Cloud detection for IASI/AIRS using imagery

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Abstract

The high spectral resolution AIRS instrument provides 2378 channels covering the spectral range between 650 cm^{-1} to 2700 cm^{-1} which allows a good "stand-alone" description of the clouds in the fov by processing an adapting subset of channels. The first part of this paper focuses on a better understanding of the capability of new high spectral resolution sounder to detect and characterize the clouds. The NESDIS, ECMWF, CO_2-slicing and MLEV schemes were used for that purpose. AIRS radiances biases correction is required before cloud detection. The resulting AIRS cloud parameters are evaluated by using independent information retrieved with the Météo-France cloud mask applied to co-registered MODIS imager data and taken as our reference.

For the time being, in most operational analysis systems, the assimilation of the satellite radiances is limited to the cloud-free pixels. The assimilation of the AIRS radiances in clear conditions is already defined at Météo-France. In parallel, developments are on-going for the assimilation of the satellite cloudy radiances, a great challenge for numerical weather prediction. In the second part of this paper, preliminary investigations for assimilating the cloud-affected radiances are undertaken using first a cloud scheme which diagnoses the clouds from the current atmospheric profile and second the direct use of retrieved cloud parameters from the CO_2-slicing scheme. Both methods are tested through a 1D-Var scheme.

1. Introduction

As we do not have a direct broadcast system for the AQUA platform at the CMS, we have level1b MODIS, AIRS and AMSU data provided by the NASA/GSFC DAAC web site for two time periods 10-20 April 2003 and 15-28 March 2004 in the North East Atlantic. The collected 35 (52) granules cover different interesting day and night situations with a variety of cloud types. Only sea situations have been processed. The AIRS data are full resolution spectra and the level1b files contain the localization data for all the instruments which avoids re-doing that complex pre-processing. The first periods of the datasets were used as training periods for the computation all the necessary thresholds and biases coefficients of the models and the validation is done on the second time periods.

For simulating clear radiances necessary in the ECMWF, CO2-slicing and MLEV schemes, we used the RTTOV-7 forward model together with the nearest in time and location French ARPEGE NWP atmospheric background. Same biases corrections were applied to the 3 schemes and the same sub-set of channels was used in ECMWF and CO2-slicing models.

2. MODIS cloud description

The Moderate Resolution Imaging Spectro-radiometer (MODIS) on board the AQUA satellite, is primarily designed for cloud imaging and sea surface temperature. The cloud mask used in this study is an adaptation to MODIS of the NWC SAF package with only MODIS channels similar to SEVIRI channels used (LeGléau and Derrien, 2001). Three main output parameters are derived: the clear/cloud flag, the cloud type and the cloud top temperature and height.

The cloud mask is based on the fact that the spectral behavior of clouds and earth surfaces are different in window channels. The method chosen is a multispectral technique applied every pixel which is efficient in term of computing time and is relatively easy to adapt. The method was prototyped with AVHRR and GOES imagery and tuned to SEVIRI and MODIS spectral conditions even before data were available. The thresholds are applied to various combinations of channels and depend on the geographical location, on the solar illumination and viewing geometry of the pixel. Thresholds are computed in-line from constant values from experience, from tabulated functions defined off-line through RTTOV simulations, from external data such as NWP forecast fields of land surface temperature and total water vapor content and from climatological atlas of sea surface temperature and albedo. For opaque clouds, the cloud top temperature is obtained through the best fit between simulated and measured 10.8µm brightness temperatures. For semi-transparent clouds, two methods are used: the CO_2-slicing method which makes use of the fact that the variation of the radiance with height and cloudiness is not the same for a window channel as for a CO_2 sounding channel. An alternative approach called the H_2O/IRW intercept method based on an IR window and a WV channel histogram analysis, is applied when the CO_2-slicing method fails.

Estimations of the accuracy and limits of the cloud mask have extensively been done for AVHRR/HIRS and GOES data during several years, by the NWC SAF team. For example, the cloud cover derived from GOES-East measurements is systematically compared to the visual observations done in meteorological stations (SYNOP observations) over continental mid-latitude regions. Also, the accuracy of the cloud top pressure retrieved with HIRS sounding channels similar to MODIS channels 32 and 34, was also compared to coincident lidar observations. Validation for MODIS and SEVIRI is in progress. More details of the validation can be found in LeGléau and Derrien, 2002 and on the website www.meteorologie.eu.org/safnwc.

3. MODIS and AIRS mapping

The processing of the MODIS pixels mapped inside the AIRS fov is an efficient way to detect small amount of clouds because of its high spatial resolution, to determine the number of cloud layers and the complexity of the situation. Also, the imager processing provides accurate cloud top pressures for each homogeneous cloud layer detected inside the AIRS ellipse.

The mapping of MODIS and AIRS is based on their navigation information given in the level1b data and on the scan geometry of the two instruments. An adjustment in line and pixel of the MODIS data in the AIRS fov is done through the minimization of the differences between AIRS brightness temperatures convoluted on MODIS 32 filter and the corresponding MODIS observations averaged on the AIRS ellipse. The adjustment depends on the AIRS scan position. Figure 1 shows the statistics of the departure for a four days period corresponding to 20 day and night granules.

From the MODIS cloud type and temperature characteristics, up to 3 cloud layers are allowed in the AIRS ellipse, each of them with a cloud cover, a cloud classification and a top temperature. The cloud classification allows to know if the cloud is semi-transparent or opaque. A situation is declared clear if less than 5% of MODIS pixels are cloudy in the ellipse.

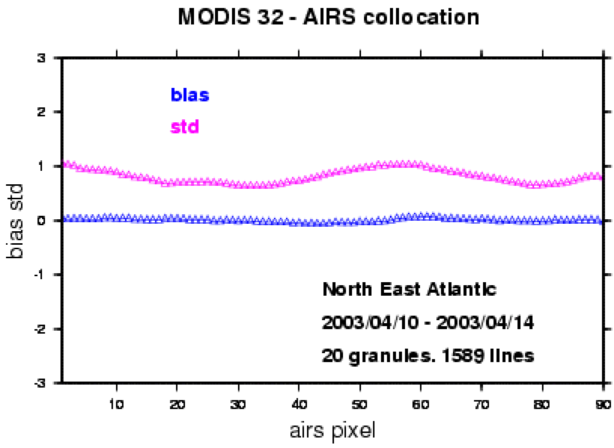


Figure 1: Statistics in bias (blue) and standard deviation (in red) function of the AIRS scan position between AIRS and MODIS Tbs for the MODIS filter 32. Day and night data. 20 granules for 4 days

4. AIRS bias correction

The comparison of observed and computed radiances shows the presence of systematic errors arising mainly from errors in the radiative transfer model, instrument measurement/calibration problems or problems in the model fields themselves. The model we used in this study to correct each AIRS channel j in the CO_2 band

$$A_0(j) + \sum_{i=1,8} (A_i(j) * (y_i - \overline{y_i})) + A_9(TWVC - \overline{TWVC}) + A_{10}(T_s - \overline{T_s}) + A_{11} * \sec$$

from these errors is based on the collocated AMSU-A observations:

Y = AMSU 6,8,9,10,11,12,13,14
Ts = surface temperature
sec= secant of the viewing angle

In our case, for these datasets and this part of the spectrum, the residual biases were slightly better using a correction based on collocated AMSU-A data than with the Harris and Kelly model usually used in the course of the NWP assimilation. The coefficients were computed on the training periods from all AIRS situations declared clear with MODIS and they were then applied on every AIRS situation of the second time periods. The correction is done before the AIRS cloud detection and identically for the ECMWF, CO_2-slicing and MLEV methods. Indeed, the accuracy of the retrieved cloud information highly depends on the correct simulation of the clear radiance.

5. AIRS cloud detection schemes

5.1. NESDIS cloud detection

The purpose of the NESDIS cloud detection scheme (Goldberg and Zhou, 2002) is the detection of the clear situations, without any cloud characterization in height. It is a very fast model based on an empirical combination of 3 tests applied to AIRS channels and co-registered AMSU-A channels. The third test is a simulation of the SST. SST thresholds were first tuned to our concerned time period and geographical location. Thresholds of -0.6K and 3.3 K allow the detection of about 99% of the clear situations and more than 95% of the cloudy situations.

The NESDIS cloud detection is interested because it does not need to apply a channel bias correction. Also, it is relatively independent of atmospheric prior information, except for sea surface temperature.

5.2. ECMWF AIRS cloud-free channels selection

The ECMWF scheme (McNally and Watts, 2003) aims to select channels un-affected by clouds which are potentially useful for the NWP assimilation system. Using forward radiative transfer calculation, each channel is assigned to the lowest pressure level at which the radiation effect of one opaque layer is less than 1%. The measured minus simulated brightness temperature are then sorted according to this pressure level and a low pass filter is applied on the ranked information in order to smooth the instrument noise and effects of surface emissivities. The application of a threshold on the filtered signal allows to select cloud free channels. In this study, only the 15µm band was used which concerns 130 channels from the 321 channels sent in near-real time by NOAA to European NWP centers. The assigned pressure level is also stored.

5.3. CO_2-Slicing cloud characterization

The CO_2-slicing method (Menzel et al, 1983) has been extensively used to retrieve cloud top pressure and cloud effective emissivities. The method based on radiative transfer principles, uses the similar subset of 130 channels than for the ECMWF scheme from 649.612 cm^{-1} to 843.913 cm^{-1}. For each channel and each pressure level of the RTTOV7 forward model, a cloud pressure function is computed using a reference 979.128 cm^{-1} window channel. The cloud top pressure level is the level which minimizes this function. The final cloud pressure is the average of the individual cloud pressures weighted by the sensitivity of the function to the pressure. Then, an effective emissivity is computed from the observations using the reference window channel and the retrieved cloud top pressure.

The method assumes that the cloud is a thin opaque layer. A first test determines the situation clear if the departure between simulated clear and observed brightness temperatures is less than 1.5*standard deviation of the residual differences from the clear monitoring. The cloud resulting information is flagged bad if the retrieved cloud effective emissivity is smaller than 0 or larger than 1.2

5.4. MLEV cloud characterization

The Minimum Local Emissivity Variance scheme (Huang and al, 2004) takes advantages of the semi-continuous high spectral resolution spectra. It is a physical method which assumes the slow spectral variation of the cloud emissivity in the CO_2 band. The cloud pressure is the one which minimizes the local variation of the effective emissivity over narrow spectral bands of $\Delta\nu=5cm^{-1}$, between 650 cm^{-1} and 850 cm^{-1}.

This method is expected to be potentially more accurate than the CO_2slicing algorithm because it takes advantage of the semi-continuous high spectral resolution of AIRS radiances. It simultaneously retrieves the top pressure and effective emissivity which allows to validate both parameters independently. The major weakness of this algorithm is the computation time required. RTTOV-7 and the same NWP background are also used as previously for simulating the AIRS clear radiances. We also have implemented a channel sensitivity to pressure of the local variance $\delta Var_{loc}(\nu) / \delta \ln p$ and the same cloud detection test as we did it in the CO_2-slicing method.

6. Results of AIRS cloud characterization

6.1. Cloud detection

The following results correspond to the processing of the second part of the 2003 dataset from 16 to 20 April with dynamic coefficients and thresholds previously determined on the training part of the dataset.

We did a systematic visual comparison (not shown here) of the different cloud parameter fields with their corresponding MODIS fields. For all schemes and granules, synoptic cloud patterns are correctly detected. Table1 shows the overall cloud masks efficiency for the different schemes when compared to MODIS. It should be noted that of course the MODIS mask has its own weakness which contributes to the comparison. The results indicate that the clouds are efficiently detected with AIRS alone for most of the clouds. Results during the night seem systematically better; this could be due to a better accuracy of the background SST used in the four models.

	Clear sit. correctly detected		**Cloudy sit. correctly classified**	
	Day	night	day	night
Number of situations	2799	5470	28510	57719
NESDIS	83.42%	85.52%	87.83%	94.80%
ECMWF	82.67%	88.45%	88.07%	94.36%
CO2-slicing	75.85%	84.11%	89.05%	94.62%
MLEV (before PCA)	76.77%	82.07%	84.33%	91.45%

Table 1: Overall cloud masks efficiency in % of the four schemes for day and night illumination.

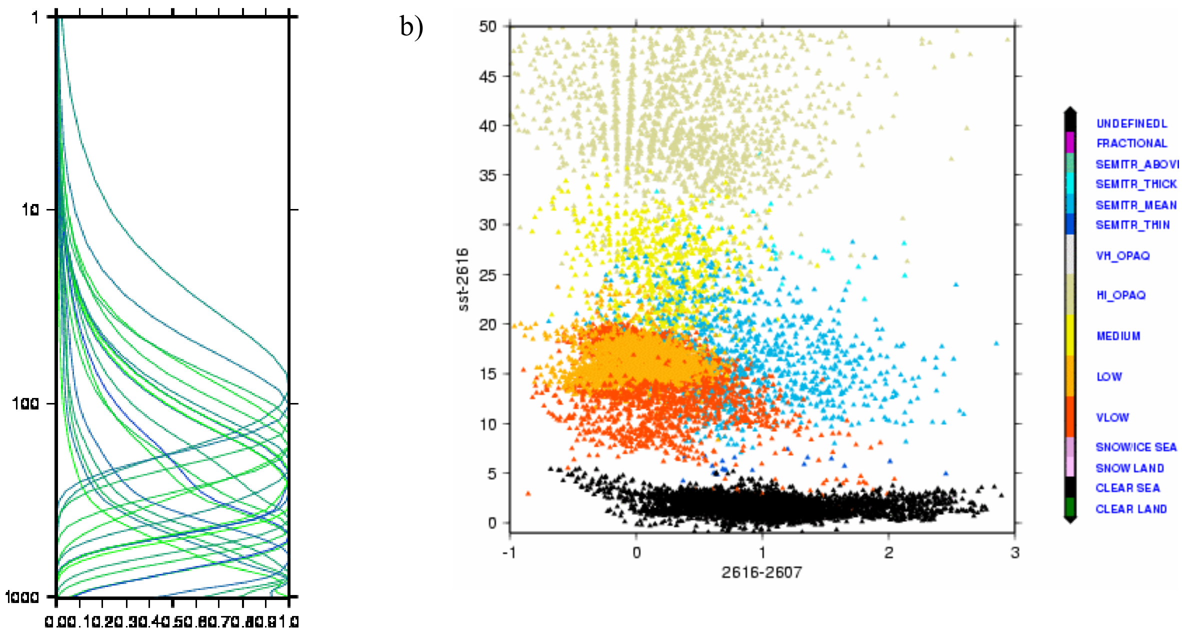
Comparison of the different methods shows very similar results. More details on the efficiency of the different cloud-detection masks with the cloud layers characteristics from MODIS (cloud cover, pressure and types) can be found in Dahoui et al, 2004. To summarize, all the schemes have a general good agreement with the MODIS cloud mask above 900hPa. However, all of them show a poor sensitivity to clouds near the surface and for small amount of clouds or for the 'difficult' clouds (unclassified with MODIS). Also, thin semi-transparent clouds are difficult to be detected when the departure between observed and simulated clear brightness temperatures is within 1 to 2K. For these situations, the AIRS footprints are generally completely overcast and the problem is mostly due to the insensitivity of the sounding-based methods to thin optical thickness layers. The study of these 'difficult' cases for which we are reaching the limits of the methods should be carried on. For example, a treatment using EOF scores (Huang and Antonelli, 2001) or the addition of specific threshold cirrus tests could improved the detection.

For a better post-processing of the sounder, the use of an associated or collocated imager seems still necessary in order to detect small cloud fractions or thin cirrus and to determine the number of cloud layers. For the future IASI interferometer on METOP, a co-registration of the AVHRR imager with the sounder will be globally done by EUMETSAT during the pre-processing stage and a clustering treatment will be applied on the mapped pixels. Six AVHRR clusters will be supplied in the global level 1c files (Patterson et al, Phulpin et al, 2002) with for each of them: the coverage in the ellipse, the mean and standard deviation of the five AVHRR channels and the position of the centre of gravity. A cloud mask on the six clusters could then be applied by NWP users to help the post-processing or assimilation of IASI data.

6.2. Cloud pressure characterization

The 2004 March test dataset was mostly used to evaluate the accuracy of the AIRS cloud top pressure inferred with the CO_2slicing method. In that run, we restricted the number of channels to a subset of 20 channels among the 130, chosen as being the less noisy from monitoring, for which the maximum of weighting function is below 85hPa and with no overlapping of the maximum of the weighting function. Figure 2a shows the weighting functions of the retained channels.

a) b)



Figures 2: a) shows the weighting functions of the subset of channels used to run the CO2slicing method. b) shows the departure between the simulated and the NWP background SST as function of the MODIS cloud classification, corresponding to different colours.

Also, a pre-process was applied to quickly detect unquestionable clear situations through the use of the super-window channel at 2616 cm^{-1}, (Aumann, 2003). This test is also implemented in the NESDIS post-launch detection scheme (Goldberg, 2003). The SST is simulated using a polynomial regression function of the observed brightness temperatures of the window channel at 2616 cm-1 and the adjacent water line at 2607 cm-1. Figure 2b shows the departure of the simulated SST with the NWP background SST for different MODIS cloud types. The black points correspond to clear situations over sea. As seen, this test is very efficient.

Figure 3 right is an example of the retrieved CO_2slicing cloud top pressure field for AIRS, compared to the corresponding information provided by MODIS in left. The colour table is the same for the two figures. As seen, there is a good coherence between both treatments. That is not surprising because they are based on the same method. However, this confirms the possibility with AIRS alone to retrieve the cloud top pressure.

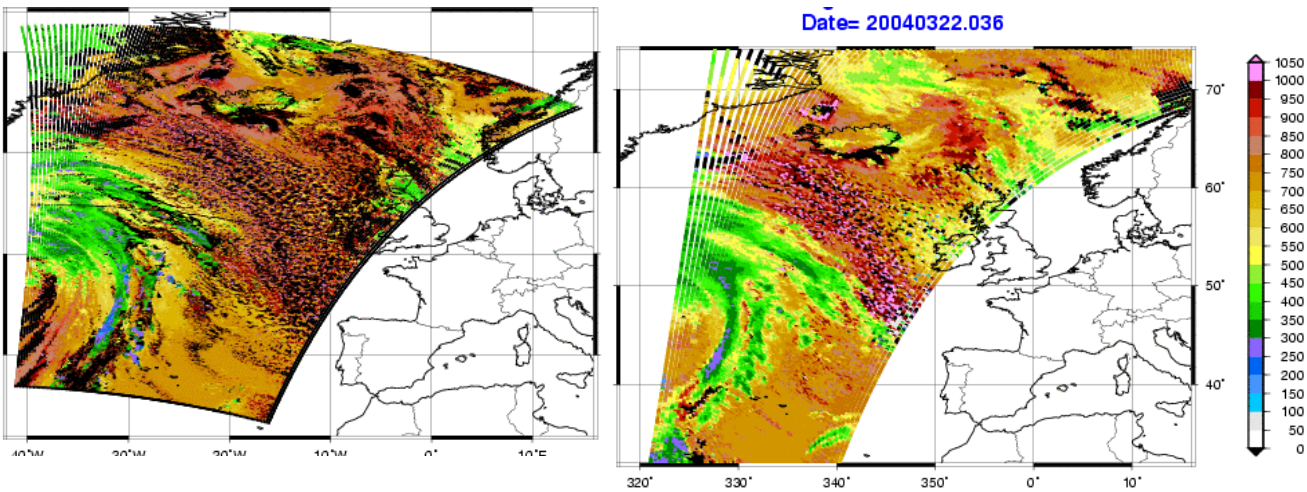


Figure 3 right is an example of the retrieved CO2slicing cloud top pressure field for AIRS, compared to the corresponding information provided by MODIS (left).

Figure 4 shows the root mean square of the differences between the observed and computed brightness temperatures in cloudy conditions. Only completely overcast situations with a single opaque layer are considered. RTTOV-7 is used in 'grey conditions' with in input the cloud top pressure inferred by MODIS and an effective emissivity of 1. No previous bias correction is applied. This figure only considers the 15µm band (130 channels from 645 cm^{-1} to 950 cm^{-1}) among the 321 received from NESDIS in near-real time. For comparison, the figure with triangles shows the corresponding statistics in clear conditions. As expected, the rms for stratospheric and upper troposphere channels are similar in clear and cloudy conditions. The rms of errors then increases when channels are peaking lower in the atmosphere reaching values from 2.5K to 4K depending of the cloud level. These results are better than what could be at present expected from the direct use of a diagnostic cloud scheme (see Chevallier et al, 2004) but not enough accuracy is reached to use all the channels in a cloudy assimilation. A criteria has to be defined to select the cloud-affected channels for their operational assimilation: a preliminary and reasonable condition could be to select the channels for which the residual errors in simulated cloud-affected channels are smaller than those induced by the standard errors of the background T,Q profiles.

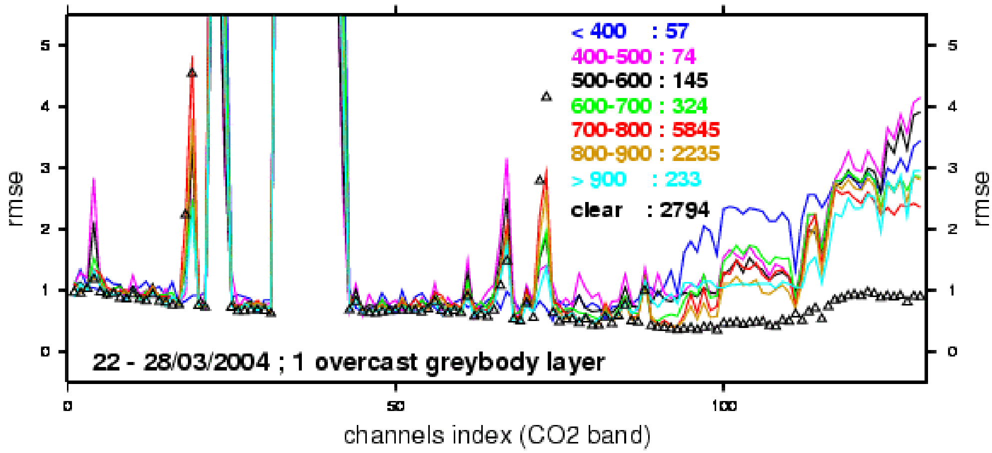
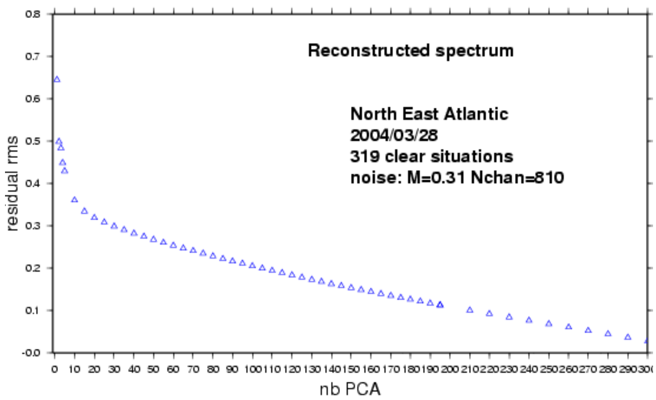


Figure 4: Statistics in rms of the departure between RTTOV7 simulated and observed brightness temperatures in cloudy conditions as function of the retrieved cloud level. The corresponding clear statistics are indicated by triangles.



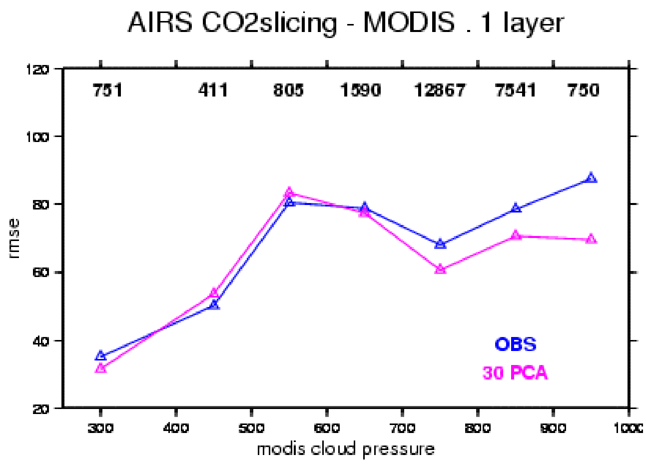


Figure 5 : left, rms of the departure between the reconstructed and observed spectrum in clear conditions for one day as function of the number of scores used. The mean noise for that part of the spectrum is of 0.31K. Right: rms of difference for seven days between AIRS and MODIS cloud top pressures when using raw spectra (blue curve) or de-noised spectra (pink curve). Number of collocations for each pressure section is given in the upper part of the figure.

We also have tested the impact of de-noised channels from a Principal Component Analysis on the cloud top pressure retrieval. For the considered 810 channels of the full resolution spectrum in the CO_2 band (from 645 cm^{-1} to 950 cm^{-1}), only 30 scores are needed to reconstruct the spectrum above the noise (figure 5 left). The CO_2slicing method was then run on the 20 reconstructed channels with 30 PCA and the retrieved cloud top pressure compared to MODIS information for single cloud layer situations (figure 5 right). The rms of departure between AIRS and MODIS increases in the low atmosphere because, in the CO_2slicing function,

the denominator which is computed from the difference between simulated clear and observed radiances becomes smaller near the surface and is more sensitive to the noise. And as expected, the use of re-constructed radiances largely improves the cloud top retrievals for low level-clouds. No improvement is observed for high level clouds. The same impact is seen on retrieved fields (not shown): the horizontal noise in AIRS retrieved top pressure fields for low level cloud layers is drastically reduced.

7. Preliminary investigations for cloudy radiances assimilation

For NWP models, the use of satellite cloudy radiances is an important issue as cloudy areas are usually the most meteorologically active. Assimilation of such data is a great challenge for the future. It requires the development of an enhanced observation operator allowing a realistic representation of cloudy situations. Current data assimilation systems require the linearity of the observation operator, at least at the vicinity of the background state. The accuracy and validity of the linearity assumption of the operational cloud schemes depend on the spectral location of channels and on the atmospheric conditions, specially on the cloud configuration. In this study, we tried to contribute to this effort by the investigation of the linearity assumption of the observation operator, applied to AIRS cloudy observations according to cloud types. Two methods are investigated in parallel in this paper, the first one considers the use of a diagnostic cloud-scheme for simulating the radiances from the atmospheric profile and another approach, relying more heavily on the data themselves is based on the description of the cloud fields retrieved directly with the CO_2slicing method. The methodology used to evaluate the linearity assumption of the observation operators is inspired of Chevallier et al, 2004.

7.1. Diagnostic cloud scheme

The developed scheme diagnoses the cloud cover, cloud liquid water vapour content and cloud ice water vapour content on the 41 vertical levels of the ARPEGE NWP model from the temperature and humidity profiles and the surface pressure. More details of the model are in Dahoui et al, 2004. For each AIRS channel, the correlation between linear and non-linear brightness temperature perturbations is computed for different cloud types. Cloud information is determined using the CO_2slicing method and situations of large-scale low, medium, high layers were visually selected for this study. Perturbations taken here are the difference between the analysis x_{an} and the background x_b. Analysis profiles are produced by the current ARPEGE operational cycle. Background profiles are produced by forecasts just prior the last operational cycle.

Figure 6 shows that, systematically in all cloud configurations, for most channels located between 649 and 700 cm^{-1} and between 1367 and 1604 cm^{-1} and for few channels around 2300 cm^{-1}, the observation operator exhibits a good linear behaviour. This is not surprising because weighting functions of those channels peak in the stratosphere and in the upper troposphere and are consequently far from the influence of the clouds. For channels around 1000cm^{-1}, the observation operator is highly non-linear for all cloud types. For all channels between 700 and 1000cm^{-1} the linearity of the observation operator depends significantly on the cloud level. For high and medium clouds, those channels show high non-linear behaviour. In the presence of low clouds, the linearity is acceptable with correlations around 0.8. This can be explained by the fact that low clouds radiate at temperatures not greatly different from the ambient surface temperature and hence their impact on the emitted terrestrial radiation stream is comparatively small. For high clouds, correlations are around 0.75 and the use of those channels is questionable. This preliminary results indicate that few channels are linear enough to be assimilated.

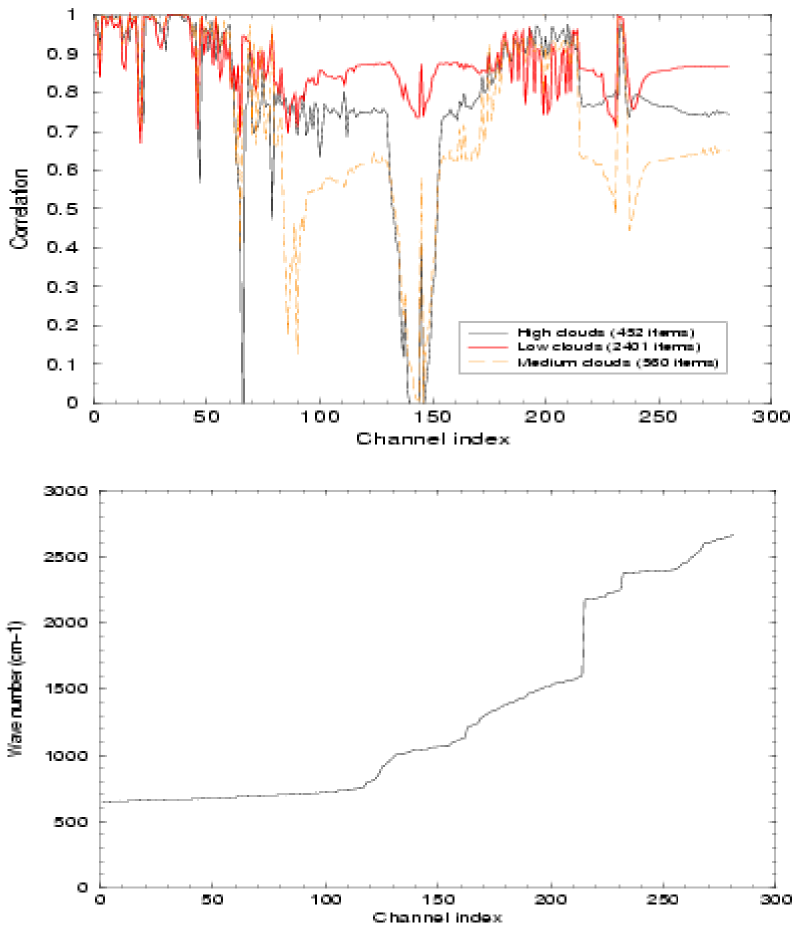


Figure 6 :Top figure shows the correlation between linear and non-linear brightness temperatures perturbations for AIRS channels (a subset of 281 channels) and for different cloud types. The number of items in the legend indicates the number of fovs used to calculate correlation. Bottom figure shows the correspondence between channel index and wave number.

7.2. Direct use of retrieved cloud information from observations

This study is a first attempt towards another approach, relying more heavily on the data themselves, based on the direct assimilation of the retrieved cloud information from the observations. An 'ideal' methodology relies on a fast radiative transfer model in presence of clouds like the last RTIASI version of Matricardi, 2004 with a two-stream Eddington's approximation for the diffusion in presence of cirrus clouds, together with a parametrisation of the clouds. Different studies (Huang et al, 2004; Smith et al, 2004) are on-going to retrieve the cloud information from the observations in terms of 3 or 4 parameters (cloud effective particule size, optical depth, cloud top height, coverage). So far, these softwares are not available and we just considered the 'grey' modelisation of the RTTOV-7 software together with the retrieved cloud top height and effective emissivity determined with the CO_2slicing method. This is of course not accurate enough for its generalisation to all clouds but could be considered as a correct assumption for single opaque clouds layers which are much more numerous than clear situations.

a) b) c)

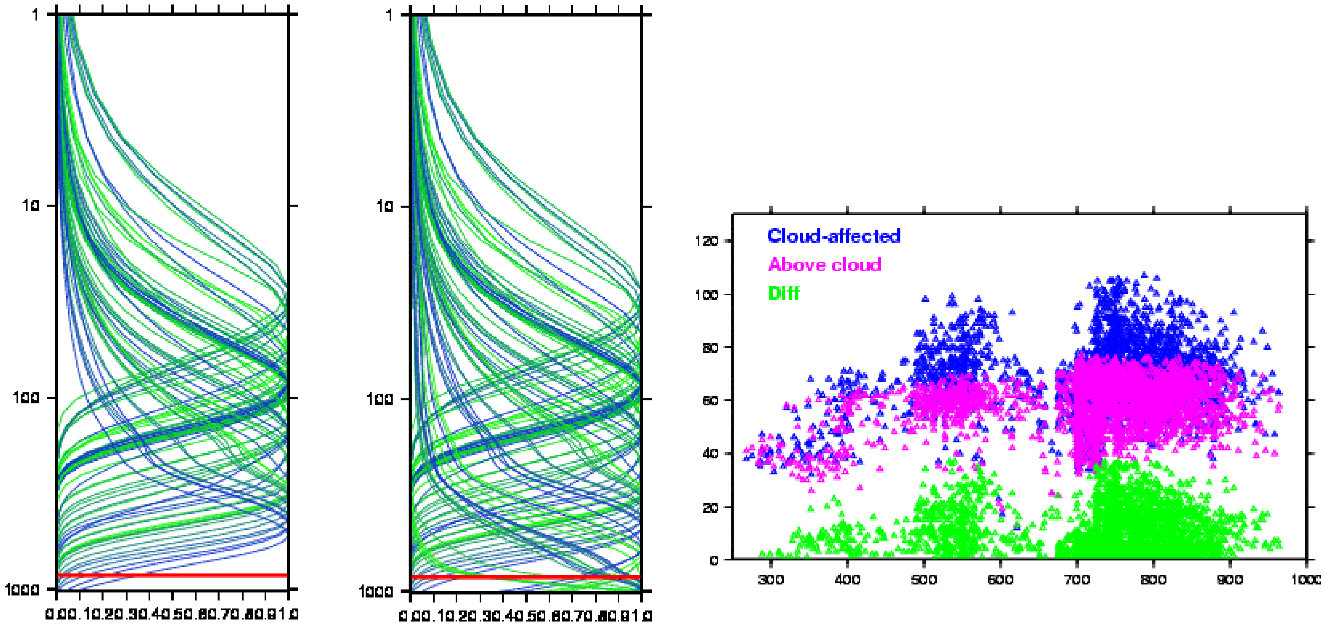


Figure 7 a) weighting functions of the cloud-free channels selected above the cloud for an example at 843hPa. b) for the same example, weighting functions of the slightly-cloud affected channels showing enough linearity for their assimilation. c) number of channels among the 130 of the CO_2 band selected as cloud-free above the cloud (pink) or slightly cloud-affected (blue). The green points correspond to the difference.

In cloudy conditions, when working with only cloud-free channels, a layer of about 200-300 hPa just above the cloud is not sounded and most of the cloud-free selected channels sound the stratosphere or the upper atmosphere even for low level clouds. See the example of figure 7a) for a cloud pressure at 843hPa for which the channels have been chosen with 2 criteria: the correlations between linear and non-linear increments exceed 0.85 and the differences between simulated clear and observed brightness temperatures are within 1.5* standard deviation from the clear monitoring. Same type of criteria is applied to select slightly cloud-affected channels (figure 7b): the correlations are larger than 0.85 to insure the linearity and the differences between simulated cloudy and observed brightness temperatures are within 1.5* standard deviation from the cloudy monitoring shown in figure 4. About 20 additional channels peaking just above the cloud have been selected. Figure 7 c) shows for single opaque cloud layer situations, the number of selected cloud-free and slightly cloud-affected channels among the 130 of the CO_2 band as function of the cloud top pressure, for a 7 days period. Up to 20-30 additional channels are selected and it is expected from a previous experiment with simulated IASI cloudy data (Lavanant, 2002) that these channels will improve the retrieved atmospheric profile just above the cloud.

8. Conclusion

Concerning the cloud detection, for the four tested schemes, the synoptic cloud patterns are correctly detected when taking the MODIS cloud mask as a reference. Comparison of the different methods shows very similar results. We have a general good agreement with MODIS above 900hPa but the sensitivity to clouds is poor near the surface and for fractional or unclassified clouds. For a better post-processing of the sounder, the use of an associated or collocated imager seems still necessary in order to detect small cloud fractions or thin cirrus and to determine the number of cloud layers. For the global processing of IASI, it will be easy to characterize the complexity of the clouds inside the sounding ellipse by running a cloud mask like Lavanant, 2002 on the 6 clusters of homogeneous AVHRR pixels mapped inside IASI provided in the level1C IASI files. Because the cloud and surface emissivity frequency spectra are different, the treatment of the PCA should be more efficient than threshold tests applied on individual channels for detecting the clouds having a small influence on the observations: this will be explored in the future months.

Concerning the cloud characterization, the CO_2slicing method gives good results with AIRS. For single cloud layers, the comparison with the MODIS cloud top pressure is within 60-80hPa and the use of de-noised channels when reconstructing the channels with 30 PCA improves the retrieved cloud information for low level layers. Also the monitoring for single overcast greybody layer situations indicates that the observation is simulated within 3-4K depending of the cloud height for channels peaking near the surface.

We also started investigations of the assimilation of cloudy situations with two independent approachs, the diagnose of the clouds from the atmospheric profile and the direct use of the retrieved cloud information from the observations. Our preliminary work was to test the linearity of both observation operators. This will be continue in the future months for the two methods. We will perform a more extensive evaluation of the diagnostic cloud-scheme comparing simulated radiances and AIRS data with RTTOV-CLD. In parallel, we will assimilate the retrieved cloud fields from observation by keeping them constant throughout the minimisation of the cloudy radiances. Prior the 4D-Var minimisation, to improve the cloud information, we will perform a 1D-Var pre-processing, starting with the CO_2slicing results as guess and keeping the profile constant.

9. References

Aumann G., 2003. AIRS SST measurements using RTG.SST in support of validation, cloud filtering and finding marine aerosol. Material presentation.

Chevallier F., P. Lopez, A. Tompkins, M. Janiskova, E. Moreau, 2004. The capability of 4D-Var systems to assimilate Cloud-affected satellite infrared radiances. Q. J. Roy. Meteor. Soc., 130, 917-932

Dahoui M., L. Lavanant, F. Rabier, A. Auligné, 2004. Use of MODIS imager to help dealing with AIRS cloudy radiances. Submitted to Q. J. Roy. Meteor. Soc.

Huang, P. Antonelli, 2001. Application of Principal Component Analysis to high resolution infrared measurement compression and retrieval. J. Applied Meteorology,**40**, 365-388

Huang et al, 2004. Minimum local emissivity variance retrieval of cloud altitude and effective spectral emissivity- Simulation and initial verification. J. Applied Meteorology. 795-809.

Huang et al, 2004. Inference of ice properties from high spectral resolution infrared observations. IEEE Trans. on Geoscience and remote sensing. **42**, 842-853.

Goldberg, L. Zhou, 2002. AIRS clear detection flag. Presentation material at a meeting

Goldberg et al, 2003. AIRS near real-time products and algorithms in support of operational numerical weather prediction. IEEE transaction on geoscience and remote sensing, 41 no 2, 379-389

Lavanant, L. 2002. Cloud processing in IASI context. Proceedings of the 12th International TOVS Study conference.

Lavanant, L., 2002. MAIA AVHRR cloud mask and classification. Internal documentation available on web site: www.meteorologie.eu.org/ici

LeGléau,, H and M. Derrien, 2001. Use of MODIS to enhance the PGE01-02 of SAFNWC/MSG. EUMETSAT documentation.

LeGléau, H. and M. Derrien, 2002. User manual for the PGE01-02-03 of the SAFNWC/MSG: Scientific part. EUMETSAT documentation.

Matricardi, M., 2004. The inclusion of aerosols and semi-transparent clouds in RTIASI. Presentation material at ISSWG-19 meeting

McNally, A., P. Watts, 2003. A cloud detection algorithm for high spectral resolution infrared sounders; Q. J. Roy. Meteor. Soc., in revision.

Menzel, P., W. Smith, T. Stewart. 1983. Improved cloud motion wind vector and altitude assignment using VAS. *J. Appl. Meteor.*, **22**,377-384.

Patterson and al. EPS Programme IASI Level 1 Product Format Specification EUM.EPS.SYS.SPE.990003

Phulpin, T., F. Cayla, G. Chalon, D. Diebel, P. Schlűssel, 2002. IASI onboard METOP: Project status and scientific preparation. Proceedings of the 12th International TOVS study Conference.

Smith W. et al, 2004. Extraction of profile information from cloud contaminated radiances. Presentation material, this issue.