DIAGNOSIS OF OBSERVATIONAL ERROR CHARACTERISTICS AND DATA ASSIMILATION SKILL AT NCEP

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1. INTRODUCTION

The diagnosis and monitoring of the data assimilation system fulfills two major roles at NCEP. The first major role of the data assimilation monitoring and diagnosis system is to ensure the proper performance of the assimilation system and to diagnose problems with the system for future improvements. The second major role is to provide statistics for use in the assimilation system. These statistics include the observational error variances, the background error variances, and the bias correction for the satellite data. Unfortunately, the monitoring and diagnosis of data assimilation systems is not straightforward. The lack of a complete and accurate truth makes the determination of statistics and diagnosis of system problems difficult. While the monitoring and diagnosis of system problems are important for NCEP, the possibilities of diagnostics have not been fully utilized. It has been difficult to develop the necessary databases and techniques to properly monitor and diagnose the data assimilation systems. Recently, however, significant progress has been made.

2. DIAGNOSTICS EXAMINING PERFORMANCE OF OPERATIONAL/TEST DATA ASSIMILATION SYSTEMS.

One of the major roles of the diagnostics of the NCEP assimilation system is the examination of proposed changes to the operational system and ensurance of good performance of the operational data assimilation/forecast system. These diagnostics consist of internal analysis/model diagnostics (analysis convergence, data counts, penalties, zonal mean winds and clouds), analysis/forecast comparisons to observations (to be discussed further below), standard evaluations of forecast skill (rms, anomaly correlation, precipitation skill scores, hurricane track measures, etc.), significant feedback from field forecasters, and various diagnostics developed to look at specific features (i.e., if changes to the cloud parameterization are being tested specific diagnostics are developed to examine the cloud fields). Similar diagnostics are performed on new systems being tested for operational implementations.

For the global model implementation at the beginning of the summer of 1998, the diagnostics of the new T170L42 global forecast model failed. After implementation, the NCEP forecasts degraded. The degradation was traced to 3 sources: an accidental reduction of the background error variance by a factor of 2, a lack of convergence in the minimization algorithm in the analysis, and an overactive tropics. Since there was a lack of computer resources to test improvements to the system, the resolution of the analysis was decreased back to

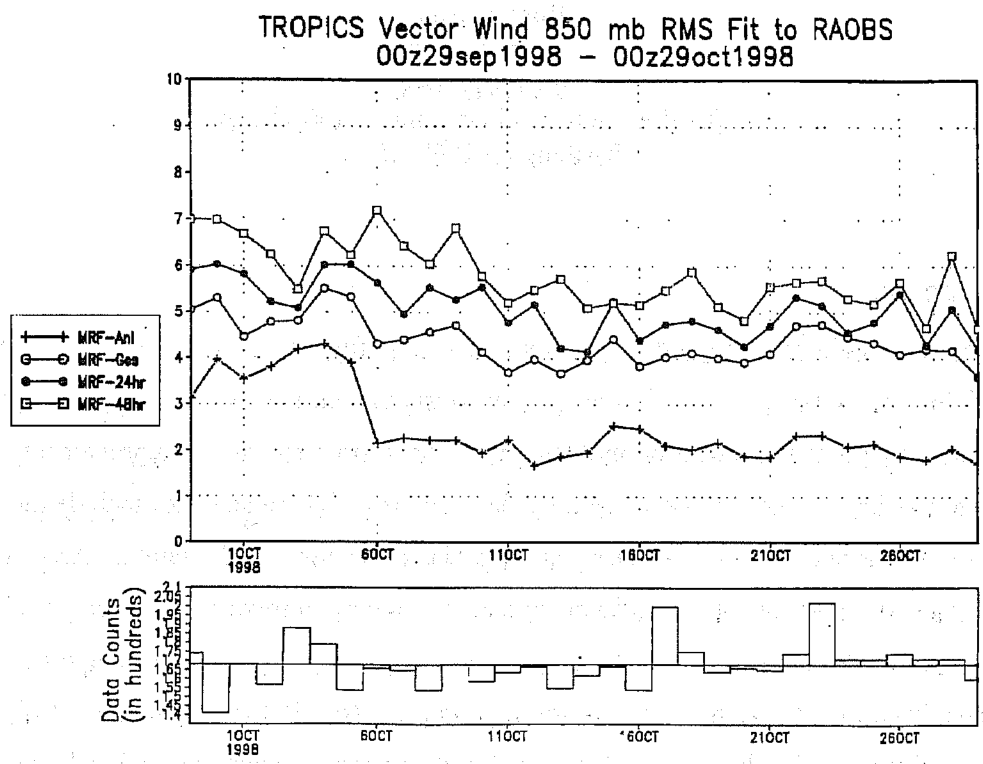

Fig. 1 Tropical rms fits of model forecasts/analysis to radiosonde observations

T126L28, the magnitude of the variance was fixed, and the number of iterations increased. By decreasing the horizontal resolution, the tropics became less active . Since this failure, additional diagnostics (primarily internal to the analysis and in the comparisons of the analysis/forecast to the observations) have been developed to ensure there is no repetition of this problem.

Fig. 1 shows the rms fit of the tropical wind radiosonde observations to the analysis, 6 hour forecast (ges), 24 and 48 hour forecasts. Note the large change in the fit of the analysis to the observations when the operational assimilation system was changed from T170L42 to T126L28, the number of iterations was increased, and the background error variance increased on Oct. 5.

2. DIAGNOSTICS USED FOR THE DEFINITION OF ANALYSIS ERROR STATISTICS.

The second major role for the diagnostics is to provide improved definition of error statistics used in the analysis. The observational error statistics, bias correction statistics, and the background error covariances represent extremely important components of any assimilation system. The definition of these statistics are based on differences from truth. Since no complete perfect observation of truth is available, the use of the observational data sets to define the statistics is not straightforward, and considerable effort is necessary to fully utilize the information. Unfortunately, at NCEP there has not been enough effort in this area. However, there has been some work recently to develop the necessary basic data sets to perform this work.

The discussion will be divided between the conventional observations and the satellite radiances.

For the conventional observations, a database has been developed containing observations and simulated observations from analyses and forecasts. The current information in this database can be viewed on the web site at http://lnx40.wwb.noaa.gov. Unfortunately, the simulated observations are not completely consistent with how the simulated observations are produced within the analysis system. The simulated observations are produced with no time interpolation and with several differences in the handling of near surface observations.

Currently, the observation statistics are used for occasional updates of the observational error variances, radiosonde radiation correction, and the previously mentioned monitoring of the assimilation system. This data base has many more potential uses. In the future, we hope to separate the observational errors and the representativeness error. This would allow the representativeness error to be situation dependent and allow a more appropriate usage of the information in the data. We plan to increase the granularity of the definition of the statistics. For example, rather than producing an observational error for radiosondes, we plan to define the observational error for radiosondes based on the instrument types. The availability of the data base could allow the definition and eventual inclusion of observational and model biases in the assimilation system. Finally, the background error covariance is currently defined empirically using the NMC method. Development of improved definitions of the background error covariance is important and should, at least partially, be based on the observation minus background database.

The monitoring and diagnosis of satellite radiances is performed differently than the conventional data with the results more directly impacting the assimilation system. These differences result primarily from the larger biases between the simulated data and the observations and the more complex quality control issues. With the satellite data, the biases can be as large or larger than the signal, and the biases are usually spatially correlated. While visiting NCEP, Tony McNally from ECMWF set up an output diagnostic file for the satellite data. While this file has been changed considerably, many of the basic components of the diagnostics are still being used. Current results from these diagnostics can be found on the web site at http://sgi62.wwb.noaa.gov:8080/RTPUB. Unlike the conventional data, the simulated observations are exactly what are used in the analysis with full time interpolation. This data set is primarily used to monitor the observations and the bias correction. In the future, the definition of the observational error covariances could be created based on this data. Currently, it is assumed that the observational errors between the various channels are uncorrelated. This is probably not true with the observational errors correlated between channels because of correlated errors in the forward models and correlated representativeness errors (e.g. from slight cloud contamination).

The source of the biases in the differences between the observations and the simulated radiances is often not clear. The biases could result from biases in the instrument or the forecast model used in the assimilation. However, it is assumed that the biases are primarily a result of error in the transformation from the model variables to the observed quantities. These errors can result from an improper specification of instrument characteristics (e.g. improper specification of the central wavenumber), errors in the line-by-line radiative transfer upon which the fast radiative transfer is based, errors in the fast radiative transfer, errors in the surface emissivity or representativeness errors. At NCEP, considerable effort has been expended to remove this bias. Some of the bias has been eliminated by improving the definition of the instrument characteristics and radiative transfer and some by an empirical correction. Of course, elimination or reduction of the biases through improvements in the definition of the instrument characteristic or radiative transfer is the more desirable solution, but currently, the biases are still too large without the empirical correction. Examination and reduction of these biases should be a priority for the improved use of this data.

The current empirical technique for reducing the bias is to first define a linear equation estimating the bias (b_t) and include the equation in the simulation of the observations.

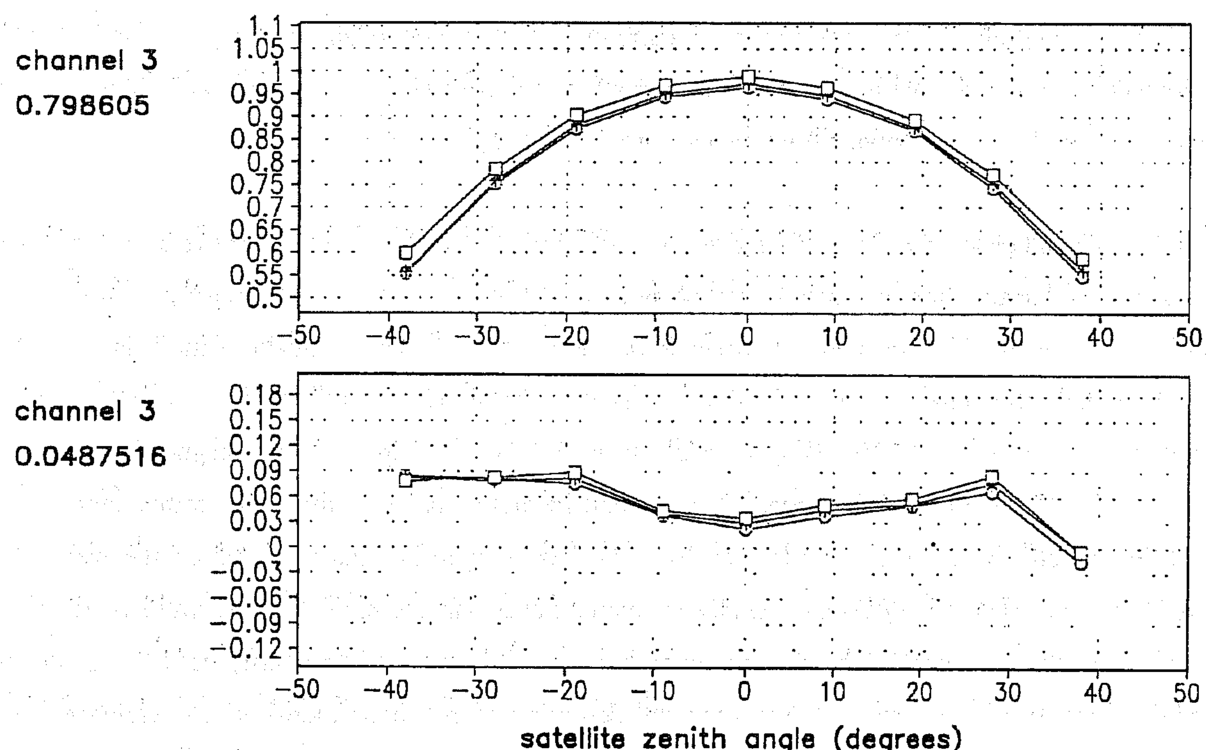

Fig. 2 Mean differences between simulated brightness temperature and observation for MSU channel 3 from NOAA-14. Top is no bias correction and bottom is with bias correction. O=1 day mean, + = 7 day mean and □ = 30 day mean.

$$b_t = \sum_{1}^{n} c_i \, p_i \tag{1}$$

The analysis vector is then augmented with the scaled coefficients (c_i) and the background error covariances augmented with values for c_i. The analysis is performed using the background c_i from the previous analysis time and produces revised values for c_i. Currently, the operational predictors (p_i) are a mean, tropospheric and stratospheric lapse rates (and their squares) and the square of the local zenith angle.

In Fig. 2, the bias corrected and uncorrected differences between the simulated brightness temperatures and observations for one channel are shown. Note the 1 day, 7 day and 30 day averages produce very similar results. The bias correction removes most of the mean and angle dependent bias (except some left right bias). In Fig. 3, bias correction coefficients corresponding to the mean term are plotted for two channels. The large jump on the 5th of Oct. is the date which the T170L42 version was replaced by a T126L28 version of the model. Other than this date, there is generally a slow evolution of the coefficients over the period.

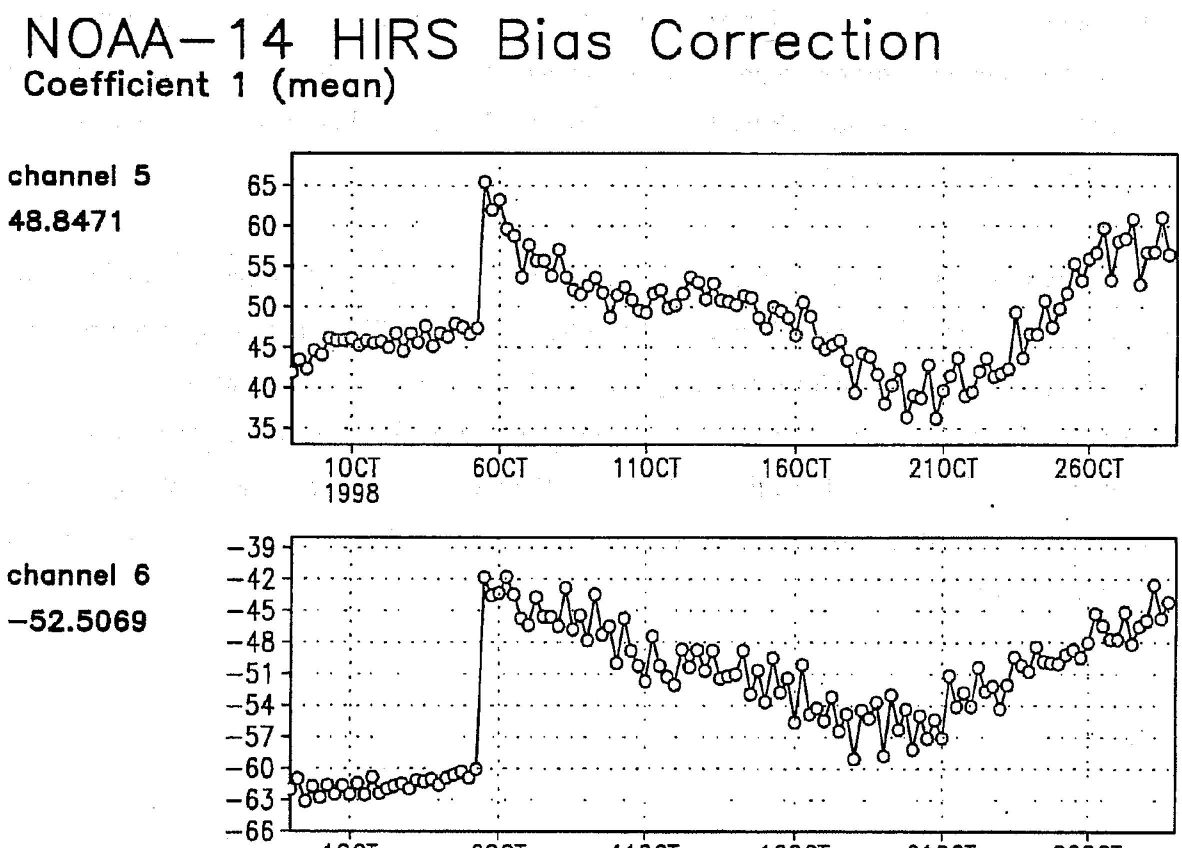

Fig. 3: Coefficient for mean bias correction predictor plotted over a one month period from HIRS channels 5 and 6.

While the current bias correction appears to work reasonably well, there is some residual bias that should be removed. For example, there appears to be a left-right bias across the scan of the instrument for some channels (especially the microwave channels) which cannot be removed with the current predictors. Improved knowledge of the structure and source of the errors should allow improvements in the specification of the predictors and the formulation of the bias correction. For example, in a formulation currently being tested, a fixed correction defined for each look position has been included in the bias correction in addition to the time dependent component. This fixed correction appears to greatly reduce the left-right scan dependent bias. Of course, the best way of eliminating the bias is to uncover and eliminate the source of the bias.

3. CONCLUSIONS/FINAL COMMENTS

In the monitoring and diagnosis of data assimilation systems, considerable improvement and development is possible. However, in recent years significant progress has been made at NCEP with the development of data bases for conventional observations and for satellite radiances. The data base for the conventional observations requires some additional improvement but is still currently providing some useful information. The greatest need at NCEP is the development of the techniques to effectively use the information contained in the database, especially for the improvement of the statistics used in the assimilation system. For the satellite radiances, a bias correction scheme has been developed which within the analysis implicitly corrects for the biases and produces good results.

At NCEP, it is anticipated that much of the effort over the next few years will be directed toward improving the moisture components of the analysis system. Effort has begun at NCEP to use precipitation observations. While there are significant problems for using this precipitation data (and eventually cloud information) which have non-Gaussian statistics, larger forecast model biases, and very large representativeness errors, we believe the benefits of using this data will also be large. However, the proper inclusion of this data requires considerable effort, including addressing model spin-down problems and direct interaction with the model's parameterization schemes.