Shorter contribution

AIRS hyperspectral data improves southern hemisphere forecasts

J. Le Marshall, J. Jung, J. Derber, R. Treadon, S. Lord, M. Goldberg, W. Wolf, H.C. Liu, J. Joiner, J. Woollen, R. Todling, P. van Delst and Y. Tahara
Joint Center for Satellite Data Assimilation, Camp Springs, USA

Introduction

In 2002, the Advanced Infrared Sounder (AIRS) (Aumann et al. 2003) was launched on the second of the Earth Observing System (EOS) polar-orbiting platforms (Aqua). This was the first advanced sounder able to provide operational data. The characteristics of the AIRS instrument are summarised in Table 1.

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 of the concentrations of absorbers such as moisture and ozone. Improvement in southern hemisphere numerical weather prediction (NWP) from the use of radiance observations taken by this instrument is documented in the impact studies reported here.

Assimilation method

Full resolution data, that is all channels for all footprints from the AIRS instrument on the Aqua satellite, have been processed into BUFR format using the current operational procedure. This has provided 281 channels of AIRS data at each footprint, these particular channels describing most of the variance of the 2378 channels (Susskind et al. 2003). The current NCEP analysis and prognosis system (Derber and Wu 1998; McNally et al. 2000; Derber et al. 2003) using the full operational database, available within real-time cut-off constraints, has been employed as the control. The database includes all available conventional data, and the satellite data listed in Table 2. The

Fig. 1 A comparison of the spectral resolution of Channels 1 to 9 of HIRS/2 (Half power Spectral Response Function) with a simulated AIRS spectra (HIRS/2 channel numbers are shown).

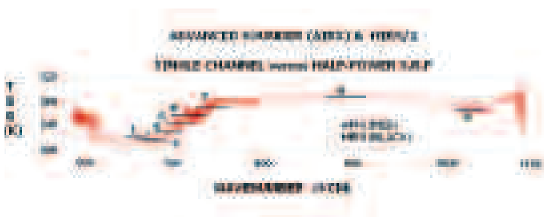


Table 1. The characteristics of the AIRS instrument.

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

Table 2. Satellite data used operationally within the NCEP Global Forecast System.

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

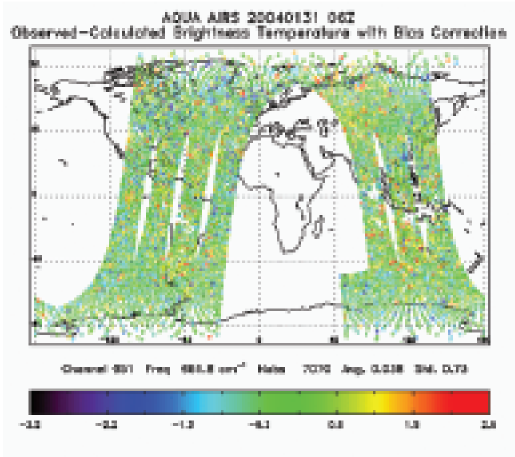
Corresponding author address: John Le Marshall, Joint Center for Satellite Data Assimilation, World Weather Building Room 808, 5200 Auth Road, Camp Springs, Maryland 20746, USA.
Email: John.Lemarshall@noaa.gov

list includes microwave and infrared sounding data (radiances) from the High Resolution Infrared Radiation Sounder (HIRS) and Advanced Microwave Sounding Unit (AMSU) instruments on the NOAA polar-orbiting satellites and infrared sounding data (radiances) from Geostationary Operational Environmental Satellite (GOES). 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, plus AIRS data currently available within operational time constraints. Typical AIRS data coverage is seen in Fig. 2, which shows that for 0600 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 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 centre of each of the boxes, which were a little larger than one degree squares. After the initial selection process, the data were subject to a stringent sea-surface temperature (SST) based cloud test. The model SST was compared with 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 had been prepared for the analysis and it had been determined which of the fields of view (fovs) were clear, the balance of the dataset 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 (i.e. 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. 200×10^6 / 281 fields of view), were input to the analysis system. From these data about 2 100 000 radiances (281 channels per analysis box) 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 per cent of the data selected for possible use. The data volumes are summarised in Table 3.

Fig. 2 AIRS data coverage at 0600 UTC on 31 January 2004 (Obs-Calc. brightness temperatures at 661.8 cm^{-1} are shown).



Studies and results

A study has been completed for the period 1 January 2004 to 31 January 2004 where full resolution AIRS data were passed to an enhanced operational analysis in current operational format (i.e. BUFR format with 281 AIRS channels). 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. A summary of the results is seen in Figs 3 to 5. 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

Table 3. AIRS data usage per analysis cycle.

Data category	*Number of AIRS channels*
Total data input to analysis	~200×10^6 radiances (channels)
Data selected for possible use	~2.1×10^6 radiances (channels)
Data used in 3D VAR Analysis (Clear Radiances)	~0.85×10^6 radiances (channels)

Fig. 3(a) **1000 hPa anomaly correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, southern hemisphere, January 2004.**

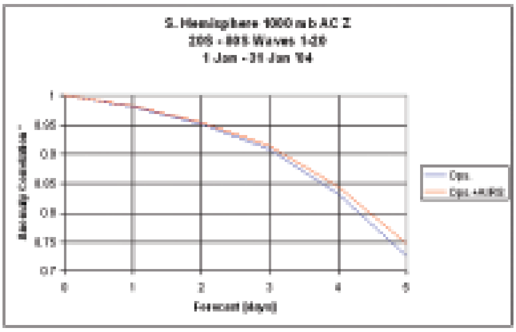


Fig. 3(b) **500 hPa Z anomaly correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, southern hemisphere, January 2004.**

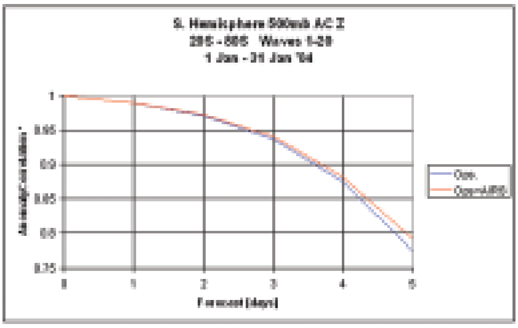


Fig. 4 **Daily 500 hPa Z anomaly correlation for five-day forecasts for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, southern hemisphere, January 2004.**

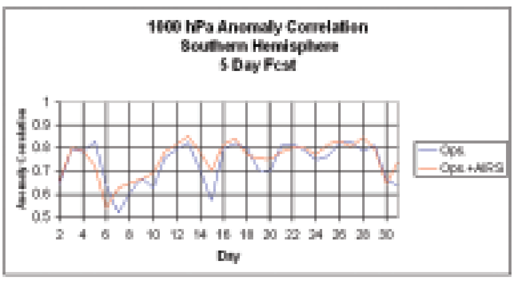


Fig. 5(a) **1000 hPa Z anomaly correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, northern hemisphere, January 2004.**

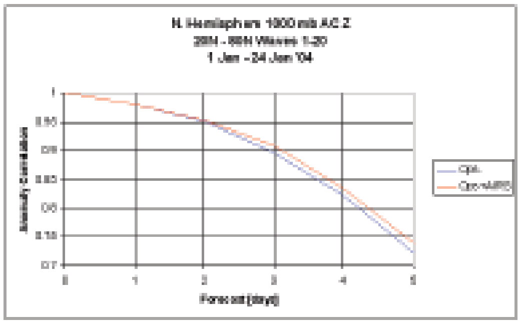
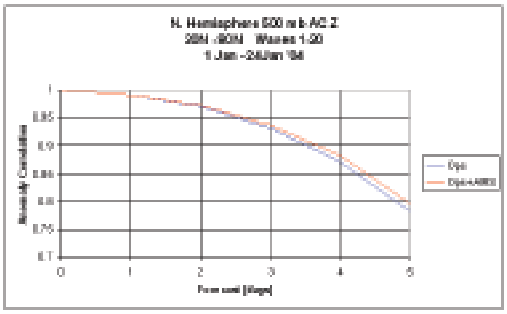


Fig. 5(b) **500 hPa Z anomaly correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, northern hemisphere, January 2004.**



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 1000 hPa. It is clear the AIRS data have had a consistent and beneficial effect on forecast skill over the southern hemisphere during this period, improving the five-day forecast at 1000 hPa by about six hours. The anomaly correlations over the northern hemisphere also showed improved forecast skill, albeit of a far smaller magnitude. This was not unexpected as the northern hemisphere enjoys greater data coverage and in these experiments, the AIRS data have only been used to a limited extent in the lower troposphere over land; they have not yet been employed at higher spatial and spectral resolution, they have been given less than full weight in the NCEP 3D VAR, and cloudy radiances have not yet been used. Recently, these runs were repeated with modified weights (error covariances) for the AIRS data and provided improved forecast skill over the northern hemisphere. The anomaly correlations for the GFS over the northern hemisphere in these later runs may be seen in Fig. 5 (a) and (b). It is intended to repeat these studies using enhanced spatial and spectral resolution data and using more data over land, with a view to increasing the difference in forecast skill between that with and without AIRS data.

Conclusions

The introduction of AIRS hyperspectral data into environmental analysis and prognosis centres was anticipated to provide improvements in forecast skill. Here we have demonstrated that AIRS hyperspectral data, used within stringent current operational constraints, have shown significant positive impact in forecast skill over the southern hemisphere for January 2004. 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 modelling, a less constrained operational environment allowing use of higher spectral and spatial resolution and cloudy data, the use of complementary data such as MODIS radiances and the effective exploitation of the new hyperspectral data, which will become available from the Infrared Atmospheric Sounding Interferometer (IASI), the Cross-track Infrared Sounder (CrIS) and Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) instruments.

Acknowledgments

Thanks are due to the many scientists who provided valuable advice and assistance in the establishment of our AIRS data assimilation system. These include W.L. Smith, M. Chahine, C. Barnett and L. McMillin. Thanks are also due to Ada Armstrong for preparing this manuscript.

References

Aumann, H.H., Chanhine, M.T., Gautier, C., Goldberg, M., Kalnay, E., McMillin, L., Revercomb, H., Rosenkranz, P.W, Smith, W.L., Staelin, D., Strow,L. and Susskind, J. 2003. AIRS/AMSU/HSB on the AQUA mission: Design, science objectives data products and processing systems. *IEEE Trans. Geosci. Remote Sens., 41(2)*, 410-17.

Derber, J.C. and Wu, W.S. 1998: The use of TOVs cloud cleared radiances in the NCEP SSI analysis system. *Mon. Weath. Rev., 126*, 2287-99.

Derber, J.C., Van Delst, P., Su, X.J., Li, X., Okamoto, K. and Treadon, R. 2003. Enhanced use of radiance data in the NCEP data assimilation system. *Proceedings of the 13th International TOVS Study Conference*, 20 October–4 November, Ste. Adele, Canada.

Goldberg M.D., Qu, Y., McMillin, L., Wolf, W., Zhou, L. and Divakarla, M. 2003. AIRS near-real-time products and algorithms in support of operational numerical weather prediction. *IEEE Trans. Geosci. Remote Sens., 41(2)*, 379-99.

Kleespies, T.J., van Delst, P., McMillin L.M. and Derber, J. 2004. Atmospheric transmittance of an absorbing gas. OPTRAN status report and introduction to the NESDIS/NCEP Community Radiative Transfer Model. *Applied Optics, 43*, 3103-9.

McNally, A.P., Derber, J.C., Wu, W.S. and Katz, B.B. 2000. The use of TOVS level-1B radiances in the NCEP SSI analysis system. *Q. Jl R. Met. Soc., 126,* 689-724.

Susskind, J., Barnet, C. and Blaisdell, J. 2003. Retrieval of atmospheric and surface parameters from AIRS/AMSU/HSB under cloudy conditions. *IEEE Trans. Geosci. Remote Sens., 41*, 390-409.