Assimilation of advanced sounders at NCEP

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1. Introduction

The optimal use of advanced sounders in data assimilation systems is dependent on many factors. Components such as information content, ability to simulate the observations, and ability to quality control and bias correct the observations are dependent on instrument characteristics and design. However, much of the ability to usefully assimilate data depends on the general characteristics and capabilities of the assimilation systems. Thus, the development of the capability to assimilate advanced sounders at NCEP has been directed both towards the development of instrument specific data handling systems, intelligent data thinning algorithms, fast radiative transfer, bias correction techniques and quality control systems and improved assimilation techniques to extract additional information from the advanced sounders (as well as all other instruments). Note that while one expects an overall positive impact, the actual or relative impact of any particular instrument may be increased or decreased as the systems is assimilation system is improved.

In this paper, a description of some of the work being done at NCEP/EMC to incorporate advanced sounders and to improve the use of all types of data will be presented. The areas discussed will include improvements to the assimilation techniques, changes to the radiative transfer, and results from experiments to use the AIRS data as an example of the work being done for the advanced sounders.

2. Improvements to the assimilation techniques

The information in the observations is projected into the appropriate scales and analysis variables by the assimilation system. The assimilation system is very dependent on the many details including the basic assimilation technique (3D-Var, 4D-Var, Kalman Filter, etc.), background and observational error statistics, quality control procedures, and observations used. The details and the priorities for development in these systems can be dependent not only on the best science, but also on externally specified constraints of each institution such as time available to perform the analysis, human resources, computational resources, availability of data, management investment in the data, etc. Given NCEP/EMC's constraints, priorities have been developed for improvements in the assimilation techniques which include the development of situation dependent background error covariances; additional analysis variables including cloud liquid water, cloud ice, CO_2, sea, land and ice surface temperatures, and snow depth; improved balance constraints between analysis variables (especially with moist variables); accounting for the time dimension in the assimilation system; improvements in the basic forecast model and the enhanced use of conventional data (especially surface data) and Doppler radar data. In this paper, only the inclusion of the situation dependent background errors will be discussed further because we believe that this aspect holds the most potential for improving the use of satellite data and in general improving the assimilation system.

The development of situation dependent background errors for use in assimilation systems has two main components. First, computational techniques must be developed to allow the application of situation dependent background errors fast enough for use in an operational NWP environment. Second, the structure of the situation dependent background errors must be appropriately specified. At NCEP/EMC, we have chosen to address the first component through the use of recursive filters (Purser et al., 2003a,b, Derber et al., 2003). The second component, the specification of the structures of the background error, has several potential possibilities and is still under development. However, the importance of the specification of the error can be seen by some examples developed for a 2-D near-surface analysis. For this case, the background error structures were made dependent only on the distance between points and the orography.

In Fig. 1, an isotropic error correlation similar to that commonly used in operational assimilation systems is shown along with the surface elevation over a region of Utah, USA. Note how the influence of an observation would be spread indiscriminately over the region with no impact of the local orography. The background error displayed in Fig. 2 is dependent on the distance and elevation over the same region as in Fig. 1. The different background errors in Fig. 1 and 2 will result in a very different spatial projection of the information in any observational data. Assuming the structures in Fig. 2 are more appropriate than those in Fig. 1, substantial improvement in the resulting analysis should occur.

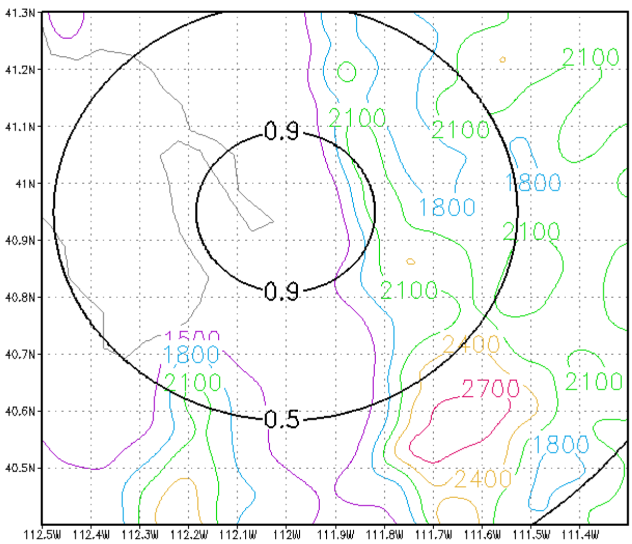

Fig. 1: Isotropic background error shown over orography from Utah, USA.

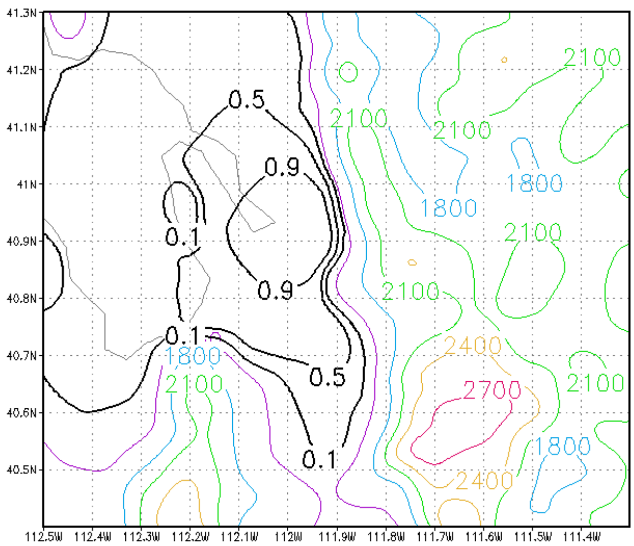

Fig. 2: Anisotropic error correlation dependent on orography over same region as Fig. 1.

3. Radiative Transfer

The radiative transfer model within the assimilation system clearly has a strong influence on the use of all satellite radiance data including those from the advanced sounders. The model used at NCEP/EMC is the Community Radiative Transfer Model (CRTM) which is based on transmittances calculations using OPTRAN (Kleespies et al., 2004). Since few resources are available for the development of the CRTM within NCEP/EMC, it is necessary to involve external groups in the development process for this system through the Joint Center for Satellite Data Assimilation (JCSDA). Considerable effort continues to be expended to make this code modular and easy to use for external developers. External projects funded by the JCSDA include four groups incorporating the influence of cloud water, ice and precipitation in the microwave and infrared. Preliminary results from one of the projects have shown encouraging results in the microwave. In addition, several projects for improving the estimates of the microwave and infrared emissivities over land, ice, snow and water have also been funded.

Two surface emissivity components have matured sufficiently to be used operationally or to be used in parallel tests. An new high spectral resolution infrared surface emissivity model (van Delst, 2003) over the ocean showed improved results over the simple band model used previously and has been implemented into operations. Also, a new microwave surface emissivity model for use over snow and sea ice (Weng et. al., 2001 and Yan et al., 2004) has been tested within parallel systems. The new surface emissivity model allows many more near surface channels to be used in the polar regions. In Fig. 3, the average number of radiances within a 2x2 degree box over a one month period is shown for AMSU-A channel 4 (a near surface channel) for both the old and new surface emissivity models. Note the large increases in observations used with the new system in the polar regions. This increased number of observations passing the quality control is reflected across all surface sensing channels.

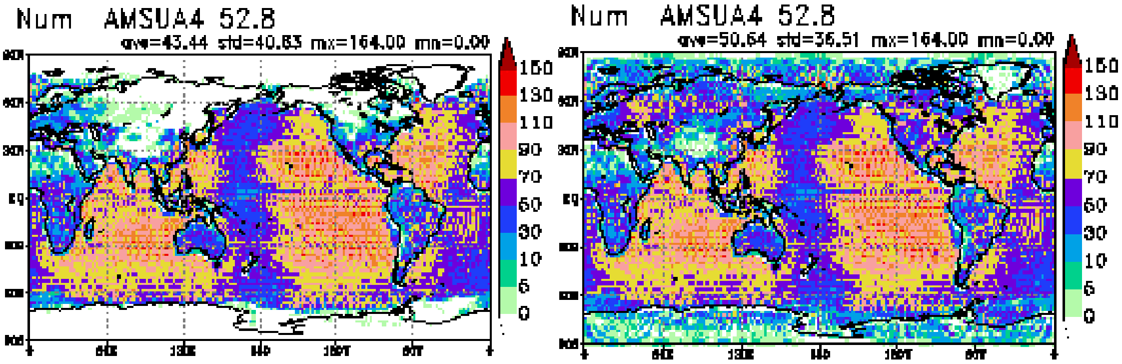

Fig. 3: Average number of observations used over one month period in 2x2 degree boxes for AMSU-A channel 4. Panel on left shows old surface emissivity model and on right the new.

The inclusion of the additional observations resulted in an increase in the near surface temperature close to the North Pole. The increase in near surface temperature is similar to that seen when an improved sea ice model currently under development at NCEP/EMC is used. Individually, both the inclusion of the new emissivity model and the improved sea ice model resulted in improved forecast skill in the polar regions. However, the combination of both the improved sea ice model and new emissivity model resulted in more significantly forecast improvements than either change alone.

4. AIRS assimilation

The incorporation of AIRS data within the NCEP/EMC assimilation system is our initial effort in using the high spectral resolution infrared sounders. To date, the experiments have been performed using the operational SSI analysis system with the high spectral resolution ocean emissivity calculations mentioned in section 3. The new microwave emissivity over snow and ice discussed in section 3 and the assimilation enhancements discussed in section 2 are not yet incorporated.

The development process for using the AIRS data has resulted in several enhancements to the assimilation system. These enhancements have included a new data selection and satellite overlap algorithm and changes to the infrared quality control. The new data selection algorithm is intended to select those observation profiles that will have the most channels pass the quality control performed at a later stage of the assimilation. Currently, the primary criterion for selecting which AIRS observations are kept by the data thinning algorithm is based on the closeness of the fit of a window channel (channel number 914) to the SST value. As a secondary consideration, observations are selected based on the proximity to the center of the box and the smallest time difference from the analysis time.

A new satellite overlap algorithm was also included. When the orbits of similar instruments overlap (whether or not the instruments are similar is defined by the user), the observations from all instruments whose orbits overlap are used and are weighted relative to the expected information content. In the experiments below, the AQUA AMSU-A instrument is equally weighted with the NOAA AMSU-A instruments. The AQUA AIRS instrument is given a much higher weight than the NOAA HIRS instruments. Thus, when the AIRS instrument orbit overlaps a HIRS instrument, almost all the weight is given to the AIRS instrument.

The infrared quality control algorithms, used to detect and remove channels that are influenced by clouds, were rewritten for AIRS to make it more objective, requiring less direct input from the developer. The increased automation of the algorithm was necessary because of the large increase in the number of channels. The cloud detection is done by, assuming that the clouds are black bodies and the same temperature as the surrounding air, finding the most likely cloud percentage and location in the vertical given the radiances. An example of the resulting cloud pressure and percentage fields is shown in Fig. 4. Note that it is not intended that the cloud pressure and percentage necessarily be correct, but rather be appropriate for the cloud signal in the data. Those channels that would have less than a 0.02K signal from the clouds are retained. This quality control procedure and a few other additional minor quality control procedures appear to be effective in removing the cloud signal. However, the quality control procedures may be too strict and may remove too many channels.

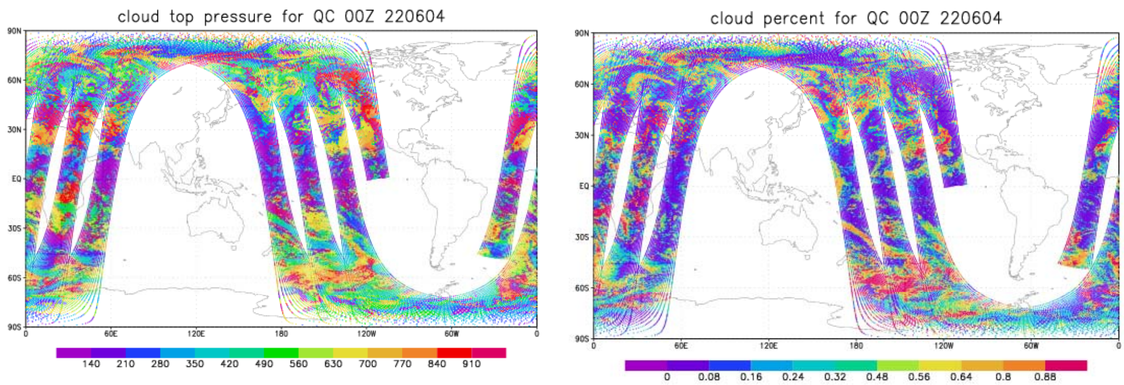

Fig. 4: Cloud top pressure and cloud percentage for one six hour period around 00GMT June 22, 2004.

The resulting percentage of channels that pass the quality control and the approximate height of the maximum of the weighting function in the vertical are shown in Fig. 5. Note that generally as the peak of the weighting function becomes lower in the atmosphere, fewer data are used. There are a few exceptions to this rule. Around channel number 35, the peak of the weighting function becomes very high, and much of the signal is above the midpoint of the top level of the model. These channels are not allowed to pass the quality control if too much of the signal is from the top layer of the model. The ozone sensitive channels (around channel 145) have a maximum sensitivity higher in the atmosphere as shown in Fig. 5, but also have secondary peak in sensitivity near the surface. For that reason, these channels react as if they are window channels in the quality control. Finally, short wave channels (greater than about 253) have a significant reflected solar radiation signal during the day that currently cannot be properly simulated. Thus, these channels are not used during the day, and the number passing the quality control is reduced.

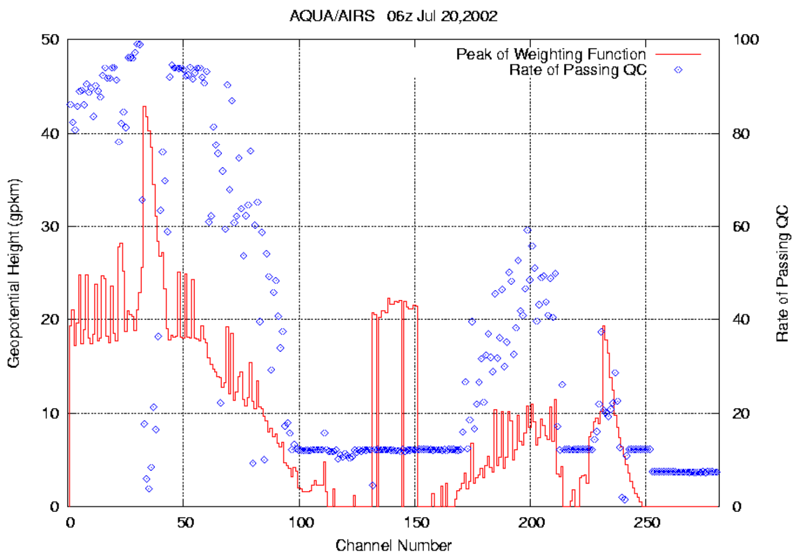

Fig. 5: Percent passing quality control (blue circles) and approximate height of maximum of weighting function (red) for 281 AIRS channels used at NCEP

Assimilation experiments have been performed using the AIRS 281 subset of channels in the NCEP/EMC assimilation system. Twenty-four of the available channels were removed because they peaked too high in the atmosphere for proper simulation (12 channels), are not in local thermodynamic equilibrium (11 channels), or appear to be bad (1 channel). The observational and representativeness error specified for the channels ranged from 1.2 to 0.6 degrees. Earlier experiments with smaller error produced worse results. The assimilation experiments spanned about one month from 10 March to 5 April 2004. All other data currently used in NCEP operations was assimilated.

Four experiments were performed:

1) Control = no AQUA data,
2) Control + AQUA AIRS data
3) Control + AQUA AMSU-A data, and
4) Control + AQUA AIRS and AQUA AMSU-A data.

In these experiments, approximately 38% of the AIRS data output by the data thinning algorithm passed later quality control and was used in the assimilation system. While individual forecasts and analyses were different, the mean forecast skill at 500hPa and 1000hPa were not significantly different between any of the experiments. Due to inadequate computational resources, the results from levels higher in the atmosphere were not archived. It is anticipated that some positive impact of this data may occur at higher levels where more data passed the quality control and the vertical resolution of the AIRS data provides more useful information. The addition of the AIRS data to our analysis system added about 7-8 minutes processing time to our analysis. Since the operational requirement to produce an analysis within 20 minutes at NCEP is very strict, the addition of the 7-8 minutes to the current 20 minutes wall time was not acceptable, and the data have not yet been added to the NCEP operational system.

5. Final Comments

The assimilation of advanced sounder data is dependent on all components of the system. Development of the next generation grid point analysis system with situation dependent background errors is proceeding well. Many enhancements to the radiative transfer, forecast model, bias correction, quality control and data selection procedures are underway. In addition, many new microwave, infrared, and GPS based satellite sensors are under development. The inclusion of any of this data must satisfy operational requirements for timeliness and computational cost as well as show some positive impact.

To date, the AIRS data has not shown a significant positive impact on the NCEP system. Also, the additional computational cost of 7-8 minutes is unacceptable given our current requirements. Additional experiments are underway with a more restricted set of channels. We note that NCEP was attempting to use more channels than ECMWF or the Met Office. Several other possible paths exist such as the use of superchannels, principle components, cloud cleared radiances, higher spatial resolution data, and a different channel selection.

6. References

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