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14. ABSTRACT

The goal of this project is to understand the fundamental dynamics of interactions between tropical cyclone (TC) and large-scale low-frequency circulation such as the monsoon gyre (MG) over the western North Pacific (WNP). Through its interaction with low-frequency flow, TC may experience unusual track change and intensity change. The project is to conduct an observational analysis to identify the impact of low-frequency motion on TCs in the WNP during the past decade (2000-2011), and to conduct idealized and real-case numerical model simulations to understand the impact of the low-frequency motion on TCs. It is anticipated that successful completion of this project would lead to advance of our current understanding of TC-low-frequency flow interaction, which may help improve current operational TC forecast skill.

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Entitled

INTERACTIONS BETWEEN TROPICAL CYCLONE AND LARGE-SCALE MONSOON GYRE

NRL BAA topic: Atmospheric effects, analysis and prediction (**75-15-01**)

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1. Project Summary

The goal of this project is to understand the fundamental dynamics of interactions between tropical cyclone (TC) and large-scale low-frequency circulation such as the monsoon gyre (MG) over the western North Pacific (WNP). Through its interaction with low-frequency flow, TC may experience unusual track change and intensity change. The project is to conduct an observational analysis to identify the impact of low-frequency motion on TCs in the WNP during the past decade (2000-2011), and to conduct idealized and real-case numerical model simulations to understand the impact of the low-frequency motion on TCs.

It is anticipated that successful completion of this project would lead to advance of our current understanding of TC-low-frequency flow interaction, which may help improve current operational TC forecast skill.

2. Research Achievement

2.1 Physical mechanism for earlier and later onset of TC season in WNP

The interannual variability of onset date of a typhoon season in the western North Pacific (WNP) during 1979-2015 was investigated (Zuo et al. 2018). An earlier onset group and a later onset group were selected, with the average date in early April for the earlier onset group and in late July for the later onset group. A diagnosis of the genesis potential index anomaly (GPIA) suggests that the key factor affecting the earlier and later groups is the background moisture field.

The earlier onset cases may be divided into two sub-groups. In the first sub-group, positive specific humidity anomalies were caused by horizontal advection of anomalous wind associated with a La Niña pattern in the equatorial eastern Pacific. In the second sub-group, positive humidity anomalies were caused by anomalous convection associated with SST anomalies (SSTA) similar to the Pacific Meridional Mode (PMM) in the tropical and subtropical eastern Pacific. In the later onset composite, negative specific humidity anomalies were accompanied by an anomalous anticyclone and a V-shape negative SSTA in the WNP.

In addition, the change of background vertical wind shear (VWS) also has an influence on the onset date of a TC season. A decreased vertical shear and anomalous easterly shear of zonal wind happens in the earlier onset composite. While in the later onset composite, there is an increased vertical shear and anomalous westerly shear of zonal wind. It's argued that both the magnitude of the VWS and the sign of anomalous zonal wind shear may affect TC formation.

2.2 Interdecadal change of TC controlling parameter in WNP

The interdecadal change of tropical cyclone (TC) controlling parameter in the western North Pacific (WNP) was investigated using observational data (Hu et al. 2018). Through the diagnosis of the relative role of each term of the TC genesis potential index (GPI), it was found that the dominant factor controlling interannual TC genesis frequency was specific humidity in 1950-1976, maximum potential intensity or sea surface temperature (SST) in 1977-1998, and relative vorticity in 1999-2014.

The change of environmental specific humidity during 1950-1976 was primarily attributed to the advection of the mean moisture by anomalous low-level wind in ENSO developing summer. The change of SST during 1977-1998 was primarily affected by a V-shape SST pattern in western Pacific in ENSO decaying summer. The change of environment relative vorticity during 1999-2014 was primarily controlled by a strong cyclonic flow anomaly associated with CP-type El Niño.

The change of dominant environmental controlling parameter is ultimately caused by the change of ENSO behavior. Compared to the first interdecadal period, a stronger EP-type ENSO variability in IP2 leads to a stronger circulation and SST response in ENSO decaying phase. The occurrence of more frequent CP type El Niño in IP3 was possibly attributed to both suppressed

convection and low-level divergence over the central equatorial Pacific and a warming trend in the tropics.

2.3 Basin-dependence of MJO modulation on TCs

The modulation of tropical cyclone (TC) genesis over the western North Pacific (WNP) and the tropical North Atlantic (NAL) by MJO was investigated based on observational analysis and numerical simulations (Zhao et al. 2019). A genesis potential index (GPI) was used to investigate relative contributions of environmental parameters associated with the MJO to TC genesis. It is found that relative humidity plays the most important role in modulating TC genesis in the WNP, the Gulf of Mexico and the western Caribbean Sea (GOM), while vertical wind shear associated with the MJO has the most significant impact on TC activities in the eastern Atlantic (EAT).

To further understand the relative importance of the MJO dynamic and thermodynamic impact on TC activities, idealized numerical model experiments were conducted using the Advanced Research version of the Weather Research and Forecasting model (WRF-ARW). The results are consistent with our observational analysis results, that is, MJO modulation on TC activities in the WNP, the GOM and the EAT are basin-dependent. MJO related moisture field is most important in regulating TC development in the WNP and the GOM, while MJO related vertical wind shear is most critical in affecting TC formation in the EAT.

2.4 Mechanism for near-equatorial TC formation

The near-equatorial tropical cyclone (TC) within the belt of 5°N – Equator in the western North Pacific (WNP) exhibits a distinctive seasonal variability with a peak phase in northern winter, as oppose to TCs in the main development region over the WNP. The mechanism for such a distinctive annual evolution was investigated through the diagnosis of the genesis potential index (GPI) (Li et al. 2018). By isolating the effect of various environmental parameters, we found that the increase of the near-equatorial GPI in northern winter is primarily attributed to low-level absolute vorticity. As season progresses from boreal summer to winter, the northeasterly trade winds turn anticlockwise near the equator, leading to a maximum low-level cyclonic vorticity near 5°N. The seasonal change of other environmental conditions such as relative humidity and SST is not critical. While the effect of area-averaged vertical wind shear is small due to an opposite sign between western and eastern sector of the WNP in northern winter, a moderate vertical shear in 2-5°N, 140-160°E may help the development of TC-like disturbances in the region. The overall analysis result suggests that dynamic parameters are more important for the formation of near-equatorial TCs.

2.5 Publish a book entitled "Fundamental of Tropical Climate Dynamics"

A textbook was written for an advanced graduate student course for master and PhD students in the major of Atmospheric, Oceanic and Climate Sciences (Li and Hsu 2017). The objective of this book is to introduce 1) fundamental dynamics of tropical atmosphere and ocean, 2) simple

and intermediate atmospheric and oceanic models, 3) observed phenomena associated with major climate modes in the tropics, and 4) current understanding of theories and mechanisms associated with these modes.

A particular focus is on atmosphere-ocean interactions and physical processes relevant to 1) tropical mean climate such as the equatorial asymmetry of the Inter-Tropical Convergence Zone (ITCZ) and the annual cycles of sea surface temperature (SST) and wind at the equator, 2) formation of tropical cyclone (TC) and synoptic-scale variability in the western North Pacific (WNP), 3) propagation and initiation of atmospheric intraseasonal oscillations such as the Madden-Julian Oscillation (MJO) and boreal summer intraseasonal oscillation (BSISO), 4) mechanisms for the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), and 5) variability of the monsoon. Theories and conceptual ideas are introduced and discussed for better understanding of physical mechanisms behind the observational phenomena.

It is the authors' hope that through this book, graduate students are able not only to gain basic knowledge in climate dynamics but also to learn a way to conduct advanced research in atmospheric, oceanic and climate sciences.

3. Publication list:

The following papers have been published and acknowledged the support of this NRL grant:

Hu, F. T. Li, J. Liu, M. Peng, 2018: Cause of Interdecadal Change of Tropical Cyclone Controlling Parameter in the Western North Pacific. *Climate Dynamics*, 51, 719-732, DOI: 10.1007/s00382-017-3951-z

Li, T. and P.-C. Hsu, 2017: Fundamentals of Tropical Climate Dynamics, *Springer*, ISBN 978-3-319-59595-5.

Li, Y., T. Li, C. Fu, and P.-C. Hsu, 2018: Near-equatorial tropical cyclone formation in western North Pacific: Peak season and controlling parameter. *Clim. Dyn.*, **52** (5-6), 2765-2773, doi:10.1007/s00382-018-4291-3.

Zhao, C. and T. Li, 2019: Basin dependence of the MJO modulating tropical cyclone genesis. Climate Dynamics, in press. DOI: 10.1007/s00382-018-4502-y

Zuo, H., T. Li, J. Liu, and M. Peng, 2018: Physical processes controlling earlier and later onset of a typhoon season in the western North Pacific. *Climate Dynamics*, 51(7), 2807-2823, DOI : 10.1007/s00382-017-4046-6.

In addition, a manuscript is currently in revision:

Ding, L., T. Li, B. Xiang, and M. Peng, 2019: On the Westward Turning of Hurricane Sandy (2012): Effect of Atmospheric Intraseasonal Oscillations. J. Climate, in revision.