16.B.2 THE INFLUENCE OF CONVECTIVE PARAMETERIZATION ON MODEL FORECASTS OF AN EAST COAST CYCLONE

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1. INTRODUCTION

It is widely recognized that convection can exert a significant influence on the development and evolution of extratropical cyclones, and it is also generally acknowledged that the representation of convection in numerical weather prediction (NWP) models is less than perfect. As NWP output continues to become an increasingly important component of the operational forecast process, it is critical that forecasters remain especially cognizant of limitations and peculiarities of numerical model representation of convection in situations where organized convective activity is expected to exert a strong influence on the forecast evolution. The purpose of this study is to document the influence of two convective parameterization (CP) schemes available in the National Centers for Environmental Prediction (NCEP) Eta model on model forecasts of an East Coast cyclone.

In the not-too-distant future, it appears quite likely that NWP models will be run at sufficiently high resolution to explicitly resolve convection, yet there will also remain a need for parameterized convection in numerical forecasts for many applications for the foreseeable future. It will be some time before sufficient computing resources exist to allow convection-resolving global model forecasts to be run in an operational environment. Another application that will require parameterized convection for the foreseeable future is ensemble forecasting; here, coarser resolution is needed so as to allow sufficient numbers of ensemble members to be run in real time, and also, varying model convective parameterization schemes adds important information to the ensemble concerning the sensitivity of the forecast to convective representation. Therefore, there remains a need for understanding of the manner in which CP schemes can influence the synoptic-scale forecast. Interactions between model CP schemes and other model grid-scale processes are complex and difficult to diagnose. Part of this complexity lies in the configuration of the CP schemes themselves, which often include both shallow (non-precipitating) adjustment schemes in addition to deep convection, and a variety of trigger functions and thermodynamic constraints and adjustment strategies.

Here we document CP scheme influence via several model sensitivity experiments designed to isolate the influence of shallow and precipitating convection on the genesis and evolution of an East Coast winter cyclone and an attendant coastal front.

2. CP SCHEME BACKGROUND

Comprehensive summaries describing the configuration of CP schemes are provided elsewhere in the literature; here we present basic background information concerning the schemes as it relates to the analysis of this case study.

2.1. Betts-Miller-Janjić (BMJ) Scheme

The BMJ CP scheme is a convective adjustment scheme designed to eliminate instability by adjusting thermodynamic profiles at active grid cells toward empirically-derived reference profiles (Betts 1986; Betts and Miller 1986) to mimic the effects of convection on the larger-scale environment. The original Betts-Miller scheme was updated with several modifications, including changes to the treatment of shallow mixing, as discussed by Janjić (1994).

The scheme first identifies the parcel with the highest equivalent potential temperature within ~200 hPa of the surface. This most unstable parcel is raised to the lifting condensation level

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(defined as cloud base) and then to the equilibrium level (EL). The level immediately beneath the EL is defined as the cloud top. If a cloud depth of at least 290 hPa results at that grid cell, then the deep convection scheme (DCS) continues by computing “reference profiles” of temperature and moisture. The temperature profiles are quasi-moist adiabatic but colder near the freezing level to represent melting effects. The moisture profiles are computed through specification of saturation deficit at the cloud base, freezing level, and cloud top. A thermodynamic constraint is applied, and if adjustment results in net warming and drying of the column then the DCS proceeds. If there is a layer in which the parcel is buoyant but the cloud depth is less than 290 hPa, then the scheme checks for shallow convection (discussed below). If the parcel is not buoyant, the DCS component of the scheme aborts.

The BMJ scheme also includes a shallow convection scheme (SCS) that can exert a significant influence on the model atmosphere (Baldwin et al. 2002). The SCS may trigger if the cloud depth requirement for the DCS is not met, or if the DCS requirements are met but the thermodynamic constraint is not. The SCS cannot produce precipitation, rather its role is to mimic the effects of shallow vertical mixing (warming and drying near the cloud base and cooling and moistening near the cloud top). The BMJ scheme does not explicitly account for mesoscale sub-cloud processes such as downdrafts, gust fronts, and mesohighs (Gallus 1999).

2.2. Kain-Fritsch (KF) Scheme

The KF CP scheme is a “mass flux” scheme, designed to eliminate CAPE by vertically rearranging mass via convective updrafts and downdrafts (e.g., Kain and Fritsch 1993; Kain et al. 2003). The trigger mechanism in the KF scheme involves the vertical velocity, w, to determine a temperature perturbation that is proportional to $w^{(1/3)}$. If grid scale upward motion is strong enough to overcome the convective inhibition imposed on a parcel originating in the lowest 300 hPa of the atmosphere in a given grid cell, then the scheme will activate (provided that the unstable layer exceeds a specified minimum depth). Because grid scale ascent facilitates activation, the KF scheme may experience a relatively strong influence from surface convergence in troughs and frontal zones. Updrafts, downdrafts, and detrainment are also accounted for in the design of the KF scheme (Kain and Fritsch 1993), while the effects of these processes are indirectly represented in the BMJ scheme.

For other detailed comparisons of the KF and BMJ CP schemes, the reader is referred to Kain and Fritsch (1993) and Kain et al. (2003, section 2) for a description of the KF scheme, Betts (1986) and Janjić (1994) for a description of the BMJ scheme, and section 3 of Gallus (1999) for discussion of the fundamental differences between these schemes.

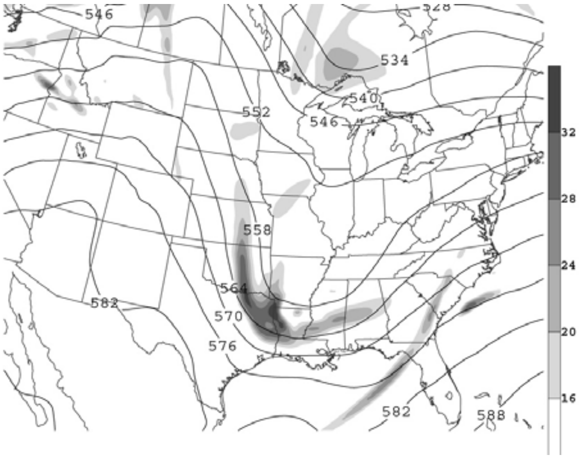

Figure 1. Eta-analyzed 500-mb geopotential height (solid, interval 6 dam) and absolute vorticity ($\times 10^{-5}$ s $^{-1}$ shaded as in legend at right of panel) valid 12 UTC 17 February 2004.

3. 17–18 FEBRUARY 2004 CASE OVERVIEW

A broad upper-level trough was centered over the Mississippi Valley at 12 UTC 17 February, 2004 (Fig. 1). Confluent flow aloft over eastern North America evident at the 500-hPa level was centered over a surface anticyclone located over Quebec. South of this anticyclone, a pronounced Appalachian cold-air damming event had become established by this time, with a wedge of cold air and relatively high pressure entrenched along and to the east of the Appalachian Mountains (Fig. 2). A coastal front was beginning to form along the southeast coast, and at this time was largely confined to the waters east of Georgia and northern Florida. As the upper system tracked eastward, forecasters anticipated the possible development of an offshore cyclone; with cold air in place over interior sections of the southeast, there was a significant threat of wintry weather from the Carolinas northward.

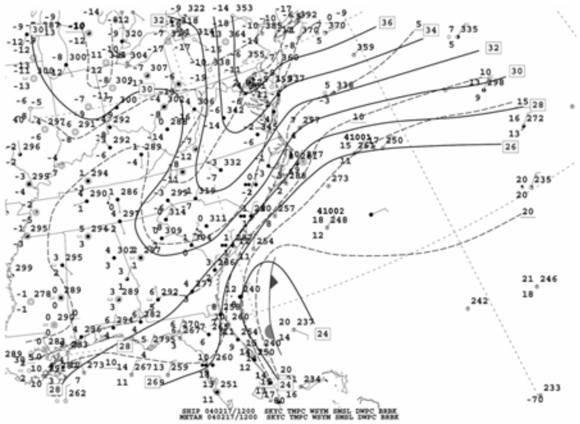

Figure 2. Manual analysis of sea-level pressure (solid, contour interval 2 hPa) and 2-m temperature (dashed, contour interval 5°C), valid 12 UTC 17 Feb 2004.

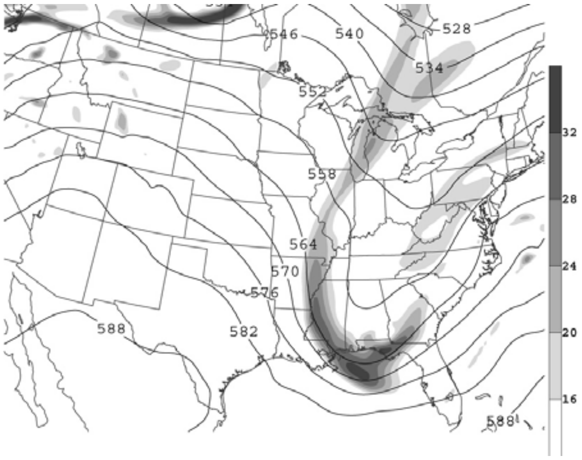

Figure 3. As in Fig. 1 except valid 00 UTC 18 Feb 2004.

By 00 UTC 18 February, a strong vorticity maximum centered to the south of the primary upper trough was located over the northern Gulf of Mexico (Fig. 3). To the east of the upper trough, a surface cyclone had formed along the coastal front and light precipitation had developed over the coastal plain (Fig. 4).

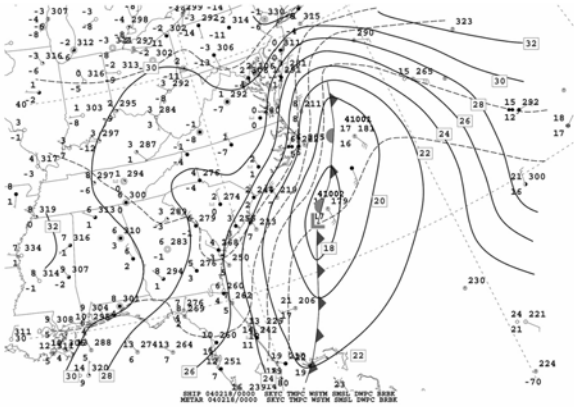

Figure 4. As in Fig. 2 except valid 00 UTC 18 Feb 2004.

During this event, the authors and operational forecasters at the Raleigh NWS office noted that the surface cyclone location was strongly tied to the occurrence of convective (parameterized) precipitation in the NCEP Eta model (Fig. 5).

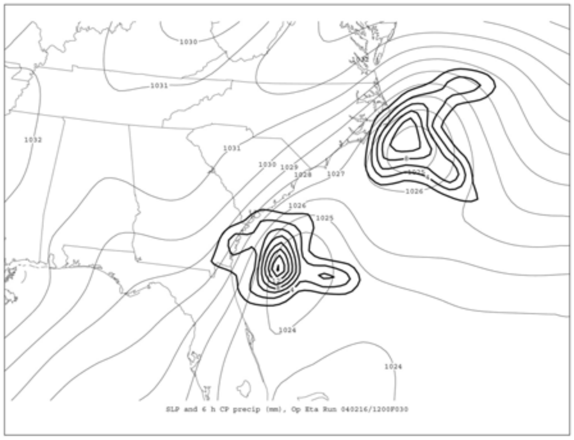

Figure 5. Operational Eta model 30-h forecast valid 18 UTC 17 Feb 2004: Sea level pressure (thin contours, interval 2 hPa) and convective precipitation (thick contours, mm)

The dual sea-level pressure minima evident in the 30-h Eta forecast are strongly coupled to convective precipitation maxima generated by the BMJ CP scheme run in the operational Eta model (Fig. 5).

4. MODEL EXPERIMENTS

The primary objective of this research is to determine the extent to which operational forecasts of the coastal front and associated coastal cyclone were sensitive to the choice of model CP scheme. In order to test the hypothesis that the character of the low-level pressure field forecast was sensitive to CP scheme choice, initial condition data for this event were obtained from NCEP, and the workstation version of the Eta model was run, first with the standard BMJ scheme (similar to the operational Eta forecast), and then with the KF scheme. Additionally, a third forecast was conducted using a modified form of the BMJ scheme that disabled the shallow mixing component. All runs featured 36-km grid spacing.

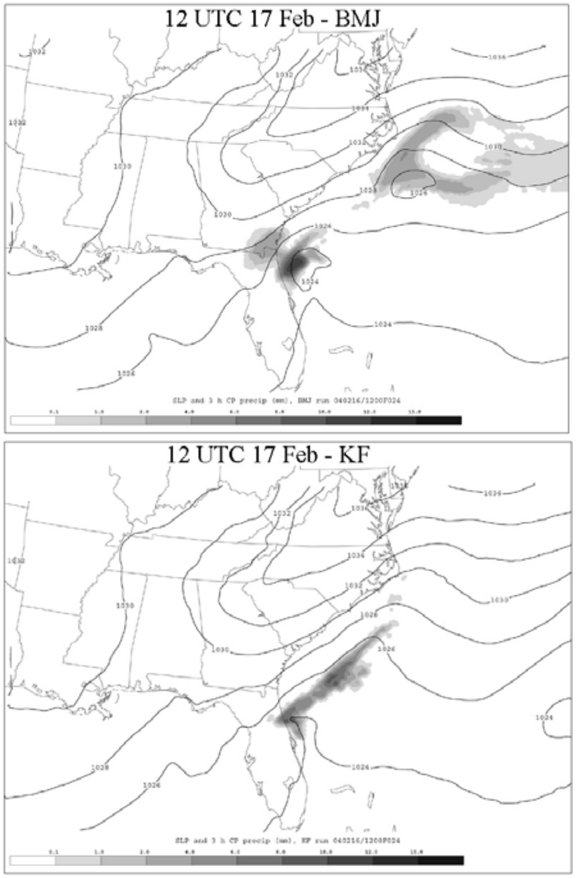

Figure 6. Workstation Eta 24-h forecast valid 12 UTC 17 February 2004: sea-level pressure (solid, interval 2 hPa) and 3-h convective precipitation (shaded as in legend at bottom of panel): (a) BMJ forecast, (b) KF forecast.

Comparison of the BMJ forecast with the KF run supports the aforementioned hypothesis. Figure 6, which displays the BMJ and KF forecasts, demonstrates that the character of the sea-level pressure field in the KF run differed substantially from that in the BMJ run in that rather than two closed cyclone centers, the KF forecast exhibits an elongated trough feature with relatively uniform precipitation distributed along it.

At 00 UTC 18 February, the 36-h forecasts from the BMJ and KF runs continued to exhibit similar differences, although the elongated trough in the KF run (Fig. 7b) had begun to consolidate into a closed cyclone that was centered between the two individual centers seen in the BMJ forecast (Fig. 7a).

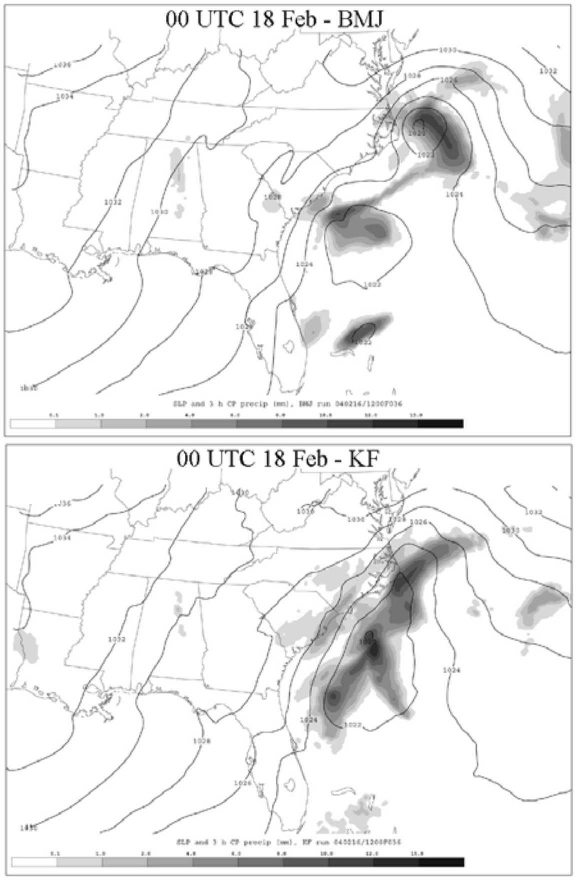

Figure 7. As in Fig. 6, except for 36-h forecast valid 00 UTC 18 Feb 2004.

Clearly the QPF distribution and the location of the initial sea-level pressure minima exhibit pronounced differences between these two model forecasts, despite identical initial conditions and all other model properties. Note that in the KF run, precipitation extends farther westward into the coastal plain of North and South Carolina whereas in the BMJ forecast precipitation is confined to the offshore waters (Fig. 7).

A detailed comparison of the coastal front and near-surface thermal field demonstrates the sensitivity of this feature to the CP scheme as well (Fig. 8). The BMJ forecast exhibits a much weaker coastal front (Fig. 8a), especially southeast of North Carolina, relative to the KF forecast (Fig. 8b). The coastal front is not only stronger, but also closer to the coast in the KF forecast, likely due to the lack of northwesterly advective flow that is present to the south of the northern cyclone center in the BMJ forecast.

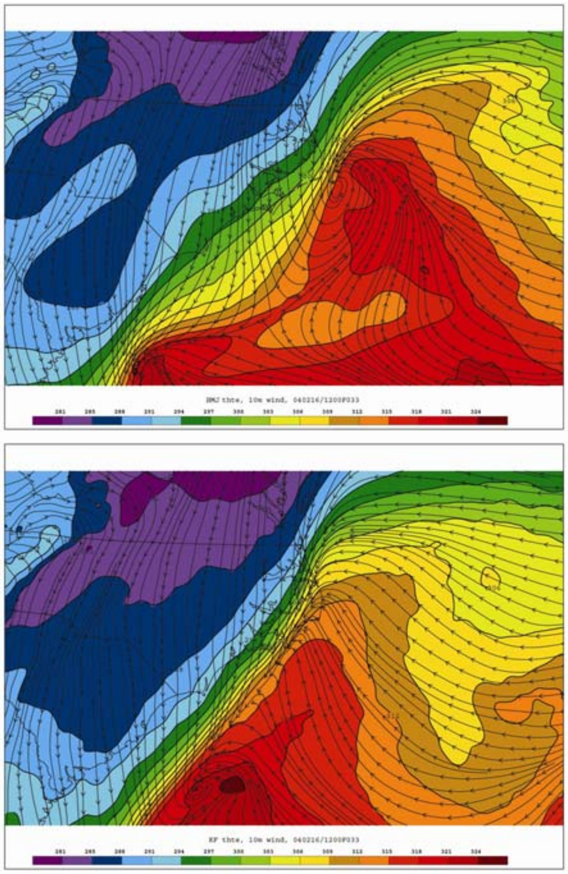

Figure 8. Coastal front representation for 33-h forecast valid 21 UTC 17 Feb: 1000 hPa equivalent potential temperature (K, shaded as in legend at bottom of panels) and 10-m wind (streamlines). (top) BMJ forecast, (bottom) KF forecast.

An additional model experiment, in which the shallow mixing component of the BMJ scheme was disabled, reveals that this CP scheme component played a major role in dictating the character of the model solution (Fig. 9). In this run, there is more of a tendency for uniform precipitation distribution along the coastal front trough, and less of a tendency for closed cyclone centers relative to the full BMJ run. Additional comparisons of this model run to the standard BMJ forecast confirm that the SCS eroded a lower-tropospheric inversion and appeared to exert a strong influence on the timing and development of convection (not shown).

5. CONCLUSIONS

A potentially high-impact winter weather event took place on 17–18 February 2004; numerical forecast uncertainty, in conjunction with a developing coastal cyclone and sub-freezing air presented forecasters with a daunting challenge (see Mahoney and Lackmann 2005 for additional details). A strong upper-level trough, Appalachian cold-air damming, a coastal front, and the developing cyclone all played roles in this complex event. During the event, the authors and NWS forecasters recognized that convective precipitation from the BMJ CP scheme in the Eta model seemed to be associated with the development of low-pressure centers along the coastal front. This raised the question as to what extent these features were tied to the choice of model CP scheme, and also the question of what attributes of the scheme were most responsible for the cyclogenesis.

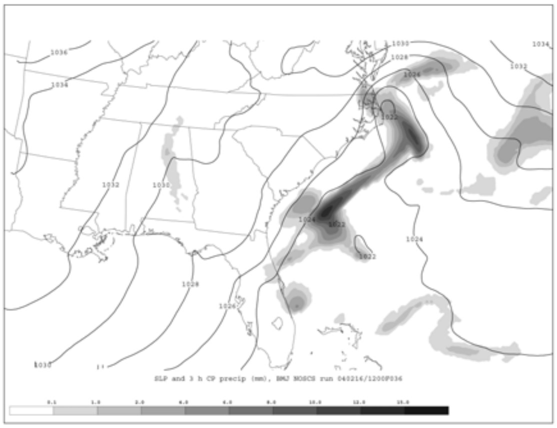

Figure 9. As in Fig. 7a, except for modified no-SCS BMJ run.

A summary of the main findings follows:

- The BMJ run developed two closed low-pressure centers, each associated with a distinct local maximum in convective precipitation. The associated coastal front was weak and farther offshore relative to the KF run.
- The KF run developed a more uniform inverted trough offshore, in accordance with a

more uniform convective precipitation field. The coastal front in the KF run was stronger and located closer to the coast relative to the BMJ run, implying a more westerly cyclone track.

- The BMJ No-SCS run revealed a solution that more strongly resembled the KF run than the full BMJ forecast that included the SCS. The trough accompanying the coastal front was more elongated, and the convective precipitation field was more cohesive in contrast to the localized "bullseye" pattern evident in the full BMJ run.

The purpose of this study was not to conclude that one or another CP scheme is superior; the main point is that forecasters should be aware of the influence that CP schemes can have on the synoptic-scale forecast. Given the large degree of uncertainty associated with convective precipitation, it is suggested that plotting either the convective precipitation field or lower-tropospheric potential vorticity could provide forecasters with a means of identifying those features of the model forecast that are strongly tied to CP scheme activity. Such features should be viewed with a lower degree of confidence relative to most other features of NWP output.

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