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THE NCEP NORTH AMERICAN MESOSCALE MODELING SYSTEM: FINAL ETA MODEL / ANALYSIS CHANGES AND PRELIMINARY EXPERIMENTS USING THE WRF-NMM

Eric Rogers* Ying Lin Kenneth Mitchell Wan-Shu Wu
National Centers for Environmental Prediction

Brad Ferrier George Gayno Manuel Pondeca Matthew Pyle Vince Wong
Science Applications International Corporation /
National Centers for Environmental Prediction

Michael Ek
University Corporation for Atmospheric Research /
National Centers for Environmental Prediction

1. INTRODUCTION

On 3 May 2005 the final set of changes to the Eta model/analysis component of the North American Mesoscale (NAM, formerly Eta) forecast system was implemented at NCEP. Changes to the Eta forecast model were also incorporated into the Downscaled GFS by Eta Extension (DGEX), which extends the ops NAM run over the CONUS (06z and 18z cycles) and Alaska (00z and 12z cycles) to 192-h.

2. CHANGES TO NAM DATA ASSIMILATION SYSTEM (NDAS)

2.1 *Assimilation of Surface Temperatures Data over Land*

Experiments conducted in the summer of 2003 (not shown) indicated that the assimilation of surface temperature observations over land in the NAM assimilation system (NDAS) caused occasional degraded Eta model forecasts. It was determined that the Eta 3DVAR analysis, using the step mountain coordinate, had difficulty in limiting the vertical influence of surface data. For this reason use of surface temperature data over land was turned off in the NDAS in September 2003.

To overcome this problem, a 2DVAR module to assimilate surface temperatures in the Eta 3DVAR was developed. This module consists of a univariate analysis performed on the first eta model level above ground, with background error correlations reformulated to take into account the Eta step-mountain orography. With these changes, the vertical influence of surface temperature increments is restricted to near the first Eta layer above the surface. Preliminary testing of the 2DVAR module at 32-km resolution (not shown) during the summer of 2004 showed none of the negative impact seen during the previous summer.

Corresponding Author Address: Eric Rogers, NOAA/NWS/NCEP, World Weather Building, 5200 Auth Road, Camp Springs, MD 20746. eric.rogers@noaa.gov

2.2 *Assimilation of NEXRAD Level II.5 radial wind "super" observations*

Assimilation of radial wind information from the WSR-88D radars was first implemented into the operational NAM in July 2003 (Ferrier *et al.*, 2003). Observations for the first four radar tilt angles (0.5, 1.5, 2.5, and 3.5 degrees) were obtained from the NWS Multicast of the NEXRAD Information Dissemination Service (NIDS) Level III products gathered from all WSR-88D sites.

Ideally, use of the raw Level II data directly from each WSR-88D site would be preferable for operational data assimilation. Use of the large volume of Level II data is hampered by bandwidth concerns and the technical problems of using such large amounts of data efficiently in an operational NWP assimilation system.

Alpert *et al.* (2004) describes the new Level II.5 radial wind super observations, which is an improvement in precision and information content compared to that from the Level III NIDS data. The Level II.5 data is created by constructing super observations from Level II data at each WSR-88D site before transmission using Open Systems RPG software (Alpert *et al.*, 2003). By early July 2005, 1-1.5 million individual Level II.5 radial wind super-obs are ingested into the 3-hourly NDAS analysis, approximately 10-15 times higher then the Level III data used prior to 3 May 2005.

2.3 *Modifications to Precipitation Assimilation*

Assimilation of observed precipitation in the NAM system was implemented in July 2001 (Rogers *et al.*, 2001). The original philosophy, as described by Lin et al. (2001) was to nudge Eta model fields into greater consistency with the observed precipitation during the NDAS via adjustment of the model's latent heat, moisture, and cloud water fields.

The precipitation assimilation in the NDAS has been refined in recent years by the use of the radar and gauge-based Level II/IV analyses (Lin and Mitchell, 2004) and implementation of a water-budget based bias adjustment to overcome a dry bias in the Level II/IV analyses (Lin et al., 2004). However, the original assimilation technique was designed to work with simple cloud microphysics whose response to small 'nudges' was relatively linear. In November 2001, the precipitation assimilation underwent extensive changes so it would work in tandem with a much more sophisticated cloud and precipitation package (Rogers et al, 2001) Under the November 2001 system, the grid-scale adjustment undergoes an iterative process to give the model a chance to adapt to the adjustment more smoothly. This cloud physics / precipitation assimilation pairing is highly complex and difficult to adapt to further changes to model cloud physics or additional hydrometeor-related observations.

To better adapt to increasingly sophisticated model physics and future NWP systems (e.g., WRF), the NDAS precipitation algorithm has been changed to be less aggressive in modifying the Eta model precipitation during the NDAS. The new precipitation assimilation retains the part that reduces latent heat and moisture fields when the model precipitation is greater than observed precipitation ($P_{mod} > P_{obs}$), while eliminating/simplifying the part where latent heat and moisture fields are increased/created (when $P_{mod} < P_{obs}$), since we can perform the former adjustment with far more confidence than we do with the latter (especially in the case when $P_{obs} > 0$ but $= P_{mod} < 0$). Under the 'scaled back' system, the model precipitation during NDAS will not be as close to observations as before. We can avoid any negative impact on soil moisture by using the hourly observed precipitation (partitioned to physics time steps) as the driver to model soil moisture field instead. To keep track of how much precipitation is fed into the soil, we keep a separate array to hold the cumulative "NDAS soil moisture-driving precipitation" (ESMDP), which, at each physics time step, is incremented by the observed precipitation allocated to this time step if precipitation assimilation is done, and by the model precipitation if otherwise. The 3-hour accumulation of ESMDP is also used (instead of 3-hourly NDAS precipitation) to compile a precipitation budget-history file used in bias-adjustment of hourly precipitation input (Lin et al., 2004).

Parallel tests of the new precipitation assimilation technique showed a neutral to slightly positive impact on QPF scores (not shown). NDAS soil moisture (Fig. 1) tends to be moister with the new technique since the previous system tended to have a dry bias because the adjusted NDAS precipitation did not exactly replicate the observed precipitation.

3. CHANGES TO ETA MODEL PHYSICS

3.1 Land-surface Model

Changes to the Noah Land-Surface Model (LSM, Ek *et al.*, 2003) in the Eta model were made to address the following low-level temperature/humidity issues:

- Summer: warm/dry bias during day, typically over areas with larger greenness fractions
- Summer: drying trend in precipitable water and low level moisture with forecast range
- Winter: cold bias during night, typically under calm/clear conditions especially over snow pack, and during day over shallow/melting snow pack

LSM changes more relevant to warm season issues include:

- Vegetation type: replace SiB 13-class 1-degree lat/lon data with high-resolution (1 km) 24-class database from USGS
- Soil type: Replace Zobler 9-class 1-degree lat/lon data with USDA STATSGO 16-class 1-km resolution database
- Bottom soil temperature: Replace 2.5 degree GFS database with 1-degree database from NCAR
- Adjust canopy conductance, minimum stomatal conductance, and other vegetation parameters which were previously tuned to maintain reasonable evaporation rates given low soil moisture biases which were removed by modifications to the precipitation assimilation algorithm
- Change to coefficient in thermal-roughness length calculation to reduce skin temperature, and hence lower the diagnosed 2-m air temperature

LSM modifications more relevant to cold season conditions include:

- In patchy snow cover conditions:

- changes to snow cover fraction (less snow depth for 100% cover)
- remove vegetation greenness factor from snow albedo formulation (leads to higher albedos)
- For the surface skin temperature formulation, give more weight given to non-snow covered portion, yielding a higher temperature since most of the sensible heat flux comes from the non-snow covered portion
- Separate snow sublimation and non-snow-covered evaporation is now considered when snowpack is shallow, reducing snow sublimation and snowcover depletion

- Added the effects of snow emissivity in the calculation of effective snow-ground surface temperature
- In very stable conditions when PBL depth equals height of the lowest Eta model level, impose lower limit on eddy diffusivity up to (and one level above) inversion height

The impact of the land-surface model changes on August 2004 Eta forecasts of near surface variables is shown in Fig. 2 (2-m temperature) and Fig. 3 (2-m RH). For this test, a 32-km EDAS/Eta run identical to the ops Eta model/analysis was compared to a 32-km parallel test with these LSM changes. The 12z forecast examples shown in Fig. 2 and 3 indicate a reduced warm bias and higher RH in both the Eastern and Western CONUS. In the eastern CONUS, a pronounced drift of the 32-km Eta control RH dry bias with increasing forecast hour was eliminated with the LSM changes.

3.5 Clouds / radiation

Two changes have been made to the Eta model to improve the treatment of clouds:

- The radiation scheme has been modified to "see" thicker clouds by removing the upper limit for cloud mixing ration when computing optical depths
- The cloud cover fraction formulation has been modified to allow for more partial cloudiness (had been too "binary")

Figs 4-6 show an example of the impact of the radiation change. 6-h forecasts of instantaneous surface shortwave flux from the operational and parallel NAM (designated NAMX) valid 18Z 2 February 2005 (Fig. 4) and the corresponding components of the NAMX total condensate field (Fig 5) shows the NAMX downward shortwave flux to be lower in the circled regions of significant total column cloud water/rain. This leads to lower 2-m temperatures in the NAMX in the circled snow-free region (Fig. 6).

4. TWO FORECAST EXAMPLES

Two examples are presented to illustrate the impact of the NAM change package on surface temperature forecasts. Fig. 7 shows the operational NAM and parallel NAMX 30-h forecast of 2-m temperature valid 18Z 4 January 2005. Comparison to the observed surface temperatures (Fig. 8) shows that the NAMX forecast did better in predicting both the position of the frontal boundary across Oklahoma and in the location of the cold air surge behind the front (compare locations of 0-3°C white shading).

The impact of these model changes on medium range DGEX forecasts is seen in Fig. 9, which shows operational and parallel DGEX 180-h forecasts of 2-m temperature valid 18Z 19 April 2005. In this example the parallel DGEX is about 2-4C warmer across eastern North Carolina southward along the coast into Georgia. The surface temperature observations (Fig. 10) reveal that the temperatures at most locations in North and South Carolina away from the coast to be 26-31°C, closer to the parallel DGEX forecast, However, both the operational and parallel DGEX forecasts missed the 28°C+ temperatures in western North Carolina. Examination of the forecast total cloud cover in both DGEX runs (not shown) reveal < 10% total cloud fraction over this region, which implies that the temperature differences are driven by the changes to the NAM LSM.

5. PARALLEL TESTING AND QUANTITATIVE VERIFICATION STATISTICS

Extensive real-time and retrospective testing of the full NAM change package was performed for both the 0-84 h NAM and the 84-192 h DGEX forecasts:

- NAM : 17 July – 31 August 2004, 14 December 2004 – 24 April 2005
- DGEX : 1 January 2005 – 24 April 2005

Detailed quantitative verification statistics over for all of the above tests can be found on-line at http://wwwt.emc.ncep.noaa.gov/mmb/Spring2005.NAMUpgrade_newweb/Spring2005.NAMUpgrade.html

6. THE NORTH AMERICAN WRF-NMM

In March 2006 NCEP plans to change the NAM system, replacing the Eta forecast model with the WRF Non-hydrostatic Mesoscale Model (WRF-NMM, Janjic *et al.*, 2001, Janjic *et al.*, 2005, Black *et al.*, 2005). Differences between the Eta forecast model in the NAM and the WRF-NMM are outlined in Table 1. Additionally, the Eta 3DVAR analysis will be replaced by the Grid-point Statistical Interpolation (GSI, Wu *et al.*, 2002) analysis. The GSI, based on the NCEP Global Spectral Statistical Interpolation (SSI) analysis, performs the analysis in NAM grid space, replacing the spectral definition for background errors with a grid-point version based on recursive filters (Purser *et al.*, 2003).

Testing at NCEP of a cycled WRF-NMM assimilation / forecast system with the GSI analysis is ongoing at press time. An example of Eta vs. WRF-NMM performance for a significant event is given in Fig. 11, which shows a sequence of operational NAM and WRF-NMM (labeled NAMX) sea level pressure forecasts valid at 18Z 10 July 2005, near to the time of landfall of Hurricane Dennis just east of Pensacola, FL. For nearly all forecast cycles the WRF-NMM outperformed the operational NAM for both the track and intensity of Dennis. Examination of the 12Z 10 July 2005 forecast (not shown) revealed that even though the operational NAM initialized Dennis in the correct location, it still exhibited a westward bias, tracking the storm northwestward into Louisiana and taking the remnants as far west as Oklahoma.

Table 1: Comparison of Eta and WRF-NMM models

Eta	Feature	WRF-NMM
Hydrostatic	dynamics	Hydrostatic plus compete nonhydrostatic corrections
12-km E-grid	grid	10-km E-grid
60 step-mountain eta levels	Vertical coordinate	60 sigma-pressure hybrid levels
Unsmoothed with silhouette treatment	terrain	Unsmoothed grid-cell mean
Mellor-Yamada Lev 2.5 dry	Turbulent mixing	Mellor-Yamada Lev 2.5 w/moist processes
M-Y Lev 2/5 dry + Paulson functions	Surface exchange	M-Y Lev 2.5 moist + Holtslag and de Bruin functions
Noah LSM	Land-sfc	Noah LSM
GFDL	Radiation	GFDL (retuned)
Betts-Miller-Janjic	Convection	Betts-Miller-Janjic (retuned)
Two-step iterative scheme (Janjic, 1979)	Horizontal advection	Adams-Bashforth
Matsuno	Vertical advection	Crank- Nicholson
Ferrier	Cloud microphysics	Ferrier

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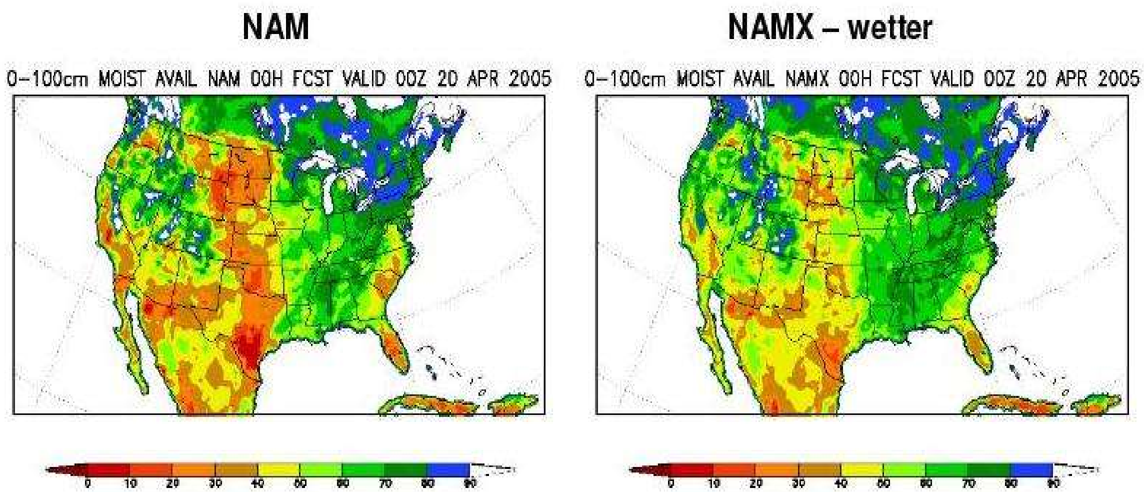

Figure 1: Operational NAM (left) and parallel NAM (right) 0-100 cm moisture availability (%) valid 0000 UTC 20 April 2005

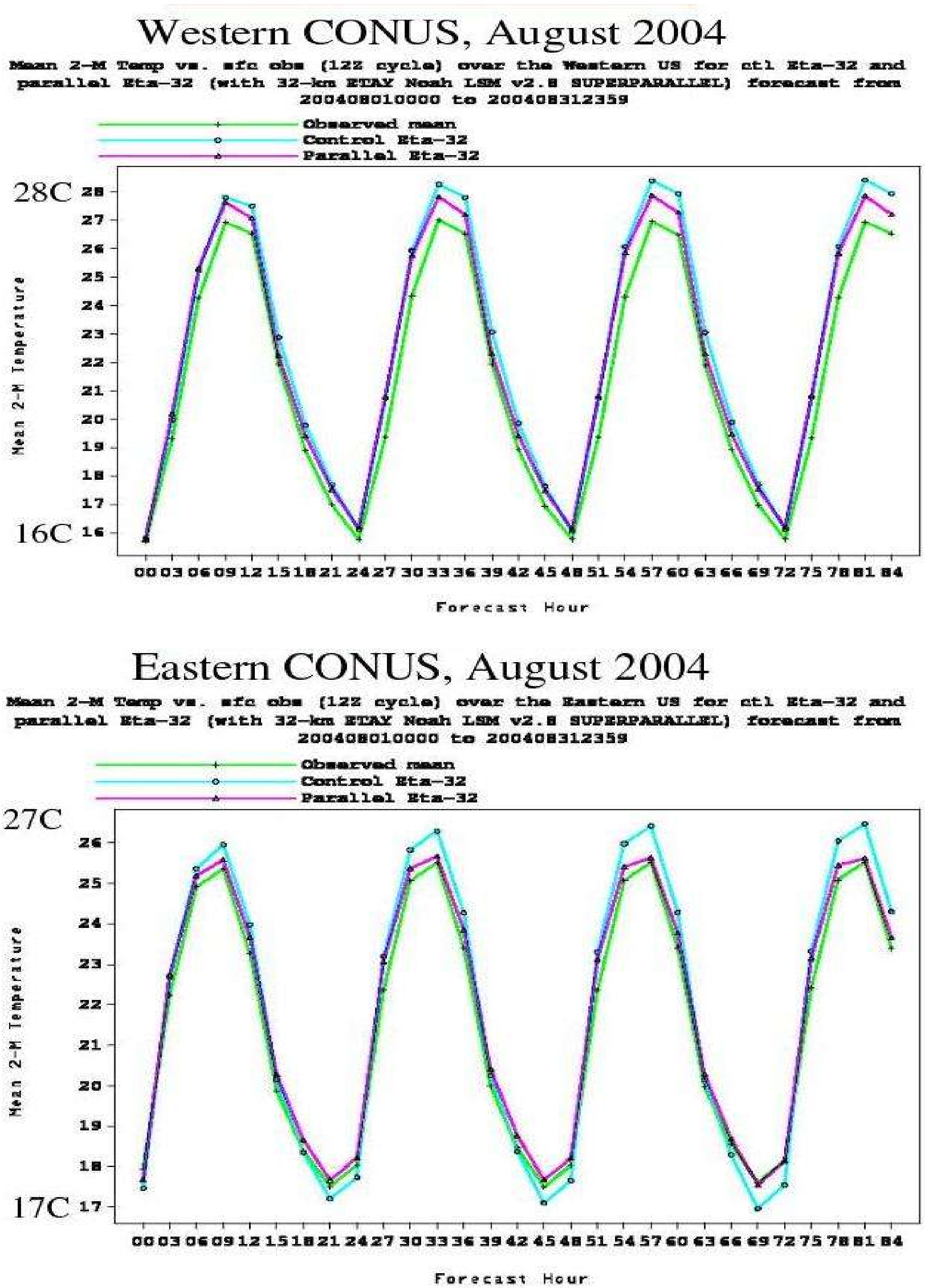

Figure 2: Observed mean surface temperature (green), 32-km Eta control 2-m temp forecast (cyan) and parallel Eta-32 forecast (magenta) 2-m temps with LSM changes for all 12Z forecasts in August 2004 over the western (top) and eastern (bottom) CONUS.

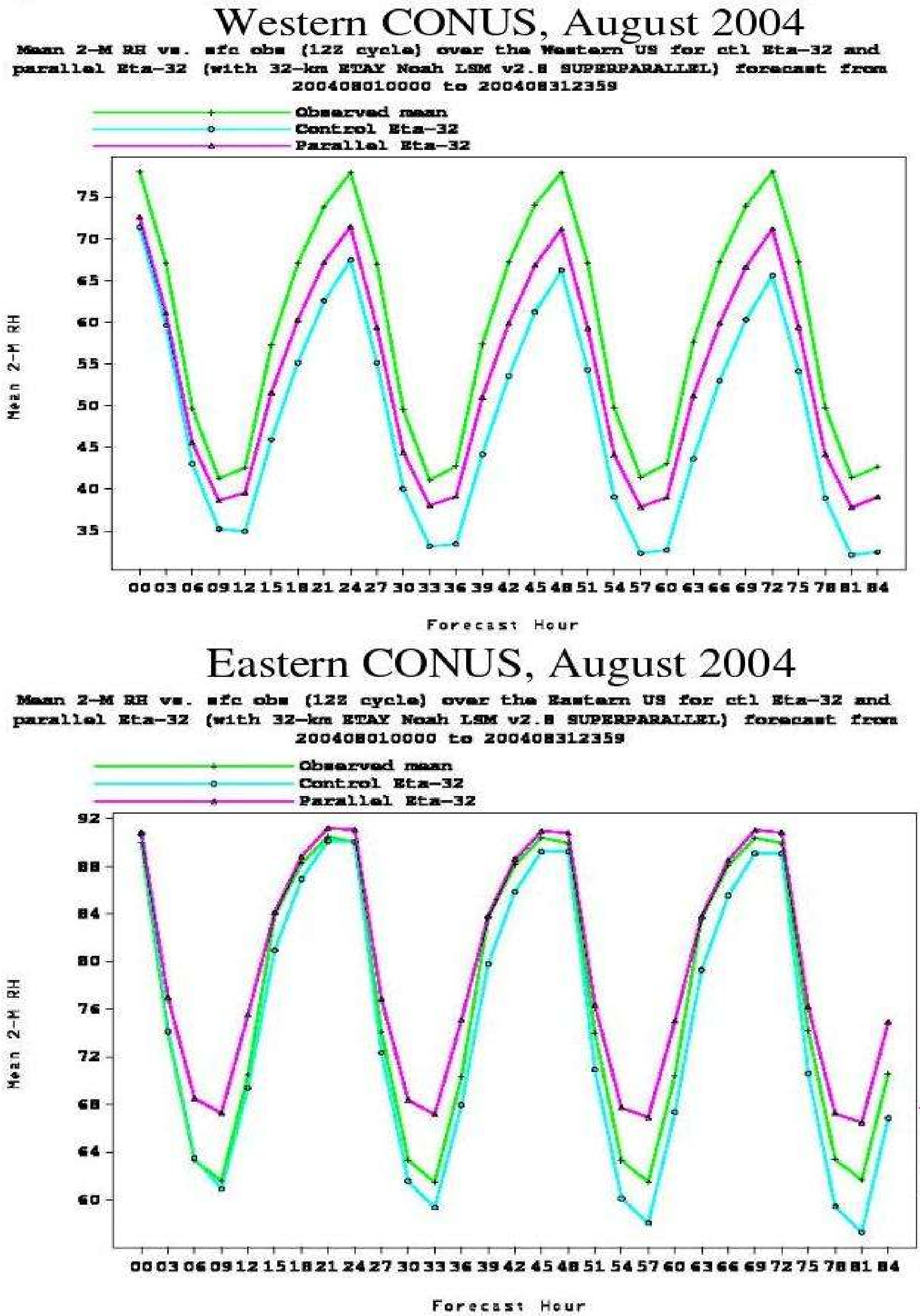

Figure 3: Same as Figure 2, but for mean 2-m relative humidity

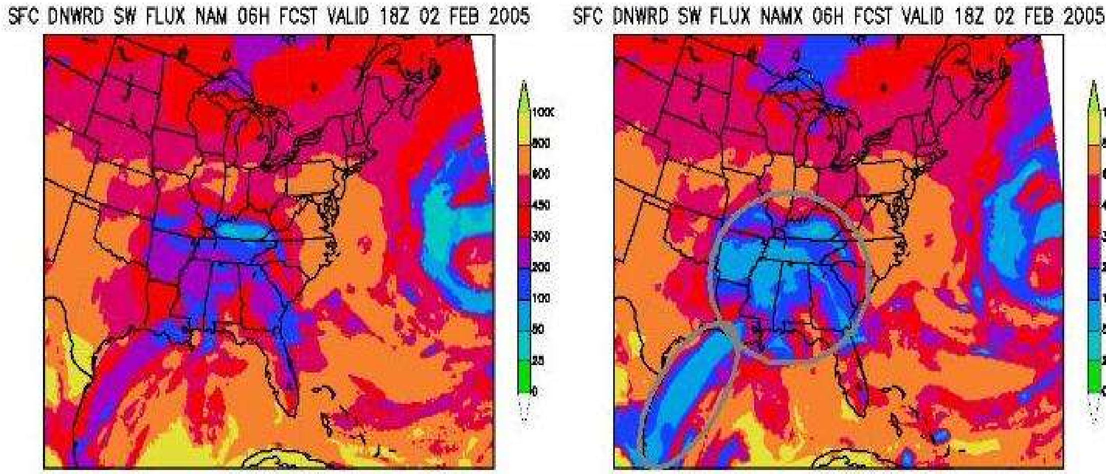

Figure 4: Operational NAM (left) and parallel NAM (right) 6-h forecast of instantaneous surface downward shortwave flux (W/m^2) valid 1800 UTC 2 February 2005

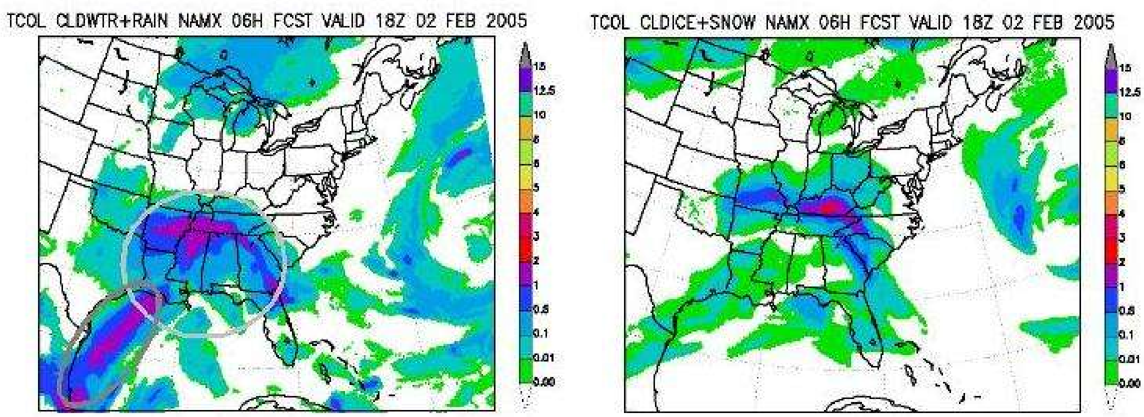

Figure 5: Same as Figure 4, but for parallel NAM total column cloud water and rain (left) and total cloud ice and snow (right) in g/kg

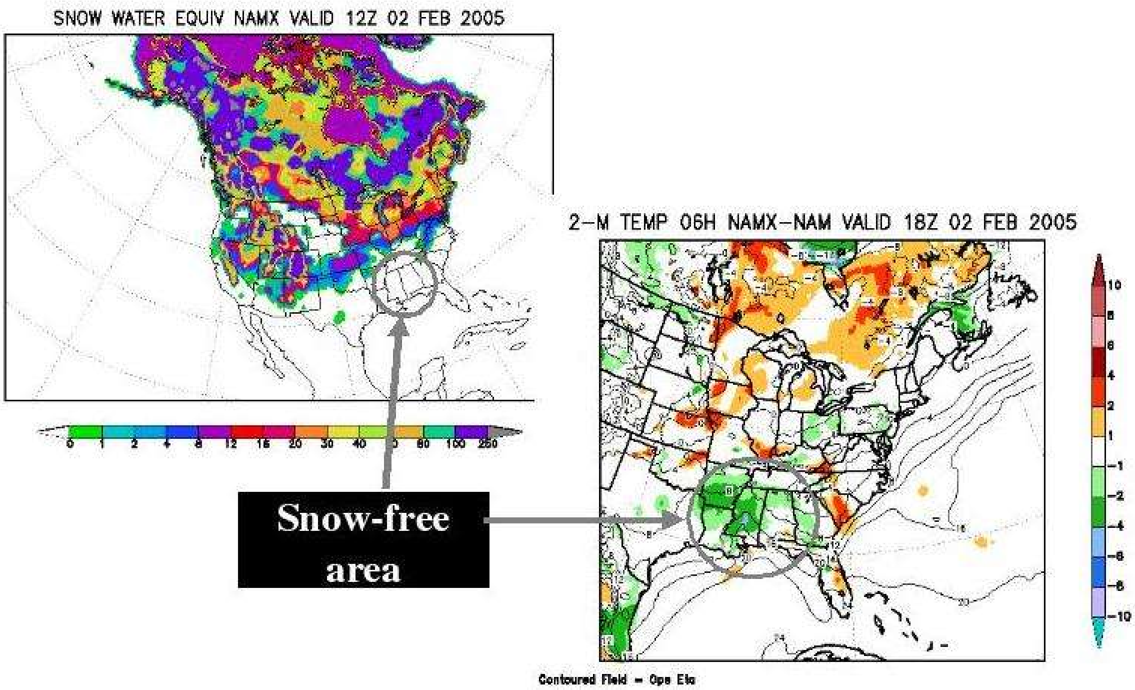

Figure 6: Top left: Parallel NAM snow water equivalent (kg/m^2) valid 12Z 2 February 2005; Bottom right : 6-h forecast of parallel NAM – operational NAM 2-m temperature difference valid 1800 UTC 2 February 2005.

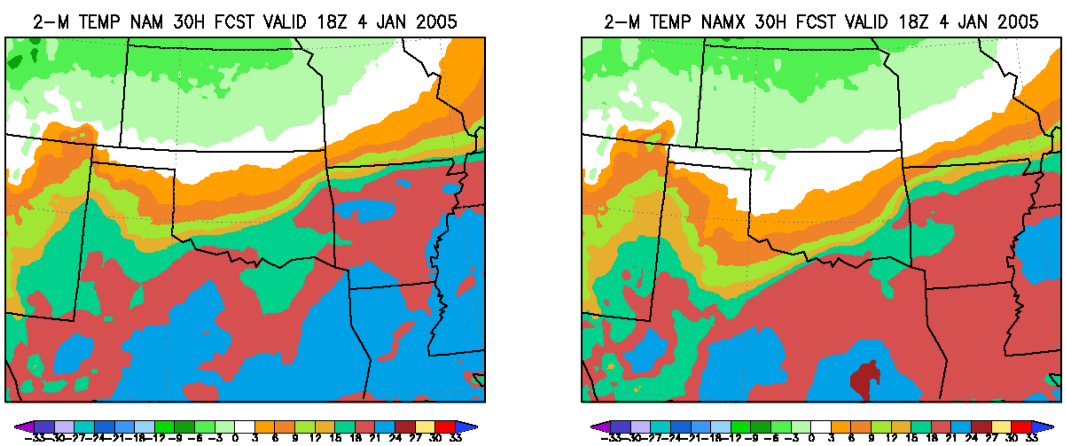

Figure 7: Operational NAM (left) and parallel NAM (right) 30-h 2-m temperature (deg C) forecast valid 1800 UTC 4 January 2005.

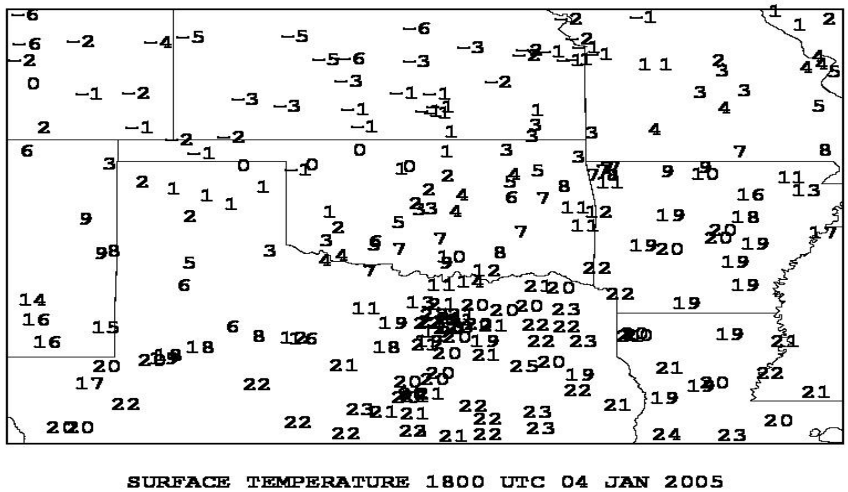

Figure 8: Observed surface temperatures (deg C) valid 1800 UTC 4 January 2005

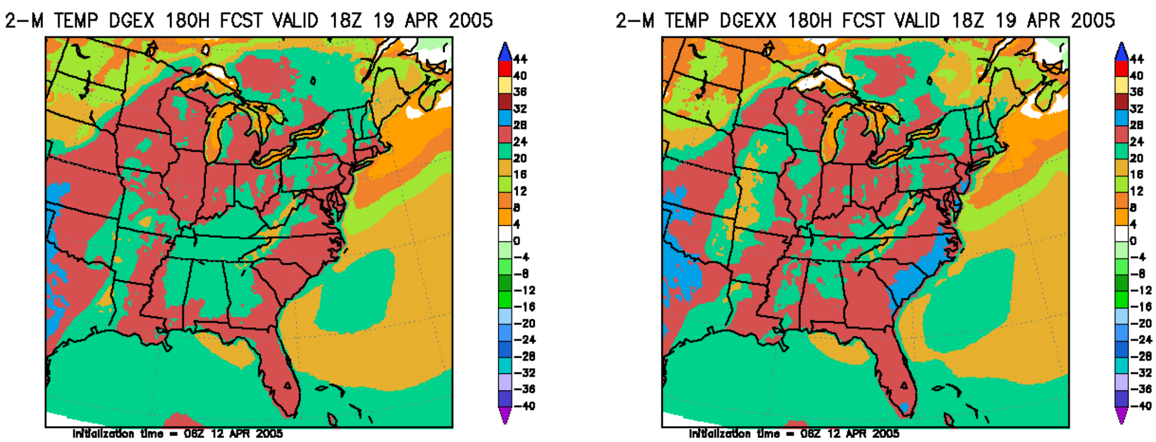

Figure 9: Operational DGEX (left) and parallel DGEX (right) 180-h forecasts of 2-m temperature (deg C) valid 1800 UTC 19 April 2005

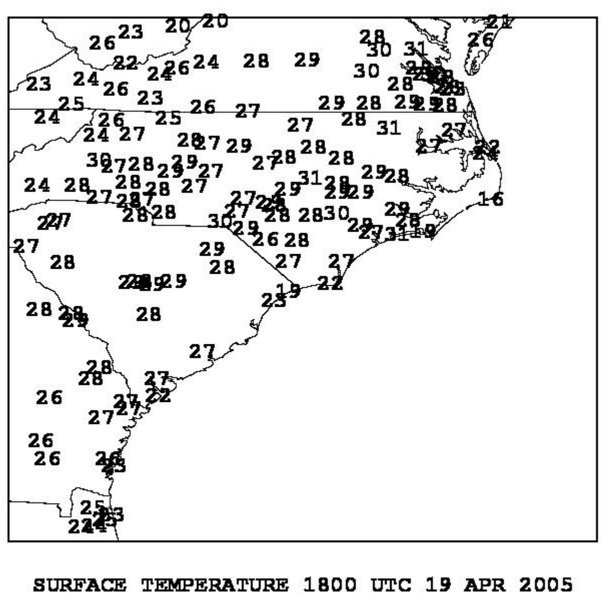

Figure 10: Observed surface temperatures valid 1800 UTC 19 April 2005

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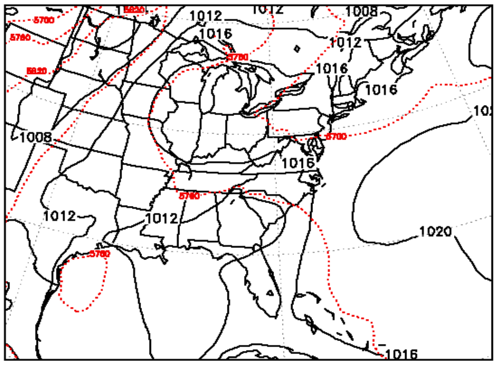
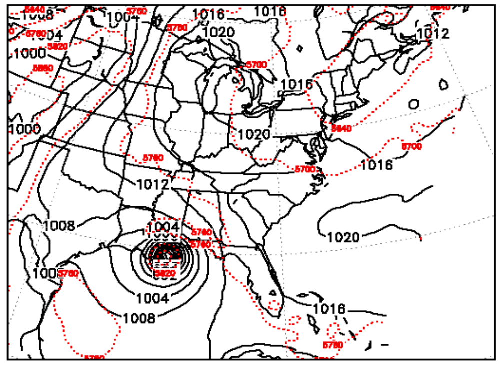


SLP NAMX 78H FCST VALID 18Z 10 JUL 2005



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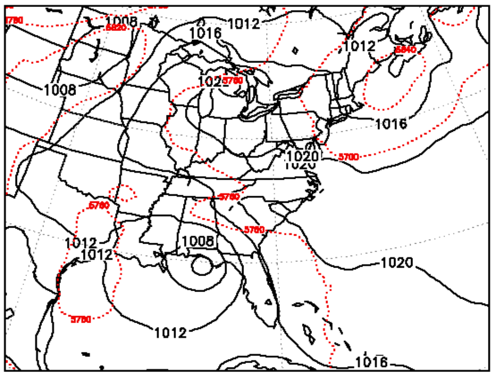

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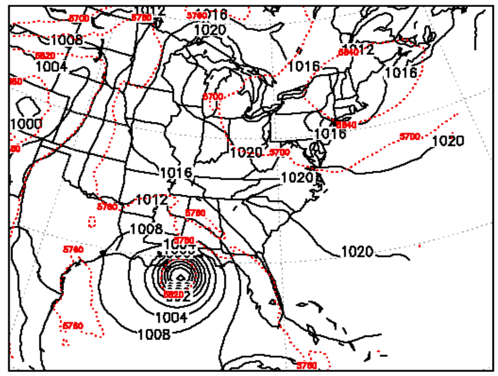

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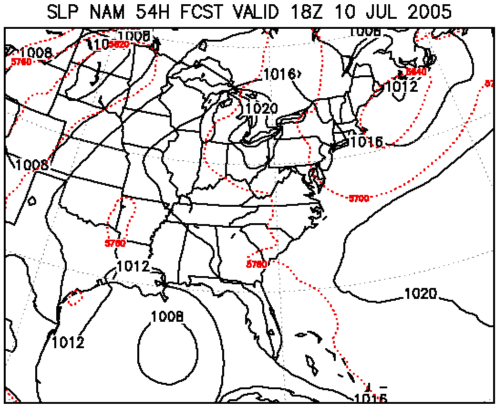

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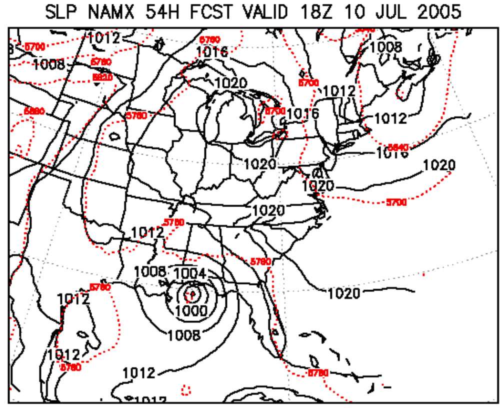

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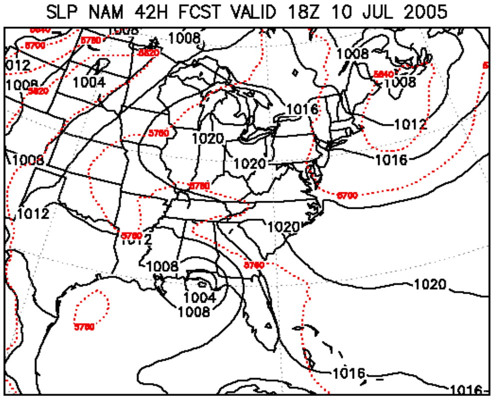

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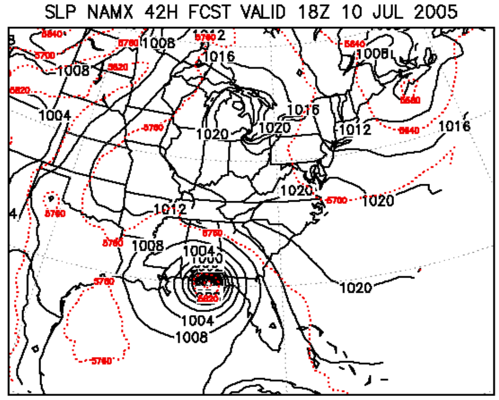

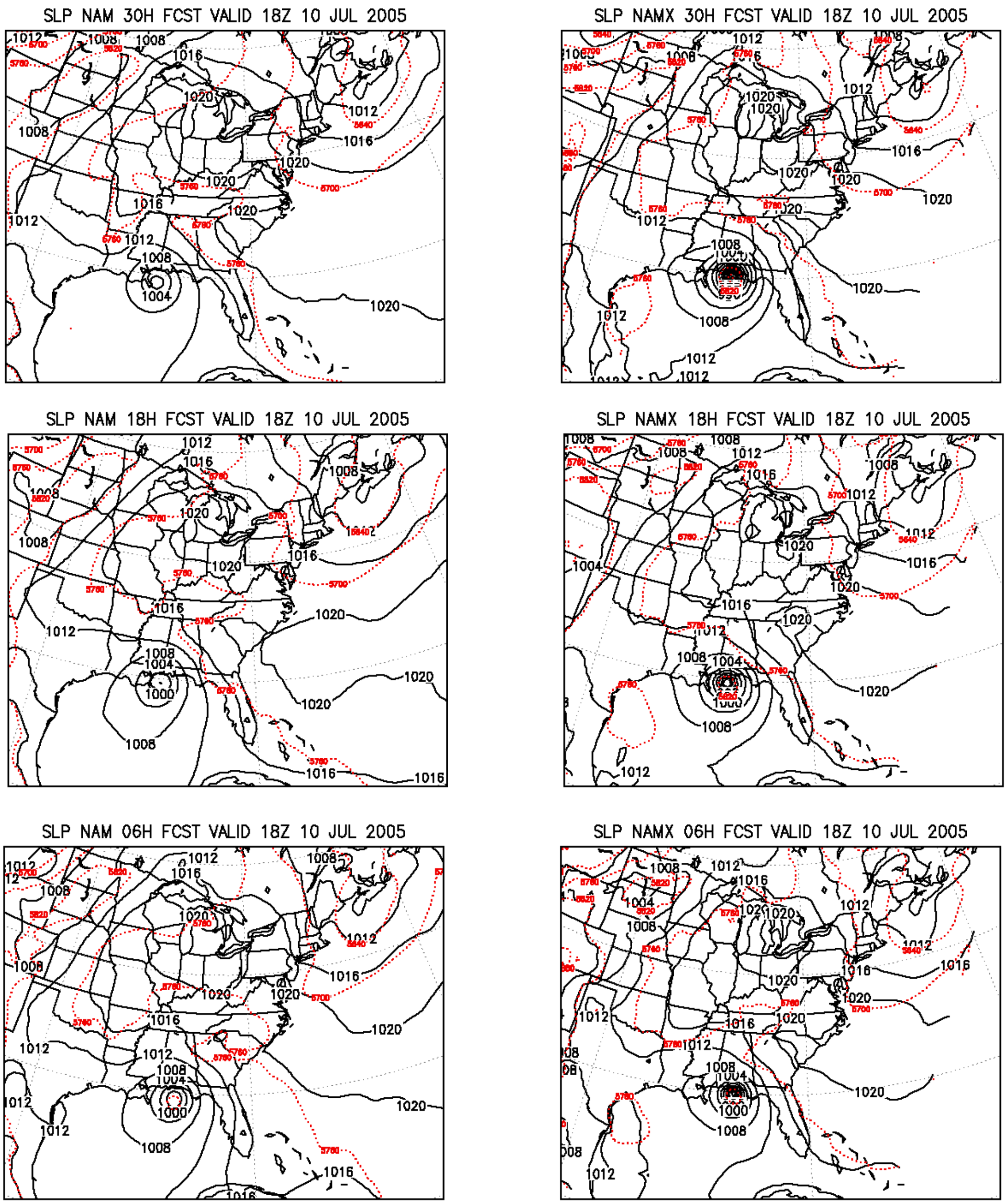

Figure 11: Sequence of operational NAM and WRF-NMM (designated NAMX) sea level pressure forecasts valid at 1800 UTC 10 July 2005 for all forecasts initialized from 1200 UTC 7 July – 1200 UTC 10 July 2005