# Can the Changes in Cloud Thickness be Monitored from Satellite-Brightness Measurements?

KUO-NAN LIOU
*Department of Meteorology, University of Utah, Salt Lake City 84112*

27 June 1974 and 3 March 1975

In a recent paper, Park *et al.* (1974) show a close correlation between cloud thickness and the brightness measured by the ATS 3 satellite. As a result of such good correlation based on statistical analyses, the concept of employing brightness data to infer the cloud thickness seems to have been strongly implied. Indeed, if the cloud thickness could be estimated from satellites in routine operations, it would be of significance for numerical weather prediction. However, I am a bit skeptical of the physical ground for deriving the cloud thickness from the measured cloud brightness presented in their paper. Thus, I shall discuss my doubt on the basis of physical arguments.

In their analyses, correlations between brightness and the cloud-top temperature are first established. The determination of cloud-top temperatures from radiance obtained by the 11.5 $\mu$m channel of the Nimbus 4 satellite relies heavily on the following two assumptions: that clouds are optically thick so that their emissivities may be treated as unity, and that a constant correction factor may be obtained to denote water vapor contributions above the cloud. The second assumption seems justified if the cloud top is fairly high in the atmosphere, though the authors have not shown the sensitivity of the correction factor on the derived cloud-top temperature. Moreover, there is no doubt that certain clouds such as cumulonimbus are optically thick, and may be considered as blackbodies. (We note that from a theoretical radiative transfer point of view that the emissivity approaches unity only when the optical depth of the cloud goes to infinity.) Most clouds that cover our planet, however, are far from perfect blackbodies. The authors apparently are aware of the difficulties in estimating the cloud-top temperature from the observed radiance and state that their primary emphasis is given to clouds of considerable depth. It is not obvious that a thick cloud with an emissivity of, say, 0.8, or a black cloud with thin cirrus above may be distinguished from a single black cloud based on satellite radiance observations. Unless a reliable radiative transfer calculation can be carried out, the uncertainties of the emissivity of thick clouds or multilayered clouds may lead to serious errors in the evaluation of cloud-top temperatures.

Although it seems unlikely that a cloud whose emissivity equals unity may be isolated from satellite observations, let us assume that the procedure may be accomplished by the help of ground facilities. Several figures in their paper clearly indicate good negative correlations between brightness and cloud-top temperature. But why should lower brightness imply higher cloud-top temperature and vice versa? We must examine and justify these relationships in the light of the physics involved. The brightness (or the reflected visible radiance) measured by satellites arises from the interaction of the scattered radiation by the cloud, the molecular atmosphere and the underlying surface. If the components of the radiance due to molecular scattering and surface reflection can be separated from the total visible radiance detected by satellites, then the information on cloud thickness is certainly there. Such information, however, also contains the cloud particle phase, concentration and size distribution. Without a prior knowledge of these parameters, it is not possible to derive cloud thickness from brightness data.

Moreover, since the brightness of an optically thick cloud is determined mainly by a combination of its thickness and composition, we note that it contains no information on the cloud location in the atmosphere. While clouds reflect sunlight, they also emit thermal IR radiation according to their temperature. The emitted IR radiance depends on the cloud temperature, and therefore it should be related to the cloud location in the atmosphere. Accordingly, there should be no direct *physical* correlation between brightness and cloud-top temperature (or cloud-top height if that cloud may be treated as a blackbody). The approach of employing emission observations in connection with brightness data seems physically misleading.

After obtaining the close correlation between brightness and cloud-top temperature, the authors further claim that the atmospheric temperature profile and the ceiling height of the cumulonimbus may be derived from the radiosonde and radar echo, respectively. Subtracting the ceiling height from the cloud-top height yields the cloud thickness. The satellite technique now requires the assistance from conventional observations. *Assuming* that black clouds may be singled out and correlations between cloud-top temperature and brightness may be physically meaningful, how would these procedures be carried out on an operational basis as appeared to be the primary purpose of their paper?

The detection of the cloud thickness from satellites is of vital significance in operational meteorology, and by taking cloud composition into consideration, it may well be that cloud thickness is related to cloud brightness. The authors' effort to estimate the thickness of cumulonimbus clouds from satellites is certainly an important one. However, the logics of the approach appear to be hampered by a number of misleading assumptions made in their statistical analyses. I believe that in order to monitor changes in cloud thickness from satellite radiation measurements, the variability of the cloud particle size distribution and concentration must be known.

*Acknowledgments.* I thank Prof. J. Businger for a useful discussion. The note was written at the Department of Atmospheric Sciences, University of Washington. My research was supported in part by the Air Force Cambridge Research Laboratory under Contract F 19628-75-C-0107.

## REFERENCE

Park, S. U., D. N. Sikdar and V. E. Suomi, 1974: Correlation between cloud thickness and brightness using Nimbus 4 THIR data (11.5-$\mu$m channel) and ATS 3 digital data. *J. Appl. Meteor.*, **13**, 402–410.