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THE EFFECTS OF ORGANIZED UPSTREAM CONVECTION ON DOWNSTREAM PRECIPITATION: PHYSICAL PROCESSES AND MODEL REPRESENTATION

Kelly M. Mahoney[+] and Gary M. Lackmann
North Carolina State University, Raleigh, North Carolina

1. INTRODUCTION

As communicated by National Weather Service (NWS) forecasters in the Southeast US and ongoing case-study research, past events have demonstrated a weakness in the ability of numerical weather prediction (NWP) models to accurately represent the effects of upstream convection (UC) on quantitative precipitation forecasts (QPF) downstream of the convection in some instances. This weakness appears to be especially pronounced for cases featuring quickly-moving upstream mesoscale convective systems (MCSs). NWS forecasters have cited examples in which NWP model forecasts significantly overpredicted QPF in portions of the Carolinas and Virginia when convection was present south or southwest of the region. While cases of QPF *under*prediction in the downstream region have been documented (Mahoney 2005), the problem of QPF *over*prediction will be the principal focus here.

The objectives of this study are to: (i) identify the physical processes through which downstream precipitation may be altered by the presence of UC; (ii) understand why operational models are challenged to produce an accurate downstream forecast in the presence of quickly-moving UC; (iii) investigate optimal model configurations for the representation of UC, and; (iv) find ways in which human forecasters may anticipate and correct model biases during UC events.

2. SOURCE OF MODEL QPF ERRORS

Initial examination of several UC cases led to the finding that environments featuring UC that moved quickly relative to the main synoptic system often led to downstream NWP model QPF overpredictions (Fig. 1). These overpredictions appear to be mainly attributable to model error in the movement of the UC feature itself (Mahoney 2005). Model experiments show that integrations employing a convective parameterization (CP) scheme and run at relatively coarse resolutions do not accurately represent the convective system motion, often leading to overpredicted northward moisture flux and precipitation amounts in the downstream region.

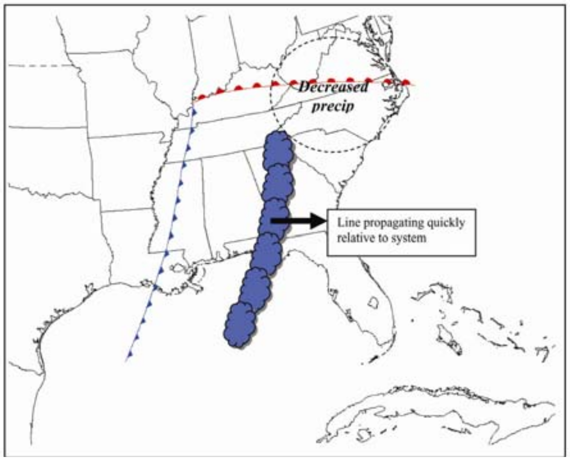

Figure 1. Schematic of downstream QPF overprediction.

3. DEC 2002 CASE STUDY AND MODEL EXPERIMENTS

The case of downstream QPF overprediciton was explored by analyzing an event that occurred on 31 Dec 2002, in which a rapidly-moving MCS tracking eastward along the coast of the Gulf of Mexico raced out ahead of the surface cold front (Fig. 2).

Operational model QPF errors were in excess of 35 mm in the downstream region across western and central SC/NC/VA, a significant model QPF

[+] *Corresponding author address:* Kelly M. Mahoney, North Carolina State University, Dept. of Marine, Earth and Atmospheric Sciences, Raleigh, NC 27695. E-mail: kmmahon2@ncsu.edu overprediction (Fig. 3). Given that other synoptic features in this forecast were well-represented (*not shown*), it was hypothesized that the fast-moving squall line featured in this case somehow impeded precipitation from falling where it was forecast to do so. Reasons for the positive QPF bias in the operational Eta model forecast were explored using numerical model experiments.

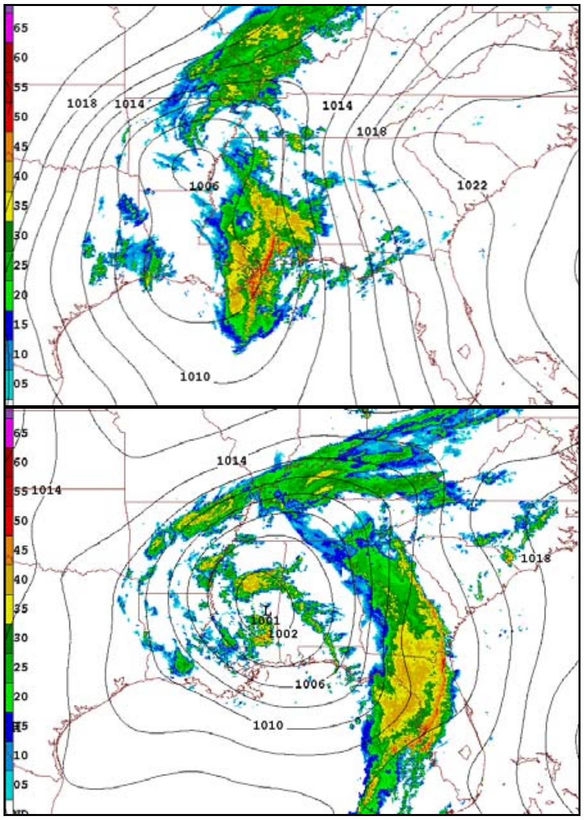

Figure 2. (top) Radar reflectivity and EDAS sea-level pressure analysis (interval 2 hPa) valid 12 UTC 31 Dec 2002; (bottom) as in (top) except valid 00 UTC 1 Jan 2003.

A 4-km convection-resolving WRF model forecast was performed for this case, and it was found that both its representation of the UC, as well as its downstream QPF, were superior to any of the model runs that had been performed at coarser resolutions and with the use of a CP scheme (Figs. 3, 4). The WRF model forecast better represented the structure, location, and movement of the UC relative to the Eta forecast (despite still being slightly too slow with respect to the system's eastward movement) (cf. Figs. 2, 4). Comparing low-level flow and moisture flux analyses to the operational Eta and 4-km WRF forecasts suggests that the UC did act to suppress moisture transport to the north of the system (Fig. 5). This aspect of the forecast was greatly misrepresented in the operational Eta model forecast, in addition to a UC feature that moved too slowly relative to the observed MCS.

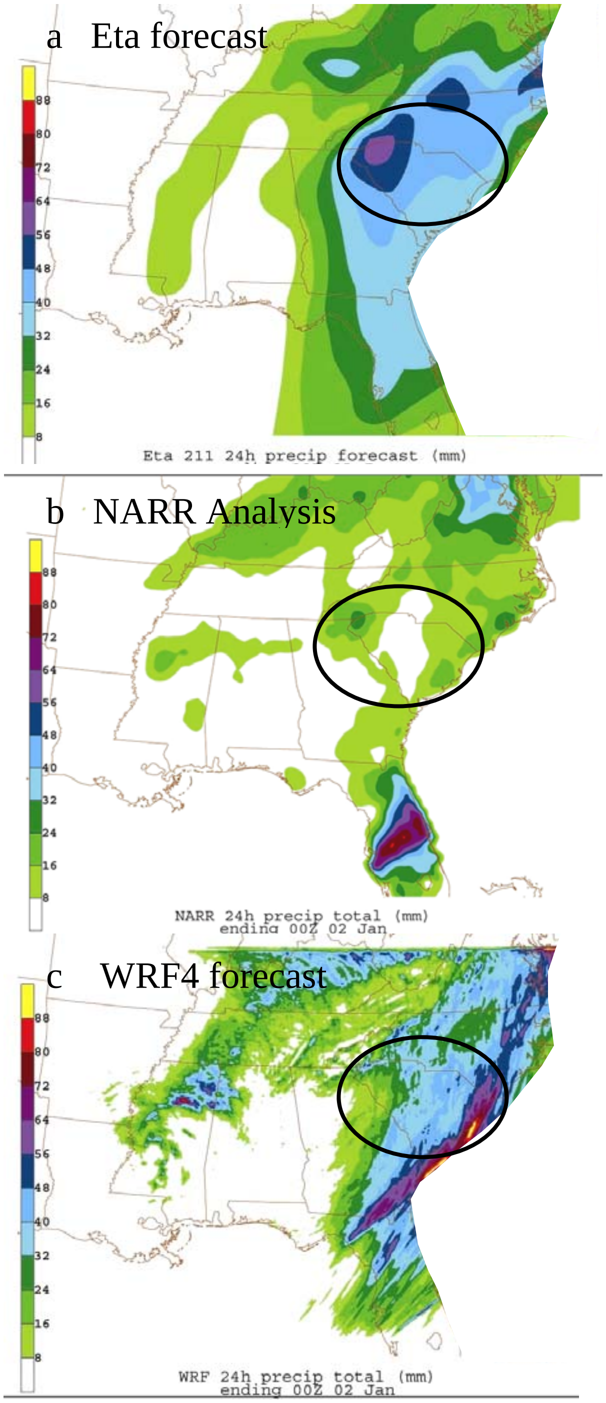

Figure 3. (a) 24-h Eta model forecast total QPF ending 00 UTC 02 Jan (mm, shaded as in legend at left of panel); (b) as in (a) except NARR analysis; (c) as in (a) except for WRF4 forecast. Black oval marks downstream region of interest. Model data over Atlantic has been masked to facilitate comparison with NARR dataset.

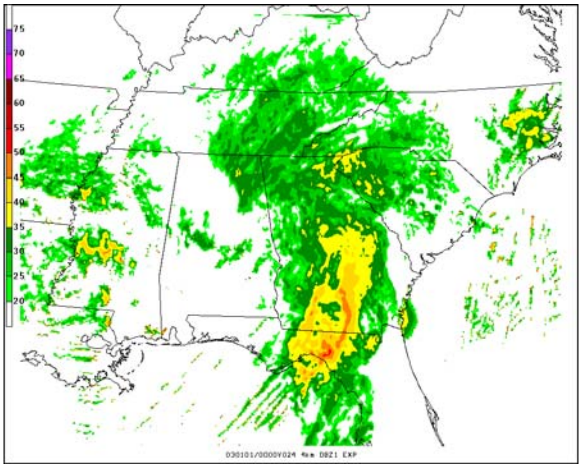

Figure 4. WRF4 simulated reflectivity (dBz, shaded as in legend at left of panel), valid 00 UTC 1 Jan.

The decreased downstream moisture in the analyses and WRF forecast are consistent with the reduced downstream precipitation amounts observed via the moisture removal mechanism. It is noteworthy that only the model run performed without a CP scheme and at a sufficiently small grid-spacing to resolve convective motions was able to significantly improve the downstream QPF. This finding suggests that perhaps (i) CP scheme limitations may inherently inhibit accurate forecasts of convective system motion and the QPF of their associated downstream environments in some quickly-moving UC situations, or (ii) the higher resolution employed in convection-resolving model forecasts allows a more realistic representation of the MCS motion.

Because the MCS moved too slowly in model forecasts that used a CP scheme, here we hypothesize that the omission of physical features and processes such as cold pool dynamics and momentum redistribution by many operational NWP model CP schemes may preclude accurate forecasts of convective system motion. The role of these processes in MCS movement is widely acknowledged, and detailed in many previous studies, e.g., Rotunno et al. (1988), Corfidi (2003) and Houze (2004). The importance of model representation of cold pool dynamics and momentum redistribution is supported by preliminary results that reveal significant differences in the handling of such features by the Eta and WRF model forecasts (Fig. 6), results that are also corroborated by the findings of Davis et al. (2003) and Done et al. (2004). Figure 6 shows that the high-resolution WRF forecast more clearly represents a lower-tropospheric cold pool below the main updraft along the leading edge of the UC line, whereas in the Eta forecast this feature is absent. These initial findings support the hypothesis that accurate downstream QPFs may be dependent upon the model representation of cold pool structures and low-level momentum fields in the presence of quickly-moving UC.

4. APPLICATIONS

The results of this study may be useful to those in the operational forecasting community striving to improve QPFs in situations involving deep convection upstream of a given region. For example, indicators such as a digging upper-level trough, katafront characteristics, strong upper-level westerlies, and bowing segments in the UC features have been identified as potentially useful signals that may aid forecasters in identifying cases of possible QPF overprediction (Mahoney 2005).

Additionally, this study also holds implications for applied NWP. At a time when NWP is moving toward ensemble forecast systems, decisions must be made regarding how to best use available computational resources (Roebber et al. 2004). That is, the question of whether to utilize computer resources to produce a small number of high-resolution, convection-resolving forecasts, versus a large ensemble of lower-resolution forecasts remains open for debate. The results presented here suggest that for UC cases featuring fast-moving convective systems, high-resolution, convection-resolving forecasts may best be able to realistically predict convective system movement as well as the physical processes necessary for accurate downstream QPFs. While ensembles of high-resolution, convection-resolving model forecasts are likely the ideal solution, computational limitations dictate that a choice between the two options will continue to be necessary, at least in the near future.

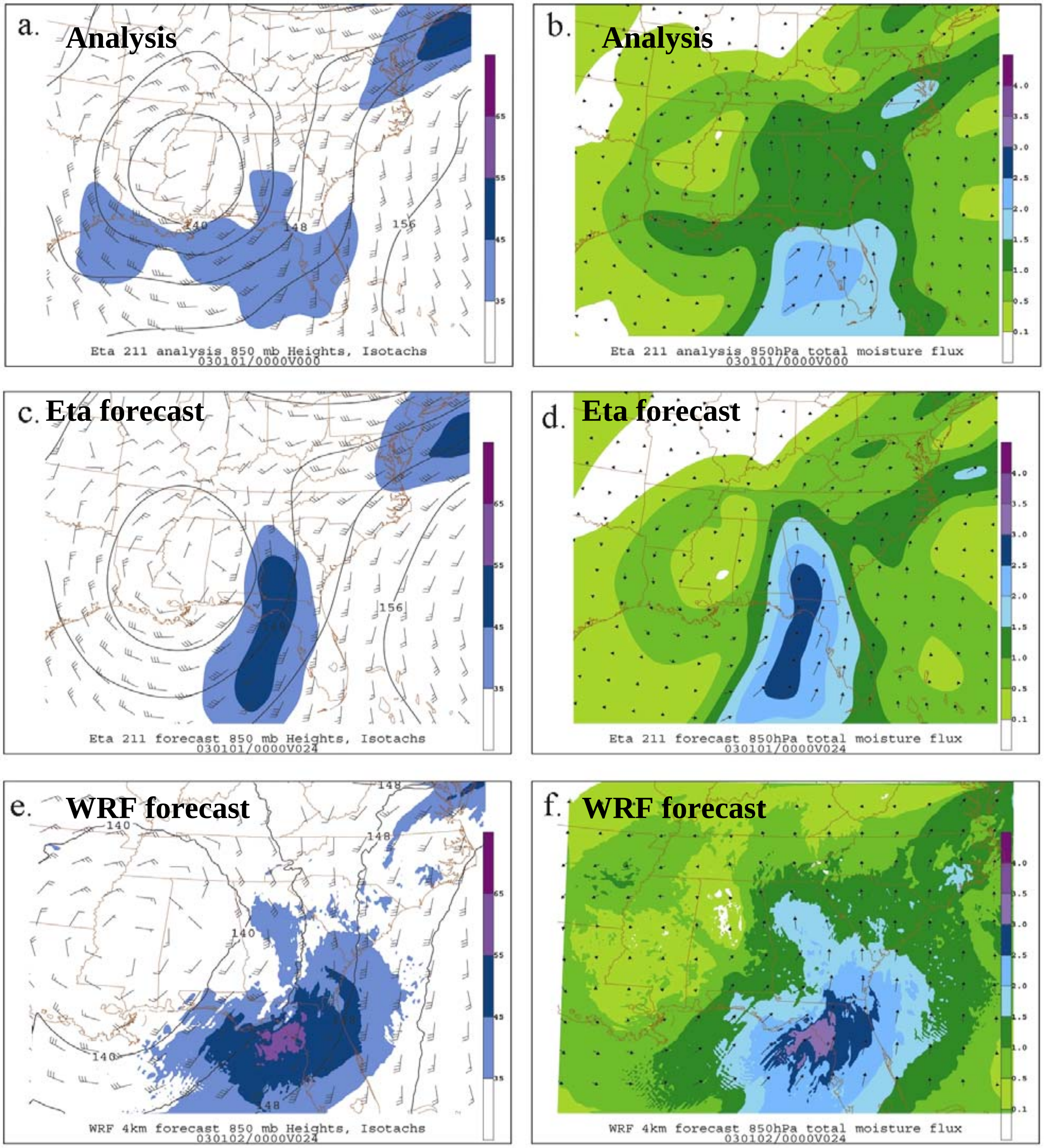

Figure 5. (a) 850-hPa Geopotential height (solid contours, interval 4 dam), 850-hPa winds (kt, barbs), and 850-hPa isotachs (kt, shaded as in legend at right of panel) for Eta analysis valid 00 UTC 1 Jan; (b) 850-hPa moisture flux magnitude (g kg^{-1} m s^{-1}, shaded as in legend at right of panel) and moisture flux vectors (arrows) for Eta analysis valid 00 UTC 1 Jan; (c) as in (a), except for 12-h Eta forecast; (d) as in (b), except for 12-h Eta forecast, (e) as in (a), except for 12-h WRF4 forecast, (f) as in (b), except for 12-h WRF4 forecast

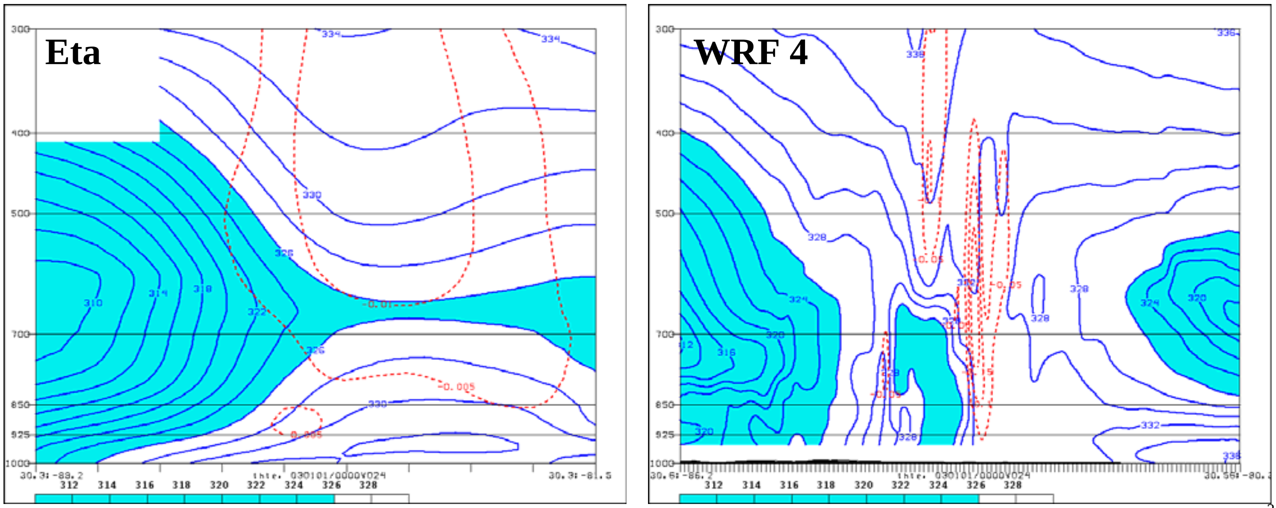

Figure 6. (left) Eta cross-section normal to UC feature valid 00 UTC 01 Jan 2003, omega (red, dashed contours, every 5 x 10^{-3} mb/s), equivalent potential temperature (blue contours, every 2K, shaded below 328K), (right) as in (left) except for 4-km WRF forecast and omega intervals every 5 x 10^{-2} mb/s.

5. CONCLUSIONS AND FUTURE WORK

This preprint summarizes the results of an initial investigation into the problem that deep UC poses to downstream precipitation forecasts in the Southeast US. While UC has also been found to be capable of *increasing* the downstream precipitation relative to model forecasts, the more common scenario of downstream QPF *over*prediction in the presence of fast-moving UC has been .emphasized here.

In the 31 Dec 2002 case study, operational model forecasts inadequately represented the speed of eastward motion of the UC, thereby allowing moisture transport into the downstream region (and precipitation there) to be over-predicted. A 4-km convection-resolving WRF forecast more accurately represented the rapid eastward UC movement, moisture transport and precipitation. Preliminary investigation of differences in the representation of the lower-tropospheric cold pool in the high-resolution WRF forecast and the Eta forecast suggest that convective processes either poorly accounted for or neglected by CP schemes (e.g. cold pool dynamics and the redistribution of momentum) may be critical for an accurate forecast of fast-moving UC and downstream QPF. Future work in this area is underway.

6. ACKNOWLEDGEMENTS

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