Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction

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Project duration

2 years: 7/1/2017 – 6/30/2019

Budget totals

Year 1: $144,251
Year 2: $148,829
Total: $293,080

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ABSTRACT

Convection-permitting ensembles (CPEs) have been shown to provide useful guidance for short-range (0-36 h) prediction of high impact severe weather events and also have potential to improve flash flooding and winter weather guidance that can lead to improved decision-making. The need for CPEs is well recognized by NOAA with active development of a future High Resolution Rapid Refresh Ensemble (HRRRE). Yet, relatively little is known on optimal ensemble forecast system design for CPEs, which require i) varied initial conditions, ii) model error representation, iii) varied boundary conditions, and iv) novel post-processing techniques to provide easily interpretable guidance products.

To aid the NOAA/Hydrometeorology Testbed (HMT) objectives to improve flash flood and winter weather hazard forecasting, the proposed work will demonstrate the value of probabilistic hazard guidance drawn from CPE forecasts. A continuously cycled ensemble analysis on a convection-permitting grid will be used to initialize CPE forecasts at frequent intervals. We will concurrently test new approaches to improve short-range prediction of high impact weather. This will be achieved by executing two experimental versions of the HRRRE, a control system operated by GSD and an experimental version developed and operated by NCAR. Innovative data assimilation methods will be demonstrated in this project that will be candidates for inclusion in the Joint Effort for Data assimilation Integration (JEDI) project. Forecast products from both HRRRE versions will be provided to the HMT with an emphasis on the development of novel probabilistic guidance for flash floods and high impact winter weather events in the 6-12 h prediction window, for the Flash Flood and Intense Rainfall (FFaIR) and Winter Weather Experiment (WWE), respectively. Team members will lead the evaluation of forecast products within the HMT FFaIR and WWE, and forecasts will be verified to assess their skill at predicting these high impact phenomena. New verification methods will be developed as needed, including object-based methods. The team will actively coordinate project development and outcomes with NOAA EMC.

The proposed work is unique in the following ways: 1) continuously cycled ensemble analysis on the same convection-permitting grid as the ensemble forecast; 2) 18 h CPE forecasts initialized at 12, 15, and 18 UTC daily during the HMT demonstration periods, and an extended 36 h ensemble forecast from 00 UTC for comparison to the SSEO/HREF forecast from the same cycle; 3) merged capability with NCEP's Gridpoint Statistical Interpolation (GSI) tool for conventional observation processing along with NCAR's Data Assimilation Research Testbed (DART) toolkit for assimilation of conventional and radar observations; and 4) two analysis and forecast system implementations will be developed and demonstrated at the testbed activities.

STATEMENT OF WORK

DURATION OF PROJECT

2 years: 7/1/2017 – 6/30/2019

INTRODUCTION

Steady advances in numerical modeling, data assimilation, observing systems, and growing access to high-end computational resources have led to better weather predictions. Despite progress, accurate numerical weather prediction (NWP) of deep convection, particularly during the warm season, remains a considerable challenge (Fritsch and Carbone 2004). While prediction capability is greater during the winter months with synoptically driven precipitation systems, high impact winter weather events can be quite sensitive to small errors in NWP model initial conditions (ICs; e.g., Zhang et al. 2003). Better prediction of high impact weather is essential for society, as heavy summertime rainfall and associated flash flooding can threaten lives (e.g., Ashley and Ashley 2008) and produce extensive damage, and heavy snowfall and blizzards can cripple travel and infrastructure leading to steep economic losses and fatalities (e.g., Black and Mote 2015).

High-resolution NWP models offer a path toward improved prediction of extreme precipitation. Contrasting coarser-resolution NWP models requiring cumulus parameterization, "convection-permitting" NWP models have sufficiently fine horizontal grid spacing to obviate the need for convective parameterization, allowing explicit prediction of convection through model dynamics. Convection-permitting NWP models have been shown to outperform convection-parameterizing models across a variety of situations (e.g., Done et al. 2004; Kain et al. 2006; Roberts and Lean 2008; Weisman et al. 2008; Schwartz et al. 2009). Moreover, convection-permitting models can successfully reproduce notable warm- and cool-season topographically-forced precipitation events (e.g., Colle and Mass 2000; Colle et al. 2005; Garvert et al. 2005; Schwartz 2014; Bartsotas et al. 2016) and extreme rainfall associated with deep moist convection (e.g., Vié et al. 2011; Schumacher et al. 2013; Schumacher and Clark 2014; Schwartz et al. 2014, 2015a,b; Dahl and Xue 2016). Convection-permitting models can also replicate banded snowfall structures typically responsible for extreme snowfall rates (e.g., Novak et al. 2004), such as lake effect snow (LES) squalls, topographically-forced snow bands, and bands within the "comma head" of mid-latitude extratropical cyclones (e.g., Koch et al. 2005; Bernardet et al. 2008; Reeves and Dawson 2013; McMillen and Steenburgh 2015a; Schumacher et al. 2015).

Nonetheless, although convection-permitting models can reproduce intense and banded precipitation across seasons for a variety of meteorological scenarios, substantial timing, placement, and amplitude errors are common, and it remains challenging for high-resolution NWP models to skillfully predict heavy precipitation. Part of the challenge regarding heavy precipitation prediction is due to the small spatial scales over which extreme precipitation typically occurs, where predictability is limited (e.g., Lorenz 1969; Zhang et al. 2003, 2006; Hohenegger and Schär 2007); in fact, Schumacher et al. (2015) showed that some snow bands may be intrinsically unpredictable.

In addition to intrinsic limits on predictability, within the context of NWP modeling, deficiencies and uncertainties regarding ICs and physical parameterizations also provide practical limits on predictability. For example, convection-permitting simulations of heavy rainfall are sensitive to both physical parameterizations and ICs (e.g., Weisman et al. 2008; Schwartz et al. 2010, 2015a; Romine et al. 2013, 2014; Schumacher et al. 2013; Dahl and Xue 2016). Furthermore, convection-permitting simulations of LES are very sensitive to both microphysics (Reeves and Dawson 2013, McMillen and Steenburgh 2015a) and planetary boundary layer (Conrick et al. 2015) parameterization schemes, and locations of mesoscale banded snowfall structures are challenging to predict (e.g., Novak and Colle 2012). Perhaps epitomizing challenges regarding predictability of lake-effect precipitation, McMillen and Steenburgh (2015b) stated "…*these results suggest that reliable deterministic prediction of [Great Salt Lake-effect precipitation events] using current convection-permitting models at the forecast lead times examined here…will be extremely difficult in practice*". Therefore, although convection-permitting NWP models can predict heavy precipitation across seasons and in multiple scenarios, the usefulness of any single deterministic high-resolution forecast is clearly limited, motivating the need for CPEs to explicitly quantify model uncertainty.

CPEs account for aspects of forecast uncertainty that arise from small differences in ICs, boundary condition forcing, or model formulation, and have been shown to provide useful guidance for short-range (0-36 h) prediction of high impact severe weather events (e.g., Kong et al. 2009; Clark et al. 2011; Schumacher et al. 2013; Schwartz et al. 2015a,b), and flash flood predictions (e.g., Schumacher and Clark 2014, Yussouf et al. 2016, Nielsen and Schumacher 2016). However, to our knowledge studies focusing on CPE forecasts of snowfall have not yet been performed over the United States. The need for CPEs is well recognized by NOAA with active development of a future High Resolution Rapid Refresh Ensemble (HRRRE). Yet, relatively little is known on optimal ensemble forecast system design for regional CPEs, which require i) varied ICs, ii) model error representation, iii) varied boundary conditions, and iv) novel post-processing techniques to provide easily interpretable guidance products.

At NCAR, CPE development activities have culminated in the real-time execution of ensemble analysis, prediction, post-processing, and verification activities exemplified in the NCAR ensemble project (http://ensemble.ucar.edu; Schwartz et al. 2015b). Furthermore, while NOAA/GSD has extensive knowledge and expertise in the development and execution of hourly updating analysis and short-fuse prediction with operational deterministic forecast systems, more recently, GSD has begun experimental development of ensemble data assimilation and prediction systems. Through this proposed collaboration, we aim to catalyze progress in CPE development through exchange of tools and capabilities between NCAR and NOAA/GSD to jointly create a skillful and reliable CPE system for short-range forecasts (e.g., 18 h) that is suitable for operationalization. Ensemble predictions in the 3-12 h time window will prove particularly valuable in filling current gaps in available probabilistic guidance within NOAA's Forecasting a Continuum of Environmental Threats (FACETs) effort.

The NOAA Weather Prediction Center (WPC) has engaged in numerous Hydrometeorology Testbed (HMT) activities to address the multi-faceted challenges to improve prediction of precipitation and hydrologic systems. For the prediction of flash floods and winter weather hazards, they have developed two unique testbed activities: The Flash Flood and Intense Rainfall (FFaIR; Barthold et al. 2015) and Winter Weather Experiment (WWE) programs. The proposed work will contribute toward these core activities by providing experimental CPE forecast products, and team members will participate in the testbed activities and evaluation of forecasts.

The proposed activities are highly relevant to the HMT science priorities. Specifically, to identify and validate new or improve methods, models, and decision support tools to:

- Improve flash flood forecasting (HMT-1)
- Support ensemble precipitation prediction (HMT-2)
- Improve heavy rainfall, snowfall, winter storm and icing forecasts and warnings (HMT-5)
- Improve understanding and evaluate performance of extreme precipitation events (HMT-6)

Specifically, research questions related to the design of CPE guidance will be executed by developing two separate experimental HRRRE versions – one executed on NCAR's Cheyenne supercomputer and another at NOAA/GSD on the Jet supercomputer under an existing allocation. The upgrade of the NCAR analysis to a CPE grid enables effective use of high-resolution surface and MRMS reflectivity observations while also providing ICs appropriate for short-fused CPE forecasts. Forecast products from both HRRRE versions will be provided to the HMT with an emphasis on the development of novel probabilistic guidance for heavy precipitation weather hazards in the 6-12 h forecast window. Members of the team will lead the evaluation of forecast products within the HMT and forecasts will be verified to assess their skill at predicting high impact phenomena, including development of new surrogates and verification methods, such as object-based techniques. We will actively coordinate project development and outcomes with NOAA/EMC during regular telecons.

Conceptual framework

Based on forecast system comparisons over the past few seasons by the NOAA/HWT, the most skillful and reliable CPE predictions have originated from aggregations of time-lag and multi-model deterministic forecasts, while formally designed CPE systems have struggled to provide better performance. As such, considerable uncertainty remains in best-practice for storm-scale ensemble design, such as i) how to generate the best initial condition mean analysis and perturbations, ii) optimal methods to treat surface and lateral boundary conditions, and iii) what approaches promote reliable error growth during the forecast model integration. The proposed method aims to build a system based on 'best-practice' analysis and forecast system design to develop skillful and reliable predictions using a singular model core and physics suite and will rely on initial and boundary condition uncertainty for forecast error growth. Following this approach enables aggregation of model error diagnostics, which we will carefully analyze to understand systematic bias and error growth characteristics and then develop an appropriate strategy to improve the forecast model and promote additional spread growth (e.g., stochastic methods) if needed.

Scientific hypotheses and objectives

Our working hypotheses are that 1) CPE predictions will improve forecasts of high impact convective weather over deterministic forecasts through probabilistic numerical guidance products, drawn from the dynamic evolution of flow-dependent initial condition uncertainty, and will lead to improved decision-making. Further, 2) ensemble forecasts from a singular model and physics suite can provide as good or even more skillful and reliable guidance than ad hoc ensemble systems (e.g., SSEO/HREF). These hypotheses will be tested by development and execution of CPEs grounded in careful model development activities based on rigorous verification, cycled ensemble analysis to generate flow-dependent initial condition uncertainty, and by leveraging operational observation processing capability supplemented by the assimilation of radar observations to improve the mean analysis state. The effectiveness of this approach will be demonstrated by comparing both the NOAA/GSD and the NCAR HRRRE versions against the SSEO/HREF in longer lead predictions (48-hr forecasts from 00 UTC daily).

Results from prior research

Our team includes NOAA experts who operationalized the RUC, RAP, HRRR, and HREF analysis and/or forecast systems. Additionally, NCAR has provided forecast products to the NOAA/HWT since 2003 and thus has a long history of contributing data to and participation in NOAA testbed activities. NCAR has more recently developed expertise in ensemble prediction, including a real-time demonstration in 2013 (Schwartz et al. 2015a) and continuously operating a real-time ensemble analysis and CPE forecast since April 2015 (Schwartz et al. 2015b). This real-time, experimental, 10-member CPE system generates daily 48-hr ensemble forecasts with 3-km horizontal grid spacing over CONUS. Forecasts are initialized at 0000 UTC daily and will be produced in real-time through at least June 2017. Forecast products will be provided to the HWT in spring 2017 supported by NOAA/HWT grant NA15OAR4590191. While The NCAR ensemble system was developed for application to next day prediction of severe storms, this system still produces skillful guidance for a broad range of applications, including flash floods and extreme winter weather. During our period of operations, several interesting prediction scenarios have occurred. A few specific examples that show the value of CPEs for flash flood and winter hazard prediction follow.

On 14 September 2015 flash flooding struck extreme southwest UT causing 19 fatalities (state record from a weather disaster) and considerable damage, particularly in the Zion National Park and Hildale, UT community. The event was quite localized, yet the NCAR ensemble successfully predicted high probabilities of substantial rain amounts in this high desert region with 24 h forecast lead, as shown in Fig. 1.

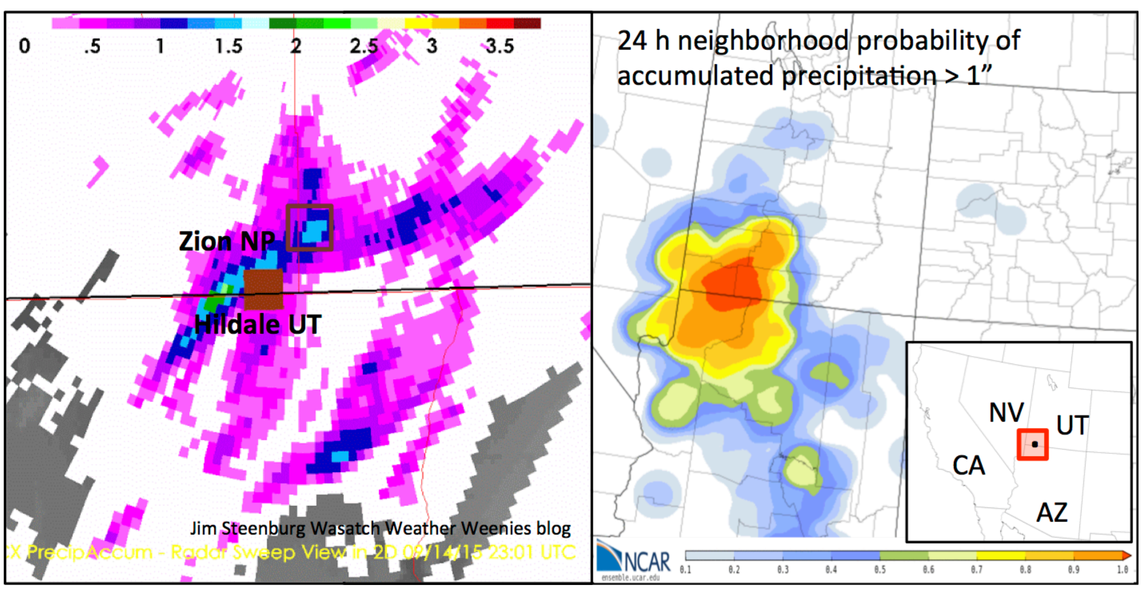


Fig 1. Left, radar estimate of accumulated precipitation from the KICX radar on 14 September 2015, and relative locations of Hildale, UT and Zion National Park. Right, neighborhood probability of accumulated precipitation greater than 1 inch within 40 km of each point ending 00 UTC 15 September 2015, initialized from the 00 UTC 14 September 2015 ensemble forecast.

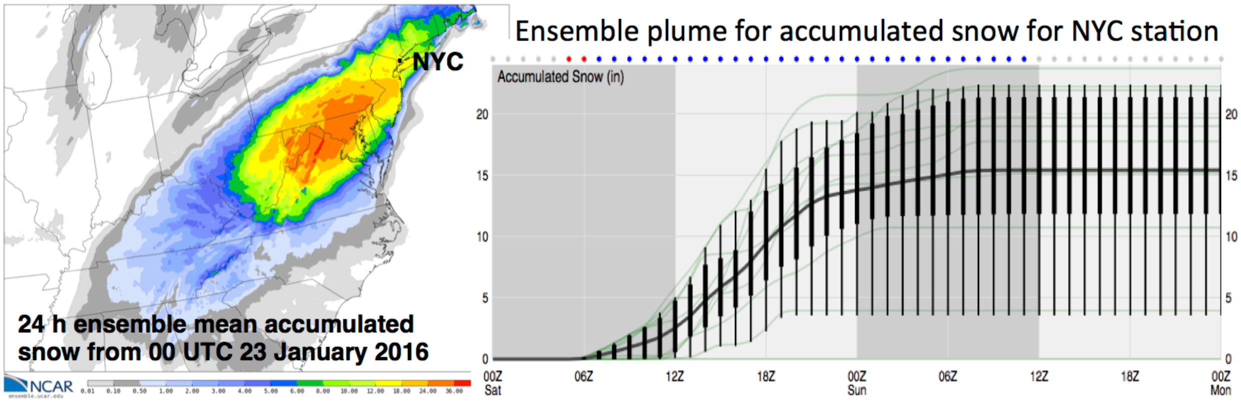


Fig. 2. Left, ensemble mean 24 h accumulated snowfall from the NCAR ensemble initialized at 00 UTC 23 January 2016. Right, plume diagram for accumulated snowfall at a New York City area station along the northern gradient in ensemble mean accumulated snowfall, where green lines are member forecast traces, the heavy black line is the ensemble mean forecast, and box plots are overlain every hour using the 10th, 25th, 75th and 90th percentiles.

Another high impact forecast event occurred in late January 2016 popularized in the media as "Snowzilla". This event was well forecast by most operational prediction systems, but there was considerable uncertainty on the location of the northern extent of the significant snowfall area. This uncertainty was well captured by NCAR ensemble forecasts as shown in Fig. 2, where accumulated snowfall predictions for New York City varied from 0" to 24" over this period.

In part due to its skillful forecasts, the NCAR ensemble has received ample attention from both researchers and operational forecasters. To date, NOAA entities have been the most frequent visitors to the NCAR ensemble website, and the NCAR ensemble has been mentioned at least 250 times in Area Forecast Discussions (AFDs) issued from at least 51 separate National Weather Service Weather Forecast Offices (WFOs). Furthermore, NCAR ensemble GRIB2 files are sent in real-time to the Storm Prediction Center and selected WFOs, who can display the data in real-time in N-AWIPS and AWIPS2, respectively.

The currently funded NOAA/HWT project has led to two peer-reviewed publications that investigate the use of severe storm surrogates to generate explicit predictions of severe storms. Sobash et al. (2016a) investigated the use of mid-level mesocyclone surrogates for prediction of any type of severe weather, while Sobash et al. (2016b) examined several new surrogates aimed at improving predictions of tornadoes and demonstrated novel application of object-based verification tools to understanding the behavior of simulated versus observed storms in similar convective environments.

PROPOSED METHODOLOGY AND WORK PLAN

The NOAA HMT coordinates two testbed activities annually, the FFaIR during mid-summer and the WWE during winter. During these testbed windows we will execute a real-time CPE analysis and produce 18 h CPE forecasts initialized at 12, 15, 18 UTC daily along with an extended 36 h forecast initialized at 00 UTC. This project will involve development of two systems, one executed at NCAR and another at NOAA/GSD. The NCAR system will have fewer constraints while the GSD system will comply with current computational and operational requirements. For

NCAR, the proposed CPE will be an improvement to the current NCAR ensemble system by upgrading the 6-hourly mesoscale analysis, currently on a mesh with 15-km horizontal grid spacing, to an hourly updated analysis on a 3-km convection-permitting grid assimilating a broader suite of observations, including radar. The NCAR CPE will feature a 10-member ARW-WRF (3-km grid spacing) forecast initialized from an 80-member Data Assimilation Research Testbed (DART) continuously cycled ensemble analysis on the same 3-km grid as the forecast. At GSD, a similar approach will be employed, but forecasts will be initialized from a 36-member continuously cycled ensemble analysis, and their forecast system will operate continuously (not just during testbed periods). The NCAR team will aim to show demonstrable improvement over the GSD implementation, and aspects of these systems will be candidates for future versions of the developmental HRRRE as initial constraints are relaxed.

The data assimilation system will leverage NCEP's Gridpoint Statistical Interpolation (GSI) data assimilation tools to process conventional observations, as is done in the operational HRRR, to compute model-simulated observations from the background ensemble (i.e., apply forward operators). Assimilation of the pre-computed observation priors will be done using the DART toolkit. Radar observations will be processed and assimilated by DART akin to NOAA's Warn-on-Forecast system (e.g., Wheatley et al. 2015). The analysis will be conducted on the same convection-permitting grid that the ensemble forecasts are initialized from.

Forecast products from both systems will be provided to the HMT customized to the needs of the testbed manager. Members of our research team will lead the evaluation of forecast products within the testbed. We will actively coordinate project development and outcomes with NOAA GSD and EMC personnel during regular conference calls and at least annual in-person meetings. Ensemble forecasts will be verified against a variety of observations and analyses to assess skill and reliability for prediction of high impact phenomena, and we will develop new surrogates and verification techniques as needed, including object-based methods. More specific details on the tools and the proposed work plan follows.

Numerical Weather Prediction: WRF

The proposed work will use version 3.8.1 of the Advanced Research Weather Research and Forecasting (WRF) community regional model (Skamarock et al. 2008) with modifications from the NOAA/GSD team to improve physics performance. Moreover, the WRF model configuration will be aligned to the operational HRRR (Smith et al. 2008; Benjamin et al. 2016) to facilitate rapid implementation of discoveries into the operational forecast system (Table 1

Table 1. Physical parameterizations that will be used in the WRF model forecasts. Cumulus parameterization will not used on the convection-permitting 3-km grid.

Physical parameterization	WRF model option	References
Microphysics	Thompson	Thompson et al. (2008)
Long- and short-wave radiation	Rapid Radiative Transfer Model for Global Climate Models (RRTMG) with ozone and aerosol climatologies	Mlawer et al. (1997); Iacono et al. (2008); Tegen et al. (1997)
Planetary boundary layer	Mellor–Yamada–Nakanishi–Niino (MYNN)	Nakanishi and Niino (2004, 2009)
Land surface model	Noah	Chen and Dudhia (2001)
Cumulus parameterization	Tiedtke	Tiedtke (1989); Zhang et al. (2011)

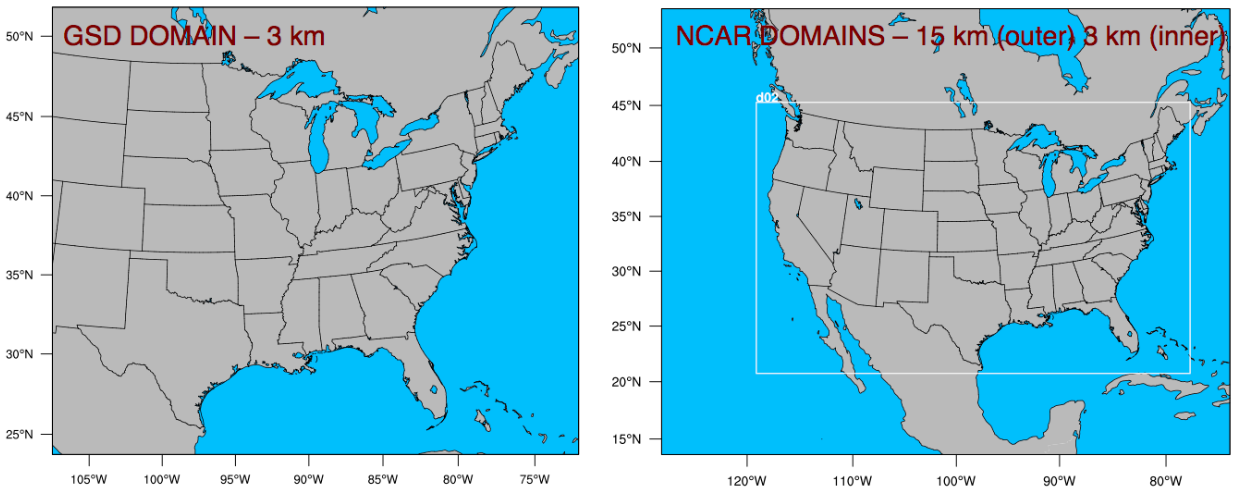


Fig. 3. The planned HRRRE domains for the GSD version (left) and the NCAR version (right) of the proposed CPE system. The NCAR version includes two domains.

lists configuration options for the NCAR version). Notably, the NCAR version will utilize the NOAH land surface model (Chen and Dudhia, 2001), while the GSD version will employ the RUC land surface model (Smirnova et al. 2016). Post-processing will apply the Unified Post-Processing (UPP) suite as well as utilizing built-in WRF diagnostic routines contributed by the Air Force Weather Agency in the release version of WRF. As shown in Fig. 3, the GSD version of the proposed CPE has a single domain with 3-km horizontal grid spacing covering most of the CONUS, while the NCAR system has a 15-km horizontal grid spacing outer domain with an inner 3-km grid spacing nest over the full CONUS. Unique lateral boundary conditions for each member forecast will be drawn from 0.25° GFS forecasts combined with random draws from global background error covariances (fixed covariance perturbation method; Torn et al. 2006) provided by the WRF variational data assimilation system (Barker et al. 2012).

Data assimilation tools: DART and GSI

The proposed work will use the DART (Anderson et al. 2009) EnKF-based ensemble data assimilation system akin to systems being tested for operational use in future NOAA/NWS warning systems (Stensrud et al. 2009). The DART EnKF provides initial conditions suitable for storm-scale ensemble analysis and forecasts by capturing uncertainty associated with convective weather events (e.g., Schwartz et al. 2015a,b). This assimilation framework is easily transitioned to the GSI-EnKF square root filter implementation for operationalization. The ongoing NCAR ensemble project successfully demonstrates a DART-based analysis and forecast system approach. Unlike nowcasting or statistical-based approaches to estimate forecast uncertainty, the EnKF approach uses a full dynamic model for probabilistic prediction. We will use a blend of tools for the hourly assimilation of conventional and radar observations. The NOAA GSI (Wu et al. 2002; Whitaker et al. 2008; Kleist et al. 2009) will be used for the model forward operators for conventional observations. Radar observation forward operators will be computed within DART or GSI. Several utilities developed to accompany the DART toolkit to accommodate the assimilation of radar observations motivate the choice to use DART for the assimilation tasks including adaptive inflation and techniques to incorporate additive noise (Dowell and Wicker 2009), which provides random, smooth, local perturbations to horizontal wind components, temperature and water vapor state at locations where observed radar reflectivity exceeds a threshold. Our initial implementation will assimilate radar reflectivity analyses provided by the NOAA Multi-Radar/Multi-Sensor (MRMS) 3D composite reflectivity products. The innovative assimilation methods that will be demonstrated in this project will be candidates for inclusion in the Joint Effort for Data assimilation Integration (JEDI) project.

Forecast evaluation and verification

Our forecast verification methods will employ several approaches to assess skill and reliability of probabilistic forecasts. Specifically, we will objectively verify probabilistic ensemble forecasts as in Schwartz et al. (2014) against gridded Stage IV analysis (ST4; Lin and Mitchell 2005) and MRMS data using metrics such as area under the relative operating characteristic (ROC; Mason and Graham 2002) curve, fractions skill score (FSS; Roberts and Lean 2008), and attributes of statistical reliability (Wilks 2006). Objective verification will focus over a fixed domain covering most of the central and eastern US where ST4 and MRMS data are most reliable. To assess the relative value of the GSD and NCAR CPE forecasts in this study, we will compare our ensemble prediction system implementations against the SSEO/HREF ensemble forecasts, particularly metrics of forecast skill and reliability. A neighborhood approach will be leveraged to assess probabilistic skill (e.g., Schwartz et al. 2010) directly from the ensemble. Precipitation bias will be addressed by use of probability matching that replaces the model rainfall distribution by that of the ST4 observations (Clark et al. 2010). Verification methods for snowfall rate (intensity) is not well established, but we will explore approaches with the HMT to achieve this. We will also investigate verification of snow water equivalent.

Work plan

We will immediately begin ensemble analysis and forecast system component testing and workflow development, including coordination with testbed managers for post-processing and product suite components and arranging product delivery methods to the testbed facilities. The GSD team anticipates having a prototype system in execution prior to the start of this funded activity. The NCAR system will be prepared and executed immediately before and during testbed activities. Our team will actively participate in HMT activities (FFaIR and WWE) provided invitation from the testbed manager. We will begin preliminary verification of CPE products provided by GSD and NCAR forecast systems concurrent with testbed activities, with more comprehensive verification efforts afterwards including comparison of longer range predictions against the SSEO/HREF prediction system. Following the initial implementation and testing of the analysis and forecast system at NCAR, we will begin development of documentation and implementation recommendations based on comparisons between experimental components of the NCAR system versus the GSD system performance. Innovations will be applied to subsequent testbed demonstrations with the NCAR system. Formal publications on the system performance for flash flood and winter weather hazard guidance will be prepared and submitted to appropriate journals. Results will also be disseminated through appropriate conference and workshop venues.

OPERATIONAL APPLICABILITY AND PAST COLLABORATIONS

The proposed rapidly updated CPE forecasts will provide valuable guidance to WPC forecasters issuing Mesoscale Precipitation Discussions (MPDs), and thus has the potential to directly benefit society through more accurate and timely flash flood and winter weather forecasts. Additionally, both the rapidly updated and longer-range ensemble forecasts will assist WPC forecasters to produce Day 1 Excessive Rainfall and Snowfall Probability Forecasts. Furthermore, the longer-range forecast initialized daily at 0000 UTC may also be useful guidance for WPC's Day 2 probabilistic and deterministic QPF products.

NCAR has long participated in the NOAA/HWT, with origins dating to near the inception of the HWT program (first NCAR participation was in 2003). NCAR also has collaborated informally with the HRRR team by sharing research results and code for modeling, assimilation and post-processing. With the ongoing NCAR ensemble project, we currently distribute data to SPC, NSSL, WPC (for the HMT WWE in 2017), and numerous local NWS offices. Members of our team from NOAA already have a long-standing relationship with the HWT as well as an established relationship with HMT through past demonstrations of the HRRR. NCAR also provided special forecasts for MPEX-mini (NSSL Director's Reserve funded activity in 2016). In the proposed work we are extending our collaborations to include EMC.

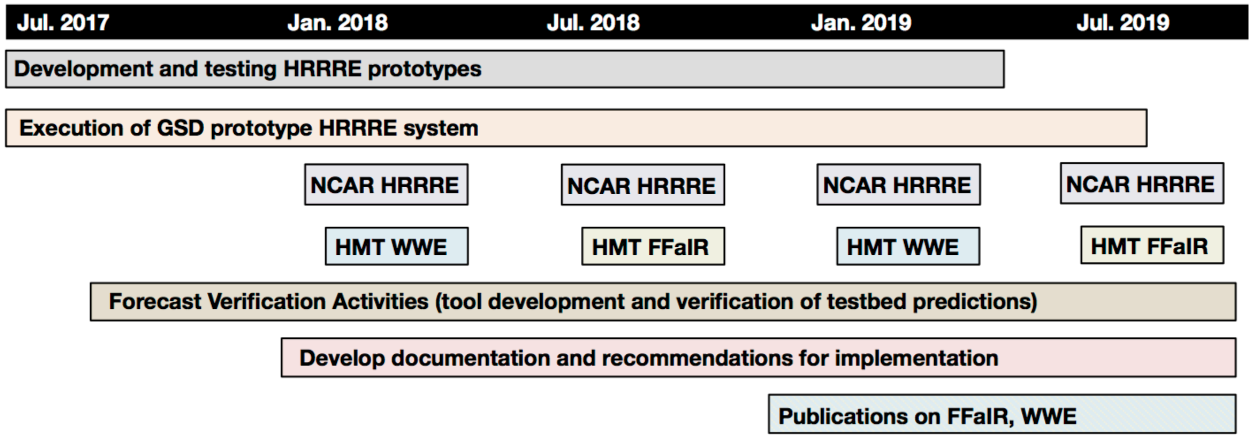
PROJECT DELIVERABLES

Our team includes GSD and EMC representatives that are leading the effort to develop the HRRRE as a possible component of future versions of the operational HREF. We will collaborate by exchanging model code, assimilation tools and methods, post-processing capability and observation data sets to achieve the planned objectives. Our forecast products will be disseminated to the testbed facility in coordination with the testbed manager. Further, NCAR will disseminate graphical forecast products on the web in a manner similar to the ongoing NCAR ensemble project (http://ensemble.ucar.edu). We expect these probabilistic forecast products from both systems to provide useful probabilistic guidance, particularly in the 6-12 h forecast window on flash flood and winter weather hazards that will lead to improved decision-making. This guidance should aid NOAA national forecast centers (e.g., WPC and SPC) in development of short-range forecast products that are disseminated to local forecast offices (e.g., Mesoscale Precipitation Discussions, Day 1 Excessive Rainfall and Snowfall Probability Forecasts). Forecast grids will also be available to local NWS offices from NCAR for download. Success will be measured by comparing forecast skill and reliability for the experimental HRRRE systems against the SSEO/HREF with an emphasis on high impact prediction performance.

READINESS LEVEL, TESTBED ACTVITIES, TRANSITION TO NOAA

The NOAA/GSD system will be a continuously operating ensemble analysis and prediction system, executed on NOAA computational resources, and will serve as a control with a higher readiness level. The NCAR predictions will be run immediately before and during testbed activities. The intent of the NCAR system is to more broadly test potential innovations to the NOAA/GSD ensemble, while also employing a larger domain, with more analysis members, and moreover will demonstrate in real-time potential improvements identified through retrospective testing. Thus, the NOAA/GSD ensemble will have a readiness level 7, while the NCAR system is expected to have a readiness level of 6. We are hopeful the CPE demonstration will lead to future components that achieve operational implementation within NOAA/WPC, such as in future versions of the operational HREF, and our team will aid in the transition. The testbed activities will provide a venue for demonstrating the effectiveness of the underlying prediction system to address a broad range of high impact prediction challenges, while also helping our team identify current deficiencies and weaknesses to prioritize development activities.

TIMELINE WITH KEY MILESTONES



Year 1: Activities will concentrate on the development of the core program tools, namely injecting WRF internal diagnostic routines, analysis, forecast, and post-processing workflows for real-time demonstration system. NCAR will not plan to demonstrate a new system for the 2017 FFaIR owing to the activity ongoing at the beginning of the funded project (although GSD expects to have a system available to demonstrate then), but may have NCAR ensemble products. Thus, NCAR will have a first HRRRE prototype for the 2018 WWE. Our team will send participants to both testbed activities (potentially GSD only for 2017 FFaIR) to demonstrate system characteristics and products, while also gathering feedback on system performance strengths and weaknesses. We will begin development of forecast verification workflows for precipitation, hazard surrogates, and conventional observations comparing the two HRRRE systems against the SSEO/HREF. We will also begin development of system documentation and recommendations based on preliminary results on the system skill and reliability. We will present results at relevant conferences and workshops.

Year 2: We will make adjustments to the analysis and forecast system as warranted from year 1 performance. We will execute a HRRRE system for both the 2018 FFaIR and the 2019 WWE. Provided a no-cost extension, we will also demonstrate a HRRRE for the 2019 FFaIR (travel funds will be carried forward from year 1). Our team will send participants to both FFaIR and WWE testbed activities to demonstrate system characteristics and products, while also gathering feedback on system strengths and weaknesses. We will continue forecast verification activities, development of documentation, and refinement of recommendations for implementation. We anticipate developing two publications related to forecast system performance for flash flood and winter weather prediction capabilities. We will present results at relevant conferences and workshops.

DESCRIPTION OF TRAVEL

Provided an invitation from the testbed manager, investigators will actively participate in the testbed activities for both FFaIR and WWE. The NCAR team will provide two members each year for each testbed for one week. At least one NOAA/EMC and two NOAA/GSD team members will participate in person at both testbed activities as well. We also aim to broadly disseminate research results, and thus we seek travel support to attend workshops and conferences with two funded trips each year.

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Data Management

Information Sharing Plan

Data and information sharing is an essential component of the proposed research activities. Data products will include convection-permitting analyses, convection-permitting ensemble forecast products, web-based graphics, verification statistics, documentation on the storm-scale ensemble analysis and forecast system, and both formal and informal publications. We plan to share data and information products in several ways, including:

Web-based distribution of graphical products: Graphical forecast products generated both at NCAR and within the HMT testbed activities (FFaIR and WWE) will be available to the public, excepting private portions of the NOAA HMT forecast evaluation web pages that are only available to HMT participants and staff. Web-based graphics will be available for the duration of the project, as well as archived on the NCAR mass storage system.

Presentations at scientific meetings: the PIs and collaborators will share results with community members by demonstrating the ensemble analysis and forecast system performance at national scientific meetings and workshops.

Ensemble analyses: The analyses generated by the NCAR cycled ensemble analysis system will be archived on the Cheyenne mass storage system for a period of 5 years. Access will be open to any user with a NCAR supercomputer user account. Data access accounts can be requested from NCAR for interested parties that do not already have a user account on the system. This data set will include the ensemble forecast initial conditions and lateral boundary condition files, as well as forecast diagnostic products further described below.

Ensemble forecast products: Owing to the large data volume of the raw forecast output (approximately 350 Tb per season), only hourly diagnostic fields will be archived from the ensemble forecasts (about 25 Tb per season). These derived diagnostic fields will include NSSL diagnostics, snow depth, accumulation rate, and snow water equivalent diagnostics, precipitation products, select atmospheric variables interpolated onto mandatory pressure levels, and other related fields. Additional products will be provided to the HMT for processing and display using internal WPC software. The initial condition and lateral boundary condition files (described above) will be available for reruns by interested parties by the end of the award period.

Verification statistics: Preliminary forecast performance statistics will be generated in pseudo-real-time (awaiting the end of the valid forecast period to process) and graphical products made available on the web. Comparisons with other ensemble forecast systems will be made retrospectively following each season, as constrained by available data sets from other ensemble forecast systems. Similarly, we will provide forecast products, as indicated above, for other groups to independently evaluate our forecast system performance.

Scientific publications: The results of the analysis and forecast system performance will be shared through multiple peer-reviewed publications.

Analysis and forecast system documentation: Documentation will be developed for an operational implementation plan, as needed, to describe the design and implementation of the analysis system and forecast model configuration, including describing supplemental diagnostic codes if not already fully documented elsewhere.

Model and analysis system codes: The planned system will utilize community analysis system and forecast model codes. Modifications from publicly available code systems will be described in the documentation noted above. Notably, the modifications to the WRF code include changes implemented in the operational HRRR. Code modifications will be fully commented within the source code.

Observations: The analysis and verification will use conventional observations and MRMS radar analyses, available through standard data streams, which will be described fully in the analysis and forecast system documentation. The observations used for analysis system will be archived and available as described under 'ensemble analyses' above.

Data and information will be made available as rapidly as practical, for both operational needs and for retrospective analysis. Forecast products will be made available for download by the HMT in real-time as available. Ensemble analyses and diagnostic fields will be available at the end of each forecast season. Similarly, web-based graphics will be available as generated during operations. Preliminary verification statistics will be made available within several days of the end of the valid forecast period. Seasonal verification statistics will be generated retrospectively at the end of each season and collectively over both seasons, in preparation for formal publications. Documentation and code will be made available before the end of the award (06/30/2019).

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Short Bio
December 2016

EDUCATION

Ph.D., Atmospheric Science, University of Illinois Urbana-Champaign, May 2008
M.S., Atmospheric Science, University of Illinois Urbana-Champaign, May 2002
B.S., Meteorology, with distinction, University of Oklahoma, May 1999

PROFESSIONAL EXPERIENCE

Project Scientist II, NCAR, 2013-present
Project Scientist I, NCAR, 2009-2013
Postdoctoral Research Associate, University of Illinois, 2008-2009
Research Associate, University of Illinois, 1999-2008
Mesonet Operations, Oklahoma Climate Survey, 1996-1999
Electrician, United States Navy, 1988-1996

COMMUNITY SERVICE

Editorships and review service

Associate Editor: 1) Monthly Weather Review, 2012-present; 2) Weather and Forecasting, 2016-present
Reviewer: Atmospheric Research, Weather and Forecasting, J. of Atmospheric Science, J. of Applied Meteorology and Climatology, Bulletin of the AMS, JGR-Atmospheres, Q. J. R. M. S.; National Science Foundation, DFG, Austrian Science Fund, NASA review panels member

Field projects

VORTEX-SE, 2016: PI, retrospective modeling studies
MPEX, 2013: Co-science operations director, modeling coordinator
DC3, 2011-2012: Assisted real-time forecasting effort
VORTEX2, 2009-2010: PI, Co-coordinator mobile disdrometers
BAMEX, 2003: Co-coordinator ground crew operations
VORTEX-99, 1999: Mobile mesonet team

American Meteorological Society, NOAA HWT

STAC committee on Severe Local Storms: Member, 2012-present; Chair, 2015-present
25th - 27th Conferences on Severe Local Storms: Member, conference committee
NOAA Hazardous Weather Testbed Experimental Forecast Program Participant, 2011, 2014-16

FUNDED GRANTS AND PROPOSALS (External)

Romine, G. S. (PI), M. C. Coniglio (co-PI), C. S. Schwartz (co-PI), R. A. Sobash (co-PI), "Resolution Dependence of Simulated Convective Storms in the Southeast United States", NOAA OAR, 2015-2017

Romine, G. S. (PI), R. A. Sobash (co-PI), "Assimilation of next-generation satellite-based products to improve severe weather forecasts", NASA ROSES-2014, 2015-2018

Romine, G. S. (PI), M. C. Coniglio (Co-PI), C. S. Schwartz (Co-PI), R. A. Sobash (Co-PI), "Convection-permitting ensemble forecast system for prediction of extreme weather", NOAA OAR, 2015-2017

Weisman, M. (PI), J.Trapp (Co-PI), C. Davis (Co-PI), **G. S. Romine (Co-PI)**, "The Mesoscale Predictability Experiment (MPEX)", NSF Lower Atmospheric Observing Facilities, 2013

Wilhelmson, R. (PI), B. Jewett (Co-PI), M. Gilmore (Co-PI), **G. S. Romine (former Co-PI)**, " Collaborative Research: Investigating Supercell/Tornado Genesis, Structure and Evolution Using Observations and Numerical Models", NSF, 2009-2013 [withdrew in 2009 with move to NCAR]

Romine, G. S. (PI), T. Schuur (Co-PI), "Collaborative Research: SGER-Measurements of Particle Size and Fall Velocity Distributions within Supercell Thunderstorms", NSF SGER, 2009-2010

EXPERTISE

Glen Romine's research is focused on predictability of high impact weather including ensemble data assimilation, observation impact, verification, diagnosis of model bias, and regional ensemble design.

PUBLICATIONS (15 past 3 years, 3 additional currently in review)

Powers, J., and **CoAuthors**, 2017: The Weather Research and Forecasting (WRF) Model: Overview, System Efforts, and Future Directions. *Bull. Amer. Meteor. Soc.*, In press.

Sobash, R. A., **G. S. Romine**, C. S. Schwartz, D. J. Gagne, M. L. Weisman, K. R. Fossell, 2016: Using explicit forecasts of low-level rotation from convection-allowing models for next-day tornado prediction. *Wea. Forecasting*, **31**, 1591-1614.

Romine G. S., C. S. Schwartz, R. D. Torn, M. L. Weisman, 2016: Impact of assimilating dropsonde observations from MPEX on ensemble forecasts of severe weather events. *Mon. Wea. Rev.*,**144**, 3799-3823.

Jewtoukoff, V., R. Plougonven, A. Hertzog, C. Snyder, **G. S. Romine**, 2016: On the Prediction of stratospheric balloon trajectories: Improving winds with mesoscale simulations. *J. Atmos. Oceanic Technol.*, **33**, 1629–1647.

Sobash, R. A., C. S. Schwartz, **G. S. Romine**, K. R. Fossell, M. L. Weisman, 2016: Severe weather prediction using storm surrogates from an ensemble forecasting system. *Wea. Forecasting*, **31**, 255-271.

Schwartz, C. S., **G. S. Romine**, R. A. Sobash, K. R. Fossell, M. L. Weisman, 2015: NCAR's Experimental Real-Time Convection-Allowing Ensemble Prediction System. *Wea. Forecasting*, **30**, 1645-1654.

Schwartz, C. S., **G. S. Romine**, M. L. Weisman, R. A. Sobash, K. R. Fossell, K. W. Manning, and S. B. Trier, 2015: A real-time convection-allowing ensemble prediction system initialized by mesoscale ensemble Kalman filter analyses. *Wea. Forecasting,* **30**, 1158-1181.

Trier, S. B., **G. S. Romine**, D. A., Ahijevych, R. J. Trapp, R. S. Schumacher, M. C. Coniglio, and D. J. Stensrud, 2015: Mesoscale thermodynamic influences on convective initiation near a surface dryline in a convection-permitting ensemble. *Mon. Wea. Rev.*, **143**, 3726-3753.

Torn, R. D., **G. S. Romine**, 2015: Sensitivity of central Oklahoma convection forecasts to upstream potential vorticity anomalies during two strongly-forced cases during MPEX. *Mon Wea. Rev.,* **143**, 4064-4087.

Lei, L., J. L. Anderson, **G. S. Romine**, 2015: Empirical localization functions for ensemble Kalman filter data assimilation in regions with and without precipitation. *Mon. Wea. Rev.,* **143**, 3664-3679.

Weisman, M. L., and **CoAuthors**, 2015: The Mesoscale Predictability Experiment (MPEX). *Bull. Amer. Meteor. Soc.*, **96**, 2127–2149.

Romine, G. S., C. S. Schwartz, J. Berner, K. R. Fossell, C. S. Snyder, J. L. Anderson, and M. L. Weisman, 2014: Representing forecast error in a convection-permitting ensemble system. *Mon. Wea. Rev.*, **142**, 4519–4541.

Schwartz, C. S., **G. S. Romine**, K. R. Smith, and M. L. Weisman, 2014: Characterizing and optimizing precipitation forecasts from a convection-permitting ensemble initialized by a mesoscale ensemble Kalman filter. *Wea. Forecasting*, **29**, 1295–1318.

Marquis, J., and **coAuthors**, 2014: An investigation of the Goshen County, Wyoming, tornadic supercell of 5 June 2009 using EnKF assimilation of mobile radar data collected during VORTEX2. Part I: Experiment design and verification of the EnKF analyses. *Mon. Wea. Rev.,***142**, 530-554.

Romine, G. S., C. S. Schwartz, C. Snyder, J. L. Anderson and M. L. Weisman, 2013: Model bias in a continuously cycled assimilation system and its influence on convection-permitting forecasts. *Mon. Wea. Rev.*, **141**, 1263-1284.

David C. Dowell
Meteorologist, NOAA Earth System Research Laboratory, Boulder, CO
David.Dowell@noaa.gov, 303-497-6872

a. Professional Preparation

Texas A&M University, College Station, TX. Computer science, BS, summa cum laude, 1991.
University of Oklahoma, Norman, OK. Meteorology, MS, 1994.
University of Oklahoma, Norman, OK. Meteorology, PhD, 2000.
National Severe Storms Laboratory, Norman, OK. Postdoctoral fellow, 2000-2001.
National Center for Atmospheric Research (ASP, MMM), Boulder, CO. Postdoctoral fellow, 2001-2004.

b. Appointments

2010-present	Meteorologist, NOAA Earth System Research Laboratory, Boulder, CO
2006-2010	Scientist, National Center for Atmospheric Research, Boulder, CO
2004-2006	Research Scientist, Coop. Institute for Mesoscale Meteor. Studies, Norman, OK
1991-1999	Research Assistant, University of Oklahoma, Norman, OK
1989-1991 (summers)	Software Engineer, Motorola, Inc., Fort Worth, TX

c. Publications

(i) Recent publications

Yussouf, N., D. C. Dowell, L. J. Wicker, K. H. Knopfmeier, and D. M. Wheatley, 2015: Storm-scale data assimilation and ensemble forecasts for the 27 April 2011 severe weather outbreak in Alabama. *Mon. Wea. Rev*., **143**, 3044-3066.

Benjamin, S. G., and Coauthors, 2016: A North American hourly assimilation and model forecast cycle: The Rapid Refresh. *Mon. Wea. Rev*., **144**, 1669-1694.

Weiss, C., D. Dowell, J. Schroeder, P. Skinner, A. Reinhart, P. Markowski, and Y. Richardson, 2015: A comparison of near-surface buoyancy and baroclinity across three VORTEX2 supercell intercepts. *Mon. Wea. Rev*., **143**, 2736-2753.

Allen, B. J., E. R. Mansell, D. C. Dowell, and W. Deierling, 2016: Assimilation of pseudo-GLM data using the ensemble Kalman filter. *Mon. Wea. Rev*., **144,** 3465-3486.

Calhoun, K. M., E. R. Mansell, D. R. MacGorman, and D. C. Dowell, 2014: Numerical simulations of lightning and storm charge of the 29-30 May 2004 Geary, Oklahoma, supercell thunderstorm using EnKF mobile radar data assimilation. *Mon. Wea. Rev*., **142**, 3977-3997.

Skinner, P. S., C. C. Weiss, L. J. Wicker, C. K. Potvin, and D. C. Dowell, 2015: Forcing mechanisms for an internal rear-flank downdraft momentum surge in the 18 May 2010 Dumas, Texas supercell. *Mon. Wea. Rev*., **143**, 4305-4330.

(ii) Other publications related to the proposed project

Dowell, D. C., L. J. Wicker, and C. Snyder, 2011: Ensemble Kalman filter assimilation of radar observations of the 8 May 2003 Oklahoma City supercell: Influences of reflectivity observations on storm-scale analyses. *Mon. Wea. Rev*., **139**, 272-294.

Dowell, D. C., and L. J. Wicker, 2009: Additive noise for storm-scale ensemble data assimilation. *J. Atmos. Oceanic Technol*., **26**, 911-927.

Dowell, D. C., F. Zhang, L. J. Wicker, C. Snyder, and N. A. Crook, 2004: Wind and temperature retrievals in the 17 May 1981 Arcadia, Oklahoma supercell: Ensemble Kalman filter experiments. *Mon. Wea. Rev.*, **132**, 1982-2005.

Marquis, J., Y. Richardson, P. Markowski, D. Dowell, and J. Wurman, 2012: Tornado maintenance investigated with high-resolution dual-Doppler and EnKF analysis. *Mon. Wea. Rev*., **140**, 3-27.

Aksoy, A., D. C. Dowell, and C. Snyder, 2009: A multi-case comparative assessment of the ensemble

Kalman filter for assimilation of radar observations. Part I: Storm-scale analyses. *Mon. Wea. Rev*., **137**, 1805-1824.
Fujita, T., D. J. Stensrud, and D. C. Dowell, 2007: Surface data assimilation using an ensemble Kalman filter approach with initial condition and model physics uncertainties. *Mon. Wea. Rev*., **135**, 1846-1868.

d. Synergistic Activities

(i) Steering committee member and field coordinator, Verification of the Origins of Rotation in Tornadoes Experiment 2 (VORTEX2)
(ii) NOAA Warn-on-Forecast team member
(iii) NOAA RAP and HRRR model team member
(iv) *Monthly Weather Review* and *Weather and Forecasting* associate editor
(v) Co-chair, AMS Severe Local Storms Conference (2008)

e. Collaborators and Other Affiliations

Recent Collaborators

Curtis Alexander (NOAA), Jeff Anderson (NCAR), Stan Benjamin (NOAA), Howie Bluestein (Univ. of Oklahoma), Don Burgess (NSSL/CIMMS), Ming Hu (NOAA), Kent Knopfmeier (NSSL/CIMMS), Paul Markowski (Penn State Univ.), Jim Marquis (Penn State Univ.), Erik Rasmussen (CIMMS), Yvette Richardson (Penn State Univ.), Glen Romine (NCAR), Chris Snyder (NCAR), David Stensrud (Penn State Univ.), Chris Weiss (Texas Tech Univ.), Steve Weygandt (NOAA), Dusty Wheatley (NSSL/CIMMS), Lou Wicker (NSSL), Josh Wurman (CSWR), Nusrat Yussouf (NSSL/CIMMS)

Graduate Advisors and Postdoctoral Sponsors

H. Bluestein, Univ. of Oklahoma, MS and PhD Thesis Advisor
L. Wicker, NSSL, Postdoctoral Advisor
C. Snyder, NCAR, Postdoctoral Advisor

Thesis and Postgraduate Advisees

A. Aksoy (NCAR), J. Beck (Texas Tech Univ.), Wiebke Deierling (NCAR), L. Frankel (Univ. of Colorado), M. French (Univ. of Oklahoma), R. Hastings (Penn State Univ.), K. Kuhlman (Univ. of Oklahoma), J. Marquis (Penn State Univ.), A. Reinhart (Texas Tech Univ.)

Craig S. Schwartz

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Phone: 303-497-1841; Email: schwartz@ucar.edu

Professional Preparation

2009	M.Sc. in Meteorology, The University of Oklahoma
2007	B.Sc. in Meteorology, The Pennsylvania State University

Appointments

2016-present	Project Scientist I, National Center for Atmospheric Research (NCAR)
2011-2016	Associate Scientist III, NCAR
2009-2011	Associate Scientist II, NCAR
2007-2009	Graduate Research Assistant, the University of Oklahoma and National Severe Storms Laboratory (NSSL)
2007	National Weather Service (Juneau, Alaska) summer hire.

Community Service and Field Programs

2016-present	Associate Editor for *Monthly Weather Review*
2014-present	Associate Editor for *Weather and Forecasting*
2014	Forecaster for the Front Range Air Pollution and Photochemistry Experiment
2013	Lead forecaster for the Mesoscale Prediction Experiment (MPEX)
2012	Lead forecaster for the Deep Convective Clouds and Chemistry (DC3) field program
2009	VORTEX2 mobile mesonet driver
2008, 2009	NOAA Hazardous Weather Testbed Spring Forecasting Experiment Program Participant

Relevant Publications

Schwartz, C. S., and R. A. Sobash, 2017: Applications of neighborhood approaches to convection-allowing ensembles: A review and recommendations. *Mon. Wea. Rev.*, Conditionally accepted.

Schwartz, C. S., G. S. Romine, K. R. Fossell, R. A. Sobash, and M. L. Weisman, 2017: Toward 1-km ensemble forecasts over large domains. *Mon. Wea. Rev.*, Conditionally accepted.

Schwartz, C. S., 2017: A comparison of methods used to populate neighborhood-based contingency tables for high-resolution forecast verification. *Wea. Forecasting*, In press.

Schwartz, C. S., 2016: Improving large-domain convection-allowing forecasts with high-resolution analyses and ensemble data assimilation. *Mon. Wea. Rev.*, **144**, 1777–1803, doi: 10.1175/MWR-D-15-0286.1.

Sobash, R. A., **C. S. Schwartz**, G. S. Romine, K. R. Fossell, and M. L. Weisman, 2016: Severe weather prediction using storm surrogates from an ensemble forecasting system. *Wea. Forecasting*, **31**, 255–271, doi: 10.1175/WAF-D-15-0138.1.

Sobash, R. A., G. S. Romine, **C. S. Schwartz**, D. J. Gagne, and M. L. Weisman, 2016: Explicit forecasts of low-level rotation from convection-allowing models for next-day tornado prediction. *Wea. Forecasting*, **31**, 1591–1614, doi: 10.1175/WAF-D-16-0073.1.

Schwartz, C. S., G. S. Romine, R. A. Sobash, K. R. Fossell, and M. L. Weisman, 2015: NCAR's experimental real-time convection-allowing ensemble prediction system. *Wea. Forecasting*, **30**, 1645–1654, doi: 10.1175/WAF-D-15-0103.1.

Schwartz, C. S., G. S. Romine, M. L. Weisman, R. A. Sobash, K. R. Fossell, K. W. Manning, and S. B. Trier, 2015: A real-time convection-allowing ensemble prediction system initialized by mesoscale ensemble Kalman filter analyses. *Wea. Forecasting*, **30**, 1158–1181, doi: 10.1175/WAF-D-15-0013.1.

Romine, G. S., **C. S. Schwartz**, J. Berner, K. R. Fossell, C. S. Snyder, J. L. Anderson, and M. L. Weisman, 2014: Representing forecast error in a convection-permitting ensemble system. *Mon. Wea. Rev.*, **142**, 4519–4541, doi: 10.1175/MWR-D-14-00100.1.

Schwartz, C. S., G. S. Romine, K. R. Smith, and M. L. Weisman, 2014: Characterizing and optimizing precipitation forecasts from a convection-permitting ensemble initialized by a mesoscale ensemble Kalman filter. *Wea. Forecasting*, **29**, 1295–1318, doi: 10.1175/WAF-D-13-00145.1.

Schwartz, C. S., 2014: Reproducing the September 2013 record-breaking rainfall over the Colorado Front Range with high-resolution WRF model forecasts. *Wea. Forecasting*, **29**, 393–402, doi: 10.1175/WAF-D-13-00136.1.

Schwartz, C. S., and Z. Liu, 2014: Convection-permitting forecasts initialized with continuously-cycling limited-area 3DVAR, ensemble Kalman filter, and "hybrid" variational-ensemble data assimilation systems. *Mon. Wea. Rev.*, **142**, 716–738, doi: 10.1175/MWR-D-13-00100.1.

Romine, G. S., **C. S. Schwartz**, C. Snyder, J. L. Anderson, and M. L. Weisman, 2013: Model bias in a continuously cycled assimilation system and its influence on convection-permitting forecasts. *Mon. Wea. Rev.*, **141**, 1263–1284, doi: 10.1175/MWR-D-12-00112.1.

Schwartz, C. S., J. S. Kain, S. J. Weiss, M. Xue, D. R. Bright, F. Kong, K. W. Thomas, J. J. Levit, M. C. Coniglio, and M. S. Wandishin, 2010: Toward improved convection-allowing ensembles: Model physics sensitivities and optimizing probabilistic guidance with small ensemble membership. *Wea. Forecasting*, **25**, 263–280, doi: 10.1175/2009WAF2222267.1.

Schwartz, C. S., J. S. Kain, S. J. Weiss, M. Xue, D. R. Bright, F. Kong, K. W. Thomas, J. J. Levit, and M. C. Coniglio, 2009: Next-day convection-allowing WRF model guidance: A second look at 2 vs. 4 km grid spacing. *Mon. Wea. Rev.*, **137**, 3351–3372, doi: 10.1175/2009MWR2924.1.

Ryan A. Sobash, NCAR/MMM
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Boulder, CO 80301 sobash@ucar.edu

Education

Ph. D., 2013 Meteorology, University of Oklahoma, Norman, OK
M.S., 2010 Meteorology, University of Oklahoma, Norman, OK
B. S., 2006 Meteorology, Pennsylvania State University, University Park, PA

Professional Experience

Project Scientist I *October 2015 - present*
National Center for Atmospheric Research/MMM, Boulder, CO
Post-Doctoral Research Associate *July 2014 – October 2015*
National Center for Atmospheric Research/MMM, Boulder, CO
Post-Doctoral Research Associate *January 2014 – June 2014*
Cooperative Institute for Mesoscale Meteorological Studies, Norman, OK
Graduate Research Assistant *August 2006 – December 2013*
University of Oklahoma/National Severe Storms Laboratory, Norman, OK

Research Interests

Convective-scale and mesoscale ensemble forecasting and data assimilation, convective-scale modeling, development of ensemble guidance for high-impact weather phenomena

Publications

1. **Sobash, R. A.,** G. S. Romine, C. S. Schwartz, D. J. Gagne, and M. L. Weisman, 2016: Explicit forecasts of low-level rotation from convection-allowing models for next-day tornado prediction. *Wea. Forecasting*, **31,** 1591-1614.
2. **Sobash, R. A.**, C. S. Schwartz, G. S. Romine, K. R. Fossell, and M. L. Weisman, 2016: Severe weather prediction using storm surrogates from an ensemble forecasting system. *Wea. Forecasting*, **31**, 255-271.
3. Schwartz, C. S., G. S. Romine, **R. A. Sobash**, K. R. Fossell, and M. L. Weisman, 2015: NCAR's experimental real-time convection-allowing ensemble prediction system. *Wea. Forecasting*, **30**, 1645-1654.
4. Schwartz, C. S., G. S. Romine, M. L. Weisman, **R. A. Sobash**, K. R. Fossell, K. W. Manning, and S. B. Trier, 2015: A real-time convection-allowing ensemble prediction system initialized by mesoscale ensemble Kalman filter analyses. *Wea. Forecasting*, **30**, 1158-1181.
5. **Sobash, R. A.** and L. J. Wicker, 2015: On the impact of additive noise in storm-scale EnKF experiments, *Mon. Wea. Rev.*, **143**, 3067-3086.
6. Weisman, M. L. and **Coauthors**, 2015: The Mesoscale Predictability Experiment (MPEX), *Bull. of Amer. Meteor. Soc.,* **96**, 2127-2149.
7. **Sobash, R. A.** and D. J. Stensrud, 2014: Assimilating surface mesonet observations with the EnKF to improve ensemble forecasts of convection initiation, *Mon. Wea. Rev*, **143**, 3700-3725.
8. **Sobash, R. A.** and D. J. Stensrud, 2013: The impact of covariance localization for radar data on EnKF analyses of a developing MCS: Observing system simulation experiments. *Mon. Wea. Rev*, **141**, 3691-3709.

9. Kain, J. S. and **Coauthors**, 2013: A feasibility study for probabilistic convection initiation forecasts based on explicit numerical guidance, *Bull. of Amer. Meteor. Soc.,* **94**, 1213-1225.
10. Clark, A. J., S. J. Weiss, I. L. Jirak, M. Coniglio, C. J. Melick, C. Siewert, **R. A. Sobash**, and Coauthors, 2012: An Overview of the 2010 Hazardous Weather Testbed Experimental Forecast Program Spring Experiment, **93**, *Bull. of Amer. Meteor. Soc.*, 55-74.
11. **Sobash, R. A.,** J. S. Kain, D. R. Bright, A. R. Dean, M. C. Coniglio, and S. J. Weiss, 2011: Probabilistic forecast guidance for severe thunderstorms based on the identification of extreme phenomena in convection-allowing model forecasts. *Wea. Forecasting*, **26**, 714-728.
12. Kain, J. S., S. R. Dembek, S. J. Weiss, J. L. Case, J. J. Levit, and **R. A. Sobash**, 2010: Extracting Unique Information from High Resolution Forecast Models: Monitoring Selected Fields and Phenomena Every Time Step. *Wea. Forecasting*, **25**, 1536-1542.

Grants and Proposals

G. Romine (PI), R. Sobash (Co-PI), Tom Auligne (Co-I) “Assimilation of next-generation satellite-based products to improve severe weather forecasts”, NASA ROSES-2014 NNX15AR60G, $343,162, 2015-2018, [granted].

G. Romine (PI), M. Coniglio (Co-PI), C. Schwartz (Co-PI), R. Sobash (Co-PI), “Resolution Dependence of Simulated Convective Storms in the Southeast United States”, NOAA VORTEX-SE, 2015-2017, [granted].

G. Romine (PI), M. Coniglio (Co-PI), C. Schwartz (Co-PI), R. Sobash (Co-PI), “Convection-permitting ensemble forecast system for prediction of extreme weather”, NOAA-HWT, 2015-2017, [granted].

Fieldwork and other projects

Plains Elevated Convection at Night (PECAN)
Mesoscale Predictability Experiment (MPEX)

Nowcasting Lead, May-June 2013 (MPEX), June 2015 (PECAN)
Led nowcasting efforts to provide situational awareness during field deployments. Provided evening forecast updates for Day 2 operations.

Verification of the Origin of Tornadoes Experiment – II (VORTEX2)

Mobile Mesonet Operator, May-June 2010
Assisted with collection of data within supercell thunderstorms using an instrumented mobile mesonet vehicle.

VORTEX Operations Center, May-June 2009
Provided nowcasting support for field operations

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R/GSD1, 325 Broadway
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Professional Preparation

Pennsylvania State University	Meteorology	B.S. 1999
University of Oklahoma	Meteorology	M.S. 2002
University of Oklahoma	Meteorology	Ph.D. 2010

Appointments

Meteorologist	NOAA /ESRL/Global Systems Division	2016-Current
Research Associate	University of Colorado CIRES/NOAA	2009-2016
Co-Principal Investigator	National Science Foundation/CSWR	2007-2008
Co-Principal Investigator	National Science Foundation/U of Okla.	2005-2007
Graduate Research Assistant	University of Oklahoma	2000-2007
Graduate Fellowship	American Meteorological Society	1999-2000
Student Trainee	National Weather Service	1997-1999
Undergrad. Teaching Assistant	Pennsylvania State University	1997-1999

Recent Publications

Hu, M., S. G. Benjamin, T. Ladwig, D. C. Dowell, S. S. Weygandt, C. R. Alexander, J. S. Whitaker, 2017: GSI 3-dimensional ensemble-variationalhybrid data assimilation using a global ensemble for the regional Rapid Refresh model. *Mon. Wea. Rev*., in review.

Griffin, S., J. Otkin, C. Rozoff, J. Sieglaff, L. Cronce, and C. Alexander, 2017: Methods for Comparing Simulated and Observed Satellite Infrared Brightness Temperatures and What Do They Tell Us? *Wea. Forecasting,* **32**, 5–25, doi: 10.1175/WAF-D-16-0098.1.

Katona, B., P. Markowski, C. Alexander, and S. Benjamin, 2016: The Influence of Topography on Convective Storm Environments in the Eastern United States as Deduced from the HRRR. *Wea. Forecasting,* **31**, 1481–1490, doi: 10.1175/WAF-D-16-0038.1.

Benjamin, S., S. Weygandt, J. Brown, M. Hu, C. Alexander, T. Smirnova, J. Olson, E. James, D. Dowell, G. Grell, H. Lin, S. Peckham, T. Smith, W. Moninger, J. Kenyon, and G. Manikin, 2016: A North American Hourly Assimilation and Model Forecast Cycle: The Rapid Refresh. *Mon. Wea. Rev.,* **144**, 1669–1694, doi: 10.1175/MWR-D-15-0242.1.

Ikeda, K., M. Steiner, J. Pinto, and C. Alexander, 2013: Evaluation of Cold-Season Precipitation Forecasts Generated by the Hourly Updating High-Resolution Rapid Refresh Model. *Wea. Forecasting,* **28**, 921–939, doi: 10.1175/WAF-D-12-00085.1.

Recent Duties and Accomplishments

CIRES Research Associate/NOAA Earth System Research Laboratory

- Developed the capability to run Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR) hourly-updating forecast models in both retrospective and real-time environments on multiple high-performance (massively parallel) computer systems to assist model development and evaluation
- Developed both the capability to assimilate sub-hourly radar reflectivity data on a 3-km scale in the HRRR and produced numerous aviation, severe weather and renewable energy model forecast diagnostic products
- Led transitions of the RAP and HRRR from experimental to operational models at the National Centers for Environmental Prediction (NCEP)
- Supervised and led model and data assimilation development efforts for the RAP and HRRR with a team of more than a dozen scientists including analysis and forecast evaluations with meteorological case studies and statistical comparisons
- Presented talks and posters of RAP and HRRR development at numerous workshops, American Meteorological Society conferences, tutorials and science reviews
- Co-wrote a funded proposal for development and operational transition of hazardous weather detection post-processing tools from storm-scale ensembles
- Assisted with prototype development of both HRRR time-lagged and hourly-cycled initial-condition perturbation ensembles

Technological Experience

- Operating systems – Unix, Linux, Mac OS X, Windows
- Programming languages – Motorola Assembler, Fortran77, Fortran90, C, C++, MPI, Informix, EDLOG, Shell Scripting, Perl, Python, HTML, KML, XML, NCL, GrADS
- Applications – Weather Research and Forecasting (WRF-ARW) Model, WRF pre-processor (WPS), Gridpoint Statistical Interpolation (GSI), NCEP unified post-processor (UPP), WRF portal, Microsoft Office Suite
- High-performance computers – Workflow manager, Sun Grid Engine, Torque and LSF batch systems, MPI, Moab resource manager and Lustre/Panasas filesystems
- Data formats – NetCDF3/4, GRIB1/2, BUFR, DORADE, PIRAQ II/X, Level II/III 88D

Recent Collaborators

Stan Benjamin (NOAA/ESRL), Steve Weygandt (NOAA/ESRL), David Dowell (NOAA/ESRL), Isidora Jankov (NOAA/ESRL), Trevor Alcott (NOAA/ESRL), Kent Knopfmeier (NSSL), Adam Clark (NSSL), Israel Jirak (NCEP/SPC), Louis Wicker (NOAA/NSSL), Jacob Carley (NCEP/EMC), Geoffrey Manikin (NCEP/EMC), Corey Guastini (NCEP/EMC), Benjamin Blake (NCEP/EMC), Sarah Perfater (NCEP/WPC), Benjamin Albright (NCEP/WPC), Joshua Wurman (CSWR), Paul Markowski (PSU), Jason Otkin (CIMSS), Corey Potvin (OU), Anthony Reinhart (TTU), Patrick Skinner (NSSL), Christopher Weiss (TTU)

Thesis and Postgraduate Advisees

Janice Bytheway (CSU)

STANLEY G. BENJAMIN

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Email: stan.benjamin@noaa.gov
Phone: 303-497-6387

Education:	Ph.D. Meteorology	Pennsylvania State University	1983
	M.S. Meteorology	Pennsylvania State University	1980
	B.A. Mathematics	Albion College	1973

Employment History:

Chief, Earth Modeling Branch (EMB) 2014-present
NOAA Earth System Research Laboratory / Global Systems Division

Chief, Assimilation and Modeling Branch (AMB) 1992-2014
NOAA Earth System Research Laboratory / Global Systems Division

Research Meteorologist 1990-present

Research Scientist 1983-1990
NOAA research affiliation with NCAR

Awards and Honors:

U.S. Department of Commerce Gold Medal 2006, 2015
Colorado Governor's Award for High Impact Research 2015
Utility Variable-Generation Integration Group Achievement Award 2015
NASA Commendation 2015
U.S. Department of Commerce Bronze Medal 2010
U.S. Department of Commerce Bronze Medal 1998
NOAA Research Employees of the Year 2013
NOAA Research Outstanding Papers of Year 2006, 2008, 2010
Fellow, Cooperative Institute for Research in Environmental Sciences (CIRES)
Fellow, American Meteorological Society (AMS)

Major model activities transitioned to operations:

Rapid Refresh (RAP) version 3	Aug. 2016
HRRR model	Sep. 2014
Rapid Refresh (RAP) version 2	Feb. 2014
Rapid Refresh (RAP)	2012
Rapid Update Cycle (RUC) digital filter initialization technique	2008
13 km RUC with cloud assimilation	2005
40 km RUC with hourly update cycle	1998
60 km RUC with 3-hourly update cycle	1994

Refereed Publications in past three years:

Powers, J.G., and CoAuthors, 2016: The Weather Research and Forecasting (WRF) Model: Overview, system efforts, and future directions. *Bull. Amer. Meteor. Soc.*, In press.

James, E.P., S.G. Benjamin, and M. Marquis, 2016: A unified high-resolution wind and solar dataset from a rapidly updating numerical weather prediction model. *Ren. Energy*. http://www.sciencedirect.com/science/article/pii/S0960148116309363

Benjamin, S. G., and CoAuthors, 2016, A North American hourly assimilation and model forecast cycle: The Rapid Refresh. *Mon. Wea. Rev.*, **144**, 1669-1694. http://dx.doi.org/10.1175/MWR-D-15- 0242.1

Benjamin, S.G., J.M. Brown, and T.G. Smirnova, 2016: Explicit precipitation type diagnosis from a model using a mixed-phase bulk cloud-precipitation microphysics parameterization. *Wea. Forecasting*, **31**, 609-619. http://dx.doi.org/10.1175/WAF-D-15-0136.1

Benjamin, S.G. and W.R. Moninger, 2016: Comment on "A Comparison of temperature and wind measurements from ACARS-equipped aircraft and rawinsondes". *Wea. Forecasting*, **31**, http://dx.doi.org/10.1175/WAF-D-16-0081.1

Katona, B., P. Markowski, C. Alexander, and S. Benjamin, 2016: The influence of topography on convective storm environments in the eastern United States as deduced from the HRRR. *Wea. Forecasting*. **31**, http://dx.doi:10.1175/WAF-D-16-0038.1

Peckham, S. E., T.G. Smirnova, S. G. Benjamin, J. M. Brown and J. S. Kenyon. 2016: Implementation of a digital filter initialization in the WRF model and application in the Rapid Refresh. *Mon. Wea. Rev.*, **144**, 99-106. http://dx.doi.org/10.1175/MWR-D-15-0219.1

Smirnova, T.G., J.M. Brown, and S.G. Benjamin, 2016: Modifications to the Land Surface Model in the transition from the Rapid Update Cycle (RUC) to the WRF-based Rapid Refresh (RAP). *Mon. Wea. Rev.*, **144**, 1851-1865. http://dx.doi.org/10.1175/MWR-D-15-0198.1

Bleck, R., and CoAuthors, 2015: A vertically flow-following icosahedral grid model for medium-range and seasonal prediction. Part I: Model description. *Mon. Wea. Rev.*, **143**, 2386-2403.

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Date: 12/30/2016

Current and Pending Support

Investigator Name: **Glen Romine**

Project Title: Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction

NCAR Prop. No 2017-0181 | Program Name: FY17 Hydrometeorology Testbed (HMT)

Sponsor: NOAA OAR | Program No.: NOAA-OAR-OWAQ-2017-2005004

Funding: 293,080 | Program Manager: Richard Fulton

POP Start Date: 07/01/2017 | Prog Mgr Phone: 301-734-1289

POP End Date: 06/30/2019 | Prog Mgr Email: richard.fulton@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 1.00 MonthsCoSp:

Status: PENDING Serving as: PI

Project Title: Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Hazardous Weather Prediction

NCAR Prop. No 2017-0050 | Program Name: FY17 Hazardous Weather Testbed (HWT)

Sponsor: NOAA OAR | Program No.: NOAA-OAR-OWAQ-2017-2005004

Funding: 285,593 | Program Manager: Richard Fulton

POP Start Date: 07/01/2017 | Prog Mgr Phone: 301-734-1289

POP End Date: 06/30/2019 | Prog Mgr Email: richard.fulton@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 1.00 MonthsCoSp:

Status: PENDING Serving as: PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016

Current and Pending Support

Investigator Name: **Glen Romine**

Project Title:	Assimilation of and Verification with Space-borne Lightning Flash Rate Observations		
NCAR Prop. No	2016-0923	Program Name:	FY17-18 NOAA GOES-R3 (Geostationary Operational Environmental Satellite - Risk Reduction)
Sponsor:	NOAA NESDIS	Program No.:	FY17-18 GOES-R3
Funding:	484,655	Program Manager:	Dan Lindsey
POP Start Date:	04/01/2017	Prog Mgr Phone:	970-491-8773
POP End Date:	03/31/2020	Prog Mgr Email:	Dan.Lindsey@noaa.gov
Cal. Months Per Yr on Project:	MonthsFunded: 1.00	MonthsCoSp:	
Status:	PENDING	Serving as:	PI

Project Title:	Resolution Dependence of Simulated Convective Storms in the Southeast United States		
NCAR Prop. No	2015-0636	Program Name:	VORTEX-SE
Sponsor:	NOAA	Program No.:	NOAA-OAR-OWAQ-2015-2004475
Funding:	200,445	Program Manager:	John Cortinas
POP Start Date:	10/1/2015	Prog Mgr Phone:	301-734-1198
POP End Date:	9/30/2017	Prog Mgr Email:	John.Cortinas@noaa.gov
Cal. Months Per Yr on Project:	MonthsFunded: 0.96	MonthsCoSp:	
Status:	AWARDED	Serving as:	PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016

Current and Pending Support

Investigator Name: **Glen Romine**

Project Title: Assimilation of Next-Generation Satellite-Based Products to Improve Severe Weather Forecasts

NCAR Prop. No 2015-0223 Program Name: NASA ROSES 2014, A.25 Severe Storm Research

Sponsor: NASA Program No.: NNH14ZDA001N

Funding: 343,162 Program Manager: Ramesh Kakar

POP Start Date: 8/1/2015 Prog Mgr Phone: 202-358-0240

POP End Date: 7/31/2018 Prog Mgr Email: ramesh.k.kakar@nasa.gov

Cal. Months Per Yr on Project: MonthsFunded: 1.44 MonthsCoSp:

Status: AWARDED Serving as: PI

Project Title: Convection-permitting Ensemble Forecast System for Prediction of Extreme Weather

NCAR Prop. No 2015-0046 Program Name: Office of Weather and Air Quality Hazardous Weather and Hydrometeorology Testbed Competitions

Sponsor: NOAA Program No.: NOAA-OAR-OWAQ-2015-2004230

Funding: 199,542 Program Manager: John Cortinas

POP Start Date: 9/1/2015 Prog Mgr Phone: 301-734-1198

POP End Date: 8/31/2017 Prog Mgr Email: John.Cortinas@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 0.96 MonthsCoSp:

Status: AWARDED Serving as: PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016 **Current and Pending Support**

Investigator Name: **Craig Schwartz**

Project Title: Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction

NCAR Prop. No 2017-0181 Program Name: FY17 Hydrometeorology Testbed (HMT)

Sponsor: NOAA OAR Program No.: NOAA-OAR-OWAQ-2017-2005004

Funding: 293,080 Program Manager: Richard Fulton

POP Start Date: 07/01/2017 Prog Mgr Phone: 301-734-1289

POP End Date: 06/30/2019 Prog Mgr Email: richard.fulton@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 1.30 MonthsCoSp:

Status: PENDING Serving as: Co-PI

Project Title: Use of NWP Models to Identify Convective Outflows for Fire Weather Forecasting

NCAR Prop. No 2017-0087 Program Name: Joint Fire Science Program

Sponsor: DOI Bureau of Land Mgmt. Program No.: FA-FON0017-0001

Funding: 344,398 Program Manager: Ed Brunson

POP Start Date: 08/01/2017 Prog Mgr Phone: 208-387-5975

POP End Date: 07/31/2019 Prog Mgr Email: ebrunson@blm.gov

Cal. Months Per Yr on Project: MonthsFunded: 2.40 MonthsCoSp:

Status: PENDING Serving as: Co-PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016

Current and Pending Support

Investigator Name: **Craig Schwartz**

Project Title: Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Hazardous Weather Prediction

NCAR Prop. No 2017-0050 | Program Name: FY17 Hazardous Weather Testbed (HWT)

Sponsor: NOAA OAR | Program No.: NOAA-OAR-OWAQ-2017-2005004

Funding: 285,593 | Program Manager: Richard Fulton

POP Start Date: 07/01/2017 | Prog Mgr Phone: 301-734-1289

POP End Date: 06/30/2019 | Prog Mgr Email: richard.fulton@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 1.40 MonthsCoSp:

Status: PENDING Serving as: Co-PI

Project Title: Resolution Dependence of Simulated Convective Storms in the Southeast United States

NCAR Prop. No 2015-0636 | Program Name: VORTEX-SE

Sponsor: NOAA | Program No.: NOAA-OAR-OWAQ-2015-2004475

Funding: 200,445 | Program Manager: John Cortinas

POP Start Date: 10/1/2015 | Prog Mgr Phone: 301-734-1198

POP End Date: 9/30/2017 | Prog Mgr Email: John.Cortinas@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 2.04 MonthsCoSp:

Status: AWARDED Serving as: Co-PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016

Current and Pending Support

Investigator Name: **Craig Schwartz**

Project Title:	Convection-permitting Ensemble Forecast System for Prediction of Extreme Weather		
NCAR Prop. No	2015-0046	Program Name:	Office of Weather and Air Quality Hazardous Weather and Hydrometeorology Testbed Competitions
Sponsor:	NOAA	Program No.:	NOAA-OAR-OWAQ-2015-2004230
Funding:	199,542	Program Manager:	John Cortinas
POP Start Date:	9/1/2015	Prog Mgr Phone:	301-734-1198
POP End Date:	8/31/2017	Prog Mgr Email:	John.Cortinas@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 2.04 MonthsCoSp:

Status: AWARDED Serving as: Co-PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016

Current and Pending Support

Investigator Name: **Ryan Sobash**

Project Title: Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction

NCAR Prop. No: 2017-0181
Program Name: FY17 Hydrometeorology Testbed (HMT)

Sponsor: NOAA OAR
Program No.: NOAA-OAR-OWAQ-2017-2005004

Funding: 293,080
Program Manager: Richard Fulton

POP Start Date: 07/01/2017
Prog Mgr Phone: 301-734-1289

POP End Date: 06/30/2019
Prog Mgr Email: richard.fulton@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 2.00 MonthsCoSp:

Status: PENDING Serving as: Co-PI

Project Title: Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Hazardous Weather Prediction

NCAR Prop. No: 2017-0050
Program Name: FY17 Hazardous Weather Testbed (HWT)

Sponsor: NOAA OAR
Program No.: NOAA-OAR-OWAQ-2017-2005004

Funding: 285,593
Program Manager: Richard Fulton

POP Start Date: 07/01/2017
Prog Mgr Phone: 301-734-1289

POP End Date: 06/30/2019
Prog Mgr Email: richard.fulton@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 2.00 MonthsCoSp:

Status: PENDING Serving as: Co-PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016

Current and Pending Support

Investigator Name: **Ryan Sobash**

Project Title: Resolution Dependence of Simulated Convective Storms in the Southeast United States

NCAR Prop. No 2015-0636 | Program Name: VORTEX-SE

Sponsor: NOAA | Program No.: NOAA-OAR-OWAQ-2015-2004475

Funding: 200,445 | Program Manager: John Cortinas

POP Start Date: 10/1/2015 | Prog Mgr Phone: 301-734-1198

POP End Date: 9/30/2017 | Prog Mgr Email: John.Cortinas@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 3.00 MonthsCoSp:

Status: AWARDED Serving as: Co-PI

Project Title: Assimilation of Next-Generation Satellite-Based Products to Improve Severe Weather Forecasts

NCAR Prop. No 2015-0223 | Program Name: NASA ROSES 2014, A.25 Severe Storm Research

Sponsor: NASA | Program No.: NNH14ZDA001N

Funding: 343,162 | Program Manager: Ramesh Kakar

POP Start Date: 8/1/2015 | Prog Mgr Phone: 202-358-0240

POP End Date: 7/31/2018 | Prog Mgr Email: ramesh.k.kakar@nasa.gov

Cal. Months Per Yr on Project: MonthsFunded: 4.50 MonthsCoSp:

Status: AWARDED Serving as: Co-PI

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

Date: 12/30/2016

Current and Pending Support

Investigator Name: **Ryan Sobash**

Project Title:	Convection-permitting Ensemble Forecast System for Prediction of Extreme Weather		
NCAR Prop. No	2015-0046	Program Name:	Office of Weather and Air Quality Hazardous Weather and Hydrometeorology Testbed Competitions
Sponsor:	NOAA	Program No.:	NOAA-OAR-OWAQ-2015-2004230
Funding:	199,542	Program Manager:	John Cortinas
POP Start Date:	9/1/2015	Prog Mgr Phone:	301-734-1198
POP End Date:	8/31/2017	Prog Mgr Email:	John.Cortinas@noaa.gov

Cal. Months Per Yr on Project: MonthsFunded: 3.00 MonthsCoSp:

Status: AWARDED Serving as: Co-PI

Note: Federal Research Meteorologists David Dowell, Curtis Alexander, and Stan Benjamin, all of the Global Systems Division of ESRL/NOAA, do not require a Current and Pending report.

In the event that a pending project is awarded and an overlap in effort occurs,the level of effort would be adjusted and/or additional personnel would be added, in concurrence with funding sources.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
National Centers for Environmental Prediction
5830 University Research Court, Suite 4600
College Park, MD 20740

23 December 2016

Dr. Glen Romine
National Center for Atmospheric Research P. O. Box 3000
Boulder, CO 80307

Glen,

This letter is to confirm my intent to collaborate with you and your team on your NOAA HMT Testbed (opportunity NOAA-OAR-OWAQ-2017-2005004) proposal entitled "Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction" that will last from 1 July 2017 through 30 June 2019. As the testbed manager for the HMT testbed, should the proposed activities be funded I am committing to invite members of the team to the Flash Flood and Intense Rainfall (FFaIR) and Winter Weather Experiment (WWE) demonstration periods where we will evaluate the performance of the proposed HRRR ensemble versions, one from NOAA/GSD and the other from NCAR. The proposed system will provide unique guidance within our testbed through rapidly updating ensemble predictions.

I look forward to working with you and the other PIs on this project.

Sincerely,

Sarah E. Perfater Digitally signed by Sarah E. Perfater
DN: cn=Sarah E. Perfater, o=Self, ou,
email=sperfater@weathercloset.com, c=US
Date: 2016.12.23 09:32:57 -05'00'

Sarah Perfater
Meteorologist, HMT
NOAA/NWS/Weather Prediction Center

I.M. Systems Group, Inc.
3206 Tower Oaks Blvd, Suite 300 Rockville, MD 20852 Telephone (240) 833-1889

NOAA/NWS/NCEP
Environmental Modeling Center
NOAA Center for Weather and Climate Prediction
5830 University Research Court
College Park, MD 20740
Phone: (301) 683-3693
Email: jacob.carley@noaa.gov

December 19, 2016

Glen Romine
National Center for Atmospheric Research
P. O. Box 3000
Boulder, CO 80307

Glen,

I would be pleased to collaborate with you and NCAR on your NOAA HMT testbed proposal entitled "Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction" which will last from 1 July 2017 through 30 June 2019. I plan to participate in a collaborative, advisory capacity on this exciting project.

EMC is committed to strengthening our partnering among NCAR, NOAA ESRL and EMC to develop next generation, convection-permitting forecast systems. I am particularly interested in approaches to initialize convection-permitting ensemble forecast systems, verification methods, and ensemble post-processing methods for improved prediction of flash flood and winter weather events. The proposed work is quite relevant to my own research interests as well as NOAA EMC's efforts to develop the next generation high-resolution ensemble forecast (HREF) system.

Regards,

Dr. Jacob R. Carley
Support Scientist, I. M. Systems Group and NOAA/EMC
jacob.carley@noaa.gov

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

28 December 2016

Dr. Glen Romine
National Center for Atmospheric Research
P. O. Box 3000
Boulder, CO 80307

Dear Glen,

I look forward to collaborate with you and your team on your NOAA HMT Testbed (opportunity NOAA-OAR-OWAQ-2017-2005004) proposal entitled "Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction", which will last from 1 July 2017 through 30 June 2019. For your proposed project, I expect the Hydrometeorological Testbed, located at the Weather Prediction Center (WPC), as well as WPC Operations, to provide instructive feedback on forecast system performance, methods for the integration of CAM guidance into testbed and operational activities, and assessment of ensemble guidance for specific WPC forecast products. This project is of interest to me owing to the increasing importance in the application of CAM ensemble guidance to the prediction of high impact weather events including short-fused flooding and extreme winter weather.

I look forward to working with you and the other PIs on this project.

Sincerely,

Greg Carbin
Chief, WPC Forecast Operations Branch

Mesoscale & Microscale Meteorology Laboratory
P.O. Box 3000, Boulder, CO 80307-3000 • Ph (303) 497-8901 • Fax (303) 497-8181
Morris Weisman • Senior Scientist • weisman@ucar.edu

Thursday, December 29, 2016

Dr. Glen Romine
National Center for Atmospheric Research P.O. Box 3000
Boulder, Co 80307

Dear Glen:

I look forward to collaborate with you and your team on your NOAA HMT Testbed (opportunity NOAA-OAR-OWAQ-2017-2005004) proposal entitled "Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction", which will last from 1 July 2017 through 30 June 2019. For your proposed project, I am committing to the verification and validation of forecasts of heavy convective precipitation, with particular emphasis on the prediction of the variety of convective modes that can lead to flash flooding. This project is of interest to me owing to my ongoing interests in the application of CAM ensemble guidance to improve prediction of high impact weather over short time scales encompassing the diurnal cycle (e.g., 0-24 h).

I look forward to working with you and the other PIs on this project.

Best Regards,

Dr. Morris L. Weisman
Senior Scientist NCAR/MMM

NCAR

National Center for Atmospheric Research
Mesoscale and Microscale Meteorology Laboratory (MMM)

Juanzhen Sun
P. O. Box 3000, Boulder, CO 80307-3000
Phone (303) 497-8957 Fax (303) 497-8181
sunj@ucar.edu

Dr. Glen Romine
National Center for Atmospheric Research P. O. Box 3000
Boulder, CO 80307

Dear Glen,

It is my pleasure to submit to you this letter of collaboration for your NOAA HMT Testbed (opportunity NOAA-OAR-OWAQ-2017-2005004) proposal entitled "Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction", which will last from 1 July 2017 through 30 June 2019. For your proposed project, I am committing to collaborate with you and your team on providing specific feedback on performance of data assimilation and forecasting system. This project is of interest to me owing to my own interest in application of CAM ensemble guidance to improve prediction of quantitative precipitation forecast and its impact on flash flood prediction.

I look forward to working with the investigator team to make the proposed project successful and in incorporating the findings from this project into the community modeling system that NCAR supports.

Sincerely,

Juanzhen Sun

Senior Scientist

NCAR/MMM

UCAR

UCAR Proposal Budget Detail

Proposal #	2017-0181
Proposal Title:	Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction
UCAR Entity:	NCAR
Period of Performance:	07-01-2017 - 06-30-2019
Principal Investigator	GLEN ROMINE

			Unit / Rate		Effort Year 1	Effort Year 2	Year 1 NOAA - Oceanic and Atmospheric Research	Year 2 NOAA - Oceanic and Atmospheric Research	Cumulative Grand Total
Salaries	**Regular Salaries**	ASSOC SCIENTIST III (TBD)	FTE		0.15	0.15	13,096	13,620	**26,716**
		PROJ SCIENTIST I	FTE		0.11	0.11	10,299	10,711	**21,010**
		PROJ SCIENTIST I	FTE		0.17	0.17	14,689	15,277	**29,966**
		PROJ SCIENTIST II	FTE		0.08	0.08	8,677	9,024	**17,701**
	Subtotal Salaries						**46,761**	**48,632**	**95,393**
Fringe Benefits		Regular Benefits @	56.00 %				26,186	27,233	**53,419**
	Subtotal Fringe Benefits						**26,186**	**27,233**	**53,419**
	Total Salaries and Benefits						**72,947**	**75,865**	**148,812**
Materials and Supplies		Publication / Page Charges					3,000	3,000	**6,000**
	Subtotal Materials and Supplies						**3,000**	**3,000**	**6,000**
Travel		Domestic - 2 trips/yr. to attend conference(s)					4,281	4,281	**8,562**
		Domestic - 4 trips/yr. to visit HMT testbed site					7,330	7,330	**14,660**
	Subtotal Travel						**11,611**	**11,611**	**23,222**
	Modified Total Direct Costs (MTDC)						**87,558**	**90,476**	**178,034**
Indirect Costs		NCAR Indirect Cost Rate (MTDC)	56.90 %				49,821	51,481	**101,302**
	Total Indirect Costs						**49,821**	**51,481**	**101,302**
MTDC Costs that Include Indirect Costs	**Computing Service Center**	Computing Service Center	$6.50 / hr				6,872	6,872	**13,744**
	Subtotal MTDC Costs that Include Indirect Costs						**6,872**	**6,872**	**13,744**
	Total MTDC + Applied Indirect Costs						**144,251**	**148,829**	**293,080**
	Total Funding To UCAR						**144,251**	**148,829**	**293,080**

UCAR NCAR Budget Justification

Demonstration of a Rapid Update Convection-Permitting Ensemble Forecast System to Improve Flash Flood and Winter Weather Prediction

NCAR Proposal 2017-0181

Period of Performance 7/1/2017 – 6/30/2019

UCAR BUDGET NARRATIVE

Total Budget

*The total UCAR budget for this 2-year effort is **$293,080** and is planned as a direct agreement from NOAA. Should this proposal be selected for funding, we request a cooperative agreement be awarded to the University Corporation for Atmospheric Research (UCAR).*

Salary and Benefits: *A total of **$95,393** for salaries and **$53,419** for benefits is requested.*

Proposed salary expenses are budgeted at estimated actual work hours for individuals. Non-work time for individuals, such as vacation, holidays, sick time, etc. are paid from the UCAR benefits pool. Salary is budgeted with an increase of 4% each fiscal year for inflation and merit raises. Benefits are calculated at 56% of salary on a base of $95,393.

Team Member	Year 1: Work Effort (Months)	Year 2: Work Effort (Months)
PI Romine, Proj. Scientist II	8% FTE (1 month)	8% FTE (1 month)
Co-PI Schwartz, Proj. Scientist I	11% FTE (1.3 months)	11% FTE (1.3 months)
Co-PI Sobash, Proj. Scientist I	17% FTE (2 months)	17% FTE (2 months)
Assoc. Scientist III (TBD)	15% FTE (1.8 months)	15% FTE (1.8 months)

Materials and Supplies: *A total of **$6,000** is requested.*

A budget of $6,000 is requested for 2 publications to disseminate the results of this work. Each publication is estimated at a cost of $3,000, which is typical of a publication with color graphics in trade journals and is based on the average cost of publications for the MMM Laboratory.

Travel: *A total of **$23,222** is requested.*

A budget of $14,660 total is requested for four separate trips per year so individual team members can each visit the NWS WPC's HMT site, located in College Park, Maryland, to represent the project's contributions throughout the testbed demonstrations. Each trip is estimated at a cost of $1,832.50 with a 5-day duration and includes: roundtrip airfare at $245, lodging at $215 per night, $69 per diem, $317 for ground transportation, which includes airport shuttle(s) and rental car cost, and $100 for misc. expenses, such as fuel, parking, etc.

Also, a budget of $8,562 total is requested for two team members to attend a domestic conference trip per year to present progress and results from this project's scope of work. Each trip is estimated at a cost of $2,140.50 with a 5-day duration and includes: roundtrip airfare at $450, lodging at $170 per night, $69 per diem, $150 for ground transportation, which includes airport shuttle(s), subway and/or taxi costs, and conference registration fee of $450, and $100 for misc. expenses. Location TBD.

The travel budget is based on UCAR experience for a typical domestic trip with a duration of 5 days, using U.S. GSA rates.

Computing Service Center (CSC): *A total of **$13,744** is requested.*

The CSC budget is a method of distributing the cost of computer networking and support personnel fairly among many different projects. The CSC rate is $6.50 per worked hour for the MMM Laboratory. The CSC rates are established each year within the framework of "Specialized Service Centers" in *(*2 CFR §200) OMB Uniform Guidance. No inflation factor is applied to the CSC rates. No indirect costs are applied to CSC.

Indirect Costs: *A total of **$101,302** is requested.*

NCAR's indirect costs are calculated at 56.9% of the Modified Total Direct Costs (MTDC) on a base of $178,034. The recovery of indirect costs is consistent with standard practices employed by non-profit organizations that perform government-sponsored research.

*(*2 CFR §200) OMB Uniform Guidance is the primary federal regulation governing UCAR cost practices.

Other NCAR Information

1. The National Center for Atmospheric Research (NCAR), a Federally Funded Research and Development Center (FFRDC) is operated by the University Corporation for Atmospheric Research (UCAR), DUNS# 078339587, under the sponsorship of the National Science Foundation (NSF). NSF, our cognizant audit agency, approves UCAR rates annually. Budgets include provisional rates, which are subject to review and approval of NSF. Mr. Sohel Ahmed of NSF may be contacted about UCAR rates at 703-292-2957. FY17 rates are used and have been approved by NSF for budgeting purposes. Rates are estimated based on current provisional rates and are subject to change. UCAR frequently does business with the US government and our audited financial statements are available here: http://www.fin.ucar.edu/treasury/afs.html.

2. For funds provided by direct agreement with UCAR, contractual arrangements should be made with Ms. Amy Smith, Manager, UCAR Contracts, 3090 Center Green Dr., Boulder, CO 80301-2252 Phone (303) 497-8872, Fax (303) 497-8501, e-mail fedaward@ucar.edu. Please refer to NCAR's proposal number 2017-0181 on all correspondence with UCAR.

UCAR/NCAR/MMM
Facilities, Equipment, and Other Resources

The following resources are available to NCAR's Mesoscale and Microscale Meteorology (MMM) Laboratory in support of the proposed project.

WRF (Weather Research and Forecasting system)

Researchers in the Mesoscale and Microscale Meteorology (MMM) Laboratory of NCAR are leading the development and support efforts for WRF, a state-of-the-art atmospheric modeling system designed for both meteorological research and numerical weather prediction. WRF offers a host of options for atmospheric processes and can run on a variety of computing platforms. WRF excels in a broad range of applications across scales ranging from tens of meters to thousands of kilometers, including meteorological studies, real-time Numerical Weather Prediction (NWP), idealized simulations, data assimilation, and Earth system model coupling. The WRF model has evolved to include several specialized variants, such as the WRF Data Assimilation (WRFDA) system, atmospheric chemistry (WRF-Chem), and Advanced Hurricane WRF (AHW). WRF also has a proven track record as a climate model, utilizing atmospheric boundary conditions from the Community Earth System Model (CESM).

DART

The Data Assimilation Research Testbed (DART), maintained by NCAR, is a community facility for ensemble Data Assimilation (DA). DART provides modelers, observational scientists, and geophysicists with powerful, flexible DA tools that are easy to implement and use and can be customized to support efficient operational DA applications. DART employs a modular programming approach to apply an ensemble Kalman filter which nudges the underlying models toward a state that is more consistent with information from a set of observations. Models may be swapped in and out, as can different algorithms in the ensemble Kalman filter. The DART algorithms are designed so that incorporating new models and new observation types requires minimal coding of a small set of interface routines, and does not require modification of the existing model code. DART is currently being upgraded to efficiently utilize many thousands of processors for large-scale assimilation algorithms. Further, DART is adaptable to utilize forward operators computed either internally or externally, such as with the NOAA Gridpoint Statistical Interpolation (GSI) assimilation tools enabling the assimilation of both conventional and satellite observations. DART also provides support routines needed to assimilate Doppler radar observations for several microphysical schemes available within WRF.

Computer Resources

As a part of UCAR and NCAR, the MMM Laboratory has access to high-end computational and mass storage resources, including "Cheyenne" which is a new 5.34-petaflops high-performance computer built for NCAR by SGI (Silicon Graphics International), located at the NCAR-Wyoming Supercomputing Center (NWSC). Cheyenne will eventually take the place of supercomputer "Yellowstone" by 2018, but until then, they both will run in parallel. In comparison, Cheyenne is 2.5x greater than Yellowstone's computational capacity and 3.5x greater than Yellowstone at its peak performance. Even with its increased power, Cheyenne is 3x more energy efficient.

MMM also has access to a visualization laboratory, and the extensive technical expertise provided by the Computational and Information Systems Laboratory (CISL). State of the art networks provide wide area connections which include a gigabit path to the Front Range Gigapop with high bandwidth connections to National Lambda Rail, Internet 2, and the commodity Internet. These systems and networks are monitored around the clock by a dedicated operations staff who are prepared to resolve problems or escalate to expert staff should the need arise.

The MMM Laboratory provides computational support for staff and visitors ranging from desktop systems to small clusters running Linux, Mac OSX, or Microsoft Windows operating systems. Additional resources to facilitate research include several computational, graphical, and productivity software packages, printers, and high speed network access.

Office Resources

Office facilities and resources available to the investigators include the overall facilities and administration of UCAR/NCAR as well as administrative support from the MMM Laboratory. This includes staff office space and fully equipped conference facilities as well as a variety of experienced support staff including administrative assistants, audio-visual technicians, system administrators, accountants, legal counsel, contract administrators, and many others.

BUDGET INFORMATION - Non-Construction Programs

OMB Number: 4040-0006
Expiration Date: 01/31/2019

SECTION A - BUDGET SUMMARY

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. FY 2017 Joint Hurricane Testbed (JHT), Hazardous Weather Testbed (HWT), and Hydrometeorology Testbed (HMT)	11.459	$	$	$ 144,251.00	$	$ 144,251.00
2. FY 2017 Joint Hurricane Testbed (JHT), Hazardous Weather Testbed (HWT), and Hydrometeorology Testbed (HMT)	11.459			148,829.00		148,829.00
3.						
4.						
5. Totals		$	$	$ 293,080.00	$	$ 293,080.00

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SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) FY 2017 Joint Hurricane Testbed (JHT), Hazardous Weather Testbed (HWT), and Hydrometeorology Testbed (HMT)	(2) FY 2017 Joint Hurricane Testbed (JHT), Hazardous Weather Testbed (HWT), and Hydrometeorology Testbed (HMT)	(3)	(4)	(5)
a. Personnel	$ 46,761.00	$ 48,632.00	$	$	$ 95,393.00
b. Fringe Benefits	26,186.00	27,233.00			53,419.00
c. Travel	11,611.00	11,611.00			23,222.00
d. Equipment					
e. Supplies	3,000.00	3,000.00			6,000.00
f. Contractual					
g. Construction					
h. Other	6,872.00	6,872.00			13,744.00
i. Total Direct Charges (sum of 6a-6h)	94,430.00	97,348.00			$ 191,778.00
j. Indirect Charges	49,821.00	51,481.00			$ 101,302.00
k. TOTALS (sum of 6i and 6j)	$ 144,251.00	$ 148,829.00	$	$	$ 293,080.00
7. Program Income	$	$	$	$	$

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SECTION C - NON-FEDERAL RESOURCES

(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e)TOTALS
8. FY 2017 Joint Hurricane Testbed (JHT), Hazardous Weather Testbed (HWT), and Hydrometeorology Testbed (HMT)	$ 0.00	$ 0.00	$ 0.00	$ 0.00
9. FY 2017 Joint Hurricane Testbed (JHT), Hazardous Weather Testbed (HWT), and Hydrometeorology Testbed (HMT)	0.00	0.00	0.00	0.00
10.				
11.				
12. TOTAL (sum of lines 8-11)	$	$	$	$

SECTION D - FORECASTED CASH NEEDS

	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$ 144,251.00	$ 36,063.00	$ 36,063.00	$ 36,063.00	$ 36,062.00
14. Non-Federal	$				
15. TOTAL (sum of lines 13 and 14)	$ 144,251.00	$ 36,063.00	$ 36,063.00	$ 36,063.00	$ 36,062.00

SECTION E - BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT

(a) Grant Program	FUTURE FUNDING PERIODS (YEARS)			
	(b)First	(c) Second	(d) Third	(e) Fourth
16. FY 2017 Joint Hurricane Testbed (JHT), Hazardous Weather Testbed (HWT), and Hydrometeorology Testbed (HMT)	$ 148,829.00	$	$	$
17.				
18.				
19.				
20. TOTAL (sum of lines 16 - 19)	$ 148,829.00	$	$	$

SECTION F - OTHER BUDGET INFORMATION

21. Direct Charges: Modified Total Direct Costs (MTDC) = $178,034

22. Indirect Charges: Indirect Costs on MTDC = $101,302

23. Remarks: Indirect Costs = FY17 rate of 56.9% x MTDC = .569 x $178,034 = $101,302

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