A cloud detection approach for AIRS radiance assimilation

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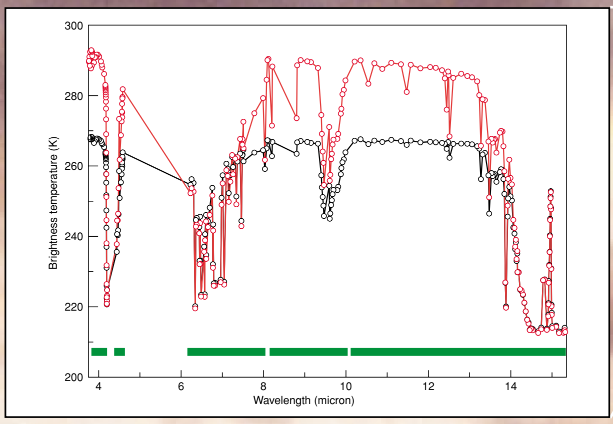
Input spectra: Observed cloudy and Simulated (NWP) clear-sky



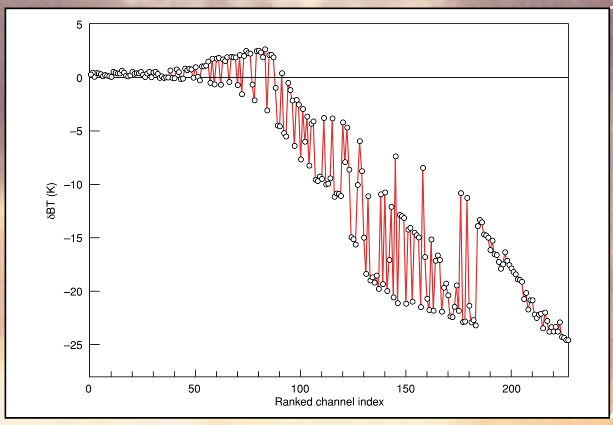
1 THE AIRS RADIANCE CLOUD DETECTION is based on comparison of the measured (and therefore potentially cloud affected) radiances with our best estimate of the cloud free values. The cloud-free values are obtained from a radiative transfer model calculation [RTTOV-6 (*Matricardi et. al.*)] based on the ECMWF forecast model analysis at time of observation.

We employ an enhanced version of the RTM (*Chevallier et. al.*) to simulate the AIRS measurements, combining both the ECMWF model atmospheric and cloud fields in the forward calculation. Realistic errors are added to the simulations:

To the measurements we add random realisations of **O**, based on Flight Model characterisation (http://www-airs.jpl.nasa.gov) and to the cloud-free estimates we add random realisations of $\mathbf{H.B.H^T}$ based on a characterisation of the ECMWF model errors, **B**, in temperature, humidity and Ozone, mapped into measurement space using the channel Jacobians, **H**.

Fig 1 shows a simulation of the input spectra to the cloud detection scheme. AIRS measurements and the modelled estimates of the clear radiances are shown in black and orange respectively. The 228 channels of the preliminary NRT dissemination are simulated. That shown is for a moderately cloud contaminated sounding; maximum clear-cloudy departures of around 20 K are seen in the window regions. High peaking channels in the strong absorption bands show low departures and indicate channels free of cloud effects. [Green bars show 'bands' (see **3**)].

State dependent ranking of channels by cloud sensitivity



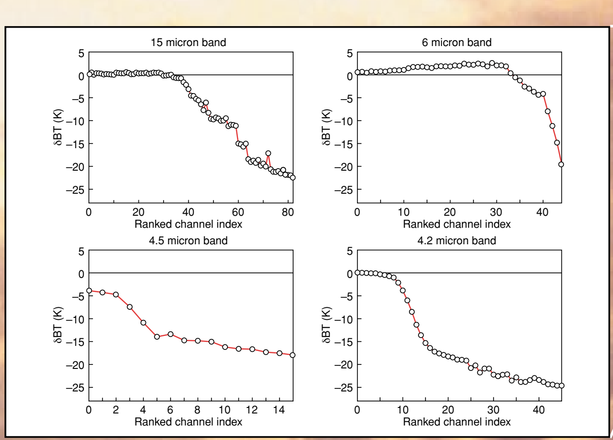
2 To meet our objective of retaining measurements in channels that are sensitive to the atmosphere ***above*** the cloud, it is necessary to determine the channels relative position, or ranking. Various measures to determine this ranking are possible; the one adopted is based on the simulated radiative effect of full cover single layer black cloud since this a) is a close approximation to the sensitivity we require and b) is readily obtained from standard RTTOV-6 output. Each channel is assigned the lowest level (in RTTOV-6 coordinates, or equivalently a pressure) at which the presence of the single layer opaque cloud causes a 1% change in radiance (or either sign), i.e. where:

$|R_{clear}-R_{slbc}(p)|/R_{clear} > 0.01$

The channels are then sorted according to the assigned levels. This operation is performed for each sounding, i.e. the ranking is based on the local NWP model state.

Fig 2 shows the brightness temperature differences (δBT; measured minus model clear) for the sounding shown in Fig 1 plotted in the ranked order. The general trend of increasing cloud effect as the channels lower in the atmosphere (towards higher channel number) can be seen. Superimposed on this trend are model errors and the variable sensitivity to cloud caused by wavelength dependent absorption characteristics.

Band separation



3 The strong wavelength or 'band' dependency of cloud effect, shown in Fig 2, has two consequences. Firstly, the effective cloud level and therefore clear measurement selection cannot be optimum for all bands if they are treated together. For example, as the shorter wavelengths scatter more and are less cloud affected, channels peaking lower than equivalent longer wavelength band channels can often be used. Secondly, the rapid oscillations of the δBT signal make identification of the effective cloud level difficult (although, strictly, the Bayesian method (see **4**) is not affected by this). The definition of bands used is:

'15 μm' CO_2: 15.4 to 10 μm
'9 μm' O_3: 10 to 8.09 μm
'6 μm' H_2O: 8.07 to 6.23 μm
'4.5 μm' CO_2: 4.58 μm to 4.44 μm
'4.2 μm' CO_2: 4.20 μm to 3.75 μm

Fig 3 shows the brightness temperature differences δBT from Fig 2 after channels have been separated into bands (the 9 μm band is not shown). The characteristic cloud signal is now seen more clearly with a distinct 'shoulder' indicating the highest channel affected. NWP model noise can been seen (clearly in the 6 μm band) and this can, especially in cases of weaker cloud effect, make the location of the lowest cloud-free channel problematic.

Pattern recognition: Bayesian or Low-pass filter

Determination of clear and cloud affected channels

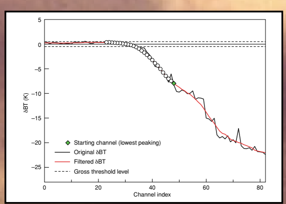


Fig 4 shows the operation of the low-pass filter method to the 15 μm band for this sounding. The black line is the original δBT vector and the red line the vector after applying a **low-pass filter** (boxcar smoother of length 10 channels in this case). From a starting channel (~47) the algorithm moves upwards until there is no significant gradient; this defines the transition channel (23)

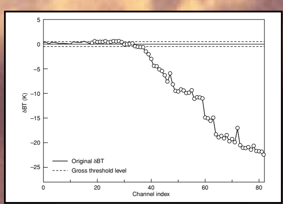


Fig 5 shows the result of applying the **Bayesian** detector to the same sounding and band as figure 4. Circles mark channels designated cloudy and, in this case, only channels with a ranking below 18 are deemed cloud-free. Both detection methods apply the gross check that the |δBT| of the transition channel is less than a threshold (0.5 K here), if this fails, the entire sounding is rejected.

4 The challenge of the cloud detection module is to successfully discriminate in the band-ranked δBT signal between observation and NWP model noise and the signal due to cloud. Two methods have been developed to achieve this:

a Based on the assumption that, in channel ordered space, a cloud signal will monotonically increase (in the direction top of atmosphere downwards) from the first affected channel. Once a significant cloud signal is detected in a low peaking channel, the δBT signal is analysed 'upwards' to establish the point at which the cloud signal ends and thus establish the first cloud-free channel. A **low pass filter** is required to smooth high frequency $\mathbf{HBH^T+O}$ noise and prevent the filter stopping prematurely.

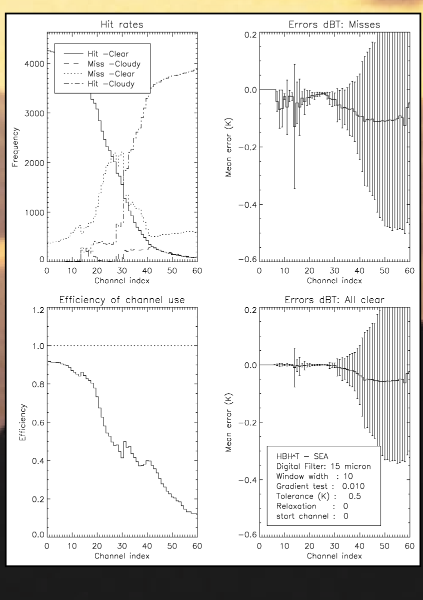
b A **Bayesian** method works by testing the probability that a measured δ**BT** vector has come from a clear sounding (*English and Eyre 1999*). Statistics of clear soundings are known since they are described by $\mathbf{HBH^T+O}$. The method is extended to detect clear channels ***within*** a sounding by testing successive segments of the entire channel set from the top of atmosphere downward. When a segment returns a sufficiently low probability of being clear, then all the channels within the segment and below are considered cloud affected.

Both methods detect 'warm' cloud over 'cold' surfaces as well as the more usual 'cold' cloud.

Performance Evaluation

Fig 6 is an analysis of the performance of the low-pass filter method for the 15 μm band over several orbits of simulated AIRS data. With simulation, the true cloud effects are known. **UPPER LEFT** plot shows that hits (solid and dot-dash) dominate the results but a significant number of missed clears are found for channel numbers between 20 and 40 (the bulk of the tropospheric channels). Missed cloudy channels are apparent in low numbers from channel 15 to the surface. The efficiency plot, **LOWER LEFT**, shows that a good proportion of upper level channels is utilized, and low peaking channel usage, e.g. channel 40, remains as high as 40%. Mean errors in the cloudy misses, **UPPER RIGHT**, are quite small (absolute values <0.05 K) for channels down to number 30 although some higher standard deviations are seen. Below this, mean errors increase steadily to about -0.1 K and standard deviations to about 0.4 K. Around the last tropospheric, non surface sensing, channel 40, the mean error is about –0.1K and the standard deviation around 0.15 K. The statistics for the all-clear cases **LOWER RIGHT** show the higher channel values reduced significantly because of domination by the clear hits. For lower channels the mean error asymptotes at around –0.06K with a standard deviation around 0.3K. At channel 40 the mean and standard deviation are respectively, –0.04 and 0.1K. This performance is quite reasonable compared to an AIRS instrument noise of around 0.2K in this band. The results described here are for an assumed noise in the surface skin temperature of 1 K, i.e. an ocean-type surface accuracy. However, results for an assumed error of 5 K, i.e. a land-type accuracy, are very similar.

Results for the Bayesian detector (not shown) are comparable, and both detectors are being developed prior to the availability of real AIRS data.



Use of cloud-free channels

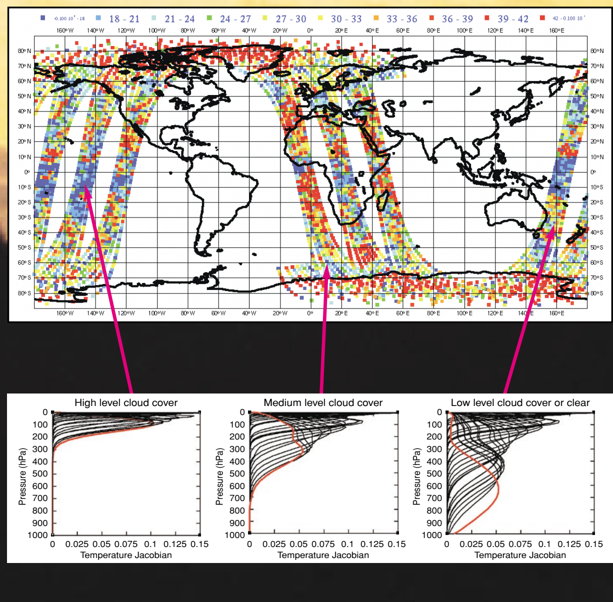


Fig 7 **ABOVE** map of the index of the lowest cloud-free channel in the 15 μm band as detected by the low-pass filter method. **BELOW** temperature Jacobians of channels detected as cloud-free in various soundings indicating potential channel availability using these detection methods.