**Application of the NMME for the Intraseasonal Prediction of Tropical Cyclones over the Atlantic and North Pacific Basins**

A Proposal for the NOAA OAR Climate Program Office FY 2015 Competition 3:

MAPP - North American Multi-Model Ensemble System Evaluation and Application

NOAA-OAR-CPO-2015-2004099

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**Abstract**

This proposal is directed to the NOAA OAR CPO FY2015 and targets the Competition of MAPP – North American Multi-Model Ensemble (NMME) system evaluation and application, Area B: Exploration of new application of NMME system predictions. The objective of this project is to develop a suite of dynamical–statistical forecast models for intraseasonal forecasts of Atlantic and North Pacific basin tropical cyclone (TC) activities using the data from the NMME-Phase 2 system.

*Introduction to the problem:* Tropical cyclones have significant social and economic impacts. Their activities exhibit large intraseasonal variability, which is modulated by the Madden–Julian oscillation (MJO). A below-normal hurricane season may have certain periods with active TC activity, and vice versa. Therefore, issuing skillful intraseasonal forecasts of Atlantic and Pacific TC activity in a timely manner would be important and beneficial for the TC-affected areas.

*Rationale:* With the development of the NMME-Phase 2 system, data at higher temporal resolution (daily and 6 hourly) are becoming available. An evaluation of CFSv2, one of the NMME models, indicates that the MJO is better represented with a higher prediction skill in CFSv2 than in CFSv1. Based on the performance of the NMME in the experimental seasonal climate prediction, it is reasonable to expect that the intraseasonal forecast skill of the MJO will be further improved with the NMME-Phase 2 system. The multi-year retrospective forecasts in the NMME-Phase 2 system offer a unique opportunity to develop and test the dynamical–statistical models for the forecasts of 30-day mean Atlantic and North Pacific TC activities.

*Brief summary of the work to be completed:*

(1) To establish the empirical relationships between the observed 30-day mean tropical cyclone activity and the NMME-Phase 2 system predicted ocean/atmosphere conditions for the same 30-day moving window throughout the entire hurricane season for the tropical North Atlantic, eastern and western tropical North Pacific regions, respectively, based on the 1982–2010 data, and identify potential predictors for the intraseasonal TC forecast;

(2) To apply a hybrid dynamical–statistical model for the intraseasonal tropical cyclone forecast with the multiple linear regression method and cross-validate the forecasting system over the 1982–2010 period using the NMME-Phase 2 system hindcast suites; and

(3) To test the model for real-time intraseasonal forecasts for the 2016 hurricane season and implement the model into operations at NCEP/CPC.

*Relevance to the Competition:* This project will explore new applications of the NMME-Phase 2 system, test and evaluate new prediction products for intraseasonal tropical cyclone activity. Therefore, it is highly relevant to the Competition of MAPP, Area B. The project will also support the NCEP/CPC Global Tropics Hazards and Benefits Outlooks. The proposed work will help accomplish the NOAA’s long-term climate goal by improving one of the core capabilities, namely, predictions and projections, and addressing the societal challenge of the changes in high-impact extremes of weather and climate, as described in the NOAA’s Next-Generation Strategic Plan.

**3. Results from Prior Research**

Dr. Schemm has had experience both with the MJO and with Atlantic tropical cyclone (TC)/hurricane activity in statistical (Waliser et al. 1999) and dynamical (Jones et al. 2000) prediction models, as well as a hybrid model (Wang et al. 2009). Since 2009, she has been responsible for dynamical hurricane season prediction at NCEP/CPC utilizing the T382 Climate Forecast System (CFS) coupled model (Schemm and Long 2009) and has been providing the dynamical prediction input for the NOAA Hurricane Season Outlook. She has performed preliminary analyses of the MJO and Atlantic TCs/hurricanes in the T382 CFS and found a favorable ability to reproduce reality for both of these phenomena. In analyzing the Northern Hemisphere tropical storms in the T382 CFS, the detection and tracking criteria used in earlier studies (e.g. Camargo and Zebiak 2002) have been adopted to this higher resolution model. The favorable T382 CFS results include not only realistic reproduction of the interannual variability in TC/hurricane activity as a result of ENSO fluctuations, but also of the shift to a more active hurricane era in the middle 1990s (Fig. 1). The dynamical system has shown considerable skill in predicting the seasonal tropical storm activities for the 2009-2013 hurricane seasons (Table 1).

Fig. 1. Interannual variability of tropical cyclone activity over the Atlantic basin during 1981–2009. Predicted number of tropical cyclones (blue line) with the T382 CFS is compared to the observed (black line) during May–Nov. hurricane season.

Recently, Dr. Schemm has been engaged in the development of prediction tools for TC activity over the Atlantic (ATL), Eastern North Pacific (ENP), and Western North Pacific (WNP) basins for weeks 3 and 4 utilizing the CFSv2 45-day forecasts. Preliminary evaluations on the CFSv2 hindcasts for the 1999–2010 period indicate that the CFSv2 has considerable skill in predicting the basin-wide number of storms as shown in Fig. 2. In general the skill level is fairly high for week 1 through week 4 periods, with time series correlation scores to the observed ranging between 0.6 and 0.8 in the ATL, ENP and WNP basins. The proposed development activity will be complementary to the CFSv2-based dynamical prediction procedure and will provide an additional prediction tool for the 30-day mean TC activity at NCEP/CPC.

Table 1. Dynamical seasonal forecasts of Atlantic tropical cyclones, hurricanes and accumulated cyclone energy (ACE) with T382 CFS, including ensemble mean (red) and forecast range (green), and verification with observations (blue) for 2009–2013 Atlantic hurricane seasons.

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Tropical Cyclones**  **Ensemble / Range / OBS** | **Hurricanes**  **Ensemble / Range / OBS** | **ACE (% of Median)**  **Ensemble / Range /OBS** |
| **2009** | 7.4 / 5–10 / 9 | 2.6 / 1–4 / 3 | 82.8 / 61–104 / 57 |
| **2010** | 21.5 / 18–25 / 19 | 10.5 / 7–14 / 12 | 262.3 / 212–312 / 185 |
| **2011** | 13.9 / 10–17 / 19 | 5.0 / 3–7 / 7 | 144.6 / 104–185 / 134 |
| **2012** | 12.4 / 10–15 / 19 | 3.7 / 2–6 / 10 | 124.4 / 89–160 / 133 |
| **2013** | 15.5 / 13–18 / 13 | 8.4 / 6–11 / 2 | 155.2 / 111–199 / 36 |

Fig. 2. Correlation scores of basin-wide number of TCs over the ATL, ENP, and WNP, basins. The socres for Week 1 forecasts are in red line, Week 2 in orange line, Week 3 in green line and Week 4 in blue line.

Dr. Wang has worked on the development of hybrid dynamical–statistical prediction systems for seasonal TC/hurricane activity over the Northern Hemisphere ocean basins since 2008. His research efforts include (a) development of a hybrid dynamical–statistical model for Atlantic/eastern Pacific hurricane seasonal prediction (Wang et al. 2009), and (b) development of a dynamical–statistical forecast model for seasonal western North Pacific TC activity (Li et al. 2013). The hybrid model (Wang et al. 2009) was built upon the empirical relationship between the observed interannual variability of TCs/hurricanes and the variability of sea surface temperature (SST) and vertical wind shear from the 26-year (1981–2006) hindcasts with the NCEP CFSv1. The model was implemented for real-time forecasts for the hurricane season at NCEP/CPC in 2008, using the CFSv1 dynamical seasonal forecasts of SST and vertical wind shear as predictors. In the past six years (2008–2013), this model provided skillful seasonal forecasts and useful information for the NOAA Hurricane Season Outlooks. Since 2013, we have successfully adopted this hybrid model for the CFSv2. A similar dynamical–statistical methodology is proposed in this project for intraseasonal forecast of 30-day meanTC activity.

Additionally, Dr. Wang has also participated in the U.S. CLIVAR Hurricane Working Group in climate modeling studies of TCs since 2011. The studies suggest that high-resolution global climate models are capable of simulating the observed interannual variability of TCs in the Atlantic and Pacific basins (Wang et al. 2014; Han et al. 2014). This indicates that the climate models are able to simulate the variability of the environmental atmospheric and ocean variables well, which are the controlling factors for the formation and development of TCs. It is also shown that multi-model ensemble has the highest correlation with observations for the interannual variability of TCs than individual models (Wang et al. 2014). Similarly, the impact of the MJO on TCs and a better representation of the MJO in the CFSv2 and the NMME-Phase 2 system (Kirtman et al. 2014) are crucial for forecasting the 30-day mean TC activity in this project.

**4. Statement of Work**

This proposal targets the NOAA OAR CPO FY2015 Competition of MAPP – NMME system evaluation and application, Area B: Exploration of new application of NMME system predictions. The project will incorporate the NMME-Phase 2 data (Kirtman et al. 2014) to develop a hybrid dynamical–statistical forecast system for predicting 30-day mean tropical cyclone (TC) activity (i.e., 30-day total basin-wide TC counts) over the tropical North Atlantic, eastern and western tropical North Pacific, respectively.

The basic working hypothesis of this proposal is as follows. Tropical cyclones over the eastern and western tropical North Pacific, as well as the tropical North Atlantic exhibit large variability on the intraseasonal timescale. An above-normal hurricane season may have certain periods with inactive TC activity, and vice versa. Observational studies (e.g., Liebmann et al. 1994; Maloney and Hartmann 2000; Camargo et al. 2009) indicate that the MJO exerts a strong influence on tropical storm and hurricane activities on this timescale. Given the close association between the MJO and the TC activity, the significant improvement of the CFSv2 in predicting the MJO three weeks ahead (Zhang and van den Dool 2012), together with an expected further improvement of the MJO prediction in the NMME-Phase 2 system (Kirtman et al. 2014), provides an opportunity to make skillful forecasts of the intraseasonal TC variability. This proposal is directed to test this hypothesis for developing a dynamical–statistical model for predicting 30-day mean TC activity based on the NMME-Phase 2 system, and to implement the model into operations.

**4.1 Identification of the problem**

Tropical storm is one of the most devastating and costly natural hazards that strikes U.S. coastal regions. Landfalling tropical cyclones and hurricanes not only cause great monetary losses, but also have tremendous impacts on society, economy, and environment. With the greatly increasing vulnerability of the human society to TCs and hurricanes, skillful prediction of their activity on seasonal and intraseasonal timescales is of critical importance to the human society near coastal regions.

In addition to the year-to-year variations, TC activity also has large month-to-month fluctuations. The most recent example is the 2012 Atlantic hurricane season, which was characterized by two very active months, August and October. During the two months, there were eight and six tropical storms, respectively, with one landfalling hurricane (Isaac in August and Sandy in October) causing catastrophic damage in the Gulf coast and the Northeast coast.

Despite major advances in our ability to dynamically or/and statistically predict interannual TC activity, predicting TC activity on the intraseasonal timescale remains a challenge. Given the relatively long period of the hurricane season (6 months) and the significant damages that may be caused by TCs on a much shorter timescale, issuing skillful forecasts of 30-day mean Atlantic and Pacific TC activities in a timely manner could greatly benefit the emergency preparedness and risk management for the tropical storms-affected areas. The demand for the forecasts of such high-impact events in this time band is also great.

Observational studies have shown that the intraseasonal variability of TCs is strongly modulated by the MJO (e.g., Maloney and Hartmann 2000; Klotzbach 2010). Our prior work on the dynamical–statistical hurricane season prediction (Wang et al. 2009; Vecchi et al. 2011; Li et al. 2013) together with a better representation of the MJO in the CFSv2 (Weaver et al. 2011) and the NMME-Phase 2 system (Kirtman et al. 2014) will help us build and test the dynamical–statistical model for the prediction of 30-day mean TC activities in the tropical North Atlantic and tropical North Pacific basins.

Our prototype test of predicting monthly tropical cyclones for the 2010 Atlantic hurricane season indicates certain forecast skill and predictability of TCs on the intraseasonal timescale. The 2010 Atlantic hurricane season was the third most active season on record with 19 tropical cyclones, among which there were 12 hurricanes and five major hurricanes. The dynamical–statistical model (Wang et al. 2009) made a successful *seasonal* prediction in May 2010 for the 2010 hurricane season with 20 tropical cyclones, 12 hurricanes, and six major hurricanes, based on the CFSv1 dynamical seasonal forecast of tropical Pacific SST and tropical North Atlantic vertical wind shear for the target hurricane season.

Additionally, the 2010 Atlantic tropical cyclone activity also had substantial variations within the hurricane season and was actually near normal in the early season and was well above normal only in September and October (Fig. 3a). To test the predictability of sub-seasonal TC activity, the same model for the seasonal prediction was applied for monthly prediction, using the CFSv1-predicted SST and vertical wind shear for the target month as predictors. The monthly TC forecasts with lead times from 3 months to 0 month are very close to observations for most of the months in the hurricane season (Fig. 3b). However, the forecast for the TC activity in September, the month of the peak TC activity, was weaker than the observations, indicating the need of improvements for the model for the intraseasonal TC prediction.

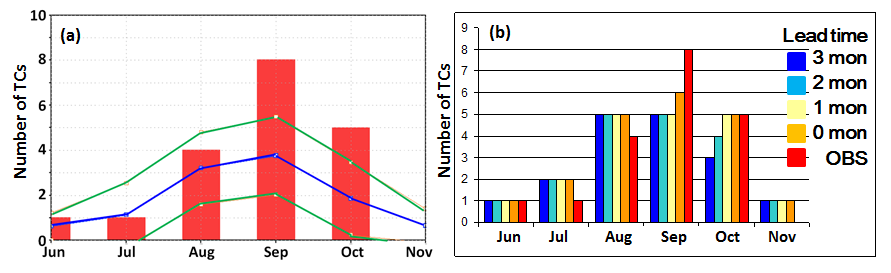


Fig. 3. (a) Monthly distribution of tropical cyclones in the 2010 Atlantic hurricane season and (b) forecasts of monthly tropical cyclones for the 2010 hurricane season using the dynamical–statistical model (Wang et al. 2009) with lead time from 3 months to 0 month. Blue line in (a) is the monthly tropical cyclone climatology (1981–2009) and green lines are +/– one-standard-deviation departure from the climatology.

With the development of the new version of the CFS, one of the NMME models, data from 45-day CFSv2 reforecasts (1999–2010) are available. An evaluation of the CFSv2 (Wang et al. 2014) indicates that the MJO is better represented with a higher prediction skill in the CFSv2 than in the CFSv1 (Fig. 4). The time range for a skillful MJO prediction was extended from two weeks in the CFSv1 (Seo, et al. 2009) to 3–4 weeks in the CFSv2 (Zhang and van den Dool 2012; Kim et al. 2014).

Also with the development of the NMME-Phase 2 system, data from multiple models at higher temporal resolution (daily and 6 hourly) are becoming available. The NMME-Phase 2 system (Kirtman et al. 2014) is a multi-model intraseasonal forecasting system, which consists of a set of eight coupled global climate models (or different model versions) from NOAA/NCEP, NOAA/GFDL, NCAR, NASA, and Canadian Meteorological Centre (CMC). An assessment of the NMME dynamical seasonal forecast (van den Dool et al. 2012) indicates that a multi-model ensemble approach has an overall better forecast skill than any single model ensemble. It is reasonable to expect that the NMME-Phase 2 system will have better intraseasonal forecasts for the MJO than individual models. Additionally, utilizing the NMME products to derive other predictors, such as SST and vertical wind shear used in our prototype test (Fig. 3b) will provide additional room for improving the forecast of the 30-day mean TC activity.

The multi-year (1982–2010) retrospective forecasts with the NMME-Phase 2 system, together with the experimental real-time forecasts for the following years, offer a necessary dataset to develop and test the dynamical–statistical approach for operational forecast of 30-day mean Atlantic and Pacific TC activities. By considering the impact of the MJO cycle on the TC activity as an additional predictor in the hybrid forecast model, we expect that this project will complement the existing dynamical–statistical seasonal forecast model at NCEP/CPC for the intraseasonal time range.

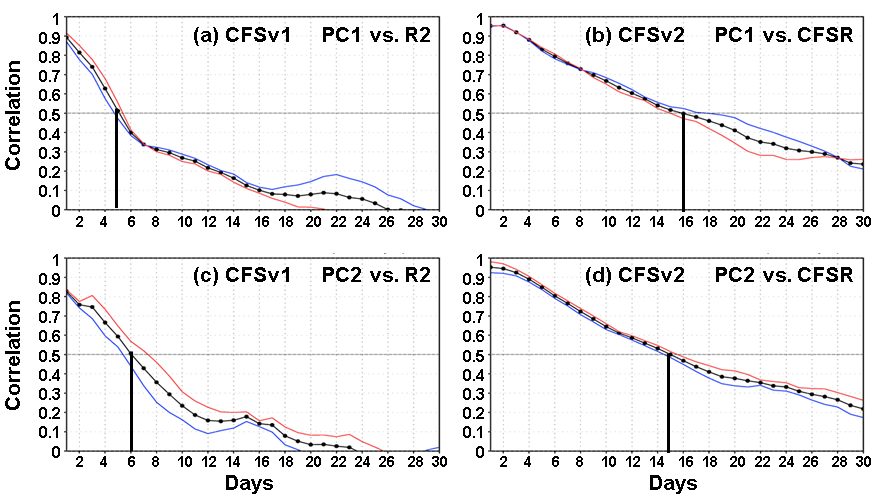


Fig. 4. MJO prediction skill expressed by the correlation coefficient (black lines with dots) between the CFS-predicted MJO indices (PC1 and PC2 of CHI200) and those derived from the reanalysis data. (a) and (c) are the correlations for PC1 and PC2, respectively, between CFSv1 and the NCEP/DOE Reanalysis (R2). (b) and (d) are the correlations for PC1 and PC2, respectively, between CFSv1 and CFS Reanalysis (CFSR). The lead times are from 0 day to 30 days.

**4.2 Scientific objectives**

This proposal is aimed at (a) developing a dynamical–statistical prediction system for the 30-day mean tropical cyclone activity in the tropical North Atlantic and eastern and western tropical North Pacific, respectively, based on the NMME-Phase 2 data and (b) implementing the model for useful operational forecasts over the two ocean basins. This will be done through investigating the dynamical linkage between the MJO cycle and the intraseasonal variability of TCs, evaluating the predictability and potential skill of the forecasts of the 30-day mean TC activity, and converting this research to operational forecast products with the hybrid model. Our overall project goals are listed as follows.

(1) To further explore and better understand the relationship between the MJO cycle and the intraseasonal variability of tropical cyclones over the North Atlantic and North Pacific basins, and to assess implications for predicting 30-day mean TC activity;

(2) To develop a hybrid dynamical–statistical model for the 30-day mean TC forecast with the multiple linear regression method and cross-validate the model over the 1982–2010 period; and

(3) To test the model for real-time forecasts for the 2016 hurricane season and implement the model into operations at NCEP/CPC starting from the 2017 hurricane season.

**4.3 Proposed methodology**

(1) Potential predictors (Objective 1)

To explore the influences of large-scale atmosphere/ocean conditions, as well as the MJO, on the intraseasonal variations of tropical cyclones, we will first establish the simultaneous relationships between 30-day mean SST/atmosphere conditions and the TC activities in the eastern and western tropical North Pacific and tropical North Atlantic regions, respectively, using observational data. The data include the NOAA Hurricane Best Track Data, Tokyo–Typhoon Center RSMC Best Track Data, and the daily CFSv2 Reanalysis data.

The analysis will be based on the correlations between 30-day mean TCs and the corresponding 30-day mean SST/atmospheric circulation fields over the 29 years from 1982 to 2010, the same years as the NMME-Phase 2 system hindcasts. Each 30-day (or 31-day) period starts from the 1st and 16th of the month to the end of the month and the 15th of the following month, respectively. There are total 13 moving 30-day periods covering the entire hurricane season from May 1 to November 30, with each starting date 15 days apart. The atmospheric fields include vertical wind shear between 200hPa and 850 hPa, sea level pressure, 500-hPa height and relative humidity, and 850-hPa wind. Two indices representing the propagating MJO will also be employed, which are derived from the first two EOFs of 200-hPa and 850-hPa zonal winds and OLR averaged between 15oS and 15oN (Wheeler and Hendon 2004).

The results will indicate local as well as remote influences of the atmospheric circulation and SST on the intraseasonal variations of TCs. Particularly, we will analyze how different phases of the MJO modulate the TC variability in different ocean basins. This will provide the physical basis for the intraseasonal forecast of the 30-day mean TC activity.

Similar correlation analyses will be performed between the observed 30-day mean TC activity and the corresponding 30-day multi-model ensemble mean SST/atmospheric circulation fields derived from the hindcasts with the NMME-Phase 2 system. The relationships depicted by the NMME-Phase 2 system will be compared with those based on the observations to validate the NMME-Phase 2 system in reproducing the associations between SST/atmospheric anomalies and the intraseasonal TC variations. For each NMME-predicted variable, the region of high correlations with the observed 30-day mean TC activity will be used for area-averaging, which will be considered as a potential predictor. For each model in the NMME-Phase 2 system, the 4 × daily 45-day forecasts for a common 30-day target period can provide a maximum of 60 ensemble members, with lead times from 15 days to 1 day.

(2) Dynamical–statistical forecast model (Objective 2)

A hybrid dynamical–statistical forecast model for 30-day mean tropical cyclone activity will be developed for the eastern and western tropical North Pacific and the tropical North Atlantic, respectively. Similar to the hybrid model in Wang et al. (2009) for the seasonal tropical cyclone and hurricane prediction, a statistical model for 30-day mean TC prediction will be developed based on the empirical relationships established in (1) with the multiple linear regressions of 30-day mean TCs versus the NMME-predicted predictors over the 1999–2014 period. For the entire hurricane season (May-November), there will be total 19 ensemble mean forecasts, each 10 days apart. In addition to the ensemble mean forecasts, the forecasts based on individual members will be used to develop a probabilistic forecast of TCs, based on the spreads among all members. Therefore, similar to what we have done for the seasonal tropical cyclone and hurricane prediction, each intraseasonal forecast will consist of the 30-day total basin-wide TC counts, a forecast range (ensemble mean ± one standard deviation of spreads), and the chances in percentage for above-normal, near-normal, and below-normal TC activity based on the distribution of all individual member forecasts.

The forecasts of the 30-day mean TC activity will be cross-validated for each hurricane season during the 1982–2010 period. The forecast skills will be assessed, including correlation score, root mean square error, and hit and false alarm rate, for various forecasts with different combinations of the predictors for the tropical North Atlantic, eastern tropical North Pacific, and western tropical North Pacific, respectively. The cross-validations will determine a set of predictors to be used in the final configuration of the model for each ocean basin.

(3) Real-time forecast and operations (Objective 3)

Real-time forecasts of 30-day mean Atlantic and Pacific tropical cyclone activity will be made for the 2016 hurricane season based on the NMME-Phase 2 dynamical forecasts. The forecasts will be updated every 10 days from May 1 to November 1, 2016 (total 19 30-day forecasts) for each ocean basin. The real-time NMME-Phase 2 forecasts have large ensemble members each day. Probabilistic forecasts of the 30-day mean TC activity for the 2016 season thus can be made with sufficient number of ensemble members but shorter lead times (e.g., lead times from 5 days to 1 day). A shorter lead time is likely to have a better forecast skill.

We will evaluate the model performance in the 2016 hurricane season and finalize the model configuration based on the assessment. The forecasting system with finalized computer codes (UNIX shell scripts and FORTRAN codes) will be transferred to the NCEP/CPC computer farm for testing and implementing into operations starting from the 2017 hurricane season.

**4.4 Relevance to the Competition and NOAA’s long-term climate goal**

The proposed work will incorporate the NMME-Phase 2 system to develop a dynamical–statistical forecast system for the intraseasonal forecasts of tropical cyclones over the tropical North Atlantic and North Pacific. Therefore, the project is highly relevant to the Competition of NMME system evaluation and application in the MAPP Program. It is most specifically relevant to Area B of this Competition: Exploration of new applications of NMME system predictions.

The project will explore, test, and evaluate the potential forecast skill for high-impact events in the 30-day time band to achieve useful operational forecast products. The outcomes of the project will support the NCEP/CPC Global Tropics Hazards and Benefits Outlooks. The goals of this proposal fit well with the NOAA’s long-term climate goal by improving one of the core capabilities, “predictions and projections”, and also addressing the societal challenge of “changes in extremes of weather and climate”, as identified in the NOAA’s Next-Generation Strategic Plan.

The proposed project will also benefit the general public and the scientific community. Given the increased temporal specificity, the prediction of tropical cyclones on the 30-day time range will have significant social and economic benefits. The influence of the MJO cycle on the TC activity over the different ocean basins, which will be examined by this project, will provide useful information for the research community to better understand the intraseasonal variability of tropical cyclones.

**4.5 Work plan**

The proposed project will be conducted over one year from August 1, 2015 to July 31, 2016. In the first five months (08/01/2015−12/31/2015), Objective 1 will be met primarily through the statistical analysis of two TC Best Track Datasets and the daily CFSv2 Reanalysis data over 1999−2014, and the daily NMME-Phase 2 hindcast/real-time forecast data. In the following four months (01/01/2016−04/30/2016), we will work on the development of the dynamical−statistical forecast model for the forecasts of 30-day mean TC activity (Objective 2), including the cross-validation for the 1999−2015 period.

In the last three month (05/01/2016–07/31.2016), the real-time intraseasonal TC forecast will be tested for the 2016 hurricane season (Objective 3). In the meantime, we will prepare the documentation for the model, write up a manuscript summarizing the project, including the model development and validation, and submit it to a journal for publication. A progress report will be submitted by June 2016 and a comprehensive final report by October 2016.

Although the project will expire on July 31, 2016 during the 2016 hurricane season, we will continue to run the forecast model until November 2016. In early 2017, the forecasting system will be implemented for operational forecasts at PIs’ home institution, the NCEP Climate Prediction Center. The procedures will include transferring finalized model codes to the CPC’s computer farm, including the scripts for extracting the NMME-Phase 2 real-time forecast data, running the forecast models, and post-processing.

**Personnel:**

As the lead PI,Dr. J. Schemm will oversee the overall research activities. Dr. H. Wang will be responsible for the statistical analyses of the relationship between intraseasonal TC activity and SST/atmospheric circulation parameters, including the MJO, the development of the hybrid dynamical–statistical model for the forecasts of 30-day mean TC activity, and the assessment of the forecasting system. A support staff will work with Drs. J. Schemm and H. Wang to process data, test and evaluate the forecast model, and implement the forecasting system for operations at NCEP/CPC.

**4.6** **References**

Camargo, S. J., M. C. Wheeler, and A. H. Sobel, 2009: Diagnosis of the MJO modulation of tropical cyclogenesis using an empirical index. *J. Atmos. Sci.*, **66,** 3061–3074.

Carmago, S. J., and S. E. Zebiak, 2002: Improving the detection and tracking of tropical cyclones in atmospheric general circulation models. *Wea. Forecasting*, **17,** 1152–1162.

Han, R., and Co-authors, 2014: Assessment of multimodel simulations of western North Pacific tropical cyclones and their association with ENSO. *J. Climate*, to be submitted.

Jones, C., D. E. Waliser, J. K. Schemm, and W. K. Lau, 2000: Prediction skill of the Madden-Julian Oscillation in dynamical extended range forecasts. *Clim. Dyn.*, **16,** 273–289.

Kim, H. M., P. J. Webster, V. E. Toma, and D. Kim, 2014: Predictability and prediction skill of the MJO in two operational forecasting systems. *J. Climate*, **27,** 5364–5378.

Kirtman, B. P., and Co-authors, 2014: The North American Multimodel Ensemble: Phase-1 Seasonal-to-Interannual Prediction; Phase-2 toward Developing Intraseasonal Prediction. *Bull. Amer. Meteor. Soc.*, **95,** 585–601.

Klotzbach, P. J., 2010: On the Madden-Julian oscillation–Atlantic hurricane relationship. *J. Climate*, **23,** 282–293.

Li, X., S. Yang, H. Wang, X. Jia, and A. Kumar, 2013: A dynamical–statistical forecast model for the annual frequency of western Pacific tropical cyclones based on the NCEP Climate Forecast System version 2. *J. Geophys. Res.–Atmospheres*, **118,** 12061–12074.

Liebmann, B., H. H. Hendon, and J. D. Glick, 1994: The relationship between tropical cyclones of the western Pacific and Indian Ocean and the Madden-Julian Oscillation. *J. Meteor. Soc. Japan*, **72,** 401–412.

Maloney, E. D., and D. L. Hartmann, 2000: Modulation of eastern North Pacific hurricanes by the Madden–Julian Oscillation. *J. Climate*, **13,** 1451–1460.

Schemm, J.-K. E., and L. Long, 2009: Dynamic hurricane season prediction experiment with the NCEP CFS CGCM. *NOAA Climate Test Bed Joint Seminar Series*, IGES/COLA, Calverton, Maryland, 21 January 2009.

Seo, K.-H., W. Wang, J. Gottschalck, Q. Zhang, J.-K. E. Schemm, W. R. Higgins, and A. Kumar, 2009: Evaluation of MJO forecast skill from several statistical and dynamical forecast models. *J. Climate*, **22,** 2372–2388.

van den Dool, H., 2012: CFSv2 in the context of NMME and IMME. *CFSv2 Evaluation Workshop*, April 30 – May 1, 2012, Riverdale, Maryland.

Vecchi, G. A., M. Zhao, H. Wang, G. Villarini, A. Rosati, A. Kumar, I. M. Held, and R. Gudgel, 2011: Statistical-dynamical predictions of seasonal North Atlantic hurricane activity. *Mon. Wea. Rev.*, **139,** 1070–1082.

Waliser, D. E., C. Jones, J. K. Schemm, and N. E. Graham, 1999: A statistical extended-range tropical forecast model based on the slow evolution of the Madden-Julian Oscillation. *J. Climate*, **12,** 1918–1939.

Wang, H., L. Long, A. Kumar, W. Wang, J.-K. E. Schemm, M. Zhao, G. A. Vecchi, T. E. LaRow, Y.-K. Lin, S. D. Schubert, D. A. Shaevitz, S. J. Camargo, N. Henderson, D. Kim, J. A. Jonas, and K. J. E. Walsh, 2014: How well do global climate models simulate the variability of Atlantic tropical cyclones associated with ENSO? *J. Climate,* **27***,* 5673–5692*.*

Wang, H., J.-K. E. Schemm, A. Kumar, W. Wang, L. Long, M. Chelliah, G. D. Bell, and P. Peng, 2009: A statistical forecast model for Atlantic seasonal hurricane activity based on the NCEP dynamical seasonal forecast. *J. Climate*, **22,** 4481–4500.

Wang, W., M.-P. Hung, S, J, Weaver, A. Kumar, and X. Fu, 2014: MJO prediction in the NCEP Climate Forecast System version 2. *Climate Dynamics*, **42,** 2509–2520.

Weaver, S. J., W. Wang, M. Chen, and A. Kumar, 2011: Representation of the MJO variability in the NCEP Climate Forecast System. *J. Climate*, **24,** 4676–4694.

Wheeler, M. C., and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.*, **132,** 1917–1932.

Zhang, Q., and H. van den Dool, 2012: Relative merit of model improvement versus availability of retrospective forecasts: The case of Climate Forecast System MJO prediction. *Wae. Forecasting*, **27,** 1045–1051.

**5. Data/Information Sharing Plan**

The forecasting system, cross-validations for 1999–2015, and real-time forecasts for the 2016 hurricane season obtained in this project will be documented and submitted to a scientific journal for publication and shared with the scientific community. In addition, we will create a website to make available the detailed descriptions of the forecast models and products of the operational forecasts of the 30-day mean Atlantic/Pacific tropical cyclone activities, illustrated with figures and tables. The purpose is to provide a guide to help general publics to understand and interpret the forecasts.

**6. Budget Table and Justification**

**Budget table**

(For this budget the year is August through July of the following year.)

**Year FY2015 Total**

**Salaries and Overhead**

Schemm (1 mo/yr) N/C

Wang (3 mo/yr) $39.0K $39.0K

Support Scientist (2 mo/yr) $21.0K $21.0K

**Supplies** $1.0K $1.0K

**Travel** $6.0K $6.0K

**Publications**  $3.0K $3.0K

**TOTALS $70.0K $70.0K**

**Budget justification**

This budget includes salaries of Dr. Hui Wang (3 months) and a support staff (2 months), indirect charges, travel costs for PIs to attend the conference/workshop related to this project ($6K), and page charges ($3K) for a journal paper summarizing this project with model description and evaluation. NCEP/CPC will make in-kind contribution of time totaling up to one month from Dr. Jae-Kyung Schemm.

**7. Federal Budget Forms**

Forms SF424, SF424A

**8. Indirect Costs**

A copy of the institution’s current Indirect Cost Rate Agreement (IDCRA) must be included.

**9. Vitae**

**Lead PI**: **Dr. Jae-Kyung E. Schemm**

**Current Position:** Research Meteorologist, Operational Monitoring Branch

NOAA/NWS/NCEP/Climate Prediction Center

**Education:**

B.S. Meteorology, 1969 Seoul National University, Seoul, Korea

M.S. Meteorology, 1972 University of Wisconsin, Madison, Wisconsin

Ph.D. Meteorology, 1981 University of Maryland, College Park, Maryland

**Employment:**

1993 to present: Research Meteorologist, Operational Monitoring Branch,

Climate Prediction Center, NCEP/NWS/NOAA

1991 to 1993: Senior Scientific Analyst, General Science Corporation.

Data Assimilation Office, GLA/GSFC/NASA

1986 to 1993: Scientific Analyst, Centel Federal Services Corporation

Global Modeling and Simulation Branch, GLA/GSFC/NASA

1985 to 1986: Research Associate, Department of Meteorology,

University of Maryland, College Park, MD

1981 to 1984: Research Associate, Institute for Physical Sciences and Technology,

University of Maryland, College Park, MD

**Recent Awards:**

US Dept. of Commerce Bronze Medal, 2000

US Dept. of Commerce Gold Medal, 2005

**Professional Services:**

APEC Climate Center NWS Focal Point and Working Group Member, 2001 – present

NAME Project of WCRP-CLIVAR/VAMOS and GEWEX, Member of Science

Working Group, 2001 - 2008

US CLIVAR, Member of Science Working Group on Extremes, 2010 – 2013

WWRP Tropical Cyclone Working Group – Intraseasonal, 2014 – present

**Recent Publications:**

Wang, H., L. Long, A. Kumar, W. Wang, **J.-K. E. Schemm**, M. Zhao, G. A. Vecchi, T. E. LaRow, Y.-K. Lim, S. D. Schubert, D. A. Shaevitz, S. J. Camargo, N. Henderson, D. Kim, J. A. Jonas, and K. J. E. Walsh, 2014: How well do global climate models simulate the variability of Atlantic tropical cyclones associated with ENSO? *J. Climate*, 27, 5673–5692.

Bell, G. D., C. W. Landsea, S. B. Goldenberg, R. J. Pasch, E. S. Blake, **J. Schemm**, and T. B.

Kimberlain, 2014: Tropical Cyclones: Atlantic Basin [in State of the Climate in 2013]*.*

*Bull. Amer. Met. Soc.,* 92(8), S86–90.

Bell, G. D., S. Goldenberg, C. Landsea, E. Blake, T. Kimberlain, **J. Schemm**, and R. Pasch,

2013: Tropical Cyclones: Atlantic Basin [in State of the Climate in 2012]*.* *Bull. Amer. Met. Soc.,* 92(8), S85–89.

Bell, G., E. Blake, C. Landsea, T. Kimberlain, S. Goldenberg, **J. Schemm** and R. Pasch, 2012: Tropical Cyclones: Atlantic Basin [in State of Climate in 2011]*.* *Bull. Amer. Met. Soc.,* 93(7), S99–105.

Mo, K., L. Long, Y. Xia, S.-K. Yang, **J. Schemm** and M. Ek, 2011: Drought indices

based on the Climate Forecast System Reanalysis and ensemble NLDAS. *J.*

*Hydromet*., 12, 181–205.

Lee, S., J. Lee, K. Ha, B. Wang and **J. Schemm**, 2011: Deficiencies and possibilities for

long-lead coupled climate prediction of the Western North Pacific–East Asian

monsoon. *Clim. Dyn*., 36, 1173–1199

**Schemm, J**., L. Long, 2009: Dynamic Hurricane Season Prediction Experiment with

the NCEP CFS. *Workshop on High Resolution Climate Modeling*, Trieste, ICTP,

Italy.

Wang, H., **J. Schemm**, A. Kumar, W. Wang, L. Long, M. Chelliah, G. Bell and P. Peng, 2009: A Statistical Forecast Model for Atlantic Hurricane Activity Based on the NCEP Dynamical Seasonal Forecast. *J. Climate*, **22**, 4481–4500.

Seo, K., W. Wang, J. Gottschalk, Q. Zhang, **J. Schemm**, W. Higgins and A. Kumar, 2009:

Evaluation of MJO Forecast Skill from Several Statisitcal and Dynamical Forecast

Models. *J. Climate*, **22**, 2372–2388.

Schubert, S. and US CLIVAR Drought Working Group Participants, 2009: A U.S.

CLIVAR Project to Assess and Compare the Responses of Global Climate Models

To Drought-Related SST Forcing Patterns: Overview and Results. *J. Climate,* 22,

5251–5272.

Mo, K., J. Schemmand S. Yoo, 2009: Influence of ENSO and the Atlantic Multi-Decadal

Oscillation on Drought over the United States. *J. Climate,* 22, 5962–5982

**Co-PI: Dr. Hui Wang**

**Current Position:** NOAA Contract Scientist

NOAA/NWS/NCEP/Climate Prediction Center and Innovim

**Education**

Ph.D. Atmospheric Sciences 1997 University of Illinois at Urbana-Champaign

M.S. Atmospheric Sciences 1987 Nanjing University, Nanjing, China

B.S. Physics 1984 Nanjing University, Nanjing, China

**Employment**

2007–present Contract Scientist, NOAA CPC and RSIS–Wyle–Innovim

2006–2007 Research Scientist, Center for Research on the Changing Earth System, MD

2000–2006 Research Scientist (II and Senior), Georgia Institute of Technology

1997–1999 Postdoctoral Research Associate, University of Arizona

**Professional Services**

Member, US CLIVAR Hurricane Working Group, 2011–present

Member, Review Panel of the NASA Modeling, Analysis and Prediction (MAP) Program, 2012

Member, Editorial Board of *International Journal of Atmospheric Sciences*, 2012–present

Member, Graduate Admissions Committee, Earth and Atmos. Sci., Georgia Tech, 2004–2005

**Publications (Selected)**

**Wang, H.**, L. Long, A. Kumar, W. Wang, J.-K. E. Schemm, M. Zhao, G. A. Vecchi, T. E. LaRow, Y.-K. Lim, S. D. Schubert, D. A. Shaevitz, S. J. Camargo, N. Henderson, D. Kim, J. A. Jonas, and K. J. E. Walsh, 2014: How well do global climate models simulate the variability of Atlantic tropical cyclones associated with ENSO? *J. Climate*, 27, 5673–5692.

**Wang, H.**, A. Kumar, W. Wang, 2013: Characteristics of subsurface ocean response to ENSO assessed from simulations with the NCEP Climate Forecast System. *J. Climate*, 26, 8065–8083.

**Wang, H.**, Y. Pan, A. Kumar, and W. Wang, 2013: Modulation of convectively coupled Kelvin wave activity in the tropical Pacific by ENSO. *Acta Meteor. Sinica*, 27, 295–307.

**Wang, H.**, A. Kumar, W. Wang, and B. Jha, 2012: U.S. summer precipitation and temperature patterns following the peak phase of El Niño. *J. Climate*, 25, 7204–7215.

**Wang, H.**, A. Kumar, W. Wang, and Y. Xue, 2012: Influence of ENSO on Pacific decadal variability: An analysis based on the NCEP Climate Forecast System. *J. Climate*, 25, 6136–6151.

**Wang, H.**, A. Kumar, W. Wang, and Y. Xue, 2012: Seasonality of the Pacific decadal oscillation. *J. Climate*, 25, 25–38.

**10. Current and Pending Support**

**Dr. Jae-Kyung E. Schemm**

**Current support**

**Agency:** NOAA CPO/MAPP

**Title:** Predictability of Atlantic Hurricane Activity by the NMME Coupled Models

**Amount:** $135K/year

**Period:** August 2012 – September 2015

**PI:**  A. Barnston

**Co-PI**: M. Tippet and J. Schemm

**Agency:** NOAA HIWPP (Sandy Supplemental)

**Title:** NMME Extension Project

**Amount:** $120K

**Period:** May 2014 – September 2015

**PI:**  Jin Huang

**Co-PI**: J. Schemm

**Pending support**

**Agency:** NOAA/NWS

**Title:** Application of a Hybrid Dynamical–Statistical Model for Week 3 to 4 Forecast of Atlantic/Pacific Tropical Storm and Hurricane Activities with CFSv2

**Amount:** $245K/two years

**Period:** May 2015 – April 2017

**PI:** J. Schemm

**Co-PI:** H. Wang

This proposal

**Dr. Hui Wang**

**Pending support**

**Agency:** NOAA/NWS

**Title:** Application of a Hybrid Dynamical–Statistical Model for Week 3 to 4 Forecast of Atlantic/Pacific Tropical Storm and Hurricane Activities with CFSv2

**Amount:** $245K/two years

**Period:** May 2015 – April 2017

**PI:** J. Schemm

**Co-PI:** H. Wang (4 months)

This proposal

**11. DUNS Number**

**12. National Environmental Policy Act (NEPA)**

No NEPA information is required with the initial application.