 presentations at the Pittsburgh meeting that focused on or discussed preliminary results from VORTEX2.

Although final analyses are not complete, some preliminary examples of work in progress on one of the more comprehensive datasets are presented here, to illustrate the diversity of the observations and the potential for integration of different datasets to better understand these storms. On 5 June 2009, VORTEX2 observed the complete life cycle of a long-lived and strong tornado. Multiple radars, mobile mesonets, pods, disdrometers, StickNet, and photogrammetry teams were deployed during all or part of the tornado's lifetime. A long-duration dual-Doppler and mobile mesonet deployment was achieved (Fig. 14). At one time, at least six different radars were observing the storm (Fig. 15). Multiple-Doppler, mobile mesonet, and other data were collected from well before the

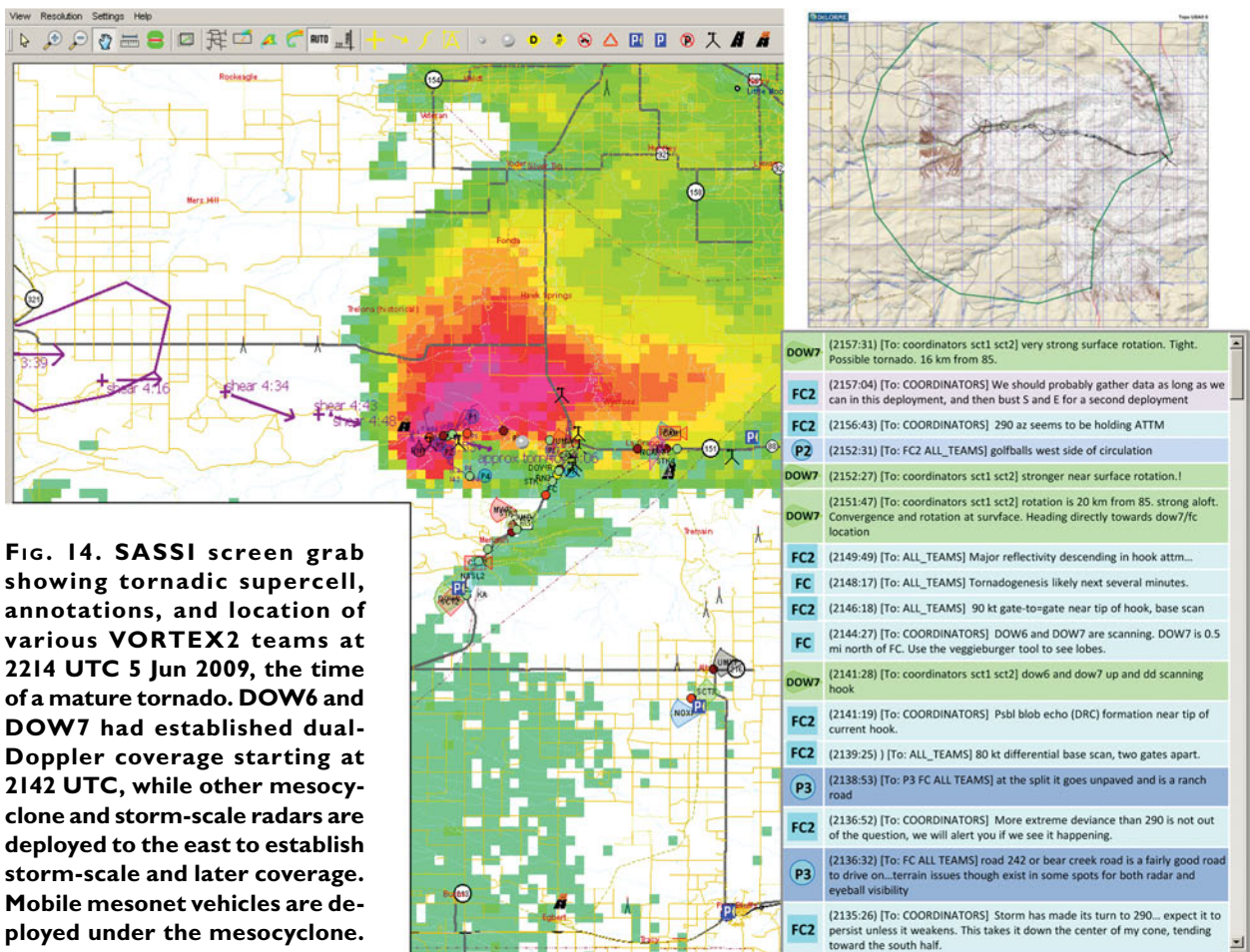


FIG. 14. SASSI screen grab showing tornadic supercell, annotations, and location of various VORTEX2 teams at 2214 UTC 5 Jun 2009, the time of a mature tornado. DOW6 and DOW7 had established dual-Doppler coverage starting at 2142 UTC, while other mesocyclone and storm-scale radars are deployed to the east to establish storm-scale and later coverage. Mobile mesonet vehicles are deployed under the mesocyclone. Photogrammetry, StickNet, disdrometer, and sounding teams are displayed. (top right) Track of tornado and DOW dual-Doppler lobe. (bottom right) Excerpt from SASSI chat among VORTEX2 teams during period leading up to tornadogenesis.

TABLE 3. High-priority analysis days from 2009 and 2010.

VORTEX2 cases—2009	Location	Description
15 May	Northwest OK	Squall line, mesovortices
5 Jun	Goshen County, WY	Tornadic and nontornadic supercells
7 Jun	Oregon to Maysville, MO	Weakly tornadic supercell
9 Jun	Ford to Greensburg, KS	Nontornadic supercell
11 Jun	La Junta to Lamar, CO	Nontornadic supercell pair
VORTEX2 cases—2010	Location	Description
6 May	Oberlin, KS	Elevated supercell
10 May	East-central OK	Tornado outbreak
12 May	Near Weatherford, OK	Weakly tornadic supercell
15 May	Near Artesia, NM	High-based storm
18 May	Dumas to Stinnett, TX	Tornado; classic → HP supercell
19 May	Near Kingfisher, OK	Weakly tornadic storm
24 May	Ogallala to Gothenburg, NE	Supercells, squall line, QLCS tornado
25 May	Tribune, KS	Landspouts and supercell tornadoes
26 May	Prospect Valley, CO	High-based nontornadic supercell
6 Jun	Grant and Ogallala, NE	Two nontornadic supercells
7 Jun	Mitchell and Scottsbluff, NE	Two tornadic supercells
10 Jun	Hoyt to Last Chance, CO	Nontornadic supercell, tornadic supercell
11 Jun	Limon to Bovina, CO	Weakly tornadic supercell
13 Jun	Perryton to Booker, TX, to Laverne, OK	Tornadic supercell
14 Jun	Wilson to Tahoka, TX	Supercell with gustnadoes, flooding

tornado formed through demise, revealing the kinematic and thermodynamic structures associated with multiple gust fronts, a descending reflectivity core (DRC), and the origins of air parcels entering the low-level mesocyclone and tornado.

Well prior to tornadogenesis, there were two distinct regions of significant cyclonic rotation: one region extended to low levels and was associated with vortex lines that arched upward out of the outflow (the orientation of these vortex lines strongly suggested they originated from baroclinic vorticity generation), and the other was associated with the midlevel mesocyclone, from which vortex lines extended into the warm sector to the south-southwest. The intensification of low-level rotation was preceded by the formation of a DRC, similar to others that have been documented in some supercells recently (Rasmussen et al. 2006; Kennedy et al. 2007a,b; Byko et al. 2009; Markowski et al. 2012a,b) (Fig. 16). During tornadogenesis, the rear-flank downdraft strengthened and a secondary rear-flank gust front similar to those recently documented in other tornadic supercells (Wurman et al. 2007a;

Marquis et al. 2008, 2012) formed. Orientation of the vortex lines/arches continued to suggest that the low-level circulation was baroclinically generated. Although the tornadic circulation primarily comprised parcels originating in the forward flank of the storm, not the rear flank, variation in secondary rear-flank downdraft strength was associated with increased convergence and tilting of horizontal vorticity near the tornadic circulation, tornadogenesis, and intensity changes in the nascent tornado (Kosiba et al. 2012, manuscript submitted to *Mon. Wea. Rev.*) (Fig. 17). Combined photogrammetric and radar analyses of the mature tornado indicate that the strongest winds near the surface were outside the visible condensation funnel and that there were separate maxima in the rotational wind, one near the surface and the other near the cloud base (Wakimoto et al. 2011; Atkins et al. 2012) (Fig. 18).

VORTEX2 is poised to address many important questions relating to tornadogenesis and tornado structure. It is also likely that analysis of the rich suite of new observations obtained by VORTEX2 will result in new, unanticipated questions. For example, an unexpected

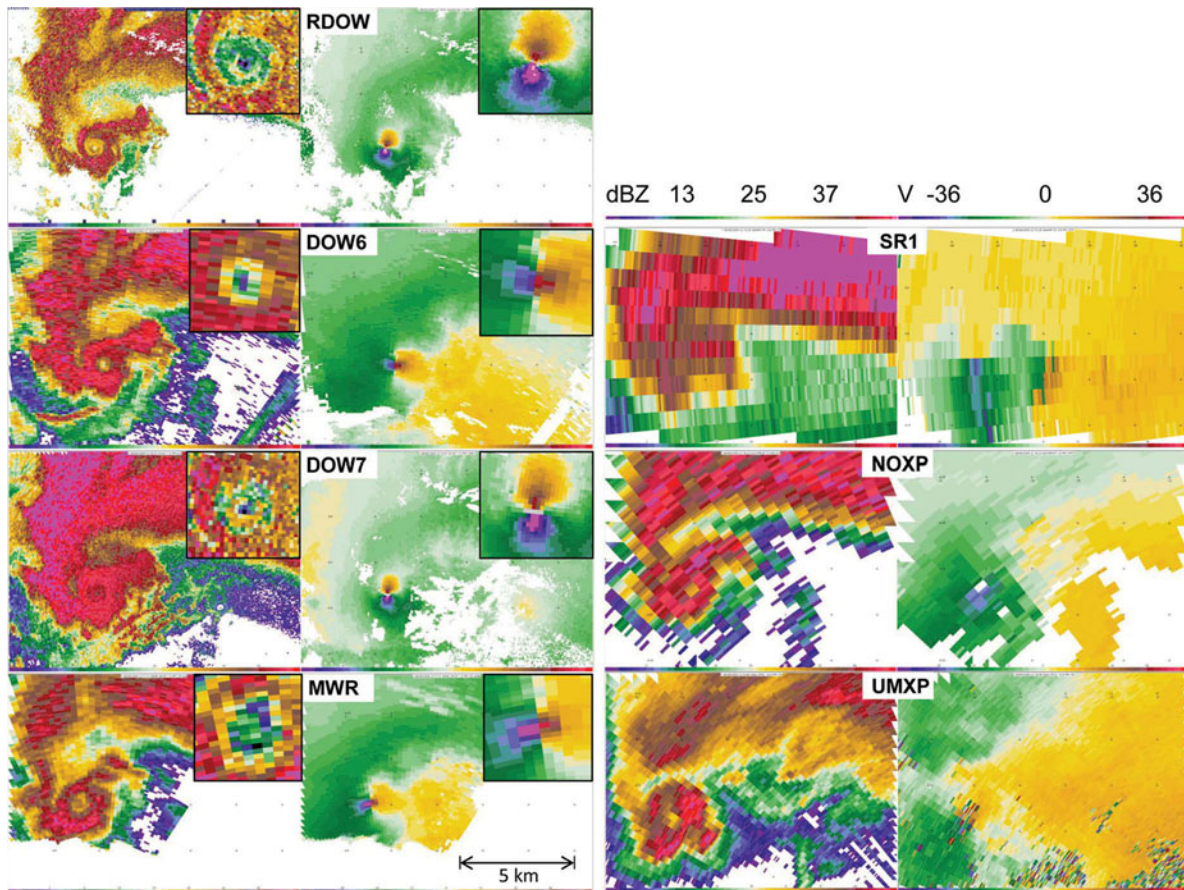


FIG. 15. Doppler velocity and reflectivity images of the 5 Jun 2009 Goshen County, Wyoming, tornadic supercell observed by seven VORTEX2 radars at approximately 2216 UTC. Viewing angles, native radar resolution, wavelength, and range to the tornado all affect the appearance of the supercell, hook echo, and tornadic region. RDOW: Rapid-Scan DOW, SRI: SMART-Radar 1, UMXP: UMASS XPol.

and as yet unexplained phenomena, a thin low-reflectivity ribbon (LRR) completely bisecting the forward and rear flanks of some supercells, was observed for the first time during VORTEX2. One LRR (5 June 2009) was characterized by deep (up to 25 dBZ) reflectivity deficit and very narrow (~600 m) width, and it extended through the full depth of a supercell, effectively bisecting the high-reflectivity regions of the forward flank and rear flank near the time of tornadogenesis. It was shown that air parcels

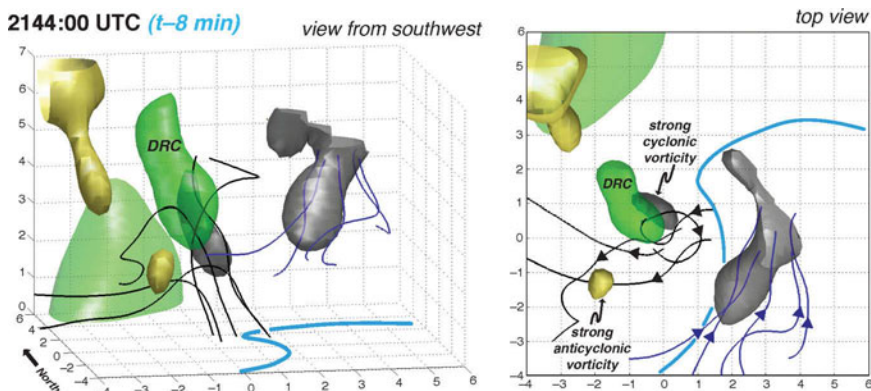


FIG. 16. View from the southwest and from above of the 55-dBZ DOW7 reflectivity isosurface (green) and vertical vorticity isosurfaces of 0.02 (gray), and -0.01 s^{-1} (yellow) at 2144 UTC 5 Jun 2009 (8 min prior to tornadogenesis). The gust front is indicated with a heavy cyan line. Vortex lines that pass through the midlevel mesocyclone are blue; these originate in the warm sector. Vortex lines that pass through the low-level mesocyclone are black and arch upward out of the outflow behind the gust front. In the view from above, the direction of the vorticity vector is indicated by the arrowheads. Axis labels are in kilometers (adapted from Markowski et al. 2012a).

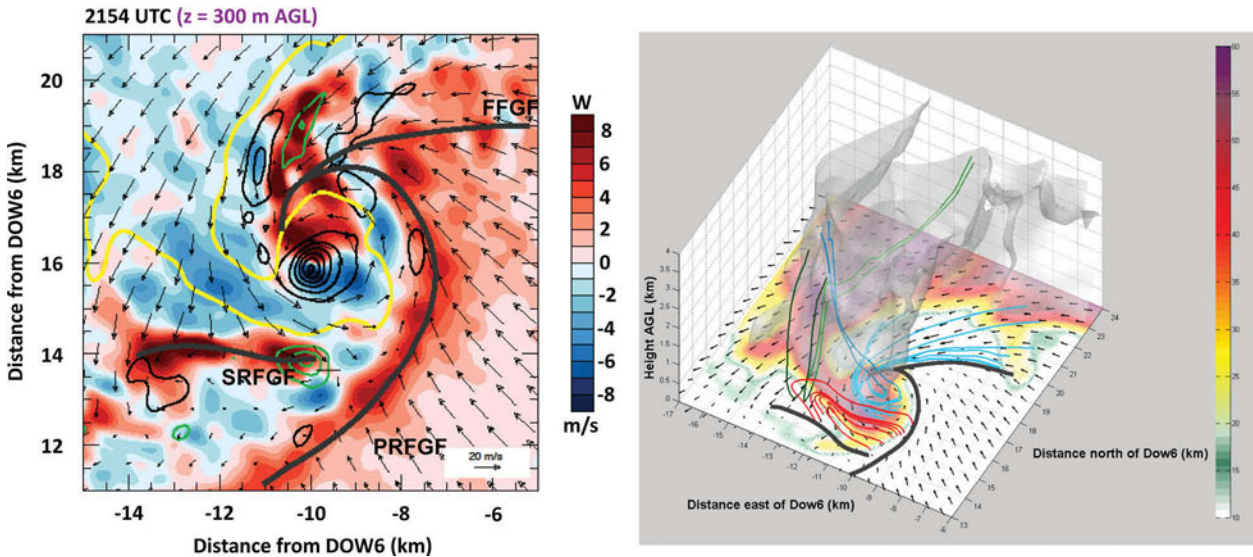


FIG. 17. (left) DOW6–DOW7 dual-Doppler winds at 300-m AGL during the tornadogenesis period. The yellow contour depicts the 30-dBZ DOW7 reflectivity isopleth, vectors represent the horizontal winds, shading depicts the vertical winds, black contours depict vertical vorticity > 0 , and green contours depict vertical vorticity < 0 and are contoured every 0.02 s^{-1} . The primary RFGF (PRFGF), secondary RFGF (SRFGF), and FFGF are delineated by solid gray lines. Evolution of the SRFGF was associated with changes in convergence and tilting of horizontal vorticity and modulations in nascent tornado intensity. (right) Air parcel trajectories enter the tornadic circulation from the forward flank (cyan) and rise (dark cyan). Parcels descending in the RFD (green) rise along the PRFGF (dark green). Vortex arches (red) suggest baroclinic generation of vorticity. Near-surface reflectivity is shaded in color and the 40-dBZ 3D isosurface is gray (adapted from Kosiba et al. 2012).

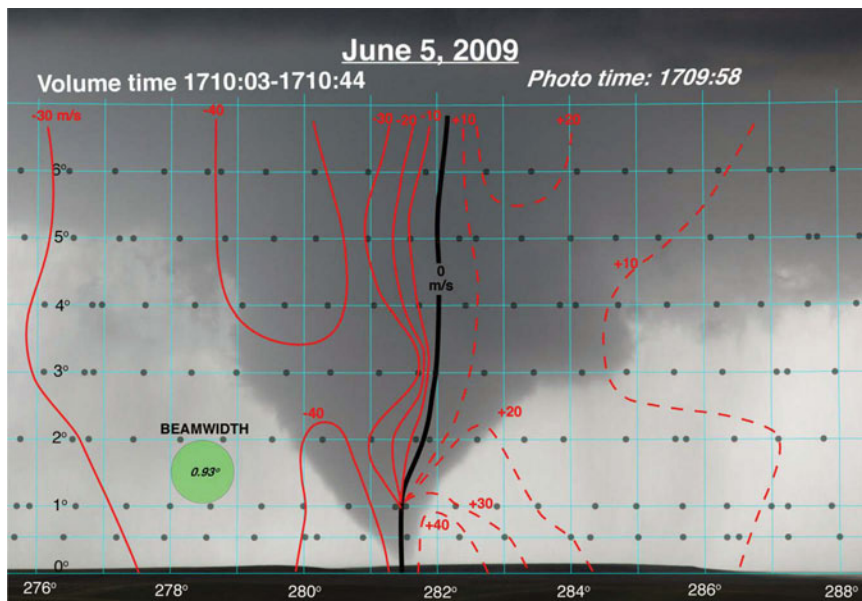


FIG. 18. Photogrammetric analysis of the 5 Jun 2009 tornado at 2210 UTC. Doppler winds (red contours) are overlaid over the visible image. Peak Doppler velocities are outside the visible condensation funnel at this time (adapted from Wakimoto et al. 2011).

entering a developing tornado passed near but not through the LRR (Kosiba et al. 2012, manuscript submitted to *Mon. Wea. Rev.*). Another LRR (13 June 2010), observed by multiple dual-polarization radars near

the time of tornadogenesis, exhibited a similar morphology and low differential reflectivity, suggestive of small rain droplets (Fig. 19). The role of these LRRs, if any, in tornadogenesis remains unclear and may inspire post-VORTEX2 study.

The field portion of the VORTEX2 project has concluded and analysis of the data is underway. The field phase resulted in unprecedentedly diverse data collection in several dozen tornadic and nontornadic supercell thunderstorms, as well as quasi-linear convective systems (QLCSs) (Bryan and Parker 2010) and other phenomena. Comparisons between the

tornadic and nontornadic cases are expected to increase our understanding of the subtle differences between them, contributing to the goal of more accurate watches and warnings.

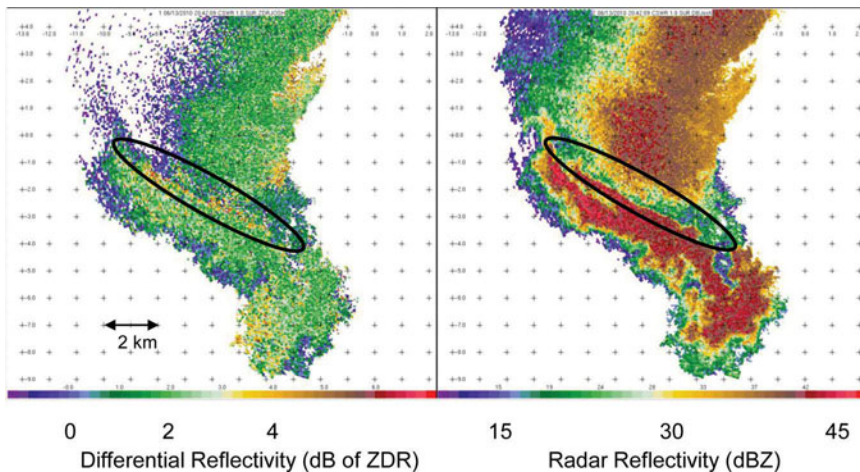


FIG. 19. LRR visible in (left) differential reflectivity and (right) radar reflectivity as observed by the DOW7 radar during VORTEX2 on 13 Jun 2010. A narrow region of substantially reduced reflectivity and low differential reflectivity, suggestive of small rain drops, completely separates the high-reflectivity forward and rear flanks of the storm.

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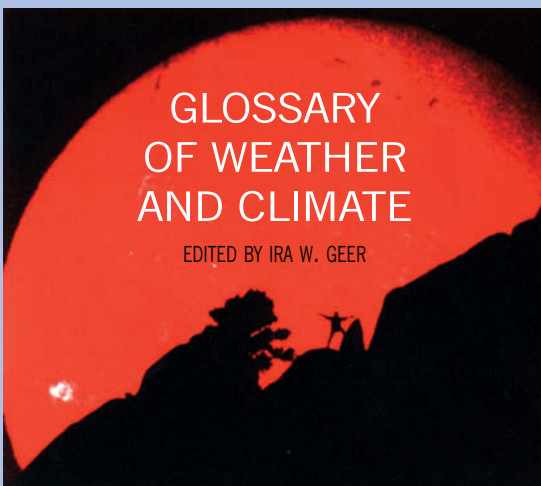
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MULTISCALE CONVECTIVE ORGANIZATION AND THE YOTC VIRTUAL GLOBAL FIELD CAMPAIGN

BY MITCHELL W. MONCRIEFF, DUANE E. WALISER, MARTIN J. MILLER,
MELVYN A. SHAPIRO, GHASSEM R. ASRAR, AND JAMES CAUGHEY

Vastly improved satellite and in situ measurements, data assimilation, and modeling make possible a virtual field study of multiscale Earth system problems, such as convective organization and its interaction with larger-scale circulation.

Day-to-day weather variations and extreme rainfall events, as well as most components of climate in the tropics, are closely associated with moist convection, the process by which the relative abundance of heat and moisture near Earth's

surface gets transported upward into the atmosphere. From there, the heat is radiated back to space and the moisture may condense and form clouds. Some of the condensate grows large enough to fall back to Earth's surface as precipitation. In this regard, moist convection plays a crucial role in the energy and water cycles of the tropics as well as the variability of the tropical climate system. In concert with its effects on the tropics per se, moist convection can generate planetary (Rossby) waves, which affect weather and climate around the globe. Therefore, the effects of tropical convection, its multiscale organization, and interaction across scales are crucial elements of weather and climate.

The organization of tropical convection is associated with a hierarchy of meteorological phenomena: (i) cumulus/cumulonimbus clouds, (ii) the meso-scale organization of fields of clouds into coherent structures, generically called mesoscale convective systems (MCSs); (iii) synoptic-scale disturbances such as tropical cyclones and easterly waves; (iv) ensembles of mesoscale systems (superclusters) embedded within planetary-scale phenomena, such as convectively coupled equatorial waves (Kiladis

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et al. 2009), the Madden–Julian oscillation (MJO; Madden and Julian 1972), the monsoons (Li 2010), and the El Niño–Southern Oscillation (ENSO; McPhaden 2004); and (v) the iconic long-term pattern of persistent convection known as the intertropical convergence zone (ITCZ). Elements of some of these phenomena are illustrated in Fig. 1 (top), and the complexity of their collective effects is apparent in the patterns of total atmospheric water (Fig. 1, bottom). Such patterns exhibit temporal variability across a wide range of scales, including the well-defined diurnal and annual cycles, and more broadband features such as synoptic time scales of a few days, and intraseasonal to interannual variability. This remarkable space–time continuum renders the distinction between weather and climate

a seamless one when considering the role and impacts of tropical convection.

Inherent to the above meteorological phenomena is the interaction between moist convection and atmospheric dynamics—such that each impacts, and yet may arise from, the other. Within the wide range of organizing scales of tropical convection referred to above are many tangible, although far from obvious, connections among small-scale clouds (e.g., cumulus), mesoscale convective systems, and planetary-scale motion. As a nexus of chaotic order in Earth’s atmosphere, convective organization raises new considerations and challenges. As noted above, one is the blurring of the traditional scale boundaries near the intersection of weather and climate, both fundamentally and from the practical viewpoint of predic-

tion. Another requirement, stemming from the first, is for our research and prediction models to concurrently represent the small-scale clouds, the intermediate (mesoscale) systems, and the largest planetary scales of motion. Models with computational grids of 1 km explicitly represent (simulate) mesoscale organization, but global models with this level of resolution are several orders of magnitude beyond our current computer capabilities. A global model with a 100-m computational grid would render convective parameterization unnecessary, but that resolution will not be possible for a very long time.

In order to reduce the scale range, the present-day practice in climate modeling is to resolve scales on the order of 100 km and “parameterize” the smaller unresolved “subgrid” scales. This raises a third challenge of the wide range of scales that has to be reckoned with. Past parameterization developments and improvements (convection

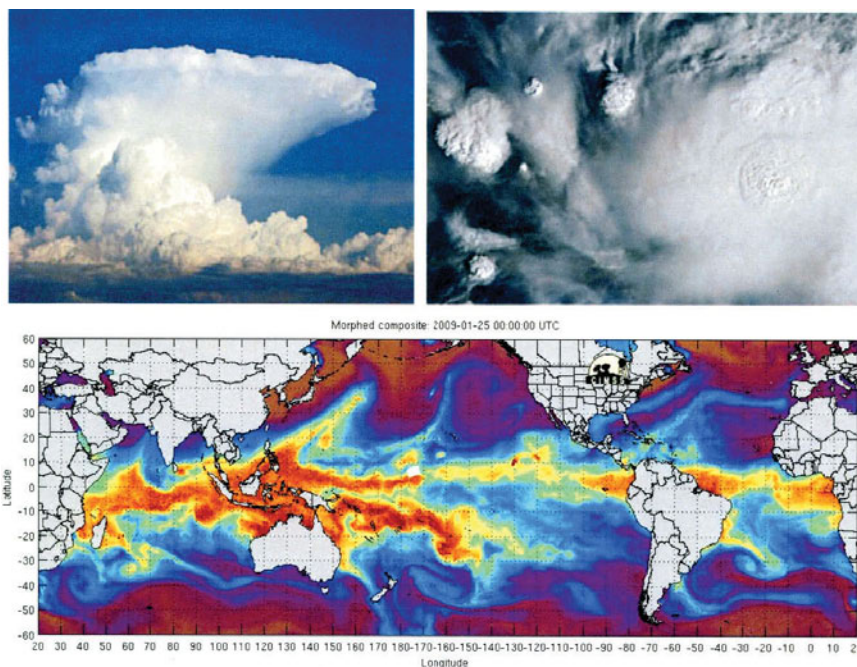


FIG. 1. (top left). Photograph of a cumulonimbus cloud. (top right). Satellite image of a mesoscale convective system. The bubbly regions in the stratiform cloud deck are overshooting cumulonimbus clouds, showing the multiscale/upscale character of convective organization. (bottom). Snapshot of the global distribution of total precipitable water (TPW) derived from the Special Sensor Microwave Imager (SSM/I) and Advanced Microwave Scanning Radiometer for EOS (AMSR-E) satellite data using the Morphed Integrated Microwave Imagery at the Cooperative Institute for Meteorological Satellite Studies (CIMSS)—i.e., MIMIC—product. The TPW ranges from 5 to 65 mm. Higher values are in red/brown hues, lower values in purple hues, and the mid-range in blue hues. High water content in the tropics (red hues) drops off rapidly in the extratropics. TPW maxima are the product of cloud systems organized on large scales (e.g., the MJO in the Indian Ocean). “Atmospheric rivers” of moisture flow poleward from the tropics associated with the incursion of midlatitude fronts, effects of planetary waves, and the extratropical transition of tropical disturbances. Courtesy of Tony Wimmers and Chris Velden, CIMSS, University of Wisconsin at Madison.

and other physical processes) have often relied upon field campaigns that deploy instruments on aircraft, buoys, balloons, etc., often in distant or remote areas. Such deployments are typically for short “intensive observation periods” of days to weeks and occasionally, in the case of large international programs, for a few months (Betts 1974; Webster and Lukas 1992). Field campaigns focus the community on selected periods and events of interest. While considerable gains have been made, this traditional approach is unable to adequately address tropical convection: it is impossible, logistically and financially, to span the enormous range of interacting scales. What is needed is a flexible and comprehensive approach that concurrently addresses the global-scale context, the intermediate-scale building blocks (e.g., MCS), and various physical processes at significantly smaller scales.

In the past couple of decades, there has been a steady and widespread investment and implementation of observing system infrastructures that, when integrated together, can be marshaled to address the above challenge (e.g., Fig. 2, top). That includes the vast increase in global satellite observations, now including quantities such as atmospheric temperature, water vapor, sea surface temperature, salinity and height, and a plethora of wind, cloud, and radiation data. In addition, arrays of observing buoys are now deployed in all three tropical ocean basins, together with near-surface measurements from hundreds of drifting buoys and profiling floats, most recently in the Indian Ocean (McPhaden et al. 2009).

Considered in isolation, these observational resources help to characterize and advance our understanding of weather and climate. An even greater advance comes through the incorporation of various observational measurements into the quantitative framework of weather prediction models via data assimilation, which has progressively improved through scientific and technical developments and by virtue of concurrent increases in computer processing power. Data assimilation, the backbone for modern robust prediction systems, provides a consistent and quantitative characterization of the atmospheric state: “global analysis” at a physical resolution of tens of kilometers in space and hours in time (e.g., Fig. 2, bottom right).

THE VIRTUAL GLOBAL FIELD CAMPAIGN.

The integration of global observations, numerical models, and data assimilation heralds tremendous advances in high-resolution prediction (e.g., Fig. 2, bottom)—a vision initiated a generation ago with the 1979 First Global Atmospheric Research Program (GARP) Experiment (FGGE). Global analysis provides

the means to conduct a *virtual global field campaign* for tropical convection that not only has a global reach but also provides unprecedented information on atmospheric structure, thermodynamics, and dynamics. Developed over several decades, this remarkable “observing” system leverages billions of dollars of investment in measurement platforms, instruments, and infrastructure. This realization, which emerged at a 2006 workshop held in Trieste, Italy, led to the recommendation to “develop an internationally coordinated computational-observational laboratory,” abbreviated herein to a “virtual global field campaign” for the integrated study of tropical convection (see Moncrieff et al. 2007).

The virtual approach complements traditional field campaigns in ways that were not possible until recently. In a global context, and with high resolution in mind, the virtual approach is the only way to address tropical convection and its scale interactions in a cost-effective, flexible and efficient manner.

- It is cost effective because of the vast amount of in situ measurements (e.g., aircraft, balloons, buoys, drifters, ships, and surface stations) and satellite measurements already available and optimally assimilated into the global analysis.
- It is flexible because the global analysis can be updated as data assimilation practices improve, as observation accuracy gets refined (e.g., via improved instrument calibrations and satellite retrievals), as the representation of the physical processes in numerical models become more reliable, and as increasing computer capacity enables ever higher resolution.
- It is efficient because the preparation of the databases (global analysis) is an integral part of operational global weather prediction.

With the virtual approach firmly in mind, the Year of Tropical Convection (YOTC) project, whose three principal components are sketched in Fig. 3, calls for a radical improvement in how tropical convection is represented in our global climate models. The deliberate focus on organized tropical convection is partly motivated by the fact that *convective organization is missing from contemporary climate models*, affecting the type and distribution of precipitation in important ways.

The focus on convection is not meant to imply that global model problems are solely the fault of convection. All the subgrid physical processes (convection, planetary boundary layer, surface exchange, microphysics, radiative transfer, turbulence) have

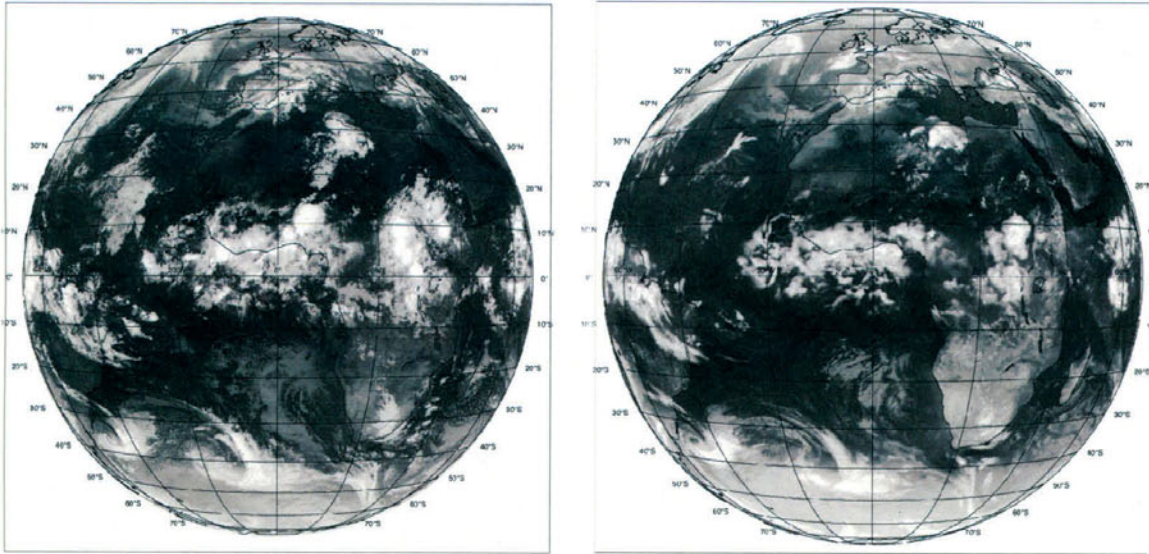
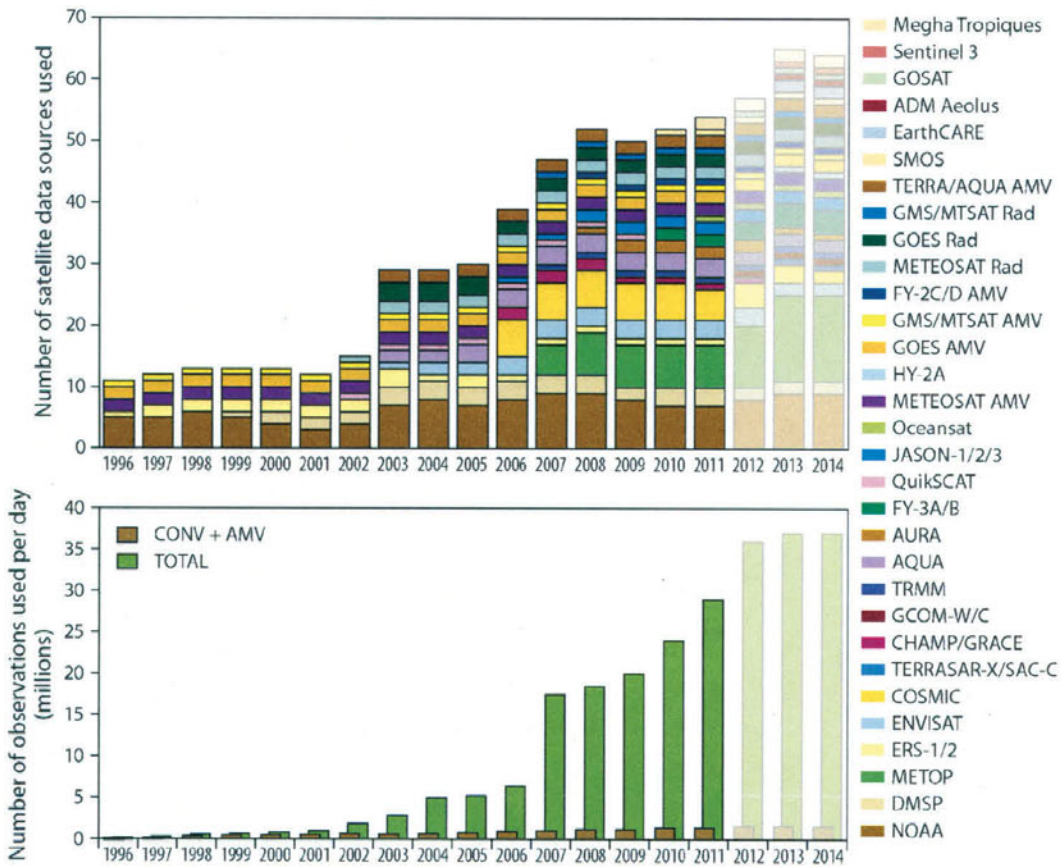


FIG. 2. (Upper bar charts) Recent time history of the data types and instruments assimilated into the ECMWF IFS. The upper chart shows information in terms of the number of data sources for the given satellite platform. The lower bar chart shows the number of observations used per day, with the brown bars indicating the number of conventional (e.g., radiosonde, surface stations) and atmospheric wind vectors (AMVs) typically derived from geostationary-observed cloud motions, and the green bars showing the total, namely with the addition of all the satellite observations shown in the upper chart. (Lower global images) (left) Meteosat-9 Spinning Enhanced Visible and Infrared Imager (SEVIRI; channel 9 IRI0.8) brightness temperature, 0000 UTC Sunday 25 May 2008. The gray scale for brightness temperature ranges from 15°C to -70°C. The whitest regions are a proxy for cold/high cloud tops and enhanced precipitation. (right) As at (left), but from the ECMWF IFS using the latest operational system as of Nov 2011. Courtesy of Peter Bauer, ECMWF, UK.

shortcomings. Improving parameterizations per se has remained an unsolved problem since the early days of numerical weather prediction, as noted by Randall et al. (2003). The basic problem of parameterization is to approximate the effects of subgrid processes as functions of the resolved variables. Unfortunately, there is no physical principle that states under what conditions such functional relationships may uniquely exist.

In the remaining sections of this paper, we provide more in-depth highlights of the motivating scientific/technological challenges, describe the YOTC project, and present a way forward by identifying some research imperatives, including near-term collaborative studies.

SCIENTIFIC AND TECHNICAL CHALLENGES.

Our intellectual gaps in fully understanding tropical convection and its scale interactions lead to shortcomings that range from the forecasting of tomorrow's weather to the projection of future climate. In recent years there has been attention to the "seamless prediction" of weather and climate, for several reasons. A practical reason is that climate and weather models are on convergent paths in regard to resolution (i.e., 10-km computational grids). The seamless prediction of weather and climate is a many-faceted problem as articulated by Dole (2008), Hurrell et al. (2009), Palmer et al. (2009), Brunet et al. (2010), Shapiro et al. (2010), and Shukla et al. (2010). The YOTC project addresses seamless prediction in a focused way through the deliberate attention to tropical convection, multiscale convective organization, and scale interaction.

The shortcomings referred to above are starkly illustrated the highly simplified framework of aquaplanet (ocean everywhere) simulations using contemporary global climate models (see Fig. 4). The panels in this figure show the evolution of precipitation patterns near the equator, as a function of longitude, for an arbitrary 30-day period. While there is no true observational counterpart of an aquaplanet to compare with, the precipitation patterns would be similar among the models if the parameterizations

of the subgrid processes were physically correct and consistent. That is far from the case. The tropical rainfall varies enormously among models in terms of its spatial distribution and variability. The difference between the shortcomings in Fig. 4 and the comparatively realistic representation in the bottom right panel of Fig. 2 is that the latter relies on an optimal blend of model and assimilation that utilizes the individual strengths of each. We have assumed that the *predictions* of convective organization in Fig. 4 are representative for each model. However, addressing the *predictability* of these organized structures would require performing an ensemble of simulations for each model.

We have difficulties with reliable representations of tropical convection in our global weather/climate models, partly because of the complex hierarchy of interacting scales, processes, and phenomena highlighted above. While convective organization is a natural component of the seamless prediction of weather and climate, and despite being identified decades ago as a shortcoming from an international field campaign (Houze and Betts 1981), *very little attention has been paid to organized convection in global models.*



FIG. 3. The three components of the YOTC project: (i) **Global analysis, forecasts, and subgrid tendencies from high-resolution global weather models;** (ii) **comprehensive measurements from instruments deployed on satellite, field campaign, and in situ platforms;** and (iii) **research programs, including diagnostic studies of meteorological events in high-resolution analyses and forecasts, cloud-system resolving numerical simulations on spatial scales up to global, idealized models and dynamical analogs for studies of multi-scale convective organization, scale interaction, and the development of improved convection parameterizations.**

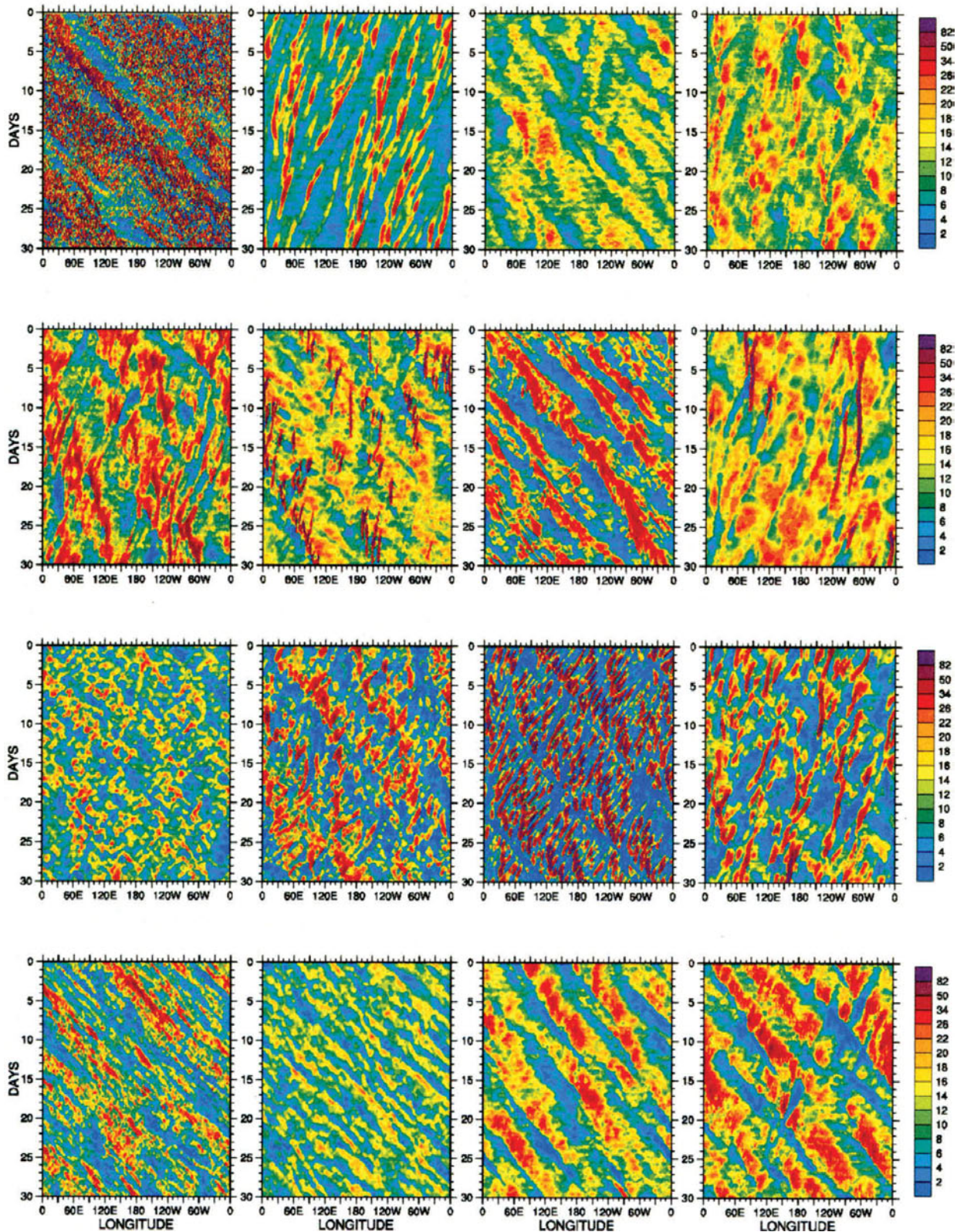


FIG. 4. Time–longitude plots of equatorial precipitation (mm day^{-1}) averaged over the -5° to $+5^\circ$ latitude band from all models in the Aqua Planet Experiment (APE). This figure with further explanation and the models identified will appear in Blackburn et al. (2012) and Williamson et al. (2012). The plate in the top left-hand corner is from a global cloud-system-resolving simulation using the Japanese NICAM model with a 7-km computational grid. Courtesy of David Williamson (NCAR) and Michael Blackburn (University of Reading, UK).

Organized convection and global models. Organized tropical convection of much larger size (mesoscale: 20–2,000 km) than the 1–10-km cumulus/cumulonimbus clouds has long been observed around the world: first in highly focused field campaigns [e.g., West Africa (Hamilton et al. 1945), the central Pacific (Zipser 1969), and Venezuela (Betts et al. 1976)] and subsequently as organized circulations and “gregarious” properties (Moncrieff 1992; Mapes 1993). The parameterization of the upscale effects associated with the evolution from cumulonimbus (upper left, Fig. 1) into mesoscale systems (upper right, Fig. 1), and subsequent interaction with large-scale dynamics, presents a formidable scientific and practical challenge.

Observations show that MCSs on the order of 100 km produce about half the total precipitation in the tropics (Schumacher and Houze 2003) and have distinctive vertical heating profiles (e.g., Houze 1993, 1997). Contemporary parameterizations are not designed to represent the upscale effects of convective organization, although a semblance of organization may emerge as a result of interactions between dynamics and parameterization in weather models (Moncrieff and Klinker 1997) and climate models (Mapes et al. 2008). Presently, no climate model incorporates a satisfactory parameterization of mesoscale organization, although attempts have been made to approximate

some thermodynamic aspects (e.g., Donner 1993; Donner et al. 2001) and aspects of organization (Mapes and Neale 2011).

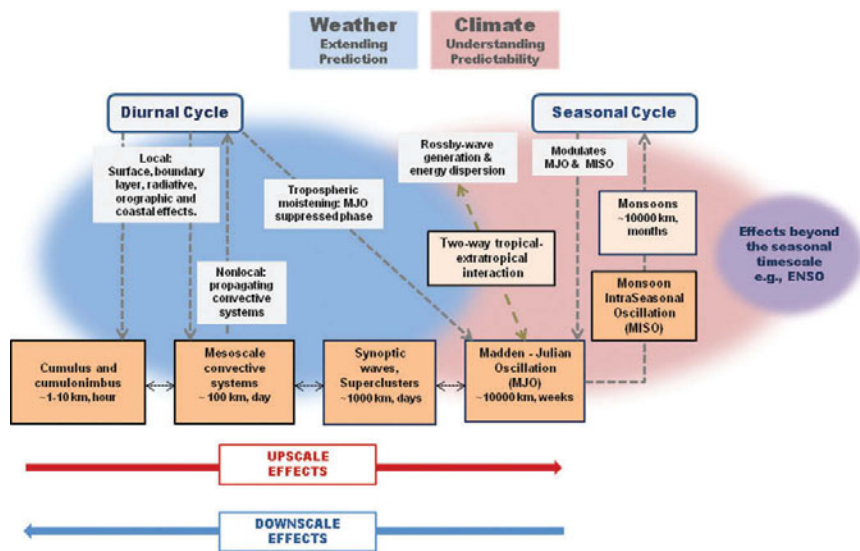
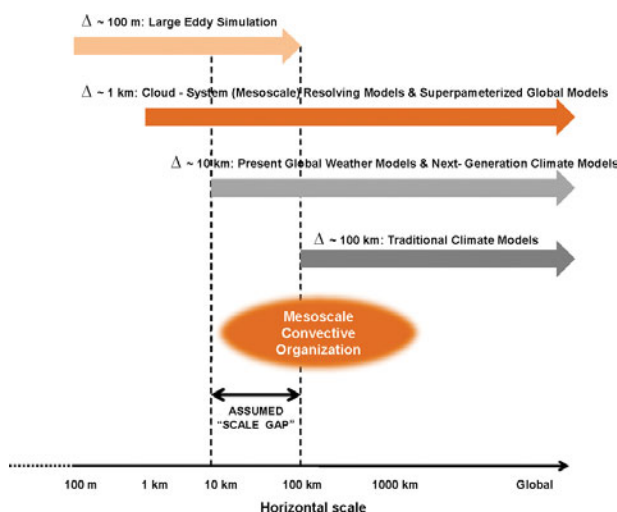


FIG. 5. (top) Temporal forcing scales of tropical convection (diurnal cycle, seasonal cycle) and the primary scales of convective organization (cumulonimbus, mesoscale convective systems, synoptic waves and superclusters, and the Madden–Julian oscillation). The monsoon intraseasonal oscillation interacts strongly



with the Asian–Australian monsoon. The organized systems exhibit hierarchical coherence: (i) mesoscale systems consist of families of cumulonimbus; (ii) cumulonimbus and MCS are embedded in synoptic waves; and (iii) the MJO is an envelope of cumulonimbus, MCS, and superclusters. The upscale effects of convective organization are not represented in traditional climate models. The mean atmospheric state exerts a strong downscale control on convective structure, frequency, and variability. The weather–climate intersection has connotations for lower-frequency climate variability (e.g., ENSO). (bottom) Mesoscale convective organization bridges the scale gap assumed in traditional convective parameterization. (i) LES resolves cumulus, cumulonimbus, and mesoscale circulations, but the computational domain is small (~100 km) and simulations short (~1 day). (ii) CSRs simulate mesoscale circulations but not cumulus/cumulonimbus. Two-dimensional CSRs in superparameterized global models permit MCS-type organization and mesoscale dynamics. (iii) High-resolution global numerical prediction models may crudely represent large MCS (superclusters). (iv) MCS, and other mesoscale dynamical systems, are conspicuously absent from traditional climate models—organized convection is not parameterized and the computational grid is too coarse.

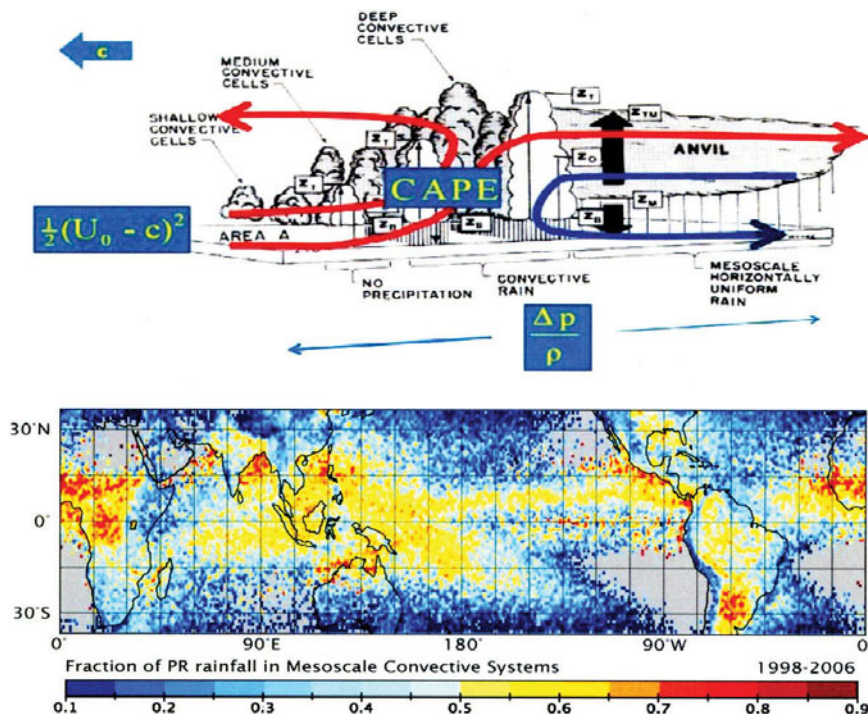


FIG. 6. (top) Organized slantwise overturning mesoscale airflow through an MCS depicted by the red/blue trajectories of upflow/downflow relative to the propagating system ($u - c$, where c is the propagation speed), represented by a dynamical model (Moncrieff 1992) superimposed on the Houze (2004) description of an MCS. Blue insets identify three forms of energy: convective available potential energy (CAPE), kinetic energy of shear and propagation, and the work done by the horizontal pressure gradient. **(bottom)** Fraction of rainfall from precipitation features ≥ 100 km in maximum size (i.e., MCS) measured by the TRMM Precipitation Radar (PR) for Jan 1998–Dec 2006 using the procedure of Nesbitt et al. (2006). Courtesy of Tao and Moncrieff (2009).

Moist convection interacts with the large-scale circulation both upscale and downscale (Fig. 5, upper panel). There are important differences between the tropics and the extratropics, with consequences for parameterization. In the extratropics, interactions among synoptic and mesoscale motion and the embedded convection are downscale controlled by the life cycle of extratropical cyclones associated with midlatitude baroclinic instability (Charney 1947; Eady 1949). In the extratropics parameterized convection in weather models has reasonable fidelity owing, in part, to the successful reproduction in these models of this downscale baroclinic control. Upscaling occurs in the midlatitude baroclinic zones as cumulonimbus develop into propagating mesoscale convective systems organized by the vertical shear.

Tropical convection differs significantly from this classical picture. Rather than being controlled by the large-scale motion, tropical convection is an integral part of that motion, organizing across scales and constructively interacting with tropical waves and their

environment (see Fig. 5, upper panel). In sheared environments downstream of mountains, convection organizes into mesoscale systems during the warm season in the midlatitudes (Carbone et al. 2002) and throughout the year in the tropics (e.g., Laing and Fritsch 1997).

The distinction between the tropics and extratropics is clearly evident in satellite measurements of atmospheric water. The structurally complex transition zone in Fig. 1 (bottom) demarks the moist tropics from the relatively dry extratropics. On weather time scales, intermittent “atmospheric rivers” of moisture flow from the tropics to higher latitudes, causing disastrous floods (Zhu and Newell 1994; Ralph et al. 2011). The rivers are associated with the incursion of midlatitude fronts, the extratropical transition of tropical

cyclones, and the remote effects of planetary waves emanating from the tropics. On seasonal time scales, the Asian-Australian monsoon and its intraseasonal variability strongly modulates the distribution of atmospheric water. Global models have great difficulty in reproducing such variability.

Scale gap and missing mesoscale in climate models.

Traditional convective parameterizations view convective clouds as much smaller than the grid scale of the numerical model: a “scale gap” in the 10–100-km range is assumed to separate cumulus convection from the resolved scales. Early global models had grids of hundreds of kilometers so this assumption was reasonable, in the sense that the gap was bigger than the cumulus clouds being parameterized. In the real world, mesoscale systems fill the gap (Fig. 5, bottom panel). Mesoscale convective organization is structurally absent from current global climate models: convective parameterizations do not represent the important dynamics (e.g., shear

effects) and the spatial resolution is too coarse to simulate the mesoscale circulations. In other words, the scale-gap assumption enforced in models does not have a reliable physical basis. This raises a formidable weather–climate intersection research challenge: *a rethinking of convective parameterization for the next generation of climate models where the scale-gap assumption is not applicable.*

For decades, MCSs have been observed in field campaigns, simulated by finescale numerical models, and dynamically modeled [see review articles of Houze (2004), Tao and Moncrieff (2009), and Moncrieff (2010)]. The lower panel of Fig. 5 shows the modern hierarchy of models: (i) Large-eddy simulation (LES), which explicitly represents organized convection *and* cumulus, albeit in small domains and for integrations lasting about a day; (ii) cloud-system-resolving models (CSRMs), which simulate mesoscale convective organization in computational domains up to global but do not resolve cumulus convection; (iii) high-resolution global weather models; and (iv) traditional climate models.

Observations and models show that convective organization is controlled by wind shear, yet convective parameterizations pay little attention to shear. The upper panel in Fig. 6 shows that slantwise convective overturning in a sheared

environment (Moncrieff 1992, 2010) approximates the organized airflow within mesoscale convective systems (e.g., Houze 1993, 2004). The two dynamical forms of energy (kinetic energy of shear and propagation, and the work done by the horizontal pressure gradient) that are key to the organization of convection in shear are not represented by contemporary parameterizations. Organized overturning is relevant to climate because it is a statistically significant contributor to the large-scale dynamics. For instance, Fig. 6 (lower panel) shows that MCSs contribute about half of the rain and latent heating in regions where

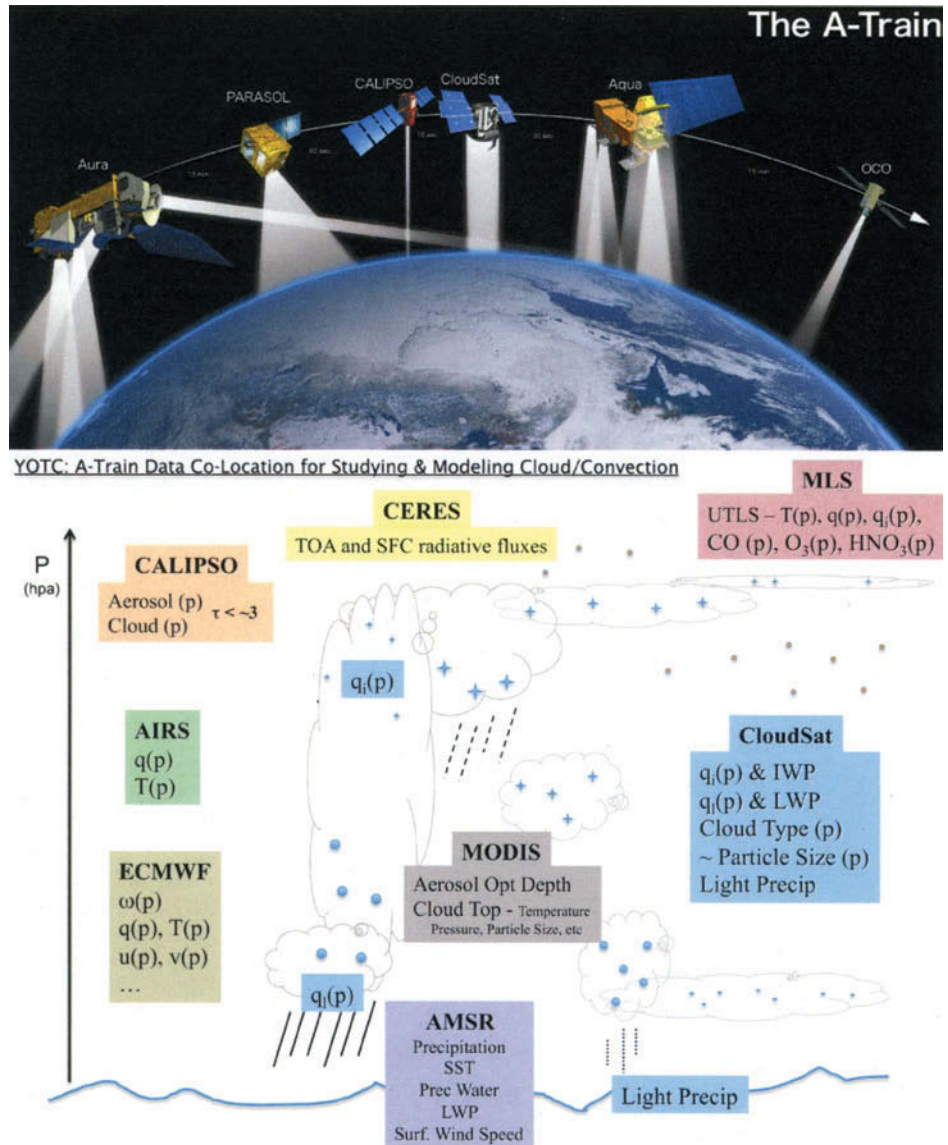


FIG. 7. Schematics of a key component of the YOTC satellite database. (top) The A-Train satellite constellation of the Earth Observing System, where “A” identifies the afternoon local equatorial crossing at 1:30 pm LT. (bottom) The comprehensive range of relevant observations for studying tropical convection, depicting a summary of a specific A-Train CloudSat-centric collocated dataset made available for YOTC at the CloudSat Data Processing Center (cloudsat.cira.colostate.edu).

climate models have difficulty with the distribution, amount, and frequency of precipitation (e.g., over continents, in the monsoons, and in the ITCZ).

THE YOTC PROJECT. Recognizing the pervasive challenges associated with tropical convection highlighted above, the World Climate Research Program (WCRP) and the World Weather Research Program (WWRP), via their prominent research program The Observing System Research and Predictability Experiment (THORPEX), jointly coordinate the Year of Tropical Convection project. A complete description is given in the YOTC Science Plan (Waliser and Moncrieff 2008), available online at www.ucar.edu/yotc. As previously summarized in Fig. 3, the YOTC project is in the spirit of a virtual global field campaign. Phenomena highlighted for research include the Madden–Julian oscillation and convectively coupled equatorial waves, easterly waves and tropical cyclones, the monsoons, tropical–extratropical interaction, and the diurnal cycle.

As noted in the introduction, there has been a vast increase in the number and types of observations available for weather and climate studies. Figure 7 shows an important component: the Earth Observing System (EOS) Afternoon-Train (A-Train) constellation of satellites (Stephens et al. 2002), which includes the *Aqua*, *Aura*, *PARASOL*, *CloudSat*, and *CALIPSO* satellites. This constellation includes sensors that measure solar and infrared radiation, cloud structure and microphysical properties, temperature and water vapor, aerosols and chemical composition, near-surface wind speed, sea surface temperature, etc. The A-Train makes near-simultaneous measurements from a variety of sensors. Along with the Tropical Rainfall Measuring Mission (TRMM) and *Terra* satellites, the A-Train samples vertical structure, including temperature, moisture, clouds, precipitation, latent heating, and radiative heating.

Along with other low-Earth orbit and geostationary satellites flying passive (infrared, visible, and microwave) and active (radar and lidar) instruments, there is a veritable armada of spacecraft measurements for tropical convection. The most recent low-Earth orbit satellite, *Megha-Tropiques*, launched in October 2011, will give useful information on the diurnal variability of MCSs, MJOs, and the monsoons. Geostationary satellite measurements complement the above mix of low-Earth orbit measurements by providing near-global, visible and infrared imagery that observe convection and clouds on the mesoscale to planetary scales as well as the diurnal cycle (Rossow and Duenas 2004).

To facilitate efficient access and manipulation of data, the YOTC Giovanni System (YOTC-GS), a web-based application developed by the National Aeronautics and Space Administration (NASA), gives swath and/or gridded data from a number of low-Earth orbit sensors. The swath data are best suited to detailed process studies, and for exploiting high spatial resolution (in some cases ~1 km), such as the statistical evaluation of regional cloud-system-resolving model output. The gridded data are suited to the study of meteorological phenomena and processes on large to global scales, for comparisons with global analyses of quantities not assimilated in models, and with hindcast/prediction products. Giovanni’s intuitive “one-stop-shop” for visualizing, analyzing, and accessing data for YOTC is described more fully online (at <http://disc.sci.gsfc.nasa.gov/YOTC>).

The ECMWF-YOTC database includes 6-hourly global analyses, multiday forecasts, and over 30 model-based subgrid tendencies from the European Centre for Medium-Range Forecasts (ECMWF) Integrated Forecasting System (IFS) on a 25-km grid (16 km for January 2010–April 2010) for the 2-yr period May 2008–April 2010. Subgrid tendencies spanning the globe in this way would be impossible to get from a real field campaign. As for a real field campaign, the 2-yr period focuses the community interest and concentrates resources on common meteorological events and phenomena (see Waliser et al. 2012). In much the same way as an atmospheric sounding network is a core element of regional field experiments, the ECMWF-YOTC database, and similar products from the National Centers for Environmental Prediction (NCEP) and the Global Modeling and Assimilation Office (GMAO), are the backbone of the virtual global field campaign approach. The YOTC global analysis complements global reanalysis, which is performed for longer time periods (decades) and at coarser resolution, typically 100–200-km grid length. More information on reanalysis can be found in Compo et al. (2011) and online at www.reanalysis.org.

For a “fast” process such as atmospheric convection, shortcomings in parameterizations can be diagnosed and addressed by short “hindcasts” of illustrative convective events. Figure 8 shows the bias in tropical precipitation for two climate models, those of the National Center for Atmospheric Research (NCAR) and the Geophysical Fluid Dynamics Laboratory (GFDL). For each model, the upper panel refers to composited 3-day weather hindcasts and the lower panel to a 20-yr climate integration. The precipitation bias in the hindcasts has a similar distribution to that in the climate integration, notably in

the Indian Ocean, west Pacific, Africa, and the ITCZ where convective organization is widespread (Fig. 6, lower panel). Running climate models in weather prediction mode is part of the YOTC project. For example, the same modeling group at the Department of Energy's Program for Climate Model Diagnostics and Intercomparison (PCMDI), which helped develop the research framework illustrated in Fig. 8, utilizes the YOTC period as a test bed for diagnosing and improving the NCAR Community Climate Model.

Most of the remaining part of this paper will describe how the experimental framework described above, involving the YOTC global analysis and observational databases, are being utilized to study and improve the prediction of the MJO.

PROGRESS WITH THE MJO. As the leading mode of tropical intraseasonal variability (e.g., Zhang 2005; Kiladis et al. 2009) and unforced convective organization ranging from cumulus to planetary scales, with cloud clusters and superclusters on the intervening scales (Nakazawa 1988), the MJO influences a wide range of weather and climate phenomena (Lau and Waliser 2011). With external forcing in mind, it is not surprising that the MJO has for long seriously challenged global models (e.g., Slingo et al. 1996; Lin et al. 2006; Sperber and Waliser 2008; Sperber et al. 2011). Its intraseasonal time scale makes the MJO a leading source of potential predictability (e.g., Waliser et al. 2003a,b; Waliser 2006) and a natural bridge between medium-range weather forecasting and seasonal prediction. Despite the challenging nature of the MJO, significant progress is being made on several fronts, as summarized below.

Global weather models. The upper panel of Fig. 9 shows that over recent years the strength and character of the MJO at hindcast lead times of 15 days in the

ECMWF IFS has improved from a barely detectable disturbance to a quite realistic propagating system (Bechtold et al. 2008). This advance is attributed to the combined effects of improved parameterizations, increased resolution (now 16-km grid), and the assimilation of vast volumes of data (up to 40 million per day from various platforms; see Fig. 2). It is not known how each of these three improvements individually affects the MJO prediction. The IFS can now maintain the amplitude of the MJO for more than 30 days (Vitart and Molteni 2010), although some problems remain (F. Vitart 2011, personal communication):

- The MJO propagates too slowly in the medium and subseasonal time range, and in the seasonal/ climate time range the MJO becomes almost stationary.
- In seasonal hindcasts the peak MJO activity is at much lower frequency than the observed 30–60-day range.
- The MJO dissipates too readily upon crossing the Maritime Continent.

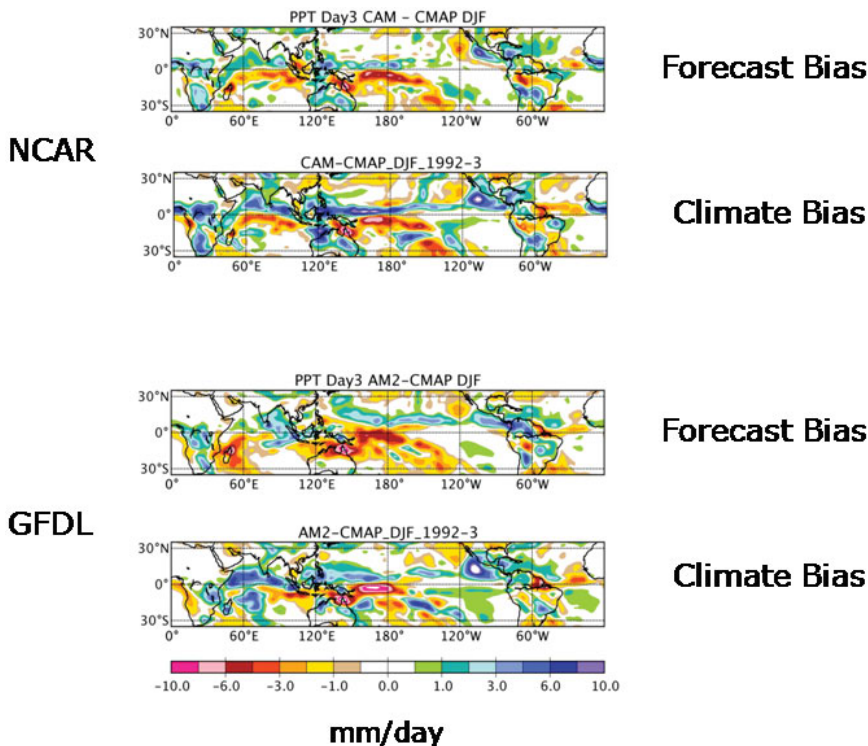


FIG. 8. Comparisons of weather and climate bias in terms of precipitation rate (mm day^{-1}) for two global modeling systems, GFDL and NCAR. The weather bias is the difference between predicted and observed precipitation rate for composited 3-day forecasts for Dec–Feb (DJF), 1992–93. The climate bias is from a 20-yr integration with prescribed sea surface temperature for Dec 1992–Feb 1993. Courtesy of Steve Klein and Jim Boyle, Lawrence Livermore National Laboratory.

- The MJO tends to regenerate more frequently from a previous MJO than observations (e.g., Matthews 2007) suggest.
- The genesis of an MJO is rarely predicted more than a week in advance, but it is not known whether this is a specific model problem or a fundamental predictability issue.

Global climate models. The shortcomings noted above for the MJO in weather models also plague climate models (e.g., Kim et al. 2009), attesting to their basic nature. The fact that MJO-like systems are simulated by cloud-system-resolving models in conditions of constant sea surface temperature indicates that atmosphere–ocean interaction is not basic to the MJO (e.g., Grabowski 2001). Climate models traditionally have weak MJOs. However, modified parameterizations have led to improvements (e.g., Wu et al. 2007; Zhou et al. 2011). While interaction with the ocean is seemingly not necessary for its existence, the MJO is considerably improved in coupled ocean–atmosphere models compared to atmosphere-only models (Subramanian et al. 2011). Unrealistic mean states can negatively affect the initiation of the MJO (Ray et al. 2011). This is a significant issue for climate models.

Global cloud-system-resolving models, an important recent development, simulate mesoscale circulations and also their interactions with the larger scales of motion. The lower panel of Fig. 9 is a snapshot of the distribution of cloud simulated by the world’s first such model, the Nonhydrostatic Icosahedral Atmospheric Model (NICAM), in this case with a 7-km grid, although the NICAM has also been run with a 3.5-km grid (Tomita et al. 2005; Nasuno et al. 2007; Satoh et al. 2008). These simulations give a visually plausible cloud distribution, including an MJO case by Miura et al. (2007). Much work remains to fully evaluate these complex models against observations, an area where the virtual global field campaign approach could be used to advantage.

Superparameterized models. In superparameterization, cloud-system-resolving models are used in place of conventional parameterizations of convection and the planetary boundary layer in each grid cell of the parent global model (e.g., Grabowski 2001; Khairoutdinov et al. 2005; Tao et al. 2009). Superparameterization has some immediate advantages over the traditional parameterization: (i) mesoscale convection is explicit, albeit two-dimensional and limited to periodic columns of the parent global model; (ii) the convective lifecycle has a built-in memory; (iii) microphysical processes interact more realistically with the

model dynamics; and (iv) convection is initiated/maintained by explicit downdraft outflows instead of needing an implicit “trigger.” Superparameterization simulates MJO-like systems (e.g., Benedict and Randall 2009), although there is a tendency for the MJO amplitude to be exaggerated and the environment to be too moist compared to observations. A possible reason is that the two-dimensional MCS simulated by the cloud-system-resolving models are overly efficient processors of energy compared to nature. Superparameterization is hundreds of times more computationally expensive than traditional parameterization, so it is not suitable for operational weather forecasting, centuries-long climate change projections, and Earth-system modeling.

SOME RESEARCH IMPERATIVES. Some research imperatives are given below, mainly in the context of the MJO and organized tropical convection.

Fundamentals. It remains to be fully understood *why* the MJO is improved in models, and *whether* the MJO is reproduced in the same way as in nature. In this respect, insights into dynamical aspects, such as upscale and downscale transport, scale interaction, multiscale organization, and convective transport are important. Considerable progress is being made through insights gained from theoretical–dynamical models and idealized numerical simulations. Examples are the role of organized convective momentum transport in the structure and evolution of the MJO and convectively coupled tropical waves (Moncrieff 1992, 2004; Grabowski and Moncrieff 2001, 2004; Biello et al. 2007; Majda and Stechmann 2009a; Khouider et al. 2011), the MJO as a neutrally stable moisture mode on intraseasonal/planetary scales (Majda and Stechmann 2009b), multcloud parameterization (Majda 2007; Khouider and Majda 2008), and the effects of multcloud parameterization on the MJO in low-resolution global models (Khouider et al. 2011).

Near-term international collaborative research. A number of activities are underway in collaboration with WCRP, WWRP/THORPEX, the Global Energy and Water Cycle Experiment (GEWEX), and a recent field campaign:

- *Vertical Structure and Diabatic Processes of the MJO: A Global Model Evaluation Project* seeks to improve physical parameterizations for global weather and climate models. The series of numerical experiments are 20-yr climate

simulations, along with 2-day and 20-day initialized hindcasts of two MJO events that occurred during the October 2009–February 2010 period of the YOTC, when El Niño conditions prevailed. This activity is summarized by Petch et al. (2011), with more information available online at www.ucar.edu/yotc (see MJO Task Force section).

- The *Transpose-Atmospheric Model Intercomparison Project (T-AMIP)* consists of hindcasts with climate models run with specified sea surface temperature for four MJOs that occurred during October 2008–July 2009 for the La Niña conditions of the YOTC. More information can be found online at hadobs.metoffice.com/tamip.
- The Dynamics of the MJO (DYNAMO; www.eol.ucar.edu/projects/dynamo) is the U.S. component of the international Cooperative Indian Ocean Experiment on Intraseasonal Variability in the Year 2011 (CINDY2011). The main objective is to investigate processes that initiate the MJO in the Indian Ocean during boreal winter. Some of the DYNAMO modeling will be collaborative with the above MJO Task Force activity.

Longer-term research. A number of physically and dynamically complex issues pertinent to the intersection of weather and climate need to be addressed, such as the following:

- Characterization of the temperature, moisture, and multiscale cloud structures within the MJO lifecycle including the roles of diabatic heating, lower-tropospheric moistening, and organized convective momentum transport.
- Initiation mechanisms for the MJO, including the relative importance of local influences (e.g., surface fluxes, diurnal cycle) and extratropical influences such as planetary waves, and wintertime cold surges emanating from the Asian continent.
- Orographic and diurnal cycle effects of the Indonesian maritime

continent on the amplitude and propagation of the MJO.

- Generation mechanisms for planetary waves by the MJO and convectively coupled tropical waves.
- Effects of intraseasonal variability on the life cycle of the Asian–Australian monsoon.
- Effects of the MJO on ENSO and vice versa.
- Interplay between parameterized convection and explicit convective organization in high-resolution global models.
- Improved parameterizations of the physical processes in global models, including but not restricted to convection.

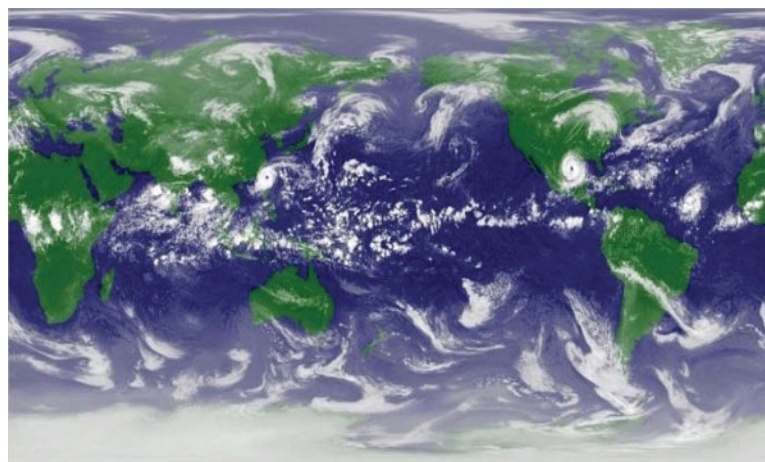
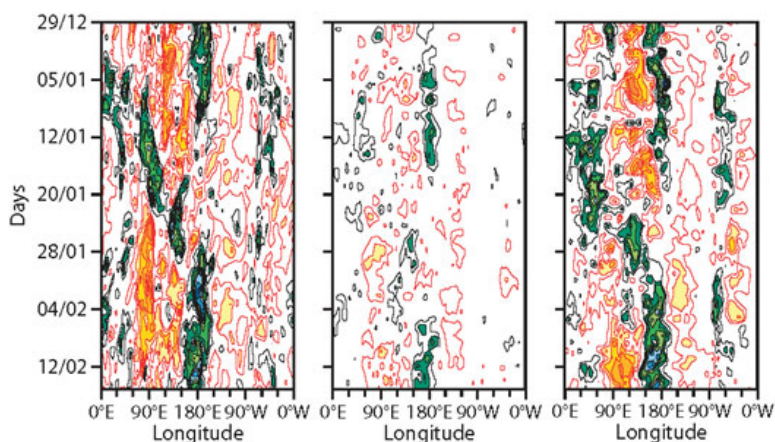


FIG. 9. (top) Progress with the MJO in the ECMWF IFS shown by the Hovmöller diagrams of the averaged outgoing longwave radiation (OLR; a surrogate for precipitation) between -10° and $+10^{\circ}$ latitude from 29 Dec 1992 to 15 Feb 1993 obtained from daily forecasts with different cycles of the IFS. Red/yellow colors denote warm regions (e.g., SST) and blue/green colors deep convection. (left) The “control” according to the 40-yr ECMWF Re-Analysis (ERA-40); (middle) a barely detectable MJO in the IFS for Sep 2004; (right) the greatly improved MJO for Sep 2009. A more complete record of progress is in Vitart and Molteni (2010). Courtesy Frederic Vitart, ECMWF. (bottom) Snapshot of the global distribution of cloud simulated by NICAM at 7-km grid spacing. Courtesy of H. L. Tanaka and the NICAM Team.

CLOSING REMARKS. The Year of Tropical Convection (YOTC) project began as a grassroots response to a recommendation arising from an international workshop. It has grown into a significant effort involving numerical prediction centers, research groups, and individual researchers around the world. The project has been promoted at numerous workshops and meetings, and recently at the 2011 YOTC International Science Symposium in Beijing, China, as reported by Moncrieff et al. (2012).

Tropical convection includes precipitation systems that display an underlying chaotic order, notably the organized mesoscale systems that are building blocks for larger-scale meteorological phenomena. The YOTC project calls for major improvements in how the tropics are represented in climate models, recognizing that it will be impossible to predict climate on regional scales or to comprehend the global water cycle in a warmer world without addressing tropical convection and its multiscale organization.

Mesoscale convective organization is a “missing process” in contemporary climate models because coherent circulations are not represented by parameterizations and the model resolution is too coarse to simulate them. The next generation of climate models (i.e., 10-km grids) will need to address convective organization and how it interacts with contemporary parameterizations. Fortunately, we have the observations, numerical models, and theoretical insights to embark upon this challenging new quest.

We deliberately focused the latter part of this paper on the MJO. However, many of the conclusions are relevant to other multiscale phenomena at the intersection of weather and climate that severely challenge global models: the monsoons, tropical–extratropical interaction, easterly waves and tropical cyclones, and the diurnal cycle.

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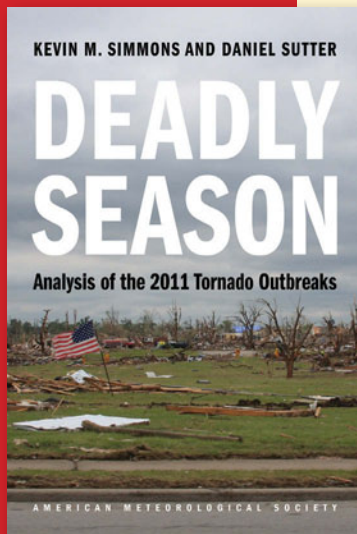
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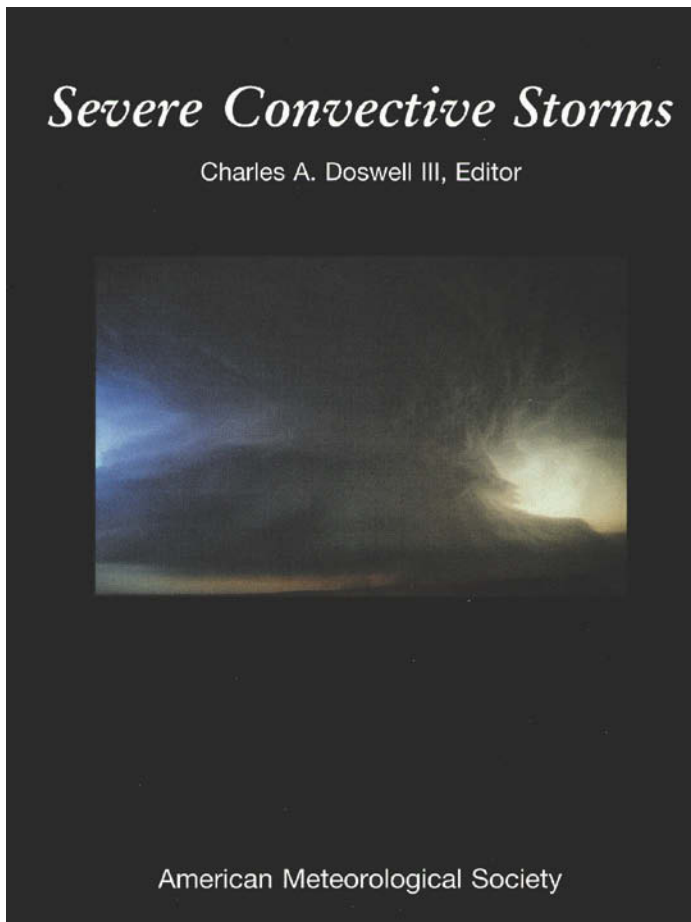
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THE “YEAR” OF TROPICAL CONVECTION (MAY 2008–APRIL 2010)

Climate Variability and Weather Highlights

BY DUANE E. WALISER, MITCHELL W. MONCRIEFF, DAVID BURRIDGE, ANDREAS H. FINK, DAVE GOCHIS, B. N. GOSWAMI, BIN GUAN, PATRICK HARR, JULIAN HEMING, HUANG-HSUING HSU, CHRISTIAN JAKOB, MATT JANIGA, RICHARD JOHNSON, SARAH JONES, PETER KNIPPERTZ, JOSE MARENGO, HANH NGUYEN, MICK POPE, YOLANDE SERRA, CHRIS THORNCROFT, MATTHEW WHEELER, ROBERT WOOD, AND SANDRA YUTER

May 2008–April 2010 provided a diverse array of scientifically interesting and socially important weather and climate events that emphasizes the impact and reach of tropical convection over the globe.

The realistic representation of tropical convection in our global atmospheric models is a long-standing grand challenge for numerical weather forecasts and global climate predictions [see companion article Moncrieff et al. (2012), hereafter M12]. Our lack of fundamental knowledge and practical capabilities in this area leaves us disadvantaged in simulating and/or predicting prominent phenomena of the tropical atmosphere, such as the inter-tropical convergence zone (ITCZ), El Niño–Southern

Oscillation (ENSO), monsoons and their active/break periods, the Madden–Julian oscillation (MJO), easterly waves and tropical cyclones, subtropical stratus decks, and even the diurnal cycle. Furthermore, tropical climate and weather disturbances strongly influence stratospheric–tropospheric exchange and the extratropics. To address this challenge, the World Climate Research Programme (WCRP) and The Observing System Research and Predictability Experiment (THORPEX) of the World Weather

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Research Programme (WWRP) jointly proposed and are implementing a coordinated research program involving observing, modeling, and forecasting of organized tropical convection—referred to as the “Year of Tropical Convection” (see www.ucar.edu/yotc). A key component of the motivation of YOTC is that there have been substantial investments in Earth science infrastructure over the previous decades. These are now realized in terms of a comprehensive satellite-observing system (e.g., Earth Observing System), operational buoy arrays in each of the tropical oceans, global analyses and forecast systems that are now carried out at resolutions less than 25 km, and a number of global, high-resolution, convection-permitting modeling systems. Based on these investments, including field programs already in place, a key precept of YOTC is that a tractable and promising research program can be constructed from the presently available resources, through a focus period approach, in much the same way field programs and specific phenomenological cases focus and magnify the community’s attention and efforts [e.g., the First Global Atmospheric Research Program (GARP) Global Experiment (FGGE), and the Tropical Ocean and Global Atmosphere Coupled Ocean–Atmosphere Response Experiment (TOGA COARE)].

The YOTC period is from May 2008 to April 2010; its choice developed from deliberations that started with the activity’s conception at a WCRP–THORPEX-sponsored meeting in 2006 (Moncrieff et al. 2007), its subsequent science planning meeting in 2007 (Waliser and Moncrieff 2008), and the YOTC implementation planning meeting in 2009 (see the implementation plan at www.ucar.edu/yotc). While the target period was initially designed to be a year, its extension to a full 2 yr was proposed and agreed to at the implementation planning meeting in concert with the realization that a second year would allow YOTC to capture a period of both La Niña and El Niño conditions (see Fig. 1). In this article, we describe this period in terms of its anomalous low-frequency characteristics as well as highlight the most interesting and impactful synoptic features. The description of the latter is largely aligned with the targeted phenomenological areas outlined in the YOTC Science Plan. These include 1) the MJO and other convectively coupled equatorial waves (CCEWs), 2) easterly waves and tropical cyclones (TCs), 3) monsoons, 4) tropical–extratropical interactions, and 5) the diurnal cycle. The objective of this overview article is to set the stage for more targeted and in-depth observation, modeling, and prediction studies for the YOTC period, following the strategies outlined in the YOTC

Implementation Plan. Following the descriptions of the low-frequency and synoptic characteristics is a summary and discussion section that highlights the more notable features of the period. It concludes with an overview of YOTC’s plans to leverage these features and events for case-study research to improve our understanding, modeling, and prediction capabilities associated with tropical convection.

BACKGROUND CONDITIONS AND LOW-FREQUENCY VARIABILITY.

Some elements of weather and higher-frequency climate variability that are targeted by YOTC depend on characteristics of the conditions set up by lower-frequency climate variability. For example, the spatial characteristics and manifestations of intraseasonal variability (e.g., MJO) can be modified by the conditions of ENSO and the Indian Ocean dipole (e.g., Hendon et al. 1999; Kessler 2001; Waliser et al. 2001; Lau 2005; Hendon et al. 2007; Rao et al. 2007; Ajayamohan et al. 2009). Moreover, these low-frequency tropical climate conditions influence the manifestations of extratropical patterns of atmospheric variability (e.g., Horel and Wallace 1982; Renwick and Wallace 1996; Kumar and Hoerling 1998; Newman and Sardeshmukh 1998; Wallace 2000; Ambaum et al. 2001; Giannini et al. 2001; Hastenrath and Greischar 2001; Ostermeier and Wallace 2003). For these reasons, we begin by documenting the background conditions and evolution of low-frequency climate patterns, including a couple of the more significant extratropical modes of climate variability. Figure 1 shows the anomalous characteristics of sea surface temperature (SST) in the three tropical ocean basins during the YOTC period. Starting with the Pacific, the early half the YOTC period is characterized by modest La Niña conditions, while the latter half is characterized by modest El Niño conditions. Closer examination shows that the 2008/09 boreal winter period is cool and the 2009/10 boreal winter period is warm, both spring-to-summer periods tend to exhibit warming conditions, and the 2008 (2009) boreal fall undergoes cooling (warming) conditions. Overall the largest and longer-lived anomalous conditions tend to be more strongly exhibited in the western half of the Pacific basin compared to the eastern half. This evolution in anomalous SST (i.e. La Niña vs El Niño) between the first half and the second half of the YOTC period represents an excellent contrast for studying its effects on tropical convection characteristics.

For the Indian Ocean, there is some similarity to the Pacific, with a tendency toward cool (warm)

conditions in the first (second) half of the YOTC period, albeit with about half or less the amplitudes exhibited in the Pacific. The characteristics of the Indian Ocean SST, particularly the anomalous east–west temperature gradient across the tropical Indian Ocean, can be linked to a number of important

regional climate effects. For example, extreme September–November rainfall in tropical East Africa has been associated with periods when the western (eastern) Indian Ocean SST is anomalously high (low)—meaning a weakening of the normal west-to-east positive SST gradient (Black et al. 2003). Similarly,

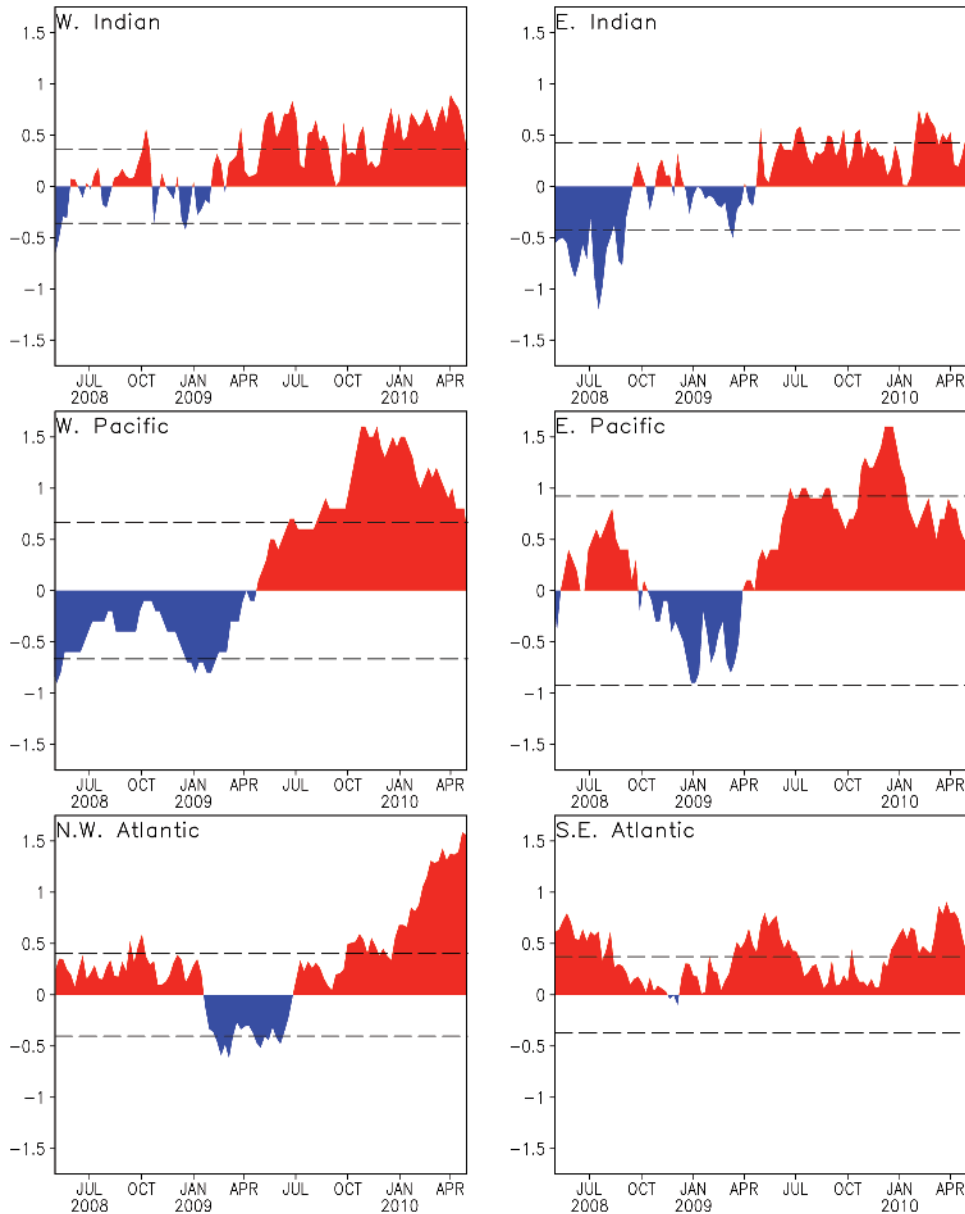


FIG. 1. Tropical ocean SST anomalies ($^{\circ}\text{C}$) in terms of weekly values during the YOTC period. (top left) West Indian Ocean (10°S – 10°N , 50° – 70°E), (top right) east Indian Ocean (10°S – 0° , 90° – 110°E), (middle left) west Pacific Ocean (5°S – 5°N , 160°E – 150°W), (middle right) east Pacific Ocean (5°S – 5°N , 150° – 90°W), (bottom left) North Atlantic (5° – 25°N , 55° – 15°W), (bottom right) South Atlantic (20°S – 0° , 30°W – 10°E). Notes: 1) The west (east) Pacific Ocean defined here is often referred to as Niño-4 (Niño-3); 2) subtracting the east from the west Indian Ocean time series gives the Indian Ocean dipole (IOD) mode index (DMI, not shown; Saji et al. 1999). Time series are from online (tropical Pacific at www.cpc.noaa.gov/data/indices/; other time series are from http://ioc-goos-oopc.org/state_of_the_ocean/).

northward-propagating intraseasonal variability (ISV) has been found to be stronger and more coherent when the western (eastern) Indian Ocean SST is anomalously low (high) (Rao et al. 2007; Ajayamohan et al. 2008, 2009). During most of YOTC, the Indian Ocean warmed, somewhat in concert with the Pacific Ocean. The western Indian Ocean was generally about 0.5°C warmer than the eastern Indian Ocean, indicating that the normal west-to-east temperature gradient in the Indian Ocean was weaker than normal throughout most of YOTC. For the

Atlantic, the most remarkable feature is the exceptional warming that develops during the winter of 2009/10, lagging the warming in the Pacific by 3–6 months (Carton and Huang 1994; Enfield and Mayer 1997). This is a peak value when considering the record back to 1982. The southern tropical Atlantic exhibits warm conditions over nearly all the YOTC period, with peak magnitudes typical when considering the most recent three decades (not shown).

Figure 2 illustrates the time evolution and spatial patterns (see caption) of three important modes of extratropical variability during the YOTC period. These three extratropical modes include the Pacific–North America (PNA), Arctic Oscillation (AO), and the Antarctic Oscillation (AAO; www.cpc.noaa.gov/data/indices/), and have been shown to be strongly correlated to tropical convection variability and influence low-frequency weather variations (Horel and Wallace 1981; Wallace and Gutzler 1981; Hurrell 1996; Thompson and Wallace 1998; Deser 2000; Thompson and Wallace 2000; e.g., Ambaum et al. 2001; L’Heureux and Higgins 2008; Pohl et al. 2010). The AO exhibits an overall anticorrelation with

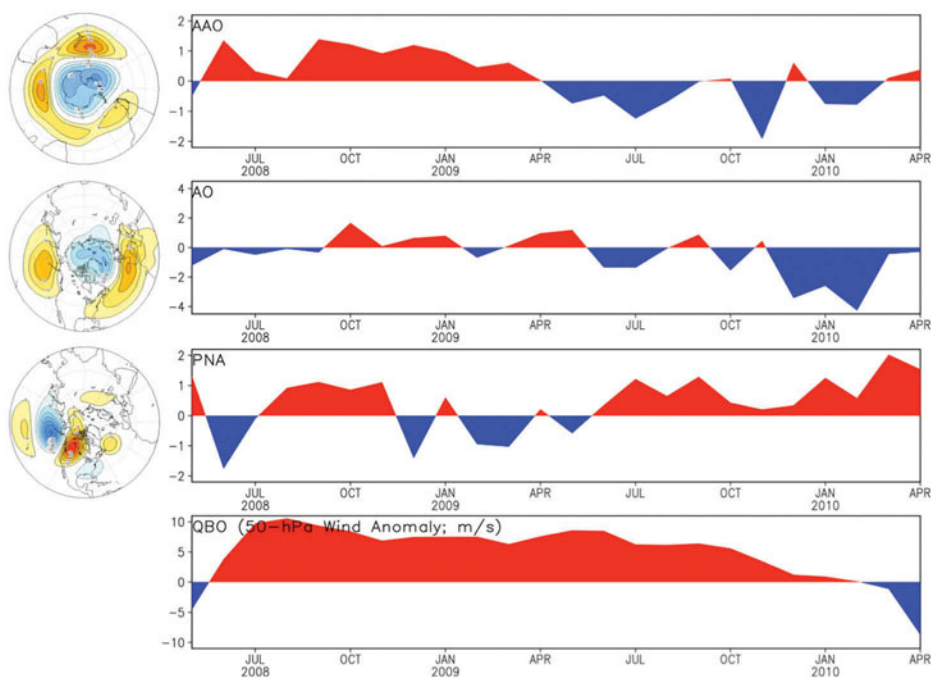


FIG. 2. Monthly time series of (from top to bottom) the AAO, AO, PNA, and the QBO for the YOTC period (unitless, except for QBO in m s^{-1}). To the left of the first three indices are the spatial patterns of the 500-hPa geopotential height anomaly patterns associated with each of the modes of variability; each contour represents 10 m. Indices are defined and the data obtained from the following two Climate Prediction Center websites (www.cpc.noaa.gov/data/indices/, www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/teleconnections.shtml). The spatial patterns of the AAO, AO, and PNA were obtained from online (at www.emc.ncep.noaa.gov/gmb/ssaha/).

tropical Pacific and northern tropical Atlantic SSTs shown in Fig. 1, being in mostly a positive (negative) phase during these two oceans’ cool (warm) periods. The AAO exhibits a strong anticorrelation to the Pacific SSTs, particularly the western Pacific, while the PNA exhibits a correlation most strongly to the eastern Pacific SSTs. Also illustrated in Fig. 2 is the evolution of the quasi-biennial oscillation (QBO) during YOTC, as indicated by the 50-hPa wind index time series. For the most part, the entire period of YOTC is dominated by a westerly phase of the QBO, with only the very ends of the period being relatively neutral. Finally, to comprehensively describe the background conditions under which the YOTC period evolved, it is worth noting that CO_2 concentration averaged over the 2-yr period was 386.8 ppm with a linear trend of about $+2.0 \text{ ppm yr}^{-1}$ (mean and least squares trend estimated for YOTC period from ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_mm_mlo.txt), the solar cycle was largely in the minimum phase of the 11-yr cycle (www.swpc.noaa.gov/SolarCycle/), and there was no significant volcanic activity that occurred in or near the tropics.

TROPICAL WAVES. Madden–Julian oscillation. The MJO is of considerable interest in YOTC due to the considerable influence it has on other components of our weather and climate system, including monsoon onset and breaks, TCs, ENSO evolution, extratropical variability, etc. (Madden and Julian 1971; Zhang 2005; Lau and Waliser 2011). An overview of MJO-related tropical convective variability that occurred during the YOTC period is provided in Fig. 3. This figure uses satellite outgoing longwave radiation (OLR) data filtered for eastward-propagating wavenumbers 1–5 and periods 30–96 days as a proxy for the convective variability associated with the MJO (Wheeler and Kiladis 1999; Wheeler and Weickmann 2001). Six cases of relatively strong MJO activity have been identified during this period (see Figs. 3a–f). By this measure, the three strongest cases of enhanced convection (i.e., negative OLR anomalies) associated with the MJO during YOTC were in April 2009 (Fig. 3d), November 2009 (Fig. 3e), and January 2010 (Fig. 3f). These periods of MJO activity also show as being the strongest, although with different relative magnitudes, when viewed using the real-time multivariate MJO index (Wheeler and Hendon 2004), which includes lower- and upper-tropospheric zonal winds in the MJO definition. Placing this activity into a historical context, the YOTC MJO cases were weaker than those that occurred in 8 of the previous 12 yr, very much weaker than the very strong MJO activity that occurred in the lead up to the 1997 El Niño, and a little weaker than the well-documented activity that occurred during TOGA COARE (not shown).

Highlighting the more notable cases, the *May–*

June 2008 (Fig. 3a) case involved modulation of convective activity over much of the tropics, including an enhancement of convection over the western Indian Ocean in late May (which approximately coincided with the start of the first northward propagation of intraseasonal convection into India of the 2008 monsoon season shown later in Fig. 8), as well as an enhancement of convection in the eastern Pacific ITCZ (as was associated with the development of several TCs). The *April–May 2009* (Fig. 3d) case included nearly two complete cycles of the MJO. The first exhibited strong interaction with other equatorial waves (see first case in the “Convectively coupled equatorial

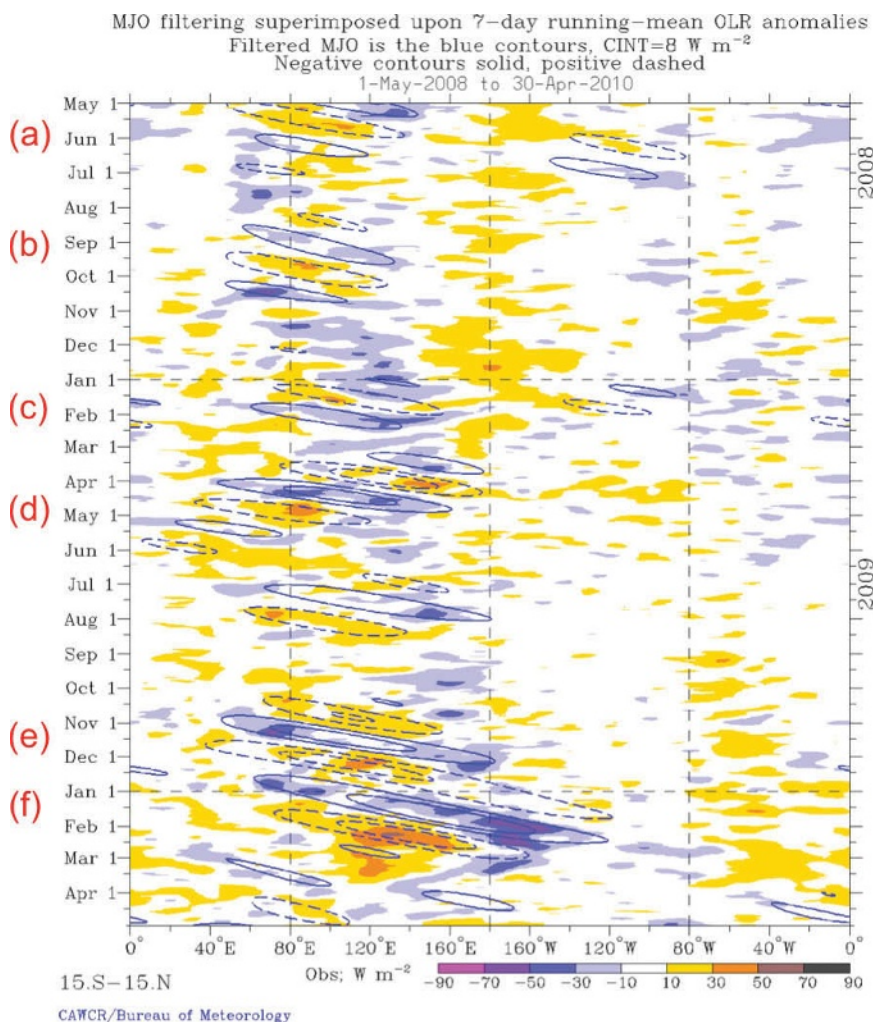


FIG. 3. Time–longitude diagram of 15°S–15°N-averaged OLR anomalies (W m^{-2}) during the YOTC period, with MJO-filtered OLR anomalies superimposed. Shading is for “total” OLR anomalies that have been temporally (7-day running mean) and spatially (R21 spectral truncation) smoothed. Contours show OLR that has been wavenumber–frequency filtered for eastward-propagating waves 1–5 and periods 30–96 days, as is used to signify convective variability associated with the MJO. Contour interval is 8 W m^{-2} , with dashed contours used for positive MJO-associated OLR anomalies. Labels (a)–(f) refer to the identified cases of MJO activity.

waves” section) and has been implicated in the shift to El Niño conditions through the enhancement of westerly surface wind anomalies across the Pacific (once convection reached the Pacific in late April). The second cycle was associated with the first northward propagation of intraseasonal convection into India for

2009 (see Fig. 8). The *October–December 2009* (Fig. 3e) case began with suppressed convection over the near-equatorial Indian Ocean in mid-October, followed by a switch to enhanced convection over Africa and the western Indian Ocean, which progressively gained in strength until peaking in the second week of

November, with the strongest negative OLR anomalies observed for the near-equatorial Indian Ocean for the whole of the YOTC period. Finally, for the *December 2009–February 2010* (Fig. 3f) case, enhanced convection reached farther eastward than any other MJO of the YOTC period, presumably helped by the warm Pacific conditions. The MJO cases discussed above, including the nuances of their initiation, propagation, possible connections, and influences on TC formation, make them excellent cases for broadening our understanding of multiscale interactions as well as for model verification studies.

Convectively coupled equatorial waves. Here we focus on just two periods of notable occurrences of CCEWs (Takayabu 1994; Wheeler and Kiladis 1999; Kiladis et al. 2009). The first case involves multiple interacting waves during the period March–April 2009 (Fig. 4, top). The MJO, ($n = 1$) equatorial Rossby (ER), and Kelvin waves were all simultaneously active, seemingly propagating through each other to account for the observed complex behavior of simultaneous eastward and westward propagation. For example, the enhanced convection that occurred near 90°E on 10 April appears to be a result of the superposition of the influence of all three waves propagating at different speeds and/or directions. The ER wave in this example originates from an earlier convective blowup that occurred well to the east about 20 days previously. The Kelvin wave, in contrast, originates from the Atlantic, crossing 0° on about 2 April. A later strong Kelvin wave

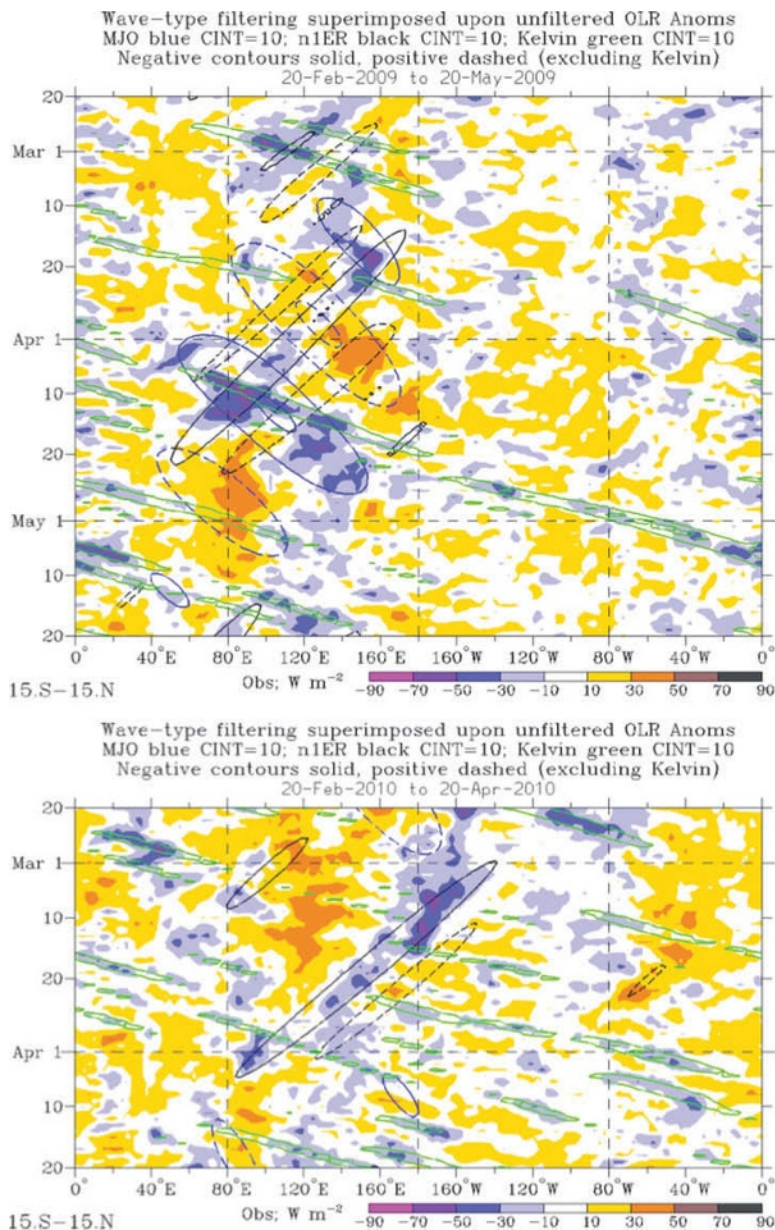


FIG. 4. (top) 15°S – 15°N -averaged OLR anomalies (W m^{-2}) for the period 20 Feb–20 May 2009, during which multiple interacting waves (MJO, equatorial Rossby, and Kelvin) existed (CCEW case 1). Shading is for the unfiltered OLR anomalies, blue contours for the MJO-filtered OLR anomalies, black contours for the $n = 1$ ER wave filtering, and green contours for the Kelvin wave filtering. Contour interval is 10 W m^{-2} . Positive contours for the MJO and ER wave anomalies are dashed, whereas the Kelvin wave positive contours are omitted. (bottom) As in (top), but for the period 20 Feb–20 Apr 2010 (CCEW case 2).

crossed the Atlantic and Africa in the first week of May.

The second case involves coherent westward movement of convection from east of the date line in the Pacific to the Indian Ocean during March 2010 (Fig. 4, bottom). Consistent with the structure of an $n = 1$ ER wave, this convection was mostly symmetric about the equator and occurred in conjunction with cyclonic circulation cells on either side of the equator. Imbedded within these cyclonic circulation cells were several TCs: TCs Tomas and Ului in the Southern Hemisphere and TC Omais (Agaton) in the Northern Hemisphere. TC Ului followed a long westward track, from $\sim 170^\circ\text{E}$ on 10 March to $\sim 150^\circ\text{E}$ on 21 March. In addition, prominent Kelvin wave activity was observed during this case period (green contours in Fig. 4). These cases, and others like them, represent stringent tests for our global models to properly represent and as of yet little attention has been paid to the verification of CCEW activity nor to the metrics used for the evaluation (see M12).

Easterly waves. As with the waves discussed above, easterly waves (EWs) play a key role in modulating tropical cyclogenesis, and are most prevalent during the Northern Hemisphere summer over West Africa

and the tropical Atlantic (Reed et al. 1977; Kiladis et al. 2006) as well as the Pacific (Reed and Recker 1971; Nitta and Takayabu 1985; Serra et al. 2008). Figure 5 shows the July–September variance of Tropical Rainfall Measuring Mission (TRMM) 3B42 precipitation rate (Huffman et al. 2007) in the “tropical depression” (TD) wavenumber frequency band (wavenumber -20 to -6 and period 2–5 days). Note that TCs may contribute to the TD-band variance, especially in the western Atlantic and Pacific Oceans, north of 15°N . The top panel is indicative of climatological EW storm tracks (Thorncroft and Hodges 2001). The middle panel shows that 2008 was characterized by anomalously high TD variance in the West African and tropical Atlantic region. The region of maximum TD variance ($6^\circ\text{--}15^\circ\text{N}$, $50^\circ\text{W}\text{--}15^\circ\text{E}$) was 13% higher in 2008 than climatology. In contrast, TD variance in 2009 was 5% lower than climatology over the same region (Fig. 5c). In 2008, TD variance was 20% below the 1998–2009 mean over the region $6^\circ\text{--}15^\circ\text{N}$, $150^\circ\text{--}80^\circ\text{W}$. Anomalously low TD variance was especially prominent in the central Pacific, consistent with the negative SST anomalies there (see “Background conditions and low-frequency variability” section), whereas TD variance was 28% above climatology in 2009 over the same region,

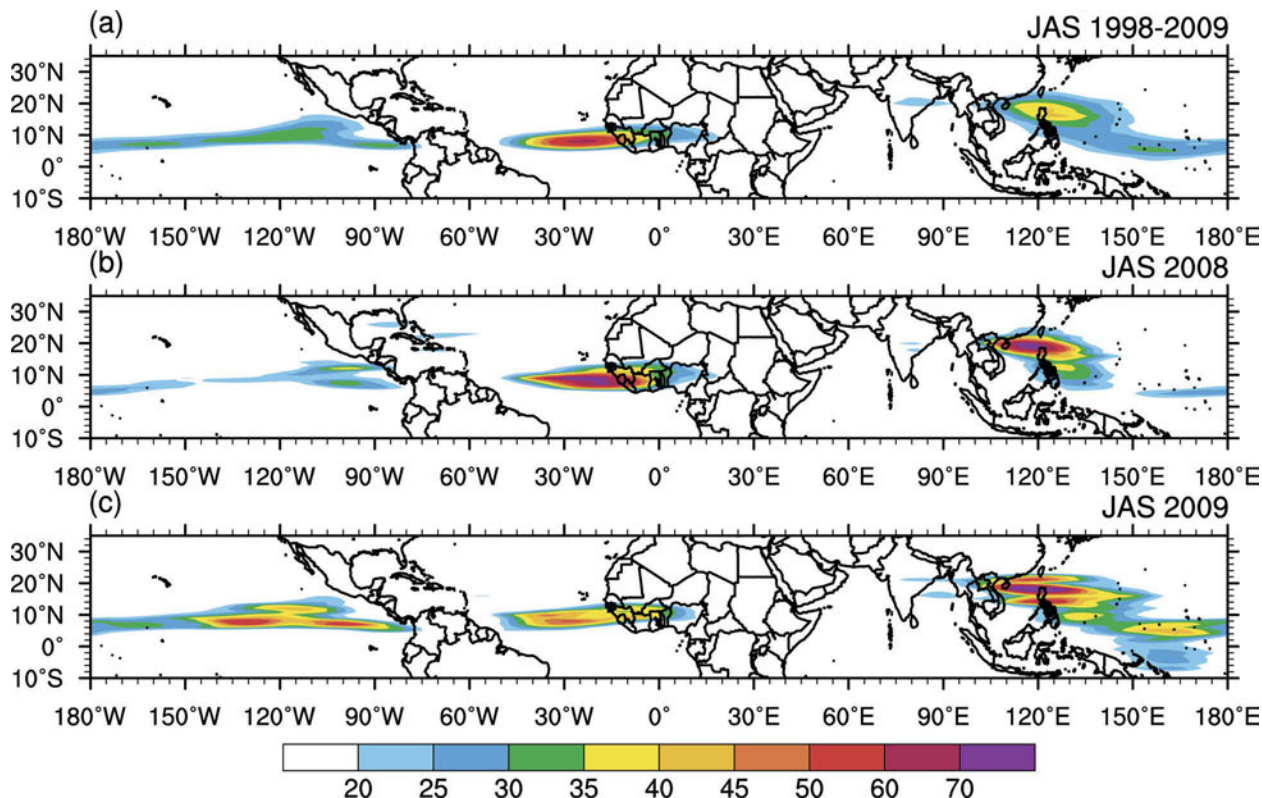


FIG. 5. Variance of TRMM 3B42 TD-filtered rain rate $[(\text{mm day}^{-1})^2]$ for Jul–Sep averaged over (a) 1998–2009 (b) 2008, and (c) 2009.

consistent with the presence of above-average SSTs. Similarly, west Pacific TD-band variance was also enhanced in 2009 (Hsu et al. 2009). The relationship between the contrasting EW activity in 2008 and 2009, ENSO, and ISV associated with the MJO and CCEWs, including how these vary with boundary forcings, is an area of research that could benefit from the YOTC. It will also be important and interesting to contrast the EW variability observed in the YOTC years with that observed during the 2006 African Monsoon Multidisciplinary Analyses (AMMA) field campaign over West Africa (Redelsperger et al. 2006; Janicot et al. 2008).

Figure 6 provides a more detailed look at the tracks and characteristics of easterly waves during July–September 2008 and 2009. The Hovmöller diagrams include precipitation rate and objectively determined EW tracks based on 700-hPa vorticity maxima (Janiga 2010). The period between mid-July and early September 2008 was associated with

numerous intense African EWs moving over tropical North Africa into the east Atlantic. Consistent with past EW composite studies [see Kiladis et al. (2006), and references therein], the peak precipitation rate is located ahead of the EW tracks or in the northerlies over Africa (Fig. 6). A closer examination of the most intense waves reveals that mesoscale convective systems formed northwest of the midlevel trough and then moved southwestward but remained fairly coupled to the wave. One example of this is an EW that moved from the Ethiopian highlands to the east Atlantic between 14 and 22 July 2008 (see dashed box in Fig. 6a). Both this wave and the preceding wave contributed to heavy rainfall and flooding in West Africa with rainfall totals between 17 and 21 July in excess of 4 cm over much of West Africa and rainfall totals exceeding 10 cm in Burkina Faso and Liberia. Another high-impact event occurred on 1 September 2009 (see dashed box in Fig. 6b) when an mesoscale convective system, tightly coupled to the

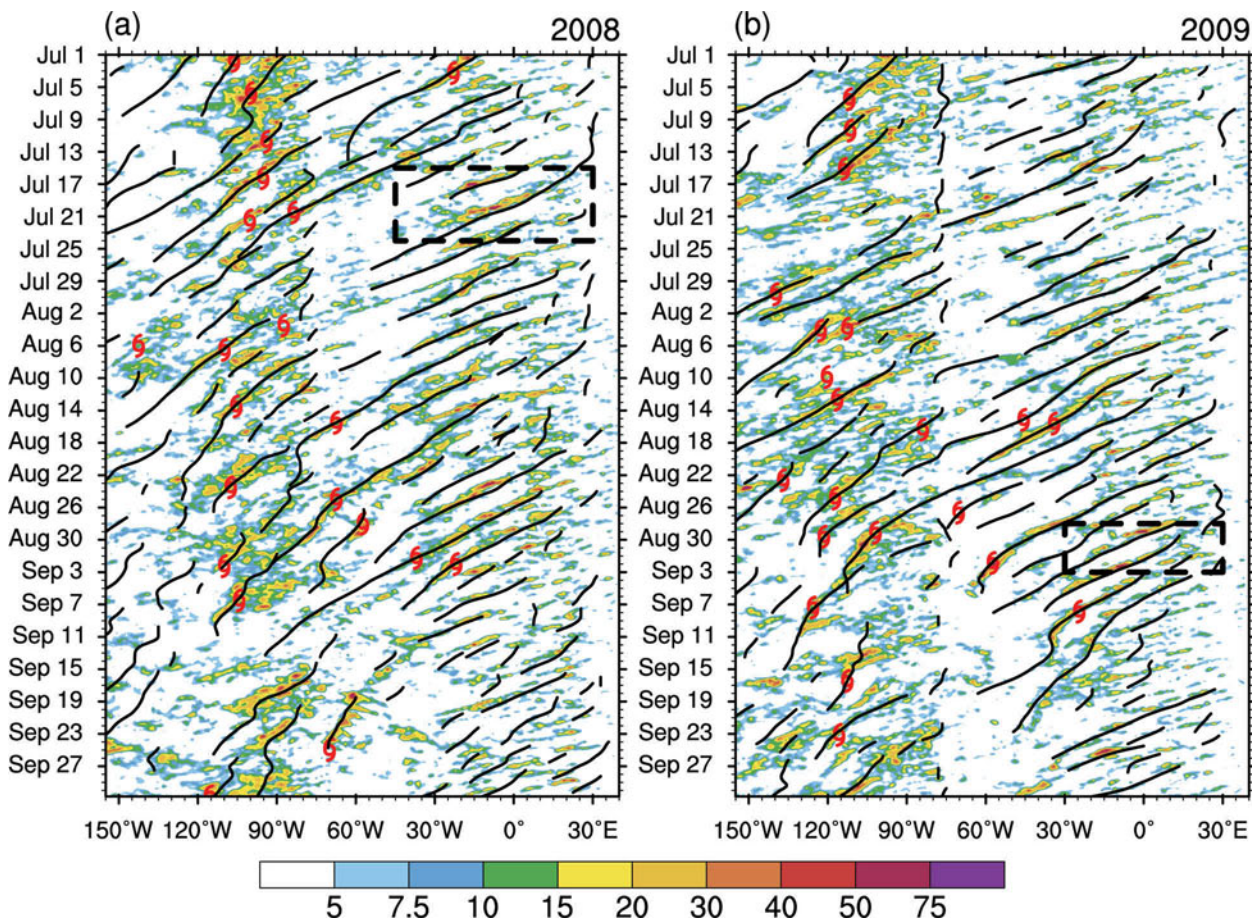


FIG. 6. Hovmöller diagram of TRMM 3B42 rain rate (mm day^{-1} , shaded) averaged between 5° and 20°N and objective tracks of vorticity centers exceeding $1 \times 10^{-5} \text{ s}^{-1}$ observed between 0° and 30°N for (a) 2008 and (b) 2009. The time and longitude of named storm genesis is indicated by the red markers. Dashed boxes highlight periods of high-impact weather referred to in the text.

midlevel trough of an EW, produced 263 mm of rainfall in Ouagadougou, Burkina Faso, according to rain gauges (not shown). Examinations of the relationship between subsynoptic aspects of the structure of the EWs and these convective systems would be greatly aided by the high resolution of the YOTC analyses.

TROPICAL CYCLONES. TCs are by far one of the most significant manifestations of organized tropical convection, notably because of their sheer elegance as a physical system but also because of the societal need for ever-increasing accurate predictions of their strength and track. Climatologically speaking, the last several years have been remarkably below average in terms of overall global tropical cyclone activity. Since the previous peak in overall global and

Northern Hemisphere accumulated cyclone energy (ACE) in 2005, tropical cyclone activity has significantly decreased, especially over the entire Pacific with the 2008/09 YOTC “year” having the lowest global ACE since 1977 (Maue 2009, 2011). Despite YOTC occurring within a historically quiet period relative to the last three decades, there were still ample TCs that developed, with some particularly unique cases and conditions.

The tracks of all TCs during the YOTC period are illustrated in Fig. 7, with those mentioned below annotated with a number at the start and end of the track. In 2008, the western North Pacific (WNP) had 25 tropical storms with 12 becoming typhoons—a season with slightly below-normal activity. Typhoon Jangmi (Fig. 7a—track 1) was the strongest TC of

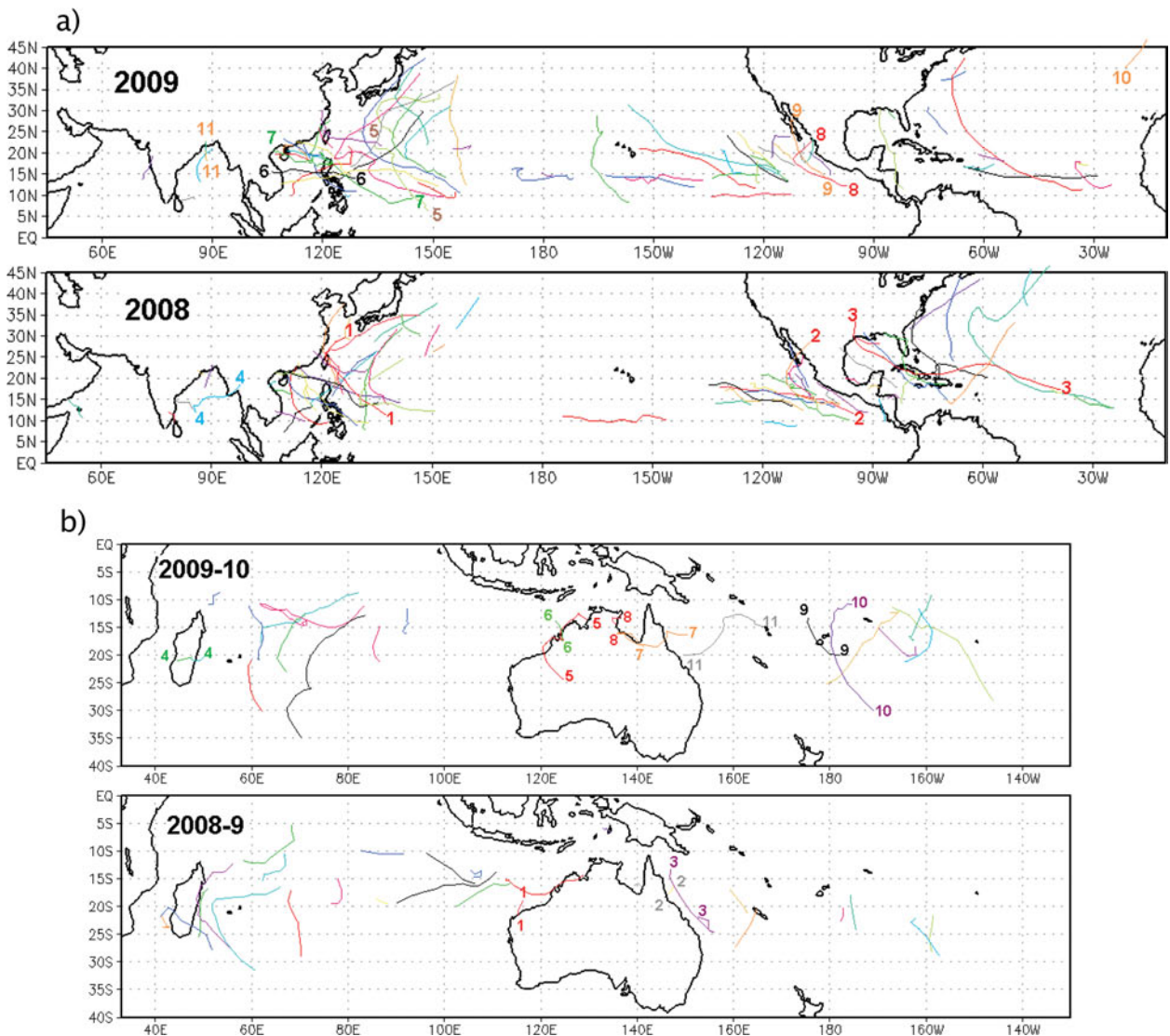


FIG. 7. (a) Northern Hemisphere TC tracks: (top) 2009 and (bottom) 2008. (b) Southern Hemisphere TC tracks: (top) 2009/10 and (bottom) 2008/09. Numbers refer to specific storms discussed in the text (see “Tropical cyclones” section).

the season across the whole Northern Hemisphere with sustained winds of 145 kt. Unusually, Japan received no direct landfalls during this season. The eastern North Pacific exhibited activity close to normal. Hurricane Norbert (Fig. 7a—track 2) was the strongest of the season and was also one of three TCs (with Julio and Lowell) to make landfall over Mexico. The North Atlantic was active; for the first time, major hurricanes (winds of 100 kt or more) occurred in each of the 5 consecutive months from July to November. Hurricanes Fay, Gustav, Ike, and Paloma all hit Cuba. Ike (Fig. 7a—track 3) was one of the largest storms (in aerial size) ever recorded in this basin and caused a storm surge of up to 7 m along the Gulf of Mexico coast. In the north Indian Ocean, the most significant storm was Cyclone Nargis (Fig. 7a—track 4), which made landfall over Myanmar and caused a huge storm surge up the Irrawaddy delta. This resulted in the loss of as many as 100,000 lives. During the 2008/09 Southern Hemisphere season, four storms brought heavy rainfall to Madagascar. Cyclones Dominic and Ellie (Fig. 7b—tracks 1 and 2) made landfall over the Australian coast, while the strongest storm of the season, Hamish (Fig. 7b—track 3), kept just offshore of the Australian east coast.

During the 2009 Northern Hemisphere season, the El Niño event induced stronger typhoons in the western North Pacific and the storm tracks tended to originate farther east into the central parts of the Pacific Ocean. The strongest typhoon of the season, Nida (Fig. 7a—track 5), peaked with sustained winds of near 160 kt. Notable events were Typhoon Ketsana (Fig. 7a—track 6), which caused extensive flooding in the Philippine capital Manila and later across Vietnam and Cambodia, and slow-moving Typhoon Parma (Fig. 7a—track 7), which dumped an estimated 1.8 m of rain over the northern Philippines. The El Niño event also resulted in higher-than-normal activity in the eastern and central North Pacific. Hurricane Rick (Fig. 7a—track 8) became the second strongest east Pacific hurricane on record, making landfall over Mexico, as did Hurricane Jimena (Fig. 7a—track 9). In the North Atlantic, the El Niño event resulted in a quiet season for the Caribbean and United States. The most unusual event of the season was high-latitude Tropical Storm Grace (Fig. 7a—track 10), which developed near the Azores and eventually tracked across the United Kingdom as an extratropical system. In the north Indian Ocean, Tropical Storm Aila (Fig. 7a—track 11) caused a storm surge of up to 3 m across Bangladesh, which resulted in hundreds of fatalities in this region. The most notable events for the 2009/10 Southern

Hemisphere season included Tropical Storm Hubert (Fig. 7b—track 4), which caused significant disruption over Madagascar. While activity was quiet around Australia, several storms [Laurence, Magda, Olga, and Paul (Fig. 7b—tracks 5–8, respectively)] impacted coastal regions. Both Mick and Tomas (Fig. 7b—tracks 9 and 10, respectively) affected Fiji, and Ului (Fig. 7b—track 11) was the strongest South Pacific cyclone for 5 yr. To round off the season, a highly unusual tropical storm in the South Atlantic developed in March 2010 and was named Anita by Brazilian meteorological organizations (not shown). It was the first such storm to develop in this region since Catarina in 2004; although unlike Catarina, Anita posed no threat to land.

TC research in YOTC benefits from the occurrence of the THORPEX Pacific Asian Regional Campaign (T-PARC) and Tropical Cyclone Structure 2008 (TCS-08) field experiments that conducted multiple aircraft operations into Typhoons Nuri, Sinlaku, Hagupit, and Jangmi. The science objectives of these campaigns included increasing understanding of TC formation, structure and intensity change, extratropical transition, and the value of targeted observations. In particular, analysis of aircraft observations are being conducted with reference to gridded YOTC analysis fields provided by the European Centre for Medium-Range Weather Forecasts (ECMWF).

MONSOONS. The monsoons exhibit considerable breadth in terms of the phenomena and range of space and time scales associated with tropical convection (e.g., Ramage 1971; Murakami 1975; Gadgil 1981; Lau and Lim 1982; Hastenrath 1987; Trenberth et al. 2000; Rodwell and Hoskins 2001; Wang 2006). This includes seasonal and planetary-scale changes in the atmospheric and ocean circulations, a preponderance of tropical wave activity, modulations of TCs' other synoptic scales, and diurnal variations. The monsoons represent highly integrating features of tropical convection and remain an ominous forecast challenge from not only their onset but for subsequent breaks and active periods, extreme events, and seasonal totals. Here, we highlight some of the notable monsoon characteristics during the YOTC period.

Indian. With the 2008 Indian summer monsoon being “normal,” garnering 98% of long-term average all India rainfall (AIR), and 2009 being one of the worst drought over the past century with AIR being 22% below the long-term average, the YOTC period provides a unique opportunity to examine and unravel differences in propagation characteristics and

structure of the monsoon intraseasonal oscillations (MISOs) and how they lead to interannual variability. Evolution of the daily rainfall over India (between 6° and 27°N and 72° and 85°E) indicates (Fig. 8) that the near-normal monsoon of 2008 had three strong, active spells of rainfall and only two weak breaks, while the severe-drought monsoon of 2009 was characterized by three long breaks and two weak active spells. This is consistent with some recent studies (Joseph et al. 2010) indicating that long breaks are characteristic features of Indian monsoon droughts. The monsoon onset over Kerala (MOK) during 2008 occurred on 31 May, close to the climatological date.

Although 2009 was a drought year, the onset took place on 23 May, a week before the normal onset date, consistent with earlier findings that MOK has no relationship with the performance of the monsoon.

Significant differences in ISV during 2008 and 2009 are noteworthy (Figs. 8c–f). The time–latitude diagrams of 30–60-day filtered OLR anomalies averaged over Indian longitudes show that the northward propagation of MISO was slower during 2008 compared to that during 2009. Also, consistent with the daily rainfall (Figs. 8a,b), the MISO during 2008 was characterized by three wet and two dry northward-propagating spells, while during 2009 there were

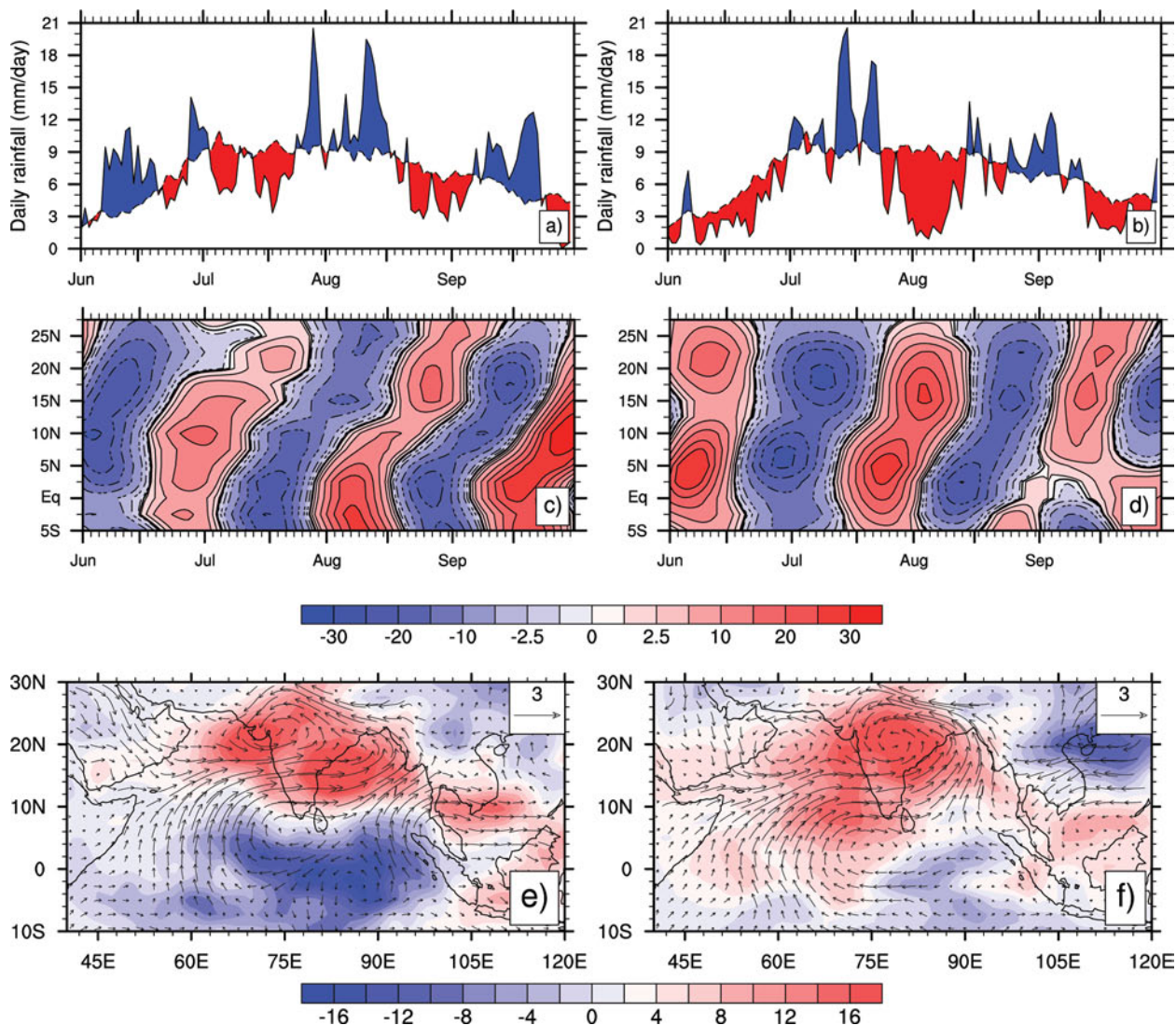


FIG. 8. (a) Daily rainfall (mm day^{-1}) over India (averaged between 72° and 85°E and 6° and 27°N) during 1 Jun–30 Sept 2008. Above (below)-normal rainfall is shown in blue (red) on either side of the daily climatology. (b) As in (a), but for 2009. (c) Northward propagation as seen from 30–60-day filtered OLR anomalies (W m^{-2}) averaged over 60°–90°E during 2008. (d) As in (c), but for 2009. (e) Lag-zero regressed structure of 10–90-day filtered OLR (shaded) and 850-hPa winds with respect to a reference time series (filtered OLR anomalies averaged over central India) during 2008. (f) As in (e), but for 2009.

two wet and three dry spells. Another important feature (Figs. 8b,d) is the intensity of the long break during August 2009 that contributed to the severity of the drought of the year. What was responsible for this intense long break during 2009? Neena et al. (2011) show that an interaction between a westward-propagating planetary-scale equatorial Rossby wave and the northward-propagating MISO may have been responsible for this intense long break. The characteristic spatial pattern associated with the MISO during the 2 yr also had notable differences. Regressed 10–90-day filtered OLR and winds at 850 hPa with respect to a reference time series (filtered OLR averaged over central India) show a canonical convectively coupled monsoon ISV structure with a meridional dipole in OLR over Indian longitudes during 2008 (Waliser 2006; Goswami 2011). During 2009, the meridional dipole structure of convection is conspicuously absent, leading to a much larger meridional scale for low-level winds during 2009 compared to 2008. Understanding what is responsible for the differences in propagation characteristics and spatial structure of ISV between these 2 yr is crucial for developing the ability to forecast them at lead times of 2–3 weeks, and is a major challenge for YOTC.

East Asian/western North Pacific. As with the Indian monsoon, the July–September seasonal-mean low-level circulation and convective activity in the East Asian/WNP (EA/WNP) monsoon region were distinctly different between 2008 and 2009. During July–September 2008, the monsoon trough was weaker than normal and confined mostly in the South China Sea, while the ridge was unusually strong and occupied the whole WNP from the equator to 50°N (Fig. 9). Rainfall was above normal for most of the WNP, and in particular in the tropics from the South China Sea all the way to the date line. The stronger monsoon trough and more rainfall were likely induced by the 2009 El Niño, which became mature in early summer (e.g., Lau and Nath 2006). In contrast, the monsoon trough was stronger and extended farther eastward than normal in July–September 2009, while the ridge shifted more northward than usual. The corresponding circulation was characterized by a cyclonic anomaly in the South China Sea and the Philippine Sea and anticyclonic anomaly in the extratropical WNP. Moreover in 2009, the tropical EA/WNP from the South China Sea to 150°E was dominated by a westerly anomaly. As a result, rainfall was above normal for most of the WNP, and in particular in the tropics from the South China Sea all the way to the date line.

Percentile maps show how anomalous the rainfall and specific humidity were during YOTC. The 850-hPa specific humidity was generally above the 85th percentile in the WNP west of 140°E but lower than the 15th percentile east of 160°E in the prevailing region of the unusually strong subtropical ridge. Extremely low rainfall (below the 10th percentile) was observed in the region between 5° and 15°N and east of 140°E where the anticyclonic circulation and easterly anomaly prevailed. In July–September 2009, the high specific humidity region extended further eastward and occupied almost the whole tropical and subtropical EA/WNP region. While rainfall was above the 50th percentile throughout most of this region, it was generally not as extreme as in specific humidity, except in the central rainfall-abundant areas, where it exceeded the 90th percentile. Extremely low rainfall was found east of Taiwan and south of Japan and in the subtropical WNP east of 160°E, in all cases where the anticyclonic anomalies prevailed. Note that typically July–September rainfall in the WNP is largely contributed by tropical cyclones, and this appears to be the case for the rainfall and TC distributions in 2008 and 2009 (see Fig. 7). The characteristics mentioned above emphasize the multiscale nature of tropical convection and the interactions between synoptic- and finer-scale convection, the large-scale circulations (e.g., monsoons and CCEWs), and basin-scale climate (e.g., ENSO).

Australian. The YOTC period covers two wet seasons in northern Australia that occur in austral summer. Figure 10 shows a daily time series of rainfall together with the climatological rainfall distribution at Darwin (blue line). Significant intraseasonal variability is exhibited, some of which may be attributed to the MJO (see “Madden–Julian oscillation” section). However, tropical cyclones also contributed significantly to Darwin rainfall, namely, TC Billy (December 2008), TC Lawrence (December 2009) and ex-TC Paula (March 2010) (see “Tropical cyclones” section; Fig. 7), as did a monsoonal low during late February 2010 and long-lived continental squall lines during late October 2009.

Through the development of an objective technique to better characterize the state of the north Australia wet season on any given day, Pope et al. (2009) showed that it is important to consider the entire wet season rather than just the embedded shorter monsoon period. This is because a significant fraction of the rainfall occurs outside the traditionally defined monsoon period. The state analysis technique involved the identification of five wet-season regimes

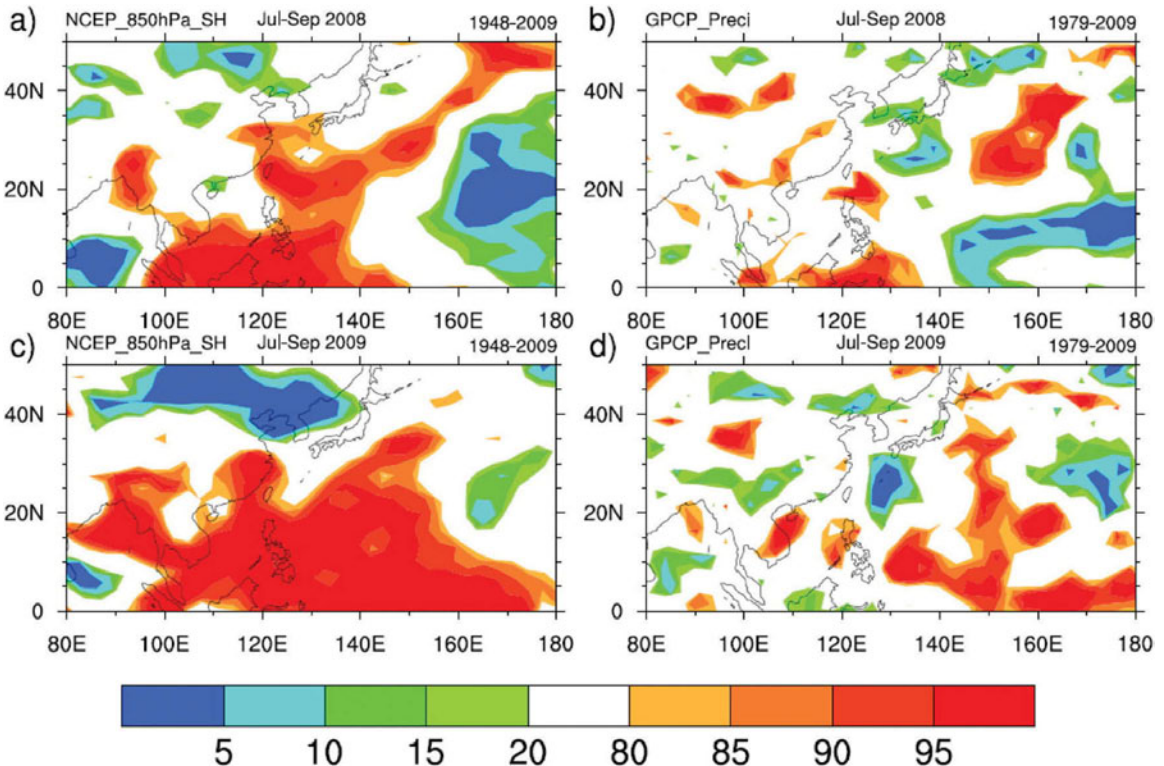
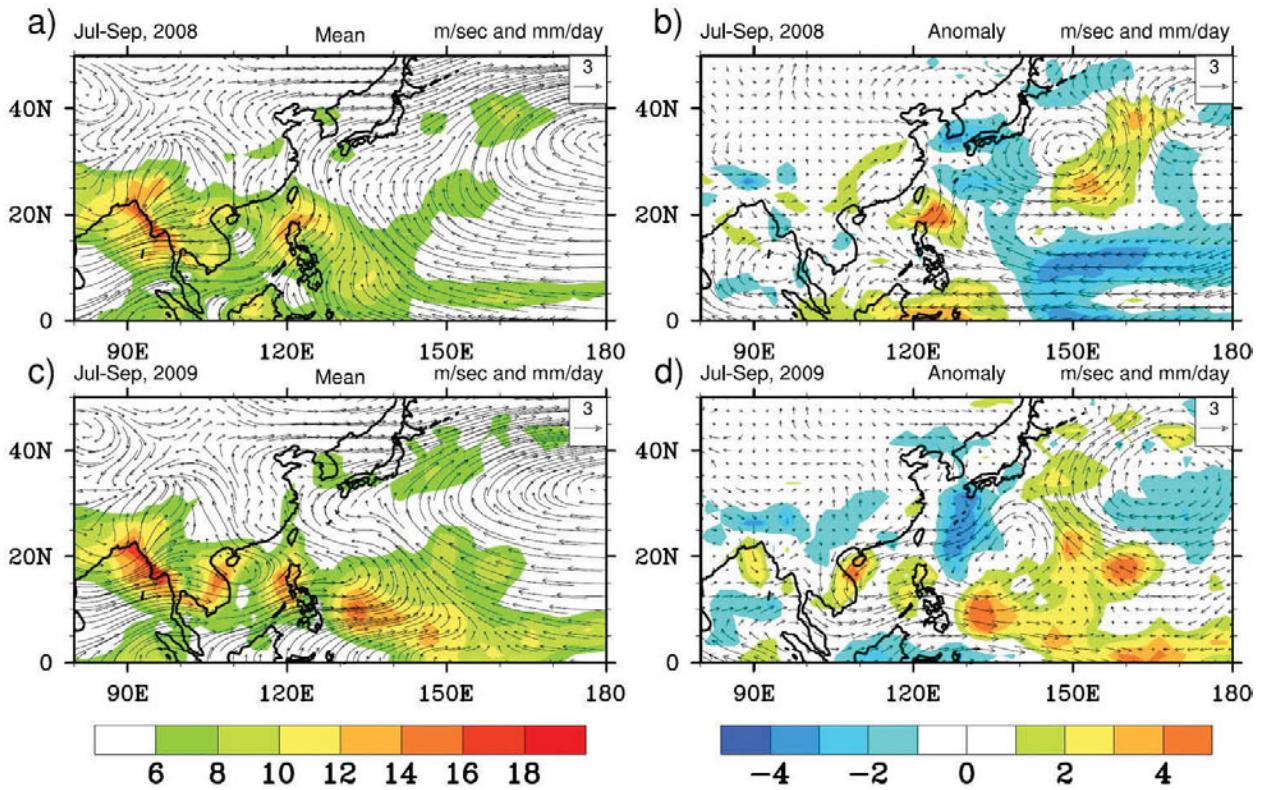


FIG. 9. (top) Rainfall (mm day^{-1}) and 850-hPa wind (m s^{-1}) in Jul–Sep (a) 2008 and (c) 2009. (b), (d) As in (a), (c), but for anomaly. (bottom) Distribution of percentile for (a), (c) 850-hPa specific humidity and (b), (d) rainfall anomalies in Jul–Sep (a), (b) 2008 and (c), (d) 2009. Base periods for calculating percentile are based on trying to use as long a record as possible for the given dataset selected, thus 1949–2009 and 1979–2009 for specific humidity and rainfall, respectively.

from daily radiosonde data at Darwin. Three of the regimes, termed *deep west*, *moist east*, and *shallow west*, are typically associated with rainfall, where deep west identifies the active phase of the monsoon and moist east signifies monsoon buildup, break, and retreat conditions. Two of the five regimes (east and dry east) represent generally dry conditions. The wet-season onset can be identified by the first significant consecutive days of the moist east regime, and monsoon onset is related to the first occurrences of the deep west regime. Likewise the retreat of the monsoon and the end of the wet season can be determined as the last days of the deep west and moist east regimes, respectively. Figure 10 shows the daily identification of wet-season regimes as described above for the two north Australia wet seasons within YOTC. Also shown are the climatological monsoon onset and retreat days (vertical dashed lines) and the monsoon onset and retreat days for the two seasons (arrows).

Using the moist east regime as an indicator, the 2008/09 wet season started in early November and lasted until mid-March. In contrast, the 2009/10 wet season started in early December and lasted well into April. This is consistent with La Niña conditions in 2008/09, which promote an early wet-season onset (Nicholls et al. 1982; Drosowsky 1996), while the slight El Niño event in 2009/10 favored a later wet-season onset. Using the definitions above, the onset in 2008 and 2009 occurred on 18 December and

15 December, respectively, close to the mean onset date 19 December (Pope et al. 2009). The retreat of the monsoon in 2008 and 2009 occurred on 17 February 2009 and 5 March 2010, respectively. Hence, the 2008/09 monsoon season was relatively short, while the 2009/10 season was of more or less average length, and the wet season as whole lasted significantly longer than in 2009/10 than in 2008/09.

North American. By measures such as all-Mexico June–August total rainfall, the 2008 North American monsoon (NAM) was the largest since 1941. Positive rainfall anomalies in gauge data (not shown) and negative peak season (July–August) OLR anomalies (Fig. 11a) were exhibited in nearly all regions of Mexico and throughout much of the U.S.-Mexico border region. Consistent with previous studies (Higgins et al. 1998; Castro et al. 2001; Gochis et al. 2007; Liebmann et al. 2008), antecedent SST conditions appear to have played a significant role in the development of this anomaly. Weakening wintertime La Niña conditions (Figs. 11c, 1) in the central and western Pacific, and an extended wintertime drought and warm surface temperatures over western Mexico and the Southwest United States helped initiate an early, robust onset to the NAM in mid-to-late June. Regional precipitation-tracking indices developed as part of the North American Monsoon Forecast Forum (Gochis et al. 2009) showed all NAM regions

experiencing anomalously high precipitation accumulations through July. Persistent diabatic heating from convective activity (inferred from negative OLR anomalies) and a northwestward shift in the 200-mb height field (Fig. 11e) during July and August helped provide a favorable pattern for sustained low-level moisture advection (not shown) from the Gulf of California, tropical eastern Pacific, and the Gulf of Mexico into the NAM region (Higgins et al. 2004). As mentioned in the tropical cyclones section, owing to favorable steering

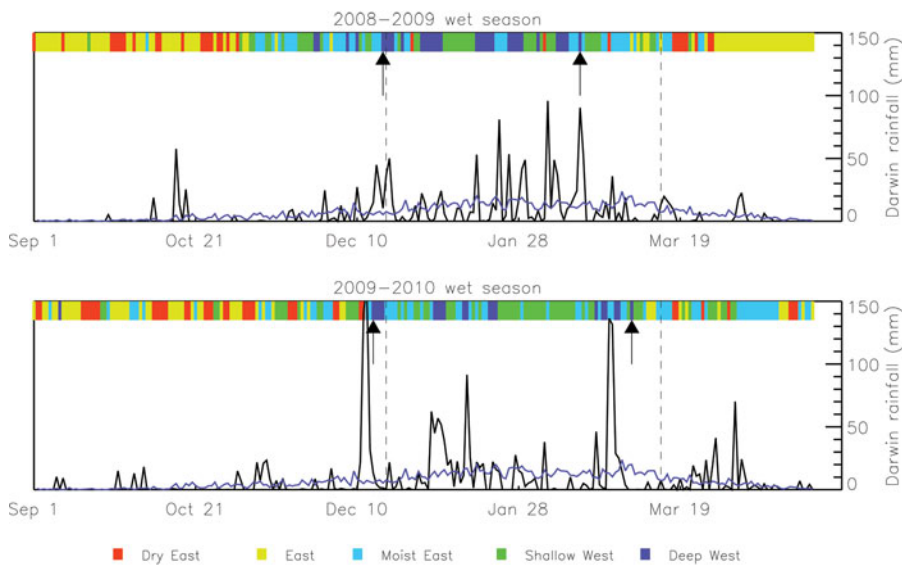


FIG. 10. Time series of daily rainfall (mm; black line) and daily wet-season regime (color bar) for the northern Australia wet seasons of (top) 2008/09 and (bottom) 2009/10. Also shown are the climatological rainfall distribution (blue line), the climatological monsoon onset and retreat days (vertical dashed lines), and the respective season’s monsoon onset and retreat days (arrows) as defined in Pope et al. (2009).

circulations, landfalling and near-shore tropical storms also made significant contributions to rainfall totals during July–September of 2008. Englehart and

Douglas (2001), Wang et al. (2008) and Serra (2009) each note that circulation patterns favorable for sustaining NAM rainfall are also likely to steer tropical

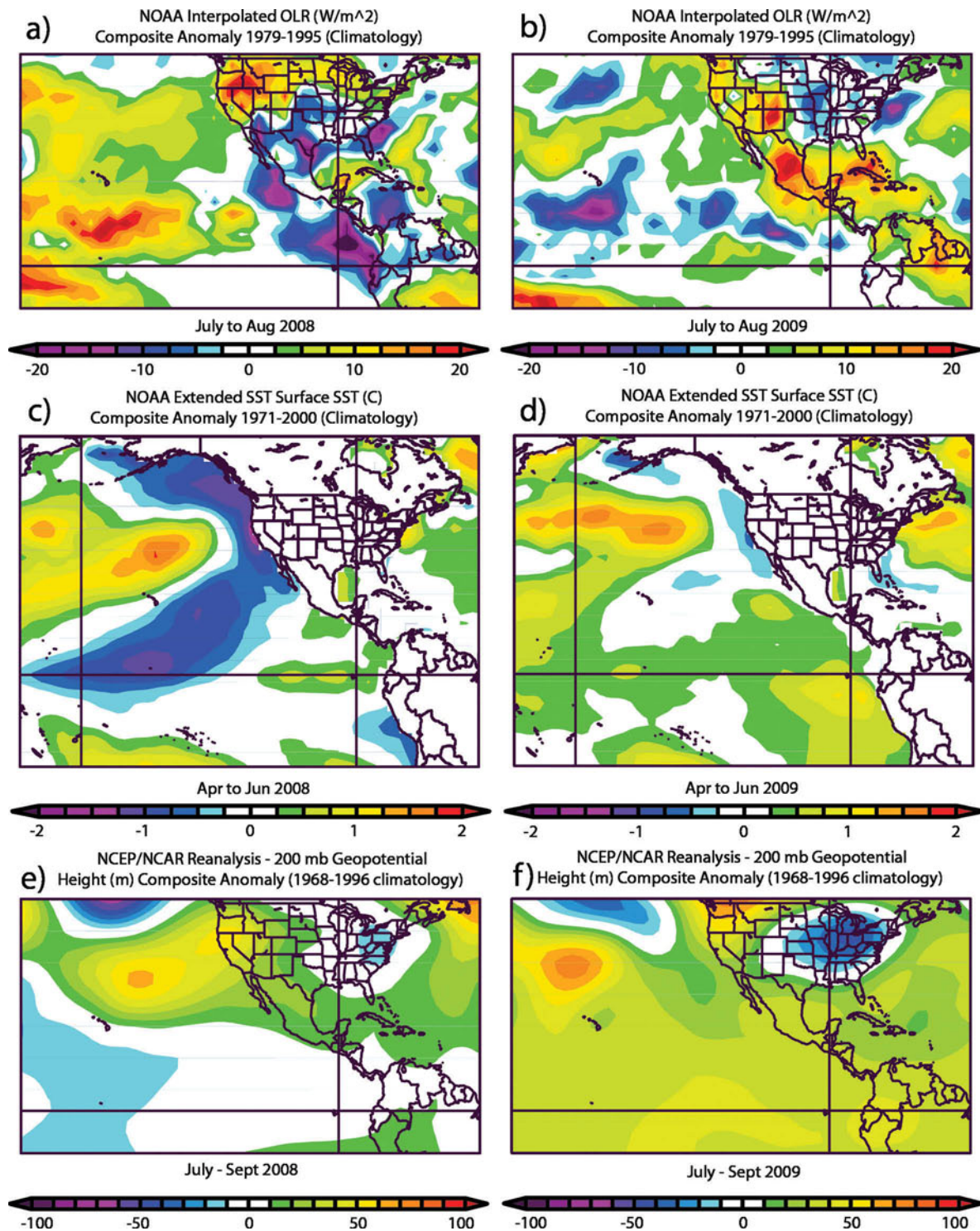


FIG. 11. (a),(b) Jul–Aug National Oceanic and Atmospheric Administration (NOAA) interpolated OLR anomalies ($W m^{-2}$), (c),(d) antecedent season (Apr–Jun) NOAA extended optimal interpolation (OI) SST anomalies ($^{\circ}C$), and (e),(f) Jul–Sep NCEP–National Center for Atmospheric Research (NCAR) reanalysis 200-hPa geopotential height anomalies (m) for 2008 and 2009, respectively.

storms into Mexico, the southwestern United States, Baja California, and the Texas Gulf Coast. Thus, for a year like 2008, both the large-scale circulation and episodic extremes appear to have contributed to the record rainfall totals.

In contrast to 2008, seasonal changes in Pacific sea surface temperatures toward moderate El Niño conditions by summertime appeared to have had a significant impact on the 2009 NAM (Fig. 11d). While the onset of the 2009 NAM was over a week early compared to climatology, the overall monsoon circulation pattern and its associated rainfall deteriorated substantially by late July. Consequently, July–August OLR anomalies (Fig. 11b) were mostly positive over the southwestern United States and Mexico. A number of areas of Mexico experienced some of the worst seasonal drought in recent history. Similarly, parts of western Arizona and the broader regions of the lower Colorado River valley experienced rainfall totals approaching only 50% of normal. Previous studies, cited above, have shown that El Niño conditions can suppress NAM rainfall, particularly over southern and eastern Mexico, by enhancing convection in the eastern Pacific ITCZ, reducing the northward transport of moisture and contributing to a poorly developed monsoon ridge structure, evidenced by the 200-mb height anomalies in Fig. 11f and a weakened overall monsoon circulation (Cavazos and Hastenrath 1990; Gochis et al. 2007). Related to this weaker-than-normal circulation pattern was a less-than-normal occurrence of tropical storm landfall and near-shore activity in both eastern and western NAM regions during 2009 (Fig. 7). The strong evolution in large-scale SST forcing and associated tropical activity during the YOTC appears to have had a significant impact on the timing (onset), intensity, and total accumulation of North American monsoon rainfall. However, seasonal forecasts had difficulty in both years predicting such impacts, highlighting the need for continued work in understanding large-scale ocean–monsoon interactions in North America.

South American. The South American monsoon (SAM) region extends from southern Amazonia and the upper Parana basin, and various studies have identified its characteristics and variability in various time scales (Ramage 1971; Zhou and Lau 1998; Vera et al. 2006; Liebmann et al. 2007; Marengo et al. 2012b). The “mature” phase of the monsoon in the SAM region occurs during the warm season, December–February, with the onset of the rainy season between September–November and the demise occurring after May [see Marengo et al. (2012b), and references

therein]. The climatological onset of the SAM ranges between mid-October to early November, depending on the definition (Liebmann and Marengo 2001; Carvalho et al. 2011; Nieto-Ferreira and Rickenbach 2011), with the mean demise occurring in early May, and with both the onset and demise dates exhibiting interannual variability. Key variability influencing the onset and demise, as well as the strength and evolution of the SAM, are the South Atlantic convergence zone (SACZ) and the South America low-level jet (SALLJ) east of the Andes. Variations in the former have been found on intraseasonal-to-interdecadal time scales (Nogues-Paegle and Mo 1997; Grimm and Zilli 2009; Grimm 2010), and they often exhibit a dipole structure in rainfall between the SACZ and the subtropical plains just to the south. A strengthening of the SALLJ typically accompanies the suppressed SACZ–wet subtropical plains phase of the dipole, which transports massive amounts of moisture from the Amazon basin into the subtropics (Silva and Berbery 2006). In addition, strong SALLJ events are linked to short-term extreme precipitation events in the plains of central Argentina (Liebmann et al. 2004; Salio et al. 2007). In contrast, a SACZ-enhanced phase induces extreme heat waves over the subtropical regions (Cerne and Vera 2011).

For the YOTC period, rainfall in the September–November 2008 onset phase was below average over central-southern Brazil and most of Argentina (deficit exceeding 200 mm), with above-normal rainfall over the northern Amazon basin and portions of southern Brazil (Fig. 12a). In the mature phase, December 2008–February 2009 (Fig. 12b), rainfall was below average over the SAM region and in southern Brazil and most of Argentina, with anomalies greater than 270 mm. Above-average rainfall was observed over the northern Amazon basin and Northeast Brazil, with anomalies larger than 200 mm. During the decay phase, March–May 2009, well above-average rainfall was observed over northeastern Brazil and northern Amazonia (Fig. 12c). This is attributed to the anomalously warm tropical South Atlantic Ocean and a southward position of the ITCZ that usually moves northward in April but stayed in place until May. This resulted in anomalously strong moisture transport from the tropical Atlantic into the Amazon region. At this same time, La Niña conditions were evident in the tropical Pacific, which typically intensify the upward branches of the Walker and Hadley cells over Amazonia, and lead to abundant precipitation conditions. As a consequence of the intense rainfall, the Amazon basin exhibited heavy flooding, with water levels higher than in several decades. In July 2009, the

levels of the Rio Negro in Manaus reached 29.75 m, a new record high since the beginning of data collection in 1903. This resulted in over 300,000 people left homeless and 40 fatalities because of the floods (Marengo et al. 2012a). Another factor contributing to the intense rainfall in Northeast Brazil during this season was the active MJO (see Fig. 3; note the active MJO in the Eastern Hemisphere; the wide latitude averaging cancels out the signal in this diagram over South America).

For the 2009/10 monsoon season, warm SST conditions prevailed in the Pacific. During the onset season (Fig. 12d), negative rainfall anomalies were widespread, with dryer conditions persisting from northern Amazonia to Venezuela. This is attributed to an anomalous northward displacement of the ITCZ induced by warm surface waters in the tropical North Atlantic. Above-average rainfall was observed over parts of southern Brazil (about 280 mm above normal) and Paraguay, in association with increased

frontal activity. During the mature phase, December 2009–February 2010 (Fig. 12e), rainfall totals were near average over the southern Amazon basin, and slightly below average over central Brazil and the north-central Amazon basin. Above-average rainfall was observed over southern Brazil, northeastern Argentina, Uruguay, and extreme northeastern Argentina, while below-average rainfall was observed over most of eastern Brazil. During March and April (Fig. 12f), rainfall totals were below average over central Brazil and Northeast Brazil and above average over Northeast Brazil. During this period, equatorial SSTs were 0.5°–1°C above average across the eastern Pacific and 0.5°–1.5°C above average in the equatorial Atlantic, west of 10°W. This facilitated a northward migration of the ITCZ with dry conditions in Northeast Brazil and tropical South America east of the Andes, leading to one of the most intense droughts in Amazonia during the last 107 years (Marengo et al. 2011).

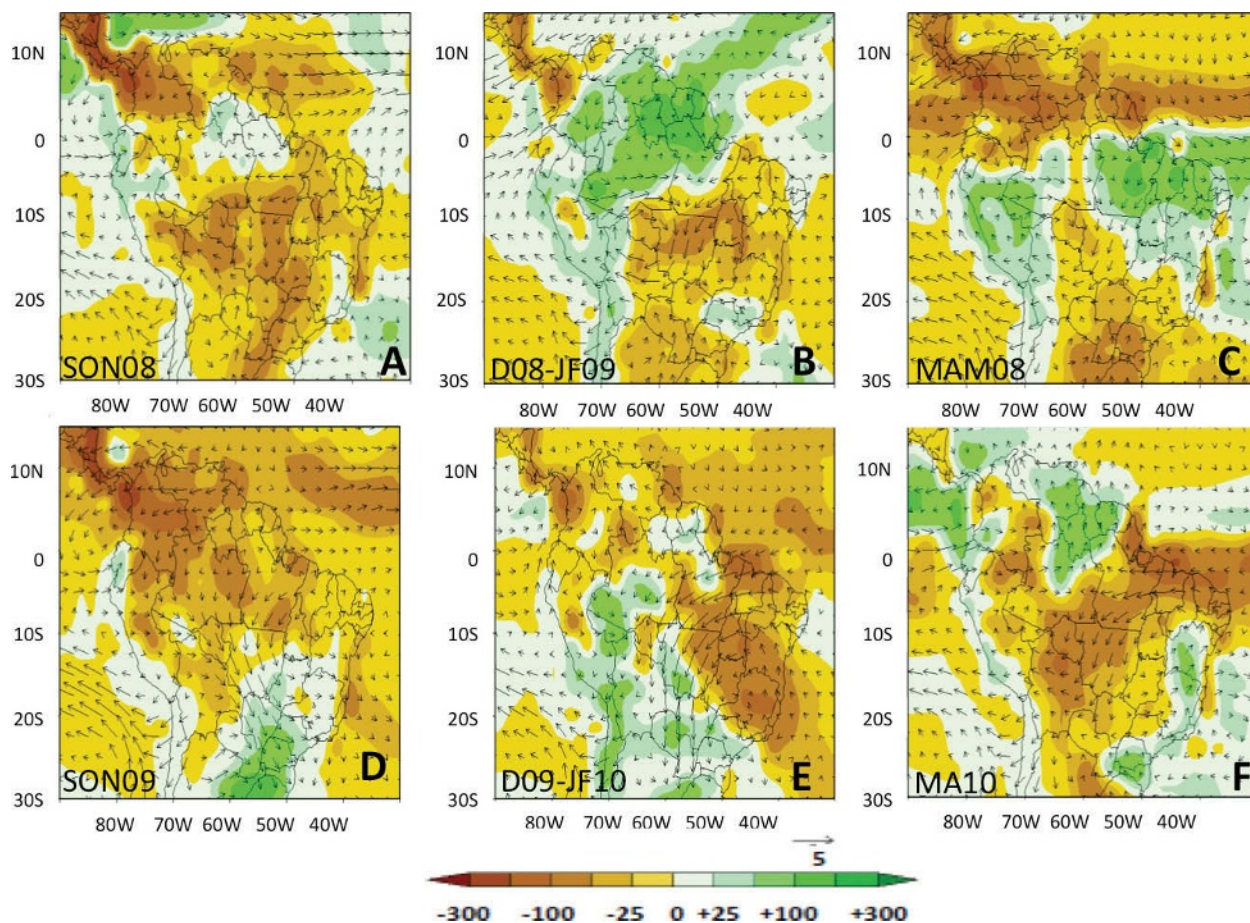


FIG. 12. Rainfall and 850-hPa winds for the SAM system. Arrows indicating wind scale (m s^{-1}) and color scale (mm) are shown at the bottom of the panel. (a) Sep–Nov 2008, (b) Dec 2008–Feb 2009, (c) Mar–May 2009, (d) Sep–Nov 2009, (e) Dec 2009–Feb 2010, and (f) Mar–Apr 2010. (Sources: CPTEC/INPE, São Paulo, Brazil, and NOAA/NCEP/CPC Maryland.)

West Africa. The year-to-year variability of Sahel rainfall, and thus the West African monsoon, is of great interest due to the very strong north–south gradient in natural and anthropogenic conditions. Figure 13 shows that both 2008 and 2009 May–September seasons were slightly wetter than the long-term average, consistent with a recent wet trend in this region (Fink et al. 2010). Further scrutiny illustrates that the anomalously wet Sahel signal in both years was mainly exhibited in the western Sahel west of about 0°E. The wet west Sahel in 2008 was part

of a regional-scale wet anomaly that covered most of the West African region down to the Guinea coast. Other notable anomalies in 2008 included a drier (wetter)-than-normal Sudan (Ethiopian highlands). While the west Sahel was also wet in 2009, the West African region as a whole was drier compared to climatology, with notable dry anomalies in Liberia and the Ivory Coast, in much of Nigeria, and most prominently (compared to 2008) in the Sudan and Chad regions. The more widespread dry anomalies seen in 2009 compared to 2008 are consistent with

the developing El Niño (Fig. 1). In addition, the relatively dry Guinea coast and wet Sahel would classify the 2009 season as a “dipole year” (Ward 1998), which is consistent with the observed cooler equatorial Atlantic during summer 2009 compared to 2008 (Fig. 1)

West African monsoon onset and within-season rainfall variability, including their predictability, have received particular attention in recent years due to their obvious societal impacts (e.g., Sultan and Janicot 2000). The YOTC dataset should be exploited to establish the extent to which these can be understood and explained in terms of dynamical processes, such as inertial instability (e.g., Sultan and Janicot 2003; Hagos and Cook 2007; Nicholson and Webster 2007) or thermodynamic processes associated with variations in the Atlantic cold tongue (e.g., Okumura and Xie 2004), the Saharan heat low (e.g., Ramel et al. 2006), influences by ISV, including the MJO (Janicot et al. 2008; Barlow 2011), and the passage of CCEWs. An important component of West African monsoon variability is the presence of well-defined synoptic EWs, which account for 25%–35% of the total variance of deep convection (e.g., Mekonnen et al. 2006). This suggests a need to improve our understanding of the two-way interactions between the EWs (see “Easterly Waves” section) and the regional environment to better understand variability in the monsoon as well as the downstream

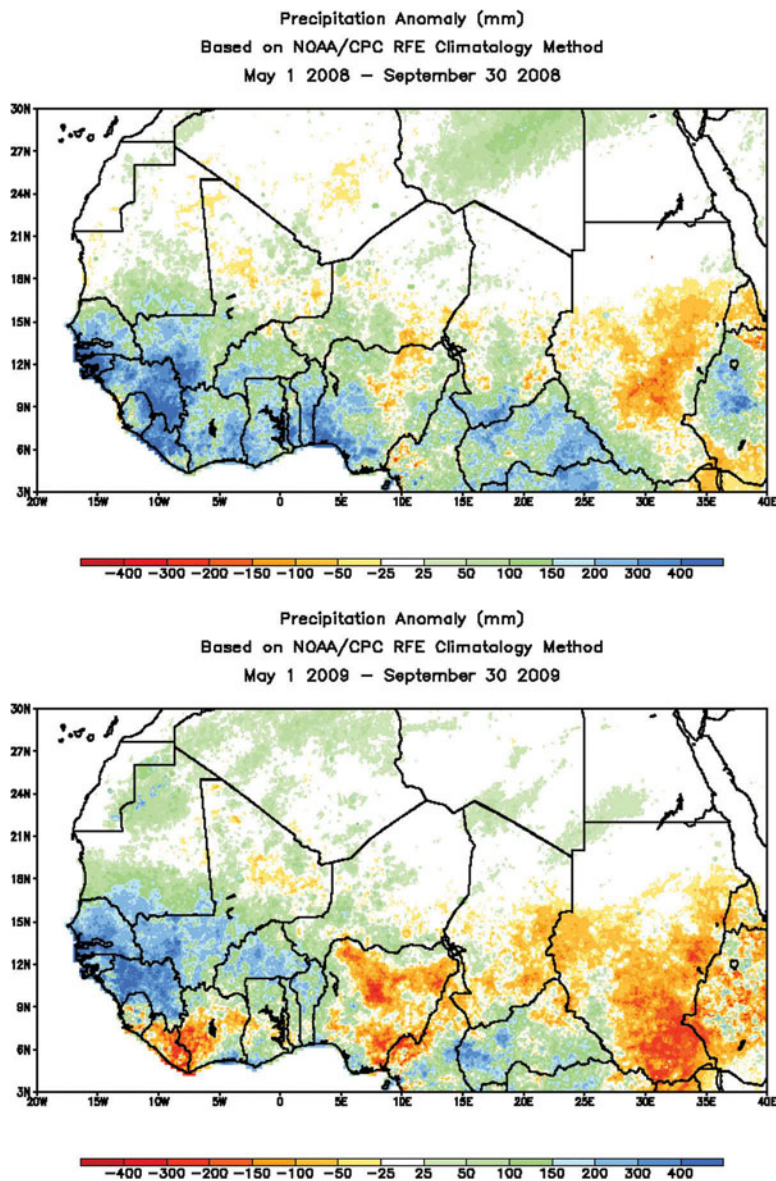


FIG. 13. Seasonal precipitation anomalies (mm) for 2008 and 2009 based on May–Sep rainfall totals and with reference to a climatology based on the years 1995–2001. Precipitation is estimated using the NOAA/CPC rainfall estimate (RFE) climatology method (see www.cpc.noaa.gov/products/fews/AFR_CLIM/afr_clim_season.shtml for more details).

tropical Atlantic. Comparing Figs. 5 and 13 highlights the fact that the 2008 season was characterized by more EW activity and was generally wetter than in 2009, suggesting a potential relationship between the EW activity and seasonal rainfall. Studies indicate that EW activity can be influenced by rainfall modulation in the EWs themselves (Hsieh and Cook 2005, 2007), stability of the African easterly jet (e.g., Leroux and Hall 2009), triggering by tropical convection (e.g., Thorncroft et al. 2008; Leroux et al. 2010), and triggering by extratropical troughs (Leroux et al. 2011). The YOTC dataset should be exploited to ascertain the relative roles of these factors. Finally, it is now well known that Kelvin waves can significantly modulate rainfall and can both trigger and intensify EWs (e.g., Mekonnen et al. 2008; Ventrice et al. 2011). Figure 4 highlights the presence of Kelvin waves in spring, when they are known to be important in the equatorial African region (Nguyen and Duvel 2008), but they are also known to influence the Guinea coastal region of West Africa (not shown). Two notably strong Kelvin wave events occurred in early May 2008 and should be strong candidates for study in the YOTC dataset.

TROPICAL-EXTRATROPICAL INTERACTIONS. *Extratropical transition of tropical cyclones.* During extratropical transition (ET), tropical cyclones undergo significant structural changes, especially with regard to the distribution of deep convection, clouds, and precipitation (Jones et al. 2003). The interaction with the midlatitude flow during ET can lead to the excitation of a Rossby wave train (Harr and Dea 2009) and thus impact the midlatitude weather and predictability far from the location of the ET event (Anwender et al. 2008; Harr et al. 2008) (see also M12). A primary objective of T-PARC, which took place during the YOTC period, was to increase understanding of the impact of tropical cyclone structure on the ET process and subsequent midlatitude downstream development.

A unique set of observations of the structural changes during the ET of Typhoon Sinlaku (2008) was obtained during T-PARC. Following recurvature, Sinlaku was significantly altered by strong vertical wind shear from the west. The vortex core was tilted toward the east and the low-level circulation center was fully exposed as deep convection was suppressed. As the decaying Sinlaku approached southern Japan, several episodes of deep convection erupted to the east and downshear of the circulation center. The tropical cyclone reintensified to typhoon strength with a circulation center collocated with new episodes

of the deep convection. In situ measurements obtained by T-PARC documented how the characteristic monopole vorticity structure evolved to a low-level center associated with the original tropical cyclone and a new vorticity center to the northeast, located in the region of the episodes of deep convection. Analysis of convective and stratiform precipitation from YOTC ECMWF analyses defined the presence of both cloud types in the region of the new vorticity maximum. Therefore, the diabatic fields indicate a tropical mesoscale circulation system with a stratiform region downstream from a leading convective cell. The reintensification period resulted in a stronger intensity and modified structure of Sinlaku as it eventually underwent ET, and thus it had an impact on its interaction with the midlatitude flow. During and following the ET, a small-scale Rossby wave train developed and appeared to interact with a larger-scale midlatitude Rossby wave train (Fig. 14c). No Rossby wave train is seen downstream of the second T-PARC ET case, Typhoon Jangmi. However, the divergent outflow from Jangmi appeared to accelerate a midlatitude jet streak.

During the YOTC period, low predictability, identified as increased standard deviation in the 3-, 5-, and 7-day forecasts of the ECMWF Ensemble Prediction System (EPS), is particularly marked when a clearly defined Rossby wave train develops or amplifies directly downstream of an ET event. This is seen for the ET of Halong in May 2008 (Figs. 14a,b), Bavi in October 2008 (Fig. 14c) and a further seven examples in the western North Pacific, two in the North Atlantic, and three in the Southern Hemisphere. In contrast, following the ET of Rammasun (Figs. 14a,b), ridging occurs downstream of the ET, but the Rossby wave train does not amplify until it reaches the eastern North Pacific. The EPS spread also increases at this stage. Similar behavior was seen in two other cases during the YOTC period. For Nakri in 2008 (Figs. 14a,b) and five Southern Hemisphere ETs, the main signal is a midlatitude Rossby wave train that is not modified during ET and exhibits weak-to-moderate EPS spread.

The YOTC period offers cases both of structural changes during ET as well as a variety of interactions between ET systems and the midlatitude flow. A priority for research with the combination of YOTC datasets and T-PARC observations will be to quantify the role of structural changes of the tropical cyclone before and during ET (e.g., increased outflow at upper levels, increased heat and moisture transport to midlatitudes) on the downstream midlatitude predictability (see M12).

Extratropical influences on the tropics. Upper-level disturbances penetrating from the extratropics into the subtropics and outer tropics can significantly influence the weather (e.g., Knippertz 2007, and references therein) and wave activity in the tropical belt, including Kelvin waves (e.g., Straub and Kiladis 2003), mixed Rossby–gravity waves (e.g., Magaña and Yanai 1995) and the MJO (e.g., Weickmann et al. 1985; see review by Roundy 2011). The eastern tropical Atlantic and Pacific Oceans and the adjacent landmasses are frequently affected by such tropical–extratropical interactions. As an example, we focus on West Africa, where upper-level disturbances regularly trigger moderate precipitation events during the boreal winter dry season (Knippertz and Fink 2008, 2009). These significant anomalies can lead to high impacts on the affected population (e.g., rotting harvests, improved mango yield and grazing conditions, locusts). In extreme cases, heavy precipitation, flooding, destruction of infrastructure, and loss of lives can occur (Knippertz and Martin 2005; Meier and Knippertz 2009).

During the two dry seasons of the YOTC period, five significant West African wet episodes occurred: 5–6 December 2008, 8–9 January 2009, 16–19 February 2009, 31 October–1 November 2009, and 12–14 December 2009. Here, we will briefly discuss the February 2009 case as an illustration of the phenomenon (Knippertz and Fink 2008,

2009). Figure 15a shows accumulated precipitation from over the 4-day February 2009 period. Heavy precipitation occurred over northern Ivory Coast, southeastern Guinea, and southern Mali, with light precipitation extending across the Sahel far into the southern Sahara. These rainfalls were preceded by a wave-breaking event over the North Atlantic that generated a trough with a strongly positive tilt in the horizontal over Morocco and Algeria on 16 February 2009 (marked in figure). Tight gradients in the geopotential at 300 hPa all across northern Africa indicate a subtropical jet streak. The mean sea level pressure (MSLP) falls significantly to the southeast of the trough (i.e., in the right entrance region of the jet streak), leading to a northward shift of the weak wintertime heat low to eastern Burkina Faso on 16 February 2009 (“X” in Fig. 15), 5° to the north of its climatological position. The associated enhanced north–south MSLP gradient at its equatorward flank allows moist air from the Gulf of Guinea to penetrate farther than usual into the continent and feed the rainfall. The upper trough drifts southwestward along the northwest African coast until 19 February while the surface low slowly weakens (not shown). The resulting rainfall is mainly related to rather short-lived cellular convection during the afternoon and evening of 16–18 February and a slightly more organized system in the early morning hours of 19 February. These systems occur at the southern end

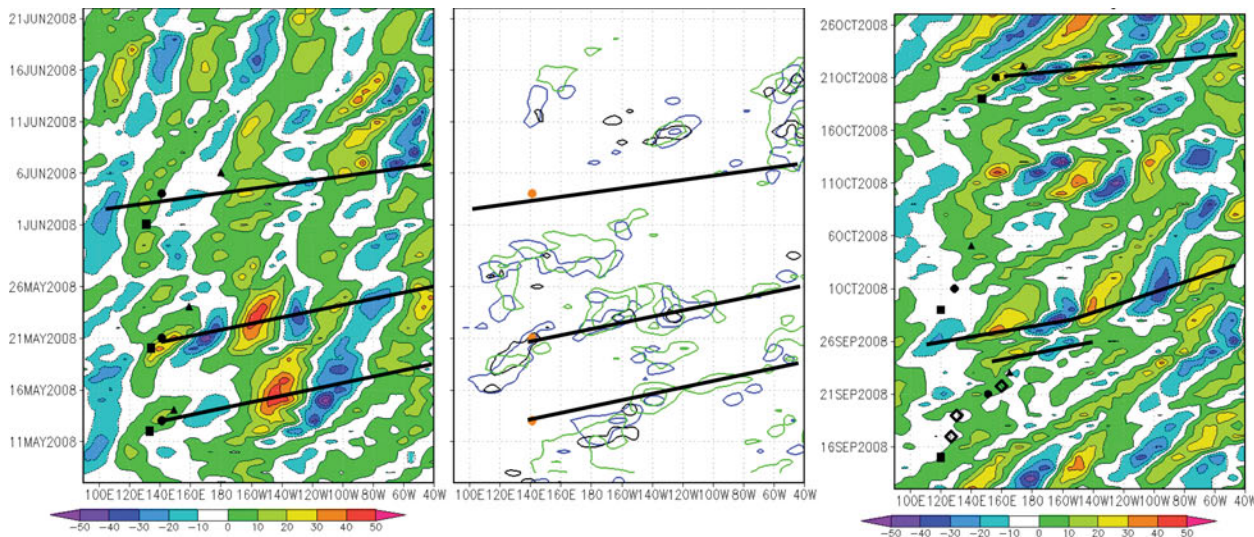


FIG. 14. Hovmöller plots across WNP of (left) 200-hPa meridional wind (m s^{-1}) from 6 May to 22 Jun 2008 averaged from 40° to 60°N, and (middle) 500-hPa height standard deviation from ECMWF EPS for 3-day forecast (black), 5-day forecast (blue), and 7-day forecast (green). (right) As in (left), but from 12 Sep to 27 Oct. Typhoon recurrence is marked on (left) and (right) by a black square, ET by a black circle, and decay point by a black triangle. The red circles on (middle) mark the ET time. Typhoons marked are (from top to bottom) Rammasun, Halong, and Nakri in (left) and (right) and Sinlaku, Jangmi, and Bavi in (right). [Figure courtesy of Julia Keller. Data taken from the ECMWF YOTC analyses and the THORPEX Interactive Grand Global Ensemble (TIGGE) database.]

of an extended southwest–northeast-oriented cloud band [a so-called “tropical plume”; see Knippertz (2007)] that drifts very slowly westward during 16–20 February in connection with the movement of the upper trough (Fig. 15c). A vertical cross section through this plume showing *CloudSat* radar reflectivity (Fig. 15d) indicates a sudden south–north decrease in cloud-top height and three bands of precipitation. Strong evaporation at low levels, however, inhibits significant accumulations (Fig. 15a).

Consistent with results by Knippertz and Fink (2009), the general northward shift of the rain zone was reasonably well predicted with 5-day leads by the ECMWF. Despite this, the relative contributions of dynamical-versus-diabatic processes to the pressure fall are not well understood (Knippertz and Fink 2008), and details of the associated moisture inflow

from the Gulf of Guinea and the ensuing tropical convection challenge present-day forecast models. Note the synergistic use of the high-resolution ECMWF YOTC analyses, station measurements, and satellite data to develop a robust characterization of this multifaceted and impactful event—a capability that YOTC objectives are focused on facilitating (see M12).

Atmospheric rivers. Atmospheric rivers (ARs) are narrow channels of enhanced atmospheric moisture transport that play a key role in the tropical–extratropical water cycle. Occupying ~10% of the Earth’s circumference in the midlatitudes, they account for over 90% of the poleward moisture transport (Zhu and Newell 1994, 1998). They largely form in the extratropical ocean basins north of the tropical moisture reservoir. Some ARs are more directly

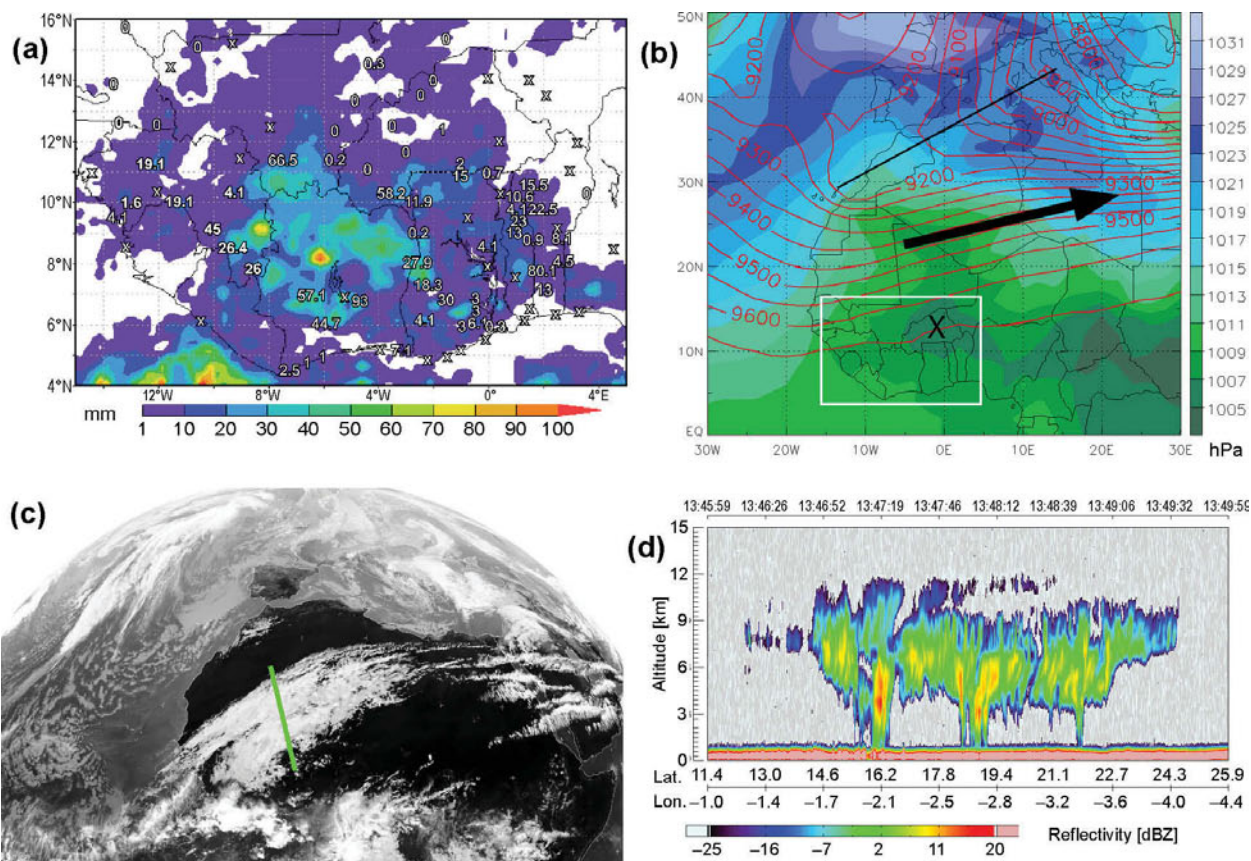


FIG. 15. An unusual dry-season rainfall event in tropical West Africa during 16–20 Feb 2009. (a) Precipitation accumulated over the 4-day period 0600 UTC 16 Feb–0600 UTC 20 Feb 2009 from the TRMM 3B42 3-hourly rainfall product (colors) and from surface rain gauges (numbers); values in mm. Symbol “x” stands for “no precipitation” and “0” stands for “traces of precipitation.” Some stations have gaps in their records and therefore amounts must be considered as lower bounds. (b) Geopotential height at 300 hPa (contours every 50 gpm) and MSLP (hPa; colors) for 1200 UTC 16 Feb 2009. Data are taken from the ECMWF YOTC analysis. The upper-trough axis, the subtropical jet streak, and the pressure minimum over Burkina Faso are indicated. The area shown in (a) is bordered by a white box. (c) Meteosat channel 9 (infrared; 10.8 μm) at 1200 UTC 19 Feb 2009. (d) Vertical profile of reflectivity (dBZ) from the *CloudSat* cloud-profiling radar along the green line shown in (c) between 1346 and 1350 UTC 19 Feb 2009.

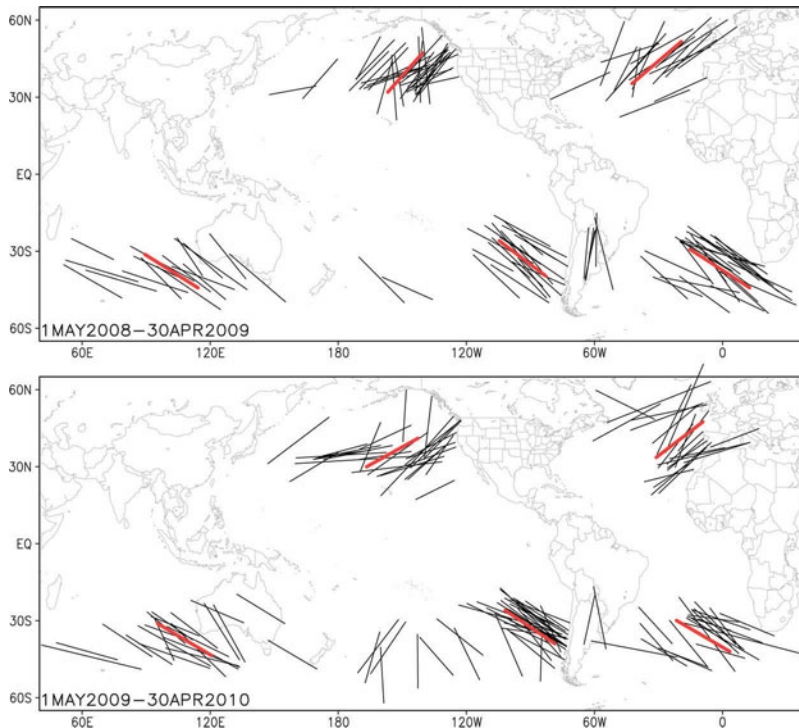


FIG. 16. Approximate locations (main axes; black lines) of ARs during the YOTC period. Red lines indicate the mean locations of the ARs within each ocean basin (the few isolated ARs west of 120°W were not included in the calculation for the southeastern Pacific). ARs are identified as long (>2,000 km), narrow (<1,000 km) plumes of enhanced (>2 cm) IWV in the daily maps observed by the AIRS instrument, following the criteria set in Ralph et al. (2004). The AIRS version 5 level 3 standard retrievals are used, which are globally available on a 1° × 1° grid. Daily means are first formed by weighting the ascending and descending satellite passes with the number of data counts within each grid cell. (top) 1 May 2008–30 Apr 2009. (bottom) 1 May 2009–30 Apr 2010.

linked to the tropics with moisture supplied by the tropical plumes, while some ARs show more of a subtropical or midlatitude moisture source (e.g., Ryoo et al. 2011). Landfalling ARs often lead to enhanced precipitation in the mountains of the west coast of North America, and are responsible for some extreme precipitation/flood events in the region (Ralph et al. 2006; Neiman et al. 2008a). Detection of ARs involves identifying narrow channels of enhanced moisture, typically identified in satellite observations of integrated water vapor (IWV) (Ralph et al. 2004; Neiman et al. 2008b). For this overview of the ARs during YOTC, daily maps of IWV from the Atmospheric Infrared Sounder (AIRS) were manually examined for AR-like structures (i.e., moisture plumes with 2 cm or greater IWV, narrower than 1,000 km, and longer than about 2,000 km; Ralph et al. 2004). Approximate locations of the ARs identified are shown in Fig. 16 for the two half periods (i.e. years) of YOTC.¹ A total of 259 ARs are identified, with 122 and 137 during the first and second half periods, respectively. In the first year, the maximum number of ARs occurred in the northeastern Pacific, with a similar number

observed there in the second year. The southeastern Pacific, in contrast, saw an increase of 70% in the number of ARs in the second year. This is likely to be an influence of ENSO but the manner in which this may be so has not been established. Noteworthy is the scarcity of landfalling ARs in California during the YOTC period, as the average occurrence is about 15 per year (Neiman et al. 2008b). It is also worth noting that the tropical plume events/wet episodes over West Africa discussed in the previous subsection were not associated with ARs according to the IWV threshold.

The impact of landfalling ARs is illustrated in Fig. 17 with an example of an extreme precipitation event in California's Sierra Nevada. There, a few Arkansas events can result in as large as 40% of the total seasonal snow accumulation (Guan et al. 2010)—an important water resource during summer. The figure shows the IWV plume and the 3-day cumulative precipitation associated with this event, which reached 9 cm on average.² A number of studies have showed the connection of the MJO to precipitation extremes in the U.S. West Coast and elsewhere (Mo and Higgins 1998b,a; Jones 2000; Bond and Vecchi

¹ AIRS data are not available during 10–25 January 2010 due to hardware failure. AR detection was not performed for that period.

² Three high-impact (3-day cumulative precipitation >9 cm in the Sierra Nevada) Arkansas events in California were identified during the YOTC period. However, none of them strictly conformed to the Ralph et al. (2011) criteria in terms of length or overall structure, including the one discussed here, which was 5% shorter than the criteria and thus is not included in Fig. 16. Three ARs meeting the criteria were identified in California during YOTC, but all with low impact (3-day cumulative precipitation <0.5 cm in the Sierra Nevada).

2003). Ralph et al. (2011) showed an interesting case in which the development of a high-impact Arkansas that made landfall over the Pacific Northwest was favored by MJO convection over the eastern Indian Ocean and equatorward Rossby wave energy propagation. Analysis of snow accumulation in the Sierra Nevada showed a preference of AR-related extreme events to occur when MJO activity is enhanced in the far western Pacific (Guan et al. 2010). Three AR-related extreme precipitation events during YOTC (including the one discussed here) occurred during relatively weak MJOs (amplitude ≤ 1) in the Indian/western Pacific Oceans. It remains to be explored and understood how conditions in the tropics (such as convection and circulation anomalies associated with MJO and ENSO) and tropical–extratropical interactions affect the formation and impact of ARs. The complexity of the multiscale interactions involved in such processes, as illustrated in Ralph et al. (2011), is of crucial interest to YOTC

SUMMARY. The discussion above highlights the diverse and impactful nature of the weather and climate associated with the WCRP–WWRP/THORPEX YOTC period of interest. Notable is the wide range of scale interactions involving tropical convection, particularly in terms of how the influence of ENSO cascades across a number of time scales and phenomena, including significant impacts on most of the monsoon circulations discussed, the nature of the intraseasonal variability, the structure and intensity of easterly waves, as well as the spatial modulation of extreme events, such as tropical cyclones and atmospheric rivers. Significant highlights, apart from the cool to warm transition in ENSO, are the severe drought monsoon for India in 2009 and the near-record setting North American monsoon in 2008. There was a fantastic tropical wave event in 2008 that impacted variability from the Indian to the Pacific/America sectors and extreme events in both the Western and Eastern Hemispheres, and other

examples of convectively coupled wave–wave interactions. There were high-impact rainfall events in Africa that derived from tropical sources (i.e. easterly waves) in both 2008 and 2009 and a number of cases that arose from the influence of the extratropics. The tropical cyclone activity during YOTC, while being exceptionally quiet relative to the last 30 years, exhibited numerous highlights, including Ike—one of the largest storms ever recorded in aerial size in the Atlantic; Nargis—which led to disastrous consequences in Myanmar, three hurricanes making landfall onto Mexico from the Pacific in 2008, the 1.8 m of rainfall over the Philippines from slow-moving Typhoon Parma; Rick—the second strongest hurricane on record in the Pacific; high-latitude Hurricane Grace tracking across the United Kingdom; and a highly unusual South Atlantic storm named Anita. Moreover, the impact of ETs on the midlatitude flow during the entire YOTC period exhibits substantial variability both in terms of the excitation of Rossby wave trains and the predictive skill of this process. The objectives of YOTC are to highlight these types of features and phenomena and promote their interrogation via theory, observations, and models so that improved understanding and predictions can be afforded.

With the backing of the World Climate Research Programme and the World Weather Research Programme/THORPEX, the YOTC research program

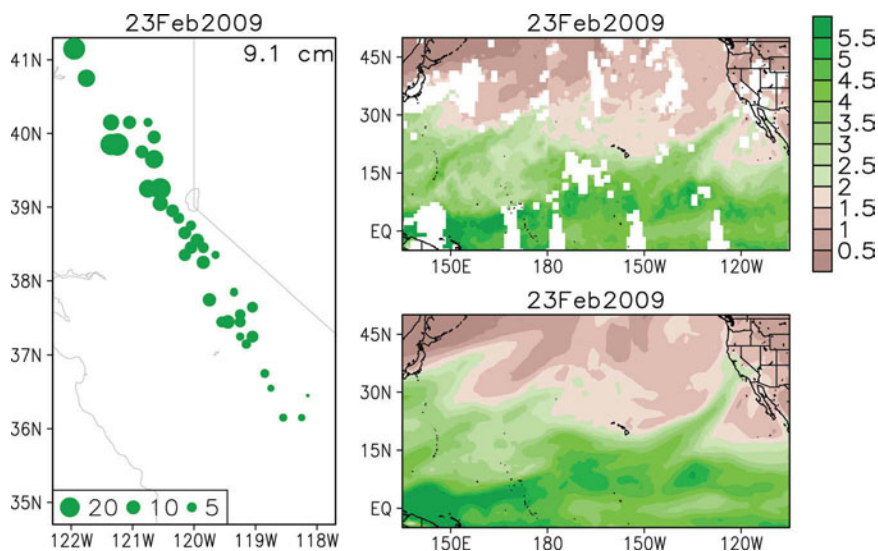


FIG. 17. An AR event on 23 Feb 2009. (left) Three-day cumulative precipitation (cm; centered on the Arkansas date) observed at snow sensor sites across the Sierra Nevada. Data were obtained from the California Department of Water Resources (<http://cdec.water.ca.gov/>). Domain-averaged precipitation is indicated in the top-right corner of the panel. (right) Daily mean IWV (cm) from (top right) the AIRS instrument and (bottom right) the ECMWF YOTC dataset.

is developing a suite of state-of-the-art datasets to examine the aforementioned weather and climate highlights in more detail. These include high-

resolution atmospheric analyses from ECMWF, the National Centers for Environmental Prediction (NCEP), and the National Aeronautics and

SHALLOW CONVECTION PROCESSES: A VOCALS AND YOTC OVERLAP

Understanding shallow convection processes is critical to achieving better simulations and predictions associated with the expansive, low-level, high-albedo cloud regions of the tropics as well as transitions between shallow and deep convection. A primary goal of the VOCALS Regional Experiment (REx) is to characterize the structural properties of the marine boundary layer (MBL) over the southeastern tropical Pacific. In particular, components of the VOCALS field campaign were designed to better characterize the dominant forms of mesoscale cellular convection (MCC), which in the southeastern tropical Pacific includes closed cell and open cell structures, the latter with broken cloud and lower albedo. Pockets of open cells (POC) usually form within overcast closed MCC (Bretherton et al. 2004; Stevens et al. 2005; Comstock et al. 2007; Wood et al. 2008). The transition from closed to open cells represents a shift from a system driven primarily by cloud-top longwave cooling to a more cumuliform structure in which lifting is in part forced at the surface by localized cold pools formed by the evaporation of drizzle (Wang and Feingold 2009; Feingold et al. 2010).

The intensive observational phase of VOCALS-REx took place during October and November 2008 and involved five aircraft, two ships, and several ground sites (Wood et al. 2010a,b). Satellite imagery of the 27/28 October 2008 POC event (Fig. SBIa) shows the formation of a POC aligned roughly NW–SE within overcast stratocumulus clouds early in the morning of 27 October. Ship radar observations (Fig. 1b sidebar) reveal locally intense drizzle cells surrounded by drizzle-free regions. The aircraft observations on the Nebraska side sampled during the evening of 27 October and early morning of 28 October reveal marked transitions in drizzle structure, and in cloud and aerosol microphysical properties across the boundary (Wood et al. 2010a). Ship radar observations in the overcast region to the southwest of the POC revealed the presence of more diffuse drizzling cells (Fig. SBIc) that have peak rain rates less than the echoes observed within the POC. Subsequently, the POC evolved by growing in width and advecting to the northwest with the synoptic flow. The VOCALS-REx dataset and the complementary elements of the

YOTC project (see companion article M12) provide promising avenues for improving our basic understanding of these processes, including capturing their bulk effects in our global weather and climate models.

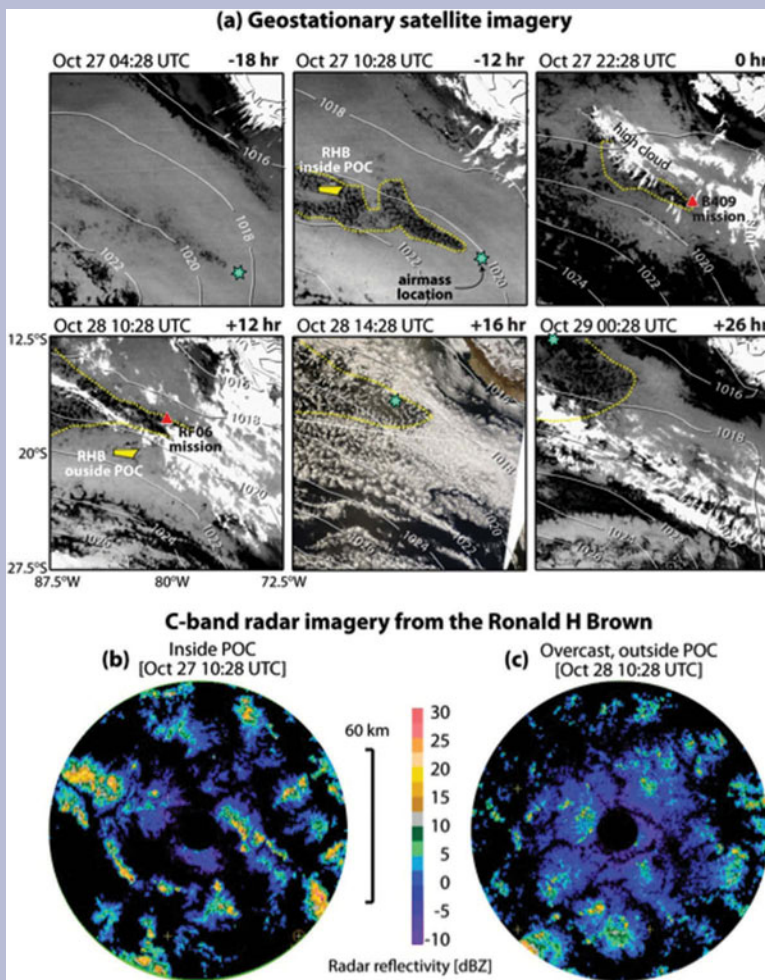


FIG. SBI. (a) Thermal infrared and visible (1428 UTC 28 Oct only) imagery for a 44-h period encompassing the intensive measurement period in which a POC is sampled by two aircraft (FAAM BAe-146 mission B409 and NSF/NCAR C-130 mission RF06) and the NOAA R/V *Ronald H. Brown* (RHB). The POC is delineated by the dashed yellow line. The blue star shows the location along a 925-hPa trajectory of an air parcel initiated at the location/time shown in the top-left panel. These locations are indicated by red triangles for the images when the aircraft were sampling. (b), (c) Images of radar reflectivity from the C-band radar on the RHB for periods when the ship was inside the POC [for (b) see top-middle satellite image for ship location] and outside the POC [for (c), see bottom-left satellite image for ship location].

Space Administration (NASA), and a number of satellite data products, including a multisensor collocated dataset based on the Earth Observing System A-Train. Moreover, the YOTC period occurred in conjunction with the T-PARC and the Variability of the American Monsoon System (VAMOS) Ocean–Cloud–Atmosphere–Land Study (VOCALS) field programs as well as a multitude of activities associated with the Asian Monsoon Year (AMY), all of which allow additional resources and focus to be brought to bear on interrelated tropical convection issues. By leveraging these activities and resources, the YOTC Implementation Plan sets a course to develop a number of programmatic research activities, model studies, and intercomparisons. One particular focus is on using models in hindcast mode to explore their sensitivities and shortcomings in conjunction with the above observation resources to drive improvements in our forecast capabilities from short-term to seasonal prediction. This program and its focus provide an initial framework to develop the techniques and know-how to approach the next generation of high-resolution models [e.g., global cloud-system-resolving models (CSRMs), multiscale modeling framework (MMF), regional and adaptive grid systems] that at present tax our abilities to fully exploit all our resources—both in terms of technical (e.g., network and analysis bandwidth) and scientific (multiscale interactions, multisensor constraints/evaluation) challenges. In this regard, YOTC provides an excellent and rich activity through which to entrain and train the next generation of weather, climate, and Earth scientists through graduate and postdoctoral research programs along with YOTC-related meetings and symposia.³ This new generation will be ideally situated to capitalize on the new capabilities that have and are being put into place, including the interdisciplinary education and landscape being established to tackle the pressing environmental and societally impactful challenges associated with tropical convection. Focused period field programs, with YOTC representing a global virtual field program, represent key resources for the training scientists for many years to decades after their initial data acquisition (e.g., www.ametsoc.org/sloan/gate/). For additional motivation,

³ Past activities include YOTC-sponsored sessions at six American Geophysical Union meetings, a session at an American Meteorological Society annual meeting, the First YOTC International Science Symposium, and a workshop on intraseasonal variability and the monsoon (see www.ucar.edu/yotc/meetings.html).

scientific underpinnings and hypotheses associated with YOTC, see M12.

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A TWO-CENTURY PRECIPITATION DATASET FOR THE CONTINENT OF AFRICA

BY SHARON E. NICHOLSON, AMIN K. DEZFULI, AND DOUGLAS KLOTTER

Extensive historical climate information for Africa survives, allowing production of a semiquantitative precipitation dataset for the nineteenth century to add to the more modern gauge data.

It is commonly believed that in Africa the instrumental record began later than in most continents. While the interior was not well represented until the 1920s or later, a large number of stations, particularly those near the coast, go back much further. Africa was a hub of activity in the nineteenth century, the focus of dozens of explorers and geographical expeditions as several European colonial powers struggled for power throughout the continent. Climate and weather were of particular interest to many of them. The French, Belgians, British, Italians,

Portuguese, Germans, and Spanish left behind a wealth of meteorological information. This consists of both gauge data and verbal reports of weather conditions.

The purpose of this article is twofold. One is to demonstrate that a lengthy record of precipitation is available for Africa. The second is to describe several new datasets that are now available to the scientific community. These include a compilation of all nineteenth-century gauge records available for Africa and several versions of a semiquantitative dataset that combines these gauge records with proxy indicators, such as documentary information and hydrological records. In the latter, statistical methods were utilized to augment the spatial coverage, so that all of Africa is covered from 1801 to 1900. When gauge data for the twentieth century are added, the result is a two-century record of rainfall variability for 90 regions of Africa. The final dataset and the data used to produce it are available from the National Oceanic and Atmospheric Administration's (NOAA's) World Data Center for Paleoclimatology.

GAUGE DATA. The African precipitation records for the nineteenth century are of three main types. The most readily usable type consists of continuous station records for modern stations that began

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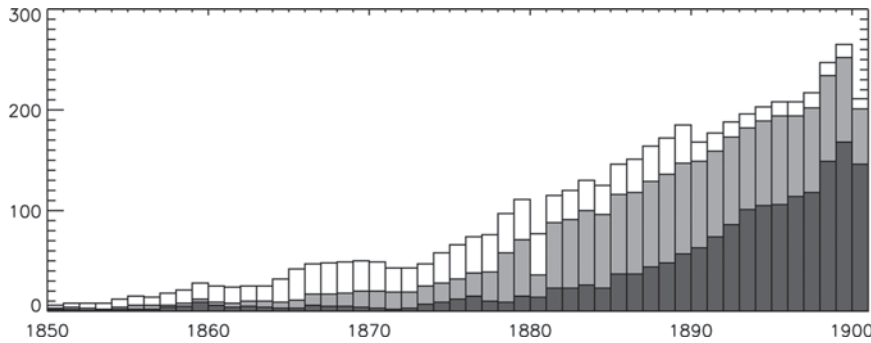


FIG. 1. Number of African rainfall stations in the gauge archive during the period 1850–1900. Light shading indicates stations in South Africa; no shading, stations in Algeria; dark shading, stations in remaining countries in Africa.

sometime in that century. Many such stations exist in Algeria, Tunisia, Senegal, Namibia, and South Africa. The second type consists of regular reporting stations established by colonial governments but generally abandoned with the departure of the colonial powers early in the twentieth century. Larger numbers of such stations existed in countries such as Togo and Tanzania, under German control, and Malawi, under British control. The third type consists of temporary nongovernmental observations, usually made at mission stations, explorers' camps, and so on. In many cases, such as the ones described below, the observations covered many years.

Figure 1 shows the number of African stations in the first and second categories from 1850 to 1899. By far the largest numbers of records are for South Africa and Algeria, so these are shown separately. Records become plentiful for Algeria in the 1860s and for South Africa in the 1880s. The early Algerian records were collected by Raulin (1876, 1882); those for South Africa were published in meteorological yearbooks from the South African Weather Bureau. For most other African countries, records commence in the late 1880s or 1890s. A particularly useful source of data for all of Africa is Supan (1898), who summarizes all available African gauge data up to the time of his publication and provides information about the source of the data for each station. Other countries notable for numerous records prior to the 1890s include Tunisia (Ginestous 1901, 1903), Namibia (Heidke 1920; Fitzner 1907), and Senegal (Borius 1875, 1880). A more extensive list of sources of nineteenth-century African precipitation records is included in Nicholson (2001a) and in Peterson and Griffiths (1997).

Some of the notable long-term station records in Algeria and the year in which regular observations commenced are Algiers (1838), Biskra

(1846), Oran (1841), and Constantine (1838). Those for South Africa include Cape Town (1838), Grahamstown (1851), and Pietermaritzburg (1854). Some sources indicate that the Cape Town record commenced in 1820, but this author has been unable to locate the earlier data. Other notable long-term records and the year in which regular observations began are given in

Table 1. For many of the stations in the table, records are available for isolated earlier years. For Freetown, Sierra Leone, for example, rainfall data are available for 1793–95, 1819, 1828, and 1847–51. Measurements were made at Lagos, Nigeria, in 1863, 1876, and 1877. In Zanzibar, rainfall was recorded in 1850, 1859, and 1864.

A handful of other multiyear records exist. For example, at the Danish Christianborg Castle, near the current city of Accra, Ghana, observations were

TABLE 1. Notable African stations with long precipitation records and first year of regular coverage. Stations in Algeria and South Africa are excluded.

Station	First year
Mogador, Morocco	1873
Tunis, Tunisia	1875
Alexandria, Egypt	1859
St. Louis, Senegal	1851
Banjul, Gambia	1884
Freetown, Sierra Leone	1875
Accra, Ghana	1886
Aburi, Ghana	1883
Lagoa, Nigeria	1886
Douala, Cameroon	1885
Zanzibar, Tanzania	1874
Luanda, Angola	1858
Rehoboth, Namibia	1884
Omaruru, Namibia	1882
Walvis Bay, Namibia	1885
Yaounda, Cameroon	1889
Mombasa, Kenya	1875
Massawa, Eritrea	1886

made during 1829–34 and 1839–42 (Table 2). Just to the north, at Aburi, Ghana, continuous records cover the years 1883–89. Although the accuracy of these two records cannot be verified and some values look questionable, the suggested occurrence of very dry years in the 1830s and wetter years in the 1840s is consistent with many other observations (Nicholson 1996) and with limnological evidence (Nicholson 2001a; Bessems et al. 2008; Verschuren et al. 2000).

Numerous multiyear records come from Senegal. Those for the French fort at Bakel cover the years 1856–62. At nearby Goree, an island near Dakar, where slaves were imprisoned prior to the trans-Atlantic passage, observations were made from 1854 to 1866. At St. Louis a French monk, Frère Constantin, made observations in 1830 and 1831, but apparently only the mean values for that period remain. At Podor, on the Senegal River, observations were made from 1857 to 1860 and again during 1873, 1874, and 1876.

The Germans, Portuguese, and Belgians made observations at many locations in western equatorial Africa in the 1870s and 1880s. Examples are the records for Sao Salvador, Zaire, from 1883 to 1887, for Caconda, Angola, in 1889 and 1890, Punte de Lenha (Banana, French Congo) for 1882–91, Luluaburg, Zaire, for 1885–86, and Kinshasa, Zaire, for 1874–76. In Gabon observations were made at Sibange farm

from 1880 to 1884 and elsewhere from 1859 to 1860 and 1863. Data from Tete, Mozambique, cover the years 1859–61 and 1889–91.

Most of the stations mentioned above lie on or near the coast. It took much longer for inland Africa to be well represented meteorologically. Regular observations began at networks of stations in the 1890s in the former British, German, and Portuguese colonies of Tanganyika (Tanzania), Mozambique, Kenya, Uganda, Northern Rhodesia (Zambia), Southern Rhodesia (Zimbabwe), and Nyasaland (Malawi). Elsewhere records generally exist for only isolated years: Fort Kita, Mali, in 1882; Bamako, Mali, in 1883; and Livingstonia, Malawi, in 1876 and 1877. Inland observations were also made at several locations along the upper Nile: Rubaga, Tanzania, for 1878–81; Bukoba, Uganda, 1861–62; Natete, Uganda, 1879–85; Ribe, Kenya, 1876–77; Wadelai, Uganda, 1885–88; and Lado, Sudan, 1881–84, as well as a handful of other locations.

Figure 2 shows one example of regionally averaged gauge records from the Sahel of West Africa (roughly the area from 10° to 25°N, and from the Atlantic coast to 25°E). This curve was produced by adding modern gauge records to the nineteenth-century dataset. The curve shows a dominance of wet years in the mid- to late nineteenth century and underscores how unusual the post-1960s drought years appear to be. However,

TABLE 2. Excerpt from the precipitation data archive. The first entry for each station includes geographical coordinates, elevation, and region number. The second line contains a mean by month and year (mm), and the third line contains a standard deviation of precipitation totals by month and year (mm). The remaining lines give monthly totals, January–December, for individual years, plus an annual total. An entry of 9999 indicates missing values.

GHANACHRST	CHRISTIANSBURG												536	-10	20	GHANA	28
GHANACHRST MEAN	15	32	58	86	130	210	53	19	45	63	33	20	763				
GHANACHRST STDV	21	38	45	48	66	146	61	24	50	50	26	27	221				
GHANACHRST1829	9999	9999	31	21	9	96	6	4	6	101	18	0	365				
GHANACHRST1830	27	47	77	33	70	35	63	4	41	40	2	19	451				
GHANACHRST1831	18	50	28	56	118	85	103	37	55	37	9999	9999	581				
GHANACHRST1832	10	51	18	4	1	294	0	0	0	22	7	20	422				
GHANACHRST1833	0	54	55	39	146	91	9999	9999	9999	9999	9999	40	9999				
GHANACHRST1834	0	4	0	9999	0	9999	9999	9999	9999	9999	9999	9999	9999				
GHANACHRST1839	9999	9999	9999	9999	9999	174	43	9	10	41	5	0	9999				
GHANACHRST1840	0	4	131	40	463	113	5	2	0	41	47	30	846				
GHANACHRST1841	10	1	13	27	83	101	102	11	17	43	6	12	445				
GHANACHRST1842	37	0	40	78	257	308	85	15	7	34	42	9999	915				

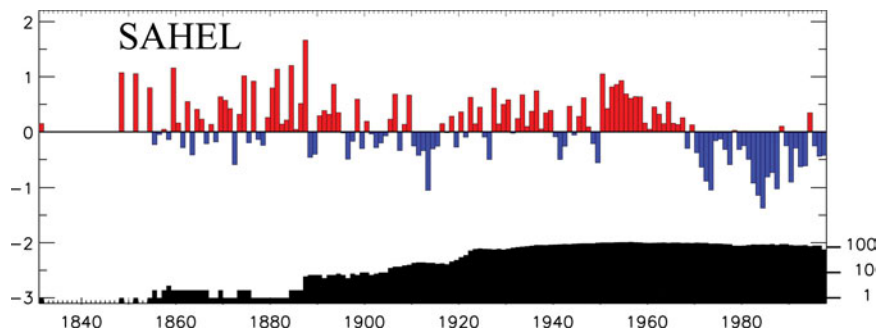


FIG. 2. Multicentury record of Sahel rainfall based on gauges. Units are standard deviations. Number of gauge records available per year is given at the bottom.

other evidence shows that the early years of the nineteenth century were similar to the more recent ones (see the section “Reconstruction of nineteenth-century continental precipitation”).

OTHER SOURCES OF INFORMATION.

Explorers, settlers, and missionaries. The nineteenth century was a time of exploration and scientific inquiry (Fig. 3). Africa was the hub of both for many European countries. At the same time, these countries vied for power and influence in Africa, and their clergy established mission stations throughout the sub-Saharan lands. In many cases, explorations were carried out by thrill-seekers vying to reach destinations such as the Mountains of the Moon, thought to be today’s Ruwenzori. In other cases, scientific expeditions were financed by governments or geographical societies. Often prizes, medals, or legions of honor were offered to those successful in their quest. The reports of explorations and expeditions were vigorously published in scientific journals of the period. Particularly useful for meteorological data were *Petermann’s Geographische Mitteilungen* and *Meteorologische Zeitschrift*, as well as the geographical journals of several national geographic societies.

A goal sought by many was reaching and returning from the fabled city of Timbuktu. The French Société de Géographie offered a prize of 10,000 francs to the first European traveler to return with detailed knowledge of the

city. The British officer Major Gordon Laing, who is credited as being the first to reach Timbuktu, arrived in 1826 but he was murdered shortly thereafter. René Caillié reached the city in 1828 and returned to claim the French prize.

The explorers Richard Burton and John Speke set out on a quest for the Nile’s source in 1857, discovering both Lake Tanganyika and

Lake Victoria, which they correctly assumed was the river’s source. The German scholar Heinrich Barth set out to cross the Sahara from Tripoli in 1850. He returned in 1855, having traversed 12,000 miles, 24 degrees of latitude (across the Sahara to Cameroon), and 20 degrees of longitude (from Lake Chad to Timbuktu).

These explorations and expeditions were tremendous sources of meteorological information. In some cases the material was merely descriptive: references to famine or drought, the character of the year’s rainy season, or the state of a lake. However, many of the explorers, such as Barth (1859), kept day-by-day records of the weather, often including even temperature measurements (Fig. 4). Speke (1864) left behind rainfall measurements for Bukoba in the 1860s. The German expedition to the Loango district of the French Congo measured rainfall during the years 1873–76 (Danckelman 1884). Barth and many others left detailed descriptions and maps of Lake



FIG. 3. African map from 1850, showing the routes of several explorers.

Chad that allowed its levels to be reconstructed since at least the late eighteenth century (Pejml 1963; Maley 1973; Nicholson 1996). Because the lake's spatial configuration and extent changes so much from year to year (Fig. 5), this information is extremely useful. Missionaries made measurements of the height of Lake Victoria over many years in the mid-nineteenth century (Nicholson 1998).

The explorations and expeditions provided transient and temporary records. Sources of more continuous and homogeneous reporting are the European settlers in various African countries and the numerous missionary stations, particularly those in the Anglophone countries. In many cases, the same mission station persisted for several decades. These sources generally give descriptive information on such things as famine, drought, the conditions of crops, unusual weather, and the status of vegetation and waterways. In some cases, rigorous observations and measurements were made. For example, the missionary A.M. Mackay kept an 8-yr record from Natete, Uganda (near Kampala).

Several authors have produced multidecadal climate chronologies for Africa from missionary records. These include chronologies for the Kalahari (Nash 1996; Nash and Endfield 2002a,b), Lesotho (Grab and Nash 2010; Nash and Grab 2010), and South Africa (Vogel 1989; Kelso and Vogel 2007).

Vogel (1989) validated her records for time periods with overlapping gauge data, supporting the accuracy and credibility of the missionary reports. The missionary records in Africa have not, however, been fully exploited in terms of climate information. Much more is available, particularly for East Africa. Support for the validity of the documentary records also comes from correlations with El Niño and the Southern Oscillation (Kelso and Vogel 2007; Nash and Endfield 2008).

Local oral tradition. West Africa has a rich historical legacy that includes one of the oldest universities in the world. The University of Timbuktu (Fig. 6), established in the twelfth century, houses a wealth of Islamic manuscripts, including historical chronicles that detail the reigns of kings over many centuries. In most cases, the information came down as oral tradition, first written down centuries later. Some of the better-known West African chronicles include those of Tichitt (Monteil 1939), Oualata and Nema (Marty 1921), the Wàlo empire (Monteil 1964), Timbuktu (Cissoko 1968), and the Bornu empire (Urvoy 1949). These cover empires that stretched across the Sahel from Mauritania to Lake Chad. Similar historical

works cover regions of the upper Nile such as Uganda (Webster 1979; Herring 1979). These provide invaluable reports of famine, droughts, and agricultural failure or prosperity over centuries.

These written records are complemented by memories of the elders and of stories passed down over generations. Many such stories were passed on to European explorers and colonists of the eighteenth and nineteenth centuries. One example is an old man reporting to Barth in 1851 that in his youth one could travel by canoe from Lake Chad to the north of the country, tens of miles along a now dry waterway (Maley 1973). Reports from the mid-nineteenth century describe Lake Ngami, in northern Botswana, as a vast water body with waves strong enough to push hippos to shore. Photos and paintings from the period document its expanse (Fig. 7). However, around 1820 an old man told of a period during his youth when Lake Ngami, then a vast sheet of water, had completely

APPENDIX XVI
FRAGMENTS OF A METEOROLOGICAL REGISTER.

Date.	Hour of the Day.	Deg. in scale of Fah.	Remarks.	Date.	Hour of the Day.	Deg. in scale of Fah.	Remarks.
1852. Nov. 25	sunrise.	41	Outside Kùkawa at the village Kalluwa.	1852. Dec. 24	sunrise.	55	Sky all this time cloudy.
	1.30 P.M.	91		25	sunrise.	43	
	sunrise.	50			1.30 P.M.	78	
27	sunrise.	74		26	sunset.	72	
28	sunrise.	52		27-31	No obs'n.		
	1.15 P.M.	91		1853. Jan. 1	sunset.	73	
	sunset.	81		2	sunrise.	55	
29	sunrise.	64		3-10	No obs'n.		
	1.30	93		11	1.30 P.M.	85	Fine morning.
	sunset.	81		12	sunrise.	56	Fine morning.
30	sunrise.	58-6		13	1.30 P.M.	87-5	
Dec. 1	sunrise.	57-5		13	sunrise.	54	Strong wind.
	2.0 P.M.	87		14	2.0 P.M.	75	
	sunset.	77		14	sunrise.	54	
2	sunrise.	59		15	1.30 P.M.	76	
	sunset.	75		15	sunrise.	51	
3	sunrise.	52		16	1.30 P.M.	76	
	2.0 P.M.	88	Heavy E. gale.	16	sunrise.	55	
4	sunrise.	51		17	sunrise.	57	
	1.0 P.M.	88		18	1.30 P.M.	77	
	sunset.	77		18	sunrise.	55	
5	sunrise.	47		19	1.30 P.M.	77	
	1.30 P.M.	94		19	sunrise.	57	
6	No obs'n.	82-3		20	2.0 P.M.	80	
7	1.30 P.M.	81-2		20	sunset.	71-5	
	sunset.	70-2		21	sunrise.	56-5	
8	sunrise.	52	Heavy northerly gale.	21	2.0 P.M.	86	
	sunset.	69-5		22	sunrise.	56	Cold wind.
9	sunrise.	48		22	2.0 P.M.	75	
	2.0 P.M.	82-5		23	sunrise.	47-2	
	sunset.	75		24	1.30 P.M.	75	
10	sunrise.	56	Foggy in the morning.	24	sunrise.	50-4	
	sunset.	73-5		25	2.0 P.M.	80-2	
11	sunrise.	54		25	sunrise.	50	Fine day.
	sunset.	75		26	1.45 P.M.	85-7	
12	sunrise.	53		26	sunrise.	48-5	
	sunset.	72-5		27	1.45 P.M.	85-2	
13	1.20 P.M.	84		27	sunrise.	51-5	
14	1.45 P.M.	83		28	1.50 P.M.	89-4	
15	sunrise.	57		28	sunrise.	59-6	
	1.30 P.M.	81		29,30	1.45 P.M.	89-5	
	sunset.	73		31	No obs'n.		
16	1.30 P.M.	83		Feb. 1	sunset.	75	
	sunset.	72-30		1	sunrise.	59-5	
17,18	No obs'n.			2	sunrise.	58-60	
19	1.30 P.M.	81		to >	1.30 P.M.	90	
	sunset.	73		24	sunset.	76	
20	sunrise.	50		25			In the evening heat-lightning toward the N.
21	sunrise.	52	Cold N.E. gale; very heavy.	26			Cloudy, the sun shining forth at times; in the afternoon the whole sky toward the S. over-
22	1.40 P.M. sunrise.	77	Very cold, but no wind.				
23	sunrise.	40	Foggy morning.				

FIG. 4. A page from the meteorological diary of the German explorer Heinrich Barth, who traversed the Sahara from north to south.

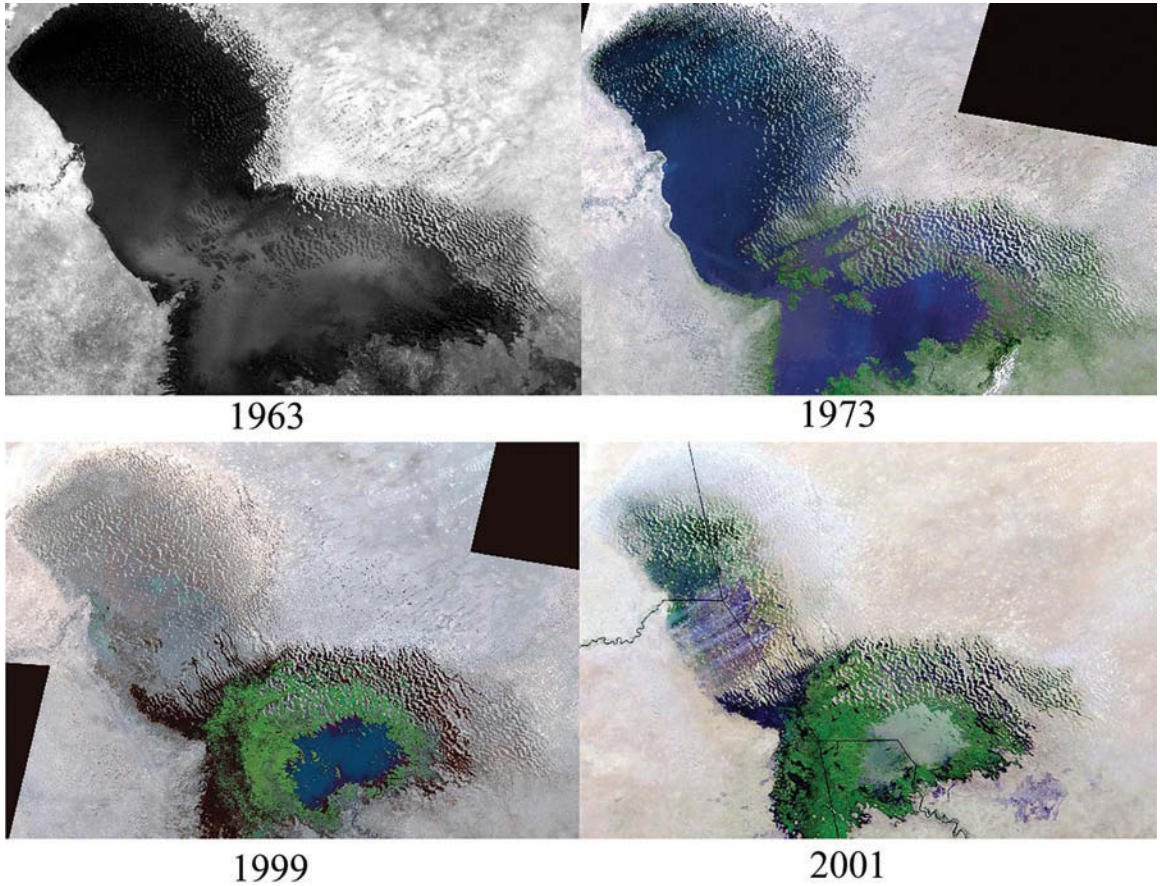


FIG. 5. Photos of Lake Chad taken from space in four different years. The 1963 photo was taken by an astronaut. The others are from satellites. All photos courtesy of the National Aeronautics and Space Administration (NASA).



FIG. 6. The Sankoré mosque, one of three branches of the University of Timbuktu.

Little credence was given to the story until Ngami once again dried out and the remnants of the streambed and trees became visible (Fig. 8).

While the validity of each individual report might be challenged, the key to producing a credible picture of historical climate is the convergence of evidence from various sources. Information from the late eighteenth century provides an excellent example. The explorer Mungo Park (1799), credited with being the first European to reach the Niger River, reported that in 1796 the rains in Bamako and Segou (Mali) did not begin until 19 June. Normally they begin sometime in May or even April. Jackson (1820) reported from Hausaland, in northwestern Nigeria,

dried out. The old man told of a stream running through a grass plain, with trees along the banks.

that no significant rain had fallen during his 2-yr stay from 1793 to 1795. At Freetown (Sierra Leone) annual



FIG. 7. Lake Ngami sketch from David Livingstone (1857).



FIG. 8. A dry riverbed in the middle of a grassy plain that was formerly covered by Lake Ngami (Botswana).

rainfall in these same years averaged 2,000 mm, compared to a modern mean of 3,400 mm (Winterbottom 1969). According to oral tradition, within the period 1790–96 a drought forced the evacuation of Agadez in northern Niger and drought depleted the grain stores in Kano, in northern Nigeria. Chronicles of Bornu reported a severe drought near Lake Chad and the locals also reported that the lake began to fall rapidly about that time.

Hydrologic records. The documentary sources described above frequently include references to lake levels. For Africa, sufficient information exists to create nineteenth-century chronologies for 11 lakes spanning the latitudes 15°N–20°S. In some cases, such as Lakes Bosumtwi (Shanahan et al. 2008) and Turkana (Ricketts and Anderson 1998), lake cores provide annual or nearly annual resolution. In addition to the lakes, quantitative monthly records of Nile flow cover most of the nineteenth century, with gaps. These have the potential to provide a wealth

of information on precipitation. Unfortunately, the interpretation is complex and generally a hydrologic model of the lake or river is needed to produce estimates of precipitation.

An example of such a model is presented in Nicholson et al. (2000). The lake levels (Fig. 9) were “inverted” to utilize Lake Victoria as a giant rain gauge. The accuracy of the estimation of rainfall in the catchment was roughly within 3%. This model was applied to estimating nineteenth-century rainfall. During the arid interval early in the century,

rainfall in the catchment was on the order of 13% below normal, but on the order of 40% above normal in the mid-1870s (Nicholson and Yin 2001).

A most interesting result of the Lake Victoria model was to show that rainfall is reflected as the difference between the levels in a sequence of two years, not in the level of the lake itself. This is probably the case for most of the other African lakes, but the response of the lake depends on the relative magnitude of the inputs and outputs. In the case of Lake Victoria, precipitation and evaporation are by far the largest terms.

The Nile is a special case. The centuries-long historical record is based on the Roda gauge, in Cairo (Toussoun 1925). It reflects a combination of flow from the Blue Nile, which flows out of the Ethiopia highlands, and the White Nile, which originates in equatorial Africa, with Lake Victoria as its source. Lamb (1966) suggested that the flood levels could be interpreted in terms of rainfall from the Ethiopian highlands, with the summer minimum reflecting equatorial rainfall. However, both regions have some

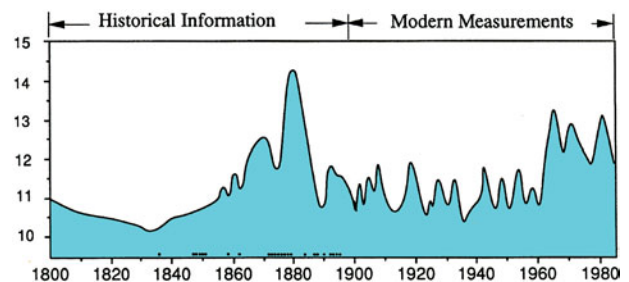


FIG. 9. Fluctuations (m) of Lake Victoria since 1800. Years for which specific references are available are indicated at the bottom with dots. Years since 1896 are based on modern measurements, and earlier years are reconstructed from historical references (from Nicholson 1998).

influence on both the maximum and minimum levels, which are also influenced by what occurs during the passage of the Nile waters across some 30 degrees of latitude.

Tree-ring records. Tree rings are excellent climate indicators on the historical time scale. For Africa, however, tree-ring analysis is limited by the fact that there are few locations where the trees have annual rings. Most of the dendroclimatological studies stem from Morocco, Tunisia, and Algeria (Touchan et al. 2008). However, some work has been done in Namibia (e.g., Trouet et al. 2001), Tanzania (Fichtler et al. 2004), and Zimbabwe (e.g., Therrell et al. 2006). The data from these studies are readily available at the NOAA World Data Center for Paleoclimatology website (www.ncdc.noaa.gov/paleo/). These data have not yet been incorporated into the dataset described in this article.

RECONSTRUCTION OF NINETEENTH-CENTURY CONTINENTAL PRECIPITATION. The information available for examining nineteenth-century precipitation in Africa is largely fragmentary, especially prior to the 1890s. A methodology has been developed to utilize these diverse bits of information to construct semiquantitative indicators of precipitation for 90 regions of the continent (Nicholson 2001a). The basis of the method is the use of regions that are homogeneous with respect to interannual variability. These regions are described in Nicholson (1986) and are evident in Fig. 11. A detailed explanation of the methodology is found in Nicholson et al. (2012). It is summarized in the following paragraphs.

A basic assumption is that information pertaining to any location within the region can be used to produce a precipitation time series representing the region. Also, because so much of the available material is descriptive rather than quantitative, a seven-class system is used to describe the “wetness” of the season. Each descriptive entry is subjectively fit into these classes, with the presence of key descriptors being used to distinguish the various categories. For example, a dry year might be classified as -1 , but a -2 categorization requires explicit mention of a drought. An entry is classed as -3 , severe drought, only if human consequences such as famine or migration are mentioned. In this scheme, a zero denotes normal conditions and $+1$ to $+3$ indicate a range from good rains to anomalously wet then very wet. The last category does not occur frequently and often indicates a flood situation. Gauge data are likewise fit

into these same categories, using a transfer function based on standard deviations.

An example of the format of the documentary records is shown in Table 3, which contains entries for several years for the Niger Bend area. The entries include the rainfall region the entry fits into, the wetness class, the general geographical region, the year to which the entry pertains, and the entry itself. When feasible, geographical coordinates are given within the descriptive section. In some cases, a wetness class cannot be ascertained. Such entries are left in the archive but cannot be utilized in producing a precipitation dataset. An example is the second entry in Table 3.

The first step in producing regional averages is combining the various entries for each individual region. Once this is complete, some regional values are filled in based on linear correlation with nearby regions. Further detail on this step is given in Nicholson (2001a) and Nicholson et al. (2012). The correlation between many of the regions is exceedingly high. In filling in the spatial detail, acceptable regional substitutions have a correlation of at least 0.4 (based on roughly 100 years of data) with the missing region. This correlation far exceeds the 1% significance level. At this step, roughly half of the 90 regions are represented by the 1840s. By 1880 at least two-thirds of the regions are represented.

The last step in the reconstruction is to utilize statistics to fill in any remaining gaps in the record. A principal component (PC) method of climate field reconstruction, similar to that of Mann and Jones (2003), is used to identify the common modes of variability in the twentieth century. The degree of dominance of each mode is then determined for each year of the nineteenth century and values for missing regions are assigned, based on the eigenvector loadings for the PCs. The end result is a complete time series commencing in 1801 for each of the 90 regions. These represent annual values only. However, in some regions certain seasons dominate the annual signal (e.g., October–December in East Africa and March–May in much of southern Africa).

Only a few results are shown here. Figure 10 shows the entire nineteenth- through twentieth-century time series for several multiregion sectors, with rainfall expressed in the seven-class system. Twentieth-century gauge data described in Nicholson (2001b) have been added to the historical dataset to produce these curves. A striking feature is the near-ubiquitous period of aridity in the earliest years of the nineteenth century. The arid interval probably

commenced around 1790, the droughts of the 1790s bearing witness to this (Nicholson 1996). The spatial pattern of anomalies for two of those years is shown in Fig. 11: 1835, a dry year throughout the continent, and 1888, a year with wet above-normal rainfall in the

subtropics of both hemispheres and abnormally dry conditions throughout the equatorial region.

ARCHIVED DATA. The African historical dataset has been contributed to the World Data Center for

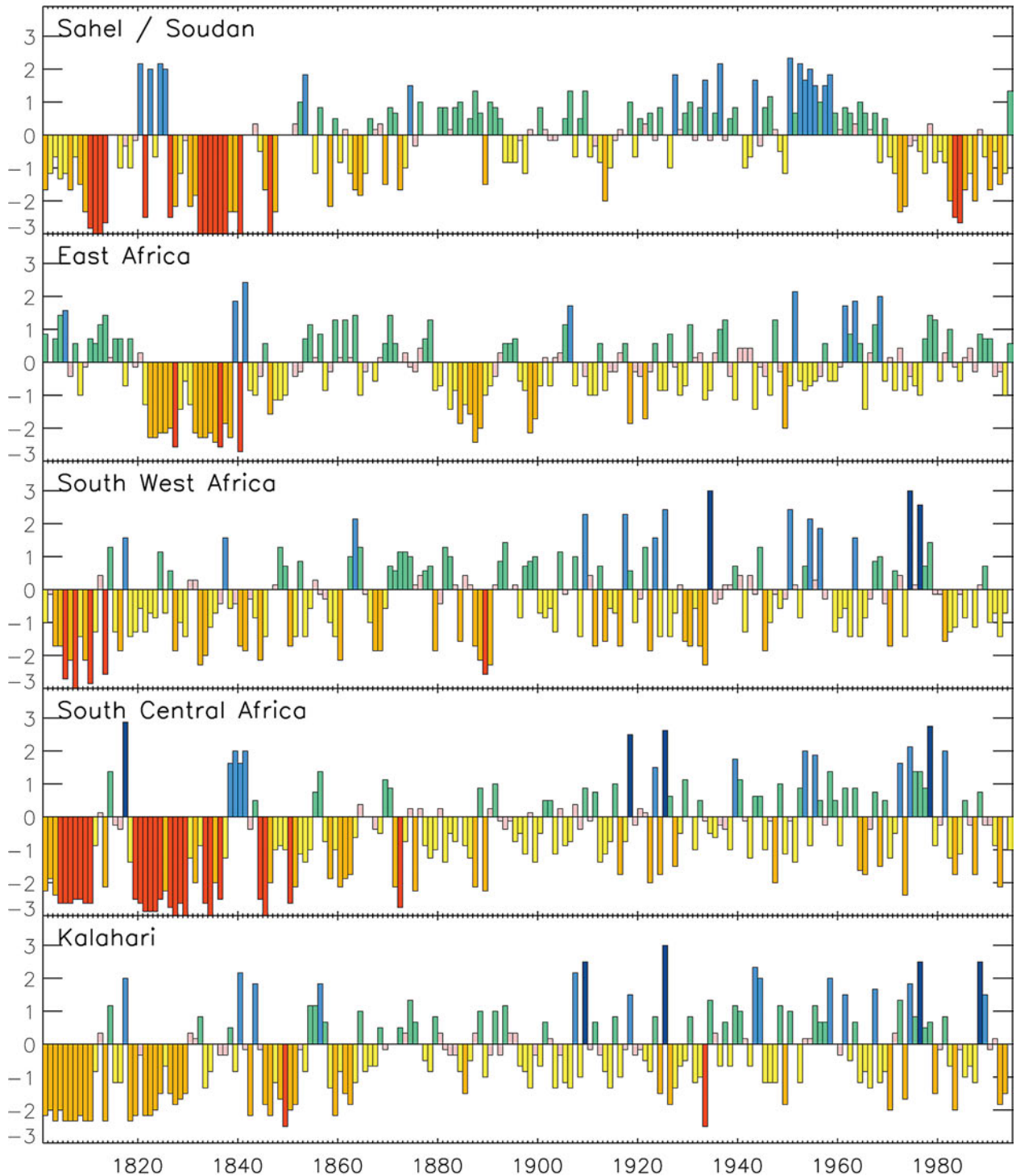


FIG. 10. A wetness index for five sectors of Africa, based on a combination of gauge and documentary data. The range of values, -3 to +3, corresponds to conditions ranging from extremely dry to extremely wet, with zero indicating normal.

TABLE 3. Example of documentary entries for the Niger Bend.

Region: I4

Rain Anomaly: -3

Country/Geographical Area: Niger Bend

Year: 1853/1854

Entry: Famine and drought in the Niger Bend (c. 17°N, 3°W) (Barth 1965).

Region: I4

Rain Anomaly:

Country/Geographical Area: Niger Bend

Year: Circa 1854

Entry: It was, near Tombouctoo, rainy on the fifteenth of January; Barth states that rain and thunder is not unusual along this quarter of the river toward the end of January and the beginning of February.

Region: I4

Rain Anomaly: -2

Country/Geographical Area: Niger Bend

Year: 1864/1865

Entry: Great drought in Oualata and the Soudan (Mali) (Marty 1927).

Region: I4

Rain Anomaly: -3

Country/Geographical Area: Niger Bend

Year: 1865/1866

Entry: Great drought and famine at Tichitt, Chinguetti, Oualata, Araouane, and I Tombouctoo (Monteil 1939).

Region: I4

Rain Anomaly: +2

Country/Geographical Area: Niger Bend

Year: 1866

Entry: This year of abundant precipitation "ended a long period of drought which affected the regions of the Sahara between Adrar in the West and Tombouctoo in the East" (Plote 1974).

Region: I4

Rain Anomaly: +2

Country/Geographical Area: Niger Bend

Year: 1880

Entry: After Lenz's passage in this year, floods of the Niger were always good, until at least 1897, and the region became very prosperous (Plote 1974). In 1880 the floods were exceptionally good, filling Lake Faguibine and the daou-nas, bringing fertility to a region that had been left sterile by many years of drought. This would imply that the 1870s were reasonably dry.

Paleoclimatology in Boulder, Colorado. This contribution is available online (at http://hurricane.ncdc.noaa.gov/pls/paleox/af?p=519:1:1071810159565685:::PI_STUDY_ID:12201). The data on the website consist of three separate entries, together with metadata and documentation. Each has been subjected to extensive quality control (see Nicholson et al. 2012). One part is the nineteenth-century gauge dataset. It includes 48 stations in Algeria, 93 stations in South Africa, and 283 stations scattered over the rest of

Africa. Its format is that shown in Table 2. The second part is the documentary record based on descriptive historical sources. Its format is that shown in Table 3.

The third part is the semiquantitative data matrix with an annual wetness values for each of the 90 regions and each year of the nineteenth century. Error estimates for each region have been obtained and are published in Nicholson et al. (2012). Two other versions of the data matrix are available on request to the first author. One uses no statistical inference

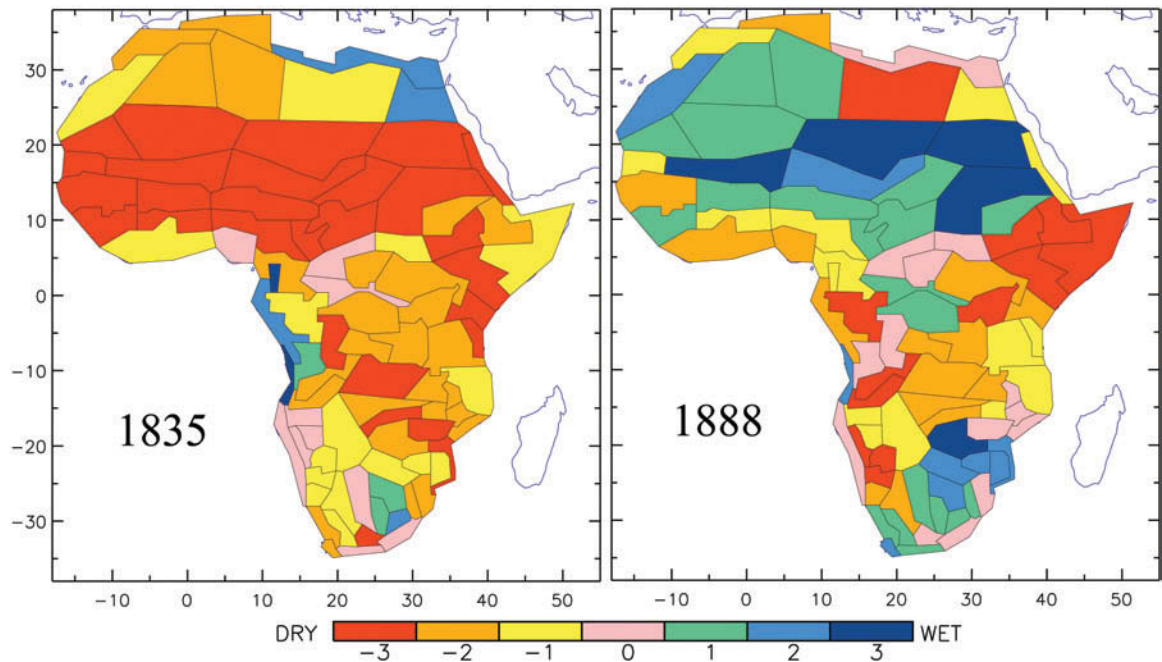


FIG. 11. Rainfall anomaly patterns for 1835 and 1888 for 90 regions of Africa (see the aforementioned wetness index in Fig. 10). The regions are homogeneous with respect to interannual variability (Nicholson 1986).

to determine values for missing regions. The other uses the linear correlations with nearby regions but does not include regions for which values are obtained through spatial reconstruction via PCS.

The twentieth-century gauge dataset, which includes roughly 1,200 stations, is available from the first author. It has also been incorporated into the Global Historical Climatology Network (GHCN) dataset maintained by the National Climatic Data Center. Some of the historical records, especially those from South Africa and Algeria, are also in the GHCN archive.

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PHYSICS AND CHEMISTRY OF CLOUDS

Dennis Lamb and Johannes Verlinde, 2011, 600 pp., \$85.00, hardbound, Cambridge University Press, ISBN 978-0-521-89910-9

Over the past decades, great progress has been made in the fields of cloud physics and chemistry. *Physics and Chemistry of Clouds* by Dennis Lamb and Johannes Verlinde, two senior scientists and educators in the field, treats cloud physics in a more detailed way than the *Short Course* by Rogers and Yau (1996), but provides far fewer references than the heavily referenced textbook by Pruppacher and Klett (2003). Thus, it can be thought of as taking a middle ground between these two standard textbooks of cloud physics.

The book is written in a pedagogical and narrative style and focuses on explaining concepts rather than presenting quantitative detail. The fact that the text is not interspersed with references is an advantage in terms of easy and fluent reading; however, it does make it harder for readers to find specific related literature beyond the few references (which mostly cite other textbooks or review articles) that are listed in each chapter. Some specific data are given in the problems at the end of the chapters, but most physical constants have to be looked up in other references. The chapters are mostly independent and can be followed separately from each other. Numerous black-and-white illustrations throughout the book help to clarify concepts that are discussed in the adjacent text.

The authors nicely demonstrate in several places that “physical” and “chemical” effects are often closely intertwined, such as in their discussion of supersaturation and ice nucleation on a molecular level. It is obvious that the authors’ own research focuses a lot on cloud microphysics, as this part of the book (part IV) makes up more than a quarter of the text and covers very recent literature in this area. Overall, the book is a great and original addition to the current textbook literature on cloud

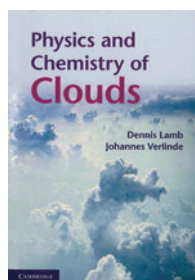
physics, as it provides a unique presentation of the current knowledge.

The parts of the book that are dedicated to cloud chemistry (parts of chapters 3 and 4, and chapter 13)—that is, chemical composition of aerosols and processes in clouds—are rather brief as compared to the comprehensive description of cloud physics.

The discussion of chemical processes in clouds is mainly restricted to sulfur oxidation; reaction systems such as oxidant formation and consumption, transition metal ion reactions that are not related to sulfur oxidation, and organic reactions that might lead to secondary organic aerosol formation and processing in cloud water are not mentioned. While chapter

4 treats gas-phase chemistry, basic differences of gas- and aqueous-phase reactions (e.g., hydration and ionic strength effects, specific aqueous phase chemical mechanisms) could have been pointed out in more detail there. In summary, for a rigorous treatment of cloud chemistry, other books are recommended that provide a broader picture of the variety of chemical species and processes in clouds and aerosols [e.g., Seinfeld and Pandis (1998) and Finlayson-Pitts and Pitts (2000)].

Ultimately, I recommend the book as a very valuable textbook that includes a wide range of concepts in cloud physics and some topics of atmospheric chemistry. The book is suited for readers—such as advanced students in atmospheric science—who are familiar with basic physical and chemical principles. Its sometimes colloquial writing style will make it appealing to readers who seek an easily understandable presentation of concepts rather than a reference book. While I expect it to become a very useful and popular textbook in atmospheric physics classes, its use in



advanced atmospheric chemistry classes might be limited to the introduction to selected aspects of cloud chemistry.

—BARBARA ERVENS

Barbara Ervens is a research scientist at the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado, and in the Chemical Sciences Division of ESRL/NOAA in Boulder, Colorado.

FOR FURTHER READING

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- Pruppacher, H. R., and J. D. Klett, 2003: *Microphysics of Clouds and Precipitation* (second revised and enlarged edition). Kluwer Academics, 954 pp.
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CLIMATE CHANGE AND CLIMATE MODELING

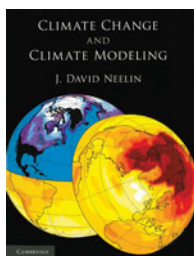
J. David Neelin, 2011, 304 pp., \$57.00, paperback, Cambridge University Press, ISBN 978-0-521-60243-3

As interest in climate change and variability grows, a need has arisen for textbooks of varying levels and areas of focus to provide an introduction to the developing field of modern climate science. *Climate Change and Climate Modeling* by J. David Neelin provides an introduction that is geared toward undergraduates who are familiar with basic calculus and physics but who are not necessarily majoring in the geosciences.

This book is primarily concerned with what is likely to be of greatest interest to

such students—namely, modern climate variability and anthropogenic climate change. Similarly to *Global Warming: Understanding the Forecast* by David Archer, it helps to fill the gap between popular science and upper-level textbooks such as *Global Physical Climatology* by Dennis Hartmann.

The author, David Neelin, has research interests in topics such as moist convection and tropical dynamics, and the material covered in the book reflects this to some extent. Early chapters provide introductions to the climate system



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THE WEATHER ALMANAC: A REFERENCE GUIDE TO WEATHER, CLIMATE, AND RELATED ISSUES IN THE UNITED STATES AND ITS KEY CITIES (TWELFTH EDITION)

S. L. Horstmeyer, 2011, 1,144 pp., \$195.00, hardbound, Wiley-Blackwell, ISBN 978-0-470-41325-8

This resource for a variety of climate and meteorological data includes domestic and international weather trends, historical weather patterns dating back 1,000 years, natural disasters, and a 20-page glossary of weather terminology. The book contains maps, pictures, and tables compiling climate data from a variety of sources, including the NWS and the U.S. Geological Survey. Topics of other chapters include extreme weather, air pollution, and El Niño/La Niña.

GLOBAL ENVIRONMENT: WATER, AIR, AND GEOCHEMICAL CYCLES (SECOND EDITION)

E. K. Berner and R. A. Berner, 2012, 460 pp., \$85.00, hardbound, Princeton University Press, ISBN 978-0-691-13678-3

This title discusses the major elements of the geochemical cycles and global fluxes found in the atmosphere, land, lakes, rivers, biota, and oceans, as well as the human effects on these fluxes. It takes an integrated, multidisciplinary, and global approach to geochemistry and environmental problems and introduces fundamental concepts of meteorology, geology, biogeochemistry, limnology, and oceanography. This new edition includes an expanded chapter on atmospheric chemistry and changing climate.

DATA ASSIMILATION AND ITS APPLICATIONS

M. Sharan and J. P. Issartel, 2012, 675 pp., \$84.95, paperback, Springer, ISBN 978-3-0348-0441-7

This volume contains many original findings in data assimilation and its applications related to atmospheric, oceanic, and environmental systems. It covers various data-assimilation techniques within Bayesian and non-Bayesian frameworks, including least-square, nudging, three-dimensional variational, four-dimensional variational, local ensemble Kalman filter, and genetic algorithm. The book also covers applications to extreme weather events, hurricanes, Asian summer monsoons, structures of the barrier layer in the equatorial Pacific ocean, and identification of emission sources.

and underlying physical processes. Later chapters describe climate variability, climate models, and analysis of anthropogenic climate change. Questions of paleoclimate are only briefly discussed, which is understandable given the already broad scope of the book. The descriptions of physical processes, feedbacks, and climate change scenarios are clear and up to date; the descriptions of climate modeling and climate variability help to make the book stand out from other introductory textbooks.

As suggested by the title, a primary aim of the book is to introduce students to climate models and their strengths and weaknesses. I view this as an important feature, given that climate models are a key tool for understanding climate change and its impacts. In addition, the nature of climate models and how they relate to other types of models in science is often poorly understood outside of the field. Compared to the older undergraduate textbook, *A Climate Modelling Primer*, by Kendal McGuffie and Ann Henderson-Sellers, Neelin discusses a more limited subset of the hierarchy of climate models, but he often gives a more up-to-date description of both scientific and modeling issues.

The principal mode of climate variability covered in the book is El Niño/Southern Oscillation (ENSO). Extensive descriptions of ENSO are given, and some of the dynamical aspects may be difficult to grasp for students without a background in geophysical fluid dynamics. But the inclusion of a solid description of an important example of climate variability is useful in its own right and helps to ground the later discussions of climate change and trends.

The text is generally well written and demonstrates the ability of the author to explain a wide range of concepts. Simplifications are sometimes made when explaining complex phenomena, as appropriate to the level of the book, with endnotes providing more nuanced explanations and references to the literature. There are only a few cases in which overly simplified explanations are given (e.g., land–ocean surface warming contrast is attributed to differences in heat capacity even

though much of the contrast persists at equilibrium). A focus on conceptual understanding of physical phenomena with relatively little mathematics means that the book should be accessible to its intended audience.

Problem sets are not included with the text, but sample problem sets, exams, and presentations are available online.

In summary, this book is a welcome addition to the set of introductory climate science books and should be especially valuable for students with a scientific background who don't major in a climate-related field. The descriptions of climate modeling and ENSO variability in the book make it useful beyond questions of anthropogenic climate change.

—PAUL A. O'GORMAN

Paul A. O'Gorman is an associate professor of Atmospheric Science at the Massachusetts Institute of Technology.

FOR FURTHER READING

- Archer, D., 2007: *Global Warming: Understanding the Forecast*. Blackwell, 194 pp.
 Hartmann, D. L., 1994: *Global Physical Climatology*. Academic Press, 411 pp.
 Henderson-Sellers, A., and K. McGuffie, 1987: *A Climate Modelling Primer*. 3d ed. Wiley, 280 pp.

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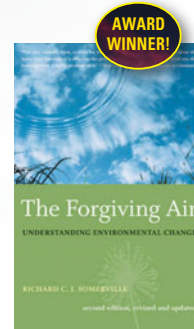


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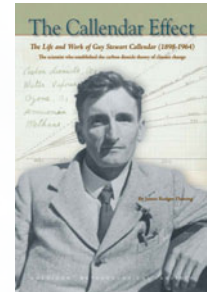
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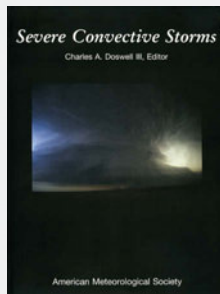
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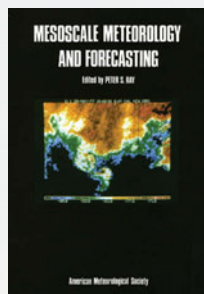


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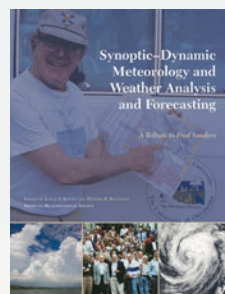
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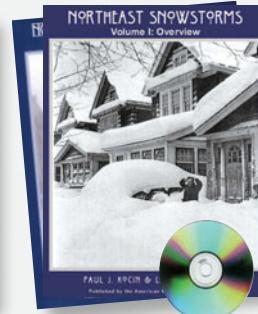


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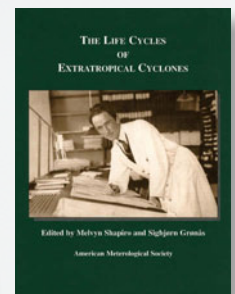


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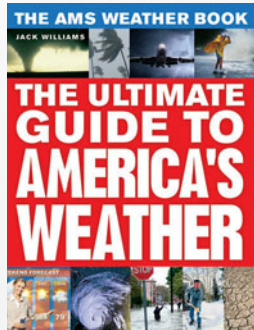
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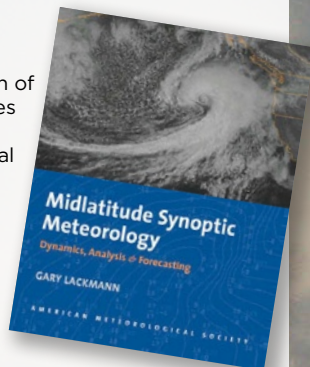
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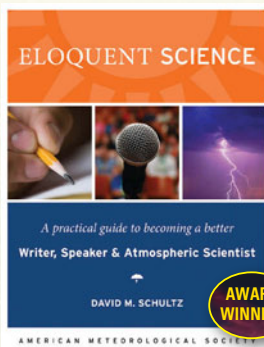
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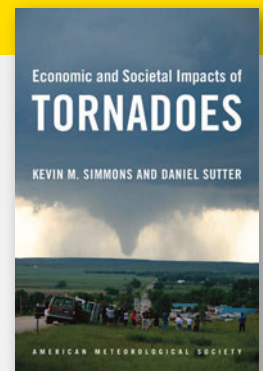
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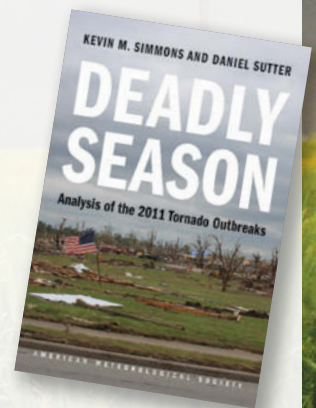
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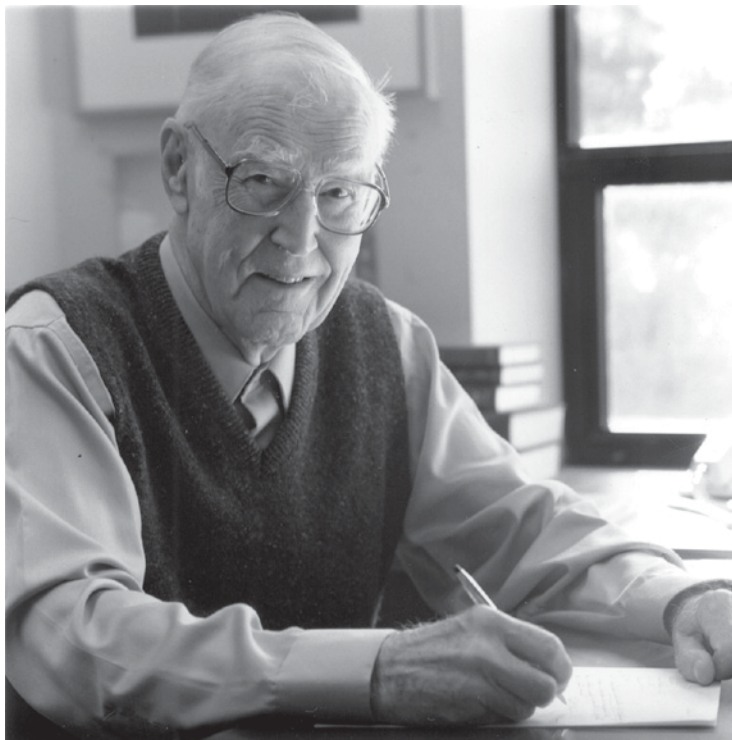


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ABOUT THE AUTHOR

Robert G. Fleagle earned degrees in physics and meteorology at The Johns Hopkins University and New York University and began his professional career in 1948 at the University of Washington (UW). His research has focused on the structure of midlatitude cyclones, the physics and structure of the surface boundary layer, and processes of air-sea interaction. He is the author of about 100 papers published in scientific journals and of books on atmospheric physics and global environmental change. Applications of science to social and political policy have been important motivations for his career and have occupied his attention increasingly as the decades passed.

Fleagle participated at close range in the beginnings and growth of a major university department and of the University Corporation for Atmospheric Research (UCAR). In 1963 and 1964 he served as a staff specialist in the Office of Science and Technology, Executive Office of the President, and in 1977-78 he served as consultant to the National Oceanic and Atmospheric Administration. He has held many administrative posts including chairman of the UW Department of Atmospheric Sciences (1967-77), chairman of the National Academy of Sciences Committee on Atmospheric Sciences (1969-73),

45 BEACON

LETTER FROM HEADQUARTERS

CHOOSING THE LEADERSHIP OF THE SOCIETY

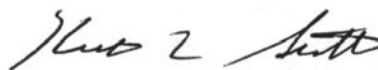
One of the great joys of being in the position of AMS executive director is the opportunity to work with the leaders of the community who make up the AMS Council. While I might joke that I have to get used to a new “boss” each year as a new AMS president assumes the helm of the organization, the truth is that I find it extraordinarily stimulating to work with those who cycle through the presidency and AMS Council. The AMS members coming into this group each year bring fresh ideas, enthusiasm for the Society, and a truly selfless dedication to the community that is simply inspiring.

It is once again time for the voting members of the Society to help choose the leadership of the AMS. This issue contains the biographies and statements for each candidate on this year’s ballot. As in prior years, all the candidates are eminently qualified to serve, and each brings a range of experience and knowledge on issues facing our broad community. It is a shame that only one will assume the role of president-elect in January and that only four will join the Council at that time.

As many of you know from last year, we have made it even easier for you to participate in the AMS election. When you go to the AMS website to renew your membership for 2013, you will be given the opportunity to jump directly to the election

page to cast your votes. (If you prefer to vote using a paper ballot, that option is available to you. Contact Melissa Weston at AMS Headquarters at 617-226-3904, and she can mail you a ballot.) You can, of course, do each process separately if you prefer, but doing both at the same time helps insure that you do not forget to vote given our busy and often hectic lives. Renewing your membership online using your personal profile is the fastest and easiest way to maintain your AMS membership, and if you have not yet created your online profile to allow you to take advantage of the online resources available to AMS members, doing so takes only a few minutes (go to www.ametsoc.org/MEMB/account/index.cfm and select “Create an Online Profile”).

The AMS Council, under the leadership of the president, sets the direction for the future of the Society. I hope you will all accept the privilege and responsibility for choosing who will take on these leadership positions and guide your Society for the next several years.



KEITH L. SEITTER, CCM
EXECUTIVE DIRECTOR

ENVIRONMENTALLY RESPONSIBLE PUBLISHING

The past few months, this column has reported some of the ways that the AMS is becoming more environmentally responsible. This month we turn our attention to publications. The Committee on Environmental Responsibility and the Publications Commission both report dramatic improvements in the publications process. It's now far simpler and uses much less paper.

Little more than a decade ago, publishing in an AMS journal produced a veritable blizzard of 8.5×11 snowflakes. Authors would mail five copies of an article to AMS, and then possibly mail another five copies a few weeks later if the standards for margins or font size hadn't been followed. Editorial assistants would mail copies to reviewers, who would mail decisions back to the editor, who would mail the author a decision, and the author would most likely have to mail five new copies of a revised article back to the editor. To complete the felling of a personal forest and subsidy of the U.S. Postal Service, the process ended with the snail-mail delivery of a weighty journal to thousands of subscribers and 50 reprints to the author (40 of which are probably still in the author's filing cabinet).

Now, says AMS publications commissioner Dave Jorgensen, "it's possible for a publication to go from a scientist's mind to a published article without a single piece of paper being printed." The author submits their manuscript electronically, including the copyright form. Editors transmit electronic copies to reviewers, who submit reviews electronically; editors send decisions electronically; and most readers will access the article electronically.

Sheridan Press, AMS's printer, has also made great strides in environmental responsibility. For example, their conversion to digital printing reduced the generation of unnecessary paper by 98%, and

their new printing process has virtually eliminated the use of volatile organic compounds. They follow printing best practices, too, recycling all their scrap paper, wooden skids, cardboard, ink, and plates. Replacement equipment is Energy-Star rated.

However, resources are still consumed in the current publications process. Many libraries still prefer bound journals, though the AMS Publications Commission is nudging libraries to go totally paperless themselves. Many scientists like the feel of a piece of paper better than an arrangement of glowing pixels on a computer screen and so will print an article, but some will appreciate the ability to select only articles that they wish to read, as opposed to being presented with 20 others from the same issue. And of course, should a fellow scientist be pondering the article online, they'll be using energy to do so. A typical desktop computer may use 100 watts of energy, and a laptop 25–50 watts, and only a tiny fraction of U.S. power is currently generated from renewables.

Consequently, much of the responsibility for a further "greening" of publications shifts from the AMS and its printer to individual authors and readers. Some questions to ask when writing and submitting an article: Do you use an environmentally thrifty process in drafting your articles, or are you editing your drafts in an "old-school," paper-intensive fashion? Is the power you're using for your computer coming from renewable sources? As a journal reader, are you careful about printing only articles you need to and only printing them once, not each time you want to consult them? Do you share printed copies with colleagues? Are there other ways you can think of to make the production and use of journal articles more environmentally responsible? Please share your thoughts with us at amspubs@ametsoc.org.

ABOUT OUR MEMBERS

Rear Admiral **David Titley** was named the next deputy under secretary for operations at NOAA. As NOAA's chief operating officer, Titley will be responsible for managing operations across NOAA's entire portfolio and will serve as one of Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator Jane Lubchenco's key advisors on NOAA program and policy issues.

A naval officer since 1980, Titley's career has included seven deployments to the Mediterranean Sea, Indian Ocean, and Western Pacific region and multiple commands. Titley has commanded the Fleet Numerical Meteorological and Oceanographic Center in Monterey, California, and was the first commanding officer of the Naval Oceanography Operations Command. He served his initial Flag tour as commander,

Naval Meteorology and Oceanography Command. In 2009, he assumed the duties of the oceanographer and navigator of the navy, and in 2012, he became acting assistant deputy chief of Naval Operations for Information Dominance.



David Titley

Titley's education includes a B.S. in meteorology from The Pennsylvania State University, an M.S. in meteorology and physical oceanography and a Ph.D. in meteorology, both from the Naval Postgraduate School. His dissertation

focused on better understanding tropical cyclone intensification. He was elected a Fellow of AMS in 2009.

Chris Velden, senior researcher at the Space Science and Engineering Center, is the recipient of the University of Wisconsin Chancellor's Award for Excellence in Research. This award, given to an independent university researcher, recognizes a lifetime achievement for significantly impacting their discipline. Velden's nomination package included strong recommendations of support from international and national institutions, including NOAA's National Hurricane Center. The award was presented in May at a special Chancellor's honors ceremony.

"Many scientists do well in a few areas, while few excel across the board," says Jeffrey D. Hawkins of the Naval Research Laboratory in Monterey, California. "Velden has participated in more than 10 field programs around the globe, illustrating his thirst to truly understand what the atmosphere is trying to tell us via multiple airborne/satellite campaigns."

Rick Knabb has been named the new director of NOAA's National Hurricane Center. He replaced outgoing director Bill Read and began in June. Well-known as The Weather Channel's "hurricane expert" for the last two hurricane seasons, Knabb is returning to familiar territory. He was a senior hurricane specialist from 2005 to 2008, and the Center's science operations officer beginning in 2001.

Born just outside of Chicago, Knabb grew up in Coral Springs, Florida, near Fort Lauderdale, and in Katy, Texas, in suburban Houston. He earned a bachelor's degree in atmospheric science from Purdue University and holds a master's degree and Ph.D. in meteorology from the Florida State University.



Rick Knabb

Knabb left the Hurricane Center in Miami and became deputy director of the Central Pacific Hurricane Center (CPHC) in Honolulu, Hawaii, for a year before arriving at The Weather Channel. The CPHC oversees tropical cyclone forecasts and warnings from 140° west longitude westward to the International Dateline, including all of the Hawaiian Islands.

Knabb also serves on the AMS Board for Operational Government Meteorologists. He has published numerous papers in AMS and other scientific journals and has given presentations on hurricanes and tropical weather at AMS and related conferences.

OBITUARIES

With great sadness, the family of James Giraytys announces his peaceful but sudden passing at his home in his beloved Frederick County, Virginia.

Born in the Rochester area of New York on 22 March 1933 as the only child of Joseph and Eliza Giraytys, Jim ultimately traveled the world as a leading meteorologist. A quiet man, Jim's chosen career allowed his scientific mind to indirectly impact many fellow Americans as well as people around the world, especially in developing countries.

As a young man, Jim served his nation as an officer in the United States Air Force (Capt.), both at home and in Europe. Later in life, he served all nations as a senior scientific officer in the United Nations scientific body, the World Meteorological Organization, based in Geneva, Switzerland.

JAMES GIRAYTYS
1933–2012

Jim's professional life was long-lived, with significant contributions to the advancement of flood and severe weather forecasting technologies. His

air force service was followed by civilian federal government service with the NWS and NOAA. During this time he worked on the development of forecasting systems that have evolved into the current ones used at the National Hurricane Center in Miami, Florida. Later, Jim worked on the Federal and 4-State Flash Flood Project, which provided early flood warning to residents of the Appalachian Valley.

In the early 1980s, Jim was recruited by the U.N. World Meteorological Organization in Geneva from the NWS/NOAA as a senior scientific officer. During this tenure, Jim was instrumental in the international implementation of weather-data relay systems that are still in use today, with weather data being relayed from aircraft and ships to a global observing system, thereby protecting people every day. Another major program Jim coordinated was an advanced weather observing technology introduction into over a dozen countries in Africa.

Upon his retirement from the U.N. in 1993, Jim settled in the Shenandoah Valley in the scenic Frederick County of Virginia, where he continued his career as an AMS Certified Consulting Meteorologist (CCM). His clients included bodies such as the NWS and NOAA, as well as many pro-bono hours with environmental groups.

Professionally, Jim was a member of the AMS, the American Geophysical Union, and the Environment and Water Resources Institute of the American Society of Civil Engineers, and a charter member of the National Weather Association. In recognition of his decades of excellence and distinguished service, the AMS elected Jim as a Fellow of AMS in 2008. In later years, he served on the AMS Board that certified new CCMs.

Jim had a B.Sc. in wood engineering from the New York State College of Forestry, completed advanced weather officer training at New York University, earned the M.Sc. in meteorology at the Pennsylvania State University, and subsequently completed a one-year advanced program at Penn State in remote-sensing techniques. While doing graduate work at Penn State, he was elected an associate member of Sigma Xi, a national honor society for people working in research and applied science. Jim also held a certificate of competency in the French language from the United Nations.

Close to his heart, and his home, was Jim's involvement with the local community. The College of Integrated Science and Technology at James Madison University (JMU) in Harrisonburg, Virginia, appointed him as adjunct assistant professor. He played a key role in developing and executing the Shenandoah Valley Air Quality Initiative (SHENAIR), a collaboration of local governments, universities, and interested citizens providing sound scientific information to local decision makers to support air-quality policies in the region. Examples of lasting parts of that initiative are installation of a meteorology station at Blandy Experimental Farms/the State Arboretum, and a spherical display theater, Science on a Sphere, at JMU. He had recently been working to assure the long-term implementation of the tower at Blandy and on securing funding to make JMU's Science on a Sphere available to K-12 students. Jim taught meteorology at the Lord Fairfax Community College in Middletown, Virginia.

Local community work also included involvement with the Regional Water Resources Policy Committee planning for water resources throughout the Shenandoah Valley. Jim volunteered with the Air Improvement Task Force for Winchester and Frederick County, and he also served on the Winchester, Virginia, Natural Resources Advisory Board.

Jim is survived by his wife of almost 60 years, Beverly Jane Giraytys (nee Lymburner). He was lovingly devoted to her until his death parted them, and she will sorely miss him. Jim was predeceased by his parents, and by his sister-in-law, Gay Louise Wilson (nee Lymburner) and Gay's husband, Arnott Wilson.

Jim also leaves behind his niece, Ann Kennerly, and nephew, Arnie Wilson, and their respective children: James Wilson Sturman, MaryLouise Wilson Sturman, and Louise Anna Wilson. All will miss their uncle and great uncle's warmth and ever-sharp mind. Jim loved discovering what young people thought and would sympathetically challenge them to expand their minds. Jim always encouraged family visits, especially at Christmas, March break, and summer holidays. He insured that mealtimes always included debate and lively discussions. He will be fondly remembered by his family as well as by a host of friends and colleagues around the world.

—FRED ZBAR, ANN KENNERLY, AND JOHN LINCOLN

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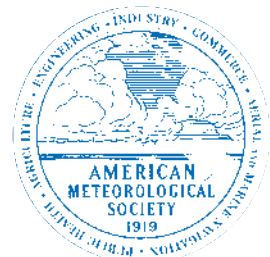
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Raymond J. Ban and William B. Gail are the 2012 candidates for AMS president-elect; the candidates for AMS councilor are Stephen F. Corfidi, Jan Dutton, John Henz, Frank D. Marks Jr., David J. Pace, Maria Pirone, Yvette Richardson, and Elizabeth A. Ritchie. To help the membership select its leaders, the Society asked the candidates to answer the following question, "What do you see as the challenges facing the Society, and how would you address them if elected?" Following are their responses, along with a brief biographical sketch of each candidate.

AMS PRESIDENTIAL CANDIDATES

RAYMOND J. BAN

The AMS is the premier scientific and professional organization in the atmospheric and related sciences. Close to a century of service guided by outstanding leadership has enabled the Society to grow into this world-class position. As an organization, we have been blessed with the skills and competencies needed to

maintain relevancy to our increasingly diverse members and provide exceptional science and education to the broader communities we serve.

However, as we are constantly reminded, past performance is not an indicator of future results. The world economy is in a much different place than we have ever experienced and the need for "environmental intelligence" to help navigate this new space will be more important than ever. Our community will face increasingly urgent calls to provide greater understanding, information, and education at a time when the funding for the observation platforms and high-performance computing that supports our research and operations is shrinking.

New fiscal realities will also impact our members and further drive the need for the AMS to grow the "membership value proposition." What do our members really need and want? Are we effectively enfranchising our younger members? Are AMS meetings and publications maintaining relevancy and more importantly, are they accessible to the majority of our members? Is AMS developing an emotional as well as a functional relationship with its members?

Many solutions that have worked in the past will not work moving forward. As a candidate for

RAYMOND J. BAN



RAYMOND J. BAN is retired executive vice president of programming, operations, and meteorology at The Weather Channel, Inc. (TWC). Most recently, he served as consultant for weather industry and government partnerships, responsible for growing TWC relationships with the atmospheric science community across the entire weather and climate enterprise. He is currently a guest lecturer at Penn State University (PSU), where he teaches one month each semester in the Weather Communications Program.

Ban has been associated with TWC for 30 years and is considered one of the founding members of the TWC team. He served as

an on-camera meteorologist in the early years, took over responsibility for the on-camera meteorologists in 1985, and was promoted to vice president of operations in 1988, heading up production and all meteorology activities. In 1996, Ban became senior vice president and was a key member of the business development team that established TWC International business in Germany, Great Britain, and South America. In 2000, he was promoted to executive vice president, and added responsibility for all programming and operations of the TWC Video Network in 2008. Ban was a member of the senior leadership team that grew The Weather Channel from a modest cable television network into a top, multiplatform media brand.

Ban has been an active member of the AMS for almost 40 years. He is a Fellow of the Society and holds both the Television and Radio Seals of Approval. Ban was the Commissioner on Professional Affairs for the AMS for six years, served as Councilor for three years, and recently served on the inaugural Steering Committee of the AMS Commission on The Weather and Climate Enterprise. He is currently a member of the AMS Planning Commission and a cochair of the Committee on Improving Climate Change Communication.

Ban is an Alumni Fellow of PSU and a Centennial Fellow of its College of Earth and Mineral Sciences. He has served on the Board of Atmospheric Science and Climate of the National Academy of Sciences, and as president of the Alumni Board of the College of Earth and Mineral Sciences at PSU. Currently, he is active on several boards and committees, including chair of the NOAA Science Advisory Board and cochair of the Weather Coalition.

Prior to joining TWC, Ban was an operational weather forecaster at AccuWeather, Inc. He graduated from PSU in 1973 with a degree in meteorology.

AMS President, I believe the Society must take the lead in building new community collaborations that will be needed to develop innovative solutions to our twenty-first century economic challenges. Through increased member engagement, we must build loyalty and pride in the Society and ensure AMS members feel they are receiving real value from their membership and are truly helping to make a difference.

Thank you for this honor and opportunity.

WILLIAM B. GAIL

We live in a special time for meteorology. It arises from a half-century science and technology revolution: improved observations through satellites, radars, and other observational systems; increasingly accurate and high-resolution models from ever-faster computers; and finally, widespread internet/mobile information access for meteorology's end-users. We are privileged to be the first generation applying the revolution's full impact—from information creation to end-use—in service of society.

All around us, we see the promise of this “new meteorology.” Hurricane and tornado information/warnings sent directly to mobile phones reach more people and save lives. Farmers in remote global areas now receive timely crop-harvest warnings and businesses routinely track space weather. Commuters adjust their plans in real time when their smartphone anticipates that rain or snow will disrupt traffic.

Given challenges from politics to budgets, the weather, water, and climate enterprise must continue to evolve if we are to deliver the vision. AMS will perform a critical role in making this happen. Strong core agencies (NOAA, NASA, NSF, DoD, and international partners) are the foundation. But we all play an essential part—atmospheric scientists and modelers, researchers in related disciplines ranging from oceanography to space weather, practicing meteorologists and hydrologists, the commercial services sector, satellite and ground-sensor developers, educators, cross-cutting experts such as

WILLIAM B. GAIL



DR. WILLIAM B. (BILL) GAIL is cofounder and chief technology officer of Global Weather Corporation (GWC), a provider of precision forecasts to businesses serving weather-sensitive sectors such as wind energy, transportation, consumer, and media. He founded GWC to broaden public benefit from next-generation forecast technologies being created in universities and national labs. He was previously a director at Microsoft, responsible for software innovation including consumer mobile and 3D weather visualization; vice president of geospatial technologies at Vexcel Corporation, where he initiated Vexcel's acquisition by Microsoft; and a director at Ball Aerospace responsible for meteorology and Earth science satellites.

Gail received his B.S. in physics and his Ph.D. in electrical engineering from Stanford University, where his research focused on space weather (specifically, wave-particle interactions in Earth's magnetosphere). During this period, he spent a winter-over year as the NSF-funded upper-atmospheric scientist at South Pole Station in Antarctica.

His career has focused on bridging the gap between science and practical applications of Earth information, working across organizations and linking science to technology and policy. He is a lifetime Associate of the National Academy of Science's research council, having participated on a number of committees, including the recent review of the NWS modernization and the 2007 NASA/NOAA Decadal Survey. Gail has served on a wide variety of editorial, corporate, and organizational boards, including Women in Aerospace (with two years as finance chair), NOAA Advisory Committee on Commercial Remote Sensing (acting), *Imaging Notes* magazine, *SPIE Journal of Applied Remote Sensing* (associate editor), IEEE Geoscience and Remote Sensing Society, Peak Weather Resources, NASA Senior Review, NASA Earth Sciences Roadmap Committee, and NASA Applied Sciences Program Advisory Group.

He has authored more than 90 refereed papers, invited and technical presentations, and policy publications, and is the holder of two patents for synthetic aperture radar calibration. His articles and editorials concerning the relationship between climate science and applications have appeared in a number of publications, including *BAMS*. Recent awards include best conference speaker from the Geospatial Information and Technology Association and excellence in scientific journal review from the American Geophysical Union.

sociologists and economists, and groups such as women that are underrepresented in the enterprise. Scientific and technical diversity is our strength.

I have lived, breathed, and advocated the new meteorology for well over a decade. I've worked on National Research Council committees to focus and realize it, including the 2007 Decadal Survey and the just-completed NWS review. I've built weather satellites and developed real-time 3D weather visualization for consumer internet mapping. I spent the last five years starting a precision-forecast services company because I believe passionately in the value of quality meteorological information to serve society. This same passion would characterize my term as AMS President.

AMS is a great institution, and it is the right organization to initiate and continue positive change. If elected, I will focus my term on leading our vital enterprise in the direction of the new meteorology through three initiatives. First, AMS should strengthen its already strong position as an international leader through our technical committees and programs—promoting debate, establishing clear standards, leading the digital evolution of meetings/publications, engaging the public, and setting policy positions to support the new meteorology. Second, we should build on our expertise to lead multidisciplinary coordination among the diverse professional organizations that address climate change, globalization of weather forecasts, and similar issues. Finally, we should promote accelerated adoption of new technologies for improving public access to weather information, including mobile phones, community-based data collection, advanced alerting systems, and social networks.

I am deeply honored to be a candidate for President. With your vote, I will help AMS and the communities we support apply the new meteorology to serve society.

Editor's Note: Profiles of councilor candidates begin on page 1248.

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— from the Foreword by Prof. Kerry Emanuel, Massachusetts Institute of Technology

Eloquent Science: A Practical Guide to Becoming a Better Writer, Speaker, and Atmospheric Scientist

DAVID M. SCHULTZ

What started out as a communications workshop for undergrads in atmospheric science evolved into a book that would benefit scientists at any stage in their careers. Drawing on Schultz's experience as a journal editor and prolific writer, the insights of his colleagues, and the best advice from hundreds of sources, this must-have reference includes:

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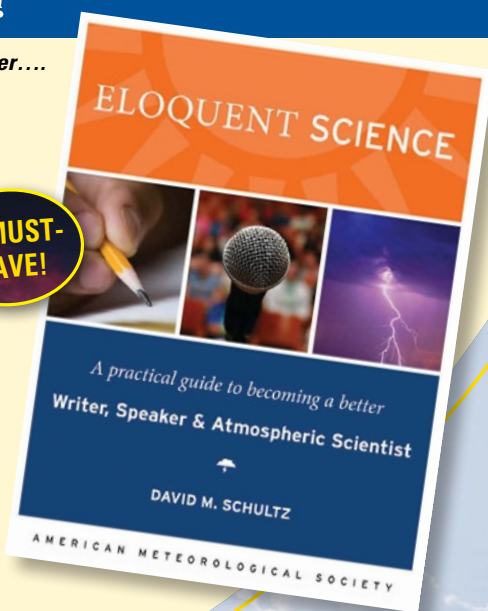
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STEPHEN F. CORFIDI

A glance through back issues of the *Bulletin* readily reveals the accelerated rate of change that has characterized the atmospheric science community—and society at large—over the last few decades due to advances in data computation and communication. For example, as recently as the 1990s, formal scientific exchange occurred primarily through conferences and paper journals. Practical application of new concepts might take months or years. While comparatively slow, such a pace encouraged careful, critical review of new ideas, especially within the context of existing ones. Today's information onslaught, in contrast, often overwhelms. The heightened need to “sort the wheat from the chaff” in the data flow—and the need to assess and adopt the new technological tools that make use of it—are just two reasons why the AMS remains more relevant than ever. This environment presents the Society with significant challenges and opportunities.

STEPHEN F. CORFIDI

STEPHEN F. CORFIDI has been a lead forecaster at the NOAA/NWS/NCEP Storm Prediction Center in Norman, Oklahoma, since July 1994. He is responsible for the issuance of tornado and severe thunderstorm watches on an as-needed basis over the continental United States, and for scheduled, nationwide severe weather and thunderstorm outlooks. He also is responsible for severe and fire weather forecasts and analyses issued by other SPC staff. Prior to this assignment, Corfidi was a forecaster with the NWS Hydrometeorological Prediction Center in Camp Springs, Maryland, where responsibilities included hemispheric

surface analyses and quantitative precipitation, flash flood, winter weather, and medium-range forecasts. He also served as an assistant forecaster at the NWS National Severe Storms Forecast Center and in the National Public Service Unit in Kansas City, Missouri. Corfidi entered the NWS as a meteorologist intern at the Baltimore-Washington Forecast Office, and at the Techniques Development Laboratory in Silver Spring, Maryland. His B.S. and M.S. degrees in meteorology are from The Pennsylvania State University.

During his 30-year career, Corfidi has conducted applied research on thunderstorm development and organization, mesoscale convective systems, elevated convection, warm-season haze, and other topics. He was a forecaster for Project VORTEX and has participated in several NOAA Hazardous Weather Testbed Spring Experiments. He has served as a mentor for Oak Ridge Institute for Science and Education and Research Experiences for Undergraduates students, and has been a guest lecturer for the Cooperative Program for Operational Meteorology, Education, and Training (COMET) Mesoscale Analysis and Prediction course.

Corfidi joined the AMS as an undergraduate student at Penn State. He was named an AMS Fellow in 2004 and has served as an officer in the Penn State (student), Kansas City, and Central Oklahoma AMS chapters. He was chair of the AMS Severe Local Storms Committee (1997–99), during which time he helped revise the AMS Policy Statement on Tornado Forecasting and Warning and initiated efforts to draft an AMS Policy Statement on Tornado Preparedness and Safety. With Gary K. Grice, he also coordinated the special August 1999 issue of *Weather and Forecasting* commemorating 50 years of tornado forecasting. Corfidi received the AMS Exceptional Specific Prediction Award in 2001. He has served as an associate editor of *Weather and Forecasting*, and received the AMS Editor's Award in 1998.

To best promote “the development and dissemination of information and education” in the atmospheric and related sciences, it is imperative that the AMS frequently review all phases of its operation to see where improvements may be made. While tedious, such self-analysis is necessary for optimal functioning of the organization. The Society's implementation of electronic manuscript submission several years ago, for example, expedited the publishing process for AMS journals. But software advances since that time present opportunity for further review—and potential streamlining—of this and other critical day-to-day functions of the Society. Technological advances also provide opportunity for the Society to consider adopting practices once deemed impractical. Might scientific inquiry be enhanced were a manuscript's peer reviews posted alongside the paper's final version, online? Self-examination also is important on the programmatic level, to ensure that the Society's strategic goals keep pace with the rapidly changing world.

As a member of the AMS Council, I would be most humbled to serve the organization that, for nearly a century, has furthered our science and profession. It would be my honor to help guide the Society through the years ahead.

JAN F. DUTTON

Our society is under ever-intensifying pressure owing to relentless population growth, global economic turmoil, and the increasing variability of weather and climate. Many of the global challenges we face in energy, agriculture, transportation, and water and resource management, for example, are intimately linked to the Earth's atmosphere and oceans. Understanding and mitigating these contemporary challenges mandates that the weather and climate enterprise focus on enhancing our understanding of the atmosphere and oceans and on applying that understanding more effectively to public and private problems and opportunities.

The AMS has long been America's advocate for the atmospheric sciences. In the current environment, the AMS must be bold and resolute in helping to demonstrate that the research and operational activities of the weather and climate enterprise lead to improved understanding and prediction of atmospheric events on all relevant time scales. The weather and climate enterprise must better understand and communicate the value that existing and improved science and its applications bring to society.

Critical decisions will be made in the future based on our contemporary understanding of the processes that drive our atmosphere and environment. The AMS should work with end-user groups and industry associations to solidify our understanding of the value of the combined activities of the weather and climate enterprise. This information will assist the AMS in its role of demonstrating that improved understanding and prediction increases economic vitality and reduces the adverse social and economic impacts of weather and climate in the United States and the world.

The AMS must also help to shape contemporary education in the atmospheric sciences so that it emphasizes the realities the science and its applications face and so that it prepares students to contribute effectively to the difficult decisions and accelerating challenges they will encounter during their careers.

As a Councilor of the AMS, I will work to strengthen the focus of the Society on advocacy for the atmospheric sciences and on emphasizing both the benefits and responsibilities of the weather and climate enterprise to the nation and our society.

JAN F. DUTTON

DR. JAN F. DUTTON is the vice president of business development at Telvent Environment, a Minneapolis, Minnesota-based company. Telvent Environment is a leading provider of business weather information. Current responsibilities include the development of international markets and partnerships. Prior to his position at Telvent, Dutton was the vice president of business development at Storm Exchange, a start-up provider of financial weather risk management services. Before joining Storm Exchange, he was the director of WeatherBug Professional, a division of Earth Networks, Inc., where he oversaw the unit's business strategy and managed a sales force.

Prior to joining Earth Networks, Dutton was a founder and executive of Weather Ventures, Ltd., which developed analysis products for the weather derivatives industry.

Dutton received a dual degree B.A. in physics and science and technology studies from Colby College in Waterville, Maine, in 1994. He received an M.S. from the Pennsylvania State University Department of Meteorology in 1996. He received his Ph.D. and an MBA from the Smeal College of Business at Penn State in 2000. His dissertation focused on the simulation of interannual climate variability using regional climate models.

JOHN F. HENZ

Our American society faces a significant challenge as aging infrastructure strains to meet the growing demands for water and energy by an increasing population centered in large metro areas, along coastlines and in semiarid environments. In short, we are becoming more vulnerable to changing weather and climate than at any time in the past century. The design of this infrastructure was done 50–70 years ago when our profession was in its infancy, and it is in dire need of updating. At the time, meteorology could not quantitatively answer the questions engineers were asking and so was “engineered out” of the design and operations.

The recent interest in high-impact weather, climate variability, and climate change has opened the door to dialogue again with the engineering profession. The AMS is in a unique position to serve as focal point for engag-

ing the entire Weather Enterprise in providing multidisciplinary input to insure we are active partners with the engineering community. The government sectors, at all levels, have a direct role in insuring updated design and operating standards are adopted that reflect our robust data and knowledge bases. The academic sector is developing multidisciplinary, educated meteorologists while performing the basic and applied research that insures a steady increase in our knowledge base. The private sector is needed as the functional interface with both the public and the engineering and business communities that insure the application of the new research and the involvement of emerging professionals.

These three initiatives can only be achieved by engaging our strongest asset, the intergenerational knowledge and passion of our Society’s members. We need to team with the engineering and related professions through direct participation and dialogue at their conferences and professional organizations by all levels of members in AMS. The AMS Council can work in concert with our commissions and boards to develop creative communication venues that foster a trusted awareness of the emerging new roles meteorology can play. If you share my enthusiasm for a “rebirthing” of our profession, I would be simply, humbly, and honestly honored to serve you as a member of the AMS Council.

JOHN F. HENZ



JOHN F. HENZ experienced a career-defining moment when he received an AMS Special Award in 1977 “for the exceptional use of radio and meteorological knowledge in the public interest during the flash flood situation in the Big Thompson Canyon on July 31 and August 1, 1976.” He saw the societal value of applying meteorological research directly into operational meteorology and developed a passion for it. His 40-plus-year career as a private meteorologist has focused on hydrometeorological problem-solving in severe weather and flood warning services for the emergency response community, quantitative precipitation forecasting, and climate variability and water-supply prediction. His interests have cross-pollinated into the multidisciplinary interactions between engineering and meteorology.

Henz is senior meteorologist/technical leader at Dewberry, a national engineering company. He is responsible for the development and operation of flood warning systems and response plans, climate variability impact studies on water supply, and radar-rainfall studies for design storms and basin modeling calibration. Prior to joining Dewberry, he was the national atmospheric science practice leader and a senior professional associate for HDR Engineering (2001–10). While at HDR, he developed a GIS-based process tool, the Extreme Precipitation Analysis Tool (EPAT), to determine the Probable Maximum Precipitation for high-elevation basins that is currently accepted as a Colorado standard of practice.

Prior to joining HDR, he held leadership positions in a number of meteorological consulting businesses. Among his contributions during this time was consulting to the JPL/NASA on the prediction of dust storms on Mars and Earth for the Viking probe landing and developing proactive flash flood prediction systems and statewide flood prediction services in Arizona and Colorado. He codeveloped the original HailTrak hail damage estimate tool, and has designed successful flood response plans and flood warning systems in six states.

Henz earned his M.S. in atmospheric science from Colorado State University and B.S. in meteorology from the University of Wisconsin—Madison. Upon graduation from UW he served as a weather officer in the U.S. Air Force (USAF). He joined AMS in 1968, has been active in local chapters, and is a former member of the Severe Local Storms Committee, the Board of Certified Consulting Meteorologists (BCCM) and the Board of Enterprise Economic Development (BEED). He chaired the BEED Water Resources Committee in 2008 and the BCCM in 2010. He was a presenter/mentor at AMS Annual Student Conferences (2007–08) and chaired the CCM Forum (2009–12).

His professional activities have been honored by the USAF and the American Consulting Engineers Council, as well as the AMS.

FRANK D. MARKS JR.

The AMS is a world leader in the quality and diversity of programs in support of atmospheric sciences and related fields, from the portfolio of scientific and technical meetings to its publications and other member services. Our Society is at the forefront in providing member services through digital access to our publications, and increased access to news and developments relevant to the Society and atmospheric science professionals in general through rapidly evolving social media formats. Yet as these services evolve and diversify, there is an ever-increasing need to educate our customers and political leaders, as well as the next generation of atmospheric scientists. I think the biggest challenge the AMS faces in the future is maintaining our ability to be a trusted source for information and guidance on atmospheric and climate related issues relevant to society in general. Political leaders and society must be able to trust the information and guidance our community provides in the face of very difficult decisions. In order to do that the AMS must encourage debate and dialogue on the important atmospheric and climate-related issues facing us today. The Society must insure that our next generation of atmospheric and climate scientists are prepared to not only push the science forward in order to address these issues, but also to articulate clearly the impacts on decisions put forward in response to these changes. AMS must embrace the diversity of our membership and use that diversity to promote dialogue and debate, as well as to inform the decision makers who must deal with these potential impacts. The Society cannot avoid the political nature of debate, but we must insure that our position is always based on sound scientific thought and is articulated clearly and concisely. I am honored to have a chance to serve the Society in such interesting times and if elected my goal will be to insure that the policies and practice of the AMS adhere to these principals and encourage a diversity of positions and opinions as we all work to address these extremely difficult issues.

FRANK D. MARKS JR.

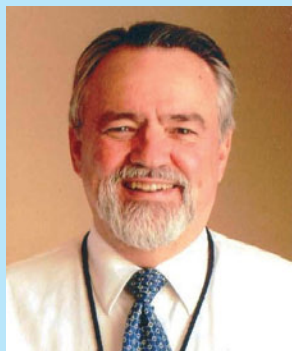
DR. FRANK D. MARKS has been a meteorologist with the Hurricane Research Division at the Atlantic Oceanographic and Meteorology Laboratories for NOAA since 1980, and director since 2003. Marks led the development of the NOAA Hurricane Forecast Improvement Project (HFIP) since 2007. Marks also cochaired the Working Group for Tropical Cyclone Research (WG/TCR) for the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) since 2008. Marks is also an adjunct professor in the Department of Meteorology and Physical Oceanography at the University of Miami, as well as a fellow of marine and atmospheric

research at both the University of Miami Rosenstiel School for Marine and Atmospheric Sciences and the University of Hawaii at Manoa. Marks joined the Society in 1971 as a student member, becoming a full member in 1973, and became a Fellow in 2000. Marks served as a member of the AMS Committee on Radar Meteorology, and was the recipient of the AMS Verner E. Suomi Medal in 2011. Marks's research interests include analyzing meteorological remote-sensing datasets (e.g., microwave radar and radiometer), particularly in tropical cyclones, and he has published more than 80 refereed articles, book chapters, and reports on these topics. Marks serves as a member of the NCAR EOL External Advisory Committee and the Review Team for NASA Earth Venture-I Investigation Hurricane and Severe Storm Sentinel (HS3). Marks received a B.S. in meteorology from Belknap College and both an M.S. and Sc.D. in meteorology from the Massachusetts Institute of Technology.

DAVID J. PACE

The AMS has a strong history of supporting the meteorological and related communities by providing a forum for review and exchange of scientific information. It has also supported the general public by being a reliable source of clear explanations of issues in the atmospheric sciences. To continue these vital services, protecting our reputation for unwavering integrity should be our priority. Without integrity, all other goals would be in jeopardy.

DAVID J. PACE



DAVID J. PACE received a B.A. in mathematics from the University of Virginia in 1969. At graduation he received a commission in the U.S. Air Force, and was soon called to active duty. He was assigned to Saint Louis University for one year of studies in meteorology to prepare him for duties in the air force's Air Weather Service. After spending two years in airfield forecasting duties, he was assigned to San Diego State University, where he was awarded an M.S. in astronomy in 1974. He went on to complete 22 years of service in the Air Weather Service, including commanding three units. His final assignment was in the

Pentagon, where he directed worldwide weather support to the President of the United States, the Secretary of Defense, and the Joint Chiefs of Staff.

In 1991, Pace became a principal system engineer for Martin Marietta Corp., preparing the alternatives analyses for FAA weather systems, coordinating systems engineering and operations research efforts, and writing FAA weather mission need statements and operational requirements documents.

In 1994, Pace moved to Advanced Management Technology, Inc. as an acquisition specialist in support of the FAA. There he wrote the acquisition plan, acquisition program baseline, and portions of the statement of work, system specification, and RFP documents for FAA weather acquisitions.

In 1997, he became a program analyst and project manager at SAIC. He wrote requirements documents, action plans, and other baseline documents associated with FAA network-centric operations as a dissemination mechanism for weather information. He served as the support meteorologist for the FAA weather research program.

In 2006, Pace became an FAA employee, serving as a meteorologist. He coordinated concepts, standards, and operating rules for the Next Generation Air Transportation System (NextGen) Weather Datacube. He organized and led a multiagency team that produced and delivered the NextGen Air Traffic Management and Weather Integration Plan. He led FAA weather harmonization efforts with China. Until retiring from the FAA in April 2012, he was the FAA leader for integrating weather into air traffic management decision processes.

Pace is a longtime member of the National Weather Association and was a session chair for the American Institute of Aeronautics and Astronautics.

Pace served the DC AMS local chapter as recording secretary and as vice-chairperson. At the national level, he served six years on the AMS Committee for Interactive Information Processing Systems. He is now serving a second three-year term as chair of the AMS Committee for Aviation, Range, and Aerospace Meteorology. Pace was honored as a Fellow of the AMS in January 2012.

In recent years, events in the news have caused many in the public and in the science alike to question the integrity of some segments of our community. There have been allegations of scientists falsifying data to support a desired conclusion and of concealing data that would be contrary to the desired conclusion. The AMS responded to these events, but some members considered the response to be tepid at best. Some members have communicated to me that they were considering resignation as a result. Their concern is not only with bias in the science but also with the earnestness of the AMS in dealing with the issue.

A key challenge facing the AMS today is to clearly reestablish itself as an unwavering guardian of scientific integrity in the field. It is not sufficient to act with excellence; it is necessary to display that excellence to ourselves and to the public. That can only be done by an increase in transparency. We must dispel any notion that decisions are made behind closed doors or with questionable motives. We must build more confidence in our processes.

I propose to address this challenge by a review of all AMS decision processes, perhaps by the establishment of a scientific ombudsman of some sort. Above all, we must add more transparency. The AMS is a great science society, but we can make it even greater.

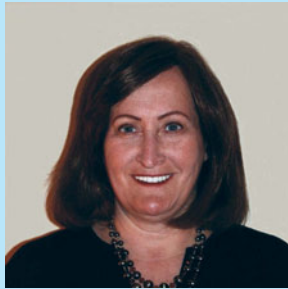
MARIA PIRONE

Over seven years ago—January 9th, 2005, to be exact—in a boardroom converted from an oversized ballroom in a San Diego hotel, the AMS Council made the momentous decision to add a new commission to its organizational structure—the first time in over 50 years that it had done so. And that one decision changed the Society forever. Today there are over 200 volunteers who are dedicated to “developing and implementing programs that address the needs and concerns of all sectors of the weather and climate enterprise while promoting a sense of community among government entities, private sector organizations, and universities” (Lyons, 2006).

If chosen to serve on the AMS Council, I would work diligently to foster continued growth within the Commission on the Weather and Climate Enterprise. Obviously, the concept is working. Members from all sectors are empowered to work through difficult issues and emerge with a better understanding of the challenges ahead. They are harnessing their interest in making the Society more relevant in today’s world—a feat one councilor alone could never accomplish.

To be successful in the long term, the AMS must continue to grow. The slowly shrinking membership will detract from the Society’s purpose and message, and our profession’s value and importance to society. Replicating the successes of the AMS Commission at the national level out in the local chapters may uncover the same interest and drive. It may also bring attention to this community of scientists that has been overlooked for far too long.

Back to that day in 2005, as I waited for the Council’s vote, I was skeptical that one decision, made by a Council of my admired peers, could have a noticeable impact on the Society. And today, it is with great humility that I ask for the opportunity to serve you and continue what they started.

MARIA PIRONE

MARIA PIRONE, senior account manager for environmental systems at Harris Corporation in Washington, D.C., has more than 35 years of experience in information technology, with 25 years in weather and climate information services. During her career she has held management positions in both the marketing and technical development of weather and climate products and services. She is currently leading business development in the area of climate and environmental systems opportunities

within the federal government and internationally.

Prior to joining Harris, she spent six years at Atmospheric and Environmental Research as vice president of product & market development and later as vice president of the commercial division. Her team of marketing and sales professionals commercialized AER research for emerging markets and expanded the product line to incorporate consulting services to the financial markets and offer full product suite of weather forecast products to energy, financial, and insurance markets.

Currently serving on the Executive Committee for the Alliance for Earth Observations, The Weather Coalition, and as a member of the AMS Ad-Hoc Network of Networks Working Group, her involvement in NSF, NAS, FAA, and AMS committees has spanned two decades. She has more than 25 nonrefereed publications, mostly in industry trade journals. She has served on the AMS Ad Hoc Committee on Member Services, Committee on Societal Impacts, Ad Hoc Committee on the Weather & Climate Enterprise, and two terms on the Board of Private Sector Meteorology. She served on the National Science Foundation GeoSciences Advisory Committee and the NSF Working Group for GeoVision, the GeoSciences Strategic Plan. She participated on two UCAR Review Panels for NWS/NCEP Aviation Weather Center and Storm Prediction Center and was a member of the FAA JPDO NextGen Weather Working Group and the FAA Weather Research Program Convective Weather Product Development Team. She served three years on the U.S. Weather Research Program (USWRP) Science Steering Committee and was president of the Commercial Weather Services Association for three years. She has reviewed four National Academies of Science National Research Council reports in addition to serving on the NRC Committee that produced the “Fair Weather Report.”

In addition, she was appointed the first private sector advisor to the U.S. Permanent Representative to the WMO (UN) for executive council meetings in 2000 and again in 2003 for the 14th Congress, and was one of six U.S. delegates at the 3rd WMO Women in Meteorology Conference in 2003. She has a B.S. in chemistry and an MBA in finance from Suffolk University in Boston. She is a licensed glider pilot.

YVETTE RICHARDSON

The AMS, through its diverse membership, is uniquely poised to facilitate progress on our nation's most pressing issues. For example, the large number of tornado deaths in 2011 despite the vast improvements in our tornado forecasts and warnings served as a wake-up call to explore the interface between weather and society. The NOAA and NSF Weather Ready Nation initiative seeks to improve our nation's resiliency

to these natural disasters, and the initial workshops related to this effort have begun to break down the barriers to communication between groups with very different backgrounds. The AMS can contribute greatly to initiatives such as this through expanded support of AMS Town Hall sessions and other forums for crossdisciplinary conversations between physical and social scientists as well as forecasters, emergency managers, and policy makers. Engaging students in these activities will make these cross-cutting conversations more natural for future generations.

Our society currently has a critical need for a coherent and trusted voice to clarify what is known and what is yet unknown in our field. While our peer-reviewed journals are an excellent source of scientific information, it is a difficult task to distill this knowledge into statements for societal use in an accurate and timely manner, yet this activity is exactly what the AMS must continue to foster and develop to serve society.

Finally, there is such a pool of talent and knowledge within the AMS membership that we must do all we can to encourage active participation from all sectors of the community, in part by controlling the costs of that participation whenever possible.

I am honored to be considered for council, and if elected, promise to put my full enthusiasm and dedication toward the activities listed above as well as the overall mission of the AMS.

YVETTE RICHARDSON



YVETTE RICHARDSON is an associate professor in the Department of Meteorology at Penn State University. Her research specialty is severe local storms. She received her B.S. degree in physics (1990) at the University of Wisconsin—River Falls and her M.S. (1993) and Ph.D. (1999) at the University of Oklahoma. Although her house was almost hit by a tornado when she was a child, she did not recognize her interest in meteorology as a career until a fortuitous encounter with a poster advertising the NASA Goddard Summer Institute on Atmospheric Sciences toward the end of her undergraduate studies. Ensuing graduate school in Oklahoma

led her to study severe storms. Her work combines theory, numerical modeling, and observations to better understand and predict tornadic storms and the initiation of convection. She has authored or coauthored more than 30 refereed publications on these topics and coauthored the book *Mesoscale Meteorology in Midlatitudes*. She has participated in numerous field projects, including the Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX), the International H₂O Project (IHOP) and the Radar Observations of Thunderstorms and Tornadoes Experiment (ROTATE). She recently served as a steering committee member for the second implementation of VORTEX (VORTEX2), the largest field project ever assembled to study tornadoes.

Richardson has served the AMS community in multiple capacities: associate editor of *Monthly Weather Review*; AMS Committee on Mesoscale Processes; Board on Women and Minorities; Annual Meeting Oversight Committee; AMS STAC Committee on Severe Local Storms (chair); AMS Ad-hoc Committee on Statements; and program chair, 22nd AMS Conference on Severe Local Storms. She also attended the inaugural AMS Summer Policy Colloquium and was an instructor for the AMS Short Course on meteorological instrumentation and observation.

Her service activities and interests extend to the broader community as well, serving as a member of the UCAR Governance Task Group; UCAR President's Advisory Committee on University Relations; NCAR Observing Facilities Assessment Panel (cochair); Program Committee for the 2013 European Conference on Severe Storms; Organizing Committee for the Weather Ready Nation Research Agenda Workshop; and the NSF Atmospheric Sciences Supercomputing Advisory Panel. Richardson also has served on several NSF and UCAR scientific review panels and participated in the Progress and Priorities of U.S. Weather Research and Research-to-Operations Activities workshop sponsored by the National Academy of Sciences Board on Atmospheric Science and Climate. In the realm of public outreach, she has done scientific consulting for the Chicago Museum of Science and Industry permanent exhibit "Science Storms," as well as the IMAX films *Tornado Alley* and *Forces of Nature*, and gave a briefing to the Congressional Natural Hazards Caucus following the 2011 tornado outbreak.

ELIZABETH A. RITCHIE

Among the greatest challenges the world faces today is the impact of weather and climate on a global population that continues to expand and grow. The discussion surrounding climate change is one of the most politically and scientifically heated topics, and it has become difficult for the general public to make sense of the importance of climate impacts on resource management. However, regardless of any question of climate change, it is clear that the expanding global population is putting increasing pressure on limited natural resources. In addition, population centers are expanding into regions that are marginal for sustaining large numbers of people or that have historically experienced weather and climate extremes.

The mission of the AMS is to promote the development and dissemination of information and education on the atmospheric and related oceanic and hydrologic sciences and the advancement of their professional applications. It has done an excellent job in this regard for almost a century. The AMS has proven itself to be an international leader in atmospheric sciences through its publication of research, its meetings, its efforts to engage and educate a broad audience from the private and public sectors to Capitol Hill, and its expert position statements on issues of public concern. It is clear that ignorance leads to poor decisions and that a properly educated society is empowered to make good decisions regarding these and any other question of national or global importance, and that this education should begin early in elementary school and continue through life. Now, more than ever, the AMS must continue to engage, inform, and educate society on matters crucial to the future of the Earth's resources. As a member of the AMS Council, I pledge to serve the AMS and its membership and help educate our public to meet the challenges facing our world today.

ELIZABETH A. RITCHIE

ELIZABETH A. RITCHIE is professor in the Department of Atmospheric Sciences at the University of Arizona (UA), Tucson, Arizona, where she has served as the director of graduate studies since 2009. In addition, she holds a joint appointment in the Department of Electrical and Computer Engineering. Her research interests are in the areas of tropical cyclone genesis, structure, and intensity change; extratropical transition; landfalling impacts; and large-scale circulation pattern controls on tropical cyclone behavior. Many of her research efforts have been a result of participation in field experiments, including

TCM-90, 92, and 93; CAMEX-4; TCS-08; and the GRIP campaign in 2010.

Prior to joining UA, Ritchie served (2001–06) on the faculty at the University of New Mexico in a joint position between the Department of Electrical Engineering and the Department of Earth and Planetary Sciences. A considerable portion of her multidisciplinary research in remote-sensing signal detection of tropical cyclone patterns is a direct outgrowth of this time. From 1997 to 2001, Ritchie was a research assistant professor at the Naval Postgraduate School, and in 1995–96 she was a postdoctoral scholar at the Pennsylvania State University.

Ritchie received her Ph.D. from Monash University in Melbourne, Australia, where she studied tropical cyclone genesis combining observations from the TCM-92/93 and TOGA-COARE field experiments with a hierarchy of numerical models in process studies. A member of the AMS since 1995, she has served the Society in a number of capacities: member and chair of the Max Eaton Award Committee (1997, 1999); associate editor of *Monthly Weather Review* (2000–04); editor of *Monthly Weather Review* (2007–10); co-organizer of the Simpson Symposium (2002–03); member of the program committee for the AMS Conference on Hurricanes and Tropical Meteorology (2000–02); chair of the program committee for the AMS Conference on Hurricanes and Tropical Meteorology (2004–06); organizer of a symposium for the AMS Annual Meeting (2011); member of the AMS STAC on Tropical Meteorology and Tropical Cyclones (2000–03); and chair of the AMS STAC on Tropical Meteorology and Tropical Cyclones [2008–11 (ex-officio, 2011)].

In the broader community, Ritchie has served on the US-Japan Natural Resources Committee on Wind and Seismic Effects (2003–08); as a member of several review panels for NSF and NASA; as rapporteur for the WMO International Workshops on tropical Cyclones (1998, 2002, 2006, 2010); as a member and chair of the recommendations committee for the IWTC (2006, 2010); as a panel member of the NASA Senior Review (2009, 2011); as a member of the Joint Hurricane Testbed Steering Committee (2008–present); and as a member of UCAR's President's Advisory Committee on University Relations (2011–present). Ritchie is a cofounder of the "Adopt-A-School" program, a recently established initiative to bring university faculty, staff, and graduate students into K–5 public-school classrooms to help enhance science and math education.

CALENDAR OF MEETINGS

The Call for Papers and Calendar sections list conferences, symposia, and workshops that are of potential interest to AMS members. **Complete information about events listed in the calendar can be found on the meetings page of the AMS Web site, www.ametsoc.org.** New additions to the calendar are highlighted.

To list an event in the calendar, please submit the event name, dates, location, and deadlines for abstracts, manuscripts, and preregistration to amsmtgs@ametsoc.org. For a submission to appear in a given issue, it must be submitted at least eight weeks prior to the month of publication (that is, to appear in the March *Bulletin*, the submission must be received by 1 January).

AMS MEETINGS

2012

AUGUST

10th Symposium on the Urban Environment and Eight International Conference on Urban Climate (ICUC8), 6–10 August, Dublin, Ireland

Abstract deadline: 20 January 2012

Initial announcement published: Nov. 2011

40th Broadcast Meteorology Conference, 22–25 August, Boston, Massachusetts

Abstract deadline: 23 March 2012

Preregistration deadline: 2 July 2012

Initial Announcement Published: Dec. 2011

AMS Short Course: From Climate to Space: Hot Topics for the Station Scientist, 24 August, Brookline, Massachusetts

Preregistration deadline: 2 July 2012

Initial announcement published: July 2012

15th Conference on Mountain Meteorology, 20–24 August, Steamboat Springs, Colorado

Abstract deadline: 20 April 2012

Preregistration deadline: 9 July 2012

Manuscript deadline: 20 September 2012

Initial Announcement Published: Nov. 2011

OCTOBER

AMS/AGU Heads and Chairs Meeting, 18–19 October, Boulder, Colorado

NOVEMBER

26th Conference on Severe Local Storms, 5–8 November, Nashville, Tennessee

Abstract deadline: 10 August 2012

Preregistration deadline: 7 September 2012

Manuscript deadline: 7 December 2012

Initial announcement published: Aug. 2011

2013

JANUARY

12th Annual AMS Student Conference: Expanding Weather and Climate Prediction—Taking Geosciences to the Next Level, 5–6 January, Austin, Texas

Abstract deadline: 1 October 2012

Registration deadline: 18 December 2012

Initial announcement published: Feb. 2012

AMS Short Course: High Performance Python for Climate Science, 5 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course: A Beginner's Course to Using Python in Climate and Meteorology, 5–6 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course on Intermediate Python: Using NumPy, SciPy, and Matplotlib, 5–6 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course on Aviation Weather—A User and Provider Perspective, 6 January, Austin, Texas

Preregistration Deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course on Big Data, Distributed systems Analyses: UV-CDAT, 6 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course on Interactive Immersion Learning: Flying Through Data Onboard The GEOpod, 6 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course on Interpretation and Use of Climate Monitoring and Prediction Information, 6 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course on Space Weather, 6 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

AMS Short Course on Techniques to Automate the Processing of Spatial Grids, 6 January, Austin, Texas

Preregistration deadline: 1 December 2012

Initial announcement published: Aug. 2012

*An exhibit program will be held at this meeting.

Special Symposium on the Transport and Diffusion of Contaminants from the Fukushima Dai-Ichi Nuclear Power Plant: Present Status and Future Directions, 6 January, Austin, Texas

Preregistration deadline: 1 December 2012
Initial announcement published: Aug. 2012

First Annual AMS Conference for Early Career Professionals, 6 January, Austin, Texas

Registration deadline: 18 December 2012
Initial announcement published: June 2012

***Robert A. Duce Symposium, 8 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***29th Conference on Environmental Information Processing Technologies (formerly known as Interactive Information Processing Technologies, IIPS), 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***27th Conference on Hydrology, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***25th Conference on Climate Variability and Change, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***22nd Symposium on Education, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***20th Conference on Applied Climatology, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***19th Conference on Planned and Inadvertent Weather Modification, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***17th Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS–AOLS), 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***16th Conference on Aviation, Range, and Aerospace Meteorology (ARAM), 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***16th Conference of Atmospheric Science Librarians International (ASLI), 6–10 January, Austin, Texas**

Abstract deadline: 1 October 2012
Preregistration deadline: 1 December 2012
Initial announcement published: July 2012

***15th Conference on Atmospheric Chemistry, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***11th Conference on Artificial and Computational Intelligence and its Applications to the Environmental Sciences, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***11th Symposium on the Coastal Environment, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***11th History Symposium, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***10th Conference on Space Weather, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

* An exhibit program will be held at this meeting.

Sponsorship Opportunities Available at AMS Meetings!

The American Meteorological Society's sponsorship program allows your company to stand out in the crowd. Reasonably priced sponsorship packages are available to small through large companies providing the sponsor with quality, value-packed exposure to our meeting attendees. For information contact Claudia Gorski, Director of Meetings, at 617-227-2426 ext. 305; cgorski@ametsoc.org.

***Eighth Symposium on Policy and Socio-Economic Research, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Sixth Conference on the Meteorological Applications of Lightning Data, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Sixth Symposium on Lidar Atmospheric Applications, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***Sixth Annual CCM Forum: Certified Consulting Meteorologists, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***Fifth Symposium on Aerosol–Cloud–Climate Interactions, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Fourth Conference on Environment and Health, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Fourth Conference on Weather, Climate, and the New Energy Economy, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Third Symposium on Advances in Modeling and Analysis Using Python, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Third Conference on Transition of Research to Operations: Successes, Plans, and Challenges, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Second Symposium on Planetary Atmospheres, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***First Annual Symposium on Improving Communication, Collaboration and Response to Weather Forecasts and Warnings, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***First Symposium on the Weather and Climate Enterprise, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Special Symposium on Advancing Weather and Climate Forecasts: Innovative Techniques and Applications, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***Special Symposium on the Joint Center for Satellite Data Assimilation, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***Special Symposium on the Next Level of Predictions in Tropical Meteorology: Techniques, Usage, Support, and Impacts, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Symposium on Prediction of the Madden–Julian Oscillation, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***Symposium on the Role of Statistical Methods in Weather and Climate Prediction, 6–10 January, Austin, Texas**

Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***IMPACTS: Major Weather Events and Impacts of 2012, 8 January, Austin, Texas**

Abstract deadline: 15 October 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

JUNE

19th Conference on Atmospheric and Oceanic Fluid Dynamics, 17–21 June, Newport, Rhode Island

Abstract deadline: 15 March 2013
Preregistration deadline: 6 May 2013
Manuscript deadline: 6 July 2013
Initial announcement published: Aug. 2012

* An exhibit program will be held at this meeting.

18th Conference on the Middle Atmosphere, 17–21 June, Newport, Rhode Island

Abstract deadline: 15 March 2013

Preregistration deadline: 6 May 2013

Manuscript Deadline: 6 July 2013

Initial announcement published: Aug. 2012

MEETINGS OF INTEREST

2012

JUNE

16th International Symposium for the Advancement of Boundary Layer Remote Sensing, 5–8 June, Boulder, Colorado

Fifth Chaotic Modeling and Simulation International Conference (CHAOS 2012), 12–15 June, Athens, Greece

Croatian–USA Workshop on Mesometeorology, 18–20 June, Zagreb, Croatia

JULY

16th International Conference on Clouds and Precipitation, 28 July–3 August, Leipzig, Germany

AUGUST

International Radiation Symposium 2012, 6–10 August, Dahlem Cube, Berlin, Germany

International Symposium on Nowcasting and Very Short Range Forecasting, 6–10 August, Rio de Janeiro, Brazil

2012 Community GSI Data Assimilation System Tutorial, 21–23 August, Boulder, Colorado

SEPTEMBER

2012 EUMETSAT Meteorological Satellite Conference, 3–7 September, Sopot, Poland

12th EMS Annual Meeting & 9th European Conference on Applied Climatology (ECAC), 10–14 September, Łódź, Poland

Third International Conference on Earth System Modelling, 17–21 September, Hamburg, Germany

OCTOBER

National Weather Association 2012 Annual Meeting, 6–11 October, Madison, Wisconsin

Fourth Tri-State Weather Conference, 13 October, Danbury, Connecticut

WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2012), 16–18 October

Meteorological Technology World Expo 2012, 16–18 October, Brussels, Belgium

NOAA's 37th Climate Diagnostics and Prediction Workshop, 22–25 October, Fort Collins, Colorado

The Second LAPS User Workshop, 23–25 October, Boulder, Colorado

2012 Conference on Intelligent Data Understanding, 24–26 October, Boulder, Colorado

Drought Task Force Meeting, 25–26 October, Fort Collins, Colorado

2013

APRIL

National Oceanic and Atmospheric Administration (NOAA) Satellite Conference for Direct Readout, GOES/POES, and GOES-R/JPSS Users, 8–12 April, Miami, Florida

MAY

6th International Conference on Fog, Fog collection and Dew, 19–24 May, Yokohama, Japan

JUNE

Second China–U.S. Symposium on Meteorology, 24–28 June, Qingdao, China

DISPLAY YOUR STUFF!

Opportunities Available to Exhibit at AMS Meetings

The exhibition program of AMS meetings provides an opportunity for professionals in the atmospheric sciences, oceanography, hydrology, and related environmental sciences to learn more about state-of-the-art developments, equipment, products, services, and research in their respective fields. In addition to an annual meeting, the AMS offers a number of niche marketing opportunities where you can showcase the products and services of your firm, institution, or agency. To learn more about exhibiting at an AMS meeting, visit the meetings page on the AMS Web site or e-mail exhibitsmanager@ametsoc.org.

CALL FOR PAPERS

ANNOUNCEMENT

Drought Task Force Meeting, 25–26 October 2012, Fort Collins, Colorado

The first Drought Task Force Meeting will take place 25–26 October 2012 in Fort Collins, Colorado. This will be an opportunity for the Drought Task Force to present its research work, make connections with other scientists and stakeholders, and plan future activities (for more information regarding the Drought Task Force visit www.climate.noaa.gov/index.jsp?pg=-/cpo_pa/mapp/drought.html). (8/12)

ANNOUNCEMENT

AMS Short Course: High Performance Python for Climate Science, 5 January 2013, Austin, Texas

The AMS Short Course on High Performance Python for Climate Science will be held on Saturday, 5 January 2013 preceding the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website (www.ametsoc.org) in mid-September 2012.

Python is rapidly expanding in the atmospheric sciences community as a great programming language for data processing and data analysis. It is, in particular, used in large-scale applications such as LLNL's UV-CDAT application and library or NCAR's PyNGL, among many others. Thanks to its simplicity and readability, it is widely used in the climate science community and well beyond by scientists and engineers for prototyping. Compared to IDL and Matlab, Python applications are also much better able to scale up to real-life applications.

But, when it comes to putting together a full-scale application, naïve implementations in pure Python will almost always contain parts

that are too slow. For other applications, memory conservation can also become an issue. We will introduce methods to identify where the speed or memory bottlenecks are. This will first include methods for memory profiling and time profiling as well as learning about some of the internals of Python and Numpy and their best practices.

We will then learn about techniques to speed up execution and/or conserve memory where necessary. We will demonstrate how to leverage the full power of Numpy, Numexpr, or moving part of a program to Cython, C/C++, or FORTRAN. Finally, we will introduce ways to do parallel processing in Python, leveraging multiple CPUs, clusters or GPUs. As a by-product, these techniques can also be applied to wrap existing libraries in C/C++ or FORTRAN. We will demonstrate that this allows the scientist to leverage legacy code when migrating to Python.

This course is targeted for an advanced audience of Python users and will assume prior knowledge of the basics of Python (looping patterns, function definition, object-oriented programming). Basic knowledge of Numpy is also recommended and familiarity with C would be a plus though not strictly necessary. The attendees are also encouraged to bring in concrete problems they are trying to tackle for open discussions. This one-day class will be followed by another advanced one-day class (with separate registration) on more specific climate science distributed data analysis tools. Students with no or little prior knowledge of Python are encouraged to sign-up for the two-day beginner's Python course and students with no prior knowledge of Numpy may consider signing up for the two-day intermediate Python course.

All attendees will need to bring a wifi-enabled laptop (with power adapter) that has Python with Numpy installed on it. Free 1-click installers for Mac, Linux, and Windows can be downloaded from www.enthought.com/epd. Students who want to follow all parts of the course will need more packages and tools. Instructions will be emailed to registered attendees before the course begins on how to download the class material and install Python or the needed packages.

Dr. Jonathan Rocher, Enthought Inc., will be delivering most of the course, with contributions from Dr. Kurt Smith and other members of Enthought to help during hands-on sessions and open discussions.

For more information please contact Jonathan Rocher (tel.: 512-536-1057; e-mail: jrocher@enthought.com). (8/12)

ANNOUNCEMENT

AMS Short Course: A Beginner's Course to Using Python in Climate and Meteorology, 5–6 January 2013, Austin, Texas

The application of object-oriented programming and other advances in computer science to the atmospheric sciences has in turn led to advances in modeling and analysis tools and methods. The opensource language Python has been at the forefront of the application of such advances, through general science packages such as *scipy* and *matplotlib*, as well as atmospheric science-specific projects such as PCMDI's CDAT and ESG end-user tools and NCAR's PyNGL, resulting in a robust computing environment for all kinds of atmospheric science, including (but not limited to) modeling, time series analysis, air quality data analysis, satellite data processing, in-situ data analysis, GIS, visualization, gridding, model

intercomparison, workflow integration, and very large (petabyte) dataset manipulation and access.

Still, to many atmospheric scientists, object-oriented programming in general, and Python in particular, seems mysterious and remote, and as a result, find the idea of learning Python to be daunting. Additionally, while a number of tutorials and other curricula exist to introduce a newcomer to Python, few are geared to the specific needs of atmospheric scientists. This course provides a gentle introduction to Python for the atmospheric scientist, specialized to the needs of the field. While we expect all participants will have basic programming experience—including basic knowledge of variables (integers, floats, strings), loops, conditionals (if/then), and functions—no other exposure to Python or object-oriented programming is assumed. If you are a moderately experienced Python programmer, this course will be a poor fit for you; please consider taking one of the other AMS Python short courses, either the intermediate course or one of the advanced courses.

All attendees will need to bring a laptop (with power adapter) that has Python installed on it. Instructions will be emailed to registered

attendees before the course begins on how to install Python. Because the course is two days, to maximize learning value for students, there will be optional homework assigned at the end of day one that will be discussed the next day.

For more information, please contact Johnny Lin (e-mail: johnny@johnny-lin.com). (8/12)

ANNOUNCEMENT

AMS Short Course on Intermediate Python: Using NumPy, SciPy, and Matplotlib, 5–6 January 2013, Austin, Texas

The AMS Short Course on Intermediate Python: Using NumPy, SciPy, and Matplotlib will be held on 5 and 6 January 2013 preceding the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website (www.ametsoc.org) in mid-September 2012.

This course builds upon the short course “A Beginner’s Course to Using Python in Climate and Meteorology”, and is geared toward those who already have some basic experience writing Python programs and understand Python control structures

such as for loops and conditional statements. This intermediate course will show how to use the Numerical Python/Scientific Python (NumPy/SciPy) and Matplotlib libraries for data analysis, modeling, and visualization. Detailed aspects of creating and formatting 1D line and bar charts, pie charts, 2D contour and surface plots, and 3D plots will be covered, along with the basemap module for plotting geographically referenced data on the globe. Spectral analysis (FFTs) using NumPy will be demonstrated, as will solving matrices and systems of equations, and basic statistical operations. Methods of slicing and indexing NumPy arrays will be covered, as will input/output of NumPy arrays and reading data from NetCDF and GRIB file formats. A capstone exercise applying Python and NumPy arrays for solving the shallow-water equations and using Matplotlib to visualize the results will conclude the short course (no prior modeling experience is assumed).

Students without Python experience are encouraged to sign-up for the two-day beginner’s Python course, while those with advanced knowledge should sign-up for one or both of the one-day advanced courses (these courses have separate registration).

STUDENT TRAVEL GRANTS

Student Travel Grants are available for senior undergraduate and graduate students to attend AMS meetings held in the United States and Canada. The travel grants are available only to members, including student members, of the AMS.

AMS recognizes the considerable benefit that students can gain from attending conferences even if they are not presenting a paper there, and AMS wants to encourage interactions between students and other conference attendees. To this end, travel grants will be awarded to a student who is not presenting a paper at the conference.

Students who are presenting papers and potentially in need of travel support should inquire of the program chair whether any funds will be available for this purpose.

For more information and to complete an application form, please visit the AMS website at www.ametsoc.org.

The course format consists of two full days of discussion and hands-on experience programming with Python and using the NumPy/SciPy and Matplotlib modules. All attendees will need to bring a laptop (with power adapter) that has Python, SciPy, NumPy, Matplotlib, and Base-map installed on it. Instructions will be emailed to registered attendees before the course begins on how to install Python and the other libraries needed.

The instructor for the course is Alex DeCaria, a professor of meteorology at Millersville University. He may be contacted for more information at 717-871-4739 or alex.decaria@millersville.edu. (8/12)

ANNOUNCEMENT

AMS Short Course on Aviation Weather—A User and Provider Perspective, 6 January 2013, Austin, Texas

The AMS Short Course on Aviation Weather—A User and Provider Perspective will be held on 6 January 2013, preceding the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website (www.ametoc.org/) in mid-September 2012.

Aviation touches nearly every part of our daily lives and the economy both domestically and abroad; and the aviation community makes thousands of safety-dependent decisions each day, nearly all of them impacted by weather. The meteorological enterprise—government, academic, and commercial sectors—supports air transportation, including commercial passenger flights, cargo, law enforcement, medical evacuation, crop dusting, oil exploration, military, and a vast array of other operations. These operations and others benefit from improved forecasts and advisories; improved interaction and under-

standing between the operators and weather providers; and from any technological or social advancement that provides more reliable, timely, and accurate weather information.

This course will provide the participants an opportunity to gain both a pilot's and meteorologist's perspective about operational aviation weather decision making during all phases of flight to include pre-flight, ground operations, enroute and landing. It will show how weather data are sensed and gathered; how the data are converted into information that is then used by computers and how meteorologists add value to it; and finally, how the weather information is made relevant to pilots, air traffic controllers, flight dispatchers, and other users such as airport authorities. This course will also highlight the types of weather that have the greatest impact on the safe and efficient operation of the National Airspace System and allow a glimpse at how these weather situations are handled by the broad aviation community. It will also provide an overview of technological advancements, promising new research, discuss the increasing role of social media, and preview the growing importance of work by social scientists to enhance the understanding of weather information by all aviation weather users. The instructors will direct the audience to sessions within the AMS conference that may provide more detailed information on specific areas of interest.

The course is aimed at both the pilot and professional aviation forecasting communities; other users and providers of weather information (e.g., air traffic controllers and flight dispatchers); students interested in broadening their perspective and awareness in aviation meteorology; teachers and broadcast meteorologists who seek a better understanding of aviation operational consider-

ations and the impact of forecasts and warnings on aviation operations. It may also be of interest and offer valuable insights to the public, which relies on a safe and efficient aviation system.

The goal is to provide the participants with a fundamental understanding of the end-to-end pathway of weather data and information that is critical to pilots' decisions. It will also provide the perspectives of both forecasters and aviation weather researchers. They will give an overview of the current state-of-the-art forecast process; a view of how weather information will be enhanced in the future through improved forecasts and delivery methods; and the involvement of social scientists and training. All of this is aimed at creating better operational decision making now and in the future. To facilitate this, the course will include a brief exercise/case study to illustrate a real world example of how weather and the decisions based on this weather led to a fatal outcome. It will then be followed by a discussion on how advanced technology, improved training with social science involvement, and/or improved forecasts might have led to a better outcome for the chosen scenario.

The course format consists of four, 45-minute segments with presentations, lectures, and discussion followed by a 30-minute case study and practical exercise. The total time will be four hours.

The instructors for the course are Dr. Bruce Carmichael—director of the Aviation Applications Program at NCAR; Dr. John Lanicci—professor, Applied Meteorology Program, ERAU; Dr. “Chip” West—NWS meteorologist-in-charge, CWSU ATL; Warren Qualley—senior weather expert, Harris Corporation; Pat Murphy—NWS warning coordination meteorologist, Aviation Weather Center; Jody James—NWS warning coordination meteorologist, Lubbock,

Texas; Jon Cunningham—Mosaic ATM, Inc.; Capt. Barry Choy—NWS Chief Science Officer, NCEP; Aviation Community Representatives. Refreshments will be available during the break.

For more information please contact Capt. Barry Choy at the National Centers for Environmental Prediction, 5830 University Research Court, Suite 4600 (W/NP), College Park, MD 20740 (tel.: 301-683-1324; cell: 202-286-2940; e-mail: barry.choy@noaa.gov). (8/12)

ANNOUNCEMENT

AMS Short Course on Big Data, Distributed systems Analyses: UV-CDAT, 6 January 2013 in Austin, Texas

The AMS Short Course on Big Data, Distributed Systems: UV-CDAT will be held on 6 January 2013 preceding the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website (www.ametsoc.org) in mid-September 2012.

Climate scientists have made substantial progress in understanding the Earth's climate system, particularly at global and continental scales. Climate research is now focused on understanding climate changes over wider ranges of time and space scales. These efforts are generating ultra-scale datasets at very high spatial resolution. An insightful analysis in climate science depends on using software tools to discover, access, manipulate, and visualize the datasets of interest. These data exploration tasks can be complex and time-consuming, and they frequently involve many resources from both the modeling and observational climate communities. Because of the complexity of the explorations, the number of tools, and the amount of data involved, provenance is critical, allowing sci-

entists to ensure reproducibility, revisit existing computational pipelines, and more easily share analyses and results. In addition, as the results of this work can impact policy, having provenance available is important for decision-making. In this class, we will cover UV-CDAT, a workflow-based, provenance-enabled system that integrates climate data analysis libraries and visualization tools in an end-to-end application, making it easier for scientists to integrate and use a wide array of tools.

This course is targeted for an advanced audience of Python users and will assume prior knowledge of the basics of Python (looping patterns, function definition, NumPy arrays, object-oriented programming). Knowledge of CDAT, ParaView and/or VisIt is also a plus. Students with no prior knowledge of Python are encouraged to sign-up for the beginner's Python course; those with some knowledge should sign-up for the intermediate Python course.

All attendees will need to bring a laptop (with power adapter) that has Python installed on it. Instructions will be e-mailed to registered attendees before the course begins on the basic requirements. The class will be taught using a Virtual Machine (VM) with all necessary materials and software preloaded.

The course will cover most features of the new Ultra-scale Visualization Climate Data Analysis Tools (UV-CDAT). Concepts covered by the class are accessing distributed datasets, analyzing big distributed data, provenance and why it matters, novel 3D visualizations, and building custom plugins for UV-CDAT.

Most of the course will be geared around discovering and using data for the Fifth Annual Report of the Intergovernmental Panel on Climate Change (IPCC AR5)

The course format consists of lectures mixed with hands-on exercises.

Strong user participation will be encouraged that could reshape the flow of the course "on-the-fly". The main instructor for the course is Charles S. Doutriaux, Program for Climate Model Diagnosis and Intercomparison at the Lawrence Livermore National Laboratory, California.

Users are expected to bring their own laptop. AC and internet access will be available. Note that this class is for users with a good knowledge of CDAT/Python. Sister classes, aimed at beginners, are also scheduled during the meeting.

For more information please contact Charles Doutriaux at PCMDI, 7000 East Avenue, Livermore, CA 94450 (tel.: 925-422-1487; e-mail: doutriaux1@llnl.gov). (8/12)

ANNOUNCEMENT

AMS Short Course on Interactive Immersion Learning: Flying Through Data Onboard The GEOpod, 6 January 2013, Austin, Texas

The AMS Short Course on Interactive Immersion Learning: Flying Through Data Onboard The GEOpod will be held on Sunday afternoon, 6 January 2013 preceding the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website (www.ametsoc.org) in mid-September 2012.

Synopsis: GEOpod is an intuitive, interactive Java module that allows users to navigate and probe an immersive 3D world. GEOpod features authentic geophysical data, which is based on actual physics, thus exhibiting technical accuracy, scientific soundness, and fidelity. GEOpod leverages the Unidata Program Center's open source Java-based visualization software, the Integrated Data Viewer (IDV), to import and render meteorological data. We will demonstrate how the GEOpod gives a user a first-person perspective of flying through

a data volume, and provides an intuitive, engaging interaction style designed to appeal to students and motivate them to explore the volume and gain a comprehensive understanding of meteorological concepts. GEOpod provides a number of useful devices and features to facilitate and enhance this exploration process while maintaining a clean, easy-to-use interface, which is accessible to novices and experts alike. The workshop is intended for faculty and students in undergraduate atmospheric or related sciences programs.

Course Goals and Objectives: 1) To introduce faculty and students to a virtual 3D immersion application that allows them to navigate through data at the controls of a virtual probe called GEOpod; 2) to expose them to a new learning tool, complete with missions and assessment rubrics, that uses real, geophysical data instead of artificial simulations to understand atmospheric structure and concepts; and 3) to provide an exciting game-like immersion that will stimulate interest and lead to better understanding.

Format: The 3½-hour short course will be divided into three main parts. In the first hour we will provide an introduction to GEOpod and demonstrate its capabilities. The second hour will focus on hands-on, instructor-guided activities with participants using their own laptops to explore the features of the software. In the third hour, participants will be given two missions to complete. A course wrap-up and user survey will fill the final 30 minutes.

Participants are required to bring their own Windows-based (Vista or later) laptop with at least 4 GB of RAM; GEOpod is not compatible with Mac OS. No previous IDV experience is necessary. Registration fee: \$25.00. Maximum enrollment: 30.

The instructors are meteorologists and a computer scientist from Millersville University: Drs. Rich-

ard Clark, Sepideh Yalda, and Gary Zoppetti. Technical support provided by Millersville students and the Unidata Program Center. For more information please contact Rich Clark at Millersville University, P.O. Box 1002, Millersville, PA 17551 (tel: 717-872-3930; e-mail: Richard.Clark@millersville.edu). (8/12)

ANNOUNCEMENT

AMS Short Course on Interpretation and Use of Climate Monitoring and Prediction Information, 6 January 2013, Austin, Texas

The AMS Short Course on Interpretation and Use of Climate Monitoring and Prediction Information will be held on 6 January 2013 preceding the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website in mid-September 2012.

The AMS Committee on Applied Climatology will offer a one-day short course on “Interpretation and Use of Climate Monitoring and Prediction Information” on 6 January 2013. This course will introduce and describe in detail the key kinds of short-term climate variability that can be used to link forecasts across the climate-weather time scale and improve user situational awareness. Specific examples will be shown along with a hands-on exercise where students can assess the current state of these patterns and apply them to their specific work environment.

The main focus of the short course will be on developing participants’ skills in interpretations of climate monitoring and prediction products as well as climate information so they can be used with confidence. Major emphasis will be given to intraseasonal to interannual climate variability such as the El Niño–Southern Oscillation (ENSO), the Madden–Julian oscillation (MJO) and teleconnec-

tion indices. Some information and discussion about inappropriate use of climate data related to the course topics is also planned. The course is intended for climate researchers, forecasters, and stakeholders from the public and private sectors, water and other natural resource managers, energy and health users of climate information, broadcast meteorologists, and students considering careers in applied climatology fields.

Many forecasters are well versed in factors that impact short-term weather forecasts of less than a week. The demand to apply extended-range forecast information continues to increase. In addition, numerous human dimension studies identify existing problems with interpretation of scientific terms used in climate monitoring and prediction products. Understanding probabilistic terminology used in many climate products is especially challenging. This problem grows larger when climate product users attempt to apply the misunderstood information for real-time practical applications. The lack of intuitive knowledge about the benefits and limitations of climate information restrains users’ ability to take full advantage of the climate services provided by many government, non-government, and academia institutions. This course will enable professionals from various fields to gain expert-knowledge for the understanding of scientific terms and tools used to create short-term climate variability forecasts.

A laptop is required for the course and wireless internet access will be available. Participants will use their laptops to access presentations, take notes, and accomplish individual and group exercises. Instructors for the course are being finalized.

For more information please contact Jon Gottschalck, NOAA/NCEP/CPC (tel.: 301-763-8000 x7753; e-mail: Jon.Gottschalck@noaa.gov) and/or

Marina Timofeyeva, NOAA/OC-WWS/CSD (tel.: 301-713-1970 x131; e-mail: Marina.Timofeyeva@noaa.gov). (8/12)

ANNOUNCEMENT

AMS Short Course on Space Weather, 6 January 2013, Austin, Texas

The AMS Short Course on Space Weather will be held on 6 January 2013 preceding the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website (www.ametsoc.org) in mid-September 2012.

The rapid advances in the technology sector and our fast-growing dependency on space-based systems have resulted in an ever-increasing vulnerability to space weather. Aviation, electric power grid operations, satellite communications, and GPS applications are all sensitive to severe space weather. Concerns have grown as these technologies have become more ingrained in everyday life. Additionally, interest has grown in the general public with the recognition of the electric power grid vulnerability and the potentially significant consequences of an extreme geomagnetic storm. As space weather becomes more and more widely recognized by the general public, meteorologists are frequently the “first line of defense” for the public, so the need has grown for them to understand and communicate these multifaceted threats.

The goal of the course is to provide sufficient background information on space weather to enable a basic understanding of a space weather event in terms of how it is detected, how is it forecast, and finally, what the impacts are to modern society and the near-Earth environment. The course is aimed at students, developing meteorologists, broadcast meteorologists, and others who desire an understanding of space weather

and its associated impacts in order to better communicate space weather information to their audience.

The course format consists of one-half day of lectures and interactive discussion with panel members (afternoon session).

The organizers for the course are: Dr. Thomas J. Bogdan, president, University Corporation for Atmospheric Research; Dr. O. C. St Cyr, NASA, Goddard Space Flight Center; Bob Rutledge, NOAA, Space Weather Prediction Center; and Lt. Col. Chris Smithtro, USAF, Air Force Weather Agency. Computers, laptops, or internet access will not be available or required for this course.

For more information please contact Bob Rutledge at NOAA/NWS/SWPC, 325 Broadway W/NP9, DSRC-Room 1C106, Boulder, CO 80305 (tel: 303-497-3029; e-mail: robert.rutledge@noaa.gov). (8/12)

ANNOUNCEMENT

AMS Short Course on Techniques to Automate the Processing of Spatial Grids, 6 January 2013, Austin, Texas

This course teaches attendees to devise and implement automated techniques to extract information from spatial grids such as radar, numerical model, or satellite imagery, or from any other data that can be placed on a spatial grid. It provides students with a foundation in topics of digital image processing and data mining as applied to geospatial datasets.

Using these techniques, lots of preparatory work for research that is done manually and in a labor-intensive way can be automated. The techniques are also useful as labor-saving devices in operations and can be helpful in devising automated algorithms for forecaster guidance. Consequently, researchers and forecasters will both benefit from this course.

The software and datasets used in this course are yours to carry home.

You should bring a laptop (Windows, Mac, or Unix are all acceptable), but you are encouraged to register early so that you can install the necessary software before you come to the course. Instructions for software installation will be distributed to registered participants. (8/12)

ANNOUNCEMENT

Special Symposium on the Transport and Diffusion of Contaminants from the Fukushima Dai-Ichi Nuclear Power Plant: Present Status and Future Directions, 6 January 2013, Austin, Texas

March 11, 2013 will be the second anniversary of the earthquake and tsunami disaster in the northeast (Tohoku) regions of Japan. The Fukushima Dai-Ichi nuclear power plant, located in the disaster area, released large quantities of radioactive materials into the environment. The Japanese government has been trying to identify the contaminated areas by taking soil samples. The findings will be used to cleanup the contaminants so that, in some areas, people will be able to return to their hometowns. Other areas may be designated as permanent evacuation zones.

The Japanese emergency response model, SPEEDI (System for Prediction of Environmental Emergency Dose Information), and other numerical prediction models were used to simulate the deposition of radiation materials. The simulated distributions of contamination were compared with measurements. In general the results were in agreement with observations, but differed in some ways. More measurements and analyses will be available in the future to help reconcile the differences.

The AMS Committee on Meteorological Aspects of Air Pollution and the Meteorological Society of Japan (MSJ) will jointly present a one-day specialty symposium to review the

present status and identify the role of meteorology for the analysis of the transport and diffusion of contaminants from the Fukushima nuclear power plant. The symposium will be held on Sunday, 6 January 2013 in conjunction with the AMS Annual Meeting in Austin, Texas. Dr. Hiroaki Kondo, from the National Institute of Advanced Industrial Science and Technology and also with MSJ, is organizing the Japanese delegates to report on the current status and future directions in Japan. Speakers from NOAA, DOE, and NCAR will be discussing atmospheric plume and marine debris modeling efforts and national emergency response preparedness.

Topics will include, but not be limited to, source term estimation, transport and diffusion, dry and wet deposition, re-suspension, transport and diffusion of debris in the ocean, effects of soil contamination on crops, and evacuation strategies. Speakers in these sessions will be invited by the symposium organizers. The meeting should provide useful information to not only meteorologists, but also to researchers in the medical and agricultural communities.

For additional information please contact the symposium co-chairs, Ted Yamada (e-mail: yamada@ysasoft.com) or Hiroaki Kondo (e-mail: kondo-hrk@aist.go.jp). (8/12)

CALL FOR PAPERS

10th Conference on Space Weather, 6–10 January 2013, Austin, Texas

The Tenth Conference on Space Weather (10th CSW), sponsored by the American Meteorological Society, and organized by the AMS Committee on Space Weather, will be held 6–10 January 2013, as part of the 93rd AMS Annual Meeting in Austin, Texas. Preliminary programs, registration, hotel, and general information will be posted on the AMS website

(www.ametsoc.org/meet/annual/) in late-September 2012.

The theme for the 2013 AMS Annual Meeting is “Taking Predictions to the Next Level: Expanding Beyond Today’s Weather and Climate Forecasts and Projections.” Over the past 60 years the meteorological community has made tremendous strides in making prediction a fundamental part of its scientific and operational/service heritage through the development and application of complex numerical models involving the atmosphere, ocean, land, and cryosphere components of the Earth system. This theme will serve as a catalyst for the 2013 AMS Annual Meeting by focusing the attention of the research and operational communities, including those who are involved in accelerating the transition of research results into operations. Furthermore, the increasing use of predictions by decision makers throughout federal, state, and local emergency management government agencies and by private/commercial sectors will serve as an important component for this annual meeting along with the extension of predictive capabilities into a broader domain, including public health, food security, air and water quality, alternative energy, navigation, communication, and responses to climate trends.

This year’s theme is highly appropriate for the 10th CSW. Compared to numerical weather prediction, the space weather discipline is still in its infancy and prediction capabilities are not as mature and sophisticated as what have been achieved for terrestrial weather. However, there have been a number of advances in our understanding of the Sun–Earth system, operational space weather models, and ground- and space-based datasets. Using meteorology as an example, the space weather community is in the early stages of delivering improved forecast capabilities for a

variety of space weather applications. The 10th CSW will highlight those burgeoning new capabilities and reflect on advances in science and prediction over the past decade since the first Space Weather Symposium was held at the AMS Annual Meeting. Both oral and poster presentations are solicited. Awards will be given to the two best student papers.

This year papers are solicited on

- Advances in space weather nowcasting and forecasting, and associated metrics
- Advances in space weather instrumentation and models
- New data sources and products
- Historical perspectives in space weather prediction (joint with History Conference)
- Space Weather Transition Plans, Challenges, Opportunities (joint with 3rd Research to Operations Conference)
- Poster Session on Heliophysics: connection between the Sun, space weather, and Earth’s climate
- General contributions (oral and poster presentations)

As part of this year’s conference, there will be a special half-day session and lunchtime town hall on Heliophysics, which aims to broaden understanding of the connection between the Sun and Earth’s climate and space weather. This session will include only invited talks, but posters are solicited.

Please submit your abstract electronically via the Web by *1 August 2012* (refer to the AMS web page at www.ametsoc.org/meet/online_submit.html). An abstract fee of \$95 (payable by credit card or purchase order) is charged at the time of submission (refundable only if abstract is not accepted). The abstract fee includes the submission of your abstract, the posting of your extended abstract, and the uploading and recording of your

presentation, which will be archived on the AMS website.

Authors of accepted presentations will be notified via e-mail by late-September 2012. All extended abstracts are to be submitted electronically and will be available online via the web. Instructions for formatting extended abstracts will be posted on the AMS website. Authors have the option to submit manuscripts (up to 10 MB) electronically by *6 February 2013*. All abstracts, extended abstracts, and presentations will be available on the AMS website at no cost.

For additional information please contact the program chairperson(s), Bob McCoy (e-mail: rpmccoy@alaska.edu) or Genene Fisher (e-mail: Genene.fisher@noaa.gov). (5/12; r8/12)

CALL FOR PAPERS

Special Symposium on Advancing Weather and Climate Forecasts: Innovative Techniques and Applications, 6–10 August 2013, Austin, Texas

The Special Symposium on Advancing Weather and Climate Forecasts, sponsored by the Weather Analysis and Forecasting Committee, will incorporate the 2013 AMS Annual Meeting Theme of “Taking Predictions to the Next Level: Expanding Beyond Today’s Weather, Water, and Climate Forecasting and Projections” by providing a one-day series of presentations emphasizing new and future techniques designed to improve forecasting capabilities across a variety of disciplines.

Oral and poster presentations are requested in four topical areas:

- New and future capabilities in observations, numerical weather prediction, ensemble-based forecasting, and data assimilation,
- Advancements in forecasting techniques and capabilities, in-

cluding testbed and forecast improvement project activities, as well as new capabilities in extended range and inter- to intra-seasonal prediction,

- Improvements in decision support services for users, incorporation of societal impact considerations, and tools to enhance forecast utility across more diverse user groups, and
- Cross-cutting applications that incorporate weather and climate forecasts within other disciplines or sectors.

Submissions from students are encouraged for oral and poster presentations, and awards will be given for outstanding presenters in both categories.

Please submit your abstract electronically via the Web by *1 August 2012* (refer to the AMS web page at www.ametsoc.org/meet/online_submit.html). An abstract fee of \$95 (payable by credit card or purchase order) is charged at the time of submission (refundable only if abstract is not accepted). The abstract fee includes the submission of your abstract, the posting of your extended abstract, and the uploading and recording of your presentation, which will be archived on the AMS website.

Authors of accepted presentations will be notified via e-mail by late-September 2012. All extended abstracts are to be submitted electronically and will be available online via the web. Instructions for formatting extended abstracts will be posted on the AMS website. Authors have the option to submit manuscripts (up to 10 MB) electronically by *6 February 2013*. All abstracts, extended abstracts, and presentations will be available on the AMS website at no cost.

For additional information, please contact the cochairpersons: Andrew Molthan (e-mail: andrew.molthan@nasa.gov) or Kelly Mahoney (e-mail:

kelly.mahoney@noaa.gov) (4/12; r8/12)

CALL FOR PAPERS

19th Conference on Atmospheric and Oceanic Fluid Dynamics, 17–21 June 2013, Newport, Rhode Island

The 19th Conference on Atmospheric and Oceanic Fluid Dynamics (AOFD), sponsored by the American Meteorological Society and organized by the AMS Committee on Atmospheric and Oceanic Fluid Dynamics, will be held jointly with 17th AMS Conference on the Middle Atmosphere on 17–21 June 2013 at the Hotel Viking in Newport, Rhode Island. Preliminary programs and registration details will be posted on the AMS website (www.ametsoc.org) in early-March 2013. General information on hotel accommodations will be available on the AMS website.

Papers are solicited in all areas of atmospheric and oceanic fluid dynamics spanning theory, observations, and modeling. Three special sessions are planned on (1) the ocean meridional overturning circulation, (2) balance/imbalance in the atmosphere and ocean, and (3) a celebration of the accomplishments and contributions of Isaac Held. In addition, joint sessions will be held with the Middle Atmosphere Conference. Final session topics will be based on the number and topics of abstracts received.

The deadline for abstract submission is *15 March 2013*. An abstract fee of \$95 (payable by credit card or purchase order) is charged at the time of submission (refundable only if abstract is not accepted). Authors of accepted presentations will be notified via e-mail by 22 April 2013. Instructions for formatting extended abstracts will be posted on the AMS website. Authors have the option to submit manuscripts (up to 10 MB) electronically by *21 July 2013*. All

abstracts, extended abstracts, and presentations will be made available on the AMS website.

For further program information please contact the program chairpersons: George N. Kiladis, NOAA/Earth System Research Laboratory, Physical Sciences Division, Boulder Colorado (e-mail: George.Kiladis@noaa.gov; tel.: 303-497-3892); Tiffany A. Shaw, Department of Earth and Environmental Science & Department of Applied Physics and Applied Mathematics, Columbia University, New York, New York (e-mail: tas2163@columbia.edu; tel.: 212-851-5935); Leif Thomas, Department of Environmental Earth System Science, Stanford University, Stanford, California (e-mail: leift@stanford.edu; tel.: 650-721-1140); Steven B. Feldstein, Department of Meteorology, The Pennsylvania State

University, University Park, Pennsylvania (e-mail: sbf1@meteo.psu.edu; tel.: 814-865-7042). (8/12)

CALL FOR PAPERS

18th Conference on the Middle Atmosphere, 17–21 June 2013, Newport, Rhode Island

The 18th Conference on the Middle Atmosphere, sponsored by the American Meteorological Society, will be held on 17–21 June 2013 at the Hotel Viking in Newport, Rhode Island.

Papers are solicited in all areas of interest to the Middle Atmosphere. Special attention will be given to the impacts of the stratosphere on the climate system, and joint sessions will be held in conjunction with the 19th Conference on Atmospheric and Oceanic Fluid Dynamics.

The deadline for abstract submission is *15 March 2013*. An abstract fee of \$95 (payable by credit card or purchase order) is charged at the time of submission (refundable only if abstract is not accepted). Authors of accepted presentations will be notified via e-mail by 22 April 2013. Instructions for formatting extended abstracts will be posted on the AMS website. Authors have the option to submit manuscripts (up to 10 MB) electronically by *21 July 2013*. All abstracts, extended abstracts, and presentations will be made available on the AMS website.

For further program information please contact the program chairperson: Lorenzo M. Polvani, Columbia University (e-mail: lmp@columbia.edu). (8/12)



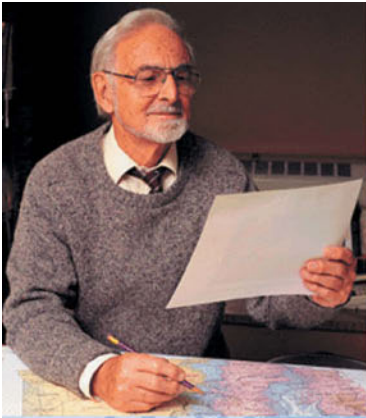
Q) What's worse than raining buckets?

Share your weather jokes and cartoons. We know you've got 'em! The best will be chosen for our *meteorologists' joke book*, to be published next year.

Cite your sources and tell us how to contact you. Groaners welcome!

**Submit to Jon Malay: jokes@jonmalay.com
TSSC LLC
P.O. Box 606
Fredericksburg, VA 22404**

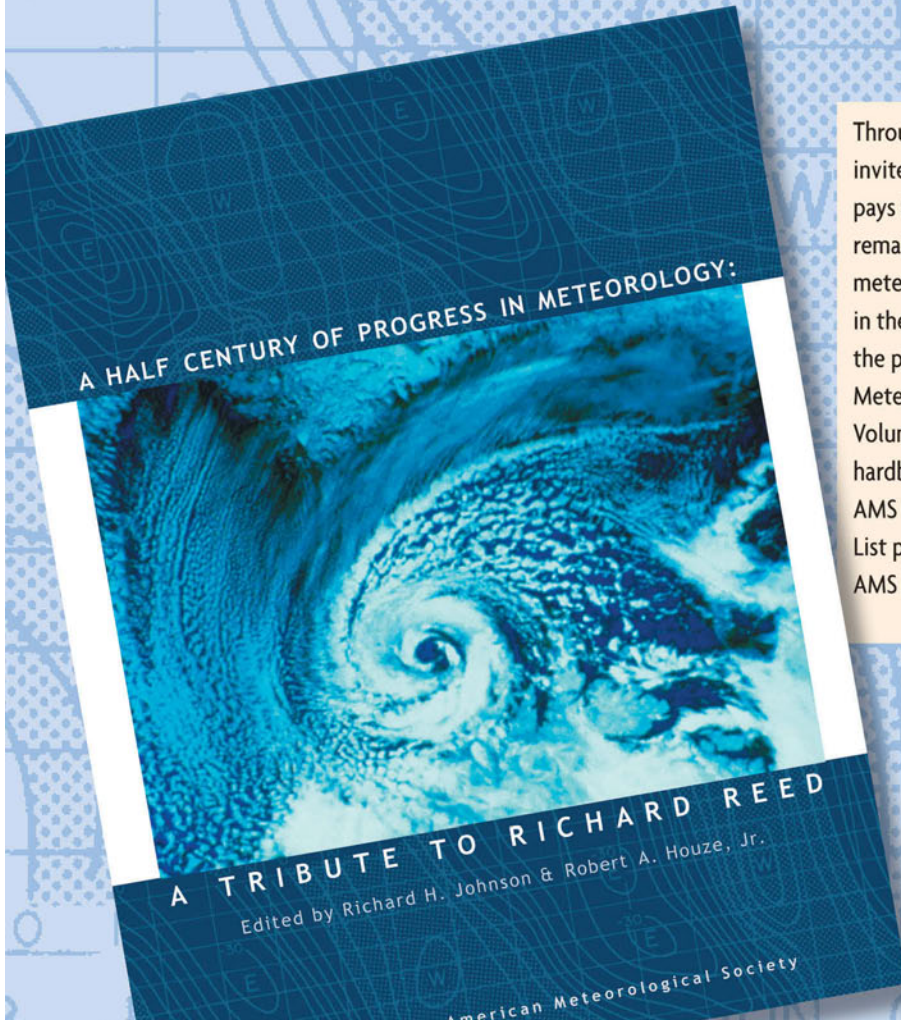
A) Hailing taxis!



A Half Century of Progress in Meteorology: A Tribute to Richard Reed

edited by Richard H. Johnson and Robert A. Houze Jr.

with selections by: Lance F. Bosart Robert W. Burpee Anthony Hollingsworth
James R. Holton Brian J. Hoskins Richard S. Lindzen John S. Perry Erik A. Rasmussen
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Through a series of reviews by invited experts, this monograph pays tribute to Richard Reed's remarkable contributions to meteorology and his leadership in the science community over the past 50 years. 2003.

Meteorological Monograph Series, Volume 31, Number 53; 139 pages, hardbound; ISBN 1-878220-58-6; AMS Code MM53.

List price: \$80.00

AMS Member price: \$60.00

ORDER ONLINE: www.ametsoc.org/amsbookstore or see the order form at the back of this issue

NOMINATION SUBMISSIONS

The Council of the American Meteorological Society invites members of the AMS to submit nominations for the Society Awards, Lecturers, Named Symposia, Fellows, Honorary members, and nominees for elective Officers and Councilors of the Society.

Information regarding awards, including award descriptions, listings of previous recipients, and the process for submitting nominations are on the AMS website www.ametsoc.org/awards.

Note: Deadlines differ and some nominations must be submitted on a specific form vs. electronic submission which is available on the AMS website or by request from Headquarters.

2013 AWARDS COMMITTEES

Each committee or commission listed below has the responsibility to select and submit to the Council the names of individuals nominated for the Society's awards listed. The name(s) of individual(s) nominated, a two-page cv, a bibliography of no more than three pages, and three supporting letters should be electronically submitted before **1 May 2013** for the awards that follow, unless stated otherwise. The nominees for awards remain on the committee's active list for three years.

ATMOSPHERIC RESEARCH AWARDS COMMITTEE

The Carl-Gustaf Rossby Research Medal
The Jule G. Charney Award
The Verner E. Suomi Award*
The Remote Sensing Prize (biennial)
The Clarence Leroy Meisinger Award
The Henry G. Houghton Award

OCEANOGRAPHIC RESEARCH AWARDS COMMITTEE

The Sverdrup Gold Medal
The Henry Stommel Research Award
The Verner E. Suomi Award*
The Nicholas P. Fofonoff Award

AWARDS OVERSIGHT COMMITTEE

The Charles Franklin Brooks Award for Outstanding Services to the Society
The Cleveland Abbe Award for Distinguished Service to the Atmospheric Sciences by an Individual
The Joanne Simpson Mentorship Award
The Award for Outstanding Services to Meteorology by a Corporation
Special Awards

EDUCATION AND HUMAN RESOURCES COMMISSION

The Louis J. Battan Author's Award (Adult and K–12)
The Charles E. Anderson Award
The Teaching Excellence Award
Distinguished Science Journalism in the Atmospheric and Related Sciences

PROFESSIONAL AFFAIRS COMMISSION

Outstanding Contribution to the Advance of Applied Meteorology
Award for Broadcast Meteorology
Award for Excellence in Science Reporting by a Broadcast Meteorologist
The Henry T. Harrison Award for Outstanding Contributions by a Consulting Meteorologist

WEATHER AND CLIMATE ENTERPRISE COMMISSION

The Kenneth C. Spengler Award

LOCAL CHAPTER AFFAIRS COMMITTEE

Local Chapter of the Year Award
(*nomination form available online at www.ametsoc.org/amschaps/index.html*)

* Recommended by the Atmospheric Research Awards Committee in even-numbered years and by the Oceanographic Research Awards Committee in odd-numbered years.

2013 AWARDS COMMITTEES

SCIENTIFIC AND TECHNOLOGICAL ACTIVITIES COMMISSION

The Charles L. Mitchell Award

The Award for Exceptional Specific Prediction

The Francis W. Reichelderfer Award

The Helmut E. Landsberg Award

The Award for Outstanding Achievement in Biometeorology

- **LECTURERS** (*Deadline: 1 October 2012*)

Robert E. Horton Lecturer in Hydrology

Bernhard Haurwitz Memorial Lecturer

Walter Orr Roberts Lecturer

- **STUDENT PAPERS**

Robert Leviton

Banner I. Miller

Max A. Eaton Prize

Spiros G. Geotis Prize

Peter V. Hobbs Student Prize

- **NAMED SYMPOSIA**

Section E, of the Policy, Guidelines, and Procedures for Awards and Lectureships provides the Policy on Named Conferences/Symposia and Special Issues of AMS Journals (*full policy description available at www.ametsoc.org/awards*):

Recognition of scientists in the fields served by the AMS, living or deceased, in the form of a named conference or symposium or a named special issue of one of the Society's journals is an honor reserved for only the most outstanding of our colleagues. It should be awarded only to those individuals who are completing a career, or who have recently died having completed a career, of significant achievements in their field and whose contributions would make them worthy of consideration for Honorary Member of the AMS...

2013 FELLOWS COMMITTEE

The Committee's function is to submit to the Council the names of individuals for election to Fellow.

Article III, Section 6, of the AMS Constitution provides that those eligible for election to Fellow shall have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years. The nominees for Fellow must be a member of the Society and remain on the committee's active list for three years.

A nomination letter and three supporting letters should be electronically submitted before 1 May 2013. A list of Fellows and the process for submitting nominations are on the AMS website (www.ametsoc.org/awards).

2013 NOMINATING COMMITTEE

The Committee's function is to submit to the Council the names of individuals for 1) the office of President-Elect for a term of one-year starting at the close of the 94th Annual Meeting (January 2014) and 2) four positions on the Council for a term of three-years starting at the close of the Annual Meeting. Nominations must be submitted prior to 1 April 2013 to the Nominating Committee.

HONORARY MEMBERS

Article III, Section 5, of the AMS Constitution provides that Honorary Members shall be persons of acknowledged preeminence in the atmospheric or related oceanic or hydrologic sciences, either through their own contributions to the sciences or their application or through furtherance of the advance of those sciences in some other way. They shall be exempt from all dues and assessments. The nominees for Honorary member remain on an active list for three years.

Deadline: 1 June 2013; a form and list of Honorary Members is available at www.ametsoc.org/awards.

CORPORATION AND INSTITUTIONAL MEMBERS

Membership in the American Meteorological Society does not imply AMS endorsement of an organization's products or services.

SUSTAINING MEMBERS

Ball Aerospace & Technologies Corporation
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REGULAR MEMBERS

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Atmospheric Technology Services Company, LLC
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Baron Services, Inc.
Belfort Instrument Company
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Bristol Industrial & Research Associates Ltd (BIRAL)
Campbell Scientific, Inc.
Climatronics Corporation
CLS America, Inc.
Coastal Environmental Systems
Computer Sciences Corporation
CSIRO Marine and Atmospheric Research
Davis Instruments Corporation
DeTect, Inc.
Earth Networks
EKO Instruments Company, Ltd.
Enterprise Electronics Corporation
Environmental Systems Research, Inc.
EWR Weather Radar Systems
Florida State University, Department of EOAS
Geophysical Institute/International Arctic Research Center
Global Hydrology and Climate Center
I. M. Systems Group
Jenoptik I Defense & Civil Systems
Johns Hopkins University, Applied Physics Laboratory
Kipp & Zonen USA Inc.
Met One Instruments, Inc.
Meteorological Technology International
MeteoStar

MeteoSwiss
Murray & Trettel, Inc.
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Naval Meteorology and Oceanography Command
Noblis, Inc.
Orbital Sciences Corporation
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Riverside Technology, inc.
Royal Netherlands Meteorological Institute
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SGT, Inc.
SigmaSpace Corporation
Sonalysts, Inc.
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Sutron Corporation
Telvent DTN
The Climate Corporation
The Weather Channel
U.S Department of Energy, Office of Science
Unisys Corporation
University of Alabama in Huntsville, Earth System Science Ctr
University of Wisconsin - Madison, SSEC
Weather Central, LP
Weather Decision Technologies
WeatherFlow, Inc.
Weather Modification, Inc.
Weather Services International, Inc.
WindLogics, Inc.
Wyle

SMALL BUSINESS MEMBERS

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Climadata Corporation
Geonor, Inc.
National Council of Industrial Meteorologists
National Weather Service Employees Organization
Remtech, Inc.
Sky Power International, LLC
The Beautiful Weather Corporation
www.WeatherVideoHD.TV
Yankee Environment Systems, Inc.

For questions relating to corporation and institutional membership, please contact Gary Rasmussen at AMS Headquarters—telephone: 617-227-2426, x3981; fax: 617-742-8718; e-mail: grasmussen@ametsoc.org; or write to American Meteorological Society, Attn: Dr. R. Gary Rasmussen, 45 Beacon St., Boston, MA 02108-3693.

CORPORATION AND INSTITUTIONAL MEMBERS

PUBLICATIONS MEMBERS

Abdus Salam International Centre for Theoretical Physics
Air Force Weather Agency
ARPA FVG, Osservatorio Meteorologico Regionale
Bureau of Meteorology
Civil Aeronautics Administration, MOTC
Colorado State University Libraries
Columbia University, Lahmont-Doherty Geological Observatory
Creighton University Reinert/Alumni Memorial Library
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Deutscher Wetterdienst
Embry Riddle Aeronautical University
Environment Canada Library, Downsview
EUMETSAT Library
Finnish Meteorological Institute
Florida International University Library
Harvard University, Gordon McKay and Blue Hill Libraries
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Illinois State Water Survey
Indian Institute of Tropical Meteorology
Indiana University Library
Institute of Global Environment and Society Library
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Japan Weather Association
Los Alamos National Laboratory
Lyndon State College, Samuel Read Hall Library
Maryland Department of the Environment
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Meteorologisk institutt
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MIT, Lincoln Laboratory
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Naval Postgraduate School, Dudley Knox Library
New York University
Niedersächsische Staats
NIWA Wellington Library
NOAA AOML Library

NOAA Central Library
NOAA – GLERL Library
NOAA National Climatic Data Center
NOAA Seattle Library
North Carolina State University Libraries
Pennsylvania State University, Paterno Library
Purdue University Libraries
Republic of Korea Air Force, Headquarters
South African Weather Service
St. Louis University, Dept. of Earth & Atmospheric Sciences
Swedish Meteorological & Hydrological Institute
U.K. National Meteorological Library
U.S Air Force, 335 TRS/UOAA
U.S. Army Corps of Engineers, Library - ERDC
U.S. Department of Commerce, Boulder Labs Library
U.S. EPA Main Library
U.S. Naval Maritime Forecast Center
Universitätsbibliothek Innsbruck
Universitätsbibliothek Trier
Universite de Versailles
University of Colorado Libraries
University of Copenhagen, Niels Bohr Institute Library
University of Delaware Library
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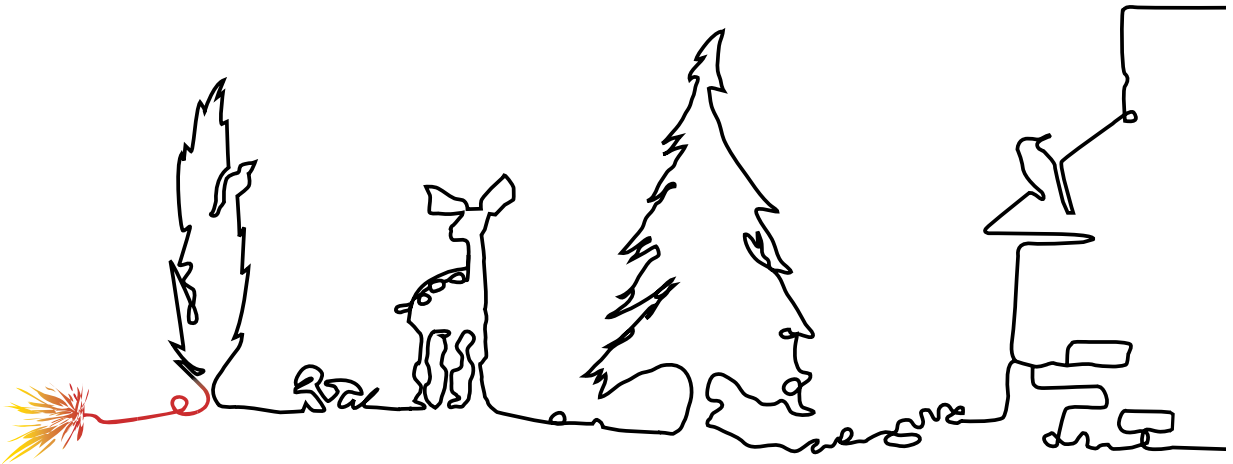
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AMERICAN METEOROLOGICAL SOCIETY

**AUDITED FINANCIAL STATEMENTS
AND SUPPLEMENTARY INFORMATION**

DECEMBER 31, 2011

INDEPENDENT AUDITOR'S REPORT

**TO THE EXECUTIVE COMMITTEE
AMERICAN METEOROLOGICAL SOCIETY**

Boston, Massachusetts

We have audited the accompanying statement of financial position of American Meteorological Society as of December 31, 2011, and the related statements of activities, changes in net assets, and cash flows for the year then ended. These financial statements are the responsibility of the Society's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We conducted our audit in accordance with auditing standards generally accepted in the United States of America and the standards applicable to financial audits contained in "Government Auditing Standards", issued by the Comptroller General of the United States. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and the significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of American Meteorological Society as of December 31, 2011, and the changes in its net assets and its cash flows for the year then ended in conformity with accounting principles generally accepted in the United States of America.

In accordance with "Government Auditing Standards", we have also issued our report dated May 1, 2012 on our consideration of American Meteorological Society's internal control over financial reporting and on our tests of its compliance with certain provisions of laws, regulations, contracts, and grant agreements and other matters. The purpose of that report is to describe the scope of our testing of internal control over financial reporting and compliance and the results of that testing, and not to provide an opinion on the internal control over financial reporting or on compliance. That report is an integral part of an audit performed in accordance with "Government Auditing Standards" and should be considered in assessing the results of our audit.

Our audit was conducted for the purpose of forming an opinion on the financial statements as a whole. The accompanying schedule of expenditures of federal awards is presented for purposes of additional analysis as required by U.S. Office of Management and Budget Circular A-133, "Audits of States, Local Governments, and Non-Profit Organizations", and is not a required part of the financial statements. The schedule of net assets by restriction is presented for purposes of supplementary analysis and is also not a required part of the financial statements. Such information is the responsibility of management and was derived from and relates directly to the underlying accounting and other records used to prepare the financial statements. The information has been subjected to the auditing procedures applied in the audit of the financial statements and certain additional procedures, including comparing and reconciling such information directly to the underlying accounting and other records used to prepare the financial statements or to the financial statements themselves, and other additional procedures in accordance with auditing standards generally accepted in the United States of America. In our opinion, the information is fairly stated in all material respects in relation to the financial statements as a whole.


May 1, 2012

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STATEMENT OF FINANCIAL POSITION**DECEMBER 31, 2011**

Assets	
Current Assets:	
Cash (Notes 2, 5 and 11)	\$ 3,120,856
Accounts receivable from members, subscribers and others (Note 1)	83,250
Short-term investments (Notes 1, 3, 5, 11 and 14)	7,287,179
Promises to give (Notes 1 and 11)	36,000
Prepaid expenses and other current assets	733,771
Inventory (Note 1)	217,545
Total Current Assets	11,478,601
Property and Equipment (Notes 1, 4, 5 and 7)	11,259,233
Other Assets:	
Long-term investments (Notes 1, 3, 5, 11 and 14)	165,323
Promises to give—long term (Notes 1 and 11)	61,573
	226,896
Total Assets	\$ 22,964,730
Liabilities and Net Assets	
Current Liabilities:	
Accounts payable and accrued expenses (Note 8)	\$ 647,514
Deferred income (Note 1)	4,987,560
Current portion of long-term debt (Notes 5 and 7)	205,720
Total Current Liabilities	5,840,794
Long-Term Liabilities:	
Fair value of interest rate swap agreement (Note 6)	371,806
Long-term debt, net of current portion (Notes 5 and 7)	5,125,866
Total Long-Term Liabilities	5,497,672
Total Liabilities	11,338,466
Commitments (Note 13)	
Net Assets (Notes 1 and 14)	
Unrestricted	9,320,980
Temporarily restricted	1,662,521
Permanently restricted	642,763
	11,626,264
Total Liabilities and Net Assets	\$ 22,964,730

The accompanying notes are an integral part of the financial statements.

STATEMENT OF ACTIVITIES**YEAR ENDED DECEMBER 31, 2011****Unrestricted Net Assets:****Revenues, Gains and Other Support (Notes 1, 3, 5, 6, 9 and 14):**

Journals	\$ 7,262,754
Meetings and exhibits	3,072,291
<i>Bulletin</i> and other member services	2,032,189
Federal financial assistance	1,822,838
Other educational assistance	1,129,093
Books and educational materials	858,284
Investment income	105,980
Net assets released from restrictions	65,223
Contributions	56,500
Realized and unrealized (losses) on investments	(76,993)
Unrealized (loss) on interest rate swap agreement	(334,941)

15,993,218**Expenses (Notes 1, 5, 7, 8, 9 and 10):**

Program services:

Journals	5,893,883
Education and policy programs	4,945,076
Meetings and exhibits	2,667,134
<i>Bulletin</i> and other member services	1,830,934
Books and educational materials	165,944

Supporting services:

Administrative and general	334,985
Interest expense	220,781

16,058,737

(Decrease) in Unrestricted Net Assets (65,519)**Temporarily Restricted Net Assets (Notes 1, 3 and 14):**

Contributions	231,077
Investment income	28,425
Net assets released from restrictions	(65,223)
Realized and unrealized gains on investments	3,330

Increase in Temporarily Restricted Net Assets 197,609**Permanently Restricted Net Assets (Notes 1, 3 and 14):**

Contributions	—
Investment income	1
Unrealized gains on investments	843

Increase in Permanently Restricted Net Assets 844

Increase in Net Assets 132,934

Net assets at beginning of year 11,493,330

Net Assets at End of Year \$ 11,626,264

The accompanying notes are an integral part of the financial statements.

STATEMENT OF CHANGES IN NET ASSETS

YEAR ENDED DECEMBER 31, 2011

	Unrestricted Net Assets	Temporarily Restricted Net Assets	Permanently Restricted Net Assets	Total Net Assets
Balance at January 1, 2011	\$ 9,386,499	\$ 1,464,912	\$ 641,919	\$ 11,493,330
Unrestricted Net Assets:				
Total unrestricted support, including net assets released from restrictions	15,993,218	—	—	15,993,218
Expenses	16,058,737	—	—	16,058,737
(Decrease) in Unrestricted Net Assets	(65,519)	—	—	(65,519)
Temporarily Restricted Net Assets:				
Contributions	—	231,077	—	231,077
Investment income	—	28,425	—	28,425
Net assets released from restrictions	—	(65,223)	—	(65,223)
Realized and unrealized gains on investments	—	3,330	—	3,330
Increase in Temporarily Restricted Net Assets	—	197,609	—	197,609
Permanently Restricted Net Assets:				
Contributions	—	—	—	—
Investment income	—	—	1	1
Realized and unrealized gains on investments	—	—	843	843
Increase in Permanently Restricted Net Assets	—	—	844	844
Changes in Net Assets	(65,519)	197,609	844	132,934
Balance at December 31, 2011	\$ 9,320,980	\$ 1,662,521	\$ 642,763	\$ 11,626,264

The accompanying notes are an integral part of the financial statements.

STATEMENT OF CASH FLOWS**YEAR ENDED DECEMBER 31, 2011****Cash Flows from Operating Activities:**

Increase in net assets	\$ 132,934
Adjustments to reconcile change in net assets to net cash provided by operating activities:	
Depreciation	318,810
Unrealized loss on interest rate swap agreement	334,941
(Increase) decrease in:	
Accounts receivable	(38,546)
Inventory	37,168
Prepaid expenses and other current assets	168,793
Promises to give	(97,573)
(Decrease) increase in:	
Accounts payable and accrued expenses	66,283
Deferred income	449,162
Unrealized and realized losses on investments	72,820
Contributions restricted for long-term investments	(231,077)
Interest and dividends restricted for long-term investments	(28,426)

Net Cash Provided by Operating Activities 1,185,289**Cash Flows from Investing Activities:**

Acquisition of property and equipment	(410,898)
Proceeds from sale of investments	2,672,525
Purchase of investments	(1,520,907)

Net Cash Provided by Investing Activities 740,720**Cash Flows from Financing Activities:**

Contributions restricted for investment in temporarily restricted funds	231,077
Interest and dividends restricted for reinvestment	28,426
Payments on long-term debt	(205,005)

Net Cash Provided by Financing Activities 54,498

Net Increase in Cash 1,980,507

Cash at beginning of year 1,140,349

Cash at End of Year \$ 3,120,856**Supplemental Disclosure for Cash Flows Information****Cash Paid During the Year for:**

Interest	<u><u>\$ 203,016</u></u>
Income taxes	<u><u>\$ —</u></u>

The accompanying notes are an integral part of the financial statements.

Note 1. Summary of Significant Accounting Policies:

Nature of activities: American Meteorological Society was formed in 1919. Interdisciplinary in scope, the Society actively promotes the development and dissemination of information on the atmospheric and related oceanic and hydrologic sciences.

Basis of accounting: The financial statements of American Meteorological Society have been prepared on the accrual basis of accounting in accordance with accounting principles generally accepted in the United States of America (U.S. GAAP) and, accordingly, reflect all significant receivables, payables and other liabilities.

Basis of presentation: Under U.S. GAAP, the Society is required to report information regarding its financial position and activities according to three classes of net assets: unrestricted net assets, temporarily restricted net assets, and permanently restricted net assets.

Donated assets: Donated marketable securities and other non-cash donations are recorded as contributions at their estimated fair values at the date of donation.

Donated collection items: In accordance with U.S. GAAP, the Society does not capitalize donated works of art or recognize them as revenues or gains. Such donations need not be recognized if they are added to collections that are held for public exhibition, education, or research in furtherance of public service rather than financial gain; are protected, kept unencumbered, cared for, and preserved; and are subject to a policy that requires the proceeds from sales of collection items to be used to acquire other items for collections.

Donated property and equipment: Donations of property and equipment are recorded as contributions at their estimated fair value at the date of donation. Such donations are reported as increases in unrestricted net assets unless the donor has restricted the donated asset to a specific purpose. Assets donated with explicit restrictions regarding their use and contributions of cash that must be used to acquire property and equipment are reported as restricted contributions. Absent donor stipulations regarding how long these donated assets must be maintained, the Society reports expirations of restrictions when the donated or acquired assets are placed in service as instructed by the donor. The Society reclassifies temporarily restricted net assets to unrestricted net assets at that time.

Note 1. Summary of Significant Accounting Policies (Continued):

Deferred revenue: Revenue from membership dues and subscription fees is deferred and recognized over the periods to which the dues and fees relate.

Donated services: No amounts have been reflected in the financial statements for donated services. The Society generally pays for services requiring specific expertise. However, many individuals volunteer their time and perform a variety of tasks that assist the Society with various programs and committee assignments.

Expense allocation: Expenses are charged to program and supporting services on the basis of periodic time and expense studies. Administrative and general expenses include those expenses that are not directly identifiable with any other specific function but provide for the overall support and direction of the Society.

Income tax status: The Society is exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code. However, income from certain activities not directly related to the Society's tax-exempt purpose is subject to taxation as unrelated business income.

In determining the recognition of uncertain tax positions, the Society applies a more-likely-than-not recognition threshold and determines the measurement of uncertain tax positions considering the amounts and probabilities of the outcomes that could be realized upon ultimate settlement with taxing authorities. As of December 31, 2011, the Society has no uncertain tax positions that qualify for either recognition or disclosure in the financial statements. The Society is not currently under examination by any taxing jurisdiction. The Society's federal and state tax returns are generally open for examination for three years following the date filed.

Inventory: Inventory, consisting of periodicals and books, is stated at the lower of cost, using the first-in, first-out method, or market.

Investments: The Society carries investments in marketable securities with readily determinable fair values and all investments in debt securities at their fair values in the Statement of Financial Position. Unrealized gains and losses are included in the changes in net assets in the accompanying Statement of Activities.

Note 1. Summary of Significant Accounting Policies (Continued):

Promises to give: Unconditional promises to give are recognized as revenues or gains in the period received and as assets, decreases of liabilities, or expenses depending on the form of the benefits received. Unconditional promises to give that are expected to be collected within one year are recorded at net realizable value. Unconditional promises to give that are expected to be collected in future years are recorded at the present value of their future cash flows. The discounts on those amounts are computed using risk-adjusted interest rates applicable to the years in which the promises are received. Amortization of the discounts is included in contribution revenue. Conditional promises to give are recognized when the conditions on which they depend are substantially met. Uncollectible promises to give are expected to be insignificant and an allowance for uncollectible promises to give is not considered necessary.

As of December 31, 2011 the Society had \$97,573 of unconditional promises to give owed to them.

Property and equipment: Property and equipment are carried at cost or, if donated, at the approximate fair value at the date of donation. Depreciation is computed using primarily the straight-line method over the estimated useful lives of the assets which range from five to thirty-nine years. Additions and betterments of \$2,000 or more are capitalized, while maintenance and repairs that do not improve or extend the useful lives of the respective assets are expensed currently.

The Society's land and building are located in a historical district and its building is classified as a historical structure. The property was donated to the Society during the 1950's and was recorded at a value of \$2. The property is considered to be a historical treasure that is worth preserving perpetually. The Society has the capacity to protect and preserve essentially the service potential of the land and building, and is doing so.

Note 1. Summary of Significant Accounting Policies (Continued):

Restricted and unrestricted revenue and support: Contributions received are recorded as unrestricted, temporarily restricted or permanently restricted support, depending on the existence or nature of any donor restrictions.

Contributions that are restricted by the donor are reported as an increase in unrestricted net assets if the restriction expires in the reporting period in which the revenue is recognized. All other donor-restricted contributions are reported as an increase in temporarily or permanently restricted net assets, depending on the nature of the restrictions. When a restriction expires, temporarily restricted net assets are reclassified to unrestricted net assets and reported in the statement of activities as net assets released from restrictions.

Use of estimates: The preparation of financial statements in conformity with U.S. GAAP requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements and the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Derivative financial instruments: The Society makes use of derivative financial instruments for the purpose of managing interest rate risk. Derivative financial instruments are recorded at fair value.

Fair Values of Financial Instruments: U.S. GAAP defines fair value as the price that would be received to sell an asset or paid to transfer a liability in an orderly transaction between market participants at the measurement date. U.S. GAAP also establishes a framework for the measurement of fair value, and enhances disclosures about fair value measurements.

Interest rate swap agreements are valued at the net present value of future cash flows attributable to the difference between the contractual variable and fixed rates in those agreements adjusted for nonperformance risk of both the counterparty and the Society. The carrying value of all other financial instruments approximates fair value.

Note 1. Summary of Significant Accounting Policies (Continued):

Advertising: The Society uses advertising to promote its programs, bulletins, journals, books and education materials among the audiences it serves. The production costs of advertising are expensed as incurred.

Date of Management's Review: The Society has evaluated subsequent events through May 1, 2012 which is the date the financial statements were available to be issued.

Note 2. Cash:

The Society places its cash in institutions which are insured by the Federal Deposit Insurance Corporation (FDIC). At times during the year, the bank balances may be in excess of the FDIC insurance limit of \$250,000 per institution. At December 31, 2011, the Society's bank balances exceeded the FDIC limit by approximately \$3,055,873. The Society has not incurred any related losses.

Note 3. Investments:

The Society's investments, which are held and managed by outside custodians, at December 31, 2011 consist of stocks, mutual funds and invested cash, including money market funds.

U.S. GAAP establishes a fair value hierarchy that prioritizes inputs to valuation techniques used to measure fair value. The hierarchy gives the highest priority to unadjusted quoted prices in active markets for identical assets or liabilities (Level 1 measurements) and the lowest priority to measurements involving significant unobservable inputs (Level 3 measurements). The three levels of the fair value hierarchy are as follows:

Note 3. Investments (Continued):

- *Level 1 inputs* are quoted prices (unadjusted) for identical investments in active markets.
- *Level 2 inputs* are quoted prices for similar instruments in active markets; quoted prices for identical or similar instruments in markets that are not active; and model-derived valuations in which all significant inputs and significant value drivers are observable in active markets.
- *Level 3 inputs* are model derived valuations in which one or more significant inputs or significant value drivers are unobservable.

In certain cases, the inputs to measure fair value may result in an asset or liability falling into more than one level of the fair value hierarchy. In such cases, the determination of the classification of an asset or liability within the fair value hierarchy is based on the least determinate input that is significant to the fair value measurement. The Select Investment Program's assessment of the significance of a particular input to the fair value measurement in its entirety requires judgment and considers factors specific to the asset or liability.

The following table summarizes the Society's financial assets measured at fair value on a recurring basis in accordance with U.S. GAAP as of December 31, 2011:

Note 3. Investments (Continued):

	Level 1	Level 2	Level 3
U.S. Corporate stock and mutual funds	\$ 4,225,624	\$ —	\$ —
Certificate of Deposit and government bonds	2,194,341	—	—
Money market funds	917,188	—	—
Planned giving assets	115,349	—	—
	<u>\$ 7,452,502</u>	<u>\$ —</u>	<u>\$ —</u>

	Cost	Unrealized Gains and (Losses)	Fair Value
Invested cash	\$ 917,188	\$ —	\$ 917,188
Mutual funds	3,774,729	439,986	4,214,715
Stocks	1	10,908	10,909
Gift annuity	104,299	11,050	115,349
Certificates of deposit	2,194,341	—	2,194,341
	<u>\$ 6,990,558</u>	<u>\$ 461,944</u>	<u>\$ 7,452,502</u>

Included in the accompanying statement of financial position as follows:

	Cost	Unrealized Gains and (Losses)	Fair Value
Short-term investments	\$ 6,847,194	\$ 439,985	\$ 7,287,179
Long-term investments	143,364	21,959	165,323
	<u>\$ 6,990,558</u>	<u>\$ 461,944</u>	<u>\$ 7,452,502</u>

The following schedule summarizes the investment returns and their classification in the statement of activities for the year ended December 31, 2011:

	Permanently Restricted	Temporarily Restricted	Unrestricted
Investment income	\$ 1	\$ 28,425	\$ 105,980
Realized gains (losses) on investments	—	3,239	(8,327)
Unrealized gains (losses) on investments	843	91	(68,666)
	<u>\$ 844</u>	<u>\$ 31,755</u>	<u>\$ 28,987</u>

Note 4. Property and Equipment:

Property and equipment consists of the following:

Land	\$ 3,643,802
Building and improvements	8,728,785
Office equipment and furniture	802,991
	13,175,578
Less accumulated depreciation	1,916,345
	\$ 11,259,233

Note 5. Long-Term Debt:

The Society entered into a loan agreement with the Massachusetts Development Finance Agency, (the “Issuer”), a public instrumentality of the Commonwealth of Massachusetts in November 2010. The note was issued with bonds, by and among the Issuer, the Society, Webster Massachusetts Security Corporation, (the “Bondholder”), and Webster Bank National Association (the “Paying Agent”). The note is payable in monthly installments of \$15,278 plus interest through November 2040. The interest rate on the note is set by the Paying Agent and will be reset from time to time. At December 31, 2011 the interest rate was 3.7075%. The bond is secured by the land and building located at 44 Beacon Street, Boston, MA.

Note 5. Long-Term Debt (Continued):

The Society also entered into a revolving line of credit agreement with Webster Bank National Association (the “Bank”) in the amount of \$500,000. As of December 31, 2011, there were no borrowings on this line of credit. The line of credit agreement contains financial and other covenants including a maximum leverage provision. At December 31, 2011 the Society was in compliance with these covenants. The line of credit is secured and cross collateralized with the tax exempt bond financing and by a first security interest in all assets of the Society.

The Society also has several capital equipment lease agreements (See Note 7).

Maturities of long-term debt at December 31, 2011 consists of the following:

	Mass. Development Finance Agency	Capital Lease Obligations	Total
2012	\$ 183,333	\$ 22,387	\$ 205,720
2013	183,333	7,810	191,143
2014	183,333	—	183,333
2015	183,333	—	183,333
2016	183,333	—	183,333
Thereafter	4,384,724	—	4,384,724
	\$ 5,301,389	\$ 30,197	\$ 5,331,586

Note 6. Interest Rate Swap Agreement:

U.S. GAAP requires certain derivative financial instruments to be recorded at fair value. An interest rate swap agreement is used by the Society to mitigate the risk of changes in interest rates associated with variable interest rate indebtedness. Under such arrangement, a portion of variable rate indebtedness is converted to fixed rates based on a notional principal amount.

The interest rate swap agreement is a derivative instrument that is required to be marked to market and recorded at fair value on the statement of financial position. At December 31, 2011, the aggregate notional principal amount under the interest rate swap agreement, with a maturity of November 1, 2040, totaled \$5,301,389. At December 31, 2011, the estimated fair value of the interest rate swap agreement was a liability of \$371,806, and is classified on the statement of financial position as an interest rate swap agreement liability as of December 31, 2011.

As described in Note 3, U.S. GAAP establishes a fair value hierarchy that prioritizes inputs to valuation techniques used to measure fair value.

The following table represents the interest rate swap agreement liability that is measured at fair value on a recurring basis at December 31, 2011:

	Level 1	Level 2	Level 3
Interest rate swap	\$ —	\$ 371,806	\$ —

The change in fair value on this interest rate swap agreement was a loss of \$334,941 for the year ended December 31, 2011, which is reflected as an unrealized loss on interest rate swap agreement in the accompanying statement of activities and changes in net assets.

Note 7. Capital Leases:

The Society leases equipment under the terms of several capital leases which expire in September 2014.

Note 7. Capital Leases (Continued):

The equipment has been capitalized and the related obligations are reflected in the accompanying financial statements based on the fair value of the asset which is lower than the present value of the minimum lease payments.

Present value of the future minimum lease payments was determined based on the Society's borrowing rate at the leases inception date (3.25%).

Minimum future lease payments as of December 31, 2011 are as follows:

Years	Amount
2012	\$ 23,037
2013	7,864
	<hr/> 30,901
Less Interest	(704)
Present value of future minimum lease payments	<hr/> <hr/> \$ 30,197

Note 8. Compensated Absences:

It is the Society's policy to reasonably estimate each year the amount of accrued vacation compensation that it anticipates to pay in the future. As a result, the accrual was increased by \$26,932 in 2011 and that effect is reflected in the statement of activities. As of December 31, 2011, the Society has an accrued liability of \$402,283 related to this policy, which is reflected in the statement of financial position.

Note 9. Program and Supporting Services:

The following program and supporting services are included in the accompanying financial statements:

Bulletin and Other Member Services

Includes all primary member services, including, among others, the maintenance of the membership database, the certification programs and the publication of the *Bulletin*.

**Note 9. Program and Supporting Services
(Continued):**Journals

Includes the publication of the Society's primary journals (*Journal of the Atmospheric Sciences*, *Journal of Applied Meteorology and Climatology*, *Monthly Weather Review*, *Journal of Physical Oceanography*, *Journal of Atmospheric and Oceanic Technology*, *Journal of Climate*, *Weather and Forecasting*, *Journal of Hydrometeorology* and *Earth Interactions* electronic journal).

Meetings and Exhibits

Includes presenting various meetings throughout the year including the annual meeting and the related exhibits. It also includes short courses offered at the various meetings.

Books and Educational Materials

Includes the production and sale of books published by the Society, distribution throughout North America of WMO publications and sale of educational material for pre-college teachers.

Education and Policy Programs

Includes federal funding and Society support of nationally recognized programs using the study of the atmosphere and ocean to enhance or create an interest in pre-college students in science and engineering. Programs now underway include, among others, Supporting NOAA's Mission by Improving Pre-College Teachers' Knowledge of the Atmospheric and Ocean Studies, Educating Leaders and Future Leaders in the Atmospheric Sciences and Developing and Implementing a Stronger National Commitment to Long-Term Earth Observations and Their Beneficial Use and DataStreame Earth's System: Creating a Sustained Community of K-12 Educators Who are Local Leaders in Climate Science and Global Change Issues. Policy programs work to strengthen the connection between public policy and Earth system science and services by building policy research and by creating opportunities for policymakers and scientists to engage and exchange perspectives to foster better-informed policy decisions.

**Note 9. Program and Supporting Services
(Continued):**Administrative and General

Includes the functions necessary to maintain a portion of an equitable employment program; ensure an adequate working environment; provide coordination and articulation of the Society's program strategy through the Office of the Executive Director; secure proper administrative functioning of the Council; maintain competent legal services for the program administration of the Society; and manage the financial and budgetary responsibilities of the Society.

Note 10. Retirement Plan:

The Society has a contributory retirement plan covering substantially all full-time employees. This is a tax deferred annuity plan under Section 403(b) of the U.S. Internal Revenue Code. The plan allows eligible employees to contribute 5% of their compensation through a salary reduction agreement. The Society contributes 10% of compensation for participating employees. The expense for this plan amounted to \$445,451 for the year ended December 31, 2011. There is no past service liability in connection with the plan.

Note 8. Concentrations of Credit Risk:

Financial instruments that potentially subject the Society to concentrations of credit risk consist primarily of cash (see Note 2), short-term investments, promises to give receivable and long-term investments. By their nature, all such financial instruments involve risk, including the credit risk of nonperformance by counter parties and the maximum potential loss may exceed the amount recognized in the statement of financial position. At December 31, 2011, in management's opinion, there was no significant risk of loss from nonperformance of the counter parties to these financial instruments.

Note 12. Federal Grant Activity:

The Society is the recipient of several federal awards. The balances of these awards as of December 31, 2011 are as follows:

Federal Granting Agency	Cumulative Grant Awards	Cumulative Costs Incurred	Unexpended Funds on Unexpired Grants	Unexpended Funds on Expired Grants
National Oceanic and Atmospheric Administration	\$ 3,729,340	\$ 2,937,494	\$ 791,846	\$ —
National Aeronautics and Space Administration	1,317,488	746,591	570,897	—
National Science Foundation	1,178,073	186,623	991,450	—
United States Department of the Navy	173,040	70,747	102,293	—
	<u>\$ 6,397,941</u>	<u>\$ 3,941,455</u>	<u>\$ 2,456,486</u>	<u>\$ —</u>

Federal funds are received on a cost reimbursement basis. Revenue with respect to the federal grants is recognized to the extent of expenses incurred in accordance with the terms of the federal grants. Upon completion or expiration of a grant, unexpended grant funds are not available to American Meteorological Society and must be returned to the federal agency awarding the grant. Total grant revenue for the year ended December 31, 2011 was \$1,822,838.

Note 13. Commitments:

The Society leases office space and equipment under various operating leases through March, 2027. Under the terms of the office space lease, the Society is obligated to pay escalation rental for certain operating expenses and real estate taxes. Rental expense under the leases amounted to \$648,586 for the year ended December 31, 2011 (including charges for operating expenses and taxes). The following is a schedule of future minimum rentals under the leases at December 31, 2011:

Year Ending December 31:	
2012	396,724
2013	498,435
2014	499,307
2015	479,397
2016	491,382
Thereafter	5,800,980
	<u>\$ 8,166,225</u>

Note 13. Commitments (Continued):

The Society subleased some of its office space to other organizations through September 2011. Rental income for 2011 amounted to approximately \$173,000.

Note 14. Endowment Funds:

In accordance with the Uniform Prudent Management of Institutional Funds Act (UPMIFA), the Society is required to act prudently when making decisions to spend or accumulate donor restricted endowment assets and in doing so to consider a number of factors including the duration and preservation of its donor restricted endowment funds. The Society classifies as permanently restricted net assets the original value of gifts donated to the permanent endowment. The remaining portion of the endowment fund that is not classified in permanently restricted net assets is classified as temporarily restricted net assets until those amounts are appropriated for expenditure by the Society in a manner consistent with the standard of prudence prescribed by UPMIFA.

Note 14. Endowment Funds (Continued):

The Society’s endowment consists of approximately 65 individual funds established for a variety of purposes. Its endowment includes both donor-restricted endowment funds and funds designated by the Executive Committee to function as endowments. As required by generally accepted accounting principles, net assets associated with endowment funds including funds designated by the Executive Committee to function as endowments, are classified and reported based on the existence or absence of donor-imposed restrictions. When the donor’s interest is not expressed in relation to the endowment fund, it is the policy of the Organization to record the income, interest, and dividends and accumulated appreciation/depreciation in each endowment fund and appropriate expenditures from each fund in a prudent manner for the uses, benefits, purpose, and duration for which the endowment fund was established. As a result, the income earned each year for each endowment fund is reflected as either unrestricted, temporarily restricted or permanently restricted depending on the intent of the donor when the original gift was made.

Interpretation of Relevant Law: The Executive Committee of the Society has interpreted the Uniform Prudent Management of Institutional Funds Act (UPMIFA) as requiring the preservation of the fair value of the original gift as of the gift date on the donor-restricted endowment funds absent explicit donor stipulations to the contrary. As a result, the Society classifies as permanently restricted net assets (a) the original value of gifts donated to the permanent endowment, (b) the original value of subsequent gifts to the permanent endowment, and (c) accumulations to the permanent endowment made in accordance with the direction of the applicable donor gift instrument at the time the accumulation is added to the fund. The remaining portion of the donor-restricted endowment fund is classified as temporarily restricted net assets until those amounts are appropriated for expenditure by the Society in a manner consistent with the standards of prudence prescribed by UPMIFA.

In accordance with UPMIFA, the Society considers the following factors in making a determination to appropriate or accumulate donor-restricted endowment funds:

Note 14. Endowment Funds (Continued):

- (1) The duration and preservation of the various funds.
- (2) The purposes of the donor-restricted endowment funds.
- (3) General economic conditions.
- (4) The possible effect of inflation and deflation.
- (5) The expected total return from income and the appreciation of investments.
- (6) Other resources of the Society.
- (7) The investment policies of the Society.

Return Objectives and Risk Parameters: The Society has adopted investment and spending policies approved by the Executive Committee for endowment assets that attempt to provide a predictable stream of funding to programs supported by its endowment funds while also maintaining the purchasing power of those endowment assets over the long-term.

Endowment assets include those assets of donor-restricted funds that the Society must hold in perpetuity or for a donor-specified period(s) as well as board-designated funds. Under this policy, as approved by the Executive Committee, the endowment assets are invested in a manner that is intended to contribute to the Society’s total return objectives and preserve principal while maintaining a competitive yield as market conditions dictate.

Strategies Employed for Achieving Objectives: To satisfy its long-term rate-of-return objectives, the Society relies on a total return strategy in which investment returns are achieved through both capital appreciation (realized and unrealized) and current yield (interest and dividends). The Society targets a diversified conservative asset allocation including marketable debt obligations and insured instruments issued by the United States Government or agencies of the U.S. Government to achieve its long-term return objectives within prudent risk constraints.

Note 14. Endowment Funds (Continued):

Spending Policy and How the Investment Objectives Relate to Spending Policy: The Society’s policy of appropriating scholarships, fellowships and other distribution of funds is determined based on the donor’s intentions and investment returns as well as taking into consideration the long-term expected return on its endowment. Accordingly, over the long-term, the Society expects the current spending policy to allow its endowment to grow at a normal inflationary rate on an annual basis. This is consistent with the Society’s objective to maintain the purchasing power of the endowment assets held in perpetuity or for a specific term as well as to provide additional growth through new gifts and investment return.

Endowment net assets composition by type of fund as of December 31, 2011:

	Unrestricted	Temporarily Restricted	Permanently Restricted	Total
Donor-restricted endowment funds	\$ —	\$ 1,662,521	\$ 642,763	\$ 2,305,284
Board-designated endowment funds	1,325,602	—	—	1,325,602
	<u>\$ 1,325,602</u>	<u>\$ 1,662,521</u>	<u>\$ 642,763</u>	<u>\$ 3,630,886</u>

Changes in endowment net assets for year ended December 31, 2011:

	Unrestricted	Temporarily Restricted	Permanently Restricted	Total
Endowment net assets, beginning of year	\$ 1,459,853	\$ 1,464,912	\$ 641,919	\$ 3,566,684
Investment return:				
Investment income	6,790	28,125	1	34,916
Net appreciation (depreciation) (realized and unrealized)	(51)	3,630	843	4,422
Total investment return	1,466,592	1,496,667	642,763	3,606,022
Contributions	444,136	231,077	—	675,213
Appropriation of endowment assets for expenditure	(585,126)	(65,223)	—	(650,349)
Endowment net assets end of year	<u>\$ 1,325,602</u>	<u>\$ 1,662,521</u>	<u>\$ 642,763</u>	<u>\$ 3,630,886</u>

SUPPLEMENTARY INFORMATION

SCHEDULE OF EXPENDITURES OF FEDERAL AWARDS

YEAR ENDED DECEMBER 31, 2011

Program Title	CFDA Number	Pass-through Entity Identifying Number	Award Number	Federal Expenditures
National Oceanic and Atmospheric Administration:				
Supporting NOAA's Mission by Improving Pre-College Teachers' Knowledge of the Atmospheric and Ocean Sciences	11.469	—	NA07SEC4690023	\$ 509,389
Educating Leaders and Future Leaders in the Atmospheric Sciences and Developing and Implementing a Stronger National Commitment to Long-Term Earth Observations and Their Beneficial Use	11.467	—	NA09NWS4670020	194,754
AMS/National Weather Service Fellowships	11.467	—	NA05NWS4671011	25,000
Subtotal by program	11.467			219,754
AMS/NOAA Graduate Fellowships	11.431	—	NA07OAR4310491	24,000
Integrated Solutions: Environmental and Health Series	11.459	—	NA08OAC4590928	11,713
Total National Oceanic and Atmospheric Administration				764,856
National Aeronautics and Space Administration:				
DataStreme Earth's System: Creating a Sustained Community of K-12 Educators who are Local Leaders in Climate Science and Global Change Issues	43.001	—	NNX10AT50A	330,805
Fellowships	43.001	—	NNX10AU52H	116,339
Developing and Implementing a Stronger National Commitment to Long-Term Earth Observations and Their Beneficial Use	43.001	—	NNX09AP56G	47,060
AMS Journals to Developing Countries	43.001	—	NNX09AP98G	25,000
Analysis and Interpretation of High Resolution Atmospheric Chemistry and Meteorological Model Data for a Time Resolved Chemistry Mission	43.001	—	NNX10ANG5G	9,308
Total National Aeronautics and Space Administration	43.001			\$ 528,512

**SCHEDULE OF EXPENDITURES
OF FEDERAL AWARDS (CONTINUED)**

YEAR ENDED DECEMBER 31, 2011

Program Title	CFDA Number	Pass-through Entity Identifying Number	Award Number	Federal Expenditures
National Science Foundation:				
AMS Summer Policy Colloquium	47.050	—	AGS-0910744	\$ 119,200
DataStreme Earth's Climate System: Training Climate Education Resource Agents who Advance Climate Science Literacy	47.050	—	GEO-1034999	89,230
AMS Climate Studies: Fostering Climate Science Literacy and Promoting Minority Participation in the Geosciences (Track 2)	47.050	—	GEO-1107968	73,035
Charles Keeling Memorial Climate-Related Science and Policy Workshops	47.050	—	AGS-0939980	69,125
Advancing Space Science and its Use Through Policy Research	47.050	—	AGS-0638377	37,863
Subtotal by program	47.050			388,453
Workshop: Weather, Climate and Communication: More than Just Talking About the Weather; 2011 American Meteorological Society Annual Meeting; Seattle, Washington; 23–27 January 2011	47.041	—	CMMI-112094	24,835
Total National Science Foundation				413,288
Department of the Navy:				
The Maury Project: Pre-College Teacher Training in the Physical Foundations of Oceanography	12.300	—	N00014-11-1-0122	69,293
The Maury Project: Pre-College Teacher Training in the Physical Foundations of Oceanography	12.300	—	N00014-05-1-0599	6,639
Total Department of the Navy				75,932
Cambridge Systematics, Inc. (Pass-Through Entity)				
FHWA Operations Support 2006 – Development of Road Weather Management Program Marketing Plan and Outreach Products	20.200	7661-370	DTF-H61- 06-D-00004	25,000
Department of Energy:				
Fellowships	81.049	—	DE-FG02- 06ER64247	12,500
Office of Federal Coordinator for Meteorology				
Scholarships	11.467			2,750
Total Expenditures of Federal Awards				\$ 1,822,838

Note 1. Basis of Presentation:

The accompanying schedule of expenditures of federal awards includes the federal grant activity of the American Meteorological Society and is presented on the accrual basis of accounting and, accordingly, reflects all significant receivables, payables and other liabilities. The information in this schedule is presented in accordance with the requirements of OMB Circular A-133, "Audits of States, Local Governments, and Non-Profit Organizations."

Note 2. Subrecipients:

During 2011, the American Meteorological Society did not provide federal awards to any subrecipients.

SCHEDULE OF NET ASSETS BY RESTRICTION**YEAR ENDED DECEMBER 31, 2011**

	Balances January 1, 2011	Receipts and Other Additions	Expenditures and Other Deductions	Total	Appreciation (Depreciation) in Fair Market Value	Balances December 31, 2011
Unrestricted Net Assets:						
General	\$ 7,926,646	\$ 137,347	\$ —	\$ 8,063,993	\$ (68,615)	\$ 7,995,378
Education	1,016,364	—	123,742	892,622	—	892,622
75th Endowment	40,558	460	—	41,018	(15)	41,003
Cooper	76,245	1,900	2,237	75,908	(6)	75,902
Fellowship	37,000	226,839	226,339	37,500	—	37,500
Scholarship	2,500	59,250	69,500	(7,750)	—	(7,750)
Student Travel Fund	51,510	1,190	1,924	50,776	—	50,776
Development	104,215	158,187	151,287	111,115	—	111,115
Glahn	11,650	1,988	47	13,591	—	13,591
Saltzman	105,830	689	5,050	101,469	(30)	101,439
Atlas	9,596	420	5,000	5,016	—	5,016
Roberts	1,791	—	—	1,791	—	1,791
Digiquartz	317	1	—	318	—	318
Ooyama	141	1	—	142	—	142
Friday	2,118	—	—	2,118	—	2,118
Hobbs	18	1	—	19	—	19
Total Unrestricted Net Assets	\$ 9,386,499	\$ 588,273	\$ 585,126	\$ 9,389,646	\$ (68,666)	\$ 9,320,980

**SCHEDULE OF NET ASSETS
BY RESTRICTION (CONTINUED)**

YEAR ENDED DECEMBER 31, 2011

	Balances January 1, 2011	Receipts and Other Additions	Expenditures and Other Deductions	Total	Appreciation (Depreciation) in Fair Market Value	Balances December 31, 2011
Temporarily Restricted Net Assets:						
Orville	\$ 199,959	\$ 74,959	\$ 5,000	\$ 269,918	\$ (21)	\$ 269,897
Hanks Scholarship	2,626	108	—	2,734	—	2,734
Schroeder	11,762	2,298	5,000	9,060	—	9,060
Reed	16,726	815	—	17,541	—	17,541
Wark	42,591	1,106	12,550	31,147	—	31,147
Leviton	2,138	41	300	1,879	—	1,879
Houghton	54,272	1,712	—	55,984	(3)	55,981
Hagemeyer Unitrust	120,817	3,255	3,050	121,022	452	121,474
Gift Annuity	116,674	5,995	4,360	118,309	(2,958)	115,351
David Johnson	75,360	480	3,050	72,790	135	72,925
Milham	3,239	—	—	3,239	—	3,239
Horton	152,802	12,647	—	165,449	(13)	165,436
Grau	54,162	323	5,000	49,485	—	49,485
Merewether	7,528	55	—	7,583	—	7,583
Murphy	2,463	353	2,000	816	—	816
L. Johnson	51,971	4,639	4,000	52,610	(7)	52,603
Baum	97,869	1,178	5,000	94,047	(39)	94,008
Hope	874	367	—	1,241	—	1,241
Eaton	700	—	100	600	—	600
Kreitzberg	2,916	2,119	2,000	3,035	—	3,035
Wesley	23,219	4,856	709	27,366	—	27,366
Vonnegut-Schaefer	75,692	1,549	5,000	72,241	215	72,456
Namias	2,115	190	50	2,255	—	2,255
Glahn	54,999	1,001	2,500	53,500	—	53,500
Atlas	99,440	2,370	—	101,810	2,366	104,176
Spengler	4,656	—	—	4,656	—	4,656
Roberts	54,641	494	—	55,135	—	55,135
Geotis	4,940	59	700	4,299	—	4,299
Digiquartz	500	—	—	500	—	500
Ooyama	78,324	678	2,000	77,002	—	77,002
Friday	44,227	344	2,654	41,917	(36)	41,881
Hobbs	1,000	—	200	800	—	800
K. Spengler	3,710	1,050	—	4,760	—	4,760
NWSA	—	136,000	—	136,000	—	136,000
Moyer	—	1,700	—	1,700	—	1,700
Total Temporarily Restricted Net Assets	\$ 1,464,912	\$ 262,741	\$ 65,223	\$ 1,662,430	\$ 91	\$ 1,662,521

**SCHEDULE OF NET ASSETS
BY RESTRICTION (CONTINUED)**

YEAR ENDED DECEMBER 31, 2011

	Balances January 1, 2011	Receipts and Other Additions	Expenditures and Other Deductions	Total	Appreciation (Depreciation) in Fair Market Value	Balances December 31, 2011	Original Endowment
Permanently Restricted Net Assets:							
Hanks Scholarship	\$ 5,000	\$ —	\$ —	\$ 5,000	\$ —	\$ 5,000	\$ 5,000
Schroeder	100,000	—	—	100,000	—	100,000	100,000
Reed	12,112	—	—	12,112	—	12,112	10,112
Sverdrup	808	1	—	809	—	809	2,754
Leviton	5,000	—	—	5,000	—	5,000	5,000
Meisinger	12,295	—	—	12,295	—	12,295	12,695
Houghton	25,000	—	—	25,000	—	25,000	25,000
Geotis	3,620	—	—	3,620	—	3,620	4,309
Jardine	15,401	—	—	15,401	—	15,401	15,401
Milham	5,000	—	—	5,000	—	5,000	5,000
Hope	50,029	—	—	50,029	(2)	50,027	50,000
Wark	249,275	—	—	249,275	725	250,000	250,000
Vonnegut-Schaefer	24,072	—	—	24,072	—	24,072	20,735
Murphy	43,690	—	—	43,690	(3)	43,687	40,000
Kreitzberg	40,740	—	—	40,740	—	40,740	28,230
Namias	49,877	—	—	49,877	123	50,000	50,000
Total Permanently Restricted Net Assets	\$ 641,919	\$ 1	\$ —	\$ 641,920	\$ 843	\$ 642,763	\$ 624,236

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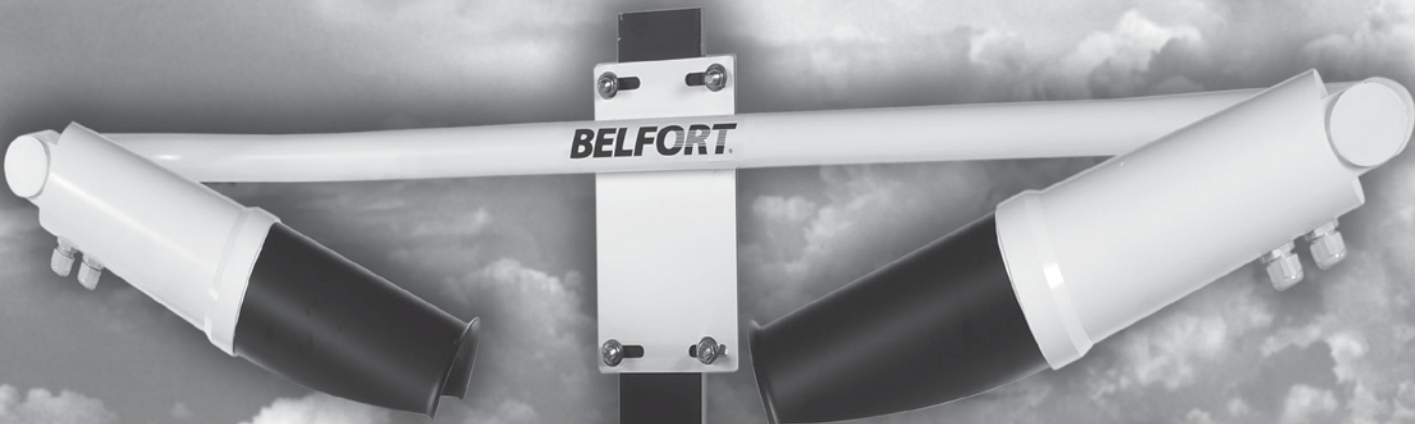
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