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THE EFFECTS OF ORGANIZED UPSTREAM CONVECTION ON DOWNSTREAM PRECIPITATION

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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. In response to such cases, conventional forecaster wisdom has evolved such that NWP model QPF in the downstream area is generally *reduced* by human forecasters to compensate. However, while many scenarios indeed exhibit reduced downstream precipitation, some studies have found that other UC scenarios may actually result in *enhanced* moisture transport to the downstream region, thereby increasing precipitation amounts (Whitaker et al. 1988; Lackmann et al. 1998; Lackmann 2002; Brennan and Lackmann 2005).

The objectives of this study are to approach the UC problem in the following ways: (i) identify the physical processes by which the downstream precipitation may be altered by the presence of UC; (ii) distinguish UC cases in which downstream precipitation is *enhanced* from those in which it is *reduced*; iii) understand why operational models are challenged to produce an accurate downstream forecast during UC; (iv) identify synoptic settings associated with different types of UC events; (v) find ways in which human forecasters may anticipate and correct model biases during UC, and; (vi) investigate optimal model configurations for the representation of UC.

2. PHYSICAL PROCESSES AND SCENARIOS

A brief climatology of Eta model QPF error was conducted in order to identify several UC cases as in-depth case-study candidates. Based on preliminary investigation of these cases in collaboration with NWS forecasters, the UC problem was divided into three scenarios in which different QPF biases were generally observed. These three major scenarios are characterized by the orientation and movement of the UC, and each was hypothesized to have a different downstream QPF error implication. In addition to these three scenarios, various physical processes were investigated for their potential role in downstream model QPF errors. The following mechanisms were hypothesized to play a possible role in the alteration of the downstream environment:

(i) moisture consumption (removal of moisture prior to its transport into the downstream area);
(ii) stabilization of downstream environment (elimination of instability in a way that reduces post-system or downstream convective precipitation, or leads to reduction of downstream synoptic-scale ascent);
(iii) alteration of lower-tropospheric moisture transport through interruption or enhancement of the low-level jet (LLJ); and
(iv) alteration of synoptic dynamics (e.g., downstream upper ridge building via latent heat release (LHR), alteration of synoptic forcing for forced ascent).

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Scenario 1 (S1) is characterized by UC that is oriented parallel to low-level flow, and the convection propagates quickly relative to the primary system, in a direction perpendicular to the lower-tropospheric flow (Fig. 1). Through possible mechanisms such as moisture removal, stabilization of the downstream environment, or inaccurate MCS movement in the model forecast, these cases were observed to often show decreased downstream precipitation relative to the model QPF (a positive model QPF bias).

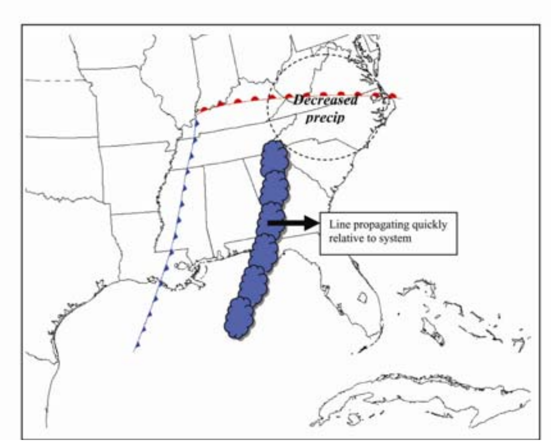

Figure 1. Scenario 1 schematic

Scenario 2 (S2) features UC that is oriented parallel to the mean flow as in S1, but that propagates slowly (or not at all) with respect to the primary system (Fig. 2). It is believed that a diabatically-enhanced low-level jet (LLJ) would act to enhance moisture transport ahead of such a system, and these cases were therefore hypothesized to yield increased downstream precipitation amounts, albeit with smaller errors.

A third scenario involving elevated, warm-frontal convection has also been documented, but is omitted here.

While the results of this study do not unambiguously identify which process is most important to a particular scenario, results from the case studies do demonstrate significant differences in the physical alteration of the downstream environment for each event. Two UC events were chosen to represent S1 and S2. Each was examined from an observational and modeling perspective in order to gain insight into the specific processes that resulted in the downstream model QPF error for each respective scenario.

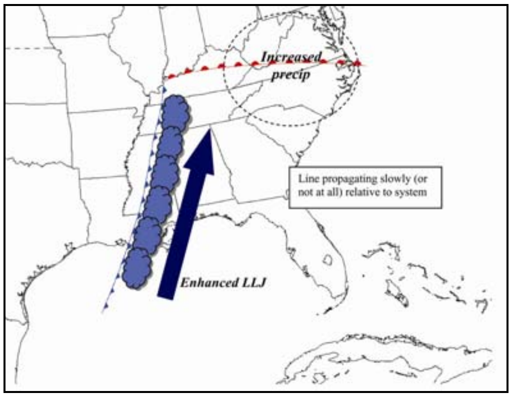

Figure 2. Scenario 2 schematic

3. SCENARIO 1 CASE STUDY

S1 was explored by analyzing an event that occurred on 31 Dec 2002, in which a rapidly-moving MCS moving eastward along the coast of the Gulf of Mexico raced out ahead of its associated surface cold front (Fig. 3).

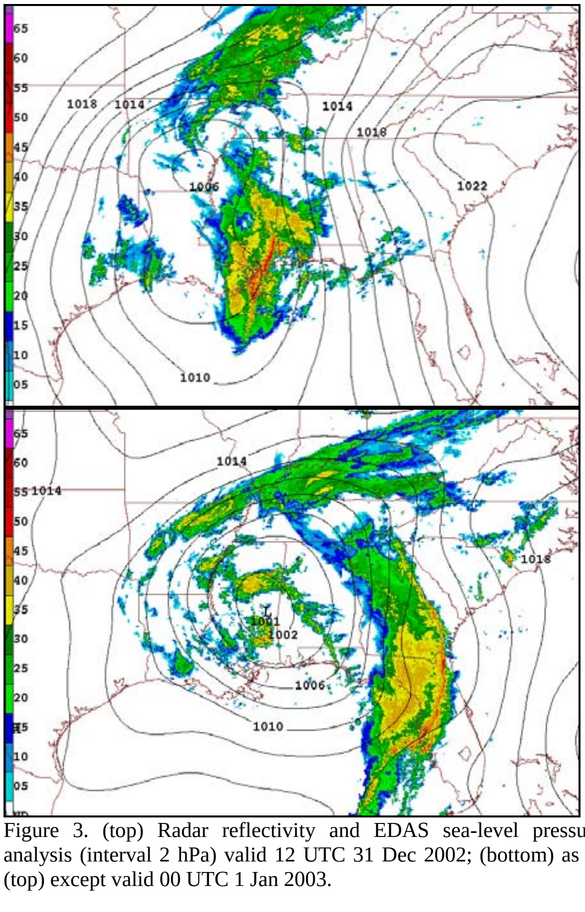

Figure 3. (top) Radar reflectivity and EDAS sea-level pressure analysis (interval 2 hPa) valid 12 UTC 31 Dec 2002; (bottom) as in (top) except valid 00 UTC 1 Jan 2003.

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 overprediction. As this event exemplifies the S1 schematic, it was therefore hypothesized that the fast-moving squall line featured in this case somehow impeded precipitation from falling where it was forecast to do so, given that other synoptic features in this forecast were well-represented (not shown). Reasons for the positive QPF bias in the operational Eta model forecast were explored using numerical model experiments.

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 lower resolutions using a convective parameterization (CP) scheme (Fig. 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. 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 motion was able to significantly improve the downstream QPF. This finding suggests that CP schemes may inherently inhibit accurate forecasts of convective system motion and the QPF of their associated downstream environments in some S1 situations. Because the MCS moved too slowly in model forecasts that used a CP scheme, here, we speculate that that the omission of a physical process such as momentum adjustment in CP schemes may preclude accurate forecasts of convective system motion. Further investigation of this problem is beyond the scope of the present study but is part of ongoing investigation. The S1 case study findings support the hypothesis that quickly-moving UC can act to decrease moisture in the downstream region, and thereby reduce downstream precipitation amounts relative to those forecasted by numerical models that use CP schemes.

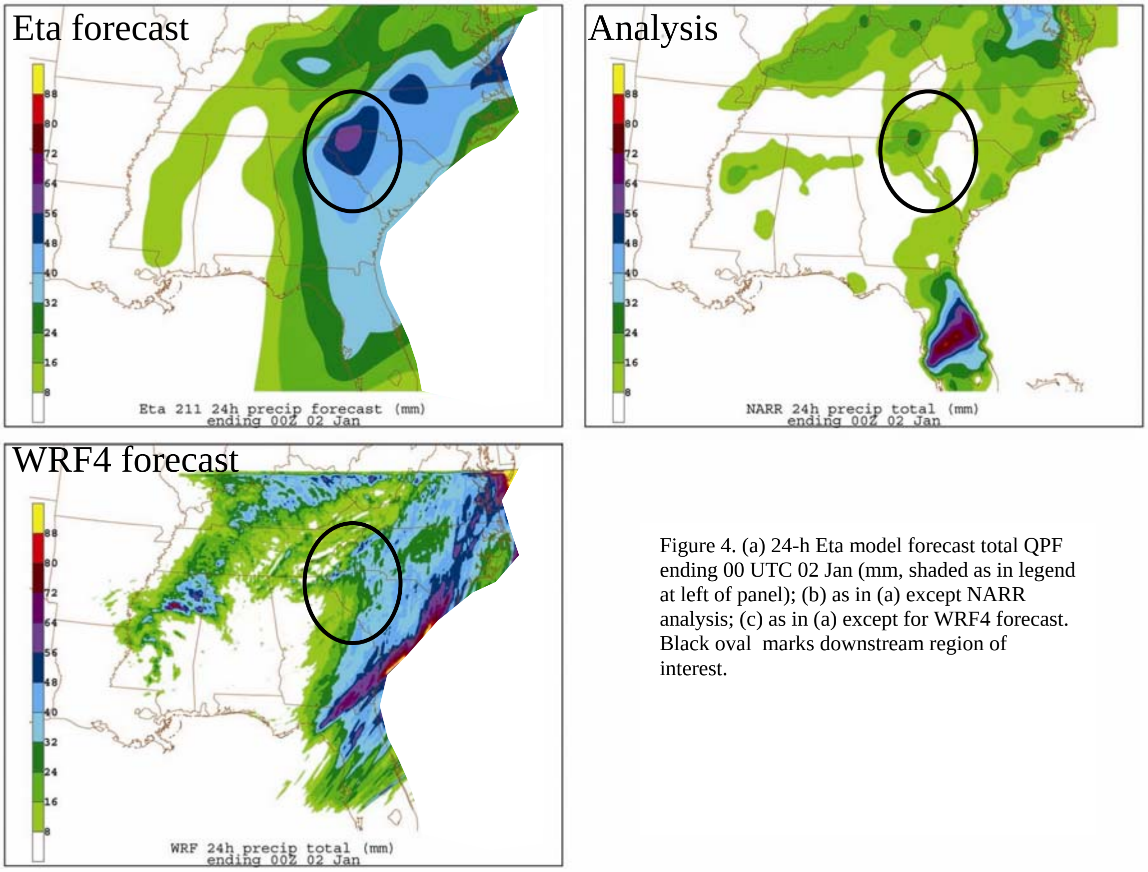

Figure 4. (a) 24-h Eta model forecast total QPF ending 00 UTC 02 Jan (mm, shaded as in legend at left of panel); (b) as in (a) except NARR analysis; (c) as in (a) except for WRF4 forecast. Black oval marks downstream region of interest.

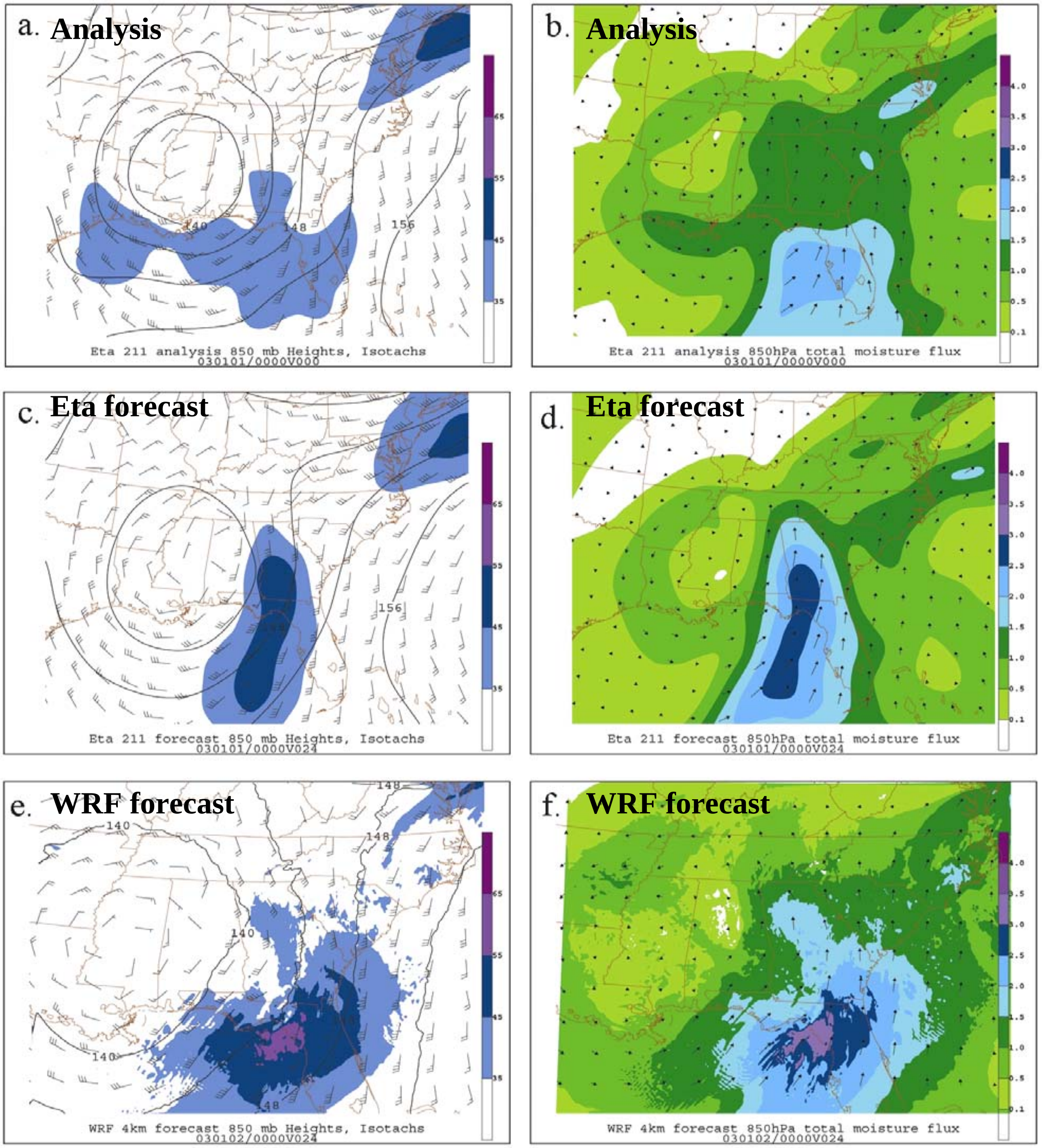

Figure 5. (a) 850-hPa Geopotential height (solid contours, interval 4 dam), 850-hPa winds (kt, barbs), and 850-hPa isotachs (kt, shaded as in legend at right of panel) for Eta analysis valid 00 UTC 1 Jan; (b) 850-hPa moisture flux magnitude (g kg^{-1} m s^{-1}, shaded as in legend at right of panel)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

4. SCENARIO 2 CASE STUDY

The scenario 2 (S2) case study selected for analysis occurred on 13–14 Jan 2005, when a slow-moving ana-cold front produced large amounts of precipitation as it passed through the middle and eastern parts of the US (Fig. 6).

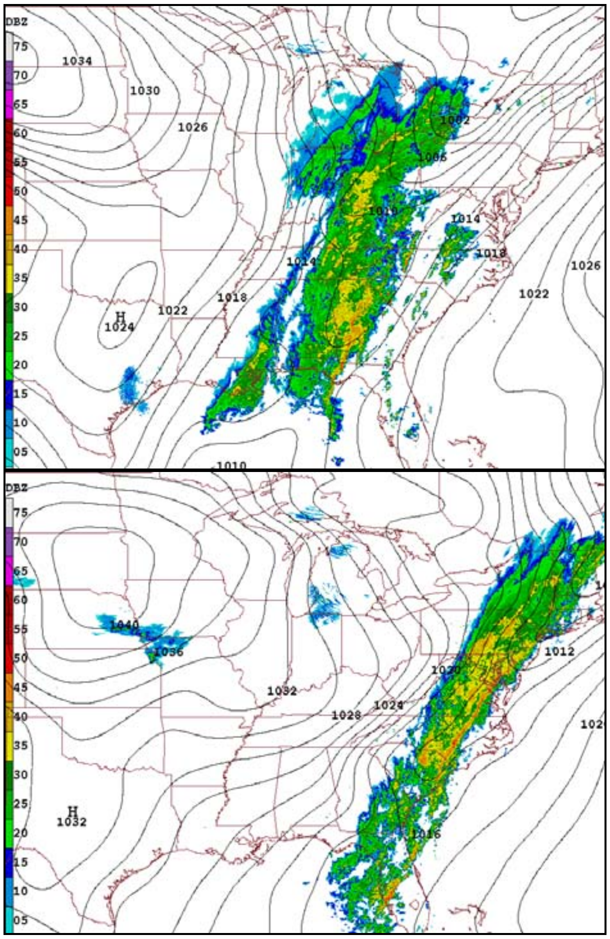

Figure 6. (top) Radar reflectivity and EDAS sea level pressure (interval 2 hPa) valid 00 UTC 14 Jan 2005; (bottom) as in (top) except valid 12 UTC 14 Jan 2005.

The operational Eta model exhibited a negative QPF bias for parts of the Southeast and Mid-Atlantic regions of the US, as precipitation amounts were significantly under-forecasted at certain times and locations. Closely matching the S2 schematic, it was hypothesized that the downstream precipitation amounts were underforecasted due to the inability of the operational models to properly account for the LHR that occurred in association with the heavy rainfall. Model inability to properly account for strong diabatic processes has been documented in the literature (e.g. Kuo et al. 1996; Lackmann et al. 2002), and potential vorticity diagnosis of these cases has demonstrated that latent heating is responsible for strengthening the pre-frontal LLJ, increasing moisture transport, and increasing precipitation in the downstream area.

Potential vorticity (PV) diagnostics were used to demonstrate that the diabatic influence of the UC acted to enhance the LLJ and increase moisture transport. An Ertel PV budget showed that while large nonadvective PV tendencies were generated by the UC, the alignment and location of such tendencies did not act to move the system eastward, as seen in S1. A quasi-geostrophic PV (QGPV) inversion (following Lackmann (2002)) showed that the diabatic cyclonic QGPV anomaly associated with the UC contributed strongly to the southerly LLJ preceding the convective line. Therefore, the S2 case study is an important counter-example to the notion that UC generally reduces downstream precipitation, as this case study demonstrates a physical process associated with the UC that instead acts to enhance moisture transport and downstream precipitation amounts.

5. FORECASTING CONSIDERATIONS

A cursory Eta QPF error climatology, in addition to several real-time UC event evaluations, has shown that S1 cases appear to occur with more frequency and produce larger QPF errors than do S2 cases. This is not to diminish the significance of S2; rather, S2 confirms that UC is not always associated positive model QPF biases, and that there exists a physical mechanism by which UC may also enhance downstream precipitation.

For forecast applications, it is important to develop the capability to distinguish between cases in which downstream precipitation may be reduced and those in which it may be enhanced. These are summarized in Table 1, and may include checking for katafront or anafront characteristics, evaluating the upper-level flow, and carefully examining the speed and motion of the UC feature. It will require future research and collaboration over an extended period with those in a real-time forecast environment to further develop and fine-tune forecast tools with which to anticipate potential UC event forecast adjustments.

Scenario 1 (S1)	***Scenario 2 (S2)***
Deep/digging upper trough (usually located over lower Midwest)	Confluent, lifting upper trough (favorable jet dynamics in downstream region)
Katafront characteristics	Anafront characteristics
Significant shear/ strong westerlies aloft	Weaker shear, weaker flow aloft
Bowing segments in UC	LLJ strength increasing in time

Table 1. Environmental characteristics common to S1 and S2 events.

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 such as the S1 case study, 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-permitting 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.

6. 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. Two differing UC scenarios and several physical processes were discussed, and two case studies were presented. The following is a summary of findings:

- UC may act to decrease *or* enhance downstream precipitation, depending on the synoptic environment as well as the character and motion of the UC feature.
- In the S1 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-permitting WRF run more accurately represented UC movement, moisture transport and precipitation.
- In the S2 case study, a QGPV inversion revealed that the UC feature significantly contributed to the southerly LLJ ahead of the system, increasing moisture transport in the downstream region.
- A number of implications exist for NWP model representation of these events, as S1 case study results show that model forecasts benefit from high-resolution, convection-resolving model configurations.

Future research is required to more fully investigate some of the findings discussed here. The challenge that convective propagation poses to CP schemes (in particular the problem that the omission of physical processes such as momentum adjustment may imply) will be one area investigated in ongoing research. Continued collaboration with operational forecasters in real-time forecast situations will also be necessary in order to further improve forecasts of these events. With time, it is expected that useful tools and applications will be developed that will improve forecaster ability to anticipate and correct for model biases during UC.

7. ACKNOWLEDGEMENTS

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