Meteorological Modeling Performance Summary

For Application to PM2.5/Haze/Ozone Modeling Projects

Kirk Baker, LADCO
Matthew Johnson, Iowa DNR
Steven King, Illinois EPA

December 10, 2004

Lake Michigan Air Directors Consortium
Midwest Regional Planning Organization
Des Plaines, Illinois

INTRODUCTION

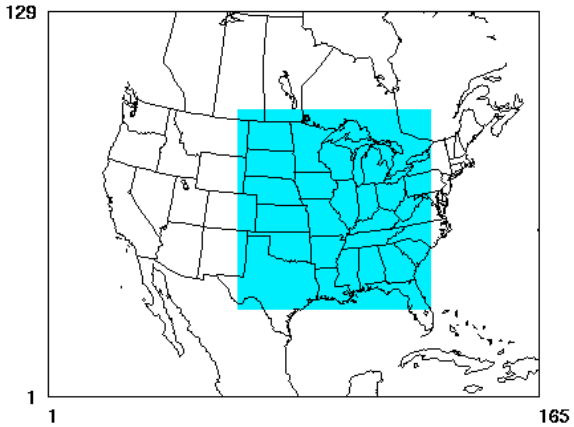
The purpose of this document is to outline the model configuration and application of the Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) v3.6.3 to support photochemical and emissions modeling projects (Dudhia, 1993 and Grell et al, 1994) at Lake Michigan Air Directors Consortium (LADCO) and the Midwest Regional Planning Organization (Midwest RPO). The computing platform supported by LADCO/Midwest RPO is the Red Hat Linux operating system and the Portland Group Fortran compiler. MM5 consists of the Mesoscale model MM5 and a suite of pre-processors including PREGRID, REGRIDDER, RAWINS, LITTLE R, INTERPF, INTERPX, and TERRAIN.

The model parameterizations and physics options outlined in this document were chosen based on the results of a series of sensitivity runs. The performance of the sensitivity tests provided a clear indication of an optimal configuration for the Upper Midwest (Johnson, 2003). The model configuration and parameterizations outlined in this document describe recent MM5 applications.

The annual 2002 36 km MM5 simulation was completed by Matthew Johnson at Iowa DNR. The 36/12 km 2-way nested simulation for the summers of 2001, 2002, and 2003 were conducted jointly by Steven King at Illinois EPA and Kirk Baker at LADCO.

TERRAIN

Figure 1



The TERRAIN processor defines the horizontal grid of the MM5 application. The 24 category USGS 10 minute (~19 km) data is used for the National RPO 36-km domain, and 5 minute (~9 km) data for 12-km domains. The National RPO grid is a Lambert conic projection centered at coordinates –97, 40 with first and second true latitudes at 33 and 45 degrees (See Figure 1).

The 36 km grid contains 165 x 129 grid cells and the 12 km has 193 x 199 grid cells. The 12 km grid is two-way nested within the mother grid to allow fine grid feedback into the coarse grid. Additional options are set to allow generation of data to support the Pleim-Xu land surface module. Variables LSMDATA and IEXTRA are both set equal to TRUE.

Table 1

Domain ID	Grid	X Cells (East-West)	Y Cells (North-South)	Cell Size (km)	Mother Domain ID	Lower Left X,Y of Nest
1	National RPO	165	129	36	1	1, 1
2	Upper Midwest	193	199	12	1	66, 30

PREGRID

The PREGRID processor converts meteorological analyses data such as NCEP or ETA to an intermediate data format that the REGRIDDER processor can utilize. For PREGRID, the following options were set:

- ETA/AWIP 3D and SF analyses data (ds609.2) is used to initialize the REGRID processor.
- Snow cover is estimated from water equivalent snow depth.
- The input analyses data is processed 3 hourly (10,800 seconds).
- The AWIP grib definition tables are used to map ETA data into MM5.
- The ETA skin temperature is used as the source of sea surface temperature. The ETA analysis files with the extension ".tm12" are not used since they are the "cold start" global analysis files.

REGRIDDER

The REGRIDDER processor takes the data extracted from analyses fields and interpolates the data to user specified pressure levels and to the user specified horizontal grid.

LITTLE R

The RAWINS and LITTLE R processors perform objective analysis on the output from REGRIDDER using surface and upper air observation data. Since these observations are incorporated into the ETA analysis fields this step is considered redundant.

Results of sensitivity tests where ETA 3-hourly analysis was utilized to initialize with and without RAWINS objective analysis demonstrated little or no difference in model performance (Baker, 2002).

Even though this step is redundant, LITTLE R is applied to enable surface nudging of soil moisture and temperature in the Pleim-Xu land surface module. NCEP ADP surface (ds 464.0) and upper air (ds 353.1 and ds 353.4) data are the appropriate data to input into LITTLE R and/or RAWINS.

INTERPF

The INTERPF processor takes the REGRIDDER/LITTLE R output that is at standard pressure levels and interpolates that data to the vertical grid defined by the user (Table 2). The vertical grid is defined in terms of sigmas, where 1 is the surface and 0 is the top of the model atmosphere. The top of the MM5 simulation is 100 millibars, which is approximately 15 kilometers above ground level.

The vertical atmosphere was resolved to 34 layers, with thinner layers in the planETAry boundary layer. The layer configuration was selected to capture the important diurnal variations in the boundary layer while also having layers in the upper troposphere to try and resolve convective activity. Output from the INTERPF processor is ready for input into MM5.

Table 2

k(MM5)	sigma	press.(mb)	height(m)	depth(m)
34	0.000	10000	14662	1841
33	0.050	14500	12822	1466
32	0.100	19000	11356	1228
31	0.150	23500	10127	1062
30	0.200	28000	9066	939
29	0.250	32500	8127	843
28	0.300	37000	7284	767
27	0.350	41500	6517	704
26	0.400	46000	5812	652
25	0.450	50500	5160	607
24	0.500	55000	4553	569
23	0.550	59500	3984	536
22	0.600	64000	3448	506
21	0.650	68500	2942	480
20	0.700	73000	2462	367
19	0.740	76600	2095	266
18	0.770	79300	1828	259
17	0.800	82000	1569	169
16	0.820	83800	1400	166
15	0.840	85600	1235	163
14	0.860	87400	1071	160
13	0.880	89200	911	158
12	0.900	91000	753	78
11	0.910	91900	675	77
10	0.920	92800	598	77
9	0.930	93700	521	76
8	0.940	94600	445	76
7	0.950	95500	369	75
6	0.960	96400	294	74
5	0.970	97300	220	74
4	0.980	98200	146	37
3	0.985	98650	109	37
2	0.990	99100	73	36
1	0.995	99550	36	36
0	1.000	100000	0	--SURF--

INTERPX

The INTERPX processor is used to extract the soil temperature and soil moisture data from MM5 output files and overwrite the soil temperature and moisture fields on the MMINPUT file for the next 5 day simulation block. This allows soil moisture and temperature to be carried over to subsequent modeling simulations.

For example, to simulate 20 days in 4 blocks of 5 days, the first block of 5 days would use the standard MMINPUT to run MM5, and the subsequent 3 blocks of 5 days would take the MM5 output and extract soil temperature and moisture data for the next 5 day block. This option is no longer recommended since it has been shown to introduce a cold bias for the temperature field, particularly in the winter months (Olerud, 2003).

MM5

The output from INTERPF, LITTLE R, and TERRAIN processors were used to run MM5. These files must be in the "./MM5/Run" directory and have the generic filenames given directly out of these processors. 3D analysis nudging for the wind field, temperatures, and moisture were applied above the boundary layer only. Analysis nudging was not performed on the rotational wind field. In addition, the observation nudging flag was turned off. This type of nudging is appropriate when there is a very dense set of observation data from a field study, which this application lacked. The default nudging weighting factors were used for all simulations: 2.5×10^{-4} for wind fields and temperatures and 1.0×10^{-5} for moisture fields.

Table 3

Configuration	36km and 12km Domains
Explicit Moisture	Mixed Phase (Reisner I)
Cumulus	Kain-Fritsch 2
PBL	Pleim-Chang (ACM)
Radiation	RRTM
Multi-Layer Soil Model	Pleim-Xu
Shallow convection	No
4-D Data Assimilation	Analysis nudging on above PBL
Moist Physics Table	No

Table 3 outlines the model configuration used for MM5 modeling up to the date of this document. All simulations use the mixed phase moisture scheme so that all four phases of water will be explicitly output by MM5. This is important since the photochemical model is applied for an annual basis and correctly characterizing the phase of water is important for several physiochemical processes.

Atmospheric radiation is calculated every 15 minutes in the model. Vertical moisture and temperature advection are set to use linear interpolation. Other important variables switched to ON include: moist vertical diffusion in clouds, temperature advection using potential temperature, diffusion using perturbation temperature, 3D coriolis force, and upper radiative boundary condition. Sea surface temperature and snow cover are set to vary with time.

The Pleim-Xu land surface module requires that 3 additional variables be set in the MM5 deck: ISMRD, NUDGE, and IFGROW. ISMRD is set to use soil moisture fields from the ETA analyses. NUDGE is set to nudge soil moisture data to the analyses fields. IFGROW is set to option 2, which takes vegETAtive growth into account based on vegETAtive fraction data from the TERRAIN file.

MODEL EXECUTION

MM5 was executed in 5 day blocks (7200 minute simulation) with a 90 second time step. Model results are output every 60 minutes and the model output files are written out (i.e. split) every 24 hours to accommodate post-processing utilities. The 2002 annual simulation was initiated at 12Z December 16, 2001 and was run through 12Z January 1, 2003.

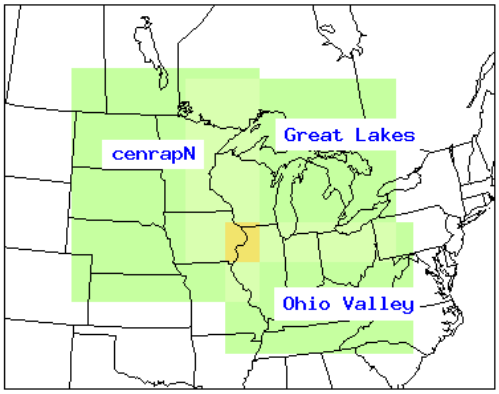
MODEL PERFORMANCE EVALUATION

Model performance was assessed quantitatively with the METSTAT tool from Environ (Emery et al, 2001). The metrics used to quantify model performance include mean observation, mean prediction, bias error, gross error, root mean square error (including systematic and unsystematic components), and index of agreement. These metrics compare model predictions to Techniques Data Laboratory U.S. and Canada surface hourly observations (NCAR dataset ds472.0).

The MM5 model outputs predictions approximately 15 meters above the surface while observations are at 10 meters. METSTAT applies micro-meteorological adjustments to the MM5 estimates to approximate 10-m values. MM5 also outputs

near-instantaneous values (90 second time step) as opposed to the values with longer averaging times taken at monitor stations. This should be considered when interpreting model performance metrics and making qualitative comparisons to satellite maps.

Figure 2



Model performance metrics were applied to a sub-region of the Upper Midwest (Figure 2), meaning the metrics are hourly spatial averages of multiple monitor locations. This will be done to gain a better understanding of MM5 performance in the Great Lakes region. All metrics are calculated within the specified model performance region for an hourly and daily time period (0Z to 23Z). Mean wind direction is estimated by averaging the U and V wind vector components and converting those averages to compass degrees.

Additional analysis of rainfall will be done on a monthly basis. Rainfall totals in each grid cell by monthly will be compared to the corresponding monthly totals at observation sites. Rainfall observation analysis data is available from the National Weather Service Climate Prediction Center on an hourly basis for the Continental United States (http://www.cpc.ncep.noaa.gov/products/precip/realtime/retro.html). The rainfall analysis resolution is 0.25 degree longitude by 0.25 degree latitude and extends from 140W to 60W and 20N to 60N.

PERFORMANCE METRICS

The *bias error* (bias) is the degree of correspondence between the mean prediction and the mean observation, with lower numbers indicative of better performance. Values less than 0 indicate under-prediction. The *gross error*, or mean absolute error, is the mean of the absolute value of the residuals from a fitted statistical model. Lower numbers indicate better model performance.

Root Mean Square Error (RMSE) is a good overall measure of model performance. The weighting of (*prediction-observation*) by its square tends to inflate RMSE, particularly when extreme values are present. With respect to a good model the root mean square error should approach zero. RMSE can be divided into a systematic and unsystematic component by least-squares regression. Since differences described by systematic RMSE can be described by a linear function, they should be relatively easy to dampen by a new parameterization of the model. Unsystematic RMSE can be interpreted as a measure of potential accuracy or noise level (Emery et al, 2001). With respect to a good model the systematic difference should approach zero while the unsystematic difference approaches RMSE.

Index of Agreement is a relative measure of the degree of which predictions are error-free. The denominator accounts for the model's deviation from the mean of the observations as well as to the observations deviation from their mean. It does not provide information regarding systematic and unsystematic errors. The index of agreement approaches one when model performance is best.

MODEL PERFORMANCE: ANNUAL 2002 36 km

The biggest issue with the performance in the Great Lakes region is the existence of a cool diurnal temperature bias in the winter and warm temperature bias over-night during the summer. The wind fields are good, although it should be noted that some diurnal errors in wind speed may not be adequately represented in the daily metric plots. The model appears to be too wet in the late spring and summer months in the Eastern United States. Mosaic tile plots showing daily bias and gross error for humidity, temperature, wind speed, and wind direction are shown in the Figures below.

Performance in the other regions is similar to the Great Lakes except where noted. The Ohio Valley has a slightly worse performance for day-time wind speed and wind direction. The central Plaines (CenrapN and CenrapS) have low peak wind speeds and a warm temperature bias in the southern Plaines/Texas region due to over-predicted night-times lows.

The Mid-Atlantic region has performance similar to the Great Lakes region. The southeast region is very wet compared to observations during the entire year. The northeast region shows degraded wind field performance compared to the other Eastern regions.

Figure 3. Daily humidity bias and gross error (day 1 top row, last day of month bottom row)

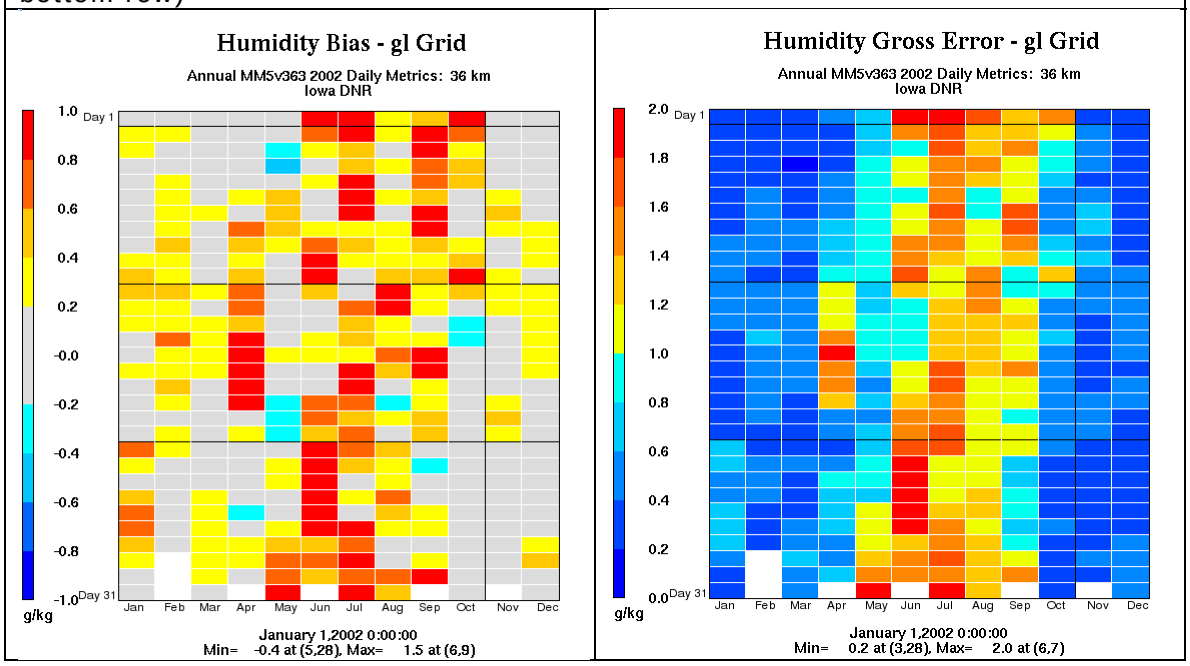


Figure 4. Daily temperature bias and gross error (day 1 top row, last day of month bottom row)

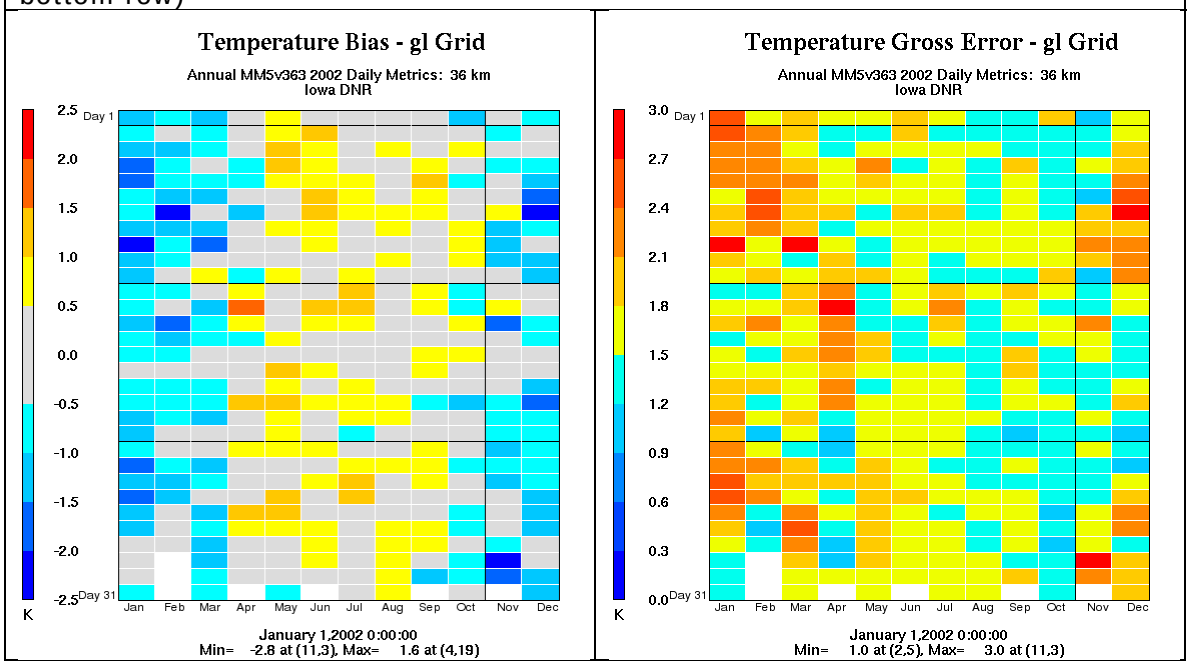


Figure 5. Daily wind direction bias and gross error (day 1 top row, last day of month bottom row)

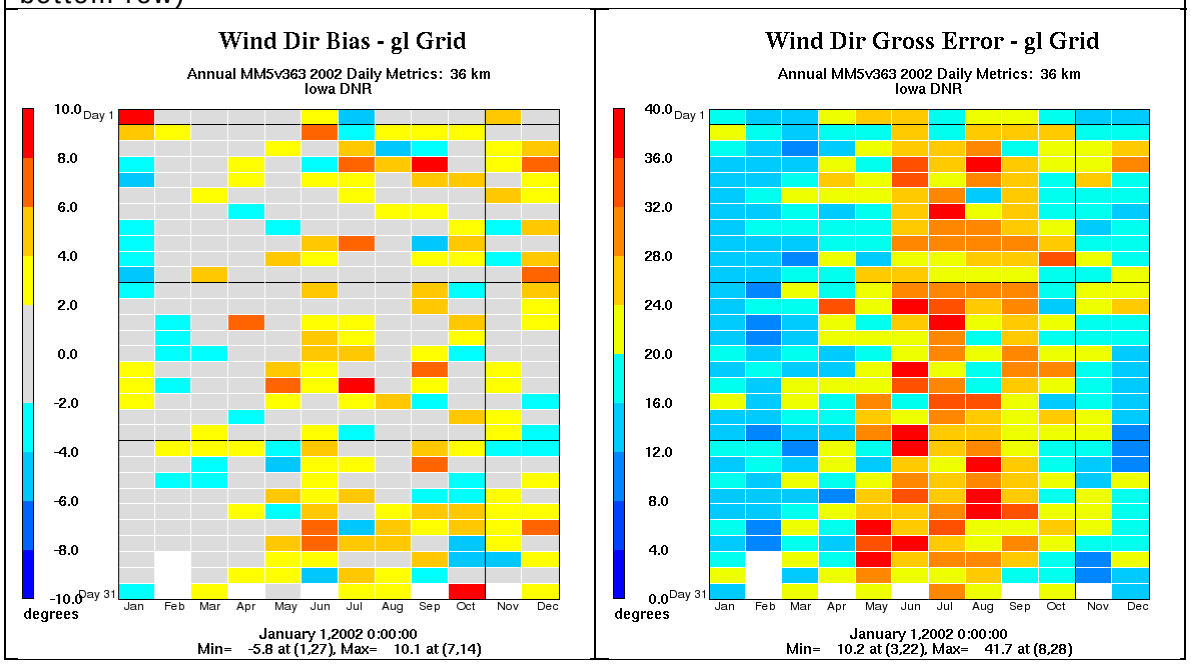
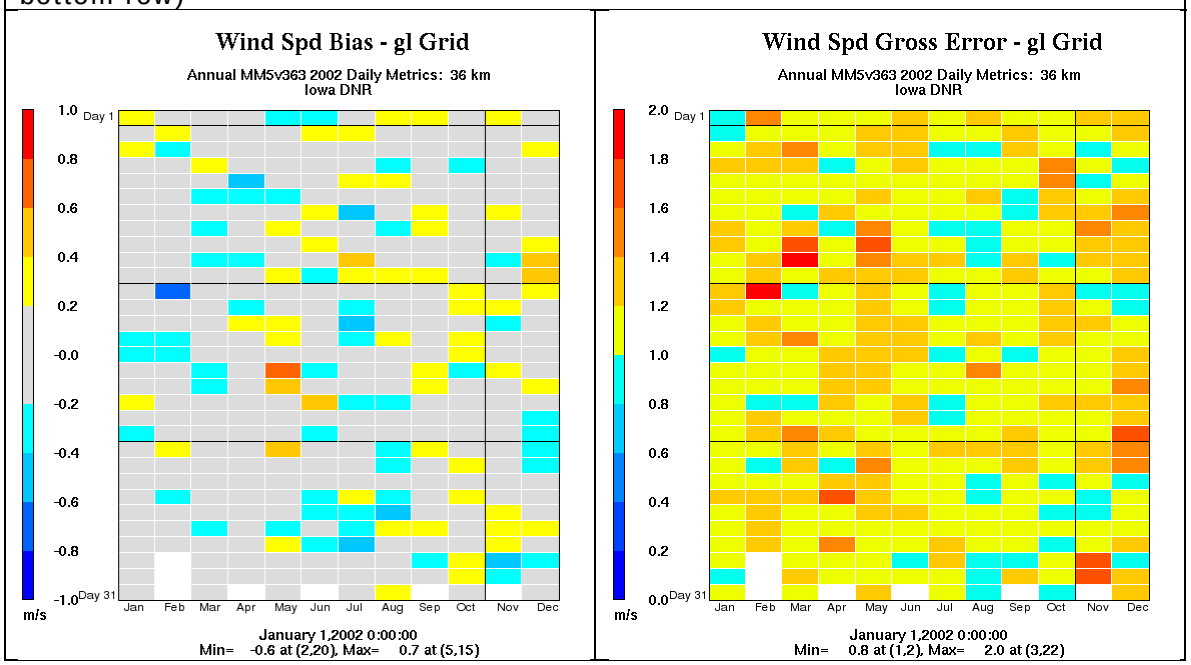


Figure 6. Daily wind speed bias and gross error (day 1 top row, last day of month bottom row)



MODEL PERFORMANCE: RAINFALL

Convective and non-convective rainfall was totaled for each 36 km grid cell in the Eastern United States by month. The National Weather Service rainfall analysis field was mapped to the same grid projection and domain and totaled by month. These plots are shown side by side in Appendix A.

The modeled and observed rainfall totals show good agreement spatially and in terms of magnitude in the winter, fall, and early spring months of 2002. There are large over-predictions of rainfall in the late spring and summer months. These over-predictions are seen spatially and in magnitude over the entire domain, particularly in the Southeast United States. These over-predictions are likely due to excessive convective rainfall being predicted in MM5.

MODEL PERFORMANCE: 36 km v 12 km

Model performance comparing the 36 and 12 km performance in the Great Lakes region is shown in the form of mosaic difference plots in Appendix B. In the Great Lakes region, a winter-time performance degradation is seen in the 12 km run compared to the 36 km run for the wind field and temperature. The temperatures have a cold bias at 36 km and get even colder at 12 km.

Daytime wind speed bias improves at 12 km, but nighttime bias degrades. The mixing ratio performance improves slightly in the Ohio Valley region at 12 km. Overall, the 12 km grid results in little if any benefit in terms of statistical model performance.

MODEL PERFORMANCE: Summers of 2001, 2002, and 2003

The model performance for the summers of 2001, 2002, and 2003 focusing on the Great Lakes Region is shown in prediction-observation time series plots in Appendix C. The predictions and observations are averages over many observation sites in the sub-region of interest. A summary of performance in the Upper Midwest is given below.

Summer of 2001:

- MM5 performs well for temperatures and wind field
- Not quite capturing temperature peaks during August 2001 ozone episode
- Overall moisture and rainfall slightly over-predicted, but spatial patterns look good

Summer of 2002:

- Capturing temperate peaks ok, but over-predicting night time minimums
- Over-predictions of moisture and rainfall in the Ohio Valley; large over-predictions of rainfall in the South
- Wind fields look ok; diurnal wind speed day time peaks not always captured during the ozone episodes

Summer of 2003:

- Wind field ok; diurnal wind speed patterns not quite captured in August ozone episode
- Temperatures ok; not getting night time minimums consistently
- Rainfall ok in Upper Midwest; over-predictions in the South

MODEL PERFORMANCE: New 2002 v. Old 2002 Simulation

An annual MM5 simulation for 2002 was previously completed using an older version of MM5, simple ice microphysics, surface nudging, and continuous soil moisture (INTERPX). The figures in Appendix D show the differences between the previous annual simulation and the current annual simulation with mosaic difference plots.

Temperatures in general show a slight degradation in the new simulation, in particular in the winter. Wind speed performance improved and wind direction improved in the Central and Western United States. Humidity results are almost the same in both simulations. The difference in model performance is largely due to the inclusion of surface nudging in the previous annual 2002 simulation. That practice improves surface performance statistics but tends to create unusual meteorological artifacts like super-adiabatic lapse rates.

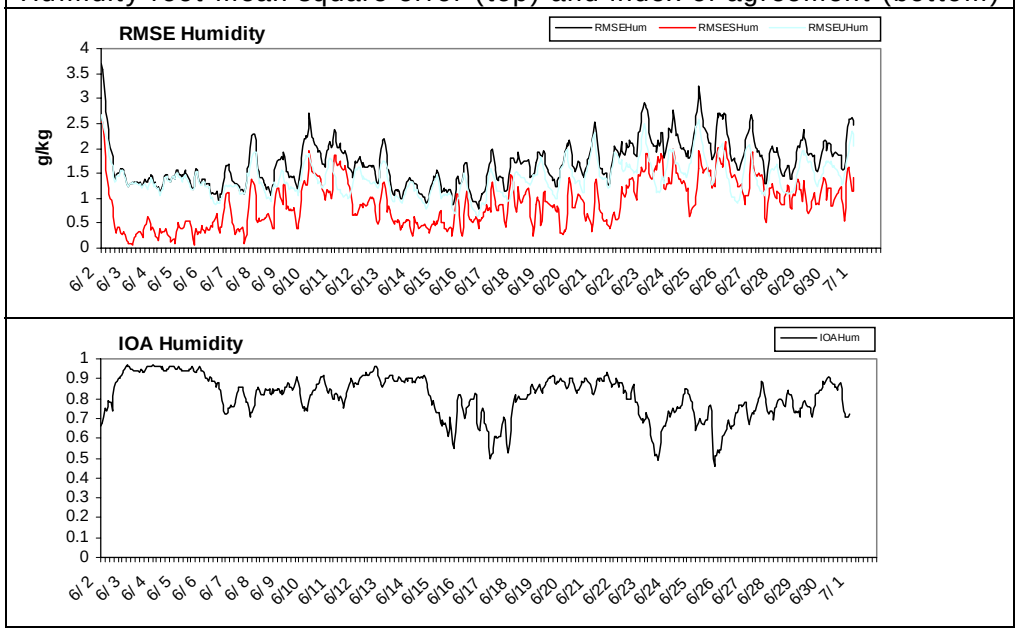
MODEL PERFORMANCE: Other Notes

The index of agreement hourly metrics for humidity are interesting in that periods of poor index of agreement do not necessarily match up to poor error. Since the metrics are averaged over a sub-domain, the hourly index of agreement tends to degrade when fronts move across the domain. This causes very different model predictions and observations on the front and back side of the frontal passage.

This lack of agreement results in a degraded index of agreement metric even though the error and actual model performance is not poor. This should be acknowledged when interpreting index of agreement over a spatial region; degraded IOA may actually show a frontal passage and not truly reflect poor performance.

The time series plots below show RMSE and IOA for June 2002. Frontal passages pass through the area on the 16th, 18th, 24th, and 27th and degrade IOA.

Humidity root mean square error (top) and index of agreement (bottom)



CONCLUSION & DISCUSSION

This document contains an overview of MM5 performance. The results shown are intended to provide a context for future meteorological modeling applications, to identify deficiencies in the MM5 output that may result in poor photochemical model performance, and to increase confidence in the photochemical modeling applications that use these meteorological modeling estimates.

REFERENCES

Baker, K. MM5 Sensitivity for the National RPO Grid, Presented at the Ad-Hoc Meteorological Modeling Meeting, Des Plaines, IL, 2002.

Dudhia, J., A nonhydrostatic version of the Penn State/NCAR mesoscale model: Validation tests and simulation of an Atlantic cyclone and cold front, *Mon. Wea. Rev.,* 121, 1493-1513, 1993.

Emery, C., Tai, E., Yarwood, G., Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes, Final report submitted to Texas Natural Resources Conservation Commission, 2001.

Grell, G. A.; J. Dudhia, and D. R. Stauffer, *A description of the Fifth Generation Penn State/NCAR Mesoscale Model (MM5),* NCAR Tech. Note, NCAR TN-398-STR, 138 pp., 1994.

Johnson, M., Meteorological Modeling Protocol: IDNR 2002 Annual MM5 Application, 2003.

Olerud, D., K. Alapaty, and N. Wheeler, *Meteorological modeling of 1996 for the United States with MM5*, Final report submitted to OAQPS, U. S. EPA, 2000.

Olerud, D., VISTAS Meteorological Modeling, Presented at the Ad-Hoc Meteorological Modeling Meeting, Des Plaines, IL, 2003.

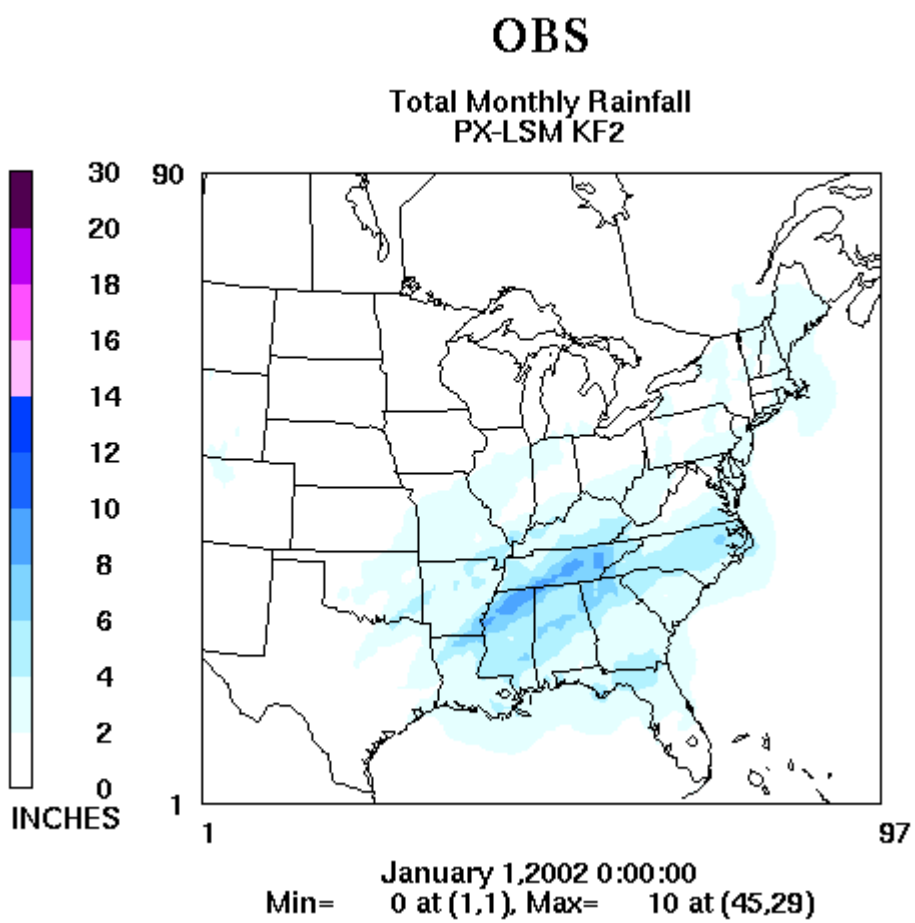
Tonnesen, G., Wang, Z., Lents. J., Gemmill, D., Morris, R., Modeling Protocol and Quality Assurance Plan for the WRAP Visibility Modeling Project, 2001.

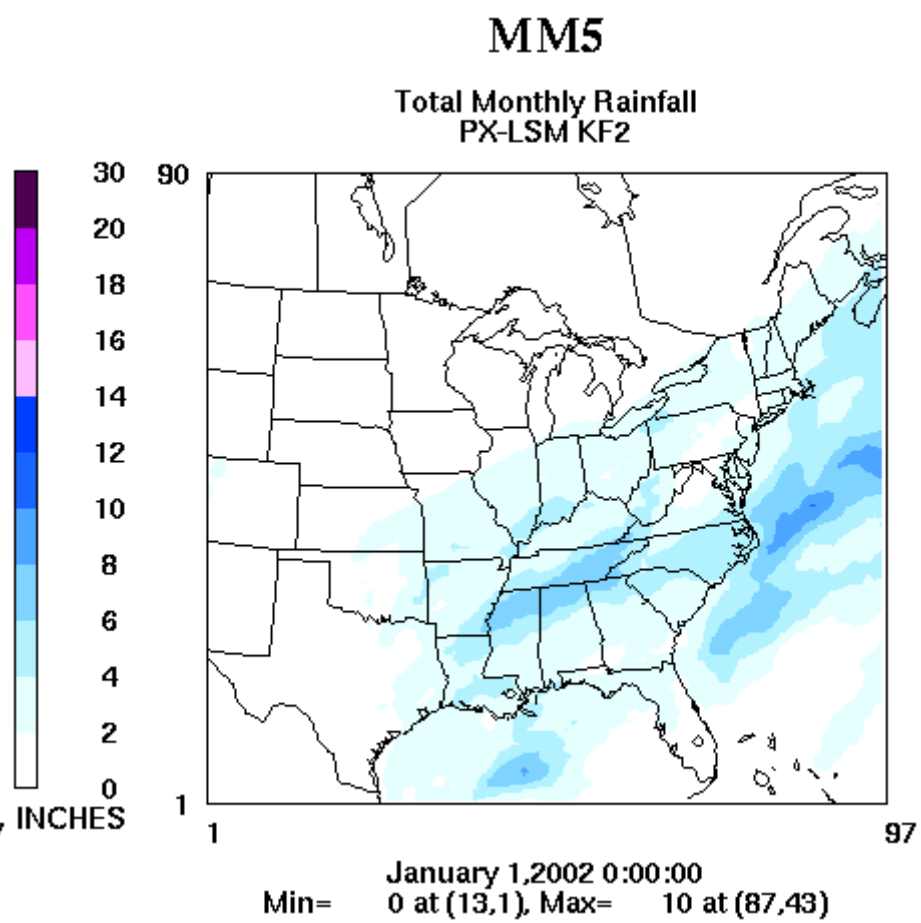
Yarwood, G. Improvements to CAMx Wet Depostion, Presented at the Spring Modeling Meeting, Des Plaines, IL, 2004.

APPENDIX A

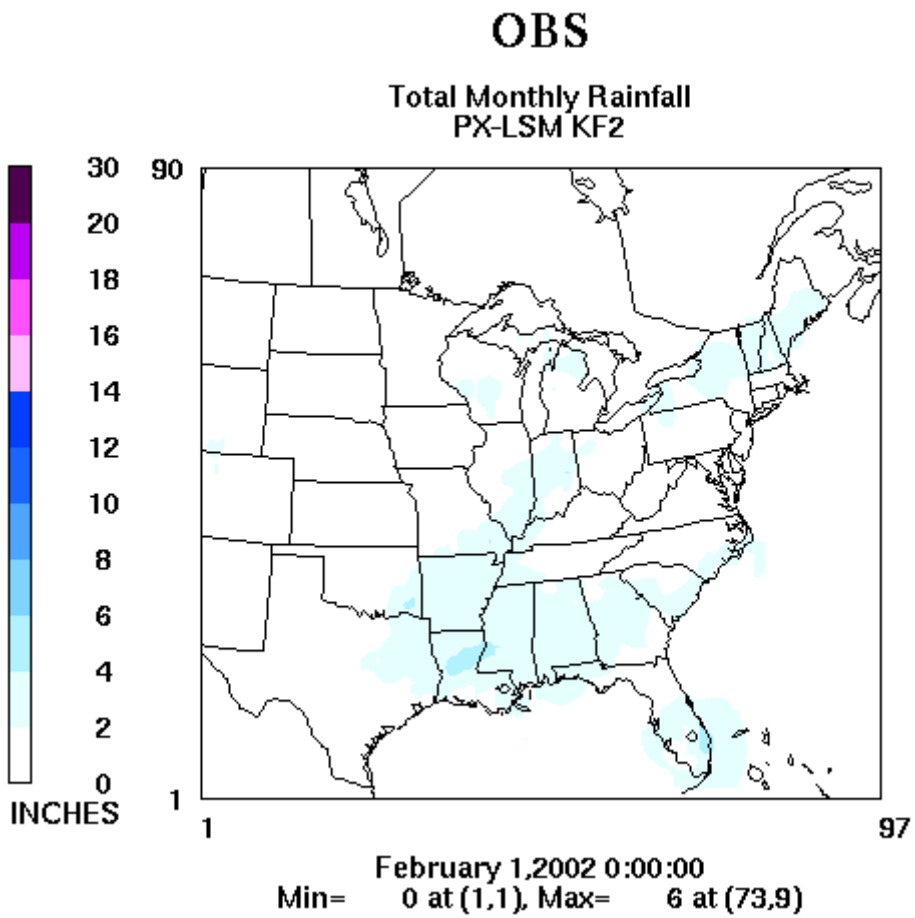
Rainfall Analysis

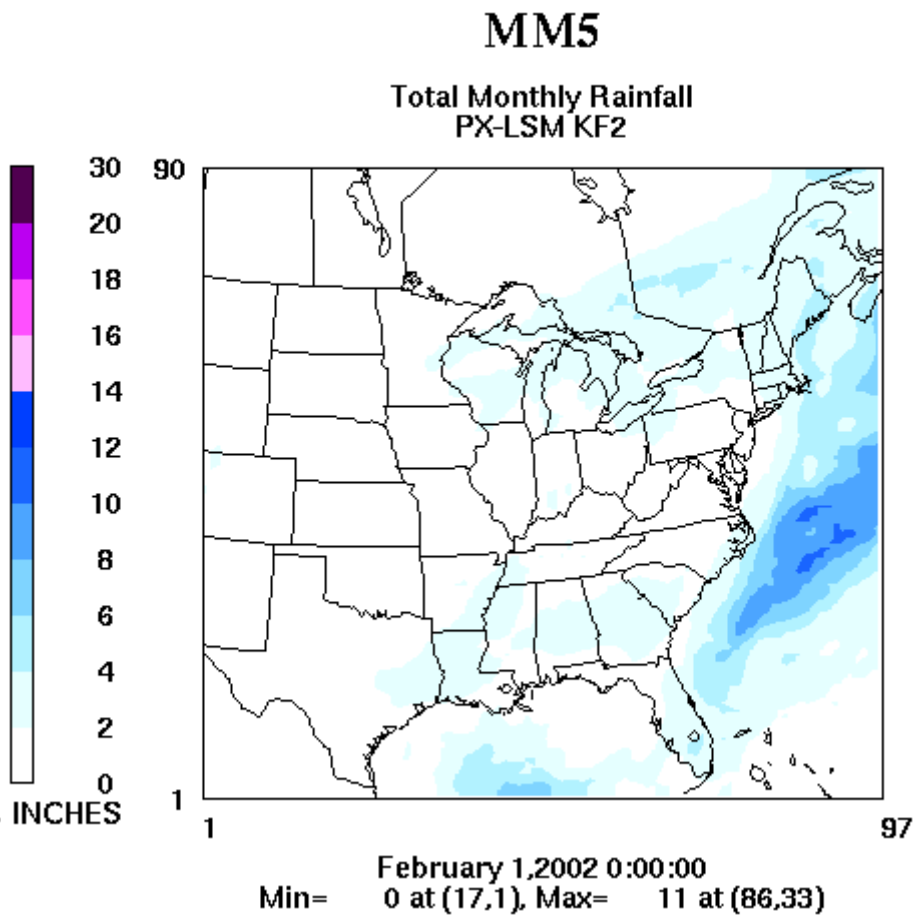
January 2002



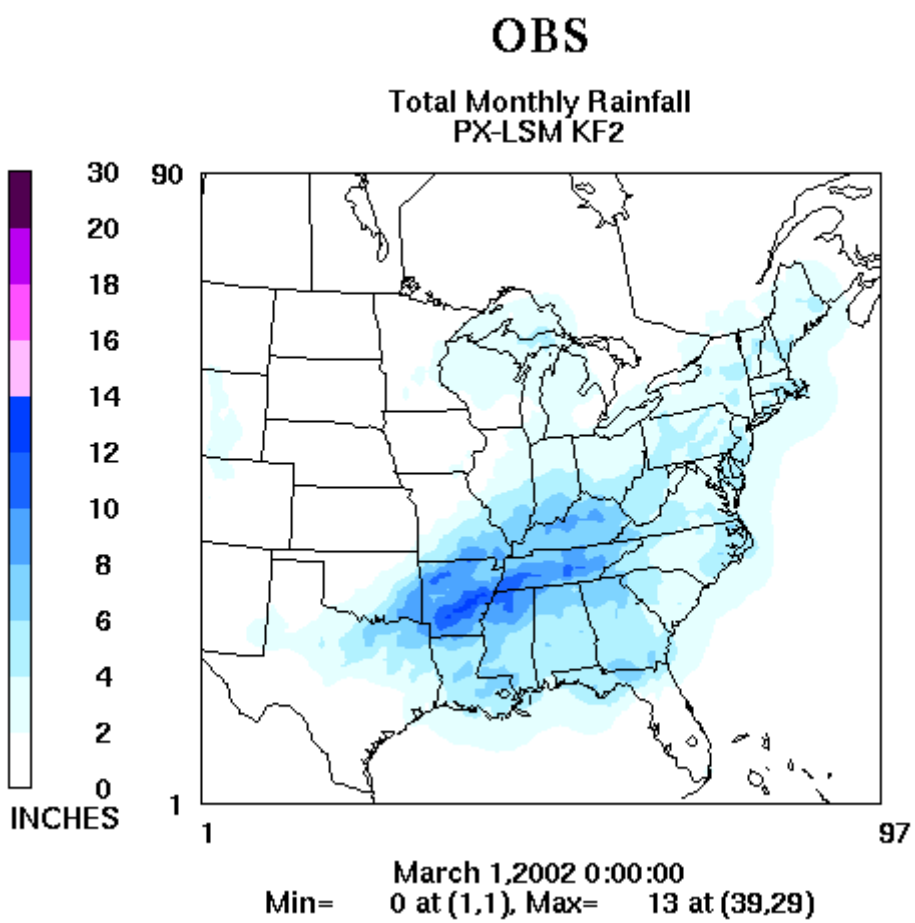


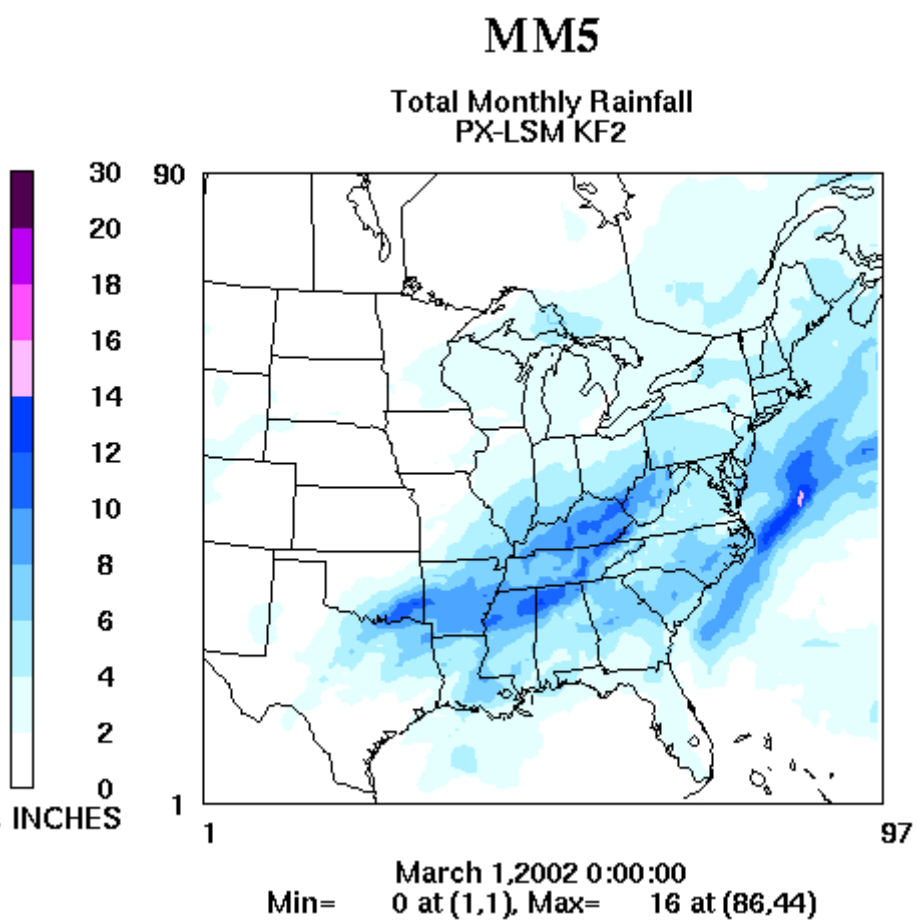
February 2002



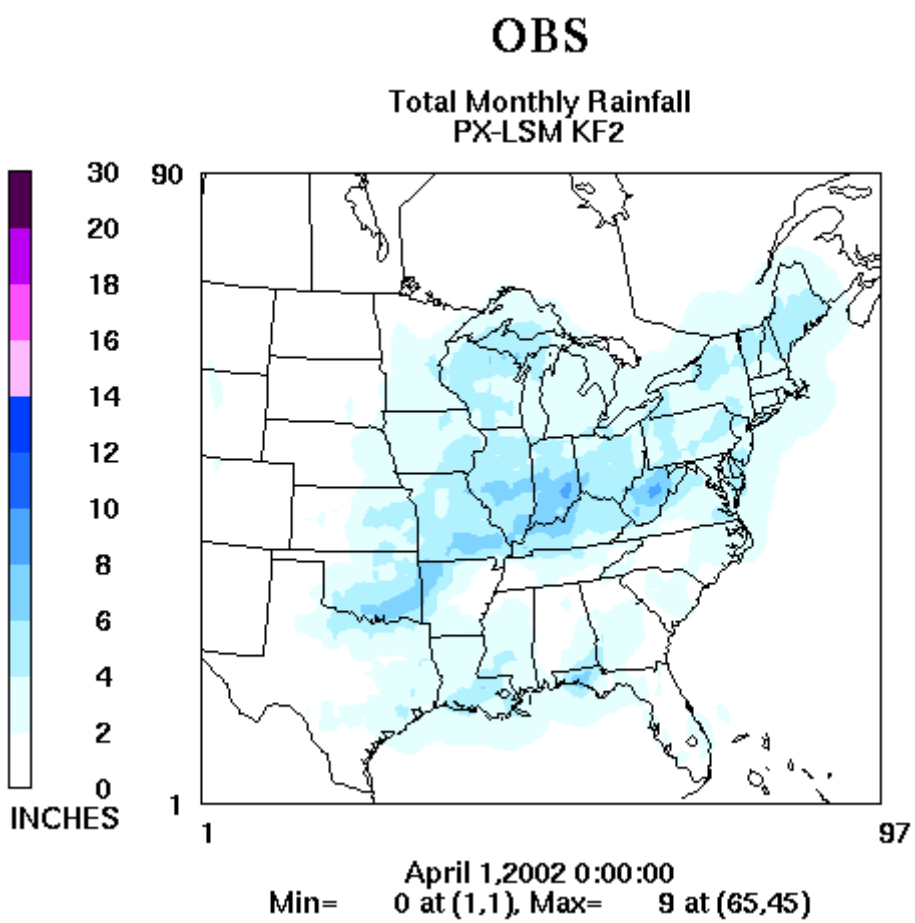


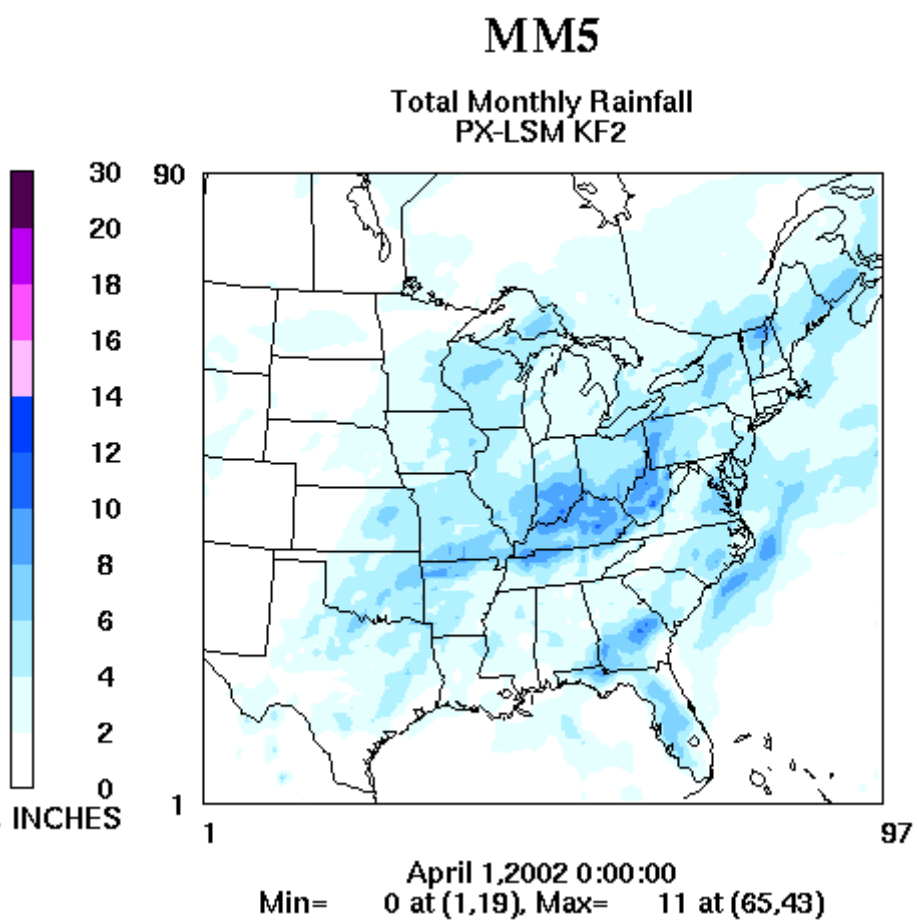
March 2002


OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
March 1,2002 0:00:00
Min= 0 at (1,1), Max= 13 at (39,29)

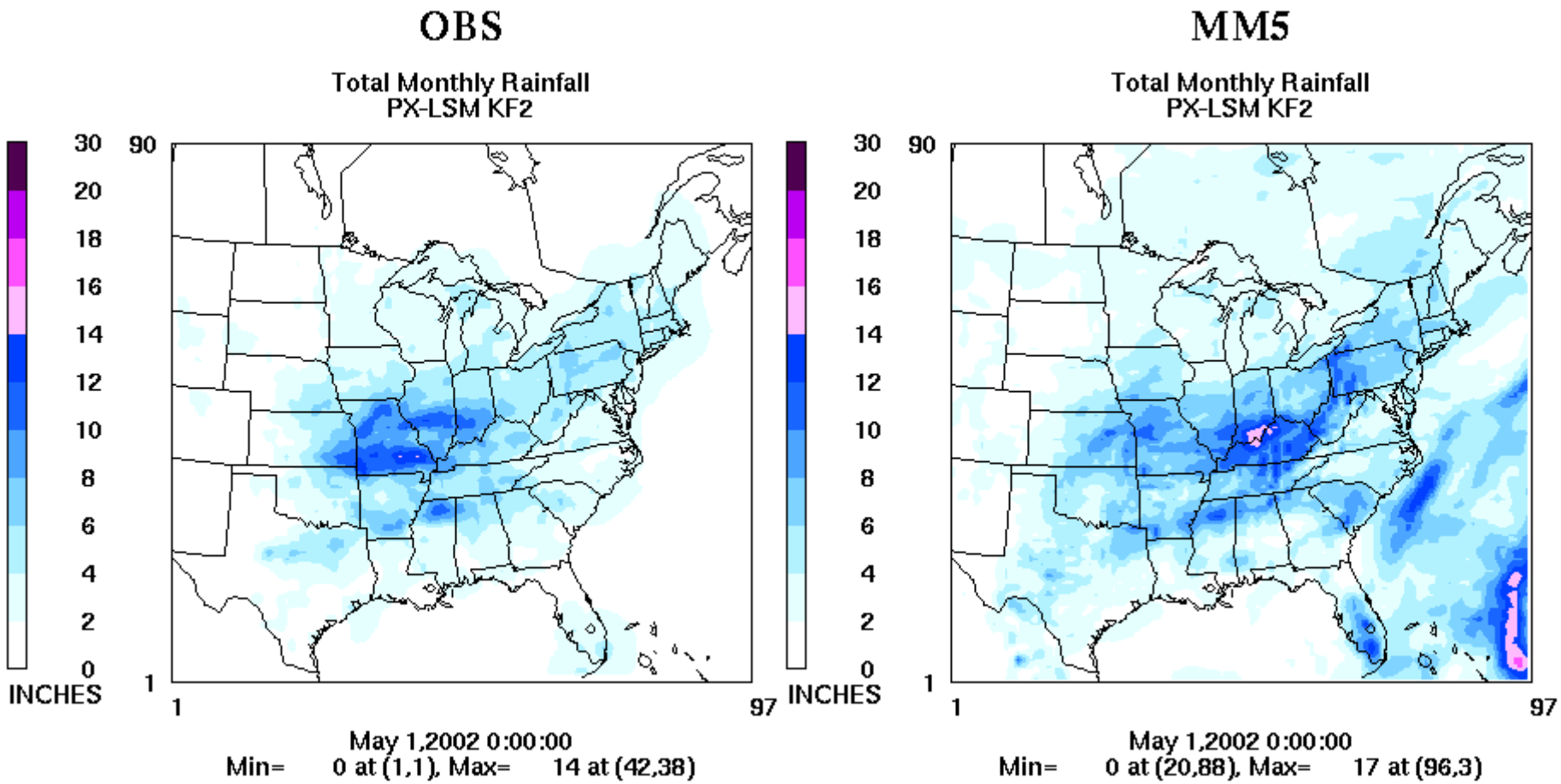

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
March 1,2002 0:00:00
Min= 0 at (1,1), Max= 16 at (86,44)

April 2002

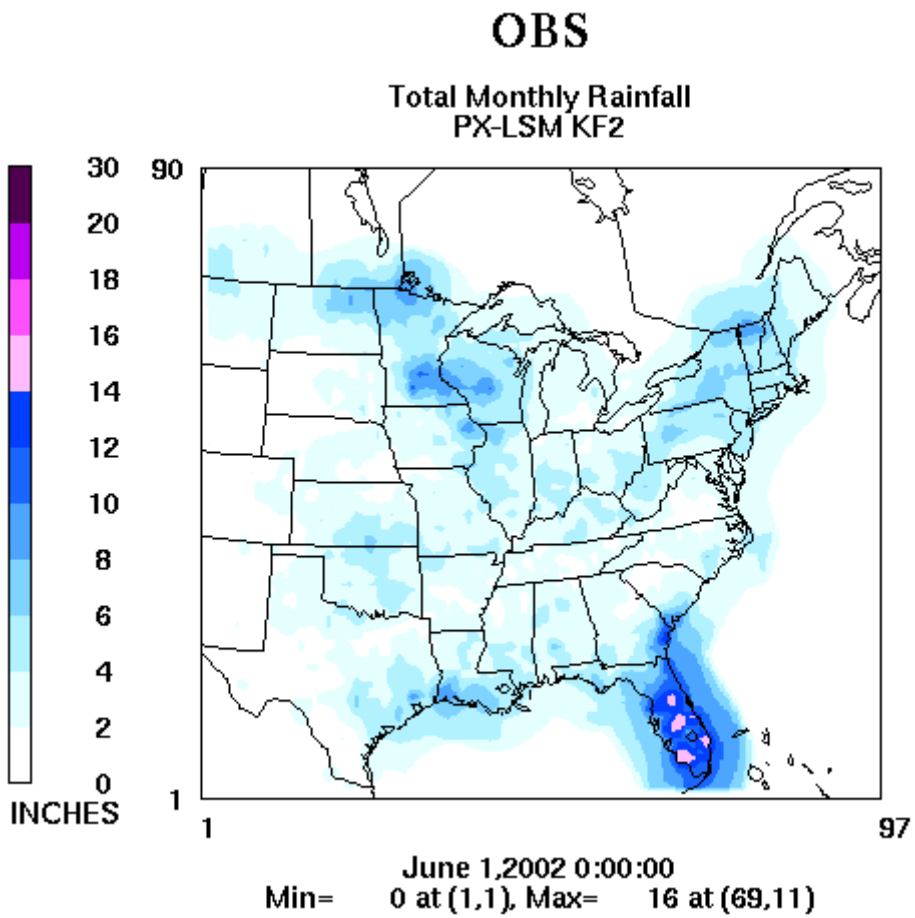

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
April 1,2002 0:00:00
Min= 0 at (1,1), Max= 9 at (65,45)

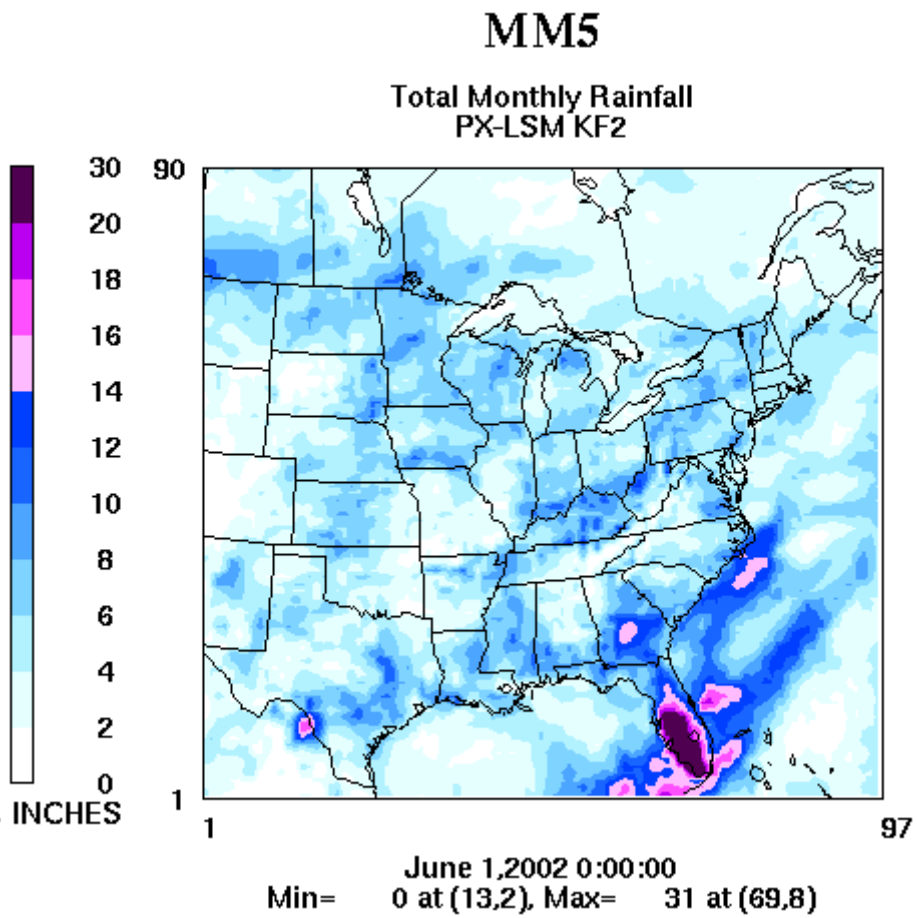

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
April 1,2002 0:00:00
Min= 0 at (1,19), Max= 11 at (65,43)

May 2002

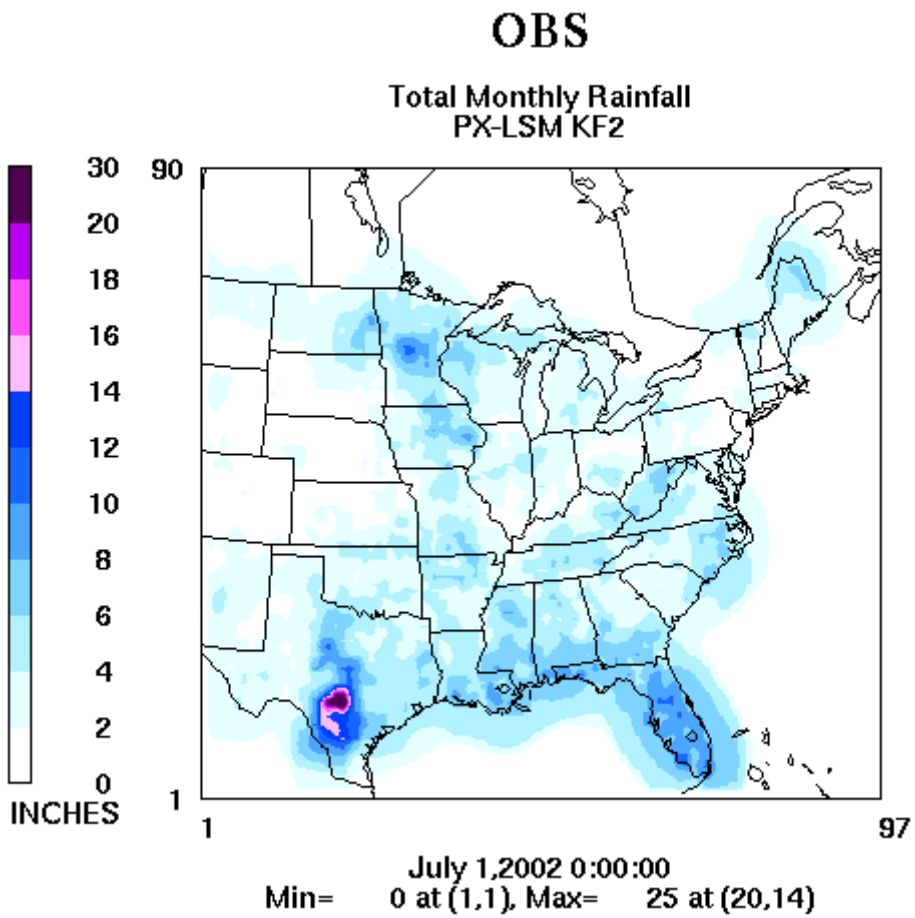

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
May 1,2002 0:00:00
Min= 0 at (1,1), Max= 14 at (42,38)
MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
May 1,2002 0:00:00
Min= 0 at (20,88), Max= 17 at (96,3)

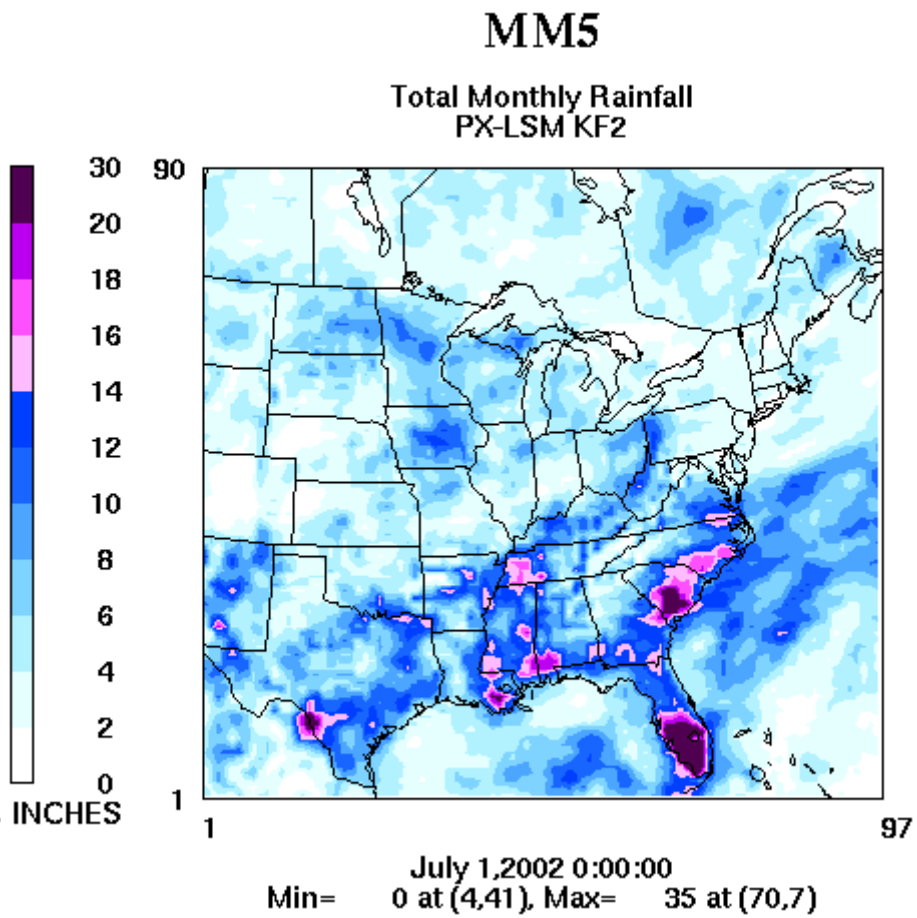
June 2002


OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2002 0:00:00
Min= 0 at (1,1), Max= 16 at (69,11)

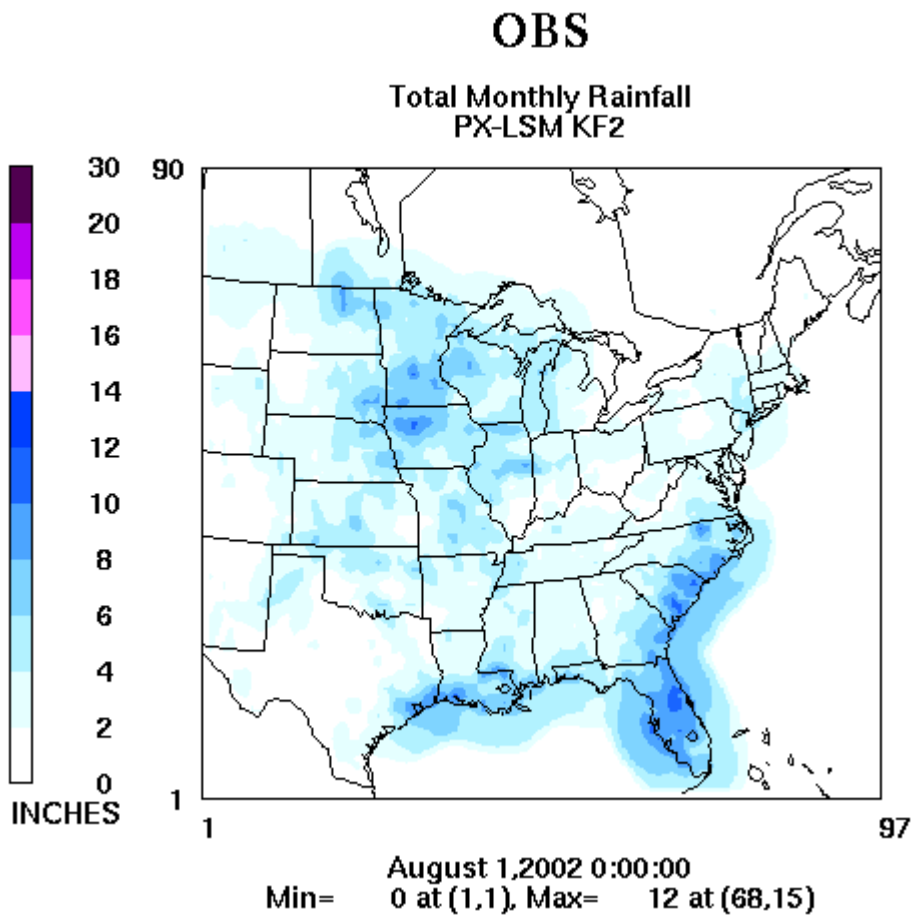

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2002 0:00:00
Min= 0 at (13,2), Max= 31 at (69,8)

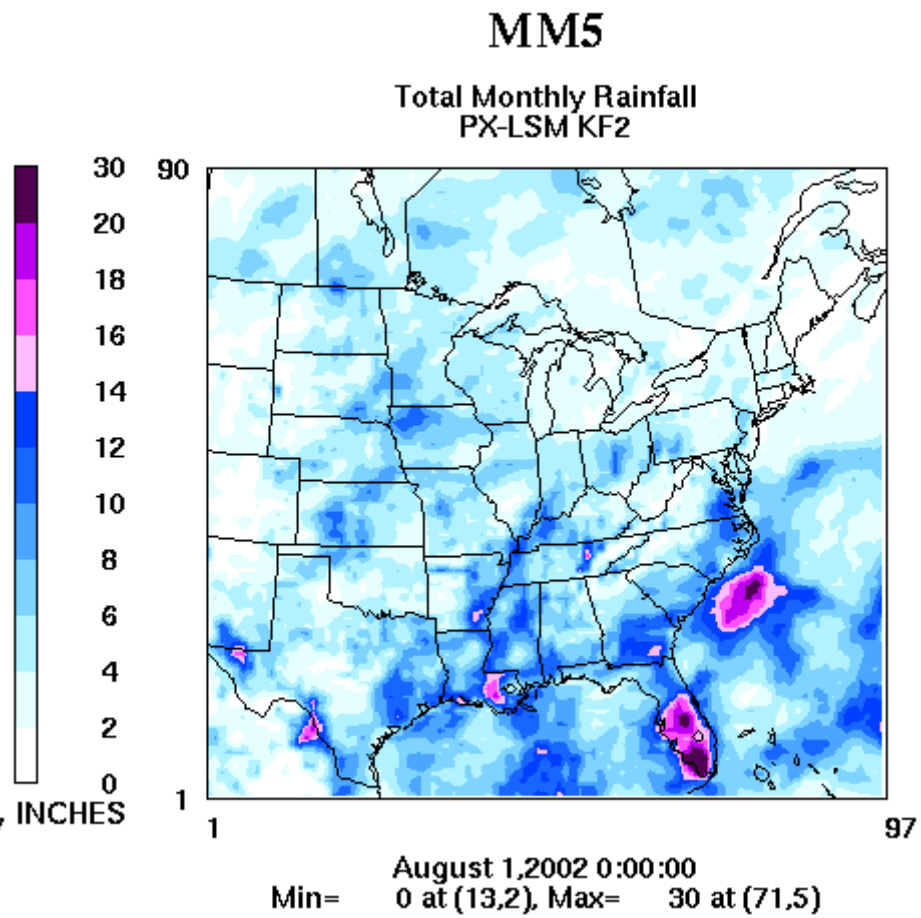
July 2002


OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2002 0:00:00
Min= 0 at (1,1), Max= 25 at (20,14)

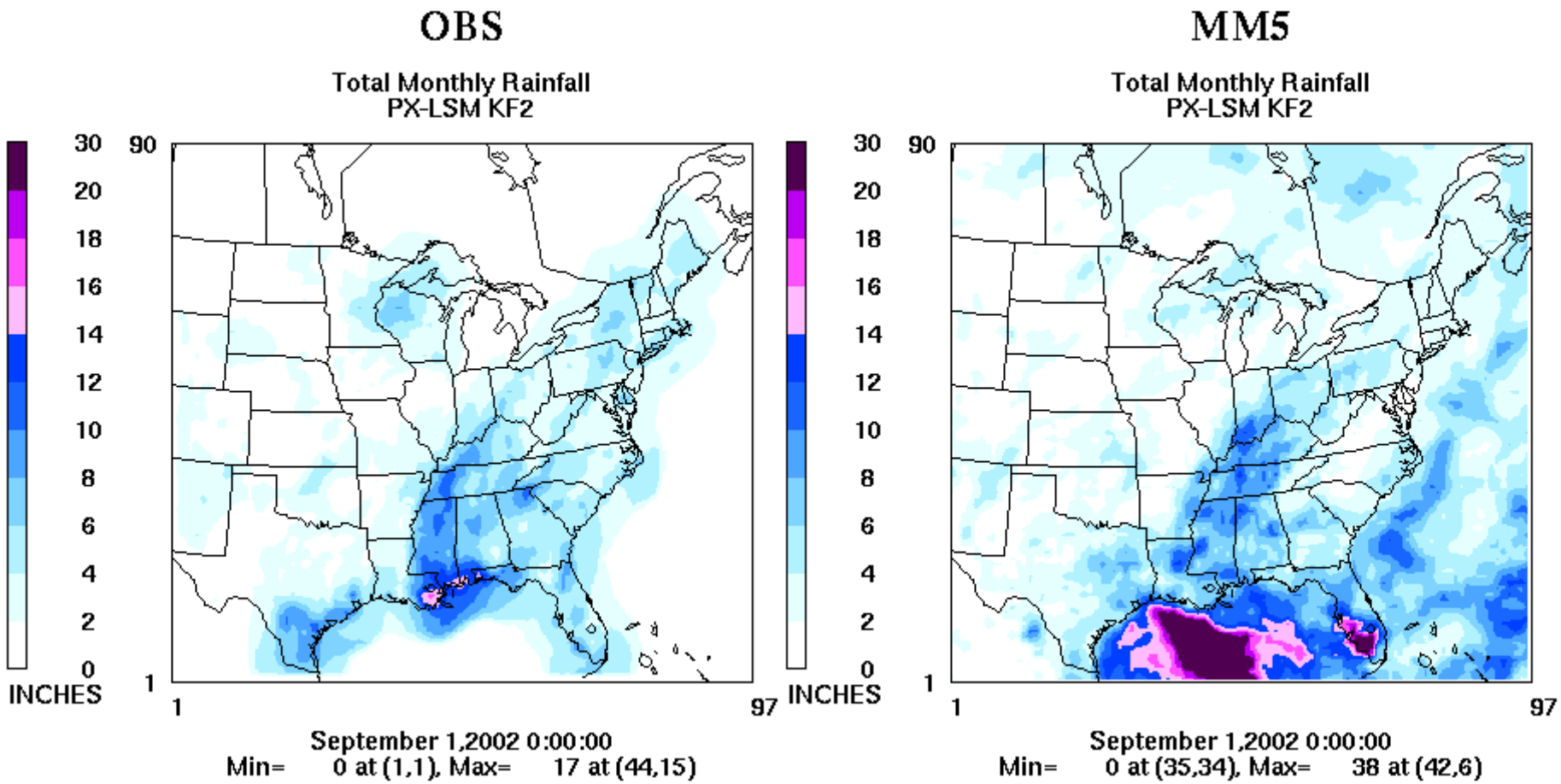

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2002 0:00:00
Min= 0 at (4,41), Max= 35 at (70,7)

August 2002

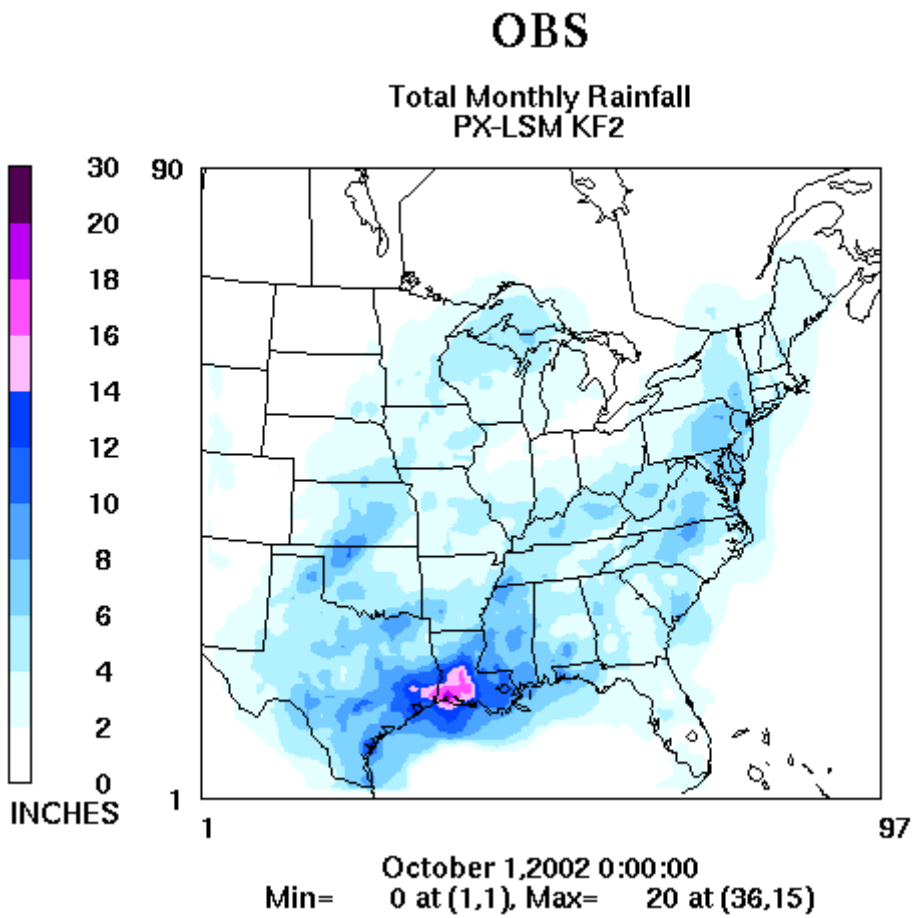

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2002 0:00:00
Min= 0 at (1,1), Max= 12 at (68,15)

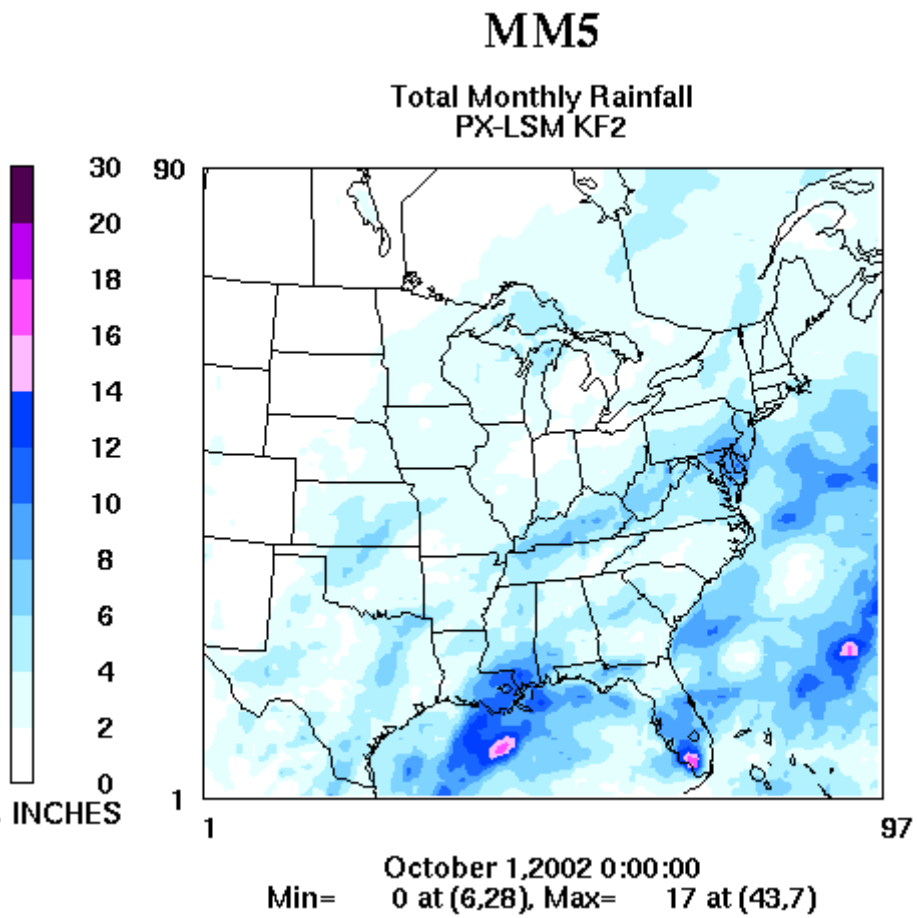

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2002 0:00:00
Min= 0 at (13,2), Max= 30 at (71,5)

September 2002

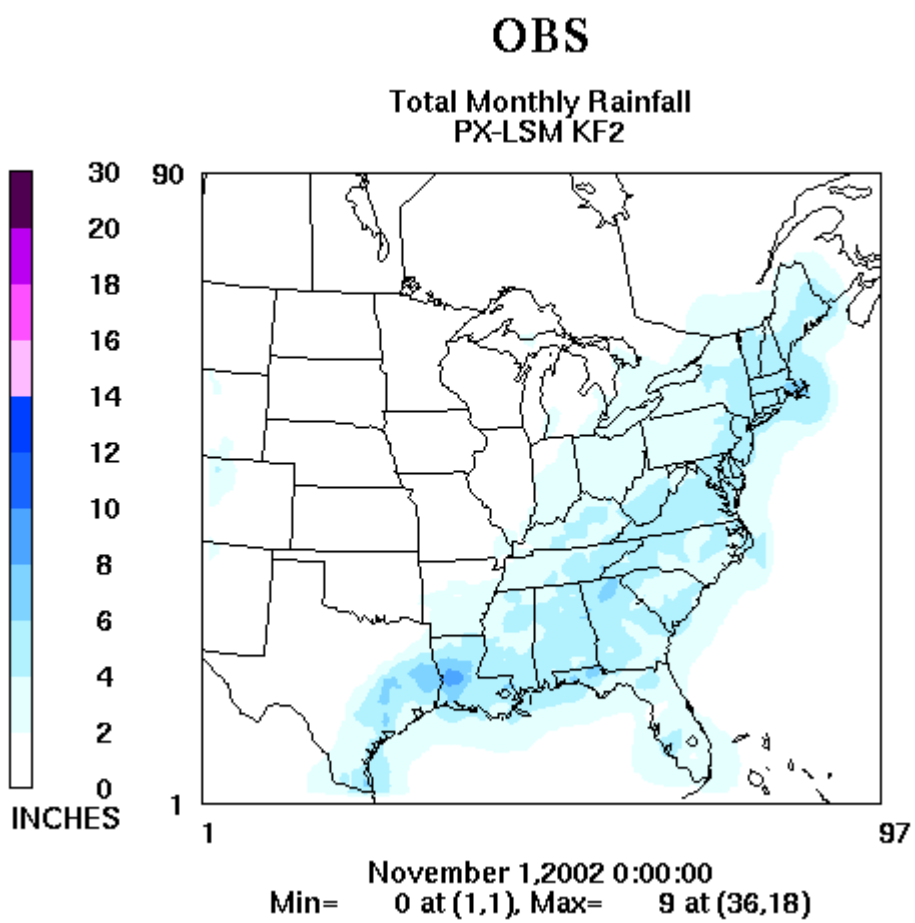


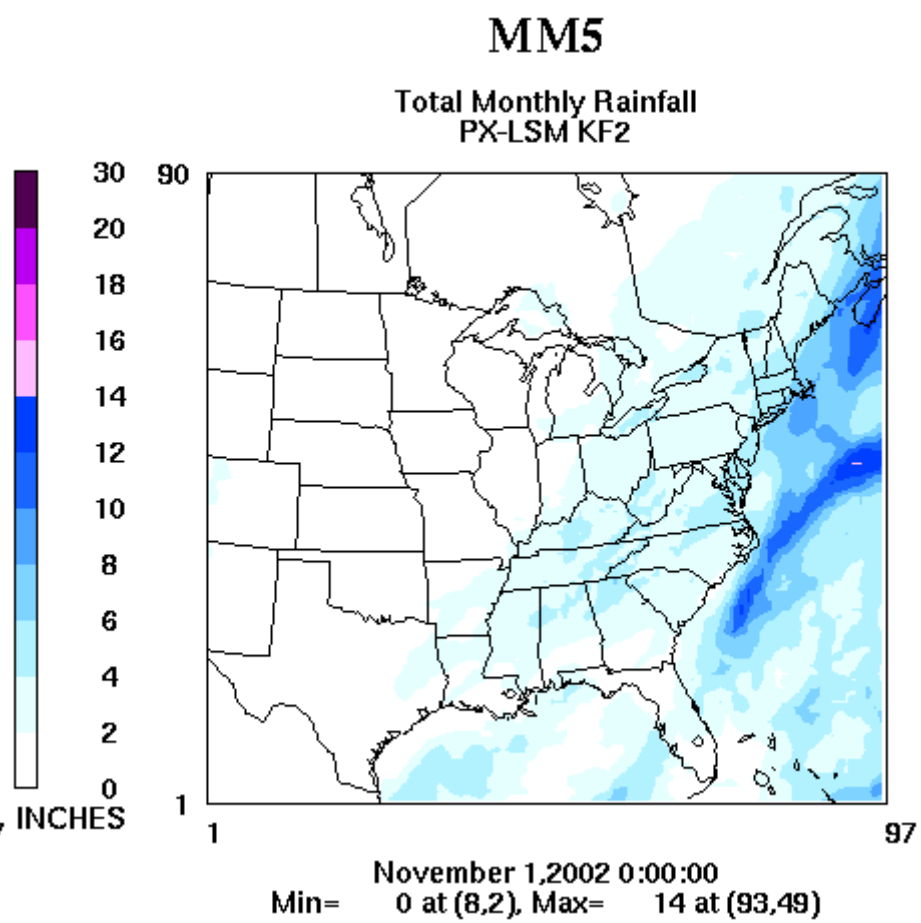
October 2002



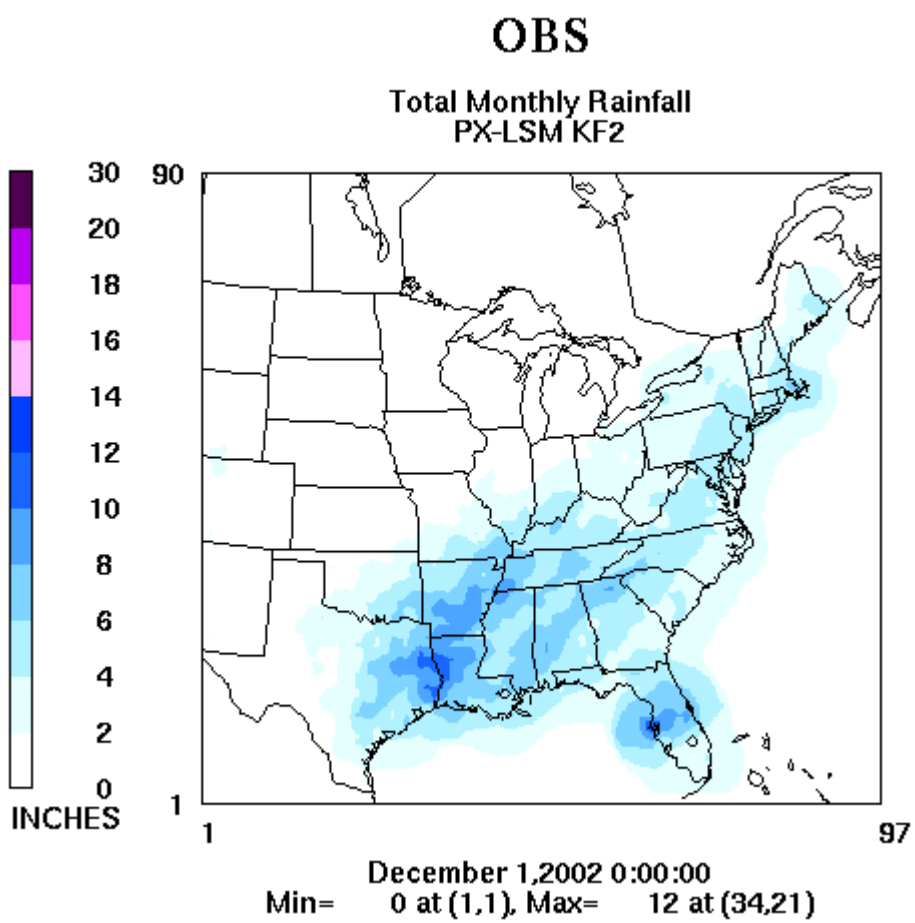


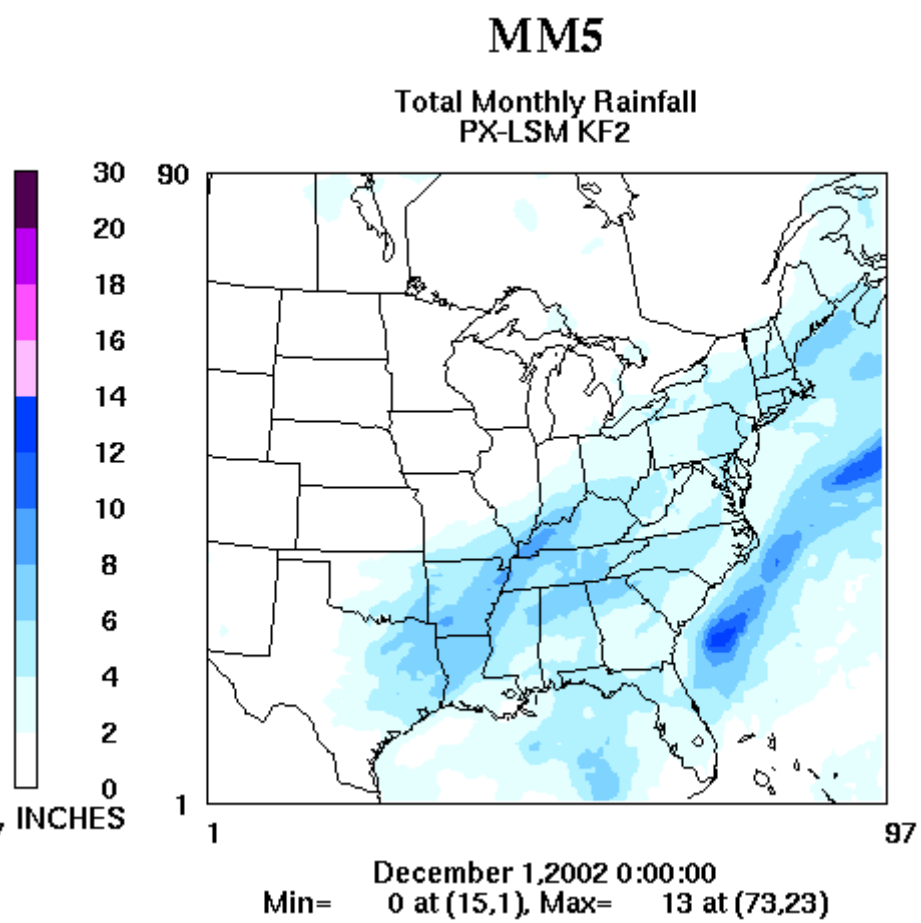
November 2002





December 2002

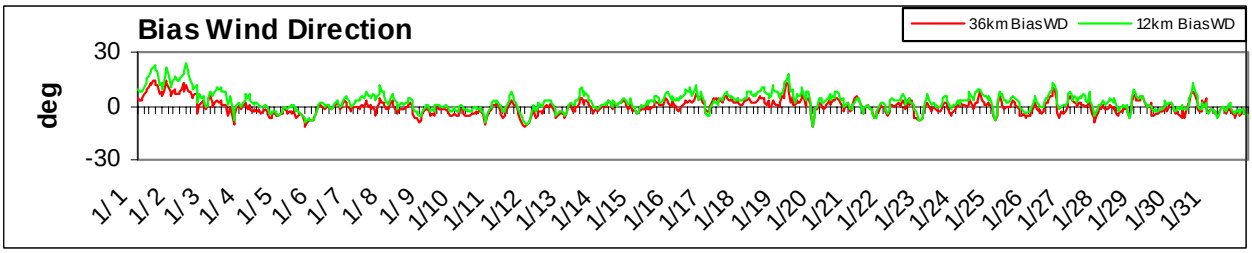


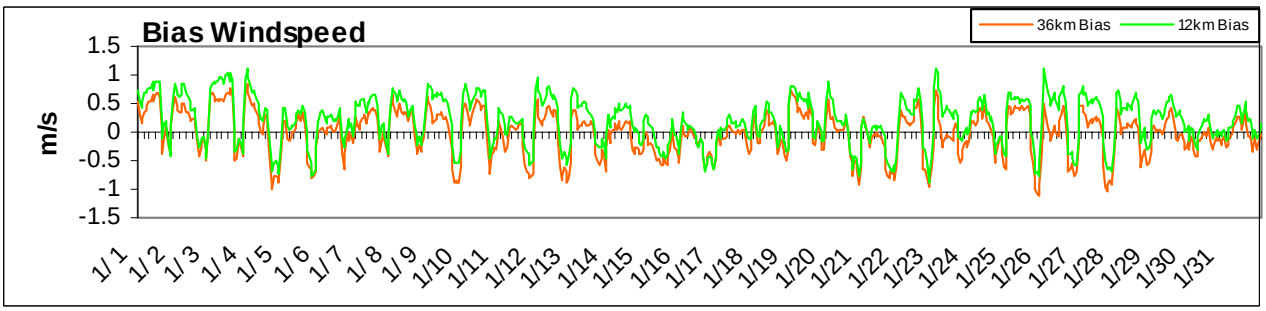


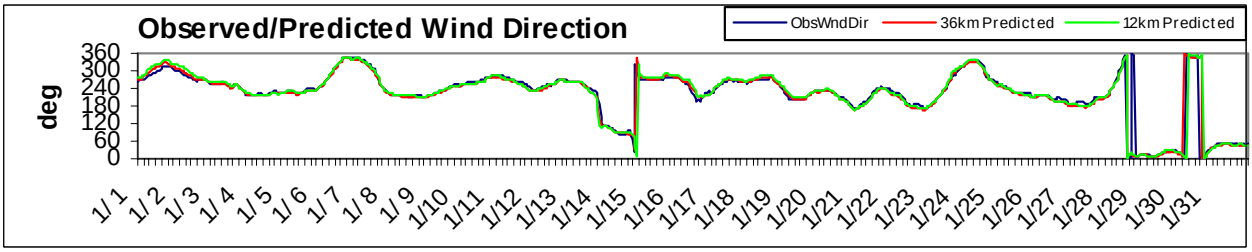
APPENDIX B

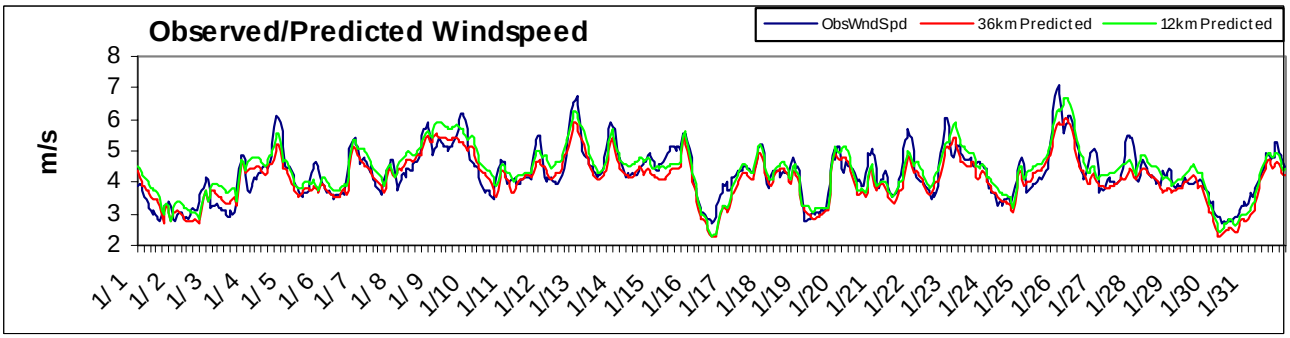
12 v 36 km Performance

Great Lakes Jan 2002

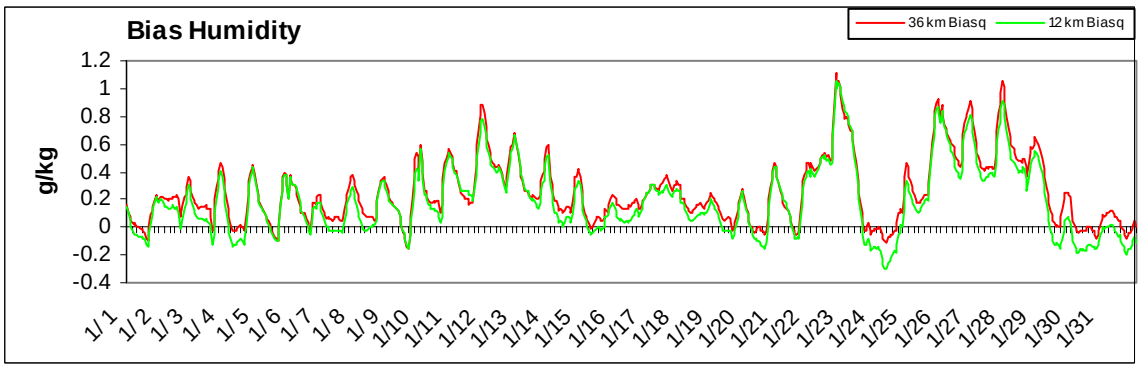


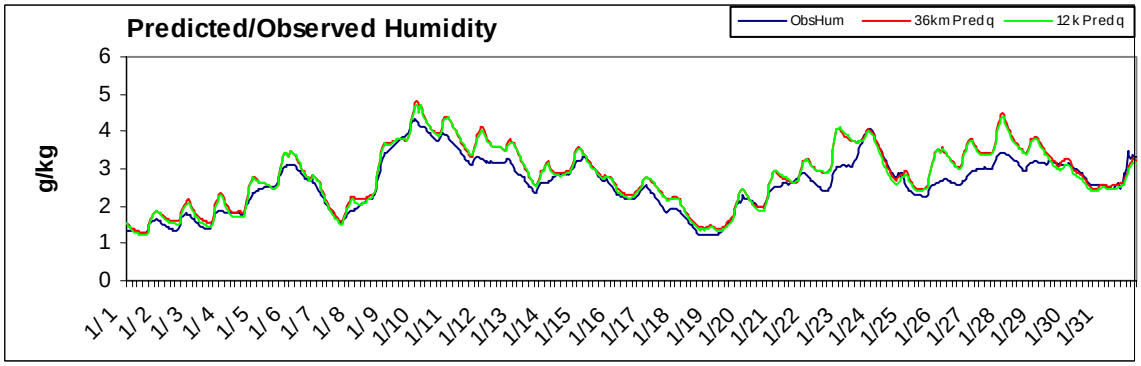


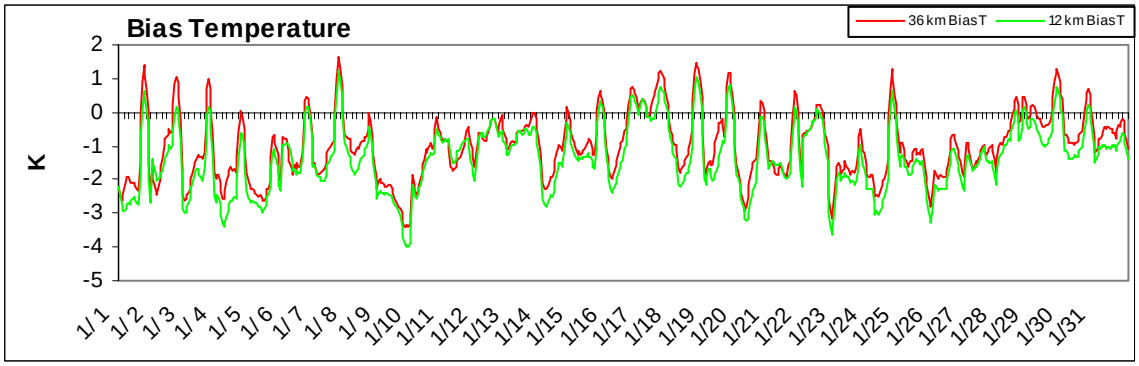


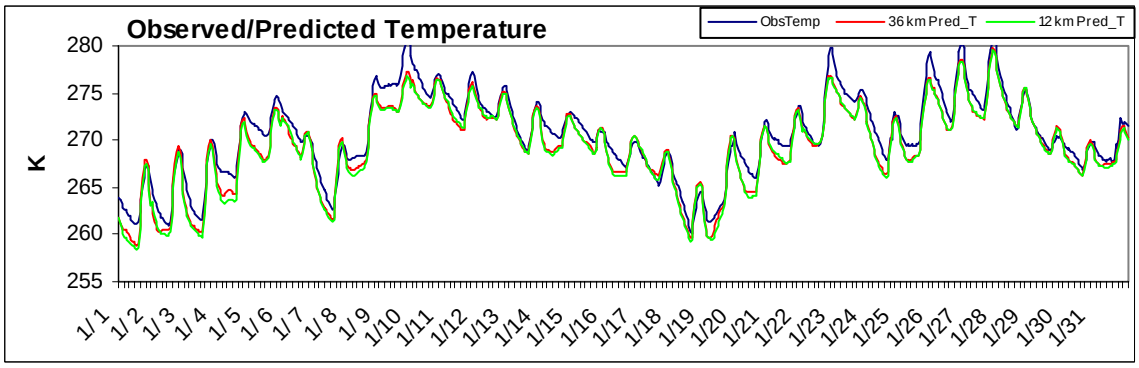


Great Lakes Jan 2002

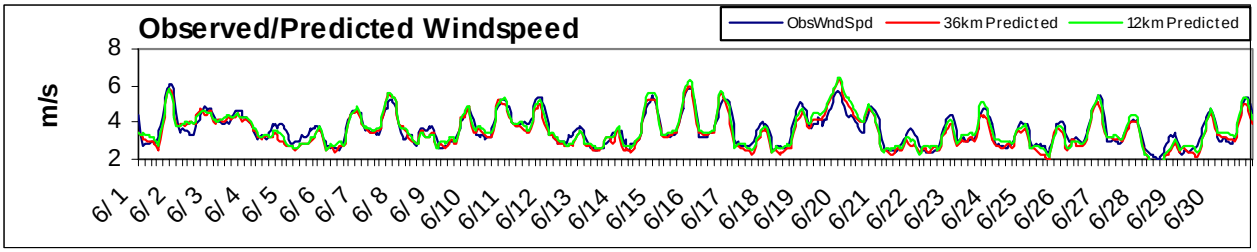


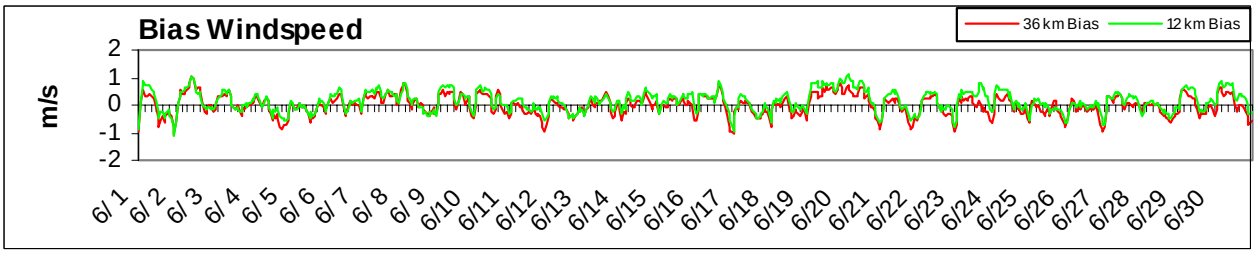


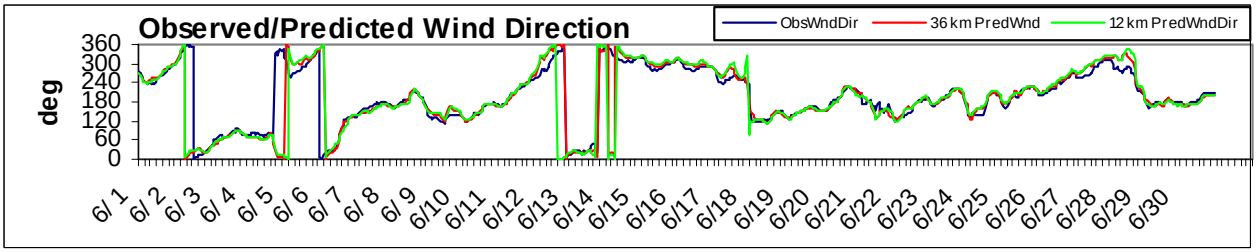


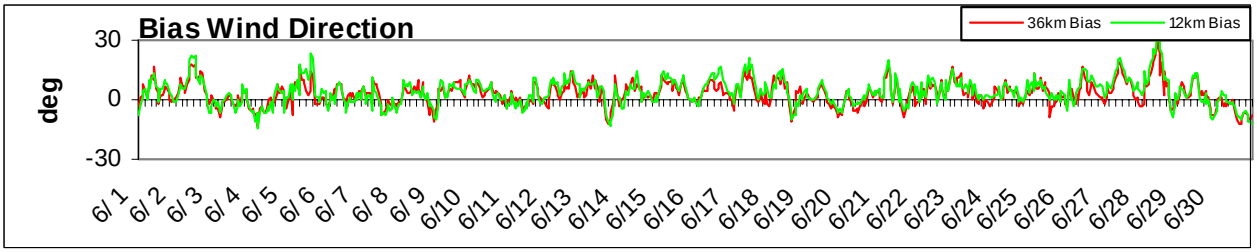


Great Lakes June 2002

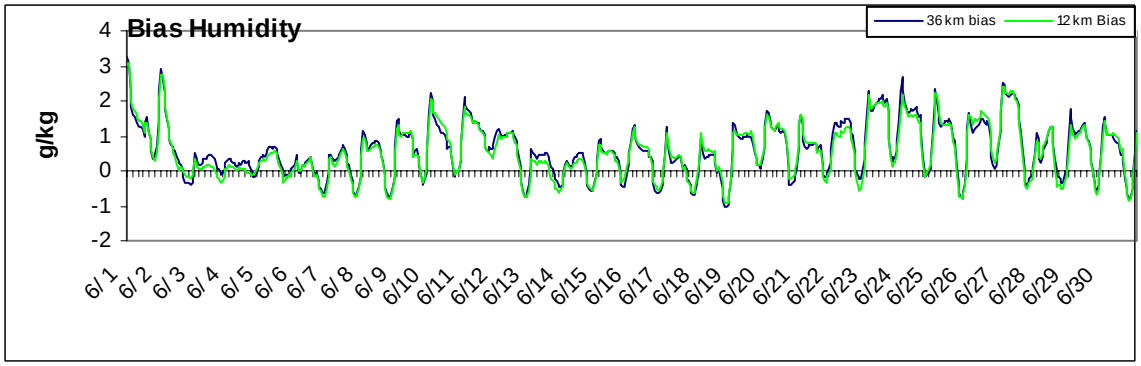


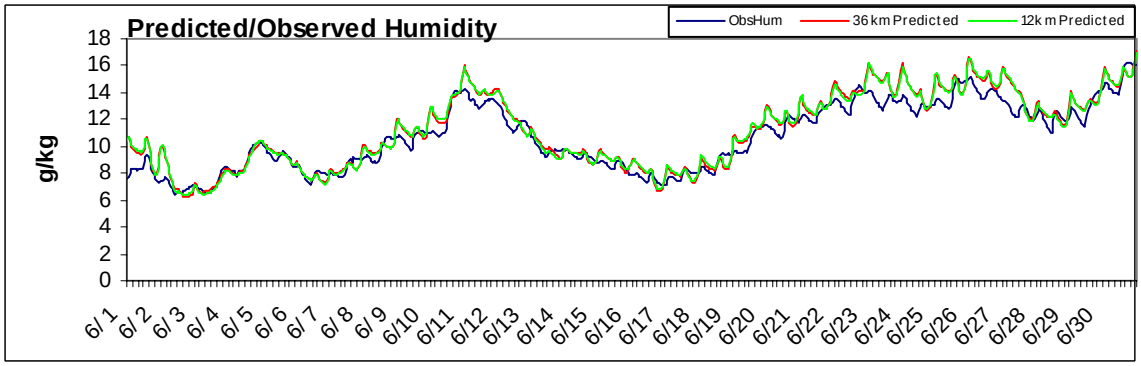


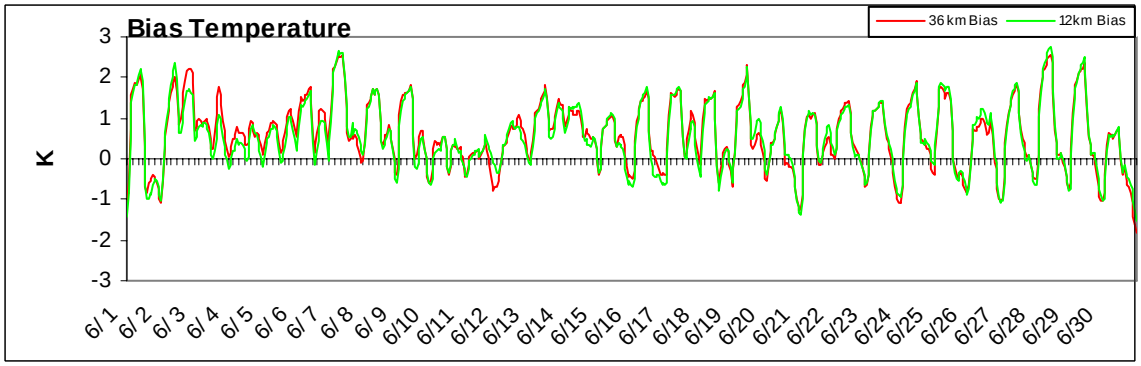


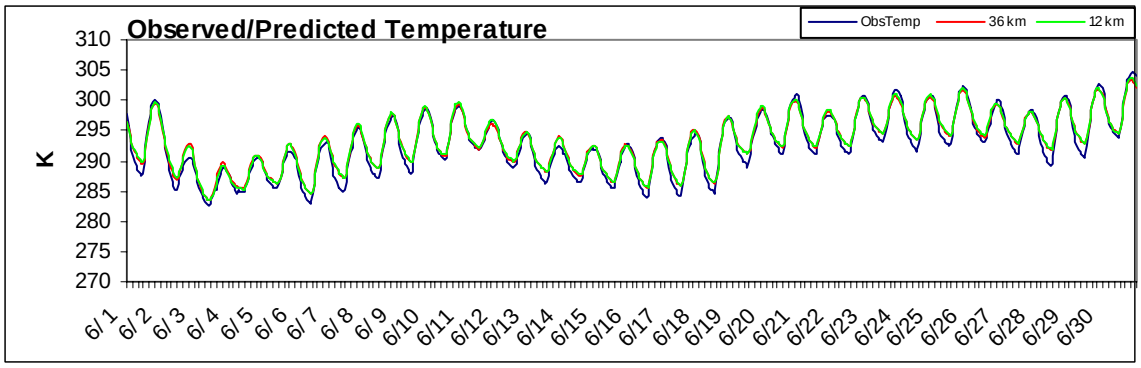


Great Lakes June 2002

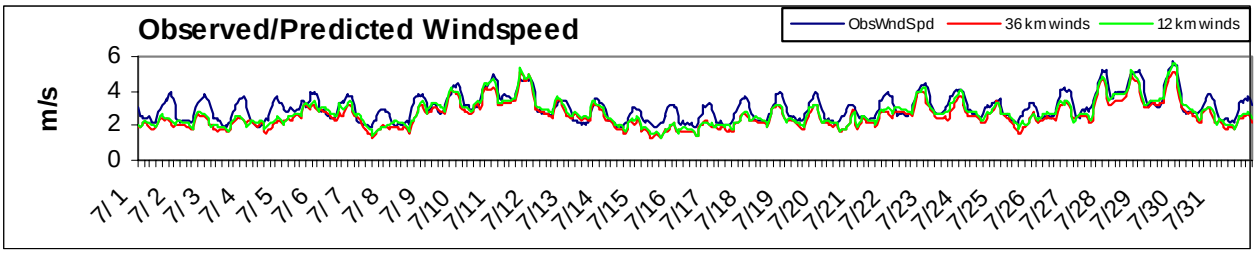


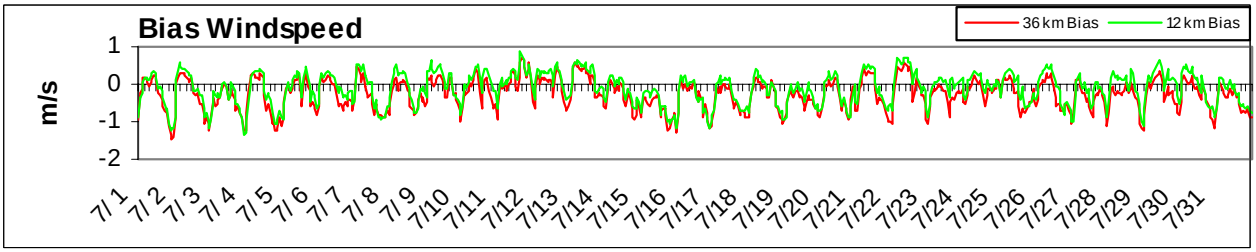


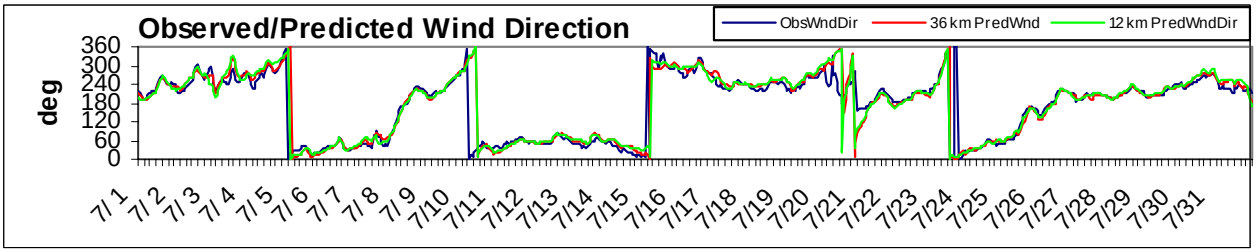


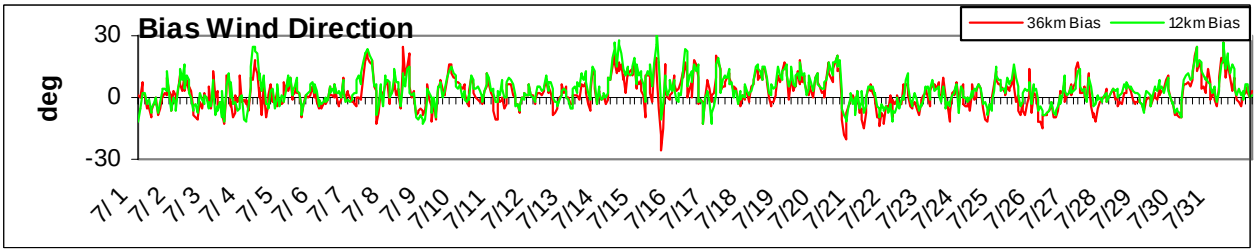


Ohio Valley July 2002

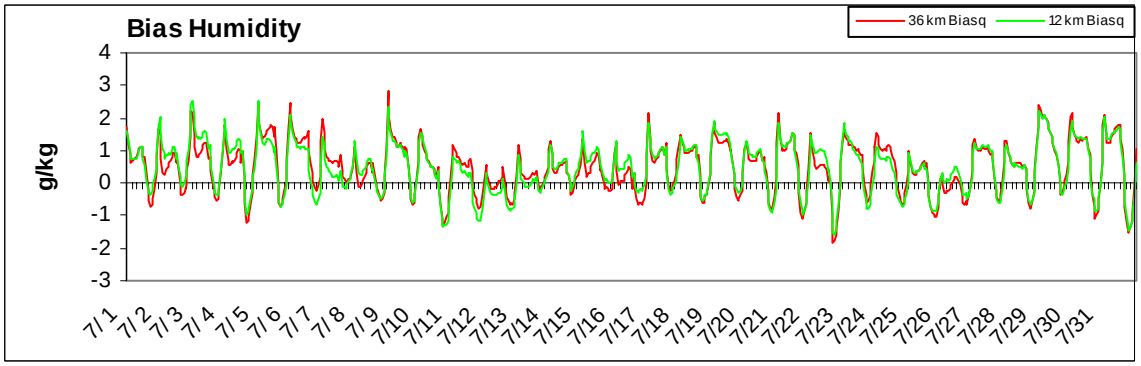


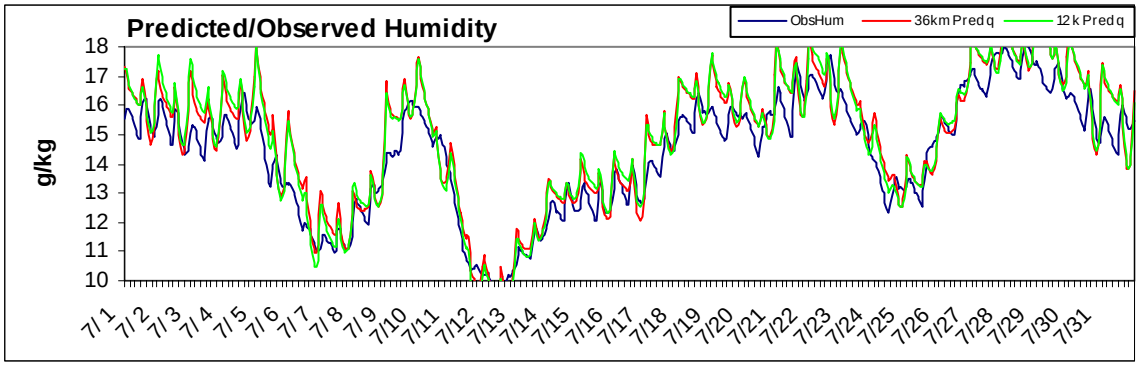


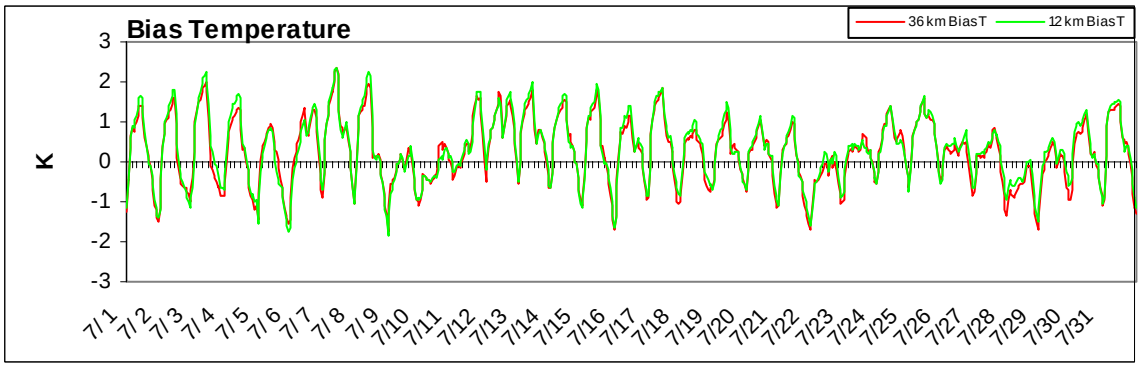


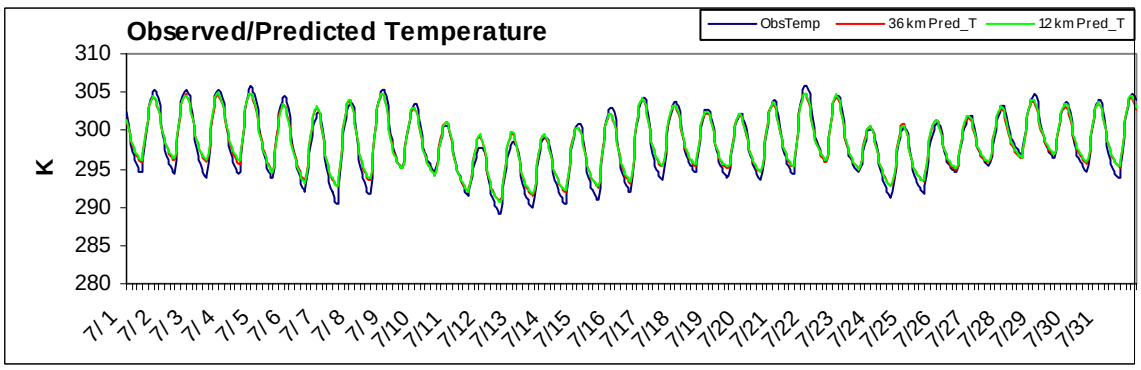


Ohio Valley July 2002





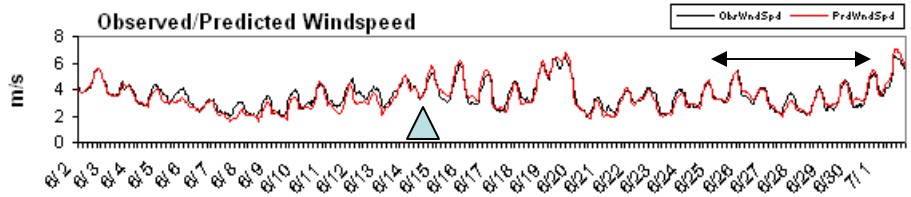


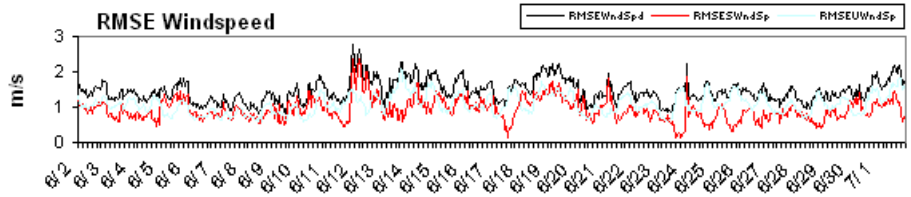


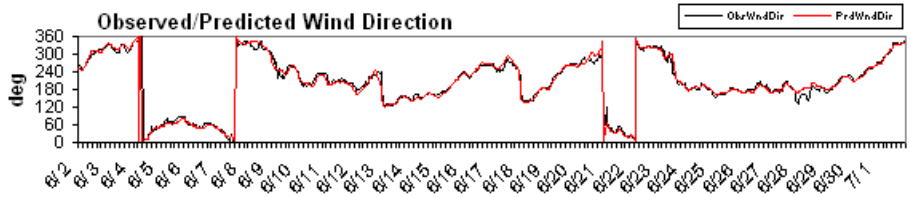
APPENDIX C

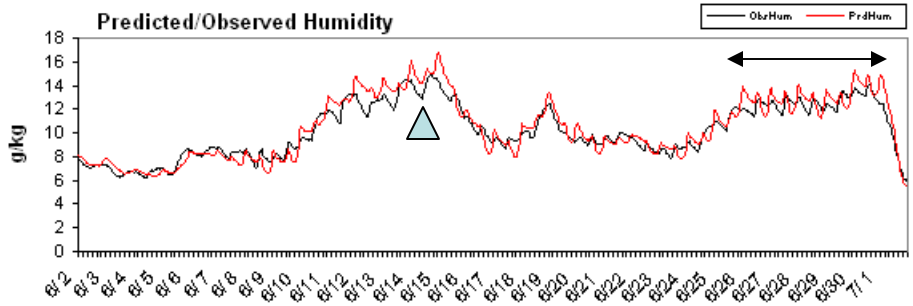
Performance for Summers 2001, 2002, and 2003

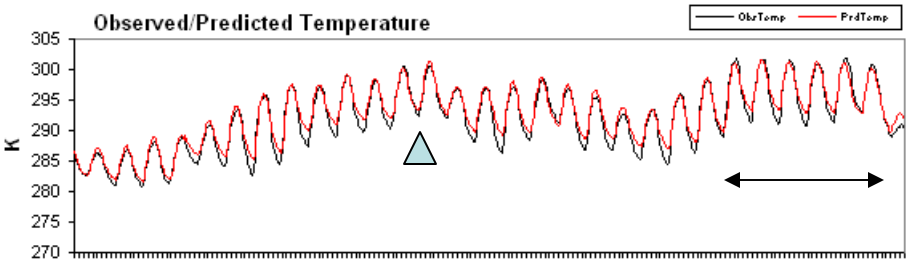
JUNE 2001

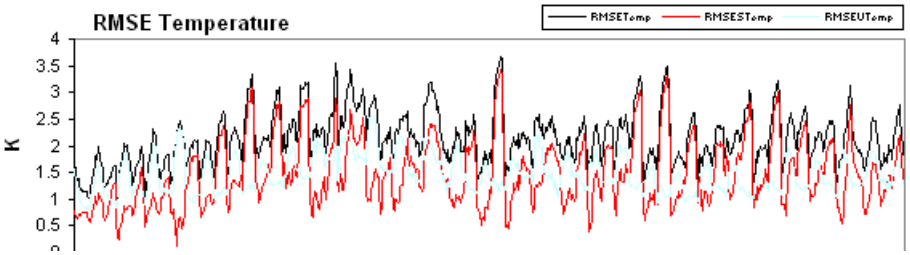

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

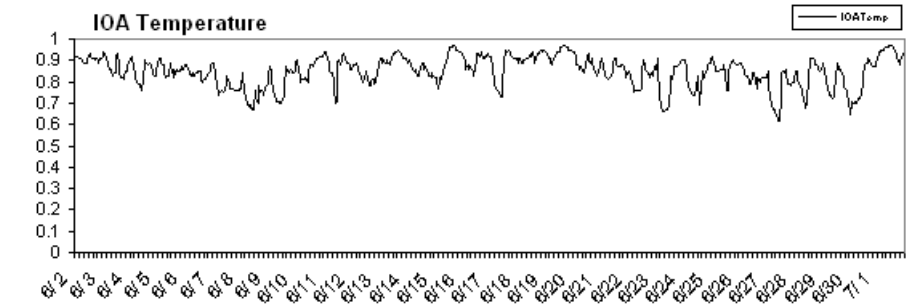

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

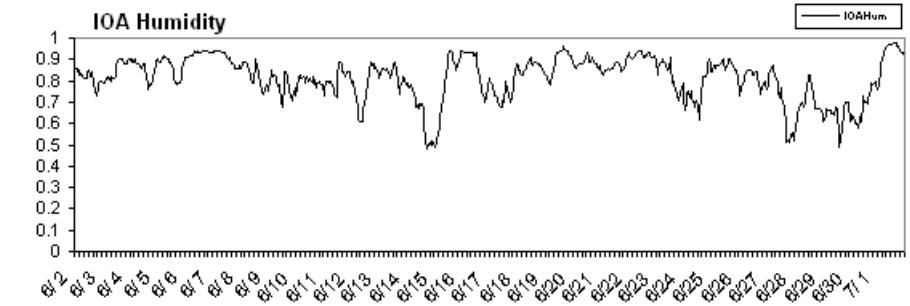

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

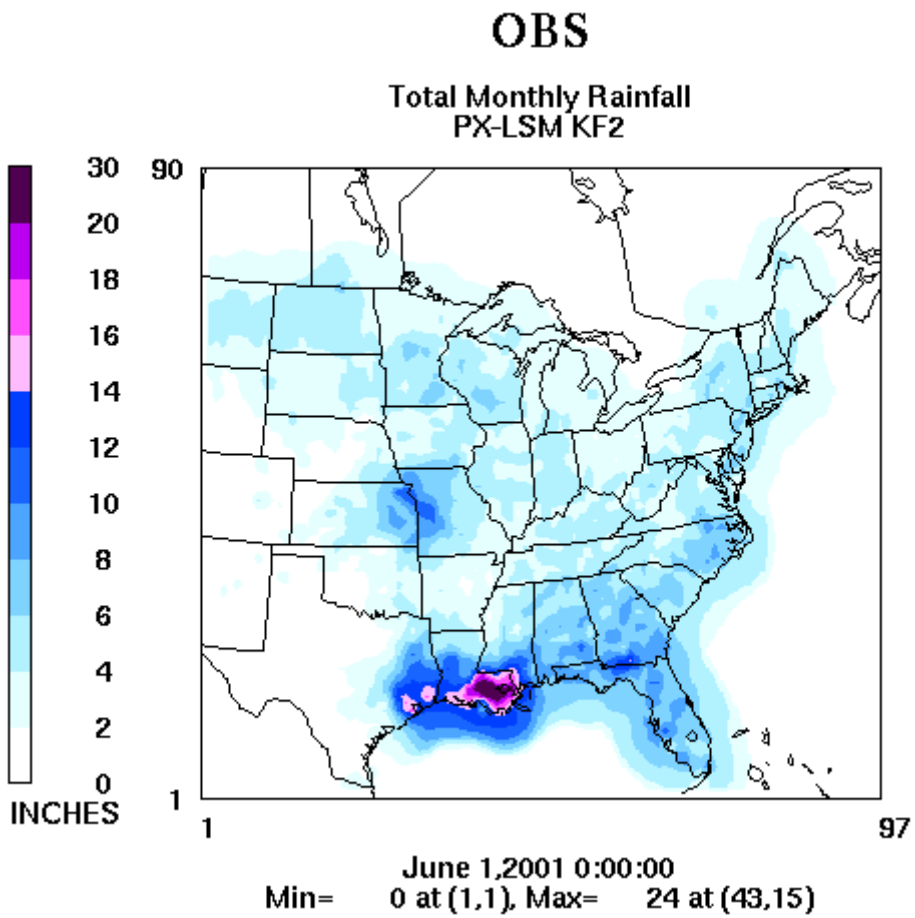

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

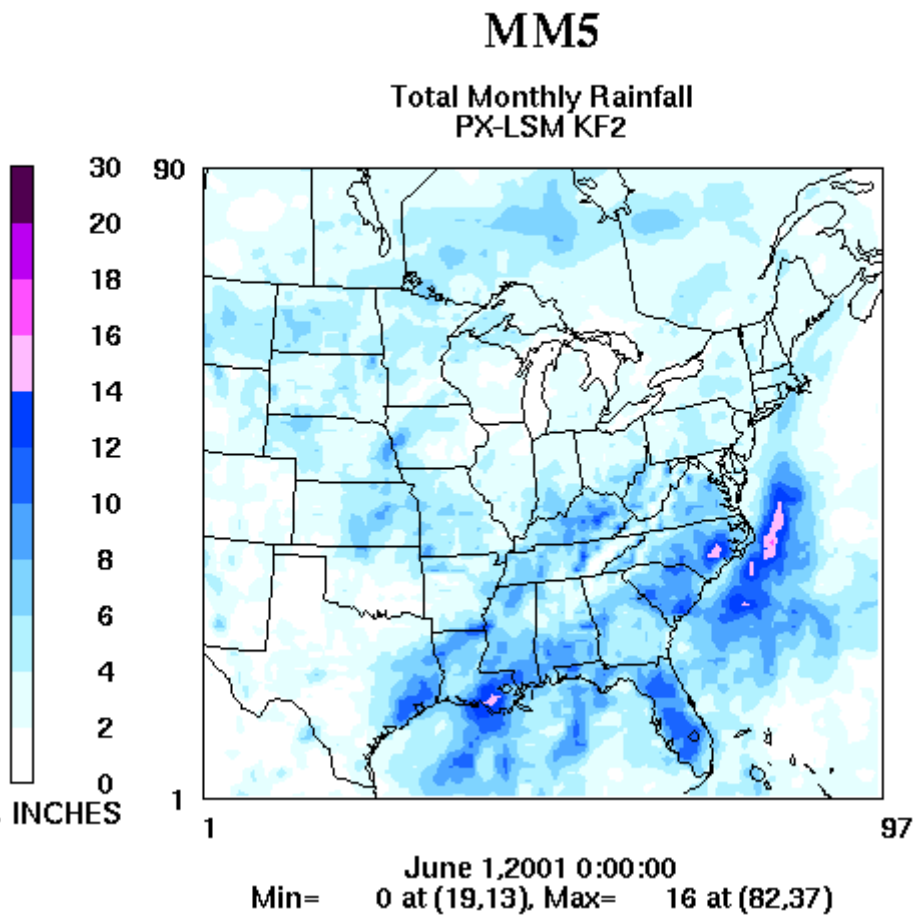

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

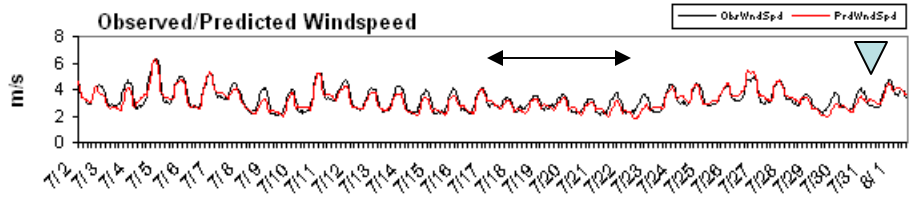

IOA Humidity
IOAHum

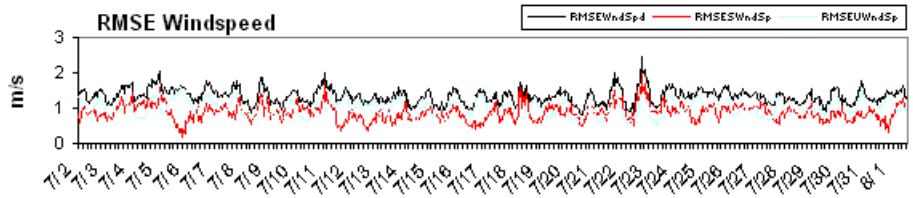
June 2001

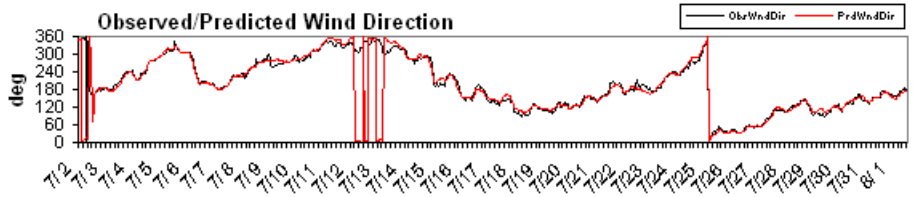

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2001 0:00:00
Min= 0 at (1,1), Max= 24 at (43,15)

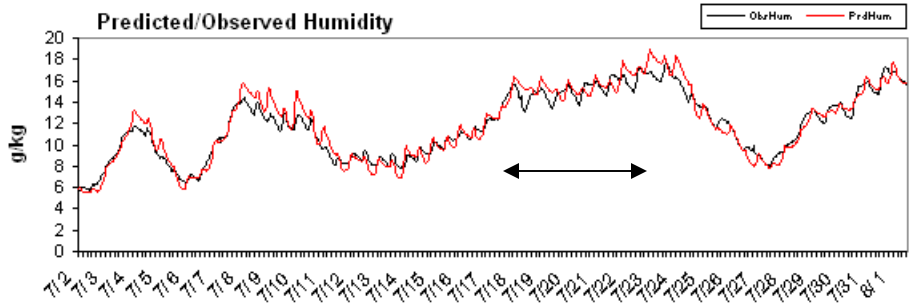

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2001 0:00:00
Min= 0 at (19,13), Max= 16 at (82,37)

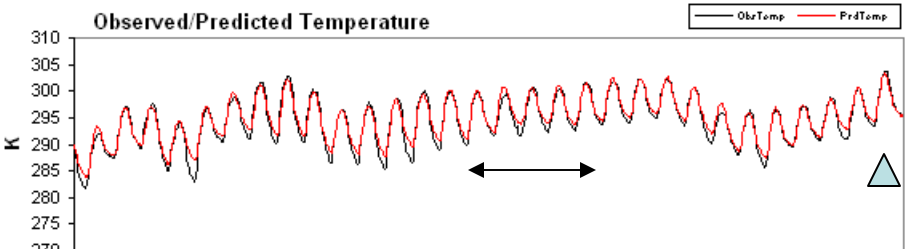
JULY 2001

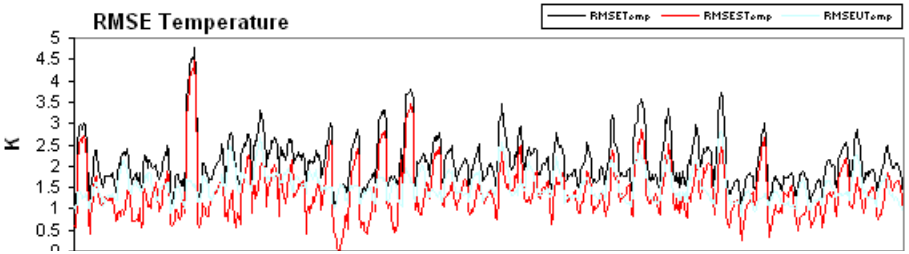

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

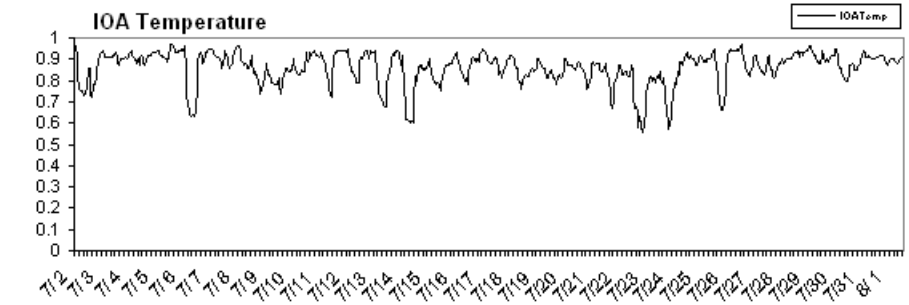

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

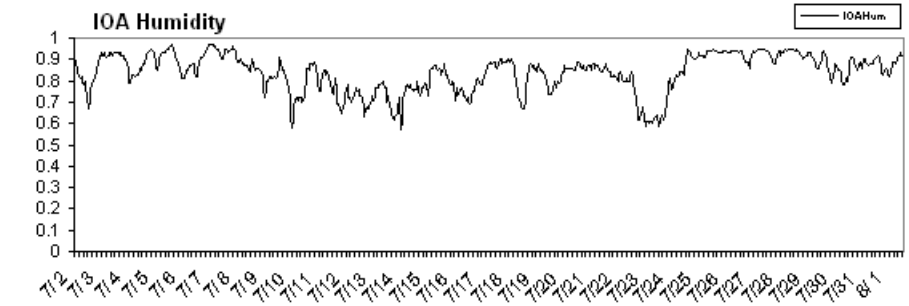

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

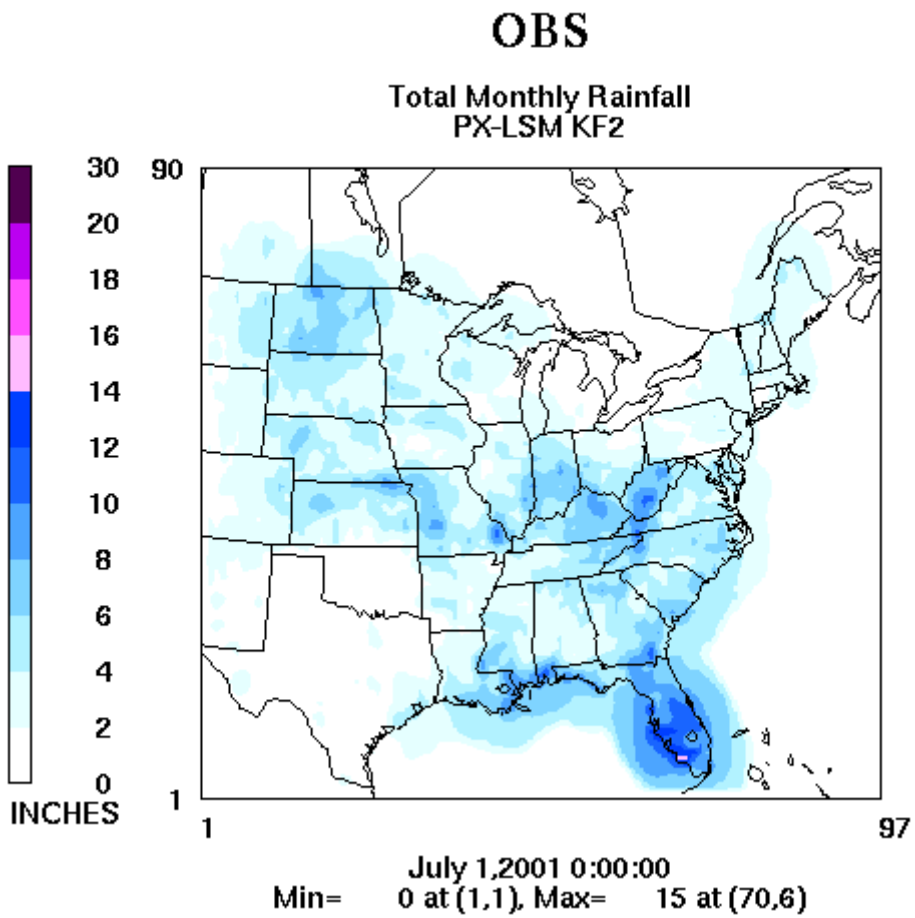

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

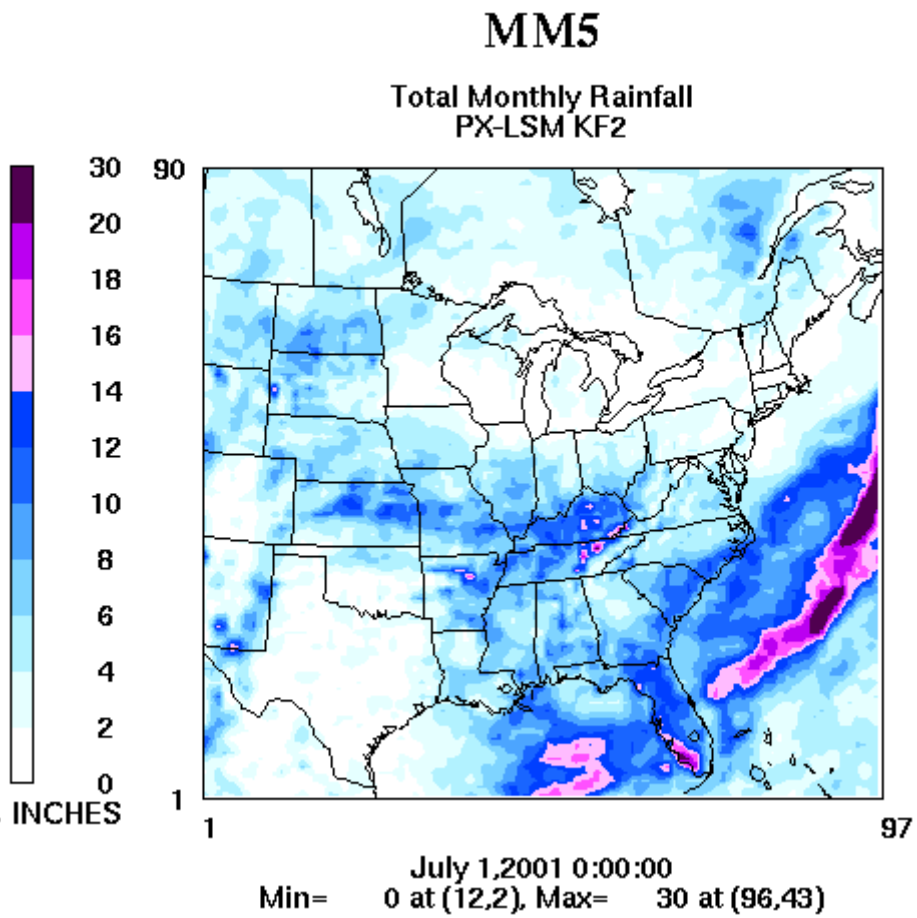

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

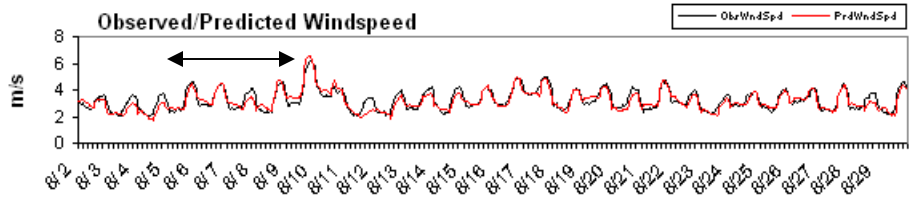

IOA Humidity
IOAHum

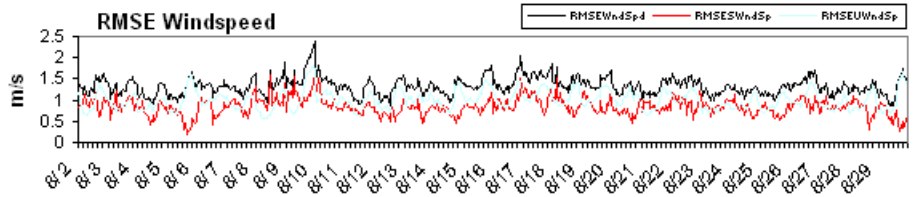
July 2001

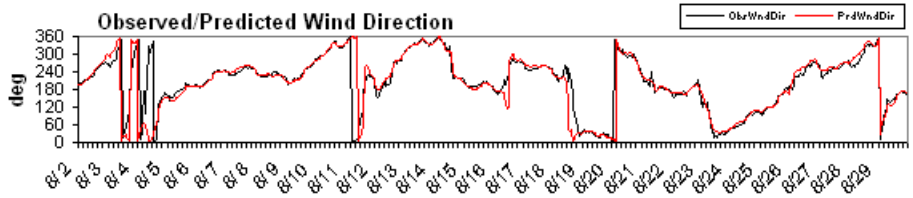

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2001 0:00:00
Min= 0 at (1,1), Max= 15 at (70,6)

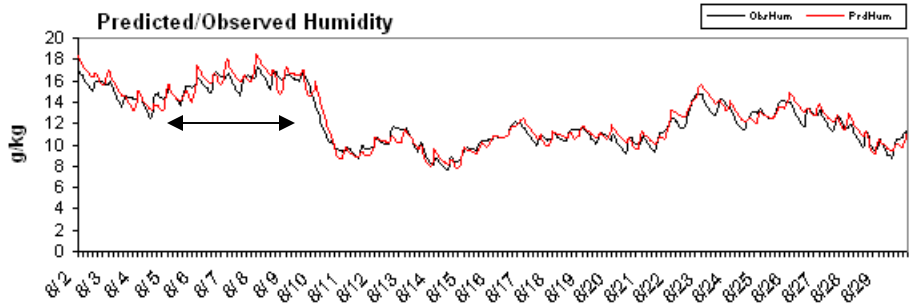

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2001 0:00:00
Min= 0 at (12,2), Max= 30 at (96,43)

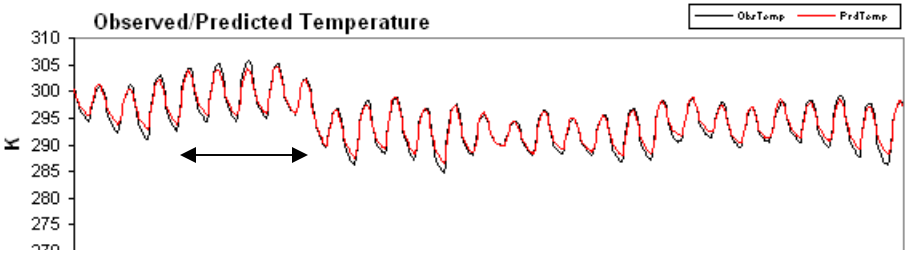
AUGUST 2001

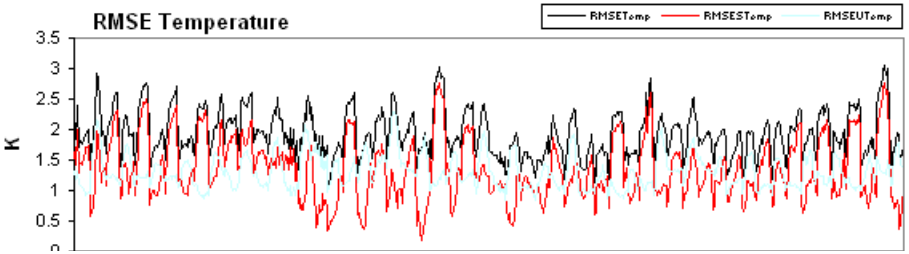

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

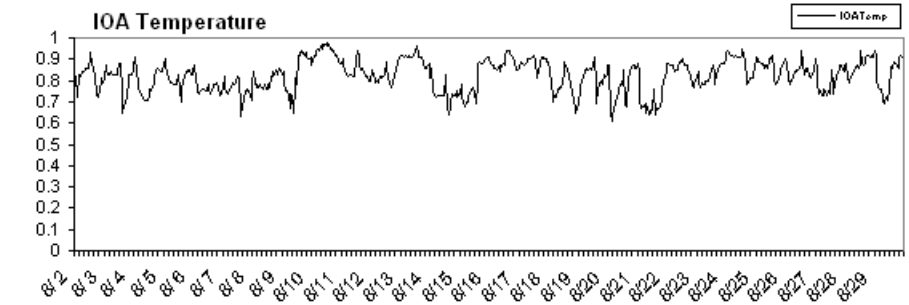

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

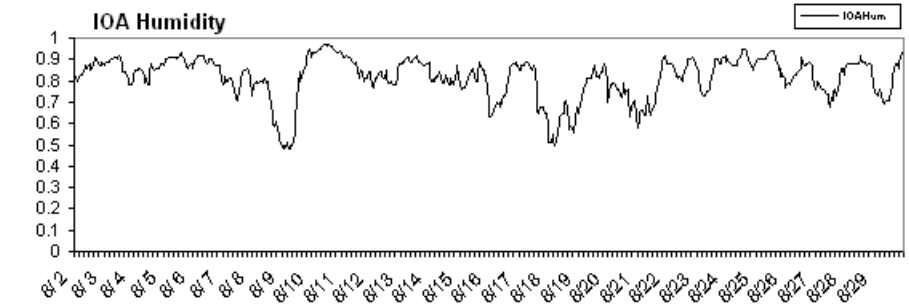

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

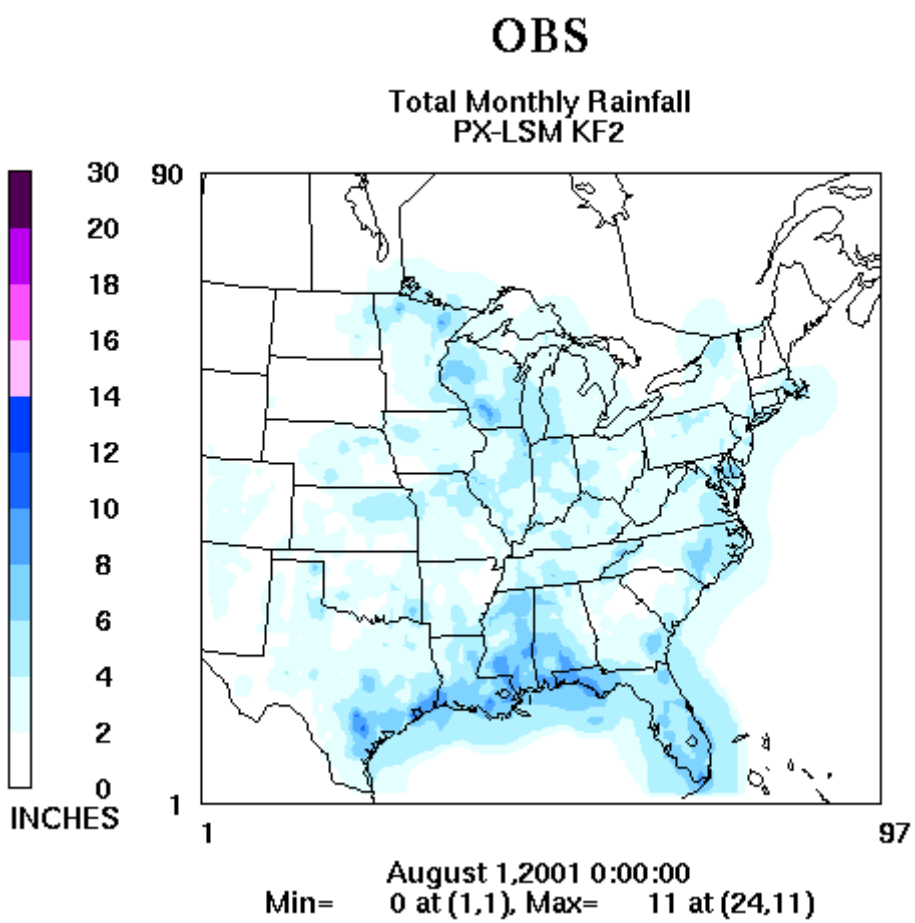

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

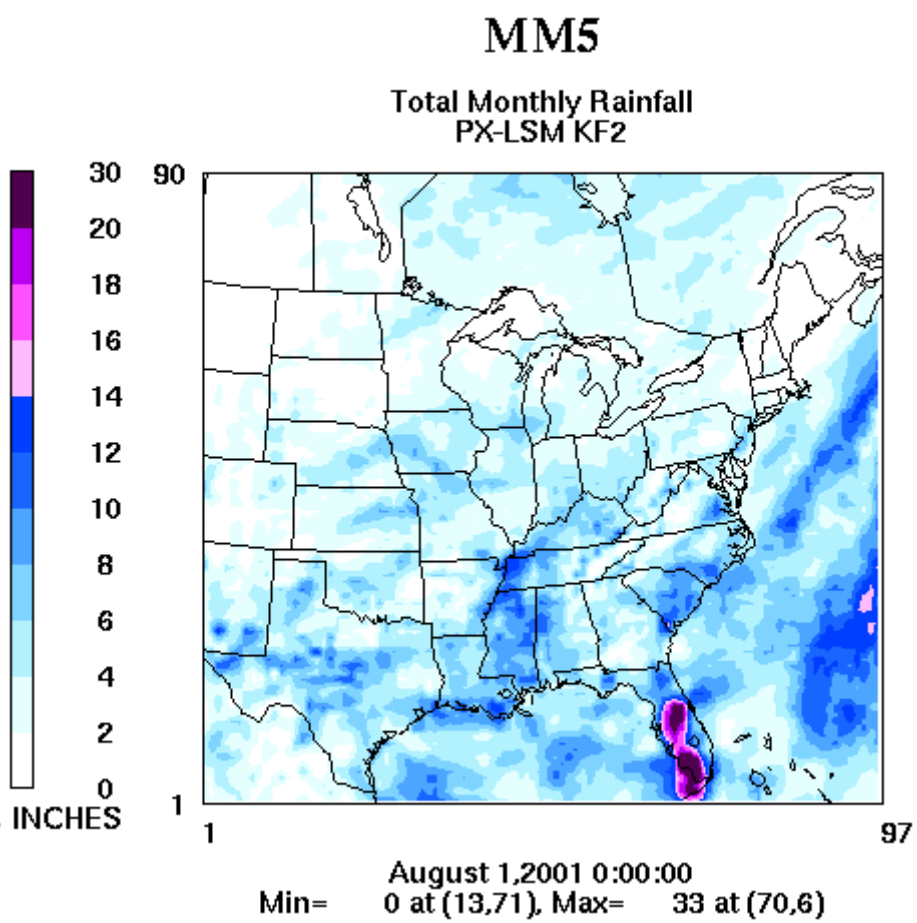

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

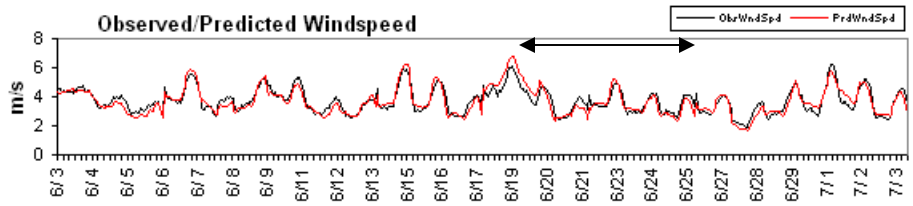

IOA Humidity
IOAHum

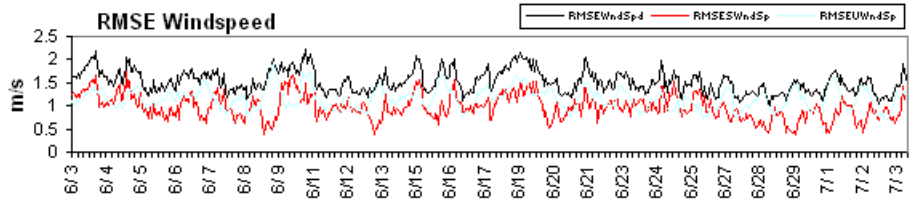
August 2001

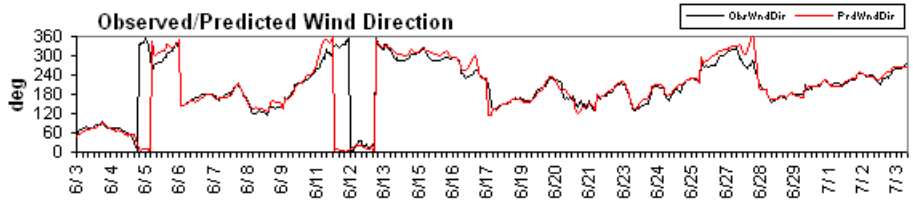

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2001 0:00:00
Min= 0 at (1,1), Max= 11 at (24,11)

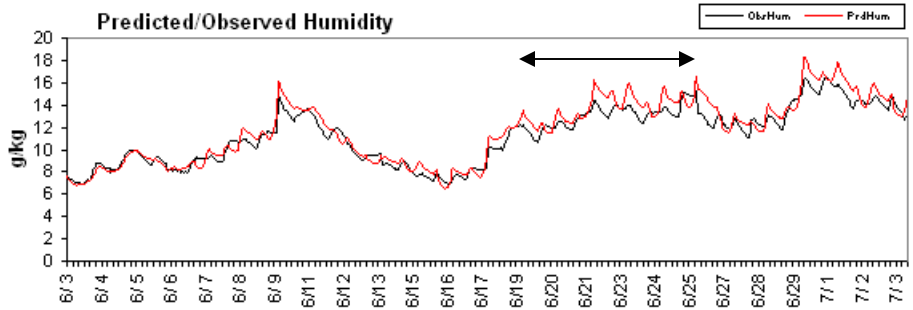

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2001 0:00:00
Min= 0 at (13,71), Max= 33 at (70,6)

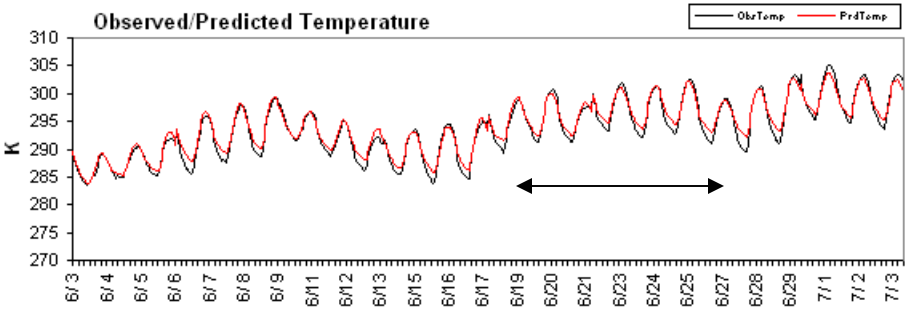
JUNE 2002

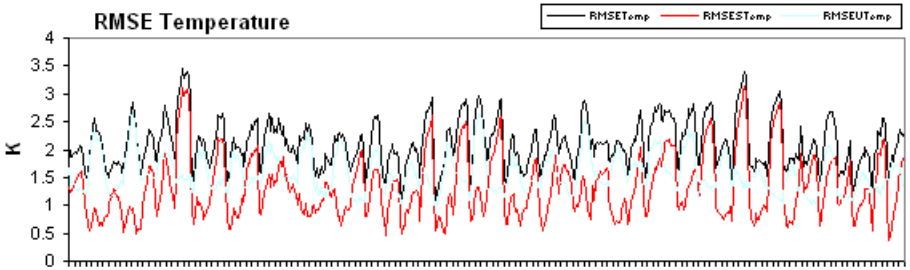

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

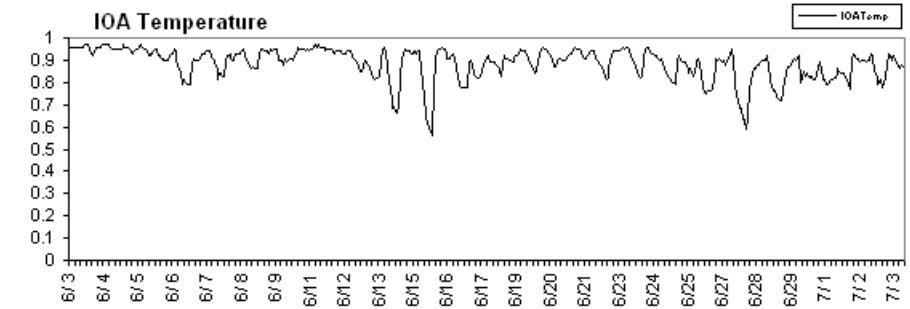

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

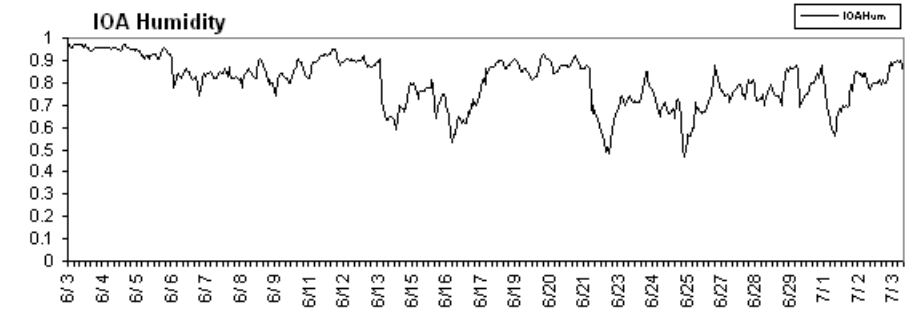

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

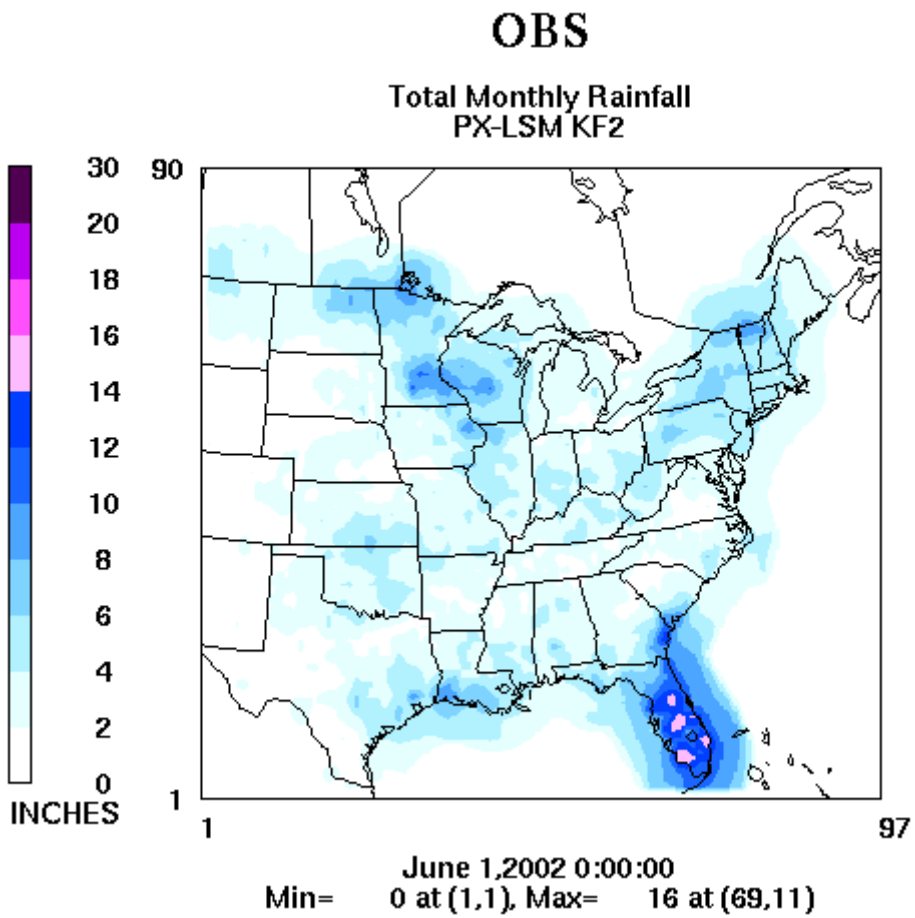

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

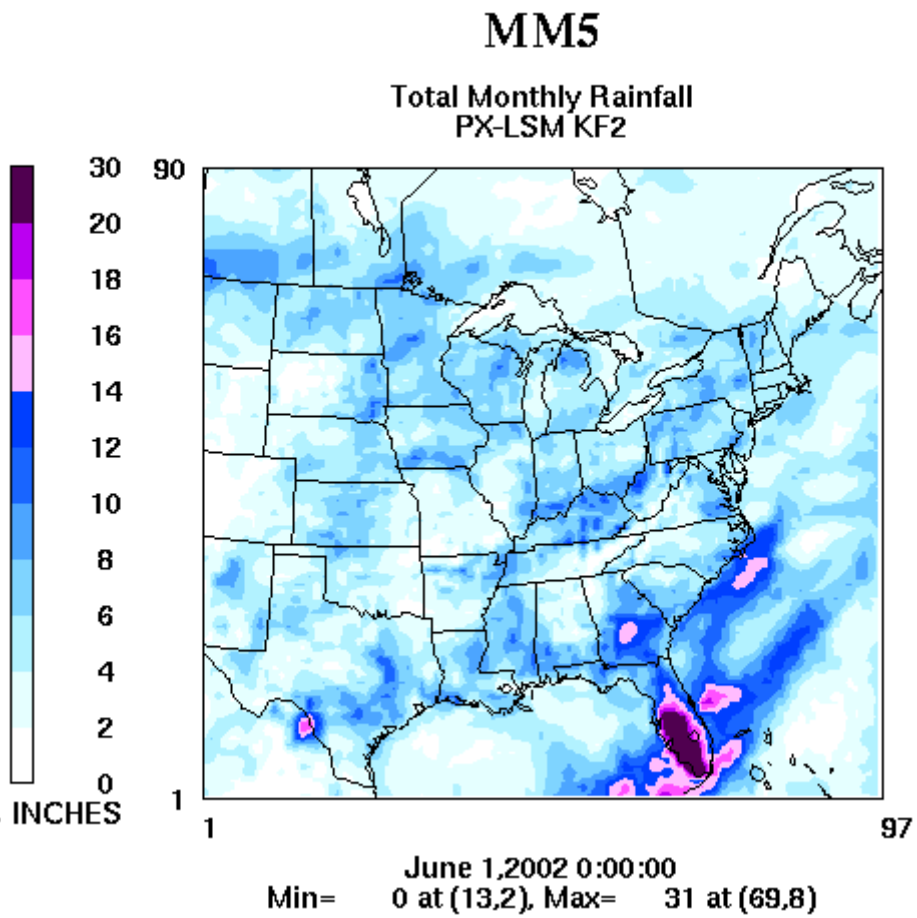

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

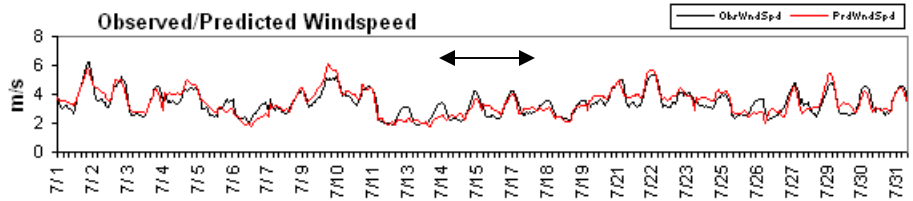

IOA Humidity
IOAHum

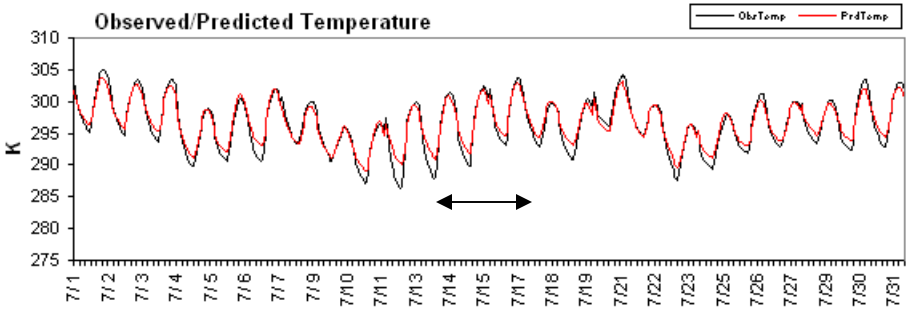
June 2002

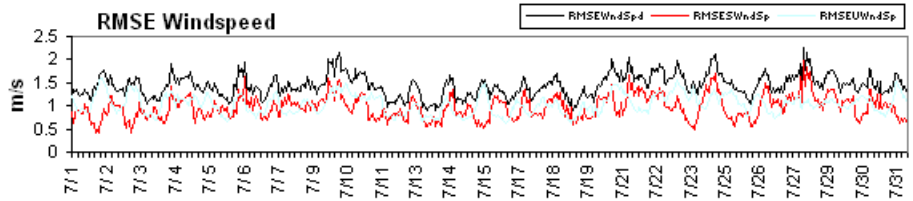

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2002 0:00:00
Min= 0 at (1,1), Max= 16 at (69,11)

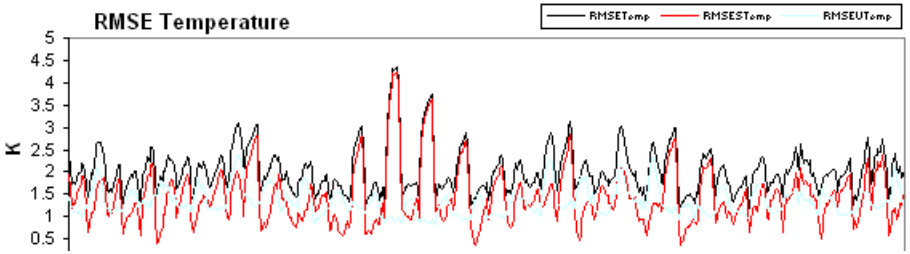

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2002 0:00:00
Min= 0 at (13,2), Max= 31 at (69,8)

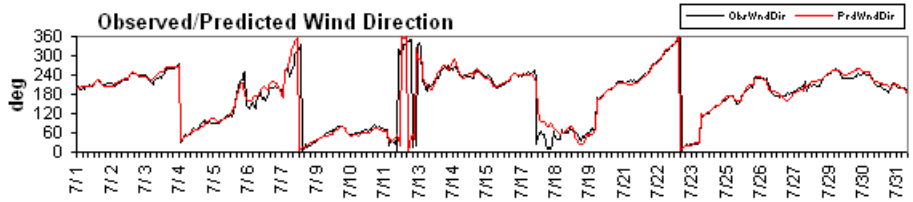
JULY 2002

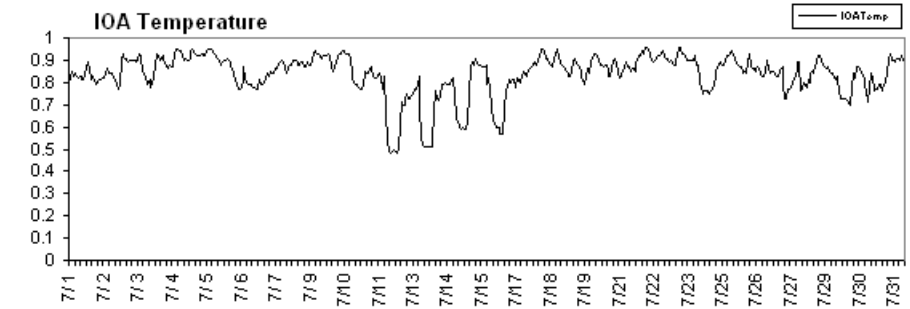

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

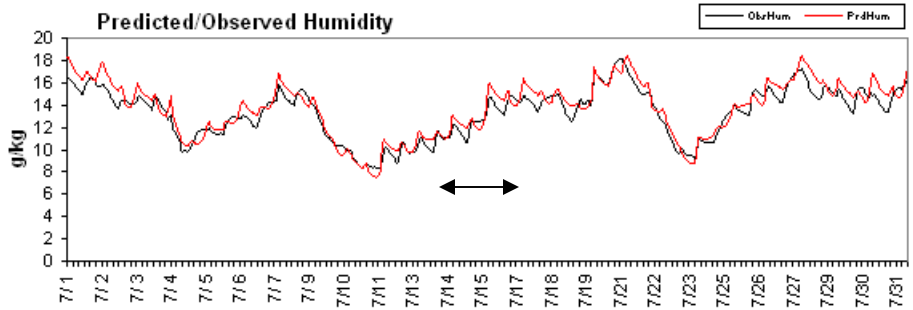

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

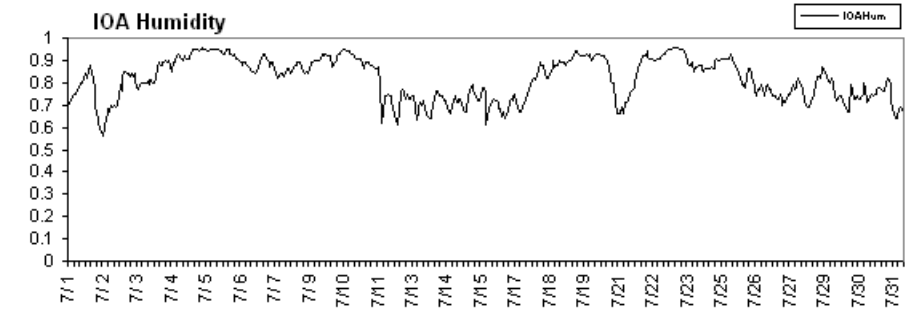

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s


RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K

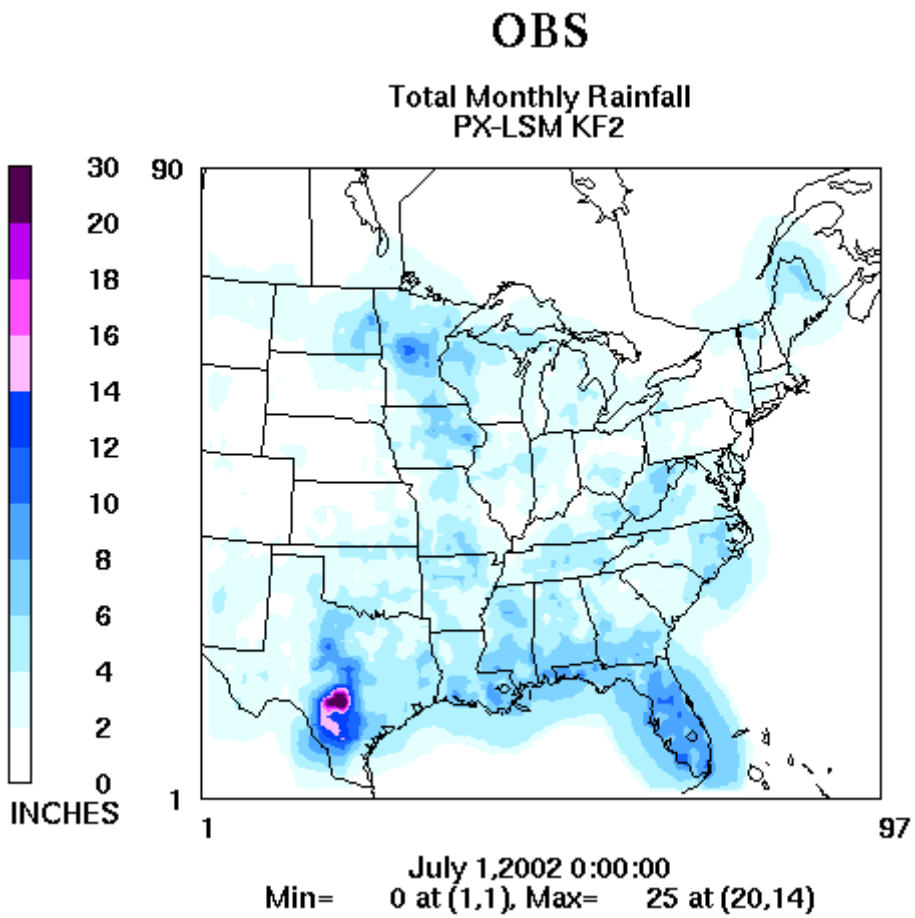

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg

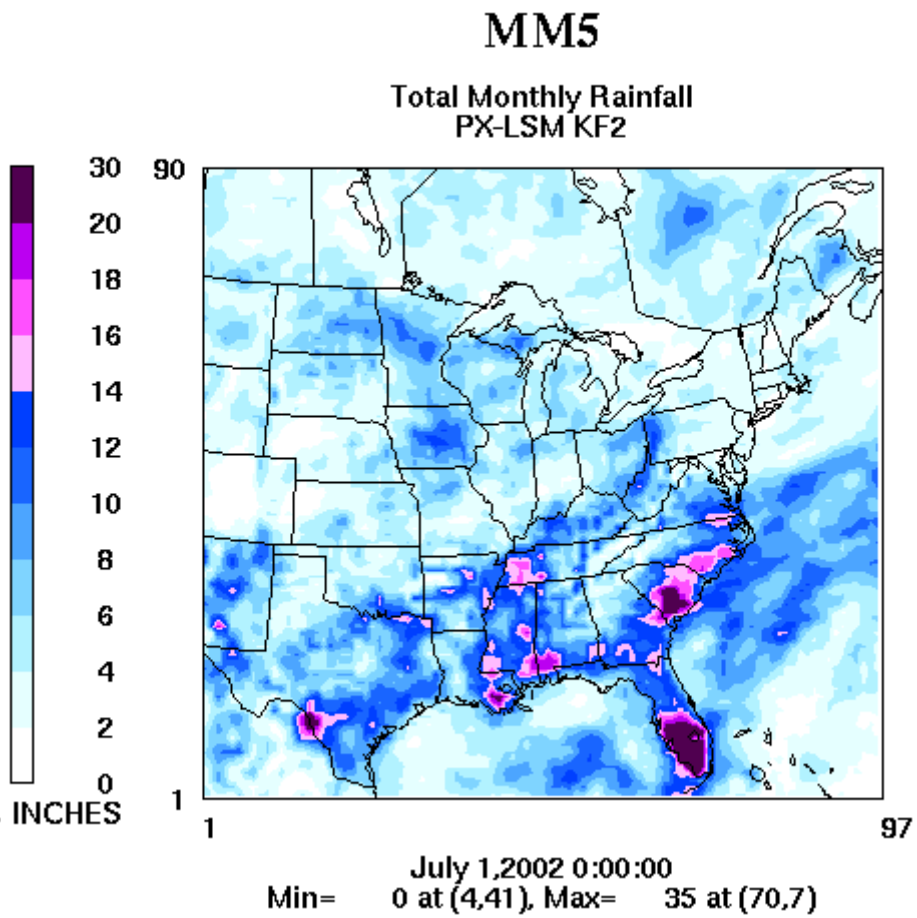

IOA Temperature
IOATemp


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

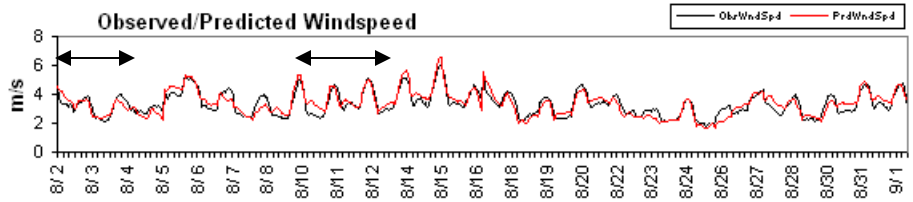

IOA Humidity
IOAHum

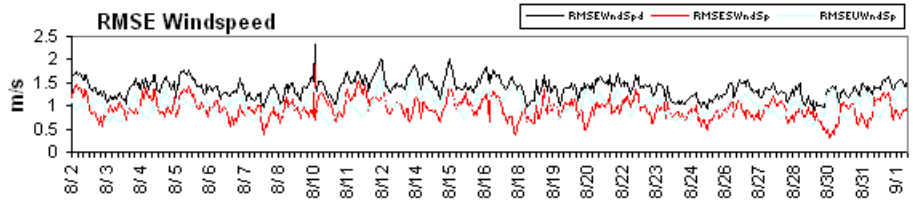
July 2002

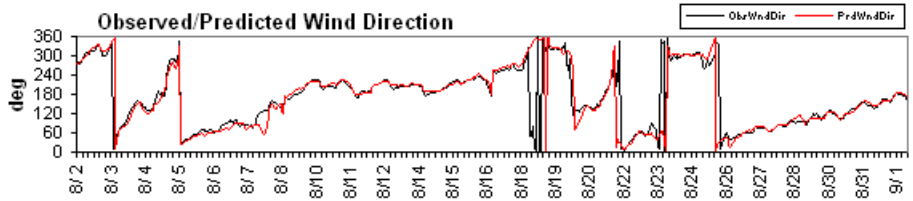

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2002 0:00:00
Min= 0 at (1,1), Max= 25 at (20,14)

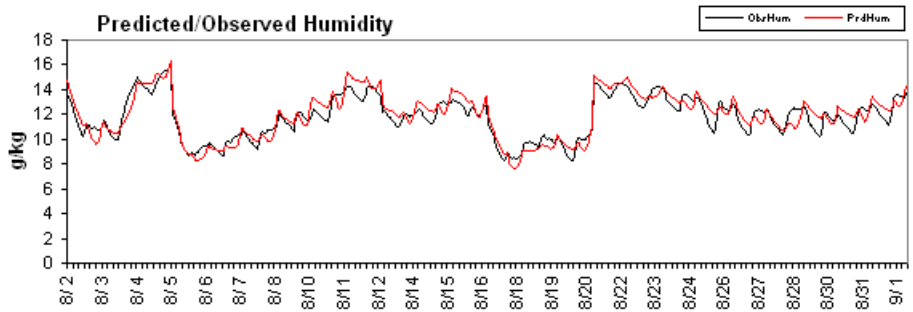

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2002 0:00:00
Min= 0 at (4,41), Max= 35 at (70,7)

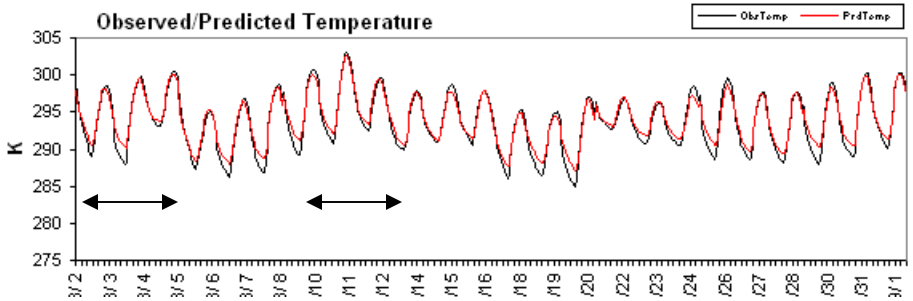
AUGUST 2002

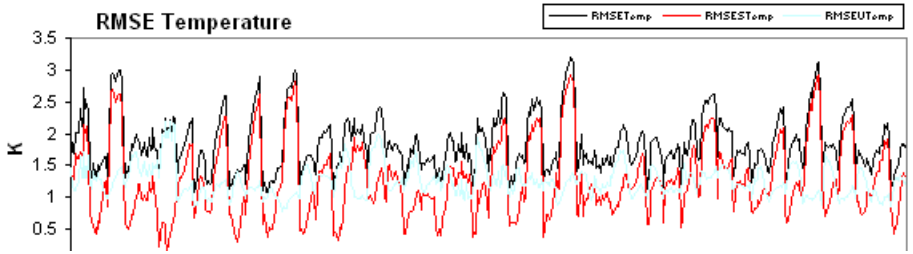

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

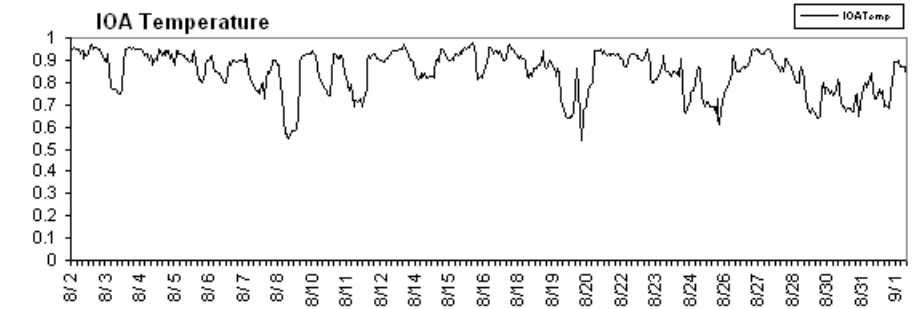

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

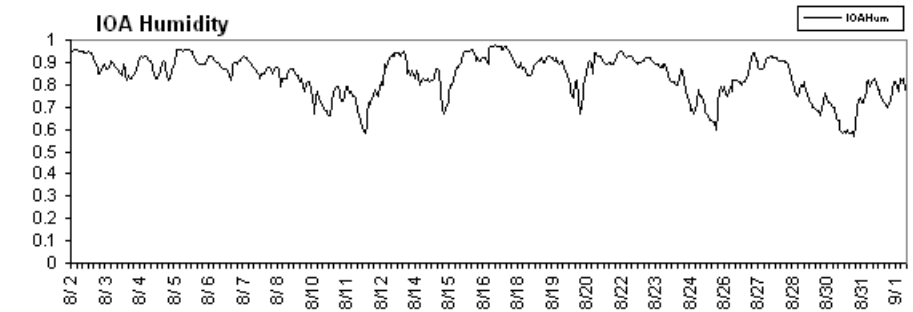

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

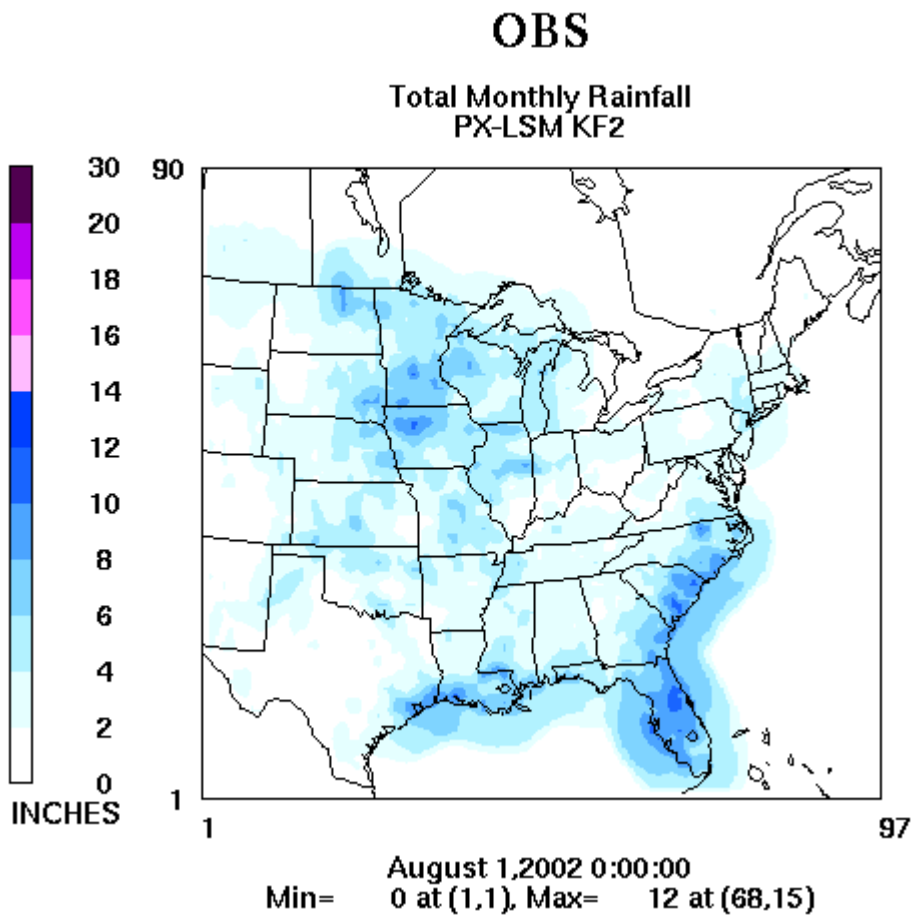

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

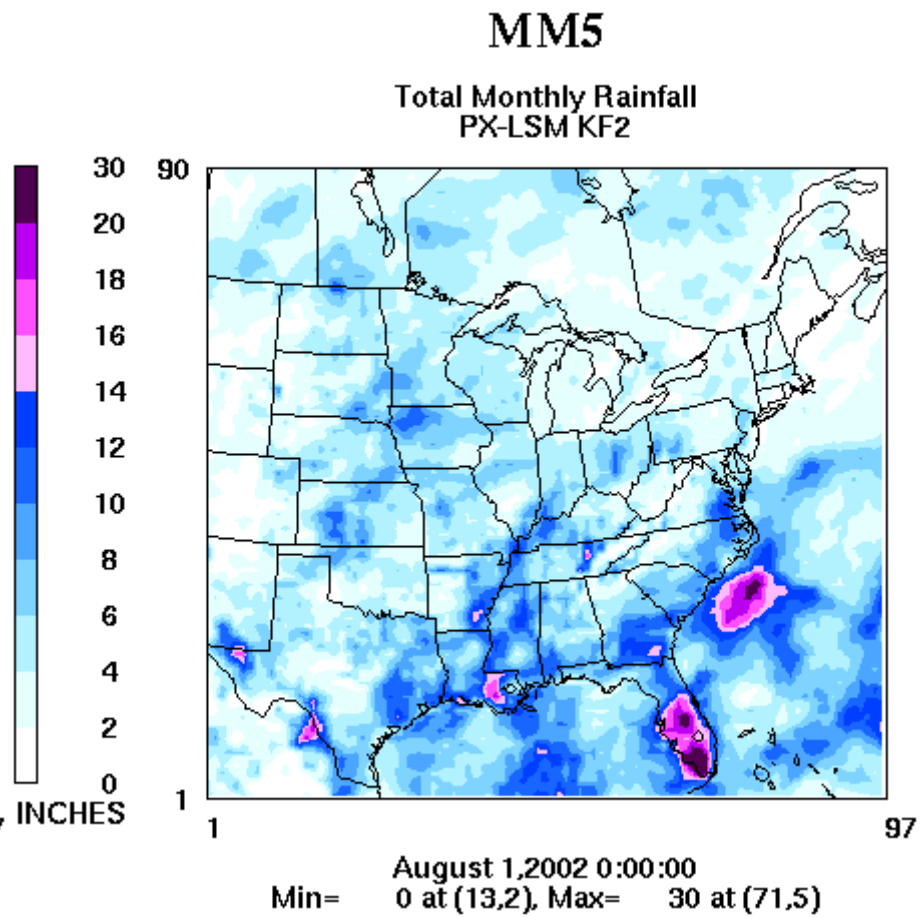

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

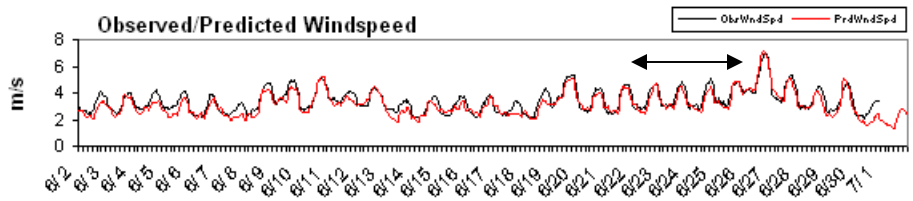

IOA Humidity
IOAHum

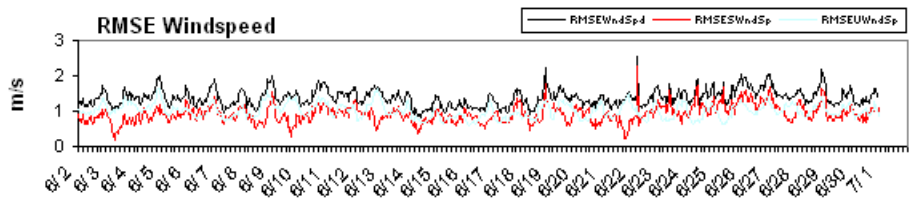
August 2002

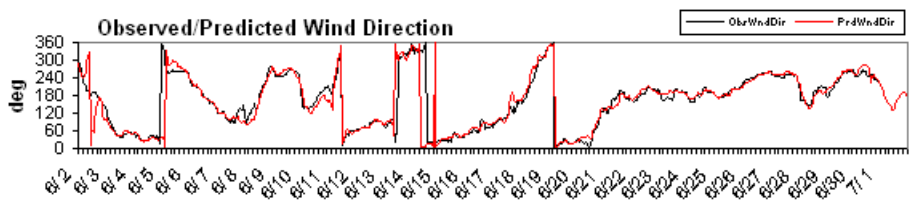

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2002 0:00:00
Min= 0 at (1,1), Max= 12 at (68,15)

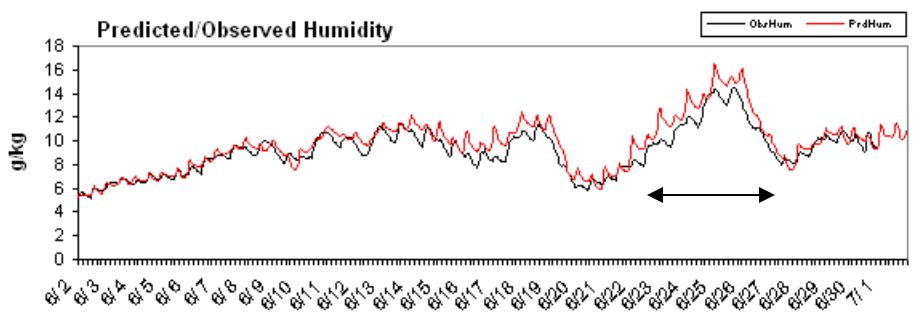

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2002 0:00:00
Min= 0 at (13,2), Max= 30 at (71,5)

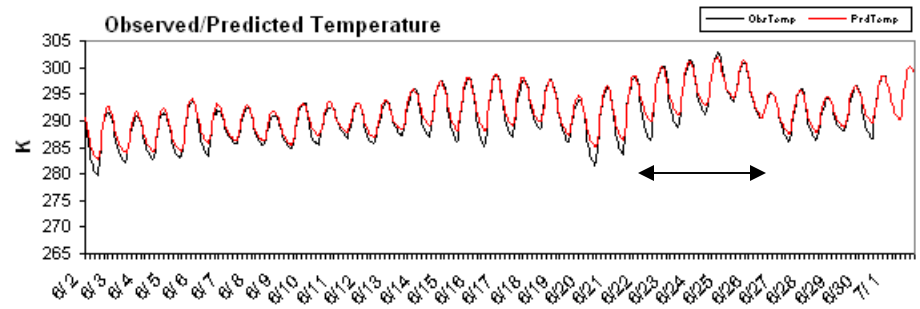
JUNE 2003

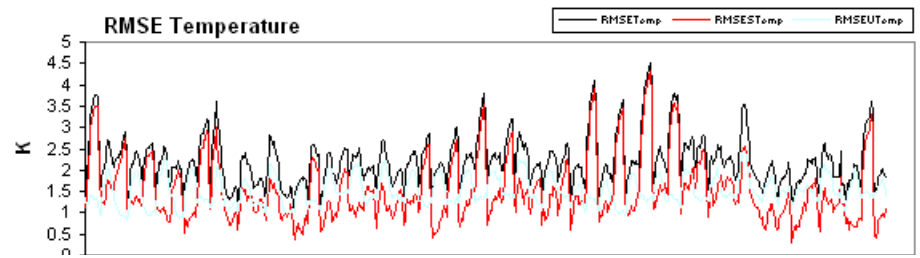

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

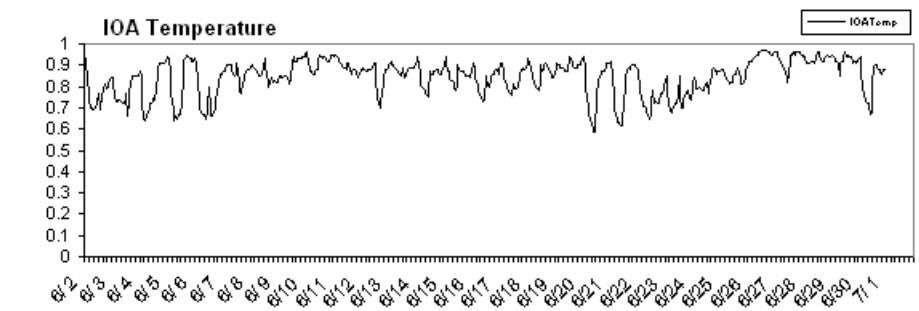

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

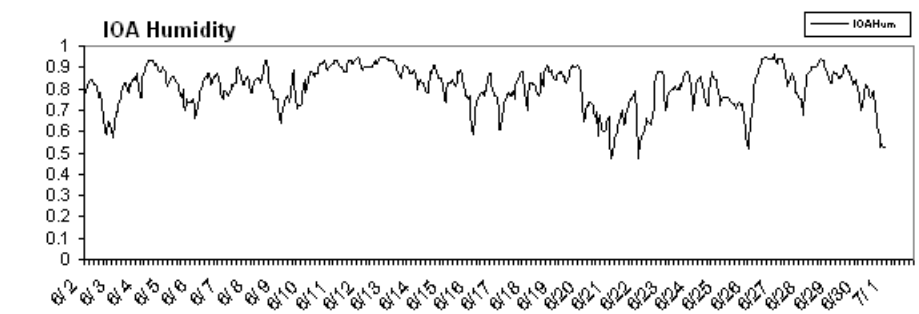

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

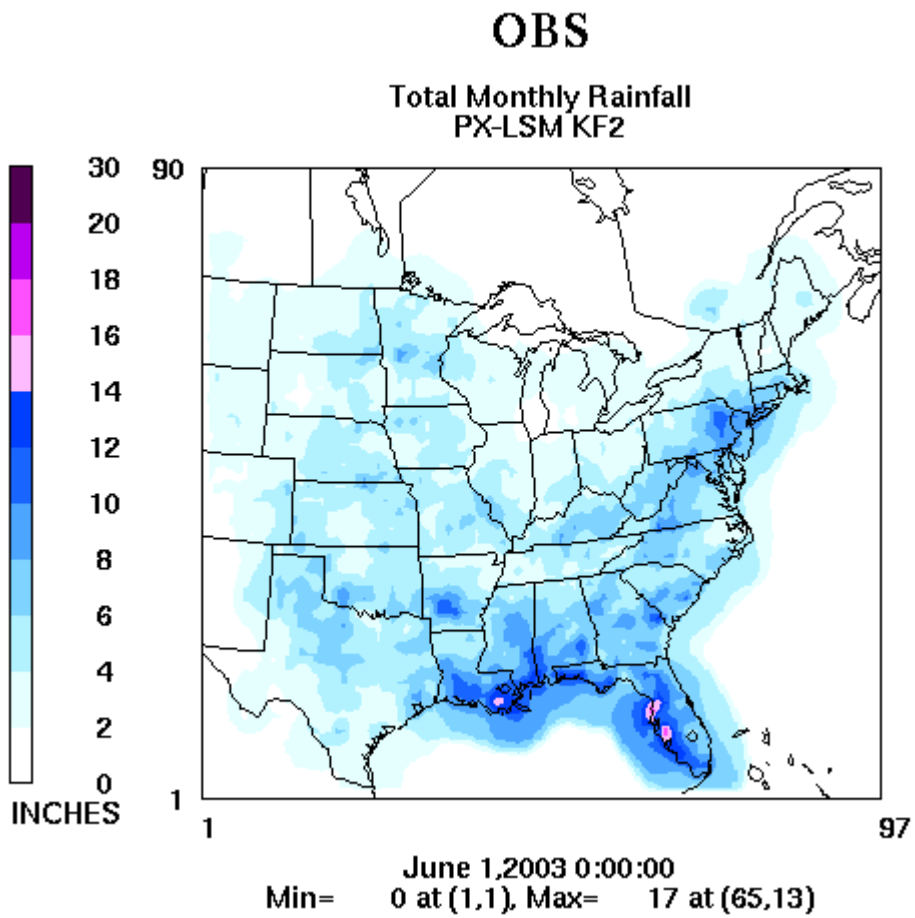

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

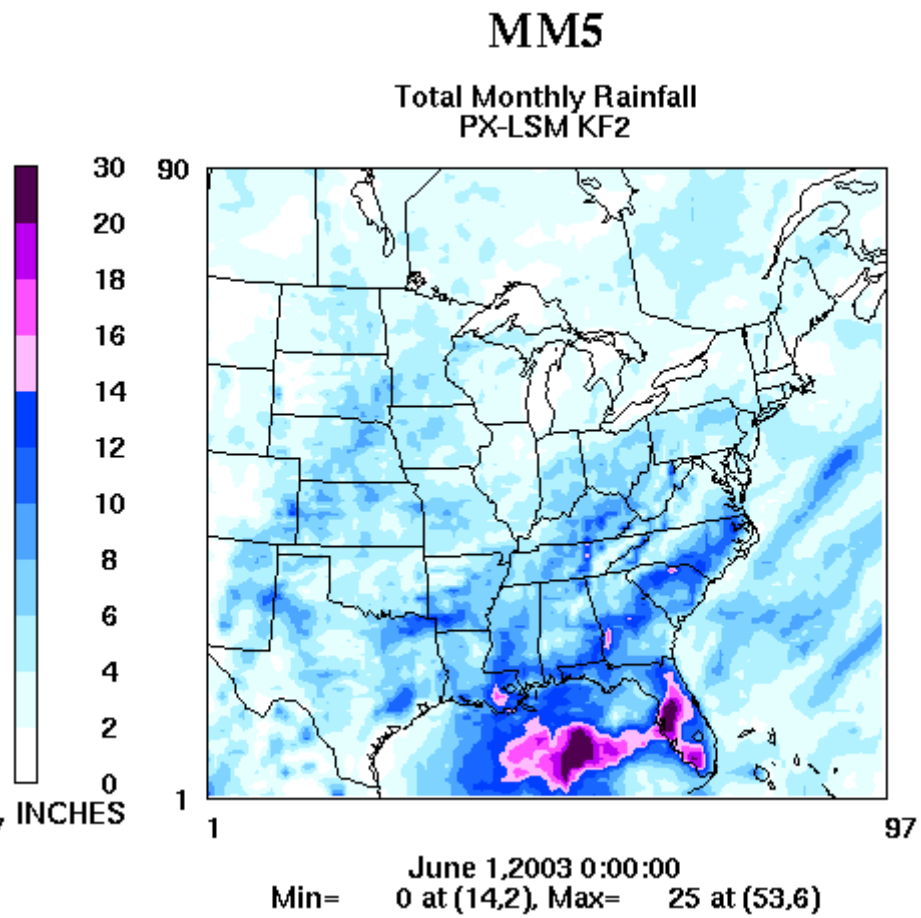

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

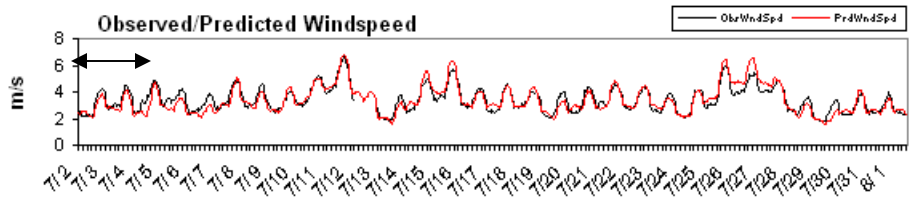

IOA Humidity
IOAHum

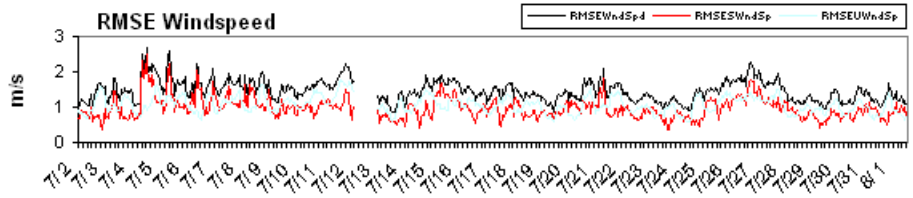
June 2003

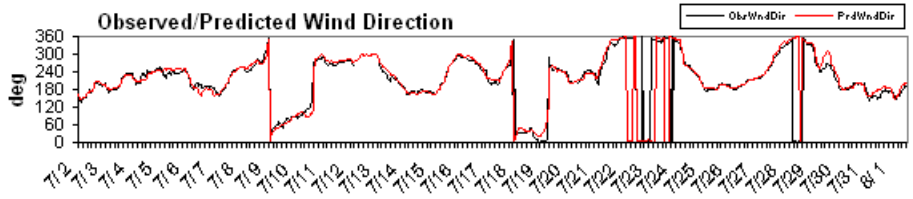

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2003 0:00:00
Min= 0 at (1,1), Max= 17 at (65,13)

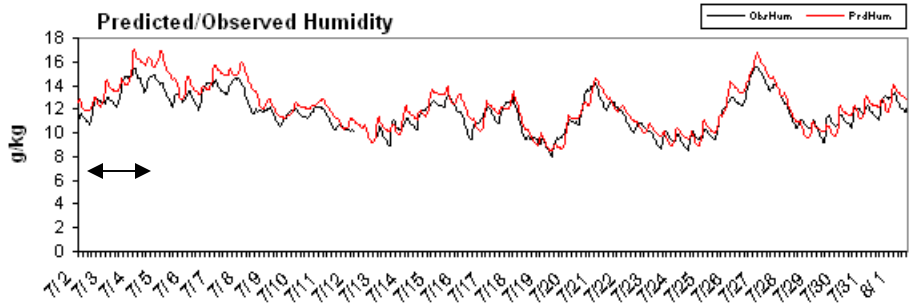

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
June 1,2003 0:00:00
Min= 0 at (14,2), Max= 25 at (53,6)

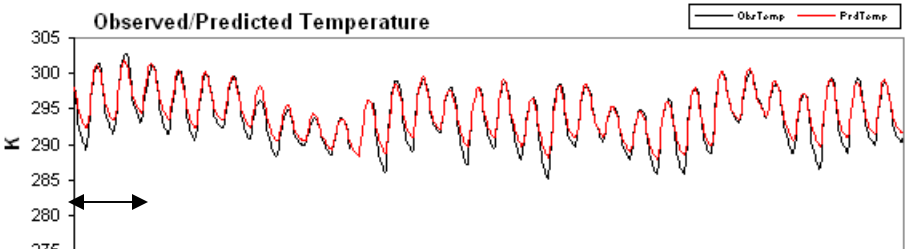
JULY 2003

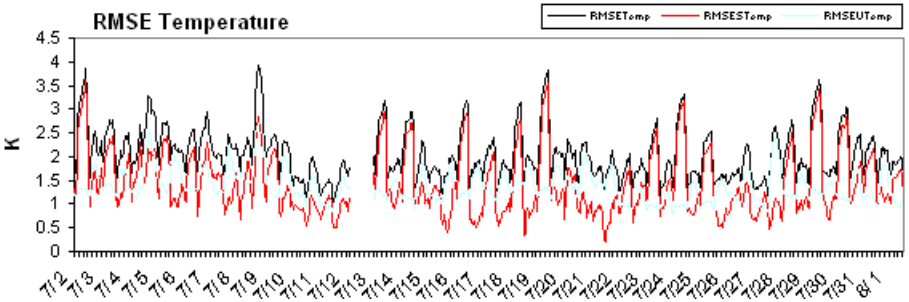

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

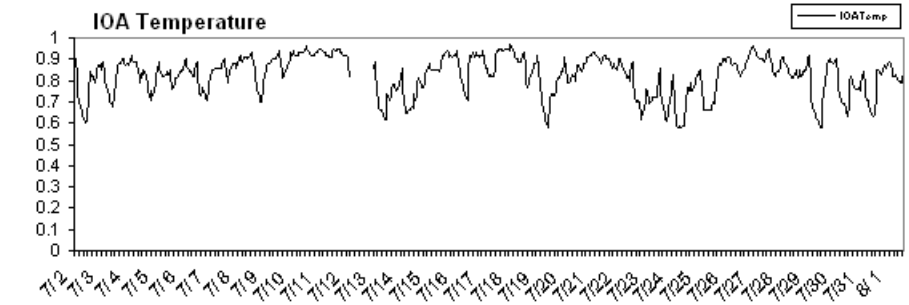

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

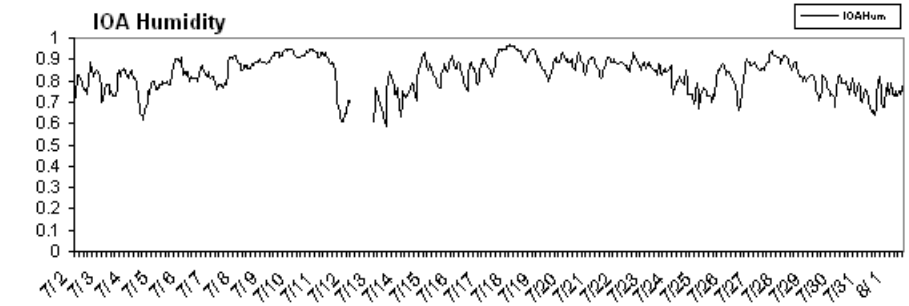

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

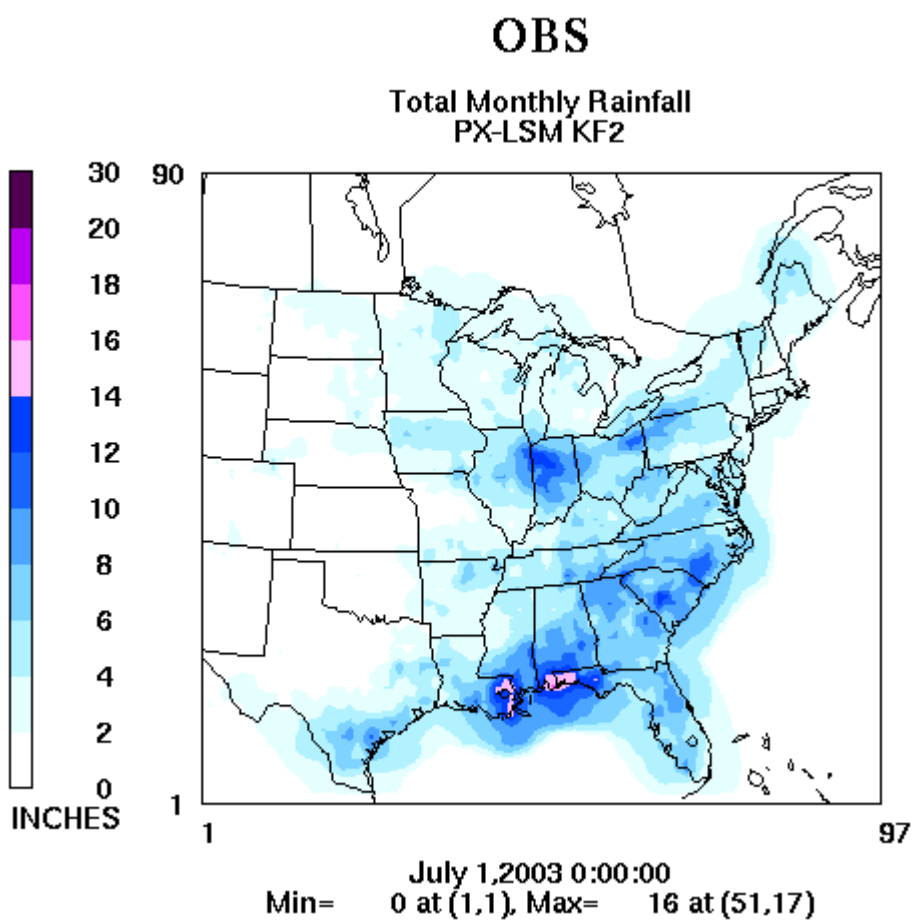

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

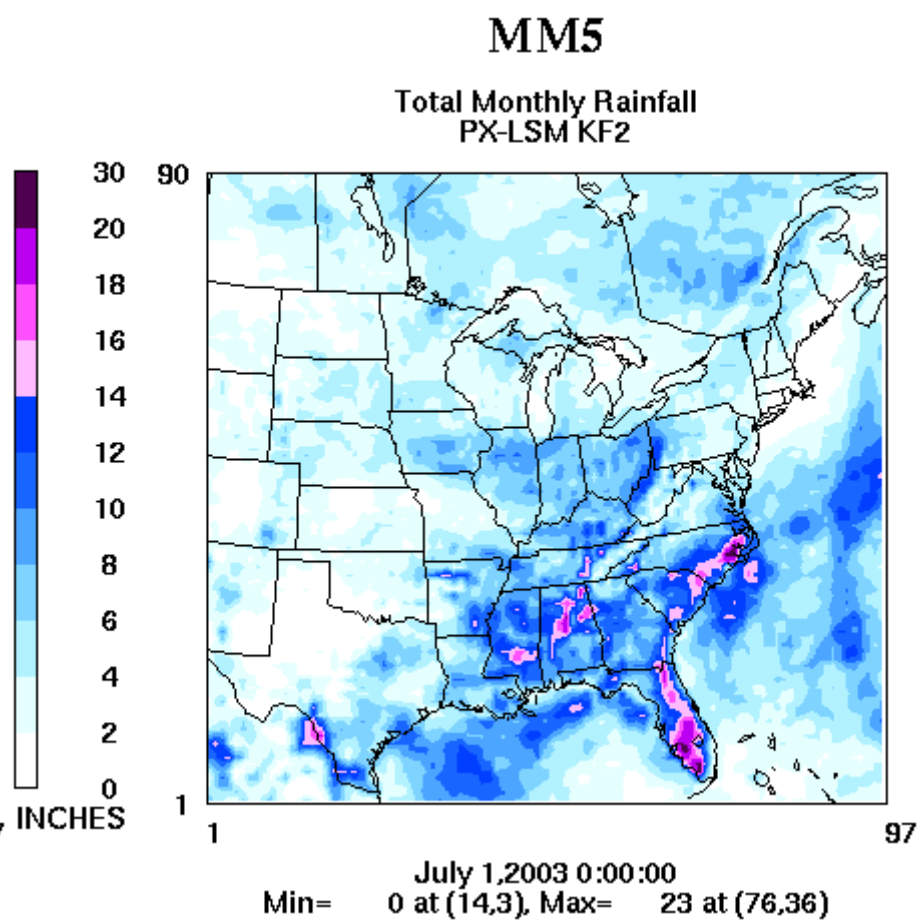

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp

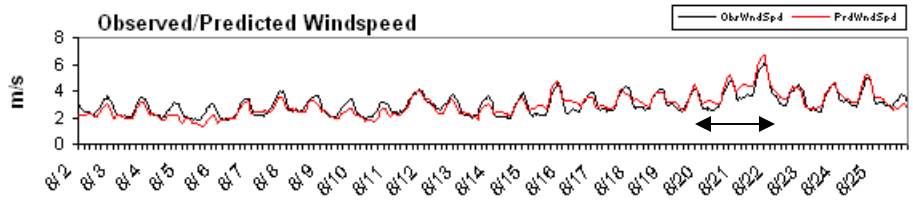

IOA Humidity
IOAHum

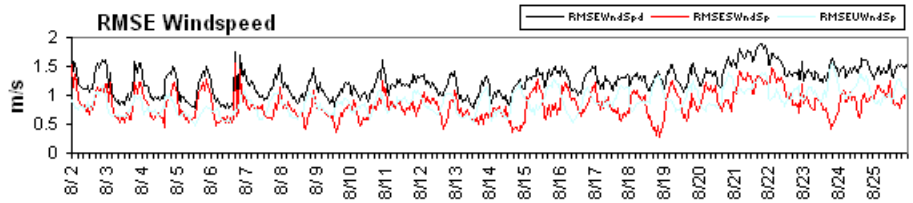
July 2003

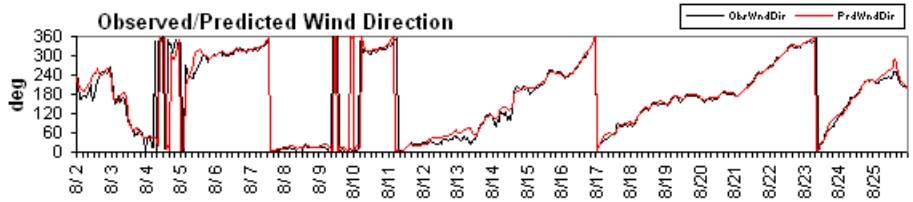

OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2003 0:00:00
Min= 0 at (1,1), Max= 16 at (51,17)

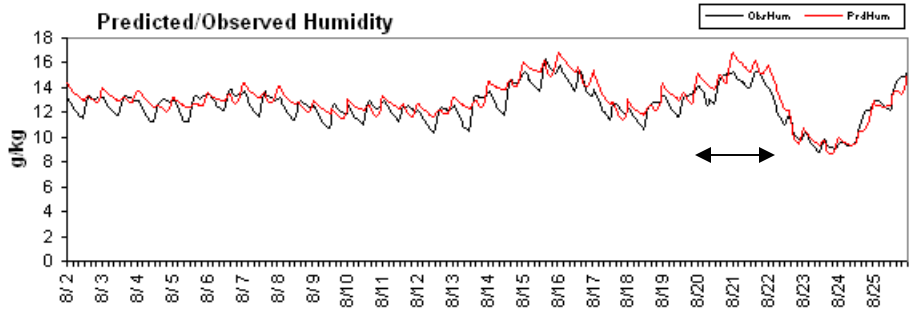

MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
July 1,2003 0:00:00
Min= 0 at (14,3), Max= 23 at (76,36)

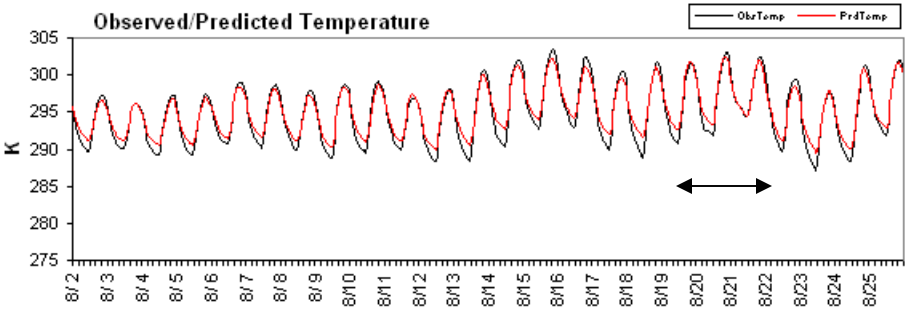
AUGUST 2003

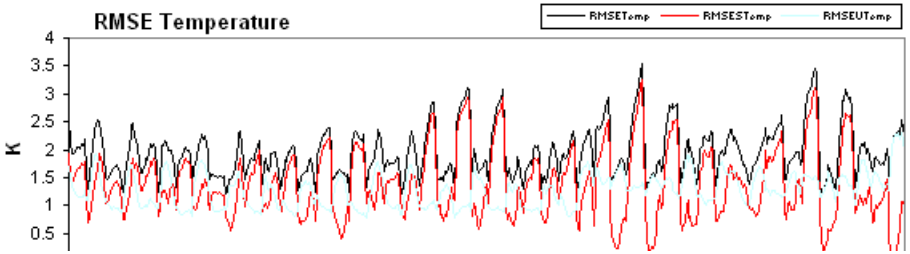

Observed/Predicted Windspeed
ObsWndSpd
PrdWndSpd
m/s

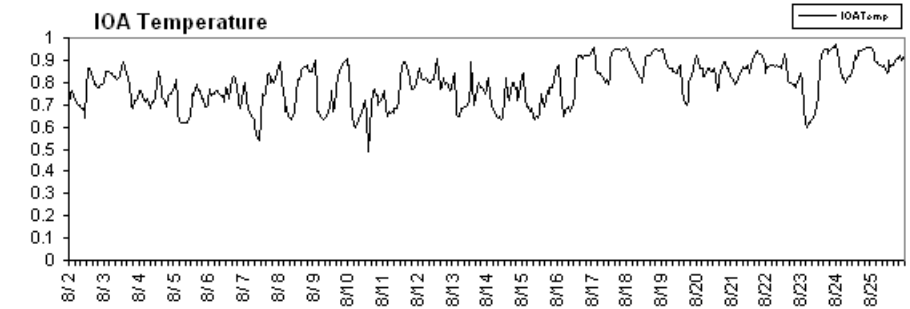

RMSE Windspeed
RMSEWndSpd
RMSESWndSp
RMSEUWndSp
m/s

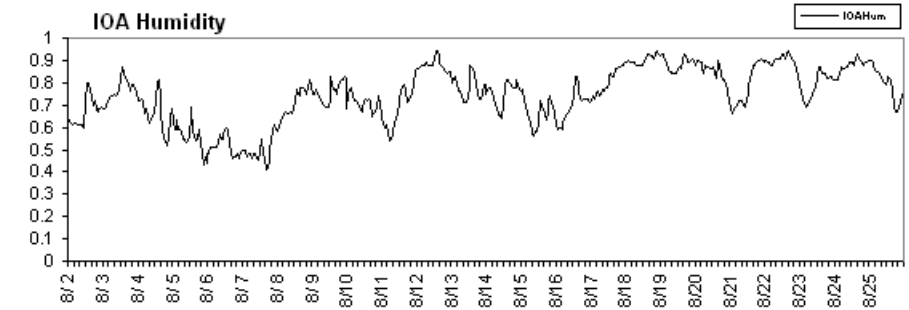

Observed/Predicted Wind Direction
ObsWndDir
PrdWndDir
deg


Predicted/Observed Humidity
ObsHum
PrdHum
g/kg

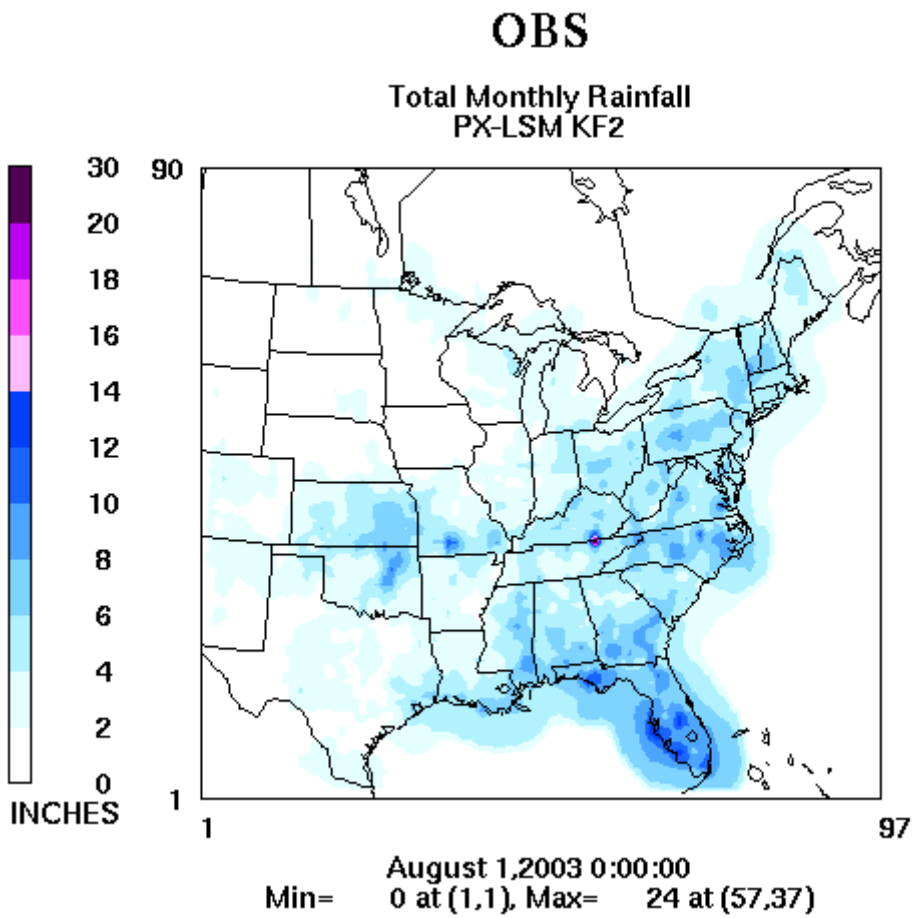

Observed/Predicted Temperature
ObsTemp
PrdTemp
K

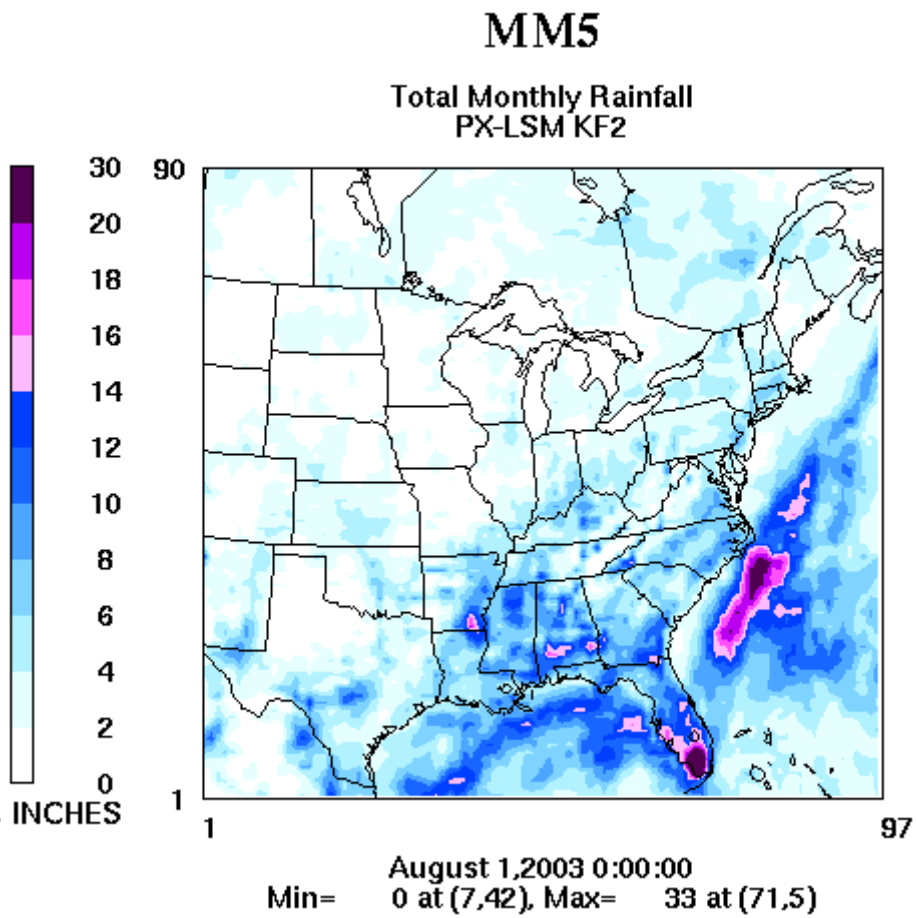

RMSE Temperature
RMSETemp
RMSESTemp
RMSEUTemp
K


IOA Temperature
IOATemp


IOA Humidity
IOAHum

August 2003


OBS
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2003 0:00:00
Min= 0 at (1,1), Max= 24 at (57,37)


MM5
Total Monthly Rainfall
PX-LSM KF2
30
20
18
16
14
12
10
8
6
4
2
0
INCHES
90
1
1
97
August 1,2003 0:00:00
Min= 0 at (7,42), Max= 33 at (71,5)

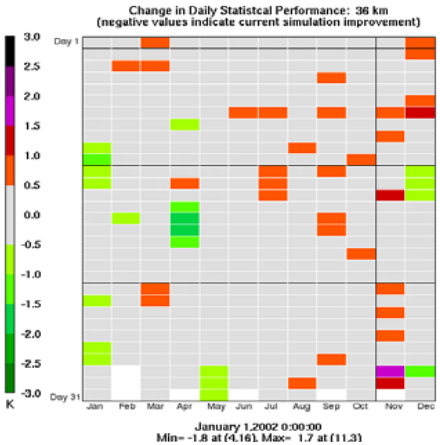
Upper Midwest High Ozone Days

- 2001:
  - June 13-14, 18-19, 25-30
  - July 16-20; July 31 – Aug 2
  - Aug 5-8
- 2002:
  - June 19-25
  - July 7-8, 14-17
  - Aug 1-4, 9-13
- 2003:
  - June 22-26
  - July 1-3
  - Aug 20-21

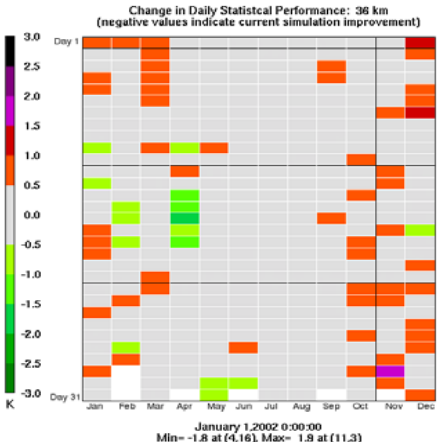
APPENDIX D

Performance Comparison: Old v. New Annual 2002 Simulation

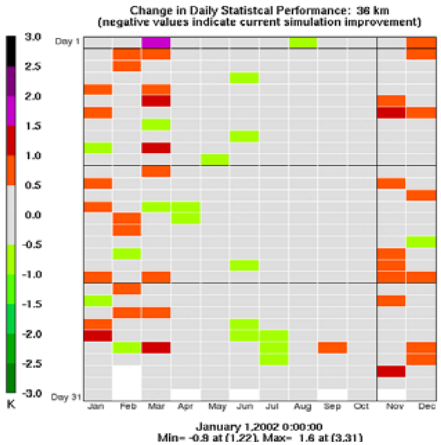
Temperature RMSE Difference - gl Grid



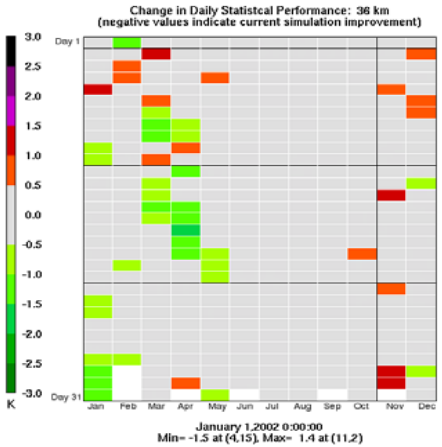
Temperature RMSE Difference - cenrapN Grid



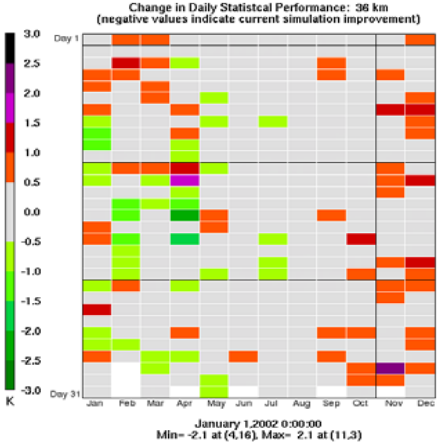
Temperature RMSE Difference - cenrapS Grid



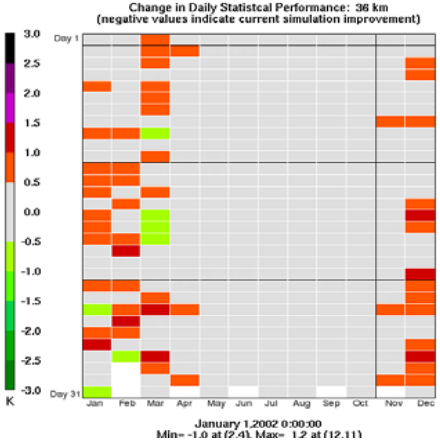
Temperature RMSE Difference - ohioval Grid



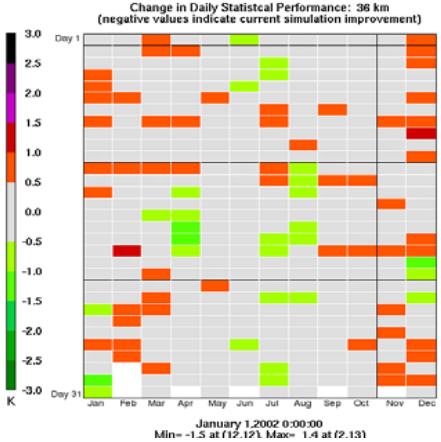
Temperature RMSE Difference - Iowa Grid



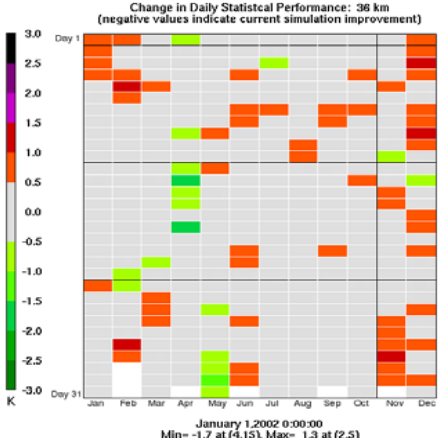
Temperature RMSE Difference - SE Grid



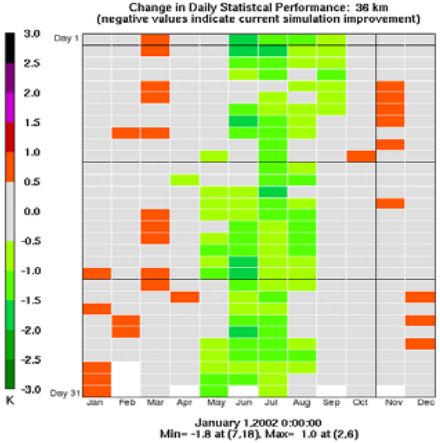
Temperature RMSE Difference - MidAtlantic Grid



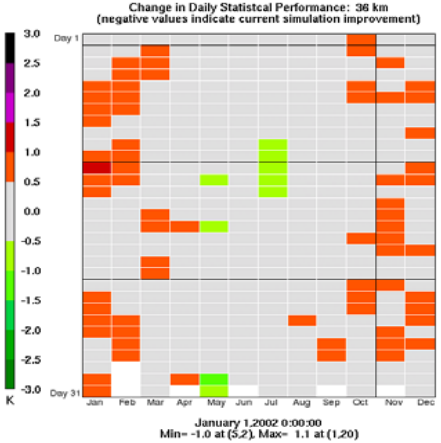
Temperature RMSE Difference - NE Grid



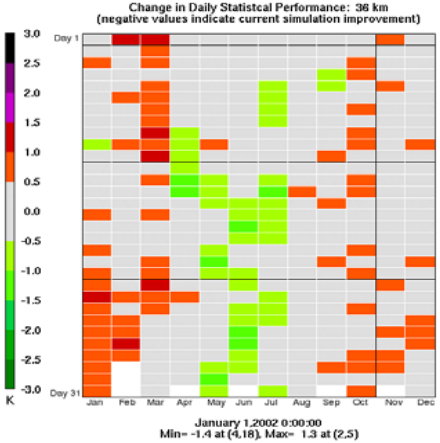
Temperature RMSE Difference - DessertSW Gric



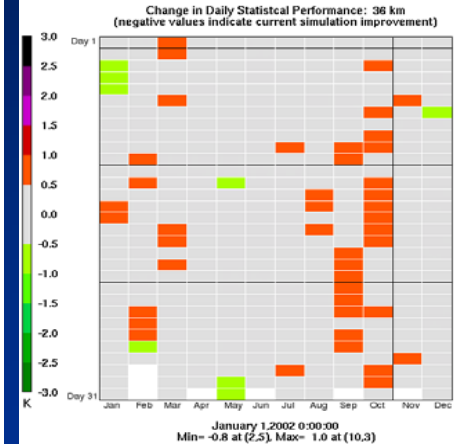
Temperature RMSE Difference - SW Grid



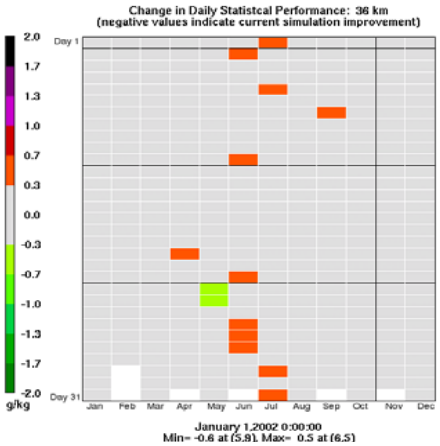
Temperature RMSE Difference - North Grid



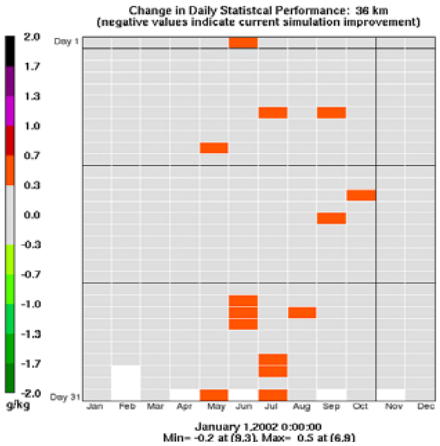
Temperature RMSE Difference - PacificNW Grid



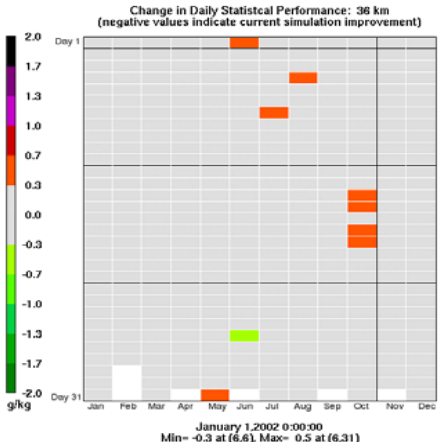
Humidity RMSE Difference - gl Grid



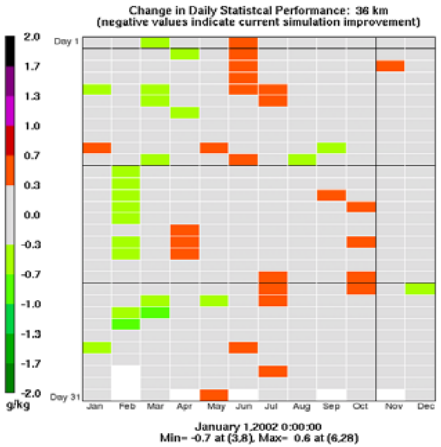
Humidity RMSE Difference - cenrapN Grid



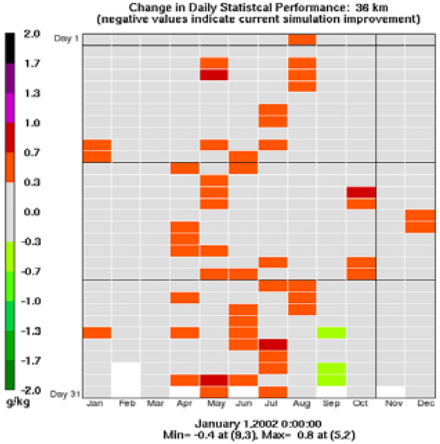
Humidity RMSE Difference - cenrapS Grid



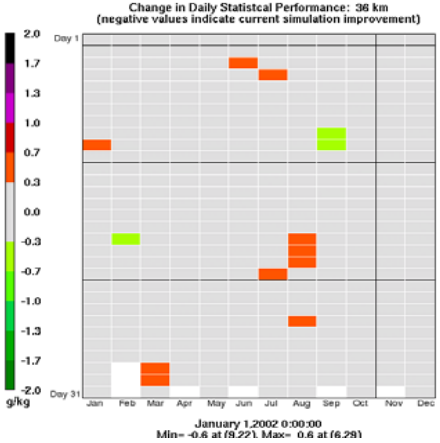
Humidity RMSE Difference - ohioval Grid



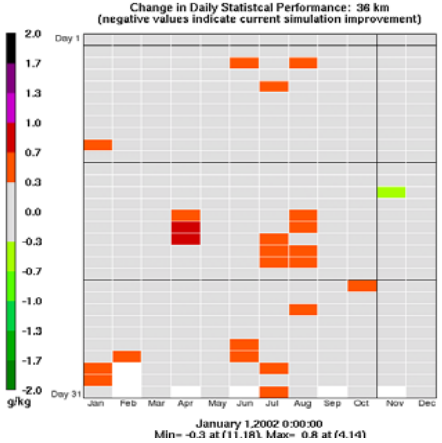
Humidity RMSE Difference - Iowa Grid



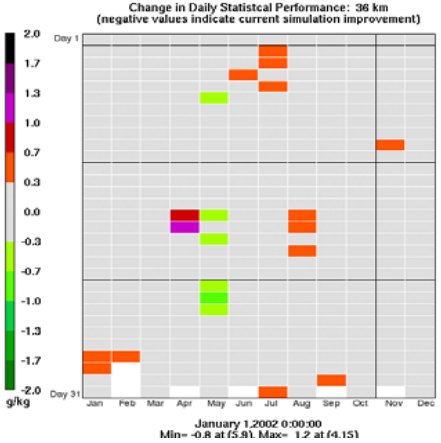
Humidity RMSE Difference - SE Grid



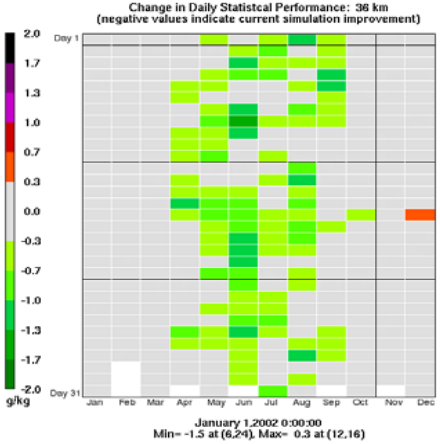
Humidity RMSE Difference - MidAtlantic Grid



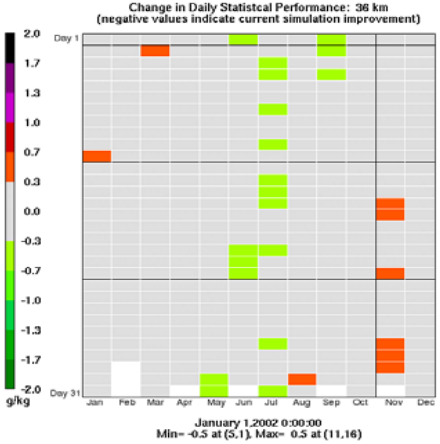
Humidity RMSE Difference - NE Grid



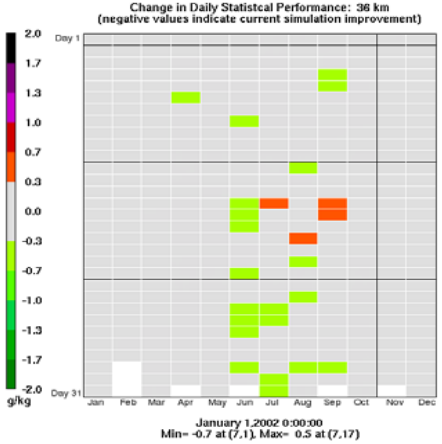
Humidity RMSE Difference - DessertSW Grid



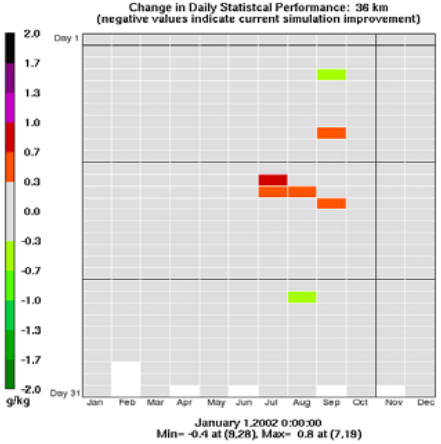
Humidity RMSE Difference - SW Grid



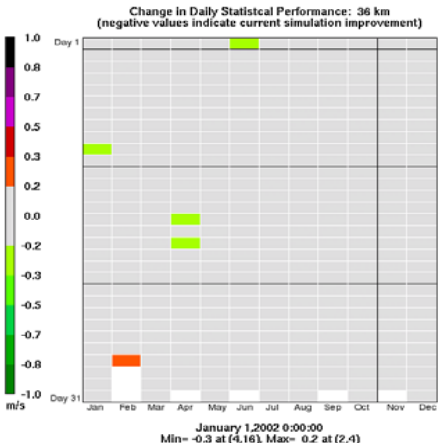
Humidity RMSE Difference - North Grid



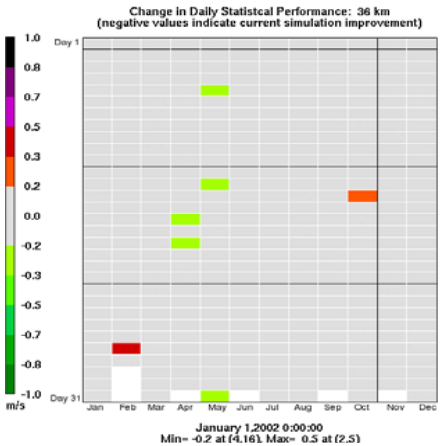
Humidity RMSE Difference - PacificNW Grid



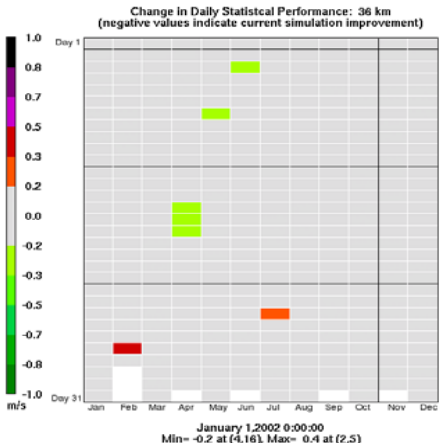
Wind Spd RMSE Difference - gl Grid



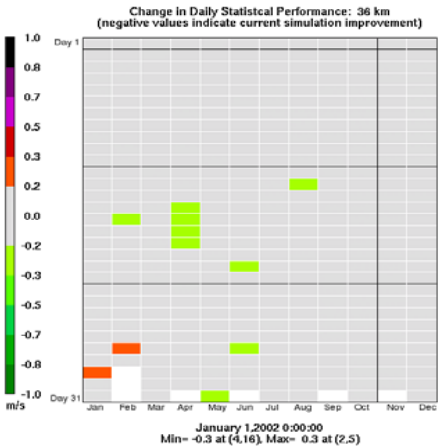
Wind Spd RMSE Difference - cenrapN Grid



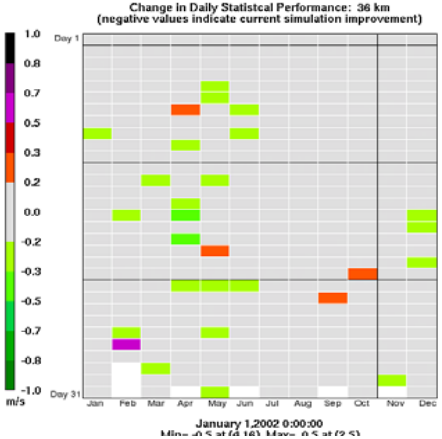
Wind Spd RMSE Difference - cenrapS Grid



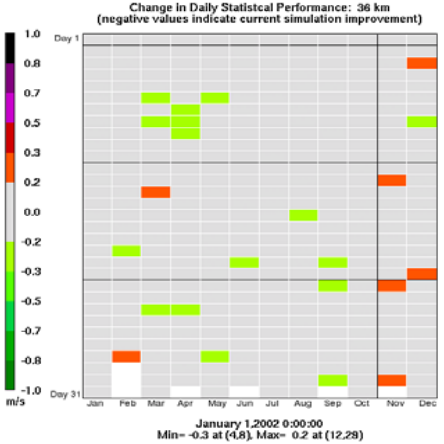
Wind Spd RMSE Difference - ohioval Grid



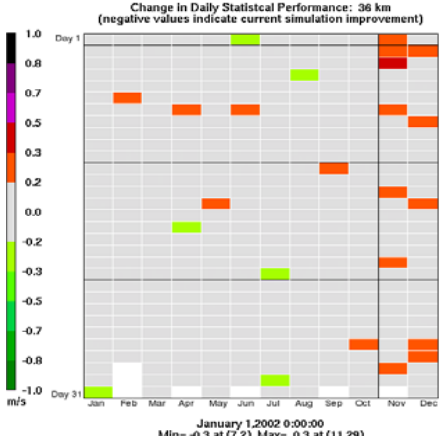
Wind Spd RMSE Difference - Iowa Grid



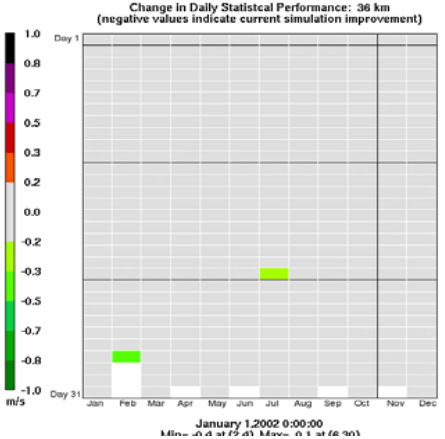
Wind Spd RMSE Difference - SE Grid



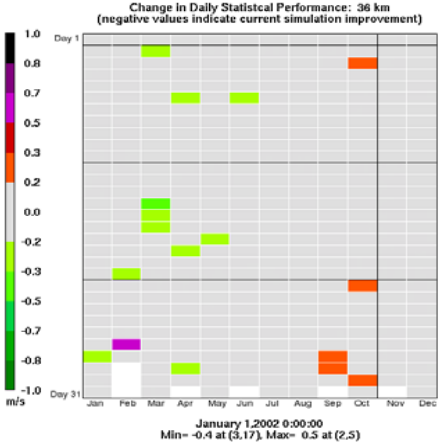
Wind Spd RMSE Difference - MidAtlantic Grid



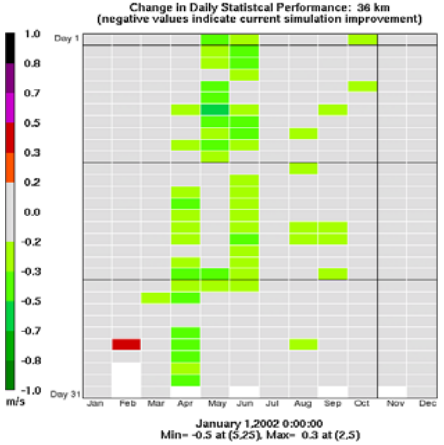
Wind Spd RMSE Difference - NE Grid



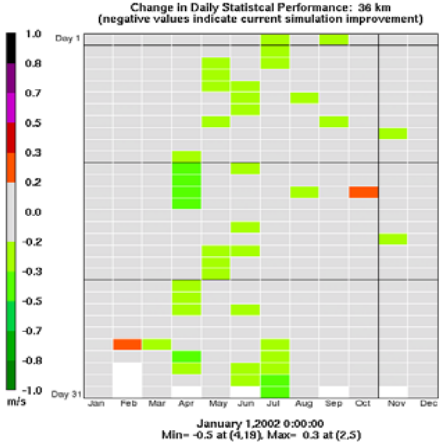
Wind Spd RMSE Difference - SW Grid



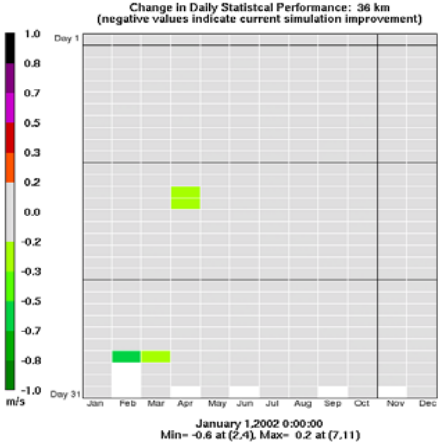
Wind Spd RMSE Difference - DessertSW Grid



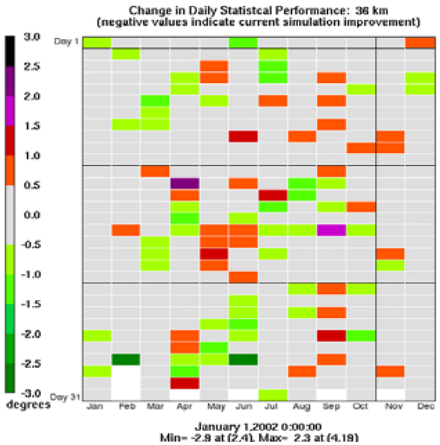
Wind Spd RMSE Difference - North Grid



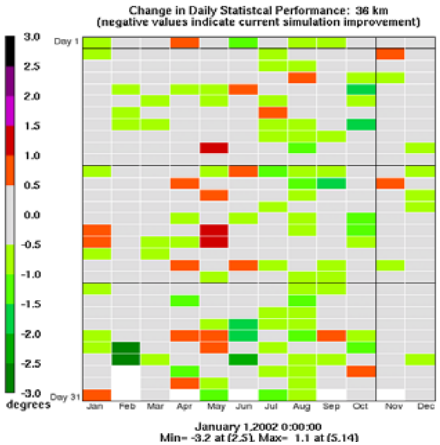
Wind Spd RMSE Difference - PacificNW Grid



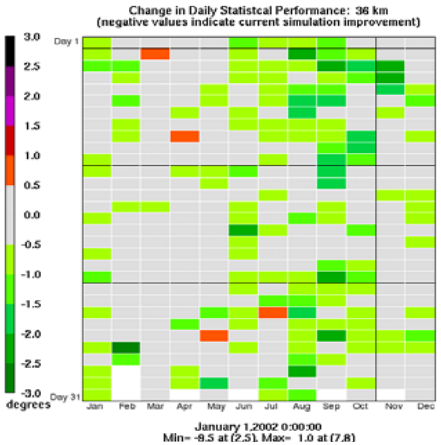
Wind Dir Gross Error Difference - gl Grid



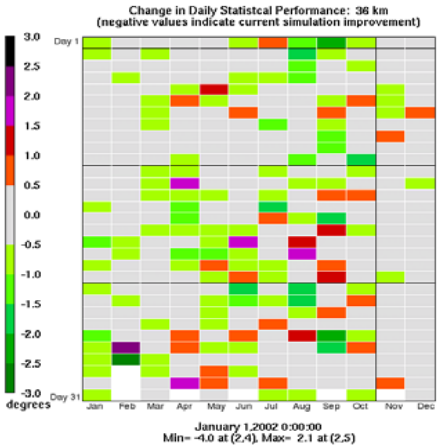
Wind Dir Gross Error Difference - cenrapN Grid



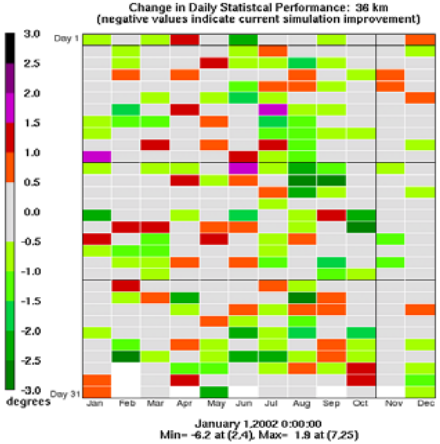
Wind Dir Gross Error Difference - cenrapS Grid



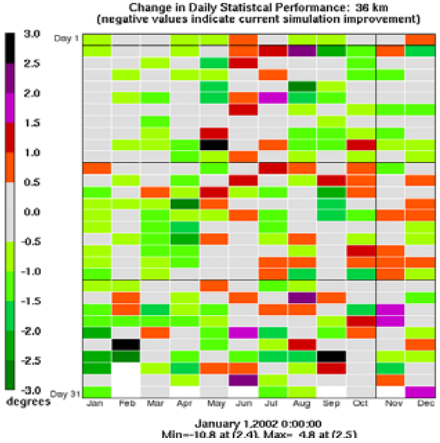
Wind Dir Gross Error Difference - ohioval Grid



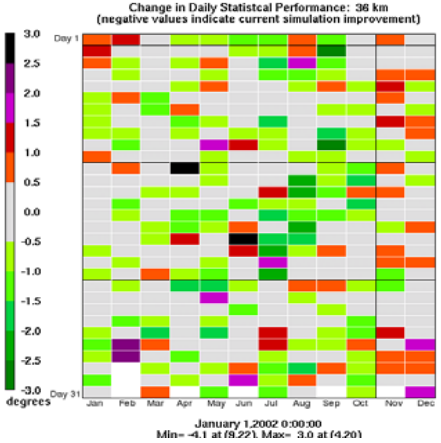
Wind Dir Gross Error Difference - Iowa Grid



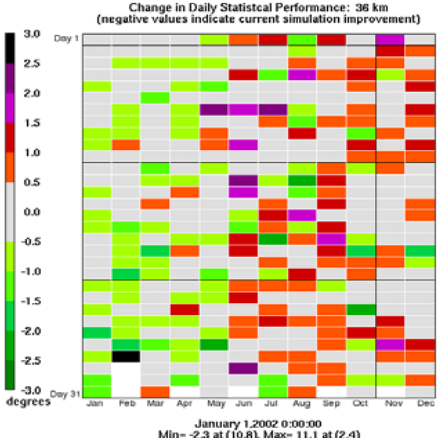
Wind Dir Gross Error Difference - SE Grid



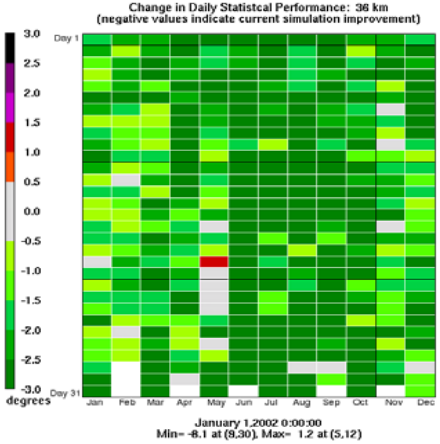
Wind Dir Gross Error Difference - MidAtlantic Grid



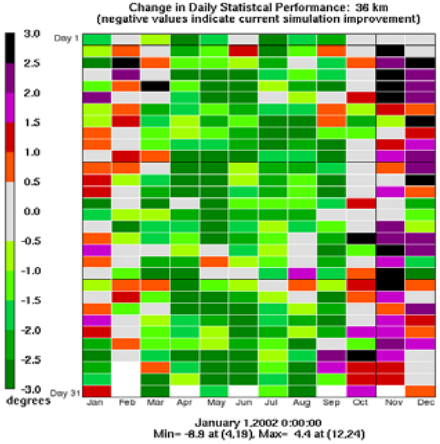
Wind Dir Gross Error Difference - NE Grid



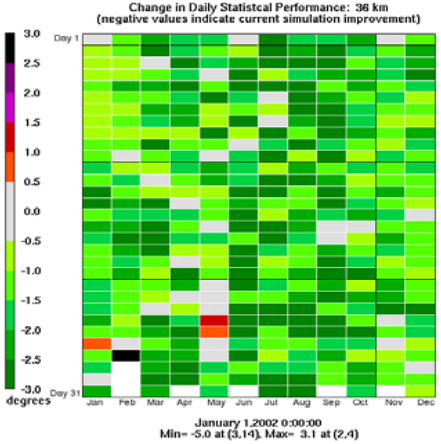
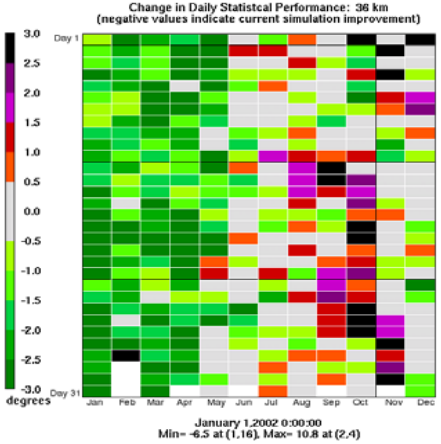
Wind Dir Gross Error Difference - DessertSW Grid



Wind Dir Gross Error Difference - SW Grid



Wind Dir Gross Error Difference - North Grid



Wind Dir Gross Error Difference - PacificNW Grid