

Operational Use of AIRS Observations at the Met Office

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Abstract

Observations from the Atmospheric Infrared Sounder (AIRS) have been operationally assimilated into the Met Office's Numerical Weather Prediction (NWP) model since 26 May 2004. AIRS observations are screened by a 1D-Var pre-processing stage before being passed to the Met Office's 4D-Var data assimilation system. The 1D-Var pre-processing stage is used for quality control, bias correction, cloud detection, channel selection and monitoring. The final quality control step is to test for good convergence in the 1D-Var retrieval, using the 6-hour forecast field from the previous assimilation cycle as the background. Currently, only cloud-free fields-of-view over the sea are selected for data assimilation. A subset of 45 and 60 channels are assimilated for day-time and night-time fields-of-view respectively.

Three pre-operational trials were carried out. Two one-month trials were run to determine the impact of the new system for summer and winter periods, and both indicated positive impact. The changes required to assimilate AIRS observations were added to the Met Office's operational system as part of a package of satellite data changes. The entire package was tested by incrementally adding each component to a trial running in parallel to operations. The results of these pre-operational trials indicate a positive impact of around 0.4–0.5 on the global NWP index from the use of AIRS observations; a satisfactory result given the conservative nature of the initial system. The global NWP index is explained in annex 1 of Hilton et al. (2005). It is planned to continue to develop the system to better exploit the potential of AIRS observations.

Introduction

The Atmospheric Infrared Sounder (AIRS) is the first of a new generation of high spectral resolution infrared sounders. AIRS is a grating spectrometer with 2378 channels and covers most of the spectral range 3–15 μm . It is mounted on Aqua, one of the satellites in NASA's Earth Observing System. The high spectral resolution of AIRS, between 0.4 and 2.1 cm^{-1} , and its large number of channels make it similar to the planned series of operational high resolution infrared instruments: IASI on MetOp and CrIS on NPOESS. The main difference is that IASI and CrIS are interferometers rather than grating spectrometers. AIRS presents an opportunity to gain experience of working with high spectral resolution infrared sounders and to prepare for these future operational instruments.

The AIRS data processing system

AIRS data is sent to the Met Office from NASA via NOAA/NESDIS. The data rate is reduced by a factor of 9 by only sending the central AIRS field-of-view in every AMSU-A footprint. The data transmission costs are further reduced by sending a subset of 324 of the 2378 channels. This BUFR data is sent over a dedicated link and is forwarded to other European NWP centres on receipt. At present, only observations from every other AMSU-A footprint are processed at the Met Office. The incoming AIRS data is converted into an internal BUFR format, containing additional fields, before being stored on the Met Office's database, see **Figure 1**.

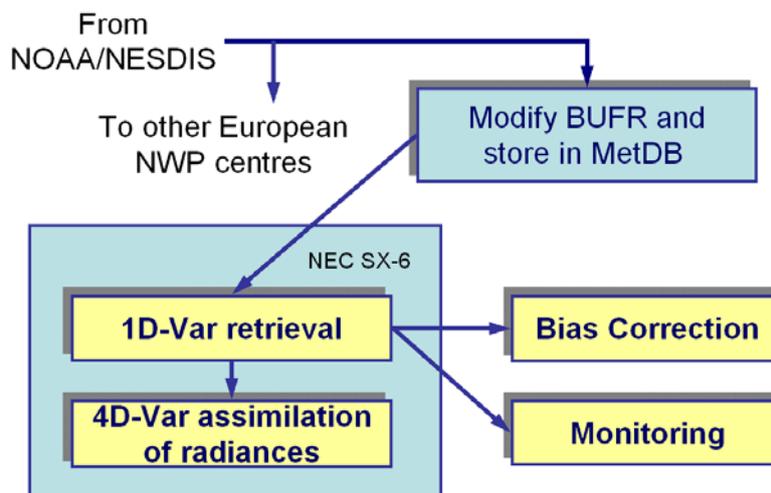


Figure 1: AIRS data processing at the Met Office

A 1D-Var pre-processing stage is used to apply quality control, bias correction, cloud detection and channel selection. Output from the 1D-Var retrieval is used to generate new bias corrections and to monitor the data quality and performance of the retrieval system. In addition to gross quality control checks and cloud detection, it is demanded that the 1D-Var converges well in its fit to the observation, before the data are selected for use in the Met Office's 4-D Var data assimilation system. The 1D-Var is also used to infer quantities required to model the observed radiances but which are not available from the NWP forecast fields, specifically the skin temperature and the temperature profile above the model top. The processing of AIRS data is also described in Collard (2004) and Collard et al. (2003).

New bias corrections (Harris et al. 2003, Cameron 2003) are typically generated using statistics from a month's worth of cloud-free observations over the sea. The bias correction uses the 800-300 hPa and 200-50 hPa model thicknesses as predictors and predictor coefficients are derived for every channel. In addition, a constant offset is derived for every channel and every AMSU-A scan position. The scan bias is very slight for AIRS channels but is quite significant for the AQUA AMSU-A channels, which are also bias corrected. None of the AMSU channels are assimilated under the AIRS system but AMSU channel 3 is used for cloud detection.

Only a small fraction of the 324 channels are used for assimilation. These channels were selected by first excluding those that are sensitive to ozone (which is not, at present, a prognostic variable in the Met Office model) and those that peak significantly above 3 hPa. The data for some of the high-peaking water vapour channels often falls outside the limits used to train the forward model, so these channels are also excluded. These considerations reduce the number of channels available for assimilation to 187. It was decided to exclude all channels in the short wavelength band for day-time fields-of-view to avoid solar contamination. The final selection used a method that considers the information content of each channel for a variety of atmospheres (Rodgers 1996). 45 channels were selected for day-time fields-of-view and 60 for night, see **Figure 2**.

Currently, only cloud-free fields-of-view over the sea are used for retrievals. Cloud affected observations are identified using the variational cloud detection method of English et al. (1999). 7 AIRS channels and AMSU-A channel 3 are used to calculate a cost function which is related to the probability of cloud in the field-of-view. **Figure 3** shows the cost function versus the observed minus background (O-B) for a long wavelength window channel. Clouds might normally be expected to make the O-B negative. Observations with a cloud cost of less

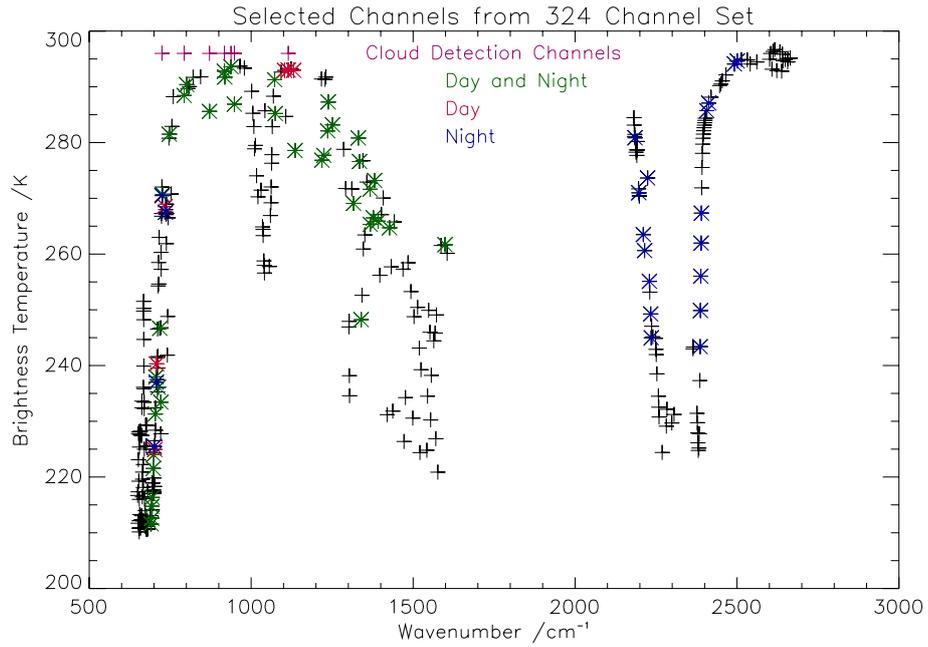


Figure 2: AIRS channel selection. 7 AIRS channels plus AMSU-A channel 3 are used for cloud detection. 45 AIRS channels are used in retrievals for day-time fields-of-view and 60 channels for night-time fields-of-view

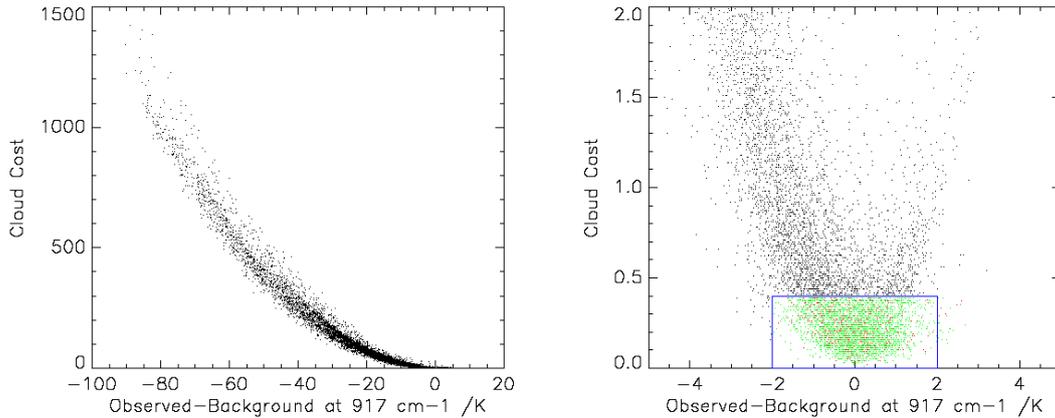


Figure 3: Plots of cloud cost versus the difference between observed and background for a long-wave window channel. The right-hand plot is a close up of the left-hand plot. The blue box indicates observations deemed to be cloud-free

than 0.4 and an |O-B| difference of less than 2K are identified as cloud free, typically 7-8% of the observations.

A 1D-Var retrieval is carried out for the cloud-free fields-of-view. The value of the cost function at the minimum is used as a final quality control check. **Figure 4** shows histograms of the final 1D-Var cost function. Observations that do not converge or have a final cost function of greater than 0.6 are rejected.

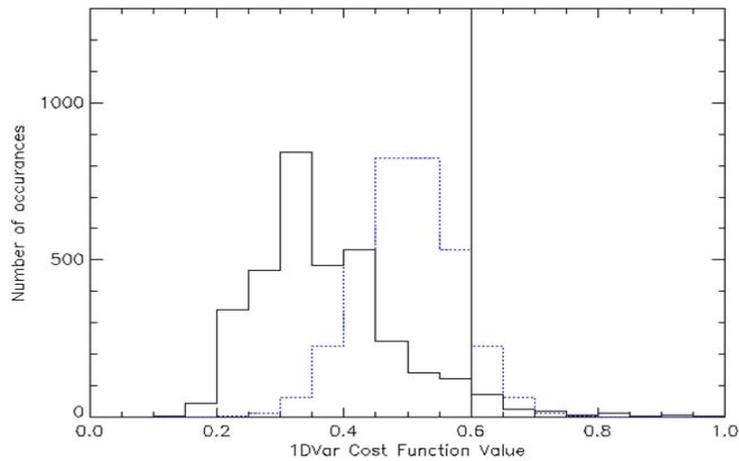


Figure 4: Histograms of the 1D-Var cost function after minimisation (normalised by the number of channels). Observations that do not converge or converge with a cost function greater than 0.6 are rejected. The blue histogram shows the theoretical distribution that would be expected for a linear problem with correctly specified Gaussian errors (Collard 2003).

Observations that pass the 1D-Var retrieval are thinned so that no two observations lie within 154 km of one another. The thinning improves the assumption of independent errors in 4D-Var and reduces the fraction of observations reaching 4D-Var to about 5%. The number of AIRS fields-of-view used in a data assimilation cycle is typically 500-1000 for a ‘main’ run and about 1700 for an ‘update’ run. Update runs are performed just before a new main run to try and produce as good a background forecast field as possible for the new data assimilation cycle. They make use of observations which did not arrive in time for the previous main run. The data cut-offs are 2 hours and 7 hours for main and update runs respectively. The observation errors assumed in the 4D-Var retrieval are higher than those used in the 1D-Var stage to allow for errors of representivity and the effect of forward model non-linearity on the minimisation, see **Figure 5**. Errors of representivity and non-linearity are particularly problematic for channels sensitive to water vapour. The analysis that results from the 4D-Var data assimilation step is used as the starting point for a new numerical weather forecast.

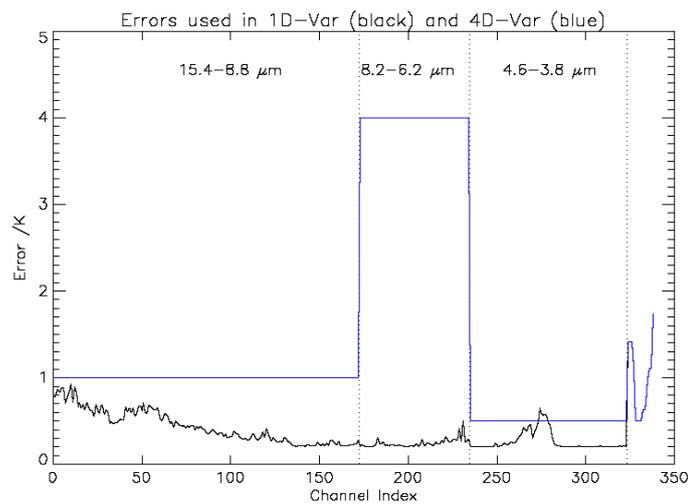


Figure 5: The observation errors assumed by the 1D-Var and 4D-Var retrievals are shown in black and blue respectively. 1D-Var errors include a 0.2 K forward model error. The 4D-Var errors are inflated to allow for non-linearities in the retrieval

Pre-Operational Trials

The AIRS system was tested for two trial periods: four weeks in December 2002 and January 2003, and three weeks in July 2003. The results, in **Figure 6**, show a positive impact in almost all fields. These fields are used in the calculation of the NWP index, the measure of forecasting skill used by the Met Office. An outline of how the calculation is done is given in annex 1 of Hilton et al. (2005). The trials indicate an improvement of 0.4–0.5% in the NWP index when verified against observations and analysis fields.

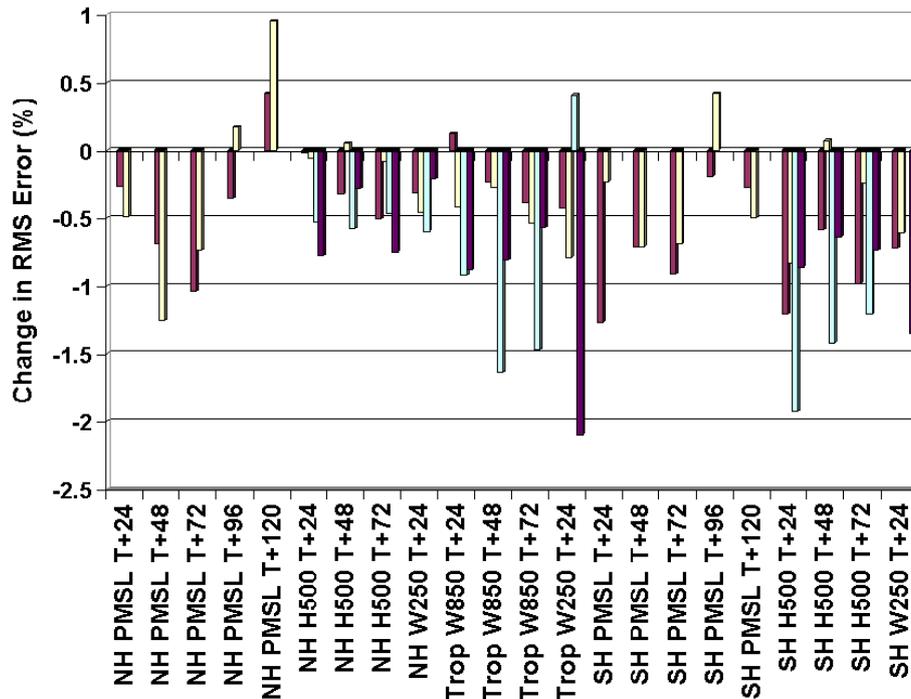


Figure 6: The results of summer and winter trials of assimilating AIRS observations. The values are the percentage change in RMS error verified against either observations or analysis fields. Negative values indicate an improvement. There was a problem with the verification of PMSL at the time of the summer trial

The AIRS system was introduced to operations as part of a package of satellite data changes and this package was first tested by running in parallel to the operational suite. Each component of the package was added incrementally to the parallel suite so that its impact could be verified. **Figure 7** shows the percentage difference in the NWP index between the parallel and operational suites; here a positive number indicates an improvement. The time axis runs from left to right and the last bar of the left-hand plot corresponds to the first two bars of the right-hand plot. The ‘Post Op’ column corresponds to the first 10 days after operational implementation. The vertical bars in the right-hand plot indicate an approximate error based upon the scatter of the results.

Switching to RTTOV7 initially gave a negative impact because the bias corrections for the new forward model were not yet tuned. The addition of AIRS data gave a 1% improvement in the NWP index but the interpretation of this is complicated by the re-tuning of biases shortly beforehand. A larger AIRS impact in the pre-operational parallel suite than that found in earlier impact trials might be expected, since the operational system had been reduced from 3 to 2 AMSU-A following the failure of NOAA-17 AMSU-A in October 2003. After a second re-tuning of the biases, the impact of the entire package levelled off at about 3%. The package was added to operations on 26 May 2004. As expected, the difference between the parallel

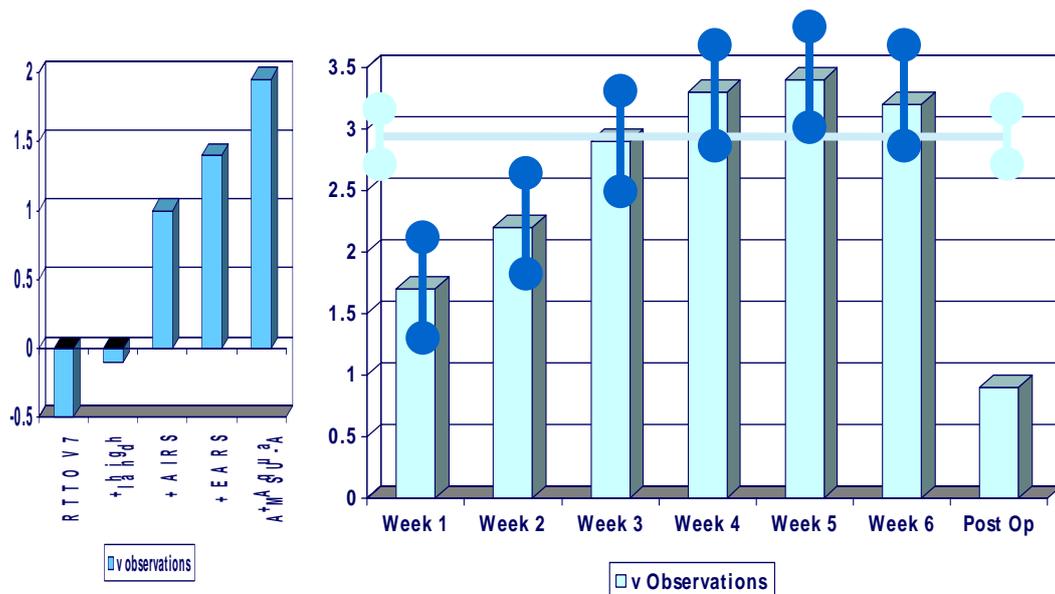


Figure 7: The results of the pre-operational trial, see the text for details

and operational suites dropped sharply after the change and the difference would have fallen to zero had the experiment been continued.

Future Developments

An initial system for assimilating AIRS observations has been successfully implemented, but there remains considerable room for making better use of AIRS data. NOAA/NESDIS are able to provide another AIRS data set that contains the warmest field-of-view for every AMSU-A footprint. This data set contains many more clear fields-of-view than the current one and should significantly increase the number of AIRS observations being assimilated into our model. It is planned to experiment with using the warmest field-of-view data set, increasing the number of channels used, revisiting the 4D-Var observation errors and using high peaking channels over land. The possibility of assimilating observations over uniform, low-level cloud is being investigated. It is hoped that these avenues of research will lead to a greater realisation of the potential of this exciting new data type.

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