J6.2 EVALUATION OF A RAPIDLY RELOCATABLE HIGH-RESOLUTION NUMERICAL MODEL FOR METEOROLOGICAL NOWCASTING BASED ON MM5

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1. INTRODUCTION

Short-term high resolution weather forecasts and nowcasts are increasingly important to the nation's economy, public safety and homeland defense. It is now quite common to require very fine-scale *nowcast* guidance (0 - ~30 min) and short-term forecasts (out to several hours) over specific areas of 1-5 km or even less. How to best provide accurate short-term highly localized predictions is a vital area of research. Generally, it is unacceptable to merely use existing models designed for mesoalpha-scale applications at much finer scales because in many cases the internal physical parameterizations may not be suitable for finer grids. Moreover, traditional static initializations of synoptic and mesoscale forecasts can require several hours to approach equilibrium states. If the time horizon of interest is 0-3 h, then the dynamic adjustments during this "spin-up" period can severely damage the accuracy of the model solutions.

2. NOWCAST MODEL DESCRIPTION

To address the need for timely high-resolution meteorological guidance, a versatile *Relocatable Nowcast/Prediction System (RNPS)* has been developed at Penn State Univ. In this paper we focus solely on the nowcast mode of the system. The RNPS is designed around a full-physics version of the Penn State/NCAR MM5 (Grell et al. 1994) that has undergone code optimizations to reduce its computational demand by ~20%. Triply nested grids of 36-, 12- and 4-km are used in the numerical RNPS, each having 30 layers in the vertical direction. The model top is at 50 hPa The outermost domain covers an area of 3600 X 3600 km. The nested 12-km domain covers 1500 X 1500 km and the innermost 4-km domain covers 500 X 500 km.

The model physics for resolved-scale precipitation includes explicit prognostic equations for the mixing ratios of cloud water/ice (q_c) and rain/snow (q_r). Sub-grid deep convection is parameterized on the 36-km and 12-km domains using the Kain-Fritsch scheme. All precipitation processes are assumed to be resolvable on the 4-km domain (no parameterized convection). The turbulence is represented in the RNPS using a 1.5-order closure scheme that explicitly predicts the turbulent kinetic energy (TKE) (Shafran et al. 2000). Long- and short-wave radiation contributions to temperature tendencies are calculated using a full-column broadband two-stream method.

Figure 1 shows a schematic diagram for the main program functionality and the flow of data through the RNPS. The system runs on a 30-min cycle. The processing of initial conditions and boundary conditions (IC/BCs) is shown at the top of the figure and currently is based the U.S. Navy's NOGAPS global model. A "Conveyor Belt" module is used to store the incoming NOGAPS fields and select for processing those needed by the MM5 at the current time. The IC/BC Generator allows the RNPS to be initialized at any current wall clock time, rather than at specific traditional times (0000 and 1200 UTC). Meanwhile, a real-time data stream, such as Unidata, supplies the incoming observations (lower part Fig. 1). The GateKeeper module selects for processing only the newest observations arriving in the past 30 minutes. These new data are quality-checked in the Rawins-QC module. To reduce numerical errors RNPS performs *real-time* four-dimensional data assimilation (FDDA), a unique approach in that the assimilation occurs only *after* the obs-time. That is, new observations are blended directly into the MM5 solutions as the model runs based on the "observation-nudging" technique of Stauffer and Seaman (1994). The Prepobs/Chronobs module collects all the quality-checked observations processed during the previous 4 h (the maximum allowed data "staleness") and projects them onto the model grids for the MM5's FDDA module.

The RNPS can run in real time on a dual-processor 933-MHz PC computer, producing a new meteorological nowcast of current conditions every 30 minutes. C-shell scripts are used to automate the execution sequence. The model domains can be relocated anywhere in the world in less than 5 minutes by an operator with little or no meteorological training.

3. APPLICATION METHODOLOGY

Model evaluation was based primarily on statistical analysis of hundreds of RNPS nowcasts run for two test periods, one for the warm season and another for the cold season. During 1-18 August 2001 the model domains were centered over southwest OK and covered much of the Great Plains. For 8-21 March 2002 the domains were shifted to place the center over Aberdeen, MD, on the East Coast. During these test periods, the RNPS was reinitialized at various intervals, so that nowcast segments were generated continuously for periods anywhere from 6 h to 120 h. This allowed evaluation of how errors accumulate over time in the RNPS nowcasts (discussed in Stauffer et al. 2002).

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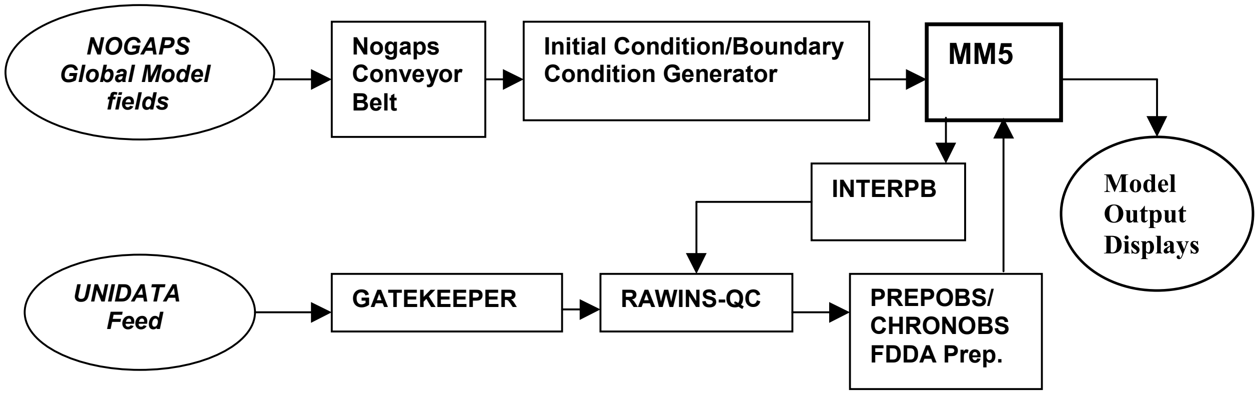

Figure 1. Schematic showing initialization and data flow through the RNPS system.

For the August 2001 test period, two sets of experiments were run. First, in Exp. FDDA the RNPS was run as described in Sec. 2. Second, in Exp. CNTL the RNPS was run with the real-time FDDA turned off. This made it possible to learn if application of FDDA in real time could reduce error growth or whether it would simply slow the propagation of weather systems and thus contribute to greater errors. The East Coast test period also consisted of two experiments, but here a comparison was made between the impact of the broad-band radiation scheme and the Rapid Radiative Transfer Model (RRTM) in MM5. Both East Coast experiments used the real time FDDA capability of the RNPS. Lastly, a simple time-and-space based post-processing system was applied to a sample nowcast run over the East Coast domains to investigate the potential for reduction of errors following completion of the numerical nowcasts. In the post-processor known error characteristics of RNPS calculated from the past are saved and applied to correct for errors in current nowcasts. Comparison of nowcast accuracy was made with and without the post-processing approach.

4. EVALUATION OF RESULTS

Before presenting the results of the statistical evaluations, we first examine the general level of model performance by making a visual comparison of analyzed fields and nowcasted fields generated by the RNPS. Figure 2 shows the NCEP surface analysis for 2100 UTC, 14 June 2001. At that time a high pressure ridge over the Rocky Mts. was pushing a cold front eastward across the Great Plains roughly in the middle of the warm-season RNPS domains. Isolated severe thunderstorms were reported just ahead of the cold front in OK and TX on this afternoon. Figure 3 shows the RNPS 4-km nowcast cold front and accompanying surface winds at 2100 UTC. The nowcast winds and frontal position agree well with the analysis and show details along the front not evident in the more sparse NWS data. The RNPS also produced isolated showers just ahead of the front and strong cold advection in the cold air behind it, as observed (not shown).

Tables 1 and 2 summarize the RNPS statistical performance for the 1-18 August 2001 period using the mean absolute error (MAE) and mean error (ME). This 18-day period was dominated by a very large persistent quasi-stationary upper-level circulation and high heights centered over OK. The deep ridge led to very light winds and variable directions through the troposphere. RNPS wind speed and direction errors in the surface and boundary layer of Exp. FDDA (Table 1) are similar to those commonly reported for data-assimilated model fields of warm season cases in air quality studies (Seaman 2000). However, surface and boundary layer temperature and moisture errors in Exp. FDDA (Table 2) are slightly larger than for recent air quality modeling simulations. Compared to Exp. CNTL, it is clear that use of real-time FDDA reduces errors for all variables.

Next, Tables 3 and 4 show the RNPS wind and mass field statistical performance on the East Coast for 8-21 March 2002. Since there was very little difference in the results with the broad-band radiation versus the RRTM, only the latter are shown in these tables. Finally, Tables 5 and 6 compare statistics with and without a simple post-processor to address the errors in the raw RNPS results. The test is run for 00 UTC, 16 April 2002 and verification is done at a special upper air site in MD (39.4 N, -76.5 W) which was withheld from both the FDDA and the post-processor. Overall, in this example the post-processor reduces model errors through the depth of the atmosphere by about one-third.

5. SUMMARY AND FUTURE DIRECTIONS

A real-time relocatable nowcast system has been evaluated and shown to have potential benefits for providing short-term meteorological nowcasts at very fine (4-km) resolution. The use of FDDA techniques in real time has been shown to reduce errors for all primary variables and application of even simple post-processing techniques can significantly reduce errors remaining in the RNPS nowcasts. With modest effort, the current demonstration system can be improved in the areas of data ingest, sub-grid physics, the FDDA approach, and post-processing. The data can be

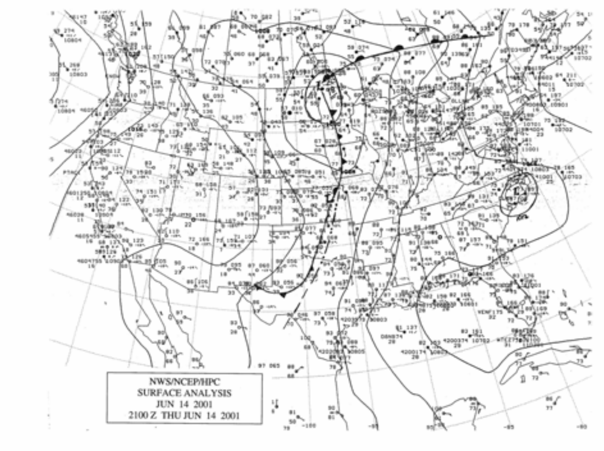

Figure 2. NCEP Surface analysis at 2100 UTC, 14 June 2001.

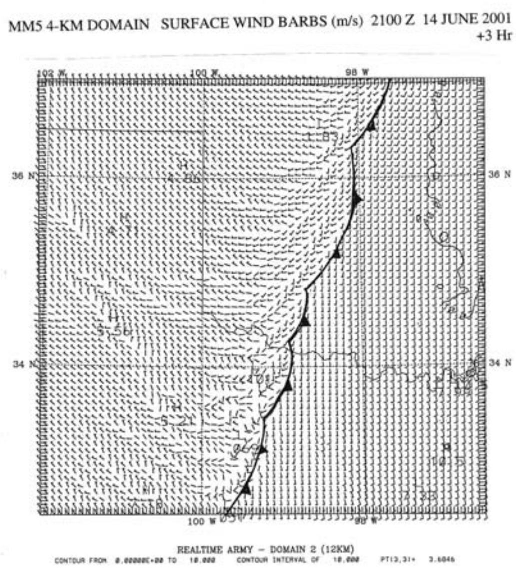

Figure 3. Surface layer winds (ms^{-1}) over TX & OK on the 4-km domain at 2100 UTC, 14 June 2001, after the RNPS had been running for 3 h. Full barb = 10 ms^{-1}.

augmented by adding satellite cloud-tracked and vapor-tracked winds, ACARS winds, etc. The FDDA scheme can be improved by developing strategies for assimilating mass field data in the PBL. More thorough post-processing of the nowcasts would help reduce the remaining biases. Future work will investigate RNPS performance for short-range forecasts of 0-3 h.

6. ACKNOWLEDGEMENTS

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Table 1. Verification of nowcasted winds simulated by the RNPS on 4-km domain vs. observations over the Great Plains for 1-18 Aug. 2001. RNPS runs are 6-120 h in length. Bold indicates experiment with best results.

Exp. Name	MAE VWD (m/s)	MAE Wind Spd (m/s)	ME Wind Spd (m/s)	MAE Wind Dir (deg)	ME Wind Dir (deg)
Stratosphere (10500-20000 m AGL)					
CNTL	5.78	3.35	-0.54	31.7	**+6.6**
FDDA	**5.42**	**3.02**	**+0.04**	**30.3**	+8.7
Upper Troposphere (5000-10500 m AGL)					
CNTL	5.37	3.17	-0.48	29.6	**+1.3**
FDDA	**4.34**	**2.57**	**+0.16**	**21.0**	+3.8
Lower Troposphere (1000-5000 m AGL)					
CNTL	4.68	2.31	-0.56	43.0	-5.0
FDDA	**3.85**	**1.98**	**-0.10**	**33.5**	**-2.0**
Boundary Layer (80-1000 m AGL)					
CNTL	5.16	2.68	+0.92	45.2	**+3.4**
FDDA	**4.26**	**2.16**	**+0.37**	**39.8**	+7.8
Surface Layer (40 m AGL)					
CNTL	3.79	2.21	+1.46	53.2	+11.8
FDDA	**2.80**	**1.60**	**+0.55**	**46.6**	**+2.3**

Table 2. Verification of nowcasted mass fields simulated by the RNPS on 4-km domain vs. observations over the Great Plains for 1-18 Aug. 2001. RNPS runs are 6-120 h in length. Bold indicates experiment with best results.

Exp. Name	MAE T (^{o}C)	ME T (^{o}C)	MAE q_v (g/kg)	ME q_v (g/kg)	MAE SLP (hPa)	ME SLP (hPa)
Stratosphere (10500-20000 m AGL)						
CNTL	2.19	1.57	0.02	0.02	N/A	N/A
FDDA	**1.26**	**0.84**	**0.02**	**0.01**	N/A	N/A
Upper Troposphere (5000-10500 m AGL)						
CNTL	0.95	0.50	0.46	-0.21	N/A	N/A
FDDA	**0.87**	**0.50**	**0.40**	**-0.18**	N/A	N/A
Lower Troposphere (1000-5000 m AGL)						
CNTL	1.32	**0.15**	2.09	-1.21	N/A	N/A
FDDA	**1.05**	0.26	**1.63**	**-0.47**	N/A	N/A
Boundary Layer (80-1000 m AGL)						
CNTL	2.15	-1.14	1.70	-0.19	N/A	N/A
FDDA	**1.86**	**-0.39**	**1.67**	**-0.17**	N/A	N/A
Surface Layer (40 m AGL)						
CNTL	2.40	-0.52	2.17	-1.60	1.33	-0.39
FDDA	**2.37**	**0.08**	**2.02**	**-1.51**	**1.20**	**-0.37**

Table 3. Verification of nowcasted winds simulated by the RNPS on 4-km domain vs. observations over the East Coast for 8-21 March 2002. RNPS runs are 4-24 h in length and use the RRTM for longwave radiation.

Exp. Name	MAE VWD (m/s)	MAE Wind Spd (m/s)	ME Wind Spd (m/s)	MAE Wind Dir (deg)	ME Wind Dir (deg)
Stratosphere (10500-20000 m AGL)					
RRTM	7.25	5.71	1.924	6.1	-2.7
Upper Troposphere (5000-10500 m AGL)					
RRTM	5.20	3.74	+0.79	6.7	-2.7
Lower Troposphere (1000-5000 m AGL)					
RRTM	5.02	3.82	+0.69	16.6	-5.2
Boundary Layer (80-1000 m AGL)					
RRTM	4.00	3.17	+1.54	21.6	-10.1
Surface Layer (40 m AGL)					
RRTM	2.52	1.83	+0.89	28.4	+1.8

Table 4. Verification of nowcasted mass fields simulated by RNPS on 4-km domain vs. observations over the East Coast for 8-21 March 2002. RNPS runs are 4-24 h in length and use the RRTM for longwave radiation.

Exp. Name	MAE T (^oC)	ME T (^oC)	MAE qQ_v (g/kg)	ME q_v (g/kg)	MAE SLP (hPa)	ME SLP (hPa)
Stratosphere (10500-20000 m AGL)						
RRTM	1.69	0.45	0.01	0.00	N/A	N/A
Upper Troposphere (5000-10500 m AGL)						
RRTM	1.18	0.64	0.13	0.01	N/A	N/A
Lower Troposphere (1000-5000 m AGL)						
RRTM	1.38	0.04	0.63	-0.24	N/A	N/A
Boundary Layer (80-1000 m AGL)						
RRTM	1.94	-0.59	0.87	0.25	N/A	N/A
Surface Layer (40 m AGL)						
RRTM	2.07	-0.53	0.69	0.39	1.56	-0.69

Table 5. Verification of raw nowcasted and post-processed winds simulated by the RNPS on 4-km domain vs. observations over the East Coast at 00 UTC, 16 March 2002 following 11.5-h run of RNPS.

Exp. Name	MAE VWD (m/s)	MAE Wind Spd (m/s)	ME Wind Spd (m/s)	MAE Wind Dir (deg)	ME Wind Dir (deg)
Stratosphere (10500-20000 m AGL)					
RAW	5.78	3.35	-0.54	31.7	**+6.6**
Post-P	**1.81**	**1.25**	**-0.35**	**3.7**	-1.8
Upper Troposphere (5000-10500 m AGL)					
RAW	5.37	3.17	-0.48	29.6	**+1.3**
Post-P	**3.22**	**1.68**	**+0.61**	**9.10**	+8.7
Lower Troposphere (1000-5000 m AGL)					
RAW	4.68	2.31	-0.56	43.0	-5.0
Post-P	**3.60**	**2.08**	**1.44**	**9.3**	**7.3**
Boundary Layer (80-1000 m AGL)					
RAW	5.16	2.68	+0.92	45.2	**+3.4**
Post-P	**3.10**	**2.78**	**+1.03**	**12.1**	-8.7
Surface Layer (40 m AGL)					
RAW	3.79	2.21	+1.46	53.2	+11.8
Post-P	**2.23**	**1.47**	**-0.57**	**30.3**	**-30.3**

Table 6. Verification of raw nowcasted and post-processed mass fields simulated by the RNPS on 4-km domain vs. observations over the East Coast at 00 UTC, 16 March 2002 following 11.5-h run of RNPS.

Exp. Name	MAE T (^oC)	ME T (^oC)	MAE q_v (g/kg)	ME q_v (g/kg)	MAE SLP (hPa)	ME SLP (hPa)
Stratosphere (10500-20000 m AGL)						
RAW	1.34	0.86	0.01	**0.00**	N/A	N/A
Post-P	**0.88**	**-0.09**	**0.01**	0.01	N/A	N/A
Upper Troposphere (5000-10500 m AGL)						
RAW	0.77	**0.22**	0.19	0.06	N/A	N/A
Post-P	**0.59**	0.48	**0.07**	**-0.01**	N/A	N/A
Lower Troposphere (1000-5000 m AGL)						
RAW	**0.85**	**0.56**	1.15	-0.70	N/A	N/A
Post-P	1.03	1.03	**0.84**	**-0.66**	N/A	N/A
Boundary Layer (80-1000 m AGL)						
RAW	1.41	**-0.05**	1.34	**-0.43**	N/A	N/A
Post-P	**0.93**	-0.93	**0.53**	0.47	N/A	N/A
Surface Layer (40 m AGL)						
RAW	2.06	**-0.31**	1.20	**-0.51**	1.78	-1.76
Post-P	**1.44**	1.44	**1.88**	1.88	**0.44**	**0.44**

7. REFERENCES

Grell, G.A., J. Dudhia and D.R. Stauffer, 1994: A description of the 5th-generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech Note NCAR/TN-398+STR, 121 pp.

Shafran, P.C., N.L. Seaman and G.A. Gayno, 2000: Evaluation of numerical predictions of boundary layer strucutre during the Lake Michigan Ozone Study. *J. Appl. Meteor.*, **39**, 412-426.

Stauffer, D.R., N.L. Seaman, A.J. Schroeder, A. Deng, A.M. Gibbs and G.K. Hunter, 2002: Evaluation of a rapidly relocatable high-resolution numerical model and data assimilation system for meteorological nowcasting. 12th MM5 Users' Workshop. 24-25 June, Boulder, CO, 4 pp.

Seaman, N.L., 2000: Meteorological modeling for air-quality assessments. *Atmos. Envn.*, **34**, 2231-2259.

Stauffer, D.R., and N.L. Seaman, 1994: Multiscale four-dimensional data assimilation. *J. Appl. Meteor.*, **33**, 416-434.