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March 8, 2013

INVITATION

Dear Dr. Lei Wang:
On behalf of the 17th Pacific Asian Marginal Seas (PAMS) Meeting Local Organizing Committee, I am pleased to invite you to participate to the 17th PAMS Meeting which to be held on 23-25 April 2013 at Hangzhou, China.

For details of the symposium, please visit the 17th PAMS Meeting Web at http://soed.org.cn/pams2013

If you have any questions, please do not hesitate to contact me. We look forward to seeing you at Hangzhou.

Sincerely,

Yuan Yaochu

Prof. Yaochu Yuan
Chair
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The 17th PAMS meeting
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Climatology of tropical cyclone genesis over the South China Sea

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Abstract: This study examines the climatology of tropical cyclone (TC) genesis over the South China Sea (SCS) using a genesis potential (GP) index developed by Emanuel and Nolan. How different environmental factors (including low-level vorticity, mid-level relative humidity, vertical wind shear, and potential intensity) contribute to the modulation of TC genesis over the SCS by the monsoon, ENSO, ENSO Modoki and global warming are investigated. The results highlight the different roles of large-scale environmental factors on the TC genesis over the SCS on different time-scales.

Keywords: tropical cyclone, South China Sea, cyclogenesis

1. INTRODUCTION

Tropical cyclones (TCs) are one of the most deadly and destructive natural disasters in terms of loss of human life and economic destruction. The South China Sea (SCS), which is a large semi-enclosed marginal sea in the western Pacific Ocean, is one region where TCs occur frequently (e.g., McGregor, 1995; Wang et al., 2007; Zuki and Lupo, 2008; Goh and Chan, 2010). Considering the dense population living on the coastal fringes and the heavy fishing and shipping activities in the SCS, the damage caused by a storm that forms over the SCS may be very serious due to the shorter warning time of these storms before landfall. The strong winds and heavy rainfall from TCs could lead to serious disasters, such as storm surge, flooding, landslides, etc., which could cause great losses of life and property. In an average year, seven TCs made landfall over China mainland and Hainan Island, and cause 28.7 billion yuan in direct economic losses and kill 472 people (Zhang et al., 2009). Understanding the nature and climatology of TC activity in the SCS is an important step toward improving risk assessment.

It is well known that TC activity in most ocean basins is strongly influenced by various modes of natural climate variability (Camargo et al., 2010). Understanding the influence of large-scale environmental factors on tropical cyclogenesis is one important problem. Empirical methods have been used to represent the relationship between large-scale environmental factors and tropical cyclogenesis due to the absence of a comprehensive theory. Emanuel and Nolan (2004) developed an empirical index called the Genesis Potential (GP) Index to relate tropical cyclogenesis to several environmental factors. Such an empirical index is helpful in understanding the influence of large-scale environmental factors on tropical cyclogenesis, and also provides an empirical quantification of the relative contributions of different environmental factors in tropical cyclogenesis. In this study, we will examine the climatology of TC genesis over the SCS using the GP index developed by Emanuel and Nolan. How different environmental factors contribute to the modulation of TC genesis over the SCS by the monsoon, ENSO, ENSO Modoki and global warming will be investigated.

2. DATA AND METHODOLOGY

The GP index developed by Emanuel and Nolan (2004) is defined as

$$GP = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 (1 + 0.1 V_{shear})^{-2} \quad (1)$$

where η is the absolute vorticity (s^{-1}) at 850 hPa, H is the relative humidity (%) at 600 hPa, V_{pot}

is the potential intensity (m s^{-1}), and V_{shear} is the magnitude of the vertical wind shear (m s^{-1}) between 850 hPa and 200 hPa. The absolute vorticity and vertical wind shear are considered as dynamic components, and the relative humidity and potential intensity are thermodynamic components. More detailed information about the index can be found in Emanuel and Nolan (2004) and Camargo et al. (2007a, b). The GP index has been tested to have the ability to reproduce observed variations in TC activity with the annual cycle, the ENSO (Camargo et al., 2007a) and the Madden-Julian oscillation (MJO) (Camargo et al., 2009). This index has already been used in many other studies related with tropical cyclogenesis (e.g., Vechi and Soden, 2007; Nolan et al., 2007; Yokoi et al., 2009; Zhang et al., 2010; Evan and Camargo, 2011).

In this study, the GP index was calculated using monthly mean atmospheric data from the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis (Kalnay *et al.*, 1996) and monthly mean sea surface temperature (SST) data were obtained from the Extended Reconstruction Sea Surface Temperature (ERSST) (Smith et al., 2004; Smith et al., 2008) during the period of 1970-2010. The observed cyclone genesis events during 1970-2010 over the SCS were taken from the Joint Typhoon Warning Center (JTWC) best-track dataset that has six-hourly TC position and intensity estimates. Genesis locations and times of TCs are defined as the first position and time for a TC that attains tropical depression strength. Monthly mean evaporations from the ocean surface were obtained from the objective analyzed air-sea fluxes (OAFlux) data set (Yu and Weller, 2007; http://oaflux.whoi.edu/). The datasets of the GFDL-CM2.0 climate model are used to analyze environmental factors in a global warming scenario. The observed cyclone genesis events during 1945-2010 over the SCS were taken from the Joint Typhoon Warning Center (JTWC) best-track dataset that has six-hourly TC position and intensity estimates.

3. RESULTS

3.1 Seasonal variation of TC genesis over the SCS

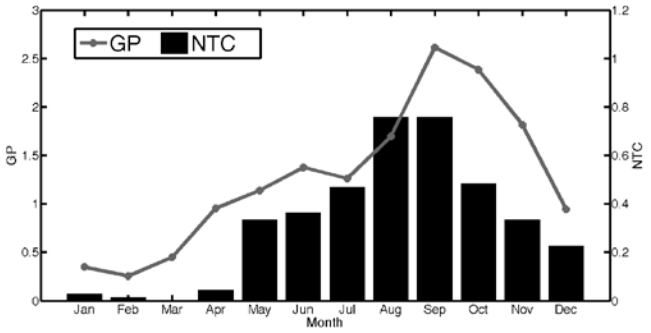

Fig. 1: Annual cycle of the climatological GP index averaged over the SCS and climatological number of TCs (NTC) during 1945-2010.

Modulation of the TC genesis over the SCS by the monsoon has been examined using a GP index. Our goals were to test the ability of the index to reproduce observed seasonal variations in TC activity with the annual cycle and monsoon and then to use modified version of the index to determine which individual physical factors are most important in causing these variations. Our primary conclusions are as follows:

1) The GP index captures the main elements of the seasonal variations of the observed frequency and location of TC genesis over the SCS.

2) The index successfully reproduces the monsoon-induced TC genesis variations over the SCS, such as the suppression of genesis over the southern SCS during the summer monsoon and the southward shift in genesis locations during the winter monsoon.

3) The different factors entering the index contribute differently to the monsoon impacts on tropical cyclogenesis over the SCS. The degree of contribution by each factor in different regions is determined quantitatively by producing composites of modified indices in which only one of the contributing factors varies, with the others set to climatology. Over the northern SCS, potential intensity makes the largest contributions to the seasonal changes in tropical cyclogenesis. Over the southern SCS, the low-level relative vorticity plays the largest role in the seasonal modulation of TC genesis frequency, and the vertical wind shear plays the secondary role in the seasonal variation of tropical cyclogenesis. Thermodynamics factors play more important roles for the seasonal variations in tropical cyclogenesis

over the northern SCS, while dynamic factors are more important in the seasonal modulation of TC genesis frequency over the southern SCS.

3.2 Interannual variation of TC genesis over the SCS

3.2.1 ENSO modulation

We examine the modulation of tropical cyclogenesis over the southern SCS by the ENSO during October-December (OND), when TC activities are most active over this region. Results reveal that there were more TCs formed in this region during La Niña years and less TCs during El Niño years. How different environmental factors contribute to these influences is investigated, using the GP index. Composite anomalies of the GP index are produced for El Niño and La Niña years separately, which could account for the changes of TC frequency over the southern SCS in different ENSO phases. The degree of contribution by each factor is determined quantitatively by producing composites of modified indices in which only one of the contributing factors varies, with the others set to climatology. Results reveal that the midlevel relative humidity makes the largest contribution to the ENSO modulation of tropical cyclogenesis over the southern SCS. Although warmer SSTs and more evaporation from the ocean surface were observed during El Niño years, anomalous descending motions due to the anomalous Walker circulation inhibited the upward transports of water vapor and led to less moisture contents in the middle troposphere in the southern SCS, which suppressed TC formations over this region. Additional analysis for neutral years suggests that the midlevel relative humidity also makes the largest contribution to the interannual variations of tropical cyclogenesis over the SSCS.

3.2.2 ENSO Modoki modulation

The modulation of tropical cyclogenesis over the SCS by the ENSO Modoki during the boreal summer is investigated. Results reveal that there were more TCs formed over the SCS during central Pacific warming years and less TC frequency during central Pacific cooling years. Composite anomalies of the GP index are produced for central Pacific warming and cooling years separately, which could account for the changes of TC frequency over the SCS in different ENSO Modoki phases. The degree of contribution by each factor is determined quantitatively by producing composites of modified indices in which only one of the contributing factors varies, with the others set to climatology. Results reveal that the vertical wind shear and low-level relative vorticity make the largest contribution, which is mainly due to the ENSO Modoki-induced anomalous circulations in Matsuno-Gill patterns.

These results suggest the different roles of large scale environmental factors and different physical processes in ENSO and ENSO Modoki modulations of tropical cyclogenesis over the SCS.

3.3 Global warming scenario

The possible impacts of global warming on TC formation over the SCS are examined by analyzing the changes of the GP Index in a global warming scenario using the datasets of the GFDL-CM2.0 climate model. The results reveal that the GP index tends to decrease over the northern SCS in the future warming climate scenario, indicating that the number of TCs formed over the northern SCS may be reduced in the future. The vertical wind shear and low-level relative vorticity are the two main factors causing the decrease of the GP index. Over the southern SCS, the GP index tends to increase in the future warming climate scenario, indicating that the number of TCs formed over the southern SCS may be increased. The mid-level humidity is found to be the main factor causing the increase of the GP index.

4. CONCLUSIONS

The climatology of TC genesis over the SCS is studied using a GP index developed by Emanuel and Nolan. How different environmental factors contribute to the modulation of TC genesis over the SCS by the monsoon, ENSO, ENSO Modoki and global warming are investigated. The results highlight the different roles of large-scale environmental factors on the TC genesis over the SCS on different time-scales.

Acknowledgments: This work was funded by the National Natural Science

Foundation of China (No.41205026).

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