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The "Maya Express": Floods in the U.S. Midwest

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The 2008 floods in the U.S. Midwest culminated in severe river flooding, with many rivers in the region cresting at record levels during May and particularly June. Twenty-four people were killed and more than 140 were injured as a result of the floods. Nine states were affected: Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, South Dakota, and Wisconsin. In Iowa, 83 of the state's 99 counties were declared disaster areas. Cedar Rapids, Iowa, was among the cities hardest hit by flooding. At one point, water covered 1300 city blocks across 24 square kilometers, inundating 3900 homes and most of the city's infrastructure and municipal facilities. The flood, which also damaged the Midwest's corn and soybean crops, was presaged by unusually heavy snowpack the preceding winter and by anomalously heavy rainfall during the spring.

It is natural to compare the events of June 2008 with the memorable Midwest floods of 1993. The U.S. Geological Survey characterized both of these incidents as "500-year floods." Using near–real time observational data sets, the characteristics of the 2008 flood have been investigated from the perspective of the atmospheric branch of the water cycle, and the flood has been compared with that of 1993 and more generally with the history of heavy precipitation and climate in the region over the past 30 years.

The floods over the central United States during June and July 1993 have been thoroughly studied. Observational studies have characterized the patterns and timing of the heavy rains that led to the floods, as well as the large-scale circulation of the atmosphere at that time. Many numerical studies using weather and climate models have attributed the flood to patterns of sea surface temperature in the tropics, quasi-stationary large-scale circulation anomalies in the atmosphere, or soil moisture conditions across sections of North America.

Back-trajectory calculations that attribute the moisture that falls as rain to specific locations where evaporation supplied that moisture have shown that a tropical source of moisture fed the 1993 floods [*Dirmeyer and Brubaker*, 1999]. Specifically, advected moisture (from an upstream area, or "fetch") was identified as coming from the western Gulf of Mexico and the western Caribbean Sea, well outside the usual sources of moisture for rainfall over the region. Did the floods of 2008 share these characteristics? Are there attributes that are common to the most severe Midwest floods?

Floods in 1993 Compared to 2008

Figures 1a and 1b show precipitation anomalies for June and July 1993 and for May and June 2008, respectively, using data from the Global Precipitation Climatology Project of the World Climate Research Programme. Both flood events were characterized by wet conditions in the months prior to

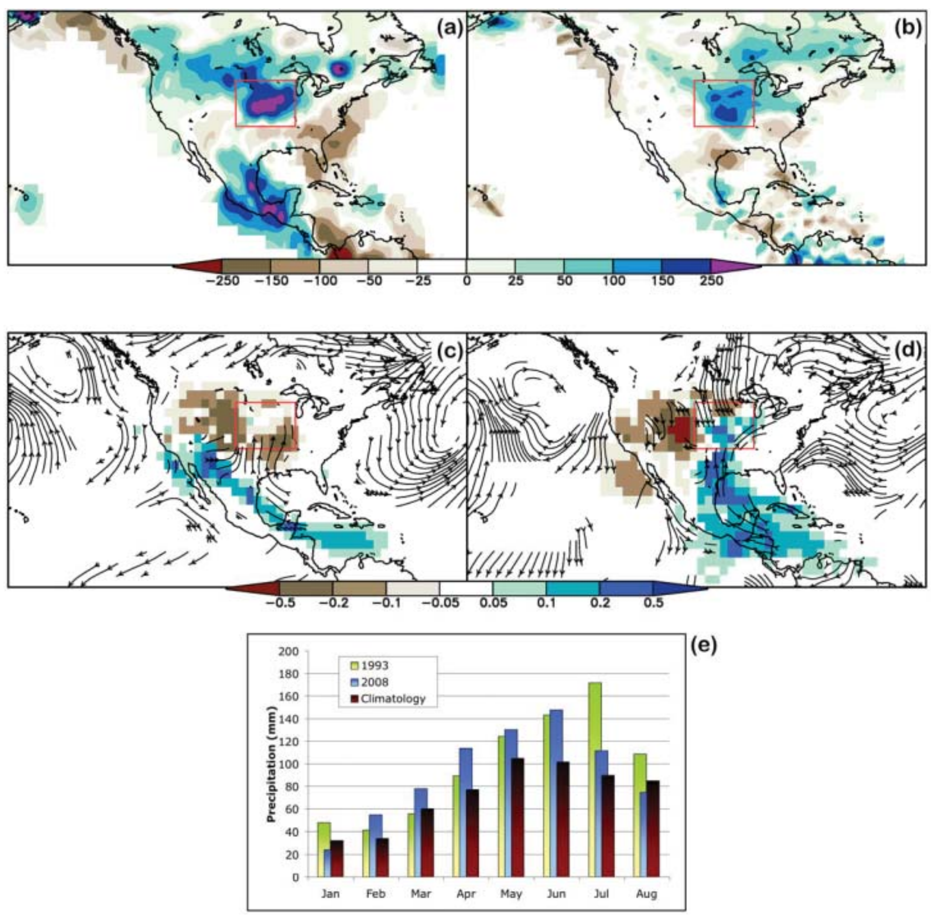

Fig. 1. Rainfall anomalies (in millimeters) for (a) June and July 1993 and (b) May and June 2008. Wind anomalies averaged over the lowest 30 hectopascals (shown only where anomalies exceed 1 meter per second) and anomalies of evaporative source supplying moisture to rainfall over the area in the red box (expressed as a percentage of total source) for (c) 1993 and (d) 2008. (e) Time series of monthly precipitation over the area in the red box for 1993 and 2008, compared with climatology (average precipitation) based on data from 1979 to 2007.

By P. A. Dirmeyer and J. L. Kinter III

the period of greatest rainfall and flooding. Greater 2-month rainfall totals were evident for 1993, compared with 2008, during the peak of flooding. Overall, the period from December 2007 through May 2008 was the second wettest recorded during the 114-year period of record for the upper Mississippi River basin. In both years, rainfall was below normal across the lower Mississippi River basin and much of the southeastern and mid-Atlantic regions of the United States.

The red box in each of Figures 1a–1d outlines the region considered as the overlapping core of flooding for both events. The region is bounded by 103°W and 88°W and 35°N and 45°N. Figures 1c and 1d show estimates of the anomalies of evaporative sources that supplied the moisture for precipitation within the red box during these months, based on methods of *Dirmeyer and Brubaker* [2007]. The evaporative source is normalized by the total rainfall within the red box and is expressed in percent. Thus, an anomaly of 0.5 in a given grid box (data are on a grid of approximately 1.9° × 1.9° resolution) means that evaporation from that grid box supplied half of one percent above average of the total moisture that fell as rain in the area bounded by the red box, based on a climatology calculated for the period 1979–2003.

In both 1993 and 2008, the floods were characterized by a fetch of moisture originating from the south and southeast over Texas and northern Mexico, and extending along the western Gulf of Mexico and across the Yucatan Peninsula and into the Caribbean. Also in both years, there was below-average moisture coming from evaporation to the west of the red box. During 1993 (Figure 1c), the band of enhanced moisture source was very narrow and appears to have included western Mexico and the Pacific. In 2008 (Figure 1d), the area of enhanced moisture source was much broader and extended farther east over the Gulf of Mexico and the Caribbean. Streamlines tangent to the velocity vector of the 2-month mean flow are shown where the anomaly in the mean wind, averaged within the lowest 30 hectopascals of the atmosphere, differed from climatology by at least 1 meter per second.

This fetch from Central America and southern Mexico including the Yucatan Peninsula inspired dubbing this the "Maya Express," analogous to the "Pineapple Express" that brings tropical moisture to the west coast of North America from sources near the Hawaiian Islands.

Both flood years also exhibited an extended period of anomalously wet conditions in the months prior to the actual flood (Figure 1e), based on the Climate Anomaly Monitoring System's outgoing longwave radiation precipitation index (CAMS-OPI) precipitation estimates. The total precipitation for the first 4 months of 1993 was 15% above average. Also above average, by 33%, was the precipitation total for the first 4 months of 2008. There were similar amounts of precipitation during May and June of both flood years, although the antecedent conditions in 2008 were wetter, and flooding ensued in these months during both years. Much of the U.S. Midwest experienced wet conditions during the preceding winter and spring. For example, in eastern Iowa and southern Wisconsin, wet conditions that were less than 2.5% likely to occur (i.e., no year in the past 40 has been so wet) persisted during the 6 months prior to the June 2008 flooding. In 1993, the peak flooding occurred during the last half of June and the first half of July. The July 1993 precipitation for the region within the red box was a staggering 91% above normal.

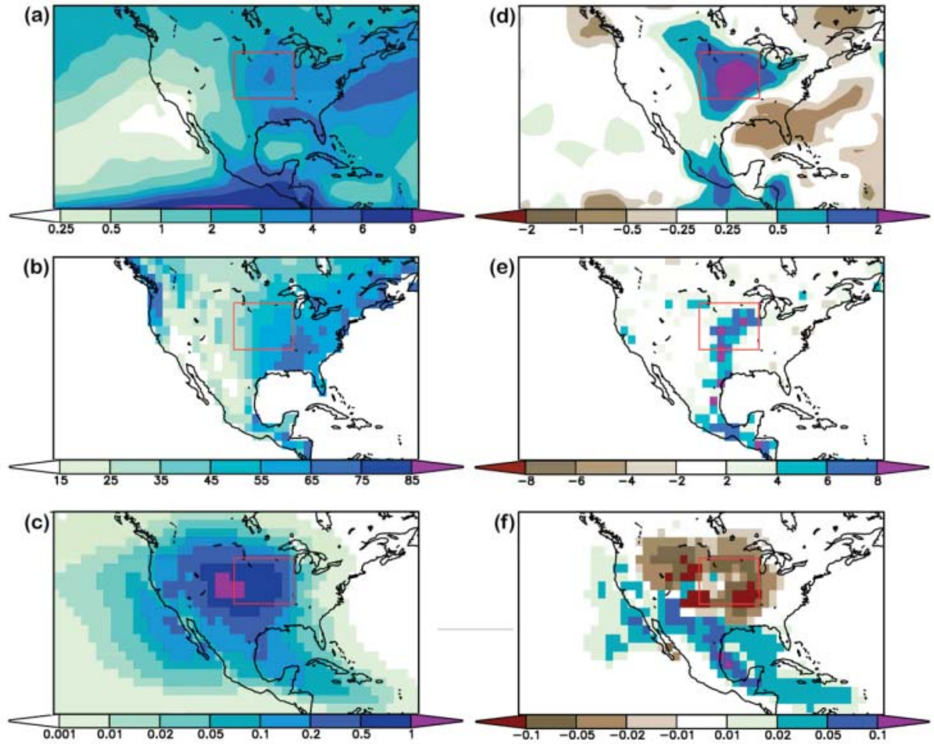

Fig. 2. May–July climatology for (a) precipitation (1979–2007; millimeters per day), (b) soil wetness (1979–2007; percentage of saturation), and (c) evaporative moisture source supplying precipitation over the area inside the red box (1979–2003; percentage of total moisture supplied). Anomalies for the 10% of months (May–July) with the highest precipitation over the area inside the red box for (d) precipitation, (e) soil wetness, and (f) evaporative source.

Climatology of Floods

Figure 2 shows the climatology for May–July of precipitation (Figure 2a) and soil moisture (Figure 2b) for the 29-year period from 1979 through 2007. Figure 2c shows the evaporative source, the percentage of the total May-June-July precipitation within the outlined red area that originally evaporated from each grid box, for the 25-year period 1979–2003. Figures 2d, 2e, and 2f show the anomalies associated with the 10% of months that have the highest precipitation averaged over the area in the red box, selected from May to July 1979–2003. The composite of precipitation anomalies (Figure 2d) shows not only high rainfall over the U.S. Great Plains extending out of the red box to the northwest, south, and east but also wet conditions across much of Mexico and Central America and into the tropical eastern Pacific Ocean. At the same time, dry conditions prevail across the southeastern United States, extending into the Gulf of Mexico and the Atlantic Ocean and also into Quebec and the Pacific coast of Canada.

Soil moisture anomalies during wet conditions in the Midwest reveal a trail of anomalously wet soil southward roughly between 100°W and 94°W into central and southern Mexico and Central America (Figure 2e). This path roughly corresponds to the western margin of an area of anomalously high relative contribution of evaporative moisture to the rainfall over the Midwest (Figure 2f). During floods in the Midwest, a large amount of moisture comes from evaporation in Texas, the western Gulf of Mexico, and the Caribbean, with a secondary source from the southwest extending into the Pacific Ocean east of Baja California. At the same time, recycling of moisture over the Midwest is low (negative relative anomalies within the area inside the red box), and there is less moisture coming from evaporation over the central and northern Rocky Mountains.

Causes and Predictability

The enhanced moisture flow from the south and drought across the southeastern United States is consistent with a strengthening or westward shift of the Atlantic subtropical ridge, a belt of high pressure sometimes called the "Bermuda High." An interesting aspect of the composites for flood conditions shown in the right-hand side of Figure 2 is the apparent connection between the Midwest and points well to the south. When composites of soil moisture, rainfall, and evaporative sources are calculated for the month immediately prior to the top 10% of rainfall events across the Midwest, it is found that the anomalies within the red box are much weaker but the wet conditions to the south persist. This implies that there may be a predictive element to these floods that can be exploited.

Analysis of evaporative moisture sources from back trajectories suggests a link through the regional water cycle that connects far-flung regions. It is clear that large-scale floods such as those in the U.S. Midwest during 1993 and 2008 are part of an even larger-scale aberration in the water cycle that involves the atmosphere, the ocean, and the land across vast distances. The "Maya Express" brought vast amounts of tropical moisture northward in an anomalous atmospheric flow. This combined with antecedent wet surface conditions to cause the major floods of 1993 and 2008. The region of flooding is also a region identified in modeling studies as one of the most likely to experience significant feedbacks between land and atmosphere [*Koster et al.*, 2004]. Additional study may pinpoint the mechanisms involved and further enhance the understanding and predictability of major flood events across the central United States.

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Author Information

Paul A. Dirmeyer and James L. Kinter III, Center for Ocean-Land-Atmosphere Studies, Calverton, Md.; E-mail: dirmeyer@cola.iges.org

G E O P H Y S I C I S T S

Honors

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Richard Alley, professor of geosciences at Pennsylvania State University, and **Veerabhadran ("Ram") Ramanathan**, professor of atmospheric and climate sciences at Scripps Institution of Oceanography at the University of California, San Diego, have been selected as recipients of the 2009 Tyler Prize for Environmental Achievement. The prize committee recognized the two "for their scientific contributions that advanced understanding of how human activities influence global climate, and alter oceanic, glacial and atmospheric phenomena in ways that adversely affect planet Earth." Considered one of the premier awards for environmental science, energy, and environmental health, the award consists of a $200,000 cash prize and a gold medallion.

Steve Elgar, senior scientist at the Woods Hole Oceanographic Institution, Woods Hole, Mass., has been selected as a 2009 National Security Science and Engineering Faculty Fellow. As one of eight fellows selected by the U.S. Office of the Secretary of Defense, Elgar will receive significant research funding for 5 years to conduct unclassified basic research on topics of interest to the Defense Department; he will also serve as a science advisor to the Office of the Secretary of Defense. Elgar's research involves manipulating nearshore morphology to determine the coupling and feedback between waves, currents, and bathymetric change.

Paul F. Hoffman, Sturgis Hooper Professor of Geology at Harvard University's Department of Earth and Planetary Sciences, Cambridge, Mass., has been selected to receive the 2009 Wollaston Medal, the highest award of the Geological Society of London. The society presents the medal annually "to geologists who have had a significant influence by means of a substantial body of excellent research in either or both pure and applied aspects of the science."

Neil Sheeley Jr., of the Space Science Division of the U.S. Department of the Navy's Naval Research Laboratory, is the 2009 recipient of the George Ellery Hale Prize. Each year, the Solar Physics Division of the American Astronomical Society presents this international award to a scientist for outstanding contributions to the field of solar astronomy over an extended period of time. The citation recognizes Sheeley "for his continuing outstanding contributions to our understanding of the solar magnetic field, coronal holes, and coronal mass ejections. His wide-ranging observational and theoretical work has laid the foundation for much current research in solar and heliospheric physics, and continues to have important applications in space weather prediction."

MEETING

A U.S. Carbon Cycle Science Plan

First Meeting of the Carbon Cycle Science Working Group; Washington, D. C., 17–18 November 2008

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The report "A U.S. carbon cycle science plan" (J. L. Sarmiento and S. C. Wofsy, U.S. Global Change Res. Program, Washington, D. C., 1999) outlined research priorities and promoted coordinated carbon cycle research across federal agencies for nearly a decade. Building on this framework and subsequent reports (available at http://www.carboncyclescience.gov/docs.php), the Carbon Cycle Science Working Group (CCSWG) was formed in 2008 to develop an updated strategy for the next decade. The recommendations of the CCSWG will go to agency managers who have collective responsibility for setting national carbon cycle science priorities and for sponsoring much of the carbon cycle research in the United States.

The first meeting of the CCSWG took place in November, with the overall goals of achieving consensus on the extent to which the 1999 plan should be updated, developing a list of overarching scientific questions to be addressed by the new plan, and identifying mechanisms for maximizing community input.

The meeting included presentations that focused on the history of the 1999 plan, the agencies' perspective on carbon cycle science, the North American Carbon Program, the "State of the carbon cycle report" released in 2007 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, and strategies for fostering community involvement. Breakout sessions and group discussions focusing on the specific goals of the workshop made up the majority of the agenda.

Three overarching scientific questions were tentatively proposed by the working group for the new plan:

1. What processes and feedbacks or mechanisms control the dynamics of atmospheric carbon dioxide and methane, and how?