Analysis of cirrus clouds by using the ICESat/GLAS data

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Abstract

Cirrus cloud height and thickness in the autumn 2003 are investigated by the cloud data obtained from the Geoscience Laser Altimeter System (GLAS) on board the Ice, Cloud, and land Elevation Satellite (ICESat).

Our results show that the vertical distribution of cirrus clouds occurrence frequency peaks at 18.5 km and 14 km in the tropics, and 15.5 km and 12 km in the northern middle latitude. The heights of cirrus top and bottom and thickness on average are 14, 12.3 and 1.7 km in the tropics, respectively. In the northern middle latitude, the heights of cirrus top and bottom are about 4 km lower than those of in the tropics, while the thickness is almost constant at any latitudes.

The number of cirrus layer is about 1.2 regardless of the latitude. The total number of cloud layer with cirrus clouds is about 3 layers, indicating that cloud exists at a high rate in the lower layer when the cirrus exists.

1. Introduction

Cirrus clouds, in the upper troposphere and lower stratosphere (e.g. PSC) affect not only the terrestrial radiative balance but also the water content and chemical balance of the stratosphere. In spite of their importance, there has been only a little discussion on the quantification of their effects in atmosphere. Consequently, although cirrus clouds affect the observational data of the remote sensing techniques, such effect is not taken into consideration by most of the data analysis algorithms, resulting in the significant uncertainties in such data.

Since the spatial distributions of cirrus clouds change dramatically with time, global observation of cirrus clouds is necessary in order to understand their characteristics in details. However, it is difficult to observe cirrus clouds because the optical thickness is thin (less then 3); and they are formed in the upper troposphere (e.g. higher than 8 km in the tropics). Further, it is known that the physical parameters of cirrus clouds such as occurrence frequency and altitude, and geometric and optical thicknesses can differ depending on the instruments used [1].

From previous *in situ* measurements (i.e. aircraft and ground based observations), it is known that the altitude of center of cirrus clouds is located at the altitude of 4 $\sim$ 20 km with the average being 9 km, and the thickness is 0.1 $\sim$ 8 km with the average being 1.5 km [2]. Since the availability of such data are limited in time and space, the global observation is needed in order to fully understand the features of cirrus clouds.

The aim of the present study is to investigate the height, thickness and optical thickness of cirrus clouds on the global scale using the Geoscience Laser Altimeter System (GLAS) data. The GLAS on board the Ice, Cloud, and land Elevation Satellite (ICESat) is a powerful instrument to detect cirrus cloud on the global scale.

2. Analysis Data

The ICESat was launched on January 13, 2003 and is one of the satellites of the Earth Observing System (EOS) mission. The purpose of the ICESat is to observe the ice mass balance, the heights of clouds and aerosol, and the topography and vegetation on the ground. The ICESat orbits the earth about 15 times per day at the altitude of 590 km with the inclination of 94 degrees. The GLAS has two laser wavelength channels: one is 1064 nm, and another is 532 nm. The 1064 nm laser channel detects mainly the surface and the height of relatively thick clouds. The 532 nm laser channel obtains the heights of clouds and aerosol [3]. The laser footprint is about 60 m, and data are taken at 40 Hz with the vertical resolution of 76.8 m.

The present study uses the top and bottom heights of cloud layer from the cloud layer height product (GLA09, Version 24.0) and the optical thickness from the thin cloud/aerosol optical depth product (GLA11, Version 24.0) in the period between September 24 and November 18, 2003 when the laser identifier is 2A. Under the present study defines, the cloud at the altitude of 5 km or above with 8 km or less and optical thickness of 2 or less is defined as cirrus clouds.

3. Results

3.1 Vertical distributions of top and bottom of cirrus clouds

Fig.1 shows the vertical distribution of cirrus cloud occurrence frequency in the tropics (15°S $\sim$ 15°N) and the middle latitude in the northern hemisphere (30°N

$\sim$ 60°N). The occurrence frequency of cirrus clouds is defined by the ratio of the number of cirrus cloud events to the total number of cloud events detected. The features that are common to both latitudes are (1) the occurrence frequencies are higher at higher altitudes; (2) that there are two peaks in the upper troposphere; this is especially noticeable in the northern mid-latitude; and (3) that the thickness of cirrus clouds peaks at around the altitude of 3 km. The similar features are found for different latitudes studied, except that frequency distribution at each of these latitudes exhibit only one peak.

In the tropics, the maximum frequencies of top and bottom of cirrus clouds are located near 18.5 km which is slightly above the climatorological tropical tropopause (17.5 km). Further, the bottom of cirrus clouds also peaks around 14 km which also corresponds to the bottom of the Tropical Tropopause layer (TTL). At this altitude (14km) in the tropics anvil cirrus clouds are frequently found. In the northern mid-latitude, there are two peaks of top and bottom of cirrus cloud height, at 15.5 and 12 km. The former peak is located nearly at the tropopause in the middle latitude. It can be inferred that cirrus clouds in the middle latitude during the autumn are formed slightly below the tropopause as in the tropics.

3.2 Cirrus cloud thickness and optical thickness

Fig.2 indicates the vertical distribution of the cirrus cloud thickness in the tropics and the northern mid-latitude. In the tropics, the thickness at the upper and lower troposphere is less than 1 km whereas its thickness at the intermediate altitude was more than 1 km. In the middle latitude, cirrus clouds in the upper and middle troposphere are thicker than ones in the lower troposphere. At the other latitude, the structure is similar to that of in the middle latitude.

Fig.3 shows the vertical distribution of the cirrus cloud optical thickness in the tropics and the northern mid-latitude. At both latitudes, the optical thickness in the upper troposphere is thin (less than 0.2); the optical thickness in the middle and lower troposphere is nearly constant at the value of 0.25. It is found from Fig.3 and Table 1 that the optical thickness of cirrus clouds increases with latitude.

4. Summary

Table 1 lists the average values of cirrus cloud top and bottom heights, thickness and optical thickness at 5 latitudes along with their global values averaged for 86°N to 86°S. This section summarizes the results of the previous section and Table 1.

From Table 1, the tropical average of heights of cirrus cloud top and bottom, and thickness is 14, 12.3 and 1.7 km, respectively. The vertical distribution of the cirrus cloud bottom has peaks at 18 km and 14 km as shown in Fig.1. These altitudes correspond to the altitude slightly below the tropical tropopause and the altitude where the anvil cirrus forms frequently. In the middle latitudes in both hemisphere, the top and bottom heights of cirrus clouds are approximately 10 and 8 km, respectively (Table 1). These altitudes are about 4 km lower than the corresponding values in the tropics.

Average cirrus cloud thickness and the number of cirrus layers were small, about 2 km and 1.2 layers, respectively, and did not depend on the latitude. The number of cloud layer with cirrus clouds is about 3, indicating that the cloud exists with higher probability in the lower layer when the cirrus exists.

The average thickness of the cirrus clouds, as noted earlier, is almost 2 km regardless of the latitude [Table 1], while the thickness distribution peaks at 3 km [Fig.1]. In the tropics, the thickness is 800 m at the altitude of 19 km, and 2 km at the altitudes between 12 and 16 km [Fig.2].

Additionally, optical thicknesses of cirrus at several latitudes were investigated (Table 1 and Fig.3). Our results show that optical thickness is thin (less than 0.2) in the upper troposphere while in the mid- and lower troposphere, it was approximately constant at 0.25 (Fig.3). Moreover, the mean value of optical thickness increases with latitudes (Table 1).

Furthermore, data used for this study are expected to be useful for the further, more detailed study for the quantification of effects of cirrus. For example, the use of radiation and climate models along with the quantities - describing the effects of the multilayer structure of cirrus clouds on the radiative, thermal and moisture fields - one can gain powerful tool to investigate the effect of cirrus on climate.

References

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Table 1. Mean values of cirrus cloud top height [km], bottom height [km], thickness [km], number of layers and optical thickness (τ) at tropics, subtropics in both hemisphere, middle latitude in both hemisphere and globe. NH (SH) indicates Northern Hemisphere (Southern Hemisphere).

	Top [km]	Bottom [km]	Thickness [km]	Layer No.	τ
Tropics (15°S-15°N)	14.0	12.3	1.7	1.3	0.237
Subtropics in NH (15°N-30°N)	11.7	10.2	1.6	1.2	0.320
Subtropics in SH (15°S-30°S)	13.2	11.5	1.7	1.2	0.276
Middle Latitude in NH (30°N-60°N)	10.3	8.4	1.8	1.1	0.429
Middle Latitude in SH (30°S-60°S)	9.7	8.0	1.7	1.1	0.358
Globe (86°S-86°N)	11.3	9.6	1.7	1.2	0.308

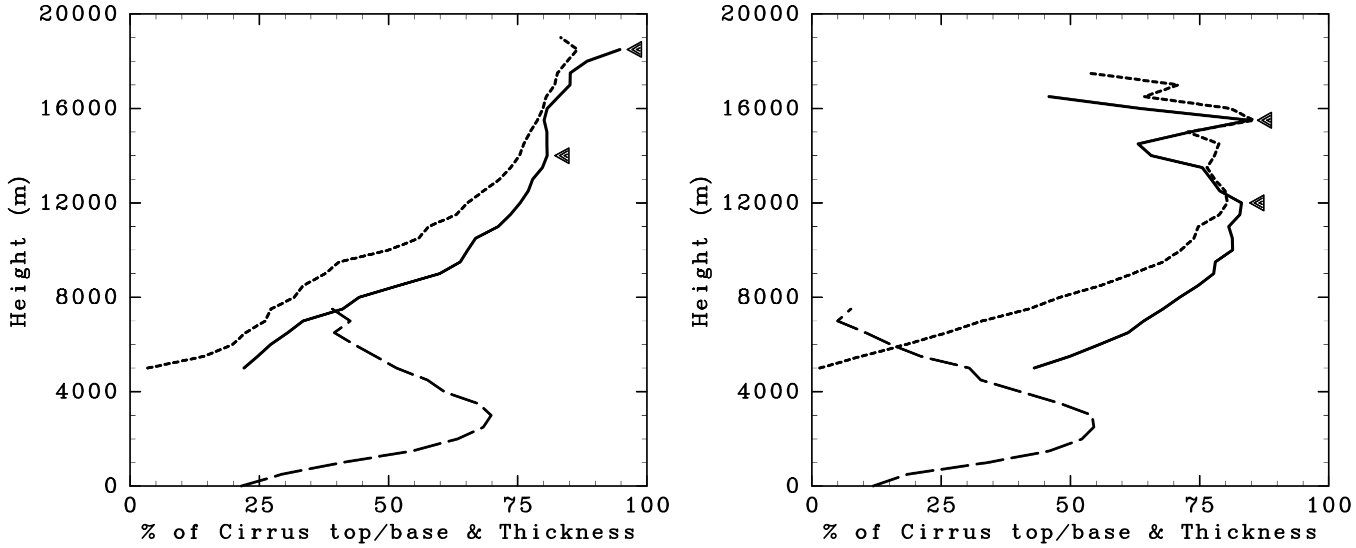

Figure 1. The vertical distribution of the fraction of cirrus cloud data to cloud data by using the ICESat/GLAS data in the tropics (15°S-15°N) (left) and the middle latitude in the northern hemisphere (30°N-60°N) (right). The dotted, solid and dashed lines indicate the vertical profiles of the cirrus top, bottom and thickness, respectively. The solid triangles indicate the peaks of the fraction of cirrus clouds.

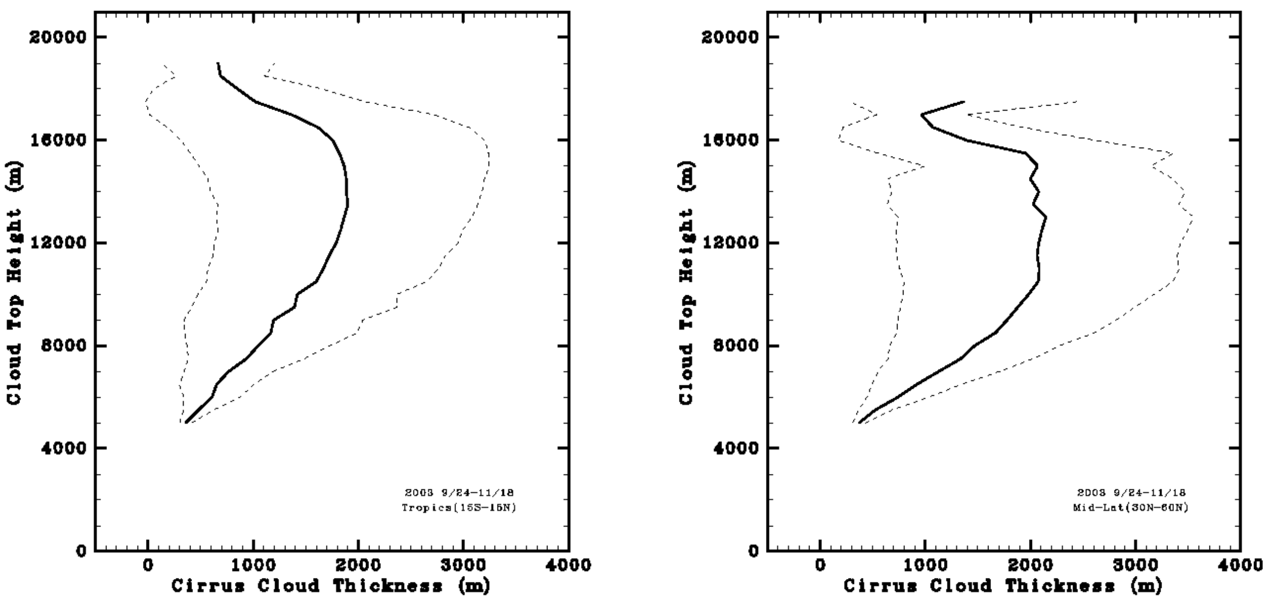

Figure 2. The vertical distribution of cirrus cloud thickness in the tropics (15°S-15°N) (left) and the middle latitude in the northern hemisphere (30°N-60°N) (right). The dash line indicates the standard deviation ($\pm 1\sigma$).

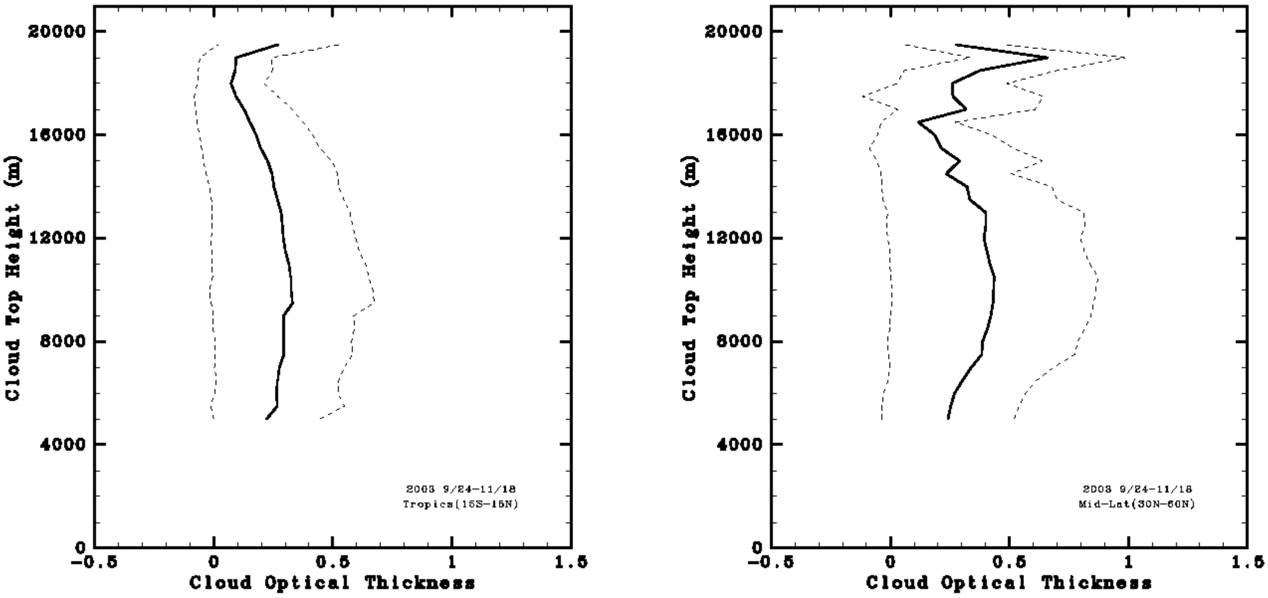

Figure 3. The vertical distribution of cirrus cloud optical thickness in the tropics (15°S-15°N) (left) and the middle latitude in the northern hemisphere (30°N-60°N) (right). The dash line indicates the standard deviation ($\pm 1\sigma$).