

AIRS RELATED ADVANCES AT THE JOINT CENTER FOR SATELLITE DATA ASSIMILATION

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1. INTRODUCTION

The Joint Center for Satellite Data Assimilation (JCSDA) was established in 2000/2001. The goal of the JCSDA is to accelerate the use of observations from earth-orbiting satellites into operational numerical analysis and prediction systems for the purpose of improving weather and oceanographic forecasts, seasonal climate forecasts and the accuracy of climate data sets. As a result, a series of data assimilation experiments were undertaken at the JCSDA as part of the preparations for the operational assimilation of AIRS data by its partner organizations (Le Marshall et al. 2005a,b). Here, for the first time, full spatial resolution 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 instrument were carefully screened for cloud effects and those radiances which were deemed to be clear of cloud effects were used by the GFS forecast system. The result of these assimilation trials has been *significant* improvements in forecast skill over the Northern and Southern Hemisphere compared to the operational system without AIRS data. The experimental system was designed in a way that rendered it feasible for operational application, and that constraint involved using the subset of AIRS channels chosen for operational distribution and an analysis methodology close to the current analysis practice, with particular consideration given to time limitations. As a result, operational application of these AIRS data was enabled by the recent NCEP operational upgrade. In addition, because of the significantly improved impact resulting from use of this enhanced data set compared to that used operationally to date, provision of a real-time “warmest field” of view data AIRS data set has been established for use by international NWP Centers.

2. BACKGROUND

In 2002, the Advanced 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 characteristics of the AIRS instrument are summarized in Table 1:

Table 1: The Characteristics of the AIRS Instrument

Spectral range 3 μm - 15 μm
2378 channels with $\Delta\lambda/\lambda \sim 1/1000$
Radiances 0.2% absolute accuracy without correction
13.5 km sub-satellite field of view
Temperature determination in 1 km layers with 1 K accuracy
Moisture determination in 2 km layers within 15% accuracy

The increased spectral resolution afforded by this instrument is seen in Fig. 1 where the bandwidth of the HIRS instrument on the NOAA satellites is displayed with simulated spectra from AIRS. The improved spectral resolution shown has led to a significant increase in vertical resolution, thermal resolution and increased accuracy in determination

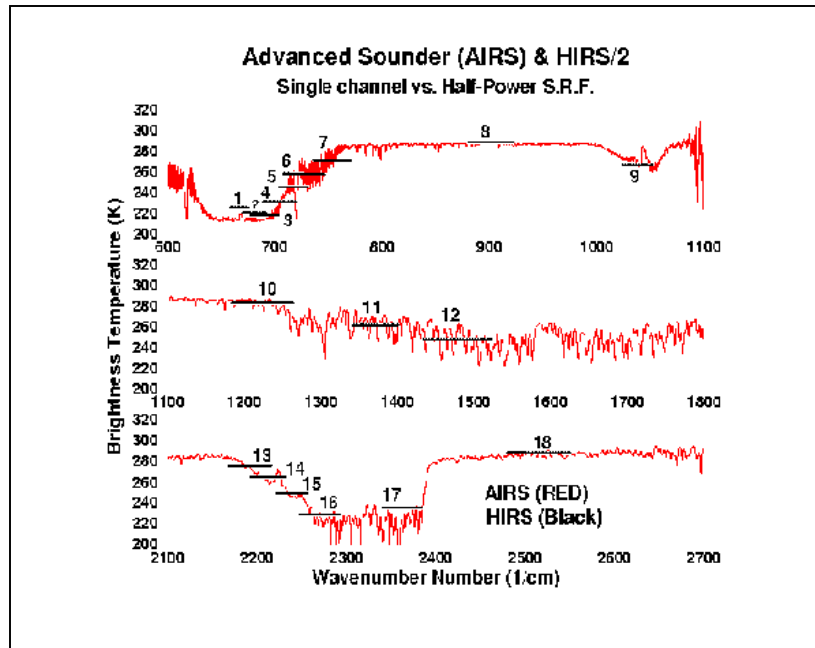


Figure 1. A comparison of the spectral resolution of HIRS/2 (Half power Spectral Response Function) with a simulated AIRS spectra. (HIRS/2 channel numbers are shown)

of the concentrations of absorbers such as moisture and ozone. Improvement in Global Numerical Weather Prediction (NWP) from the use of radiance observations taken by this instrument are documented in the impact studies reported here.

3. ASSIMILATION METHOD

Full resolution data, that is all channels for all footprints from the AIRS instrument on the AQUA satellite, were processed into the current operational BUFR format. This has provided 281 channels of AIRS data at each footprint, these particular channels describing most of the variance of 2,378 channels (Susskind et al., 2003). The NCEP analysis and prognosis system (Derber and Wu, 1998, McNally et al, 2000, Derber et al, 2003) which used the full operational data base available within real-time cut-off constraints was employed as the *control*. The data base included all available conventional data, and the satellite data listed in Table 2. The list includes microwave and infrared sounding data (radiances) from the HIRS and AMSU instruments on the NOAA polar orbiting satellites and infrared sounding data (radiances) from GOES. Radiative transfer calculations were performed using the JCSDA Community Radiative Transfer Model (CRTM), (Kleespies et al., 2004).

Table 2:Satellite data used operationally in the NCEP Global Forecast System(2004)

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

The *experimental* system also employed the operational global analysis and prognosis system (GFS) with the full operational database, plus AIRS data available within operational time constraints. Typical AIRS data coverage is seen in Fig. 2, which shows the data distribution for 06 UTC on 31 January 2004. The global analysis was modified to expand the use of AIRS data and the experimental system designed to determine the impact on operations of these hyperspectral radiance data. The AIRS data were passed

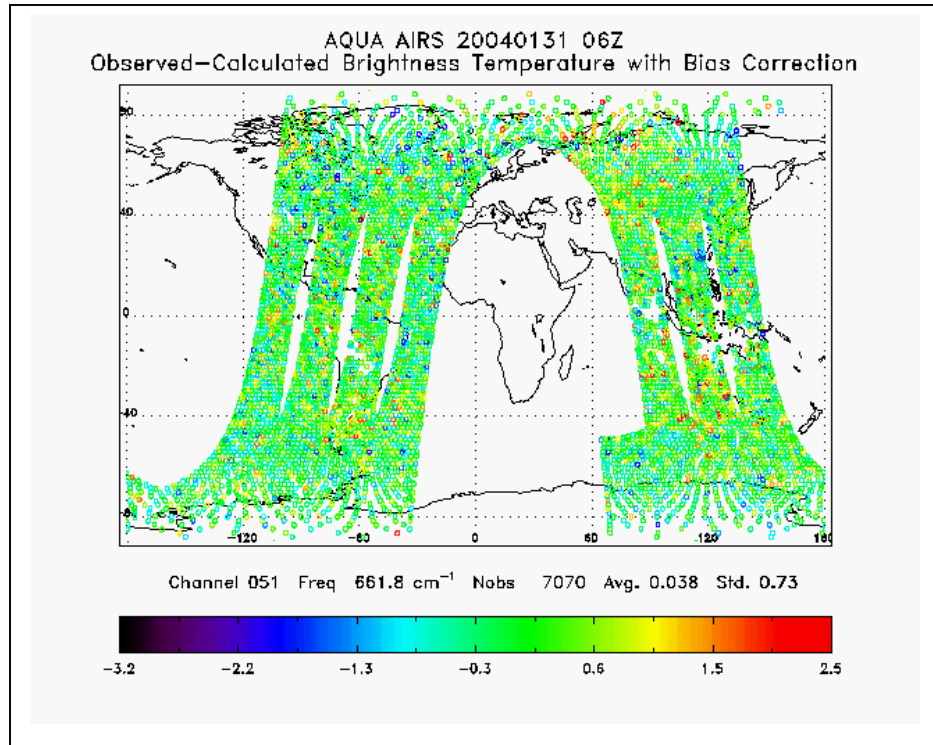


Figure 2. AIRS data coverage at 06 UTC on 31 January 2004. (Obs-Calc. Brightness Temperatures at 661.8 cm^{-1} are shown)

through the operational analysis screening procedure and the warmest (clearest) data were chosen for each analysis sub-grid, on the basis of the brightness temperature of the window channel information and their proximity to the center of each of the analysis sub-grids, which were a little larger than one degree squares. After the initial selection process, the data were subject to a stringent SST based cloud test. The model SST was compared to the SST estimated from AIRS window channel radiances using a multi-channel algorithm (Goldberg et al., 2003) and the data were flagged as cloudy or clear. *At night*, the AIRS data were *initially* deemed to be clear if the AIRS determined SST was greater than the model SST minus 0.8 degrees. The data that passed this initial clear test then had to pass a low-cloud/cirrus check which involved examining the difference between the 3.4 micron and 11 micron channels. Data passing all checks were assumed to be clear of cloud. *During the day* the clear check was an AIRS based SST check. Once this enhanced dataset was prepared for the analysis and it had been determined which of the fields of view (*fovs*) 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 those from clear *fovs*), 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, McNally et al., 2000, Derber et al, 2003).

In a typical global cycle (i.e. every six hours) approximately 200 million AIRS radiances (i.e. $200 \times 10^6 / 281$ fields of view), were input to the analysis system. From these data about 2,100,000 radiances (281 channels per analysis sub-grid) were selected for possible use, and resulted in about 850,000 radiances free of cloud effects being used in the analysis process. That is effective use was made of approximately 41% of the data selected for possible use. The data volumes are summarized in Table 3.

Table 3: AIRS Data Usage per Analysis Cycle

Data Category	Number of AIRS Channels
Total Data Input to Analysis	$\sim 200 \times 10^6$ radiances (channels)
Data Selected for Possible Use	$\sim 2.1 \times 10^6$ radiances (channels)
Data Used in 3D VAR Analysis (Clear Radiances)	$\sim 0.85 \times 10^6$ radiances (channels)

4. STUDIES AND RESULTS

An initial study was completed for January 2004 where full spatial resolution AIRS data in current operational format (i.e. BUFR format with 281 AIRS channels) were used in an enhanced version of the NCEP operational analysis. The cloud free AIRS radiance data were identified and used, employing the methods described earlier. The verification statistics were derived using the NCEP operational verification scheme.

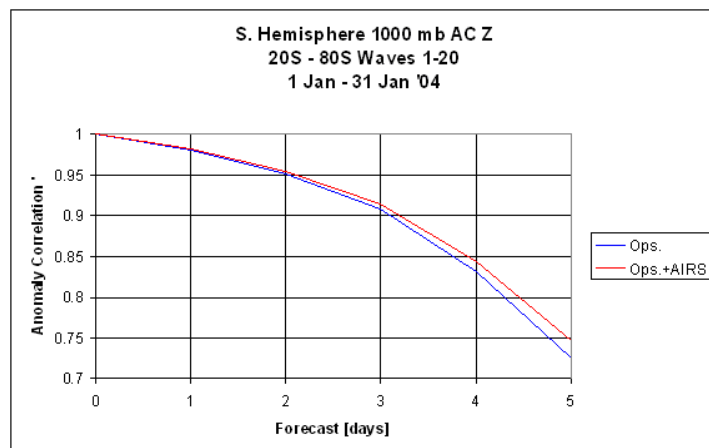


Figure 3(a). 1000hPa Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004

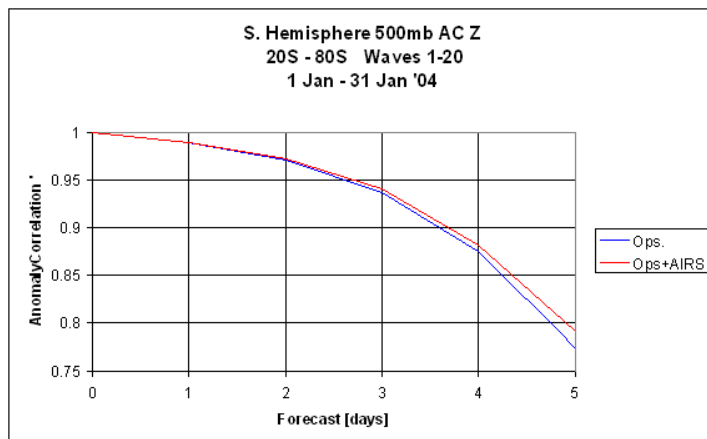


Figure 3(b). 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004

A summary of the results is seen in Figures 3 to 6. Figures 3 (a) and (b) show Anomaly Correlations (AC) for the GFS over the Southern Hemisphere for January 2004 at one to five days, with and without AIRS data. Figure 3(a) shows the impact at 1000 hPa. Figure 3(b) shows the impact at 500 hPa. Figure 4 shows the daily variations of Anomaly Correlation for the five day forecast at 1000hPa. It is clear the AIRS data had a consistent and beneficial effect on forecast skill over the Southern Hemisphere during this period, improving the five day forecast at 1000hPa by about 6 hours.

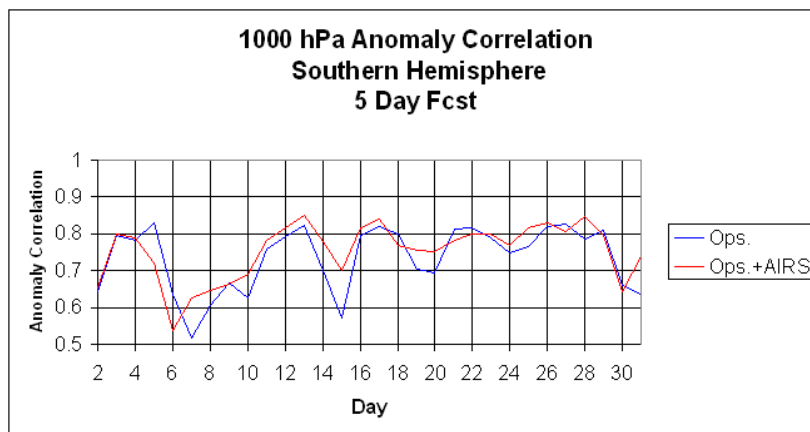


Figure 4. Daily 1000hPa Z Anomaly Correlation for 5 day forecasts for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern Hemisphere, January 2004.

The Anomaly Correlations over the Northern Hemisphere also showed improved forecast skill, albeit of a smaller magnitude. This was not unexpected as the Northern Hemisphere

enjoys greater data coverage and in these experiments, the AIRS data had only been used to a limited extent in the lower troposphere over-land, they had not yet been employed at higher spectral resolution, they have been given less than full weight in the NCEP 3D VAR, and cloudy radiances had not yet been used. These runs were subsequently repeated with modified weights (error covariances) for the AIRS data and provided improved forecast skill over the Northern Hemisphere.

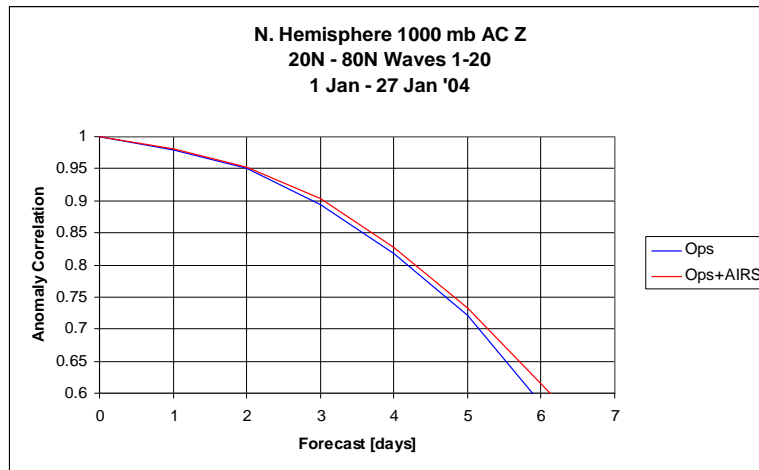


Figure 5(a). 1000hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Northern hemisphere, January 2004

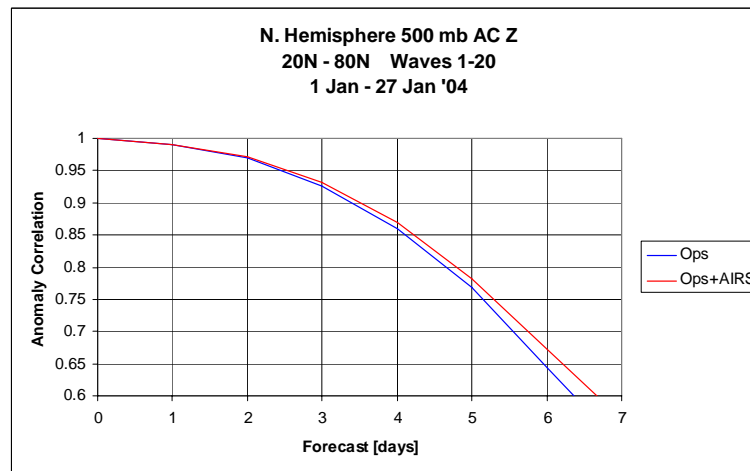


Figure 5(b). 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Northern hemisphere, January 2004

The Anomaly Correlations for the GFS over the Northern Hemisphere in the subsequent runs is shown in Fig. 5. (a) and (b). These results probably represent the first significant

impact of hyperspectral data seen over the whole globe. It is intended to repeat these studies using enhanced spectral resolution data and using more data over-land, with a view to increasing the difference in forecast skill between with and without AIRS data.

To further emphasize the importance of using the full spatial resolution AIRS data, results from another data assimilation experiment for August/September 2004 are also included. Here forecasts which used radiances from the currently available (thin- one in eighteen fovs) real time AIRS data set is compared to results from the use of a full spatial resolution (thick) data set (Fig. 6). Identical analysis and forecast systems were used in both cases. It is clear and from this and other experiments, that the increased information related to atmospheric temperature and moisture, contained in the full spatial resolution data set, results in improved analyses and forecasts.

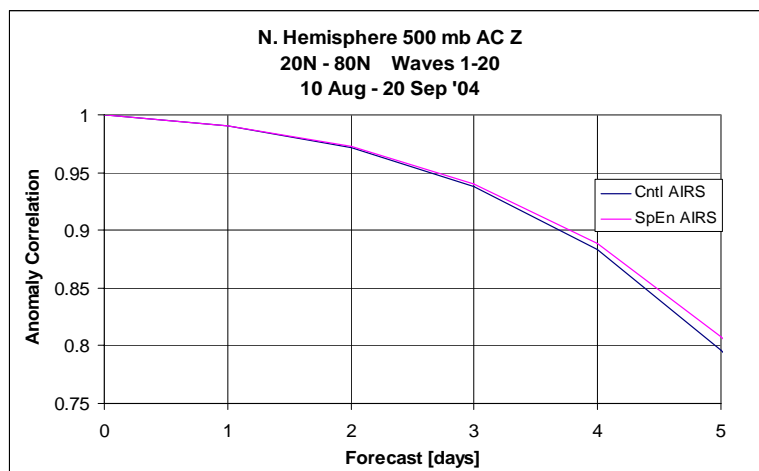


Figure 6. 500hPa Z Anomaly Correlations for the GFS with current thinned – one fov in 18 AIRS (Cntl)) and for the GFS using all AIRS fovs (SpEn), Northern hemisphere, August/September, 2004

5. CONCLUSION

The introduction of AIRS hyperspectral data into environmental analysis and prognosis centers was anticipated to provide improvements in forecast skill. Here we have demonstrated that full spatial resolution AIRS hyperspectral data, used within stringent current operational constraints, have shown (probably for the first time) significant positive impact in forecast skill over *both* the Northern and Southern Hemispheres. Given the opportunities for future enhancement of the assimilation system, the results indicate a considerable opportunity to improve current analysis and forecast systems through the application of hyperspectral data. It is anticipated the current results will be further enhanced through improved physical modeling, a less constrained operational

environment, allowing use of higher spectral and spatial resolution data and cloudy observations, the use of complementary data such as MODIS radiances and the effective exploitation of the new hyperspectral data, which will become available from the IASI, CrIS and GIFTS instruments.

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