PSC and cirrus cloud detection over the high latitudes using thermal infrared spectra observed by TANSO-FTS/GOSAT

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Objective and about GOSAT

Greenhouse gases observation SATellite (GOSAT) was launched in 2009 and has been operating normally. However, the areas where the greenhouse gases can be retrieved are still limited especially in high and middle latitudes. That is mainly because Cloud and Aerosol Imager(CAI) onboard GOSAT, which is used for cloud screening, covers only reflected sun light ranged from ultraviolet to near infrared, and has relatively low sensitivity to optically thin clouds such as cirrus clouds. On the other hand, Thermal And Near infrared Sensor for carbon Observation – Fourier Transform Spectrometer (TANSO-FTS) which is the main sensor of GOSAT has a thermal infrared band and expected to have ability to detect optically thin clouds. However, the cloud detection in high latitudes is not easy even thermal infrared band data are combined to CAI images because of lower surface and atmospheric temperature in this regions. Furthermore, the situation is more complicated if the polar stratospheric clouds (PSCs), whose optical thickness is thinner than cirrus clouds, exist in the lower stratosphere. In this study, we improved cirrus detection method using thermal infrared spectra and tried to detect clouds globally involving high latitude winter.

Single Channel Cloud Screening

Because of the limitation of calculation time for pre-analysis screening processes we adopted a single channel cloud screening method using thermal infrared (TIR) band data of TANSO-FTS. On the other hand, CO_2 slicing method is used as a post-analysis screening to evaluate cloud parameters because it needs larger computer resources. The analytical procedure of the single channel screening is as follows;

1)Determine land cover type of an IFOV of TANSO-FTS using MODIS land type database
2)Estimate of the surface emissivity in the scene based on the ASTER spectral library
3)Calculate the brightness temperature (Tbb) in a micro-window based on the meteorological analysis data (JMA-GPV), Sea Surface Temperature (AVHRR-AMSR), and the surface emissivity estimated in the previous step.
4)Determine the cloudiness in the IFOV through the comparison of Tbb between theoretical calculation and observation.

Figure 1 shows examples of cloud CAI images which cover IFOV of FTS. The cloud flags determined by CAI and FTS (TIR) are compared, and the results are shown as a global map, seasonal variation of monthly mean, and variation of scores as a function of threshold for TIR data, in Figs. 2, 3, 4, respectively. Consequently, the results show that the single channel screening under estimate the cloud score compared to the screening using CAI. It is found that the underestimation is caused by that of the surface temperature (Ts) which is estimated from the surface level temperature over the land.

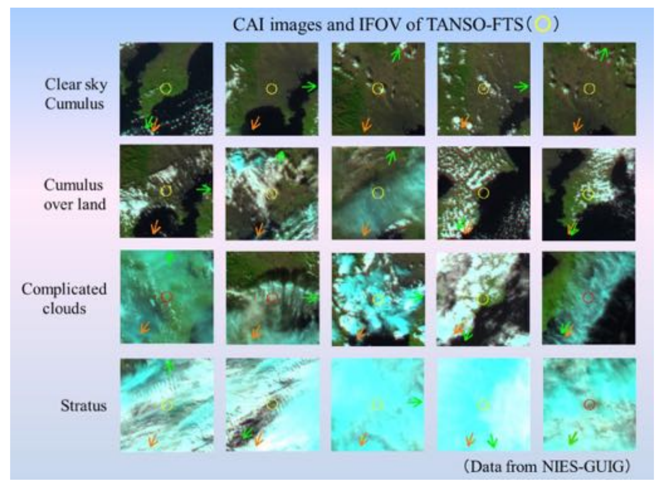

Figure 1. Examples of TANSO-CAI imageries for various types of clouds. Yellow circles indicate the location of IFOV of TANSO-FTS.

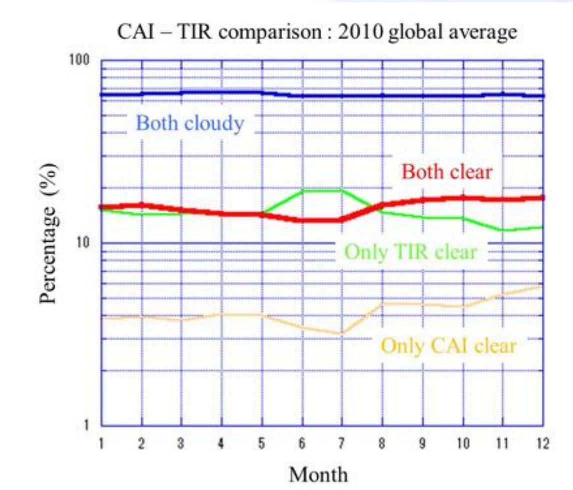

Figure 3. Seasonal variation of cloud flags in 2010.

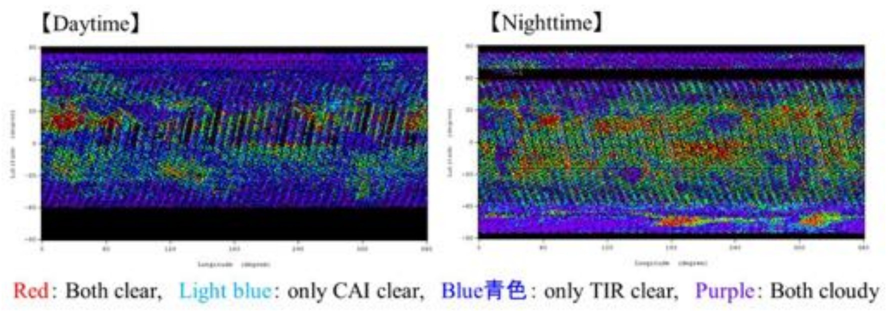

Figure 2. Comparison of cloud flags determined by CAI and TANSO-FTS (TIR) for daytime and nighttime. Data were obtained in a period from May 1 to May 20, 2010.

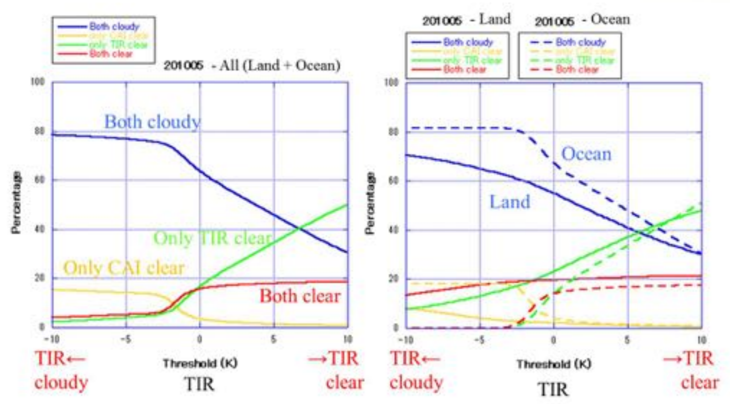

Figure 4. Cloud flag comparison as a function of Tbb used as a threshold for TIR data. Data are same as in Figure 2.

CO_2 slicing method

Usage of spectral pseudo channels

In this study, CO_2 slicing method which was developed for cirrus detection was applied. The equation of this method is written as

$$\frac{R_{\lambda_1}-R^{cl}_{\lambda_1}}{R_{\lambda_2}-R^{cl}_{\lambda_2}} = \frac{\varepsilon_{\lambda_1}\int_{p_s}^{p_c}\tau_{\lambda_1}(p)dB_{\lambda_1}}{\varepsilon_{\lambda_2}\int_{p_s}^{p_c}\tau_{\lambda_2}(p)dB_{\lambda_2}},$$

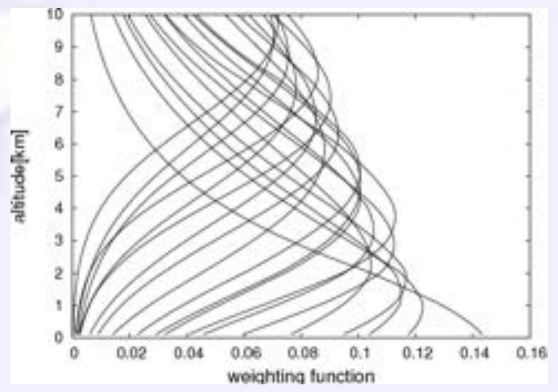

Figure 5. The weighting function profiles for each pseudo channels.

where R is the observed radiance by the sensor, R^{cl} is the calculated radiance for clear sky, B is prank function, τ is transmittance, ε is emissivity, p_c is cloud top pressure, and p_s is surface pressure, respectively. For calculating R^{cl}, a line-by-line radiative transfer code, LBLRTM (Clough et al, 2005), was used. According to this formula, p_c is determined so as that difference between left hand and right hand is minimum.

It is reported from the GOSAT project office that wavenumber position of each spectral channel of TANSO-FTS slightly fluctuate because of instability of sampling laser, which causes random shifting of weighting function peak of each spectral channel. In order to increase the robustness against this effect, we use the spectral pseudo channels which consist of real channels having weighting function peaks in the same height range. The pseudo channels were set for each 0.5 km height range of weighting function peak shown as Figure5. Most of pseudo channels were consisted of 5 through 50 real channels depending on atmospheric condition in a spectral range from 700 to 750 cm^{-1}.

Channel optimization

Once the pseudo channels were set, the optimal combination of them was determined based on simulation studies using a multi-scattering radiative transfer code, Polarized radiance System for Transfer of Atmospheric Radiation (Pstar). This optimization was carried out for various latitudinal zone and temperature profile patterns based on the meteorological analysis data provided from meteorological agency (JMA-GPV). The classification was made according to temperature range at 500hPa height level.

For each profile, the clouds were assumed with changing optical thickness and cloud top height (CTH) as following in Pstar calculations and investigated the accuracy with each channel combination.

- Latitudinal zone and temperature profile patterns classified:
  Latitudinal zones : north high, north middle, low, south middle, south high
  Temperature patterns: each 5K bines between min. - max. for each latitudinal zone
- Cloud parameters changed in the simulations:
  Optical thickness : 0.1-5.0
  Cloud top height (CTH) : 3-15km(low latitude),
  3-12km(high and middle latitude),
  3-24km(south high latitude winter)

Figure 6 shows an example of the accuracy of CTH detection defined as the standard deviation of retrieval error for each pseudo channel combination. This figure was made for all temperature profile patterns, and the optimal channel combinations were determined so as to have minimum standard deviation of retrieval error.

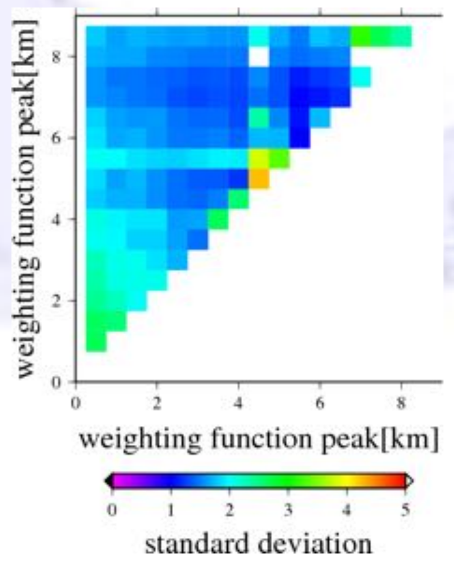

Figure 6. An example of the standard deviation of CTH retrieval error for each channel combination. In this case temperature profiles was one for the southern high latitude ranging from 220K to 225K.

Results

Antarctic (PSCs)

The slicing method algorithm was applied to the analysis of GOSAT data observed in August 19-21, 2010. Retrieved CTH distribution was compared with that from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation(CALIPSO) (Winker et al., 2003) observations as shown in Figure 6. In this figure, high level clouds, which can be recognized as PSCs, retrieved from both of data particularly over an area 0-60 W and 70-90 S affected to gravity waves.

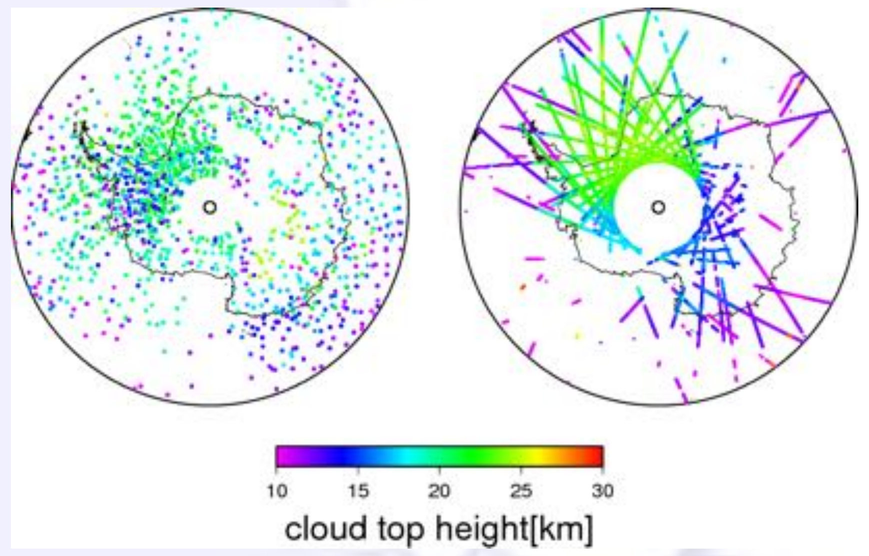

Figure 7. CTH distribution retrieved from by GOSAT data with slicing method (left) and that of cloud and stratospheric matter observed by CALIPSO (right). Data were obtained over the Antarctic during a period of August 19-21, 2010.

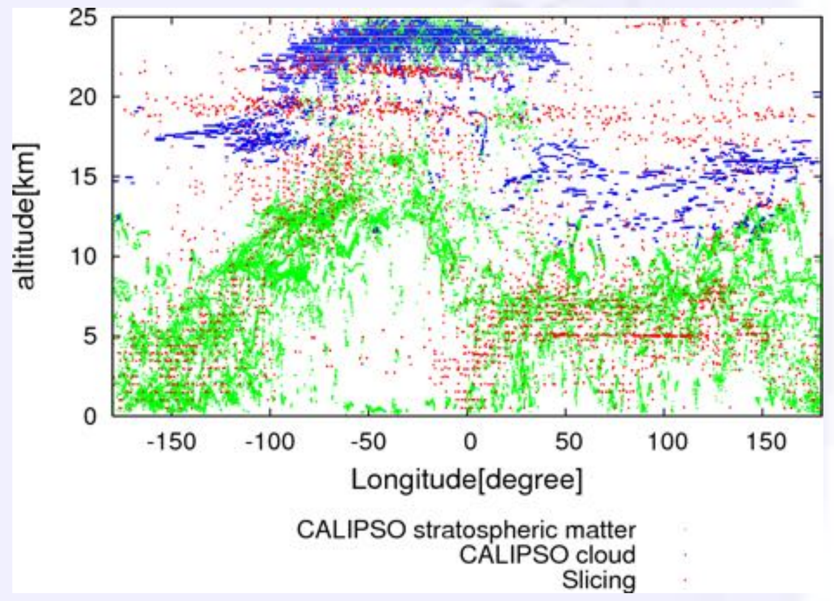

Figure 8. Longitude-altitude distribution of CTH retrieved with the slicing method for GOSAT data and that of cloud and stratospheric matter top observed by CALIPSO. Both data were obtained in latitudes of 60S-90S.

Figure 8 is longitude-altitude distribution of CTH. In this figure, low cloud top distribution retrieved by slicing method is fairly similar to that from CALIPSO except an longitudinal region in 90W - 0. When high level clouds or PSCs exist, lower clouds were generally not detected because the slicing method has sensitivity only to the first layer of cloud. On the other hand, CALIPSO can detect lower clouds if the upper level clouds is not so thick.

Global

Global CTH distribution was also derived as well as in the Arctic region. An example of the results are shown in Figure9. In this case, there a large blank area in the mid-latitude area of the southern hemisphere, where the slicing method is not effective to detect clouds because the temperature lapse rate is too small in the upper troposphere.

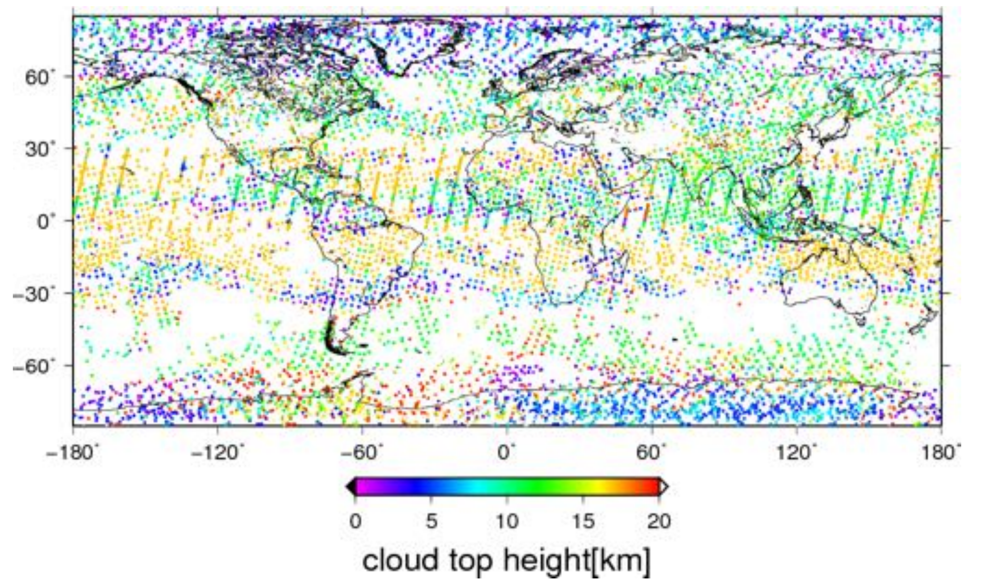

Figure 9. An example of global distribution of CTH retrieved with the slicing method. Data were observed in a period of August 19-21,2010.

Figure 10 is latitude-altitude distribution of retrieved CTH. There are tendency that CTH goes down with latitude in most of height levels as expected. However, some unrealistic feature can be seen around 17km level in low latitudes showing an uniform level of cloud top. This height is nearly equal to inflection point of temperature profiles, and the strange feature may be caused by unrealistic setting of the surface temperature, but it is still under investigation.

Figure 11 is comparison between cloud top temperature estimated with slicing method and single channel cloud screening described in the first section. On this scatter map, various types of cloud are identified according to the temperature ranges for both methods (SL: slicing, SC: single channel) as follows;

- Cirrus clouds: SL~190-300K, SC~280-300K
- PSCs: SL~180-195K, SC~200-250K
- Very cold land (not clouds): SL~210-250K, SC~180-240K

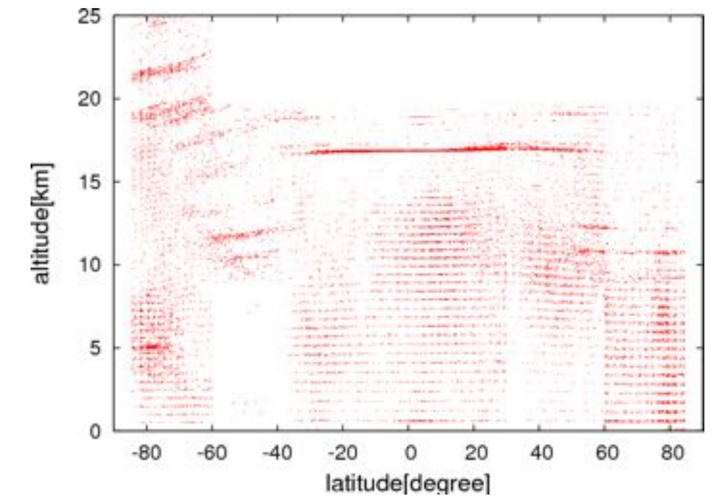

Figure 10. Latitude-altitude distribution of CTH retrieved with the slicing method.

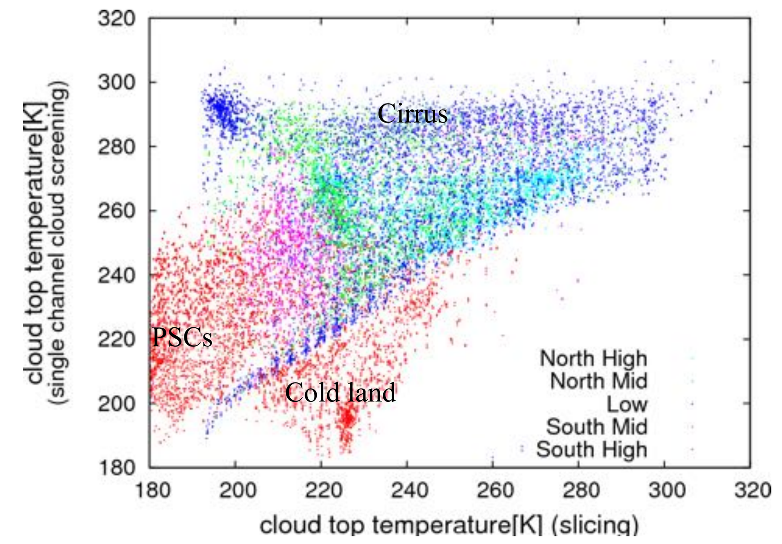

Figure 11. Comparison of cloud top temperature retrieved with slicing the method and single channel cloud screening.

Summary

- Key technique of this study is that Slicing method was modified for usage of spectral pseudo channels and channel optimization.
- High clouds recognized as PSCs were detected by this algorithm. The area PSCs were derived was almost coincident with that by CALIPSO but there were some differenced with height.

Reference

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