A Proposal Submitted to the
NOAA OAR FY2013 Joint Hurricane Testbed (JHT)
NOAA-OAR-OWAQ-2013-2003469

Developing a Hybrid Dynamical–Statistical Model for Intraseasonal Forecast of Atlantic/Pacific Tropical Cyclone Activities

Principal Investigators:

Jae-Kyung E. Schemm (PI)
Climate Prediction Center, NCEP/NWS/NOAA
NCWCP, W/NP5, Rm. 3007
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
Wyle ST&E Group
NCWCP, W/NP5, Rm. 3012
5830 University Research Court
College Park, MD 20740
Tel: 301-683-3397, fax: 301-683-1558
E-mail: Hui.Wang@noaa.gov

Arun Kumar (Co-PI)
Climate Prediction Center, NCEP/NWS/NOAA
NCWCP, W/NP5, Rm. 3000
5830 University Research Court
College Park, MD 20740
Tel: 301-683-3385, fax: 301-683-1557
E-mail: Arun.Kumar@noaa.gov

Budget Period: August 1, 2013 - July 31, 2015

Budget:	Year 1	Year 2	Total
	$88,000	$93,000	$181,000

Authorization

Jae-Kyung Schemm, PI
Climate Prediction Center, NCEP/NWS/NOAA

R. Wayne Higgins, Director
Climate Prediction Center, NCEP/NWS/NOAA

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Jae-Kyung E. Schemm[1], Hui Wang[1,2], and Arun Kumar[1]
[1]NOAA/NWS/NCEP Climate Prediction Center and [2]Wyle ST&E Group

Budget Period: Aug. 1, 2013 - Jul. 31, 2015; Total Budget: $181,000

Abstract

This proposal is directed to the FY2013 Joint Hurricane Testbed (JHT) call for proposals, and targets the program priority for developing quantitative guidance tools for seasonal tropical cyclone (TC) forecasts using statistical and dynamical methodologies (NHC-17/JTWC-14). The proposal is aimed at developing a dynamical-statistical forecast model for intraseasonal TC prediction over the tropical North Atlantic and Pacific based on the NCEP's new version of Climate Forecast System (CFSv2) 45-day dynamical forecasts and implementing the model into operations at the National Hurricane Center (NHC) and the Joint Typhoon Warning Center (JTWC), and also at the Climate Prediction Center (CPC). The project will enable us to help accomplish the JHT mission through utilizing the state-of-the-art climate model forecasts to develop new applications, testing and evaluating new products for TC forecast.

TC activity is modulated by the MJO and exhibits large sub-seasonal variations over the tropical North Atlantic and Pacific. Issuing a skillful intraseasonal forecast of Atlantic and Pacific TC activities in a timely manner could greatly benefit the emergency preparedness and risk management for the TC-affected areas. With the development of CFSv2, data from 45-day CFSv2 reforecasts (1999-2010) and real-time forecasts (2011-2012) are available. This dataset, together with a better skill for the MJO prediction in CFSv2, offers a unique opportunity to develop and test the dynamical–statistical model for operational forecast of 30-day mean Atlantic and Pacific TC activities. We expect that this model will complement the existing dynamical-statistical seasonal forecast model at the CPC on the intraseasonal time scale.

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

(1) To establish the empirical relationships between the observed 30-day mean TCs and the CFSv2-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 1999-2012 data, and identify potential predictors for the intraseasonal TC forecast;
(2) To develop a hybrid dynamical-statistical model for the intraseasonal TC forecast with the multiple linear regression method and cross-validate the model over the 1999-2012 period; and
(3) To test the model for real-time intraseasonal forecasts for the 2014 hurricane season and implement the model into operations at NHC and JTWC.

Statement of Work

1. Duration of the project

The proposed work will be conducted over a two-year period. The dynamical-statistical model for the intraseasonal forecast of Atlantic/Pacific tropical cyclone (TC) activities will be developed during the first year. In the second year, real-time forecasts for the 2014 hurricane season will be tested and transitioned to operations at the National Hurricane Center (NHC) and the Joint Typhoon Warning Center (JTWC). The operational intraseasonal forecast of the Atlantic/Pacific TC activities will commence during the 2015 hurricane season.

2. Description of the project

2a. Prior research results

Our relevant prior research includes (a) development of a hybrid dynamical-statistical model for Atlantic/eastern Pacific hurricane seasonal prediction (Wang et al. 2009), (b) seasonal hurricane prediction with a high-resolution coupled model (Schemm and Long 2009), and (c) development of a dynamical-statistical forecast model for seasonal western Pacific TC activity (Li et al. 2012). 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 Climate Forecast System version 1 (CFSv1). The model was implemented for real-time forecasts for the hurricane season at the NOAA Climate Prediction Center (CPC) in 2008, using the CFSv1 dynamical seasonal forecasts of SST and vertical wind shear as predictors. In the past five seasons, this model provided skillful seasonal forecasts and useful information for the NOAA Hurricane Outlooks. SSTs from the CFSv1 seasonal forecasts have also been used in the dynamical-statistical forecast model developed at GFDL for predicting seasonal Atlantic hurricane activity (Vecchi et al. 2011).

With the same dynamical-statistical approach, a forecast model was also developed for predicting seasonal TCs over the western North Pacific (Li et al. 2012). Based on the empirical relationship between the observed seasonal TC activity and the dynamical predictions of large-scale oceanic and atmospheric conditions from the new version (v2) of CFS, and further, using the CFSv2 predicted July–October tropical North Atlantic SST, vertical shear of zonal wind, 500-hPa height, and 850-hPa zonal wind over the tropical and subtropical Pacific as predictors, the model demonstrates skillful seasonal forecasts for the western Pacific TCs. This model is competitive with other statistical models currently used for the seasonal TC predictions over the same region and is being implemented for operational forecast at the Hainan Meteorological Service of the China Meteorological Administration.

In 2009, a dynamic hurricane season prediction system was implemented operationally at NCEP/CPC utilizing the T382 CFS CGCM (Schemm and Long 2009) and it has been providing the dynamic prediction input for the NOAA Hurricane Season Outlook. The hindcast experiments were performed with the dynamic prediction system for the 1981-2008 period to establish the model climatology and to conduct skill evaluation on the seasonal tropical storm activities. 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 results from the T382 CFS prediction system include very realistic reproduction of the interannual variability in tropical storm activity as well as the shift to a more active hurricane era in the middle 1990s. The dynamic system has shown considerable skill in predicting the seasonal storm activities for the 2009-2011 period.

Despite major advances in our ability to dynamically or/and statistically predict seasonal TC activity, predicting TC activity on a sub-seasonal time scale remains a challenge. Given the increased temporal specificity, prediction of TC activity on intraseasonal time scale 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 TCs, respectively, with one landfall 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 significant damages that may be caused by TCs and hurricanes, issuing skillful sub-seasonal forecasts of Atlantic and Pacific TC activities in a timely manner could greatly benefit the emergency preparedness and risk management for the TC-affected areas. Observations have shown that the sub-seasonal TC activity is strongly modulated by tropical intraseasonal variability, known as 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 new version of CFS (Weaver et al. 2011) will help us to build and test the dynamical-statistical model for the intraseasonal prediction of TC activity over the tropical North Atlantic and tropical North Pacific regions.

2b. Working hypothesis and objectives

The basic working hypothesis of this proposal is as follows. The TC activities over the eastern and western tropical North Pacific, as well as the tropical North Atlantic, exhibit large variability on the sub-seasonal time scale. 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 the TC activity on this time scale. 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) provides an opportunity to make skillful forecasts of the TC activity on the intraseasonal time scale.

This proposal is directed to test this hypothesis to develop a dynamical-statistical model for TC intraseasonal prediction, and to implement the prediction system into operations. The project targets the program priority of quantitative guidance tools for seasonal tropical cyclone forecasts using statistical and dynamical methodologies (NHC-17/JTWC-14). The outcomes of the proposal will also enable us to help accomplish the JHT mission through utilizing the state-of-the-art climate model forecasts to develop new applications, testing and evaluating new products for tropical cyclone forecast.

Our prototype test of predicting monthly TCs for the 2010 Atlantic hurricane season indicates certain forecast skill and predictability of TCs on the sub-seasonal time scale. The 2010 Atlantic hurricane season was the third most active season on record with 19 TCs, among which there were 12 hurricanes and five major hurricanes. However, the TC activity had substantial variation within the hurricane seasons and was actually near normal in the early season and was well above normal only in September and October (Fig. 1a). The dynamical-statistical model (Wang et al. 2009) made a successful *seasonal* prediction in May 2010 for the 2010 hurricane season with 20 TCs, 12 hurricanes, and six major hurricanes, based on the CFSv1 dynamical seasonal forecast of SST and vertical wind shear for the target season. To test the predictability of intraseasonal TC activity for the 2010 season, the same model was also applied to monthly data, using the CFSv1-predicted vertical wind shear for the target month as a predictor. 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. 1b). However, the forecast for TCs in September, the month of peak TC activity, was weaker than the observations, indicating the need of improvements for the model for the TC intraseasonal prediction.

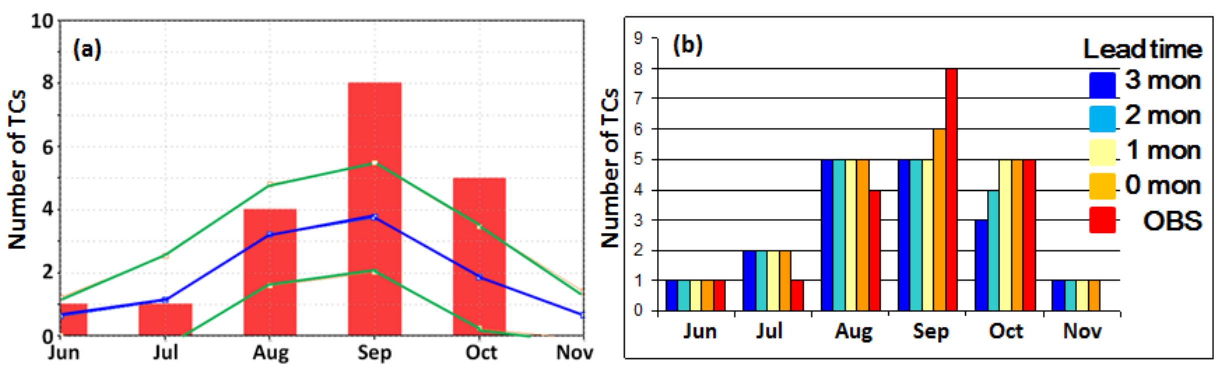

Fig. 1. (a) Monthly distribution of TCs in the 2010 Atlantic hurricane season and (b) forecasts of monthly TCs for the 2010 hurricane season using the dynamical-statistical model (Wang et al. 2009) with lead time from 3 months to 0 month. Blue line in (a) is the monthly TC climatology (1981-2009) and green lines are +/- one-standard-deviation departure from the climatology.

With the development of the new version of CFS, data from 45-day CFSv2 reforecasts (1999–2010) are available. An evaluation of CFSv2 (Weaver et al. 2012) indicates that the MJO is better represented with a higher prediction skill in CFSv2 than in CFSv1 (Fig. 2). The time scale for a skillful MJO prediction was extended from two weeks in CFSv1 (Seo, et al. 2009) to three weeks in CFSv2 (Zhang and van den Dool 2012). The 12-year retrospective forecasts, together with the real-time 45-day CFSv2 forecasts starting from 2011, offer a unique opportunity to develop and test the dynamical–statistical model approach for operational forecast of 30-day mean Atlantic and Pacific TC activities. We expect that this model will complement the existing dynamical–statistical seasonal forecast model at CPC on the intraseasonal time scale.

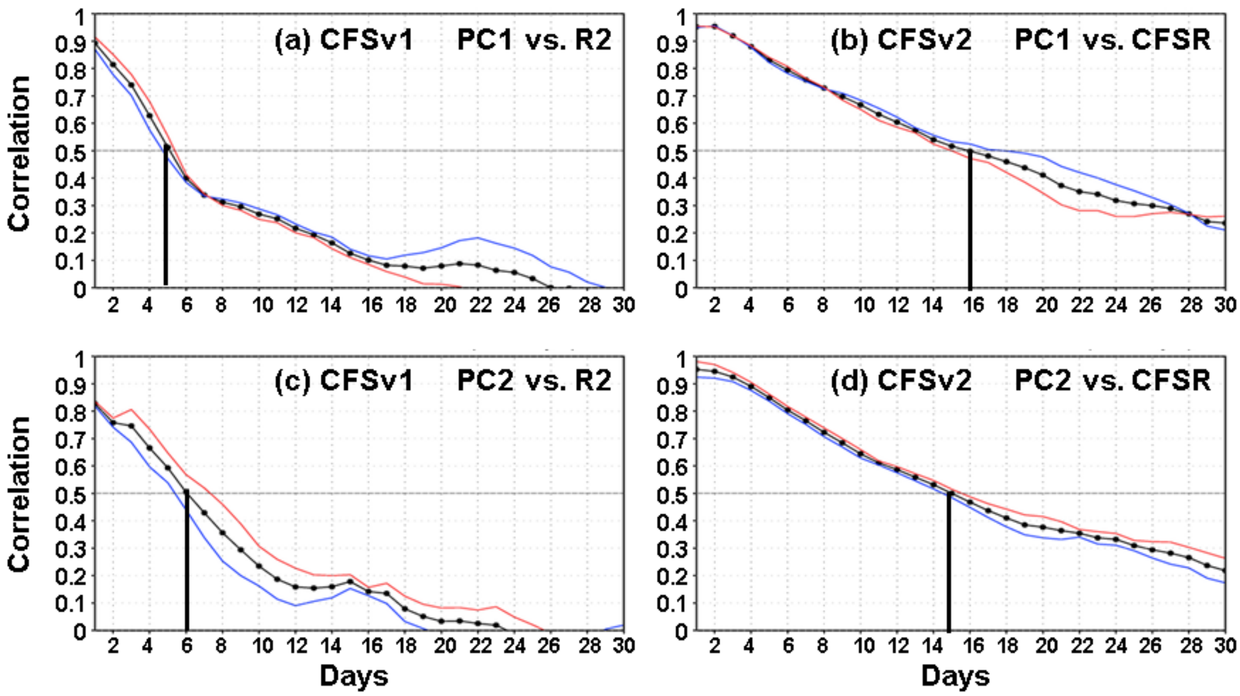

Fig. 2. MJO prediction skill expressed by the correlation coefficient (black lines with dots) between the CFS-predicted MJO indices (PC1 and PC2 of CHI200) and those derived from the reanalysis data. (a) and (c) are the correlations for PC1 and PC2, respectively, between CFSv1 and the NCEP/DOE Reanalysis (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.

This proposal is thus aimed at developing a dynamical-statistical forecast model for the intraseasonal TC activities in the tropical North Atlantic and Pacific based on the CFSv2 45-day dynamical forecasts and implementing the model into operations at two operational forecast centers (NHC and JTWC) and CPC. The objectives of this project are as follows:

(1) To establish the empirical relationship between the observed 30-day mean TCs and the CFSv2-predicted ocean/atmosphere conditions for the same 30-day period throughout the entire hurricane season for the tropical North Atlantic, eastern and western tropical North Pacific regions, respectively, and select potential predictors for the intraseasonal TC forecast;

(2) To develop a hybrid dynamical-statistical model for the intraseasonal TC forecast with the multiple linear regression method and cross-validate the model over the 1999-2012 period; and

(3) To test the model for real-time forecasts for the 2014 hurricane season and implement the model into operations at NHC and JTWC.

2c. Proposed methodologies

(1) Potential predictors (Objective 1)

To select potential predictors for the intraseasonal forecast of TC activity, we will first establish the simultaneous relationships between 30-day mean large-scale ocean/atmosphere conditions and the TC activity 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 30-day mean TCs and 30-day mean SST/atmospheric circulation fields over the 14 years from 1999 to 2012. Each 30-day period starts from 1st, 11th, and 21st of the months from May to November, respectively. There are total 19 moving 30-day periods covering the entire hurricane season from May 1 to November 30, with each starting date 10 days apart. The atmospheric fields include vertical wind shear, sea level pressure, 500-hPa height, and 850-hPa wind. An index representing the 30-day mean activity of the MJO will also be employed.

A similar correlation analyses will be performed between the observed 30-day mean TCs and the 30-day mean SST/atmospheric circulation fields derived from the 45-day CFSv2 reforecasts (1999-2010) and CFSv2 real-time forecasts (2011-2012). The relationships depicted by CFSv2 will be compared with those based on the observations to validate CFSv2 in reproducing the associations between SST/atmospheric anomalies and the intraseasonal TC variations. The data from CFSv2 are ensemble means. The 4 x daily 45-day forecasts for a common target 30-day period provide a maximum 60 ensemble members, with lead times from 15 days to 1 day. For each CFSv2-predicted variable, the region of high correlations with the 30-day mean TC 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 intraseasonal TC activity will be developed for the eastern and western tropical North Pacific and the tropical North Atlantic, respectively. Similar to the model in Wang et al. (2009) for the seasonal TC/hurricane prediction, a statistical model for a 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 CFSv2-predicted predictors over the 1999-2012 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 60 members will be used to develop a probabilistic forecast of TCs, based on the spreads among the 60 members. Therefore, similar to what we have done for the seasonal TC/hurricane prediction, each forecast will consist of the 30-day mean TCs, 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 intraseasonal forecasts of 30-day mean TCs will be cross-validated for each hurricane season during the 1999–2012 period. The forecast skills will be assessed (e.g., 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 forecasts of 30-day mean Atlantic and Pacific TCs will be made for the 2014 hurricane season based on the 45-day CFSv2 dynamical forecasts. The intraseasonal forecasts will be updated every 10 days from May 1 to November 1, 2014 (total 19 30-day forecasts) for each ocean basin. The real-time 45-day CFSv2 forecasts have much more ensemble members each day then the 45-day CFSv2 reforecasts (16 vs. 4). Probabilistic forecast of TCs for the 2014 season thus can be made with enough 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 increase the forecast skill.

In the meantime, the forecast model with detailed documentations and computer codes (UNIX shell scripts and FORTRAN codes) will be transferred to the National Hurricane Center (NHC) and the Joint Typhoon Warning Center (JTWC) for testing and implementing into operations. Alternatively, the forecast procedures may be implemented operationally at CPC and the final forecast products will be transmitted to NHC and JTWC

3. Work plan

The proposed project will be conducted over a two-year period (08/01/2013−07/31/2015). 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 1999-2012 period, and the 45-day CFSv2 reforecasts (1999−2010) and the 45-day CFSv2 real-time forecasts (2011−2012) in the first five months (08/01/2013−12/31/2013). In the following four months (01/01/2014−04/30/2014), we will work on the development of the dynamical-statistical forecast model for the intraseasonal TC prediction (Objective 2), including the cross-validation for the 1999−2012 period, and prepare the documentation for the model. The progress of the model development and validation will be reported at the annual Interdepartmental Hurricane Conference (IHC) in March 2014.

During the 2014 hurricane season (05/01/2014−11/30/2014), the model will be tested for the real-time intraseasonal TC forecast (Objective 3) at PIs' home institution, the NOAA Climate Prediction Center, as well as at the two operational forecast centers, the National Hurricane Center (NHC) and the Joint Typhoon Warning Center (JTWC). The real-time operational data needed as the model input will be the 45-day CFSv2 forecasts. The data will be used to derive and obtain the predictors for the target 30-day period, which are the 30-day mean SST/atmospheric circulation anomalies averaged over the specific regions with high correlations with the 30-day mean TC activity. The test of the real-time forecasts at the two operational centers will also serve as practice for the forecasters at the two centers to get familiar with the model.

In the following three months (12/01/2014–02/28/2015), we will evaluate the model performance in the 2014 hurricane season and finalize the model configuration based on the assessment. A related report will be presented at the annual IHC in March 2015. In the last five months (03/01/2015–07/31/2015), the model will be implemented for operational forecasts at the two operational centers (NHC and JTWC; Objective 3). The procedures will include transferring finalized codes to the local computer at the two operational centers and training local forecasters to extract the 45-day CFSv2 real-time forecast data and run the forecast model.

4. Timeline for project delivery

The timeline for delivering scientific and technical documentation and training materials are list below, which will be formalized with the coordination between the PIs and the JHT/JTWC focal points if the proposal is funded.

03/31/2014	Scientific and technical documentations of the model
03/31/2014	Training materials with model codes
04/30/2014	Real-time forecast for the 2014 hurricane season
05/31/2015	Finalized model for operations

5. Schedule for travel

The PIs plan to attend the annual Interdepartmental Hurricane Conference (IHC) each year (March 2014 and March 2015) and present the progress and results of the project. Additionally, there will be two short visits to each operational center (NHC and JTWC) for one of the PIs in April 2014 for testing the real-time intraseasonal forecast for the 2014 hurricane season and in May 2015 for implementing the model into operations.

6. Estimates of staff, computer, and facility requirements

At PIs' home institution, we have all the computer equipment necessary to carry out the work of this project, including UNIX workstations and NOAA R&D supercomputers (Zeus and Gaea), as well as access to HPSS. The proposed budget includes funds for partial support of one of the PIs and a support staff to help PIs with data processing. We also have teleconferencing facilities at the NOAA CPC for communications with the two operational centers (NHC and JTWC). The forecast model will be a statistical model and can be run on any workstations. It should be easy for implementation into operations at the two forecast centers. The two centers do need to have remote access to the 45-day CFSv2 real-time forecasts used as the model input.

7. References

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8. Budget

(For purposes of this budget the years are August through July of the following year.)

Year	2013	2014	Total
Salaries and Overhead			
Schemm (1 mo/yr)	N/C	N/C	
Kunar (1 mo/yr)	N/C	N/C	
Wang (4 mo/yr)	$51.0K	$54.0K	$105.0K
Support Scientist (3 mo/yr)	$30.0K	$33.0K	$63.0K
Equipment			
Peripherals	$2.0K	$0.0K	$2.0K
Supplies and			
Data Costs (5Tb data storage)	$0.5K	$0.0K	$0.5K
Travel	$4.5K	$6.0K	$10.5K
TOTALS	$88.0K	$93.0K	$181.0K

Budget explanation

Personnel: Drs. J. Schemm and A. Kumar are federal employees and are supported by the CPC base. They will make an in-kind contribution of up to 1 month per year each on the project and will oversee the overall research activities. Dr. H. Wang will be responsible for statistical analyses on relationship between subseasonal TC activities and SST/atmospheric circulation parameters and testing the proposed intraseasonal TC activity prediction system.

Travel: The travel is based on an estimate of one domestic trip per year ($1500) for the PIs and support staff to attend scientific meetings relevant to this research project and short visits to the two operational centers as proposed.

Other direct costs: 4 month salary of a Co-PI (Wang) and 3 month salary of a support staff is requested for each year. Salaries include an overhead and benefits factor of 1.8 for contractor support. The stipends are projected to increase 5% per year. Support is also being sought for disk space for data storage.

9. Data sharing plan

The forecast model, cross-validations, and real-time forecasts for the 2014 hurricane season obtained in this project will be published in a scientific journal and shared with the scientific community. In addition, we will create a website to make available the detailed models and products of the operational intraseasonal forecasts of the Atlantic/Pacific TC activities, illustrated with figures. The purpose is to provide a guide to help general publics to understand and interpret the forecasts.

10. Curriculum Vitae

10a. PI: **Dr. Jae-Kyung E. Schemm,** Research Meteorologist

Current Position: Research Meteorologist, Development Branch, CPC/NCEP/NWS/NOAA

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, Development 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 & Technology, University of Maryland, College Park, MD

Recent Awards:

US Dept. of Commerce Bronze Medal, 2000
US Dept. of Commerce Gold Medal, 2005

Community 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 – present

Recent Publications:

Schemm, J., L. Long, 2009: Dynamic Hurricane Season Prediction Experiment with the NCEP CFS. *Workshop on High Resolution Climate Modeling*, Trieste, ICTP, Italy.

Bell, G., E. Blake, S. Goldenberg, T. Kimberlain, C. Landsea, R. Pasch and **J. Schemm** 2009: Tropical Cyclones: Atlantic Basin [in State of Climate in 2008]. *Bull. of Amer. Met. Soc.,* 90(8), S79-83.

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10b. Co-PI: Dr. Hui Wang

Educational Background

Ph.D.	1997	University of Illinois	Atmospheric Sciences
M.S.	1987	Nanjing University	Atmospheric Sciences
B.S.	1984	Nanjing University	Physics

Employment History

2007–present	Atmospheric Scientist, NOAA CPC and Wyle ST&E Group
2006–2007	Research Scientist, Center for Research on the Changing Earth System
2003–2006	Senior Research Scientist, Georgia Institute of Technology
2000–2003	Research Scientist II, Georgia Institute of Technology
1997–1999	Postdoctoral Research Associate, University of Arizona

Professional Services

Panel reviewer, NASA Modeling, Analysis and Prediction (MAP) Program, 2012
Member, US CLIVAR Hurricane Working Group, 2011–present

Recent Publications

Hu, Z.-Z., A. Kumar, H.-L. Ren, **H. Wang**, M. L'Heureux, and F.-F. Jin: Weakened interannual variability in the tropical Pacific Ocean since 2000. *J. Climate*, in press, 2012.

Kumar, A., **H. Wang**, W. Wang, Y. Xue, and Z.-Z. Hu: Does knowing the oceanic PDO phase help predict the atmospheric anomalies in subsequent months? *J. Climate*, in press, 2012.

Li, W., L. Li, R. Fu, Y. Deng, and **H. Wang**: Reply to Comments on "Changes to the North Atlantic subtropical high and its role in the intensification of summer rainfall variability in the southern United States.". *J. Climate*, in press, 2012.

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Quan, X., M. P. Hoerling, B. Lyon, A. Kumar, M. A. Bell, M. K. Tippett, and **H. Wang**: Prospects for dynamical prediction of meteorological drought. *J. Appl. Meteoro. Climato.*, **51,** 1238–1252, 2012.

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Huang, B., Y. Xue, **H. Wang**, W. Wang, and A. Kumar: Mixed layer heat budget of the El Nino in NCEP Climate Forecast System. *Climate Dyn.*, 39, 365–381, 2012.

Kim, S. T., J.-Y. Yu, A. Kumar, and **H. Wang**: Examination of the two types of ENSO in the NCEP CFS model and its extratropical associations. *Mon. Wea. Rev.*, **140,** 1908–1923, 2012.

Chen, M., W. Wang, A. Kumar, **H. Wang**, and B. Jha: Ocean surface impacts on the seasonal precipitation over the tropical Indian Ocean. *J. Climate*, **25,** 3566–3582, 2012.

Sooraj, K. P., H. Annamalai, A. Kumar, and **H. Wang**: A comprehensive assessment of CFS seasonal forecast over the tropics. *Wea. Forecasting*, **27,** 3–27, 2012.

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

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

Li, W., L. Li, R. Fu, Y. Deng, and **H. Wang**: Changes to the North Atlantic subtropical high and its role in the intensification of summer rainfall variability in the Southeastern United States. *J. Climate*, 24, 1499–1506, 2011.

Wang, H., R. Fu, A. Kumar, and W. Li: Intensification of summer rainfall variability in the Southeastern United States during recent decades. *J. Hydrometeoro.*, 11, 1007–1018, 2010.

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

10c. Dr. Arun Kumar

Climate Prediction Center
National Centers for Environmental Prediction
5830 University Research Court, Rm 300
College Park, MD 20740, USA
Phone: 301-683-3385
Fax: 301-683-1557
Email: arun.kumar@noaa.gov

Professional and Educational Experience:

July 2007-present, Chief, Development Branch, Climate Prediction Center, NCEP, NOAA
January 2007-June2007, Acting Director, Climate Prediction Center, NCEP, NOAA
October 2003-December 2006, Deputy Director, Climate Prediction Center, NCEP, NOAA
June 2002-September 2003, Acting Deputy Director, Climate Prediction Center, NCEP, NOAA
January 2002-June 2002: Meteorologist, Climate Prediction Center, NCEP, NOAA
1994-2001: Meteorologist, Climate Modeling Branch, NCEP, NOAA
1990-1994: Contract Meteorologist, Coupled Model Project, EMC, NOAA

1986-1990: M.S. and Ph.D. in Meteorology from Florida State University, Tallahassee.
1983-1986: Research Assistant, Department of Meteorology, FSU, Tallahassee, FL.
1980-1983: Research Assistant, Department of Physics, IIT, Kanpur, India.
1979: M.S., Physics, Lucknow University, India.

Relevant Publications

Li, X., S. Yang, H. Wang, X. Jia, and A. Kumar, 2012: A dynamical–statistical forecast model for western Pacific tropical cyclones based on the NCEP Climate Forecast System. *J. Geophys. Res.–Atmospheres*, submitted.

Zhou, S., M. L'Heureux, S. Weaver, and A. Kumar, 2012: A composite study of the MJO influence on the surface air temperature and precipitation over the Continental United States. Climate Dynamics, 38, 1459-1471.

Kumar, A., and Co-authors, 2012: An Analysis of the Non-stationarity in the Bias of Sea Surface Temperature Forecasts for the NCEP Climate Forecast System (CFS) Version 2. Mon. Wea. Rev., 140 ,3003-3016.

Wang, H., A. Kumar, W. Wang, and Y. Xue, 2012: Seasonality of the Pacific Decadal Oscillation, J. Climate, 26, 25-38.

Vecchi, G., and Co-authors, 2011: Statistical-Dynamical predictions of seasonal north Atlantic hurricane activity. Mon. Wea. Rev., 139, 1070-1082.

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

Kumar, A., M. Chen, and W. Wang, 2011: An analysis of prediction skill of monthly mean climate variability. Climate Dynamics, 37, 1119-1131.

Wang, H., and Co-Authors, 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. Chen, and A. Kumar, 2009: Impacts of ocean surface on the northward propagation of the boreal summer intraseasonal oscillation in the NCEP climate forecast system. J. Climate, 22, 6561-657

Seo, K.-H., and Co-authors, 2009: Evaluation of MJO Forecast Skill from Several Statistical and Dynamical Forecast Models. J. Climate, 22, 2372-2388.

Seo, K.-H., J.-K. E. Schemm, W. Wang, and A. Kumar, 2007: The boreal summer intraseasonal oscillation in the NCEP Climate Forecast System (CFS): The effect of sea surface temperature. Mon. Wea. Rev, 135, 1807-1827.

11. Current and pending support

11a. PI: Dr. Jae-Kyung E. Schemm

Current support
Agency: NOAA CPO/CTB
Status: Current
Title: Multi-model ensemble forecasts of MJO
Amount: $170K/year
Period: July, 2010 – June 2013
PI: B. Wang
Co-PI: D. Waliser
Co-Is: S. Schubert, B. Kirtman, H. Hendon, I. Kang, J. Lee, X. Fu, P. Liu, J. Gottschalck, A. Kunar, J. Schemm, S. Lord and A. Vintzileos

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

Pending support
This proposal

11b. Dr. Arun Kumar

Dr. Arun Kumar is base funded through CPC and the budget listed below is for contract support.

Current:

Title: A methodology for North American decadal climate prediction
PI: Arun Kumar
Source Support: NOAA/MAPP
Period: August 2012– July 2015
Budget (contract support): $40,000/ year

Pending:

Title: Understanding Hydrological Cycle in CFSR and MERRA
Co-PI: Arun Kumar

Source Support: NOAA/MAPP
Period: August 2013– July 2016
Budget (contract support): $80,000/ year

Title: Research towards the next generation of NOAA Climate Reanalyses
Co-PI: Arun Kumar
Source Support: NOAA/MAPP
Period: August 2013– July 2016
Budget (contract support): $318,000/ year

This proposal

11c. Dr. Hui Wang

No current funded project

Pending support
This proposal