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It summarizes the changes made in 9 FEBRUARY, 1998, 3 JUNE 1998, and corrections made to the 3DVAR on 3 May.

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Changes to the NCEP Operational Eta Analysis

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The 3DVAR corrections have been scheduled for all operational Eta runs on 13 May.

I. INTRODUCTION

In an effort to improve the timeliness of NCEP's mesoscale forecast guidance, a series of changes to the operational "Early" Eta system were made in 1998. These changes were implemented in two stages :

9 FEBRUARY 1998 (detailed in Rogers et.al, 1997)

- Resolution increased from 48 km / 38 levels (Eta-48) to 32 km / 45 levels (Eta-32)
- Replacement of the Eta Optimum Interpolation analysis with a regional 3-dimensional variational analysis (3DVAR, Parrish et.al 1996).
- Use of a "partial" continuous cycle in the Eta Data Assimilation System (EDAS), in which soil parameters, turbulent kinetic energy (TKE), and cloud water are obtained from the previous EDAS cycle instead of the NCEP Global Data Assimilation System (GDAS), accompanied by an increase in the number of soil layers from two to four.

3 JUNE 1998:

- The EDAS was converted to "full" cycling mode, with atmospheric variables (temperature, wind, moisture) cycled from the previous EDAS cycled in addition to soil/cloud/TKE parameters.
- The 0300 UTC Eta-29 (so-called "Meso" Eta), which had continued unchanged after the 9 February 1998 implementation, was replaced by the Eta-32, initialized from the fully cycled EDAS. The 1500 UTC Eta-29 was replaced by an 1800 UTC run of the Eta-32, also initialized from the fully cycled EDAS.

Examination of Eta-32 3DVAR analyses by NCEP scientists and NWS field forecasters revealed that the greatest deficiency in the 3DVAR was its degraded analysis of surface and lower tropospheric data, particularly moisture. This problem is illustrated in Fig. 1, which shows the observed and analyzed sounding at Rapid City, SD at 0000 UTC 13 July 1998. The analysis is from a cycled 80-km EDAS which runs the same 3DVAR analysis as the operational Eta-32. The 80 km dew point temperature is clearly deficient below 700 mb, with a 5 deg C error at 850 mb. A similar signal was seen in the operational Eta-32 (not shown), After careful examination of the of this case, it was determined that the vertical correlation error length scale for moisture and the background error covariances were both too low. These problems would cause the 3DVAR analysis to give more weight to the first guess and would prevent it from accurately analyzing details in the low-level moisture field. Additionally, an error was found in the 3DVAR which caused it to essentially exclude all surface data. Accordingly, the 0000 UTC 13 July 1998 analysis was rerun with modifications made to alleviate the above problems. The new analysis at Rapid City is shown in Fig. 2. The low-level moisture analysis, while still too dry, is a clear improvement over the 80 km analysis using the original operational 3DVAR analysis shown in Fig. 1.

These changes were tested for a 3 week period in July 1998 using the 80 km Eta parallel system (limited computing resources at NCEP prohibited any extensive testing at 32 km resolution). The results (not shown) revealed improved analysis fits to surface and rawinsonde data (especially moisture) with little impact on forecast performance over the contiguous U.S. Based on these findings, these changes were implemented into the operational Eta-32 on 3 November 1998.

II. DEFICIENCIES IN THE 3 NOVEMBER 1998 VERSION OF 3DVAR

During the winter of 1998-99 it became increasingly apparent to NWS field forecasters, EMC personal, and academic observers that the Eta model forecasts had decreased skill from the previous winter in comparison to the Nested Grid Model (NGM) and the NCEP Global Aviation Model (AVN). Fig. 3 shows the 24-h forecast precipitation equitable threat score for December 1997 - February 1998 for the Eta, NGM, and AVN models, while Fig. 4 shows the same skill scores for December 1998 - February 1999. Comparison of these charts show that during 1998-99 all three models had a drop in skill at the lower thresholds compared to the previous winter. The Eta model's skill dropped at all thresholds, with a decreases of ~20% at the 0.75 inch and 1.00 inch thresholds. The AVN model had a slight increase in skill at these same thresholds, undoubtedly due in part to model/analysis changes made during 1998 (Derber et.al, 1998).

The most persistent feature observed in Eta model forecasts during the 1998-99 time frame was degraded analyses and forecasts in the eastern Pacific Ocean. Junker (personal communication, 1999) observed that the Eta model moved amplifying mid-tropospheric short wave troughs faster than the AVN and NGM. Mass (personal communication, 1999) observed that the AVN analysis of cyclones in the eastern Pacific during this period was consistently better, with the AVN producing better forecasts than the Eta model. An example of such behavior is depicted in Fig. 5, which shows the 48-h eastern Pacific Eta-32 and AVN sea level pressure forecasts valid at 1200 UTC 17 March 1999. The offshore cyclone was predicted to explosively deepen to < 980 mb by the AVN model, while the Eta model predicted a much weaker storm. The GDAS analysis valid at this time (Fig. 6) shows that although the AVN forecast position about 300 km too far south, the central pressure forecast was nearly perfect. The NGM 48-h forecast (not shown) position was closer to the observed center than the AVN but with a central pressure forecast of 990 mb.

Although there are many differences between the EDAS/Eta and GDAS/AVN initialization procedures, including a different observation mix (e.g., later data cutoff time for the AVN vs. Eta on-time analysis; use of satellite radiance data in GDAS vs. satellite thickness retrievals in the EDAS over water), a preliminary examination of the Eta vs. AVN observation differences in the 15 March 1999 case and others (not shown) revealed that there was no obvious data source issue that would explain the poor performance of the Eta model in the eastern Pacific. Thus, it became apparent that the November 1998 changes to the Eta 3DVAR should be revisited.

. In a well-behaved multivariate analysis scheme (such as optimum interpolation or 3DVAR) wind-only observations will modify the mass field through a balance condition, which for the Eta 3DVAR is a thermal wind constraint (Parrish et.al., 1996). Conversely, mass-only observations will modify the wind field through the same balance condition. Where mass and wind are both observed together (e.g., rawinsondes) the observation itself should define the balance. Balance problems can arise with an incorrectly tuned analysis in regions where there are predominately mass or wind-only observations (such as satellite winds over oceans) or single-level observations.

Upon closer examination of the Eta analyses in the eastern Pacific, it was obvious that there was an overall lack of geostrophic balance between mass and wind analysis corrections away from the reference level (500 mb) in the 3DVAR analysis. An example at 850 mb from a cycled 80 km EDAS run valid at 0000 UTC 15 March 1999, using the current operational 3DVAR analysis is shown in Fig. 7. This chart shows the analysis-first guess height difference for wind and height, along with the rawinsonde height/wind-first guess difference. If the balance constraint is well behaved, then a positive height correction (such as the one associated with the St. Paul Island, Alaska rawinsonde near 57N 170W) will be accompanied by a anticyclonic wind correction coincident with the height correction center. As one can see from Fig. 7, the wind correction is displaced about 10 degrees longitude west of the height correction. A similar (though less severe) displacement of the wind correction is associated with the negative height correction near 42N 152W.

Since the 3DVAR (and most objective analysis schemes) can not simultaneously perform a perfect fit to observations and have exact adherence to mass-wind balance, it is apparent that the November 1998 tuning of the 3DVAR to improved the analysis fit to the rawinsonde data weakened the ability of the analysis to created balanced mass-wind analysis corrections, leading to analyses which were essentially univariate. This problem would be most severe in regions and at analysis times without widespread rawinsonde data.

III. MODIFICATIONS TO THE 3DVAR ANALYSIS - SINGLE OBSERVATION TESTS

The observed 3DVAR analysis problems described above has led to an extensive examination of the 3-dimensional structure of the analysis increments in the current operational system. In addition to the poor mass-wind balance, it was determined that the horizontal and vertical correlation length scales were too short. These length scales will determine the horizontal and vertical extent to which an observation will modify the first guess away from its location. Thus, adjustments were made to both improve geostrophic coupling of mass/wind increments and to lengthen the horizontal and vertical correlation length scales. To illustrate the impact of these changes, single observation tests of the 3DVAR analysis at 32 km and 80 km were performed. Fig. 8a shows a vertical cross-section of the analysis height and wind correction caused by a single observation with height observation-first guess difference of 10 m at 200 mb. Fig. 8b shows the same feature from the modified 80-km 3DVAR analysis. The modified 3DVAR analysis not only produced a larger wind increment with a greater vertical extent, it also increased the height correction. Fig. 9a and 9b show the same experiment using the 32 km 3DVAR analysis.

These single observation tests were also performed at 900 mb and 500 mb and these tests showed a similar response to those done at 200 mb. They can be viewed at:

http://sgi62.wwb.noaa.gov:8080/3DVAR_STATS/index.html

IV. STATISTICAL SUMMARY OF NEW 3DVAR ANALYSIS PERFORMANCE : PRECIPITATION SKILL SCORES AND GRID-OBSERVATION VERIFICATION

The modified 3DVAR analysis tested in a retrospective 80 km parallel system for the period 3 December 1998 - 16 January 1999. A fully cycled EDAS was run to initialize both the control and experimental Eta-80 forecasts. The equitable threat score for 24-h accumulated precipitation from control and experimental Eta-80 forecast is shown in Fig. 10. A 10-20% increase in skill is seen at all thresholds. The similar bias scores observed for the same period (Fig. 11) indicated that the improved skill scores are not the result of an increase in forecast precipitation.

To assess the impact of the new 3DVAR analysis on the mass, wind, and moisture forecasts, the 00-h, 24-h, and 48-h forecast vs. rawinsonde root-mean-square (RMS) error of temperature (Fig. 12), vector wind (Fig. 13), geopotential height (Fig. 14) and relative humidity (Fig. 15) are presented. On these figures, the solid lines are the 80-km control run using the operational 3DVAR analysis (designated ETAV) and the dashed lines are the 80-km forecasts with the modified 3DVAR analysis (designated ETAY).

More details on this statistical summary and additional charts can be found at:

http://sgi62.wwb.noaa.gov:8080/3DVAR_STATS/index.html

A) TEMPERATURE

Since the modified analysis was tuned to improve the mass-wind balance, one would expect the 00-h forecast fit to observations to worsen. This is confirmed by the 00-h temperature trace in Fig.12, which shows a higher RMS at all levels. However, by 24-h the errors between the control and experimental forecasts are similar, and the experimental run has slightly lower temperature errors at most levels by 48-h.

B) VECTOR WIND

Fig. 13 shows that the improved mass-wind balance in the modified 3DVAR analysis had a dramatic positive impact on the RMS vector wind errors. The forecasts from the modified analysis had lower wind errors at all levels and at all times, with the greatest impact at jet stream level. At 200 mb the 24-h RMS vector wind error from the experimental run is very close to the 00-h RMS vector wind error from the control run

C) GEOPOTENTIAL HEIGHT

The RMS errors for geopotential height in Fig. 14 mirror the temperature errors described above, with a slightly degraded fit to the height data by the modified 3DVAR analysis. There is a tendency for the difference in control-experimental RMS height error difference to increase with forecast hour.

D) RELATIVE HUMIDITY

The RMS error of relative humidity (Fig. 15) from the experimental Eta-80 forecasts is very similar to the control run. This indicates that modified 3DVAR had the desired effect of retaining the improved fit to moisture data implemented in the November 1998 version of 3DVAR.

V. IMPACT OF ANALYSIS CHANGES :15 MARCH 1999 CASE

In addition to the December 1998-January 1999 retrospective test, a real-time 80 km test of a fully cycled EDAS with the modified 3DVAR analysis was done from 13-31 March 1999. The impact on quantitative skill scores (not shown) mirrors the results seen from the December 1998 - January 1999 retrospective test.

Fig. 16 shows the wind and height increments from a cycled EDAS analysis valid at 0000 UTC 15 March 1999 the modified 3DVAR system. Compared to the control 80 km run shown in Fig. 7, there is better balance between the mass and wind increments, as can be seen in the better coherence associated with the positive height correction north of St. Paul Island, Alaska than was seen in the control run. Fig. 17 shows the control and experimental 48-h Eta-80 forecasts valid at 1200 UTC 17 March 1999. The forecast using the modified 3DVAR produced forecast the cyclone to move more slowly eastward and predicted a central pressure of 994 mb, 8 mb deeper then the control Eta-80 forecast.

VI. CONCLUSIONS

By improving the mass-wind balance and the correlation length scales in the 80-km 3DVAR analysis, forecasts using this modified version improve Eta-80 forecasts and reduce the observed biases seen in the operational Eta system. An appendix which will soon be attached to this TPB will present results from a limited number of Eta-32 forecasts using the modified 3DVAR analysis.

VII. REFERENCES

Derber, J., and coauthors, 1998: Further changes to the 1997 NCEP operational MRF Model Analysis/Forecast System : The use of TOVS level 1-b radiances and increased vertical diffusion. NWS Technical Procedures Bulletin No. 449, NOAA/NWS, Washington, DC.

Parrish, D. and coauthors, 1996: The regional 3D-variational analysis for the Eta model. Preprints, 11th AMS Conference on Numerical Weather Prediction, 19-23 August 1996, Norfolk, VA.

Rogers, E., and coauthors, 1997: Changes to the NCEP Operational "Early" Eta Analysis /

Forecast System. NWS Technical Procedures Bulletin No. 447, NOAA/NWS, Washington, DC. [Available at http://www.nws.noaa.gov/om/tpb/447.htm]

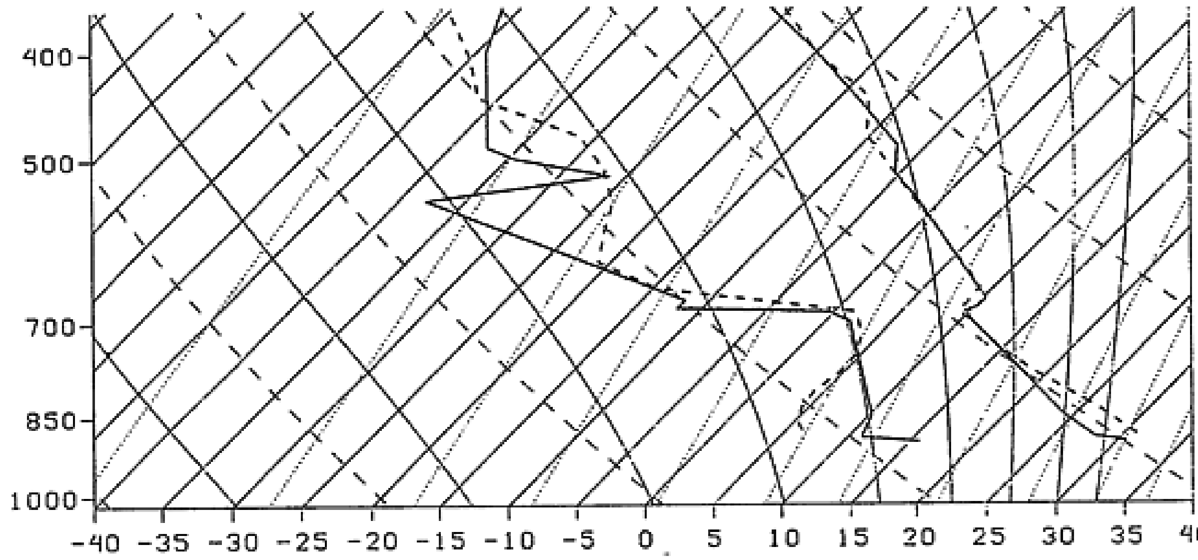

Figure 1: Observed (solid) and 80 km control 3DVAR analysis (dashed) sounding at Rapid City, SD valid 0000 UTC 13 July 1998

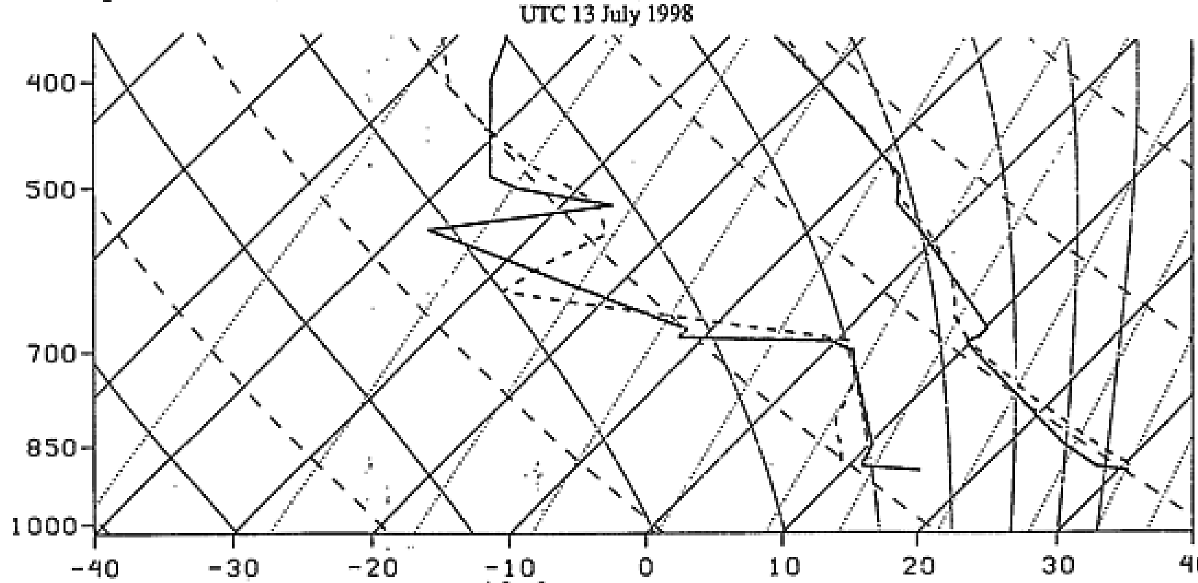

Figure 2: Same as Figure 1, but with modified 80 km 3DVAR analysis

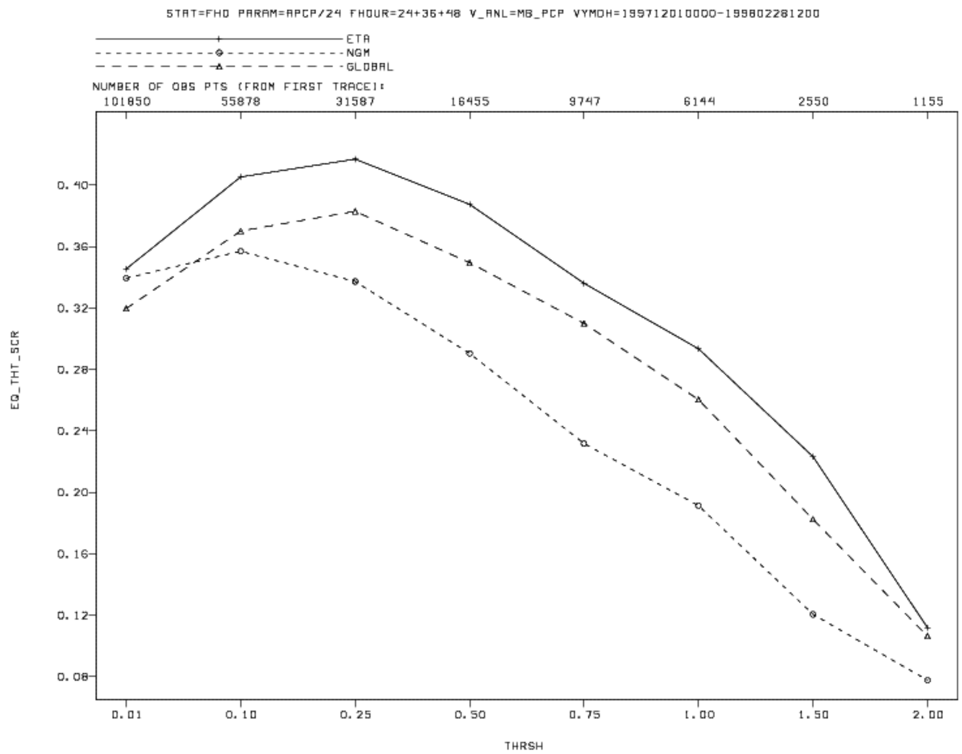

Figure 3: Equitable threat score for 24-h accumulated precipitation for the Eta (solid), AVN (long dash) and NGM (short dash) for 1 December 1997 - 28 February 1998

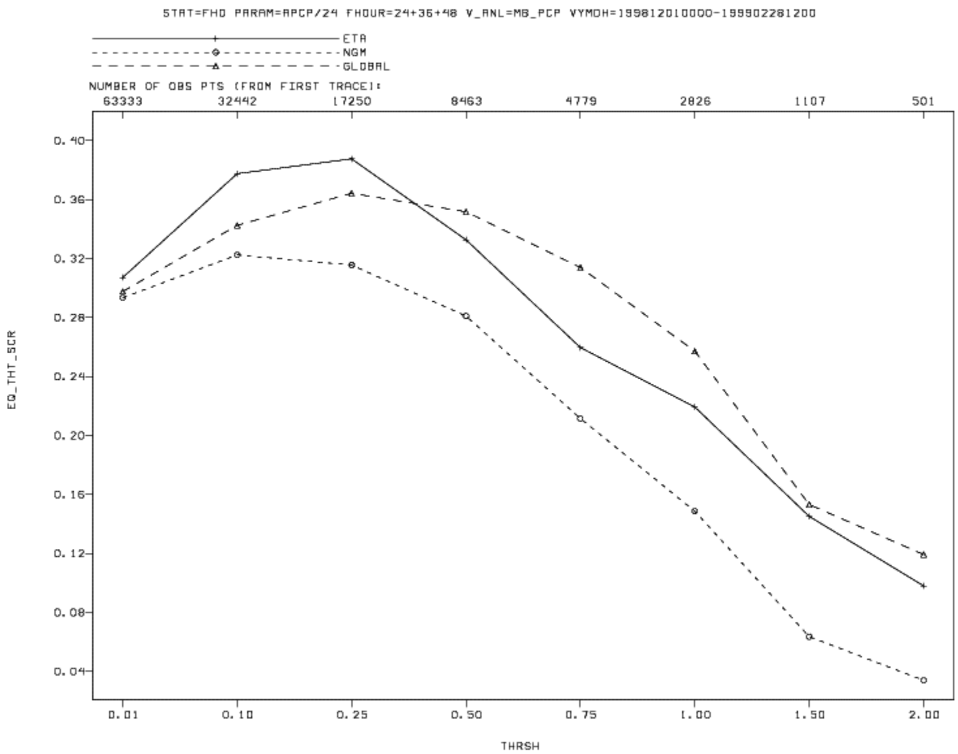

Figure 4: Same as Figure 3, but for the period 1 December 1998 - 28 February 1999

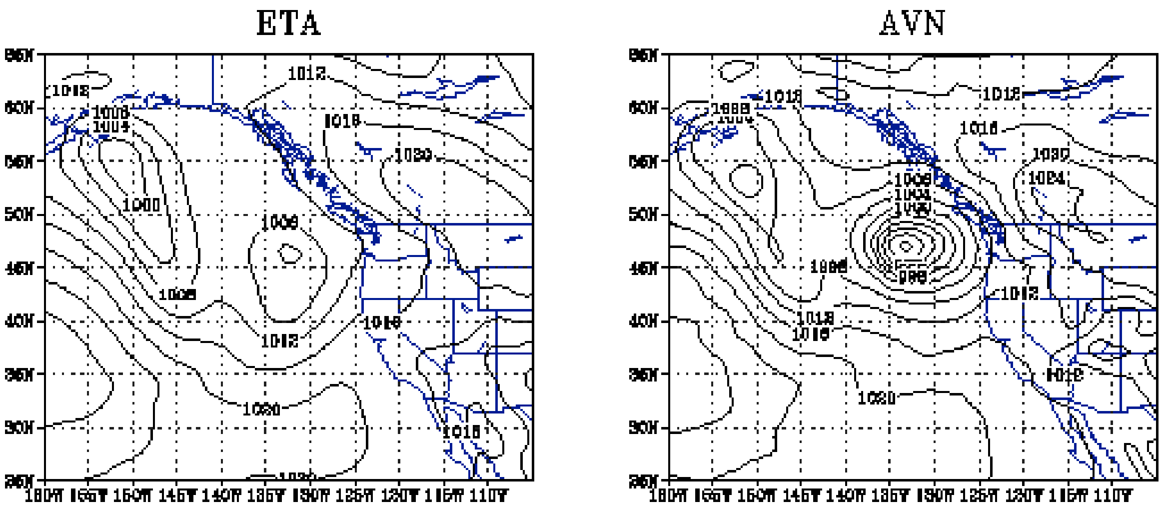

Fig 5: 48-H Sea Level Pressure Forecast valid 1200 UTC 17 MARCH 1999

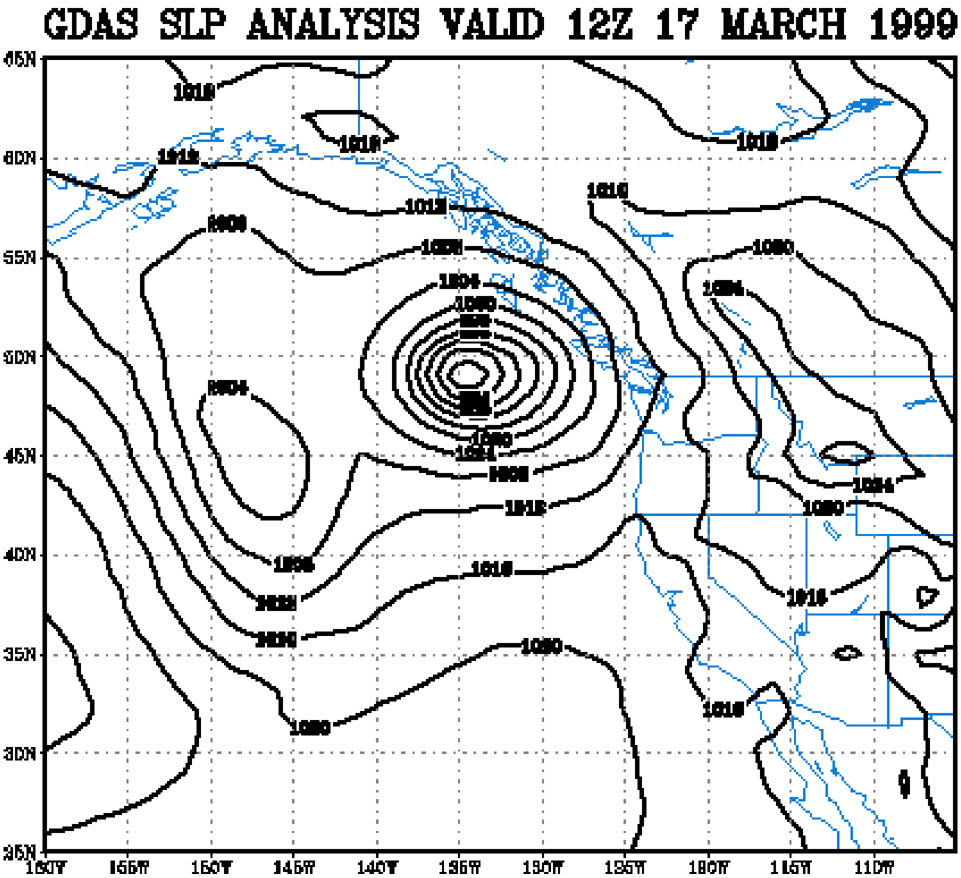

Fig 6: GDAS Sea Level Pressure Analysis valid 1200 UTC 17 March 1999

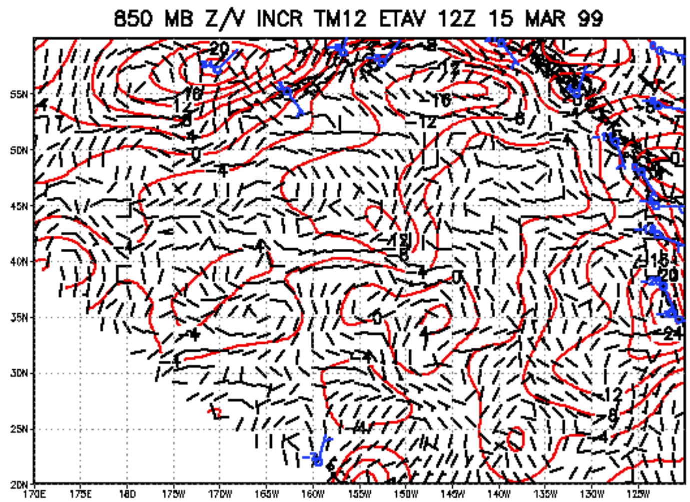

Figure 7 : 850 mb analysis - first guess height and wind differences for the control 80 km EDAS analysis valid 0000 UTC 15 March 1999. Blue station model is rawinsonde - first guess difference

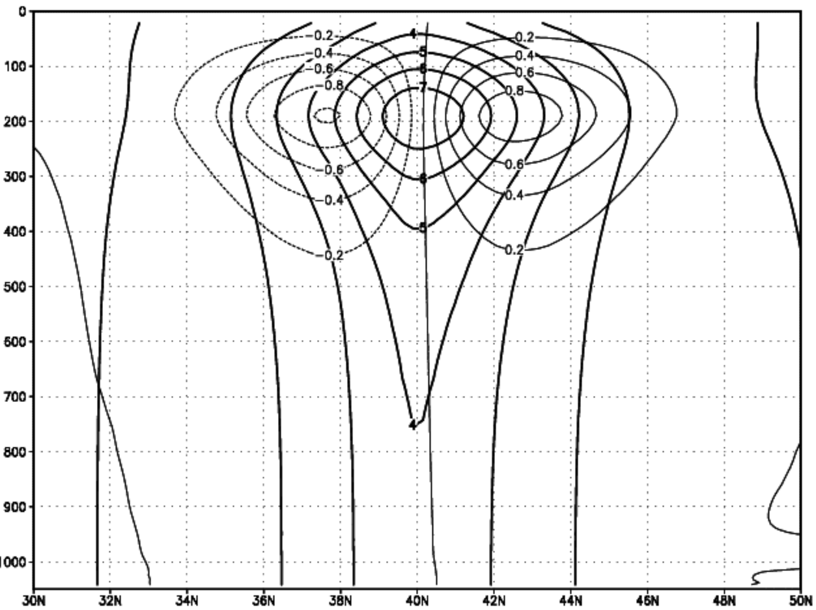

Figure 8a: Control 80-km 3DVAR analysis height increment (m, dark) and wind increment (m/s, light) resulting from a single height observation with a 10 m increment at 200 mb

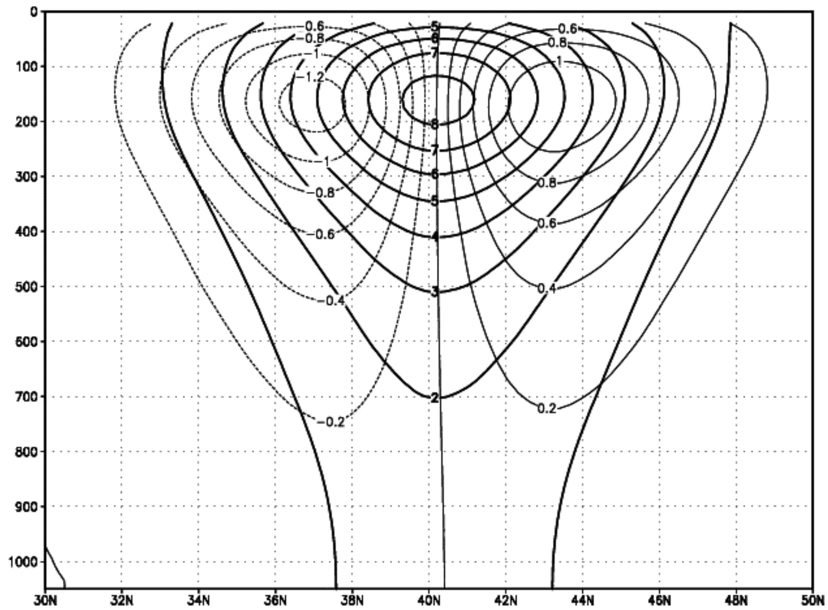

Figure 8b: Same as Figure 8a, but for the modified 3DVAR analysis

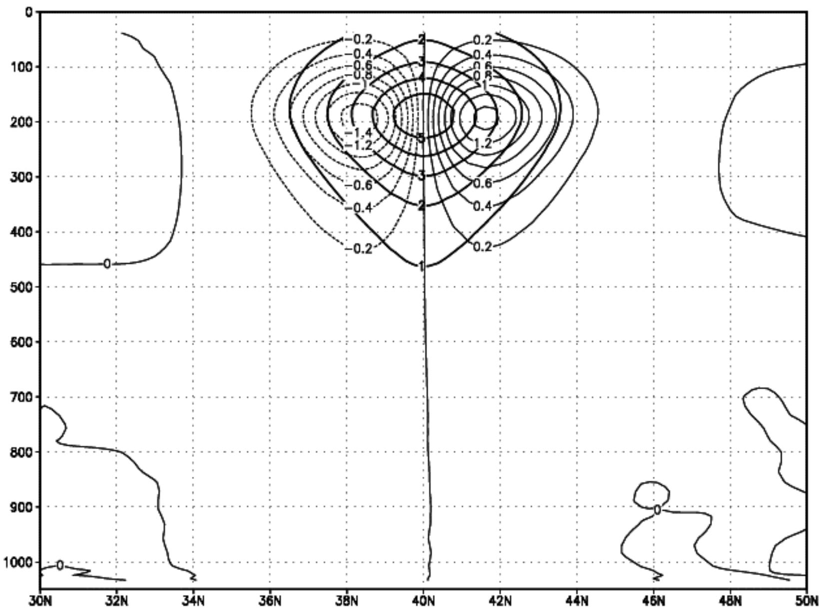

Figure 9a : Same as Figure 8a, but for the 32-km 3DVAR analysis

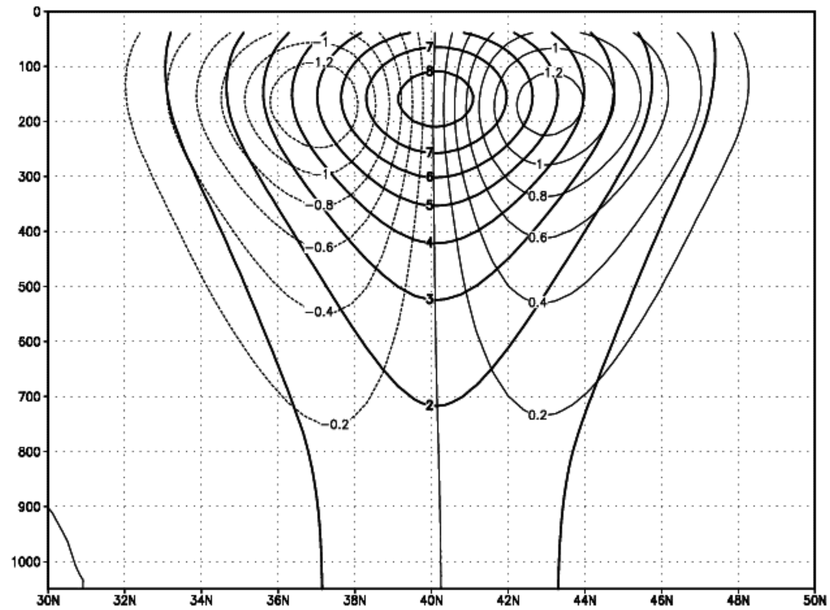

Figure 9b : Same as Figure 9a, but for the experimental 3DVAR analysis

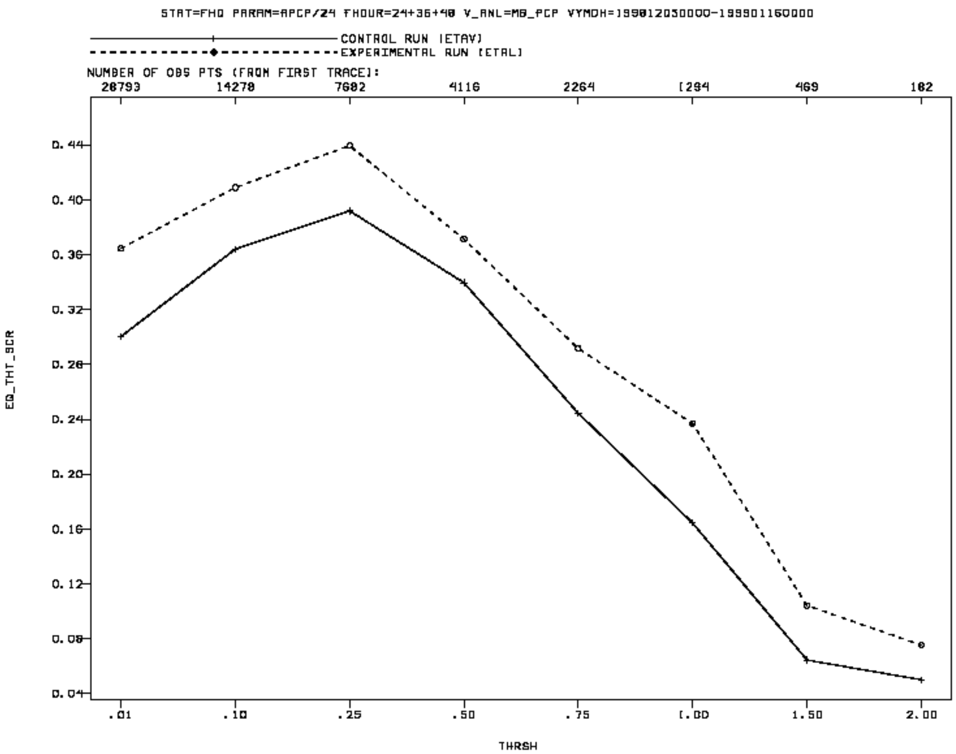

Fig 10: 24-h forecast accumulated precipitation equitable threat score for Eta-80 control (solid) and experimental (dashed) runs

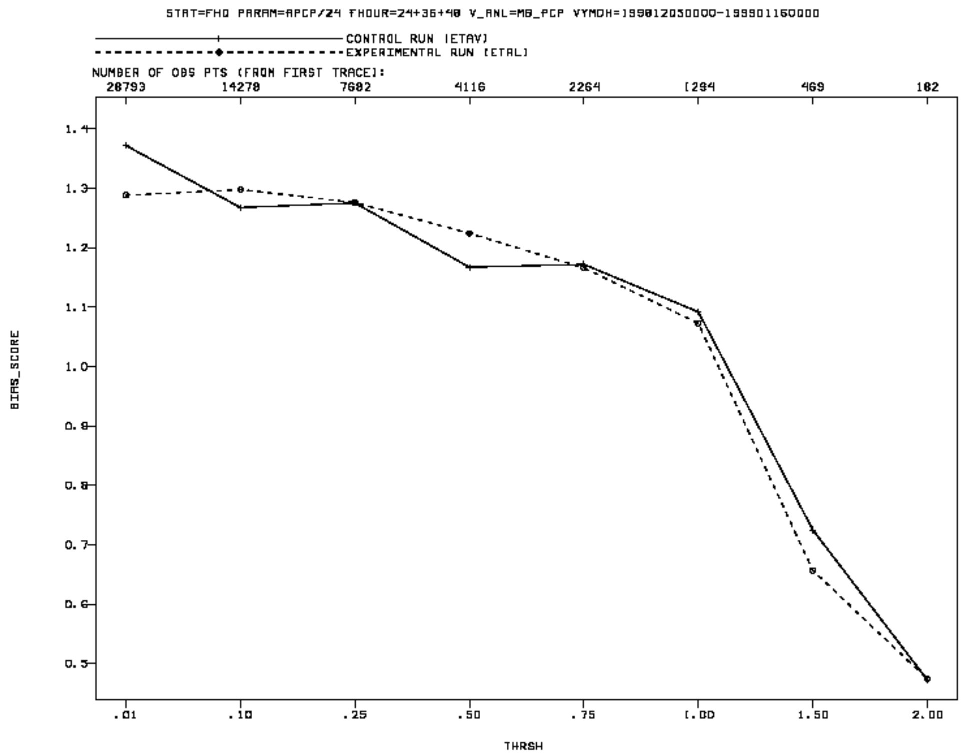

Figure 11 : 24-h accumulated precipitation bias scores for the Eta-80 control run (solid) and experimental run (dashed)

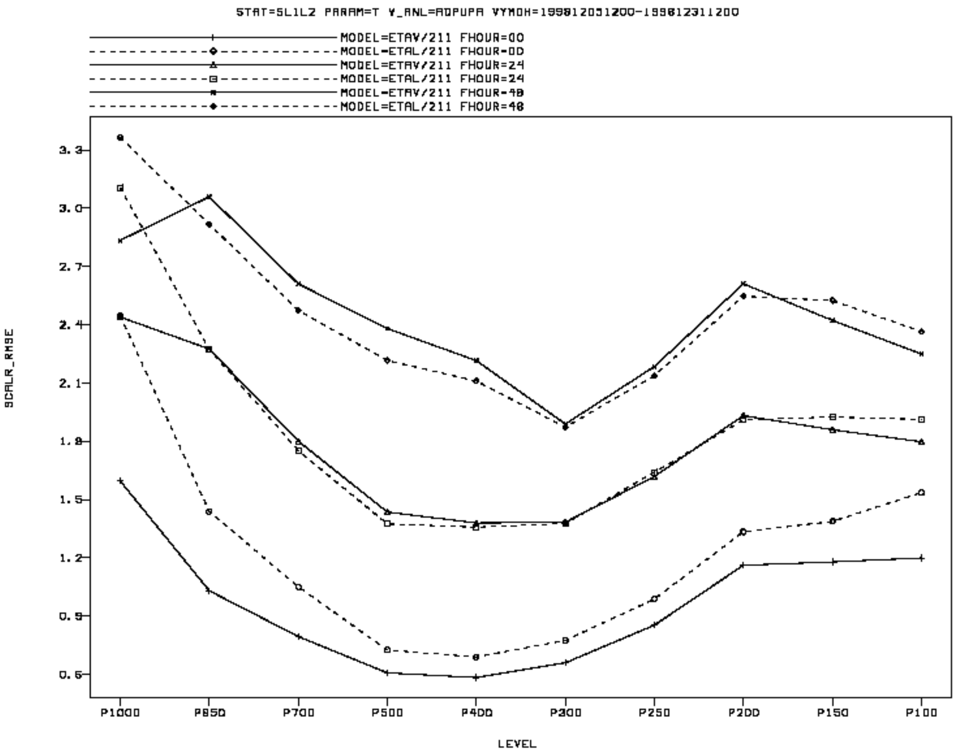

Figure 12: 00-h, 24-h, and 48-h forecast vs. rawinsonde temperature RMS error for the Eta-80 control (solid) and experimental (dashed) runs

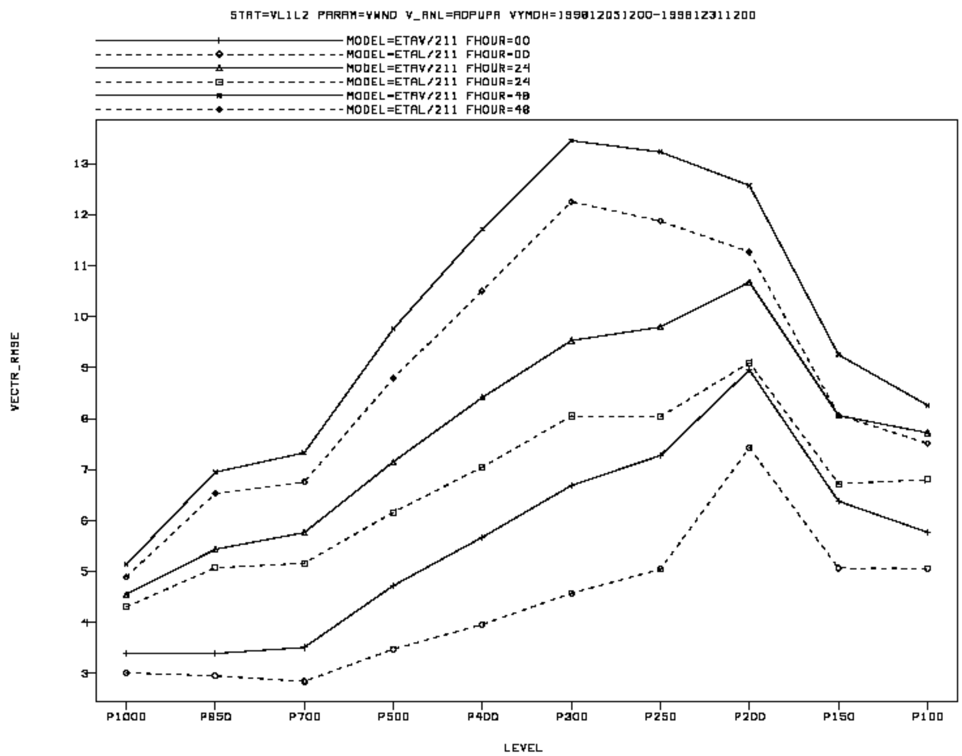

Figure 13: Same as Figure 12, but for RMS vector wind errors

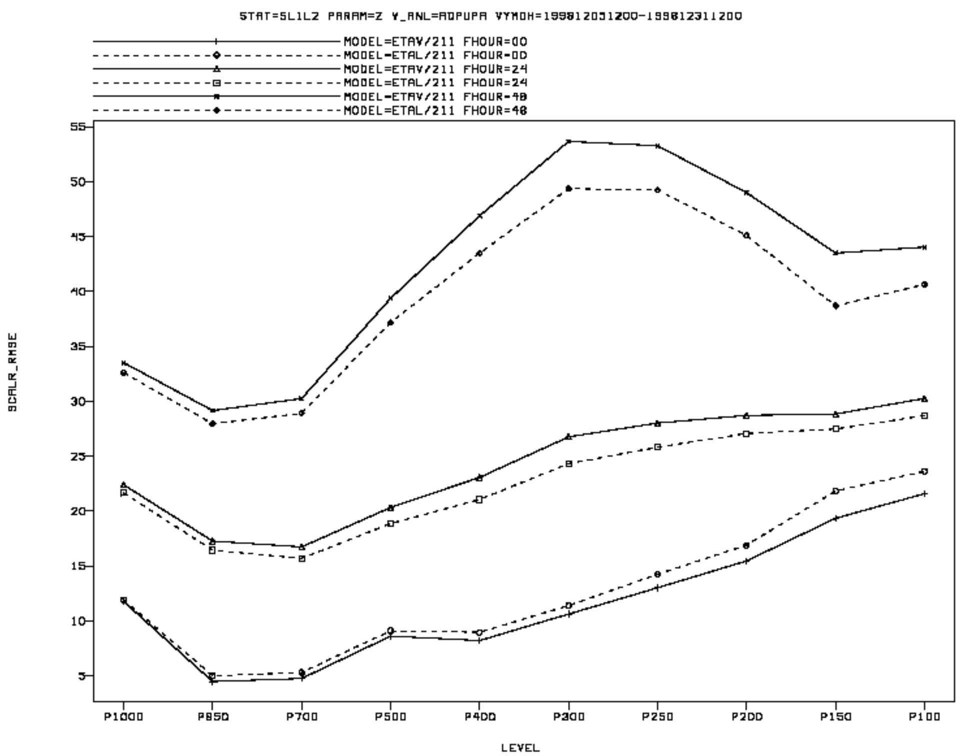

Figure 14 : Same as Figure 12, but for geopotential height

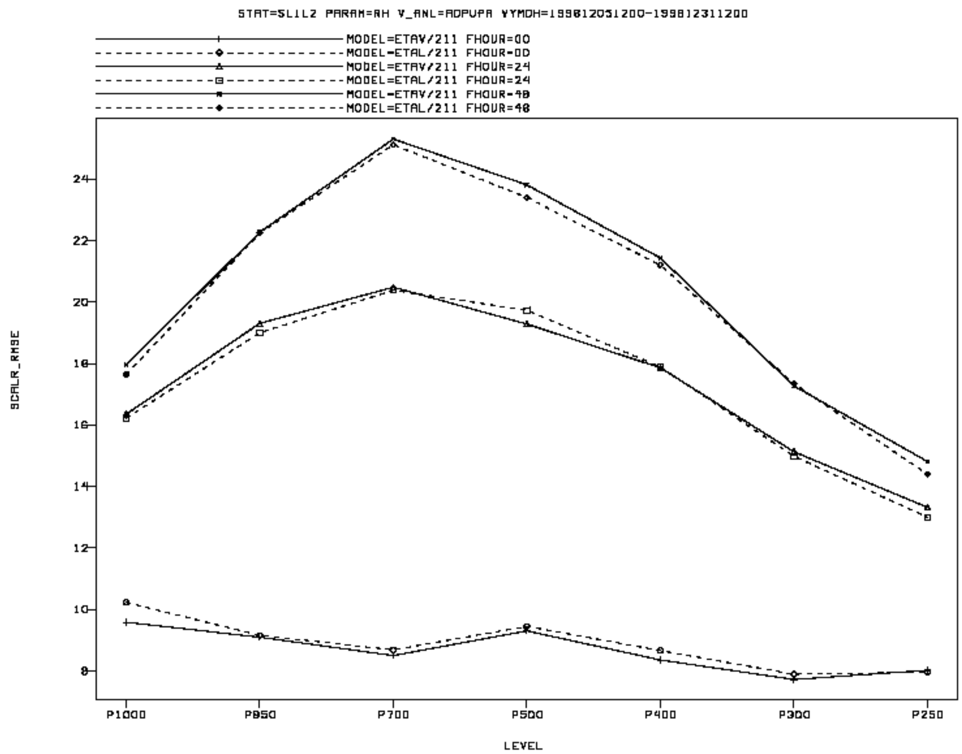

Figure 15 : Same as Figure 12, but for relative humidity

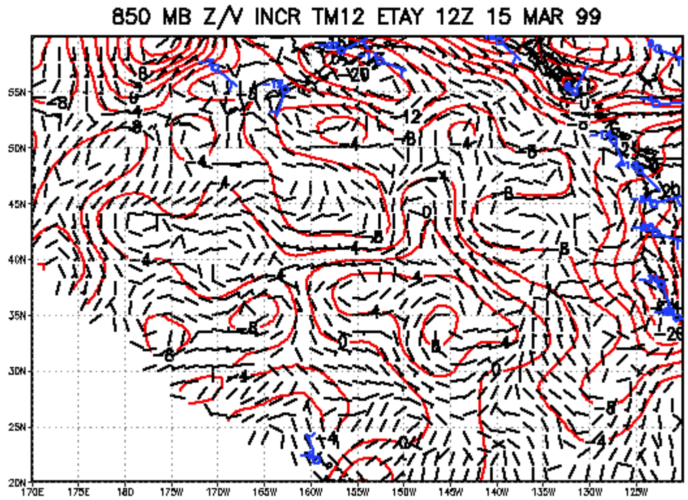

Figure 16 : Same as Figure 7, but for the experimental 3DVAR analysis

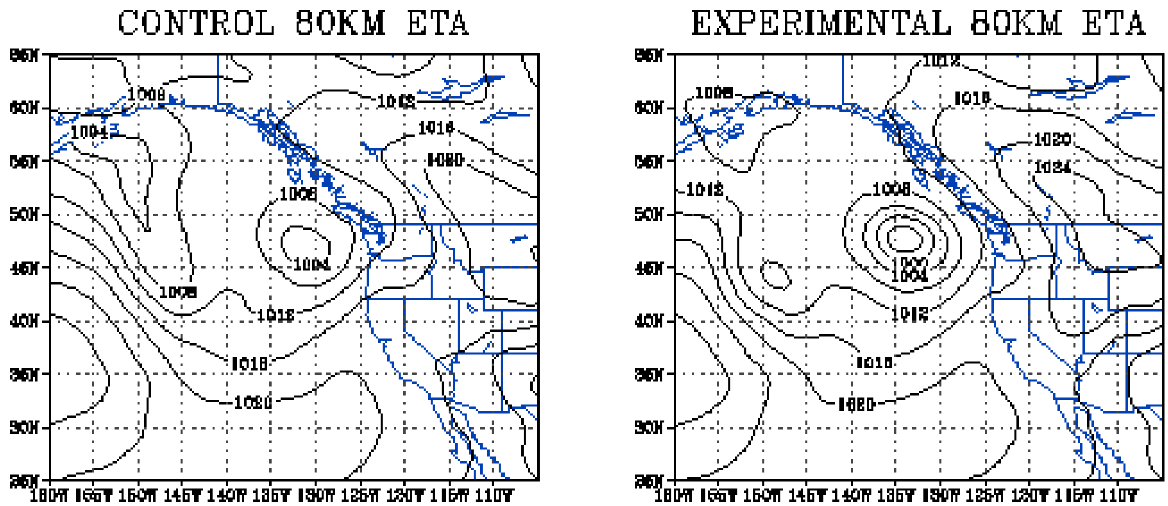

Fig 17: 48-H Sea Level Pressure Forecast valid 1200 UTC 17 MARCH 1999