

Cloud Parameters from Infrared and Microwave Satellite Measurements

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INTRODUCTION

Due to the crucial role of clouds, the knowledge of the horizontal and vertical distribution and the optical properties of globally distributed clouds is of fundamental importance to the understanding of the Earth radiation and heat balance, and of weather and climate of the atmosphere. Measurements of radiation from space play a fundamental role in helping us to understand how radiation depends on cloud properties. They can also help us to identify which are the most critical cloud properties to measure. The advantage of satellite-based measurements is that they offer the only practical way of making cloud measurements over the entire globe. The improvement of spatial resolution and spectral characterisations of satellite sensors allows us to apply sophisticated retrieval procedures and to derive new cloud products with enhanced accuracy. Since clouds are practically opaque in the infrared frequencies and since the majority of the clouds are transparent in the microwave regions, it appears that a proper combination of infrared and microwave measurements may be useful to determine the cloud coverage and the vertical cloud structure and composition.

First of all the paper explores the performance of a cloud detection scheme applied to Atmospheric Infrared Sounder (AIRS) data, then it explores the errors in CO₂-slicing cloud top height retrievals due to the presence of multilayered clouds, and finally the improvements in retrieving cloud parameters using a combination of microwave and AIRS data

AIRS CLOUD DETECTION VALIDATION

Cloud detection depends on the contrast between cloudy and cloud free pixels. The contrast depends on wavelength, thus a multispectral approach gives more reliable results. Cloud free and fully cloudy pixels considerably differ in their spectral properties and allow simple threshold techniques. Partially cloudy pixels always require a decision about their cloud coverage. In the microwave region thin clouds have a negligible effect on the radiances. For this reason using information from AMSU data can be useful to improve cloud detection algorithm. The threshold tests based on AIRS/AMSU inter-channel regressions allows us to detect all the overcast FOVs. Thin clouds, cirrus and partially cloudy FOVs are detected using IR threshold tests (windows channel tests, AIRS inter-channel regression tests, polar regions tests, horizontal coherency tests).

Using RTTOV (J. Eyre, 1991) and RT3 (Amorati et al, 2002) forward models, spectral clear radiances and spectral cloudy radiances are calculated for different cloud types in order to compute the dynamic thresholds. The dynamic thresholds are a function of observing geometry and they are selected on the basis of AMSU brightness temperature, of liquid water path derived from AMSU, and the highest AIRS brightness temperature values in the AIRS granule. In order to validate the AIRS cloud detection, the MODIS (Moderate-Resolution Imaging Spectroradiometer) cloud mask is collocated within the AIRS footprint. MODIS measures Earth radiances in two visible bands at 250 m resolution, in five other visible bands at 500 m resolution and the remaining bands at 1 km resolution.

The cloud detection is performed at 1 km resolution for all scenes and also at 250 m in daytime only (Ackerman et al, 1998). AIRS cloud mask have been compared with those derived from MODIS data. The AIRS FOVs is declared clear if a fixed percentage (70%, 90% and 100%) of MODIS pixels within AIRS IR FOV has been determined to be confidently clear or probably clear. The three different cloud mask obtained in this way have been compared with the cloud mask derived from AIRS cloud detection algorithm. Table 1 lists briefly the data set used for the exercise, encompassing different areas and months and Table 2 shows the results of the comparison.

Tab.1 Data set used: 1500 AIRS and MODIS granules collocated on SEVIRI data set.

SEVIRI DATA SET		
28 OCT	2004	DAY/NIGHT
20 NOV	2004	DAY
10 DEC	2004	DAY/NIGHT
15 JAN	2005	NIGHT
15 FEB	2005	DAY
20 MAR	2005	DAY/NIGHT
15 APR	2005	NIGHT
01 MAY	2005	DAY/NIGHT

When MODIS is used to validate an AIRS cloud detection scheme, it is very important to take into consideration the different spatial resolutions of the sensors. The MODIS cloud-tests generates a cloud mask on the MODIS grid, and then it must be convoluted into the AIRS grid; only the clear (i.e detected as clear) MODIS FOVs contribute to determine the percentage clear on AIRS grid. When there are many partially cloudy MODIS FOVs, AIRS FOV results have an high fraction of cloud coverage even if this does not necessarily imply that the AIRS radiances are strongly affected by these clouds. MODIS often overestimates cloud fraction on AIRS grid and the percentages reported in Table 2 overestimate the number of failures.

In the same way the SEVIRI cloud mask (SAF/NWC) is collocated within the AIRS footprint. AIRS cloud mask have been compared with those derived from SEVIRI data. The AIRS FOVs is declared clear if a fixed percentage (70%, 90% and 100%) of SEVIRI pixels within AIRS FOV have been determined to be clear and the three different cloud mask have been compared with the cloud mask derived from AIRS cloud detection algorithm. Table 3 shows the comparison for the whole data set.

Tab.2 Comparison between AIRS and MODIS cloud masks at AIRS resolution.

MODIS CLEAR FOVS PERCENTAGE	FOVS DETECTED EXACTLY
70 %	84.1 %
90 %	96.3 %
100 %	90.7 %

Tab. 3 Comparison between AIRS and SEVIRI cloud masks at AIRS resolution.

SEVIRI CLEAR FOVS PERCENTAGE	FOVS DETECTED EXACTLY
70 %	86.3 %
90 %	96.7 %
100 %	93.7 %

Finally a comparison between MODIS and SEVIRI cloud mask has been carried out for the complete data set at SEVIRI resolution and the overall result is that the FOVS detected in the same way by MODIS and SEVIRI represent the 95.4% of the total number of SEVIRI FOVS. Detailed examination of the results has shown that the differences between MODIS and SEVIRI cloud mask are due to incorrect detection of clouds over snow-covered surface. The AIRS algorithm detects low stratiform clouds better than MODIS and SEVIRI.

MULTILAYERED CLOUD DETECTION

Current satellite cloud retrievals are usually based on the assumption that all clouds consist of an homogenous single layer despite the frequent occurrence of cloud overlap. As such, cloud overlap usually cause large errors in the retrievals of many cloud properties. In this study, we investigate the errors in CO₂-slicing (Wylie and Menzel, 1989, 1991) AIRS cloud top pressure retrievals due to the presence of multilayered clouds. When many layers are present, CO₂ slicing produces cloud top pressures located somewhere between the upper and lower cloud layers. Different methods have been proposed to detect multilayered clouds using passive remote sensing data and for this study we have used two. The first is based on MODIS data (Baum et al. 1995) and identifies MODIS pixels that contain thin cirrus overlying lower-level water clouds. We use the 2.13 μm band reflectance (for daytime), the 8.5 and 11 μm band brightness temperatures and the MODIS retrieved CO₂ slicing as a function of observed 11- μm BT. The second method is based on AIRS and AMSU data and multilayered clouds are identified as those cloudy FOVs that have significant differences between the IR and MW cloud top temperature. CO₂ slicing has been used to retrieve cloud top pressure from AIRS infrared data. Based on radiative transfer principles, this technique is independent of intrinsic cloud properties and knowledge of the fraction of cloud cover is not required. It also allows both the calculation of cloud top altitude and cloud emissivity from a temperature profile and the profiles of atmospheric transmittance for two spectral channels sufficiently close. In this study ECMWF temperature and humidity profiles have been used. The cleared AIRS brightness temperature have been estimated using the Kriging cloud scheme (Cuomo et al. 1999). In order to improve the number of AIRS FOVs cleared, MODIS data have been introduced in the scheme. The root mean square error of the Kriging clear brightness temperatures estimates is well below 0.5 °K for any AIRS channels and the bias is about ± 0.1 °K. In order to retrieve microwave cloud top height a lookup table for clear and cloudy AMSU/B brightness temperature was produced. To estimate LWP, Cloud water content (CWC, liquid or ice), and microwave cloud top T(MW), the infrared cloud top T(IR) is used to select a value of T(MW) and LWP from the lookup table to start AMSU simulation. If the difference between the observed and the estimated reaches a minimum, the retrieval process finishes, otherwise the cloud top is displaced downward and the steps are repeated. If the minimum is not reached the other parameters (CWC, LWP) are also changed. Figure 1 shows the infrared cloud top temperature as a function of microwave cloud top temperature. Where large differences are found between the two cloud top temperatures (microwave and infrared) correspond to multilayered clouds, as detected from collocated MODIS data.

AIRS CLOUD TOP HEIGHT RETRIEVAL

The cloud top height has been estimated using a new approach for all the FOVs where multilayered clouds are detected. A modified RT3 code searches for the best solution, simulated brightness temperatures are compared to the observed for a selected set of 300 AIRS channels. Cloud top estimated using CO₂ slicing is used to start the simulation. If the difference between the observed and the estimated reaches a minimum, the retrieval process finishes, otherwise the cloud top is moved up. The 300 AIRS channels have been selected on windows and CO₂ absorbing regions. Figure 2 is a

scatter plot of cloud top height estimated from cloud radar and using CO₂ slicing (red dots) and this new approach (green dots).

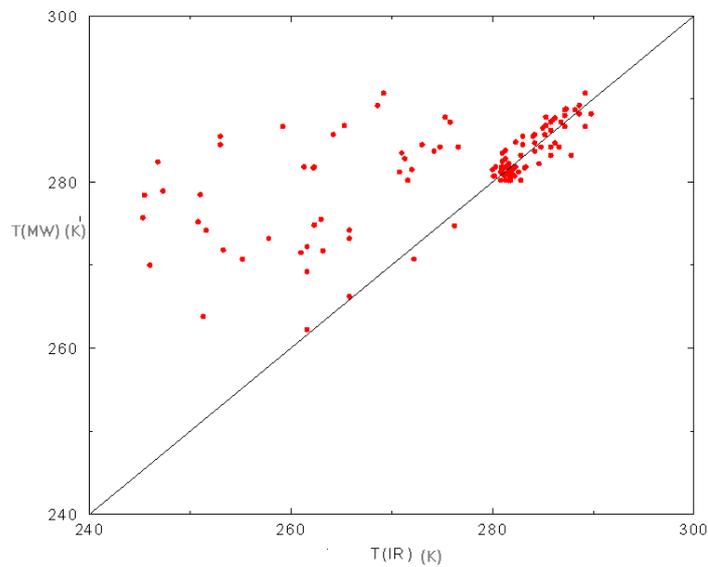


Fig.1 Infrared Cloud top as function of microwave cloud top

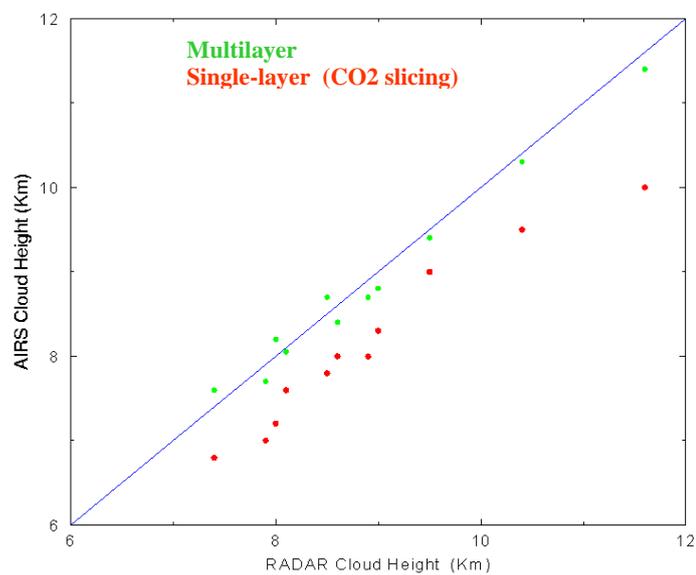


Fig.2 Comparison between the cloud top pressure estimate by CO₂ slicing (red) and using this new approach (green).

The new technique shows a better agreement with the ground-based radar estimates of cloud top height.

In case of multi-level cloud the technique described in preceding section can be used to find the best solution for the second level cloud parameters using observed and simulated (by running the modified RT3 code) brightness temperatures at AMSU/B frequencies. At the present time a detailed comparison of retrieved multi-level cloud parameters, as explained in the previous paragraphs, against the values retrieved from ground based radar and microwave radiometer data (MW) is being done. The first results are very encouraging and Figure 3 and Table 4 provides an example.

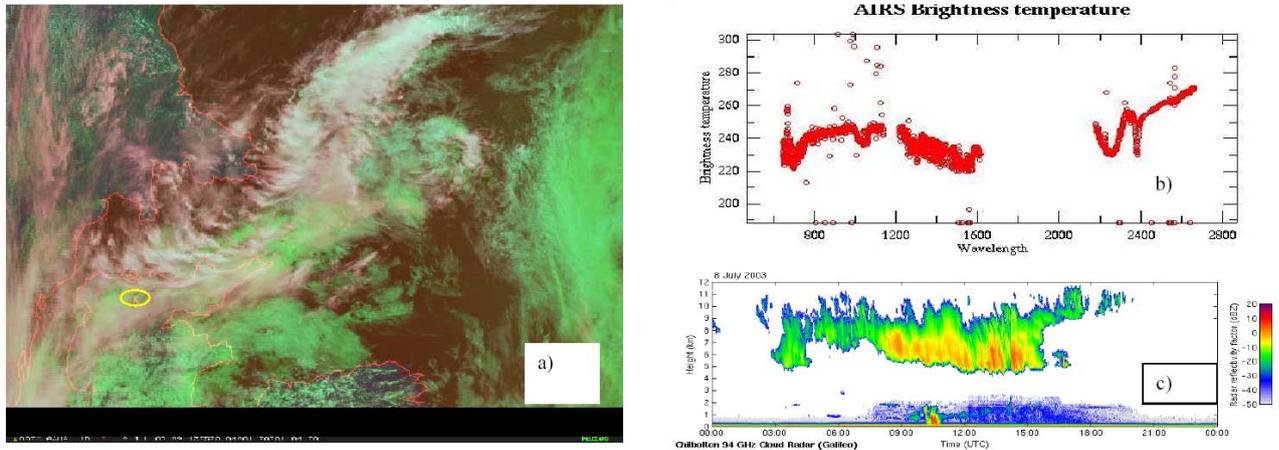


Fig.3 a) MODIS image (note the red dot inside a yellow ellipse denoting the Chilbolton site; b) AIRS spectrum over Chilbolton (measured at 13.25 UT of 08/07/2003); c) cloud radar time-height cross section for same day.

Tab. 4 Preliminary comparison between cloud parameters retrieved from satellite and ground- based instrumentation at the Chilbolton site and ECMWF fields.

Variable	Radar	MW	AIRS	AMSU/B	ECMWF
Top cloud layer: cloud top height (km)	9.35		9.50		
Top cloud layer: cloud thickness (km)	4.20		4.30		
Lower cloud layer: cloud top height (km)	1.30			1.00	
Lower cloud layer: cloud thickness (km)	1.10			0.80	
Liquid Water Path (LWP kg/m^2)		0.09		0.12	0.11
Integrated Water Content (IWC kg/m^2)		31.9		30.5	29.7
Ice Content of top cloud layer (ICW kg/m^3)		0.026		0.019	0.030

CONCLUSION AND FUTURE WORK

A proper combination of infrared and microwave measurements can be usefully exploited to determine the cloud coverage and the vertical cloud structure. AIRS cloud mask has been validated using MODIS and SEVIRI collocated data. In this study the errors in CO_2 -slicing cloud top height retrievals due to the presence of multilayered clouds have been investigated. Since the CO_2 -slicing technique assumes a single cloud layer, when two cloud layers are present the result is a cloud top height located somewhere between the upper and the lower cloud layer. The new approach, based on the comparison between measured and simulated data for 300 AIRS selected channels, gives preliminary results that agree reasonably well with values derived from ground-based radar and microwave and is being extended to a large data set.

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