SPECIFICATIONS FOR A SPACEBORNE CLOUD RADAR: ALGORITHMS AND SYNERGY FOR RETRIEVING CLOUD PROPERTIES.

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Extensive sets of aircraft observations of cloud particle sizes and concentrations in stratocumulus and cirrus have been analysed to predict how cloud characteristics could be derived from future spaceborne radar and lidar observations. The spaceborne radar is discussed in terms of a 94GHZ transmitter, a 1km footprint, an along track integration of 10km to achieve a sensitivity of -30dBZ, and a vertical resolution of 500m.

LWC FROM Z? Figure 1 (from 4000km penetrations in stratocumulus) shows that the presence of occasional drizzle drops in stratocumulus often raises Z by up to 20dB, but has little effect on the LWC. Each spectra is derived from 10 seconds (1km) of flight We conclude that it should be much easier to detect stratocumulus with a spaceborne radar and that attenuation by the liquid clouds should not be a problem , but that, contrary to previous suggestions, quantitative values of LWC cannot be deduced from Z (Fox and Illingworth, 1997).

DETECTION OF ICE CLOUD? The analysis of Brown et al (1995) on cirrus clouds has been extended. Figure 3, based on 22,800km of tropical cirrus (CEPEX: 10 second or 20km spectra) and 5,100km of mid-latitude cirrus (EUCREX - 5 second or 0.5km spectra), demonstrates that, assuming the cirrus 1km deep, a -30dBZ radar threshold should detect over 90% of radiatively significant cirrus; i.e. with an optical depth > 0.05 (mid-latitude) and >0.02 (tropical). Note that Atlas et al (1995) deduced a far lower fraction, but included all clouds sampled no matter how tenuous.

IWC from Z? Brown et al (1995) suggested that the errors in estimating IWC from Z alone are about a factor of two, but that, if simultaneous lidar provided a measure of mean particle size, then this error could be reduced to +50%/-34% Figure 3 demonstrates the rather surprising result that classification by temperature (here in terms of bins 6K wide) reduces the error to an amount comparable to that from knowing the mean particle size.

SIMULTANEOUS LIDAR/RADAR RETRIEVALS. Intrieri et al (1995) retrieved cirrus particle size from the radar/IR lidar backscatter ratio assuming the ice particles to be spheres of solid ice. Figure 4 suggests that care must be taken if a visible lidar is used, because this backscatter ratio is then not a monotonic function of particle mean size if the ice density not that of solid ice. It has been suggested that the radar and lidar could be flown on separate satellites flying close together; Figure 5 shows that there is little to be gained in doing this and the two instruments must be flown on the same platform. Once the footprint separation is more than 3.9 km, then the error in the inferred IWC is about a factor of two (standard deviation of the log is above 0.3); and that this error is exceeded for more than 70% of cases. This error is no improvement on the performance of the radar alone.

DUAL WAVELENGTH RADAR. Lidar has the advantageous that it can detect aerosol, but in thick cloud it suffers from total attenuation and multiple scattering. In the above analyses we have assumed that these effects have been corrected for. However, for sensing cirrus from sapce a radar operating even at a frequency of 215GHZ should suffer only slight attenuation although a ground based one wold be severely affected. Hogan and Illingworth (1998) suggest that the reflectivity ratio at 94 and 215GHz could be used to derive both the concentration and size of cirrus particles. Figure 6 shows how the reflectivity ratio of radars at two wavelengths can be used to derive particle size.

REFERENCES;

Atlas et al, (1995) J Appl Meteor, 34, 2329-2345.
Brown et al, (1995) J Appl Meteor, 34, 2346-2366.
Fox and Illingworth (1997) J Appl Meteor, 36, 676-687.
Hogan and Illingworth (1998). Submitted: J Atmos Oceanic Technol.
Intrieri J. et al. (1993) J Appl Meteor, 32, 1074-1082.

RADIATIVELY SIGNIFICANT ICE CLOUD.

FOR AN INVERSE-EXPONENTIAL SIZE DISTRIBUTION,

THE EFFECTIVE RADIUS R_e = 1.5D*

ASSUME CLOUD 1KM (1000m) THICK

SO OPTICAL DEPTH, τ = (3 1000 IWC/ 4 1.5 D*)

GRAPH COMPARES 5 AND 10 W M^{-2} THRESHOLD

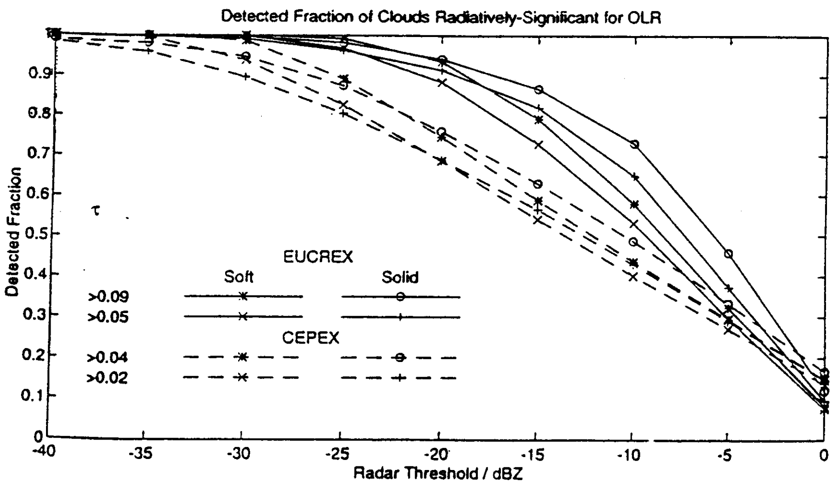

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Figure 2:

Detected cirrus cloud fraction variation with the radar detectability threshold for tropical (CEPEX) and mid-latitude (EUCREX) cirrus aircraft observations. The curves correspond to the fraction exceeding a give optical depth for an assumed cloud depth of 1km. Solid is for an assumed ice density of 0.9g.cm3, and soft for a density = 0.07D**-1.1, where D is in mm.

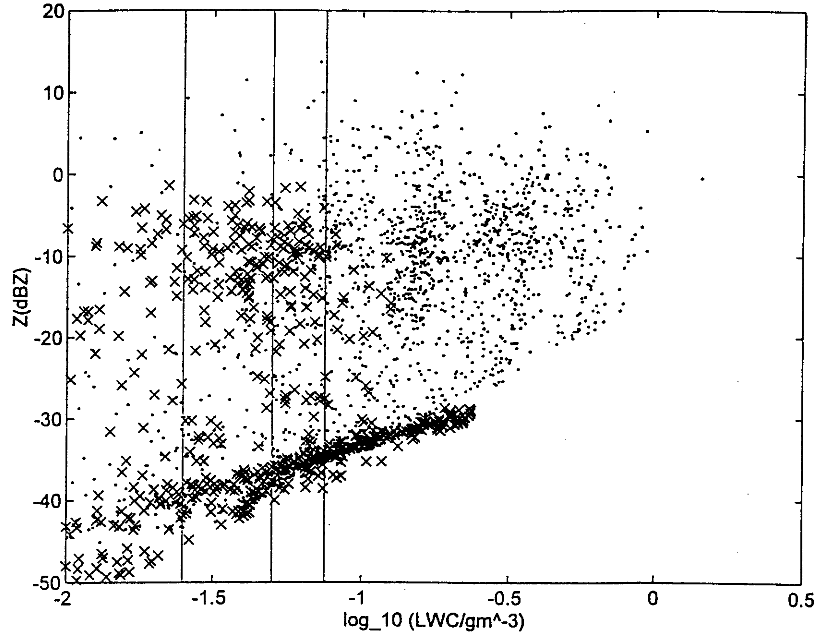

Figure 1;

Values of Z and LWC computed from cloud drop spectra measured by aircraft for maritime (.) and continental (x) stratocumulus. The three vertical lines correspond to liquid water contents of 0.025, 0.05 and 0.075g/m3. The presence of occasional drizzle drops raises the values of Z up to 20dB whilst having little affect on the LWC.

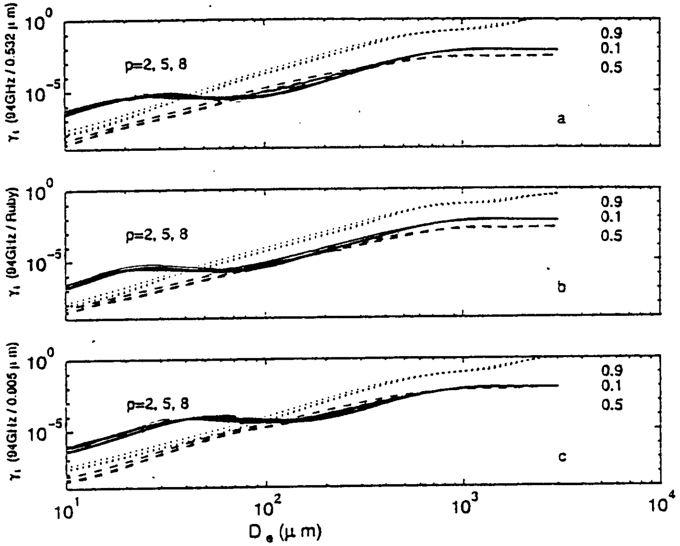

Figure 4:
The backscattering ratio (94GHz radar/visible lidar) variations with mean size for different assumed ice particle densities. Solid line density = 0.1; dashed line 0.5; and dotted line 0.9g/cm3.
The three lines for each density are for p=2,5 and 8 in the gamma distribution.

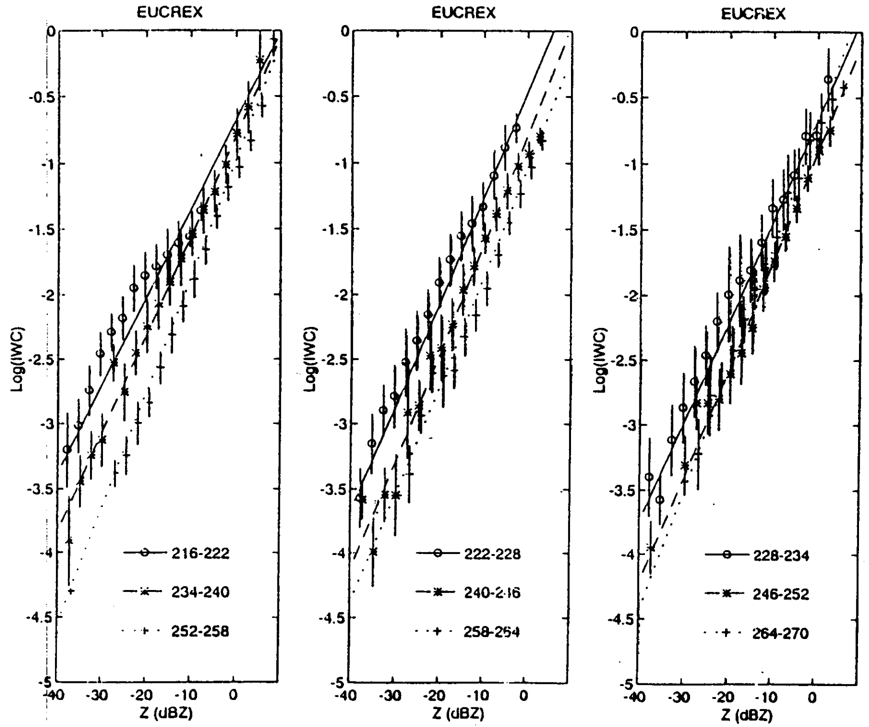

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Figure 3:
The mean values of log(IWC) for data falling within 2.5dBZ ranges of Z calculated from the EUCREX cirrus mid-latitude data set. The error bars indicate plus and minus one standard deviation. Classifying in 6K ranges of temperature reduces the errors in derived IWC to about +50/-34%.

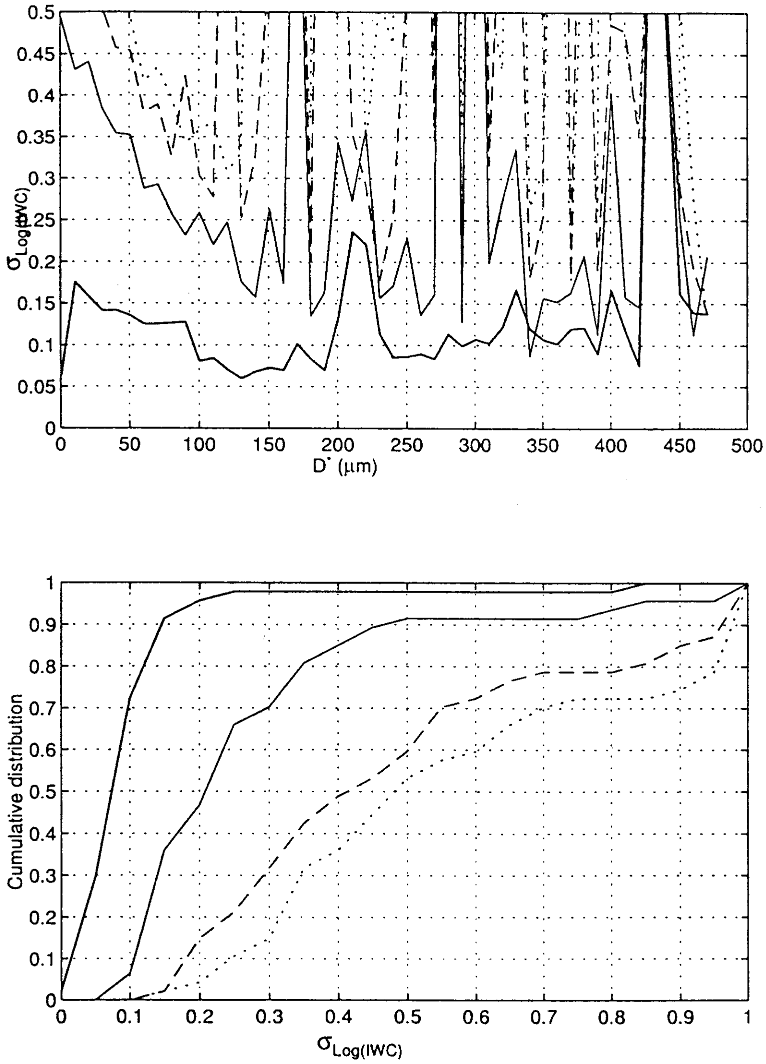

Figure 5.
The error in derived IWC from the radar/lidar backscatter measurements as a function of footprint separation. Thick solid line 0km; thin solid line 1.9km; dashed line 3.9km and dotted line 5.85km.
For a separation of 3.9km the error in IWC exceeds a factor of two (log >0.30) for 70% of the cases.

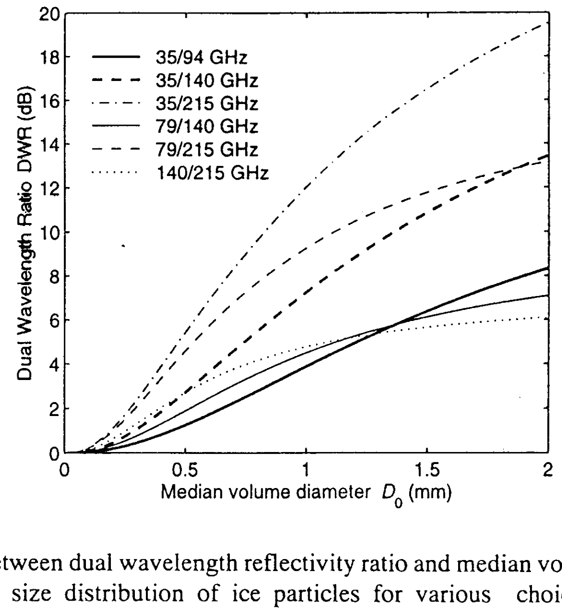

Figure 6.
The relation between dual wavelength reflectivity ratio and median volume diameter in an exponential size distribution of ice particles for various choices of the two wavelengths. The ratio 94/215GHz seems optimum for a future spaceborne mission.