

Improving Global Analysis and Forecasting with AIRS

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The NASA Atmospheric InfraRed Sounder (AIRS), the first of the new generation of meteorological advanced sounders for operational and research use, is part of a large international investment to upgrade the operational meteorological satellite systems. The new systems include the NOAA Cross-track Infrared Sounder (CrIS) and the Hyperspectral Environmental Suite (HES) instruments, on U.S. operational polar-orbiting and geostationary platforms, respectively, and the Infrared Atmospheric Sounding

Interferometer (IASI), on the operational European METOP polar-orbiting platform. Demonstration of the beneficial impact of this significant technological investment on numerical weather prediction (NWP) has been a high priority. Here, for the first time, are data-assimilation studies with the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) using full spatial resolution hyperspectral radiances, available in real time from AIRS. AIRS hyperspectral radiance data at slightly

reduced resolution have also been used, for different study periods, in the NASA Global Modeling and Assimilation Office (GMAO) Global Forecast Systems. These studies incorporate those radiances that were deemed to be clear of cloud effects.

AIRS was launched in 2002 on the second of the NASA Earth Observing System (EOS) polar-orbiting platforms, *Aqua*. The mission, characteristics, and first results of the AIRS instrument are described in the companion paper, "The

Atmospheric Infrared Sounder (AIRS) Providing New Insights into Weather and Climate for the 21st Century," by Chahine et al. The advantage of AIRS over the high-resolution infrared sounder (HIRS) instrument on the current NOAA satellites is clear (see Table 1). The improved spectral resolution significantly increases vertical resolution, thermal resolution, and accuracy in determining the concentrations of absorbers such as moisture and ozone. Our assimilation trials show for the first time significant improvements in forecast skill in both the Northern and Southern hemispheres, compared to the

TABLE 1. The characteristics of the AIRS and current operational HIRS sounding instruments.

| Instrument | HIRS | AIRS |
|-------------------------|----------------------|-----------------------------|
| Spectral range | 3.7–15 μm | 3.7–15 μm |
| Spatial resolution | 17.4-km subsatellite | 13.5-km subsatellite |
| Number of channels | 20 | 2378 |
| $\Delta\lambda/\lambda$ | $\sim 1/70$ | $\sim 1/1200$ |
| Vertical resolution | ~ 3 km | ~ 1 km |
| Temperature accuracy | ~ 1.5 – 2 K | 1 K accuracy in 1-km layers |
| Moisture accuracy | $\sim 30\%$ | 15% accuracy in 2-km layers |

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TABLE 2. The 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 |

global systems without AIRS data. This magnitude of improvement would normally take several years to achieve at an operational weather center. Because the experimental systems were designed to be feasible for operational application (e.g., using the subset of AIRS channels chosen for operational distribution), the AIRS data are now used operationally within the NCEP operational NWP suite.

DATA ASSIMILATION. Using the current procedure with the NCEP operational GFS, all channels for all fields of view (fovs) from the AIRS were processed into operational binary universal form for the representa-

tion of meteorological data (BUFR) format. At each footprint, this provided 281 channels of AIRS data describing most of the variance of the 2,378 total channels. The *control* was the current NCEP analysis and prognosis system using the full operational database, available within real-time cut-off constraints. The database includes all available conventional data, and the satellite data listed in Table 2. Radiative transfer calculations were performed using the JCSDA Community Radiative Transfer Model (CRTM).

The *experimental* system also employed the operational global analysis and prognosis system (GFS) with the full operational (Ops) database plus AIRS radiance data, currently available within operational time constraints. Typical data coverage is seen in Fig. 1, which shows AIRS data coverage at 0600 UTC on 31 January 2004. The global analysis was modified to include AIRS data, and the experimental system was 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 on their proximity to the center of each of the boxes, which were a little larger than one-degree squares. After the initial selection, 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 (described by Goldberg et al. in the February 2003 *IEEE Transactions on Geoscience and Remote Sensing*), 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 Kelvin. The data that passed this initial clear test then had to pass a low-cloud/cirrus check that involves examining the difference between 3.4- and 11- μm channels. We assumed data passing all checks were cloud clear. During the day, the clear check was an AIRS-based SST check. Once we had prepared this enhanced da-

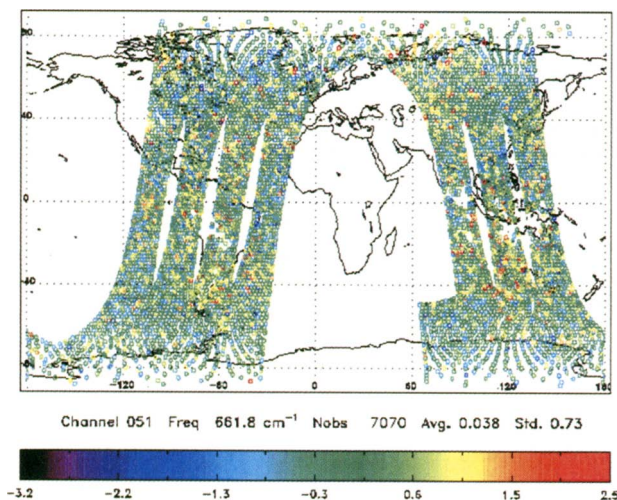


FIG. 1. AIRS data coverage at 0600 UTC on 31 January 2004 (observed-calculated brightness temperatures [Kelvin] at wavenumber 661.8 cm⁻¹ are shown).

taset for the analysis and had determined which fovs were clear, we further examined the balance of the dataset in relation to the forecast radiances to determine which of the individual channel radiances were cloud free. The radiances deemed clear by the SST and cloud checks (i.e., 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.

In a typical global cycle (i.e., every 6 h), approximately 200 million radiances of AIRS data [i.e., $[(200 \times 10^6)/281]$ fovs] 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, with 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 3.

In the complementary studies using the GMAO finite volume forecast model, the AIRS fovs used were the warmest (clearest) selected from every second Advanced Microwave Sounding Unit (AMSU) footprint (i.e., one in two AIRS radiances were available for preprocessing and thinning to the analysis grid box).

FORECAST ACCURACY. In the impact study using the current NCEP operational GFS, full-resolution AIRS data for January 2004 were BUFR-ized and 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 above. The verification statistics were derived using the NCEP operational verification scheme. Figures 2 and 3 clearly demonstrate that the AIRS data had a consistent and beneficial effect on 500-hPa forecast

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 |
| Data selected for possible use | $\sim 2.1 \times 10^6$ radiances |
| Data used in 3D VAR analysis (clear radiances) | $\sim 0.85 \times 10^6$ radiances |

skill over the Southern Hemisphere during this month. Improvements are also seen at other levels; for example, the 5-day forecast at 1000 hPa is improved by over 4 h. The results for the Northern Hemisphere (Fig. 4) again show improved forecast skill, albeit of a slightly smaller magnitude. This is not unexpected, as the Northern Hemisphere enjoys greater data coverage, and in these experiments, the AIRS data have not been used extensively in the lower troposphere over land and have not yet been employed at higher spatial and spectral resolution, and cloudy radiances

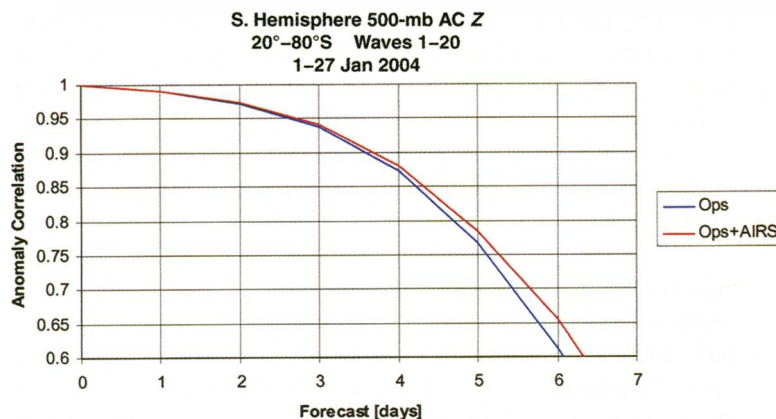


FIG. 2. 500-hPa Z anomaly correlations for the GFS with (Ops + AIRS) and without (Ops) AIRS data, Southern Hemisphere, January 2004.

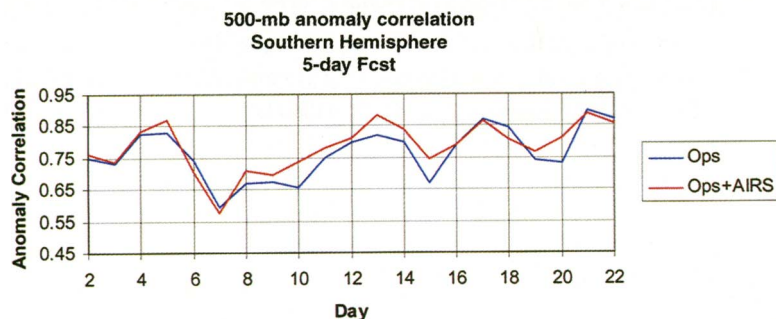


FIG. 3. Daily 500-hPa Z anomaly correlation for 5-day forecasts for the GFS with (Ops + AIRS) and without (Ops) AIRS data, Southern Hemisphere, January 2004.

have not yet been used. In the case of the GMAO studies (which are not reported in detail here), experiments again showed positive impacts in complementary experiments using 2003 data.

CONCLUSIONS. AIRS hyperspectral data (from one orbital instrument), used within current stringent operational constraints, show significant positive impact in forecast skill over both the Northern and Southern Hemisphere for January 2004. The results indicate a considerable opportunity to improve operational analyses and forecasts with hyperspectral data.

We anticipate that results will be further enhanced through improved physical modeling, 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 from the IASI, CrIS and Geostationary Imaging Fourier Transform Spectrometer (GIFTS) instruments.

The AIRS data are now used operationally within NCEP, with imminent system upgrades expected to further increase the impact of the AIRS data.

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FOR FURTHER READING

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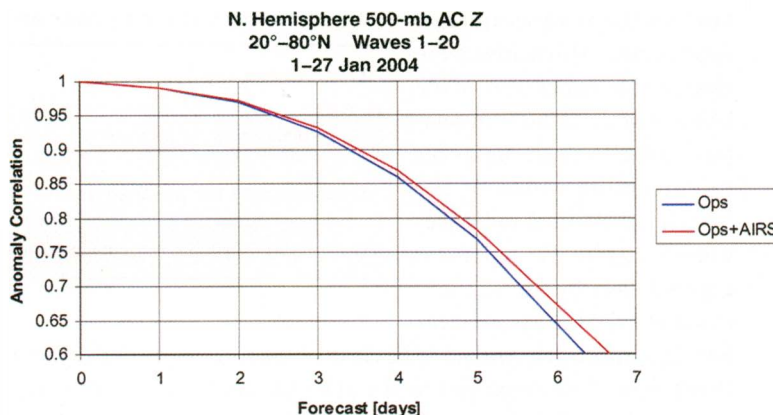


FIG. 4. 500-hPa Z anomaly correlations for the GFS with (Ops + AIRS) and without (Ops) AIRS data, Northern Hemisphere, January 2004.

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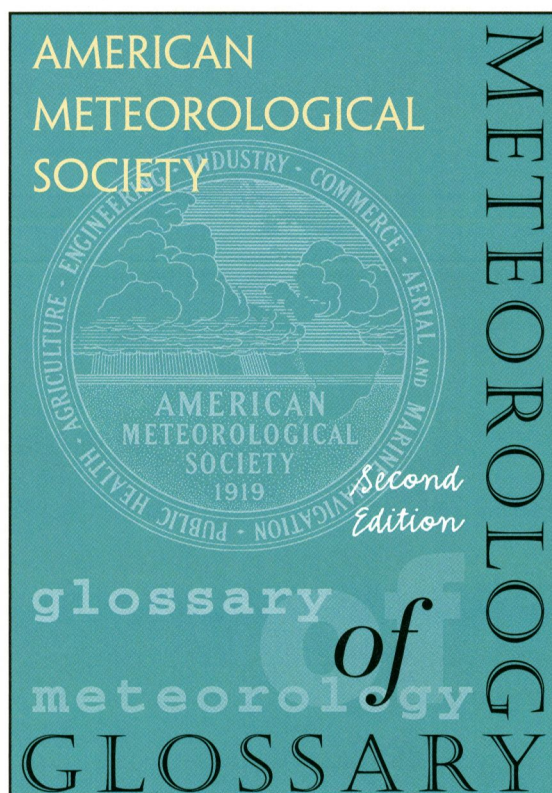
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