Direct Use of TOVS Radiances in NCEP'S SSI Analysis System

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Abstract

TOVS radiances have been used operationally at National Centers for Environmental Prediction (NCEP) in the global data assimilation system since October 1995. A large positive impact on the forecast skill over that produced using the NESDIS retrievals was found. The direct use of the radiances was made possible by the development and operational use of a 3-D variational analysis known as Spectral Statistical Interpolation(SSI). The incorporation of the radiances requires the used of a fast radiative transfer model (RTTOV, acquired from the ECMWF) and the development of a bias correction scheme, a total ozone and the skin temperature analysis, and a radiance-based quality control system.

1. Introduction

With improved accuracy of model and initial conditions, it is necessary to improve the usage of satellite data to get a positive impact on numerical weather prediction. Theoretically, it is far better to include the radiances as integral quantities (as they are observed) than attempt to make a retrieval and then use the data.

The development of analysis system such as SSI (Parrish and Derber 1992)) in the NECP and three-dimensional variational analysis system (Courtier et al. 1993) in ECMWF, has made the incorporation of the radiances directly in an analysis and assimilation system practical in an operational environment. The analysis then becomes essentially a 3-D retrieval of the mass, momentum and moisture fields derived from all available data including the radiances, with the radiance data being used as integral quantities of temperature and moisture. In the 3-D analysis a very accurate background field, and all other data, i.e. surface observations, radiosonde data, radiances from different satellite are available. The 3-d variational analysis system blends this information naturally and extends the influence of the data in both the horizontal and the vertical.

A description of the operational use of cloud-cleared radiances in the NCEP analysis and assimilation system will be described and the results of the impact study will be presented.

2. Method

The SSI analysis system (Parrish and Derber 1992, Derber et al., 1991) produces an analysis through the minimization of an objective function given by;

$$2J=(x-x_b)^T(x-x_b)+(K(x)-y)^T O^{-1}(K(x)-y))+J_c$$

where x is the analysis variable, x_b is the background field (a 6-hour forecast), y is a vector of all the observations, O is the observational and representativeness error covariance matrix, and K is a transformation operator from the analysis variable to the form of the observation vector. The J_c term is a dynamical constraint term included in the procedure to increase the balance in the analysis increment.

The theory of 3-D variational data assimilation allows the inclusion of observational information if one can transform the analysis variables into the same form as the observation. For the radiance data the transformation is complex. The temperature and the moisture on the Gaussian grid are bilinearly interpolated in the horizontal to the observation location to create a temperature and moisture profile. Additional interpolation in the vertical to 40 pressure surfaces for the temperature and 15 pressure surfaces for the moisture is required to use the radiative transfer code. Above the top of the model (about 2.7 mb), the

NESDIS operational retrieval is used for the background profile (see section 4).

In addition to the vertical profiles, the integration of the radiative transfer data also needs a surface skin temperature and a total ozone value. The surface skin temperature is included in the control variable and is solved with the other model variables in the analysis procedure. The background surface skin temperature is produced by the forecast model over land and from the global SST analysis over ocean. A simple, 2D univariate, total ozone analysis which uses the operational NESDIS TOVS total ozone retrievals as input, provides the needed total ozone value. With all these components the RTTOV radiative transfer code described in Eyre(1991) is then used to produce simulated brightness temperature. For computational consideration, tangent linear approximation is assumed so that the radiative model does not have to be calculated during each iteration of the solution procedure.

When the observed quantities are compared to the model simulated values large biases are noted. The source of the biases could be from instrument calibration problems, the ground processing of the data, in adequacies in the forward modeling, or the biases in the forecast model fields. To remove the spatially dependent biases a bias correction scheme is built inside the analysis system. As predictors of the bias we have chosen scaled values of a constant term, MSU channels 2-4, HIRS channel 1, the solar zenith angle, the approximate satellite zenith angle(SZA) and the square of SZA. These predictors are multiplied by a set of coefficients to produce the bias correction. The coefficients are created by augmenting the analysis vector with the bias coefficients and solving for them along with the rest of the analysis variables. The error covariances for radiances is assumed to be spatially uncorrelated and the interchannel correlations is chosen to be zero.

We used the full 120km resolution data including all clear, cloudy and partly cloudy soundings which pass the quality control. The quality control is performed by a combination of two test, a gross check and a check against the predicted values from nearby observations. The basic observation quality parameter is set based on the expected observational error variance for that channel. This quantity is modified by the position across the track of the scan, whether it is over land or sea, if it is in a region of transition between land, sea and ice, the elevation, the difference between the model and the real orography and the latitude (the criterion is made tighter in the tropics). Note that some of the modifications are to eliminate observations which are contaminated and some are to eliminate situations where the simulated observations are deficient. The observation quality parameter is then compared to the observation and simulated observation difference. At the same time it is compared to a simple interpolation of nearby observational increments to the observation location. Note that the rejections were performed independently for each channel.

3. Results

Experiments on August 95 data for 3 weeks period were produced using the direct use of cloud cleared radiances (RAD), the use of NESDIS operational retrieval (RET) and no satellite sounding data (NOSAT) Fig. 1&2 show the temperature and wind differences for 500mb in south-east Asia which differ only because of the different use of the satellite data and different quality control decisions. All three analysis were produced using the same background field. Note the larger differences and smoother pattern in most area in the RAD case than in the RET case. The changes in the wind fields are the results of the linear balance constraint between the mass and momentum fields. The statistics (not shown) indicate that the improvements in the wind fields of the 6-hour forecasts are more significant than those of the temperature field.

The measure of the quality of system can be evaluated by comparing forecasts from each system. Five-day forecasts were produced for each day of the three week period. Each of the forecasts were verified against their own analysis. The avenged 500mb anomaly correlations are shown in Fig. 3. The RAD experiment scores more than one/two point better than the RET/NOSAT in the northern hemisphere and more than five/ten points better in the southern hemisphere. Similar results are observed for 1000mb.

The results from this study are quite encouraging for using observations directly in the analysis system. The impact of directly using the radiances in the analysis system was one of the largest recent impacts on the quality of the forecasts. There are many additional sources of data which could also be incorporated in this manner.

4 Recent Changes

To properly calculate the fit of the guess to the radiances, the forcing of the analysis procedure, we exclude the information from the retrieval soundings and directly use the background fields to evaluate the fit of the guess to the observation data. We also turn off HIRS channels 16,18, and 19, because tests indicate small improvement. These changes decrease the temperature bias found between 100mb to 300mb and improve 6hr forecasts fit to the data. The results from the T126 parallel test in Aug. 96 for over a month show slight positive impact on the day 5 forecasts. These changes will be implemented in the operational data assimilation system soon.

References

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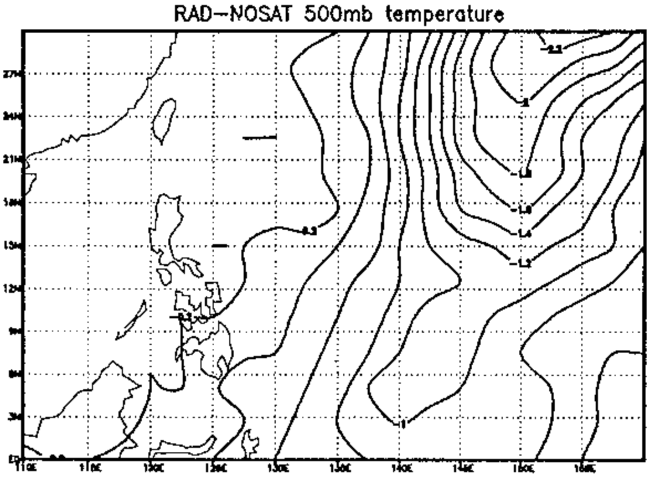
RAD–NOSAT 500mb temperature



RET–NOSAT 500mb temperature

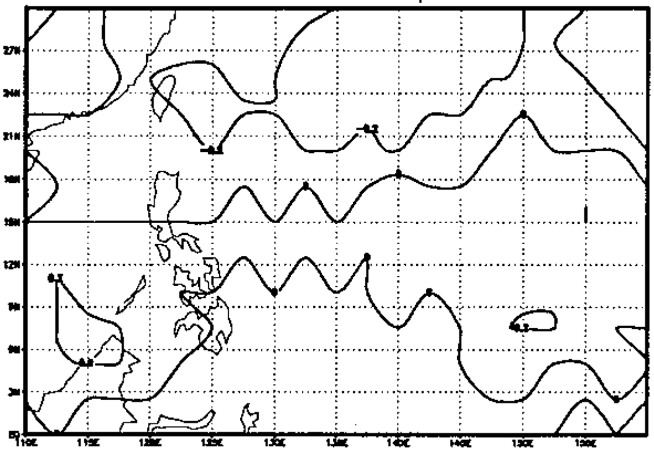
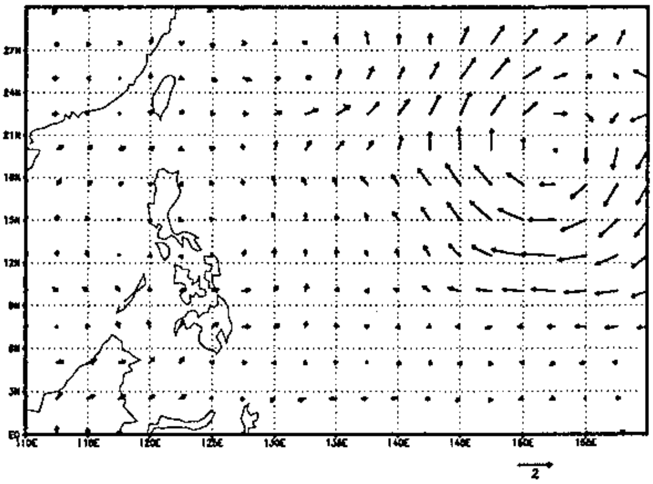


Fig. 1 Temperature differences at 500mb for different use of the data (different quality control).

RAD–NOSAT 500mb wind



RET–NOSAT 500mb wind

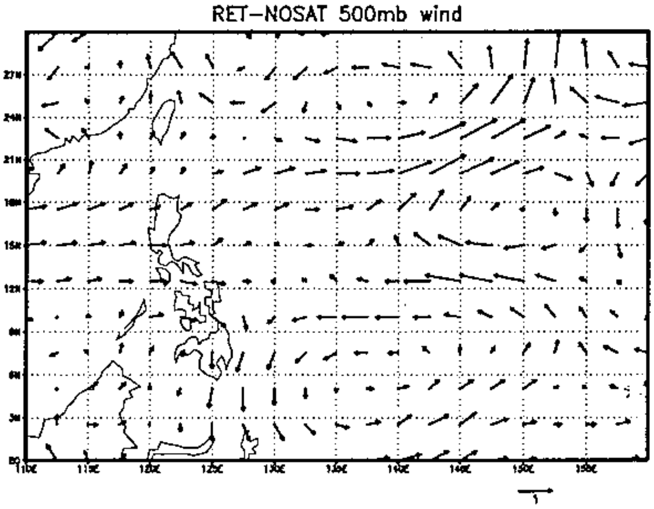


Fig. 2 Same as Fig. 1 except for winds

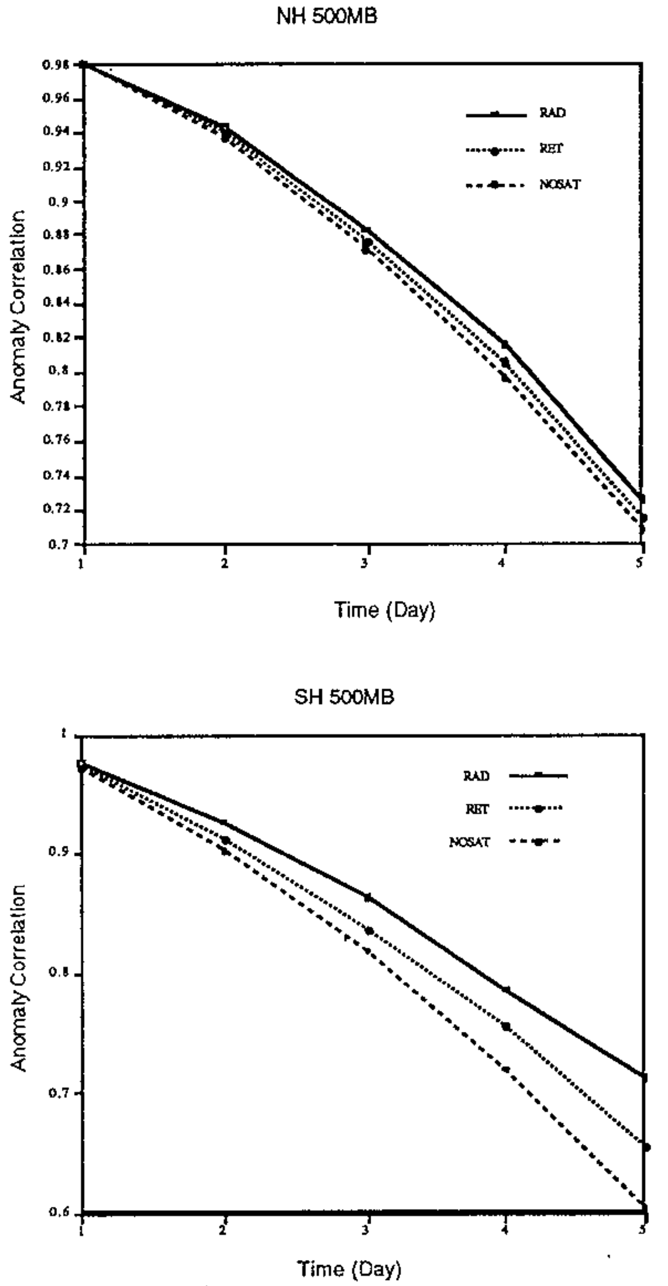


Fig. 3 Averaged 500mb anomaly correlation for a) northern hemisphere and b) southern hemisphere