

## Cloud properties from AIRS

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### Abstract

Since May 2002 the Atmospheric Infrared Sounder (AIRS), in combination with the Advanced Microwave Sounder Unit (AMSU), onboard the NASA Aqua satellite provides measurements at very high spectral resolution of radiation emitted and scattered from the atmosphere and surface. The instrument was developed to provide atmospheric temperature and water vapour profiles at a vertical resolution of about 1 km and 2 km, respectively, but the high spectral resolution of this instrument also allows the retrieval of cloud properties (especially cirrus), aerosol and surface properties as well as the quantity of trace gases.

We present a cloud property retrieval scheme, which is based on a weighted  $\chi^2$  method using channels around the 15 micron CO<sub>2</sub> absorption band, to determine effective cloud emissivity and cloud pressure. The influence of channel choice, cloud detection, spatial resolution and of assumed atmospheric profiles on the retrieval are discussed. Results for July 2003 and January 2004 are compared to ISCCP and MODIS cloud properties of the same time period, as well as to the cloud climatology of TOVS Path-B.

### Cloud property retrieval

The AIRS instrument sounds the atmosphere in three spectral bands (3.74-4.61 micron, 6.20-8.22 micron and 8.80-15.40 micron) using 2378 channels. 324 channels optimal for sounding have been selected to be provided to the different AIRS Science Team members. The spatial resolution of these measurements is 13.5 km at nadir. Nine AIRS measurements (3x3) correspond to one AMSU footprint. AIRS L2 atmospheric profiles are retrieved from cloud-cleared AIRS radiances (Chahine et al. 2001) within each AMSU footprint (Susskind et al. 2003). They provide temperature and water vapour mixing ratio at 28 pressure levels from 0.1 hPa to the surface. A validation with radiosonde data (Divakarla et al. 2006) has shown that the accuracy is close to 1°K in 1 km layers for temperature and better than 15% in 2 km layers for water vapour.

For the 324 AIRS channels at all viewing zenith angles clear sky radiances and cloudy radiances at 30 pressure levels have been simulated using about 2000 representative atmospheric temperature and humidity profiles and the Automatized Atmospheric Absorption Atlas (4A) radiative transfer model (Scott and Chédin 1981; code available at <http://www.noveltis.net/4AOP/>). These 2000 atmospheric situations have been classified into five air masses (from tropical to polar) in the Thermodynamic Initial Guess Retrieval (TIGR) dataset (Chevallier et al. 1998) which also archives the simulated AIRS radiances, at present only for the surface type ocean. The determination of IR surface emissivities over land (Péquignot 2006) will allow pursuing the simulations over different land surface types. Systematic biases between observed and simulated brightness temperatures due to the radiative transfer model and to instrument calibration are removed by applying corrections to the measured AIRS brightness temperatures. At present, these corrections have been computed only during night for the latitude band from 30°N to 30°S over ocean. Therefore the cloud property retrieval has so far only been applied to the AIRS measurements at 10:30 PM and to these regions.

A multi-spectral cloud detection has been developed, making simultaneous use of the AMSU microwave sounder, to discard cloudy scenes for CO<sub>2</sub> retrieval in the upper troposphere (C. Crevoisier 2004) and for aerosol retrieval in the lower troposphere (C. Pierangelo 2005). Since microwave radiation is insensitive to clouds, the brightness temperature difference between AMSU and AIRS channels with peak contributions at different levels in the atmosphere should be small for clear sky. Thresholds have been established in dependence of air mass, surface emissivity and viewing zenith angle.

The cloud property retrieval is based on a weighted  $\chi_w^2$  method (Stubenrauch et al. 1999), computing the effective cloud emissivity  $\varepsilon$  as in Eq. 1 at different wavelengths  $\lambda_i$  and assuming 30 different cloud heights  $p_k$  (from surface to 106 hPa).  $I_m$  is the measured radiance,  $I_{clr}$  is the clear sky radiance and  $I_{cld}$  is the radiance emitted by a homogenous opaque single cloud layer.

$$\varepsilon(p_k, \lambda_i) = \frac{I_m(\lambda_i) - I_{clr}(\lambda_i)}{I_{cld}(p_k, \lambda_i) - I_{clr}(\lambda_i)} \quad \text{for } i = 1, N \quad (1)$$

Minimizing  $\chi_w^2$  in Eq. 2 leads to a coherent answer in effective emissivity  $\varepsilon$  and the corresponding pressure  $p_{cld}$  of the cloud. Empirical weights  $W^2(p_k, \lambda_i)$  reflect the effect of the brightness temperature uncertainty on the cloudy and clear radiances at each cloud level within the air mass class closest to the observation (Stubenrauch et al. 1999). When the  $\chi_w^2$  method does not provide a physical value of  $\varepsilon$  ( $> 200\%$ ), the scene is reset to clear sky. The accuracy in  $p_{cld}$  is limited to the pressure level step of about 35 hPa in the simulations.

$$\chi_w^2(p_k) = \sum_{i=1}^N [(I_{cld}(p_k, \lambda_i) - I_{clr}(\lambda_i)) \cdot \varepsilon(p_k) - (I_m(\lambda_i) - I_{clr}(\lambda_i))]^2 * W^2(p_k, \lambda_i) \quad (2)$$

We have chosen AIRS channels corresponding closely to the 5 channels used in the TIROS-N Operational Vertical Sounder (TOVS) Path-B cloud retrieval (Stubenrauch et al. 1999): 87, 102, 99, 126 and 136 (out of the 324 channels). The contribution of these channels in measuring the atmosphere is shown in Fig. 1 as the derivative of the transmission function and pressure.

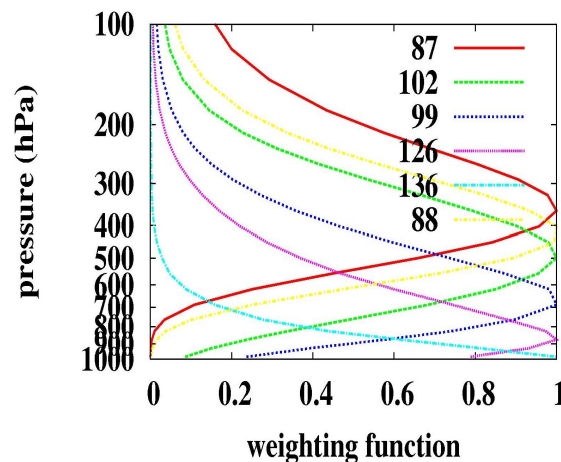


Fig. 1: Weighting functions of six AIRS channels (out of the 324 channels) used in the cloud property retrieval.

The clear sky radiance used in Eq. 2 corresponds to the clear sky situation of the TIGR profiles closest to the retrieved atmospheric profiles. Therefore the AIRS L2 atmospheric profiles (version 4) have been combined with the AIRS radiance measurements and have then been interpolated to the 4A pressure levels. A proximity recognition between the retrieved atmospheric profiles (21 temperature levels between surface to 106 hPa and 8 water vapour layers between surface and 162 hPa) and the TIGR profiles leads to the TIGR profile closest to the observation. The clear and cloudy radiances in Eq. 2 are averages, using TIGR profiles for which the difference to the AIRS L2 data in temperature and water vapour, summed over all levels and layers, lies within 5% of the minimum difference. The difference in water vapour is weighted by a factor 2 when added to the temperature difference. The cloud property retrieval is applied to all cloudy AIRS spots.

## Datasets for comparison

Cloud properties are given by different satellite climatologies: The International Satellite Cloud Climatology Project (Rossow and Schiffer 1999) makes use of imagers on geostationary and polar orbiting NOAA satellite from 1983 up to now. Among the many variables we use monthly mean cloud amount and cloud pressure as well as high, midlevel and low cloud amount (all determined during daytime) from July 2003 and January 2004 for the comparison with AIRS.

The MODIS instrument onboard the NASA Terra and Aqua satellites provides cloud properties (King et al. 2003, Platnick et al. 2003) since 2000. We use MODIS MOD08-M3 (from Terra observed at 13h30) and MYD08-M3 (from Aqua observed at 10h30) monthly averages during daytime of cloud amount and cloud pressure. These data were acquired using the GES-DISC Interactive Online Analysis Infrastructure (Giovanni) as part of the NASA Goddard Earth Sciences Information Services Center (DISC).

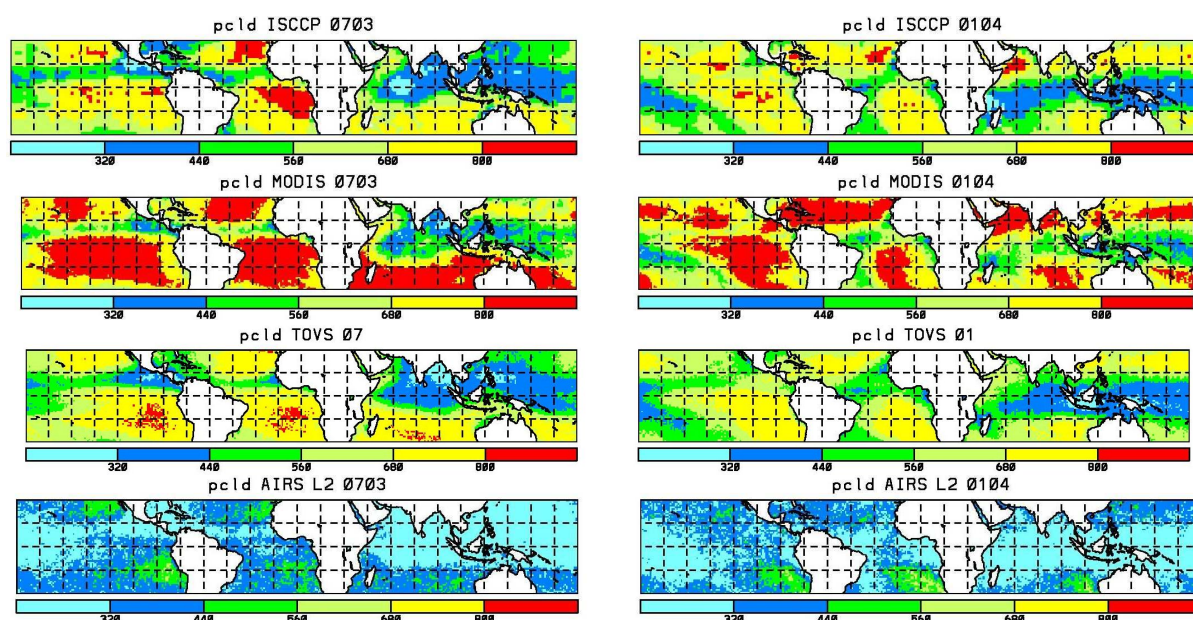


Fig. 2: Geographical maps of  $p_{\text{cld}}$  over ocean for July (left) and January (right) using the datasets ISCCP, MODIS, TOVS Path-B and AIRS L2 described above.

The TOVS Path-B climatology (Scott et al. 1999, Stubenrauch et al. 2006) is established from TIROS-N Operational Vertical Sounder measurements onboard the polar orbiting NOAA satellite and covers at present the period from 1987 to 1995. Since TOVS Path-B cloud properties are given at a

spatial resolution of  $1^\circ$  latitude  $\times$   $1^\circ$  longitude, effective cloud amount, which is the effective cloud emissivity multiplied by cloud fraction, is shown for this dataset. This should be smaller than cloud amount and smaller or equal to effective cloud emissivity.

The AIRS L2 retrieved products (version 4) provide in addition to the atmospheric profiles also effective cloud amount and cloud pressure (Susskind et al. 2003).

Fig. 2 presents geographical maps of  $p_{\text{cld}}$  over ocean for July and for January as provided by ISCCP, MODIS, TOVS Path-B and AIRS L2. The cloud structures of ISCCP and TOVS Path-B are quite similar with the Intertropical Convergence Zone (ITCZ) appearing as a band of low cloud pressure around the equator, shifting about  $10^\circ$  from July to January towards the summer hemisphere. The cumulostratus regions in the subtropics off the West coasts of South America and Africa are a little bit better identified by ISCCP. Both datasets have been thoroughly evaluated (Rossow and Schiffer 1999, Stubenrauch et al. 2005). The Infrared Sounders are more sensitive to cirrus clouds (Stubenrauch et al. 2006). Considering MODIS and AIRS L2 average  $p_{\text{cld}}$ , one observes that in general MODIS provides larger cloud pressures and AIRS L2 much smaller cloud pressures. With MODIS the ITCZ is less apparent than with ISCCP and TOVS Path-B. Monthly  $p_{\text{cld}}$  averages of AIRS L2 do not exceed 700 hPa. Since the AIRS L2 cloud properties are very different from the ones of the other datasets we will not consider them further for comparison.

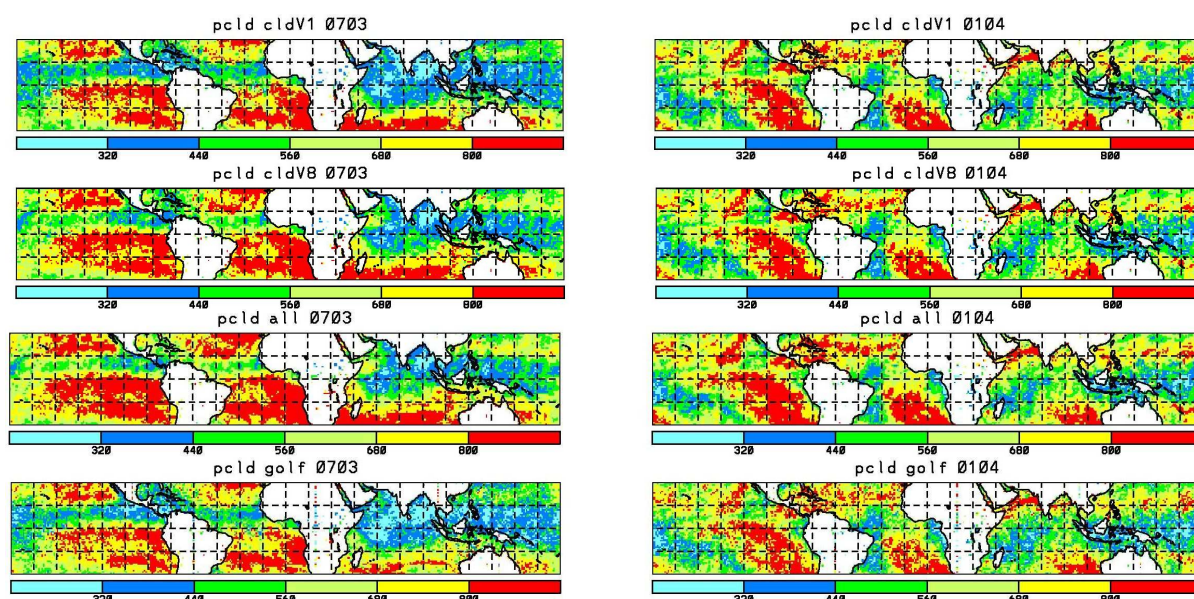


Fig. 3: Geographical maps of  $p_{\text{cld}}$  over ocean at 10:30 PM for July 2003 (left) and January 2004 (left), retrieved by using the  $\chi^2$  method on AIRS data. Retrieval is applied to cloudy AIRS spots detected by V1 and V8, to all AIRS spots and to cloudy (V1) AIRS measurements averaged over 9 spots (golf).

Fig. 3 represents geographical maps of  $p_{\text{cld}}$  over ocean during night (10:30 PM) as retrieved from AIRS data by using the  $\chi^2$  method described in the first section. Compared are retrievals using different cloud detections (V1 and V8, see next section), a retrieval on all AIRS spots and on cloudy AIRS measurements (V1) averaged over 9 spots. In general, these maps are quite similar to the maps of ISCCP, TOVS Path-B and MODIS. Different treatments in cloud detection or spatial resolution lead to changes, but the features of  $p_{\text{cld}}$  stay the same: By tightening the cloud detection (V1, V8, all) the average  $p_{\text{cld}}$  increases, because for partly cloudy scenes  $p_{\text{cld}}$  is overestimated. Averaging the AIRS radiances over nine spots before the  $\chi^2$  retrieval leads to slightly lower  $p_{\text{cld}}$  values, in better agreement

with the TOVS Path-B climatology. Nevertheless in regions with low clouds AIRS seems to pick them up better than TOVS, probably still due to the better spatial resolution (45 km x 45 km instead of 100 km x 100 km).

In the next section we compare the datasets more quantitatively by considering latitudinal averages.

## Sensitivity analysis

In the following we investigate the effect of channel choice, cloud detection, spatial resolution, and choice of atmospheric profiles on the retrieved effective cloud amount and on  $p_{\text{clid}}$ . Therefore we make the corresponding changes in the retrieval procedure and compare then the AIRS cloud properties for July 2003 and January 2004 to cloud properties of the datasets described in the previous section.

### Effect of channel choice

In a first step we have examined if adding channels to the  $\chi^2$  method would affect the retrieved cloud properties. Fig. 1 shows that channel 88 would slightly improve the vertical resolution in the middle to upper troposphere. However, cloud properties retrieved by using six (or even seven) channels are very similar to those using the initial five channels.

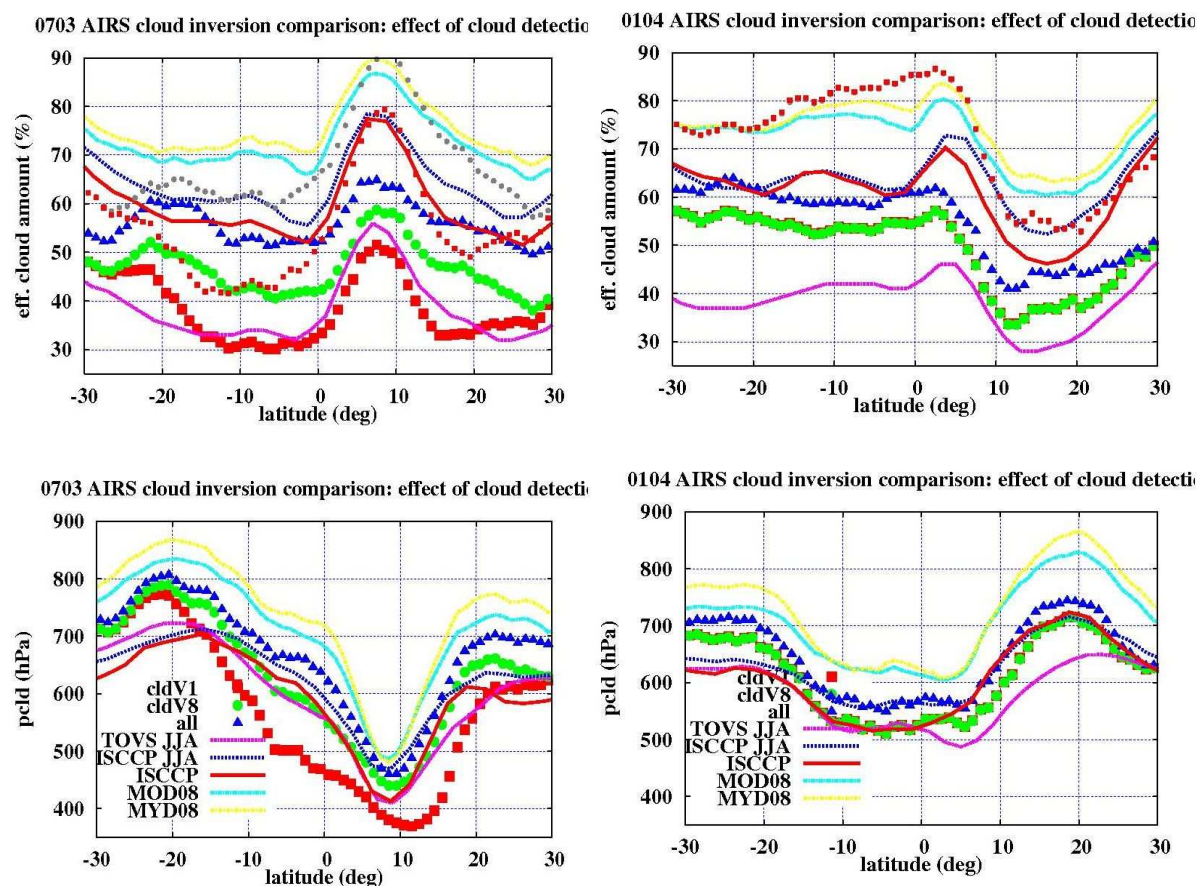


Fig. 4: Effective cloud amount (AIRS and TOVS Path-B) or cloud fraction (ISCCP, MODIS, AIRS) (above) and  $p_{\text{clid}}$  (below) as function of latitude for July 2003 (left) and January 2004 (right). For AIRS results are presented of cloudy AIRS spots using the initial multi-spectral cloud detection (V1) and a tighter cloud detection (V8) as well as of a cloud retrieval applied to all AIRS spots (all). For comparison are also shown results of the TOVS Path-B and ISCCP (day) climatologies.

**Effect of cloud detection**

The latitudinal shapes of cloud amount (CA) and effective cloud amount (ECA) of the different datasets in Fig. 4 are similar, but absolute values are different. The cloud detection V1 has been tightened to obtain clear sky of better quality for the CO<sub>2</sub> retrieval (cloud detection V8), leading to an increase of cloud amount by about 10 to 20% in July, as can be observed in Fig. 4 comparing the small grey dots, representing the V8 CA, to the small red squares, representing the V1 CA. However, in January both cloud detections give very similar CA.

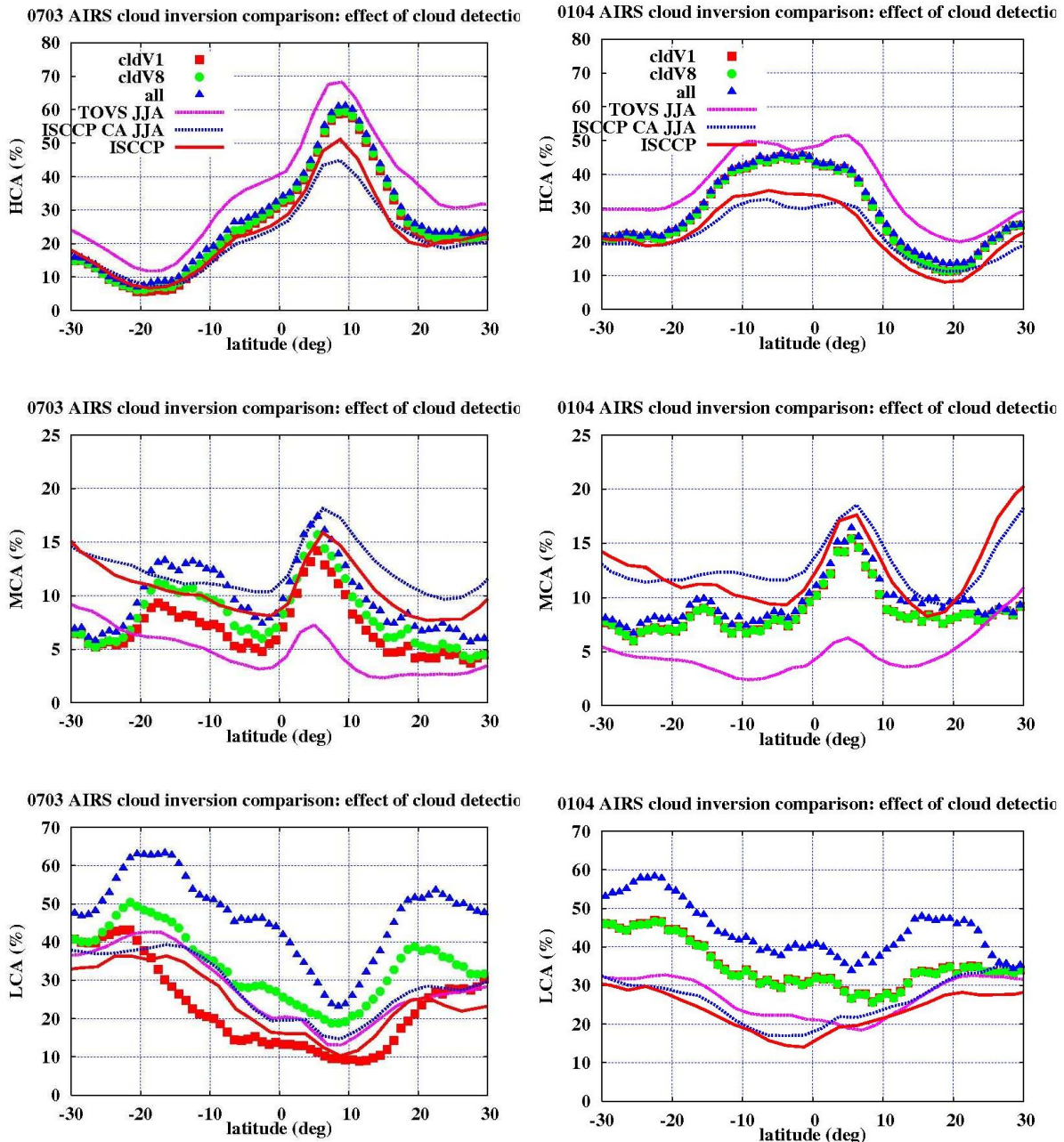


Fig. 5: Latitudinal averages of high, midlevel and low cloud amount (HCA, MCA and LCA) shown for three AIRS cloud detections and for ISCCP (day) and TOVS Path-B.

For comparison are shown latitudinal CA from MODIS day measurements at 10:30 AM (AQUA satellite, light blue) and at 1:30 PM (TERRA satellite, yellow) and from ISCCP (red line). The MODIS CA is the highest. In July the AIRS V1 CA agrees with ISCCP in the ITCZ (zone of

maximum CA) and is 15% smaller than ISCCP in the region between 5°S-15°S. The V8 CA agrees with the MODIS CA in the ITCZ and lies between MODIS and ISCCP CA in the other regions. In January the situation is different: both AIRS cloud amounts agree with the MODIS CA in the southern hemisphere, and in the northern hemisphere they agree with the ISCCP CA, which is about 10% smaller than the one from MODIS. Considering ECA the AIRS V1 cloud detection leads to a better agreement with the TOVS Path-B climatology than the V8 cloud detection. When the cloud retrieval is applied on all AIRS spots (solutions with unphysical  $\epsilon$  values are reset to clear sky), ECA is the highest and the contrast between the ITCZ and the subtropics is much less pronounced. Considering  $p_{\text{cld}}$  one observes, as already on the maps, that on average MODIS  $p_{\text{cld}}$  is the largest, followed by  $p_{\text{cld}}$  of AIRS treating all spots as cloudy. ISCCP and TOVS Path-B agree quite well in July, but in January TOVS Path-B has lower values between 5°N and 20°N. Regarding the different cloud detections, AIRS average  $p_{\text{cld}}$  increases with cloud amount, because partly or falsely identified clear sky situations lead to a large  $p_{\text{cld}}$ . To indicate the difference between the actual situation and the climatic values we also added ISCCP data averaged over the same 8 year period as TOVS Path-B. This shows that the cloud amount has been 5 to 8% lower in the subtropics in July 2003 and in the NH subtropics in January 2004 than over the period 1987 to 1995.

Fig. 5 presents separately high, midlevel and low cloud amount (HCA, MCA and LCA). Cloud types are defined according to ISCCP: high clouds are clouds with  $p_{\text{cld}} < 440$  hPa, low clouds are distinguished by  $p_{\text{cld}} > 680$  hPa and midlevel clouds are inbetween. Cloud detection does not affect HCA which is slightly lower than HCA of TOVS Path-B and in the ITCZ about 10% higher than HCA of ISCCP. Tight cloud detection leads to more LCA, as already observed in the previous figures.

### **Effect of spatial resolution**

In a next step we have investigated the effect of spatial resolution on the cloud property retrieval. For this study we have averaged the AIRS radiances over the spots which have been declared as cloudy by the V1 cloud detection within each AMSU footprint (or ‘golf ball’ consisting of 9 AIRS spots). Then the cloud property retrieval had been applied to the radiance averages. Thus we compare a spatial resolution at nadir of 13 km to one of about 40 km. This procedure is similar to the TOVS Path-B cloud property retrieval which was applied to averages of cloudy HIRS radiances (with an initial spatial resolution of 17 km at nadir) over MSU footprints of about 100 km x 100 km.

The left panel of Fig. 7 compares latitudinal averages of HCA, MCA and LCA from AIRS, using ‘spots’ and using ‘golf balls’, from ISCCP and TOVS Path-B. In general, spatial resolution has only a small effect on these cloud amounts. However, it is interesting to note that in the region of the ITCZ the better spatial resolution leads to 5% less HCA and 5% more LCA.

A more detailed comparison with TOVS Path-B can be obtained by distinguishing seven cloud types, according to  $p_{\text{cld}}$  and  $\epsilon$ : high opaque clouds with  $\epsilon > 0.95$ , cirrus with  $95 > \epsilon > 0.5$  and thin cirrus with  $\epsilon < 0.5$ , and two classes of midlevel and low clouds, each with  $\epsilon > 0.5$  and  $\epsilon < 0.5$ . Fig. 6 presents distributions of these cloud type frequencies for the NH subtropics (15°N-30°N), tropics (15°N-15°S) and SH subtropics (15°S-30°S) over ocean. One observes that the AIRS distributions are more similar to the TOVS Path-B distributions when worsening the spatial resolution. This indicates that probably the thin cirrus amount given by TOVS Path-B is slightly overestimated (by about 5%). These distributions also show that the AIRS cloud retrieval leads to slightly more midlevel clouds and to thicker lowlevel clouds than the TOVS Path-B climatology. Some of these changes can come from improvements in the radiative transfer model 4A and spectroscopy (Jacquinet-Husson et al. 2003) to build a new TIGR dataset. This has to be investigated further when reanalysing the TOVS Path-B dataset.

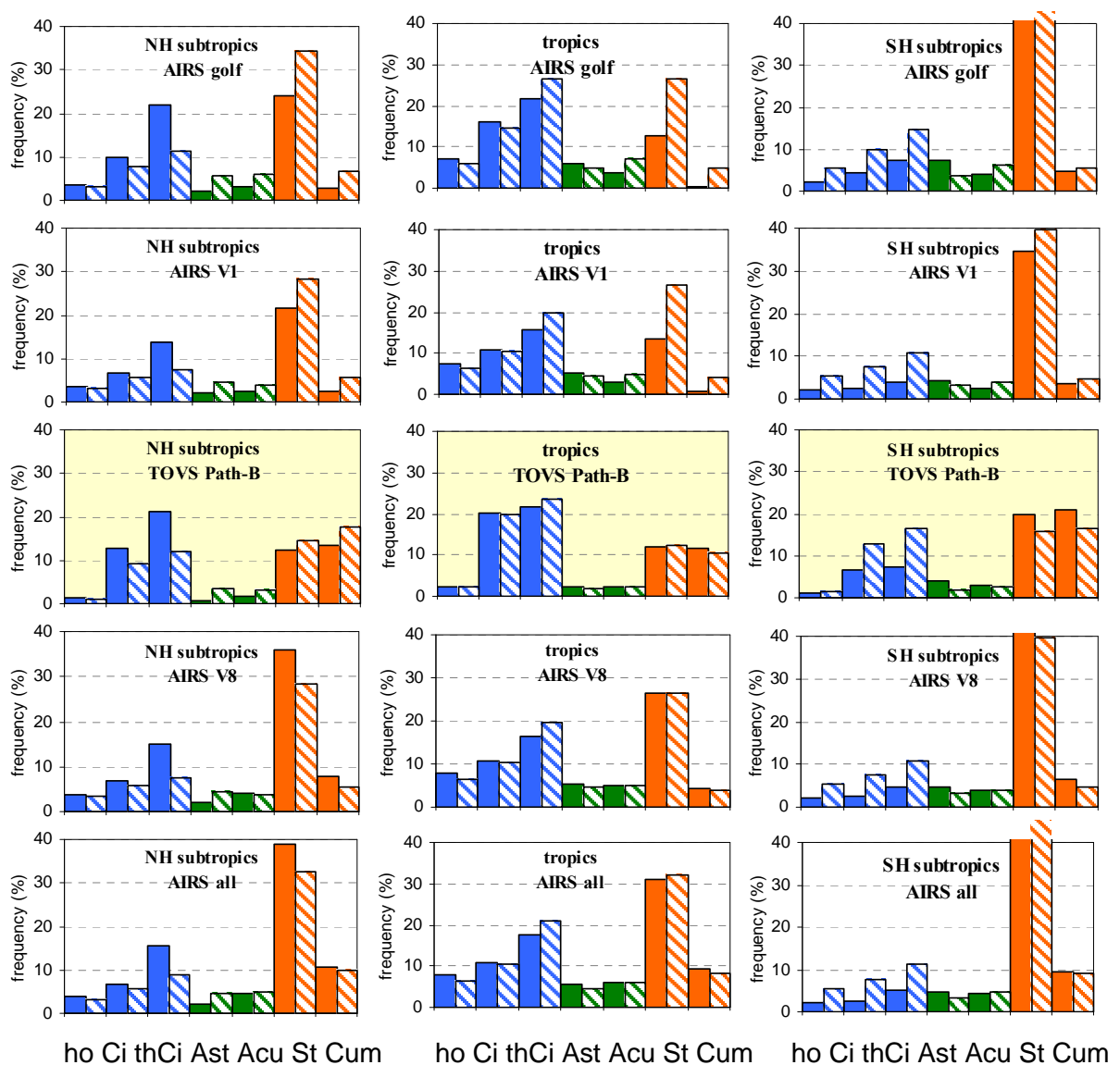


Fig. 6: Frequency distributions of seven cloud types distinguished according to  $p_{\text{cid}}$  and to  $\epsilon$  for NH subtropics (left), tropics (middle) and SH subtropics (right) over ocean, separately for July (plain) and for January (hatched) using different cloud detection and spatial resolution in the AIRS retrieval and from the TOVS Path-B climatology. The cloud types are high opaque, cirrus, thin cirrus, Altostratus, Altocumulus, Stratus and Cumulus.

### Effect of choice in atmospheric profiles

The right panel of Fig. 7 presents latitudinal averages of HCA, MCA and LCA from AIRS, comparing four different treatments to obtain the TIGR atmospheres which are used to compute the clear sky and opaque cloud radiances in Eqs. 1 and 2: the legend ‘1 prof’ corresponds to the case when taking only one TIGR atmospheric profile closest to the AIRS L2 profile (using 21 temperature levels between surface and 106 hPa and 8 water vapour layers between surface and 162 hPa, water vapour difference with weight 2 relative to temperature difference for the proximity recognition). The following cases use more than one closest TIGR profiles (within a maximum distance of  $1.05 \times$  minimum distance): ‘all lev’ corresponds to the case using 23 temperature levels between surface and 70 hPa and 9 water vapour layers between surface and 106 hPa (water vapour difference with weight 2) for the proximity



recognition; ‘fact 2’ corresponds to the case using 21 temperature levels between surface and 106 hPa and 8 water vapour layers between surface and 162 hPa, water vapour difference with weight 2 for the proximity recognition; ‘fact 5’ corresponds to the case using 21 temperature levels between surface and 106 hPa and 8 water vapour layers between surface and 162 hPa, water vapour difference with weight 5 for the proximity recognition.

One observes that the difference between the cases leads to nearly identical latitudinal averages of HCA. Using a weight of 5 instead of 2 leads to a slight increase of MCA (and decrease of LCA) between 15°S and 20°S, which can also be observed on the maps in Fig. 8 (first row). The maps in Fig. 8 show that regional differences in  $p_{\text{cld}}$  are less than 50 hPa.

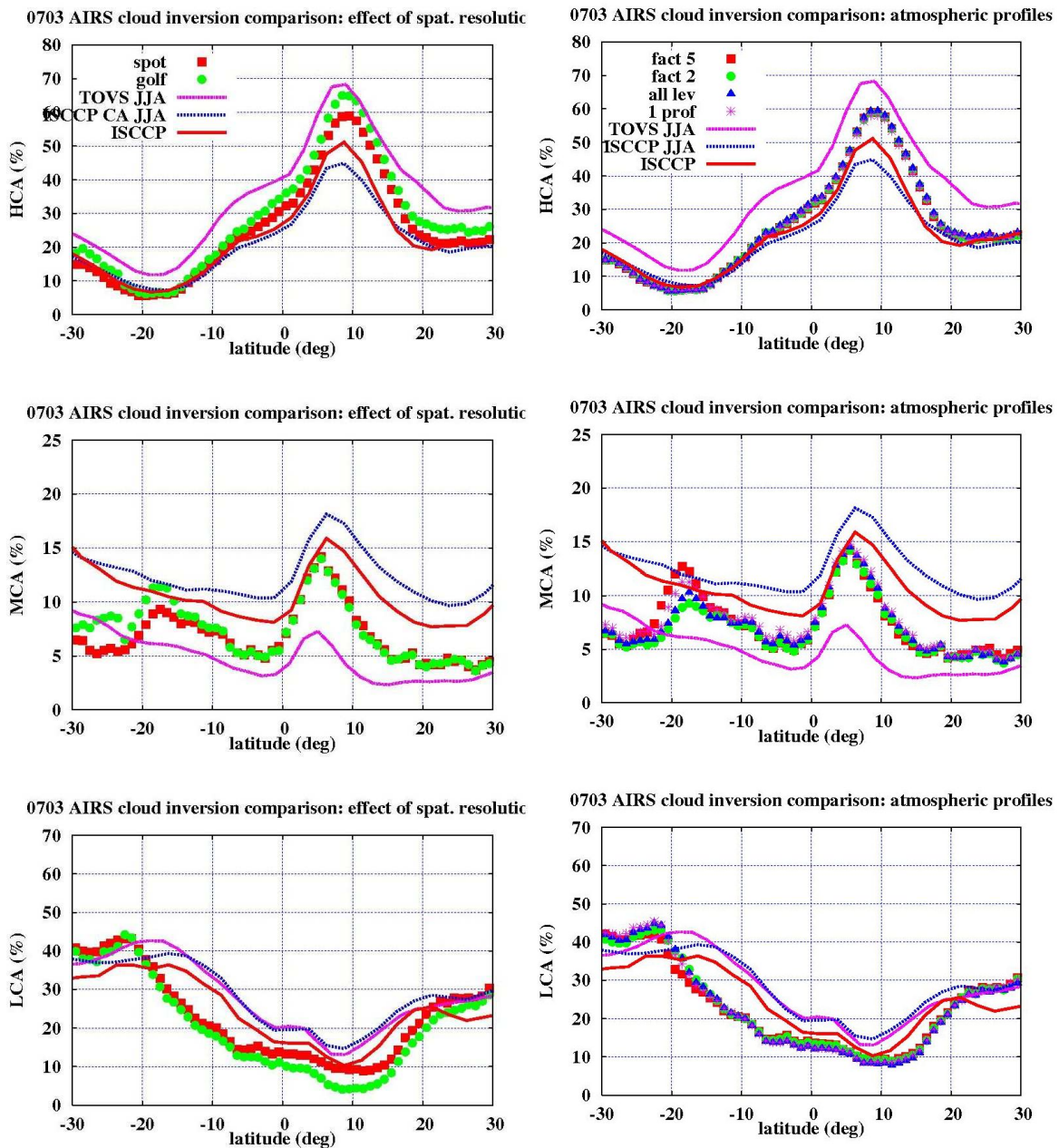


Fig. 7: Latitudinal averages of high, midlevel and low cloud amount (HCA, MCA and LCA) shown for AIRS using different spatial resolution (left panel) and using different proximity recognition between AIRS L2 and TIGR atmospheric profiles (right panel) for the cloud property retrieval, compared to ISCCP (day measurements) and TOVS Path-B data.

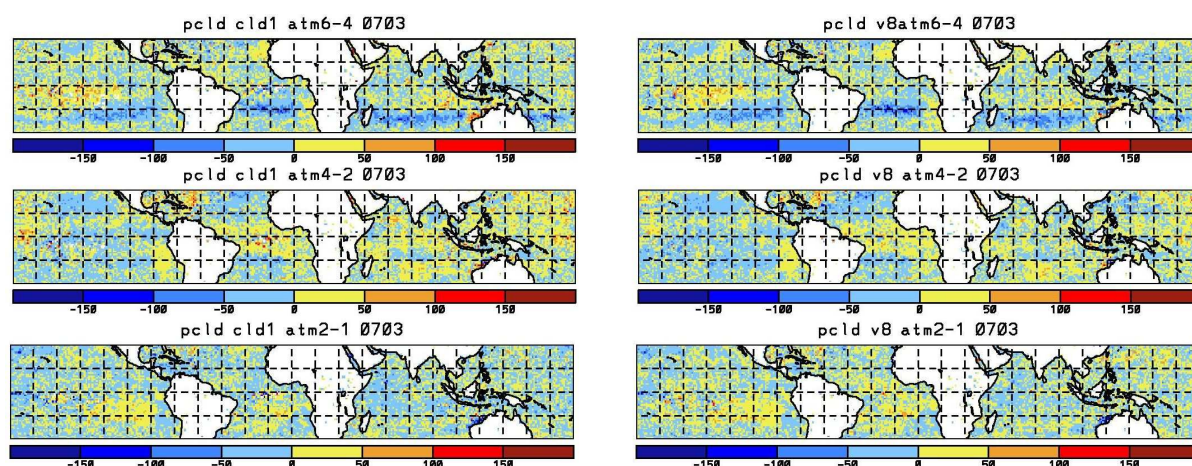


Fig. 8: Geographical maps of differences in  $p_{\text{cld}}$  for July 2003, using different proximity recognition between the AIRS L2 and TIGR atmospheric profiles. Left panel: V1 cloud detection, right panel: V8 cloud detection. First row: versions using weight 5 and using weight 2 (default) for water vapour difference in proximity recognition; second row: version using 21 temperature levels and 8 water vapour layers (default) and version using 23 temperature levels and 9 water vapour layers in proximity recognition; third row: version using several TIGR profiles (default) and only one in proximity recognition.

## Conclusions

First results of the AIRS cloud retrieval using a weighted  $\chi^2$  method on the radiances around the 15  $\mu\text{m}$   $\text{CO}_2$  absorption band have been presented over ocean during night in a latitude band between 30°N and 30°S. The cloud properties retrieved from the AIRS are very similar to those from the TOVS Path-B climatology. AIRS HCA is however about 8% lower, and MCA is 2 to 10% higher. LCA is similar or larger, depending on the season. This is probably closely linked to the cloud detection, which has to be studied more carefully. LCA of ISCCP and of the TOVS Path-B climatology are quite close in July and in January. In the ITCZ AIRS HCA (night) is about 10% larger than HCA of ISCCP (day). A coarser spatial resolution leads to higher HCA in the ITCZ. The ITCZ is much better apparent with AIRS, TOVS and ISCCP than with MODIS data. The AIRS L2 data show in general average cloud pressures which are much lower than the other datasets.

Cloud detection plays an important role in the cloud property retrieval: the tighter the cloud detection the larger the average  $p_{\text{cld}}$  and LCA, because partly cloudy spots are identified as low opaque clouds. This could probably also explain the large averages of  $p_{\text{cld}}$  from MODIS. Adding more channels in the cloud property retrieval did not affect the results, probably because most of the information is already contained in the five channels which sound the atmosphere. The most important factor in choosing the TIGR atmospheric profiles closest to the AIRS L2 profiles is the weight between temperature and water vapour in the proximity recognition, but again the sensitivity is smaller than for spatial resolution or cloud detection.

## References

Chahine, M. T., and Coauthors, cited 2001: AIRS level 2 unified retrieval of core products ATBD. [Available online at [http://eosps0.gsfc.nasa.gov/eos\\_homepage/for\\_scientists/atbd.](http://eosps0.gsfc.nasa.gov/eos_homepage/for_scientists/atbd.)]

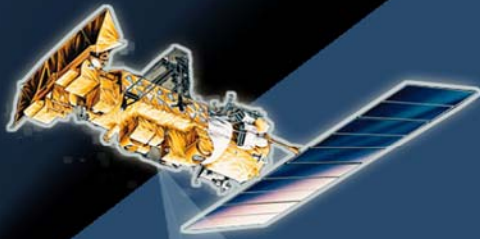
- Chevallier, F., Cheruy, F., Scott, N. A., and Chédin, A. 1998. A neural network approach for a fast and accurate computation of longwave radiative budget. *J. Appl. Meteor.*, **37**, 1385-1397.
- Divakarla, M. G., Barnet, C. D., Goldberg, M. D., McMillin, L. M., Maddy, E., Wolf, W., Zhou, L., and Liu, X., 2006: Validation of Atmospheric Infrared Sounder temperature and water vapour retrievals with matched radiosonde measurements and forecasts. *J. Geophys. Res.*, **111**, doi: 10.1029/2005JD006116.
- Jacquinet-Husson, N., Scott, N. A., Chédin, A., and Chursin, A. A., 2003: The GEISA spectroscopic database system revisited for IASI direct radiative transfer modelling. *Atmospheric and Oceanic Optics*, **16**, 256-282.
- King, M. D., and Coauthors, 2003: Cloud and aerosol properties, precipitable water, and profiles of temperature and water vapour from MODIS. *IEEE Trans. Geosci. Remote Sens.*, **41**, 442-458.
- Péquignot, E., 2006: Détermination de l'émissivité et de la température des surfaces continentales. Application aux sondeurs spatiaux infrarouges HIRS et AIRS/IASI. PhD thesis, 320 pp., available at : <http://ara.lmd.polytechnique.fr>.
- Pierangelo, C., 2005: Apports du sondage infrarouge à l'étude des aérosols atmosphériques. PhD thesis, 282 pp.. Available at : <http://ara.lmd.polytechnique.fr>.
- Platnick, S., King, M. D., Ackerman, S. A., Menzel, W. P., Baum, B. A., Riedi, J. C., and Frey, R. A., 2003: The MODIS cloud products: Algorithms and examples from Terra. *IEEE Trans. Geosci. Remote Sens.*, **41**, 459-473.
- Rossow, W. B. and Schiffer, R.A. 1999. Advances in understanding clouds from ISCCP. *Bull. Amer. Meteor. Soc.*, **80**, 2261-2287.
- Scott, N. A., and Chédin, A. 1981. A fast line-by-line method for atmospheric absorption computations: the 4A Automated Atmospheric Absorption Atlas. *J. Appl. Meteor.*, **20**, 801-812.
- Scott, N. A., Chédin, A., Armante, R., Francis, J., Stubenrauch, C. J., Chaboureau, J.-P., Chevallier, F., Claud, C. and Chéruey, F. 1999. Characteristics of the TOVS Pathfinder Path-B data set. *Bull. Amer. Meteor. Soc.*, **80**, 2679-2701.
- Stubenrauch, C. J., Chédin, A., Armante, R. and Scott, N.A. 1999. Clouds as seen by Infrared Sounders (3I) and Imagers (ISCCP): Part II) A New Approach for Cloud Parameter Determination in the 3I Algorithms. *J. Climate*, **12**, 2214-2223.
- Stubenrauch, C.J., Eddounia, F. and Sauvage, L. 2005. Cloud heights from TOVS Path-B: Evaluation using LITE observations and distributions of highest cloud layers, *J. Geophys. Res.*, **110**, D19203,doi:10.1029/2004JD005447.
- Stubenrauch, C. J., Chédin, A., Rädcl, G., Scott, N. A. and Serrar, S. 2006. Cloud properties and their seasonal and diurnal variability from TOVS Path-B. *J. Climate*, **19**, 5531-5553.
- Susskind, J., C. Barnet, and J. Blaisdell, 2003: Retrieval of atmospheric and surface parameters from AIRS/AMSU/HSB data in the presence of clouds. *IEEE Trans. Geosci. Remote Sens.*, **41**, 390-409.

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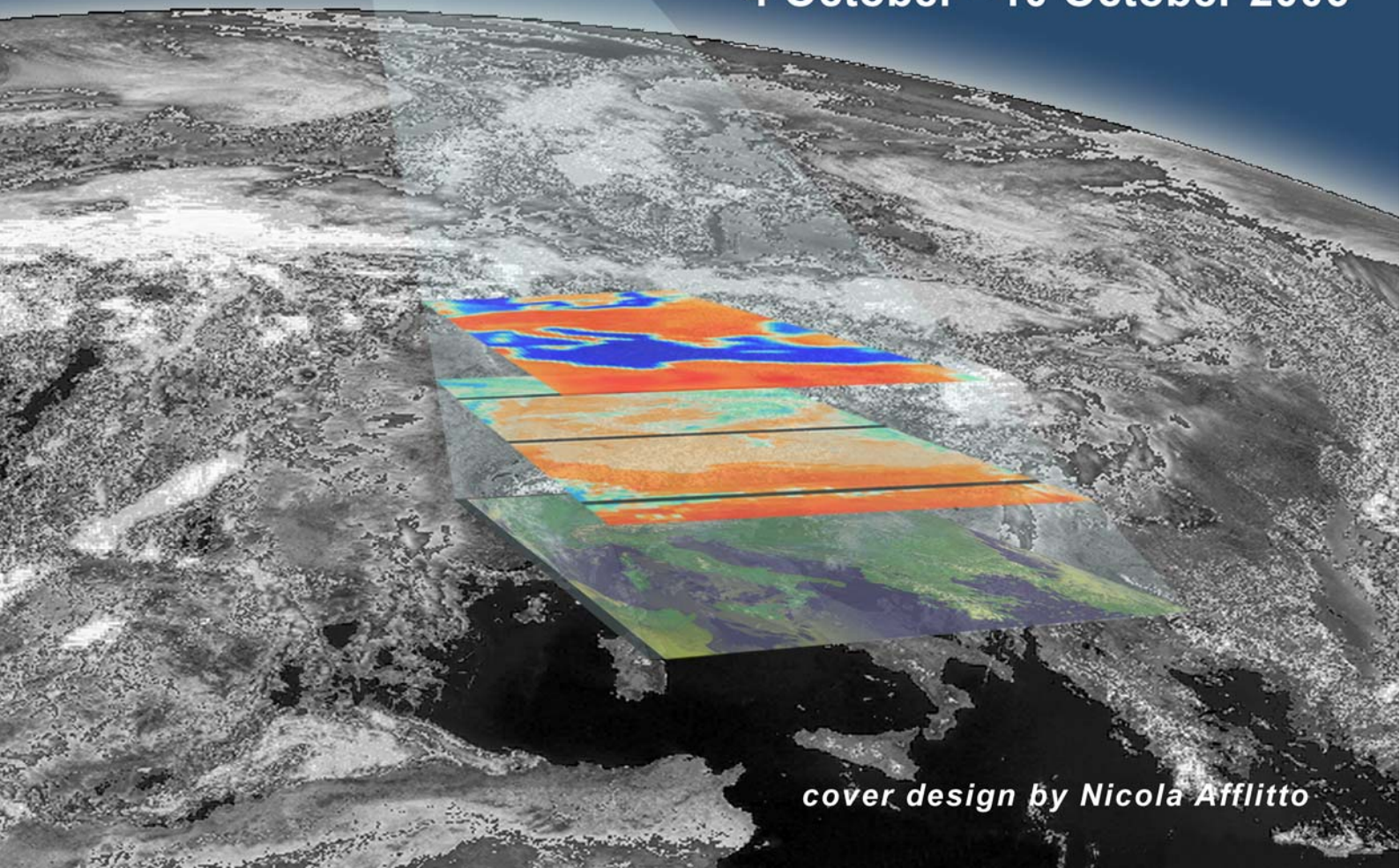
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