Modulation of Tropical Cyclone (TC) Activity over the Intra-Americas Sea by Intraseasonal Variability: Implications for Dynamical TC Prediction on Intraseasonal Time Scales

PI: Xianan Jiang; Co-PI: Ming Zhao

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Final Report

1. Results and accomplishments:

The following summarizes main achievements from both PI (Jiang) and co-PI (Zhao) during the four years of this project, with contributions from a post-doc (Xiang) at GFDL, and two postdocs (Neena, Zhao) at UCLA.

1. Improvement of GFDL HiRAM for simulating and predicting the Madden-Julian Oscillation

To construct a skillful forecast system based on GFDL GCM for prediction of the intraseasonal hurricane genesis proposed in this project, the Co-PI (Zhao) took significant model development efforts based on an earlier version of the GFDL HiRAM (high resolution atmospheric model). The developed new model has evolved into the new generation GFDL AM4, which is highly capable of representing observed characteristics of the Madden-Julian Oscillation (MJO; Zhao et al., 2016). Several modifications in the new AM4 based on the University of Washington Shallow Cumulus scheme used in the HiRAM include, 1) an additional bulk plume for representing deep convection, 2) dependence of the entrainment rate in the deep plume on column-integrated relative humidity, 3) deep convective closure based on CAPE or cloud work function relaxation, 4) tuning of deep plume precipitation efficiency to enhance the detrainment of ice condensate, 5) consideration of precipitation re-evaporation in both shallow and deep plumes. As the main tool for studies proposed in this project, a hindcast system was then constructed based on a coupled version of AM4, i.e., CM4, with a nudging approach to generate both atmospheric and oceanic initial conditions. This coupled hindcast system was used to assess predictive skill and predictability of global MJO as well as intraseasonal hurricane genesis as reported below.

2. Evaluation of prediction skill for the MJO in hindcasts based on GFDL CM4

Led by the postdoc (Xiang) at GFDL, we first conducted a comprehensive evaluation of MJO prediction skill in boreal wintertime (November–April) by analyzing a series of hindcast experiments during 11 years (2003–13). Using the real-time multivariate MJO (RMM) index as a predictand, it is demonstrated that this forecast system shows excellent MJO prediction skill of about 27 days if measured by 0.5 of bivariate correlations of RMM1 and RMM2, on the bar of the best MJO predictive models in the community. The MJO prediction skill is also shown to be about 29 days during the Dynamics of the MJO/Cooperative Indian Ocean Experiment on Intraseasonal Variability in Year 2011 (DYNAMO/ CINDY) field campaign period. This model's potential predictability, the upper bound of prediction skill, extends out to 42 days, revealing a considerable unutilized predictability and a great potential for improving current MJO prediction. The skillful prediction of the MJO in GFDL CM4 justifies its potential capability for extended-range prediction of hurricane activity. A manuscript on comprehensive study on MJO predictive skill based on GFDL CM4 has been published in J. Climate (*Xiang et al.*, 2015b).

3. Intraseasonal prediction of hurricane genesis for Sandy and Haiyan based on GFDL CM4

By analyzing hindcasts from the new GFDL coupled forecast system with initial conditions generated by a simple atmospheric and oceanic SST nudging method, predictability of two destructive landfall tropical cyclones (TCs), i.e., Hurricane Sandy in 2012 and Super Typhoon Haiyan in 2013, is investigated. Results illustrate that geneses of these two TCs are highly predictable with the maximum prediction lead time reaching 11 days. This ''beyond weather time scale'' predictability of tropical cyclogenesis is primarily attributed to the model's skillful prediction of the MJO and the westward propagating tropical easterly waves. Meanwhile, the landfall location and time can be predicted one week ahead for Sandy's U.S landfall, and two weeks ahead for Haiyan's landing in the Philippines. The promising extended-range predictive skill for Sandy and Haiyan, together with low false alarms, indicates a great potential of using the GFDL coupled model for intraseasonal predictions of TC activity. This study has been published in Mon. Wea. Rev. (*Xiang et al.*, 2015a).

4. Intraseasonal predictability of tropical storm genesis based on coupled GFDL model system

As an extension of the study on predictability of TC genesis on two hurricane cases in Xiang et al. (2015a), we have conducted a comprehensive evaluation of TC genesis predictability by analyzing hindcasts for more than 600 TCs over global oceans during 11 years (2003-2013) by the coupled forecast system based on GFDL CM4. These 50-day hindcasts were initialized on 1st, 6th, 11th, 16th, 21st, and 26th day of each month with 12 ensemble members for each hindcast.

While potential predictability of about 11 days was found for Sandy and Haiyan in Xiang et al. (2015a), averaged predictability of TC genesis is much limited when evaluated for 600 TCs over global oceans. Relatively higher predictability is found over the western and eastern Pacific, than that over the north Atlantic. Further examination illustrates that genesis of TCs with higher genesis predictive skill are largely observed over the tropical western and eastern Pacific, and the main development region over the North Atlantic, collocated with regions where the tropical intraseasonal variability, and synoptic-scale waves, e.g., easterly waves, are active. In contrast, a large portion of the TCs with low genesis predictive skill are found to form over subtropical regions. Further analysis confirms that TCs with good predictive skill are significantly modulated by local intraseasonal variability modes and synoptic waves, particularly over the western and eastern Pacific, further suggesting important role of the intraseasonal variability and synoptic waves for providing predictability source of TC genesis.

It is further demonstrated based on GFDL CM4 hindcasts that predictability of several large-scale variables, which are considered important in regulating TC activity, including 850hPa vorticity, 500hPa moisture, vertical zonal wind shear between 200hPa and 850hPa, maximizes over the tropical western and eastern Pacific, and North Atlantic MDR regions, corresponding to local active intraseasonal variability and synoptic waves, in agreement with higher genesis predictive skill over these regions. A manuscript on this study will be submitted to J. Climate (*Jiang et al.*, 2016).

5. Exploring predictability and predictive skills for the ISV over the EPAC

The eastern Pacific (EPAC) warm pool is a region of strong intraseasonal variability (ISV) during boreal summer. While the EPAC ISV is known to have large-scale impacts that shape the weather and climate in the region (e.g., tropical cyclones and local monsoon), simulating the EPAC ISV is still a great challenge for present-day global weather and climate models. In this study, partly supported by this project with the aid from a post-doctoral researcher, Neena Mani, we investigated predictive skill and predictability of the EPAC ISV in eight coupled model hindcasts from the Intraseasonal Variability Hindcast Experiment (ISVHE). Relative to the prediction skill for the boreal winter MJO in the ISVHE (~15–25 days; *Neena et al.*, 2014b), the skill for the EPAC ISV is considerably lower in most models, with an average skill around 10 days. On the other hand, while the MJO exhibits a predictability of 35–45 days, the predictability estimate for the EPAC ISV is 20–

30 days. The prediction skill was found to be higher when the hindcasts were initialized from the convective phase of the EPAC ISV as opposed to the subsidence phase. Higher prediction skill was also found to be associated with active MJO initial conditions over the western Pacific (evident in four out of eight models), signaling the importance of exploring the dynamic link between the MJO and the EPAC ISV. The results illustrate the possibility and need for improving dynamical prediction systems to facilitate more accurate and longer-lead predictions of the EPAC ISV and associated weather and short-term climate variability. A manuscript on this study has been published in J. Climate (*Neena et al.*, 2014a).

6. Process-oriented diagnosis for the EPAC ISV

Supported by this project, the PI also contributed to a study led by Eric Maloney at Colorado State University in exploring process-oriented metrics in modeling the EPAC ISV based on eight AGCM simulations. Several process-oriented diagnostics are verified to identify key model processes for skillful model representation of the eastern Pacific ISV. It is suggested that a diagnostic based on the difference in 500-850hPa averaged relative humidity between the top 5% and the bottom 10% of precipitation events exhibits a significant correlation with the amplitude of the leading ISV mode across these model simulations. Diagnostics based on the vertically-integrated moist entropy budget also suggest the gross moist stability to be a good metric to discriminate models with strong and weak variability. In particular, the vertical component of gross moist stability exhibits a correlation of -0.9 with the ISV amplitude, suggesting that models in which convection and associated divergent circulations are less efficient at discharging moisture from the column are better able to sustain strong ISV. A manuscript on this study has been published in J. Climate (*Maloney et al.*, 2014a).

7. Participation of MAPP CMIP5 Task Force

Partly supported from this project, the PI (Jiang) participated in a coordinated activity led by the MAPP Program's CMIP5 Task Force. Collaborating with Eric Maloney, we assessed model fidelity in representing the ISV over the EPAC and Intra-America Sea (IAS) based on simulations from CMIP5 GCMs at 20th century condition and under future projection scenarios. The results suggest that a realistic summer mean state in a model could be critical for faithful simulations of the ISV over the EPAC. A manuscript (*Jiang et al.*, 2013) on this study has been published in J. Climate. Meanwhile, the PI also contributed to several overview papers in summarizing the coordinated CMIP5 Task Force activities, led by Justin Sheffield (*Sheffield et al.*, 2013) and Eric Maloney (*Maloney et al.*, 2014b).

8. Organization of the MJO Task Force / GEWEX GASS MJO Diabatic Heating Project

This MAPP project also partially supported the PI (Jiang)'s great efforts in co-leading the WCRP-WWRP/THORPEX YOTC/MJO Task Force - GEWEX GASS MJO model inter-comparison project (http://www2.cgd.ucar.edu/research/interdisciplinary-projects/yotc/mjo/vertical) during 2012-2015. At UCLA, we were mainly in charge of organization and analyses for the climate simulation component of this project. We co-organized a workshop in Singapore in June 2013 for this project, and presented results obtained from this project in various international conferences. A paper in summarizing the climate simulation component of this project, which is led by the PI with more than 30 coauthors, has been published in JGR-Atmospheres (*Jiang et al.*, 2015), along with other three companion manuscripts for the 2-day and 20-day hindcast components of this project, as well as a synthesis paper on this model evaluation project (*Xavier et al.*, 2015; *Klingaman et al.*, 2015b; *Klingaman et al.*, 2015a). This project has a great impact in tropical climate research community. Results from Jiang et al. (2015) paper on the climate simulation component of this project was highlighted in AGU research spotlight (https://eos.org/research-spotlights/circulation-models-cannot-simulate-organized-tropical-convection). Also the multi-model dataset generated from this project is

being actively used in the community.

9. Intraseasonal variability over the eastern Pacific and marine low-clouds

In this study, marine low cloud variability on intraseasonal time scales is characterized, with a particular focus over the Pacific basin during boreal summer and its association with the dominant mode of tropical ISV over the EPAC ITCZ. Analyses indicate that when anomalous ISV convection is enhanced over the elongated EPAC ITCZ, reduction of low cloud fraction (LCF) is evident over a vast area of the central north Pacific. Subsequently, when the enhanced ISV convection migrates to the northern part of the EPAC warm pool, a "comma shaped" pattern of reduced LCF prevails over the subtropical north Pacific, along with a pronounced reduction of LCF present over the southeast Pacific (SEPAC). Further analyses indicate that surface latent heat fluxes and boundary heights induced by anomalous low-level circulation through temperature advection and changes of total wind speed, and mid-level vertical velocity associated with the EPAC ISV, could be the most prominent factors in regulating the intraseasonal variability of LCF over the north Pacific. For the SEPAC, temperature anomalies at the top of the boundary inversion layer between 850-800hPa play a critical role in the local LCF intraseasonal variations. Results presented in this study not only provide improved understanding of variability of marine low clouds and the underlying physics, but also provide a prominent benchmark in constraining and evaluating the representation of low clouds in climate models. A paper on this study has been published in J. Climate (*Jiang et al.*, 2014).

10. Boreal summer synoptic-scale waves over the Western North Pacific in multi-model simulations

During boreal summer, vigorous synoptic-scale wave (SSW) activity, often evident as southeast–northwest oriented wave trains, prevails over the western North Pacific (WNP). In spite of their active role for regional weather and climate, modeling studies on SSWs are rather limited. In this analysis, working with a visiting scholar H. Zhao, we conducted a comprehensive survey on climate model capability in representing the WNP SSWs by analyzing simulations from 27 GCMs. Key model processes for realistic simulations of the western Pacific SSWs are also explored. Considering strong modulation of tropical cyclone genesis by SSWs as mentioned in 1), this study is highly related to investigations on intraseasonal hurricane predictability.

Results suggested that only two models out of the 27 GCMs generally well simulate both the intensity and spatial pattern of the observed SSW mode. Analyses further fillustrated that GCM skill in representing the spatial pattern of the SSW is highly correlated to its skill in simulating the summer mean patterns of the low-level convergence associated with the WNP monsoon trough, and conversion from eddy available potential energy (EAPE) to eddy kinetic energy (EKE). Meanwhile, simulated SSW intensity is found to be significantly correlated to the amplitude of 850-hPa vorticity, divergence, and conversion from EAPE to EKE over the WNP. Moreover, further examination shows that the observed modulations of SSW activity by the MJO are able to be captured in several model simulations. A paper on this study has been published in J. Climate (*Zhao et al.*, 2016).

Additionally, the PI also greatly appreciates partial support from this MAPP project, which has made possible for him to contribute to a variety of collaborative research activities, including a review article on tropical synoptic waves and the MJO (*Serra et al.*, 2014), an MJO predictability study based on the ISVHE (*Neena et al.*, 2014b), an observational study on modulations of tropical cyclone by the MJO (*Zhao et al.*, 2015), a multi-model comparison study on key processes for boreal summer ISV associated with the Asian Monsoon fluctuations (*Neena et al.*, 2016), analyses of MJO modulations on tropical waves based on observations and multi-model simulations (*Guo et al.*, 2014; *Guo et al.*, 2015), and application of TRMM latent heating estimates atmospheric process studies with emphasis on the MJO (*Tao et al.*, 2016).

2. Publication from this Project:

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