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Subject: Changes to the NCEP Regional Analysis and Forecast System (RAFS) : Initial conditions for the Nested Grid Model (NGM)

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This bulletin was written by Eric Rogers, Geoffrey DiMego and David Parrish of the Mesoscale Modeling Branch, Environmental Modeling Center, National Centers for Environmental Prediction. It describes the changes to the Changes to the NCEP Regional Analysis and Forecast System (RAFS) : Initial conditions for the Nested Grid Model (NGM).

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Changes to the NCEP Regional Analysis and Forecast System (RAFS) : Initial conditions for the Nested Grid Model (NGM)

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I. Introduction

The Regional Analysis and Forecast System (RAFS, Hoke et al., 1989) was implemented by the National Meteorological Center (now the National Centers for Environmental Prediction (NCEP)) on 27 March 1985. These are the major milestones in the development of RAFS:

MARCH 1985:
Model : Nested Grid Model (NGM; Phillips, 1979): sigma coordinate with 16 vertical levels, hemispheric model, 3 nested grids with two-way interactive boundaries, innermost grid resolution approximately 80 km over North America

Analysis: Regional Optimum Interpolation (ROI; DiMego 1988); 6-h forecast from the NCEP Global Data Assimilation System (GDAS) used for first guess

Initialization : Non-linear normal mode (Carr et al., 1989)

DECEMBER 1988:
Initialization : Implicit normal mode (Parrish 1989)

AUGUST 1991
Model: Changed from three to two nested grids (Fig. 1), innermost grid expanded

Analysis : First guess obtained from the Regional Data Assimilation System (RDAS; DiMego et al. 1992), a 12-h intermittent data assimilation scheme with 3-h ROI analysis updates and 3-h NGM forecasts.

The August 1991 implementation constituted the "final" set of changes to the RAFS. The system was frozen after August 1991 to avoid compromising the efforts of the Techniques Development Laboratory (TDL) to develop Model Output Statistics (MOS) guidance from a fixed configuration of the NGM.

II. Rationale for changes to the RAFS

The 27 September 1999 fire at the NOAA Central Computing Facility in Suitland, Maryland, which destroyed NCEP's Cray C-90 supercomputer, necessitated moving the RAFS to a backup system on a slower Cray J-90 machine. Although the new IBM-SP Class VIII computer was installed and undergoing testing by this time, the NGM had not yet been converted to run on this computer. Since the backup Cray is 3-4 times slower than the C-90, there is no time to run the RDAS. Therefore, the RAFS uses a GDAS forecast as first guess to the ROI analysis. With the RAFS running on a slower computer, NGM products are now available for users about one hour later then they were before the fire.

Anticipating the possible discontinuance of the NGM MOS products in the future, TDL has been developing MOS guidance from the Aviation (AVN) run of the NCEP Global Spectral Model. A one year test period is planned during which both the AVN and NGM MOS will be available to NWS and private sector forecasters. TDL anticipates that the full AVN MOS package will be ready for distribution by April 2000. Since there are no funds available to keep the Cray J-90 computer in operations beyond March 2000, a capability to run the NGM on the IBM-SP computer is required. Conversion of all codes to run both the NGM and the RDAS, with the redesign of the NGM to use the new Message Passing Interface (MPI) on the IBM, would take approximately 2 person years. Such a concentrated effort of this magnitude, which would severely impact development of the NCEP Eta mesoscale model, was deemed not to be cost effective.

Instead, a strategy has been developed to allow for conversion of fewer RAFS codes to the IBM SP. This calls for the NGM to be initialized from the "Early" Eta 3-d variational analysis (3DVAR; Rogers et al., 1998, 1999) over North America and from a GDAS forecast over the rest of the hemisphere. This strategy also calls for running all codes on a single node of the IBM-SP, thus eliminating the need for MPI. While the NGM code runs slower on the IBM than it did on the Cray C-90, use of the Early Eta analysis instead of the ROI analysis to initialize the model allows for the NGM job to be started approximately 45-60 minutes sooner. With this earlier start the NGM will finish at roughly the same time as it did on the Cray C-90 computer, or roughly 60-70 minutes sooner than it is currently finishing on the slower Cray J-90.

III. The NGM on the IBM-SP : Configuration and differences from the Cray version

Fig. 1 shows the two-grid system which has been used in the NGM since 1991. Since the demise of the RDAS, the RAFS suite starts by getting the best available NCEP Global Spectral Model forecast and interpolating it vertically to the 16 NGM vertical levels and horizontally to all NGM grid points. At T+2:10 h (T=00Z or 12Z) all available observations within both grids are ingested and the difference between the GDAS forecast values and observations (called the observation increment) is obtained. After quality control is performed to remove unrealistic observations, a ROI analysis of the observed increments is performed to get the analyzed increment. The analysis increment is then added to the GDAS forecast to get the full-field analysis. After the implicit normal mode initialization is performed, a 48-h NGM forecast is done.

Fig. 2 shows the new two-grid configuration of the NGM. Since the Early Eta domain (dotted outline in Fig 2) does not extend beyond the North Pole into Europe and Asia, the higher resolution B-grid was modified to be similar in size to the Eta computational grid. Thus, to perform an NGM forecast on the IBM-SP, the following steps are taken:

The best available NCEP global spectral model forecast (usually the 6-h forecast from the NCEP Final 06Z or 18Z analysis) is interpolated to both NGM grids.

The Eta analysis is interpolated to NGM vertical levels and to all NGM B-grid points within the computational domain of the Eta model, replacing the values from the GDAS forecast in the NGM initial condition file. For B-grid points outside of the Eta domain, the GDAS forecast is used. Since the top of the Eta model is at 25 mb, one would have to extrapolate the Eta analysis to get values in the top layer of the NGM. To avoid potential problems caused by vertical extrapolation of the Eta analysis, the values from the GDAS forecast are used in the top NGM layer.

The implicit normal mode initialization is performed.

A 48-h NGM forecast is done, with boundary values for the fine resolution B-grid obtained from the forecast on the coarse resolution A-grid.

There are potential advantages and disadvantages by using the Eta analysis to initialize the NGM:

ADVANTAGES

Possible positive impact of observation types used by the Eta 3-d variational analysis which are not used by the Regional OI analysis, such as aircraft temperatures, surface winds over land, VAD winds from NEXRAD radars, GOES (land and ocean) and SSM/I (ocean only) retrieved precipitable water data, and SSM/I oceanic surface winds.

Possible positive benefit to the NGM forecast through improvements to the Eta analysis, such as direct use of satellite radiances, NEXRAD radial velocities, and assimilation of hourly precipitation data.

DISADVANTAGES

Possible degradation due to the lack of an analysis update on all of the A-grid and any part of the B-grid outside of the Eta model domain.

Since the Eta runs in the NCEP early slot, the data cutoff time is 71 minutes after 00Z or 12Z, as opposed to 127 minutes after 00Z or 12Z for the RAFS. Therefore, any data which arrives after 0111Z or 1311Z would not be available for use in the Eta analysis and by default, in the NGM initialized from that analysis. An example of the difference in data coverage is shown by the plot of satellite temperature retrievals available to the Eta analysis (Fig. 3) and the RAFS analysis (Fig. 4) at 00Z 14 February 2000. For the Eta analysis, satellite temperature data coverage was limited to the area south of 35N and west of 130W. Since the RAFS has a later data cutoff time, it obtained additional TOVS data located further north and west. The Eta uses TOVS data with higher resolution (80 km vs. 220 km in the RAFS), which explains the higher data density. The rawinsonde coverage for the Eta and RAFS analyses at the same time is shown in Fig. 5 and Fig. 6, respectively. For this time all North American stations were used in both analyses, including those in Mexico (which occasionally arrive too late to be included in the Eta analysis). Also at this time there are three dropwindsonde observations east of Hawaii and two in the Atlantic which were transmitted too late to be included in the Eta analysis.

Any systematic bias in the Eta model could be introduced to the NGM since the Eta model is initialized with the Eta Data Assimilation System (EDAS, Rogers at al 1996), which consists of 3-h Eta model forecasts and analysis updates. Since June 1998 the EDAS has been run with full cycling of atmospheric variables and soil parameters.

IV. Verification

Two parallel tests of the new version of the NGM have been made: the current parallel test which started at 12Z 16 December 1999 and a warm season retrospective test from 2 July - 2 August 1999. The complete set of verification charts for both tests can be found at http://sgi62.wwb.noaa.gov:8080/NGMSTAT/ . Computed were 1) the forecast bias and root-mean-square (RMS) error versus rawinsonde height, wind, temperature, and relative humidity data over the contiguous US (CONUS) and Alaska, 2) both time series and cumulative bias / RMS errors of forecast surface temperatures over the CONUS, and 3) 24-h forecast precipitation skill scores over the CONUS. Highlights from these results are presented below:

a. Fits to Rawinsondes - Cold Season

The vertical distribution of the RMS error versus rawinsondes over the CONUS for the 12-h, 24-h, and 48-h operational and parallel NGM forecasts from 16 December 1999 - 14 February 2000 are shown in Fig. 7 (height), Fig. 8 (temperature), Fig. 9 (vector wind) and Fig. 10 (relative humidity. For height, temperature and wind there are small differences in RMS error at all 3 forecast times between the surface and 500 mb. Above 500 mb there is a tendency for the parallel NGM to have higher RMS errors, especially for geopotential heights. For winds, the greatest difference between the operational and parallel NGM is at the jet stream level between 300 and 200 mb. In examination of the 00-h Eta and parallel NGM 250 mb wind charts, the author occasionally observed that wind maxima in the Eta analysis (such as the subtropical jet in the eastern Pacific) would be lower by 10-15% after interpolation to the NGM vertical levels. Vertical resolution at jet level of the current 32-km, 45 level Eta model is 25-30 mb, while in the NGM it is 70-75 mb. It is possible that details are lost during the vertical interpolation (especially for intense, narrow jet streaks) of wind. For relative humidity over the CONUS there are small differences between the two NGM forecasts

Over Alaska (Fig. 11) the difference or spread between the operational and parallel NGM vector wind RMS errors is similar to that observed over the CONUS in Fig. 9. This indicates that the absence of an analysis update on the coarse resolution A-grid does not disproportionally worsen forecast skill in regions close to the A-grid/B-grid interface.

b. Fits to Rawinsondes - Warm Season

The vertical distribution of RMS error versus rawinsondes over the CONUS for the 12-h, 24-h, and 48-h operational and parallel NGM forecasts from 2 July 1999 - 2 August 1999 are shown in Fig. 12 (height), Fig. 13 (temperature), Fig. 14 (vector wind) and Fig. 15 (relative humidity. For heights, RMS errors for the parallel NGM are higher at 12-h and 24-h, similar to the cool season results, but are lower than the operational NGM by 48-h. The warm-season RMS temperature errors are uniformly lower in the parallel NGM than in the operational NGM through most of the middle and upper troposphere. Vector wind errors are slightly lower in the parallel run at most pressure levels, while the relative humidity errors are generally lower in the first 24-h of the parallel NGM forecast. This could reflect the improvement in the initial moisture in the parallel NGM through the use of GOES and SSM/I precipitable water data in the Eta analysis.

c. Fits to surface temperature data

For NWS field forecasters and private users one of the most important products from the NGM is the MOS guidance, which includes predicted temperatures every 3-h at station locations over North America. TDL is producing the full MOS package from the parallel NGM run as part of the overall evaluation. Although TDL's results are not available as this bulletin is being written, a possible hint to NGM MOS temperature performance can be inferred from the cumulative fit of the operational and parallel NGM surface temperature forecasts to surface observations over the CONUS, shown in the tables below:

TABLE 1: Mean bias and RMS surface temperature errors (deg C) for the operational and parallel NGM forecasts over the CONUS from 12Z 16 December 1999 - 00Z 14 February 2000

Forecast Hour	OPER NGM RMS Error	Parallel NGM RMS Error	OPER NGM Bias Error	Parallel NGM Bias Error
12	4.86	4.58	3.09	2.79
24	5.29	5.14	3.44	3.31
48	5.51	5.58	3.44	3.52

TABLE 2: Mean bias and RMS surface temperature errors (deg C) for the operational and parallel NGM forecasts over the CONUS from 00Z 2 July 1999 - 12Z 2 August 1999

Forecast Hour	OPER NGM RMS Error	Parallel NGM RMS Error	OPER NGM Bias Error	Parallel NGM Bias Error
12	5.34	5.26	3.95	3.87
24	5.80	6.05	4.35	4.70
48	5.83	6.10	4.25	4.61

Overall, the differences in the surface temperature errors are small, with the mean bias difference no greater that 0.36ºC. The performance of the parallel NGM tends to be slightly worse in the warm season, which may reflect a warm bias in the Eta model (which would transmitted to the parallel NGM through 3-h Eta model forecasts during the Eta Data Assimilation System (EDAS)).

d. 24-h Accumulated Precipitation - Bias and Equitable Threat Scores

The bias score and equitable threat score for operational and parallel NGM forecasts of 24-h accumulated precipitation are presented in Fig. 16 and Fig. 17, respectively, for the period 12Z 12/16/1999 - 00Z 2/14/2000. Over the CONUS, there is a 5-10% decrease in both skill scores for the cool season test. In an attempt to gain more insight to the degradation in forecast precipitation skill, equitable threat scores were computed for the two regions (western and eastern U.S.) shown in Fig. 18. From these regional scores (Fig. 19 and Fig. 20) it is clear that almost all the degradation is occurring in the western U.S. Three factors may be contributing this degradation: possible problems with the Eta 3DVAR analysis is the eastern Pacific, analysis uncertainty in the eastern Pacific due to the earlier data cutoff time, and a less accurate forecast on the A-grid in the parallel NGM, since no analysis update is done. Any error in the A-grid forecast would be propagated to the B-grid via the two-way interactive boundary condition interaction between the A-grid and he B-grid.

An example which illustrates the above problem is seen in the operational (Fig. 21) and parallel (Fig. 22) NGM forecasts of 24-h accumulated precipitation valid at 12Z 2/4/2000. This case (Cairns, personal communication), was notable in that the Eta model (not shown) failed to predict snowfall over the crest of the Sierra Nevada mountains in California, while the operational NGM did predict precipitation in this region. As seen in Figs. 21 and 22, the operational NGM predicted a much stronger offshore precipitation band, while the parallel NGM did not predict precipitation over t(not showne he Sierra Nevada region at all, similar to the Eta forecast (not shown). Examination of the Eta moisture analysis (not shown) revealed that at 12Z 2/3/2000 the Eta 3DVAR analysis decreased the deep layer moisture (when compared to the EDAS first guess) by 5-10% along the southern part of the offshore frontal boundary. At 500 mb (not shown) the offshore low/trough in the 00, 12, and 24-h forecasts was ~60 m deeper in the operational NGM. Since the parallel NGM precipitation forecast closely resembles the Eta forecast, it is clear that Eta analysis deficiencies over the Pacific is the probable reason for the differences between the NGM precipitation forecasts. It is hoped that the direct assimilation of satellite radiance data in the Eta 3DVAR analysis (planned to be operational by fall 2000) will help alleviate the persistent problems seen in the eastern Pacific during the cool season, with positive benefits for the NGM forecasts initialized from this analysis.

The precipitation scores for the warm season parallel (Fig. 23 and Fig. 24) show smaller differences between the operational and parallel NGM forecasts then was seen in the cool season scores described above. The eastern and western U.S scores for the warm season test (not shown) at http://sgi62.wwb.noaa.gov:8080/NGMSTATS/ reveal that although the eastern U.S. scores are better than in the west, there is much less degradation in the western U.S. then was seen in the cool season scores. The greater degradation seen in the western U.S. during the cool season reinforces the impression that the EDAS/Eta has problems in the eastern Pacific, especially with major precipitation producing systems. Although the other changes in the parallel NGM (smaller B-grid, A-grid initialized from a 6-h forecast) may also contribute to this problem, they are probably not a major factor given the lack of severe degradation seen in Alaska as described above.

V. Forecast example : the East Coast Storm of 24-25 January 2000

The storm of 24-25 January 2000 produced severe winter weather in all major metropolitan areas of the eastern United States, extending from North Carolina into New England. Snowfall totals in excess of 12 inches were reported at many locations throughout the mid-Atlantic states. Although the NCEP short-range models did predict off-shore cyclogenesis, model forecasts initialized 12-h to 24-h prior to the event failed to predict the location and intensity of the precipitation over the heavily populated areas of the northeastern U.S.

Fig. 25 shows the 24-h forecast precipitation valid at 12Z 1/25/2000 from the operational and parallel runs of the NGM. Although neither forecast predicted precipitation in the Baltimore / Washington area (which ultimately received 6-19 inches of snow), the parallel NGM forecast did predict heavier amounts over the Delmarva peninsula and extreme southeastern Virginia. The parallel NGM predicted the surface cyclone to be much closer to the coastline than the operational NGM (Fig. 26). Big differences are seen at 500 mb (Fig. 27), with a stronger vorticity maximum associated with the oceanic cyclone and with the upstream short-wave trough over the Great Lakes. In general, the parallel NGM resembled the forecast from the operational Eta (not shown). A detailed analysis of NCEP model performance for this storm can be found at http://www.emc.ncep.noaa.gov/mmb/research/blizz2000 .

VI. Conclusion

The performance of the IBM-SP version of the RAFS, in which the NGM is initialized from the operational Eta analysis, has been described in this bulletin. During the warm season test, there were small differences between the operational and parallel NGM forecasts when verified against rawinsonde data, 24-h observed precipitation data, and surface temperature observations. During the cool season, the results vary by pressure level and by region. In the lower and middle troposphere over the CONUS and Alaska, there were small differences in the error statistics versus rawinsondes between the two NGM forecasts. Over the CONUS there was little difference in the fit of the parallel NGM forecasts to the surface temperature observations. In the eastern U.S. there were small differences between the operational and parallel NGM forecast precipitation skill scores. In the western U.S., the parallel NGM did show less skill in forecasting precipitation, which is probably due (in order of importance) to: 1) deficiencies in the Eta analysis over the eastern Pacific during the winter months, 2) fewer oceanic observations ingested in the Eta analysis due to the earlier data cutoff time, and 3) no analysis update on the 160 km NGM A-grid. One of EMC's primary goals in the next 6-12 month period is to address the problems in the EDAS by testing (and hopefully introduce into the EDAS) direct assimilation of satellite radiances and assimilation of observed cloud and precipitation.

TDL produced average verification statistics from 700+ sites in the CONUS and Alaska for both the operational and parallel NGM. For the two NGM runs the errors are comparable through the 12-36 h period, with slight degradation (4% for the cool season temperature) for the parallel NGM's 60-h MOS temperature forecast. Further details on the TDL verification of the parallel NGM can be found at http://www.nws.noaa.gov/tdl/synop/ngmcafti.htm.

At the 3/1/2000 meeting of the NWS Committee on Analysis and Forecast Techniques Implementation (CAFTI) approval for the operational implementation of the parallel NGM was given. This implementation has been scheduled for 12Z 3/15/2000.

VII. References

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Appendix : Feedback from NWS forecasters

During the course of the real-time NGM parallel EMC asked for comments/feedback from NWS field forecasters, two of which are reproduced here. The first is from Dick Wagenmaker, Science and Operations Officer for the NWS office in suburbian Detroit, MI:

I've had a couple of weeks to look at the operational and parallel NGM runs on the web page as you have requested. If this is satisfactory for CAFTI...please forward it to Geoff. If you need more, let me know.

In short, I think the change in the NGM for use on the IBM SP is acceptable.

For sure it was a very limited sample of only 8 or 9 cycles but I tried to look at it both quantitatively and qualitatively. The differences in the two models for MSLP, 850 Temps, and 500 Heights at DTW were essentially insignificant. Although the Operational NGM was slightly better overall for most projections - again it was insignificantly so. At no forecast projection did MSLP differ by more than 2 mb at DTW or 2C for 850 mb temps. In other words, there were no gross differences or errors. I qualitatively looked at cyclone positions for the two significant lows that came out of the plains during the period. Where there were differences, the parallel run tended toward the Eta (which was better anyway). I'm also happy to say (I guess) that the parallel runs certainly maintained a northward bias on surface lows lee of the divide.

I didn't look in detail at the MOS output, but when I did scan them both temps and POPs seemed in line with each other at DTW. For sure minor differences will seem important for someone, somewhere, at sometime. But thats the way it goes. I think we need to take the long view here.

The other comments are from Joseph Ronco, Science and Operations Officer for the NWS office in Grey, Maine: I can't say that I've seen really big differences between the operational and parallel versions of the NGM. However, they are not the same and the MOS generated from them is not the same either. I have seen a difference of five degrees in MOS temperature at Concord, NH (CON), but most of the time the differences are a degree or two. MOS probabilities are usually close to each other, but can be 15 percent different also. This can make a difference in the wording of the forecast between using "likely" and "chance" or "likely" and "categorical" wording.

I'll send you some examples to see. The first set shows the two versions (Operational PWM and parallel TST) of the NGM for March 1, 2000, 1200Z model run from BUFKIT. The MOS (not shown) is about the same for each version, but the precipitation type from BUFKIT is not. The operational version changes from rain to snow (green to blue) much quicker than the parallel version. Also, the operational version has slightly more precipitation than the parallel version (.295 inch vs .236 inch).

The second set shows output from the March 2, 2000, 0000Z model run. In this case the MOS PoPs differ by 15 percent in the second and third forecast periods with the operational version being the higher of the two. When looking at the operational and parallel NGM moisture and omega fields in BUFKIT, it was noted that the operational version had the most moisture (green). Also, it produced the most precipitation (.122 inch vs .024 inch). This may not sound like much, but it is the difference between a trace and an inch when talking about snowfall. That can have a big impact on the public, especially if it occurs at peak traffic times.

Figures

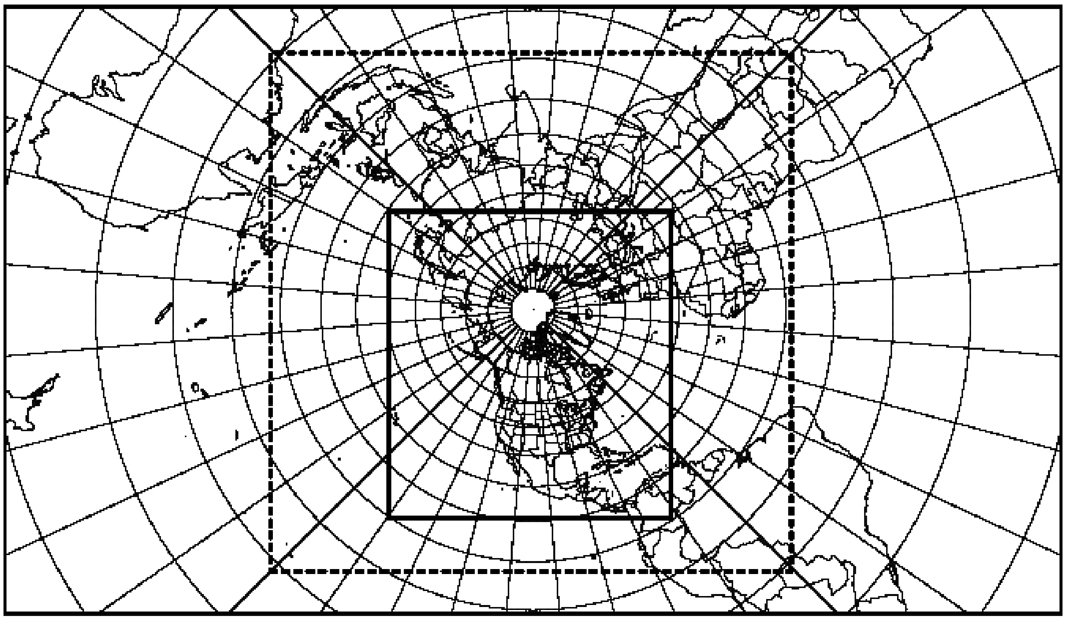


Figure 1: Operational NGM grid configuration. Dashed = 160 km A-grid; Solid = 80 km B-grid

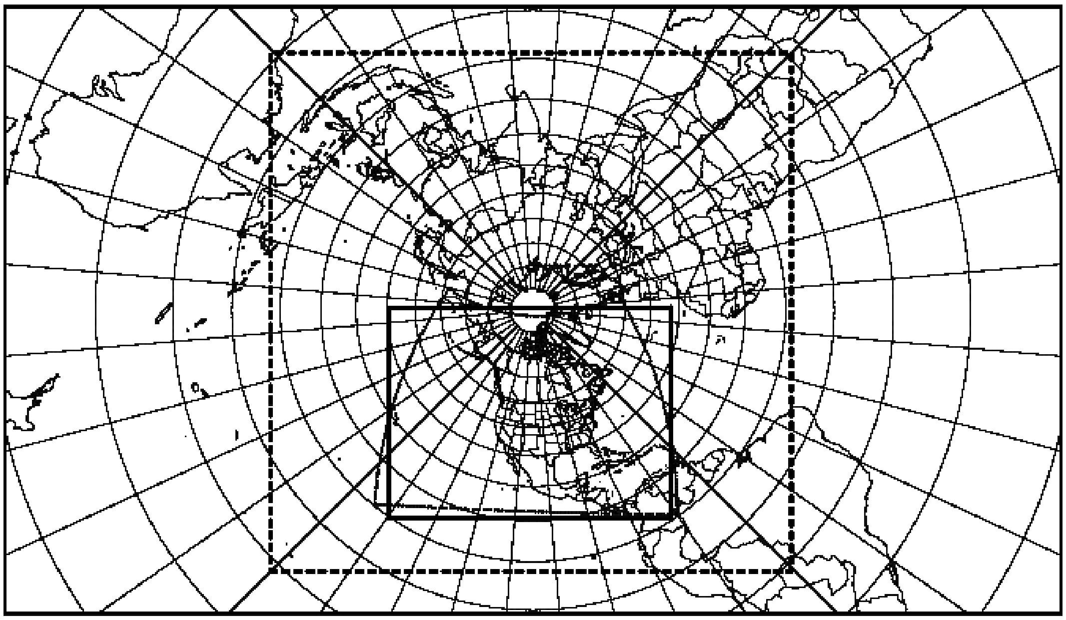


Figure 2: Parallel NGM grid configuration. Dashed = 160 km A-grid; Solid = 80 km B-grid; Dotted = Eta-32 computational grid

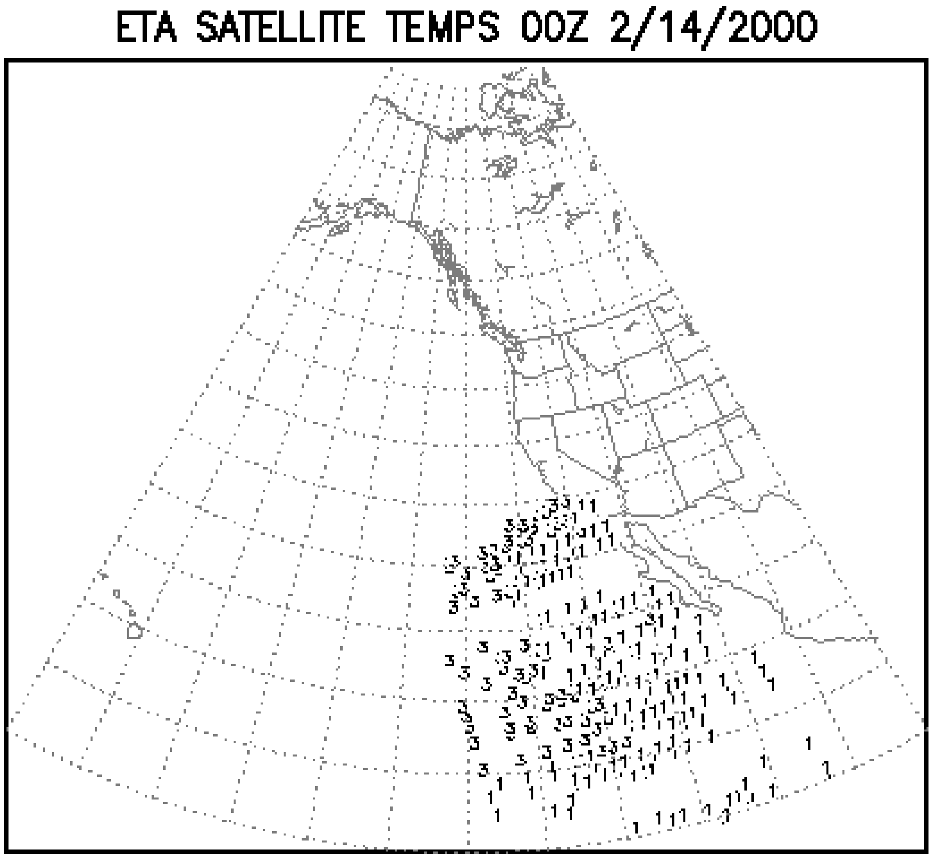


Figure 3: Locations of satellite temperature observations used by the 00Z 2/14/2000 Eta analysis

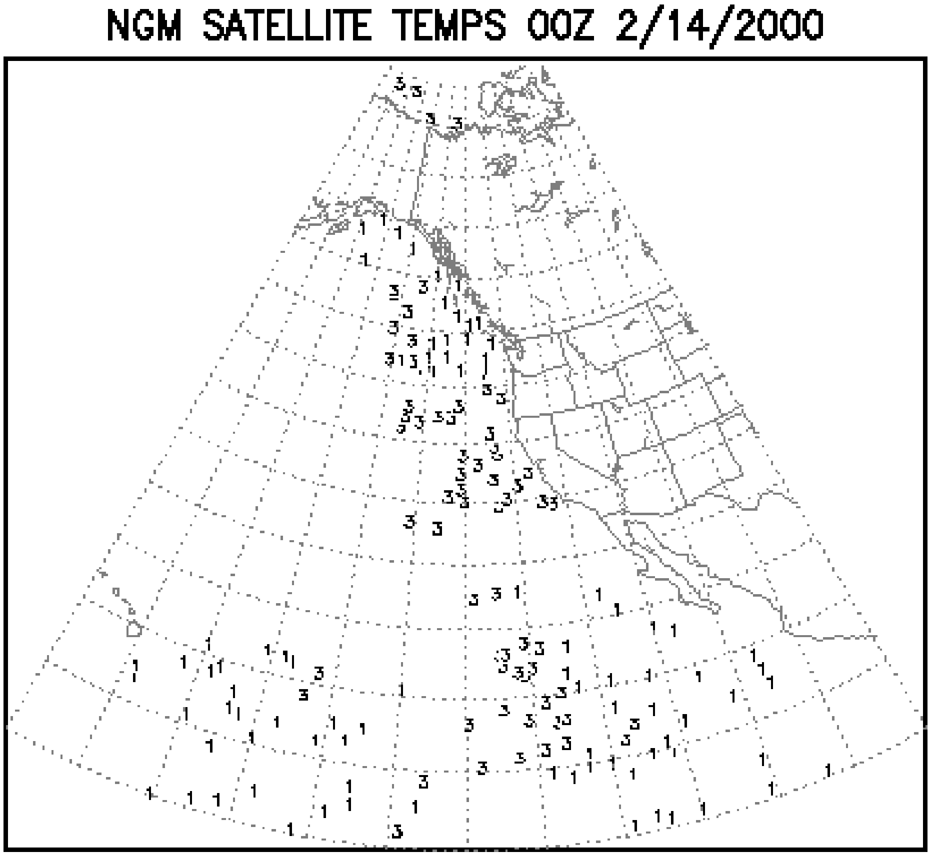


Figure 4: Locations of satellite temperature observations used by the 00Z 2/14/2000 RAFS analysis

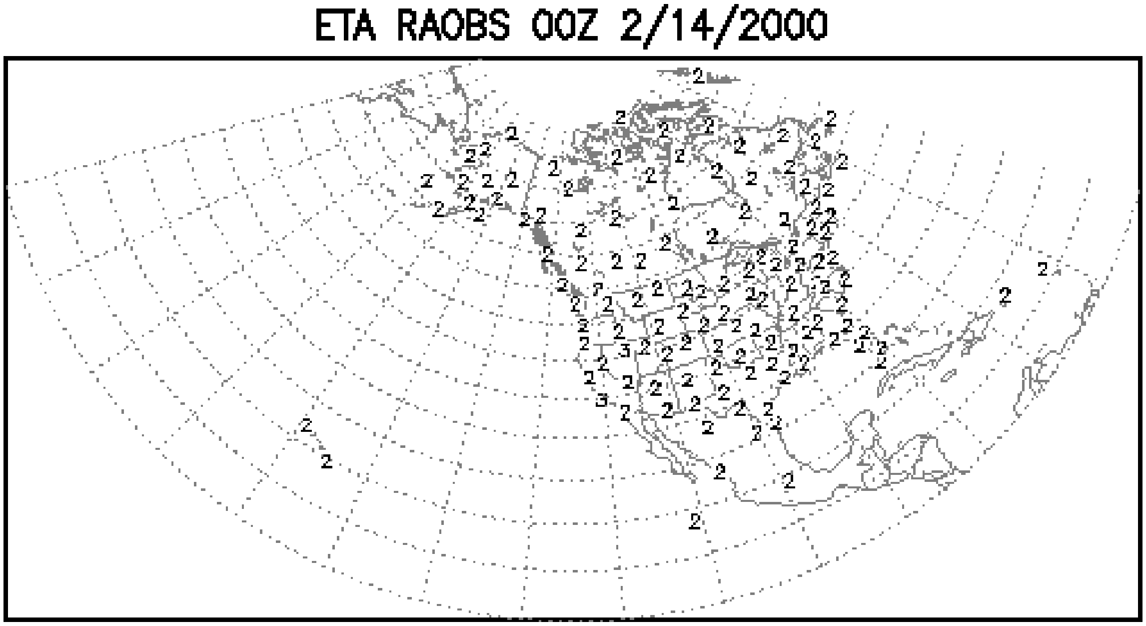


Figure 5: Locations of rawinsonde observations used by the 00Z 2/14/2000 Eta analysis

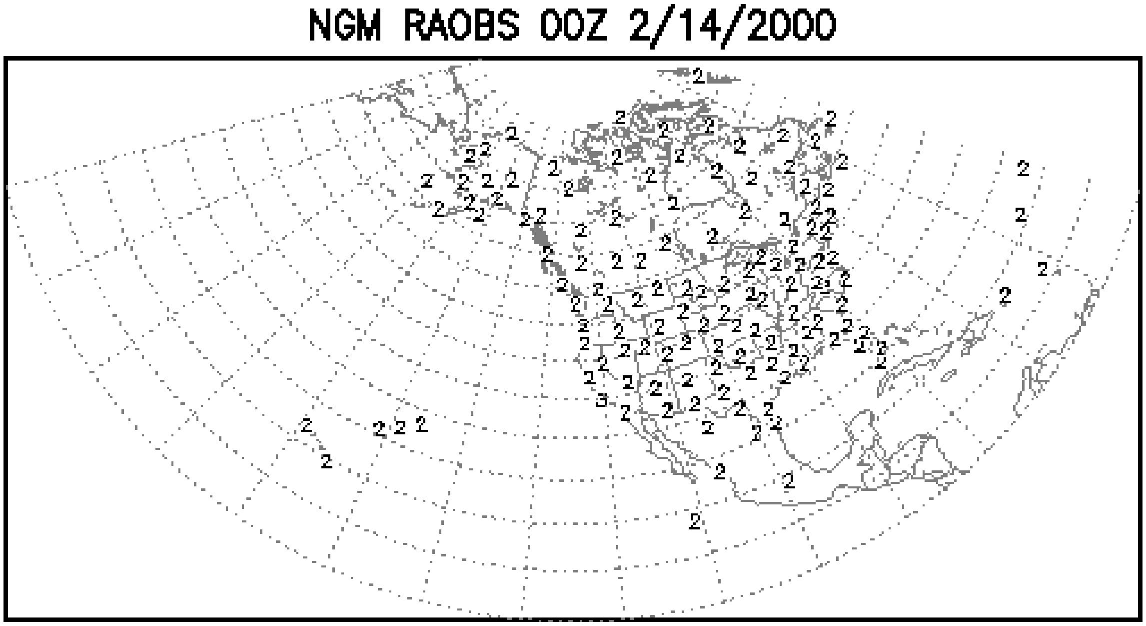


Figure 6: Locations of rawinsonde observations used by the 00Z 2/14/2000 RAFS analysis

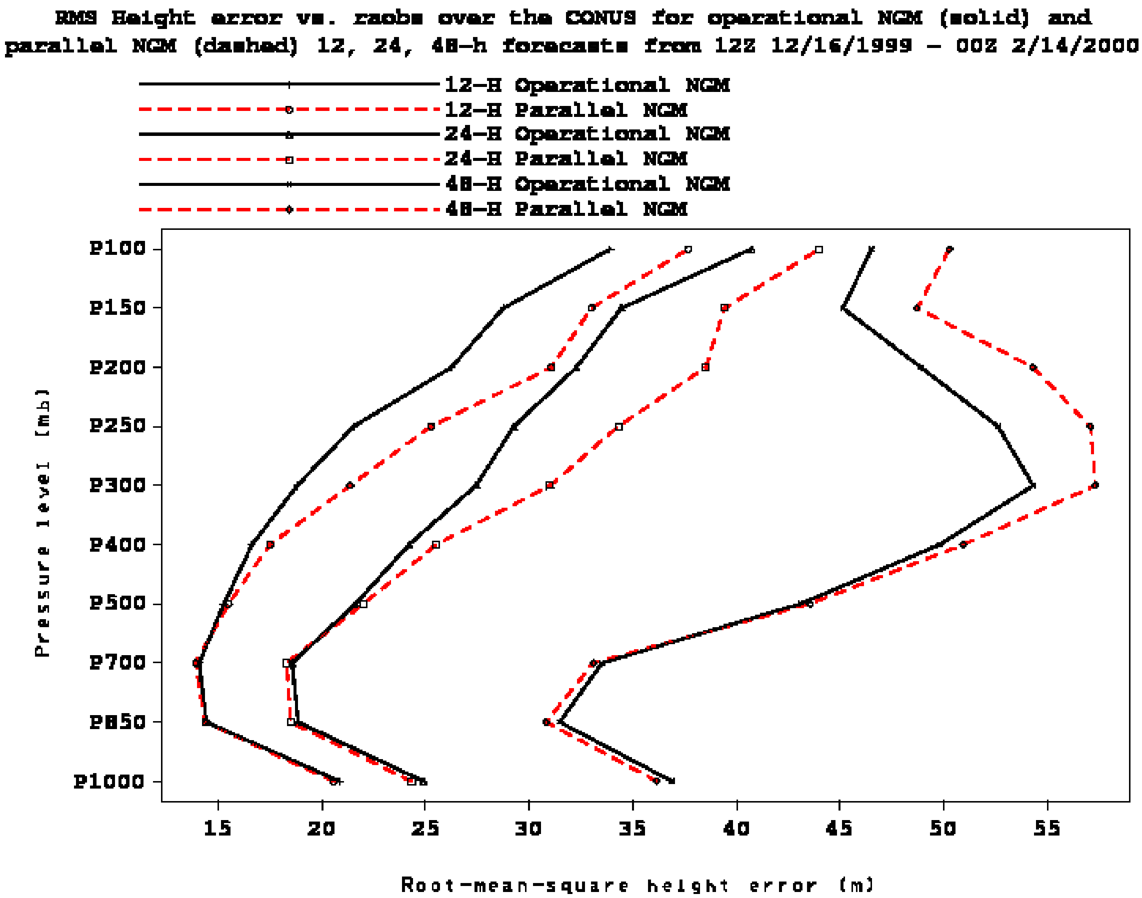


Figure 7: RMS Height error vs. rawinsondes over the CONUS for the operational NGM (solid black) and the parallel NGM (dashed red) 12, 24, and 48-h forecasts from 12Z 12/16/1999 - 00Z 2/14/2000

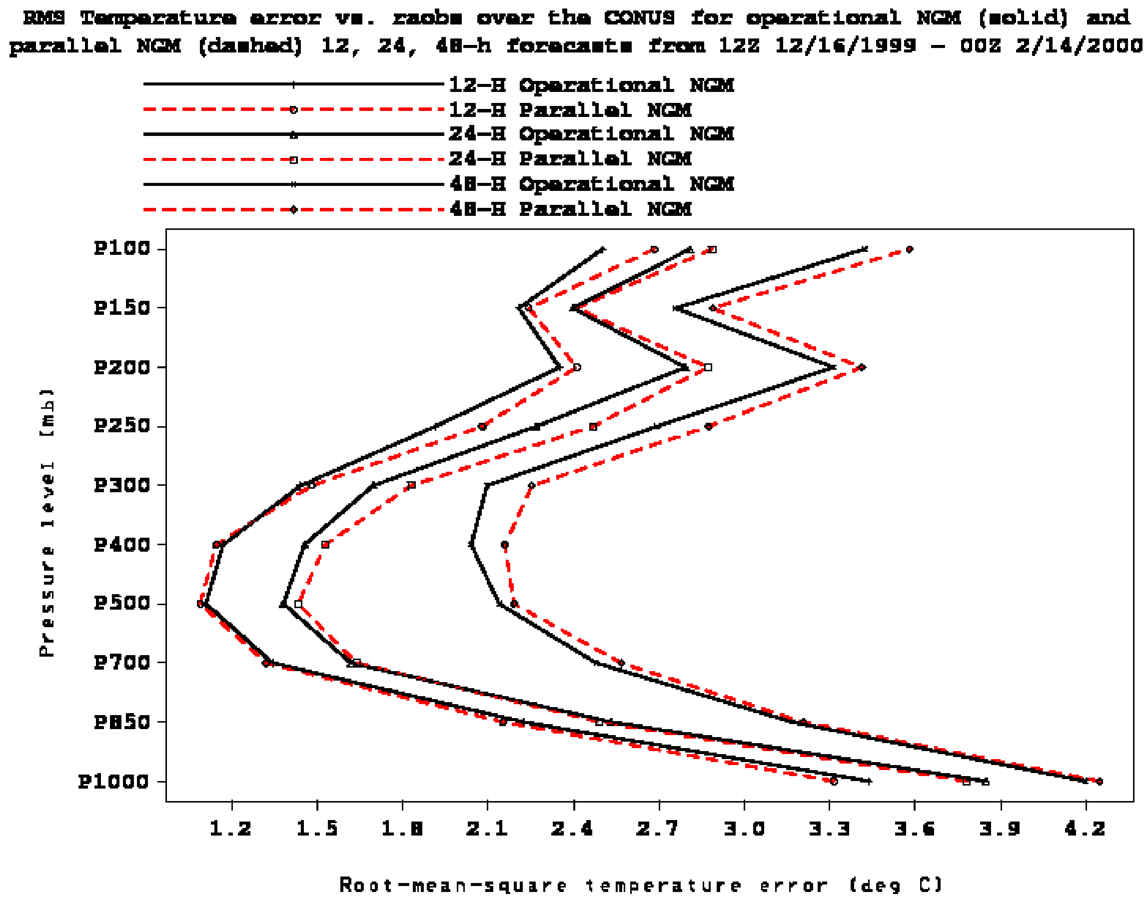


Figure 8: Same as Figure 7, but for temperatures

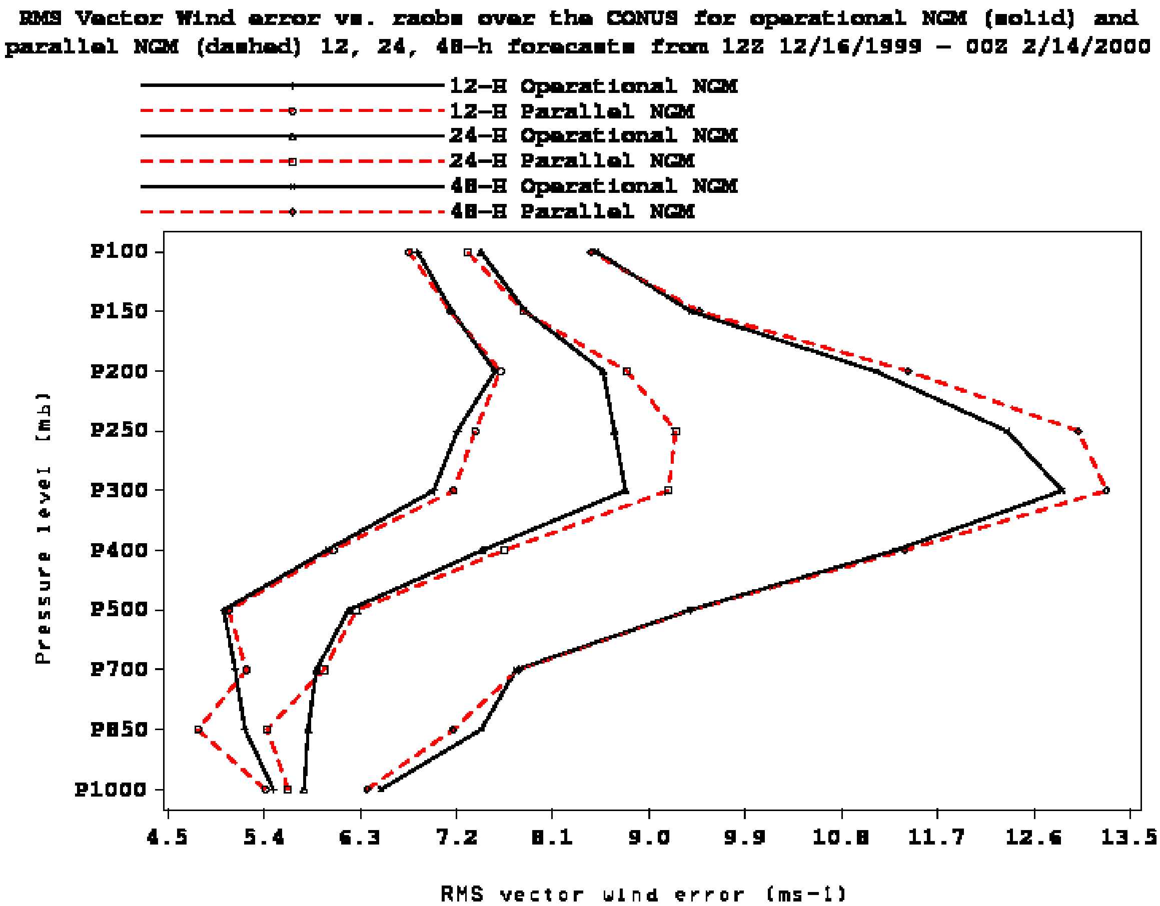


Figure 9: Same as Figure 7, but for vector wind

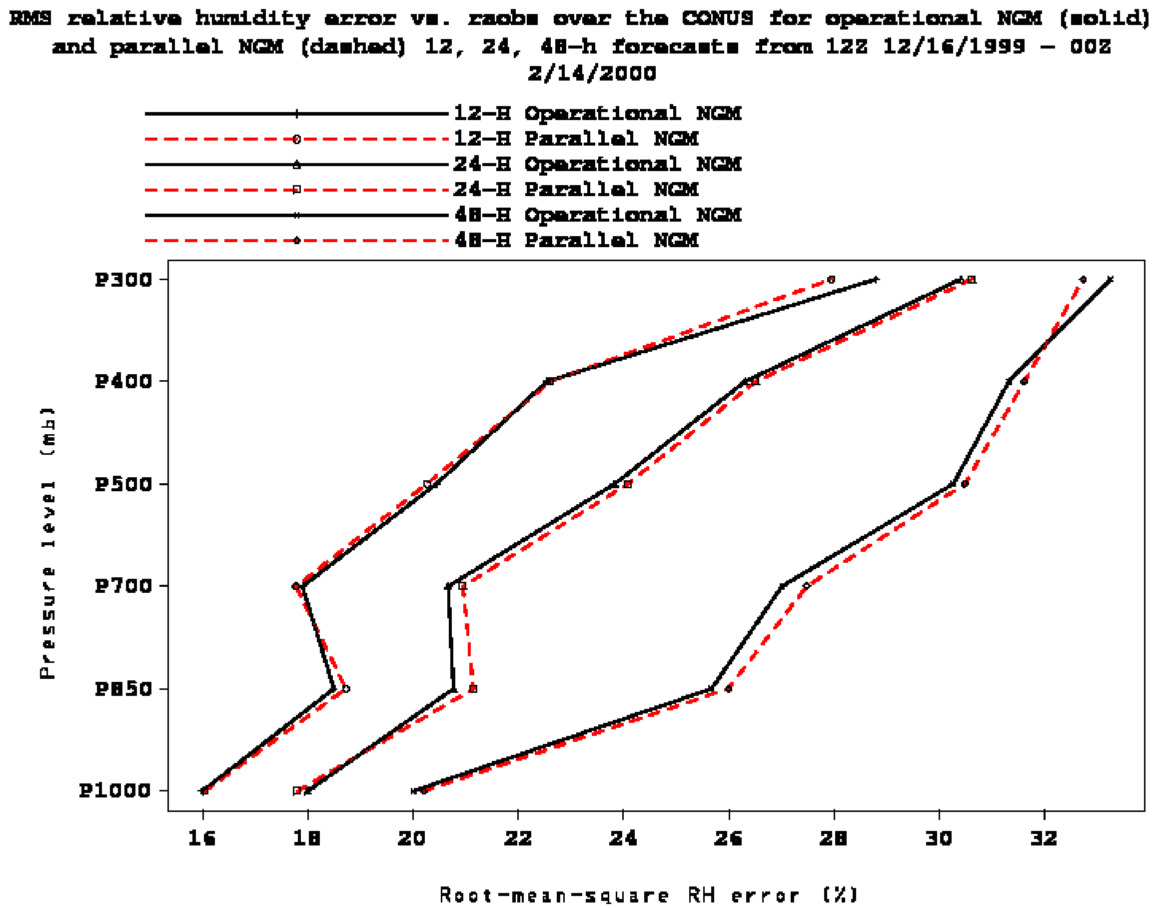


Figure 10: Same as Figure 7, but for relative humidityFigure 10: Same as Figure 7, but for relative humidity

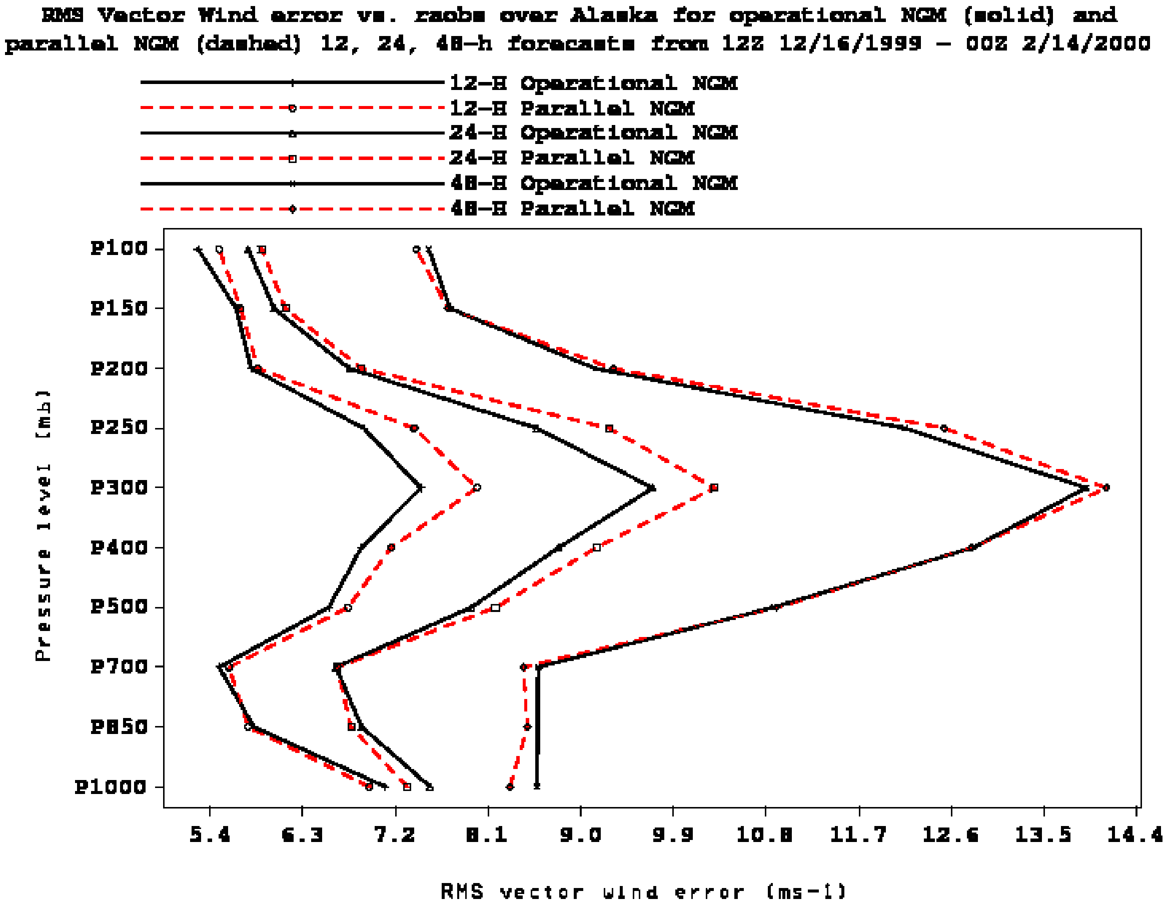


Figure 11: Same as Figure 9, but over Alaska

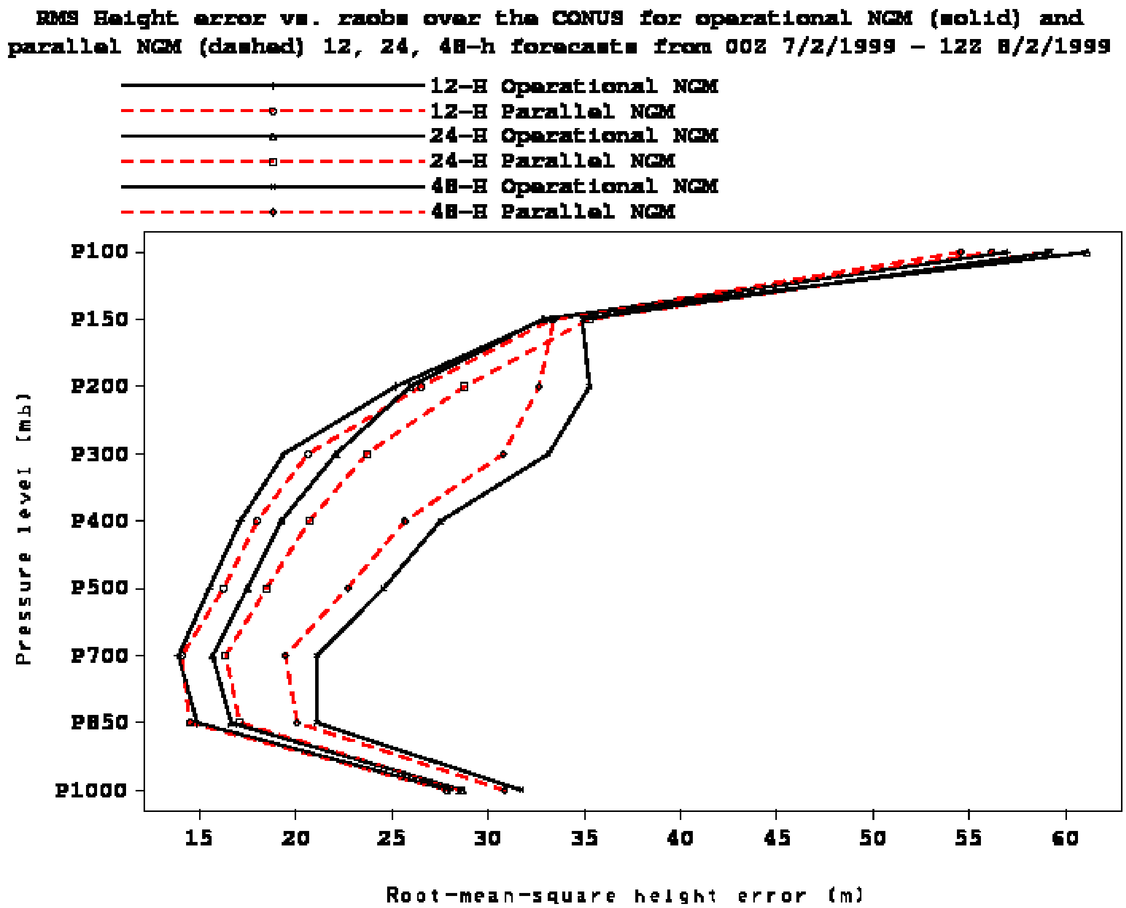


Figure 12: Same as Figure 7, but for the period 00Z 7/2/1999 - 12Z 8/2/1999

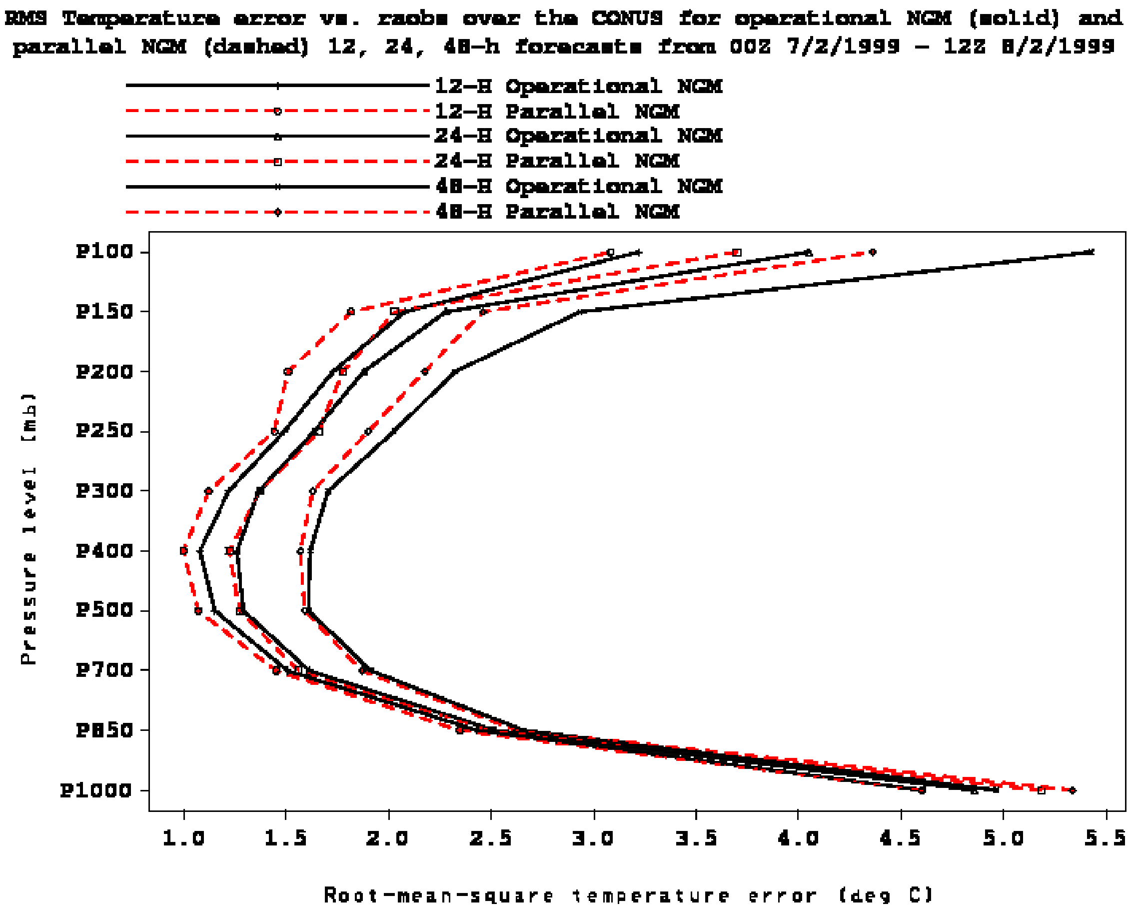


Figure 13: Same as Figure 8, but for the period 00Z 7/2/1999 - 12Z 8/2/1999

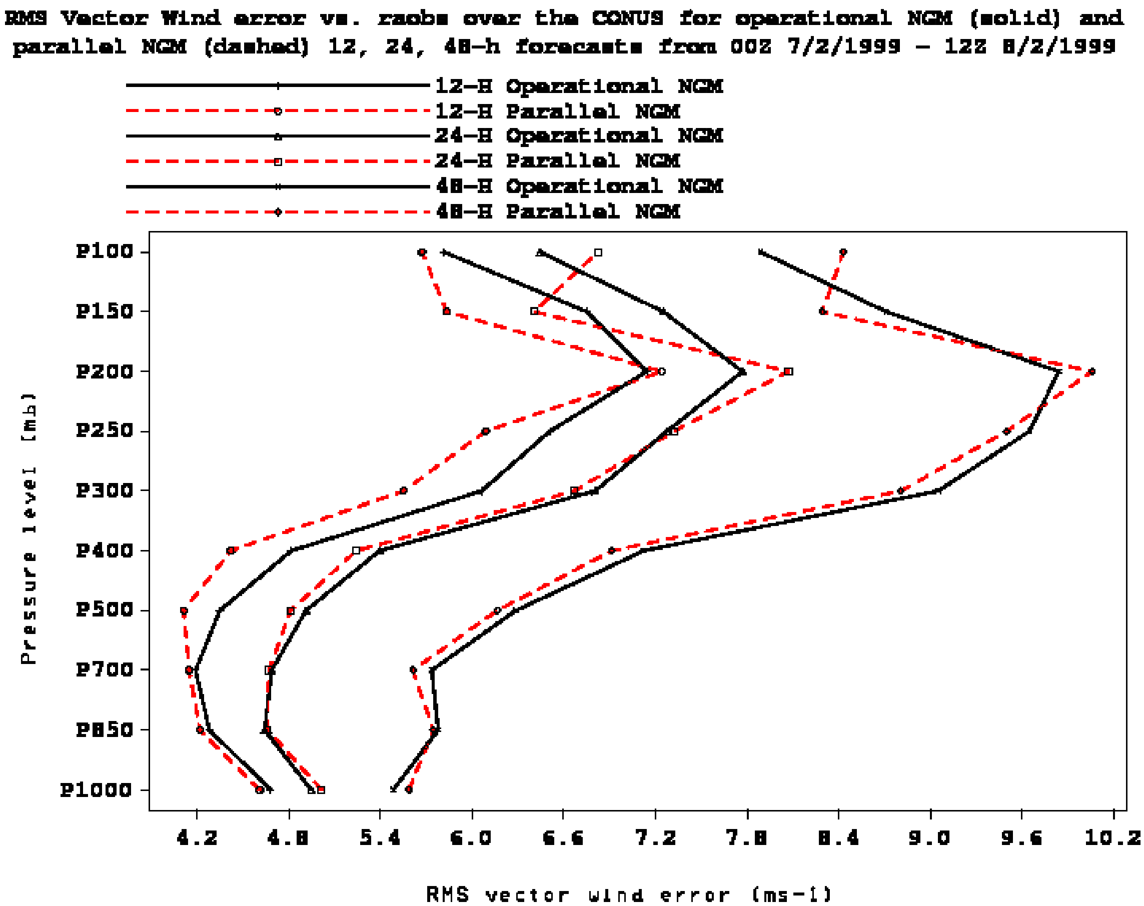


Figure 14: Same as Figure 9, but for the period 00Z 7/2/1999 - 12Z 8/2/1999

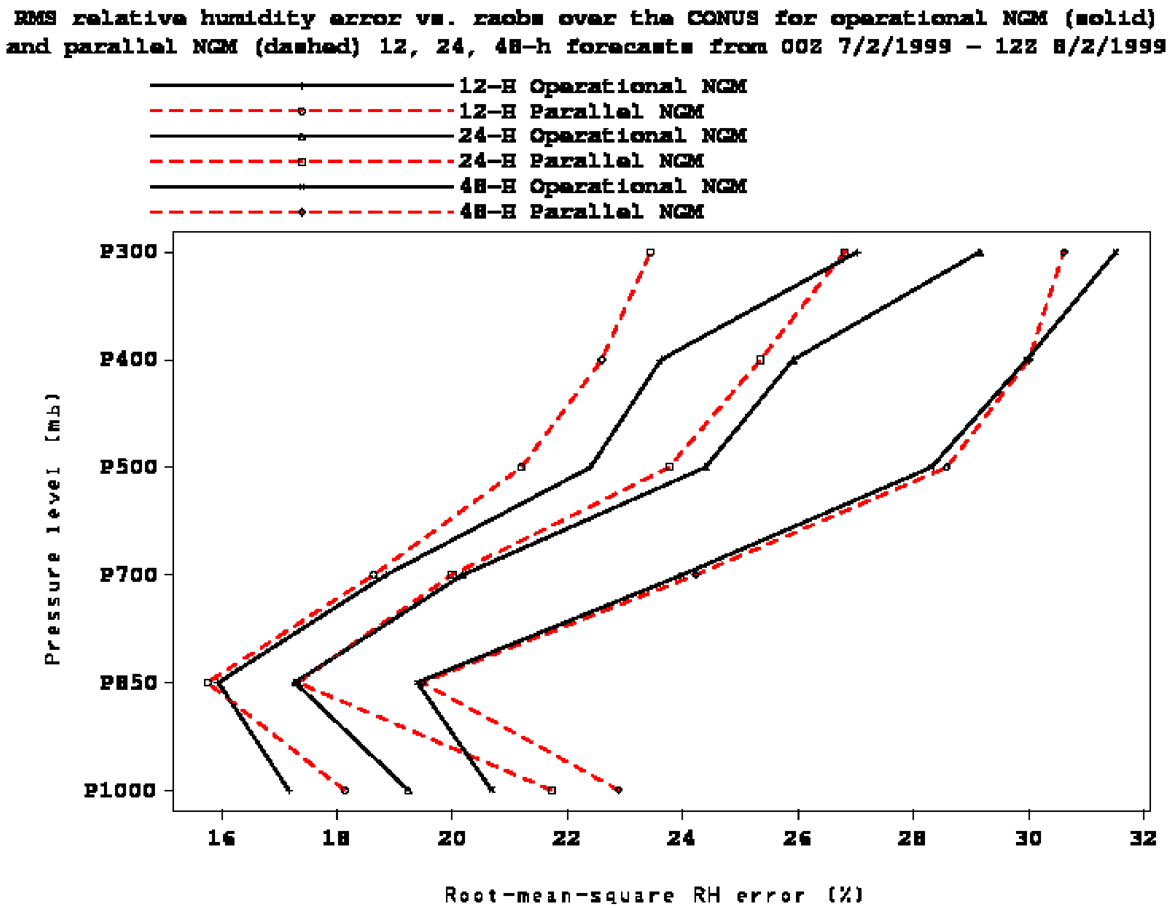


Figure 15: Same as Figure 10, but for the period 00Z 7/2/1999 - 12Z 8/2/1999

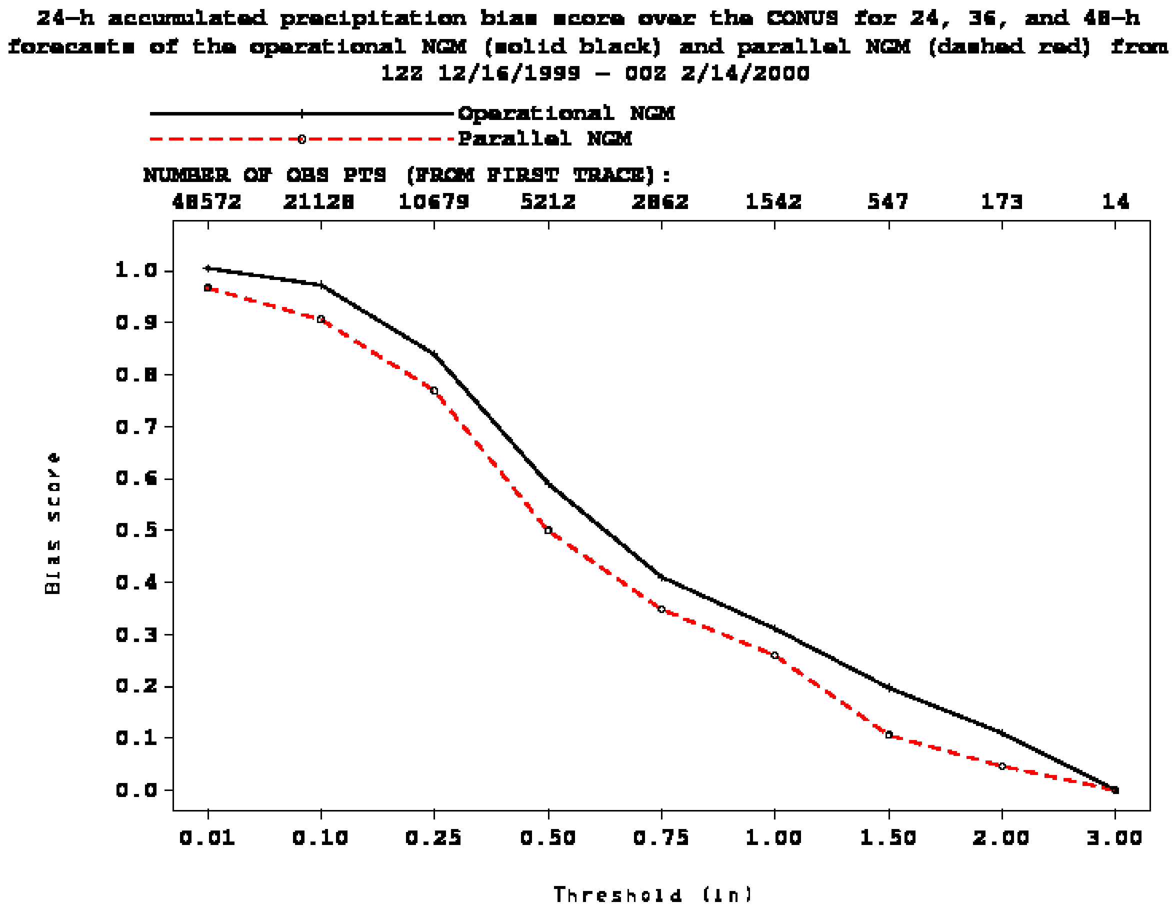


Figure 16: 24-h accumulated precipitation bias score for all operational NGM (solid black) and parallel NGM (dashed red) forecasts for the period 12Z 12/16/1999 - 00Z 2/14/2000

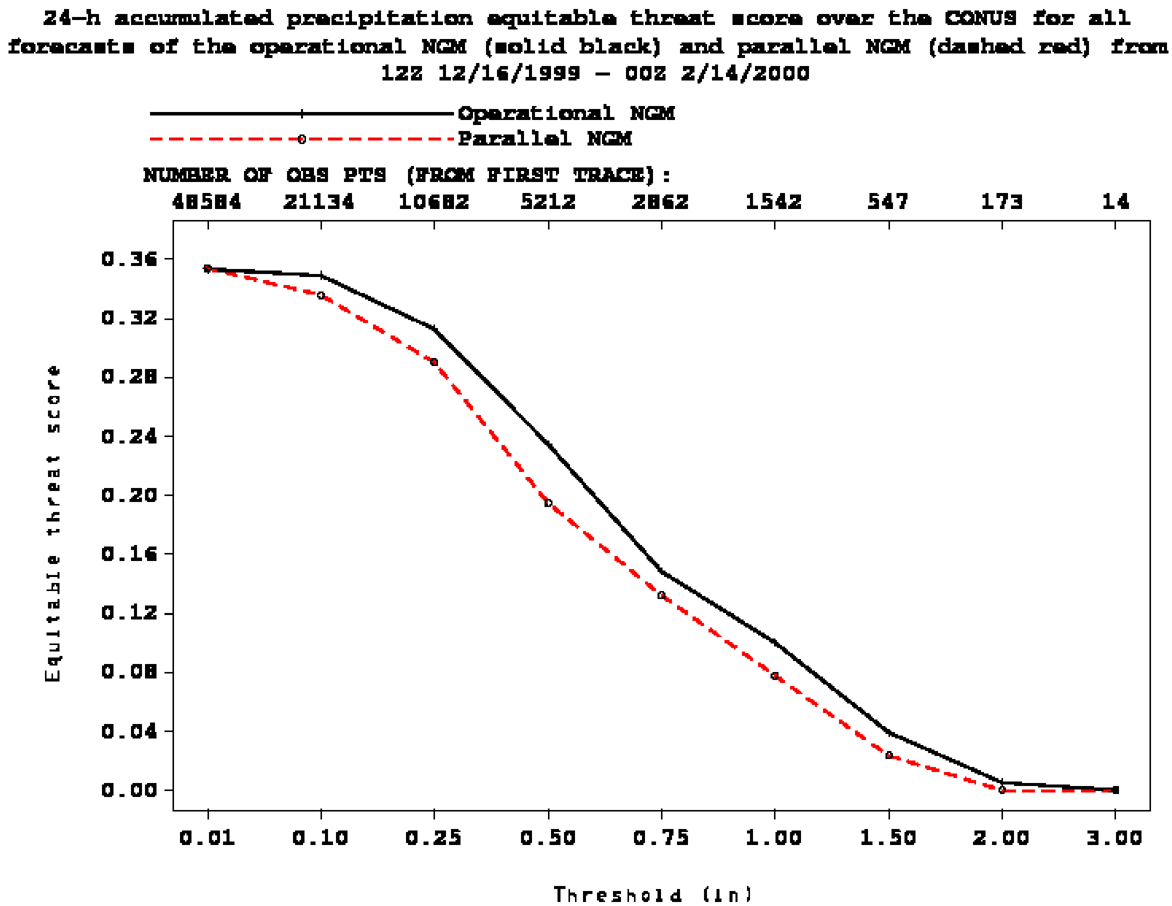


Figure 17: Same as Figure 16 but for 24-h accumulated precipitation equitable threat score

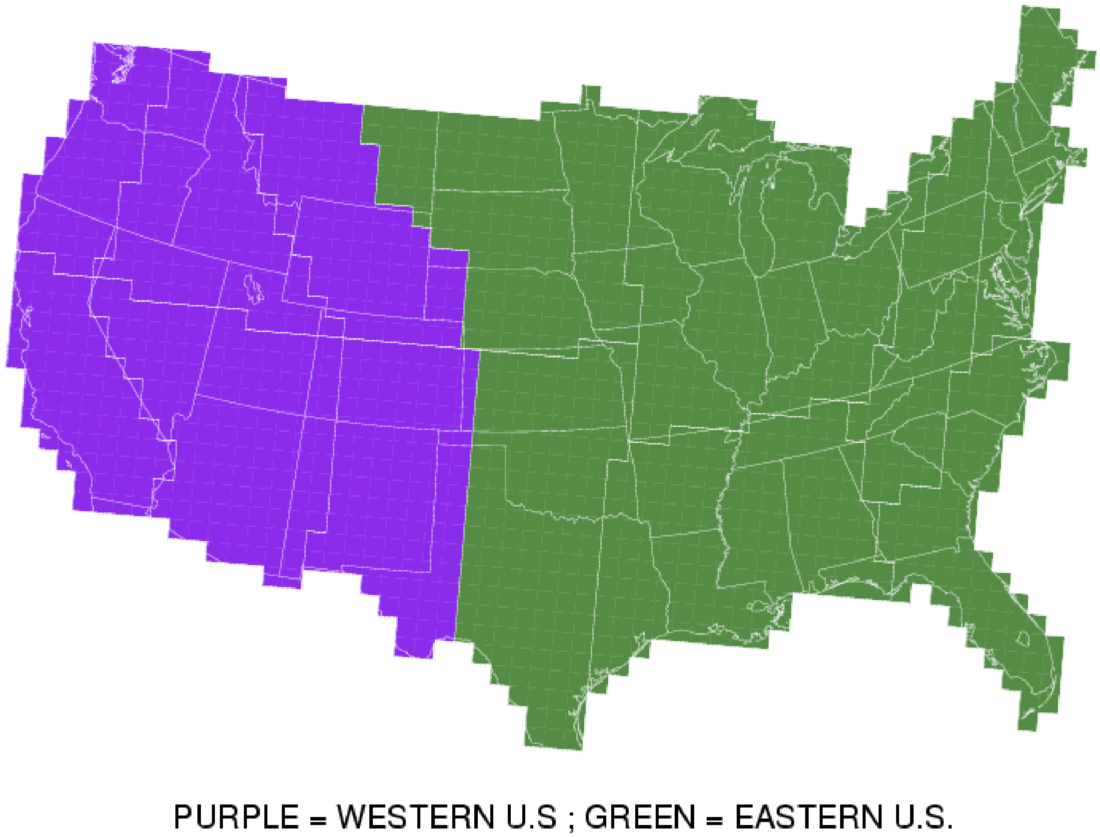


Figure 18: Purple area = region used for western U.S. precipitation skill score computation; Green area = region used for eastern U.S. precipitation skill score computation;

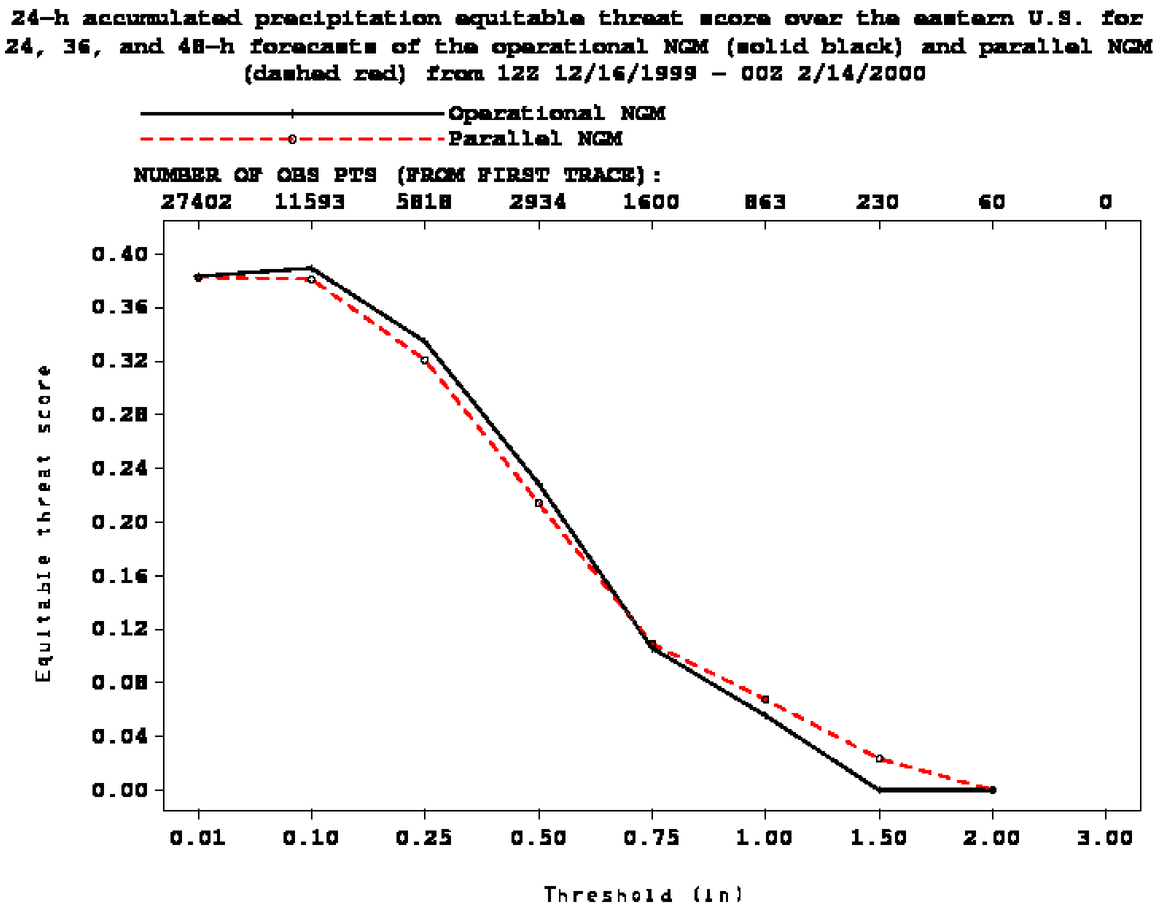


Figure 19: Same as Figure 17 but for the eastern U.S. (area defined in Figure 18)

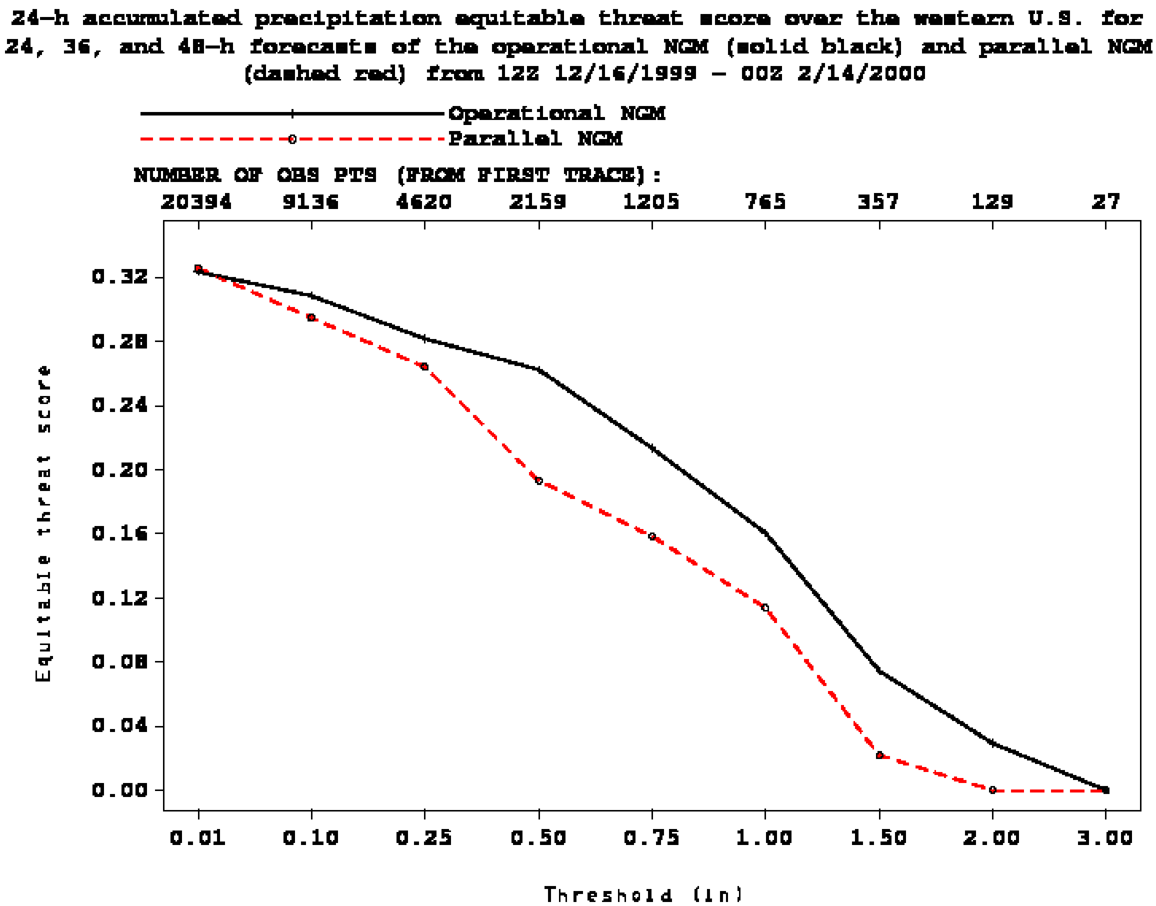


Figure 20: Same as Figure 17 but for the western U.S. (area defined in Figure 18)

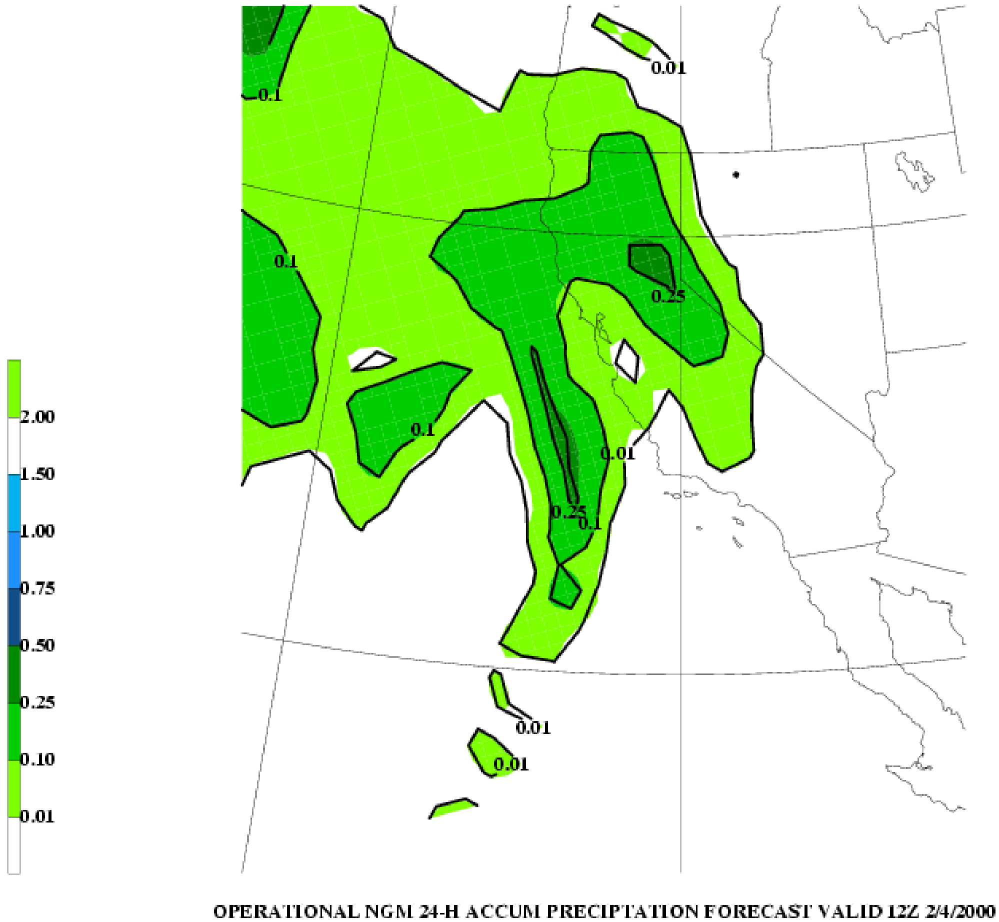
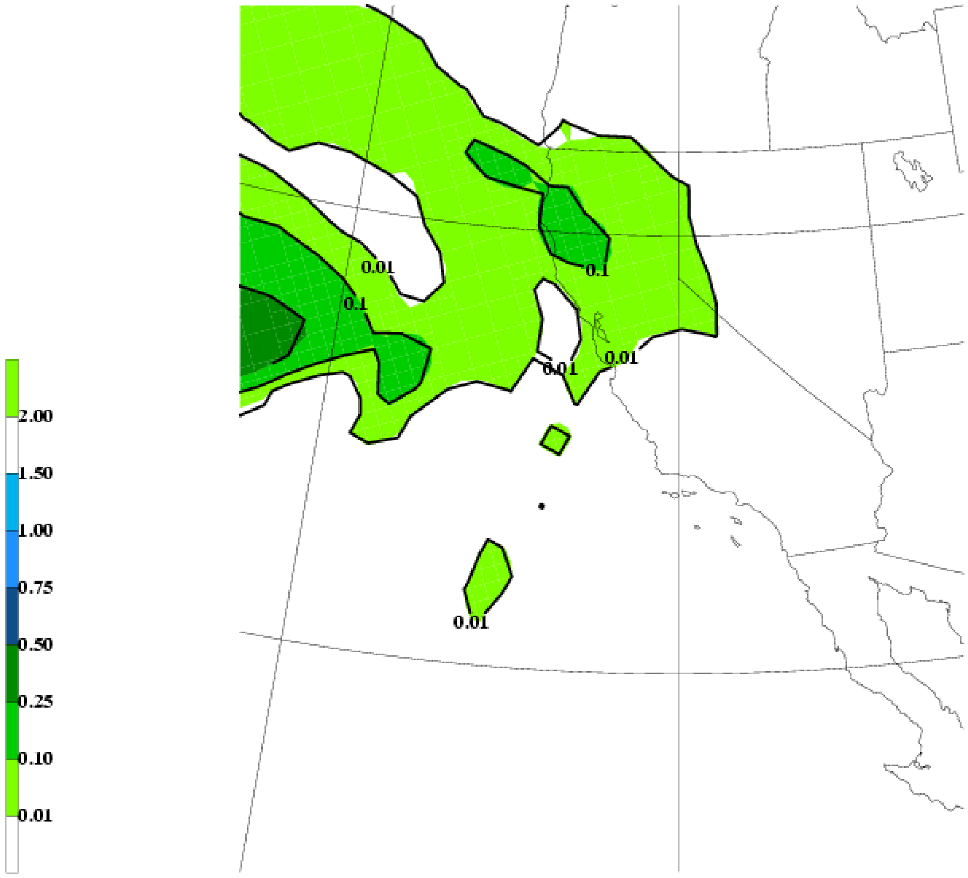


Figure 21: Operational NGM 24-h accumulated precipitation forecast valid 12Z 2/4/2000



PARALLEL NGM 24-H ACCUM PRECIPITATION FORECAST VALID 12Z 2/4/2000

Figure 22: Parallel NGM 24-h accumulated precipitation forecast valid 12Z 2/4/2000

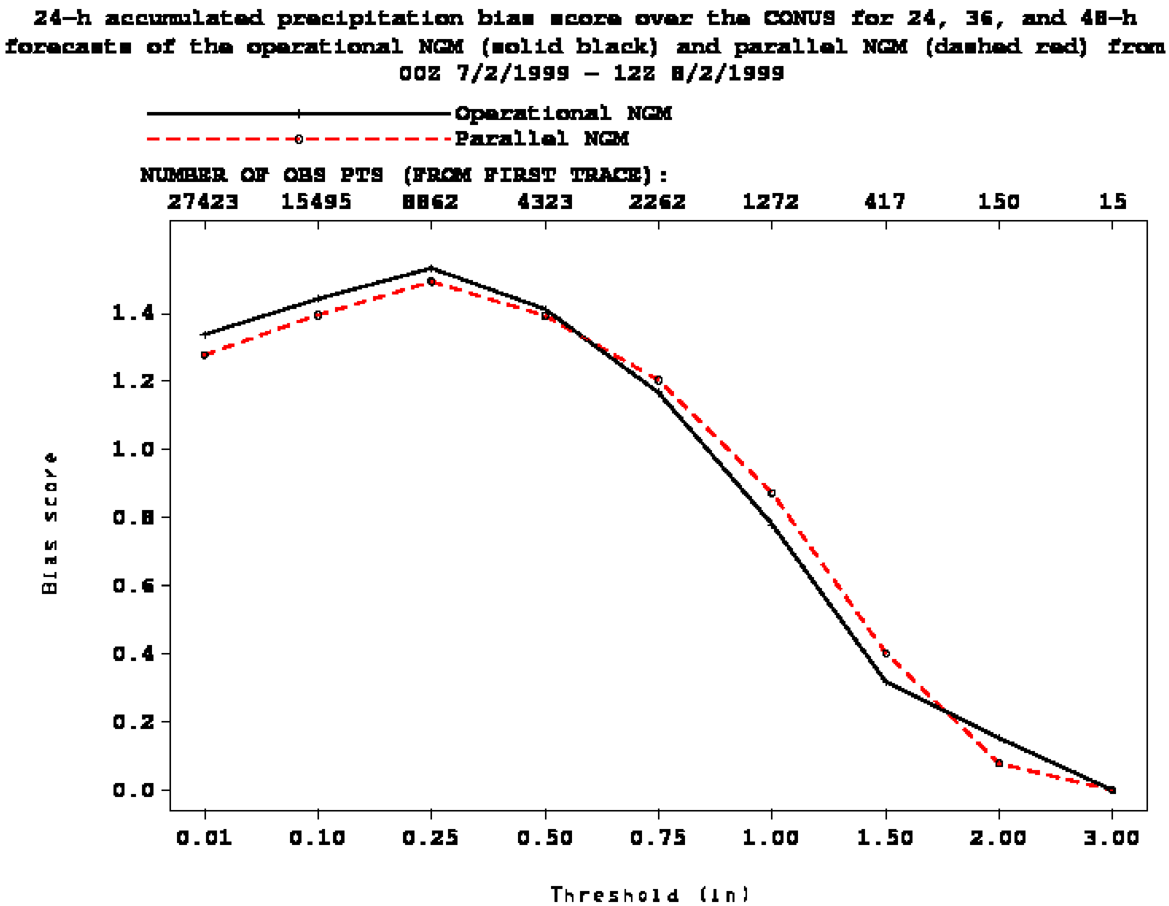


Figure 23: Same as Figure 16, but for the period 00Z 7/2/1999 - 12Z 8/2/1999

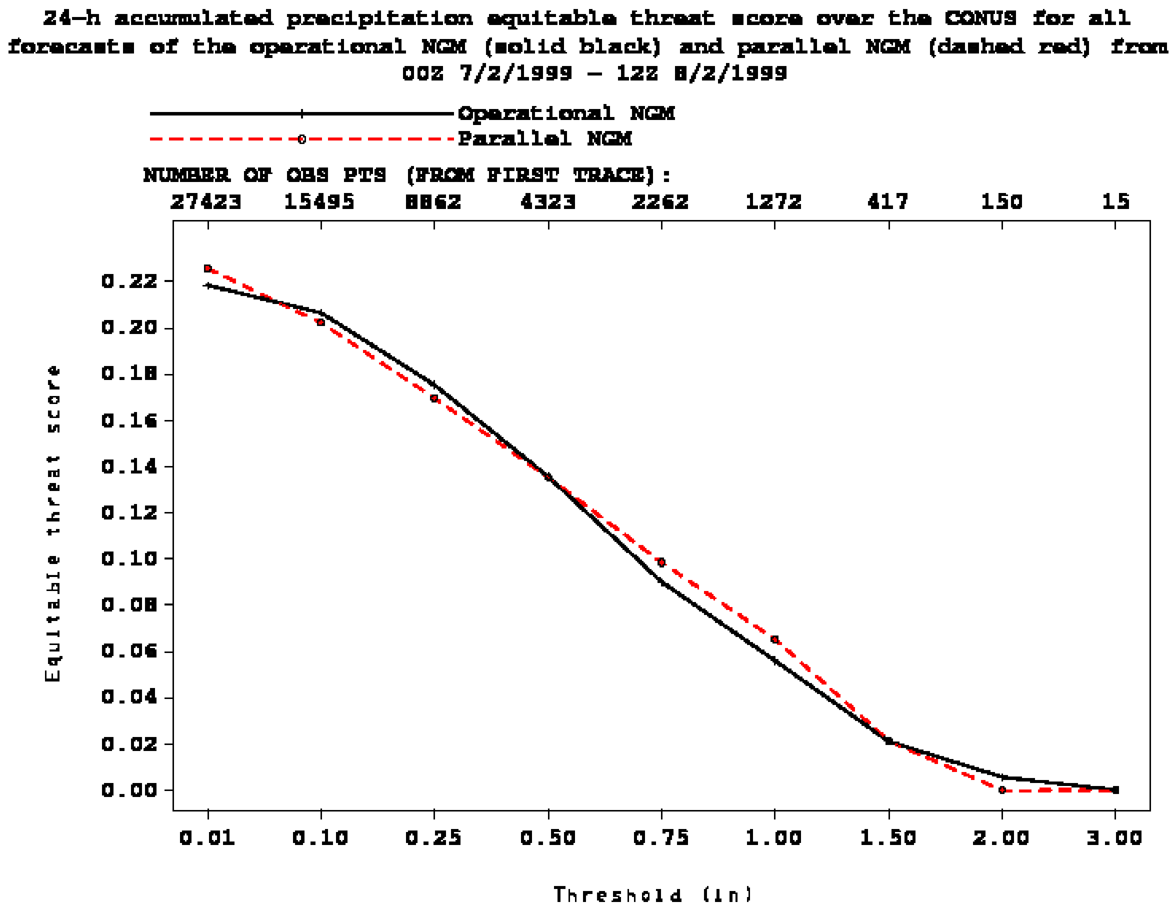


Figure 24: Same as Figure 17, but for the period 00Z 7/2/1999 - 12Z 8/2/1999

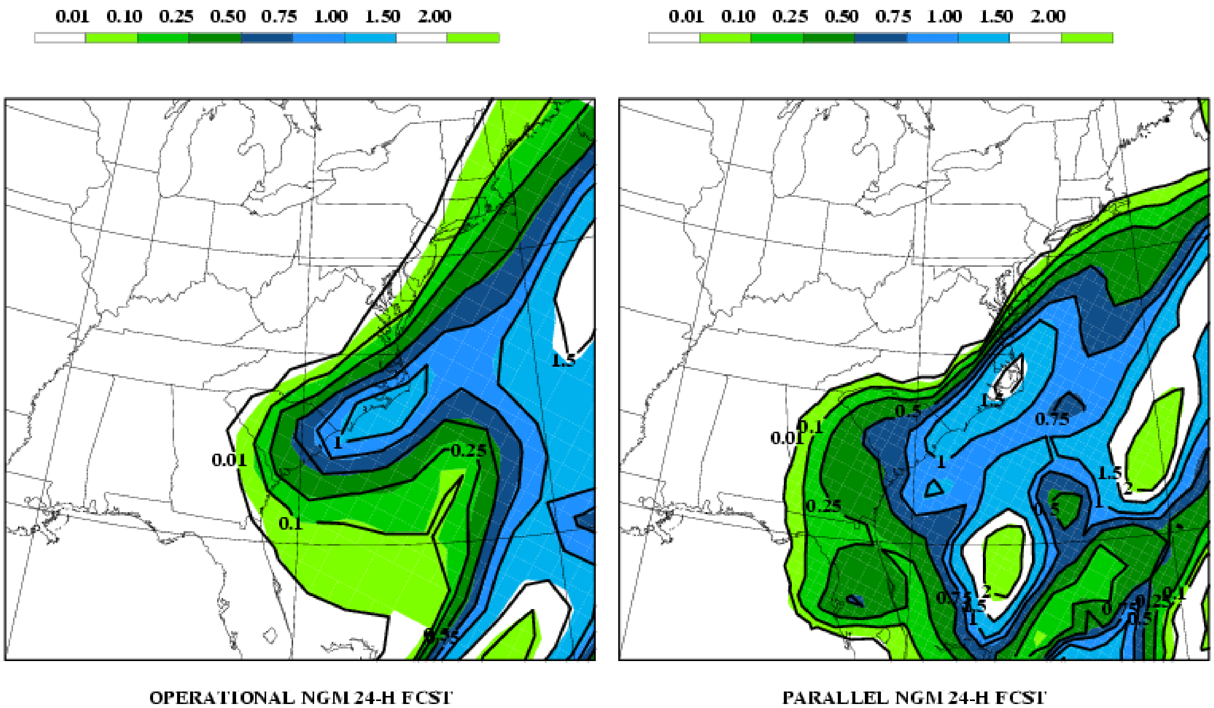


Figure 25: Operational NGM (left) and parallel NGM (right) 24-h forecast of accumulated precipitation (in) valid 12Z 1/25/2000

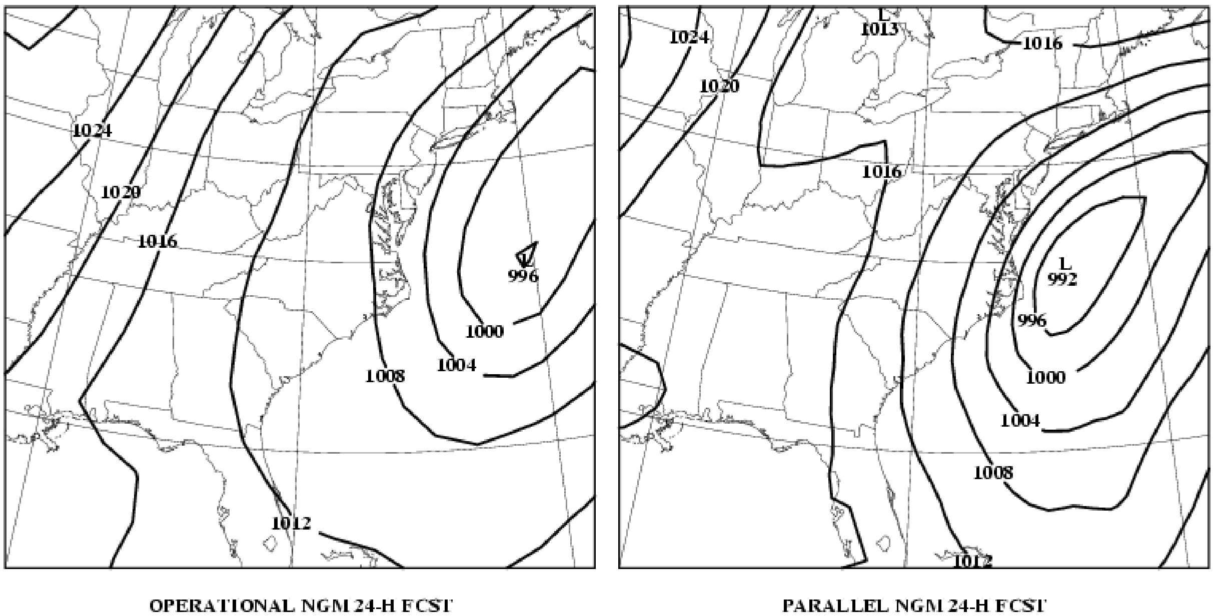


Figure 26: Same as Figure 25, but for sea level pressure

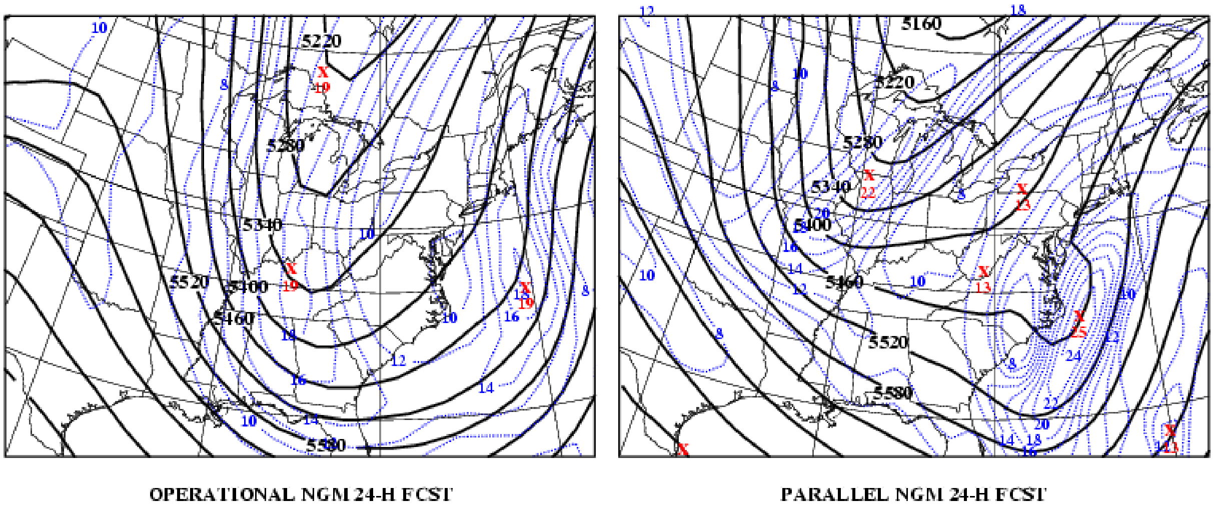


Figure 27: Same as Figure 25, but for 500 mb geopotential heights and absolute vorticity