EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 91 NUMBER 10
9 MARCH 2010
PAGES 93–100

EDITORIAL

Eos Introduces "Research Spotlight"

PAGE 93

To give greater visibility and prominence to the high-quality research published in AGU journals, *Eos* introduces "Research Spotlight" (see page 100). This column, which metamorphosed from the "Journal Highlights" section, has livelier text, an eye-catching design, and colorful images to enhance the article summaries.

Research Spotlight aims to draw attention to salient and groundbreaking research that is of interest to the geophysics community. Our goal is to put that research into the broader context for *Eos*'s diverse readership, which includes students and journalists as well as scientists in a wide variety of subfields.

Editors of AGU's journals have been asked to select well-written, topflight papers to feature in Research Spotlight. As was done for Journal Highlights, *Eos* staff will write the summaries of the papers selected by journal editors and work closely with the authors of the research papers to ensure accuracy and clarity. Our goal is to spotlight outstanding research in a lucid, vibrant, and appealing way.

—Barbara T. Richman, Editor in Chief, *Eos*

Is Hurricane Activity in One Basin Tied to Another?

PAGES 93–94

Each year, tropical cyclones and hurricanes leave millions homeless worldwide and account for, on average, over $100 billion of damage in the United States alone [*Schmidt et al.,* 2009]. In 2005, a record-breaking 15 hurricanes formed in the North Atlantic, four of which reached category 5 strength. Over the course of that season, more than 3000 hurricane-related deaths occurred and fiscal damage reached $157 billion.

Because a better understanding of when and where tropical cyclones and hurricanes will form and strike will help societies better prepare for adverse effects, improving the understanding of these storms is very important. In the Western Hemisphere, tropical cyclones can form and develop in both the tropical North Atlantic and eastern North Pacific oceans, which are separated by the landmass of Central America. From the point of view of large-scale atmospheric circulation and its influence on tropical cyclones [e.g., *Bell and Chelliah,* 2006], it is not surprising that tropical cyclone variabilities in these two basins are related, because of their geographic proximity. But several questions remain: How they are related? What physical mechanisms drive this relation?

By C. Wang and S.-K. Lee

New research combined with careful analysis of historical data shows an out-of-phase relationship between tropical cyclone variability in the North Atlantic and the eastern North Pacific, meaning that when one basin has high storm occurrence, the other has low storm occurrence. This implies that the seasonal hurricane outlook may be improved by considering the North Atlantic and eastern North Pacific together.

Relationship Between Tropical Cyclones in the North Atlantic and Eastern Pacific

The accumulated cyclone energy index is a measure commonly used to express the activity of individual tropical cyclones and entire tropical cyclone seasons. It represents an approximation of the energy used by a tropical cyclone over its lifetime. Using the hurricane reanalysis database of the U.S. National Oceanic and Atmospheric Administration's (NOAA) Atlantic Oceanographic and Meteorological Laboratory (AOML), in Miami, Fla. (http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html), scientists calculate accumulated cyclone energy indices by summing the squares of the estimated maximum sustained wind speeds of all tropical cyclones at 6-hour intervals in a season. Figure 1a clearly shows that accumulated cyclone energy indices in the North Atlantic and eastern North Pacific vary out of phase. That is, when tropical cyclone activity in the North Atlantic increases, tropical cyclone activity in the eastern North Pacific decreases, and vice versa. Although not shown in the figure, the accumulated cyclone energy indices in the North Atlantic and eastern Pacific during the 2008 and 2009 hurricane seasons also vary out of phase.

An exmination of the data on a longer time scale shows the signal of the Atlantic multidecadal oscillation, an oscillatory climate mode occurring in North Atlantic sea surface temperature that varies primarily on time scales of 30–80 years [e.g., *Delworth and Mann,* 2000]. During one of the more recent oscillations, North Atlantic sea surface temperatures were cool from 1970 to 1994 and warm before 1970 and after 1995 [e.g., *Enfield et al.,* 2001]. Figure 1b shows that when the Atlantic multidecadal oscillation was in its cool phase, tropical cyclones in the North Atlantic were inactive, whereas tropical cyclones in the eastern North Pacific were active. Similarly, the warm phases of the Atlantic multidecadal oscillation after 1995 and before 1970 were associated with active tropical cyclones in the North Atlantic and inactive tropical cyclones in the eastern North Pacific.

Also buried in the accumulated cyclone energy indices are signals of interannual variations (Figure 1c), related to the El Niño–Southern Oscillation (ENSO), a phenomenon where warm and cold sea surface temperatures oscillate in the equatorial Pacific every 2–7 years, influencing weather patterns across the globe. Generally, during an El Niño event and/or a cold tropical North Atlantic, tropical cyclone activity in the eastern North Pacific is active, whereas tropical cyclone activity in the North Atlantic is inactive. The reverse is also true—during a La Niña event and/or a warm tropical North Atlantic, tropical cyclone activity in the eastern North Pacific is inactive, whereas activity in the North Atlantic is active. This is because both ENSO and tropical North Atlantic sea surface temperature can affect the oceanic and atmospheric environments in the North Atlantic and eastern North Pacific, which in turn modulate tropical cyclone activity in these two basins.

Impact of Vertical Wind Shear

Tropospheric vertical wind shear—a wind speed difference between the upper and lower troposphere—is an important factor that affects the formation and development of tropical cyclones. A strong wind shear produces a large ventilation of heat away from the developing disturbance and is thus unfavorable for tropical cyclone formation and intensification. Similar to a typical wind shear definition in the literature [e.g., *Goldenberg et al.,* 2001], vertical wind shear is represented as the magnitude of the vector difference between horizontal winds at 200 millibars (~12,000 meters in altitude) and 850 millibars (~1500 meters in altitude).

A regression analysis is performed, which estimates how vertical wind shear linearly varies with North Atlantic tropical cyclone activity. Figure 2 shows that, on average, the wind shear in the main region where hurricanes develop in the North Atlantic tends to be opposite the wind shear in the eastern North Pacific for summer and fall. This means that the vertical wind shear in the hurricane main development region of the North Atlantic is reduced during the hurricane season, whereas the wind shear in the eastern North Pacific is enhanced. Because a strong vertical wind shear is unfavorable for tropical cyclones (and vice versa), the opposite wind shear patterns in the main storm development regions of the North Atlantic and eastern North Pacific may be why hurricane and cyclone activity is oppositely synched in the North Atlantic and eastern North Pacific. These results still hold for interannual and multidecadal time scales—for example, if Figure 2 is separated into interannual and multidecadal variability, the opposite patterns of wind shear between the hurricane main development regions of the North Atlantic and eastern North Pacific prevail on both time scales [*Wang and Lee*, 2009].

The opposite vertical wind shear patterns in the tropical North Atlantic and eastern North Pacific are attributed to large-scale atmospheric circulation change in this region. For example, an active hurricane season in the North Atlantic is associated with easterly wind anomalies in the upper troposphere of both the tropical North Atlantic and eastern North Pacific [*Wang and Lee*, 2009]. The easterly wind anomalies reduce the mean westerly wind in the upper troposphere of the tropical North Atlantic and increase the mean easterly wind in the eastern North Pacific, resulting in an out-of-phase relationship of vertical wind shear variability between the tropical North Atlantic and the eastern North Pacific. Similar relationships hold for an active cyclone season in the eastern North Pacific.

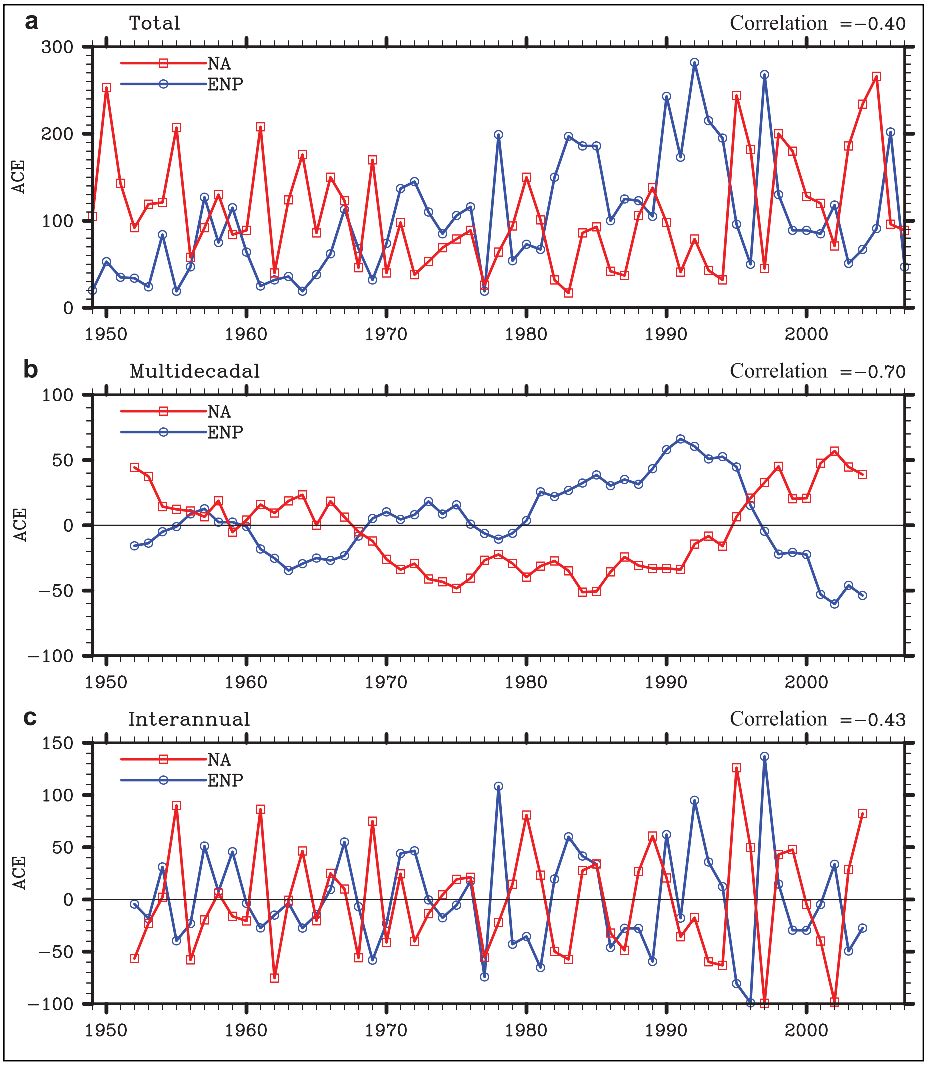

Fig. 1. Time series of accumulated cyclone energy (ACE; depicted on the y-axis in units of 10^4 square knots) in the North Atlantic (NA) and eastern North Pacific (ENP) from 1949 to 2007. Shown are the (a) total, (b) multidecadal, and (c) interannual variations. The multidecadal variability is obtained by performing a 7-year running mean after the linear trend is removed from the ACE indices. The interannual variability is calculated by subtracting the multidecadal variability from the detrended ACE indices.

Impact of Other Factors

In addition to vertical wind shear, tropical cyclones are influenced by other factors such as atmospheric convective instability, humidity, vorticity, and seawater temperature. Convective instability of the atmosphere refers to its ability to resist vertical motion. In an unstable atmosphere, vertical air movements tend to become larger, resulting in turbulent airflow and more convective activity. Thus, convective instability is favorable for the formation and development of tropical cyclones. Atmospheric instability can be measured by convective available potential energy, which represents the amount of buoyant energy available to accelerate an air parcel vertically. The higher the value of the convective available potential energy, the more energy is available to foster storm growth [e.g., *Emanuel,* 1994]. When convective available potential energy is enhanced in the tropical North Atlantic, it is reduced in the eastern North Pacific [*Wang and Lee,* 2009]. In other words, atmospheric convective instability can also make a contribution to the out-of-phase relationship between tropical cyclones in the North Atlantic and eastern North Pacific.

It is well known that seawater temperature change is important for tropical cyclones. An active tropical cyclone year in the North Atlantic is associated with a cold tropical eastern Pacific Ocean and a warm tropical North Atlantic Ocean or a large pool of warm water in the tropical Atlantic (the Atlantic warm pool). Similarly, an inactive cyclone year in the North Atlantic is associated with a warm tropical eastern Pacific and a cold tropical North Atlantic. Hand-in-hand with this relationship, the influence of ENSO, the Atlantic warm pool, and the Atlantic multidecadal oscillation [e.g., *Gray,* 1984; *Wang et al.,* 2008; *Goldenberg et al.,* 2001] strongly depends on sea surface temperature. Thus, a combination of a La Niña year, a warm year in the tropical North Atlantic, and a warm phase of the Atlantic multidecadal oscillation will greatly increase the probability of an active hurricane season in the North Atlantic and an inactive season in the eastern North Pacific. Similarly, a combination of an El Niño year, a cold year in the tropical North Atlantic, and a cool phase of the Atlantic multidecadal oscillation will greatly increase the probability of an inactive hurricane season in the North Atlantic and an active season in the eastern North Pacific. Thus, in certain years, the combination of ENSO, the Atlantic warm pool, and the Atlantic multidecadal oscillation can serve to amplify hurricane or cyclone activity.

Relative humidity, which describes the amount of water vapor in air, and relative vorticity, seen as rotational patterns in the wind velocity field, are also related to tropical cyclone activity. Generally, large values of relative humidity and relative vorticity in the lower troposphere are conducive to tropical cyclones. However, their changes cannot explain the out-of-phase relationship between North Atlantic and eastern North Pacific tropical cyclone variability [*Wang and Lee,* 2009].

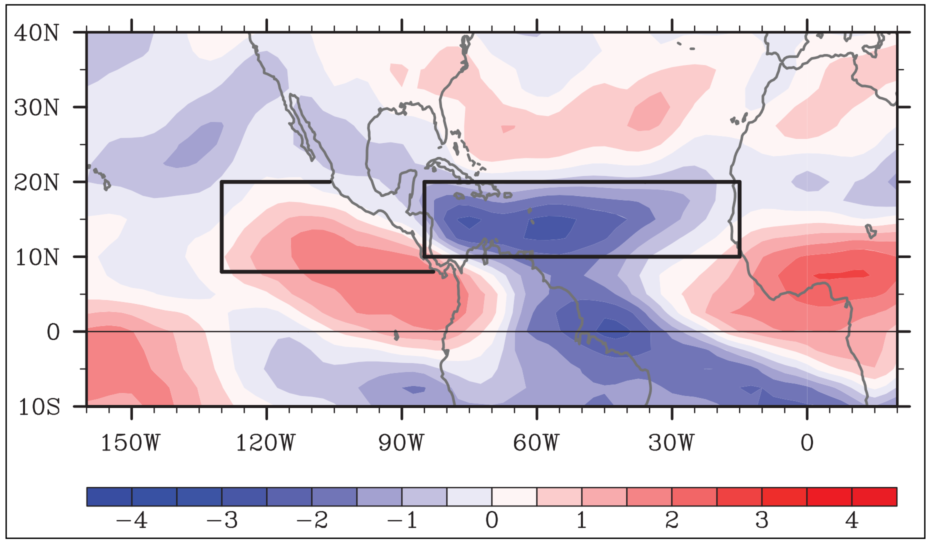

Fig. 2. Regression of vertical wind shear between 200 millibars (~12,000 meters in altitude) and 850 millibars (~1500 meters in altitude) from June through November onto the North Atlantic detrended ACE index. The North Atlantic and eastern North Pacific hurricane main development regions are marked by the areas defined in boxes (note that the Pacific region abuts the coast).

Acknowledgments

Five reviewers gave excellent comments on this article. This work was supported by the NOAA Climate Program Office, the NOAA National Hurricane Center Joint Hurricane Testbed Program, and the base funding of the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML). The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the funding agency.

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