COMET Partners Project: Final Report

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Project Type:	COMET Partners Project
Project Title:	"Extreme Precipitation Across the Tallahassee, FL NWS Forecast Area Associated with Tropical Storm Fay (2008): Physical Understanding and Ensemble-Based Forecast Utility"
UCAR Award No.:	Z11-91832
Date:	18 September 2012

1. Summary of Project Objectives

The primary objectives of our collaborative project were to:

- Highlight and better understand the physical processes responsible for the observed extreme rainfall across the Tallahassee, FL CWA associated with Tropical Storm Fay (2008).
- Quantify the skill of an ensemble of high-resolution ($\Delta x = \Delta y = 4$ km) numerical simulations of Fay (2008) in forecasting the observed extreme rainfall totals.
- Understand how NWS forecasters utilize ensemble-based numerical guidance when faced with a non-routine, high-impact forecast event.

2. Project Accomplishments and Findings

With respect to the first of the above-listed primary objectives,

- The observed extreme precipitation amounts associated with Tropical Storm Fay (2008) – exceeding 500 mm over 48 h in North Florida and South Georgia – were first evaluated from a climatological perspective. The observed three-day (22-24 August 2008) rainfall at Tallahassee, FL is the second-highest three-day rainfall total on record there between 1948-2010. Each of the top twenty highest three-day rainfall events featured large-scale ascent and warm air advection in a moist environment. Compared to other tropical cyclones (seven of nineteen cases) among these events, Fay was unique for moving westward, rather than north or east, during the period of heaviest rainfall.
- A nested 4/1.33 km simulation of Fay (2008) using version 3.2.1 of the WRF-ARW forecast model was conducted and used as a proxy for the observed event. Preliminary interrogation suggests that subtle changes in the lower tropospheric circulation promoted enhanced convergence in a moist environment dominated by warm rain processes, leading to increased precipitation efficiency across the Tallahassee, FL CWA. These findings were presented at the American Meteorological Society's 30th Conference on Hurricanes and Tropical Meteorology (Evans 2012).

Further analysis of the physical processes responsible for the observed extreme rainfall across the Tallahassee, FL CWA associated with Fay (2008) is on hold pending submission, revision, and publication of the results from the second and third above-listed primary objectives of this project.

With respect to the second of the above-listed primary objectives,

- A sixteen-member ensemble of high-resolution numerical simulations was conducted. Ensemble members were obtained by varying initial and lateral boundary conditions (of the atmospheric and oceanic states), varying the parameterizations of the planetary boundary layer and microphysical processes, and selectively utilizing a stochastic kinetic energy backscatter atmospheric perturbation scheme. Ensemble diversity achieved through variations in the initial and lateral boundary conditions of the atmospheric state resulted in notable differences in the location of the heaviest rainfall, suggesting a significant synoptic to meso-β scale control on the precipitation event. The remaining sources of ensemble member diversity led to notable spread only in the precise rainfall accumulations along the forecast corridor of the heaviest rainfall.
- Assessment of ensemble output revealed that 1) the ensemble exhibited meaningful skill compared to climatology at all precipitation thresholds up to 350 mm, 2) the ensemble mean was more skillful than the best deterministic forecast, and 3) the ensemble was underdispersive with a slight wet bias and a distinct clustering of solutions around those provided by the two large-scale numerical forecast guidance products (NAM and GFS) used to initialize the atmospheric state for each ensemble member.

With respect to the third of the above-listed primary objectives,

- A forecaster exercise was developed to assess how NWS forecasters use ensemble forecast products in an operational forecast setting. Forecasters were first asked to create a 72-h QPF forecast using only available deterministic and operational forecast guidance. Subsequently, forecasters were presented with output from the aforementioned sixteen-member ensemble and asked to create a revised 72-h QPF forecast incorporating these data. Forecasters were surveyed after each phase of the exercise to gauge their thinking and how they used the ensemble data to modify their initial forecast. To mitigate impacts from forecasters recognizing the four year old event, all products were shifted in name ("Trixie") and in space (Texas Gulf Coast) before being presented to the forecasters in the exercise.
- Output from the forecaster exercise was evaluated. Key findings include, but are not limited to, the following:
    - Forecaster confidence notably increased when the ensemble data agreed with their initial thinking, particularly when forecasting high QPF amounts.
    - Forecasts made with the benefit of the ensemble data were generally more skillful than those made without such data, although substantial variability between forecasters exists. The causes of such variability are uncertain, however, the generality of these findings is limited given the small sample sizes inherent to the study.
    - A few forecasters correctly identified that the ensemble was underdispersive. However, each of these forecasters handled this in different ways, with one declining to revise their forecast given the underdispersive characteristics of the ensemble. The remaining forecasters utilized the underdispersive ensemble data to revise their forecasts based upon which of the two forecast clusters they believed to be most likely to be accurate.
    - Finally, forecasters used the ensemble forecast data in two disparate ways. One subset utilized only information relating to the maximum, minimum, and mean forecast QPF amounts, whereas the other subset desired information relating to the variability in forecast QPF amounts between all ensemble members.

3. Benefits and Lessons Learned: Operational Partner Perspective

3.1 Benefits to Operational Partner

This project benefitted the NWS in two key ways. First, the forecaster exercise provided an excellent opportunity to provide hands-on training to NWS forecasters regarding the forecasting heavy rainfall from tropical cyclones utilizing an ensemble forecasting approach. Second, innovative graphics were created to display a large amount of ensemble forecast output in a clear, concise fashion. This allowed forecasters to spend the bulk of their time on analyzing and thinking about the output rather than switching between graphics. The scripts used to create such graphics are currently being used in real-time to display Short Range Ensemble Forecast (SREF) output, allowing forecasters to concisely view far more information than they would be able to otherwise given display constraints imposed by the current version of AWIPS. This promotes improved forecast decision-making, particularly during high impact events.

3.2 Problems Encountered

There were two primary problems encountered by the NWS partner. The first problem involved obtaining enough NWS forecasters to participate in the forecaster exercise. A sample size on the order of 30 forecasters was desired in order to permit meaningful statistical significance testing on the hypothesis that, in the mean, the utilization of the high-resolution ensemble forecast system led to improved forecast skill at all precipitation thresholds. Unfortunately, our attempts to engage other NWS offices in the conduct of the forecaster exercise were not met with success. As a result, only ten forecasters completed the forecaster exercise. In light of this issue, we narrowed the focus of our analysis of the forecaster exercise to documenting several interesting aspects of how forecasters utilized the ensemble forecast system output (described above) that we believe are worth further study.

The second problem arose in Spring 2012 upon learning that funding for NWS travel to the American Meteorological Society's 30th Conference on Hurricanes and Tropical Meteorology would not be available. This meant that the Operational partner would be unable to present the preliminary results obtained from the forecaster exercise (Van Dyke et al. 2012a). This problem was addressed by having the University partner, who was able to travel to the conference as planned, present the results.

4. Benefits and Lessons Learned: University Partner Perspective

4.1 Benefits to University Partner

Participation in this collaborative project has produced several benefits to the University partner. These include, but are not necessarily limited to, the following:

- With encouragement from the Operational partner based off of his practical experience, the sensitivity in the numerical precipitation forecasts to differing but equally-viable representations of the initial sea surface temperature was examined. For the strongly-forced tropical cyclone case evaluated here, forecast differences were subtle but nevertheless on a similar scale to those obtained by varying model physical parameterizations. With this as motivation, we plan to embark upon an investigation into the sensitivity of short-range forecasts of the initiation of deep, moist convection across the central and eastern United States to the initial representation of the sea surface temperature. This holds promise in helping to quantify inherent limitations in the numerical predictability of convection initiation.

- Also with insight from the Operational partner, we examined the sensitivity in the numerical precipitation forecasts to variance in the representation of the atmospheric state on the lateral boundaries of the forecast domain, located 5-10º latitude/longitude away from our area of interest. We found sufficient sensitivity to impact the forecasts and, potentially, their interpretation. This gave us a better appreciation for the limitations facing operational forecasters when interpreting real-time model guidance for both routine and non-routine events.
- The evaluation of how forecasters use deterministic and ensemble-based numerical guidance products as part of the forecast process that occurred as a part of our forecaster exercise gave us a better appreciation for the importance of involving both the research and operational communities in facilitating the transfer of research to operations. This particularly applies to 1) the dissemination of ensemble forecast system output in clear, concise ways that forecasters can easily understand and use and 2) how those outputs are actually used by forecasters. Our findings fostered insightful discussions with Rich Grumm (SOO, NWS WFO State College, PA), Evan Kuchera (Ensembles Team Lead, Air Force Weather Agency), and Paul Roebber (University of Wisconsin-Milwaukee) on these topics.
- Collaboration with the Operational partner on this project partially motivated our participation in the National Hurricane Center's (NHC's) Visiting Scientist Program in August 2012. This three-day visit enabled us to shadow NHC and Tropical Analysis and Forecast Branch (TAFB) forecasters; interact with a number of the operational, technological, and scientific support groups housed at the NHC; and gain a better appreciation for current challenges and future opportunities inherent to NHC operations. The NHC is an integral partner with the research community in the Joint Hurricane Testbed (JHT) program and we feel that the experienced gained in working with a partner in operations during this project will prove fruitful in future projects targeted at addressing chief JHT priorities.

4.2 Problems Encountered

Three problems were encountered by the University partner. The first problem was a technical problem. In its first iteration, the sixteen-member ensemble forecast system utilized 0-h NAM and GFS operational analyses for both initial and lateral boundary conditions. While such a methodology may be appropriate for retrospective, research-oriented applications, real-time mesoscale forecast systems must instead rely upon forecast data for lateral boundary conditions. Before proceeding with the forecaster exercise, the Operational partner encouraged us to investigate the sensitivity in the ensemble forecasts to the lateral boundary conditions. Finding sufficient sensitivity to impact the forecasts and, potentially, their interpretation, the ensemble forecast system was re-run in the appropriate configuration.

The second problem was an availability issue. Initially, we planned to visit WFO Tallahassee, FL twice, once each in Fall 2011 and Winter 2012. Unfortunately, however, teaching constraints prevented us from being able to travel to the WFO in Winter 2012. Nevertheless, we were able to make use of teleconferences and e-mail communication to accomplish the tasks that we had planned to accomplish in person, keeping this from impacting the conduct of our research.

The third problem was a financial issue. We were notified in April 2012 that NWS funding for publication press charges would not be available for FY12 (through 30 September 2012) and may not be available for FY13 (through 30 September 2013). Despite this limitation, which remains without resolution as of the preparation of this report, we plan to pursue the publication of our research findings using a combination of limited university funds and page charge waivers.

5. Presentations and Publications

Evans, C., 2012: Factors influencing extreme precipitation associated with Tropical Storm Fay (2008) across north Florida and southwest Georgia. *Abstract, 30th Conf. on Hurricanes and Tropical Meteorology*, Ponte Vedra Beach, FL, Amer. Meteor. Soc., P1.9.

Van Dyke, D. F., C. Evans, and T. Lericos, 2012: Convection-resolving ensemble-based forecasts of extreme precipitation associated with landfalling tropical cyclones: assessment of skill and utility in the operational forecasting process. *Abstract, 30th Conf. on Hurricanes and Tropical Meteorology*, Ponte Vedra Beach, FL, Amer. Meteor. Soc., 5C.1.

Van Dyke, D. F., C. Evans, and T. Lericos, 2012: How do forecasters utilize output from a convection-permitting ensemble forecast system? Case study of a high-impact precipitation event. Manuscript in preparation; to be submitted to *Wea. Forecasting*.

6. Summary of University/Operational Partner Interactions and Roles

The University partner took the lead role in accomplishing the following tasks:

- Assessing the physical processes responsible for the extreme rainfall observed with Fay.
- Developing the sixteen-member ensemble forecast system.

The Operational partner took the lead role in accomplishing the following tasks:

- Developing and executing the forecaster exercise.
- Obtaining the Stage-IV accumulated precipitations estimates used in ensemble evaluation.

The University and Operational partners worked collaboratively on the following tasks:

- Objectively evaluating ensemble characteristics (dispersion, etc.) and skill.
- Working together to determine the focus, scope, and goals of the forecaster exercise.
- Objectively and subjectively evaluating forecaster exercise results.

Collaboration between the University and Operational partners was two-pronged in nature. A one-week visit with the Operational partner by the University partner in late October 2011 promoted the determination of the focus, scope, and goals of the forecaster exercise. Otherwise, continual dialogue via e-mail and teleconference was used to discuss the division of labor, key research findings shortly after being obtained, and to provide an alternative perspective on the tasks being undertaken by each partner. We believe that this level of interaction proved instrumental to substantially accomplishing the stated objectives of this project despite the limitations encountered during its conduct.