Assimilation of hyperspectral infrared sounder radiances in the French global numerical weather prediction ARPEGE model

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Abstract

The Atmospheric Infrared Sounder (AIRS) is the first advanced sounder with thousands channels. It was launched in May 2002, 4 years before IASI (Infrared Atmospheric Sounding Interferometer). The use of this instrument is a good practice for the preparation of the assimilation of IASI. It is also now known that the sensitive regions, where forecast errors can rapidly increase, are often cloudy. This motivates our research efforts to deal with the infrared cloudy radiances. The aim of this paper is to present the efforts made at Meteo-France to assimilate the infrared advanced sounder radiances for clear and cloudy observation conditions.

At present, only 20 AIRS stratospheric channels are used operationally in the four dimensional variational (4D-Var) assimilation scheme of the French global numerical weather prediction model, ARPEGE. Work was performed to implement a variational bias correction. Cloud detection is another key parameter of the clear radiance assimilation, which prevents the assimilation of cloudy observations. The cloud detection scheme used at ECMWF has also been implemented. Trials are currently made to extend the assimilation to channels sounding at the tropopause and in the upper-troposphere. As IASI was launched in October 2006, the preparation of the IASI radiance monitoring in the ARPEGE model is also under way for the preparation of the assimilation.

In research mode, we also attempted to assimilate AIRS cloudy radiances inside the 4D-Var assimilation scheme. Two approaches were used: the first one is based on a combination of the simplified diagnostic cloud scheme of ARPEGE together with the radiative transfer model RTTOVCLD to simulate AIRS cloudy radiances. The second approach made use of the cloud top pressure and the cloud cover derived from the CO2-slicing technique. In a first stage, CO2-slicing outputs were directly used by RTTOV to simulate the cloud-affected spectrum. In a second stage, CO2-slicing outputs are adjusted by a prior 1D-VAR before being used by RTTOV.

Preliminary experiments had been conducted in a simplified framework. The number of channels from cloudy pixels assimilated in the 4D-Var was small with the diagnostic approach and larger with the CO2-slicing approach. A very slight and non-significant impact on the forecast was found for the first approach. With a slightly more positive impact, results with the second approach were encouraging. With the prior adjustment by the 1D-Var of cloud parameters, the positive impact was more pronounced. Results were thus significantly but weakly improved in the southern hemisphere. Finally, some points to be studied in the near future will be presented.

INTRODUCTION

Infrared hyperspectral sounders such as AIRS and IASI represent major advances in the atmospheric sounding. They lead to challenges for the assimilation in Numerical Weather Prediction (NWP) as they consist of thousands of channels per observation point. New methods have to be developed for their assimilation. Moreover the assimilation of cloudy radiances is a challenge for NWP centres as it is now well established that the sensitive areas for the forecast of cyclogeneses are cloudy ones (McNally, 2002; Fourrié and Rabier 2004). In a first step, Dahoui et al (2005) assessed various cloud detection schemes suitable for the assimilation of AIRS radiances with MODIS observations. The authors showed that the ECMWF and the CO2-slicing algorithms were very accurate. Both were implemented in the ARPEGE 4D-Var data assimilation scheme. In the second part of their paper, they tried to select, according to the cloud type, the AIRS channels for which the observation operator has a good linear behaviour. This observation operator consisted of the RTTOV radiative transfer model containing a cloud-processor module (RTTOVCLD) and a simplified cloud diagnostic scheme modelling only the large-scale clouds. This paper attempts to assimilate cloudy radiances in the 4D-Var of ARPEGE.

Two approaches had been chosen for the assimilation of cloudy observations. The first one used a simplified diagnostic cloud scheme together with a radiative transfer model that could take into account multiple cloud layers. The second one was based on the CO2-slicing approach.
In a first section, the operational use of AIRS and in the ensuing section the preparation of IASI monitoring in ARPEGE are described. Then the two approaches and the experimental settings for the assimilation of AIRS cloudy radiances are presented. Preliminary results are then given and in the last section, some conclusions are drawn and the future work is discussed.

OPERATIONAL USE OF AIRS AND CURRENT DEVELOPMENTS

20 stratospheric channels (peaking between 60 and 100 hPa) are assimilated in operations since September 2006. The bias correction is flat and static and a simple cloud detection is also used. The latter is based on observations:

- If the brightness temperature of surface channel 914 is lower than 270K the whole observation is discarded.
- If the sea surface temperature of the model is too far from a simulated temperature with 4 surface channels, the observation is also considered as cloudy and therefore rejected.

These two components of the system are very simple and are sufficient for the assimilation of the stratospheric channels. However, efforts are made to extend the use of AIRS to upper-tropospheric channels, and bias correction and cloud detection have to be improved. The variational bias correction used at ECMWF (Derber and Wu, 1998, Dee, 2004 and Auligné et al, 2007) has been implemented in ARPEGE. Moreover the cloud detection scheme of the ECMWF (Mc Nally and Watts, 2003) has also been added to the existing cloud detection. These new implementations together with the addition of 29 channels sounding near the tropopause (the maxima of the weighting function are included in the range of 100 and 400 hPa) have been tested. The first results show a neutral to a slightly positive impact on the short range forecast of the temperature, mostly located at 150 hPa in the Tropics and in the southern hemisphere (Fig 1). This impact is statistically significant according to the Student test.

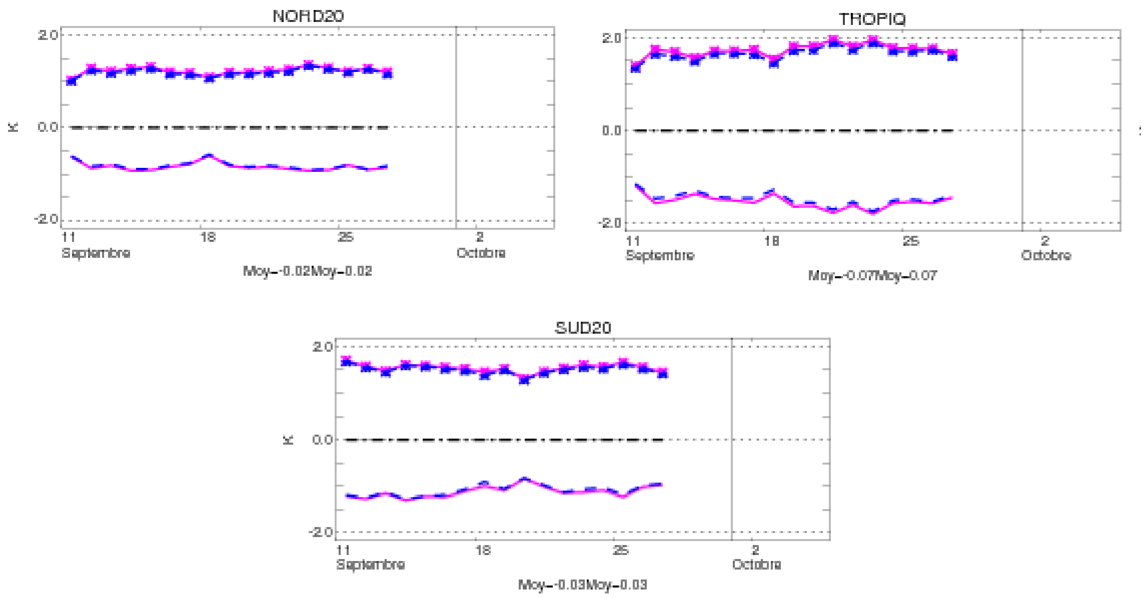

Figure 1: Root mean square error (K) of the 12 hour range forecast for the temperature at 150 hPa as a function of time, over the 3 large domains Nord20 (latitudes greater than 20°N), Tropics and Sud 20 (latitudes below 20°S) for the experiments assimilating the 29 tropospheric channels (in blue) and the reference (in pink).

MONITORING OF IASI

The monitoring of IASI in ARPEGE has started in research mode. 314 channels are kept for monitoring. These channels correspond to the 300 channels selected by Collard (2007) and to 14 additional channels for comparison purposes. The same cloud detection (as the one of the ECMWF) has been used. Figure 2 shows the impact of the cloud detection on the distribution of the observation minus first-guess difference for two channels peaking in the mid- and in the low troposphere. Without any bias correction, the cloud detection successfully removes the cold tail of the observation departure distribution.

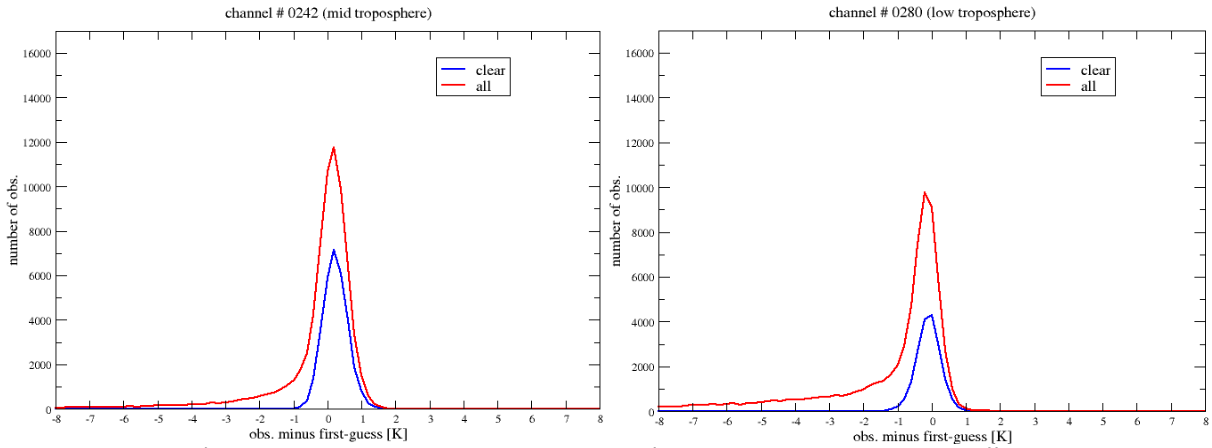

Figure 2: Impact of the cloud detection on the distribution of the observation departures (differences between the observation and the simulation from the background, in K).

The monitoring of the 314 channels has started with the variational bias correction. An example of statistics obtained for the 17 of August 2007 at 06 UTC is shown in figure 3, that is 8 days after the start of the experiment. The bias correction removes the bias existing in the observations for all the 314 channels. The monitoring of IASI should be put into operations before the end of 2007.

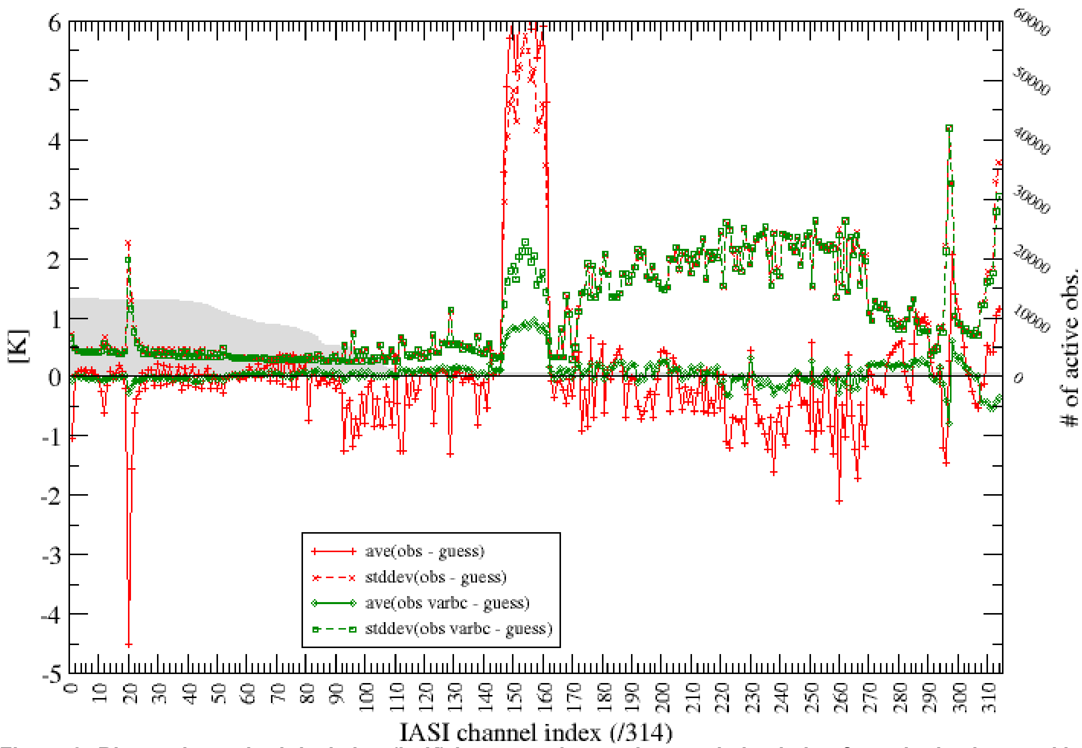

Figure 3: Bias and standard deviation (in K) between observations and simulation from the background before (in red) and after (in green) the bias correction for the 314 IASI channels monitored for the 2007/08/17 06 UTC. The number of monitored observations is plotted in shaded grey.

ASSIMILATION OF CLOUDY RADIANCES

This work is part of the research work by Dahoui (2006).

How to deal with clouds in the radiative transfer for the assimilation of cloudy radiances?
In this section we describe the observation operators used for both approaches in the 4D-Var assimilation of the AIRS cloudy radiances.

For the first method, the observation operator consists of a cloud diagnostic scheme and of a radiative transfer model. For the radiation scheme, we rely on the RTTOVCLD model (Saunders et al, 2002, RTTOV model with a cloud-processor module). The cloud scheme used is a simplified version of the ARPEGE operational cloud scheme (Gérard, 2001). Only the large scale clouds are modelled.
The cloud scheme diagnoses, from the temperature and humidity profiles and the surface pressure, the cloud cover, the cloud liquid and cloud ice water contents at the vertical levels of the ARPEGE model. All these output parameters are supplied as input together with the atmospheric control variables T, q, P_s to RTTOVCLD.
For the clear observations, the cloud profiles are set to zero and the same observation operator as for the cloudy observations is used.

The CO2-slicing method (Chahine 1974; Menzel et al; 1983; Lavanant, 2002) has been extensively used to retrieve the cloud-top pressure and the cloud effective emissivity. The algorithm, based on the radiative transfer principles, uses the measured radiances of a subset of 124 AIRS channels selected in the CO2 absorption band (between 649.612 and 843.913 cm^{-1}), which is very sensitive to the presence of clouds. In this case, the cloud parameters are computed during the screening and do not change during the minimisation step of the 4D-Var .
The 1D-Var is able to improve the cloud characterization (in terms of cloud effective emissivity and top pressure), particularly for the low level clouds, for which the CO2-slicing alone is less accurate.
The inputs of the 1D-Var are the temperature and the humidity profiles, the surface pressure and the cloud parameters (cloud top and effective emissivity). The 1D-Var gives an adjustment of the temperature and humidity profiles, and of the cloud parameters, but only the latter are kept for the 4D-Var minimisation. The observation operator of the 1D-Var consists of RTTOV with the simulation of a single thin and opaque cloud layer. The 1D-Var is run during the screening step and the cloud parameters are then kept constant during the 4D-Var minimisation as in the previous approach.

Experimental settings
5 experiments have been conducted during 10 days. They have been performed to test the feasibility of the assimilation of AIRS cloudy channels. Only low-level clouds for which the cloud top pressure is between 600 and 950 hPa are selected in order to compare more easily the results obtained with the diagnostic approach with the other ones. In addition, the effective emissivity of the cloudy observations has to be included between 0.3 and 0.99 to discard low-level cloud cases with small emissivity for which the CO2-slicing method is less accurate.
Furthermore, to make the comparison of the cloudy observation impact easier, cloudy observations are assimilated only in the extra-tropics (beyond [-40°; 40°]) because the "diagnostic" method is only valid for stratiform clouds.

Here are the different experiments studied:

- A control experiment with the assimilation of clear sky radiances detected with the CO2-slicing algorithm (called here-after "control").
- An experiment with the ECMWF cloud detection. In this case, clear channels are assimilated (called here-after "clear ECMWF").
- An experiment with the assimilation of clear pixels and cloudy pixels with the cloud diagnostic scheme (called here-after "diagnostic")
- An experiment with the assimilation of clear pixels and clouds pixels with the CO2-slicing (called here-after "CO2-slicing").
- An experiment with the assimilation of clear pixels and cloudy pixels with the cloud top pressure and the cloud cover adjusted with the 1D-Var (called here-after "CO2+1D-Var").

The observation errors are the same for clear and cloudy channels. They vary between 0.5 and 2 K. The same bias correction is applied for all experiments. This bias correction is flat (no robust varying bias correction was available at the beginning of the experimentation). In addition, at the beginning of the experiments, 102 channels were assimilated in a pre-operational suite.

Results

Table 1 presents the different observations and channels assimilated in the 5 experiments for the first analysis cycle of the period. The first-guess is the same for this first analysis time for all the experiments and facilitates the comparison between experiments. With respect to the control, the number of clear observations is similar for the 3 cloudy experiments. The number of clear observations assimilated with the clear ECMWF experiment is larger than the control one and the number of clear pixels is similar.

experiments	Observation number			Channel number		
	clear	cloudy	total	clear	cloudy	total
Reference	1 033	0	1 033	103 561	0	103 561
Clear ECMWF	-	-	1 696	106 319	0	106 319
Diagnostic	994	515	1 509	99 713	15 622	115 335
CO2-slicing	985	549	1 534	98 812	34 094	132 906
CO2+1D-Var	966	750	1 716	96 861	49 101	145 992

Table 1: Number of observations and channels assimilated as a function of cloudiness for the first date of the experiments (8/6/2005 00UTC).

For cloudy observations, 50% and 75% additional observations are assimilated. The CO2+1D-Var assimilates the largest number of cloudy pixels and the total number of assimilated AIRS observations (1700) is similar to the ECMWF experiment. The diagnostic experiment only takes 15% additional data into account. The number of additional cloudy observations is larger for the experiments based on the CO2-slicing (30% and 45% of addition channels for the CO2slicing and the CO2+1D-Var experiments respectively).

We have also looked at the impact on the other observation types in the assimilation. This impact is globally neutral in term of number of assimilated observations and in term of innovation statistics (not shown). For the whole period of the study, the more pronounced impact is for the AMSU-B observations for which we have a small increase of the assimilated observations with the CO2slicing (+0.5%) and with the CO2+1D-Var (+1.8%) experiment. It gives us an indirect indication of a slightly better quality of the background for the CO2+1D-Var experiment.

Impact on the forecasts

Figure 4 shows the impact on the forecast of the different experiments versus the control run. The reference used here is the radiosondes.

For the diagnostic experiment, the impact of the cloudy radiances is very small, with a slight improvement in the northern hemisphere and a slight degradation in the southern hemisphere. The impact is neutral in the Tropics as no cloudy observation is assimilated in these regions in our study. This can be explained by the fact that the observation operator requires strong selection criteria for the assimilation of channels which leads to a very small number of additional assimilated data.

For the "CO2-slicing" experiment, the impact of the cloudy radiances on the geopotential forecasts is slightly positive in the southern hemisphere and almost neutral in the northern hemisphere and in the Tropics.

For the CO2-1D-Var experiment, the positive impact is more pronounced in the southern hemisphere while the impact in the northern hemisphere is slightly negative. The adjustment of the cloudy parameters by the 1D-Var leads to a positive impact that is statistically significant, even if small, at a 42-hour forecast range.

For the clear ECMWF experiment, the impact is positive at the end of the forecast range on the southern hemisphere and neutral elsewhere. It should be mentioned that these are preliminary results as only a 10-day period has been tested. The bias correction and the error specification should also be improved.

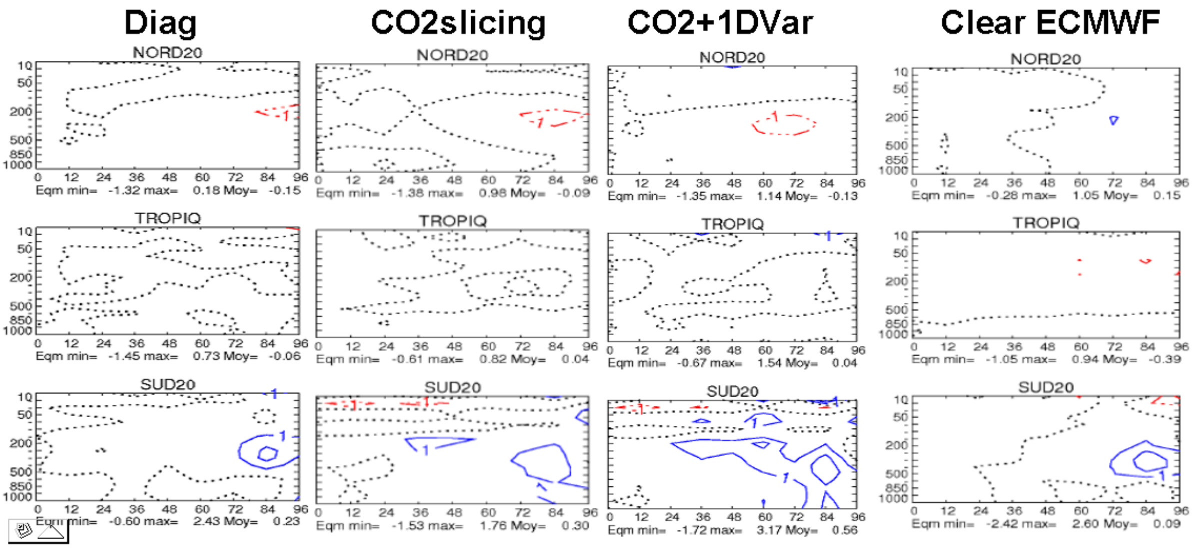

Figure 4 : RMS of forecast errors (in m) computed against radiosondes for geopotential fields.

CONCLUSION AND FUTURE WORK

The approach used for the assimilation of AIRS radiances in operations is very conservative. However, we plan to increase the number of assimilated AIRS channels next year. The variational bias correction has been extended to all the other polar orbiting satellite data and should be put in the operational suite rapidly. The cloud detection scheme of ECMWF should also be put in the operational suite together with the increase of the number of channels assimilated in the upper troposphere.

The monitoring of IASI has started in a research mode and 314 channels are compared to simulated brightness temperatures. It should be put soon in the operational suite.

A research work has also been done on the assimilation of AIRS cloudy radiances. The goal of this study was to test the feasibility of assimilating AIRS cloudy observations in the ARPEGE model.
To do so, two approaches have been used. The first one made use of a simplified cloud diagnostic scheme and the second one used the cloudy parameters derived from the observation themselves in the radiative transfer model. For the second approach, an adjustment of the cloudy characteristics has also been tested.

These three methods have been compared to a control experiment that assimilated only clear observations and with an ECMWF-like experiment that assimilated only clear channels over a ten days period.

We have shown that the more pronounced impact with respect to the control experiment is obtained for the experiment that uses the CO2-slicing method and a 1D-Var for the cloud characteristics. It allowed to take into account the largest number of cloudy observations in the analysis.

However, more effort should be devoted to these experiments. The bias correction and the observation errors should be specific to cloudy observations, the period of study has to be extended. In addition, to optimize the impact of the cloud characteristics, the minimisation on the cloud parameters inside the 4D-Var should bring improvement through a better coherence between the atmospheric profile and the cloud characteristics.

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