D Band Cloud Flagging Anomaly

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Contents

1 Introduction

The presence of cloud particles in the field of view of infrared remote sounding instruments influences observations and measurements registered, due to extraneous absorption, emission and scattering features in a large range of wavelengths. While retrievals can cope with small amounts of cloud by fitting a continuum term for each microwindow in parallel with the retrieval of the target species, it is nevertheless important to recognize and to be reliably able to identify the presence of clouds in such measurements before analysis is carried out upon such datasets.[1,5]

There are a couple of a common and simple techniques used to identify the presence of cloud in the field of view of an instrument working in the infrared such as the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), most of which involve thresholding of radiance values. A very basic method is the Simple Radiance Threshold test which simply uses a statistically gathered threshold upon radiance to detect cloud by assuming that clouds have a warmer brightness temperature than a clear limb view. A second generation detection method is Colour Index Thresholding, which improves consistent and reliable detection by reducing the influence of variations in pressure and temperature. Colour indices work on the principle of radiance ratios between two different regions (called microwindows, and denoted MW1 and MW2) of the spectrum which respond differently to cloud. The microwindows are chosen such that the first microwindow MW1 responds very little to the presence of clouds whereas the second microwindow MW2 shows a large reaction.[1,5]

The colour index is defined to be the ratio of the mean radiances of the two microwindows: $CI = \bar{L}_{MW1}/\bar{L}_{MW2}$. When the colour index is large ($CI > 4$, for conventionally chosen microwindows), cloud-free conditions exist and when the colour index is approximately one optically thick clouds are present. The range of colour indices represents the range of optical thickness of clouds present, with thicker clouds appearing blackbody-like with $CI \approx 1$ and thinner, tenous clouds registering increasingly larger colour indices.[1,5]

The presence of cloud is then determined by setting a threshold for the colour index of interest below which it is said that cloud occurs and below which, cloud is said to not occur. In the interest of only conservatively discarding data which is truly contaminated by thick cloud, a low threshold is frequently chosen, below which it is certain that cloud occurs and above which cloud is said to not occur, even though it is well known that above this threshold cloud can indeed occur, either as an optically thin cloud or by only partially filling the instrument field of view.[1,5]

For MIPAS, there are colour indices defined for bands A, B, C and D.

Colour Index	*MW1* (cm^{-1})	*MW2*(cm^{-1})	*Threshold*
CI-A	788.0 – 796.0	832.0 – 834.0	1.8
CI-D	1929.0 – 1935.0	1973.0 – 1983.0	1.8

Table 1: Definition of microwindows and thresholds used in the calculation of colour indices for the A and D bands of MIPAS.

Table 1 defines the quantities important in the calculation of the indices (the microwindows' spectral locations, and the usual threshold value) for the A and D bands.[1,5]

It should be noted that the definition of colour index breaks down above about 30 km due to decreased signal-to-noise-ratio, particularly in the more transparent and intrinsically noisier second microwindow.

In the past, the A band has been confidently used to flag the presence of cloud in MIPAS measurements. It is a useful check to use the other bands available as a verification of cloud as well, and for the most part the colour indices calculated for the different spectral bands yield the same result. Generally, the A and B bands exhibit similar variability while the D band varies much more significantly. There are also cases in which it is only a certain part of the spectrum which is affected by a particular cloud type - for instance, the C and D bands are strongly affected by solar scattering from polar stratospheric clouds (PSCs) so stratospheric retrievals during winter days need to use the D band cloud flag rather than those of the other bands.[2,3,4]

As would be quite predictably expected, there are instances in which the cloud detection by way of calculated colour indices for the various the MIPAS bands do not agree. However quite frequently the D band flags cloud while the A band does not. This is an important observation since it may be possible that the D band may be better suited to detect certain cloud types than the tried-and-trusted A band, and hence occasions whereby the D band flags cloud while the A band does not is treated as a flagging anomaly. As well, it has been suggested that there is a correlation between this flagging anomaly and unrealistically low water vapour volume mixing ratio retrieved values. Furthermore, there appears to be a day/night difference in the behaviour of the D band and indeed in terms of the frequency of cloud flagging. [2,3,4]

This work investigates the behaviour of such anomalous points of MIPAS data using the colour index method as the cloud detection technique, looks at the day/night difference in the D band, and addresses the association of the anomaly with very low water vapour volume mixing ratios.

2 Results

2.1 General Behaviour of A and D Band Colour Indices

The ESA offline Level 1B spectra for the day of 15 August 2003 were used to calculate the colour indices for the D and A bands. The general rule of thumb is to threshold the indices CI-A and CI-D at 1.8, whereby below this value there is definitely cloud and above this value there is no optically thick cloud, although there has been speculation into lowering the D band threshold to 1.2 [4]. It should be noted however that optically thin cloud or optically thick cloud partially filling the field of view can occur with colour indices up to 3 or 4. For comparative purposes, Fig. 1 shows the height distribution of the colour indices of all of the data points measured on 15 August 2003. The A band colour index behaves in a manner that is expected, detecting cloud (CI-A < 1.8) at lowish altitudes ($5 - 20$ km) and not detecting cloud in higher regions where there should not be cloud climatologically ($20 - 30$ km). Above 30 km, the definition of cloud index breaks down due to noise, so it is unimportant that the CI-A values reported for such higher altitudes have quite low values. The D band colour index is less convincing. It does indicate detection of clouds in the lower altitude range where clouds are indeed expected, however the D band exhibits positive detection of clouds in the higher altitude range where there should be no cloud registered. Clearly the A band seems to more reliably flag cloud, whereas the D band, by contrast, detects cloud where there should simply not exist any.

2.2 Correlation of Low H_2O Volume Mixing Ratio and Flagging Anomaly

Previous work done [2,3,4] noted that in the southern hemisphere wintertime there was a correlation between the D band flagging but the A band not flagging cloud and unrealisticlly low values of water vapour volume mixing ratio (10^{-10} ppmv). These 10^{-10} ppmv values occur when the retrieval records negative values of water vapour volume mixing ratio and are placed simply as a marker of poor data retrieval. If such a correlation does exist between the flagging anomaly and these low water vapour volume mixing ratios, occurrence of the anomaly could be used to predict and avoid bad water vapour retrievals. Fig. 2 shows the existence and altitude distribution of these low water vapour retrieval points for an arbitrary test day, 15 August 2003.

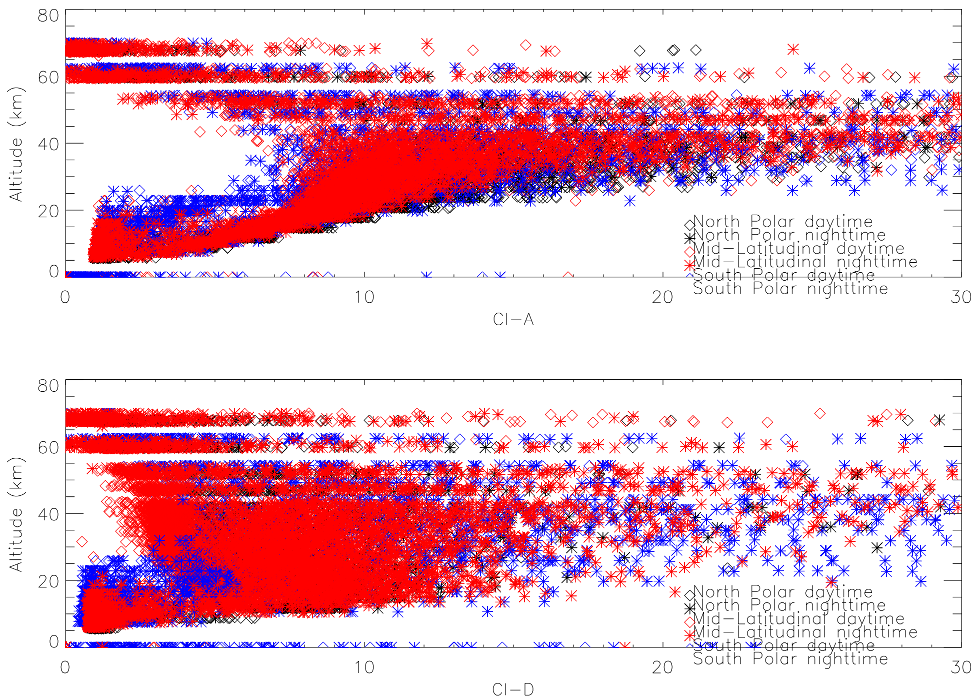

Figure 1: Height distribution of CI values for all data points taken on 15 August 2003, filtered into three latitude bins (north polar [60N, 90N], mid-latitudinal [60S, 60N] and south polar [60S, 90S]) and into day- and night-time measurements.

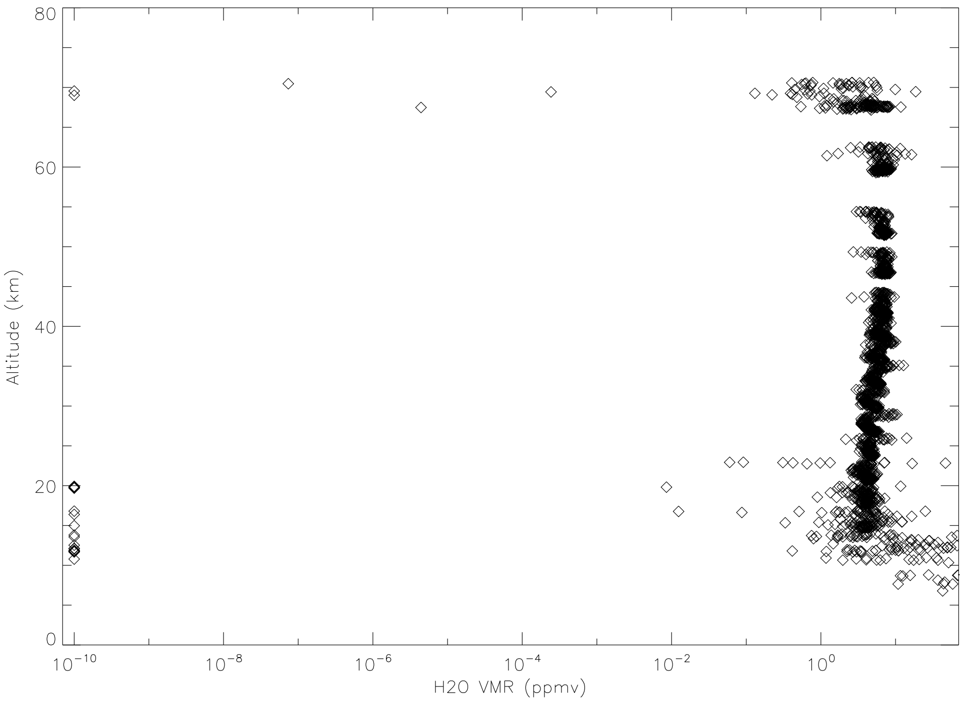

Figure 2: ESA retrieved water vapour profiles for 15 August 2003. Note the extremely low 10^{-10} ppmv values.

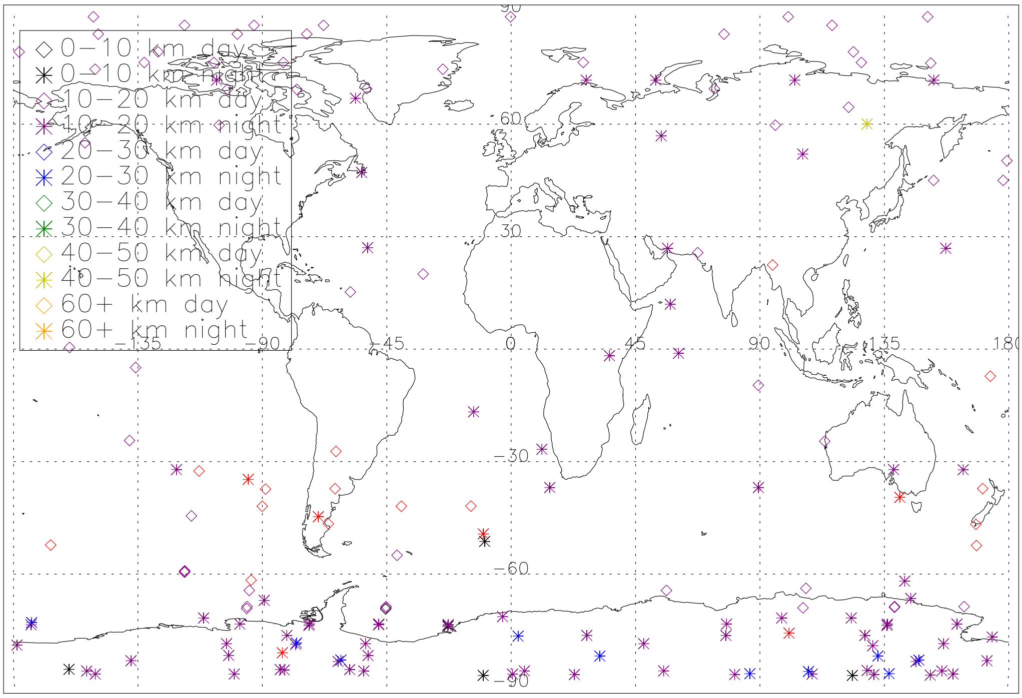

Figure 3: Points having extremely low (10^{-10} ppmv) water vapour volume mixing ratio values for 15 August 2003.

As a starting point, all of the ESA offline retrievals (version 4.61) for 15 August 2003 were filtered to locate the points having water vapour vmr of 10^{-10} ppmv from MIPAS Level 2 data. Fig. 3 shows the geo-location of these points for the day, highlighting whether or not they are day- or night-time points and the altitude range of the tangent height. It is obvious that there exists a fairly random distribution of these points, but that there does appear to be a higher concentration of these in the southern polar region, at fairly low altitudes (less than 20 km) and primarily at night, although this may just reflect the fact that it is antarctic winter.

From the corresponding Level 1B data, colour indices for both the D and A bands were calculated and, if for a given data point the D band flagged cloud but the A band did not flag cloud, an anomalous flagging event was said to occur. It was found that if a measurement had such a low water vapour volume mixing ratio, then 20% of the occurrences exhibited the flagging anomaly.

Conversely, starting first with the Level 1B data and calculating the colour indices, the anomalous flagging situations were obtained. Using then the corresponding Level 2 retrievals, it was checked if for the given anomalous event the retrieval showed a low water vapour retrieval. It was found that 8 % of the flagging anomalies had low water vapour volume mixing ratios and could thus be associated with bad water vapour retrievals.

The correlation between the flagging anomaly and the extremely low water vapour volume mixing ratio retrievals is thus weak at best, and hence occurrence of the anomaly cannot be used as a detection mechanism for bad water vapour retrievals. For instance, if one were to use the flagging anomaly as a filter for poor water vapour retrievals, in all probability over 90 % of the discarded data would indeed have yielded good retrievals.

2.3 Calculation of CI-A and CI-D for Low H_2O VMR Events

The Level 1B spectra corresponding to these low Level 2 water vapour volume mixing ratio retrieval values were obtained, and for these the colour indices for the D and A bands were calculated. Fig. 4 shows the corresponding colour indices for the A and D bands of the low water vapour volume mixing ratio values plotted against each other - clearly there exist quite a few instances of this anomaly.

Looking at the region of interest, where CI-D $\leq$ 1.8 but CI-A $\geq$ 1.8 (D flagged but A unflagged), Fig. 5 indicates that most of the instances occur in the southern polar region at daytime and hence can be, given the altitude registered, taken to be polar stratospheric clouds. It is important to note, however, that even though the A band technically does not flag the presence of these PSCs, CI-A is still sufficiently low in most of the cases that it would be assumed that cloud existed. The majority of the mid-latitude cases registered are noted to correspond to high altitudes (tangent heights of more than 45 km) and are disregarded since the definition of colour indices breaks down at about 30 km altitude due to increased noise levels.

2.4 Radiance Spectra of Anomalous Points

Next, the radiance spectra of the lower-altitude mid-latitude instances were compared with standard spectra obtained from the RFM (including the ten most absorbing atmospheric species and non-LTE effects) and experimentally from Level 1B data. Fig. 6 exhibits the standard daytime clear sky and cloudy radiance spectra in the A and D bands.

It is worth noting that several definitive features of the standard spectra:

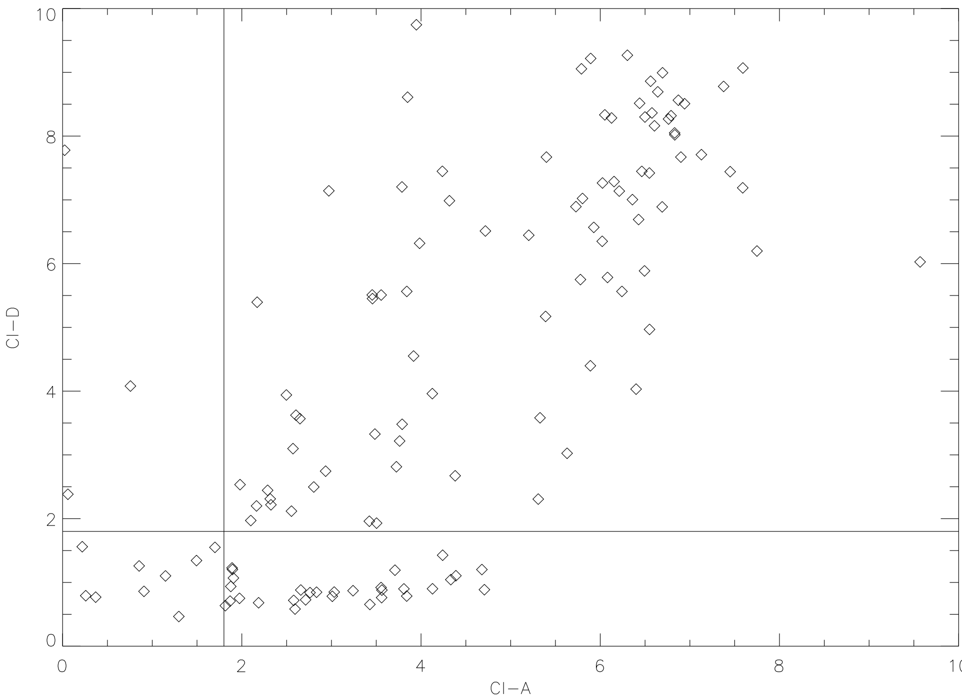

Figure 4: Colour indices for the D and A bands of points having extremely low (10^{-10} ppmv) water vapour volume mixing ratio values for 15 August 2003. Note the threshold value of cloudiness is 1.8 in the A band and is taken as either 1.8 in the D band. For the remainder of this work, we will use a threshold of 1.8 for the D band.

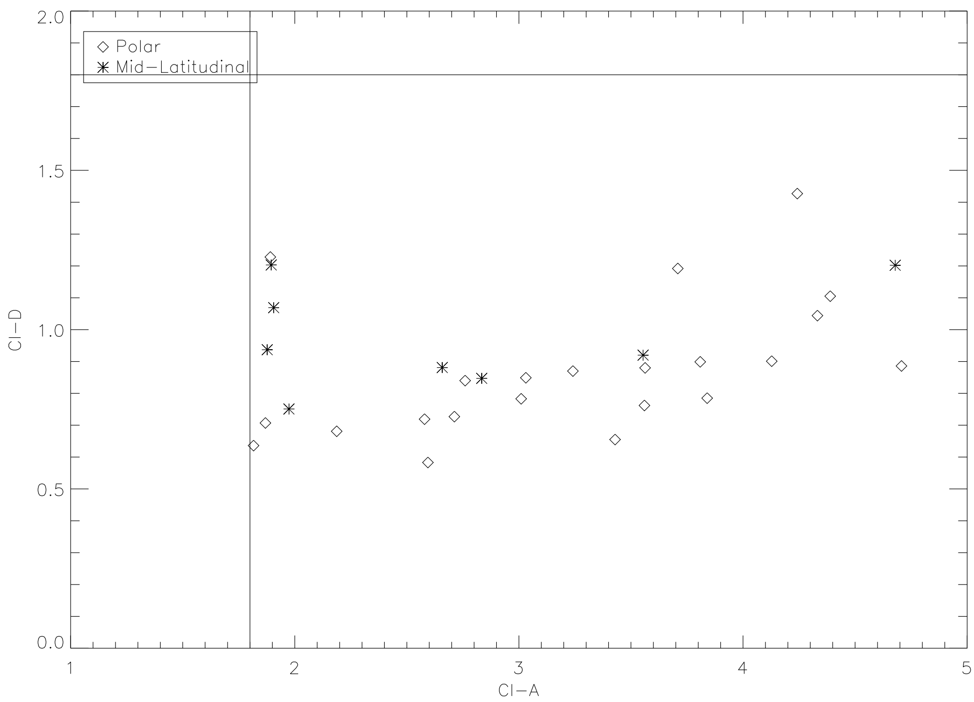

Figure 5: Colour indices for the D and A bands of points having extremely low (10^{-10} ppmv) water vapour volume mixing ratio values for 15 August 2003 within the region of interest where the D band is flagged as cloud but the A band remains unflagged.

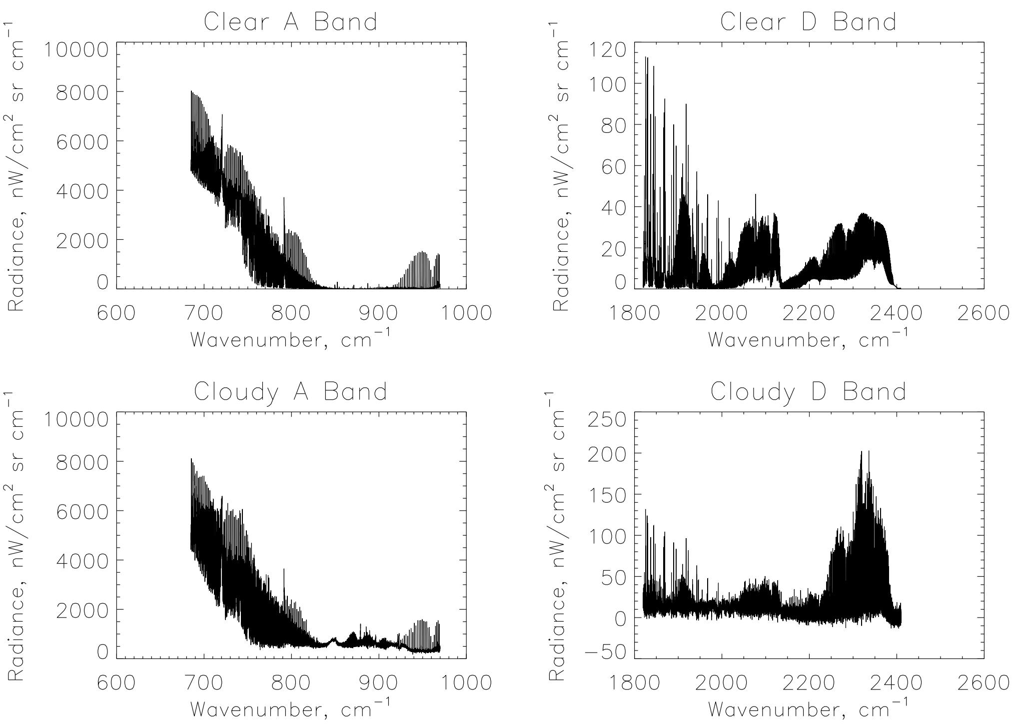

Figure 6: Standard clear sky and cloudy radiance spectra in the two bands of interest, A and D.

- A band clear: level zero-magnitude baseline; day/night spectra have same relative shape;
- A band cloudy: slanted baseline heightened in magnitude above zero; day/night spectra have same relative shape;
- D band clear: level zero-magnitude baseline; day/night spectra have same relative shape;
- D band cloudy: slanted baseline heightened in magnitude above zero; daytime spectra exhibits large non-LTE feature at approximately 2350 cm^{-1};

Comparing these standard spectra to the anomalous spectra (an example of which is shown in Fig. 7), it is obvious that for most of the cases, the A band, though unflagged, does appear to have cloudy spectra. The D band appears to have a non-LTE feature at approximately 2350 cm^{-1} but "matches" the cloudy "day" standard spectrum.

In the hopes of being able to eliminate cloud presence as a possible cause of these anomalies, a search was carried out for instances of low water vapour vmr having the D band flagged for cloud but the A band unflagged in an altitude range of $20 - 30$ km where there should be no clouds in the mid-latitudes. For the test day, there were no such cases, so the search was extended to a month's worth of data. For the month of 15 July 2003 to 15 August 2003, there were only four points showing extremely low water vapour vmr in the mid-latitudes in the desired altitude range and of these, unsatisfyingly, two registered as having flagged D bands but unflagged A bands and the other two points both registered resoundingly as having no clouds present with colour indices of greater than eleven. Hence, it can neither confirmed nor denied thatcloud presence could be causing the flagging anomaly.

Fig.8 following shows the spectrum of one of the two D band flagged spectra. The A band appears to have a clear spectrum, as supported by the relatively high CI-A value of 3.55 however the D band has a strange negative feature located approximately where the non-LTE feature was in the lower-latitude examples (approximately at 2350 cm^{-1}). This negative feature is a fairly strong argument for errors from some source in such spectra.

In fact, it may be that the D band may not be such a reliable candidate for cloud flagging. Since cloud spectra should essentially limit to the Planck blackbody function, it is reasonable to expect that the Planck function should always register a positive cloud flag. Using typically height-varying temperatures, the colour indices for the Planck function were evaluated for the A

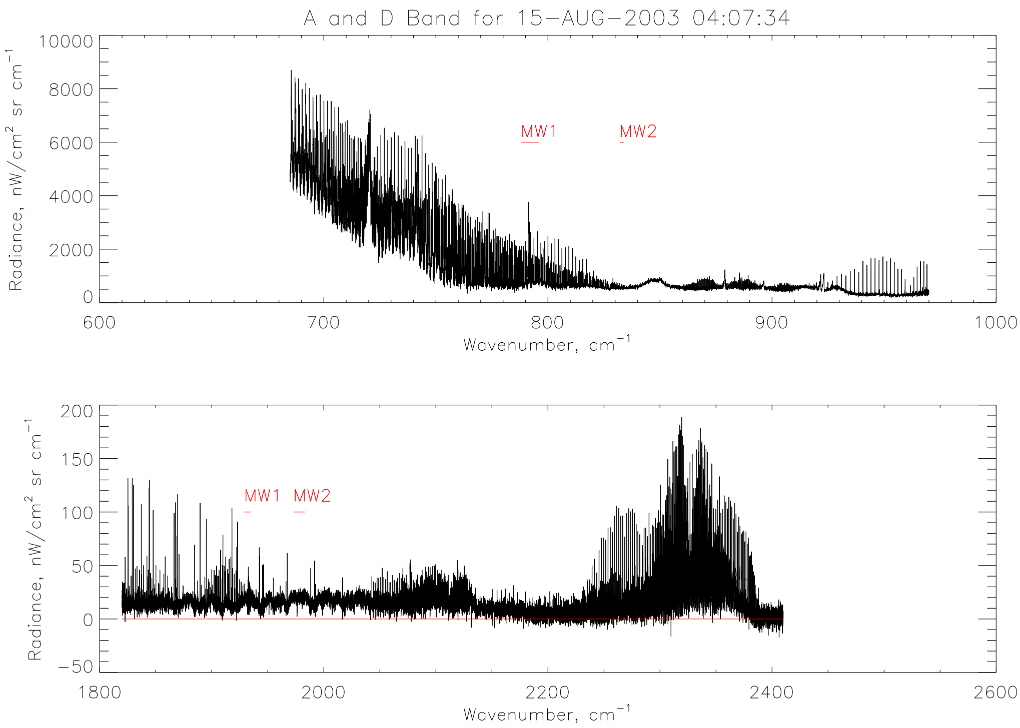

Figure 7: A low altitude, mid-latitude example where the D band flags cloudy and the A band does not flag. Here CI-D = 0.94, CI-A = 1.88, latitude = $-9.6°$, altitude = 16.4 km and it is daytime.

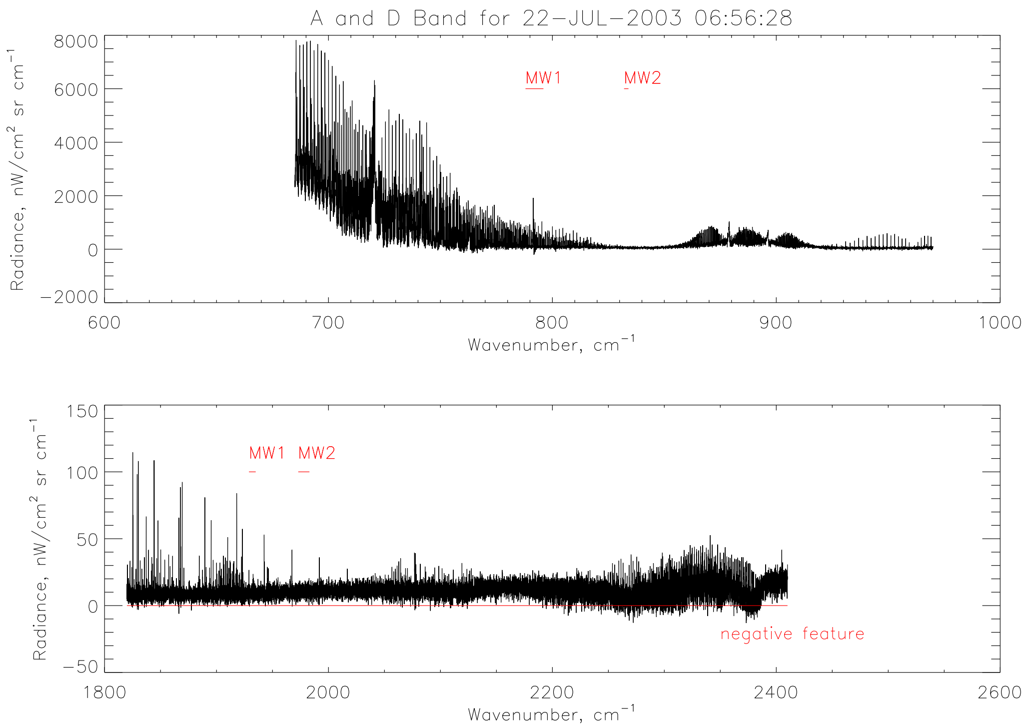

Figure 8: A higher altitude, mid-latitude example where the D band flags cloudy and the A band does not flag. Here CI-D= 0.95, CI-A = 3.55, latitude = $-58°$, altitude = 22.3 km and it is daytime.

	190 K	*203 K*	*209 K*	*219 K*	*224 K*
CI-D	1.32	1.29	1.28	1.26	1.25
CI-A	1.17	1.15	1.14	1.13	1.12

Table 2: Colour indices calculated for the Planck blackbody function. Since the Planck function describes a blackbody (such as an optically thick cloud), all colour indices should be flagged as cloudy - ie. having values less than 1.8.

and D bands. It was found that the Planck function for a blackbody (such as an optically thick cloud) at a temperature T_B is reliably flagged as a thick cloud in the reliable A band and while the D band does a fairly reliable job of detection here, the margin between the threshold and the colour index value is small at lower brightness temperatures. As well, since some suggest that the D band threshold should be lowered to 1.2, this result immediately indicates that for most atmospheric temperatures the D band colour index would not flag a blackbody. Table 2 highlights the colour indices for the Planck function evaluated at temperatures consistent with ECMWF results.

To further investigate this, the Reference Forward Model (RFM) was used to model clear and cloudy atmospheric conditions in mid-latitudinal, equatorial, summer polar and winter polar regions. The cloudy atmospheres have been defined by creating an optically thick region of aerosols which extend from the ground to one kilometer above the tangent height of the simulation, in a step-function fashion. Shown in Fig. 9, it is obvious that the D band colour index is quite unreliable as a cloud detection method, frequently indicating clear or cloudy conditions for the opposite input atmospheric state.

So, clearly there is something fundamentally wrong with using the D band as a reliable cloud flagging candidate range.

2.5 Statistics

The phenomena studied occur quite rarely. Table 3 highlights statistics of occurence for the low H_2O vmr for the test day of 15 August 2003.

Table 4 highlights statistics of occurence for the flagging anomaly for the test day of 15 August 2003.

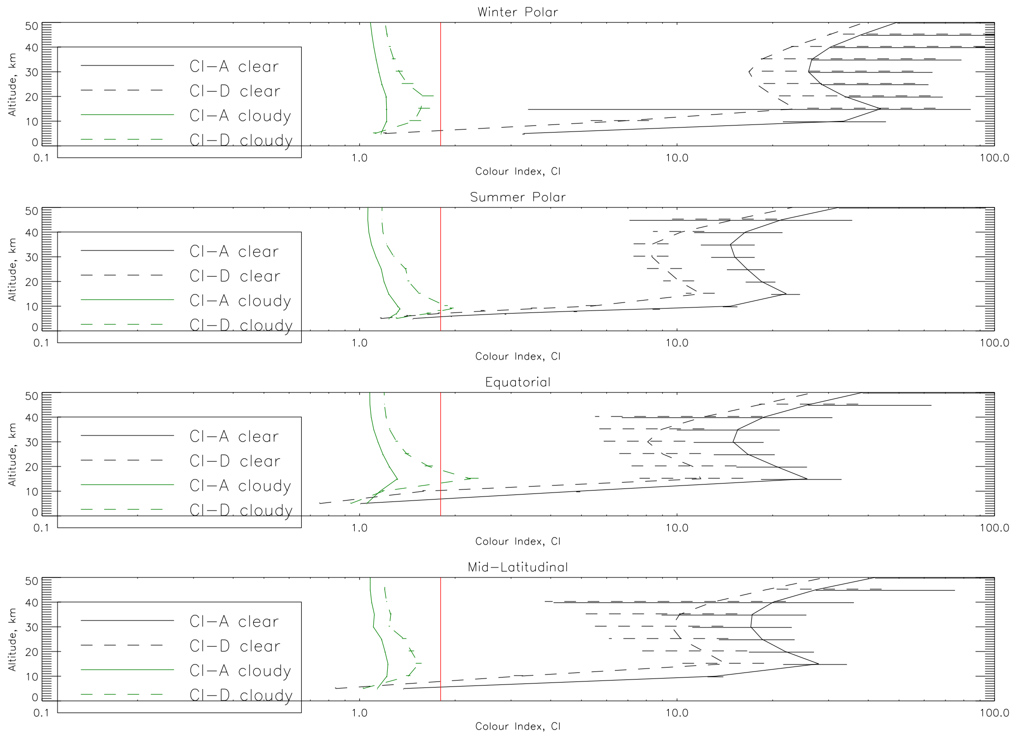

Figure 9: Colour indices with uncertainty bars for RFM simulated MIPAS data in clear and cloudy atmospheric conditions.

Occurence of low H_2O vmr 1.44% (173/12041)	
day/night	42.8% (74/173) daytime
	57.2% (99/173) nighttime
altitude	78% (135/173) 10 – 20 km
	5.8% (10/173) 20 – 30 km
latitude	68.8% (119/173) polar
	31.2% (54/173) mid-latitudinal
flagging	17.9% (31/173) D flagged/A unflagged
	82.1% (142/173) otherwise

Table 3: Statistics of Occurence for low H_2O vmr.

Occurence of flagging anomaly 2.93% (353/12041)	
day/night	44.8% (158/353) daytime
	55.2% (195/353) nighttime
altitude	45.8% (162/353) 5 − 10 km
	47.5% (168/353) 10 − 20 km
	6.8% (23/353) 20 − 30 km
latitude	37.4% (131/353) polar
	62.6% (222/353) mid-latitudinal
H_2O vmr	8.2% (29/353) low
	91.8% (324/353) normal

Table 4: Statistics of Occurence for the flagging anomaly.

3 Conclusions and Recommendations

The correlation between the flagging anomaly and the extremely low water vapour volume mixing ratio retrievals is quite weak, with the flagging anomaly having an 8 % occurrence rate for low water vapour volume mixing ratio and conversely with the low volume mixing ratio having a 20 % occurrence rate of the flagging anomaly. The minimal associability of low water vapour volume mixing ratio with the flagging anomaly implies that detection of such anomalies should not be used as a detection mechanism for bad water vapour retrievals.

The D band might well be showing an increased sensitivity to clouds, but if it is indeed, it does not do so reliably. The D band flags cloud where climatologically there is simply none expected (ie. 20 − 30 km altitude in the mid-latitudes, see section 2.4). At higher altitude ranges, when the D band detects cloud but the A band does not, there generally exists a strange negative spectral feature at approximately 2350 cm^{-1}, a telltale sign of possible data issues (see section 2.4). In the lower altitude range where cloud presence is expected, the cases where the D band flags cloud while the A band does not are mostly quite marginal, having both indices quite close to the threshold and the A band spectra appearing cloudy in any case (see section 2.3) and there generally exists a large non-LTE feature in the cloudy D band spectra (mid-latitude cases only - polar cases have smaller feature in the same spectral location).Most compellingly, even the limiting case of an optically thick cloud in the field of view (as modelled as a Planck blackbody and using the Reference Forward Model) is not consistently detected using the colour index method in the D band, while it is resoundingly detected as a thick cloud in the A band (see section 2.4).

In conclusion, the analysis indicates that the D band is not reliable for detecting cloud using the colour index method, particularly during the day-time. The anomalous cases for which cloud is detected in the D band but not in the A band appear to result from the unreliability of the D band cloud flag CI-D and possibly of contaminated data.

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