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Assimilation of Advanced InfraRed Sounder (AIRS) observations at the JCSDA

J. Le Marshall*, J. Jung, J. Derber, R. Treadon, M. Goldberg, W. Wolf and T. Zapotocny

NASA, NOAA and DoD Joint Center for Satellite Data Assimilation (JCSDA),Camp Springs,MD, USA

1. INTRODUCTION

The Advanced InfraRed Sounder (AIRS) on the NASA AQUA platform was the first of a new generation of meteorological advanced sounders to provide data for operational and research use. A large investment has been made on an international scale to upgrade the operational meteorological satellite systems to carry these advanced instruments. The NOAA Cross-track Infrared Sounder (CrIS) and the Hyperspectral Environmental Suite (HES) instruments, on US operational polar orbiting and geostationary platforms respectively, and the Infrared Atmospheric Sounding Interferometer (IASI) on the operational European METOP polar orbiting platform represent significant investment in these systems. As a result, demonstration of the beneficial impact of these data on NWP has been a high priority. For the first time, full spatial resolution hyperspectral radiance data, available in real-time from the AIRS instrument were used at the JCSDA in data assimilation studies over the globe utilizing the operational NCEP Global Forecast System (GFS). The radiance data from each channel of the AIRS instrument available for real time NWP were carefully screened for cloud effects and those radiances which were deemed to be clear of cloud effects were used by the global forecast systems. The result of these assimilation trials was significant improvements in forecast skill, compared to the global systems without AIRS data over the Northern and Southern Hemispheres. The magnitude of the improvement was quite significant and would normally take several years to achieve at an operational weather center. This magnitude of the improvement was related to the use of full spatial resolution data as opposed to the sampled data then employed by operational agencies. The experimental system was designed in a way that rendered it feasible for operational application. As a result, operational use of AIRS data at NCEP began after the June 2005 operational upgrade. Further improvements to the system are planned and are being supported by studies examining the impact of spatial data density, data spectral content and development related to the synergistic use of MODIS data, estimating surface emissivity and effective cloud detection.

Corresponding Author: J. Le Marshall, JCSDA, World Weather Building, 5200Auth Rd. Camp Springs MD. 20746. john.lemarshall@noaa.gov

2. BACKGROUND

In 2002, the Atmospheric Infrared Sounder (AIRS) (Aumann et al., 2003) was launched on the second of the EOS polar orbiting platforms (AQUA). This was the first advanced sounder able to provide operational data. The improved spectral resolution it provided has lead to a significant increase in vertical resolution, thermal resolution and increased accuracy in determination of the concentrations of absorbers such as moisture and ozone. Improvement in Numerical Weather Prediction (NWP) from the use of radiance observations taken by this instrument is documented in the impact studies below.

3. DATA ASSIMILATION STUDIES

3.1 Full Spatial Resolution AIRS Data

In this trail, using the NCEP operational T254 64 level version of the GFS, all channels for all fields of view (*fov*s) from the AIRS instrument on the AQUA satellite were processed into BUFR format using the current operational procedure. This provided 281 channels of AIRS data at each footprint. These particular channels describe most of the variance of the 2,378 AIRS channels (Susskind et al., 2003). The NCEP analysis and prognosis system (Derber and Wu, 1998, Derber et al, 2003) using the full operational data base, available within real-time cut-off constraints, was employed as the *control*. The data base includes all available conventional data, and the satellite data listed in Table1. The radiances from the AQUA AMSU-A instrument were not included in the control or experimental data base. Radiative transfer calculations were performed using the JCSDA Community Radiative Transfer Model (CRTM), (Kleespies et al., 2004)

The *experimental* system also employed the operational global analysis and prognosis system (GFS) with the full operational database (ie the control data base) plus full spatial resolution AIRS radiance data, currently available within

Table1: The satellite data used by the *control* forecasts

HIRS sounder radiances
AMSU-A sounder radiances
AMSU-B sounder radiances
GOES sounder radiances
GOES, Meteosat atmospheric motion vectors
GOES precipitation rate
SSM/I ocean surface wind speeds
SSM/I precipitation rates
TRMM precipitation rates
ERS-2 ocean surface wind vectors
Quikscat ocean surface wind vectors
AVHRR SST
AVHRR vegetation fraction
AVHRR surface type
Multi-satellite snow cover
Multi-satellite sea ice
SBUV/2 ozone profile and total ozone

operational time constraints. The global analysis was modified to include the use of these AIRS data and the experimental system designed to determine the impact on real time operations of the hyperspectral AIRS radiance data.

The AIRS data were passed through the operational analysis screening procedure and the warmest (clearest) data were chosen for each analysis box, on the basis of the brightness temperature of the window channel information and their proximity to the center of each of the boxes which were a little larger than one degree squares. After the initial selection process, the data were subject to cloud tests including a stringent SST based cloud test. Once this enhanced dataset had been prepared for the analysis and it had been determined which of the *fov*s were clear, the balance of the data set was further examined in relation to the forecast radiances to determine which of the individual channel radiances were cloud free. The radiances which were deemed clear by the SST and cloud checks (ie from clear *fov*s), and those determined to be clear by the forecast check were then employed in the 3D VAR analysis down to the surface in its multivariate determination of atmospheric state (Derber and Wu, 1998, Derber et al, 2003).

In a typical global cycle (i.e. every six hours) approximately 200 million radiances of AIRS data (i.e. [$200x10^6$ / 281] fields of view), were input to the analysis system. From these data about 2,100,000 radiances (281 radiances (channels) per analysis box) were selected for possible use, and result in about 850,000 radiances free of cloud effects being used in the analysis process. That is effective use is made of approximately 41% of the data selected for possible use. The data volumes are summarized in Table 2.

Table 2: AIRS Data Usage per Analysis Cycle

Total Data Input to Analysis	$\sim 200x10^6$ radiances
Data Selected for Possible Use	$\sim 2.1x10^6$ radiances
Data Used in 3D VAR Analysis (Clear Rads)	$\sim 0.85x10^6$ radiances

3.2 Full And Reduced Spatial Resolution AIRS Data

In order to examine the importance of using the full spatial resolution AIRS data as opposed to the one in eighteen fields of view currently used for operational NWP, results from another data assimilation experiment for August/September 2004 are recorded. In this study, forecasts which used radiances from the currently available thin (one in eighteen fovs) real time AIRS data set in addition to the full operational data base *including AQUA AMSU-A,* are compared to results from the use of a full spatial resolution (thick) AIRS data set in addition to the operational data base *including AQUA AMSU-A* . The trail again used the NCEP operational T254, 64 level version of the GFS.

3.3 Full and Reduced Spectral Coverage

The full NCEP operational data base *including AQUA AMSU-A*, for the period 2-27 January 2004, has been used to provide a series of <u>control</u> analyses and forecasts from the operational NCEP GDAS T254 Spectral Model and SSI analysis.

The analyses and forecasts have been repeated using the full operational data base plus full spatial resolution AIRS observations from the 115 AIRS channels whose central wavelength is less than 9.3 microns. In a third series of analyses and forecasts, the full operational database has been used with all (251 channels) AIRS data i.e., full spatial resolution, including 251 of the 281 channels currently available for real time NWP.

4. DATA ASSIMILATION RESULTS

4.1 Full Spatial Resolution AIRS Data

In the impact studies using full spatial resolution AIRS data with the NCEP operational GFS, cloud free AIRS radiance data were identified and used, employing the methods described above. The verification statistics were derived using the NCEP operational verification scheme.

A summary of the results are seen in Figures 1 to 3. Figure 1 shows the Anomaly Correlations (AC) for the GFS at 500hPa over the Southern Hemisphere for January 2004 at one to five days, with and without AIRS data. Figure 2 shows the daily variations of Anomaly Correlation for the five day forecast at 500hPa. It is clear the AIRS data have had a consistent and beneficial effect on forecast skill over the Southern Hemisphere during this period. Figure 3 shows the Anomaly Correlation over the Northern Hemisphere. The results again show improved forecast skill.

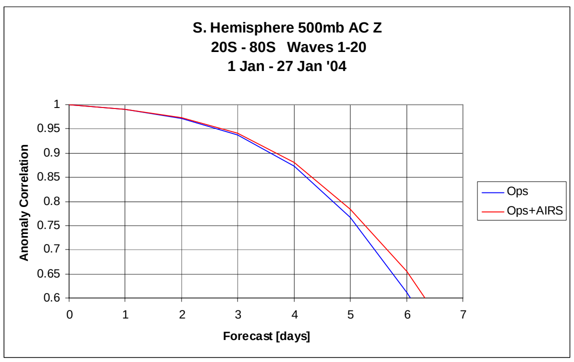

Figure 1. 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004

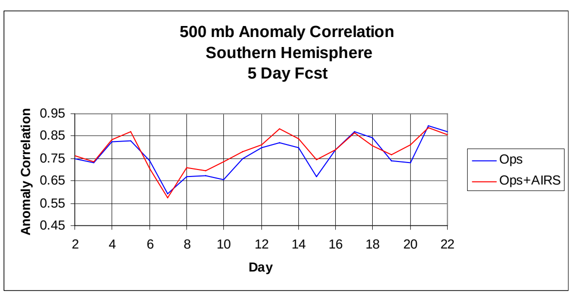

Figure 2. Daily 500hPa Z Anomaly Correlation for 5 day forecasts for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern Hemisphere, January 2004.

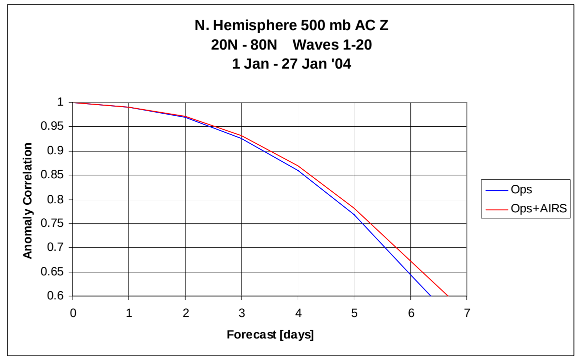

Figure 3 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Northern hemisphere, January 2004

During these impact studies using full spatial resolution AIRS data, an examination was undertaken of the moisture field in the lower troposphere. An example of the Forecast Impact is seen in Figure 4 where *Forecast Impact* evaluates which forecast (with or without AIRS) is closer to the analysis valid at the same time.

Impact = 100* [Err(Cntl) – Err(AIRS)]/Err(Cntl)

where the first term on the right is the error in the Control forecast. The second term is the error in the AIRS forecast. Dividing by the error in the control forecast and multiplying by 100 normalizes the results and provides a percent improvement or degradation. A positive Forecast Impact means the forecast is better with AIRS included. Fig.4 shows a degree of improvement over a significant area in the relative humidity at 925 hPa in the 12 hour forecast. Significant areas of improvement were also seen in the 850 hPa relative humidity and in the Total Precipitable Water at 12 hours.

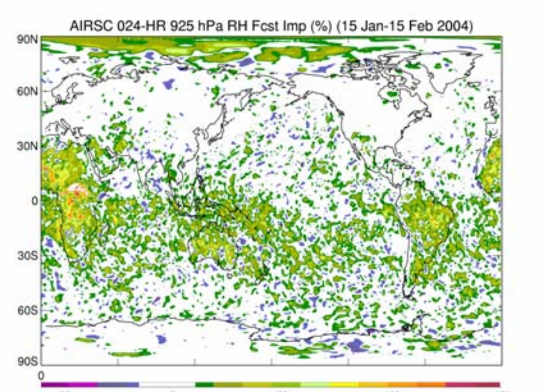

Fig 4. Forecast Impact improvement/degradation (%) of the 12 hr Relative Humidity forecast at 925 hPa .

4.2 Full And Reduced Spatial Resolution AIRS Data

In the experiment to examine the importance of using the full spatial resolution AIRS data as opposed to the one in eighteen fields of view currently used in operational NWP, results for an assimilation experiment in August/September 2004 are shown below. In this study, forecasts which used radiances from the currently available thin (one in eighteen fovs) real time AIRS data set in addition to the operational data base, *which in this case included AQUA – AMSU-A* were compared to results from the use of a full spatial resolution (thick) data set in addition to the operational data base, *which included AQUA – AMSU-A* (see Fig. 5). Identical analysis and forecast systems were used in both cases. It is clear, the increased information related to atmospheric temperature and moisture, contained in the (thick) full spatial density data set, has resulted in improved analyses and forecasts.

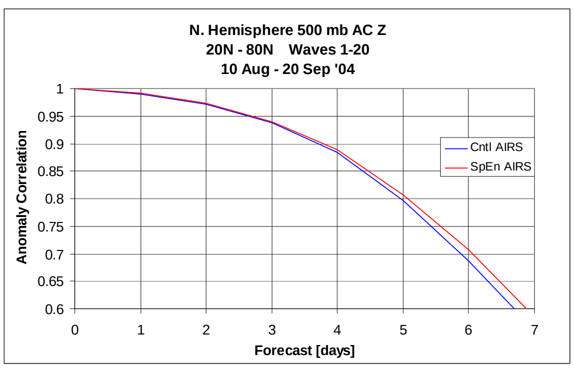

Figure 5. 500hPa Z Anomaly Correlations for the GFS with current thin – one AIRS fov in 18 (Cntl AIRS) and for the GFS using all AIRS fovs (SpEn AIRS), Northern Hemisphere, August/September, 2004

4.3 Full and Reduced Spectral Coverage

Results from a comparison of i) the control (full operational database, including AQUA AMSU-A) analyses and forecasts, ii) using the full operational data base plus full spatial resolution AIRS observations from the 115 AIRS channels whose central wavelength is less than 9.3 microns ("Short (115 ch.)") and iii) a third series of analyses and forecasts, where the full operational database has been used with all (251 channels, central wavelengths 4 to 15 microns) AIRS data (i.e., full spatial resolution, including 251 of the 281 channels currently available for real time NWP), are displayed opposite.

A Bar graph is shown for 1000 hPa five day forecast Anomaly Correlations for the Southern Hemisphere. It was apparent in this trial that addition of the shortwave channels (Short (115 ch.)) to the operational observation database generally provided a positive increment at five days with a larger improvement being seen in the Southern Hemisphere 500hPa fields. It was also clear for this period, that addition of longwave channels (channels whose central wavelength is greater than 9.3µm) generally provided noticeably improved forecasts in each of the categories. The clear positive impact of using the full spectral range of the data was seen in these experiments for this period.

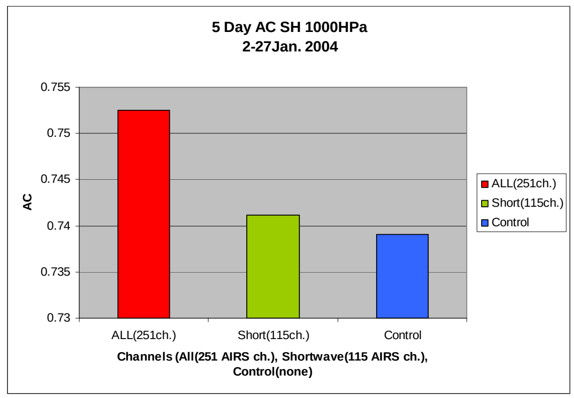

Figure 6. 1000hPa Z Anomaly Correlations for the GFS for the Control, Short (using 115 AIRS shortwave channels) and ALL (using 251 out of the 281 channels available for real time NWP), Southern Hemisphere, January, 2004

5. CONCLUSIONS

The introduction of AIRS hyperspectral data into environmental prognosis centers was anticipated to provide improvements in forecast skill. Here we have noted results where AIRS hyperspectral data, used within stringent operational constraints, have shown significant positive impact in forecast skill over both the Northern and Southern Hemisphere for January 2004. The magnitude of the improvement is quite significant and would normally take several years to achieve at an operational weather center. We have also noted the improvement gained from using AIRS at a spatial density greater than that used generally for operational NWP. In addition we have also completed some initial studies to look at impact of spectral coverage and found for the limited period studied, use of the full AIRS spectral range, namely 4 to 15 microns, appears to provide superior forecasts.

In conclusion, given the opportunities for future enhancement of the assimilation system and of the data base, the results indicate a considerable opportunity to improve current analysis and forecast systems through the application of hyperspectral data. It is anticipated current results will be further enhanced through use of higher spectral and spatial resolution and cloudy data and the use of complementary data such as MODIS radiances. Improvements are also expected from the effective exploitation of the new hyperspectral data which will become available from the IASI, CrIS and geostationary instruments such as the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) and the Hyperspectral Environmental Sounder (HES).

6. REFERENCES

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