Remote Spectroscopic Sounding of Liquid Water Path in Thick Clouds in Winter Conditions

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The liquid water path (LWP) in mixed clouds is restored based on remote measurements of spectral brightness of a cloudy layer in the spectral range 2.15-2.35μm. The results of spectroscopic sounding of dense clouds sounding are presented.

Introduction

Since the 1980s, in A. M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, the original methodology of sounding of dense clouds has been under development [1-3]. The methodology analyzes, the process of multiple scattering of radiation in a cloudy layer, is analyzed by considering separate trajectories of photons in a cloud.

Researchers use the methodology to determine the effective length of photon trajectories in a cloud by probing weak absorption bands of stable atmospheric gases O_2 and CO_2, for which optical density of the absorption band is the known function of the wavelength of light in the absorbing medium [4-6].

In the present work, spectroscopic sounding methodology is applied to research on the mixed clouds. The LWP is restored for this particular case.

For sounding of the mixed clouds, three intervals in a spectrum of solar radiation are analyzed: 0.97-1.03 μm; 1.60-1.70 μm; and 2.15-2.35 μm (Figure 1). When sounding in the first interval, it is necessary to take into account the absorption of soot. Measurements in the second interval are not sufficient because of a weak change of absorption by ice. Mass factor of drop absorption practically does not depend on size particles distribution [2,3,5] and is, for example, 0.53 and 50 m2/g at 1 μm and 2.35 μm, respectively. Therefore, measurements in the third spectral interval are more effective when using high-sensitivity radiation detectors for sounding mixed clouds.

Technique

To sound of the mixed clouds, the technique of remote sounding of water clouds was proposed [3]. The technique is based on passive sounding of clouds in spectral intervals differing by drop absorption. Measured brightness of a cloud makes it possible to restore optical thickness of absorbing drops along an effective path of radiation in a cloud, from which it is possible to proceed to a distribution function of radiation J (WL) on lengths of paths L in a cloud with identical water content WL along paths. Water

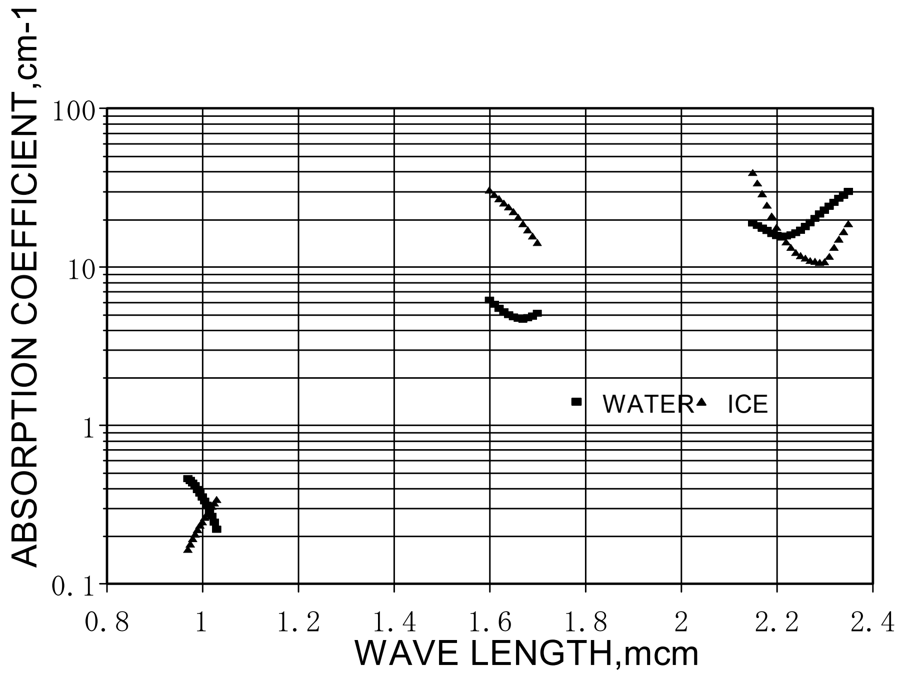

Figure 1.

content WL along paths is the product of W (liquid water mass concentration) and the path L in a cloud. One parameter of the distribution function is water liquid path WH (H - thickness of a cloud), which is restored most readily. The estimated accuracy of the restoration is 10-15% [2,3].

Equipment

A specially developed infrared spectrometer was applied. For radiation detection, the specially chosen high-sensitivity photoresistor PbS with spherical optics (working area of a sensitive element 0.1 x 0.1 mm_2) was used. The specially developed system of fast spectral scanning was applied in measurements.

Measurements Procedure

The flux of solar radiation scattered by a cloud was directed from the zenith on the entrance aperture of the spectrometer by a rotary mirror. The recording of the spectrum at 1.7-2.8 μm (Figure 2) was made during 30s. In this interval, there are regions of complete absorption of radiation by water vapor. Therefore, it was possible to receive a level of a “zero” signal. In addition, this interval includes absorption bands of CO_2 at 2.00 and 2.06 μm to which the exact binding on a spectrum was made. Received brightness spectrum of a cloudy layer contains information about solar irradiance, a cloudless part of the atmosphere and cloud in case of conservative scattering, and also about optical depth of absorbing water drops $\tau_w = \alpha_w(\lambda)W_wL$ and ice $\tau_i = \alpha_i(\lambda)W_iL$ along the effective path L of radiation in a cloud. For allocation of total optical thickness $\tau_w + \tau_i$ and minimization of influence of water vapor

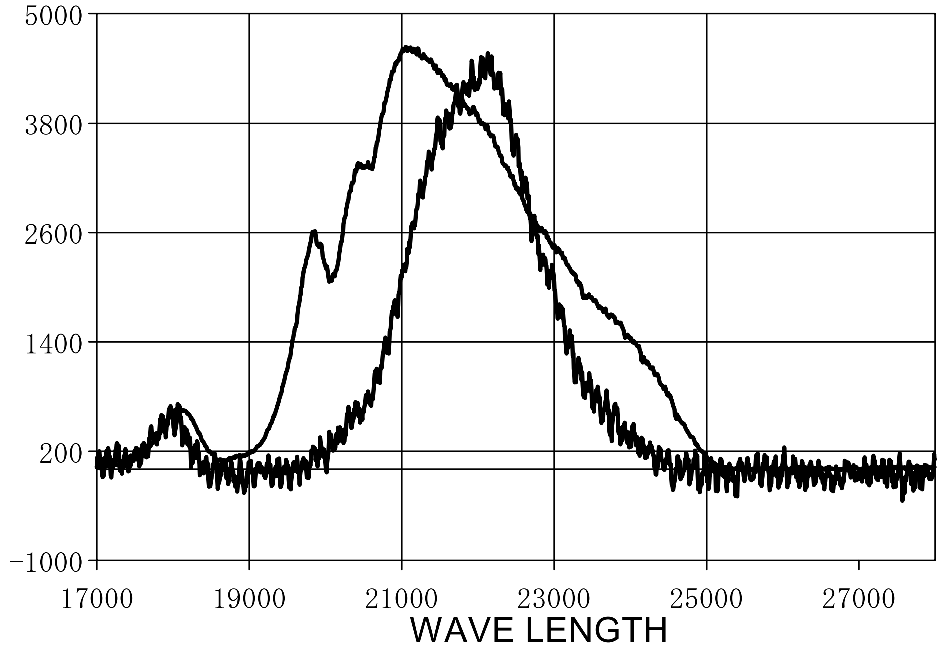

Figure 2.

absorption, the received cloudy spectrum was divided on a spectrum of brightness of the clear-sky (Figure 2). The spectrum of brightness of the clear-sky was registered in gleams between clouds or was taken from the databank.

Spectra Processing

Using refractive indices of water and ice [7-9], the mass factors of absorption of water drops and ice crystals were calculated. Then values of total optical depth of water and ice in a cloud in an interval of a spectrum 2.15-2.35 μm (Figure 3) were calculated and compared to values received from measurements. The calculated spectrum was compared to a measured spectrum, and the relation of volumetric factors of absorption of water drops and ice crystals then was obtained with accuracy estimated at 20-30%. Assuming the calculated spectrum is equivalent to the measured one (i.e., W_i = O), it is possible to analyze a spectrum of absorption of water and to determine liquid water path in the mixed cloud.

Results of Measurements

Sounding of the mixed clouds was carried out in Zvenigorod from January through March in 2000, 2001, and 2002. The overall experiment sough to improve the technique of sounding and the definition of LWP and liquid water content (LWC) on paths of radiation in mixed cloud. Basically, the studied situations included dense clouds (disk of the sun was not seen) with height of the cloud bottom no more than 1 km. All sounded clouds consisted of water and ice. The winter experiment exhibited the relationship WL = K* WH (K = 1.2 - 1.4), under WH >50 - 80 g/m^2. Monte Carlo calculations show

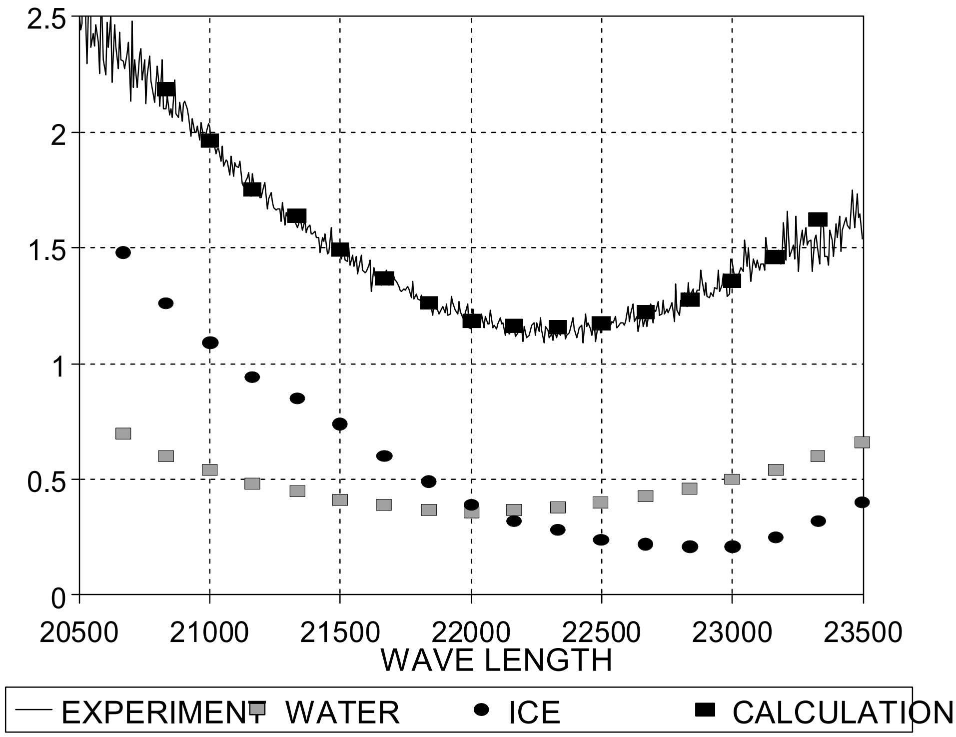

Figure 3.

that the unchanging ratio WL/WH under changing LWP means that droplet size is constant. During the experiment, WH varied from near zero to 400 g/m^2, while the scattering coefficient of droplet mass ranged as follows: first group - 600-1300 cm^2/g (clouds near the earth surface), and second group - 2000-5000 cm^2/g (clouds with the bottom height near 2-3 km).

Conclusion

The measurements in the mixed clouds in conditions of negative temperatures have shown that, with the accuracy of knowledge of ice optical constants, we can replicate the total optical thickness of water and ice absorption and the relation of their volumetric factors of absorption. The procedure described above, comparing calculated and measured spectra, makes it possible to separately obtain the effects of absorption by water and ice in the mixed clouds and, hence, to estimate not only LWC but also ice content along an effective path of radiation in a cloud. In the future, we intend to continue the development of different methods of spectroscopic remote sensing of cloud parameters based on the ideology considered above. First of all, we have in mind methods that are near completion, such as methods of spectroscopic inference of soot in clouds.

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