Assessment of the Sensitivity in Moisture Transport and Regional Climate Model Statistics to Convective Parameterization in the North American Monsoon

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Section 1: Introduction

Given the documented sensitivities in regional climate models (RCM) the purpose of this work was to quantitatively assess the performance of the MM5v3.4 mesoscale model (Grell et al 1994) run in a pseudo regional climate mode, with three different cumulus parameterizations in the simulation of the North American Monsoon evolution during the summer of 1999. We use the term 'pseudo' here because we have predefined a spin-up period of six weeks which should be adequate for the thorough propagation of lateral boundary conditions but may not be adequate for full spin-up of certain land surface conditions. The work presented here is organized as follows. Section 2 briefly describes the model configuration, verification data and simulation procedures. References should be followed for detailed descriptions. Section 3 presents the results obtained from the simulations and Section 4 provides a summary of the results.

Section 2: Model and Data

The model used is the PSU/NCAR MM5 mesoscale model version 3.4 (Grell et al, 1994). A two way interacting nested configuration (90km and 30km) was used whose interior domain covers much of Mexico and the southwestern United States. (see Figure 1) The model was integrated from 00z May 16 through 00z August 2nd 1999 and the lateral boundary conditions for the coarse domain were provided by the NCEP/NCAR Re-analysis data set (Kalnay et al, 1996). Time varying sea-surface temperatures (SST's) were prescribed to 6-hour interpolated values using the weekly SST dataset of Reynolds and Smith (1994). Three different simulations were conducted using the cumulus parameterizations of Betts-Miller-Janjic (Janjic (1994)), Kain and Fritch (1991), hereafter referred to as KF, and the scheme of Grell (Grell et al, 1993 and 1994), hereafter referred to as GR. Model output was saved every 3 hours for calculations of performance statistics. Other significant model options are listed in Table 1.

Physics Option		Model Setup
Explicit Microphys.		Simple Ice (Grell et al 1994)
Surface Layer		OSU/ETA (Chen and Dudhia 2000)
P.B.L.		MRF (Hong and Pan 1996)
Radiation		Cloud Rad. Scheme (Grell et al 1994)
Cumulus	(90 km)	Betts-Miller-Janjic (Janjic 1994)
	(30 km)	Kain-Fritsch (Kain and Fritsch 1993)
		Grell (Grell et al 1994)
		Betts-Miller-Janjic (Janjic 1994)

Table 1. Model Options used in simulations

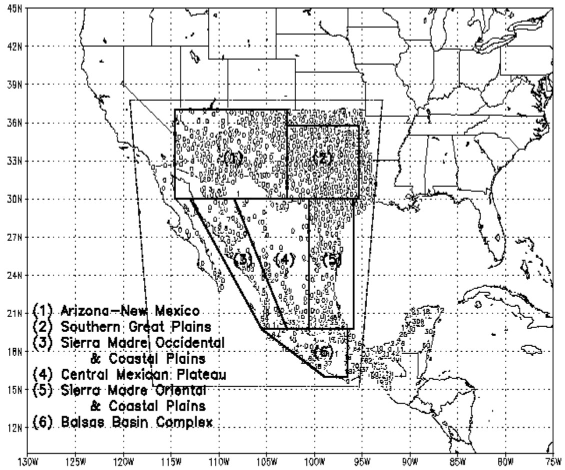
Surface Climate Evaluation

Model calculated 2-m surface daily average temperature (Tav) and daily average dew point temperature (Td) were matched to surface station observations provided by the National Climatic Data Center. Rainfall data used in this study were daily total rainfall observations from Mexico (Art Douglas, pers. comm.) and the U.S. cooperative climate network. (small numbers in Figure 1) Spatial averaging of both model gridpoints and observations was performed within a one-degree radius of the station and respective model grid cells. Monthly statistics in the form of mean bias (BIAS), root mean square error (RMSE) were estimated and then averaged over the physiographically similar regions shown in Figure 1. (Region 0=Entire Domain, Region 1 = AZ-NM, Region 2 = Southern Great Plains, Region 3 = Sierra Madre Occidental, Region 4 = Central Plateau, Region 5 = Sierra Madre Oriental, Region 6 = Balsas Basin Complex) This procedure allowed for a regional assessment of model error with regards to the chosen surface climate variables. The statistical significance in the differences between model mean bias values was assessed at the 95% level using a Mann-Whitney test.

Upper Level Evaluation

Monthly mean profiles of temperature, specific humidity and equivalent potential temperature at mandatory levels were compared between the model and 7 sounding station observations in Mexico and the U.S.: Chihuahua (MCV), Guaymas (GYM), Mazatlan (MZT), Manzanillo (MAN) and Guadalajara (GUD), Tucson, AZ (TUS) and Del Rio, TX (DRT). No spatial averaging was performed on the upper air variables.

Figure 1 Nested Model Domain and Analysis Subregions



Section 3: Results

Surface Climate Evaluation

Regionally averaged error statistics of surface temperature, dewpoint temperature, and precipitation are given in Table 2. It is immediately noticed that there is a universal tendency for the negative bias in Td to be greater in GR and BMJ as opposed to KF, thus indicating a drier surface climate in the GR and BMJ schemes. The overall negative bias in Td seems to indicate the model, regardless of cumulus scheme, is having increased difficulty establishing low level moisture over the NAM especially in regions on the northern periphery of the system.

The error statistics for Tav are similar to those for Td, although none of the inter-simulation differences in mean biases are statistically significant at 95%. For this variable, the RMSE (not given) in Region 0 is greatest in the simulation with the BMJ scheme, followed by that with the GR then the KF schemes. In all the simulations, the errors are greatest in Region 2 (the southern Great Plains) followed by those in Region 1. There is less consistency in the RMSE values for T_{av} in Regions 3, 4, 5, and 6, in Mexico, than in the regions within the U.S.

Upper Level Evaluation

The RMSE and mean bias statistics for specific humidity and equivalent potential temperature averaged over all stations and at all levels are given in Table 3. Statistically significant differences between mean biases, at the 95% level, are denoted by the special marks next to each simulation title. Significance in the upper are variable differences was tested using a Students t-test adjusted for unequal variances.

There are substantial differences between each station error profile but also some common features (see Gochis et al, 2001 for plots of profiles). As

Regionally averaged surface daily average dew point statistics (deg C)

		BIAS		
		BM ^	*KF **	*GR "*
Jul-99				
Region:	0	-3.8	-2.0	-4.5
	1	-6.8	**-3.7 "**	**-9.2 ***
	2	-4.3	-1.9	-4.5
	3	-2.5	-1.7	-2.3
	4	-2.5	-0.9	-2.7
	5	1.8	-1.3	-2.4
	6	-1.1	-0.7	-1.4

Regionally averaged surface daily average temperature bais (deg C)

		BIAS		
		BM ^	*KF **	*GR "*
Jul-99				
Region:	0	2.0	0.7	1.8
	1	1.9	-0.2	2.0
	2	4.1	2.2	3.6
	3	-0.4	-1.4	-0.6
	4	0.5	-0.8	0.3
	5	1.2	0.3	0.6
	6	-0.4	-0.9	-0.3

Regionally averaged total precipitation statistics (mm)

		BIAS		
		BM ^	*KF **	*GR "*
Jul-99				
Region:	0	**17.5 * "**	**27.6 ^ "**	**-49.8 ^ ***
	1	**-44.2 * "**	**6.8 ^ "**	**-74.6 ^ ***
	2	**-34.5 * "**	**21.1 ^ "**	**-32.9 ^ ***
	3	**171.3 * "**	**96.3 ^ "**	**-3.5 ^ ***
	4	**21.6 * "**	**48.8 ^ "**	**-64.5 ^ ***
	5	**-38.8 * "**	**-5.0 ^ "**	**-89.5 ^ ***
	6	**169.8 * "**	**52.5 ^ "**	**-15.1 ^ ***

Table 2. Regional Mean Model Biases. Special symbols (*, ^, ") indicate which mean biases are significantly different from another at the 95% level.

reported by Gochis et al., (2000), the model run using the GR scheme consistently produces atmospheric structures that are cooler and drier than observed, especially at mid-levels and at northernmost stations (e.g. TUS, DRT, GYM and MCV). This is reflected by the overall negative biases in temperature, specific humidity, and equivalent potential temperature

The BMJ simulation tends to produce a July-mean atmosphere that is cooler and drier than observed, although less pronounced than with the GR scheme. It is clear from Table 3 that using the KF scheme yields a modeled atmosphere that most resembles observations. When averaged over all

	Specific Humidity		Theta-e	
	RMSE	BIAS	RMSE	BIAS
	(kg kg-1)	(kg kg-1)	(K)	(K)
BMJ ^	0.0008	-0.004 *	3.1	-1.8 *
KF *	0.0006	0.0000 ^ "	2.6	0.3 ^ "
GR "	0.0010	-0.0006 *	3.8	-2.8 *

Table 3. Monthly model root-mean-square-errors and mean biases for all stations at all levels. Symbols denote significantly different mean bias values at the 95% level.

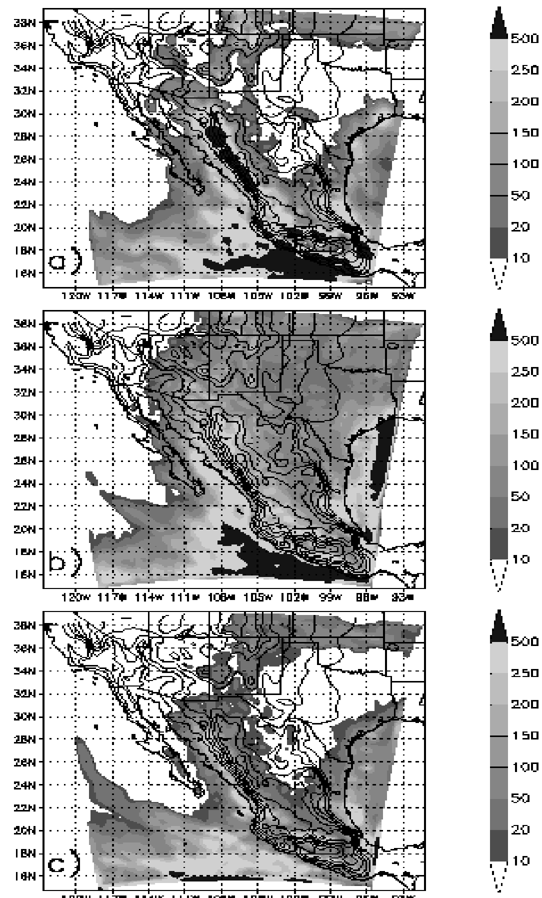
measurements, the net bias when using the KF scheme is small and is significantly better than either the BMJ or the GR simulations at the 95% level.

Using error profiles of equivalent potential energy convective stability was assessed. In most cases (except for TUS and MZT) the simulation using GR maintains a less stable atmosphere than observed, which is largely due to cooler and drier air at mid-levels. Longitude/height transects of equivalent potential temperature at three different latitudes (not shown) as well as plots of convective available potential energy (CAPE) also reveals this feature. The results using the BMJ and KF schemes do not show such a consistent tendency.

Precipitation Evaluation
Figure 2 shows the spatial distribution of modeled precipitation from the three simulations. Clearly the simulation with the KF scheme produces more extensive precipitation than with either the BMJ or GR schemes. There is a substantial difference in the magnitude and extent of the modeled rainfall over Arizona, New Mexico, Texas, Oklahoma, and central Mexico. The mean bias for precipitation given in Table 2 shows errors are lowest with the KF scheme in Regions 1, 2, and 5, although this scheme slightly overestimates precipitation in these regions. Note that all inter-simulation differences in regional mean biases are significant at the 95% level.

Several features of the precipitation fields are worth noting. First, there appears to be substantial discrepancy in the estimation of precipitation in Region 3, the core of the monsoon region along the western slopes of the Sierra Madre Occidental. RMSE statistics (not provided) indicate a substantial error, with a significant positive bias in the simulation with the BMJ scheme and, to a lesser degree, the KF scheme. With the GR scheme, the RMSE is less than that with both BMJ and KF schemes and its mean bias is close to zero. Second, the simulation with the KF scheme appears to suffer from a boundary condition problem along the eastern boundary of the inner domain where a monthly total precipitation in excess of 500mm is

Figure 2. Modeled Monthly Precipitation (mm) for July 1999 and orographic contours. a) BMJ, b) KF, c) GR



simulated. Such a feature is due to interaction between the convection scheme and the model boundary condition as found in Stensrud et al. (1995). Finally, both the KF and the BMJ schemes appear to markedly over-estimate rainfall along the southwest coast of Mexico. The exact cause of this feature is unknown at this writing.

Integrated Moisture Flux Patterns
Stationary, vertically integrated moisture flux patterns (not shown) for July of 1999 showed some substantial differences along with some similarities. The Great Plains low-level jet is clearly the dominant feature in each simulation. Each simulation also possesses locally strong moisture fluxes emanating northward out of the northern Gulf of California. However, while both the BMJ and the KF simulations were able to produce continuous, albeit weak flux patterns northwestward up the entire Gulf of California from the eastern tropical Pacific, the GR simulation failed to produce any such similar pattern. It is suspected that the lack of moisture flux into the northern NAM regions in the GR scheme is partly responsible for its comparatively large dry bias. Similar to other recent analyses of moisture transport over the NAM region the transient

component of the integrated moisture flux was approximately an order in magnitude smaller than the stationary component except over the northern Gulf of California.

Section 4: Summary

The following points summarize the results of the model analyses and are presented in two forthcoming articles (Gochis et al 2001a, (under review); Gochis et al 2001b (in preparation):

- Substantial differences in both the thermodynamic and circulation structure of the simulated July 1999 NAM atmosphere evolve when different CPS schemes are used.
- In addition to entire-domain error tendencies, sub-regional error tendencies are also prevalent and many of the inter-simulation differences are statistically significant.
- As reported by Gochis et al (2000), the MM5 simulation using the GR scheme yields an atmosphere in July 1999 that is drier than observed in terms of lower and upper tropospheric moisture content and precipitation.
- MM5 simulations with both the BMJ and GR schemes give a marked underestimation of convective precipitation in the northern and interior NAM regions, the KF simulation shows only a slight positive bias across these same regions.
- The error in the modeled surface dewpoint temperature field is greater in the northern monsoon regions than in other regions, regardless of the convective scheme used. The error is greatest in these regions for the simulation with the GR scheme, followed by that with the BMJ scheme, while the error with the KF scheme is least.
- As a result of the difference in the CPS's, markedly different regional circulation patterns evolve which are revealed in the integrated low-level streamline and divergence fields (not shown). The KF scheme results in a broader distribution of low-level convergence which, extends into central Mexico and into the southwestern U.S. In contrast, convergence is more localized and locked primarily to the highest topographic features when both the BMJ and GR schemes are used.
- Large differences occur in the mean low-level wind structure between the three simulations. The KF simulation maintains a continuous flow of southeasterly low-level wind across the eastern GC that appears to transport moisture from far south of the mouth of the GC. Southeasterly flow is confined to portions of the eastern GC in the BMJ simulation and is almost absent in the simulation with the GR scheme.
- Differences in the circulation fields result in markedly different fields of column-integrated precipitable water. Apparently, appreciable whole-column water vapor is advected northward into Arizona and the central Mexican plateau only when the KF scheme is used in MM5.

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