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Near Infra-red Radiances Observed by the UK C130 Multi-channel Radiometer during the marine stratocumulus IFO and preliminary comparison with model calculations

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1. Introduction

This paper presents a preliminary analysis of some of the narrow band radiance data measured on the UK Meteorological Office's C130 aircraft during the marine stratocumulus intensive field observation of FIRE, San Diego 29 June to 18 July 1987. The data are compared with Monte Carlo calculations of the reflectance and transmittance of the cloud based upon the observed droplet size distribution. The main scientific question being addressed is whether there is any evidence of anomalous absorption within the cloud which has been observed in similar measurements (Rozenberg et al 1974; Twomey and Cocks 1982; Foot 1988). The measurements also indicate the potential for remotely sensing cloud properties.

2. Introduction

A full description of the multi-channel radiometer (MCR) fitted to the C130, its calibration and performance during FIRE '87 is given by Barrowcliffe, Dewey and Foot (1988). The instrument is essentially the same as used on another aircraft and described by Doherty and Houghton (1984) and Foot (1988). Table 1 shows the filter fit of the visible and near infra-red channels (denoted by channel numbers B1, B2, B3, B4, D1, D2, D3 and D4), additionally there was an 11.0µm (A1) channel operative during FIRE. Channels with the same number (eg. B2 and D2) make simultaneous measurements.

Table 1 Filter Characteristics

				Refractive index: real imaginary			
No	50% peak µm	Transmission µm	Gaseous absorption	Liquid Water		Ice	
B1	0.534	0.574	O_3+ Rayleigh	1.334	$2.0x10^{-9}$	1.310	$3.1x10^{-9}$
B2	2.240	2.281	Window	1.290	$3.3x10^{-4}$	1.277	$2.0x10^{-4}$
B3	1.031	1.052	Window	1.325	$1.5x10^{-6}$	1.301	$2.7x10^{-6}$
B4	1.331	1.354	H_2O edge	1.320	$2.0x10^{-5}$	1.296	$1.5x10^{-5}$
D1	1.229	1.256	Window	1.332	$8.9x10^{-6}$	1.297	$1.4x10^{-5}$
D2	1.994	2.027	CO_2	1.304	$1.1x10^{-3}$	1.291	$1.6x10^{-3}$
D3	1.536	1.562	Window	1.317	$1.2x10^{-4}$	1.294	$5.8x10^{-4}$
D4	1.838	1.875	H_2O	1.311	$1.4x10^{-4}$	1.292	$6.3x10^{-5}$

The visible and near infra-red channels are calibrated in flight using a diffusing shutter to scatter sunlight into the instrument. Radiances are converted into normalised reflectances and transmittances on the basis that the observed layer in a perfect Lambertian diffuse reflector or transmitter, as was carried out in the earlier work, Foot (1988). Details of the atmospheric transmission for the B1, B4 and D2 channels which are applied are given in Barrowcliffe, Dewey and Foot (1988). The D4 channel being centrally placed in a water vapour band is strongly absorbed and produces no valuable information for FIRE. The estimated absolute accuracy of the reflectance or transmittance is 6% for the window channels and slightly poorer for the other channels. Some of the intercomparison data during FIRE between the MCR and the University of Washington's C-131, radiometer (CAR) is being presented by King et al (1988) at this meeting.

The other principal instrument used in this study is the PMS FSSP used to provide droplet size spectra on the level runs or profiles through the cloud.

3. Data

Details of the C130's flight patterns during FIRE are given in FIRE Technical Report No 1 (Kloesel et al 1988). The flights were conducted over fixed ground patterns on either a fixed straight leg or an L pattern. Levels flown include runs just above the stratocumulus and beneath the main base providing vertical reflectance and transmittance of the cloud. Runs in cloud, particularly near cloud top, and profiles through the cloud provide the droplet size distributions and liquid water contents. Although the MCR did take some measurements at angles other than the vertical, these are not treated in this paper. The normalised vertical reflectances and transmittances are denoted by the channel number, thus B1↑ is the reflectance of the cloud at 0.55μm and D1↓ is the transmittance of the cloud at a wavelength of 1.25μm.

4. Model

A Monte Carlo model, as used in the earlier work, has been used to simulate the observations. Various simplifications have been made in this initial analysis which will be explored later in sensitivity studies. All these simplifications were found to be satisfactory in the earlier work although the cloud studied then was optically much thicker (τ ~48). The assumptions are:-

(1) The observed size distributions have been fitted to a single analytic expression which provides a reasonable fit to the observations allowing only one variable, the effective radius, r_e. Mie calculations have been performed on this analytic function.

(2) The observed variation of r_e with height in the cloud is ignored. A value appropriate to the top quarter (where most of the liquid water is present) is used for the whole cloud.

(3) The optical depth, τ, is assumed to be identical for all the channels.

5. Results

Figure 1 shows the variation of the average reflectance of three cloud layers plotted against the absorption coefficient of liquid water. The examples shown have similar reflectances at 0.55 µm, a similar solar zenith angle but different values of r_e near cloud top. The reflectance is mainly constant where the absorption of water is $<10^2 m^{-1}$, the variation may not be significant bearing in mind the absolute accuracy is 6%. The reflectance decreases where water is a stronger absorber and is lower for the cloud with larger droplets.

It is instructive to study the individual synchronised measurements, ie D1/B1, D2/B2 and D3/B3, rather than averaged data over a cloud with variable optical depth. Plots of reflectance (and transmittance) ratios of D/B have been made against the reflectance (or transmittance) B. An example is shown in Figure 2. This run was over a very variable cloud which gradually became thicker at one end; the maximum optical depth is estimated to be 24. As $B3^{\uparrow}$ increases, ie the optical depth increases, so the ratio $D3^{\uparrow}/B3^{\uparrow}$ has decreased because of increased absorption. This result is unlike the earlier work Foot (1988) where the optical depth was very high but there was considerable variation in a single run in the ratio which could be attributed to variation in r_e or variation in cloud top structure.

Variation between the ratio plots using D1/B1, where absorption is weak, for different flight occasions is small. Small changes could result from variations in the daily amounts of ozone and particle above the cloud. Variation in the ratio plots for D2/B2 and D3/B3 are however larger and seem correlated with the value of r_e. Both the observations and calculations suggest that variation in solar zenith angle between 10 to 30° do not significantly change these plots.

Figure 3 and 4 show the D3/B3 ratio plots for the reflectance and transmittance of the cloud. The lines are best fits to individual values as (Figure 2). There is clearly a separation with occasion with large r_e showing the strongest absorption. The points plotted are a first attempt to model the variations: two optical depths and four values of r_e having been used. The variations on a single day in the observations are consistent with variation in optical depth without any change in effective radius. The data from flight H804 seems to substantiate this in that the variation of r_e near cloud top between the thicker and thinner ends of the layer was small. The agreement between the observations and calculations for both transmission and reflection tend to indicate that the measurements show stronger absorption than the calculated values, particularly for the largest r_e value. Further work is needed to quantify any disagreement.

Figure 5 shows the reflectance ratio at the other pair of channels $D2^{\uparrow}/B2^{\uparrow}$ for the same clouds as Figure 3 and 4. These separate out in a similar way. The two flights with similar r_e values show similar behaviour in Figure 4 and 5 but the reflectance data in Figure 3 do show a systematic difference.

6. Discussion

The data and method of presentation discussed here clearly separates out clouds in terms of the size of the cloud droplets. All of the daytime C-130 FIRE flights have been studied and are consistent with the data presented in this short paper. There appears to be no peculiarities that might arise, for example if pollution were to be a significant factor in determining cloud absorption. Variation in the inferred size parameters, r_e, along runs are also very small; this is unlike previous results Foot (1988) and Twomey and Cocks (1982). Further calculations and sensitivity studies are required before we can confidently state whether or not the observations presented here are consistent with our model.

As well as this narrow band work there are also broad band observations which we are just starting to interpret. There is also a limited amount of data on the optical properties of cloud water and interstitial aerosol collected during FIRE: a report on this will be issued soon.

Attendants at the FSET meeting wishing further details may request information through Mr R Barlow, UK Met Office who is attending this meeting.

References

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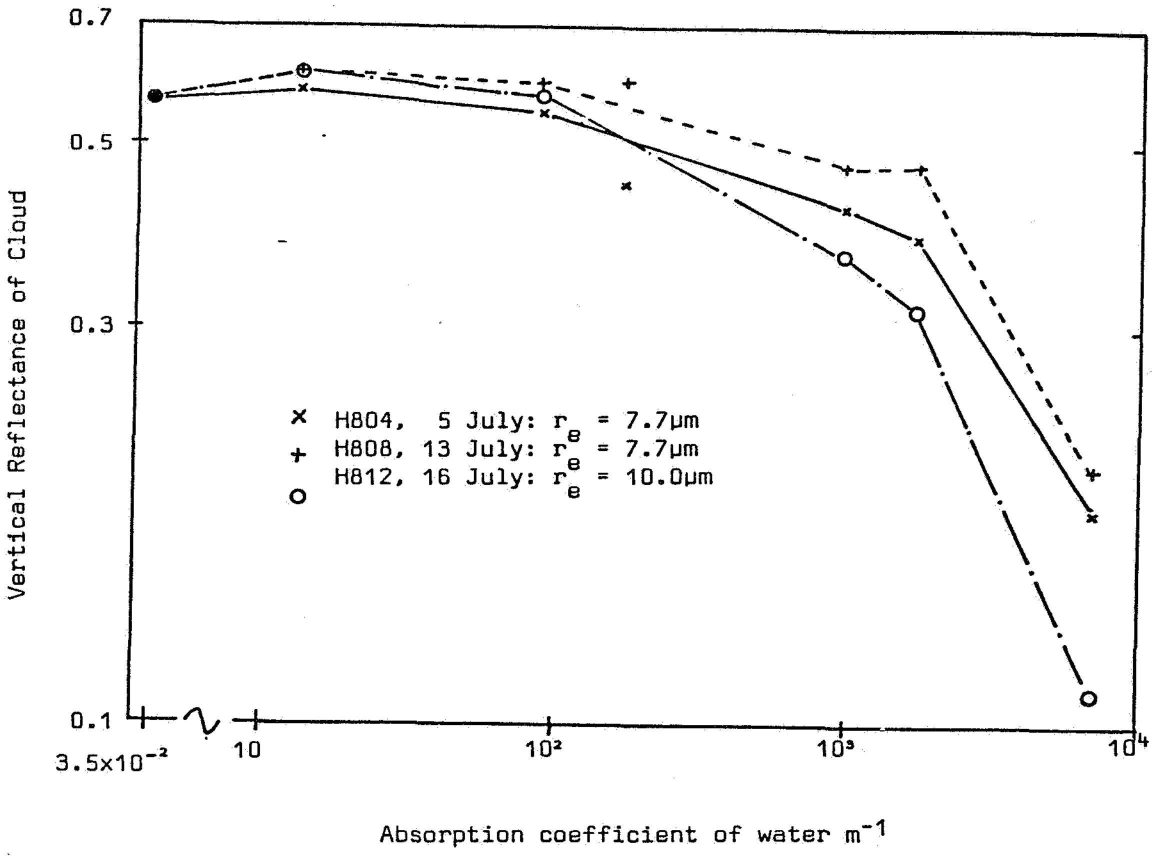

Figure 1

Average Vertical Reflectance of three cloud layers as a function of cloud water absorption.

(Lines are drawn to join points for the same flight excluding the B4 channel because of the extra uncertainty of calculating the atmospheric transmission in the water vapour band.)

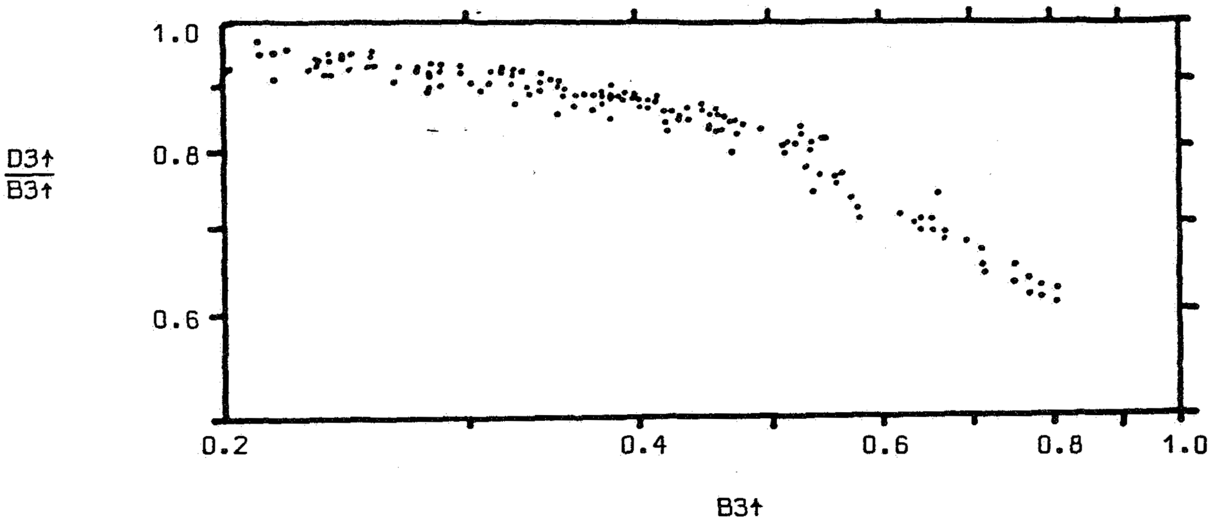

Figure 2

Individual observations of reflectance ratio D3↑/B3↑.
Data from flight H804, 5 July 1987
Solar zenith angle 30°.

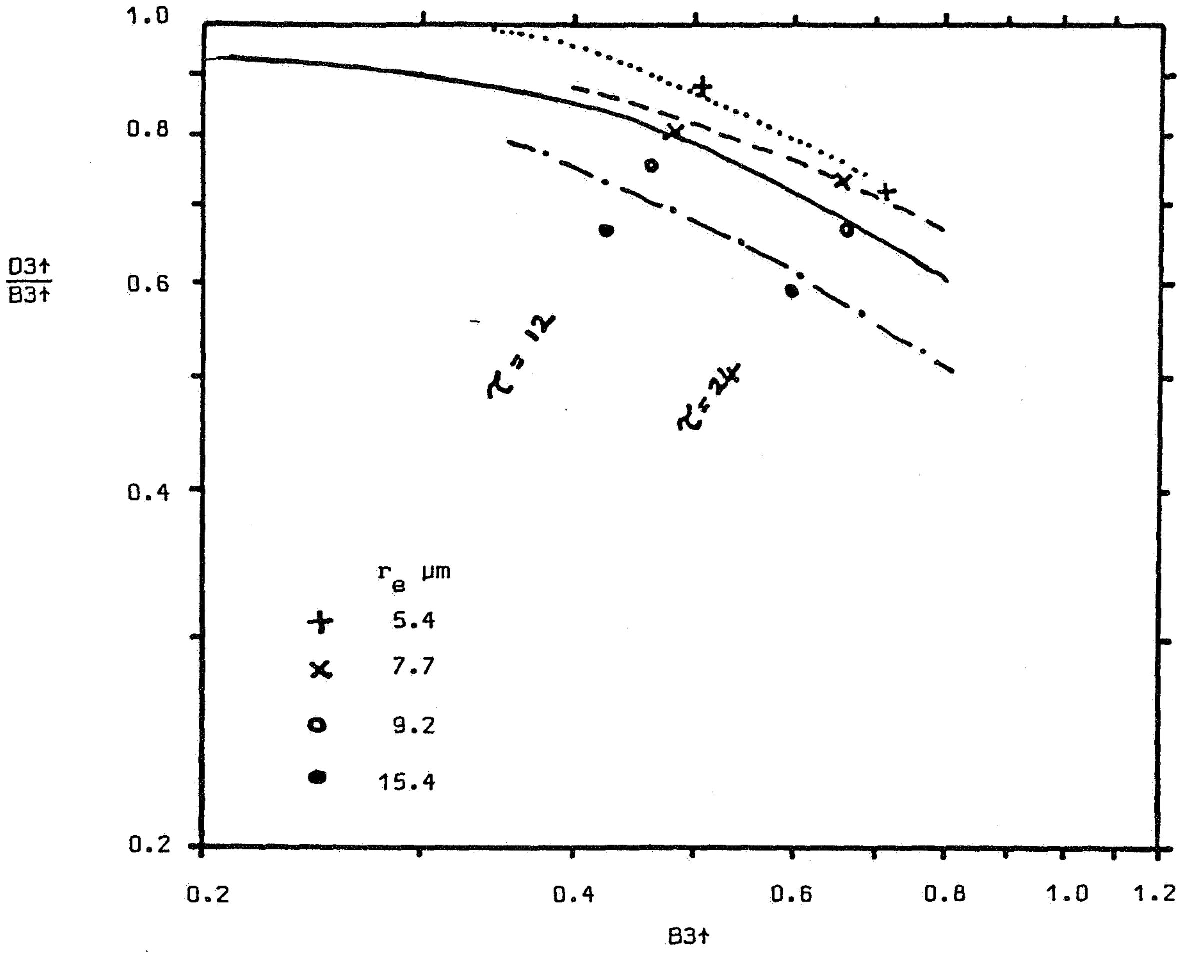

Figure 3 Comparison between observed and calculated reflectance ratio D3↑/B3↑. Lines represent observations and points are calculations.

Dotted line	Flight H813	18 July	r_e = 5.4 μm
Solid line	Flight H804	5 July	r_e = 7.7 μm
Dashed line	Flight H808	13 July	r_e = 7.7 μm
Dashed/Dotted line	Flight H812	16 July	r_e = 10.0 μm

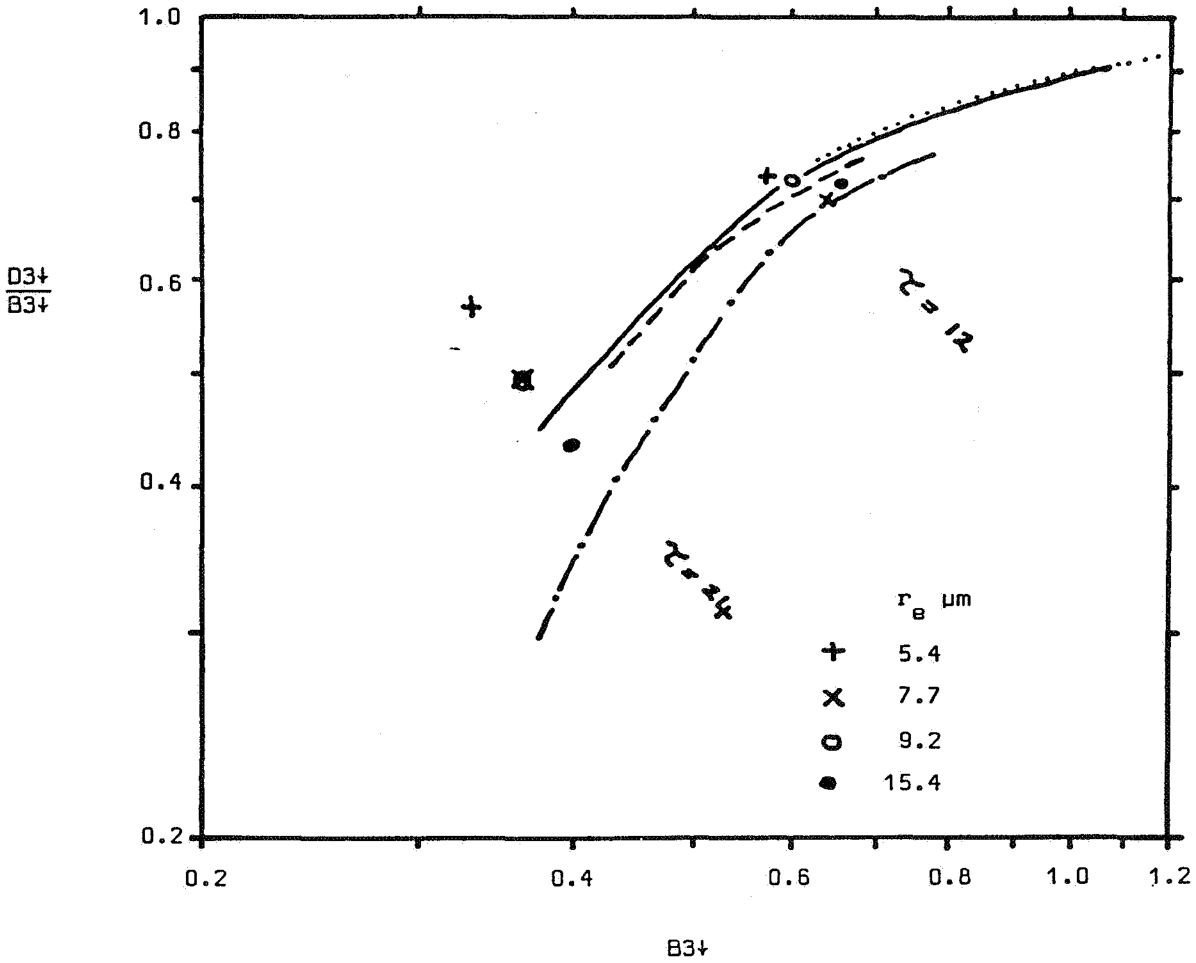

Figure 4 Comparison between observed and calculated transmittance ratio D3↓/B3↓. Key as Figure 3.

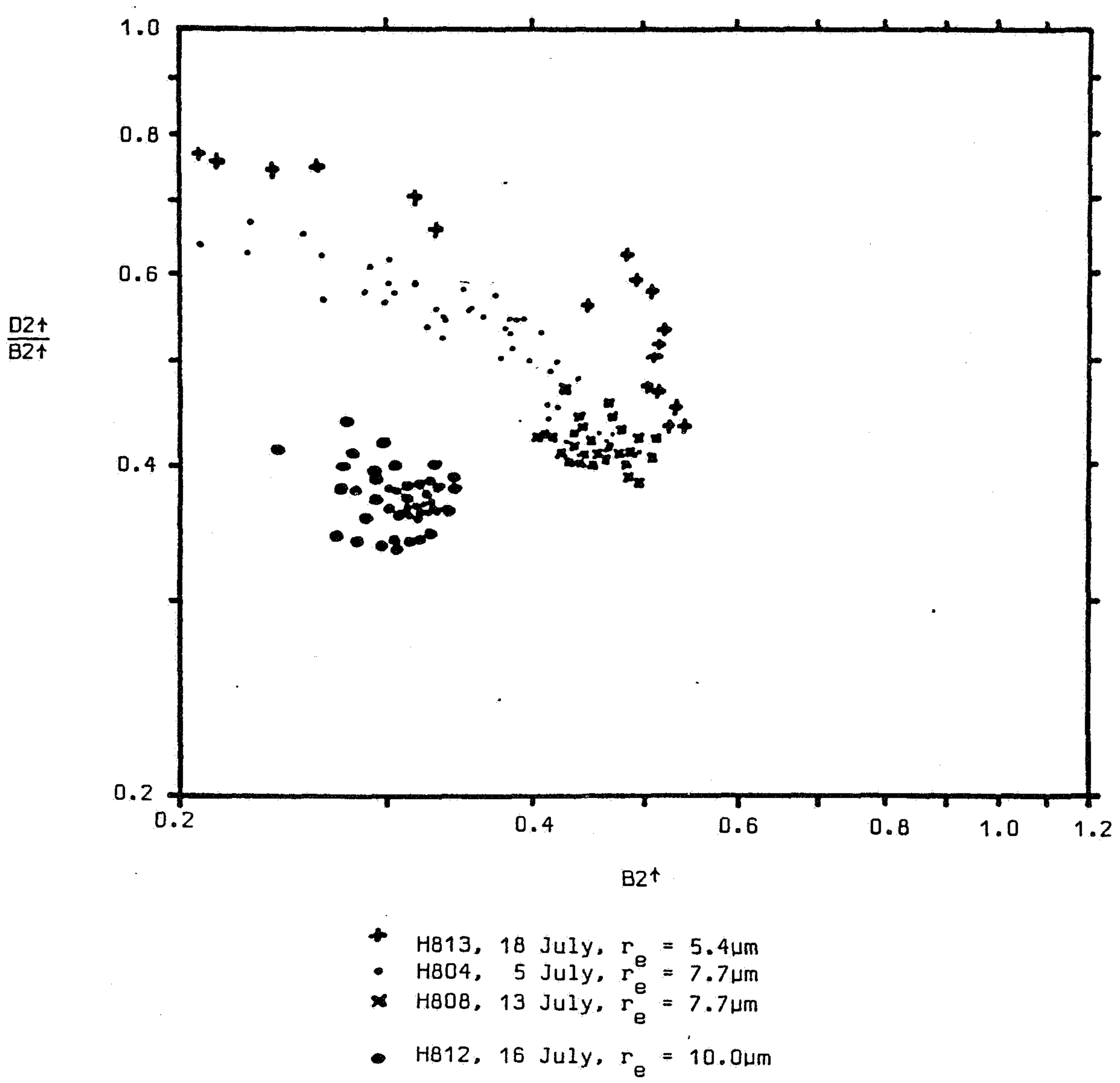

Figure 5

Individual observations of reflectance ratios D2↑/B2↑ for four flights