Microwave and IR Radiometry for Estimation of Atmospheric Radiation Balance and Sea Ice Formation

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Introduction

It is well known that space-born microwave and infrared (IR) polarization measurements allow the development of advanced technologies for permanent snow and ice pack monitoring in the Arctic region. But the interpretation of these data are complicated because variations of atmospheric radiation start to be close to the brightness contrasts of different types of ice. On the other hand, the same absorbing/scattering properties of the atmosphere play a key role in the shortwave radiation balance and therefore make a big impact in sea ice formation (freezing/melting). One of the first attempts to investigate sea ice formation using satellite-born IR and microwave instruments was made with the USSR "Meteor-18" satellite by Gorelik et al. (1978). Several statistically valuable data for determining the periods of sea ice melting in the Laptev Sea and Okhotsk Sea were obtained as well as mapping the sea ice structure. The comparison demonstrates that there is not a bad qualitative correspondence of the retrieved and observed data, but unfortunately, as shown in more recent works, it is the qualitative mapping. Retrieving the quantitative parameters, such as sea ice depth or melting of the ice under snow coverage, is a much more complicated task that needs detailed knowledge about transformation of the radiation received by space-born instruments. Although different atmosphere components take part in the formation of its absorbing/scattering properties (water vapor, aerosols, fogs, and so on), the importance of clouds is well recognized. The problem of accounting for the impact of clouds on the short radiation fluxes is enforced because of high temporary and spatial variability of cloud parameters. The parameterization of cloud properties using some integrative parameters has been proposed and been widely used recently. It is considered now that the main parameters of clouds that influence the radiation balance are (1) space structure, (2) height of clouds (cloud top and base in case of deep clouds), (3) average temperature of clouds, (4) integral liquid water content (LWC), and (5) integral ice water content. Some of the above-mentioned parameters are measured now by using regular meteorological satellites. However, retrieving the cloud base from satellite measurements is still a problem at least over the land surface as well as the average temperature of the clouds. The accuracy of retrieving the integral liquid/ice water content on the basis of satellite measurements is much less than that of ground-based instruments. Thus, the development of the ground-based validation measurements of different cloud parameters is the problem discussed in the presented work.

Classification of Clouds and Set of Measuring Techniques

Classification assumed by us is based on the optical properties of clouds and therefore is very simple. The whole variety of clouds is divided into three classes: (1) thin or transparent for visible radiation clouds (τ<1Np), (2) middle or semi-transparent clouds (1Np<τ<7Np), and (3) thick or non-transparent clouds (τ>7Np). In terms of the division of common cloud types, the first class is feted to Ci, Ac tr, St; the second one is feted to St, Ac, Sc; the third one is feted to Cu, Ns.

The ground-based investigation of thin (transparent) clouds was conducted in the Dolgoprudny, Moscow region from 1971 to 1978. The measuring system was composed with two IR (8 mkm to 12 mkm) "0" level radiometers, 1.35 cm wavelength microwave radiometer, and decimeter range radio tracing system for pointing to the exact sun position in the presence of clouds. The method of observations involved measuring the radiation of the clear atmosphere in IR and microwave range simultaneously with the IR measurements of the sun radiation attenuated by the atmosphere. For this purpose, one IR radiometer was placed on the sun tracing system when the other IR radiometer and microwave ones were pointed in the zenith direction. In the presence of clouds, the same measurements were taken until the brightness temperature of clouds in the IR range was saturated. The technical parameters of the employed instruments are given by Gorelik et al. (1976).

Measurements of the middle (semi-transparent) cloud parameters were provided in Moscow and at Issik Kul Lake from 1983 to 1997. The measuring system involved IR radiometer (8 mkm to 12 mkm), microwave 3-mm wavelength radiometer, and a visible range pulse light detection and ranging (LIDAR). The method of observation was based on simultaneous measurements of the IR and microwave radiation of different types of non-precipitable clouds jointly with LIDAR sounding of the same volume of the cloud. The whole system was able to provide synchronous scanning in different directions, so the soundings were made at a number of elevation and azimuth angles. In contrast with the thin clouds, the measurements were continued when the IR radiometer got saturation of the brightness temperature. In these observations, the LIDAR data were used as an indicator for the measurements end: it was made on the basis of the LIDAR output pulse analysis. The technical parameters of the employed instruments are given by Zuravleva et al. (1983). The common view of the measuring system for semi-transparent cloud monitoring is presented in Figure 1.

The thick (non-transparent) cloud parameters were measured in the Moscow region and Ontario province during a number of winter seasons from 1985 to 2000. The basic instrument DHS for these measurements is the system consisting of two microwave radiometers operating at 3 mm and 8 mm working wavelengths. The system recently has operated in unattended mode with the ability of self calibration, self thermo stabilization, and self cleaning from precipitation. Such options allow the system to operate reliably in a very wide range of harsh weather conditions including heavy snowfall and freezing drizzle. The measurements are based on receiving the radiation of precipitable clouds in the zenith direction simultaneously and from the same sample of the cloud. For this reason, the antenna beamwidths for both radiometers are strictly the same. The common view of the DHS measuring system is presented in the Figure 2 and technical parameters are given in Koldaev et al. (1996).

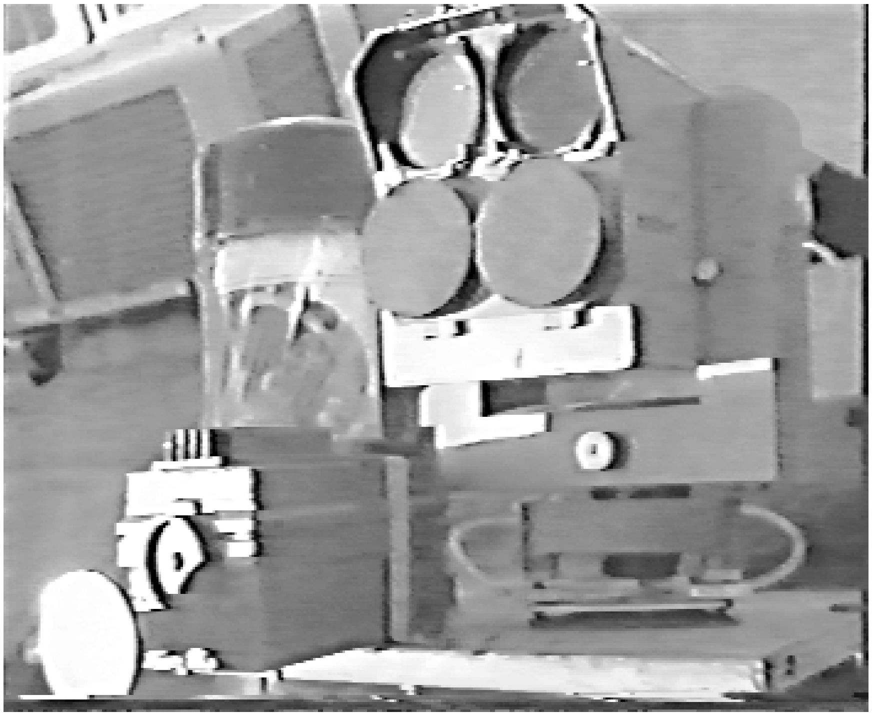

Figure 1. Common view of the system for semi-transparent cloud monitoring.

Figure 2. Common view of DHS.

Retrieving Algorithms

The algorithm of cloud parameters retrieved during investigation of the transparent clouds was based on the assumption that the cloud and atmosphere optical properties are not changed within the conic angle at 5 degrees. When one of the IR radiometers was facing the sun and measured the signal I', this signal was really composed of four fluxes of radiation: I1-sun attenuated by the clouds and atmosphere, I2-radiation of the clouds attenuated by the atmosphere beneath the cloud, I3-radiation of the atmosphere in nadir direction, and I4-radiation of the earth surface reflected by the cloud. Then the radiometer antenna beam was moved 2.5 degrees from the exact direction to the sun and received the radiation I''. If we take into account the assumption above, it is obvious that this signal is composed just by the three last terms: I2, I3, and I4. According to the Buger-Berr equation, the optical depth of the cloud and its emission were calculated. The transparency function of the clear atmosphere was estimated on the basis of independent measurements with the second IR and microwave radiometers, which received the radiation of the atmosphere. Gorelik et al. (1976) describe the algorithm in more detail.

The retrieving algorithm of middle or semi-transparent cloud parameters is based on the general assumption regarding the cloud microstructure and, namely, on the three-parameter Gamma distribution of the cloud particle size. In general, to determine three independent parameters, we have to have three independent measurements. In our case, the independent measured parameters were integral LWC as measured by IR or microwave radiometer, reflectivity as retrieved from the LIDAR backscatter pulse form, and attenuation as retrieved jointly with reflectivity. Depending on the shape of this pulse, the analysis was made by three different methods. When we can retrieve three parameters of Gamma distribution, we can easily calculate any other optical and micro physical properties of the clouds. For instance, height distribution of LWC can be calculated (Zuravleva et al. 1983).

A cloud parameters-retrieving algorithm in the case of thick or non-transparent clouds in application to the winter clouds was described by Koldaev et al. (1996). For this reason, we will just remember here the main principle. Because the absorption of the radiation by the clouds depends mostly on two parameters, integral LWC and average drop temperature, we have to have two independent measurements to retrieve these values. In our work, 3-mm and 8-mm wavelength radiometers were used. Because of the temperature dependence of the absorption coefficients at these wavelengths, it allows us to construct the linear function of these coefficients' ratio, which is independent of the liquid water path (LWP).

Experimental Results

Although one of the main results obtained during the investigation of thin clouds does not have a direct relation with cloud optical properties, it is very important for retrieving algorithm. It was found that the optical depth of the clear sky measured at the IR (8 mkm to 12 mkm) and the same measured by the microwave 1.35-cm radiometer were closely correlated to one another. Moreover, clear-sky optical depth calculated on the basis of radiosonde data compared to the optical depth measured by IR radiometer shows less correlation. This case led us to the understanding that accounting for the clear-sky opacity is better performed using microwave remote sensing than in situ radiosonde measurements. Optical properties transparency P_2, emission ε, and optical depth τ of the transparent clouds are presented in Table 1.

Table 1. Optical properties transparency, emission, and optical depth of transparent clouds.

Parameters	**Ac tr**					**Ci**				
	$\bar{x}$	x_{max}	x_{min}	σ	θ	$\bar{x}$	x_{max}	x_{min}	σ	θ
$\bar{P}_2$	0,48	0,76	0,23	0,18	37,1	0,75	0,88	0,67	0,06	8,4
ε	0,52	0,77	0,24	0,18	34,6	0,25	0,33	0,12	0,06	24,0
τ	0,72	1,47	0,27	0,39	54,2	0,29	0,40	0,14	0,08	24,4

The last measurements of thick or non-transparent cloud parameters as integral LWC or LWP, average temperature of the liquid water layer were made within the Alliance Icing Research Study project (AIRS) conducted in Ontario, Canada, during the winter season 1999-2000. The probability distributions of the LWP are presented in Figure 3.

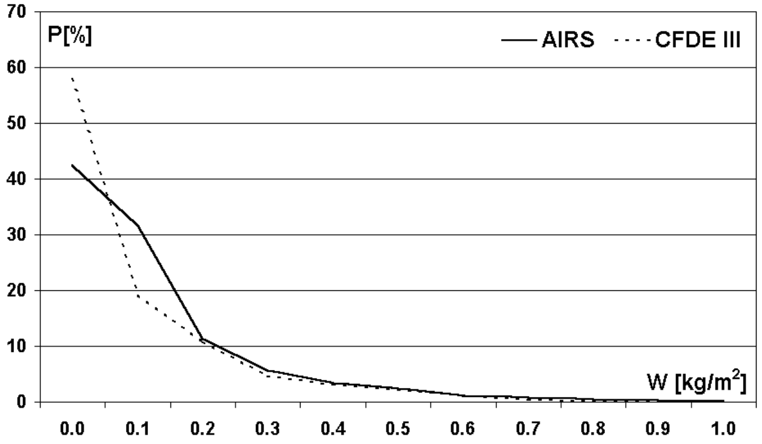

Figure 3. Distribution of LWP.

Interestingly, the same distribution obtained in the same region two years earlier (winter 1997-1998) within the framework of the Canadian Freezing Drizzle Experiment III (CFDE III) is very similar; it is shown by the dashed line in Figure 3. In contrast, the distribution of average cloud temperature during AIRS compared to the same for CFDE III looks completely different. Both of these distributions are presented in Figure 4. This low correspondence of the data for average cloud temperature may lead to concern that the average cloud temperature is not so stable a climatic factor that it would be suitable as a parameter for Global Circulation Models (GCMs). Nevertheless, we have calculated the average cloud height on the basis of radiosonde data on temperature profiles of the cloudy atmosphere, which were available 6 times a day. The launching site of radiosondes was in the immediate vicinity of the radiometers measurement site, so the use of the temperature profile data for estimation of the cloud

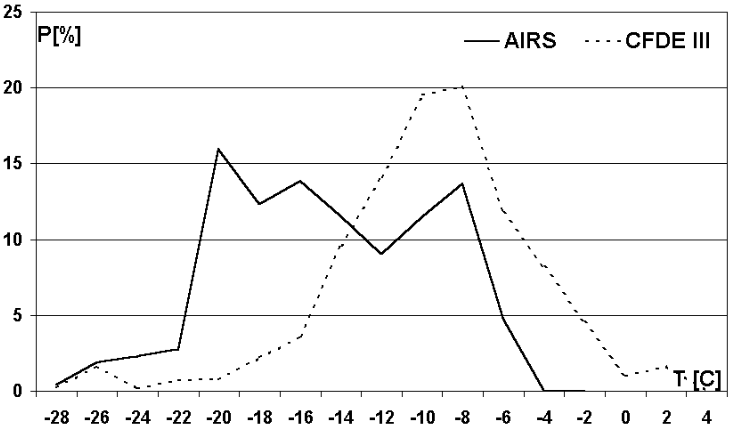

Figure 4. Distribution of average temperature of LWP during AIRS and CFDE III.

height seems to be reliable. The probability distribution of the average cloud height compared to AIRS and CFDE III are presented in Figure 5. The distributions in Figure 5 indicate that although the average cloud temperature is different within two experimental seasons, the average height distributions remain the same. In this connection, it should be highlighted that the widely used parameter in GCMs as average cloud temperature is probably good enough for upper troposphere clouds, but is not stable for the middle and low troposphere. To account for the radiation transfer properties of the cloud in the lower part of troposphere, the parameter as average cloud height seems to be more attractive.

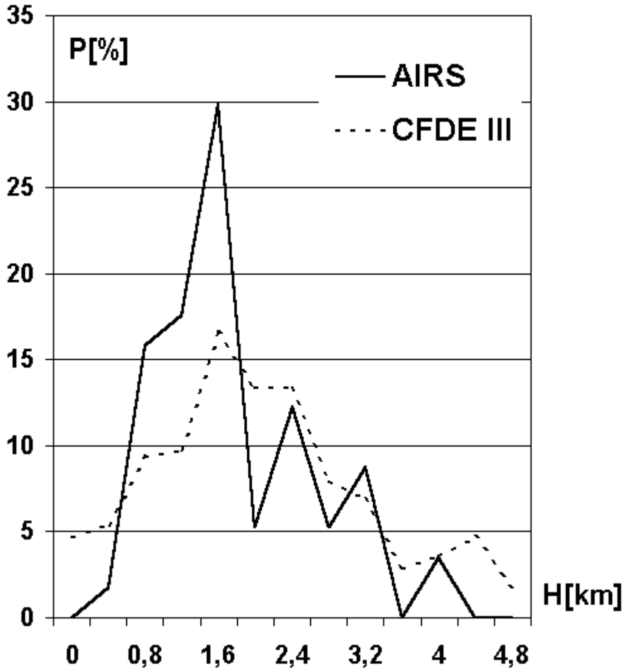

Figure 5. Distribution of liquid water zone average altitude during AIRS and CFDE III.

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