Topical Report

Episodic Application of MM5 for a Summer 2001 Episode in the Eastern United States

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INTRODUCTION

Over the past half decade, emergent requirements for direct numerical simulation of urban and regional scale photochemical and secondary aerosol air quality—spawned largely by the new particulate matter ($PM_{2.5}$) and regional haze regulations—have led to intensified efforts to construct high-resolution emissions, meteorological and air quality data sets. The concomitant increase in computational throughput of low-cost modern scientific workstations has ushered in a new era of regional air quality modeling. It is now possible, for example, to exercise sophisticated mesoscale prognostic meteorological models and Eulerian and Lagrangian photochemical/aerosol models for the full annual period, simulating ozone, sulfate and nitrate deposition, and secondary organic aerosols (SOA) across the entire United States (U.S.) or over discrete subregions.

This report describes an application of the Pennsylvania State University/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) for a simulation from 12 July 2001 through 14 August 2001 for a domain covering the continental United States, with a higher resolution domain over the eastern U.S.

METHODOLOGY

The methodology for this approach is very straightforward. The MM5 model is applied for the episodic period and the model results are compared with available observations and synoptic weather charts.

Model Selection and Application

Below we give a brief summary of the MM5 input data preparation procedures we propose for the episodic and annual modeling exercises.

<u>Model Selection</u>: The most recent version of the publicly available non-hydrostatic version of MM5 (version 3.5) is used. The MM5 released terrain, pregrid, little_r and interpf processor were used to develop model inputs.

<u>Horizontal Domain Definition:</u> The computational domain is presented in Figures 2-1. The outer domain is a 36km grid with 165 x 129 cells, selected to maximize the coverage of the ETA analysis region. The higher resolution eastern grid is a 12km grid with 245 x 245 grid cells. The projection is Lambert Conformal with the "national RPO" grid projection pole of 40^0, -97^0 with true latitudes of 33^0 and 45^0.

<u>Vertical Domain Definition:</u> The MM5 modeling is based on 34 vertical layers with an approximately 38 meter deep surface layer. The MM5 vertical domain is presented in both sigma and height coordinates in Table 2-1.

<u>Topographic Inputs:</u> Topographic information for the MM5 is developed using the NCAR and the United States Geological Survey (USGS) terrain databases. The 36 km and 12km grids are based the 5 min (~9 km) Geophysical Data Center global data. The terrain data is interpolated to the model grid using a Cressman-type objective analysis scheme. To avoid interpolating elevated terrain over water, after the terrain databases are

interpolated onto the MM5 grid, the NCAR graphic water body database will be used to correct elevations over water bodies.

Vegetation Type and Land Use Inputs: Vegetation type and land use information is developed using the most recently released NCAR/PSU databases provided with the MM5 distribution. Standard MM5 surface characteristics corresponding to each land use category will be employed.

Atmospheric Data Inputs: The focus of this study is to examine the influence the choice of "first guess" meteorological fields has on the MM5 model predictions. The first guess fields are taken from the NCAR ETA archives. Surface and upper-air observations used in the objective analyses, following the procedures outlined by Stauffer and Seaman at PSU, are quality-inspected by MM5 pre-processors using automated gross-error checks and "buddy" checks. In addition, rawinsonde soundings undergo vertical consistency checks. The synoptic-scale data used for this initialization (and in the analysis nudging discussed below) are obtained from the conventional National Weather Service (NWS) twice-daily radiosondes and 3-hr NWS surface observations.

Water Temperature Inputs: The NNRP and ETA database contains a "skin temperature" field. This can be used as a water temperature input to MM5. It is recognized that these skin temperatures can lead to temperature errors along coastlines. However, for this analysis, focusing on bulk continental scale transport, this issue is likely not important.

FDDA Data Assimilation: This simulation uses an analysis-nudging technique where the observations are nudged toward a field prepared by objective analyzing surface and aloft monitor data into the first-guess fields. For these simulations a nudging coefficient of 2.5×10^{-4} was used for winds and temperature and 1×10^{-5} for mixing ratio. Only 3D analysis nudging was performed and thermodynamic variables are not nudged within the boundary layer.

Physics Options: The MM5 model physics options in this simulation is as follows:

Kain-Fritsch Cumulus Parameterization
Pleim-Xiu PBL and Land Surface Schemes
Simple Ice Moisture Scheme
RRTM Atmospheric Radiation Scheme
Multi-layer Soil Temperature Model

Model Timing: The model was run for 5 ½ days with a restart occurring at 12Z every fifth day. To assure continuity in the surface moisture, the model initial conditions were updated with the soil conditions from the end of the previous 5 ½ day period using the USEPA "INTERPX" processor.

Grid Nesting: The model was run with the 12km grid as a one-way nest from the 36km grid with hourly updated boundary conditions.

1.1 Evaluation Approach

The model evaluation approach is based on a combination of qualitative and quantitative analyses. The qualitative approach is to compare the model estimated sea level pressure and radar reflectivity fields with observed values from historical weather chart archives. The statistical approach is to examine the model bias and error for temperature, mixing ratio and the Index of Agreement for the windfields.

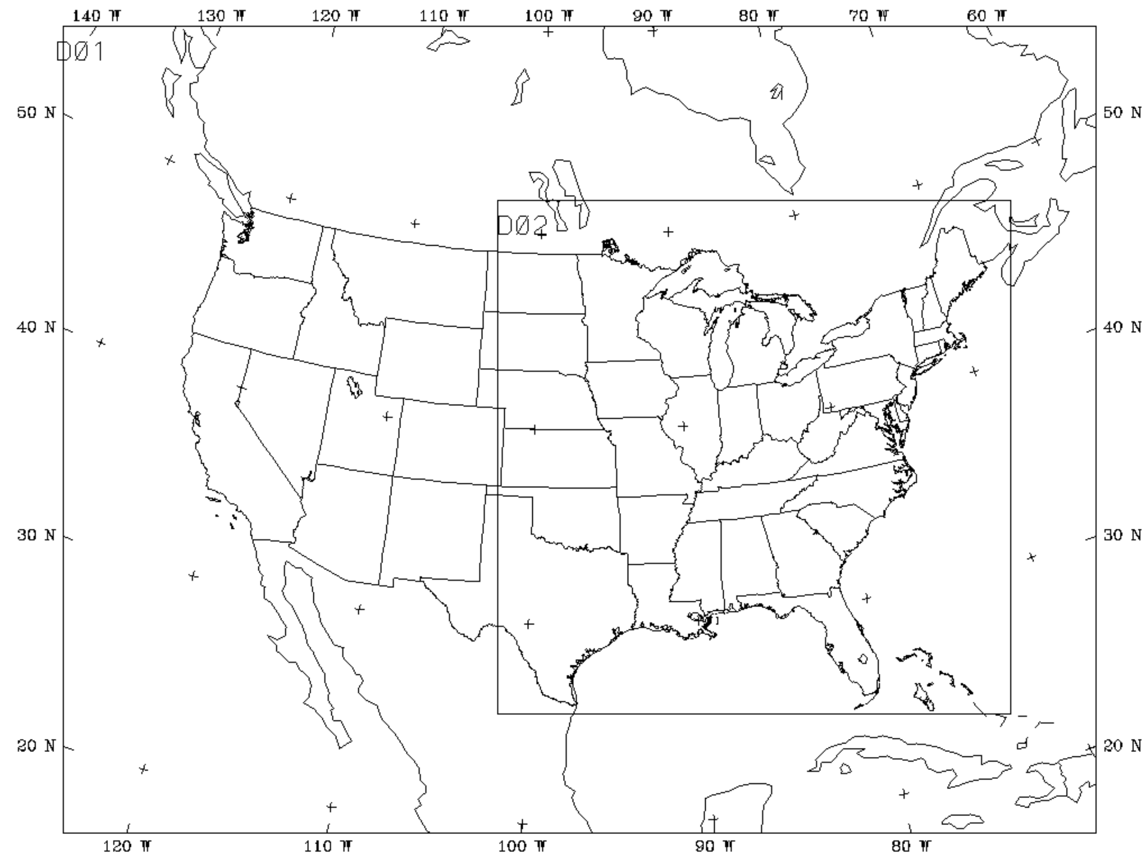
Interpretation of bulk statistics over a continental scale domain is problematic. It is difficult to detect if the model is missing important sub-regional features. For this analysis the statistics are performed on a state-by-state basis, a Regional Planning Organization (RPO) basis, and on a domain-wide basis.

The observed database for winds, temperature, and water mixing ratio used in this analysis is the NOAA Techniques Development Lab (TDL) Surface Hourly Observation database obtained from the NCAR archives. The rain observations are taken from the National Climatic Data Center (NCDC) 3240 hourly rainfall archives.

Table 2-1: MM5 Vertical Domain Specification.

k(MM5)	sigma	press.(mb)	height(m)	depth(m)
34	0.000	10000	15674	2004
33	0.050	14500	13670	1585
32	0.100	19000	12085	1321
31	0.150	23500	10764	1139
30	0.200	28000	9625	1004
29	0.250	32500	8621	900
28	0.300	37000	7720	817
27	0.350	41500	6903	750
26	0.400	46000	6153	693
25	0.450	50500	5461	645
24	0.500	55000	4816	604
23	0.550	59500	4212	568
22	0.600	64000	3644	536
21	0.650	68500	3108	508
20	0.700	73000	2600	388
19	0.740	76600	2212	282
18	0.770	79300	1930	274
17	0.800	82000	1657	178
16	0.820	83800	1478	175
15	0.840	85600	1303	172
14	0.860	87400	1130	169
13	0.880	89200	961	167
12	0.900	91000	794	82
11	0.910	91900	712	82
10	0.920	92800	631	81
9	0.930	93700	550	80
8	0.940	94600	469	80
7	0.950	95500	389	79
6	0.960	96400	310	78
5	0.970	97300	232	78
4	0.980	98200	154	39
3	0.985	98650	115	39
2	0.990	99100	77	38
1	0.995	99550	38	38
0	1.000	100000	0	0

Figure 2-1: National ETA Computational Grid.



2 RESULTS

2.1 Model Evaluation Results

The synoptic and statistical evaluations for simulation are presented in the following sections.

2.1.1 Synoptic Evaluation

One very important metric of model performance is to qualitatively assess how well the model is able to capture the evolution of synoptic systems. Sea level pressure and radar reflectivity plots for every 36 hours throughout the episode are presented in Figures 3-1 through 3-66. Figure 3-1 through 3-66 consist of 22 groups of three plots. The first plot in each group presents the 36km model estimated fields with the blue lines being 850 mbar heights, the red vectors are wind barbs and the shaded areas are regions of simulated radar reflectivity. The second plot presents the same information for the 12km grid. The final plot is the archived surface chart from weather.unisys.com with the 850 Mbar heights in bold lines and shaded regions of radar reflectivity.

Some general conclusions from these figures are:

The model tends to generate more mesoscale structure in the 850 Mbar height fields, particularly over the western mountains.

The model generally captures long wave patterns. The model has no tendency to either lag systems behind the observations, or to advance systems faster than suggested by the observations at either the 12km or 36km grid scales.

The model generally captures the regions of organized radar reflectivity, but the model underestimates the geographic extent. The underestimation is approximately the same at both the 12km and 36km horizontal grid spacing.

2.1.2 Statistical Evaluation

The results for the statistical evaluation are presented in this section. The tables present the statistical metric for each state, for each Regional Planning Organization (RPO), and for the entire modeling domain (including only the United States). Several issues related to the quantitative model performance must be taken into account in assessing the model performance

The mixing ratio (i.e., specific humidity) and temperature measurements are typically taken at a 2 m shelter height while the model predictions are derived from the node (middle point) of the first level in the MM5 model, 19 m. Thus, there is an unavoidable mismatch between the height of the measurement (2 m) and the height of the prediction (19 m). For wind speed and direction the comparison is from nominal anemometer height (10m) to the MM5 grid node (19 m). This introduces differences between the model estimated field and the observation that are quite independent of any error in the measurement or model prediction. In practice, this proves to be an inherent limitation of a rigorous performance appraisal of the meteorological model since no reliable method is presently available to transform the prediction and measurement to a common height.

Additional care must be exercised in the 12km Western Regional Air Partnership (WRAP) RPO evaluation since the majority of the WRAP lies outside the 12km modeling domain.

Temperature bias and error results are presented in Tables 3-1 and 3-2 for the 36km and 12km domains, respectively. For the entire domain at 36km resolution the model has a bias of –0.77 K. At 12km horizontal grid spacing the model has a temperature bias of –0.41 K. This is, the model is too cool by 0.41 K. The model has a temperature error of 2.04 K at 36km grid spacing and 1.64 K at 12km resolution.

Domain mean temperature plots are presented in Figure 3-67 and Figure 3-68 for the 12km and 36km domains, respectively. The model generally tracks within a couple of degrees of the observations. Mean temperature plots for the CENRAP states are presented in Figures 3-67 and 3-68. The model is able to capture overall trends.

Temperature spatial mean plots for the MANE-VU RPO region are presented in Figures 3-71 and 3-72. The most notable feature is the ability of the model to accurately capture the frontal passage on 26 July. Plots for the Midwestern RPO are presented in Figures 3-73 and 3-74. Again, the model is able to accurately time the frontal passage on 25 July. VISTAS RPO plots are presented in Figure 3-75 and Figure 3-76. For all these regions the seasonal patterns are generally captured and nominally weeklong synoptic patterns are replicated.

Finally, the WRAP RPO mean temperature bias is presented in Figure 3-77 and 3-78. For the WRAP region the model shows much more difference in the 36km and 12km model estimates. This is because the majority of the WRAP area lies outside the 12km domain so different stations are being used in the 12km and 36km spatial mean calculation.

Mixing ratio bias and error (g/kg) results are presented in Tables 3-3 and 3-4 for the 36km and 12km domains, respectively. Averaged over the entire domain at 36km, the model shows a negative bias of 0.32 g/kg. Over the 12km domain the model shows a negative bias of 0.92 g/kg. This means that the model is slightly too dry.

Domain averaged mean mixing ratio are presented in Figures 3-81 and 3-82. The model is too dry for the majority of the episode, particularly during the first week of the episode. The model is tending to do slightly better in the 12km domain than in the 36km domain. Mean mixing ratio for the CENRAP region is presented in Figures 3-81 and 3-82. In the CENRAP region the model shows the same low bias as the domain wide analysis early in the episode, but the model, particularly at 12km resolution does better during the rest of the episode. The drying period on 8 and 9 August is accurately captured both in timing and in magnitude. Figures 3-83 and 3-84 present the spatial mean mixing ratio results in the northeastern MANE-VU states. The MANE-

VU region shows less dry bias than other regions early in the episode and the drying period from 25 through 28 July is accurately captured. The Midwestern RPO results are presented in Figures 3-85 and 3-86. As with MANE-VU, the drying period in late July is accurately captured, but the model tends to be slightly too dry. The southeastern VISTAS states are in Figures 3-87 and 3-88. The VISTAS results agree more closely than the other RPO's, with the model being slightly too dry during the early simulation period. Finally, the WRAP results are presented in Figures 3-89 and 3-90. As with the temperature results, the model performs less well in the WRAP states than any of the other RPO's. For the majority of the year the model is too dry by 1 to 2 g/kg.

Accumulated precipitation bias for the entire domain, and each state and RPO region for the 12km and 36km domains are presented in Tables 3-5 and 3-6, respectively. The accumulated precipitation is computed by summing the observed precipitation over the entire period at each station, and summing the model estimated precipitation at the station location over the same period. By using the accumulated precipitation metric we are able to relax the timing of rainfall events and to focus on rainfall trends. For the entire 12km domain, summed over the entire episode, the model is overestimating rainfall by 1.29 cm. For the entire 36km domain, the model is overestimating precipitation by 1.44 cm.

Weekly observed and estimated total precipitation for the 36km and 12km domains are presented in Figures 3-92 and 3-93, respectively. The model is able to accurately replicate the weekly average precipitation. Weekly rainfall comparisons for the CENRAP region are presented in Figure 3-94 and Figure 3-95. In the CENRAP region the model is tending to overestimate rainfall. Weekly rainfall comparisons for the MANE-VU region are presented in Figure 3-96 and Figure 3-97. Midwestern RPO results are presented in Figure 3-98 and Figure 3-99. Both the MANE-VU and Midwestern RPO results show very close agreement. In the VISTAS states, Figure 3-100 and Figure 3-101, the model is quite accurate during the first half of the episode, but does more poorly during the second half by overestimating the precipitation by approximately 25 percent. Figures 3-102 and 3-103 present the WRAP results. For the limited portion of the WRAP in the 12km domain, the higher rainfall in the first half and the dryer period in the second half is accurately portrayed.

Wind speed index of agreement are presented in Tables 3-7 and 3-9. The 36km and 12km domains show nearly identical values of 0.90 and 0.89 for the 36km and 12km domains, respectively. Examination of Figures 3-104 and 3-105 reveals no general trends in the index of agreement over the course of the episode. Index of Agreement time series plots for the entire domain, and for each RPO are presented in Figures 3-106 through 3-115.

Figure 2-1: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 13 July 2001.

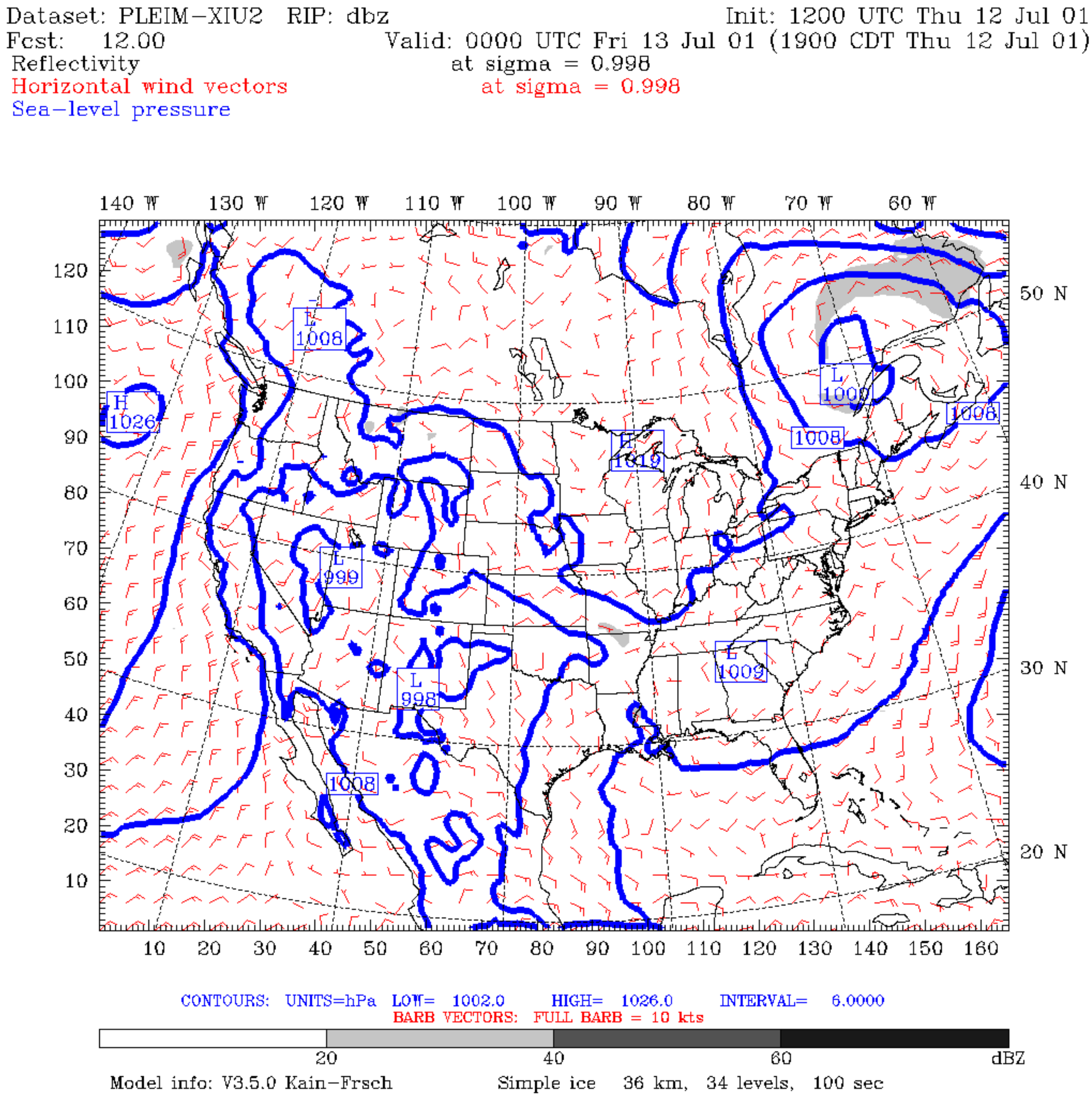


Figure 2-2: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 13 July 2001.

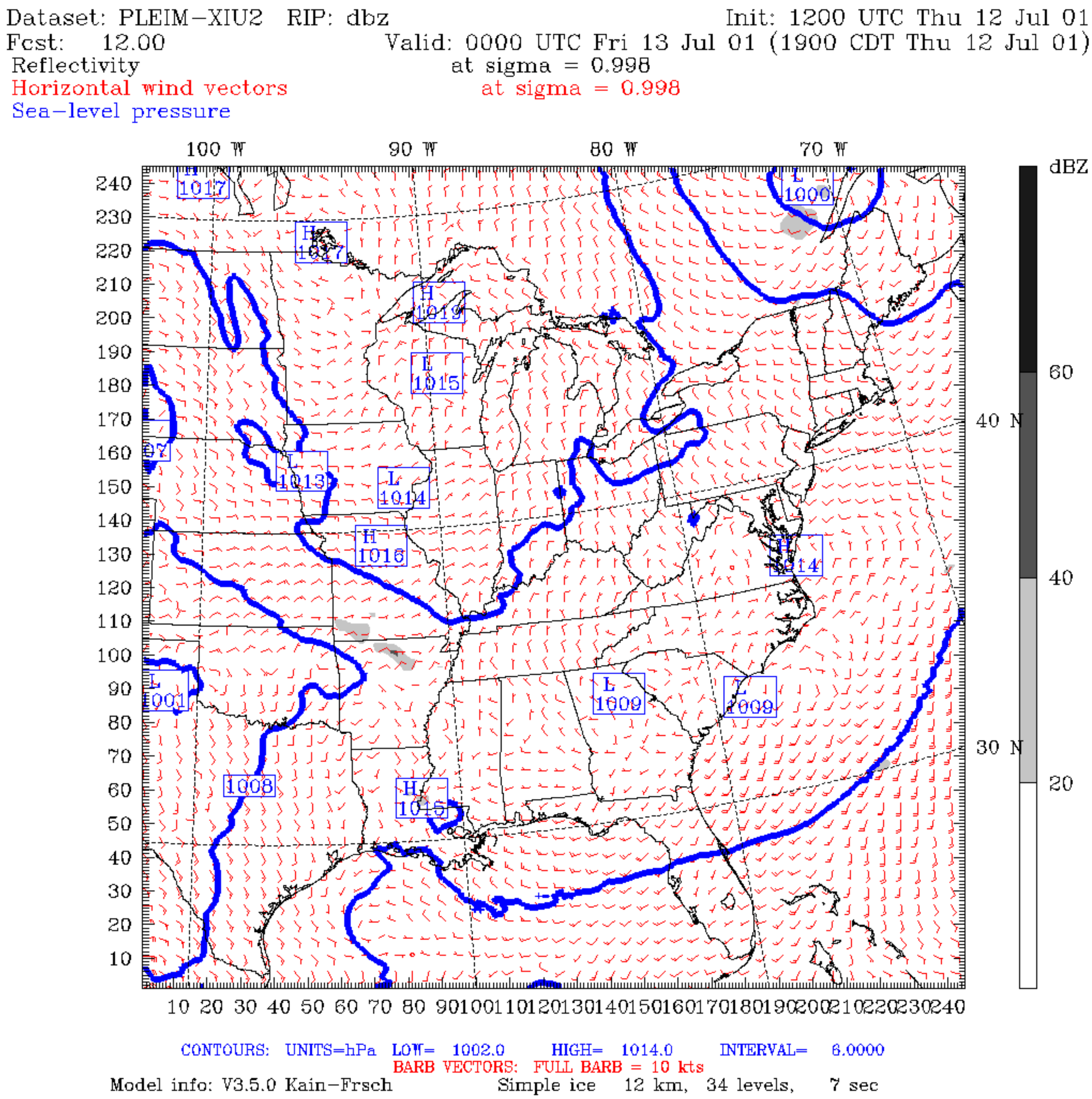


Figure 2-3: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 13 July 2001.

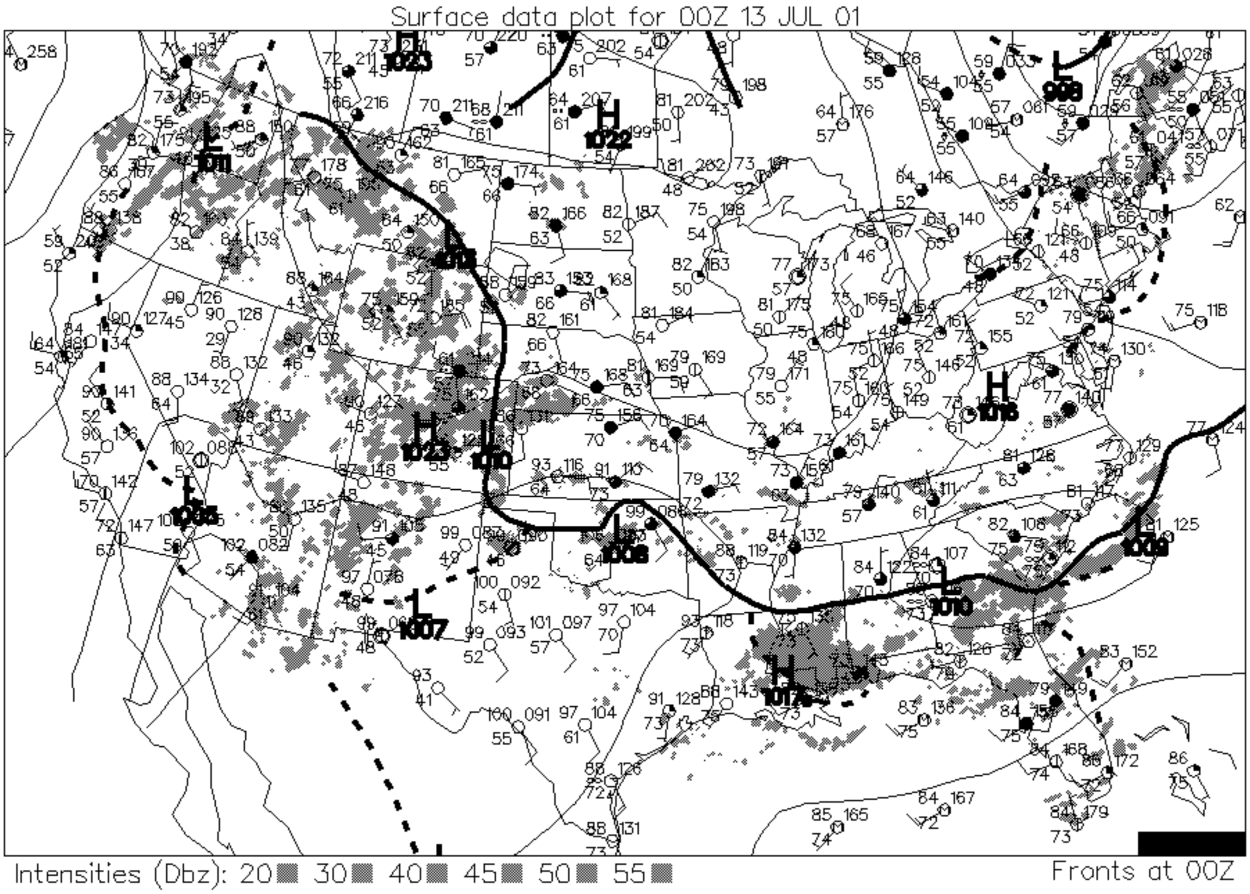


Figure 2-4: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 02Z 14 July 2001.

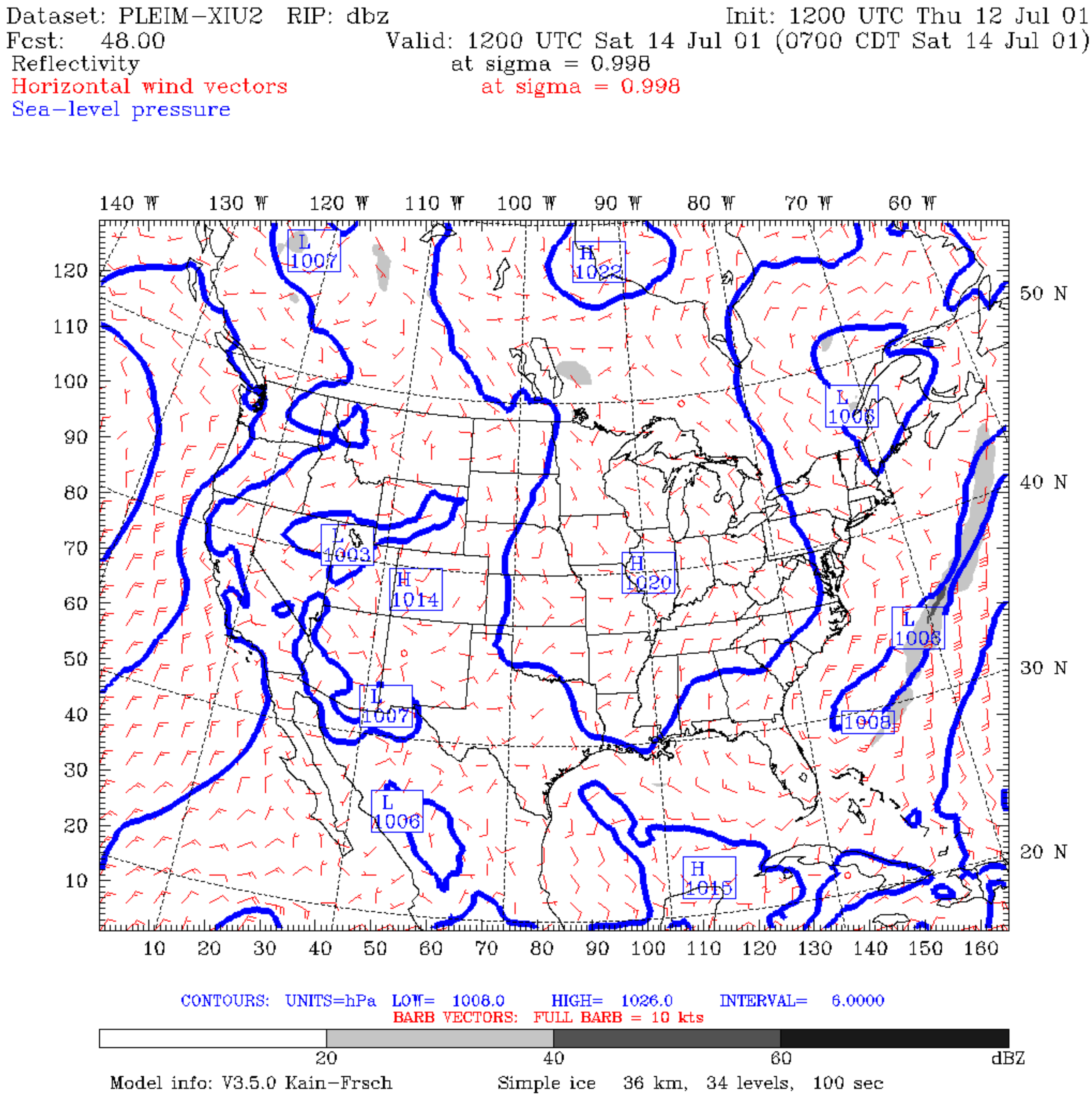


Figure 2-5: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 02Z 14 July 2001.

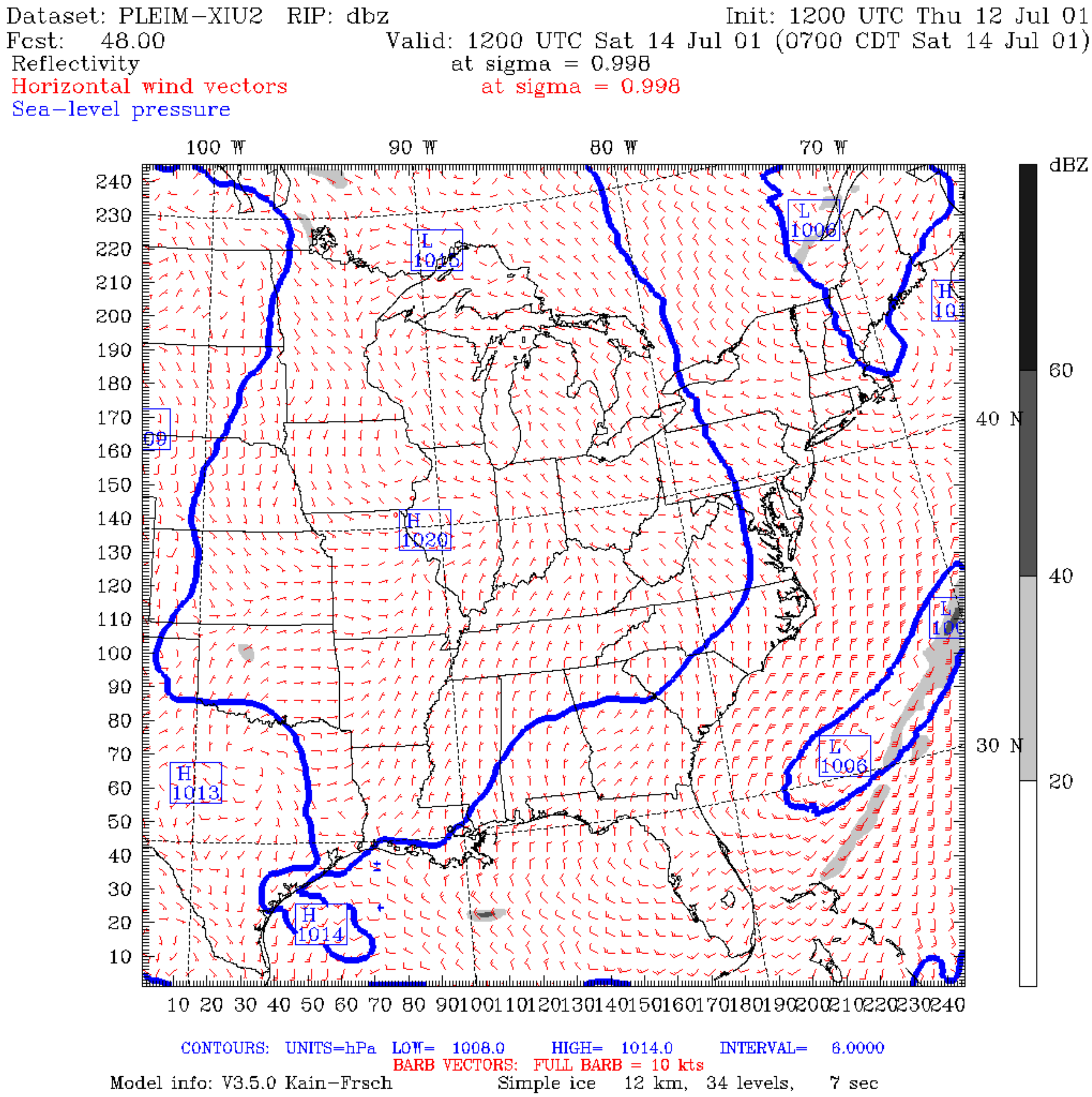


Figure 2-6: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 02Z 14 July 2001.

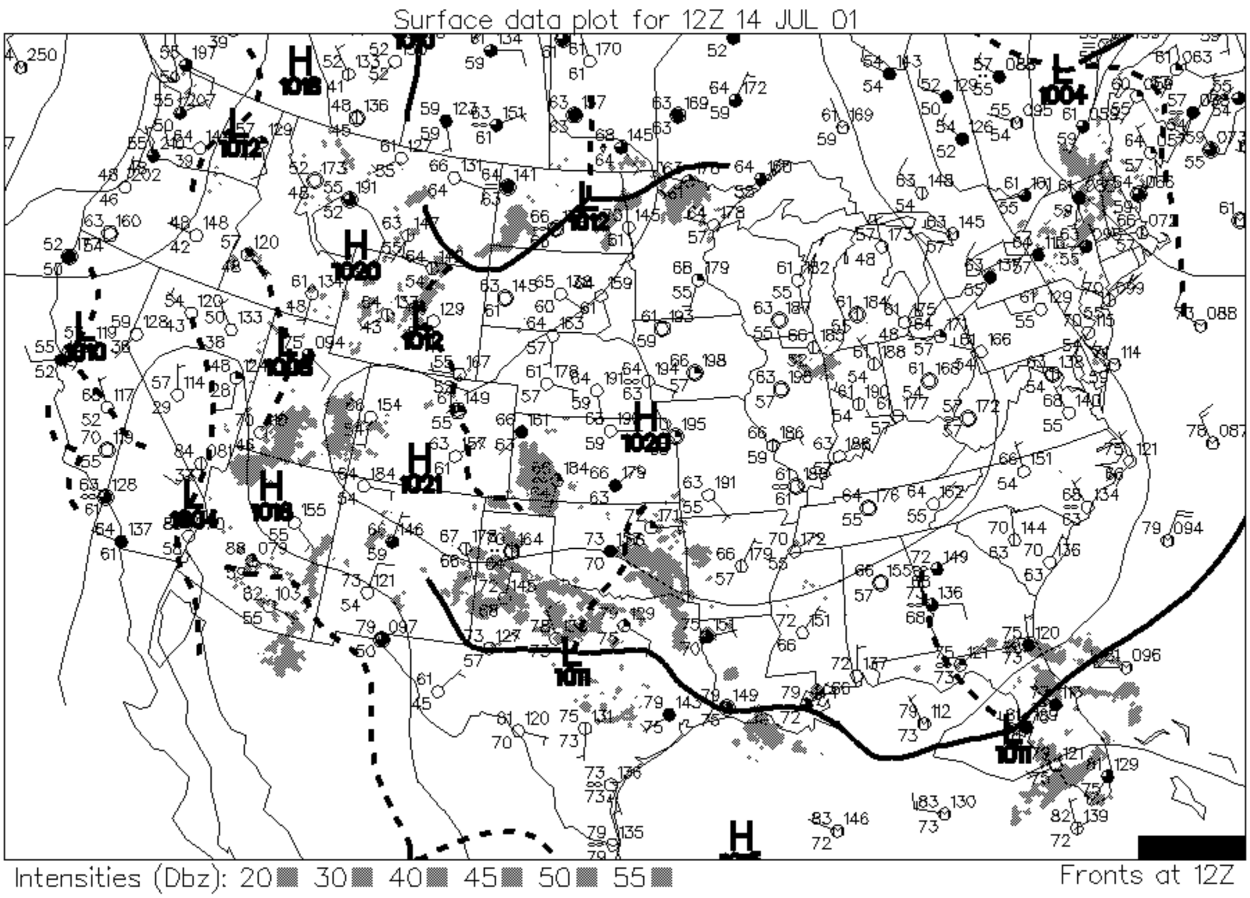


Figure 2-7: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 16 July 2001.

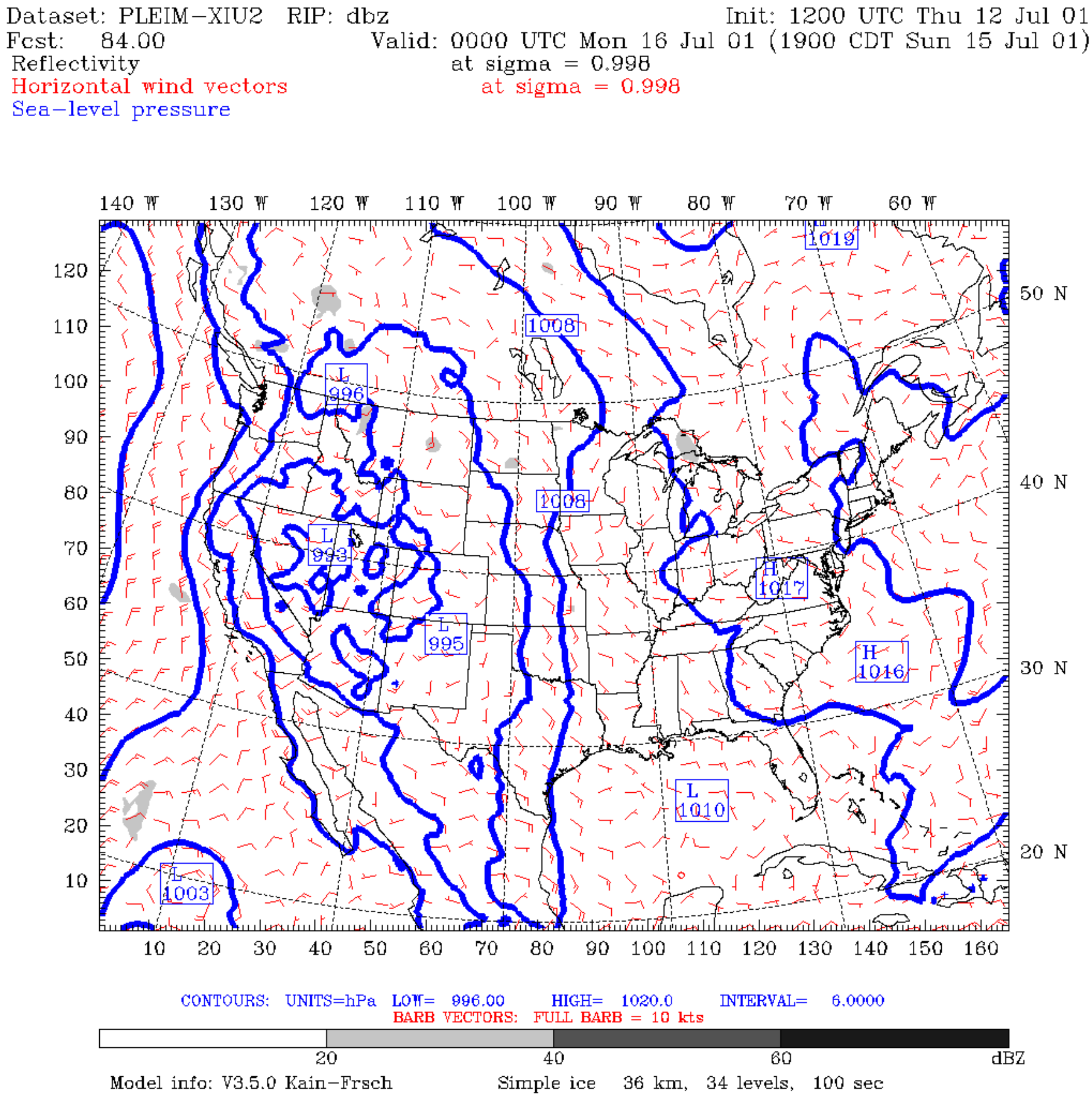


Figure 2-8: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 16 July 2001.

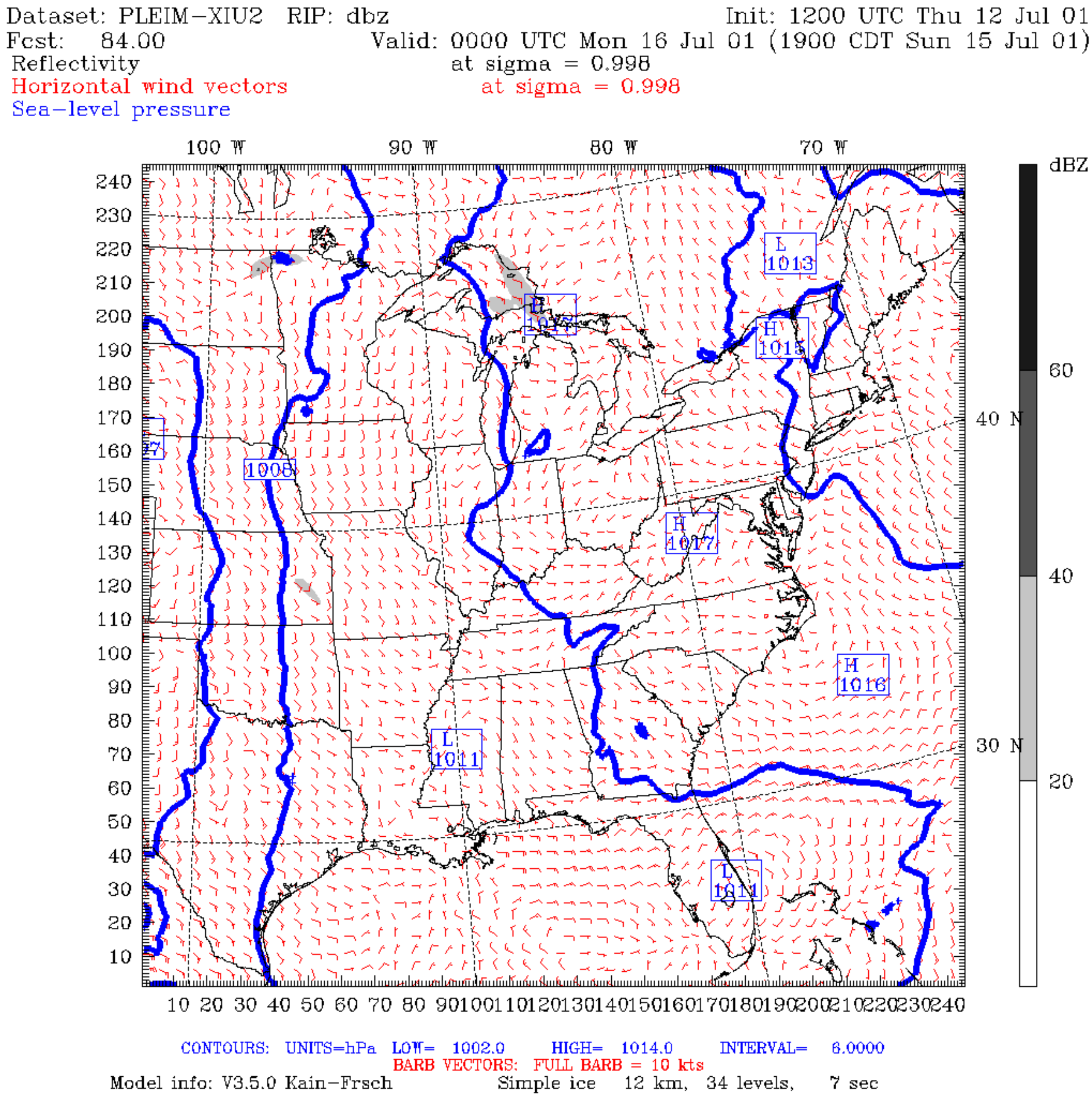


Figure 2-9: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 16 July 2001.

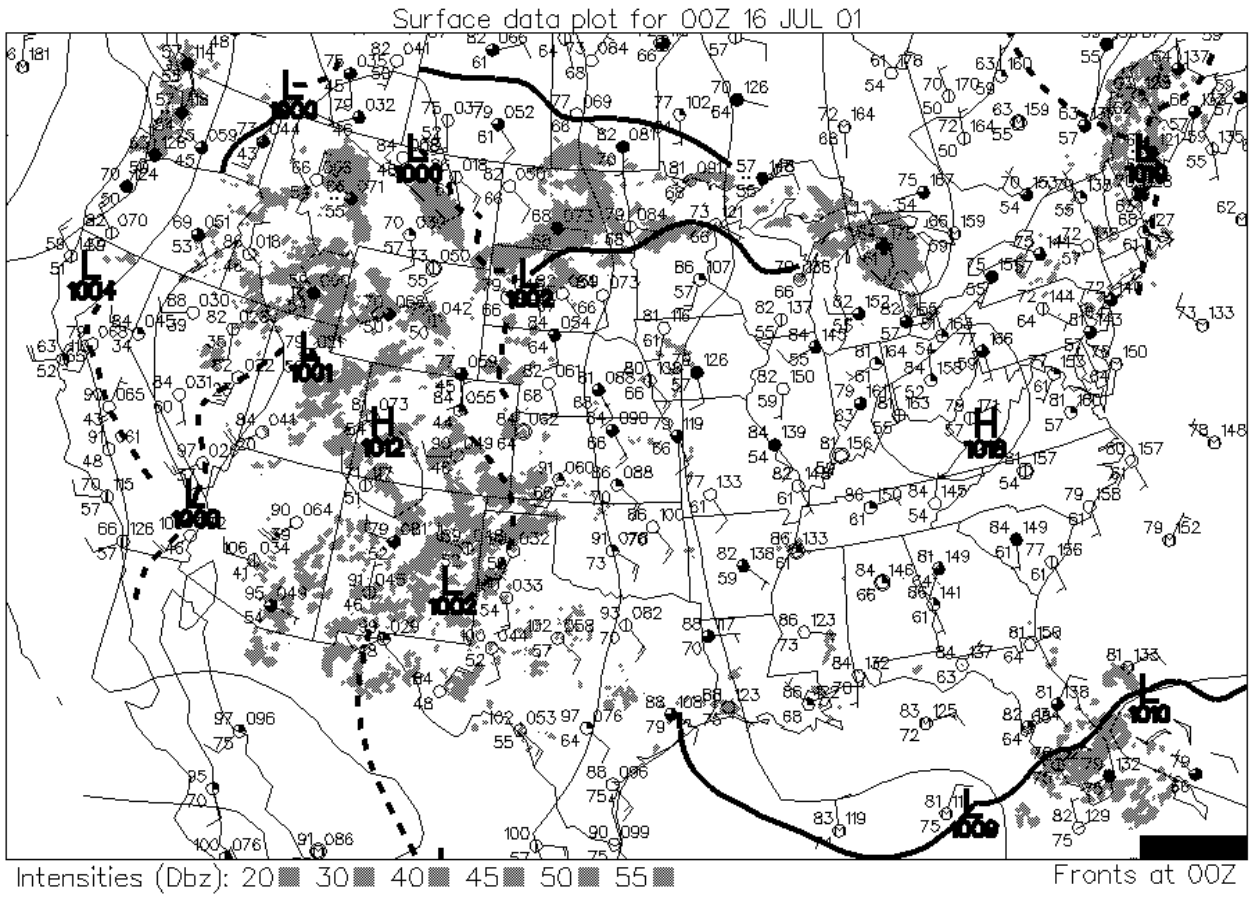


Figure 2-10: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 17 July 2001.

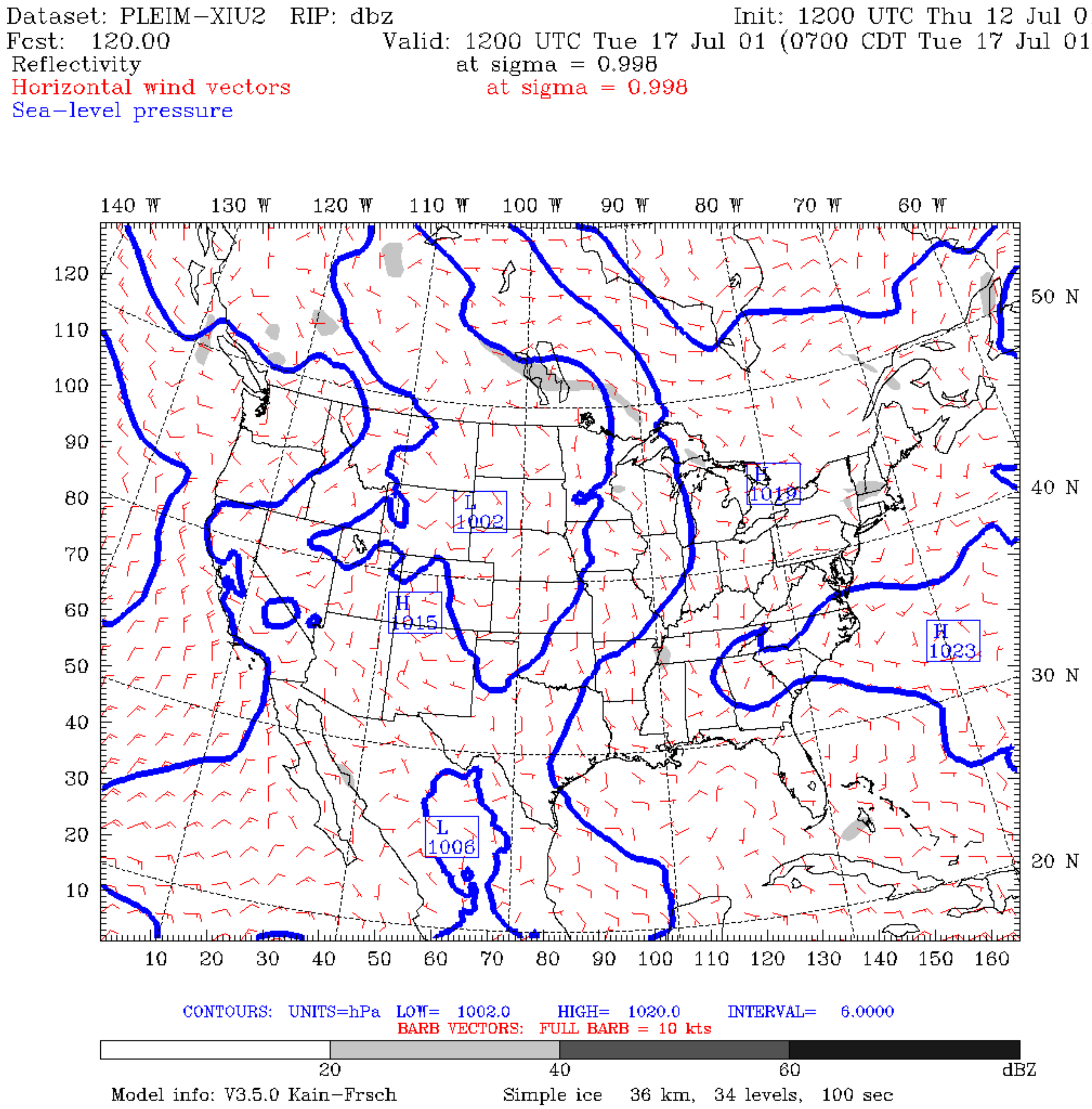


Figure 2-11: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 17 July 2001.

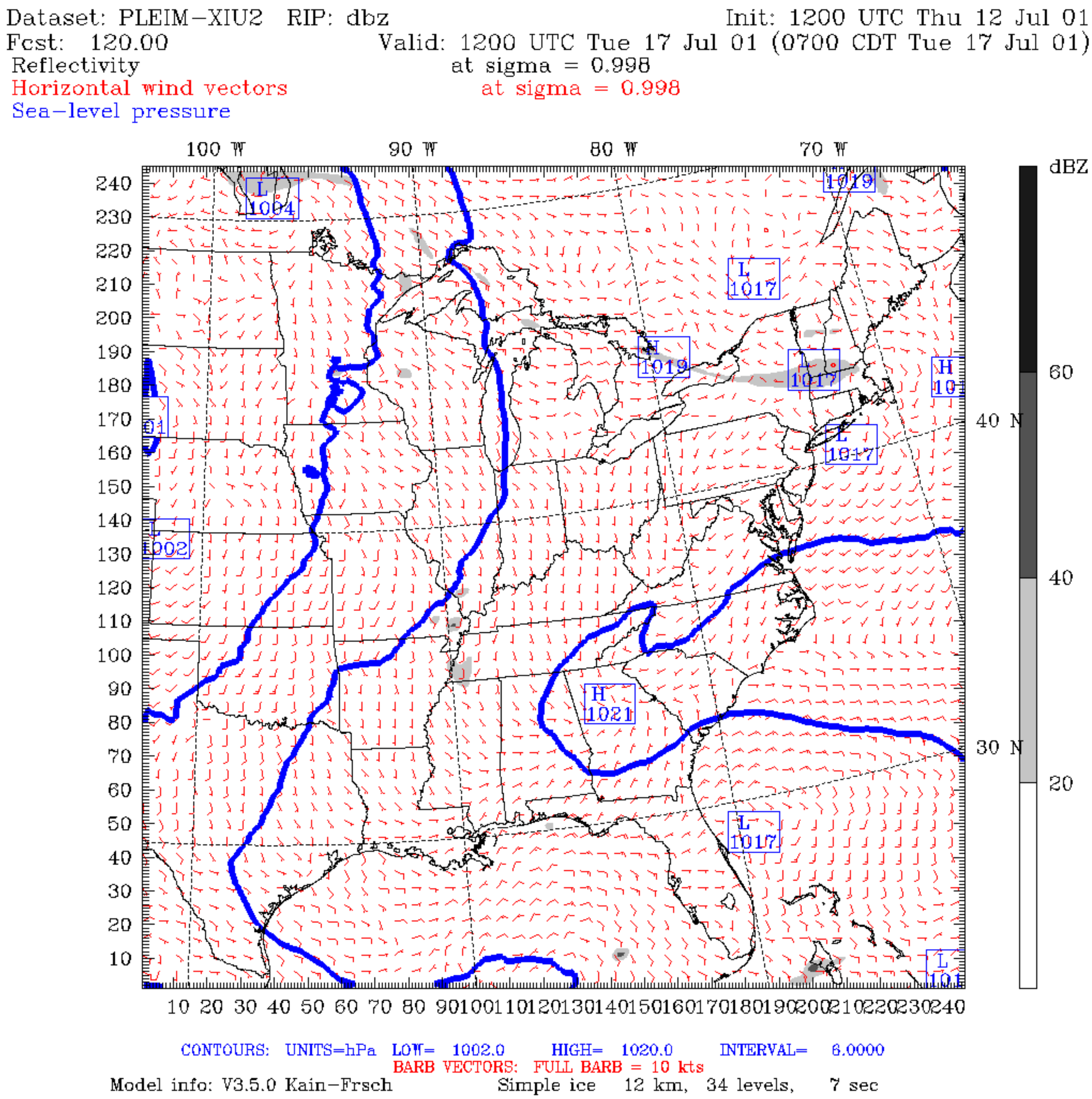


Figure 2-12: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 17 July 2001.

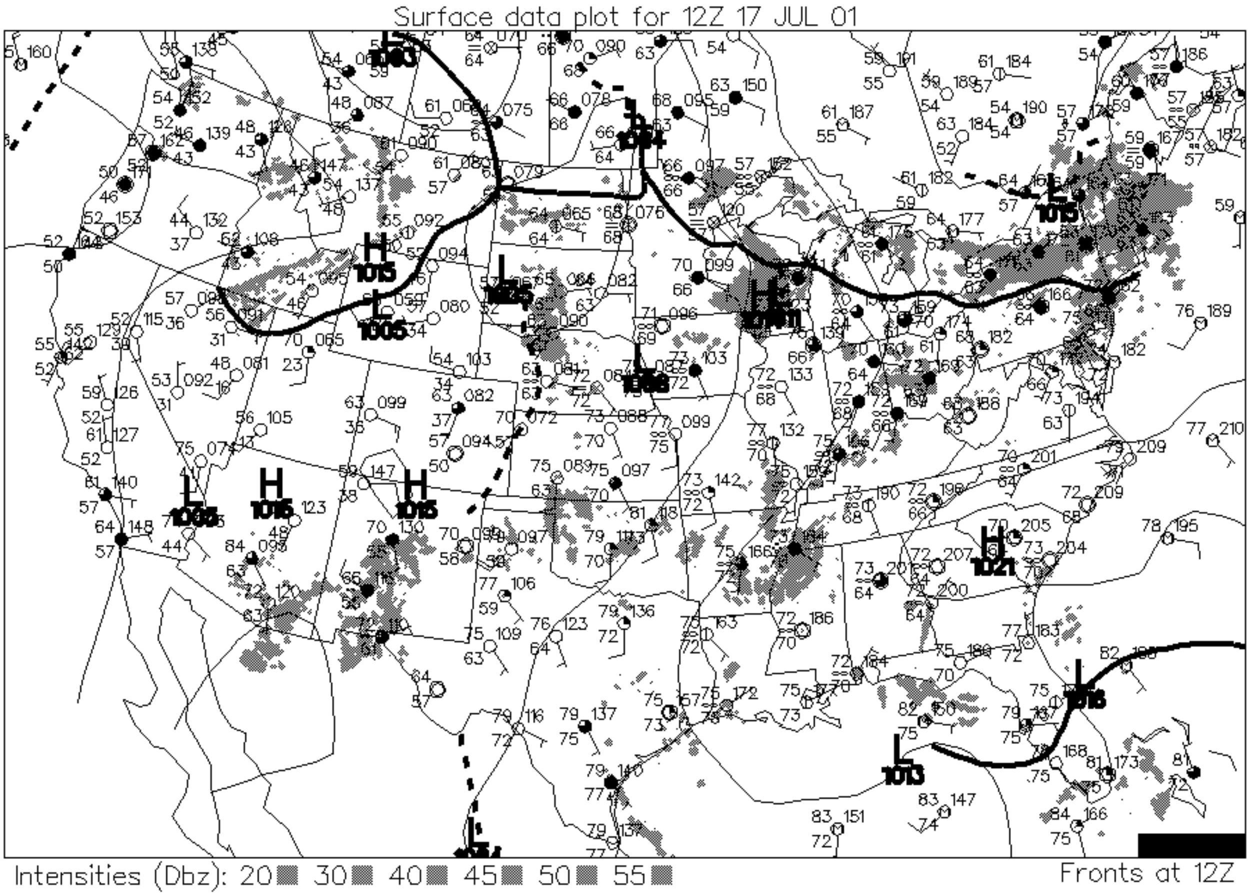


Figure 2-13: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 19 July 2001.

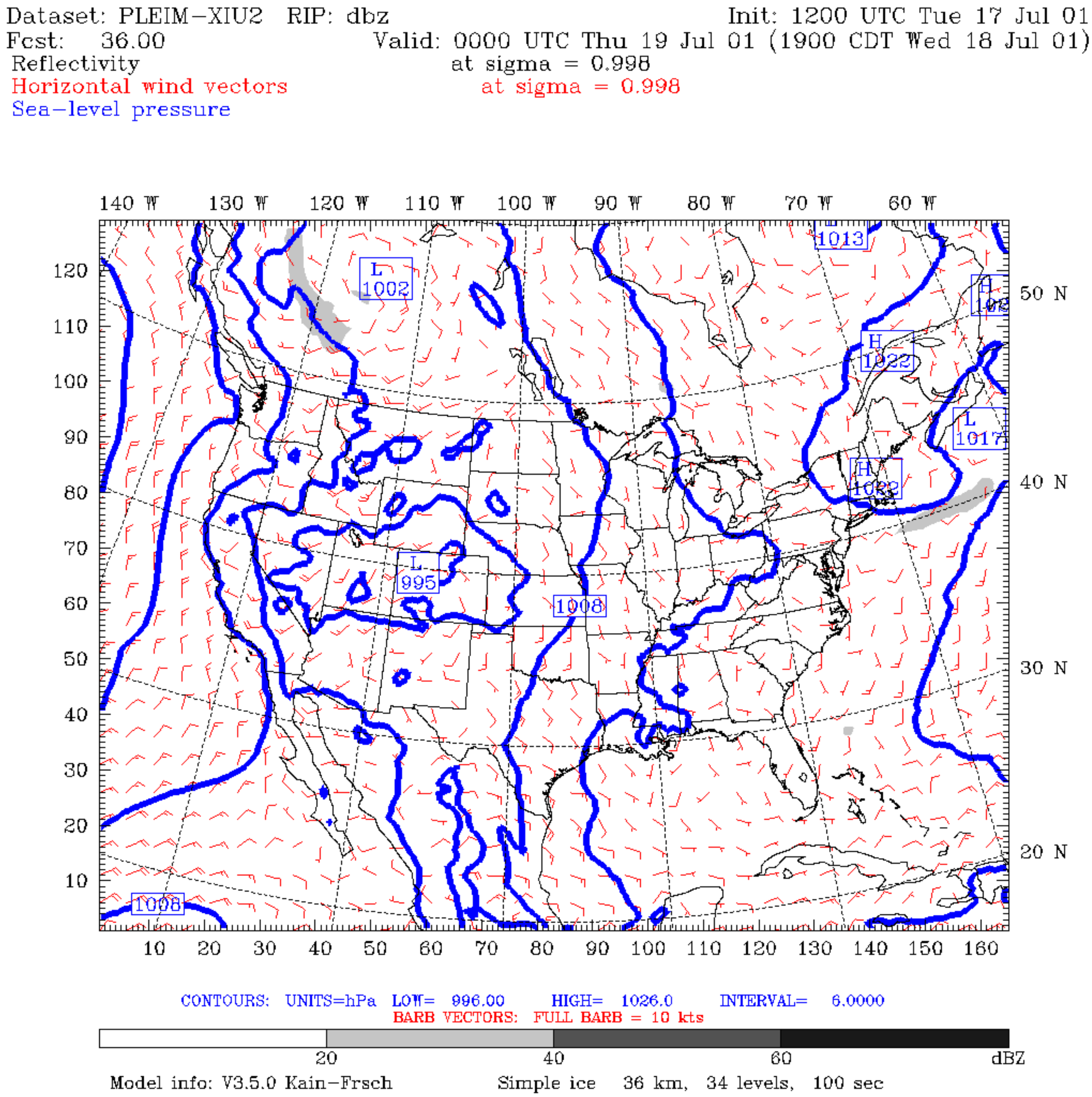


Figure 2-14: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 19 July 2001.

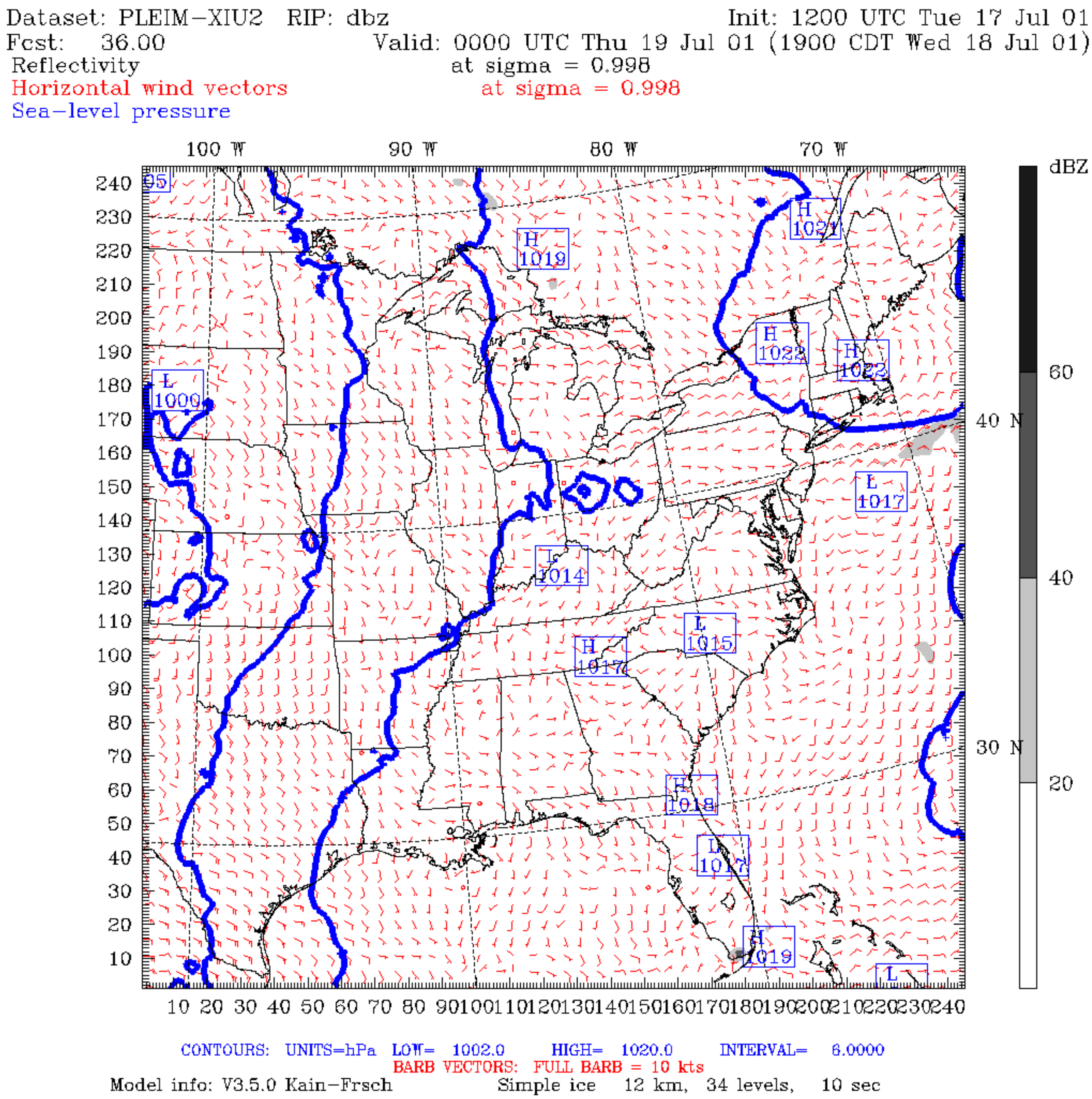


Figure 2-15: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 19 July 2001.

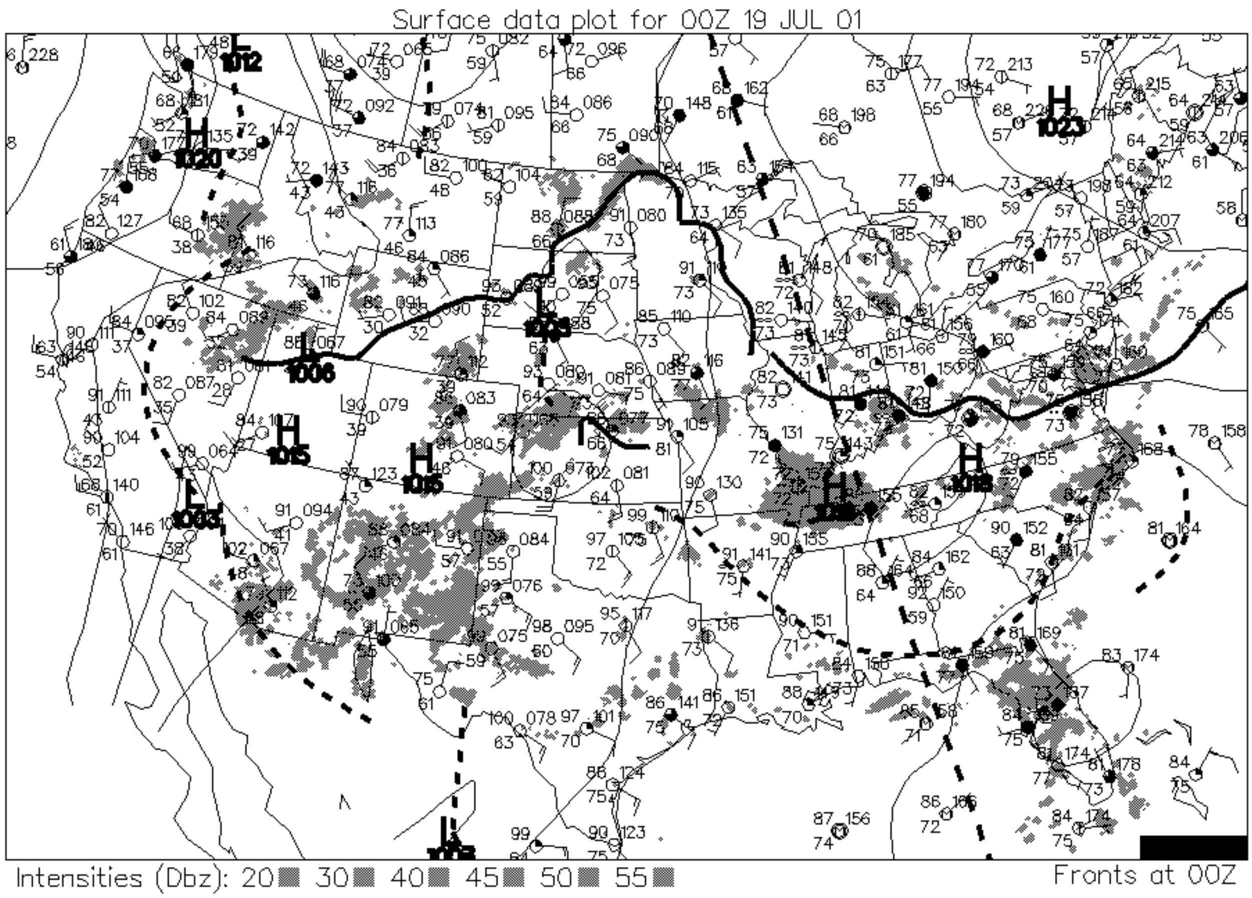


Figure 2-16: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 21 July 2001.

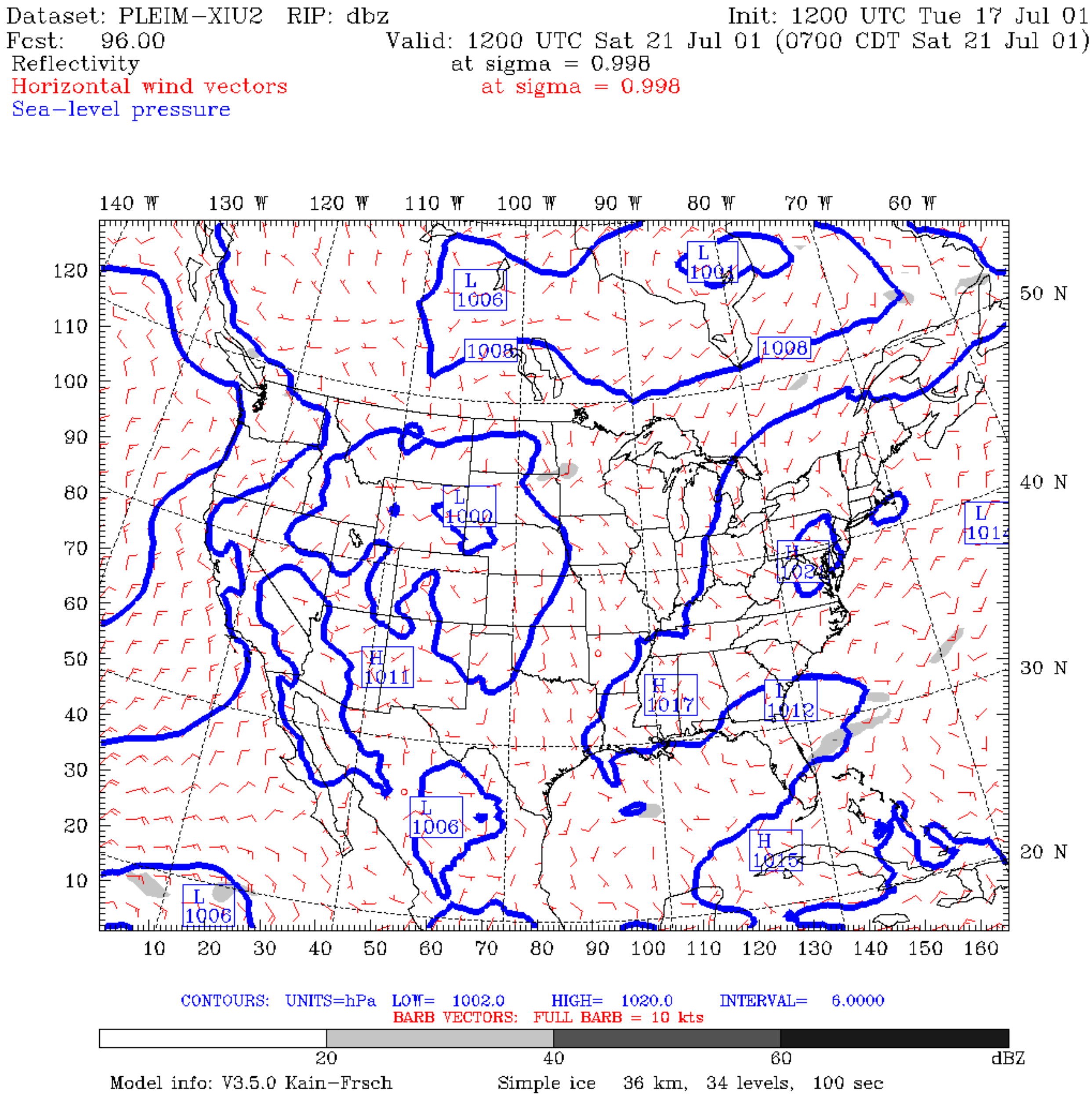


Figure 2-17: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 21 July 2001.

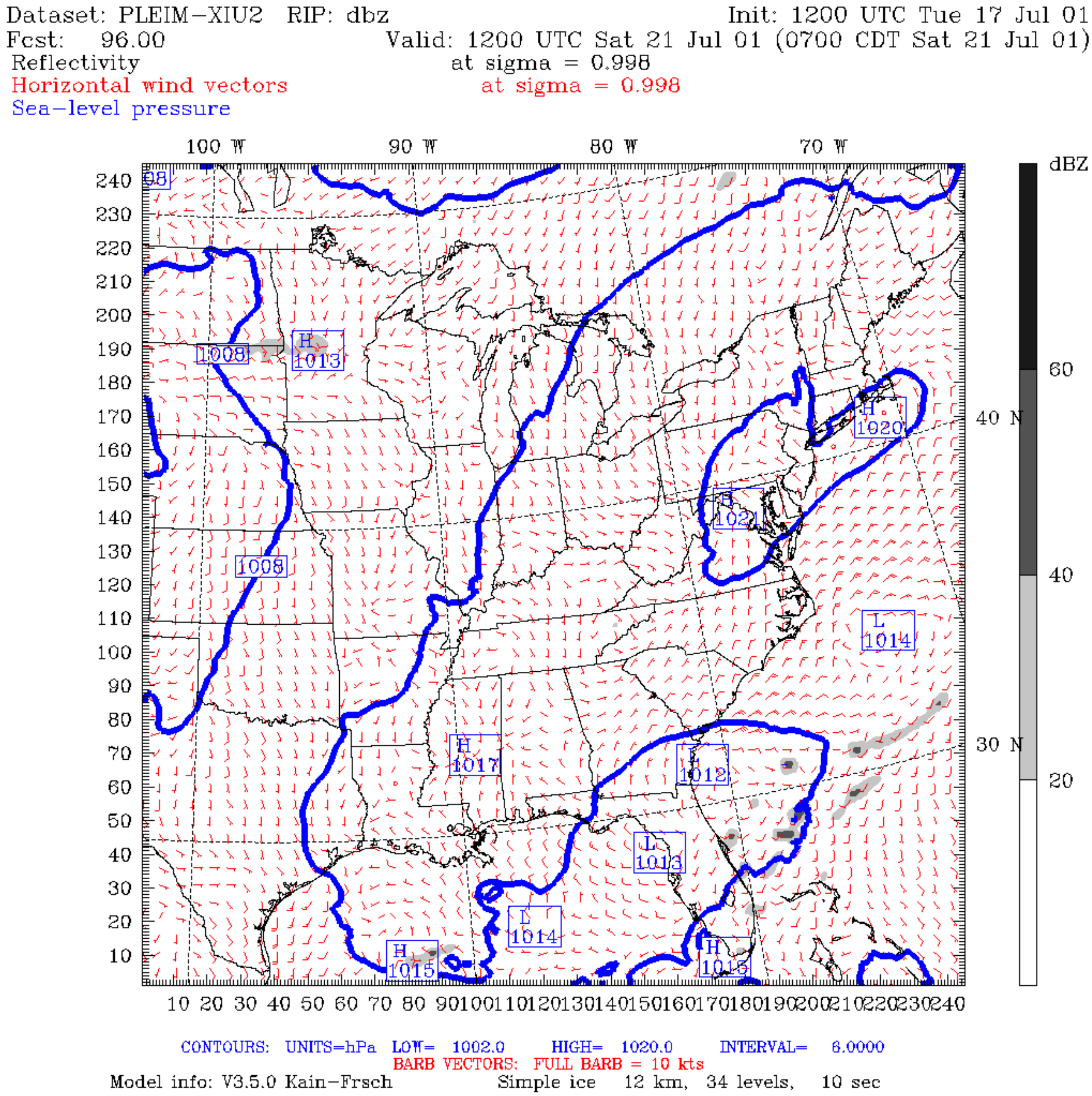


Figure 2-18: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 21 July 2001.

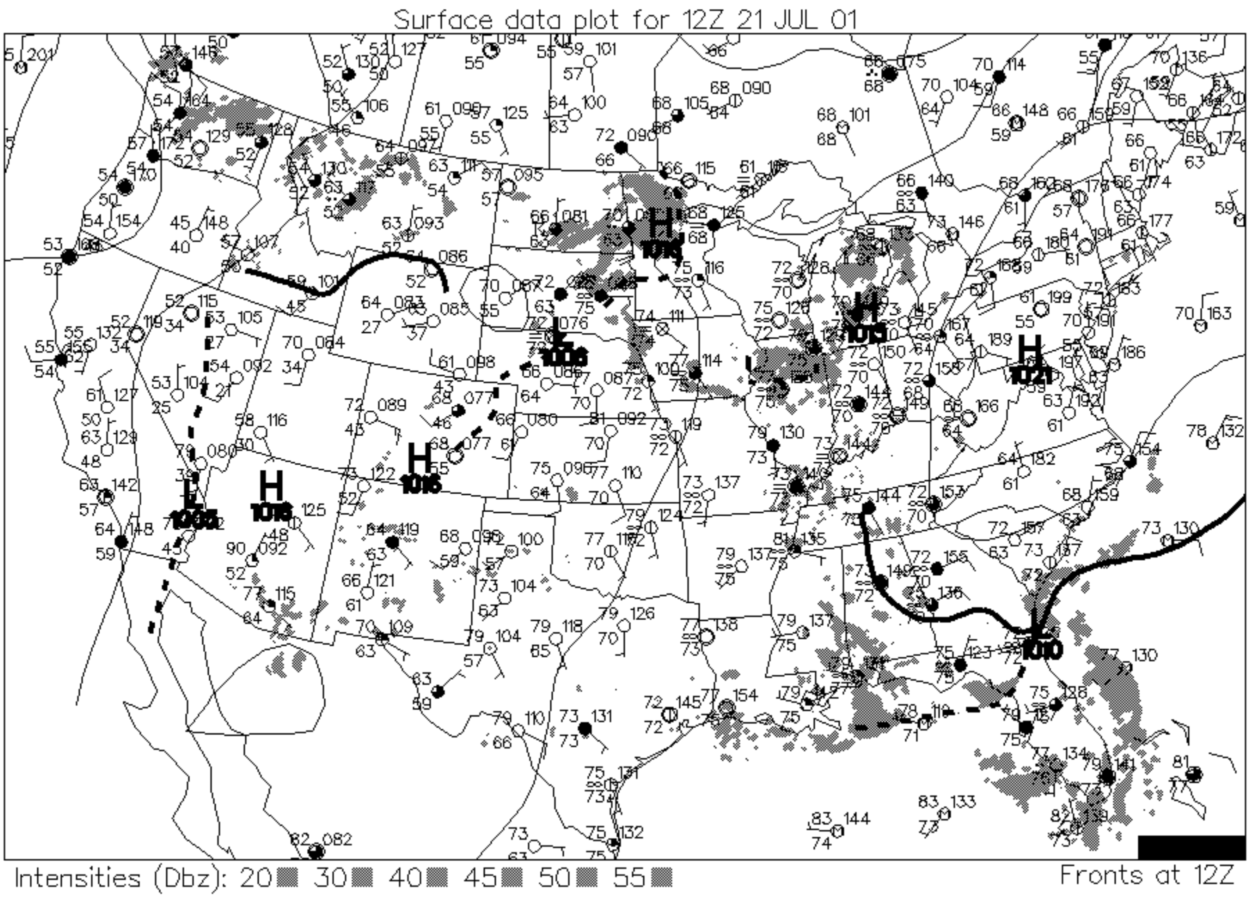


Figure 2-19: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 23 July 2001.

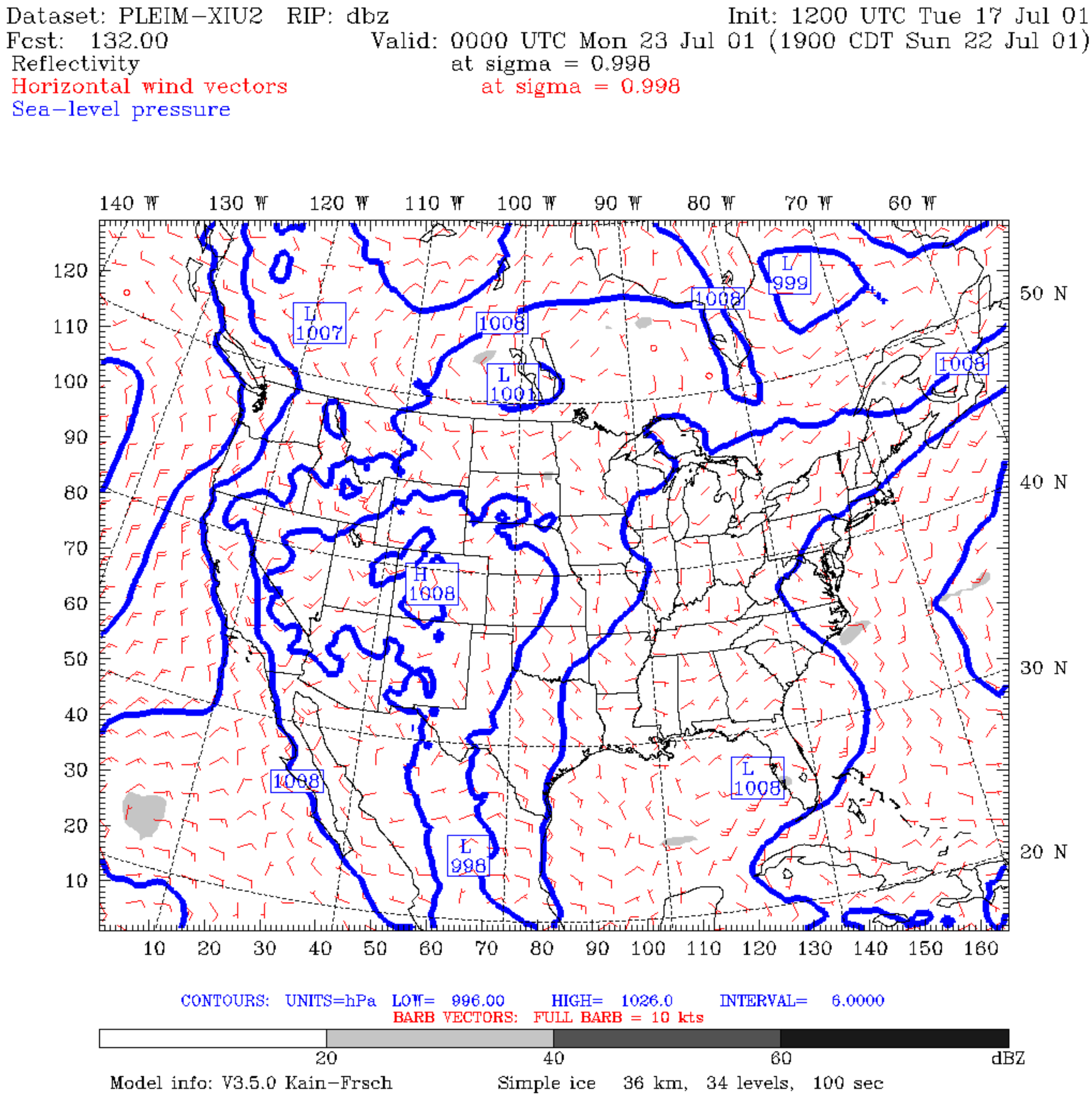


Figure 2-20: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 23 July 2001.

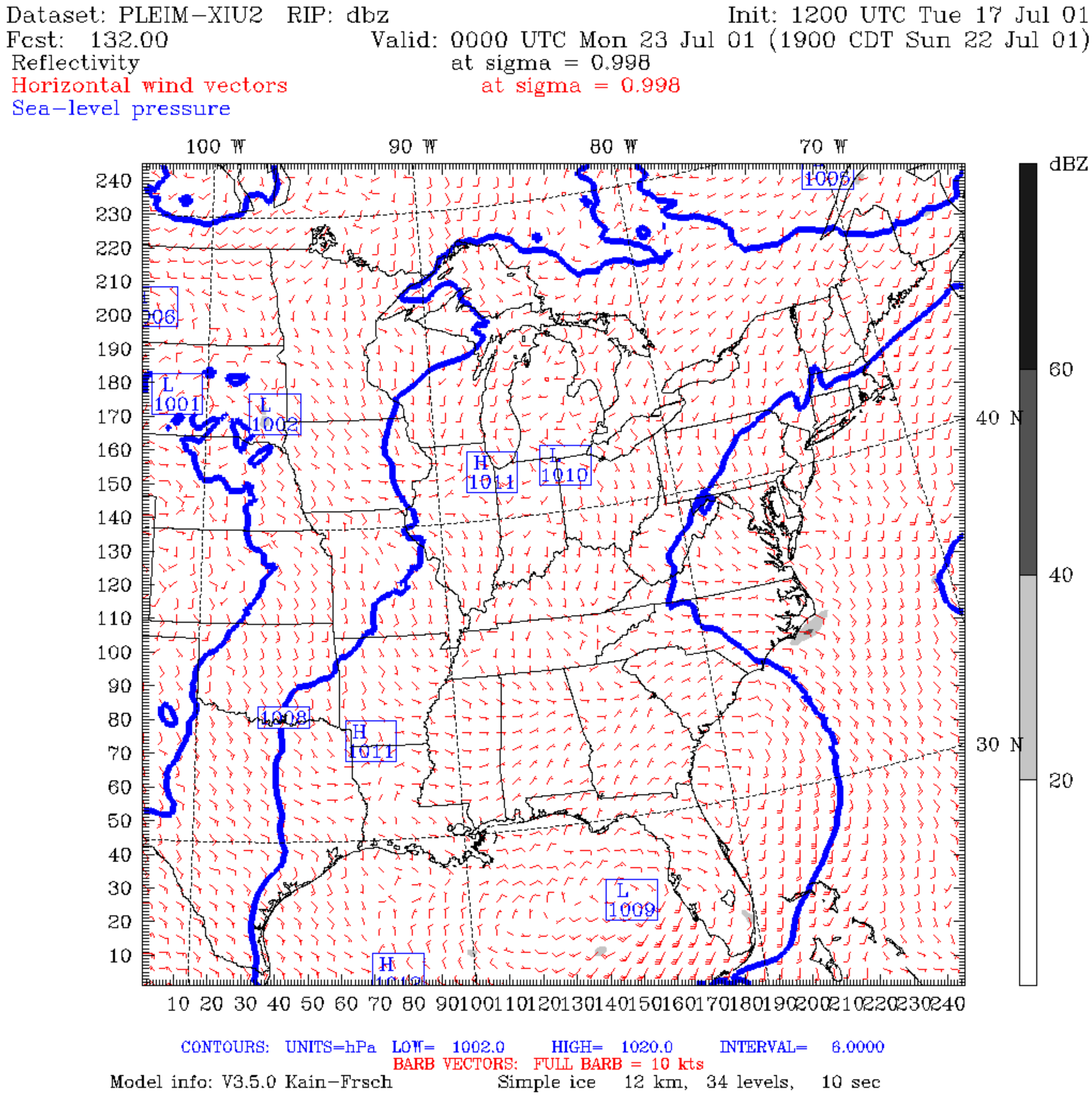


Figure 2-21: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 23 July 2001.

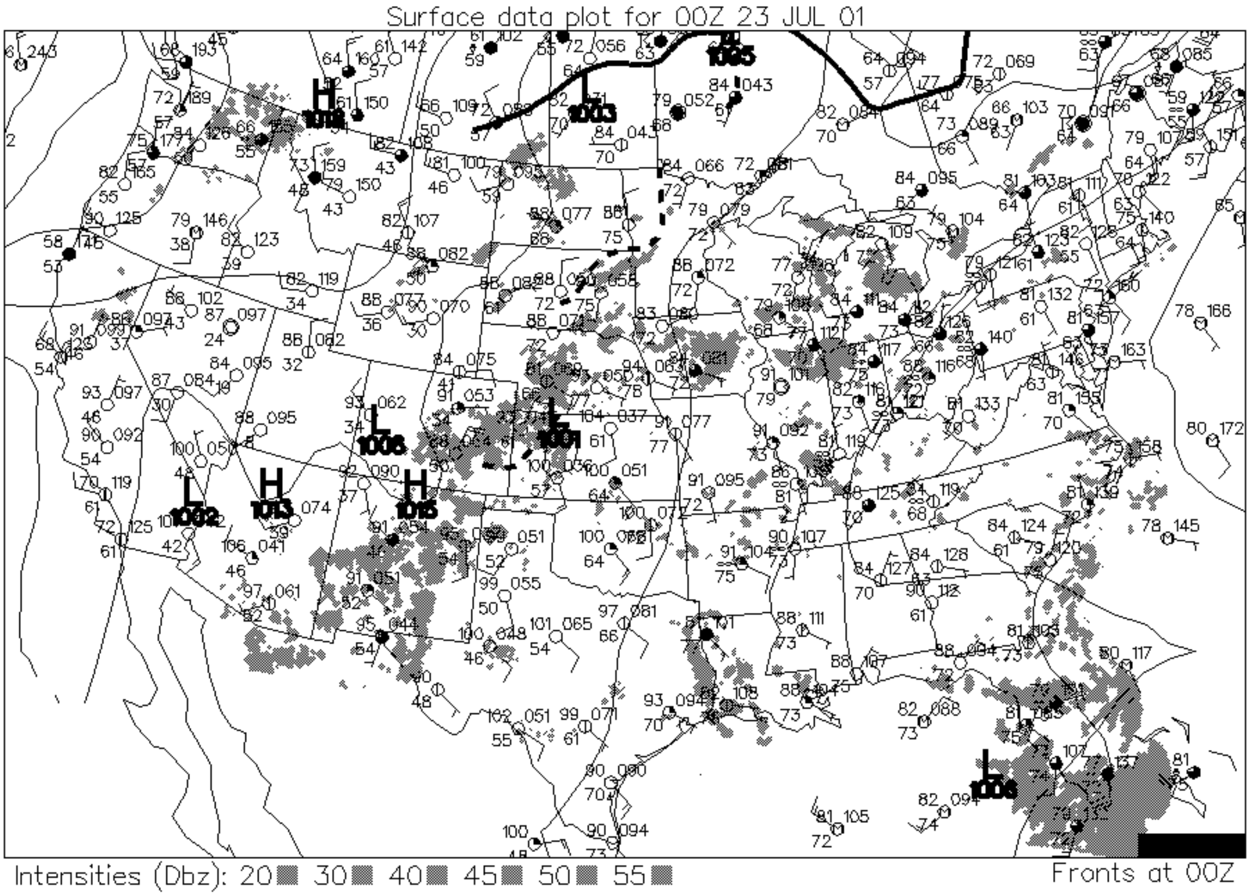


Figure 2-22: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 24 July 2001.

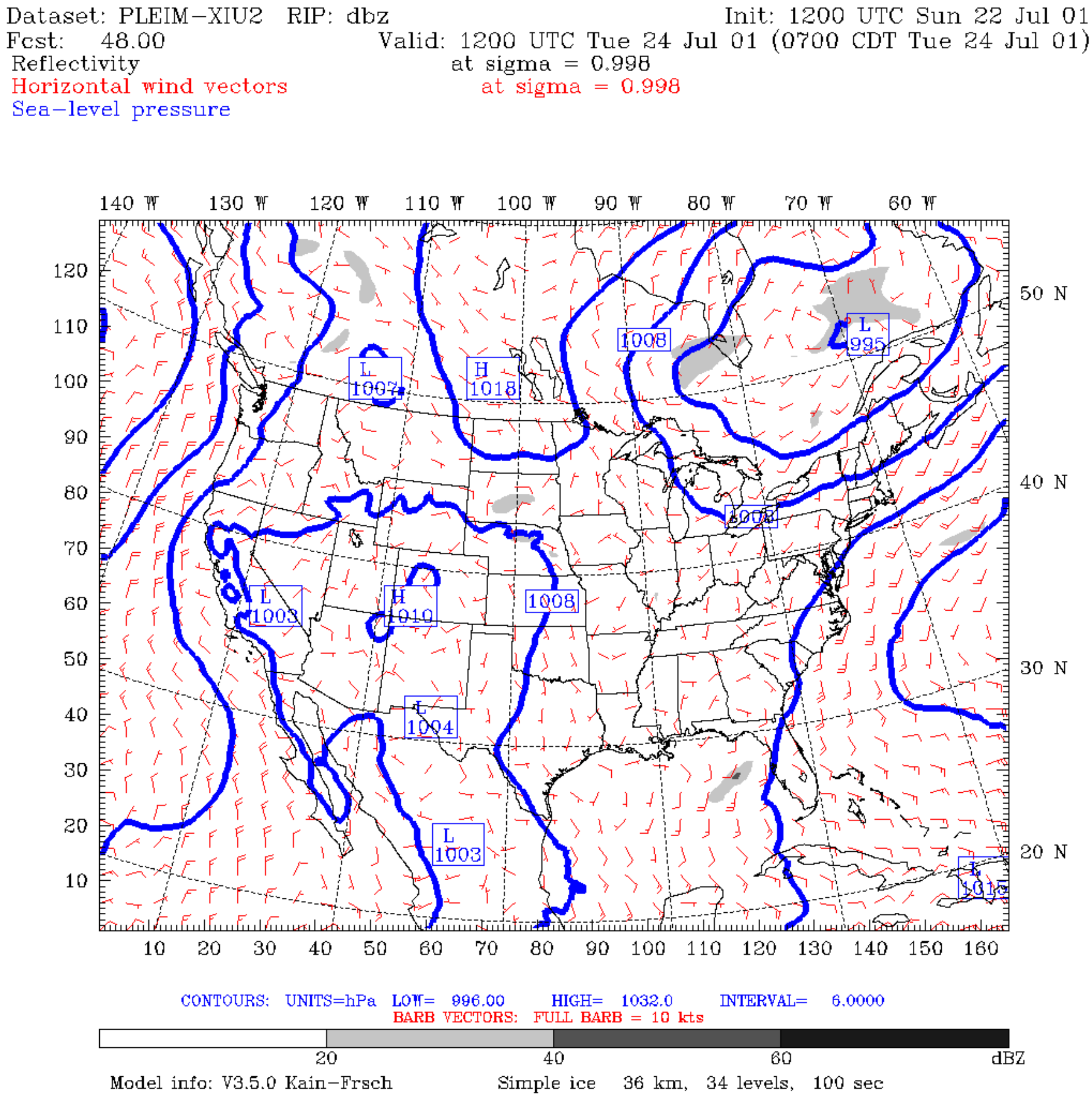


Figure 2-23: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 24 July 2001.

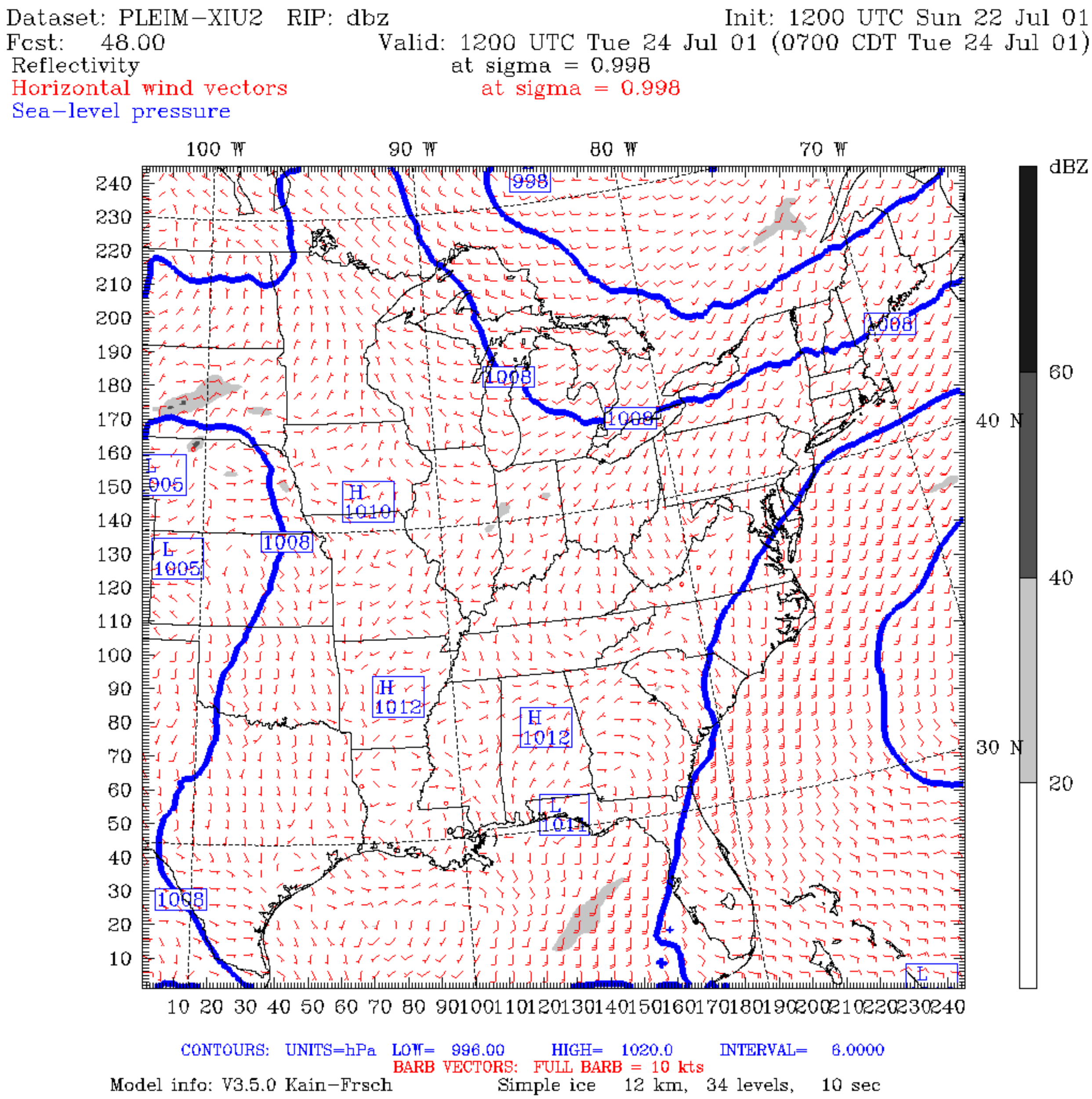


Figure 2-24: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 24 July 2001.

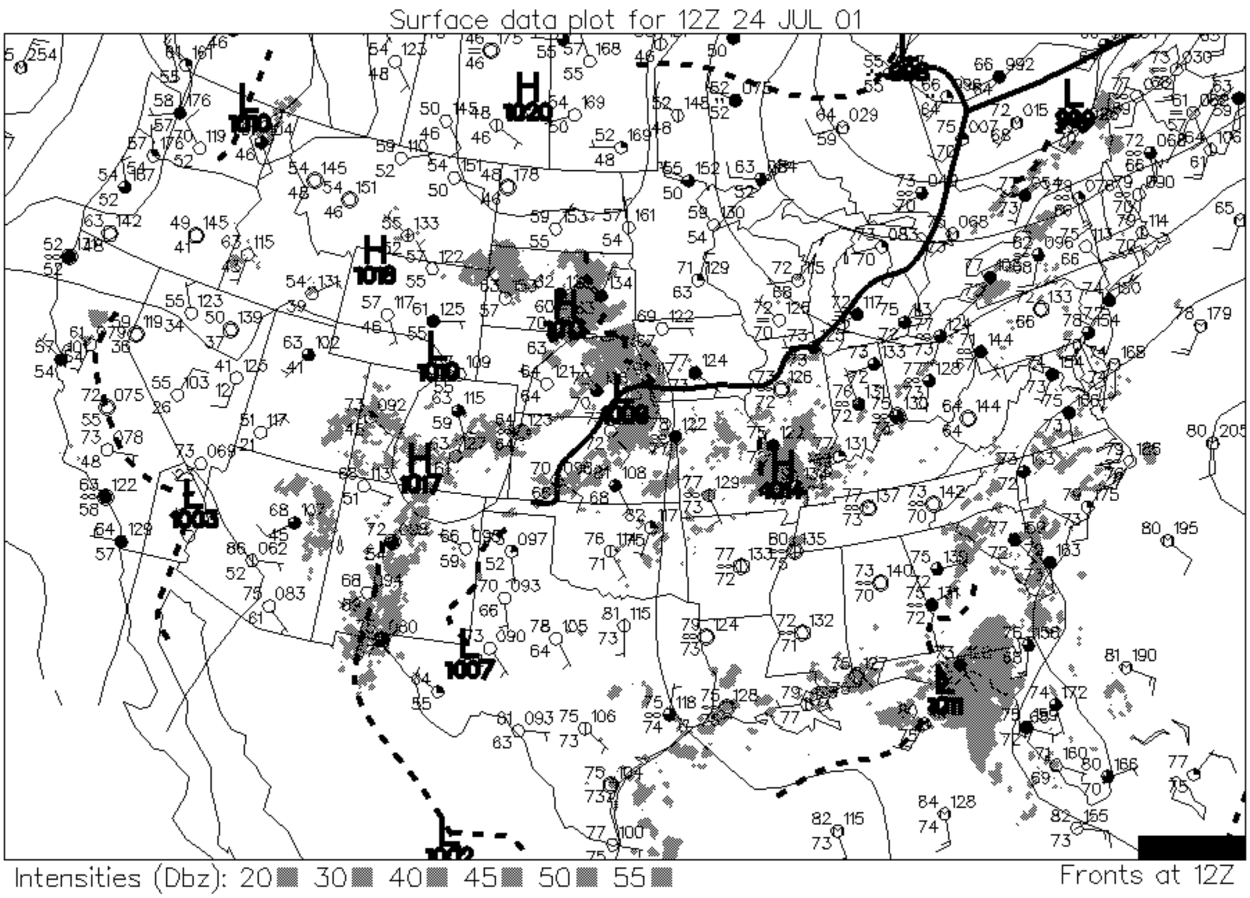


Figure 2-25: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 26 July 2001.

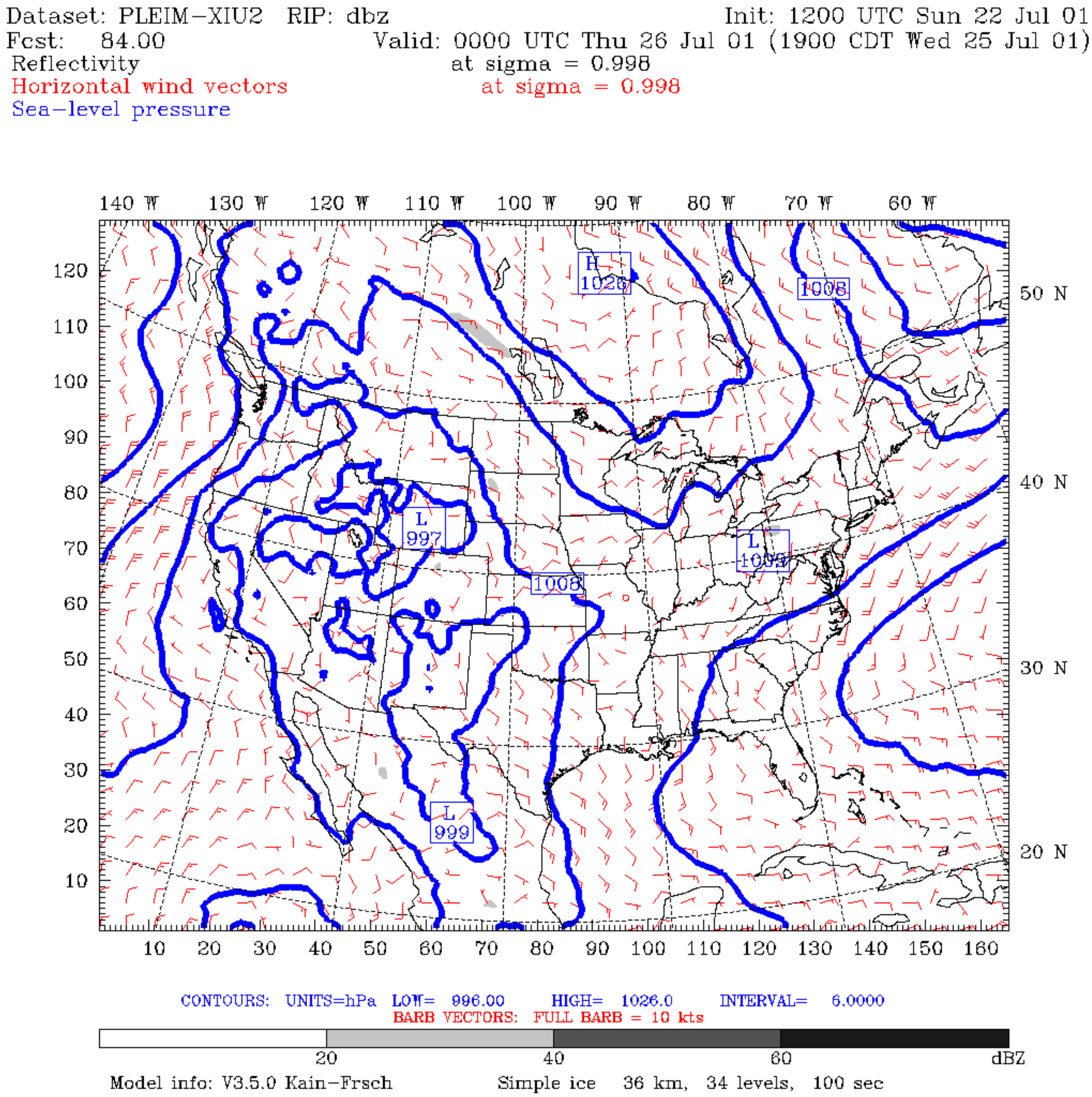


Figure 2-26: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 26 July 2001.

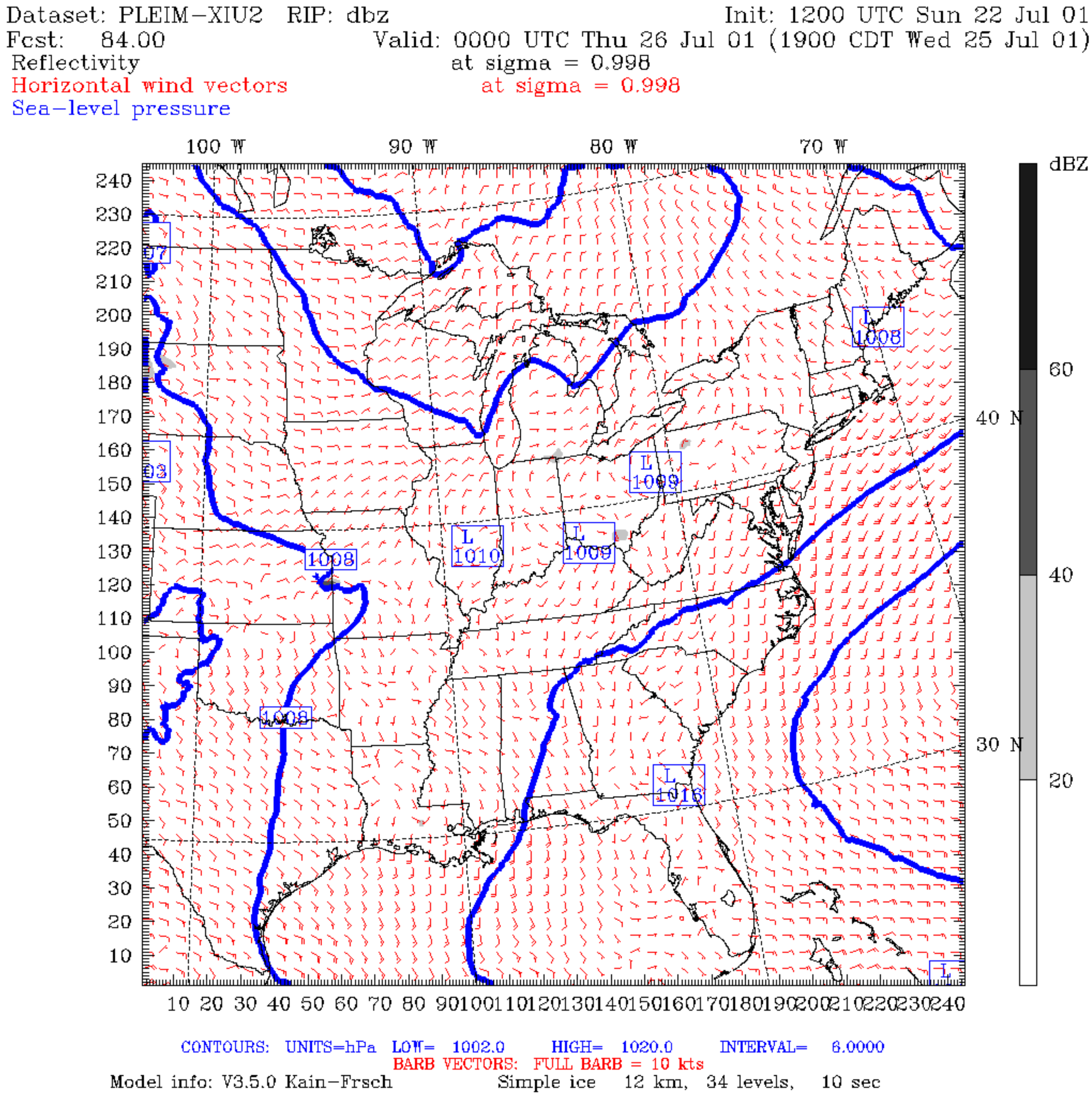


Figure 2-27: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 26 July 2001.

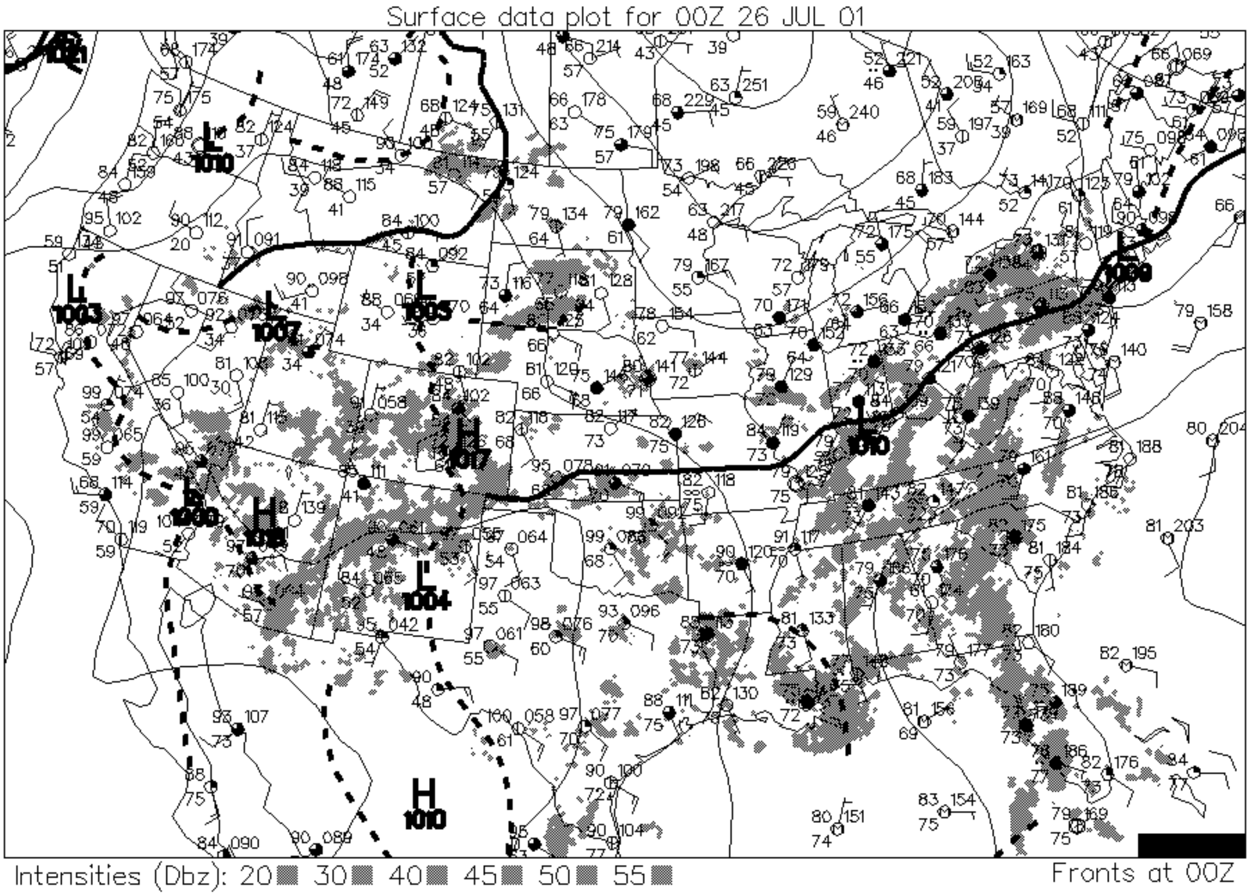


Figure 2-28: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 27 July 2001.

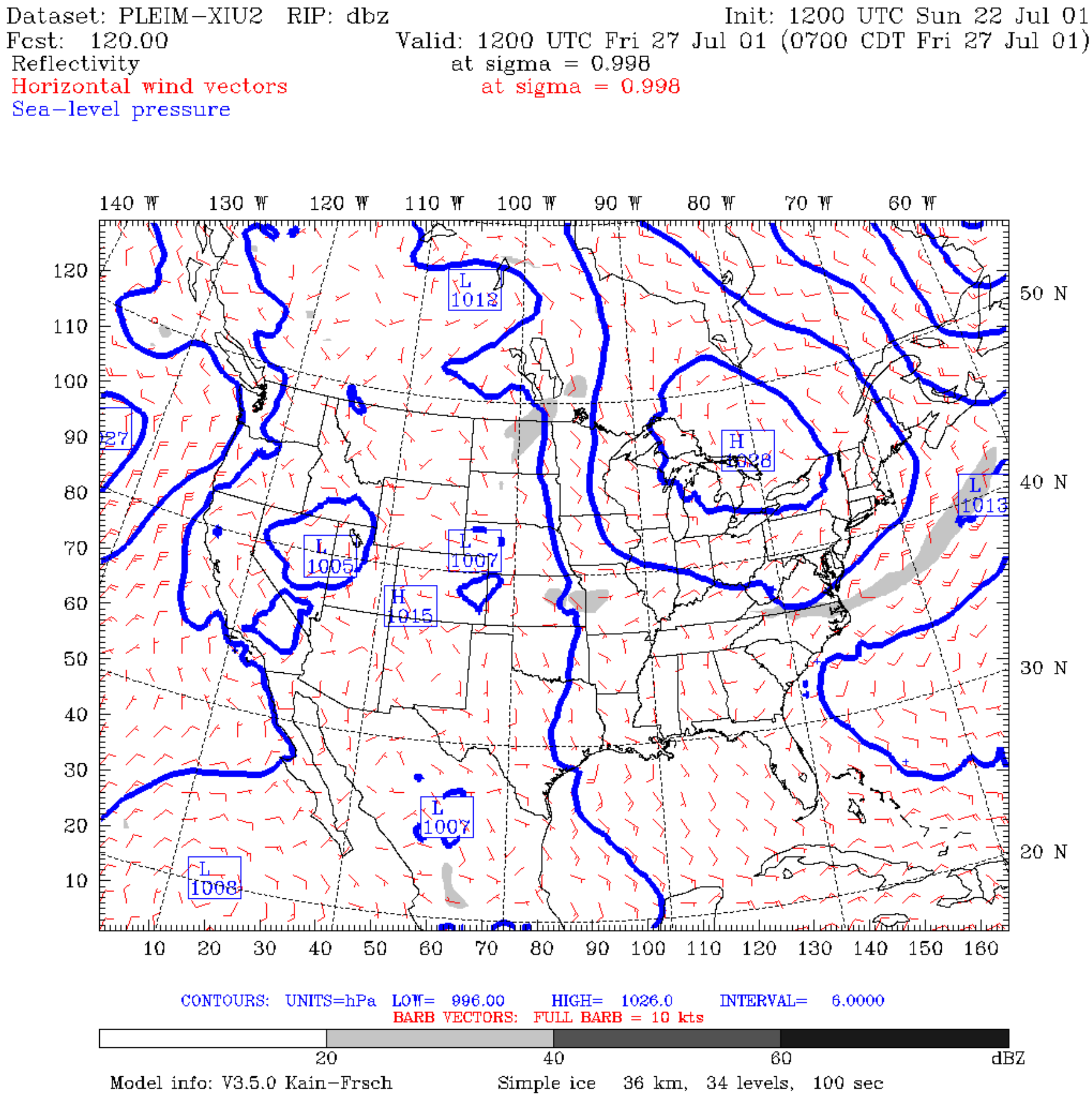


Figure 2-29: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 27 July 2001.

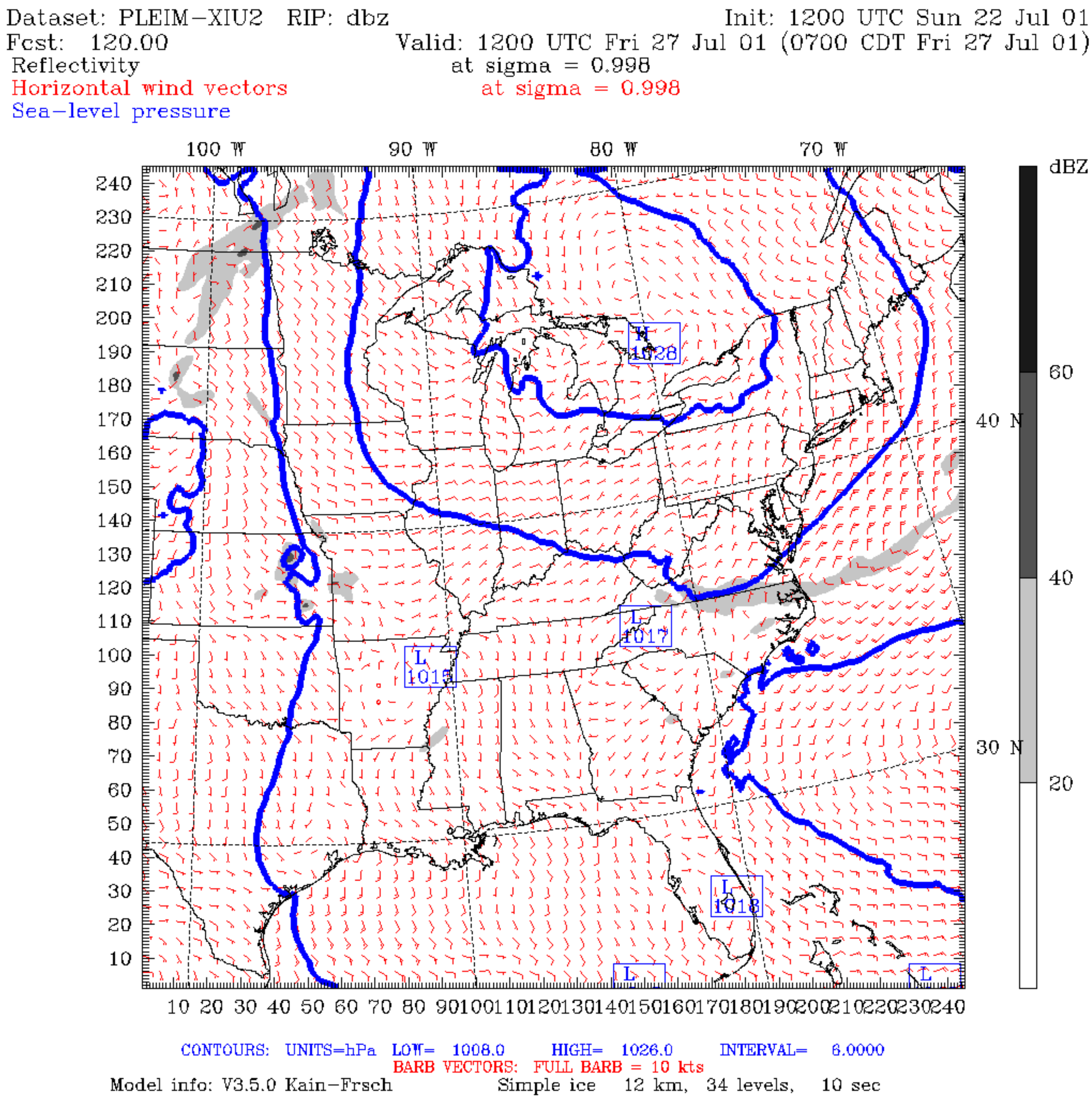


Figure 2-30: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 27 July 2001.

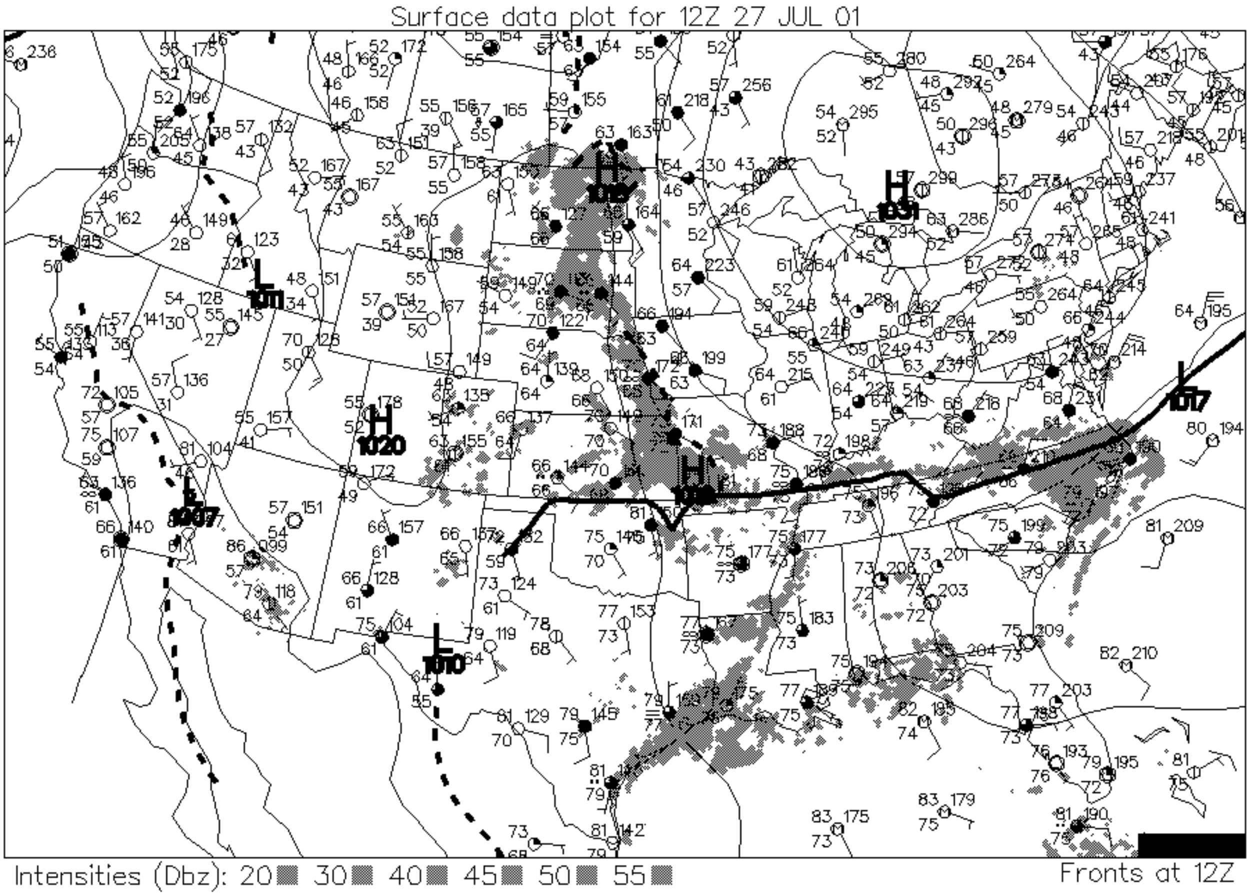


Figure 2-31: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 29 July 2001.

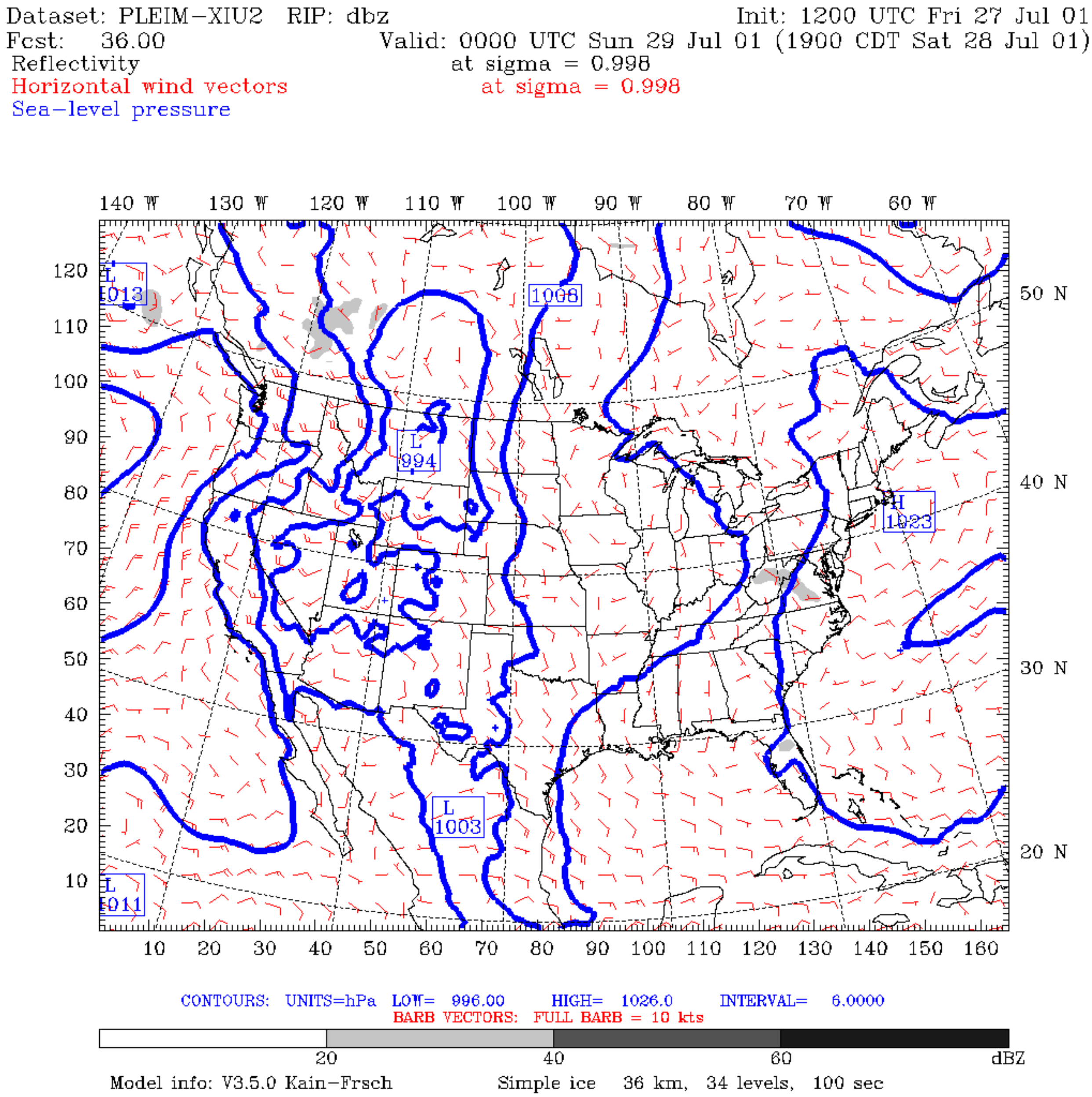


Figure 2-32: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 29 July 2001.

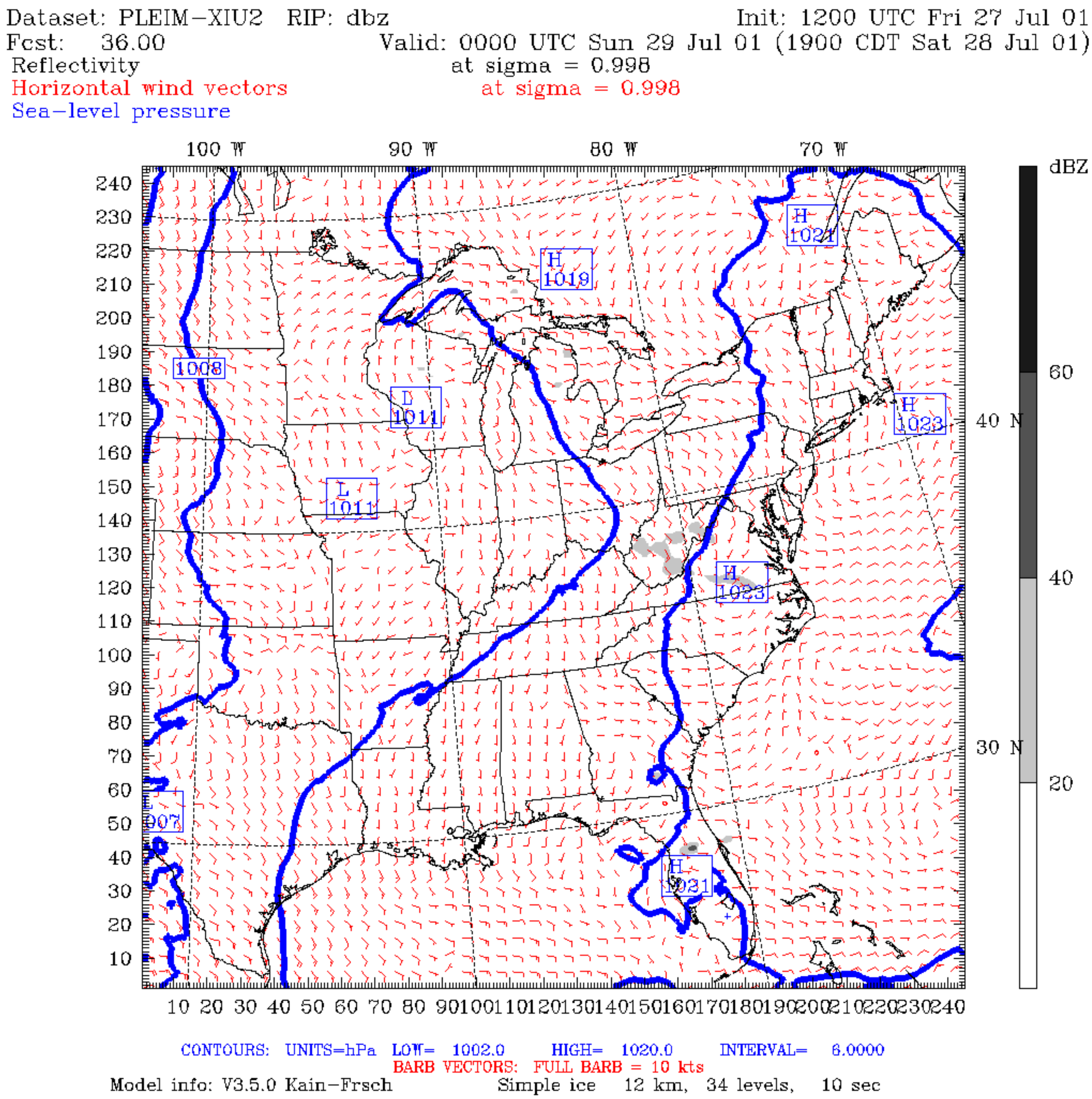


Figure 2-33: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 29 July 2001.

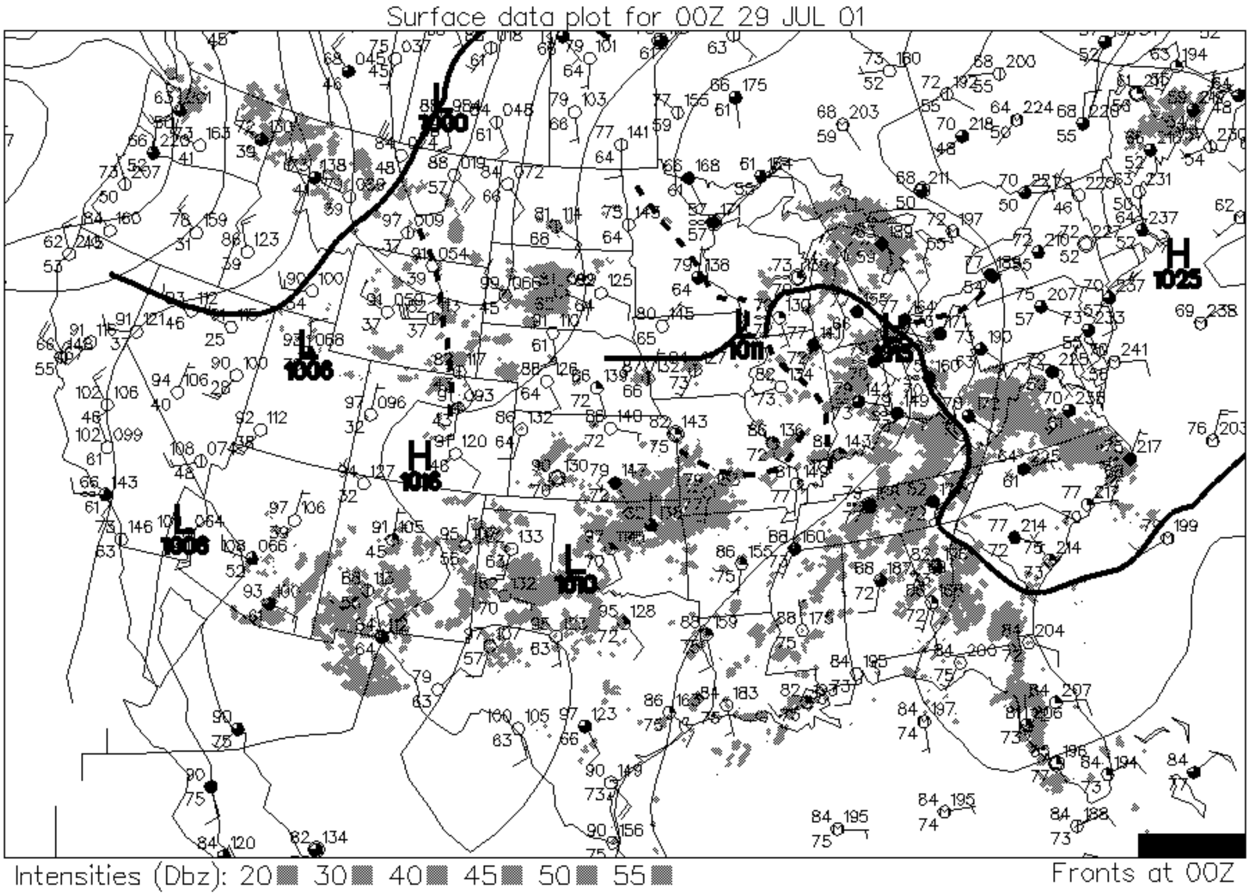


Figure 2-34: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 30 July 2001.

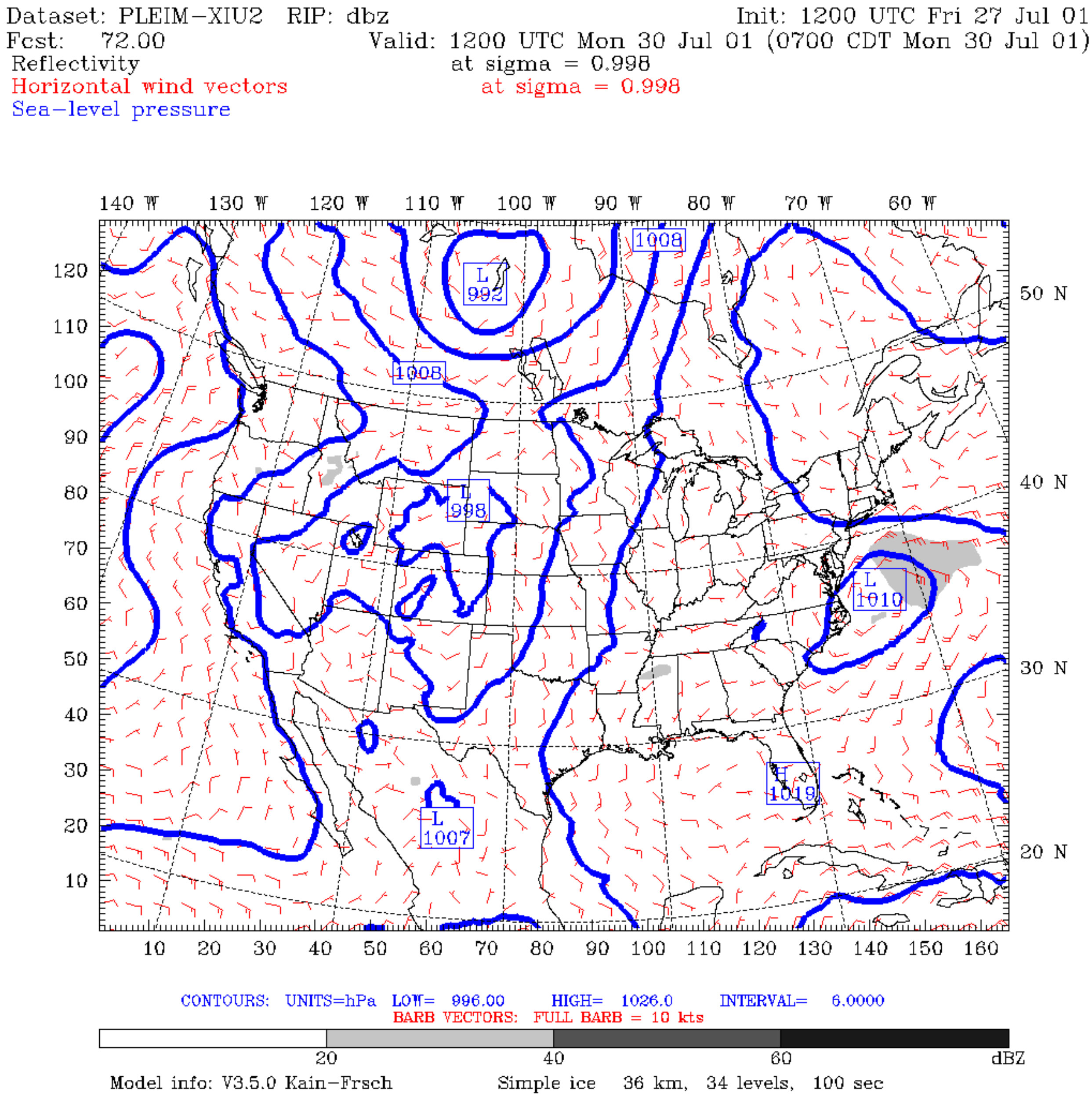


Figure 2-35: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 30 July 2001.

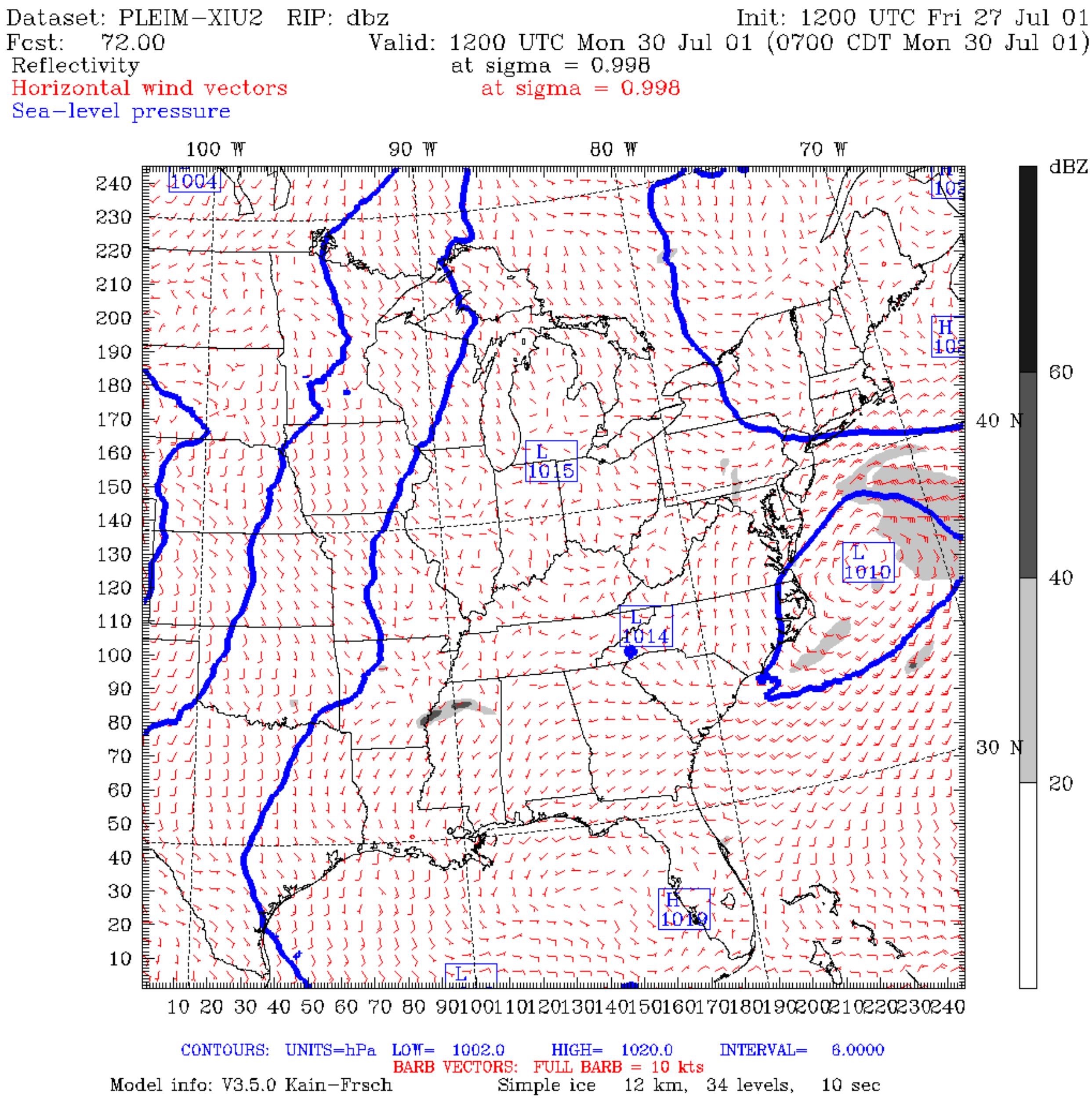


Figure 2-36: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 30 July 2001.

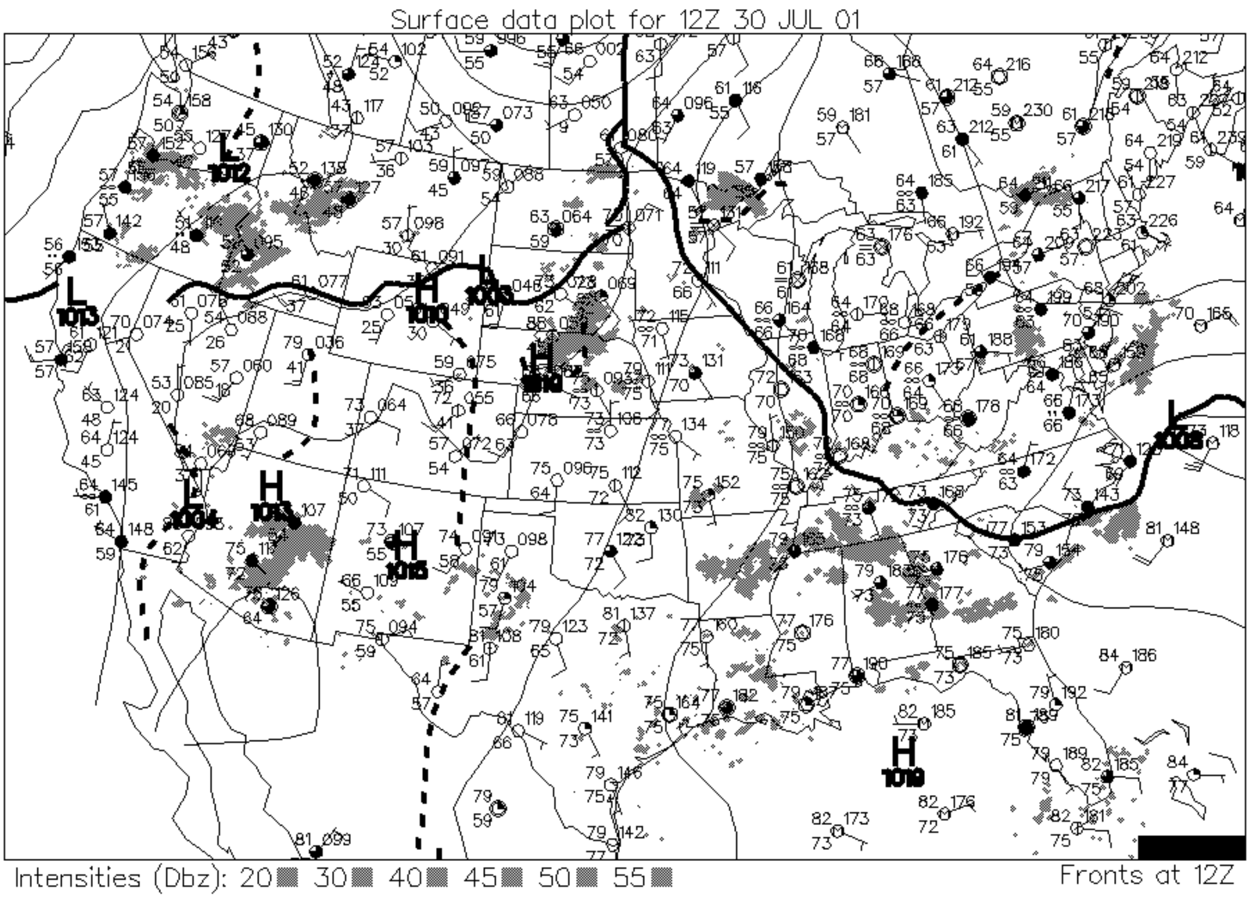


Figure 2-37: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 1 August 2001.

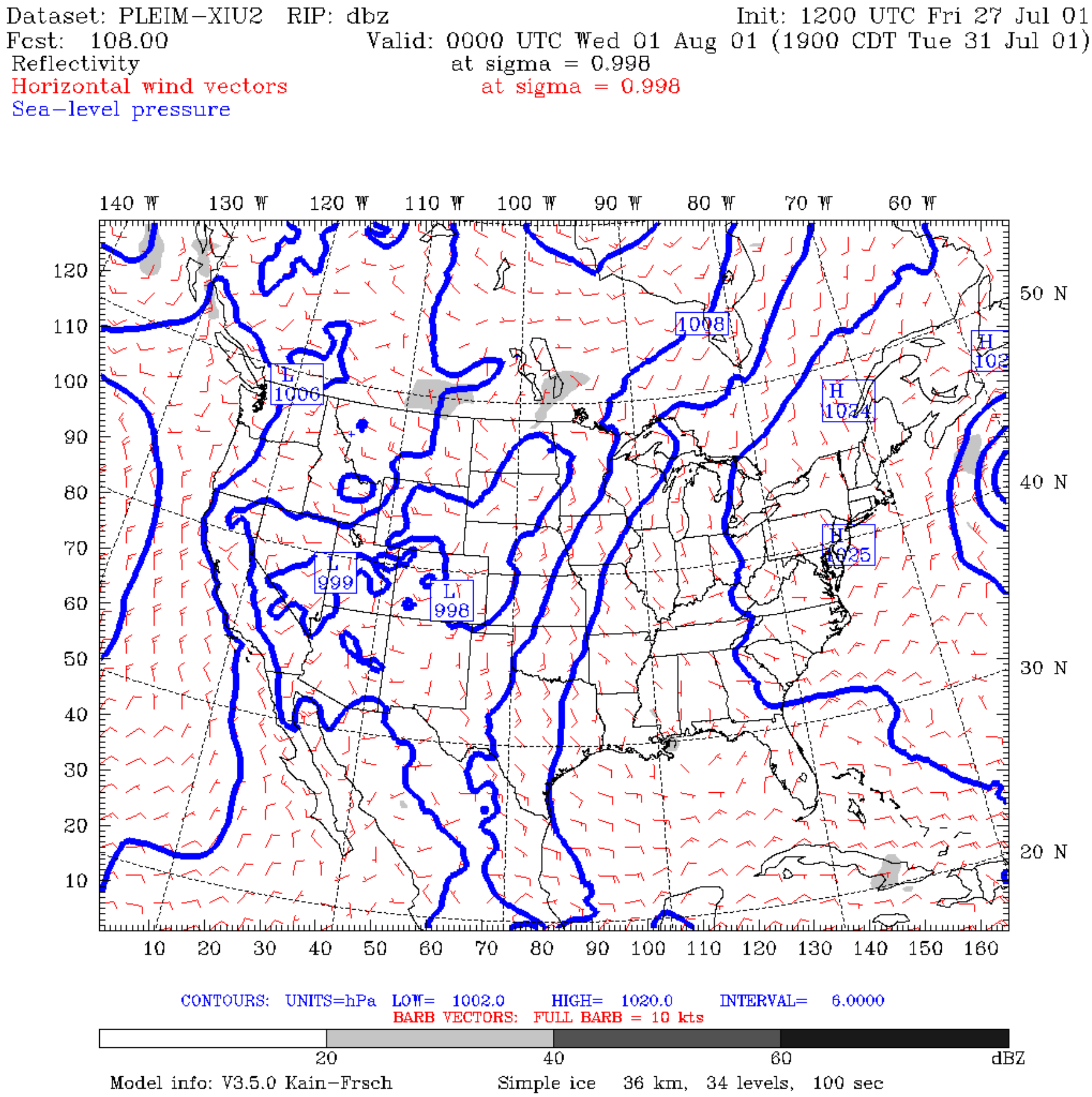


Figure 2-38: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 1 August 2001.

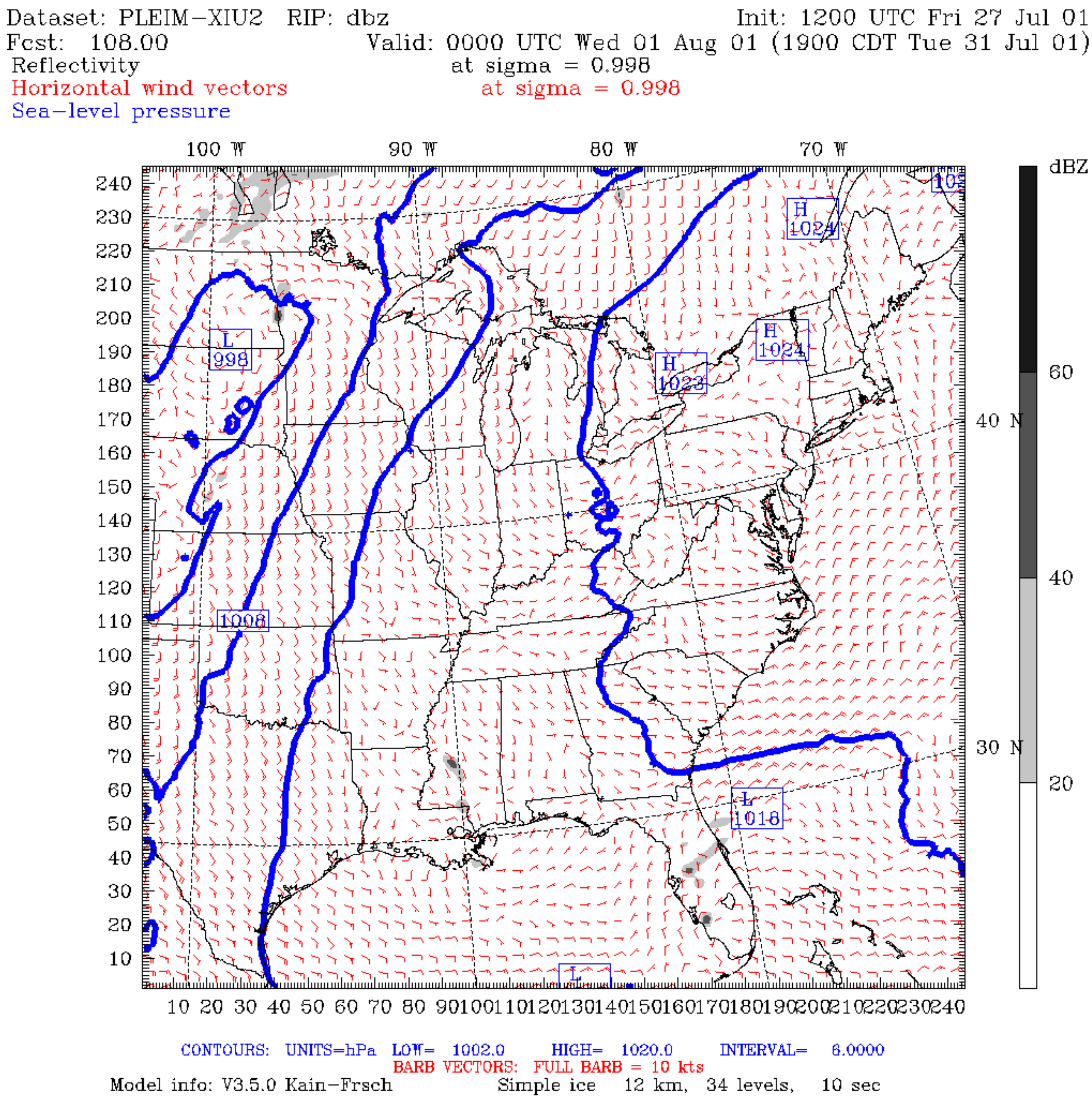


Figure 2-39: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 1 August 2001.

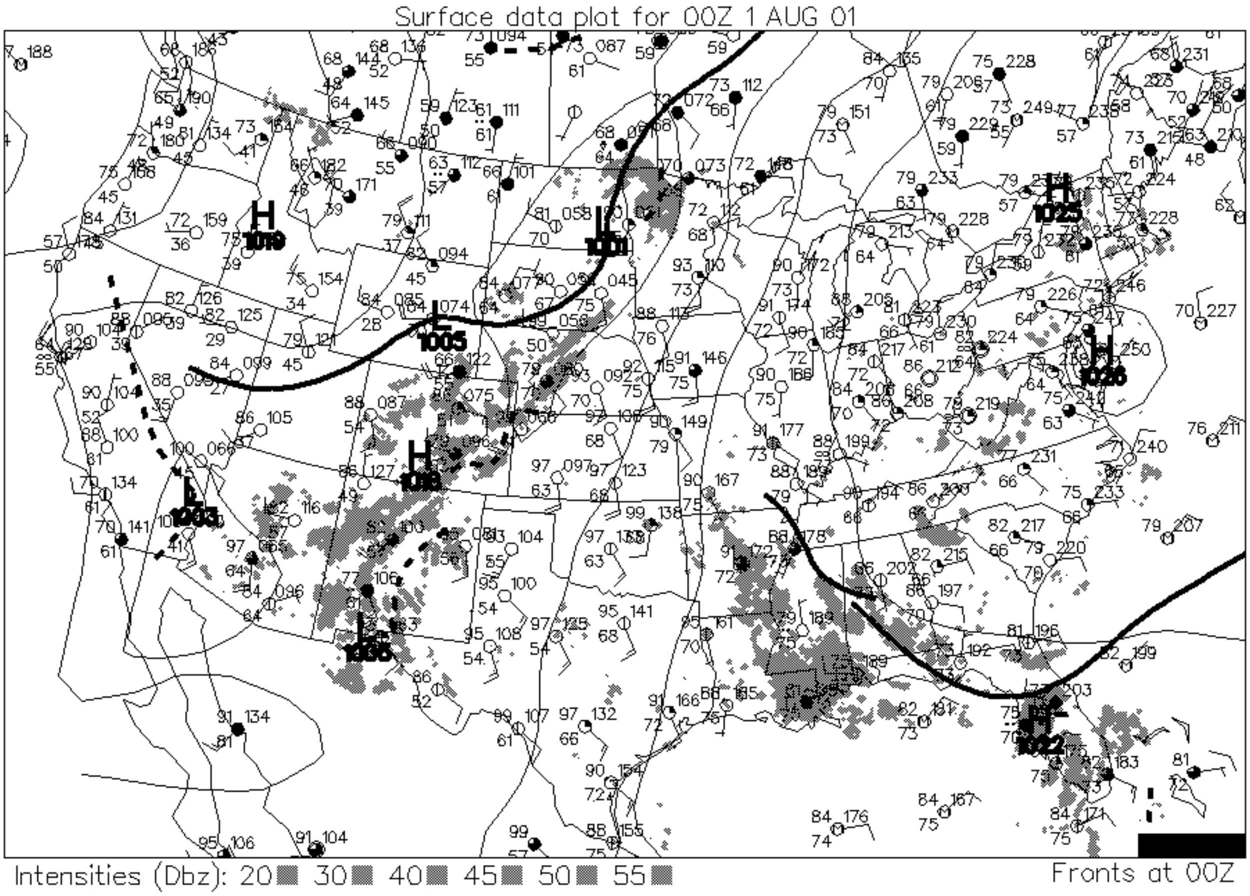


Figure 2-40: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 2 August 2001.

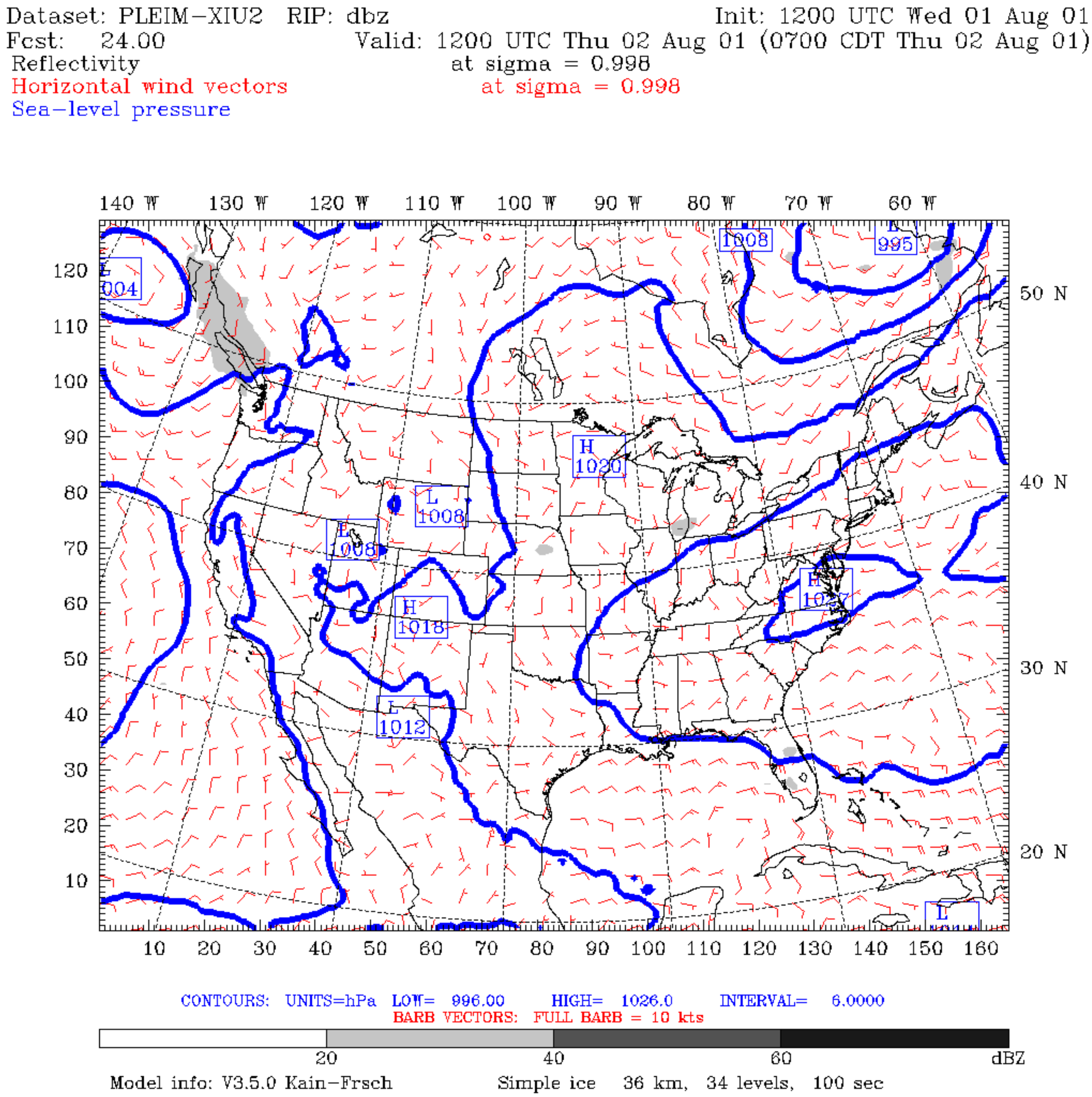


Figure 2-41: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 2 August 2001.

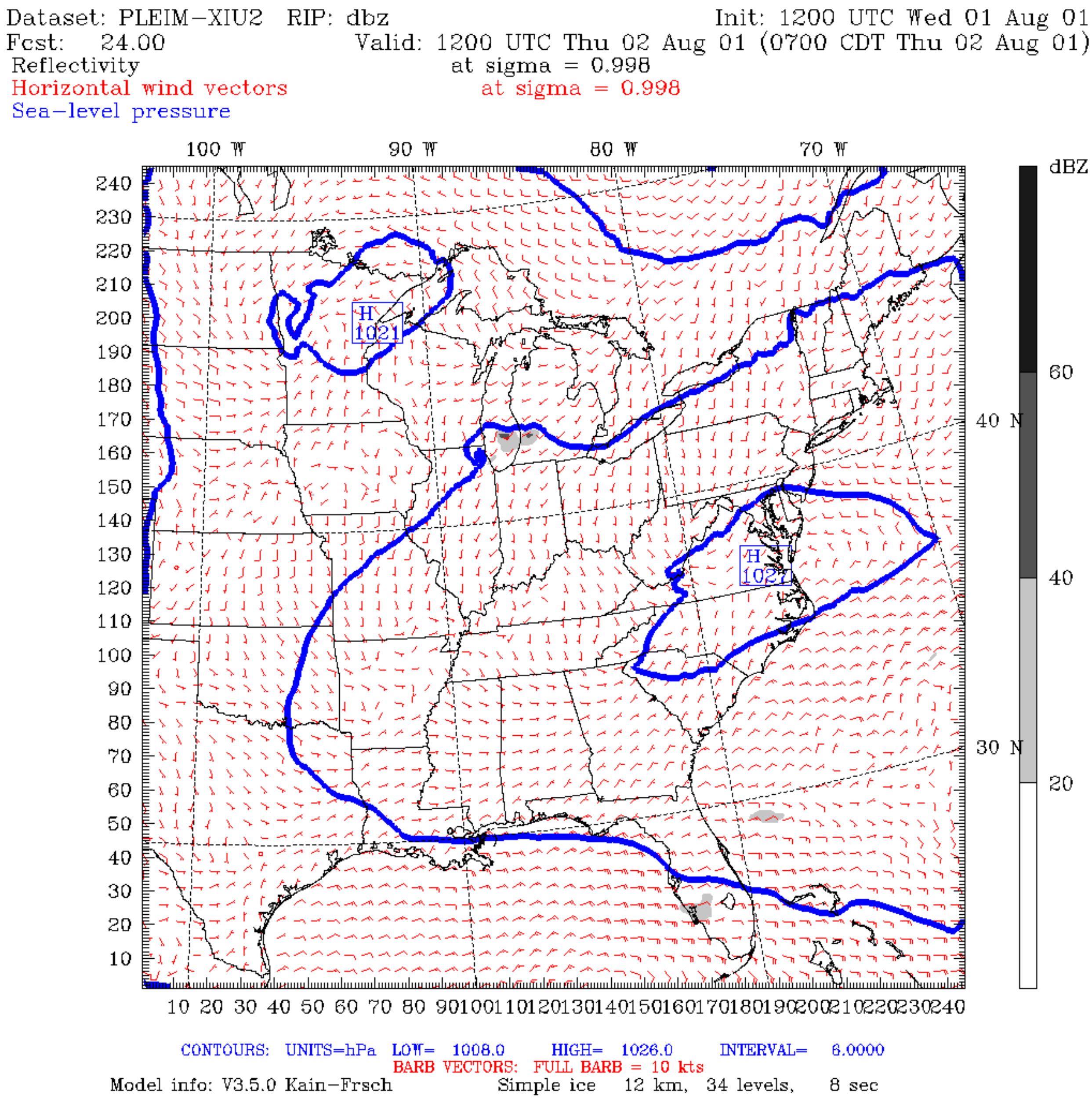


Figure 2-42: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 2 August 2001.

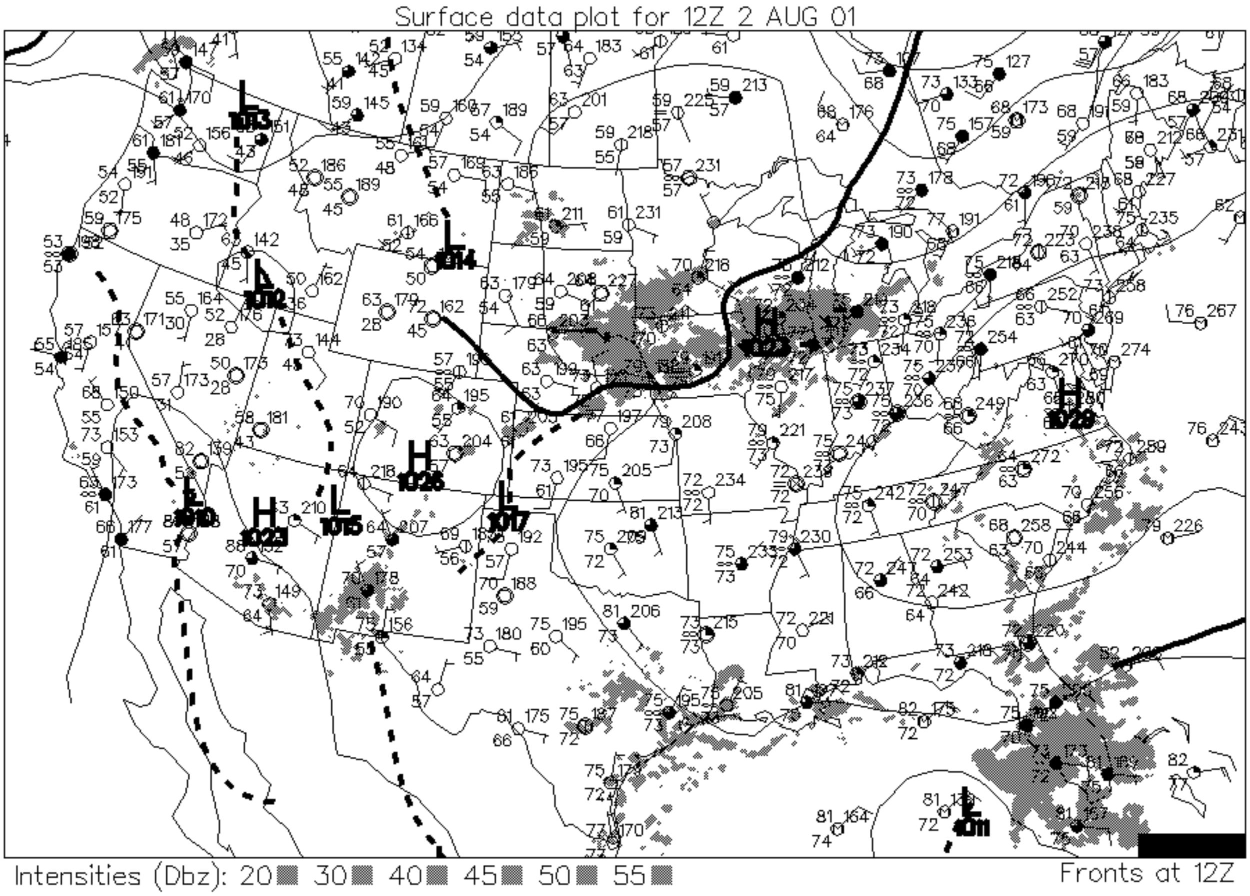


Figure 2-43: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 4 August 2001.

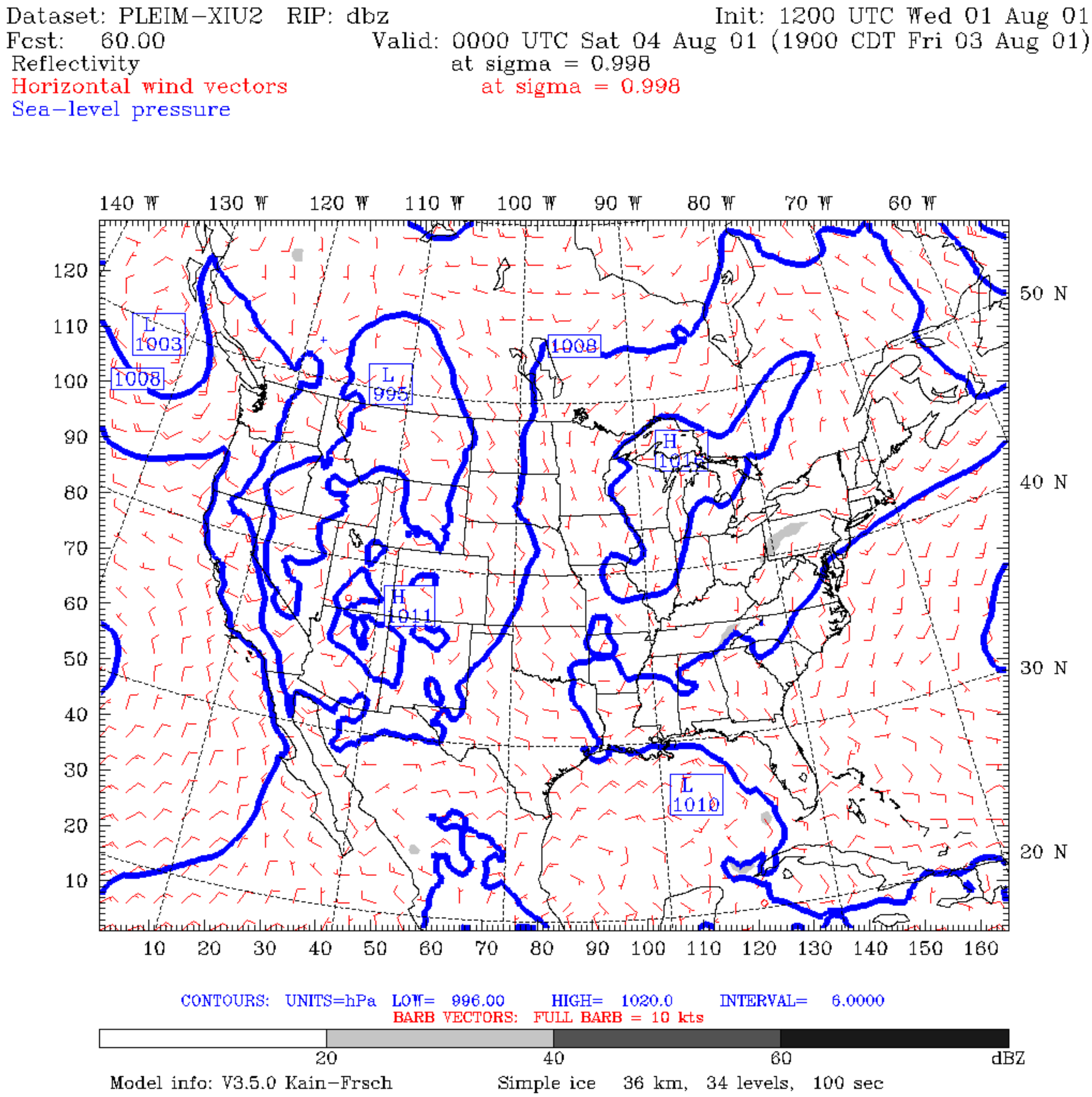


Figure 2-44: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 4 August 2001.

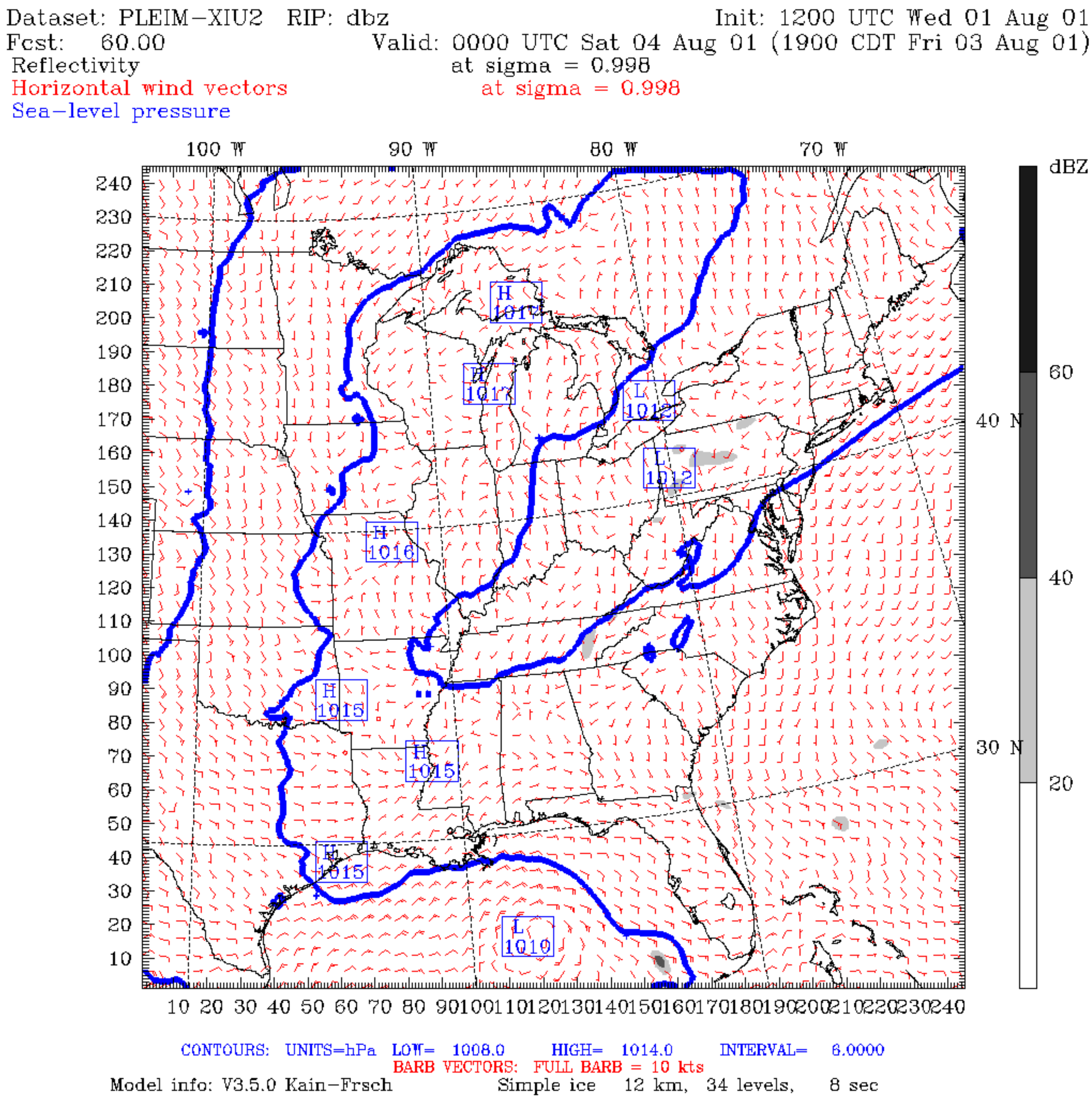


Figure 2-45: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 4 August 2001.

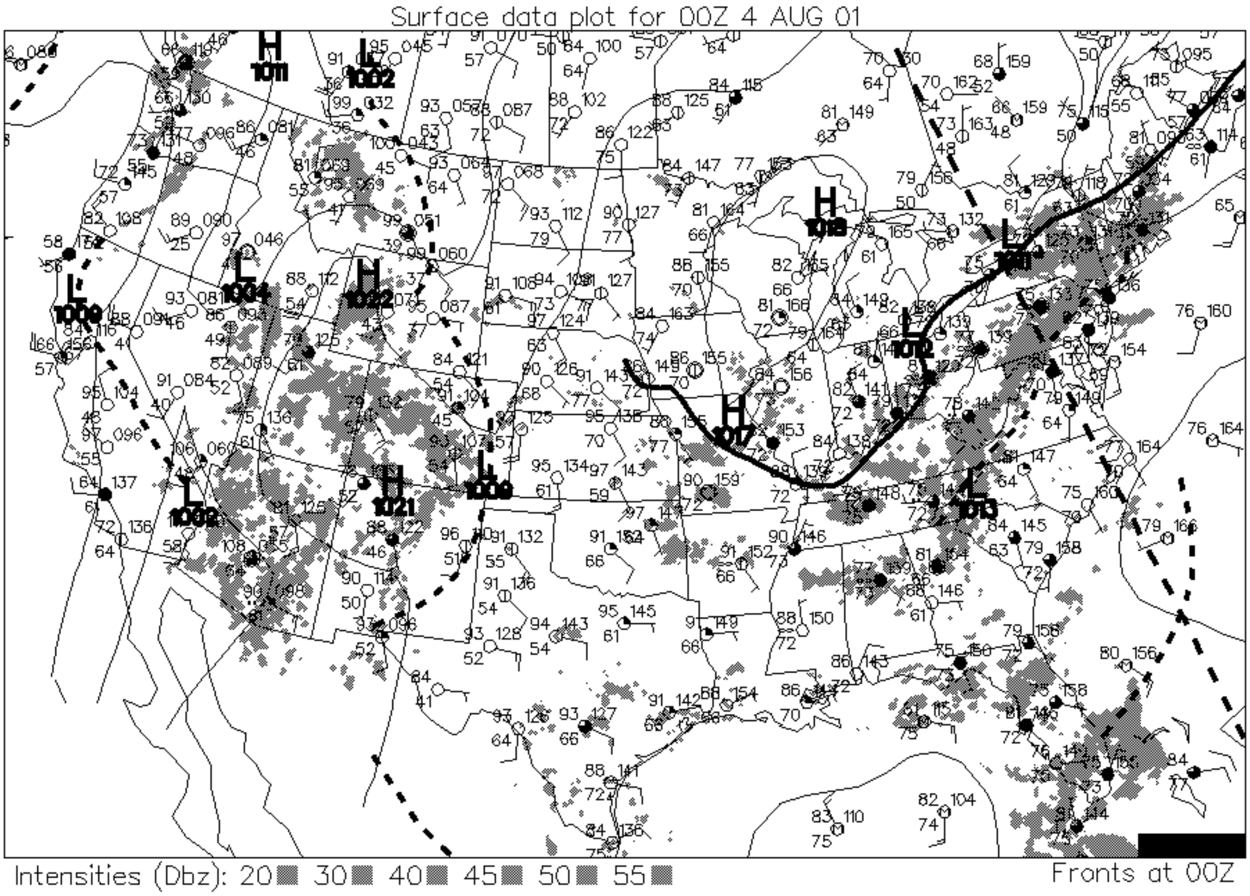


Figure 2-46: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 5 August 2001.

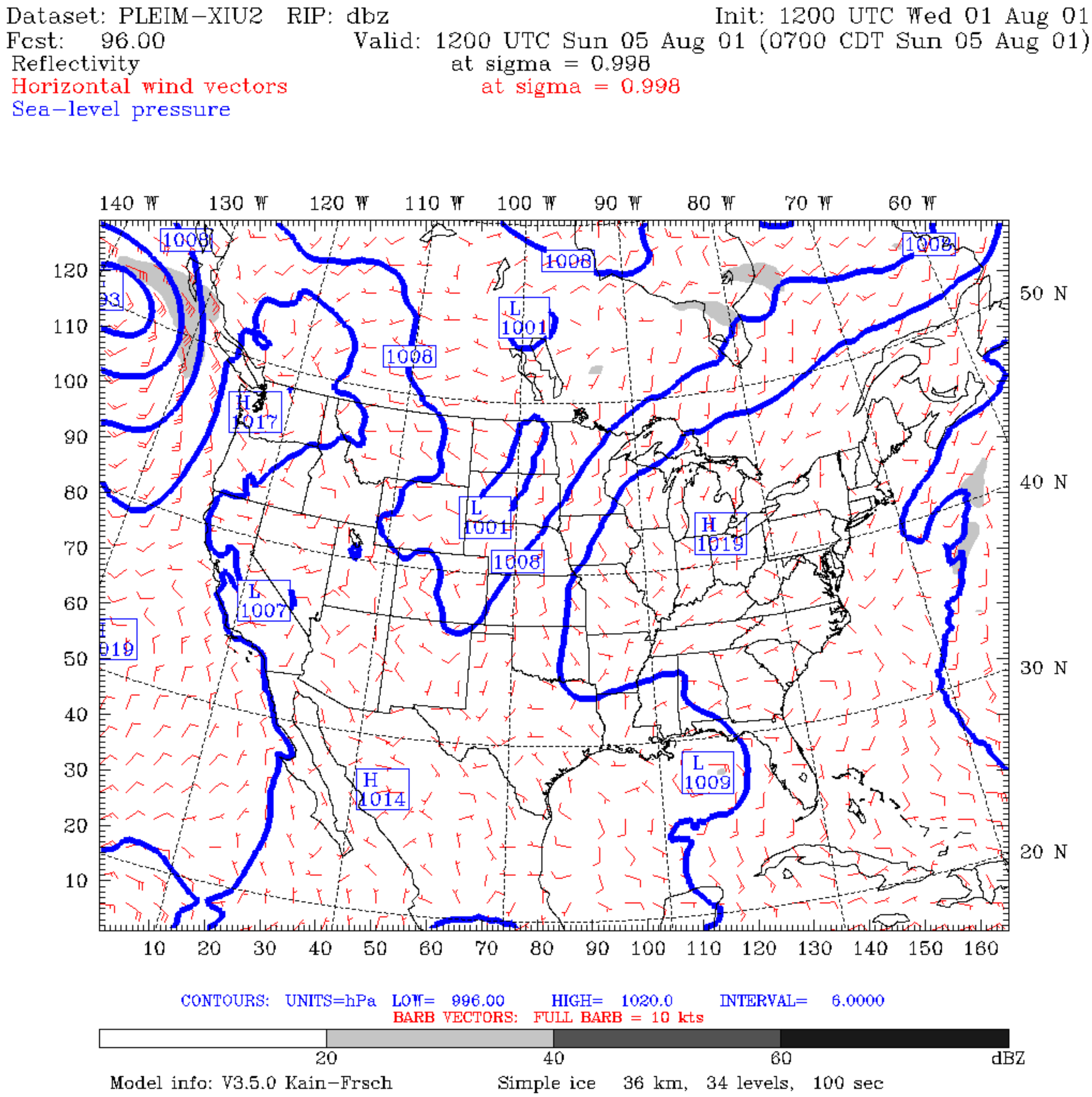


Figure 2-47: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 5 August 2001.

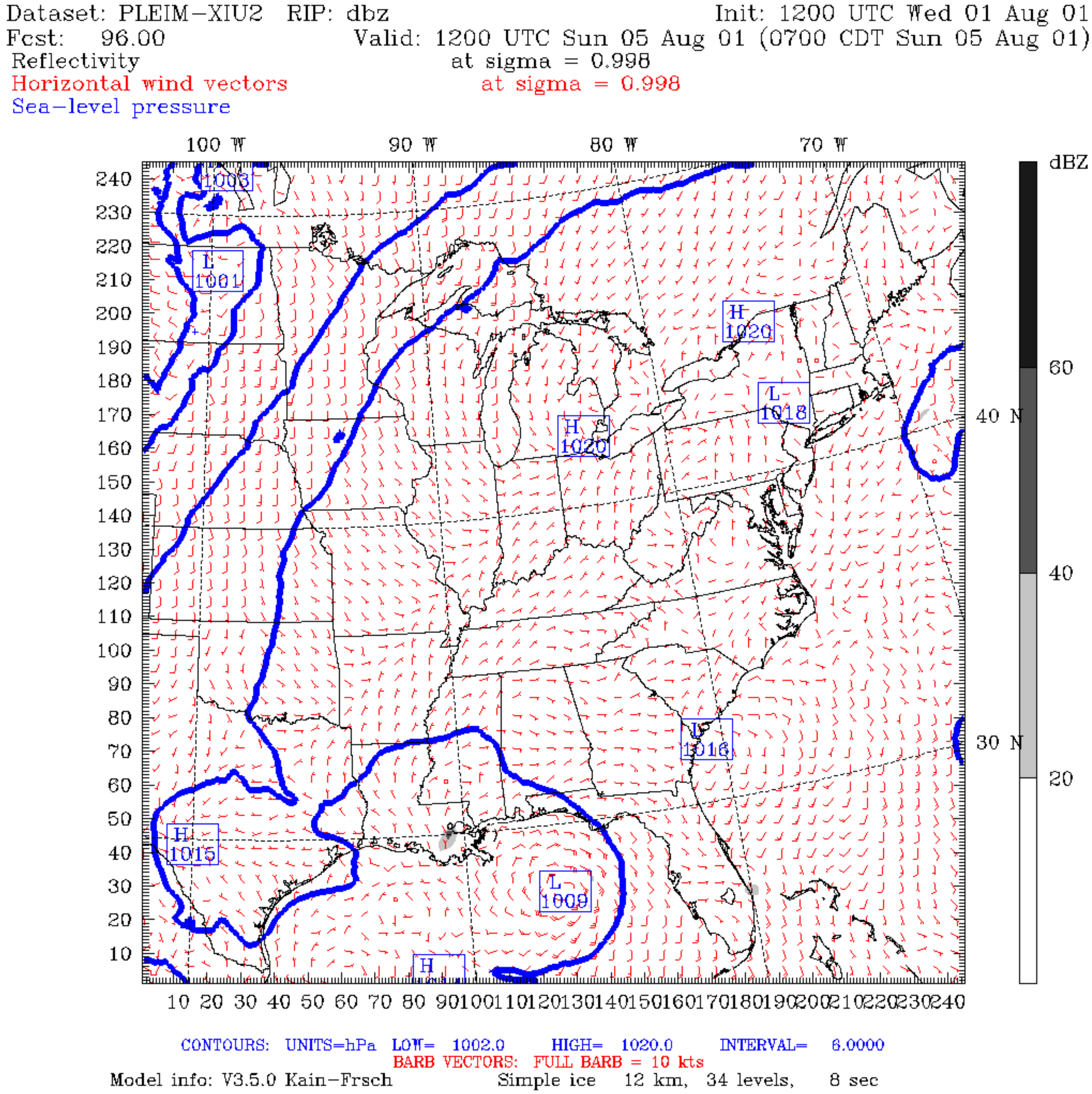


Figure 2-48: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 5 August 2001.

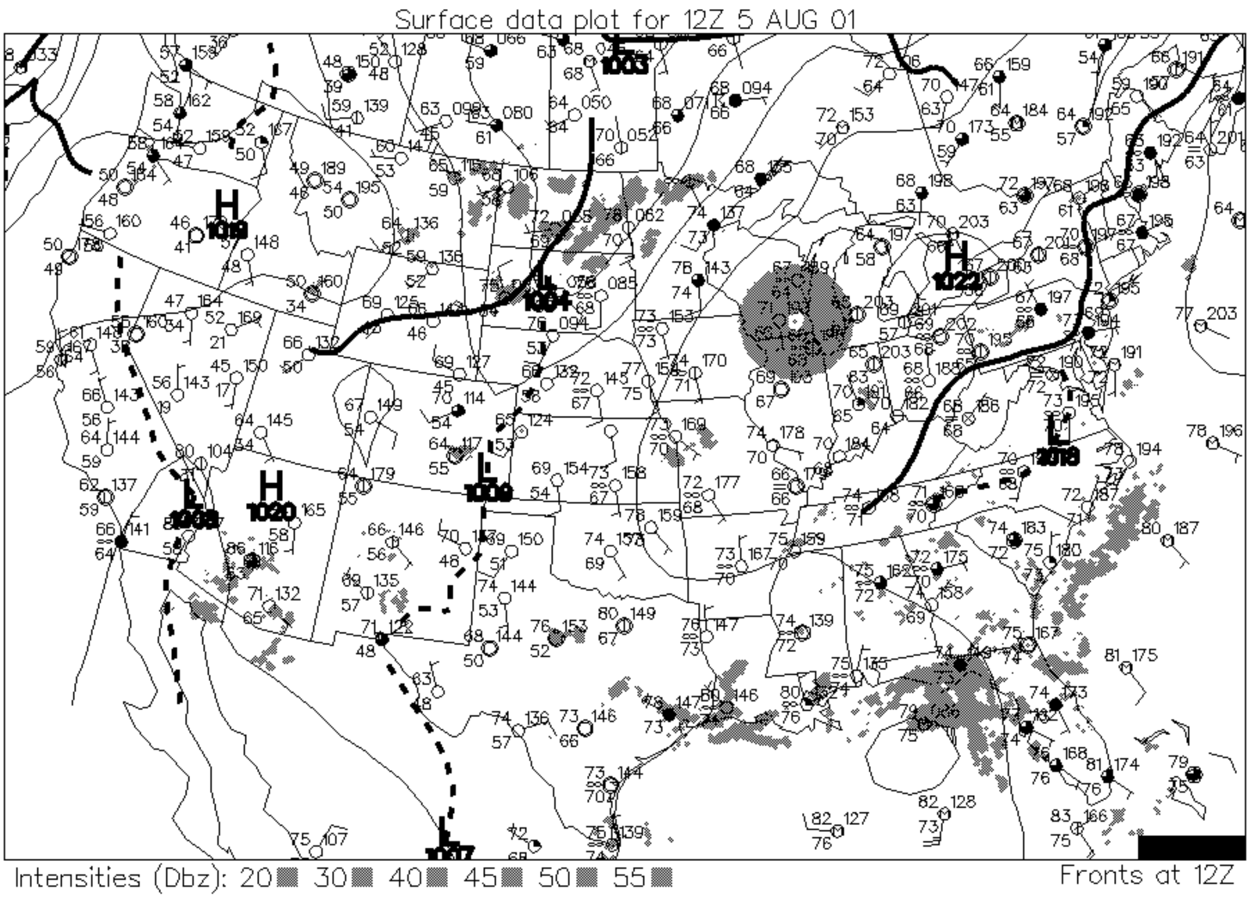


Figure 2-49: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 7 August 2001.

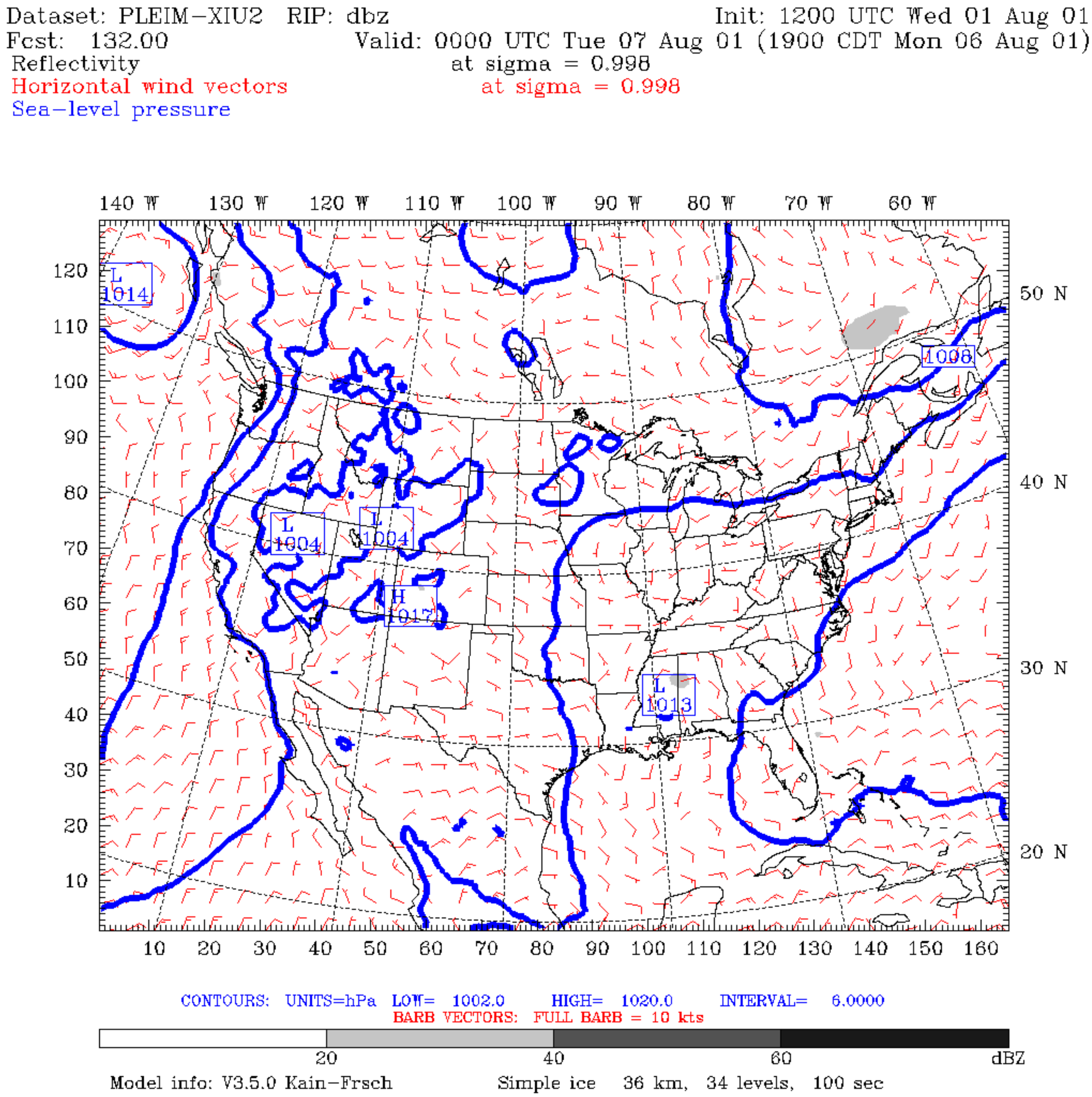


Figure 2-50: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 7 August 2001.

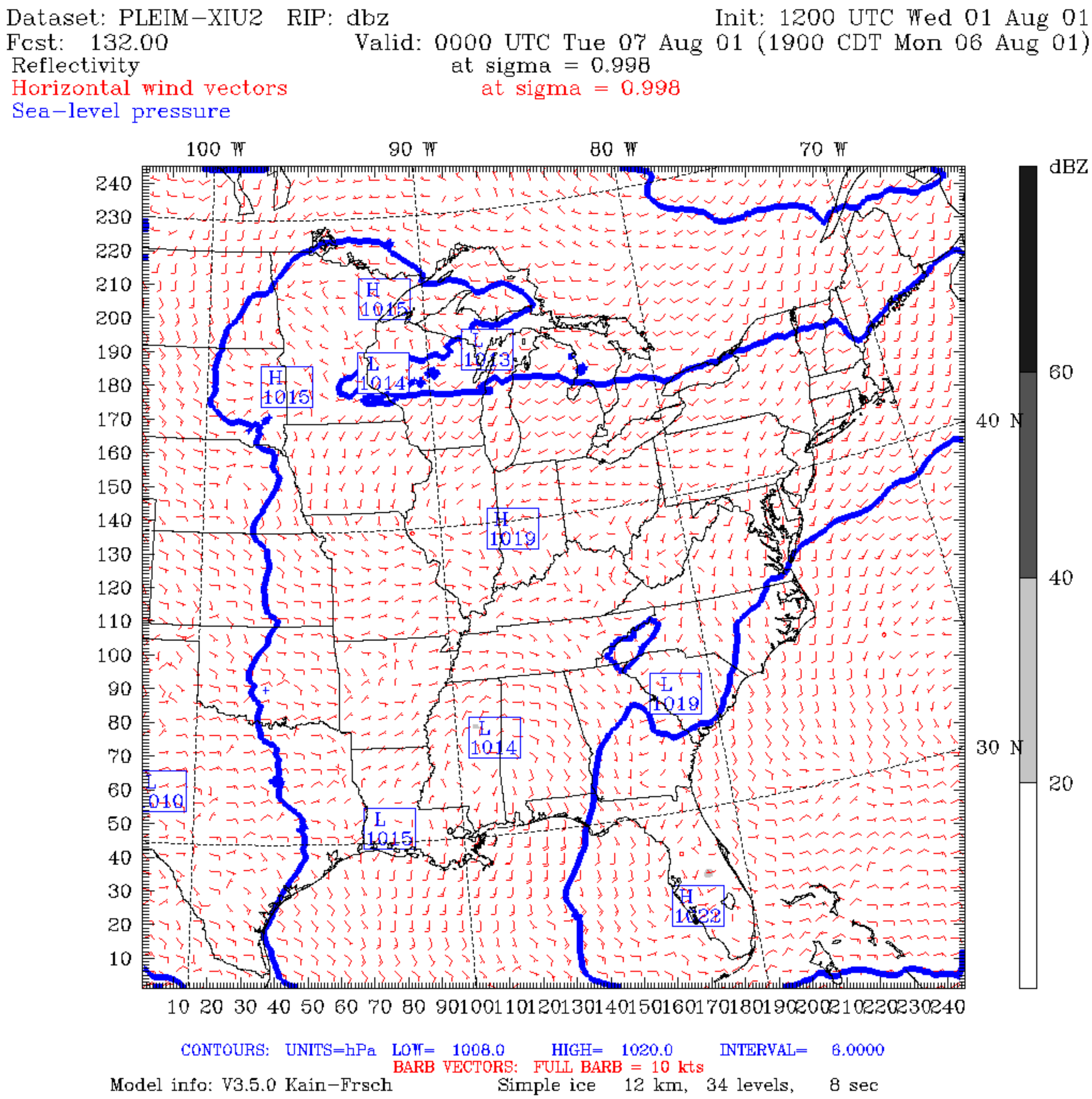


Figure 2-51: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 7 August 2001.

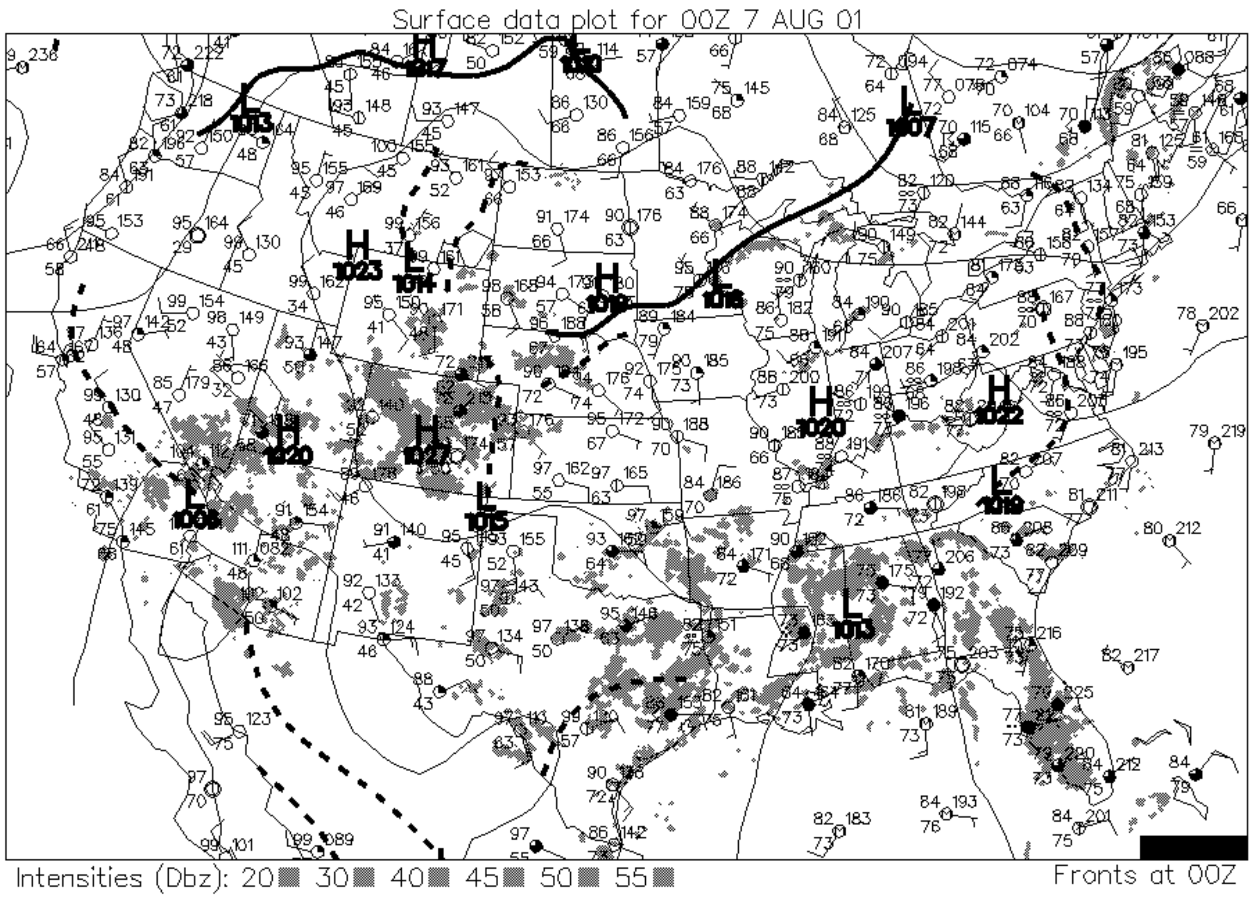


Figure 2-52: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 8 August 2001.

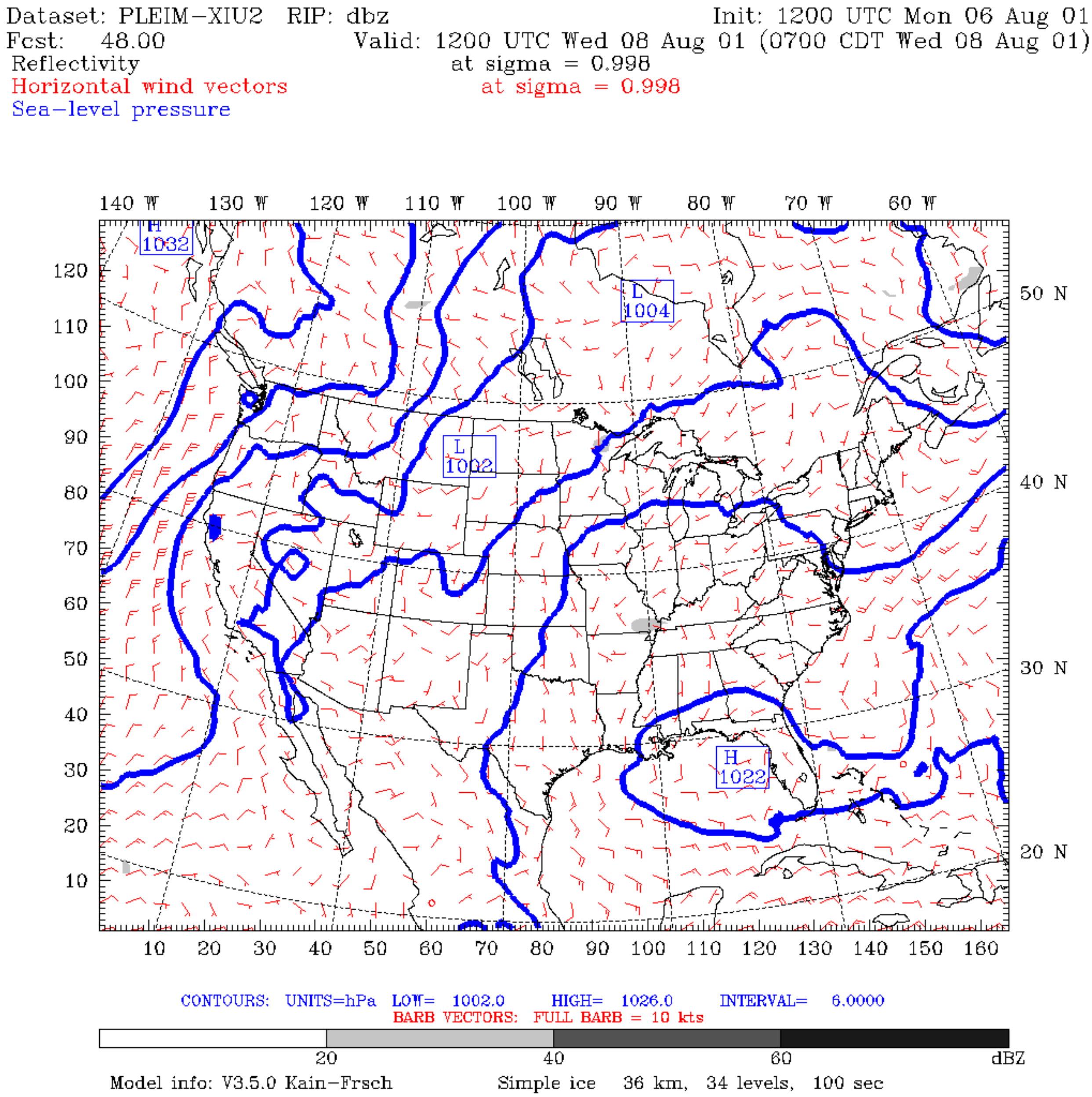


Figure 2-53: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 8 August 2001.

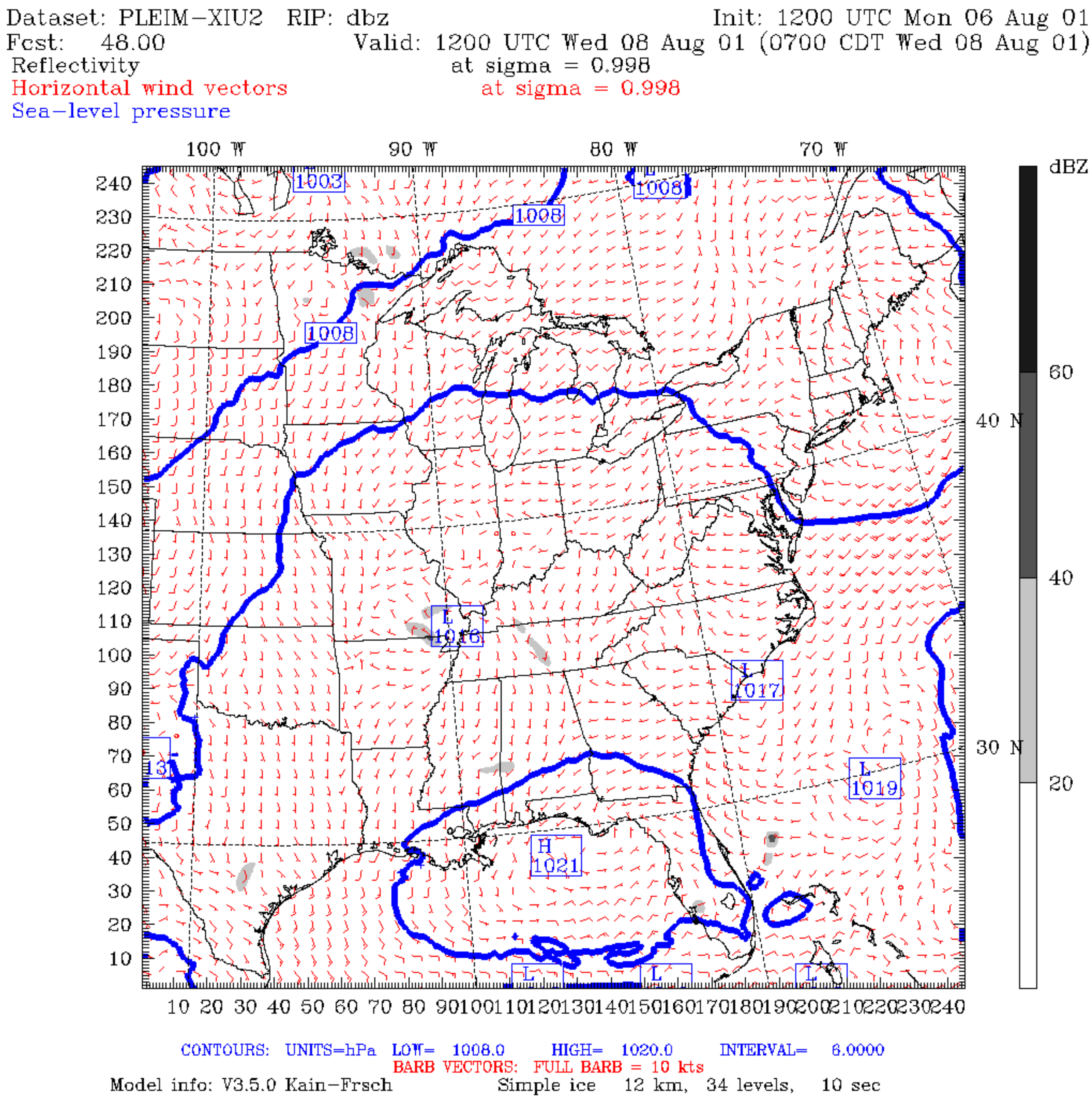


Figure 2-54: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 8 August 2001.

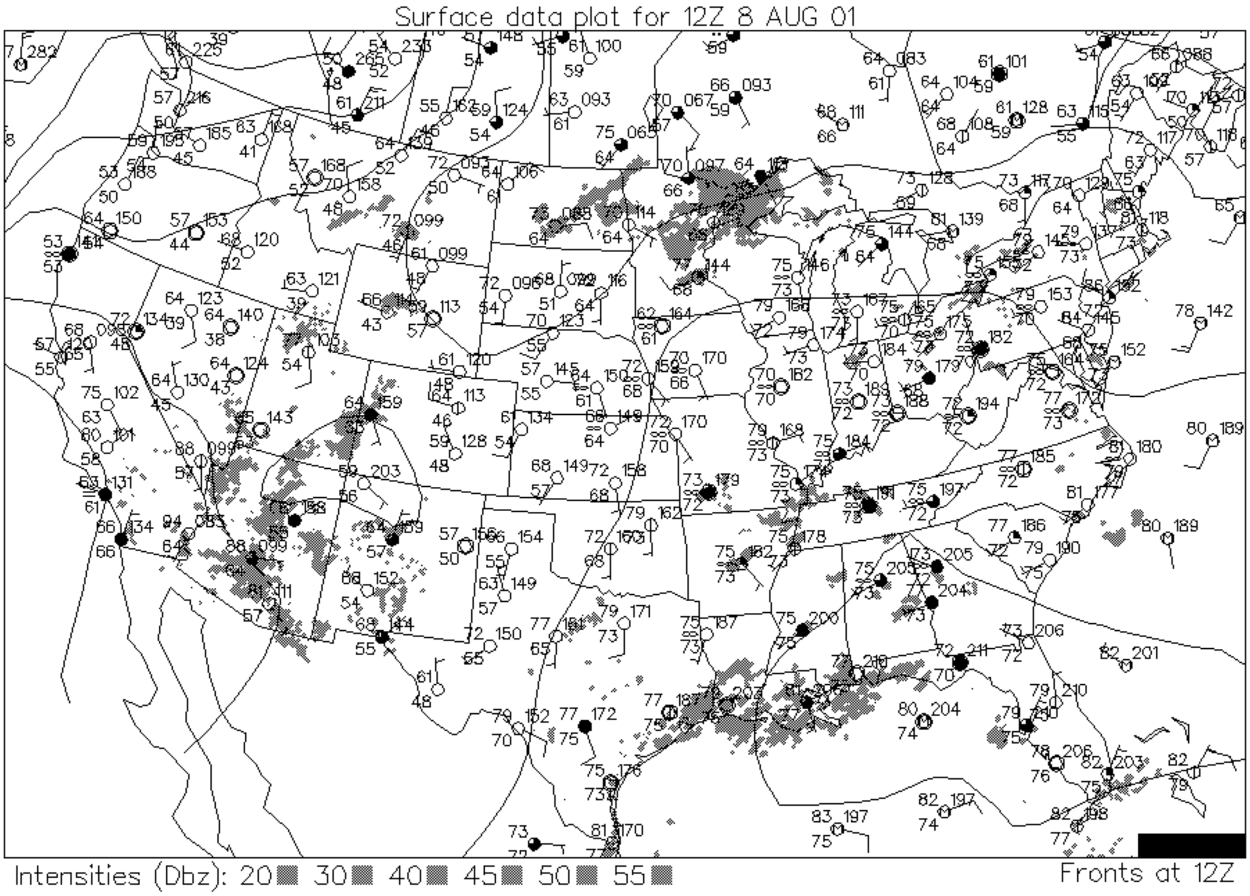


Figure 2-55: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 10 August 2001.

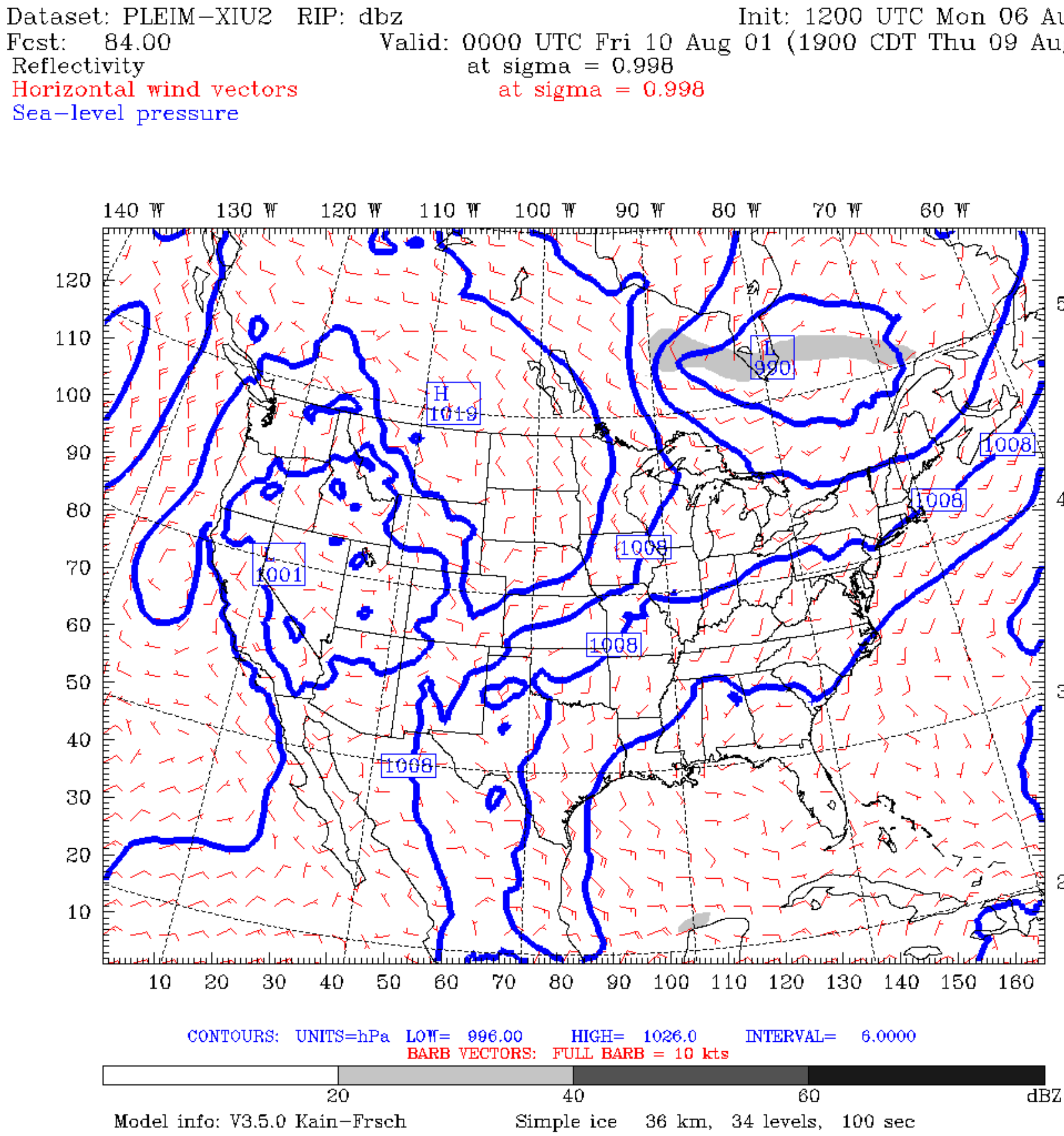


Figure 2-56: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 10 August 2001.

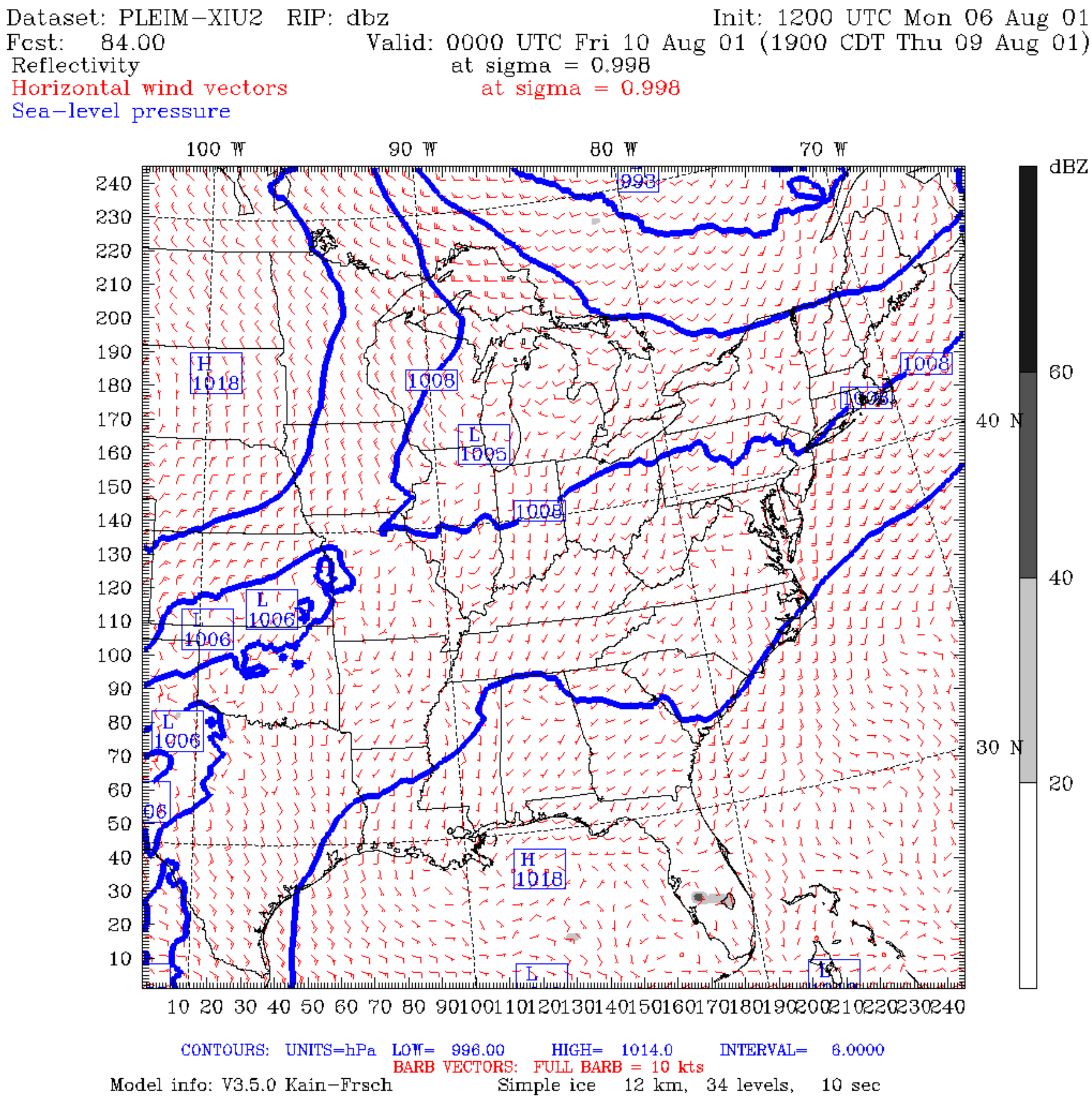


Figure 2-57: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 10 August 2001.

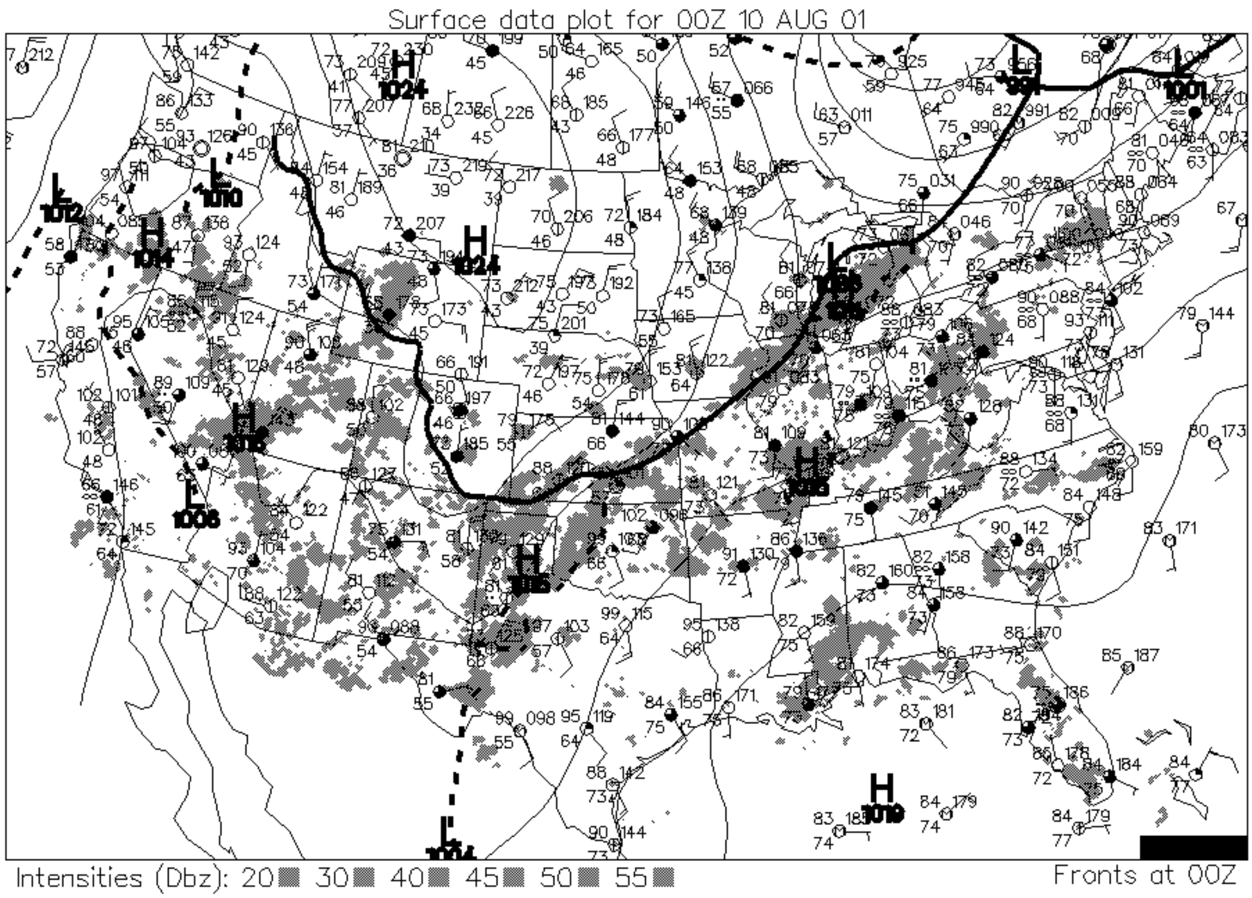


Figure 2-58: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 11 August 2001.

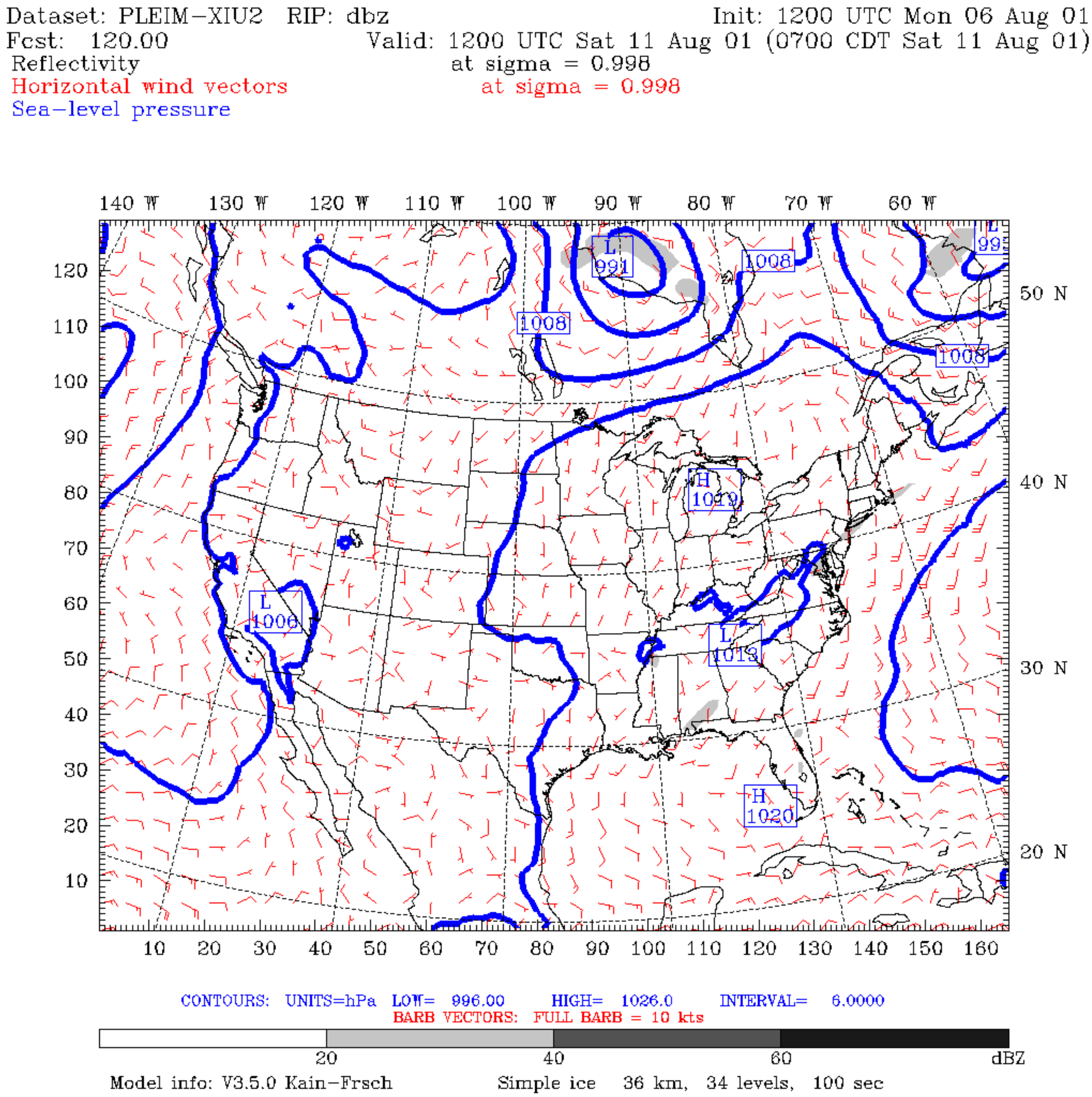


Figure 2-59: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 11 August 2001.

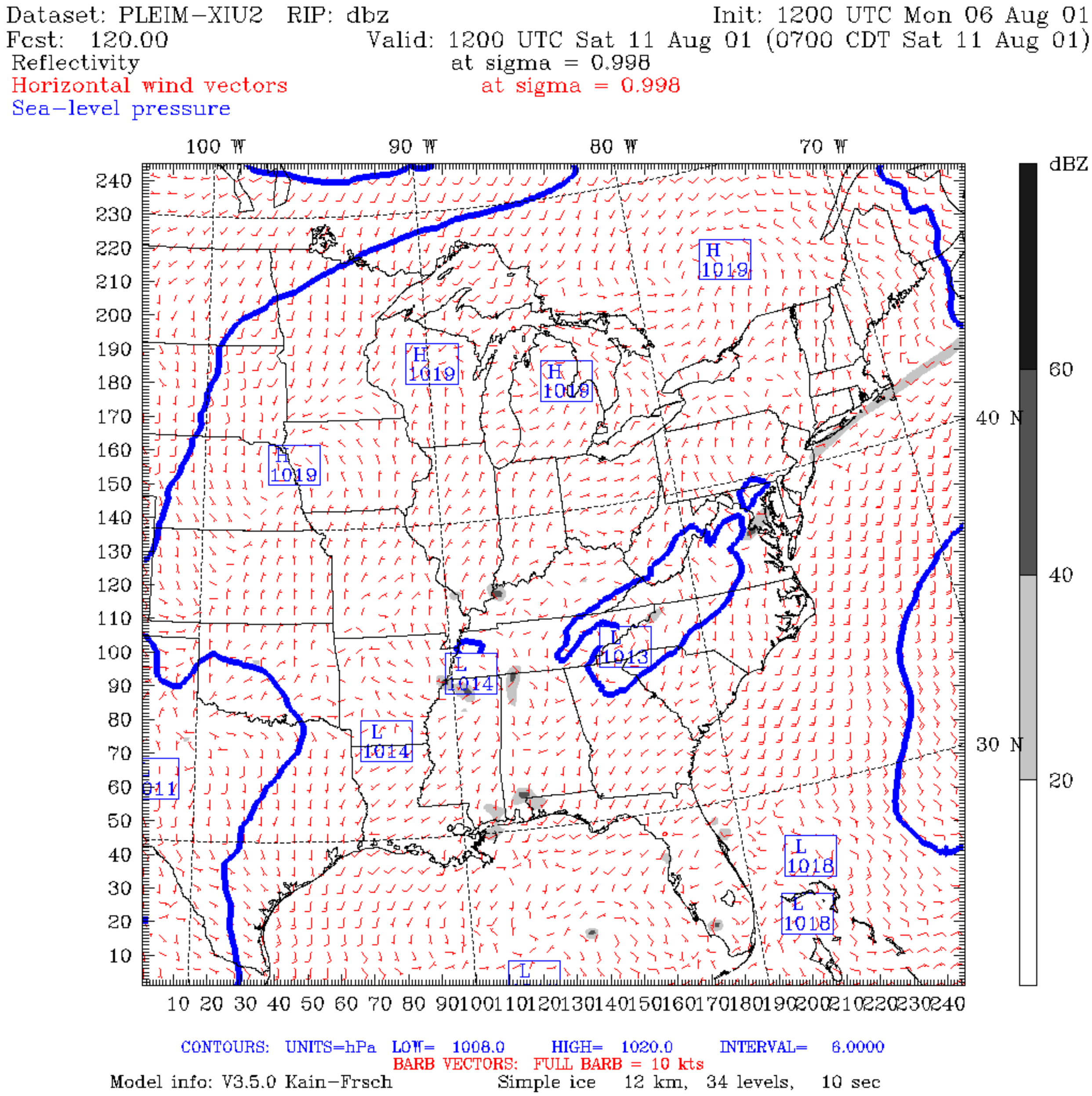


Figure 2-60: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 11 August 2001.

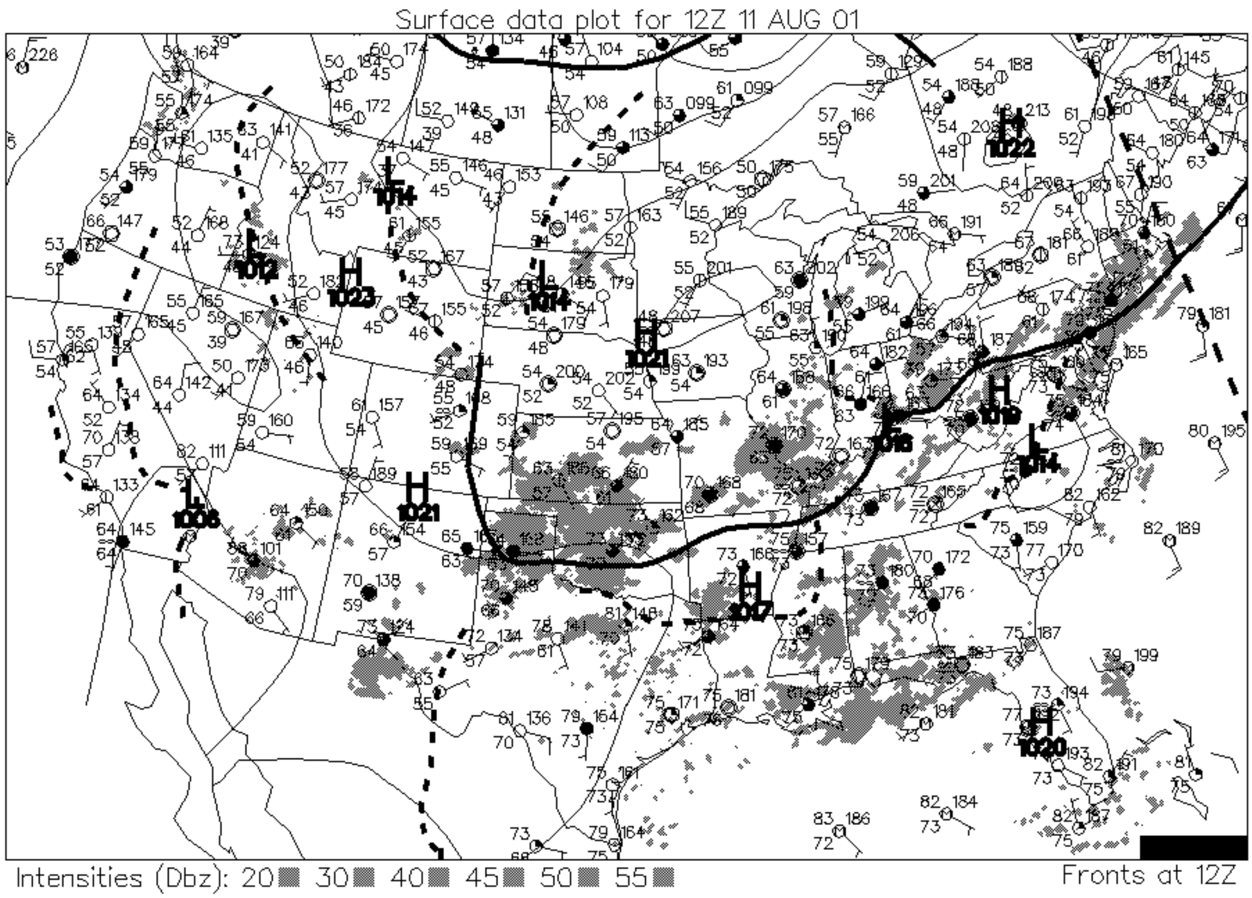


Figure 2-61: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 13 August 2001.

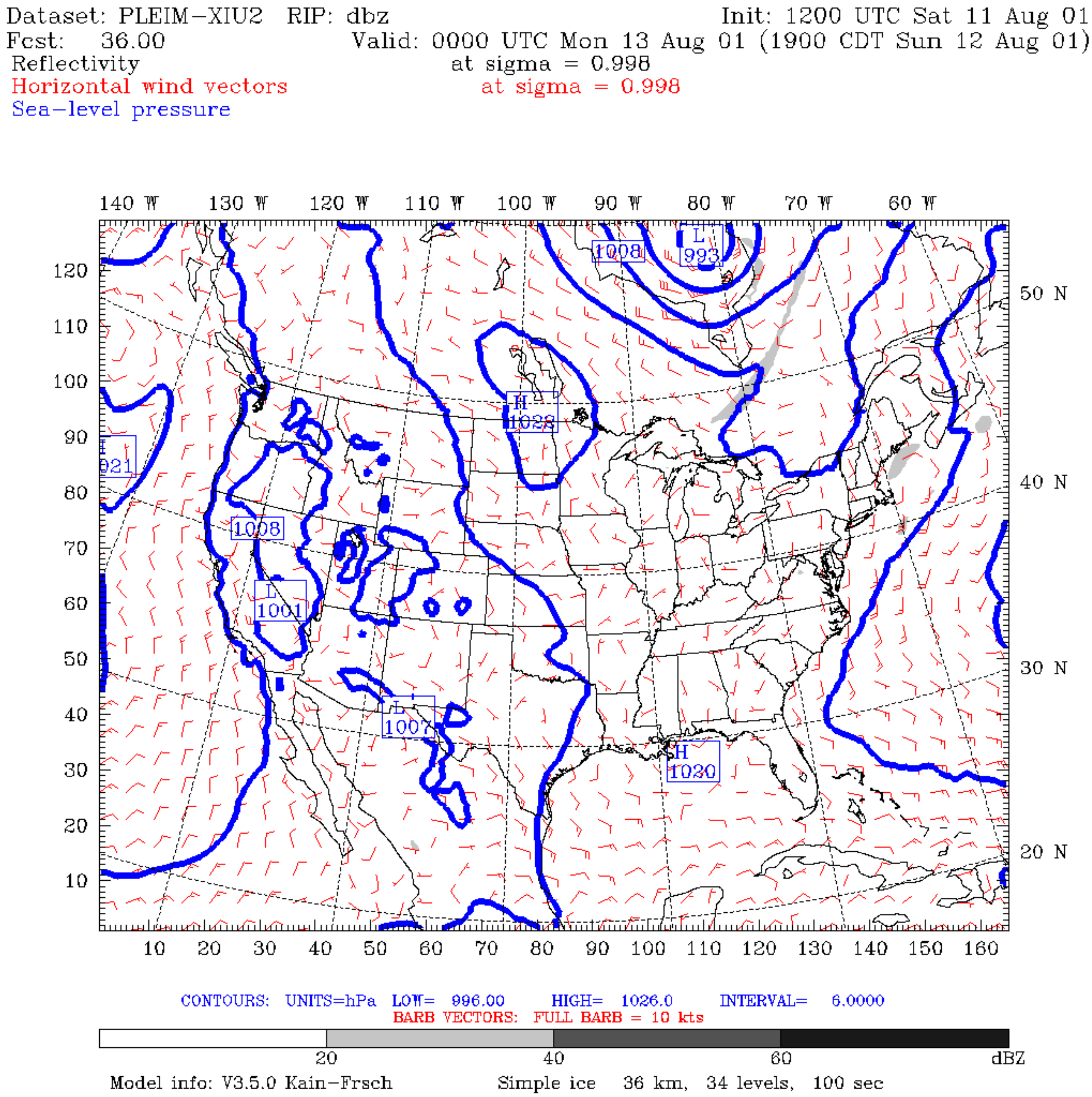


Figure 2-62: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 13 August 2001.

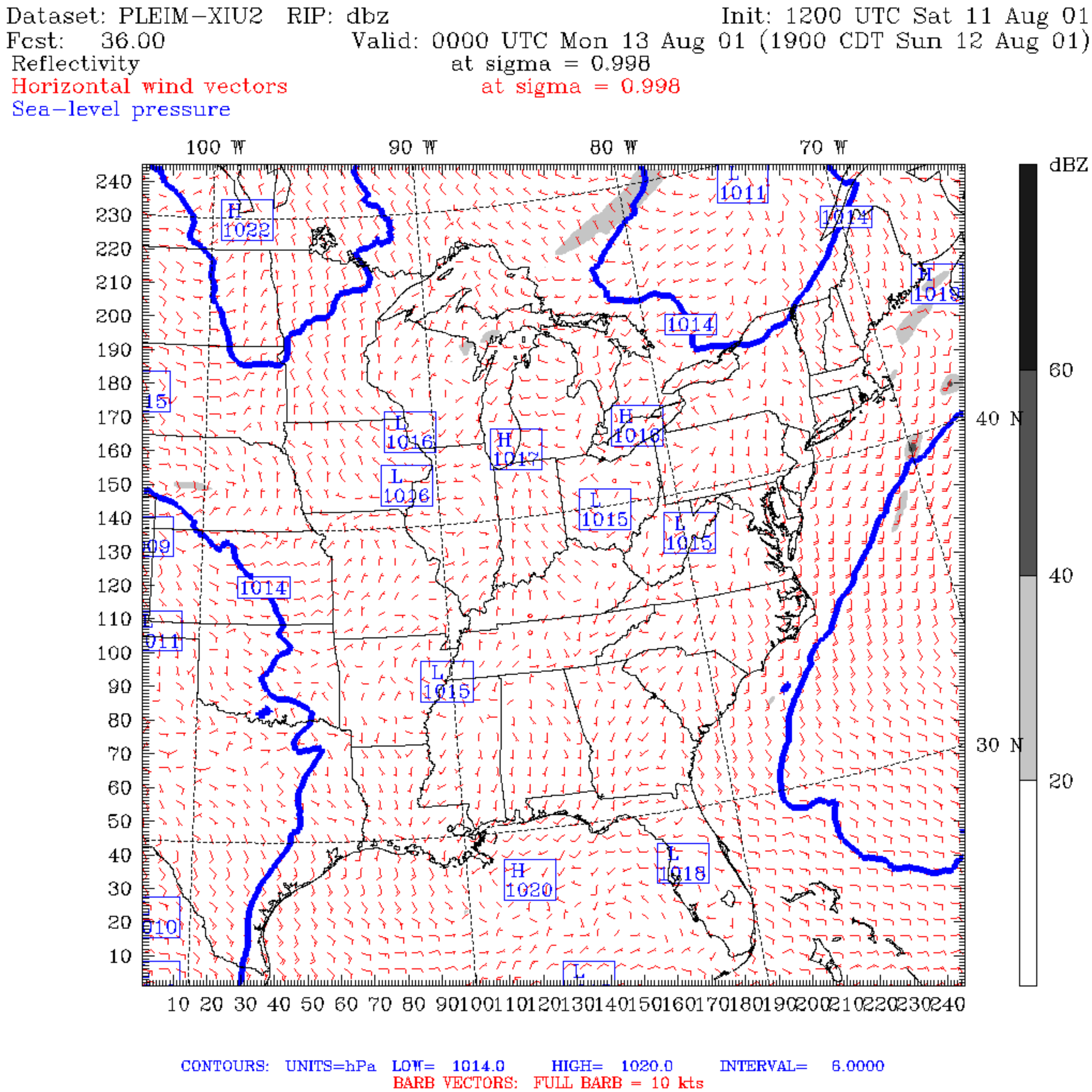


Figure 2-63: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 00Z 13 August 2001.

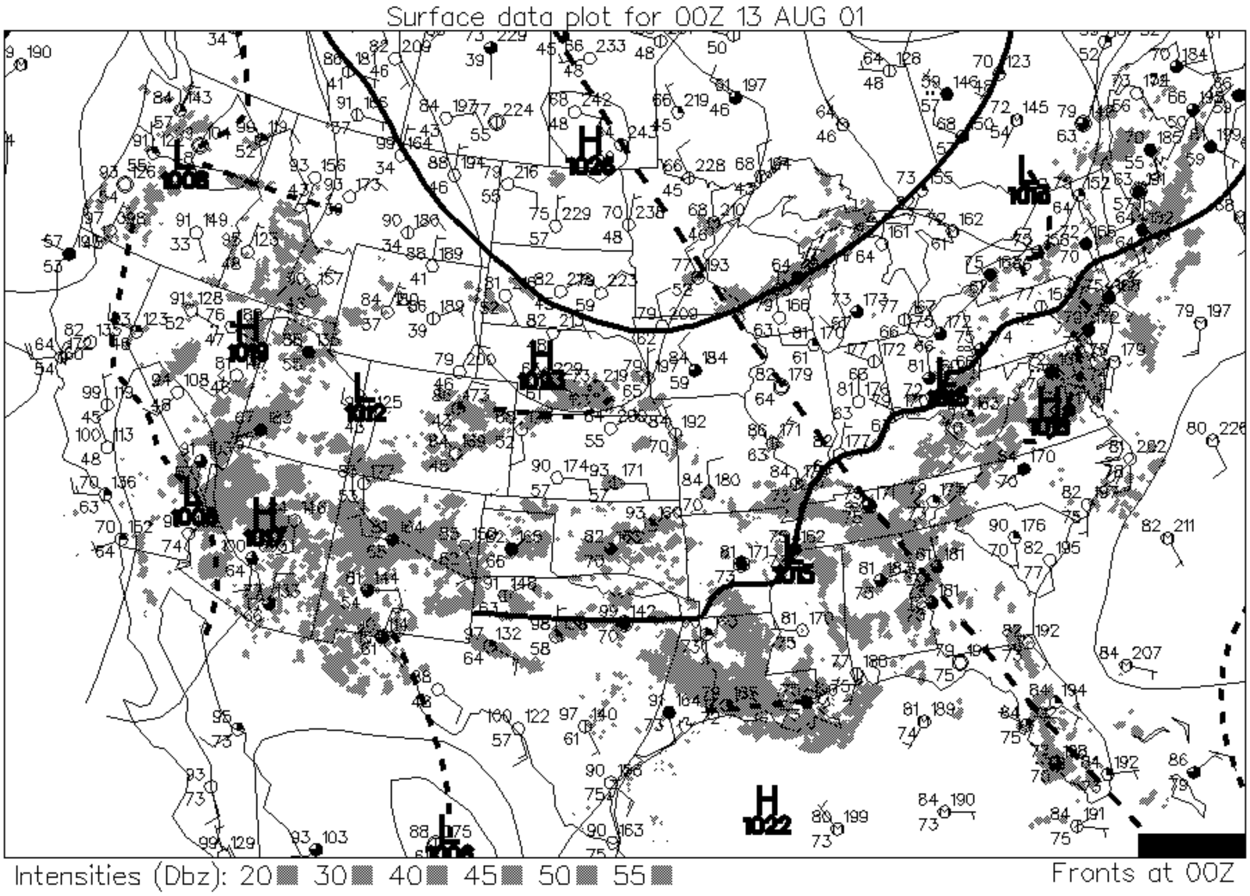


Figure 2-64: 36 km Model Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 14 August 2001.

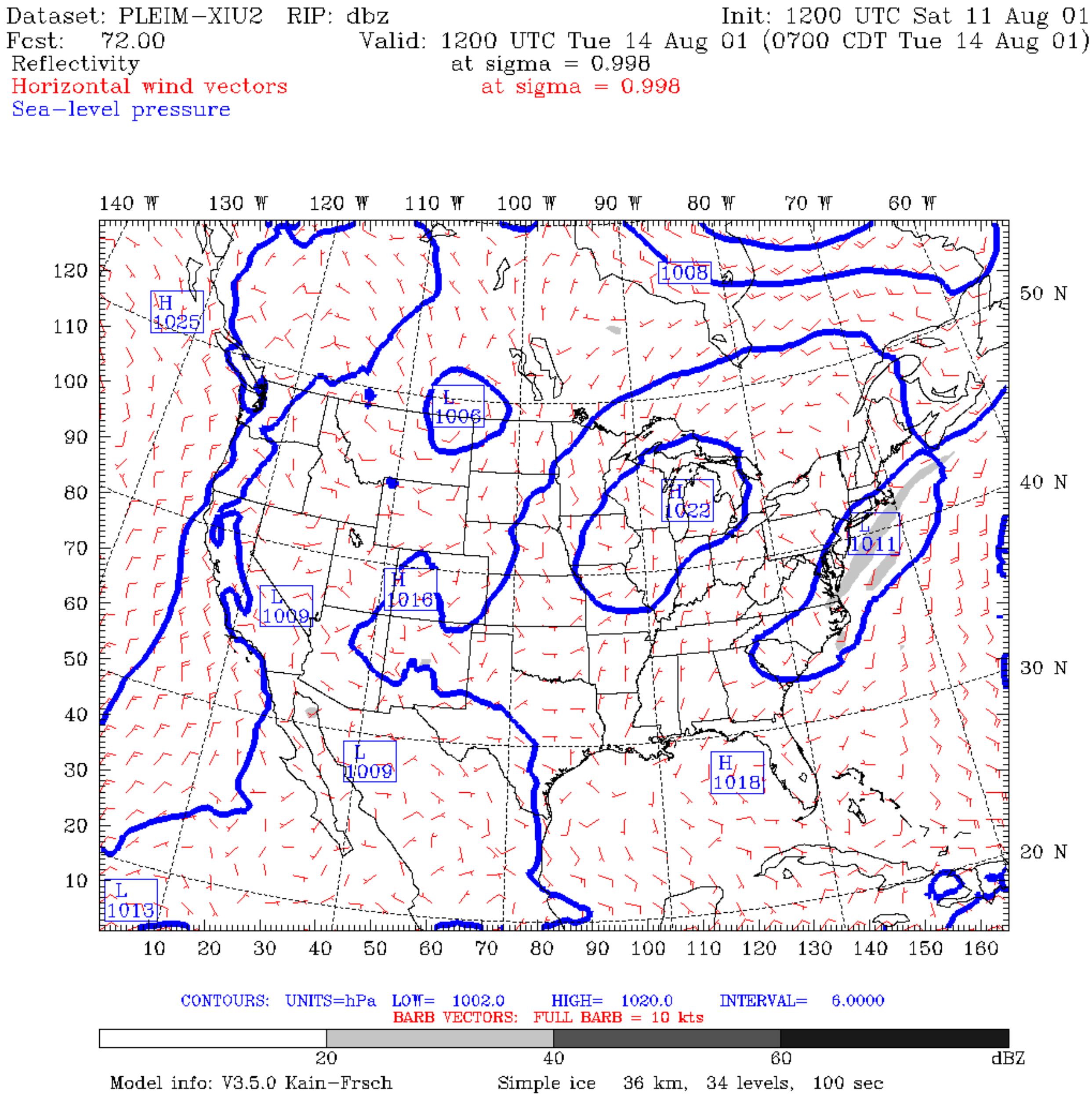


Figure 2-65: 12km Predicted 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 14 August 2001.

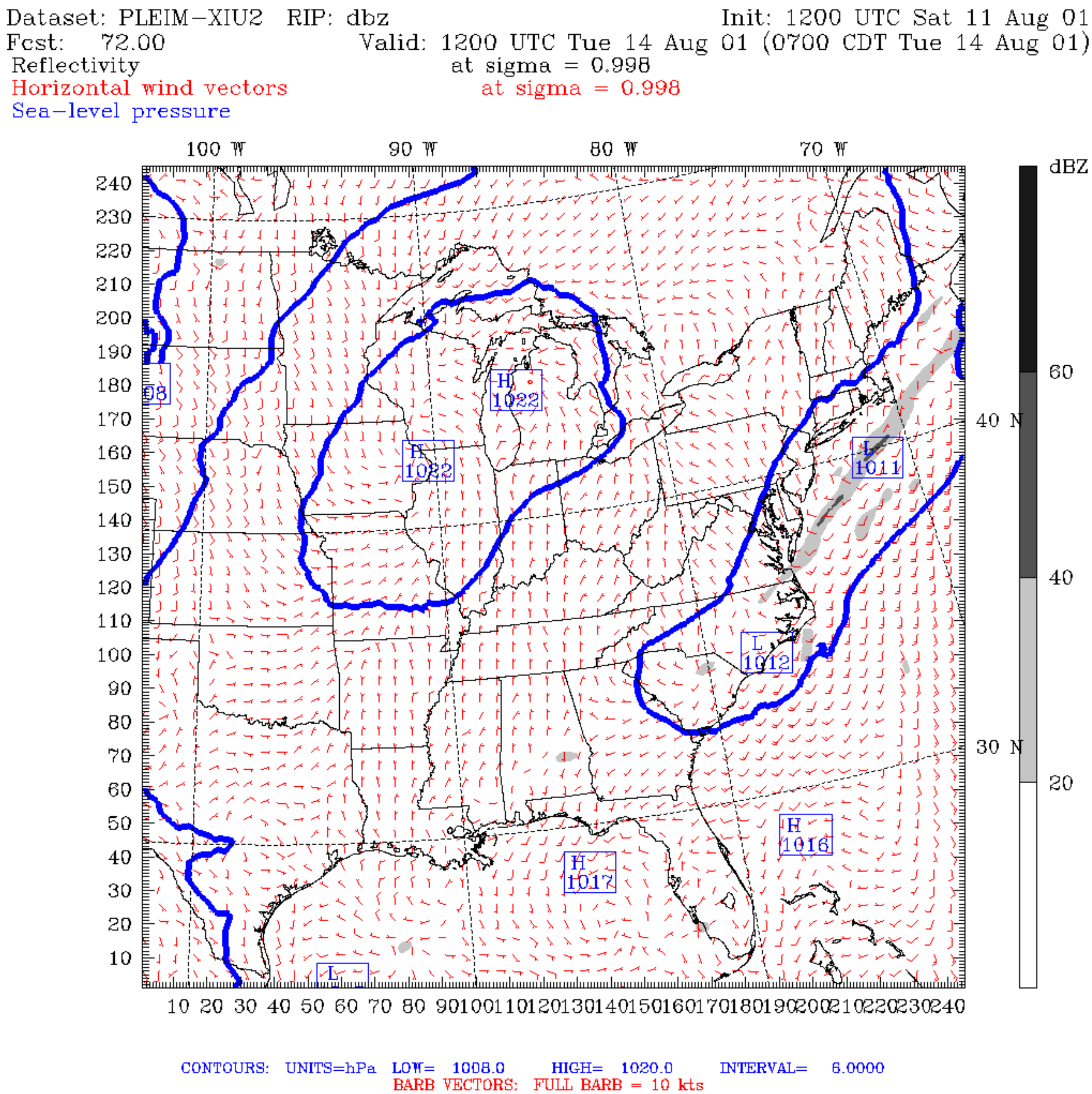


Figure 2-66: Observed 850 Mbar Heights, Surface Wind Vectors and Radar Reflectivity valid 12Z 14 August 2001.

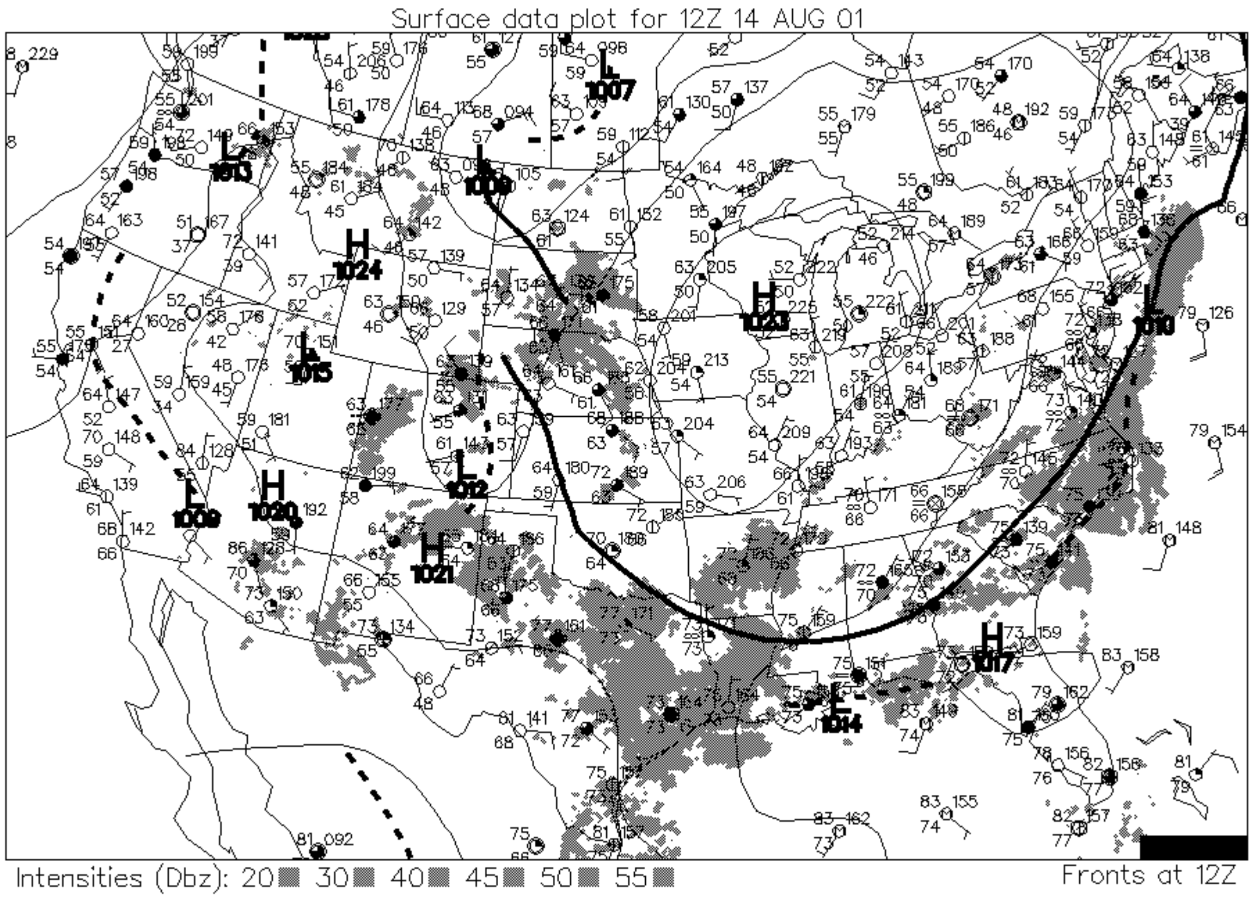


Table 2-1: Temperature Bias and Error (K) by State and RPO in the 36km Grid.

Region	36km Bias	36km Error
ALL	-0.77	2.04
AL	-0.42	1.54
AK	-1.01	1.47
AZ	-2.38	3.44
AR	-0.18	1.65
CA	-2.78	3.36
CO	-2.12	3.06
CT	-0.33	1.64
DE	-0.48	1.54
DC	-1.50	1.57
FL	-0.48	1.64
GA	-0.36	1.45
ID	-0.74	2.86
IL	0.06	1.66
IN	-0.04	1.60
IA	-0.15	1.60
KS	-1.03	2.00
KY	-0.40	1.51
LA	-0.44	1.74
ME	-0.19	1.71
MD	-0.38	1.75
MA	0.02	1.66
MI	-0.18	1.94
MN	0.40	1.72
MS	-0.22	1.59
MO	-0.24	1.51
MT	-1.33	2.51
NE	-0.57	1.81
NV	-2.61	3.79
NH	0.39	2.64
NJ	-0.64	1.80
NM	-1.99	2.92
NY	-0.63	1.91
NC	-0.45	1.61
ND	-0.23	1.71
OH	-0.22	1.63
OK	-1.26	2.06
OR	-1.64	2.60
PA	-0.57	1.72
RI	-0.06	1.44
SC	-0.60	1.46
SD	-0.55	1.89
TN	-0.61	1.53
TX	-1.17	1.78
UT	-1.58	3.18
VT	-0.29	2.14
VA	-0.71	1.82
WA	-0.83	2.10
WV	-0.03	1.52
WI	0.14	1.74
WY	-2.21	3.14
CENRAP	-0.46	1.76
MANE_VU	-0.36	1.83
MW	-0.05	1.76
VISTAS	-0.46	1.60

Table 2-2: Temperature Bias and Error (K) by State and RPO in the 12km Grid.

Region	12km Bias	12km Error
ALL	-0.41	1.64
AL	-0.45	1.48
AR	-0.3	1.65
CO	-1.11	2.3
CT	-0.4	1.51
DE	-0.17	1.03
DC	-1.22	1.36
FL	-0.71	1.6
GA	-0.43	1.45
IL	-0.03	1.59
IN	-0.17	1.57
IA	-0.3	1.6
KS	-0.89	1.86
KY	-0.36	1.46
LA	-0.52	1.62
ME	-0.09	1.63
MD	-0.28	1.54
MA	-0.05	1.57
MI	-0.33	1.81
MN	0.22	1.63
MS	-0.29	1.53
MO	-0.29	1.49
NE	-0.45	1.67
NH	0.4	2.37
NJ	-0.64	1.71
NY	-0.48	1.72
NC	-0.47	1.53
ND	-0.18	1.67
OH	-0.3	1.56
OK	-1.23	2.02
PA	-0.65	1.64
RI	-0.08	1.32
SC	-0.64	1.46
SD	-0.54	1.76
TN	-0.59	1.46
TX	-1.05	1.63
VT	-0.43	2.06
VA	-0.57	1.7
WV	-0.01	1.42
WI	-0.08	1.66
CENRAP	-0.47	1.67
MANE_VU	-0.33	1.69
MW	-0.2	1.67
VISTAS	-0.51	1.54

Figure 2-67: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) for 36km Grid.

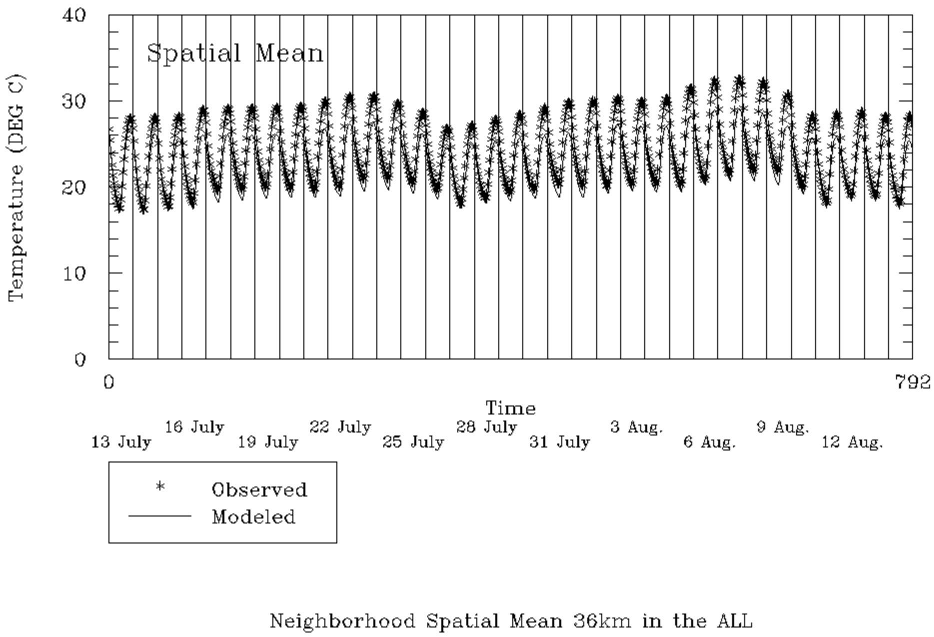


Figure 2-68: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) for 12km Grid.

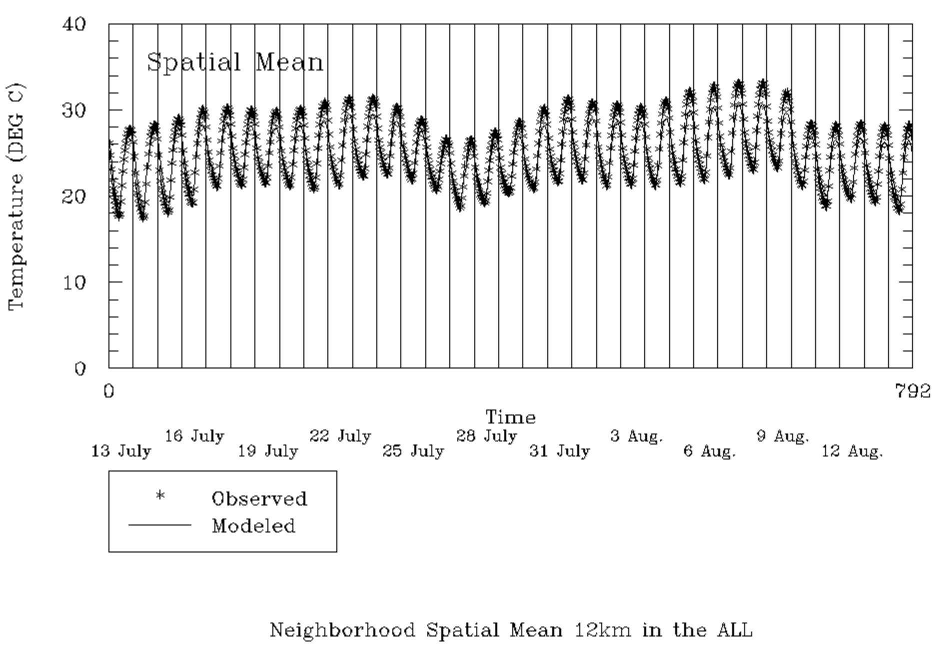


Figure 2-69: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 36km grid for the CENRAP States.

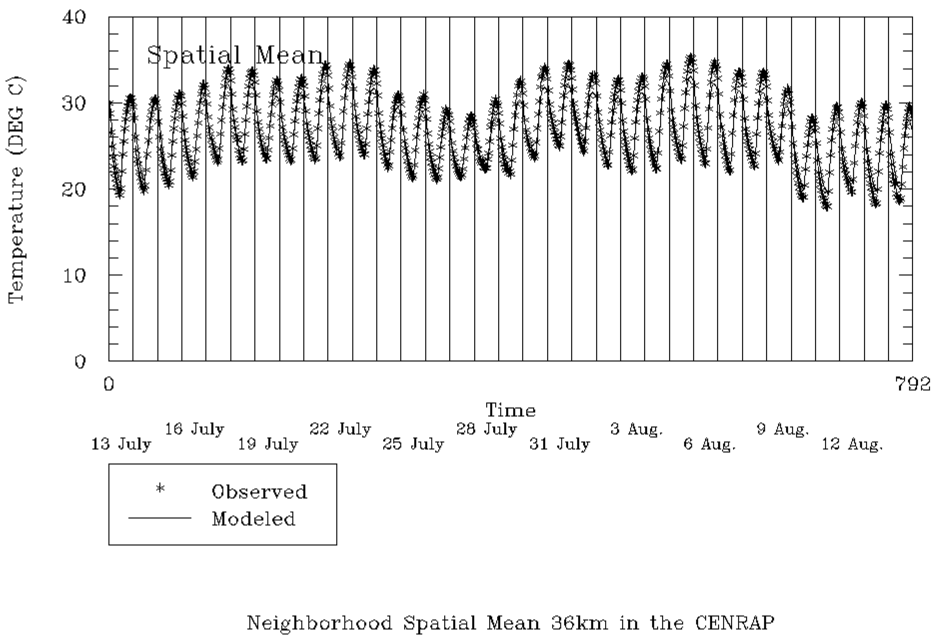


Figure 2-70: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 12km grid for the CENRAP States.

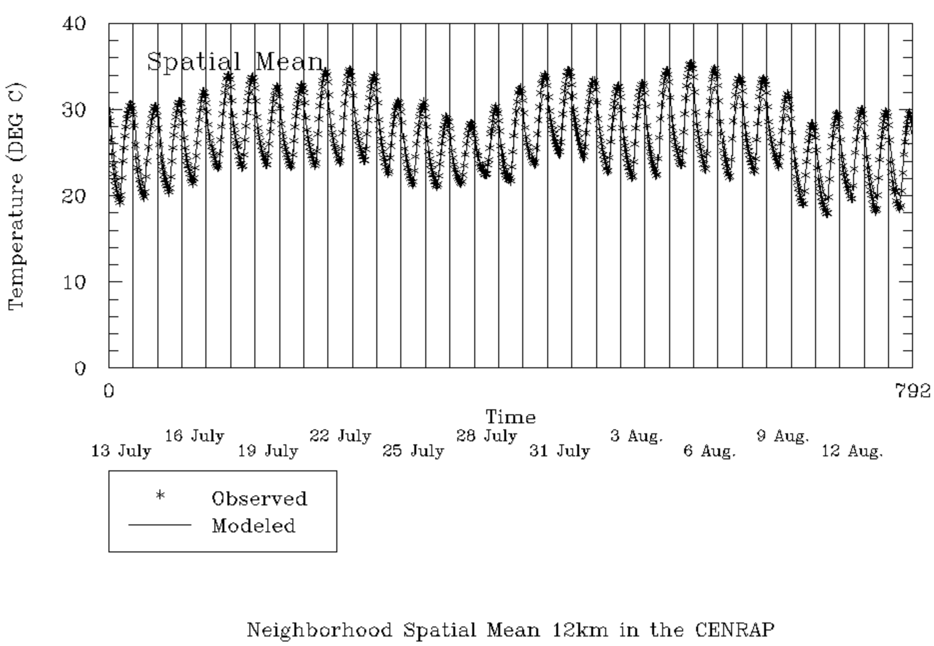


Figure 2-71: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 36km grid for the MANE-VU States.

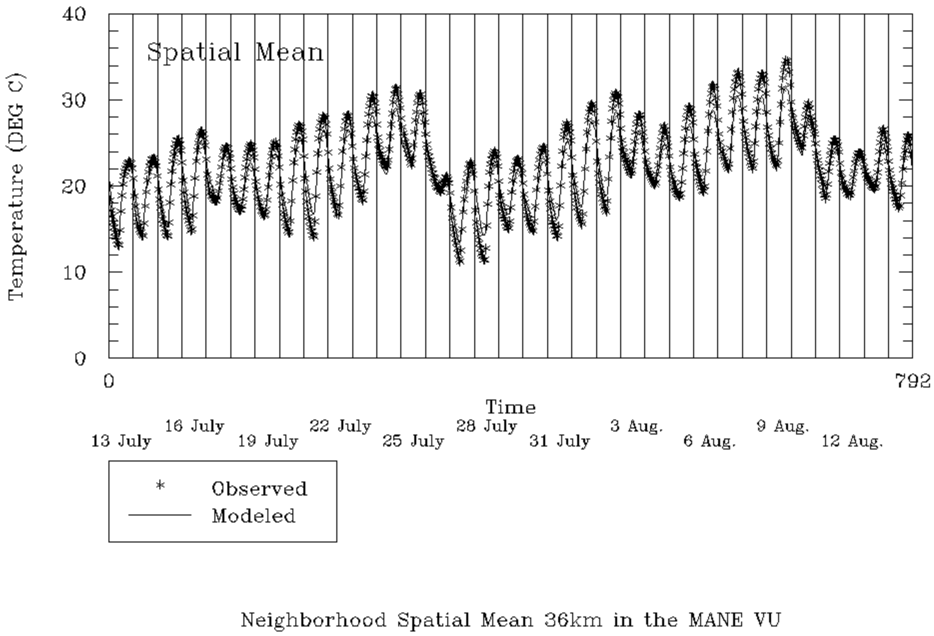


Figure 2-72: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 12km grid for the MANE-VU States.

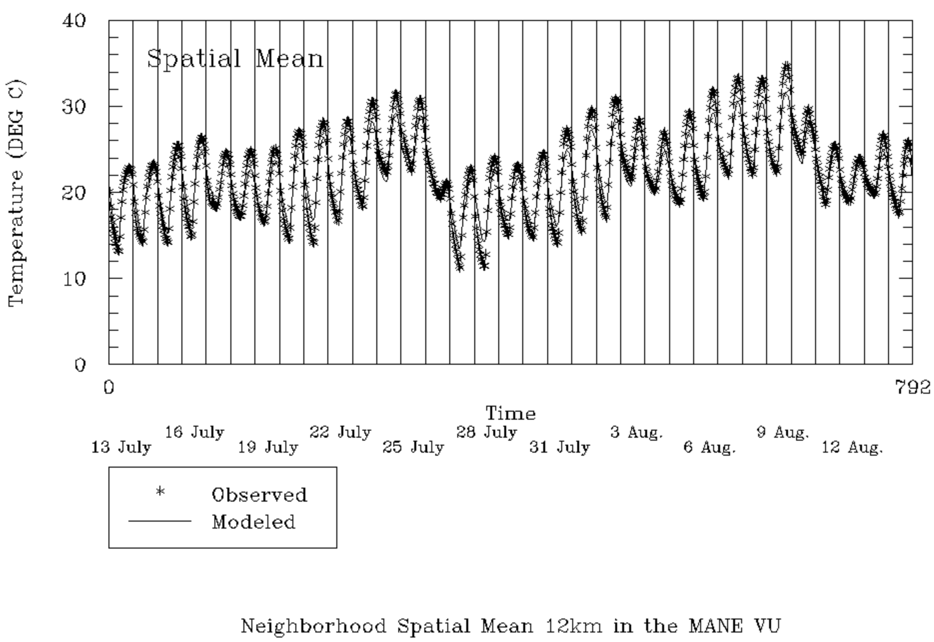


Figure 2-73: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 36km domain for the Midwestern RPO States.

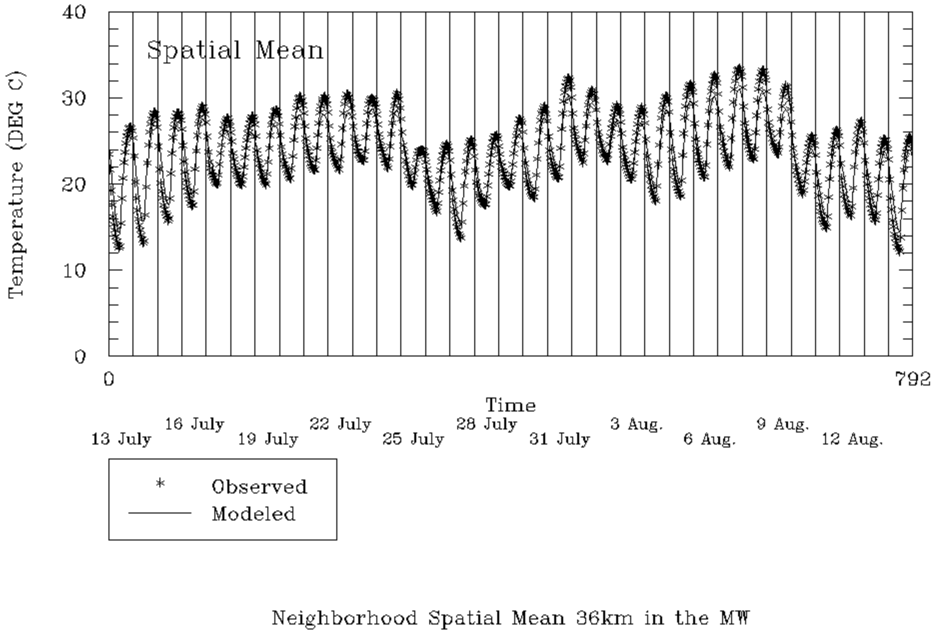


Figure 2-74: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 12km domain for the Midwestern RPO States.

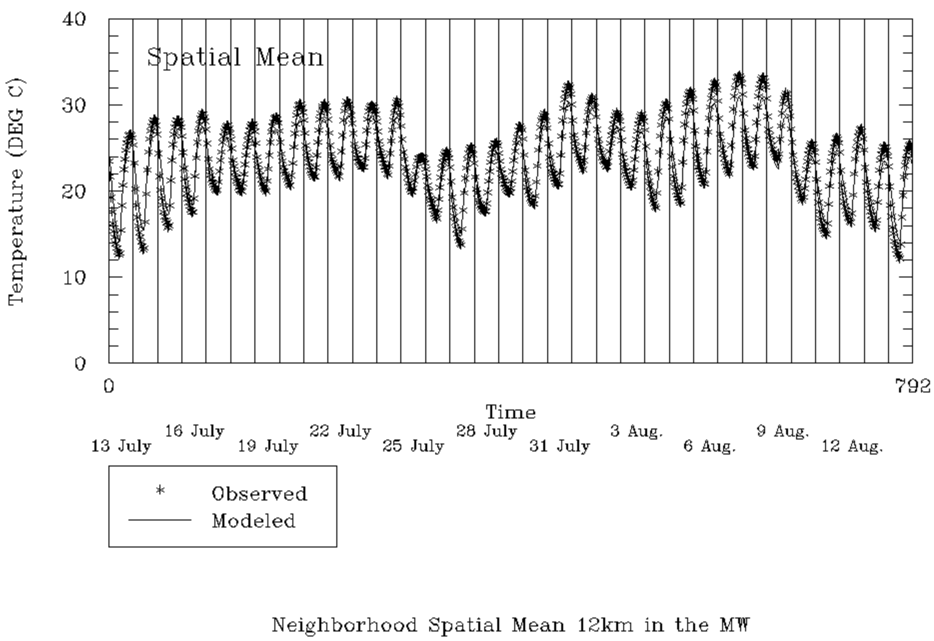


Figure 2-75: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 36km grid for the VISTAS States.

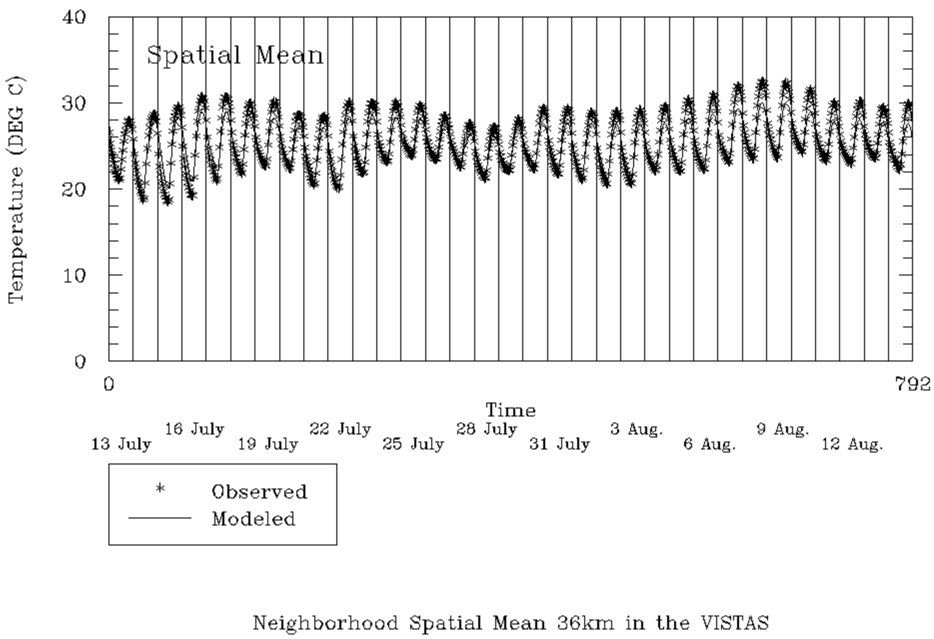


Figure 2-76: Model Estimated and Observed Spatial Me an Temperatures (Deg. C) in the 12km grid for the VISTAS States.

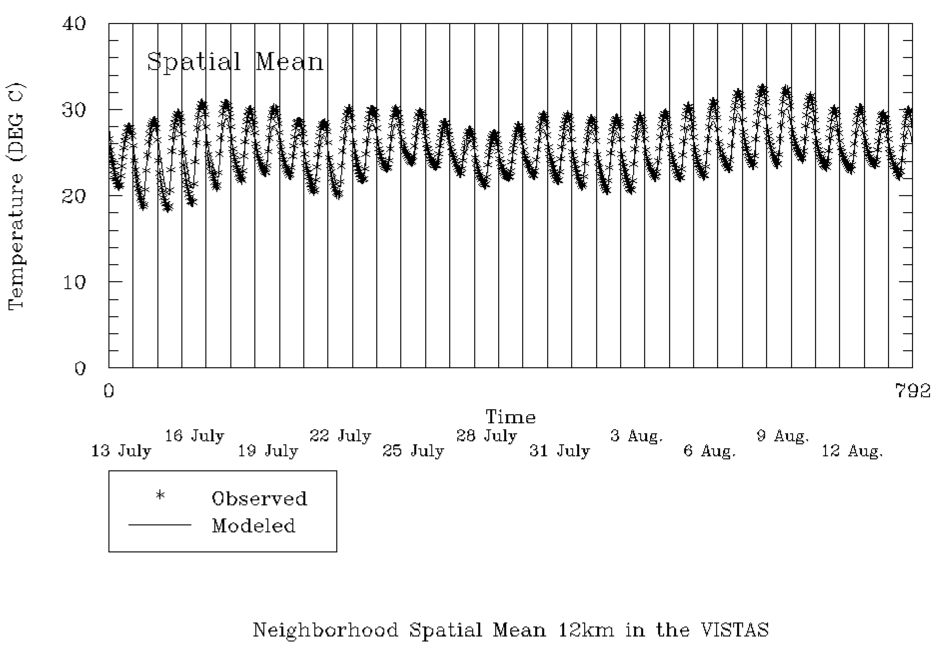


Figure 2-77: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 36km grid for the WRAP States.

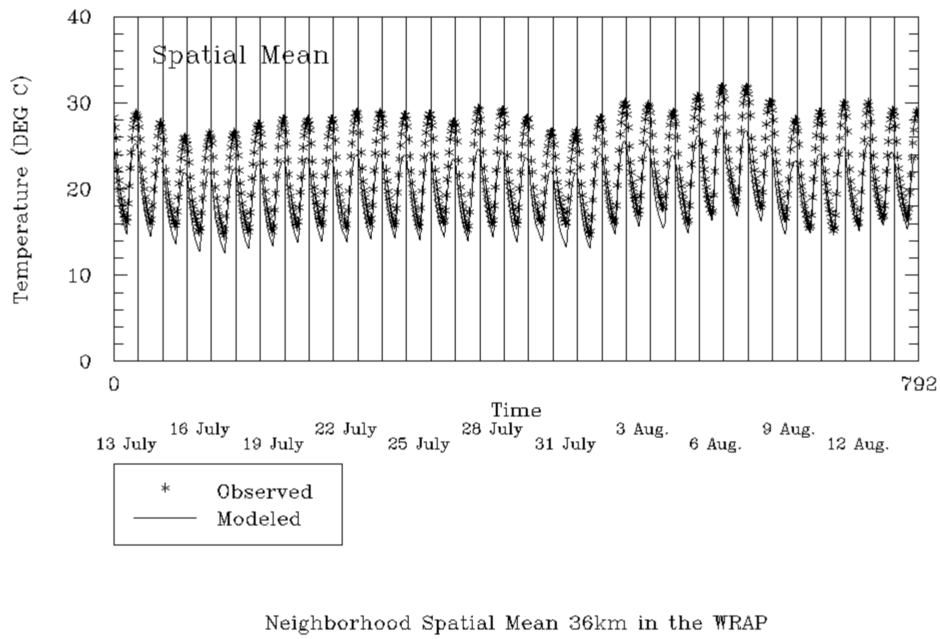


Figure 2-78: Model Estimated and Observed Spatial Mean Temperatures (Deg. C) in the 12km grid for the WRAP States.

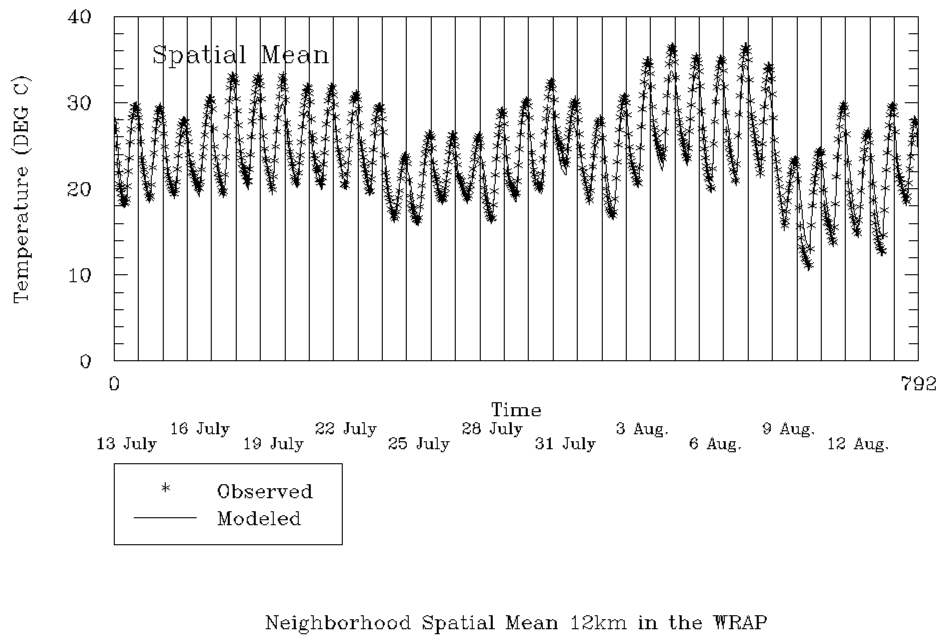


Table 2-3: Mixing Ratio Bias and Error (g/kg) by State and RPO in the 36km Grid.

Region	36km Bias	36km Error
ALL	-0.32	1.63
AL	-0.49	1.46
AK	0.04	0.67
AZ	0.71	2.63
AR	-0.38	1.59
CA	-0.48	1.42
CO	-0.43	1.95
CT	-0.59	1.36
DE	-0.74	1.44
DC	-0.84	1.44
FL	-0.65	1.52
GA	-0.84	1.62
ID	-0.31	1.59
IL	-0.39	1.84
IN	-0.60	1.55
IA	-0.52	1.86
KS	0.05	1.84
KY	-0.10	1.49
LA	-0.14	2.21
ME	0.15	1.31
MD	-0.32	1.40
MA	-0.38	1.22
MI	-0.24	1.37
MN	-0.26	1.77
MS	-0.51	1.52
MO	-0.73	1.70
MT	-0.27	1.57
NE	0.04	1.75
NV	0.54	2.07
NH	-0.32	1.24
NJ	-0.55	1.48
NM	0.07	2.24
NY	-0.40	1.34
NC	-0.33	1.56
ND	-0.55	1.69
OH	-0.52	1.45
OK	-0.33	2.17
OR	-0.07	1.24
PA	-0.19	1.51
RI	-0.17	1.05
SC	-0.29	1.40
SD	0.04	1.75
TN	-0.42	1.40
TX	-0.19	1.88
UT	0.54	2.02
VT	-0.33	1.39
VA	-0.89	1.67
WA	-0.45	1.09
WV	-0.96	1.69
WI	-0.44	1.60
WY	0.08	1.81
CENRAP	-0.27	1.85
MANE_VU	-0.31	1.36
MW	-0.39	1.53
VISTAS	-0.58	1.55

Table 2-4: Mixing Ratio Bias and Error (g/kg) by State and RPO in the 12km Grid.

Region	12km Bias	12km Error
ALL	-0.92	1.86
AL	-1.04	1.75
AR	-0.94	1.89
CO	0.52	2.25
CT	-1.04	1.62
DE	-1.01	1.58
DC	-1.49	1.91
FL	-1.39	2.00
GA	-1.17	1.83
IL	-1.31	2.23
IN	-1.44	2.01
IA	-1.24	2.20
KS	-0.32	1.94
KY	-0.90	1.81
LA	-0.79	2.64
ME	0.01	1.31
MD	-0.99	1.78
MA	-0.78	1.41
MI	-0.70	1.55
MN	-0.83	1.88
MS	-1.10	1.84
MO	-1.62	2.26
NE	-0.23	1.79
NH	-0.51	1.33
NJ	-1.09	1.72
NY	-0.76	1.53
NC	-0.88	1.79
ND	-0.81	1.75
OH	-1.29	1.89
OK	-0.74	2.32
PA	-0.70	1.68
RI	-0.70	1.29
SC	-0.65	1.56
SD	-0.22	1.74
TN	-0.87	1.65
TX	-0.75	2.04
VT	-0.43	1.43
VA	-1.31	1.92
WV	-1.45	1.97

Region	12km Bias	12km Error
WI	-1.05	1.86
CENRAP	-0.83	2.05
MANE_VU	-0.70	1.53
MW	-1.05	1.84
VISTAS	-1.13	1.85

Figure 2-79: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 36km Grid.

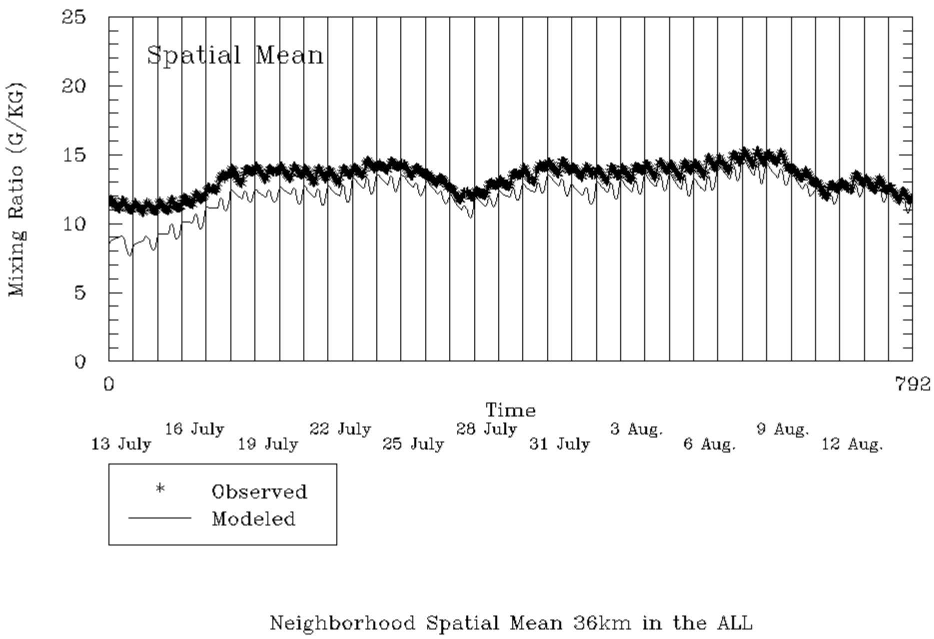


Figure 2-80: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 12km Grid.

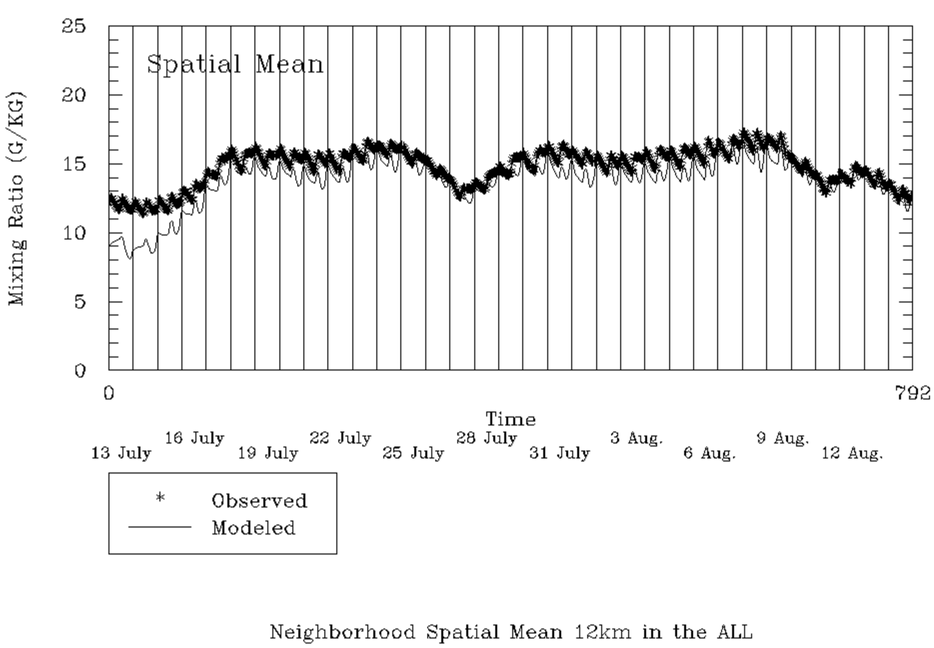
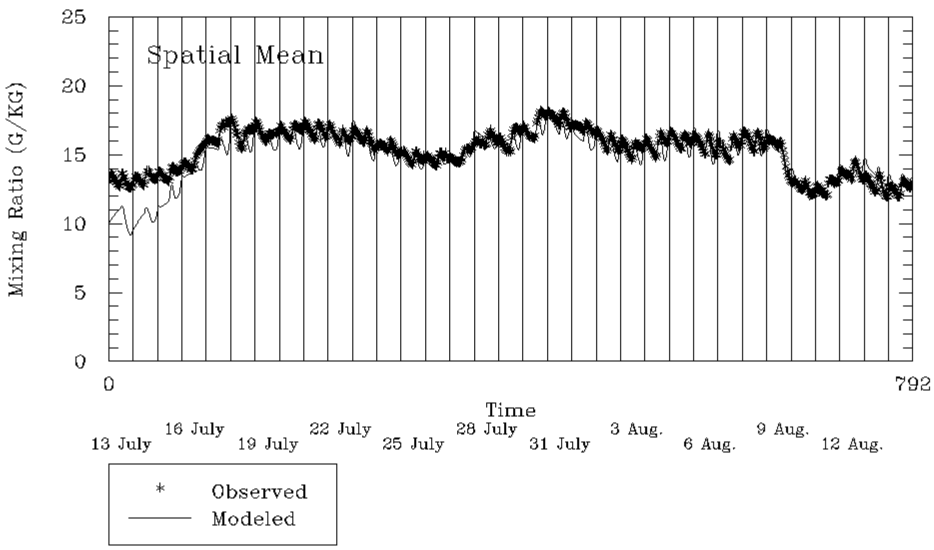
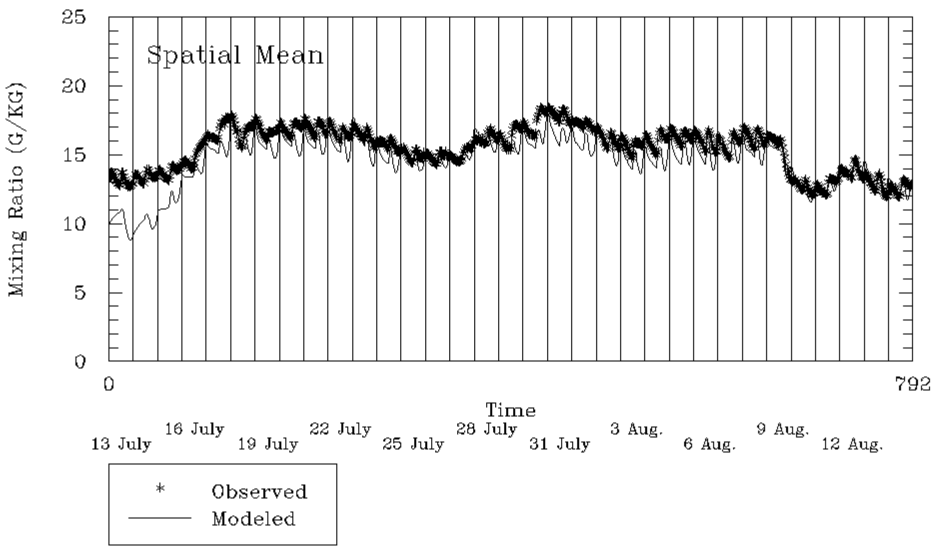


Figure 2-81: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 36 km Grid for the CENRAP States.



Neighborhood Spatial Mean 36km in the CENRAP

Figure 2-82: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 12 km Grid for the CENRAP States.



Neighborhood Spatial Mean 12km in the CENRAP

Figure 2-83: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 36km Grid for the MANE_VU States.

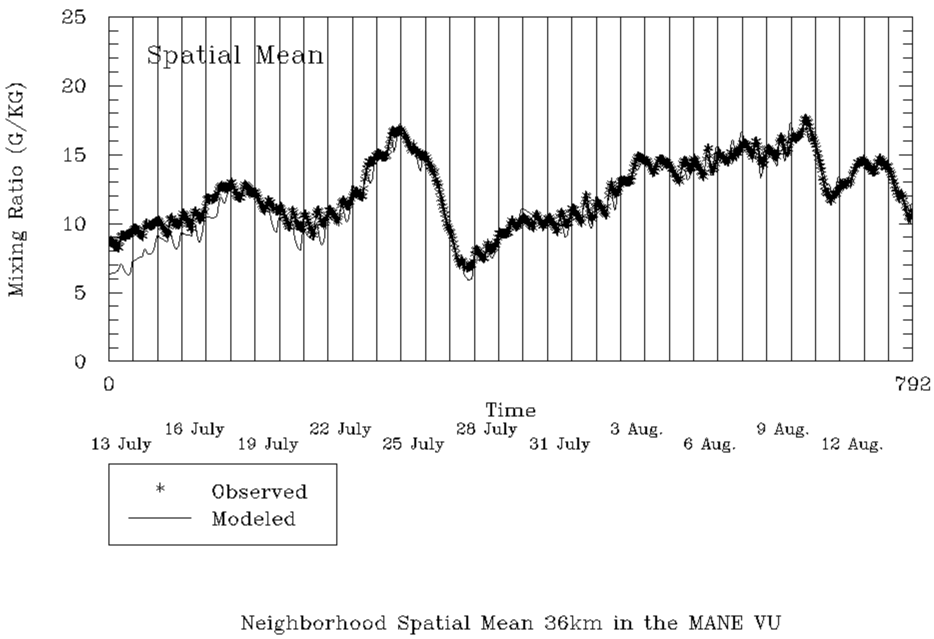


Figure 2-84: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 12km Grid for the MANE_VU States.

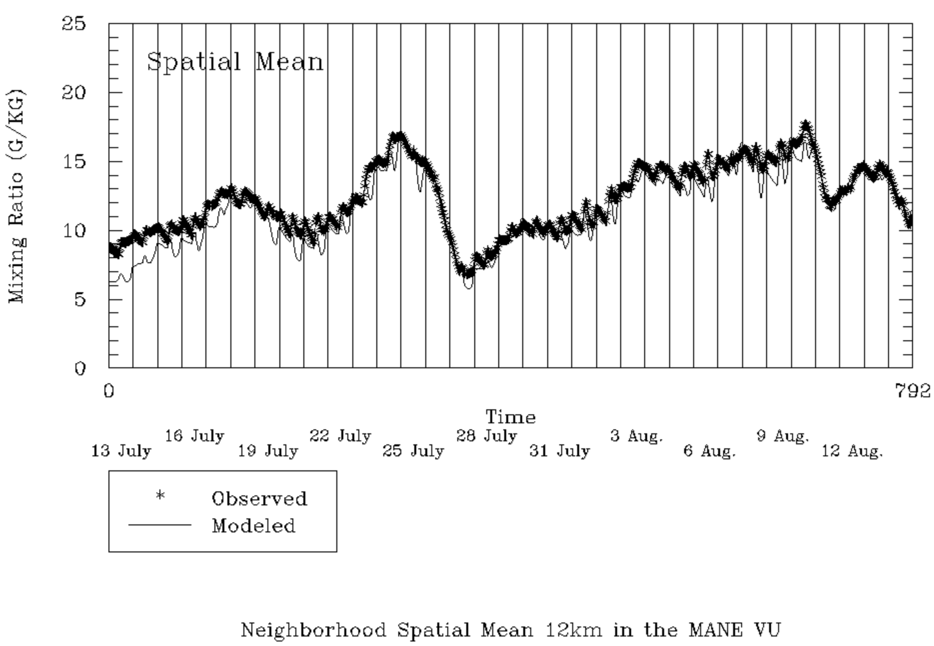


Figure 2-85: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 36km Grid for the Midwest RPO States.

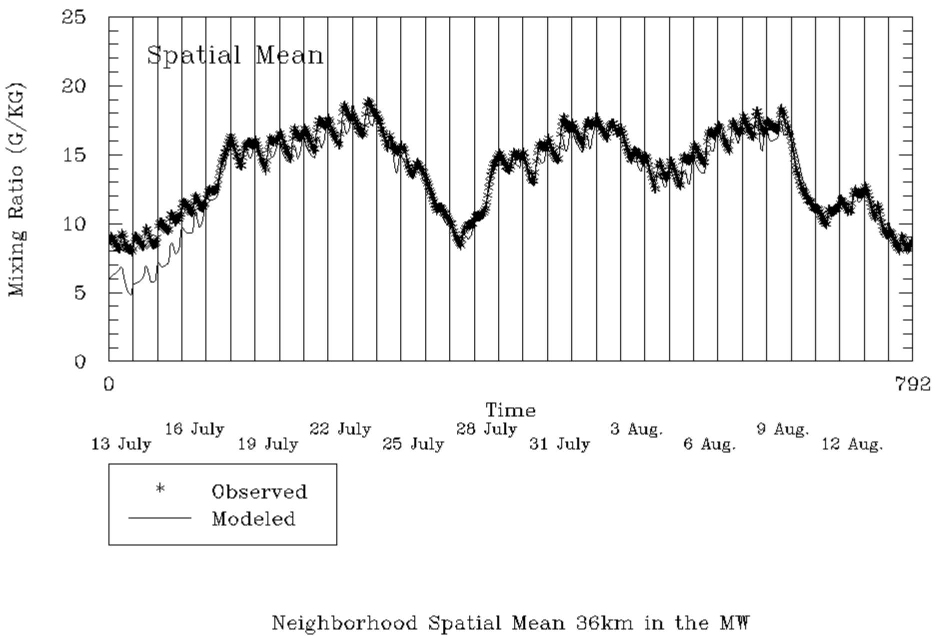


Figure 2-86: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 12km Grid for the Midwest RPO States.

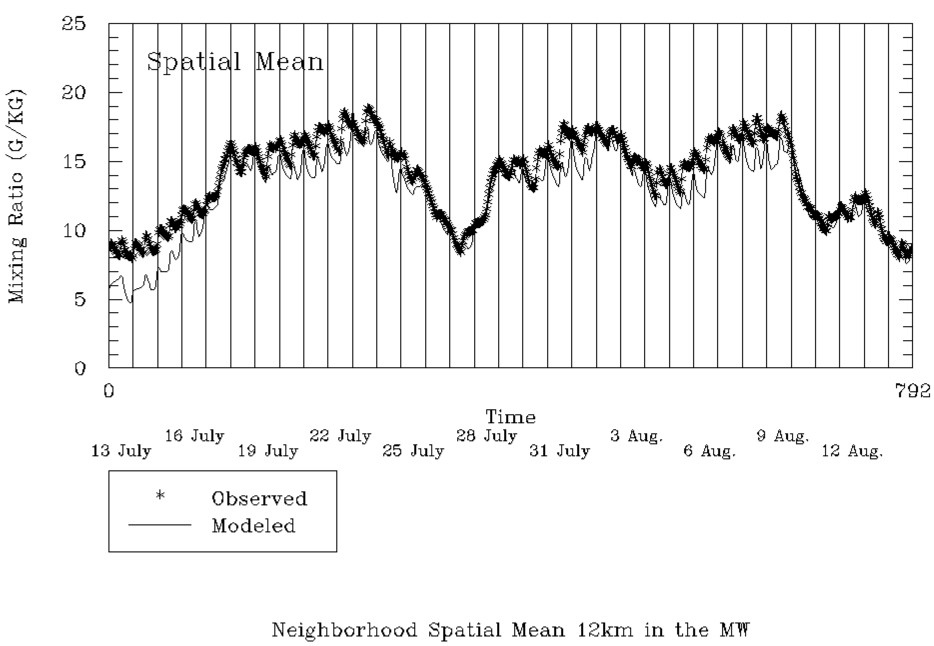


Figure 2-87: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 36km Grid for the VISTAS RPO States.

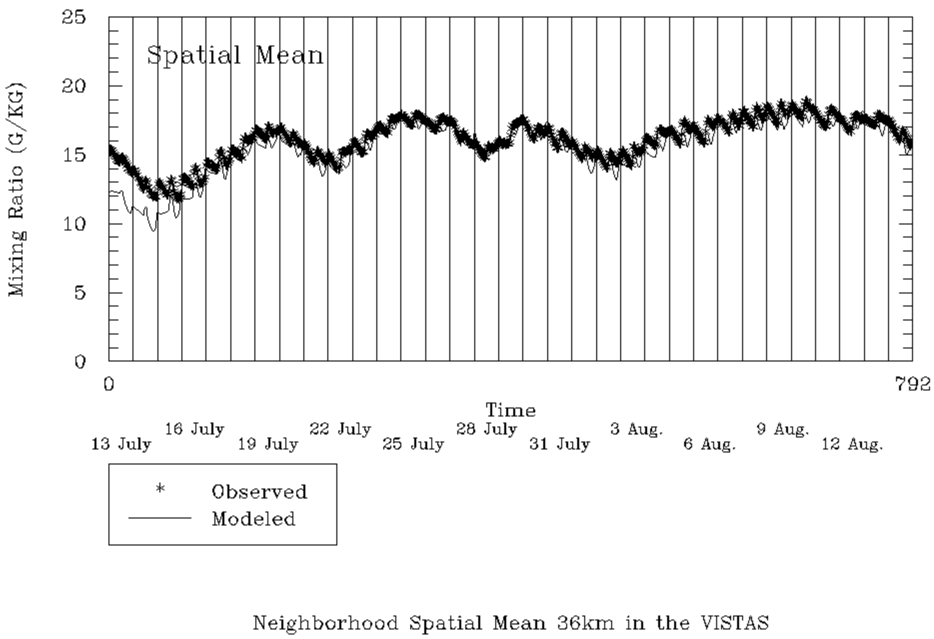


Figure 2-88: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 12km Grid for the VISTAS RPO States.

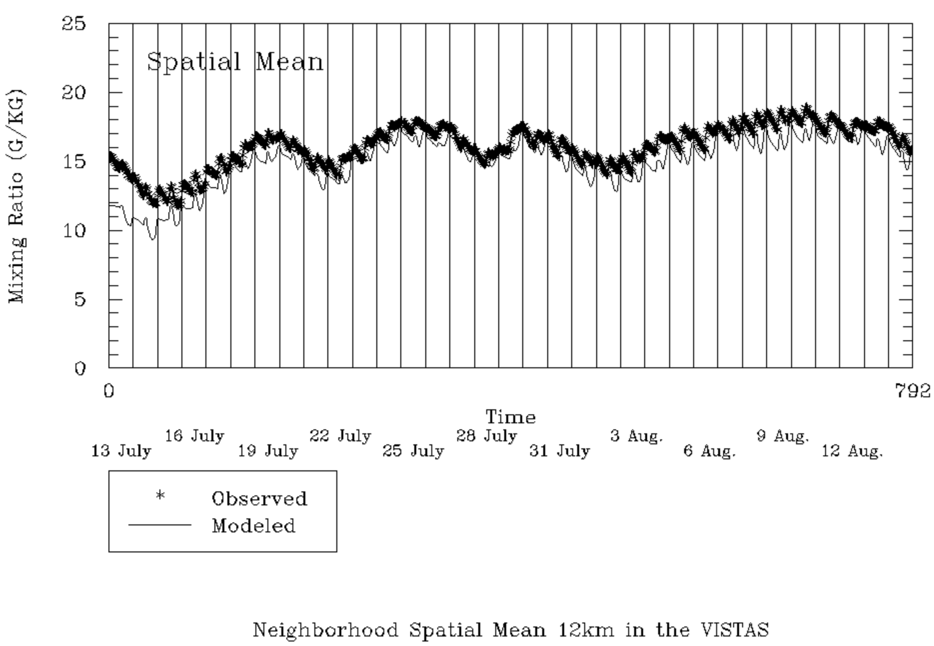


Figure 2-89: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 36km Grid for the WRAP States.

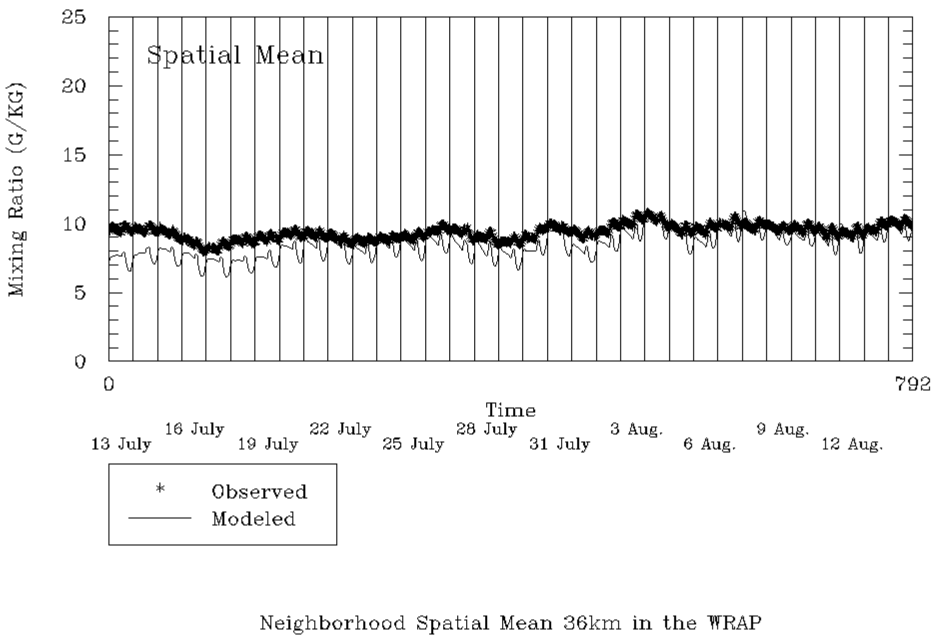


Figure 2-90: Model Estimated and Observed Spatial Mean Mixing Ratio (g/kg) in the 12km Grid for the WRAP States.

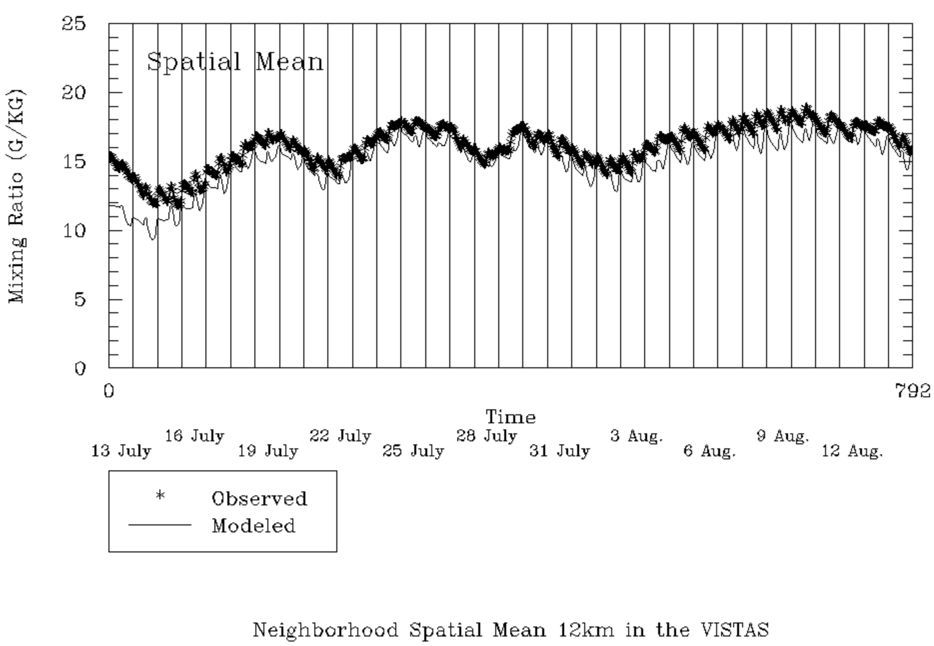


Table 2-5: Accumulated Precipitation Bias and Error (cm) by State and RPO in the 36km Grid.

Region	36km Bias	36km Error
ALL	1.29	2.43
AL	1.34	2.76
AK	-0.64	0.79
AZ	1.87	2.71
AR	3.35	3.99
CA	-0.13	0.66
CO	0.18	1.16
CT	-0.33	1.25
DE	1.64	1.64
FL	2.06	5.11
GA	0.58	2.79
ID	0.08	0.61
IL	1.73	2.72
IN	1.35	2.56
IA	2.01	2.91
KS	3.18	4
KY	2.84	4.02
LA	1.51	2.89
ME	0.48	1.07
MD	1.23	2.22
MA	-0.38	1.12
MI	0.46	1.3
MN	0.42	2.13
MS	1.77	3.3
MO	2.93	3.9
MT	0.39	1.1
NE	1.4	2.62
NV	0.95	1.11
NH	0.07	1.1
NJ	1.1	1.71
NM	2.04	2.56
NY	0.29	1.17
NC	1.33	2.64
ND	0.53	2.24
OH	0.96	2.05
OK	1.98	3.11
OR	-0.24	0.54
PA	1.44	1.99
RI	-0.1	0.66
SC	2.05	3.44
SD	0.63	2.05
TN	2.95	4.17
TX	1.75	2.17
UT	0.77	1.19
VT	0.97	1.55
VA	1.02	2.26
WA	-0.61	0.8
WV	1.24	2.37
WI	0.01	2.19
WY	1.16	1.22
CENRAP	2.25	3.22
MANE_VU	0.73	1.53
MW	0.98	2.25
VISTAS	1.68	3.31

Table 2-6: Accumulated Precipitation Bias and Error (cm) by State and RPO in the 12km Grid.

Region	12km Bias	12km Error
ALL	1.44	2.73
AL	1.14	2.87
AR	3.21	4.04
CO	0.47	1.31
CT	-0.32	1.22
DE	2.10	2.10
FL	2.46	5.43
GA	1.02	3.02
IL	1.70	2.83
IN	1.42	2.61
IA	1.78	2.73
KS	2.67	3.45
KY	2.81	4.21
LA	1.73	3.36
ME	0.29	1.10
MD	1.28	2.46
MA	-0.38	0.99
MI	0.42	1.29
MN	0.30	1.92
MS	1.92	3.42
MO	2.42	3.25
NE	1.31	2.53
NH	0.02	0.97
NJ	0.24	2.02
NY	0.15	1.11
NC	1.13	2.25
ND	0.62	2.15
OH	0.88	2.26
OK	1.24	2.44
PA	1.28	1.98
RI	0.60	0.70
SC	2.75	3.94
SD	1.07	2.26
TN	3.12	4.17
TX	1.46	1.86
VT	0.96	1.62
VA	0.73	2.14
WV	1.05	2.55
WI	-0.18	2.17
CENRAP	2.02	3.01
MANE_VU	0.58	1.52
MW	0.94	2.35
VISTAS	1.75	3.40

Figure 2-91: Model Estimated and Observed Mean Weekly Total Precipitation in the 36km Domain.

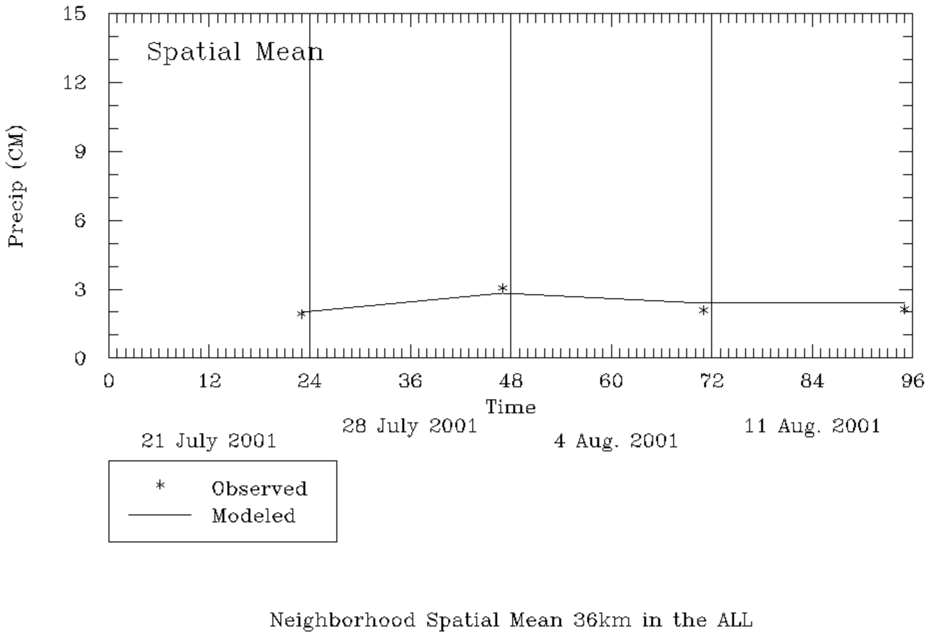


Figure 2-92: Model Estimated and Observed Mean Weekly Total Precipitation in the 12km Domain.

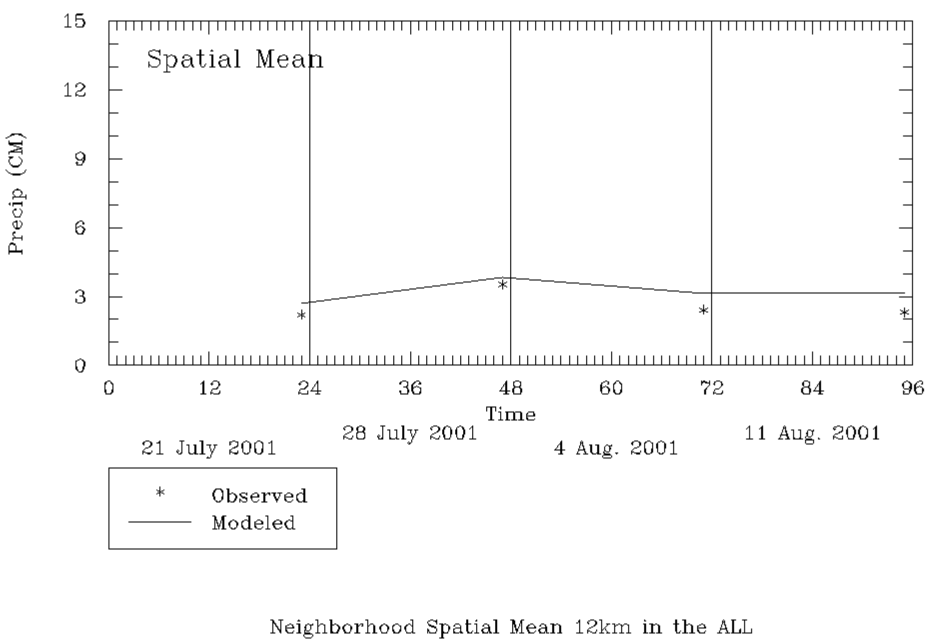


Figure 2-93: Model Estimated and Observed Mean Weekly Total Precipitation in the 36km Domain for the CENRAP States.

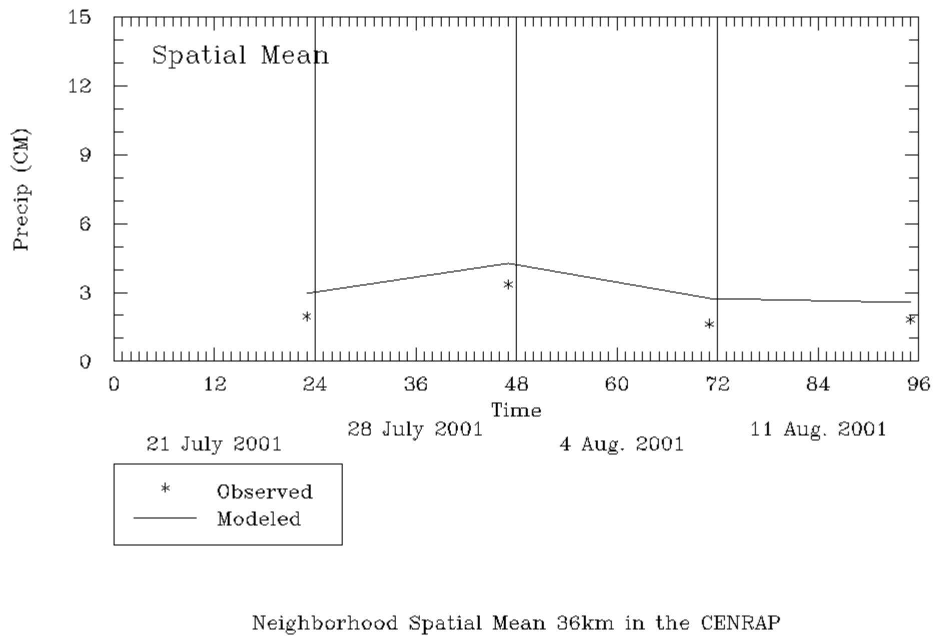


Figure 2-94: Model Estimated and Observed Mean Weekly Total Precipitation in the 12km Domain for the CENRAP States.

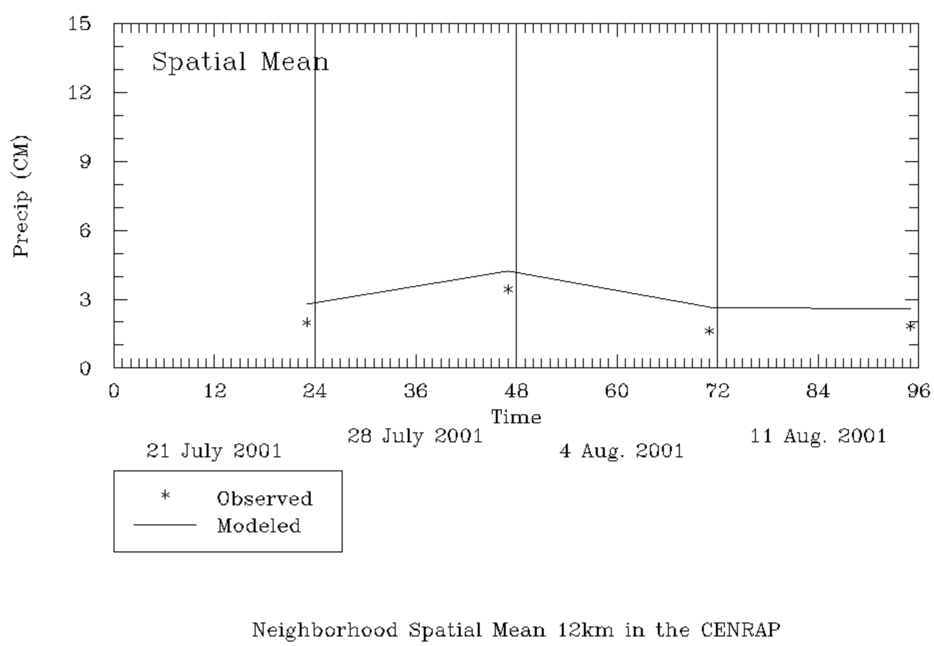


Figure 2-95: Model Estimated and Observed Mean Weekly Total Precipitation in the 36km domain for the MANE_VU States.

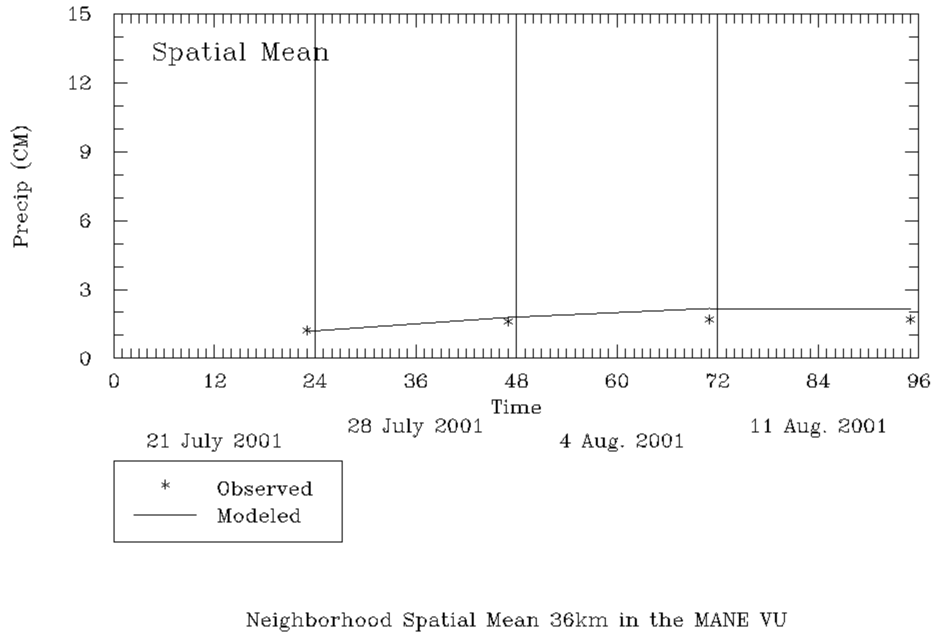


Figure 2-96: Model Estimated and Observed Mean Weekly Total Precipitation in the 12km Domain for the MANE-VU States.

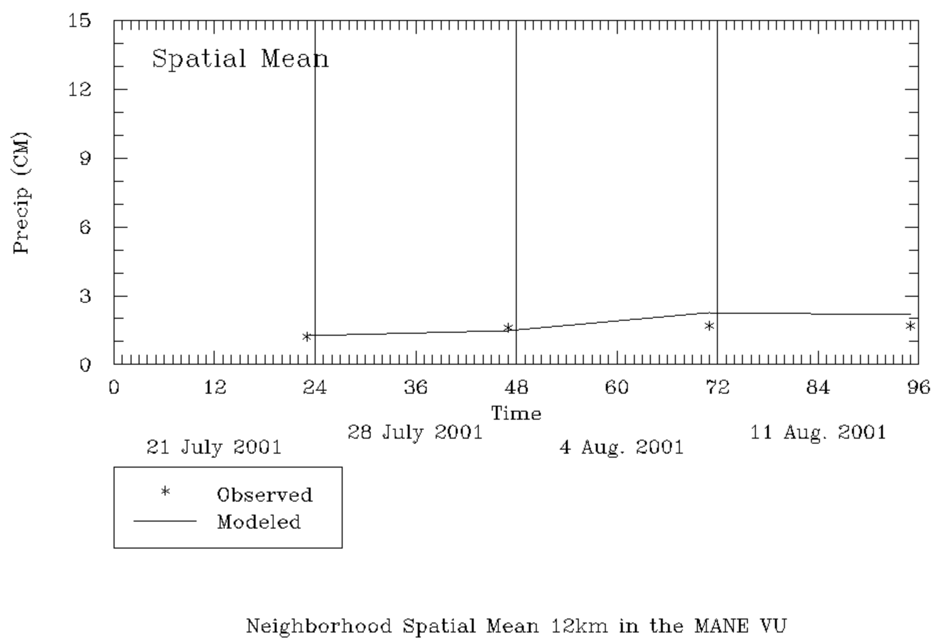


Figure 2-97: Model Estimated and Observed Mean Weekly Total Precipitation in the 36km Domain for the Midwest RPO States.

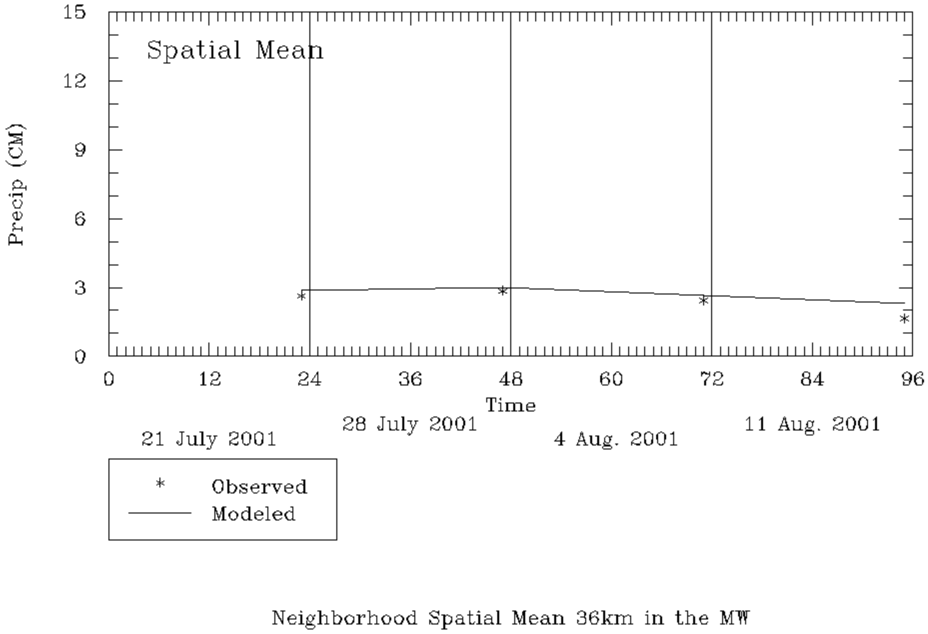


Figure 2-98: Model Estimated and Observed Mean Weekly Total Precipitation in the 12km Domain for the Midwest RPO States.

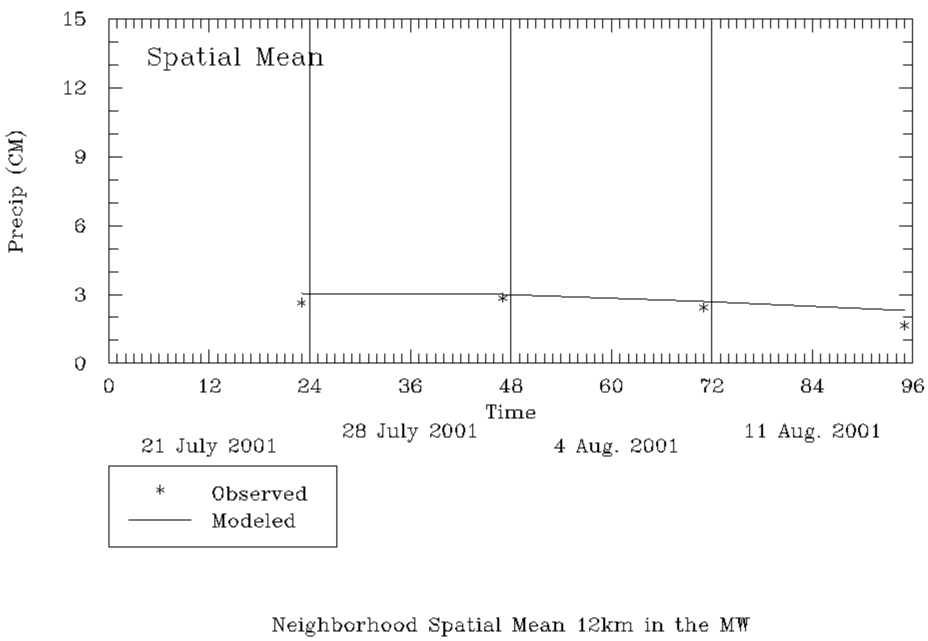


Figure 2-99: Model Estimated and Observed Mean Weekly Total Precipitation in the 36km Domain for the VISTAS States.

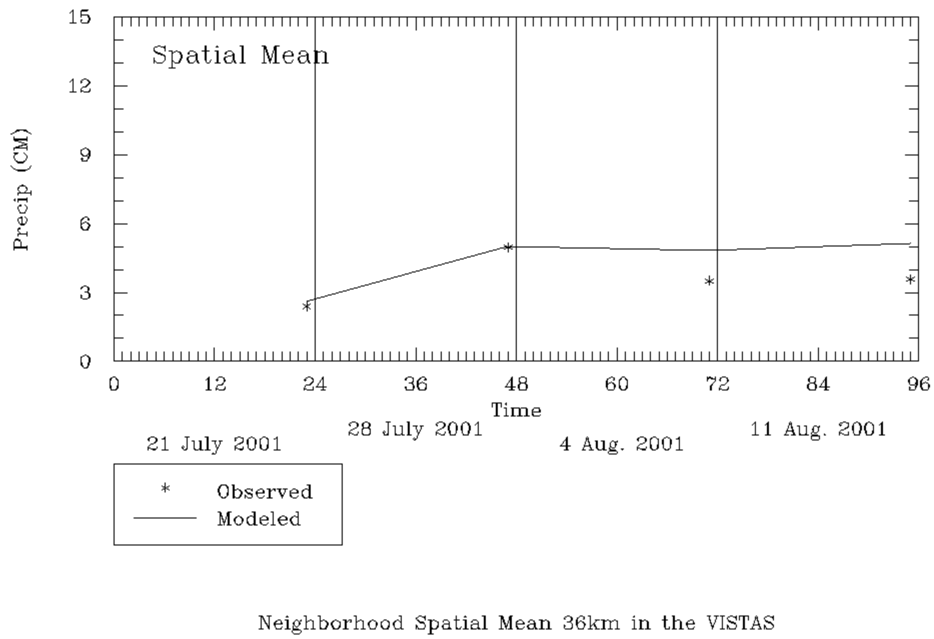


Figure 2-100: Model Estimated and Observed Mean Weekly Total Precipitation in the 12km Domain for the VISTAS States.

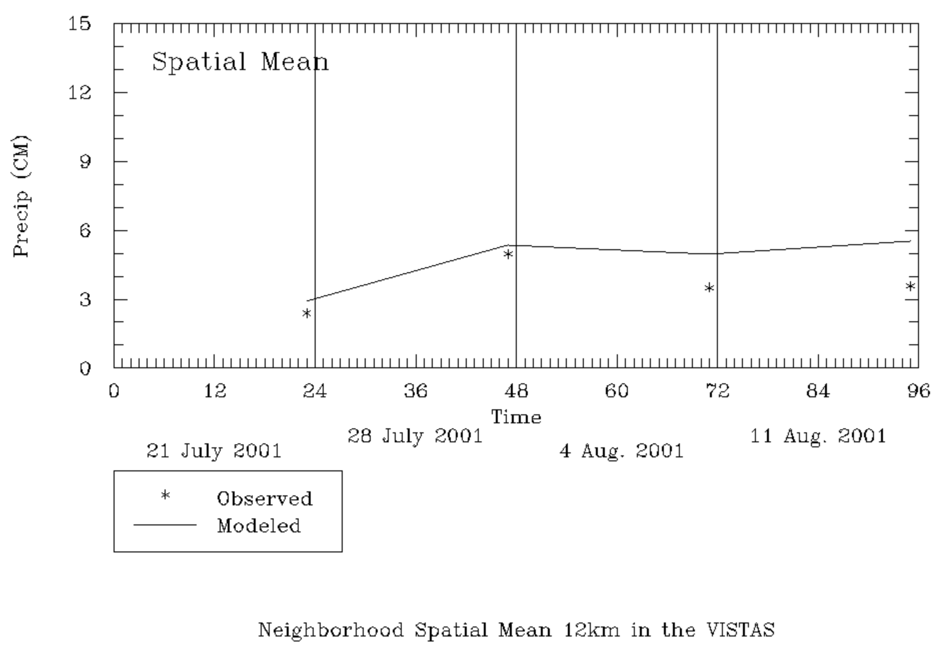


Figure 2-101: Model Estimated and Observed Mean Monthly Total Precipitation in the 36km Domain for the WRAP States.

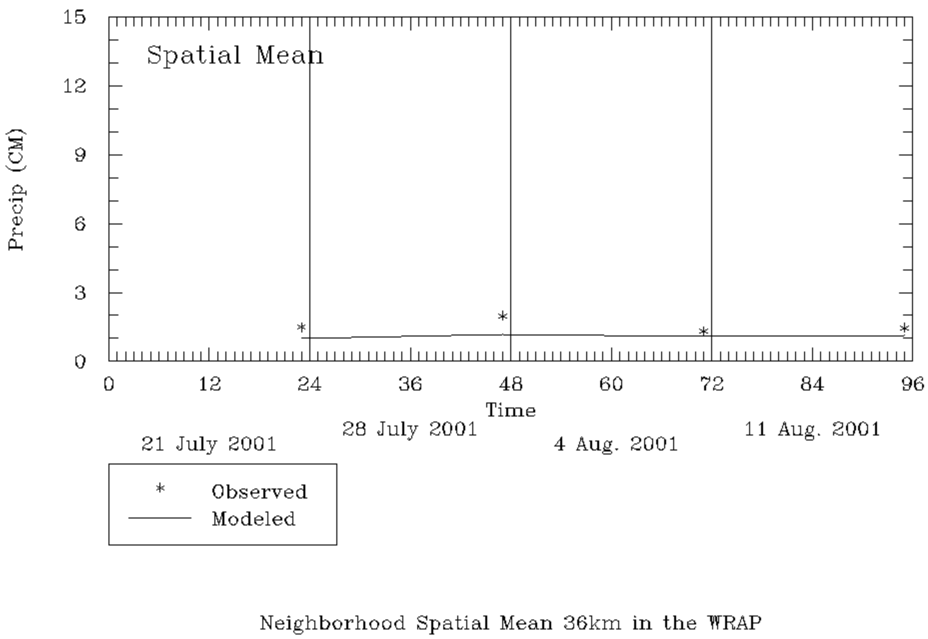


Figure 2-102: Model Estimated and Observed Mean Monthly Total Precipitation in the 12km Domain for the WRAP States.

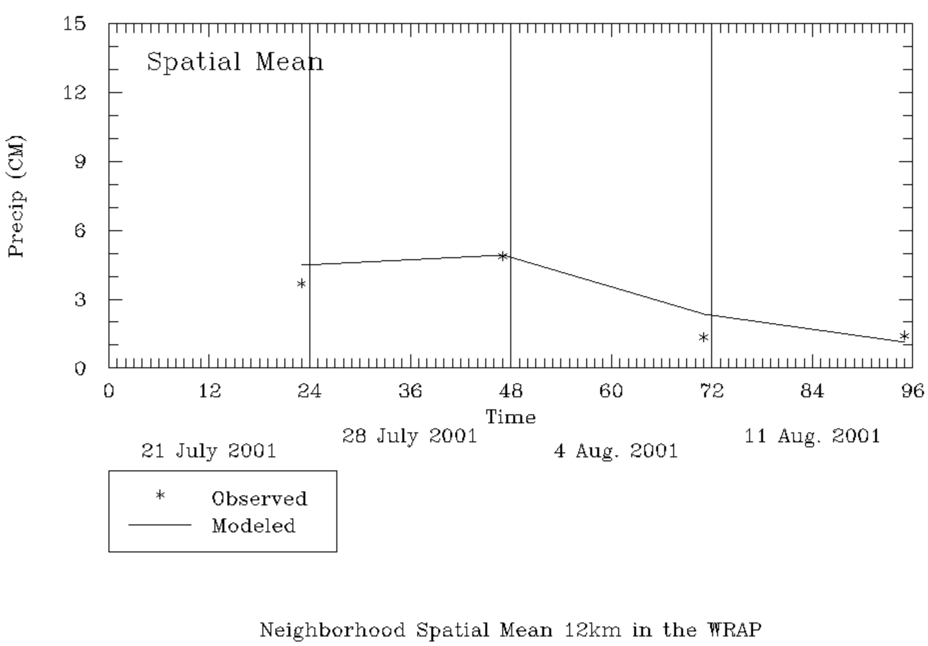


Table 2-7: Wind Index of Agreement by State and RPO in the 36km Grid.

Region	IA
ALL	0.90
AL	0.62
AK	0.69
AZ	0.73
AR	0.62
CA	0.78
CO	0.83
CT	0.47
DE	0.92
FL	0.77
GA	0.71
ID	0.65
IL	0.68
IN	0.57
IA	0.67
KS	0.69
KY	0.56
LA	0.82
ME	0.64
MD	0.49
MA	0.71
MI	0.73
MN	0.65
MS	0.55
MO	0.68
MT	0.79
NE	0.68
NV	0.75
NH	0.63
NJ	0.56
NM	0.79
NY	0.72
NC	0.64
ND	0.65
OH	0.59
OK	0.64
OR	0.81
PA	0.68
RI	0.49
SC	0.64
SD	0.80
TN	0.60
TX	0.79
UT	0.68
VT	0.60
VA	0.62
WA	0.76
WV	0.56
WI	0.67
WY	0.76
CENRAP	0.82
MANE_VU	0.76
MW	0.79
VISTAS	0.76

Table 2-8: Wind Index of Agreement by State and RPO in the 12km Grid.

Region	IA
ALL	0.89
AL	0.65
AR	0.63
CT	0.47
DE	0.68
FL	0.77
GA	0.73
IL	0.68
IN	0.60
IA	0.69
KS	0.69
KY	0.59
LA	0.69
ME	0.67
MD	0.62
MA	0.74
MI	0.74
MN	0.65
MS	0.57
MO	0.71
NE	0.68
NH	0.64
NJ	0.55
NY	0.71
NC	0.66
ND	0.65
OH	0.60
OK	0.65
PA	0.67
RI	0.56
SC	0.65
SD	0.70
TN	0.57
TX	0.79
VT	0.61
VA	0.63
WV	0.58
WI	0.68
CENRAP	0.82
MANE_VU	0.75
MW	0.80
VISTAS	0.77

Figure 2-103: Wind Speed Index of Agreement for the 36km Domain.

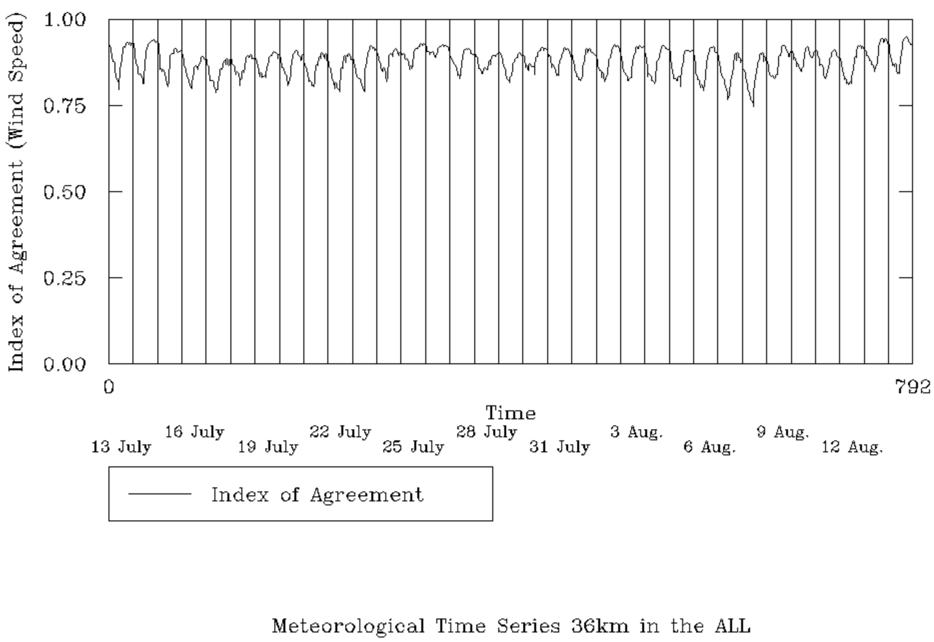


Figure 2-104: Wind Speed Index of Agreement for the 12km Domain.

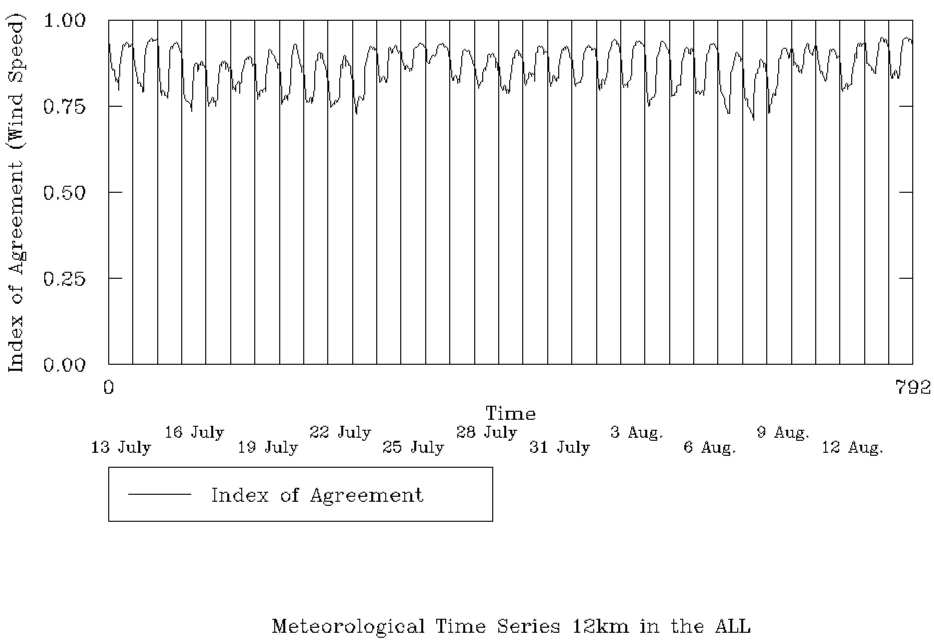


Figure 2-105: Wind Speed Index of Agreement in the 36km Domain for the CENRAP States.

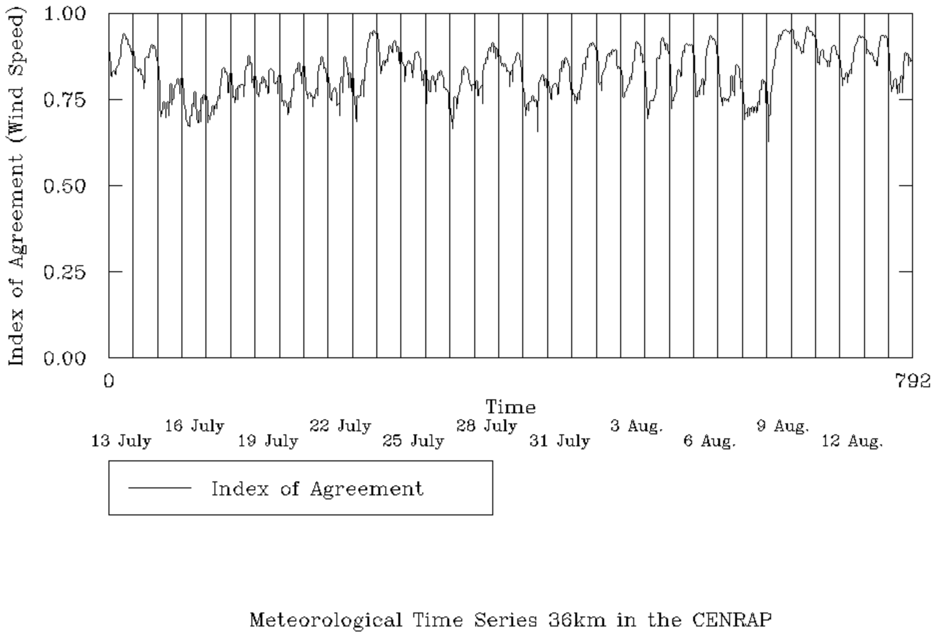


Figure 2-106: Wind Speed Index of Agreement in the 12km Domain for the CENRAP States.

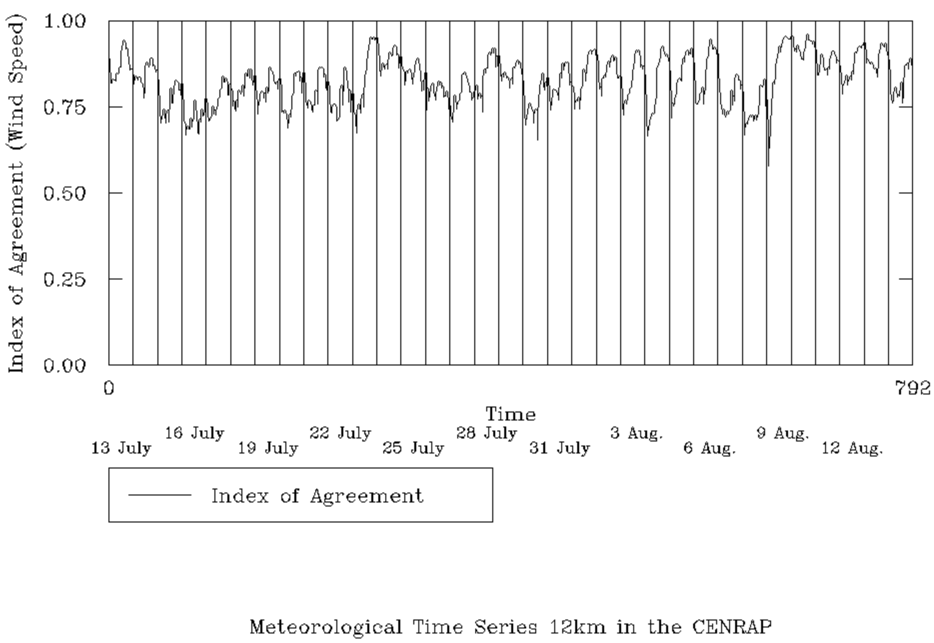


Figure 2-107: Wind Speed Index of Agreement in the 36km Domain for the MANE_VU States.

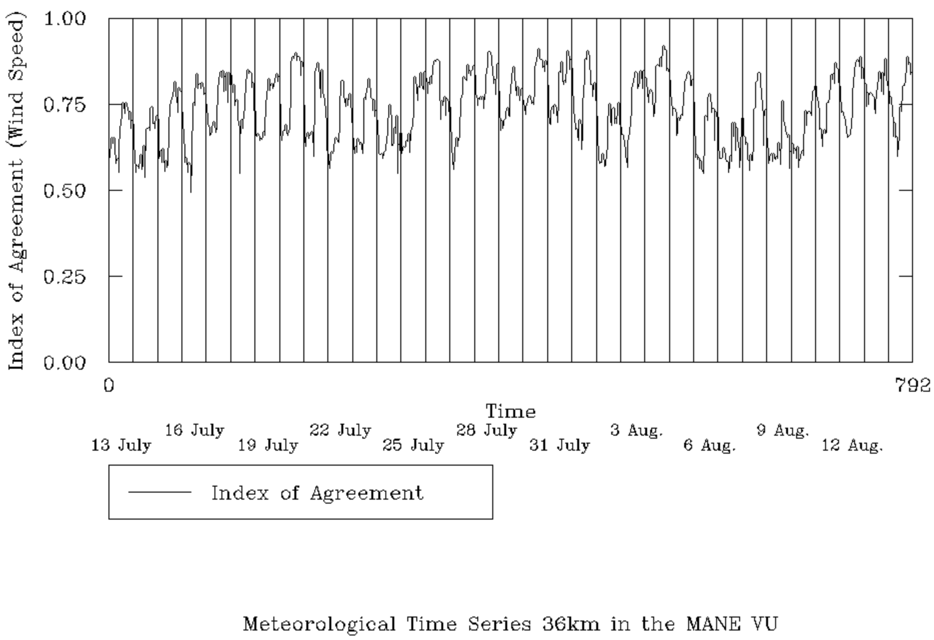


Figure 2-108: Wind Speed Index of Agreement in the 12km Domain for the MANE_VU States.

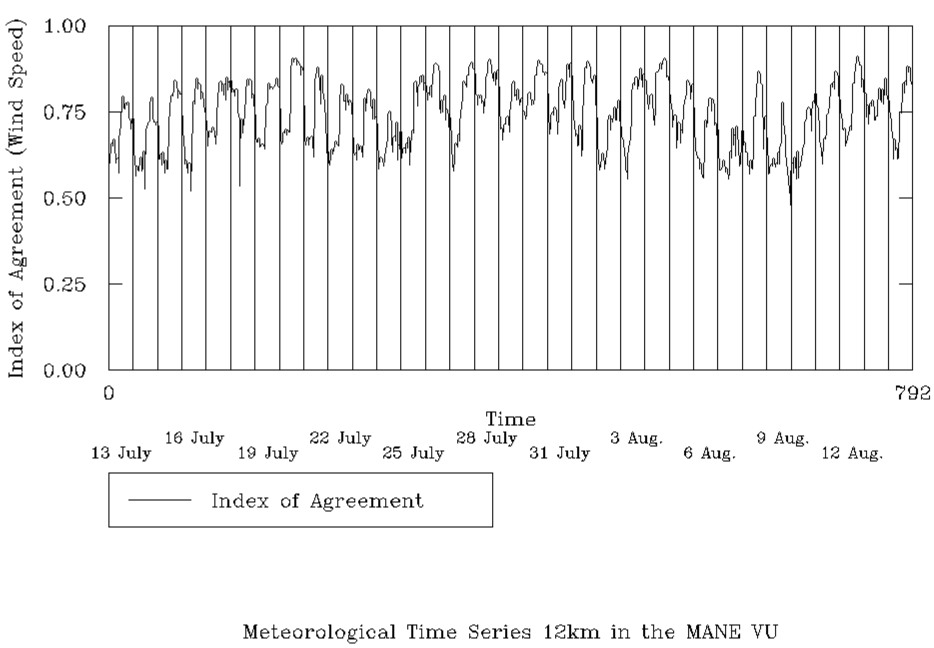


Figure 2-109: Wind Speed Index of Agreement in the 36km Domain for the Midwest RPO States.

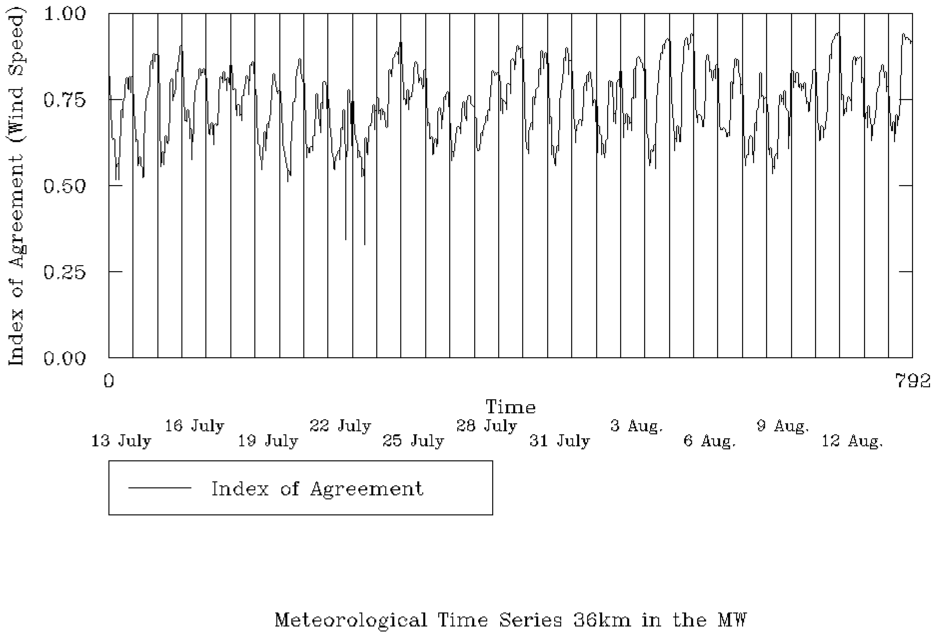


Figure 2-110: Wind Speed Index of Agreement in the 12km Domain for the Midwest RPO States.

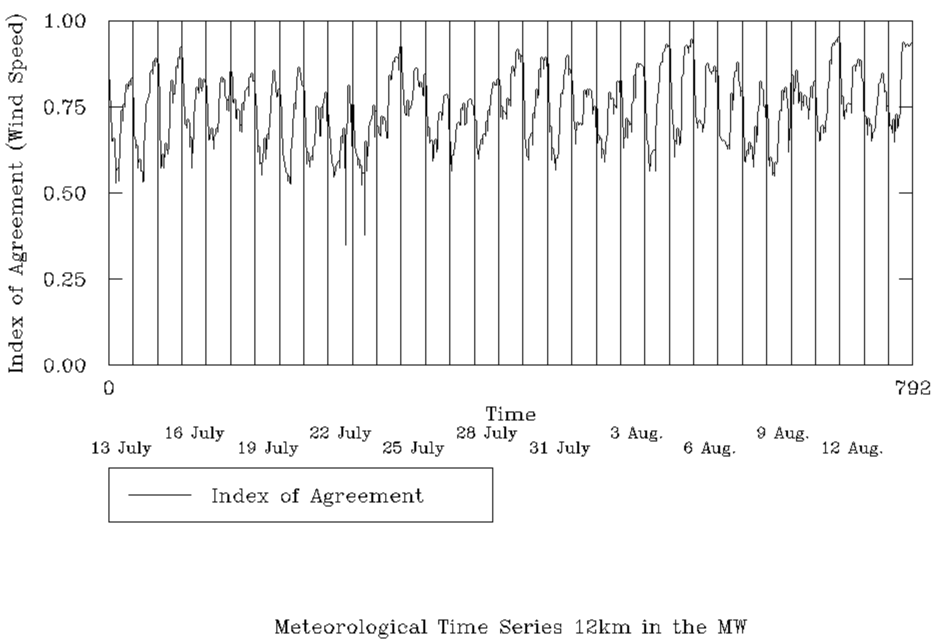


Figure 2-111: Wind Speed Index of Agreement in the 36km Domain for the VISTAS States.

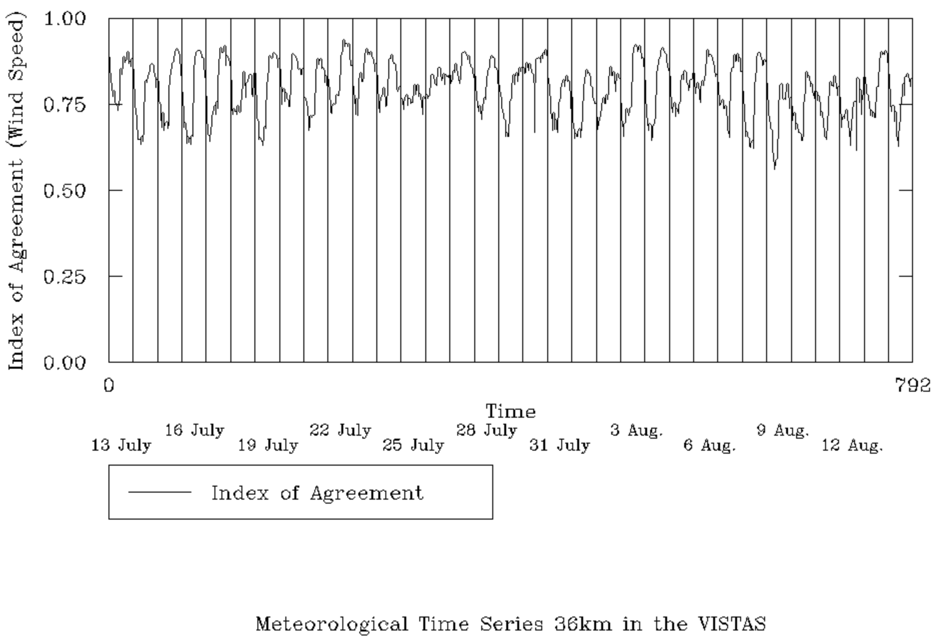


Figure 2-112: Wind Speed Index of Agreement in the 12km Domain for the VISTAS States.

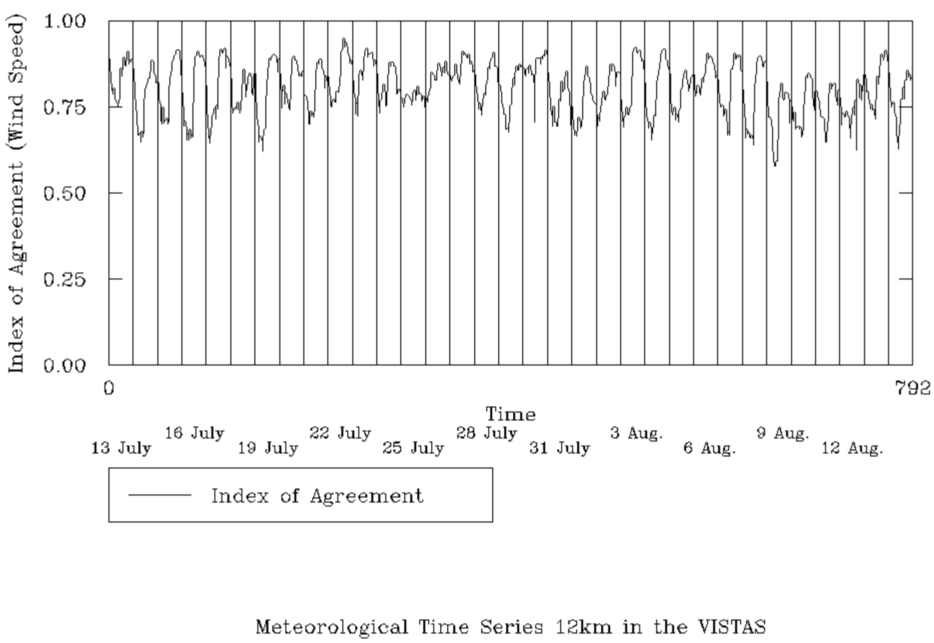


Figure 2-113: Wind Speed Index of Agreement in the 36km Domain for the WRAP States.

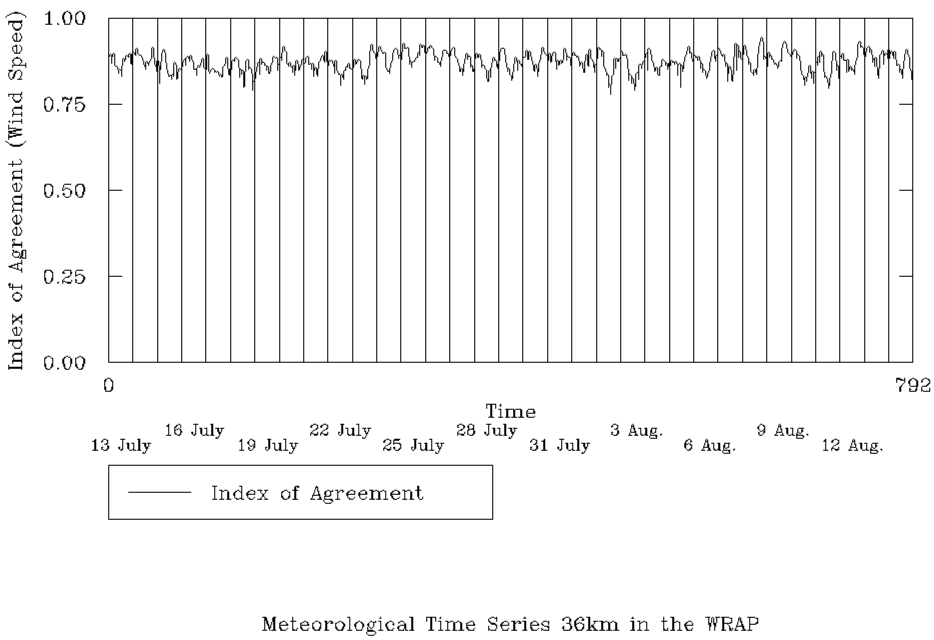
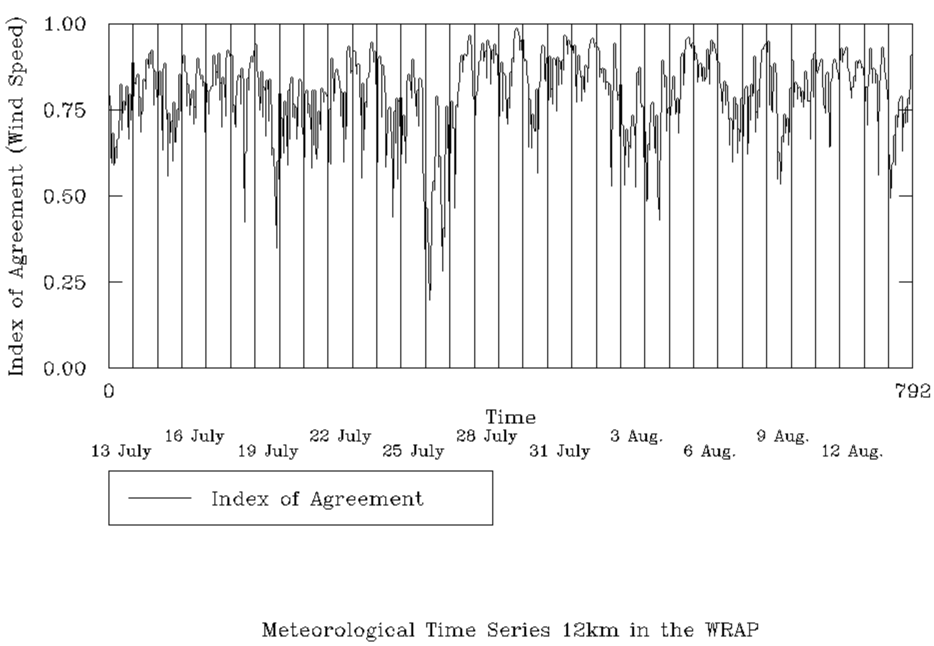


Figure 2-114: Wind Speed Index of Agreement in the 12km Domain for the WRAP States.



3 DISCUSSION

A key question addressed in this analysis is whether the 36/12 km nested MM5 meteorological fields contain any significant errors or flaws that might compromise their utility for use in supporting future air quality modeling and analysis.

While this analysis has not revealed the presence of significant flaws in the MM5 data sets, there is no simple way to answer definitively whether the meteorological fields are 'good enough'. First, there are no commonly accepted performance benchmarks for prognostic meteorological models that, if passed, would allow one to declare the MM5 fields appropriate for use. For complex atmospheric modeling problems like the ones likely to be addressed with this modeling dataset, it is quite doubtful that any set of quantitative performance criteria will ever be completely sufficient. Benchmarks are needed and useful, but they do not provide the whole answer. Additional performance evaluation procedures in the form of 'weight of evidence' analyses are also required to supplement these simplified statistical measures.

The question of meteorological data set adequacy depends, at a minimum, upon the specific host emissions and air quality models and the nature of the modeling episodes being used. Meteorological fields that might be adequate for use in an ozone model over a simple urban setting, for example, may be quite deficient in a seasonal PM episode over the great lakes region since the specific needs of the air quality model and the particular chemical and physical processes that must be simulated are different. Thus, quantitative statistical and graphical performance criteria, though helpful, are inherently insufficient in aiding modelers and decision-makers in deciding whether meteorological fields are adequate for air quality modeling. Other considerations must be brought to bear.

To add insight into the judgment of MM5 data set adequacy, we have adopted the process used in several recently completed air quality modeling studies (e.g., SAMI, PFOS, Denver/San Juan EAC's). These studies utilized a formalism employing meteorological model 'performance benchmarks' proposed by Emery et al., (2001) which draw on earlier work by Roth, Tesche and Reynolds (1998) and Tesche et al., (2000, 2003c,d). In particular, three recent studies (Tesche et al., 2000; 2003b; Emery et al., 2001) formulate a set meteorological model performance benchmarks based on the most recent prognostic meteorological model evaluation literature. The purpose of these benchmarks is not to assign a passing or failing grade to a particular meteorological model application, but rather to put its results into a useful decision-making context. These benchmarks have proven to be helpful to decision-makers in understanding how poor or good their results are relative to the range of other model applications in other areas of the U.S.

Since the mid 1990s, Alpine has performed nearly six dozen MM5 and RAMS model performance evaluations over grid scales ranging from 1.33 km to 36 km (see

Table 4-1). The results of these varied model evaluations provide a foundation against which to compare the current modeling results. Using this database as a guide, we consider the meteorological model performance benchmarks suggested by Emery et al, (2001):

Parameter	**Measure**	**Benchmark**
Wind Speed	**RMSE:**	**≤ 2 m/s**
	Bias:	**≤ ±0.5 m/s**
	IOA:	**³ 0.6**
Wind Direction	**Gross Error:**	**≤ 30 deg**
	Bias:	**≤ ±10 deg**
Temperature	**Gross Error:**	**≤ 2 K**
	Bias:	**≤ ± 0.5 K**
	IOA	**³ 0.8**
Humidity	**Gross Error:**	**≤ 2 g/kg**
	Bias:	**≤ ±1 g/kg**
	IOA:	**³ 0.6**

Table 4-2 presents the results of comparing the 12 km statistical results with the proposed meteorological modeling benchmarks and the results of the historical studies. Shaded cells in the table correspond to those meteorological variables that fall just outside of the benchmark ranges. For this episode on the 12 km grid, the surface temperature bias and error, mixing ratio bias and error, and wind speed average error, index of agreement, and RMSE error all fall within the benchmarks. In contrast, the surface wind direction difference fall somewhat outside of the *ad hoc* benchmarks.

Table 3-1: Summary of Prognostic Meteorological Model Evaluations.

No	Study	Domain	Model	Ref	Episode	Temp, (deg C)		MixR, (gm/Kg)		Surface Winds (m/s)			
						Bias	Error	Bias	Error	Error,%	RMSE	Indx A	WDir Dif
1	DAQM	Rocky Mtns	MM5	13	12-20 Jan '97	0.52	1.65	0.80	2.40	52.20	2.52	0.66	65.00
2	DAQM	Rocky Mtns	MM5	13	28-30 Dec '87	0.31	1.63	0.40	0.20	-5.20	2.76	0.71	2.00
3	SAMI	SE U.S.	RAMS	7	24-29 May '95	-1.00	1.90	0.10	0.80	35.00	1.90	0.76	13.00
4	SAMI	SE U.S.	RAMS	7	11-17 May '93	-1.50	2.10	-0.08	0.80	51.00	1.90	0.76	6.00
5	SAMI	SE U.S.	RAMS	7	23-31 Mar '93	-1.30	2.20	0.04	0.60	53.00	2.27	0.74	100.00
6	SAMI	SE U.S.	RAMS	7	8-13 Feb '94	0.50	2.10	-0.30	0.40	63.00	2.76	0.72	103.00
7	SAMI	SE U.S.	RAMS	7	3-12 Aug '93	-0.40	1.60	-0.60	1.10	65.00	2.18	0.75	25.00
8	SAMI	SE U.S.	RAMS	7	22-29 Jun '92	-1.10	1.80	0.10	1.00	66.00	1.89	0.75	20.00
9	SAMI	SE U.S.	RAMS	7	24Ap-3My '91	-0.80	1.80	-0.10	0.70	60.00	2.35	0.81	4.00
10	COAST '93	Cent. U.S.	MM5	11	4-11 Sept '93	0.20	1.80	0.10	1.40	61.40	2.20	0.69	15.00
11	COAST '93	Cent. U.S.	MM5	12	6-11 Sept '93	-0.30	1.90	2.37	12.79	50.00	1.77	0.55	65.00
12	COAST '93	Cent. U.S.	RAMS	12	6-11 Sept '93	-0.50	2.40	3.60	8.60	10.20	1.12	0.57	82.00
13	COAST '93	Cent. U.S.	SAIMM	12	6-11 Sept '93	-0.60	1.40	1.20	2.40	4.20	0.79	0.85	7.00
14	TexAQS2000	Cent. U. S.	MM5-T	12	25Aug-1 Sep '00	0.20	1.60	-0.50	1.90	13.20	1.88	0.61	14.00
15	TexAQS2000	Cent. U. S.	MM5-M	12	25Aug-1 Sep '00	-0.40	2.00	0.20	2.30	19.47	1.96	0.44	27.00
16	TexAQS2000	Cent. U. S.	MM5-NG	14	25Aug-1 Sep '00	0.30	1.50	-0.30	1.20	21.20	1.94	0.65	33.00
17	TexAQS2000	Cent. U. S.	RAMS-PNL	14	28ug-1 Sep '00	1.30	2.50	-0.60	1.80	-5.97	1.68	0.50	7.00
18	PFOS-1	SE U.S.	MM5	10	16-24 Apr '99	0.10	1.50	-0.10	1.20	20.90	1.94	0.78	10.00
19	PFOS-2	SE U.S.	MM5	10	2-10 May '97	0.20	1.60	0.10	1.20	21.00	1.95	0.78	32.00
20	PFOS-3	SE U.S.	MM5	10	25-30 Aug '97	0.20	1.70	-2.00	2.30	30.60	1.86	0.73	32.00
21	PFOS-4	SE U.S.	MM5	10	4-10 Apr '99	-0.40	1.30	0.80	1.50	18.10	1.80	0.80	8.00
22	PFOS-5	SE U.S.	MM5	10	17-23 Sep '97	0.10	1.60	-0.40	1.60	27.90	1.84	0.72	9.00
23	PFOS-7	SE U.S.	MM5	10	25-28 Aug '98	0.20	1.50	0.90	1.80	51.20	1.76	0.78	32.00
24	PFOS-7	SE U.S.	MM5	10	8-10 May '99	0.20	2.20	0.30	1.40	49.80	1.69	0.77	19.00
25	PFOS-8	SE U.S.	MM5	10	20-28 Apr '98	0.40	1.50	0.00	1.00	27.90	1.83	0.81	20.00
26	PFOS-9	SE U.S.	MM5	10	26Jul-1Aug '99	0.30	2.40	-0.30	1.20	33.20	1.90	0.81	22.00
27	PFOS-resrch	SE U.S.	MM5	10	18-24 Apr '98	0.30	1.30	-0.20	0.90	24.00	1.79	0.78	26.00
28	MoKAN	Midwest U.S.	MM5	8	8-15 Jul '95	0.20	1.70	-0.60	1.60	10.30	1.86	0.41	1.00
29	MoKAN	Midwest U.S.	MM5	8	14-21 Aug '98	2.00	2.30	2.40	2.60	47.50	1.83	0.45	4.00
30	MoKAN	Midwest U.S.	MM5	8	11-24 Jun '95	-0.30	1.60	-0.90	1.30	31.60	1.88	0.48	20.00
31	Pittsbrg SIP	East U.S.	MM5	1	31Jul-2 Aug '95	0.80	2.40	0.20	2.20	12.60	1.78	0.75	8.00
32	SARMAP	West U.S.	MM5	4	3-6 Aug '90	0.20	2.90	-0.20	1.90	22.60	2.13	0.80	3.00
33	CRC-LMOS	Midwest U.S.	RAMS	6	26-28 June '91	0.10	1.40	-0.10	1.20	11.90	1.82	0.69	17.00
34	CRC-LMOS	Midwest U.S.	RAMS	6	17-19 Jul '91	0.00	1.90	0.40	1.40	3.50	1.73	0.64	7.40
35	CRC-LMOS	Midwest U.S.	MM5	6	26-28 Jul '91	-0.50	1.60	-0.10	1.20	5.80	1.70	0.79	14.00
36	CRC-LMOS	Midwest U.S.	MM5	6	17-19 Jun '91	-0.30	1.70	-0.60	1.50	15.60	1.65	0.77	7.00

No	Study	Domain	Model	Ref	Episode	Temp, (deg C)		MixR, (gm/Kg)		Surface Winds (m/s)			
37	OTAG	East U.S.	RAMS	3	13-21 Jul '91	1.60	2.10	0.00	1.20	4.60	1.61	0.74	27.00
38	OTAG	East U.S.	MM5	3	13-21 Jul '91	-0.10	2.00	-0.30	1.40	23.00	1.92	0.73	17.00
39	OTAG	East U.S.	MM5	2	1-11 Jul '88	-0.60	3.30	-1.40	2.00	65.60	3.21	0.64	8.00
40	OTAG	East U.S.	MM5	1	12-15 Jul '95	-0.20	2.00	-1.50	2.20	21.20	1.91	0.68	15.00
41	Cincy SIP	Midwest U.S.	MM5	5	18-22 Jun '94	-0.70	2.40	-1.60	2.20	82.40	2.69	0.80	0.00
42	BAMP	SE U.S.	MM5	9	6-11 Sept '93	-0.40	2.10	-0.60	1.00	89.40	2.36	0.60	22.00
43	BAMP	SE U.S.	MM5	9	15-19 Aug '93	-0.30	2.40	-1.50	1.90	93.60	2.66	0.65	120.00
44	Den EAC-pro	Western U.S.	MM5	15	15-21 Jul '02	-1.10	2.25	0.20	1.83	-10.38	2.32	0.82	17.00
45	Den Sum '02	Western U.S.	MM5	18	6 Jun-19 Jul '02	-1.90	3.00	0.50	1.90	0.00	2.34	0.85	27.00
46	Denver E1	Western U.S.	MM5	18	16-22 Jul '02	0.45	2.30	-0.66	1.57	-5.70	2.61	0.78	60.00
47	Denver E2	Western U.S.	MM5	18	24 Jun-2 Jul '02	0.65	2.75	-0.17	1.59	33.30	2.77	0.80	29.00
48	Denver E3	Western U.S.	MM5	18	8-12 Jun '02	0.19	2.39	-0.58	1.63	65.90	2.59	0.84	38.00
49	San Juan pro	Western U.S.	MM5	15	30 Jul-5 Aug '00	-1.03	2.93	-0.66	2.11	6.00	2.50	0.80	24.00
50	SJ Sum '02	Western U.S.	MM5	19	4 Jun-23 July '02	-0.40	2.40	-1.20	1.80	54.50	2.28	0.88	11.00
51	San Juan E1	Western U.S.	MM5	19	4-9 Jun '02	-0.18	2.20	-0.69	1.16	20.60	3.10	0.72	0.00
52	San Juan E2	Western U.S.	MM5	19	16-19 Jun '02	0.04	2.12	-0.69	1.40	17.80	2.95	0.70	22.00
53	San Juan E3	Western U.S.	MM5	19	30 Jun-3 Jul '02	0.90	2.18	-0.71	1.28	16.40	3.47	0.70	50.00
54	San Juan E4	Western U.S.	MM5	19	16-19 Jul '02	0.68	2.15	-0.73	1.45	5.88	3.29	0.71	30.00
55	WE Energ-12	Midwest U.S.	MM5	17	16 Jun-14 Aug '01	-0.20	1.70	-0.30	1.46	37.93	1.87	0.82	5.00
56	EPA/MM5	Entire U.S.	MM5	16	1 Jan -31 Dec '01	-0.60	2.08	-0.19	0.97	33.00	2.00	0.86	25.00
57	VISTAS-1	Southeast US	MM5	20	2-20 Jan '02	-1.48	2.38	0.16	0.49	30.58	1.94	0.86	4.73
58	EPA/MM5	Entire U.S. (36)	MM5	21	12 July – 14 Aug '01	-0.77	2.04	-0.32	1.63	29.03	2.01	0.87	21.44
59	EPA/MM5	Eastern U.S. (12)	MM5	21	12 July – 14 Aug '01	-0.41	1.64	-0.92	1.86	37.17	1.85	0.86	1.12
	Ad Hoc	***Benchmark***				0.50	2.00	1.00	2.00		2.00	0.60	30.00
	Mean in U.S.					-0.10	2.00	-0.12	1.78	31.71	2.11	0.72	24.62
	Lower Sigma					-0.82	1.55	-1.04	0.00	6.75	1.60	0.61	0.00
	Upper Sigma					0.62	2.45	0.80	3.58	56.68	2.62	0.84	50.43
	Std. Dev.					0.72	0.45	0.92	1.81	24.97	0.51	0.11	25.82

Table 3-2: Summary of MM5 Performance on the 12km Grid Domain. [Comparisons Relative to the Ad-Hoc Performance Benchmarks and Previous Experience in Regulatory Modeling Studies.]

Episode	Temperature, deg C		Mixing Ratio, gm/Kg		Surface Wind, m/s			
	Bias	Error	Bias	Error	Error	RMSE	I	WD diff
July-Aug '01	-0.41	1.64	-0.92	1.86	37.17%	1.85	0.86	37.17
Benchmark	$\leq \pm 0.5$	≤ 2.0	$\leq \pm 1.0$	≤ 2.0	--	≤ 2.00	≥ 0.60	≤ 30
U.S. Average	-0.10	2.00	-0.12	1.78	31.7%	2.11	0.72	25

Note: Shading indicates instances where the episode composite statistics fall outside the *Ad Hoc* performance goals for mesoscale meteorological models. These goals have no regulatory significance; they are merely intended to assist in the interpretation and evaluation of alternative prognostic mesoscale model simulations for air quality studies.

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