On the impacts of central Pacific warming events on Atlantic tropical storm activity

Sang-Ki Lee[1,2], Chunzai Wang[2] and David B. Enfield[1,2]

[1]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami FL

[2]Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami FL

Submitted to Geophysical Research Letters

March 2010

Corresponding author address: Dr. Sang-Ki Lee, NOAA/AOML, 4301 Rickenbacker Causeway, Miami, FL 33149, USA. E-mail: Sang-Ki.Lee@noaa.gov.

Abstract

A recent study by Kim et al. [2009] claim that central Pacific warming (CPW) events in 1969, 1991, 1994, 2002 and 2004 are associated with a greater-than-average frequency of tropical storm and increasing landfall potential along the Gulf of Mexico coast and Central America. Based on independent data analysis of tropical cyclone activity in the five CPW years and some modeling experiments, we show here that only 1969 is characterized with a greater-than-average cyclone activity in the Gulf of Mexico and Caribbean Sea, which is due to the presence of a very large Atlantic warm pool in that year. Therefore, we conclude that Kim et al. [2009] may be falsely associating central Pacific warming events to an increased frequency of cyclone activity in the Gulf of Mexico and Caribbean Sea. Future investigations on the remote impact of CPW events must be supported by a much longer time series data, with the effect of tropical North Atlantic SST removed, to achieve a statistically significant result. Nevertheless, our model experiments show that the vertical wind shear responses in the main development region (MDR) for Atlantic hurricane to 1969, 1991, and 2004 CPW events are all positive, suggesting that the anomalous Walker circulations in the MDR during CPW events may be similar to that during eastern Pacific warming (EPW) events associated with El Niño, only weaker because the amplitude of CPW events is generally smaller than that of EPW events.

1. Introduction

The so-called central Pacific warming (CPW) phenomenon, which is characterized by anomalously warm sea surface temperature (SST) in the central equatorial Pacific Ocean, has received some attentions in recent years [e.g., *Ashok et al*., 2007; *Weng et al*., 2007; *Kug et al*., 2009; *Yeh et al*., 2009]. According to the externally forced model simulations for the 21st century used in the Intergovernmental Panel for Climate Change - 4th Assessment report, the frequency of CPW events is significantly increased between 2000 and 2100, whereas the frequency of eastern Pacific warming (EPW) events associated with El Niño is decreased [*Yeh et al.*, 2009]. *Yeh et al.*, [2009] argued that the change in the occurrence ratio of CPW to EPW (or shift in El Niño pattern) is associated with flattening of the thermocline in the equatorial Pacific under the influence of anthropogenic global warming [*DiNezio et al.*, 2009]. By using the historical El Nino indices of Niño3 and Niño4 SSTs to distinguish two variations of El Niño for the period of 1954-2007, *Yeh et al*. [2009] further argued that the modification of El Niño pattern due to anthropogenic global warming is already in progress since the CPW has been occurring more frequently since the 1990s.

It is well known that the canonical EPW pattern associated with El Niño suppresses Atlantic cyclone activity because the anomalous Walker circulation associated with El Niño tends to increase the vertical wind shear over the main development region (MDR) for Atlantic hurricane [e.g., *Goldenberg and Shapiro*, 1996]. A recent study by *Kim et al.* [2009] (KWC09) claimed that, "*in contrast to EPW events, CPW episodes are associated with a greater-than-average frequency and increasing landfall potential along the Gulf of Mexico coast and Central America*". They also stated that "*compared to climatology, track density for CPW increases across the Caribbean, the Gulf of Mexico, and the U.S. east coast*". However, it is shown in this study that neither our independent data analysis of Atlantic tropical cyclones nor further numerical modeling experiments supports the alleged impact of CPW events on increasing the Atlantic tropical storm activity reported in KWC09.

2. Data Analysis

KWC09 used a criterion of detrended Niño4 warming exceeding 1 standard deviation while Niño3 stays below this range in the extended reconstructed sea surface temperature version 2 (ERSST2) [*Smith and Reynolds*, 2004] to identify five CPW events in 1969, 1991, 1994, 2002 and 2004. Their conclusions are based on the five-year average of tropical storm data. The hurricane reanalysis database of HURDAT at NOAA AOML (http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html) for the period of 1950-2006 is used to generate detrended hurricane indices for the five individual years as shown in Table 1. The last column in Table 1 is the number of tropical storms that either form inside or move into the Gulf of Mexico (100^{o}W – 80^{o}W, 20^{o}N – 30^{o}N) and Caribbean Sea (90^{o}W – 60^{o}W, 10^{o}N – 20^{o}N), referred to as Intra-Americas Sea (IAS) cyclone activity hereafter. Also included in this table are the detrended Niño4, the detrended size of Atlantic warm pool (AWP), which is defined as the tropical Atlantic sea surface area of its surface temperature exceeding 28.5^{o}C [*Wang et al.*, 2006], and the detrended vertical wind shear between 200 and 850 mb in the main development region (MDR: 85^{o}W-15^{o}W, 5^{o}N-20^{o}N) for Atlantic hurricane obtained from NCEP reanalysis [*Kalnay et al.*, 1996], all averaged for the Atlantic hurricane season of June to November. KWC09 used hurricane indices averaged for August-September-October (ASO). However, it is important to include the early season of June and July because a large of portion of the IAS storms typically form in those two months (e.g., *Inoue et al.*, 2002; *McAdie et al.*, 2009).

All of the five hurricane indices, including IAS cyclone activity, indicate that Atlantic cyclone activity is either below average or neutral in 1991 and 1994. In both 2002 and 2004, the number of cyclones formed in or moved into the IAS is 6.7, which is slightly greater than the 57-year (1950-2006) mean of 5.8. However, the difference is statistically insignificant at 99% confidence [*Efron*, 1979]. Therefore, among the five CPW years, 1969 was the only year of significantly greater-than-average cyclone activity in the IAS.

To have a better perspective of the potential relationship between the CPW events and IAS cyclone activity, it is useful to examine other cyclone indices. According to the tropical storm index, for instance, only 1969 and 2004 can be characterized with a greater-than-average frequency of tropical storm, whereas 1991, 1994 and 2002 have either a neutral or a lesser-than-average frequency. The number of hurricanes, the number of major hurricanes, and the accumulated cyclone energy (ACE) index also show the same result. The five-year averaged tropical storm index is slightly above the climatological mean mainly because of 1969 and 2004, which were quite active years. It is immediately noticed that the AWP is significantly larger than average in both 1969 and 2004, whereas it is smaller than average in 1991, 1994 and 2002 [*Wang et al.*, 2006]. Earlier studies based on theory, observations and models have consistently shown that local sea surface temperature (SST) in the tropical North Atlantic can greatly influence the cyclone activity because warm (cold) tropical North Atlantic SSTs reduce (increase) the MDR vertical wind shear [e.g., *Knight et al*., 2006; *Wang et al*., 2006; *Zhang and Delworth*, 2006; *Vimont and Kossin*, 2007; *Saunders and Lea*, 2008]. Consistent with this robust relationship among the AWP, MDR vertical wind shear and Atlantic tropical storm activity, Table 1 clearly shows that the MDR vertical wind shear is significantly reduced in the summer of both 1969 and 2004, during which the AWP was significantly larger than average and the cyclone activity was significantly above normal. Therefore, it is quite logical to presume that the spread of tropical storm frequency among the five CPW years can be readily explained by the local SST index of the AWP without invoking a remote influence from the tropical Pacific.

3. Model Experiments

It is clear from the above discussion that the presence of a very large AWP in 1969 and 2004 makes it difficult to attribute the increased cyclone frequency to the CPW events. Therefore, in an effort to isolate the remote influence of the 1969 and 2004 CWP events from the local SST influence, we perform multiple sets of ensemble model experiments using the NCAR atmospheric general circulation model coupled to a slab mixed layer ocean model [*Lee et al.*, 2008]. The model experiments are performed by prescribing the evolution of SSTs only in the tropical Pacific (15^{o}S-15^{o}N; 120^{o}E–coast of the Americas) for 1969 and 2004, and for a typical EPW year of 1987 (KWC09 used a criterion of detrended Niño3 warming exceeding 1 standard deviation in the ERSST2 to identified nine EPW years, which includes 1987), while predicting the SSTs outside of the tropical Pacific using the slab ocean model. It is important to understand that these experiments are not designed to reproduce observations but to isolate the remote impacts of CPW from the local impact of AWP. The detailed methodology is described in *Lee et al.*, [2008].

Figure 1 shows the simulated vertical wind shear change for the 1969, 1987 and 2004 cases. The simulated vertical wind shear for the 1987 EPW case is greatly increased over the MDR (MDR-averaged vertical wind shear change = 1.1 m/s) as in the observation (not shown), suggesting that the 1987 EPW event is responsible for significantly reduced cyclone activity in that year: the detrended tropical storm index for 1987 is 6.3, which is significantly less than the climatological mean of 10.7. However, the simulated MDR vertical wind shear for the 1969 CPW event, in which the local impact of a large AWP in 1969 is removed, is slightly increased from the climatology (MDR-averaged vertical wind shear change = 0.3 m/s), and thus indicates that the 1969 CPW event is not likely to be responsible for the observed decrease in the MDR vertical wind shear and increased cyclone activity in 1969. The 2004 CPW case is more interesting because the vertical wind shear in the western and central parts of the MDR is increased as much as in the 1987 EPW case, although the MDR-averaged vertical wind shear increase is modest (0.3 m/s) due to a negative response in the eastern part of the MDR. The upshot is that the simulated vertical wind shear responses to the 1969 and 2004 CPW events are positive. Thus, the model experiments support our hypothesis that the large AWPs in the summer of 1969 and 2004 are primarily responsible for the observed decreases in the MDR vertical wind shear and increased cyclone activity in those years.

We also performed another set of ensemble experiments for the 1991 CPW case to find that the simulated MDR vertical wind shear response is also positive, with the MDR-averaged vertical wind shear increase of 0.5 m/s (not shown). Therefore, the simulated MDR vertical wind shear responses to the 1969, 1991 and 2004 CPW events are all positive as in the case of 1987 EPW event, which represents the canonical EPW pattern associated with El Niño. This suggests that the anomalous Walker circulation in the MDR associated with CPW events may be similar to that during EPW events, only weaker because the amplitude of CPW events (i.e., Niño4 index) is generally smaller than that of EPW events (i.e., Niño3 index) [e.g., *Ashok et al.*, 2007].

4. Summary and Discussions

In summary, our independent data analysis of tropical cyclone activity in the five CPW years and the modeling experiments suggest that only 1969 has significantly greater-than-average storm activity over the Gulf of Mexico and Caribbean Sea, which is likely due to the presence of a very large Atlantic warm pool in that year. Therefore, we conclude that KWC09 may be falsely associating CPW events to an increased frequency of cyclone activity in the Gulf of Mexico and Caribbean Sea. It is worthwhile to point out that KWC09 used different storm indices (*i.e.*, the number of tropical cyclones per month and storm track density during ASO). Nevertheless, if their finding were a robust one, our independent data analysis and model experiments would have supported it.

Future investigations on the remote impact of CPW events must be supported by a much longer time series data (or many more cases of CPW event), with the effect of tropical North Atlantic SST removed, to achieve a statistically significant result. Nevertheless, our model experiments show that the simulated MDR vertical wind shear responses to the 1969, 1991 and 2004 CPW events are all positive, suggesting that the anomalous Walker circulations in the MDR during CPW events may be similar to that during EPW events, only weaker because the amplitude of CPW events (i.e., Niño4 index) is generally smaller than that of EPW events (i.e., Niño3 index) [e.g., *Ashok et al*., 2007].

Acknowledgments. We wish to thank Frank Marks for thoughtful comments and suggestions. We are also indebted to Robert Atlas for his encouragement and support. This work was supported by a grant from National Oceanic and Atmospheric Administration (NOAA) Climate Program Office. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the funding agency.

References

Ashok, K., S. Behera, A. S. Rao, H. Y. Weng, T. Yamagata (2007), El Nino Modoki and its possible teleconnection, *J. Geophys. Res*., **112**, C11007, doi:10.1029/2006JC003798.

DiNezio, P. N., A. C. Clement, G. A. Vecchi, B. J. Soden, B. P. Kirtman, and S.-K. Lee (2009), Climate response of the equatorial Pacific to global warming. *J. Clim.*, 22, 4873-4892.

Efron, B. (1979), Computers and the theory of statistics: thinking the unthinkable, *SIAM Rev.*, **21**, 460-480.

Goldenberg, S. B. and L. J. Shapiro (1996), Physical mechanisms for the association of El Niño and West African rainfall with Atlantic major hurricane activity, *J. Clim.*, **9**,1169-1187.

Inoue, M., I. C. Handoh, and G. R. Bigg (2002), Bimodal distribution of tropical cyclogenesis in the Caribbean: characteristics and environmental factors. *J. Clim.*, **15**, 2897–2905.

Kalnay et al. (1996), The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc.*, **77**, 437-470.

Kim, H.-M., P. J. Webster, J. A. Curry (2009), Impact of shifting patterns of Pacific Ocean warming on North Atlantic tropical cyclones, *Science*, **325**, 77-80.

Knight J. R., C. K. Folland, A. A. Scaife (2006), Climate impacts of the Atlantic Multidecadal Oscillation, *Geophys. Res. Lett*. **33**, L17706, doi:10.1029/2006GL026242.

Kug, J.-S., F.-F. Jin and S.-I. An (2009), Two-types of El Nino events: cold tongue El Nino and warm pool El Nino, *J. Clim.*, **22**, 1499-1515.

Lee, S.-K., D. B. Enfield, and C. Wang (2008), Why do some El Ninos have no impact on tropical North Atlantic SST?, *Geophys. Res. Lett.*, **35**, L16705, doi:10.1029/2008GL034734.

McAdie, C. J., C. W. Landsea, C. J. Neumann, J. E. David, E. Blake, and G. R. Hamner (2009), Tropical cyclones of the North Atlantic Ocean, 1851-2006. Historical climatology series 6-2, NCDC-NHC, 238 pp.

Saunders, M. A., and A. S., Lea (2008), Large contribution of sea surface warming to recent increase in Atlantic hurricane activity, *Nature*, **451**, 557-560.

Smith, T. M., and R. W. Reynolds (2004), Improved extended reconstruction of SST (1854-1997), *J. Clim.*, **17**, 2466-2477.

Vimont, D. J., and J. P. Kossin (2007), The Atlantic meridional mode and hurricane activity, *Geophys. Res. Lett.*, **34**, L07709, doi:10.1029/2006GL029683.

Wang, C., D. B. Enfield, S.-K. Lee, and C. W. Landsea (2006) Influences of Atlantic warm pool on western hemisphere summer rainfall and Atlantic hurricanes, *J. Clim.*, **19**, 3011-3028.

Weng, H. Y., K. Ashok, S. Behera, A. S. Rao, T. Yamagata (2007), Impacts of recent El Niño Modoki on dry/wet conditions in the Pacific rim during boreal summer, *Clim. Dyn.* **29**, 113-129.

Yeh, S.-W., J.-S. Kug, B. Dewitte, M.-H. Kwon, B. Kirtman, and F.-F. Jin (2009), El Niño in a changing climate, *Nature*, **461**, 511-514.

Zhang R., T. L. Delworth (2006), Impact of Atlantic multidecadal oscillations on India/Sahel rainfall and Atlantic hurricanes, *Geophys. Res. Lett.* **33**, L17712, doi:10.1029/2006GL026267.

Table 1. Detrended hurricane indices for the five CPW years (1969, 1991, 1994, 2002 and 2004), the five-year mean and the climatological mean for 1950 - 2006 period. The 5th, 6th and 7th columns represent the number of tropical storm (TS), hurricane (HR) and major hurricane (MH, categories 3 - 5). The 8th column is the accumulated cyclone energy (ACE). The 9th column is US landfalling hurricanes (USL). The last column is the number of tropical storms that either form inside or move into the Gulf of Mexico (100^{o}W – 80^{o}W, 20^{o}N – 30^{o}N) and Caribbean Sea (90^{o}W – 60^{o}W, 10^{o}N – 20^{o}N), referred to as Intra-Americas Sea cyclone activity (IAS). Also included in this table are the detrended Niño4 index, the size of Atlantic warm pool (AWP), and the vertical wind shear between 200 and 850mb in the MDR (85^{o}W-15^{o}W, 5^{o}N-20^{o}N), all averaged for the Atlantic hurricane season of June to November. To construct this table, the hurricane reanalysis database of HURDAT, the ERSST2, and NCEP reanalysis, all for the period of 1950-2006 are used. All data values are detrended. Any value larger (smaller) than the climatological mean with above the 99% significance is in bold (italic). In the case of MDR vertical wind shear, the bold and italic are switched.

Year	Niño4 (^{o}C)	AWP (%)	VWS (m/s)	TS (#)	HR (#)	MH (#)	ACE (10^4 kt^2)	USL (#)	IAS (#)
1969	**0.62**	**67.9**	**-0.8**	**18.7**	**12.1**	**4.9**	**159.3**	2.1	**10.1**
1991	**0.59**	*-33.8*	*1.4*	*7.0*	*3.8*	2.1	*32.2*	*0.9*	*1.8*
1994	**0.70**	*-54.6*	-0.3	*5.8*	*2.8*	*0.2*	*29.8*	*0.0*	*3.8*
2002	**0.69**	-7.0	*0.9*	10.1	*3.6*	2.2	*62.7*	*0.8*	6.7
2004	**0.51**	**51.3**	**-1.5**	**13.0**	**8.6**	**6.3**	**220.4**	**5.8**	6.7
CPW mean	**0.62**	4.8	-0.1	10.9	6.2	3.1	100.9	1.9	5.8
Climatology	0.00	0.0	0.0	10.7	6.2	2.7	101.9	1.6	5.8

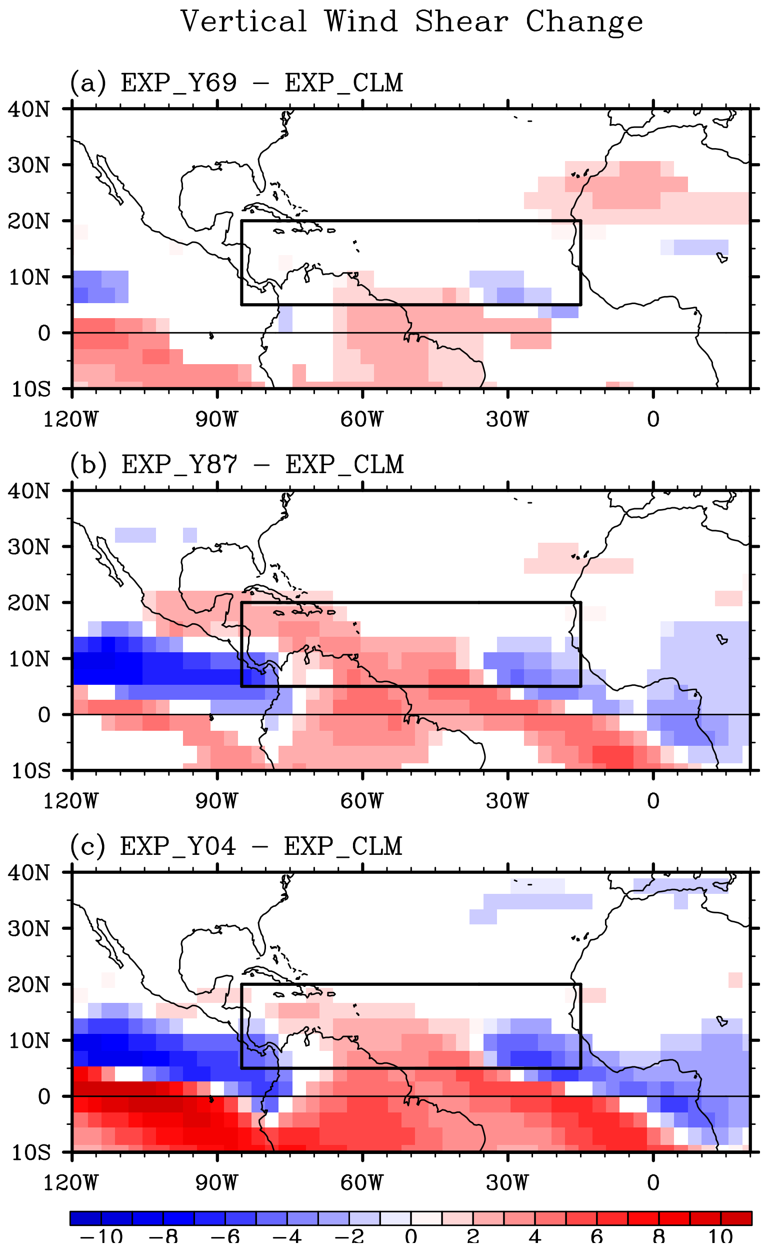

Figure 1. Tropospheric vertical wind shear (200mb minus 850mb) difference (ms^{-1}) in June-November between (a) EXP_Y69 and EXP_CLM, between (b) EXP_Y87 and EXP_CLM, and between (c) EXP_Y04 and EXP_CLIM. For EXP_Y69, EXP_Y87, EXP_Y04 and EXP_CLM, the SSTs in the tropical Pacific region (15^{o}S-15^{o}N; 120^{o}E–coast of the Americas) are prescribed with those of 1969, 1987, 2004 and climatology, respectively, while predicting the SSTs outside of the tropical Pacific using the slab ocean model. Each experiment consists of ten model

integrations that are initialized with slightly different conditions to represent internal atmospheric variability. The shading denotes a statistical confidence at the 95% or above based on a student-t test.