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THE IMPACT OF PARAMETERIZED SHALLOW CONVECTION ON PRE-DEEP-CONVECTIVE SOUNDING STRUCTURES IN THE ETA MODEL

John S. Kain[*,1,2], Michael E. Baldwin[1,2,3], Steven J. Weiss[3], and Michael P. Kay[4,5]

[1]*Cooperative Institute for Mesoscale Meteorological Studies*
[2]*University of Oklahoma/NOAA Research - National Severe Storms Laboratory*
[3]*NOAA/NWS/Storm Prediction Center*
[4]*Cooperative Institute for Research in Environmental Sciences (CIRES)*
[5]*University of Colorado/NOAA Research – Forecast Systems Laboratory*

1. INTRODUCTION

Convective parameterization is a necessary component of mesoscale and larger scale models. An important function of convective schemes is to generate precipitation in unstable model environments before saturation occurs at individual grid points. This helps models to predict the timing of convective initiation more accurately, an obvious benefit for forecasters. However, generation of precipitation is not the most important role of parameterized convection. The more significant function is to modify convective instability and redistribute moisture in model soundings. By stabilizing vertical columns before saturation occurs over a deep layer, convective parameterizations act to prevent potentially explosive and unrealistic growth of small-scale disturbances, also known as "numerical point storms" (Lilly 1960; Rosenthal 1979; Molinari and Dudek 1986; Giorgi 1991). A properly formulated convective parameterization can suppress these unrealistic features and play an important role in generating accurate quantitative precipitation forecasts (QPF).

The operational convective parameterization in the Eta Model (Black 1994) is the Betts-Miller-Janjic scheme (Betts 1986; Betts and Miller 1986; Janjic 1994; hereafter BMJ). Verification of QPF from this model has been favorable ever since it was introduced (Mesinger 1996), and the BMJ scheme deserves a lot of credit for this level of performance, particularly for warm season forecasts. However, certain aspects of this scheme, while designed to produce the best possible QPF, may generate artificial structures in vertical profiles of temperature and humidity, i.e., model-forecast soundings (Manikin et al. 2000).

This can be problematic when these soundings are used to forecast certain elements of the weather. For example, forecasters frequently examine model soundings to evaluate the potential for convective activity. Forecast soundings from the Eta Model are useful for predicting convection, but the BMJ scheme can mask important details of the vertical structure and affect calculations of convective inhibition (CIN), Convective Available Potential Energy (CAPE), and other parameters used in the forecast preparation process (Hart et al. 1998). The utility of the soundings could be enhanced considerably if forecasters learned to recognize when the convective scheme has been active in the model and how it has modified thermodynamic profiles.

Considering the important role that model soundings have come to play in the forecast preparation process and the enduring prominence of the Eta Model, a detailed examination of the characteristic structures associated with the BMJ scheme is warranted. These structures are quite distinctive and the trained eye can often recognize the "signature" of BMJ activity quite readily. The purpose of this paper is to provide guidance for forecasters in recognizing the characteristic impact of the BMJ scheme on model soundings, providing a set of skills that will allow them to make more insightful judgments about model predictions.

This preprint is a condensed version of a full article that has been accepted for publication in Weather and Forecasting and is also available on the web (Baldwin et al. 2002). The full article describes the algorithm used by the BMJ scheme in some detail and provides several examples of the impact of the BMJ scheme on model-sounding evolution. In this paper, we show one of these examples and provide a discussion and summary. At the conference, several recent cases will be highlighted as we continue to monitor the impact of the BMJ scheme.

2. A BRIEF OVERVIEW OF THE BMJ SCHEME

The BMJ parameterization is a convective adjustment scheme, meaning that it determines "reference" profiles of temperature and dewpoint towards which it nudges the model soundings at individual grid points. The first step in the scheme is to locate the most unstable (highest θ_e) model parcel within the lowest ~200 mb above the ground. It "lifts" this parcel to its LCL (lifting condensation level), which it defines as cloud base. From there, the parcel is lifted moist adiabatically until the equilibrium level (EL) is reached. Cloud top is then defined as the highest model level at which the parcel is still buoyant, typically just below the EL. If the parcel is not buoyant at any level, convection is not activated and the scheme moves on to the next grid column. If the "cloud" is less than 200 mb deep, the scheme attempts to initiate shallow (non-precipitating) convection. Otherwise, it checks to see if deep (precipitating) convection can be activated. As discussed in Baldwin et al. (2002), the scheme often reverts to shallow convection even when initial estimates of cloud depth are greater than

[*] *Corresponding author address:* Jack Kain, NSSL, 1313 Halley Circle, Norman, OK 73069 e-mail: kain@nssl.noaa.gov

200 mb. This often occurs when the convectively unstable layer is relatively dry. In the case discussed below, the scheme begins by parameterizing the effects of shallow convection, but transitions to deep convection as the environment moistens.

3. A CASE OF SHALLOW CONVECTION TRANSITIONING TO DEEP CONVECTION

On 24 April 2001, a vigorous upper level short wave trough was lifting northeastward across the Great Lakes toward the northeastern states. An associated deep surface low over Quebec was also moving to the northeast. Trailing southwestward from this low was a surface cold front. This front extended along the Appalachians into the southeastern U.S. The front was advancing slowly eastward over the Mid-Atlantic States, into a region of moderate instability over the Carolinas and Virginia. The upper level forcing associated with this front was weak.

The model initial (1200 UTC) condition at Greensboro, North Carolina (GSO) showed good agreement with observations (Fig. 1a). The sounding was nearly saturated above about 300 mb, relatively dry through mid levels, and quite moist below 800 mb. The BMJ scheme determined that no CAPE existed for parcels rooted in the lowest 200 mb, so no convection was activated at this time. CAPE continued to be absent through 1400 UTC, but solar heating led to the development of

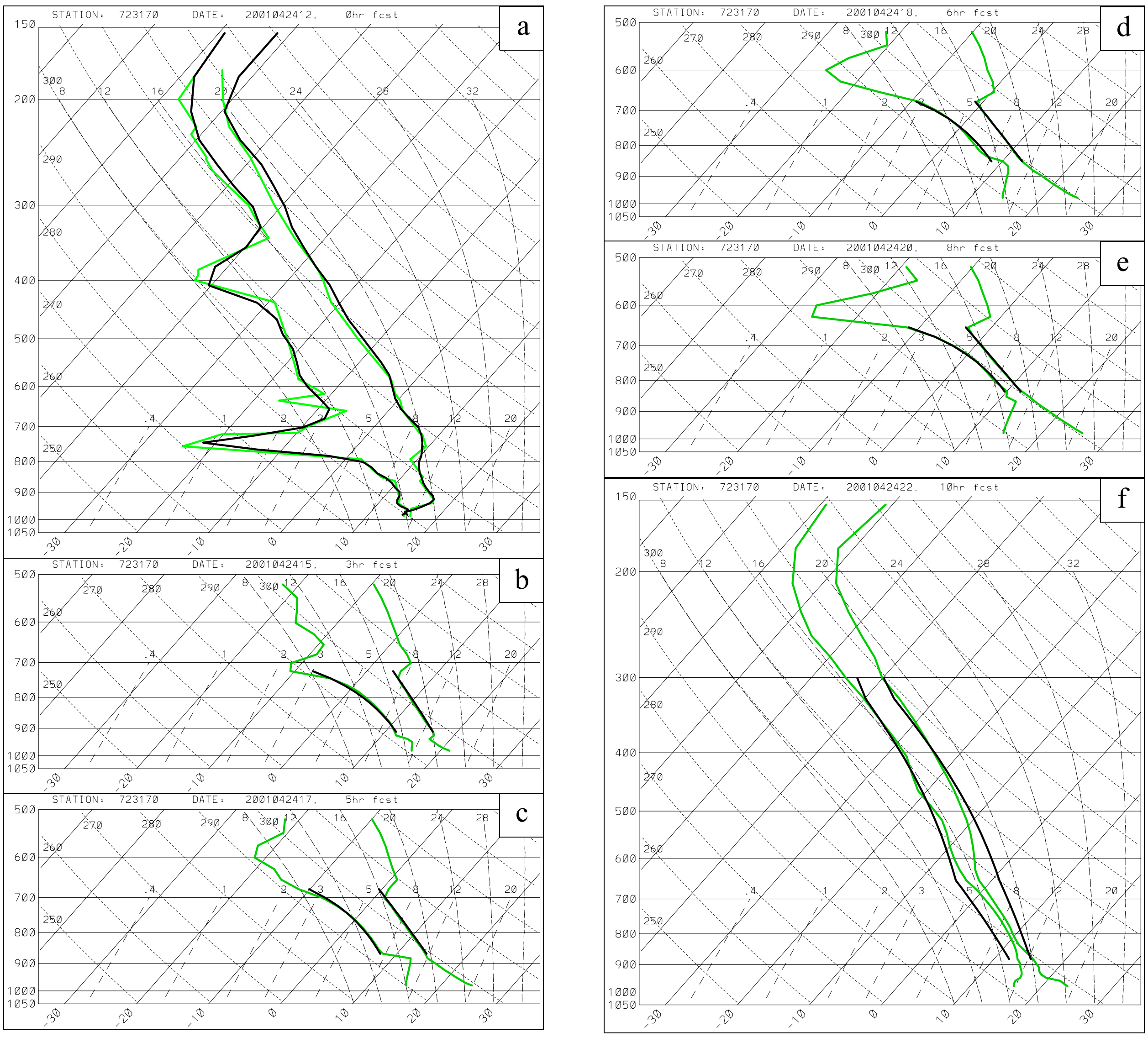

Fig. 11. A sequence of Eta model forecast soundings valid from 1200 UTC to 2200 UTC 24 April 2001 over Greensboro, NC (KGSO). a) Model initial condition (thick dark curves) overlaid on the observed sounding (thick light curves); b) BMJ shallow-convection reference profiles (thick dark curves) overlaid on the model 3 h forecast, valid 1500 UTC; c) as in b), but for the 5 h forecast, valid 1700 UTC; d) as in b), but for the 6 h forecast, valid 1800 UTC; e) as in b), but for the 8 h forecast, valid 2000 UTC; f) as in b), but for the 10 h forecast, valid 2200 UTC.

some instability during the following hour.

During this hour, the scheme activated shallow convective feedbacks, nudging the environment toward the reference profiles shown in Fig. 1b. Note the distinctive character of the shallow convective reference profiles. The temperature profile appears as a nearly straight line on a skew-T/log P diagram, while the dewpoint profile has a convex shape, tailing off to sharply lower dewpoints at higher levels (*i.e.*, at the top of the shallow cloud layer, as determined by the BMJ scheme). Even though parameterized shallow convection had been active for less than an hour by 1500 UTC, the scheme had clearly placed its footprint on the sounding. Specifically, the scheme had significantly cooled and moistened the layer near 750 mb, introduced a monotonic decrease in temperature from about 920 to 740 mb and imposed a smooth convex moisture profile over the same layer (Fig. 1b). At this time the scheme was acting over a depth of 200 mb, which is the maximum allowable depth the *shallow* convective adjustment.

The character of the scheme's influence changed little over the next 2 hours (1500 – 1700 UTC). In particular, thermodynamic profiles within the shallow-cloud layer retained the same shape, although solar heating caused cloud base to rise with time and this allowed cloud top to rise as well (Fig. 1c). By 1800 UTC, low-level convergence associated with the advancing cold front was quite strong (not shown) and boundary layer depth was increasing rapidly. Boundary layer moisture was not decreasing significantly as the layer deepened, suggesting the presence of strong moisture convergence. At the same time, there appeared to be little if any upward motion aloft.

Since the computed shallow cloud base was near the top of the boundary layer, the scheme effectively transported moisture from the top of the well-mixed layer (or just above the top) into the lower to middle part of the shallow cloud layer (Fig. 1d). Note the substantial moistening of the shallow cloud layer between 1700 and 1800 UTC (cf. Figs. 1c and d). At the same time, shallow convection was effectively communicating with the convective boundary layer (through turbulent diffusion), removing moisture from low-levels. This communication between parameterized boundary layer turbulence and shallow convection is frequently reflected in Eta Model simulations.

Between 1800 and 2000 UTC, boundary layer depth began to peak. Parameterized shallow convection continued to moisten the cloud layer and cool its upper half. Yet, above about 650 mb, the atmosphere remained dry, precluding the development of parameterized deep convection (Fig. 1e). After 2000 UTC, upward motion commenced aloft within the model and BMJ deep convection activated between 2100 and 2200 UTC. By the latter time, the remnants of the shallow convective structures were still evident, but it can be seen that the sounding was evolving toward the familiar BMJ deep convective reference profiles (Fig. 1f), where the temperature profile is slightly less stable than moist adiabatic, and moisture profile is subsaturated with a dewpoint depression that varies linearly from about 3^{o} C at cloud base, to ~7 ^{o} C at the freezing level, and back to ~4 ^{o} C at cloud top.

4. SUMMARY AND DISCUSSION

All convective parameterizations contain arbitrary parameter settings and have characteristic behaviors that are sometimes inconsistent with reality. So, this study is not intended to single out the BMJ scheme as somehow inferior or inadequate. On the contrary, this scheme has been critically important to the success of the Eta Model running at the National Centers for Environmental Prediction (NCEP) and its enduring status as the primary 1-2 day operational forecast model in the United States. Other convective parameterizations have been tested in the Eta Model but none has produced consistently higher QPF verification scores than the BMJ scheme.

At the same time, the BMJ scheme is particularly amenable to critical examination because the shape and character of its "footprint" are much easier to identify than characteristic profiles produced by other schemes – and there is value in knowing when and where a convective parameterization has been active in a model! Most importantly, a detailed examination of BMJ behaviors is warranted because model-forecast soundings from the Eta Model have come to play an important role in preparing forecasts for many types of weather.

Forecasters concerned about thunderstorm development can benefit from knowing how to identify when parameterized shallow convection has been active. The BMJ shallow component warms and dries model layers near the LCL while cooling and moistening the model sounding near the computed cloud top. It nudges the environment towards profiles characterized by linear decreases in θ and q_v as a function of decreasing pressure. Oftentimes this process distorts the shape and structure of the CIN layer, sometimes completely eliminating a stable layer that can be critical for inhibiting convective development. This tendency can be very evident over the Great Plains of the U.S., where elevated mixed layers create strong capping inversions with some regularity during the warm season (Carlson et al. 1983; Lanicci and Warner 1991). When the LCL is close to the top of a convective boundary layer, within which turbulent mixing is parameterized separately in the model, the combination of convection and turbulence parameterizations can effectively mix moisture out of the boundary layer up towards the shallow cloud top while mixing high θ air downward into the boundary layer. When some or all of these processes are active in the model, convective parameters such as CAPE and CIN are significantly impacted. If forecasters can learn to identify these characteristic tendencies associated with BMJ shallow convection, they can make more informed assessments of the likelihood of convective initiation and intensity.

It is also important for forecasters to be able to recognize when BMJ deep convection has been active.

Unlike parameterized shallow convection, deep convective activity is easy to confirm by examining the convective rainfall field. Its characteristic thermodynamic profiles are easy to recognize as well. The temperature profile is slightly unstable from cloud base to the freezing level, then marginally stable (lapse rate slightly less than moist adiabatic) up to the computed cloud top. The dewpoint depression is specified to vary linearly from about 3-5^{o} C at cloud base, to 7-9 ^{o} C at the freezing level, back to 3-5 ^{o} C at cloud top. As with the shallow convective signature, the active convective layer is often first recognizable by its characteristic lack of small-scale structure. Small-scale vertical structures in both the temperature and moisture fields are transformed quickly into curves with nearly monotonic decrease in temperature and dewpoint with height when either deep or shallow convection activates with the BMJ scheme.

It is hoped that this study will promote the direct analysis of model-forecast soundings, rather than relying on 2-D plan view plots of diagnosed quantities such as CAPE or CIN. Not only should this help in removing ambiguity on how such fields are computed (e.g., which parcel was lifted, whether or not the virtual temperature correction (Doswell and Rasmussen 1994) was used, etc.), but this will also lead to better understanding of the characteristic behaviors of the BMJ scheme. Examination of model-forecast soundings can provide valuable clues to help forecasters comprehend and interpret overall model behavior. Yet, these soundings must always be used with caution. Developing a more complete understanding of the BMJ scheme can help forecasters distinguish between those characteristics of model soundings that have a meteorological origin and those that are more of a computational anomaly.

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