16B.3 THE IMPACT OF DIFFERENT WRF MODEL PHYSICAL PARAMETERIZATIONS AND THEIR INTERACTIONS ON WARM SEASON MCS RAINFALL

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Introduction

In recent years, a mixed physics ensemble approach has been increasingly investigated as a method to better predict Mesoscale Convective System (MCS) rainfall. For mixed physics ensemble design and interpretation, knowledge of the general impact of various physical schemes and their interactions on warm season MCS rainfall forecasts would be useful. Numerous studies have shown the large impact the convective scheme has on rainfall forecasts. The choice of planetary boundary layer (PBL) scheme can substantially affect temperature and moisture profiles in the lower troposphere, which could interact with other schemes such as the convective parameterization to influence simulation of precipitation (e.g., Bright and Mullen 2002; Wisse and Vila-Guerau de Arellano 2004). However, the impact of different PBL schemes and microphysical schemes on warm season rainfall fields and the interactions of all three of these physical process schemes have received little attention. The main objective of the present study is to investigate the general impact that various physical schemes as well as their interactions have on warm season MCS rainfall forecasts under different initial conditions.

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Methodology

A matrix of 18 12-km grid spacing WRF variants created using different combinations of physical schemes was run for 8 International H_2O Project (IHOP) convective cases. The IHOP domain covered a roughly 1500x1500 km region centered over the south-central United States (Fig. 1).

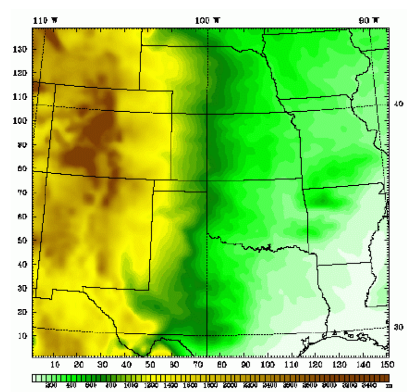

Figure 1. The domain of integration.

For each case, three different treatments of convection were used: the Kain-Fritsch (KF) scheme (Kain and Fritsch 1993), the Betts-Miller-Janjic (BMJ) scheme (Betts 1986, Betts and Miller 1986, Janjic 1994), and the use of no convective scheme (NC). For each of these 3 choices, 3 different microphysical schemes were used: Lin et al. (1983), NCEP-5 class (Hong et al. 1998), and Ferrier et al. (2002). These schemes will be referred to as MPL, MPN, and MPF, respectively, hereafter. Within these 9 possible configurations, two different PBL schemes were used: MRF (Troen and Mahrt 1986) and Eta (Janjic 1994). It is important to note that the exploration of impacts and interactions between all possible combinations of physical schemes was slightly affected by the choice of the 'control run' (4 out of 17 possible interactions were neglected). In the present study, the 'control run' used the KF convective scheme, MRF PBL and MPN microphysics. For the rainfall validation, observed 6-hour accumulated precipitation fields from the NCEP Stage IV analysis were used. The runs were initialized with both a diabatic Local Analysis and Prediction System (LAPS) 'hot' start initialization (Jian et al. 2003) and 40 km Eta GRIB files.

As a measure of forecast accuracy, Equitable Threat Score (ETS) and bias were calculated. As a measure of the sensitivity to the physics changes the Correspondence Ratio and Squared Correlation Coefficient were calculated. Correspondence Ratio (Stensrud and Wandishin 2000) was computed when two of three model physical schemes were held fixed and the third was varied. Correspondence Ratio (CR), defined as the ratio of the area of the intersection (I) of all individual field values to the area of union (U) of the same field values, is a useful measure of the sensitivity to physical scheme changes, and is written

$$CR = \frac{I}{U} \qquad (1)$$

where I and U are defined using threshold values of rainfall. The same approach that was used for the CR calculation was repeated in the calculation of the Squared Correlation Coefficient (r^2).

In order to quantify the impact of varying two different model physical schemes on the simulated rainfall field, the factor separation methodology formulated by Stein and Alpert (1993) was adopted. Based on this methodology:

$$f_{xy} - f_0 = (f_x - f_0) + (f_y - f_0) + \hat{f}_{xy} \qquad (2)$$

where f_0 represents the control run simulated rainfall amount, f_{xy} represents the rainfall amount simulated by a run with changes in both physical schemes of interest (two physical schemes changed compared to the control run), f_x stands for the rainfall amount produced by a run that has one of the two physical schemes of interest changed (as compared to the control run), f_y represents the rainfall amounts simulated by a run with another physical scheme of interest changed (as compared to the control run), and $\hat{f}_{xy}$ stands for a synergistic term reflecting, in the present study, the rainfall amount associated with the non-linear interaction between two physical schemes. This term may be thought of as the difference between the actual rainfall occurring in the run in which two schemes have been changed and the rainfall expected by adding the impacts of each individual change. Assuming a continuum of physical schemes, Eq. 2 is then equivalent to Taylor's series second order expansion in two variables. The first two terms in the right hand side (RHS) of Eq. 2 represent the contribution of the first order derivatives, while the third term (synergistic term) is a mixed second order derivative (the non-mixed second order derivatives are zero). In essence, if the synergistic term is equal to zero, no interaction occurs between the two changed physical schemes.

Results

ETS and bias averaged over all 8 cases, for all 18 configurations, and for both initial conditions indicated that no one configuration was obviously best at all times and thresholds (not shown). However, it should be pointed out that for light thresholds, NC runs initialized with LAPS analyses had higher ETSs than runs using a convective scheme while for the heavier thresholds NC runs had the lowest ETSs. For runs initialized with Eta 40 km analyses, NC and BMJ runs had higher ETSs for both thresholds. For bias, NC runs always performed better than runs with convective schemes, especially in the case of BMJ runs when bias errors were strongly positive.

In order to objectively test the sensitivity of the rainfall forecast pattern to physics changes, CR was calculated using Eq. 1. Figure 2 shows values of CR for runs initialized with the LAPS analyses for changes in microphysical, PBL, and convective schemes at the 0.01 and 0.5 in. thresholds. It can be seen that the sensitivity to the choice of convective treatment dominated during the whole 24-hour forecast period. For light rainfall, sensitivity to convective treatment was the highest (lowest CR) among all physics options during the first 6 hours of the forecast, becoming at later times more similar to (though still higher than) the sensitivities to the other two physical process schemes. Sensitivity to PBL scheme choice increased with time, while no pronounced trend was present with respect to choice of microphysical scheme. For heavier rainfall, the CR for the set of different convective schemes was highest in the first 6 hours and much lower at later times. At all times sensitivity to changes in the convective scheme exceeded that of the two other physical schemes. An analysis of Correlation Coefficient led toward the same conclusion. Finally, The same trends in CR and r^2 were present for runs using a 40 km Eta initialization (not shown) except the magnitudes were often larger.

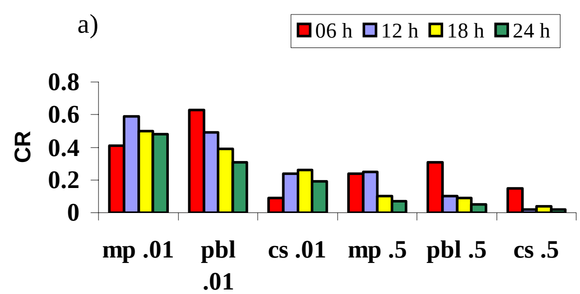

Figure 2. Values of Correspondence Ratio (CR) for changes in microphysical (mp), PBL (pbl), and convective schemes (cs), for the two thresholds indicated on the abscissa (0.01 in. and 0.5 in.) and for the four 6-hourly periods ending at the times indicated in the legend.

For both LAPS and 40 km Eta initializations the factor separation results when one physical parameterization was changed indicated generally the same trends in areal coverage, rain rate and rain volume (i. e., switch from KF to BMJ for the 0.01 in. threshold resulted in an areal coverage increase, while the opposite was the case for the 0.5 in. threshold). The statistical significance of the obtained results was determined by following a resampling method suggested by Hamill (1999). Only statistically significant results will be discussed further.

Table 1 illustrates the changes in physical schemes that significantly affected areal coverage for two different initializations and two different thresholds. It can be seen that in the case of the LAPS analysis for the 0.01 in. threshold, changes in PBL, microphysics and a switch from KF to BMJ all significantly increased areal coverage. In the case of runs initialized with Eta 40 km output, areal coverage was significantly affected only when changes were made in the convective treatment. A switch from KF to NC significantly reduced areal coverage while the opposite was the case for a switch from KF to BMJ. For runs using the LAPS analysis at the 0.50 in. threshold, areal coverage was increased by changes in microphysics while for runs using the Eta 40 km analysis, areal coverage increased with a switch in microphysics (MPN to MPL) and decreased with a switch in convective treatment (KF to NC).

Areal coverage

Threshold (in.)	LAPS	Eta
0.01	MRF-ETA** MPN-MPL** MPN-MPF** KF-BMJ**	KF-NC* KF-BMJ**
0.50	MPN-MPL** MPN-MPF**	MPN-MPL** KF-NC*

Table 1. Factor separation method results related to areal coverage. Red, yellow, and green colors stand for results statistically significant at the 95%, 90-95%, and 80-90% confidence levels, respectively. '**' represents an increase while '*' implies a decrease.

For the 0.01 in. threshold for both initializations, changes in microphysics and convective treatments impacted the rain rate the most (Table 2). Changes in microphysics and the change from KF to NC generally increased rain rate. For initializations using 40 km Eta analyses a change from KF to BMJ resulted in a rain rate decrease, accompanying the significant increase in areal coverage that occurred when BMJ was used (Table 1). With regard to heavier amounts, rain rates for runs initialized with the LAPS analysis were only affected by a change from MPN to MPL. In the case of 40 km Eta initialization, changes in PBL scheme and microphysics from MPN to MPL resulted in a rain rate increase, while a change from KF to BMJ reduced the rain rate significantly. It is important to note that in terms of magnitudes (not shown) the largest impact on rain rate was due to changes in convective treatment for both LAPS (KF to NC) and 40 km Eta initialization (KF to BMJ).

System average rain rate

Threshold (in.)	LAPS	Eta
0.01	MPN-MPL** MPN-MPF** KF-NC**	MPN-MPL** MPN-MPF** KF-NC** KF-BMJ*
0.50	MPN-MPL**	ETA-MRF** MPN-MPL** KF-BMJ*

Table 2. As in Table 1 except for system average rain rate.

With regard to rain volume (Table 3), for runs initialized with a LAPS analysis, significant impacts occurred from changes in microphysics for both thresholds. In addition, for the 0.5 in. threshold, a switch from KF to BMJ resulted in a significant decrease in rain volume. This might be expected due to the BMJ scheme tendency to overpredict areas of light rain with very limited areas of heavier amounts. For initializations using a 40 km Eta analysis, for the 0.01-

inch threshold, only a change from MRF to ETA affected rain volume significantly. For the 0.5 in. threshold, a change in PBL scheme, a change from MPN to MPL microphysics and both changes in convective treatment resulted in significant impacts.

Domain total rain volume		
Threshold (in.)	LAPS	Eta
0.01	MPN-MPL** MPN-MPF**	MRF-ETA**
0.50	MPN-MPL** MPN-MPF** KF-BMJ*	MRF-ETA** MPN-MPL** KF-NC* KF-BMJ*

Table 3. As in Table 1, except for domain total rain volume.

In terms of magnitudes (not shown), the largest impact on rain volume in the case of runs initialized with a LAPS analysis was due to changes in microphysics while in the case of runs using 40 km Eta analyses the largest impact was due to changes in convective treatments.

The impact of interactions (synergy) of different physical schemes (Table 4), for runs initialized with a LAPS analysis was found to vary greatly and typically not to be statistically significant. The only exception was for the interaction of ETA with MPL or MPF which did significantly reduce the rain volume increase that had been noted for the heavier threshold when the microphysics were switched from MPN. In the case of 40 km Eta-initialized runs more of the physical scheme interactions turned out to be statistically significant compared to runs initialized with the LAPS analyses. For the 0.01 in. threshold interactions between MPL and NC led toward an even larger increase in rain rate than what had been produced by switching from MPN to MPL and switching from KF to NC. The same was the case for the 0.5 in. threshold. On the other hand, for the 0.01 in. threshold the interaction between MPF and NC resulted in a reduction of an increase in rain rate that had been caused by switching from MPN to MPF and from KF to NC. In addition, for the 0.01 in. threshold, the interaction between ETA and MPF significantly reduced an increase in rain rate produced when MRF had been changed to ETA and MPN to MPF.

System average rain rate		
Th (in.)	LAPS	Eta
0.01	- -	MPN-MPL&KF-NC** MPN-MPF&KF-NC*!
0.50	- -	MRF-ETA&MPN-MPF*! MPN-MPL&KF-NC**
Domain total rain volume		
0.01	- -	MRF-ETA&KF-NC**! MPN-MPF&KF-NC**!
0.50	MRF-ETA&MPN-MPL*! MRF-ETA&MPN-MPF*!	MRF-ETA&KF-BMJ* MPN-MPL&KF-NC** MPN-MPF&KF-BMJ*!

Table 4. System average rain rate and domain total rain volume related synergistic terms for runs initialized with LAPS and 40 km Eta analyses for the 0.01 and 0.5 in. thresholds. As in Table 1 '**' indicates an increase, and '*' indicates a decrease a '!' indicates that the synergistic trend is opposite to the individual trends.

With regard to rain volume (Table 4) in Eta-initialized run, for the 0.01 in. threshold nonlinear interactions between both ETA and MPF with NC reduced the decrease in rain volume caused by individual changes from MRF to ETA and from MPN to MPF combined with the change from KF to NC, respectively. For the 0.5 in. threshold the interaction between ETA and BMJ led toward an additional decrease of rain volume compared to the decrease that had been produced by changing from MRF to ETA and KF to BMJ independently. The interaction between MPL and NC led toward an additional increase of rain volume compared to the individual changes. Finally, an interaction between MPF and BMJ resulted in a reduction of the rain volume increase that occurred when MPN was changed to MPF and KF to BMJ.

In general, results indicated larger sensitivity to the changes in microphysics for runs initialized with the LAPS analyses compared to those initialized with the 40 km Eta output. One possible explanation might be that the 40 km Eta output comes from an assimilation system (EDAS) that uses the BMJ scheme, which has a tendency to generate large areas of light rainfall while substantially drying the atmosphere and reducing the grid-resolved component of precipitation. Thus, runs initialized with 40 km Eta output may be too dry initially for the microphysical schemes to activate in areas where precipitation is likely to be occurring, and the role of microphysics is restricted until later forecast times when the impact of initial conditions is no longer present.

It was also found that for runs initialized with the LAPS analyses the change in PBL schemes does not significantly affect the rainfall forecast, while the opposite was the case for runs initialized with 40 km Eta analyses. One might speculate that the change in PBL scheme might not have much impact early in the forecast when dynamically balanced initial conditions, such as the LAPS 'hot' start analyses, are used. Perhaps the LAPS initialization results in conditions so conducive to precipitation formation that the changes in the boundary layer associated with the use of different PBL schemes have limited impact on rainfall characteristics.

Finally, the change from KF to BMJ appeared to significantly impact simulated precipitation when the 40 km Eta analyses were used, but not when LAPS analyses were used. On the other hand a change from KF to NC had a significant impact on simulated rainfall for both initializations. This, once again, may imply that the BMJ scheme used in the EDAS influences the initial conditions in such a way that when another scheme is used in the model, the impact on simulated precipitation is large.

Summary

General trends in the impact of various physical schemes and their interactions on warm season MCS rainfall forecasts were evaluated under different initial conditions. A matrix of 18 WRF model configurations, with 12–km grid spacing, was created using different physical scheme combinations for 8 IHOP MCS cases. For each case, three different treatments of convection were used, with 3 different microphysical schemes and two different PBL schemes. The runs were initialized with both a diabatic Local Analysis and Prediction System (LAPS) 'hot' start initialization (Jian et al. 2003) and 40 km Eta GRIB files.

ETS and bias scores for both initializations indicated that no single model configuration was clearly best. Both Correspondence Ratio and Squared Correlation Coefficients for both initial conditions indicated that the highest sensitivity was to the choice of convective treatment, with less sensitivity to the PBL scheme, and the least to microphysics.

The factor separation method (Stein and Alpert 1993) was used to quantify

the impacts of the variation of two different physical schemes compared to a ‘control run’ (KF-MRF-MPN) and their interaction (synergy) on the simulated rainfall. For runs using a LAPS analysis, significant changes in areal coverage occurred with changes in microphysics, while for runs using a 40 km Eta analysis changes in convective treatment impacted the areal coverage the most. For both initializations, changes in convective treatment affected the rain rate the most. For runs initialized with the LAPS analysis rain volume was affected the most by changes in microphysics, while for runs initialized with 40 km Eta GRIB files it was influenced most by choice of convective treatment. Information about the interactions among different physical schemes obtained through the synergistic term analyses might be useful in an ensemble calibration procedure.

In conclusion, if an ensemble designed for MCS rainfall prediction lacks sufficient spread, model runs with different convective schemes should be included. If rain volume is a desired quantity (e. g., hydrological purposes), and initialization uses LAPS analyses, runs with MPL and MPF microphysical schemes may require different bias correction or weighting in an ensemble compared to runs using MPN. In contrast, when ETA 40 km GRIB files are used for initialization, runs with NC and BMJ would require different weighting as compared to KF runs.

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