Spectroscopic Remote Sensing of Clouds

S. V. Dvoryashin and G. S. Golitsyn
A. M. Obukhov Institute of Atmospheric Physics
Russian Academy of Sciences
Moscow, Russia

Introduction

Cloud investigations using remote sensing are becoming increasingly significant. Parameters of particular interest include optical thickness, liquid water content, and liquid water path. At present, the following cloud parameters can be obtained from ground-based measurements:

- optical thickness - from measurements of sunlight fluxes transmitted by a cloud
- liquid water path - from measurements of absorption of microwave radiation by cloud droplets
- cloud-bottom height - with the use of Lidar.

The application of these methods of cloud investigation encounter some problems because measurements are made with various kinds of instrumentation, the methods need some atmosphere or cloud parameters at the moment of measurement, and the real accuracy of these methods has not been determined.

We developed a new approach to complex remote sensing of dense cloud systems using sun as a light source. This approach is based on consideration of different photon paths of varying directions and length affected by multiple scattering on cloud droplets (Van de Hulst and Irvine 1963). If the absorption is weak one assumes that within a cloud a spacial net of photon trajectories is formed and one can take into account absorption along each trajectory separately.

We propose an experimental determination of the trajectory effective length L_{eff}, using as a "sonde" weak absorption bands of well-mixed and stable gases such as O_2 and CO_2, the optical density for which is the known function of the photon path length (Gusev and Dvoryashin 1990). If we know this we can determine, for example, absorbent concentration by measuring the structure of its absorption band near the referenced one.

Following this idea, we developed methods for the remote sensing of liquid water content (Dvoryashin and Dianov-Klokov 1988), liquid water path (Dvoryashin and Pugachev 1992), cloud effective height (Dvoryashin and Pugachev 1991), methods for estimating cloud optical depth, scattering mass coefficient of droplets (Dvoryashin 1994), and cloud phase composition (Dvoryashin 2000). Sounding in the visible allows one to estimate the amount of soot in the cloud (Dvoryashin 2001).

From 1997 to 2001, ground-based remote sensing of thick clouds was performed at Zvenigorod, Russia. The purpose was to estimate the accuracy of this new approach, to determine the liquid water path WH and liquid water content WL_{eff} along the effective way of radiation in a cloudy layer, as well as to estimate cloud optical depth, scattering mass coefficient of droplets, and phase structure.

The measurements are based on optically passive (sun as a source of radiation) remote sensing of clouds in several spectral intervals (2.0 - 2.32 μm), differing in absorption by water and ice. The effective photon path length in clouds is measured with the use of absorption bands of CO_2. The measurements were carried out using a quick-scanning infrared spectrometer controlled by a computer. The computer-generated synthetic spectrum was then compared with the measured one, allowing us to restore the relation of volume coefficients of absorption of water and ice.

The results of winter measurements show that all sounded clouds consist of water and ice. The ratio of volume absorption of water and ice varied from 0.4 to 3 when the air surface temperature changed from -20° to 0°C.

liquid water path WH in all measurements ranged from 50 to 350 g/m^2, while liquid water content WL on an effective path of radiation in a cloud did not exceed 500 g/m^2 (see Figure 1). The scattering mass coefficient of droplets (σ) was in the range of 400 to 4000 cm^2/g (see Figure 2).

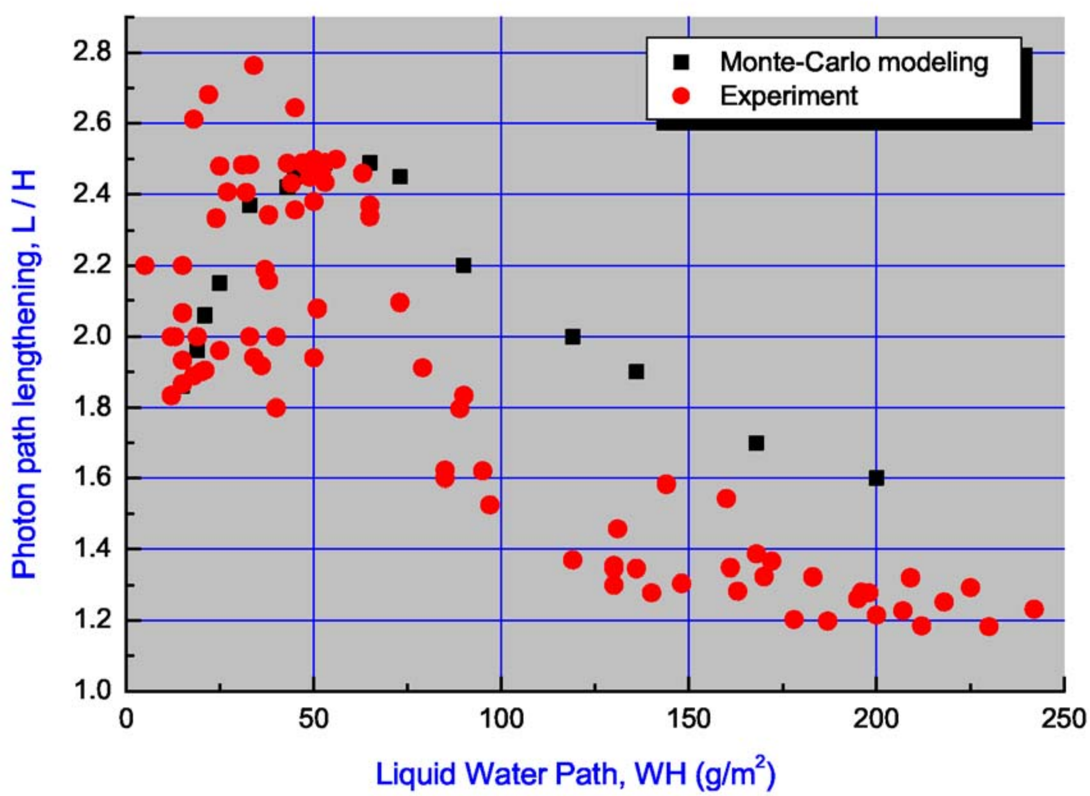

Figure 1. Liquid water content.

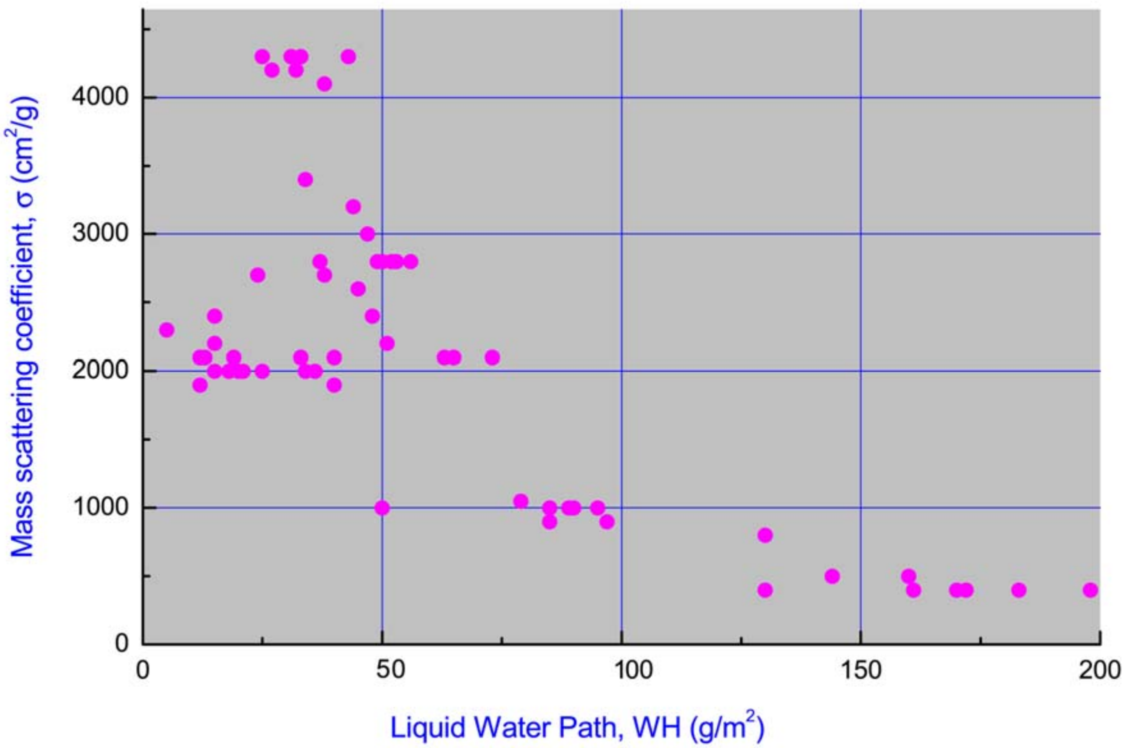

Figure 2. Scattering mass coefficient of water droplets.

Measurements have shown that we can estimate cloud microstructure and the degree of cloud inhomogeneity with the aid of parameters WH and WL. If we have unchanging ratio WL/WH and changing liquid water path, it means that liquid water content or the thickness of clouds change, but droplet size (scattering mass coefficient) remains constant. Figures 3 and 4 show time diagrams of values WH, WL, and lengthening L/H for two cloud situations.

To estimate the real accuracy of this new approach, we must measure some cloud parameters by using different methods. For this purpose, we propose to determine, in a similar way, the mean temperature within clouds along the photon trajectory. This is based on the determination of the water vapor amount along the photon effective path and on the assumption of 100 percent relative humidity within the cloud, which is the direct function of cloud temperature. For practical purposes, we use the photometry of 0,71 - 0,78 μm spectral interval. It includes the water vapor absorption band 0,72 μm and the oxygen absorption band 0,76 μm. The bands do not overlap, either with each other or with any other bands of gases. The water drop absorption can be ignored here. Uncertainty in estimating the absolute humidity and, therefore, cloud temperature, will be determined by our knowledge of the precision of the transmission functions in the H_2O and O_2 absorption bands. For example, if the precision is within one percent we may determine the absolute humidity with an accuracy of 10 percent. For cloud temperatures in the range of -5° to 10°C, the accuracy of the cloud temperature determination would be on the order of 1°C.

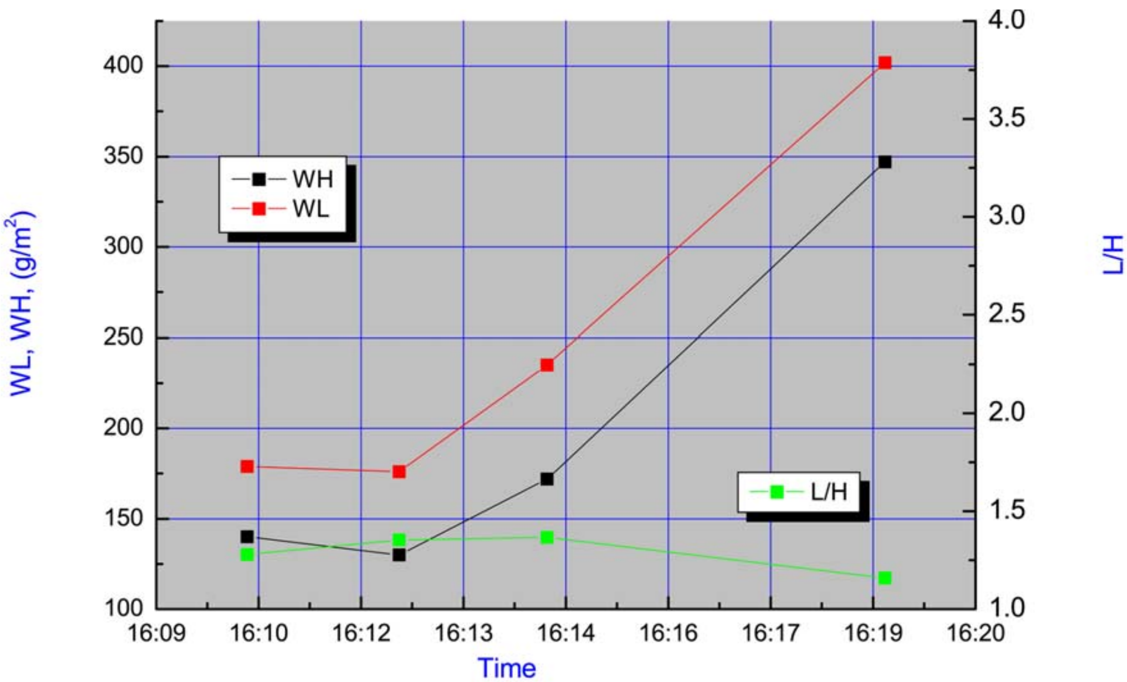

Figure 3. Values of WH, WL, and lengthening L/H (Cloud Situation 1).

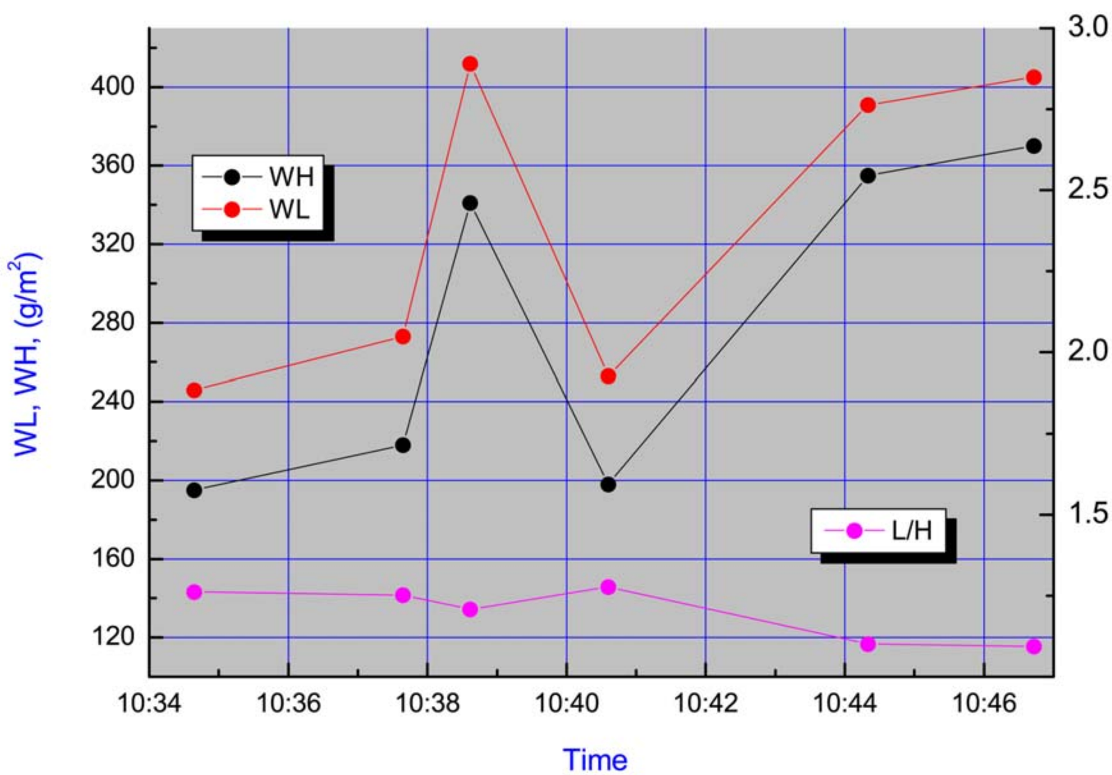

Figure 4. Values of WH, WL, and lengthening L/H (Cloud Situation 2).

Conclusions

We intend to continue the development of different methods of spectroscopic remote sensing of cloud parameters on the basis of the methodology described here. The first, which is near completion, is the use of a spectroscopic method to infer soot in clouds.

Acknowledgments

This work was supported by the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program (Contract 354760-A-Q1 and 354476-A-Q4) and RFFI Grant 98-05-64456.

Corresponding Author

S. V. Dvoryashin, dvorjashin@mail.ru

References

Dvoryashin, S. V., 2001: Remote sensing of soot within cloud. *Izvestiya, Atmospheric and Oceanic Physics*, in press.

Dvoryashin, S. V., 2000: Remote sensing of cloud haze structure. *Izvestiya, Atmospheric and Oceanic Physics*, in press.

Dvoryashin, S. V., 1994: Remote sensing of cloud parameters. *Izvestiya, Atmospheric and Oceanic Physics*, **30**, [1]2, 223-229.

Dvoryashin, S. V., and N. S. Pugachev, 1992: Spectroscopic method for measuring the cloud liquid water total column content. *Izvestiya, Atmospheric and Oceanic Physics*, **28**, 1159-1162.

Dvoryashin, S. V., and N. S. Pugachev, 1991: Spectroscopic measurements of cloud effective height. *Izvestiya, Atmospheric and Oceanic Physics*, **27**,182-186.

Dvoryashin, S. V., and V. I. Dianov-Klokov, 1988: Remote sensing spectroscopic method for liquid water content measurements in clouds. *Izvestiya, Atmospheric and Oceanic Physics*, **24**, 1011-1016.

Gusev, I. S., and S. V. Dvoryashin, 1990: The reconstruction of photon path length in cloud via spectral cloud brightness. *Izvestiya, Atmospheric and Oceanic Physics*, **26**, 728-733.

Van de Hulst, M. C., and W. M. Irvine, 1963: Scattering in model planetary atmospheres. *Meteorol. Soc. Roy. Sci. Liege*, 1963, Ser. 5, N1, p. 78-86.