Cloud Optical Properties Obtained from the Multi-Filter Rotating Shadowband Radiometer Instrument: Methodology and Analysis of Data Obtained in Fairbanks, Alaska

E. Leontieva and K. Stamnes
Geophysical Institute
University of Alaska
Fairbanks, Alaska

Introduction

A retrieval technique is presented to infer the cloud optical depth from data obtained by a ground-based, multi-channel radiometer operating in the solar and near-infrared (IR) range. An approach is introduced that uses observed and model-simulated transmittances rather than irradiances.

Cloud optical depth retrievals are most meaningful under completely overcast cloud conditions. The observed atmospheric transmittances under fractional cloud cover are of interest by themselves but may also be viewed as a way to assign an "effective optical depth" or a "cloud transmittance" of a partly cloudy atmosphere.

Dealing with transmittances allows us to utilize an efficient computational algorithm. We applied this technique to the radiation measurements by the Multi-Filter Rotating Shadowband Radiometer (MFRSR) instrument (Harrison et al. 1994) in Fairbanks, Alaska.

Algorithm

The algorithm consists of the following steps:

- Step 1 - Observations of atmospheric spectral transmittances under completely overcast cloudy skies.
- Step 2 - Modeling of the optical properties of the cloud-free and cloudy (overcast) atmosphere.
- Step 3 - Computations of lookup tables of spectral atmospheric transmittances (for a specific observational site) over a non-reflecting lower boundary using a comprehensive radiative transfer code:

$$T = T(\tau, csza) \tag{1}$$

where τ is the cloud optical depth and *csza* is the cosine of the solar zenith angle. Transmittances at a specific cloud optical depth are computed simultaneously for all *csza*.

- Step 4 - Calculations of operational lookup tables for any specific surface albedo alpha using an analytic formula:

$$T_\alpha = T + \alpha a_{sph} T / (1 - \alpha a_{sph}) \tag{2}$$

where a_{sph} is a spherical albedo for illumination of the atmosphere from below computed in Step 3.

Observations of Atmospheric Transmittance

Analyzing direct-normal component measurements by means of the Langley regression method we obtain 1) the atmospheric optical depth under true cloud-free conditions, and 2) the uncalibrated extra-terrestrial solar irradiances at the passbands. Atmospheric optical depths determined from Langley regressions based on 11 days of observations are presented in Table 1.

Table 1. Total optical depths in Fairbanks, 1994, 11 days of observations.

Wavelength (nm)	Morning		Afternoon	
	Mean	St. Deviation	Mean	St. Deviation
0.414	0.403	0.024	0.399	0.028
0.499	0.230	0.020	0.226	0.024
0.608	0.183	0.019	0.173	0.023
0.662	0.128	0.015	0.119	0.020
0.859	0.069	0.001	0.061	0.015

Using the total-horizontal component (uncalibrated) measured under cloudy conditions we obtain the atmospheric transmittance. Figure 1 presents the observed spectral atmospheric transmittances (cloudy sky) over snow and snow-free surfaces. Note that there is a substantial spread in the spectral transmittances for optically thin cloudiness at high albedo as compared to that at low surface albedo.

Efficient Computation of Transmittance

Background atmospheric optical properties were computed by the MODTRAN 3 code and the total atmospheric optical depths were adjusted to the observed values at the MFRSR passbands. Cloud properties were computed by Mie theory, assuming the cloud drop equivalent radius to be 8 mkm.

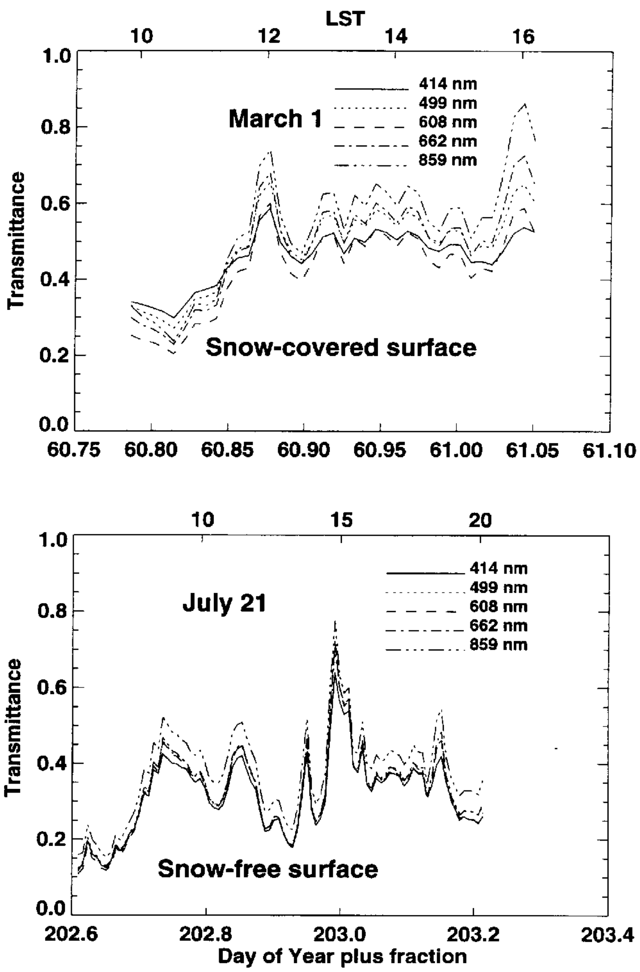

Figure 1. Observed spectral transmittances of cloudy atmosphere.

The above optical properties were used as input to the radiative transfer code DISORT based on the discrete ordinate method (Stamnes et al. 1988).

Since we are interested in the transmittance (rather than the irradiance) it is computationally efficient to use an approach developed by Stamnes (1982) and implemented it into the DISORT code. This approach allows us to find transmittances for a black surface boundary at a specific cloud optical depth for all desired solar angles simultaneously. Operational lookup tables corresponding to a specific albedo are calculated analytically (Step 4), avoiding radiative transfer computations.

Sample of Data Analysis

The impact of multiple reflections between the cloud and the surface on transmittance becomes especially strong over snow surfaces. Our data lack the measurements of surface albedo at the MFRSR wavelengths, but separate albedo measurements obtained with a spectrometer indicate that the albedo of snow increases with wavelength (from 400 nm to 800 nm) by 0.1 at our observational site. Based on previous studies (Ricchiazzi et al. 1995; Stamnes and Leontieva 1995) we attempted to use the measurements of atmospheric transmittances at 414 nm and 859 nm for simultaneous retrievals of both cloud optical depth and surface albedo. Figure 2 shows diurnal variations (10 min. averages) of observed atmospheric transmittances (completely overcast conditions) and corresponding changes in inferred cloud optical depths. The averages over the whole day of retrieved spectral albedo were used to infer the cloud optical depth. These results are pending further verifications with cloud optical depth retrievals based on the simultaneous direct measurements of surface spectral albedos by a MFRSR unit that operates looking down.

Acknowledgments

This research work was supported by the Environmental Sciences Division of the U.S. Department of Energy under contract 091574-A-Q1 to the University of Alaska as part of the Atmospheric Radiation Measurement Program. The authors are grateful to Mr. North Larsen for providing assistance with the MODTRAN code, and to Mr. Nels Larson and Mr. John Schmelzer of the Pacific Northwest National Laboratory for their help with the maintenance of the instrument and clarification of the procedures required to process the MFRSR data.

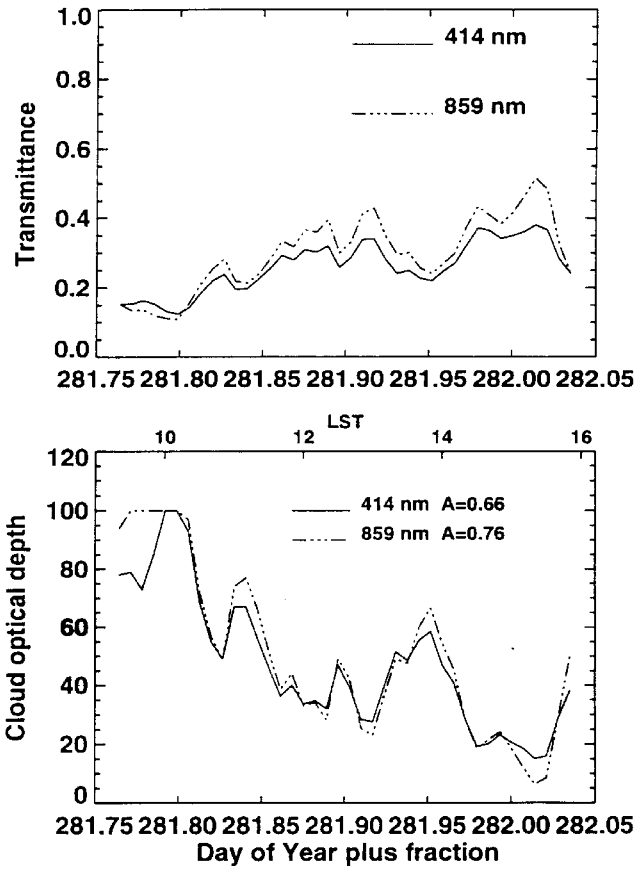

Figure 2. Observed transmittances (upper panel) and inferred cloud optical depth (lower panel) in Fairbanks on October 8, 1994.

References

Harrison, L., J. Michalsky, and J. Berndt, 1994: The automated Multi-Filter Rotating Shadowband Radiometer: An instrument for optical depth and radiation measurements, *Appl. Optics*, **33(22)**, 5118-5125.

Ricchiazzi, P., C. Gautier, D. Lubin, 1995: Cloud scattering optical depth and local surface albedo in the Antarctic: simultaneous retrieval using ground-based radiometry, *J. Geophys. Res*., **100**, D10, 20, 21091-21105.

Stamnes, K., 1982: Reflection and transmission by a vertically inhomogeneous planetary atmosphere, *Planet. Space Sci.*, **30(7)**, 727-732.

Stamnes, K., and E. Leontieva, 1995: MFRSR-PIR Platform in Fairbanks: Scientific Objectives. In the *Proceedings of the Fifth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, March 19-23, 1995, San Diego, California.

Stamnes, K., S.-C. Tsay, W.J. Wiscombe, and K. Jayaweera, 1988: Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media, *Appl. Optics*, **27**, 2502-2509.