STATE of the CLIMATE in 2009

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The year was characterized by a transition from a waning La Niña to a strengthening El Niño, which first developed in June. By December, SSTs were more than 2.0°C above average over large parts of the central and eastern equatorial Pacific. Eastward surface current anomalies, associated with the El Niño, were strong across the equatorial Pacific, reaching values similar to the 2002 El Niño during November and December 2009. The transition from La Niña to El Niño strongly influenced anomalies in many climate conditions, ranging from reduced Atlantic basin hurricane activity to large scale surface and tropospheric warmth.

Global average surface and lower-troposphere temperatures during the last three decades have been progressively warmer than all earlier decades, and the 2000s (2000–09) was the warmest decade in the instrumental record. This warming has been particularly apparent in the mid- and high-latitude regions of the Northern Hemisphere and includes decadal records in New Zealand, Australia, Canada, Europe, and the Arctic. The stratosphere continued a long cooling trend, except in the Arctic.

Atmospheric greenhouse gas concentrations continued to rise, with CO_2 increasing at a rate above the 1978 to 2008 average. The global ocean CO_2 uptake flux for 2008, the most recent year for which analyzed data are available, is estimated to have been 1.23 Pg C yr^{-1}, which is 0.25 Pg C yr^{-1} smaller than the long-term average and the lowest estimated ocean uptake in the last 27 years. At the same time, the total global ocean inventory of anthropogenic carbon stored in the ocean interior as of 2008 suggests an uptake and storage of anthropogenic CO_2 at rates of 2.0 and 2.3 ±0.6 Pg C yr^{-1} for the decades of the 1990s and 2000s, respectively. Total-column ozone concentrations are still well below pre-1980 levels but have seen a recent reduction in the rate of decline while upper-stratospheric ozone showed continued signs of ongoing slow recovery in 2009. Ozone-depleting gas concentrations continued to decline although some halogens such as hydrochlorofluorocarbons are increasing globally. The 2009 Antarctic ozone hole was comparable in size to recent previous ozone holes, while still much larger than those observed before 1990. Due to large interannual variability, it is unclear yet whether the ozone hole has begun a slow recovery process.

Global integrals of upper-ocean heat content for the last several years have reached values consistently higher than for all prior times in the record, demonstrating the dominant role of the oceans in the planet's energy budget. Aside from the El Niño development in the tropical Pacific and warming in the tropical Indian Ocean, the Pacific Decadal Oscillation (PDO) transitioned to a positive phase during the fall/winter 2009. Ocean heat fluxes contributed to SST anomalies in some regions (e.g., in the North Atlantic and tropical Indian Oceans) while dampening existing SST anomalies in other regions (e.g., the tropical and extratropical Pacific). The downward trend in global chlorophyll observed since 1999 continued through 2009, with current chlorophyll stocks in the central stratified oceans now approaching record lows since 1997.

Extreme warmth was experienced across large areas of South America, southern Asia, Australia, and New Zealand. Australia had its second warmest year on record. India experienced its warmest year on record; Alaska had its second warmest July on record, behind 2004; and New Zealand had its warmest August since records began 155 years ago. Severe cold snaps were reported in the UK, China, and the Russian Federation. Drought affected large parts of southern North America, the Caribbean, South America, and Asia. China suffered its worst drought in five decades. India had a record dry June associated with the reduced monsoon. Heavy rainfall and floods impacted Canada, the United States, the Amazonia and southern South America, many countries along the east and west coasts of Africa, and the UK. The U.S. experienced its wettest October in 115 years and Turkey received its heaviest rainfall over a 48-hr period in 80 years.

Sea level variations during 2009 were strongly affected by the transition from La Niña to El Niño conditions, especially in the tropical Indo-Pacific. Globally, variations about the long-term trend also appear to have been influenced by ENSO, with a slight reduction in global mean sea level during the 2007/08 La Niña event and a return to the long-term trend, and perhaps slightly higher values, during the latter part of 2009 and the current El Niño event. Unusually low Florida Current transports were observed in May and June and were linked to high sea level and coastal flooding along the east coast of the United States in the summer. Sea level significantly decreased along the Siberian coast through a combination of wind, ocean circulation, and steric effects. Cloud and moisture increased in the tropical Pacific. The surface of the western equatorial Pacific freshened considerably from 2008 to 2009, at least partially owing to anomalous eastward advection of fresh surface water along the equator during this latest El Niño. Outside the more variable tropics, the surface salinity anomalies associated with evaporation and

precipitation areas persisted, consistent with an enhanced hydrological cycle.

Global tropical cyclone (TC) activity was the lowest since 2005, with six of the seven main hurricane basins (the exception is the Eastern North Pacific) experiencing near-normal or somewhat below-normal TC activity. Despite the relatively mild year for overall hurricane activity, several storms were particularly noteworthy: Typhoon Morakot was the deadliest typhoon on record to hit Taiwan; Cyclone Hamish was the most intense cyclone off Queensland since 1918; and the state of Hawaii experienced its first TC since 1992.

The summer minimum ice extent in the Arctic was the third-lowest recorded since 1979. The 2008/09 boreal snow cover season marked a continuation of relatively shorter snow seasons, due primarily to an early disappearance of snow cover in spring. Preliminary data indicate a high probability that 2009 will be the 19th consecutive year that glaciers have lost mass. Below normal precipitation led the 34 widest marine terminating glaciers in Greenland to lose 101 km^2 ice area in 2009, within an annual loss rate of 106 km^2 over the past decade. Observations show a general increase in permafrost temperatures during the last several decades in Alaska, northwest Canada, Siberia, and Northern Europe. Changes in the timing of tundra green-up and senescence are also occurring, with earlier green-up in the High Arctic and a shift to a longer green season in fall in the Low Arctic.

The Antarctic Peninsula continues to warm at a rate five times larger than the global mean warming. Associated with the regional warming, there was significant ice loss along the Antarctic Peninsula in the last decade. Antarctic sea ice extent was near normal to modestly above normal for the majority of 2009, with marked regional contrasts within the record. The 2008/09 Antarctic-wide austral summer snowmelt was the lowest in the 30-year history.

This 20th annual *State of the Climate* report highlights the climate conditions that characterized 2009, including notable extreme events. In total, 37 Essential Climate Variables are reported to more completely characterize the *State of the Climate* in 2009.

I. INTRODUCTION—M. O. Baringer and D. S. Arndt

The primary goal of the annual *State of the Climate* collection of articles is to document the weather and climate events in 2009 from around the world and put them into accurate historical perspective, with a particular focus on unusual or anomalous events. The year also marks the end of the first decade of the 21st century, so whenever possible the climate anomalies over this decade are highlighted.

This year the *State of the Climate* report brings together more than 300 authors from every continent and from over 160 different research groups to collaborate, share data and insights, and describe the observed changes in climate from different perspectives. The 2009 El Niño and the global consequences described herein highlight the global scope of connections between weather, climate, and, one could argue, climate scientists. In keeping with the increasingly global perspective of this report, the authors and editors seek to provide an inclusive synthesis of diverse weather and climate data to describe what took place across our planet last year. For example, recognizing the importance of providing error statistics, differing analysis products and datasets are included where possible (e.g., see sidebar on ocean heat content analyses in Chapter 3). We expect this trend to continue in future reports. Notably, the document's editors represented three disciplinary backgrounds (meteorology, oceanography, and biology). This composition reflects the increasing recognition that the natural world is embedded within, impacted by, and exerts influence on the physical climate system. We expect these connections to be explored in future issues of *State of the Climate*.

As a guiding principle behind the inclusion of certain climatic events into this report, the Global Climate Observing System has identified Essential Climate Variables (ECVs, see GCOS 2003) (see appendix for a full list of abbreviations) necessary to support the United Nations Framework Convention on Climate Change and the Intergovernmental Panel on Climate Change. These variables are defined as those required for international exchange and should be economically and technically feasible to acquire (Table 1.1). The *State of the Climate* report has evolved to include an increasing number of these climatically important variables as data availability increases and the analysis techniques and attributions improve. The degree to which each of these ECVs can be assessed and reported depends largely on the level of data availability both currently and as a homogeneous historical record and, hence, can be divided into categories: (1) being monitored, (2) partially monitored, and (3) not yet monitored. To be listed as monitored, the ECV not only must be observed across much of the world, but also needs a moderately long-term dataset with accompanying analysis. Also the dataset needs to be updated in near-real time and have a peer-reviewed article documenting the reliability of all of these steps. This year land cover/use is not reported because the data are only updated every five years and last year's report covers the most recent data available. Lake levels, biomass, and fire disturbance ECVs were included—at least partially-monitored—for the first time this year (see Chapter 2). Other variables important for research purposes are not included as ECVs, however the GCOS list of ECVs as well as the variables presented in this report are continually reassessed as improved observing technologies emerge. Continual advancement of the number of ECVs reported herein will not be possible without increasing international efforts to make the observations of the underlying variables and provide access to these data.

A brief overview of the findings in this report is presented in the Abstract and shown in Fig. 1.1. The remainder of the report is organized starting with global scale climate variables in Chapter 2, into increasingly divided geographic regions described in chapters 3 through 7. Chapter 3 highlights the global ocean and Chapter 4 includes tropical climate phenomena such as El Niño and hurricanes. The Arctic and Antarctic respond differently through time and hence are reported in separate chapters. For a regional perspective authored largely by local government climate specialists, see Chapter 7. Seasonal patterns are encapsulated in Chapter 8.

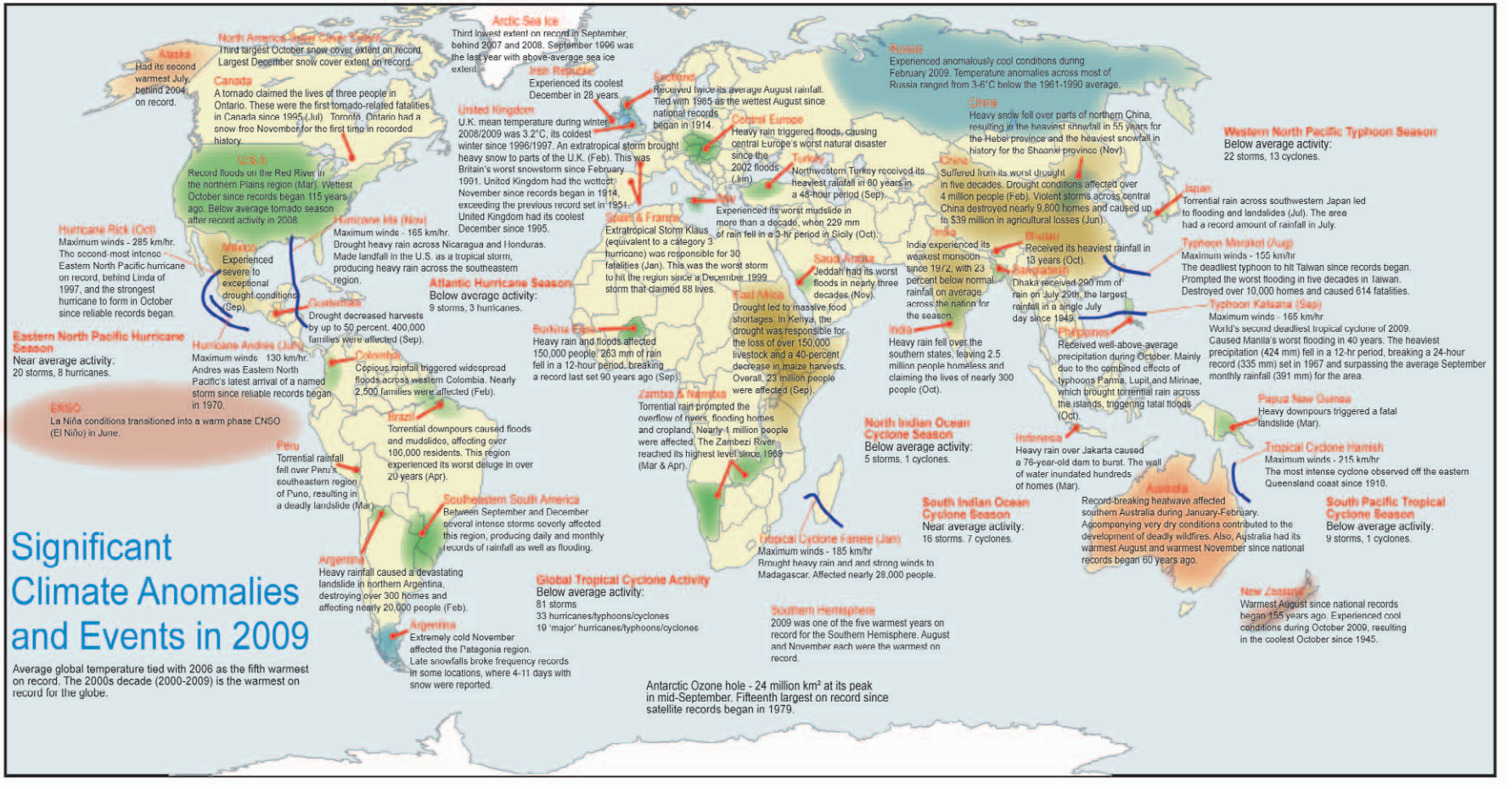

Fig. 1.1. Geographical distribution of notable climate anomalies and events occurring around the planet in 2009.

Table 1.1 The GCOS Essential Climate Variables (ECVs, see GCOS 2003) and their monitoring status, as reported in this and recent editions of the *State of the Climate*, are listed with the following color coding: Green indicates this ECV is being monitored on a global or near-global scale and that this report includes a section describing its changes over time; Yellow indicates the ECV is explicitly discussed in this year's *State of the Climate*, but the data are not updated globally through the year or a dataset has not yet been adequately documented in the peer-reviewed literature to prove it is an accurate indication of how this ECV has changed over time; Red indicates more work needs to be done in order to monitor this ECV. The missing ECVs in 2007 reflect the evolution and expansion of the GCOS list.

Essential Climate Variable	2007	2008	2009
Atmospheric Surface			
Air temperature	Y	Y	Y
Precipitation	Y	Y	Y
Air pressure	N	Y	Y
Surface radiation budget	N	N	N
Wind speed and direction	P	P	P
Water vapor	N	N	N
Atmospheric Upper-Air			
Earth radiation budget (including solar irradiance)	P	Y	Y
Upper-air temperature (including MSU radiances)	Y	Y	Y
Wind speed and direction	N	N	N
Water vapor	N	Y	Y
Cloud properties	P	Y	Y
Atmospheric Composition			
Carbon dioxide	Y	Y	Y
Methane	Y	Y	Y
Ozone	Y	Y	Y
[Other long-lived greenhouse gases]:	N	N	P
Nitrous oxide	Y	Y	Y
Chlorofluorocarbons	Y	Y	Y
Hydrochlorofluorocarbons	Y	Y	Y
Hydrofluorocarbons	Y	Y	Y
Sulphur hexaflurorides	Y	Y	Y
Perfluorocarbons	N	N	N
Aerosol properties.	Y	Y	Y
Ocean Surface			
Sea surface temperature	Y	Y	Y
Sea surface salinity	Y	Y	Y
Sea level	Y	Y	Y
Sea state	N	N	N
Sea ice	Y	Y	Y
Current	Y	Y	Y
Ocean color (for biological activity)	Y	Y	Y
Carbon dioxide partial pressure	P	P	P

Essential Climate Variable	2007	2008	2009
Ocean Subsurface			
Temperature	Y	Y	Y
Salinity	N	N	N
Current	P	P	P
Nutrients	N	N	N
Carbon	Y	P	P
Ocean tracers	N	N	N
Phytoplankton	N	N	N
Terrestrial			
Soil moisture and wetness	P	P	P
Surface ground temperature	N	N	N
Subsurface temperature and moisture	N	N	N
Snow and ice cover	Y	Y	Y
Permafrost	P	P	P
Glaciers and ice sheets	Y	P	P
River discharge		P	P
Water use		N	N
Ground water		N	N
Lake levels		N	Y
Albedo		N	N
Land cover (including vegetation type)[1]		P	N[1]
Fraction of absorbed photosynthetically active radiation (FAPAR)		Y	Y
Leaf area index (LAI)		N	N
Biomass		N	P
Fire disturbance		N	P

[1] The land cover data set used in the *State of the Climate* in 2008 (Di Gregorio and Jansen 2000) is updated once per five years.