THE USE OF ATOVS DATA AT NCEP

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Summary: NCEP has been using HIRS-3 and AMSU-A level-1b data from NOAA-15 operationally since March 1999. The use of this data was relatively straightforward with techniques that were developed for the previous NOAA satellites. However, the incorporation of the new data set required the development of new data handling routines, new quality control procedures for the AMSU-A, modifications to the bias correction, and the inclusion of a new surface emissivity model. In addition, other modifications to the analysis procedure were incorporated into the system recently which allowed better use of the NOAA-15 data and all other observation types. The incorporation of the ATOVS data has resulted in a significant improvement in the forecast models skill especially at upper levels and in the Southern Hemisphere.

1. INTRODUCTION

Over the last 5 years, there has been a substantial increase in the impact of satellite data on numerical analyses and forecasts. Since there was little change in the satellite sounding instrument characteristics, prior to the launch of NOAA-15, much of this increase impact can be attributed to enhanced techniques for incorporating satellite data in assimilation systems (e.g., Derber and Wu, 1998 and McNally et al., 2000). With the launch of NOAA-15, a new set of instruments have been available for use in the assimilation system. The NOAA-15 satellite includes a slightly modified infrared instrument (HIRS-3) and two new instruments (AMSU-A and AMSU-B) replacing the Microwave and Stratospheric Sounding Units (MSU and SSU). AMSU-B has had interference problems until very recently and has not yet been used at NCEP.

Since NCEP has been using the level-1b data from previous polar orbiting satellites (McNally et al., 2000), much of the infrastructure for using the data was already available. However, the incorporation of the NOAA-15 data required the development of new data handling routines and quality control procedures, modifications to the bias correction, and an incorporation of a new surface emissivity model. In addition, other improvements in the analysis system have been made recently which impact the use of the radiance data. Parallel tests data showed a significant improvement in the NCEP global model forecast skill using the NOAA-15 data, especially in the stratosphere and the Southern Hemisphere. Because of these positive results, the NOAA-15 data was incorporated into the operational NCEP global data assimilation system on March 8, 1999 (about 10 months after the launch of the satellite).

2. RECENT MODIFICATIONS TO THE ASSIMILATION SYSTEM

Prior to or during the inclusion of the NOAA-15 data, several important modifications were made to the global analysis and assimilation system. While these changes do not depend on the inclusion of the NOAA-15 data, the changes impact how completely the information in the data is used in the analysis and thus impact the use of the NOAA-15 data. In this section, a short summary of the most relevant changes to the assimilation system are presented.

2.1 External iteration

The minimization algorithm inside the NCEP global variational analysis system does not assume linearity. However, the computational costs of including all the nonlinearities in the minimization procedure make it desirable to approximate some parts of the cost function and linearize around the background or previous solution. To partially account for these missing nonlinearities, an external iteration has been included in the analysis system. In the external iteration, some components of the forward model are linearized around the solution from the previous external iteration. In the first external iteration, the linearization is around the background. For example, the forward model for the radiances is linearized around the background in the first external iteration and then is linearized around the solution from the first external iteration in the second external iteration. This procedure allows the inclusion of some of the nonlinearities (especially in the moisture channels) in the radiative transfer equation at a fraction of the cost.

Most of the missing nonlinearity is accounted for with just two external iterations. Some slight additional improvement could be seen with additional iterations but was deemed not cost effective. Therefore, in the current implementation, only two external iterations are used.

2.2 Non-unity surface emissivity for IR

With the incorporation of GOES radiances in the assimilation system, a large angle dependent bias was noted. At the suggestion of Tim Schmit of NESDIS, a simple approximation to the IR surface emissivity model by Masuda et al. (1988) was incorporated. The use of this model virtually eliminated the angle dependent bias. This initial approximation was then improved further by Tom Kleespies of NESDIS, and his model was incorporated in the NCEP system. A separate presentation on this IR emissivity model is given at this workshop.

The largest impact of this emissivity model was with the GOES data, but some reduction in an angle dependent correlated error was also noted with the polar orbiting IR data.

2.3 Improved time interpolation

In previous versions of the analysis, there was a time interpolation to the observation time from the previous analysis (-6hr) and the background field. If the observation time was after the background time, the background value was used. By saving a 3-hour forecast and extending the data assimilation forecast to 9 hours, it became possible to interpolate to the observation time using a 3, 6 and 9 hour forecast. The changes to the time interpolation resulted in a small but significant reduction in the background fits to the data, especially with the satellite data.

2.4 Updated background error covariance term

The background error covariance determines the spatial and multivariate distribution of the information in the data. Therefore, the definition of the background error covariance is extremely important for determining the quality of the analysis. The background error covariance term was modified to one similar to that described by Derber and Bouttier (1999). The change has resulted in considerable alteration of the structure of the analysis increments.

2.5 Inclusion of limits on moisture in analysis

Within the minimization procedure, it was noted that occasionally moisture negative areas and significantly supersaturated areas developed. A term was introduced in the analysis which penalized the presence of negative and supersaturated moisture values (>120%). The inclusion of this term is quite nonlinear, resulting in some slowing of the convergence rate, and can modify the distribution of the information in the moisture channels of the radiance data when the values are close to zero or close to supersaturation.

3. THE INCLUSION OF NOAA-15 DATA

Much of the infrastructure necessary for incorporating the NOAA-15 level-1b data had already been developed for using the level-1b data for earlier NOAA satellites. However, there were major differences from the earlier data in the format of the level 1b data files, the replacement of the MSU and SSU data with the AMSU-A and AMSU-B data, the new frequencies in the AMSU-A data and the much larger volume of data.

The radiative transfer was accomplished using transmittance calculations using OPTRAN. OPTRAN will be discussed in other papers at this workshop. For the NOAA-15 data, as with any new instrument, new coefficients were needed and were supplied by Tom Kleespies of NESDIS.

New decoding and data handling routines were written for the NOAA-15 level 1b data. The new format contained many new pieces of information, including quality information and the local zenith angle. The local zenith angle in the file was calculated using more accurate definitions of the earth's shape and the satellite elevation. Therefore, a small reduction in the differences between the simulated and observed radiances resulted from using the local zenith angle contained in the file.

The MSU instrument has frequencies only in the 50GHz region. The microwave surface emissivity model acquired from NESDIS worked quite well for these frequencies. However, since the AMSU instrument has frequencies outside this region, a new microwave surface emissivity model was used. This model, created by Steve English of the UKMO and acquired through NESDIS, substantially reduced the differences between the simulated and observed radiances for channels 1 and 2. These channels play an important role in the quality control algorithm described below.

The previous bias correction algorithm simulated MSU channels 2, 3 and 4 at every radiance location and used the differences between these simulated values in the bias correction. The idea behind using these differences in the bias correction was to approximate deep layer lapse rates. Since these simulated radiances were necessary at all locations, the calculations became expensive since they were being calculated at all IR locations as well as MSU locations. With the higher resolution AMSU data, the expense of these calculations were prohibitive. Therefore, the bias correction was changed to a less expensive algorithm. First, a term was included based on the integrated lapse rate over the weighting function of the channel. This term was multiplied by a coefficient constant in time. Second, predictors which were differences in deep layer means of temperatures were created. These predictors replaced the differences in the simulated MSU channels in the evolving bias correction term. Finally, to account for fixed mean errors and a cross-track bias, a scan position bias correction which was fixed in time was included. It should be noted that these changes were applied not only to the new NOAA-15 data but also to all other radiance data.

The quality control of the radiance data is extremely important. For the IR HIRS-3 data, the quality control developed for the previous HIRS instruments was used. This quality control was primarily based on the ability to fit the window channel (channel 8) observation with the simulated values. The AMSU data required the development of a new set of criteria. Channels 1, 2 and 3 are impacted by precipitation, cloud liquid water and surface emissivity. The quality control was intended to eliminate channels in the profile significantly influenced by precipitation and cloud liquid water. Therefore, a criterion based on the magnitudes of the changes necessary in the emissivity for channels 1, 2 and 3 to fit the observations was set. If these changes are too large (3-5% based on channel), channels 1-6 are not used. Application of this quality control algorithm has appeared to work well within the NCEP system. The areas of observations which have been removed correspond well to estimated precipitation regions from SSM/I. In addition, it was necessary to not use AMSU channels 11-14 because the top of the model was not high enough. Over land, AMSU channels 1-6 are not used because simulations of the surface emissivity are not accurate enough to perform quality control.

Finally, it was necessary to thin the AMSU-A observations because of the computational expense. There are 30 cross-track scan positions. To avoid repeatedly throwing out the same locations in the scan, one cannot use every 2nd, 3rd, 5th, 6th or 10th position. Every 4th was thought to be still too many profiles, so currently we use every 7th profile.

In addition to the NOAA-15 data, NCEP is using HIRS level 1b data from NOAA-11, and 14. Channels 2-15 are being used over the ocean (when not rejected by the quality control). Over land/ice and ocean, channels 2 and 3 are used with a thinning procedure which takes every 5th profile. Channels 2-4 for the NOAA-14 MSU are used over the ocean and channels 3-4 are used over land when the quality control is passed. Over the ocean, GOES-8 radiances are used where NESDIS does not detect clouds and our quality control does not reject the data. Only channels 2-12 are currently being used because of instrument noise in the short wave channels.

4. RESULTS

Comparisons of analyses produced with and without the NOAA-15 data show that the largest changes in the analyses occur in the southern hemisphere and at higher atmospheric levels. When cycled in an assimilation system, most of the improved fit to conventional data initially occurred in the southern hemisphere and at higher atmospheric levels. However, after cycling for a longer period of time, the improvements extended into the lower levels of the atmosphere. Finally, comparisons of forecast skill between assimilations using the NOAA-15 data resulted in significant improvement in both Northern and Southern Hemisphere forecast skill (see Fig.1). The improvement is larger in the Southern Hemisphere as might be expected with the greater dependence of the analysis on satellite data.

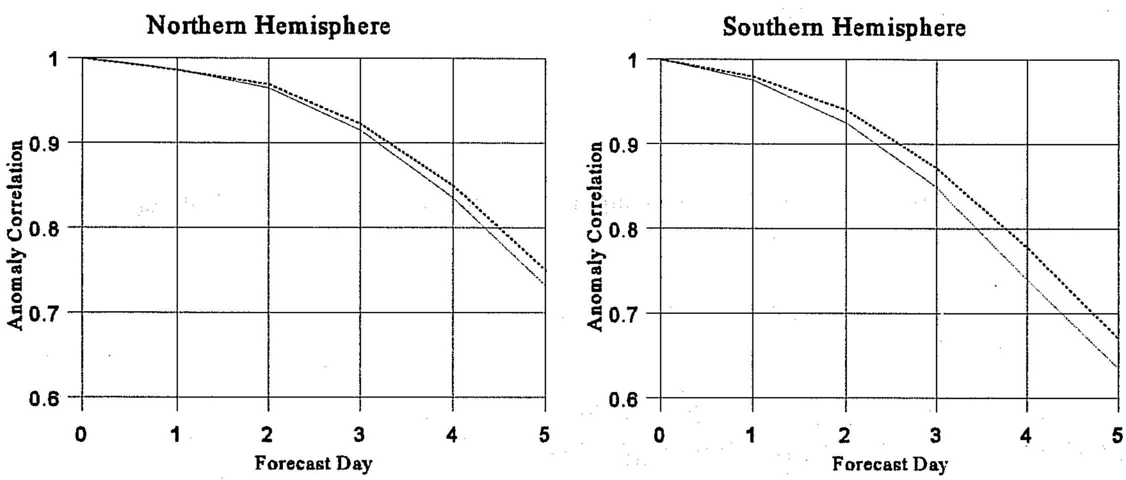

Fig. 1 Anomaly Correlations for Northern and Southern Hemisphere. Solid line is control. Dotted line is experiment with NOAA-15 data. All other components of experiment are the same. Plots are average of 17 cases.

5. CONCLUSIONS/FINAL COMMENTS

The use of satellite data in NCEP data assimilation system is gradually evolving. The evolution involves not only the improved use of satellite data and the incorporation of new types of satellite data but also the improvement of other components of the assimilation system. Recently, changes to the background error covariance, time interpolation, moisture constraints, and IR surface emissivity calculations. The incorporation of the NOAA-15 data in the NCEP data assimilation system was made easier by the development for the previous NOAA satellites. By using the level 1b data, the basic components of the system used for previous satellites were easily extended to the NOAA-15 data. The inclusion of the NOAA-15 data has resulted in a significant positive impact on the NCEP assimilation system, especially in the stratosphere and the Southern Hemisphere.

Considerable work remains for the assimilation of satellite data. There is a need to identify and remove the sources of model-radiance bias. Considerable quantities of data are not being used because they are over land and ice. Techniques to properly incorporate the surface effects and to perform the quality control must be developed. The AMSU-B data contains considerable moisture information. The full utilization of this data will require the development of cloud and precipitation assimilation techniques. In addition, there are many new data sources which are anticipated (e.g., AIRS, IASI, NPOESS). Substantial resources and effort will be necessary to fully utilize new data sources and many currently available data.

References

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