Properties of Cirrus from Multispectral AVHRR Imagery Data

J.A. Coakley, Jr.
Department of Atmospheric Sciences
Oregon State University
Corvallis, OR 97331-2209

The discovery that the 11 μm and 12 μm window channels of AVHRR could be used to detect and even characterize the properties of cirrus (Inoue, 1985 and others) stimulated the present study which re-examines the general multispectral approach for retrieving cirrus cloud top temperature and emissivity. The approach is based primarily on work done for METEOSAT by Szejwach (1982) and draws on a wealth of previous investigations of multispectral approaches (Coakley, 1983; Platt, 1983; Arking and Childs, 1985). The generalized multispectral approach described here compliments the "CO_2 slicing method" used by Wylie (1988) and the bispectral threshold method used by Minnis et al (1988).

The approach is based on the recognition that for a cloud system that is semitransparent in the infrared, the emission for channel i which senses radiation with wavelength λ_i is given by

$$I_i = I_{si} + \varepsilon_{ci} A_c (I_{ci} - I_{si}) \qquad (1)$$

where I_{si} is the emission from the cloud-free region of the field of view and A_c is the fractional cloud cover within the field of view. ε_{ci} in (1) is an "effective mean" emissivity for the clouds within the field of view. Effects due to reflection of thermal radiation by the clouds are ignored in (1). I_{ci} is the emission that the clouds would have were they blackbodies. Determining I_{ci} is equivalent to determining the cloud top temperature.

Consider now the behavior of observations at independent infrared wavelengths λ_i and λ_j under three conditions: 1) single-layered, opaque clouds, 2) single-layered, semitransparent clouds (cirrus) and 3) multi-level opaque clouds. In general, a cloud system will exhibit any combination of these three cases. Here, wavelengths that are independent are taken to be those that exhibit different sensitivities of the emission to temperature, i.e. are at substantially different wavelengths, or they exhibit different sensitivities to the dependencies of the optical properties to hydrometeor concentrations or both.

For single-layered, opaque clouds, i.e. clouds that possess a single cloud top temperature, I_s and I_{ci} are constants at all wavelengths for the region containing the system. Likewise, because the clouds are opaque the emissivities, ε_c, are also constants and equal to the maximum values that the clouds can obtain. As a result, I_i is linearly proportional to I_j. This linear relationship is shown in Figure 1 for the 11 μm and 12 μm radiances obtained from NOAA-9 on the afternoon of October 28, 1986 during the case study period. The data is for a 250 km region containing the array of lidars that participated in the case study (Sassen et al, 1989). The linear relationship that is shown in the figure indicates that the upper-level clouds were opaque at 11 and 12 μm at the time of the satellite overpass. On the basis of the 11
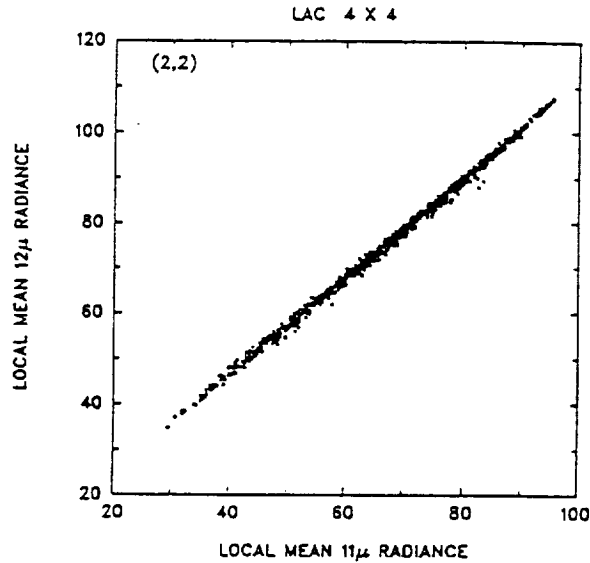
Figure 1. 11 μm and 12 μm AVHRR radiances for the afternoon NOAA-9 pass on October 28, 1986. The data is for a 250 km region containing the array of lidars that participated in the Cirrus IFO case study. Each point in the figure represents a 4 km portion of the 250 km region. The linear relationship between the radiances indicates that from the view of the satellite, the clouds are opaque at 11 and 12 μm. The variability in the 11 and 12 μm radiances indicate that the clouds are broken.
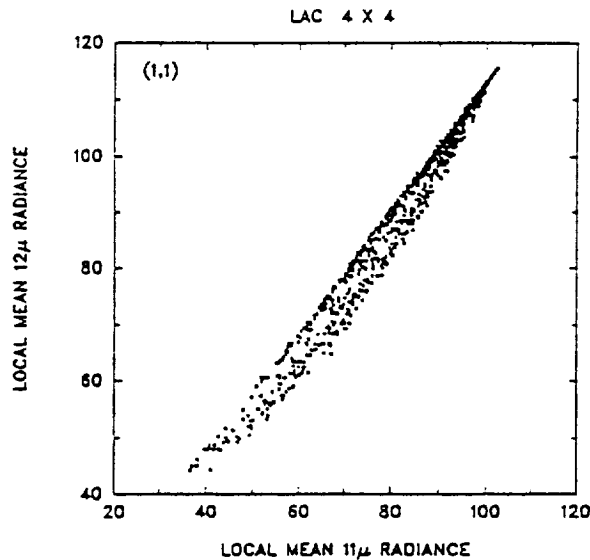

Figure 2. Same as Fig. 1 but for the 250 km region to the southwest of the lidar array. The curvature of the lower envelope of points indicates that the upper level clouds are semitransparent at some locations within the region. The intersections of the linear and nonlinear envelopes gives the cloud-free radiances, I_s and the radiance associated with opaque clouds, I_c. The cloud top temperature could be estimated from I_c.

and 12 μm radiances, these clouds would not be interpreted as cirrus with missivities less than unity. While effects due to the reflection of thermal radiation have been ignored in this discussion, it is recognized that the maximum values of the emissivities attained by the clouds may be less than unity. The differential between unity and the maximum emissivity will affect the estimate of the cloud top temperature.

For a single-layered, semitransparent cloud system I_s and I_{ci} are constant for the region containing the clouds. The emissivities, however, can vary according to their dependence on hydrometeor concentrations. In general ε_{ci} is a nonlinear function of the hydrometeor concentration, and as a result ε_{ci} is a nonlinear function of ε_{cj}. Consequently, I_i will also be a nonlinear function of I_j . This nonlinear relationship is exhibited in Figure 2 which shows 11 μm and 12 μm radiances from the October 28 NOAA-9 pass for the 250 km region southwest of the lidar array. The curvature exhibited by the envelope of points is due to the semitransparency of the upper level clouds. The linear relationship exhibited by the other envelope indicates that within this 250 km region, the upper-level clouds also become opaque at some locations.

For clouds that are opaque but distributed in altitude, I_c will no longer be constant for the region containing the clouds. The emissivities, ε_c, will however be constant and near unity. As a result, the relationship between I_i and I_j will closely follow the dependence of the Planck function on temperature. That is, the relationship between I_i and I_j will again be nonlinear. In this case, however, the curvature will be opposite to that shown in Figure 2.

One notes that taking the three cases together, one obtains a linear relationship between I_i and I_j for opaque, single-layered clouds, a nonlinear relationship between I_i and I_j for semitransparent, single-layered clouds and another nonlinear relationship for opaque, multi-layered clouds which follows the relationship given by the Planck function. The latter relationship may be calculated *apriori*. All three curves, however, intersect at I_s and I_c where I_c is that of the upper-level system which is semitransparent. So, in principle, one should be able to extract estimates for the cloud top temperature from the intersection. Having the cloud top temperature, one then estimates the distribution of $\varepsilon_c A_c$ in (1) from the distribution of observed intensities.

While the results shown here were for 11 and 12 μm radiances, better definition of the cloud top temperature is probably obtainable using 3.7 μm radiances in combination with the 11 and 12 μm radiances. During the day, however, at least for the cases shown in Figs. 1 and 2, reflection of solar radiation at 3.7 μm by low-level water clouds makes the analysis untenable. At night, at least with the NOAA-9 AVHRR, instrument noise in the 3.7 μm channel also makes the analysis untenable. The identification of semitransparent systems using 3.7 μm radiances has, however, been noted elsewhere (Molnar and Coakley, 1985).

References

Arking A. and J.D. Childs, 1985: Retrieval of cloud cover parameters from multispectral satellite images. *J. Climate Appl. Meteor.*, **24**, 322-333.

Coakley, J.A., Jr., 1983: Properties of multi-layered cloud systems from satellite imagery. *J. Geophys. Res.*, **88**, 10818-10828.

Inoue, T., 1985: On the temperature and effective emissivity determination of semitransparent cirrus clouds by bi-spectral measurements in the 10-μm window region, *J. Meteor. Soc. Jpn.*, **63**, 88-99.

Minnis, P., J. Alvarez, D.F. Young, P.W. Heck and K. Sassen, 1988: Cirrus cloud properties derived from coincident GOES and lidar during the 1986 FIRE Cirrus IFO. FIRE Science Team Workshop, July 11-15, Vail, 145-149.

Molnar, G., and J.A. Coakley, Jr., 1985: The retrieval of cloud cover from satellite imagery data: A statistical approach. *J. Geophys. Res.*, **90**, 12960--12970.

Platt, C.M.R., 1983: On the bispectral method for cloud parameter determination from satellite VISSR data: Separating broken cloud and semitransparent cloud. *J. Climate Appl. Meteor.*, **22**, 429-439.

Sassen, K., C.J. Grund, J. Spinhirne, M. Hardesty and J. Alvarez, 1989: The 27-28 October 1986 FIRE IFO cirrus case study: A five lidar overview of cloud structure and evolution. (preprint)

Szejwach G., 1982: Determination of semi-transparent cirrus cloud temperature from infrared radiances: Application to METEOSAT. *J. Appl. Meteor.*, **21**, 384-393.

Wylie, D., 1988: Where are cirrus clouds and why are they there? FIRE Science Team Workshop, July 11-15, Vail, 13-18.