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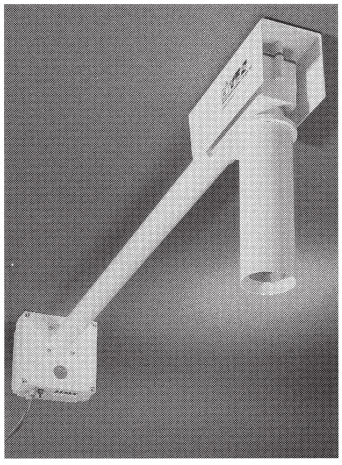

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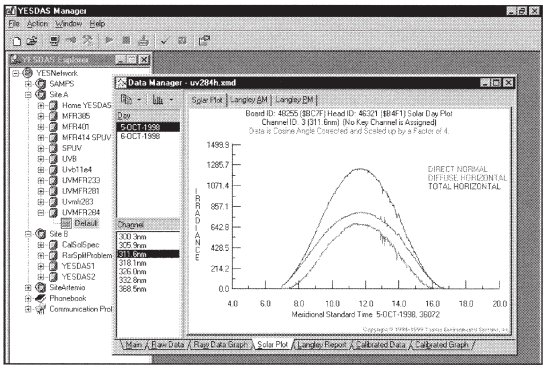

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ARTICLES

MEETING SUMMARIES

Supplements ( ) and online content are available online at http://journals.ametsoc.org/toc/bams/94/8.

ON THE COVER

Xin Li and colleagues describe a wide ranging four-year experimental program aiming to characterize the eco-hydrology of the Heihe River basin of China through installation of a world-class observing system and related modeling and research advances. See more about HiWATER on p. 1145.

READINGS

CONTENTS

NOWCAST

45 BEACON

DEPARTMENTS

FOLLOW AMS

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LETTER FROM THE EDITOR: YET ANOTHER MISTAKE ON THE COVER?

Last month the cover of *BAMS* showed three images produced by the Suomi satellite's Visible Infrared Imaging Radiometer Suite (VIIRS). The article was about VIIRS, but the cover was also about the tornado this spring in Moore, Oklahoma. The three images progressed from the synoptic scale of the outbreak to the mesoscale of cloud tops and finally to the microscale specific to Moore. The first two showed the actual tornado outbreak, while the final image, from the following night (21 May), revealed the damage swath.

Thinking that the images visually and logically led to the microscale, we labeled the cover "Moore, OK, 21 May 2013." Of course, we were getting too fancy for our own good, and astute readers promptly pointed out to us that the tornado had struck on 20 May.

All of which has prepared us for your letters again. What's the problem with the cover this time? Well, we're featuring a comprehensive effort in China to study the Heihe River Basin—only there isn't a river to be seen on this cover. Not a drop of water. Just people working atop an instrument tower with a big chunk of blue sky in the background.

Actually, we don't think this is a mistake. In selecting this image, we thought it was worth reinforcing the point that watershed science is as much about the atmosphere as about soils, vegetation, and water. We can talk watersheds without looking at water.

For the same reason, we could feature an article on sea level rise with a cover showing glaciers in Greenland. And, as Straneo et al. show us in their article in this issue, the glaciers of Greenland are themselves subject to myriad processes that aren't just about ice. The loss of mass from the Greenland ice sheet has accelerated in the last decade, but not all of this is due to ice melt at the tops of the glaciers where they interface with warming air. Some Greenland glaciers have been moving faster, retreating and thinning at a greater rate due to their interface with the ocean. Instead of the iconic images of withering ice, we in fact could imagine a cover image for this article showing the waters of the North Atlantic, without ice, because some scientists suspect the glacial melt driving sea level rise is in turn driven by oceanic processes.

Interestingly, in this issue, Ralph et al. point out a key characteristic of testbeds. These programs are in part successful in bridging the gap between research and forecasting because they are fundamentally "outsiders" to both forecast community goals and research community goals. (Speaking of Outsiders, brace yourself for another correction: *Monthly Weather Review* Chief Editor Dave Schultz notes that, contrary to my column about inseparables last month, Batman works mostly without his sidekick, Robin.)

There are indeed advantages to being outsiders, even in science, but in our community there are surprisingly few true outsiders. Make no mistake, this issue clearly shows that atmospheric scientists are not outsiders in watershed studies; nor are oceanographers outsiders in glaciology studies.

—*Jeff Rosenfeld,* Editor-in-Chief

ABSTRACTS

CHALLENGES TO UNDERSTAND THE DYNAMIC RESPONSE OF GREENLAND'S MARINE TERMINATING GLACIERS TO OCEANIC AND ATMOSPHERIC FORCING

The recent retreat and speedup of outlet glaciers, as well as enhanced surface melting around the ice sheet margin, have increased Greenland's contribution to sea level rise to 0.6 ± 0.1 mm yr^{-1} and its discharge of freshwater into the North Atlantic. The widespread, near-synchronous glacier retreat, and its coincidence with a period of oceanic and atmospheric warming, suggests a common climate driver. Evidence points to the marine margins of these glaciers as the region from which changes propagated inland. Yet, the forcings and mechanisms behind these dynamic responses are poorly understood and are either missing or crudely parameterized in climate and ice sheet models. Resulting projected sea level rise contributions from Greenland by 2100 remain highly uncertain.

This paper summarizes the current state of knowledge and highlights key physical aspects of Greenland's coupled ice sheet–ocean–atmosphere system. Three research thrusts are identified to yield fundamental insights into ice sheet, ocean, sea ice, and atmosphere interactions, their role in Earth's climate system, and probable trajectories of future changes: 1) focused process studies addressing critical glacier, ocean, atmosphere, and coupled dynamics; 2) sustained observations at key sites; and 3) inclusion of relevant dynamics in Earth system models.

Understanding the dynamic response of Greenland's glaciers to climate forcing constitutes both a scientific and technological frontier, given the challenges of

ABSTRACTS

obtaining the appropriate measurements from the glaciers' marine termini and the complexity of the dynamics involved, including the coupling of the ocean, atmosphere, glacier, and sea ice systems. Interdisciplinary and international cooperation are crucial to making progress on this novel and complex problem. *(Page 1131)*

HEIHE WATERSHED ALLIED TELEMETRY EXPERIMENTAL RESEARCH (HIWATER): SCIENTIFIC OBJECTIVES AND EXPERIMENTAL DESIGN

A major research plan entitled "Integrated research on the eco-hydrological process of the Heihe River Basin" was launched by the National Natural Science Foundation of China in 2010. One of the key aims of this research plan is to establish a research platform that integrates observation, data management, and model simulation to foster twenty-first-century watershed science in China. Based on the diverse needs of interdisciplinary studies within this research plan, a program called the Heihe Watershed Allied Telemetry Experimental Research (HiWATER) was implemented. The overall objective of HiWATER is to improve the observability of hydrological and ecological processes, to build a world-class watershed observing system, and to enhance the applicability of remote sensing in integrated eco-hydrological studies and water resource management at the basin scale. This paper introduces the background, scientific objectives, and experimental design of HiWATER. The instrumental setting and airborne mission plans are also outlined. The highlights are the use of a flux observing matrix and an eco-hydrological wireless sensor network to capture multiscale heterogeneities and to address complex problems, such as heterogeneity, scaling, uncertainty, and closing water cycle at the watershed scale. HiWATER was formally initialized in May 2012 and will last four years until 2015. Data will be made available to the scientific community via the Environmental and Ecological Science Data Center for West China. International scientists are welcome to participate in the field campaign and use the data in their analyses. *(Page 1145)*

TOWARD A STANDARDIZED METADATA PROTOCOL FOR URBAN METEOROLOGICAL NETWORKS

With the growing number and significance of urban meteorological networks (UMNs) across the world, it is becoming critical to establish a standard metadata protocol. Indeed, a review of existing UMNs indicate large variations in the quality, quantity, and availability of metadata containing technical information (i.e., equipment, communication methods) and network practices (i.e., quality assurance/quality control and data management procedures). Without such metadata, the utility of UMNs is greatly compromised. There is a need to bring together the currently disparate sets of guidelines to ensure informed and well-documented future deployments. This should significantly improve the quality, and therefore the applicability, of the high-resolution data available from such networks. Here, the first metadata protocol for UMNs is proposed, drawing on current recommendations for urban climate stations and identified best practice in existing networks. *(Page 1161)*

THE EMERGENCE OF WEATHER-RELATED TEST BEDS LINKING RESEARCH AND FORECASTING OPERATIONS

Test beds have emerged as a critical mechanism linking weather research with forecasting operations. The U.S. Weather Research Program (USWRP) was formed in the 1990s to help identify key gaps in research related to major weather prediction problems and the role of observations and numerical models. This planning effort ultimately revealed the need for greater capacity and new approaches to improve the connectivity between the research and forecasting enterprise.

SEND US YOUR THOUGHTS

We encourage readers to write to us with comments on what they read (or would like to read) in *BAMS*, as well as comments on AMS events and initiatives, or simply thoughts about what's happening in the world of atmospheric, oceanographic, hydrologic, and related sciences. When writing via e-mail, please send your messages to letterstotheeditor@ametsoc.org, or write to Letters to the Editor/*BAMS*, American Meteorological Society, 45 Beacon St., Boston, MA 02108. Your submissions will be considered for the "Letters to the Editor" column of *BAMS*.

Out of this developed the seeds for what is now termed "test beds." While many individual projects, and even more broadly the NOAA/National Weather Service (NWS) Modernization, were successful in advancing weather prediction services, it was recognized that specific forecast problems warranted a more focused and elevated level of effort. The USWRP helped develop these concepts with science teams and provided seed funding for several of the test beds described.

Based on the varying NOAA mission requirements for forecasting, differences in the organizational structure and methods used to provide those services, and differences in the state of the science related to those forecast challenges, test beds have taken on differing characteristics, strategies, and priorities. Current test bed efforts described have all emerged between 2000 and 2011 and focus on hurricanes (Joint Hurricane Testbed), precipitation (Hydrometeorology Testbed), satellite data assimilation (Joint Center for Satellite Data Assimilation), severe weather (Hazardous Weather Testbed), satellite data support for severe weather prediction (Short-Term Prediction Research and Transition Center), mesoscale modeling (Developmental Testbed Center), climate forecast products (Climate Testbed), testing and evaluation of satellite capabilities [Geostationary Operational Environmental Satellite-R Series (GOES-R) Proving Ground], aviation applications (Aviation Weather Testbed), and observing system experiments (OSSE Testbed). *(Page 1187)*

A FEASIBILITY STUDY FOR PROBABILISTIC CONVECTION INITIATION FORECASTS BASED ON EXPLICIT NUMERICAL GUIDANCE

The 2011 Spring Forecasting Experiment in the NOAA Hazardous Weather Testbed (HWT) featured a significant component on convection initiation (CI). As in previous HWT experiments, the CI study was a collaborative effort between forecasters and researchers, with equal emphasis on experimental forecasting strategies and evaluation of prototype model guidance products. The overarching goal of the CI effort was to identify the primary challenges of the CI forecasting problem and to establish a framework for additional studies and possible routine forecasting of CI. This study confirms that convection-allowing models with grid spacing ~4 km represent many aspects of the formation and development of deep convection clouds explicitly and with predictive utility. Further, it shows that automated algorithms can skillfully identify the CI process during model integration. However, it also reveals that automated detection of individual convection cells, by itself, provides inadequate guidance for the disruptive potential of deep convection activity. Thus, future work on the CI forecasting problem should be couched in terms of convection-event prediction rather than detection and prediction of individual convection cells. *(Page 1213)*

NOWCAST

NEWS AND NOTES

Atmospheric Bromine in Arctic Arises from Sunlit Snow

Climate change in the Arctic is occurring more rapidly than in other parts of the world, and a new study published in *Nature Geoscience* has found that significant changes are also taking place in the atmosphere above the Arctic Sea. The research focused on bromine, a halogen gas derived from sea salt that plays a major role in the atmospheric chemistry of the Arctic.

Atmospheric bromine is a vital component in chemical reactions that purge the atmosphere of certain pollutants. As Arctic winter fades, lower-atmosphere ozone interacts with increasing sunlight and water vapor to create an oxidizing agent that removes pollution from the atmosphere. But this low-level ozone itself is toxic to humans and plants. That's where gaseous bromine steps in, efficiently reacting with and practically eliminating the ozone present in the lower atmosphere each spring. Bromine also reacts strongly with mercury, a toxic metal that is becoming more plentiful in the Arctic as the region thaws.

The new research revealed that a significant amount of this bromine originates from sunlit snow, and that surface snowpack sitting atop Arctic sea ice is an important player in the bromine cycle. As Arctic sea ice levels have been diminishing at a greater pace in recent years, these findings suggest the potential for considerable changes in the atmospheric chemistry of the region.

In the study, scientists went to Barrow, Alaska, to study first-year sea ice, saline icicles, and snow. They performed experiments in which they placed snow and ice samples into a "snow chamber"—an aluminum box with a clear acrylic top and a special coating to prevent surface reactions. Experimenting in both darkness and natural sunlight, the researchers fed clean air with and without ozone through the chamber. They also took flights to measure the levels of bromine monoxide, a compound formed when bromine atoms react with ozone. Their work revealed that the source of the gaseous bromine was the snow sitting on top of both the sea ice and tundra. Their flight measurements were consistent with their snow chamber experiments, finding that the bromine monoxide was most prevalent over snow-covered first-year sea ice and tundra.

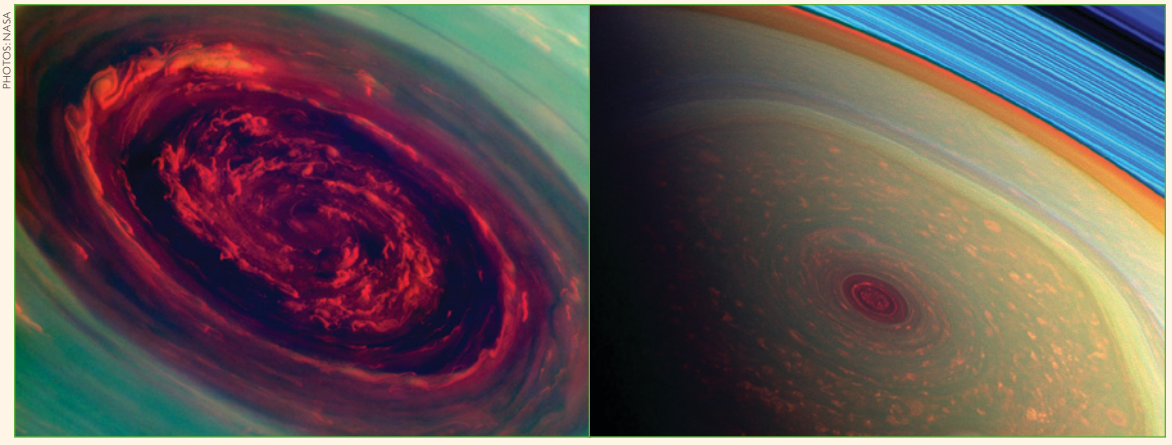
"Sea ice had been thought to be the source of the gaseous bromine," explains Purdue University's Kerri Pratt, the study's lead author. "We had an 'of course!' moment when we realized it was the snow on top of the sea ice. The snow is what is in direct contact with the atmosphere."

ECHOES

"There was this sort of magical switch. The days with dust you see one thing, and the days without dust you see a different thing."

— Kim Prather, an atmospheric chemist at the University of California, San Diego, and coauthor of a recent paper in *Science* that connected significant amounts of African and Asian dust with storms in California's Sierra Nevada that produced large amounts of precipitation. The study utilized atmospheric samples taken in 2009–11 while flying through Sierra storm clouds as well as ground measurements taken in Tahoe National Forest during the storms. The data revealed that when dust and biological particles from Asia and Africa showed up in the samples, the Pacific storms had produced more precipitation—as much as 40% more in one storm comparison. Without the particles, less precipitation was observed. The dust samples were sourced through chemical fingerprinting and examination of satellite data and numerical weather models tracking global air masses, and were found to be from the Sahara Desert as well as deserts in Mongolia and China. The authors of the paper say the study is the first to make such a direct connection. "The fact that something happening on another continent in terms of dust generation could influence precipitation patterns in the U.S.—that's a challenging problem," notes NOAA's Marty Ralph, a coauthor of the research. (Source: *Los Angeles Times*)

PHOTOS: NASA



A Hurricane on Saturn

The false-color image on the left shows a giant hurricane at Saturn's north pole, as captured by NASA's *Cassini* spacecraft last November. The hurricane's eye is approximately 1,250 miles (2,000 km) wide, making it about 40 times larger than the average Earthly hurricane eye. The thin clouds at the storm's outer edge are spinning around the hurricane at 330 mph, and the wind in the eyewall blows more than four times faster than in hurricanes on Earth. Additionally, the hurricane on Saturn stays in one place, unlike storms on Earth, which form in one area and move to another. But the appearance of the Saturnian storm is not significantly different than that of a hurricane on Earth: it has a central eye, tall clouds forming an eyewall, other high clouds around the eye, and a counterclockwise spin in the northern hemisphere.

"We did a double-take when we saw this vortex because it looks so much like a hurricane on Earth," says Andrew Ingersoll of the California Institute of Technology, who is part of the *Cassini* imaging team. "But there it is at Saturn, on a much larger scale, and it is somehow getting by on the small amounts of water vapor in Saturn's hydrogen atmosphere."

Scientists believe this storm has been active for years and hope to learn more about hurricanes on Earth by studying how this storm uses water vapor to sustain itself.

The right-hand false-color image is a broader view of Saturn's north pole, with the hurricane swirling in the center and the hexagonal jet stream (in yellowish-green) framing it. The planet's rings are in bright blue at the top right. (Source: NASA)

Pratt noted that the sea ice is critical to the process as well: without it, "the snow would fall into the ocean, and this chemistry wouldn't take place," she explains. "This is among the reasons why the loss of sea ice in the Arctic will directly impact atmospheric chemistry."

The research revealed that sunlight prompted the release of the bromine gas from the snow, and that more bromine was produced when ozone was present.

"Salts from the ocean and acids from a layer of smog called 'arctic haze' meet on the frozen surface of the snow, and this unique chemistry occurs," Pratt says. "It is the interface of the snow and atmosphere that is the key." (Source: National Science Foundation)

Cloud Composition Connected to Dust and Metal

Understanding cloud formation is an important element of climate modeling, and two new studies have made potentially significant progress in identifying the substances that constitute clouds. Both studies point to the importance of mineral dust and metallic particles in cloud formation. With global pollution levels continuing to increase, understanding the impact of these particles on cloud dynamics is increasingly important.

In one study, published in *Science*, researchers utilized high-altitude aircraft equipped with single particle mass spectrometers and particle collectors to take samples of cirrus clouds. The aircraft collected ice crystals from the clouds and, as the ice thawed and the moisture evaporated, left be-

hind were the seeds around which the crystals had formed. These seeds were studied in real time by the spectrometer and then stored in the particle collector for lab analysis. The onboard results and the lab study both revealed that more than 60% of the ice crystals formed around mineral dust and metallic particles, which is surprising because these substances are not particularly common at

THE NOT-SO-WONDERFUL BLIZZARD OF OIL

More than three years after the Deepwater Horizon oil spill in the Gulf of Mexico, a fundamental question persists: What happened to all of the spilled oil? Officials have been unable to account for some of the more than 200 million gallons that spilled out into the Gulf. New research presented at the Gulf of Mexico Oil Spill and Ecosystem Science Conference presents a theory with an intriguing name: the "dirty blizzard." Through analysis of DNA samples of sediments taken from the sea floor as well as the examination of thorium, lead, and radiocarbon isotopes, scientists discovered that spilled oil had combined with plankton and other materials in the water and fell to the sea floor in what they compared to a dirty blizzard. Jeff Chanton of Florida State University, who participated in the research, said that the sediments fell "at a rate 10 times the normal deposition rates. It was, in essence, an underwater blizzard." Because, as Chanton says, "the oil just sucked everything out of the surface," the dirty blizzard provides an explanation for why the water was not clouded with plankton after the oil spill, but instead appeared surprisingly clear: the plankton and other particles were spiraling to the ocean floor. Separate and ongoing research found that the spill also killed off millions of foraminifera—amoeba with shells that float in the water and that are the basis of the Gulf's aquatic food chain. Analysis of core samples taken from the bottom of the Gulf over the last three years revealed the die-off of the foraminifera, which followed a plume of oil flowing out of the wellhead. "Everywhere the plume went, the die-off went," says David Hollander, a University of South Florida researcher involved in that study. (Sources: Florida State University; *Tampa Bay Times*)

high altitudes in the atmosphere. Additionally, other substances that have effectively formed cloud particles in labs, such as black carbon and fungal spores, were barely detected at all in the seeds from the cirrus clouds.

"For most clouds, nucleation occurs around small aqueous droplets containing sulfates or organics," says Dan Cziczo, professor at the Massachusetts Institute of Technology and lead author of the study. "But in our samples the ice nucleation occurred mainly around particles of mineral dust, with some metallic particles."

Mineral dust is generally considered to be a natural substance, but Cziczo explained that it can also originate from man-made sources, such as agriculture, transportation, and industry. And the metal substances found in the cloud seeds—tiny fragments of lead, zinc, tin, copper, and silver—"are almost certainly from industrial activities, such as smelting and open-pit burning of electronics," according to Cziczo. Thus, he explains, there is "a human ability to change these clouds."

The second study identified mineral dust and metal in the formation of sulfates within clouds. Sulfates are believed to increase cloud formation and cause clouds to scatter more light—both of which have a cooling effect on Earth. The new research, also published in *Science*, involved the analysis of the isotope ratios of sulfur in atmospheric sulfur dioxide that entered a hilltop cloud. Comparing the ratios outside and inside the cloud revealed that within the cloud, the oxidation of sulfur dioxide occurred on the surface of coarse mineral dust particles and was catalyzed by metal ions within the dust particles. This finding contradicts the previously held belief that sulfates form in clouds predominantly through the action of peroxide formed during photochemical reactions. The authors of the study say this is a significant distinction with major implications for cloud as well as climate modeling.

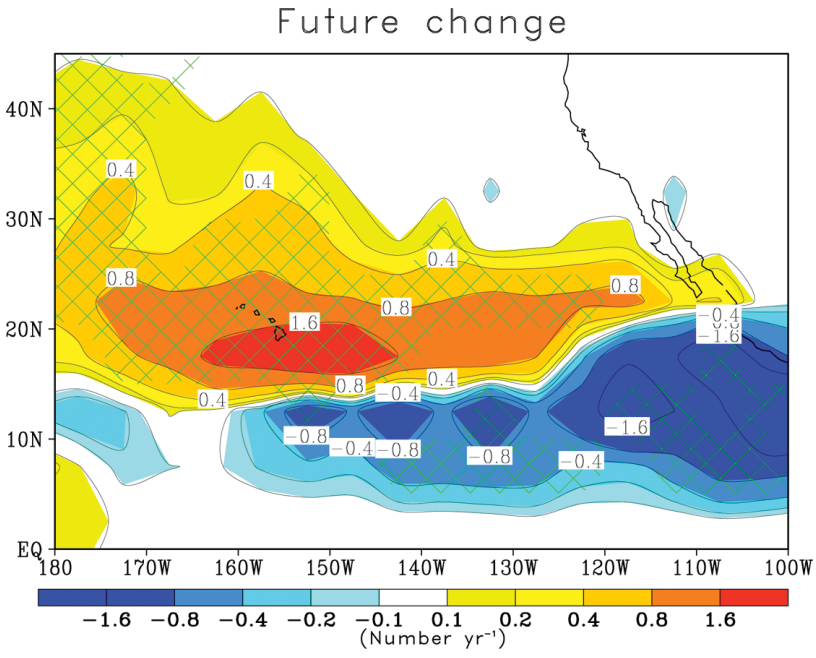
"Because peroxide has a very different distribution across the globe to mineral dust, the models predict that [sulfur dioxide] is oxidized in completely different places," says the study's lead author, Eliza Harris of the Max Planck Institute for Chemistry. "Also, because the reaction takes place on large particles, these fall out of the cloud very quickly, so the sulfate will not remain in the cloud for as long as previously thought, reducing its influence. This suggests that the cooling effect of sulfate is much less than we thought."

Cziczo noted that Harris's research had some "very interesting overlaps" with his own cloud research, noting that both studies show that "the models are incorrect because the chemistry is incorrect." He added that "we are both finding new things that will hopefully result in better predictive models." (Source: *Chemistry World*)

A Projected Uptick in Hawaiian Hurricane Activity

While most models forecast a decline in the number of tropical cyclones throughout the world as the climate grows warmer in the future, this prediction does not necessarily apply to all areas. A case in point is a new study that used high-resolution global climate modeling to project that Hawaii will experience more hurricanes by the end of this century than the current frequency of about one tropical cyclone every four years in the region.

Published in *Nature Climate Change*, the research utilized climate modeling to compare recent tropical cyclone activity in the North Pacific with a scenario for the years 2075–99 in which



Projected change in number of tropical cyclones near Hawaii per year from present day to the last quarter of this century. The green stippling indicates statistical significance at the 99% confidence level. (Photo: Hiroyuki Murakami, University of Hawaii)

global atmospheric temperatures would be about 2°C higher than today. The model projected a two-to-threefold increase in tropical cyclones around Hawaii under the future scenario. According to the study, the main reasons for this increase are variations stemming from climate change that affect large-scale moisture conditions, wind flow patterns, and surface temperature patterns.

Hurricane activity in Hawaii generally originates south of the Baja California Peninsula, where warm ocean temperatures, weak vertical wind shear, and an abundance of atmospheric moisture create ideal conditions for the development of tropical cyclones. However, before they are able to travel the 3,000 miles to Hawaii, most of those storms are cut down by a combination of cooler ocean temperatures, dry conditions over the subtropical central Pacific, and wind shear from the westerly subtropical jet. However, the new study determined that the subtropical jet will move poleward, creating an easterly mean steering flow. This, in combination with warmer sea surface temperatures, will improve conditions for storms originating near Baja California to travel all the way to Hawaii. (Interestingly, forecasts call for fewer tropical cyclones to form around Baja California in the future, but these changing conditions mean that more storms than Hawaii has now will reach the islands, though the number is expected to be low.) The research also indicates that hurricanes could form in the open ocean near Hawaii due to warming of the equatorial central Pacific.

ON THE WEB

Using Crowdsourcing to Identify Power Plants and Emissions

In his quest to discover how much CO_2 is released by all the power plants in the world, Arizona State University (ASU) Professor Kevin Gurney first had to identify the locations of the approximately 30,000 plants. He enlisted a number of undergraduate students in his lab to scour Google Earth for the locations of the largest plants, but after six months they had only found 500 across the globe. Realizing that the effort was "like looking for 25,000 needles in a giant haystack," as Gurney described it, he has now taken another approach, by creating an online game that utilizes contributions from the general public to pinpoint the locations of power plants and hopefully quantify the amount of CO_2 each releases into the atmosphere.

The project is called Ventus (http://ventus.project.asu.edu/index.html), which is Latin for "wind." In the game, players are asked for four pieces of information: the location of the power plant within a few hundred meters, the type of fuel used at the plant, the amount of electricity the plant generates, and the amount of CO_2 that is emitted from the plant. Participants in the game can contribute as much information as they have by placing pins on a Google map at the location(s) of the plants. When the game is com-

pleted in 2014, the person who contributed the largest amount of useable information will be declared "Supreme Power Plant Emissions GURU!" and will receive a trophy, as well as be a coauthor on a scientific paper about crowdsourcing in scientific research.

"Our logic is that for every power plant in the world, there are probably at least a dozen people who live near it, work at it, or know someone who works at it" explains ASU's Darragh O'Keefe, who built the website. "With the proliferation of phones and GPS, it makes it pretty easy to locate things."

Gurney notes that power plants account for close to half of all fossil-fuel CO_2 emissions in the world. But surprisingly, accurate information on power-plant emissions—and even their locations—is severely lacking, and he hopes that Ventus will help address that shortcoming.

"We hope to gather a global team of people who want to make a difference—and do so, right now," says Gurney. "The information we gather from Ventus can ultimately help determine what we as a society can do locally and globally about climate change." (Sources: *Los Angeles Times*; Phys.org)

CHAPTER CHANNEL

Historic Flash and River Flooding in and around Duluth

In March, the Twin Cities chapter hosted speakers Dan Miller and Diane Cooper. Miller is the science and operations officer at the National Weather Service (NWS) office in Duluth, Minnesota, and Cooper is the service hydrologist from the NWS office in the Twin Cities, whose responsibilities also cover the NWS Duluth area of responsibility. They talked about the historic heavy rainfall event of 19–20 June 2012 in northeast Minnesota and northwest Wisconsin, and the resultant flash flooding and river flooding.

Miller spoke first, and he summarized the event with some statistics: between 6 and 11 inches of rain fell in less than 24 hours; resultant severe flash flooding covered more than 2,500 square miles; record or near-record river flooding lasted for over two weeks; no known direct fatalities and only one known direct injury from the flooding (a child swept away in a fast-flowing stream, but rescued); preliminary infrastructure damage estimated to be $80–$100 million, but the true economic cost losses will not be known for many years; analysis by the NWS Office of Hydrologic Development showed that this event had a 0.02% to 0.05% annual chance of occurrence, making it a 200- to 500-year rainfall event for areas in and around Duluth, Cloquet, southern St. Louis County, and a small part of adjacent areas in extreme northwest Wisconsin. One of the major challenges following this event was effectively communicating recurrence intervals from both a rainfall and a hydrologic perspective to the media and other decision makers. The next time an event of this magnitude occurs in these locales, the hydrologic response could be quite different, since erosion with the 2012 event changed topography and drainage channels between 2 and 5 feet in some areas.

ECHOES

"The weather map . . . looks like something out of *The Twilight Zone*."

—Minneapolis meteorologist Paul Douglas, writing in a blog post about the unusually cold and snowy April many parts of the United States endured this year. The Rocky Mountains, the upper Midwest, and the northern Great Plains bore the brunt of the unpleasant weather, which was caused by a blocking area of high pressure over the North Atlantic Ocean, eastern Canada, and Greenland that allowed cold air from the Arctic and Canada to spill into the central and eastern United States. A number of cities—including Boulder, Colorado; Duluth, Minnesota; and Rapid City, South Dakota—experienced their snowiest month on record in April, and more than 3,000 cold records and 1,000 snow records were established across the country during the month. The cold also adversely affected crops throughout the Great Plains, causing farmers to abandon some of their winter wheat due to conditions that caused the wheat to look like "someone sprayed a defoliant on it," according to Kansas farmer Gary Millershaski. At least the extended cold weather had one positive effect: it caused the ground around Fargo, North Dakota, to rapidly thaw and absorb the snowmelt, limiting runoff and keeping the Red River—which has had five of its eight highest crests since 2001—well below its predicted spring peak. (Sources: *USA Today*; Bloomberg.com; WeatherNationTV.com)

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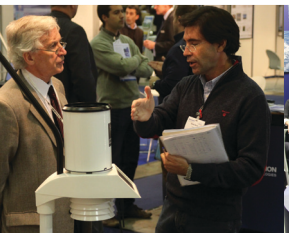
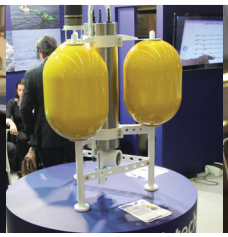


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Miller explained that the KDLH WSR-88D radar had been upgraded to dual-polarization (dual-pol) capability about a month prior to the flood event, but several factors, including clutter suppression and the cone of silence resulted in major challenges for radar-estimated precipitation amounts. In particular, some of the heaviest rainfall rates occurred almost directly over the radar, resulting in significant underestimation of the rainfall over the city of Duluth, where many of the greatest rain gauge reports were received. While the dual-pol radar-estimated rainfall estimates were significantly better than the legacy radar precipitation accumulation algorithms, even the dual-pol estimates were underestimated by 2–4 inches in some locations. Poststorm analyses indicated rainfall rates had exceeded 2 inches per hour during eight separate time intervals during the event, with one 15-minute time period exceeding rates of 8 inches per hour.

Another contributing factor to severe flash flooding in Duluth and the immediate surrounding areas along the north shore of Lake Superior was the unique nature of the geography and topography. The city of Duluth is situated on a steep hill that rises to the northwest between 800 and 1,000 feet from the shoreline of Lake Superior. The soil is largely granite rock, which facilitates rapid downhill runoff in the numerous small creeks and streams in extreme rainfall rate events. Some locations have a 20%–25% grade.

Miller also discussed the meteorological setup for this event, which was a fairly textbook one for heavy rainfall and flash flooding from an ingredients-based perspective. The upper-air sounding from the Twin Cities upper-air site the evening of 19 June was located within the warm sector inflow air mass and revealed an exceptionally high freezing level near 15,100 feet. Hence, along and south of the warm front a very deep layer existed for warm rain processes to occur. The sounding measured a precipitable water of 1.97 inches, which was above the 99th percentile of climatology for that day. From a synoptic and process perspective, the area was located beneath the right-entrance region of an anticyclonically curved downstream jet maximum, promoting a strong southerly low-level jet within the warm sector. The low-level jet was a critical feature, promoting copious low-level moisture transport into a quasi-stationary frontal zone that was located just south of the heavy rain area. In addition, the low-level jet also supported enhanced low-level warm/moist advection and strong low-level frontogenesis within the frontal zone, providing sufficient lift for continued redevelopment of thunderstorms for nearly 18 hours over the same area.

The effects from the event were severe and wide-ranging. Ten counties were declared disaster areas due to damage from flooding. In addition to the significant infrastructure damage in and around the Duluth area, rail lines between the Iron Range of northern Minnesota and the ports of Duluth and Superior (Wisconsin) were washed out, prompting the use of dump trucks to ferry supplies back and forth for five days at tremendous economic cost. In addition, there were also effects at the ports of Superior, Duluth, and Two Harbors (Minnesota). The Port of Duluth did not officially close, but most docks were inaccessible for a period of up to nine days due to strong currents, also at significant economic cost.

SUPER GRASS TO STOP FLOODS

What do you get when you cross two breeds of grass? According to a group of plant, soil, and water scientists from the United Kingdom, that would be a hybrid grass that has the potential to reduce flooding. When they cross-bred perennial ryegrass with meadow fescue, the researchers discovered that the hybrid, named Festulolium, reduced water runoff from agricultural grassland by up to 51% compared to the perennial ryegrass and by 43% compared to meadow fescue. "Hybrid grasses of this type show potential for reducing the likelihood of flood generation while providing pasture for food production under conditions of changing climate," comments Kit Macleod, catchment scientist at the James Hutton Institute and one of the authors of a paper about the research that appeared in the online journal *Scientific Reports*. He explains that the reduced runoff is due to the hybrid's intense initial root growth and subsequent rapid turnover, which allows more water to remain in the soil. They found that the grass also provides high-quality forage with resistance to weather extremes, making it even more beneficial for farmers. The scientists note that the financial savings of mitigating flooding will far outweigh any cost of producing the hybrid grass. (Source: Biotechnology and Biological Sciences Research Council)

ECHOES

"Flatulence also raises the PM level."

—Unidentified user of the Chinese microblogging service Sina Weibo, commenting on the city of Beijing's crackdown on unlicensed street vendors of mutton skewers, which was partially undertaken in an attempt to combat air pollution in the city. "Flatulence" is a Chinese slang term for nonsensical talk, which this commenter apparently felt was an appropriate description for the unpopular move to limit the number of vendors and the availability of their popular fare. A spokesman for Beijing's bureau of city administration and law enforcement stated that the stands "create serious air pollution and undesired noise for the neighborhoods," and unlicensed grill operators were facing fines of up to 5,000 yuan ($815) as well as confiscation of their grilling equipment. But while the state-run *China Daily* newspaper quoted a health official who said that smoke from the barbecue stands was a "very common" source of the unhealthy airborne particulate matter known as PM2.5, others felt the government was simply trying to harass the vendors. (Source: *The Wall Street Journal*)

Miller also showed data comparing the 2012 heavy rain event in and around Duluth to two separate heavy rainfall events on 20 August and 20 September in 1972. Overlaying isohyets from the three events revealed that the 2012 event produced much heavier rainfall, by far, over a much larger area than either of the events in 1972.

Cooper then spoke about the river flooding facet of this storm. She mentioned river stage, stream flow readings, and lake levels that resulted from the rainfall and runoff:

- Mississippi River at Aitkin: Second-highest flow on record [A diversion was built after the 1950 flood of record (FOR) to help decrease river levels in the town.]
- Mississippi River at Brainerd: 17.6 feet (A river gauge was installed in 1988, so this site has a shorter measured historical record. The actual FOR occurred in 1950, which washed out the Brainerd Dam.)
- St. Louis River at Scanlon: 16.7 feet (New FOR: USGS calculated this was a 0.002% chance of recurring, or a 500-year flood.)
- Lake Superior rose about 6 inches through June, which was enough water to cover the coterminous U.S. to a depth of 0.5 inches.

For the Mississippi River, much of the heaviest rainfall occurred downstream of flood control structures. The Corps of Engineers, which operates some of the dams there, held water, but the rain that fell flowed through uncontrolled areas. This, in addition to the fact that the USACE had computer problems during the initial part of the flood, created some challenging forecast issues.

Cooper spent a considerable amount of time talking about the flooding on the St. Louis River, which flows directly into Lake Superior. Questions were raised, including the concept of when does a flash flood become a river flood? And how do you communicate that a river flood situation is becoming significantly worse? She mentioned that the issuance of a flash-flood emergency during the evening/overnight of 19–20 June for the flooding in Duluth proper was the first such use in Minnesota.

Cooper also indicated they had forecast challenges with the St. Louis River. Typically, this river is slower responding given the flatter terrain and marshes and bogs upstream of Scanlon. There are few river gauges on the river, and Scanlon is the only river forecast point for the North Central River Forecast Center (NCRFC). The 6-hour model that NCRFC uses did not pick up on the rapid rise of the river primarily because of the rainfall intensity and the 6-hour time-step limitation.

Another challenge was Thompson Reservoir which was created by a main dam and 21 smaller structures to contain the lake. During the height of the event, all the dam's gates were open, and water was moving through the uncontrolled spillway, yet the reservoir was still rising. Downstream from the dam, the road is about 80 feet above the river bed. During the worst of the flooding, the water was at the bridge deck. The significantly high water in the St. Louis River prevented the flood water from Otter Creek, which flows in from the west just below Thompson Reservoir, to be able to move into the larger river. Hence, water backed up Otter Creek and flooded the town of Carlton. In addition, on 21 June, Thompson Reservoir overtopped four of the smaller dam's structures. This caused the flooding in the town of Thompson. Flooding also occurred in Moose Lake and Barnum on the Moose Horn River due to the heavy rain that fell upstream.

—Chris Bovitz
Twin Cities chapter

NASA'S SOIL MOISTURE ACTIVE PASSIVE (SMAP) MISSION AND OPPORTUNITIES FOR APPLICATIONS USERS

BY MOLLY E. BROWN, VANESSA ESCOBAR, SUSAN MORAN, DARA ENTEKHABI, PEGGY E. O'NEILL, ENI G. NJOKU, BRAD DOORN, AND JARED K. ENTIN

Water in the soil—both its amount (soil moisture) and its state (freeze/thaw)—plays a key role in water and energy cycles, in weather and climate, and in the carbon cycle. Additionally, soil moisture touches upon human lives in a number of ways—from the ravages of flooding to the needs for monitoring agricultural and hydrologic droughts. Because of their relevance to weather, climate, science, and society, accurate and timely measurements of soil moisture and freeze/thaw state with global coverage are critically important.

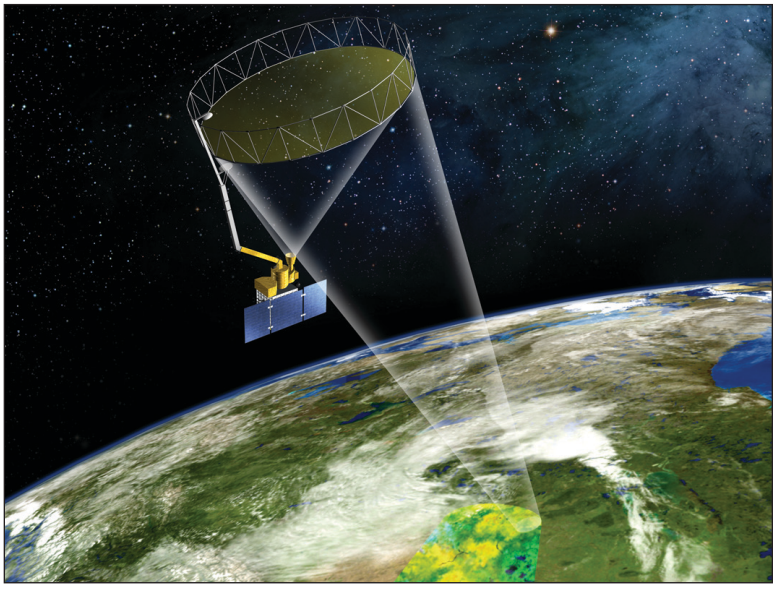

FIG. 1. The SMAP L-band radar and radiometer share a common feed and reflector antenna system. The instruments conically scan across a wide swath allowing global mapping with frequent revisit.

To address this need, NASA has initiated the Soil Moisture Active Passive (SMAP) satellite mission, as recommended by the National Research Council in their 2007 report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." Set to launch in October 2014, SMAP will use a combination of an active radar and a passive radiometer to provide global measurements of surface soil moisture and soil freeze/thaw state (Fig. 1). The synergy of active and passive microwave observations, combined with SMAP's wide swath, enables measurements of soil moisture and freeze/thaw state with high resolution and adequate sensitivity, area coverage, and revisit frequency. This design will address many scientific problems in hydrology, meteorology, and ecology, as well as provide information to science applications such as flood forecasting, drought monitoring, and numerical weather prediction.

The 2007 report tasked NASA with ensuring that "emerging scientific knowledge is actively applied to obtain societal benefits," and emphasized the importance of early and sustained interaction of the Earth science community with a broad range of organizations and individuals. From its inception, SMAP has been committed to a strong, integrated program of

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Table 1. Anticipated SMAP Mission products.

Product	Description	Gridding (resolution)	Latency*	
L1A_Radiometer	Radiometer data in time-order	—	12 h	**Instrument data**
L1A_Radar	Radar data in time-order	—	12 h	
L1B_TB	Radiometer T_B in time-order	(36 × 47 km)	12 h	
L1B_S0_LoRes	Low-resolution radar σ_o in time-order	(5 × 30 km)	12 h	
L1C_S0_HiRes	High-resolution radar σ_o in half-orbits	1 km (1–3 km)**	12 h	
L1C_TB	Radiometer T_B in half-orbits	36 km	12 h	
L2_SM_A	Soil moisture (radar)	3 km	24 h	**Science data (half-orbit)**
L2_SM_P	Soil moisture (radiometer)	36 km	24 h	
L2_SM_AP	Soil moisture (radar + radiometer)	9 km	24 h	
L3_FT_A	Freeze/thaw state (radar)	3 km	50 h	**Science data (daily composite)**
L3_SM_A	Soil moisture (radar)	3 km	50 h	
L3_SM_P	Soil moisture (radiometer)	36 km	50 h	
L3_SM_AP	Soil moisture (radar + radiometer)	9 km	50 h	
L4_SM	Soil moisture (surface and root zone)	9 km	7 days	**Science value-added**
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	

* Mean latency under normal operating conditions. Latency is defined as the time from data acquisition by the instrument to its availability in a designated data archive. The SMAP project will make a best effort to reduce these latencies.

** Over outer 70% of swath.

engagement with potential data users in applied and operational domains—the first NASA mission to have such a program before the satellite is launched. The SMAP Applications program is designed to first increase and then sustain the interaction between application users and scientists involved in mission development. The SMAP project has sponsored several applications meetings and workshops. To better reach the applications users, some of these have been held at user locations such as the U.S. Department of Agriculture (USDA), U.S. Geological Survey (USGS), and NOAA headquarters, among others. Feedback from user communities is formally and actively reported to mission scientists to broaden and facilitate eventual SMAP data access and enhance opportunities to use mission data to address societal needs. For example, collaboration between the SMAP mission and the USDA's Foreign Agriculture Service (FAS) has elicited the requirements of yield forecasting and familiarized analysts with soil moisture data. Another example pertains to the Emergency Response and Operational users, who have worked with the SMAP mission to plan for providing data in friendly formats (KMZ and GeoTIFF) for a more rapid ingestion of soil moisture data into decision-making environments.

The SMAP Applications program is ground-breaking and serves as an example for other NASA missions to expand their focus to include user communities' needs in the early phases of mission development. Through a team that includes an applications lead on the Science Definition Team (SDT), leadership from the mission, and an applications coordinator, the applications program works to characterize the community of mission data users through workshops and applied research. We have also initiated a program of Early Adopters to promote application research in the prelaunch stages of the mission, in order to provide a better understanding of how SMAP data products can be scaled and integrated onto organizations' policy, business, and management activities. These efforts will expand the use of the data after launch, and increase the societal benefit of the mission.

ECHOES

"The more unique colors that a sensor can see, the more accurately we can slice the onion into thinner slices."

— John Elwell, of Utah State University's Advanced Weather System Foundation, on the capabilities of a satellite called Sounding and Tracking Observatory for Regional Meteorology, or STORM, which is scheduled to be mounted on an AsiaSat commercial communications satellite launching in 2016. If the launch of the satellite with the sensor takes place—this particular technology has suffered the budget axe before—it will be the first hyperspectral sounder to fly in geosynchronous orbit and could become the first-ever commercially hosted weather sensor. Compared to current geosynchronous weather satellites that collect 18 channels of data, STORM takes in about 1,800 channels, giving it the capacity to create a 3D picture of the atmosphere in a process that Elwell, the project manager for STORM, describes as "peeling the onion." Since each atmospheric gas reflects a distinct wavelength of light, STORM's ability to observe the atmosphere through 1,800 wavelengths will provide unprecedented details on the movements of gases including water vapor through the atmosphere. "Storm will provide significantly earlier warning for severe weather and climate instability, and it will do so faster, more frequently, and with finer detailed measurements than any capability in orbit today," stated David Crain, CEO of GeoMetWatch, the private company that is building STORM. Long-term plans call for five more STORM payloads to hitch rides on communications satellites. (Source: *Popular Mechanics*)

The overall strategy for the SMAP Applications program is to develop a community of end users and decision makers who are interested in using SMAP products in their applications by providing opportunities to learn about SMAP's unique capabilities and scientific objectives. The SMAP science objectives are to acquire space-based hydrosphere state measurements to 1) understand processes that link the terrestrial water, energy, and carbon cycles; 2) estimate global water and energy fluxes at the land surface; 3) quantify net carbon flux in boreal landscapes; 4) enhance weather and climate forecast abilities; and 5) develop improved flood prediction and drought-monitoring capabilities. To meet its scientific goals, SMAP will fly a dedicated satellite in a near-polar, sun synchronous orbit, crossing the equator at 6:00 a.m. and 6:00 p.m. local time. The satellite will carry an L-band (1.26-GHz) radar and an L-band (1.4-GHz) radiometer that share a deployable lightweight mesh parabolic reflector, which provides a conically scanning antenna beam with a constant surface incidence angle of approximately 40° and will measure a swath approximately 1000 km wide. The combined observations from the two sensors will allow accurate estimation of soil moisture and freeze/thaw states at spatial scales valuable for both hydrometeorological (10 km) and hydroclimatological (40 km) studies.

After launch, the satellite's instruments will be calibrated (an expected time period of three months). Once calibrated, the SMAP mission will deliver estimates of soil moisture in the top 5 cm of soil with an accuracy of 0.04 cm^3/cm^3 volumetric soil moisture, at 10-km resolution, with 3-day average intervals (Table 1). Global maps will also be available of landscape freeze/thaw state derived from L-band radar at 3-km spatial resolution with a 2-day refresh rate for the high northern latitudes (i.e., latitudes above 45°N). Measurements will be made over the global land area, excluding regions of snow and ice, mountainous topography, open water, and areas of extremely dense vegetation such as tropical forests (see http://smap.jpl.nasa.gov for latency, resolution, and other details).

In addition to the instrument measurements and derived products for the surface layer, SMAP will also provide Level 4 data assimilation products by ingesting active and passive observations into land surface models to provide root-zone soil moisture (to a depth of 100 cm). A net ecosystem exchange product will also be developed that integrates freeze/thaw mea-

surements into a carbon model to provide ecosystem exchange at 9-km resolution. As these two products are intended to serve a broad community, there is an opportunity for user engagement now to optimize the design of these products so that they can ultimately satisfy user requirements.

The SMAP Applications program facilitates applied research to provide a fundamental understanding of how SMAP data products can be scaled and integrated into a user's decision-making process to improve policy, business, and management activities. By working with relevant users and early adopters before the satellite is launched, SMAP hopes to improve the pace of incorporation of the new measurements in decision-making during the life of the mission, which is expected to be at least three years. To join the SMAP Applications Working Group, which is dedicated to enabling scientists and others interested in SMAP to engage with the SMAP Science Definition Team, readers are encouraged to go to the following website: http://smap.jpl.nasa.gov/science/wgroups/applicWG.

ACKNOWLEDGMENTS. This research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

FOR FURTHER READING

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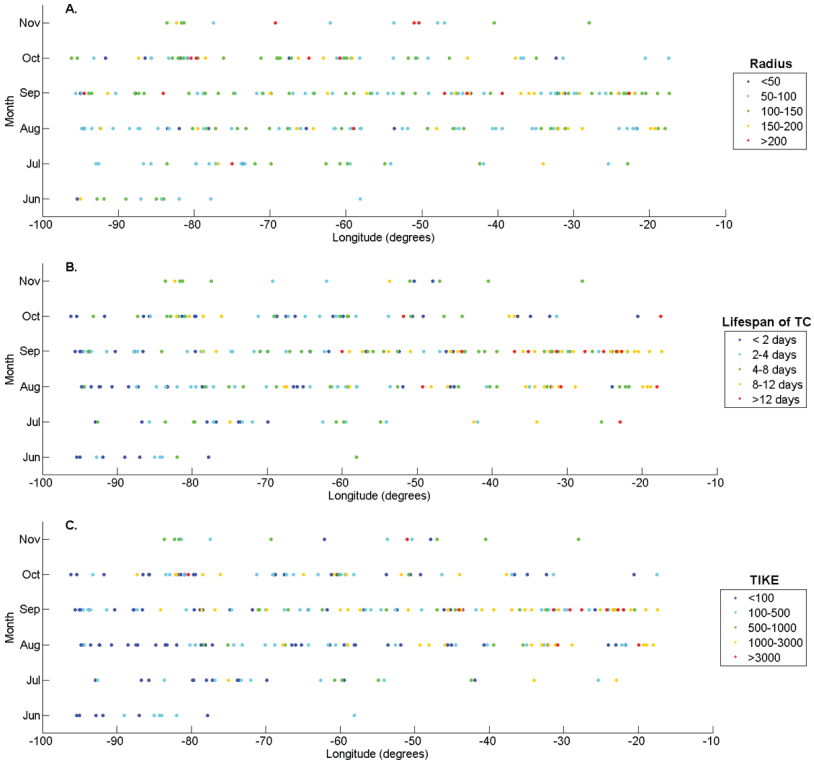
"SMAP Applications Plan" document, available at http://smap.jpl.nasa.gov.

PAPERS OF NOTE

Researchers Build New Metric for Hurricane Destruction Potential

Integrated kinetic energy (IKE) is possibly one of the better measures of hurricane destructive potential, as it relates to storm surge better than the more familiar Saffir-Simpson (Category 1–5) scale. In our research, we add a time component to IKE, essentially summing up the IKE values throughout the lifecycle of a storm. The new metric—track integrated kinetic energy (TIKE)—can then be calculated for every storm during hurricane season, creating an important metric for the destructiveness of that season.

With TIKE, kinetic energy within tropical storms and hurricanes that drives winds and



Scatter plot showing the month and longitude of formation for all storms used in the TIKE calculations. Storms are color-coded based on (a) the median radius of ≥ 17 m s^{-1} (tropical storm) winds (defined over the life span of each tropical cyclone) in nautical miles; (b) the length of time over which IKE was integrated; and (c) the value of TIKE (TJ).

waves, including storm surge, is computed by volume-integrating the 10-m level sustained winds of tropical strength or higher, quadrant by quadrant, during the lifespan of the tropical cyclone. In effect, TIKE accounts for the intensity, duration, size, and structure of the tropical cyclones.

Existing metrics such as accumulated cyclone energy (ACE) or the power dissipation index (PDI) only consider the peak wind in the storm, which is difficult to measure and typically only covers a very small area, contributing little to storm surge and wave damage. TIKE takes into account the wind forcing over a large area surrounding the storm and is therefore much more reliable as an objective measure of hurricane destructive potential.

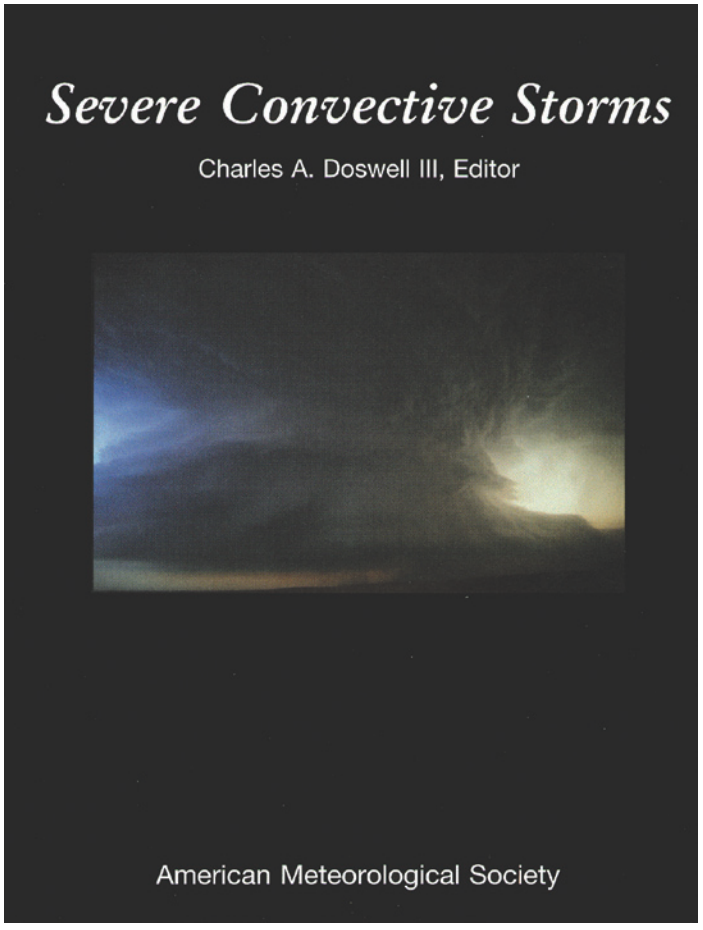
Our research established how TIKE varies through a typical season, from one season to the next, and geographically within the Atlantic basin. We used wind speed and radii data for Atlantic tropical cyclones from 1990 through 2011 and found that TIKE peaks in September with large and long-lived tropical cyclones—the so-called Cape Verde hurricanes—coinciding with the peak of hurricane season when the Atlantic basin is its warmest. TIKE is also related to sea surface temperature variations in the equatorial Pacific (warmer temperatures there coincide with lower TIKE in the Atlantic) and the Atlantic (its warmer temperatures coincide with higher TIKE there). And we discovered that hyperactive hurricane years such as 2005 do not always appear as anomalous TIKE seasons, largely because many tropical cyclones comprising such seasons are small and short-lived.

Our discovery that the busiest seasons may not equate to the highest TIKE leads us to recommend using TIKE as a complimentary metric along with existing ones (ACE, PDI, number of forecast tropical cyclones) for assessing the relative seasonal destructiveness from tropical cyclones.—Vasu Misra (Florida State University), S. DiNapoli, and M. Powell. *"The Track Integrated Kinetic Energy of the Atlantic Tropical Cyclones," in a forthcoming issue of* Monthly Weather Review.

SEVERE CONVECTIVE STORMS

Meteorological Monograph No. 50

Edited by Charles Doswell III



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CHALLENGES TO UNDERSTANDING THE DYNAMIC RESPONSE OF GREENLAND'S MARINE TERMINATING GLACIERS TO OCEANIC AND ATMOSPHERIC FORCING

BY FIAMMETTA STRANEO, PATRICK HEIMBACH, OLGA SERGIENKO, GORDON HAMILTON, GINNY CATANIA, STEPHEN GRIFFIES, ROBERT HALLBERG, ADRIAN JENKINS, IAN JOUGHIN, ROMAN MOTYKA, W. TAD PFEFFER, STEPHEN F. PRICE, ERIC RIGNOT, TED SCAMBOS, MARTIN TRUFFER, AND ANDREAS VIELI

An interdisciplinary and multifaceted approach is needed to understand the forcings and mechanisms behind the recent retreat and acceleration of Greenland's glaciers and its implications for future sea level rise

Mass loss from the Greenland and Antarctic ice sheets tripled over the last two decades, from 100 ± 92 Gt yr^{-1} (0.28 ± 0.26 mm yr^{-1} sea level equivalent) during 1992–2000 to 298 ± 58 Gt yr^{-1} (0.83 ± 0.16 mm yr^{-1}) during 2000–11 [see Shepherd et al. (2012) and references therein]. It presently accounts for about one-quarter of the observed global sea level rise (SLR) from 1992 to 2008 of 3.4 ± 0.4 mm yr^{-1} (Cazenave and Llovel 2010; Church and White 2011). This increase is largely due to Greenland, whose loss rose from 51 ± 65 Gt yr^{-1} (1992–2000) to 211 ± 37 Gt yr^{-1} (2000–11) (Shepherd et al. 2012). Independent geodetic measurements of continental uplift and Earth rotation support these changes (e.g., Jiang et al. 2010; Nerem and Wahr 2011; Bevis et al. 2012). Greenland's loss, in turn, is approximately equally partitioned between increased surface melting due to rising air temperatures (Cappelen 2010) and the unpredicted, surprising, and rapid speedup, retreat, and thinning of glaciers (Howat et al. 2007; Luckman et al. 2006; van den Broeke et al. 2009). Even though the precise chain of events is still debated, the widespread and near-synchronous glacier retreat and its coincidence with a period of oceanic and atmospheric warming suggest a common climate driver. A growing body of evidence points to the marine margins of these glaciers as the region from which this dynamic response originated (Figs. 1 and 2), leading to the hypothesis that the recent dynamic mass loss from the Greenland Ice Sheet

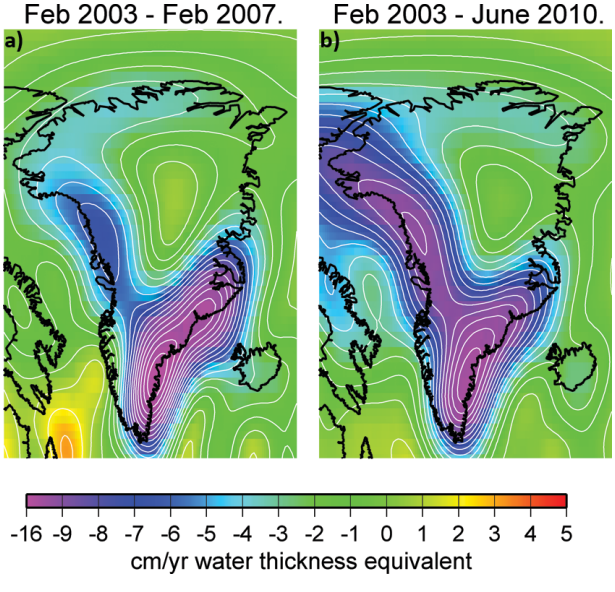

FIG. 1. Recent mass loss from Greenland is concentrated along the coastal margins of southern Greenland and spreading along western Greenland. Rate of mass loss (in centimeters per year water equivalent thickness) from Gravity Recovery and Climate Experiment (GRACE) measurements (a) between Feb 2003 and Feb 2007 and (b) between Feb 2003 and Feb 2010 [redrawn and extended from Khan et al. (2010); courtesy of S. A. Khan, DTU, Denmark].

(GrIS) was triggered by perturbations at the ice front of outlet glaciers, where it is in contact with ocean waters.

While a similar scenario is invoked to explain recent changes in Antarctica (Joughin and Alley 2011; Joughin et al. 2012), Greenland warrants special attention. First, it is not evident that Antarctic-derived results can be applied to Greenland's marine-terminating glaciers, given the different coastal and climatic conditions at the two poles, and the different types of ice flow behavior encountered (Truffer and Echelmeyer 2003). Second, the proximity of Greenland to the North Atlantic's dense water formation regions (in particular, the Greenland, Irminger, and Labrador Seas) implies that an increasing discharge of freshwater from Greenland (Bamber et al. 2012) could potentially impact the large-scale overturning circulation of the North Atlantic with possible far-reaching consequences for global heat transport and climate [see among the early studies Manabe and Stouffer (1988), and most recently Weijer et al. (2012), and references therein].

The significance of the dynamic response has been appreciated only recently and was not captured by the previous generation of ice sheet models (Little et al. 2007). Indeed, in the 2007 Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4), this shortcoming was identified as *the* largest source of uncertainty in SLR projections (Lemke et al. 2007). The global-scale problem was described in a National Science Foundation (NSF) report on "A Research Program for Projecting Sea Level Rise from Land Ice Loss" (Bindschadler et al. 2011). New-generation ice sheet models contain significant improvements that allow for more realistic simulation of outlet glaciers and their future evolution (e.g., Favier et al. 2012; Larour et al. 2012; Seddik et al. 2012). However, understanding of the relevant climate forcings and interaction with other components of the climate system has not yet reached the level necessary for realistic coupling of ice sheet models to global climate models. As a result, projections of SLR from Greenland by 2100 vary from 0.01 to 0.54 m (Meier et al. 2007; Rahmstorf 2007; Pfeffer et al. 2008; Vermeer and Rahmstorf 2009; Price et al. 2011). Overcoming this problem will require the inclusion of the forcings and mechanisms driving the dynamic responses of ice sheets in global climate models, either explicitly or in parameterized form. This becomes a priority in light of the predicted large changes in the atmosphere and ocean around Greenland. For example, using 19 Coupled Model Intercomparison Project, phase 3 (CMIP3)/AR4 climate models, Yin et al. (2011) estimate a warming of 1.7°–2°C of the upper ocean around Greenland by 2100, almost twice the global mean. More concern follows from the fact that several of Greenland's large outlet glaciers and ice streams, such as the "North-East Greenland Ice Stream" or Jakobshavn Isbræ, lie in submarine troughs that extend tens of kilometers into the ice sheet interior (Allen 2010). Destabilization of these outlet glaciers could lead to rapid and large mass losses (Hughes 1986), a scenario currently under debate (e.g, Joughin et al. 2012).

Under the sponsorship of U.S. Climate Variability and Predictability (CLIVAR), a working group on Greenland Ice Sheet–Ocean Interactions (GRISO), composed of representatives from the multiple disciplines involved, was established in January 2011 to develop strategies to address dynamic response of Greenland's glaciers to climate forcing (U.S. CLIVAR Project Office 2012b). This paper, led by this group but including the input of a broader group of interested scientists, summarizes the state of knowledge, identifies the most pressing issues, and makes recommendations on how to move forward collectively.

OBSERVATIONS, MECHANISMS, AND FORCINGS.

Evidence from observations. Approximately half of the GrIS increased mass loss over the

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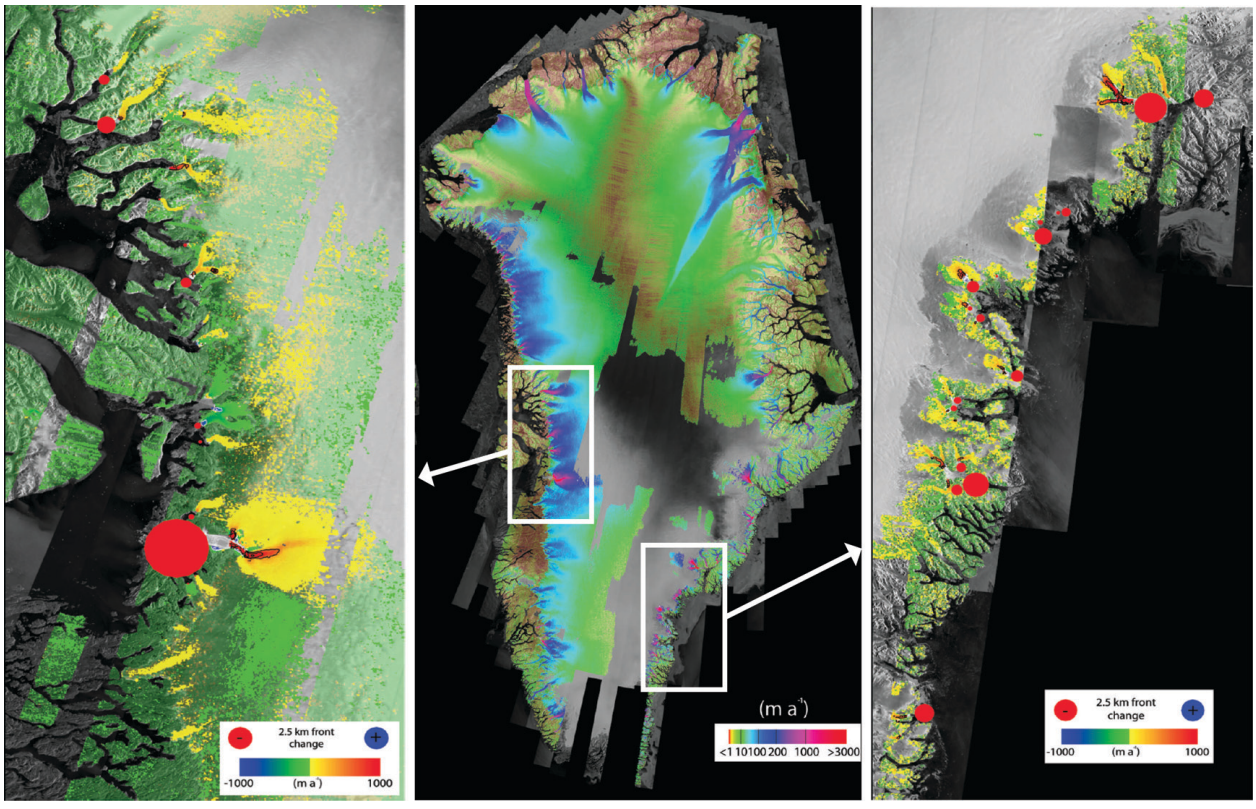

Fig. 2. (middle) Surface flow speed (in meters per annum, i.e., meters per year) showing how Greenland's fast-flowing outlet glaciers terminate into long, narrow fjords. Speedup (colors) and terminus retreat (circles) of outlet glaciers between 2000–01 and 2005–06 in (left) western and (right) southeastern Greenland (from Joughin et al. 2010).

last decade is attributed to the speedup and retreat of outlet glaciers in western and southeastern Greenland (Luckman et al. 2006; Howat et al. 2007; Stearns and Hamilton 2007; van den Broeke et al. 2009; Howat et al. 2011). These are marine-terminating or "tidewater" glaciers discharging into long, narrow, and deep fjords (Sole et al. 2008; Moon et al. 2012), such as Helheim (Fig. 3) and Kangerdlugssuaq glaciers, and Jakobshavn Isbræ. They are characterized by relatively short, floating ice tongues or grounded termini (Fig. 4a). Their mass balance is largely controlled by seasonal calving, which contributes to the presence of an ice mélange, a mixture of sea ice and icebergs, in front of the glacier termini (Amundson et al. 2010). For such glaciers, ice flow at the front, as well as the circulation of ocean waters and of the mélange, is strongly constrained by the fjord setting (e.g., MacAyeal et al. 2012). Since their speedup in the early 2000s, some glaciers have subsequently slowed down (although not necessarily to their preacceleration velocity), while others have continued in their state of accelerated flow (Howat et al. 2011; Joughin et al. 2012). In general, the spatial and temporal variability of the glaciers' speedups are complex, reflecting influence from a combination of forcings (Moon et al. 2012). Likely these combined forcings also explain why some glaciers adjacent to the glaciers that have sped up have maintained constant flow rates.

Similarly, no clear trend toward increasing speed is found for Greenland's northern glaciers (Moon et al. 2012), some of which are characterized by long floating ice tongues (10–90 km; Fig. 4b), for example, Petermann Glacier (Rignot and Steffen, 2008) and Nioghalvfjerdsbrae/79 North Glacier (Mayer et al. 2000; Joughin et al. 2001). These glaciers still calve, but, unlike the glaciers discussed above, their mass balance is largely controlled by surface and submarine melting, and their calving is likely influenced by quasi-permanent sea ice (Reeh et al. 2001). Petermann Glacier, in particular, lost about 25% of its tongue in August 2010 and another break-up of about half this size occurred in July 2012. Whether these triggered a dynamic response upstream is subject to ongoing research (Falkner et al. 2011; Nick et al. 2012).

The synchronous nature of glacier speedups and their clustering in the western and southeastern sectors of Greenland (Figs. 1 and 2; Howat et al. 2007; Rignot and Kanagaratnam 2006) suggest that glaciers

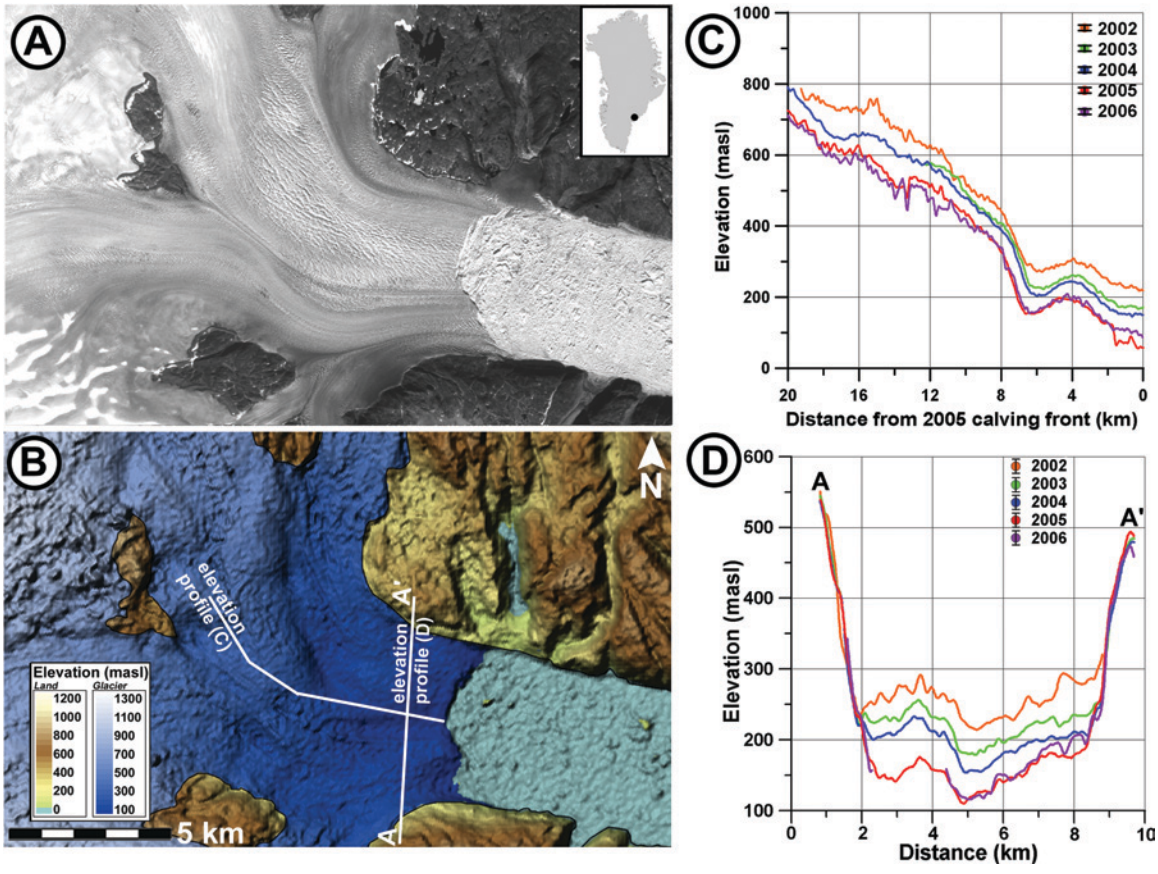

Fig. 3. Retreat and thinning of a large Greenland tidewater glacier, Helheim Glacier, in southeastern Greenland. (a) Advanced Spaceborne Thermal Emission and Reflection (ASTER) image acquired 29 Aug 2005. (b) Surface topography derived from (a). (c) Surface elevation change on the along-flow elevation profile labeled in (a) (0 km is the terminus). (d) Surface elevation change on the across-flow elevation profile labeled in (a) (from Stearns and Hamilton 2007).

are responding to a common climate forcing (Vieli and Nick 2011; Moon et al. 2012). The precise chain of events is not fully resolved, but recent work indicates that increases in speed began at the marine termini (Pfeffer 2007; Sole et al. 2008; Price et al. 2008, 2011; Pritchard et al. 2009; Nick et al. 2009) and followed a mostly similar sequence of events. Initial retreat of the marine terminus led to decreased resistance to flow, and resulted in speedup, rapid surface thinning, increased calving, and, possibly, amplification due to positive ice dynamics feedbacks (Joughin et al. 2004; Thomas 2004; Price et al. 2008; Vieli and Nick 2011; Joughin et al. 2012). Hence, the relevant climatic forcings (atmospheric, oceanic, or both) are those responsible for the initial glacier retreat.

Oceanic and atmospheric forcing of Greenland's glaciers. Greenland's large outlet glaciers terminate in fjords, which are typically less than 10 km wide, tens of kilometers long, and hundreds to 1,000 m deep. These fjords connect the ice sheet margins to Greenland's continental shelf, where cold, fresh Arctic waters flow alongside of or above warm, salty Atlantic waters (Fig. 5). Recent surveys have shown that both water masses are present in the fjords and that the warmest Atlantic waters (~2°–5°C) are found in fjords in southeastern and western Greenland at the margins of the North Atlantic's subpolar gyre [see Straneo et al. (2012), and references therein]. Deep troughs stretching across the continental shelf (e.g., Sutherland and Pickart 2008) and fjord sills that are deeper than the Atlantic–Arctic water interface contribute to the inflow of Atlantic waters into the fjords (e.g., Straneo et al. 2010; Johnson et al. 2011; Christoffersen et al. 2011), but the mechanisms controlling this exchange are largely unknown.

The bulk of the glaciers that accelerated during the last decade are located at the margins of the North Atlantic's subpolar gyre and its extension into Baffin Bay in southeastern and western Greenland. The waters in the subpolar gyre began to warm roughly at the same time as the glaciers started to retreat (Bersch et al.

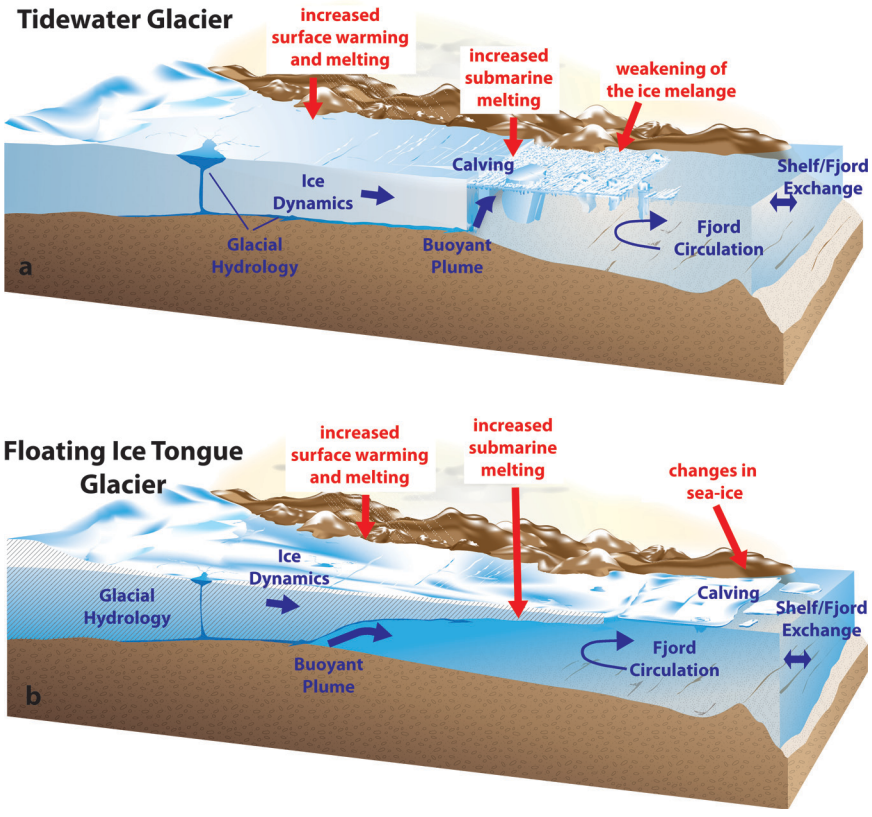

Fig. 4. Schematic of (a) tidewater and (b) floating ice tongue glacier. Proposed mechanisms for glacier retreat and ensuing glacier acceleration are shown in red (see "Overview of proposed hypotheses and mechanisms"). Key processes that need to be addressed are identified in blue (see "Process studies targeting specific dynamic regimes").

2007; Zweng and Munchow 2006), leading investigators to suggest that the glacier retreat was driven by oceanic warming (Holland et al. 2008; Murray et al. 2010; Motyka et al. 2011). Yet the mechanisms linking ocean warming with glacier retreat remain largely speculative because of a lack of long-term records from the glaciers and the fjords and a limited understanding of the dynamics involved. Some support for the ocean-driven hypothesis, however, is found in recent paleoreconstructions. Lloyd et al. (2011) have linked changes in the terminus position of Jakobshavn Isbræ over the last ~100 years to changes in water temperatures on the western Greenland shelf as reconstructed from paleoproxies. Andresen et al. (2012) linked calving activity of Helheim Glacier over the last 120 years (reconstructed using sediment cores) to variations in several oceanic and atmospheric indices, including a proxy for ocean water properties on Greenland's southeastern shelf.

If glacier retreat was due to oceanic warming, then we may expect the changes

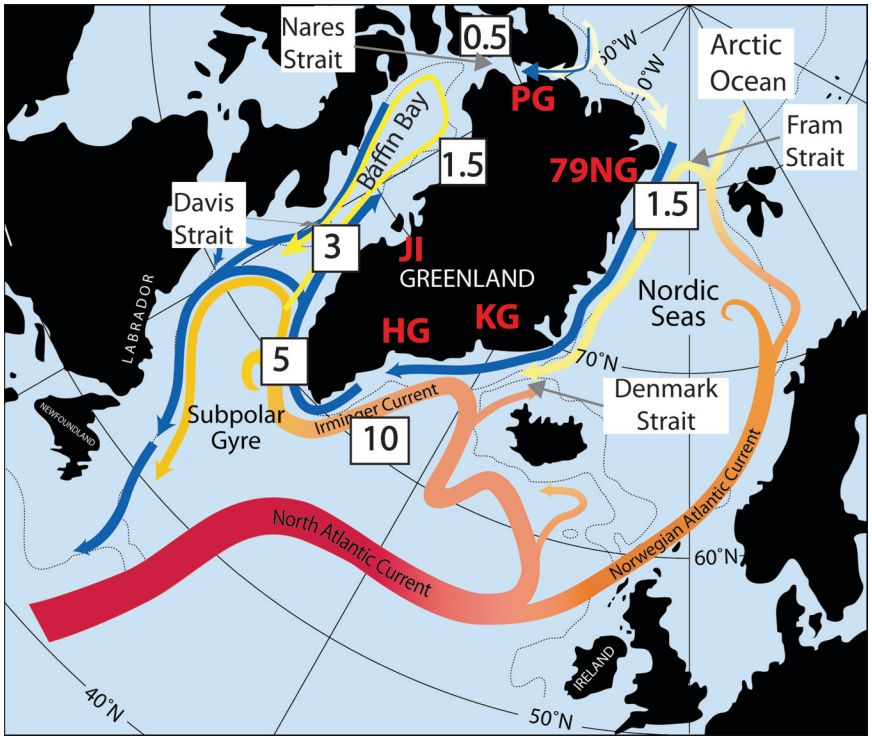

Fig. 5. Schematic circulation of warm Atlantic (red to yellow) and cold Arctic (blue) water masses around Greenland. Numbers indicate the mean temperature (°C) of the Atlantic water on the continental shelf (from Straneo et al. 2012).

to continue, since climate models predict that the ocean region around southern Greenland will experience a pronounced ocean warming (Yin et al. 2011). Furthermore, if oceanic variability can trigger glacier retreat, then it is unlikely that changes in Greenland will be confined to one region. Indeed, recent data (e.g., Schauer et al. 2008; Polyakov et al. 2004) indicate warming of the waters in the Nordic seas and Arctic Ocean, raising the question of whether the glaciers in northeastern and northern Greenland may soon start to retreat. The extent to which these glaciers, many of which are fairly slow moving with land-terminating or slowly calving termini (Moon et al. 2012), are susceptible to warming remains to be established.

Summer surface melt occurs around the marine margins of the GrIS and extends far inland in southern and western Greenland. Melting has increased (and spread farther) in the last decade according to both satellite-based observations and models (Hall et al. 2008; van den Broeke et al. 2009), thus generating larger amounts of surface and subglacial discharge that is funneled toward the tidewater glaciers and discharged in the fjords. The increase in surface melt is attributed both to rising air temperatures over Greenland (Cappelen 2010) and to a decrease in the surface albedo triggered by increased melting (Tedesco et al. 2011; Fettweis et al. 2011). Warming air temperatures over Greenland, in turn, have been linked to anomalous advection of warm air due to changes in the subpolar jet stream (Hanna et al. 2009). Another important atmospheric forcing of Greenland's tidewater glaciers is the strong wind events generated by the interaction of the large-scale atmospheric circulation (and the jet stream, in particular) with Greenland's steep orography—including barrier winds, katabatic winds, tip jets, etc. (e.g., Klein and Heinemann 2002; Moore and Renfrew 2005; Davini et al. 2012).

Overview of proposed hypotheses and mechanisms. The leading hypotheses proposed to explain the initial glacier retreat may be grouped into three broad types of trigger mechanisms (see also Vieli and Nick 2011):

1) increased submarine melting at the ice–ocean interface,
2) reduction or weakening of the ice mélange,
3) increased crevassing and structural weakening of the glacier from surface warming and melt.

Understanding how these mechanisms may act to perturb the ice sheet is key to elucidating the chain of events that led to the glaciers' increased flow speed. Below, we review these mechanisms and their links to oceanic and/or atmospheric forcings, highlighting what is and is not known.

Submarine melting at the ice–ocean interface. Ocean waters at temperatures above freezing that come in contact with the ice front can drive submarine melting. This melting contributes to the overall glacier mass balance (e.g., it is a major mass sink for Antarctica and northern Greenland's ice shelves/floating tongues), but it can also affect glacier stability by modifying the ice front. Thus, it is possible for increased rates of submarine melting, as a result of oceanic warming, to lead to increased calving and/or terminus retreat (e.g., Jakobshavn Isbrae; Vieli and Nick 2011; Motyka et al. 2011; Holland et al. 2008), disintegration of the ice tongues, and glacier speedup (Joughin et al. 2004).

In Greenland, recent surveys have shown that submarine melting is primarily driven by Atlantic waters (Rignot et al. 2010; Johnson et al. 2011; Straneo et al. 2012). [The surface layers of the fjords are warm in summer, due to surface heating (Murray et al. 2010; Christoffersen et al. 2011), but it is unclear whether these waters reach the glaciers.] These surveys have also shown that the fjords contain enough heat to melt significant amounts of ice (e.g., Holland et al. 2008; Rignot et al. 2010; Johnson et al. 2011; Motyka et al. 2011; Straneo et al. 2012; Sutherland and Straneo 2012), and that melting is limited not by the available heat but by the rate of "heat delivery" to the ice. This heat delivery, in turn, depends on a range of glaciological, oceanic, and atmospheric processes and parameters that are poorly understood.

At the ice front, the exchange of heat and mass across the ice–ocean boundary occurs on scales of millimeters to centimers, which are not resolved by either field observations or models. Hence, these transfers are heavily parameterized (e.g., Hellmer and Olbers 1989; Holland and Jenkins 1999) and dependent on the velocity and temperature (and to a lesser extent salinity) in the oceanic boundary layer (Jenkins et al. 2010). Here, the flow is conceptualized as a buoyant plume, tens of meters thick, and carrying meltwater that rises along the ice–ocean interface (Jenkins 1991, 2011). Its dynamics are influenced by glaciological factors including ice geometry (including the slope of the glacier front/ice shelf/floating tongue); ice roughness [including the impact of channels in the ice as observed at Nioghalvfjerdsfjorden/79 North (Seroussi et al. 2011), Petermann (Rignot and Steffen 2008), and Jakobshavn (Motyka et al. 2011)]; and the discharge

of surface or basal melt through the glacier's channels (Rignot et al. 2010; Jenkins 2011; Straneo et al. 2011; Xu et al. 2012; Sciascia et al. 2013).

The oceanic boundary layer and the plume are also influenced by the circulation and supply of Atlantic water driven by forcings other than the glacier itself, including tides, regional winds, and shelf variability (e.g. Haine et al. 2009). Indeed, recent surveys have revealed the fjord circulation to be complex and highly variable (Sutherland and Straneo 2012; Mortensen et al. 2011). At present only a few estimates of summer submarine melting of various Greenland glaciers have been obtained from ocean measurements (e.g., Rignot et al. 2010; Johnson et al. 2011; Sutherland and Straneo 2012). They are highly uncertain, though, given the intrinsic challenges of measuring heat transport in highly variable, iceberg-choked fjords.

Variability of the ice mélange or landfast sea ice in front of the glacier. Changes in the ice mélange and sea ice (Fig. 4a) can affect the rate of calving and the glaciers' stability (Reeh et al. 2001; Amundson et al. 2010; Walter et al. 2012). The mélange varies seasonally in extent and rigidity, which may modulate calving and speedup of outlet glaciers (Howat et al. 2010). The presence of a "solid" boundary at the water surface can dampen externally forced fjord circulation (e.g., MacAyeal et al. 2012) and reduce the surface forcing. For glaciers with long floating ice-tongues, the presence of landfast sea ice (Fig. 4b) can similarly influence calving (e.g., Reeh et al. 2001).

Both the ice mélange and the sea ice at the edge of Greenland's tidewater glaciers are susceptible to oceanic and atmospheric forcing. Weakening and potential break up of the ice can result from increased submarine melting (e.g., from warming ocean waters), increased surface melting (e.g., from rising air temperatures), or increased mechanical stresses (e.g., by an increase in the surface wind stress or surface currents).

Increased crevassing, calving, and reduced structural coherence due to surface warming and increased surface melt. Recent observational and modeling work suggests that enhanced lubrication at the bed from sustained increased surface melt likely does not play a major role in the retreat of fast-flowing glaciers (Joughin et al. 2008; Nick et al. 2009; Schoof 2010; Andersen et al. 2011; Bartholomew et al. 2012). In fact, delivery of additional meltwater to the bed might result in ice flow deceleration (e.g., Schoof 2010; Sundal et al. 2011; Hoffman et al. 2011). Meltwater filling of crevasses, however, might lead to mechanical and rheological weakening of ice, which, in turn, can enhance ice flow, as suggested by modeling and observations (Phillips et al. 2010; van der Veen et al. 2011; Colgan et al. 2011). In general, the connection between calving activity and climate forcings is not straightforward (Post et al. 2011). For many of Greenland's tidewater glaciers, however, glacier calving responds to seasonal forcing (Sohn et al. 1998); thus, irrespective of which processes drive calving, warming that extends summer and shortens winter should lead to greater calving rates.

A RESEARCH STRATEGY. The gap in our understanding of the mechanisms linking climate forcings, perturbations at marine glacier margins, and their dynamic responses constitutes a major obstacle to reducing uncertainties in Greenland's projected mass change. An interdisciplinary and multifaceted approach is needed, combining fieldwork, remote sensing, sustained observations, laboratory experiments, modeling, data analysis, and synthesis. It requires the development of existing systems as well as the establishment of new systems in a number of spheres:

- **methodology:** new approaches, theories, numerical methods to study ice–ocean coupled systems at various spatial and temporal scales;
- **technology:** new methods and instrumentation systems (e.g., to observe ice and seawater properties in harsh environments);
- **human:** close collaboration between diverse communities of scientists (oceanographers, glaciologists, sea ice and atmospheric scientists, observationalists, theoreticians, and numerical modelers) and across international borders; and
- **organizational:** proposal review and project coordination may unleash a leveraging effect, especially in terms of field campaign coordination. This is particularly the case at an international level, where no obvious field coordination mechanisms exist.

To move forward we propose three distinct scientific approaches: 1) process studies targeting specific dynamic regimes, 2) sustained observation of key systems in Greenland, and 3) inclusion of the dynamics into Earth system models. In addition to these approaches (described in detail below), several key parameters must be available to understand and model the relevant dynamics, including fjord and continental shelf bathymetry, subglacial topography, paleoproxy records, and well-resolved oceanic, atmospheric, and sea ice boundary conditions.

Process studies targeting specific dynamic regimes. Studies are needed to understand the following relevant processes and to develop/improve model parameterizations.

- **Ice–ocean boundary layer and plume dynamics:** Key measurements and modeling of the turbulent processes and their controls are needed to estimate submarine melt rates and to develop appropriate melt-rate parameterizations. Basic questions relate to how ice roughness, ice base slope, subglacial discharge, fjord circulation, and other local forcings influence the dynamics of the buoyant plume, the turbulent mixing, the circulation, and the submarine melt rate at the ice–ocean interface.
- **Fjord circulation and exchanges with the continental shelf:** Integrated observational, modeling, and data analysis efforts are needed to understand how the fjord and shelf dynamics impact properties at the ice–ocean boundary, including the sea ice and/or the ice mélange. Establishing commonalities and differences in the fjord/shelf dynamics for the large ice tongues in northern Greenland compared with the rapidly calving glaciers in the south is also key to understanding all regimes of fjord/glacier systems.
- **Glacial hydrology:** Knowledge of glacial hydrology, including the amount and timing of discharge of surface melt into the fjord environment, is key to understanding ice flow, submarine melt rate, and plume dynamics. Efforts are needed to link local atmospheric forcing to glacial hydrology, and subsequent hydrologic processes (e.g., glacier sliding) to both the ice and water drainage regimes of an outlet glacier.
- **Glacier dynamics:** Process studies need to address the transition in ice flow from large catchment basins to narrow outlet glaciers, in order to understand how the changes in stress distribution and large-scale bed geometry influence the flow of ice and its supply to the terminus. High-resolution bedrock topography beneath outlet glaciers and their catchment basins are therefore crucial.
- **Calving:** Calving plays a crucial role in both ice loss at the terminus and (indirectly) on the acceleration of inland ice flow, but its description remains elusive. Observational, theoretical, and experimental modeling efforts are necessary to develop a full understanding and realistic parameterizations of glacier calving.

Sustained observations of key systems in Greenland. Understanding the time-evolving relationship between climate forcings, perturbations at the ice–ocean interface, and the responses in terms of glacier flow and mass loss requires sustained observations. Measurements should capture glacier flow; local meteorology; oceanic conditions near the glacier front, in the fjord, and on the continental shelf; and ice mélange conditions. Data collected should also provide a measure of the heat and freshwater transport into and out of key fjords to enable budget analyses and provide boundary conditions for the ocean general circulation models (GCMs).

A sustained measuring system should include both in situ as well as air- and spaceborne components. Essential variables including ice elevation, mass balance and flow speed, ocean temperaturee and salinity, and sea ice conditions should be collected on a quasi-continuous basis at a few key sites. Space- and airborne data, such as laser and radar altimetry, synthetic aperture radar (SAR) interferometry, gravimetry, ice-penetrating radar, and optical sensors, provide valuable information to constrain many of the controlling processes because of their broad spatial and temporal coverage.

An observing system sustained over decadal time scales, while ambitious, might be within reach because the majority of the drainage across the marine margins is confined to a small number (~10) of major outlet glacier/fjord systems. The observing system may take advantage of elements already in place, including the Greenland GPS Network (GNET) constructed from 2007 onward (Bevis et al. 2012), the oceanic Arctic Observing Network (AON) and Arctic–Subarctic Ocean Fluxes (ASOF) moored arrays, and planned systems such as the Overturning in the Subpolar North Atlantic Program (OSNAP), a transbasin mooring array conceived to measure the North Atlantic subpolar gyre circulation to the east and west of southern Greenland (U.S. CLIVAR Project Office 2012a). Closer coordination of the international scientific effort already focused on Greenland outlet glaciers, fjords, and adjacent Arctic and subpolar seas; some investment in key science infrastructure (oceanographic moorings, weather stations, GPS networks, etc.); and pooling of the available logistical infrastructure would provide an essential starting point.

Complementing the sustained measurement program, a compilation and evaluation of relevant geochemistry and paleoproxy information should provide an extremely valuable context of long-term outlet glacier evolution. Mix et al. (2012) discuss the specific needs to gather new paleoproxy records and exploit existing ones.

Synthesis of the results into Earth system models. Results of process-oriented studies and sustained observations should be integrated into large-scale circulation and Earth system models to enable improved simulations and predictions of future changes in the GrIS. Coordinated modeling efforts should focus on improving:

- **Physically based parameterizations of unresolved processes.** Comprehensive representation of the dynamics of Greenland outlet glaciers and fjords (at spatial resolution on the order of 100 m or less) is beyond the capabilities of large-scale climate models, currently operating at 50–100-km grid spacing. Key physical processes identified and explored in the process studies need to be incorporated into global circulation and Earth system models. This will require new developments in the ice, ocean, atmosphere, and sea ice physical parameterizations and numerical methods capable to implement them in a computationally efficient manner. A close interdisciplinary collaboration has to be established to ensure progress.
- **Data assimilation and parameter optimization constrained by observations.** Drawing on experience from ongoing oceanographic state estimation efforts [e.g., the Estimating the Circulation and Climate of the Ocean (ECCO) project (Wunsch et al. 2009)] and in parameter inversion efforts within the ice sheet modeling community, new methodologies capable of assimilating data of diverse nature and from a variety of sources in a meaningful way are needed. State and parameter estimation requires development of comprehensive, well-structured, and sophisticated databases and data formats to allow rapid access and optimal use of the hard-won data. Maintaining and distributing these datasets will require adequate data management infrastructures, a task best taken on by experienced data centers [e.g., the National Snow and Ice Data Center (NSIDC), and the National Oceanographic Data Center (NODC)].
- **Coupling of the various components of the Earth system models.** Representing feedbacks between GrIS variability and the large-scale ocean/atmosphere circulation or other climate system components requires interactive coupling between ice sheet and climate models or components thereof. Ongoing coupling efforts are uncovering obstacles to be addressed—from fundamental assumptions of various modeling components (e.g., fixed boundaries in atmospheric and ocean GCMs vs evolving boundaries in the ice sheet models) to disparity of the characteristic temporal and spatial time scales. To make progress, a closer interaction between the communities involved and the model developers needs to be established. Given the multitude of disciplines involved, the emergence of a new generation of scientists with an interdisciplinary background would greatly benefit this problem.
- **Model testing, analysis, and intercomparison.** The hierarchy of modeling approaches described above is required as a quantitative basis for model verification and validation, and identification of systematic biases. The hierarchy covers small-scale process modeling for the purpose of developing parameterizations for inclusion into large-scale Earth system models, to model-data synthesis frameworks to integrate available observations with models, both small scale and global scale.
- **Observing system design and evaluation.** Observing system studies are required to assess which processes have the strongest impact on constraining ice mass loss, and where, with what accuracy, and at which frequency these should be sampled. In conjunction with synthesis/data assimilation systems, this can be achieved through observing system simulation experiments (OSSEs). The large scale–small scale and observation–model feedback loops should ultimately point to more targeted field campaigns to close the major gaps in linking process understanding and climate model representation. The synthesis/data assimilation systems also provide suitable frameworks for quantifying uncertainties in the link between climate forcings and glacier responses.

CONCLUSIONS. This document provides clear evidence that understanding of ice sheet–ocean interactions is a fundamental requirement for providing realistic projections of Greenland's behavior in coming decades to centuries, which, in turn, are key to reducing uncertainties in sea level rise projections and freshwater discharge into the climate-sensitive North Atlantic and Arctic Oceans. Critical aspects of Greenland's coupled ice sheet–ocean system are identified, and a research agenda is outlined that will yield fundamental insights into how the ice sheet and ocean interact, their role in Earth's climate system, their regional and global effects, and probable trajectories of future changes.

Key elements of the research agenda are focused process studies, sustained observational efforts at key sites, and inclusion of the relevant dynamics in Earth system models. Interdisciplinary and multiagency efforts, as well as international cooperation, are

crucial to making progress on this novel and complex problem. Integration of this new knowledge into a comprehensive picture of the coupled North Atlantic–Arctic–Greenland system will be a significant step toward fulfilling the goal of credibly projecting sea level rise over the coming decades and century.

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HEIHE WATERSHED ALLIED TELEMETRY EXPERIMENTAL RESEARCH (HiWATER)

Scientific Objectives and Experimental Design

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An eco-hydrological experiment designed from an interdisciplinary perspective addresses problems including heterogeneity, scaling, uncertainty, and closing water cycle at the watershed scale.

A major research plan entitled "Integrated research on the eco-hydrological process of the Heihe River Basin" (hereafter referred to as the Heihe Plan) was launched by the National Natural Science Foundation of China (NSFC) in 2010. The scientific objectives of the Heihe Plan is to reveal the processes and mechanisms of the eco-hydrological system in an inland river basin at different scales (e.g., leaf, individual plant, community, landscape, and watershed scales); to improve the research capabilities and predictability of the evolution of hydrological, ecological, and economic systems; to determine the responses of eco-hydrological processes to climate change and human activities; and to provide fundamental theory and technical support for water security, ecological security, and sustainable development in inland river basins. Eventually, the implementation of the Heihe Plan will establish a research platform that integrates the observation, data management, and model simulation of both physical and socioeconomic processes to foster twenty-first-century watershed science in China.

The Heihe River basin (HRB) in the arid region of northwest China has been selected as an experimental watershed to carry out this research plan. This area was selected because, first, the HRB is a typical inland river basin (endorheic basin). Inland river basins occupy approximately 11.4% of world's land

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area. Most of them are distributed over arid regions, where water-stressed ecosystems are massively distributed (Rodriguez-Iturbe and Porporato 2004), eco-hydrological processes are more complicated, and the environment is more fragile to climate change and anthropogenic disturbance and therefore the water conflict between ecosystem's demand and economic development is more severe. All of the above extremes are found in the HRB (Cheng, 1996; Wang and Cheng 1999; Li et al. 2001). Second, the HRB has long served as a test bed for integrated watershed studies as well as land surface or hydrological experiments (Cheng 2009). Comprehensive experiments such as the Heihe Basin Field Experiment (HEIFE; Hu et al. 1994) and Watershed Allied Telemetry Experimental Research (WATER; Li et al. 2009) have taken place in the HRB. A prototype watershed observing system has been developed (Li et al. 2010b). The above-mentioned reasons have made the HRB an ideal field laboratory to further pursue integrated eco-hydrological studies and integrated river basin management that can benefit both the natural ecosystem and society.

Heihe Watershed Allied Telemetry Experimental Research (HiWATER) was initialized based on the reasons provided in the background above. It is designed to be a comprehensive eco-hydrological experiment in the framework of the Heihe Plan, based on the diverse needs of the interdisciplinary studies of the research plan and the existing observing infrastructures in the basin. The overall objective of HiWATER is to improve the observability of hydrological and ecological processes, to build a world-class watershed observing system, and to enhance the applicability of remote sensing in integrated eco-hydrological studies and water recourse management at the basin scale. However, determining how these goals are to be met is a challenging task.

The first challenge is how to take advantage of new trends in hydrological and ecological experiments as well as new Earth observing techniques. In Earth science, there is a tradition of using comprehensive experiments as a tool to improve the understanding of processes, and to test scientific hypotheses and new measurement techniques. However, most land surface or hydrological experiments conducted to date put their emphases on large-scale processes to serve the parameterization of subgrid processes for general circulation or land surface models (André et al. 1986; Sellers et al. 1988). River basin hydroclimatic studies have also focused on the continent scale (Stewart et al. 1998; Raschke et al. 2001; Lawford et al. 2004). Only in recent years has the trend shifted toward using the watershed as a basic observing entity. Some research plans, such as the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI; CUAHSI 2007), Critical Zone Observatories (Anderson et al. 2008), Water and Environmental Research Systems Network (NRC 2010), and Terrestrial Environmental Observatories (TERENO; Bogena et al. 2006) have selected representative river basins in different climate zones to carry out comprehensive experiments or build multiscale observatories. Indeed, measurement techniques are rapidly advancing. Remote sensing is reshaping hydrological observations. Many traditionally unobservable variables, such as groundwater and river flow, can now be retrieved by remote sensing (NRC 2008a). On the ground, new technologies, such as the eddy covariance system (EC), large aperture scintillometer (LAS), cosmic-ray neutron probe, and wireless sensor network are being applied (NRC 2008b). However, how to effectively use these technical advances in modeling and understanding eco-hydrological processes remains elusive. Understanding how to take advantage of the aforementioned research trends is therefore a serious challenge in HiWATER.

The second challenge is how to capture the strong land surface heterogeneities and associated uncertainties within a watershed. Observing and modeling at the watershed scale is more challenging than at the point scale because of inherent multiscale heterogeneity (Sivapalan et al. 2003). New generation observing techniques (e.g., those introduced in the paragraph above) are reliable in their direct measurements. However, in terms of spatial representativeness, which requires appropriate scaling, both remote sensing and in situ observations feature much greater uncertainties. In terms of the reliability of retrieval and estimation models, which transform direct measurements into the necessary hydrological and ecological variables or parameters, these observations also feature much greater uncertainties. This means, while the original measurements do capture the heterogeneities, translating these measurements into useful information in understanding eco-hydrological processes requires appropriate scaling schemes and carefully developed models that can provide reliable retrievals. In turn, optimal observation network designs and sampling strategies as well as suitable approaches to quantify the uncertainties associated with scaling and estimation/retrieval models are needed.

The third challenge is more specific: how to close the water cycle in a river basin. Water should be closed on the various scales of drainage basins,

from tens of square kilometers to hundreds to tens of thousands of square kilometers for entire river basins. This problem, though not difficult in principle, still involves great uncertainties in the measurement and estimation methods used to study many water cycle components. Evapotranspiration might be the most uncertain component. Its measurement using the EC technique is challenged by the energy balance closure problem (Foken 2008); its remote sensing estimation is far from reaching a mature stage (NRC 2008a). Precipitation, in both cold and arid regions, features great spatiotemporal heterogeneity. Reliable areal estimations of total precipitation and the associated spatiotemporal variation require careful calibrations for different types of precipitation and a specially designed ground observation network (Yang et al. 2009). Soil moisture, when measured by remote sensing, is currently only available at a very coarse resolution that is not particularly useful for watershed-scale applications. Snow water equivalent in mountainous areas still cannot be accurately measured from space (NRC 2008a). Therefore, although HiWATER will measure both hydrological and ecological processes, closing water cycle is a top priority.

Addressing the above-mentioned challenges with innovative ideas will make HiWATER different from previous hydroclimatic experiments and its predecessor WATER. In short, HiWATER is a watershed-scale eco-hydrological experiment designed from an interdisciplinary perspective to address complex problems, such as heterogeneity, scaling, uncertainty, and closing the water cycle at the watershed scale.

SCIENTIFIC OBJECTIVES. The overall objective of HiWATER is to improve the observability of hydrological and ecological processes, to build a world-class watershed observing system, and to enhance the applicability of remote sensing in integrated eco-hydrological studies and water recourse management at the basin scale.

This is being achieved through the following specific objectives:

1) To develop a watershed observing system that serves watershed science and integrated water resource management;
2) To precisely measure each component of water cycle using multiscale observations in order to close water cycle at the river basin scale;
3) To obtain multiscale data critical to understanding ecosystem dynamics and its relationship with water resource availability in the inland river basin;
4) To produce a series of high-quality remote sensing products that can support basin-scale integrated eco-hydrological studies;
5) To validate remote sensing models, algorithms and products through purposeful validation experiments; and
6) To integrate observation data and remote sensing products into a distributed hydrology model, coupled surface water-groundwater-crop growth model and water consumption model upstream, middle stream and downstream of the HRB, respectively. It is expected that through these empirical case studies the applicability of remote sensing in eco-hydrological studies and water recourse management can be enhanced.

There are six scientific questions that will be explored in HiWATER. Most of the questions are proposed from a methodological point of view.

1) How well can remote sensing data be used to improve our understanding of the eco-hydrological processes in a river basin? How can we develop more reliable and robust eco-hydrological remote sensing methods through field experiments?
2) Which types of remote sensing products are urgently needed in eco-hydrological studies? How can remote sensing products be tailored toward water cycle and ecological processes at the watershed scale with better quality and finer resolution?
3) How well can we capture the spatio-temporal variations of each observation item at the basin scale? How well can we design an in situ observation network? What is the optimum density and scale of each individual observation sensor?
4) How can we design in situ sampling strategies aimed at remote sensing validation? How can we acquire ground truths at the pixel scale over heterogeneous land surfaces that can be used as a reference truth for remote sensing validation?
5) How can we effectively use remote sensing observations and products in integrated eco-hydrology studies?
6) How can we integrate remote sensing observations, in situ measurements, and model simulations to accurately estimate the state variables and fluxes in water cycle and ecological processes, and to improve the accuracies of hydrological and ecological simulations and predictions at the basin scale?

EXPERIMENTAL AREA. The experiment will be performed in the Heihe River basin (Fig. 1), which is

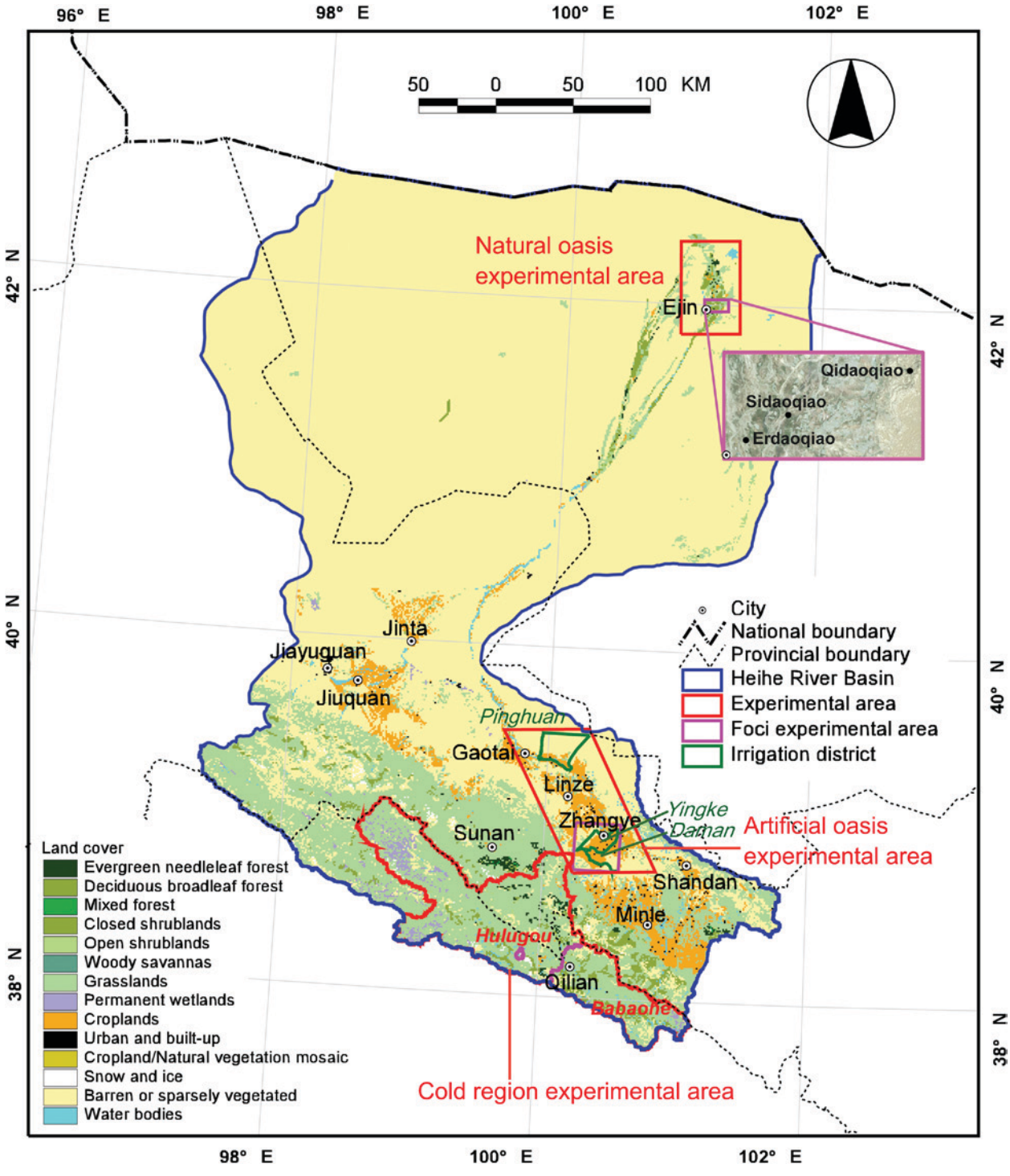

Fig. 1. Experimental areas in HiWATER.

located within 37.7°–42.7°N, 97.1°–102.0°E, covering an area of approximately 1,432,000 km^2.[1] This basin is characterized by its distinct cold and arid landscapes: glaciers, frozen soil, alpine meadow, forest, irrigated crops, riparian ecosystem, and desert, which are distributed upstream to downstream. In the whole river basin, three key experimental areas (KEAs) were selected to conduct intensive and long-

[1] The areal coverage and the area of the HRB are different from those in WATER. This is because we re-delineate the river basin boundary.

term observations. These KEAs are the cold region experimental area in the mountain cryosphere of the upper reaches, the artificial oasis experimental area in the middle reaches, and the natural oasis experimental area downstream. Within each KEA, the foci experimental area (FEA), the experiment site (ES), and the elementary sampling plot (ESP) were designed as hierarchically nested locations of multiscale ground observations.

1) The cold region experimental area consists of the upstream regions of the main stream of the Heihe River (102,009 km^2). Observation experiments are performed at three scales: the main stream basin, sub-basin (Babao River basin), and watershed (Hulugou catchment).

   The Babao River basin is a sub-basin in the upper reaches of the HRB with an area of approximately 2452 km^2 and an elevation ranging from 2640 to 5000 m. The Hulugou catchment is a typical alpine catchment with an area of 23.1 km^2. These two FEAs have almost all of the typical landscapes of cold regions, including alpine grassland, swamp, alpine meadow, valley bush, *Picea crassifolia*, and *Qilian juniper*, among others. Permafrost, seasonal frozen soil, alpine cold desert, snow, and glaciers exist in the area.
2) The artificial oasis experimental area is located in an artificial oasis–riparian ecosystem–wetland–desert compound in the middle reaches of the HRB. Some typical irrigation districts (e.g., Yingke and Daman as well as Pingchuan) are selected as the FEAs. The precipitation in this area is approximately 100–250 mm per year, but potential evaporation is as high as 1200–1800 mm per year. The major crops are maize, wheat, and vegetables.
3) The natural oasis experimental area is located in the Ejin Banner oasis, which is downstream of the HRB. The landscapes are composed of sandy and gravel deserts, a natural oasis dominated by *Populus euphratica*, *Tamarix*, and other arid region species, as well as terminal lakes. Regions of the river bank from Erdaoqiao to Qidaoqiao are selected as the core FEA. This area is an extremely arid region, with precipitation of less than 50 mm per year and potential evaporation of approximately 3755 mm per year.

OBSERVING VARIABLES AND PARAMETERS. Three categories of variables/parameters are to be observed. These include the state variables and fluxes of key eco-hydrological processes, atmospheric forcing data, and parameters (e.g., vegetation, soil, terrain, hydrology, and aerodynamic parameters). These variables and parameters were selected with reference to some typical distributed hydrological models, groundwater models, crop growth models, dynamic vegetation models, and land surface models; most of these models have been employed in hydrological and ecological studies in the HRB (Li et al. 2010a). The major referenced distributed hydrological models are the Distributed Hydrology Vegetation Model (DHSVM; Wigmosta et al. 1994), the Soil and Water Assessment Tool (SWAT; Arnold and Fohrer 2005), GEOtop (Rigon et al. 2006), and a distributed biosphere hydrological model (WEB-DHM; L. Wang et al. 2009). Various versions of ModFLOW are used as core groundwater models (Harbaugh et al. 2000). The Lund–Potsdam–Jena Dynamic Global Vegetation Model (LPJ-DGVM; Sitch et al. 2003) is the dynamic vegetation models and WOFOST (Vandiepen et al. 1989) is the crop growth model. The Simple Biosphere Model, version 2 (SiB2; Sellers et al. 1996), Common Land Model (CoLM; Dai et al. 2003), and Community Land Model (CLM; Oleson et al. 2010) are referenced as land surface models. The newly developed coupled models for the HRB have also been used as reference models (Tian et al. 2012; Zhang et al. 2013; Zhou et al. 2012).

Tabulation of the variables and parameters can be found online at http://hiwater.westgis.ac.cn/english/index.asp.

EXPERIMENT COMPOSITION. HiWATER is composed of fundamental, thematic, application experiments and integrated studies.

Fundamental experiments. The fundamental experiments focus on the establishment of observing system, provision of basic datasets, enhancement of observation capabilities, and development of reliable and robust methods. The four following experiments are included.

Airborne remote sensing experiment. An imaging spectrometer, light detection and ranging (lidar) system, charge-coupled device (CCD), multi-angle thermal infrared camera, and microwave radiometer are used in the airborne missions. The goal of these missions is to improve the remote sensing methods for observing key eco-hydrological processes and to develop scaling methods by acquiring multispatial-resolution remote sensing data.

The airborne sensors used in HiWATER are listed in Table 1.

Table 1. Airborne sensors used in HiWATER.

	Instrument	Major instrument characteristics
	Lidar+CCD	Leica ALS70, maximum flight altitude: 5000 m AGL, field of vision (FOV) 75°, first, second, and third return intensities, vertical placement accuracy: 5–30 cm, integral digital camera: 1280 × 1024 pixels
	CASI-1500 VNIR & SASI-600 SWIR imaging spectrometer	CASI: spectral range: 380–1050 nm, 1500 across-track pixels, 48 bands, bandwidth: 7 nm, FOV: 40°; SASI: spectral range: 950–2450 nm, 600 across-track pixels, 101 bands, bandwidth:15 nm, FOV: 40°
	TASI-600 pushbroom hyperspectral thermal sensor system	Spectral range: 8000–11500 nm, 600 spatial pixels, 32 bands, bandwidth:110 nm, FOV: 40°
	Wide-angle infrared dual-mode line/area array scanner	Thermal imaging camera: 8–12 μm, FOV: 80°, observation angles: ±46° (+forward, -backward); CCD camera: five bands at 550, 650, 700, 750, and 750 nm, 1360 × 1024 pixels, observation angles: ±52°
	PLMR	Frequency: 1.413 GHz, bandwidth: 24 MHz, resolution: 1 km (flight altitude: 3 km AGL), adjustable incident angle: ±7°, ±21.5°, ±38.5°, sensitivity <1 K, polarization: V/H
	L-band passive microwave radiometer	Frequency: 1.413 GHz, bandwidth: 20 MHz, sensitivity: 0.08 K, beam angle: 15°, incident angle: 45°, polarization: V/H
 	K- and Ka-band passive microwave radiometers	Frequency: 18.7 GHz (K-band) & 37 GHz (Ka-band), bandwidth: 400 MHz, sensitivity: 0.15 K, beam angle: 2.5°, incident angle: 45°, polarization: V/H, imaging scan range: ±12°

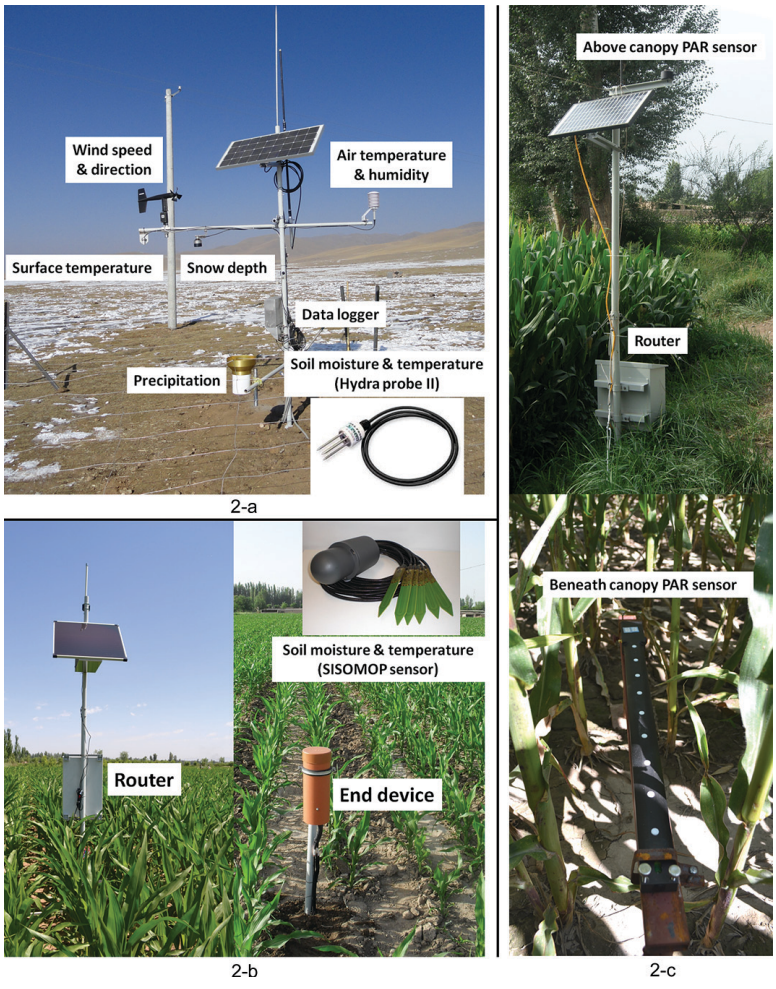

Fig. 2. Wireless sensor network: three types of new sensor nodes used in HiWATER: (a) WATERNET, (b) SoilNet, and (c) LAI measurement system.

Hydrometeorological network. This aims to establish a comprehensive hydrometeorological observation network composed of super, research, ordinary, and conventional stations that cover the whole HRB to provide representative atmospheric forcing data and validation data for the watershed models.

The ordinary automatic meteorological station (AMS) measures the radiation, precipitation, air pressure, wind speed and direction, air temperature, humidity, soil moisture and temperature profiles, and soil heat flux. The superstation is outfitted with an EC system, a Bowen ration energy balance system, an LAS, and a lysimeter (optional) to measure fluxes at multiple scales. Additionally, besides the standard observations performed in an ordinary station, photosynthetically active radiation (PAR) and land surface temperature (LST) are measured at a superstation.

Precipitation is highly uncertain in cold and arid regions for wind-induced error and wetting loss (Yang et al. 2009). Therefore, a precipitation correction experiment is carried out to develop calibration formulas for different rain gauges employed in the HRB. Additionally, intensive river runoff observations supplement existing hydrological stations along the mainstream of the Heihe River.

Eco-hydrological wireless sensor network. The eco-hydrological wireless sensor network (WSN) in HiWATER aims to integrate a variety of hydrological, ecological, and meteorological observation facilities distributed in the HRB. Three types of new sensor nodes are designed or used, including the WATERNET (Fig. 2a), SoilNet (Fig. 2b), and leaf area index (LAI) measurement systems (Fig. 2c). The AMSs and flux towers are reconfigured with wireless transmission capacities. Relevant studies about the optimal spatial sampling strategy of the sensor nodes have been performed to capture the spatiotemporal variations of key eco-hydrological parameters over heterogeneous land surface, for example, at the watershed or pixel scale (Ge et al. 2012).

The sensor nodes communicate with the data center through wireless transmission techniques such as Zigbee, General Packet Radio Service (GPRS), and microwave antenna. A software platform for the WSN has been developed. This system has the functions of transmitting and archiving automatically observed data and controlling sensor nodes and instruments remotely. As a result, the platform is anticipated to establish an automatic, intelligent, and remote-controllable eco-hydrological WSN in the HRB (Jin et al. 2012).

Calibration and validation experiment. The main tasks of the calibration and validation experiment are as follows.

- Calibration. Measurements on the radiometric calibration, atmospheric correction, and geometric rectification of airborne and satellite remote

sensing data are carried out. In particular, air temperature and humidity profiles and aerosol properties are measured by a digital sounder and sun spectrophotometers. GPS-tracking sounding balloons are released before and after each airborne mission. The wind speed at various heights above the ground and the thermodynamic structure of the lower layer of the atmosphere are measured by an acoustic wind profiler, with a vertical range of up to 1000 m above the ground.

- Ground-based remote sensing. The emissivity spectra of different land surfaces during different seasons are systematically measured by an infrared spectrum analyzer. The microwave radiation characteristics of typical land surfaces are measured using a ground-based microwave radiometer.
- Validation. The remote sensing products to be validated are products of land cover type, plant structure, vegetation type, LST, albedo, soil moisture, snow depth, LAI, fraction of PAR (FPAR), fraction of vegetation cover (FVC), net primary production (NPP), and net ecosystem production (NEP). Pixel-scale ground truths are obtained simultaneously with airborne and satellite overpasses with the aid of the WSN.

Thematic experiments. The thematic experiments are concentrated on specific hydrological or ecological processes. The first thematic experiment in HiWATER is the multiscale observation experiment on evapotranspiration (ET) over inhomogeneous land surfaces (Liu et al. 2013, unpublished manuscript). During the lifetime of HiWATER, more thematic experiments are planned, such as one for soil moisture and one for ecosystem biomass.

ET is the most important component of the water cycle in arid regions. It is also a key process that links hydrology with ecosystem dynamics, from stoma to landscape scales. Therefore, a multiscale observation experiment on ET using a flux observing matrix is carried out to reveal the spatial heterogeneities of ET, to explore the energy balance closure problem, to identify scaling effects, and to provide ground truths that correspond to the development of the remote sensing models and scale transformation approaches for ET over heterogeneous land surfaces (Jia et al. 2012).

Application experiments. The application experiments aim to prove the applicability of remote sensing in integrated eco-hydrological modeling and water resource management by carrying out comprehensive experiments in the upper, middle, and lower reaches of the HRB, in association with fundamental experiments. The following experiments are included.

Remote sensing hydrology experiment for cold regions. Carefully designed observations will be performed to calibrate and validate distributed cold region hydrological models that feature detailed descriptions of snow and soil freeze/thaw processes. Algorithms for the estimation of snow cover area (SCA) under complex terrains and a dynamic function between SCA and snow water equivalent (SWE) at the grid scale will be developed and validated through airborne missions and in situ measurements. These algorithms are expected to improve the forecasting of runoff, especially spring runoff, in mountainous areas by assimilating remote-sensed SCA and soil moisture products into a distributed cold region hydrological model.

Remote sensing experiment for optimal allocation of irrigation water in the middle stream of the HRB. Measurements of water balance components in some irrigation districts are being carried out to calibrate and improve coupled surface water–groundwater–crop growth models. With the aid of remote sensing products, such as vegetation type, vegetation coverage, phenophase, NPP, and soil moisture, the coupled model is to be expanded to the irrigation district scale based on a state-of-the-art data assimilation method. With these data, the coupled model is expected to realize real-time monitoring and the short-term forecast of water demand/supply and crop growth situation at the irrigation district scale to further optimize irrigation management and enhance water use efficiency.

Remote sensing experiment to support scale transformation of ecosystem water consumption in the downstream oases of the HRB. This experiment will carry out multiscale comprehensive observations to measure the water consumption of the oasis ecosystem downstream to validate and calibrate scale transformation approaches of water consumption from the single plant-canopy-community to regional scale. Airborne lidar missions will be performed to acquire key vegetation structure parameters that are needed in scale transformation. In this context, the water consumption of the riparian forest ecosystem will be quantified with the support of remote sensing.

Integrated studies. Except for field campaigns, integrated research also plays an important role in HiWATER. These studies aim at producing remote

sensing products to study water cycle and key ecological processes.

For water cycle, a daily SCA product with a resolution of 500 m will be created by using Moderate Resolution Imaging Spectroradiometer (MODIS) data and based on a nonlinear spectral mixture analysis model. A soil moisture product with a resolution of 1 km will be generated by merging microwave remote sensed data and MODIS VI products. Hourly precipitation products with resolutions of 1–5 km will be created by assimilating passive microwave observations, Doppler radar, and ground measured rainfall data into the Weather Research And Forecasting (WRF) model.

For ecological variables/parameters, monthly vegetation maps across the whole HRB will be generated based on differences in topography, vegetation type, and vegetation structure to reveal the characteristics of vegetation phenology. The data products of FVC, LAI, FPAR, NPP, and other key parameters that can represent plant growth processes will be produced with a spatial resolution finer than 1 km.

INSTRUMENT SETTINGS AND AIRBORNE MISSIONS.

Upstream area. Three-level nested experimental areas are chosen. The first level is the upstream area of the Heihe River main stream, the second level is composed of the two FEAs, and the third level consists of a snow observatory and a frozen soil observatory (Fig. 3).

Airborne missions. A high-resolution CCD camera and an imaging spectrometer are flown over the Heihe River Valley. In the Hulugou and other selected catchments, a 1-m resolution digital elevation model (DEM) is to be generated using airborne lidar. The L-, K-, and Ka-band radiometers are flown with manned and unmanned missions to develop more reliable remote sensing methods for deriving soil moisture (including surface soil freeze/thaw status), snow depth, and SWE.

The upstream area of the Heihe River main stream. The whole region is equipped with 10 AMSs and 3 flux towers (Fig. 3a). The flux towers are installed in a permafrost area, a seasonally frozen ground area and a snow-covered area.

The Babao River basin. It will be instrumented with a densely distributed network of AMSs and WSN. Six ordinary AMSs and a superstation at A'rou will be installed in different landscapes and elevation zones to capture the heterogeneity of near-surface atmospheric states (Fig. 3b). A WSN with more than 40 WATERNET nodes will be deployed according to an optimal design based on the spatial variation of terrain, soil moisture, and soil temperature, so that the major hydrological heterogeneity can be captured (Ge et al. 2012) (Fig. 3b). The observation items of a WATERNET node include soil moisture, soil temperature, LST, precipitation, snow depth, air temperature, humidity, and wind speed and direction.

Snow observatory and frozen soil observatory. In the Hulugou catchment, a snow observatory was constructed (Fig. 3c). A γ-ray (GMON) observation system is employed to measure the SWE with a footprint of 100 m^2. A snow water sensor (SWS) is used to measure the snowpack liquid water content, snow density, and SWE. FlowCapt records the blowing snow flux and the EC system observes the evaporation and sublimation on the snow surface. A snow pillow records the SWE and the melts. A digital camera monitors snow coverage. Snow stakes are laid out at an interval of 10 m to periodically measure snow depth.

The frozen soil observatory is located at the A'rou Superstation. In addition to the basic observations configured in the superstation, the top 30-cm depth soil is stratified into 5-cm intervals and the soils at a depth of 30–100 cm are stratified into 10-cm intervals. In each layer, soil temperature and moisture are measured. Soil heat flux and water potential are measured in selected layers. Additionally, a footprint-scale (approximately 600-m diameter) soil moisture is measured by a cosmic-ray soil moisture observing system, in association with WSN (Fig. 3d).

Middle stream area. Airborne missions. VNIR imaging spectrometers (i.e., the CASI and SASI systems) are flown over the experimental area (Fig. 4) to support the inversion of surface reflectance, albedo, FPAR, LAI, chlorophyll content, and FVC. The TASI imaging spectrometer is utilized to measure the emission characteristics of soils, vegetation, and desert and for the retrieval of LST and emissivity. The WiDAS is flown to measure the directional characteristics of surface reflectance and thermal radiation. The lidar and CCD camera are to measure the structure parameter of crops and other vegetation and to derive the aerodynamic roughness. The L-band microwave radiometer is flown during different growing seasons to derive soil moisture products and to validate the soil moisture algorithms. These observations will be further used to estimate some components of water and carbon cycles, such as ET and NPP.

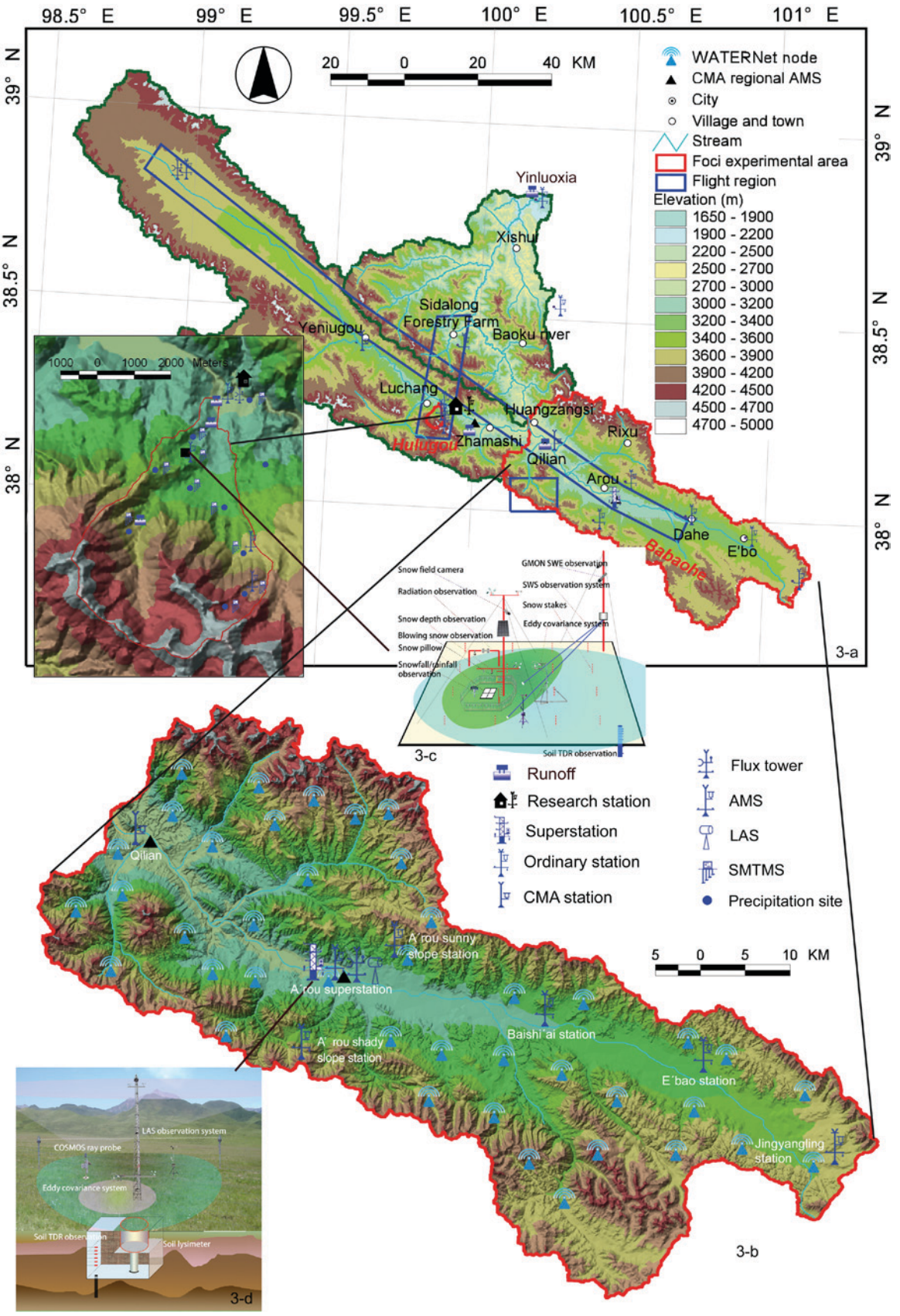

Fig. 3. Instrumentation setting and the airborne mission flight regions in the upstream area of the Heihe River basin and the snow and frozen soil observatories.

Very high-resolution airborne CCD images (~20 cm) are used to map land cover and vegetation types and to obtain the characteristics of the channels in the irrigation district, including their spatial distribution, types, roughness, and other static parameters.

Multi-scale observation on ET. The instrumentation plan is illustrated in Figs. 4a and 4b. In larger areas, the observation system is used to monitor the spatial–temporal variation of ET and its impact factors within the oasis–desert ecosystem. Four AMSs are installed around the oasis (i.e., sandy desert, desert steppe, Gobi, and wetland stations) and each one is supplemented with an EC system (Fig. 4a). The Daman Superstation is installed in the central oasis, which is a 40-m boundary layer tower.

Within the oasis, an observing matrix composed of 17 EC towers and ordinary AMSs and 4 pairs of LAS systems that span 2–3 km each are located in the Yingke and Daman irrigation district, where the land surface is heterogeneous, dominated by seed corn, corn interplanted with spring wheat, vegetables, orchards, and residential areas (Fig. 4b). Continuous single-point and simultaneous multipoint soil evaporation and vegetation transpiration partitioning measurements are implemented using stable isotope technology to obtain the temporal and spatial patterns of soil evaporation and vegetation transpiration. A WSN composed of 50 WATERNET, 50 SoilNet, and 45 LAI measurement system nodes and another soil moisture measurement system are deployed to capture the heterogeneity of soil moisture, soil temperature, LST, and LAI (Fig. 4b). The configuration of the WSN has been optimized by the means of surfaces with the stratified nonhomogeneity method (J.-F. Wang et al. 2009; J. Kang et al. 2012, unpublished manuscript).

Irrigation and the water balance. Other components of water balance in an irrigation district (conceptualized in Fig. 4c) are measured, including the surface water irrigation that flows into and the surface return flow that drains out of the irrigation district, the lateral groundwater flow that seeps into and drains out of the irrigation district, and channel evaporation. In particular, because of the effects of seepage and channel evaporation, the amount of water loss accounts for 49% of the total amount of water in the channels, so this phenomenon cannot be ignored. Therefore, flow meters are installed at the entrance and terminal in some typical main canals, subcanals, and field ditches to observe flows in different levels of the channels, in association with section measurements to calculate the amount of water losses based on water balance method. The leakage pools are set up to obtain the amount of water seepage. Eventually, the water use efficiency of different channels can be calculated.

Meanwhile, groundwater exploitation and spring flow are also key components in irrigation water balance. Water meters are performed to quantify the amount of groundwater exploited. Spring flows are estimated from measurements at wells. All these data support determining the total and segmental amount of irrigation water in the channels and different farmland parcels.

Downstream area. In Ejin Basin, *Populus euphratica* and *Tamarix* are primarily distributed in the area between Erdaoqiao and Qidaoqiao, which is selected as the aviation area (Fig. 5). Airborne lidar is flown to acquire structure parameters (e.g., tree height and diameter at breast height of the typical vegetation). The airborne multi-angle VNIR and thermal imager are used to estimate land surface albedo, LST, canopy temperature, FPAR, LAI, and chlorophyll content.

Two ESs equipped with EC towers and AMSs as well as LAS are to be established to measure the sensible and latent heat fluxes over the heterogeneous landscapes (Fig. 5b). In between, a WSN will be set up to capture the spatial variation of soil moisture and soil temperature. Intensive ground measurements are performed in several relatively homogeneous plots toward *Populus euphratica* and *Tamarix*. In these plots, which are focused on a "standard tree" (Fig. 5c), a series of instruments, including sap flow instruments, Li-6400, TDRs, and tensiometers, are set up to measure the parameters related to multiscale eco-hydrological processes to eventually improve our understanding of these processes in arid regions.

DATA MANAGEMENT AND SATELLITE DATA COLLECTION.

Data management in HiWATER involves data collection, standardization, quality control, processing, warehousing, and release. It must achieve the following tasks to provide data services for HiWATER: 1) formulate observing specifications and standards for various observations and data and metadata formats; 2) design, plan, and implement data gathering and management; and 3) perform quality control and store data (including metadata).

Various satellite remote sensing data from VNIR, thermal infrared, and active and passive microwave and lidar sensors are being collected by data sharing

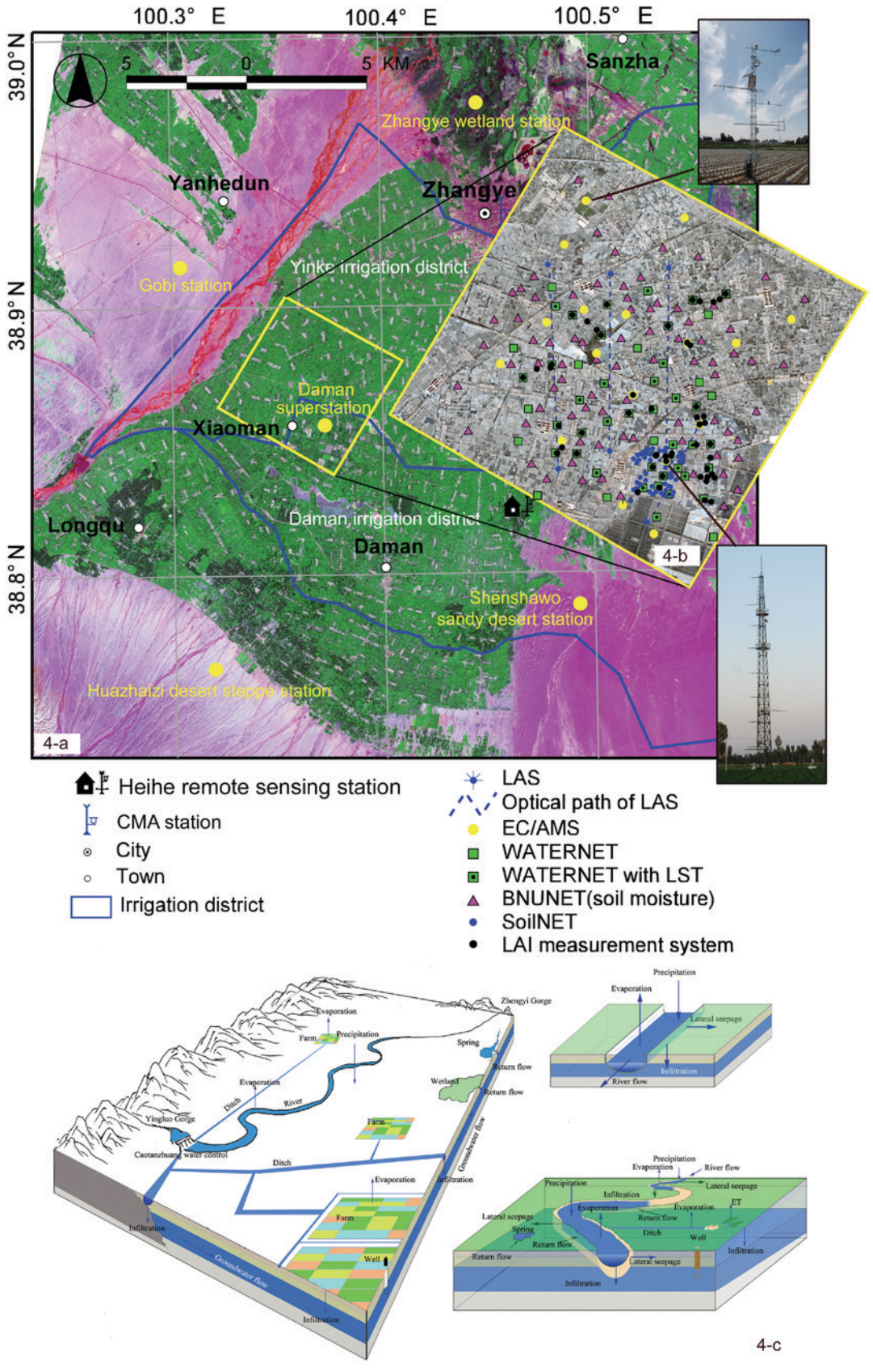

Fig. 4. Instrumentation setting in the middle stream area of the Heihe River basin and the conceptualization of the water balance at the irrigation district scale.

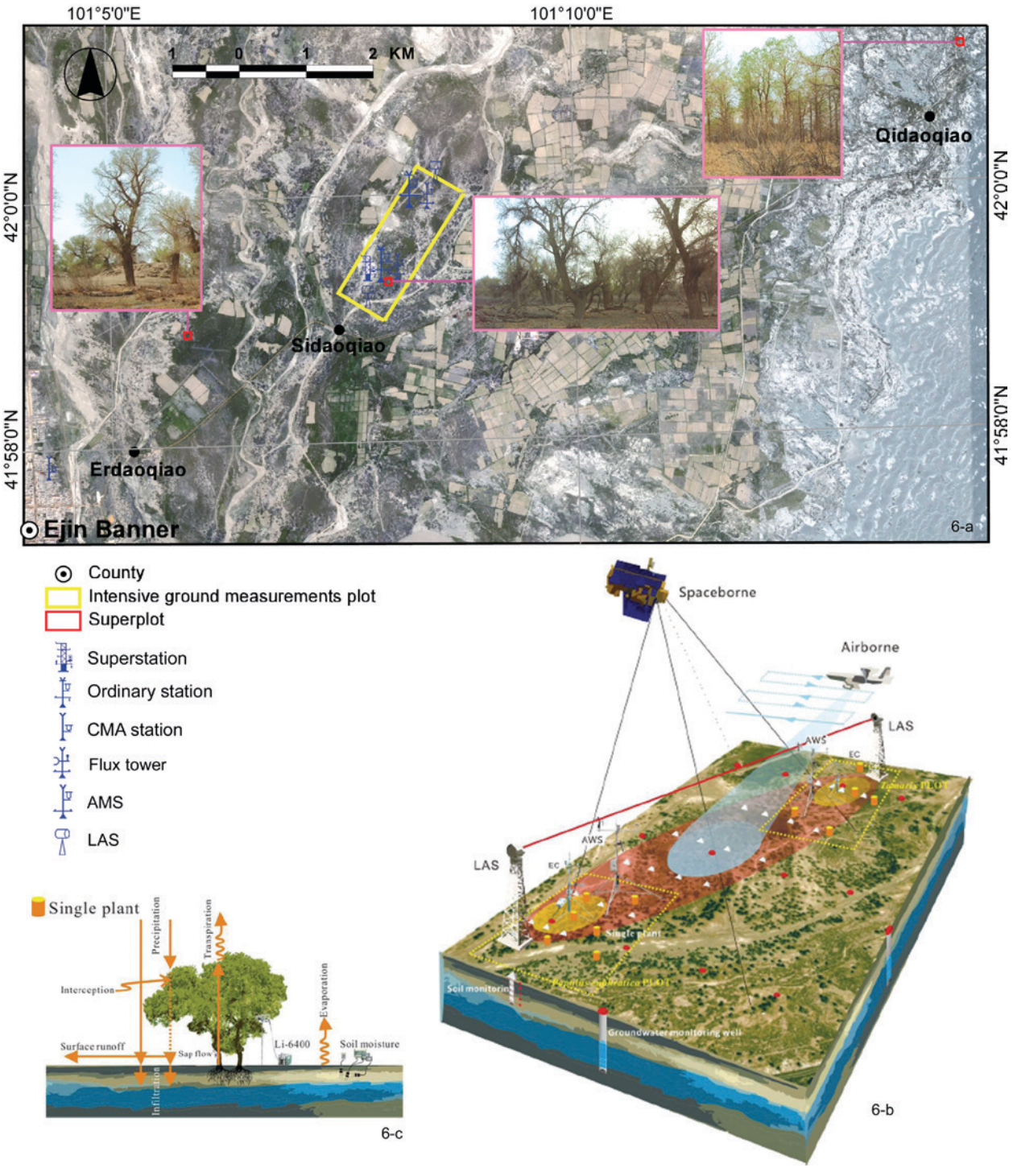

Fig. 4. Instrumentation setting in the middle stream area of the Heihe River basin and the conceptualization of the water balance at the irrigation district scale.

programs, international cooperation, and limited commercial purchase. Data are ordered before airborne missions and in situ measurements are deployed to guarantee the completion of simultaneous satellite–airborne–ground-based observations and corresponding calibration/validation activities. In addition, to run data assimilation systems, medium and low spatial resolution remote sensing data will be acquired on a daily basis from 2012 to 2015.

The open data policy of HiWATER will ensure that the experimental data are timely and adequately utilized. However, there will be a protection period so

that observers can have priority in using original data. After the data protection period, HiWATER data will be submitted to the data management and sharing platform of the Environmental and Ecological Science Data Center for West China (http://westdc.westgis.ac.cn/).

EXPERIMENTAL DURATION. HiWATER is planned to last four years, from 2012 to 2015. Within this period, a 1-yr intensive observation will be conducted in each of the three KEAs. The HiWATER intensive observation period field work started in May 2012 from the middle stream. The persistent observations period over the whole river basin will continue from 2013 to 2015. Airborne missions with a manned airplane are mainly executed in summer 2012. Unmanned airborne missions are to be performed periodically in three KEAs according to the requirements.

SUMMARY. This paper introduces the background, scientific objectives, and overall experimental design of HiWATER. The instrumental setting and airborne mission plans of HiWATER are also outlined. More detailed information regarding the implementation plan can be found online at http://hiwater.westgis.ac.cn.

HiWATER has formally kicked off in May 2012, the field campaigns are currently going on, and some important data have been obtained. Data will be available half a year later for each experiment. Scientists internationally are welcomed to participate in the field campaigns and use the data in their analyses.

As a comprehensive eco-hydrological experiment, HiWATER should make a difference in continental-scale hydroclimatic or hydrometeorological experiments. It should address the large issues that have puzzled watershed-scale hydrological and ecological studies for a long time, such as heterogeneity, scaling, uncertainty, and closing water cycle at the watershed scale. Practical utilization for water resource management should also be considered.

Compared with WATER, HiWATER will be more oriented toward answering scientific questions and more organized, with more information integration. It will provide a test bed to testify or falsify new ideas on eco-hydrology and new hypotheses on scaling because it is designed to capture multiscale heterogeneities within a river basin with very diverse landscapes.

Finally, HiWATER must be well coordinated, within the experiment itself and within the NSFC Heihe Plan, to ensure that the scientific objectives envisioned are accomplished and to best meet the diverse needs of interdisciplinary studies in the Heihe Plan and ultimately the needs of integrated eco-hydrological studies.

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TOWARD A STANDARDIZED METADATA PROTOCOL FOR URBAN METEOROLOGICAL NETWORKS

BY CATHERINE L. MULLER, LEE CHAPMAN, C.S.B. GRIMMOND, DUICK T. YOUNG, AND XIAO-MING CAI

Bringing together the disparate guidelines for best practices in observing and documenting urban stations and existing meteorological networks should improve the quality and applicability of the increasing amount of data gathered by high-resolution urban networks.

The complexity of urban atmospheric processes makes them impossible to measure adequately using traditional surface observation approaches consisting of a few individual monitoring stations. However, in recent years, meteorological observations have benefited from automated monitoring, advancement of sensor technologies (e.g., miniaturization, wider range of sensor types), lower cost of sensors, and improved data transmission to near-real-time communications networks. Once combined, these have enabled the creation of urban meteorological networks (UMNs) with the capability to operate at a range of atmospheric scales (Table 1). Hence, a UMN can be defined as cooperative, spatially distributed meteorological monitoring equipment across an urban environment with autonomous,

TABLE 1. Relations between spatial scales and UMNs, from largest to smallest areal extent [from Muller et al. (2013), with modifications].

Spatial scale[a]	Areal extent (m)	Atmospheric scale (Orlanski 1975)	Description
Regional/ mesoscale	10^4–10^6	Meso-α	Regional mesoscale conditions in the urban, peri-urban, and surrounding rural areas. Mesoscale phenomena may be hazardous and undetected without densely spaced or dynamic monitoring.
Urban/ city scale[b]	10^4–10^5 [b]	Meso-β	Whole city or urban area—dense array of sensors required because of the complex morphology of urban areas.
Neighborhood/ local scale	10^2–10^4	Meso-γ	Minor landscape features (parks, ponds, small topographic features) and neighborhoods with similar types of urban development (surface cover, size, and spacing of buildings, and activity), e.g., city center, old dense residential, or industrial zone.
Microscale	$\leq 10^2$	Micro-γ Micro-β Micro-α	Horizontal and vertical variability cause large differences over small distances. Influenced by dimensions of component elements, e.g., buildings, trees, roads, streets, blocks, courtyards, and gardens. Processes such as turbulence, radiation, and thermal heating are very irregular at these scales; numerous sensors required to represent the processes.

[a] Networks contain individual sensors collecting measurements that can be representative of the mesoscale, local scale, or microscale.

[b] Scale added for the purpose of defining urban networks, since many networks are smaller than mesoscale networks but larger than local-scale networks, covering just the urban areas—spatial scale wide ranging, as it depends on size of city.

near-real-time communication capabilities for transmitting data. The specific scale and type of UMN implemented is dependent upon required coverage, the variables observed, and the atmospheric processes being studied, which, along with resource availability, have an impact on the communications system, physical arrangement of sensors, power sources, size, and topology of the network [see Muller et al. (2013) for a detailed review of such networks]. These advances allow urban environments to be monitored at much finer spatial scales over a wider range of temporal scales than was previously possible, furthering our understanding of atmospheric processes and the impacts of climatic changes. As such, this high-resolution information can help to improve decision making, emergency preparation, weather forecasting, urban climate research, and urban planning for critical infrastructure needs (Chapman et al. 2013).

Because of the growing usage of urban meteorological data, it is imperative that UMNs are implemented and managed to a high standard, using common guidelines where possible. However, existing guidelines and recommendations are for synoptic-scale national networks or for individual urban monitoring stations (e.g., Oke 2004, 2006a; WMO 2008), rather than for UMNs. The divergent requirements, implementation, and management of UMNs suggest that there is an equivalent need for recommendations or standards for UMNs. This would benefit developers and data users by increasing confidence in data representativeness and quality. Indeed, technical information about UMNs is frequently difficult to ascertain because of insufficient reporting and documentation of methodologies and procedures. As data quality may therefore be questionable (NRC 2012; Muller et al. 2013), it makes the ability to cross reference networks difficult. For example, the need to standardize approaches has been identified as critical from the Word Climate Conference-3 (WCC-3, in 2009) for urban areas (Grimmond et al. 2010) and in the United States (NRC 2009, 3–4):

> The status of US surface meteorological observations capabilities is energetic and chaotic, driven mainly by local needs without adequate coordination. . . An over-arching national strategy is needed to integrate disparate systems. . . . Increased coordination amongst existing surface networks would provide a significant step forward and would serve to achieve improved quality checking, more complete metadata, increased access to observations, and broader usage of data serving multiple locally driven needs.

Similarly, the NRC (2012, p. 94) report on urban meteorology prioritizes the need for "regularly updated metadata of the urban observations using standardised urban protocols" as a key short-term need for the advancement of urban meteorology. Furthermore, they note that the value of observational data is maximized only when accompanied by comprehensive metadata, including information on site selection, quality assurance, and management procedures, which are often lacking for urban sites and networks.

Frequently, urban meteorological studies have been critiqued because of poor metadata and/or siting (e.g., Grimmond and Oke 1999; Roth 2000). Most recently Stewart's (2011) review of urban heat island (UHI) studies found a large number failed to adequately describe experimental design, choice of sites, exposure of instruments, and contained a lack of sufficient instrument metadata. To ensure high-quality usage of the data for applications and urban research, recommendations and guidelines must be followed and adequate information reported.

ESTABLISHED GUIDELINES AND RECOMMENDATIONS.

The term *metadata* is commonly used for any scheme of resource description for any type of object, digital or nondigital (NISO 2004). It provides the key aspect in any protocol and is essential to effective integration of diverse data sources (NRC 2009). The importance of documenting detailed metadata is highlighted in the Global Climate Observing System (GCOS) climate monitoring principles document (WMO 2003), which states that metadata should be "treated with the same

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Fig. 1. Two very different meteorological stations in terms of siting (e.g., height of sensor, surface cover, distance from obstacles), instrumentation (e.g., type, performance characteristics), and exposure (representativeness would need to be assessed via micro- and local-scale surveys; see main text and supplementary material at http://dx.doi.org/10.1175/BAMS-D-12-00096.2). Both are located within the city boundaries of Birmingham, United Kingdom: (a) a city-center site and (b) an urban park site.

care as the data themselves." Metadata ensure that the end user has "has no doubt about the conditions in which data have been recorded, gathered and transmitted" (Aguilar et al. 2003, p. 2) in order to ensure accurate interpretation, manipulation, and evaluation of results with minimal assumptions regarding data quality or homogeneity (WMO 2008). If detailed metadata are collected, then data can be interpreted accurately, and anomalies or patterns adequately explained and accounted for, whereas if insufficient metadata are collected, then it is difficult or impossible to assess site representativeness and therefore perform reliable data analyses (Stewart 2011). Hence, for meteorological datasets (from in situ monitoring equipment or networks), this includes all supplementary information, characteristics, and descriptions of the monitoring equipment (*instrument*, *sensor*, and *variable metadata*), the monitoring site itself (*site, station,* and *enclosure metadata*), the network (*network* or *subnetwork metadata*), and the network management procedures and communications methods (*cyberinfrastructure* or *network operations metadata*). For example, Fig. 1 shows two different meteorological stations, both located within the same city—detailed metadata are clearly essential for data interpretation at these very different locations.

Existing World Meteorological Organization (WMO) guidelines for the measurement of meteorological variables and climatological practices (e.g., WMO 2008, 2011) are mainly concerned with national and/or global instrument networks whose objective is to collect regionally representative data (i.e., not within urban areas). These standard guidelines contain essential and detailed information relevant to making meteorological observations, including details on requirements for each variable, siting and exposure, instrument calibrations, operating practices, data management and quality assurance/quality control (QA/QC) techniques. However, it is difficult and often inappropriate to conform to standard WMO guidelines when siting equipment in cities, since there are numerous obstructions to airflow and radiation

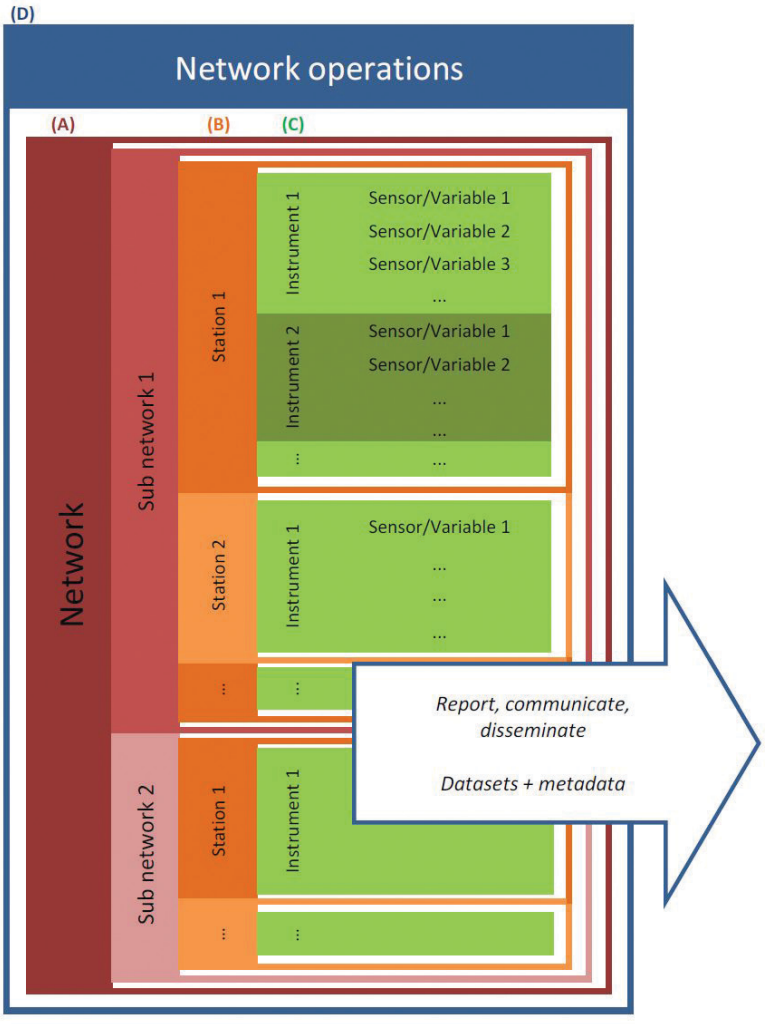

Fig. 2. Schematic of the urban climatological network metadata protocol components—a summary of the metadata elements required for each individual component [(a)–(d)] corresponding to Table 2 (Note: colors correspond to the metadata tables). Please refer to main text for more information.

exchange caused by anthropogenic surfaces, objects, and activities (Oke 2004).

Oke (2006b, 2009) was among the first to call for common urban climate protocols (particularly paying attention to issues related to scales, experimental design, site classification, instrument exposure, and metadata collection), suggesting it would be valuable to have a "manual" for workers in urban climate to aid with the design of observational networks (Oke 2006b). Specific recommendations do exist for siting and exposure of equipment in urban areas (e.g., Aguilar et al. 2003; Manfredi et al. 2005; NOAA 2004; Oke 2006a; WMO 2008, 2011) and outline the type of information that needs to be included as *urban station metadata* in order to obtain representative measurements (e.g., Oke 2004, 2006a,b; WMO 2008). Within these guidelines and others (e.g., Aguilar et al. 2003; NOAA 2004; Manfredi et al. 2005), specific concepts, definitions, approaches, and recommendations relevant to urban stations are discussed. Furthermore, these guidelines also provide general recommendations for collecting and documenting additional *instrumentation*, *network*, and *operations* metadata that are not intrinsic to a particular station but are equally important (Grimmond 2006; WMO 2011). These additional metadata are essential for anyone utilizing network data, comparing data from different networks, or setting up a new network. For example, Aguilar et al. (2003) and WMO (2011) include comprehensive recommendations for *instrument metadata*, including sensor type, manufacturer, serial number, method of measurement and observation, units, resolution, accuracy, response time, time constant, time resolution, date of installation, corrections and calibrations, and comparison results. These guidelines also call for information on *operational procedures*, such as data processing methods and algorithms, resolution, input source, parameter values, QA/QC, constants, storage procedures, access and processing methods, and communications and transmission methods. McGuirk and May (2003) include similar recommendations but further distinguish between station and network metadata (comprising instrument, research, software, and network procedures). However, such recommendations are often specific to the application (e.g., road weather monitoring, large-scale measurement networks and facilities, individual sites), meaning that certain aspects that are important for UMNs (as discussed in the "Proposed UMN protocol" section) are lacking in these guidelines.

Although metadata and technical information are difficult to ascertain for many established UMNs, there are some for which the complete technical details of their network and the protocols employed have been documented [e.g., Oklahoma City Micronet (Basara et al. 2010); Oklahoma Mesonet (Brock et al. 1995; Shafer et al. 2000; McPherson et al. 2007); West

Texas Mesonet (Schroeder et al. 2005); Helsinki Testbed (Poutiainen et al. 2006)]. As such, these may also be used as a source of guidance for implementing other UMNs. For example, technical information for both the Oklahoma Mesonet and the Oklahoma City Micronet is published and available online. These include information about the station and network architecture and design, site selection and classifications, sensors (including type, accuracy, etc.), sensor locations, communication infrastructure, instrumentation, monitoring, and network operations (e.g., QA/QC, calibration, and maintenance procedures). Additionally, Basara et al. (2010) and Schroeder et al. (2010) outline the land classification procedures used for the Oklahoma Micronet. However, as acknowledged by the NRC (2009), such a level of technical information is very disparate for the majority of UMNs.

By reviewing these existing guidelines, collating recommendations and best practices and establishing where information is missing, this paper endeavors to produce a comprehensive, standardized protocol for assisting those involved in implementing and/or utilizing UMNs.

PROPOSED UMN PROTOCOL. Metadata are required to cover the instrumentation, site, network, and operations; therefore, a number of factors need to be considered in developing an urban meteorological network protocol (UMNP). Figure 2 and Table 2 summarize the proposed UMNP components, from whole network operations metadata to individual sensor metadata. The elements are derived from urban network literature (e.g., Mikami et al. 2003; Basara et al. 2010; Koskinen et al. 2011; Muller et al. 2013), recommendations available for urban stations (e.g., Oke 2004, 2006a), and larger-scale meteorological monitoring networks (e.g., Aguilar et al. 2003; WMO 2008, 2011), as well as the authors' experiences of setting up urban networks. The following sections provide an overview of each metadata component of the proposed UMNP (from the whole network scale to the individual sensor scale, concluding with the network operations-scale metadata), outlining and explaining the individual elements and their necessity for inclusion.

It should be noted at this stage that this protocol is designed as a guideline document to assist with collecting and documenting meaningful metadata, for use by the end user and those implementing and managing UMNs. UMNs are often designed for a specific purpose, and therefore have specific siting requirements depending on a number of aspects, including required network density, available equipment, applications, partners involved, site access, etc. (Muller et al. 2013). The metadata protocol is one of many tools needed to assist in UMN implementation. Others include, for example, instrumentation selection, communications selection, data protocols, network design, and management approach—each of which

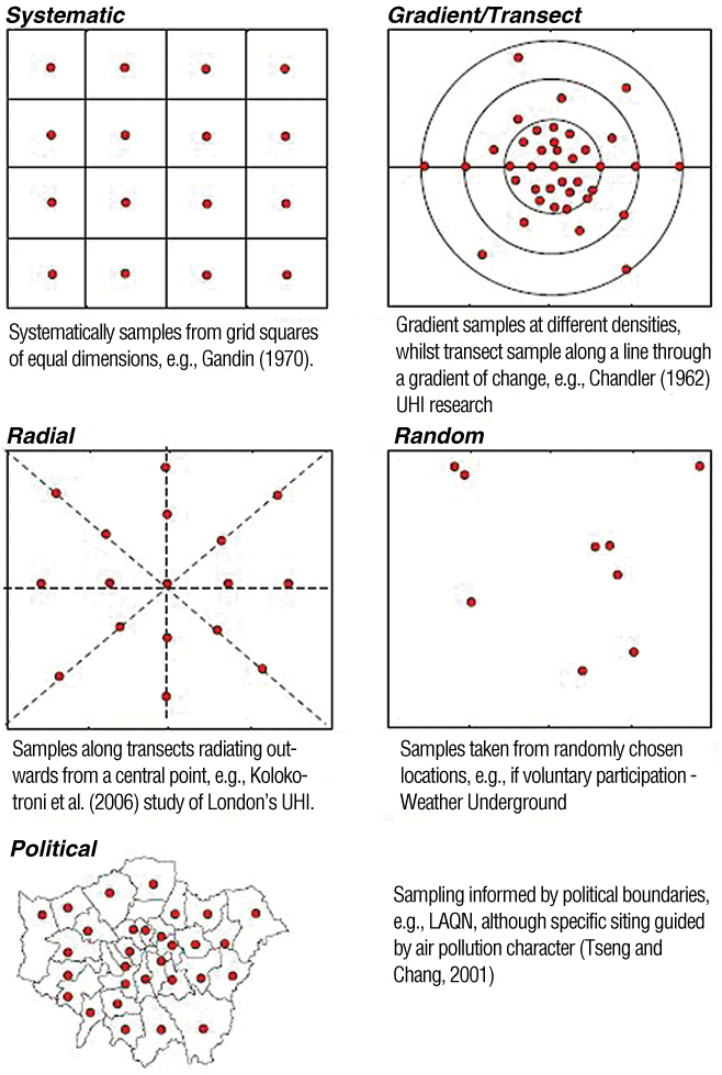

Fig. 3. Main approaches taken toward network design, with references (after Robinson 2010).

Table 2. Summary of minimum metadata required. More complete details in Tables 3, 4, 6, and 8. Letters correspond to those in Fig. 2.

(a) Network (and subnetworks)	(b) Individual station/site		(c) Instrumentation	(d) Network operations	
Network type	Site	Maintenance	Instrument	Communication network topology	Formulas
Network contact	Status	Relocation	Manufacturer	Data format	Language
Network variables	Site name	Enclosure	Model	Version numbers	Website
Network contact e-mail	Site alias (es)	Enclosure latitude	Type	Correction	Management
Network history	Type of site	Enclosure longitude	Variables	Measurement units	
Network implementation date	Latitude	Enclosure elevation	Representativeness	Missing data flag	
Network end date	Longitude	Mount location	Installation date	Language	
Network offline dates	Elevation	Type of mount	Decommissioned	Spatial resolution	
Network areal extent	Orographic setting	Height of sensor(s)	Start date	Temporal resolution	
Network spatial density	Date of metadata collection	Surface cover	End date	Time format	
Number of sites	Version number	Material below cover	Operating principals	Geographic extent	
Network map(s)	Observer	Terrain slope	Instrument communication type	Access rights	
	Start date	Building type	Data transmission frequency	Processing level	
	Stop date	Source areas	Sampling time	Other special codes	
	Instruments	Tree height	Averaging period	Metadata	
	Type of measurements	Traffic density	Precision	Server	
	Noticeable changes	Irrigation	Range	Storage	
	Station history	SVF	Response time	Backup	
	Remarks	Aspect ratio	Reporting frequency	Transmission	
	Urban structure (mean)	Moisture/heat vents	Accuracy	Access	
	Water bodies	Maps/sketches	Corrections	Archive data center	
	Mountain ranges	Photographs (winter and summer)	Known errors	Software	
	Traffic density	Relocation	Measurement units	Hardware	
	Surface cover	Site classification		Processing	
	Urban fabric			Error flags	
	Urban metabolism			QC/QA	
	Buildings (mean)			Filtering	
	Terrain			Data reduction	
	Aspect ratio			Programs	
	Maps/imagery			Algorithms	

have extensive literatures that are rapidly evolving. For example, Fig. 3 summarizes some of the main approaches toward network design; however, this also needs to take into account the land cover characteristics in the urban area when determining the appropriate number of stations and their location. Thus, how to classify urban areas—such as Stewart and Oke's (2012) local climate zones (LCZs) driven by urban heat island characteristics or Loridan and Grimmond's (2012a,b) urban zones for energy partitioning (UZE) developed for characterizing observations and for numerical modeling (Loridan et al. 2013)—needs to be part of the process of the overall UMN design. Similarly, how a UMN is managed depends on such things as the requirements of network owners, partners, number of staff employed, and resources.

Network metadata. First and foremost, details are required about the network itself (Table 3). Such network information would include the type/purpose of the network (e.g., meteorological, air pollution), a description of the network (e.g., objectives, partners), operating authority, contact details, and information regarding the operational time frame (e.g., implementation date, periods offline). Additional geomorphological, orographic, geographic, and socioeconomic data that may characterize the overall setting are also necessary (e.g., digital elevation models; census data; GIS data such as percent built, percent vegetation cover, satellite imagery, thermal imagery). Such metadata are useful for end users to appreciate the network setting and for determining land classifications, but they are also useful during the network design stages, for assisting with source area calculations (see "Site metadata" section), and for interpreting results.

Metadata management requires not only the protection of the data itself but also regular updating. Table 3 and subsequent metadata tables provide an indication of the recommended frequency to ensure that updates or changes are documented. For example, changes to the number of sites or areal extent of the network [including updated map(s)], dates when the network is offline, changes to the morphology of the area (major redevelopment, changes to specific boundaries, etc.), and vegetation characteristics (e.g., growth, planting, removal) all need to be documented.

Second, the network architecture needs documenting (e.g., number of subnetworks and individual sites, network maps, and size of the network), which will include the areal extent of the networks and the density of the array (e.g., number of sensors per area or distance between sensors). The specific size of the network will depend on its objectives, such as the atmospheric processes to be observed and the temporal and spatial resolutions required (Grimmond 2006).

Site metadata. Next, the schema includes established guidelines for individual urban meteorological stations (e.g., Oke 2004, 2006a) that are used as the basis for recommendations (Table 4). Measurements from individual sensors observe atmospheric processes from a particular source area or field of view that is representative of a specific scale. The scales of interest across and within an urban area are *mesoscale* (i.e., regional climate, covering urban, peri-urban, and rural areas), *local scale* (i.e., distinct neighborhoods), and *microscale* (i.e., urban canyons or lots) (Oke 1982, 1984, 2004, 2006b, 2009, 2006a; WMO 2008, 2011). The representativeness of individual measurements (i.e., the surrounding area an instrument "observes") or "exposure" is a function of the area influencing a measurement ("source area" or "footprint"). Source areas for many instruments and/or variables over urban areas are often difficult to calculate. They depend on the location of the instrument (e.g., height, distance to obstacles); the specific variable and temporal scale being observed; the measurement method of the instrument; the morphology of the area and the nature of the underlying surface; and in some cases, the meteorological conditions (Oke 2004; Grimmond 2006). Therefore, thorough metadata collection is paramount to inform estimates of source areas, particularly for instrumentation located within the urban canopy layer (UCL). Metadata provide additional important understanding, both about the site and the local surface characteristics that influence the measurements that are crucial to the interpretation of observations from a particular instrument.

Frequently, the siting of instrumentation in urban areas causes difficulties with respect to the representativeness of measurements. For example, it may be necessary to locate equipment over a range of surfaces (e.g., asphalt, concrete, grass) at variable heights, to split instruments over different locations, or to locate instruments nearer to buildings or anthropogenic heat/moisture sources than would otherwise be recommended by standard WMO guidelines (Oke 2004). With the impact of the urban morphology being a key aspect of the environment to be observed (Stewart and Oke 2012), the standardization of the sensor location explicitly has to relate to its 3D characteristics (height and density/spacing), rather than to the more traditional objective of being a set distance away from the roughness elements. Oke (2006b) provides

Table 3. Network level [(a) in Fig. 2] and subnetwork(s) (when the subnetworks can also standalone, the information differs) metadata directory [based on established metadata guidelines from WMO (Oke 2004, 2006a; WMO 2008, 2011), other recommendations (e.g., Aguilar et al. 2003; NRC 2009; Manfredi et al. 2005; Muller et al. 2012), individual UMN guidelines (e.g., McPherson et al. 2007; Shafer et al. 2000; Koskinen et al. 2011) plus additional elements]. Information will need to be recorded at different time intervals (R = as required, O = once).

Metadata element	Description	Time
Network administration and general information		
Network type	Type of network (e.g., climate, air pollution)	O
Network description	Purpose of network (e.g., educational/research, projects, aims, end users)	O
Project partners	Project partners (commercial, academic, local government)	R
Operating authority	Operating authority or responsible organization (e.g., university, local government)	O
Network contact	Key network contact person/manager	R
Network contact address	Address for network contact person	R
Network contact phone umber	Phone number for network contact person	R
Network contact e-mail	E-mail for network contact person	R
Network variables	Variables monitored (temperature, wind, rainfall, pressure, etc.)	R
Network history	General historical network information (e.g. social, political, institutional changes or any other significant changes)	R
Operational time frame		
Network implementation date	Network implementation date	O
Network end date	End date (if applicable)	O
Network offline dates	Periods when offline	R
Size of network		
Network areal extent[a]	Areal extent of network[a] (regional/mesoscale; city, local scale/neighborhood; microscale, specific area)	R
Network spatial density[a]	Spatial density[a] (coarse array, wide array, fine or dense array, microarray)—based on distance between sensors (i.e., km^{-2})	R
Number of subnetworks	Number of subnetworks (e.g., nested network across the same area)	R
Number of sites	Number of sites within network (including reference stations)	R
Network map(s)	Maps of network layout and sites	R
Network geomorphology	Geomorophological data for the network area	R
Network orography	Orographic setting of the area (e.g., Wanner and Fillinger 1989)	R
Geographic/socioecomic data	Geographic and socioeconomic information about the network area (i.e., population, land use, wards, etc.)—wide ranging	R

[a] See Table 7 for proposed definitions of classifications.

Table 4. Site and enclosure(s)-level [(b) in Fig. 2] metadata directory [based on established metadata guidelines from WMO (Oke 2004, 2006a; WMO 2008, 2011), other recommendations (e.g., Aguilar et al. 2003; NRC 2009; Manfredi et al. 2005; Muller et al. 2013), individual UMN guidelines (e.g., McPherson et al. 2007; Shafer et al. 2000; Koskinen et al. 2011) plus additional elements]. Information will need to be recorded at different time intervals (H = hourly, D = daily, W = weekly, S = seasonal, A = annual, R = as required, O = once).

Metadata element	Description	Time
	Station administrative and geographical information	
Site identification	Station identifier or code	O
Status	Active/closed	R
Site name	Station name (i.e., town or village, school name)	O
Site alias(s)	Any alternative name(s) the station may be known by	R
Type of site	Station type (i.e., meteorological, hydrological, air pollution, etc.)	O
Latitude	Latitude (in units of 0.0001°N/S)	R
Longitude	Longitude (in units of 0.0001°E/W)	R
Datum	Precise datum used	O
Elevation	Elevation (MSL)	R
Orographic setting	Orographic setting of the site (e.g., Wanner and Fillinger 1989)	A
Location	Relative location of site within area (e.g., urban fringe, urban core, rural)	A
Site address	Address of station location	R
Site contact person[a]	Contact person/person responsible	R
Site phone number[a]	Phone number for site contact/person responsible	R
Site contact e-mail[a]	E-mail for site contact/person responsible	R
Date of metadata collection	Date of metadata collection/update/revision	R
Version number	Version number of metadata (e.g., if alterations made, such as instrument moving, site changing)	R
Frequency of visits	Frequency of visits to update metadata, check sites, equipment, etc.	A
Observer	Person(s) collecting the metadata	R
Start date	Date station started recording observations (opening date)	R
Stop date	Date station stopped recording observations (closing date)	R
Power supply	Power supply type (if necessary), e.g., mains, solar, battery	R
Instruments	List of instruments on site (e.g., rain gauge, temperature sensor)—includes details such as type/make of instrument	R
Type of measurements	Meteorological variables measured (i.e., temperature, wind, precipitation—direct and indirect measurements)	R
Noticeable changes	Noticeable changes since last visit (occurring at each visit)	R
Station history	Station history—changes the site has undergone during its lifetime (linked to maintenance log and QA/QC), i.e., changes in sheltering and exposure, land use changes, changes to instrumentation, etc.	R
Remarks	Notable remarks about station/points to highlight	R

Continued on next page.

Table 4. Continued.

Metadata element	Description	Time
	Site communications/data transmission [also part of network operations, (d) in Fig. 2]	
Communications type	Wired/wireless facilities [including type, i.e., ZigBee, Wi-Fi, local area network (LAN), broadband, dial-up]	R
Signal transport information[a]	Any additional information related to signal transport (i.e., type, type and modification of signal modification unit, length and type of cables, etc.)	R
Communications name[a]	Network name [e.g., name of the Wi-Fi network, service set identification (SSID)]	R
Communications password[a]	Network password/passkey	R
Communications backup[a]	Is there a backup solution for times when the network is unavailable? What?	R
Technical information[a]	Additional information required for data transmission [e.g., Internet protocol (IP) address, subnet mask, gateway, encryptions, etc.]	R
Communications network owner[a]	Communications network owner (e.g., school, authority)	R
ICT contact[a]	Contact details for the relevant information communications technician	R
	Local-scale survey[b]	
	Urban structure (typical): Fetch—similar or patchy—values by direction (min, mean, max)	
Building spaces	• Spaces between buildings (m)	A
Building density	• Building density (buildings per square meter)	A
Street widths	• Street widths (m)	A
Tree height	• Tree height (m)	S
Tree species	• Tree species (e.g., deciduous, coniferous—possibly specific type)	S
Water bodies	Proximity and size of water bodies	A
Mountain ranges	Mountainous areas across the locale	A
Traffic density	Traffic density (e.g., none, light, medium, heavy)	D, W, H
Surface cover	Surface cover (percent built, percent vegetated, percent bare soil, percent impervious, percent water)	A
Urban fabric	Urban fabric (construction, impermeable and natural materials)	A
Urban metabolism	Urban metabolism (heat, water, pollutants)	A
	Buildings (typical)	
Stories	• Number of stories	A
Roof types	• Roof type (e.g., flat, slanted)	A
Roof material	• Roofing material (e.g., clay tile, asphalt)	A
Building materials	• Materials (e.g., brick, concrete, wood)	A
Building types	• Residential detached/attached/school, etc.	A
Building age	• Age	A
Terrain	Slope (steepness and direction)	A

Aspect ratio	Aspect ratio [height of main roughness element divided by average spacing (Z_H/W)]	A
	Maps/imagery	
Local maps	• Local to mesoscale maps (~1:5000; ~1:25,000; and ~1:100,000)	A
Aerial photography	• Aerial photographs	S
Sketch map	• Annotated sketch map of local environment	S
Satellite imagery	• Satellite imagery (optical, infrared)	S
Relocation	Dates of station relocation	R
Microscale survey for each separate instrument enclosure on site[b] (information essential for assessing instrument exposure)		
Enclosure	Name to identify the enclosure (if more than one at a site)	R
Enclosure latitude	Latitude (in units of 0.0001°N/S)—for separate enclosure (if necessary)	R
Enclosure longitude	Longitude (in units of 0.0001°E/W)—for separate enclosure (if necessary)	R
Enclosure elevation	Elevation (MSL)—for separate enclosure (if necessary)	R
Mount location	Mount location and shelter description (i.e., lamppost, sign, fence, etc.)	R
Type of mount	Type of mount (i.e., on mast, post, tripod, open lattice guyed, etc.) and description; height above surface	R
Height of sensor(s)	Height of sensor(s) above ground level [for each instrument, (c) in Fig. 2, e.g., thermometer, gauge rim, anemometer heights]	R
Surface cover	Surface cover below station (i.e., artificial surfaces, agricultural surfaces, natural vegetation and open areas, wetland, and water bodies and types)	S
Material below cover	Soil/material below cover (type, profile)	S
Terrain slope	Slope of terrain (steepness and direction)	A
Building type	Building types (number of stories, roof type, materials, detached/attached, age, etc.)	A
Source areas	Source areas (footprints) for radiation and turbulence	S
Tree height	Mean tree height Z_T and locations	S
Traffic density	Traffic density (i.e., none, light, medium, heavy)	W,D,H
Irrigation	Proximity to irrigation and frequency (where applicable)	S
SVF	Optical, or use horizon method below	S
Horizontal distances	Horizontal distance to buildings W (m)	A
Building heights	Height of buildings Z_H (m/story)	A
Aspect ratio	Aspect ratio	S
Moisture/heat vents	Presence of moisture or heat vents	S
	Maps/sketches	
Horizon map	• Radiation horizon map (aids SVF and building height estimates)	S
Sketch map	• Sketch map of microscale environment surrounding instrument location	A
Enclosure diagram	• Sketch map/diagram of instrument enclosure/mount layout	A

Continued on next page.

Table 4. Continued.

Metadata element	Description	Time
	Photographs (winter AND summer)	
Site photo	• Photograph of the station locations	S
Cardinal photos	• Photos from cardinal directions of instrument	S
Panoramic photos	• Panoramic photo	S
Fisheye photo	• Fisheye photo (to calculate SVF)	S
Relocation	Dates of instrument relocation	R
Maintenance	Routing maintenance log [i.e., station inspection, equipment inspection, instrument checks, recalibrations, replacements, malfunctions, corrections, cleaning, mowing, instrument relocations (Note: if instrument is moved, then a new station number or updated metadata with version number is required)]—part of QA/QC procedures in (d) in Fig. 2	R
	Site classification, based on classification criteria methods[c], e.g.,	
LCZ[c]	Local climate zones (Stewart and Oke 2009, 2012)	A
UCZ[c]	Urban climate zones (Oke 2004)	A
UTZ[c]	Urban terrain zones (Ellefsen 1991)	A
DRC[c]	Davenport roughness class for terrain roughness (Davenport et al. 2000)	A

[a] Information kept private for network managers/technicians only—not supplied as metadata to end user.

[b] Please see supplemental material, e.g., UMN station metadata documentation template.

[c] See Table 5 for overview of classification schemes.

a detailed recommendation for locating instruments, primarily for those within the UCL, and for calculating source areas. There continues to be a need for more developments in source area modeling for use within the UCL and above that are applicable beyond neutral conditions.

Given the dynamic nature of urban areas, the site metadata should also include maps, photographs, aerial photography, sketches, geographic information, site descriptions, and maintenance logs at regular intervals. Site or station metadata require local scale and microscale site surveys. Currently, approximate and arbitrary areas of 500 m × 500 m and 50 m × 50 m, centered on the sensor site, are designated for conducting the local-scale and microscale surveys, respectively, since it has been found that on average the source area for a screen-height temperature sensor in neutrally stable atmosphere is no more than a few hundred meters (Tanner 1963; Mizuno et al. 1990/1991; Runnalls and Oke 2006; Stewart and Oke 2012). However, since the precise domain (size, shape, orientation) of these source areas does vary with meteorological conditions, stability, and the temporal resolution being investigated, conducting source-area analyses using a footprint model (e.g., Kljun et al. 2002; Schmid 2002) would be ideal and may be required for certain UMN applications. Stewart and Oke (2012) discuss this in more detail and provide a good illustration in Fig. 5 of their paper.

Site surveys will examine the structure of the area (building types, materials and mean heights, roof types, mean tree heights, distance between buildings, etc.), urban cover (e.g., built up, vegetated, water, soil), urban fabric (e.g., road, wall materials), and urban metabolism (e.g., anthropogenic activities, anomalous and typical heat, water and pollutants, traffic density) at the respective scales (Oke 2006a). Tracking disturbances in the area (e.g., from roadwork and construction) is important but may be difficult at many sites. With the increasing availability of lidar datasets, digital surface models (DSMs), and aerial imagery, the local

and microscale 3D morphological influences can now be readily identified (e.g., Kidd and Chapman 2012). Additional site surveys provide key additional information about vegetation, materials, and nearby activities (e.g., vehicle parking, vent locations) relative to the instruments. The microenvironmental factors (building types, materials, heights, distance between buildings, roof types, tree heights, surface material, traffic density, heat/moisture vents, etc.) include creating sketch maps (radiation horizon, site sketch map), taking numerous photographs of the site (e.g., location, cardinal directions, panoramic, and hemispherical), documenting location information (e.g., latitude, longitude, elevation), and other factors [sky view factor (SVF), aspect ratio, heights of sensors, etc.]. Since instruments can be placed at different locations within a site (e.g., on masts and rooftops, at more open locations, in different enclosures), different microscale surveys are required for each instrument enclosure.

Standardized site information is needed so data users are aware of site variations, since they rarely have the luxury of being able to visit each station across a network (Oke 2006b). If adequate metadata are available, then this should not create limitations for end users. Indeed, the majority of urban heat island studies fail to communicate the physical nature of the surfaces surrounding the instruments (Stewart 2011). To characterize urban locations for meteorological and climatological purposes, a number of schemes have been proposed (e.g., Table 5). However, no standard presently exists (Basara et al. 2010) and the current schemes may not be internationally applicable or definitive, as sites may fall into more than one category. It is therefore important that generalized and/or customized classification techniques implemented for interpreting results be documented and the assigned type reported for all sites. Critical details that should be documented include the area used for classification (e.g., 100 m^2, 500 m^2, 2 km^2), the source of data (e.g., year, aerial photos, ground surveys), and the assumptions (e.g., dominant, weighted average) for repeatability and consistency. The complete station history (maintenance logs, metadata updates) is also essential, so instrumental and site changes can be distinguished, and will include dates and details of any changes; interruptions; inspection visits; and comments about the exposure, quality of observations, changes to the site, and operations (WMO 2011).

While many aspects of this UMNP are designed to aid with the collection of high-quality data and to assist the end user with data analysis (QA/QC, station metadata, representativeness, etc.), there are other aspects specifically to assist network owners, managers, and technicians, since it is also important to provide guidance for the implementation and running of an UMN to ensure that networks are efficiently established. Therefore, additional elements are required for sites that form part of an UMN—for example, information about the local communications network or local node that is being used to transmit the data [this will vary for each UMN and depend on the type of information required; however; e.g., it may include network type, encryptions, passwords, etc., which are also part of the "network operations" component (see "Network operations metadata" section)] and the relevant contact details [e.g., if a school site is used, then it might be useful to have liaison details for information and communications technology (ICT) staff]. Furthermore, since access to different elements of the metadata will vary, it is expected that some of the metadata are stored in an encrypted format and not released to most end users (e.g., passwords, network information, personal details, and other details to comply with data protection laws). Thus, only the portion of the metadata regarded as useful to the end user would be initially provided with the data. This would be managed by the UMN data manager or technician.

Aguilar et al. (2003) and Oke (2004, 2006a) provide templates for collecting the minimum information necessary for individual urban stations. Based on these, an adaptable UMNP station metadata template (see supplementary material at http://dx.doi.org/10.1175/BAMS-D-12-00096.2, along with a completed example) has been developed with additional elements included (e.g., information on the communication network, contacts, instrumentation, type of site). Collection of these metadata in the field should typically take no more than 30 min, with some additional time required (prior to and postfield collection) using Internet-based resources (such as Google Earth, GIS, satellite datasets, etc.) to explore the local area (to determine land classifications, Davenport roughness class, land cover, etc.) and to collate additional logistical and instrumental data. The aim of this template is to facilitate the regular update of station metadata in order to assess any changes occurring at the sites, which can then be used in conjunction with the detailed account of the station history (whether equipment has been moved, replaced, etc.). It is expected that individual UMNs will need to adapt the form for their specific needs—for example, not all fields may be required and/or additional fields may be necessary. However,

Table 5. Examples of urban site classification schemes.

Terrain roughness length—based on Davenport et al. (2000) classification for urban roughness

No.	Class name	Roughness length z_0 (m)	Landscape description
1	Sea	0.0002	Open water, featureless plain, fetch > 3 km
2	Smooth	0.005	Obstacle-free land with negligible vegetation; marsh, ridge-free ice
3	Open	0.03	Flat open grass, tundra, airport runway; isolated obstacles separated by >50 obstacle heights H
4	Roughly open	0.10	Moderately open country with occasional obstacles (i.e., isolated low buildings or trees) at relative horizontal separations of >20H
5	Rough	0.25	Scattered obstacles (buildings) at relative distances of 8–12H for low solid objects
6	Very rough	0.5	Area moderately covered by low buildings at relative separations of 3–7H and no high trees
7	Skimming	1.0	Densely built-up area without much building height variation
8	Chaotic	≥2	City centers with mix of low- and high-rise buildings

UTZ from Ellefsen (1991)

Attached UTZ		Detached building (close set) UTZ		Detached building (open set) UTZ	
A1	Attached buildings; commercial offices, retail; core area; low rise; mass and framed constructions; constructed from earliest times through to present	Dc1	Detached buildings; commercial office; high-rise; light-clad framed; built since 1950	Do1	Detached buildings; shopping centers; beyond core; low rise; mass and framed construction; post WWII
A2	Attached buildings; apartments/hotels; near core area; complete fitting of block frontages; four or more stories high; built mostly in the pre-World War II (WWII) period	Dc2	Detached buildings; residential apartments/row houses; >75% block frontages; widely distributed locations; built through to present	Do2	Detached buildings; residential apartments and low housing; less than 75% block frontages; low to medium rise; widely distributed locations; low rise to high-rise; built largely since the end of WWII
A3	Attached buildings; apartments and abutted-wall houses; adjacent to core area; fewer than four stories; mostly pre-WWII	Dc3	Detached buildings; residential houses; 75% and more block frontage; widely distributed locations; built through the present	Do3	Detached buildings; houses; less than 75% frontage; low rise; widely distributed locations; built through to present
A4	Attached buildings; industrial/storage; near core area; on ordered blocks with little or no setback; medium rise; mass and framed construction; built mostly pre-WWII	Dc4	Detached building; industrial/storage; linear building pattern; railroad or dock related; low rise; built through the present	Do4	Detached buildings; industrial/storage; truck related; widely distributed locations; ordered pattern (buildings fairly evenly spaced; separated by parking lots, storage areas); low rise; post 1920s
A5	Attached buildings; commercial ribbon development; on some arterials outward from core area and elsewhere; virtually complete filling of block frontages along street; low to medium rise; built mostly pre-WWII	Dc5	Detached buildings; elder commercial ribbons; along pre-WWII string streets; limited off street; parking; low rise (fewer than five stories)	Do5	Detached buildings; modern commercial; ribbon development; along major new arterials; open pattern (buildings separated by intervening parking lots and open storage areas); low rise (fewer than five stories); post early 1950s
		Dc8	Detached buildings; commercial (outer city); at metropolitan-area periphery; high-rise; light-clad framed; built early 1950s through to present	Do6	Detached buildings; administrative/cultural (i.e., government, schools, hospitals); low to medium rise; widely distributed locations; ordered building pattern; built through to present

Simplified set of classes based on the above-mentioned classification schemes—see Oke (2004) for images associated with each UCZ					
UCZ	**Approximate UTZ**	**Descriptions**	**DRC**	**Aspect Ratio [Z_H/W – average height of the main roughness elements (buildings, trees) divided by their average spacing]**	**Percentage built [average proportion of the area covered by impermeable surfaces (i.e., buildings, pavements, roads, etc.)]**
1	Dc1, Dc8	Intensely developed urban with detached close-set high-rise buildings with cladding, i.e., central business district skyscrapers	8	>2	>90
2	A1–A4, Dc2	Intensely developed high-density urban with 2–5 stories; attached or very close-set buildings, often of brick or stone, i.e., old city core	7	1.0–2.5	>85
3	A5, Dc3–5, Do2	Highly developed medium-density urban with row houses or detached but close-set houses; stores and apartments, i.e., urban housing	7	0.5–1.5	70–85
4	Do1, Do4, Do5	Highly developed, low- or medium-density urban, with large low buildings; paved parking, i.e., shopping centers, warehouses	5	0.05–0.2	70–95
5	Do3	Medium-developed low-density suburban, with 1- or 2-story houses, i.e., suburban housing	6	0.2–0.6 (up to >1 with trees)	35–65
6	Do6	Mixed use with large buildings in open landscape i.e., hospitals, universities, airports	5	0.1–0.5 (depends on trees)	<40
7	None	Semirural development; scattered houses in natural or agricultural areas, i.e., farms, estates	4	>0.05 (depends on trees)	<10

LCZs—see Stewart and Oke (2012) for methods, sketches, photographs, full descriptions, and associated values and properties						
Code	**Zone**	**Definition**	**SVF**	**Aspect ratio**	**DRC**	**Impervious surface fraction**
LCZ-1	Compact high-rise	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials	0.2–0.4	>2	8	40–60
LCZ-2	Compact midrise	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	0.3–0.6	0.75–2	6–7	30–50
LCZ-3	Compact low rise	Dense mix of lowrise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	0.2–0.6	0.75–1.5	6	20–50
LCZ-4	Open high-rise	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	0.5–0.7	0.75–1.25	7–8	30–40
LCZ-5	Open midrise	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	0.5–0.8	0.3–0.75	5–6	30–50

Continued on next page.

Table 5. Continued.

LCZs—see Stewart and Oke (2012) for methods, sketches, photographs, full descriptions, and associated values and properties						
Code	**Zone**	**Definition**	**SVF**	**Aspect ratio**	**DRC**	**Impervious surface fraction**
LCZ-6	Open low rise	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, concrete construction materials.	0.6–0.9	0.3–0.75	5–6	20–50
LCZ-7	Lightweight low rise	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	0.2–0.5	1–2	4–5	<20
LCZ-8	Large low rise	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	>0.7	0.1–0.3	5	40–50
LCZ-9	Sparsley built	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	>0.8	0.1–0.25	5–6	<20
LCZ-10	Heavy industrial	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard packed. Metal, steel, and concrete construction materials.	0.6–0.9	0.2–0.5	5–6	20–40
LCZ-A	Dense trees	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.	<0.4	>1	8	<10
LCZ-B	Scattered trees	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.	0.5–0.8	0.25–0.75	5–6	<10
LCZ-C	Bush, scrub	Open arrangement of bushes; shrubs; and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.	>0.9	0.25–1.0	4–5	<10
LCZ-D	Low plants	Featureless landscape of grass or herbaceous plant cover. Few or no trees. Zone function is natural grassland, agriculture, or urban park.	>0.9	<0.1	3–4	<10
LCZ-E	Bare rock or paved	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.	>0.9	<0.1	1–2	>90
LCZ-F	Bare soil or sand	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture	>0.9	<0.1	1–2	<10
LCZ-G	Water	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.	>0.9	<0.1	1	<10

we highlight those elements considered "mandatory" (e.g., latitude, longitude, elevation, local-scale sketch map and information, microscale sketch map and information, and station and cardinal photographs). Once the metadata have been collected during the initial installation, they can be input electronically (into a form and/or a database), used for subsequent visits, and quickly updated. Indeed, with the recent proliferation of smart devices/tablets, updating can now be done quickly and directly in the field. Overall, this would form part of the network QA/QC procedures (see the "Network operations metadata" section) and is an essential part of the station metadata to ensure homogeneity (Aguilar et al. 2003).

Instrumentation metadata. As with existing site protocols, separate information is mandatory for each piece of equipment at each site (Table 6), including information about the instrument itself (e.g., manufacturer, model, serial number, installation and calibration dates, and calibration and testing results; see also the "Network operations metadata" section). Operational instrument-specific information about the communication system will need to be safely documented (passwords, IP address, MAC address, etc.—see Table 6 for detailed list).

Some instruments incorporate multiple sensors (e.g., temperature and humidity) or multiple variables are obtained (e.g., wind components, virtual temperature), so additional metadata are required for each sensor and/or variable. This includes information specific to the sensor (height of gauge rim above ground for precipitation, type and size of screen for temperature, etc.) in addition to performance characteristics of the sensor (sensitivity, range, etc.) and data and/or measurement characteristics (sampling time, averaging periods, etc.).

The *representativeness* of each measurement or "instrument exposure" (see "Site metadata" section) will also need documentation. As highlighted in Muller et al. (2013), the use of "scale"-related terms can cause confusion when applied to networks, as information on network and station scales is often difficult to establish since it is not explicitly stated, is unclear, or uses inconsistent terminology to define urban sensor networks. Specifically, this relates to the distinction between spatial or areal *extent* of the network, which is often reported as the "network scale" or "network size" (see "Network metadata" section), spatial *resolution* or *density* of the network (which is dependent upon the density of individual sensor sites), and spatial representativeness or *scale length* of the individual measurements (which is dependent on the actual location of the instrumentation, measurement interval, and exposure; Oke 2006a). This "confusion of scales" has recently been highlighted as a common flaw in urban climate investigations (Stewart 2011) and is particularly true of urban networks. For example, a sensor network may be classified as a "mesoscale network" since it covers hundreds of square kilometers consisting of urban, suburban, and rural areas. However, the representativeness of the individual sensors or monitoring stations, and the number of sensors in the network could be classified on very different scale. Hence, a network areal extent may be "mesoscale" but the individual measurements could be more representative of mesoscale, local scale, or microscale processes. Presently, and in most cases, UMNs have been defined solely by their spatial extent. Although information about the number of sensors and location of sensors is often given, information about "network density" and "representativeness" of measurements should be explicitly defined, since it affects both the application of the network and what is appropriate with cross network comparisons (Oke 2004, 2006a).

The proposed network-scales UMN classification scheme is given in Table 7. The areal extent or size, the spatial density, and the representativeness of individual monitoring stations within the network are the key descriptors.

Network operations metadata. Details of network operation (Table 8) can be broken down into hardware components and cyberinfrastructure, which includes the data flow from the sensor to initial analysis, data management, data display, and usage (Hart and Martinez 2006; Muller et al. 2013). This consists of computer systems, instrumentation, data acquisition, data storage systems and repositories, visualization systems, management services, and technicians, linked by software and communications networks (Estrin et al. 2003; Brunt et al. 2007; Muller et al. 2013).

Hardware and cyberinfrastructure. Documentation of the hardware assets of a network (e.g., sensors, loggers, communications, and computers) is important not only for reporting purposes but also for keeping track of equipment, especially important for wide-area deployments. Recorded information should be as extensive as possible, with make, model, manufacturer, serial number, purchase date, and current location being minimum requirements for hardware in storage. However, for equipment deployed in the field (i.e., sensors), much more detailed information is required.

Table 6. Instrumentation-level [(c) in Fig. 2] metadata directory [based on established metadata guidelines from WMO (Oke 2004, 2006a; WMO 2008, 2011), other recommendations (e.g., Aguilar et al. 2003; NRC 2009; Manfredi et al. 2005; Muller et al. 2013), individual UMN guidelines (e.g., McPherson et al. 2007; Shafer et al. 2000; Koskinen et al. 2011) plus additional elements]. Information will need to be recorded at different time intervals (Se = seconds, M = minute, H = hour, D = daily, W = weekly, S = seasonal, A = annual, R = as required, O = once)

Metadata element	Description	Time
	Instrument administrative information	
Instrument ID	Instrument number (specific to the network/project)	O
Manufacturer	Manufacturer and part numbers	O
Make	Make of instrument/sensor	O
Model	Model	O
Size	Approximate size of instrument	O
Type	Type of instrument(s) (e.g., thermister, radar wind profiler, cup anemometer)	O
Variables	Variables monitored (e.g., air temperatures, relative humidity, rain rate, etc.)	O
Serial number[a]	Serial number for sensor	O
Installation date	Date of installation/upgrade	O
Decommissioned	Date taken offline/decommissioned (if applicable)	R
Start date	Start of data collection	O
End date	End of data collection	O
Operating principals	Operating principals (specific to network)	R
Condition	Condition (age)	R
Power supply	Power supply (battery, solar, mains)	R
Transducer	Transducer type (if applicable)	O
Local data storage	Local data storage capabilities (i.e., datalogger)	R
Representativeness[b]	Representativeness of measurement[c] (e.g., mesoscale, local scale, microscale)	R
	Details specific to sensor type[c]	
Temperature and relative humidity	Type and size of screen and ventilation (temperature and humidity)	O
Wind	Method of azimuth alignment (wind)	O
Precipitation	Type and gauge rim diameter, rim height above ground, presence of heating device (precipitation)	O
Sunshine	Type and thresholds for automatic sunshine recorders (sunshine)	O
Evaporation	Any coverage applied to evaporation pan (evaporation)	O

Instrument communications/data transmission [also part of network operations (d) in Fig. 2]		
Instrument communications type	Wired/wireless (including type, i.e., ZigBee, Wi-Fi, LAN, broadband, dial-up)	R
Media access control (MAC) address[a]	Instrument MAC address	O
Password[a]	Password if needed	R
One-way/two-way communications[a]	One-way/two-way communications?	R
Data transmission frequency	Frequency of data transmission	R, D, H, M
Sampling time	Time of observations (and No. of observations)	R, D, H, M, Se
Averaging period	Output averaging period	R, D, H, M, Se
Precision	Sensitivity/precision	O
Range	Measurement range	O
Response time	Response time	R, D, H, M, Se
Reporting frequency	Reporting frequency	R, D, H, M, Se
Accuracy	Accuracy (uncertainty)	O
Corrections	Corrections/calibration constants	A
Known errors	Known errors	A
Measurement units	Measurement units	O

[a] Information kept private for network managers/technicians only—not supplied as metadata to end user.

[b] See Table 7 for proposed definitions of classifications.

[c] There will be a specific set of features that need reporting depending upon the specific type of instrument—please refer to WMO guidance for details.

This includes a description of what the sensor observes [variable(s)], observation method (e.g., direct observation or sampling), observation frequency/period, performance characteristics (e.g., resolution, precision, range, and accuracy), calibration information (e.g., date since last calibration, method, and calibration coefficients), and deployment dates (see Table 8 for a complete list). Records should be kept throughout the sensor deployment of any site visits, problems encountered, changes around the location, and routine/nonroutine maintenance. These records not only provide a history that can be referred to to highlighting issues encountered, but also form an important part of network QA/QC procedures (Fiebrich et al. 2010).

Dense sensor networks may be installed to explore spatiotemporal variability across heterogeneous urban terrain. However, the reliability of the observed variability across a network may be significantly compromised by observation errors, and instrument drift and failure. To minimize these impacts and to ensure any observed fluctuations are credible, a proactive approach to instrument calibration is recommended as part of QA/QC procedures. This approach requires predeployment (both in the laboratory and field), routine site visits (including onsite testing) and postdeployment calibration of each sensor across the network with the methods utilized and frequency clearly stated within the metadata (Shafer et al. 2000; McPherson et al. 2007; Fiebrich et al. 2010).

Table 7. Overall UMN scale classification requires all three components to be specified.

Areal extent/size of network			
Climate scale	**Orlanski (1975)**	**Network covers**	**Spatial area (function of urbanized and nonurbanized extent) (km^2)**
Mesoscale/regional	Meso-α	Urban, suburban and rural areas	10^2–10^4
City	Meso-β	Whole city	10–10^3
Local/neighborhood	Meso-γ	A neighborhood with similar urban development	10^{-1}–10
Microscale	Micro-γ, -β, -α	Small areas of neighborhoods (e.g., street canyons)	10^{-6}–10^{-1}
Spatial density of network			
Array classification	**To assess**	**Mean distance between sensors**	
Coarse array	Large-scale variations	>10 km	
Wide array	Medium-scale variations	1 km–10 km	
Fine or dense array	Small-scale variations	100 m–1 km	
Micro array	Microscale variations	<100 m	
Representativeness of individual measurements		**Location criteria/siting requirements**	
Scale length	**Sensor measurements representative of**	**Sensors sited to take measurements**	
Mesoscale	Climate across the region	Representative of the wider mesoscale region; a single canopy-layer station cannot adequately represent climate across an urbanized area (Oke 2004)—scale relevant for boundary layer instrumentation	
Local scale	Climate over the local area	Avoid microclimate effects and collect measurements that are representative of the local area	
Microscale	Microscale climate variations	Examine microclimates, e.g., side of building, on roof of building, street canyon	

A simple review of the manufacturer calibration certificate should aid assessment of what was used as the reference instrument and its associated quality. Calibration against international standards is preferred but a traceable reference/working standard is acceptable (WMO 2008). Similarly, in-house calibrations need to consider the quality of the reference instrument. In-house interinstrument comparisons are critical prior to and after network deployment. The results of performance tests, QA/QC procedures, calibration, intercomparisons, research, processing, management techniques, and technical specifications should be made available and easily obtainable through peer-reviewed literature, conference papers, presentation, technical notes, and end-user guides using standardized terms (e.g., metadata, scales) (McGuirk and May 2003; Oke 2006b; Stewart 2011).

Cyberinfrastructure elements include network communications (e.g., wireless sensor node topology, mode of transmission, frequency of transmission), equipment and data processing techniques (which are critical prior to and after data collection), dataset information (e.g., data formats, measurement units, time formats, processing levels, calibration coefficients, constants), data management (e.g., QA/QC, error reporting, missing data flags, filtering, algorithms, programming language/software), and data storage (e.g., servers and storage media used, data backup, where archived, how to access).

Reporting, and communication and information dissemination. Entire network-level metadata will require regular updates and need to be easily obtainable in electronic form via appropriate inventories and catalogues (WMO 2011). The entire network metadata will be encoded, stored, and distributed: with the data itself as an accompanying text file [e.g., comma-separated values (CSV) file] or database {e.g., online using My Sequel (MySQL), Oracle, PostgreSQL, or as attribute data contained within the data file itself [e.g., network Common Data Form (netCDF), hierarchical data format (HDF), gridded

Table 8. Network-operations-level [(d) in Fig. 2] metadata directory [based on established metadata guidelines from WMO (Oke 2004, 2006a; WMO 2008, 2011), other recommendations (e.g., Aguilar et al. 2003; NRC 2009; Manfredi et al. 2005; Muller et al. 2013), individual UMN guidelines (e.g., McPherson et al. 2007; Shafer et al. 2000; Koskinen et al. 2011) plus additional elements]. Information will need to be recorded at different time intervals (refer to Fig. 6). BADC = British Atmospheric Data Centre. NASA = National Aeronautics and Space Administration. NERC = Natural Environment Research Council.

Metadata element	Description	Time
Hardware testing [also part of instrumentation, (c) in Fig. 2]		
Instrument testing	Details on testing of instrument (laboratory/field, intercomparisons, equipment involved)	O
Sensor calibration	Calibration procedures (methods, details, results)	O, A
Traveling calibration	Results of comparisons with traveling standards (for each instrument)	A
Network cyberinfrastructure [see (c) instrumentation for communications details specific to instrument and site in Fig. 2]		
Communications network topology	Arrangement of wireless devices (if applicable)	R
Transmission	Mode of transmission (e.g., landline, wireless, uplink to satellite)	R
Observing practices for reported datasets and metadata[a]		
Data format	Data format(s)	R
Version numbers	Details on version numbers linked with station history and instrument maintenance logs (i.e., if equipment moved, version number updated)	R
Correction	Postcollection correction or offset to be applied	R
Measurement units	Measurement/scale units	R
Missing data flag	Details on when missing data are flagged	R
Language	Programming language used	R
Spatial resolution	Spatial resolution	R
Temporal resolution	Temporal resolution	R
Time format	Standard time (UTC)	R
Geographic extent	Geographic/areal extent of the network	R
Access rights	Access rights for different users/different metadata	R
Processing level	Processing level (raw, processed)	R
Constant(s)	Constant(s) and parameter values	R
Other special codes	Other codes reporting special circumstances, i.e., missing data, errors, wrong values, suspicious data, trace precipitation, etc.	R
Metadata	Digitized metadata system (e.g., KML, GML, netCDF, database, etc.)—including all metadata information	R
Data storage		
Server	Servers used (in house, external)	R
Storage	Storage media type	A, D, H

Continued on next page.

Table 8. Continued

Metadata element	Description	Time
Back-up	Backup storage information	A, D
Transmission	How data are transmitted (to server, end user)	R, D, H, M
Access	Details on how and where to access data	R
Archive data center	Archive at data center (e.g., BADC, NASA, NERC)	A, D
Software	Software used/recommended	R
Hardware	Hardware and operating platform(s) (e.g., Windows, UNIX, Linux, Mac)	R
Data management methods		
Processing	Processing techniques (on-site/off-site)	R, D, H, M, Se
Error flags	Error reporting/flags [if adjustments are made, or missing data are filled, then this would include information regarding percentage missing data, algorithms employed (i.e., for interpolation schemes); period for which data were interpolated etc.]	R, D, H, M, Se
QC/QA	Data QC/QA methods (i.e., gross error check, tolerance tests, internal consistency checks, temporal coherency, spatial coherency, homogeneity adjustments plus additional information regarding amended data or procedures (i.e., percentage missing data, algorithms used, data period, etc.)	R, A, D, H, M, Se
Filtering	Filtering techniques used	R, A D, H, M, Se
Data reduction	Data reduction methods	R, A, D, H, M, Se
Programs	Programs used	R, A, D, H, M, Se
Algorithms	Details of specific algorithms	R, A, D, H, M, Se
Formulas	Formulas for calculations	R, A, D, H, M, Se
Language	Programming language used	R
Other		
Power[b]	Power source, power backup options, power management	R
Website	Website [uniform resource locator (URL), real-time visualization, data display, information)]	R, A, D, H, M
Staff	Staff (technicians, researchers, managers)	R
Management	Network management, monitoring, and maintenance procedures	O, R, A, D

[a] This does not include the complete list of information required for electronically reporting "dataset metadata"—this would be based on the information collected following this protocol, but it would also include additional elements specific to the dataset itself and chosen method of reporting (i.e., identifiers, character set, dataset period, version numbers, file formats, geographic bounding information, etc.). There are also specific terminologies, definitions, codes, and a standard format for reporting metadata—please refer to the main text for more information on standards for encoding and reporting metadata electronically.

[b] Information kept private for network managers/technicians only—not supplied as metadata to end user.

binary (GRIB), and binary universal form for the representation of meteorological data (BUFR) to list but a few but many other acceptable formats]}. Encoding methods such as extensible markup language (XML) provide a logical choice of format for this purpose and are already recommended by WMO as the standard method. However, XML variants are perhaps better suited to documenting the geographic component of UMN's because of their capabilities of providing a visualization of the metadata [e.g., geography markup language (GML) or keyhole markup language (KML); Open Geospatial Consortium 2012].

Overall, *dataset metadata* need to adhere to the relevant "schemas" for the chosen encoding method(s) that provide(s) the "structure" for describing digital geographic datasets (e.g., WMO Core Metadata Profile and the ISO19100 series, especially the ISO19115 geographical metadata standard and/or the ISO19136 GML metadata standard). These schemas explicitly define metadata elements and structures while establishing a common set of metadata terminology, definitions, and extension procedures for reporting. The network metadata directory (Table 8) includes the universal information required for inclusion in any of the aforementioned metadata-encoding mechanisms.

CONCLUSIONS. This first effort to create a standardized metadata protocol for UMNs draws upon recommendations from a range of sources to regularize UMN data (and improve compatibility with other nonmeteorological UMNs). The goal is to standardize UMN metadata based on best practices, personal experiences, and official recommendations. It is particularly clear that standardized terms, specific site classification techniques, and an urban network classification scheme would be of benefit to network implementers and end users alike. With implementations and discussion, the urban meteorological community will hopefully arrive at a consensus that is appropriate for current technologies, including more detailed requirements (e.g., variable-specific QA/QC procedures). The intent of this paper is to promote further discussions to facilitate this process.

Long-term, baseline datasets obtained from UMNs are required for a broad spectrum of applications, but the datasets need to be high quality and reliable in order to ensure accurate usage, thus furthering our understanding of increasingly important urban environments. It is acknowledged that it is difficult to ensure guidelines are universally adhered to (Stewart 2011); however, the publication of such protocols significantly increases the likelihood of adoption and is essential to further the understanding of the urban climate.

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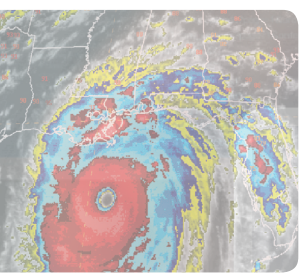

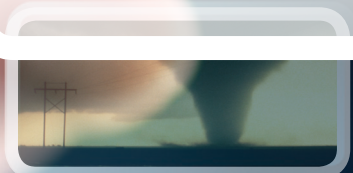

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THE EMERGENCE OF WEATHER-RELATED TEST BEDS LINKING RESEARCH AND FORECASTING OPERATIONS

BY F. MARTIN RALPH, JANET INTRIERI, DAVID ANDRA JR., ROBERT ATLAS, SID BOUKABARA, DAVID BRIGHT, PAULA DAVIDSON, BRUCE ENTWISTLE, JOHN GAYNOR, STEVE GOODMAN, JIANN-GWO JIING, AMY HARLESS, JIN HUANG, GARY JEDLOVEC, JOHN KAIN, STEVEN KOCH, BILL KUO, JASON LEVIT, SHIRLEY MURILLO, LARS PETER RIISHOJGAARD, TIMOTHY SCHNEIDER, RUSSELL SCHNEIDER, TRAVIS SMITH, AND STEVEN WEISS

Test beds have become an integral part of the weather enterprise, bridging research and forecast services by transitioning innovative tools and tested methods that impact forecasts and forecast users.

Over roughly the last decade, a variety of "test beds" have come into existence focused on high-impact weather and the core tools of meteorology—observations, models, and fundamental understanding of the underlying physical processes. They have entered the proverbial "valley of death" between research and forecast operations (NAS 2000), and have survived. This paper provides a brief background on how this happened; summarizes test bed origins, methods, and selected accomplishments; and provides a perspective on the future of test beds in our field. Dabbert et al. (2005) provides a useful description of test beds from early in their development and Fig. 1 summarizes the role of test beds.

Many trace their origins to the U.S. Weather Research Program (USWRP)'s goals of linking weather research and forecasting operations more effectively. Although USWRP leadership initially envisioned that the associated gaps in capabilities and funding could be filled

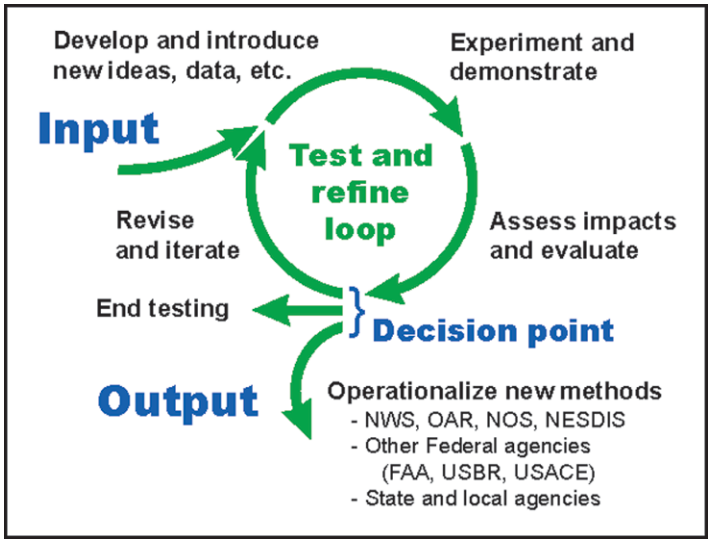

FIG. 1. Conceptual schematic of the test bed process for a hypothetical project, tool, or concept—including innovation, demonstration, evaluation, and, where suitable, a transition to operations within a federal, state, or local organization. NOS = National Ocean Service; USBR = United States Bureau of Reclamation; and USACE = U.S. Army Corps of Engineers.

through major new federal appropriations (on the order of $100 million per year), no singular such funding was achieved. Instead, the National Oceanic and Atmospheric Administration (NOAA) received roughly $3 million per year in core funding for USWRP, which has seeded the development of several test beds, some of which now receive core, long-term funding from their host agencies and are no longer supported directly by NOAA/USWRP. Today, test beds involve multiple agencies—including NOAA, the National Aeronautics and Space Administration (NASA), the Federal Aviation Administration (FAA), and the Department of Defense (DoD)—and represent a major focus of effort in meteorology; although exact numbers are difficult to pin down, current investments are easily in the tens of millions of dollars per year. Individual test beds often have a scope of effort of roughly $1–$5 million per year including "core" funding and "project" funding. The core funding establishes a long-term foundation and capability, while project funding leverages this and delivers on specific tasks for the project sponsors, often in a highly synergistic manner. Their creation has typically involved ramping up over 2–4 years, starting with $100–$500K of funding. Table 1 lists the 10 test beds covered in this paper and briefly summarizes their key attributes.[1]

Test bed accomplishments cover a wide range of applications and techniques, from new scientific understanding to better modeling and predictive tools, greater awareness of how weather information is used, and improved outcomes for society. These are achieved through a diverse set of technical and organizational approaches that have emerged organically to meet the needs represented by individual gaps in existing predictive or scientific capabilities. In spite of this diversity in approaches, there are some interesting symmetries between test beds. They often include a core research laboratory upon which scientific staff and tools can be leveraged and administrative infrastructure used. There is usually a specific National Centers for Environmental Prediction (NCEP) "center" that is integrated into the test bed activities including planning, testing, and adoption of suitable new methods and tools. Weather Forecast Offices (WFO) and River Forecast Centers (RFC) are often engaged, as are key users of forecasts. University investigators and students have been involved, which has led to employment opportunities for recent graduates and an infusion into the National Weather Service (NWS) and NOAA laboratories of people with experience and a mindset adapted to bridging research and forecasting operations. Test bed activities can yield results characterized as advancing

[1] Each of the test beds described here were represented at a NOAA Testbed Workshop, where a brainstorming meeting was held to discuss developing this article. Most also can trace their roots to support from USWRP and are focused on NOAA mission requirements. Although there are now many other test beds (in the United States and Europe) that could have been included here (e.g., Helsinki Testbed, European Severe Storms Laboratory Testbed, National Weather Radar Testbed), it was not practicable to do so. It is envisioned that this article will increase awareness of this emerging type of activity that is helping our field to better link research and forecasting operations (including by those test beds not described herein).

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science or predictions, and can occur in the form of "intangibles," such as the spawning of a new research direction by exposure of scientists to operational forecasting challenges, or the realization by a forecaster exposed to new science or tools that a valuable new way of using existing observations, models, or forecast tools can be achieved with minimal effort.

As it became clear, by 2008, that several test beds had been created and were producing important results (publications, demonstrations of new tools/methods, transitions into forecasting operations, etc.), it was decided to hold a "NOAA Testbeds Workshop," which was carried out in April 2009. Roughly 70 participants gathered for two days to share experiences and lessons learned. Two additional workshops have been held thus far—in 2010 and 2012. One of the outcomes of the first workshop was the creation of a NOAA Testbeds website (www.testbeds.noaa.gov) and a NOAA Testbed newsletter (Fig. 2). The second workshop revealed a need for greater coordination regarding recommendations from multiple test beds for major new NOAA observational or modeling infrastructure. Additionally, gaps were identified in capabilities across test beds, and the need for advocacy of test beds as a strategy for NOAA was recognized. In response, NOAA formed a Testbeds and Proving Ground Coordinating Committee, which was approved formally by NOAA leadership. This committee, which includes a manager for each test bed/proving ground and representatives from relevant

Table 1. Overview of test bed descriptions and information (details at NOAA Testbed portal website: www.testbeds.noaa.gov).

Test bed	Focus	Location and partners	Key NOAA/ NCEP center
JHT	Hurricane prediction	JHT is led by the National Hurricane Center in Miami, FL, with partners at federal laboratories, academia, and the private sector.	NHC
HMT	Extreme precipitation, QPE, QPF, hydrology, snow, decision support tools	HMT is led by NOAA/ESRL's Physical Sciences Division in Boulder, CO, with partners across NOAA, other agencies, and universities.	HPC
JCSDA	Numerical data assimilation	The JCSDA is located at the National Center for Weather and Climate Prediction in College Park, MD.	EMC
HWT	Severe weather	The HWT is a joint facility managed by NSSL, SPC, and the NWS Oklahoma City/Norman WFO located at the National Weather Center in Norman, OK.	SPC
SPoRT	Nowcasting, short-term forecasting, severe weather	SPoRT is located in Huntsville, AL, and partners with NOAA/NESDIS and NWS, University of Wisconsin—Madison/Cooperative Institute for Meteorological Studies (CIMSS), Colorado State University (CSU)/Cooperative Institute for Research in the Atmosphere (CIRA), and Naval Research Laboratory (NRL).	NHC, HPC, Ocean Prediction Center (OPC), AWC
DTC	Mesoscale modeling	The DTC is located jointly at NCAR and NOAA/ESRL in Boulder, CO. DTC personnel include scientists from NOAA, NCAR, and universities.	EMC
CTB	Climate forecasts	The CTB facility is located at NCEP, Camp Springs, MD. CTB personnel include scientists from NCEP and other NOAA and non-NOAA organizations.	CPC
GOES-R	Weather-Ready Nation, high-impact weather	The Proving Ground is a collaborative effort between the GOES-R program office, cooperative institutes, WFOs, NCEP, and NOAA test beds across the country.	AWC, HPC, NHC, OPC, SPC
AWT	Aviation weather	Execution of the AWT, located at the AWC in Kansas City, MO, is accomplished via close collaboration with partners including the FAA, NCAR, MIT, and NOAA/NCEP, and ESRL.	AWC
OSSE	Observing system simulation experiments	Development is being led and managed through NOAA/AOML, in Miami, FL, for use by USWRP partners and academia in collaboration with NESDIS/STAR, NOAA/ESRL, and the JCSDA.	EMC

NOAA line offices, organized the third workshop including identification of extreme precipitation as an integrating theme that engaged several test beds.

The test bed summaries herein were prepared by their respective leadership and are presented roughly in the order each was created (Table 1 and Table ES1 of the online supplement contain a listing and brief descriptions of each test bed). Each section includes information regarding the primary focus, objectives, tools used, organizational approach, selected accomplishments, and links to further information. The report concludes with a brief synopsis and description of potential future directions.

JOINT HURRICANE TESTBEDS (JHT). The USWRP formed the JHT in late 2000 in response to the need articulated by the National Research Council's workshop report to bridge advances in research to the operational environment (NAS 2000). The JHT's mission is to smoothly and rapidly transfer new technology, research results, and observational advances into improved tropical cyclone analysis and prediction at operational centers. This mission is accomplished by identifying promising techniques, applications, or systems being developed by external scientists, and by supporting their testing, evaluation, and modification in a quasi-operational environment.

The JHT is located at the National Hurricane Center (NHC) and is governed by a terms of reference document (www.nhc.noaa.gov/jht/JHTTOR.13Sep2002.pdf) summarizing its organization and operation. Federal assistance through NOAA allows scientists to tailor their techniques for the operational environment. The total annual JHT budget has varied between about $1 million and $1.5 million, all of which has been provided by the USWRP to fund proposals submitted by the research community. Although NOAA/USWRP provides funding for some of JHT's infrastructure, JHT relies on NHC for critical forecaster, administrative, technical, and logistical support. NHC forecasters serve as scientific "points of contact," providing guidance throughout the project cycle. The NHC also maintains JHT computer equipment, provides real-time data, and collaborates with project investigators to facilitate testing and evaluation. Researchers also work with other national centers [e.g., NCEP/Environmental Modeling Center (EMC)] with facilitation provided by the JHT. The NOAA/Atlantic Oceanographic and Meteorological Laboratory (AOML)'s Hurricane Research Division (HRD) is a primary research partner with JHT and has contributed staff members to two important JHT positions for almost 10 years. One HRD senior scientist sits on the JHT's Steering Committee (SC), and has served as the SC's research colead. HRD also staffs one of the two administrative assistant positions supporting the JHT director. HRD scientists have submitted numerous test bed project proposals that have been awarded funding. Some of these have benefited NHC's forecast operations.

Administration of the JHT comprises a director, two administrative assistants (each devote a quarter of their time), and a full-time information technology (IT) facilitator. The JHT IT environment closely mimics the basic NHC IT environment (data flow and formats, communications, hardware platforms, software applications, etc.) in order to test and to best prepare each technique for possible operational implementation at the conclusion of the project. NHC provides real-time access to the operational data stream to the JHT environment. The JHT Steering Committee advises the JHT director on all JHT activities, and its primary responsibility is to review proposals submitted to the JHT by the research community. The steering committee comprises seven members who broadly represent the tropical cyclone community, including representatives from NOAA

FIG. 2. NOAA Testbed newsletters published since fall 2009.

and DoD tropical cyclone operations and research, as well as academia.

A biennial Announcement of Opportunity (AO) inviting projects is the initiation for JHT proposal-driven transitions, which includes the program objectives and priorities, and contains a list of NHC, Central Pacific Hurricane Center (CPHC), Joint Typhoon Warning Center (JTWC), and EMC analysis and forecast improvement needs that have been identified and prioritized by these centers. Researchers submit proposals as part of a competitive process. Proposal evaluation criteria are the scientific merit of the technique, readiness for real-time testing based on factors like research maturity, analysis–forecast issue priority, technical compatibility with operational systems, and costs.

After 1–2 years of testing, the conclusion of a JHT project is followed by the submission of a final JHT report to NHC's director and/or other operational center(s) if applicable. This report comes from the JHT staff and is based on its evaluation and input from the project scientist(s) and NHC's points of contact. NHC's director makes the decision on whether to begin the process of operational implementation of the techniques resulting from the project—decisions on model changes are made at EMC, with NHC input. The NHC director's decisions are based on an analysis of forecast or analysis benefit, efficiency, IT compatibility, and sustainability.

Since the JHT's inception, NHC and other operational centers (e.g., CPHC and JTWC) have interacted with scientists on 74 projects, with over half of them implemented into operations. Rappaport et al. (2012) examined the first 10 years of the JHT, its impact on operations, and JHT's contributions to NHC's forecast operations. One project of note developed a way to describe the probability of tropical cyclone wind speed thresholds

DEFINITION AND OBJECTIVES FOR NOAA TEST BEDS AND PROVING GROUNDS

TEST BEDS

i) Definition and purpose: A NOAA test bed is a working relationship for developmental testing in a quasi-operational framework among researchers and operational scientists/experts (such as measurement specialists, forecasters, and IT specialists) including partners in academia, the private sector, and government agencies, aimed at solving operational problems or enhancing operations in the context of user needs. A successful test bed involves physical assets as well as substantial commitments and partnerships.

ii) What is tested: Advances to be considered include candidates for more effective observing systems, better use of data in forecasts, improved forecast models, and applications for improved services and information with demonstrated economic/public safety benefits.

iii) Objectives: Test beds accelerate the translation of research and development (R&D) findings into better operations, services, and decision making. Outcomes from a test bed are capabilities that have been shown to work with operational systems and could include more effective observing systems, better use of data in forecasts, improved forecast models, and applications for improved services and information with demonstrated economic/public safety benefits. Successfully demonstrated test bed capabilities are ready for advanced predeployment testing, in a full simulation of real-time operational conditions, leading to "go/no go" deployment decisions.

OPERATIONS AND SERVICES PROVING GROUNDS

i) Definition and purpose: Operations and services proving grounds are a framework for NOAA/NWS to conduct testing of advanced operations, services, and science and technology capabilities that address the needs of both internal and external users. Successful testing demonstrates readiness to implement into operations.

ii) What is tested: Capabilities to be tested in operational proving grounds have already passed developmental testing. Such capabilities include advanced observing systems, better use of data in forecasts, improved forecast models, and applications for improved services and information with demonstrated economic/public safety benefits.

iii) Objectives: Testing in real time, in an operations-like setting to demonstrate achievement of performance metrics, including testing any workflow changes, needed for implementing in operations as well as end-to-end delivery of services. Performance metrics are defined for each candidate capability in categories of objective performance (e.g., accuracy/skill), subjective evaluations of utility (e.g., user feedback on balance positive), and production/engineering readiness (e.g., systems and communications reliability/security/backup, data retention). Performance criteria for objective and subjective evaluations by users internal to NWS include expected impacts to workflow and workload, except when advanced capabilities have no impact on workflow/workload (e.g., in the case of improvements to numeric quality of current operational guidance and tools). Successful predeployment testing is necessary for approval to implement into operations. (Excerpted from Davidson et al. 2012.)

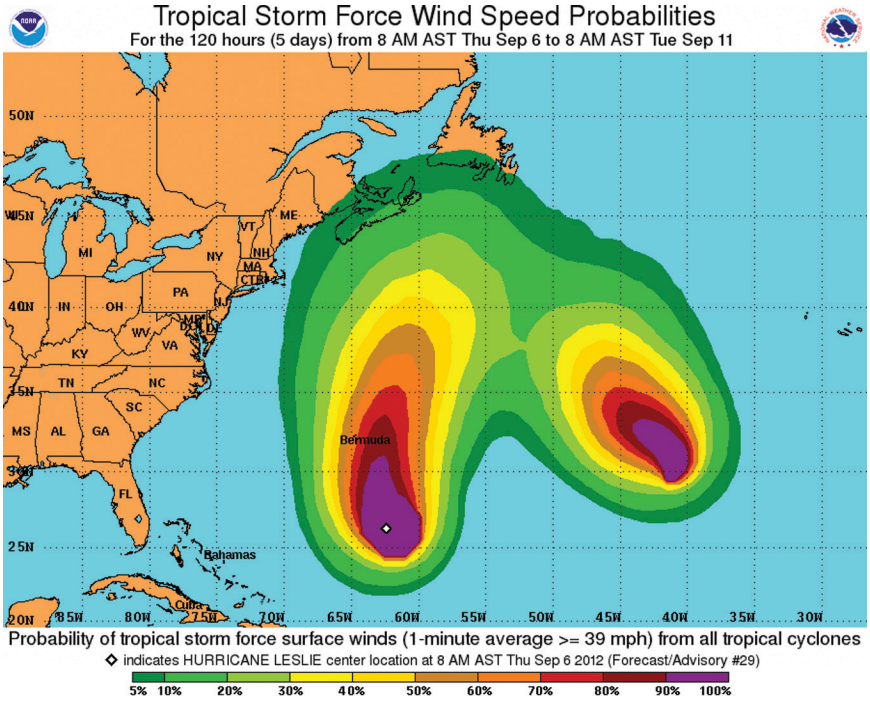

Fig. 3. NHC's wind speed probability product for 1-min average tropical storm force wind (34 kt, where 1 kt = 0.51 m s^{-1}) for (left) Hurricane Leslie and (right) Hurricane Michael issued on 1200 UTC 6 Sep 2012. The shading represents the probability (percentage) of sustained tropical force surface winds will occur during the forecast period in the shaded area on the map.

(DeMaria et al. 2009), which is now a routine operational product (Fig. 3 shows an example of two hurricanes). Improvements in tropical cyclone monitoring and prediction in recent years can be credited to the successful implementation of JHT projects.

NOAA'S HYDROMETEOROLOGY TESTBED (HMT). Extreme precipitation and the related hydrometeorological "forcings" that contribute to flooding, such as soil moisture and snowpack, are the focus of HMT (Ralph et al. 2005). Flooding has triggered more presidential disaster declarations than any other single natural hazard and has contributed on average to more than $3 billion per year of damages nationally. Additionally, a recent study of public use and perceptions of weather forecasts determined that precipitation forecasts were the single most used component of weather forecasts (Lazo et al. 2009).

In spite of its crucial role in both extreme and day-to-day events, quantitative precipitation forecasting (QPF) has remained one of the great challenges in meteorology, especially for extreme events (e.g., Reynolds 2003; Ralph et al. 2010). Currently, NOAA's QPF performance is measured in terms of the "threat score" for forecasts of 1 in. or greater rainfall in 24 h with 1-day lead time. These are issued by NWS's Hydrometeorology Prediction Center (HPC). QPF skill scores typically range between 0.25 and 0.35 (1.0 is a "perfect" forecast). However, this verification metric does not address the highest-impact events, which can often exceed 3–5 in. of rain in 1 day, or >8 in. in 3 days (Ralph and Dettinger 2012), and are even more difficult to predict.

To address these gaps, HMT conducts research on precipitation and weather conditions that can lead to flooding, fosters transition of scientific advances and new tools into forecasting operations, and supports the broad needs for twenty-first-century precipitation information for flood control, water management, and other applications. Guided by NWS operational requirements, emerging scientific questions, and new technologies, HMT directly engages forecasters and scientists in research and development. New ideas, technologies, and predictive models are developed, demonstrated, evaluated, and refined through the test bed before being transitioned to operations. HMT will provide prototypes for state-of-the-art forcings for hydrologic prediction systems at NOAA's National Water Center.

A key driver of HMT was the desire expressed by the NWS forecast community and NOAA stakeholders for more continuous engagement with researchers following two field experiments—"CalJet" and "PacJet"—associated with extreme precipitation in West Coast storms in 1997/98 and 2001/02 (Morss and Ralph 2007). In response, the Physical Sciences Division (PSD) of NOAA/Earth System Research Laboratory (ESRL) sponsored HMT pilot studies in 2003/04 in Northern California's flood-prone Russian River region (Ralph et al. 2006). These studies addressed QPF, which had been identified by USWRP as a priority topic. Next steps for HMT were informed by an interagency planning workshop on cool-season QPF (Ralph et al. 2005). This workshop, plus stakeholder interest driven by the near-catastrophic flood of 1997 that put downtown Sacramento,

California at risk of up to 10 ft of inundation, led HMT to focus next on the American River basin above Sacramento starting in the winter of 2005/06.

HMT is led by ESRL/PSD, the core sponsor, and includes the following key partners: ESRL/Global System Division (GSD); NCEP/HPC; Office of Hydrological Development (OHD); National Environmental Satellite, Data, and Information Service (NESDIS); NWS Western Region RFCs and WFOs; and the state of California's–Department of Water Resources (CA–DWR). HMT has a program director; five "major activity areas," each with two coleads; two regional field implementations; two transition coordinators for weather and water forecasting; and a field operations coordinator. HMT has collaborated with DTC on mesoscale modeling focused on precipitation. Several grants to universities address HMT's quantitative precipitation estimation (QPE) and QPF activity areas. HMT's purpose, organization, and foci are summarized in its charter, including the identification of five major activity areas representing the primary service performance gaps being addressed: i) QPE, ii) QPF, iii) snow information, iv) hydrologic applications and surface processes, and v) decision support tools (DST). For each area a team of researchers and forecast experts have defined a 5-yr implementation plan that includes key technical tasks with milestones and deliverables aligned with their funding sources. These tasks are addressed using observations, modeling, diagnostics, DST development, training, and transition, and are represented in each year's annual operating plan.

Extreme precipitation and flooding have diverse origins meteorologically and vary greatly by region, from land-falling extratropical cyclones on the West Coast to hurricanes in the east and south to deep convection in the interior and the Southwest. This requires regionally distinct research and development (Ralph et al. 2005). HMT-West is the first regional demonstration, which established that the bulk of heavy precipitation associated with land-falling winter storms is often triggered by "atmospheric rivers" (ARs) (Fig. 4; Ralph et al. 2011; Ralph and Dettinger 2011, 2012). As a consequence of HMT-West research, the NWS began training sessions focused on ARs to improve situational awareness for forecasters and water resource managers. This included creating a COMET training module on ARs (https://www.meted.ucar.edu/training_module.php?id=904). HMT-developed tools that focus on water vapor transport and ARs (Neiman et al. 2008; Junker et al. 2008; Ralph and Dettinger 2012; White et al. 2012) are used in NWS operations, and HPC and ESRL/PSD led an AR Retrospective Forecasting Experiment to advance AR predictions.

In summary, HMT-West has fostered innovative research to improve understanding, monitoring, and

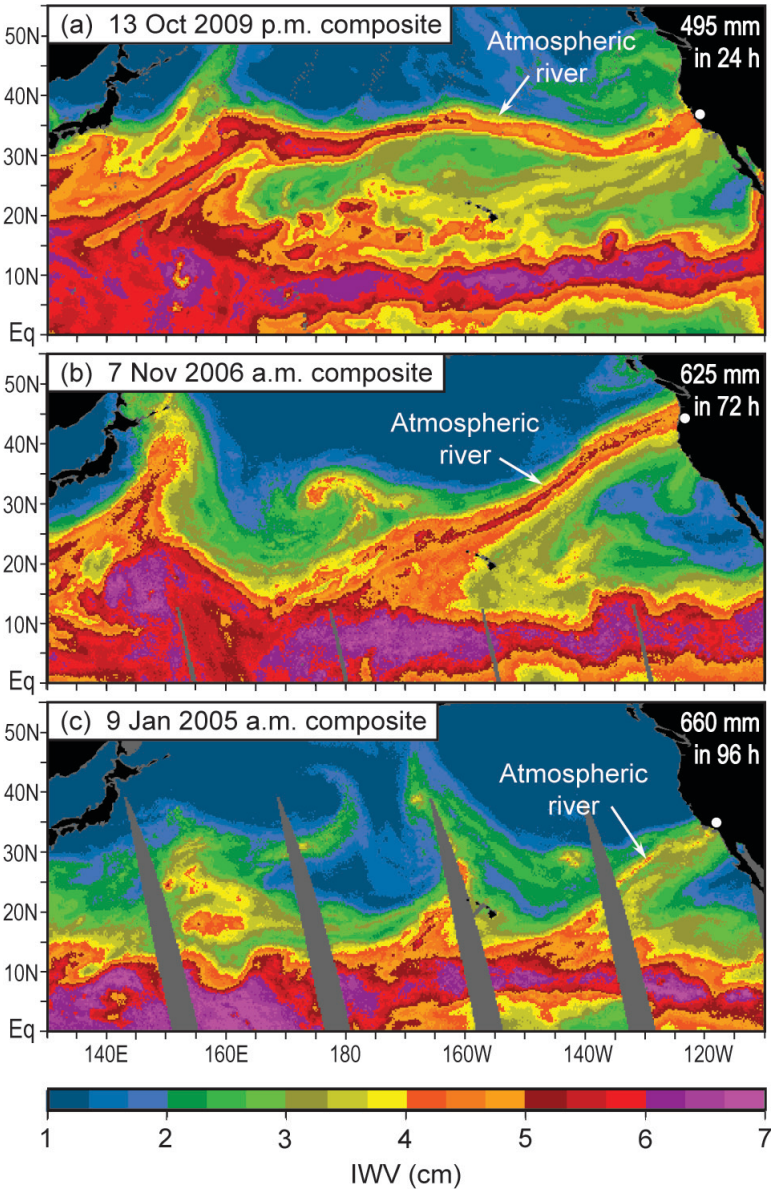

Fig. 4. Examples of atmospheric river events (from Ralph et al. 2011).

Table 2. Select accomplishment highlights and impacts from HMT.		
Region	**Highlights**	**Impact**
HMT-West: California, Pacific Northwest area	ARs identified as the major cause of extreme events on U.S. West Coast; shallow rainfall is key but missed by Next Generation Weather Radar (NEXRAD); NWS forecaster and water managers trained; new observing network for California; invented Atmospheric River Observatories (AROs); new forecast performance measures proposed for snow level and extreme QPF	Better "situational awareness" of extreme events; new snow-level forecasting methods; HPC-extended QPF to include 6–7-day lead time
HMT-West: Seattle area	Innovations from HMT-West were central to NOAA's rapid response to the Howard Hanson Dam crisis	USACE used HMT-developed tools in flood control decision making
HMT-West: San Francisco area	KPIX scanning radar installed by TV station near San Francisco based on HMT demonstration of radar gap	Better data in heavy precipitation events in flood-prone area
HMT-West	NOAA, U.S. Geological Survey (USGS), Scripps Institution of Oceanography, California Energy Commission, and Department of Energy (DOE) carried out a field experiment based on leveraging HMT-West	"CalWater" conducted in winters 2009–11 to study impacts of changing climate on precipitation
HMT-West: Sacramento area	Created a long-term monitoring network in the American River basin for precipitation, soil moisture, and runoff	NSF major research infrastructure deployment for snow in the American River basin leverages HMT
HMT-Southeast	HMT conducted planning for a regional implementation of HMT in the Southeast United States	NASA's Precipitation Measurement missions selected this region for a major ground validation study to leverage HMT

prediction of extreme precipitation (evidenced by >60 peer-reviewed publications), and is now active in several regions outside of California (Table 2). HMT will soon complete a 93-station observing network in California and associated decision support tools, including an early warning system for extreme atmospheric river events (Fig. 5). HMT innovations were key in NOAA's rapid response to the Howard Hanson Dam flood risk management crisis near Seattle, Washington (White et al. 2012). HMT-Southeast will begin in 2013 in North Carolina, in partnership with the NASA Global Precipitation Measurement (GPM) mission. Finally, HMT represents a core NOAA capability to address "understanding and predicting the water cycle," which is one of the Grand Science Challenges identified by NOAA in its 2010 report "Strengthening NOAA Science" (NOAA Science Workshop Program Committee 2010).

JOINT CENTER FOR SATELLITE DATA ASSIMILATION (JCSDA). The JCSDA was established in 2001 to improve and accelerate the use of research and operational satellite data in numerical weather, ocean, climate, and environmental analysis and prediction. NOAA and NASA were the founding partners and DoD (U.S. Navy and Air Force) joined later. USWRP provided seed funding to initiate JCSDA prior to the creation of new core funding. It is a distributed and collaborative effort that provides a focal point for the development of common software and infrastructure for the partner agencies (Le Marshall et al. 2007). The partnership allows these agencies to enhance the usefulness of the billions of satellite observations currently available daily and to fully prepare for the flood of data from the advanced satellite instruments to be launched during this decade. This is a challenging task given satellite data volume has been increasing at a rate of 100,000-fold per decade—in the last decade alone 50 new instruments were introduced.

The day-to-day activities of the JCSDA are managed by an executive team composed of the director, the deputy director, and associate directors representing all the JCSDA partner agencies [NOAA/NWS, Oceanic and Atmospheric Research (OAR), and NESDIS; NASA Goddard Space Flight Center (GSFC); and Air Force Weather Agency (AFWA) and U. S. Navy]. The executive team is overseen by and receives high-level guidance from a management

oversight board with members from all the JCSDA partners. The JCSDA receives regular independent reviews of its scientific priorities and strategic directions from an external science steering committee and advisory panel.

The JCSDA supports scientific development work in priority areas including radiative transfer, clouds and precipitation, advanced instruments, land data assimilation, ocean data assimilation, and atmospheric chemistry and aerosols (Fig. 6). Examples of success include advances in formulating the Community Radiative Transfer Model (CRTM), assessing the impact of assimilation of Advanced Infrared Sounder (AIRS) and Moderate Resolution Imaging Spectrometer (MODIS) data, and provision of AIRS data to operational centers worldwide after the data have been "thinned" appropriately (Le Marshall et al. 2007).

The JCSDA research and preoperational implementation experiments are conducted by JCSDA-affiliated scientists with proposal-based funds (internal research) or through external grants and contracts awarded via a competitive process open to the broader scientific community (external research). There are also core projects that are regulated by an agreement between the funding agency and the project principal investigators (directed research). In addition, the JCSDA partners conduct their own internal projects, some of which are directly related to the JCSDA activities. These projects are considered by the JCSDA as in-kind support of JCSDA objectives.

JCSDA activities center on improving the assimilation of satellite data from research and operational sensors on national and foreign satellites and leveraging the efforts of all JCSDA partners. All kinds of satellite data are considered:

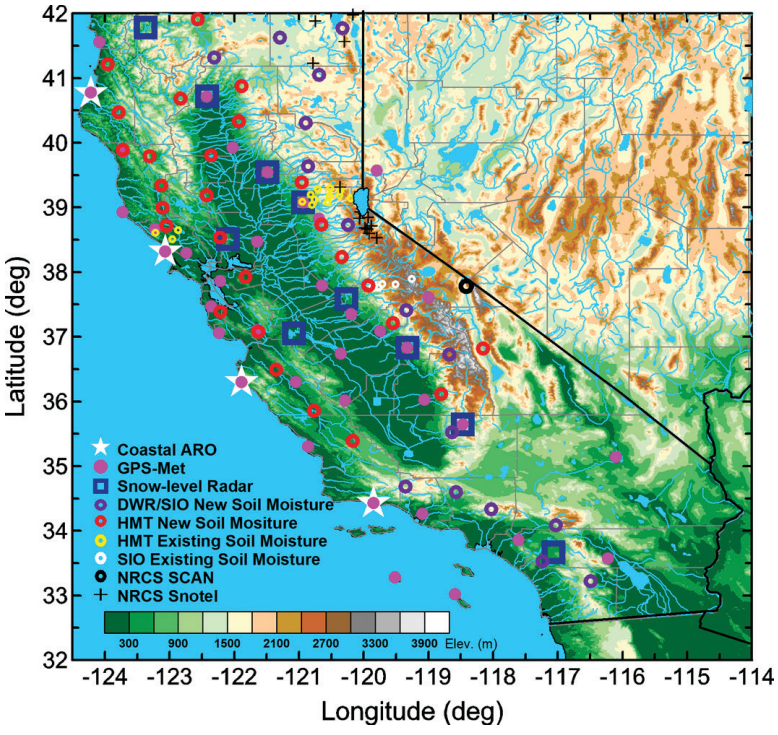

Fig. 5. HMT-West Legacy mesonet being installed in California by NOAA and partners as part of the CA-DWR's Enhanced Flood Response and Emergency Preparedness Observing Network.

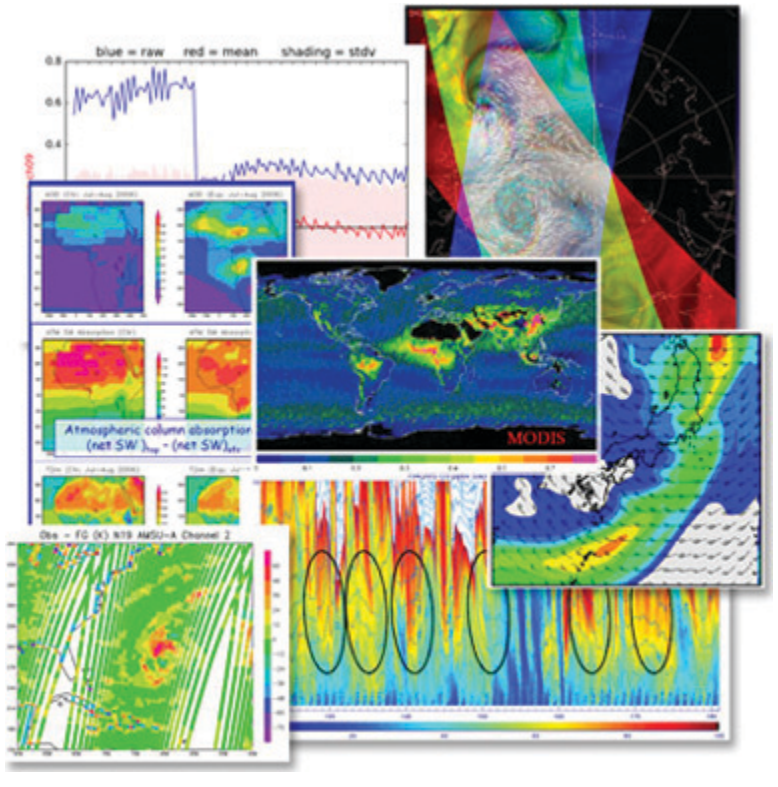

Fig. 6. JCSDA enhances the usefulness of current satellite observations and accelerates the assimilation of data from new instruments, including infrared, microwave, active, passive, and geo- and polar-based measurements.

Table 3. Select accomplishment highlights and impacts from JCSDA.	
Highlights	**Impact**
CRTM	World-class radiative transfer model used for a large number of applications including primarily satellite data assimilation (all U.S. operational NWP centers use it), calibration and validation of remote sensing products, climate monitoring, retrievals, etc.
Satellite data assimilation of new sensors	Improved medium-range weather forecast skills (of NOAA models) when new sensors were assimilated by JCSDA scientists [GPS–Radio Occultation (RO) data from Constellation Observing system for Meteorology, Ionosphere, and Climate (COSMIC), hyperspectral data from NASA AIRS and *Meteorological Operation-A (MetOp-A)*/Infrared Atmospheric Sounding Interferometer (IASI), etc.]
Expedited R2O transition: Faster turnaround in satellite data assimilation of data from newly launched Suomi National Polar-orbiting Partnership (NPP) sensors	Traditionally, it took several years to get new sensors assimilated operationally in NOAA models. JCSDA has been instrumental in speeding up this process and therefore increasing the useful lifetime of these sensors [this work is in progress for NPP/Advanced Technology Microwave Sounder (ATMS)].
Outreach to external researchers in the academia, private sector, and other state and federal agencies	Through the external research program, the JCSDA has been able to tap into expertise residing outside of the JCSDA partners. Examples include the possibility to assimilate lightning data for upcoming GOES-R data, improved spectroscopy and line-by-line models, assimilation of satellite remote sensing data to improve regional modes forecast skills, and hurricane track and intensity forecast.
General data impact experiments and OSSE activities	A better analysis on the impact of the different sensors on the forecast skills errors reduction, as well as an assessment tool to predict the global impact of future missions on the medium-range weather forecast systems.
An operations-to-research (O2R) environment	Researchers, funded by or affiliated with JCSDA, have access to an environment that mimics the operational systems, but in a research-friendly setup. This infrastructure allows the running of global and regional assimilation and forecast models, and processes the results. This allows the scientists to test their science and/or products in a system identical to operations.

direct measurements of radiances and brightness temperatures and derived products; observations from both polar-orbiting and geostationary satellites; measurements of instruments sensing in the ultraviolet, visible, infrared, and microwave spectral regions; and data from passive and active sensors, including radio occultation measurements. Recent achievements are listed in Table 3.

The JCSDA organizes annual scientific workshops on satellite data assimilation that are crucial for the technical coordination of the efforts between the different JCSDA partners. It also organizes a data assimilation summer colloquium, every 2–3 years, engaging graduate students and researchers with early postdoctoral appointments in the science of satellite data assimilation for the atmosphere, land, and oceans. The program includes lectures by international experts in data assimilation, and allows students to interact with the lecturers in an informal setting. The objective of the program is to foster the development of the next generation of data assimilation scientists to support environmental modeling. The JCSDA also publishes a quarterly newsletter highlighting recent research and implementation accomplishments, and conducts a monthly seminar series that is webcast nationally and internationally.

HAZARDOUS WEATHER TESTBED (HWT). The HWT has its roots in a culture of collaboration established decades ago among severe weather enthusiasts with a commitment to excellence in both forecasting and research. This collaboration can be traced back to the 1950s when forecasters from the Severe Local Storms Warning Service (SELS) and research scientists with the National Severe Storms Project (NSSP) conducted pioneering forecast and research activities out of Kansas City, Missouri (Corfidi 1999). Interaction between these two groups waned somewhat when NSSP became the National Severe Storms Laboratory (NSSL) and moved to Norman, Oklahoma, in the early 1960s, but NSSL scientists forged new partnerships with the local WFO in Oklahoma City in the 1960s [the WFO is now in Norman].

Proximity and passion for severe weather were key ingredients in these partnerships. One element of the collaboration revolved around development and field testing of Doppler weather radar and dual

polarization improvements (Scharfenberg et al. 2005). NSSL researchers made significant efforts to transition this science and technology to forecasting operations. Specifically, they engaged in month-long visits to more than a dozen WFOs nationwide to provide training, solicit direct feedback from a wide variety of operational forecasters, and facilitate operational implementation (e.g., Lakshmanan et al. 2007). The Norman-based collaboration also focused on forecast improvements (e.g., Doswell and Flueck 1989; Brooks et al. 1993), which led to the creation of an experimental forecast facility (EFF) in the mid-1990s, staffed by both researchers and forecasters and located adjacent to the operational forecast floor in the Norman WFO (Auciello and Lavoie 1993).

When the blueprint for NCEP was presented in the early 1990s (McPherson 1994), it reflected a strong desire to collocate each new operational center with a complementary research and/or academic institution. One of these new operational centers was the Storm Prediction Center (SPC)—formerly SELS. Given the historical linkage between the SPC and NSSL and the preexisting collaborative framework in central Oklahoma, the SPC was relocated to Norman where space for SPC operations was created within existing NSSL facilities. Additionally, a separate room was reserved for an EFF-like arrangement with dataflow, visualization, and computational resources that mirrored SPC operations. Leaders from NSSL and SPC identified a small group of researchers and forecasters with mutual interests in specific operationally relevant research topics and encouraged these individuals to use the new facilities and develop a framework for a long-term working relationship. This eventually gelled around the topic of more effective use of numerical weather prediction (NWP) models for severe weather forecasting, focusing on educating forecasters about the models, informing researchers about the needs and constraints of operational forecasters, and a two-way transfer of knowledge, tools, and insight between research and operations (Kain et al. 2003).

Concentrating on these themes, the first "spring program" was conducted in the spring of 2000 and became the basis for similar initiatives each spring thereafter. The focus on springtime ensured that compelling real-time convective weather forecasts would be presented nearly every day. The experiments were designed to challenge both model developers and forecasters. About half of each day was devoted to preparing and issuing severe weather forecasts and the other half on critical interrogation of experimental numerical-model guidance. Activities were conducted by small groups containing at least one representative from forecast operations and one model developer or researcher, allowing model developers to gain a broader understanding of how frontline forecasters use model output and the forecasters to develop insight that helped dramatically with interpretation of model guidance for severe weather. The process laid the foundation for new long-term working relationships.

This paradigm—challenging forecasters and researchers to work side by side in small groups to tackle difficult meteorological problems in real time—proved to be very effective (Fig. 7). It galvanized collaborative activities in the Norman meteorological community and inspired the formation of the HWT, even though no funding was available for such a test bed. When NSSL, SPC, and the Norman WFO all joined the University of Oklahoma (OU) School of Meteorology in the National Weather Center building in 2006, a physical space for the HWT was created

Fig. 7. Experimental warning exercises during the 2011 HWT Spring Experiment. Shown are (left) Steve Keighton (Blacksburg, VA, WFO) and (right) Kevin Brown (Norman, OK, WFO). In the background is the Norman WFO forecast operations center.

between the SPC and the WFO and the test bed was formally created (Fig. 7).

The original HWT framework included two programs: 1) the Experimental Forecast Program (EFP), anchored by SPC-related forecasting research (Kain et al. 2006); and 2) the Experimental Warning Program (EWP), focusing on the development and testing of new science, applications, and remote sensing tools to assist the short-term (0–2 hours) nowcasting and warning decision-making process. In recent years the Geostationary Operational Environmental Satellite-R Series (GOES-R) Proving Ground has become part of the HWT, and other partners, most notably the Center for Analysis and Prediction of Storms (OU-CAPS), have become core contributors. Within these major programs, multiple experiments are conducted each year—the EFP conducts the Spring Forecasting Experiment (e.g., Clark et al. 2012) and the EWP conducts multiple experiments during this same spring time frame. For example, recent EWP experiments include the evaluation of phased array radar (Heinselman et al. 2008), a network of 3-cm wavelength radars (Brotzge et al. 2010), and multiradar/multisensor-blended algorithms (Lakshmanan et al. 2007). Individual initiatives emanating from the GOES-R Proving Ground have been intertwined within many of these experiments and have been exceptionally productive, both in terms of scientific publications and contributions to forecast and warning operations (e.g., Kain 2004; Lakshmanan et al. 2007; Kain et al. 2010), yet the HWT remains largely unfunded, except for internal support from the NSSL, SPC, and WFO. At the 2012 American Meteorological Society (AMS) Annual Meeting, the Hazardous Weather Testbed team was awarded the Kenneth C. Spengler Award "for bringing the government, academic, and private sectors together in a visionary, proactive, and exemplary manner to deal with the challenges posed by hazardous weather."

SHORT-TERM PREDICTION RESEARCH AND TRANSITION (SPORT). The SPoRT program transitions unique NASA, NOAA, and DoD satellite data and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale. NASA established the test bed in 2002, drawing on real-time MODIS, AIRS, and Advanced Microwave Scanning Radiometer for Earth Observing System (EOS) data from direct broadcast ground stations to address forecast problems common to WFOs in the Southeast United States. It is based at a NASA facility in Huntsville, Alabama, and is collocated with a NWS WFO. SPoRT management receives advice from an interagency science advisory committee of experts across disciplines who serve for 4-yr terms.

Since its establishment, SPoRT has expanded its collaborations to WFOs in all six NWS regions and to several national centers. SPoRT focuses on problems such as the timing and location of severe weather; changing weather conditions influenced by terrain and other local features; reduced surface visibility due to smoke, fog, and low clouds; predicting weather variations due to land–sea breeze circulations; and monitoring weather conditions in data-void regions. SPoRT involves forecasters in the entire process—matching forecast problems to data and research capabilities, testing solutions in a quasi-operational environment, and then transitioning proven solutions into the forecaster's decision support system. SPoRT also develops product training and involves forecasters in the assessment of the utility of the products on the relevant forecast challenges. The suite of SPoRT and collaborative partner products transitioned to the operational weather community is presented in the online supplement (Tables ES2).

A suite of real-time high-resolution MODIS imagery has been successfully used to improve situational awareness for a variety of nowcasting applications. A notable impact on hydrologic forecasting in the upper plains states has been documented by Loss et al. (2009). Atmospheric information from AIRS has been assimilated into weather forecast models and shown to improve the initial conditions and subsequent forecasts of sensible weather elements with the Weather and Research Forecasting (WRF) model (Zavodsky et al. 2012; Chou et al. 2009; McCarty et al. 2009; Lee et al. 2010). The improved initial fields are also being used in a diagnostic mode at various WFOs.

SPoRT scientists work collaboratively on forecast problems and product transitions with several other NOAA test beds. A high-resolution enhanced MODIS/Advanced Microwave Scanning Radiometer for EOS (AMSR-E) sea surface temperature (SST) composite product (e.g., Jedlovec et al. 2009; Haines et al. 2007), land surface information from the NASA's Land Information System (LIS) as implemented by Case et al. (2011), and atmospheric sounding information from AIRS were all used in deterministic real-time WRF forecasts that were evaluated at HWT's 2011 EFP. Near-real-time LIS runs and the SST composite product are also linked to the WRF Environmental Modeling System (Rozumalski 2007) to provide forecasters with unique tools for regional forecast applications. SPoRT has also partnered with the GOES-R Proving Ground to develop and

transition proxy data and products from the Advanced Baseline Imagery (ABI) and Geostationary Lightning Mapper (GLM) instruments in advance of launch to prepare forecasters for these new observational capabilities (Stano et al. 2010). Total lightning measurements from ground-based networks have been used to provide additional lead time in severe weather warnings issued by southern region WFOs. Similar measurement capabilities from the GLM on GOES-R will contribute to improved warnings in the future. Other applications of SPoRT data have been documented by forecasters on the Wide World of SPoRT blog (weather.msfc.nasa.gov/sportblog).

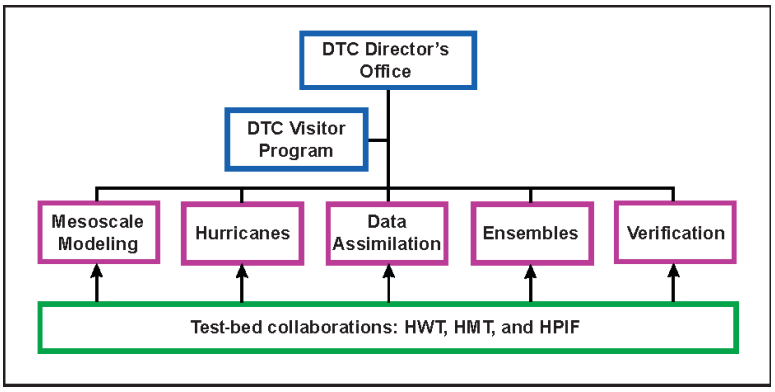

Fig. 8. Schematic diagram of activity areas of the DTC.

SPoRT is extending its transition activities to include new satellite observations integrated into advanced decision support systems in WFOs around the country over the next few years. Data from the Visible/Infrared Imager Radiometer Suite (VIIRS) imaging and Cross-Track Infrared Sounding (CrIS) sounding instruments on the Joint Polar Satellite System (JPSS) will provide follow-on capabilities to those of the NASA MODIS and AIRS instruments. The existing and new data streams from JPSS and NASA Decadal Survey missions will be integrated into the NWS's Advanced Weather Interactive Processing System (AWIPS-II) to extend the use of unique high-resolution data in WFOs.

DEVELOPMENTAL TESTBED CENTER (DTC). The mission of the DTC is to facilitate research-to-operations (R2O) transition in numerical weather prediction (Bernardet et al. 2008). To accomplish this objective, the DTC supports operational systems, performs testing and evaluation of promising NWP techniques, organizes workshops on important NWP areas, and hosts a DTC visitor program. The DTC was officially established in July 2003, at which time it was funded principally by the National Center for Atmospheric Research (NCAR) and USWRP. During 2011, DTC's budget reached ~$5.4 million, which included newly created core funding from NOAA/OAR that is the majority of support. Additional sponsorship is provided by the U.S. Air Force, NCAR, National Science Foundation (NSF), and USWRP. DTC is based primarily at NCAR and at NOAA/ESRL/GSD, operates under a charter, and receives advice from an executive committee (agency executives), a management board (primarily sponsors), and from a science advisory board. Execution is organized around five activities (Fig. 8), all of which include both testing and evaluation and community support components: mesoscale modeling, hurricanes, data assimilation (DA), ensembles, and verification. Additional collaborations exist with other test beds (principally HMT and HWT) and with the NWS Hurricane Forecast Improvement Project (HFIP).

Mesoscale modeling (MM). The MM team has focused on testing and evaluation of potential R2O code transitions. In addition to direct model-to-model intercomparisons, the MM team has provided baseline configuration results to the NWP community (both operational and research) as designated WRF reference configurations (www.dtcenter.org/config). These carefully controlled, rigorous tests and accompanying verification statistics provide the research community with baselines against which the impacts of new techniques can be evaluated and the operational community guidance for selecting configurations with potential value for operational implementation. In addition, the MM team has helped NOAA's EMC identify appropriate configurations for the next implementation of the operational Short Range Ensemble Forecast (SREF) system. In 2011, DTC collaborated with EMC and universities to organize a workshop, which provided valuable recommendations and guidance for the NWP community (www.dtcenter.org/events/workshops11/mm_phys_11).

Hurricanes. The focus of the hurricane team is the transfer of new research and development to operations to improve tropical cyclone NWP. The work currently focuses on the Hurricane Weather Research and Forecasting (HWRF) model—a NOAA operational model. First, a solid code management

capability was established in collaboration with NCEP/EMC that allows all HWRF developers (from AOML, ESRL, and other close collaborators) to use a single code base. Second, HWRF was expanded into a well-documented, supported community code, with over 400 registered users. The use of HWRF by a large community on a variety of computational platforms led to a more robust model. Finally, the DTC conducts extensive testing and evaluation of HWRF.

Data assimilation (DA). The DA team bridges the data assimilation research and operational communities by providing the current operational Gridpoint Statistical Interpolation (GSI) capability to researchers [operations to research (O2R)] by enabling the research community to contribute to operational GSI development (R2O), and by facilitating collaboration between distributed GSI developers through the GSI review committee and the community GSI repository. The DA team provides the research community with an annual GSI release containing the latest GSI capabilities, as well as updated documentation. In addition, the DA team actively works with community researchers to help them merge their new DA innovations with GSI software and provides assistance with the process of committing innovations to the GSI repository. Significant R2O activities have included the assimilation of surface observations (air pollutants with diameter of 2.5 mm or less) for the Community Multiscale Air Quality (CMAQ) regional model and the WRF with Chemistry (WRF-Chem) model, the addition of control and state variables for cloud analysis, and GSI enhancements for Rapid Refresh model applications

Ensembles. The DTC Ensembles Team (DET) brings the latest ensemble developments from the community into operations. These developments often come from experimental real-time ensemble forecast systems. Because they are usually run at a horizontal resolution higher than those available to operations, evaluation of these systems provides an opportunity to influence future operational ensembles. To build on this opportunity for enhanced R2O potential, the DET collaborates with the EMC and other test beds—particularly, HMT and HWT. Both have applied convection-allowing (3- or 4-km horizontal resolution) ensembles to the forecast process and offered lessons learned. Focused verification of QPF by the HMT and reflectivity forecasts by the HWT have provided important guidance as the EMC approaches decisions about the ultimate membership of next-generation operational ensemble forecast systems. Tollerud et al. (2013) provides further details of the infrastructure and objectives of the DET.

Verification. Statistical verification of numerical forecasts is beneficial to both forecasters and end users because it can supply objective data about the quality or accuracy of their forecasts. These findings can feed back into decision processes, including those involved with R2O decisions about model elements to be transitioned to operations. Furthermore, routine, continuing verification of operational observations, models, analyses, and forecasts helps NOAA meet its obligations for information quality under the Information Quality Act. The DTC verification team primarily develops, tests, and demonstrates tools and methods for verification, including the Model Evaluation Tools (MET) (www.dtcenter.org/met/users/). Although the primary application for MET is the WRF model, the tools can also be applied to most other forecast models. In addition to providing MET to the community, the software package has become instrumental in collaborative efforts between the DTC and other test beds, including HMT, HWT, and HFIP (e.g., the development of atmospheric river–focused verification methods with HMT that have been implemented in MET). Most recently, focus has been on implementation of new tools and methods for verification of hurricane forecasts.

CLIMATE TESTBED (CTB). NOAA's NWS/NCEP is the lead agency with responsibility for improving our nation's operational climate predictions on time scales from weeks to years. These predictions enhance our collective ability to understand and predict the state and evolution of the climate system, including linkages between climate and weather (including extremes) on all time scales. In 2004, NCEP and the OAR/Climate Program Office (CPO) jointly established a Climate Test bed facility. The mission of the CTB is to accelerate the transition of research and development into improved NOAA operational climate forecasts, products, and applications. The CTB objectives are

- to accelerate implementation of advances in model improvements, multimodel techniques, forecaster tools, datasets, and observing systems into NOAA climate forecast operations;
- to provide the climate research community with access to operational models, forecast tools, and datasets to enable collaborative research that accelerates additional improvements of NOAA climate forecast products; and

- to develop new and improved operational climate forecast products for use in planning and decision making.

The CTB facility is located at NCEP/Climate Prediction Center (CPC) in College Park, Maryland. CTB projects are carried out jointly by scientists from NCEP, other NOAA organizations, and the broader research community through competitive projects funded using annual AOs and resourced and managed by the CPO. The CTB facility at NCEP provides an operational infrastructure (computing support and scientists at NCEP centers). The CTB has a science steering board to provide independent scientific advice, broad direction, and endorsement of ongoing and planned activities.

The CTB has made significant progress toward its objectives and major contributions to the NCEP operational forecasts and products, including a multimodel ensemble (MME) climate prediction system, improvements to the Climate Forecast System (CFS), and development of climate forecast products.

MME climate prediction system. The CTB and the broader community have done extensive experimental multimodel prediction research and provided evidence that MME prediction approach yields superior forecasts compared to any single model. CTB developed a prototype the MME prediction system as a proof of concept to demonstrate the potential benefits of a MME system using a NCAR model and NCEP CFS (Kirtman and Min 2009; Paolino et al. 2012). CTB scientists also explored recalibration and consolidation methodologies in multimodel ensembling (Tippett et al. 2008; DelSole and Tippett 2008).

In 2011, CTB organized a team effort to develop a national multimodel ensemble (NMME) strategy (Kirtman 2011) and implemented the experimental NMME prediction system to produce real-time forecasts for the CPC operational monthly/seasonal forecasts. The current NMME system contributors include NOAA's NCEP and Geophysical Fluid Dynamics Laboratory, University of Miami, Center for Ocean–Land–Atmosphere Studies, International Research Institute, NASA, and NCAR with others expected in the next two years. This NMME prediction system directly transfers the modeling advances from other U.S. modeling centers to CPC forecast operations.

NCEP Climate Forecast System improvements. The CTB strategy to improve CFS involves joint team efforts with participation from the external community and NCEP scientists and to use the NCEP operational model as a research tool. For example, scientists from NOAA/ESRL and NCEP identified polar vortex issues and improved the troposphere–stratosphere coupling in the current version, CFSv2 (Shaw and Perlwitz 2010; Shaw et al. 2010). CTB also funded a NCEP Climate Process Team (CPT) to evaluate and improve the representation of stratocumulus-to-cumulus transition in NCEP and NCAR climate models (e.g., Chung and Teixeira 2012; Suselj et al. 2012; Teixeira et al. 2011; Xiao et al. 2012).

CTB has made progress improving two-way communication between NCEP and the external community. The CFSv3 planning workshop provided a more cooperative, multilateral environment for identifying the needs for CFS improvement and future development strategies. CTB is currently working with NCEP and the external community to develop a NCEP climate modeling strategy.

Climate forecast products. To improve the skill of NCEP operational climate forecasts and thus the quality of climate forecasts, CTB works with the user community to improve access to and understanding of climate forecast products. A CTB team from CPC and the Regional Integrated Sciences and Assessments/Climate Assessment for the Southwest (RISA/CLIMAS) developed and implemented a web-based service (Fig. 9) that allows dynamic interaction between users and CPC products, supports user-centric forecast evaluations, and develops user-customized forecast products.

CTB also funded focused research to develop and improve drought monitoring and prediction products in support of the National Integrated Drought Information System. A CTB team with scientists from the U.S. Department of Agriculture (USDA), NESDIS, NCEP, and universities produced satellite-based evapotranspiration and soil moisture indices for drought monitoring (Anderson et al. 2011).

In the future, CTB will continue to focus on transition of research to NCEP climate operations and enhancing collaborations between NCEP, other test beds, and the external community. CTB will continue to improve the NMME capability and facilitate the planning and implementation of the NCEP climate modeling strategy. CTB will work directly with the RISA and Regional Climate Centers to improve NCEP's regional climate services.

GOES-R PROVING GROUND. The GOES-R Proving Ground is an initiative that began in 2008 to accelerate user readiness for the next generation of U.S. geostationary environmental satellites beginning

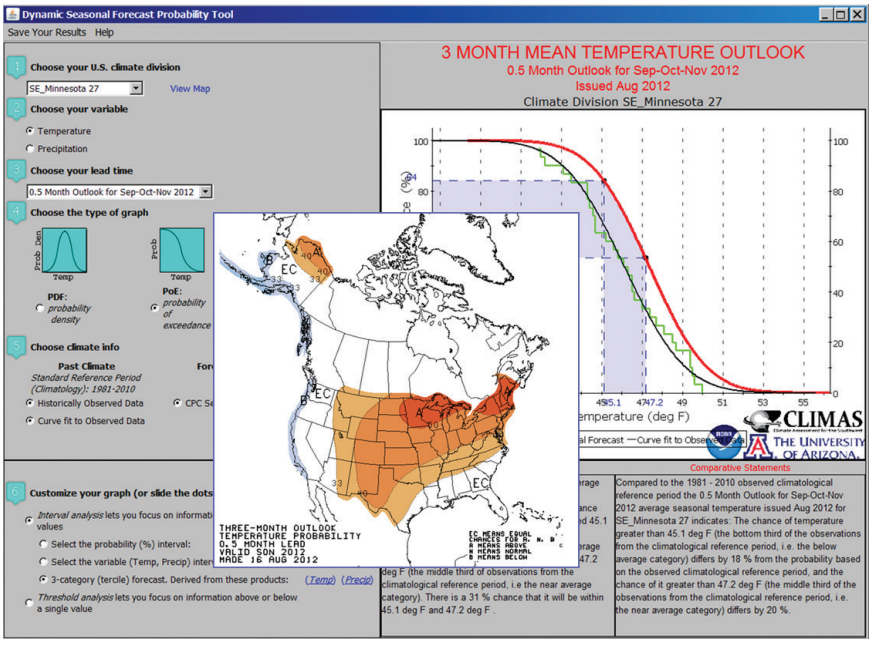

Fig. 9. CLIMAS–CPC collaborative development of an interactive web tool for CPC 3-month Climate Outlook.

with the launch of the GOES-R satellite in late 2015 (Goodman et al. 2012). The origin of the GOES-R Proving Ground was a recommendation from the third GOES Users Conference in 2004 (DOC/NOAA/NESDIS 2004) to bridge the gap between research and operations by engaging the NWS forecast, watch, and warning community and other-agency users in pre-operational demonstrations of the new and advanced capabilities to be available from GOES-R compared to the current GOES constellation. To ensure user readiness, forecasters and other users must have access to prototype advanced products within their operational environment with access through AWIPS and transitioning to AWIPS-II well before launch.

Prototypes of the future GOES-R capabilities can be emulated from current satellite and terrestrial observing systems having higher spatial, spectral, or temporal resolution than the current operational GOES imager, or through synthetic cloud and moisture imagery that can be derived from weather forecast models such as the WRF model. Products being demonstrated in the Proving Ground include (Fig. 10) improved volcanic ash detection, lightning detection, 1-min-interval rapid-scan imagery, dust and aerosol detection, and synthetic cloud and moisture imagery (Grasso et al. 2008; Otkin and Greenwald 2008). These new or enhanced product capabilities will be made possible by the ABI, a 16-channel imager with two visible channels, 4 near-infrared channels, and 10 infrared channels that will provide three times more spectral information, four times the spatial coverage, and an increase in temporal resolution that is more than five times the current imager (Schmit et al. 2005). Other advancements over current GOES capabilities include total lightning detection and mapping of in-cloud and cloud-to-ground flashes never before available to forecasters from the GLM (Goodman et al. 2013) and increased dynamic range, resolution, and sensitivity in monitoring solar X-ray flux with the Solar UV Imager.

A key component of the GOES-R Proving Ground is the two-way interaction between the researchers who introduce new products and techniques and the forecasters who then provide feedback and ideas for improvements that can best be incorporated into NOAA's integrated observing and analysis operations. At the HWT, for example, the GOES-R Program provides funding for 10–15 forecasters from across the nation, chosen by the HWT management, to participate in the evaluation of forecast and warning products enabled by GOES-R capabilities (e.g., WRF-simulated cloud and moisture imagery, convective initiation, overshooting top detection, and total lightning) relevant to severe and high-impact weather. Collocated at select NWS national centers, NOAA test beds, and at the NWS Alaska and Pacific Region headquarters there are also long-term on-site Proving Ground visiting scientist technical liaisons—that is, subject matter satellite application experts who aid in the transition from research to operations by actively participating in product demonstrations, interpreting the added value of the satellite-derived information, and conducting training. Developers work with the satellite liaisons and forecasters to build capacity within the forecast office or national center. Summary reports of the product demonstrations conducted in the operational environment of the Proving Ground as well as near-real-time blog postings for recent high-impact weather events are posted at the Proving Ground website (www.goes-r.gov/users/proving-ground.html) and at the websites of the NOAA Cooperative Institute partners.

Administration of the Proving Ground is led by the GOES-R Program Office with new product planning, development, and demonstrations directed toward operational needs overseen by a Science and Demonstration Executive Board (SDEB). The SDEB is advised by 1) the NWS Operational Advisory Team, which is composed of the NWS region Scientific Services Division chiefs; 2) a technical advisory group representing NOAA line offices; and 3) an independent advisory committee composed of senior-level scientists from other government agencies, universities, international satellite organizations, and other national meteorological services. These advisory groups provide guidance, technical assistance, and subject matter expertise about the proposed activities to the executive board. A program review is held during the annual NOAA Satellite Science Week, where the researchers, forecasters, advisory committees, and program managers meet to evaluate the progress toward meeting the program goals and objectives, and determine priorities for the coming year. Performance measures include the number of products demonstrated, the number of products transitioned into operations, and the forecaster evaluations of the science and applicability of the products documented in the demonstration test reports. Annual funding for the Proving Ground and its various program elements is ~$2 million per year.

The next-generation GOES will continue providing valuable data to support high-impact weather warnings as well as key inputs for global and regional NWP models. The large quantities of GOES-R data will present new challenges and opportunities that require more intelligent integration of information derived from blended satellite products (e.g., geostationary and polar satellite observations); multidimensional classification of severe storm potential by combining satellite, radar, in situ data, and models; and new ways of visualizing GOES-R data within the AWIPS-II forecaster workstation. Algorithm developers at NESDIS, NASA SPoRT, and the NOAA Cooperative Institutes are already creating JAVA-based satellite application plug-ins for AWIPS-II, which will quickly accelerate the R2O transitions at NWS. During the *GOES-14* out-of-storage period from 16 August to 31 October 2012, special 1-min rapid-scan imager datasets are being collected (sometimes concurrently with 3D total lightning and 1-min radar data) to showcase the benefit of GOES-R products and high-temporal-resolution geostationary measurements. These include, but are not limited to, imagery, convective initiation, cloud-top cooling, cloud microphysical properties,

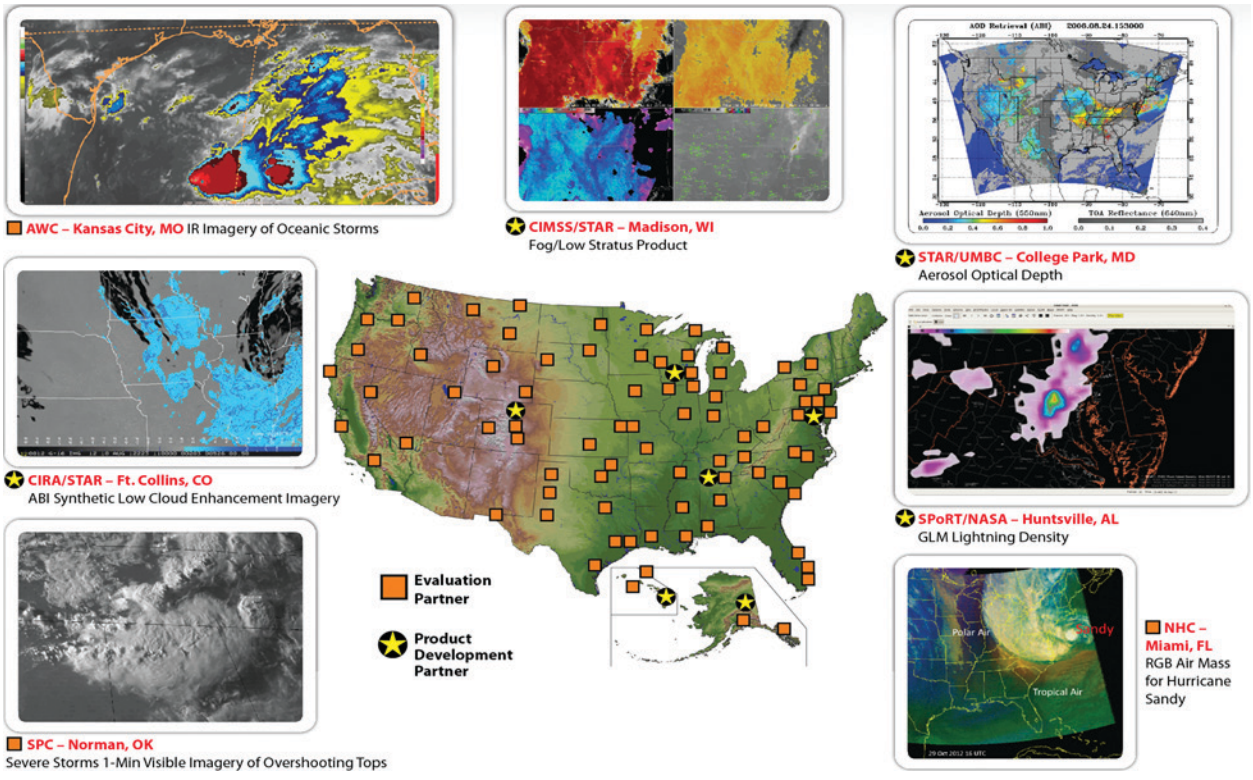

Fig. 10. GOES-R Proving Ground partners and sample products demonstrated to forecasters.

Fig. 11. Participants collaborate together in the AWT during the 2011 Summer Experiment.

atmospheric motion vectors, etc. (http://cimss.ssec.wisc.edu/goes/srsor/GOES-14_SRSOR.html). NHC forecasters find the rapid-scan imagery especially useful for center fixing tropical cyclones and hurricanes at sunrise. In 2012 and beyond, the GOES-R Proving Ground will continue to test and validate display and visualization techniques (Hillger et al. 2011), decision aids, future capabilities, training materials (e.g., COMET; www.meted.ucar.edu/), and the data processing and product distribution systems to enable greater use of these products in operational settings.

AVIATION WEATHER TESTBED (AWT). The AWT, located at the Aviation Weather Center (AWC) in Kansas City, Missouri, creates an environment for the transfer of new and innovative aviation weather forecast technology into real-time AWC operations for safe, efficient, and environmentally friendly flight, and to engage in the strategic implementation of the FAA's Next Generation Air Transportation System (NextGen) requirements for aviation weather. AWT's primary objective is to test, evaluate, and refine promising aviation weather research in partnership with the AWC's government, academic, and private sector stakeholders, with the eventual goal of implementing new ideas into a robust, secure, and real-time operational forecast system (Levit et al. 2011).

Prior to the AWT's reorganization in 2009, the AWT existed primarily to transfer research concepts from the Aviation Weather Research Program into AWC operations, and was composed of a small area on the AWC forecast floor. Now, the AWT is housed in a new state-of-the-art room (completed in 2010) with computer workstations that replicate the operational workstations used by AWC meteorologists, as well as advanced video teleconferencing capability that allows for broadcasting output from one workstation to one of several large overhead flat-panel monitors (Fig. 11). This room was designed to foster maximum interaction between teams located at different areas, so evaluations could be achieved in a team-oriented environment. The test bed reorganization also launched new collaborations between the AWC and other research groups, such as NCAR, AFWA, ESRL/GSD, GOES-R satellite program, NWS's Office of Science and Technology, Massachusetts Institute of Technology (MIT)/Lincoln Laboratories, and NCEP/Meteorological Development Laboratory (MDL), etc. Several of these groups have or are providing funding for AWT projects, either directly or through joint support within collaborative projects. The test bed is now organized to be a leading entity for the transfer of aviation weather research to operations and to serve as a conduit to provide research personnel with an opportunity to interact with an operational aviation weather center.

The AWT was used extensively during the 2011 Summer Experiment from 27 June to 22 July 2011. The experiment focused on testing new and emerging weather datasets for forecasting convection in the "golden triangle" (Chicago, IL–New York, NY–Atlanta, GA) high-air-traffic area of the United States. Approximately 40 people, from nearly 15 organizations, visited the AWT and collaborated to produce two daily forecast products outlining the impact of convection to the National Airspace System: the "aviation weather impact" product (Fig. 12a), which depicts important convective weather features for the golden triangle, and the "probability exceedance" product (Fig. 12b), which contours regions where a 30% and 60% probability of exceeding composite reflectivity of 40 dBZ and radar echo tops at or exceeds 37,000 ft exist.

Numerous new and existing datasets were tested during the experiment and each were used to create the graphics, as already noted. High-resolution ensemble and deterministic numerical weather prediction models were tested for their ability to correctly resolve the timing, location, morphology, mode,

and porosity of convection. The deterministic 3-km High Resolution Rapid Refresh (HRRR), and the Consolidated Storm Prediction for Aviation (Wolfson et al. 2008), along with a 4-km 12-member AFWA ensemble model and NCEP's SREF system, were used in combination with derived air-traffic-impact forecasts from NCAR to determine the forecast graphics. In addition, the GOES-R program supplied the "nearcast" forecasts (Petersen and Aune 2009), a short-term forecast of convective initiation derived from satellite, and Rapid Update Cycle (RUC) model data. As a result of the experiment, the 3-km HRRR model and hourly SREF data were integrated into AWC operations. The AWT held another summer experiment in June 2012 to test similar datasets and concepts with experimental forecasts.

Beyond the planned annual summer experiment, the test bed is also evaluating new interactive weather data display software—AWIPS-II is the next-generation data display system for the NWS. Also, the Interactive Calibration of Grids in Four Dimensions (IC4D; Petrescu and Hall 2009) software, an extension of the Graphical Forecast Editor in AWIPS, is undergoing evaluation by the AWC forecast staff within the AWT. The IC4D system can be used to combine observations, model data, and algorithms to create a gridded forecast—a concept for the "4-D Weather Cube" envisioned by NextGen.

Many new concepts for the future forecast process and support of NextGen exist and the AWT will be an important resource in helping to decide which ideas have meaningful and demonstrated benefits, are efficient and reliable to implement, have long-term sustainability, and are compatible with information technology infrastructures.

OBSERVING SYSTEM SIMULATION EXPERIMENT TESTBED (OSSE). The most recent test bed effort is the Observing System Simulation Experiment Testbed. OSSEs are an important tool for evaluating the potential impact of proposed new observing systems, as well as for evaluating trade-offs in observing system design, and in developing and assessing improved methodology for assimilating new observations on numerical weather prediction (Atlas 1997). The test bed development is being led and managed through NOAA/AOML for use by USWRP partners and academia in collaboration with NESDIS/Center for Satellite Applications and Research (STAR), NOAA/ESRL, and the JCSDA. The OSSE test bed will be applicable

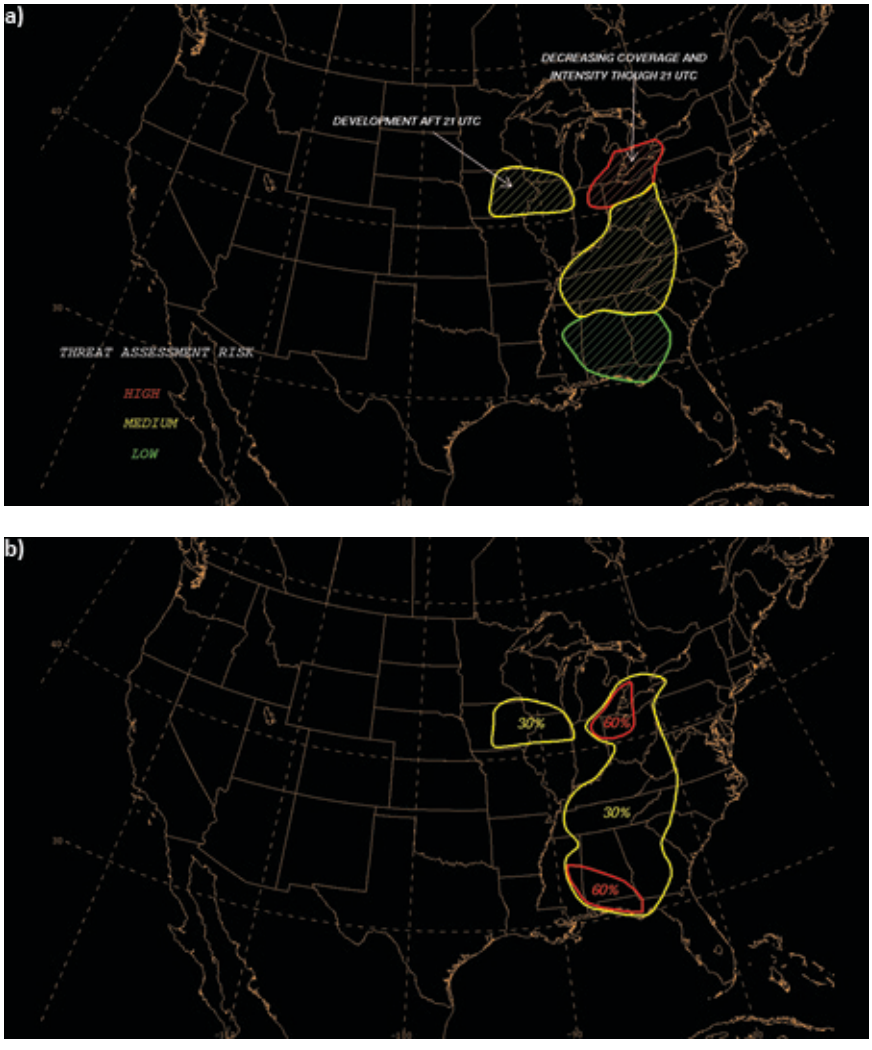

Fig. 12. (a) Example of the aviation weather impact graphic forecast. Contours highlight a high, medium, or low potential threat of convection impacts to the golden triangle area of the National Airspace System. (b) Example of the "probability exceedance" graphic. Contours indicate either a 30% or 60% probability of convection reaching a combined reflectivity value of 40 dBZ and a radar echo height of 37,000 ft or greater.

to analysis-/forecast-impact studies, observing system design, instrument trade studies, future instrument constellation planning, and data utility investigations. Through the OSSE test bed concept, the goal is to generate an OSSE process that invites participation by the broad community of agency planners, research scientists, and operational centers. The goal for establishing this numerical test bed is to enable a hierarchy of experiments to

- determine the potential impact of proposed space-based, suborbital, and in situ observing systems on analyses and forecasts;
- evaluate trade-offs in observing system design;
- assess proposed methodology for assimilating new observations in coordination with JCSDA; and
- define both the advantages and limitations of a hierarchy of OSSEs that includes rapid prototyping of instrument or data assimilation concepts, as well as the more rigorous "full" OSSEs.

Although only started in 2010 through seed funding by NOAA USWRP, the OSSE test bed has had several key accomplishments: provided expertise on OSSEs to NOAA and JCSDA partners and academia, and evaluated the global OSSE system and the experiments being performed; finalized regional OSSE nature runs at 3- and 1-km resolution, which required an exhaustive number of iterations of the WRF model embedded within an ECMWF global nature run; confirmed the validity (strong points and weaknesses) of both the 3- and 1-km nature runs over a 13-day period; completed the first phase of a global OSSE for the Unmanned Aircraft System (UAS) and completed a report and one refereed article from this OSSE; and established an external advisory committee for the OSSE test bed.

During the next several years, test bed activities include a survey across NOAA line offices to take stock of existing Observing System Experiment (OSE) and OSSE capabilities. This will include capturing the capabilities and expertise of each organization and the ability of each organization to perform and/or analyze experiments. Through the NOAA Observing System Council, the OSSE test bed will determine the most critical observing system questions to be addressed and their priority. In addition to providing expertise on OSSEs to NOAA and JCSDA partners and academia, the test bed will coordinate information on global and regional OSEs and OSSEs to be performed, the needed resources, and the role of each organization. Specifically, the test bed will conduct global and regional OSSEs for NOAA's UAS program and HFIP and perform OSSEs relating to the polar-orbiting satellite program and wind lidar. Efforts continue to develop the framework for the full OSSE test bed.

CONCLUSIONS AND FUTURE DIRECTIONS. Test beds have become an integral part of the meteorological community. They have helped foster new forecast innovations and their transition into operations. These developments have powered opportunities for businesses and agencies to improve their products and services. Along the way, a community of subject matter experts has been created that have in-depth experience with bridging research and operations. Not surprisingly, as key forecast challenges and gaps are identified, new regionally focused test bed ideas have been proposed. Lining up support, connecting key research and NWS center "champions," establishing other-agency partners, and identifying resources are all part of developing new test bed concepts.

A major risk for test beds is based on their inherent nature as a "bridging" entity. In other words, they tend to be "outsiders" relative to either the core mission of forecasting or the core mission of research. In spite of this, they enable more rapid improvements in forecast services and demonstrate tangible relevance of research centers to forecast services while not being entirely beholden to them.

For NWS, implementation into operations to meet service requirements includes successful demonstration of key criteria (defined for the specific model/phenomena/capability), such as objective performance (e.g., model accuracy or sensor accuracy), subjective performance (e.g., utility of capability and impact on workflow/workforce), and production readiness (analogous to technology performance measures, but includes necessary IT infrastructure and backups, maintenance procedures, archiving, and in-place verification approach to ensure timely and reliable operational production). These are demonstrated in proving grounds; in some cases test beds also perform these functions—for example, for tools that are implemented directly in NHC systems, JHT can perform this function. Given that the level of effort to carry out these "transition oriented" steps could rapidly consume test bed investments in innovation and demonstration at stages prior to transition, it is vital that management and oversight for these key steps are primarily the responsibility of the operations, rather than the research, organization. The sidebar "GPRA measures" describes issues and perspectives on measuring performance of test beds and forecasting. Possible approaches for measuring performance that are adoptable by test beds and forecast centers include

A FRAMEWORK FOR PERFORMANCE MEASURES FOR TEST BEDS

With the advent of the Government Performance Requirements Act (GPRA), agencies are held highly accountable for performance. For NOAA, several of its "GPRA measures" represent forecasting skill (e.g., hurricane track forecast error, flash flood warning lead time, quantitative precipitation forecast skill, and tornado warning lead time). These measures have become a major focus of current forecasting and their improvements that represent the "requirements pull" of today's services. They are calculated by NOAA/NWS and NOAA reports them to the Department of Commerce, the White House, and to congressional committees.

While quite useful, these GPRA measures are difficult to change, and it is difficult to add new ones, even when well justified by forecast user needs. Understandably, it is risky for NOAA to promise too rapid an improvement in these challenging forecast topics. This inhibits setting ambitious goals that can drive innovation in the research community. Analogously, the science and technology communities have well-established measures of research and development performance (e.g., publications, citations, patents). Such measures tend not to reward focusing on the implementation of the new findings beyond the research community, thus inhibiting efforts to "take the next step" beyond publications and grants (NAS 2000). While NOAA laboratories help fill some of this gap, the differences between the standard measures used for science and those used for forecasting represent part of the divide between research and operations.

Several constraints have inhibited progress both in innovation and in transition to daily forecast operations. Here are some key examples:

- science and technology (S&T) advances are a foundation of NOAA's service improvements, yet are often not initially measurable in the "service" GPRA scores;
- improving the service GPRA scores requires service programs to adopt new methods, yet this may have a cost and require services to let go of existing methods; and
- while research suggests fast improvements in GPRA scores may be possible, operational goals must be reasonably achievable or the risk of "failure" is increased.

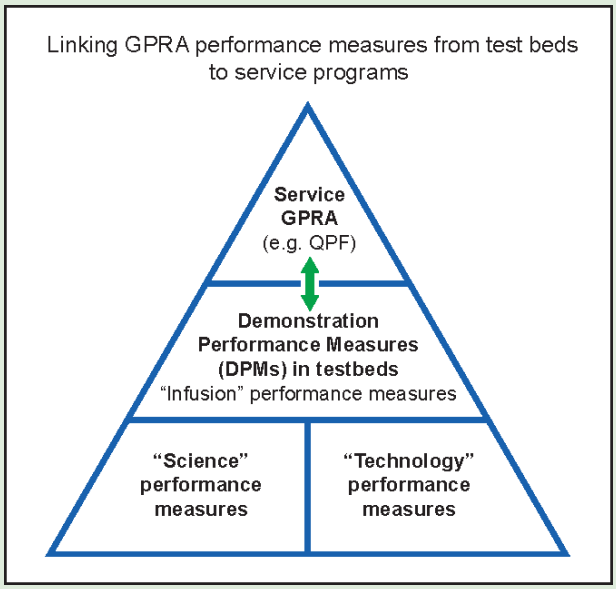

Fig. SB1. Today's predictive services exist on a foundation of prior science and technology innovation.

Because the GPRA measures focus on products issued by NWS, and improvements in these products are often the result of a combination of many inseparable individual advances, a traceable connection between specific S&T advances and formal NWS service improvements is often not very tangible. This creates an underlying issue for the research community and for related test beds—that is, how to measure research and test bed performance in ways that reasonably represent both the underlying advances needed in S&T to enable transformative improvement in forecast services, as well as the near-term incremental improvements that typically build on existing operational tools.

Test beds have the potential to help by developing and monitoring what could be called DPMs, which would be used internally to the agency and test bed. These could be "stretch" versions of current measures (i.e., faster rate of improvement) or entirely new measures that address major societal needs [e.g., rapid hurricane intensity change; QPF for extreme precipitation; river flood warning lead time; snow-level aloft (White et al. 2010)]. The concept, illustrated in Fig. SB1, conveys the following:

- goals for GPRA-like DPM scores can be set higher in test beds than in full operations;
- adoption of new methods for full operations requires proof of concept;
- proof of concept can be demonstrated by limiting tests to small areas, times, and tools;
- by limiting the scope of tests, the costs can be kept within reasonable bounds;
- researchers and forecasters jointly define strategies to demonstrate impacts on the suitable DPM goal during the tests; and
- if regional testing demonstrates improvement, extend results nationally (as appropriate) with follow-up testing.

This demonstration concept has been the de facto approach to date, but has not been codified and adopted in a transparent manner useable by test beds. NCEP uses it to evaluate whether model changes should be adopted operationally. JHT uses this approach extensively, and is a model of how to apply to a specific well-defined forecast problem with one NCEP center. Warning decision support tools turn new data into forecast usable information.

- internal measures suitable for state-of-the-art science and technology development (i.e., measure the innovation that underpins future breakthrough advances—the S&T "push");
- "infusion"-oriented measures, including test bed demonstration performance measures (DPM);
- internal measures in "forecast service" programs tracking implementation of infusion (i.e., measure the services' "pull" for S&T);
- internal measures tracking the rate at which innovation is assimilated into forecast operations and the rate at which outdated forecast tools are discontinued; and
- use of technical readiness levels to help define the status of key transition activities.

Carrying this out requires adequate capacity and investment in the test beds and a commitment from forecast centers and laboratories. The recent creation by NWS of the "Operations Proving Ground" in Kansas City, which focuses on testing full integration of new tools and methods in a quasi-operational environment, is an example of progress in this regard. It also requires a vibrant research community following the well-established path for exploratory research and development—that is, transformational research today that can enable breakthrough advances in forecast services in the future. Major components of today's core forecast service capabilities are the result of past innovations, some of which were not "programmed" into detailed road maps of their eras. While it is clear that the "requirements driven" road map is critical, it should also be recognized that many of today's requirements emerged as it became apparent that new science and technology could enable meeting them (recall the parable that if Henry Ford had followed a typical requirements-driven approach, he would likely have focused on inventing a better horse, rather than the automobile).

It is recommended for each test bed to work with its research and forecasting experts and stakeholders to identify possible DPMs—for excample, stretch goals for current forecast measures, new forecast variables, measures of prototyping, and scientific advances (peer-reviewed papers). Also, from a NOAA perspective, the Testbed and Proving Ground Coordinating Committee has the potential to collect these measures from each test bed and offer support in coordinating across test beds on key measures. Recent successes in coordination across test beds include the establishment of an annual NOAA Test beds Workshop, identification of a cross-test bed-integrating theme on intense precipitation for the most recent workshop in 2012, creation of the *NOAA Testbed News*, and development of a parameterization assessment and improvement effort with NCEP/EMC that heavily engaged DTC, HMT, and HWT (Wolff et al. 2012).

In closing, test beds have become an integral part of the weather enterprise. They have developed, tested, and transitioned innovative tools and methods that are impacting forecasts and forecast users. A key direction is to identify commonalities in major gaps identified across multiple test beds (i.e., observations, modeling, and physical understanding) and coordinate requests for agencies to fill these gaps. The need to bridge research and forecast services represents a grand challenge to meteorology—a challenge that test beds have emerged over the last 10 years to address.

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A FEASIBILITY STUDY FOR PROBABILISTIC CONVECTION INITIATION FORECASTS BASED ON EXPLICIT NUMERICAL GUIDANCE

BY JOHN S. KAIN, MICHAEL C. CONIGLIO, JAMES CORREIA, ADAM J. CLARK, PATRICK T. MARSH, CONRAD L. ZIEGLER, VALLIAPPA LAKSHMANAN, STUART D. MILLER JR., SCOTT R. DEMBEK, STEVEN J. WEISS, FANYOU KONG, MING XUE, RYAN A. SOBASH, ANDREW R. DEAN, ISRAEL L. JIRAK, AND CHRISTOPHER J. MELICK

For practical purposes, the convection initiation forecasting challenge should be framed in terms of the initiation of mesoscale convective events rather than the formation and growth of individual cumulonimbus clouds.

The annual Spring Forecasting Experiment (SFE) is conducted by the National Severe Storms Laboratory (NSSL) and Storm Prediction Center (SPC) in the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) during the climatological peak of severe convective weather in the United States (Clark et al. 2012a). This experiment is uniquely designed to bring together meteorological scientists who conduct applied research and practitioners who focus on forecasting to work on emerging problems of mutual interest. In 2011, a major component of the SFE (hereafter SFE2011) was a pilot study on the initiation of thunderstorms, also known as convection initiation (CI).[1] The focus on CI was motivated by two primary factors: 1) CI remains a scientifically challenging problem (e.g., see Markowski and Richardson 2010, chapter 7), and 2) there is a growing awareness that CI prediction is one of the weak links in forecasts of thunderstorm activity, presenting a significant challenge for forecasters, including those who specialize in prediction of severe convective weather, flash flooding, aviation hazards, and other specific threats.

A CI focus was also inspired by the encouraging performance over the contiguous United States (CONUS) of emerging convection-allowing models (CAMs) with 3–4-km grid spacing, as documented by numerous recent studies (e.g., Weisman et al. 2008; Kain et al. 2008; Coniglio et al. 2010; Clark et al. 2009, 2010a,b, 2012a). These models have sufficiently fine resolution to allow deep moist convection to develop and evolve explicitly on the model grid and they have shown skill in the prediction of multiple aspects of severe weather (e.g., Sobash et al. 2011; Marsh et al. 2012; Clark et al. 2012b), but the skill of their CI forecasts has never been evaluated objectively and systematically over the CONUS. A primary goal of SFE2011 was to provide

[1] The alternate term "convective initiation" has been applied to CI in some previous studies.

a preliminary quantitative assessment of the skill of CAMs in predicting CI.

Such an evaluation requires specific definitions, but to our knowledge there is no generally accepted definition of CI. From a process-oriented perspective, CI can be thought of as the sequence of events in which air parcels accelerate upward beyond their level of free convection, resulting in a clearly visible growth of cloud top, a rapid increase in cloud depth, and possibly the formation of precipitation and development of lightning (e.g., Weckwerth and Wakimoto 1992; Crook 1996; Ziegler and Rasmussen 1998; Doswell 2001; Houston and Niyogi 2007). For practical purposes (i.e., societal impacts), this sequence of events is not necessarily noteworthy. For example, sometimes this process results in nothing more than "turkey towers" (e.g., Corfidi et al. 2008) that have little impact at ground level. Other times, it leads to short-lived isolated thunderstorms that bring lightning and brief heavy downpours but affect only a very small and localized segment of the population. In other cases, however, CI episodes are clustered in association with specific mesoscale dynamic forcing and/or focusing mechanisms (e.g., Wilson and Roberts 2006). In these cases, CI can mark the beginning of a major disruptive event such as a squall line, an outbreak of supercells, or a derecho that interferes with human activities over a large area. Thus, if societal impact is to be considered in defining CI, it might be appropriate to include criteria for the intensity and longevity of individual (or representative) storms, changes in frequency of nearby CI episodes, tendencies for consolidation of storms, upscale growth rates, overall coverage, and perhaps other factors. A second goal of SFE2011 was to explore the use of different criteria for defining CI, considering both scientific and practical priorities.

This exploration was conducted in the context of experimental forecasting exercises, which have become a cornerstone of interactions between forecasters and researchers in the HWT (e.g., Clark et al. 2012a). Strongly forced convective events were the primary focus of these exercises, partly because of the predominance of these events east of the Rockies during the spring but also because this focus complemented simultaneous experimental forecasts for severe convection that were conducted as part of another component of SFE2011. During forecasting exercises CAM output was examined for evidence of CI itself and for the presence of meteorological features and physical processes that are often precursors to CI. For example, CI appears to be modulated by low-level airmass boundaries and convergence zones (e.g., Wilson and Schreiber 1986), horizontal convective rolls (HCRs) (e.g., Weckwerth 2000), the depth and intensity of cloud-scale lifting along boundaries and HCR-like circulations (Ziegler and Rasmussen 1998; Ziegler et al. 2007), orography (e.g., Groenemeijer et al. 2009; Barthlott et al. 2011; Behrendt et al. 2011), mesoscale and larger-scale dynamic effects aloft (e.g., Griffiths et al. 2000), gravity waves and bores (e.g., Koch and O'Handley 1997), and many other factors (see Browning et al. 2007; Wilson and Roberts 2006; Weckwerth and Parsons 2006, and references therein). A third goal of SFE2011 was to examine how well CAMs with 3–4-km grid spacing can represent some of these important features and processes.

SFE2011 was conducted from 9 May through 10 June 2011, Monday through Friday. Experimental activities and preliminary results from the CI component are highlighted in this paper, beginning with a description of relevant data and methods, followed by a presentation of key results, and finishing with concluding remarks.

NUMERICAL MODELS, DIAGNOSTIC TOOLS, AND EXPERIMENTAL FORECASTS.

Models. The primary guidance tool for CI forecasting and diagnostics was the Advanced

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Research Weather Research and Forecasting model (ARW-WRF) modeling framework (Skamarock et al. 2008). The configurations of two forecasting systems used during the experiment are highlighted below.

1) *NSSL-WRF*: SPC forecasters have used output from this single-member experimental modeling system, configured with 4-km grid spacing, since the fall of 2006. This system is run by NSSL once daily at 0000 UTC throughout the year over a full CONUS domain with forecasts to 36 h. Initial and lateral-boundary conditions (IC/LBCs) are provided by the operational North American Mesoscale model (NAM; Rogers et al. 2009). Forecast graphics are available online at www.nssl.noaa.gov/wrf/. This modeling system is used as the "alpha" testing framework for many diagnostic tools that are used in SFEs, as was the case for the CI diagnostics used in SFE2011. The model configuration is described in Kain et al. (2010).
2) *CAPS ensemble*: The University of Oklahoma Center for Analysis and Prediction of Storms (CAPS) generated numerical guidance using a 50-member storm-scale ensemble forecast (SSEF) system with grid spacing of 4 km, multiple dynamic cores, and forecasts to 36 h (0000 UTC initialization) covering a CONUS domain during SFE2011 (Kong et al. 2011). Only 29 members of the ensemble were used for the CI component of the experiment in order to focus on the ARW-WRF dynamic core, systematic variations in planetary boundary layer (PBL) parameterizations, and a core subensemble with perturbations in both IC/LBCs and model physics. Specifically, of these 29 members, 12 used identical IC/LBCs but different parameterizations of the PBL (hereafter the PBL members), while 18 were initialized with both IC/LBCs and physics perturbations (hereafter the core members). Note that the "control" member was included in both subsets.

Diagnostic tools. Unique model diagnostic tools were developed to identify convectively active (CA) grid points and to provide insight into simulated physical processes related to CI.

1) Identifying CA points. Prior to the start of SFE2011, three distinct definitions were developed to identify CA points objectively, at 5-min intervals, during integration of the models. One was based on simulated total lightning (McCaul et al. 2009), another was based on explicit kinematic properties and hydrometeor content of simulated updrafts, and a third was based on simulated reflectivity. All three definitions were used during SFE2011 and were found to be equally useful for identifying significant deep convective features, but only the simulated reflectivity approach was readily verifiable with directly analogous CONUS-scale observational datasets [Zhang et al. (2011) describe the observed-reflectivity dataset], so the other two are not discussed further here.

   For the reflectivity-based definition, a threshold value of 35 dB*Z* was used as the discriminator between convective and nonconvective points, following Roberts and Rutledge (2003), Mecikalski and Bedka (2006), and others. This threshold check was applied at the −10°C level to avoid brightbanding effects (see Gremillion and Orville 1999). The height of this temperature level was found by searching downward from the model top and interpolating within individual layers, using hourly temperature analyses from the Rapid Update Cycle (RUC) model (Benjamin et al. 2004) for observed reflectivity and individual CAM temperature fields for simulated reflectivity. Simulated reflectivity was computed as in Kain et al. (2008).
2) Model forecast soundings. Hourly soundings were generated for over 1100 locations across the CONUS for the PBL members of the CAPS ensemble. Each of these soundings was then processed through a custom-built version of the SPC's National Skew-*T*/Hodograph Analysis and Research Program (NSHARP; Hart and Korotky 1991) and output for each forecast location was postprocessed into an ensemble-data format readable by the National Weather Service Warning Decision Training Branch's Buffalo Toolkit for Lake Effect Snow (BUFKIT) sounding analysis tool (Mahoney and Niziol 1997). This tool enabled very efficient visualization of large quantities of sounding output with powerful user controls. For example, it allowed users to view forecast soundings from multiple members simultaneously (overlaid, color coded) at any of the preset model output times and locations.
3) Convective boundary layer kinematics and thermodynamics. Interactive analysis of full three-dimensional output grids from CAPS ensemble members was not possible during the real-time experiment, but convective boundary layer processes were sampled effectively in many situations by saving data from just one specific lower-tropospheric model level, located approximately 1.1 km above ground level. The

water vapor mixing ratio, temperature, pressure, and u, v, and w wind components from all ensemble members were saved at this level for every forecast hour. In addition, following Kain et al. (2010), diagnostic code was implemented to extract unique individual gridpoint data at this same vertical level, including the maximum vertical velocity in the last hour and the number of model time steps that boundary layer vertical velocity exceeded 0.25 m s^{-1} in the last hour. These data were designed to measure the maximum magnitude and persistence of boundary layer updrafts, respectively. The threshold of 0.25 m s^{-1} was chosen because empirical evidence in pre-experiment testing showed that it was useful for identifying the stronger, deeper mesoscale updrafts that were associated with surface-based CI in the CAMs. This threshold was effective but not necessarily optimal. Standard surface variables were also extracted and used to identify mesoscale features such as drylines, fronts, and cold storm-outflow boundaries.

Human forecasts for CI. During SFE2011, forecasters worked together with researchers and other participants, using model guidance, diagnostics, and all available observations to make experimental team forecasts for CI. These forecasts consisted of spatial categorical outlooks over limited regional domains for 3-h periods. The spatiotemporal domain was relocated each day with the intention of isolating "clean slate" environments (i.e., environments with no preexisting deep moist convection) in which specific anticipated CI events would occur. Within the selected spatial domain, any areas in which the likelihood of CI in the 3-h period was deemed to be greater than 10%[2] were outlined as categorical "slight" probability areas. Contours of moderate and high probability were added on some days to indicate areas of enhanced likelihood of CI, but these higher categories were not assigned specific quantitative probability levels for this preliminary effort. Each participant was also asked to predict the specific location where the first CI episode was most likely. Clusters of these points were highlighted with hatching in the forecast graphic.

The forecasts were typically issued in the morning, focusing on anticipated afternoon CI. Disciplined preparation of these experimental forecasts was a very valuable exercise because it catalyzed an open exchange of ideas among scientists, forecasters, and other participants. Furthermore, it effectively promoted a critical examination of model guidance and key considerations for defining the CI problem.

WHAT MAKES A SUCCESSFUL CAM FORECAST FOR CI? CAM output was used as guidance for daily experimental CI forecasts and subjective comparisons with observations were made following each event. The motivation for this effort was to develop metrics for identifying and measuring those characteristics of model forecasts that made them useful as guidance for CI. The ultimate goal is to develop ways to objectively quantify these characteristics so that benchmark measures of skill for CI prediction by CAMs can be established. Many of these characteristics are evident in the two example events highlighted below. The first is a clean slate event in which clearly discernible CI leads directly to a mesoscale convective event. A significant event occurs in the second case as well, but its evolution is more complex.

24 May 2011, Oklahoma. A significant severe weather outbreak was predicted for the eastern two-thirds of Oklahoma and surrounding areas on this day as exceptionally strong upper-level forcing for large-scale ascent, vertical wind shear, and convective instability moved over the area. The first storms formed along a dryline (not shown) in western and southwestern Oklahoma around 1900 UTC (Fig. 1a) and quickly evolved into discrete supercells. The dryline moved eastward and it focused meridional expansion of active CI episodes over the next two hours (Figs. 1d,g). Some cells consolidated and new cells continued to form for several hours thereafter and a quasi-linear broken line with embedded supercells was evident from south-central Kansas into north-central Texas by 2300 UTC (Figs. 1j,m) This sequence of observed radar images provides an excellent example of a "clean slate" convection initiation event with no preexisting storms that began with a singular instance of initiation followed in rapid succession by multiple additional initiation episodes along a common boundary, consolidation and upscale growth, and eventual emergence of a clearly identifiable mesoscale convective system (MCS).

This event was predicted fairly well by the CAMs used in the CAPS ensemble. Output fields from two of the PBL members were selected to highlight the comparison. The primary CI event in the member

[2] Specifically, the probability was defined as CI within 20 km of any point, to be consistent with the SPC's Thunderstorm Outlooks.

using the Yonsei University (YSU) PBL parameterization was about an hour late and too far east by several counties (cf. Figs. 1b,e and 1a,d), but the early evolution of the overall predicted convective event was quite similar to observations, showing a rapid formation of discrete storms both to the north and south along the dryline (cf. Figs. 1h,k,n and 1g,j,m). The member using the Mellor–Yamada–Janjić (MYJ) PBL also initiated the first storms a bit late. Furthermore, it suffered from a northeastward location bias (Figs. 1c,f) and differed in its prediction of the early evolution of the event. Specifically, the rapid expansion of storm coverage in the first two hours after initiation was conspicuously absent (Figs. 1i,l). However, by 2300 UTC this member did "fill in" along the dryline, suggesting the formation of a line of strong discrete storms, similar to observations and the forecast from the YSU member. Thus, the MYJ member also provided a strong signal for a significant convective event, but there was some ambiguity about when and where the "event" started in the forecast from this member because of the relatively discontinuous evolution between the first deep convective cells and subsequent widespread convective development.

The real-time experimental forecast for this event, valid for the 1900–2200 UTC time period, is shown in Fig. 2. It included a large area of high probability for CI, indicating high confidence that initiation would occur within the specified time–space window. The forecast team hedged westward and earlier in time compared to guidance from the CAPS ensemble, in response to model and observational data updates from the morning of the event.[3] This

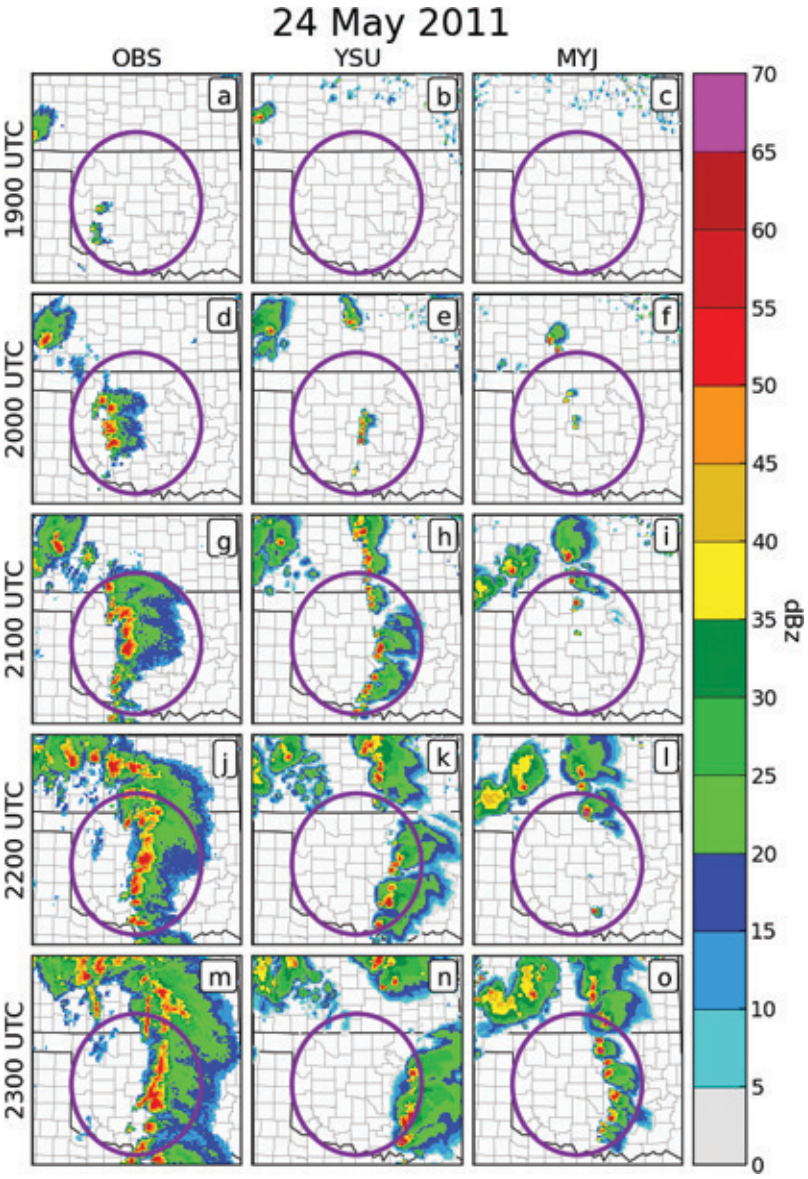

Fig. 1. Hourly composite reflectivity plots from (left) observations and (middle),(right) two PBL members from the CAPS ensemble for a CI event from 24 May 2011. The purple ellipse outlines a hypothetical "isolation domain" over which event-specific diagnostic analyses could be performed. The two PBL members used the YSU (Hong 2010) and MYJ (Janjić 1990) PBL parameterizations, respectively, but were otherwise configured identically.

[3] The forecasted dryline location from the 0000 UTC 24 May NAM (which provided time-dependent lateral boundary conditions for the CAMs) was considerably farther east than in the subsequent 1200 UTC 24 May NAM forecast and much farther east than the observed position (not shown). The dryline was the focusing mechanism for CI on this day; the CAMs were inherently biased toward the east in their CI guidance. This highlights an important challenge of forecasting CI probability from CAM guidance given the possible occurrence of forecast errors of dryline or other synoptic-scale boundary locations (e.g., Ziegler et al. 1997).

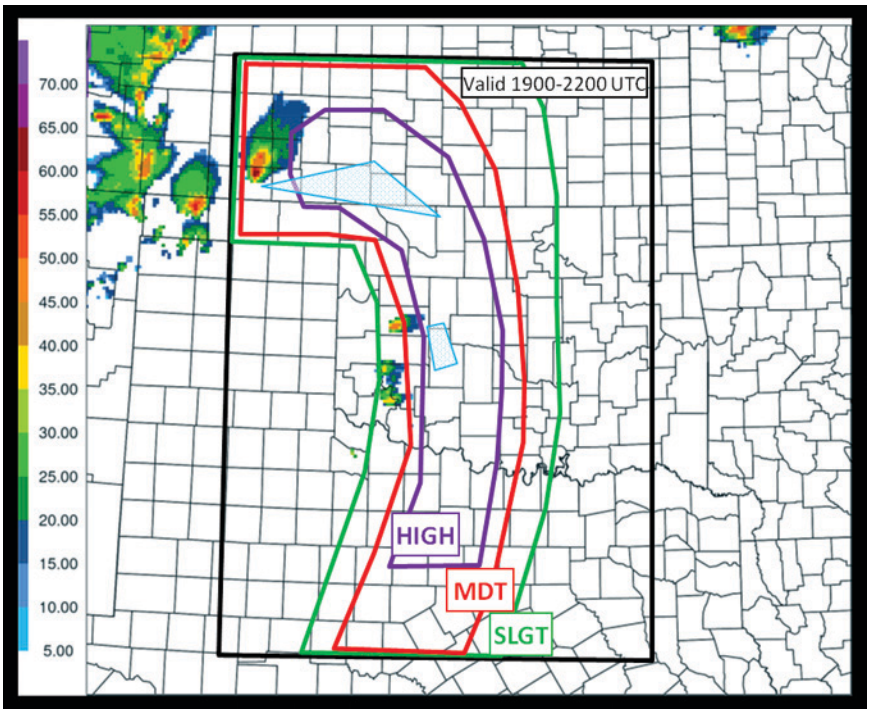

Fig. 2. Observed reflectivity at the –10°C level at 1901 UTC 24 May 2011 with the experimental CI forecast for the period 1900–2200 UTC overlaid. The thick black line outlines the intended boundaries of the forecast domain, and the green, red, and purple lines outline the slight, moderate, and high probability areas for CI, respectively. The hatched areas represent clusters of first CI locations predicted by individual members of the forecast team.

adjustment was in the right direction, but perhaps not bold enough—early CI episodes occurred to the west of clusters of predicted first CI points (see caption) in both the northern and central parts of the outlook area.

26 May 2011, mid-Atlantic region. The upper-level system that triggered severe weather over the southern plains on 24 May played a role in focusing storm development over the mid-Atlantic region two days later. However, the convective forcing and focusing mechanisms were not so sharply defined on this day. This assessment was reflected in the SPC 1300 UTC day 1 convective outlook (www.spc.noaa.gov/products/outlook/archive/2011/day1otlk_20110526_1300.html), which stated that, despite weak upper-level forcing, storms would likely form as daytime heating proceeded within a broad warm sector extending from the central Appalachians into upstate New York. Specific forcing mechanisms were expected to include low-level convergence along residual outflow boundaries from overnight convection and local terrain effects, but there was no discernible dryline and the main synoptic-scale surface cold front was well to the west of this area (not shown).

The CI focus area for this day extended from southeastern West Virginia northeastward to north-central Pennsylvania. CI was observed at multiple locations within this area between 1800 and 1900 UTC (Fig. 3a). Storms generally remained discrete and moved to the northeast for the next 1–2 h (Figs. 3d,g), but by 2100 UTC storms began to consolidate, especially from south-central Pennsylvania into southeastern West Virginia (Figs. 3g,j,m). By 2300 UTC 27 May, an intense line segment had taken shape in south-central Pennsylvania and northern Maryland, posing a substantial threat for severe weather and disruption to aviation over this region.

Output from the same two ensemble members examined in the first event reveals that both members initiated convection close to the high terrain near northeastern West Virginia and also over north-central Pennsylvania by 1900 UTC (Figs. 3b,c). Furthermore, they both initiated and maintained discrete storms over the northern half of the focus area through 2200 UTC (Figs. 3e,f,h,i,k,l). However, they failed to predict the discrete CI episodes over southeastern West Virginia and consequently failed to predict the convective evolution that led to the most significant feature observed in this time–space window—the intense line segment over south-central Pennsylvania and northern Maryland (Figs. 3n,o). Interestingly, both members eventually (after 0000 UTC; not shown) produced intense convective lines that moved from Pennsylvania into New York, but these lines appeared to emanate from convection directly linked to the synoptic-scale boundary rather than the discrete initiation events that actually occurred well into the warm sector. These differences are significant not only from a timing and evolution perspective, but also because the model solutions imply a lower threat of supercellular convection owing to their apparent association with linear (i.e., frontal) forcing.

In this case the models appeared to do well in predicting the timing of the first CI episodes in the northern half of the region—and the isolated character of these storms. However, they missed important initiation episodes farther south, and it was the activity associated with these episodes that eventually grew upscale and became the dominant convection feature. Clearly, there were significant errors in the details of the model convection forecasts, but it is not clear what specific metrics might help to quantify the relevant errors.

Lessons learned. These two cases highlight some of the important considerations for objectively measuring the success of numerical forecasts of CI. Specifically, they demonstrate that accurate predictions of the timing and location of specific CI episodes are certainly desirable, but the timing and location of the first convective cells tell only part of the story. Perhaps even more important is the subsequent evolution of activity, including changes in areal coverage, intensity, and convective mode, particularly if these changes involve upscale growth of activity into organized MCSs.

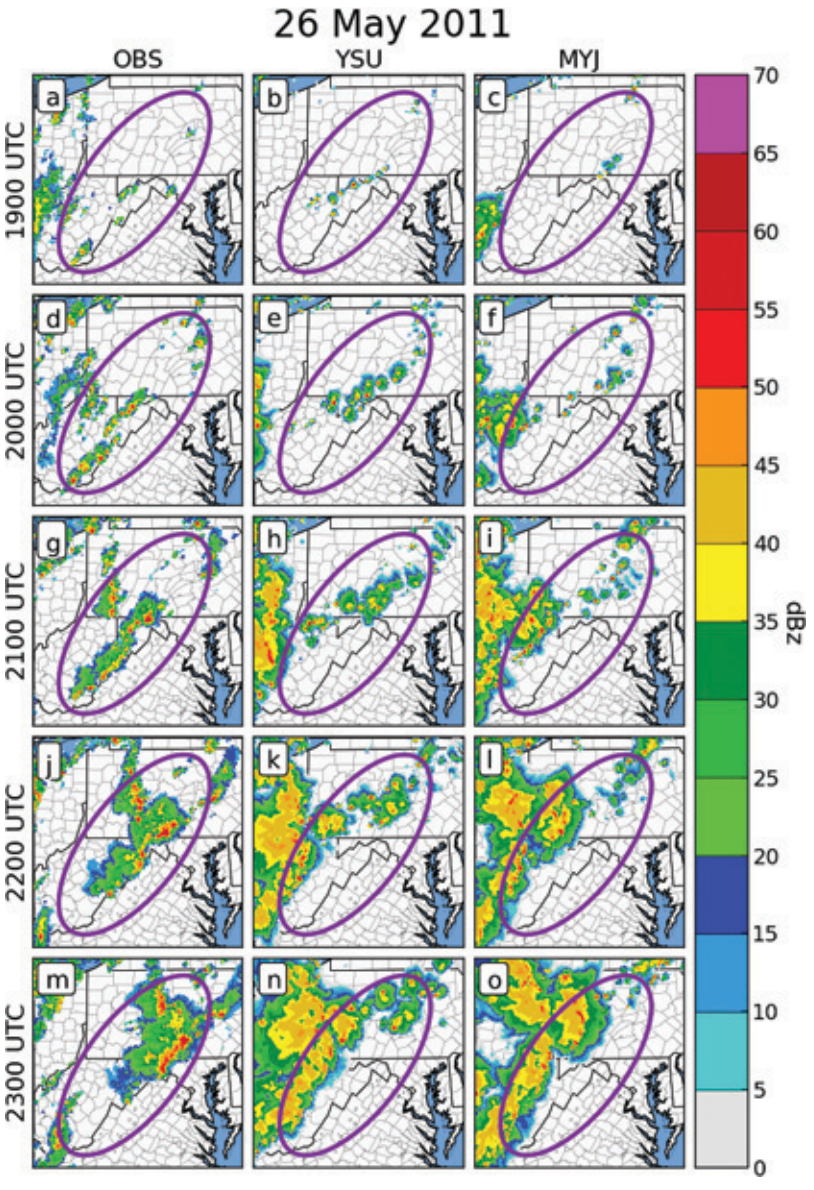

Fig. 3. As in Fig. 1, but for 26 May 2011.

A PRELIMINARY ESTIMATE OF SKILL IN ENSEMBLE FORECASTS FOR CI.

Most meteorologists would say they know CI when they see it, but as suggested above, objective quantification of skill in CI forecasts is challenging. A relatively simple verification framework was established based on lessons learned during SFE2011 to provide a preliminary estimate of timing skill in CAM-based ensemble forecasts. In this framework, an event-specific spatiotemporal window was specified to isolate a particular observed CI event from other convective activity. Spatially, this involved subjective drawing of an isolation domain, based on the location and early evolution of a specific observed convective event. Representative examples of these isolation domains are shown in Figs. 1 and 3.

Comparably sized mesoscale domains were drawn to isolate 14 other events from the SFE2011 time period, for a total sample size of 16 events. These events were scattered over the eastern two-thirds of the CONUS and all occurred during the late morning/afternoon time period (15–24-h forecasts for the CAPS ensemble). The specific measured quantity in this evaluation was the time of first CI in each model forecast (within the limited domain) relative to observed CI. The search encompassed a time window covering ±5 h of each observed CI event.

CI points were identified as a subset of CA points using an object-based time-domain methodology similar to the one described in Clark et al. (2012b). Specifically, in postanalysis of individual events,

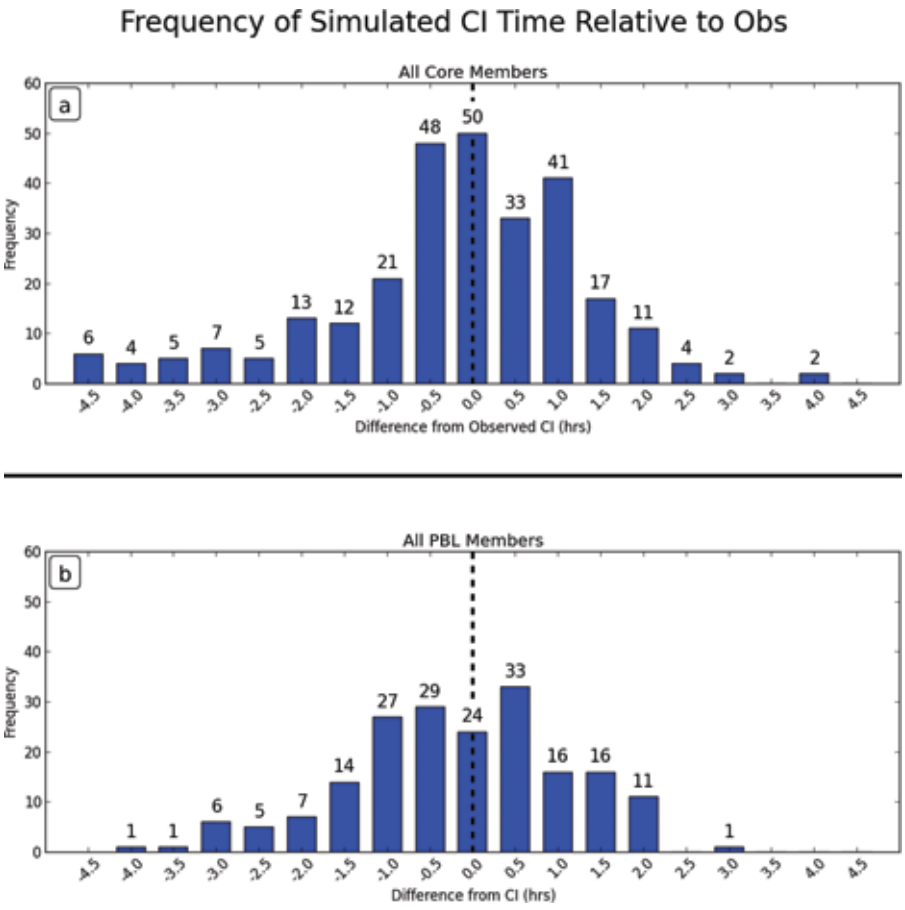

Fig. 4. Frequency histograms of the difference between the CI time predicted by CAPS ensemble members and the observed time, for (a) the core 18 ARW-WRF members and (b) the PBL members. The data are based on 16 selected events from SFE2011.

time-domain CA objects were defined as groups of CA points contiguous in space and time. For example, adjacent grid points became part of a single CA object if they were classified as CA points at the same sample time, immediately preceding the sample time, or immediately following the sample time. Objects that did not span a time period greater than 30 min were not considered. Within each CA object, CI points were identified as local time minima (i.e., CA points without adjacent CA points at earlier times). This algorithm appeared to successfully identify CI points associated with any storms lasting greater than 30 min. It was applied to model output on the native grid and observed reflectivity interpolated to the same grid.

The probability of detection (POD) for CI was very high for these 16 events. Specifically, CI was detected in 456 out of 464 model forecasts (16 events, 29 members), within the specified time–space window, for a POD of 0.98.

The difference in first CI time between each model forecast and the corresponding observation was determined for all events, and a frequency histogram of the differences was constructed. For the 18 core ensemble members, CI times were clustered within about ±2 h of the observed time, with a few outliers, especially on the early side of the histogram (Fig. 4a). The 12 PBL members appeared to be clustered more tightly within the same time window and with fewer outliers (Fig. 4b).

These results are encouraging, suggesting that *when CI occurred in both models and observations* there was very little systematic bias in CI timing for the 4-km CAPS ensemble. The variance in timing was substantial, but the temporal histogram likely provides at least an approximate reflection of true temporal uncertainty in CI and this concept may prove to be useful for developing probabilistic guidance for the timing of CI, and perhaps of other processes as well.

ENVIRONMENTAL PRECURSORS TO CI IN CAMS. Surface-based[4] CI is strongly modulated by a multitude of PBL processes and constrained by thermodynamic profiles within and near the top of the PBL. As described previously, numerous diagnostic tools were developed for SFE2011 to help visualize relevant processes in model output. One set of diagnostic fields was based on model-predicted mass and momentum fields on a fixed sigma level corresponding to about 1.1 km AGL. This level was

[4] A storm is often referred to as "surface based" (as opposed to "elevated") if the air parcels that feed its main updraft originate in a convective planetary boundary layer.

typically within or near the top of the PBL during the afternoon heating cycle within the focus areas for experimental forecasts. Examination of these fields often allowed one to infer important information about PBL processes related to model CI. For example, judicious presentation of vertical velocity and moisture fields can indicate the presence of horizontal convective rolls within the boundary layer, transverse rolls near the top of the boundary layer, and the correlation between the upward-motion branch of these rolls and the moisture field (Fig. 5). A causal relationship between these features and specific CI events has been suggested by observational studies (e.g., Ziegler and Rasmussen 1998; Wilson et al. 1992; Ziegler et al. 2007) and an analogous association was often discernible in the model output during the experiment.

Examination of model-predicted sounding structures revealed that temperature and moisture profiles often varied significantly within the simulated late-day convective boundary layer (e.g., Fig. 6). Over the course of SFE2011, there was a clear trend for certain PBL members of the ensemble to produce relatively cool and moist boundary layer structures, while others were systematically warmer and drier. The process of quantifying these biases and explaining their association with specific PBL parameterizations is underway (Coniglio et al. 2013). CI is undoubtedly sensitive to these details in sounding structure.

Perhaps the most intriguing aspect of these results is that, in individual CAM simulations during SFE2011, the combination of sounding evolution and dry dynamic processes—including subcloud-layer updrafts with a seemingly appropriate combination of persistence, penetration depth, and intensity—allowed some parcels to reach their level of free convection and start the CI process at approximately the right time and place. Like the timing statistics, these results are encouraging. Nonetheless, they only scratch the surface of our efforts to understand the CI process in CAMs more generally because, for example, they are derived

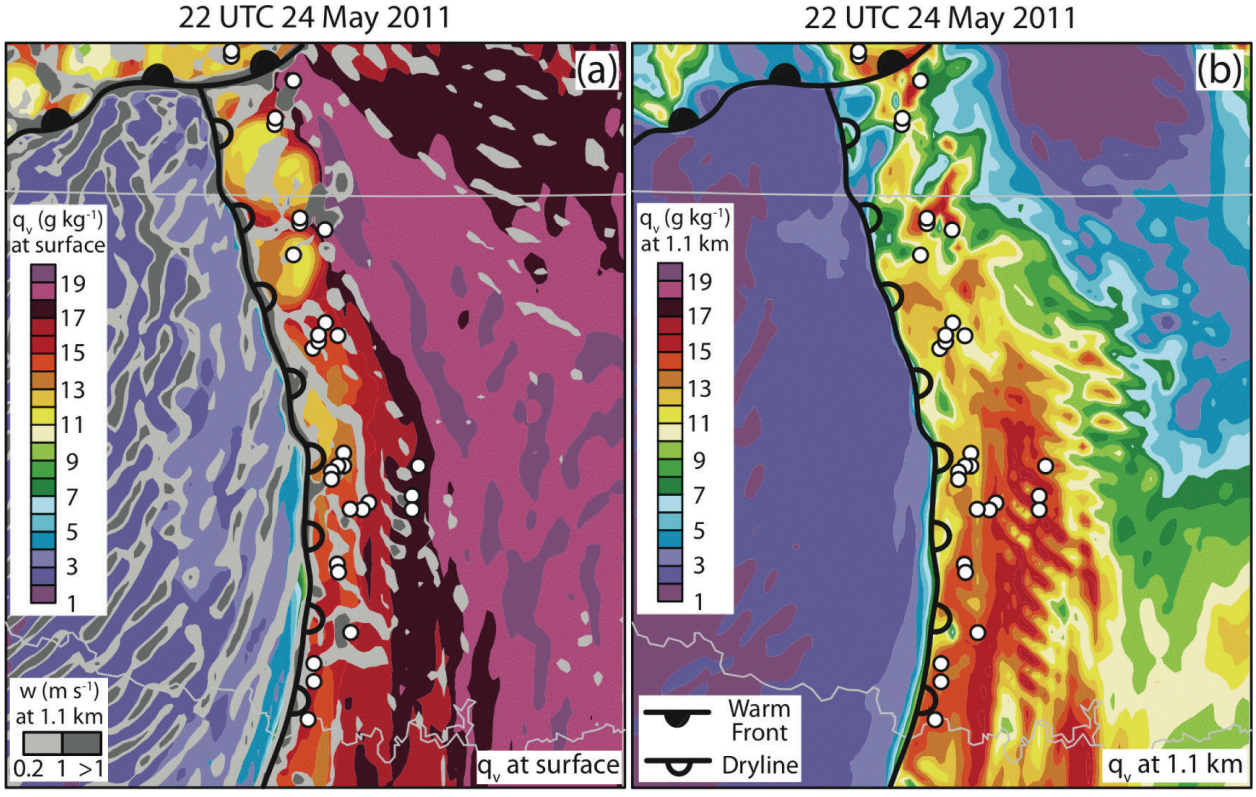

Fig. 5. Sample diagnostic plot from the CAPS ARW-WRF ensemble control member valid at 2200 UTC 24 May 2011 showing diagnosed CI points within ±30 min of the plot time (white-filled black circles) and water vapor mixing ratio (color fill) at (a) the surface and (b) a model level at approximately 1.1 km AGL. In (a), updraft at 1.1 km AGL is indicated by gray fill. Note the HCR-like features in the dry air west of the dryline, the pronounced (>1 m s^{-1}) updrafts along the dryline and warm front, and the elevated transverse rolls in stable air at the top of the PBL to the east of the dryline in central Oklahoma. The CI points are associated with the combination of dryline- and transverse-roll updrafts with deeply lifted, large PBL water vapor mixing ratios.

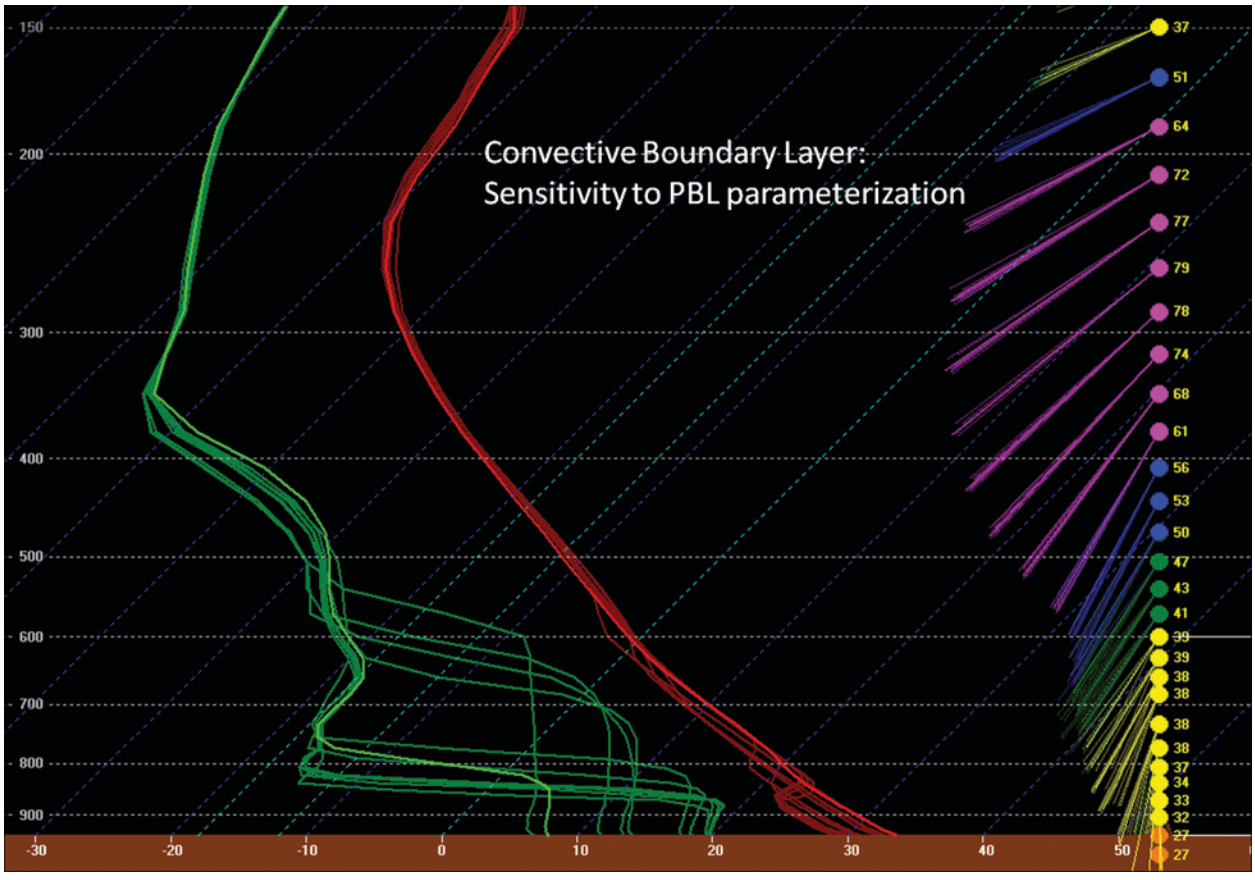

Fig. 6. Forecast soundings valid at a single time and location from each of the PBL members from the CAPS ensemble.

from a limited set of environmental conditions that are commonly observed over the eastern two-thirds of the U.S. landmass in the springtime; most of the sampled events were strongly forced and all of them were surface-based; and the results are more qualitative than quantitative. Much more work is needed to gain complete insight into how sounding structure and dynamic PBL processes modulate the CI process in CAMs.

SUMMARY. A primary objective of the CI component of SFE2011 was to examine the potential utility of CAMs with ~4-km grid spacing in providing guidance for CI forecasts. The models proved to be quite useful in spite of the fact that many convective and preconvective processes were coarsely represented with this grid spacing. For example, in the model forecasts, the pattern and orientation of updrafts rooted in the convective boundary layer often implied the presence of HCR-like features and local airmass boundaries that are known to play a role in the CI process. Because of the relatively coarse model resolution, the scale of these features was likely too large, but their mere presence and association with CI inspired confidence among SFE2011 participants that the CAMs were able to represent physical processes known to be important for CI.

The models also showed promise in predicting the timing of CI over targeted mesoscale areas, particularly when a probabilistic, ensemble-based approach was considered. Specifically, for those events in which convective cells were both observed by radar and predicted by a 4-km ARW-WRF ensemble, there appeared to be no systematic ensemble bias in the timing of first cell initiation. Frequency histograms of timing differences between observations and model predictions, aggregated over many events, had a quasi-Gaussian distribution, suggesting that the ensemble could provide useful probabilistic forecast guidance on the timing of CI with minimal calibration.

Before the start of SFE2011, a considerable amount of effort was spent developing prototype algorithms that first identified convectively active grid points and then found the subset of these points that corresponded to CI. Only one of these algorithms is described here, but they all proved to be very useful for automating the identification of "new" deep

convective cells (i.e., cells that are not directly associated with ongoing deep convection) in either model output or radar-based observations.

Identification of these cells is important, but the consensus that emerged from the experiment was that the algorithms were often inadequate indicators of impending hazardous or disruptive weather. In the springtime when the SFE is conducted, patterns of deep convection can be very complex, with merging and splitting of convective activity on multiple scales and convective instability emanating from multiple layers in the atmosphere. During SFE2011 CI algorithms often flagged initiation episodes related to weak, elevated convection in the warm sector of larger-scale systems, but these flags were false alarms for the initiation of the stronger, surface-based convective events that forecast teams were targeting. When the algorithms were applied to CAM output, interpretation was further complicated by the fact that, while CAMs are known to have skill in predicting the occurrence of some significant convective events (e.g., Done et al. 2004), they commonly suffer from substantial errors in timing, location, orientation, and other system attributes in the prediction of such events—and, of course, they totally miss some events.

Since algorithms that identify local CI processes are useful but not sufficient for predicting the disruptive potential of convective storms and larger-scale systems, perhaps future CI algorithm development should be couched in terms of feature-specific prediction (Carley et al. 2011). In this context the timing and location of initiation are only two of many relevant attributes of convective features. These features could be individual convective cells or they could be scale-selective envelopes of convective activity. For example, other *convective cell* attributes might include size, intensity, rotation characteristics, longevity, and movement, while relevant *convective system* attributes could include initiation, porosity, expansion rate, orientation, movement, etc. It is anticipated that development and testing of feature-specific prediction algorithms will be an important part of future SFEs in the NOAA HWT.

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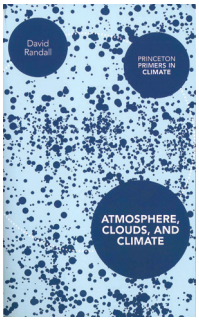
BOOK REVIEWS

ATMOSPHERE, CLOUDS, AND CLIMATE

David Randall, 2012, 288 pp., $27.95, paperbound, Princeton University Press, ISBN 978-0-691-14735-0

For those of us who, perversely, spend our days studying climate and then go home and spend our leisure time reading about climate, there is no doubt that David Randall's *Atmosphere, Clouds, and Climate* is a great read. It is a whirlwind tour of grad-school topics, with sprinklings of historical context, related fields, and advanced topics that keep the pages turning. This book is part of the *Princeton Primers in Climate*, though, so we are not the intended audience. Instead, this book is aimed at college undergraduates according to the preface, and at "students, researchers, and scientifically-minded general readers" according to the back cover. Bearing in mind these audiences, how effective is this book?



The breadth of this slim volume is impressive. Basic processes like radiative transfer, condensation, and turbulence are covered, as are climatic features like monsoons. Cumulus convection is covered in detail, and nicely tied to large-scale phenomena like the Hadley-Walker Circulation and ENSO. Climate feedbacks are described, surpassing the expected thumbnail view using the ice-albedo feedback as an example to include more nuanced (and more interesting) effects like the fixed-anvil temperature hypothesis for tropical cirrus longwave effects and the shortwave effects of low-level clouds. Predictability gets its own chapter, as do coupled processes. All this is achieved in just over 200 paperback pages, and with uncommon succinctness and clarity.

Throughout my reading of the book, I tried to channel my past self: an undergraduate physics major who has a vague notion about climate (and/or clouds) being an interesting topic for graduate study. The broad scope of the book provides a survey of topics that could help a prospective graduate student hone their personal statement. More than that, the book opens the door to the climate system by providing physical reasoning for many fundamental atmospheric processes. One clear strength of this book is that its arguments are consistently presented in terms of energy and mass, for which the science or engineering student should have developed some understanding and intuition. Incorporating moist thermodynamics can get messy, but is dealt with deftly here, for example by using moist static energy instead of introducing the arcane "temperatures" that have perplexed more than just graduate students over many years.

The tone is conversational, and the language is kept simple with as little jargon as possible. These are good features for a book aimed at novices. It is terse, though, with jokes and puns averaging about one per chapter (yes, I kept track). A cynic might ask whether, in an age of Twitter and YouTube, today's undergraduates have the tenacity to reach the end of the book. Those who do, I think, will be well rewarded. They might be drawn toward the field of climate science, too, as there are a few baited hooks within the pages: allusions to using the world's most powerful computers, the allure of studying chaotic systems, the adventure of wading into the world of big data, and the applicability to important societal issues. These are the lures that climate science has at its disposal for recruitment.

As for researchers and scientific-minded general readers, the breadth and clarity of the book should satisfy most. For those in other fields looking to better understand climate science, this book will pair well with some of the popular accounts of the field, allowing the reader to gain a deeper appreciation for the physical science. Graduate students in other disciplines, especially those whose work might be related to climate science, will likely reap the greatest benefits from a careful reading. Nonexperts who teach undergraduate courses on climate should cull from this book useful analogies and explanations, and for small classes this would make a terrific supplementary text to complement a course.

The book has some weaknesses, but they probably vary depending on what the reader is expecting. Experts will undoubtedly feel their own topic has been short-changed, but there is no way around that, even across the whole series of primers in climate. Casual readers might think the text is too dry, but this book is not a history lesson, memoir, nor a narrative account, and it makes no claims to be so. There are historical references that help illustrate the concepts being discussed, but there are no stories or personal accounts or biographical sketches of the founders of the field. Some of the end notes, references, and further reading suggestions will guide interested readers to other sources, and both popular and technical literature is included. Given the brevity of most sections, however, readers might need a little more help. An annotated "further reading" section could have provided that extra nudge toward the most appropriate reading on each topic. Similarly, the final chapter, "Frontiers," could have been expanded. After the expeditious survey of the first eight chapters, it would have felt better to slow down and ruminate on future directions and challenges. The last chapter is only a fleeting glance toward the wider world of current and future research.

I have never read a book like *Atmosphere, Clouds, and Climate*. At the level presented, there is no better description, to my knowledge, of the role that clouds play in the climate system. The clarity and authority that Randall brings to the work are obvious in every chapter. A wide spectrum of readers will be satisfied by this book, but hopefully not so satisfied that they stop here. This book is, as a primer should be, an initiation to a vast field, providing the tools and motivation necessary to take the next steps.

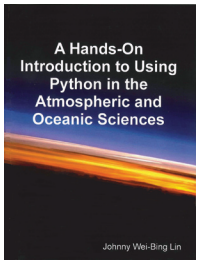
—Brian Medeiros

Brian Medeiros is a project scientist at the National Center for Atmospheric Research in Boulder, Colorado.

A HANDS-ON INTRODUCTION TO USING PYTHON IN THE ATMOSPHERIC AND OCEANIC SCIENCES

Johnny Wei-Bing Lin, 2012, 207 pp., $20.00, paperbound, Lulu Enterprises, ISBN 978-1-300-07616-2

The Python programming language has gained support and use within the atmospheric and oceanic sciences over the last several years, and rightly so. The language allows for a powerful, modern programming framework for many different applications. With the growing use of Python in meteorology, the AMS has offered short courses, included symposia at Annual Meetings, and published brief articles in the *Bulletin*. However, Python resources for researchers in the atmospheric and oceanic sciences remain scarce. Johnny Wei-Bing Lin, the author and a large proponent of using Python in the field, is specifically targeting this void with *A Hands-On Introduction to Using Python in the Atmospheric and Oceanic Sciences*.



The author clearly outlines his intended audience and purpose for the book early in the text. The book gives an overview of how to transition to the Python programming language or, at a minimum, how to implement Python into existing research workflows. The author targets individuals in the meteorological field who have had no exposure to Python but have familiarity with another programming language such as MATLAB, IDL, and modern releases of FORTRAN. Individuals with a working knowledge of how to program in Python will find this text of little use except to see the author's approach to using Python. Because the text is designed as a short course in Python, it does not work well as a resource or reference text, nor does it teach how to program. The author uses a course-like structure and an informal tone that makes for an easy, fast read for individuals hoping to try or switch to Python. For teaching purposes, instructors may want to use the text to help outline a course or as a reference for the basics of the Python programming language in an atmospheric and oceanic sciences context. The exercises provided in the book lack the depth needed for course assignments at an undergraduate or graduate level, but instructors could build upon the concepts presented in the book to design assignments for a programming course.

The book is available in three formats: a black-and-white print version (used for this review), a PDF version with color and hyperlinks for navigation, and a free PDF version. A more complete description of the three formats is included at the beginning of the book and on the book's website (www.johnny-lin.com/pyintro/). In addition to information about the book, example code and data files may be downloaded, allowing readers to use and follow the text with ease—at least in theory. One problem associated with the example code quickly becomes evident. If the example uses data in the netCDF format, some individuals may encounter issues based on

their system's Python configuration. The author provides a fix in the addenda, in the errata, and on the book's website. With minimal effort, all of the examples run. It would be beneficial to provide two stable versions of the code to aid novice Python users and limit frustration.

The author organized the book into five sections. In chapters 1–2, he addresses why to use Python, how others currently use Python, and how to install Python and associated scientific tools. He covers the basics of programming in Python in chapters 3–5. The author follows the basics with practical examples of implementing Python to research through fundamental data processing and visualization in chapters 6 and 9. He introduces the object-oriented programming paradigm in chapters 7–8. In chapter 10, the author directs the reader to additional Python resources for more advanced features and application-specific tools.

Of the various sections within the book, the practical examples in chapters 6 and 9 are the most useful. Chapter 6 highlights different approaches to solving the same problem using Python. This is important because it demonstrates how easy it is to transition from another language while showing that code can maintain a similar feel to the reader's existing coding practices. This chapter also demonstrates that adopting a more Python-like approach exploits more of the features offered by the language, enhances maintainability, enlarges expandability, and increases versatility of the user's code. Chapter 9 is a short primer on data visualization via Python, but the chapter contains great atmospheric and oceanic sciences examples.

Even to readers with formal object-oriented programming training, the section related to this programming paradigm may be initially confusing and abstract. In fairness, most of the ambiguity stems from the lexicon associated with object-oriented programming rather than the author's explanations of the topic. The examples in this section prove essential to grasping the programming paradigm. The atmospheric and oceanic sciences framework of the examples displays how to use object-oriented programming in the field. As a result, the examples salvage what feels like a weaker section of the book.

A Hands-On Introduction to Using Python in the Atmospheric and Oceanic Sciences is an excellent introduction for any researcher in these fields seeking to transition to the Python programming language. Programming examples included throughout the book are effective, clear, and to the point while maintaining relevance to the reader. Johnny Wei-Bing Lin's tone and the structure of the book allow readers to move efficiently through the material and reach the ultimate goal of the book—learning to program in Python.

—Christopher Slocum

Christopher Slocum is a graduate research assistant in the Department of Atmospheric Science at Colorado State University.

NEW PUBLICATIONS

SECRETS OF THE ICE: ANTARCTICA'S CLUES TO CLIMATE, THE UNIVERSE, AND THE LIMITS OF LIFE

V. Meduna, 2012, 225 pp., $40.00, hardbound, Yale University Press, ISBN 978-0-300-18700-7

Each year hundreds of scientists travel to Antarctica to investigate the climate, examine the continent's life forms, and seek answers to far-reaching questions about the universe. In this book, the author shares the scientists' stories and explains their discoveries. Meduna provides firsthand accounts of the wide range of scientific activity in Antarctica today along with portraits of the men and women conducting it. More than 150 color photographs are included in the text.

STORM KINGS: THE UNTOLD HISTORY OF AMERICA'S FIRST TORNADO CHASERS

L. Sandlin, 2013, 266 pp., $26.95, hardbound, Pantheon Books, ISBN 978-0-307-37852-1

The author of this title explores America's fascination with and relationship to tornadoes—what the early settlers of the central plains called "storm kings." Drawing on memoirs, letters, eyewitness testimonies, and archives, the book recreates descriptions of some of the most devastating storms in America's history, including the Tri-state Tornado of 1925 and the Peshtigo "fire tornado," and brings to life scientists such as James Espy, America's first meteorologist. It also details the history of the National Weather Service.

THE EARTH'S CRYOSPHERE AND SEA LEVEL CHANGE

L. Bengtsson et al., Eds., 2012, 343 pp., $169.00, hardbound, Springer, ISBN 978-94-007-2062-6

This text provides a comprehensive overview of our present understanding of the Earth's cryosphere, its changes, and their consequences for mean sea level changes. Since the middle of the nineteenth century, there has been an increase in sea level height of 20–25 centimeters—about 10 centimeters due to net losses from glaciers and the remainder due to mass losses from land ice and thermal expansion of the oceans. The book gives an up-to-date survey of the present knowledge of this increase.

HISTORY

Weather on the Air:
A History of Broadcast Meteorology

ROBERT HENSON

From low humor to high drama, *Weather on the Air* documents the evolution of weathercasts—the people, technology, science, and show business that combine to deliver the weather to the public each day. An invaluable tool for students of broadcast meteorology, this book will entertain anyone fascinated by the public face of weather. Includes over 100 photographs!

©2010, HARDCOVER, 264 PAGES, ISBN 978-1-878220-98-1 , AMS CODE: WOTA

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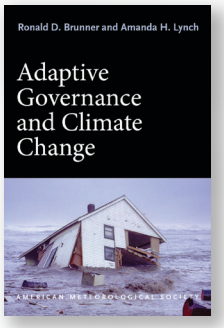
CLIMATE CHANGE

ASK ABOUT THE HISTORIC ARCHIVE OF CALLENDAR'S PAPERS AVAILABLE ON DVD.



Adaptive Governance and Climate Change

RONALD D. BRUNNER AND AMANDA H. LYNCH

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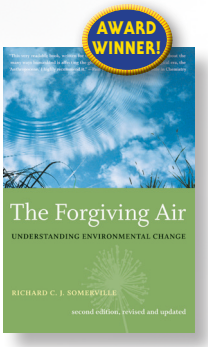

The Forgiving Air: Understanding Environmental Change, 2nd ed.

RICHARD C. J. SOMERVILLE

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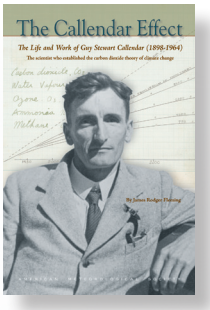

The Callendar Effect: The Life and Work of Guy Stewart Callendar (1898–1964)

JAMES RODGER FLEMING

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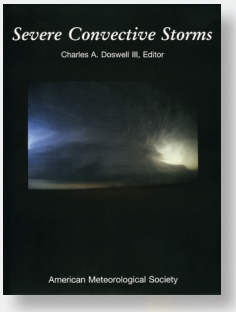

Severe Convective Storms

EDITED BY CHARLES A. DOSWELL III

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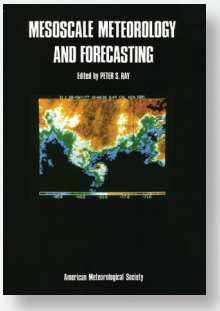

Mesoscale Meteorology and Forecasting

EDITED BY PETER S. RAY

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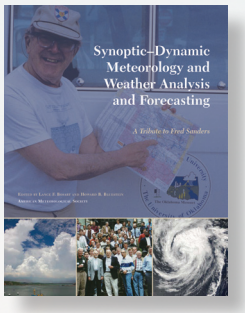

Synoptic–Dynamic Meteorology and Weather Analysis and Forecasting: A Tribute to Fred Sanders

EDITED BY LANCE F. BOSART AND HOWARD B. BLUESTEIN

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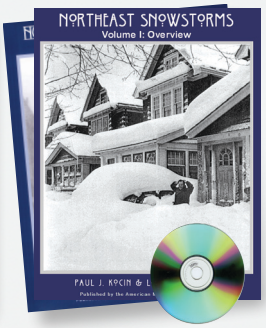

Northeast Snowstorms (Volume I: Overview, Volume II: The Cases)

PAUL J. KOCIN AND LOUIS W. UCCELLINI

© 2004, TWO HARDCOVER VOLS, 818 PAGES, MM VOL. 32, NO. 54, ISBN 978-1-878220-64-6, AMS CODE: MM54

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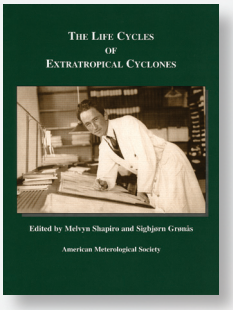

The Life Cycles of Extratropical Cyclones

EDITED BY MELVYN A. SHAPIRO AND SIGBJØRN GRØNÅS

© 1999, HARDCOVER, 359 PAGES, ISBN 978-1-878220-35-6, AMS CODE: LEC

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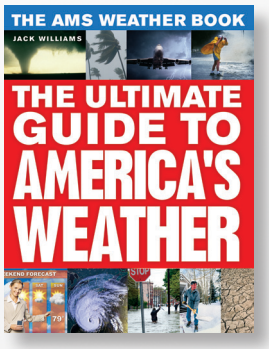
BESTSELLERS

The AMS Weather Book:
The Ultimate Guide to America's Weather

JACK WILLIAMS WITH FOREWORDS BY RICK ANTHES, PRESIDENT OF NCAR, AND STEPHANIE ABRAMS OF THE WEATHER CHANNEL



Former *USA Today* Weather Page editor Jack Williams has written the most comprehensive, up-to-date guide to the weather and atmosphere, covering everything from daily weather patterns to air pollution and global warming.

©2009, HARDCOVER, 368 PAGES, ISBN 978-0-226-89898-8, AMS CODE: AMSWX

LIST $35 MEMBER $25

This CD companion to *The AMS Weather Book* provides more than one hundred detailed graphic illustrations.

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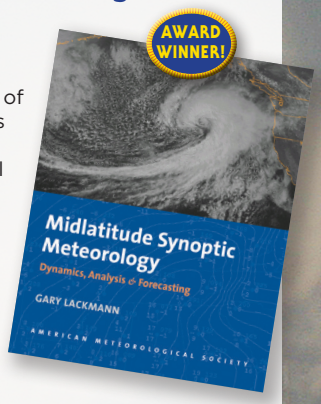
Midlatitude Synoptic Meteorology:
Dynamics, Analysis, and Forecasting

GARY LACKMANN



This textbook links theoretical concepts to modern technology, facilitating meaningful application of concepts, theories, and techniques using real data. It serves those planning careers in meteorological research and weather prediction and provides a template for the application of modern technology in the classroom. Extratropical cyclones and fronts, topographically trapped flows, weather forecasting, and numerical weather prediction are all covered in depth.

©2011, PAPERBACK, 360 PAGES, ISBN 978-1-878220-10-3, AMS CODE: MSM

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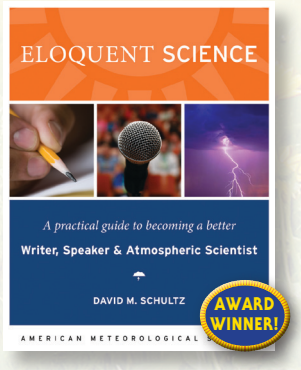
Eloquent Science:
A Practical Guide to Becoming a Better Writer, Speaker, and Atmospheric Scientist

DAVID M. SCHULTZ



The ultimate communications manual for undergraduate and graduate students as well as researchers in the atmospheric sciences and their intersecting disciplines. Every student, teacher, and science department should have a copy.

© 2009, PAPERBACK, 440 PAGES, ISBN 978-1-878220-91-2, AMS CODE: ESCI

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2013 HIGHLIGHTS

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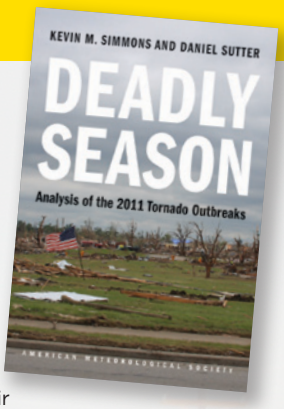
NEW!

Deadly Season:
Analyzing the 2011 Tornado Outbreaks

KEVIN M. SIMMONS AND DANIEL SUTTER



In 2011, the U.S. was hit by the deadliest tornado season in decades. Simmons and Sutter examine the factors that contributed to the outcomes of these tornadoes, identifying both patterns and anomalies. Their conclusions, and assessment of early recovery efforts, are aimed at helping community leaders and policymakers keep vulnerable populations safer in the future.

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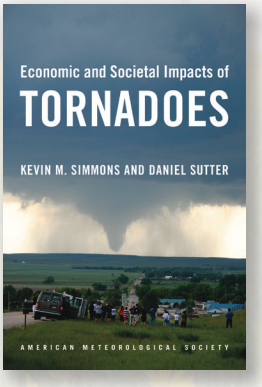
Economic and Societal Impacts of Tornadoes

KEVIN M. SIMMONS AND DANIEL SUTTER



Two economists' unique database has enabled a fascinating and game-changing study of tornado impacts and how factors such as storm timing and warning lead time affect impacts; whether Doppler radar and shelters are worth the investment; and more. For meteorologists, social scientists, and emergency managers.

©2011, PAPERBACK, 296 PAGES, ISBN 978-1-878220-99-8, AMS CODE: ESIT

LIST $30 MEMBER $22

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YOUR CHANCE TO SHAPE THE DIRECTION OF THE SOCIETY

Last month, this column discussed the leadership that has been provided by the AMS Council and the AMS Executive Committee in setting a path for the Society to maintain and strengthen its support for the community despite the tough economic situation the Society finds itself in this year. Our community is blessed to have dedicated and very capable volunteers who are willing to step up to the challenge of leading the Society and chart its direction to best serve this community. It is now time for all voting members of the AMS to decide who will join the governance of the Society to continue meeting that challenge. This issue includes more information on the candidates for president-elect and Council running in this year's election.

I was reminded recently that not all members understand the governance of the Society and the critically important role played by those volunteers elected by the membership to serve on the AMS Council. It is worth taking a little time to remind everyone of the structure of the Society. Simply put, the AMS Council is the voice of the Society, and oversees all AMS programs and initiatives. All policies of the Society are set by the Council, and the priorities established by the Council govern the way resources are utilized across the many programs and initiatives of the Society. The Council oversees the volunteer structure, appointing the leaders of the six Commissions of the AMS within which more than a thousand volunteers serve on more than one hundred separate boards and committees. The Society's journals, meetings, certification programs, student programs, awards, statements, and so many other activities are all guided by Council directive. The three years of service provided by those elected to the Council (with one-third of the full body elected each year) are extremely meaningful, and each Councilor leaves a mark on the future of the Society through his or her leadership.

The AMS President serves as chair of the Council, and provides overall leadership for the Society. His or her term begins with a year as president-elect, allowing a year of preparation before the presidential year. For continuity, each president serves two additional years as part of the governance, with specific leadership roles carved out for the first and second past-presidents in the Society's awards procedures. The four individuals in the presidential rotation serving on the Council, plus two Councilors elected by the Council to represent them, make up the AMS Executive Committee. The Executive Committee provides direct guidance and oversight to the staff in the execution of the priorities and policies established by the Council.

Given the important role of the Council in determining the Society's future directions, there is always an emphasis on having its membership reflect the membership of the Society itself. The Nominating Committee and Executive Committee strive to create a ballot offering balance and diversity in a number of ways, including discipline, gender, race, and professional sector. In addition, the AMS Constitution calls for the Council to appoint one Council member each year, and that selection is used to achieve balance where needed.

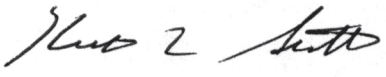
For many years, the Council ballot each fall had eight candidates, from which four were elected. Even with a diverse set of candidates, there was no guarantee that appropriate forms of balance would be reflected in the elected Council, and historically, the Council has had an underrepresentation of individuals associated with the private sector. With the amendments to the AMS Constitution that were approved by the membership last year, this situation can now be addressed through the ballot structure, and this year a new ballot structure has been implemented. Instead of eight candidates, there are nine, with three

each identified as being associated with the academic, government, and private sectors based on their current professional positions. Members will be asked to choose one candidate from each sector group and an additional candidate from any group. The candidate with the highest vote count in each sector group will be elected, along with the candidate with the most votes after those three.

It is not always easy to categorize many of our members in terms of their professional sector, and in fact, the Council benefits greatly from members whose career path spans sectors (just as it benefits from those whose work spans disciplines). This new ballot structure will ensure, however, that at least one Council member elected this year will be affiliated with the academic, government, and private sectors.

I should also mention that we have a special case in this year's election. Earlier this year, past-president Louis Uccellini needed to step down from the Council due to his professional commitments as he assumed the role of director of the National Weather Service—leaving a vacancy on the Council. The AMS Constitution has provisions for dealing with this situation (which comes up in some form about once or twice per decade), calling for the candidate who receives the next-highest number of votes after the four regularly elected Council members to be elected for a short term to complete the term of the vacancy. Therefore, whoever comes in fifth place in this fall's election will be elected to the Council for a one-year term.

The election process is open right now. Please take the time to review the bios and statements of this year's candidates that are included in this issue and log into the AMS website (http://ametsoc.org/) to cast your votes for those you feel will best lead the Society.

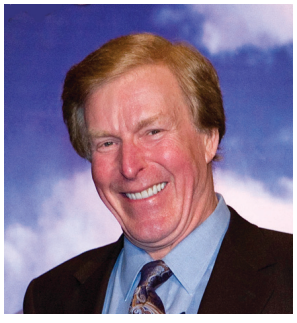


Keith L. Seitter, CCM
Executive Director

ABOUT OUR MEMBERS

After 33 years of forecasting the weather on-air, **Bob Ryan** retired in May from WJLA in Washington, D.C.

Ryan has a bachelor's degree in physics and a master's degree in atmospheric science from the University at Albany. He worked as an atmospheric researcher at Arthur D. Little Inc., and then became a meteorologist at WCVB-TV in Boston before working at *The Today Show*. Ryan went on to join NBC affiliate WRC-TV in Washington, and served as chief meteorologist from 1980 to 2010, after which he moved on to WJLA.



Bob Ryan

Ryan is a past president of the AMS, the first and only president to have worked in broadcast weather. He wrote and published the *Weatherwise Almanac*, an annual meteorology almanac that detailed weather events of the year.

"He's not just an on-air personality, he's a scientist," comments Fred Ryan (no relation), the president and chief operating officer of Allbritton Communications, WJLA's parent company. "He's an iconic figure in weather circles."

Ryan said he plans to remain active, writing and blogging about the weather. He may also appear on WJLA as a "fill-in" forecaster but has ruled out joining another local station.

Rear Admiral **David W. Titley** was appointed as a faculty member in the College of Earth and Mineral Sciences at The Pennsylvania State University. Titley will serve as senior scientist and director of a new center being formed on weather and climate risk solutions in the Department of Meteorology.

As director of the center, Titley is responsible for forging a pathway for research, development, communications, and learning at the intersection of business and weather and climate risk.

David W. Titley

In addition to serving as a naval officer for 32 years, his career has included duties as oceanographer and navigator of the U.S. Navy and deputy assistant chief of naval operations for information dominance. While

serving in the Pentagon, Titley initiated and led the U.S. Navy's Task Force on Climate Change. After retiring from the navy, he served as the deputy undersecretary of commerce for operations—the chief operating officer position at NOAA.

Titley holds a bachelor of science degree in meteorology from The Pennsylvania State University and a master of science degree in meteorology and physical oceanography and a doctorate in meteorology, both from the Naval Postgraduate School in Monterey, California. He was elected a Fellow of AMS in 2009 and holds an honorary doctorate from the University of Alaska, Fairbanks.

Ken Crawford, former Regents' Professor of Meteorology at the University of Oklahoma (OU), received the Order of Civil Merit from the Republic of Korea in a ceremony in May. The award, also known as the Dongbaek Medal, is the primary series of honors for Korean civilians. The award was given to Crawford for his meritorious contribution to the development of the nation and society through improving the quality of the meteorological services.

Crawford served as the vice administrator of the Korea Meteorological Administration (KMA) between August 2009 and February 2013. Prior to his time in Korea, Crawford spent 20 years as a senior faculty member in OU's School of Meteorology. In his role as vice administrator, Crawford was charged with advancing the meteorological capabilities of the KMA.

During his tenure with NOAA, Crawford served 5 years as a research meteorologist for the National Severe Storms Laboratory, 15 years as an operational meteorologist, and 10 years as a senior field manager for the NWS. In his last NWS position, he was the Oklahoma area manager at the NWS Forecast Office in Norman.

Crawford is a Fellow of AMS, served three years as an AMS councilor, and was awarded the Cleveland Abbe Award in 2002. He is a longtime member of the National Weather Association (NWA); in that organization he held the title of national president in 1988, served as councilor in 1990–91, and was named Member of the Year in 1991. Crawford also is the past president of the American Association of State Climatologists. He served for six years on the National Research Council's NWS Modernization Committee, and was awarded a Silver Medal from the U. S. Department of Commerce in 1988 and the NOAA Administrator's Award in 1985. In October 2007, Crawford was named a "Water Pioneer" by the Oklahoma Water Resources Board for noteworthy contributions in the management and conservation of Oklahoma's water. He has also given numerous invited lectures to international audiences in the People's Republic of China, Korea, Canada, Italy, and Morocco, as well as at many locations in eastern Australia.

Professor of geography, research meteorologist and AMS President **J. Marshall Shepherd** has been appointed the inaugural Athletic Association Professor in the Social Sciences at the University of Georgia (UGA). The special appointment was made by the Board of Regents at their May 2013 meeting and became effective immediately.

J. Marshall Shepherd

Director of the UGA Atmospheric Sciences Program and a professor in the Franklin College of Arts and Sciences Department of Geography, Shepherd joined the university faculty in 2006 after 12 years as a research meteorologist in the Earth-Sun Exploration Division at NASA's Goddard Space Flight Center. At UGA, he conducts research on weather and climate systems using advanced satellites, experimental aircraft, radars, and computer models. The research seeks to understand weather processes—such as thunderstorms, hurricanes and rainfall—and atmospheric processes and relate them to current weather and climate change.

"I am very grateful to the UGA Athletic Association and honored to be selected for this professorship," Shepherd comments. "The resources from the professorship will support a synergistic study of how urban landscapes and pollution modify temperature, rainfall, storms, and flooding. The honor further solidifies UGA as a leader in urban weather–climate research and will enable new perspectives on how atmospheric sciences affects policy, economics, health, urban planning disaster response, water-supply planning, and agriculture."

RICK BRANDT
Technical Editor

Like many in the field, Rick Brandt's interest in meteorology began at a young age when his fourth-grade teacher gave an assignment to record daily high and low temperatures, sky conditions, and precipitation based on the evening news report. He later joined the Meteorology Club in high school.

"Along the way, I also became interested in grammar and writing, beginning with the dreaded diagramming of sentences," Rick remembers. "Little did I know that the opportunity to combine my two interests would later present itself at the AMS."

Rick attended California University of Pennsylvania for his undergraduate studies. He started forecasting in the newly formed Cal U Weather Center and also became fascinated with regional phenomena. In graduate school at Texas Tech University, he studied the dryline, went storm chasing, and forecasted during several deployments of the Wind Engineering Mobile Instrumented Tower Experiment. Rick also joined the student chapter of the AMS and was a student volunteer at the AMS Annual Meeting in Dallas in 1999.

While finishing his Master's degree, he briefly worked as a meteorological technician at Fort Huachuca, Arizona, before returning to Lubbock as a meteorologist intern with the National Weather Service. Rick enjoyed his job but found that the world of rotating shifts was not for him. He decided take another U-turn to study climatology at the University of Arizona.

"My doctoral research focused on the North American monsoon system and wildland fires," Rick explains. "I also had the opportunity to work as an assistant forecaster for the North American Monsoon Experiment in 2004."

For the experiment, Rick worked a five-day shift with two lead forecasters at the Tucson NWS office. He used surface and upper-air observations to write summaries of the previous day, including precipitation amount and pressure patterns. He also developed the 24-hour forecast while the lead forecasters worked on forecasts for 24–48 hours, 3–5 days, and 6–10 days. There were also daily weather briefings in which the forecasters, science directors, and other participants discussed current and forecasted conditions and the possibility of using additional data-gathering methods.

Relocating to Arizona allowed Rick to experience the physical environment and culture of the Southwest, which always fascinated him, and he met many diverse and interesting people, including his future wife, Sarah. In addition, he gained experience in writing and publications via the Southwest Climate Outlook, several white papers, and the local running club's newsletter.

Upon graduation in 2006, the Brandts moved to the Boston area. For the next several years, Rick taught meteorology, climatology, and geography courses at Salem State College. He also gained contacts at publishers and wrote several chapters for reference books.

During the fall of 2009, a job announcement for a technical editor (TE) at the AMS caught his attention.

"It was a great opportunity," Rick says. "It could combine my interests in the atmospheric sciences, writing, and editing, and it would allow for more evening and weekend time to spend time with my wife and our new daughter."

Rick is currently the lead technical editor for the *Journal of the Atmospheric Sciences*, but he also edits manuscripts and proofs for several of the Society's journals.

"It's interesting to work with authors from around the world who are at various stages of their publishing careers—from students submitting their first papers to leaders in the field," Rick comments.

In addition to editing, Rick gives presentations for the School Talks Organized by Research Meteorologists (STORM) program.

"Following my own grade-school assignment, I hand out charts that allow the students to record

weather data," Rick explains. "I often find myself hoping that students are getting as much out of presentations as I do."

An avid runner, Rick also enjoys joining other AMS staff at local road races sporting the "Natural Disasters" team shirts.

"Looking back at the path that led me to my current TE role at AMS, I'm amazed at how the pieces came together," Rick says. "I feel so fortunate to be working with great people at a job that I enjoy and in the field that grabbed my interest so long ago."

—Rachel S. Thomas-Medwid

AMS STATEMENT

CLIMATE SCIENCE IS CORE TO SCIENCE EDUCATION

A Policy Statement of the American Meteorological Society

(Adopted by the AMS Executive Committee on 23 May 2013)

The Next-Generation Science Standards (NGSS) developed in collaboration with 26 states and several scientific organizations is a transformative set of guidelines for teaching science in the United States. For the first time, climate change is recommended as a core concept for U.S. science curricula, including an emphasis on anthropogenic or "human-caused" effects. As an association of scientists and science-based professionals, the American Meteorological Society (AMS) affirms the inclusion of climate change in the NGSS. Climate change science is firmly rooted in peer-reviewed scientific literature; as science, it is as sound as other NGSS subjects such as earthquakes and the solar system.

The preamble of the 2012 AMS Statement on Climate Change[1] states

> "This statement provides a brief overview of how and why global climate has changed over the past century and will continue to change in the future. It is based on the peer-reviewed scientific literature and is consistent with the vast weight of current scientific understanding as expressed in assessments and reports from the Intergovernmental Panel on Climate Change, the U.S. National Academy of Sciences, and the U.S. Global Change Research Program."

Efforts to properly teach climate science are regularly challenged by those seeking to frame it as somehow different from other scientific subjects, often with claims that it is either "uncertain" or "controversial." They advocate the need for a special approach to its teaching, such as added effort to balance perspectives. With this statement, the AMS seeks to confirm the solid scientific foundation on which climate change science rests, and to emphasize that teaching approaches different from other sciences are not warranted. Uncertainty is a natural component of all scientific endeavor. The existence of uncertainty does not undermine the scientific validity of climate change science; to the contrary, it provides a sound example for broader instruction of the scientific method.

SCIENTIFIC VALIDITY: The primary findings of climate change science have been well established in the peer-reviewed science literature and replicated by numerous independent investigators and methodologies. Blue-ribbon panels of scientists convened by organizations such as the National Academy of Sciences have carried out formal evaluations of scientific studies and provide a consensus opinion regarding climate change. Leading scientific organizations beyond the AMS (e.g., American Association for the Advancement of Science, American Geophysical Union, and European Geophysical Union) have considered the state of the science and are in consensus on the topic as well. There are small scientific differences as research continues to refine the details, but there is strong agreement on the primary findings and essentially no controversy with respect to them.

Science is an enterprise that systematically acquires and organizes knowledge in the form of test-

[1] See www.ametsoc.org/policy/2012climatechange.html

able explanations and verifiable predictions about the natural world. Despite differences in methods, all activities we recognize as scientific share some common characteristics, principles, and values. Science is always based on observations and experimentation. Scientists insist on disclosure of hypotheses, observations, methods, and interpretation of the results through a process known as peer review, which provides other scientists an opportunity to evaluate their methods and the logic that led to their conclusions. A published result may not be fully accepted until other scientists further investigate the ideas through reanalysis of the original observations, taking new observations, repeating their experiments, or running a numerical model—whatever it takes to test the idea. Because of the skeptical nature of scientists, new ideas are accepted very slowly and only after a great deal of scrutiny. In fact, what authority science achieves is based on the openness by which scientific results are presented for review, evaluation, and additional testing. Inclusion in a precollege science curriculum should be limited to topics that meet these rigorous standards, and climate change science as presented in the broad peer-reviewed literature has earned its place within the broader educational framework of the nation.

SCIENCE AND UNCERTAINTY: The 2012 AMS Statement on Climate Change provides the context for the current science of climate change and also conveys where there is uncertainty (e.g., in the role of melting permafrost in the rate of climate change). Scientists acknowledge and work routinely within a framework of uncertainty. The broader public and educational communities may erroneously conclude that such uncertainties render climate science unreliable or in question. By contrast, the public consumes information daily that includes uncertainty. For example, a forecast of an 80% chance of rain contains a statement of uncertainty, but most people would grab an umbrella given that forecast. Aspects of climate science such as the greenhouse effect, the flows of solar and terrestrial radiation, and feedbacks are as scientifically sound as gravity, the human genome, or orbital mechanics.

It falls on educators and policy makers to provide an environment, from elementary through graduate school, that exposes students to the nature and meaning of science as well as the rich cache of scientific knowledge. It is essential that educators instill in the next generation the following: how and why science works; how it is self-correcting; the importance of evidence and the value of uncertainty; why through a series of stops, starts, and sidetracks it will move toward an explanation of reality; and why science is the basis for many of society's technological advancements.

Climate literacy in the next generation of U.S. citizens will ensure a firm foundation of knowledge and discourse as society faces decisions on how to best deal with a changing climate. The nationwide adoption of the NGSS, with its inclusion of climate change science in curricula, will help improve overall climate literacy.

[This statement is considered in force until May 2017 unless superseded by a new statement issued by the AMS before this date.]

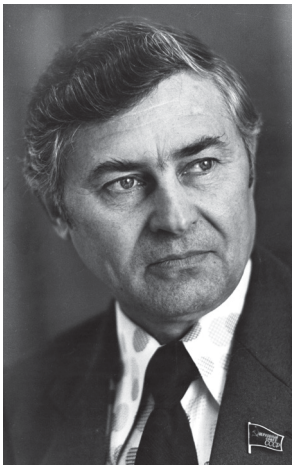
OBITUARIES

GURI IVANOVICH MARCHUK
1925–2013

Guri Ivanovich Marchuk was born in 1925 in the Orenburg region of Russia. Upon graduating from the Department of Mathematics and Mechanics at the Leningrad State University, he entered the graduate program and in 1952 defended his Ph.D. thesis, which was titled "Dynamics of Large-Scale Meteorological Fields in the Baroclinic Atmosphere." From 1953 to 1962, he worked in the Institute of Physics and Energetics at Obninsk, first as laboratory director and later as chair of the Department of Mathematics. There, he proposed new methods for the numerical modeling of the physics of nuclear reactors that are still widely used in operational practice. Of special importance in this work is the treatment of radiative transfer. The results of his investigations were summarized in his 1956 doctoral dissertation, "Numerical Methods for Computing Nuclear Reactors," and in a monograph under the same title. Between 1959 and 1961, Marchuk was among the members of a research team responsible for the development of principles for ensuring the safety of industrial nuclear power plants.

In 1961, he was awarded the Lenin prize for his scientific achievements in the field of nuclear reactors. In 1962, he was elected a corresponding member of the USSR Academy of Sciences, and in 1968 he became a full member of the academy.

Marchuk was an author of some 350 scientific works, including 25 monographs. These works addressed the development and study of efficient algorithms in numerical mathematics, computational methods for nuclear reactors, mathematical modeling addressing problems of environment, immunology, and topics in informatics and computer science.



Guri Ivanovich Marchuk

In the field of numerical mathematics, Marchuk made many important contributions to the development of finite-differencing schemes. He developed many efficient schemes for the classes of equations that arise in the theory of nuclear reactors, and he proposed a technique for constructing finite-difference schemes on the basis of integral identities that has been further developed by both Russian and foreign scientists. Together with his former students, he developed a number of differencing and variational-differencing schemes to address problems of mathematical physics. Among his most notable contributions was the development of splitting methods and perturbation algorithms based on adjoint equations, as well as novel numerical methods of linear algebra. Based on adjoint equations and perturbation algorithms, he elaborated principles for constructing efficient small-group models of nuclear reactors. He also made important contributions to numerical weather prediction and to the development of atmospheric general circulation models used in simulating the behavior of the climate system.

The main thrust of Marchuk's work in atmospheric dynamics was to devise efficient methods for solving systems of equations based on various approximations of the primitive equations. Most of the methods that he and his colleagues developed have been incorporated into the codes of numerical weather prediction models used operationally by the Hydrometeorological Service of the USSR and in atmospheric general circulation models and climate models.

The first study in this series, "On the Dynamics of Large-Scale Atmospheric Processes," coauthored with N.I. Buleev in 1958, was formally devoted to the study of the influence function for various meteorological parameters in determining the distribution of geopotential, temperature tendency, and vertical motion. This study introduced an efficient method for solving the three-dimensional quasigeostrophic equations, which became the basis of the prognostic scheme for short-term weather forecasts at the Hydrometeorological Service of the USSR for many years. In this study, the authors formulated an equation for the conservation of a quantity essentially equivalent to quasigeostrophic pseudopotential vorticity, from which they computed the geopotential tendency using an analytical Green's function technique to invert the three-dimensional elliptic operator.

By the 1950s it had become apparent that the main problem in numerical weather prediction was the instability of the climate-system trajectory with respect to small perturbations in initial data and external forcings, which renders solutions of the governing equations unstable in the Lyapunov sense, and therefore unstable with respect to perturbations in the terms on the right-hand side. It follows that to improve forecast skill, it is necessary to revert to the full primitive equations involving diabatic heating, even for short-term weather prediction models. In the early 1960s, Marchuk turned his attention to this problem, starting with his paper, "A Theoretical Model for Weather Prediction," published in 1964 in *Doklady of the USSR Academy of Sciences*. This study described a model based on the primitive equations in (x, y, p) coordinates that includes radiative transfer and moist processes. In the finite-difference algorithm used to solve the equations, the terms involving physical processes and the advection terms are split into separate equations that are solved in successive time steps.

Marchuk's mathematical analysis of the system of equations used in short-term weather prediction includes consideration of the existence of solutions of the differential problem, the degree of approximation and stability of the finite-difference solutions, and the convergence properties of finite-difference solutions to the exact solution in various prescribed functional spaces. This pioneering line of investigation, which

is now called "mathematical geophysical hydrodynamics," was launched with the paper of Marchuk and Demidov titled, "Theorem of the Existence of a Solution of the Problem of Short-Term Weather Forecasting," which proved the existence of a solution to a simplified version of the governing equations in which diabatic heating and the horizontal and vertical diffusion of heat are neglected. It was not until fairly recently that most of the set of problems posed by Marchuk can be considered to have been solved, many of them by scientists whom Marchuk had personally mentored.

Marchuk also made seminal contributions to the mathematical modeling of the oceanic circulation. His contributions in this area can be categorized as 1) investigations of correctness of the formulation of the governing equations, 2) construction of efficient schemes for numerical solution of the governing equations on the basis of splitting methods, and 3) formulation and solution of direct and inverse problems in ocean dynamics using adjoint equations. As a test bed for ocean models, he promoted a series of oceanographic field campaigns under the umbrella of "sections," which proved to be the most ambitious observational program in support of climate research in the history of Russian science.

In applying the adjoint equations to geophysical fluid dynamics, Marchuk drew upon his experience working with linear operators in solving problems of neutron physics and satellite meteorology. His formalism was based on the idea of quasilinearization, which leads to nonuniqueness of the adjoint operator. He employed an intuitive quasilinearization that is correct from a physical point of view with respect to Lagrangian coordinates. This approach could potentially be applied to a broad class of problems for which the adjoint equations satisfy the Lagrange identity in the nonlinear case. An example is the diagnostic study, "Numerical Calculation of the Adjoint Problem for Modeling the Thermal Interaction between the Atmosphere and Ocean," coauthored with Yu. N. Skiba in 1976.

Marchuk also attempted to model the environmental impacts of industrial pollution. His idea of using the theory of adjoint equations describing the transport and diffusion of pollutants enabled him to formulate and efficiently solve the problem of optimal siting of industrial plants to minimize pollution in prescribed ecological zones.

In 1962, Marchuk was invited to join the Siberian Branch of the USSR Academy of Sciences. He was authorized to use the Computing Center of the Institute of Mathematics of the USSR Academy of Sciences as a basis for organizing an independent research institution equipped with modern computer facilities for advancing scientific and industrial progress in Siberia. Under his direction, the Computing Center launched intensive research projects in important fields of computational mathematics and its applications to a number of contemporary problems in science and technology, including atmospheric and oceanic physics, the theory of radiative transfer, geophysics, and continuum mechanics, as well as computer technology and software support. Within this framework, he organized a number of ongoing seminar series, topical conferences, and symposia. The institute that he directed soon became the major scientific research center in computational mathematics in Siberia.

In his role as vice chairman and later as chairman of the Siberian Branch and vice president of the USSR Academy of Sciences, Marchuk developed an extensive program aimed at extending basic and applied research and training scientists. In 1986, he was elected president of the USSR Academy of Sciences. In 1980, he founded the Department of Computational Mathematics in Moscow at the Presidium of the USSR Academy of Sciences, which was later renamed the Institute of Numerical Mathematics.

Marchuk will be known for novel and at times surprising applications of mathematics. In 1974, he became interested in the mathematical modeling of immune reactions in the human body in response to viral and bacterial infections. He was the first to develop a system of nonlinear differential equations with a delayed argument that adequately describes these processes. On the basis of this and subsequent achievements in mathematical immunology, Marchuk gained recognition as one of the founders of a promising new branch of applied mathematics, and the results

IN MEMORIAM

GEORGE W. CRY
1930–2013

THEODORE F. FATHAUER
1946–2013

GLEN R. FREY
1940–2013

WAYNE MOUNT
1927–2013

of his immunological research are being extended and widely used in medical practice.

Marchuk's awards and honors included appointment as a foreign member of the Bulgarian, Czecho-Slovak, Finnish, Indian, Polish, and French Academies of Sciences; honorary doctorates at the Universities of Toulouse, Carlow, Dresden, Calcutta, Houston, Oregon State, and others; a Gold Medal for Services to Science and Humanity of the Czecho-Slovak Academy of Sciences, a Silver Medal of the Academy of Sciences of the French Institution, the A. Karpinskiy Medal and Prize (Germany), and an Order of the Commander of Knights of the French Legion of Honor. He was an Honorary Member of the AMS.

All who knew Marchuk were impressed by his enormous capacity for work and by the unfailing optimism that characterized his scientific, social, and personal life. Marchuk's close friends are familiar with the story of his decision to treat (successfully, as it turned out) his own chronic lung inflammation on the basis of model-calculated data on the immune response to viral and bacterial infections. Despite his many achievements and his stature in science and government, he was a humble and polite man. There is a story that residents of Obninsk defined a unit of politeness, the "guri," in his honor, where the politeness of ordinary people is estimated to be on the order of 1 microguri. Marchuk was a lover of nature who enjoyed long walks and had a passion for fishing. His family was an important part of his life. He and his wife were married for 62 years. Their three sons are all mathematicians with doctoral degrees, and they have six grandchildren and six great-grandchildren. One of their granddaughters is now living in the Silicon Valley in California with her husband and three children.

—Valentin P. Dymnikov and John M. Wallace

The 2013 candidates for AMS president-elect are Jennifer Alexander and Sandy MacDonald. This year's candidates for AMS councilor are: Private sector—Heidi Cullen, Steve Hanna, Veronica Johnson Weems; Government—Ruby Leung, Michael Morgan, Louis Zuccarello; Academic—Dennis Lettenmaier, Brenda Philips, Wendy Schreiber-Abshire.

A new ballot structure has been implemented for this year's Councilor elections. Instead of eight candidates, there are nine, with three each identified as being associated with the academic, government, and private sectors based on their current professional positions. When voting, members should choose one candidate from each sector group and an additional candidate from any group. The candidate with the highest vote count in each sector group will be elected, along with the candidate with the most votes after those three.

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

JENNIFER C. ALEXANDER

It seems that no part of our Society or profession has gone untouched by the current fiscal challenges of our members' respective nations—all of us are doing "more with less." However, my experiences in meteorology over the last 20 years indicate that we are still incredibly relevant, and we owe it to those we support to continue to provide our best. How do we provide not just more, but *better*, with less? We innovate!

If elected, I will focus my term on promoting innovation and efficiencies. We are an organization filled with extraordinary talent and brilliant minds, and I know, with your help, we can make real changes to ensure that we're ready for our next 100 years of service to society. Specifically, I'd like to tap into our amazing local chapters, and use their energy and enthusiasm to boost our voice in our communities, and generate actionable ideas to maximize our positive impact on our profession. I also know from experience that our many dedicated volunteers have great suggestions for streamlining Society operations, and I will, with the guidance and help of our AMS staff, incorporate as many of those outstanding ideas as possible. In today's fiscal environment, even the smallest of efficiencies may have a huge impact.

JENNIFER C. ALEXANDER

Lieutenant Colonel Jennifer C. Alexander is the international security assistance force joint command chief meteorological officer in Kabul, Afghanistan. Alexander most recently served as the director, Commander's Action Group, Dean of the Faculty, at the U.S. Air Force Academy. She has distinguished herself in a variety of leadership positions within the operations and technology transition disciplines, and has served in key positions in support of U.S. Air Force, U.S. Army, and joint operations.

She has received a number of major awards and decorations, including the Meritorious Service Medal with two oak leaf clusters, the Air Force Commendation Medal with two oak leaf clusters, the Joint Service Achievement Medal, the Air Force Achievement Medal with two oak leaf clusters, the Air Force Merewether Award (best weather technical achievement), the Air Force Weather Agency Moorman Award member (Outstanding Specialized Weather Unit), and the Air Force Space Command Outstanding Specialized Weather Unit Award member.

Alexander received her B.S. in atmospheric science from the University of Arizona (1992), her M.S. in meteorology from Texas A&M University (1996), and her Ph.D. in meteorology from the University of Utah (2004).

She has served on the AMS Council and Executive Committee, as well as on a number of AMS boards and committees, including the Board for Operational and Government Meteorologists; the Committee on Environmental Responsibility; the Local Chapter Affairs Committee; the Aviation, Range, and Aerospace Committee; and the Weather Analysis and Forecasting Committee. She has also participated in a number of Student Conferences at the AMS Annual Meeting, making presentations on "Air Force Weather Opportunities."

So, my challenge to you, whether you vote for me or not: be thinking of ways to better our Society! We are already a highly respected, well-run, impactful organization, with a distinguished history and an exciting future. But we must always strive to be better. Thank you for this honor and amazing opportunity.

ALEXANDER E. "SANDY" MACDONALD

The need for the best our AMS community can deliver has never been greater. In just the last year we have seen the devastation that storms such as Hurricane Sandy and the Moore tornado can bring. While we deplore the destruction, we are justly proud of our progress in preparing and protecting the public, something our entire community has had a role in. Together we bring the best science to the question of our future climate, droughts, floods, and the planetary changes driven by human causes. This progress owes much to the unifying effects of our Society. It unifies the academic, commercial, and government members, and it joins members of related disciplines such as atmospheric, oceanic, and social sciences. My commitment to the members of the AMS is to build on the true strength of the Society as a unifying force while fostering the spirit of inclusion.

I have always appreciated the willingness of AMS members and leadership to embrace change. In the mid-1980s, I and several others went to the Society with a request to create a new conference dedicated to the emerging interactive computing and display technology. The result has been a long-running and extraordinarily successful branch of AMS, beginning with the Interactive Information Processing Systems conference. This conference accelerated the role of information technology in helping operational weather, and at the same time was an engine for bringing U.S. commercial companies into the global weather information system market. Later, as an

ALEXANDER E. "SANDY" MACDONALD

Dr. Alexander E. "Sandy" MacDonald is director of NOAA's Earth System Research Laboratory (ESRL) in Boulder, Colorado, and also the chief science advisor for NOAA's Oceanic and Atmospheric Research (OAR) line office. Like many meteorologists, he became interested in weather as a child and has spent his career in the field. After obtaining a degree in math and physics from Montana State University, he started his professional career as an officer and forecaster in the U.S. Air Force, and then earned M.S. and Ph.D. degrees in meteorology from the University of Utah. He started working for NOAA in the NWS Western Region Headquarters in Salt Lake City in 1973. When the Program for Regional Observing and Forecasting (PROFS) was established by NOAA Research in 1980, MacDonald became leader of its advanced weather prediction development team. He subsequently served as the first director of NOAA's Forecast Systems Laboratory (1988) and later became the first director of NOAA's Earth System Research Laboratory. From 2006 to the end of 2012, he was the deputy assistant administrator of NOAA OAR while serving as ESRL's Director.

Throughout his career, MacDonald has focused on advancing science and technology toward the improvement of services. His experience in the air force showed him not only the significance of weather forecasting, but also its many limitations. While developing his first weather prediction model at the University of Utah he became fascinated with the potential of computers and information technology to improve geophysical prediction. Under his leadership, PROFS and Forecast Systems Laboratory were able to contribute greatly to the modernization of the NWS.

MacDonald has been a leader in many important areas of research and development. He has pushed for new observing technologies such as Unmanned Aircraft Systems, and has published extensively in advanced weather prediction modeling. He has published important policy-relevant discussion of the dangers of regional climate change. His invention of Science On a Sphere® (a display system exhibited in about 100 museums and other institutions around the world) educates people of all ages about our science.

MacDonald's many awards include a Service to America nomination, a Department of Commerce Gold Medal, and four Presidential Rank Awards. He has been an active member of the AMS for more than 40 years and is a Fellow of the Society.

AMS councilor and Executive Committee member, I fought to broaden our journals into areas of ocean and climate science that are so crucial to humankind's future. Finally, in the late 1990s I was made chairman of a symposium called "Integrated Observing Systems." After a couple of years of low attendance, I remember asking AMS Executive Director Ron McPherson if I could broaden the symposium to include assimilation of all types. The result is the vibrant symposium that is now called "Integrated Observing Systems and Assimilation for Oceans, Atmosphere, and Land Surface." In the last couple of years, I have worked through the AMS to find better ways to connect our growing commercial weather community with the AMS academic and government sectors. If I am elected President of the AMS, you can count on creativity and inclusiveness in the ongoing improvement of the Society.

Education and diversity are important to me. I created Science On a Sphere to educate people around the world about our home planet. The most important kind of inclusiveness is to assure that everyone, including women, minorities, and young talent, have the full range of opportunity in our Society.

The job before us is profoundly important. Decades of science, much of it fostered by the Society, have put us in a position to inform and warn people better than we imagined even a few years ago. Global satellite and in situ data, advanced numerical models, and the central role of scientific understanding have led to improved ability to protect people now and in the future. As President of the AMS, I would aggressively move the Society to play the extraordinary role that it can and should play in helping the people of the world. I would be honored to serve the Society in this role.

HEIDI CULLEN (PRIVATE SECTOR)

A May 2012 AMS Policy Workshop report titled *Earth Observations, Science, and Services for the 21st Century* highlights one of the many important challenges facing the Society today—namely, the state of our critical Earth observations infrastructure. As important as our power grid, communication networks, financial systems, highways, and waterworks are, Earth observations enable us to respond to changing weather and climate conditions on time scales spanning from minutes to decades and beyond. Sadly, our Earth observations, science, and services (Earth OSS) are in trouble. They have fallen victim to cost increases, technological glitches, changes in Congressional and administration priorities and—above all—a lack of adequate resources. This is one challenge facing the Society that I would like to focus on.

One of the ways I would work to address this challenge is to continue to build new community collaborations and strengthen our status as an international leader. Having worked in the academic, private, and nonprofit sectors, I would seek multidisciplinary coordination among the diverse array of professional organizations. Ultimately, our success depends upon an active, engaged, and strong Society capable of clearly articulating our relevance. I would be a strong advocate for new technologies to improve public access to weather information, including mobile phones, community-based data collection, advanced alerting systems, and social networks. We need to build the strongest possible weather, water, and climate enterprise.

I care deeply about this institution as well as the science of meteorology and climatology. I am honored to be a candidate for AMS Council. If elected, I will actively push to further strengthen and connect this great institution, helping it to remain relevant to the community it serves and society at large.

HEIDI CULLEN

Dr. Heidi Cullen serves as chief climatologist for Climate Central—a nonprofit science journalism organization headquartered in Princeton, New Jersey. She is a visiting lecturer at Princeton University and a senior research fellow at the Wharton Risk Management and Decision Processes Center at the University of Pennsylvania. Cullen is the author of *The Weather of the Future*, published by HarperCollins. Before joining Climate Central, Cullen served as The Weather Channel's first on-air climate expert and helped create *Forecast Earth*, a weekly television series focused on issues related to climate change and the environment. Prior to that, Cullen worked as a research scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. She received the NOAA Climate & Global Change Fellowship and spent two years at Columbia University's International Research Institute for Climate and Society working to apply long-range climate forecasts to the water-resources sector in Brazil and Paraguay. Cullen also serves as a member of the NOAA Science Advisory Board. She received a Bachelor of Science degree in industrial engineering from Columbia University and went on to receive a Ph.D. in climatology and ocean–atmosphere dynamics at the Lamont-Doherty Earth Observatory of Columbia University.

STEVEN R. HANNA (PRIVATE SECTOR)

Everywhere I look, I see meteorology intersecting with other disciplines. It is becoming increasingly difficult to work just on a narrow topic. The AMS and its members should continue their efforts to broaden their view at all stages of their education and careers, and actively develop relations with other fields that feed into meteorology or make use of the information provided by meteorologists. The latter includes that feared group—policymakers. The entire field of climate change is the most widely known example of this need to work collaboratively, with attention to providing the outputs and interpretations that can be most easily understood and are of most use to the policymakers. In my own area of air quality studies, I am currently participating in EPA workshops where experts in emissions, meteorology, dispersion, monitoring, statistics, exposure, and health effects are brought together to discuss whether the SO_2 standard needs revision.

A second challenge is how to deal with the reality that live meteorologists are being gradually replaced with technology (e.g., monitors with wireless signals sent to computers, remote sounders, automated statistical packages, WRF and CFD models doing everything, etc.).

My final challenge is how we meteorologists and the AMS can deal with "outsourcing" of meteorological work to nonmeteorologists. I often see this in my small consulting business, where large basic ordering agreement-type projects sponsored by government agencies are usually won by a large general-purpose company. The few work orders involving meteorological analysis are sometimes assigned to nonmeteorologists with little or no experience in our area. I wish that the AMS could strengthen the CCM program and perhaps add other certifications so that they are more widely recognized and even built into work specifications, thus increasing the likelihood that meteorological work is given to meteorologists.

STEVEN R. HANNA

Dr. Steven R. Hanna is the president of Hanna Consultants, a Kennebunkport, Maine-based consulting company founded in 1997 that carries out meteorology and air quality-related studies for government and industrial clients. He is an adjunct associate professor in the Harvard School of Public Health in Boston, Massachusetts. Previously, he cofounded Sigma Research Corporation in Lexington, Massachusetts, in 1985, was a principal meteorologist with ERT in Concord, Massachusetts, from 1981 to 1985, and was research meteorologist and acting director of the NOAA/ERL/ARL Atmospheric Turbulence and Diffusion Lab in Oak Ridge, Tennessee. From 1997 to 2001, he was also adjunct professor at George Mason University, where he directed a DOD-sponsored research group developing improved meteorological and diffusion models. He is a specialist in atmospheric turbulence and diffusion, in the analysis of meteorological and air quality data, and in the development, evaluation, and application of air quality models. Current projects include development and evaluation of urban dispersion models, analysis of meteorological and tracer concentration data from DOD and DHS urban field experiments, planning and analysis of field experiments and development of improved dispersion models for large releases of chlorine and ammonia, development of revisions to modules in AERMOD for low wind dispersion, and enhancement of links between transport and dispersion, exposure and dose, and health modeling systems in urban neighborhoods. Hanna also consults and testifies on legal cases.

Hanna is a Fellow of the AMS, the 1994 recipient of the Award for Outstanding Contribution to the Advance of Applied Meteorology, and the 2010 recipient of the Helmut Landsberg Award for contributions to applied meteorology and urban studies. He is a Certified Consulting Meteorologist. From 1988 to 1997, he was chief editor of the *Journal of Applied Meteorology*.

VERONICA JOHNSON WEEMS (PRIVATE SECTOR)

I have been a member of the American Meteorological Society (AMS) as long as I can recall working in weather. The AMS is, and will always be, the steward for weather integrity. It is why I joined and why I feel we need the AMS, now more than ever. The members of the AMS and extended family of our weather and climate community continue to face some very complex weather issues. We have an aging U.S. weather infrastructure and, as of recently, more financial strain. We are also dealing with a changing climate and the impact on agriculture and health worldwide. Finally, as the leading organization promoting the communication of atmospheric, oceanic, and hydrological information, the AMS is challenged with how to broadcast that information faster, particularly after major weather events. To support our weather and climate community and do our jobs effectively, our weather community must support the AMS as it supports us.

Government cuts before and during sequestration will leave our weather community having to operate with less—from a possible gap in satellite coverage to less regular maintenance of the national radar network. In addition, furloughs and thin staff at some of the nation's busiest weather offices will leave a great strain on the nation's security and safety.

We have come a long way in discussing climate change over the last 25 years. In 1990, the Intergovernmental Panel on Climate Change (IPCC) issued its report that acknowledged the issues and gave us a glimpse of its consequences. Now, in 2013, the U.S. Department of the Interior has formed a Climate Change Advisory Committee to provide sound science that will help inform policymakers. In fact, over the last 10 years, there have been numerous committees worldwide that have formed to help understand and communicate just about everything about climate change.

Twitter, Utterli, 12 seconds, Brightkight, Jaiku, MySay, and many other forms of microblogging are fast becoming the favored sources of natural disaster updates and keeping people connected. Social media is here to stay, and those in the weather community must learn to use these tools to share critical information. As a broadcaster, I understand that need and will help facilitate new avenues of advancement.

The job of the AMS is not necessarily to solve these issues, but they can provide venues for our weather community to learn, discuss, and share concerns. This to me is the biggest challenge of the AMS: identifying user needs and promoting the capabilities of the meteorological community.

VERONICA JOHNSON WEEMS

Veronica Johnson Weems is a meteorologist with the News4 weather team in Washington, D.C. Her forecasts can be seen weekdays on News4 at 4 as well as on www.NBCWashington.com. She also hosts "News This Week," a weekly 30-minute news show that airs both on NBC4 and on NBCWashington nonstop.

Prior to joining News4 in 2000, Johnson Weems worked in Baltimore, both at WMAR and WBFF, in New York at WABC, and at The Weather Channel. She has contributed to local radio shows and programs on The Discovery Network.

Johnson Weems holds a degree in atmospheric science from the University of North Carolina at Asheville and is very active in her field. She is an AMS seal holder and served on the AMS board from 2005 until 2007. In 2011, she received the AMS Fellow Award, a prestigious award presented to only a few scientists each year. Johnson Weems has served on the Inaugural Board of Enterprise Communication (including as its chair) and on the AMS Station Scientist Group. She is currently serving on the AMS Board on Enterprise Communication Press Release Committee as cochair. In addition, she has served on the advisory board of Eyes on the Environment and on DC's Joint Center Advisory Committee on Climate Change.

In the community, Johnson Weems volunteers for several youth development programs, such as EnvironMentors. She was honored by the New York City Chapter of the NAACP as Black Journalist of the Year, and in 2006 received the Women's Pioneer Award from the DC Female Firefighters.

DENNIS P. LETTENMAIER (ACADEMIC)

First, I want to express my gratitude to AMS on behalf of the hydrologic community for welcoming hydrologists into AMS, including its journals (notably the *Journal of Hydrometeorology*, which provides a "home" for papers that bridge between the hydrologic and atmospheric sciences), encouraging nomination of hydrologists for AMS awards, and inclusion of hydrologists in AMS governance. I nonetheless have serious concerns about both of the two central activities of AMS—journals and meetings. AMS journals now have a reputation of being expensive (to authors) and slow, and this cannot help but impact quality. An attempt at "fast response" articles hasn't worked (at least so far)—the editors don't seem to understand the meaning of "fast." Why isn't AMS publishing a *Climate Research Letters*, for instance, with three weeks to first review response, and recapture this area—which is central to the AMS mission? Meetings likewise need some new thinking. In my view, AMS needs to get past the present Annual Meeting format, which is a collection of multiple conferences, in favor of an integrated Annual Meeting that bridges across the atmospheric, hydrology, and ocean sciences, while playing to its strength of being a modest-sized scientific meeting rather than a "convention." While I know that AMS views the American "X" Union (to which many AMS members also belong) as the "Evil Empire," it should not be above looking at what the competition is doing, and adopting the best aspects where there is an opportunity for improvement. None of this will be easy—AMS, along with other academic publishers, is going to be forced to go to open-access publication, and this will require restructuring its cost model. At the same time, meetings, and meeting revenues, will be impacted by government travel restrictions, which may not go away any time soon. All of this requires, in my view, some new thinking. AMS is a great organization, but it cannot afford to sit by while the world passes it by. If I'm elected to AMS Council, expect some stirring and shaking.

DENNIS P. LETTENMAIER

Dennis P. Lettenmaier is the Robert and Irene Sylvester Professor of Civil and Environmental Engineering at the University of Washington. He received his B.S. in mechanical engineering (summa cum laude) from the University of Washington in 1971, his M.S. in civil, mechanical, and environmental engineering from the George Washington University in 1973, and his Ph.D. from the University of Washington in 1975. He joined the University of Washington faculty in 1976. In addition to his service at the University of Washington, he spent a year as visiting scientist at the U.S. Geological Survey in Reston, VA (1985–86) and was the program manager of NASA's Land Surface Hydrology Program at NASA Headquarters in 1997–98.

He is a member of AMS, as well as the American Geophysical Union (AGU), the American Water Resources Association, the European Geosciences Union, the American Society of Civil Engineers (ASCE), and the American Association for the Advancement of Science (AAAS). He is a Fellow of AMS, as well as of AGU and AAAS. He was a recipient of ASCE's Huber Research Prize in 1990 and AGU's Hydrology Section Award in 2000. He was the AMS Walter Orr Roberts Lecturer in 2005, and the AMS Robert E. Horton Lecturer in 2008. He was elected to the International Water Academy in 2002 and to the National Academy of Engineering in 2010. He was the inaugural chief editor of AMS's *Journal of Hydrometeorology*, a position in which he served from 2000 to 2005. He is the author or coauthor of more than 300 refereed journal articles. He is the immediate past-president of the AGU Hydrology Section, and has served on AGU's Council as well as its Council Leadership Team. He has also served in numerous positions in international science organizations, such as the WCRP Global Energy and Water Experiment (GEWEX) and the Global Water System Project, and on many National Research Council and other review committees.

RUBY LEUNG (GOVERNMENT)

The human population has been increasingly exposed to hazards associated with weather and climate due to changes in human settlement and evolving weather and climate patterns toward higher likelihoods of climate extremes. The weather and climate challenges that our society faces are expanding at a fast pace. To meet the challenges, we must build a stronger and deeper science foundation to transform our understanding and ability to predict weather and climate. The American Meteorological Society has the vision to "broaden the appreciation of the advances that have been made in the atmospheric and related sciences and the value those advances can provide to the nation and the world." More than ever, we must reach out to other fields such as computational and mathematical sciences and other physical sciences and engineering fields to strengthen our foundation and develop new insights and capabilities. Working in a multidisciplinary national laboratory, I have witnessed cross seeding of ideas from different fields that inspired new science questions and ignited new research directions. Through my experience working across multiple government agencies, I have also been inspired by achievements made possible when government, academic, and private sectors work together to put research into practical use. If I am elected a Councilor of AMS, I would like to strengthen the focus of the Society in its role to encourage and provide opportunities for cross-disciplinary research and education. We need to train a next generation of researchers and educators with a strong disciplinary foundation as well as a broader appreciation of exciting new concepts and tools from other fields. The Society can also play key roles in promoting communication and collaborations among government, academic, and private sectors to bridge fundamental research and practical solutions to address the weather and climate challenges we face in the twenty-first century.

RUBY LEUNG

Dr. L. Ruby Leung is a laboratory fellow at the Pacific Northwest National Laboratory (PNNL) and an affiliate scientist at the National Center for Atmospheric Research (NCAR). She is an international expert in regional climate modeling and analysis and modeling of the hydrological cycle. She leads the regional climate modeling working group of the Weather Research and Forecasting (WRF) model, which is a widely used community atmospheric model. She has made significant contributions to advancing the capabilities of this state-of-the-art model for regional climate modeling. Her climate research has provided important insights on climate change effects on regional hydrological cycle, atmospheric circulation, and air quality in regions of complex terrain. Leung's research interests are wide-ranging. Beside modeling and analysis of regional climate processes, she has also made important contributions to advancing understanding and modeling of land surface processes and land–atmosphere interactions, mountain hydrometeorology, aerosol effects on regional climate, monsoon climate, and processes of water cycle extremes.

Leung has organized key workshops sponsored by the U.S. Department of Energy, the National Science Foundation, NOAA, and NASA, and served on advisory panels and a National Research Council committee that define future directions and research priorities in climate modeling and hydroclimate research. She is an editor of the *Journal of Hydrometeorology* and an associate editor of the *Journal of Geophysical Research—Atmospheres*.

Leung received a B.S. in physics from the Chinese University of Hong Kong and an M.S. and a Ph.D. in atmospheric science from Texas A&M University. She is a Fellow of the AMS and the American Association for the Advancement of Science. She was a contributing author of the Intergovernmental Panel on Climate Change (IPCC) *Assessment Report* in 1996, 2001, and 2007. Leung has published more than 110 peer-reviewed journal articles and has been an invited speaker in many workshops and conferences.

MICHAEL C. MORGAN (GOVERNMENT)

The AMS has advanced the atmospheric and related sciences communities through its broad portfolio of activities including science and technical meetings, publications, and educational and policy activities. The challenges facing the AMS are in our being able to articulate continually to the public and policy makers the incredible progress in the fundamental understanding, technological advances, and the predictive capability our field has achieved over the last century, and the need to continue this progress with targeted investments. In addition, the AMS will be challenged to highlight the potential impact of these skillful forecasts on our nation's economic well-being, engage and nurture an increasingly diverse pool of talented young scientists, and build further relationships with professional societies of allied science fields to ensure that the beneficial outcomes of federal investments in basic and applied atmospheric science research are more fully realized.

While the first two challenges can be met by aggressive communications efforts and a rigorous quantification of the economic value of the weather and climate enterprise, the last two require a different approach. AMS conferences serve as important venues for sharing emerging atmospheric and related sciences research foci and the associated applications this research may have. AMS must foster stronger relationships with other relevant professional societies—perhaps by holding joint meetings on focused topics. Such meetings would provide our students a glimpse of the awesome connectedness the atmospheric sciences has with other fields. For early-career scientists, furthering these relationships provides solid opportunities to develop an inter- and transdisciplinary professional network that would support their successful participation in emerging cross-disciplinary opportunities.

As a member of the AMS Council, I would work with the broad AMS membership, members of the various STACs, and others on the Council to ensure that the Society's focus is on addressing the aforementioned challenges. I would be honored to serve on the AMS Council.

MICHAEL C. MORGAN

Michael C. Morgan is director for the Division of Atmospheric and Geospace Sciences at the National Science Foundation (NSF). Since June 2010, he has been on an intergovernmental personnel act assignment at NSF from the University of Wisconsin—Madison, where he is a professor in the Department of Atmospheric and Oceanic Sciences. Morgan's research interests are on the analysis, diagnosis, prediction, and predictability of midlatitude and tropical weather systems. He has authored and coauthored numerous refereed publications on these topics in AMS publications, including *Bulletin of the American Meteorological Society*, *Monthly Weather Review*, *Weather Analysis and Forecasting*, and *Journal of the Atmospheric Sciences*. His recent work has focused on developing synoptic interpretations of adjoint-derived forecast sensitivity fields.

Morgan has competed in the National Collegiate Weather Forecasting Contest, finishing in first place in the graduate student division in 1991–92 and in the faculty/staff division in 2002–03. He has been chair of his department's undergraduate program (2005–07, 2008–10) and chair of the Curriculum Committee of the College of Letters and Science at UW—Madison during the 2009–10 academic year. Morgan has served the AMS community as a member of the Board on Women and Minorities (2007–09) and on the AMS STAC Committee on Atmospheric and Oceanic Fluid Dynamics (2005–07).

While on sabbatical leave during the 2007–08 academic year, Morgan was an AMS/University Corporation for Atmospheric Research Congressional Science Fellow. During his fellowship year, he worked in the office of U.S. Senator Benjamin Cardin (MD) as a senior legislative fellow. His work in Senator Cardin's office focused on energy and environment issues and was recognized in a Congressional Record statement on 31 July 2008. Morgan served on the 2009 UCAR NCEP review panel reviewing NCEP's EMC and NCO.

Morgan received his S.B. (1988) and Ph.D. (1994) degrees from the Massachusetts Institute of Technology.

BRENDA PHILIPS (ACADEMIC)

I am writing this statement just after the May 2013 tornadoes in Moore and El Reno. These events highlight the complexity of work facing the AMS. These two dramatically different, back-to-back tornadoes offer many lessons for our community, including how building code policies impact outcomes; how access to sheltering options strongly influences public response; the importance of geographically specific forecasts and observations; how the professionalism and skill of our first responders and NWS forecasters save lives; and how, even in one of the nation's most richly instrumented regions offering the best observations and forecast models, the warning messages issued do not always result in the most effective public response. None of these issues can be addressed in academic or practitioner silos. They require a deep understanding of the interplay between technology, policy, society, and psychology if we are to create effective and actionable solutions both for the short and long term. Moore and El Reno are the most recent examples, but there are similar stories to be told for flooding, climate, and public health. I advocate that the complexity of weather and climate warrants the use of test beds that mirror realistic implementation scenarios and provide the most effective way to confirm theory, evaluate current practice, test new concepts, and collect empirical data to build insights. Such test beds should involve all parts of the weather enterprise as they provide a forcing function for the establishment of stronger public–private linkages and partnerships, leading to deeper mutual understanding, cooperation, and evolution of roles. The AMS should aggressively promote test beds for multisector and multidisciplinary research and demonstrations through its committees, conferences, journals, and advocacy. Test beds, linkages, and public-private partnerships are not new areas for the AMS; however their importance seems more critical in responding to shifts in both our global and political climate. If elected to the AMS council, I look forward to bringing my experience, perspectives, and passion to address these issues.

BRENDA PHILIPS

Brenda Philips is deputy director of CASA, an NSF Engineering Research Center (ERC) for Collaborative Adaptive Sensing of the Atmosphere based at the University of Massachusetts Amherst with other academic and practitioner partners. CASA has pioneered radar-based weather information systems based on dense networks of X-band radars. Over the past 10 years, Philips has led CASA's end-user integration research thrust, a multidisciplinary group of academics and practitioners who study technical, social, and behavioral issues related to severe weather warning systems. Her research focuses on end-to-end analysis of warning systems, bridging the gap between the technical system performance, forecaster, and emergency manager decision-making and public response outcomes.

A hallmark of CASA has been the creation of quasi-operational test beds involving networks of CASA radars providing high spatiotemporal resolution observations and forecasts to end users such as NWS forecasters, emergency managers, weather-sensitive industries, and the public. These end users evaluate the system by making decisions with CASA data as severe weather occurs. Moving the original CASA test bed from Oklahoma to the Dallas-Fort Worth metroplex and doubling its size from four to eight radars was a project spearheaded by Philips. This test bed, to evaluate the benefits of a CASA system in a densely populated urban environment, engages local groups, such as emergency managers and a regional development council, by making them not only stakeholders in the data products but also participants in the ownership and operation of the radar network as part of a new multisector partnership model. In addition, the test bed serves as a platform for ongoing research related to mesoscale observations and forecasts through CASA's involvement in the National Mesonet Program.

Philips is PI of several grants from the NSF Partnerships for Innovation program, the NWS Office of Science and Technology, the North Central Texas Trauma Regional Advisory Council, and the National Mesonet Program, and was co-PI from 2007 to 2011 on CASA's NWS Forecaster Evaluation Project through NOAA Hazardous Weather Test Bed.

A longtime AMS member, she has served on the Ad Hoc AMS Committee on Nationwide Network of Networks, the Ad Hoc Committee on Uncertainty in Forecasts, and the Board on Enterprise Economic Development.

Philips is based at the University of Massachusetts Amherst, Dept. of Electrical and Computer Engineering. She has a BA (1981) and an MBA (1986) from Yale University, and is currently pursing a doctorate in resource economics at the University of Massachusetts. She also has a part-time appointment as senior research associate at the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State.

WENDY SCHREIBER-ABSHIRE (ACADEMIC)

The AMS is challenged to continuously evolve to maintain its relevance. As a longtime member I have witnessed an increased willingness to try "new things" to ensure the Society maintains its viability and broadens its impact. As a member of Council I would work to encourage this trend. Recent successes include the addition of the Commission on the Weather and Climate Enterprise, the growth of the Student and Early Career Conferences, and dramatically evolving Society publications.

If elected, the timing for my service on the Council would be fortuitous because as the incoming chair of the Membership committee I will actively work to address topics of importance to both the Council and membership—specifically, reexamining member services, recruitment, and retention. I believe these topics are best addressed by leveraging the passion of all the volunteers spread throughout our 125+ committees, boards, and commissions, and by listening to both members and nonmembers alike.

The AMS mission 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. The ongoing challenge, that I take very seriously, is to strive to make a great organization even better at these essential activities. This requires constant evaluation of Society endeavors and is a key responsibility of the AMS staff and leadership, including Council members. It would be a tremendous honor to serve in this role as a part of the AMS Council. I wholeheartedly believe that the Society has great purpose beyond the advancement of our exciting sciences. We must ensure that our scientific advancements benefit the public and serve decision makers and the world for the betterment of all. If given the opportunity, I am eager to participate in this service on your behalf.

WENDY SCHREIBER-ABSHIRE

Wendy Schreiber-Abshire is a senior program manager and meteorologist at UCAR's COMET Program, where she has participated in and led education and training endeavors on a wide variety of geoscience topics for over 20 years. Her foci include remote sensing, hydrology, and climate topics. She is also serving as the interim director of UCAR's SPARK Education Program. Her most recent service to the greater weather enterprise was as councilor, and then vice president, of the National Weather Association (2009–12). During her tenure she devoted herself to the success of the NWA and worked on synergy between the NWA and AMS. She is also a member of AGU.

Schreiber-Abshire began her involvement with the AMS through the Metropolitan State student chapter, and she has been a member of the national AMS since 1982. She is a graduate of the University of Wyoming Atmospheric Science department, is a Fellow of the Society, and is currently serving as the chair-elect of the Membership Committee, cochair of the AMS 2015 Meeting, and a member of the Planning Commission. After several terms as officer in the Denver-Boulder Local Chapter, she is currently enjoying participating as a member.

Her prior service to the Society includes seven years on the Board on Outreach and Pre-college education (four years as chair); cochair of the 86th Annual Meeting; and seven years on the Local Chapter Affairs committee (four years as chair). She is particularly proud of her roles leading to the establishment of the Beacons Program, AMS Chapters of the Year and chapter posters at Annual Meetings, creation of precollege AMS Chapters, and the authoring of the statement on the value of K–12 Earth science education.

Schreiber-Abshire began her career contributing to atmospheric research through participation in groundbreaking field projects and peer-reviewed publications centered on microbursts and convection initiation. Recently, she gained insight to academic interests and challenges in our field through seven years of service on UCAR's President's Advisory Committee on University Relations (2005–11). Schreiber-Abshire further enriches her professional life through her role as an ombudsperson at UCAR, multiyear participation as a SOARS® Program mentor, and personal outreach to students of all ages through school groups, Scouts, and AMS Student Conferences.

LOUIS V. ZUCCARELLO (GOVERNMENT)

There are many challenges facing our nation that will have a profound impact on the future of the American Meteorological Society. Whether it is the economic and budgetary realities we face in the near term, the devastating effects of significant weather events that have claimed lives and property, or the challenge of developing our future scientists and engineers, the Society must continue to develop and communicate a bold strategy to effectively address these issues throughout the meteorological community. The Society has an impressive record of success articulating these needs and challenges and then finding ways to satisfy them.

There are three specific challenges that the AMS will need to address in the future: how do we leverage the strengths of a variety of meteorological agencies and organizations across the public and private sectors to maximize their effectiveness? How do we transition the innovative ideas and technologies from our educational institutions, private industry, and governmental agencies into operations? And, how do we continue to develop our next generation of meteorologists, engineers, and scientists to realize our future vision of a "weather-ready" nation?

Our current economic situation requires that we work to leverage the best that each sector of our meteorological community brings to bear to improve our ability to address forecasting accuracy and timeliness, climatic variability and long-term planning, and meteorological research that benefits all aspects of our profession. The AMS must continue to sponsor and encourage meetings, conferences, and forums to allow this exchange to take place, but, in addition, must find creative ways to virtually connect the various sectors to better share ideas and proposals and enact plans of action.

Innovation is the key to taking good ideas and turning them into reality. The various sectors of our meteorological community are continuously working on innovative ways to solve problems. The AMS must continue to foster an environment of sharing of innovative ideas and technologies from each sector and ensuring that we maximize their visibility among all our membership and beyond. Individual institutions must be encouraged to both give and take for the betterment of the entire community. The AMS has traditionally been the forum for this most beneficial exchange and must continue to be in the future.

The AMS has made incredible strides in the development of our next generation of meteorologists, engineers, and scientists. The number of educational opportunities, programs, and scholarships is incredible when compared to the offerings of just a couple of decades ago. The AMS must continue this commitment and invest resources in this area for years to come. The return on investment will continue to be impressive and of incalculable value to our community and the nation.

I am honored to have been nominated to serve on the AMS Council and, if elected, will do everything I can to better the organization and support the people who make up this great community.

LOUIS V. ZUCCARELLO

Colonel Louis V. Zuccarello is the Commander, Air Force Weather Agency, Offutt Air Force Base, Nebraska. He leads more than 1,400 active duty, civil service, and contractors at 24 locations around the world, providing centralized weather products and services to air force, army, special operations, intelligence community, and other Department of Defense activities. He executes a worldwide weather support mission that provides decision assistance to combat, reconnaissance, command and control, presidential support, treaty verification, and airlift missions directed by the Joint Chiefs of Staff, theater, and major command commanders.

Zuccarello was commissioned in 1985 as a distinguished graduate of the Air Force Reserve Officer Training Corps program at The Pennsylvania State University. He has served in a variety of staff and operational assignments at the Joint Staff, Air Staff, Air Force Weather Agency, Air Force Personnel Center, HQ Air Weather Service, 100th Air Refueling Wing, and Air Force Global Weather Central. He has been awarded multiple military decorations, including the Legion of Merit, Defense Meritorious Service Medal, Air Force Meritorious Service Medal, Air Force Commendation Medal, National Defense Service Medal, and Global War on Terrorism Service Medal.

Zuccarello received a B.S. in meteorology with high distinction (1985) and an M.S. in meteorology (1994) from Penn State, an M.S. in military operational art and science (2000) from the Air University, and an M.S. in national resource strategy (2005) from the National Defense University. He has served as the president of the Penn State branch of the AMS and as a member of local AMS chapters in Omaha and St. Louis. He is a member of the Air Force Association, Military Officers Association of America, and the Penn State Alumni Association.

NEW MEMBERS

The Council has approved the election of the following candidates to the grade of **Full Member:**

F Brent Abbott
Gab Abramowitz
Terri M. Adams
Rebecca D. Adams-Selin
Santha Akella
Omowumi O. Alabi
Dan Amarante
Bogdan A. Antonescu
Anthony C. Anuforom
Oscar Arango
Kyle Armour
Marcus D. Austin
Xuezhi Bai
Peter G. Baines
Benjamin C. Balk
Ali Behrangi
Cesar Beneti
Srinivas Bettadpur
Amitava Bhattacharjee
Evan M. Bing
Satyaban Bishoyi Ratna
Jennifer Boehnert
Margret Boone
Felecia L. Bowser
Peter N. Bronecke
David Brown
Jeremiah Brown
Kelly Bryant
Joan Bunbury
Matt A. Burger
Susannah M. Burrows
Hugh C. Butler
Michael Butler
Alex C. Bynum
David B. Caldwell
Christopher A. Cantrell
Jan Cermak
Aashish Chaudhary
Hector Chikoore
Gene Chiorello
Steven R. Chiswell
Andrew J. Chiuppi III
Kyoung-Ho Cho
Vladimir V. Chukin
James P. Cipriani
Jeffrey A. Cole
Thomas P. Connolly
Melissa Constanzer
James R. Cumbie
Joseph A. Daniele
Taumi Daniels
Davide Del Vento
Laura M. Delgado Lopez
Yue Deng
Gael Descombes
Robert S. Detrick
Jim Dickey
Michael Dinniman
Stephen S. Doyle
Matthew P. Drews
Joshua D. Eachus
Michael Elliott
Gregory S. Elsaesser
John D. Evans
Clayton C. Fain
Fernando Felquer
John E. Fink
Emily C. French
Chuen Meei Gan
Wenhua Gao
Ned Gardiner
Chad J. Garick
Ronald A. Gates
Philip G. Gill
Kristine Gjesdal
Heather M. Grams
Geoffrey Grek
Stacia Gudmonson
Madhulika Guhathakurta
Wei-Dong Guo
Ethan D. Gutmann
Arjumand Habib
Daria J. Halkides
Rafiq Hamdi
Janel Hanrahan
Christa A. Hasenkopf
Jessie Hawila
Gina R. Henderson
Geoffrey M. Henebry
Michael S. Henry
Elizabeth Higgins
Rick M. Hluchan
Nicole Homeier
Christopher D. Hoyt
Jonathan M. Hunter
Michael J. Hunter
Junshi Ito
Mintesinot Jiru
Jihoon Jung
Khadija Kabidi
Jatin Kala
Juliana Karloski
Ryohei Kato
Christopher M. Kihneman
Alicia M. Kinoshita
Alexander Kirchner
Vladimir Kostylev
Louisa J. Kramer
Alek J. Krautmann
Lauren M. Kusik
Rebekah J. LaBar
Jerome Lafeuille
Kathryn Lane
Erik Langaker
Scott Larrimore
Maria A. Latyszewskyj
Reginald B. Lawrencee
Alex Russell Lechler
Irene Lee
Lukasz Legutko
Hang Lei
Eric M. Leibensperger
Casey E. Letkewicz
Steven L. Levine

The Executive Committee has approved the election of the following candidates to the grade of **Associate Member—Precollege Student:**

Natalie K. Albers
Kristen D. Baldridge
Charlotte R. Butler
Paige J. Campbell
Matthew E. Cappucci
Michael E. Follensbee
Nathan G. Hooven
Kamaria Horton
Todd M. Lewis
Samantha M. Lulka
Julia A. Manobianco
Andrew K. Moffitt
Paul D. Mykolajtchuk
Jonathan E. O'Brien
Alex R. Smith
Jacob W. Smith
Vaughn M. Steiner
Kevin J. Tesoro
Alexander M. Tomoff
Rosemary Uyeda
Kaelyn E. Veselsky

The Executive Committee has approved the election of the following candidates to the grade of **Associate Member/K–12 Teacher:**

Staci M. DeSchryver
Sara Hummelsheim
Stephen S. Lane

NEW MEMBERS

David R. Lewis
Mingxing Li
Qian Li
Stefan Liess
Erin K. Lipp
Christopher P. Loughner
James Lunny
Mark F. Luttrell
Takashi Maki
Jeff A. Makowski
Lesley Marangola
Elinor R. Martin
Matus Martini
Tamara L. McDunn
Thomas J. Meiners
Andrew R. Metcalf
Anne Miglarese
Michael J. Mihalik Jr.
Lee-Ann V. Miller
James Mitchell
Marion P. Mittermaier
Harvin C. Moore
Matthew J. Morin
Megan M. Mulford
Catherine L. Muller
Mark Mutchler
Jennifer Myers
Mactar Ndiaye Sr.
Ryan R. Neely III
Jillian G. Neustel
Robert Neuwirth
Andrew Nicholas
Arielle L. Nixon
Pertti Nurmi
Marjorie M. Nussbaum
Ryan O'Kuinghttons
Randy T. Odle
Travis E. Oliphant
Jacobus J. Oschmann
Taewon Park
Alessandro Perotto
Brian Pettegrew
Rita Pongracz
Christopher J. Porter
Christopher Provan
Jennie Raab Barnes
Anand Radhakrishnan
Nicole Ranger
Brad J. Reinhart
Roger G. Rempel
Anthony Reynes
Nicole Rietmann
Alec Robinson
David W. Rodgers
Eric A. Rosenberg
Jeff L. Royed
Gunther Schauberger
Robert L. Scheinhartz
Benjamin A. Schenkel
Tsuyoshi Thomas Sekiyama
Patrick A. Selmer
Artem N. Semakin
Jerry L. Shields
Trey R. Shrawder
Sudhir R. Shrestha
Steven B. Silver
Michael S. Silverwood
Douglas Simonian
Matthew Sitkowski
David Skutnik
Samantha R. Slease
Timothy S. Smoker
Nigel Snoad
Jenise Marie Snyder
Lawrence J. Spencer
Venkataramana R. Sridhar
Kari Strenfel
Peter J. Strzyz
Ove Sundell
Qi Tang
Byron D. Tapley
Sourav Taraphdar
Amanda Terborg
Josh Thompson
Michael J. Thompson
Justin Thompson-Gee
Fred Trofholz
Evangelia Tsairidis
Zbigniew Ustrnul
Michael Van Tress
Panagiotis Vergados
Mark Verschell
Matthew J. Villafane
Stephen Volz
Chrissie Walsh
Lei Wang
William J. Weiss
Kelli Wensel
Kirien R. Whan
Danielle E. Whipple
Jeffrey A. Williams
John K. Williams
Charlie Wilson Jr.
Matthew B. Wilson
Victoria Wittig
Cimarron J. Wortham
Russell G. Wright
Ana Vera M. Wynne
Yuanfu Xie
Bin Xu
Mingxi Yang
Ping Yang
Stanley Young
Tianle Yuan
Kai Zhang
Kai Zhang
Li Zhang
Man Zhang
John F. Zhu

The Executive Committee has approved the election of the following candidates to the grade of **Associate Member:**

Michael J. Abel
Roy H. Ballinger
Michael Batsimm
Daniel Biggio
David Bordelon
Robert J. Busquets
Jamie Castle
Jason Clark
Kenyatta L. Esters
Michael Furtado
Craig Jimenez
Rick P. Leuck
Kathleen A. Malone
Lisa Punzo
Matthew Roach
Mike A. Ruhland
David J. Ruskey
Michael J. Sabetta
Dan Wallace
David E. Williams
Fernando J. Zavala
Christine E. Ziebarth

NEW MEMBERS

The Executive Committee has approved the election of the following candidates to the grade of **Student Member:**

Katherine Adams
Arielle Alpert
Jacob M. Anderson
Barry D. Baker II
Kari Bankston
Michael C. Barnett
Julie I. Barnum
Brandon D. Bookman
Brandy L. Bourque
Derek Andrew Bowen
Quentin T. Brooks
Danielle Browarski
Danielle M. Buckley
Ethan C. Burwell
Alex Calamia
Nicole Campbell
Daniel R. J. Canales
Jesse Canfield
Zachary A. Cardell
Stephen E. Carr
Shawnie M. Caslin
Michelle Cohen
Evan Couzo
Katlin Crooks
Heather F. Culley
Jeffrey D. Cwagenberg
Stephen A. Decatur
Kelly Dobeck
Wayana Dolan
Kia Dorsey
Aaron Doucett
Colton Eddy
Mark Eslick
S. H. M. Fakhruddin
Victoria E. Faranca
Brandi Fava
Chad V. Furl
Margaret E. Garcia
Janelle D. Gergely
David A. Goldmintz
Eric Graham
Nick R. Gunter
Donna I. Haga
Shawn L. Handler
Glen S. Hanson
Kandice Harper
Matthew S. Haynes
Nicholas K. Heath
Chad W. Hecht
Curran Hendershot
Marcus L. Hereford
Emilie Hillman
James R. Hite Jr.
Travis Holder
Sarah E. Hoogenboom
Saffia Hossainzadeh
Jonathon Isbell
Andrew D. Jensen
Alex Kalmikov
Alexandra M. Keclik
Abby Kenyon
Margaret M. Kovach
Genesis M. Langum
Marisa A. LaRouche
Nicholas M. Leonardo
Gregory G. Leone
Emily N. Lewis
Yue Li
Nissa Lomax
Curtis O. Lynch
Megan B. Martin
Seth Masten
Devin K. Mastrodomenico
Cynthia P. Mawe
Krista B. McEnany
Tyler J. Melso
Robert P. Millette
Tyler A. Molleur
Kyle R. Morris
Nicholas C. Moyo
Joseph M. Nash
Brandi W. Newton
Benjamin Ng
Carley Nickles
Lukas Nonnenmacher
Neil T. Obetz
Tyler B. Penland
Justin T. Petrutsas
Nic M. Petrykowski
Maryam Pournasiri Poshtiri
Matthew R. Price
Joshua Pringle
Konstantine Pryles
Brie E. Puican
Sarah G. Purkey
Vargas Julio Jesus Quijano
Ajay Raghavendra
Quinn Rambo
Kyle Raypole
Jeffrey C. Reagan
Sally M. Riccardi
Bradley Riedel
Lydia Rill
Carly B. Robinson
Carolina Del Mar Rodriguez-Sanchez-Vahamonde
Karleisa A. Rogacheski
Lindsay Ross
James Oliver Harvey Russell
Whintey Rutledge
Hossein Sadeghi
Mark R. Scafonas
Daniel Schaffer
Christopher J. Scheele
Ryan K. Schultz
Andrew Schwartz
Ashley N. Sebree
Kevin Sheehan
Jay Shelton
Xiaoming Shi
Roop K. Singh
Amy Solomon
Kayleigh A. Somers
Jennifer Stanonis
Rebecca A. Starks
Jennifer L. Strait
Katarina L. Strnad
Lauren F. Stuart
Angela Sturgill
Juan C. Sulca Sr.
Jessica Swetish
Samantha S. Tabor
Katelyn L. Thomas
Takashi Unuma
Ricardo K. Uribe
Teresa Velasco
Natalie Vezina
Leah K. Visakowitz
Dalton R. Walker
Quentin A. Walker
Hollis Watkins
Nicholas M. Weber
Ryan S. Werkheiser
Andrew S. Whitmyer
RJ B. Wiersma
Austin R-K Williams
Jessica Wood
Wen Xu
Walter Yerk
Daniel Young
Paul R. Zechiel
Fadi Zoghzoghy

The Council has approved the election of the following candidate to the grade of **Full Member with Student Privileges:**

Ali Saeed Alghamdi
Jyoti Narayan Bhate
Shu Chen
William B. Clements
Caleb J. Corpora
Stephen Gregg
Rafael Kaup
Marie L. Kersey
Anna Mebust
Paul Miller
Greg Porter
Danielle M. Richter
Michelle Serino
Lukas Strauss
Kyle Ross Thurmond
Marcelino Q. Villafuerte II

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 website, 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

2013

AUGUST

15th Conference on Mesoscale Processes, 6–9 August, Portland, Oregon
Abstract deadline: 5 April 2013
Preregistration deadline: 24 June 2013
Manuscript deadline: 9 September 2013
Initial announcement published: Feb. 2013

SEPTEMBER

36th Conference on Radar Meteorology, 16–20 September, Breckenridge, Colorado
Abstract deadline: 10 May 2013
Preregistration deadline: 9 August 2013
Manuscript deadline: 11 September 2013
Initial announcement published: Jan. 2013

AMS 19th Satellite Meteorology, Oceanography and Climatology Conference and the 2013 EUMETSAT Meteorological Satellite Conference, 16–20 September, Vienna, Austria
Abstract deadline: 18 February 2013
Initial announcement published: Nov. 2012

OCTOBER

10th Symposium on Fire and Forest Meteorology, 15–17 October, Bowling Green, Kentucky
Abstract deadline: 3 June 2013
Preregistration deadline: 2 September 2013
Manuscript deadline: 18 November 2013
Initial announcement published: Jan. 2013

2014

FEBRUARY

***13th Annual AMS Student Conference: Opportunities in the New Job Climate and Beyond, 1–2 February, Atlanta, Georgia**
Abstract deadline: 1 October 2013
Preregistration deadline: 23 December 2013
Initial announcement published: Feb. 2013

Second AMS Conference for Early Career Professionals, 2 February, Atlanta, Georgia
Preregistration deadline: 23 December 2013
Initial announcement published: May 2013

Stanley A. Changnon Symposium, 4 February, Atlanta, Georgia
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

Edward S. Epstein Symposium, 5 February, Atlanta, Georgia
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: March 2013

Donald R. Johnson Symposium, 6 February, Atlanta, Georgia
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: April 2013

***30th Conference on Environmental Information Processing Technologies, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***28th Conference on Hydrology, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: April 2014

***26th Conference on Climate Variability and Change, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: April 2014

***26th Conference on Weather Analysis and Forecasting/22nd Conference on Numerical Weather Prediction, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***22nd Symposium on Education, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: June 2013

*An exhibit program will be held at this meeting.

***22nd Conference on Probability and Statistics in the Atmospheric Sciences, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***18th Joint Conference on the Applications of Air Pollution Meteorology with the A&WMA, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***18th Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS-AOLS), 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***17th Conference of Atmospheric Science Librarians International, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Initial announcement published: July 2013

***16th Conference on Atmospheric Chemistry, 2–6 February, Atlanta Georgia**
Abstract seadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: May 2013

***12th History Symposium, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: May 2013

***12th Symposium on the Coastal Environment, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: May 2013

***12th Conference on Artificial and Computational Intelligence and its Applications to the Environmental Sciences, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***11th Symposium on the Urban Environment, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: May 2013

***11th Conference on Space Weather, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***10th Annual Symposium on New Generation Operational Environmental Satellite Systems, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***10 IMPACTS: Major Weather Events and Societal Impacts of 2013, 4 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***Ninth Symposium on Policy and Socio-Economic Research, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***Seventh Annual CCM Forum, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: June 2013

***Sixth Symposium on Aerosol–Cloud–Climate Interactions, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***Fifth Conference on Weather, Climate, and the New Energy Economy, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: May 2013

***Fifth Symposium on Environment and Health, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: April 2013

***Fourth Symposium on Advances in Modeling and Analysis Using Python, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

* An exhibit program will be held at this meeting.

***Fourth Aviation, Range and Aerospace Meteorology Special Symposium, 5 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***Fourth Conference on Transition of Research to Operations, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***Second Annual Symposium on the Weather and Climate Enterprise, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***Second Symposium on Building a Weather-Ready Nation: Enhancing Our Nation's Readiness, Responsiveness, and Resilience to High Impact Weather Events, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

***Second Symposium on Prediction of the Madden–Julian Oscillation: Impacts on Weather and Climate Extremes, 2–6 February, Atlanta, Georgia**
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: July 2013

Second Symposium on the Joint Center for Satellite Data Assimilation, 6 February, Atlanta, Georgia
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Aug. 2013

Superstorm Sandy and the Built Environment: New Perspectives, Opportunities, and Tools, 6 February, Atlanta, Georgia
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: Feb. 2013

Special Symposium on Severe Local Storms: The Current State of the Science and Understanding Impacts, 5 February, Atlanta, Georgia
Abstract deadline: 1 August 2013
Preregistration deadline: 1 December 2013
Manuscript deadline: 6 March 2014
Initial announcement published: April 2013

MEETINGS OF INTEREST

2013

AUGUST

ISALSaRS'13—The Third International Symposium on Atmospheric Light Scattering and Remote Sensing, 29 July–2 August, Nagoya, Japan

Workshop on Analyses, Dynamics, and Modeling of Large Scale Meteorological Patterns Associated with Extreme Temperature and Precipitation Events, 20–22 August, Berkeley, California

MEDGEO 2013—The Natural Environment & Health: Hidden Dangers, Unlimited Opportunities, 25–29 August, Arlington, Virginia

SEPTEMBER

13th EMS Annual Meeting & 11th European Conference on Applications of Meteorology (ECAM), 9–13 September, Reading, United Kingdom

Traversing New Terrain in Meteorological Modeling, Air Quality and Dispersion, 10–12 September, Davis, California

OCEANS '13 MTS/IEEE, 23–26 September, San Diego, California

Modelling Atmospheric and Oceanic Flows: Insights from Laboratory Experiments and Numerical Simulations, 24–26 September, Berlin, Germany

OCTOBER

61st International Congress of Aviation and Space Medicine (ICASM 2013), 6–10 October, Jerusalem, Israel

Sixth WMO Data Assimilation Symposium, 7–11 October, College Park, Maryland

NOAA's 38th Climate Diagnostics and Prediction Workshop, 21–25 October, College Park, Maryland

14th Northeast Regional Operational Workshop (NROW), 22–23 October, Albany, New York

GSA 2013 Annual Meeting: 125th Anniversary "Celebrating Advances in Geoscience", 27–30 October, Denver, Colorado

NOVEMBER

Seventh Graduate Climate Conference, 1–3 November, Woods Hole, Massachusetts

DECEMBER

Mathematical Technology of Networks, 4–7 December, Bielefeld, Germany

2014

APRIL

Ninth Weather Radar and Hydrology (WRaH) International Symposium, 7–9 April, Washington, D.C.

SEPTEMBER

20th International Congress of Biometeorology, 28 September–2 October, Cleveland, Ohio

* An exhibit program will be held at this meeting.

CALL FOR PAPERS

CALL FOR PAPERS

Second Symposium on the Joint Center for Satellite Data Assimilation, 6 February 2014, Atlanta, Georgia

The Second Conference on the Joint Center for Satellite Data Assimilation, sponsored by the American Meteorological Society, will be held on 6 February 2014, as part of the 10th Annual Symposium on New Generation Operational Environmental Satellite Systems at the 94th AMS Annual Meeting in Atlanta, Georgia. Preliminary programs, registration, hotel, and general information will be posted on the AMS Web site (www.ametsoc.org/meet/annual/) in late-September 2013.

The theme for the 2014 AMS Annual Meeting is "Extreme Weather—Climate and the Built Environment: New perspectives, opportunities, and tools." Herein, we broadly define weather and climate extreme events to include, but not be limited to, severe storms, tornados, tropical cyclones, floods, winter storms, drought, temperature extremes, derechos, aircraft turbulence, wildfires, extreme solar activity, and ocean–land responses (e.g., storm surges, landslides, debris flows). Under the auspices of the proposed theme, traditional topics related to advances in observations, modeling, and applications can be explored.

Much of the progress seen in environmental prediction applications (weather, climate, oceans, air quality) has been made possible by the development of better data assimilation systems that in turn have made it possible for the operational prediction centers to increase and improve their use of a wider range of observing systems. For certain application areas—especially numerical weather prediction—the increased use of satellite data has been a critical element of this overall thrust since comprehensive spatial and temporal coverage of weather data for the full global domain can only be obtained from space.

The Joint Center for Satellite Data Assimilation is an interagency collaboration sponsored by NASA, NOAA, the U.S. Air Force, and the U.S. Navy that is tasked with improving and accelerating the use of satellite data and related research in operational environmental prediction systems. Chief among its responsibilities the JCSDA strives to help the operational agencies implement data from new satellites as quickly as possible after launch to help the nation maximize the benefits from its investment in these systems. The symposium will include both invited and contributed presentations and we solicit presentations highlighting the role of satellite data in numerical weather prediction, as well as on the current and potential future use of satellite data in air quality, ocean, and climate prediction systems. Contributions may focus on the data themselves or on algorithmic developments that are/will be necessary to optimize the use of the data.

Please submit your abstract electronically via the web by *1 August 2013* (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 2013. 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*

March 2014. All abstracts, extended abstracts, and presentations will be available on the AMS web site at no cost.

For additional information please contact the program chairperson, Lars Peter Riishojgaard, JCSDA (e-mail: Lars.P.Riishojgaard@nasa.gov), or Jim Yoe, JCSDA (James.G.Yoe@noaa.gov). (8/13)

ANNOUNCEMENT

20th International Congress of Biometeorology, 28 September–2 October 2014, Cleveland, Ohio

The International Society of Biometeorology, formed in 1956, will hold its 20th International Congress of Biometeorology (ICB2014) in Cleveland, Ohio, from 28 September–2 October 2014. This conference is cosponsored by the American Meteorological Society. An excursion (TBD) is planned for 2 October and will incur an additional fee.

The theme for the meeting will be "Adaptation to Climate Risks." The integration of weather, water, and climate information with biological and social sciences will be used increasingly to guide communities into improved risk management. Along with place-based issues there are also new networked communities communicating and interacting to address broader biological and environmental challenges in the human dimension. This Congress will afford an opportunity to examine and learn how biometeorology can shape adaption to climate risks. We believe this theme will reflect local and regional environmental priorities, long-term research and sustainability opportunities will be a theme that resonates with the climate risks facing communities and partners around the world. We hope to bring together at ICB2014 a diverse array of climate, physical, and social scientists.

Abstract submissions will open mid-August. 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 early-July 2014. All abstracts, manuscripts, and PowerPoint presentations will be available on the AMS website at no cost. This conference will not be recording the presentations on-site.

We look forward to your participation in ICB2014. Questions may be sent to Scott Sheridan, chair of the ICB2014 Organizing Committee (e-mail: ssherid1@kent.edu). (8/13)

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.

2014 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 2014** 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.

2014 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 2013)*
  Robert E. Horton Lecturer in Hydrology
  Bernhard Haurwitz Memorial Lecturer
  Walter Orr Roberts Lecturer
- **PAPER**
  Banner I. Miller
- **STUDENT PAPERS**
  Robert Leviton Student Prize
  Max A. Eaton Student Prize
  Spiros G. Geotis Student 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…

2014 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 2014. A list of Fellows and the process for submitting nominations are on the AMS website (www.ametsoc.org/awards).

2014 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 95th Annual Meeting (January 2015) 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 2014 to the Nominating Committee.

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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 2014; a form and list of Honorary Members is available at www.ametsoc.org/awards.

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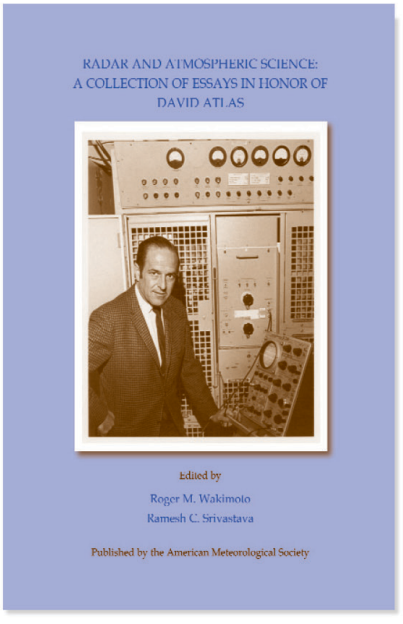

AMERICAN METEOROLOGICAL SOCIETY

AUDITED FINANCIAL STATEMENTS AND SUPPLEMENTARY INFORMATION

DECEMBER 31, 2012

Fulchino, O'Reilly & Company PC

Certified Public Accountants

INDEPENDENT AUDITOR'S REPORT

TO THE EXECUTIVE COMMITTEE
AMERICAN METEOROLOGICAL SOCIETY
Boston, Massachusetts

We have audited the accompanying financial statements of American Meteorological Society which comprise the statement of financial position as of December 31, 2012, and the related statements of activities, changes in net assets, and cash flows for the year then ended, and the related notes to the financial statements.

Management's Responsibility for the Financial Statements

Management is responsible for the preparation and fair presentation of these financial statements in accordance with accounting principles generally accepted in the United States of America; this includes the design, implementation, and maintenance of internal control relevant to the preparation and fair presentation of financial statements that are free from material misstatement, whether due to fraud or error.

Auditor's Responsibility

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. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free from material misstatement.

An audit involves performing procedures to obtain audit evidence about the amounts and disclosures in the financial statements. The procedures selected depend on the auditor's judgment, including the assessment of the risks of material misstatement of the financial statements, whether due to fraud or error. In making those risk assessments, the auditor considers internal control relevant to the entity's preparation and fair presentation of the financial statements in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the entity's internal control. Accordingly, we express no such opinion. An audit also includes evaluating the appropriateness of accounting policies used and the reasonableness of significant accounting estimates made by management, as well as evaluating the overall presentation of the financial statements.

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion.

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, 2012, and the changes in its net assets and its cash flows for the year then ended in accordance with accounting principles generally accepted in the United States of America.

Other Matters

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.

Fulchino, O'Reilly & Company PC

May 1, 2013

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STATEMENT OF FINANCIAL POSITION — DECEMBER 31, 2012

Assets		
Current Assets:		
Cash (Notes 2, 5 and 11)	$	3,639,903
Accounts receivable from members, subscribers and others (Note 1)		42,359
Short-term investments (Notes 1, 3, 5, 11 and 14)		7,471,782
Promises to give (Note 1)		37,000
Prepaid expenses and other current assets		820,325
Inventory (Note 1)		254,187
Total Current Assets		12,265,556
Property and Equipment (Notes 1, 4, 5 and 7)		11,014,774
Other Assets:		
Long-term investments (Notes 1, 3, 5, 11 and 14)		435,764
Promises to give—long term (Note 1)		20,753
Total Assets	$	23,736,847
Liabilities and Net Assets		
Current Liabilities:		
Accounts payable and accrued expenses (Note 8)	$	712,910
Deferred income (Note 1)		4,756,095
Current portion of long-term debt (Notes 5 and 7)		191,143
Total Current Liabilities		5,660,148
Long-Term Liabilities:		
Fair value of interest rate swap agreement (Note 6)		426,386
Long-term debt, net of current portion (Notes 5 and 7)		4,934,723
Total Long-Term Liabilities		5,361,109
Total Liabilities		11,021,257
Commitments (Note 13)		
Net Assets (Notes 1, 5, and 14)		
Unrestricted		10,338,151
Temporarily restricted		1,734,739
Permanently restricted		642,700
		12,715,590
Total Liabilities and Net Assets	$	23,736,847

The accompanying notes are an integral part of the financial statements.

Unrestricted Net Assets:		
Revenues, Gains and Other Support (Notes 1, 3, 5, 6, 9 and 14):		
Publications	$	**7,723,096**
Meetings and exhibits		**3,223,327**
Bulletin and other member services		**2,046,281**
Federal financial assistance		**1,843,961**
Other educational assistance		**1,805,770**
Investment income		**120,937**
Net assets released from restrictions		**65,791**
Contributions		**76,500**
Realized and unrealized gains on investments		**459,580**
Unrealized (loss) on interest rate swap agreement		**(54,580)**
		17,310,663
Expenses (Notes 1, 5, 7, 8, 9 and 10):		
Program services:		
Publications		**6,345,428**
Education and policy programs		**4,730,881**
Meetings and exhibits		**2,892,895**
Bulletin and other member services		**2,039,025**
Supporting services:		
Administrative and general		**87,473**
Interest expense		**197,790**
		16,293,492
Increase in Unrestricted Net Assets		**1,017,171**
Temporarily Restricted Net Assets (Notes 1, 3 and 14):		
Contributions		**90,378**
Investment income		**30,921**
Net assets released from restrictions		**(65,791)**
Realized and unrealized gains on investments		**16,710**
Increase in Temporarily Restricted Net Assets		**72,218**
Permanently Restricted Net Assets (Notes 1, 3 and 14):		
Contributions		**—**
Investment income		**1**
Unrealized (losses) on investments		**(64)**
(Decrease) in Permanently Restricted Net Assets		**(63)**
Increase in Net Assets		**1,089,326**
Net assets at beginning of year		**11,626,264**
Net Assets at End of Year	$	**12,715,590**

The accompanying notes are an integral part of the financial statements.

STATEMENT OF CHANGES IN NET ASSETS — YEAR ENDED DECEMBER 31, 2012

	Unrestricted Net Assets	Temporarily Restricted Net Assets	Permanently Restricted Net Assets	Total Net Assets
Balance at January 1, 2012	$ 9,320,980	$ 1,662,521	$ 642,763	$ **11,626,264**
Unrestricted Net Assets:				
Total unrestricted support, including net assets released from restrictions	17,310,663	—	—	**17,310,663**
Expenses	16,293,492	—	—	**16,293,492**
Increase in Unrestricted Net Assets	1,017,171	—	—	**1,017,171**
Temporarily Restricted Net Assets:				
Contributions	—	90,378	—	**90,378**
Investment income	—	30,921	—	**30,921**
Net assets released from restrictions	—	(65,791)	—	**(65,791)**
Realized and unrealized gains on investments	—	16,710	—	**16,710**
Increase in Temporarily Restricted Net Assets	—	72,218	—	**72,218**
Permanently Restricted Net Assets:				
Contributions	—	—	—	**—**
Investment income	—	—	1	**1**
Realized and unrealized (losses) on investments	—	—	(64)	**(64)**
(Decrease) in Permanently Restricted Net Assets	—	—	(63)	**(63)**
Changes in Net Assets	1,017,171	72,218	(63)	**1,089,326**
Balance at December 31, 2012	$ 10,338,151	$ 1,734,739	$ 642,700	$ **12,715,590**

The accompanying notes are an integral part of the financial statements.

Cash Flows from Operating Activities:		
Increase in net assets	$	1,089,326
Adjustments to reconcile change in net assets to net cash provided by operating activities:		
Depreciation		334,611
Unrealized and realized (gains) on investments		(476,226)
Unrealized loss on interest rate swap agreement		54,580
(Increase) decrease in:		
Accounts receivable		40,891
Inventory		(36,642)
Prepaid expenses and other current assets		(86,556)
Promises to give		39,820
(Decrease) increase in:		
Accounts payable and accrued expenses		65,396
Deferred income		(231,465)
Contributions restricted for long-term investments		(90,378)
Interest and dividends restricted for long-term investments		(30,922)
Net Cash Provided by Operating Activities		672,435
Cash Flows from Investing Activities:		
Acquisition of property and equipment		(90,152)
Proceeds from sale of investments		400,000
Purchase of investments		(378,816)
Net Cash (Used in) Investing Activities		(68,968)
Cash Flows from Financing Activities:		
Contributions restricted for investment in temporarily restricted funds		90,378
Interest and dividends restricted for reinvestment		30,922
Payments on long-term debt		(205,720)
Net Cash (Used in) Financing Activities		(84,420)
Net Increase in Cash		519,047
Cash at beginning of year		3,120,856
Cash at End of Year	$	3,639,903
Supplemental Disclosure for Cash Flows Information		
Cash Paid During the Year for:		
Interest	$	252,307
Income taxes	$	—

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, 2012, 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, 2012 the Society had $57,753 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.

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.

Note 1. Summary of Significant Accounting Policies (Continued):

Restricted and unrestricted revenue and support (Continued): 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.

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.

Note 1. Summary of Significant Accounting Policies (Continued):

Date of Management's Review: The Society has evaluated subsequent events through May 1, 2013 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, 2012, the Society's bank balances exceeded the FDIC limit by approximately $3,812,800. The Society has not incurred any related losses.

Note 3. Investments:

The Society's investments at December 31, 2012, which are held and managed by outside custodians, 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, 2012:

	Level 1	Level 2	Level 3
U.S. corporate stock and mutual funds	$ 4,934,566	$ —	$ —
Certificates of deposit and government bonds	1,838,311	—	—
Money market funds	1,016,358	—	—
Planned giving assets	118,311	—	—
	$ 7,907,546	$ —	$ —

	Cost	Unrealized Gains and (Losses)	Fair Value
Invested cash	$ 1,016,358	$ —	$ 1,016,358
Mutual funds	4,029,214	889,725	4,918,939
Stocks	1	15,626	15,627
Gift annuity	99,907	18,404	118,311
Certificates of deposit	1,838,307	4	1,838,311
	$ 6,983,787	$ 923,759	$ 7,907,546

Included in the accompanying statement of financial position as follows:

	Cost	Unrealized Gains and (Losses)	Fair Value
Short-term investments	$ 6,582,053	$ 889,729	$ 7,471,782
Long-term investments	401,734	34,030	435,764
	$ 6,983,787	$ 923,759	$ 7,907,546

The following schedule summarizes the investment returns and their classification in the statement of activities for the year ended December 31, 2012:

	Permanently Restricted	Temporarily Restricted	Unrestricted
Investment income	$ 1	$ 30,921	$ 120,937
Realized gains (losses) on investments	—	—	6,353
Unrealized gains (losses) on investments	(64)	16,710	453,227
	$ (63)	$ 47,631	$ 580,517

Note 4. Property and Equipment:

Property and equipment consists of the following:

Land	$	3,643,802
Building and improvements		8,758,245
Office equipment and furniture		863,682
		13,265,729
Less accumulated depreciation		2,250,955
	$	11,014,774

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, 2012, the interest rate was 3.7076%. 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, 2012, 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, 2012 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, 2012, consist of the following:

	Mass. Development Finance Agency	Capital Lease Obligations	Total
2013	183,333	7,810	191,143
2014	183,333	—	183,333
2015	183,333	—	183,333
2016	183,333	—	183,333
2017	183,333	—	183,333
Thereafter	4,201,391	—	4,201,391
	$ 5,118,056	$ 7,810	$ 5,125,866

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, 2012, the aggregate notional principal amount under the interest rate swap agreement, with a maturity of November 1, 2040, totaled $5,118,056. At December 31, 2012, the estimated fair value of the interest rate swap agreement was a liability of $426,386, and is classified on the statement of financial position as an interest rate swap agreement liability as of December 31, 2012.

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, 2012:

	Level 1	Level 2	Level 3
Interest rate swap	$ —	$ 426,386	$ —

The change in fair value on this interest rate swap agreement was a loss of $54,580 for the year ended December 31, 2012, 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 2013.

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.

Note 7. Capital Leases (Continued):

Present value of the future minimum lease payments was determined based on the Society's borrowing rate at the leases inception date (3.25%).

The present value of future minimum lease payments through September 2013 is $7,810.

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 $20,040 in 2012 and that effect is reflected in the statement of activities. As of December 31, 2012, the Society has an accrued liability of $449,255 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.

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.

Note 9. Program and Supporting Services (Continued):

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 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, DataStreme Earth's System: Creating a Sustained Community of K-12 Educators Who are Local Leaders in Climate Science and Global Change Issues and DataStreme Earth's Climate System: Training Climate Education Resource Agents Who Advance Climate Science Literacy. 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.

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 $467,635 for the year ended December 31, 2012. There is no past service liability in connection with the plan.

Note 11. 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, 2012, 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, 2012 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	$ 1,742,275	$ 1,078,935	$ 663,340	$ —
National Aeronautics and Space Administration	1,010,488	928,167	82,321	—
National Science Foundation	1,585,756	403,691	1,182,065	—
United States Department of the Navy	259,560	165,543	94,017	—
Department of Energy	140,171	29,635	110,536	—
	$ 4,738,250	$ 2,605,971	$ 2,132,279	$ —

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, 2012 was $1,843,961.

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 $448,784 for the year ended December 31, 2012 (including charges for operating expenses and taxes). The following is a schedule of future minimum rentals under the leases at December 31, 2012:

Year Ending December 31:	
2013	498,435
2014	499,307
2015	479,397
2016	491,382
2017	503,666
Thereafter	5,297,314
	$ 7,769,501

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.

Note 14. Endowment Funds (Continued):

Interpretation of Relevant Law (Continued): In accordance with UPMIFA, the Society considers the following factors in making a determination to appropriate or accumulate donor-restricted endowment funds:

(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, 2012:

	Unrestricted	Temporarily Restricted	Permanently Restricted	Total
Donor-restricted endowment funds	$ —	$ 1,734,739	$ 642,700	$ 2,377,439
Board-designated endowment funds	1,308,338	—	—	1,308,338
	$ 1,308,338	$ 1,734,739	$ 642,700	$ 3,685,777

Changes in endowment net assets for year ended December 31, 2012:

	Unrestricted	Temporarily Restricted	Permanently Restricted	Total
Endowment net assets, beginning of year	$ 1,325,602	$ 1,662,521	$ 642,763	$ 3,630,886
Investment return:				
Investment income	10,593	30,921	1	41,515
Net appreciation (depreciation) (realized and unrealized)	168	16,710	(64)	16,814
Total investment return	10,761	47,631	(63)	58,329
Contributions	487,941	90,378	—	578,319
Appropriation of endowment assets for expenditure	(515,966)	(65,791)	—	(581,757)
Endowment net assets, end of year	$ 1,308,338	$ 1,734,739	$ 642,700	$ 3,685,777

SCHEDULE OF EXPENDITURES OF FEDERAL AWARDS YEAR ENDED DECEMBER 31, 2012

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	$ **481,205**
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	**58,648**
AMS/National Weather Service Fellowships	11.467	—	NA05NWS4671011	**36,500**
Subtotal by program	**11.467**			**576,353**
AMS/NOAA Cooperative Program for Earth System Education: Sustaining DataStreme Teacher Professional Development and Promoting Public Literacy in the Atmospheric and Oceanic Sciences	11.008	—	NA125EC0080020	**79,292**
AMS/NOAA Graduate Fellowships	11.431	—	NA07OAR4310491	**54,494**
Integrated Solutions: Environmental and Health Series	11.459	—	NA08OAC4590928	**52,405**
Subtotal direct programs				**762,544**
Pass-Through Program from University Corporation for Atmospheric Research: Gathering and Analyzing Information for Understanding Regional Capabilities Important for Aligning Science and Adaptation	11.431	Z12-96970	NA06OAR4310119	**22,594**
Total National Oceanic and Atmospheric Administration				**785,138**
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	**276,107**
Fellowships	43.001	—	NNX10AU52H	**101,835**
Developing and Implementing a Stronger National Commitment to Long-Term Earth Observations and Their Beneficial Use	43.001	—	NNX09AP56G	**150,347**
AMS Journals to Developing Countries	43.001	—	NNX09AP98G	**25,000**
Total National Aeronautics and Space Administration	**43.001**			$ **553,289**

Program Title	CFDA Number	Pass-through Entity Identifying Number	Award Number	Federal Expenditures
National Science Foundation:				
AMS Summer Policy Colloquium 2012–2014	47.050	—	AGS-1239660	$ **117,000**
DataStreme Earth's Climate System: Training Climate Education Resource Agents who Advance Climate Science Literacy	47.050	—	GEO-1034999	**48,993**
AMS Climate Studies: Fostering Climate Science Literacy and Promoting Minority Participation in the Geosciences (Track 2)	47.050	—	GEO-1107968	**213,656**
Total National Science Foundation	**47.050**			**379,649**
Department of the Navy:				
The Maury Project: Pre-College Teacher Training in the Physical Foundations of Oceanography	12.300	—	N00014-11-1-0122	**96,250**
Department of Energy:				
Climate Information Needs for Improved Financial Analysis Workshop, Fall 2012	81.049	—	DE-SC0008480	**17,635**
Fellowships	81.049	—	DE-SC0008363	**12,000**
Total Department of Energy	**81.049**			**29,635**
Total Expenditures of Federal Awards				$ **1,843,961**

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 2012, the American Meteorological Society did not provide federal awards to any subrecipients.

SCHEDULE OF NET ASSETS BY RESTRICTION — YEAR ENDED DECEMBER 31, 2012

	Balances January 1, 2012	Receipts and Other Additions	Expenditures and Other Deductions	Total	Appreciation (Depreciation) in Fair Market Value	Balances December 31, 2012
Unrestricted Net Assets:						
General	$ 7,995,378	$ 596,544	$ 15,000	$ 8,576,922	$ 452,890	$ **9,029,812**
Education	892,622	15,000	—	907,622	—	**907,622**
75th Endowment	41,003	773	—	41,776	(98)	**41,678**
Cooper	75,902	1,756	15,088	62,570	(12)	**62,558**
Fellowship	37,500	278,329	310,329	5,500	—	**5,500**
Scholarship	(7,750)	76,500	60,500	8,250	—	**8,250**
Student Travel Fund	50,776	1,397	5,303	46,870	123	**46,993**
Development	111,115	130,181	127,196	114,100	—	**114,100**
Glahn	13,591	1,885	—	15,476	—	**15,476**
Saltzman	101,439	669	5,050	97,058	154	**97,212**
Atlas	5,016	2,414	5,000	2,430	—	**2,430**
Roberts	1,791	363	—	2,154	—	**2,154**
Digiquartz	318	1	—	319	—	**319**
Ooyama	142	781	—	923	—	**923**
Friday	2,118	451	2,500	69	—	**69**
Hobbs	19	1	—	20	—	**20**
Reeves	—	3,035	—	3,035	—	**3,035**
Total Unrestricted Net Assets	$ 9,320,980	$ 1,110,080	$ 545,966	$ 9,885,094	$ 453,057	$ **10,338,151**

SCHEDULE OF NET ASSETS BY RESTRICTION (CONTINUED) — YEAR ENDED DECEMBER 31, 2012

	Balances January 1, 2012	Receipts and Other Additions	Expenditures and Other Deductions	Total	Appreciation (Depreciation) in Fair Market Value	Balances December 31, 2012
Temporarily Restricted Net Assets:						
Orville	$ 269,897	$ 85,584	$ 5,000	$ 350,481	$ 290	**$ 350,771**
Hanks Scholarship	2,734	83	—	2,817	—	**2,817**
Schroeder	9,060	2,101	5,000	6,161	184	**6,345**
Reed	17,541	661	—	18,202	—	**18,202**
Wark	31,147	2,069	15,050	18,166	453	**18,619**
Leviton	1,879	38	—	1,917	—	**1,917**
Houghton	55,981	1,739	—	57,720	68	**57,788**
Hagemeyer Unitrust	121,474	3,199	50	124,623	6,839	**131,462**
Gift Annuity	115,351	3,286	3,948	114,689	7,352	**122,041**
David Johnson	72,925	853	3,050	70,728	154	**70,882**
Milham	3,239	—	—	3,239	—	**3,239**
Horton	165,436	2,882	—	168,318	118	**168,436**
Grau	49,485	293	5,000	44,778	—	**44,778**
Merewether	7,583	50	—	7,633	—	**7,633**
Murphy	816	1,184	2,000	—	123	**123**
L. Johnson	52,603	3,668	2,000	54,271	14	**54,285**
Baum	94,008	4,777	5,000	93,785	(306)	**93,479**
Hope	1,241	613	—	1,854	123	**1,977**
Eaton	600	—	—	600	—	**600**
Kreitzberg	3,035	1,616	2,000	2,651	—	**2,651**
Wesley	27,366	1,486	116	28,736	—	**28,736**
Vonnegut–Schaefer	72,456	1,159	5,050	68,565	192	**68,757**
Namias	2,255	519	50	2,724	123	**2,847**
Glahn	53,500	—	—	53,500	197	**53,697**
Atlas	104,176	—	—	104,176	540	**104,716**
Spengler	4,656	—	150	4,506	—	**4,506**
Roberts	55,135	100	2,000	53,235	—	**53,235**
Geotis	4,299	54	—	4,353	—	**4,353**
Digiquartz	500	—	—	500	—	**500**
Ooyama	77,002	100	2,000	75,102	154	**75,256**
Friday	41,881	—	—	41,881	92	**41,973**
Hobbs	800	—	—	800	—	**800**
K. Spengler	4,760	350	827	4,283	—	**4,283**
NWSA	136,000	156	7,500	128,656	—	**128,656**
Moyer	1,700	2,679	—	4,379	—	**4,379**
Total Temporarily Restricted Net Assets	$ 1,662,521	$ 121,299	$ 65,791	$ 1,718,029	$ 16,710	**$ 1,734,739**

	Balances January 1, 2012	Receipts and Other Additions	Expenditures and Other Deductions	Total	Appreciation (Depreciation) in Fair Market Value	Balances December 31, 2012	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	809	1	—	810	—	**810**	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	50,027	—	—	50,027	(27)	**50,000**	50,000
Wark	250,000	—	—	250,000	—	**250,000**	250,000
Vonnegut-Schaefer	24,072	—	—	24,072	—	**24,072**	20,735
Murphy	43,687	—	—	43,687	(37)	**43,650**	40,000
Kreitzberg	40,740	—	—	40,740	—	**40,740**	28,230
Namias	50,000	—	—	50,000	—	**50,000**	50,000
Total Permanently Restricted Net Assets	$ 642,763	$ 1	$ —	$ 642,764	$ 843	$ **642,700**	$ 624,236

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