Update of The Eta-CMAQ Forecast Model run at NCEP operations and its performance for the Summer 2004

Jeff McQueen*, Pius Lee, Marina Tsidulko, Geoff DiMego
Mesoscale Modeling Branch
NOAA/NWS/NCEP/Environmental Modeling Center

Rohit Mather, Tanya Otte, Jon Pleim, George Pouliot, Daiwen Kang and Ken Schere
NOAA/ARL/Atmospheric Sciences Modeling Division
(On assignment to the EPA/National Exposure Research Laboratory)

Jerry Gorline and Michael Schenk
NOAA/NWS/Meteorological Development Laboratory

Paula Davidson
NOAA/NWS/Office of Science and Technology

1. INTRODUCTION

NOAA and EPA have developed and operationally implemented a new ozone forecast capability, in response to Congressional direction (Davidson et al. 2004). This capability builds on decades of research collaboration, culminating in a NOAA-EPA MOA for air quality forecasting, signed in 2003. The NWS/ National Centers for Environmental Prediction (NCEP) Eta model at 12 km was used to provide meteorological predictions for the EPA Community Multi-scale Air Quality (CMAQ) model to produce 48 h ozone predictions. The CMAQ system simulates various chemical and physical processes that are important for modeling atmospheric trace gas transformations and distributions.

This paper describes the improvements to and performance of the NOAA Eta-CMAQ modeling system that was run on the NWS/NCEP operational computer center for real-time air quality forecasting. Two systems were tested and evaluated in the Summer 2004; the experimental NE domain runs and the developmental Eastern U.S domain runs. Both systems were run twice per day at 12 km resolution at 06 and 12 UTC with forecasts to 48 hours. This year the system was run with updates to the both the Eta-12 and CMAQ modeling systems including 6 hour cycling for initial CMAQ conditions, use of the NCEP Global Forecast System(GFS) ozone predictions (Lee, et al, 2004) to prescribe CMAQ upper lateral boundary conditions, and updates to the CMAQ model PBL mixing and emissions. Both experimental and developmental systems were run with gas-phase chemistry only, however, research runs were made over the Eastern U.S. with aerosols turned on.

Specifically, this paper will overview the operational and experimental system implemented including the NCEP-Eta weather model fields used drive CMAQ. The NCEP Forecast Verification Systems (FVS) and NWS/MDL verification systems were used to summarize general model performance and biases as compared to the EPA AIRNOW observational network.

2. 2004 NOAA-EPA AQ PREDICTION SYSTEM

Beginning in June 2003, NCEP ran the coupled Eta-CMAQ air quality prediction system to provide 48 h predictions of surface ozone for the Northeastern U.S. In 2004, an expanded grid developmental run and research grid aerosol run were tested (See Table 3).

The experimental NE U.S. domain and developmental expanded domains are shown in Fig. 1. All systems consisted of the following components:

- *The NCEP/EMC North American Eta 12 km 60 level prediction system* for gridded meteorological model predictions at hourly intervals. (Rogers et al. 1996). Recent improvements to the Eta system are described by Ferrier et al. (2003). These changes included improved grid-scale cloud microphysics and interactions with short

*Corresponding Author Address: Jeff McQueen, NCEP/EMC, W/NP22 Room 207, 5200 Auth Road, Camp Springs, MD 20746-4304; jeff.mcqueen@noaa.gov

and long-wave radiation. Direct analysis of the WSR-88D radar radial velocities and use of NOAA-17 satellite radiances were incorporated into the EDAS 3DVAR assimilation system.

- *The modified Eta product generator,* interpolates Eta native grid model outputs (rotated lat-lon Arakawa E grid) to an intermediate grid with 22 terrain-following sigma vertical layers. (Table 1).
- *The CMAQ preprocessor, PREMAQ,* prepares the CMAQ-ready meteorological and emissions files. Table 2 summarizes the PREMAQ configuration used for the summer 2004.
- *The CMAQ atmospheric chemistry model* (Byun and Ching, 1999) provides the ozone forecasts. The CMAQ configuration is described in Table 3. In 2004, a minimum limit was set on PBL mixing of chemistry to improve over-predictions in rural areas.
- *Boundary conditions*: For the summer 2004, the NCEP Global Forecast System (GFS) ozone predictions were used above 6 km (Lee, et al, 2004). Below 6 km, a climatological chemical profile was assumed for the lateral boundary conditions, which were kept constant with time.
- *Initial Conditions*: A 6-hour cycling system was developed and run 4 times per day to initialize CMAQ chemistry and soil fields to reduce spinup of soil and chemical constituents. (McQueen, et al*., 2004)*

Table 1. Fields added to the Eta post-processor to couple with CMAQ. Fields are output hourly and on the CMAQ sigma layers.

Eta Variable name	**Used for CMAQ:**
Geopotential height	*Transport*
Pressure	*Transport*
Temperature	*Biogenics, vertical mixing*
Specific humidity	*Cloud processes, photolysis*
U & V winds	*Transport*
Vertical velocity	*transport*
Canopy conductance	Air-sfc exchange
PBL height	Vertical mixing
Plant canopy water	Air-sfc exchange
Vertical Eddy Heat diffusivity	Tested w/ mixing

3. FORECAST PRODUCTS

Predictions of ground-level ozone concentration were made twice each day driven by the 0600 and 1200 UTC Eta forecast cycles. Both 0600 and 1200 UTC CMAQ forecasts were run to 48 h.

The CMAQ system was run on the NCEP IBM SP super-computer using 33 (NE 1x domain) or 65 processors (East 3x domain). 48 hour CMAQ forecasts required 45 minutes of cpu time for the NE domain. The 0600 and 1200 UTC model guidance was required to be available on the NWS Telecommunications Operations Center server by 1730 UTC, while the 0600 UTC 48 hour guidance was required by 1300 UTC.

Predicted 1-hour and 8 hour average surface ozone concentrations were output on the CMAQ grid in WMO GRiB format for further visualization and evaluation against the data provided by EPA's AIRNOW surface ozone measurement network (Wayland, et al., 2002). Additional fields were also output and several levels plotted for the NE and Eastern U.S. Domain. These included the following at 19, 65, 350 and 1250 m AGL: NOx, NOy, NO, NO2, Formaldehyde, and CO. Several meteorological predicted parameters were also produced including cloud cover, incoming radiation, PBL heights and ventilation index. Examples of ozone forecasts on both the NE (1x) and expanded Eastern U.S. (3x) domains are shown in Figure 1.

Table 2. PREMAQ Emission Configuration	
Point Sources	Pre-computed (updated for 2004) temporal emissions factors with met. Dependent plume rise effects calculated each hour.
Area	Pre-computed (updated for 2004) for each day of year.
Mobile	Pre-computed emission factors from MOBILE 6 with hourly temperature-dependent effects.
Biogenic	BEIS-3, using Eta temperature and radiation variables (Pierce et al. 2002)

4. SYSTEM EVALUATION TOOLS

Statistical evaluation for June–Sept, 2004 for ozone monitors in each of the CMAQ domains was performed with the NCEP FVS and NWS MDL verification systems. Both systems performed standard statistics (RMSE, Bias, etc) and contingency statistics (accuracies, Probability of detection, skill scores). FVS Examples are shown in Fig. 2 for the 1200 UTC cycle prediction. Additional evaluations are shown at: http://wwwt.em.ncep.noaa.gov/mmb/aq/ The RMSE and biases (not shown) for 1-h average predictions all indicate an over prediction of ozone with errors highest during the night time hours. For both grids, larger errors were found over the NE US as compared to the SE sub- region. In general, the expanded 3x CMAQ domain forecasts over the NE 1x domain show slightly larger errors as compared to the 1x domain forecasts. The cause of the larger errors over the 3x domain is currently being investigated.

Eta predictions were also evaluated for the Northeastern U.S. during the Summer 2004 NE High Resolution Temperature program. Boundary layer profilers and surface radiation budget stations deployed were used to further diagnose errors in the Eta-CMAQ prediction system. During the Summer 2004, Eta surface temperature predictions were slightly warmer than observed in the daytime in the NE (Fig. 3). Incoming solar insolation (Fig. 4) was slightly over-predicted on average by as much as 50-100 W/m2 as represented by the Pennsylvania State University solar radiation observation site. For the 2004 AQ system, over predicted solar insolation would affect only the biogenic emissions because predicted photolysis rates were affected primarily by cloud coverage, derived from Eat forecasted RH.

5. SUMMARY

This paper summarized an experimental air quality prediction system that coupled the NWS operational Eta-12 meteorological model with the CMAQ model to produce twice-daily ozone guidance. Care was taken in coupling the two models to reduce interpolation errors caused by converting Eta meteorological fields to the CMAQ grids. In addition, CMAQ was optimized to run efficiently in a forecast mode.

Over prediction of ozone was reduced from 2003 results in most areas. Some of this error was explained by incorrect land use coupling. Future upgrades include improved coupling with the Eta boundary layer and radiation parameter predictions, improving CMAQ chemical boundary conditions and further testing with aerosols.

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The views expressed are those of the authors and do not necessarily represent those of NOAA or the EPA.

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Table 3. 2004 CMAQ NE and Expanded Grids Configuration

(began-)	NE U.S. (5/1/04-)	East U.S. (6/1/04-)	Aerosols (7/16/04-)
Grid	Lambert-Conformal Arakawa C Centered at 40.5N, 79.5W and true at 36N and 46N.	Lambert-Conformal Arakawa C true at 33N and 45N.	Lambert-Conformal Arakawa C true at 33N and 45N.
Nx,Ny	166x142	268x259	268x259
Grid Spacing	12 km, lower-left corner at: (32.353N, 89.994W)	12 km, lower-left corner at:(24.595N, 100.99W)	12 km:lower-left corner at:(24.595N, 100.99W)
Runs/day	06Z, 12 Z out to 48hrs	06Z, 12 Z out to 48 hrs	12Z out to 24 hours
Run-time/12z	45 mins/15:30 UTC	3 hrs/ 18:30 UTC	6 hrs/ 21 UTC

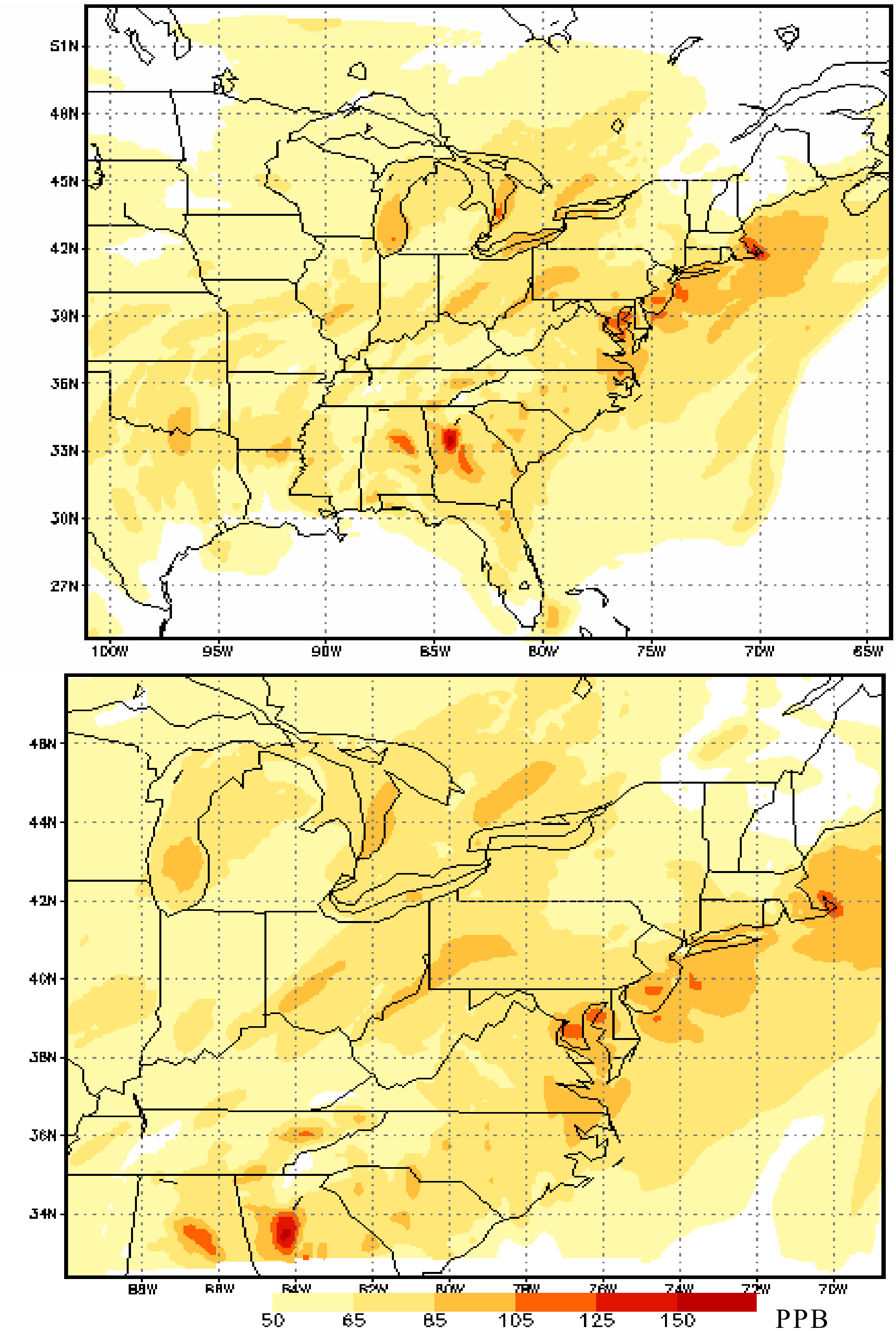
51N
48N
45N
42N
39N
36N
33N
30N
27N
100W
95W
90W
85W
80W
75W
70W
65W
46N
44N
42N
40N
38N
36N
34N
88W
86W
84W
82W
80W
78W
76W
74W
72W
70W
50
65
85
105
125
150
PPB

Figure 1. Example of ozone predictions for July 21, 2004. A) Day 1 max imum O_3 (ppb) on the NE grid (CMAQ 1x) and B) Eastern US grid (CMAQ 3x).

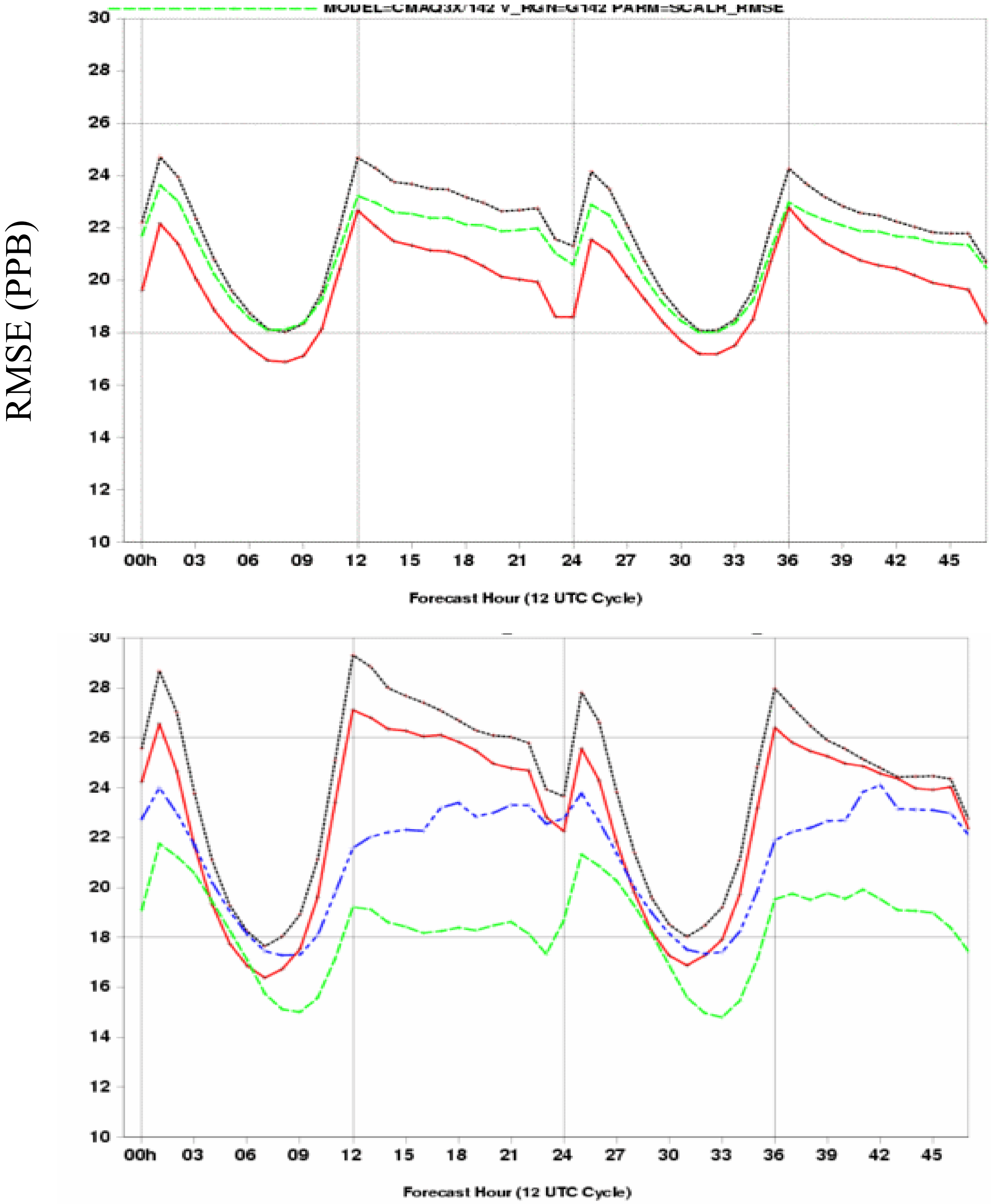

Figure 2. Mean predicted CMAQ ozone concentration errors in ppb for August 2004 A) Root Mean Square error (red: CMAQ 1x. Black: CMAQ 3x errors only over 1x domain, Green: CMAQ 3X whole domain) B) Sub-regional RMSE over the NE sub-region for the CMAQ 1x (red) and CMAQ 3x (black) forecasts and the SE sub-region for the CMAQ 1x (green) and CMAQ 3x (blue) forecasts.

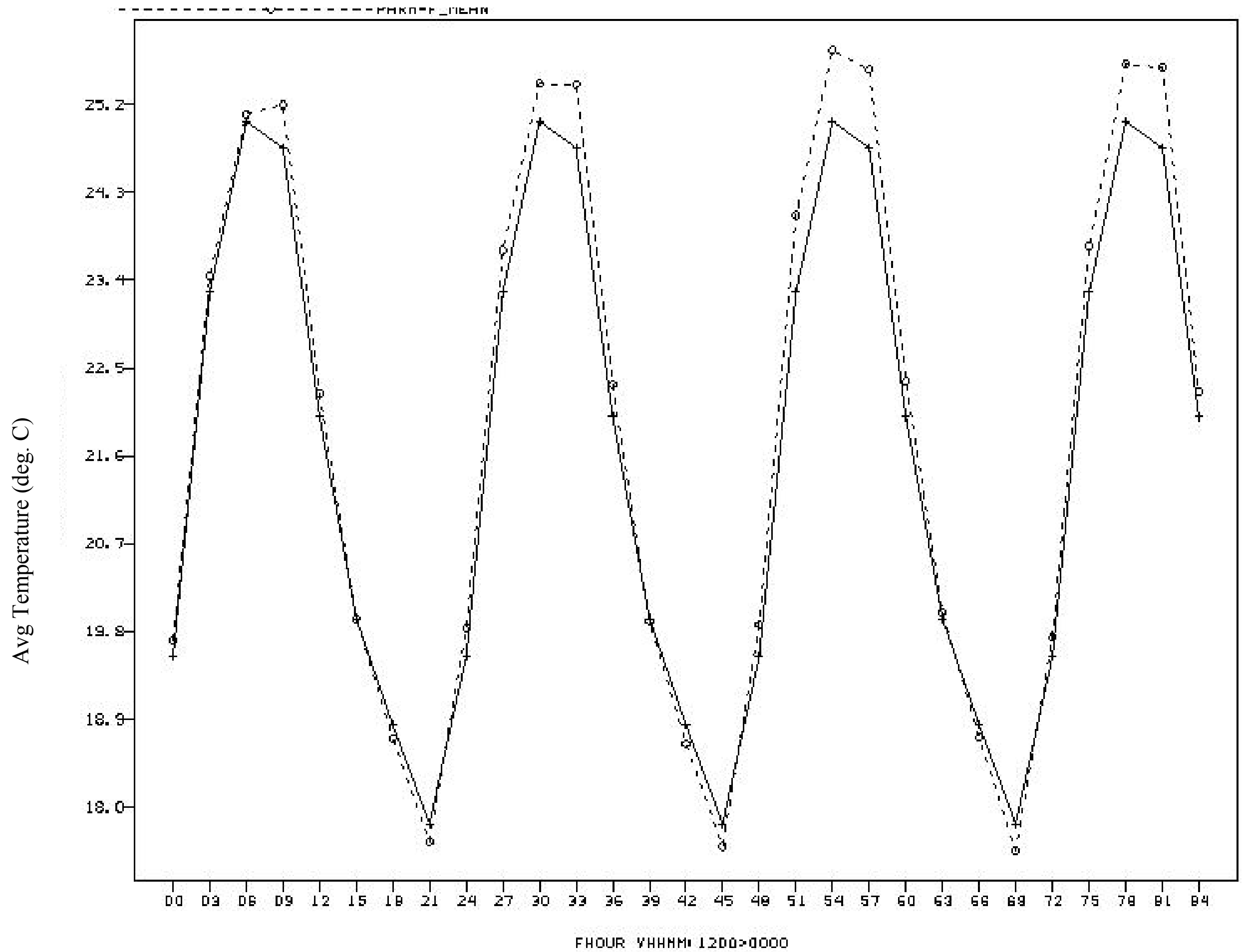

Figure 3. Mean errors from the Eta forecast 12 UTC cycle during August 2004 of 2 m temperature averaged by forecast hour over the NE region (deg. C) , observed(solid line) Eta (dashed).

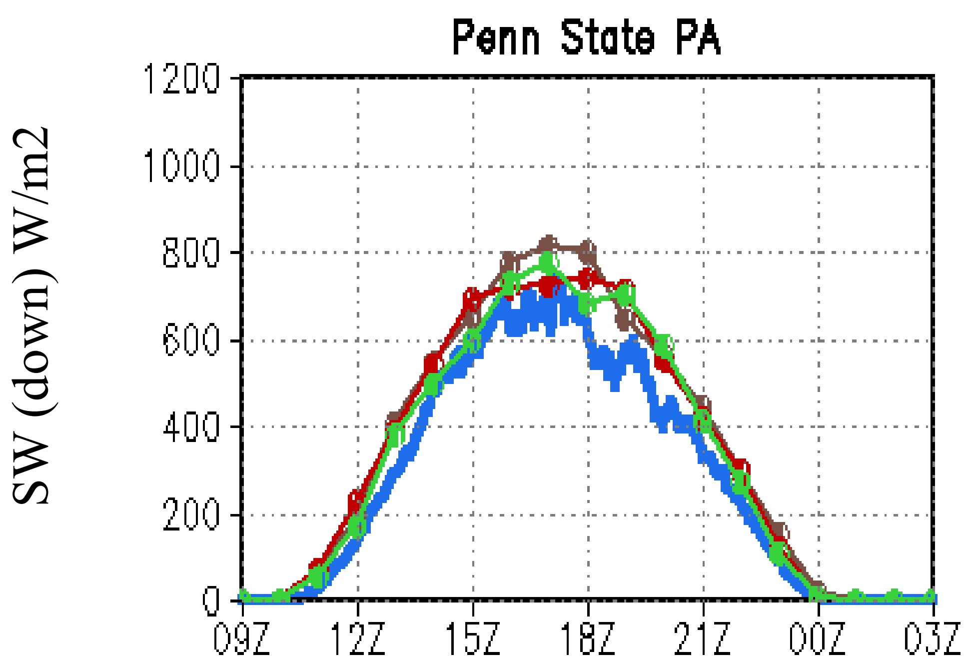

Figure 4. Mean errors from the Eta forecast 12 UTC cycle during August 2004 of Incoming short wave heat fluxes averaged by UTC hour (W/m^2 , observed(blue), Eta forecast(red), Experimental Eta forecast w/ GFS radiation scheme (green) and the Eta Data Assimilation System (EDAS, brown).