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Partners or Cooperative Project: **Partners**

Project Title: **Improving Anticipation of the Influence of Upstream Convection on QPF**

UCAR Award No.: **COMET Outreach Project S06-58392**

Date: **21 December 2007**

Section 1: Summary of Project Objectives

This project is concerned with improving the understanding and anticipation of model quantitative precipitation forecast (QPF) biases during conditions of upstream convection (UC) in the southeastern U.S. The original motivation for this project stemmed from the M.S. thesis research of Kelly Mahoney, who identified differing model QPF biases during the analysis of two UC events. For a case of fast-moving convection (FC), the NAM exhibited a substantial positive QPF bias, whereas for a case with slow-moving convection (SC), the model under-predicted the precipitation amount in the downstream region. These two scenarios are illustrated in Fig. 1, taken from the Mahoney and Lackmann (2006) manuscript.

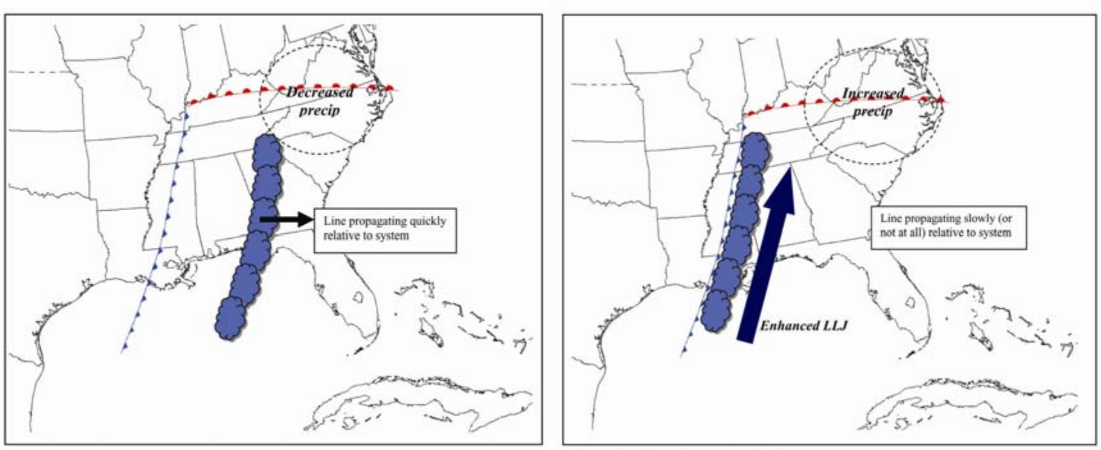

Fig. 1. Idealized schematics depicting relative location of upstream convection to synoptic-scale frontal boundaries: (a) fast-moving convection case; (b) slow-moving convection case.

Despite promising results from the two case-study analyses of Mahoney and Lackmann (2006), several additional tasks remained before these results could be utilized by operational weather forecasters. Most importantly, a larger sample of cases needed to be considered before these results could be generalized. A related goal was to build a large database of UC events with which to generate composites and look for operationally useful signals that forecasters could use to anticipate and correct model QPF biases for different UC scenarios. Our initial research focus was to seek ways to anticipate fast- or slow-moving UC prior to the event. As stated in the original proposal, our objectives were to:

(i) Undertake additional case study analyses with which to better illustrate environmental differences between fast and slow moving upstream convective scenarios;

(ii) Develop presentation materials, AWIPS procedures, and Weather Event Simulator (WES) case studies to assist forecasters in recognizing differences in the environments of fast and slow upstream convection;

(iii) Build a "bridge of understanding" connecting the model representation of atmospheric processes to operational weather forecasting. This involves further developing NWP training materials and VISIT sessions designed to familiarize forecasters with physical process limitations and convective representation in both operational and locally run NWP models so as to assist forecasters in model bias anticipation.

Section 2: Project Accomplishments and Findings

a.) Development of UC Database

Graduate student Christian Cassell, in collaboration with Gary Lackmann and Kelly Mahoney, went about the formidable and time-consuming task of identifying a large number of UC events between December 1999 and April 2007. Only cool season events were considered (from October through the end of April). The UC cases were identified using online radar imagery archives available from UCAR (http://locust.mmm.ucar.edu/case-selection/) and NCDC (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?WWNEXRAD~Images2). Events were required to have a contiguous area of upstream convection exceeding 40 dBz in this 2-km radar mosaic. The area of UC was required to form east of the Mississippi and west of the east coast of Georgia, and north of the Gulf coast and south of the Tennessee border (Fig. 2).

Figure 2. Schematic map of the defined UC region (rectangle), and area of precipitation averaging (circle).

The result of this painstaking process was the identification of 201 UC candidate events during this 8 year time period. The sheer size of this database ensures that statistically significant results can be obtained even for sub-samples of the case archive. Another result that is immediately apparent is that UC events are a common forecasting problem for this region, with an average of ~4 events per month.

Various statistics were computed for each case in the database, including an estimation of the speed of the UC, in keeping with our hypothesis and primary objective of providing forecasters with guidance in determining the environmental factors that related to the speed of the UC, and also to check the sign of model precipitation biases for the collective set of cases. This laborious task also fell to Christian Cassell, who used distance calculations in conjunction with radar imagery to estimate this speed. In addition, Christian used NARR sea-level pressure fields to compute front-relative speeds for the convection; this was also related to the hypothesis developed from the initial case studies of Mahoney and Lackmann (2006).

b.) Gridded fields and composites

For each of the cases, a set of gridded analyses spanning the time of the event was required, in order to allow the construction of composite fields. The North American Regional Reanalysis (NARR) dataset, with 32-km grid spacing, is well suited to this task as it has sufficient resolution to provide mesoscale details of the important patterns and processes for UC events. Some of these data were in place, but most were not, and Christian Cassell downloaded the NARR grids for the period spanning the UC case inventory, and converted these grid files into GEMPAK format for plotting and analysis.

Next, in order to check the model biases for large samples of cases, we needed model gridded QPF data for as much of the case sample as possible. Of course, there is a major challenge in that the operational NCEP models, such as the NAM and GFS, have changed in configuration during the time period for the UC database. This is especially important in the case of the NAM, which changed from the Eta model to the WRF-NMM in June, 2006. However, the problems with model representation of organized convection are suspected to be due in part to the use of convective parameterization (CP) schemes, and are strongly resolution dependent. The NAM still makes use of the Betts-Miller-Janjic CP scheme, even though the model core changed significantly. Nevertheless, we thought it would still be insightful to compare the NAM QPF for various samples of UC events to the NARR precipitation analysis. The NAM forecasts were obtained for all of the UC events either from an in-house archive or from the Iowa State GEMPAK archive; these forecasts were stored on the WMO 211 grid, which features ~80-km grid spacing.

c.) Composite analyses and results

A large number of different composite stratifications have been undertaken for this project, many with differing objectives. In keeping with our original hypothesis that fast UC cases would tend to produce less precipitation and a positive model bias relative to those with slow-moving UC, we composited the cases with the fastest observed UC speed relative to those with the slowest. The results were unexpected: (i) the composite fields for the fast and slow convection samples appeared to be very similar (not shown); (ii) the amount of precipitation that fell in the downstream region (computed for a circle of 200-km radius centered near Raleigh, NC using NARR data) was not appreciably different between the fast and slow case samples (not shown).

This finding was not entirely contradictory to previous results, as we did not compute the model biases for these events. However, it necessitated a more important preliminary question of utmost importance to operational forecasters: What environmental characteristics were most important for heavy or light precipitation in the downstream region during UC events? In order to address this question, a composite was constructed from the 20 wettest and 20 driest events in order to seek distinguishing characteristics for these events. Figure 3 presents the dry and wet composite sea level pressure and 500-hPa geopotential height fields for 24-h prior to the onset of UC.

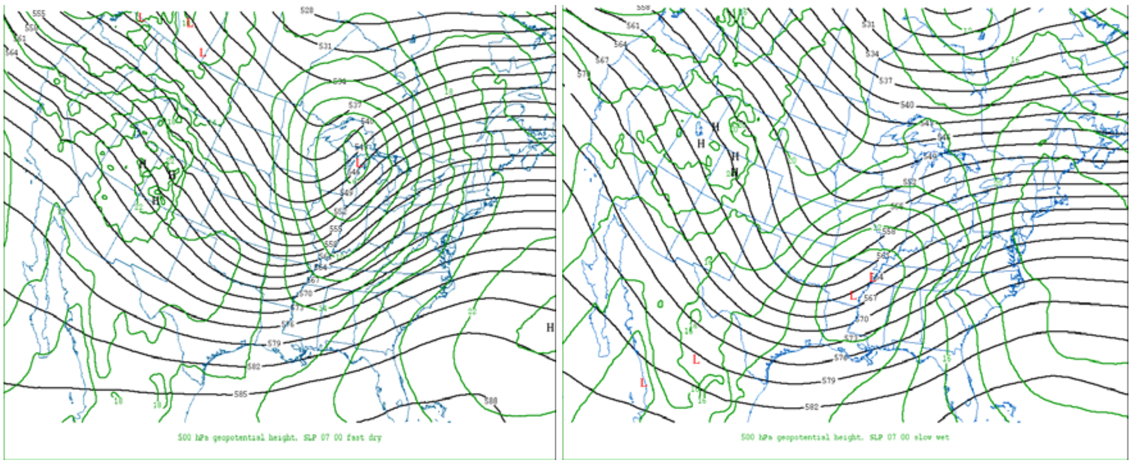

Figure 3: Composites for (a) the 20 driest UC events in downstream region, and (b) for the 20 wettest: 500-hPa geopotential height (interval 3 dam) and sea-level pressure (green contours, interval 2 hPa).

A critical result to be derived from Fig. 3 is the presence of the “Atlantic feed” in the wet cases, along with much stronger warm advection (evident from the strong geostrophic veering) over the southeastern US. We interpret this to mean that when UC is present, for heavy precipitation to occur in the circled region of Fig. 2, a compensating moisture transport mechanism (the Atlantic moisture feed) and strong quasigeostrophic forcing for ascent are present over the study region. The weaker forcing and lack of Atlantic moisture transport are clearly evident in Fig. 3a.

Important operational results here are that (i) if Atlantic moisture can enter the downstream region in the presence of strong forcing, heavy rain will still occur, and (ii) the speed of the UC is perhaps less critical than originally hypothesized in determining the absolute amount of downstream precipitation. These results were presented at the AMS WAF/NWP conference in Utah during July, 2007 (Cassell et al. 2007).

However, the question remained as to the model QPF biases, which was the original objective of the study. Therefore, we undertook a comparison of the model QPF and the NARR analyzed precipitation for each of the events. To simplify the analysis, we utilized the area-averaged precipitation values for the circle shown in Fig. 2, for both model forecasts and NARR analyses. In computing the overall statistics, it was evident that for UC events, the sign of the cumulative model bias over all the events was positive.

However, there were a significant number of events with both positive and negative bias. By generating composites of the cases with the largest positive bias versus those with the largest negative bias, further insight into the processes and patterns associated with differing error sign for the model was derived.

Figure 4 compares composites obtained from the 10 largest negative QPF bias events (Fig. 4a) with those from the largest positive bias events (Fig. 4b). Striking differences exist in the composites, including (i) the presence of a more northerly low pressure system in the negative bias cases, and (ii) a clear signature of cold-air damming (CAD) in the positive bias cases. It is interesting that the positive bias composite resembles the “wet UC case” composite, indicating that model QPF bias may be largest in cases where the signals are in place for a heavy precipitation event. The negative bias cases do not exhibit a prominent Atlantic moisture feed, but they do exhibit geostrophic veering (warm advection) between the southeastern U.S. and New England.

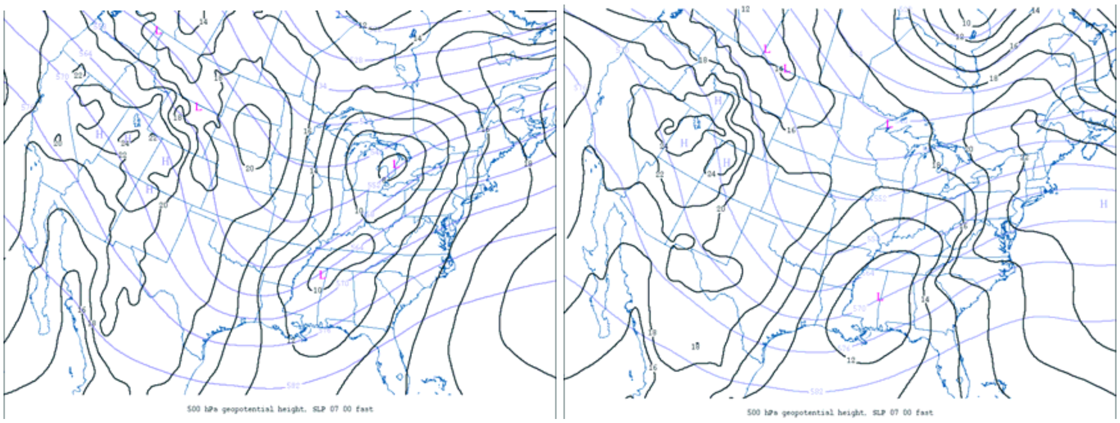

Figure 4: Composite 500-hPa geopotential height (light blue) and sea level pressure (black, interval 2 hPa) for (a) the 10 largest negative model QPF bias cases, and (b) the 10 largest positive model QPF bias cases .

d.) WRF composite initial conditions

During the course of this research project, an idea came to light regarding the use of composites as representative examples of a given phenomenon. If a composite field was used to initialize a high-resolution mesoscale model, such as the Weather Research and Forecasting (WRF) model, then a pseudo-idealized simulation could be obtained which would serve as a “super case study” with which to analyze the event dynamics in higher detail, and to produce model forecasts and conduct additional experiments.

Using the composites for fast UC and slow UC, we initialized two different WRF simulations. By comparing the behavior of convection between these two model runs, we would then be able to determine if a useful signal concerning the character of convection was in fact contained within the composite grids.

WRF simulations based on composites for the 20 fastest and 20 slowest UC events were conducted using a 12km/4km outer-inner domain, with the Kain-Fritsch convective parameterization used only on the outer domain. The lower boundary was made uniform, and the simulation was run for 48 hours, initialized prior to the onset of convection in the composite samples.

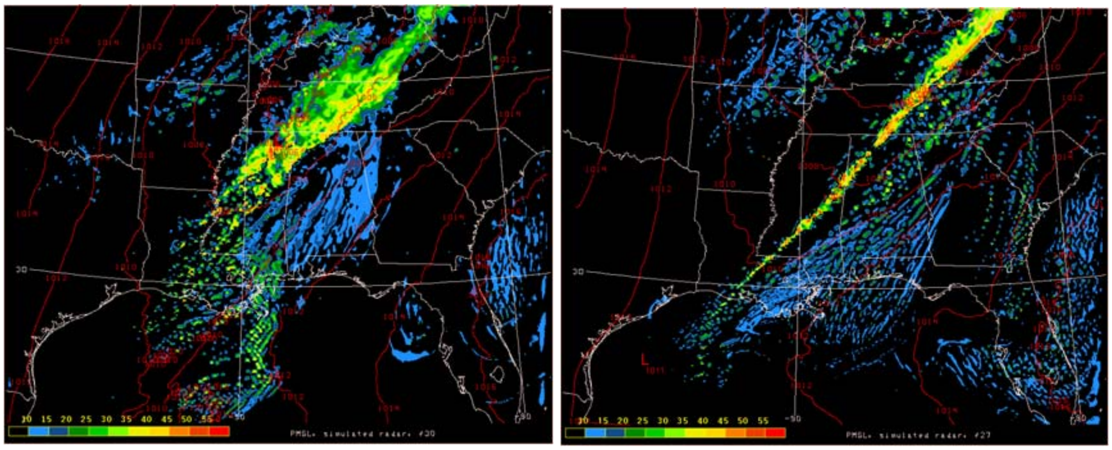

Figure 5. WRF simulated reflectivity for hour 27 of the model runs for (a) fast-convection composite initialization, and (b) slow-convection composite initialization.

As evident in Fig. 5, there is some tendency for precipitation corresponding to the UC to move eastward more quickly in the Gulf of Mexico, but the differences farther north are not striking. The similarity of these composites led us to reconsider the approach used in generating the composites.

More important implications of these results include: (i) this technique represents a novel tool for event and phenomenological analysis that could be extended to many other research problems, and (ii) this provides an excellent test of whether significant results exist between two composite samples. We plan to develop this idea further, and perhaps publish a note in an AMS journal discussing the potential utility of this technique in other studies.

e.) Other activities, accomplishments, and findings

This project has supported M.S. student Christian Cassell for 1 year of his thesis work, and this has allowed the development of a powerful database with which to better understand UC and QPF in the southeastern and Mid-Atlantic region of the U.S.

In keeping with objective (iii) listed above, Gary Lackmann presented a VISIT session on numerical weather prediction (NWP) to several forecast offices in the NWS Eastern Region on 3 November 2006. Twelve different NWS offices participated, with 62 individuals attending (Jonathan Blaes, personal communication 2006). The VISIT session on 3 November 2006, entitled “Model Precipitation Mechanisms”, is available for download from: http://www.meas.ncsu.edu/nws/www/colab/.

A conference publication (Cassell et al. 2007) was presented at the AMS WAF/NWP conference in Park City, Utah (see section 5).

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

List the benefits to the NWS office from the collaboration and any significant lessons learned during the study. Please be as specific as possible, particularly in regard to any improvements in forecasting resulting from the COMET project (see examples). Identify any major problems encountered and describe their resolution.

The initiation of this study produced an increased awareness of this particular forecast problem at WFO RAH. Forecasters were initially exposed to the project and related research during a presentation at the winter (cool season) familiarization sessions held in November 2006. As awareness of the impact of deep upstream convection increased, forecasters have become more cognizant of synoptic and mesoscale patterns that dictate the evolution of deep convection and its implication on precipitation.

Forecasters are becoming increasingly aware of the potential impact that an Atlantic feed of moisture has on downstream precipitation. Recognition of the need for stronger quasigeostrophic forcing when upstream convection is ongoing is another factor that forecasters are now noting. As discussed in part C of section 2, if Atlantic moisture can enter the downstream region in the presence of strong forcing, heavy rain will likely still occur. In addition, forecasters will need to note that the speed of the upstream convection does not appear to be as critical to downstream precipitation as previously thought. Finally, the existence of the Atlantic moisture transport and forcing does not preclude model guidance from having a significant positive model bias. These items are obviously of great value to the operational forecaster and form the basis of an upstream convection conceptual model for precipitation forecasting.

This collaboration continues to stimulate real time discussion among various WFOs and researchers on the CSTAR list server about significant events, making forecasters much more sensitive to the issue of QPF in environments downstream from deep convection. (A list server operates mailing lists and distributes new messages, newsletters, or other postings from list members to a list of subscribers. The list server was developed to support various collaborative research projects between the NWS and NCSU.) Discussions on the list server have included over 10 WFO's and RFC's from Virginia across the Carolinas and Georgia, the Hydrologic Prediction Center and the NWS Eastern Region SSD.

AWIPS forecast procedures that allow for easy application of the research results are being finalized. Initial versions of these procedures have already helped forecasters diagnose the effects of upstream convection and examine low level Atlantic moisture flux and quasigeostrophic forcing that can impact downstream precipitation. These procedures along with supporting documentation will be shared with other NWS offices once they are completed this cool season.

A critical component in the sharing and implementation of the results of this project will be with the delivery of a VISIT tele-training session. Recent VISIT sessions resulting from NCSU-NWS collaborative efforts have been very well received with positive results. The VISIT session not only shares the important findings and operation impact of this investigation but it promotes continued investigation with real-time time evaluation and discussion on the CSTAR list server during events in the future.

This project has provided an opportunity to reconnect forecasters with the numerical weather prediction (NWP) guidance they use. The VISIT session on NWP was excellent and allowed forecasters to get a better understanding of how the model configuration is critical in NWP output. In the current era where NWP with parameterized and explicit convection is available to forecasters, this is extremely important.

In addition, numerous cases have been archived from AWIPS producing a large local case archive available to the NWS for use on the Weather Event Simulator (WES) for analysis, case study review, and procedure development.

The process and mechanism to archive cases for later review on the WES can be somewhat laborious and time consuming. In addition, the archiving hardware and software on AWIPS are not thoroughly supported and the local WFO is typically responsible for its maintenance. While most of the analysis of past events is being conducted by NCSU, it is important for some cases to be available in the WES for training and study in software used by forecasters at WFO RAH. Long tem national support and vision for this valuable resource to the WFO is needed.

Section 4: Benefits and Lessons Learned: University Partner Perspective

The university derives considerable benefit from all collaborative activities with the WFO Raleigh, including the open house and intern course mentioned in Section 6 below. Many of our students are inspired by these experiences to pursue careers in the NWS, and some aspire to graduate school research projects relating to operational forecasting. These activities provide our students with experience and knowledge beyond what can be delivered in a classroom setting.

More specifically to the COMET project, this grant provides financial support to graduate student Christian Cassell, who is working with Gary Lackmann and Kelly Mahoney to best implement the results of Kelly's previous M.S. thesis research into operations.

Section 5: Publications and Presentations

Presentations:

Gary Lackmann presented a VISIT session on numerical weather prediction (NWP) to several forecast offices in the NWS Eastern Region on 3 November, 2006. Twelve different NWS offices participated, with 62 individuals attending (Jonathan Blaes, personal communication 2006). This VISIT session, entitled "Model Precipitation Mechanisms", is available from: http://www.meas.ncsu.edu/nws/www/colab/.

Once staffing situations allow it, we are planning to present the most recent results of this research to the regional NWS offices via another VISIT session in the coming months.

Publications:

Mahoney, K. M., and G. M. Lackmann, 2007: The Effect of Upstream Convection on Downstream Precipitation. *Wea. Forecasting*, **22**, 255–277.

Mahoney, K. M., 2005: The effect of upstream convection on downstream precipitation. M.S. thesis, Dept. of Marine, Earth, and Atmospheric Sciences, North Carolina State University, 204pp.

——, and G. M. Lackmann, 2005: The effects of organized upstream convection on downstream precipitation. *Extended abstracts, 21st Conference on Weather Analysis and Forecasting/17th Conference on Numerical Weather Prediction*, Washington, DC, Amer. Meteor. Soc., 3.1.

Cassell, C. M., G. M. Lackmann, K. M. Mahoney, R. Gonski, G. Hartfield, and J. Blaes, 2007: Improving anticipation of the influence of upstream convection on downstream precipitation. *Extended abstracts, 22nd Conference on Weather Analysis and Forecasting/18th Conference on Numerical Weather Prediction*, Park City, Utah, Amer. Meteor. Soc.

Section 6: Summary of University/Operational Partner Interactions and Roles

In developing the case-selection criteria, and for an inventory of diagnostic notes for each case, Christian has frequently consulted with Gary Lackmann and Kelly Mahoney (NCSU) for details. We have held periodic meetings with Gail Hartfield, Jonathan Blaes, and Rod Gonski of WFO RAH to double check our procedures, and obtain input on how to guide the research in a way that maximizes operational utility.

WFO Raleigh has developed AWIPS procedures, based on preliminary research results and hypotheses, that assist forecasters in the detection of possible cases of reduced QPF from upstream convective processes. They have also provided invaluable feedback on the case selection process.

Christian Cassell has taken on the most labor-intensive aspects of this project with regard to the case selection, but with consultation and feedback from all parties. Gary Lackmann undertook the VISIT session preparation, with abundant assistance from Jonathan Blaes, Gail Hartfield, and Rod Gonski. The NWS involvement was to help focus the material in the VISIT session in a way that increased relevance for forecasters.

An overview of the forecast problem and an introduction to the investigation was presented at the winter (cool season) familiarization sessions held in November at WFO RAH.

Various WFOs in the mid Atlantic have participated in active discussions of this forecast problem on the CSTAR list server. The interest in this forecast problem is obvious and the discussions continue to foster a collaborative "community" between NCSU and WFOs in the Mid Atlantic.

WFO RAH hosted an open house in October for students in the Department of Marine, Earth, and Atmospheric Sciences at NCSU. A team of 7 forecasters participated in the open house with over 40 students taking advantage of the opportunity. Although this function was not a direct result of the COMET project, it was related in that it is part of the larger sense of collaboration taking place between NCSU and WFO RAH. http://www.erh.noaa.gov/rah/news/content/MEAS.open.house.20061019.html