Title Page

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Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach

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Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach

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Proposed Budget: $415,219; Budget Period: May 1, 2015 to April 30, 2017

Abstract

The recent 2011 *Strategic Plan* for the National Weather Service (NWS) emphasizes the goal of a "Weather-Ready Nation," which will require users to better synthesize NWS forecasts to take preventative actions towards the protection of life and property. The proposed project will address the program priorities in advances in post-processing to improve model evaluation and development (focus area #6), and advancing weather prediction 6-10 days (area #2a). Extratropical storms and their associated fronts are responsible for much of the high impact weather over mid latitudes. Unfortunately, many of the current verification metrics used in operations are grid point relative (e.g., regional), and averaging over a fixed geographic region will smooth many important processes and significant weather features around the cyclone. Some verification metrics are gathered for cyclones, but they are usually limited to central pressure, displacement, and cyclone density errors. In order to better understand operational model and ensemble performance and processes that may be leading to any systematic errors of significant weather around the cyclone, a cyclone-relative verification approach is needed. Knowledge of the performance of cyclone-relative features, such as jets, precipitation bands, and fronts, can also help develop confidence metrics and tools for forecasters about the skill in predicting those features at various lead times from 0 to 10 days.

This project will involve collaboration between Stony Brook University (SBU) and several NWS operational centers (Environmental Modeling Center, Weather Prediction Center, Ocean Prediction Center, and Aviation Weather Center) as well as the Developmental Testbed Center (DTC). SBU will work with the DTC to modify the Model Evaluation Tools (MET) verification software to interface with the extratropical cyclone tracker code and output at EMC. Using a cyclone-relative approach within MET, the errors associated with the cyclones will be related to the various important physical processes (moisture flux, stability, strength of upper-level PV anomaly and jet, surface fluxes, and precipitation), and the results will be separated by different stages of the cyclone (genesis, mature, and decay), cyclone intensity, and large-scale flow regime. This approach will help model developers and forecasters better understand the origin of cyclone biases (e.g., hypothesized underdeepening of surface cyclones in the GFS in the medium range), and the ensemble performance for the significant weather around the cyclone. This project will result in four main deliverables: (1) verification of extratropical cyclones, associated significant weather, and the physical processes within the Global Forecast System (GFS) model and GFS ensemble; (2) comparison of the verification results with any parallel model runs and new models to help validate and develop the next generation of models; (3) provide the cyclone-relative software package to the operational centers and the broader community, so they can utilize it in their research and operational verification; and (4) work with the operational centers to utilize the code in testbeds and experiments (e.g., Winter Weather Experiment at WPC).

Results from Related Prior Research

Brian A. Colle

Dr. Brian Colle has conducted cooperative research with NOAA and the National Weather Service (NWS) for the last 15 years. Under funding from the cooperative grants program of CSTAR, COMET, NOAA-Seagrant, US Forest Service, Office of Naval Research, and the National Science Foundation, a wide range of research has been completed that has led to substantial contributions to operational forecasting and over 35 refereed publications that have linkages to operational forecast issues. Some recent project examples include:

NOAA-CSTAR1 (PI: Colle): Predictability of High Impact Weather during the Cool Season over the Eastern U.S: From Model Assessment to the Role of the Forecaster
05/01/2010 - 04/30/14. Amount: $306,895.
The CSTAR1 project focused on the predictability of extratropical cyclones (and associated Rossby wave packets-RWPs) over the eastern U.S. and adjacent offshore waters for the days 1-7 predictions (Colle and Charles 2011), and select mesoscale phenomena associated with cyclones (1-2 day predictions), with particular emphasis on precipitation bands (Novak and Colle 2012). Souders et al. (2014a,b) developed automated tracking algorithm for RWPs and a RWP climatology for the northern and southern hemispheres. A real-time ensemble sensitivity web page was developed (Chang et al. 2012) and applied operationally (Zheng et al. 2013). There are substantial interactions with several NWS forecast offices and WPC/OPC/EMC within NCEP. The CSTAR web page is at: http://itpa.somas.stonybrook.edu/CSTAR/. Tutorials on Rossby wave packets, ensemble sensitivity, and ALPS ensemble display systems were made and put on this page.

NOAA-CSTAR2 (PI: Colle): An Evaluation and Application of Multi-Model Ensembles in Operations for High Impact Weather over the Eastern U.S.
05/01/2013 - 04/30/16. Amount: $337,722
CSTAR2's goal is to increase the use of ensembles in operations by (1) demonstrating multi-model ensemble performance for high impact weather during the cool season along the U.S. East coast, (2) calibrating ensemble gridded data, and (3) developing and training forecasters on new ensemble display tools to better understand ensemble predictions and the evolution of uncertainty. Recent efforts have been to link relatively large forecast spread/errors in global ensembles (GEFS and EC) over the eastern U.S. and the presence of RWPs. This project has expanded the real-time ensemble sensitivity analysis to include more high impact weather variables (e.g., precipitation) and (2) is evaluating new software (ALPS and eventually AWIPS2) in the forecast offices to interact with ensemble data. Layer and Colle (2014) verified non-convective high wind events in the NCEP short-range ensemble forecast system.

Edmund Chang

1. NOAA-CSTAR1 (P.I.: Colle)
Project Title: *Predictability of high impact weather during the cool season over the eastern U.S.: From model assessment to the role of the forecaster*
5/1/2010-4/30/2013 (grant amount: $306,895)

NOAA-CSTAR2 (PI: Colle): An Evaluation and Application of Multi-Model Ensembles in Operations for High Impact Weather over the Eastern U.S.
05/01/2013 - 04/30/16. Amount: $337,722
See same items under relevant prior research for Brian Colle.

2. NSF ATM-0757250 (P.I.: Chang)
Project title: *Dynamics of interactions between wave packets and explosive cyclogenesis over western North Pacific*
5/1/08-4/30/12 (grant amount: $445,579)
In this project, the dynamics of the interactions between wave packets and explosive cyclogenesis over western North Pacific is examined using ensemble data assimilation and forecasts in conjunction with dynamical diagnoses. An EnKF data assimilation system has been set up to perform ensemble data assimilation using DART-CAM at NCAR for selected case studies, and ensemble sensitivity has been computed to examine the dynamics of these cases. Medium range ensemble sensitivity analysis was developed and tested in this project and has been implemented for real-time application under support by our NOAA CSTAR project (item 1 above).

Project Description

Introduction

The recent 2011 *Strategic Plan* for the National Weather Service (NWS) emphasizes the goal of a "Weather-Ready Nation," which will require better forecasts of more extreme weather. Extratropical cyclones are responsible for a wide range of hazardous weather, including flooding, severe convection, strong winds, snow, and freezing rain. The skill of numerical weather prediction models in forecasting these major storm events has varied. Some storms, such as the Superstorm of 1993 along the U.S. East Coast, are relatively well forecasted several days in advance (Uccellini et al. 1995). However, there are many exceptions, such as the 8-9 February 2013 and 26-27 December 2010 U.S. East coast snowstorm events. Operational models can perform poorly with forecast lead times of 1-2 days, such as the well-documented 25 January 2000, cyclone event over the U.S. mid-Atlantic and southeast states (Zhang et al. 2002).

In order to quantify the ability of NWP models to predict these high impact storms, more event-based verification for operational models is required. There have been some recent published efforts to verify extratropical cyclones in operational models. Charles and Colle (2009a,b) (hereafter, referred to as CC09a and CC09b) highlighted the performance of the North American Mesoscale (NAM) model, Global Forecast System (GFS), and Short-Range Ensemble Forecast (SREF) models around North America and adjacent oceans for the 0-60 h forecasts of extratropical cyclones during the 2002-2007 cool seasons. CC09a showed that the GFS analysis had more accuracy for the initialized cyclone pressures than the NAM and the North American Regional Reanalysis, especially over the oceanic regions. In addition, the NCEP GFS had a more accurate cyclone intensity and position for the 0-60 h forecasts than the NAM over the continental U.S. and adjacent oceans, especially over the eastern Pacific, where the NAM underdeveloped cyclones on average. These results are consistent with other recent GFS and NAM forecast comparisons of sea-level pressure around North America (McMurdie and Casola

2009). CC09a showed little improvement in the 0-2 day cyclone forecasts during the past 5 years over the eastern U.S., while there has been a relatively large improvement in the cyclone pressure predictions over the eastern Pacific in the NAM. CC09b showed that the deterministic GFS has more accuracy than the SREF mean for cyclone central pressure and position for most forecast times and regions around North America, while the SREF had slightly greater probabilistic skill than the combined GFS and NAM for central pressure.

Uccellini et al. (2009) compared the skill of oceanic cyclone predictions over the Atlantic and Pacific by the forecasters at the NOAA/NCEP Ocean Prediction Center (OPC) during the 1992-93 and 2002-05 cool seasons. Since the early 1990s, the day 4 cyclone central pressure and displacement errors by OPC forecasters have improved by ~15%. The cyclone strength for 2002-2005 was under-forecast by ~3 (~4.3) mb over the Pacific (Atlantic). Cyclone position errors are generally ~7% smaller in the Atlantic than the Pacific. For more intense cyclones, the Pacific position errors have decreased 15-20% since the early 1990s.

The flow patterns associated with some of these cyclone errors have also been diagnosed. Colle and Charles (2011) used GFS cyclone tracks and spatial composites using the daily NCEP reanalysis to illustrate flow patterns and source regions for some of the large GFS cyclone errors and biases. The under-deepened GFS cyclone errors (> 1.5 standard deviation errors) at day 4 over the western Atlantic are associated with an anomalous ridge over the western U.S. and trough over the eastern U.S., and most of the under-deepening occurs with cyclones tracking east-northeastward across the Gulf Stream. Many of the over-deepened cyclones have tracks more parallel to the U.S. East coast (Fig. 1). The under-deepened cyclones over the central and eastern Pacific tend to occur further south (35-45 ^{o}N) than the over-deepened events. However, the physical processes associated with these errors were not diagnosed, and there has been little operational effort to link the cyclone errors with any physical processes in the models.

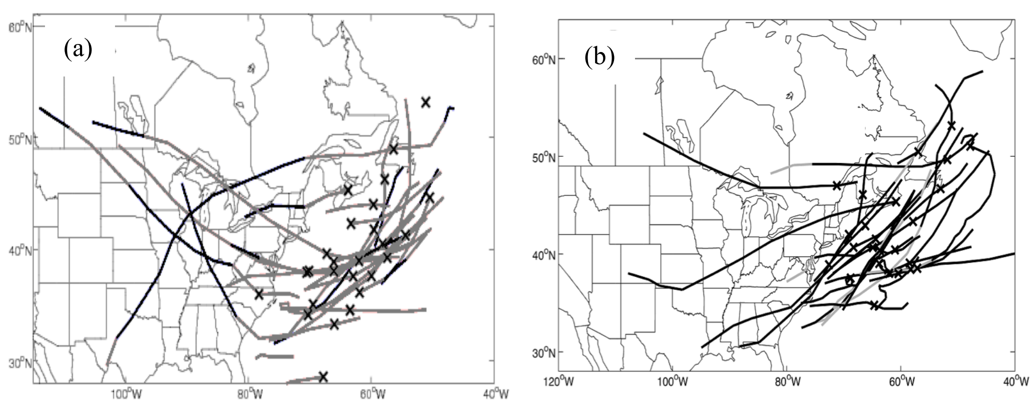

Figure 1. From Colle and Charles (2011). Forecast cyclone tracks for western Atlantic (WA region) GFS cyclones with large (> 1.5 standard deviation) central pressure errors for cases with (a) positive and (b) negative central pressure errors at hour 96 that are more than 1.5 standard deviations above (below) the mean error of all cyclones with positive (negative) error. The gray line segments indicate 6-h periods when the forecast cyclone growth rate (weakening) is slower (faster) than observed. Meanwhile, black lines indicate 6-hour periods when the forecast cyclone is deepening (or filling) faster (slower) than observed. The black x's indicate the location of the forecast cyclones at hour 96.

Motivation

Many of these previous studies focused on the operational model performance in predicting cyclones from 0-7 days. The Environmental Modeling Center (EMC) at NCEP has developed a storm track verification system (Guang Ping Lou, in Geoff DiMego's Mesoscale Modeling Branch, is leading), which is based on an extension of the tropical cyclone verification system originally developed by Tim Marchok of NOAA's Geophysical Fluid Dynamics Laboratory (GFDL: available from the DTC). In extratropical cyclone mode, EMC is using it routinely for both NAM and GFS. The cyclone performance is being used for upgrades of GFS/GDAS system.

Most previous verification studies of numerical weather prediction models focused on metrics for cyclones such as central pressure and track errors. However, the systematic errors associated with cyclones are the result of several physical processes and parameterizations, which also should be verified to determine the source of the model cyclone error. Since certain processes are favored in various sectors of the cyclone (e.g., warm sector convection, precipitation bands in the comma head, frontogenetical forcing, post-frontal shallow convection, moisture flux from subtropics, etc…), a cyclone relative approach can help determine what processes may be leading to various errors in the models. This approach also allows significant weather phenomena around the cyclone to be verified (e.g., heavy precipitation, low-level jets, fronts, etc.). The cyclone relative approach has been used to validate Global Climate Models (GCMs) (Bauer et al. 2006) and extratropical cyclones in the reanalyses (Chang and Song 2006).

One of our partners in this proposal, the Developmental Testbed Center (DTC), has developed the Model Evaluation Tools (MET – Fowler et al, 2010; Tollerud et al., 2013) that will be the foundation for the development of the cyclone relative verification diagnostics. The MET software package was developed to provide the scientific community with a comprehensive set of forecast evaluation tools for diagnostic investigation of NWP and climate prediction systems. MET was developed by the DTC with funding from the Air Force Weather Agency (AFWA) and the National Center for Atmospheric Research (NCAR), and is supported to the community by the Joint Numerical Testbed Program (JNTP) at NCAR. This software can compute standard verification scores using model gridded data and object-based verification. To date, this software has primarily been used in the research community and select operational centers (AFWA, WPC, and AWC), but this project will develop MET to complete the cyclone-relative verification and diagnostics, and implement it more broadly within these and other operational centers (EMC and OPC).

The DTC also maintains the Mesoscale Model Evaluation Testbed (MMET: http://www.dtcenter.org/eval/meso_mod/mmet/), which provides model initialization and observational datasets for a number of high impact cases and field studies. This facility will be very useful to provide model developers with a variety of initialization and observation datasets for cases that have relatively large cyclone errors, to allow for these events to be re-run by the community-at-large with new model techniques and verified using new diagnostic tools developed and distributed as part of this work. A METViewer graphical user interface (GUI) was developed to provide database and display system capabilities to systematically archive, aggregate and visualize statistics generated with MET. A more detailed description along with access to the MET software package can be obtained from the DTC website: http://www.dtcenter.org/met/users/.

This proposal will contribute to improving and establishing the Next Generation Global Prediction System (NGGPS), since our procedure will also validate several different processes relevant to the models out to day 10, such as the moisture budget around the storm, surface fluxes, precipitation coverage/intensity, stability at various levels, etc. This will be important for model developers, who need to understand how changes in the physical parameterizations are impacting significant weather predictions. The results and our tool will be useful for the Winter Weather Experiment at WPC, as well as operations within the other centers and WFOs. The verification tools will be shared with all groups, so they can continue verification efforts well after this project.

There are several research to operations (R2O) motivations for this project:

1. There has been little effort to quantify operational forecast errors for significant weather associated with extratropical cyclones.
2. The verification efforts need to move to a more feature-based approach.
3. We hypothesize that one of the reasons why forecasters have not utilized ensembles to the full extent is their limited understanding/verification of the capabilities of these ensembles to predict high impact weather events, such as extreme weather related to cyclones.
4. Model developers and forecasters need more opportunities to interact with verification data.
5. New verification approaches are needed that focus more on the processes associated with various weather phenomena, and these processes need to be compared within the operational model suite.

Overview of Project Goals

The proposed project will address the program priorities in advances in post-processing to improve model evaluation and development (focus area #6), and advancing weather prediction 6-10 days (area #2a). Extratropical storms and associated fronts are responsible for much of the high impact weather over mid latitudes. Unfortunately, many of the current verification metrics used in operations are grid point relative (e.g., regional), and averaging over a fixed geographic region will smooth many important processes and significant weather features around the cyclone. Some verification metrics are gathered for cyclones, but they are usually limited to central pressure, displacement, and cyclone density errors. In order to better understand operational model and ensemble performance and processes that may be leading to any systematic errors of significant weather around the cyclone, a cyclone-relative verification approach is needed. Knowledge of the performance of cyclone-relative features, such as jets, precipitation bands, and fronts, can also help develop confidence metrics and tools for forecasters about the skill in predicting those features at various lead times from 0 to 10 days. To help improve verification of cyclone-relative features, the goals of the project will include:

1. Collaborate with NCEP/EMC on the cyclone validation of the operational GFS and Global Ensemble Ensemble Forecast (GEFS) using one or more tracking algorithms.
2. Complete cyclone relative verification for different cyclone stages (from genesis to decay) and intensity of the temperature, moisture, precipitation and winds around the cyclone. Look at not only mean stats, but also various thresholds to separate the stronger cyclone events. Separate the bias results by flow regimes using compositing approaches.
3. Map the cyclone relative data back to the Earth-relative grid to determine geographical variations in the errors, which will help link results to various terrain/water features.
4. Also develop cyclone-relative verification for some physical processes: stability, surface fluxes, cloud cover, moisture flux, etc.
5. Develop a software interface for operational experiments (e.g., Winter Weather Experiment) and for EMC to continue the validation efforts after the end of this project.
6. Develop cases that allow model developers and forecasters to better understand the origin of model errors, re-run cases, and access enhanced diagnostic tools to apply to additional cases.

Proposed Approach

1. Datasets and region of interest

The full U.S. domain and the surrounding coastal oceans will be used for this study, since different regions of the U.S. will be used to focus on certain processes. This study will focus on the GFS and GEFS to day 10, since some of the focus will be on the medium to long-range improvement of NCEP models. Operational model data every 3-h or 6-h exists on the TIGGE, NOMADS, and NCEP servers back to early 2006, and the Global Ensemble Forecast System re-forecast is available from 1983-2013. The GEFS will be used to separate (especially for more extreme cases) any systematic model errors (bias) from random error.

For each model or ensemble member, two different analyses will be used to validate the larger-scale fields (e.g., temperature, moisture, winds, etc. around the cyclone). For the historical period, the Climate Forecast System Reanalysis (up to 2010), and the operational CFSv2 analysis after 2010, which is the same as the CFSR system. As a comparison, the Rapid Update Cycle (after 2006) will also be used. This long-term dataset can be used to separate the verification results by flow regime as well as weak versus more intense cyclonic systems defined based on different metrics.

Several different observational datasets will be used as well, such as available surface and upper-air observations available on the Meteorological Assimilation Data Ingest System (MADIS: http://madis.noaa.gov/). For precipitation over land, we will utilize the hourly Multi-sensor Precipitation Estimation (MPE) dataset on a 4x4km grid that merges radar and rain gauge estimates since 2002. Although the surface precipitation estimate over the ocean is more uncertain, there are NOAA-Star Hydro-Estimator products available.

2. Cyclone tracking

Since cyclone tracking is an important component of this project, two different tracking algorithms will be used to test the sensitivity of the results using 6-h model data. EMC currently has a tracking approach that runs 4 times daily (http://www.emc.ncep.noaa.gov/gmb/tpm/emchurr/tcgen/). This approach is similar to that used in Charles and Colle (2009; hereafter CC09a), which involved using a 2 hPa closed contour threshold and a sea-level pressure (SLP) gradient of 1.5-hPa per 1000 km anywhere within 300 km of this pressure minimum. Each forecast cyclone is paired with the closest observed cyclone (not to exceed 800 km separation). More details on this automated cyclone identification and pairing with observations can be found in CC09a. To get a GFS cyclone track, first, a mean-depth steering flow is calculated using the winds averaged from 850 to 500 hPa at a particular GFS forecast time. Then, the existing cyclone position is advected downstream according to this flow for 6 hours to guess a new cyclone position to compare with the GFS forecast 6-h in the future. The closest cyclone to this guess position completes the track.

Stony Brook University (SBU) also has extensive experience with tracking cyclones in operational and climate models and assessing the impacts of cyclones on significant weather such as precipitation and high winds (CC09a,b; Colle and Charles 2011; Colle et al. 2013; Chang 2013; Chang and Song 2006). SBU has also implemented the Hodges (1994) cyclone tracking scheme using either 850 hPa vorticity or SLP. Although the vorticity tracking is better at describing smaller-scale systems, it also tends to identify some open-wave troughs as cyclone centers. Meanwhile, SLP tracking does not work well in areas on high terrain because of pressure reduction issues. For SLP, a spectral bandpass filter was used to preprocess the data. The wavelength is set to 8000 km for planetary scale removal and 900 km for the high frequency cutoff. The details are described in Colle et al. (2013). To determine the correspondence between feature points, a constrained optimization using a cost function is applied. The identified storms are filtered to retain only those that last at least 24 hours and move farther than 1000 km.

We also appreciate the uncertainties in tracking these storms. Therefore, we will also test the sensitivity of our results to tracking different cyclone-related features (central pressure, 850/500 hPa vorticity, warm conveyor belts or moisture plumes/atmospheric rivers, etc., or a combination of these) to develop an optimal strategy that tracks and validates features that best relate to the predictability of high impact weather associated with cyclones. The Hodges code can be used to track more amorphous features, such as moisture plumes. For example, the Hodges approach was recently used to track Rossby wave packets within our research group (Souders et al. 2014a,b).

3. Cyclone relative verification and diagnostics

The MET package has been designed to be modular and adaptable. For example, individual modules can be applied without running the entire set of tools. New tools can easily be added to the MET package due to this modular design. MET computes a variety of traditional statistics such as bias, root-mean squared error (RMSE), correlation coefficient, and mean absolute error (MAE), which are commonly computed for continuous variables. For categorical measures, statistics such as Probability of Detection (POD), Probability of False Detection (POFD), False Alarm Ratio (FAR), and Critical Success Index (CSI) are computed in MET. In addition to providing traditional forecast verification scores for both continuous and categorical variables, confidence intervals are also produced using parametric and non-parametric methods. Confidence intervals take into account the uncertainty associated with verification statistics due to sampling variability and limitations in sample size.

MET provides tools that can be applied to spatial fields for various comparisons. A standard tool within MET is Point-Stat, which calculates statistics for verification between a grid and a point. For example, this tool can be used for validation studies between gridded forecast fields and point measurements. A second tool that can be used for verification is the Grid-Stat tool in MET. This tool can be used to compute traditional statistical measures for grid-to-grid validation such as the comparison between gridded precipitation forecasts and gridded precipitation analyses. MET recently added the MET-TC tool for verifying tropical cyclone tracks and intensities. It duplicates and extends NHC verification capability for A Decks (forecast) and B Decks (best-track) in the ATCF file format. This tool will be very helpful in evaluating the general characteristics of the cyclones in a manner similar to EMC's approach described below.

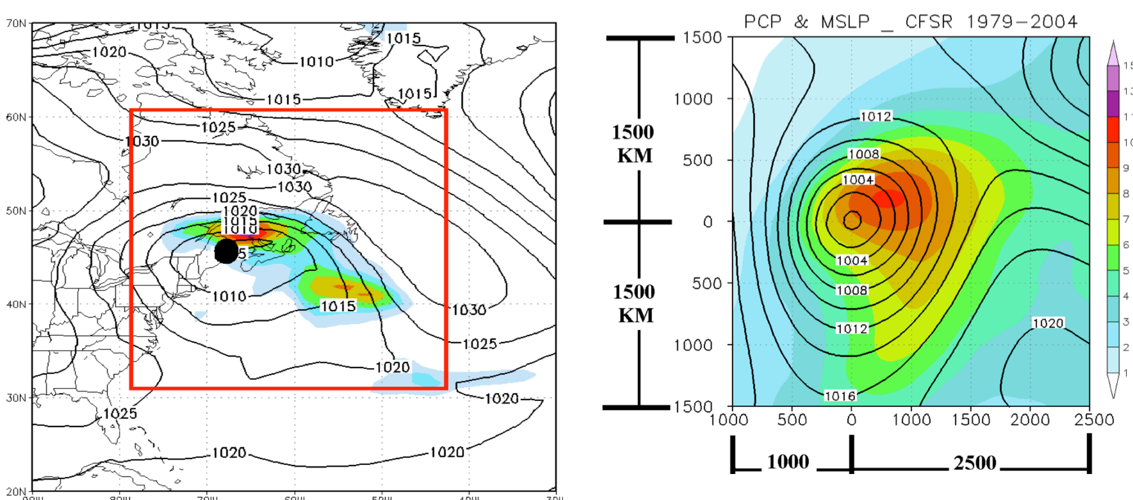

Figure 2: (left) CFSR sea-level pressure (every 5 hPa) and precipitation (shaded), and (right) daily-average CFSR precipitation (shaded in mm/day) and sea-level pressure (every 2 hPa) using the cyclone relative approach.

A cyclone-relative verification approach will be implemented, utilized, and transitioned to operations for this project. SBU has already implemented a cyclone relative validation approach for the global CMIP5 models using the Matlab software language. The SBU software allows the user to define the box dimensions around the cyclone to be used, which moves with the cyclone center obtained from the cyclone tracker. The forecast variables within the box (e.g., precipitation, temperature, wind, etc…) are extracted and saved for each forecast time. This results in a three-dimensional grid around the cyclone for each time that can be used to calculate the composite fields and verification metrics for various quantities. Figure 2 shows the composite setup around a sample cyclone in the CFSR and the cyclone precipitation, as well a composite of precipitation and pressure for all cyclones within a few hundred kilometers of the U.S. East coast from 1979-2005 cool seasons (Oct-March).

The gridded data for each cyclone can also be put back to the geographical map according to their latitude/longitude position, such that one can compare the results for different geographic regions. The results can also be partitioned several ways. For example, the cyclone precipitation cases can be separated for different seasons, flow regimes (as measured by PNA, NAO, etc…), stages of the cyclone (genesis, mature, and decay), as well as different cyclone intensities as shown in Fig. 3.

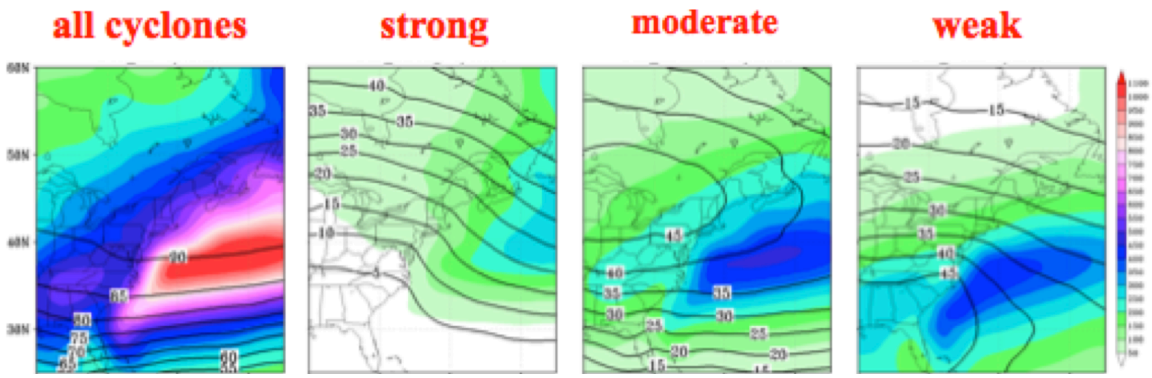

Figure 3. Precipitation (shaded in mm) for all CFSR cyclones mapped back to the geographical grid and separated for all cyclones, strong (< 990 hPa), moderate (990-1005 hPa), and weak (> 1005 hPa) storms. The percentage contributions of the various cyclone groupings towards the cool season (Oct-March) total precipitation.

The flow regimes for various model errors will be determined using a compositing approach using the CFSR analysis and model forecasts that is relative to the cyclone position (to minimize smoothing issues). The domain will be large enough to see if there are any larger-scale biases that may be impacting cyclones errors (e.g., amplitude of West Coast ridge for an East coast cyclone).

During year 1, the DTC will help transition this cyclone relative code to the MET software, so our operational partners can utilize this approach and results in this project. MET will also be used to validate the basic precipitation, near surface temperature (2-m), and surface winds (10-m) around the cyclone. The GFS and GEFS will be compared against a cyclone-relative grid from the CFSR and RUC analysis (after 2006). The model will also be validated using MET against available observational data around the cyclone, which include surface, upper-air soundings, satellite derived winds, cloud cover, and multi-sensor precipitation products. For the GEFS, the probability of reaching certain thresholds or ranges for winds, precipitation, fluxes, etc… will be verified using probabilistic metrics available in MET, such as reliability diagrams and receiver operating characteristic (ROC) curves and the Brier skill score (using deterministic GFS or climatology as reference) which can be separated into the reliability and resolution components. Rank histograms can be constructed for values around all or sectors of the cyclone as well. The reforecast GEFS will allow the sample size to be large enough to gain statistical significance. The longer availability of the GEFS reforecast will also provide opportunities to quantify model performance for the more high-impact precipitation, wind, and temperature extremes associated with cyclones. The results will be compared to that obtained for new models, such as the new GFS currently planned for release in November 2014, which will have a horizontal resolution of 13-km.

The gridded fields around the cyclone will also provide the opportunity to track and validate smaller-scale features around the cyclone using additional object-based approaches such as MODE (Method for Object-Based Diagnostic Evaluation) software developed by the DTC and available within MET (Davis et al. 2006, 2009; Gilleland et al. 2009, Wolff et al. 2014). MODE is useful for evaluating model characteristics of both discontinuous fields (e.g., precipitation and winds) and continuous fields (e.g. temperature and pressure) exceeding a given threshold.

MODE-Time Domain (MODE-TD) was recently developed by the DTC to incorporate tracking objects through time. While this tool is not yet included in MET, a goal of this project is to demonstrate its use for additional cyclone-specific evaluation. Figure 4 shows a comparison of the impact of several microphysics parameterizations on the path of peak rainfall from convectively driven precipitation systems (Clark et al. 2014). These tracks look very similar to those from the SBU tracker depicted in Figure 1 and might be able to provide additional information on cyclone system evolution like lifetime, timing of initiation and dissipation, and movement.

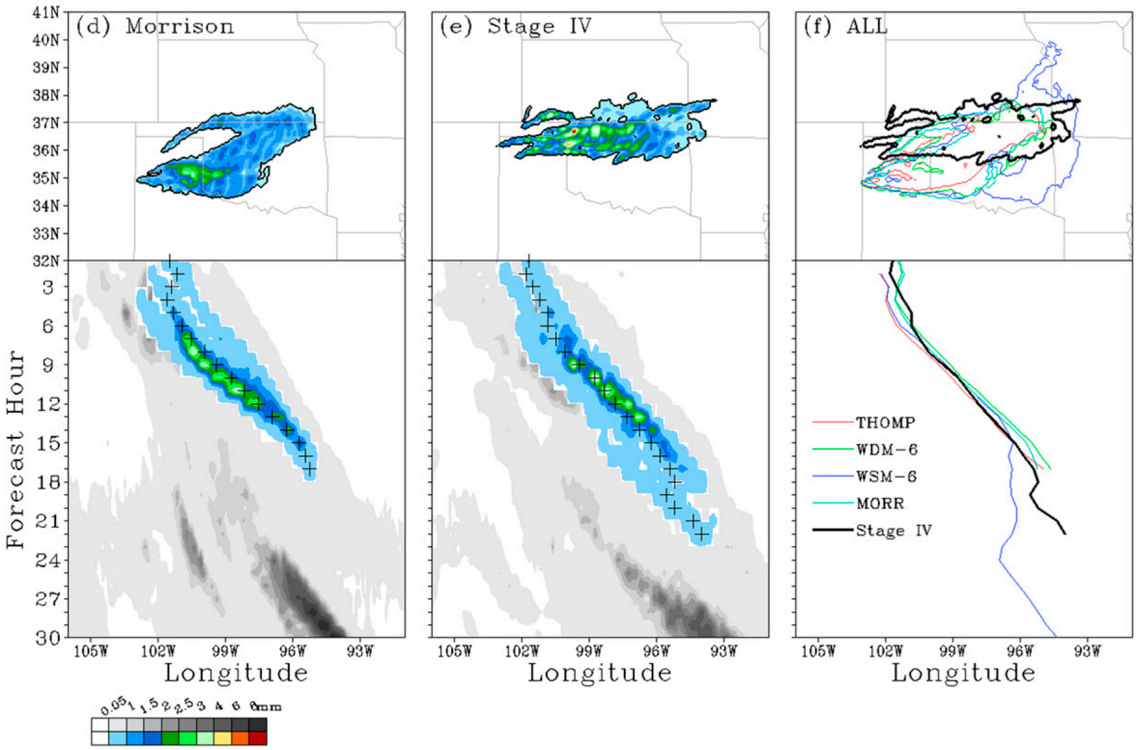

Figure 4. Example from the MODE-TD precipitation objects defined using a threshold of 0.25 in and a smoothing radius of 8km for (d) Morrison microphysics scheme applied to WRF and (e) stage IV observations. The top panel shows the maximum precipitation (mm) over the lifetime of the object and the bottom shows the time-longitude diagrams of the corresponding precipitation objects indicated by colored shading with the plus sign (+) marking the centroid longitude at each time the object was present. (f) In the top panel, the outer object contours for each of five microphysics schemes included in Clark et al (2014) study. In the bottom panel, the time-

longitude location of the centroids. Figure and description excerpted from Clark et al (2014). Panels (a)-(c) are similar to (d) so not included here due to space limitations.

MODE will allow one to verify the regions of heavier precipitation, areas with wind-speeds exceeding a threshold, precipitation coverage for a certain threshold, the areal extent of highs and lows around the cyclone. It may be useful to track other features associated with the cyclone, such as the low-level jet, moisture plume (e.g., atmospheric river), and areas of significant frontogenesis or warm/cold advection. Tracking these phenomena would provide a reference frame that more directly evaluates the model in predicting these features.

The cyclone-relative approach will also allow us to explore some of the physical linkages to these errors, which helps model developers and forecasters. For example, if the strong winds with the cyclone are underforecast, the typical approach is to simply verify the strength of the cyclone. However, we can validate the size of the cyclone, the strength of the low-level jet above the surface, and the precipitation intensity and stability, which helps determine how much vertical momentum mixing there will be. If the precipitation is overforecast in a certain part of the cyclone, we can calculate the integrated moisture fluxes to the area of interest, the stability, and the strength of forcing (e.g., frontogenesis, PV advection, jet strength, etc…).

Operational applicability and research to operations

There are three ways that this project will have research to operational impacts. First, there will be a comprehensive verification of the GFS/GEFS cyclones and their associated fields. The results will be shared with EMC during twice annual visits to discuss results and give a seminar, conference calls, formal papers, and archived data/plots from the analysis. Second, the tools used in this project can be applied to NWP experiments within the NCEP centers, such as the Winter Weather Experiment at WPC (http://www.wpc.ncep.noaa.gov/hmt/experimentsummaries.shtml). Third, the MET verification tools will be developed such that they can be ported to the various operational centers, such as EMC and WPC and in general to the broader scientific community.

The cyclone relative diagnostics developed for this project will be implemented in MET. MET provides the user the ability to configure the evaluation region, including user-defined masking regions. A recent addition to the masking capability includes the ability to define a standard circle from a given point. When these masks are composited along the track of a cyclone, a swath region may be defined for verification purposes. Figure 5 provides an example of this approach applied to precipitation predicted by two configurations of HWRF for Super-Storm Sandy.

During the "NWP workshop on model physics with an emphasis on short-range prediction" (Wolff et al. 2012) the need for establishing and maintaining a common dataset and modeling framework to provide to the research community, in general, and model developers, in particular, was highlighted. From this recommendation, the MMET was established by the DTC to assist the research community in efficiently demonstrating the merits of new developments that could positively impact an operational modeling system in the future. MMET provides a variety of initialization and observation data sets for a number of routine and high-impact cases and baseline results for each of the MMET cases have also been established by the DTC using select operational configurations. MMET "data sets of opportunity" are housed at the DTC and accessible to the community-at-large via a web interface (http://dtcenter.org/repository). RAMADDA, a Repository for Archiving, Managing and Accessing Diverse DAta, is used as the foundation for hosting and distributing the data. For this proposal, several new cases of interest will be added to MMET, accompanied by newly-developed tools for producing cyclone relative verification and diagnostics through the use of MET. Through this effort, the research community will have the opportunity to perform direct comparisons between multiple innovations (e.g., physics schemes) and/or against the baseline operational configurations established by the DTC to better understand the physical processes responsible for specific model errors associated with cyclones.

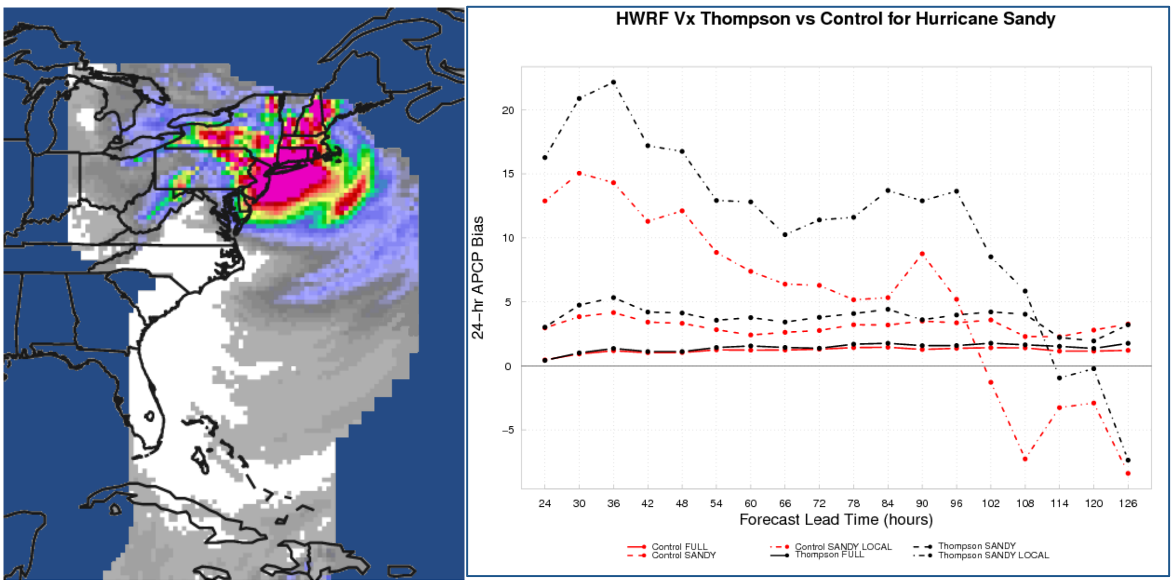

Figure 5. Example of swath-like evaluation domain for Super Storm Sandy (left) overlaid on the 12hr HWRF control simulation valid at 00 UTC on 20121101. Bulk statistics (right) were computed for 24-hour accumulated precipitation fields within the HWRF control (red) and Thompson microphysics (black) simulations and plotted for all lead times. Bias for three different evaluation regions are provided: Full domain (solid); Sandy sub-domain (rectangle encompassing entire Sandy path - dash) and Sandy swath (dot dash). Example taken from testing and evaluation work performed by the DTC Hurricane Task.

Interactions with the National Weather Service and Operational Centers

There has been a close interaction between SBU and NWS offices for several years in the area of numerical weather prediction. The proposed project will involve several NCEP centers and the DTC, and their interests and efforts are summarized below. Letters of support from these centers are attached at the end of this proposal.

1. NWS Environmental Modeling Center (Geoff DiMego, lead)

EMC's participation in the project can take on several aspects. First, EMC will provide real time extratropical cyclone tracks that are based on the Barnes analysis scheme. Second, EMC will determine how these parameter extractions could be added to the existing verification system so that it aligns with operational forecasts. Third, EMC will test the system and provide feedback to the PIs to improve the system. Fourth, if the system ultimately passes tests and is found to be useful, EMC will include it in a future upgrade to the model verification suite.

EMC will also provide information on how to access and process EMC model output, evaluate the output of the verification system for accuracy and for relevance to model development, compare the output to other verifications and diagnostics of model performance and seek to diagnose the output of the verification system to gain insight into how to improve model performance. EMC has a potentially useful venue for presentation of results of this work in the Model Evaluation Group weekly meetings, which is attended by a wide range of operational forecasters and model developers. Their reaction to the results of this work will provide invaluable feedback to the developers of this verification system and should increase operational forecasters' knowledge of model strengths and weaknesses in analyzing and predicting specific synoptic features.

The proposed verification system should help EMC evaluate proposed changes to the operational models and should significantly increase EMC's understanding of the interaction between physical forcing and synoptic events. It should accelerate improvements to physical parameterizations. It should increase EMC's understanding of forecast failures by pointing to much more specific synoptic elements than current EMC verification and should benefit both meso-scale and global forecast systems.

2. NWS Weather Prediction Center (David Novak and Mark Klein, leads)

The development of the proposed verification tools will bring significant improvements to at least two aspects of WPC operations: medium range forecasting, as WPC explores expanding daily forecasts from Day 7 to Day 10, and model evaluations, with the goal of improving NWS implementations.

One of the most challenging aspects to WPC's medium range forecasters is timely evaluation of available model guidance. Forecasters are inundated with multiple deterministic and ensemble forecast systems; sorting through the data and creating a forecast, particularly on days with large model spread, requires new tools to optimize forecaster time. The proposed verification tools will assist with daily model assessments in determining the predictability of synoptic scale features. One of the stated goals of this project is to stratify results by flow regime, which will be especially helpful if there is high confidence in the predictability of a given long wave pattern, even if the shorter wavelengths are poorly handled.

WPC developers will work with SUNY collaborators to make the verification results available to WPC personnel and provide training to medium range forecasters on the usage of the tools (in person or remote sessions). WPC and SUNY will maintain regular interactions as forecasters evaluate the tools and report results.

This study's planned expansion of feature-based verification (e.g., low-level jet, 2-meter temperature, etc.) will assist with evaluation of parallel models at NCEP. Assessment of parallel guidance by WPC is mostly subjective, and traditional verification techniques used at EMC (500mb anomaly correlations for the Northern Hemisphere) are too large-scale and often not easily applicable to specific WPC functions (e.g. QPF, surface temperature, and surface winds). WPC has heavily invested in the use of MODE, and based on the value of that investment, WPC has become the first operational center in the US to use the MODE verification technique for QPF. WPC makes the analysis publically available (http://www.wpc.ncep.noaa.gov/verification/mode/mode.php#page=page-1). Based on our experience, we expect applying this technique to more sensible weather fields from both operational and parallel guidance will result in more robust evaluations, as well as evaluations relevant to WPC's and WFO's interests in sensible weather elements. In addition, the cyclone-relative nature may aid determination of the mass or moisture field(s) responsible for differences in operational and parallel forecasts of a given weather system.

WPC's Winter Weather Experiments (WWE) will play a key role testing the proposed tools, as participants are able to focus, in a non-operational environment, on specific events. WPC's Hydrometeorological Testbed (HMT) will work with SUNY collaborators to create training materials for participants in advance of the WWE. During the experiment, WWE will analyze the cyclone-relative parameters included in the tool and determine which can provide useful information about the predictability of a given winter weather event. The HMT will work with SUNY to provide a summary report of the results.

Finally, we have budgeted travel funds for frequent visits to NCWCP, including a planned WPC R2O Workshop.

3. NWS Ocean Prediction Center (Joseph Sienkiewicz, lead)

The proposed verification tools for cyclone parameters will significantly help Ocean Prediction Center (OPC) forecasters better quantify, understand, and apply the relevant predictive skill of numerical weather prediction systems. OPC will benefit in several predictive ranges, 0 to 48 hours, 48 to 96 hours, and day 5-7. Presently, the day 5-7 forecasts are produced in gridded form via the Graphical Forecast Editor tool in AWIPS II for the western Atlantic and eastern Pacific with no real formal verification for cyclone relevant parameters such as wind speed and the areal coverage of warning criteria winds or hazards.

The OPC has long utilized remotely sensed ocean winds from satellites to enhance forecaster awareness of warning criteria conditions over the oceans. We envision scatterometer winds from the European ASCAT instruments on the METOP series of satellites as serving as a "sea" truth for numerical predictions. The OPC generates a gridded scatterometer wind product that could potentially be used as validation of near surface wind features such as low level jets and the cold conveyor belt.

Although ensemble forecast systems have been utilized within major meteorological centers and services across the globe. Quantification of such systems of feature-based weather parameters is an area that fully needs to be exploited. Weather services have been slow to proceed in fully embracing probabilistic forecasts in part because quantification of probabilities of significant weather features has been lacking or minimal. An opportunity exists as a result of this effort to extend the forecast window for days 7-10 with a well understood validation of forecast skill for cyclone relevant features.

4. NWS Aviation Weather Center (David Bright, lead)

The Aviation Weather Center (AWC) is responsible for predicting meteorological phenomena impacting both the safety and efficiency of flight in the United States and across the globe. Users of AWC products include commercial and private aviators, comprised of both instrumented and noninstrumented flight operations, as well as partners in government and private industry, such as the Federal Aviation Administration (FAA) and commercial airlines.
Hazards specific to aviation safety and traffic flow management with substantial dependencies on operational models may benefit from a cyclone relative approach, including icing, turbulence, convection, and the numerical prediction of explicit cloud hydrometeors. Recent observations such as the GOES-based detection of icing and turbulence, automated aircraft-based measurements of turbulence via the Eddy Dissipation Rate (EDR), and other analyses such as NCAR/FAA's Graphical Turbulence Guidance (GTG) and Current Icing Potential (CIP) may prove useful in aligning cyclone-relative model predictions to observed aviation hazards.

We will collaborate with SBU and DTC to use MODE to validate parameters around the cyclone relevant to aviation, such as aircraft turbulence, icing (super-cooled water in model), and cloud cover.

5. Developmental Testbed Center (Paul Kucera and Jamie Wolff, leads)
The DTC is a distributed facility that promotes testing and evaluation of new model techniques for use in the NWP community. The fundamental purpose of the DTC is to serve as a coordinating mechanism that acts as a bridge between research and operations, thereby facilitating the activities of both communities in pursuit of their own objectives. The DTC provides the research community access to the latest operational NWP code packages for research applications, while the extensive testing and evaluation conducted by the DTC provides the operational community with valuable information on the strengths and weaknesses of new NWP advances prior to consideration for operational implementation. The goals of the DTC are to:

- Link Research and Operational Communities
- Speed transition of research results into operations
- Accelerate improvement in weather forecasts
- Develop and test promising new NWP techniques
- Provide an opportunity for NWP community to perform cycled or real-time tests of model and data assimilation systems

This proposed effort supports DTC's goals by providing both the research and operational communities, through the development of new tools, the ability to better evaluate significant weather features and the provision of an opportunity for model developers to test and evaluate new NWP techniques for significant weather events. Overall, the impact of this effort will result in additional support to transition research results to operations.

Task Timeline and Deliverables:

Year 1:

1. Dataset collection (GFS and GEFS forecasts). – SBU
2. Tracking of cyclones and matching of obs/model (SBU and EMC)
3. Basic verification metrics for cyclones (intensity, speed, track) using analyses (CFSR and RUC). (SBU and EMC).
4. Collection of other observational datasets and interpolation to grid (multi-sensor precipitation, cloud products, etc.). (SBU and DTC)
5. Track other important cyclone features instead of central pressure (moisture plumes, low-level jets, etc…). (SBU and DTC)
6. Complete cyclone relative verification for different cyclone stages (from genesis to decay) and storm intensity of the temperature, moisture, precipitation, and winds around the cyclone. Look at not only mean stats, but also various probabilistic metrics using various thresholds for these variables. (SBU – with visits to DTC, and DTC)
7. Separate the verification results by regimes using large-scale and regional flow composites. (SBU)
8. Develop MET module (METViewer) to composite statistics around cyclone (plot spatially and calc metrics), and ability to map results back to geographic grid. Potential approaches include 1) extending tropical cyclone QPF compositing capability currently under development within the DTC; 2) development of percentile thresholding capability to be able to identify key synoptic features for both categorical statistics calculations and the MODE tool; 3) extending current series analysis capability to plot time-series analysis geographically; 4) use MODE-Time Domain algorithms on cyclones to diagnose additional track attributes. (DTC)

Year 2:

9. Apply MODE to validate important features around the cyclone (e.g. jet streaks, low-level jets, heavy precipitation, strong surface winds, etc.) (DTC).
10. Map the cyclone relative verification results back to the Earth-relative grid, so the results can be related to various terrain, coast and sea-surface temperature features. (SBU and DTC).
11. Compute yclone relative verification for relevant physical processes: stability, surface fluxes, temperature gradients, cloud cover, and a moisture budget around the storm (flux into/out of box, surface moisture flux, and precipitation fallout). (SBU).
12. Provide MET software tools for various operational centers to continue the validation efforts after this project for next generation of models. (DTC and EMC).
13. Use software and scripts for operational ensembles and in WPC Winter Weather Experiment. (SBU and WPC).
14. Add several additional cases to the Mesoscale Model Evaluation Testbed (MMET) based on results of the analyses, to make them available to others in the community. (DTC).

Proposed Budget

	Year 1	Year 2	Total
A. SALARIES AND WAGES			
1. Senior Personnel			
a. Principal Investigators			
1/2,1/2 summer months (Colle)	7,200	7,416	14,616
1/2,1/2 summer months (Chang)	6,800	7,004	13,804

b. Associates			
2. Other Personnel			
a. Professionals			
b. Research Associates			
c. Grad Research Asst 1 in yr 1, 2 in yrs2-3	28,000	28,840	56,840
d. Post Docs			
e. Secretarial-clerical			
f. Technical			
Total Salaries and Wages	42,000	43,260	85,260
B. FRINGE BENEFITS	6,020	6,201	12,221
Total Sal, Wage, Benefits (A+B)	48,020	49,461	97,481
C. TRAVEL			
1. Domestic	6,000	5,500	11,500
2. International			
D. EQUIPMENT			
E. SUPPLIES			
Computer supplies (disk drives, backups)	2,000	2,000	4,000
F. CONTRACTUAL (subawards)	102,680	113,192	215,882
G. CONSTRUCTION			
H. OTHER COSTS			
1. Publications and Documentation	0	6,000	6,000
2. Graduate RA Tuition	4,188	4,188	8,376
TOTAL OTHER COSTS	4,188	10,188	14,376
TOTAL DIRECT COSTS (A THROUGH G)	162,888	180,341	343,229
INDIRECT COSTS	40,510	31,480	71,990
TOTAL COSTS	415,219		

Budget Justification

Salaries: Half month of summer salary is requested for the PIs (Colle and Chang) for years 1 and 2. One graduate student will be supported. Annual salary is requested for the student and in-state tuition. The tuition amount is not subject to indirect costs. The PIs and student will travel to our Partners at NCEP for 2-3 weeks during the year work half time at the local National Weather Service Upton, NY office as part of the collaboration with this project, so the research effort is 75% on campus. A 3% inflation rate is used for the PIs' and graduate change to student's salary increase

Travel: $6000 is requested for the two PIs or graduate student to make a trip to NCEP in Washington DC and the Developmental Testbed Center (DTC) within the National Center for

Atmospheric Research in Boulder, CO for a total 4 weeks ($1500 per week). One trip during year 2 for the PIs and graduate student is requested to present results at a scientific workshop or conference. The cost is estimated to be $2500 per conference trip. $3000 per year is requested for year 2 for the PIs and graduate student to make a trip to NCEP in Washington DC for 2 weeks.
Publications: An amount of $6000 is requested for year 2 to support two publications of scientific articles and/or conference preprint fees. These estimates are based on past publishing experience (2-3 papers per year at 20-25 pages each) and page charge rates for AMS ($135/page) and AGU ($150/page) journals.
Supplies: Disk space will be purchased for this project to store data and backup results (4 3-Tb disks at $250 each, total $1000). Annual software licenses (Matlab toolboxes at $500 and IDL license $500) are needed for the PI and graduate student workstations. A total amount of $2000 is requested for supplies during year 1 and 2.
Subcontracts: We will subcontract with the Developmental Testbed Center at the National Center for Atmospheric Research (Boulder, CO) for $102,680 (direct costs) during year 1 and $113,192 during year 2. This group will lead efforts to develop the cyclone relative tool within the Model Evaluation Tools (MET).
Overhead: Overhead is charged on the Modified Total Direct Coast Base at the federally approved rate of 50% for research performed 75% at Stony Brook campus and 25% off campus at the National Centers for Environmental Prediction and the Developmental Testbed Center within the National Center for Atmospheric Research (NCAR).

CURRICULUM VITAE:

Brian. A. Colle
Stony Brook University / SUNY
School of Marine and Atmospheric Sciences, Tel:631-632-3174
Stony Brook, New York 11794-5000, Email: brian.colle@stonybrook.edu

a. Professional Preparation:
Ohio University, Geography/Meteorology, 1991, B.S
University of Washington, Seattle, WA, Meteorology,1994, M.S.
University of Washington, Seattle, WA, Meteorology,1997, Ph.D.

b. Appointments:
2010-present *Professor*, School of Marine and Atmospheric Sciences, SUNY-Stony Brook
2005-2010 *Associate Professor*, School of Marine and Atmospheric Sciences, SUNY-Stony Brook
1999-2005 *Assistant Professor,* School of Marine and Atmospheric Sciences, SUNY-Stony Brook
1997-1999 *Research Associate*, Department of Atmospheric Sciences, University of Washington, Seattle, WA
1992-1997 *Research Assistant*, Department of Atmospheric Sciences, University of Washington.

c. Awards:
2007: AMS Editor's Award for the journal *Monthly Weather Review*
2000-2001: ONR Young Investigator Award
1991-present: Phi Beta Kappa National Honor Society
1991-1992: AMS Graduate/Industry Fellowship

d. Recent Related Publications:
Souders, M.B., B.A. Colle, and E.K.M. Chang, 2014: The climatology and characteristics of Rossby wave packets using a feature-based tracking technique. Mon. Wea. Rev., 142, 3528-3548.

Souders, M.B., B.A. Colle, and E.K.M. Chang, 2014: A description of an automated approach for feature-based tracking of Rossby wave packets. Mon. Wea. Rev., 142, 3505-3527.
Colle, B.A., D. Stark, and S.E. Yuter, 2014: Surface microphysical observations within East coast winter storms on Long Island. *Mon. Wea. Rev,* **142**, 3126-3146.
Zheng, M., E.K.M. Chang, and B.A. Colle, 2013: Ensemble sensitivity tools for assessing extratropical cyclone intensity and track predictability. Wea. Forecasting, 28. 1133-1156.
Colle, B.A., Z. Zhang, K.A. Lombardo, E.K.M. Chang, P. Liu, and M. Zhang, 2013: Historical evaluation and future prediction of eastern North American and western Atlantic extratropical cyclones in the CMIP5 models during the cool season. J. Climate, 26, 6882-6903.
Erickson, M.E., B. A. Colle, and J. Charney, 2012: Impact of bias correction type and conditional training on Bayesian model averaging over the northeast United States. In Press to *Wea. Forecasting*.
Novak, D. and B. A. Colle, 2012: Diagnosing snowband predictability using a multi-model ensemble system.. Sin *Wea. Forecasting*, **27**, 565-585.
Lombardo K., and B. A. Colle, 2011: Convective storm structures and ambient conditions associated with severe weather over the Northeast U.S. *Wea. Forecasting*., **26**, 940-956.
Colle, B. A., and M. E. Charles, 2011: Spatial distribution and evolution of extratropical cyclone errors over North America and adjacent oceans in the NCEP Global Forecast System model. *Wea. Forecasting,* **26**, 129-149.
Charles M.E., Colle B.A., 2009a: Verification of extratropical cyclones within the NCEP operational models, Part I: Analysis errors and short-term NAM and GFS forecasts. *Wea. and Forecasting*, **24**, 1173-1190.
Charles M.E., Colle B.A., 2009b: Verification of extratropical cyclones within the NCEP operational models, Part II: The short-range ensemble forecast system. *Wea. and Forecasting*, **24**, 1191-1214.
Jones, M., B. A. Colle, and J. Tongue, 2007: Evaluation of a short-range ensemble forecast system over the Northeast U.S., *Wea. Forecasting*, **22**, 36-55.

e. Select Synergistic Activities:
Editor: *Weather and Forecasting*, 04/07-08/12.
Associate Editor: *Monthly Weather Review*, 1/02-12/03; 01/06-12/07
Associate Editor: *Weather and Forecasting*, 01/06-12/07
Member of Unidata Policy Committee (09/08-09/11).
Member of Advisory Board for WRF Developmental Test Center (06/05-present).

f. Students Advised: Yanguang Zeng (M.S. 2004), Matthew Jones (M.S. 2005), Joseph Olson (Ph.D. 2007), Michael Charles (M.S. 2008), Yanluan Lin (Ph.D. 2008), David Novak (Ph.D. 2009), Tom DiLiberto (M.S. 2009), John Murray (M.S. (2009), Joe Pollina (M.S. 2011), Sean Bratton (M.S. 2012), David Stark (M.S. 2012), Matthew Souders (M.S. 2013), and Michael Layer (M.S. 2014).

Edmund K.M. Chang

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Stony Brook, NY 11794-5000
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a. Professional Preparation:
Undergraduate Institution:
California Institute of Technology Physics B.S. (Hon) 1982
Graduate Institutions:
Princeton University Astrophysical Sciences M.A. 1984
Princeton University Atmospheric and Oceanic Sciences M.A. 1991

Princeton University Atmospheric and Oceanic Sciences Ph.D. 1993

Postdoctoral Institution:

Massachusetts Institute of Technology Atmospheric Sciences, Jan 1993 – Jun 1994

b. Appointments:

Sep. 2008 – Current Professor of Atmospheric Sciences
Stony Brook University

Sep. 2001 – Aug. 2008 Associate Professor of Atmospheric Sciences
Stony Brook University

Sep. 1999 – Aug. 2001 Associate Professor of Meteorology
Florida State University

July 1994 – Aug. 1999 Assistant Professor of Meteorology
Massachusetts Institution of Technology

c. Recent publications:

Souders, M.B., B.A. Colle, and E.K.M. Chang, 2014: The climatology and characteristics of Rossby wave packets using a feature-based tracking technique. Mon. Wea. Rev., 142, 3528-3548.

Souders, M.B., B.A. Colle, and E.K.M. Chang, 2014: A description of an automated approach for feature-based tracking of Rossby wave packets. Mon. Wea. Rev., 142, 3505-3527.

Xia, X., and E.K.M. Chang, 2014: Diabatic damping of zonal index variations, J. Atmos. Sci., 71, 3090-3105.

Chang, E.K.M., 2014: Impacts of background field removal on CMIP5 projected changes in Pacific winter cyclone activity, J. Geophys. Res. Atmos., 119, 4626-4639.

Maloney, E.D., S.J. Camargo, E. Chang, et al., 2014: North American climate in CMIP5 experiments: Part III: Assessment of twenty-first-century projections, J. Climate, 27, 2230-2270.

Zheng, M., E.K.M. Chang, and B.A. Colle, 2013: Ensemble sensitivity tools for assessing extratropical cyclone intensity and track predictability. Wea. Forecasting, 28. 1133-1156.

Chang, E.K.M, 2013: CMIP5 projection of significant reduction in extratropical cyclone activity over North America. J. Climate, 26, 9903-9922.

Colle, B.A., Z. Zhang, K.A. Lombardo, E.K.M. Chang, P. Liu, and M. Zhang, 2013: Historical evaluation and future prediction of eastern North American and western Atlantic extratropical cyclones in the CMIP5 models during the cool season. J. Climate, 26, 6882-6903.

Chang, E.K.M., Y. Guo, X. Xia, and M. Zheng, 2013: Storm track activity in IPCC AR4/CMIP3 model simulations. J. Climate, 26, 246-260.

Chang, E.K.M., M. Zheng, and K. Raeder, 2013: Medium range ensemble sensitivity analysis of two extreme Pacific extratropical cyclones. Mon. Wea. Rev., 141, 211-231.

Chang, E.K.M., Y. Guo, and X. Xia, 2012: CMIP5 multimodel ensemble projection of storm track change under global warming. J. Geophys. Research, 117, D23118.

Chang, E.K.M., and Y. Guo, 2012: Is Pacific storm track activity correlated with the strength of the upstream wave seeding? J. Climate, 25, 5768-5776.

d. Professional Services

Associate editor of Monthly Weather Review (2002, 2007-2009)

Contributing author for IPCC AR4

Member, AMS Committee on AOFD (2006-2011)

Program Co-Chair, AMS 18th Conference on Atmospheric and Oceanic Fluid Dynamics

Chair, US THORPEX Science Steering Committee (2011-present)

e. Awards:

Sigma Xi Award for best piece of undergraduate research (Caltech 1982)

NOAA ERL Outstanding Paper Award (1994) for Chang and Orlanski (1993)

f. Collaborators:
Thesis Advisor: Dr. Isidoro Orlanski , Postdoc Advisor: Dr. Richard Lindzen
Ph.D. Students (graduated): Dr. Pablo Zurita-Gotor, Dr. Xiaosong Yang, Dr. Yanjuan Guo, Dr. Xiaoming Xia
M.S. Students (graduated): Yijian Chen
Postdocs advised: Dr. Yunfei Fu, Dr. Nili Harnik, Dr. Pablo Zurita-Gotor, Dr. Yanjuan Guo

Current and Pending Support

Investigator: **Brian A. Colle**
Current
Title: Employing ensemble data assimilation, parameter estimation, and field data to improve fire weather predictions in mesoscale models. (Lead PI)
Amount: $62,439. Period covered: 08/01/13-07/15/15
Support: Active Source: U.S. Forest Service
Title: Collaborative Research: Observations and modeling of mesoscale precipitation in cool season extratropical cyclones. (Co-PI).
Amount: $355,466 Period covered:02/01/14-01/31/17
Support: Active Source: NSF
Title: An Evaluation and Application of Multi-Model Ensembles in Operations for High Impact Weather over the Eastern U.S. (Lead PI)
Amount: $337,772. Period covered: 10/01/13-09/30/16
Support: Active Source: NOAA-CSTAR
Title: Hazard SEES Type 2: Dynamic Integration of Natural, Human, and Infrastructure Systems for Hurricane Evaluation and Sheltering (Co-PI)
Amount: $478,362. Period covered: 09/01/13-08/31/17
Support: Active Source: NSF
Title: Prediction, Validation, and Calibration of Coastal Storms and Associated High Impact Weather in Ensemble Regional Climate Simulations Over the Northeast U.S. (Lead PI)
Amount: $564,258 Period covered:09/01/11-08/31/15
Support: Active Source: NOAA
Title: Improving atmospheric models for offshore wind resource mapping and prediction using LIDAR, aircraft, and in-ocean observations (Lead PI)
Amount: $675,219 Period covered:09/01/11-06/30/15
Support: Active Source: DOE
Title: Using field and satellite measurements to improve snow and riming processes in cloud resolving models. (Lead PI)
Amount: $310,375. Period covered: 03/01/13-02/28/16
Support: Active Source: NASA

PENDING SUPPORT
Source: NSF
Project Title: Characteristics of Rossby wave packets and their downstream impact on predictability – An investigation contributing to DOWNSTREAM science and operations
Requested Amount: $448,487
Requested Period: 3/1/15 – 2/28/18

Investigator: **Edmund K.M. Chang**
CURRENT SUPPORT
Source: NOAA Climate Program Office
Project Title: Prediction, validation, and calibration of coastal storms and associated high impact weather in ensemble regional climate simulations over the northeast US

Award Amount: $564,258
Award Period: 9/1/11 – 8/31/14 (no cost extension to 8/31/15)
Investigator months: 0.75 month summer (role: co-PI, PI: Colle)

Source: NSF
Project Title: New perspectives on storm track dynamics, variability, and change
Award Amount:$573,068
Award Period: 3/16/13 – 2/29/16
Investigator months: 1.5 months summer, 0.5 month academic year

Source: NOAA CSTAR
Project Title: An evaluation and application of multi-model ensembles in operations for high impact weather over the Eastern US
Award Amount: $337, 772
Award Period: 5/1/13 – 4/30/16
Investigator months: 0.25 month summer (role: co-PI, PI: Colle)

PENDING SUPPORT

Source: NSF
Project Title: Characteristics of Rossby wave packets and their downstream impact on predictability – An investigation contributing to DOWNSTREAM science and operations
Requested Amount: $448,487
Requested Period: 3/1/15 – 2/28/18
Investigator months: 1.0 month summer, 0.5 month academic year
Source: NOAA NWS, this proposal

Data Sharing Plan

The operational model, observations, and verification results will be stored on a 40-Tb RAID5 array at Stony Brook University via a Linux server. We will use Unidata's Repository for Archiving, Managing and Accessing Diverse DAta (RAMADDA) to access and share these archived datasets, which will be publically available. RAMADDA is a content management system that can provide access to data, metadata, source code, presentations, images, and analysis of geoscience data. It makes it possible to access large datasets on remote servers as if they were on the user's own computer. RAMADDA will simplify user data access in this project, which frees our collaborative partners users from the many details of file storage and naming. Collaborators will also be allowed to add their own datasets (e.g., EMC's cyclone tracks) and results to the RAMADDA server as well.

Case studies for more in depth exploration and training will be saved at DTC as part of their Mesoscale Model Evaluation Testbed (MMET). These "data sets of opportunity" are housed at the DTC and accessible to the community-at-large via a web interface (http://dtcenter.org/repository). RAMADDA will also used as the foundation for hosting and distributing this data.

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NCAR

National Center for
Atmospheric Research

Research Applications Laboratory

3450 Mitchell Lane, Boulder, CO 80301 USA

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www.ral.ucar.edu

22 September 2014

Dr. Brian A. Colle
Professor of Atmospheric Sciences
School of Marine and Atmospheric Science
Stony Brook University
State University of New York

Dear Prof. Colle:

I acknowledge that the Development Testbed Center (DTC) staff at NCAR are identified as critical team members in the proposal you are submitting entitled "Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach" in response to request for proposals announcement: National Oceanic and Atmospheric Administration (NOAA) Collaborative Science, Technology, and Applied Research (CSTAR) Program Funding Opportunity # NOAA-NWS-NWSPO-2015-2004117 CFDA # 11.468, Applied Meteorological Research. The DTC intends to carry out all responsibilities identified within the proposal.

This collaboration leverages and expands on DTC's goals of improving the connections between research and operational communities; fostering the transition of research results into operations; and accelerating the improvement of weather forecasts, especially in this critical need of improving forecast skill for significant weather events.

I understand that the extent and justification of the DTC's participation as stated in the proposal will be considered during the peer review process in determining, in part, the merits of that proposal.

If you have any questions, please don't hesitate to call me at 303-497-8910 or email me at: kuo@ucar.edu.

Sincerely,

Bill Kuo

William Kuo, Ph.D.
National DTC Director

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
National Centers for Environmental Prediction
5830 University Research Court, Suite 4600, W/NP
College Park, MD 20740

29 September 2014

To Whom It May Concern:

I am writing this to establish my support for the proposed research project "Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach" being submitted to the R2O initiative by SUNYSB's Brian Colle et al.

The recent 2011 Strategic Plan for the National Weather Service (NWS) emphasizes the goal of a "Weather-Ready Nation," which will requires users to better synthesize (NWS) forecasts to take preventative actions towards the protection of life and property. The models and ensembles run within the NWS are an important component of this decision-making process, thus it is important that these modeling systems be improved, especially for extreme weather events. Verification of these models is an important component of this model improvement process, but there are currently a few issues limiting progress in this area: (1) the verification is typically done regionally on a grid and therefore there is lack of understanding of the errors associated with different types of extreme weather phenomena; (2) important processes associated with high impact weather events need to be better diagnosed with the verification, so it is difficult to isolate the model issues and make improvements to these models; and (3) there is no common next generation package that is shared among the operational centers.

To help address these challenges, Professor Colle and colleagues at Stony Brook University have organized a project to focus on an R2O effort to develop and implement a cyclone relative approach in the Meteorological Evaluation Testbed software being developed by DTC, in which the verification results and software will be shared with our NWS partners. This will lead to better understanding the origin of the model biases for these cyclone events, as well as the significant weather associated with these cyclones (heavy precipitation, strong winds, moisture plumes, freezing lines, etc…).

I strongly support this activity and enthusiastically endorse funding of the proposal. The proposed work has direct relevance for our ongoing efforts to improve the quality of numerical guidance from my branch and from NCEP Production Suite. I expect to be an active participant in the research as described in the proposal, and look forward to starting this important collaborative work.

Sincerely,

Geoff DiMego
Chief, Mesoscale Modeling Branch
Environmental Modeling Center, NCEP/NWS/NOAA/DOC
geoff.dimego@noaa.gov 301-683-3764

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
National Centers for Environmental Prediction
Weather Prediction Center
5830 University Research Court
College Park, Maryland 20740

September 26, 2014

Research to Operations Initiative
NOAA/NWS
1325 East-West Highway
Rm 15328
Silver Spring, MD 20910

Dear Mr. Hedge and Reviewers:

The recent 2011 Strategic Plan for the National Weather Service (NWS) emphasizes the goal of a "Weather-Ready Nation," which requires users to better synthesize (NWS) forecasts to take preventative actions towards the protection of life and property. The models and ensembles run within the NWS are an important component of this decision-making process, thus it is important that these modeling systems be improved, especially for extreme weather events. Verification of these models is an important component of this model improvement process, but there are currently a few issues limiting progress in this area: (1) the verification is typically done regionally on a grid and therefore there is lack of understanding of the errors associated with different types of extreme weather phenomena; (2) important processes associated with high impact weather events need to be better diagnosed with the verification, so it is difficult to isolate the model issues and make improvements to these models; and (3) there is no common next generation package that is shared among the operational centers.

To help address these challenges, Stony Brook University is collaborating with several NWS Operational Centers (EMC, OPC, WPC, and AWC), and the Developmental Testbed Center (DTC) in the proposal titled: **"Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach."** This project will focus on a research to operations (R2O) effort to implement a cyclone relative approach in the Meteorological Evaluation Testbed software being developed by DTC, in which the verification results and software will be shared with our NWS partners. This will lead to better understanding the origin of the model biases for these cyclone events, as well as the significant weather associated with these cyclones (heavy precipitation, strong winds, moisture plumes, and freezing lines).

WPC strongly supports this activity and enthusiastically endorses funding of this proposal. The proposed work has direct relevance for a number of our ongoing projects at our center, including:

1) Medium range forecasting, including expanding daily forecasts from Day 7 to Day 10. The proposed verification tools will assist with daily model assessments in determining the predictability of synoptic scale features.
2) Model evaluations. We expect applying the proposed verification techniques to more sensible weather fields from both operational and parallel guidance will result in more robust evaluations, as well as evaluations relavant to WPC's and WFO's interests in sensible weather elements.

3) WPC's Winter Weather Experiments (WWE) can play a key role testing the proposed tools, as participants are able to focus, in a non-operational environment, on specific events.

WPC will be an active participant in the activities as described in the proposal, and we look forward to starting this important collaborative work.

Sincerely,

David Novak
Acting Director, Weather Prediction Center

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Aviation Weather Center
7220 NW 101st Terrace, Room 101
Kansas City, Missouri 64153-2371

September 29, 2014

Research to Operations Initiative
NOAA/NWS
1325 East-West Highway
Rm 15328
Silver Spring, MD 20910

Dear Mr. Hedge and Reviewers:

The NOAA/NWS Aviation Weather Center (AWC) and Aviation Weather Testbed (AWT) endorse the project proposed by Professors Brian Colle and Edmund Kar-Man Chang of Stony Brook University, as described in their proposal titled, "Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach."

The AWC is undergoing a modernization of its products and services for aviation. The NWS 2011 Strategic Plan describes a "Weather-Ready Nation" anchored by state-of-the-science and decision support services. Similarly, the National Academy of Public Administration (NAPA) report, "Forecast for the Future: Assuring the Capacity of the NWS" and the recent National Transportation Safety Board (NTSB) Safety Recommendations A_14_17-21 directed to the NWS align in their calls for new and innovative ways to communicate a consistent NWS forecast. These calls are ultimately anchored in the capability of the NWS models and ensemble systems. It is thus critically important that these systems be improved, especially for extreme weather events affecting aviation safety (e.g., icing (clouds), turbulence, and the prediction of low clouds (ceilings) and restricted visibility) and National Airspace System efficiency. Verifying high-impact weather is an important component of ensuring model-based improvements as well improvements to post-processing, calibration, and decision support services.

On behalf of the AWC and the AWT, I fully support Professors Colle and Chang's project and enthusiastically endorse funding the proposal. The proposed work has direct relevance for a number of AWC/AWT ongoing projects, such as:

1) Achieving an NWS Common Operating Picture (COP) for both convection and clouds. These two important projects are national in scope and highly visible across the NWS. A cyclone relative validation of model and ensemble output will improve our understanding of NWP capability, and assist NWS Milestones aimed at developing national experimental probabilistic guidance for convection and clouds.

2) The AWC is transitioning its meteorologist produced Collaborative Convective Forecast Product (CCFP) into a Collaborative Aviation Weather Statement (CAWS). This new on-demand statement will discuss short-term (0 to 6 hours) weather impacts to aviation efficiency and safety across the U.S. A cyclone-relative verification of model (e.g., HRRR, SREF) convection, precipitation, wind, and other high-impact phenomena,

especially over the critically important Northeast Corridor, will benefit the development of these new operational decision support services.

I am committed to being an active participant in the research as described in the proposal, and will obligate resources from the AWT to ensure its success. I look forward to starting this important collaborative work.

Sincerely,

BRIGHT.DAVID.R.1365
872488

Digitally signed by BRIGHT.DAVID.R.1365872488
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=OTHER, cn=BRIGHT.DAVID.R.1365872488
Date: 2014.09.29 11:02:24 -05'00'

DRB

Dr. David R. Bright
Chief, NOAA/NWS/AWC Aviation Support Branch
NOAA Aviation Weather Testbed

cc: CAPT Robert W. Maxson (ret.)
Director, NOAA/NWS Aviation Weather Center

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
National Centers for Environmental Prediction
Ocean Prediction Center
NOAA Center for Weather and Climate Prediction
5830 University Research Court
College Park, Maryland 20740

September 29, 2014

Research to Operations Initiative
NOAA/NWS
1325 East-West Highway
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Silver Spring, MD 20910

Dear Mr. Hedge and Reviewers:

The recent 2011 Strategic Plan for the National Weather Service (NWS) emphasizes the goal of a "Weather-Ready Nation," which will require users to better synthesize (NWS) forecasts to take preventative actions to the protect life and property. The models and ensembles run within the NWS are an important component of this decision-making process, thus it is important that these modeling systems be improved, especially for extreme weather events. Verification of these models is a very important component of the model improvement process, presently there are a few issues limiting progress in this area: (1) the verification is typically done regionally on a grid and therefore limiting the ability to understand the errors associated with different types of extreme weather phenomena; (2) important processes associated with high impact weather events need to be better diagnosed with the verification, presently it is very difficult to isolate the model issues and make improvements to these models; and (3) there is no common next generation verification package that is shared among the operational centers.

To help address these challenges, Stony Brook University is collaborating with several NWS Operational Centers (EMC, OPC, WPC, and AWC), and the Developmental Testbed Center (DTC) in the proposal titled: "Validation of Significant Weather Features and Processes in Operational Models Using a Cyclone Relative Approach." This project will focus on a research to operations (R2O) effort to implement a cyclone relative approach in the Meteorological Evaluation Testbed software being developed by DTC, in which the verification results and software will be shared with our NWS partners. This will lead to better understanding of the origin of the model biases for cyclone events, as well as the significant weather associated with these cyclones (heavy precipitation, strong winds, moisture plumes, freezing lines, etc…).

I strongly support this activity and enthusiastically endorse funding of this proposal. The proposed work has direct relevance to the Ocean Prediction Center operations including:

1) Improved cyclone track and intensity verification
2) Parameter based verification of warning category winds

I expect to be an active participant in the research as described in the proposal, and look forward to starting this important collaborative work.

Sincerely,

Joseph M. Sienkiewicz
Chief, Ocean Applications Branch
NOAA/NWS Ocean Prediction Center