Observations of subvisual cirrus clouds with a lidar in Tarawa, Kiribati

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ABSTRACT

In order to research characteristics of subvisual cirrus clouds (SVCs), we installed a lidar in Tarawa (1 ^{o}N, 173 ^{o}E), Kiribati and have been measuring cirrus clouds since late in December 2005, where the sensitivity at a wavelength of 532 nm is approximately 4×10^{-7} (3×10^{-7}) [1/m/str] in the daytime (nighttime) for 5 minutes and 100 m averaging. The data in January 2006 show (1) heights of most SVC tops were the same as those of the cold point temperature, (2) most SVCs were falling and the rates were a few cm/s while one cirrus moved upward at approximately 5 cm/s, (3) the SVC occurrence frequency was the maximum from 16 to 17 km high and SVC occurrence frequency was 0.84.

1. INTRODUCTION

Subvisual cirrus clouds (SVCs), which are defined as cirrus with an optical thickness less than 0.03 [1], generally exist at a height of around 17 km in the tropical tropopause layer (TTL). Reference [2] showed that at times the occurrence frequency of SVCs is greater than 50% over the warm water pool by using the Stratospheric Aerosol and Gas Experiment (SAGE) II data. Reference [3] observed SVCs in the Lidar Inspace Technology Experiment (LITE) mission, and reported that the horizontal scale size is approximately 500 km. Thus, the tropics is usually covered by SVCs.

The effects of SVCs have been studied by many researchers. Reference [2] showed that SVCs significantly affect the radiation budget. Reference [4] reported that SVCs lead to the dehydration of air entering the stratosphere. Reference [5] reported on the basis of computations that water vapor is the most important contributor to the TTL radiation balance; the water vapor content itself is affected by SVCs. Therefore, SVCs play an important role in controlling radiation and water vapor content in the TTL. Historical and recent studies on SVCs are summarized in Chapter 12 in [6] and [7].

Reference [8] was the first paper to analyze lidar and radiosonde data and reported that the SVCs are generated by negative temperature anomalies induced by Kelvin waves. Reference [9] analyzed the same data over 7 months, including the month analyzed by [8]. They concluded that "High cirrus with a cloud base z_b > 15 km do not coincide with negative temperature anomalies as often as found by [8]." References [10] and [11] analyzed ship-borne lidar data and their study was in agreement with [9]. Though their hypothesis in [8] might be incorrect or insufficient, extensive observations and analyses of SVCs by a lidar and radiosondes have been performed by many researchers.

In order to research characteristics of SVCs, we installed one lidar in Tarawa (1 ^{o}N, 173 ^{o}E), Kiribati in December 2005. In addition, Soundings of Ozone and Water in the Equatorial Region/Pacific Mission (SOWER) group have installed a lidar in Biak (0 ^{o}N, 136 ^{o}E), Indonesia and other Japanese science groups also installed lidars in Kototabang (0 ^{o}N, 100 ^{o}E), Indonesia. Hence joint researches with other lidar data are possible. Note all lidars can measure the depolarization ratio.

The specifications of our lidar are described in Section 2. We report our preliminary results in Section 3 and summarize in Section 4.

2. INSTRUMENTS

We installed our lidar in Tarawa, Kiribati in December 2005. The lidar uses the Nd:YAG laser whose transmitted energy is 20 mJ per pulse at a wavelength of 1064 nm and 532 nm, respectively, and the pulse repetition rate is 10 Hz. Lidar return is received by a telescope of which diameter is 20 cm, then it is measured with an avalanche photo diode (APD) at 1064 nm and two photomultiplier tubes (PMTs) at 532 nm, where we observe two polarization at 532 nm. We set the laser to transmit beams for 5 minutes and cool down for 10 minutes then fire again in order to save a lifetime of a flashlamp which induces a laser pulse, hence each data is averaged for 5 minutes. Besides, we also set the vertical resolution to be 6 m. The time and vertical resolutions are variable by a laptop computer. The lidar has a capability to measure backscattering by gas at a wavelength of 532 nm up to approximately 12 km (15 km) high in a clear day (night) when we average for 5 minutes and 100 m; hence the sensitivities at 532 nm is about 4×10^{-7} [1/m/str] in the daytime and 3×10^{-7} [1/m/str] in the nighttime, respectively.

MET office in Tarawa checks the lidar on weekdays and sends the lidar data by mail once a month. Unfortunately, signals at 1064 nm have not been detected since 11 January 2006 due to a trouble.

3. OBSERVATIONS

Figure 1 shows a time-height section of backscattering coefficient at 532 nm, β(532nm), averaged for 1 hour and 100 m in January 2006. The data are eliminated when optically dense clouds exist below 10 km. "x" denotes a height of the cold point temperature (H_{Tmin}). β(532nm) is calibrated by fitting with the vertical profiles of backscattering coefficients of gas, which are estimated by radiosonde data, between 8 and 10 km high, where radiosondes were launched at the same place the lidar was installed. This is because a cloud occurrence frequency in January was the least at the height and measurements of gas backscatter above SVCs are not possible. This fitting corrects aerosols and gas extinction below 10 km where the extinction is significant especially at 532 nm.

Figure 1 shows that heights of most SVC tops were the same as those of the cold point temperature where the temperatures were from –86 °C to –94 °C. Note there was a large gap of H_{Tmin} from 17 to 18 January; H_{Tmin} was 16.6 km on 17 and 18.4 km on 18. The gap may be induced by a downward-displacement phase of a Kelvin wave.

Figure 2 shows heights of SVCs (H_{SVC}). To extract the heights, we chose them of which β(532nm) was the maximum between 16 km and 19 km high. Then we selected clouds which appeared more than 6 hours to exclude noise data. Besides, to distinguish the same cloud layer or not, we assumed to be different cloud layers when a difference of H_{SVC} in sequent time was more than 500 m. Figure 2 shows that most clouds tended to fall in a few cm/s if the clouds were horizontally uniform. The speed is comparable with the terminal velocity of SVC particles (Figure 4 of [10]). On the other hand, one cirrus, which appeared on 31 January, moved upward (Figure 3; 16.1 km high at 10 a.m. and 17.7 km at 19 p.m.) and the rate was approximately 5 cm/s. Therefore, the sedimentation of SVC is not simply explained by the terminal velocity and we have to consider updraft and downdraft at the TTL.

Figure 4 shows the vertical distribution of SVC occurrence frequency which is defined "the occurrence number of cirrus clouds" divided by "the occurrence number with no dense clouds below 10 km" where 80 % of the observations had no dense clouds below 10 km. Figure 4 shows that the occurrence frequency was the maximum from 16 to 17 km high. In addition, the SVC occurrence frequency, which is defined as "the occurrence number of clouds appeared from 16 to 19 km high" divided by "the occurrence number with no dense clouds below 10 km", was 0.84. Hence, Kiribati was usually covered by SVC in January 2006. On the other hand, many dense clouds appeared in February; the SVC occurrence frequency was 0.54 and 55 % of the observations had no dense clouds below 10 km (not shown).

4. SUMMARY

We installed a lidar in Kiribati and have been measuring cirrus clouds since late in December 2005. The sensitivities at 532 nm is about 4×10^{-7} (3×10^{-7}) [1/m/str] at a height of 15 km in clear daytime (nighttime) when we average for 5 minutes and 100 m. We showed (1) heights of most SVC tops were the same as those of the cold point temperature, (2) most clouds fell in a few cm/s if the clouds were horizontally uniform while one cirrus moved upward at approximately 5 cm/s. Therefore, the sedimentation of SVC is not simply explained by the terminal velocity and we have to consider updraft and downdraft at TTL. (3) the SVC occurrence frequency was the maximum from 16 to 17 km high and SVC occurrence frequency was 0.84.

We will report seasonal variations and depolarization properties of SVC in our presentations.

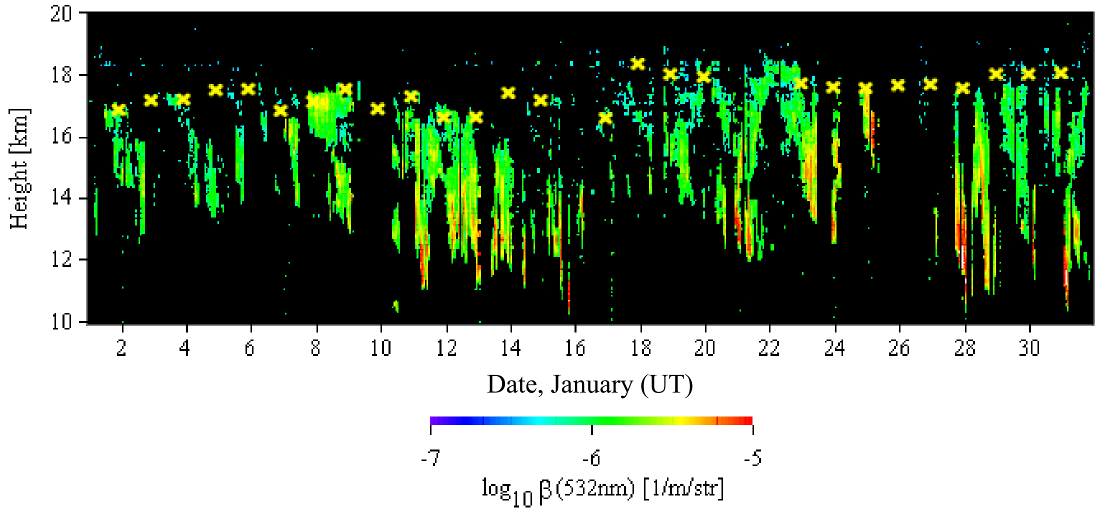

Figure 1 Backscattering coefficient of 532 nm lidar for one month averaged for 1 hour and 100 m. "x" denotes the altitude of the cold point temperature. x- and y-axis denote date in January (UT) and height [km], and each color denotes β(532nm) [1/m/str] in the logarithmic scale.

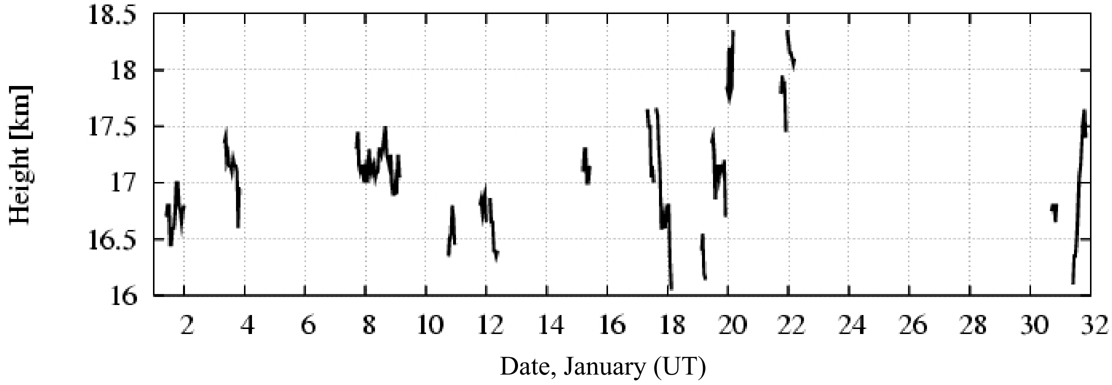

Figure 2 Heights of cirrus clouds. x- and y-axis denote date in January (UT) and height [km]. Each curve denotes the height of which β(532nm) is the maximum between 16 km and 19 km high.

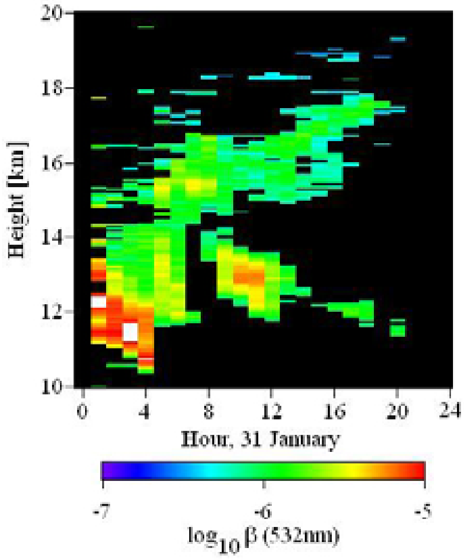

Figure 3 A magnification of Figure 1 on 31 January. A cirrus cloud moves upward from 16.1 km high at 10 a.m. to 17.7 km at 19 p.m.

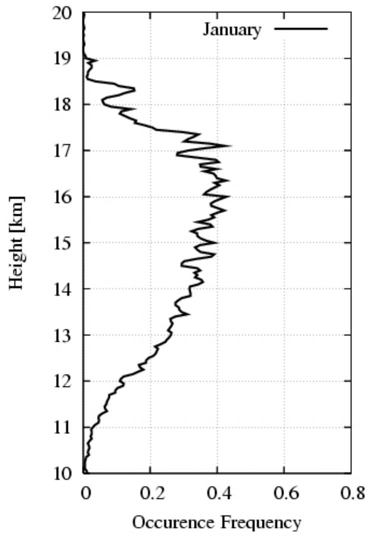

Figure 4 The vertical distribution of SVC occurrence frequency which is defined "the occurrence number of cirrus clouds" divided by "the occurrence number with no dense clouds below 10 km."

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