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Operational Systematic Error Correction for the NMC Operational Medium Range Forecast Model

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Introduction

Recent improvements in NWP are due in part to a number of factors such as improved resolution, analysis, and physics, e.g., gravity wave drag, cloud and convection specification, to name a few. However, in spite of improvement NWP models still have significant errors, some of which occur systematically. Described in this presentation is a method to correct for such systematic errors as well as some options for the disposition of the output of statistically modified model forecasts.

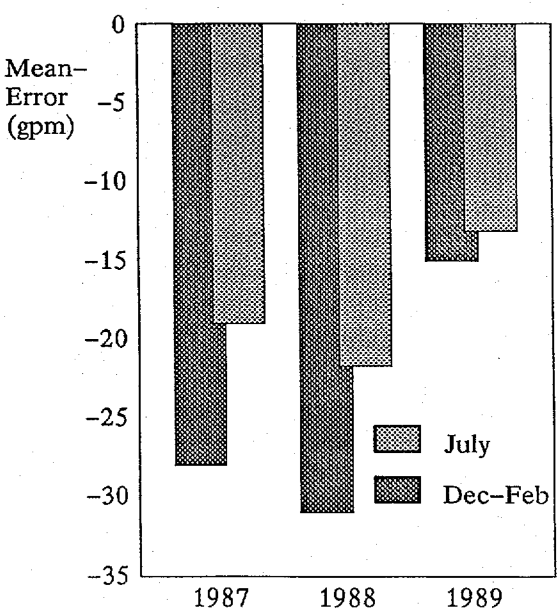


Fig. 1 Mean-errors of 5-day forecasts of 500mb height between 20 and 80 deg. N for summer and winter.

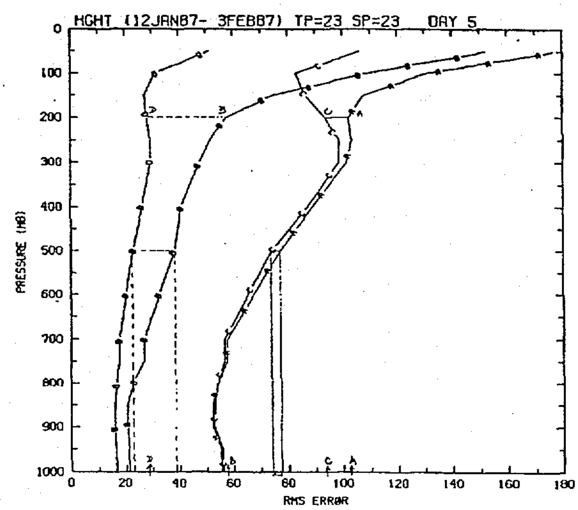


Fig. 2 RMS forecast geopotential height error (gpm) as a function of pressure (mb) for a 5 day forecast. Curve A is the total error uncorrected, curve B is the time-mean error uncorrected, curve C is the total error corrected and curve D is the time-mean error corrected.

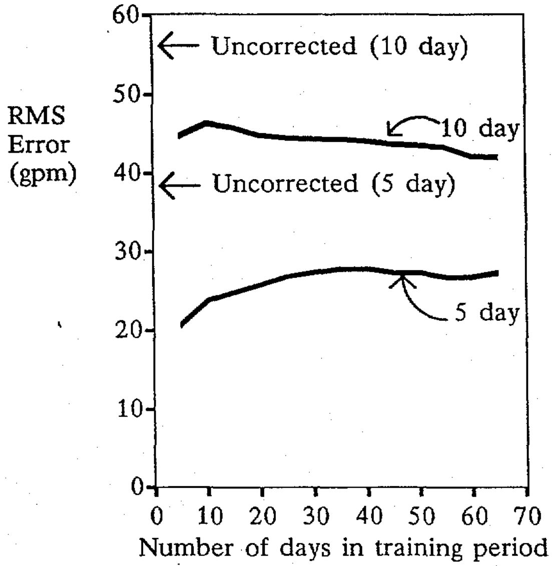


Fig 3 Geopotential 500mb corrected forecast error for 15 independent 5 and 10 day forecasts in July 1987 vs the length of the training period.

Some background on the systematic forecast error problem.

Fig. 1 shows that the mean–error primarily consists of a too low geopotential height bias for 500 mb forecasts during the last three years which appears to be decreasing in 1989. The truly systematic error is not known precisely and is replaced here by the 'time–mean' error over the N most recent forecasts (where 'N' is our so–called 'training period').

Operational guidance often includes the application of various statistically formulated methods to the numerical weather forecasts. One of these methods, the perfect prog approach, requires unbiased predictors, therefore, one should remove the bias from the model prediction. In doing so, some flow–dependence of the mean–error may, in fact, be accounted for by our corrections. In the case of the MRF and AVN run data, Techniques Development Laboratory, the Hurricane Center and Climate Analysis Center either are using the perfect prog approach or plan do to so. Each have requested certain unbiased MRF/AVN forecast fields.

Systematic MRF model error and its correction

Extensive experiments were carried out by the author and Suranjana Saha at NMC. These experiments examined the systematic error in height, wave number and length of the training period to quantify the kind of improvements possible from this technique. The method used for these experiments, and in the operational implementation, requires a moving training period which consists of the time averaged forecast error. The RMS forecast error is used to order the largest amplitude contributions to the forecast error for each day's training period. The largest M (M=7 in the current implimentation) spectral modes of the forecast error, in terms of amplitude, are then selected and subtracted from the forecast. The new error corrected forecasts are marked with the Office Note 84 Derivation word to distinguish them from the uncorrected forecasts so that after the forecast is produced, known model bias is removed before the perfect prog method or other uses are applied.

Fig 2 shows the variation in height of the systematic and total RMS forecast error averaged for a 23 day period in winter 1987 for a 5 day forecast. The total error and the mean–error show improvement at all

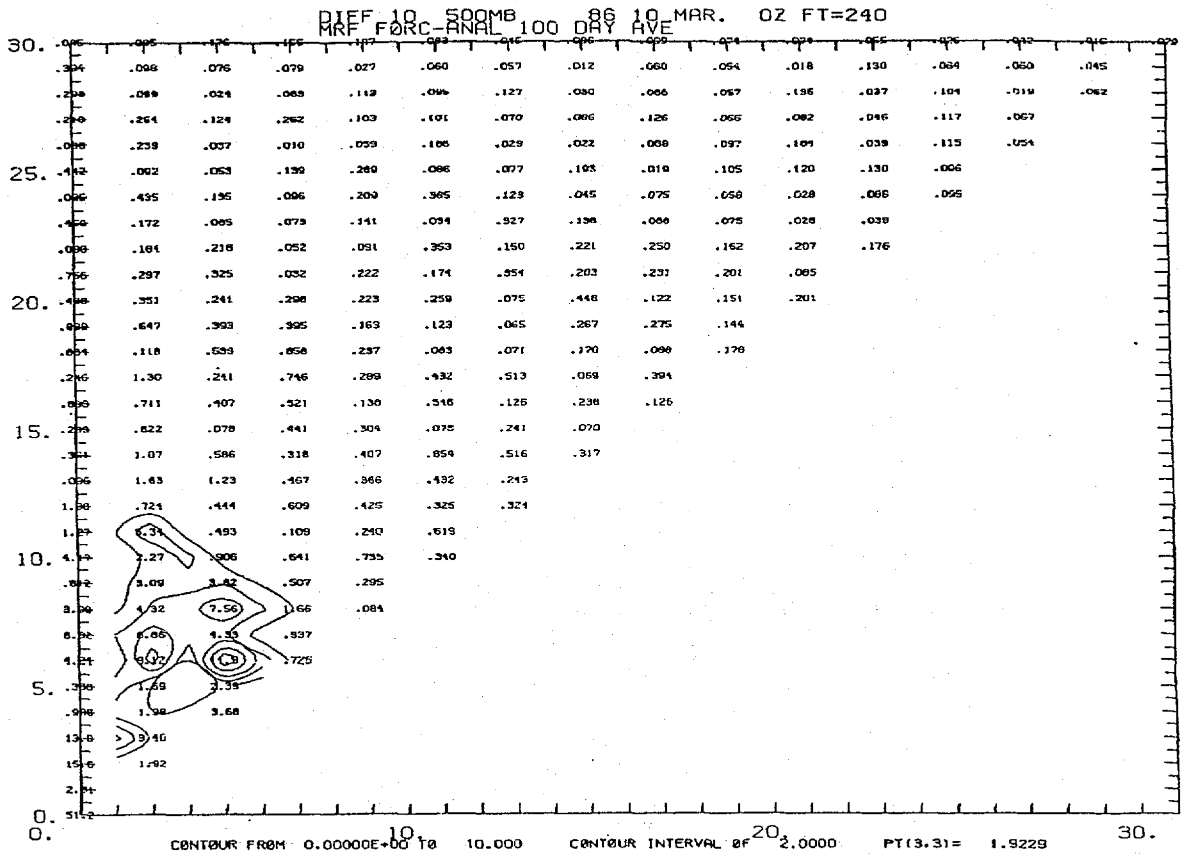


Fig 4 Spectral (T30) diagram of the forecast error amplitude (500mb) geopotential height (gpm) for winter 1986. Planetary index m, is on the abscissa and the meridional index n, is on the ordinate. (The (0,0) component appears a factor of 1.4 too large due to normalization.)

levels however, above 250mb the improvement is spectacular. The training period for each of the 23 forecasts was 23 days. The behavior in other seasons is similar considering the yearly trends shown in Fig 1. Thus, for the 23 consecutive days shown, the corrected forecasts verified with similar but lower RMS total errors in upper levels and improved mean–errors at all levels when compared to the operational forecasts. On average, improvements in the RMS total geopotential error are a few meters at 500mb and increase to 10 meters at 200mb. The mean–error or model bias is corrected by 20 meters at 500mb and 30 meters at 200mb. The values change for different seasons and as shown in Fig 1, the decreasing time–mean error in the last year leaves less to correct.

The systematic error is the average error in the forecasts averaged over a training time period of length N. The length of the training period made little difference so long as it is at least 25 to 30 days as shown on Fig 3. Longer forecast times benefit from longer training periods. This trend is reversed for shorter forecast times (day 5 or less). These characteristics generally repeat for other vertical levels. The proposed implementation version uses 30 days as a training period.

The wave number domain diagram shown in Fig 4 is an example of how the horizontal scale of the forecast error distributes itself. Fig 4 is averaged over 100 winter days (the results are similar for monthly averaged data which is not shown), and indicates the major part of the systematic error is in the global average followed by the first few zonal components and then a few large scale wave components. Note

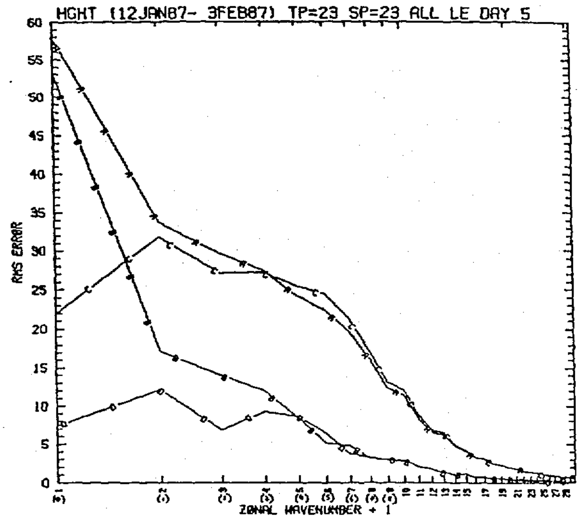


Fig 5 The RMS error in the forecast height fields, averaged over all levels as a function of total wave number for a 5 day forecast from 12 Jan 87 to 3 Feb 87. A, B, C, and D have the same meaning as in Fig 2.

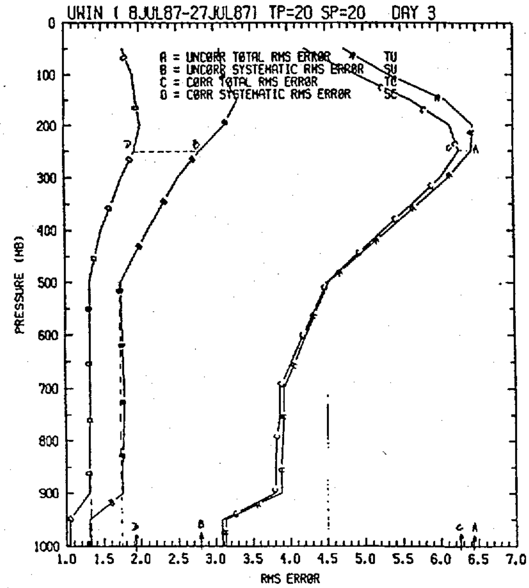


Fig 6 RMS mean– and RMS error of the u–component of the wind corrected and uncorrected for a 3 day forecast as a function of pressure. A, B, C, and D have the same meaning as in Fig 2.

that there is little power in the small scale and medium scale waves. In this period (winter '86) the wave (4,6) and some neighbors also contributed significantly to the forecast error.

The spectral decomposition over total wave number is shown in Fig 5 in terms of the RMS error as a function of zonal wave number for day 5 forecasts in January. An average of all vertical levels is made. For the zonal waves the uncorrected time mean–error is large and can practically be eliminated. Some improvement can be obtained up through wave 3 or 4. Total RMS errors show smaller gains from the correction and almost only in the zonal waves. The major contribution to the improvements are from the upper layers as shown in Fig. 2.

The systematic error correction method applied to the geopotential height field above can also be applied to winds and moisture however, it was decided to implement the corrections only on the heights and u–component of the wind. Temperature can be derived hydrostatically from the geopotential height using the surface pressure which is available. In Fig 6 the mean– and RMS error of the u–component of the wind is shown corrected and uncorrected for a 3 day forecast as a function of pressure. Again the errors increase with height, with up to a 1m/s improvement in the mean–error on the average (20 days) at 250 mb. The RMS difference between the operations and forecast error correction is very small. These statistical corrections although smaller than their geopotential counterpart may still have impact when computing mean layer winds that include the upper troposphere.

The verification for these experiments as well as calculation for the forecast error are made against model initial conditions. There are some differences between initial conditions and analysis which for the purposes of this work are not significant. The implementation version of the forecast error corrections will calculate the training period averaged forecast error against analysis instead of initial conditions. The next section presents these results. One difference between analysis and initial conditions worth mentioning is the occurrence of isolated small scale centers of large amplitude error which can occur in the analysis field. These can come from an isolated observation or an error which gets by the data quality control mechanism. Such bulls eyes in the field are smooth away in the initial condition by the normal mode initialization whenever they occur. In the case of the forecast error calculation only the first few largest scale modes make any contribution to the correction therefore small scale features described above are filtered out.

Operational Verification

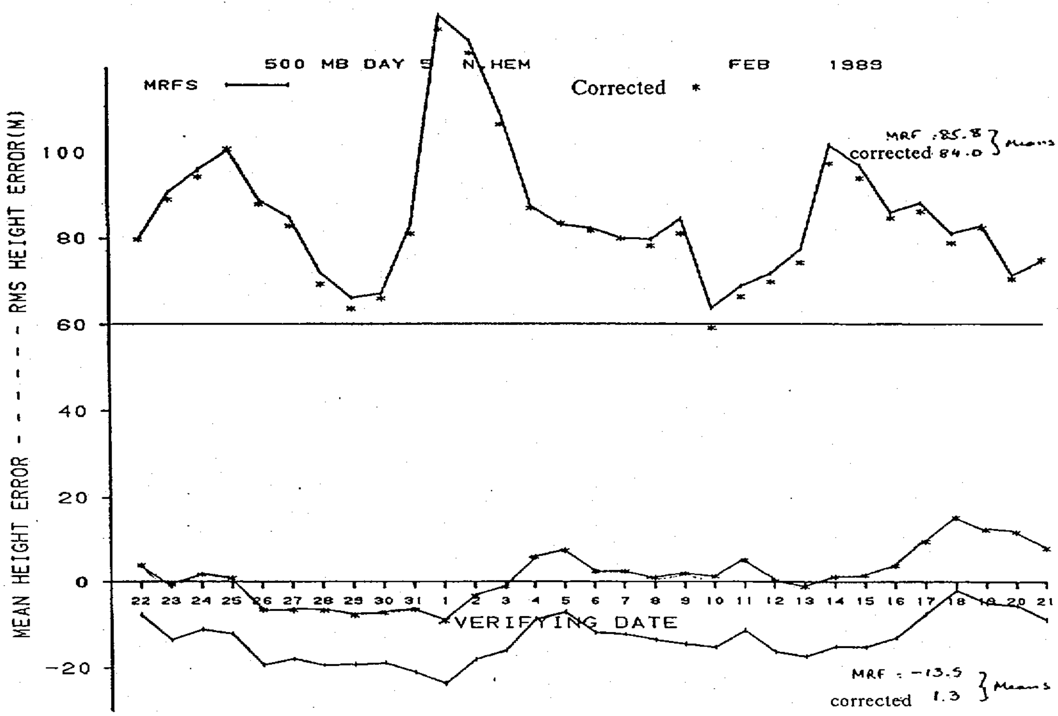
The averaged statistics presented above show the skill expectation of using the recent time averaged forecast error as a proxy for correcting the global forecast. This can mask occasional detriments that occur from day to day. However, Saha and Alpert (1989) found that, by limiting the spatial scale of the corrections to only the largest forecast error modes, the RMS error and anomaly correlation are rarely decreased. At the same time the mean–error is usually improved. An example of what one can expect from this simple correction scheme is shown for anomaly correlation, RMS and mean–error skill scores verified against analysis as routinely presented in Development Division briefings in Fig 7. The mean–error is on average improved and, except for the period 17–21 Feb, individual days are also improved. For many days the mean–error is virtually removed. The averaged operational mean–error for the entire period was –13.5 meters while the corrected average was 1.3 meters. The RMS error is also improved slightly (85.8m operations vs 84.0m with correction) while the anomaly correlation is unchanged.

An example of a bias corrected forecast compared with present operations is shown in Fig 8. The 5880m contour covers a much larger area in the corrected field in the South Alantic, Pacific and Indian Oceans reflecting a correction of the too low height bias well known in the MRF model. The axis of troughs and ridges remain unchanged as do polar values. The 5920m contour shows up in the sub–tropical high in the corrected forecast but not in the operational forecast. Note that these plots are taken from the standard NMC 65x65 northern hemisphere grid so the equatorial areas cannot be plotted correctly due to insufficient data for interpolation. The corrections to the operational forecast are shown in Fig 9 as well as the verifying operational analysis for the above 5 day forecasts. The corrections are computed only for the largest 7 modes so the resulting field contains large scale waves. For this particular day, a zonal wave 3 pattern stands out even though the largest amplitude contribution is from the global average and zonal (zonal wave 0) components. The largest corrected errors are found near the sub–topical highs with minimums in high latitudes. This pattern changes for different initial conditions. The area coverage of the 5880m contour is in closer agreement with the corrected fields than the operational field. The analysis valid for this 5 day forecast shows a subtropical high in North Africa of 5930m which is also indicated on the corrected field but not in the operations. Smaller scale errors are not addressed in the correction scheme but experiments have shown that this method will correct for many small scale errors in amplitude and phase. At some point in time the atmosphere will no longer persist in making the same type of error on the smaller scale and the correction will become a detriment to the forecast. The larger scale corrections have been shown to be more consistent and thus removable as a model bias.

Implementation

An excerpt from the Job Implementation notice is shown in appendix I. The programs have separate data sets for spectral and grid point forecast error corrections. The data set names of each file are listed in appendix II. The derivation word in the Office Note 84 header is set to signify that the field has been modified by the statistical scheme. Also included is a transfer of the daily corrected MRF forecasts at 500 mb to the VDUC system on 12 hour intervals such that a loop of the MRF error corrected fields may be animated as is done daily with the uncorrected operational MRF forecasts. If one observes these color enhanced forecast loops with blue to red for cold to warm representation and compares the operations and error corrected loop, one sees that the gradient of colors which normally extend from blue to red extend from blue to brown by day 4 or 5 in the operations but is retained in the corrected forecasts. The corrected fields maintain the red colors indicating the position of sub–tropical highs through out the MRF 10 day forecasting period. The implementation of this process under current guide lines requires that the data be present in the communication files.

If operations should fail there are several levels of recovery. For example, if archive data are destroyed but operations is intact, the system reverts to the previous days correction using only the global average.



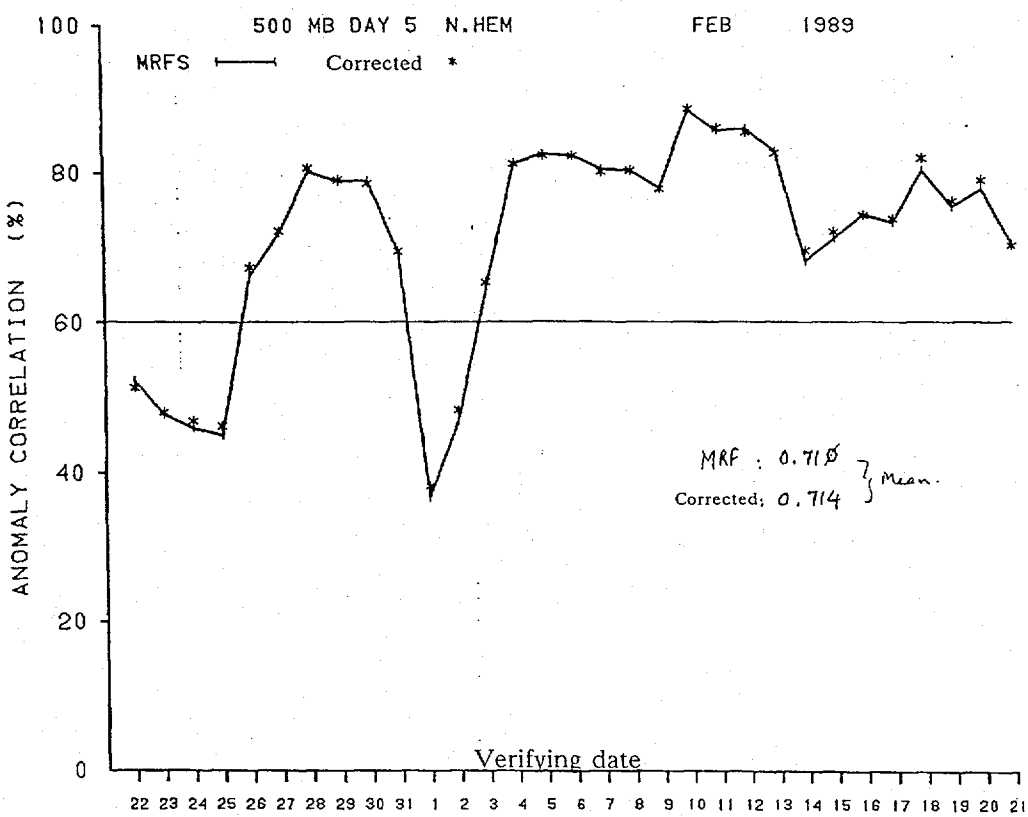


Fig 7 RMS geopotential height (gpm) verification (top), Mean-error (gpm) (middle) and anomaly correlation (%) (bottom) of MRF 5 day forecasts (500 mb) from 22 Jan 1989 to 21 Feb 1989. (Verification against GDAS analysis.)

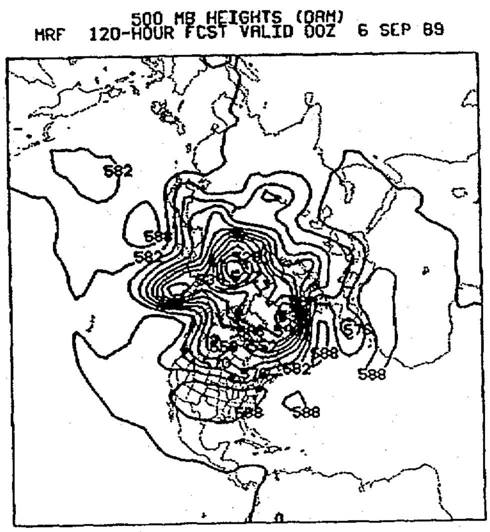


Fig 8 Operational (left) and corrected (right) 500 mb geopotential (gpm) 5 day forecasts valid on 6 September 89. Contours are every 60m.

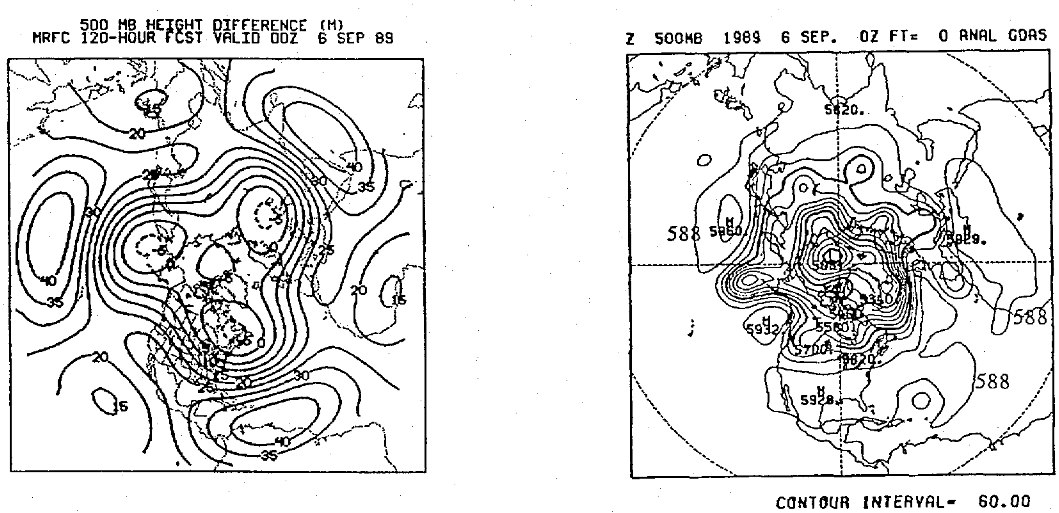


Fig 9 Difference (5m contour) between the operational and error corrected forecasts shown in Fig 8 (left) and and the 500 mb operational analysis (right) valid for 6 September 89.

Other unforeseen failures to operations will cause the error correction archive to be replenished from the non–operational archive which also has been programmed to recover from missing days.

In its present form the forecast error correction system generates records similar to the operational VSAM data sets but in separate files. One reason for this is there is no room in these operational files for any more records. However, these files are scheduled to be expanded. At that time it is proposed that the error corrected records be placed in the operational files. Direct user access to the data would be available as well as the opportunity to have corrected fields provided to field forecasters through standard NMC mapping. One can always distinguish between a corrected and uncorrected forecast by standard procedures laid out in O.N. 84.

Summary and Conclusion

The central reason for distributing a statistically modified forecast product is to provide the best product possible to users and the field forecaster. The case for implementation of an optional forecast error correction system for the MRF/AVN model bias removal, given the demand and results described herein, is self evident.

AFOS is presently the sole system used at field offices to receive graphics. To make the corrected height fields available to forecast field offices, a replacement of the current geopotential height products with the corrected ones is required since AFOS is saturated. As a by product the statistically corrected geopotential height will be available on the Family of Services and facsimile. Replacement of the current product with he corrected ones on the Global Telecommunications System is also proposed since it constitutes the best product available from NMC. The current development and integrity of the model output will not be compromised in terms of model verification since the spectral coefficients which are used for such purposes remain unmodified. It is recommended that the statistically modified geopotential heights replace the current NMC product on the Global Telecommunications System as well as in the NMC suite of products.

References

Saha, S., and J. C. Alpert: Systematic Errors in NMC Medium Range Forecasts and their Correction. Eighth Conference on Numerical Weather Prediction, Baltimore, Maryland 1988.

Appendix I

Job Implementation memo excerpt from October 20 1989

Recent improvements in NWP are due in part to a number of factors such as improved resolution, analysis, and physics, e.g., gravity wave drag, cloud and convection specification, to name a few. However, in spite of improvement, NWP models still have significant errors, some of which occur systematically. The following items will implement a method to correct for such systematic errors as well as some options for the disposition of the output of statistically modified model forecasts.

510. ZROFLV - job 900. (Farley, NMC42). This jobstep is being added to the MRF network to initialize the forecast error correction files being implemented in the following package.

511. CYPOST - job 926. (Alpert, NMC23). This new program, a modification of CYPSTVFN, generates forecast error corrected gridded and/or spectral (R30) fields from R40 Cyber output of the MRF operational model. Height and wind (u-component) on mandatory pressure levels are modified for the gridded fields (lat/lon and 65x65) and R30 spectral unmodified spectral R30 fields are also written (as a function of switches) for archiving. This jobstep is being added to job 926 to output days one through six.

512. MEGAIJP - job 926. (Alpert, NMC23). A second order IJP will be made to submit a job if the CYPOST for days 1-6 fails. This job will replenish the operational files NMC.PROD.FCSTnn.CORMRF, which contain the archive information for days 1-6, where nn=24-144.

513. MEGAIJP - job 926. (Alpert, NMC23). A second order IJP will be made to submit a job to make plots of MRF days 1-6 forecast error corrections. A few fields are selected for plotting to monitor the modifications.

514. CYPOST - job 946. (Alpert, NMC23). This new jobstep is being added to job 946 to output the MRF forecast error correction fields for days seven through ten.

515. MEGAIJP - job 946. (Alpert, NMC23). A second order IJP will be made to submit a job if the CYPOST for days 7-10 fails. This job will replenish the operational files NMC.PROD.FCSTnn.CORMRF, which contain the archive information for days 7-10, where nn=156-240.

516. MEGAIJP - job 946. (Alpert, NMC23). A second order IJP will be made to submit a job to make plots of MRF days 7-10 forecast error corrections. A few fields are selected for plotting to monitor the modifications.

Appendix II

Data Set Names

Name	*Contents*
NMC.PROD.VSnn.CORMRF	VSAM forecast error corrected spectral coefficients of Φ and U at standard levels.
NMC.PROD.VFnn.CORMRF	VSAM forecast error corrected gridded 65x65 and lon/lat northern hemisphere fields of Φ and U at standard levels.
NMC.PROD.FCSTnn.CORMRF	Sequential 30 day archive of spectral T8 forecast coefficients of Φ and U at standard levels.

nn is the forecast time beginning at 12 hours and extenting through 240 hours at 12 hour intervals.