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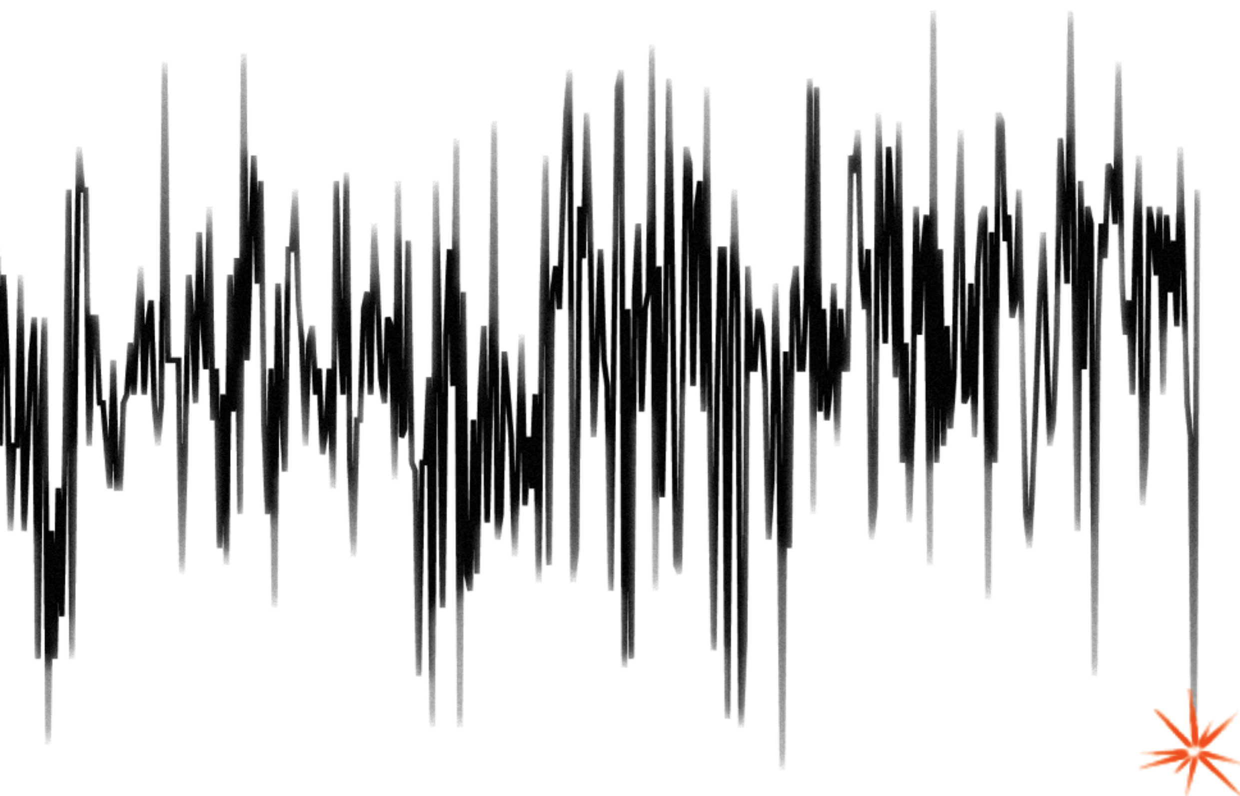
HERBERT RIEHL'S LEGACY

GOES-R PROVING GROUND

AEROSOLS IN TROPICAL CYCLONES

WEATHER *EXTREMES* OF 2011 IN CLIMATE PERSPECTIVE



Taking Attribution Science to the Limits

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IN BOX

ARTICLES

MEETING SUMMARY

online content is available online at http://journals.ametsoc.org/toc/bams/93/7.

ON THE COVER

Peterson et al. demonstrate several different methods of evaluating the climatic causes of 2011 weather extremes, showing the cutting edge of attribution science and how it can be employed in rapid response to recent events. For details, see page 1041. [Cover graphic based on Fig. 14 of the article.]

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DEPARTMENTS

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LETTER FROM THE EDITOR: TAKING THE LONG VIEW

Meteorology is one profession where you will be excused if you have your head in the clouds. The truth is, however, that meteorology does not particularly attract people who are too distracted to focus on reality. Instead, the study of the atmosphere seems to attract two contrasting personality types very different from the airheads we associate with that phrase.

One type is tenaciously drawn to weather because they are focused on experiencing the here and now, enriching their connection with their surroundings through better understanding. It takes an unusually aware, grounded person to observe changes in the weather. People motivated to measure atmospheric properties regularly are even more grounded in immediate reality.

The second common type treats weather as the widest possible frame of their experiences. They enrich their connection with the here and now by taking the perspective that the atmosphere links people across the globe and across centuries. For these people, the momentary moods of the atmosphere must be understood in the context of planetary processes or of historical events and trends. Weather, in their view, is best understood from temporal and spatial distance.

It took both types of thinking—the immediate and the long-range—to conceive of a long-lived scientific observing project in Cuba during the tail end of the Cold War (page 1017). Juan Carlos Antuña Marrero and his colleagues managed to chart a path to meaningful research into the stratosphere, clouds, and solar radiation. They started with Soviet assistance but, when that ended, pieced together a working observatory through determination, patience, and practicality. Particularly noteworthy was their conviction that atmospheric research is an international enterprise and that science transcends economic and political isolation.

Similarly, it takes both types of thinking these days to work in climatology, both to maintain critical observing networks and to analyze current weather in the context of broader climatic causes. Attribution science, as this latter branch is called, is still in its infancy, yet these days the public hungers for quick judgments about the causes of recent weather extremes, stretching scientific capabilities. It takes an unusual focus on the here and now for a climatologist—normally a long-view person—to draw conclusions quickly enough about recent events to keep up with the news cycle.

The analysis of extremes of 2011 by Tom Peterson and colleagues (page 1041) attempts this timeliness as part of a long-range vision. The article is a natural accompaniment to the "State of the Climate" supplement mailed with this issue: the "State of the Climate" reports events, while Peterson et al. venture a broader perspective. Their explanations of weather extremes in climatic terms test the limits of attribution capabilities, thus looking ahead to regular, rapid-response climate attribution services. As such, Peterson et al. provide long-term perspective on the weather as well as lay groundwork for long-term improvement in their science, fully aware that immediate attribution of weather extremes is only now becoming more practical than having your head in the clouds.

—*Jeff Rosenfeld,* Editor-in-Chief

HERBERT RIEHL: INTREPID AND ENIGMATIC SCHOLAR

Herbert Riehl, known as the "father of tropical meteorology," certainly made outstanding contributions to this field of study. Yet, when his oeuvre is examined retrospectively, there is strong evidence that his view was global and encompassed processes that cut across the latitudinal bands of the tropics, subtropics, and midlatitudes. His pathway into meteorology was unique as a Jewish man who immigrated to the United States from Germany in 1933—that point in time when the fascist regime in Germany gained significant power. Meteorology was not his first choice as a career, but circumstances related to imminent world war led him to the study of meteorology. He was inspired by his teaching and research experiences at the Institute of Tropical Meteorology in Puerto Rico during World War II. Further, he found his scientific calling in the milieu of "Rossby's School" at the University of Chicago (U of C) following the war. Particular attention is paid herein to his early work from the mid-1940s through the late 1950s while professor at the U of C—a period when he ventured into the relatively unknown field of tropical meteorology. The strength of his early research contributions along with his mastery of language and adeptness in scientific debate drew many first-rate students into the field. However, his unorthodox brand of mentorship and his hard-edged nature created challenges that are further examined through first-person verbal portraits or vignettes. This article explores in some detail the interaction between Riehl and one of his students, Joanne Simpson. Finally, Riehl's scientific legacy is discussed. *(Page 963)*

ABSTRACTS

AEROSOL EFFECTS ON MICROSTRUCTURE AND INTENSITY OF TROPICAL CYCLONES

Improving the forecasts of the intensity of tropical cyclones (TCs) remains a major challenge. One possibility for improvement is consideration of the effects that aerosols have on tropical clouds and cyclones. The authors have been pursuing this under the Hurricane Aerosol and Microphysics Program, supported by the U.S. Department of Homeland Security. This was done through observations of aerosols and resulting cloud microphysical structure within tropical cyclones and simulating their effects using high-resolution TC models that treat cloud internal processes explicitly. In addition to atmospheric aerosols, special attention was given also to the impact of the intense sea-spray-generated aerosols and convective rolls in the hurricane boundary layer (BL) under hurricane-force winds.

The results of simulations and observations show that TC ingestion of aerosols that serve as cloud condensation nuclei can lead to significant reductions in their intensities. This is caused by redistribution of the precipitation and latent heating to more vigorous convection in the storm periphery that cools the low levels and interferes with the inflow of energy to the eyewall, hence making the eye larger and the maximum winds weaker. The microphysical effects of the pollution and dust aerosols occur mainly at the peripheral clouds. Closer to the circulation center, the hurricane-force winds raise intense sea spray that is lifted efficiently in the roll vortices that form in the BL and coalesce into rain of mostly seawater already at cloud base, which dominates the microstructure and affects the dynamics of the inner convective cloud bands. *(Page 987)*

THE ROLE OF THE PACIFIC ENSO APPLICATIONS CLIMATE CENTER IN REDUCING VULNERABILITY TO CLIMATE HAZARDS: EXPERIENCE FROM THE U.S.-AFFILIATED PACIFIC ISLANDS

The Pacific ENSO Applications Center (PEAC) was established in August 1994 as a multi-institutional partnership to conduct research and produce information products on climate variability and impacts related to the El Niño–Southern Oscillation climate cycle for the U.S.-Affiliated Pacific Islands (USAPI). The name of the center was changed to Pacific ENSO Applications Climate (PEAC) Center in 2007. Over the years, the PEAC Center effectively provided advanced warning as part of the hazard management program for the small island countries in the USAPI region. The primary focus of this paper is to synthesize the overall hazard management activities of the PEAC Center by visiting various aspects of the historical and current operational framework, including i) forecasting, ii) interpretation and message formulation, iii) warning preparation and dissemination, iv) responses and feedback, and v) review and analysis. *(Page 1003)*

DEMONSTRATING THE POTENTIAL FOR FIRST-CLASS RESEARCH IN UNDERDEVELOPED COUNTRIES: RESEARCH ON STRATOSPHERIC AEROSOLS AND CIRRUS CLOUDS OPTICAL PROPERTIES AND RADIATIVE EFFECTS IN CUBA (1988–2010)

Optical properties of stratospheric aerosols and cirrus clouds and their radiative effects are currently important subjects of research worldwide. Those investigations are typical of developed countries, conducted by several highly specialized groups dedicated separately to instrumental observations, their interpretation in the context of the weather and climate, and the numerical simulation of their radiative effects. In Camagüey, Cuba, the Grupo de Óptica Atmosférica de Camagüey [Optics Atmospheric Group of Camagüey (GOAC)] has been conducting all those research projects together for a little more than 20 years, following a self-designed long-term

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strategy. The results of the strategy applied by GOAC demonstrates that, even in the conditions of an underdeveloped country, it is possible to build local scientific and technical capacities for conducting state-of-the-art research for the benefit of society, both locally and worldwide. *(Page 1017)*

THE GOES-R PROVING GROUND: ACCELERATING USER READINESS FOR THE NEXT-GENERATION GEOSTATIONARY ENVIRONMENTAL SATELLITE SYSTEM

The Geostationary Operational Environmental Satellite R series (GOES-R) Proving Ground engages the National Weather Service (NWS) forecast, watch, and warning community and other agency users in preoperational demonstrations of the new and advanced capabilities to be available from GOES-R compared to the current GOES constellation. GOES-R will provide significant advances in observing capabilities but will also offer a significant challenge to ensure that users are ready to exploit the new 16-channel imager that will provide 3 times more spectral information, 4 times the spatial coverage, and 5 times the temporal resolution compared to the current imager. In addition, a geostationary lightning mapper will provide continuous and near-uniform real-time surveillance of total lightning activity throughout the Americas and adjacent oceans encompassing much of the Western Hemisphere. To ensure user readiness, forecasters and other users must have access to prototype advanced products within their operational environment well before launch. Examples of the advanced products include improved volcanic ash detection, lightning detection, 1-min-interval rapid-scan imagery, dust and aerosol detection, and synthetic cloud and moisture imagery. 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. In 2012 and beyond, the GOES-R Proving Ground will test and validate display and visualization techniques, decision aids, future capabilities, training materials, and the data processing and product distribution systems to enable greater use of these products in operational settings. *(Page 1029)*

EXPLAINING EXTREME EVENTS OF 2011 FROM A CLIMATE PERSPECTIVE

Attribution of extreme events shortly after their occurrence stretches the current state-of-the-art of climate change assessment. To help foster the growth of this science, this article illustrates some approaches to answering questions about the role of human factors, and the relative role of different natural factors, for six specific extreme weather or climate events of 2011.

Not every event is linked to climate change. The rainfall associated with the devastating Thailand floods can be explained by climate variability. But long-term warming played a part in the others. While La Niña contributed to the failure of the rains in the Horn of Africa, an increased frequency of such droughts there was linked to warming in the Western Pacific–Indian Ocean warm pool. Europe's record warm temperatures would probably not have been as unusual if the high temperatures had been caused only by the atmospheric flow regime without any long-term warming.

Calculating how the odds of a particular extreme event have changed provides a means of quantifying the influence of climate change on the event. The heatwave that affected Texas has become distinctly more likely than 40 years ago. In the same vein, the likelihood of very warm November temperatures in the UK has increased substantially since the 1960s.

Comparing climate model simulations with and without human factors shows that the cold UK winter of 2010/2011 has become about half as likely as a result of human influence on climate, illustrating that some extreme events are becoming less likely due to climate change. *(Page 1041)*

Marine Community Adopts New Thermodynamic Equation of Seawater (TEOS-10)

In a move that reminds us that mathematical equations are not necessarily fixed in stone, an international body of oceanographic scientists has adopted a new thermodynamic description of seawater and oceanic ice properties to be used by oceanographers and marine scientists in their technical work. Touted as "a new way to look at water," the International Thermodynamic Equation of Seawater-2010, or TEOS-10 as it's cryptically known, replaces algorithms and variables that have been employed by an equation of seawater in use since 1980, EOS-80. The switch to TEOS-10 employs the use of two new variables: absolute salinity to replace practical salinity, and conservative temperature to replace potential temperature—a benefit that for the first time allows technical calculations to systematically account for the influence of the spatially varying composition of seawater.

Upon accepting the recommendation of the Scientific Committee on Oceanic Research (SCOR) and the International Association for the Physical Sciences of the Oceans (IAPSO) to begin using absolute salinity as the salinity argument in the TEOS-10 algorithms for seawater, the Intergovernmental Oceanographic Commission (IOC) noted that the salinity reported to national databases must remain practical salinity as determined on the Practical Salinity Scale of 1978. The practice of storing one type of salinity (practical) in national databases but using a different type of salinity (absolute) in publications, the IOC announcement stated, is exactly analogous to the present practice with temperature: in situ temperature is stored in databases (since it is the measured quantity), but the temperature variable that is used in publications is a calculated quantity. Under EOS-80, potential temperature (θ) was calculated, but it is now conservative temperature (Θ) under TEOS-10.

To avoid confusion while the use of practical salinity in scientific publications is phased out, the IOC requested that authors and editors specifically identify salinity as being either practical, with the symbol S_P, or absolute, with the symbol S_A. Additionally, the method used to compute the location-dependent relationship between S_P and S_A should be explicitly stated in journal articles.

The IOC noted that the new salinity variable, S_A, is measured in SI units: g kg^{-1}. Its announcement also noted other prominent advantages of TEOS-10 compared with EOS-80:

- In the open ocean, the use of S_A has a nontrivial effect on the horizontal density gradi-

ECHOES

"The ultimate goal is to save lives. In order to do so, we have to have a better understanding of what worked and didn't work."

—Hermann Fritz, Georgia Tech professor, on his study of the 2011 Japan tsunami. Fritz used terrestrial laser scanners and eyewitness videos of the tsunami to create a three-dimensional hydrograph of the flood zone in the town of Kesennuma Bay. That location has been vulnerable to tsunamis in the past, and 1,500 residents of the town were killed in last year's event. Fritz's research showed that the tsunami reached a maximum height of 9 meters in the Kesennuma Bay narrows, and that outflow currents were moving at 11 meters per second—faster than any person or vessel could overcome—about 10 minutes after the main peak of the wave. "What we can learn from the hydrograph is confirmation that the water goes out first, drawing down to more than negative 3 meters on the landward side of the trench, which can make vessels hit ground inside harbors," Fritz explains. "During the subsequent arrival of the main tsunami wave, the water rushing back in changed the water level by [12 meters], engulfing the entire city in 12 minutes." The study, published recently in *Geophysical Research Letters*, could help planners in vulnerable areas design more tsunami-resistant buildings, seawalls, and breakwaters. (Source: Georgia Institute of Technology)

ECHOES

"It's a lot like flipping a coin and have it land perfectly on its edge."

—Jason Persoff, a University of Colorado doctor and storm chaser, on the factors involved in surviving a tornado. While luck remains the primary factor, Persoff noted that odds of survival may increase when an oversized object such as a mattress, bathtub, or door is thrown with the individual. This can protect the person from flying debris, but can also easily become the deadly debris itself. Other factors include age, a tornado's speed, and where the person lands, with the young and old more vulnerable. (Source: msnbc.com)

ent, and thereby on the ocean velocities and transports calculated via the "thermal wind" relation.

- The Gibbs function approach of TEOS-10 allows the calculation of internal energy, entropy, enthalpy, potential enthalpy, and the chemical potentials of seawater, as well as the freezing temperature, and the latent heats of freezing and of evaporation. These quantities were not available from EOS-80 but are essential for the accurate accounting of "heat" in the ocean and for the consistent and accurate treatment of air–sea and ice–sea heat fluxes in coupled climate models.
- In particular, conservative temperature Θ accurately represents the "heat content" per unit mass of seawater, and is to be used in place of potential temperature θ in oceanography.
- The thermodynamic quantities available from TEOS-10 are totally consistent with each other; this was not the case with EOS-80.

A brief introduction to TEOS-10, "Getting Started with TEOS-10 and the Gibbs Seawater (GSW) Oceanographic Toolbox", is available on the TEOS-10 website (www.TEOS-10.org). It lists all the functions in the GSW computer software toolbox and illustrates the differences associated with using absolute salinity and conservative temperature, compared with using practical salinity and potential temperature.

TEOS-10 computer software, the TEOS-10 manual, *The International Thermodynamic Equation of Seawater–2010: Calculation and Use of Thermodynamic Properties*, and other documents may be obtained from www.TEOS-10.org. (Source: Intergovernmental Oceanographic Commission)

NWS Testing New Tornado Warnings

National Weather Service offices in Missouri and Kansas recently began an experiment testing new tornado warnings that utilize more descriptive language than has been used in the past to describe potential effects of storms. The experiment is called "Impact-Based Warning," and is meant to bluntly tell residents in the path of tornadoes what could result if they don't seek shelter. By using phrases such as "mass devastation" and "unsurvivable if shelter not sought below ground," the NWS is hoping to "better convey the threat and elevate the warning over a more typical warning," according to Dan Hawblitzel of the Pleasant Hill, Missouri, NWS office.

The new alerts got their first big test in April when more than 100 twisters were reported in Kansas, Oklahoma, Nebraska, and Iowa. While the NWS Storm Prediction Center issued a warning of possible life-threatening storms in several Midwest states days before they touched down, in Kansas the words used in the new alerts were particularly trenchant: "You could be killed if not underground or in a tornado shelter. Many well-built homes and businesses will be completely swept from their foundations." And the warnings seem to have worked. Despite the large number of storms, only six people were killed—all in an overnight tornado that hit Woodward, Oklahoma. The effectiveness of the new warnings was evident in Wichita, Kansas, where a twister tore through a mobile-home park during nighttime hours but there were no fatalities.

The Impact-Based Warning experiment was developed in consultation with social scientists and includes some key additions to regular tornado warnings, such as information identifying the hazard (hail, winds, tornado, etc.), indicating whether the hazard has been spotted by radar or by people on the ground, and describing potential effects of the hazard (loss of life, damage to trees or buildings, etc.). The graphic warnings are designed not only to get people's attention and trigger action but to get the word out further by reposting the information to social media. And, the warnings can be used not only for tornadoes, but also to signify life- or property-threatening thunderstorms. The experiment is scheduled to run through the end of November, at which point

The 2011 tornado season is examined in the new AMS book, *Deadly Season: Analysis of the 2011 Tornado Outbreaks*, by Kevin M. Simmons and Daniel Sutter. The book is a follow-up to the authors' *Economic and Societal Impacts of Tornadoes*, published by AMS in 2010. The new title looks at possible factors contributing to the outcomes of 2011 tornado outbreaks, including assessments of Doppler radar and storm warning systems, as well as early recovery efforts. Both books can be purchased at https://secure.ametsoc.org/amsbookstore.

THIRSTY PLANTS MAKE HEARTIER PLANTS

Plants have a good memory, it seems. Researchers found that when subjected to a previous drought, the plants rebounded from a subsequent lack of water much quicker. Seasoned gardeners have used this method, known as drought hardening, before moving plants to make the transition less stressful. "This phenomenon of drought hardening is in the common literature but not really in the academic literature," explains Michael Fromm, a University of Nebraska—Lincoln plant scientist who was part of the research team. "The mechanisms involved in this process seem to be what we found." The researchers worked with Arabidopsis, a member of the mustard family, "training" them by holding back water. The prestressed plants recovered faster the next time they were dehydrated, while the nontrained plants wilted more quickly, with their leaves losing water at a faster rate than trained plants. The researchers hope that the discovery of this plant memory can lead to crops that would better withstand drought. For now, home gardeners can take advantage of the method when replanting. (Source: University of Nebraska—Lincoln)

it will be reviewed and considered for more widespread use.

The initiative comes just one year after tornadoes killed more than 500 people in the United States in the deadliest season in almost 60 years. This spring saw more damaging twisters, with an early-March outbreak of more than 60 tornadoes killing 40 people in Kentucky, Indiana, Ohio, and Alabama. And a wave of at least 20 twisters that swept through Dallas and other parts of eastern Texas in early April caused no fatalities, but more than 300 homes were destroyed. (Source: *The Kansas City Star*)

March Weather Madness

The month of March broke a whole lot of high-temperature records in the United States—more than 15,000 of them. Unprecedented warmth dominated the nation east of the Rockies, leading to the warmest March monthly temperature since official recordkeeping began in 1895. According to NOAA, the average temperature of 51.1°F in the lower 48 states was 0.5°F warmer than the previous record holder, March 1910, and 8.6°F above the twentieth-century average for the month.

Included in the records were hundreds of all-time highs for the month of March, with summerlike temperatures in the 90s as far north as the Great Lakes region. Even though most of the record-breakers were in the lower United States, every state had at least one record-warm daily temperature, NOAA reported. The first three months of 2012 combined were also much warmer than average in the contiguous United States, with numerous cities experiencing a record-warm January–March. (Source: National Climatic Data Center)

ON THE WEB

New Ocean CO_2 Atlas Now Available Online

A comprehensive dataset of surface water carbon dioxide (CO_2) measurements for the oceans was launched in April and is now available through the project's website (www.socat.info). A collaboration of the science community, the Surface Ocean CO_2 Atlas (SOCAT) project provides long-term access to regularly updated data with potential applications for carbon budgets; studies of seasonal, year-to-year, and decadal variation in oceanic CO_2 uptake; and research into the processes driving these variations.

This new dataset was assembled by a team of more than 100 experts from around the world and includes 6.3 million global observations since 1968.

"Assembling this dataset has been a major undertaking by seagoing marine carbon scientists from across the world for the last four years," notes Dorothee Bakker of the University of East Anglia. "We believe SOCAT will become an invaluable resource for anyone studying the ocean carbon cycle and its influence on global temperatures."

Are Olsen, from the Bjerknes Centre for Climate Research, where the dataset was physically assembled, adds: "The unique aspect of this dataset is that the observations have been combined into a single uniform format and quality controlled. Reformatted input data and recalculated output data are publicly available [at www.pangaea.de]. The methods we have used are transparent and fully documented."

The researchers used an online data visualization and manipulation tool called the Live Access Server to make the SOCAT dataset user friendly. The server provides interactive maps that enable users to work with the data. According to the scientists, results from SOCAT will be used in the next IPCC report, and work on the next SOCAT update has already started. (SOURCE: University of East Anglia)

DATA ANALYSIS

DETECTING AND REPAIRING INHOMOGENEITIES IN DATASETS

Assessing Current Capabilities

To study climate variability, the original surface observations are indispensable, but these have to be used with care. Long observational records always contain changes due to nonclimatic factors. Such inhomogeneities can be either sudden jumps (breaks) or gradual trends in one station.

Most surface stations are not operated for climatic purposes, but rather to meet the needs of weather forecasting, agriculture, and hydrology. Consequently, the average period between detected inhomogeneities, or breaks, in Western instrumental records is only 15–20 years. The typical size of the breaks is of the same order as the climate-change signal during the twentieth century. Specific inhomogeneities are typical for certain periods and common to many stations; these can collectively lead to artificial biases in climate trends across large regions. Inhomogeneities are thus a significant source of uncertainty in the estimation of secular trends and decadal-scale variability.

To the general public, the best-known inhomogeneity is probably the urban heat-island effect. The temperature in cities can be warmer than in the surrounding countryside, especially during calm nights. As cities have grown, they have encroached on many weather stations, raising the ambient temperature. Worldwide, the advent of aviation led to relocation of stations from cities to nearby, typically cooler airports. In general, relocations are an important cause of inhomogeneities.

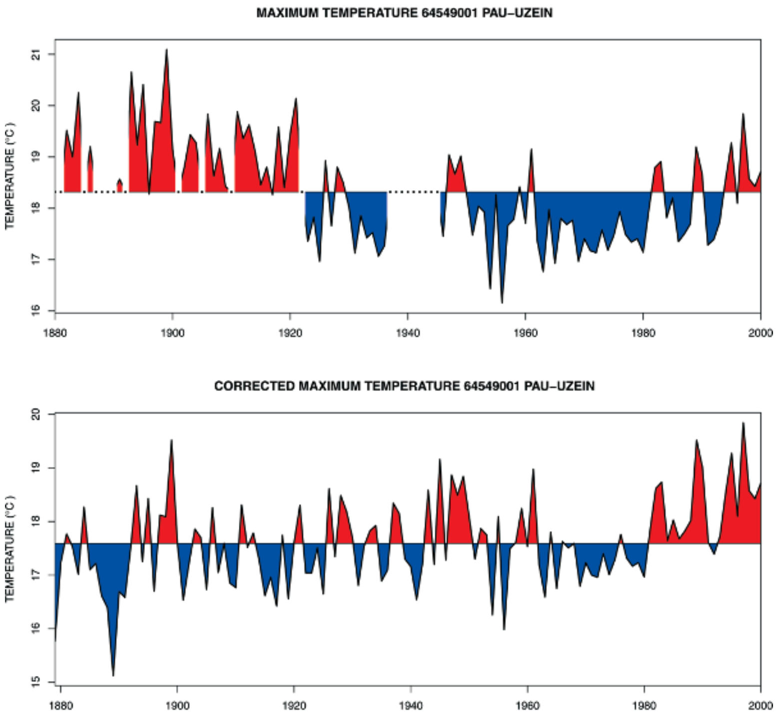
Inhomogeneities caused by changes in the screens that protect the instruments from radiation and wetting are also common. In nineteenth-century Europe, it was common to install the instruments in a metal screen near a window on a north-facing wall. However, the building may warm the screen, leading to higher temperature measurements. When this problem was realized, screens such as the cotton region shelter were introduced. Other typical causes of inhomogeneities are changes in the surrounding environment (e.g., land-use change and building activity). An important recent inhomogeneity is the changeover to automatic weather stations.

Ideally, the date of a change of instruments, location, or observing practices would be recorded as "metadata," and parallel measurements made with the original and the new setup for several years, allowing reliable estimation of the inhomogeneity. By making parallel measurements with replicas of historical instruments, screens, etc., the influence of some historical inhomogeneities can still be studied today.

However, metadata are often incomplete or lacking, so statistical homogenization is necessary as well. The most commonly used principle to detect and remove the artificial changes is relative homogenization. This assumes that nearby stations are exposed to almost the same climate signal, but not any nonclimatic changes. By looking at the difference between nearby stations, the year-to-year variability of the climate is removed, as well as the regional climatic trend. In such a difference time series, a clear and persistent jump can easily be detected and can only be due to changes in the measurement conditions.

A jump (break) in a difference time series of a pair of stations does not pinpoint the responsible station. Furthermore, time series typically have more than just one jump. These two features make statistical homogenization a challenging and beautiful statistical problem. Homogenization algorithms typically differ in how they solve these two fundamental problems.

Indeed, many statistical procedures have been developed to detect and correct inhomogeneities. As



Raw (top) annual averages of maximum temperatures in Pau, a city on the northern edge of the Pyrenees. The data were homogenized (bottom) using a pairwise comparison with surrounding stations, which were also used to fill gaps in the Pau record. The change in 1921 (–1.4°C), which is clearly visible in the uncorrected station data shown here, is due to a relocation from the primary school in Pau-Lescar to the military airport and a shelter change. However, several other changes had significant influence on this series: a shelter move in 1932 (–0.67°C), the relocation to Pau-Uzein civil airport in 1946 (+0.53°C), and installation of a Mistral automatic weather station in 1985 (–0.46°C).

a result, a coordinated European initiative, Advances in Homogenization Methods of Climate Series: An Integrated Approach (HOME), was established in order to facilitate comparisons of methods, to produce standard methods, and to promote the most efficient methods of homogenization.

As part of this initiative, we created a benchmark temperature and precipitation dataset with inhomogeneities inserted to make it a realistic test of homogenization methods (see paper published in *Climates of the Past*, 10 January 2012). We applied all the most common and most developed algorithms for homogenization to this made-up dataset. The main novelty of this experiment was that it was a blind test—the benchmark was generated, and the analysis of results performed, by independent researchers who did not homogenize the data themselves.

THE BENCHMARKING TEST. The benchmark dataset created for our test mimics station networks and their data problems with unprecedented realism. Homogeneous surrogate data were generated reproducing the cross- and autocorrelation functions, as well as the non-Gaussian distribution of climate observations. Added to these data were random break-type inhomogeneities, as well as breaks occurring simultaneously in multiple stations. Furthermore, local trends were inserted, either continuing at the end (to model, for instance, the urban heat-island effect) or reverting to baseline (to model growing vegetation that is subsequently cut back). The sizes of the breaks and local trends follow a normal distribution with a width of 0.8°C. Finally, a stochastic nonlinear network-wide trend was added. Everyone was invited to homogenize the data; 25 homogenized blind contributions were returned.

We tested three types of homogenization methods: absolute, relative, and direct algorithms. In absolute homogenization, only the station time series itself is used. With this approach, it is difficult to distinguish small inhomogeneities from climate variability. In traditional relative homogenization, a candidate series is compared with a composite reference time series computed from its neighboring stations. This composite reference is assumed to be homogeneous due to averaging, which is only approximately true. The main research impetus for the last two decades has been the development of a new approach to relative homogenization—the so-called direct homogenization algorithms that also function with an inhomogeneous reference time series.

The first main conclusion is that relative homogenization improves the temperature data; it reduces the root-mean-square error of the data and its linear trend coefficients and does not cause artificial climate trends. This conclusion can be stated with confidence because the test was blind and because of the realism of the data. The exceptions, where relative homogenization made the data more inhomogeneous, could mostly be explained by inexperienced users or be traced back to algorithms (or parts thereof) newly written for this exercise. This shows an important disadvantage of blind studies: mistakes discovered after the results are shared with participants cannot be corrected. The results also demonstrate that statistical absolute homogenization can make climate data more inhomogeneous. In contrast to the results for temperature, the results for precipitation are more mixed; still, all but one relative method did improve the station trends.

The second main conclusion is that direct homogenization algorithms are clearly better than traditional ones. A realistic benchmark dataset was needed to see this difference with such clarity. With mathematical argumentation, climatological reasoning, and the benchmark metrics all pointing in the same direction, we thus strongly recommend the use of direct homogenization algorithms.

The performance ranking of the homogenization methods depends on the error metric considered; whether the root-mean-square error is computed on the monthly, yearly, or decadal data; and whether it is computed on the station data or on the network mean climate signal. These rankings also do not correlate strongly with the error in the linear trend estimates (or break detection scores). In other words, it is difficult to compute one error metric that would signify the remaining error after homogenization for all climatic purposes. The computation and communication of the remaining uncertainties of homogenized data should be one of the research priorities for the coming years.

We feel that benchmarking has helped the homogenization community to mature. The discussions about properties of benchmarks, the nature of inhomogeneities, and homogenization methods, as well as the joint work on the same dataset, helped to bring scientists closer together in a way that writing individual papers cannot. The International Surface Temperature Initiative has started a follow-up benchmarking program for homogenization algorithms. This benchmark will be global and even more realistic, especially due to the inclusion of metadata, biased inhomogeneities, and random missing data.

Everyone is invited to download and analyze the benchmark dataset. The homogeneous, inhomogeneous, and homogenized datasets are published on the Internet. Another offspring of the European initiative is a package with homogenization methods written in the statistical programming language R (known as HOMER). This open-source, state-of-the-art package is based on the best homogenization methods and also performs basic quality control. Furthermore, a mailing list for researchers working on homogenization has been started. All these resources can be accessed via the initiative website, www.homogenisation.org, which will be kept running for the coming years and which contains an extensive bibliography.

With advanced and well-validated statistical methods, the homogenization of annual and monthly station data is a mature field. The homogenization of daily data, however, is still in its infancy. Daily data are essential for studying extremes of weather and climate, and therefore are the basis for important political decisions with huge socioeconomic consequences. For such studies, the complete distribution needs to be homogenized. Looking at the physical causes of inhomogeneities, one would expect that many of them especially affect the tails of the distribution of the daily data. The IPCC AR4 report warns that changes in extremes are often more sensitive to inhomogeneous climate-monitoring practices than changes in the mean. This is of concern, given that homogenization methods for daily data are often limited to adjustments on the mean of the distribution. Some correction algorithms for the distribution do exist, but these only reliably correct the first three moments, have currently only been applied to some networks, and require highly correlated neighboring stations. A better understanding of the nature of daily inhomogeneities and better tools to correct them will be the main challenges for the coming years.

—Victor Venema
University of Bonn

FOR FURTHER READING

Venema, V., and Coauthors, 2012: Benchmarking homogenization algorithms for monthly data. *Climate of the Past*, **8**, 89–115.

Miniaturized Satellite Captures Auroral Disturbance

In October, a Delta II rocket launched and deployed the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project satellite, as well as six small satellites called CubeSats, built by university students. One of those CubeSats, from the University of Michigan, recently made the first-ever recording of naturally occurring auroral turbulence. The achievement could help scientists foresee future disturbances in the auroral ionosphere, which can be damaging to communication systems and GPS satellites.

The Radio Aurora Explorer (RAX) CubeSat, one of a class of miniature satellites known as nanosatellites, used an onboard radar receiver to register the electromagnetic echoes over Fairbanks, Alaska. The turbulence was generated by a geomagnetic storm, triggered by a large solar flare. Its distinct signature on radar is caused by irregularities in the density of plasma in the ionosphere.

"The RAX radar echo discovery has convincingly proved that miniature satellites, beyond their role as teaching tools, can provide high-caliber measurements for fundamental space-weather research," notes Moretto Jorgensen of the National Science Foundation.

The ground-to-space bistatic coherent-scatter radar system of the RAX satellite is able to make measurements from an orbital vantage point that conventional ground-based radars cannot access. The nanosatellite was specifically designed to analyze the irregular plasma structures streaming through the upper atmosphere and help understand how those irregularities affect the performance of communication and navigation satellites.

The CubeSats were created as part of NASA's Educational Launch of Nanosatellites (ELaNa) initiative. ELaNa provides students with hands-on experience and NASA with opportunities to test emerging technologies and economical, off-the-shelf components that may be useful in future space missions.

At press time, the 3-kilogram RAX CubeSat had completed 18 different experiments. (Source: SpaceDaily.com)

Making Tunnels Flood-Proof

When cities are flooded, underground tunnels used for mass transit and other purposes can be especially vulnerable. Flood prevention in tunnels is challenging, not only due to the tremendous water mass and pressure that can build up, but also because the walls and floors of the tunnels are covered with pipes, vents, tracks, and other objects that can hinder a tight blockage of the water. A new initiative called the Resilient Tunnel Project (RTP) has addressed this problem by creating a giant inflatable plug that fits the contours of a tunnel and blocks off oncoming water.

The plug has two layers of liquid-crystal polymer fiber and another of polyurethane. It can be kept in a small storage space in the tunnel until it is needed, at which point it can be inflated with water or air remotely from a command center. Its circumference is larger than that of the tunnel itself, so that the plug can be fit around the various irregularities on the walls of the tunnel. The plug performed successfully in a recent test conducted in a specially built tunnel that recreated conditions of a tunnel flood well below sea level.

"No one's ever done this before," says John Fortune of the Department of Homeland Security (DHS)'s Science and Technology Directorate. "It's a completely novel technology."

The RTP is a collaboration of DHS, the Pacific Northwest National Laboratory, West Virginia University, and ILC Dover—an engineering company that develops flexible materials such as NASA space suits. (Source: U.S. Department of Homeland Security)

ECHOES

"It's a game-changer, complete game-changer."

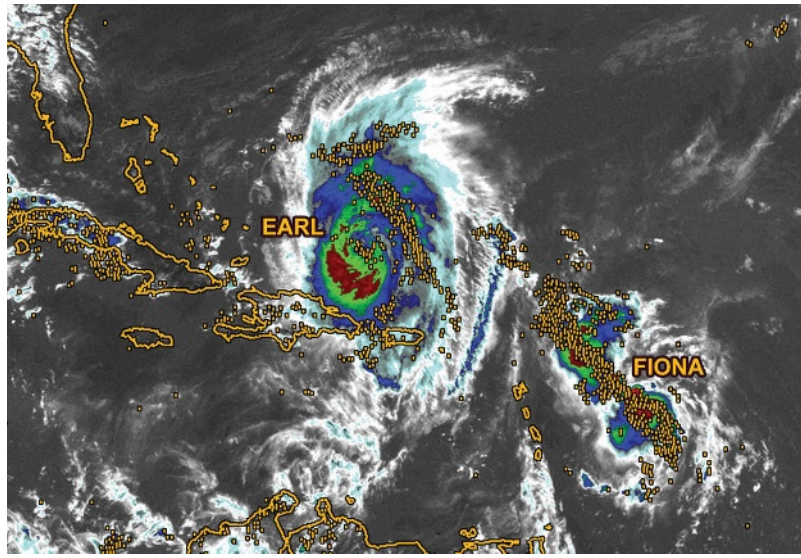
—Kelvin Droegemeier, professor of meteorology and vice president of research at the University of Oklahoma, on using supercomputers and data mining to gather important information about tornado formation. Research conducted by Amy McGovern at the University of Oklahoma simulated thunderstorms on supercomputers to analyze how constantly changing storm components interact with one another. Droegemeier explains that while radar is good at detecting something that's already present, the numerical model gives the opportunity to generate the tornadic storms from those meshing and melding atmospheric variables. Then, he says, the model can project it and predict it far in advance, which could lead to tornado warnings being issued "before a storm is even present in the sky." (Source: RedOrbit)

Tropical Cyclone Lightning and Rapid Intensity Change

Lightning activity is associated with updraft strength in the mixed-phase region of clouds above the freezing level where water exists in both liquid and frozen forms. It might then seem obvious that increased lightning activity in tropical cyclones (TCs) would be associated with more vigorous convection and, consequently, intensification. Our study uses a large sample of Atlantic and eastern Pacific TCs to show that the relationship between lightning and TC intensity change is more complex and that an outbreak of lightning near the storm center is a signal that an intensification period is coming to an end.

We examined data from the ground-based World Wide Lightning Location Network (WWLLN) for the entire life cycle of 81 Atlantic and 91 eastern Pacific TCs from 2005 to 2010. From this dataset we determined the lightning density (strikes per unit area and time) over 6-h periods in 100-km radial intervals from each storm center.

Our results generally confirm those from previous studies, where the average lightning density decreases with radius from the storm center, tropical storms tend to have more lightning than hurricanes, intensifying storms tend to have greater lightning density than weakening cyclones, and the lightning density for individual cyclones is very episodic. The results also show that Atlantic TCs tend to have greater lightning density than eastern Pacific storms. However, we determined that the largest lightning density values are associated with sheared cyclones that do not intensify very much.



Six-hour lightning locations (gold dots) centered at 1815 UTC on 31 Aug 2010 from the WWLLN displayed on a color-enhanced infrared satellite image of the western Atlantic. Hurricane Earl in the middle of the image has less lightning near its center than the much weaker Tropical Storm Fiona to its southeast. This figure is an example of the complex relationship between tropical cyclone lightning and intensity changes, where lightning outbreaks can be associated with intensification as in the case of Earl, or with a sheared environment with little strengthening as in the case of Fiona. (DeMaria et al.)

WINE IS RIPE FOR ADAPTING

When it comes to growing grapes for wine, it's important to be able to adapt, given that many factors play a role in the ripening process. New research analyzing grape-harvest diaries from southern Australia discovered that 9 out of 10 sites had trends toward earlier ripening. The scientists from the University of Melbourne and CSIRO examined 25–64 years of berry-sugar concentration records, rather than harvest dates, to determine grape maturity and found that ripening was speeding up by about eight days per decade. They attribute the change, which can determine wine-grape quality, to a variety of factors, among them climate warming, a decline in soil water content, lower crop yields, and even changing management practices at vineyards. "The study will give wine growers a head start in developing adaptation strategies to meet [an] evolving temperature and soil moisture shift," notes climate scientist and viticulturist Leanne Webb, who took part in the study. Along with managing crop yield, some examples of the strategies include irrigation and mulching, which manage soil moisture content, and vine rootstock choice. The researchers believe that in addition to informing the wine industry of adaptation options, the study is also relevant to other agricultural and nonagricultural sectors, where trends in timing of biological phases have been noted. (Source: CSIRO Australia)

Our results also show that when the lightning density is compared with intensity change in the subsequent 24 hours, Atlantic cyclones that rapidly weaken have a larger inner-core (0–100 km) lightning density than those that rapidly intensify. In contrast, the lightning density in the rain-band regions (200–300 km) is higher for those cyclones that rapidly intensified in the following 24 hours in both the Atlantic and eastern Pacific.

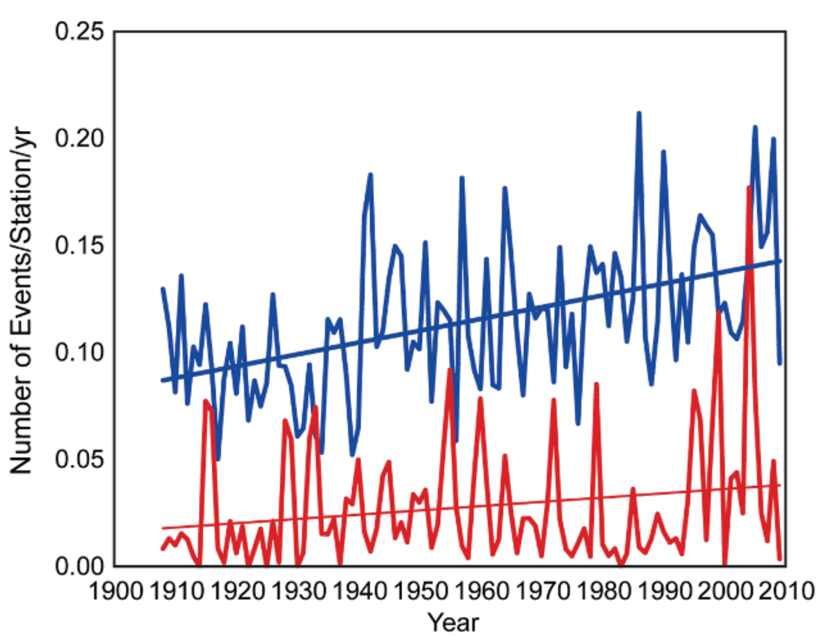
We hypothesize that vertical shear enhances asymmetric updrafts and cloud mass flux through interaction with the vertical column of potential vorticity (PV) associated with cyclone circulation, resulting in many of the inner-core lightning outbreaks. However, the negative influence of the shear dominates in the longer term, preventing intensification and sometimes leading to rapid weakening. The rain band regions are further from the PV column, so increased lighting there is a better measure of the convective instability of the storm environment and is a better indicator of future intensification.—Mark DeMaria (NOAA), R. T. DeMaria, J. A. Knaff, and D. Molenar. *"Tropical Cyclone Lightning and Rapid Intensity Change," in a forthcoming issue of* Monthly Weather Review.

Causes of Observed Trends in Extreme U.S. Precipitation Events

Numerous studies have documented that extreme precipitation events have increased in the United States over the past 30 years or so. While there has been some research on the influence of tropical cyclones on extreme event trends, no one has looked systematically at all of the meteorological phenomena causing extreme events and how they are contributing to the observed trends. Our study performed a comprehensive analysis of the meteorological causes of extreme precipitation events over the period 1908–2009. Results show an increase in the number of tropical cyclone–related and frontal extreme-precipitation events.

We used a network of 935 cooperative observer stations with nearly complete daily precipitation values to identify extreme events. There are many possible definitions of an extreme precipitation event, and it was necessary to choose just one to constrain the effort. Our definition was a station-specific threshold magnitude defined by a return period threshold and a duration. The chosen duration was daily and the return period was 1 in 5 years, or the daily threshold amount that will occur on average once every 5 years. Each event was assigned a meteorological cause, categorized as near the warm or cold front of an extratropical cyclone (FRT), near the center of an extratropical cyclone low (ETC), tropical cyclone (TC), mesoscale convective system (MCS), air mass (isolated) convection (AMC), North American monsoon (NAM), and upslope flow (USF). Maps of surface pressure, temperature, and precipitation as well as daily weather maps were the primary sources of information on which we based the classification.

The key result was that on a national scale, there are upward trends in events associated with fronts and tropical cyclones, but no trends for other meteorological causes. On a regional scale, statistically significant upward trends in the frontal category are found in five of the nation's nine geographic regions. For ETCs, there are statistically significant upward trends in the Northeast and East North Central regions. For the NAM category, the trend in the West is upward. The Central region has seen an upward trend in events caused by TCs. The percentage of events ascribed to each cause were



Time series of the number of daily, 1-in-5 year extreme precipitation events caused by fronts (blue) and tropical cyclones (red). (Kunkel et al.)

54% for FRT, 24% for ETC, 13% for TC, 5% for MCS, 3% for NAM, 1% for AMC, and 0.1% for USF.

As might be expected, there are substantial regional variations in the dominant causes of extreme events. In the Northwest and West regions, ETCs account for 80% or more of the events. The FRT category is the dominant cause in the remaining regions with the exception of the Southeast, where TCs are the most-frequent cause. MCSs are the third most-frequent cause in the West North Central and East North Central. TCs are a prominent cause in the Northeast and South. The NAM is responsible for 21% of the events in the Southwest. The minor categories of AMC and USF occur primarily in the Southeast (2%) and Southwest (2%), respectively.

This project was a very large undertaking—we assigned a cause to more than 18,000 individual station events. While we employed some automated procedures, the bulk of the decisions about a cause were arrived at through expert judgment. We based our results on consistently applied definitions of described causes and the ability to identify the causes from the available data. Occasionally, multiple categories could be identified as potential causes of a single event. A hierarchy was used in determining the primary causes, and we typically based the decisions on the forcing mechanism scale, with the largest scales identified as the primary causes.

There has not been a trend in U.S.-landfalling tropical cyclones, and the observed upward trend in TC-caused events is due to an increase in the number extreme precipitation events per TC. However, a climatology of fronts and their characteristics does not exist and frontally caused events are both the single largest contributor overall to the number of extremes and the largest contributor to the observed upward trend. This leads to some followup research questions that should be explored: Have there been any secular changes in the number of fronts? Have the characteristics of fronts (cross-front gradients in temperature and other state variables, speed of movement, etc.) changed over time?—Kenneth E. Kunkel (North Carolina State University), D. R. Easterling, D. A. R. Kristovich, B. Gleason, L. Stoecker, and R. Smith. "*Meteorological Causes of the Secular Variations in Observed Extreme Precipitation Events for the Conterminous United States,*" *in a forthcoming issue of* Journal of Hydrometeorology.

The 2011 Tornadoes and the Future of Tornado Research

BY KEVIN M. SIMMONS AND DANIEL SUTTER

The 27 April 2011 tornado outbreak across the southern United States set a record for the most tornadoes in a 24-h period and was the second deadliest in U.S. history. Less than a month later, the Joplin, Missouri, tornado added another record: the most fatalities from a single storm since official records began being kept. Numerous commentators have asked how such a death toll could occur today, given all of the available communications technologies and extensive knowledge of atmospheric conditions leading to the formation of tornadoes. Both the Joplin tornado and the 27 April outbreak were well anticipated and warned; the Storm Prediction Center's convective outlook for 27 April included an area of high risk centered over northern Alabama, where the deadliest tornadoes occurred, and all of the deaths occurred within tornado watches. Similarly, the Joplin tornado had watches covering the area and a tornado warning of more than 20 minutes.

The societal impact of tornadoes or any natural disaster depends on both the natural phenomenon and human action. The information needed to evaluate the death toll in these outbreaks is not yet completely available, so all observations about the outbreaks remain provisional. Preventing a repeat of this event in the future may require insights from meteorologists, social scientists, and others, and will likely take time for any definitive policies to mature. Nonetheless, these tragic outbreaks spur discussion of some innovative directions for future tornado research that our work (Simmons and Sutter 2011) suggests could reduce fatalities in future tornado outbreaks.

AFFILIATIONS: SIMMONS—Austin College, Sherman, Texas; SUTTER—Troy University, Troy, Alabama
CORRESPONDING AUTHOR: Kevin M. Simmons, Economics, Austin College, 900 N. Grand Suite 61591, Sherman, TX 75090
E-mail: ksimmons@austincollege.edu

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The tornadoes of 2011 highlight a unique—and perhaps the toughest—problem in protecting the public from severe weather: the long-track, violent [enhanced Fujita (EF)-4 or EF-5] tornado. Permanent homes offer adequate protection for weak and even strong (EF-2 or EF-3) tornadoes, provided residents receive a warning and take shelter in an interior closet or bathroom prior to impact. Improvements in the probability of detection and warning lead times and the reduction in area warned with storm-based warnings, along with new technologies for delivering the warnings, continue to reduce permanent home fatalities in both weak and strong tornadoes. However, insuring residents receive a warning and take shelter in an interior bathroom or closet will not prevent fatalities because these rooms often fail to protect residents from an EF-4 or EF-5 tornado. In addition, the longer a tornado remains on the ground, more structures and people are placed at risk.

To address this threat, engineers have developed safe rooms and underground shelters capable of protecting residents from even the strongest tornadoes. When a significant event occurs, there is enhanced interest and some political pressure to increase the use of shelters. However, violent tornadoes are just too rare to make hardening millions of homes in tornado-prone states cost effective.

To illustrate, Alabama suffered 232 fatalities in the 27 April outbreak and 608 from tornadoes since 1950, or 9.8 deaths per year. According to the U.S. Census Bureau, Alabama has an estimated 1.45 million single-family homes. Equipping every one of these homes with a tornado shelter could cost at least $3.6 billion and would prevent at most only fatalities that occur in permanent homes. Since 1995, 32% of U.S. tornado fatalities have occurred in permanent homes, so tornado shelters might prevent about 3.1 fatalities per year. Assuming a 50-yr expected life of a shelter and a 3% real interest rate, the cost per life saved for

permanent home shelters is $44 million. (For more on the value of tornado shelters, see chapter 5 of Simmons and Sutter 2011.) This substantially exceeds the value of a statistical life typically revealed in risky tradeoffs (see Viscusi and Aldy 2003). Consequently, we should not expect to see widespread installation of shelters or safe rooms, even in tornado-prone states.

Getting people out of the path of violent tornadoes may offer a more promising approach to saving lives from future outbreaks. Many reasonable objections could be raised against "evacuations" for tornadoes, and the objections illustrate the research required to make evacuations a safety-improving measure. For instance, permanent homes provide substantial protection for residents against most tornadic winds. People who evacuate would face substantially greater risk if caught in a vehicle or outside in a tornado than in their homes. In addition, leaving their home increases the risk from accompanying thunderstorm threats (winds, lightning, and flooding rains). Thus, we would need to know the strength of a tornado in real time, because permanent home residents will only want to get out of the path of a violent tornado. We would also want to know if a violent tornado is likely to maintain its strength, and be able to precisely forecast the path of the tornado. Emerging technologies like mobile Doppler radars, short-wavelength radars, and phased-array radars may allow the observation of the lower levels of thunderstorms to identify the winds in a tornado. The path forecast would need to be more precise than reflected in current storm-based warnings, to insure that residents are not directed into the tornado path and prevent too many people from attempting to flee the storm. Large urban areas are vulnerable to traffic problems, and shadow evacuations would result in greater vulnerability than if people remained in permanent homes. Longer lead times for warnings may help residents prepare to evacuate (e.g., arrange to go to a friend's or relative's house a safe distance from the tornado) and may be feasible in the future with warn-on-forecast for tornadoes (see the 2009 *BAMS* article by Stensrud et al.). Of course, an accurate forecast of the tornado path an hour in advance will still be critical.

The requirements for evacuations to reduce risk may seem daunting, but a 2007 *BAMS* paper by Wurman et al. highlighted the deadly potential of a long-track, violent, urban tornado. The cost per life saved indicates that shelters will not be widely deployed, so evacuations offer the only hope for reducing the death toll in a long-track EF-5 tornado. In a 2002 *Weather and Forecasting* article, Hammer and Schmidlin found that many residents of Moore, Oklahoma, successfully fled their homes in cars in advance of the 3 May 1999 F5 tornado, limiting the death toll in this powerful tornado. Residents of mobile homes are currently encouraged to abandon their homes in a tornado, and so we are perhaps informally moving toward limited-scale tornado evacuations. Research by meteorologists could help provide the additional information needed to insure that evacuations by permanent-home residents reduce risk.

One concern regarding evacuations of any type is for officials to be cognizant of the needs of those in the community who may find evacuation difficult or impossible. Lower-income residents may not have access to a car. People with diminished mobility would be left behind. State officials have taken great care to create inventories of high-need populations for other hazards. If "limited evacuations" are to be a policy consideration, then care must be given to consider those who may have trouble following the recommended action in advance of a large tornado.

A second possible response is a longer-term endeavor contingent on knowledge that currently does not exist and is only now beginning to be discussed, while being met with considerable skepticism. Tuscaloosa, Alabama, has been hit by multiple tornadoes over the past 15 years (prior to 2011, there have been 33 tornadoes in Tuscaloosa County since 1995 resulting in 44 deaths; SPC tornado archive: www.spc.noaa.gov/wcm) and suffered tornado damage less than two weeks before the 27 April tornado. Such incidents suggest to the public that there might be some local differences in the probability of tornado damage. Given the current state of knowledge, persistent tornado tracks or local differences in tornado probability cannot be proven to exist, and the perception that they exist may simply reflect our selective perception and the rarity of tornadoes. Yet, an inability to document the existence of persistent tornado tracks today does not prove that they do not exist. When the term "persistent tornado tracks" is used, it is often assumed to refer to areas that "always" or "never" get hit. However, societal impacts could be substantially reduced if areas of relatively low (but not necessarily zero) local risk can be identified. New critical facilities like hospitals, schools, and utilities could be located in the relatively safe areas, as could vulnerable facilities like mobile home parks or nursing homes. Relocation to low-probability areas would substantially reduce mobile-home fatalities and could be accomplished at relatively low cost due to the nature of mobile-home facilities. Identification of relatively high-risk locations may spur residents and facility operators to take mitigation measures like installing tornado shelters.

The ability to investigate whether local geography affects tornado tracks may soon be possible. If accurate historical tornado paths can be overlaid on precise topographical maps, researchers could search for patterns. New radars able to observe the lower portion of tornadic thunderstorms will then allow researchers to determine if patterns in the path records reflect changes in the storm structure. This would allow us to determine if persistent tracks are merely coincidental before we have decades of detailed observations.

Neither of the directions for research offered here will allow a reduction of the societal impacts of tornadoes tomorrow. The research needed to make local evacuation or relocation of critical facilities feasible will likely require years. Some other elements of tornado vulnerability, however, are unlikely to be effectively addressed with available information and technology. Hopefully, our observations here will help researchers focus their efforts on providing the information needed to reduce fatalities in future tornado outbreaks.

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http://www.weather.gov/om/hazstats.shtml

HERBERT RIEHL

Intrepid and Enigmatic Scholar

BY JOHN M. LEWIS, MATTHEW G. FEARON, AND HAROLD E. KLIEFORTH

After escaping Germany in 1933 followed by a venture on Wall Street, Riehl was drawn into meteorology by war, found his calling in Rossby's School, and went on to become the "father of tropical meteorology."

The pathways that led thousands of scientifically and mathematically inclined young people into meteorology during World War II (WWII) exhibited a wide variance as might be expected. The course followed by Herbert Riehl (1915–97) was one of the most unusual—a passageway that began in 1933 when his Jewish mother realized that escape from Nazi Germany was critically important to the welfare of her only child, 18-year-old Herbert. And although it would be another seven years before Riehl entered the field of meteorology, once he embarked on this course it quickly became apparent that he possessed a natural talent for understanding the complex atmospheric system.

In the immediate post-WWII period when dynamics of midlatitude weather was the rage, Riehl ventured into the study of low-latitude weather—the weather of the tropics and subtropics, that region of limited observations and poorly understood dynamical constraints.[1] His foray into this challenging scientific landscape set the stage for others to follow and he became known as the "father of tropical meteorology" (Gray 1998).

We explore the roots of Riehl's broad-spectrum view of meteorology and identify those who exerted great influence on this view. We pay particular attention to Riehl's ▶

PHOTO. Herbert Riehl (1915–97) in a contemplative mood on Montgomery Peak, White Mountains on the California–Nevada border. (June 1961) (Courtesy of H. Klieforth).

[1] In this manuscript, we assume the following latitudinal boundaries for the subtropics and midlatitudes: subtopics adjacent to the tropics (23.5°N/S to 35°N/30°S) and midlatitudes from 35N°/30°S to 60°N/S).

accomplishments during the first two decades of his career, from the mid-1940s through the late 1950s. It was during this time period that he established himself as an original thinker about the global atmospheric system. We examine his experiences as an instructor at the Institute of Tropical Meteorology in Puerto Rico during WWII and follow with his experiences in the milieu of "Rossby's School" at University of Chicago (U of C).

As a professor of meteorology at U of C following WWII, he drew a cadre of exceptional graduate students into his zone through the eminently successful course in tropical meteorology. And from this course came his classic text, *Tropical Meteorology* (Riehl 1954). Through presentation of vignettes from several of these students, Riehl's style of mentorship is revealed. The interactions between Riehl and one of his students, Joanne Simpson,[2] are examined in detail.

Beyond the first two decades of Riehl's career, we briefly examine his disconnection from the computational age of research in meteorology and his role in the foundation of the Department of Atmospheric Science at Colorado State University (CSU). We end with an epilogue that strives to assess his unique scholarship in meteorology.

ESCAPE FROM GERMANY. Herbert Riehl was Jewish and the only child of a wealthy German couple. With the rise to power of the fascist National Socialist German Workers Party (Nationalsozialistische deutsche Arbeiterpartei or Nazi Party) in the early 1930s, the Riehl family began planning for departure from Germany. As remembered by William Gray, one of Riehl's doctoral students at U of C during the late 1950s:

> Riehl's mother [Olga Betha (née Bach) Riehl][3] was Jewish and his father [Herbert Anton Maxamillon Riehl] gentile. His mother came from wealth and his father was a medical doctor serving with the German Army where he died of pneumonia on the western front in 1915 [when Herbert was about 1 month old]. Riehl attended a lyceum[4] [the Humanistisches Gymnasium in Berlin with accents on classics] and he finished this education around the time that Hitler came to power [Hitler was named Chancellor in March 1933]. I recall Riehl telling me that the day after he graduated from the lyceum, Hitler announced that no more Jews could graduate from high schools in Germany (Zentner and Bedürftig 1991; W. Gray 2011, personal communication).

Upon Herbert Riehl's graduation from the Humanistisches Gymnasium in March 1933, his mother sent him to England to perfect his use of the English language. And in the absence of his family, he immigrated to the United States in September 1933.[5] He immediately began work for the J. S. Bache and Co. stockbrokerage firm on Wall Street. His uncle, Jules Semon Bache,[6] was the gifted entrepreneur behind this eminently successful investment company [discussed in Birmingham (1967)]. Between late 1933 and 1936, Herbert worked all stations on the stock market floor, but arrogance and a condescending attitude toward his uncle led to his dismissal and disinheritance (J. Riehl 2011, personal communication). With the writing skills that came with his classic education, he had the desire to become a scriptwriter for the film industry. According to Gray, "… because of his fluent German and issues related to the war in Europe, he achieved his dream of becoming a scriptwriter in Hollywood" (Gray 1998; W. Gray 2011, personal communication). In fact, Riehl bought a car in 1936 and drove to California by way of Route 66. He had a "letter of introduction" in hand and obtained a job as tour guide at Metro-Goldwyn-Mayer (MGM) in Culver City, California. He advanced to scriptwriter at MGM and remained there until 1939 (J. Riehl 2011, personal communication).

AFFILIATIONS: Lewis—National Severe Storms Laboratory, Norman, Oklahoma, and Desert Research Institute, Reno, Nevada; Fearon and Klieforth—Desert Research Institute, Reno, Nevada
CORRESPONDING AUTHOR: J. M. Lewis, National Severe Storms Laboratory, Norman, OK 73072
E-mail: jlewis@dri.edu

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[2] In this paper, reference is also made to Joanne Malkus, her name before marriage to Robert Simpson in 1965.

[3] The authors have inserted the bracketed information within the quotes.

[4] Lyceum is the English word for an advanced secondary school ("prep school")—referred to as *Gymnasium* in Germany and *Lycée* in France.

[5] Riehl managed to get his mother and stepfather (Dr. Ernst Moll) out of Germany in 1939 through work with the Marlene Dietrich "underground" (transport from Germany to Cuba). (J. Riehl 2011, personal communication)

[6] Bache was the Americanized version of Bach.

Fig. 1. Athelstan Spilhaus (left) and Gardner Emmons at NYU (c. 1940) (Courtesy A. Spilhaus).

Upon his return to New York City in 1939, Riehl was granted U.S. citizenship. He then worked for a wholesale Italian greengrocer until he saw a newspaper advertisement for Army Air Corps cadets to serve in various branches of engineering.[7] Riehl passed their first test and chose electrical engineering, but he was told that every category was filled except meteorology. Riehl then spoke with Professor Athelstan Spilhaus, head of the Department of Meteorology and Oceanography at New York University (NYU), one of the five universities chosen to offer the Cadet Program in meteorology. The other universities offering this program were the California Institute of Technology, the University of California at Los Angeles (UCLA), the University of Chicago, and the Massachusetts Institute of Technology (MIT).[8] Riehl had graduated *Abitur* from the gymnasium in Berlin and his high academic achievement qualified him for the Cadet Program at NYU (Riehl 1983). He enrolled in fall 1940. Although there is scant information about Riehl's education and experiences at NYU, we know he finished first in his class. Riehl's later prowess as a synoptic analyst also leads one to believe that Gardner Emmons, an outstanding NYU teacher of synoptic meteorology, put his mark on Riehl.[9] Emmons is shown beside Spilhaus in Fig. 1. Not only did Riehl complete the Cadet Program at NYU, he did sufficient extra work to earn the M.S. degree. Although promised a commission in the Air Corps upon completion of the program, Riehl was given an honorable discharge. He never knew what happened to create the change.

Riehl's top rank in the graduating class and receipt of the M.S. degree was undoubtedly related to his strong foundation in logic and excellent performance in mathematics (J. Riehl 2011, personal communication; Riehl 1983).[10] In the absence of a commission in the Air Corps or appointment as an instructor in the Cadet Program at NYU, he visited Rossby at the U of C's Institute of Meteorology (founded in fall 1940; Byers 1976). As he recalled,

> My first acquaintance with Rossby was in 1941 when I visited him just starting in Chicago. He had obtained my first meteorology job for me at the U. of Washington after finishing the 1-year course at NYU. One year later I came back as instructor in the lab in Chicago (H. Riehl 1991, personal communication).

IMMERSION INTO METEOROLOGY.

Instructor in the cadet program. To fortify the instructional staff for the large "A" classes in the Cadet Program at U of C, Horace Byers (Rossby protégé and administrator of the Cadet Program at U of C) added Phil Church and Herbert Riehl to the Officers of Instruction for the 1942–43 academic year (Fig. 2).[11] As noted in Fig. 2, Riehl was an instructor (most likely a lab instructor based on the oral history statement given at the end of section 2). Information in Fig. 3 lists Byers and Riehl as instructors for Meteorology 211 (Synoptic Meteorology) and Church is listed as the instructor for Oceanography (Meteorology 221). In Fig. 4, we find a photograph

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[7] Most of the information in this paragraph comes from three letters sent to the authors by Janis Riehl, Herbert Riehl's widow.

[8] The Cadet Program prepared students for the job of weather forecaster (primarily in the U. S. Army Air Corps or U. S. Navy). The "A" school was a nine-month program for students with the equivalent of a baccalaureate in science. The "B" school was a 6-month program for those without the bachelor's degree—a preparatory course for the "A" program where the subjects of math, science, and communication were included. This Cadet Program was started in October 1940 (Walters 1952).

[9] Personal communications with the following meteorologists attest to Emmons' talent as a forecaster and analyst: R. Fleagle (1993), P. Clapp (1994), and A. Spilhaus (1994).

[10] In addition to Riehl's classic education at the Humanistisches Gymnasium, he attended and excelled in mathematics at the Grunevald Science Gymnasium in Berlin.

[11] Church was professor of geography at University of Washington before the war and would play a major role in the post-war establishment of the meteorology department at University of Washington.

INSTITUTE OF METEOROLOGY
OFFICERS OF INSTRUCTION

Carl-Gustaf Arvid Rossby, Sc.D., Director of the Institute of Meteorology and Andrew MacLeish Distinguished Service Professor Meteorology.
Horace Robert Byers, Sc.D., Secretary of the Institute and Professor of Meteorology.
Helmut Erich Landsberg, Ph.D., Associate Professor Meteorology.
Erwin Reinhold Biel, Ph.D., Visiting Associate Professor Climatology.
Michael Ference, Jr., Ph.D., Associate Professor Meteorology.
Victor P. Starr, Sc.M., Assistant Professor of Meteorology.
Phil Edwards Church, Ph.D., Research Associate in Oceanography.
Oliver Reynolds Wulf, Ph.D., Research Associate in Physics.
Vincent J. Oliver, S.B., Instructor in Meteorology.
Lynn L. Means, S.B., Instructor in Meteorology.
Herbert Riehl, S.M., Instructor in Meteorology.
Leonid Hurwicz, LL.M., Research Associate and Instructor in Meteorology.
George W. Platzman, S.M., Instructor in Meteorology.
Mildred Boyden Oliver, A.B., Instructor in Meteorology.
John Cary Bellamy, Ph.M., Instructor in Meteorology.
Clayborn D. McDowell, S.B., Instructor in Meteorology.
Sidney Teweles, S.M., Instructor in Meteorology.
George T. Benton, Instructor in Meteorology.
Glenn E. Stout, Jr., A.B., Instructor in Meteorology.
Robert Gardner Beebe, A.B., Instructor in Meteorology.
David Hinshaw Shideler, S.B., Instructor in Meteorology.
Robert Richard Bentley, S.B., Instructor in Meteorology.
Albert Cahn, Jr., A.B., Instructor in Meteorology.
Jack Indritz, S.M., Instructor in Meteorology.
Lawrence F. Markus, S.B., Instructor in Meteorology.
George G. Cohn, A.B., Instructor in Meteorology.
Josephine Ann Peet, S.B., Instructor in Meteorology.
Abe Rosenbloom, S.M., Instructor in Meteorology.
John G. Phillips, S.B., Instructor in Meteorology.
Verner E. Suomi, B.E., Instructor in Meteorology.
Eleanor Martha Hanson, S.B., Instructor in Meteorology.
Ward Chennell, Assistant in Meteorology.

INTRODUCTORY

The Institute of Meteorology has as its objectives: (1) advancement of the understanding of atmospheric processes and measurements, (2) instruction in the principles of meteorology, and (3) training of graduate students for professional work in meteorology. To meet the need for great numbers of newly trained professional meteorologists in the military and civil weather services, the Institute has geared its instruction to a highly intensified, productive program. A majority of the students are officers and men of the United States Army Air Forces. In addition to its all-out war instruction program, the Institute of Meteorology has taken a forward position in research directed toward the solution of problems of foremost importance in both war and peace.

FACILITIES

For meteorological instruction and research, the University provides complete synoptic-analysis laboratories, including files of several years of analyzed weather maps and upper-air charts for various regions of the world. The usual meteorological instruments and equipment for pilot-balloon observations are used by the students, and a completely equipped laboratory for radiosonde observations of the upper atmosphere is provided. A special feature is the mobile weather unit which, mounted on a truck, provides experience similar to that encountered in combat areas. The mobile unit is equipped with pilot-balloon and radiosonde apparatus, and weather-charting equipment permitting a complete weather observation, analysis, and forecast in the field. A complete hydrodynamics laboratory is used in the instruction and research. An official observatory of the United States Weather Bureau is located on the Quadrangles. Well-equipped shops make possible construction of special apparatus for research. A special library of meteorological books and journals is in the Institute of Meteorology.

Fig. 2. Officers of Instruction, Department of Meteorology, U of C, academic year 1943/44 (Courtesy of Special Collections, U of C Libraries).

of graduating students in the 3rd Cadet class at U of C and officers of instruction including Church and Riehl. The nine-month period of study for the 3rd Cadet class was from March through November 1942. Line drawings copied from this photograph are used to identify some of the individuals. The line drawings are found in appendix A.

Epiphany at Rio Piedras. By 1942, the Japanese had overrun Burma, Malaysia, the Netherlands East Indies, the Philippines, and Thailand. Japan's steady expansion led to the urgent need for knowledge of tropical weather. In response to Japan's military expansion into the tropical latitudes, Rossby approached the U.S. Army Air Corps Directorate of Weather and asked them to consider an augmentation to the 9-month Cadet program at the five universities: the addition of a tropical meteorology component. Rossby had support from some of the commanding officers in the field, who said, "… there is a lack of ability in analyzing and forecasting upper-air flow and other problems peculiar to the tropics" (Walters 1952, p. 87).

By early 1943, the Directorate authorized specialized training in tropical meteorology at Rio Piedras, Puerto Rico, home of the University of Puerto Rico.[12] Rio Piedras is located about 10 km inland from San Juan on the northern coast of this Caribbean island. The training took place at the Institute of Tropical Meteorology (ITM), an on-campus institute jointly operated by the University of Puerto Rico and the University of Chicago. Puerto Rico, then as now a U.S. Protectorate, spans ~0.5° of latitude (18°–18.5°N). Thus, it is positioned farther south than the Hawaiian Islands and comes under the influence of the Atlantic Trades and of course experiences the passage of hurricanes. In short, this was the Atlantic Ocean counterpart to the active islands of war in the central Pacific (e.g., the Northern Mariana Islands and the Philippines).

Clarence Palmer and Gordon Dunn, meteorologists with extensive experience in tropical analysis, established the course of instruction at the ITM during the months of March–May 1943 (Burpee 1989). By mid-1943, the ITM began offering courses.

[12]The Directorate also approved specialized training in oceanography (at Scripps Institution of Oceanography, La Jolla, California) and in chemical warfare (at Dugway Proving Grounds, Utah).

Although the ITM was officially an extension of the U of C Cadet Program, graduates from any of the cadet-program institutions were eligible for assignment at the institute. Palmer was appointed director of the ITM after he had gained fame as a tropical analyst and forecaster before and during the war (Palmer 1951). Prior to his appointment as director, he served as a Royal New Zealand Air Force Officer at Guadalcanal.[13]

Although there is an absence of information on the ITM in the archives of the U of C, we have relied on input from Reid Bryson and Riehl. Bryson was assigned to the ITM in October 1943. After completion of his training, he was retained as an instructor at the ITM until May 1944.[14] We quote from Bryson's reminiscence:

COURSES OF INSTRUCTION

For information concerning quarters when courses are given, see "Schedule of Courses" above. Courses 312 to 319, inclusive, offer credit either in Meteorology or in Physics. Courses marked * require payment of a laboratory fee (see p.21).

201. Introductory Meteorology.--Structure of the atmosphere; atmospheric motions and meteorological processes; air masses and fronts; tropical and extratropical cyclones. Tu-F, 10, BYERS, STARR.

203. Applied Climatology.--The climates of the world with special emphasis on war theaters. Tu-F, 9, LANDSBERG, BIEL.

205. Field Course.--Instruments and technique of weather observations; special atmospheric measurements at the observatory and in the field. ½C. Hrs to be arranged, LANDSBERG, STAFF.

211. Synoptic Meteorology.--Radiation, convection, evaporation, etc., in relation to the properties of air masses; formation and structure of fronts; the tropical and extra-tropical cyclones. Tu-F, 11, BYERS, RIEHL.

212. Synoptic Meteorology.--Details of frontal activity; motions on isentropic surfaces; lateral divergence and vorticity; physics of condensation and precipitation; phenomena affecting aeronautics. Tu-F, 11, BYERS.

***216. Meteorological Laboratory**.--Synoptic weather observations; decoding and plotting of synoptic messages; isobaric and frontal analysis of the weather map and practice in the utilization of upper-air data. 2Cs. Afternoons and evenings, MEANS.

***217. Meteorological Laboratory**.--Three-dimensional synoptic analysis, including isentropic and other upper-air charts; displacement of pressure systems and fronts; forecasting practice. 2Cs. Afternoons and evenings, OLIVER, MEANS.

***218. Meteorological Laboratory**.--Complete three-dimensional synoptic analysis, including isentropic and other upper-air charts; displacement of pressure systems and fronts; forecasting practice. 2Cs. Afternoons and evenings, OLIVER.

***221. Oceanography**.--The physical geography of the sea; elementary dynamics of ocean currents ½C. Tu-F, 9, CHURCH.

***246. Advanced Calculus for Meteorologists**.--Selected topics in advanced calculus, including partial derivatives, line and surface integrals, and the elements of ordinary and partial differential equations with emphasis on applications to mechanics and physics. [Not given 1943-44].

312. Hydrodynamics.--Review of classical mechanics including equations of motion in rotating coordinate systems. Hydrodynamics of nonviscous fluids, Euler's equation, potential flow, vortex motion. Concepts illustrated with experiments. Tu-F, 8, FERENCE.

313. Hydrodynamics of Viscous Flow.--Continuation of classical hydrodynamics with emphasis on special problems in potential flow. Navier-Stokes' equation, creeping motion, applications to lubrication, introduction to boundary layer theory. This course includes a few laboratory experiments. Tu-F, 10, FERENCE.

314. Hydrodynamics of Turbulent Flow.--Special topics in turbulent motion, including laboratory work. Hrs to be arranged, FERENCE.

315. Dynamic Meteorology.--The general circulation of the atmosphere; thermodynamics and statistics. Prereq: Physics 105, 106, 107, and preferably Math 247. Students without Met 312 are urged to take it simultaneously. Tu-F, 11, ROSSBY, STARR, PLATZMAN.

316. Dynamic Meteorology.--Introduction to the dynamics of the atmosphere. Prereq: Met 315, 312. Tu-F, 8, ROSSBY, STARR, BELLAMY.

317. Dynamic Meteorology.--Application of dynamic concepts to forecasting and special problems related to warfare. Tu-F, 8, ROSSBY, BELLAMY.

318. Physics of the High Atmosphere.--Composition and properties of the atmosphere at great heights; atmospheric ozone; radiation and ionization. Tu-F, 10, WULF.

***319 Technique of Upper-Air Observations (laboratory)**.--The various types of radiosonde and other instruments for observations in the upper air. ½C. Hrs to be arranged, BELLAMY.

341, 342, 342, 344. Experimental Meteorology.--Introductory courses leading usually to a Master's thesis. Problem will be assigned in consultation with the instructor. Prereq: Met 216, 217, 218, 319. Hrs to be arranged, ROSSBY, BYERS, LANDSBERG, FERENCE, STARR.

399. Professional Forecasters' Course.--A special, intensive course for professional meteorologists, involving mainly individual study of the application of results of new research to weather forecasting. Registration only after consultation with appropriate instructor. 3Cs. Each qr, hrs to be arranged, STAFF.

406, 407, 408, 409. Research Course.--For students prepared to undertake special research, leading to a Doctor's thesis. Hrs to be arranged, ROSSBY, BYERS.

420. Reading and Research in Foundations of Meteorology.--Prereq: Facility in reading German. Each qr, STAFF.

* Optional.
† May be taken first quarter.
‡ Geography 203 and Meteorology 221 are two half-courses in sequence.

Fig. 3. Course listing, Department of Meteorology, U of C, academic year 1943/44 (Courtesy of Special Collections, U of C Libraries).

[13]Clarence Palmer (1911–73) was appointed Associate Professor of Meteorology at UCLA in 1948 and remained there until retirement in 1972.

[14]Following WWII, Bryson returned to the U of C where he received his Ph.D. (meteorology) in 1948. He was instrumental in establishing the Department of Meteorology at University of Wisconsin—Madison in 1948.

Fig. 4. Graduation photograph of the 3rd Cadet Class at U of C in Nov 1942. A chart identifying graduates and teachers is found in appendix A (Courtesy of Noburo Nakamura and the Department of Geophysical Sciences, U of C).

> It [ITM] was really controlled by Rossby … even to choosing the instructors. There were about 30 students in each class … [and] the training program was two months … I remained as instructor after completion of the two-month program.… [The two months] really exhausted what the instructors had to say. Basically little was known, and much of what was "known" was subsequently found to be either wrong or inapplicable. The instructors busily tried to produce small papers for text purposes (e.g., Civilian Staff of the Tropical Institute of Meteorology 1945). Among the military instructors were Carlos Bonnot and George Duncan, who had worked in Panama, and my roommate Phil Allen (Bryson 1993, personal communication).

Riehl's memory of the ITM is contained in a letter sent to the author (J. L.) in 1993. A copy of this letter is found in appendix B.

It appears that Riehl's assignment was justified through his examination of records obtained from Pan American Airlines and other airlines that flew into tropical latitudes. He arrived at the ITM in July 1943 as an instructor but replaced Palmer as director in early 1945 when Palmer's health deteriorated in response to contracting malaria (J. Riehl 1991, personal communication).[15]

When one reads the preface of Riehl's opus, *Tropical Meteorology* (Riehl 1954), it becomes clear that he had a transformative experience soon after he arrived in Rio Piedras. In what comes close to poetry in a scientific book, Riehl describes his first encounter with tropical rain in the book's preface:

> On the first evening some of the staff walked along the beach and admired the beauty of the trade cumuli in the moonlight. Well schooled in the ice-crystal theory of formation of rain, they had no suspicions about these clouds with tops near 8,000 feet where the temperature is higher than +10°C. Suddenly, however, the landscape ahead of them began to dim; then it disappeared; a roar approached as from rain hitting roof tops. When some minutes later they stood on a porch, drenched and shivering, they had realized that cloud tops with temperatures below freezing were not needed for production of heavy rain from trade-wind cumulus (Riehl 1954).

THE MILIEU IN U OF C'S METEOROLOGY DEPARTMENT. ***Riehl's early research theme: Disturbances at the tropical/subtropical boundary.*** Riehl's first taste of research came with his assignment to the ITM. Here he came under the influence of Dunn, not by direct contact, but through Dunn's seminal paper: *Cyclogenesis in the Tropical Atlantic* (Dunn 1940). In his lectures on tropical meteorology at UCLA in the late 1940s, Palmer expressed the opinion that Dunn's paper was the outstanding contribution to tropical meteorology up to that point in time (Palmer 1949). Even when read today, Dunn's paper is filled with vitality and the reader feels the excitement of a meteorologist trying to unravel the mysteries of a wave pattern (labeled the "isallobaric wave" by Dunn but later referred to as the easterly wave). The wave was detected by analysis of surface pressure changes (therefore the term "isallobaric") in the absence of upper-air observations—other than wind estimates from cloud drift and pilot balloon (pibal). The wave disturbance was often associated with heavy rainfall and the development of tropical cyclones. Riehl extended Dunn's exploration of this wave through use of data he collected at the ITM.

The strength and originality of Riehl's contribution (Riehl 1945), published in the well-known series of University of Chicago Miscellaneous Reports, rested on his analysis of temperature structure accompanying the wave as a response to evaporative cooling in the rain areas and adiabatic descent/warming in the rain-free areas. He also relied on Rossby's vorticity conservation principles to estimate the phase speed of the wave relative to the typical wind speed of the current.

Upon his return to the U of C in autumn 1945, Riehl complemented the easterly wave work with a study of interaction between the tropics and subtropics, especially as the interaction was related to thunderstorm activity along the Gulf Coast (the coast of the Gulf of Mexico) (Riehl 1947). Support came from the U. S. Weather Bureau (USWB) and the work was intimately tied to the Thunderstorm Project under the direction of his doctoral advisor Horace Byers and Roscoe Braham (Byers and Braham 1949; Braham and Malone 2001). A photo of Byers in the company of associates involved in the Thunderstorm Project is shown in Fig. 5. In essence, the study examined the summertime upper-air flow patterns that typified two synoptic regimes: a "polar days" regime where midlatitude structures dominated the subtropical weather, and "tropical days" where the easterly flow aloft dominated the subtropical weather. The research was a form of synoptic typing and he submitted it to the U of C as

[15]The third and final director of the ITM was John Bellamy, one of the officers of instruction at U of C (see Fig. 2) (Byers 1970).

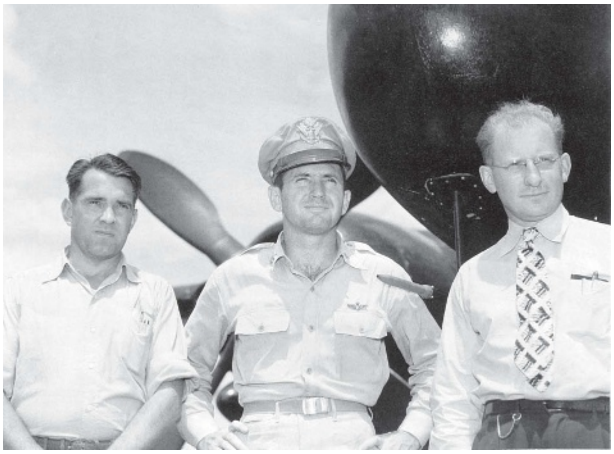

Fig. 5. Thunderstorm Project personnel (left to right): Ferguson Hall (Field Research Coordinator), Colonel Lewis Meng (Air Force Operations), and Horace Byers (Project Director). Background: P-61 aircraft used for flights through thunderstorms (c. 1947) (Courtesy of Douglas Allen).

Fig. 6. Photograph taken near Mirror Lake, CA, en route to Mt. Whitney summit (31 Jul 1951). Mountain climbers (circling clockwise from the bottom left) are Jim Angel, Harold Klieforth, Leon Sherman, Larry Eber, Harry Thompson, Einar Hovind, Herbert Riehl, and Art Belmont (Courtesy of H. Klieforth).

partial fulfillment for the doctoral degree. He was awarded the Ph.D. in 1947. He was listed as assistant professor with the M.S. degree in the *Division of Physical Sciences Catalog* (1946–47). In the 1948–49 catalog, he was listed as assistant professor with the Ph.D. It thus appears that he was promoted to assistant professor before he received his doctoral degree.[16] A photo of Riehl shortly after receipt of his degree is shown in Fig. 6.

Eric Palmén. Carl Rossby was well known for the liveliness he injected into the institutes and university programs that he led from the late 1920s through the late 1950s—at MIT and Woods Hole Oceanographic Institution (WHOI) during 1928–39, at U of C during 1940–54, and at University of Stockholm during 1948–57.[17] The parade of impressive scientific visitors was a major source of the vitality that defined "Rossby's Institutes." Among the visitors for short and long periods at the U of C were Eric Palmén, Zdenek Sekera, Tor Bergeron, Erwin Biel, Alf Nyberg, Einar Hoiland, and Halvor Solberg—Biel and Palmén taught formal classes and Bergeron assisted in synoptic meteorology (W. Saucier 1991, personal communication). For stimulating discussions of the *esprit de corps* at the U of C during this time, the reader is referred to first-hand reminiscences by Chester Newton and Riehl. We excerpt from these reminiscences:

Fig. 7. The building that housed the U of C's Meteorology Department at 5727 University Avenue. The map briefings were held in the lower level room facing the street, and the Quadrangle Club tennis courts are shown in the foreground.

> … it was a small department consisting of a half dozen people and not much more than a half a dozen graduate students. It was greatly enriched by these visitors … the atmosphere in the department was remarkable … interaction on a very informal basis (Newton 1990).
>
> The most enduring visitor, at first accompanied by Dr. Alf Nyberg, was Palmén, who kept returning to Chicago for 20 years … In the whole winter of 1946–47 there was a veritable forum in the Chicago meteorology department, centered on the first floor of the building [see Fig. 7]. There George Cressman offered daily discussions and forecasts

[16]These details were obtained from the Special Collections Research Department, U of C.

[17]Rossby had affiliations with both U of C and University of Stockholm during the late 1940s through the early 1950s.

with all available maps … and there was no end of arguments about general and cyclone circulations which followed the initial discussions…. Rossby and Palmén were almost always present and they joined in leading the arguments (Riehl 1990).

Figure 8 displays one of these discussions at a U of C map briefing. It seems to fit George Platzman's memory of these events: "It was delightful to see Palmén, an easygoing and somewhat irreverent gentleman, interrupt and argue with Rossby" (G. Platzman 1990, personal communication).

Key arguments centered on 1) respective roles of the mean meridional circulation and transient eddies in the momentum and energy budgets, 2) the mechanism(s) for maintenance of the westerlies (jet stream), and 3) the dynamical basis for alternation of the wind regimes at the surface (pattern of easterlies, westerlies, and back to easterlies, respectively, from equator to pole). By the late 1940s, there was a consensus on the three-cell meridional circulation pattern (Bergeron 1928; Palmén 1951): the thermally direct Hadley cell that spanned the tropics into the subtropics, the thermally indirect "Ferrel" cell (the "reverse" cell) that straddled the poleward part of the subtropics and extended into the midlatitudes, and the thermally direct cell poleward of the midlatitudes.[18]

The controversy that had bearing on Riehl's later work was the issue of meridional circulation vs. transient eddies in transporting momentum and energy from the tropics to midlatitudes and to the pole. It was an emotionally charged controversy that found its way into the correspondence section of the *Journal of Meteorology* (Rossby and Starr 1949; Palmén 1949; Starr 1949). The reader is referred to an informative discussion of this controversy in Wallace (1978). It would take more than a decade for the controversy to be resolved and part of the resolution came with Norman Phillips' simulation of hemispheric circulation (Phillips 1956). The simulation indicated that both mechanisms were operative. As recalled by Phillips,

Palmén and [V. P.] Starr had missing features in their respective views. Starr could not explain the low-level westerlies without the indirect meridional circulation, and Palmén could not explain the upper-level westerlies without the eddies (N. Phillips 1997, personal communication).

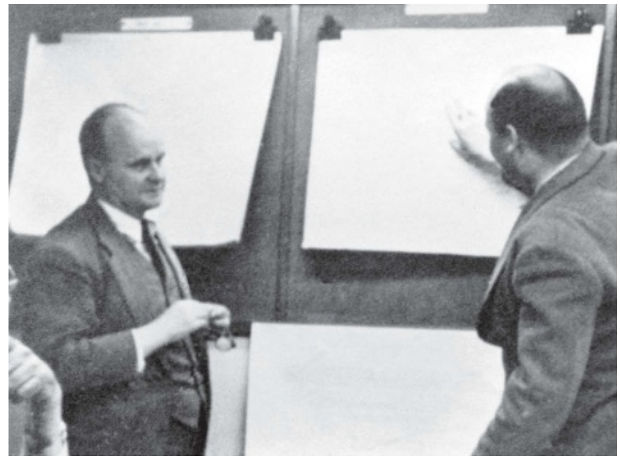

Fig. 8. Eric Palmén (middle), C.-G. Rossby (right), and Tor Bergeron (seated left) at a U of C weather briefing (c. 1947) (Courtesy of George Cressman).

Amidst this controversy, Riehl and fellow doctoral student Tu Cheng ("T. C.") Yeh sided with Palmén and decided to observationally search for evidence of the Hadley circulation.

Rossby with his dynamic personality and Byers with his obvious business/management acumen had strong influence on Riehl, but it was Palmén with his manner and style of research that most influenced Riehl (H. Riehl 1991, personal communication). As recalled by Riehl,

Palmén certainly was one of the most pleasant people we, one generation younger, encountered. He did not throw his weight around, helped people on various problems, and also was a very personable entertainer. The stress in research always remained on the physics and the nature of events, not the prediction (H. Riehl 1994, personal communication).

A photograph of Palmén and Sverre Petterssen is shown in Fig. 9.

RIEHL'S EXPANSIVE VIEW. ***Jet stream.*** Shortly after completion of his doctoral research, Riehl was entrained into the General Circulation and Jet Stream Project sponsored by the Office of Naval Research (ONR) (administered by Dan Rex, a Rossby protégé who received his D.Sc. at Stockholm under Rossby in 1951).[19] In one of the project's principal publications, the authorship appears as "staff

[18]See Lorenz (1967) for a stimulating history of atmospheric general circulation including a discussion of Bergeron's modification of Hadley's one-cell direct circulation from equator-to-pole into a three-cell pattern.

[19]Dan Rex's doctoral thesis was titled "On atmospheric blocking action: A study in climate dynamics" (Rex 1950a,b). His name is remembered through reference to the synoptic-scale "omega" blocking pattern—often referred to as "Rex blocking."

members" (Staff Members 1947).[20] Riehl recalled his first experiences with the jet stream and the associated activity at U of C:

> I first heard that term [jet stream] when coming to Chicago … to be sure we were most impressed by the news, that B-29's were sent westward to Tokio [Tokyo] became almost stationary over the target! It [the term "jet stream"] first was used tentatively but soon was taken seriously, as it indicated not only the speed of a current but also the narrowness. From the first Rossby was the chief scientist and we all followed along (H. Riehl 1994, personal communication).

Riehl's earliest independent work on the jet stream focused on multiple cases of westerly jets that overlaid weak low-level disturbances (Riehl 1948). He found that the likelihood of cyclogenesis was directly tied to the strength and latitudinal narrowness of the westerlies. He further explored the narrowness of the jet stream via observations aboard Navy aircraft (Riehl et al. 1955). The enjoyment he took in the jet stream work, especially the 1948 contribution, is evident in his following retrospective statement:

> … the prime article [on the jet steam] was by Rossby in BAMS [Bulletin of the American Meteorological Society], 28, 53–68, 1947 early. Later that year we had Staff Members, BAMS, 28, 255–280, 1947, now Palmén and Rossby as Principal Scientists and myself and others also contributing. I had a follow-up article in TAGU [Trans. Amer. Geophys. Union], 29, #2, 175–186, 1948 (still reads well, I should have stayed with that type of work) (H. Riehl 1994, personal communication).

The technical report titled "Jet streams of the atmosphere" (Riehl 1962) is a tribute to Riehl's comprehensive knowledge of the stream and this large volume is impressive for its pedagogical slant.

Hadley circulation. In parallel with his work on the jet stream, Riehl instigated two research efforts that further defined his macroscopic view of the atmosphere: 1) analysis of the Hadley circulation as a means of supporting Palmén's view on the global transport of momentum and heat [Riehl and Yeh (1950) and Riehl et al. (1950)], and 2) an elaboration on the ideas in his dissertation that connected the large-scale upper-air flow in the tropics, subtropics, and midlatitudes (Riehl 1950). And as stated in the Yeh vignette below, the study of the Hadley circulation spurred Riehl and Yeh to investigate the trade wind regime—a phenomenon that spanned the midlatitudes, the subtropics, and the tropics.

Fig. 9. Eric Palmén (left) and Sverre Petterssen in discussion at the Scandinavian–American Meteorological Society meeting in Bergen, Norway (Jun 1958) (Courtesy of H. Klieforth).

The Pacific trades. One of the twentieth century's celebrated contributions to meteorology is the study of the Northeast trade winds of the Pacific Ocean by Riehl, Yeh, Joanne Malkus, and Noel LaSeur (Riehl et al. 1951). The structure of the surface streamlines associated with the trades had been well known since the mid- to late-nineteenth century through the combined efforts of Maury and Köppen [reviewed in Lewis (1996)]. The summertime streamline pattern for the Pacific trades is displayed in Fig. 10a.

Understanding the trade wind inversion, the extremely stable slab between the lower-level marine air, cool and moist, and the upper-level potentially warm and dry air was central to the investigation.[21] In its most elementary form [as found in explanations for stratus and fog off the California coast by Petterssen (1938), Neiburger (1944), and Lilly (1968)], the inversion can be viewed as that interface between potentially warm and dry air in the large-scale descending branch of the Hadley circulation and the substantially cooler ocean surface. Because of the ocean's large

[20]Staff members: Jule Charney, George Cressman, Dave Fultz, Seymour Hess, Alf Nyberg, Eric Palmén, Herbert Riehl, Carl-Gustaf Rossby, Zdenek Sekera, Victor Starr, and Tu Cheng Yeh.

[21]The use of the word "potential" refers to potential temperature, a derived temperature that is especially valuable in tagging or marking air parcels because of its conservative property (see Saucier 1955).

heat capacity (extreme heat gain or loss is necessary to change its temperature), a temperature inversion or stable layer must form between the two air masses. Riehl and collaborators were most interested in understanding this stable layer and its role in the heat balance of the atmosphere, and answering the question: How do the trades support restoration of thermal equilibrium in the global atmosphere? As stated in the introduction to Riehl et al. (1951),

> Since the net radiational heat balance of the higher latitudes is negative and that of low latitudes positive, a poleward export of heat from the tropics takes place in the atmosphere that maintains approximate thermal equilibrium. The thermodynamic processes in the trade-wind belt are a principal link to this heat exchange.

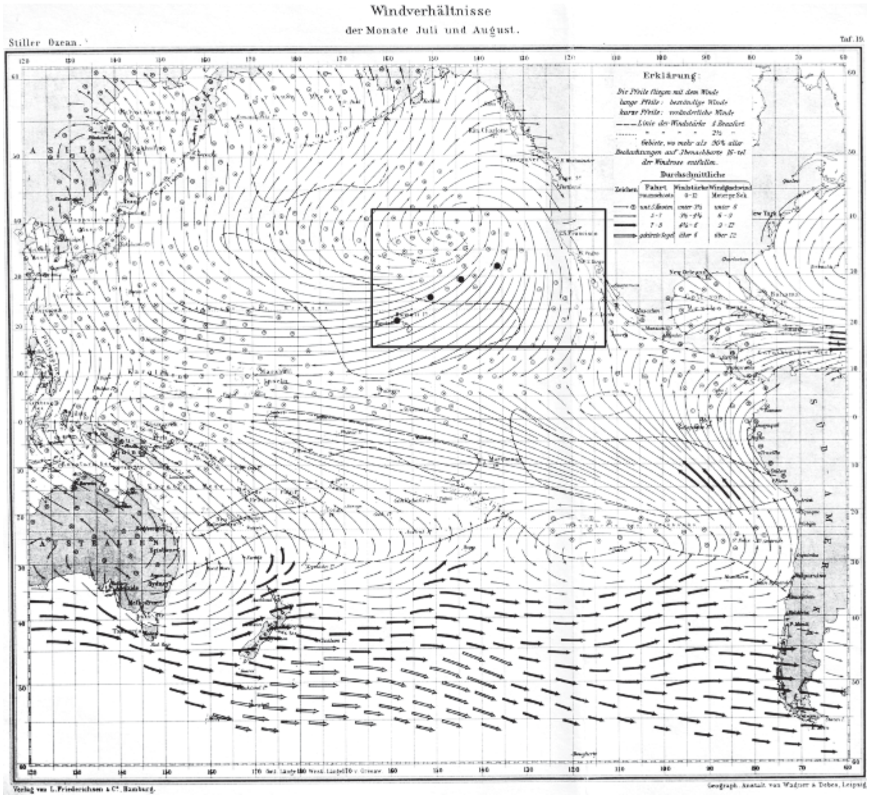

Fig. 10a. Wind analyses for the Pacific Ocean in summer (extracted from the *Segelhandbuch für den Stillen Ozean*). Average winds during the period are denoted by arrows (that "fly with the wind"). Steadiness of the wind is indicated by the length of the arrows (longest arrows are the steadiest). Categories of wind are distinguished by speeds in both m s^{-1} and numbers for the Beaufort scale. Translation: Fahrtraumschoots: "flowing sheets" under favorable winds, and Gekürzte segel: "reduced sheets" in the presence of gale-force winds. The dotted and dashed lines are isotachs of Beaufort Force 2 1/2 (no breaking waves: speed 6–7 kt) and 4 (numerous whitecaps: speed 11–16 kt), respectively. The circles indicate speeds under 5 kt.

But how would they contribute to understanding this transfer process? The availability of a unique set of observations helped define their line of research. They came into possession of upper-air observations from stationary U.S. Navy ships that operated from July to October 1945 [with twice daily radiosondes and frequent pilot balloon observations (up to 3 km)]. The ships were aligned with the flight track from San Francisco to Honolulu that in turn follows along the mean surface streamlines in summer (see Fig. 10b). And when the upper-air observations from Hickam Field

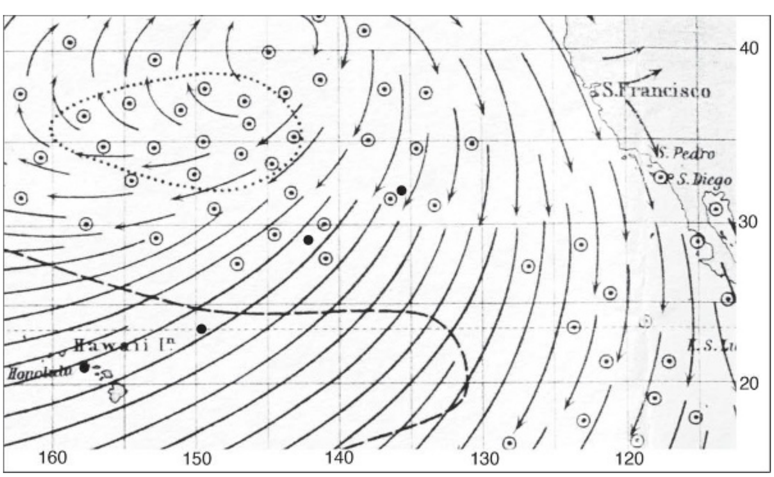

Fig. 10b. A zoom of the rectangular area outlined in Fig. 10a. The four upper-air sites used in the Riehl et al. (1951) study are denoted by the black circles. The sites east of the Hawaiian Islands are stationary U.S. Navy ships, and the westernmost site is Hickam Field. The stations fall along a curved path close to the mean surface streamlines and cover a distance of approximately 2,500 km.

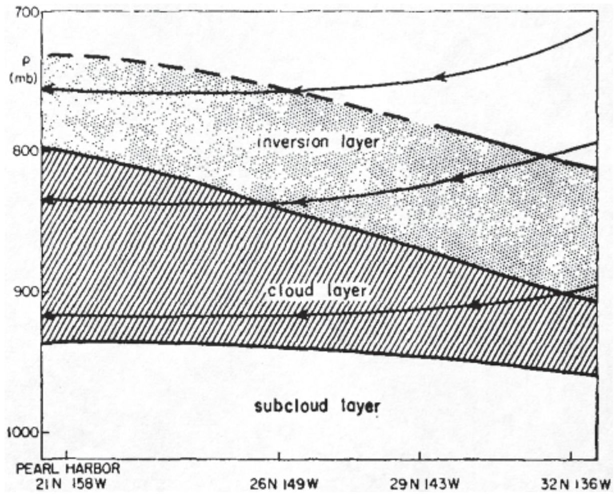

Fig. 11. Figure 8 from Riehl et al. (1951) defining the lower-level structure of the atmosphere along a cross section that follows the average streamlines in the trades.

(close to Honolulu) were added to the set, the upper-air data extended over a distance of approximately 2,500 km. Because of the steadiness of the stream, Riehl and collaborators were able to examine average conditions associated with the trades along the cross section connecting the upper-air sites.

A schematic cross section from Riehl et al. (1951; their Fig. 8) is shown in Fig. 11. This helps define atmospheric structures central to discussions that follow. The major result from their analysis was a gradual increase in the height of the inversion from inflow to outflow end of the section despite continuous divergence and sinking of air columns (the section ran from the position of the easternmost ship at 32°N, 136°W to Hickam Field at 21°N, 164°W). And in the face of earlier conjectures that the inversion was nearly impenetrable (Riehl 1954, ch. 2), these results indicated that a continuous influx of mass occurred across the inversion (from top to bottom). To use Joanne Simpson's term, the inversion was a "leaky wall" (J. Simpson 2009, personal communication). And associated with the leaky wall was the formation of cumulus cloud that pushed into the inversion and lifted it. In essence, the latent and sensible heat from the ocean had a way to escape into the levels above the inversion. As recalled by Simpson,

> One day we [Riehl and I] were just sitting there discussing the aircraft and sounding data from that line of ships.… I was trying to relate my ideas surrounding cumulus clouds forming around the trade wind inversion and the fact that the clouds were there not uselessly but probably serving a function of transporting something [see Fig. 12] … then Riehl drew this picture of a cumulus cloud with the top of it cut off. That diagram was published in the paper [Fig. 24 in Riehl et al. (1951), shown herein as Fig. 13]. I worked out the mathematical and physical basis for how these clouds were responsible for raising the height of the trade wind inversion and then wetting the cloud layer and making it deeper as the air flowed from the subtropical high down to the equatorial trough.… Clouds are a key part of the atmosphere's engine and in the regions where there is a trade wind inversion it makes holes in it and gradually lifts it up and in the equatorial trough, clouds transfer some of the heat energy from the ocean surface to the high troposphere (J. Simpson 2009, personal communication).

Despite significant advances in parameterization of the boundary layer over the ocean and associated parameterization of cloud in the decades following Riehl's study of the trades, climate models are unable to faithfully simulate the stratocumulus clouds in the trade wind regime (Moeng and Stevens 2000).[22] The incorrect simulation of cloud leads to erroneous estimates of the radiation—that is, incorrect albedo

Fig. 12. Aerial photograph of trade wind cumulus near Puerto Rico taken during the Wyman–Woodcock expedition in 1946 (Courtesy of the Schlesinger Library, Radcliffe Institute, Harvard University).

[22]Science historian Paul Edwards has written a stimulating article on the history of GCM development that includes discussion of parameterization (Edwards 2000).

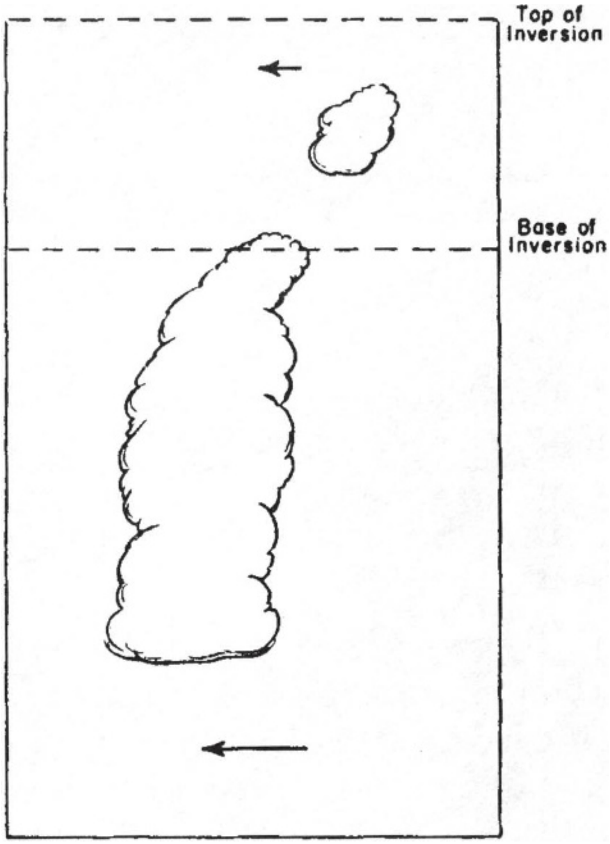

Fig. 13. Riehl's line drawing of a cumulus cloud breaking through the trade wind inversion [Fig. 24 in Riehl et al. (1951)].

that affects the amount of radiation reaching Earth's surface and incorrect estimates of the outgoing longwave radiation. The incorrect radiation in turn leads to poor simulation of the global circulation.

In response to a question about the difficulty of forecasting cloud in the trades, Akio Arakawa (personal communication, 2009) said that "… most GCMs [general circulation models] do not do well with prediction of the planetary boundary layer and then they cannot make good predictions of the cloud. Dave Randall showed this in his thesis [i.e., Randall 1976] … simulating the transition from stratiform to cumulus is especially challenging … One must be careful and try to unify the boundary layer with the upper levels of the model." A recent publication by Arakawa and Jung (2011) offers another line of attack that couples the GCMs with cloud-resolving models in the hopes of improving the forecast of cumulus clouds such as those in the trade wind regime.

Hydrodynamics Laboratory experiments. Further evidence of Riehl's interest in the "big picture" of the atmospheric processes was his linkage with fellow faculty member and hydrodynamicist Dave Fultz. Together, they conducted laboratory studies of global circulation (Riehl and Fultz 1957, 1958). A photograph of Fultz in the U of C Hydrodynamics Laboratory is shown in Fig. 14. The apparatus for the Riehl–Fultz experiments consisted of a small rotating water-filled dishpan (radius: 15.6 cm, depth: 4 cm, rotation rate: ~1 revolution per 3 seconds). As noted in the abstract of the 1957 paper, "… the flow pattern resembles the basic features of the midlatitude atmosphere in a remarkable way. Mobile long waves in a jet stream overlie cyclonic and anticyclonic vortices further down." This work was indeed gratifying to Riehl and it was complementary to his earlier work on the jet stream (Riehl 1948). As he recalled: "Now some of my happiest memories are of working with Dave Fultz and the rotating dishpan in the hydrodynamics laboratory at the University of Chicago; it was a pity that funding for this dried up with the advent of numerical modeling" (Riehl 1983).

VIGNETTES AND RIEHL–SIMPSON COLLABORATION.[23]

While Riehl pursued studies depicting hemispheric-scale processes in the atmosphere, he did not neglect studies of tropical cyclones and other smaller-scale phenomena in the tropics. Some of the strict tropical meteorology themes are featured in the next two sections that highlight Riehl's interaction with doctoral students and colleagues.

Protégés' verbal portraits of Riehl. T. C. Yeh. I got the Ph.D. in 1948 [dissertation published as Yeh (1949)]. My advisor was Professor C.-G. Rossby. Besides Professor Rossby, Professor Starr and Professor Riehl influenced me. I got a part-time job with Professor Riehl and his group. He was the lead of the group and I was second to him. This group was the most active group [in the U of C's Department of Meteorology]. Many scientists from the world came to U of C and the exchange was exciting. The problem of interest was the process of transferring momentum from the tropics to the midlatitudes. There were two ideas, one from Professor Starr and the other from Professor Palmén. Palmén's idea was that the Hadley circulation was the important part of the transfer. Professor

[23]A list of doctoral students at U of C who studied with Riehl is found in Table 1. The first Ph.D. in meteorology at U of C was awarded to Morris Neiberger in 1945. By 1961, the year that Riehl left U of C, 38 Ph.D.'s in meteorology had been awarded (U of C Archives).

Riehl and I proved the existence of the Hadley circulation examining all the winds from a ship in the tropical area, and we believed the Palmén idea was the most important [Riehl and Yeh (1950); Riehl et al. (1950)]. This also gave us interest in the trade winds and so we started that project…. One of my memories of Professor Riehl's group was that he asked us to write down our ideas on what should be studied and put these ideas in a little box. At the beginning of each month he took these ideas out of the box and we discussed them. This had a great influence on me in my career after I returned to China. I kept a small book with me and wrote whatever I think is important to study. After each month, I make a review of my thoughts. This is a very good way to think what ought to be done.

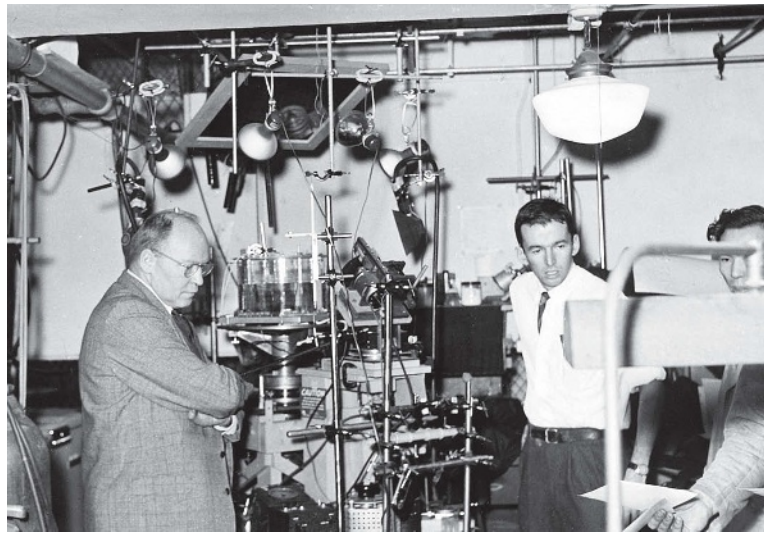

Fig. 14. C.-G. Rossby (left), Dave Fultz (center), and post-doc Yoshi Nakagawa (right) in the hydrodynamics laboratory (basement of Rosenwald Hall on the U of C campus) (c. 1955) (Courtesy of D. Fultz).

Robert Simpson. My first acquaintance with Herbert Riehl was through our exchanges of correspondence during my four Weather Bureau years in Hawaii, and his early exposure to tropical meteorology as an instructor at the Navy's (then) new Institute of Tropical Meteorology in Rio Piedras, Puerto Rico. This acquaintance soon devolved from a collegial friendship into a student–professor relationship, *I* the student, as Riehl rapidly gained recognition as a budding young scientist and prolific author of significant papers in meteorology, who finally established his preeminence in tropical meteorology with publication of his widely acclaimed textbook on that subject (Riehl, H., 1954: *Tropical Meteorology*) [see references].

Table 1. Protégés of Herbert Riehl who received their doctoral degrees in meteorology at University of Chicago. Although C.-G. Rossby was T. C. Yeh's thesis advisor, we include him in this list since he can be considered a junior colleague of Riehl. Year that the degree was granted is given in the left column.

Year	Name	Title of dissertation
1948	Tu-Cheng Yeh	On energy dissipation in the atmosphere
1949	Joanne Malkus	Certain features of undisturbed and disturbed weather in the trade wind region (Malkus 1949)
1953	Noel LaSeur	On the asymmetry of the circumpolar vortex in temperate latitudes
1955	Mikhail Alaka	A case study of an easterly jet in the tropics
1956	Charles Jordan	An experiment in low-latitude prediction with the barotropic model
1959	Tiruvalam Natarajan (T. N.) Krishnamurti	The subtropical jet stream in winter
1960	Jose Colon	On the heat balance of the troposphere and water-body of the Caribbean Sea
1962	Robert Simpson	Analysis of a large-scale atmospheric disturbance in the lower mesosphere
1963	William Gray	On the scales and internal stress characteristics of the hurricane

In my view Riehl, like many others with exceptionally creative minds, was basically a meticulous explorer in setting the stage for his research, the plan for which usually emerged from his personal assessment of the problem as displayed in exploration or from earlier research. I found Riehl quick—sometimes abrasive but fair—in responding to the worthiness of his own work, or that of his Ph.D. students, most of whom regarded him as an outstanding mentor. Yet as a classroom lecturer he had a reputation for making life quite difficult for students he considered unworthy, or who showed little interest in his lectures. However, while Riehl and I often found reason to disagree on procedural matters of scientific interpretations, we enjoyed a lifelong friendship, marred only by a single occurrence:

In 1954 [1956], to my surprise, I was appointed director of the National Hurricane Research Project, a position which Riehl had hoped to receive. It was understandably a major career blow for him, and in disappointment he resolved to have nothing to do with NHRP. But thanks to the Finnish scientist Eric Palmén, and Joanne Malkus, Riehl was soon convinced he needed to contribute to the NHRP program, which he promptly did. At West Palm Beach he was greeted with open arms, and arrangements were immediately made for him to plan and direct several hurricane research missions: Therewith a friendship was rescued; the Riehl–Malkus collaboration using NHRP research data was resumed; and a little later Riehl became sponsor of my Ph.D. program.

Years later, Riehl joined me as co-author of a book *The Hurricane and its Impact* (Simpson and Riehl 1981) during which Riehl rekindled our common zest for exploration, and mountain climbing as the two of us mused the future of hurricane prediction.

T. N. Krishnamurti. I moved to Professor Riehl's lab in 1955. He was most gracious in accepting me. As a Ph.D. student, I had felt that a global rendition of wind analysis of the subtropical jet was needed to describe its global extent. Professor Riehl was most supportive of that idea. My dissertation topic was "The subtropical jet stream of winter" [Krishnamurti 1961] and my committee included Riehl, Palmén, Petterssen, Platzman, and Fultz. That was a heavy defense and followed up with a usual warm up at the Tropopause Room[24] (of Rossby's fame) at the Windermere Hotel at the lake shore of Chicago. One of the highlights of my Chicago schooling days was also watching, at first hand, the science of Riehl and Malkus (Joanne was a part of the Riehl's lab and a constant visitor from Woods Hole) on hurricane and equatorial trough's heat budgets. We watched often the experienced style of Herbert Riehl where he could remove the noise from the important signal.

William gray. During the summer of 1958, I received tremendous encouragement from Riehl. He took me to Florida and got me a flight into a hurricane. I started working with aircraft data and just kept going. As I completed my master's and pursued a Ph.D., Riehl left for Colorado [State University]. Sverre Petterssen and Horace Byers became my direct supervisors. Riehl still provided support and offered me an associate position at CSU in 1961 which partially funded my dissertation work on the internal structure of hurricanes [Gray 1964]. However, Riehl's discontent with folks in Miami [National Hurricane Research Project (NHRP)], a funding avenue for me, caused trouble for me. Through this fallout, Riehl wanted me to completely change the direction of my Ph.D. I pondered the idea of switching to western water (a relevant topic to Riehl at that time) in order appease him, but in the end, I decided I could not. When I finished in 1963, I joined the faculty at CSU per encouragement from Riehl.

Nobody supported and encouraged me more than Herbert did in my M.S. and early Ph.D. days at Chicago from 1957 to 1960. He saw a potential in me that many others did not. Later on when I developed ideas which were different from Riehl's we had some problems. Herbert did not like (and took offense) to have his ideas challenged and not given the highest possible regard by former students that he had previously mentored. I think most of his former Ph.D. students (except for Joanne) had some problems in this regard that other of his associates did not have. However, Riehl encouraged me, and I have great respect for his scientific philosophy and approach. I am a disciple of his observational methodology.

Riehl–Simpson collaboration. During the spring semester of 1947, nearly finished with his Ph.D., Riehl taught his first course in tropical meteorology at the U of C.[25] The course began with a two-week review

[24]This was a lower-level lounge in the hotel that was so frequently used by Rossby and associates that the hotel unofficially called it the "Tropopause Room" in honor of Rossby (C. Newton 1990, personal communication).

[25]The course titled "Tropical Meteorology" first appeared in the Department of Meteorology's catalog in 1944–45. Riehl taught the course at the ITM during that year.

of the Wyman–Woodcock field program (Woodcock and Wyman 1947; Blanchard 1986) and ended with a compilation of Riehl's experiences and research at the ITM. Impressed by the course material and the teacher, doctoral student Joanne Malkus established her first connection with Riehl and he agreed to be her thesis advisor. A photo of Malkus is shown in Fig. 15.

With a long history of interest in aviation and clouds, Malkus began her doctoral research that included the subject of entrainment into developing cumulus—the exchange of mass between the rising column of cloudy air and its environment. Henry Stommel, oceanographer at Woods Hole, had just published what would become the cardinal contribution to this area of research (Stommel 1947). Following Stommel's general line of reasoning regarding entrainment, Malkus added terms to the governing equations that accounted for the differential horizontal wind speed between cumulus cloud and the environment—a differential speed that was estimated from time-lapse photography. Results indicated that if the cloud's horizontal speed is greater than the environment's speed, cloud droplets are detrained and left behind the advancing cloud and vice versa for the case when the cloud speed is less than the environment's speed. In her remembrance (J. Simpson 2009, personal communication), she made the succinct statement referring to this process: "The clouds shed moist air and thereby moisten the environment."

Riehl knew little about tropical clouds but sensed their importance and connectivity to meridional circulation and the trade wind inversion. Excerpts from an unpublished journal housed with the Malkus–Simpson oeuvre expand on this aspect of the Riehl–Malkus interaction:

> Riehl agreed to be my supervisor while insisting he did not know much about cumulus clouds…. The entrainment hypothesis by Stommel was revolutionary, but also very controversial at first. Once it was recognized that cumulus clouds exchanged air with their surroundings, a whole new area of research was opened. On this foundation, we could pioneer in recognizing the essential role of cumulus convection in tropical circulations…. Actually Riehl learned about cumulus clouds very fast, because he soon suspected they might play a crucial role in the Pacific trade-wind layer … (Joanne Simpson Archive, Schlesinger Library/Radcliff Institute, Harvard University).

Fig. 15. Joanne Malkus in the cockpit of a D.C.-3 in preparation for taking observations over the Caribbean (1956) (Courtesy of the Schlesinger Library, Radcliffe Institute, Harvard University).

The landmark paper on the Pacific Trades with Riehl as lead author and Malkus as coauthor was their first in a long series of joint publications through the decade of the 1950s.

Malkus took a full-time position at WHOI in 1951 and the geographical separation served to make collaboration more challenging. Nevertheless, Joanne made regular short-period visits to U of C where the research sessions with Riehl were intense and sometimes contentious, but never unproductive.[26] A working manuscript would generally follow the visit. Although Riehl detested challenging arguments from his protégés as mentioned by Bill Gray and Bob Simpson (personal communications, 2011), he begrudgingly tolerated these exchanges with Malkus. His dependence on her knowledge of clouds was at the heart of his tolerance. Some idea of the exchanges between Riehl and Malkus can be gleaned from Riehl's oral history with Joanne as interviewer (Riehl 1989). The exchanges are sharp 30 years after their collaborative work!

One of the major contributions that stemmed from the Riehl–Malkus collaboration was formulation of a hypothesis related to the equator-to-pole heat budget. They proposed that hemispheric thermal equilibrium could be achieved in the presence of select

[26]Despite the contentious interaction, there is evidence that Riehl exhibited a strong sense of "paternal protection" towards Malkus (J. Simpson 2009, personal communication; Reiter 1998).

[27]The name "hot towers" does not imply that cloud tops near the tropopause were necessarily warmer than their environment. The name more reflects the depth of the undiluted cloudy air (Joanne Simpson Archive, Schlesinger Library, Radcliff Institute, Harvard University).

cumulonimbi that they called "hot towers."[27] These hot towers were conjectured to effectively transport latent and sensible heat from the low-level marine layer to the upper levels of the atmosphere. Further, the select cumulonimbi were assumed to be undiluted (i.e., free from entrainment of environmental dry air) and to rise to levels of the tropopause and higher. A series of papers on the subject appeared in the mid- to late 1950s (Malkus and Ronne 1954; Malkus 1956; Riehl and Malkus 1957, 1958) with a follow-up paper in the late 1970s that benefitted from improved observations (Riehl and Simpson 1979). Researchers continue to actively investigate this subject (e.g., Tao et al. 2003; Fierro et al. 2009, 2012).

The Riehl–Simpson collaboration on hurricanes was extensive, with a focus on genesis and structural maintenance of storms (Malkus and Riehl 1960, 1964; Riehl and Malkus 1961). These contributions have been thoroughly reviewed in Yanai (1964) and more informally in Zipser (1976). Much of this research was tied to support from the NHRP. But prior to this active period of contributions to the subject of hurricanes, Riehl distanced himself from the NHRP after failure to be named director of the Project in 1956 [discussed earlier in Robert Simpson's vignette]. Riehl's failure to be named director was due in large part to USWB Chief Francis Reichelderfer's opinion that Riehl lacked diplomacy in dealing with the tropical meteorological community (R. Simpson 2009, personal communication). The strength of the relationship between Riehl and Malkus is exemplified by Malkus's "rescue" of Riehl after this great disappointment.

The value of teamwork between Riehl and Malkus is exhibited in the following vignette from Michio Yanai, a visitor to CSU soon after Riehl arrived there in 1960:

> In 1962–1964, I visited CSU by Professor Riehl's invitation. We never met before, probably he heard about my work from Charney. They were good friends…. My salary at CSU came from Riehl's contract with NHRP. During my stay at CSU, Professor Riehl was busy as first chairman of the department. He was too busy and I was mostly left to do whatever I wanted … but the best thing happened when Joanne Malkus visited Riehl and told me she wanted me to write a review paper on the formation of typhoons. I was surprised. Why did she pick me? I'm only a post-doc. I wrote it as an extension of my dissertation [for dissertation, see Yanai (1961); for review, see Yanai (1964)]. That was really interesting for me (M. Yanai 2009, personal communication).

The respect and mutual admiration between Riehl and Joanne Simpson lasted their lifetimes. It is an example of strong personalities joining forces and where the excitement of research and complementary talents reigned supreme.

U OF C DEPARTURE. Herbert Riehl was promoted to full professor at U of C during the 1956–57 academic year. However, he was open to other opportunities, as indicated by his interest in the directorship of NHRP.

A key factor in Riehl's decision to leave the U of C was the groundswell of support for a broad-based geosciences department that would merge geology and meteorology (Goldsmith 1991). Scientific justification for the merger rested on unification of the U of C's diverse talents in fluid dynamics. As stated by Goldsmith, a long-standing professor of geology at U of C: "Why shouldn't fluid dynamicists talk to paleontologists?" Riehl viewed these suggested changes with skepticism and it contributed to his decision to leave the U of C as he stated years later:

> … after Rossby had gone back to Sweden, his department of meteorology was combined with geology into a geophysical department [Department of Geophysical Sciences]. I felt that there would not be the same future for me in meteorology in Chicago anymore (Riehl 1983).[28]

The efficacy of this change to a geophysical sciences department at U of C in 1961 has been debated in a thought-provoking article (Wakefield 1994). The pros and cons appear to balance out in this article, but it is clear that the new philosophy was inconsistent with Riehl's strict synoptic–dynamic approach to meteorology.

In the face of imminent changes likely to take place in the meteorology program at Chicago, Riehl decided to take a leave of absence from U of C during the academic year 1960–61. He spent the year as a visiting professor in the department of civil engineering at CSU. His connection with CSU indirectly came from Walter Orr Roberts, the scientific leader of the University of Colorado's (CU's) High Altitude Observatory in Boulder, Colorado, during the 1950s. Roberts invited Riehl to give summer courses in meteorology at CU in 1955 and 1957 (Riehl 1989; Reiter 2011, personal communication). As Riehl recalled:

[28]Riehl made a similar statement in his interview with Joanne Simpson (Riehl 1989, p. 17).

> At that time [summer of 1955], I also went around and visited Fort Collins, Colorado State University. Looked around there on the campus and went on again. Nothing further…. [But] in 1957, we [Riehl and family] came back for another summer session and then also went to CSU. That coincided with the time that I had been doing the work with Dave Fultz and the rotating basin in Chicago. And in Fort Collins, they [Professor Jack Cermak and team] were doing wind tunnel work on the flow of the air across mountains, from the front range of Colorado, in particular, over Long's Peak and down. So they were interested in model experiments on that subject … so some time after that I had the inquiry from them whether I wouldn't like to come there and essentially open a meteorological activity (Riehl 1989).

Riehl formally resigned from U of C in 1961 and became a faculty member in CSU's department of civil engineering during the 1961–62 academic year. His move to CSU was not solely based on academic considerations, however, as he recalled in oral history:

> Anyway there was this invitation [to join the faculty at CSU], and then there came another factor, in the form of my then 5-year old daughter [Natalie] … [who] contracted pneumonia in Chicago and wound up in an oxygen tent, so for her the much drier climate was suggested. That was a real factor in accepting there. I mustn't leave the personal factor out of it. It wasn't just purely a university political or scientific decision (Riehl 1989).

With strong support from CSU's upper-level administrators including President William Morgan, a Department of Atmospheric Science—a graduate program—with Riehl as chair was created in 1962. His vision for the department had "observational methodology" at the forefront where students had opportunities to make observations (highlighted in Gray's vignette). And in the tradition of Rossby, theory underpinned analyses of observations in the Atmospheric Science Department at CSU where Ferdinand Baer and Desiraju Bavanarina ("D. B.") Rao, theoreticians out of the Chicago School, were among the first faculty hired by Riehl. Regarding Riehl's vision, it is eminently clear that he had great reservations about the cultural research change that came with the "great mutation," the phrase used by Lorenz to signify research based on the products of numerical simulation (Lorenz 1996). He was not strictly opposed to numerical simulation as a tool in research, rather he was opposed to the emphasis and the disproportionate government funding for numerical simulation at the expense of his observationally-based approach that included laboratory work in hydrodynamics (Pulwarty 2012, personal communication).

Despite the challenges of building the new department at CSU, Riehl found time to take part in the Barbados Oceanographic and Meteorological Experiment (BOMEX) and Venezuelan International Meteorological Hydrological Experiment (VIMHEX) field experiments from the late 1960s to early 1970s that had tropical air–sea interaction and tropical cumulus as central themes. And once again, his ability to inspire the young scientist was paramount as remembered by Alan Betts, an advanced doctoral student from Imperial College who took part in VIMHEX:

> Riehl was not a hands-on mentor. He would explain what he thought should be done and believed that students and post-docs would produce if they were capable…. [The problem he gave me] was calculating mesoscale vertical transports by convective systems…. He suggested it and left me to it for two years, showing little further interest—except that I knew I was expected to produce a publishable analysis! [The resulting publication is Betts (1973)] (Betts 2011, personal communication).

EPILOGUE. The first easily accessed document from Herbert Riehl's hand is the paper that he published in the series of University of Chicago miscellaneous reports (Riehl 1945). The paper is impressive for several reasons including a meaningful extension of Dunn's classic work (Dunn 1940). But beyond the extension of the earlier work, there is an indication of adroit expression with language and argument. It is thus easy to understand why Riehl took the job as a scriptwriter for MGM in Culver City. For whatever reason, that line of work was terminated and imminent war opened a narrow pathway into academic training in meteorology, a subject which was little known to him based on the following reminiscence:

> They told me that one place was still available at New York University in a course in meteorology, whatever that was (Riehl 1983).

Although it is doubtful that he could foresee a career in meteorology after the short one-year course of study at NYU, the milieu at "Rossby's School," and more particularly the independence and joy of youthful discovery that he experienced at Rio Piedras made him realize he could contribute to this field.

And while others rushed into the exciting field of midlatitude dynamics where the governing equations were amenable to the power of mathematical physics, Riehl ventured into the tropics and subtropics where the poorly understood cumulus cloud and weaker pressure gradients were central to the dynamic constraints. Here he found a scientific home that was little populated and it suited his fancy.

His primary teachers were Rossby and Palmén. But Riehl's view was more in line with Palmén, the deep-thinking synoptician whose forte was investigation of global circulation and the imbedded extratropical cyclones (Newton and Holopainen 1990). Through Yeh and Riehl's effort to more clearly understand the action of the Hadley circulation, they realized it was the trades that needed further investigation. The study of the trades by these young researchers in the company of Noel LaSeur and Joanne Malkus connected weather across a wide swath of latitudes—an approach reminiscent of the Jacob Bjerknes–Eric Palmén investigation of a midlatitude depression through the simultaneous release of radiosondes ("swarm ascents") from 11 European countries (Bjerknes and Palmén 1937). Riehl and collaborators made a major advance in understanding the transport of heat and moisture from the sea surface to the upper level of the troposphere and from thence to the midlatitudes. And as found in recent publications, the solution to this challenging problem remains evasive yet attracts a host of researchers equipped with multiscale models and observations that dwarf those available 50 years ago.

When one examines Riehl's oeuvre with subject matter ranging from first-hand accounts of traverses through the jet stream to his venture into search for the Hadley circulation, and that Herculean effort to connect the tropics/subtropics with midlatitudes, his trademark is careful analysis of observations as a means to understanding the physical processes behind the phenomenon. And although Riehl exhibited a hard-edged elitist attitude that complicated his interaction with students, he was true to the principle of mentorship as espoused by Harriet Zuckerman in her study of celebrated physicists: "… it is not knowledge or skills that protégés acquire from their masters so much as a 'style of thinking.' It is problem finding as much as problem solving" (Zuckerman 1977).

Herbert Riehl stands out as a unique thinker about the complex working of the Earth–atmosphere system. His uniqueness stems from a pioneering spirit in the exploration of tropical meteorology, but in the context of a global view. Palmén was his guide, but Riehl followed a separate path and the boldness of his scientific expeditions inclined others to follow.

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Expansive letters from Herbert Riehl's widow, Janis Riehl, supplied critical information on the life of her husband. Vital details on Riehl's life, some included in the manuscript, are a gift to all readers. The capital suggestion to contact Mrs. Riehl came from BAMS editor Edward Zipser and Ferd Baer.

We are indebted to the former students and associates of Herbert Riehl who provided oral history related to his life and work. Those who contributed are the following: Ferdinand Baer, Alan Betts, Russell Elsberry, William Gray, T. N. Krishnamurti, Robert Maddox, Roger Pulwarty, Elmar Reiter, Joanne and Robert Simpson, Michio Yanai, and T. C. Yeh. Beyond input from these close associates of Riehl, the following input was critically important to the project:

1) Four letters from Herbert Riehl in the early to mid-1990s detailing his experiences at the U of C and the ITM,
2) Reid Bryson's remembrances of the Tropical Institute of Meteorology and his identification of faculty and students in the 3rd Cadet class at U of C (Fig. 4),
3) Information from Phillip Clapp, Robert Fleagle, and Athelstan Spilhaus concerning the NYU meteorology program in the 1940s,
4) Reminiscences from Chester Newton, Norman Phillips, George Platzman, and Walter Saucier concerning the milieu in "Rossby's School,"
5) Oral history interviews with Akio Arakawa and Michio Yanai related to GCMs and tropical clouds, and
6) Cogent suggestions from formal reviewers that were followed and led to an improved manuscript.

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Photo credits are as follows: Fig. 1, Athelstan Spilhaus; Figs. 2 and 3, Special Collections, U of C; Fig. 4, Noburo Nakamura; Fig. 5, Douglas Allen; Frontispiece and Figs. 6 and 9, coauthor Harold E. Klieforth's collection; Fig. 7, author John Lewis's collection; Fig. 8, George Cressman; Fig. 10, Monika Stutzbach-Michelsen, Bundesampt für Seeschiffahrt (Seewarte), Hamburg, Germany; Fig. 12, Radcliffe Institute, Harvard University; Fig. 14, Dave Fultz; and Fig. 15, Radcliffe Institute–Harvard University. Figures 11 and 13 were copied from the *Quarterly Journal of the Royal Meteorological Society* and we are grateful to John Wiley & Sons Ltd. through Verity Butler for permission to reproduce these figures. We also thank Erin Gleason for her careful and skilled work that prepared photographs for electronic submission.

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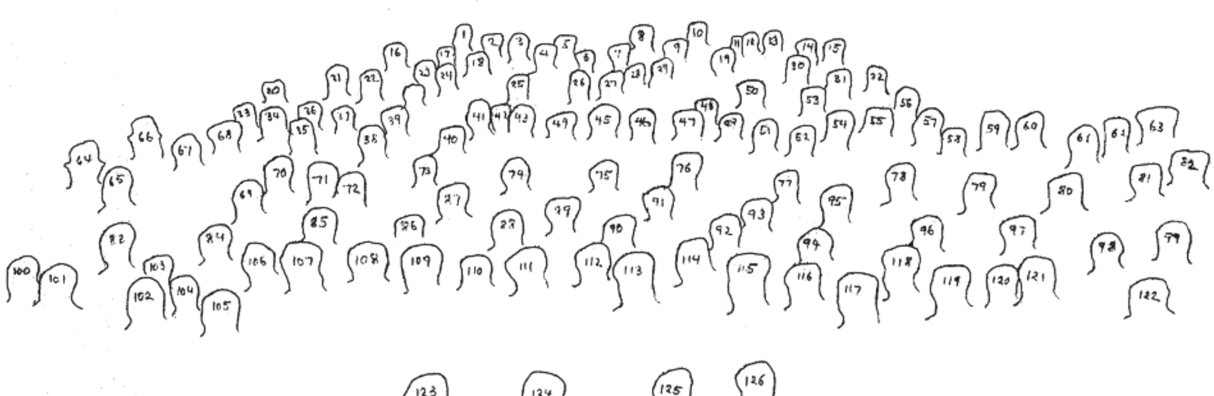
APPENDIX A. A refined version of line drawings of the heads that correspond to Fig. 3 (Original Courtesy of the Department of Geophysical Sciences, U of C). Reid Bryson identified the following faculty and students in Fig. 3: Verner Suomi (16); Reuben Belongia (41); Reid Bryson (45); Ben Bullock (49); Lynn Means (52); Oscar Singer (54); Robert Beebe (58); Ralph Nelson (59); John ? (62); Fred White (63); Bill Plumley (65); Micheal Ference (66); John Finch (67); Chidley [Ken] Johnston (69); Larry Curtis (72); John X. Jamrich (75); Mike Chancellor (80); Glenn Stout (81); Phil Smith (82); Earl Fowler (83); Vince Oliver (98); W.T. Reid (101); Phil Church (102); Herbert Riehl (103); Victor Starr (104); Leonid Hurwicz (105); Raymond Wexler (106); Joshua Holland (108); Lawrence Markus (110); Robert Bentley (112); George Haltiner (113); George Platzman (114); Massey (115); Jack Indritz (116); ? Stanley Beloy (118); Frank Snodgrass (121); Earnest Bice (122); Oliver Wulf (123); Capt. Starbuck (124); Carl Rossby (125); Horace Byers (126).



APPENDIX B (FACING PAGES). Letter sent to the author (J. L.) in 1993 by Herbert Riehl containing Riehl's reminiscences of the ITM.

18 October 1993

John Lewis,NSSL
1313 Halley Circle
Norman OK 73069

Dear Mr.Lewis,

Thank you for your recent letter inquiring about of University of Chicago's Institute of Tropical Meteorology at the University of Puerto Rico, Rio Piedras P.R This was an event now 50 years ago and my recollection about it is very poor.

The institute functioned from the middle of 1943 to the autumn of 1945 when the war ended and the U of Chicago cancelled funding.Your copies of the history leading to the founding of the institute is very interesting. I had heard some of it,but the main reason then was support for the SE Ferry route from Miami along the coast of Brasil to Ascension Island and N to the African coast, From there the planes could fly to Ñorth Africa to take part in the military campaign there. I don't think this objective was ever accomplished what with total lack of data from Puerto Rico to Recife, Ascension etc. Later, there was no need as larger aircraft stopped using this route.

For the two years of its existence the institute mainly served instruction in the SE Asian theatre, from which the first director Clarence Palmer was drawn and where he had experienced fighting until he became a victim of Malaria.I was assigned on the basis that I had been collecting microfilm from PAA mostly and other airlines lso wherever such records then existed in Washington archives about the tropics, their weather and flying methods.practised. There was general agreement that polar front cyclone weather as then taught everywhere did not serve at all in the equatorial zone.The prevailing concept was that,hurricanes apart, convection was randomly distributed with a seasonal and diurnal rhythm and stationary effects of topography.Thus the energy stored in the air in form of water vapor could only made available to the middle latitude turbulent systems through advection of air at very high levels
from the tropics having high potential energy from the ascent in the random cumuli with conversion of water vapor through condensation and freezing, plus vapor transport in the surface layers.Because of the random aspect the vapor transport could only be shown by averages around latitude circles.Models of that type,dating from the time of Hadley,were the exclusive. presentation of the energy transport from low to high latitudes until about 1945 and this oversimplified concept still has not disappeared entirely as yet.

Riehl 2

I think that the institute has contributed to pointing up the fallacy of the random convection theory through noting that the principal occurence of heavy deep convection occurs in organized weather patterns with scale of 1000 miles plus, called the synoptic scale in middle latitudes. In contrast to the usually widespread precipitation in extratropical storms,the tropical convection often occurs in banded forms that yield high amounts of precipitation not unlike summer middle latitude systems, also convection, where squall lines with duration of an hour may produce substantial percentages of mean monthly precipitation, in dry areas the whole monthly average or more.The bands are moving,mostly westward to northwestward.In the course of several days they can deliver an average of 2 cm+ of water over wide areas,Interaction between such rain events in the West Atlantic and the higher latitude storms was noted quite early. The tropical rain systems, and also what has been called "intertropical front" are not fronts in the sense of airmass differences but convergence zones related to the mechanisms initiating convection on various scales.

Special mountain effects are known worldwide. Quite extreme events could be seen near the institute from clouds derived from a mountain some 15 miles to the SE.Under right wind conditions a narrow cloud remained stationary for some hours, precipitation up to 7 inches in a one-mile wide zone, length perhaps 30 miles,and very clear skies to N and S. The cloud top was near 3 km, below freezing, with strong rotation about the horizontal axis(horizontal tornado?). With no data for quantitative analysis,nothing has ever been published.

Finally, the mere existence of the institute appears to have acted as a stimulus for a worldwide start of tropical research abandoning the random hypothesis.

I hope to get a write-up of your output again,

Sincerely,

Herbert Riehl

Herbert Riehl

P.S. If the war had lasted longer, more would have come from the ITM.

AEROSOL EFFECTS ON MICROSTRUCTURE AND INTENSITY OF TROPICAL CYCLONES

BY DANIEL ROSENFELD, WILLIAM L. WOODLEY, ALEXANDER KHAIN, WILLIAM R. COTTON, GUSTAVO CARRIÓ, ISAAC GINIS, AND JOSEPH H. GOLDEN

Because dust and pollution redistribute the latent heating through precipitation processes in a way that weakens tropical cyclones, incorporating these effects in models may improve prediction of storm intensities.

BACKGROUND AND MOTIVATION. Tropical cyclones (TC) are energized by the huge amount of latent heat that is released by the condensation of water and its subsequent precipitation. Therefore, it can be expected that changes in the precipitation-forming processes that would change or redistribute the precipitation in the TC would also redistribute the latent heating and respectively affect the dynamics of the storm and its intensity. This concept was first invoked in the STORMFURY hurricane-mitigation experiment (Willoughby et al. 1985) that focused on glaciogenic seeding of vigorous convective clouds within the eyewall. Seeding with silver iodide of these strong cloud towers at the outer periphery of the eyewall was postulated to freeze supercooled water (i.e., liquid water cooled to below 0°C) and release the latent heat of freezing. According to the conceptual chain, this would invigorate the convection (Simpson et al. 1967) in these clouds at the expense of air converging to the eyewall, and hence lead to its reformation at a larger radius, and thus, through partial conservation of angular momentum, produce a decrease in the strongest winds. Because a TC's destructive potential increases with the cube of its strongest winds, a reduction as small as 10% in its wind speed could reduce the destructive power of these storms by 33%. In fact, STORMFURY intended to cause the process that was later recognized as the naturally occurring secondary eyewall formation in mature TCs (Willoughby et al. 1982).

AFFILIATIONS: ROSENFELD AND KHAIN—Institute of Earth Sciences, The Hebrew University of Jerusalem, Jerusalem, Israel; WOODLEY—Woodley Weather Consultants, Littleton, Colorado; COTTON AND CARRIÓ—Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado; GINIS—Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island; GOLDEN—Golden Research and Consulting, Boulder, Colorado
CORRESPONDING AUTHOR: Daniel Rosenfeld, Institute of Earth Sciences, The Hebrew University of Jerusalem, Jerusalem 91904, Israel
E-mail: daniel.rosenfeld@huji.ac.il

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Unfortunately, that also meant that the very process that STORMFURY was trying to initiate—robbing the inner core of its energy—also happens naturally in mature TCs and could mask the seeding effect, if it existed.

The STORMFURY experiment also failed to show a detectable effect on the seeded hurricanes because seeding probably did not have the intended microphysical effect. It is now understood that the amount of supercooled water in the TCs is too small to expect much of a seeding effect upon freezing, and this small amount of water freezes naturally quickly above the 0°C level. This is because the cloud drops in tropical maritime clouds become sufficiently large to undergo effective coalescence and produce warm rain well below the freezing level (Andreae et al. 2004). Much of the rain precipitates without ever freezing (e.g., Khain et al. 2008a; Khain 2009). The water that manages to reach supercooled temperatures is composed of large cloud drops and supercooled rain. As shown in several modeling studies (Cotton 1972; Koenig and Murray 1976; Scott and Hobbs 1977), the presence of these large drops enhances the rapidity of glaciation of clouds and also produces greater concentrations of ice particles by the rime-splinter ice multiplication process (Hallett and Mossop 1974; Koenig 1977; Lamb et al. 1981). Thus, the window for artificial conversion of supercooled liquid water to ice in inner rainband and eyewall clouds by glaciogenic seeding is quite small. Budget considerations indicate that most of the latent heat release is caused by droplet condensation, and then by freezing resulting from riming within a deep supercooled cloud layer (Khain 2009). Freezing of the small amounts of supercooled water that may occur at upper levels should not lead to any significant effects on cloud updrafts.

Much more recently Rosenfeld et al. (2007) and Cotton et al. (2007) independently hypothesized that the invigoration of convective clouds near the periphery of the TC well away from the eyewall might be achievable by adding hygroscopic aerosols that slow the warm rain-forming processes. This was postulated to take place at the expense of the eyewall by intercepting some of the energy being transported toward the inner core and weakening the storm. In contrast, STORMFURY focused directly on the clouds just outside the eyewall in an attempt to weaken the storm using a different rationale and approach that did not prove to be productive for reasons that are now understood.

This focus on aerosols is relevant not only to hypothesized seeding methods for decreasing intensities of tropical cyclones; it is relevant also to natural changes in storm intensities. In this respect, we should also acknowledge the pioneers who recognized the possible role of African dust and other land-based aerosols on Atlantic tropical weather disturbances (Prospero et al. 1970; Prospero and Carlson 1972) and severe storms over the United States (Danielsen 1975).

There is considerable evidence for the hypothesized aerosol-induced microphysical changes and the subsequent response of the cloud dynamics. Remote sensing (Rosenfeld 1999) and in situ (Andreae et al. 2004) measurements have shown that adding large concentrations of smoke aerosols to marine tropical clouds can delay the formation of warm rain to above the 0°C isotherm within the cloud. This is done by the nucleating activity of aerosols called cloud condensation nuclei (CCN). Larger concentrations of CCN nucleate more numerous, and respectively smaller, cloud drops. The smaller drops are slower to coalesce into raindrops. Therefore, more CCN means slower conversion of cloud droplets into raindrops. The cloud water that did not precipitate as rain can either reevaporate at low levels or rise with the updraft above the freezing level, creating enhanced amounts of supercooled water, and thereby producing ice hydrometeors with the consequent enhancement of the release of the latent heat of freezing. This added heat release invigorates the convection and often enhances rain amounts in a moist tropical atmosphere (Khain et al. 2005, 2008a,b; Seifert and Beheng 2006; van den Heever et al. 2006; van den Heever and Cotton 2007; Rosenfeld et al. 2008). Greater amounts of supercooled water with stronger updrafts and more ice hydrometeors are expected to produce more lightning (Williams et al. 2002; Andreae et al. 2004). This hypothesis was supported by additional observations (Koren et al. 2005, 2010) and simulations (Wang 2005; Khain et al. 2008b). Simulations show that the invigoration also enhances the downdraft and low-level evaporative cooling (Khain et al. 2005; van den Heever et al. 2006; van den Heever and Cotton 2007; Lee 2011).

These considerations prompted Rosenfeld et al. (2007) to test by simulation the hypothesis that suppressing coalescence in the peripheral clouds of a TC would invigorate the convection there and reduce the intensity of the storm. At the same time, reports of decreasing storm intensity associated with desert dust (Dunion and Velden 2004) motivated similar independent simulations by H. Zhang et al. (2007, 2009). These simulations showed a decreasing intensity of maximum wind speed and an increase in the central pressure when aerosols were added and coalescence was suppressed.

In the wake of the disaster inflicted on the United States by Hurricane Katrina, the U.S. Department of Homeland Security (DHS) organized a workshop to develop a program to study the potential for TC mitigation. The workshop took place in Boulder, Colorado, in February 2008. William D. Laska became the DHS program manager of a project that eventually was named the Hurricane Aerosol Microphysics Program (HAMP). A science team composed of W. Woodley, W. Cotton, J. Golden, I. Ginis, A. Khain, and D. Rosenfeld was formed, and funds were established to begin research on TC mitigation. HAMP had hardly gotten underway when DHS administrators began to back off on supporting a TC mitigation research project, and instead directed that the effort be refocused on research on the effect of aerosols on tropical cyclone intensities. The emphasis was to be on improved forecasts of the intensities of tropical cyclones. Finally, by November 2010, HAMP funding was discontinued, presumably a result of changes in DHS management and its priorities.

During its brief existence, HAMP was able to establish a productive partnership between observational and modeling research. The observational effort provided the basis for the "real world" understanding of tropical clouds and cyclones, and it provided the standard for evaluating the numerical models and their simulations. Model simulations cannot pass muster unless they are consistent with actual observations of the modeled entities, where such observations have proved possible. Once this has been accomplished, a validated model can be used to provide insights into other processes at temporal and spatial scales not yet addressed by observations. This interactive process between observations and model simulations is viewed as the key to research progress. In situ aircraft measurements of cloud–aerosol interactions were planned but were not realized because of the discontinuation of HAMP. Unfortunately, no such measurements of boundary layer (BL) CCN and the microstructure of clouds that ingest these aerosols are available for TCs from other projects. This is a major gap in our knowledge that we believe needs and can be filled with aerosol and cloud physics instruments on the National Oceanic and Atmospheric Administration (NOAA) reconnaissance hurricane airplanes. Some observational support to the simulations was obtained from satellite retrievals of cloud microstructure, as reported here in the "Quantitative relationships between aerosol amounts and TC intensity" section.

In spite of its brief existence, a great deal was accomplished in the HAMP research effort. It initiated a process that got a life of its own, where the impacts of the microphysical interactions of aerosols with clouds on the dynamics of TCs was recognized to be a factor that has to be taken into account for proper understanding and accurate predictions of these storms. Here we report the main results of this research.

MODEL SIMULATIONS OF AEROSOL EFFECTS.

Simulations of impacts of pollution and dust aerosols. Building on the earlier dust simulations of H. Zhang et al. (2007, 2009), Carrió and Cotton (2011) performed idealized simulations of the direct insertion of CCN in the outer rainband region of a TC. The Regional Atmospheric Modeling System (RAMS; Cotton et al. 2003) was used in those idealized simulations that included a two-moment microphysics scheme described by Cotton et al. (2003; Saleeby and Cotton 2005, 2008), which emulates bin microphysics for drop collection, ice particle riming, and sedimentation. New algorithms for sea-spray generation of CCN and precipitation scavenging were added (Carrió and Cotton 2011). These simulations supported the hypothesis that much of the variability to enhanced CCN concentrations found in the H. Zhang et al. (2009) simulations was due to the variable intensity of outer rainband convection when the enhanced CCN advected into that region. Moreover, the CCN are not always transported efficiently from the environment in which the storm is embedded into outer rainband convection because transport is at the mercy of the local flow in those regions. Furthermore, those simulations showed a clear step-by-step response of the TC to the direct insertion of enhanced CCN in the outer rainband of the storm as described in the basic hypothesis.

Simulations by Krall (2010) and Krall and Cotton (2012) of Typhoon Nuri, which propagated into widespread pollution from the Asian mainland, revealed that during the early period of pollution ingestion (see Fig. 1) the storm intensified, but later on the storm weakened in strength in accordance with the basic hypothesis. It is speculated that the reason the storm intensified during the early period of pollution ingestion was because the simulated storm did not produce well-developed spiral rainbands and a closed eyewall, so that the pollution plume invaded the clouds around the circulation center and invigorated them with little interference from downdrafts and cold pools, as in a fully developed TC. This suggests that aerosols might enhance weak and poorly organized TCs. In both the Carrió and Cotton (2011) and Krall and Cotton (2012) simulations, the response to enhanced

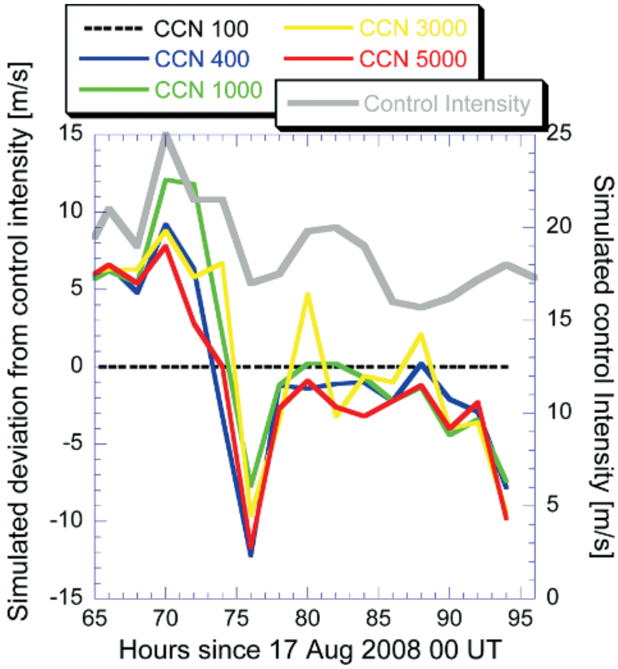


Fig. 1. (left axis) Difference of near-surface maximum wind speeds as a function of concentrations of CCN in the aerosol pollution plume with respect to the control run with 100 CCN cm^{-3}. (right axis) The maximum wind speed of the control run is shown. [After Krall and Cotton (2012).]

aerosol was monotonic up to a "tipping point" after which enhanced CCN suppressed ice particle riming and led to excessive transport of water substance to anvil levels, thereby moderating the change in storm intensity by aerosols.

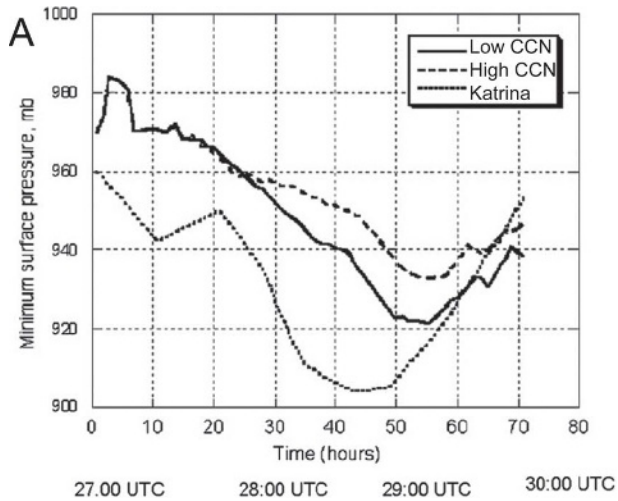
Sensitivity simulations of Hurricane Katrina to the impacts of pollution aerosols showed similar results (Khain et al. 2008b, 2010; Khain and Lynn 2011) using the Weather Research and Forecasting Model (WRF) with the implementation of a spectral bin microphysical (SBM) scheme (Khain et al. 2004). Penetration of continental aerosols to the TC periphery caused by the TC circulation approaching the land was simulated. As a result of the aerosol penetration, concentration of CCN (at 1% of supersaturation) increased at the TC periphery (radial distance from the center > ~200 km) from 100 to about 1,000 cm^{-3}. This increase in CCN concentration in the lower atmosphere and successive penetration of these CCN into rainbands at the TC periphery resulted in an increase of 16 hPa in the central pressure of the storm, as shown in Fig. 2a (Khain et al. 2010). Maximum wind speed weakened by 10–15 m s^{-1} and the area of strong winds significantly decreased (Fig. 2b). Comparisons against bulk microphysics on the same WRF dynamic framework showed that the spectral bin microphysics gave the results that were closer to the observed intensity of the storms and a tropical depression (Khain and Lynn 2011). Remarkably, the SBM TC model that interacted with aerosols drawn from the mainland predicted the TC weakening as much as several hundred kilometers from the coastline, whereas TC models with other parameterization of convective processes that do not interact with aerosols predicted the maximum intensity just at the coastline. The observations agreed best with the SBM simulation. The simulation showed that penetration of continental aerosol to the TC periphery leads to dramatic intensification of convection at the TC periphery, which competes with the convection in the eyewall (see Fig. 3). Cloud water content was substantially larger in the polluted clouds at the periphery, including above the 0°C isotherm. The extra latent heat release caused by extra droplet condensation on small droplets and by freezing of the supercooled water (largely by riming) caused an increase in updraft velocities and cloud-top heights. The maximum vertical velocities exceeded 10 m s^{-1}, which is quite rare for maritime TC clouds (Jorgensen et al. 1985; Jorgensen and LeMone 1989). At the same time, such high velocities are required to form lightning. The location of the simulated enhanced cloud electrification is similar to the observed lightning (Shao et al. 2005), and is ascribed to pollution aerosols drawn from the mainland United States when Katrina approached landfall. An increase in cloud-top height within polluted air was observed from satellites (Koren et al. 2005, 2010) and simulated in many recent studies dedicated to aerosol effects on cloud dynamics (see reviews by Rosenfeld et al. 2008; Khain 2009).

Convection outside the eyewall was observed to introduce air with low equivalent potential temperature (θ_e) into the boundary layer inflow, resulting in blocking of the inflow of the warm air to the eyewall (Barnes et al. 1983; Powell 1990). The simulations of Rosenfeld et al. (2007) showed that the suppressed warm rain caused low-level cooling in the lowest 3–4 km, probably resulting from reevaporation of some of the cloud water that did not precipitate and the enhanced colder downdrafts from the invigorated convection at the periphery. The added aerosols in the simulations of H. Zhang et al. (2009) and Carrió and Cotton (2011) also invigorated the convection at the spiral rainbands and enhanced cold pools by producing downdrafts and the evaporative cooling of rain. These cold pools blocked the surface radial inflow transporting high θ_e air into the eyewall, and led to its weakening and widening in a mechanism similar to that of an eyewall replacement (Willoughby et al. 1982).

Simulating impacts of giant CCN and sea spray. Another type of aerosol that can affect TC intensity are giant CCN (GCCN), with particles greater than 2 μm in diameter that initiate raindrop formation, even in clouds that are composed of numerous small drops (e.g., Johnson 1982; Feingold et al. 1998; Blyth et al. 2003). GCCN have been found to accelerate precipitation formation in marine stratocumuli and trade wind cumuli when CCN concentrations are large, but have little effect when CCN concentrations are small (Feingold et al. 1998; Reiche and Lasher-Trapp 2010). Therefore, sea-spray-generated aerosols (GCCN) may partially restore the rain in clouds that would be otherwise suppressed by aerosol pollutants (Rosenfeld et al. 2002). Note that sea-spray-generated GCCN concentrations increase sharply with surface wind speed, especially when reaching hurricane force (Woodcock 1953; Clarke et al. 2006; Fairall et al. 2009). The spray droplets at 10 m above sea level typically exceed 10 μm in radius, with maximum radii of 200–300 μm (Andreas 1998). Investigations of Shpund et al. (2011) indicated a synergetic effect of spray and the evolution of roll vortices in the TC boundary layer.

Recent observational and theoretical studies by Foster (2005), Lorsolo et al. (2008), Zhu (2008), and J. A. Zhang et al. (2009) indicate that helical rolls (large eddies) are an inherent phenomenon of the TC boundary layer. Ginis et al. (2004) showed numerically that strong winds typical of a TC BL trigger formation of such rolls within the BL, where they are directed along the background wind direction. When rolls are present, the direct transfer of momentum, heat, and water vapor by these structures across the BL represents a potentially important contribution to the overall transport of momentum and enthalpy that is not currently included in TC models.

Under HAMP funding a numerically efficient 2D large-eddy simulation model was developed that allowed explicit simulation of roll vortices and their interaction with the 3D mean flow in the marine BL. The model was used to investigate the physical process controlling the formation and evolution of roll vortices in the marine BL in high-wind conditions. Numerical simulations revealed dynamical interactions between the clouds, roll vortices, and internal gravity waves. Roll vortices supply clouds with moisture within the updrafts on the upwind



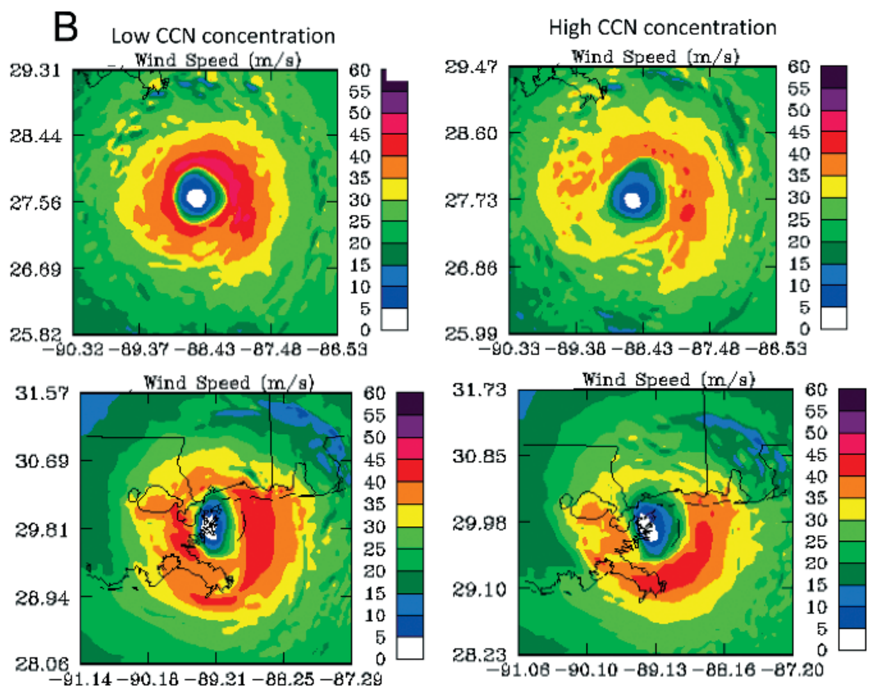


Fig. 2. Model simulations of aerosol effects on Hurricane Katrina. (a) The time-dependence of minimum pressure for low and high CCN concentrations at the periphery of the storm. The lowest line represents the observed minimum pressure. (b) The maximum wind speed for (left) low CCN concentrations and (right) continental aerosols at the periphery of the storm (top) at 2200 UTC 28 Aug and (bottom) during landfall at 1200 UTC 29 Aug. [From Khain et al. (2010).]

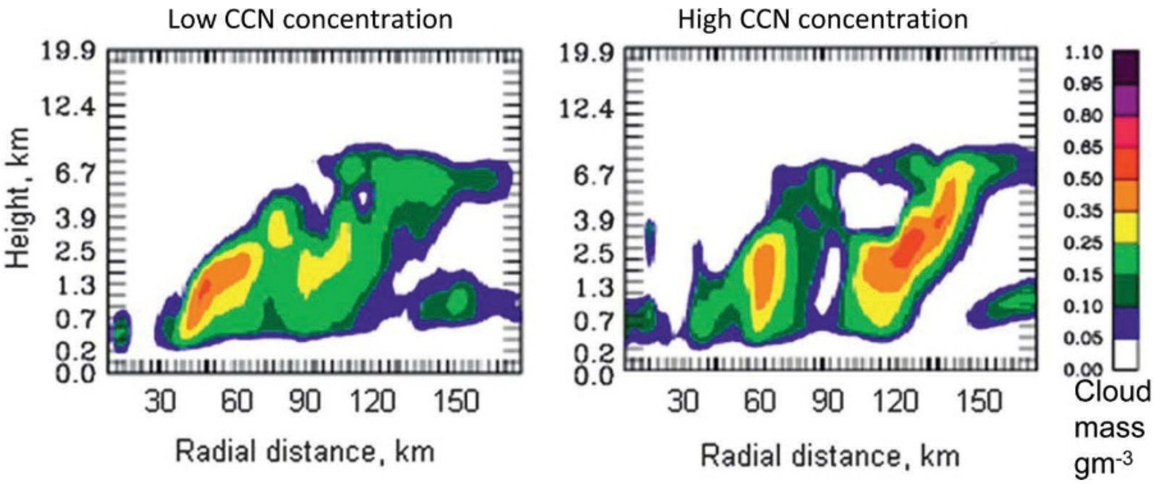


Fig. 3. The cross section of azimuthally averaged cloud water content (g m^{-3}) in (left) maritime simulations and (right) polluted at times when the maximum difference in the TC intensities took place. [From Khain et al. (2010).] Note that the polluted case (right) developed stronger and more water-rich clouds at the storm periphery, whereas the eye is not well defined and widened.

side of the clouds and lead to a well-mixed BL in agreement with observations. In the presence of strong internal gravity waves, the distance between the clouds is determined by the wave's wavelengths. The rising branch of the rolls produce updrafts that typically exceed 1.5–2 m s^{-1} and transfer spray drops upward efficiently, which dramatically changes the microstructure of the boundary layer. Consequently, the rolls nearly double the surface fluxes of heat and spray, compared to unorganized wind-induced turbulence (Ginis et al. 2004; Shpund et al. 2011).

Enhanced surface fluxes of heat and heavy sea spray have a major impact on the microstructure and dynamics of the clouds that occur over the areas with hurricane-force winds (>32 m s^{-1}). Simulations of these conditions with explicit treatment of sea spray in hurricane-force winds was performed using a Lagrangian model of the boundary layer in which ~3,700 adjacent and interacting Lagrangian parcels with a linear size of ~8 m were moving within this flow (Pinsky et al. 2008; Magaritz et al. 2009; Shpund et al. 2011). Dynamical parameters determining the statistics of the wind field in the TC boundary layer were taken from observations (J. A. Zhang et al. 2009, 2010). The dynamic and thermodynamic structure of the atmospheric BL, amount and size of spray drops reaching the base of convective clouds, and fluxes from the surface were found to be strongly dependent on the combined effect of rolls and spray. The rising branch of the rolls lift the spray efficiently while undergoing diffusional growth and coalescence that lead to formation of raindrops (with radii exceeding ~50–100 μm) at levels of 300 m that are composed mostly of seawater. This means that spray-induced rain begins near the base of deep convective clouds, having been generated by the coalescence of sea spray already at the cloud-base height. These seawater raindrops are ingested into the cloud base and accrete efficiently the cloud water, hence greatly accelerating the conversion of cloud drops into rain (Fig. 4). One can see extremely rapid formation of warm rain below freezing level (4.5 km). Raindrops do not penetrate above the 5-km level, and most of the raindrops fall out; the remainder freeze to form graupel. One can see that clouds arise at the background of shallow convective clouds (rolls) transporting spray drops upward. The spray also adds additional vapor and heat flux to the clouds and makes them grow taller, as shown in Fig. 4.

The intense sea spray that seeds the clouds in the inner spiral cloud bands and the eyewall, where hurricane-force winds occur, diminishes the suppression effects of air pollution aerosols that might be ingested into the inner parts of the storm, as already suggested by Rosenfeld et al. (2007). This would limit the effect of aerosols to invigorate the peripheral spiral cloud bands mainly, not the inner clouds or the eyewall. Such differential invigoration is consistent with the hypothesis that invigoration of the outer cloud bands would be at the expense of the eyewall, and therefore would decrease the maximum wind speeds.

OBSERVATIONS OF AEROSOL IMPACTS ON CLOUD BANDS IN TROPICAL CYCLONES.

Direct aircraft measurements of aerosols within TC circulations are relatively rare as is aircraft documentation of the properties of their banded clouds, especially supercooled cloud water contents, droplet sizes, and draft structures. Despite the general low intensities of updrafts in TCs (Black et al. 1996), aircraft measurements in a TC cloud band that ingested heavy desert dust showed unusually vigorous convection (Jenkins et al. 2008).

Fortunately, a comparison of polluted versus pristine TC spiral cloud bands is possible on a large scale from the vast array of various measurements available from satellites. Here we used satellite observations in a TC environment of aerosols, and the inferred vertical profiles of cloud microstructure, precipitation radar reflectivity, and lightning flashes. The aerosol optical depth (AOD) of the cloud-free air just outside the storm was obtained from the National Aeronautics and Space Administration's (NASA's) Moderate Resolution Imaging Spectroradiometer (MODIS). Additional information on the vertical distribution of the aerosols was obtained from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). The cloud microstructure was inferred by relating the cloud-top particle effective radius (r_e, at accuracy of 1–2 μm) to cloud-top temperature (T, at accuracy of ~1°C), as retrieved from the MODIS data, using the method of Rosenfeld and Lensky (1998). The combination of r_e from cloud tops at different T reproduces the vertical evolution of cloud top r_e with its vertical growth (Lensky and Rosenfeld 2006). The vertical evolution of the T–r_e relation can be used to infer the precipitation properties—nonprecipitating, warm rain, mixed phase, or ice precipitation processes (Rosenfeld and Lensky 1998; Rosenfeld and Woodley 2003). The relationship between aerosols that were ingested into the spiral bands can be obtained from MODIS, and the subsequent precipitation and lightning in them can be obtained from the Tropical Rainfall Measuring Mission (TRMM) satellite. The T–r_e relation can be retrieved from the Visible and Infrared Scanner (VIRS) on board TRMM. The TRMM precipitation radar (PR) provides the three-dimensional structure of the precipitation reflectivity, and the Lightning Imaging Sensor measures the lightning flashes that occur during 90 s in the field of view of the TRMM satellite during its overpass.

A clear example of the effects of aerosols on TC cloud microstructure is presented in Fig. 5 for Typhoon Nuri, which made landfall in Hong Kong on 21 August 2008. The figure inset shows NASA MODIS *Aqua* AOD, which is superimposed on surface wind flags, as calculated from the National Centers for Environmental Prediction (NCEP) reanalysis. Rectangles and their numbers match those in Fig. 6. Black solid lines delimit the TRMM PR swath, shown in the top-right inset in Fig. 7.

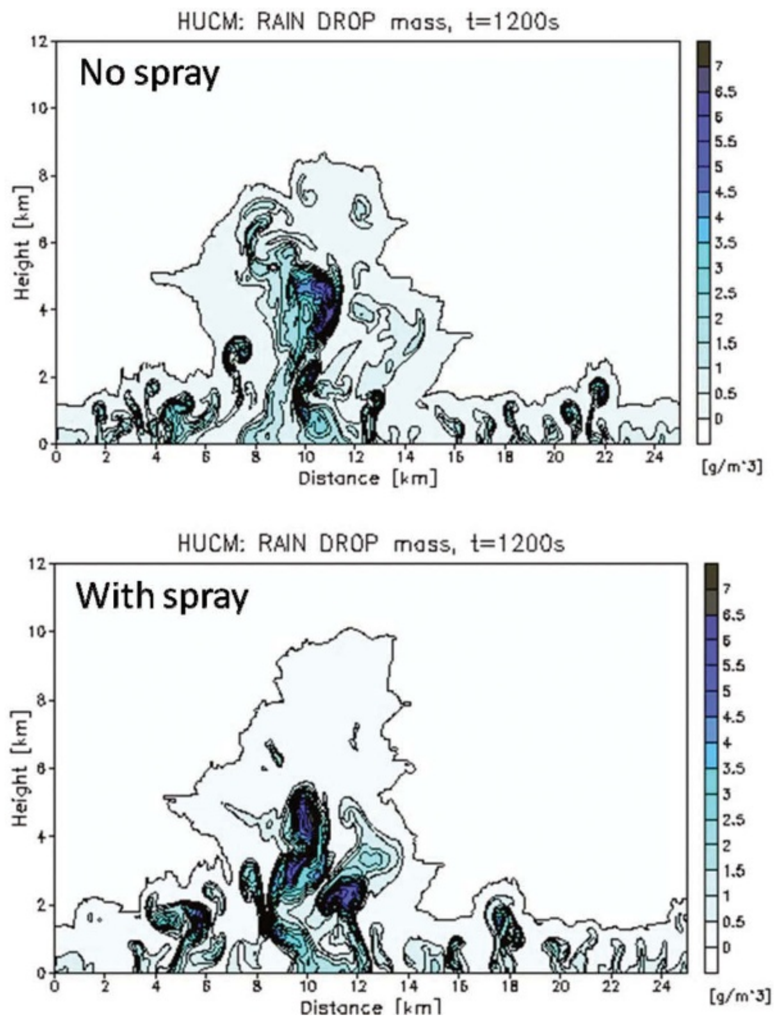


Fig. 4. Fields of rainwater content in clouds developing from the BL in the case of (top) no sea spray and (bottom) intense spray production. Note the greater amount of rain and cloud development in the case of spray. The cloud is simulated using the Hebrew University Cloud Model (HUCM) with grid spacing of 50 m [see Khain et al. (2011) for model description].

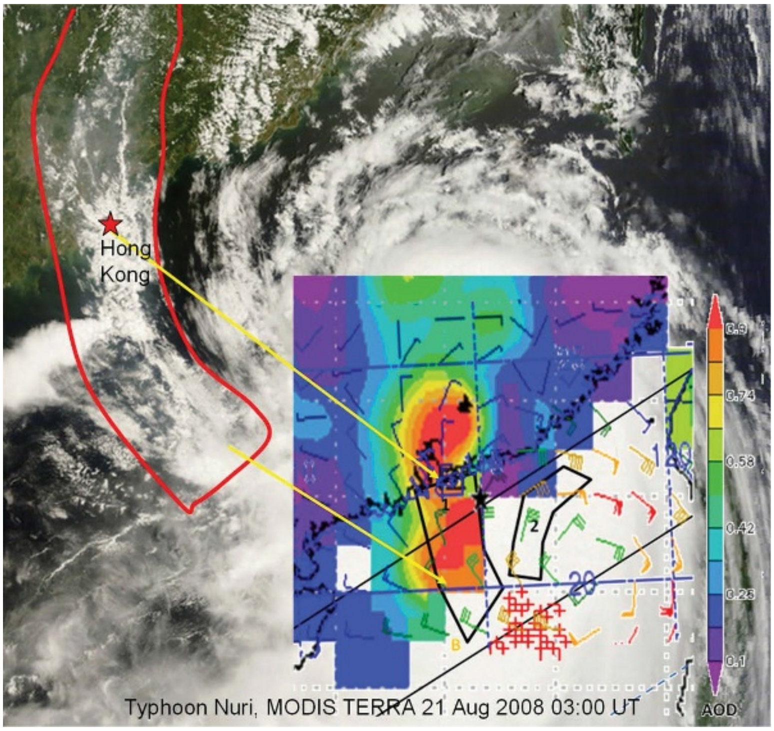


Fig. 5. True color image taken by *Terra*'s MODIS satellite from 0255 UTC 21 Aug 2008. The image size is approximately 850 km in the north–south and 1,100 km in the east–west directions. The inset shows NASA MODIS *Aqua* AOD, which is superimposed on surface wind flags, as calculated from the NCEP reanalysis. Rectangles and their numbers match those in Fig. 6. (inset) The TRMM PR swath (black solid lines), shown in Fig. 7. TRMM-measured lightning flashes are denoted (red crosses). The shaded red areas are those containing AOD > 0.9.

TRMM-measured lightning flashes in Fig. 5 are denoted by the red crosses. The shaded red areas are those containing AOD > 0.9.

As can be seen in the figures, the storm entrained heavily polluted air from mainland China while clean maritime air converged to the storm from the East China Sea. The pollution was visibly seen from space as haze that partially obscured the land surface (Fig. 5). The haze, delimited by the area bounded by the red line in the top-left corner, is seen clearly in the inset of Fig. 5 as a north-to-south red strip of MODIS AOD > 0.9. According to CALIOP (not shown), the haze was composed of a mixture of pollution aerosol in the lowest 2–3 km of the atmosphere. This haze converged into a cloud band that spiraled toward the center of the typhoon. The polluted clouds reduced the MODIS-retrieved cloud-drop size in that band to less than half in comparison to the cloud drops at the same height in the nonpolluted clouds.

The height for reaching the precipitation threshold of median $r_e \approx 14\ \mu$m (Rosenfeld and Gutman 1994; Lensky and Drori 2007) in the polluted clouds increased from the 12°C isotherm level to about –13°C (see the T–r_e relations for rectangles 1 and 2 in Fig. 6, respectively), which means delaying the rain initiation from heights of about 3 to 7 km, respectively. This is a dramatic difference between the polluted clouds and the pristine clouds in the same TC. The pristine clouds (rectangle 2 in Fig. 6) produced early warm rain and lost much water by raining out before glaciating quickly above the 0°C isotherm level, as indicated by the sharp increase of r_e beyond 14 μm below the 10°C isotherm level. The r_e of the polluted clouds remained well below 10 μm below the 0°C isotherm, implying little cloud-drop growth by coalescence, which indicates strong suppression of warm rain. The sharp increase of r_e above the –13°C isotherm indicates that mixed phase precipitation-forming processes occurred there, leading to glaciation at about –22°C, as seen by the r_e values reaching its saturation value. Simulations with the model of Khain and Lynn (2011) replicated the dramatic impact of pollution aerosols on the evolution of cloud-drop size as observed and shown in Fig. 6.

According to the TRMM PR, the polluted cloud band developed high reflectivities well above the freezing level, associated with numerous lightning flashes (see Figs. 5 and 7). This is in sharp contrast to the other bands that ingest pristine maritime air. The highest reflectivities there were weaker than in the polluted cloud band by 5–10 dBZ and were confined below the freezing level at heights of about 5 km. The pristine microphysically clean maritime cloud bands did not produce any detectable lightning, indicating scarcity of interactions between supercooled water and ice particles. The cloud-base temperatures of the polluted and clean clouds were similar, as indicated by the warmest cloudy pixels. There are no meteorological reasons other than aerosols that could conceivably serve as a potential alternative explanation to the indicated microphysical differences between the polluted and pristine clouds.

QUANTITATIVE RELATIONSHIPS BETWEEN AEROSOL AMOUNTS AND TC INTENSITY.

In addition to known sources of biases

in intensity forecasts from existing operational numerical models (e.g., inadequate horizontal resolution, incorrect representation of the vortex in the initial conditions, deficient parameterizations of surface exchange, and mixing processes), the failure to account for the impact of aerosols on TC structure and intensity is thought to contribute to existing biases. To test this idea, Rosenfeld et al. (2011) used observed TC data and forecasted TC data to statistically analyze the relationships between TC intensity and aerosol quantities at the TC's periphery. They separated the aerosol's effect on TC intensity from all other effects by using data of TC prediction models that take into account all meteorological and sea surface temperature properties, but not the aerosols. The models used were the dynamically based Geophysical Fluid Dynamics Laboratory (GFDL; Bender et al. 2007) and the statistically based Statistical Hurricane Intensity Prediction Scheme

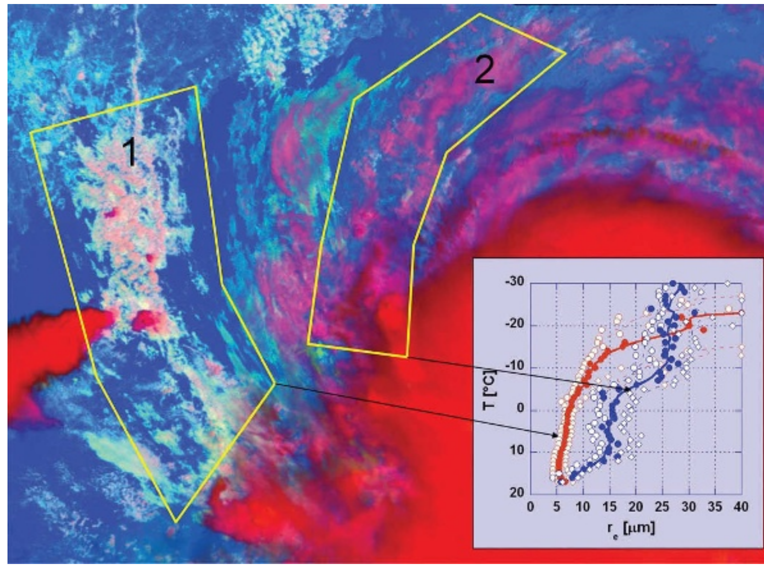


Fig. 6. Satellite microphysical analysis of Typhoon Nuri. A NASA MODIS *Terra* image from 0255 UTC 21 Aug 2008, for the same area as in Fig. 5. The colors signify different cloud properties: visible reflectance (red), 3.7-μm reflectance (green; approximating cloud-top particle effective radius r_e), and the inverse of 10.8-μm brightness temperature (blue). The inset presents the evolution of r_e (μm) on the *x* axis as a function of cloud-top temperature (°C) on the *y* axis. The median r_e for a given *T* is represented by the filled color circles, and the 15th and 85th percentiles of the distribution of r_e for a given *T* are shown by the white circles. The main text addresses the details of the analysis.

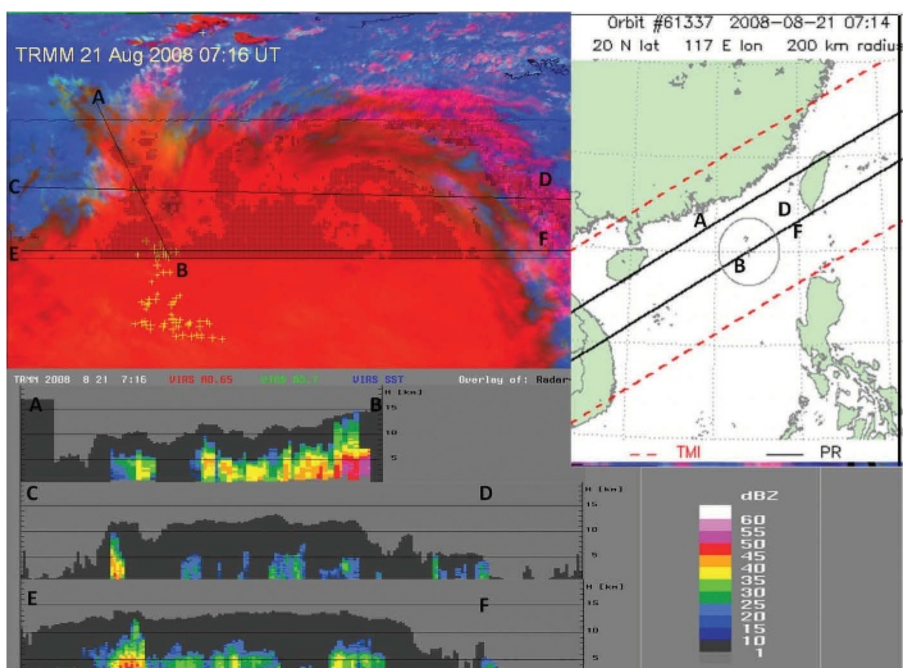


Fig. 7. TRMM satellite VIRS image of Typhoon Nuri. From 0716 UTC 21 Aug 2007 (the color scheme is the same as in Fig. 6). (top-right inset) The geographic coverage of the TRMM overpass is given. The swath between the two red lines is the maximum viewing area of the TRMM VIRS. The swath of the PR is delineated (two center lines). (top-left inset) The swath of PR is delimited on the main figure (topmost and bottommost black lines). Areas with the dark gray overlay are PR-detected precipitation from the spiral bands of the storm, which are present under the high cloud canopy. Lightning flashes are denoted (yellow crosses). (bottom inset) The three vertical cross sections along the lines AB, CD, and EF are represented on the VIRS image by black solid lines, with the respective letters (e.g., the left end is point A and the right end is point B). The precipitation reflectivity (dBZ) is represented (colors), as measured by the TRMM PR. The main text addresses the details of the analysis.

(SHIPS; DeMaria et al. 2005) models. The hypothesis was that if greater aerosol amounts actually act to decrease storm intensity, then the forecast model would tend to overpredict the observed intensities of the more "polluted" storms. Rosenfeld et al. (2011) tested this hypothesis by examining the prediction errors of the maximum sustained wind velocities (dV_{max}) and their statistical relationship with the AOD that was calculated by the Goddard Chemistry Aerosol Radiation and Transport (GOCART) hindcast model (Chin et al. 2000). The GOCART was used to obtain aerosols under cloudy conditions and to avoid the challenge of measuring aerosols from space in a mostly cloudy atmosphere. The results showed that the variability of aerosol quantities at a TC's periphery can explain about 8% of the forecast errors of the TC. Indeed, the actual intensities of polluted TCs were found to be, on average, lower than their predicted values, providing additional evidence for the hypothesis. Quantitatively, an increase in AOD by 0.01 is associated on average with a decrease of 0.3 kt (0.15 m s^{-1}) in the peak wind speed. No distinction between aerosol types could be made. It was also found that TC intensity might be more susceptible to the impacts of aerosols during their developing stages and less in the TC's mature and dissipating stages, consistent with the modeling results of H. Zhang et al. (2009).

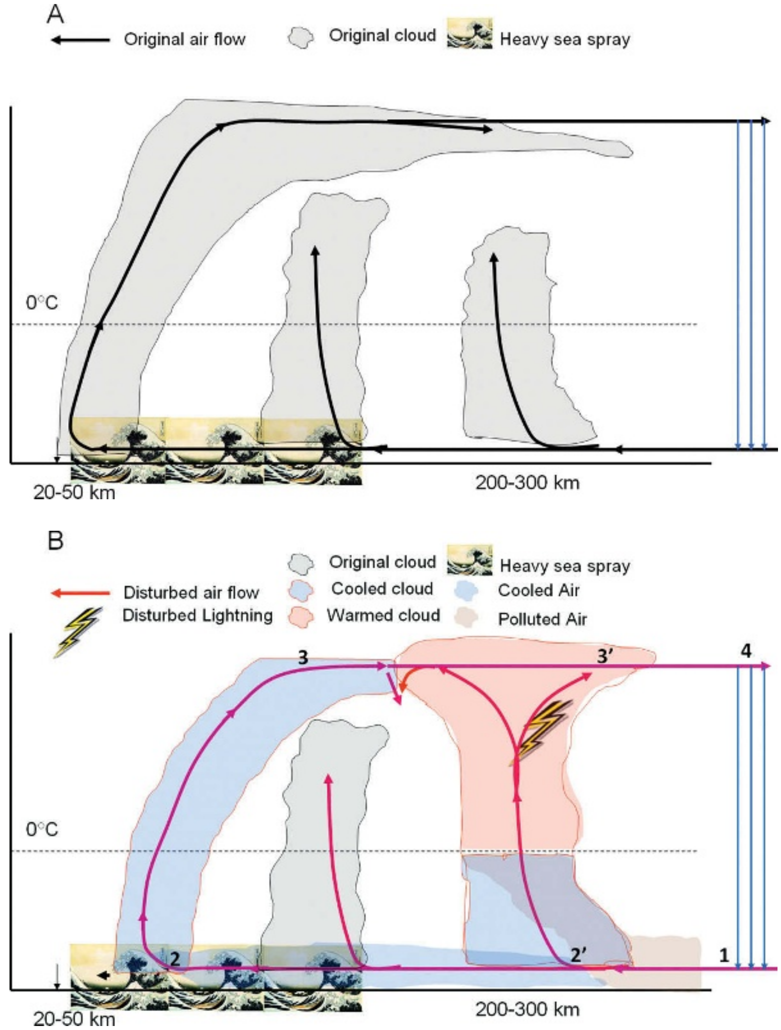


Fig. 8. Conceptual model of aerosol impacts on tropical cyclones. The (a) undisturbed and (b) disturbed states are shown. (b) Pollution or dust aerosols slow the formation of warm rain in the peripheral clouds, causing invigoration and electrification of the clouds and warming aloft, coupled with stronger downdrafts and intensified low-level cool pools. Strong nucleation and precipitation scavenging and sea spray from the rough sea promotes warm rain in the inner cloud bands and eyewall clouds, which reduces the suppression effect resulting from any remaining pollution aerosols that were not washed down, so that little aerosol-induced invigoration can occur there. The convection in the outer cloud band decreases the inflow toward the eyewall. The cold pools also partially block the inflow, causing cooling, weakening and widening the eyewall, leading to weaker winds. The closure of the circulation system with subsiding air far away from the TC is denoted (blue lines).

SUMMARY AND FUTURE DIRECTIONS.

Based on the above observations and simulations, our present understanding of the effect of aerosols on tropical clouds and cyclones is summarized in the following links in the conceptual chain, which is illustrated in Fig. 8:

1) Small (submicron) CCN aerosols in the form of particulate pollution and/or desert dust nucleate larger numbers of smaller cloud drops that slow the coalescence of the cloud drops into raindrops.
2) The CCN aerosols present in the peripheral clouds of the TC slow the rain-forming processes there.
3) The delayed formation of rain decreases the amount of early rainout from the rising air; hence, more water can ascend to freezing levels as supercooled water where ice precipitation particles form.

4) The greater amount of freezing water aloft releases extra latent heat that invigorates the convection. The invigoration and the added supercooled water are manifested in greater cloud electrification and lightning discharges.
5) The greater vigor of the peripheral clouds draws more ascending air at the periphery of the storm, thereby bleeding the low-level airflow toward the eyewall. The weakened convergence toward the center causes the central pressure to rise; less air ascends in the eyewall, and there is respectively lower maximum wind speed.
6) The intensified ice precipitation in the peripheral clouds melts and evaporates at the lower levels, thereby cooling the air that converges into the center of the storm.
7) Stronger low-level cooling produces cold pools that favor the intensification of storm cells in the outer rainbands, which transport more water vertically leading to enhanced latent heating and stronger convection in a positive feedback loop.
8) Additional low-level cooling occurs when the cloud drops that did not precipitate and did not ascend to the freezing level reevaporate.
9) The storm is further weakened by cooling of the low-level air that converges to the center, in addition to the air bleeding effect that was discussed in the first five points. The cooler air has less buoyancy and hence dampens the rising air in the eyewall, thereby weakening further the convergence and the maximum wind speed of the storm.
10) Under hurricane-force winds very intense sea spray is lifted efficiently by roll vortices in the BL and induces rain of mostly seawater at the height of the convective cloud base. This restores the warm rain processes and offsets the delaying effect of small CCN aerosols on rain-forming processes. Furthermore, the core of the TC is nearly saturated at low levels; thus, cold pool formation in that region is inhibited. Therefore, the CCN aerosol effect would be most effective in the peripheral clouds of the storm, where the wind speeds can be much less than hurricane force. Strengthening of the winds there would reduce the sensitivity of the storm to the weakening effect of the CCN aerosols.

These links in the conceptual model are components of a hypothesis that requires additional investigation. However, its physical plausibility underlines the importance of understanding precipitation-forming and evaporation processes in TC clouds and the need to simulate them and the resultant cold pools properly in order to obtain additional improvements in TC prediction models.

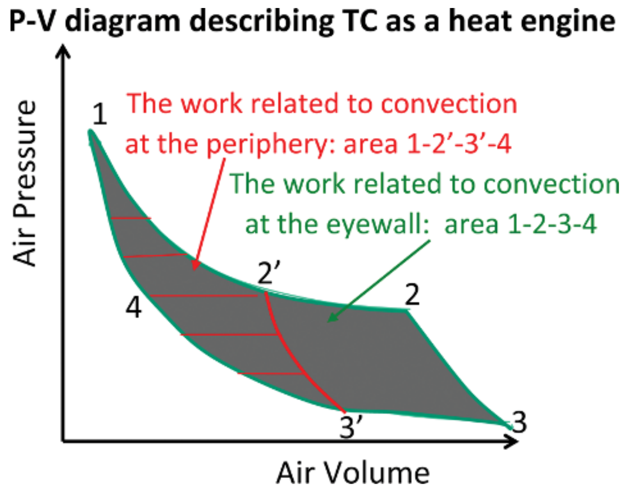


Fig. 9. Illustration of the TC as a heat engine, and the impact of aerosol-induced change in circulation on the work done. The undisturbed circulation goes near the surface from outside of the TC (point 1) to the eyewall (point 2), to the cloud top (point 3) and outside the TC aloft (point 4), and then back with the subsidence to point 1. The location of each point is shown in Fig. 8b. Air that rises already at the periphery of the TC or in an eyewall with enlarged radius and higher central pressure follows the thermodynamic trajectory of 1–2'–3'–4. Because the enclosed area denotes the work done by the TC heat engine, shortcutting through 2'–3' decreases the work done by an air parcel that is processed by the TC, and hence the intensity of the storm.

On a fundamental level, weakening of a TC resulting from aerosol-induced intensification of convection at its periphery can be derived from consideration of the TC as a heat engine (Emanuel 1986), as illustrated in Fig. 9. Only the radial component of the wind that crosses the pressure gradient produces work. This radial flow is illustrated in Fig. 8. The same numbers mark the same points in the airflow in the physical cross section (Fig. 8b) and thermodynamic (Fig. 9) space of air pressure P and volume V of an air parcel that circulates through the TC. The air temperature in the BL (interval 1–2) and in the upper troposphere (interval 3–4) is nearly independent of radius, so corresponding curves in the PV diagram are isotherms. The part of air trajectory 2–3 corresponds to moist adiabatic ascent of air in the eyewall. Accordingly, interval 2–3 in the PV diagram is the moist adiabat. The rate or increasing V for a given decrease in P is larger for moist adiabatic than the isothermal process, as illustrated in the larger slope of section 2–3 compared to 1–2. At last, the interval

4–1 corresponds to the heating of air during its subsidence from the upper troposphere to the BL. The whole work produced by this heat engine can be represented by the area bounded by 2–1–3–4 in Fig. 9. An air parcel that rises at the TC periphery follows the trajectory of 1–2'–3'–4. The respective work is represented by the area 1–2'–3'–4, which is lower than that of the parcel that rises at the eyewall (area 2–1–3–4). Similarly, increasing the radius of the eye and increasing its central pressure would decrease the work (which can be related to the wind damage) done by the storm. This consideration shows how increasing the fraction of air that rises farther away from the circulation center causes the TC to produce less work, which corresponds to TC weakening.

The results of HAMP clearly show that significant progress in prediction of TC intensity as well as prediction of the development of tropical depressions can be achieved if model physics will be significantly improved to allow simulation of microphysical and thermodynamic effects related to aerosols and spray. From an operational perspective, implementation of a complete aerosol system in TC forecast models is not trivial. First, one has to interface the TC forecast model with an aerosol forecast model that has realistic aerosol data assimilation. Moreover, the aerosol/TC model has to be able to predict the concentrations and chemistry of CCN, including sea-spray generation of CCN and GCCN. It has also to take into account the radiative effects of the aerosols on the atmospheric and surface heating. An example is the WRF-Chemistry (WRF-Chem) interface to RAMS for CCN prediction as described by Ward and Cotton (2011). However, this model has identifiable biases that limit its predictive accuracy. In addition, the TC forecast model must contain the essential physics of cloud and aerosol interactions either through a full bin microphysics model or with a bin-emulating approach. Finally, in order to predict aerosol impacts on TCs, models need high enough resolution and microphysics to represent convective-scale dynamical responses to aerosols as well as environmental properties affecting cold pools. Grid spacings of at least 3 km are required to represent the full range of dynamical and microphysical responses to aerosols.

There is a great need for microphysical measurements of aerosols, cloud microstructure, precipitation-forming processes, and cold pools in TCs. We recommend that hurricane reconnaissance and research airplanes are equipped with aerosol and cloud physics instruments and fly patterns that will allow such measurements. These patterns should include flying in the marine boundary layer to measure the aerosols, cloud-base and vertical evolution of cloud-drop size distribution and precipitation in the peripheral clouds, where surface winds are still not reaching strengths that present flight safety limitations. Measurements of the amounts of the supercooled water and its rate of freezing and resulting latent heating can be made throughout the storm. A combination of remote sensing and unmanned vehicles should be used in areas where safety concerns preclude aircraft measurements. Emphasis should be given to contrasting highly polluted cloud bands with pristine bands. These measurements have to be coupled with model simulations with explicit cloud microphysics simulations that will be validated and constrained by the measurements, so that the impact of the aerosols on the storm's dynamics can be calculated with credibility.

We believe that the research path described here has to be continued for further progress in understanding and predicting tropical cyclones. Hopefully this publication will foster this recognition and facilitate making this vision into reality in the coming years.

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Edited by Roger M. Wakimoto and Ramesh Srivastava

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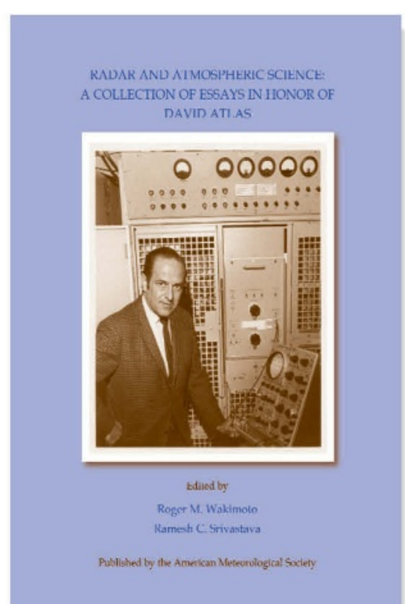

THE ROLE OF THE PACIFIC ENSO APPLICATIONS CLIMATE CENTER IN REDUCING VULNERABILITY TO CLIMATE HAZARDS

Experience from the U.S.-Affiliated Pacific Islands

by Thomas A. Schroeder, Md Rashed Chowdhury, Mark A. Lander, Charles Chip Guard, Charlene Felkley, and Duncan Gifford

The forecast, warning, and response experience of PEAC can help small island countries in the Pacific develop adaptation strategies for longer time-scale climate variability and change.

The U.S.-Affiliated Pacific Islands (USAPI) is composed of the Territory of Guam (Guam), Commonwealth of the Northern Mariana Islands (CNMI; Saipan), Republic of Palau, Marshall Islands (RMI; Majuro, Kwajalein), Federated States of Micronesia (FSM; the States of Chuuk, Kosrae, Pohnpei, and Yap), and American Samoa (Pago Pago; see Fig. 1). The small size of the islands, their remoteness, and their limited financial and natural resources render them, their populations, and their ecosystems highly vulnerable to climate variability and change (Shea et al. 2001). Many of the islands are low-lying atolls (Fig. 2), which are periodically affected by coastal inundation. Even the high islands are not immune, because most of the transportation and commerce are located near the coastline. Most of the USAPI (throughout, USAPI and the USAPI region are synonymously used) are located near the center of activity of the major variations in atmospheric and oceanic circulation associated with El Niño–Southern Oscillation (ENSO; see, e.g., Bjerknes 1966, 1969; Ropelewski and Halpert 1987; Barnston and He 1996; Chu and Chen 2005; McPhaden et al. 2006). These variations, which can greatly impact the USAPI, appear in sea level patterns (Chowdhury et al. 2007a), seasonal rainfall distribution (Yu et al. 1997), and tropical cyclone activity (Lander 1994). For example, the 1997/98 ENSO warm event resulted in water rationing in RMI and the Federated States of Micronesia, crop losses in the Federated States of Micronesia, grass fires in Guam

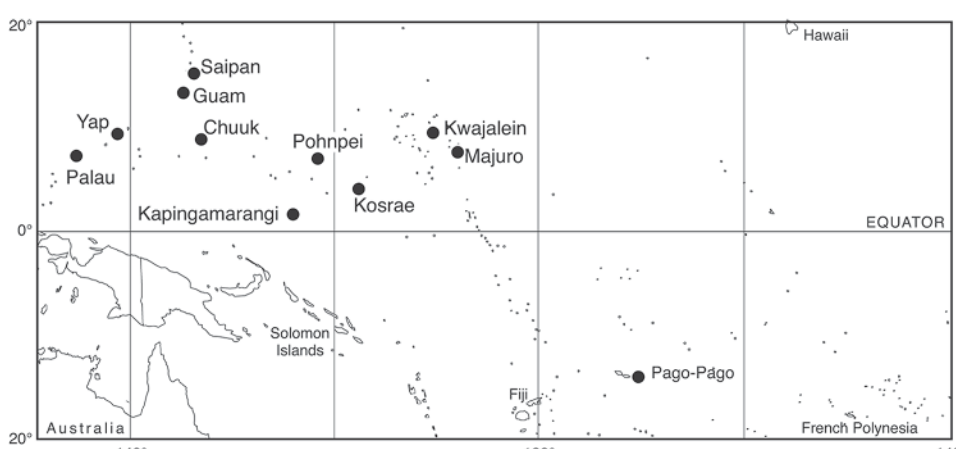

Fig. 1. Locations of USAPI; those discussed here are labeled (large black circles).

and the Federated States of Micronesia, death of livestock on Tinian (CNMI), and increases in unemployment in many locales (Hamnett et al. 1999). Despite these impacts, the people and local governments were able to make early preparations to better endure the event with minimal suffering. This was in part due to the accurate predictions of the Pacific ENSO Applications Center (PEAC) (Hamnett et al. 1999; also see Lynch and Brunner 2010). During the 2007/08 long-lasting La Niña, several episodes of unusually large surf coupled with anomalously high sea levels inundated land and damaged roads and infrastructure on the northern and eastern shores of many islands. The high surf also impacted aquaculture, and altered surface and groundwater quality (Chowdhury et al. 2010). While PEAC scientists flagged the potential for coastal inundation, they did not initially anticipate such a large impact from this event.

Fig. 2. Typical Pacific Island coastal area, Chuuk, FSM, illustrating a coastal inundation event. [Photo courtesy of Joe Konno, Chuuk.]

In the early 1990s, governments in the USAPI expressed concerns about their vulnerability to climate variability and their need for customized climate services. In response, in 1994 the PEAC was established within the Joint Institute for Marine and Atmospheric Research (JIMAR) at the University of Hawaii at Manoa. The center's name was changed to Pacific ENSO Applications Climate (PEAC) Center in 2007. Collaborating partners were the National Oceanic and Atmospheric Administration (NOAA)/Office of Global Programs, the National Weather Service (NWS) Pacific Region, the University of Guam (UoG), the Pacific Basin Development Council (a consortium of USAPI governments plus the state of Hawaii), and the East-West Center. In the early 2000s, NOAA's involvement largely shifted to the Weather Forecast Offices (WFOs) at Honolulu, Hawaii, and Guam. There is now very close coordination and collaboration between those NWS offices and PEAC. The current mission of PEAC is multifaceted and can be summarized as follows: i) to provide tailored, understandable technical information and products for support of planning and management in climate-sensitive sectors, such as water resources, fisheries and aquaculture, agriculture, emergency management, utilities, and coastal zones; ii) to identify impacts from and provide advisories for current and expected 1-yr seasonal changes in rainfall, sea level, and tropical cyclone activity through publication of the quarterly *Pacific ENSO Update* newsletter (hereafter "newsletter"); and iii) to provide periodic educational and event warning outreach to the USAPI.

By 1994, scientific advances in seasonal-to-interannual climate prediction led to the ability to generate skillful ENSO forecasts with lead times of up to 1 yr (McPhaden et al. 2006). In addition, substantial progress had been made in understanding regional behaviors and impacts of the ENSO cycle, which is the

AFFILIATIONS: Schroeder—Joint Institute for Marine and Atmospheric Research, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii; Chowdhury—Pacific ENSO Applications Climate Center, Joint Institute for Marine and Atmospheric Research, University of Hawaii at Manoa, Honolulu, Hawaii; Lander—Water and Environmental Research Institute of the Western Pacific, University of Guam, Agana, Guam; Guard—National Oceanic and Atmospheric Administration/National Weather Service/Weather Forecast Office, Honolulu, Hawaii; Felkley—Pacific ENSO Applications Climate Center, NOAA/National Weather Services, Honolulu, Hawaii; Gifford—Pacific ENSO Applications Climate Center, Department of Meteorology, University of Hawaii at Manoa, Honolulu, Hawaii
CORRESPONDING AUTHOR: Rashed Chowdhury, 2525 Correa Road, HIG 350, Honolulu, HI 96822
E-mail: rashed@hawaii.edu

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dominant source of climate variability for the region (also see McPhaden et al. 2006, and references therein). Because of this, PEAC's initial focus was to i) improve the historical rainfall datasets for the main islands and develop datasets for the "outer" islands in the tropical Pacific basin; ii) develop the rainfall and tropical cyclone relationships with ENSO; iii) expand access to and interpretation of ENSO forecast products developed by the NWS, the International Research Institute for Climate and Society (IRI), and other forecasting and research institutions in the region; iv) increase public awareness of the ENSO cycle, its societal impacts, and the potential societal benefits of forecasts; and v) identify specific applications needs. The first two objectives led to development of *A Precipitation Climatology for Stations in the Tropical Pacific Basin* atlas (He et al. 1998), which was important to the development of improved predictions at the PEAC and the Climate Prediction Center (CPC). The latter two focus elements entailed outreach to the USAPI entities. One of the keys to the success of the PEAC was that it met "eyeball to eyeball" with the stakeholders, listened to their needs, attempted to incorporate most of those needs into the products, and provided a sense of partnership. From the beginning, personnel support to the PEAC has also been provided via the NOAA Commissioned-Officer Corps. The NOAA corps officer conducts the monthly conference call, edits and disseminates the quarterly newsletter, and is one of the leaders in the regional climate information system.

The work of PEAC consists of coordinated research and applications activities. The spatial resolution of climate models is too coarse to render them directly applicable to local island environments (Hamnett et al. 1999). As such, the large-scale models used widely by climate researchers and modelers do not meet the critical needs of the people with whom PEAC works. PEAC scientists directed their research effort to the study of local island climates during each stage of ENSO, and to the development of statistical models to tailor long-range forecasts for specific islands. With a richer knowledge of local environments, the outputs of large-scale models were used to help develop canonical correlation analysis (CCA) statistical models for rainfall and sea level forecasts on seasonal time scales for each of the main islands and a few of the outer islands with unique climate responses. In large part, PEAC plays the role of both provider and user of its own unique products and expertise. These tailored island-specific forecasts have allowed the USAPI governments to respond to seasonal climate variability, either avoiding or minimizing potentially disastrous impacts.

As a facilitator of cooperation among various stakeholders, PEAC has strengthened the ties among the scientists, forecasters, and users in a participatory process of design, delivery, and evaluation. The major objective of this paper is to synthesize the current operational procedures of PEAC and illustrate how these procedures contribute to the development of plans and actions that help mitigate the effects of short-to-medium time-scale climate variability. This paper also suggests that the PEAC experience can positively contribute to the development of capabilities for addressing longer time-scale climate variability and change for the small island countries in the Pacific.

PEAC'S METHODOLOGY FOR REDUCING VULNERABILITY TO CLIMATE HAZARDS.

The current operational "Climate forecasting, warning, and response" activities of PEAC are organized broadly into the following five categories: i) forecast preparation, ii) forecast interpretation, iii) forecast dissemination, iv) response and feedback, and v) review and analysis [e.g., Parker (2003, and references therein) for a review of forecasting, warning, and response systems].

Forecast preparation: On the basis of previous and current meteorological, oceanic, and hydrological conditions, this stage predicts the occurrence and magnitude of hazards. The value of seasonal forecasts depends on their accuracy and on the taking of appropriate actions by all participants [e.g., Stern and Easterling (1999) for a review of consensus forecasts]. PEAC forecasts (sea level, rainfall, tropical cyclone activity, ENSO status, etc.) are produced with contributions from the regional NWS WFO (e.g., Guam), local Weather Service Offices (WSOs; e.g., Majuro, Pohnpei, Yap, Chuuk, Koror, and Pago Pago), and climate representatives from the main island communities. Proposed PEAC forecasts are presented for prereview via e-mail, and are set up for formal discussion within a PEAC-sponsored monthly teleconference. The WSO representatives are invited to participate in this conference. Representatives from the prediction centers [i.e., the IRI, CPC, WFO Honolulu, WFO Guam, and National Climatic Data Center (NCDC)] are also invited. During this hour-long teleconference, issues related to past, present, and future ENSO conditions are discussed. Within a teleconference format, technical and nontechnical discussions are held on regional and local climate dynamics, forecast methodologies, and numerical model seasonal predictions. Near the end of the meeting, a final consensus forecast is achieved from a blend of forecast model output (see "rainfall forecasts" section for the list of models) and some fine-tuning from the recommendations of the teleconference participants. For each zone, rainfall forecasts for the upcoming season are expressed as tercile probabilities of occurrence, while the CCA statistical sea level forecasts are expressed in a deterministic format. The other types of forecasts (i.e., the anticipated status and evolution of ENSO) that the PEAC produces are based on interpretation of the existing dynamical/statistical model outputs, and discussion with international climate communities via the teleconference and via e-mail. The following sections discuss the types of forecasts prepared at PEAC and the methodology for producing them.

Rainfall forecasts. At present, a probabilistic outlook on seasonal rainfall is prepared subjectively by PEAC forecasters on the basis of experience, visual interpretation of current and forecast conditions, and knowledge of the area. Every month, the PEAC produces a 3-month outlook on a monthly basis for 14 stations within the USAPI and Hawaii. Outputs from six dynamical and one statistical model are consulted for these interpretations. The dynamical models are the Met Office (UKMO) seasonal forecasts, National Aeronautics and Space Administration's (NASA's) Seasonal-to-Interannual Prediction Project (NSIPP), the European Centre for Medium-Range Weather Forecasts (ECMWF), IRI Climate Prediction (IRICP), National Centers for Environmental Prediction (NCEP) coupled, and the Pacific Region Integrated Data Enterprise (PRIDE). The lone statistical model is NCEP constructed analog (CA). While it can be difficult to quantify and determine the exact seasonal changes in rainfall accurately with these subjective assessments, these 3-month rainfall forecasts have proven to be very useful in identifying expected trends in seasonal rainfall for the USAPI region. Since 2006, these forecasts have been evaluated monthly using the Heidke skill score (Barnston 1992), which has shown a continued increase in forecast skill (Fig. 3, positive numbers show skillful forecasts). Finally, a composite of subjective and objective assessments is assembled to present the seasonal rainfall outlook in tercile format, expressing probabilities of below-normal, near-normal, and above-normal rainfall occurrence with respect to the long-term mean.

The local variability summaries found in PEAC's quarterly newsletter contain long lead-time forecasts for rainfall, an outlook for tropical cyclone activity, and, when significant, an outlook for sea level out to 1 yr. The forecasts for the first 3-month block of the year-long outlooks found in the newsletter mirror the 3-month forecasts determined for each locality in the most recent PEAC teleconference. Routine model guidance is usually not available for lead times of 1 yr for most climate variables, so the forecast status of ENSO for the upcoming year plays a dominant role in developing the specific 1-yr lead-time subjective forecasts for rainfall distribution. These 1-yr lead-time forecasts are based on the anticipated status and evolution of ENSO. In order for the PEAC forecasts to be useful for planning in the USAPI, it is necessary that the forecast distributions go beyond 3 months. The performance of the PEAC during 1997 is one of the reasons that it became (and remains) a trusted source of climate information in the USAPI region. The forecasts are based on well-known relationships between the state of ENSO and climate variables in the USAPI; when one is confident of the status of ENSO (e.g., it is the fall of a strong El Niño year), it is then possible to skillfully outline the evolution of climate variables for up to 1 yr.

The Pacific rainfall atlas is particularly helpful in assessing rainfall trends given the status of ENSO and the time of the year. It is worth noting that a statistical approach known as the CA (van den Dool and Barnston 1995) is one of the most skillful aids for the 3-month local island rainfall forecasts.

Tropical cyclone forecasts. The relationships between tropical cyclone (TC) activity in the USAPI and ENSO are strong in the western North Pacific (Lander 1994). The largest effects are a) a shift to the west in TC activity during La Niña years and in the year following an El Niño event (regardless of whether or not the follow-on year evolves to be ENSO neutral or La Niña), and b) a shift to the east in TC activity during an El Niño year. The TC forecasts for the Pacific are based on forecasts made from four independent groups—i) the Laboratory for Atmospheric Research (LAR) at City University of Hong Kong (western North Pacific activity; see http://weather.cityu.edu.hk/tc_forecast/2011_forecast_APR.htm), ii) CPC (central and eastern North Pacific activity; see www.cpc.ncep.noaa.gov/products/Epac_hurr/Epac_hurricane.html), iii) the Benfield Hazard Research Centre, University College London (Atlantic, Australian region, and western North Pacific activity; see http://weather.cityu.edu.hk/tc_forecast/2011_forecast_APR.htm), and iv) and an evolving experimental statistical forecast of western North Pacific activity produced at the Guam WFO. On the basis of these four TC activity outlooks, PEAC scientists at the University of Guam and the WFO Guam make their own interpretations of yearly typhoon behavior in the western Pacific (www.prh.noaa.gov/peac/peu/2011_4th/tc_summary.php), while PEAC scientists in Hawaii generate hurricane outlooks for their region. PEAC TC activity forecasts are primarily based on the status and forecast evolution of ENSO, and the available guidance from the aforementioned sources, which generate TC activity forecasts at least 6 months in advance of the time period of interest and provide updates at selected times in the progress of the year.

ENSO FORECASTS. PEAC scientists study most available dynamic and statistical ENSO forecast models and develop probable impact scenarios for the USAPI region. While most of the major climate models are consulted, the ENSO diagnostic discussions provided by CPC and IRI largely shape the contents of the ENSO outlook for the quarterly newsletter and the 1-page monthly "Pacific ENSO discussion" produced by the WFO Guam. PEAC makes every effort to have ENSO forecasts and outreach material that is consistent with CPC and IRI guidance. This is partly guaranteed by coordination made during the monthly conference calls, and by continual behind-the-scenes discussion. To avoid confusion, PEAC is extremely careful to synchronize its discussion of the status of ENSO and the forecast evolution of ENSO with the latest thinking of the CPC and the IRI. In this respect, the actual determination of the status of ENSO and the forecast evolution of ENSO is one of the least time-consuming activities of the PEAC (although there is always ongoing background discussion and feedback among PEAC scientists and the major ENSO players).

While the general rule is that the weaker the event, the weaker the impacts, there are exceptions to that rule. For example, moderate El Niño events are worse than strong events for TC threats to American Samoa. The PEAC is constantly assessing the uncertainty of the predictions and conveys that uncertainty to the customers. By keeping in close contact with the WFO Guam and with the customers that may be impacted by an event, PEAC can make timely recommendations as to when the customer needs to respond. This way, unnecessary funds are rarely expended. For strong events, the impacts are more certain. Threats associated with La Niña events are generally not as severe as those associated with El Niño events. Because the PEAC newsletter is published every quarter, forecasts that begin to degrade are improved during the next set of predictions. Occasionally, conditions

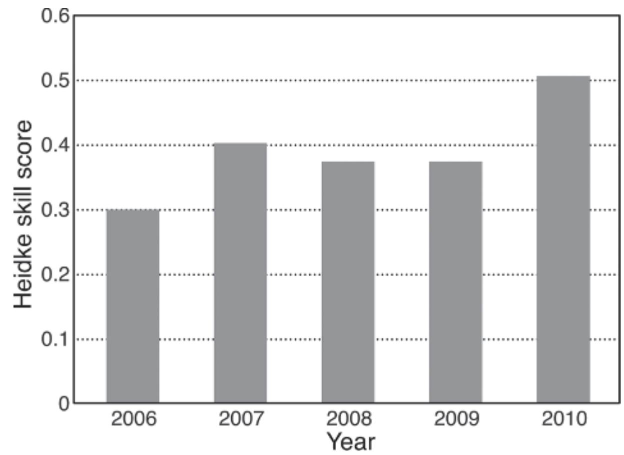

FIG. 3. Three-month seasonal rainfall outlook verification by Heidke skill score (2006–10) for 14 stations. Note that the Heidke skill score is a common statistical measure of forecast performance. The scale of this metric ranges from minus infinity to plus one, with negative numbers indicating poor performance, zero indicating no improvement over a "standard" (in this case random) forecast, and one indicating a perfect forecast (also see Barnston 1992).

can change rapidly, and an amended ENSO update is published. However, the monthly ENSO conference call and the WFO Guam Drought Information Statements allow the PEAC to flag trends and deviations rather early, making customers aware of potential changes and impacts.

SEA LEVEL FORECAST. PEAC, at present, develops a prediction of seasonal mean sea level in the USAPI using the teleconnections with tropical SSTs. Based on an operational CCA statistical model, this scheme can predict sea level in real time, quantifying the skill at lead times of several months or longer (Chowdhury et al. 2007b). The ENSO climate cycle and the sea surface temperatures (SSTs) in the tropical Pacific Ocean are taken as the primary factors in modulating sea level variability on seasonal time scales or longer. The CCA model provides useful skill (Fig. 4) in predicting sea level in the Pacific Islands. Based on this operational forecasting technique by the CCA model, PEAC has been publishing the real-time forecast of sea level deviations for nine USAPI stations at its official website (available at www.prh.noaa.gov/peac/sea-level.php). This information has also been distributed through the printed version of the newsletter.

Based on the generalized extreme value (GEV) model, PEAC provides information on the extremes of sea level on seasonal and annual time scales (Chowdhury et al. 2009). The demand for this product is increasing due to the occurrence of dangerously

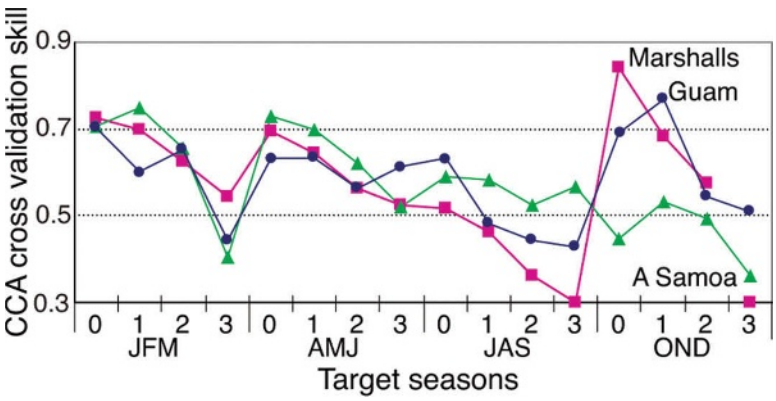

Fig. 4. CCA cross-validation hindcast skills of sea level forecasts for Guam, Marshall Islands (Majuro), and American Samoa (Pago Pago). Here 0, 1, 2, and 3 represent seasons of lead time and January–March (JFM), April–June (AMJ), July–September (JAS), and October–December (OND). Also note that forecasts are thought to be of useful skill (or at least fair skill) if the CCA cross-validation value is greater than 0.3. Higher skills correspond to greater expected accuracy of the forecasts. Skill levels greater than 0.4 and 0.5 are thought to be fair and good, respectively, while skill levels greater than 0.6 are thought to be high. [Source: Reproduced from Chowdhury et al. (2007b).]

high (low) water levels and the associated erosion and inundation (coral exposure and bleaching) problems in the USAPI region. Therefore, information related to various temporal fluctuations in water level is necessary to plan and implement strategies to protect coastal infrastructure, aquifers, and agriculture (e.g., taro patches) on short-to-longer-term time scales. These seasonal extremes are also distributed through the web and hardcopy newsletter. Added to this, NOAA's website for tides and currents (available at http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Tide+Predictions) are used to generate high and low water-level plots for 3-month periods. Based on the availability of data, currently predicted water-level plots are prepared for three to five USAPI stations. This information is distributed through the web version of the newsletter.

Finally, based on information from CCA forecasts, GEV results, and predicted tides, a scenario on seasonal sea level outlook is generated. This outlook has significantly enhanced the capabilities of the USAPI governments to make preparation for the impacts of sea level fluctuations on short-to-medium time scales. Then, the WFO of Guam combines this information with astronomical new and full moon phase predictions, satellite data, and WAVEWATCH III (Tolman 2009) ocean swell predictions to issue high-surf advisories and coastal inundation "warnings" for the USAPI.

When all the forecasts are done, the PEAC always tries to identify if there is any gap between what the users want (i.e., more accurate, more downscaled information) and what science can provide (i.e., often neither accurate nor finescaled enough information) and attempts to bridge this gap. For example, it can be stated here that initially the PEAC newsletter provided only qualitative rainfall forecasts. The U.S. Navy indicated that it needed quantitative predictions to support its water management models for the reservoir on Guam. Thus, PEAC began providing quantitative forecasts for Guam. As PEAC began to look at the developing 1997 El Niño in 1996, it became apparent that all locations would need quantitative predictions. Rainfall climatology, especially in relation to ENSO, was not available. This shortfall was identified, and the NOAA/CPC partnered with PEAC to develop the NCEP/CPC atlas (He et al. 1998) rainfall climatology. That atlas provided statistical relationships of rainfall at selected Pacific Islands under El Niño, La Niña, and average conditions. This enabled PEAC to predict the timing and duration of the events. PEAC selected the 1982/83 El Niño event as a likely analog to the 1997/98 event. PEAC then used an outstanding unpublished study of Micronesian rainfall characteristics based on provisional U.S. Geological Survey (USGS) data acquired during the 1982/83 El Niño drought to estimate the amplitude and the likely associated impacts. Afterward, PEAC scientists derived rainfall climatologies for the outer islands that only had short rainfall records. PEAC scientists used tropical cyclone information from the Joint Typhoon Warning Center (JTWC) to assess the relationships between tropical cyclones and the ENSO state. Predictions were refined with the development of formalized Pacific tropical cyclone prediction programs based largely on the state of ENSO.

Finally, background historical information has a considerable role to play in forecast preparation and applied research at PEAC, and the historical information databases are continuously being updated. Statistical studies on regional climatology and the ENSO cycle are conducted at the University of Hawaii, the Water and Environmental Research Institute (WERI) at the UoG, and at the WFOs at Honolulu and Guam. These background information sources identify ENSO-related impact criteria for the islands, through examination of historical floods and droughts, their causes, and their impacts on agriculture, water resources, and other sectors in each regional area. Therefore, information related to the patterns of severe weather phenomena, such as hurricane and typhoon frequency in each regional area, is generated here. Also, based on the ENSO climate cycle, diagnostic discussions on the characteristics of sea level variability, both from the current situation and from a historical perspective, are regularly prepared.

Interpretation and stakeholders. THIS STAGE IDENTIFIES THE ONSET, DURATION, AND PROBABLE IMPACTS OF HAZARDS ON VULNERABLE COMMUNITIES. A broad-based development approach that incorporates input from the users, a clear understanding of the needs and abilities of the targeted at-risk audience, and, as observed in a PEAC review survey, a respect for the local culture and indigenous practices, has led to a high level of credibility and high confidence in the system. The stakeholders of PEAC products include local WSO officials, local administrative offices (e.g., agricultural, fisheries, emergency management, utilities, etc.), nongovernment organizations (NGOs; e.g., Red Cross), and international organizations [the Secretariat of the Pacific Environmental Program (SPREP), International Organization for Migration (IOM), etc.]. They require information on sea level (height, time, and duration of anticipated extremes), rainfall (specific locations/areas, onset times, magnitude, and duration of drought conditions or potential for flash floods and mudslides), and TC activity (seasonal anomalies, track distribution, and risk). The PEAC prepares impact scenarios about the probable effects of anticipated hazards. Experience from similar past events helps guide the development of the contents of these impact scenarios. For example, it can be restated here that during the El Niño of 1997/98, which resulted in severe water rationing in Majuro (Fig. 5), in Yap State, Chuuk State, and Pohnpei State in the Federated States of Micronesia; in Palau; in CNMI; and eventually in American Samoa, PEAC proactively worked to help people by providing preemptive information about the impact of El Niño. In the USAPI, drought can be a life or death event. Therefore, as early as April 1997, the PEAC had predicted very dry conditions in Micronesia for early 1998. As early as July 1997, the PEAC predicted that a near-record drought comparable to the 1982/83 El Niño–associated drought would affect Micronesia. The information was reflected in the respective quarterly newsletters. In August, it became evident that the islands were not responding to the predictions, so the PEAC scheduled outreach visits to each of the main Micronesian islands. A UoG hydrologist and/or meteorologist visited Palau, Yap, Chuuk, Pohnpei, Kosrae, and Majuro to make presentations about the upcoming drought and its likely impacts. Before the scientists left each major island, the respective president or governor formed a drought-response committee and allocated funds to combat the drought. The PEAC scientist(s) helped the committees formulate a drought-response plan. The need to actually visit the islands and converse with the island leadership in order to elicit a desired response was coined eyeball-to-eyeball interaction. The islands were given 6–8 months of lead time concerning the severe drought, but only responded after the eyeball-to-eyeball outreach resulted in a clear understanding of the potential consequences of not responding. This occurred 2–4 months before the onset of the severe drought conditions, depending on the location. PEAC outreach trips were delayed a few weeks because the timing coincided with the new fiscal year budgetary process. Because of the large magnitude of the drought, the Federated States of Micronesia and

FIG. 5. People line up for water in the Marshall Islands in early 1998 to receive a ration once every 14 days. [Photo courtesy of Federal Emergency Management Agency.]

RMI rapidly exhausted their internally allocated funds and had to depend on outside assistance. The eyeball-to-eyeball outreach process allowed the island leadership to measure PEAC's credibility, determine its intentions, and ascertain its sincerity.

The PEAC was convinced that the evolving drought would result in death and suffering unless fresh water could be delivered before April. The PEAC contacted the Federal Emergency Management Agency (FEMA), which was able to assist the Federated States of Micronesia and the Marshall Islands in developing and submitting presidential declaration requests. They were elevated to U.S. President Clinton, who rapidly approved them. Thus, FEMA addressed a new hazard, drought, and introduced a new paradigm of response in acting to avert a disaster instead of responding to one after it had already occurred. Similarly in 2007/08, when high sea levels inundated land and damaged roads and infrastructure throughout the atolls of Chuuk State (Fig. 6), PEAC provided early warnings to people on the probable impact of La Niña and its accompanying elevated sea level. In addition to 1997/98 and 2007/08, there were many other ENSO-related extreme events for which PEAC advised people well ahead of time (e.g., 3–8 months) about the potential impacts of those extreme ENSO events. Such advance information helped people develop a real-time response plan. For example, restricting water distribution in Majuro to 7 h every 15 days was an effective response to address the ENSO-related water crisis in 1997/98 until desalination units could be provided several months into the record drought. Similarly, the use of boulders and sandbags to protect the land from saltwater intrusion and massive erosion in 2010/11 was an effective mitigation plan for many of the small atolls and islands of the Federated States of Micronesia (Fig. 7) and atolls of the RMI.

Fig. 6. (top) Inundated roads in Wichap Village (Weno, Chuuk, FSM; photo courtesy of J. Berdon, WSO Chuuk), and (bottom) results of coastal erosion at Blue Lagoon Resort (Weno, Chuuk, FSM) during the La Niña of 2007/08. [Photo courtesy of C. Guard, WFO Guam.]

Process of dissemination. This stage communicates and distributes the climate information and warning messages to disaster management agencies and vulnerable communities. In this stage, two different lines of dissemination take place. The first is communication from the PEAC to the local authorities and WSO officials via the same monthly PEAC teleconference and printed newsletter. Subsequently, the WSOs disseminate climate information to their respective vulnerable communities. The information is translated into the local language and disseminated by e-mail and Federated States of Micronesia radio on the main islands and by AM and HF radio to the remote outer islands.

Since January 2005, PEAC has been conducting the monthly teleconference with representatives from WERI, CPC, IRI, WFO Honolulu, WFO Guam, WSO Pago Pago, WSO Yap, WSO Koror, WSO Chuuk, WSO Pohnpei, and WSO Majuro. This hour-long teleconference begins with a recap of the previous month's climate (rainfall, sea level, etc.). The current ENSO situation is also evaluated here, and a 3-month sea level outlook for selected Pacific islands is given. Finally, a 3-month rainfall outlook for each island group is derived using several rainfall forecast model predictions in combination with the participant's knowledge of the local climate. The monthly PEAC teleconference has improved the understanding and awareness of seasonal climate variability in the USAPI, and has empowered the regional WSOs to become knowledgeable climate information providers within their respective jurisdictions.

The decisions reached during the PEAC teleconferences form the starting point for the information presented in the quarterly newsletter, which is intended to supply information for the benefit of those involved in climate-sensitive sectors in the USAPI. The newsletter summarizes current climate conditions (e.g., the status of ENSO, the observed patterns of SST, recent TC activity, observed sea level change, and the adequacy of recent rainfall). There are sections in the newsletter for each major island jurisdiction wherein the current climate situation is discussed and tailored regional and individual island forecasts are presented. Pertinent official advisory or warning messages (e.g., the CPC's El Niño Alert or WFO Guam Drought Information Statement) are also referenced in the bulletin. The number of subscribers for this hardcopy newsletter now stands at about 500. Depending on the severity of a forecast hazard and the accuracy of the current newsletter, a special issue of the newsletter is occasionally issued, as was done for the strong El Niño event of 1997/98. During 2004/05, the number of e-mail subscribers increased considerably and now number over 200. In response to this increasing demand and customer feedback, a new online newsletter was created for low-bandwidth customers. A web version of the newsletter is now available (www.prh.noaa.gov/peac/update.php).

The second stage of dissemination is from the local authorities and WSO officials to the vulnerable communities. The local authority disseminates area-specific warnings and important climate information to the villagers via radio, posters, handouts, training sessions, and individual contacts. Also, in the case of events where serious impacts are expected, personnel from the PEAC and WFO Guam conduct site visits and organize agency meetings throughout the region. These site visits provide the opportunity to educate users on the ENSO cycle, on the expected hazards and impacts, and on application of the climate forecasts. During the 1997/98 El Niño event, it was that eyeball-to-eyeball outreach that provided the impetus for the jurisdictions to mobilize. After the tailored PEAC presentations, legislatures appropriated funds to help mitigate the impacts. With the assistance of the PEAC, local drought-response committees were activated and drought-response plans were developed.

The PEAC website (www.prh.noaa.gov/peac) is an important part of the information dissemination process. Rainfall and sea level outlooks are updated monthly and are presented in a clear and concise format. Stakeholders and users are kept up to date in a "what's new?" section, and links to relevant articles pertaining to the ENSO cycle and the various USAPI are updated frequently. Additionally, PEAC has integrated Google Maps GIS technology to provide users with a dynamic geographic view of local island information and outlooks. Other PEAC projects or case studies not directly related to seasonal forecast products are also documented on the site.

Fig. 7. Mitigation-adaptation at the Blue Lagoon Resort, Weno, FSM, Chuuk prior to the La Niña of 2010/11. [Photo courtesy of C. Guard, WFO, Guam.]

Response and feedback. This stage addresses concerns aired by agencies and threatened communities for information about the hazards and response to warnings. Once warning messages and other important climate information are disseminated to the people, feedback from them is essential to evaluate the accuracy and usefulness of the forecasts, and to confirm that the warnings were received, understood, and disseminated to local users. Such information is essential to improve the quality of forecasts and to confirm the acceptability and utility of the warning messages. A feedback system is well established in PEAC. At first, the accuracy and promptness of forecasts are evaluated at the local level by the respective WSOs. The local office in collaboration with other agencies also examines the public awareness and response to warning messages. The local office communicates its findings on weakness of forecasts, warning, and response opportunities to the PEAC for improvement. The PEAC teleconference now serves as the primary venue for receiving user feedback through the participating WSO representatives. Shorter-term inquiries or requests are usually satisfied by the responsible NWS WFO. Also, the site visits and agency meetings throughout the region enrich the feedback programs. For example, PEAC, in collaboration with WFO Guam and WERI, conducts workshops, focus group meetings, and local briefings about ENSO in all of the client jurisdictions. This has proved to be an effective way to provide end-to-end climate education and forecasts. At these on-site briefings, PEAC identifies the concerns of participants on potential impacts of El Niño and La Niña events, and elicits information about the specific kinds of ENSO forecast information needed. In summary, the PEAC makes all necessary efforts to ensure sustained partnerships and to strengthen the shared sentiment that "we are all in this together."

Review and analysis. This stage is where PEAC scientists monitor the performance of the various components of its activities and evaluate them for possible improvement. Extensive validation of PEAC products and activities needs to be conducted periodically and the process also needs to be debated within the context of user feedback. A 10-yr review workshop convened in Honolulu on 1–3 June 2004. Detailed results of the workshop are available online (www.pacificrisa.org/pubs/PEACReviewFinal.pdf; see also Shea 2005, 2006). Workshop participants included scientists from the East-West Center, the University of Hawaii, the University of Guam, the University of Colorado, Harvard University, the New Zealand National Institute of Water and Atmospheric Research (NIWA), and the IRI. Representatives of the U.S. NWS, the Australia Bureau of Meteorology, and a number of Pacific Island national meteorological services, emergency management offices, and utility agencies, fisheries, coastal resource offices, and other climate-sensitive sectors were also present at the workshop.

As part of the review process, individuals and representatives of institutions currently receiving PEAC forecast products and users of the PEAC website were formally requested to complete surveys either in writing or online. In addition, interviews were conducted to provide an overall evaluation of PEAC performance from the current partners at the University of Hawaii, the University of Guam, the Pacific Basin Development Council, and NOAA, including the National Weather Service Pacific Region, NCEP/CPC, and the NOAA's Office of Global Programs. In addition to their perspectives on current and future applications, these individuals were asked to evaluate PEAC's performance in terms of products, programs, plans, and documentation.

Although the number of completed surveys was not sufficient to be statistically significant, the results of surveys and interviews with the users of PEAC services were analyzed and summarized during a presentation at the Honolulu workshop. Of the total number of users, 31% were representatives of a government agency, 26% were from the private sector, 16% were from NGOs, 11% were from universities, 11% were from Pacific regional organizations, and 5% identified themselves as being an employee of a national weather service in the region (Shea 2006). The survey questionnaire was designed to elicit input on both PEAC products and the process PEAC used to engage users and identify and respond to their information needs. Using a scale of 1–5 where 5 represented the highest score, PEAC products received high marks for clarity/readability (4.3), relevance (4.2), scientific and technical credibility (4.1), content (3.8), and accessibility (3.8). With an average score of 3.4, survey respondents indicated that the timing of PEAC products and services could be improved. In terms of the process that PEAC used to develop and provide its services, the survey respondents gave high marks to PEAC in terms of responsiveness to questions and queries (3.8), engaging participation of users (3.7), providing opportunities for evaluation of products (3.6), and providing opportunities to identify additional needs (3.6). With scores of 3.5 and 3.3, survey respondents suggested that there was room for improvement in terms of understanding and responding to local concerns and developing new products, respectively.

When asked to identify additional climate products that would be useful, survey respondents identified the following: sea level forecasts (now a part of PEAC forecasts), hydrological forecast and information (which were provided, but perhaps not recognized), wind predictions (general predictions are given), winter swell predictions (general predictions are given), an update to the Pacific rainfall atlas (currently in progress), longer lead forecasts (currently in progress), information on long-term climate variability (currently in progress), information on the skill of current seasonal forecasts (i.e., validation, which is regularly done now), summary articles describing the current models used to produce seasonal forecasts (regularly added to the PEAC newsletter), and information on innovative ways in which other people are applying seasonal-to-interannual forecasts (currently in progress).

As a follow-up to the PEAC review workshop, a PEAC scientist and the PEAC outreach officer traveled to several locations in the USAPI region during 7–18 August 2007 to meet with personnel at the local WSOs, local participants of the earlier Honolulu PEAC review workshop, and other officials involved in climate-sensitive sectors. The primary objective of this visit was to discuss with the user community on how to best enhance the collective efforts of scientific and outreach activities in PEAC at each of these locations. A similar field visit was also conducted in 2011.

SUMMARY AND DISCUSSIONS. The overall activities of PEAC and specific avenues for improvements are as follows.

- *Hydrological background information*: The statistical studies on regional climatology and the ENSO cycle are important components for forecast preparation, especially for the main islands. More comprehensive databases and more reliable statistical information are needed for the outer islands. It would be very helpful if more historical background information, such as historical floods and droughts, their impacts, and other information concerning water resources in each regional area, were added to the PEAC database. This would help to better address ENSO-related impacts on the individual islands.
- *Rainfall forecast:* At present, a probabilistic outlook on seasonal rainfall is prepared subjectively by PEAC forecasters on the basis of visual interpretation and experience and knowledge of the area. PEAC is working with other agencies to create a consolidated ensemble forecast.
- *TC forecast:* The forecasts of TC activity in the western North Pacific from any source have yet to stray more than one standard deviation from normal (i.e., approximately plus/minus four named storms). PEAC therefore only ventures to make a prediction of more than four named TC's fewer than normal for a year that follows a strong El Niño. For the foreseeable future, PEAC will continue to monitor the progress of seasonal tropical cyclone forecasting within its area of responsibility, and make bolder predictions of enhanced TC activity (or inactivity) commensurate with validated skill of the aids. A forecaster at WFO Guam is currently working on a technique that will provide predictions specifically for regions of Micronesia.
- *ENSO forecasts:* Based on globally available ENSO forecast models, PEAC prepares an impact scenario for the USAPI region. While studies of ENSO-related impacts, such as historical flooding and drought, are numerous, studies concerned with ENSO-related sectorwise socioeconomic impacts are not regularly conducted in PEAC. There is a need for examination of the way in which people occupying areas exposed to hazards perceive and respond to each hazard, and the manner in which they deal with losses caused by hazards. This societal concern can be a taken as a new and essential research component in the future.
- *Sea level forecast:* PEAC currently publishes the CCA and GEV model results for nine tide gauge stations. Work is ongoing to generate these results for additional tide stations. It is also necessary to expand the use of probabilistic forecasts for sea level variability in the region, but with considerable training on its interpretation and application. While the CCA and GEV model results are useful in their current form, attention should be given to linkages to area-specific impacts, such as patterns of historical coastal flooding. As mentioned, the large-scale climate models and modelers most often do not provide more accurate and downscaled information. This creates a gap between "what the users of PEAC's products want" and "what science can provide for them." In order to bridge this gap, PEAC scientists directed their research effort to development of statistical models (e.g., CCA) for seasonal forecasts by utilizing the outputs of large-scale models and local tide gauge data.
- *Dissemination:* The strength of ENSO events may vary from strong to weak and the impacts may vary from sector to sector. For example, an early onset of El Niño may severely affect the agriculture sector but may not affect tourism. Therefore, sector-specific warning messages and tailored climate information are needed. An historical analysis of sector-specific impacts from various manifestations of ENSO is needed to develop useful impact scenarios for them.
- *Review:* The last PEAC review workshop was a good opportunity for providers and users of the climate forecasting products of PEAC to explore how effectively these products served the information needs of intended user communities. It also revealed how effectively PEAC's structure and activities contribute to a comprehensive information delivery system for the region and what could be done to strengthen that system. The workshop was very helpful in identifying information gaps between PEAC products and user needs. One of the major recommendations of the review workshop was to improve the timing of PEAC products and services. Over the years, PEAC has successfully maintained a relatively consistent schedule of dissemination of these products and has considerably improved the quality of forecasts for rainfall and tropical cyclone activity, and the interpretation of ENSO and its impacts. There was a need for sea level forecasts on month-to-seasonal time scales. That product has been provided in the form of mean sea levels, extreme sea levels, and tidal fluctuations for the various locations. There

were also requests for longer lead forecasts on climate variability and change, which are currently under consideration at PEAC. The general wind outlooks (easterly with La Niña and westerly with El Niño) and 1-yr hydrological forecasts are also provided.

During the last decade, enhanced trade winds and high sea levels were dominant throughout much of the USAPI region. Extended drought conditions were particularly noticeable in the Republic of the Marshall Islands. Because of this peculiar decadal shift of climate, the demand for more accurate and area-specific information has increased. Similarly, the demand for PEAC products has considerably increased. Therefore, another review workshop is suggested to revisit the user demands and to improve the products and services of PEAC.

CONCLUSIONS. As PEAC evolved through the 1990s and 2000s, increasing levels of concern developed over matters associated with observed and projected global warming and its implications for local climates. PEAC received a growing number of inquiries about the impacts of global warming, especially as a cause of sea level rise. Currently, we are continually approached with requests to expand our efforts to predict climate variability on longer time scales as well as to ascertain the local climate changes anticipated in a warmer world. We therefore have gradually added climate change to our suite of services. We are now working on this broad issue by using global climate models (GCMs). As a first step, we have made progress to statistically downscale the results of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)-coupled GCMs to project the sea level rise in the USAPI region. However, we will continue to provide seasonal forecasts and maintain our practice of applied research and outreach, which has served our clients well.

Despite the limited resources of PEAC, this organization has been identified as a model of success for reducing the vulnerability to climate hazards for small island countries (e.g., Hamnett et al. 1999; Lynch and Brunner 2010). This U.S.-based PEAC program is also an example of increasing diversity and empowering underrepresented groups in atmospheric sciences. Over the last two decades this model has considerably increased human, technical, and physical capacity through the knowledge base developed by PEAC's research, information dissemination, outreach activities, and hands-on experiences. While the PEAC experience and model is limited to the USAPI region now, it can easily be applied to other regions vulnerable to climate hazards.

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DEMONSTRATING THE POTENTIAL FOR FIRST-CLASS RESEARCH IN UNDERDEVELOPED COUNTRIES

Research on Stratospheric Aerosols and Cirrus Clouds Optical Properties, and Radiative Effects in Cuba (1988–2010)

BY JUAN CARLOS ANTUÑA MARRERO, RENÉ ESTEVAN ARREDONDO, AND BORIS BARJA GONZÁLEZ

A strong research team developed in Camagüey, Cuba, by pursuing clear and precisely defined capacity building and research goals with the help of international cooperation.

INITIAL STAGE: COOPERATION WITH THE SOVIET UNION (1988–91). From the early 1980s to the early 1990s, the Camagüey Meteorological Center (CMC) was the experimental site for the Joint Cuban–Soviet Laboratory for Tropical Meteorology. CMC (21.4°N, 77.9°W) belongs to the Cuban Meteorological Institute [Instituto de Meteorología de Cuba (INSMET)], located in the city of Camagüey, about 500 km east of Havana. The site was equipped with aerological sounding, meteorological radar, as well as a network of six surface meteorological stations. Soviet and Cuban scientists jointly conducted cloud seeding experiments and associated research during that period (Medveded et al. 1986).

By the end of 1988, a Maket-2 lidar instrument for stratospheric aerosol (SA) measurements was installed at CMC (Fig. 1), which was afterward known as the Camagüey Lidar Station (CLS). The main parameters of the instruments appear in Table 1. The Soviet team in charge of the lidar was led by Professor Sergey Khmelevtsov, from the Institute of Experimental Meteorology (IEM), Obninsk, Russia. IEM sent engineers and physicists to Camagüey, Cuba, at the end of 1988 and early 1989 to set up the lidar and to share knowledge

FIG. 1. Maket-2 lidar instrument installed at Camagüey in 1988.

Table 1. CLS lidar instrument main parameters. Nd:YAG = neodymium-doped yttrium aluminium garnet. PMT = photomultiplier.

Parameter	Magnitude/characteristic
Laser, wavelength	Doubled-frequency Nd:YAG 532 nm
Laser energy/pulse	300 mJ
Pulse repetition rate	50 Hz
Receiver diameter	30 cm
Receiver field of view	8–10 mrad
Receiver bandwidth	2 nm
Detector	PMT FEU-136
Signal processing	Photon counting recorder with PC XT

of how to use the lidar system with us, their Cuban counterparts: specifically, an engineer for maintenance and repair; and the lead author, who learned operation, data quality control, and processing. In 1989, both of us received one month of specialized training at the IEM in Obninsk.

Because of technical problems, we conducted only a few measurements of background conditions in the stratospheric aerosol layer in 1990. During 1991 the lidar was inoperative, but the Soviets upgraded the instrument and it became operative in January 1992 (Antuña and Sorochinski 1995). This coincided with the disintegration of the Soviet Union, interrupting the scientific cooperation, so we took charge of the project, assuming fully the operation, maintenance and repair of the instrument; meanwhile, the eruption of the Mount Pinatubo on 15 June 1991 challenged us to make the lidar measurements, despite these enormous operational obstacles.

Before 1992, while the lidar was mainly inoperative, we dedicated ourselves to intense study and self-preparation in, among other subjects, lidar technique, its measurement principles, processing and quality control; and SA and cirrus cloud (CC) properties, formation, and evolution as well as their climatic effects (Antuña 1996; Antuña et al. 1994). The local monthly mean sounding was derived for calculating the lidar molecular backscattering with the highest possible precision (J. C. Antuña et al. 1991, unpublished manuscript). We also conducted measurements to characterize the local tropopause because of its connection to SA and to some CCs (J. C. Antuña et al. 1992, unpublished manuscript).

AFFILIATIONS: Antuña Marrero, Estevan Arredondo, and Barja González—Grupo de Óptica Atmosférica de Camagüey, Centro Meteorológico Provincial de Camagüey, INSMET, Camagüey, Cuba
CORRESPONDING AUTHOR: Dr. Juan Carlos Antuña Marrero, Camagüey Meteorological Centre, Grupo de Óptica Atmosférica de Camagüey, P.O. Box 134, Camagüey 70100, Cuba
E-mail: anadelia@caonao.cu

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THE ISOLATION PERIOD (1992–95). The following years of hardships are known in Cuba as the "Special Period," but the Cuban scientific authorities continued supporting the researchers' salaries. In early 1991 despite limited resources, Dr. Rosa Elena Simeon who was the head of the Cuban Ministry of Science, Technology and Environment at that time, assigned a 286 personal computer (PC) to the CLS to replace the outdated "Elektronika 60" Soviet minicomputer that was no longer in service. The new PC was based on the Intel 80286 processor, and would become CMC's most advanced PC. At that time the very few IBM Personal Computer XTs (PC XTs) at the CMC (and in the whole country) worked all day around the clock. The demand for access to the 286 made the lidar room a computer center during the day, when the lidar was not measuring. To end that situation, we exchanged the 286 with a less powerful XT, on the condition that the CLS team had exclusive use of the XT. The Cuban government's commitment at that time was to preserve the scientific and technical capacity already built, with the intention of utilizing it again fully upon the recovery of the economy. In those years we had only one source of spare parts: the dismantling of decommissioned Soviet computers and instruments. This approach, combined with the sustained effort of the CLS personnel and other colleagues of the CMC, allowed the lidar to stay in operation until late 1998, when no more spare parts were available.

With Soviet cooperation interrupted, several engineers from the Radar Group at the CMC provided highly valuable engineering support to CLS. Their inventive work was decisive in maintaining the lidar for so long.

In 1994, in the middle of those difficult years, the second author was assigned to work full time at the CLS. This assignment had noticeable consequences for CLS and the subsequent research unit formed from it. The second author, a high school graduate, after he finished serving in the military, began to work at CMC in 1989 in the security team. He showed enthusiasm for studying and, even before his incorporation into CMC, attended courses to become a meteorological observer and a meteorological technician, graduating in 1990. He was interested in the lidar technique, and he began to participate in the lidar measurements during his free time. Because of his dedication and seriousness, the lead author designed for him an informal but rigorous plan of professional education to pursue in parallel with his work. Through regular study of papers, all then in English, he learned the physics of stratospheric aerosols, the physics and technology of the lidar technique, and English. From 1998 to 2003, he studied electrical engineering at the University of Camagüey without abandoning his daily work at CLS (Estevan et al. 1998). Then he began graduate studies under the supervision of the lead author, receiving his doctoral degree early in 2010 (Estevan 2010). His career is a vivid example of how far a person can progress professionally based on personal effort and taking advantage of the educational facilities in Cuba.

At the same time we were continuing with measurements, data processing, quality control, and analysis, we began working on other tasks with other, long-term perspectives. Our Soviet colleagues had provided the software code for processing the lidar measurements, and for retrieving the profiles of stratospheric aerosol extinction, but not the binary data format of the files containing the photon counting profiles. By applying reverse engineering, we retrieved the binary format, allowing us several years later to produce our own processing software, with an updated algorithm, to retrieve SA and CC extinction profiles from the lidar photon counting profiles (BSPA 2004).

Another decisive development for CLS was widening our access to scientific literature. Our Soviet colleagues had provided literature in Russian about lidar and SA, which was very useful initially. Further learning, however, was blocked by the lack of Western literature; INSMET did not have the financial resources to subscribe to scientific journals. But with a little creativity, this situation was overcome. From the references in the available Russian literature, we could identify non-Russian researchers and their refereed papers on lidar and SA. Using whatever means possible (other than e-mail, which was only available to us at Camagüey several years later), we searched for the addresses of those researchers and sent letters requesting reprints of their papers, including an additional request for more recent papers of which we were not aware. After a little more than a year of literature requests, a cascade effect took place. The information, reprints, reports, chapters of books, and conference papers we began to receive provided new references to find more scientists in the field. From the few letters per month we were sending by the early 1989, the search expanded to a dozen of letters per week by 1992. That volume of specialized scientific information guaranteed the necessary information for us to increase our capabilities. By late 1993 we began to have access to e-mail in Camagüey. It was a great step, allowing more efficient communication with scientists worldwide and making the request of scientific information easier and faster.

After the CLS began to measure SA from Mount Pinatubo, the requests of literature were accompanied by information about the measurements we were conducting. As result, the research we were conducting began to be known by scientists all over the world. Among the many people we contacted at that time were two scientists who were going to play a decisive role in our efforts to get in regular contact with the scientific community in our field and to gain access to scientific knowledge.

Dr. Rumen Bojkov, then advisor to the World Meteorological Organization (WMO) secretary general, visited Cuba in early 1994 to inaugurate an ozone measurement facility in Pinar del Rio in western Cuba. He was aware of our SA lidar measurements because we had written to him requesting literature. Upon his request, the Cuban scientific authorities brought him to Camagüey to visit CLS in January 1994. During the few hours visit to the CLS, a fruitful exchange took place. He was impressed by the Mount Pinatubo SA lidar dataset we were able to compile. He offered to make arrangements for the leading author to present the CLS results at a conference on Mount Pinatubo that would take place later that year. The presentation to the North Atlantic Treaty Organization (NATO) Advanced Research Workshop on the effects of the Mount Pinatubo eruption on the atmosphere and climate, held in Rome on 26–30 September 1994, was a success (Antuña 1996). Attending the conference allowed fruitful exchanges with the attendees, who provided valuable information about the state of science about the SA in general and about the Mount Pinatubo eruption in particular. Many ideas were discussed, and several attendees committed to

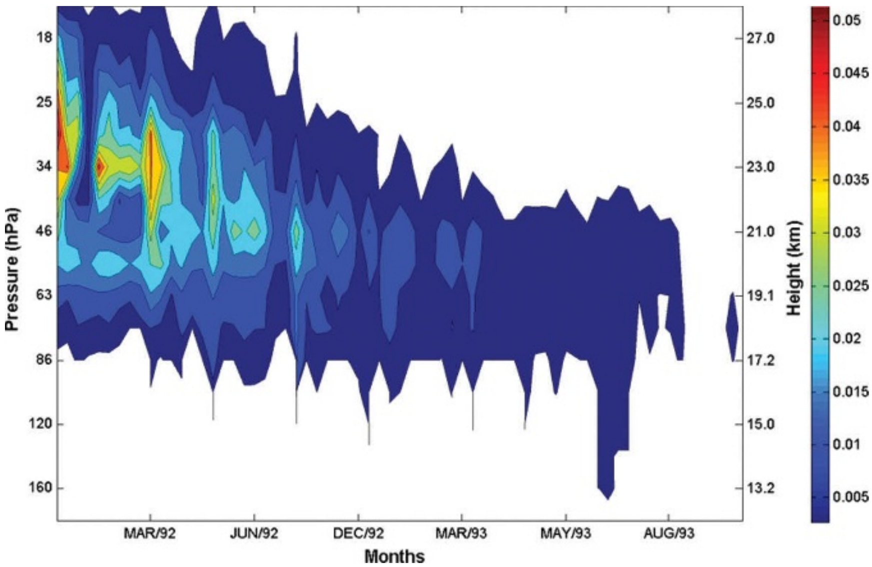

Fig. 2. Mount Pinatubo SA extinction coefficients as a function of pressure, measured by lidar (λ = 0.532 μm) at Camagüey, Cuba, for the period Jan 1992–Nov 1993.

holding a workshop on lidar measurements in Latin America the following year. Although that workshop was never held, it was the germ of what are today the workshops on lidar measurements in Latin America (Antuña et al. 2010). Another result was the donation of a PC to the CLS. By the middle of 1995, the WMO secretary general made the long-term loan of a 386 PC for the CLS, providing a powerful tool for processing and analyzing the lidar measurements.

But the most important result of attending the NATO Advanced Research Workshop was meeting in person Professor Alan Robock of the University of Maryland (currently of Rutgers University), and arranging all the details for the lead author to apply for graduate studies in the United States. Professor Robock had earlier, on request, provided plenty of reprints of his papers on SA climatic effects. Those papers were the basis for our initial studies of the local climatic effects of the SA cited above. His scientific and personal contributions over the years were among the main reasons that CLS evolved into what is today the Grupo de Óptica Atmosférica de Camagüey (GOAC).

As result of our lidar measurements between 1988 and 1997, we collected two unique datasets in the tropical zone. The first one consists of the vertical profiles of SA lidar backscattering, covering the 15 July Mount Pinatubo volcano eruption. These data were collected beginning in January 1992 until the complete decay of the volcanic aerosol presence, shown in Fig. 2, and include SA background conditions before and after the eruption. The second dataset features vertical profiles of CC lidar backscattering. In some cases the SA lidar measurements, conducted at night, were affected by the presence of CCs. Those measurements, originally discarded by the Soviet colleagues, were preserved by the Cuban team. In those cases, several more measurements were conducted, with fewer laser shots than for the SA but with higher vertical resolution. The amount of SA and CC measurements conducted by the CLS is listed in Table 2. The former datasets have been broadly used by the CLS/GOAC team as well as by several researchers abroad (Stenchikov et al 1998, Stevermer et al. 2000, and Torres et al. 1998).

Table 2. Amount of measurements of SA and CCs conducted by the CLS during the period the lidar was operative.

Year	SA	CC
1988	14	—
1989	7	—
1990	5	—
1992	33	35
1993	35	27
1994	20	25
1995	30	25
1996	33	21
1997	9	11
1998	—	23

INTERNATIONAL COOPERATION PERIOD (1996 TO THE PRESENT). The core of the CLS team was completed with the incorporation of the third author in 1996. Then a fourth-year student of physics at the University of Oriente, he was assigned to CLS for his graduation thesis, fulfilling it successfully. Upon obtaining a bachelor's degree, he formally began work at CLS the following year. While working full time at CLS, he earned his master of science degree in optics by 2003 and began doctoral studies under the supervision of the lead author in 2004, completing it by the end of 2010 (Barja 2010). The Optical Society of America awarded Barja a share of the prize for best student presentation (for a method of obtaining the lidar ratio for subvisible CC) at the Third Workshop on Lidar Measurements in Latin America (Antuña and Barja 2006).

The leading author's master of science (1996–98) and doctoral (1999–2002) studies in the United States under Professor Robock's supervision granted access to state-of-the-art knowledge in the field. Working with Professor Robock provided contact with the higher standards of scientific methodology, expertise, and ethics for conducting scientific research. It also opened doors to contact with scientists all over the world. It should also be acknowledged the enormous personal commitment and effort made by Robock from the beginning and to the completion of the leading author's graduate studies. The U.S. government blockade against Cuba represents a serious obstacle to the scientific and academic exchange between scientists from both countries. Moreover, because the leading author's wife and son were denied U.S. visas to accompany him during his studies, he traveled every year to Cuba to visit them. Each time the difficult process for obtaining a new U.S. visa began again. Professor Robock systematically and firmly supported each one of the annual processes for getting the visa, many times contacting the U.S. Department of State and his congressman to support the application. The doctoral dissertation of the leading author allowed validation of the SA measurements of the 1991 Mount Pinatubo eruption made by the Stratospheric Aerosol and Gas Experiment II (SAGE II) satellite instrument with surface lidar measurements (Antuña et al. 2002) and the first determination of the spatial and temporal variability of the SA produced by a volcanic eruption (Antuña et al. 2003). The former characterization was conducted using SAGE II space coincident (±1° in latitude and ±5° in longitude) sunrise and sunset measurements in a 12-h window. Figure 3 shows the average percent differences between the pairs of sunset and sunrise coincident extinction profiles at 1.02 μm for the periods before (January–March 1991), during (July 1991–March 1992), and after (July 1992–July 1993) the most intense presence of the Mount Pinatubo SA. Below 25 km, where the bulk of Pinatubo aerosols were located, there was a noticeable increase in the average percentage differences from values around 15%–25% for the periods January–March 1991 and July 1992–July 1993 to values ranging between 40% and 60% during the period July 1991–March 1992. As result of this comparison, it was estimated that the aerosol extinction variability in the core of the cloud in the tropical region for the period of approximately six months following the Mount Pinatubo eruption ranged between 20% and 40% at the same point over the Earth's surface in a time lapse of 12 hours. After the lead author completed his doctoral degree and returned to Camagüey, mutual working visits to Rutgers and from Professor Robock to Camagüey have maintained active exchanges and cooperation up to the present.

As a result of the multiple exchanges facilitated by Antuña's graduate studies in the United States, a proposal for conducting research of the SA was submitted to the Program to Expand Scientific Capacity in the Americas (PESCA), in response to a call for proposals made by the Inter-American Institute for Global Change Research (IAI) in 1999.

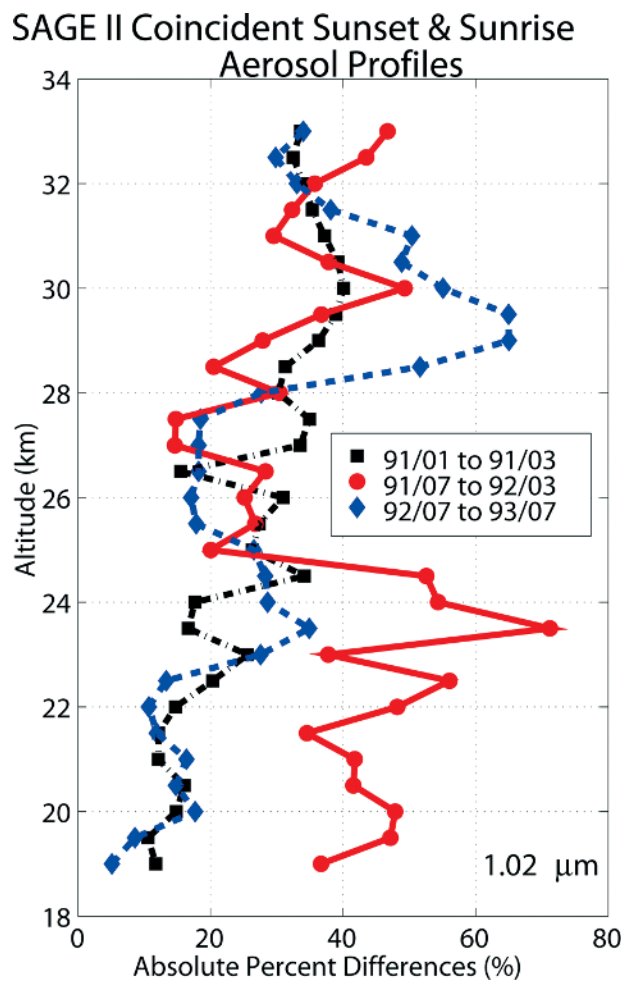

Fig. 3. Average extinction percentage difference profiles for three subperiods between Jan 1991 and Dec 1993 for the set of coincident sunset and sunrise SAGE II measurements. (Fig. 1 from Antuña et al. 2003.)

The project was accepted and funded. The principal investigator (PI) was Dr. Pablo Canziani, then in the Department of Atmospheric Sciences at the University of Buenos Aires, Argentina. Antuña was the co-PI, and CLS personnel in Cuba and Professor Robock were also participants. The research results were presented at several international meetings and conferences. An important result of the project was the implementation of a joint initiative of the CLS team and Professsor Robock—the First Workshop on Lidar Measurements in Latin America, hosted by the CLS team in Camagüey, Cuba, on 6–8 March 2001 (Robock and Antuña 2001a,b). That initiative developed into a still-active series of regular workshops every two years (Antuña et al. 2010). The leadership of the CLS team in building up of the lidar community in Latin America has been an important contribution to the development of this emerging field in the atmospheric sciences in our region and in the world.

The cited project also allowed the training of the second author on SAGE II measurement interpretation and use at Rutgers. The know-how acquired in that training was applied a few years later for characterizing the upper tropososphere (UT) and lower stratosphere (LS) aerosols in the wider Caribbean under SA background conditions (Antuña et al. 2005); updating and validating the CLS lidar measurements of SA (Estevan and Antuña 2006); and characterizing the physical and spatiotemporal features of CCs in the wider Caribbean area (Barja and Antuña 2010). For the CLS it was the first international project after the end of the Soviet cooperation. Since that time the CLS team has prepared and submitted to multiple international funding agencies a total of 17 research projects, resulting in 5 approved and funded projects, including the one described above.

Fig. 4. (left) CIMEL sun photometer and (right) collecting nose of the impactor operated by GOAC at Camagüey, Cuba, under a joint cooperation agreement with the GOA-UVA. Sun photometer measurements are contributed by RIMA and AERONET.

Between 2005 and 2006, a research project supported by the Program of Scientific Cooperation between Argentina and Cuba was conducted between the División de Radares Láser del Centro de Investigaciones en Láseres y Aplicaciones (CEILAP), Argentina, and the CLS team. The project addressed the measurements of SA and CCs, both in Argentina and Cuba. The main results of the project were the demonstration that certain CEILAP lidar tropospheric aerosol measurements could be also processed for deriving SA extinction profiles; those lidar SA extinction profiles were compared with SAGE II coincident SA extinction profiles (Estevan et al. 2008). Also, a combination of methods to derive the optical and geometrical properties of CCs were implemented; the preliminary results showed very encouraging performances for measurements of CCs conducted by both CEILAP in Argentina and CLS in Cuba (Lavorato et al. 2008).

During Antuña's visit, in the late 2005, to the Grupo de Óptica Atmosférica (Optics Atmospheric Group) at the University of Valladolid (GOA-UVA), Spain, a letter of agreement was signed with Dr. Angel de Frutos-Baraja, chair of GOA-UVA. The goal was to establish cooperation for aerosols research between both institutions, by installing a sun photometer and a particle impactor at Camagüey, under CLS responsibility. In November 2007, after further negotiation, the international cooperation agreement between the University of Valladolid, Spain, and the Institute of Meteorology, Cuba, was signed in Camagüey. Under that agreement a low-volume particulate impactor, Dekati PM10, and a CIMEL-318 sun photometer were installed at CMC in 2008 (Fig. 4). Further, two joint research projects have been conducted, one of them still running, and a third one is in the process of gaining approval by scientific authorities of both countries.

The impactor allows us to determine the particulate matter mass concentration with aerodynamic diameter <10 μm (PM10) and <1 μm (PM1) fractions. Some of the impactor measurements of the first eight months were also the subject of chemical analysis. The analysis of the PM10 and PM1 fractions and chemical composition during that period showed the highest concentration of PM between May and August, with coarse and fine modes in almost the same proportion. High concentrations of Cl^-, Na^+, NO^{3-}, and SO_4^{2-} were found in the coarse mode; in the fine mode, the higher concentrations belong to SO_4^{2-} and NH_4^+ (Barja et al. 2011a).

The sun photometer is operated and replaced annually, following the protocols of the Aerosol Robotic Network (AERONET). The measurements are contributed by the Red Ibérica de Medida Fotométrica de Aerosoles (RIMA) and AERONET. Thus, this is the first and only Cuban sun photometer contribution to such a National Aeronautics and Space Administration (NASA) program. The study of the first year of the measurements of the aerosol's optical properties at Camagüey showed a maritime mixed environment—results that agree with other studies for similar sites in the Atlantic Ocean. The arrival of Saharan dust to Camagüey, Cuba, was demonstrated during multiple events in July 2009, assessed by backtrajectory analysis using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Estevan et al. 2011).

In June 2010 AERONET began implementing the measurements in "cloud mode" at several selected stations, including Camagüey. Those measurements are conducted when no aerosol measurements are possible because of clouds, allowing instead the calculation of the cloud optical depth (COD). Preliminary comparison of those COD measurements with hourly cloud reports from the actinometrical station operating at Camagüey reveals good agreement with the natural behavior of the clouds in our region, with a value of 15 for the maximum frequency of occurrence of the COD (Barja et al. 2011b).

Because of the cooperative engagements by CLS, the leading author was invited in late 2001 to participate in the Stratosphere–Troposphere Processes and their Role in Climate (SPARC) Assessment of Stratospheric Aerosols Properties' kickoff meeting. The CLS team participated over the years in the scientific exchanges conducted by the panel. It contributed in particular to chapters 3 and 4 of the assessment as well as to the whole report published several years later (Thomason and Peter 2006).

Also the Global Change System for Analysis, Research, and Training (START) Visiting Scientist Award Program supported in 2004 a one-month visit by the lead author to the department of Earth Physics II of the Complutense University of Madrid, Spain. Dr. Ricardo Garcia-Herrera and his team provided full scientific support to help us learn meteorological data rescue principles and techniques. The fruitful exchanges with Dr. Garcia-Herrera and members of his team and the ongoing communication maintained over the years allowed the CLS team to rescue more than 40 years of the solar radiation dataset from the Camagüey meteorological station, resulting in the first paper ever published in the *BAMS* by Cuban scientists (Antuña et al. 2008). The rescued dataset has been fully reprocessed and quality controlled by properly designed computer software, and it has proven useful in both research and services. Research applications include the calculation of the frequencies of clear-sky conditions and of the broadband aerosol optical depth (Fonte and Antuña 2011); the evaluation of the tropospheric aerosols' radiative effects; and the evaluation of a radiative transfer model adjustment to the climatic conditions of Camagüey (Fonte 2011). Service applications are provided online at GOAC (2011), which contains both hourly observations in real time and historical values of solar radiation variables for the period 1981–2007. The solar radiation data rescue process as well as the derived applications and results are completely new for Cuba and for the Caribbean (Antuña et al. 2011).

Our efforts first to rebuild the old lidar and then to get a new one have not achieved results, however. Having a lidar system again working at Camagüey is still a goal integrated with our broader goals of research and services. The GOAC maintains an active cooperation with the lidar community in Latin America and all over the world. We have shared our expertise in processing and analyzing lidar aerosol and cloud measurements with several teams in the region and have facilitated contacts between these new lidar teams and the rest of the lidar community. Also, we participate actively in the implementation of the Global Atmosphere Watch (GAW) Aerosol Lidar Observation Network (GALION), representing and promoting the lidar groups in Latin America (Bösenberg et al. 2007).

TRANSITION FROM CLS TO GOAC. After the lead author returned from his doctoral studies in 2002, he shared what he learned in the United States with the rest of the team. To make possible the doctoral work by the second and third authors (on the radiative effects of SA and CC, respectively), the Geophysical Fluid Dynamics Laboratory column radiative transfer code (Freidenreich and Ramaswamy 2005) was adapted for use on the PCs and for the local conditions at Camagüey. SA and CC extinction profiles derived from lidar and SAGE II measurements were used for characterizing their physical properties and also for feeding the radiative code. The radiative effects of SA and CC were determined and subject to analysis, producing interesting and valuable results.

In the case of the CC radiative effects, a noticeable result (to the author's knowledge, not reported in the literature before) was the finding of a double

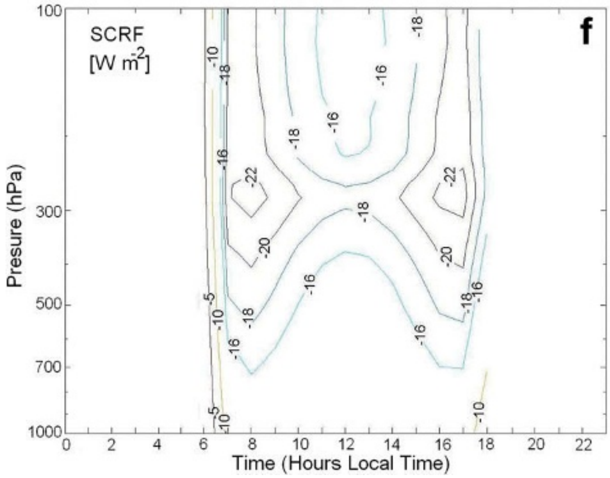

Fig. 5. Diurnal cycle of the solar CC radiative forcing for the CCs measured at 0815 UTC 25 Aug 1996 showing a double maximum around noon (Fig. 1f from Barja and Antuña 2011).

maximum in the diurnal cycle of the solar CC radiative forcing around noon at the CC base height for the thin and opaque CCs, shown in Fig. 5. An explanation for such a feature was proposed based on the different magnitudes of the contribution to the solar irradiance increase during the day, both by the cirrus cloud atmospheric optical path and the elevation of the sun (Barja and Antuña 2011). Another example was the numerical simulation of the vertical distribution of the heating rate produced by the SA from the Mount Pinatubo eruption over the Caribbean for the year 1992, depicted in Fig. 6. Although the values of the heating rate are low compared to the reports from other authors (because of the lack of longwave radiation in the model we used), the effects produced by SA plus some of the components of the atmosphere, such as ozone and water vapor, are evident. At the level of maximum concentration of SA (~24 km) the maximum heating rate is achieved, with positive values above that maximum and negative below in the troposphere (Estevan and Antuña 2010).

In this way, 2002–09 was the most intense capacity building period for the team. By the end of 2009, the team was in a new stage. Two doctoral students were ready to make their defenses the following year and two new technicians—students in the third year of a bachelor of science degree in meteorology—were integrated into the team. Professors and students from the computer sciences department at Camagüey University began to cooperate with us in both upgrading existing software and developing new ones.

The scientific "critical mass" and the attendant results further facilitate the consolidation and evolution of the team. Given our general goal, the study of radiative transfer processes in the atmosphere in the conditions of our country, and its implications in our long-term strategy, we decided to become the GOAC (Fig. 7). The second author assumed management of the team, and the lead author concentrated on scientific advising and on promoting cooperation. It was natural to begin allowing a new postdoctoral associate with so much work experience to develop his management skills.

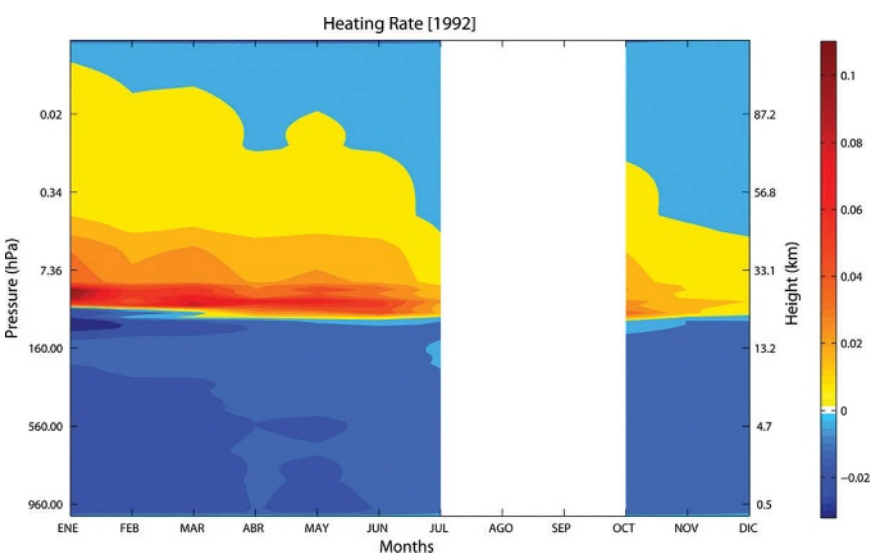

Fig. 6. Numerical simulation of the vertical distribution of the heating rate produced by the SA from the Mount Pinatubo eruption over the Caribbean for the year 1992 in the total spectral band (from Estevan and Antuña 2010). Because of weather conditions, no measurements were conducted between July and September, which is indicated by the white gap in the figure.

SUMMARY. The setup of the lidar at Camagüey in the late 1980s was envisaged even then by the lead author as a unique opportunity for creating a local scientific team for radiative transfer studies with a high level of independence from the standpoint of its scientific and technical capabilities. Thus, we took advantage of the Soviet researchers sharing technology and know-how on lidar SA measurements. Making the project sustainable as a full-time professional research facility was based on several principles:

complete personal dedication and engagement of the members of the team, professional quality research, and ongoing international cooperation for accessing state-of-the-art scientific knowledge and tools, together with an intense effort for developing local scientific expertise. There has also been a practical flexibility in exploiting opportunities when they appear. Also central to this enterprise has been the ability to combine in a small team the diverse investigations that typically are conducted by several highly specialized groups.

Fig. 7. Members of the GOAC: (right to left) Dr. Boris Barja, Mrs. Teresita Hernández, Mr. Carlos Enrique Hernández, Dr. René Estevan, and Dr. Juan Carlos Antuña.

For a little more than 20 years, this work has demanded an intense effort by each one of the team members, facilitated in no small part by making decisions by consensus.

The work involved international cooperation combined with local scientific capacities to guarantee the sustainability of a self-sufficient research team in the face of severe local economic limitations, the collapse of the Soviet Union, and the initial lack of local and regional expertise.

Ours is not a unique experience in Cuba. There is, for example, the modernization of the Cuban meteorological radar network, conducted by the radar group of the CMC (Peña et al. 2000; Rodríguez et al. 2005). Several other research teams in Cuba have overcome difficulties and achieved notable scientific results. They all combine strong personal commitment, clear definition of its goals, and effective strategies for reaching them. Those experiences could serve as examples for research teams in underdeveloped countries facing similar difficulties and obstacles. We are convinced, however, that there is not just one recipe for developing scientific teams in undeveloped countries. Each case should take into account the particular conditions of each country and the availability of international cooperation.

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THE GOES-R PROVING GROUND

Accelerating User Readiness for the Next-Generation Geostationary Environmental Satellite System

BY STEVEN J. GOODMAN, JAMES GURKA, MARK DEMARIA, TIMOTHY J. SCHMIT, ANTHONY MOSTEK, GARY JEDLOVEC, CHRIS SIEWERT, WAYNE FELTZ, JORDAN GERTH, RENATE BRUMMER, STEVEN MILLER, BONNIE REED, AND RICHARD R. REYNOLDS

By demonstrating the advanced capabilities of the next generation of geostationary satellites, the proving ground addresses user readiness and the research-to-operations-to-research loop.

The Geostationary Operational Environmental Satellite R series (GOES-R) Proving Ground (PG) is an initiative to accelerate user readiness for the next generation of U.S. geostationary environmental satellites. The GOES-R system is a joint development between the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), with NASA responsible for the space segment (spacecraft and instruments) and NOAA responsible for the overall program and ground segment. The GOES-R PG is a collaborative effort between the GOES-R Program Office (GPO); NOAA Cooperative Institutes; NASA's Short-Term Prediction Research and Transition Center (SPoRT); National Weather Service (NWS) Weather Forecast Offices (WFOs); NWS National Centers for Environmental Prediction (NCEP); National Environmental Satellite, Data, and Information Service (NESDIS) Office of Satellite and Product Operations (OSPO) and the Center for Satellite Applications and Research (STAR); and NOAA test beds to conduct demonstration activities to gain early experience with GOES-R capabilities in an operational environment. Improved spacecraft and instrument technology will support expanded detection of environmental phenomena, resulting in more timely and accurate forecasts and warnings. The Advanced Baseline Imager (ABI), described by Schmit et al. (2005), is a 16-channel imager with 2 visible channels, 4 near-infrared channels, and 10

AFFILIATIONS: GOODMAN AND GURKA—NOAA/NESDIS/GOES-R Program Office, Greenbelt, Maryland; DEMARIA— NOAA/NESDIS/Center for Satellite Applications and Research, Fort Collins, Colorado; SCHMIT—NOAA/NESDIS/Center for Satellite Applications and Research, Madison, Wisconsin; MOSTEK—NOAA/National Weather Service, Boulder, Colorado; JEDLOVEC—NASA Short-Term Prediction Research and Transition Center, Huntsville, Alabama; SIEWERT—Cooperative Institute for Mesoscale Meteorological Studies, Norman, Oklahoma; FELTZ AND GERTH—Cooperative Institute for Meteorological Satellite Studies, Madison, Wisconsin; BRUMMER AND MILLER—Cooperative Institute for Research in the Atmosphere, Fort Collins, Colorado; REED—General Dynamics Information Technology, Fairfax, Virginia; REYNOLDS—Short and Associates, Inc., Silver Spring, Maryland
CORRESPONDING AUTHOR: Steven J. Goodman, GOES-R Program Senior Scientist, NOAA/NESDIS GOES-R Program Office, NASA GSFC Code 417, Greenbelt, MD 20771
E-mail: steven.j.goodman@noaa.gov

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infrared (IR) channels that will provide 3 times more spectral information, 4 times the spatial coverage, and an increase in temporal resolution that is more than 5 times the current imager. Other advancements over current GOES capabilities include total lightning detection and mapping of in-cloud and cloud-to-ground (CG) flashes never before available to forecasters from the Geostationary Lightning Mapper (GLM; Goodman et al. 2010) and increased dynamic range, resolution, and sensitivity in monitoring solar X-ray flux with the Solar UV Imager (SUVI). Figure 1 provides a listing of the GOES-R baseline products, those that are funded for operational implementation as part of the ground segment base contract, and potential GOES-R future capabilities, by sensor. The GOES-R is scheduled for launch in October 2015, followed by an on-orbit postlaunch test that will consist of both engineering and science phases. Additional information on the GOES-R program can be found online (at www.goes-r.gov).

Preparing the user communities for the GOES-R series addresses key recommendations from the National Research Council (2000) and the challenge to transition research into operations that "NOAA should form a team at the start of sensor development … to plan the full scope of the data research and utilization effort as part of sensor design with a budget to support the activity" (National Research Council 2000, p. 51). It is critical for mission success to start early with product demonstrations, assessment, and feedback on product utility with added attention to the situational awareness element of GOES-R products, especially as they contribute to the NWS warning decision support services.

PG DESCRIPTION. The GOES-R PG program enables the transition from research to operations with the principal emphasis on NOAA's operational forecast office environment. This focus is accomplished by utilizing existing capabilities to simulate GOES-R products and techniques, which are then demonstrated and evaluated at NWS WFOs, NCEP, and NOAA test beds. Those users provide valuable feedback on the use of decision aids, training, and products to the development teams who make up the GOES-R Algorithm Working Group (AWG). The AWG manages and coordinates development of GOES-R products and validation activities. Research activities in satellite algorithm design and development are transferred to operations through such programs as the NOAA Hazardous Weather Testbed (HWT) and Joint Hurricane Testbed (JHT). GOES-R Risk Reduction (GOES-R3) and AWG activities provide a solid basis for development of GOES-R proxy datasets and other user-relevant applications in synergy with other satellite, radar, in situ, or model information. A

Baseline Products

Advanced Baseline Imager (ABI)

Aerosol Detection (Including Smoke and Dust)
Aerosol Optical Depth (AOD)
Clear Sky Masks
Cloud and Moisture Imagery
Cloud Optical Depth
Cloud Particle Size Distribution
Cloud Top Height
Cloud Top Phase
Cloud Top Pressure
Cloud Top Temperature
Derived Motion Winds
Derived Stability Indices
Downward Shortwave Radiation: Surface
Fire/Hot Spot Characterization
Hurricane Intensity Estimation
Land Surface Temperature (Skin)
Legacy Vertical Moisture Profile
Legacy Vertical Temperature Profile
Radiances
Rainfall Rate/QPE
Reflected Shortwave Radiation: TOA
Sea Surface Temperature (Skin)
Snow Cover
Total Precipitable Water
Volcanic Ash: Detection and Height

Geostationary Lightning Mapper (GLM)

Lightning Detection: Events, Groups & Flashes

Space Environment In-Situ Suite (SEISS)

Energetic Heavy Ions
Magnetospheric Electrons & Protons: Low Energy
Magnetospheric Electrons: Med & High Energy
Magnetospheric Protons: Med & High Energy
Solar and Galactic Protons

Magnetometer (MAG)

Geomagnetic Field

Extreme Ultraviolet and X-ray Irradiance Suite (EXIS)

Solar Flux: EUV
Solar Flux: X-ray Irradiance

Solar Ultraviolet Imager (SUVI)

Solar EUV Imagery

Future Capabilities

Advanced Baseline Imager (ABI)

Absorbed Shortwave Radiation: Surface
Aerosol Particle Size
Aircraft Icing Threat
Cloud Ice Water Path
Cloud Layers/Heights
Cloud Liquid Water
Cloud Type
Convective Initiation
Currents
Currents: Offshore
Downward Longwave Radiation: Surface
Enhanced "V"/Overshooting Top Detection
Flood/Standing Water
Ice Cover
Low Cloud and Fog
Ozone Total
Probability of Rainfall
Rainfall Potential
Sea and Lake Ice: Age
Sea and Lake Ice: Concentration
Sea and Lake Ice: Motion
Snow Depth (Over Plains)
SO_2 Detection
Surface Albedo
Surface Emissivity
Tropopause Folding Turbulence Prediction
Upward Longwave Radiation: Surface
Upward Longwave Radiation: TOA
Vegetation Fraction: Green
Vegetation Index
Visibility

Fig. 1. GOES-R baseline products and future capabilities, by sensor. TOA = top of atmosphere; EUV = extreme ultraviolet.

key component in user readiness is the training and demonstration that builds the forecaster's knowledge base as part of NOAA's evolving operations.

> *"We saw several instances where the total lightning was picking up on storms before the AWIPS lightning [NLDN CG] program picked up on them. One could see the utility of this in the future, bringing with it a potential for lightning statements and potentially lightning-based warnings."*
>
> —Pat Spoden (SOO, NWSFO, Paducah, Kentucky)

PG PARTICIPANTS. The PG participants can be categorized as either developers or users. Developers are satellite algorithm scientists who develop and deliver the demonstration product(s) and related training materials to the end users. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) and the Advanced Satellite Products Branch (ASPB) of the NESDIS STAR located at the University of Wisconsin—Madison; the Cooperative Institute for Research in the Atmosphere (CIRA) and the Regional and Mesoscale Modeling Branch (RAMMB) at Colorado State University; and NASA SPoRT in Huntsville, Alabama, are the three main developers within the GOES-R PG program. The users (e.g., test bed operators and forecasters) are those users who work with the providers to integrate the product(s) for demonstration into an operational setting for forecaster interaction and provide the product assessments. At select NCEP offices, there are also onsite long-term visiting scientist technical liaisons (i.e., subject matter satellite application experts, or "satellite champions") that aid in the transition from research to operations by actively participating in the product demonstrations, interpreting the added value of the satellite-derived information, and conducting training. The developers work with the satellite champions to build capacity within the forecast office or national center.

DEMONSTRATION ACTIVITIES. Activities at the HWT, National Hurricane Center (NHC), and those involving the Air Quality PG (AQPG) customers are described in detail below to illustrate the wide variety of products demonstrated at various facilities.

Hazardous weather test bed spring experiment demonstration. The GOES-R PG principal collaboration for severe convective weather occurs within NOAA's HWT and Storm Prediction Center (SPC) in Norman, Oklahoma. Since 2009, the GOES-R PG has participated in the annual SPC/National Severe Storms Laboratory (NSSL)/WFO Spring Experiment (www.nssl.noaa.gov/projects/hwt/). Between 17 May and 18 June 2010, a total of 20 visiting scientists and 15 NWS forecasters, invited by the GOES-R PG, participated in real-time forecasting and warning exercises using a variety of experimental GOES-R products within the Spring Experiment's Experimental Forecast Program (EFP) (www.nssl.noaa.gov/projects/hwt/efp/) and Experimental Warning Program (EWP) (http://ewp.nssl.noaa.gov/). In 2011, the campaign ran from 9 May to 10 June 2011, with 24 NWS forecasters participating.

Products generated from current satellite-, land-, and numerical model–based datasets such as convective initiation (CI) nowcasting (Mecikalski and Bedka 2006; Mecikalksi et. al. 2010; Sieglaff et al. 2011), overshooting top (OT) and thermal couplet detection (Bedka et al. 2010), pseudo-geostationary lightning mapper (PGLM) (Fig. 2), and simulated satellite imagery (Fig. 3) helped demonstrate GOES-R products to operational forecasters and the broader scientific community. Other future capability products demonstrated included a 1–9-h GOES sounder-based precipitable water/θ_e nearcast model, a 0–3-h severe hail probability product, and a NSSL Weather Research and Forecasting model (WRF) simulated lightning threat forecast (McCaul et al. 2009). Weather Event Simulator (WES) cases were developed to demonstrate GOES-R PG products within the EWP for training purposes during periods of inactive weather. The products included in the Spring Experiment are described in greater detail below.

The University of Wisconsin Convective Initiation (UWCI) algorithm utilizes a box-averaged approach for monitoring cloud-top cooling rates of immature, vertically growing convective clouds. The box-averaged approach is computationally inexpensive, uses a physically based IR-only cloud-type algorithm allowing day/night independence, and is portable from one geostationary imager platform to another. The UWCI algorithm separates false cloud-top cooling associated with horizontal cloud advection from true cloud-top cooling associated with vertical cloud growth through a series of tests (Sieglaff et al. 2011). After the true cloud-top cooling signal is isolated, the cooling pixels are assigned convective

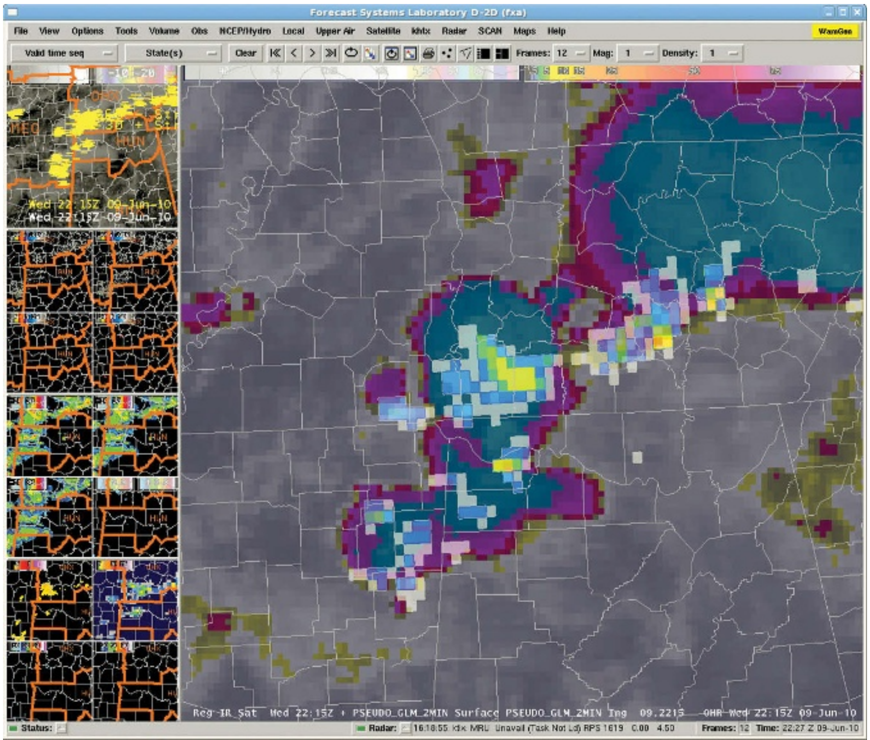

Fig. 2. Forecaster AWIPS display of PGLM flash extent density product and IR image over central Tennessee and northern Alabama at 2215 UTC 9 Jun 2010. The overlay of PGLM on IR allowed the forecaster to focus on the most active convective cores.

initiation nowcast categories based upon cloud-type classification and trends. Three nowcast categories exist, pre-CI cloud growth, CI likely, and CI occurring, which represent vertically growing water cloud, vertically growing supercooled/mixed phase cloud, and vertically growing and recently glaciated cloud, respectively.

The Satellite-Based Convection Analysis and Tracking (SATCAST) is a proxy for the AWG version of the GOES-R CI algorithm. The algorithm uses a daytime statistically based convective cloud mask (Berendes et al. 2008) and performs multiple spectral differencing of IR fields (Mecikalski and Bedka 2006). SATCAST then quantifies and monitors cumulus cloud objects (Goodman et al. 2011) while applying object-based atmospheric motion vectors (AMV) to track cloud objects being monitored for future CI (Zinner et al. 2008). SATCAST is also available at nighttime using an identification approach to identify cumulus clouds (Jedlovec et al. 2008). SATCAST output has provided additional insight when implemented in well-established decision support systems, such as Consolidated Storm Prediction for Aviation (CoSPA; Wolfson et al. 2008). The CoSPA integrates radar observations, numerical weather prediction (NWP) winds and stability fields, and other data to assist in developing CI nowcasts and convective storm evolution forecasts over the 0–8-h period. NWP data also help remove spurious false alarms in SATCAST by requiring convective available potential energy (CAPE) indications of instability in the near-storm environment. False alarms may also be caused by mesoscale AMV tracking errors, view-angle-related problems that affect interest field thresholds and the inherent difficulties associated with tracking growing cumulus in 4-km IR data. Separately, the NESDIS Office of System Development (OSD) is evaluating the two CI products in support of validating them for possible operational implementation. Forecaster comments from the HWT were provided to OSD in support of the validation activities.

The overshooting top detection (OTD) product identifies those deep convective storm updraft cores of sufficient strength to rise above the storms' general equilibrium level near the tropopause region and penetrate into the lower stratosphere. Thunderstorms with overshooting tops that penetrate the tropopause frequently produce hazardous weather at Earth's surface such as heavy rainfall, damaging winds, large hail, and tornadoes (Adler et al. 1985; Brunner et al. 2007; Dworak et al. 2012). Turbulence and CG lightning are found to occur most frequently near the OT region (Bedka et al. 2010), indicating that OTs represent significant hazards to ground-based and in-flight aviation operations. This algorithm will also help better detect areas of potential turbulence, giving pilots ample warning of potentially dangerous flying conditions. In addition, the OTD product identifies features in the IR cloud tops associated with the enhanced-V signatures that have been shown to be associated with severe weather at the ground (Brunner et al. 2007).

The PGLM product utilizes total lightning data from three ground-based Lightning Mapping Array (LMA) networks (central Oklahoma; northern

> *"The band difference has a lot of potential . . . you can get a head start by looking at the trends in the data that help you anticipate what's going to happen."*
>
> —HWT Forecaster on WRF Band Difference (KPPs)

Alabama; and Washington, D.C.) and the Lightning Detection and Ranging (LDAR) network (Kennedy Space Center, Florida) that detect very high-frequency (VHF) radiation from lightning discharges. The real-time lightning data are resampled to the GLM nadir pixel resolution of 8 km and summed into 1- or 2-min intervals, depending on the network, and sorted into flashes using spatiotemporal clustering algorithms available through the Warning Decision Support System–Integrated Information (WDSS-II). Following flash sorting, a flash extent density product, which can be looped in the Advanced Weather Interactive Processing System (AWIPS) and trended with time, is created at 8-km resolution to match the GOES-R GLM lightning detection event product. The PGLM product is a nowcasting and warning tool that aids forecaster situational awareness by identifying rapidly developing and intensifying thunderstorms with the potential to produce severe or high-impact (e.g., microbursts) convective weather (Goodman et al. 2005; Gatlin and Goodman 2010; Schultz et al. 2009).

The WRF lightning threat forecast is a model-based method for making quantitative forecasts of lightning threat. The algorithm uses microphysical and dynamical output from high-resolution, explicit convection runs of the WRF (Skamarock et al. 2005) conducted daily during the Spring Experiment time period. The algorithm uses two separate proxy fields to assess lightning flash rate density and areal coverage, based on storms simulated by the WRF. One field, based on the flux of large precipitating ice (graupel) in the mixed-phase layer near −15°C, has been shown to be proportional to lightning flash peak rate densities while accurately representing the temporal variability of flash rates during updraft pulses (McCaul et al. 2009). The second field, based on vertically integrated ice hydrometeor content in the simulated storms, is proportional to peak flash rate densities while also providing information on the spatial coverage of the lightning threat, including lightning in storm anvils. A composite gridded threat field is created by blending the two aforementioned ice and graupel fields, after making adjustments to account for differing sensitivities to specific configurations of the WRF used in the forecast simulations. One chief advantage of a physically based lightning threat forecast is that it predicts a much smaller region for strong–severe thunderstorm activity than would be suggested by more general indicators of potential instability such as CAPE. The regional LMA networks are used to support the validation of the lightning threat forecasts.

Simulated GOES-R ABI imagery and band differences generated from the NSSL WRF 0000 UTC 4-km model run are provided by CIMSS and CIRA for display within the HWT National Advanced Weather Information Processing System (NAWIPS). One of the most useful aspects of simulated satellite imagery from a model is the ability to compare the output directly to observed satellite imagery to determine model performance, as well as having a one-stop 3D representation of the model atmosphere.

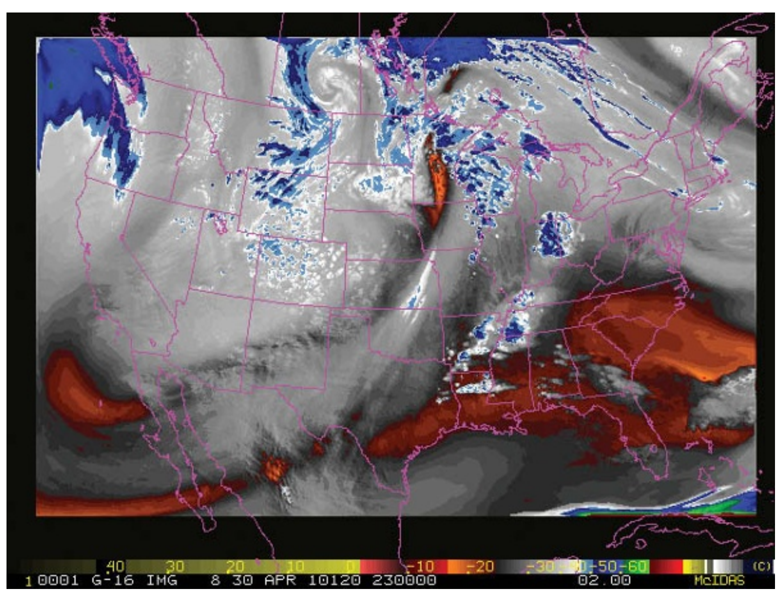

Fig. 3. Example of a synthetic 6.185-m image at 2300 UTC 30 Apr 2010. The image is based on a 23-h forecast from NSSL's 4-km Advanced Research WRF (ARW-WRF), run through a forward radiative transfer model to produce ABI brightness temperatures.

> *"A lot of the time to increase my lead time in the morning, I like to take a look at PW* [precipitable water] *and WV* [water vapor] *... so I found that this was a nice utility because it was indicative of finding areas of greatly deep instability, or moisture source regions."*
>
> —HWT Forecaster on Nearcast (Legacy Atmospheric Profiles)

CIMSS provides simulated satellite data for one visible and all nine nonsolar GOES-R ABI IR bands from the NSSL WRF for 12–36-h forecast periods. The three ABI water vapor channels, each peaking at a different level in the atmosphere, provide three layers of water vapor information unavailable from the current series of operational GOES satellites. In addition, CIRA provides the HWT with three GOES-R specific band differences not available from the current GOES satellites. Features such as low-level moisture pooling and boundary identification are useful in the forecast of convective initiation. Data from both CIMSS and CIRA arrived at SPC by 1415 UTC to produce the imagery, with the band differences available an hour later.

The CIMSS/ASPB nearcast model applies a Lagrangian framework to advect temperature and moisture retrievals from the 18-channel GOES sounder (Schmit et al. 2002) to generate forecasts of conditional instability out to 9 h from the initialization time. A nearcast model of vertical moisture and θ_e gradients shows skill at identifying regions of rapidly developing, convective destabilization up to 6 h in advance. The nearcast model thus addresses the information gap between extrapolating observations for nowcasting to longer-range NWP. The nearcast model must be able to detect and retain substantial gradients in the atmosphere (especially moisture fields) and incorporate large volumes of high-resolution synoptic data while remaining computationally efficient. A Lagrangian approach uses hourly, full-resolution (10–12 km) multilayer retrieved parameters from the GOES sounder to optimize the impact and retention of information. Forecasters find the model enhances current operational NWP forecasts by capturing and retaining details of atmospheric structure that are key to the development of convective instability several hours in advance, even after subsequent IR satellite observations become cloud contaminated.

Statistical hail probability provides forecasters with a product created by fusing satellite and numerical forecast model information. The product is based on a statistical model built by using observed severe hail reports over three years, along with the corresponding (in space and time) GOES observations and analyses and forecasts from the SPC's surface mesoanalysis and the Rapid Update Cycle (RUC) model. GOES data include the 10.7-μm brightness temperatures and the locations of overshooting tops derived from the OTD product discussed above. Additional inputs include convective instability information, surface dewpoint, and severe hail (greater than or equal to 1 in. in diameter) climatology. Output from the real-time product provides the probability of severe hail within the 0–3-h time window on a 0.5° × 0.5° latitude/longitude grid across the eastern two-thirds of the United States, roughly within the GOES-East domain. The product was designed to provide additional guidance to SPC forecasters who generate hail probability forecasts several times per day as part of their convective outlooks. It may also assist in the issuance of mesoscale discussions and severe thunderstorm watches.

Forecasters and participants of the Spring Experiment at the HWT provided feedback via real-time blogging (http://goesrhwt.blogspot.com), online postevent surveys, and daily postmortem discussions throughout the 5-week experiment. The feedback gathered was essential in identifying training needs and potential uses of the GOES-R products prior to their operational deployment. Forecasters identified specific information that they would like to see within training modules, as well as additional WES case types, to help better demonstrate the utility of GOES-R products. Feedback from NWS forecasters has also been essential in developing effective situational awareness display techniques within their current AWIPS/NAWIPS and future AWIPS II systems for next-generation satellite products.

National Hurricane Center hurricane season demonstration. A set of GOES-R products was tested at the NHC during the most active part of the 2010 hurricane season. The official GOES-R baseline product set includes one product specifically designed for tropical cyclones, the hurricane intensity estimate (HIE). However, data and products from the ABI and GLM have many potential applications to tropical cyclone analysis and forecasting, and a subset was chosen for evaluation within the NHC demonstration. Products evaluated at the NHC included the HIE; three red, green, and blue (RGB) imagery products (Miller et al. 2006, 2012); and an experimental rapid intensification index (RII) that used lightning data as one of the inputs. Super-Rapid Scan Operations (SRSO) 1-min imagery was also collected. The initial products and decision aids were chosen through early planning coordination with NHC forecasters, which began several months in advance of the experiment that ran from 1 August to 30 November 2010.

The experimental products were evaluated directly by forecasters from the NHC Hurricane Specialist Unit and the Tropical Analysis and Forecast Branch. Onsite training was provided prior to the start of the demonstration and associated documentation on the GOES-R products was also available online (http://rammb.cira.colostate.edu/research/goes-r/proving_ground/cira_product_list). A midterm project review was held at the NHC in early September 2010, and a postdemonstration meeting was held in January 2011 to obtain forecaster feedback on the utility of the GOES-R products.

The HIE is a state-of-the-art algorithm that provides an objective estimate of the maximum sustained surface wind of tropical cyclones using IR window channel input. The algorithm is based on the advanced Dvorak technique (ADT) (Olander and Velden 2007), which is now used operationally at the NHC and other global tropical cyclone (TC) analysis centers to complement the subjective Dvorak technique (SDT) intensity estimates. The ADT has been shown to be competitive in skill with the SDT and has the distinct advantage of rapid refresh (30-min estimates vs typical 6-hourly SDT estimates). The HIE algorithm was adapted by CIMSS to use the increased horizontal and temporal resolution that will be available from the ABI and tested using Spinning Enhanced Visible and Infrared Imager (SEVIRI) data as a proxy for the ABI. Real-time demonstrations have been provided to the NHC via a dedicated web page for product evaluation.

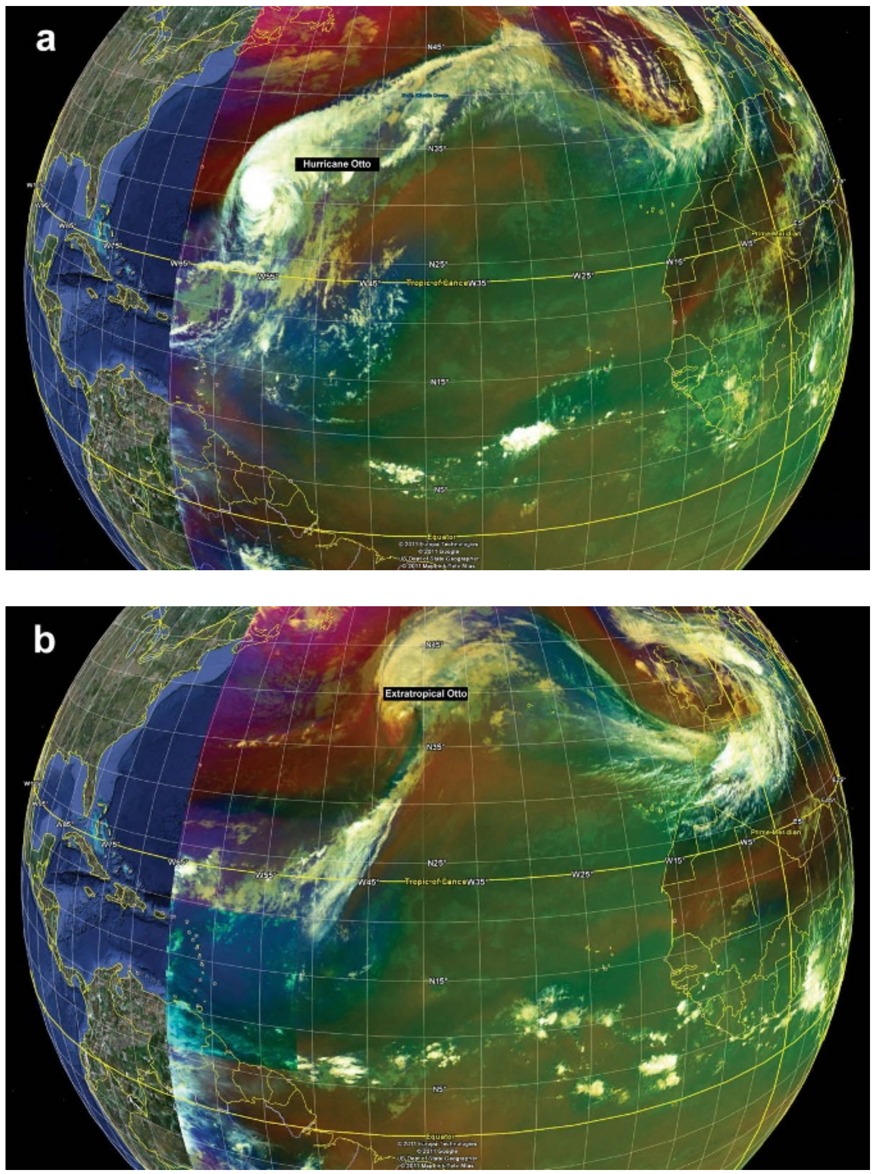

Fig. 4. An example of the RGB airmass product in Google Earth format for Hurricane Otto at (a) 0500 UTC 9 Oct and (b) 0500 UTC 10 Oct 2010. On 9 Oct, the airmass product showed that the cyclone was near an airmass boundary, as indicated by the color contrast to the west of the storm, with the red colors indicating much drier and higher ozone content typical of polar air. By 10 Oct in (b), Otto had transitioned to an extratropical cyclone, where the polar air mass surrounded the cyclone by that time.

> *"The RGB airmass and dust products were very useful in showing that the pre-Irene disturbance was going to have dry air issues initially. I think this helped us give the system a low chance of development in the early tropical weather outlooks."*
>
> —Jack Beven
> NHC

With 16 ABI channels, it will be more difficult and time consuming for forecasters to extract all the information directly from that data. For this reason, the use of image combinations designed to highlight features of interest will be of greater importance in the GOES-R era. To prepare for these applications, three RGB image products were demonstrated at the NHC. The first of these was the RGB airmass product (Fig. 4). Originally designed by scientists at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), it has been adapted for tropical applications to highlight differences between dry, tropical, and midlatitude air masses (EUMETSAT User Service Division 2010). The second product demonstrated was the RGB dust product, which works in a similar fashion. The dust product is designed to monitor the evolution of dust storms during both day and night. Dust plumes in the tropical Atlantic have been hypothesized to slow tropical storm development and to affect sea surface temperatures directly where tropical cyclones form (Evan et al. 2006). The third RGB product was the Saharan air layer (SAL) product, which is another example of an enhanced image product potentially related to tropical cyclone evolution by tracking dry, dusty air in the lower to middle levels of the atmosphere (Dunion and Velden 2004). The RGB products were provided by CIRA and CIMSS in a Google Earth format via a web page. SEVIRI data were used as a proxy for the ABI, and the domain covered most of the northeastern tropical Atlantic east of the Lesser Antilles. The Google Earth format was used previously because of the color display limitations of the NAWIPS systems, but in future demonstrations the RGB products will transition from Internet based to AWIPS II access.

A number of studies have suggested a relationship between lightning activity and tropical cyclone intensity changes (e.g., Abarca et al. 2011). To evaluate the predictive capability of the lightning information, an experimental version of the operational RII product described by Kaplan et al. (2010) was developed. The ground-based World Wide Lightning Location Network (WWLLN) data from 2005 to 2009 were used as a proxy for the GLM for the algorithm development (Rodger et al. 2004). Although the WWLLN detects cloud-to-ground and not total lightning activity, the reported spatial accuracy of 10–15 km over the oceans provides a good approximation to the spatial resolution of the GLM. These data combined with multichannel imagery can be used to explore the added utility of lightning observations to monitor high-impact convective weather over data-sparse regions. The lightning-based RII was run in real time and provided to NHC forecasters for evaluation. The Vaisala Global Lightning Dataset 360 (GLD-360) was used for the real-time evaluation (Demetriades and Holle 2009). Figure 5 shows an example of a 6-h composite of lightning locations from the GLD-360 network. Correction factors developed from a period of overlap in 2009 were applied to the GLD-360 data to account for differences from the WWLLN data. The experimental RII, provided to the NHC via an FTP site in a text format similar to the operational version, uses lightning data input from the inner core and rainband regions.

To gain experience with high-temporal-resolution imagery of tropical cyclones, several periods of 1-min GOES SRSO data were collected (Hillger and Schmit 2009). Fortunately, the recently launched *GOES-15* was in checkout mode during the most active part of the 2010 season (http://rammb.cira.colostate.edu/projects/goes-p/), which allowed for much more SRSO data to be collected than is normally possible after the satellites become operational. Extended periods of SRSO were obtained from Hurricanes Danielle, Earl, Igor, and Karl. These were available to the NHC forecasters in real time via a web page and will be used for later research and training on the use of high time resolution for hurricane analysis.

Forecaster feedback provided valuable information regarding the prototype GOES-R products. A possible bias in the HIE minimum pressure estimates was identified, which is being investigated by the product developers. The RGB products were found to be a useful way to identify features of interest, but they also have some shortcomings, including false alarms. To further exploit the advanced capabilities of GOES-R, there will be a range of automated, quantitative products describing aerosols, dust, ash, moisture, ozone, etc. The "recipes" for the RGB products are being adapted and address these issues. Preliminary results with the RII showed that the lightning data reduced the bias by a few percent in both the Atlantic and eastern Pacific. Additional tests in the postseason showed that larger reductions (up to 16% in the Atlantic) in the bias were obtained when the RII was run with lightning data input from the WWLLN instead of the GLD-360. In addition, other measures of probabilistic forecasts such as the Brier skill score improved with the WWLLN data. The improvement with the WWLLN data is primarily because those are the same data from which the statistical algorithm was developed. Time series of the lightning activity in radial bands around tropical cyclones, which were provided as part of the RII, were found to have some value in monitoring storm evolution. More research is needed to determine the value of the SRSO data. Efforts to collect SRSO data for a U.S. land-falling hurricane will continue, because this was not obtained in 2010. The feedback from forecasters will be used to improve the NHC PG activities, which will likely continue up until the launch of GOES-R. Additional products will also be tested as they become available using proxy data.

Air Quality Proving Ground demonstration. The goal of the AQPG is to demonstrate emulative GOES-R air quality–related products in near–real time so the air quality user community can use, get familiar with, test, and evaluate the products. A user advisory group provides constructive feedback to algorithm/product developers on the value and needed changes to products for increased utility. The GOES-R ABI air quality products to be demonstrated include suspended matter/aerosol optical depth (AOD), aerosol type, aerosol detection (smoke/dust), and fire detection. These proxy retrievals are derived or simulated from existing Moderate Resolution Imaging Spectroradiometer (MODIS) radiances or from the Community Multiscale Air Quality (CMAQ) model, the WRF with Chemistry (WRF-Chem), and the Community Radiative Transfer Model (CRTM).

The GOES-R ABI suspended matter/aerosol optical depth and aerosol detection products have applicability within the NWS for visibility assessment and direct comparison to the NWS prototype aerosol forecast product. PM2.5, denoting particulate matter with particles smaller than 2.5 μm in diameter, has harmful health consequences with important economic impacts and is monitored by the Environmental Protection Agency (EPA) for federal air quality standard compliance. Satellite-derived AODs have been shown to be a good proxy for surface PM2.5 (e.g., Wang and Christopher 2003; Engel-Cox et al. 2004; Hoff and Christopher 2009). The currently operational GOES and MODIS AOD products are widely used by the EPA and other agencies in assessing PM2.5 spatial distributions.

Aerosol detection (including smoke and dust) is a qualitative imagery product that provides presence/absence information of smoke or dust in a GOES-R ABI pixel. This information, combined with location of fires detected by the GOES-R ABI, helps the forecasters with the identification of the nonanthropogenic pollution sources and the spatial distribution patterns of the smoke and dust. The NWS/NCEP is currently testing the MODIS dust mask product to use in verifying the operational Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) forecast. The air quality (AQ) demonstration has evaluated the MODIS dust mask product and, based on the NWS feedback, modified the algorithm to avoid classifying thin dust as cloud.

The GOES-R AQPG held its kickoff users and advisory group workshop at the University of Maryland, Baltimore County, in September 2010. To help the AQPG team understand user needs, state and local AQ forecasters gave a series of presentations about air quality forecasting and analysis across the country. The talks highlighted how satellite observations fit into the forecasting process. Users described their current and planned use of GOES

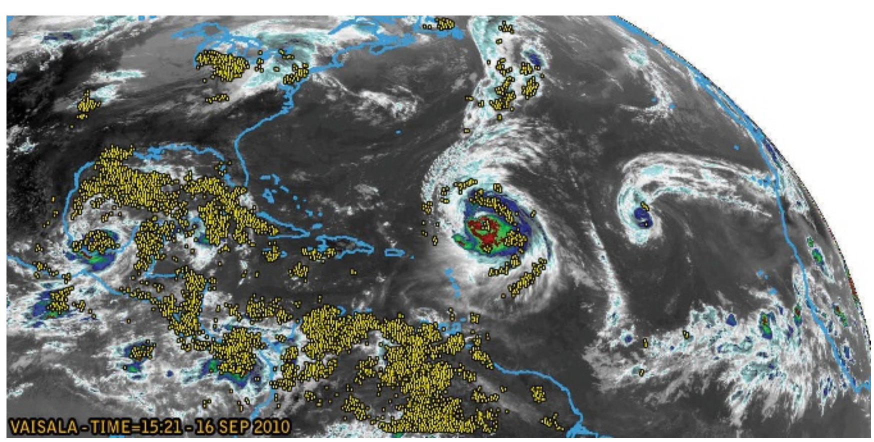

Fig. 5. Lighting locations (gold points) within 3 h of 1500 UTC 16 Sep on a color-enhanced GOES IR image. Three hurricanes (Igor in the center, Julia to the east of Igor, and Karl in the southwestern Gulf of Mexico) were in the Atlantic basin at this time.

> *"Total lightning data preceded the CG network anywhere from 10–40 minutes. I was able to quickly determine when flash rate was significantly increasing, and then compare with satellite and updraft/downdraft parameters for a nice big picture."*
>
> —HWT Forecaster on Lightning Detection

products and imagery in the preparation of real-time forecasts and in retrospective analysis to address the exceptional event rule when smoke/dust/ozone/PM2.5 levels resulted in air quality nonattainment. Users are looking forward to the increased spatial and temporal resolution of the ABI instrument and more accurate air quality products. Future EPA air quality rules for ozone and PM2.5 particulates are expected to increase the demand for archived satellite data in retrospective analysis.

TRAINING. The GOES-R PG is both a user and developer of satellite-related training. The participants in the PG activities need to be cognizant of the characteristics of the proxy GOES-R products and their utility within NOAA's complex operational environment. The knowledge users gain in applying these products is then passed back to product developers, GOES-R, other NOAA program managers, and the broader user communities outside of NOAA.

There are numerous sources of training for PG participants, including the GOES-R PG website, the Cooperative Program for Meteorology Education and Training (COMET), the Virtual Institute for Satellite Integration Training (VISIT), Satellite Hydrometeorology Course (SHyMet) courses, the Environmental Satellite Resources Center (ESRC), SPoRT, and WES cases. More training and information are available at CIMSS and VISIT satellite blogs. The PG website provides a list of available proxy GOES-R products and descriptions of the products, how they are developed, and their strengths and limitations. Training website addresses are listed in Table 1.

Table 1. Training links.

COMET	www.comet.ucar.edu/
VISIT	http://rammb.cira.colostate.edu/training/visit/
SHyMet	http://rammb.cira.colostate.edu/training/shymet/
ESRC	www.meted.ucar.edu/
SPoRT	http://wwwghcc.msfc.nasa.gov/sport/
WES	www.wdtb.noaa.gov/tools/wes/index.htm

WES cases are developed as part of the PG concept to prepare forecasters for the dramatic increase in spatial, spectral, and temporal resolution from the ABI and new lightning detection capabilities from the GLM. The PG partners are developing WES scenarios for a variety of operational high-impact weather situations, including convective outbreaks over the midwestern United States, land-falling hurricane events and other tropical systems, and severe weather outbreaks. Forecasters are provided simulated ABI images and products to learn how to integrate them into their operations.

FUTURE PLANS. There is a good deal of additional work to be done within the PG framework to ensure user readiness. Demonstration plans have been completed for activities at NWS's Ocean Prediction Center and the Hydrometeorological Prediction Center. Plans for aviation-related products have been developed and were initiated in early 2011 for the Aviation Weather Center (AWC) and the Alaska Aviation Weather Unit (AAWU). The aviation products include volcanic ash, cloud-top height, turbulence, lightning detection, precipitation, icing, and low clouds and fog. A plan for a Space Weather Prediction Center PG demonstration includes many of the products that will become available from the SUVI on GOES-R and will be derived from the NASA Solar Dynamics Observatory's Atmospheric Imaging Assembly (AIA). Within the HWT, additional experiments are being planned to utilize additional GOES-R products outside of the severe weather spectrum that are directly applicable to SPC operations, including fire weather, heavy precipitation, and winter weather forecasting. 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 (e.g., RGB imagery-derived products akin to those generated by EUMETSAT from the Meteosat Second Generation SEVIRI; Roesli et al. 2006; Hillger et. al.

2011). Indeed, the GOES-R satellite series will usher in a revolutionary change in the utility of geostationary satellite information.

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EXPLAINING EXTREME EVENTS OF 2011 FROM A CLIMATE PERSPECTIVE

THOMAS C. PETERSON, PETER A. STOTT AND STEPHANIE HERRING, EDITORS

Using a variety of methodologies, six extreme events of the previous year are explained from a climate perspective.

INTRODUCTION

PETER A. STOTT—MET OFFICE HADLEY CENTRE, UNITED KINGDOM; THOMAS C. PETERSON—NOAA NATIONAL CLIMATIC DATA CENTER, ASHEVILLE, NORTH CAROLINA; STEPHANIE HERRING—NOAA OFFICE OF PROGRAM PLANNING AND INTEGRATION, SILVER SPRING, MARYLAND

Every year, the Bulletin of the AMS publishes an annual report on the State of the Climate [e.g., see the Blunden and Arndt (2012) supplement to this issue]. That report does an excellent job of documenting global weather and climate conditions of the previous year and putting them into accurate historical perspective. But it does not address the causes. One of the reasons is that the scientists working at understanding the causes of various extreme events are generally not the same scientists analyzing the magnitude of the events and writing the State of the Climate. Another reason is that explaining the causes of specific extreme events in near-real time is severely stretching the current state of the science.

Our report is a way to foster the growth of this science. Other reports, such as those by the Intergovernmental Panel on Climate Change (IPCC), have focused on understanding changes over longer time scales and larger geographic regions. For example, assessing the state of the climate and science, IPCC (Field et al. 2012) concluded that "it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale" and that "there is medium confidence[1] that anthropogenic influences have

[1] Likely indicates probability greater than 66%; see IPCC guidance on uncertainty language (Mastrandrea et al. 2010), which also includes guidance on expression of levels of confidence.

AFFILIATIONS: PETERSON—NOAA National Climatic Data Center, Asheville, North Carolina; STOTT—Met Office Hadley Centre, United Kingdom; HERRING—Office of Program Planning and Integration, NOAA, Silver Spring, Maryland
CORRESPONDING EDITOR: Thomas C. Peterson, NOAA National Climatic Data Center, 151 Patton Avenue, Asheville, NC 28803
E-mail: thomas.c.peterson@noaa.gov

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contributed to intensification of extreme precipitation at the global scale".

This first edition of what is intended to be an annual report starts out with an assessment on causes of historical changes in temperature and precipitation extremes worldwide to provide a long-term perspective for the events discussed in 2011. That section also considers the use of the term "extreme" in climate science so as to provide a context for the extreme events discussed in the rest of the report. The report then goes on to examine only six extreme events assessed by teams of experts from around the world. We are not attempting to be comprehensive nor does our selection of extreme events reflect any judgment about the importance of the events discussed here relative to the many other extreme events around the world in 2011.

By choosing a few noteworthy events to analyze there could be a risk of selection bias if the events chosen are thought of as representative of the weather observed in 2011, which they are not. However, our purpose here is to provide some illustrations of a range of possible methodological approaches rather than to be comprehensive. We hope that the examples we have chosen will serve to stimulate the development of attribution science and lead to submissions that, in future years, look at different regions and a wider range of extreme events. Developing objective criteria for defining extreme weather and climate events ahead of time, and applying predetermined methodologies, should minimize the risk of bias resulting from selective choice of criteria based on what actually occurred (e.g., Stott et al. 2004).

Currently, attribution of single extreme events to anthropogenic climate change remains challenging (Seneviratne et al. 2012). In the past it was often stated that it simply was not possible to make an attribution statement about an individual weather or climate event. However, scientific thinking on this issue has moved on and now it is widely accepted that attribution statements about individual weather or climate events are possible, provided proper account is taken of the probabilistic nature of attribution (Nature Publishing Group 2011).

One analogy of the effects of climate change on extreme weather is with a baseball player (or to choose another sport, a cricketer) who starts taking steroids and afterwards hits on average 20% more home runs (or sixes) in a season than he did before (Meehl 2012). For any one of his home runs (sixes) during the years the player was taking steroids, you would not know for sure whether it was caused by steroids or not. But you might be able to attribute his increased number to the steroids. And given that steroids have resulted in a 20% increased chance that any particular swing of the player's bat results in a home run (or a six), you would be able to make an attribution statement that, all other things being equal, steroid use had increased the probability of that particular occurrence by 20%. The job of the attribution assessment is to distinguish the effects of anthropogenic climate change or some other external factor (steroids in the sporting analogy) from natural variability (e.g., in the baseball analogy, the player's natural ability to hit home runs or the configuration of a particular stadium).

There have been relatively few studies published in the literature that attempt to explain specific extreme events from a climate perspective and this report covers some of the main methodological approaches that have been published to date. A position paper produced for the World Climate Research Program (Stott et al. 2012) reviewed some of these studies including attribution assessments of the 2000 UK floods (Pall et al. 2011), the 2003 European heat wave (Stott et al. 2004), the cool year of 2008 in the United States (Perlwitz et al. 2009) and the 2010 Russian heat wave (Dole et al. 2011). Such studies have demonstrated how the changed odds of an individual extreme weather or climate event can be calculated and attributed—very likely more than doubled for the 2003 European heat wave. In other cases, such as the case of the cool year of 2008 in the United States, conditions apparently inconsistent with the expected effects of ongoing climate change can be explained by the interplay of human influence on climate decreasing the odds of such extremes and natural variability, La Niña in the case of the U.S. temperatures in 2008, increasing the odds.

This report also considers other approaches distinct from those that seek to apportion changed odds. Analyzing how temperatures within particular flow patterns have changed helps to illustrate how long-term climate change is altering the typical weather associated with a particular flow regime. Such a regime-based approach (Cattiaux et al. 2010a) has shown how the cold northwestern European winter of 2009/10, associated largely with a very negative North Atlantic Oscillation (NAO), would have been even colder were it not for a long-term warming associated with ongoing climate change. Other related approaches involve using statistical models or climate models to tease apart the effects of climate variability and long-term warming on the observed occurrence of particular extreme weather events. By not quantifying the link to human emissions, such analyzes do not fully answer the attribution question, but they do help to put extreme events into a climate perspective.

While the report includes three examples of the odds-based attribution analyzes discussed earlier, the challenges of running models and analyzing data in time for this report have meant that only the final analysis (of the cold UK winter of 2010/11, section 8) has the climate model simulations available to explicitly calculate the change odds attributable to human influence. Therefore this new report is a step along the road towards the development of the regular near-real time attribution systems advocated by Stott et al. (2011) rather than the final product. While there may be an increasing focus on such near-real time attribution activities by operational centers around the world, there remains much underpinning science to be done in the development of such a service. An informal group of scientists, the Attribution of Climate-Related Events group (ACE; Schiermeier 2011), is meeting in September 2012 to discuss how to take such activities further (www.metoffice.gov.uk/research/climate/climate-monitoring/attribution/ace).

One important aspect we hope to help promote through these reports is a focus on the questions being asked in attribution studies. Often there is a perception that some scientists have concluded that a particular weather or climate event was due to climate change whereas other scientists disagree. This can, at times, be due to confusion over exactly what is being attributed. For example, whereas Dole et al. (2011) reported that the 2010 Russian heatwave was largely natural in origin, Rahmstorf and Coumou (2011) concluded it was largely anthropogenic. In fact, the different conclusions largely reflect the different questions being asked, the focus on the magnitude of the heatwave by Dole et al. (2011) and on its probability by Rahmstorf and Coumou (2011), as has been demonstrated by Otto et al. (2012). This can be particularly confusing when communicated to the public.

We hope that this new venture will help develop the means of communicating assessments of the extent to which natural and anthropogenic factors contribute to the extreme weather or climate events of a particular year. As such we seek your reactions to this report, which will be invaluable in determining how we should continue in future years. It will also help inform the dialog about how best to enable a wider public to appreciate the links between the weather they are experiencing and the effects of long-term climate change.

HISTORICAL CONTEXT

Francis W. Zwiers—Pacific Climate Impacts Consortium, University of Victoria, Victoria, British Columbia, Canada; Gabriele C. Hegerl—School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom; Seung-Ki Min—CSIRO Marine and Atmospheric Research, Aspendale, Victoria, Australia; Xuebin Zhang—Climate Research Division, Environment Canada, Toronto, Ontario, Canada

The occurrence of high-impact extreme weather and climate variations invariably leads to questions about whether the frequency or intensity of such events have changed, and whether human influence on the climate system has played a role. Research on these questions has intensified in recent years, culminating in two recent assessments (Karl et al. 2008; Field et al. 2012), and in proposals to formalize "event attribution" as a global climate service activity (Stott et al. 2012). In order to provide historical context for later sections, this section discusses the extent to which human influence has caused long-term changes in the frequency and intensity of some types of extremes.

The nature of extreme events. The term "extreme" is used in a number of contexts in climate science. It refers to events that may in fact not be all that extreme, such as the occurrence of a daily maximum temperature that exceeds the 90th percentile of daily variability as estimated from a climatological base period, or it may refer to rare events that lie in the far tails of the distribution of the phenomenon of interest. A characteristic of extremes is that they are understood within a context—and thus seasonal or annual means may be "extreme" just as an unusual short-term event, such as a daily precipitation accumulation, may be extreme. Certain phenomena, such as tropical cyclones that have been classified on the Saffir–Simpson scale, or tornadoes that have been classified on the Fujita scale, are considered extreme as a class. The general definition of extremes that was adopted by the IPCC for its Special Report on Extremes (Field et al. 2012) applies to most extremes considered in this report, and across the range of space and time scales that are considered here. That definition describes an extreme as the "occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable." A full discussion of the definition of an extreme can be found in Seneviratne et al. (2012). In addition, Zwiers et al. (2012, unpublished manuscript) provide a discussion of the language surrounding extremes that is used in the climate sciences.

Challenges in detection and attribution of extremes. The discussion in this section reflects the fact that most detection and attribution research on long-term changes in the probability and frequency of extremes thus far has focused on short duration events that can be monitored using long records of local daily temperature and precipitation observations. These changes are generally captured as indices that document the frequency or intensity of extremes in the observed record rather than focusing on individual rare events. In contrast, many of the events considered in later sections of this report are individual events, often of longer duration than the extremes considered here, and are also usually events with longer return periods. Nevertheless, the finding that human influence is detectable in some types of short duration events that can be conveniently monitored from meteorological observations provides important context for the interpretation of other types of events. For example, feedbacks and physical processes that influence individual large events (Fischer et al. 2007; Seneviratne et al. 2010) will often also be at play in events that are reflected in indices. Thus, index-based studies are helpful for providing context for the attribution of individual events, and evaluate the ability of models to realistically simulate events that are affected by different feedbacks from those affecting mean climate.

While not discussed in this section, the detection and attribution of changes in the mean state of the climate system often also provides important context for the understanding of individual extreme events. An example is the European 2003 heat wave, which can be characterized both by very extreme warm daily maximum and minimum temperatures, and by an extremely warm summer season. The demonstration that human factors had influenced the climate of southern Europe in a quantifiable way over the latter part of the twentieth century was an important element in establishing that human influence had probably substantially increased the likelihood of an extreme warm summer like that experienced in the region in 2003 (Stott et al. 2004).

The frequency and intensity of extremes can be affected by both the internal variability of the climate system and external forcing, and the mechanisms involved can be both direct (e.g., via a change in the local energy balance) and indirect (e.g., via circulation changes). This makes the attribution of events to causes very challenging, since extreme events in any location are rare by definition. However, global-scale data make it possible to determine whether broadly observed changes in the frequency and intensity of extremes are consistent with changes expected from human influences, and inconsistent with other possibilities such as climate variability. Results from such detection and attribution studies provide the scientific underpinning of work determining changes in the likelihood of individual events.

Observed changes in extremes. We briefly consider historical changes in frequency and intensity of daily temperature and precipitation extremes. There is a sizable literature on such events, in part because reliable long-term monitoring data are gathered operationally by meteorological services in many countries. Many other areas remain understudied, such as whether there have been changes in the complex combinations of factors that trigger impacts in humans and ecosystems (e.g., Hegerl et al. 2011), or areas that are subject to greater observational and/or process knowledge uncertainty, such as the monitoring and understanding of changes in tropical cyclone frequency and intensity (e.g., Knutson et al. 2010; Seneviratne et al. 2012).

Changes in extreme temperature and the intensification of extreme precipitation events are expected consequences of a warming climate. A warmer climate would be expected to have more intense warm temperature extremes, including longer and more intense heat waves and more frequent record-breaking high temperatures than expected without warming. It would also be expected to show less intense cold temperature extremes and fewer record-breaking low temperatures than expected before. Both of these expected changes in the occurrence of record-breaking temperatures have indeed been observed (e.g., Alexander et al. 2006; Meehl et al. 2009). Further, a warmer atmosphere can, and does, contain more water vapor, as has been observed and attributed to human influence (Santer et al. 2007; Willett et al. 2007; Arndt et al. 2010). This implies that more moisture is available to form precipitation in extreme events and to provide additional energy to further intensify such events. About two-thirds of locations globally with long, climate-quality instrumental records [e.g., as compiled in the Hadley Centre Global Climate Extremes dataset (HadEX); Alexander et al. 2006] show intensification of extremes in the far tails of the precipitation distribution during the latter half of the twentieth century (Min et al. 2011).

Detection and attribution of changes in intensity and frequency of extremes. A number of studies (e.g., Christidis et al. 2005, 2010; Zwiers et al. 2011; Morak et al. 2011, 2012) have now used various types of detection and attribution methods to determine whether the changes in temperature extremes predicted by climate models in response to historical greenhouse gas increases and other forcings are detectable in observations. The accumulating body of evidence on the human contribution to changes in temperature extremes is robust, and leads to the assessment that "it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures on the global scale" (Seneviratne et al. 2012). Results tend to show that the climate models used in studies simulate somewhat more warming in daytime maximum temperature extremes than observed, while underestimating the observed warming in cold extremes in many locations on the globe. It remains to be determined if this model-data difference occurs consistently across all models, or whether it is specific to the small set of phase 3 of the Coupled Model Intercomparison Project (CMIP3) climate models used in the studies.

Heavy and extreme precipitation events have also received a considerable amount of study. Heavy precipitation has been found to contribute an increasing fraction of total precipitation over many of the regions for which good instrumental records are available (Groisman et al. 2005; Alexander et al. 2006; Karl and Knight 1998; Kunkel et al. 2007; Peterson et al. 2008; Gleason et al. 2008), indicating an intensification of precipitation extremes. Direct examination of precipitation extremes, such as the largest annual 1-day accumulation, or the largest annual 5-day accumulation, also shows that extreme precipitation has been intensifying over large parts of the global landmass for which suitable records are available (Alexander et al. 2006; Min et al. 2011; Figs. 1 and 2), with an increase in the likelihood of a typical 2-yr event of about 7% over the 49-yr period from 1951 to 1999 (Min et al. 2011). It should be noted, however, that the spatial extent of regions for which long records of daily and pentadal precipitation accumulations are available is still severely limited (e.g., Alexander et al. 2006; see also Fig. 1), and that spatial patterns of change are still noisy.

The intensification of extreme precipitation is an expected consequence of human influence on the climate system (e.g., Allen and Ingram 2002; Trenberth et al. 2003) and is simulated by models over the latter half of the twentieth century in response to anthropogenic forcing, albeit with weaker amplitude than observed, which is at least partly due to differences in the spatial scales resolved by climate models and station-based local records (Chen and Knutson 2008). Nevertheless, Min et al. (2011) recently showed, using an ensemble of models and an index of extreme precipitation that is more comparable between models and data than records of intensity of events, that the observed large-scale increase in heavy precipitation cannot be explained by natural internal climate variability, and that human influence on climate provides a more plausible explanation. The body of research available on precipitation extremes is in an earlier stage of development than for temperature extremes, and thus Seneviratne et al. (2012) did not give a quantified likelihood assessment concerning precipitation extremes, but rather stated that "there is medium confidence[2] that anthropogenic influences

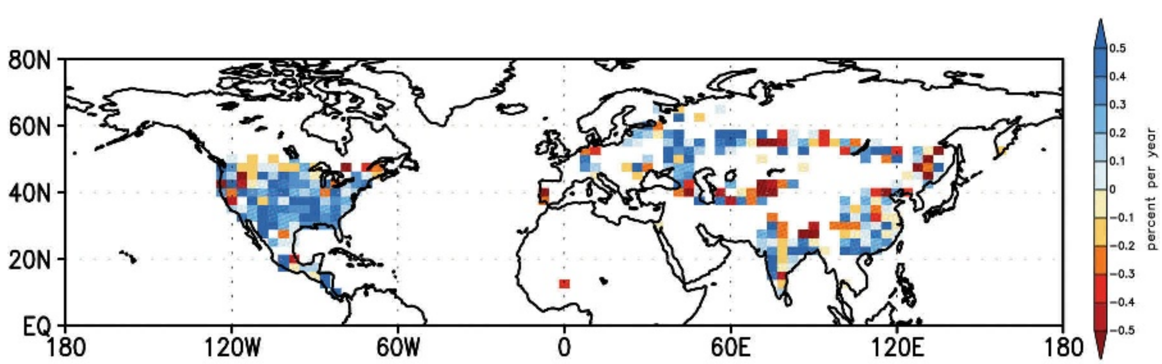

Fig. 1. Geographical distribution of trends of probability-based indices (PI) of extreme precipitation during 1951–99 for 1-day precipitation accumulations. Annual extremes of 1-day accumulations were fitted to the Generalized Extreme Value distribution, which was then inverted to map the extremes onto a 0%–100% probability scale. Blue colors indicate intensification of extreme precipitation, which is observed at about two-thirds of locations. From Min et al. (2011).

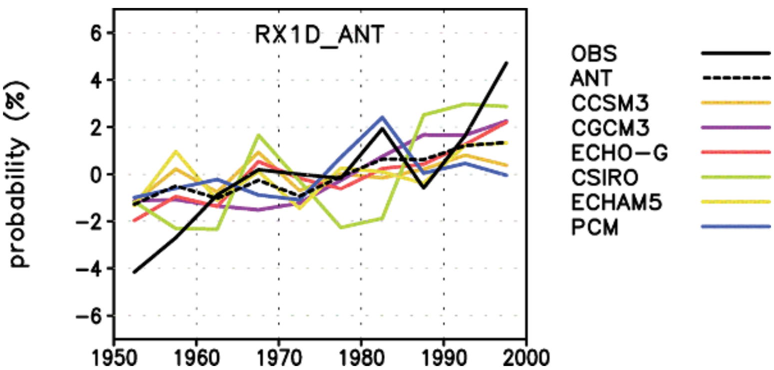

Fig. 2. Time series of five-year mean area-averaged PI (as defined in Fig. 1) anomalies (%) for 1-day annual extreme precipitation anomalies over Northern Hemisphere land during 1951–99. Black solid line represents observations and the dashed line represents the multimodel mean for the models indicated in the legend. Model simulations were run with anthropogenic forcings. Colored lines indicate results for individual model averages [see Supplementary Table 1 of Min et al. (2011) for the list of climate model simulations and Supplementary Fig. 2 of Min et al. (2011) for time series of individual simulations]. Each time series is represented as anomalies with respect to its 1951–99 mean.

have contributed to intensification of extreme precipitation on the global scale."

Few detection and attribution studies that include observations of temperature or precipitation extremes in the first decade of the twenty-first century have yet been performed (exceptions include Morak, et al. (2011, 2012, manuscript submitted to *J. Climate*), who detect anthropogenic influence in the frequency of occurrence of temperature extremes in data that extend to 2005]. However, studies of changes in extremes that include more recent observations show that ongoing changes in temperature extremes are regionally consistent with those observed in the latter half of the twentieth century. Examples include studies of the frequencies of warm and cold days and nights in North America (Peterson et al. 2008); the frequency of record breaking temperatures in the United States (Meehl et al. 2009); and the frequency of temperature extremes in multiple regions globally (Morak et al. 2011, 2012, manuscript submitted to *J. Climate*). Results from recent studies of precipitation extremes are more mixed. Some studies do show changes consistent

[2] See Mastrandrea et al. (2010) for a description of IPCC confidence language used in the IPCC Fifth Assessment, including the Special Report on Extremes (Field et al. 2012).

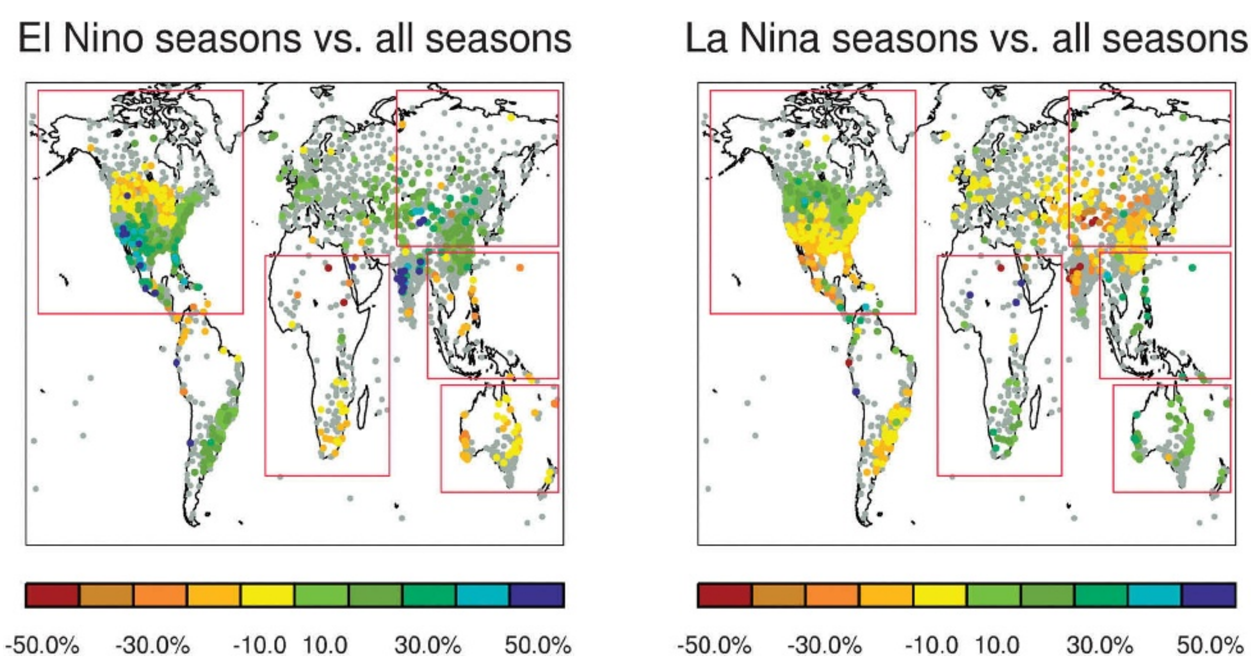

Fig. 3. Impact of (left) El Niño and (right) La Niña on the intensity of the largest 1-day precipitation event monthly in the November–April half of the year. Based on station data from the Global Historical Climatology Network-Daily (GHCN-D) for 1949–2003. From Kenyon and Hegerl (2010).

with those observed in the latter part of the twentieth century [e.g., the fraction of U.S. land area affected by extreme precipitation (Gleason et al. 2008), change in various extreme precipitation indicators in North America (Peterson et al. 2008), and heavy precipitation in Europe (Zolina et al. 2010)], while others do not demonstrate evidence of statistically significant trends [e.g., Choi et al. (2009) for the Asia-Pacific region and Aguilar et al. (2009) for central Africa; see also the assessment of Seneviratne et al. (2012)]. Overall, changes in precipitation remain regionally mixed, testifying to the high spatial variability of precipitation.

Natural low frequency internal variability of the climate system also affects the intensity and frequency of temperature and precipitation extremes, generally with a mixed pattern of increasing and decreasing responses depending on regions and seasons. For example, El Niño strongly influences both temperature and precipitation extremes globally (Kenyon and Hegerl 2008, 2010; see Fig. 3) and can alter the likelihood of rare damaging wintertime precipitation events by more than a factor of 4 in some parts of the United States, particularly in the southwest (Zhang et al. 2010). Any human influence on extreme weather risk combines with these episodic variations and the chance fluctuations that are inevitable when dealing with rare events; hence we should not assume that, if human influence is making a particular type of event more likely over time, it will necessarily occur with greater than average likelihood every year.

THE ABSENCE OF A ROLE OF CLIMATE CHANGE IN THE 2011 THAILAND FLOODS

Geert Jan van Oldenborgh—KNMI, De Bilt, Netherlands; Anne van Urk—CoDeWa, Reeuwijk, Netherlands; Myles Allen—Atmospheric, Oceanic and Planetary Physics, Department of Physics, and Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, United Kingdom

Thailand experienced severe flooding in 2011. During and after an unusually wet monsoon (July–September) in northern Thailand, rivers on the flood plains in the center and the south flooded their banks and inundated large parts of the country, including the former capital Ayuttha and neighborhoods of the present capital Bangkok. Large-scale industrial estates were submerged by 2.5 m of water for nearly 2 months and the economic damage was considerable. The reinsurer SwissRe estimated an insured damage between 8 and 11 billion U.S. dollars (USD) (SwissRe 2011). The total damage is much more uncertain, the World Bank estimates a value of 45 billion USD (World Bank 2011).

Flooding events are not uncommon in Thailand. However, the scale of the 2011 event was unprecedented. In this article we perform a first analysis of the meteorological component of the flood: how unusual was the rainfall in the catchment of the Chao Phraya river in northwestern Thailand, and are future monsoon rainfall trends expected due to climate change? It should be emphasized, however, that nonmeteorological factors were much more important in setting the scale of the disaster. Examples are the changing hydrography of the river (the levels of the Chao Phraya were in some places more than 0.5 m higher than in 1995 for even a slightly lower discharge), conversion of agricultural land to much more vulnerable industrial usage, and reservoir operation policies.

Observed rainfall anomaly and return time. We use the Global Precipitation Climatology Centre (GPCC) V5 1° rainfall analyzes (Schneider et al. 2011) to estimate historical rainfall over Thailand. This dataset nominally starts in 1901, but up to 1915 there are very few reporting stations in Thailand. The number of stations included rises from 35 in 1915 to 80 in recent years (A. Becker 2011, personal communication). We therefore start our analysis in 1915. For 2010 and 2011 the dataset was extended using the GPCC monitoring product. On the overlap period 1986–2010 the correlation is 0.99 but the monitoring dataset has a slightly lower mean and variability. A linear correction for the mismatch leads to a 2.7% increase in the values for 2010 and 2011.

Figure 4a shows the time series of rainfall in the middle and upper Chao Phraya basin, approximated by the region 15°–20°N, 99°–101°E, which is shown by the box in Fig 5. In this estimate the monsoon season 2011 is the wettest in the record, but comparable to 1995. To estimate the return time we fitted a generalized Pareto distribution (GPD; Coles 2001) to the highest 80% of the distribution before 2011. This gives a central estimate of a return value of 140 years although the 95% confidence interval encompasses a range from 50 to several thousand years. In terms of large-scale meteorology, the 2011 monsoon was not very different from previously observed seasons.

La Niña has a statistically significant but small effect of rainfall in the area: the linear correlation coefficient with the Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST1) Niño-3.4 index is about −0.25 (between −0.07 and −0.39 with 95% confidence), slightly weaker than the spring teleconnection to the Netherlands (van Oldenborgh et al. 2000). Under the assumption that the empirical distribution shifts linearly with the Niño-3.4 index, the observed weak La Niña (Niño-3.4 = −0.5) implies an increase of the probability of "above-normal" precipitation from 33% to 45% in July–September 2011. From the scatterplot Fig. 4b one can see that all extreme rainfall events in the past occurred at neutral or La Niña conditions. However, the return time of the 2011 event was not lower relative to the regression line than the 140 years quoted above. The extra 17 ± 13 mm (2σ error) explained by the weak La Niña is counteracted by other changes in the tail within the large uncertainties of the empirical distribution function.

Have Thailand rainfall extremes become more likely due to climate change? One method to answer this question is to analyze the observations only. Given the intrinsic rarity of extreme events, this implies that one has to make statistical assumptions on the distribution of the data. One possibility is the assumption that the probability distribution function of monsoon rainfall does not change shape but is shifted to higher or lower values by the changing climate (van Oldenborgh 2007). The trend of the time series in Fig. 4 is not significantly different from zero: the mean precipitation has not changed beyond the natural variability. The 20-yr running mean and standard deviation also do not show significant variations.

The second method is to use climate models rather than statistical models, which in principle can give a physics-based estimate of the change in PDF. A full analysis would have to involve a validation of the representation of the Southeast Asian monsoon in these models. Here we simply note that the 17 climate models available in the CMIP5 archive (Taylor et al. 2012) at the time of writing

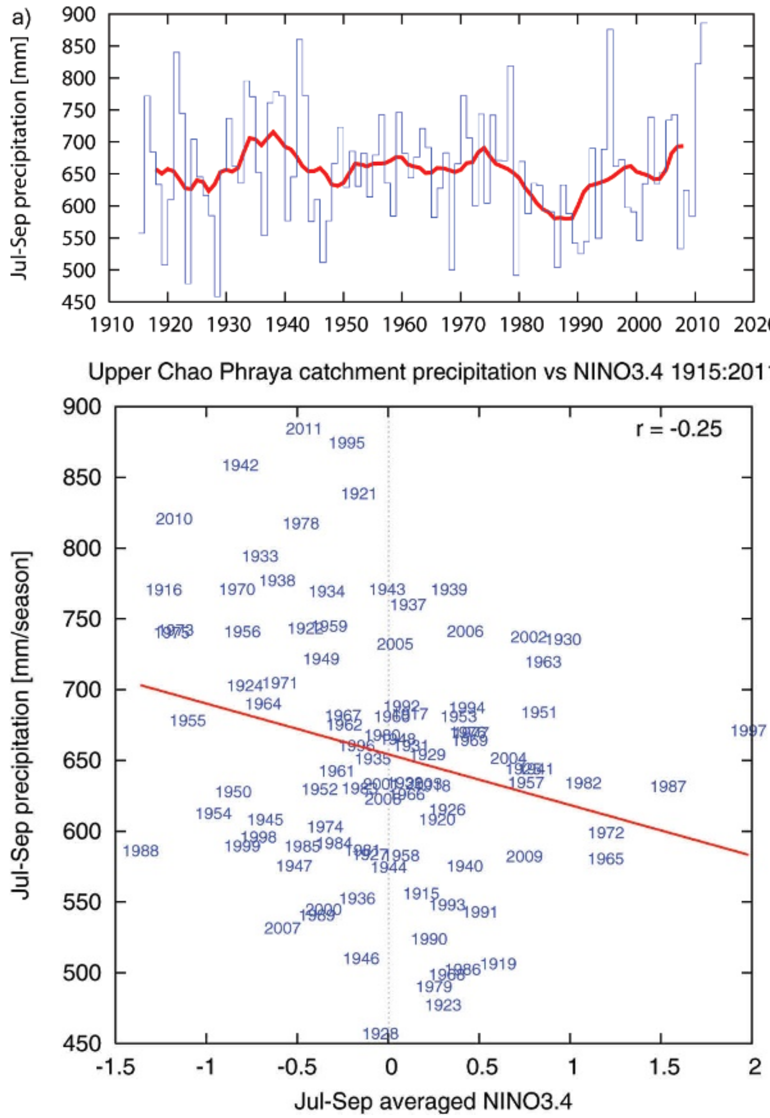

Fig. 4. (a) July–September precipitation (mm) in the upper catchment of the Chao Phraya river that flooded in 2011. The rainfall has been approximated by the 10 grid boxes in 15°–20°N, 99°–101°E in the GPCC V5 1° analysis 1915–2009, extended with the GPCC monitoring analysis linearly adjusted to agree on the overlap period. The red line denotes a 10-yr running mean. (b) Scatterplot of this precipitation against the HadISST1 Niño-3.4 index. The least squares regression line has been drawn red.

show no trend in the region of the catchment of the Chao Phraya up to 2011 in either mean or variability. They do show an increase of 10%–20% in both mean and standard deviation by 2100, indicating that the frequency of very active monsoons is projected to increase in the future by these models. We again stress that the credibility of any projected change depends on the simulation of climatology of the Asian monsoon, which is as yet untested in this ensemble and has been shown to be highly variable across models (Kim et al. 2008).

Conclusions. Although the damage caused by the 2011 floods on the Chao Phraya river in Thailand was unprecedented, the available data show that the amount of rain that fell in the catchment area was not very unusual. Other factors such as changes in the hydrography and increased vulnerability were therefore more important in setting the scale of the disaster. Neither in the precipitation observations nor in climate models is there a trend in mean or variability up to now, so climate change cannot be shown to have played any role in this event. Current models do project increases in both mean and variability in the future that would increase the probability of extremes. It may be advisable to take this into account when addressing current vulnerabilities.

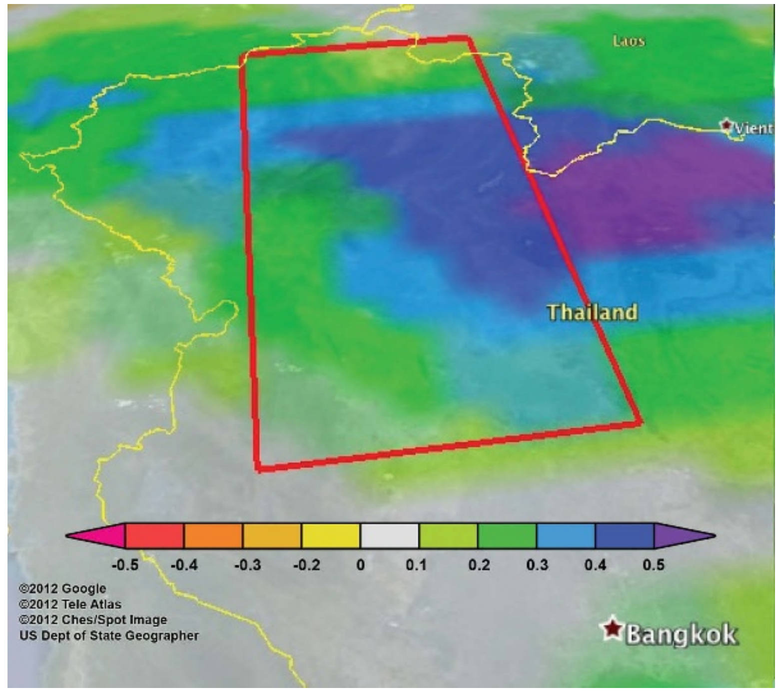

Fig. 5. Relative precipitation anomalies in Southeast Asia during July–September 2011. The value 0.5 means 50% more precipitation than normal in this season. The red box denotes our approximation of the middle and upper catchment basin of the Chao Phraya River, which runs south through Bangkok to the Gulf of Thailand. Data: GPCC V5 plus monitoring datasets at 1° resolution.

EXCEPTIONAL WARMING IN THE WESTERN PACIFIC–INDIAN OCEAN WARM POOL HAS CONTRIBUTED TO MORE FREQUENT DROUGHTS IN EASTERN AFRICA

Chris Funk—U.S. Geological Survey, and University of California, Santa Barbara, Climate Hazard Group, Santa Barbara, California

In 2011, East Africa faced a tragic food crisis that led to famine conditions in parts of Somalia and severe food shortages in parts of Ethiopia and Somalia. While many nonclimatic factors contributed to this crisis (high global food prices, political instability, and chronic poverty, among others) failed rains in both the boreal winter of 2010/11 and the boreal spring of 2011 played a critical role. The back-to-back failures of these rains, which were linked to the dominant La Niña climate and warm SSTs in the central and southeastern Indian Ocean, were particularly problematic since they followed poor rainfall during the spring and summer of 2008 and 2009. In fact, in parts of East Africa, in recent years, there has been a substantial increase in the number of below-normal rainy seasons, which may be related to the warming of the western Pacific and Indian Oceans (for more details, see Funk et al. 2008; Williams and Funk 2011; Williams et al. 2011; Lyon and DeWitt 2012). The basic argument of this work is that recent warming in the Indian–Pacific warm pool (IPWP) enhances the export of geopotential height energy from the warm pool, which tends to produce subsidence across eastern Africa and reduce onshore moisture transports. The general pattern of this disruption has been supported by canonical correlation analyzes and numerical experiments with the Community Atmosphere Model (Funk et al. 2008), diagnostic evaluations of reanalysis data (Williams and Funk 2011; Williams et al. 2011), and SST-driven experiments with ECHAM4.5, ECHAM5, and the Community Climate Model version 3 (CCM3.6) (Lyon and DeWitt 2012).

An increased frequency of East African droughts. Here we present 1979–2010 GPCP data (Adler et al. 2003), augmented by 2011 estimates based on the Climate Prediction Center's RFE2 (Xie and Arkin 1997) dataset (the RFE2 data were regressed against the GPCP data and used to fill in 2011, which is not included in the current GPCP archive).

Dry areas, based in the 1999–2011 anomalies, were identified for the March–June and June–September seasons. These regions are shown with brown (March–June) and blue (June–September) polygons in Fig. 6a. The background shading in Fig. 6a shows 2005 Gridded Population of the World population densities. The region impacted is one of the most densely populated areas of Africa. The population density and population for the March–June region shown in Fig. 6a are 44 people km^{-2} and 28.5 million people. The population density and population of the June–September dry region is 49 people km^{-2} and 30.5 million people. These regions also have large chronically undernourished and food-insecure populations. As Fig. 6b shows, these highly vulnerable regions have experienced a large number of below-normal rainfall seasons, especially since 1999.

Has ocean warming led to decreased East African rainfall during La Niña episodes? While the La Niña event of 2010/11 played a central role in triggering the 2010/11 food crisis, it is impossible to unambiguously attribute a single event to anthropogenic climate change. There has been recent research, however, that has emphasized that the long-term trend in IPWP SSTs (Williams and Funk 2011), rainfall, and winds could interact dangerously with interannual La Niña climate events. The latter observation helped trigger effective early warning of the 2011 East African food crisis (Ververs 2012; Funk 2011). More recent SST-driven climate simulations have emphasized the important role of post-1999 warming in the Pacific in driving the 2011 drought (Lyon and DeWitt 2012).

How much has the IPWP been warming? Figure 7 shows the recent IPWP warming, as measured by SSTs and an air temperature index. Also shown is a new CMIP5 multimodel ensemble IPWP SST average, based on 55 simulations from five models running the historical climate experiment (Taylor et al. 2011). In the historical experiment models are initialized in

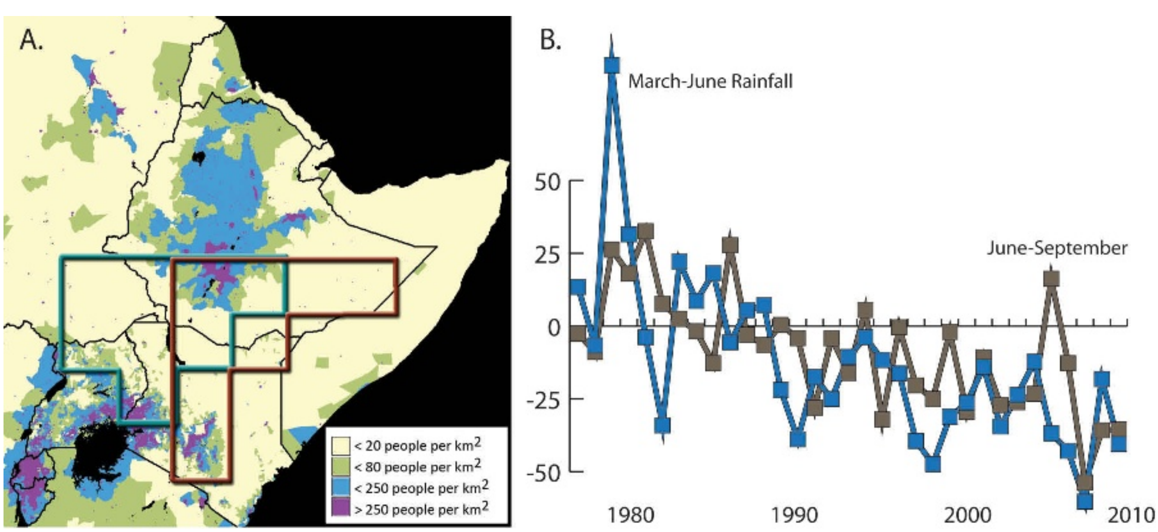

Fig.6. (a) 2005 gridded population of the world overlain with polygons showing locations where recent GPCP rainfall values have declined substantially. (b) Time series of GPCP March–June and June–September rainfall anomalies (%) for these locations.

1850, and the coupled ocean–atmosphere models run through 2005, with the primary forcing being changes in greenhouse gases and aerosols. Annual 2001–11 IPWP SSTs have been very warm (Fig. 7), 28.4°C, which is 0.7°C greater than their 1900–50 mean. The interannual variability in the IPWP SST time series is very low (0.25°C). A 0.7°C increase represents a large change, vis-à-vis the IPWPs historic variability, as measured by the 1890–1970 standard deviation of decadal SSTs (0.10°C).

We can confirm the exceptional warming in the IPWP with an independent index we computed by averaging selected long-running GHCN v3 (Lawrimore et al. 2011) air temperature stations.[3] The 2001–11 air temperature index recorded a 0.5°C increase since 1950, a large increase when compared with the 1890–1970 standard deviation of decadal averages of the air temperature index. Both SSTs and terrestrial station data converge on substantial warming.

Between 1864 and 2011, 10-yr running averages of the IPWP SSTs are highly correlated with global National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS) (Hansen et al. 2010) temperatures (r = 0.99; Fig. 7). Over the past 160 years, the simulated IPWP SSTs have also covaried strongly with the simulated global temperatures in the CMIP5 archive. While formal attribution studies have been made for the southern and northern Indian and Pacific Oceans (Barnett et al. 2005; Pierce et al. 2006), specific attribution of the IPWP has not been made. It is interesting, however, to note how closely the magnitude of warming in the 12-member CMIP5 ensemble matches the observations (Fig. 7).

Conclusions. The ~0.7°C IPWP warming, given the already warm state of the region, is likely to have had substantial dynamic impacts, as supported by recent modeling experiments (Lyon and DeWitt 2012). The relationship between rainfall and SSTs is nonlinear. Between 26° and 29°C average rainfall rates increase by a factor of 5, and observational studies based on GPCP data suggest that a change from mean SSTs of 27.7°–28.4°C might be associated with a change of rainfall rates from 3.4 to 5.5 mm day^{-1} (Folkins and Braun 2002); and this rate of change is similar to recent analyzes of GPCP data within the rising portion of the Pacific Walker circulation, which identified an increase of ~1 mm day^{-1} decade^{-1} (Zhou et al. 2011).

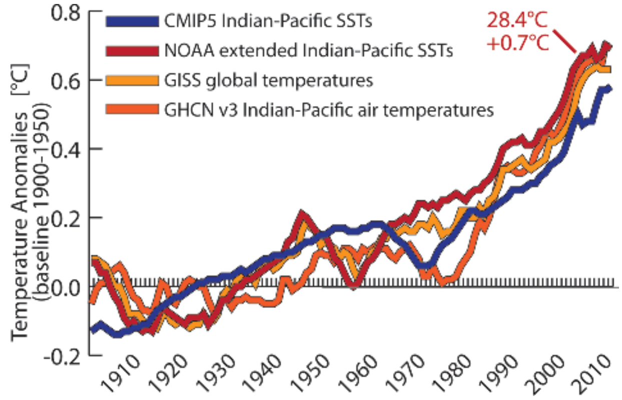

Fig. 7. Long time series of smoothed temperature indices for the IPWP CMIP5 SSTs, IPWP National Oceanic and Atmospheric Administration (NOAA) extended v3 SSTs, NASA GISS global air temperatures, Wilson tropical coral SST reconstruction, and a GHCN IPWP air temperature index.

It is interesting to note that while SST-driven simulations of the 2011 March–May (MAM) season clearly show the important role played by the warm western Pacific (Lyon and DeWitt 2012), and while the new CMIP5 SSTs exhibit substantial warming during the 1990s and 2000s, these increasing SSTs do not appear to produce corresponding large changes in evaporation or rainfall over eastern Africa or the IPWP oceans. While Held and Soden (2006) suggested that the coupled models' weak hydrologic response to warming could help explain their predictions of a weakening of Walker circulation and more El Niño–like weather, recent observations indicate increases in evaporation and rainfall (Yu and Weller 2006; Zhou et al. 2011). An intensification of these hydrologic responses and the southeast trade winds across the Pacific, potentially associated with more La Niña-like climate, might help explain the differences between the observations and model projections. In any event, recent research has suggested that continued warming in the IPWP will likely contribute to more frequent East African droughts during the boreal spring and summer (Funk et al. 2008; Williams et al. 2011, 2011.).

[3] Bombay/Mombassa, Madras, Port Blair, Mannar, Trincomalee, Puttalam, Colombo, Nuwara Eliya, and Sandaka.

DID HUMAN INFLUENCE ON CLIMATE MAKE THE 2011 TEXAS DROUGHT MORE PROBABLE?

David E. Rupp and Philip W. Mote—Oregon Climate Change Research Institute, College of Earth, Ocean, and Atmospheric Science, Oregon State University, Corvallis, Oregon; Neil Massey—Atmospheric, Oceanic and Planetary Physics, Department of Physics, and Smith School of Enterprise and the Environment, University of Oxford, Oxford, United Kingdom; Cameron J. Rye—Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford, Oxford, United Kingdom; Richard Jones—Met Office Hadley Centre, Exeter, United Kingdom; Myles R. Allen—Atmospheric, Oceanic and Planetary Physics, Department of Physics, and Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, United Kingdom

In 2011, the state of Texas experienced an extraordinary heat wave and drought. The 6-month growing season of March–August (MAMJJA) and the three summer months of June–August (JJA) were both, by wide margins, the hottest and driest in the record that dates back to 1895 (Fig. 8). (See also Nielsen–Gammon, Office of the State Climatologist Report: The 2011 Texas drought, a briefing packet for the Texas Legislature, Oct. 21, 2011).

As with other extreme events discussed in this volume, we pose this question: Was the likelihood of either the heat wave or the drought altered by human influence on global climate? This question is portentous because an affirmative answer implies that such events, with their severe impacts on ecosystems and economics, may become more frequent. Here we endeavor to quantify the change in the likelihood of the heat wave and drought since the 1960s to the present, a period during which there has been a significant anthropogenic influence on climate. We analyze a very large ensemble of simulations from a global climate model (GCM), with greenhouse gas concentrations and other climate forcings representative of the 1960s and present day (Pall et al. 2011; Otto et al. 2012). Through the use of public volunteered distributed computing (Allen 1999; Massey et al. 2006), we obtain an ensemble size that is large enough to examine the tails of the distribution of climate variables (see the later section on the changing odds of warm Novembers and cold Decembers in England for more details).

Along with anthropogenic greenhouse gases and other climate forcings, natural sources of interannual variability will result in differences in probability distributions between years. The El Niño–Southern Oscillation (ENSO), for one, is considered to be a key driver of drought conditions in the central United States (Trenberth et al. 1988; Palmer and Brankovic 1989; Atlas et al. 1993; Hong and Kalnay 2000). Hence, to assess the role of multidecadal trends on the 2011 heat wave and drought, we compared years with similar La Niña conditions, separated by four decades, to evaluate how the probability of hot/dry conditions differed between them. The years were 1964, 1967, 1968, and 2008, with 2008 serving as a proxy for 2011 because simulations for 2011 were not available.

Data and methods. Values of observed monthly temperature and precipitation for the years 1895–2011 and spatially averaged over the state of Texas were obtained from the U.S. National Climatic Data Center (NCDC) Climate at a Glance dataset (www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html).

The atmospheric and land surface climate of the decades 1960–70 and 2000–10 were simulated with the UK Meteorological Office's Hadley Center Atmospheric General Circulation Model 3P (HadAM3P) with SST and sea–ice fraction taken from the HadISST observational dataset (Rayner et al. 2003) and using observed greenhouse gas concentrations. A large ensemble of runs with varying initial conditions was completed, resulting in many plausible realizations of the climate of these decades. See the later section on the changing odds of warm Novembers and cold Decembers in England for more information on the modeling and the climate forcings used.

Because simulations under 2011 forcing conditions were not available, we chose 2008 as a proxy for 2011, and compared it to the years 1964, 1967, and 1968. The years 1964 and 2008 were similar with respect to sea surface temperature patterns in the tropical and northern Pacific, as given by the Niño-3.4 and Pacific decadal oscillation (PDO) indices, respectively. The years 1967 and 1968 were also La Niña years (though weaker than 1964) and had negative values of the PDO index. The inclusion of three La Niña years from the 1960s allows us to examine interannual variability not driven by ENSO alone. Moreover, any influence of the Mt. Agung volcanic eruption (Indonesia, 18 February 1963) on Texas climate would have been greatly reduced by 1967 (Robock 2000).

A spatial, weighted average was calculated from the 27 GCM grid boxes that fell within Texas, with weights proportional to the cosine of the latitude. Surface air temperature and cumulative precipitation were also averaged over MAMJJA and JJA and the return period for each value from each ensemble member was calculated. Totals of 171, 1464, 522, and 1087 ensemble members were analyzed for 1964, 1967, 1968, and 2008, respectively. We attempted no model bias correction because our objective was to examine changes in the entire modeled probability distribution between the 1960s and 2008, and not to estimate the actual return period of the 2011 heat wave in a nonstationary setting.

Results. The GCM captured the inverse correlation between temperature and precipitation that is evident in the observations (Fig. 8), though the model in general generated a climate that was too dry and too warm. Between 1964 and 2008, the simulated ensembles show shifts towards warmer and slightly drier conditions (Fig. 8). The relationship is similar between 1967–68 and 2008 (not shown).

The return period for a given low precipitation event was slightly longer for the years in the 1960s than for 2008 (Fig. 9, top; e.g., a simulated 100-yr return period MAMJJA precipitation under 1964 conditions has a 25-yr return period under 2008 conditions). This may indicate an increased contribution of precipitation deficit to drought conditions in 2008, but larger sample sizes and a more in depth analysis including looking at other years are required before firmer conclusions can be drawn.

For extreme heat events, the difference between the years in the 1960s and 2008 was much more pronounced, with the return period of a particular extreme heat event being more than an order of magnitude shorter for 2008 than for any of the 3 years from the 1960s (Fig. 9, lower panel). As an example, 100-yr return period MAMJJA and JJA heat events under 1964 conditions had only 5- and 6-yr return periods, respectively, under 2008 conditions.

Conclusions. We are assessing how the combined impact of changing atmospheric composition and surface temperatures have affected the risk of extreme hot and dry conditions in Texas: since most of the large-scale warming that has occurred over the past 50 years is thought to be attributable to the anthropogenic increase in greenhouse gas levels, this provides one component of a multistep attribution process (Hegerl et al. 2010) relating the 2011 event to human influence.

We found that extreme heat events were roughly 20 times more likely in 2008 than in other La Niña years in the 1960s and indications of an increase in frequency of low seasonal precipitation totals. With 2008 serving as our proxy for 2011, this suggests that conditions leading to droughts such as the one that

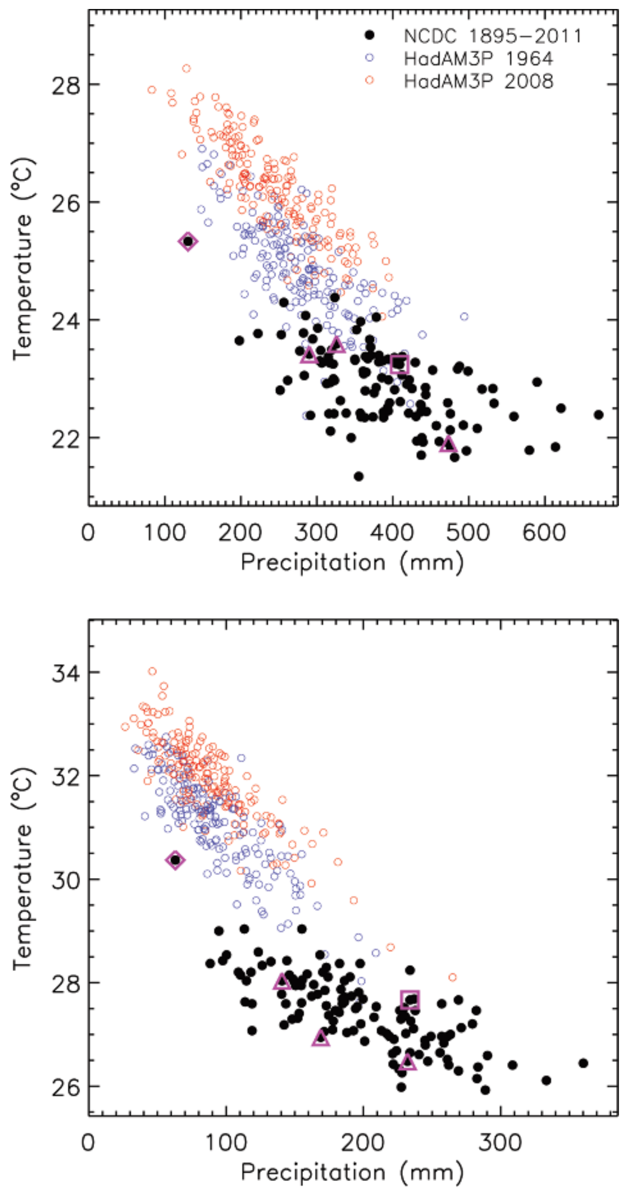

Fig. 8. Texas mean temperature against total precipitation for (top) MAMJJA and (bottom) JJA from NCDC and the HadAM3P ensembles. The observed years 1964, 1967, and 1968 are highlighted by the magenta triangles, and the observed years 2008 and 2011 are highlighted by the magenta square and diamond, respectively. To facilitate comparison between model years, only a random sample of the HadAM3P 2008 dataset, equal in size to the 1964 dataset, is shown.

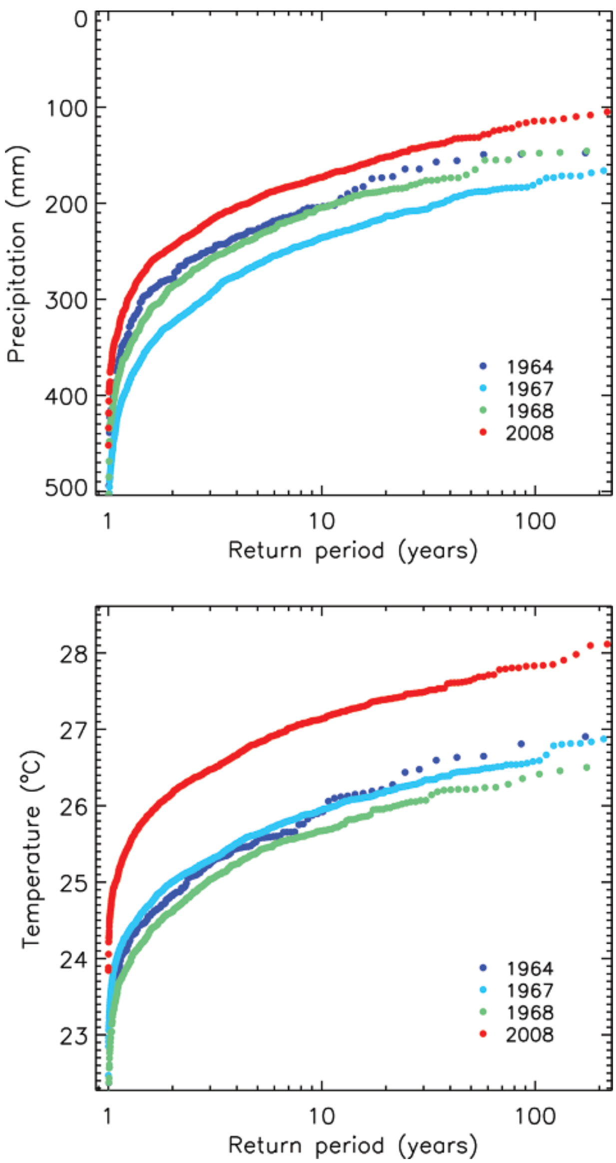

Fig. 9. Return periods of (top) total precipitation and (bottom) mean temperature, Texas, MAMJJA, 1964, 1967, 1968, and 2008, from HadAM3P ensembles.

occurred in Texas in 2011 are, at least in the case of temperature, distinctly more probable than they were 40–50 years ago.

However, there are two main factors in the model driving the differences in the 1960s and 2008 probability distributions of precipitation and temperature. One factor is the effects of external climate forcings, dominated by the increase in greenhouse gas concentrations due principally to anthropogenic emissions. The second factor is the difference in the SST/sea–ice-fraction fields between the years. However, the difference in SST/sea–ice-fraction fields itself has a contribution from increased anthropogenic greenhouse gases, and a second contribution that is due to natural variability. We chose to compare years with similar values of the Niño-3.4 and PDO in order to reduce the contribution due to natural variability; however, other SST patterns may have played significant roles (e.g. McCabe et al. 2004; Schubert et al. 2009).

Progress toward quantifying attribution will include analysis of more years to further evaluate the natural variability and test the robustness of the results presented here. Furthermore, we will explore uncertainty in atmospheric response using perturbed physics ensembles.

Modeling studies such as this allow us to quantify how much the probability of extreme hot and dry conditions in Texas has changed. Quantifying the absolute probability of such extreme conditions is much more difficult, since the models we use are subject to bias, particularly affecting tails of distributions, and data records are too short to quantify absolute probabilities empirically. Hence, while we can provide evidence that the risk of hot and dry conditions has increased, we cannot say that the 2011 Texas drought and heat wave was "extremely unlikely" (in any absolute sense) to have occurred before this recent warming.

CONTRIBUTION OF ATMOSPHERIC CIRCULATION TO REMARKABLE EUROPEAN TEMPERATURES OF 2011

Julien Cattiaux—CNRM/Météo-France, Toulouse, France; Pascal Yiou—LSCE/IPSL, Gif-sur-Yvette, France

Western Europe witnessed remarkable temperature events during the year 2011. Hot and dry spring and autumn (the warmest and second warmest in France, respectively) have contrasted with an uneven summer and a cold and snowy winter 2010/11 (including cold records over the United Kingdom in December 2010). Our scientific challenge consists in putting such regional events into the context of climate change, either by evaluating anthropogenic fingerprints on each event [e.g. with calculations of fractions of attributable risk (Stott et al. 2004)] and/or by understanding how climate change affects physical processes at regional scales. The second approach is taken in this paper. In Europe,

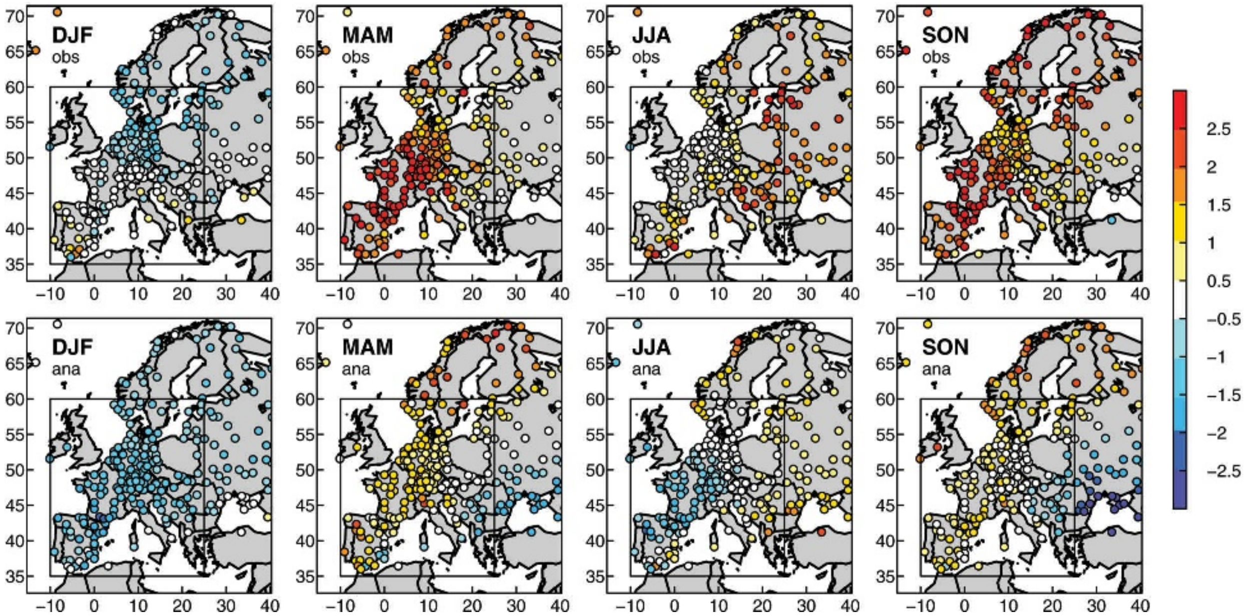

Fig. 10. (top) Observed temperatures of December–February (DJF), March–May (MAM), June–August (JJA), and September–November (SON) 2010/11, represented as normalized anomalies (*σ* levels) relative to 1971–2000 climatologies at each station. The box over western Europe encompasses the area retained for the regionally averaged statistics along the paper (171 stations over 306). (bottom) As at top, but for analog temperatures. Observed temperatures are quasi-systematically higher than analog ones, while spatial patterns are well correlated (Table 1).

studies have highlighted that recent temperatures have been systematically warmer than expected from the North Atlantic dynamics, which controls their intraseasonal to interannual variability (e.g., Cattiaux et al. 2010b; Vautard and Yiou 2009). Here we investigate the contribution of large-scale circulations to temperatures anomalies of 2011 using the same flow-analogue approach as in the analysis of winter 2009/10 by Cattiaux et al. (2010a, C10 hereafter).

Were 2011 temperatures anomalously warm compared to those expected from their flow analogues? We use in situ measurements provided by the European Climate Assessment dataset at more than 2500 stations over the period 1948–2011 (Klein-Tank et al. 2002). Similarly to C10, 306 stations are selected on the basis of (i) an altitude lower than 800 m, (ii) the availability of more than 90% of daily values between 1 January 1948 and 31 December 2011, and (iii) only one station per 0.5° × 0.5° latitude/longitude box for spatial homogeneity. We compute anomalies relative to 1971–2000 climatological standards [mean and standard deviation σ].

Winter 2010/11 was particularly cold in northern Europe, falling below −1σ at most of stations above 50°N (Fig. 10, top). Over western Europe (defined by the insert box in Fig. 10), it ranks as the nineteenth coldest winter of the whole period 1949–2011 (Table 1) and the fifth coldest of the last 25 years (after 1987, 1996, 2010, and 2006). It was followed by exceptionally warm anomalies from March to May 2011, especially over western Europe where seasonal temperatures locally exceeded 2.5σ, making 2011 the second hottest spring between 1948 and 2011 (after 2007). In this region, the temperature rise initiated in March climaxed during April, with respectively 25 of 30 and 14 of 30 days above 1 and 2σ (Fig. 11a). As shown in recent studies, dry soils in early summer are a necessary, but not sufficient, condition for the genesis of heat waves such as those experienced in 1976 and 2003 (e.g., Vautard et al. 2007).

In 2011, despite important deficits in soil moisture at the end of spring (comparable to those that preceded summer 2003 heat waves), summer temperatures turned out to be close to normal over most of western Europe. With a cool July and a warm spell at the end of August, it ranks as the fourteenth warmest summer of the period 1948–2011 but the third coolest since 2000 (after 2004 and 2005). The rest of the year was marked by anomalously mild temperatures over all of Europe, punctuated by a few moderate cold spells. Seasonal anomalies of autumn 2011 exceeded 2.5σ in most stations of western Europe, especially during September with respectively 17 of 30 and 9 of 30 days above 1 and 2σ, making 2011 the second warmest autumn of 1948–2011 (after 2006). Overall, the calendar year 2011 (January to December) is the

Table 1. Normalized anomalies of observed and analog temperatures averaged over western Europe (171 stations inside the box in Fig. 10), for DJF, MAM, JJA, and SON 2010/11 and the whole year 2011, with corresponding rankings in superscripts. Spatial (patterns in Fig. 10), intraseasonal (series in Fig. 11a), and interannual (series in Fig. 11b) correlations between observed and analog temperatures are all significant at 5%. Flow-analogues quality, as evaluated from mean correlations between observed and analog SLP.

	DJF	MAM	JJA	SON	Year (J–D)
Observed anomaly	-0.8^{45}	2.4^{2}	1.1^{14}	2.5^{2}	2.1^{1}
Analog anomaly	-1.3^{51}	0.9^{12}	-0.5^{36}	0.5^{15}	0.7^{10}
Spatial correlation	0.5	0.55	0.63	0.72	—
Intraseasonal correlation	0.59	0.57	0.44	0.24	0.55
Interannual correlation	0.85	0.70	0.60	0.58	0.75
Flow-analogues quality	0.72	0.68	0.63	0.67	0.68

warmest year over western Europe in our dataset (2.1σ, Fig. 11b). However, the hottest 12-month-long period remains July 2006–June 2007, which contains three seasonal warm records (autumn, winter, and spring) and an anomaly that reaches 3.8σ.

The contribution of the large-scale dynamics to temperature anomalies of 1948–2011 is estimated from the same flow-analogue approach as used in C10. For each day, we selected the 10 days with the most correlated atmospheric circulation among days of other years but within a moving window of 31 calendar days (for details, see Lorenz 1969; Yiou et al. 2007). The following results are insensitive to (i) the number of selected days (here 10) and (ii) the metrics used for assessing analogy (here Spearman's rank correlation). Further methodological details can be found in C10 and Vautard and Yiou (2009). Circulations are derived from sea level pressure (SLP) anomalies of National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) reanalyzes (Kistler et al. 2001) and considered over the period 1948–2011 and the area (22.5°–70°N, 80°W–20°E). The quality of flow analogues for 2011 was checked by verifying that mean correlations between observed and analog SLP indicated in Table 1 were close to the 1948–2010 mean (not shown).

For all seasons of 2011, mean analog temperatures (i.e., averaged over the 10 analog days) were lower than observed ones at respectively 76%, 88%, 86%, and 89% of western Europe

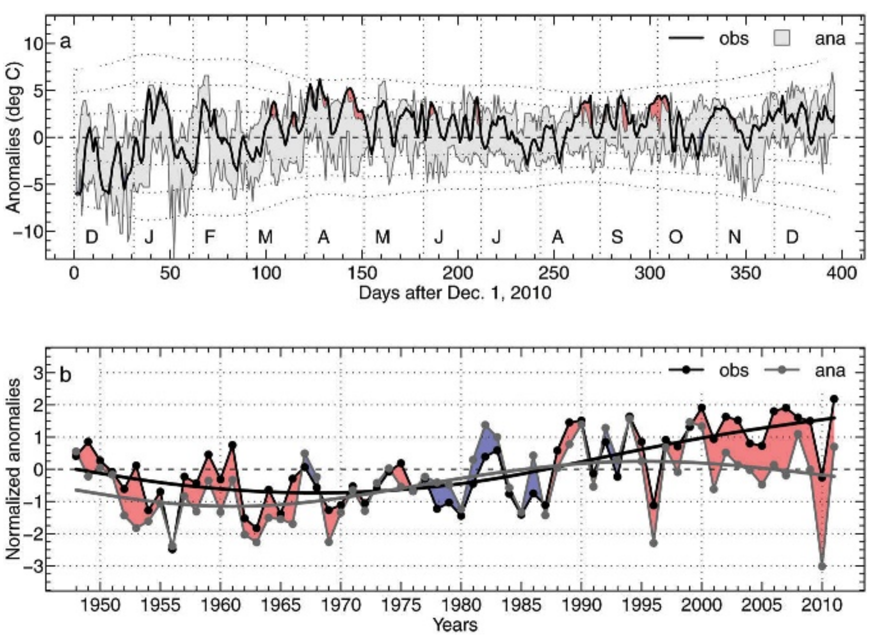

Fig. 11. (a) Daily anomalies (°C) of observed (black line) and analog (gray spread encompassing the 10 values) temperatures from December 2010 to December 2011. Dashed lines indicate climatological σ levels (higher variability in winter than in summer), and red (blue) indicates days with observed temperatures above (below) the 10 analog values. (b) Yearly observed (black) and analog (gray) temperatures averaged over western Europe, represented as normalized anomalies relative to the period 1971–2000. Smoothing by splines with 4 degrees of freedom is added, and red (blue) indicates years with observed temperatures above (below) analog ones. The recent tendency for observed temperatures to be warmer than analog temperatures is particularly prominent in both 2010 (cold record in analogues while close to normal in observations) and 2011 (warm record in observations while <1σ in analogues).

stations (Fig. 10, bottom, and Table 1). The persistence of a strong negative phase of the North Atlantic Oscillation in December 2010 could have made 2010/11 the thirteenth coldest winter since 1948 if large-scale dynamics was the sole driver of temperature variations. During this particular season the difference between observed and analog temperatures peaks over southwestern Europe, suggesting that local processes may have inhibited the maintenance of cold anomalies in this region. For all other seasons, spatial patterns of observed and analog anomalies are better correlated. In particular, large-scale circulations contributed to both exceptionally warm spring and autumn over western Europe, up to respectively ~40% and ~20% of observed anomalies. Summer dynamics were rather favorable to cold weather over France and Spain, thus preventing the development of a potential heat wave that dry conditions at the end of spring could have nurtured.

At the intraseasonal time scale, observed temperatures of 2011 were 29% of the time above the maximum of the 10 analog temperatures, and 77% above the median (Fig. 11a). This is significantly higher than the expected statistical values, respectively 1/11 = 9% (2.5–20%) and 1/2 = 50% (35%–65%) (brackets indicate 95% confidence intervals obtained from binomial quantiles assuming 40 independent days among the 396 of Fig. 11a). The heat waves of late April, late August, and late September were largely underestimated by the analogues, despite relatively high correlations between observed and analog SLP during these three periods (not shown). Overall, the analog temperature of year 2011 reaches 0.7σ, suggesting that large-scale circulations contributed to ~33% of the observed anomaly (Fig. 11b).

Conclusions. 2011 fits into the pattern of recent years where observed temperatures are distinctly warmer than analog temperatures. This is true for seasons with cold anomalies which are not as cold as expected from flow-analogues (e.g., winter 2009/10; see C10) and warm seasonal anomalies, that are hotter than the corresponding analog seasons (e.g., autumn–winter 2006/07; see Yiou et al. 2007). In addition, high interannual correlations between observed and analog temperatures confirm that the North Atlantic dynamics remains the main driver of European temperature variability, especially in wintertime.

HAVE THE ODDS OF WARM NOVEMBER TEMPERATURES AND OF COLD DECEMBER TEMPERATURES IN CENTRAL ENGLAND CHANGED?

N. Massey—Atmospheric, Oceanic and Planetary Physics, Department of Physics, and Smith School of Enterprise and the Environment, University of Oxford, Oxford, United Kingdom; T. Aina—Oxford e-Research Centre, University of Oxford, Oxford, United Kingdom; C. Rye—Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford, Oxford, United Kingdom; F. E. L. Otto—Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, United Kingdom; S. Wilson and R. G. Jones—Met Office Hadley Centre, Exeter, United Kingdom; M. R. Allen—Atmospheric, Oceanic and Planetary Physics, Department of Physics, and Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, United Kingdom

The Central England Temperature (CET) data set is the oldest continuously running temperature dataset in the world (Manley 1974) and records temperatures over a central area of England stretching between Lancashire, Bristol, and London. The decade of 2002–11 has been a particularly interesting one for CETs, with a number of warm autumns (2009, 2011), along with a number of cold winters (2009/10, 2010/11).

The emergent science of probabilistic event attribution is becoming an increasingly important method of evaluating the extent of how this human-influenced climate change is affecting localized weather events. Studies into the European heat wave of 2003 (Stott et al. 2004), the England and Wales floods of 2000 (Pall et al. 2011), and the Russian heat wave of 2010 (Dole et al. 2011; Rahmstorf and Coumou 2011; Otto et al. 2012) have sought to determine to what extent the risks of these events occurring have increased because of anthropogenic global warming.

We follow a similar methodology to Pall et al. (2011), which uses very large ensembles of global climate models (GCMs) to assess the change in risk of autumn flooding in the United Kingdom under two

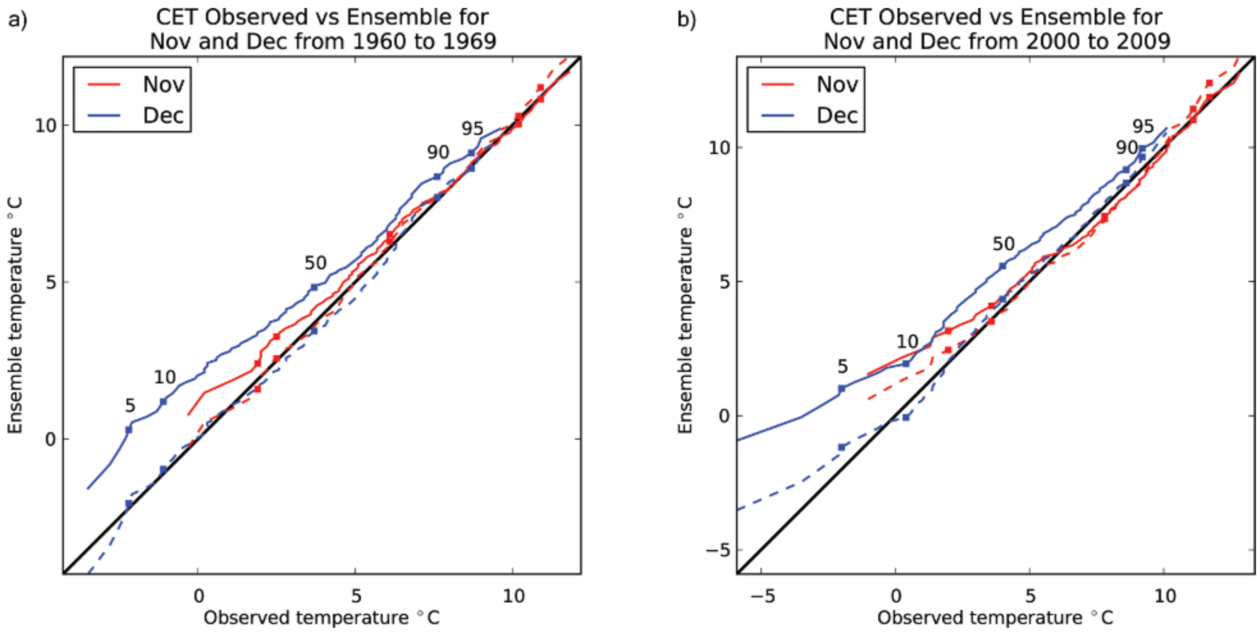

FIG. 12. (a) Quantile-quantile plot for November and December of the 1960–1969 decade. Uncorrected ensemble data are shown with a solid line, whereas the same ensemble data corrected for bias in the mean and standard deviation are shown with a dashed line. The squares denote the 5th, 10th, 50th, 90th, and 95th percentiles. (b) As in (a), but for the 2000–2009 decade.

different climate scenarios: observed autumn 2000 and a natural-only forcing autumn 2000. However, our two climate scenarios are based both on observations, one scenario for the 1960s decade and one for the 2000s. The method of Pall et al. (2011) decouples the anthropogenic signal from the natural variability by ensuring that the natural variability is the same in both scenarios. Although our method does not permit decoupling, using decadal long scenarios reduces some of the effects of natural variability and allows both scenarios to be validated against observed data. We have also expanded the method to use a regional climate model (RCM) embedded within a GCM. The increased resolution of the RCM results in a more realistic simulation of localized weather events, including cold and warm temperatures (Jones et al. 2004).

In this section we use large ensembles of the two climate scenarios to evaluate whether the frequency of warm Novembers and cold Decembers occurring has altered between the 1960s and 2000s, this being the period during which there has been a significant anthropogenic influence on climate.

Method. Weatherathome is a volunteer-distributed computing project that uses idle computing time from a network of "citizen scientists" home computers to run an RCM embedded within a GCM. The models used are HadAM3P, an atmosphere only, medium-resolution (1.875° × 1.25°, 19 levels, 15-min time step) GCM and HadRM3P, a high-resolution (0.44° × 0.44°, 19 levels, 5-min time step) RCM. Both models have been developed by the UK Met Office and are based upon the atmospheric component of HadCM3 (Pope et al. 2000; Gordon et al. 2000) with some improvements to the sulfur cycle and cloud parameterizations (Jones et al. 2004). The coupling between the models is performed every 6 h when the lateral boundary conditions of the RCM are relaxed to the GCM across four perimeter grid boxes (Jones et al. 2004)

Each volunteer's computer runs both models for a model year at a time, with initial conditions being provided by model runs previously completed by other volunteers. In this way, very large ensembles of RCMs can be computed, on the order of thousands, which in turn allows greater confidence when examining the tails of the distribution of climate variables.

The results examine the changing frequency of warm Novembers and cold Decembers since the 1960s. Two periods are analyzed, the 2000s and the 1960s which both use sea surface temperatures (SST) and sea ice fractions (SIF) from the HadISST observational dataset (Rayner et al. 2003). Atmospheric gas concentrations, including CO_2, N_2O, CH_4, O_3, and the halocarbons, are taken from observations and Special Report on Emissions Scenarios (SRES) scenario A1B (Nakicenovic and Swart 2000). Natural

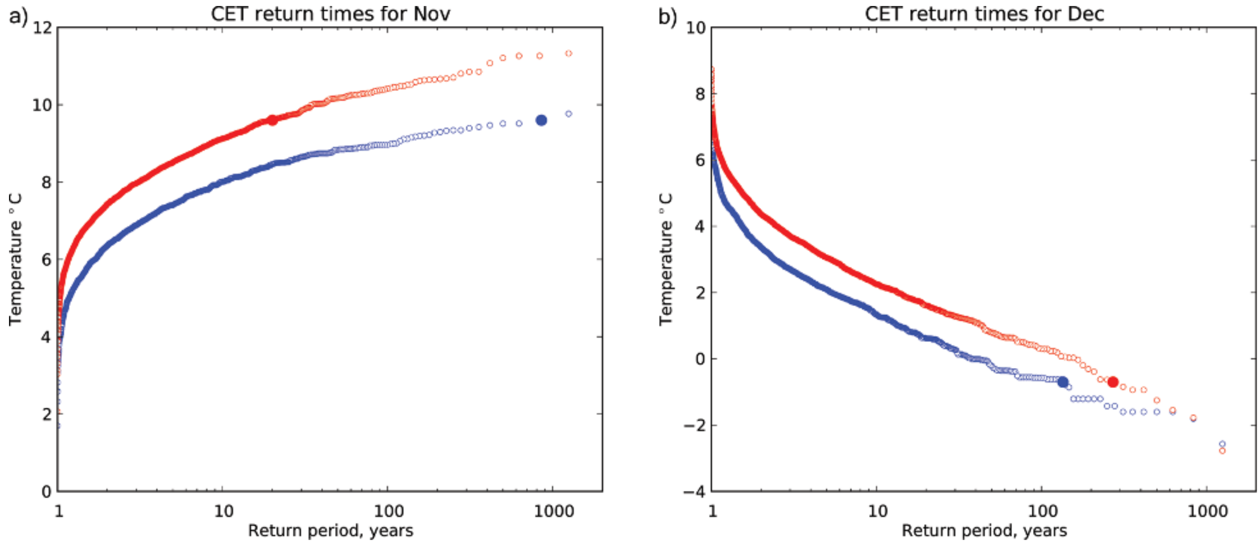

FIG. 13. (a) Return times of temperatures for November in the 1960–1969 decade (blue curve) and the 2000–2009 decade (red curve). The observed value for the warm November 2011 of 9.6°C is shown on both curves as a solid, larger circle, with a return period in 1960–1969 of 1250 years and in 2000–2009 of 20 years. (b) Return times of temperatures for December in the 1960–1969 decade (blue curve) and the 2000–2009 decade (red curve). The observed value for the cold December 2010 of −0.7°C is again shown as a solid, large circle, with a return period in 1960–1969 of 139 years and in 2000–2009 of 278 years.

volcanic emissions are assigned values from Sato et al. (2011). Finally, a modification to the model allows a variable solar forcing, which is taken from Krivova et al. (2007) and Lockwood et al. (2011). The topography and land use remain unchanged between scenarios.

Validation and bias correction. To analyze the results from the regional modeling experiment, four separate ensembles are formed from the data. Each data point in each ensemble is the mean of 27 grid boxes from the regional model, corresponding to 9 grid boxes centered over London, 9 over Bristol, and 9 over Manchester, which replicates the spatial distribution of the CET. The four ensembles are: all the Novembers occurring in the 1960s, all Decembers in the 1960s, all Novembers in the 2000s, and all Decembers in the 2000s. To ensure that the distribution of temperatures in these ensembles are representative of the distribution of the observed Central England Temperature, a validation exercise is performed.

Figure 12a shows quantiles of temperatures in the ensembles of 1960s Novembers and Decembers against the corresponding quantiles in the CET dataset. Figure 12b shows the same for the 2000s ensembles. The solid lines are the raw ensemble data, whereas the dashed lines are the result of applying a simple bias correction to ensure the means and standard deviations of the ensembles match the means and standard deviations of the observed CET dataset. The same bias correction is applied to both the 1960s and 2000s.

After the bias correction, there is good agreement between the ensembles and observations, giving confidence that any change in return time is representative of the change in return time in the observations.

Results and conclusions. Figure 13a shows the return times of warm temperatures in November in both the 1960s ensemble (blue) and 2000s ensemble (red). The temperature of a 100-yr event in Novembers in the 2000s has increased to 10.42°C from 8.97°C. The warm November of 2011, which is the second warmest in the CET, has a monthly mean temperature of 9.6°C. This corresponds to a return period of 20 years in the 2000s, but a return period of 1250 years in the 1960s, an approximately 62 times increase in occurrence.

Figure 13b shows the return times of cold temperatures in December in both the 1960s and 2000s. Although the occurrence of a cold December in the 2000s has decreased from the 1960s, the difference in temperature of the 100-yr event is 0.87°C. The cold December of 2010, which is the second coldest December and coldest since 1890, has a monthly mean temperature of −0.7°C, which has a return period of 139 years in the 1960s and a return period of 278 in the 2000s. Therefore, a cold December of −0.7°C is half as likely to occur in the 2000s when compared to the 1960s.

LENGTHENED ODDS OF THE COLD UK WINTER OF 2010/11 ATTRIBUTABLE TO HUMAN INFLUENCE

Nikolaos Christidis and Peter Stott—Met Office Hadley Centre, Exeter, United Kingdom

The winter of 2010/11 began with the coldest December in the UK series dating back to 1910 and the second coldest December in the Central England Temperature (CET) record dating back to 1659 (Manley 1974), with a –5.3°C anomaly in the monthly average temperature relative to the 1961–90 mean. There were many adverse consequences of the extreme temperatures, including closed airports and schools. There was also the novel experience for many children, wherever they lived in the United Kingdom, of a white Christmas. Here we put the cold winter of 2010/11 into the long-term context of climate variability and change through an analysis of the 353 yr central England temperature record and the application of a new modeling system for attribution of extreme weather- and climate-related events. Because February was much milder, with a positive temperature anomaly of 2.6°C, we concentrate in this paper on the first two months of winter.

Figure 14 shows how the early part of the 2010/11 winter compares to the other winters in the central England temperature record. Both the combined 2-month mean temperature for December and January and the mean December 2010 temperature stand out as exceptionally cold, although in neither case was the temperature unprecedented in this unique multi-century instrumental record. The question we seek to answer is whether the chances of such cold winter temperatures were greater or less in 2010/11 as a result of human influence on climate.

Has human influence on climate changed the chances of cold winters? The main tool we use to address this question is the Met Office Hadley Centre attribution system (Christidis et al. 2012, manuscript submitted to *J. Climate*). This is based on HadGEM3-A, the atmospheric component of the model used for seasonal forecasting at the Met Office (Arribas et al. 2011) and which has a resolution of 1.25° longitude by 1.875° latitude and 38 vertical levels. We compare a 100-member ensemble of model simulations forced with observed SSTs and sea ice and current levels of greenhouse gases with two alternative 100-member ensembles in which human influence has been subtracted from the SSTs and sea ice and in which greenhouse gases and aerosols are reduced to preindustrial levels following a similar methodology to that of Pall et al (2011). Here, estimates of the change in SST due to human influence are derived from transient simulations of three coupled climate models, HadGEM1, HadGEM2-ES, and HadCM3. Further details of the attribution system are given in Christidis et al (2012, manuscript submitted to *J. Climate*).

Verification of model statistics against observations helps assess the trustworthiness of the attribution system. Based on a five-member ensemble of simulations forced with observed SSTs from 1960 to 2010, Christidis et al. (2012, manuscript submitted to *J. Climate*) concluded that the model has a realistic representation of UK temperature variability although its reliability in capturing the predictability of UK temperatures is not as high as for temperatures over the region affected by the Russian heat wave of 2010 (Christidis et al. 2012, manuscript submitted to *J. Climate*). Nevertheless the model is expected to produce a reliable estimate of the overall changed odds of cold winters in the United Kingdom due to human influence, all other factors being equal, even if the odds could additionally have been affected in recent years by factors we do not calculate here such as the recent minimum in solar activity (Ineson et al. 2011). As a further check on the robustness of the model-based results, we determine whether they are broadly consistent with observational estimates derived from the multicentury CET record.

Change of odds in the model. The change of odds of cold December and January temperatures in 2010/11 attributable to climate change can be seen in Fig. 15 (top), which shows the ratio of the probability of such cold temperatures in the current world (P1) to the world had human influence not affected climate (P0). The three estimates, based on attributable SST changes derived from the HadGEM1, HadGEM2-ES, and HadCM3 models, have median values of approximately 0.5, indicating that human influence has halved the probability of temperatures as cold as seen in 2010/11 with 5th–95th-percentile uncertainty ranges of 0.24–0.80, 0.25–0.70, and 0.26–0.82 depending on which coupled model is used to define the change in SSTs. In summary, model results indicate that human influence has reduced the odds by at least 20% and possibly by as much as 4 times with a best estimate that the odds have been halved.

Change of odds estimated from the CET record. An observationally based consistency check of these numbers is obtained by calculating empirically the number of times prior to 1910 CET was colder than 2010/11 (28 times) and comparing this to the number of times CET would have been colder than observed in 2010/11 if CET had warmed between 0.3 and 1 K because of human influence on climate (between 20 and 7 times, respectively). These representative values for CET human-induced warming span the range of human-induced SSTs in the vicinity of the United Kingdom according to the HadGEM1, HadGEM2-ES, and HadCM3 models. This corresponds to a reduction of probability of between 0.25 and 0.71 consistent with the estimates obtained from the model. A more direct but more approximate calculation (given the fewer number of data points available for the calculation) is to note that whereas temperatures colder than 2010/11 were observed only once in the last 30 years (P1 = 1/30) and temperatures as cold or colder twice (P = 2/30), colder temperatures were observed from 1 to 6 times in samples of 30-yr periods taken from the CET record before 1910. This difference in probabilities corresponds to a ratio of

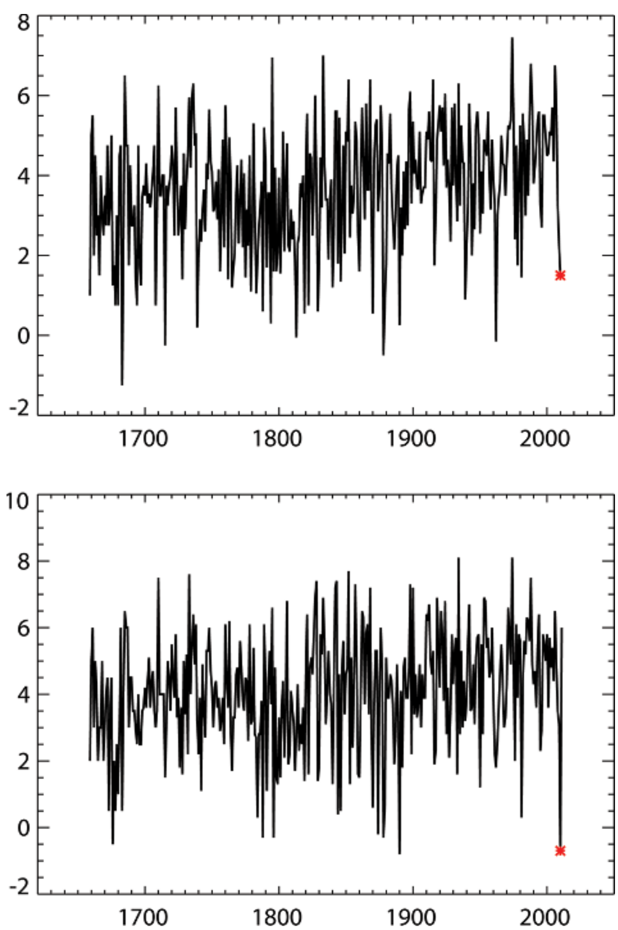

Fig. 14. Central England temperature averaged over (top) December and January combined and (bottom) December. Winter of 2010/11 shown as red stars. December/January 2010/11 was the thirty-fourth coldest December/January in the record and December was the second coldest December in the record.

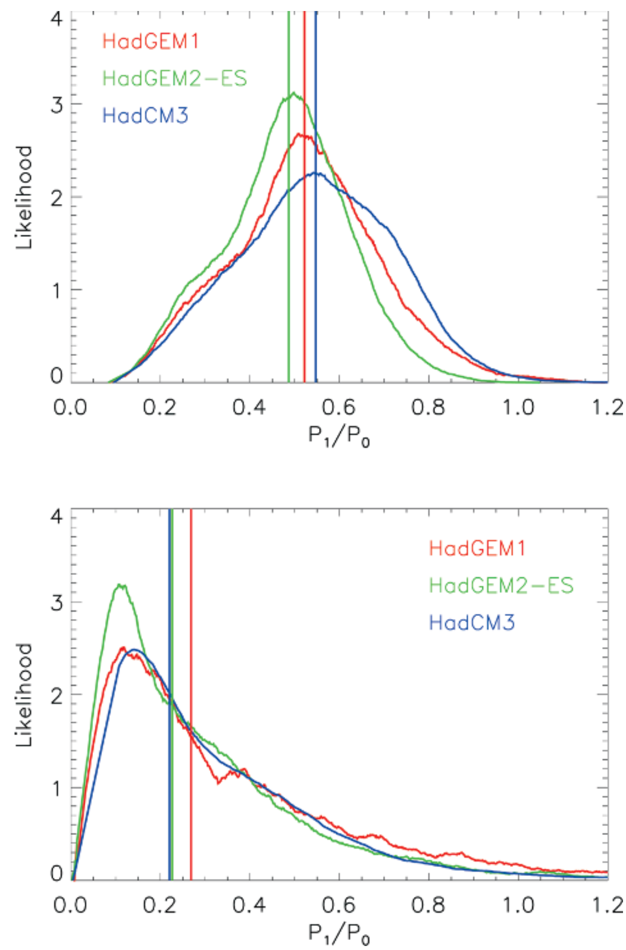

Fig. 15. Attributable change in probability (P1/P0) of (top) December/January temperatures as cold as observed in 2010/11 and (bottom) December temperatures as cold as observed in 2010, where P1 is the probability of a temperature as cold as that observed in the winter of 2010/11 in the current climate, and P0 is the probability of such cold temperatures had human influence not affected the climate of 2010/11. The uncertainty in this number is shown as likelihood distributions representing modeling uncertainty estimated by a bootstrap procedure (Christidis et al. 2012, manuscript submitted to *J. Climate*). Likelihood distributions are calculated for three specifications of alternative SSTs (red, green, and blue curves) estimated from simulations of the HadGEM1, HadGEM2-ES, and HadCM3 coupled climate models. The vertical lines mark the median values. A value of 0.5 indicates that the probability has halved and a value of 1.0 indicates there is no change.

probabilities of from 0.17 to 1 with a median value of 0.5, also consistent with the model-based estimates but with a larger range (due to the greater sampling uncertainty). In this calculation we assume P1 is equally likely to be 1/30 or 2/30 and we treat each overlapping 30-yr segment of CET before 1910 as equally representative of preindustrial temperatures.

For the single month of December 2010, the HadGEM3-A-based attribution system estimates that the ratio of probabilities P1/P0 lies between 0.06 and 1.00 (5th–95th percentiles) with a median of 0.27 when HadGEM1 SSTs are used and between 0.05 and 0.79 with a median of 0.23 when HadGEM2-ES SSTs are used and between 0.05 and 0.74 with a median of 0.22 when HadCM3 SSTs are used (Fig. 15, bottom). The larger uncertainties than for December and January combined are associated with a more extreme temperature excursion. Given the rare nature of this event in the observational record—only two occurrences of temperatures as cold as December 2010 have been seen since 1659 (Fig. 14)—it is not possible to make the same direct observationally based empirical calculation of the change in odds as was done for the combined December/January temperatures.

Conclusions. The winter of 2010/11 was a rare weather event, even in the context of the 352 years of the central England temperature record. Yet while the odds of such an event have lengthened as a result of human influence on climate, such unlikely events can still happen, as the winter of 2010/11 demonstrated. Further refinements of such calculations could include calculations of how the risk of extremely cold temperatures in a specific winter might vary as a result of natural factors, such as a minimum in the solar cycle (Ineson et al. 2011).

CONCLUSIONS

Peter A. Stott—Met Office Hadley Centre, Exeter, United Kingdom; Thomas C. Peterson—NOAA National Climatic Data Center, Asheville, North Carolina; Stephanie Herring—Office of Program Planning and Integration, NOAA, Silver Spring, Maryland

"Climate is what a boxer trains for but weather throws the punches" (D. Arndt 2012, personal communication). Attribution analyzes, such as those in this article, have the potential to inform the necessary training and adaptation options for societies in dealing with the punches weather and climate extremes throw their way.

The section on historical context summarizes the evidence that human influence has affected trends and long-term behavior of temperature and precipitation extremes around the globe, thus altering the types and frequencies of punches for which our boxer must train. This is to be anticipated from theoretical expectations of a warmer world. The recent IPCC SREX report (Field et al. 2012) concluded that "it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperature at the global scale" and that "there is medium confidence that anthropogenic influences have contributed to intensification of extreme precipitation at the global scale." But even if human influence is making a particular type of event more likely on average, because of natural variability it does not necessarily follow that its likelihood is greater every year. So while it has been argued that in the anthropocene[4] all extreme weather or climate events that occur are altered by human influence on climate (Trenberth 2011), and although it is difficult to prove that a particular extreme weather or climate event was not in some way influenced by climate change, this does not mean that climate change can be blamed for every extreme weather or climate event. After all, there has always been extreme weather.

The contributions in this article examining some of the specific extreme weather or climate events of 2011 demonstrate the importance of understanding the interplay of natural climate variability and anthropogenic climate change on their occurrence. We should not expect that climate change plays the major role in every extreme weather or climate event and indeed the rainfall associated with the devastating Thailand floods was not especially unusual. In this case, nonclimatic factors such as changes in land use and water management probably played a bigger role in the disaster. Thus attribution of the impacts of weather-related events to climate variability and change requires careful consideration

[4] The anthropocene is the most recent geological era in which human activities have had a significant global impact on the Earth's ecosystems (Crutzen 2002).

of possible confounding factors not related to climate (Hegerl et al. 2010).

The development of a regular attribution service whose results are available shortly after the month or season in question depends on the implementation of an established methodology. For example, the same circulation regime–based technique used to analyze the very cold northwestern European winter of 2009/10 (Cattiaux et al. 2010a) was used to investigate European seasonal temperatures in 2011. All four seasons were warmer in many parts of Europe than would be expected from the average of previous years with similar atmospheric flow conditions. While 2011 had the warmest annual mean temperatures in western Europe since the start of the analysis in 1948, temperatures expected from the observed atmospheric flow conditions would not have been unusual. The implication is that without long-term warming, 2011 would not have been a record breaker by this measure.

Another approach that supports a regular attribution service is based on estimating the changed probabilities of extreme weather or climate events from ensembles of atmosphere only climate models with different sea surface temperatures (SSTs) and altered concentrations of greenhouse gases and other climate forcings. This technique has been used to show that human-induced greenhouse gas emissions have increased the risk of the UK flooding seen in 2000 (Pall et al. 2011). A similar analysis of the cold UK winter of 2010/11 determined that temperatures as cold as seen in the early part of the winter were less likely as a result of human influence on climate and when looking at combined December/January temperatures they were half as likely. Examining the unique multicentury record of central England temperatures allows a simple verification of such statistics for the United Kingdom.

An important future development of such attribution systems is to allow the changed risk of extreme weather or climate events to be calculated quickly and disseminated on a regular basis. The Weather Risk Attribution Forecast (WRAF) system, which is based on a seasonal forecasting modeling system, has been trialled in this way, providing regularly updated estimates of risks of temperature and precipitation extremes. It will be crucial to understand the strength and limitations of such systems for the weather and climate events to which they are being applied. This should include an assessment of the reliability of the models being used (Christidis et al. 2012, manuscript submitted to *J. Climate*).

Providing such attribution results in time for this issue has proved extremely challenging given the delays involved in collecting observations, running models and analyzing data. Two analyzes presented here used preexisting climate model simulations to compare event statistics for recent years with years from the 1960s. While this approach does not explicitly calculate the extent of changes attributable to human influence because natural external forcing and natural internal variability could have contributed to the change in the likelihood of events since the 1960s, it does address how the long-term warming trend has affected weather odds. By carefully choosing years with patterns of SSTs similar to those of 2011, it was possible to determine that heat waves such as the one that affected Texas have become distinctly more likely than they were 40 years ago. In the United Kingdom there has been a much greater increase in the likelihood of the very warm November temperatures seen in 2011 than the reduction in likelihood of the very cold December temperatures seen the previous winter. This interesting seasonal asymmetry in the change of extreme climate and weather odds seems worthy of further investigation.

It has been questioned whether attribution studies might neglect many of the regions most vulnerable to extreme weather because of the greater difficulties of collecting climate observations and undertaking climate modeling in developing countries (Hulme 2011). Therefore the analysis of the East African drought of 2011 is particularly interesting because it demonstrates the potential for attribution in tropical regions that lack robust international exchange of climate observations. Low-latitude regions generally have higher ratios between the signal of climate change in temperature and variability than other regions (Mahlstein et al. 2011) and there appears to be potential skill in seasonal forecasting of impact-relevant metrics such as the onset of seasonal rains in Africa (Graham and Biot 2012). While La Niña had a large role to play in the failure of the rains in East Africa, there is evidence that warming in the western Pacific–Indian Ocean warm pool has contributed to an increased frequency of droughts in this region. While such a conclusion is supported by a deeper body of literature, the hypothesis of a link between ocean warming and a greater risk of drought in this region remains controversial. All attribution assessments are necessarily subject to change as science advances. A key challenge for attribution assessments remains to accurately characterize their levels of confidence given current understanding.

2011 was a year during which the weather threw plenty of punches [see Blunden and Arndt's (2012) supplement to this issue]. While much work remains to be done in attribution science, to develop better observational datasets, to improve methodologies, to make further progress in understanding and to assess and improve climate models, the contributions in this article demonstrate the potential that already exists for meaningful assessments of the connection between specific extreme weather or climate events that occurred in a particular year and climate change. Whether readers react with excitement at the possibilities already demonstrated, or with irritation at the gaps and limitations still present, our hope as editors is that this initial selection of investigations encourages further development of the capability to produce timely and reliable assessments of recent extreme weather or climate events. Such an enterprise is much further advanced for climate monitoring—as shown by the maturity of the annual State of the Climate report (e.g., Blunden and Arndt 2012)—but even there important uncertainties exist and new assessments of past years will emerge, just as they will for attribution as understanding develops. By developing the scientific underpinning, the ability to put recent extreme weather or climate events into the longer-term context of climate change should improve as each year goes by.

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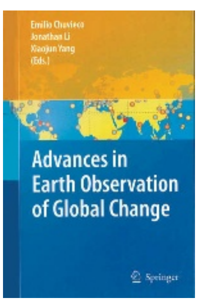
ADVANCES IN EARTH OBSERVATION OF GLOBAL CHANGE

Emilio Chuvieco, Jonathan Li, and Xiaojun Yang, Eds., 2010, 283 pp., $129.00, hardbound, Springer, ISBN 978-90-481-9084-3

This collection of conference papers surveys the rapidly expanding area of research on observing global change in the Earth system. Remote-sensing applications to land use, coastal and marine ecosystems, snow and ice, and natural hazards, as well as geodetic and geospatial data processing techniques employed in global change research, are surveyed in 19 chapters by an international group of more than 60 authors.



Audience. The book's blurb suggests it will be of use "to researchers and practitioners in the field of remote sensing, geographical information, meteorology and environmental sciences. Also scientists and graduate up to postgraduate level students in environmental science will find valuable information in this book." However, issues with the editing of the book (see below) reduce its usability somewhat.

I could see this book being used as an optional resource in a graduate-level course in remote sensing or global change, but I personally would not adopt it as a text.

Strengths. The international breadth of the authors and locations addressed, from China and Japan and Africa to Europe, Iran, and the United States, is remarkable. Similarly, there is an impressive range of use of different remote-sensing datasets (e.g., synthetic aperture radar, LANDSAT, radiometer, spectrometer, and GPS data) sampling a wide range of phenomena (e.g., urbanization, coastal water quality, earthquakes, and fire). Chapters are generally 10–20 (relatively small) pages; therefore, in most cases, a reader who wishes to get a taste of the range of applications of remote sensing to this subject can do so without drowning in too many details.

Weaknesses. This book is poorly edited, particularly in the preface and the early chapters. While scientific peer review is said to have taken place, there are significant editing issues that slipped past the editors and the publisher. For example, an entire paragraph in the first chapter on p. 2 is repeated virtually verbatim on p. 4. In chapter 6, three sentences on p. 71 are repeated virtually verbatim on p. 72. There are innumerable examples of poor English throughout most of the book, a few comical (as on p. 63, where the word "assess" lost its final "s"). Missing or incorrect articles and sentence fragments abound. Speaking as someone who has served as an associate editor for three different journals, I would not have accepted at least one-third of the chapters in this book pending revisions to improve the English.

In addition to the poor editing, the editors made a strange choice by leading off this collection with a paper that does not directly address the actual use of remote sensing in global change studies, but only proposes a technique (small satellites) for doing so. After having read the entire book, I wondered if the chapters could have been reorganized so as to place the strongest and best-written chapters (I vote for the snow cover, geodetic observing system, and landslide chapters) nearer the beginning, with the more speculative chapter on small satellites placed nearer the end.

While I cannot pretend to be an expert in the wide range of subjects presented here, I was surprised to not find reference to the two decades' worth of well-cited research by Elaine Prins (e.g., Prins and Menzel 1992) in the chapter by Chuvieco and Justice, which used data on biomass burning as detected by MODIS.

Illustrations. As with most collections of papers from large groups of authors, the quality of illustrations is uneven. Some are too small to be legible; others are excellent. My favorite diagram is the simple-but-effective black-and-white depiction by X. Yang of landslides in China due to the May 2008 Sichuan earthquake.

Bottom Line. This book is in many ways a sequel to *Earth Observation of Global Change*, also edited by Chuvieco and published by Springer, in 2008. Both are collections of papers presented at international conferences on the subject. My impression is that this book contains chapters with narrower foci topically, and an overall broader coverage geographically, than the 2008 book.

I cautiously recommend this book to researchers in remote sensing and global change studies. There is valuable, reasonably current research presented here. Be prepared, however, for a "tough go" if attempting to read some of the most poorly edited chapters.

—John A. Knox

John A. Knox is an associate professor of geography in the atmospheric sciences program at the University of Georgia in Athens, Georgia.

FOR FURTHER READING

Chuvieco, E., Ed., 2008: *Earth Observation of Global Change: The Role of Satellite Remote Sensing in Monitoring the Global Environment*. Springer, 223 pp.

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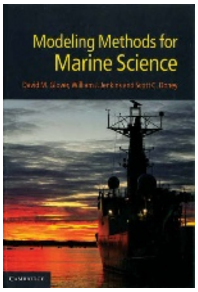
MODELING METHODS FOR MARINE SCIENCE

David M. Glover, William J. Jenkins, and Scott C. Doney, 2011, 571 pp., $85.00, hardbound, Cambridge University Press, ISBN 978-0-521-86783-2

All three authors of this book work in the Department of Marine Chemistry and Geochemistry at the Woods Hole Oceanographic Institution. The material covered started out as a course called "Modeling, Data-Analysis and Numerical Techniques for Geochemistry" that the authors have taught at Woods Hole for a number of years. So, this book was written with graduate students and advanced undergraduate students in mind, and will be useful to a broad spectrum of students in geophysics. In my opinion, the book starts out at this level, but ends up at a more advanced level. I learned some new things from this book, especially about geochemistry, which is not my speciality. The authors say this book should have a slot on one's shelf between Stumm and Morgan's *Aquatic Chemistry* and Broecker and Peng's *Tracers in the Sea* on one side, and Pedlosky's *Geophysical Fluid Dynamics* and Wunsch's *The Ocean Circulation Inverse Problem* on the other. On my shelf, this book might topple over, as I don't have the chemistry books.



NEW PUBLICATIONS

FUNDAMENTALS OF NUMERICAL WEATHER PREDICTION

J. Coiffier, 2012, 368 pp., $85.00, hardbound, Cambridge University Press, ISBN 978-1-107-00103-9

This book provides an overview of numerical model techniques used in the environmental sciences, particularly in the fields of weather forecasting and climate prediction. It places emphasis on the design of the most recent numerical models of the atmosphere. It presents a short history of numerical weather prediction and its evolution, and then describes the various model equations and how to solve them numerically. It outlines the main elements of a meteorological forecast suite, and the theory is illustrated throughout with practical examples of operational models and parameterizations of physical processes.

THE CHALLENGE OF CLIMATE CHANGE: WHICH WAY NOW?

D. D. Perlmutter and R. L. Rothstein, 2011, 248 pp., $42.50, paperbound, Wiley-Blackwell, ISBN 978-0-470-65497-2

This title looks at the complex interlocking issues of public policy, multilateral negotiation, and technological advancement as applied to climate change. It explores both the problems and the opportunities presented by international agreements, and examines the technological developments and policy goals that can be pursued to effect the changes necessary. Each topic is presented from both technical and policy perspectives as a means to evaluate the variety of proposals that have been offered as remedies to climate change.

FIRST PRINCIPLES OF METEOROLOGY AND AIR POLLUTION

M. Lazaridis, 2011, 362 pp., $179.00, hardbound, Springer, ISBN 978-94-007-0161-8

This book's primary objective is to decipher the main processes in the atmosphere and the quantification of air pollution effects on humans and the environment, through first principles of meteorology and modeling/measurement approaches. It focuses on such topics as the integrated study of air pollution, the comprehensive study of meteorology and air pollution and their interactions, atmospheric chemistry and physics, indoor air pollution in conjunction with human exposure, and air pollution legislation and human health.

Chapters 1–7 cover a wide range of topics about the machinery of data analysis, including least-squares techniques, principal component analysis, and sequence analysis. Right from the beginning, the book talks about MATLAB as an important resource for data analysis, and goes into much detail about how it should be used. A nice feature of the book is that these chapters, and many later ones, include problems set at the end, and the reader is encouraged to use MATLAB as the book is being read. Chapters 8–12 introduce some techniques of modeling, and here the book becomes somewhat more interesting. Chapter 9 starts with the philosophy of modeling and builds up to a well-known five-box model of phosphorus in the global ocean, which was originally in Broecker and Peng's book. Chapter 10 is a little pedestrian, but I liked chapter 12 because it has interesting ways to tease out stability constraints for simple 1D numerical schemes.

Chapters 13–18 cover actual published models of ever-increasing dimensionality and complexity. Chapter 14, on "One-Dimensional Models in Sedimentary Systems," is a bit disconnected from the rest of the material in the book. Nevertheless, it introduced me to several new words and concepts, so it was informative. Chapter 15 gets into a high level of detail about 1D upper-ocean models, with the addition of several gases, including oxygen. I especially liked chapter 16, on "Two-Dimensional Gyre Modeling." There is a nice analysis of 2D model artifacts, including numerical diffusion. The next section shows how to model the invasion of tritium and the stable, inert isotope helium-3 into the classical Stommel gyre circulation. Then there is a very nice exposition of how to model the percent oxygen saturation on a particular density surface in the North Atlantic midlatitude gyre. Chapter 17 is a broad overview of "Three-Dimensional General

REANALYSIS

Looking back at the *Bulletin* of August–September 1933:

DROUGHT CAUSING MIGRATION OF JACKRABBITS

Thousands of jackrabbits, driven from the parched areas of southwest Kansas and southeastern Colorado, are migrating to greener pastures north and east in search of food, according to a recent dispatch in the *Kansas City Star.*

Lane and Ness counties, 100 miles northeast of the southwest corner of Kansas, which are not so badly burned by the drought, are fairly swarming with the rabbits, and a recent traveler to that section reports he found it almost impossible to drive along the country roads without killing them. Pastures in the extreme southwestern counties are burned brown, wheat is almost a complete failure, and spring planted crops have made little or no growth.

—*Bull. Amer. Meteor. Soc.,* **14,** 216

ABRUPT CLIMATE CHANGE: MECHANISMS, PATTERNS, AND IMPACTS

H. Rashid and L. Polyak, 2011, 242 pp., $120.00, hardbound, American Geophysical Union, ISBN 978-0-87590-484-9

This title brings together a diverse group of paleoproxy records such as ice cores, marine sediments, terrestrial archives, and coupled ocean–atmosphere climate models to document recent advances in understanding the mechanisms of abrupt climate changes. It includes discussions of records of past climate variability, meridional overturning circulation, land–ocean–atmosphere interactions, feedbacks in the climate system, and global temperature anomalies.

FOUNDATIONS OF COMPLEX SYSTEMS: EMERGENCE, INFORMATION AND PREDICTION (SECOND EDITION)

G. Nicolis and C. Nicolis, 2012, 384 pp., $118.00, hardbound, World Scientific, ISBN 978-981-4366-60-1

This book provides a self-contained presentation of the physical and mathematical laws governing complex systems. It discusses complex systems arising in natural, engineering, environmental, life, and social sciences from a unifying point of view using an array of methodologies, such as microscopic and macroscopic level formulations, deterministic and probabilistic tools, modeling, and simulation.

HAWAII'S MAUNA LOA OBSERVATORY: FIFTY YEARS OF MONITORING THE ATMOSPHERE

F. M. Mims III, 2011, 480 pp., $60.00, hardbound, University of Hawaii Press, ISBN 978-0-8248-3431-9

For more than 50 years, beginning with atmospheric chemist Charles Keeling's readings of carbon dioxide levels in the atmosphere, the Mauna Loa Observatory has provided climate scientists with a continuous record of the atmosphere's increasing concentration of carbon dioxide—and in the process helped spark the international debate over global warming. This book tells the story of the men and women who made these and many other measurements near the summit of the world's largest volcano.

Circulation Models," and chapter 18 is the same for "Inverse Methods and Assimilation Techniques." These two chapters are much more difficult material than the rest of the book, and are out of the realm of MATLAB and any exercises for the reader. I liked chapter 17, which covers my own area of expertise, but I found chapter 18 a lot less easy to read, as it briefly covers very complex assimilation methods.

There is a final chapter on "Scientific Visualization," which returns to a much more low-level description of how to present one's data and results. Finally, there is an appendix titled "Hints and Tricks," about using MATLAB, so I hope no climate skeptics are reading this review!

I believe that no other book covers the same topics as this book does, so in that sense it is unique. It was written very much with graduate students in mind, and so is obviously suitable as the textbook for teaching courses in the analysis of ocean data and numerical modeling. The book has many black-and-white figures that are all clearly reproduced. It also has very few typographical errors for a book of this length; the two most egregious typos occur within a few lines of each other on page 476. The book's strengths are the clear exposition of the subject matter, the use of MATLAB throughout the text and in the problems set, and in the writing style and good humor. Therefore, I very highly recommend this book for use in courses that cover modeling methods in oceanography or geophysics, and to researchers who want to refresh their knowledge or learn new aspects of their subject.

—Peter R. Gent

Peter R. Gent is a senior scientist in the Oceanography Section of the National Center for Atmospheric Research.

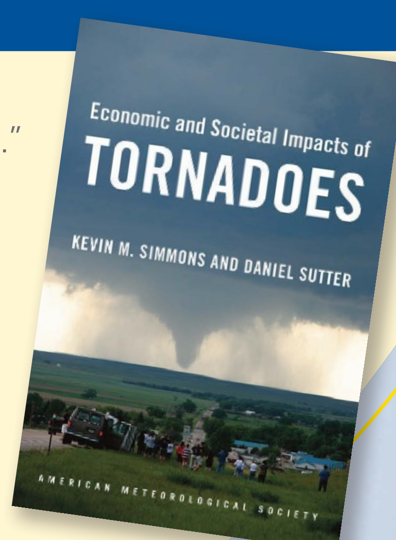
FOR FURTHER READING

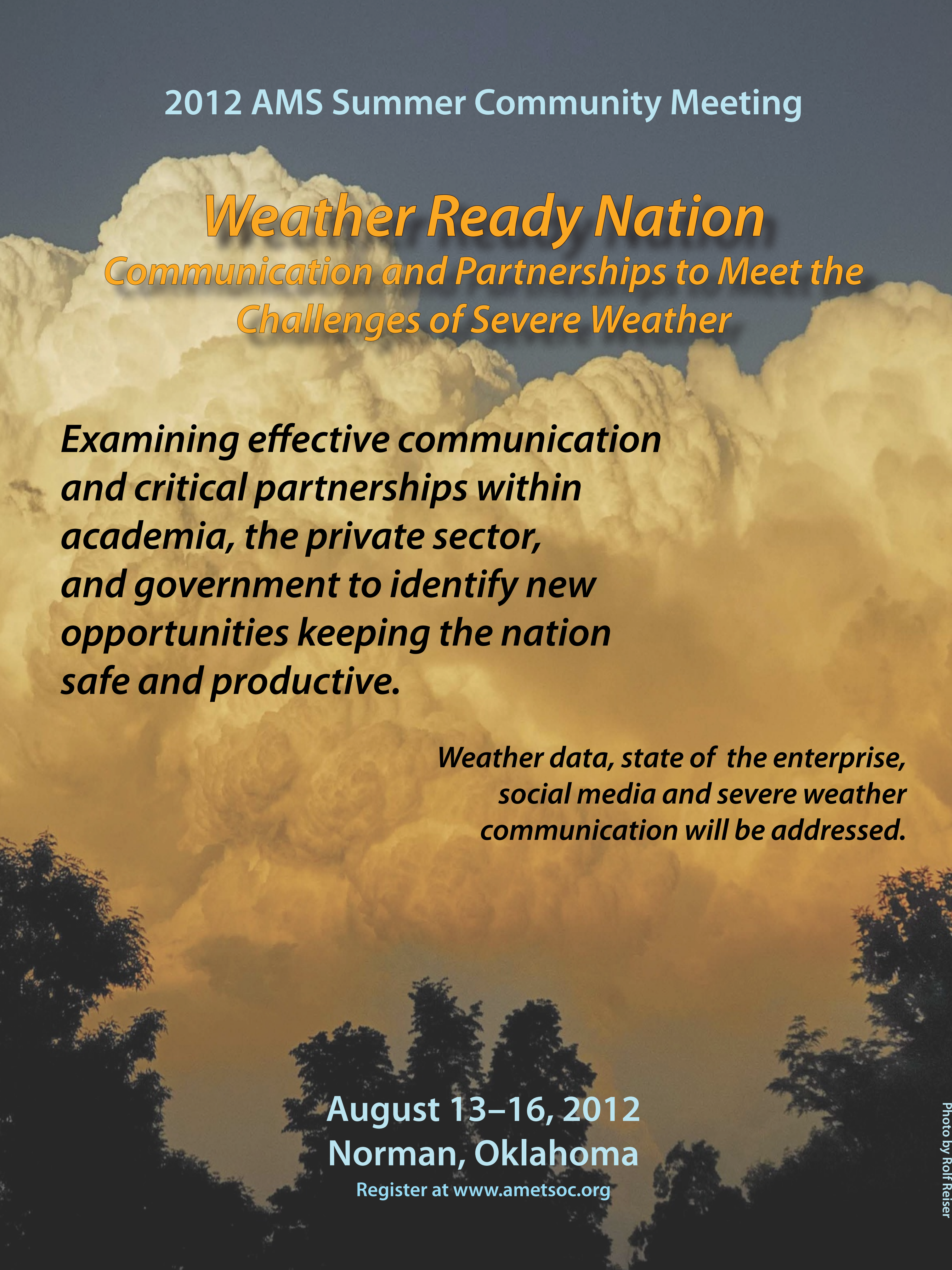
Broecker, W. S., and T.-H. Peng, 1982: *Tracers in the Sea*. Eldigio Press, 690 pp.

Pedlosky, J., 1979: *Geophysical Fluid Dynamics*. Springer Verlag, 624 pp.

Stumm, W., and J. J., Morgan, 1970: *Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters*. Wiley-Interscience, 583 pp.

Wunsch, C., 1996: *The Ocean Circulation Inverse Problem*. Cambridge University Press, 442 pp.

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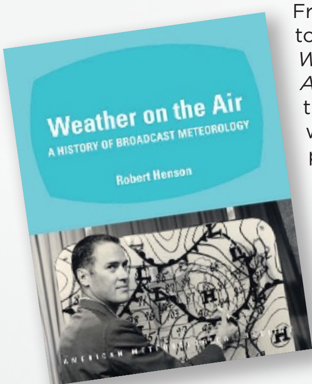
HISTORY

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!

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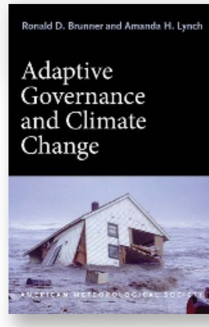

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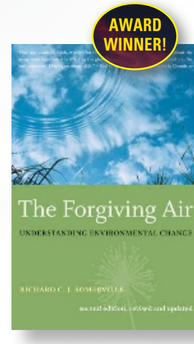

The Forgiving Air: Understanding Environmental Change, 2nd ed.
RICHARD C. J. SOMERVILLE

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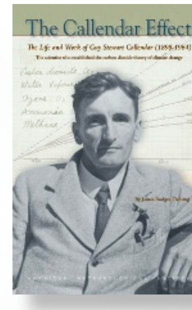

The Callendar Effect: The Life and Work of Guy Stewart Callendar (1898–1964)
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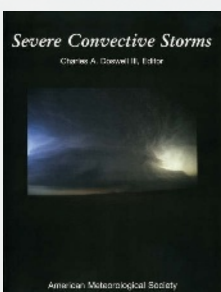

Severe Convective Storms
EDITED BY CHARLES A. DOSWELL III

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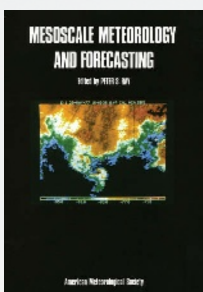

Mesoscale Meteorology and Forecasting
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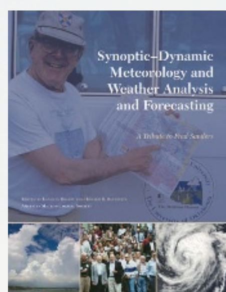

Synoptic–Dynamic Meteorology and Weather Analysis and Forecasting: A Tribute to Fred Sanders
EDITED BY LANCE F. BOSART AND HOWARD B. BLUESTEIN

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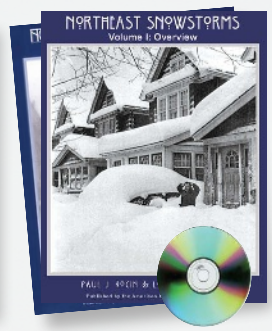

Northeast Snowstorms (Volume I: Overview, Volume II: The Cases)
PAUL J. KOCIN AND LOUIS W. UCCELLINI

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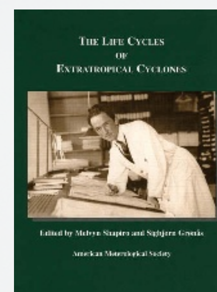

The Life Cycles of Extratropical Cyclones
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HIGHLIGHTS

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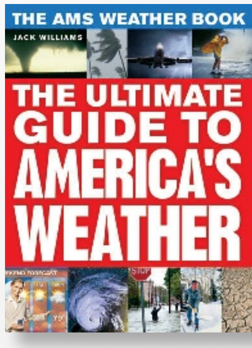
The AMS Weather Book:
The Ultimate Guide to America's Weather

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.



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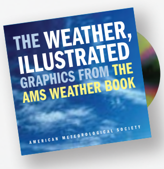

SPRING 2012

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

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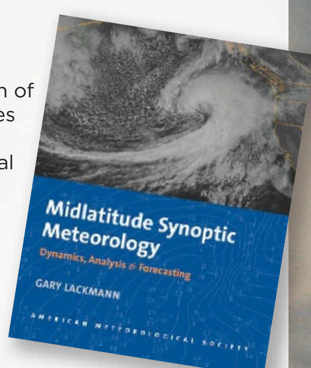
Dynamics, Analysis, and Forecasting

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.



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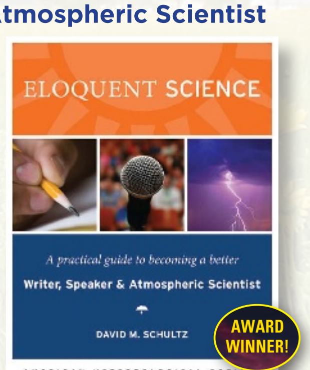
Eloquent Science:
A Practical Guide to Becoming a Better Writer, Speaker, and Atmospheric Scientist

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.



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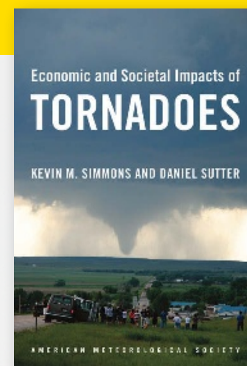

Economic and Societal Impacts of Tornadoes

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.

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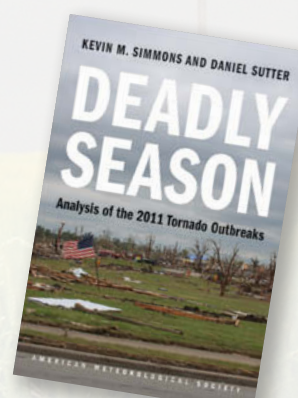
Deadly Season:
Analyzing the 2011 Tornado Outbreaks

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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45 BEACON

LETTER FROM HEADQUARTERS

How *Not* to Improve Communication on Climate Change Issues

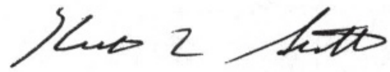
One year ago in this column (July 2011 *BAMS*, p. 923), I discussed efforts to work toward effective communication on climate change. That column summarized the results of research on "cultural cognition," which refers to how people tend to view information in ways that align with their cultural values. That research has shown how easy it is to increase the polarization of a population with respect to a controversial issue even if you try to concentrate solely on presenting scientific facts. The column also discussed the early work of the AMS Committee to Improve Climate Change Communication (CICCC), whose charge is to provide opportunities for open and respectful dialogue on the science of climate change, with the goal of decreasing the divisiveness within our own community on this extremely important topic.

I think we are learning a great deal about how to help foster useful communication among those who have differing views on climate change. Workshops conducted by the CICCC at the AMS Annual Meeting in New Orleans last January—which brought together small groups of individuals with widely differing views on the science of climate change—were excellent examples of that. Follow-up discussions with those involved in the workshops revealed that almost everyone who participated came away with a deeper appreciation for the views of the other participants, and several have indicated that they felt this approach could lead to real progress in reducing the divisiveness and conflict that we see now.

While the AMS has been actively pursuing ways to bring together our community to discuss this very complicated topic and find common ground from which to move forward, some organizations have been pursuing a different approach. They are trying to apply public pressure on those whose views are different. One organization, for example, publishes on its website a list of broadcast meteorologists who are identified as "deniers" based on views that they have expressed with respect to climate change (sometimes apparently using a single ambiguous or noncommittal statement by that individual as the basis for being included in the list). One gets the sense that those pursuing this tactic expect it to force broadcasters who are currently unconvinced that humans play a significant role in our changing climate to change their mind and begin promoting action to mitigate climate change. Almost every aspect of this approach, however, flies in the face of scholarly research on how to reduce polarization on a controversial topic and bring a population toward collective support for specific actions. These are examples, quite simply, of how not to improve the discussion on climate change.

If our goal is to help society deal with climate change based on the best scientific understanding available, we need a depolarization of the dialogue on climate change. We need a dialogue that allows respectful discussion of the science of climate change among those who are unconvinced of the role of humans in that change, as well as those who are convinced. We need to have that discussion clearly separate the science of what is happening, which we seek to understand through careful analysis of observations and through the physically realistic models that are at the core of the atmospheric and related sciences, from the policy options that address possible mitigation and adaptation, which involve value judgments and are therefore inherently political.

There is no shortage of examples of how not to communicate effectively on the topic of climate change, and we see evidence of this almost daily. I hope you will join me in trying to support avenues for respectful and open discussion on this topic, and think about ways you can promote a depolarization of the dialogue, both within our small community of the atmospheric and related sciences and within the general public.



KEITH L. SEITTER, CCM
EXECUTIVE DIRECTOR

EARLY CAREER PROFESSIONAL HIGHLIGHT

The Formation of the Board for Early Career Professionals

Over the past decade, the AMS has developed a strong student membership base due in part to the continued success of the annual student conference and AMS student chapters. Students often find the AMS a source for networking opportunities and information that will guide them into and during the early part of their careers. However, the Society has noted that early career professionals begin to lose touch with the organization during their transition to the workforce or graduate school.

To address these issues, the AMS has developed a membership subcommittee to better understand the needs of early career professionals. Feedback was solicited from AMS members during the Early Career Professional Receptions hosted at the Annual Meetings in Seattle and New Orleans. To implement a response to this feedback, the AMS established the Board for Early Career Professionals to assist AMS members and provide them with resources to develop and advance their careers.

THE COMMITTEE. The following individuals have volunteered to serve on the newly formed board and begin building resources for early career professionals.

- Andrew Molthan, Ph.D. (Chair)—Research Meteorologist, NASA Marshall Space Flight Center
- Marc Baribault—Meteorologist, US Engineering Solutions Corporation

Early career professionals networking at the Second Annual Reception for Early Career Professionals in New Orleans.

- Jill Hasling, CCM and AMS Fellow—President and Executive Director, Weather Research Center, Inc.
- Holly Hassenzahl, M.S.—Meteorologist/Science Analyst, Weather Central, LP
- Matthew Lacke, M.S.—Meteorologist, Jefferson County Department of Health
- Scott Mackaro, Ph.D.—Numerical Weather Prediction Scientist, Vaisala, Inc.
- Chris Schultz, M.S.—Graduate Research Assistant, University of Alabama in Huntsville
- Chris Slocum—Graduate Research Assistant, Colorado State University
- Marcus Walter, M.S.—Weekend Weather Anchor, WKYC

OUR PLANS. *The Highlight.* The purpose of The Highlight in *BAMS* is to feature successful early career professionals and share their keys to success for the benefit of other early career professionals. In addition, The Highlight will include insightful advice from more senior professionals.

Do you have advice for early career professionals? Would you like to nominate a successful early career professional for The Highlight? Do you have suggestions on what you would like to read in The Highlight? We would like to hear from you! Feel free to contact the chair of the Board for Early Career Professionals via e-mail at *andrew.molthan@nasa.gov.*

First Conference for Early Career Professional. The 93rd AMS Annual Meeting in Austin, Texas, will include the First Conference for Early Career Professionals, specifically designed to include speakers and panels targeted to the needs of early career professionals. Conference organizers will also solicit feedback on how to increase the relevance of the AMS to this portion of the membership.

Continuation of the Early Career Professional Reception. The reception has proven to be an effective way for early career professionals to interact and network, as well as a means for the board to learn how to target its activities. Following the workshop, the board will host the Third Annual Reception for Early Career Professionals.

Social Networking Presence. In an effort to bring the latest information to early career professionals, the Board has created the "AMS Early Career Professionals" Facebook page. We encourage early career professionals, students, and senior professionals to "like" and interact with people on the page.

The Board members look forward to further developing resources for the Society's early career professionals, and we hope for the active involvement of the Society's members.

GOING GREEN

GREENING THE AMS INVESTMENT PORTFOLIO

What is the color of money? While U.S. currency is green, not all financial investments are "green" in the sense of environmental stewardship. Like many other organizations, the AMS tries to manage its financial concerns with a diversified investment portfolio. But we also have environmental concerns, perhaps more so than many other organizations because of our special connection to the natural environment borne of our professional interests and affiliations. Recently, the AMS Committees on Investments and on Environmental Responsibility have teamed up to review the idea of green investing.

Green investing is a special category of social investing that typically embraces companies focused on sustainability and the environmental sector, such as pollution control, organic and natural foods, environmental cleanup, and renewable energy. Green investing also could include companies that are committed to environmentally conscious business practices.

Dan Wilson, a member of the AMS Investment Committee who also oversees UCAR's investment portfolio, puts it this way: "Green investment strategies are diverse and can be difficult to navigate. There are definitely many shades of green. What if a company makes a green product but causes toxic pollution through its production process? Would we want to invest in the risky solar panel production business that loses money and has poor investment return?"

The AMS Investment Committee has considered this issue previously and has discussed such problems as the dilemma of nuclear power being screened as a "bad" environmental choice while a coal-burning power company with excellent pollution controls might be rated as a "good" choice. Since the AMS does not buy individual stocks, as that would increase risk, it would have to choose a mutual equity or fixed-income fund that best matches the environmentally friendly goals, but that also has good investment returns. It's not a simple task to implement a "green investing" strategy.

As Rich Clark, a member of the Committee on Environmental Responsibility, sees it: "With the wider range of values-driven investment products, our hope is that AMS will be able to add more green to the color of its investment portfolio as opportunities present themselves. Admittedly, the risks may be more palatable in a bullish market, but as an organization that is inherently conscious of its environmental stewardship, it is imperative that we continue to study green funds that also have the potential for good long-term returns."

To that end, the two committees are committed to maintaining a focus on helping the AMS formulate an investment strategy that is both financially and environmentally responsible. Past President Jon Malay, who sits on both committees, offers this perspective: "The work of the AMS—enabled by our financial health and stability—is inherently 'green.' Therefore, a professionally managed and responsible investment strategy that supports our work for the long run is our true goal, and one we're committed to achieving."

ABOUT OUR MEMBERS

John Knox, an associate professor of geography at the University of Georgia, and **Jonathan E. Martin**, professor and chair of atmospheric and oceanic studies at the University of Wisconsin—Madison, have been included in The Princeton Review's new book, *The Best 300 Professors*.

The Best 300 Professors is the first comprehensive guidebook to America's top undergraduate professors. Knox and Martin, both atmospheric scientists, were chosen using students' anonymous teaching evaluations posted on the website www.RateMyProfessors.com. The Princeton Review teamed up with the website, the highest-trafficked college professor rating site in the country, to collect both qualitative and quantitative data from surveys and ratings.

"We developed this project as a tribute to the extraordinary dedication of America's undergraduate college professors and the vitally important role they play in our culture, and our democracy," says Robert Franek, The Princeton Review's senior vice president. "One cannot page through this book without feeling tremendous respect for the powerful ways these teachers are enriching their students' lives, their colleges and, ultimately, our future as a society."

PROFESSIONAL PRACTICES

This is the second in a series of articles encouraged by the Board of Certified Consulting Meteorologists and the National Council of Industrial Meteorologists to explore the ethical issues that can be encountered conducting business in the meteorological community. The purpose is to initiate a discussion within the broader membership about how the professional guidelines section of the AMS constitution comes to life in the conduct of everyday life of professional meteorologists. Comments are welcome and should be addressed to the authors. More formal responses can also be made to the editor of BAMS.

THE ETHICS OF DEFINING A PROFESSIONAL

Who Is a Meteorologist?

BY JERRY D. HILL, CCM, AND GERALD J. MULVEY, CCM

What is a "professional?" There are professional athletes, professional actors, and the term is even sometimes used by tradesmen to indicate the quality of their work, such as "professional plumbers." In the most basic sense, professionals are people who earn their living in a profession. More broadly, a professional has specialized skills and knowledge that required independent learning and effort on their part to attain. Before the AMS had its current categories of memberships, one of the categories was "professional member."

AFFILIATIONS: HILL—Consulting Meteorologist, Houston, Texas; Mulvey—Northrop Grumman, Redondo Beach, California
CORRESPONDING AUTHOR: Jerry D. Hill, Consulting Meteorologist, 7518 Chevy Chase, Houston, TX 77063
E-mail: Jerryd_hill@sbcglobal.net

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In any occupation, there is usually a sense of pride of profession. People in that occupation can resent others who attempt to portray themselves as a member of that profession without "paying their dues." This is particularly true in the atmospheric sciences profession, where the complexity of our science often warrants admiration from others.

To call oneself a professional in a certain occupation is intended to bring respect and inspire confidence. To protect the public, many professions, such as medicine, engineering, or public accounting, are regulated by state laws that establish the training, examination process, and experience required to qualify for a license. People using a title such as "medical doctor" or "certified public accountant" when not actually licensed in such a field are guilty of more than just a violation of ethical standards; they can land in jail or at least owe a hefty fine for the misrepresentation.

States have never licensed professional meteorologists, however, and some people have claimed publicly to be a meteorologist even with limited or no scientific training. Such representations might be considered a breach of personal ethics or professional conduct, even though no laws prohibit such actions.

We might define what, in a strict sense, the qualifications are for a person to be considered a meteorologist. In 1990, the AMS adopted a guideline (www.ametsoc.org/policy/whatisam.html) that describes a meteorologist as "an individual with specialized education who uses scientific principles to explain, understand, observe or forecast the earth's atmospheric phenomena and/or how the atmosphere affects the earth and life on the planet." This specialized education would involve a bachelor's or higher degree in meteorology, or atmospheric science, consistent with the requirements set forth in a separate AMS guideline on attributes of university programs for bachelor's degree programs in atmospheric science (www.ametsoc.org/policy/2010degree_atmosphericscience_amsstatement.html). The guideline says further: "There are some cases where an individual has not obtained a B.S. or higher degree in meteorology, but has met certain educational requirements and has at least three years professional experience in meteorology. Such an individual also can be referred to as a meteorologist."

The specialized education leading to a bachelor's degree referred to in the AMS guidelines should contain 24 hours of credit in atmospheric science plus supporting course work in mathematics, physics, and computer science. The hours in atmospheric science must be specifically related to meteorology topics. The mathematics and physics coursework should be that required for other physical science and engineering majors. The physics coursework must be calculus-based and must include a lab.

A degree in a related science with a few course hours in meteorology does not qualify one as a meteorologist under these guidelines. An example might be someone with a degree in statistics who has taken a specialty statistics course in a meteorology department or online and is working in the area of climate data analysis. The person would still be considered professionally as a statistician and not a meteorologist, even though he or she is working with meteorological data.

In a different venue, the U.S. Federal Civil Service has established a standard for classifying government employees as "meteorologists" when they hold a degree from an accredited college or university and have earned at least 24 semester hours (36 quarter hours) of credits in meteorology/atmospheric science (see www.opm.gov/qualifications/standards/IORs/gs1300/1340.htm). An alternate federal standard has been established for persons who normally do important weather-related work such as performing calculations, operating specialized meteorological equipment, and making weather observations. These are people who have received technical or military training in meteorology but do not meet the academic standards to be classified as meteorologists. Under the Civil Service guidelines, they are classified as "meteorological aids" or "meteorological technicians," but not meteorologists.

Meeting the AMS or the relevant Federal Civil Service guidelines would be considered sufficient for persons to represent themselves as meteorologists. Otherwise, it would not be illegal, but would certainly be considered unethical, to use that label for oneself professionally.

One area where some people have historically taken liberties identifying themselves as meteorologists is in the broadcasting industry. In recent years, some broadcasters have taken meteorology courses available online to become self-appointed "meteorologists." To help deal with this trend, the AMS took steps in the public interest to create a standard for scientific training people must meet before they can be given a seal of recognition as a "Certified Broadcast Meteorologist" (CBM).

The CBM must possess a degree in atmospheric science/meteorology or have completed coursework considered equivalent to a degree in atmospheric science/meteorology. Some weathercasters who hold bachelor's degrees in communications or related subjects may have earned additional credits in meteorology to meet the academic requirements for equivalence to a degreed meteorologist. This additional training in meteorology should also be sufficient for them to be considered as professional meteorologists and referred to as such on the air.

People considering a career in broadcasting where they might use a university's distance learning coursework to supplement a nonmeteorology undergraduate degree in order to meet the AMS guidelines for becoming a meteorologist should examine the institution's curriculum closely. Distance learning programs do not normally offer the opportunity to meet the AMS requirement to complete physics coursework that is calculus-based and includes a lab. Also, to earn the Society's CBM seal requires coursework in atmospheric thermodynamics and dynamic meteorology that has calculus as a prerequisite.

In 2005, a bill was introduced in the Texas Legislature by a Dallas-area representative that would have made it a misdemeanor to call yourself a meteorologist unless you met specific academic requirements that were included in the bill. The standards used in the bill's language were tantamount to having a four-year bachelor of science degree in meteorology and were identical to the standards for National Weather Service meteorologists. The proposal would have established the only state-set standards for meteorologists in the country. The bill's sponsor claimed to have only one motive for the bill: the safety of the public. The sponsor said, "A very real possibility exists that some unqualified person, calling himself or herself a meteorologist, might someday misinterpret meteorological data in a weather emergency and lead the public into danger."

The bill did not pass the Texas legislature, but caused a storm among the state's weathercasters, some of whom did not meet the criteria set in the proposed bill but believed their experience gave them the equivalent skill of degreed meteorologists. There has been no effort to reintroduce the bill since 2005, and perhaps the establishment of the AMS's CBM seal, also in 2005, serves as an adequate substitute. However, the public still may not be making the connection between displaying the seal and the weathercaster's academic qualifications.

Representing oneself to the public as a meteorologist requires very specific qualifications. These differ slightly between the AMS definition and the Federal Civil Service definition. However, the fundamental academic requirements are nearly identical. Ethical questions arise when someone who clearly does not meet any of the qualifications represents himself or herself as a meteorologist—for personal aggrandizement, to gain public trust, or for financial gain. At this time, there is no law in the United States that would make this a punishable offense, but it reflects adversely on the character of the person who does this or allows others to do so on their behalf.

AWARDS

The following awards were presented at the 30th Conference on Hurricanes and Tropical Meteorology, held 16–20 April 2012 in Ponte Vedra Beach, Florida.

2012 Banner Miller Award—Mark DeMaria

The 2012 Banner Miller Award was presented to Mark DeMaria for his insightful application of the logistic growth equation as a simple dynamical prediction system (LGEM) for tropical cyclone intensity. In this system, the growth rate of a tropical cyclone is assumed to be a linear function of basic environmental parameters that are readily available in forecast operations. Although this application replicates the basic evolution of a tropical cyclone using a much smaller number of state parameters than complex dynamical and statistical models, LGEM is recognized as a skillful forecast aid upon which operational forecasters rely.

2012 Max Eaton Award—Zachary Handlos and Daniel Chavas

The Max A. Eaton Prize is awarded for the best student paper presented at each technical conference on hurricanes and tropical meteorology. The paper is judged on content and presentation by a panel selected by the conference program committee. Entrants must be currently enrolled in high school, college, or graduate school. The prize, an AMS reference book, $100, and a certificate, was established to recognize Max A. Eaton's lifelong contributions to tropical meteorology and the encouragement he gave to so many young researchers.

There was a tie for the 2012 award: Zachary Handlos for "Estimating Vertical Motion Profile Shape within Tropical Weather States" and Daniel R. Chavas for "Equilibrium Tropical Cyclone Size in an Idealized State of Axisymmetric Radiative–Convective Equilibrium."

MAYNARD E. SMITH
1920–2012

Maynard E. Smith, an AMS member since 1941 and a Fellow, died 17 April 2012 at the age of 92. Smith had moved to northern Connecticut after being a meteorologist with the U.S. Army and Brookhaven National Laboratory and then heading his own company, Meteorological Evaluation Services, Inc.

Immediately after graduating from Princeton in 1941, Smith became a member of the second aviation cadet class at New York University. He received his M.A. in meteorology as well as his appointment as a 2nd Lieutenant in the U.S. Army Air Corps in February 1942. His first major assignment was to the newly formed Joint Weather Center in Washington, D.C.—a group composed of U.S. Air Corps, Navy, and Weather Bureau personnel. Smith became head of the Upper Air Analysis Section, whose major responsibility was forecasting flight weather, winds, and temperatures for the North Atlantic ferry transport of fighters and bombers to the United Kingdom. In this assignment, he began a lifelong friendship with Ken Spengler, who became the AMS Executive Secretary after the war. Smith also worked with Ben Holzman, Henry Harrison, and Harry Wexler, developing new techniques for upper-air analysis and forecasting.

One of Smith's favorite stories about this phase of his work involved the group's failure to recognize the first indications of the jet stream. At that time, upper-wind observations were based on "Pibals"—balloon measurements that seldom exceeded 20,000 feet. Once in a great while, one would ascend higher, intersecting the jet stream, but the analysts would cheerfully discard the data as obviously flawed. Not until the advent of the B-29 bombers late in the war did anyone realize that the jet stream existed.

Following this, Smith developed a system for segregating the atmosphere into layers of varying thickness, each of which was characterized by temperature, wind, moisture, and stability. He and Ralph Nelson coded this information into a teletype transmission form called MESRAN (MESmith RANelson), which became widely used in the United States and Europe. And, as a further outgrowth, the system was translated into a form that could be used by the artillery and anti-aircraft people to correct shellfire. (In 1943, the U.S. Army was still basing its artillery fire correction tables on surface wind observations and the so-called "standard atmosphere" densities.)

In the spring of 1944, Smith was assigned to the 21st Weather Squadron, Ninth Air Force, where Colonel Tommy Moorman set him to work developing a program to provide the U.S. Army ground forces with whatever weather data they could conceivably use, including the correction system for artillery fire. (The ground forces had no weather service of their own at that time.) The new Ground Force Weather Detachments began landing in Normandy on D-Day plus one, and Smith became commanding officer of both these detachments and the Advanced Headquarters of the 21st Weather Squadron in Normandy.

During the remainder of World War II in Europe, he divided his time between making the rounds of his 13 Ground Force Detachments to keep their staff, supplies, and training up to date, and developing new methods of assessing and forecasting such new items as soil trafficability, ice thickness, etc., for ground operations.

After the war, Smith spent three years with American Airlines, forecasting flight weather in the New York region, and then joined the Meteorology Group at Brookhaven National Laboratory, under Norman Beers. This group designed and built one of the most elaborate low-level research facilities available at the time, consisting of a fully instrumented pair of towers, 420- and 150-feet high, respectively, and including an oil-fog generating facility for tracer studies. Brookhaven was building an air-cooled nuclear reactor, and information on low-level atmospheric diffusion was important for the safety of the public and the laboratory staff. Data from these studies resulted in early estimates of

IN MEMORIAM

MELVIN GOLDSTEIN
1946–2012

FRANK SHERWOOD ROWLAND
1927–2012

DAVID W. SAXTON
1933–2012

CLIFFORD SPOHN
1915–2012

the "diffusion parameters" as defined by the English meteorologists Sutton and Pasquill.

Simultaneously with the development of the Brookhaven research program, close relationships were established with the New York University and Pennsylvania State University meteorological staffs, under Bernard Haurwitz and Hans Panofsky, respectively. These relationships strengthened the Brookhaven program and provided extensive turbulence and diffusion data for university graduate investigations.

As in the air force upper-air work, a practical application arose because industrial executives in the United States were becoming aware of the importance of curbing air pollution, and Smith and Irving Singer, his colleague of 24 years, left Brookhaven in 1973 to form Meteorological Evaluation Services, Inc (MES). The new company devoted its efforts to analyzing existing air pollution problems and helping locate and design new facilities, primarily for nuclear and coal-fired electric utilities and chemical and aluminum plants. MES also continued to refine computerized techniques for summarizing and assessing both meteorological and air quality data.

Smith retired from MES in December 1986 but continued his relationship with the meteorological profession by chairing the Steering Committee of the AMS/EPA Cooperative Agreement, in which a group of scientists advised the EPA on the mathematical modeling of air quality problems and the data required for them.

He and his late wife, Doreen Dallam, spent most of their 41 years together on Long Island, in Massapequa and Southold. Since 1994, he had been living in Connecticut with his companion of 25 years, June Stern. He is survived by his daughter, Kathleen Smith, of Madrid, Spain; two grandchildren, Daniel Clay Smith and Bonnie Virginia Sims; and one great grandson, Matthew Elijah Smith.

—Written by Maynard Smith
prior to his passing

STANLEY WASSERMAN
1934–2011

A few outstanding individuals appear in each generation, and Stanley Wasserman was one such individual. Stan was full of energy, insightful and curious about the atmosphere and life in general. He studied meteorology at the City College of New York and received an M.S. in meteorology and did additional graduate work at New York University.

Stan's entire career was spent in the National Weather Service (NWS), except for a two-year stint in the U.S. Army at Ft. Huachuca, Arizona, providing meteorological support for artillery. Stan's career in the NWS began at Newark, New Jersey, and progressed in research in the Scientific Services Division, the Data Acquisition Division, and as chief of the Meteorological Services Division at the Eastern Region of the NWS. He concluded his long government career as meteorologist-in-charge at the forecast office in New York City.

Wasserman was instrumental in improving interpretation of satellite information, probability forecasting, issuance of watches and warnings, hurricane preparedness, and nuclear plant disaster readiness. During his career, he also found time to act as a consultant to NBC on early manned space flights and to teach part-time at the SUNY Maritime College. He received numerous awards from the U.S. Department of Commerce, the NWS, and the AMS. As a certified consulting meteorologist, his counsel was sought and he brought credit to the profession. He also served as chair of the NYC Chapter of the AMS and the Atmospheric Science Section of the New York Academy of Science.

Stan was too energetic to retire to a life of leisure, and so he became a real estate broker after retirement. He had many Chinese clients and came to understand their culture of feng shui in searching for a home. He also was one of the first to express apprehension about subprime mortgages, which would later lead to the great recession.

Stan is survived by his wife, Muriel, a daughter, two sons, and six grandchildren.

—Fred Zuckerberg,
with the aid of Mark Kramer

[Editor's Note: The following post is excerpted from William Hooke's blog, Living on the Real World (www.livingontherealworld.org/). Hooke is director of the AMS Policy Program.]

Demography's Role in Sustainable Development
(Originally posted on 21 March 2012)
From time to time, readers post comments here citing humanity's sheer numbers . . . 7 billion and climbing, on its way to what looks to be 9 billion at a minimum . . . as the biggest challenge to sustainable development. So many people means a big global appetite for food, water, and energy. Per capita, those appetites are increasing, in response to economic growth and globalization. It's hard for this many people, however well-intended, to avoid degrading the environment, destroying natural habitat, threatening endangered species, and the like. And the numbers imply crowding higher populations and greater economic activity into locations vulnerable to natural hazards . . . coastal zones, unstable slopes, and seismically active areas.

But how to carry the discussion further? Those who are so inclined and looking for a suitable starting point might take note of a multi-authored letter posted in the February 24, 2012 issue of *Science*.

Here are their five bits of advice:

1. Recognize that the numbers, characteristics, and behaviors of people are at the heart of sustainable development challenges and of their solutions.
2. Identify subpopulations that contribute most to environmental degradation and those that are most vulnerable to its consequences. In poor countries especially, these subpopulations are readily identifiable according to age, gender, level of education, place of residence, and standard of living.
3. Devise sustainable development policies to treat these subpopulations differently and appropriately, according to their demographic and behavioral characteristics.
4. Facilitate the inevitable trend of increasing urbanization in ways that ensure that environmental hazards and vulnerabilities are under control.
5. Invest in human capital—people's education and health, including reproductive health—to slow population growth, accelerate the transition to green technologies, and improve people's adaptive capacity to environmental change.

Maybe you can improve upon this list. Perhaps the authors have omitted some dimension or issue, or framed what they've considered in an awkward way. In several if not all of the five instances, the statements fall short of specifics—actionable steps. But however you look at it, these observations are food for thought, worth keeping in mind, improving, building upon, as the world lugubriously lumbers along toward the RIO+20 Earth summit.

And what's the provenance of the list? Well, the writers had participated in a meeting convened by the International Institute for Applied Systems Analysis (IIASA) specifically considering how demographic factors foster or hinder sustainability. A fuller discussion of conclusions and recommendations from their full report, "Demographic Challenges for Sustainable Development," is available at www.iiasa.ac.at/Research/POP/Laxenburg%20Declaration%20on%20Population%20%20Development_final_logos%20.pdf.

NEW MEMBERS

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

Matthew R. Alto
Virva D. Aryan
Kenji Baba
Lori O. Bator
Anton Beljaars
Tod Benedict
David S. Biggar
Kenneth A. Blumenfeld
Stephen P. Bone
Adriana Bravo
Janna K. Brown
Judsen Bruzgul
Deborah J. Callender
Benjamin Cathey
Carl S. Cerniglia Jr.
Edwin M. Chewning
Lyle R. Chinkin
Myungjin Choi
John L. Cintineo
Josefino C. Comiso
Sara Crepinsek
James A. Curtin
Peter C. D'Abreton
Michael Daniels
Susana M. Dasneves Mendes
Cory D. Davis
Idamis Del Valle Martinez
Alison Dobbin
Stephen L. Durden
Kathryn Feingold
Louise Fode
Adam J. French
William O. Gallery Jr.
Luis Garcia-Carreras
Julia B. Gaudinski
Jack T. Gerfen
Seyavosh Ghamari
Eric L. Gottshall
Donald G. Gray
Steve R. Guimond
Lawrence L. Hallock Jr.
Nathan H. Harrington
Paul Hastings
Robert Hepper
Forrest M. Hoffman
Katherine L. Howard
ShihMing Huang
Rachel H. Humphrey
Mike James
Liwei Jia
Lindsay E. Johnson
Mary R. Keller
Dong-Soon Kim
Jung-Hoon Kim
Monika Kopacz
Bruce E. Kurtz
Roger Hiu Fung Kwok
Pete Lahm
Sally L. Lavender
Dallin M. Lewis
Min Li
AnnMarie Lofwenberg
Kelly A. Lombardo
Thomas A. Lundquist
Ana L. F. Macedo
Katherine S. Maclay
Rahul Mahajan
Vani Starry Manoharan
Robert E. Marshall
Luciano Massetti
Peter K. Mattschei
Jackie C. May
John A. Mayers
Daniel E. McCanty
Andrew M. McCawley
Gregory L. McIntyre
Scott A. McLaughlin
Scott McPeake
Shalini Mohleji
Susanna Mohr
Fred Moshary
Kate C. Musgrave
Daniel Muth
Amelia L. Nahmias
Taro Nakai
Vijay Krishna Nemalapuri
Ljubov J. Nevvonen
Akira Noda
Ian S. Oliver
Dipak Oza
Blair Mason Palmer
Renee Perkinson
Melissa Petty
Marcus Radlach
Laureen G. Reed
Federico Pablo Renolfi
Katherine A. Rojowsky
Matthew Rudkin
Evan Ruzanski
Barbara J. Ryan
Arindam Samanta
Emilie Scherer
Mitchell Schull
Joel P. Scott
William R. Simmons
Clayton Spann
Elizabeth A. Stuckmeyer
Shao-Liang Sung
Samuel E. Swindler
Jon Thompson
Ali Tokay
Natalie D. Tourville
Andrew Tupper
Daniel P. Tyndall
Antonio Viudez-Mora
Daniela Viviana Vladutescu
Kai Wang
Zhihua Wang
John George Watson
Ryan M. Watts
David R. Weise
Eric E. Wertz
Gregory E. Whitaker
George P. Widas
Wesley Williams II
Eiichi Yoshikawa
Joseph K. Zajic
Mark D. Zelinka
David A. Zelinsky

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

Hua Chen
Andrea L. Dill
Zaneta K. Gacek
Aaron Paul Goldner
Christyna Gordon
Diar Hassan
Keun-Ok Lee
Justin Edward Luna
Virgilio J. Maisonet
Zachery Maye
Sunyoung Pyo
Ryan H. Rogers
Dennis W. Seeley
Amber Silver
David P. Whittleston

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

Peggy A. Brecheisen
Victoria E. Peterson

NEW MEMBERS

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

Alex D. Alecci
James G. Allen
Salem Saeed Alshebli
Ekaterina Altman
Kimberly Anderson
Ali Asaadi
Matthew E. Baker
Brad Baldridge
Sanda Barkidija
Audra E. Basal
James H. Bergman
Tachanat Bhatrasataponkul
Regina Bird
Melissa Blacketer
Lindsay R. Blank
Alan Brammer
Joshua O. Bregy
Chris Brinson
Samantha M. Brown
Sierra L. Brune
Dexter Campbell
Allison C. Camras
Brad Carlberg
Nicholas J. Carr
Mallory Cato
Jingyi Chen
Victoria Chow
Joseph R. Clamp
Samara Clarke
Jenae' M. Clay
Scott Clement
Michael R. Colbert
Jerry Combs
Russell J. Cool Jr.
Anthony J. Cosio
Virginia Costilla
Peter Crank
Roger Delgado
Mark J. Dempsey
Edward R. Dixon
Pamela D. Eck
Chad Eilering
David L. Erzinger
Blake M. Foust
Adam Frantz
Chelsae Fullilove
Cale R. Galloway
Brittany R. Gill
Paul S. Grabkowski Jr.
Jeremiah Grant
Sloan E. Grever
John Hamilton
Brian Harvey
Jennifer Henley
Carlee Lynn Hoffman
Stephanie M. Holmer
Heather R. Hornick
Wes Houx
Natalia Hryniw
Samantha L. Huddleston
Paul Huff
Melyssa Hunter
Vandana Jha
Caleb D. Johnson
Chase D. Johnson
Rebekah D. Jones
Reena L. Joubert
Ana Juracic
Connor J. Keef
Angie Lassman
Michael Layer
Nicole Lehtola
Michael Leitzke
Niki M. Leupold
Rachel A. Lezman
Wei-Wei Li
Ying Li
Hailong Liu
Ann M. Lockard
Rachel Lupold
Amber Macchia
Andrew R. Margolin
Jared W. Marquis
Sean Mason
Molly A. Matott
Ryan A. Michael
Daniel R. Miller
Brett R. Mitstifer Jr.
Erika L. Moore
Kelly Mulvoy
Brian J. Murphy
Michael J. Murphy Jr.
Amanda Myers
Casey B. Newell
Melinda R. Nicewonger
Chantawan Noisri
Eric J. Notarangelo
Serkan Ozturk
James M. Parish II
Luca Peppe
Elizabeth H. Peress
Lee M. Picard
Binod Pokharel
Sean Poling
Christopher Prebish
Matthew Reagan
Michelle Reinke
Brian Rico
Dawn Roberts-Semple
Jared D. Robinson
Nicholas Rothfuss
Mariel Ruiz
Aqeel Saeed
Steven M. Schlorf
Allison N. Schwier
Genevieve S. Scott
Joseph M. Seborowski Jr.
Zachary P. Sefcovic
Nicholas T. Siler
Jason Simon
Elizabeth Skilton
Laura N. Spindler
Mark D. Spychala
Jessica E. Stanley
Kosana Suvocarev
Jared S. Taber
Wan-Ling Tseng
Paula R. Tucker
Marisa M. Valentic
Thomas A. Vaughan
Brian T. Walder
David M. Wallace II
Cody J. Webb
Hope-Anne L. Weldon
Nathan Wendt
Justin W. Whitaker
Diandre T. Williams
Janelle M. Williams
Christopher M. Wilson
Meredith L. Wood
Peter J. Woolcox
Tingyin Xiao
Xin Xie
Albert Yau
Katherine G. Yee
Lin Zhu

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

Kristen M. Allison
Robert W. Brewerton
Steven W. Engerrand
Jordan Haedtler
Mark E. Hildreth
John R. Jacobs
David E. Johnson
Victor Kilo
Jeffrey H. Madison
Daniel Souweine
Marina Tunik

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

Sara Bruegel
Shelby L. Bush
Samuel J. Collins
Kelton Halbert
Kyle J. Hanson
Sydney Kuizin
Jeremy S. Rachels
Ryan K. Schultz
Jordan Shickman
Ross Stark
Brandon G. Wagner

CALENDAR OF MEETINGS

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

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

AMS MEETINGS

2012

JULY

20th Symposium on Boundary Layers and Turbulence, 8–13 July, Boston, Massachusetts
Abstract deadline: 5 April 2012
Preregistration deadline: 1 June 2012
Manuscript deadline: 13 August 2012
Initial announcement published: Aug. 2011

18th Conference on Air–Sea Interaction, 8–13 July, Boston, Massachusetts
Abstract deadline: 5 April 2012
Preregistration deadline: 1 June 2012
Manuscript deadline: 13 August 2012
Initial announcement published: Aug. 2011

AUGUST

10th Symposium on the Urban Environment and Eight International Conference on Urban Climate (ICUC8), 6–10 August, Dublin, Ireland
Abstract deadline: 20 January 2012
Initial announcement published: Nov. 2011

40th Broadcast Meteorology Conference, 22–25 August, Boston, Massachusetts
Abstract deadline: 23 March 2012
Preregistration deadline: 2 July 2012
Initial Announcement Published: Dec. 2011

AMS Short Course: From Climate to Space: Hot Topics for the Station Scientist, 24 August, Brookline, Massachusetts
Preregistration deadline: 2 July 2012
Initial announcement published: July 2012

15th Conference on Mountain Meteorology, 20–24 August, Steamboat Springs, Colorado
Abstract deadline: 20 April 2012
Preregistration deadline: 9 July 2012
Manuscript deadline: 20 September 2012
Initial Announcement Published: Nov. 2011

OCTOBER

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

NOVEMBER

26th Conference on Severe Local Storms, 5–8 November, Nashville, Tennessee
Abstract deadline: 10 August 2012
Preregistration deadline: 7 September 2012
Manuscript deadline: 7 December 2012
Initial announcement published: Aug. 2011

2013

JANUARY

12th Annual AMS Student Conference: Expanding Weather and Climate Prediction—Taking Geosciences to the Next Level, 5–6 January, Austin, Texas
Abstract deadline: 1 October 2012
Registration deadline: 18 December 2012
Initial announcement published: Feb. 2012

First Annual AMS Conference for Early Career Professionals, 6 January, Austin, Texas
Registration deadline: 18 December 2012
Initial announcement published: June 2012

***Robert A. Duce Symposium, 8 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***29th Conference on Environmental Information Processing Technologies (formerly known as Interactive Information Processing Technologies, IIPS), 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***27th Conference on Hydrology, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***25th Conference on Climate Variability and Change, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***22nd Symposium on Education, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

*An exhibit program will be held at this meeting.

***20th Conference on Applied Climatology, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***19th Conference on Planned and Inadvertent Weather Modification, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***17th Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS–AOLS), 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***16th Conference on Aviation, Range, and Aerospace Meteorology (ARAM), 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***16th Conference of Atmospheric Science Librarians International (ASLI), 6–10 January, Austin, Texas**
Abstract deadline: 1 October 2012
Preregistration deadline: 1 December 2012
Initial announcement published: July 2012

***15th Conference on Atmospheric Chemistry, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***11th Conference on Artificial and Computational Intelligence and its Applications to the Environmental Sciences, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***11th Symposium on the Coastal Environment, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***11th History Symposium, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***10th Conference on Space Weather, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Eighth Symposium on Policy and Socio-Economic Research, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Sixth Conference on the Meteorological Applications of Lightning Data, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Sixth Symposium on Lidar Atmospheric Applications, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***Sixth Annual CCM Forum: Certified Consulting Meteorologists, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***Fifth Symposium on Aerosol–Cloud–Climate Interactions, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Fourth Conference on Environment and Health, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Fourth Conference on Weather, Climate, and the New Energy Economy, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

Modeling and Analysis Using Python, 6–10 January, Austin, Texas
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Third Conference on Transition of Research to Operations: Successes, Plans, and Challenges, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Second Symposium on Planetary Atmospheres, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***First Annual Symposium on Improving Communication, Collaboration and Response to Weather Forecasts and Warnings, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***First Symposium on the Weather and Climate Enterprise, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Special Symposium on Advancing Weather and Climate Forecasts: Innovative Techniques and Applications, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***Special Symposium on the Joint Center for Satellite Data Assimilation, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***Special Symposium on the Next Level of Predictions in Tropical Meteorology: Techniques, Usage, Support, and Impacts, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

***Symposium on Prediction of the Madden–Julian Oscillation, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: April 2012

***Symposium on the Role of Statistical Methods in Weather and Climate Prediction, 6–10 January, Austin, Texas**
Abstract deadline: 1 August 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: May 2012

***IMPACTS: Major Weather Events and Impacts of 2012, 8 January, Austin, Texas**
Abstract deadline: 15 October 2012
Preregistration deadline: 1 December 2012
Manuscript deadline: 6 February 2013
Initial announcement published: Feb. 2012

MEETINGS OF INTEREST

2012

JUNE

16th International Symposium for the Advancement of Boundary Layer Remote Sensing, 5–8 June, Boulder, Colorado

Fifth Chaotic Modeling and Simulation International Conference (CHAOS 2012), 12–15 June, Athens, Greece

Croatian–USA Workshop on Mesometeorology, 18–20 June, Zagreb, Croatia

JULY

16th International Conference on Clouds and Precipitation, 28 July–3 August, Leipzig, Germany

* An exhibit program will be held at this meeting.

AUGUST

International Radiation Symposium 2012, 6–10 August, Dahlem Cube, Berlin, Germany

International Symposium on Nowcasting and Very Short Range Forecasting, 6–10 August, Rio de Janeiro, Brazil

2012 Community GSI Data Assimilation System Tutorial, 21–23 August, Boulder, Colorado

SEPTEMBER

2012 EUMETSAT Meteorological Satellite Conference, 3–7 September, Sopot, Poland

12th EMS Annual Meeting & 9th European Conference on Applied Climatology (ECAC), 10–14 September, Łódź, Poland

Third International Conference on Earth System Modelling, 17–21 September, Hamburg, Germany

OCTOBER

National Weather Association 2012 Annual Meeting, 6–11 October, Madison, Wisconsin

Fourth Tri-State Weather Conference, 13 October, Danbury, Connecticut

WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TEC0-2012), 16–18 October

Meteorological Technology World Expo 2012, 16–18 October, Brussels, Belgium

NOAA's 37th Climate Diagnostics and Prediction Workshop, 22–25 October, Fort Collins, Colorado

The Second LAPS User Workshop, 23–25 October, Boulder, Colorado

2012 Conference on Intelligent Data Understanding, 24–26 October, Boulder, Colorado

2013

JUNE

Second China–U.S. Symposium on Meteorology, 24–28 June, Qingdao, China

CALL FOR PAPERS

ANNOUNCEMENT

AMS Short Course: From Climate to Space: Hot Topics for the Station Scientist, 24 August 2012, Brookline, Massachusetts

The AMS Short Course "From Climate to Space: Hot Topics for the Station Scientist" will be held on 24 August 2012 at the Clay Center in Brookline, Massachusetts, at the conclusion of the 40th AMS Conference on Broadcast Meteorology. Programs, registration, hotel, and general information are posted on the AMS Web site (www.ametsoc.org).

The paradigm of broadcast meteorology has changed. Newsrooms are increasingly relying upon weathercasters to inform the public about and add proper perspective to a number of related science and environmental issues. Broadcast meteorologists are now becoming "station scientists," with responsibilities far beyond "just" presenting the weather. This short course (as well as the station scientist session earlier that day during the conference) will provide weathercasters with a depth of knowledge about two of the most popular and important topics the public wants to stay informed about: climate change and astronomy.

The course will be divided into two parts. The first half is devoted to climate change and features two papers about the impacts of climate change on marine life, followed by a 90-minute question and answer session with a very distinguished panel of some of the world's most respected climate scientists. Attendees should come prepared with questions and be ready for a lively discussion of this issue.

The second half is devoted to popular astronomy topics, including near-Earth objects, meteorites, space weather, Mars, and the search for other Earthlike planets. The short course will wrap up with an astronomical viewing session at the Clay Center's observatory.

A dinner will be provided during the short course. Computers, laptops, or internet access will not be available or required for this course.

For more information please contact AMS Station Scientist Committee chairman, Paul Gross, WDIV-TV, 550 West Lafayette Blvd., Detroit, MI 48226-3140 (tel: 313-222-0444; e-mail: paulg@wdiv.com). (7/12)

AMS/AGU Heads and Chairs Meeting, 18–19 October 2012, Boulder, Colorado

The 18th Biennial AMS/AGU Heads and Chairs Meeting will take place 18–19 October 2012 in Boulder, Colorado, at the National Center for Atmospheric Research (NCAR) Center Green Campus immediately following the Annual UCAR Members' Meeting.

Planned topics for discussion include the trend toward transdisciplinary programs in universities, maintaining and documenting academic standards including a report on the AGI study of program classification, discussion of Student Learning Outcomes in Atmospheric Science programs, and online degree programs. A follow-up discussion from the previous Heads and Chairs Meeting on the health of university programs in the aftermath of the Great Recession is being considered as well as a session entitled "Climate Sciences: A Return to Relative Obscurity?".

Please forward additional suggestions and ideas to the planning committee through the committee chair, Tony Hansen, St. Cloud State University (e-mail: arhansen@stcloudstate.edu). (7/12)

CALL FOR PAPERS

16th Annual Conference of Atmospheric Science Librarians International (ASLI): Taking Atmospheric Sciences Information to the Next Level: Expanding Beyond Today's Library Collections and Resources, 9–11 January 2013, Austin, Texas

Atmospheric science libraries and information centers continue to evolve as researchers seek more and more information online, from increasingly remote locations, and in a multitude of digital formats. How can librarians partner with their clients to navigate a multifaceted environment of information and data to find what they need? There are many opportunities for libraries and information centers to repackage collections, resources, and services to make them more accessible and discoverable. By identifying user needs libraries and information centers can create and expand beyond their traditional services and implement innovative solutions to more than meet researchers' expectations of atmospheric sciences information and data.

The purpose of this meeting, to be held 9–13 January 2013 in Austin, Texas, is to focus on how the library community is taking meteorology and climate resources to the next level by utilizing and developing tools that enhance access, delivery, information literacy, and management. Possible proposal topics include use of analytic/metric tools, mobile applications, data sets, ebooks, mobile/tablet devices, social media channels, and videoconferences/webinars for further atmospheric science information.

Submissions should include full contact information, a presentation title, and brief abstract of less than 250 words. We will repeat last year's successful "Technology Tools and

Tips" session and invite anyone who is using a useful new technology or an old technology in new and interesting ways to participate in this "lightning round" session, consisting of back-to-back five-minute talks. We also invite proposals for panel discussions that will provide the opportunity for librarians of different institutions to share experiences or strategies in relation to a specific topic (i.e., eBooks or open access). Students are particularly encouraged to submit proposals.

Please submit proposals electronically to Jennifer Harbster, ASLI Chair-elect (tel: 202-707-4751; e-mail: jehar@loc.gov.) The deadline for receiving abstracts is *1 August 2012*. For additional information please reference the ASLI Conference website at www.aslionline.org/. (7/12)

CALL FOR PAPERS

Eighth Symposium on Policy and Socio-Economic Research, 6–10 January 2013, Austin, Texas

The AMS Symposium on Policy and Socio-Economic Research provides a forum for scholars to (i) share their policy and socio-economic research results and report on recent progress to other scholars in this field, (ii) converse with scientists about these results, and (iii) dialogue and engage with policy makers, practitioners, and federal agency officials in this area. This symposium therefore allows for better coordination, iteration, and direction of the field, as well as an assessment of the body of knowledge designed to inform existing decision-making processes.

The theme for the 2013 AMS Annual Meeting is "Taking Predictions to the Next Level: Expanding Beyond Today's Weather, Water, and Climate Forecasting and Projections." Over the past 60 years the meteorological community has made tremendous strides in making prediction a fundamental part of its scientific and operational/service heritage through the development and application of complex numerical models involving the atmosphere, ocean, land, and cryosphere components of the Earth System. This theme will serve as a catalyst for the 2013 AMS annual meeting by focusing the attention of the research and operational communities, including those who are involved in accelerating the transition of research results into operations. Furthermore, the increasing use of predictions by decision makers throughout federal, state, and local emergency management government agencies and by private/commercial sectors will serve as an important component for this annual meeting along with the extension of predictive capabilities into a broader domain, including public health, food security, air and water quality, alternative energy, and responses to climate trends.

Following this theme, the Eighth Symposium on Policy and Socio-Economic Research is soliciting papers within the following subthemes:

- Social Science for a Weather-Ready Nation: Empirical or theoretical developments in social and behavioral research related to the Weather-Ready Nation initiative, including people's understandings and behavior while under watches, warnings, and severe events.
- The Private Sector: Challenges, opportunities, and experiences related to international operations, and specifically disaster mitigation, response, and recovery.
- Place-Based Understanding of Weather and Climate: Local understandings of weather and climate phenomena, and associated responses to hazards, framings of risk, behavioral geography and environmental perception, and more.

STUDENT TRAVEL GRANTS

Student Travel Grants are available for senior undergraduate and graduate students to attend AMS meetings held in the United States and Canada. The travel grants are available only to members, including student members, of the AMS.

AMS recognizes the considerable benefit that students can gain from attending conferences even if they are not presenting a paper there, and AMS wants to encourage interactions between students and other conference attendees. To this end, travel grants will be awarded to a student who is not presenting a paper at the conference.

Students who are presenting papers and potentially in need of travel support should inquire of the program chair whether any funds will be available for this purpose.

For more information and to complete an application form, please visit the AMS website at www.ametsoc.org.

- Communicating Uncertainty: Explore and discuss the communication of forecast uncertainty and risk, including discussions of the role of and access to media in shaping perceptions, understanding, and responses to weather and climate phenomena of all scales; capabilities for various media to communicate about weather and climate; innovative methods for communicating uncertainty, including verbal, graphical, mapped, and multimedia depictions; and more.
- Economic Value of Improved Forecast Information: Explore the diverse array of forecast domains and the economics thereof, from short-range weather to long-range climate forecasts, and innovative decision-support services based on emerging forecast technologies.
- Human Factors in Forecasting: Discuss the forecasting process, and anticipated or documented learning styles, behaviors, warning decision-making, time pressures, opportunities, and challenges relating to emerging forecasting technologies.
- Policy and Socio-Economic Research Methods and their Applications: Highlight methodological techniques from the social sciences used to address societal problems.
- Emerging Policy and Socioeconomic Issues and Challenges: All new areas of research not covered in the other categories.

For additional information please contact the program chairpersons, Randy A. Peppler (tel: 405-325-6667; e-mail: rpeppler@ou.edu) and Kim Klockow (e-mail: kklockow@ou.edu).

Please submit your abstract electronically via the Web by *1 August 2012* (refer to the AMS Web page at www.ametsoc.org/meet/online_submit.html). An abstract fee of $95 (payable by credit card or purchase order) is charged at the time of submission (refundable only if abstract is not accepted), which covers the submission of abstract, posting of extended abstract, and uploading and recording of presentation that will be archived on the AMS Web site.

Authors of accepted presentations will be notified via e-mail by late-September 2012. All extended abstracts are to be submitted electronically and will be available online via the web. Instructions for formatting extended abstracts will be posted on the AMS website. Authors have the option to submit manuscripts (up to 10 MB) electronically by *6 February 2013*. All abstracts, extended abstracts, and presentations will be available on the AMS Web site at no cost. (2/12; r7/12)

NOMINATION SUBMISSIONS

The Council of the American Meteorological Society invites members of the AMS to submit nominations for the Society Awards, Lecturers, Named Symposia, Fellows, Honorary members, and nominees for elective Officers and Councilors of the Society.

Information regarding awards, including award descriptions, listings of previous recipients, and the process for submitting nominations are on the AMS website www.ametsoc.org/awards.

Note: Deadlines differ and some nominations must be submitted on a specific form vs. electronic submission which is available on the AMS website or by request from Headquarters.

2013 AWARDS COMMITTEES

Each committee or commission listed below has the responsibility to select and submit to the Council the names of individuals nominated for the Society's awards listed. The name(s) of individual(s) nominated, a two-page cv, a bibliography of no more than three pages, and three supporting letters should be electronically submitted before **1 May 2013** for the awards that follow, unless stated otherwise. The nominees for awards remain on the committee's active list for three years.

ATMOSPHERIC RESEARCH AWARDS COMMITTEE

The Carl-Gustaf Rossby Research Medal
The Jule G. Charney Award
The Verner E. Suomi Award*
The Remote Sensing Prize (biennial)
The Clarence Leroy Meisinger Award
The Henry G. Houghton Award

OCEANOGRAPHIC RESEARCH AWARDS COMMITTEE

The Sverdrup Gold Medal
The Henry Stommel Research Award
The Verner E. Suomi Award*
The Nicholas P. Fofonoff Award

AWARDS OVERSIGHT COMMITTEE

The Charles Franklin Brooks Award for Outstanding Services to the Society
The Cleveland Abbe Award for Distinguished Service to the Atmospheric Sciences by an Individual
The Joanne Simpson Mentorship Award
The Award for Outstanding Services to Meteorology by a Corporation
Special Awards

EDUCATION AND HUMAN RESOURCES COMMISSION

The Louis J. Battan Author's Award (Adult and K–12)
The Charles E. Anderson Award
The Teaching Excellence Award
Distinguished Science Journalism in the Atmospheric and Related Sciences

PROFESSIONAL AFFAIRS COMMISSION

Outstanding Contribution to the Advance of Applied Meteorology
Award for Broadcast Meteorology
Award for Excellence in Science Reporting by a Broadcast Meteorologist
The Henry T. Harrison Award for Outstanding Contributions by a Consulting Meteorologist

WEATHER AND CLIMATE ENTERPRISE COMMISSION

The Kenneth C. Spengler Award

LOCAL CHAPTER AFFAIRS COMMITTEE

Local Chapter of the Year Award
(nomination form available online at www.ametsoc.org/amschaps/index.html.)

* Recommended by the Atmospheric Research Awards Committee in even-numbered years and by the Oceanographic Research Awards Committee in odd-numbered years.

2013 AWARDS COMMITTEES

SCIENTIFIC AND TECHNOLOGICAL ACTIVITIES COMMISSION

The Charles L. Mitchell Award
The Award for Exceptional Specific Prediction
The Francis W. Reichelderfer Award
The Helmut E. Landsberg Award
The Award for Outstanding Achievement in Biometeorology

- **LECTURERS** *(Deadline: 1 October 2012)*
  Robert E. Horton Lecturer in Hydrology
  Bernhard Haurwitz Memorial Lecturer
  Walter Orr Roberts Lecturer

- **STUDENT PAPERS**
  Robert Leviton
  Banner I. Miller
  Max A. Eaton Prize
  Spiros G. Geotis Prize
  Peter V. Hobbs Student Prize

- **NAMED SYMPOSIA**
  Section E, of the Policy, Guidelines, and Procedures for Awards and Lectureships provides the Policy on Named Conferences/Symposia and Special Issues of AMS Journals *(full policy description available at www.ametsoc.org/awards):*

> Recognition of scientists in the fields served by the AMS, living or deceased, in the form of a named conference or symposium or a named special issue of one of the Society's journals is an honor reserved for only the most outstanding of our colleagues. It should be awarded only to those individuals who are completing a career, or who have recently died having completed a career, of significant achievements in their field and whose contributions would make them worthy of consideration for Honorary Member of the AMS…

2013 FELLOWS COMMITTEE

The Committee's function is to submit to the Council the names of individuals for election to Fellow.

> Article III, Section 6, of the AMS Constitution provides that those eligible for election to Fellow shall have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years. The nominees for Fellow must be a member of the Society and remain on the committee's active list for three years.

A nomination letter and three supporting letters should be electronically submitted before 1 May 2013. A list of Fellows and the process for submitting nominations are on the AMS website (www.ametsoc.org/awards).

2013 NOMINATING COMMITTEE

The Committee's function is to submit to the Council the names of individuals for 1) the office of President-Elect for a term of one-year starting at the close of the 94th Annual Meeting (January 2014) and 2) four positions on the Council for a term of three-years starting at the close of the Annual Meeting. Nominations must be submitted prior to 1 April 2013 to the Nominating Committee.

HONORARY MEMBERS

Article III, Section 5, of the AMS Constitution provides that Honorary Members shall be persons of acknowledged preeminence in the atmospheric or related oceanic or hydrologic sciences, either through their own contributions to the sciences or their application or through furtherance of the advance of those sciences in some other way. They shall be exempt from all dues and assessments. The nominees for Honorary member remain on an active list for three years.

Deadline: 1 June 2013; a form and list of Honorary Members is available at www.ametsoc.org/awards.

CORPORATION AND INSTITUTIONAL MEMBERS

Membership in the American Meteorological Society does not imply AMS endorsement of an organization's products or services.

SUSTAINING MEMBERS

Ball Aerospace & Technologies Corporation
Harris Corporation
ITT Exelis
Lockheed Martin Corporation
Northrop Grumman Corporation
The Boeing Company
University Corporation for Atmospheric Research
Vaisala, Inc.

REGULAR MEMBERS

3TIER Environmental Forecast Group, Inc.
AccuWeather, Inc.
ADNET Systems, Inc.
Aerospace & Marine International Corporation
AirDat LLC
All Weather, Inc.
Atmospheric and Environmental Research, Inc.
Atmospheric Technology Services Company, LLC
AWS Truepower, LLC
Baron Services, Inc.
Belfort Instrument Company
Botswana Meteorological Services
Bristol Industrial & Research Associates Ltd (BIRAL)
Campbell Scientific, Inc.
Climatronics Corporation
CLS America, Inc.
Coastal Environmental Systems
Computer Sciences Corporation
CSIRO Marine and Atmospheric Research
Davis Instruments Corporation
DeTect, Inc.
Earth Networks
EKO Instruments Company, Ltd.
Enterprise Electronics Corporation
Environmental Systems Research, Inc.
EWR Weather Radar Systems
Florida State University, Department of EOAS
Geophysical Institute/International Arctic Research Center
Global Hydrology and Climate Center
I. M. Systems Group
Jenoptik I Defense & Civil Systems
Johns Hopkins University, Applied Physics Laboratory
Kipp & Zonen USA Inc.
Met One Instruments, Inc.
Meteorological Technology International
MeteoStar
MeteoSwiss
Murray & Trettel, Inc.
National Centre for Medium Range Weather Forecasting
Naval Meteorology and Oceanography Command
Noblis, Inc.
Orbital Sciences Corporation
Pelmorex Media Inc.
R. M. Young Company
Radiometrics Corporation
Raytheon Company
Riverside Technology, inc.
Royal Netherlands Meteorological Institute
Scintec AG
SeaSpace Corporation
SGT, Inc.
SigmaSpace Corporation
Sonalysts, Inc.
SpectraSensors, Inc.
Sutron Corporation
Telvent DTN
The Climate Corporation
The Weather Channel
U.S Department of Energy, Office of Science
Unisys Corporation
University of Alabama in Huntsville,Earth System Science Ctr
University of Wisconsin - Madison, SSEC
Weather Central, LP
Weather Decision Technologies
WeatherFlow, Inc.
Weather Modification, Inc.
Weather Services International, Inc.
WindLogics, Inc.
Wyle

SMALL BUSINESS MEMBERS

Atmospheric Systems Corporation
Climadata Corporation
Geonor, Inc.
National Council of Industrial Meteorologists
National Weather Service Employees Organization
Remtech, Inc.
Sky Power International, LLC
The Beautiful Weather Corporation
www.WeatherVideoHD.TV
Yankee Environment Systems, Inc.

For questions relating to corporation and institutional membership, please contact Gary Rasmussen at AMS Headquarters—telephone: 617-227-2426, x3981; fax: 617-742-8718; e-mail: grasmussen@ametsoc.org; or write to American Meteorological Society, Attn: Dr. R. Gary Rasmussen, 45 Beacon St., Boston, MA 02108-3693.

CORPORATION AND INSTITUTIONAL MEMBERS

PUBLICATIONS MEMBERS

Abdus Salam International Centre for Theoretical Physics
Air Force Weather Agency
ARPA FVG, Osservatorio Meteorologico Regionale
Bureau of Meteorology
Civil Aeronautics Administration, MOTC
Colorado State University Libraries
Columbia University, Lahmont-Doherty Geological Observatory
Creighton University Reinert/Alumni Memorial Library
Dartmouth College Baker Library
Desert Research Institute
Deutscher Wetterdienst
Embry Riddle Aeronautical University
Environment Canada Library, Downsview
EUMETSAT Library
Finnish Meteorological Institute
Florida International University Library
Harvard University, Gordon McKay and Blue Hill Libraries
Hong Kong Observatory Library
Illinois State Water Survey
Indian Institute of Tropical Meteorology
Indiana University Library
Institute of Global Environment and Society Library
Irish Meteorological Service
Japan Weather Association
Los Alamos National Laboratory
Lyndon State College, Samuel Read Hall Library
Maryland Department of the Environment
MBL/WHOI Library
Meteo-France
Meteorological Service of New Zealand Ltd.
Meteorologisk institutt
Millersville University, Department of Earth Sciences
MIT, Lincoln Laboratory
National Weather Center Library
Naval Postgraduate School, Dudley Knox Library
New York University
Niedersachsische Staats
NIWA Wellington Library
NOAA AOML Library
NOAA Central Library
NOAA – GLERL Library
NOAA National Climatic Data Center
NOAA Seattle Library
North Carolina State University Libraries
Pennsylvania State University, Paterno Library
Purdue University Libraries
Republic of Korea Air Force, Headquarters
South African Weather Service
St. Louis University, Dept. of Earth & Atmospheric Sciences
Swedish Meteorological & Hydrological Institute
U.K. National Meteorological Library
U.S Air Force, 335 TRS/UOAA
U.S. Army Corps of Engineers, Library - ERDC
U.S. Department of Commerce, Boulder Labs Library
U.S. EPA Main Library
U.S. Naval Maritime Forecast Center
Universitatsbibliothek Innsbruck
Universitatsbibliothek Trier
Universite de Versailles
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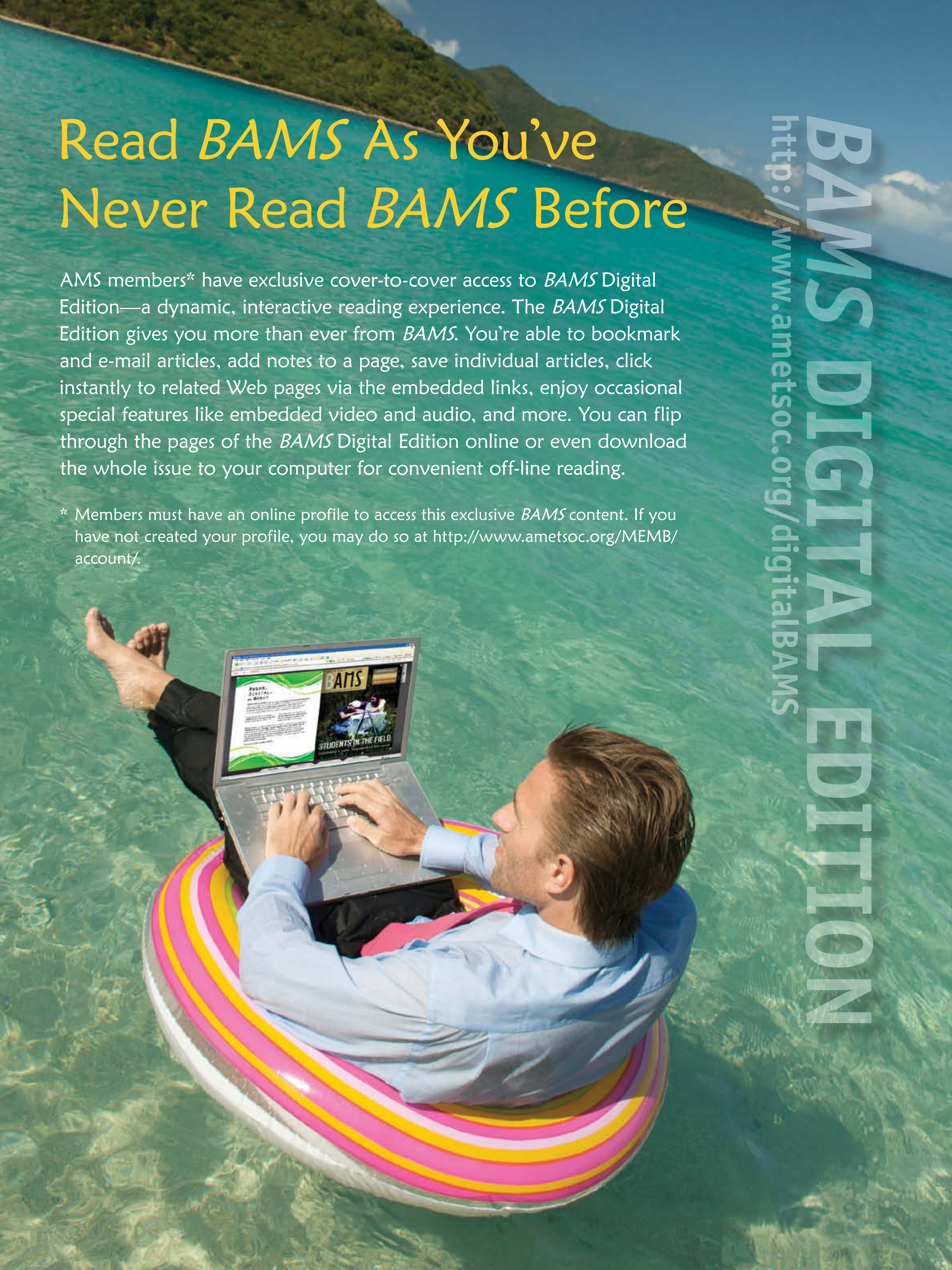
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