

First results of the assimilation of AIRS data in Météo-France Numerical Weather Prediction model

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Abstract

A subset of channels from AIRS (Atmospheric InfraRed Sounder) aboard AQUA satellite is provided operationally by NOAA/NESDIS to Numerical Weather Prediction (NWP) centers. Studies have been carried out to assimilate this data in the Météo-France NWP suite. They require performance monitoring and bias correction of the observations. The impact of the early assimilation of AIRS on numerical weather forecast is presented.

Infrared radiances are contaminated by clouds in most cases. Therefore, there is a need for a cloud detection scheme. This study focuses on the NESDIS method (Goldberg et al., 2003) that has been validated in a comparison study by Lavanant et al. (2003). In order to take more advantage of the available data, the assimilation of cloudy radiances is investigated, using a radiative transfer model in cloudy conditions (RTTOVCLD). Results from monitoring and 1D-Var assimilation experiments are shown.

Introduction

The Atmospheric InfraRed Sounder (AIRS), launched by NASA in 2002 aboard the AQUA satellite is the first instrument of a new generation called “advanced infrared sounders” (Aumann et al., 2003). 2378 channels are available within the 3.7-15.4 micron range, most of them showing an excellent performance regarding their spectral response and sensitivity. The AQUA polar-orbiting platform provides global coverage of measurements. Thus, an important impact of the assimilation of AIRS data is expected on weather forecast skills.

On the other hand, new challenges are directly linked to this generation of instruments and they need to be solved in order to take full benefit of the data. The first and probably main problem is the dramatic increase of the number of channels (about two orders of magnitude). This results in communication, computing and storage issues. Since NWP centers have a “real-time” constraint for data assimilation, it is currently impossible to assimilate all AIRS channels operationally.

A constant subset of 328 channels is provided by NOAA/NESDIS for AIRS center pixel of every other AMSU field of view (*i.e.* 1 AIRS pixel over 18). Using this product, a first assimilation suite has been implemented to study the impact of AIRS data on weather forecast.

The potential use of cloudy radiances is investigated in a uni-dimensional, non-linear variational algorithm. A diagnostic cloud scheme linking temperature and humidity to cloud variables has been implemented in order to use selected AIRS cloudy radiances to retrieve temperature and humidity profiles.

A conservative assimilation suite

AIRS is providing so many channels that it becomes very difficult to tune the assimilation system for each individual channel. Experiments have shown that mis-using a single channel can degrade dramatically the whole assimilation. Thus it is much easier to degrade the system than to improve it. In this perspective, a conservative suite has been operated that relies on simple tools and should constitute a solid basis for step-by-step developments. An important part of good quality data is currently rejected in the assimilation, decreasing the impact of AIRS on weather forecast, but the main concern in this first experiment is to make sure of the quality of the information introduced in the system.

The NWP system is the French operational model ARPEGE. It is a global spectral model with a linear truncature T358 and 41 vertical levels. The horizontal grid is stretched with a factor C2.4, leading to a resolution from 25km over France to 150km at the antipodes. The assimilation system is a multi-incremental 4D-Var with T107 and T161 truncatures and a stretching factor C1. The assimilation time-window has a range of 6 hours. In this study the latest version of ARPEGE is used ; it includes the assimilation of AMSU-A and HIRS radiances.

To perform the assimilation of AIRS data we follow the general steps needed for the assimilation of a new instrument. Since ARPEGE is very close to IFS model from the European Center for Medium range Weather Forecast, many tunings are identical to the ones chosen by ECMWF. The subset from NOAA/NESDIS includes AIRS pixels with a horizontal sampling of about 90 km; thus no additional thinning is performed. A data quality flag is available in the provided files and is used as a first information for rejection. The screening starts with the calculation of the model-equivalent observation using RTTOV-6M radiative transfer model. Temperature and humidity profiles are needed to 0.1 hPa, so the model is extrapolated above its 1 hPa top.

A gross check is performed on the observations and departures (*i.e.* observation minus model-equivalent observation) for every channel to make sure they stand in reasonable bounds. Then a first-guess check rejects channels whose departures are not compatible with error statistics. These statistics are defined very simply : the background error is set constant for all channels, and the observation errors are defined for wide ranges of the spectrum (0.6 K for upper-temperature channels, 1 K for lower-temperature channels, 2 K for water-vapor channels).

Within the 324 channels provided in the NOAA/NESDIS subset, several are blacklisted (*i.e.* not used in the assimilation). This is the case for channels peaking above or near the model top (1hPa) where the model performance is not sufficient, for channels in the ozone band since ARPEGE only uses climatological ozone information, for channels in the short-wave region that are contaminated by solar reflection during day-time.

Data over land, where surface emissivity is not known precisely enough, are rejected. The edges of the scan, showing significant biases in the radiative transfer calculation, are also not used.

Infrared radiances are contaminated by clouds; the method chosen in this study consists in selecting pixels that are clear. To achieve this goal, we use the NESDIS cloud detection scheme (Goldberg et al., 2003) based on several tests using AIRS selected channels and the model Sea Surface Temperature (SST). First the brightness temperature for a long-wave window channel (965.43 cm^{-1}) needs to be higher than 270 K. Then the model SST is compared to a predicted SST (from channels 918.65 , 965.32 , 1228.09 , 1236.40 cm^{-1}) and during the night-time to a short-wave window channel (2016.095 cm^{-1}), with thresholds that have been recomputed for ARPEGE performance. This scheme has been compared to other cloud detection schemes and to the MODIS cloud mask collocated with AIRS in a validation study by Lavannant et al. (2003).

During the day-time an additional test has been implemented, rejecting data where AIRS VIS/NIR imager shows more than 10% of cloud inside the AIRS field of view.

After blacklisting, data-quality and cloud-contamination tests, only a small amount of the initial data (about 3 %) is flagged “active” and will go through the rest of the assimilation. An example of the status for window channel 917.31 cm^{-1} is displayed in Fig. 1.

For an initial dataset, a constant bias is calculated for each channel within active data. This flat bias correction is then applied to the corresponding departures during the assimilation. Fig. 2 represents the initial and residual biases for active data within a 6h time-window.

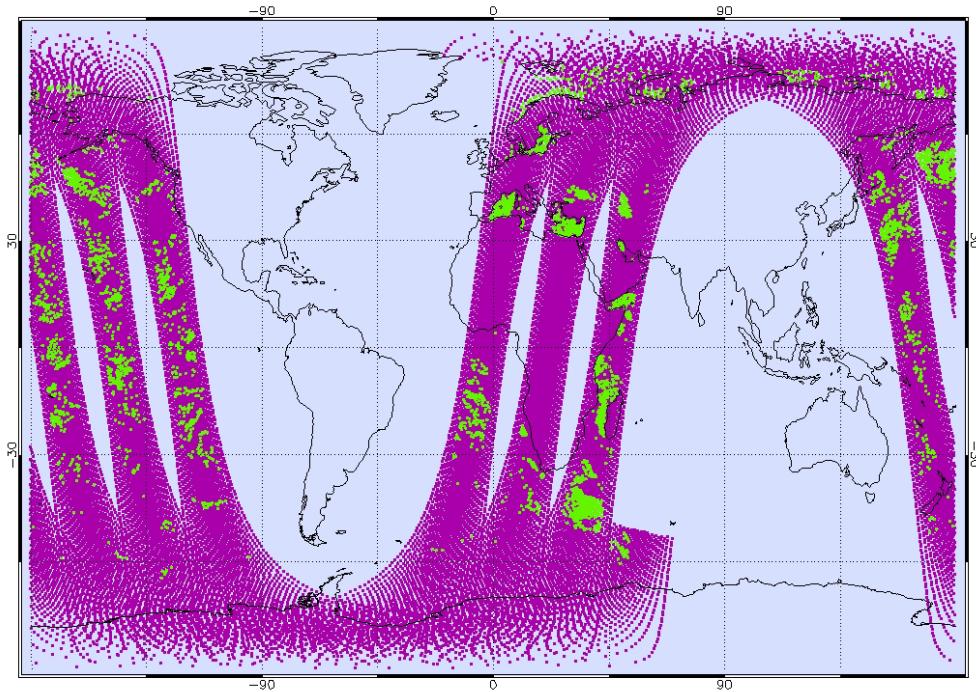


Fig. 1: Status of AIRS window channel 917.31 cm^{-1} after screening. 6h time-window for 2003/08/01 at 00UTC. Green means active ; purple corresponds to rejected data.

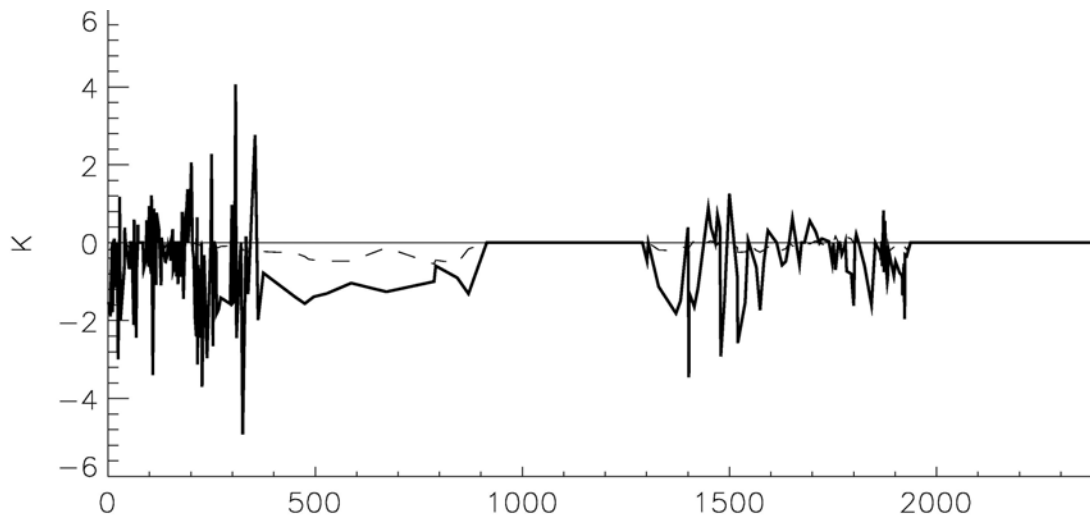


Fig. 2: Observed minus calculated brightness temperatures (in K) averaged for active data within the 6h time-window as a function of AIRS channel number (1→2378). The thick solid line represents the bias before flat bias correction and the dashed line corresponds to the residual bias after bias correction.

Impact of AIRS data on weather forecast

An impact study is performed on the period from the August 1st to August 19th 2003. The “CTRL” experiment is the most recent ARPEGE suite, while the “EXP” experiment is the same suite with the additional assimilation of all the available AIRS data in the 6-hour assimilation time-window. More iterations are allowed in the second 4D-Var minimisation of EXP in order to deal with the overhead of information.

Fig. 3 displays the difference of root mean square errors of CTRL minus EXP with respect to radiosondes. Green lines mean a positive impact of AIRS; red lines correspond to a negative impact. It is first important to notice that the differences between the two experiments are small. Considering the conservative approach followed to introduce AIRS data, where most of the information is rejected, this result is fully understandable.

For geopotential over all domains (Fig. 3a), the impact of AIRS is negative above 200 hPa. This can be partially explained by the bias of radiosondes, used here as verification, that increases with the altitude but is not currently corrected. When using ECMWF analysis as verification (not shown), this negative signal is greatly decreased. A slight positive impact for geopotential over the whole troposphere is seen at the latest ranges of forecasts, especially over Europe.

This pattern is also seen for humidity (Fig. 3c) over Europe. Mid-to-high tropospheric humidity is slightly improved with AIRS for 72-96h range forecasts over the southern hemisphere. Temperature (Fig. 3b) is globally neutral, with a small negative impact in most cases at low levels overlooked by a slight positive effect of AIRS for the rest of the troposphere at long range.

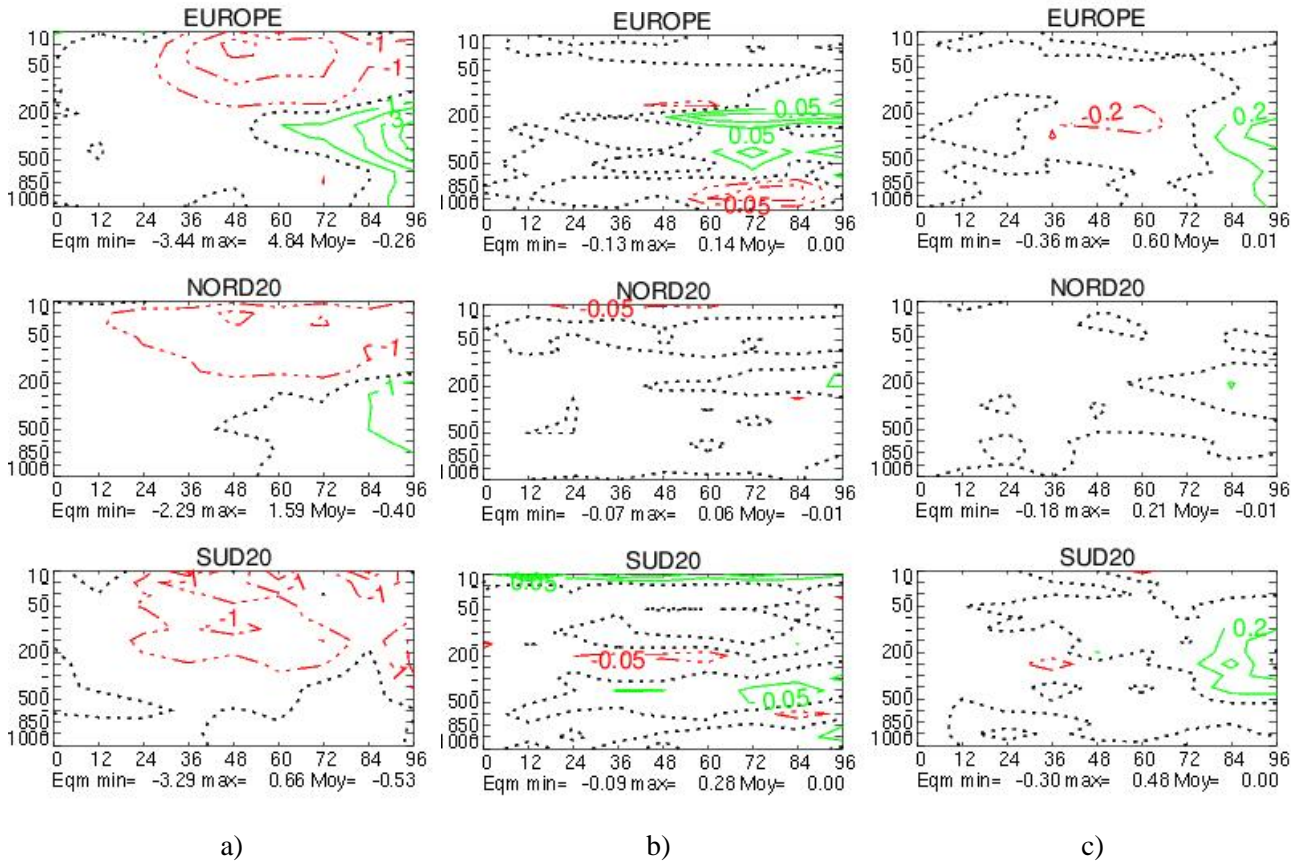


Fig. 3: Root Mean Square Error (RMSE) of CTRL minus RMSE of EXP with respect to radiosondes for a) geopotential, b) temperature, c) humidity. The X and Y axis define respectively the forecast range and the vertical pressure levels. Positive values are represented in green, negative in red.

1D variational retrieval experiments in cloudy conditions

Developments are on-going at Météo-France for the use of cloudy radiances. For the sake of simplicity, the problem is currently considered uni-dimensional. The approach is based on a non-linear 1D-Var algorithm and the aim is to use selected AIRS cloudy radiances to retrieve temperature and humidity profiles. The observation operator includes RTTOV-7 radiative transfer model which contains a cloud-processor module RTTOVCLD (Saunders and Brunel, 2002). A simple diagnostic cloud scheme has been implemented. It reproduces the features from the operational ARPEGE cloud scheme (Gérard, 2001) with a cloud cover evaluation following Xu and Randall (1996). Cloudiness has three origins: large scale (stratiform cloud), subgrid shallow convection and subgrid deep convection over-saturations. For this preliminary study only stratiform and shallow convection clouds are modelled. Indeed, deep convection requires precipitation fluxes from the previous time step. The developed scheme diagnoses the cloud cover, cloud liquid water content and cloud ice water content for the 41 ARPEGE vertical levels. These output parameters are supplied as input, together with control variables T , q and p_s , to RTTOVCLD.

To be in agreement with our simple cloud scheme, we use AIRS cloud information derived from the CO₂-slicing algorithm (Lavanant et al., 2003) to select AIRS FOVs covered by low stratiform clouds (characterized by a cloud top pressure around 800 hPa and a high effective emissivity).

Some retrieval experiments in cloudy conditions (Dahoui et al., 2003) result in improvements on temperature especially at high levels, and in a less pronounced way on humidity (not shown).

During our validation experiments, we noted that the observation operator (cloud scheme + RTTOVCLD) is strongly non-linear for a large number of AIRS CO₂ channels (depending on cloudiness amount). However for some of the tropospheric channels (listed in Table 1) the observation operator is nearly linear in every condition. This result confirms the conclusions from Chevalier et al. (2003). Unfortunately, these channels are far from the influence of low clouds. One can try to perform retrievals in the presence of high and medium-level large-scale clouds.

Table 1: AIRS channels used in 1D-Var retrievals

AIRS Channel	Wavenumber (cm ⁻¹)	Wavelength (μm)
6	650.81389	15.365376
28	656.12392	15.241023
42	659.55137	15.161821
55	662.76824	15.088230
71	666.77337	14.997599
124	680.41240	14.696969
139	689.77010	14.497584
145	691.39968	14.463414
157	694.68279	14.395059
162	696.06025	14.366572
192	704.44434	14.195586
198	706.14606	14.161376

Conclusion and perspectives

AIRS data has been introduced in Météo-France 4D-Var assimilation system in a conservative manner. The results on weather forecast skills are neutral to slightly positive. They need to be confirmed with more extensive experiments and will be improved by adapting the system to the special requirements of Advanced Infrared Sounders.

Harris and Kelly (2001) bias correction scheme is implemented. It performs a linear regression with fixed predictors derived from the model fields and scan angle with a latitude dependency. A new bias correction scheme based on artificial neural networks is also investigated.

The cloud detection used in this study provides information on a pixel-by-pixel basis. Therefore most of the information AIRS instrument could bring is rejected because of possible cloud contamination. We believe that the assimilation of data from cloudy pixels is one of the major issues for the full exploitation of advanced infrared sounders. A new cloud detection scheme based on a channel-by-channel basis (McNally and Watts, 2001) that can retain information above the cloud top is currently under study.

The first 1D-Var experiments of retrievals in cloudy conditions are encouraging but face the problem of strong non-linearity for most AIRS channels when they are cloud-contaminated. Retrieving cloud top pressure and emissivity for the assimilation of channels that peak near the cloud top could be an alternative and needs to be studied. Finally cloud-cleared radiances presented by Goldberg et al. (2003) show an important potential benefit for NWP and will be addressed in a close future.

Even when regarding clear pixels, assimilating only a constant subset of channels means a significant loss of the available information. On the other hand NWP centers cannot afford to assimilate operationally all channels the “usual” way and this would be pointless because of the strong correlations existing between the channels. Data mining needs to be performed and a good candidate for this operation is Principal Component Analysis as presented by Huang and Antonelli (2001) that furthermore shows special abilities in filtering the instrument noise.

References

- Aumann H., Chahine M., Gautier C., Goldberg M., Kalnay E., McMillin L., Revercomb H., Rosenkranz P., Smith W., Staelin D., Strow L., Susskind J., 2003 : AIRS/AMSU/HSB on the AQUA mission: Design, science objectives, data products, and processing systems, *IEEE transaction on geoscience and remote sensing*, **41**, 253-264.
- Chevalier F., Lopez P., Tompkins A., Janiskova M. and Moreau E., 2003 : The capability of 4D-Var systems to assimilate cloud-affected satellite infrared radiances. *NWP-SAF document*, NWPSAF-EC-TR-008.
- Dahoui M., Auligné T., Lavanant L., Rabier F., 2003 : Use of Modis imager data to help dealing with AIRS cloudy radiances in interesting synoptic situations, *NWP-SAF document*, NWPSAF-MF-VS-003.
- Gérard L., 2001 : Physical Parametrizations in ARPEGE-ALADIN operational model. *Météo-France internal documentation*.
- Goldberg M., 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 transaction on geoscience and remote sensing*, **41-2**, 379-389.
- Harris B. and Kelly G., 2001 : A satellite radiance-bias correction scheme for data assimilation. *Q. J. Roy. Meteor. Soc.*, **127**, 1453-1468.
- Huang A. and Antonelli P., 2001 : Application of Principal Component Analysis to high resolution infrared measurement compression and retrieval. *J. Applied Meteorology*, **40**, 365-388.
- Lavanant L., Dahoui M., Rabier F., Auligné T., 2003 : Use of MODIS imager to help dealing with AIRS cloudy radiances, *ITSC13 proceedings*.
- McNally A. And Watts P., 2003: A cloud detection algorithm for high spectral resolution infrared sounders. *Q. J. Roy. Meteor. Soc.*, in revision.
- Saunders R. and Brunel P., 2002 : RTTOV-7 technical report, *NWP-SAF document*, NWPSAF-MO-TR-009.
- Xu and Randall, 1996 : A semiempirical cloudiness parametrization for use in climate models. *Journal of Atmospheric Sciences*, **53**, 3084-3101.