Remote Sensing of Average Liquid Water Content Layer Height in Winter Clouds

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Introduction

The importance of cloud liquid water in the radiation balance does not need to be proven. The main parameters that influence the optical properties of clouds are: total amount of the liquid water in the vertical column—liquid water path (LWP); depth of the liquid water layer in clouds—liquid water depth (LWD); and height of the liquid water layer over the ground—liquid water height (LWH).

The information about these three parameters as a main part of empirical data for radiation transfer models is supplied by "in situ" airborne measurements and by the special liquid water radiosonde (Hill 1994). However, using aircraft measurements for the launching of expensive radiosondes could not provide (within reasonable cost) continuous long-term data sets for synoptic scale models.

The limitation of remote technologies to get all three parameters mentioned above is well known: the millimeter wavelength radars cannot receive backscatter signals from small liquid water drops; lidar radiation is attenuated in clouds so much that information could be received just from the first 200 m to 300 m into the cloud; and microwave radiometry could get the data about LWP (Westwater and Guirand 1980), but in its classical application, it does not have space resolution.

The aim of the present work was to investigate the possibilities of getting data about LWH from the ground by means of a microwave radiometer system. The approval of such a possibility as well as the reliability of a developed microwave system confirmed by three field projects are discussed also.

The Method of LWH Remote Sensing

The physical idea of microwave remote sensing of LWH is based on the properties of liquid water to change the absorption coefficient depending on the thermodynamic temperature of it.

The brightness temperature of the clouds T^b received from zenith direction by ground-based microwave radiometer during the absence of liquid precipitation can be given by the equation (Westwater and Guirand 1980):

$$T_b(f) = T_a\{1-\exp[-\tau(f)]\} \tag{1}$$

where T_a is average atmosphere temperature and $\tau(f)$ is total opacity of the atmosphere at the frequency of sounding f. Far from the absorption lines of the atmospheric gases, the opacity $\tau(f)$ can be presented as a sum of absorptions in liquid water, water vapour, and molecular oxygen:

$$\tau(f)= B(t,f)W + C(f)Q + \tau_{02}(f) \tag{2}$$

where B(t,f) = absorption coefficient on frequency f of the liquid water drops at temperature t, W = integral liquid water content LWP, C(f) = absorption coefficient of water vapour on frequency f, Q = integral water vapour content, and $\tau_{02}(f)$ = absorption by the molecular oxygen.

If measurements are conducted by means of a two wavelength system, the scatter plot in the coordinates $\tau(f_1)$ x $\tau(f_2)$ can be constructed for any set of data. During clear-sky conditions, when W = 0 and just the integral water vapour is varied, the points of the scatter plot will be approximated by a straight line with the tangent of inclination angle equal to $C(f_1)/C(f_2)$, because the absorption in oxygen is almost constant. During cloudy conditions, the variations of the LWP are much faster, and the absorption in liquid water is much higher, so the straight line best fitted to the scatter plot will have the tangent of inclination angle equal to $B(t,f_1)/B(t,f_2)$. Thus, the tangent of inclination angle of the best fitting line in $\tau(f_1) \times \tau(f_2)$ will depend only on liquid water drop temperature.

It was shown (Haikin and Koldaev 1994) that for wavelengths of 3 mm and 8 mm, the function $F(t) = B(t,f_1)/B(t,f_2)$ is almost linear with a deviation less than 3% within the cloud drop temperature range -20° C/+5° C.

As soon as we are able to get the average temperature of cloud drops, the height of the liquid water layer can be counted on the basis of standard radiosonde data about the vertical atmosphere temperature profile.

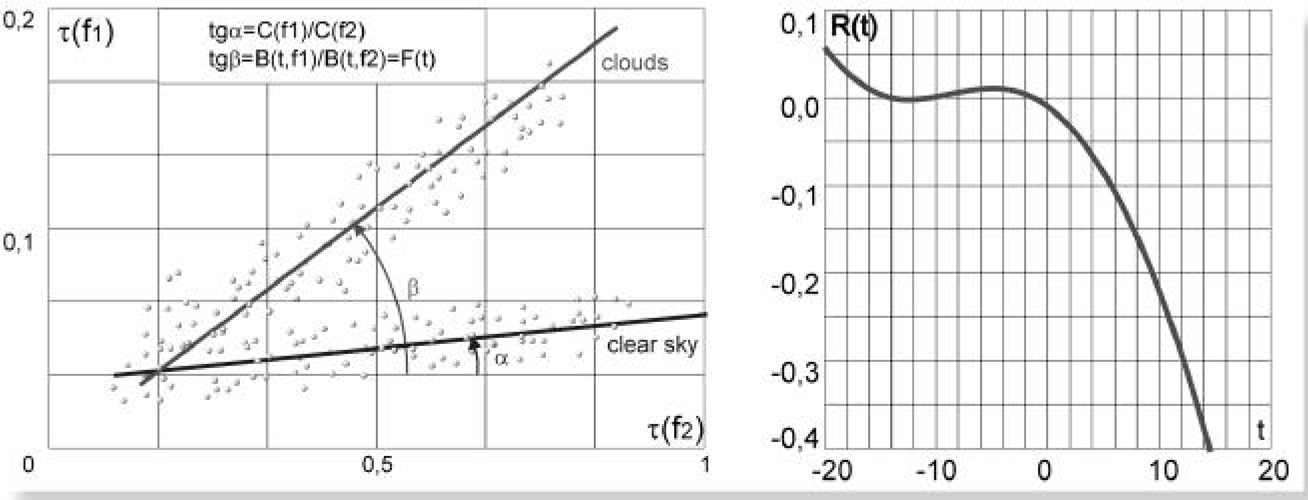
The illustration of the procedure discussed above is given in Figure 1a. The deviation of approximation F(t) by the straight line is given in Figure 1b. A detailed description of the method and the algorithm of LWP and LWH retrieving was reported in Haikin and Koldaev (1994).

Instrumentation

A system consisting of two solid-state Dickey-type microwave radiometers with working frequencies of 37.5 GHz and 94.2 GHz has been developed and manufactured by the Scientific and Production Company “ATTEX” (Russia) and has the same parameters as described in Koldaev et al. (1996).

During the last few years the same company developed and constructed the meteoprotection housing for the unattended operation of different microwave radiometers (Figure 2). The housing has the shape of a tube with a diameter of 14 in. and a length 32 in. The tube consists of two parts: one is stationary and the second is rotating. The stationary part includes a microwave radiometer with antenna, thermostabilising system, step motor, microprocessor control board and set of sensors. The rotating part includes a flat metallic reflector and calibration unit. The connection between the rotating and stationary part is waterproof.

The thermostabilising system consists of thermosensors, heaters and fans, is able to support the stable inside temperature regime of the radiometer within the environmental conditions +40° C (without direct sun)/-40° C. The output signals of the radiometer as voltage are received by the microprocessor control board. This board makes a digital conversion of the signals and supports RS232 serial transmission of the data in digital form to the standard serial port of any PC computer. At the same time, this control board manages the thermostabilizing system and manages the step motor. There are two possibilities of operations for this microprocessor board: 1) an operation using a hard algorithm that is written in the permanent memory of it, and 2) a PC computer-induced operation with an execution of the routine procedure as digitized by the microprocessor itself.



(a) (b)

Figure 1. Illustration of the retrieving procedure.

Figure 2. The general view of the all-weather unattended two wavelength microwave system.

The rotating part with a flat reflector is covered by Teflon, which is rigid enough to create the same tube shape. The volume of the stationary and rotating parts are open to each other, so the reflector is kept continuously at a normal (warm) temperature. Precipitation as snow or rain can create the absorbed or reflected layer at the external surface of the Teflon that can lead to the wrong interpretation of the data. To exclude such a possibility, the rotating part is rotated 360° within the customer specified interval (adjusted by software) depending on the intensity of precipitation. Two standard car windshield cleaners are rigidly installed on two opposite sides in the horizontal plane of the stationary part. So, during rotation, the Teflon is cleaned by these cleaners.

Field Projects

Measurements with the two-wavelength microwave system were made during three field projects conducted by the Atmospheric Environment Service of Environment Canada within the last 3 years.

I. BASE - Beaufort and Arctic Storms Experiment

BASE was held in Inuvik, Northwest Territories of Canada, in fall 1994 (31 August-10 October). During the experiment, a wide set of instruments were used to get simultaneous data about different parameters of the atmosphere. Among the instruments were a specially equipped research aircraft "Convair-580" owned and operated by the National Research Council of Canada; two 3-cm Doppler radars; enhanced radiosondes; and special surface precipitation monitors.

The main purpose of the microwave radiometers was to obtain statistical distributions of the LWP over the experimental region. However, the schedule of the experiment also allowed a comparison for the first time of direct "in situ" aircraft measurements of liquid water layer height with the average height of the liquid water retrieved from remote data. Because the set of data appropriate for comparisons was restricted, the comparisons were continuous during the next Canadian Freezing Drizzle Experiment (CFDE) II.

II. CFDE II - Canadian Freezing Drizzle Experiment II

CFDE II was carried out in St. John's (Newfoundland) during February-March 1995. The same instrumentation as in BASE were used in this project. Research aircraft data routinely documented the vertical distribution of the liquid water in clouds from ground level to 3000 m to 5000 m during take off and landing at St. John's airport. Vertical profiles of the temperature, dew-point, liquid water content (LWC), and ice water content (IWC) were constructed for each flight. An estimate was made of the temperature range where LWC layers were encountered, using aircraft microphysics probes [LWC, forward scattering spectrometer probe (FSSP)].

III. Pre-phase of CFDE III - Canadian Freezing Drizzle Experiment III

The pre-phase of CFDE III was done with the support of Transport Canada at the Environment Canada weather radar site in King City (40 km North of Toronto). The two wavelength ground-based microwave measurements were made in non-interrupted continuous mode within 4 months during the winter season of 1996-1997. The purpose of this measurement was to get first time statistically valuable data about liquid water in clouds for a whole winter season. As a result, the frequency distributions were obtained for different parameters of liquid water zones in winter clouds. The distributions of the average temperature and average height of the liquid water zones were constructed also. Taking into account a huge set of data and the length of time for the measurements, it appears reasonable to compare both these parameters with radiosonde data. Although the nearest radiosonde launching site was 150 km south (Buffalo, USA) of the radiometer experimental site, the comparisons of statistical distribution of the parameters as a liquid water layer height in winter clouds still makes sense. This is more obvious if we take into account the average horizontal size of the liquid water zone in winter clouds is about 100 km and very often exceeds this range twice or triple.

Discussion of the Results

The statistical results about distributions of the liquid zone parameters, such as LWP, and the average duration of such zones has been discussed earlier (Koldaev et al. 1996). In this article, we focus on the discussion of the results concerned with the possibility of remote estimation of liquid water height in clouds.

On the basis of simultaneous ground-based microwave sensing and aircraft data obtained during BASE and CFDE II, we have constructed the scatter plot presented at the Figure 3.

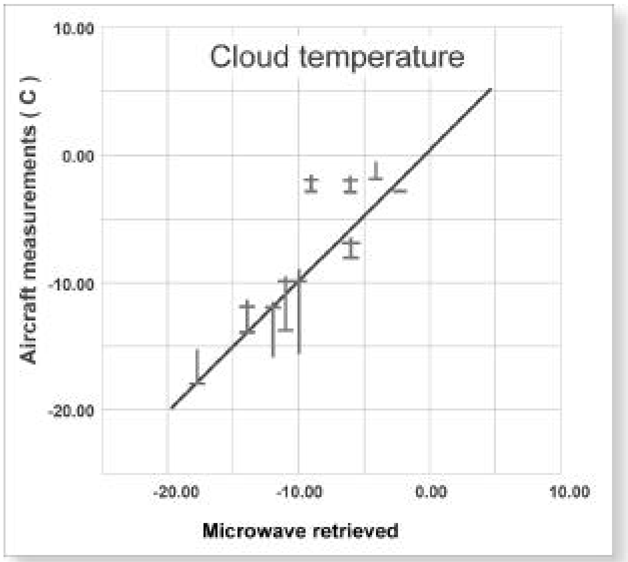


Figure 3. Comparisons of in situ and remote estimation of average temperature of liquid water layer.

The average temperatures of the liquid water layer retrieved from remote data are presented as an ordinate. The data exactly correspond to the time when research aircraft had take-off or landing. From the aircraft data about the LWC profile and temperature profile, we estimated the temperature of the top and bottom of the LWC layer in clouds. These corresponded values are presented as a line along the abscissa. It is easy to see that direct comparison gives good linear correspondence of “in situ” and remote obtained data. The restricted volume of compared data can be explained by the technical difficulty of executing the flights exactly over the radiometer installation site for interpretation of multilayer cases and cases with inversions in temperature profile. The last two situations—multilayer structure of the liquid water into the clouds as well as cases with temperature inversions—should be interpreted as current restrictions of the method applications; however, the comparison of the simple cases provides the first positive indications of principal possibility.

The statistical comparison of the average height of the liquid water layer with radiosonde data was made on the basis of pre-phase CFDE III data. For this comparison, two probability distributions were constructed and presented in Figure 4.

Figure 4a shows the distribution of the liquid water layer temperature which is microwave retrieved average temperature of liquid water layer. Figure 4b shows the distribution of the temperature of saturated layers in the atmosphere as it is given by radiosonde data. Saturated layer is defined as a layer with relative humidity exceeded 95%, which is identified as a part of the cloud-contained liquid water drops. Often the saturated layer has a sufficient vertical extension or multi-layer indications. For definition, we used the upper height where relative humidity exceeded 95% for the construction of the Figure 4b. For the construction of both distributions, we used about 470 cases of LWC zones registrations. If the LWC zones were registered between launching of the radiosonde, the radiosonde data were interpolated.

The comparison of Figures 4a and 4b gives reliable proof that microwave-retrieved height of the liquid water layer in winter clouds makes sense, at least from a statistical point of view. Thus, we can conclude that the two wavelength ground-based microwave system could be used for investigations of Arctic clouds especially for getting statistically valuable data about the height of the liquid water layers in clouds.

Acknowledgments

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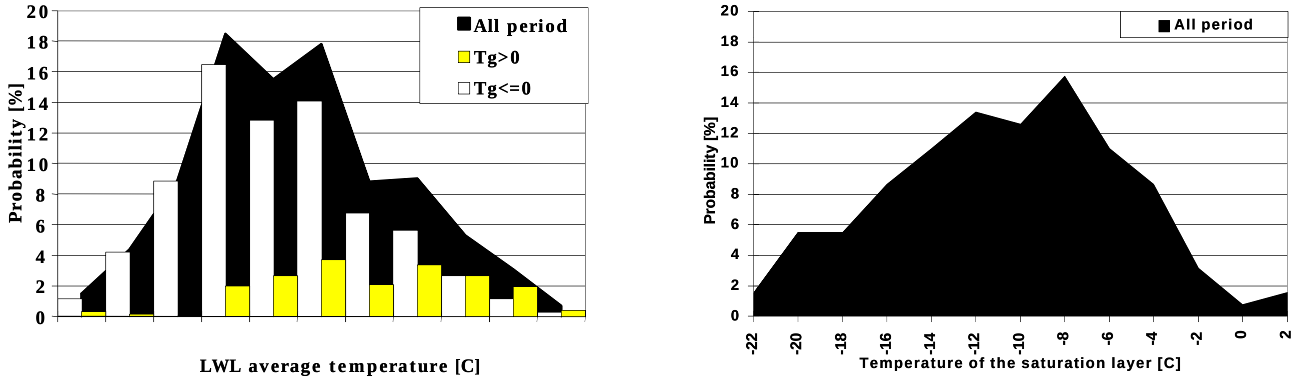

Figure 4. Comparison of radiometer (a) and radiosonde (b) distributions of the liquid water temperature in winter clouds. (For color version of this figure, please see http://www.arm.gov/ docs/documents/technical/ *conf_9803/koldaev-98.pdf.)*

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