Changes to the 1997 NCEP Operational MRF Model Analysis/Forecast System

Wan-shu Wu, Mark Iredell, Suranjana Saha and Peter Caplan
Global Modeling Branch
Environmental Modeling Center, NCEP

1. INTRODUCTION

On 5 November 1997, 1200Z the following small changes in the global analysis/forecast system were implemented:

```
1. New observation errors in SSI analysis
2. Changes in assimilation of TOVS radiances
3. Inclusion of several additional data sources
4. Elimination of spurious "valley snow"
5. Soil moisture nudging toward climatology
6. Conservation of dry mass
7. Model structural changes
8. Changes in some GRIB output files
  **(some of the ouput changes have been delayed see appendix)
```

2. CHANGES TO THE ANALYSIS SYSTEM

2.1 New observation errors in SSI analysis (W.-S. Wu)

In data assimilation, the weights given to the data are derived from the inverse of the observation error covariance, while the weights for the fit to the first guess are determined by the inverse of the background error covariance. Since the observation errors include both the errors from the observations themselves and errors of representativeness as well, their magnitudes are larger than what is needed to account for just instrument and measurement errors. The statistics of the current operational data assimilation system at NCEP indicate that for some quantities the first guess fit to the data is better than the observational error used in the SSI analysis. Since the guess fit includes not only the observation error but also the model error, then the observation errors are overestimated. With the guess fit to the data as guidance, we adjusted the observational error mainly according to Stoffelen, et al., 1996. As an example, the new temperature errors for rawindsondes and dropsondes are shown in Fig. 1 .

The modified error table was tested in the full resolution (T126) parallel run in April, 1996 for

	NH		SH	
	MRF	X	MRF	X
mean	.743	.758	.592	.606
stdev	.067	.063	.151	.133

Table 1. Anomaly correlations for 5-day forecasts of 500-mb gopotential, operational (MRF) vs new errors (X)

2.2 Changes in assimilation of TOVS radiances (W.-S. Wu)

The main changes in the direct use of the TOVS radiances in the SSI analysis system are (a) the exclusion of HIRS channels 16, 18 , and 19, and (b) the elimination of NESDIS temperature retrievals above the top of the model in favor of using model layers to represent the whole profile. These changes have been found to decrease the temperature bias found between 100 and 300 hPa and to improve the fit of the 6-hour guess to the data. Results from a month of parallel testing at T126 in August, 1996 show very little impact on the 500-hPa geopotential anomaly correlations for 5-day forecasts given in Table 2.

	NH		SH	
	MRF	X	MRF	X
mean	.729	.732	.691	.696
stdev	.057	.055	.066	.064

Table 2. Anomaly correlations for 5-day forecasts of 500-mb geopotential: operational (MRF) vs TOVS changes (X)

2.3. New data sources

The following data sources are included in the new system:

1. Wind soundings from the Profiler

2. ERS-2 winds

3. CHANGES TO THE OPERATIONAL MRF MODEL

3.1 Moisture diffusion change (M. Iredell)

For a number of years users of the MRF have complained of persistent fixed For a number of years, users of the MRF have complained of persistent fixed (Fig. 2 , left side). The cause has been traced to the use of a time-saving approximation for the elimination of errors in the conversion of horizontal diffusion on the model's sigma surfaces to diffusion on pressure surfaces. The approximation to the correction term used in the diffusion equation is

$$\nabla_p^4 q \approx \nabla_\sigma^4 q - \frac{\partial \bar{q}}{\partial \ln \sigma} \nabla_\sigma^4 \ln P_s \qquad (1)$$

where Ps is the surface pressure and q-bar is the global average of q, the specific humidity. It is the vertical derivative of the global average of specific humidity that creates spurious moisture sources in valleys in arctic air, moisture deficits over high terrain, and spurious gradients. The prominent wave patterns are a result of the inability of a spectral model to handle such intense gradients properly. The current problem has been greatly reduced by the elimination of this correction (Fig 2 right side) but a permanent solution will require the development of a better parameterization of horizontal diffusion.

3.2 Soil moisture nudging toward climatology (S. Saha)

Since there are no widespread routine soil moisture measurements, the GDAS system calculates updates for soil moisture from the model forecast. Consequently, deficiencies in model precipitation and runoff forecasts may cause the soil moisture to drift far from reality and, in the process, cause drifts in other model fields as well. In order to prevent this, we are implementing a relaxation scheme to nudge the model soil moisture to the climatological values. The relaxation time of 60 days is chosen so that we can allow a within-season response of the soil to seasons with either drought or abundant rainfall, while keeping the longer-term soil moisture bounded. The climatology is a recent product of the Climate Prediction Center of NCEP that makes use of both observed precipitation and surface air temperature climatology.

Extended-range operational model runs (up to twenty years) have shown that while the model soil moisture does not lead to disasters (i.e., permanent desert or swamp), there can be significant departures from climatology that do not correspond to observed anomalies in precipitation. This can still vary in response to the changing atmospheric water load.

3.4 Structural changes: Surface cycling and entire forecast in one execution

The global spectral model can now be run in a single step and can now invoke surface cycling (to update climatology). These restructurings allow model scripts to be more flexible, especially for longer forecasts and climate runs; they change model architecture only and do not affect the model results.

4. PARALLEL TESTING AND EVALUATION (P.Caplan)

The changes that are to be implemented were each tested separately for various periods of time at T62 resolution, and then together for over three months at T126 in parallel with the operational MRF. These parallel runs were not only evaluated objectively with standard statistical measures, but also subjectively by the Medium Range Desk and the International Desk.

4.1 Objective scores against analyses

The results of testing the above changes in the parallel system for three continuous months (March through May of 1997) are given in the next series of figures. Fig. 3a and Fig. 3b show anomaly correlations for 500 hPa geopotential height forecasts for latitudes 20-80 degrees in each hemisphere, with each model verified against its own analysis. The new system (labeled X) scores slightly higher than the MRF system at all forecast lengths and for all zonal wavelengths. Fig 4 shows just the 5-day forecasts from the above data, plotted as a scatter diagram of the new system (X) against the operational(MRF). The amount of scatter is much greater in the Southern Hemisphere, as usual. In the tropics (20S-20N), the models are also close, with the operational MRF better at 850 hPa and the X better at 200 hPa, as can be seen both from the anomaly correlations of the wind components (Fig. 5) and the rms vector errors (Fig. 6).

4.2 Objective scores against observations - wind and temperature

The 72-h wind and temperature forecasts from the two systems were evaluated also against observations from near the surface up to 100 hPa over the above three-month period, plus June. Against rawinsondes in the Northern Hemisphere and in the tropics the two systems performed almost identically, while in the Southern Hemisphere a slight improvement (up to 3%) was noted in the rms vector errors in the middle and upper troposphere (Fig. 7). For temperature errors,

4.3 Objective scores against observations - precipitation

For 1-day and 2-day precipitation forecasts over the continental United States the performance of the new system was quite similar to that of the old. Fig. 9 shows equitable threat scores and biases averaged for March through June. (The threat scores with the new system were slightly worse in March and April, and slightly better in May and June).

4.4 Results of subjective evaluations

As is the current procedure for implementations, parallel forecasts from the new system were examined side-by-side with those from the operational system at the daily map discussions in the Meteorological Operations Division at NCEP. Over North America there were noticeable but non-systematic differences from day to day, but no clear winner in skill. In the tropics, where both systems are prone to generating spurious shallow disturbances along the ITCZ, the new model at times seemed somewhat noisier than the operational. Elsewhere in the tropics there was little difference.

5. CHANGES IN OUTPUT FILES

The output GRIB files will also contain a few slight changes. For the AVN runs only, the 10 new levels will be added to the 0-, 12-, 24-, and 36-h forecast files so that the minimum vertical resolution will be 50 hPa. In addition, three fields describing convective clouds will be added - coverage, level of the tops and level of the bottoms. There will also be some changes in labeling to clarify the contents of several of the existing GRIB files (see appendix).

6. SUMMARY

Minor changes have been made to the GDAS/MRF analysis and forecast system Potentially the most significant of these is the reduction of the errors assigned to the observations so that the analysis can draw more closely to the data. In the forecast model the nudging of the soil moisture toward climatology should insure against excessive model drifts where precipitation is poorly forecast. The change in moisture diffusion should largely eliminate spurious wavelike paterns of snow in arctic air masses.

These changes led to a slight improvement in anomaly correlation scores against analyses for 500-hPa geopotential in the Southern Hemisphere. In the tropics, the new model seemed slightly focused in four major areas:

- First the number of data sources available to the data assimilation system will increase when GOES sounder and DMSP T/T2 radiances are incorporated. Later, use of NOAA-K AMSU-A/B data will be developed and tested. All of these data sources are particularly important for moisture analysis to help maximize the amount of data available for moisture analysisis, which is a prerequisite for other developments.

- One of the most serious (and difficult) problems in the current data assimilation system is the moisture (water vapor, clouds and precipitation) analysis. Over the next year, all satellite data available to the analysis will be used more effectively with improved calculation of radiative transfer for those instrument channels most sensitive to atmospheric moisture. Other analysis upgrades should also produce an improved moisture analysis. A major research effort to use satellite-based cloud and precipitation information in the analysis will be initiated, which should improve the moisture/dynamics coupling and provide considerably improved precipitation forecasts.

- In addition to the improvement of initial conditions for the forecast models, improved precipitation products using the global ensembles will be produced. Probabilistic quantitative precipitation forecasts (PQPFs) that have been corrected for model bias will be introduced. This will be done in conjunction with ensemble techniques, thus implementing a powerful methodology for providing more information to the forecaster on 3-5 day forecast rainfall and for correcting persistent model biases.

- Last, upgrades to model physics should improve precipitation scores. It is believed that a major cause of the large bias is the interaction of the over-land boundary layer with the surface, particularly for evaporation during nighttime. Current tests of surface physics upgrades and modifications to the model vertical diffusion, along with increased resolution in the data assimilation, are not complete at this time but are very encouraging. A scheme to include prognostic cloud water in the global forecast model will continue to be developed and tested.

In summary, major development will occur on the primary ingredients for QPFs: improved moisture analysis, precipitation products geared to maximum forecaster usage, and changes to model physics.

REFERENCE

APPENDIX

NOTE!!! The changes in the number of levels in the AVN output were temporarily withdrawn at the request of some users. They will appear at a future date.

(1) Both the pressure GRIB file and the surface flux file have the following changes and additions:

(a) The maximum and minimum temperature fields now reflect the time period over which they are valid. Previously, they were imprecisely labeled instantaneous. For instance, the PDS for the 24-hour MRF forecast used to be:

```
00001C02 074E0380 0F690002 610A0E00 00010018 0A000000 14000001 2 HTGL T MAX 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 10690002 610A0E00 00010018 0A000000 14000001 2 HTGL T MIN 24 HRS AFTER
00Z 14 OCT 1997
```

The PDS now is:

```
00001C02 074E0380 0F690002 610A0E00 00010C18 02000000 14000001 2 HTGL T MAX 12 - 24 HRS
AFTER 00Z 14 OCT 1997
00001C02 074E0380 10690002 610A0E00 00010C18 02000000 14000001 2 HTGL T MIN 12 - 24 HRS
AFTER 00Z 14 OCT 1997
```

(b) There are three new convective cloud fields:

```
00001C02 074E0380 47E00000 610A0E00 00010C18 03000000 14000000 CCY T CDC 24 HRS AFTER 00Z
14 OCT 1997
00001C02 074E03C0 01DF0000 610A0E00 00010C18 03000000 14008001 CCTL PRES 24 HRS AFTER 00Z
14 OCT 1997
00001C02 074E03C0 01DE0000 610A0E00 00010C18 03000000 14008001 CCBL PRES 24 HRS AFTER 00Z
14 OCT 1997
```

TO BE IMPLEMENTED LATER:

(2) For the AVN only, and only at forecast hours 00, 12, 24, and 36, extra pressure levels are added to the pressure GRIB file so that the minimum resolution is 50 mb. Thus the new fields for these few files are:

```
00001C02 074E0380 076403CF 610A0E00 00010018 0A000000 14000001 975 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 076403B6 610A0E00 00010018 0A000000 14000001 950 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 07640384 610A0E00 00010018 0A000000 14000001 900 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 07640320 610A0E00 00010018 0A000000 14000001 800 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 076402EE 610A0E00 00010018 0A000000 14000001 750 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0764028A 610A0E00 00010018 0A000000 14000001 650 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 07640258 610A0E00 00010018 0A000000 14000001 600 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 07640226 610A0E00 00010018 0A000000 14000001 550 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 076401C2 610A0E00 00010018 0A000000 14000001 450 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0764015E 610A0E00 00010018 0A000000 14000001 350 ISBL HGT 24 HRS AFTER
00Z 14 OCT 1997

00001C02 074E0380 216403CF 610A0E00 00010018 0A000000 14000001 975 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 216403B6 610A0E00 00010018 0A000000 14000001 950 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 21640384 610A0E00 00010018 0A000000 14000001 900 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 21640320 610A0E00 00010018 0A000000 14000001 800 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 216402EE 610A0E00 00010018 0A000000 14000001 750 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 2164028A 610A0E00 00010018 0A000000 14000001 650 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
```

00001C02 074E0380 21640258 610A0E00 00010018 0A000000 14000001 600 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 21640226 610A0E00 00010018 0A000000 14000001 550 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 216401C2 610A0E00 00010018 0A000000 14000001 450 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 2164015E 610A0E00 00010018 0A000000 14000001 350 ISBL U GRD 24 HRS AFTER
00Z 14 OCT 1997

00001C02 074E0380 226403CF 610A0E00 00010018 0A000000 14000001 975 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 226403B6 610A0E00 00010018 0A000000 14000001 950 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 22640384 610A0E00 00010018 0A000000 14000001 900 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 22640320 610A0E00 00010018 0A000000 14000001 800 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 226402EE 610A0E00 00010018 0A000000 14000001 750 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 2264028A 610A0E00 00010018 0A000000 14000001 650 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 22640258 610A0E00 00010018 0A000000 14000001 600 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 22640226 610A0E00 00010018 0A000000 14000001 550 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 226401C2 610A0E00 00010018 0A000000 14000001 450 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 2264015E 610A0E00 00010018 0A000000 14000001 350 ISBL V GRD 24 HRS AFTER
00Z 14 OCT 1997

00001C02 074E0380 0B6403CF 610A0E00 00010018 0A000000 14000001 975 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B6403B6 610A0E00 00010018 0A000000 14000001 950 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B640384 610A0E00 00010018 0A000000 14000001 900 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B640320 610A0E00 00010018 0A000000 14000001 800 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B6402EE 610A0E00 00010018 0A000000 14000001 750 ISBL TMP 24 HRS AFTER

00Z 14 OCT 1997
00001C02 074E0380 0B64028A 610A0E00 00010018 0A000000 14000001 650 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B640258 610A0E00 00010018 0A000000 14000001 600 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B640226 610A0E00 00010018 0A000000 14000001 550 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B6401C2 610A0E00 00010018 0A000000 14000001 450 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 0B64015E 610A0E00 00010018 0A000000 14000001 350 ISBL TMP 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 276403CF 610A0E00 00010018 0A000000 14000003 975 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 276403B6 610A0E00 00010018 0A000000 14000003 950 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 27640384 610A0E00 00010018 0A000000 14000003 900 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 27640320 610A0E00 00010018 0A000000 14000003 800 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 276402EE 610A0E00 00010018 0A000000 14000003 750 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 2764028A 610A0E00 00010018 0A000000 14000003 650 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 27640258 610A0E00 00010018 0A000000 14000003 600 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 27640226 610A0E00 00010018 0A000000 14000003 550 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 276401C2 610A0E00 00010018 0A000000 14000003 450 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 2764015E 610A0E00 00010018 0A000000 14000003 350 ISBL V VEL 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 346403CF 610A0E00 00010018 0A000000 14000000 975 ISBL R H 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 346403B6 610A0E00 00010018 0A000000 14000000 950 ISBL R H 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 34640384 610A0E00 00010018 0A000000 14000000 900 ISBL R H 24 HRS AFTER
00Z 14 OCT 1997
00001C02 074E0380 34640320 610A0E00 00010018 0A000000 14000000 800 ISBL R H 24 HRS AFTER
00Z 14 OCT 1997

00001C02 074E0380 346402EE 610A0E00 00010018 0A000000 14000000 750 ISBL R H 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 3464028A 610A0E00 00010018 0A000000 14000000 650 ISBL R H 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 34640258 610A0E00 00010018 0A000000 14000000 600 ISBL R H 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 34640226 610A0E00 00010018 0A000000 14000000 550 ISBL R H 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 346401C2 610A0E00 00010018 0A000000 14000000 450 ISBL R H 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 3464015E 610A0E00 00010018 0A000000 14000000 350 ISBL R H 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 296403CF 610A0E00 00010018 0A000000 14000006 975 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 296403B6 610A0E00 00010018 0A000000 14000006 950 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 29640384 610A0E00 00010018 0A000000 14000006 900 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 29640320 610A0E00 00010018 0A000000 14000006 800 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 296402EE 610A0E00 00010018 0A000000 14000006 750 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 2964028A 610A0E00 00010018 0A000000 14000006 650 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 29640258 610A0E00 00010018 0A000000 14000006 600 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 29640226 610A0E00 00010018 0A000000 14000006 550 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 296401C2 610A0E00 00010018 0A000000 14000006 450 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997
00001C02 074E0380 2964015E 610A0E00 00010018 0A000000 14000006 350 ISBL ABS V 24 HRS AFTER 00Z 14 OCT 1997

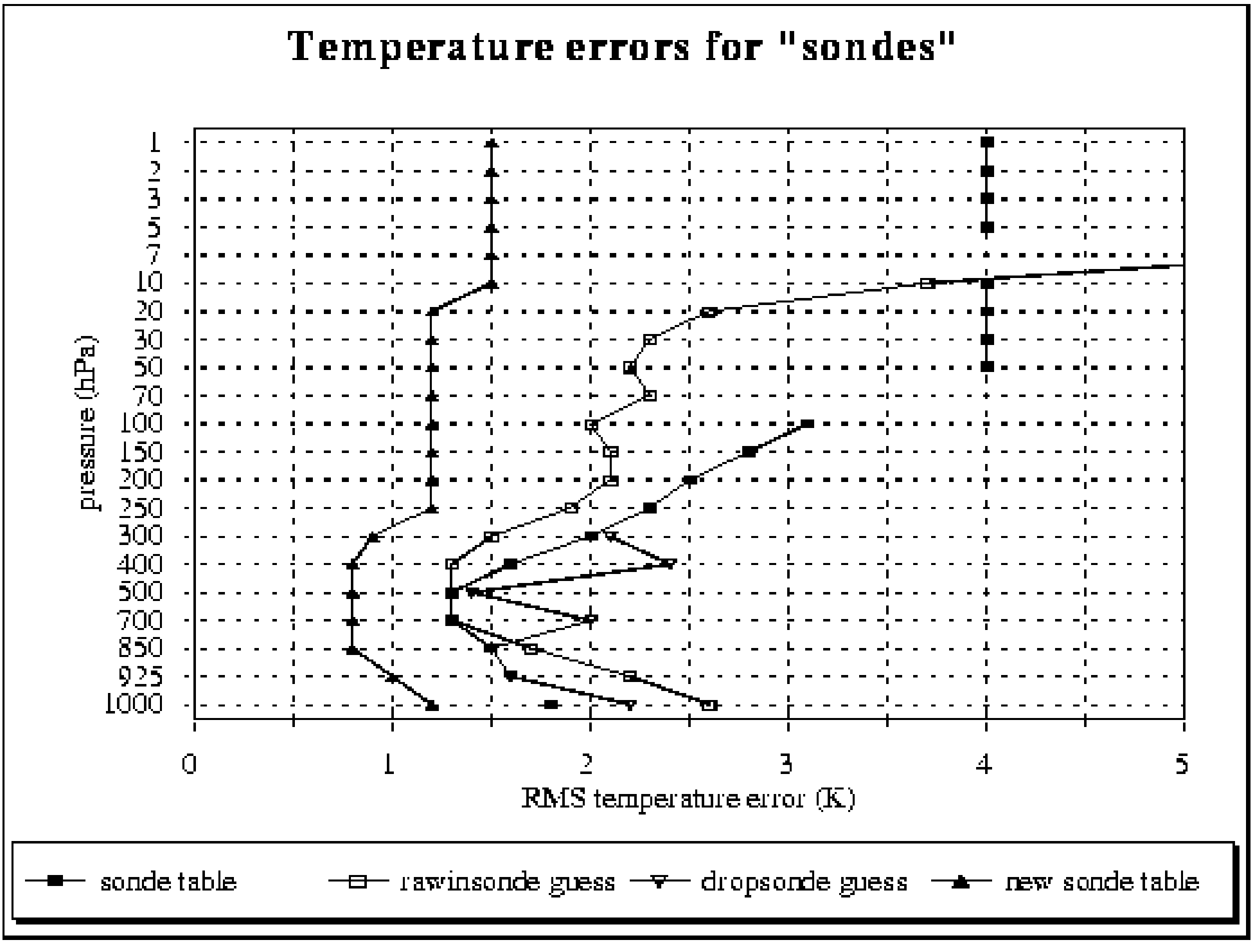

Fig. 1 Rms temperature errors as a function of pressure level for the guess for rawinsondes (open rectangles) and dropsondes (open triangles) and for the rawinsonde observations in the operational system (filled rectangles) and the new system (filled triangles)

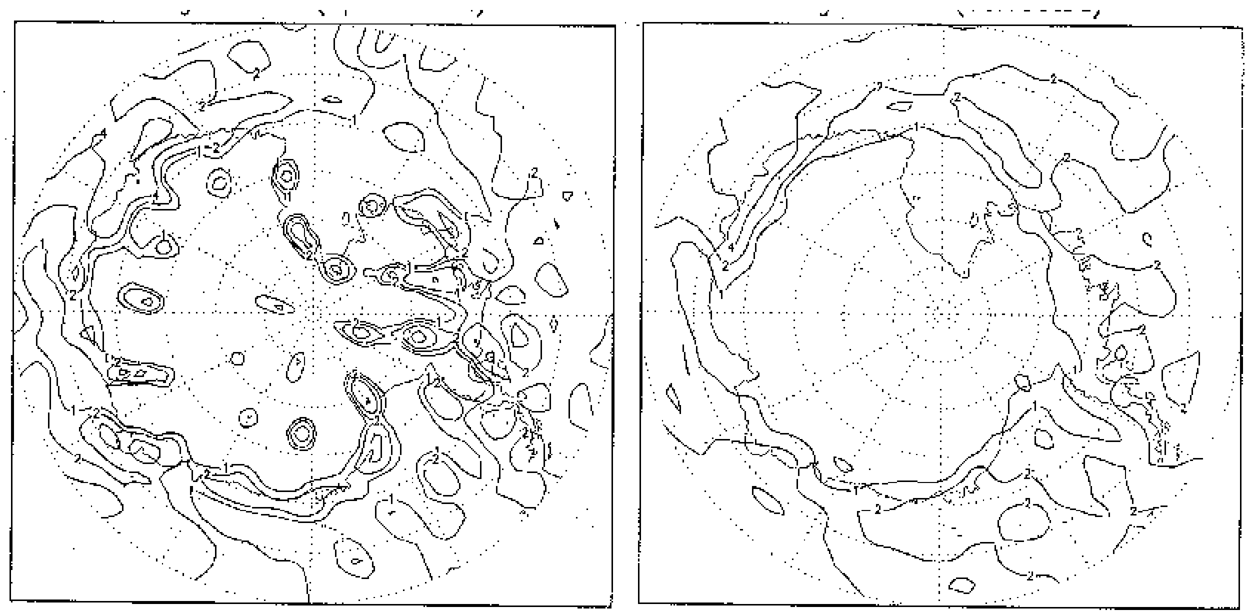

Fig. 2 Precipitation for the first 24 hours of the forecasts over Antarctica averaged over the month of August, 1996 for the operational system (left) and the new system (right)

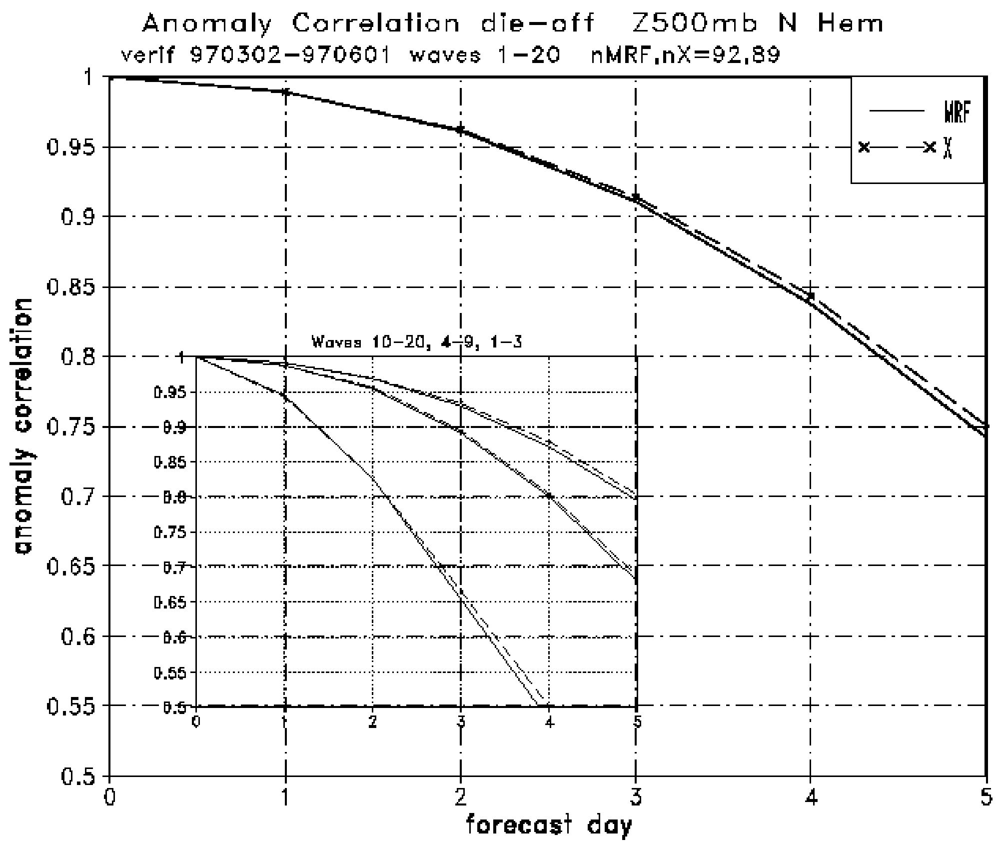

Fig. 3a Anomaly correlations for 500-hPa geopotential, forecast days 0-5, latitudes 20-80 N, operational system (MRF, solid lines) versus new system (X, dashed lines). The results are averaged for forecasts verifying over the period 2 March through 1 June 1997 with 92 cases for the MRF and 89 cases for the X. Four zonal wave number groups are shown. Each model is verified against its own analysis.

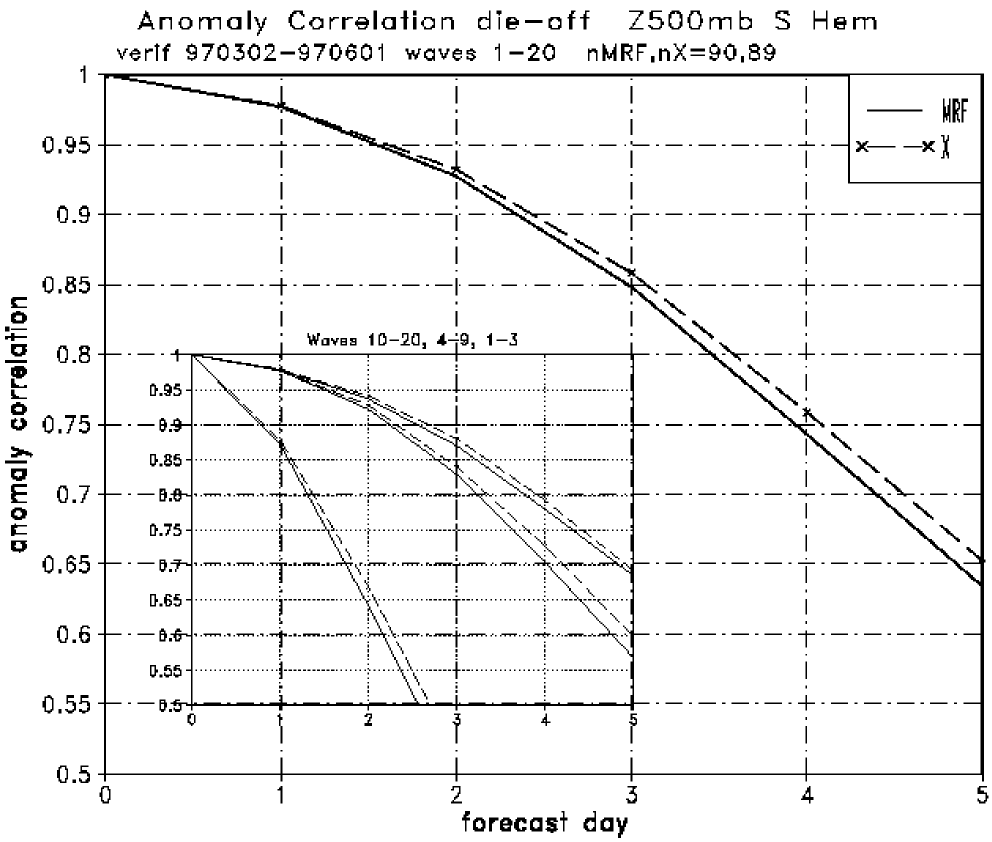

Fig. 3b As in Fig 3a, but for the Southern Hemisphere.

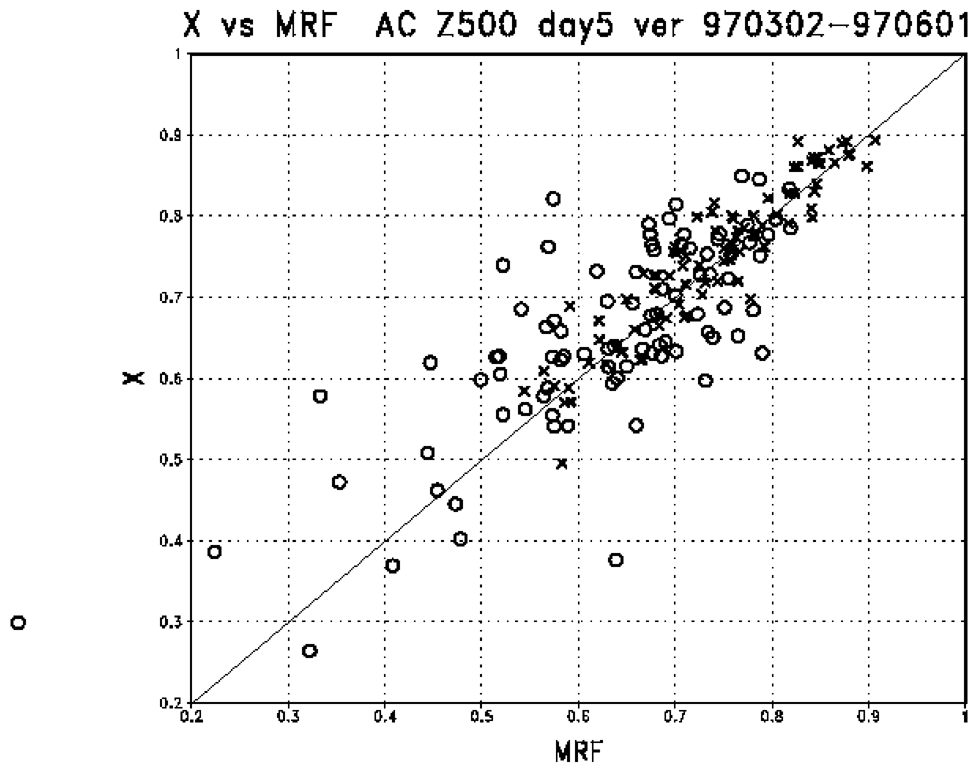

Fig. 4 Anomaly correlations for 5-day forecasts of 500-hPa geopotential for the regions and period shown in Fig. 3 for operational (MRF) vs. new system (X). N. Hem scores given by (x) and S. Hem by (o)

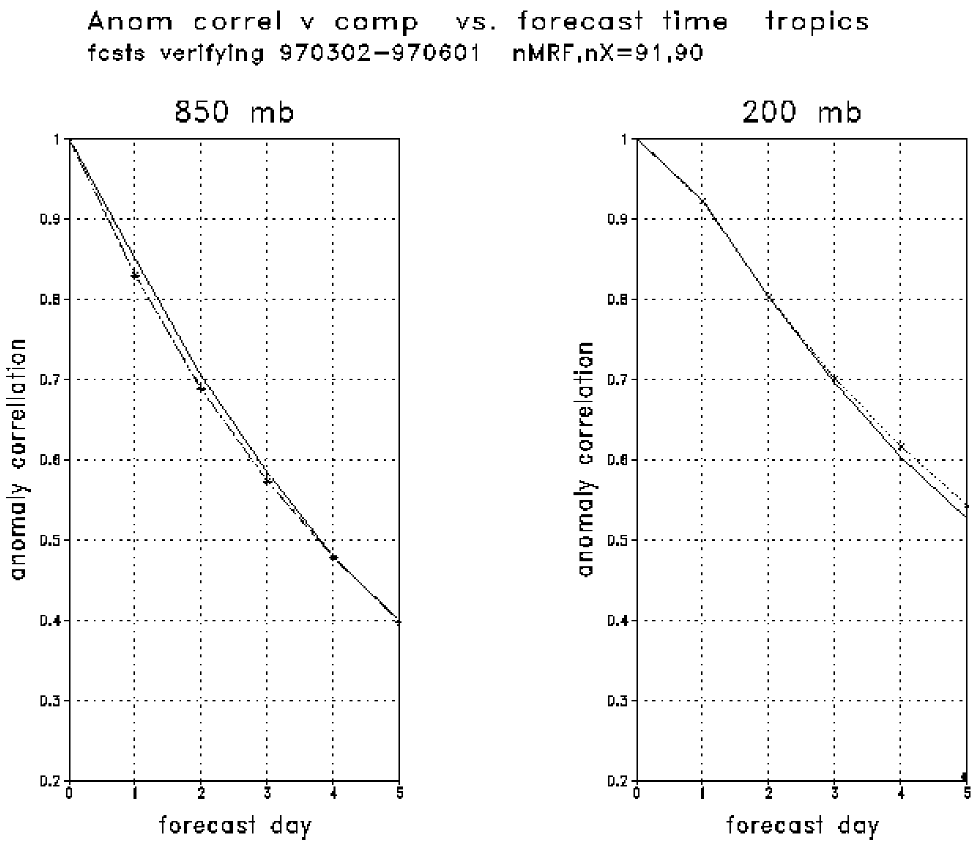

Fig. 5 Anomaly correlations for the v-component of winds in the tropics (20S-20N) for forecast days 0-5 at the 850- and 200-hPa levels, operational model (solid lines) vs new system (dashed lines), forecasts verifying 2 Mar through 1 Jun 1997.

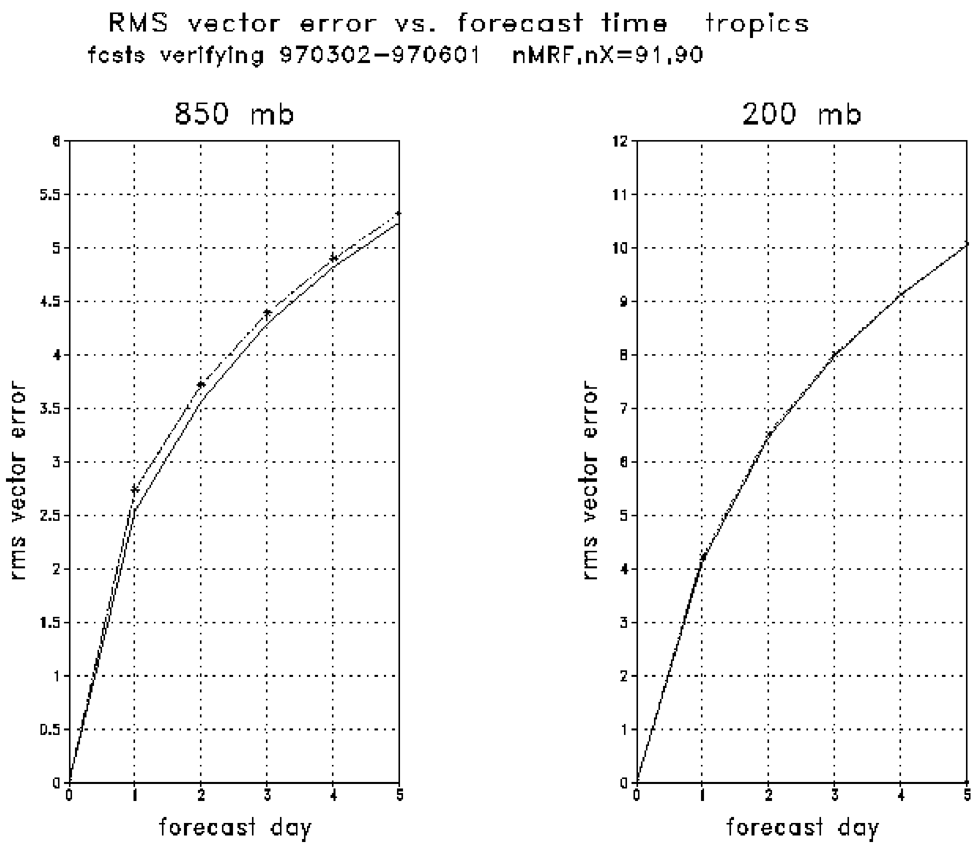

Fig. 6 As in Fig. 5, but for rms vector wind error.

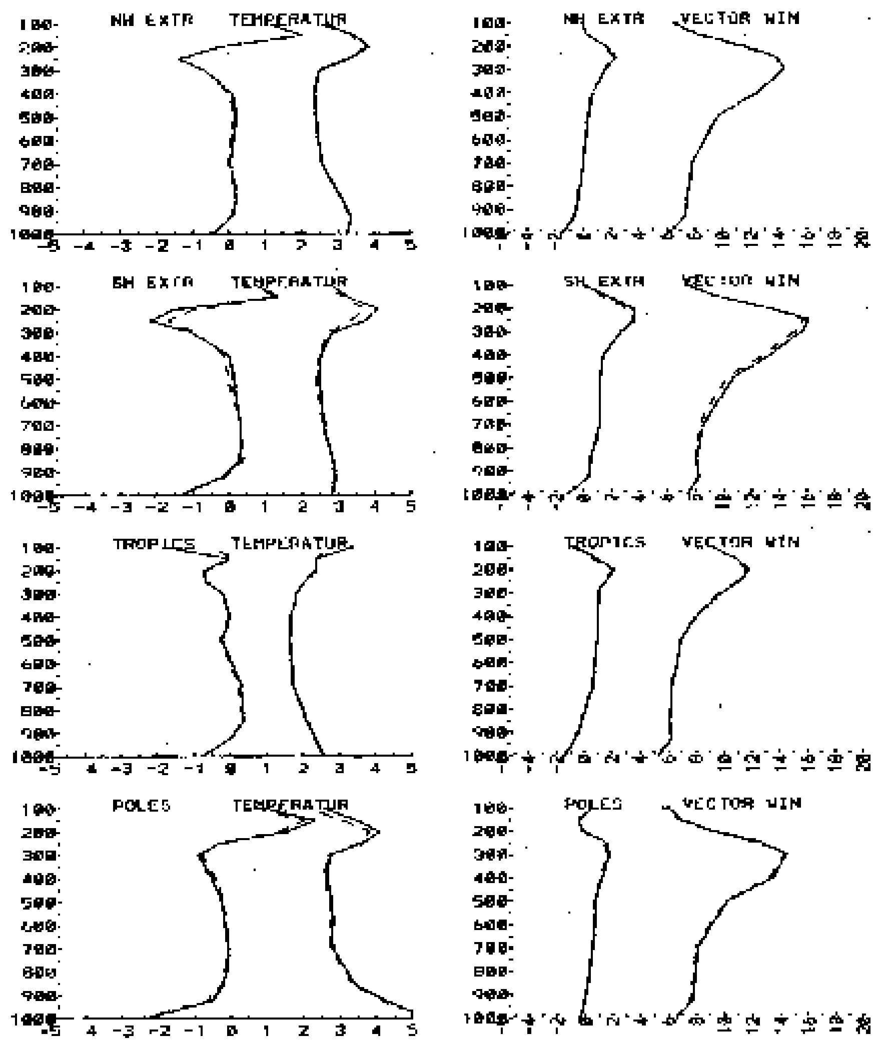

Fig. 7 Four–month average of vertical profiles of temperature errors (first column) and wind errors (second column) for 3–day forecasts verified against rawinsonde observations. The left–hand pair of each set of four curves is the bias, the right–hand pair is rms error, for operational (solid) and new system (dashed). The third column shows number of observations in the average. Different regions are shown in different rows, NHem. extratropics in the top row, then S. Hem. extratropics, then tropics, then polar regions.

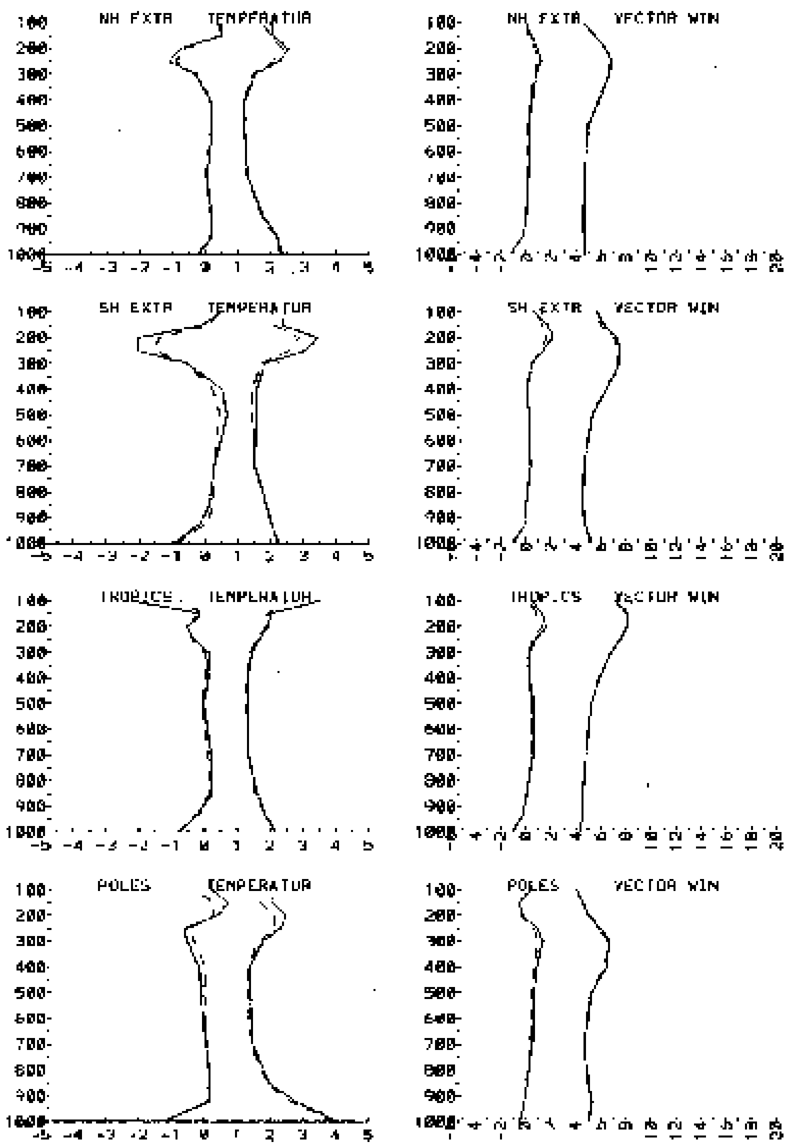

Fig. 8 As in Fig 7, but for the 6–h guess

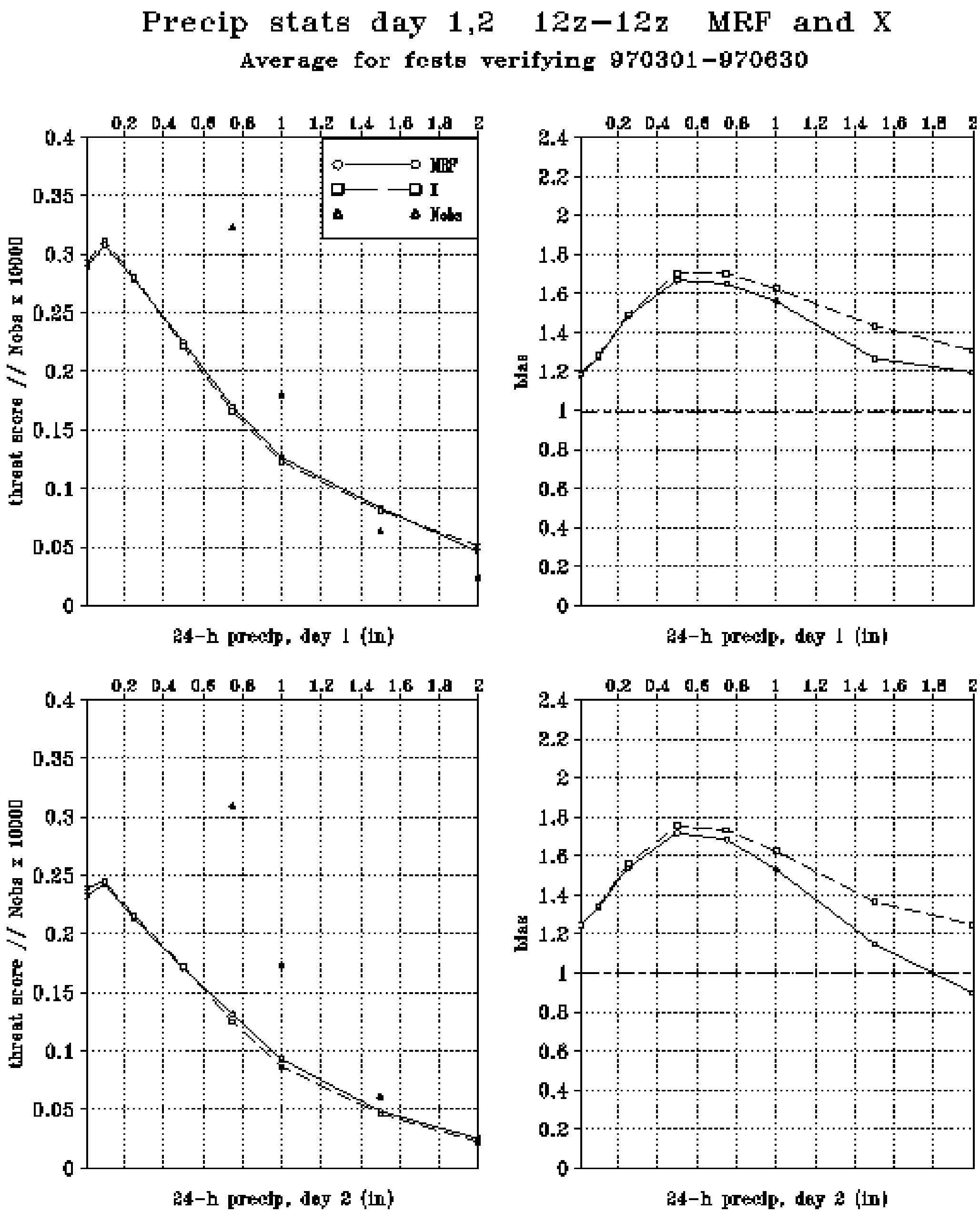

Fig. 9 Threat scores (left) and biases (right) for 24-h total precipitation for forecasts verifying Mar through June, 1997, for day 1 (12-36 h, upper row) and day 2 (36-60 h, lower row). Operational forecasts are solid lines, new system dashed. Number of grid boxes (scaled by 10,000) where observed precipitation exceeded ea ch threshold is indicated by triangles. Thresholds are in inches.