STATE OF THE CLIMATE IN 2011

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STATE OF THE CLIMATE IN 2011

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1. INTRODUCTION—D. S. Arndt and J. Blunden

This is the 22nd annual edition of the *State of the Climate* series, from its origin as NOAA's *Climate Assessment*, and the 17th consecutive year of its association with the *Bulletin of the American Meteorological Society*. As always, its primary goals are to document the weather and climate events of the year and place them into accurate historical perspective, and to provide information on the state, trends, and variability of the climate system's many variables and phenomena.

The vast influence of La Niña across much of the climate system was pervasive during 2011, and is understandably pervasive in this document. La Niña's influence is shared among climate's many disciplines and across its many regions, but in different ways, and with different sensitivities. As such, multiple definitions have evolved to characterize it. In this report, La Niña is described in some sections as a protracted episode beginning in late 2010 and lasting through 2011, and in some as a "double dip" episode, separated by a brief ENSO-neutral period during mid-2011. We have chosen not to enforce a standard description across the document, opting to preserve the authors' perspective on a section-by-section basis.

This series has been consciously conservative with statements of attribution regarding drivers of events on the scale of climate variability and change. Only widely-understood and established attribution relationships, such as those for ENSO's influence, are employed here. However, recognizing emerging demand and utility for event-focused attribution, the *Bulletin* has decided to publish an annual collection of such analyses, coincident with this series, the first of which was produced this year (Peterson et al. 2012). This allows this series to continue its focus as a chief scorekeeper of the climate's evolving state.

In recent years, this series has pursued a broader representation of the climate system by adding essential climate variables (ECVs, as defined in GCOS 2003). This year's edition adds albedo to the ECVs addressed in this series. It is fitting that this new section draws upon satellite-borne observations for its analysis. As satellite-based data records continue to evolve and mature, they have become more integrated into the climate monitoring community's various portfolios, and indeed through the sections of this document. This chapter's Sidebar (1.1) takes a broad view of the advantages, challenges, and opportunities of constructing climate data records from multiple satellite sensors. In the Global Climate chapter, another Sidebar (2.2) focuses on how satellite information is used to examine a single ECV, soil moisture. Ocean acidity, a recently-recognized GCOS ECV, is an important climate indicator and is now the focus of both a new section in the Arctic chapter and a new subsection in the Global Oceans chapter.

The following ECVs, included in this edition, are considered "fully monitored", such that they are observed and analyzed across much of the world, with a sufficiently long-term dataset that has peer-reviewed documentation:

- Atmospheric Surface: air temperature, precipitation, air pressure, water vapor.
- Atmospheric Upper Air: earth radiation budget, temperature, water vapor, cloud properties.
- Atmospheric Composition: carbon dioxide, methane, ozone, nitrous oxide, chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, sulfur hexafluorides, perflurocarbons, aerosols.
- Ocean Surface: temperature, salinity, sea level, sea ice, current, ocean color.
- Ocean Subsurface: temperature, salinity.
- Terrestrial: snow and ice cover, albedo.

ECVs in this edition that are considered "partially monitored", meeting some but not all of the above requirements, include:

- Atmospheric Surface: wind speed and direction.
- Atmospheric Composition: long-lived greenhouse gases not listed as fully monitored above.
- Ocean Surface: carbon dioxide.
- Ocean Subsurface: current, carbon.
- Terrestrial: soil moisture, permafrost, glaciers and ice sheets, river discharge, groundwater, lake levels, fraction of absorbed photosynthetically-active radiation, biomass, fire disturbance.

ECVs that are expected to be added in the future include:

- Atmospheric Surface: surface radiation budget.
- Atmospheric Upper Air: wind speed and direction.
- Ocean Surface: sea state.
- Ocean Subsurface: nutrients, ocean tracers, phytoplankton.
- Terrestrial: surface ground temperature, subsurface temperature and moisture, water use, land cover, leaf area index.

An overview of this report's findings is presented in the Abstract and Fig. 1.1. Chapter 2 features global-scale climate variables; Chapter 3 highlights the global oceans; and Chapter 4 includes tropical climate phenomena including tropical cyclones. The Arctic and Antarctic respond differently through time and are reported in separate chapters (5 and 6, respectively). Notably, the Arctic chapter has been freshened and broadly reorganized by its editors. Chapter 7 provides a regional perspective authored largely by local government climate specialists. Sidebars included in each chapter are intended to provide background information on a significant climate event from 2011, a developing technology, or an emerging dataset germane to the chapter's content. Chapter 8 has been renamed Appendix 1. Additionally, a list of relevant datasets and their sources for all chapters is now provided in Appendix 2.

Finally, we have often commented that the *State of the Climate* series not only offers annual snapshots of the climate's state, but also of our capacity to monitor it. However, this year's edition served as a sober reminder that the series also reflects our ability to compile and collaborate. Human events and economies contributed to the loss of data or authorship from several nations, including Egypt, Iraq, and parts of the South Pacific. We wish our colleagues in these places our best and look forward to working with them in a future with fewer obstacles to their participation.

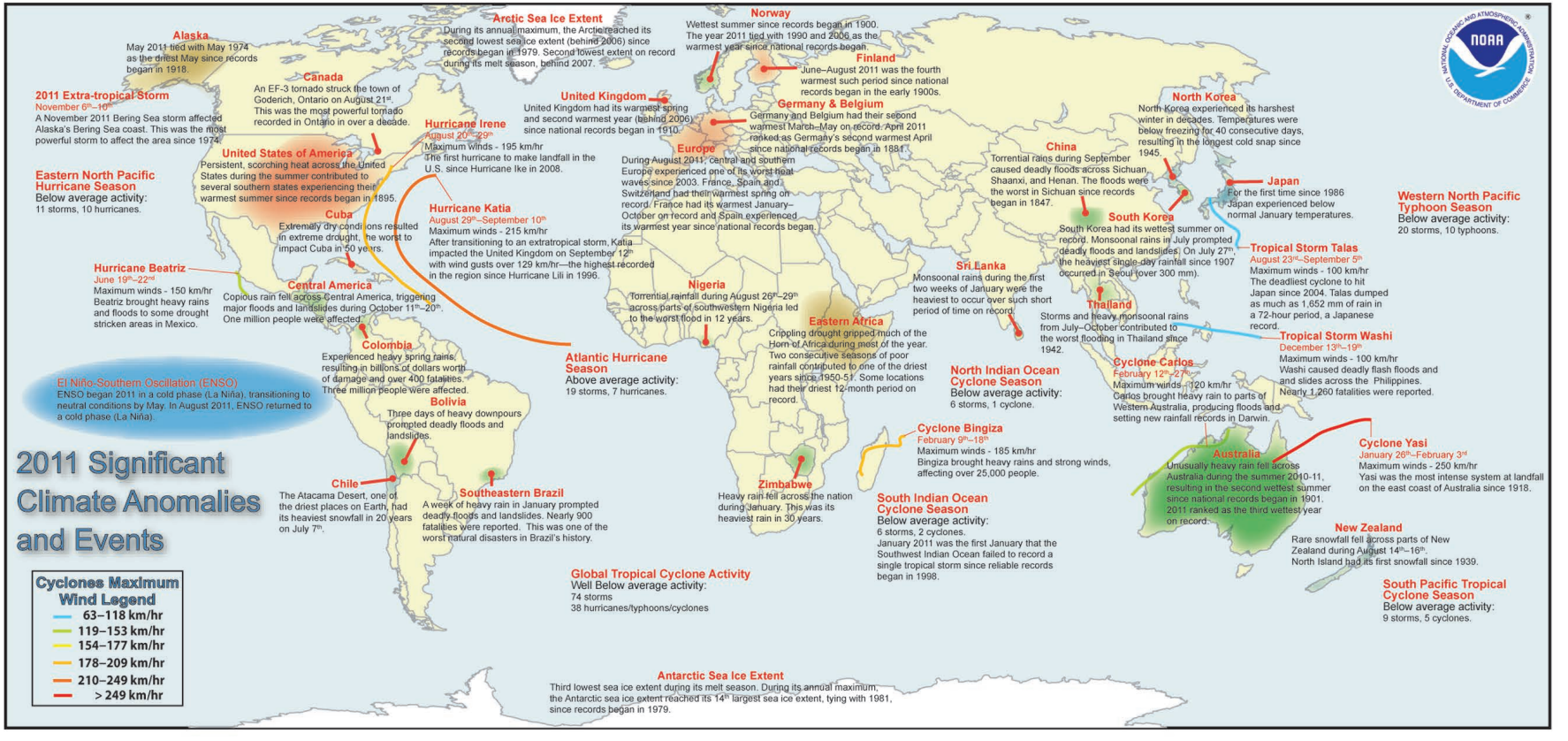

Fig. 1.1. Geographical distribution of notable climate anomalies and events occurring around the world in 2011.

SIDEBAR 1.1: SATELLITE CLIMATE DATA RECORDS COME OF AGE—J. L. PRIVETTE AND J. J. BATES

Climate assessments in prior *BAMS State of the Climate* supplements have primarily drawn on the many in situ measurements available for the land, oceans, atmosphere, and ice sheets. These records tend to be long term—some spanning more than a century—and mature, in that their characteristics are well understood. Nevertheless, they are often limited in their spatial extent for multiple reasons. Thus, while some parts of Earth are densely measured by in situ techniques, other parts remain unmeasured.

In the late 1970s, NOAA and the Department of Defense (DoD) initiated routine observations of Earth's environment through operational satellite programs. The early satellite sensors and algorithms were designed primarily for weather applications and were basic by today's standards. However, a continuing stream of technological and scientific advancements has so increased the diversity and quality of satellite products (in many cases retroactively) that these records are now the desired input to many large-scale analyses. Perhaps more importantly, the periods of record for many satellite observations have achieved climate-relevant lengths in recent years (e.g., see Sidebar 2.2). It is fair to say that satellite climatology has come of age.

The National Research Council (NRC 2004) defines a climate data record (CDR) as a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. Satellite CDRs offer unique information that can complement or supplement traditional in situ records. Indeed, the two observation types are necessary companions in that satellite products are usually calibrated, validated, or corroborated with in situ measurements, and in situ data are often put in spatial context using satellite observations.

The development of climate-quality satellite records has been neither fast nor easy. The inhospitable environment of space, the complexity of satellite sensors, and the inability to repair hardware in orbit means that sensor performance tends to deteriorate continuously with time. Thus, new satellites—sometimes with improved designs—are regularly launched to carry on the work of ailing instruments. The cumulative result is long-term records composed of multiple sensor-specific segments of data, each with unique idiosyncrasies. To create a valid CDR, experts must scientifically correct, normalize, and stitch together these segments (Fig. SB1.1).

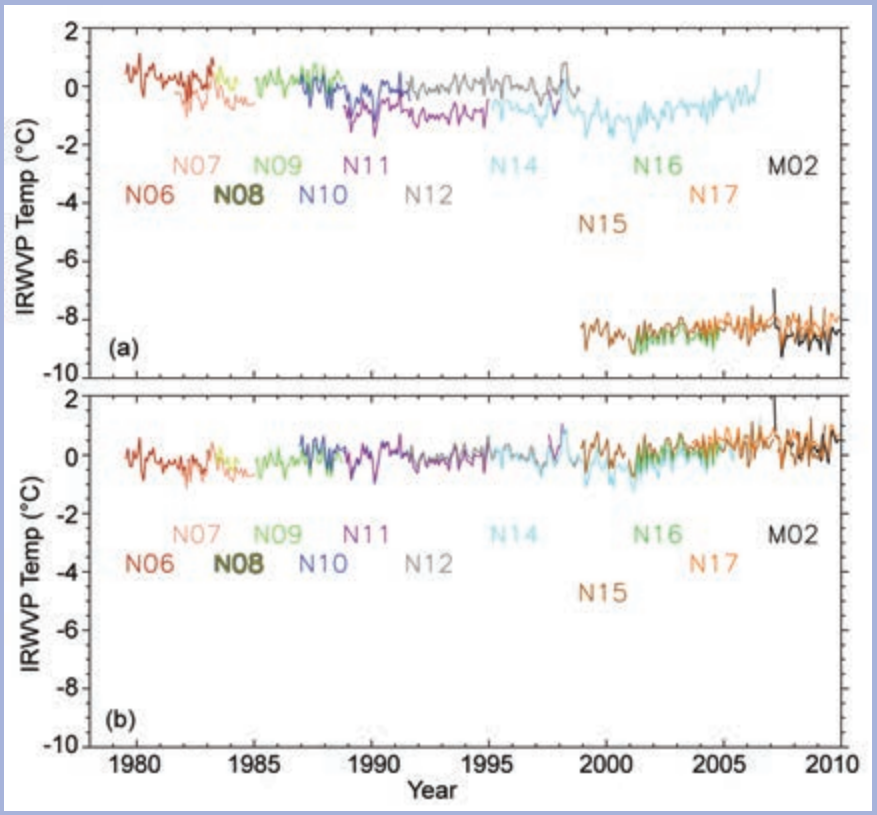

Fig. SB1.1. Raw data from the High Resolution Infrared Radiation Sounder (HIRS) instruments, carried onboard successive NOAA's Polar-Orbiting Environmental Satellites, is initially inconsistent due to the unique and changing character of the different flight instruments. The top pane (a) shows the monthly-averaged temperature over the tropics for HIRS channel 12, a channel sensitive to upper tropospheric water vapor. After cocalibration and normalization, the data can be merged into a coherent climate data record from which climate signals can be detected (b). Figures courtesy of Lei Shi, NOAA's National Climatic Data Center.

More than two decades of community research has produced a wide set of proven techniques for these tasks. Starting in the early 1990s, NOAA and NASA cosponsored the Pathfinder Program to develop precursor CDRs and to advance satellite data management methods (NOAA 2004). This marked the first time that the incongruent data segments from multiple NOAA and DoD operational satellites had been fully recovered, cataloged, cocalibrated, and processed into coherent long-term records. Subsequent funding solicitations further developed the methods.

In recent years, several US and foreign agencies have leveraged the Pathfinder lessons to produce modern CDRs. For example, NOAA initiated a Climate Data Record Program (CDRP) in 2009 to develop and sustain CDRs in an operational context (Privette et al. 2009). Here, "operational" is loosely defined as the generation of products on time, all the time, including decision-support systems, modeling, and climatology. Following guidance from the NRC (2004), the CDRP developed its CDR requirements, specifically that they be:

- scientifically defensible
- extensible
- continuously assessed and improved
- transparent
- reproducible
- sustainable
- preserved
- accessible

The CDRP is currently developing and implementing systems and processes based on these requirements.

NOAA is initially focused on CDRs that address Earth's water and energy cycles to facilitate integrative assessments. Nearly a dozen competitively-selected CDRs—including data sets, algorithms, and documentation—have been developed, are publicly available, and are being sustained operationally. Three of these are in the present *State of the Climate* supplement, namely sea ice extent, mean layer temperatures, and sea surface temperature. Additional CDRs are in various stages of development. The program is also developing climate information records (CIRs), i.e., CDR-derived products of particular phenomena or regions of interest to society or industry. Detailed information about NOAA's CDR program and related CDR products are available at: http://www.ncdc.noaa.gov/cdr.

As CDR development has matured and interest proliferated, several international organizations have become active in fostering CDR quality, interoperability, and agency coordination. For example, the Global Climate Observing System (GCOS 2011) recently issued guidelines for CDR producers. The Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM; WMO 2009) activity seeks to, among other things, ensure continuity and overlap in the reprocessing of climate-relevant data to support integrated climate analysis and reanalysis. The recently-formed Committee for Earth Observing System (CEOS 2012) Working Group on Climate seeks to facilitate the implementation and exploitation of essential climate variable time series through coordination of CEOS member agencies.

After decades of progress in satellite technology and remote sensing science, NOAA and others have instituted programs that reprocess the more than three decades of global satellite data into consistent and accurate time series records that provide new insights into climate change and variability. These records, in concert with traditional in situ measurements, are leading to more precise and comprehensive climate assessments, including those in the *State of the Climate* supplements. By sustaining these records operationally, producers will also be able to support increasingly sophisticated decision-support systems throughout society.

Libraries: Please file with the *Bulletin of the American Meteorological Society*, Vol. 93, Issue 7