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Cirrus Parameterization from the FIRE ER-2 Observations

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Primary goals for the FIRE field experiments were validation of satellite cloud retrievals and study of cloud radiation parameters. The radiometer and lidar observations which were acquired from the NASA ER-2 high altitude aircraft during the FIRE cirrus field study may be applied to derive quantities which would be applicable for comparison to satellite retrievals and to define the cirrus radiative characteristics. The analysis involves parameterization of the vertical cloud distribution and relative radiance effects. An initial case study from the October 28, 1986 cirrus experiment has been carried out, and results from additional experiment days are to be reported.

The meaning of cloud parameters retrieved from remote sensing are to an extent defined by the observation and analysis technique by which the parameter is derived. Satellite retrievals such as the ISCCP products which involve observations at limited wavelength channels and large spatial averages are in particular subject to interpretation. The ER-2 observations included combined active and high resolution passive observations. Due to the large difference in observational scales and techniques, the eventual comparison between the aircraft and satellite derived parameters is of interest. A discussion of analysis procedures and the parameterization from the aircraft observations is given in more detail by Spinhirne and Hart (1989).

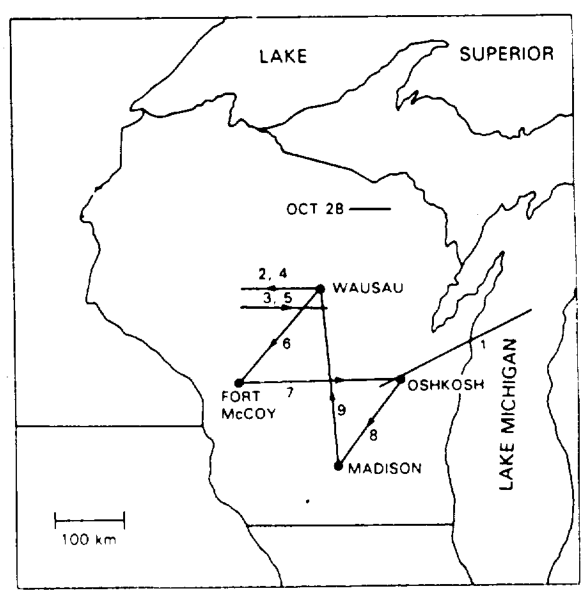

Fig. 1 ER-2 flight line map for October 28 1986.

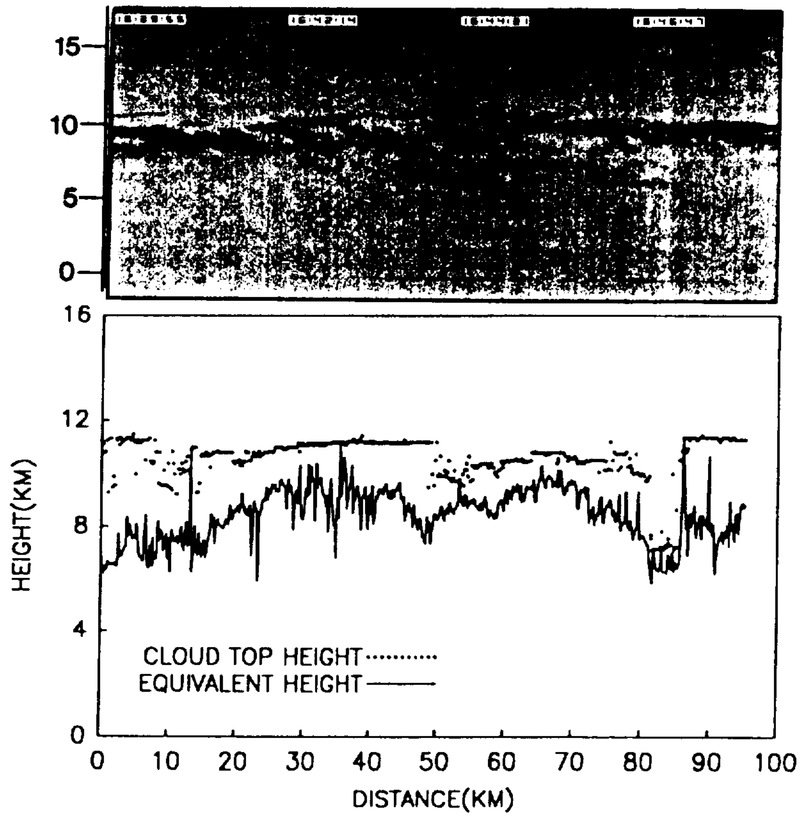

Fig. 2 The lidar observed vertical cloud structure for the fourth flight line of October 28 and the calculated equivalent cloud height.

I. Cloud Height and Vertical Structure

Cloud height is an important variable for satellite cloud retrievals and for the general meteorological description of clouds. The cloud top height z_t detected by lidar is very sensitive to even small increases of scattering above clear air levels, and the top of even thin subvisible cirrus is accurately found. However cirrus layers may be many kilometers thick and the top height is not a singularly meaningful description. An alternate cloud height level may be defined for cirrus which more closely relates to satellite observations and radiative influence. The equivalent height z_e may be defined such that

$$\epsilon = \frac{L_m - L_s}{b(T(z_e)) - L_s}$$

where ϵ is the emittance derived from a calculation procedure that makes use of the distributed vertical structure of the cirrus cloud as obtained from the lidar measurements. The radiance L_m and L_s are the measured cloud top and cloud base values. The equivalent height is thus the weighted level which would define the upward radiance of an isothermal layer of the lidar defined effective emittance.

On a typical FIRE field experiment day ER-2 observations were acquired over a 1500 km operational distance. The flights were broken into a series of approximately ten flight lines. A map of flight lines for October 28 is shown in the first figure. Lidar backscatter data for the fourth flight line is shown Fig. 2. In the figure is also given the comparison between the lidar derived true cloud top and the calculated equivalent cloud height. The equivalent height is several kilometers lower than the cloud top height in most instances. In some areas where the cloud density increased toward the cloud base the equivalent height is closer to the cloud base height than to the actual cloud top.

From the combined lidar and radiometer data analysis, an average vertical structure may be defined for the cloud field which was overflown. The analysis involves a correction for attenuation for the lidar data and an iterative solution for radiation parameters. The averaged vertical distribution of the derived infrared absorption cross section (10.8 μm) for the entire data set of October 28 is shown in Fig. 3. The averaged vertical source function, defined as the relative contribution to the upward 10.8 μm radiation, is also given. The cloud layers extend over a six kilometer altitude range. The lower cloud layers are seen to have dominated the infrared radiative effects, but for the overall observations of October 28, the upper cirrus layers remain significant. The cirrus heating and cooling influence would have been important for this case from cloud bases at 6 km to the tropopause at 11.4 km.

II. Visible reflectance and infrared emittance

An important aspect of cirrus are the relative visible and thermal radiative influence. An initial parameterization to study the relative influence is the relation

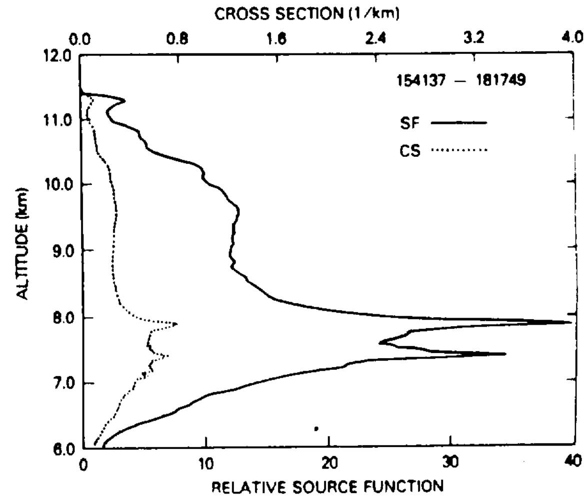

Fig. 3 Average vertical structure of infrared absorption cross section and upward source function.

between visible reflectance and infrared emittance at selected wavelengths. The relation of reflectance and emittance is also a key factor for satellite cloud retrievals such as the ISCCP algorithm. The ER-2 data permits a direct correlation between reflectance and emittance over a small field of view. The relative visible reflectance at 0.76 μm and emittance at 10.8 μm for October 28 is shown in Fig. 4. The two main groupings of points for the scatter diagram are the result of the difference of surface reflectance for the lake and land surface which were over flown on the first flight line. The dispersion of points for the land surface grouping is also primarily due to the variability of surface reflectance. In general the dispersion of the cirrus reflectivity and emittance relation is not, in comparison, strongly influenced by the variation of cloud type that was found to occur.

For satellite observations the surface

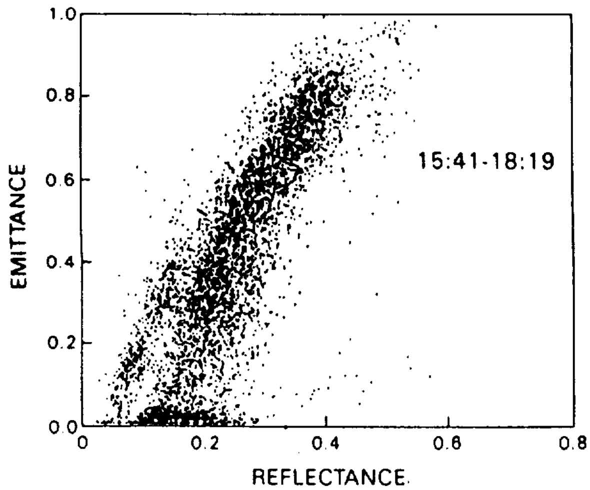

Fig. 4 Emittance and reflectance for the entire October 28 data set.

reflectivity may be obtained from previous clear air observations of a scene and a correction to the cloud reflectivity estimated. That is not possible from the aircraft observations. However an overall surface reflectivity for a scene type may be estimated by extrapolating the data as in Fig. 5 to zero emittance. Using the lidar derived effective beam transmittance, the influence of the surface reflectance on the total reflectance may be estimated for a pixel and a normalized cirrus reflectance derived. If a parameterization for cirrus bidirectional reflectance is assumed, a

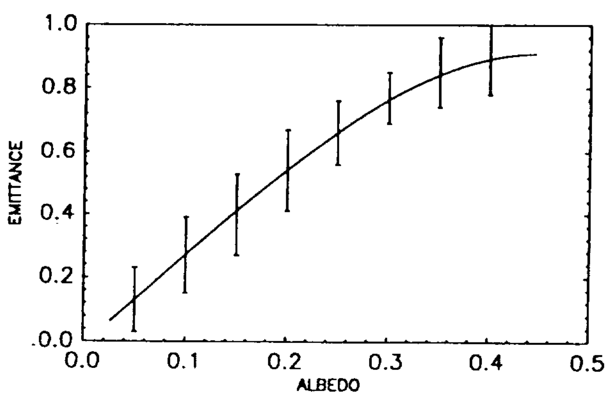

Fig. 6 Functional fit and variance of overall values of the cirrus emittance and defined albedo.

defined visible albedo for the cirrus may be obtained from the normalized reflectance. A significant dispersion to emittance values is still found which would most probably result from the average nature of the surface reflection correction and inhomogeneity and shadow effects for the cirrus.

The calculated emittance and albedo relation for the entire October 28 data set is summarized Fig. 5. A third order polynomial was fitted to the scatter of measurement to give the line shown, and the error bars in Fig. 5 represent two standard deviations of the emittance for an average over 0.05 albedo intervals. The functional line fit for the overall effective emittance and defined cirrus albedo a may be reproduce by the equation below up to the limit of a=0.45.

$$\epsilon = 2.709a + 1.603a^2 + 6.870a^3$$

III. Summary

The observations reported in this abstract are for one day. Analysis of the many other cirrus observation cases from the FIRE study show variability of results. In addition, only a fraction of the spectral and other data that was collected for this one case has been studied. Additional parameterization of cirrus properties from the aircraft remote sensing data and comparison to satellite retreivals are planned.

Reference.

Spinhirne, J. D. and W. D. Hart, 1989: Cirrus structure and radiative parameters from airborne lidar and spectral radiometer observations: the 28 October 1986 FIRE study. (submitted to Mon. Wea. Rev.).