Click Here for Full Article

Co-variability of tropical cyclones in the North Atlantic and the eastern North Pacific

Chunzai Wang[1] and Sang-Ki Lee[2]

Received 22 October 2009; revised 17 November 2009; accepted 25 November 2009; published 30 December 2009.

[1] In the Western Hemisphere, tropical cyclones (TCs) can form and develop in both the tropical North Atlantic (NA) and eastern North Pacific (ENP) Oceans, which are separated by the narrow landmass of Central America. Here it is shown that TC activity in the NA varies out-of-phase with that in the ENP on both interannual and multidecadal timescales. That is, when TC activity in the NA increases (decreases), TC activity in the ENP decreases (increases). Our analyses show that both vertical wind shear and convective instability contribute to the out-of-phase relationship, whereas relative humidity and vorticity variations at the lower troposphere do not seem to cause the relationship. The paper also discusses its association with the Pacific and Atlantic sea surface temperatures. An implication is that seasonal hurricane outlook can be improved by considering the NA and ENP together. It is hoped that this article will stimulate more research regarding TC activity in both the NA and ENP.

Citation: Wang, C., and S.-K. Lee (2009), Co-variability of tropical cyclones in the North Atlantic and the eastern North Pacific, *Geophys. Res. Lett.*, *36*, L24702, doi:10.1029/2009GL041469.

1. Introduction

[2] Improving the understanding of variability of tropical cyclones (TCs) or hurricanes is very important both scientifically and socially. In the Western Hemisphere, TCs can form and develop in both the tropical North Atlantic (NA) and eastern North Pacific (ENP) Oceans, which are separated by the narrow landmass of Central America. In comparison with TCs in the NA, TCs in the ENP have received less attention although TC activity is generally greater in the ENP than in the NA [e.g., *Maloney and Hartmann*, 2000; *Romero-Vadillo et al.*, 2007]. Needless to say, few studies have focused on the relationship between TCs in the NA and ENP. From the point view of large-scale atmospheric circulation influence on TCs [*Landsea et al.*, 1998; *Bell and Chelliah*, 2006], it is not surprising that TC variability in these two basins is related to each other because of their geographic proximity. But, the questions are how they are related and under what physical mechanisms they are related. The purpose of this article is to report an out-of-phase relationship between TC variability in the NA and ENP and to discuss possible causes of the relationship.

2. Data Sets

[3] Several data sets are used in this study. The first one is an improved extended reconstructed sea surface temperature (SST) data set on a 2° latitude by 2° longitude grid [*Smith and Reynolds*, 2004]. To be consistent with other data sets, we only analyze the monthly SST data from 1949 to 2007. The second data set is the NCEP-NCAR reanalysis from 1949 to 2007 on a 2.5° latitude by 2.5° longitude grid [*Kalnay et al.*, 1996].

[4] Another data set is the hurricane data based on HURDAT reanalysis database [*Landsea*, 2007] which is available at the website of NOAA/AOML (http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html). This database does not include the index of accumulated cyclone energy (ACE) in the ENP. Therefore, we calculate the NA and ENP ACE indices by summing the squares of the estimated maximum sustained wind of every TC at six-hour intervals using HURDAT data. We validate and confirm our ACE calculation by comparing the NA ACE index with that already in HURDAT.

3. Relationship Between TCs in the NA and ENP

[5] The ACE index is one of the most commonly used indices to measure TC activity, which takes into account the number, strength and duration of all TCs in a season. Figure 1a clearly shows that ACE indices in the NA and ENP vary out-of-phase. That is, when TC activity in the NA increases (decreases), TC activity in the ENP decreases (increases). Since the NA and ENP Oceans are separated by Central America, the relationship must be controlled by physical processes associated with a large-scale atmospheric variability (next section).

[6] The longer timescale variability of the NA and ENP ACE mainly shows the signal of the Atlantic multidecadal oscillation (AMO) as displayed in Figure 1b. When the AMO is in the cold phase during 1970–1994 (black curve in Figure 1b) [*Delworth and Mann*, 2000; *Enfield et al.*, 2001], TCs in the NA are inactive, whereas TCs in the ENP are active. The warm phases of the AMO after 1995 and before the 1970s are associated with active TCs in the NA and inactive TCs in the ENP. The interannual variability of ACE mainly reflects the interannual variations of ENSO and/or the tropical North Atlantic SST influence (Figure 1c). Generally, during an El Niño (La Niña) year and/or a cold (warm) tropical North Atlantic, TC activity in the ENP is active (inactive), whereas TC activity in the NA is inactive (active). This is because both ENSO and tropical NA SST

[1]Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, Florida, USA.
[2]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, Florida, USA.

0094-8276/09/2009GL041469$05.00

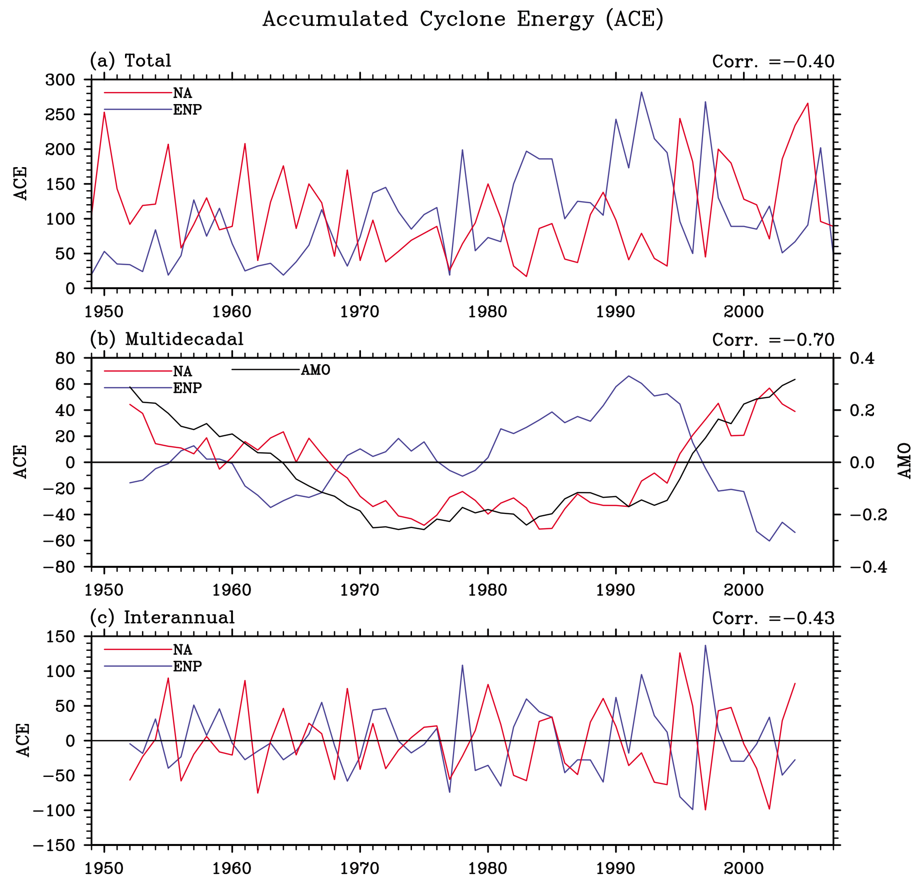


Figure 1. Time series of the accumulated cyclone energy (ACE; 10^4 kt^2) in the North Atlantic (NA) and eastern North Pacific (ENP) from 1949–2007. Shown are the (a) total, (b) multidecadal, and (c) interannual variations. The multidecadal variability is obtained by performing a seven-year running mean to the detrended ACE indices. The interannual variability is calculated by subtracting the multidecadal variability from the detrended ACE indices. The AMO index in Figure 1b is calculated as the seven-year running mean of detrended NA (from the equator to 60°N) SST anomalies during June to November. The correlation coefficients between the NA and ENP ACE indices are shown in the top right of each plot.

can affect oceanic and atmospheric environment in the NA and ENP, which in turn modulates TC activity in these two basins.

[7] The observed out-of-phase relationship between TCs in the NA and ENP is statistically significant. The correlations between the NA and ENP ACE indices in Figures 1a, 1b, and 1c are −0.40, −0.70, and −0.43, respectively, all of which are above the 99% significance level. Figure 1 also shows that the out-of-phase relationship seems to become stronger in the recent decades. For example, if the total ACE indices are from 1979 to 2007, the respective correlations are increased to −0.54, −0.79, and −0.59. This probably reflects that the quality of tropical cyclone data is improved in the recent decades.

4. Tropospheric Vertical Wind Shear

[8] The vertical wind shear between the upper and lower troposphere in the hurricane main development region (MDR) is an important factor that affects TCs, with a weak (strong) wind shear being favorable (unfavorable) for the formation and development of TCs. Following a typical wind shear definition in the literature [e.g., *Goldenberg et al.*, 2001], we calculate vertical wind shear as the magnitude of the vector difference between winds at 200-mb and 850-mb. Figure 2a shows a dipole wind shear pattern in the NA and ENP MDRs. That is, the negative wind shear regression in the NA MDR is associated with the positive wind shear regression in the ENP MDR. This dipole wind shear pattern can explain the out-of-phase relationship between NA and ENP TCs shown in Figure 1a. The cause of the dipole wind shear pattern can be attributed to tropical SST variability [e.g., *Wang et al.*, 2008].

[9] Next we examine why the vertical wind shear in the NA MDR is opposite to that in the ENP MDR. The regressions of 200-mb and 850-mb winds onto the NA ACE index are shown in Figures 2b and 2c, respectively. The upper (lower) troposphere displays an easterly (westerly) wind anomaly pattern that extends across both the NA and ENP MDRs. In the NA MDR, the mean wind during June–November in the upper troposphere is westerly, whereas the mean wind in the lower troposphere is easterly (not shown). In the ENP MDR, the mean winds during June–November in both the upper and lower troposphere are easterly although the amplitude of the lower troposphere mean easterly is relatively small (with the lower troposphere

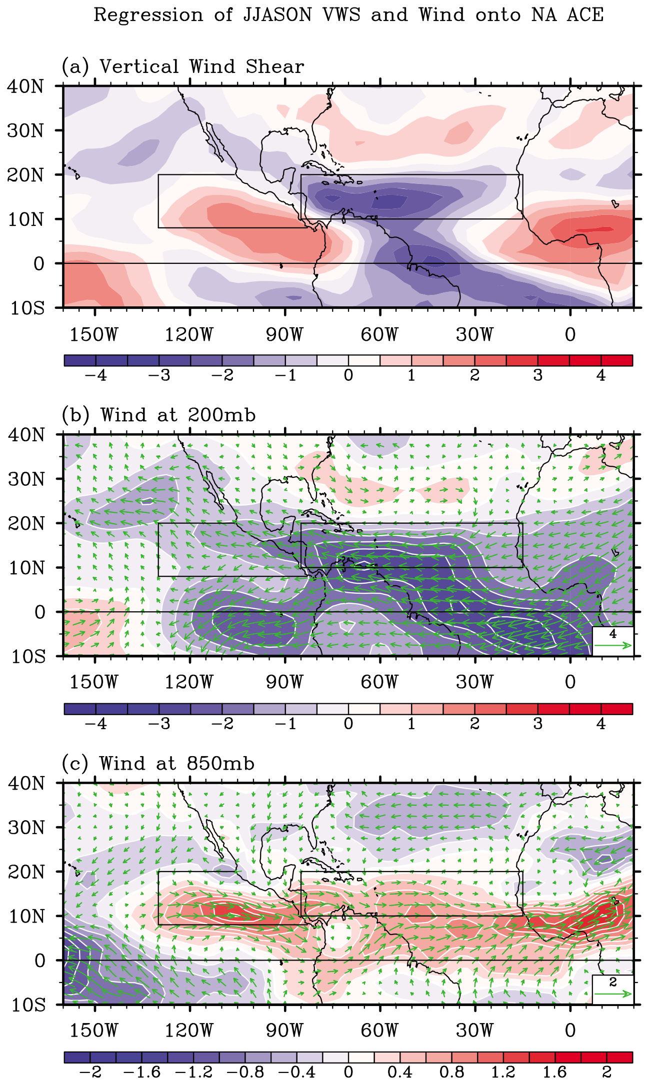


Figure 2. Regressions (0.01 m/s per ACE) of vertical wind shear and winds during June–November onto the NA detrended ACE index. Shown are the (a) regression of vertical wind shear between 200-mb and 850-mb, (b) regressions of wind vector (arrows) and zonal wind (contours) at 200-mb, and (c) regressions of wind vector (arrows) and zonal wind (contours) at 850-mb. The NA and ENP hurricane main development regions (MDRs) are respectively marked by the areas of 10°N–20°N, 85°W–15°W and 8°N–20°N, 130°W to the Pacific American coast.

mean westerly in September). Considering these mean wind states, we can conclude that an active (inactive) NA TC year is associated with easterly (westerly) wind anomalies in the upper troposphere that extend across the NA and ENP MDRs (Figure 2b). The easterly (westerly) wind anomalies reduce (enhance) the mean westerly wind in the NA and increase (decrease) the mean easterly wind in the ENP, resulting in an out-of-phase relationship of wind change in the upper troposphere between the NA and ENP. However, due to the mean easterly wind of the lower troposphere in both the NA and ENP, the regression westerly wind anomalies in Figure 2c reduce the lower-level easterly wind in both the NA and ENP MDRs. Because the reduction of the lower-level easterly wind in the ENP is relatively small, the net result is that the vertical wind shear pattern follows the sign in the upper troposphere, i.e., an out-of-phase vertical wind shear relationship between the NA and ENP MDRs. Note that in September the mean wind of the lower troposphere is westerly in the ENP MDR and easterly in the NA MDR. This means that the westerly wind anomalies in Figure 2c enhances the mean westerly in the ENP MDR and reduces the mean easterly in the NA MDR. Thus, in September both the upper and lower troposphere can contribute to the opposite wind shear pattern between the NA and ENP.

[10] The vertical wind shear regressions into interannual and multidecadal variability are shown in Figure 3. In general, the out-of-phase relation can be seen on both interannual and multidecadal timescales. On interannual timescale, the wind shear pattern is similar to that in Figure 2a except with the maximum negative wind shear located in the Caribbean Sea. For multidecadal variation, the negative wind shear is maximized in the tropical central NA, whereas the positive wind shear in the Pacific side is retreated westward and weaker.

5. Atmospheric Moist Static Instability

[11] Convective available potential energy (CAPE) is a measure of the moist static instability of the troposphere, representing the amount of buoyant energy available to

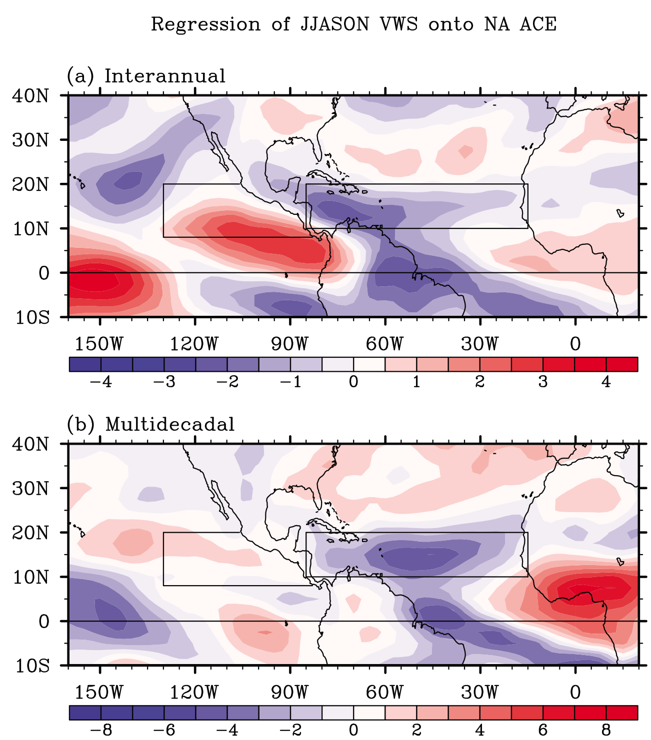


Figure 3. Regressions (0.01 m/s per ACE) of vertical wind shear between 200-mb and 850-mb during June–November onto the NA detrended ACE index for the (a) interannual and (b) multidecadal variations.

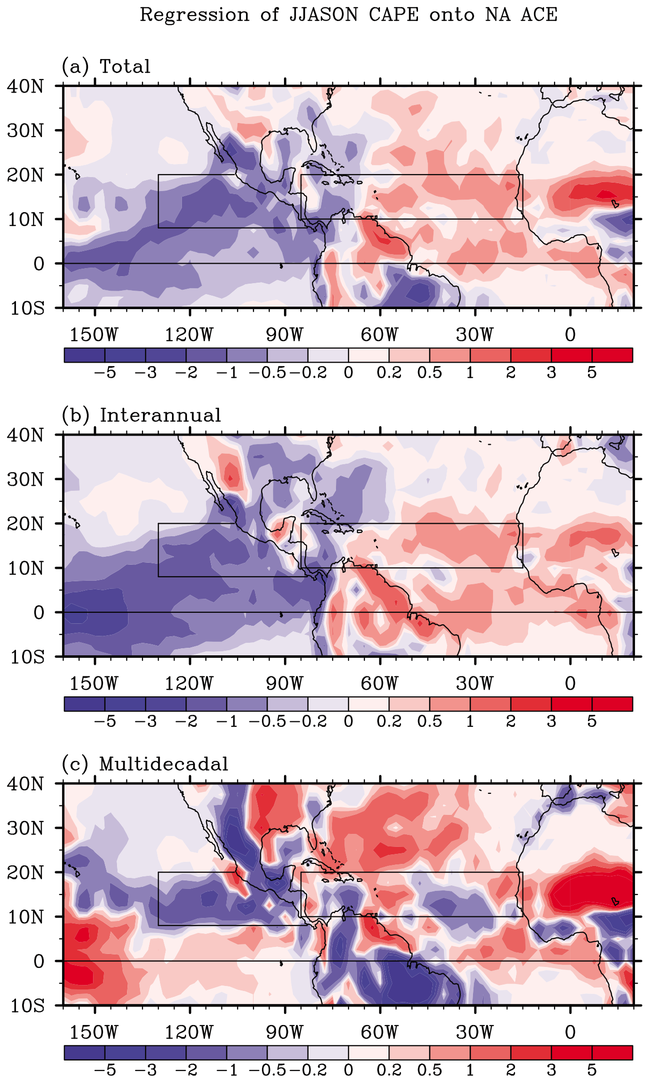


Figure 4. Regressions (J/kg per ACE) of convective available potential energy (CAPE) during June–November onto the NA detrended ACE index. Shown are the (a) total, (b) interannual and (c) multidecadal regressions. In the calculation of CAPE, air parcels are initiated from the surface using the NCEP-NCAR reanalysis.

accelerate an air parcel vertically, or the amount of work an air parcel does on the environment. CAPE is especially important when air parcels are able to reach the level of free convection. The higher the CAPE value, the more energy available to foster storm growth. Since CAPE provides the fuel for moist convection, it also is a potential indicator of hurricane intensity [*Emanuel*, 1994].

[12] To examine how CAPE varies with TC activity, we calculate the regressions of CAPE during the Atlantic hurricane season of June–November onto the NA ACE index (Figure 4). A dipole pattern can be still seen in the CAPE distribution. The cold surface air temperature anomaly is responsible for decreasing CAPE over the ENP region, whereas the warm low-tropospheric air temperature anomaly is responsible for increasing CAPE in the NA region. However, unlike the wind shear dipole pattern, the CAPE regression in the Caribbean Sea and the Gulf of Mexico shares the same sign as that in the ENP. In general, positive CAPE regression is located in the tropical central and eastern NA, whereas negative CAPE regression is in the ENP MDR, the Caribbean Sea, and the Gulf of Mexico. This indicates that CAPE may also make a contribution to the out-of-phase relationship between TCs in the NA and ENP.

[13] The CAPE regressions into the interannual and multidecadal variability are displayed in Figures 4b and 4c. On interannual timescale the CAPE regression pattern is similar to that in Figure 4a, with an east-west seesaw distribution. However, for multidecadal variability the CAPE regression is on average negative in both the NA and ENP MDRs. The latter suggests that on multidecadal timescale the out-of-phase relationship of TCs in the NA and ENP is not due to CAPE variability.

6. Atlantic and Pacific SSTs and Other Parameters

[14] We have shown that both vertical wind shear and CAPE can make a contribution to the out-of-phase relationship between NA and ENP TC activity. What are oceanic conditions in association with these atmospheric patterns or changes? To answer this question, we calculate the regressions of SST during June–November onto the NA ACE index (Figure 5). An active (inactive) NA TC year is associated with a cold (warm) tropical eastern Pacific and a warm (cold) tropical NA. A further calculation shows that the distribution of SST on interannual timescale is a La Niña-like pattern in the Pacific and a warm tropical NA (Figure 5b). This distribution is consistent with previous work of ENSO's influence on NA TCs [e.g., *Gray*, 1984] and of the impact of the Atlantic warm pool on NA TCs [e.g., *Wang et al.*, 2006, 2008]. On multidecadal timescale, the regression pattern of SST resembles the distribution of the AMO, with a warming of the NA and eastern tropical Pacific (Figure 5c). This is also consistent with *Goldenberg et al.* [2001] who showed that an active (inactive) NA hurricane era is associated with a long-term warm (cold) SST in the NA. Thus, a combination of a La Niña (El Niño) year, a warm (cold) year in the tropical NA, and a warm (cold) phase of the AMO will greatly increase the probability of an active (inactive) hurricane season in the NA and an inactive (active) season in the ENP.

[15] Other parameters such as low-level humidity and vorticity can also influence the development and formation of TCs. Regressions of relative humidity at 700-mb and relative vorticity at 850-mb during June–November onto the NA ACE index are shown in Figures S1 and S2 of the auxiliary material.[1] Generally, the regressions of relative humidity and relative vorticity in the NA and ENP MDRs share the same sign, indicating that they do not cause the out-of-phase variability between NA and ENP TCs.

[16] **Acknowledgments.** We thank two reviewers' comments and suggestions. This work was supported by National Oceanic and Atmospheric Administration (NOAA) Climate Program Office and the base

[1]Auxiliary materials are available in the HTML. doi:10.1029/2009GL041469.

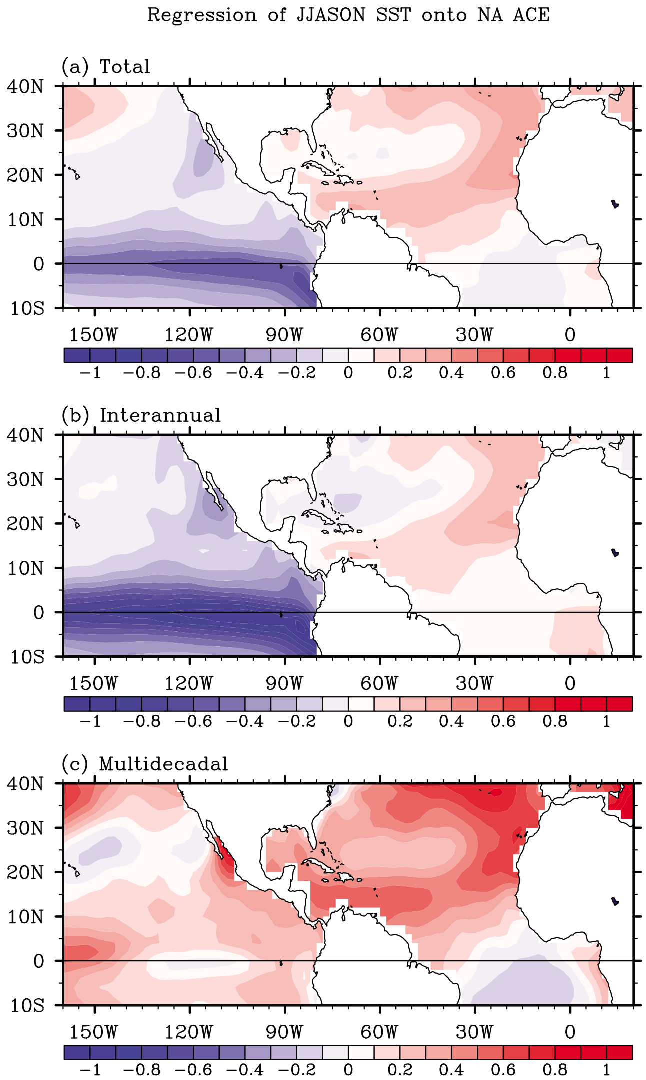


Figure 5. Regressions (0.01°C per ACE) of SST during June–November onto the NA detrended ACE index. Shown are the (a) total, (b) interannual and (c) multidecadal regressions.

funding of NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML). The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the funding agency.

References

Bell, G. D., and M. Chelliah (2006), Leading tropical modes associated with interannual and multidecadal fluctuations in North Atlantic hurricane activity, *J. Clim.*, *19*, 590–612, doi:10.1175/JCLI3659.1.

Delworth, T. L., and M. E. Mann (2000), Observed and simulated multidecadal variability in the Northern Hemisphere, *Clim. Dyn.*, *16*, 661–676, doi:10.1007/s003820000075.

Emanuel, K. A. (1994), *Atmospheric Convection*, 580 pp.Oxford Univ. Press, New York.

Enfield, D. B., A. M. Mestas-Nunez, and P. J. Trimble (2001), The Atlantic Multidecadal Oscillation and its relationship to rainfall and river flows in the continental U.S., *Geophys. Res. Lett.*, *28*, 2077–2080, doi:10.1029/2000GL012745.

Goldenberg, S. B., C. W. Landsea, A. M. Maestas-Nunez, and W. M. Gray (2001), The recent increase in Atlantic hurricane activity: Causes and implications, *Science*, *293*, 474–479, doi:10.1126/science.1060040.

Gray, W. M. (1984), Atlantic seasonal hurricane frequency. Part I: El Niño and 30 mb quasi-biennial oscillation influences, *Mon. Weather Rev.*, *112*, 1649–1668, doi:10.1175/1520-0493(1984)112<1649:ASHFPI>2.0.CO;2.

Kalnay, E., et al. (1996), The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Meteorol. Soc.*, *77*, 437–471, doi:10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2.

Landsea, C. W. (2007), Counting Atlantic tropical cyclones back to 1900, *Eos Trans. AGU*, *88*(18), doi:10.1029/2007EO180001.

Landsea, C. W., G. D. Bell, W. M. Gray, and S. B. Goldenberg (1998), The extremely active 1995 Atlantic hurricane season: Environmental conditions and verification of seasonal forecasts, *Mon. Weather Rev.*, *126*, 1174–1193, doi:10.1175/1520-0493(1998)126<1174:TEAAHS>2.0.CO;2.

Maloney, E. D., and D. L. Hartmann (2000), Modulation of eastern North Pacific hurricanes by the Madden-Julian Oscillation, *J. Clim.*, *13*, 1451–1460, doi:10.1175/1520-0442(2000)013<1451:MOENPH>2.0.CO;2.

Romero-Vadillo, E., O. Zaytsev, and R. Morales-Perez (2007), Tropical cyclone statistics in the northeastern Pacific, *Atmosfera*, *20*, 197–213.

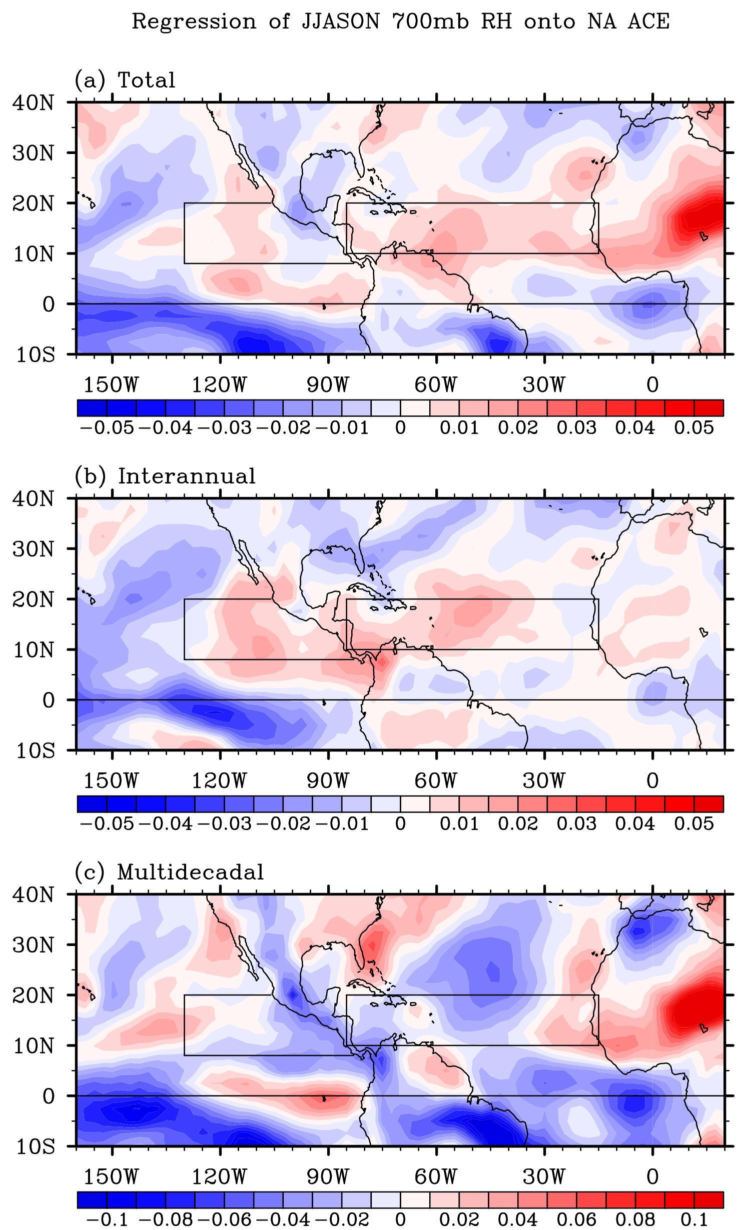
Smith, T. M., and R. W. Reynolds (2004), Improved extended reconstruction of SST (1854–1997), *J. Clim.*, *17*, 2466–2477, doi:10.1175/1520-0442(2004)017<2466:IEROS>2.0.CO;2.

Wang, C., D. B. Enfield, S.-K. Lee, and C. W. Landsea (2006), Influences of the Atlantic Warm Pool on Western Hemisphere summer rainfall and Atlantic hurricanes, *J. Clim.*, *19*, 3011–3028, doi:10.1175/JCLI3770.1.

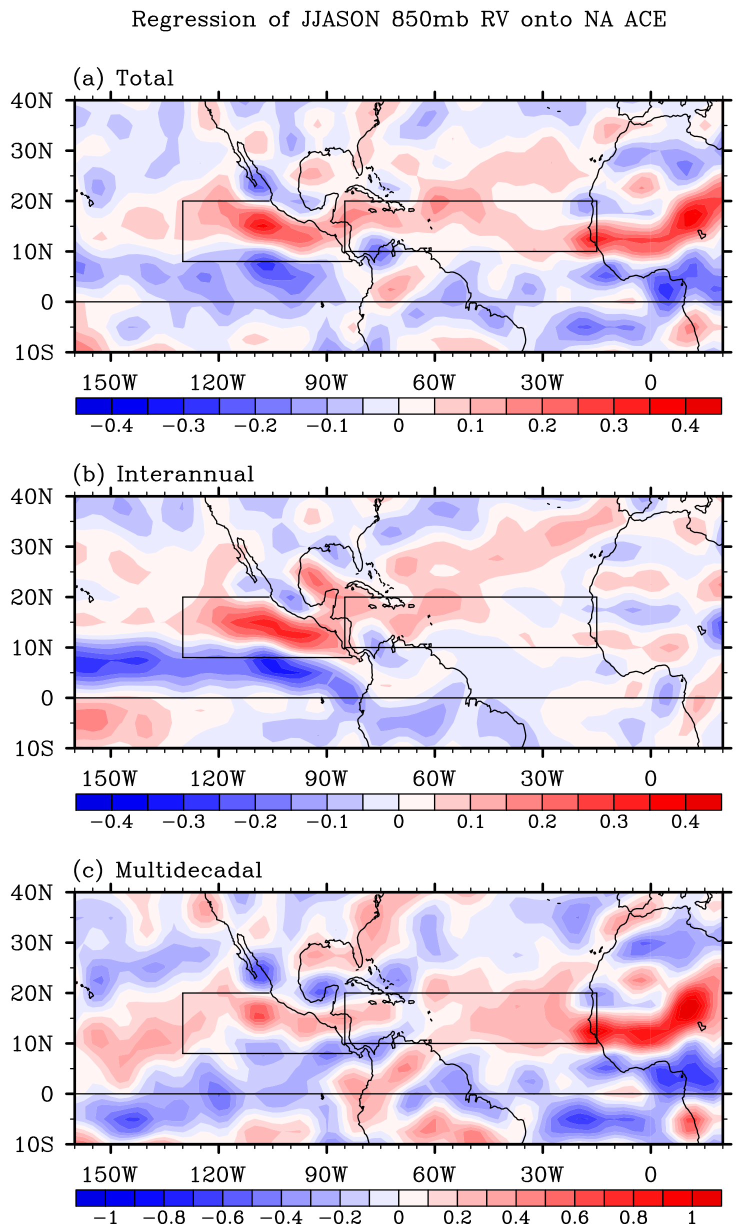
Wang, C., S.-K. Lee, and D. B. Enfield (2008), Atlantic Warm Pool acting as a link between Atlantic Multidecadal Oscillation and Atlantic tropical cyclone activity, *Geochem. Geophys. Geosyst.*, *9*, Q05V03, doi:10.1029/2007GC001809.

S.-K. Lee, Cooperative Institute for Marine and Atmospheric Studies, University of Miami, 4301 Rickenbacker Cswy., Miami, FL 33149, USA.

C. Wang, Atlantic Oceanographic and Meteorological Laboratory, NOAA, 4301 Rickenbacker Cswy., Miami, FL 33149, USA. (chunzai.wang@noaa.gov)



Supplementary Figure 1. Regressions (% per ACE) of relative humidity at 700-mb during June-November onto the NA detrended ACE index. Shown are the (a) total, (b) interannual and (c) multidecadal regressions.



Supplementary Figure 2. Regressions (10-7 s-1 per ACE) of relative vorticity at 850-mb during June-November onto the NA detrended ACE index. Shown are the (a) total, (b) interannual and (c) multidecadal regressions.