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

A Proposal for the NOAA/NWS Round 1 of Research to Operations Initiative

NOAA-NWS-NWSPO-2015-2004117

**Investigators:**

Jae-Kyung E. Schemm (Lead PI) Climate Prediction Center, NCEP/NWS/NOAA

Meteorologist 5830 University Research Court, College Park, MD 20740

Tel: 301-683-3392, Fax: 301-683-1557

E-mail: Jae.Schemm@noaa.gov

Hui Wang (Co-PI) Climate Prediction Center, NCEP/NWS/NOAA & Innovim

Contract Scientist 5830 University Research Court, College Park, MD 20740

Tel: 301-683-3397, Fax: 301-683-1557

E-mail: Hui.Wang@noaa.gov

Budget Period: May 1, 2015 – April 30, 2017

Budget: Year1 Year 2 Total

NCEP/CPC $120K $125K $245K

**Authorization by Institutional Representative:**

 (Signature)

Michael S. Halpert Climate Prediction Center, NCEP/NWS/NOAA

Acting Director 5830 University Research Court, College Park, MD 20740

Tel: 301-683-3427, Fax: 301-683-1557

E-mail: Mike.Halpert@noaa.gov

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

Jae-Kyung E. Schemm1 and Hui Wang1,2

1NOAA/NWS/NCEP/Climate Prediction Center and 2Innovim

Budget Period: May 1, 2015 – April 30, 2017; Total Budget: $245K

**Abstract**

This proposal is directed to the FY2015 NOAA/NWS Round 1 of Research to Operations (R2O) Initiative, and targets the program priority of Prediction: 2b. Weeks 3–4. The objectives of this project are (1) to explore the impact of the MJO cycle on sub-monthly tropical storm and hurricane activities in the Atlantic and North Pacific basins, (2) to develop a dynamical–statistical model for week 3 and week 4 forecasts of Atlantic and North Pacific basin tropical storm activity, as well as hurricane activity, and (3) to implement this model for operational forecasts for the entire hurricane season with updates on a weekly basis. The project will enable us to help accomplish one of the goals of the R2O Initiative through utilizing the NCEP Climate Forecast System version 2 (CFSv2) operational forecast products to develop hurricane and tropical storm prediction subsystems and to test and evaluate forecasts for high-impact events at the week 3 to 4 time range. The project will be part of the NOAA Climate Testbed (CTB) efforts at Climate Prediction Center (CPC) and will also support the NCEP/CPC Global Tropics Hazards and Benefits Outlooks.

Tropical storm activity is modulated by the Madden–Julian oscillation (MJO) and exhibits large sub-monthly variations over the tropical North Atlantic and North Pacific. Issuing skillful week 3 to 4 forecasts of Atlantic and North Pacific tropical storm and hurricane activities in a timely manner could greatly benefit the emergency preparedness and risk management for the tropical storm-affected areas. With the development of the CFSv2, data from 45-day CFSv2 reforecasts (1999–2010) and real-time forecasts (2011–2014) are available. This dataset, together with a better skill for the MJO prediction in the CFSv2, offers a unique opportunity to develop and test the dynamical–statistical model for operational forecast of week 3 to 4 Atlantic and Pacific tropical storm and hurricane activities. We expect that this forecast system will enhance the capabilities of NCEP week 3 to 4 operational forecasts and complement the existing dynamical–statistical seasonal forecast system at the NCEP/CPC on the 15–30 day time range.

We propose the following work to be completed for this project.

(1) To explore and better understand the impact of the MJO cycle on the sub-monthly variability of tropical storms and hurricanes in the tropical North Atlantic, eastern and western tropical North Pacific regions, respectively, and to assess implications for week 3 to 4 predictions.

(2) To develop a hybrid dynamical–statistical model for week 3 to 4 tropical storm and hurricane forecasts with the multiple linear regression method and cross-validate the model over the 1999-2015 period; and

(3) To test the model for real-time week 3 to 4 forecasts for the 2016 hurricane season and implement the model into operations at NCEP/CPC starting from 2017 hurricane season.

**3. Results from Prior Research**

Dr. Schemm has had experience both with the MJO and with Atlantic hurricane activity in a statistical prediction model (Waliser et al. 1999) as well as a dynamical model (Jones et al. 2000; 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 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 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 storm activities for the 2009-2013 hurricane seasons (Table 1).

Fig. 1. Interannual variability of tropical storm activity over the Atlantic basin during 1981–2009. Predicted number of tropical storms (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 tropical storm (TS) activity over the Atlantic (ATL) and Eastern North Pacific (ENP) basins for the 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 fairy 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 Western North Pacific (WNP) basins. The proposed development activity will be complementary to the CFSv2 –based dynamic prediction procedure and will provide an additional prediction tool for the week 3 to 4 TS activity prediction at CPC.

Table 1. Dynamical seasonal forecasts of Atlantic tropical storms, 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 Storms****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 TS over the ATL, ENP, WNP, Northern Indian (NI), Southern Indian (SI), Australian (AUS) and Southern Pacific (SP) basins. The socres for Week 1 forecasts are in red line, Week 2 in orange line, Week3 in green line and Week 4 in blue line.

Dr. Wang has worked on the development of hybrid dynamical–statistical prediction systems for seasonal tropical storm 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 tropical storm activity (Li et al. 2013). The hybrid model (Wang et al. 2009) was built upon the empirical relationship between the observed interannual variability of tropical storms/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 week 3 and week 4 forecasts of tropical storm and hurricane activities.

Additionally, Dr. Wang has also participated in the U.S. CLIVAR Hurricane Working Group in climate modeling studies of tropical storms. The studies suggest that high-resolution global climate models are capable of simulating the observed interannual variability of tropical storms 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 tropical storms. Similarly, the impact of the MJO on tropical storms and hurricanes and a better representation of the MJO in the CFSv2 are the physical bases for forecasting week 3 to 4 tropical storm and hurricane activities in this project.

**4. Project Description**

**Statement of Work**

The basic working hypothesis of this proposal is as follows. Tropical storms and hurricanes over the eastern and western tropical North Pacific, as well as the tropical North Atlantic exhibit large variability on a sub-monthly timescale. An above-normal hurricane season may have certain periods with inactive tropical storm 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 tropical storm and hurricane activities, the significant improvement of the CFSv2 in predicting the MJO three weeks ahead (Zhang and van den Dool 2012) provides an opportunity to make skillful week 3 to 4 forecasts of tropical storm and hurricane activities. This proposal is directed to test this hypothesis for developing a dynamical-statistical model for week 3 and week 4 predictions of tropical storm and hurricane activities, and to implement the prediction system into operations.

The project targets the NWS R2O Initiative program priority of 2. Prediction, 2b. Service impacts: Weeks 3–4 by testing and evaluating the potential forecast skill for high-impact events in this time band to achieve useful operational forecast products. The project will enable us to help accomplish one of the goals of the R2O Initiative through utilizing the NCEP CFSv2 operational forecast products to develop hurricane and tropical storm prediction subsystems. The project will be part of the NOAA CTB activities at CPC and the outcomes of the project will also support the NCEP/CPC Global Tropics Hazards and Benefits Outlooks. The proposed work will have significant implications in improving the NCEP’s forecast capabilities at the week 3 to 4 time range and will provide useful operational forecast products for the sub-monthly variability of tropical storms and hurricanes. Therefore, the project is highly relevant to the R2O Initiative. The related physical bases for the dynamical–statistical forecast model also indicate a high level of science maturity in this project.

**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 storms 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 tropical storms and hurricanes, skillful prediction of their activity on seasonal and shorter time scales is of critical importance to the human society near coastal regions.

Despite major advances in our ability to dynamically or/and statistically predict seasonal tropical storm and hurricane activities, predicting their activity on a sub-monthly timescale remains a challenge. Given the increased temporal specificity, the prediction of tropical storms and hurricanes on the week 3 to 4 time range may have a more significant social impact. The most recent example is the 2012 Atlantic hurricane season, which was characterized by two very active months, August and October. During each month, 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.

Given the relatively long period of the hurricane season (6 months) and the significant damages that may be caused by tropical storms and hurricanes on a much shorter (weekly) timescale, issuing skillful week 3 to 4 forecasts of Atlantic and Pacific tropical storm and hurricane activities in a timely manner could greatly benefit the emergency preparedness and risk management for the tropical storms-affected areas. The demand from stakeholders for the forecasts of such high-impact events in this time band is also great. Observations have shown that the sub-monthly tropical storm and hurricane activities are strongly modulated by the MJO (e.g., Maloney and Hartmann 2000; Klotzbach 2010). Our prior work on the hurricane season prediction together with a better representation of the MJO in the CFSv2 (Weaver et al. 2011) will help us build and test the dynamical–statistical model for the week 3 to 4 prediction of tropical storm and hurricane activities in the tropical North Atlantic and tropical North Pacific regions.

Our prototype test of predicting monthly tropical storms for the 2010 Atlantic hurricane season indicates certain forecast skill and predictability of tropical storms on a sub-seasonal timescale. The 2010 Atlantic hurricane season was the third most active season on record with 19 tropical storms, 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 storms, 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 storm 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. 2a). To test the predictability of sub-seasonal tropical storm 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 tropical storm 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. 2b). However, the forecast for tropical storms in September, the month of peak tropical storm activity, was weaker than the observations, indicating the need of improvements for the model for the tropical storm intraseasonal prediction.



Fig. 2. (a) Monthly distribution of tropical storms in the 2010 Atlantic hurricane season and (b) forecasts of monthly tropical storms 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 storm climatology (1981–2009) and green lines are +/– one-standard-deviation departure from the climatology.

With the development of the new version of the CFS, 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. 3). 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). The 12-year retrospective forecasts, together with the real-time 45-day CFSv2 forecasts starting from 2011, offer a necessary dataset to develop and test the dynamical–statistical approach for operational forecast of week 3 to 4 Atlantic and Pacific tropical storm and hurricane activities. By considering the impact of the MJO cycle on the tropical storms and hurricanes as an additional predictor in the forecast model, we expect that this model will complement the existing dynamical–statistical seasonal forecast model at NCEP/CPC for the 15–30 day time range.



Fig. 3. 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 developing a dynamical–statistical prediction system for week 3 and week 4 tropical storm and hurricane activities in the tropical North Atlantic and eastern and western tropical North Pacific and 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 sub-monthly variability of tropical storms and hurricanes, evaluating the predictability and potential skill of the week 3 to 4 forecasts of tropical storms and hurricanes, and converting this research to operational forecast products. Our overall project goals are listed as follows.

(1) To further explore and better understand the relationship between the sub-monthly variability of tropical storms and hurricanes and the MJO cycle, and to assess implications for week 3 to 4 prediction;

(2) To develop a hybrid dynamical–statistical model for the week 3 to 4 tropical storm and hurricane forecast with the multiple linear regression method and cross-validate the model over the 1999–2015 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 sub-monthly variations of tropical storms and hurricanes, we will first establish the simultaneous relationships between weekly mean SST/atmosphere conditions and the tropical storm and hurricane 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 Dataset and the daily CFSv2 Reanalysis data.

The analysis will be based on the correlations between weekly mean tropical storms/hurricanes and the corresponding weekly mean SST/atmospheric circulation fields over the 16 years from 1999 to 2014. The weekly periods start from May 1 to November 27 of each year. There are total 31 consecutive 7-day periods covering the entire hurricane season from May 1 to November 30, with each starting date 7 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 were 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 atmosphere circulation and SST on the sub-monthly variations of tropical storms and hurricanes over each ocean basin. Practically, we will analyze how different phases of the MJO modulate the tropical storm and hurricane activities in different ocean basins. This will provide the physical basis for week 3 to 4 forecasts of tropical storms and hurricanes.

A similar correlation analyses will be performed between the observed weekly mean tropical storms/hurricanes and the corresponding weekly mean SST/atmospheric circulation fields derived from the 45-day CFSv2 reforecasts (1999-2010) and the CFSv2 real-time forecasts (2011–2014). The relationships depicted by the CFSv2 will be compared with those based on the observations to validate the CFSv2 in reproducing the associations between SST/atmospheric anomalies and the sub-monthly tropical storm and hurricane variations. The data from the CFSv2 are ensemble means. The 4 × daily 45-day forecasts for a common target week 3 and week 4 period provide a maximum of 60 ensemble members, with lead times from 15 days to 1 day. For each CFSv2-predicted variable, the region of high correlations with the weekly mean tropical storm/hurricane activity will be used for area-averaging as a potential predictor.

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

A hybrid dynamical–statistical forecast model for the week 3 to 4 tropical storm and hurricane activities 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 storm and hurricane prediction, a statistical model for weekly mean tropical storm and hurricane prediction will be developed based on the empirical relationships established in (1) with the multiple linear regressions of weekly mean tropical storms/hurricanes versus the CFSv2-predicted predictors over the 1999–2015 period. For the entire hurricane season (May-November), there will be total 28 ensemble mean forecasts, each 7 days (one week) apart. In addition to the ensemble mean forecasts, the forecasts based on individual 60 members will be used to develop a probabilistic forecast of tropical storms and hurricanes, based on the spreads among the 60 members. Therefore, similar to what we have done for the seasonal tropical storm/hurricane prediction, each forecast will consist of the weekly mean tropical storms and hurricanes for week 3 and week 4, respectively, a forecast range (ensemble mean ± one standard deviation of spreads), and the chances in percentage for above-normal, near-normal, and below-normal tropical storm and hurricane activities based on the distribution of all individual member forecasts.

The week 3 to 4 forecasts of weekly mean tropical storms and hurricanes will be cross-validated for each hurricane season during the 1999–2015 period. The forecast skills will be assessed, including correlation score, root mean square error, 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 week 3 to 4 forecasts of weekly mean Atlantic and Pacific tropical storms and hurricanes will be made for the 2016 hurricane season based on the 45-day CFSv2 dynamical forecasts. The forecasts will be updated every Monday from May 1 to November 7, 2016 (total 28 week 3 to 4 forecasts) for each ocean basin. The real-time 45-day CFSv2 forecasts have much more ensemble members each day than the 45-day CFSv2 reforecasts (16 vs. 4). Probabilistic forecasts of tropical storms and hurricanes for the 2016 season thus can be made with sufficient number of ensemble members but shorter lead times (e.g., 80 ensemble members, 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 Work plan**

The proposed project will be conducted over a two-year period from May 1, 2015 to April 30, 2017. In the first year, Objective 1 will be met primarily through the statistical analysis of the NOAA Hurricane Best Track Dataset and the daily CFSv2 Reanalysis data over the 1999-2014 period, and the 45-day CFSv2 reforecasts (1999−2010) and the 45-day CFSv2 real-time forecasts (2011−2014) in the first six months (05/01/2015−10/31/2015). In the following six months (11/01/2015−04/30/2016), we will work on the development of the dynamical−statistical forecast model for the week 3 to 4 forecasts of tropical storms and hurricanes (Objective 2), including the cross-validation for the 1999−2015 period.

In the second year, the real-time forecast will be tested for the 2016 hurricane season during the first six months (05/01/2016–10/31/2016). In the last six months of the project, the model will be implemented for operational forecasts at PIs’ home institution, the NOAA/NWS/NCEP Climate Prediction Center. The procedures will include transferring finalized model codes to the CPC’s computer farm, as well as the scripts for extracting the 45-day CFSv2 real-time forecast data, running the forecast model, and post-processing. We will also 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.

Quarterly progress reports and yearly reports, as well as the final closeout report from the PIs will be submitted to the program manager and/or the project office. (Attend any webinar and present results?)

**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 sub-monthly tropical storm and hurricane activities and SST/atmospheric circulation parameters, including the MJO, the development of the hybrid dynamical–statistical model for week 3 to 4 forecasts, 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.

**4.5** **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.

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.

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. Budget and Proposed Budget Justification**

**Budget**

(For this budget the years are May through April of the following years.)

**Year FY2015 FY2016 Total**

**Salaries and Overhead**

Schemm (1 mo/yr) N/C N/C

Wang (4 mo/yr) $60.0K $62.0K $122.0K

Support Scientist (5 mo/yr) $51.5K $53.5K $105.0K

**Equipment**

Workstation $ 0.0K $ 0.0K $ 0.0K

Peripherals $ 2.0K $ 0.0K $ 2.0K

**Supplies** $ 0.5K $ 0.5K $ 1.0K

**Travel** $ 6.0K $ 6.0K $ 12.0K

**Publications**  $ 0.0K $ 3.0K $ 3.0K

**TOTALS $120.0K $125.0K $245.0K**

**Budget justification**

This budget includes salaries of Dr. Hui Wang (4 months) and a support staff (5 months), indirect charges, travel costs for PIs to attend the conference/workshop related to this project ($6K each year), 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 per year from Dr. Jae-Kyung Schemm.

**6. 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.

**7. Current and Pending Support**

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

**Current support**

**Agency:** NOAA CPO/MAPP

**Status:** Current

**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)

**Status:** Current

**Title:** NMME Extension Project

**Amount:** $120K

**Period:** May, 2014 – September, 2015

**PI:**  Jin Huang

**Co-PI**: J. Schemm

**Pending support**

This proposal

**Dr. Hui Wang**

This proposal

**8. NEPA Questions to Be Answered**

This program does not require any NEPA questions to be answered as part of the application

**9. Data Sharing Plan**

The forecasting systems, 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 models and products of the operational week 3 to 4 forecasts of the Atlantic/Pacific tropical storm activities, illustrated with figures. The purpose is to provide a guide to help general publics to understand and interpret the forecasts.