Cirrus Cloud-Top Height Estimation using Geostationary Satellite Split-Window Measurements Trained with CALIPSO and CloudSat data

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Introduction

•We developed a method for the estimation of cloud-top height (**CTH**) using only split-window channels of infrared observations from geostationary satellites. The split-window method is based on the premise that difference of two brightness temperatures at different wavelengths in the atmospheric window range is large for semi-transparent clouds like cirriform clouds (Inoue, 1985).

•The original version (Hamada and Nishi 2010) was made using the lookup tables (**LUT**s) based on regression with direct observations of CTH from the Cloud Profiling Radar (CPR) onboard CloudSat. It was effective for monitoring the activity of mesoscale convection and dense anvil clouds because the estimated cloud tops are close to the actual tops in the cases of precipitating clouds and/or the surrounding dense stratiform clouds.

•However, cirriform clouds generally have lower optical depths but may be geometrically thick; thus, the CTHs of the cirriform clouds observed by the CPR could be considerably different from the actual cloud-top heights [Figs.1,2], which can cause bias in the LUTs.

Summary

- In this study, LUTs were constructed based on regression with direct observations of cloud top height from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard CALIPSO. By using CALIOP data, we succeeded in reducing the underestimation of the height of cirriform clouds.
- Although CALIOP can detect optically thin clouds around the tropopause, top heights including such thin clouds unfortunately cannot be estimated well using split-window observations [Fig.3b].
- By defining the altitude at which the optical depth from the top had a specified value $\tau_{\min}$ (= 0.2) as the cloud-top height, we could create a practical LUT [Figs. 3,4,5].
- In the LUT, the underestimation of the heights of cirriform cloud was corrected substantially, while reducing the annoying effect of the low sensitivity of split-window observations to thin tropopause cloud.

Data: July 2015–June 2017

- **CPR**(CloudSat) 2B-GEOPROF and 2B-TAU (version 4)
- **CALIOP**(CALIPSO) level 2 cloud profile (version 3)
- **IR split-window data** of a geostationary satellite: Himawari-8.
  - brightness temperature at 10.4 μm ($T_{10.4}$) and 12.4 μm ($T_{12.4}$)

Example of clouds observed by CPR / CALIOP

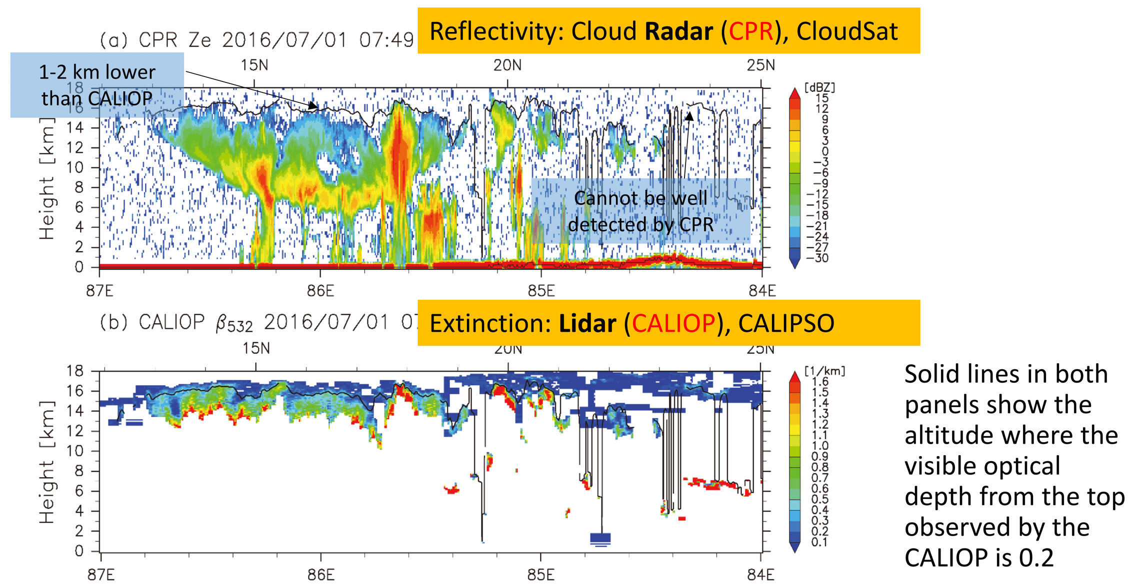


Fig.1

The cloud-top heights of cirriform clouds observed by the CALIOP are much closer to the heights of actual cloud top. CPR miss many thin cirriform clouds observed by CALIOP.

Histogram of the Cloud top height (CTH)

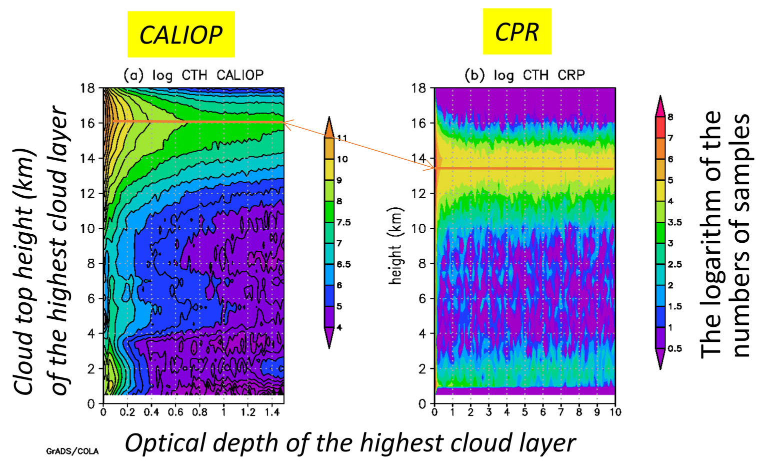
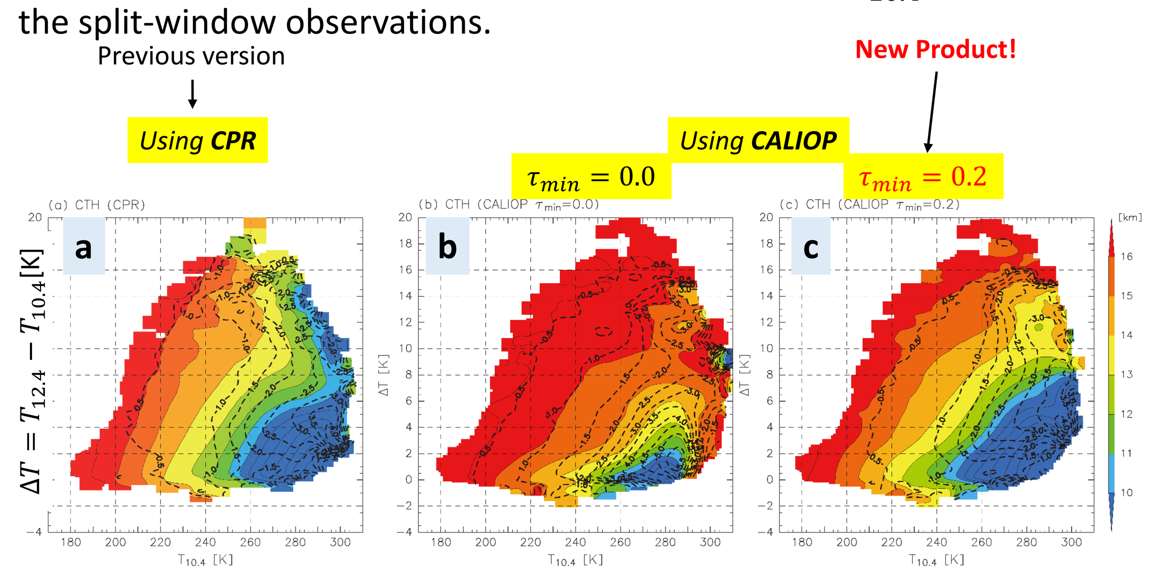


Fig.2

The largest frequency of CPR cloud top is found at 13.5 km, far below that of the CALIOP. The CALIOP cloud tops are considered much closer to the actual cloud tops. Therefore we attempted to make LUT with CALIOP data.

Comparison of Lookup Tables

Estimated CTH (color and thin solid contours) and standard deviations of samples (dashed contours) of CTH (km) obtained by regression of the CTHs of all samples of the CPR or the CALIOP over $T_{10.4}$ and ΔT of the split-window observations.



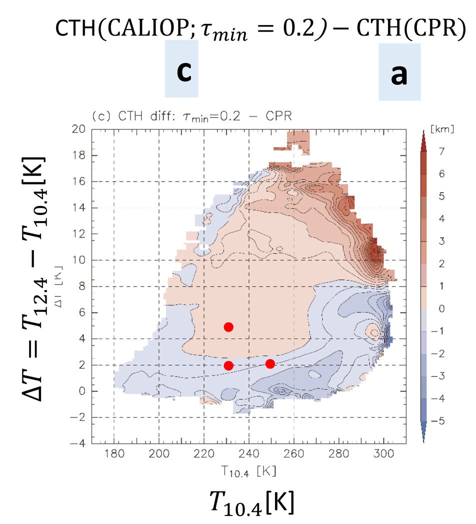
τ_{min} : the altitude at which the optical depth from the top had a specified value τ_{min} as the cloud-top height

Fig.3

a Original method with CPR underestimates the CTH for cirriform clouds

b Method with CALIOP ($\tau_{min} = 0.0$, *i.e. cloud top*) has little sensitivity; very high CTH is estimated for most of the split-window parameters. This table is useless when using split-window data to estimate CTHs.

c New method with CALIOP ($\tau_{min} = 0.2$) shows reasonable pattern. Underestimation for cirrus is reduced compared with CPR result.



Comparison between CALIOP table ($\tau_{min} = 0.2$) and CPR. Red color shows the CALIOP values is higher than that of CPR.

Fig.4

Dependence on τ_{min}

Estimated cloud-top height (CTH) when using some τ_{min} values (of CALIOP) and using the CPR

(For 3 red points in Fig.4)

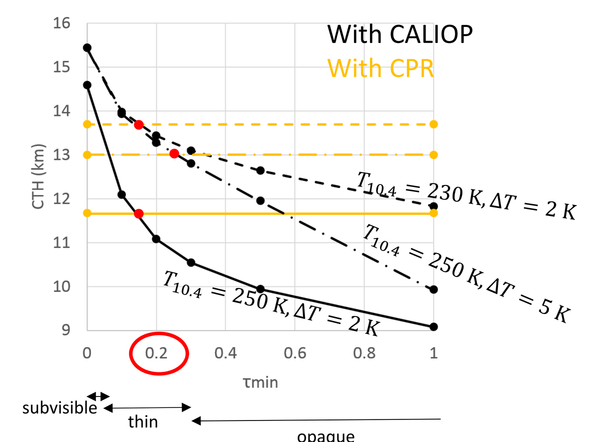


Fig.5

If the τ_{min} value is larger than 0.3, CALIOP estimations are lower than those with CPR in most of the region in LUT. On the other hand, if it is much smaller than 0.2, the LUT would be trivial one shown in Fig.3b.

The value 0.2 is thought to be the most reasonable choice.

Our choice of $\tau_{min} = 0.2$ → *close to border between "thin" and "opaque" in the traditional kind of cirriform clouds. When using this LUT, we will miss most of the subvisible and thin clouds, but will not miss most of the opaque clouds. In many usage, this choice may be the best choice when using split-window observations.*

Future works

- In the lower half of LUTs, the estimated CTH with τ_{min}=0.2 is LOWER than those with CPR. It may be one demerit with this dataset. We propose a better LUT which adopt the higher estimated CTH values in CALIOP estimation and CPR estimation at each point in the LUT.
- LUT with CPR has small seasonal dependence. However, this new scheme with CALIOP has considerable seasonal dependence due to the seasonal change of this TTL clouds. We should consider making LUT for each season.
- The merit of our method is to use only split-window data which have long historical records since 1990s. We will extend this table to the past by comparing the IR radiance of many geostationary and polar orbital satellites which have simultaneous observations.

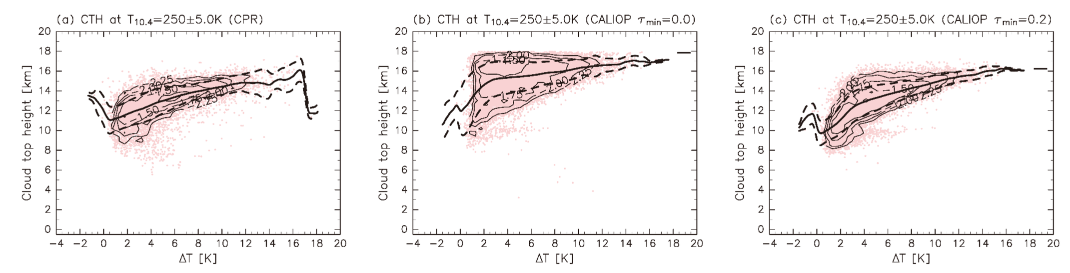
References

The detail of the methods shown here is shown in Nishi et al. (2017) [*SOLA*, **13**, 240–245, doi:10.2151/sola.2017-044.]

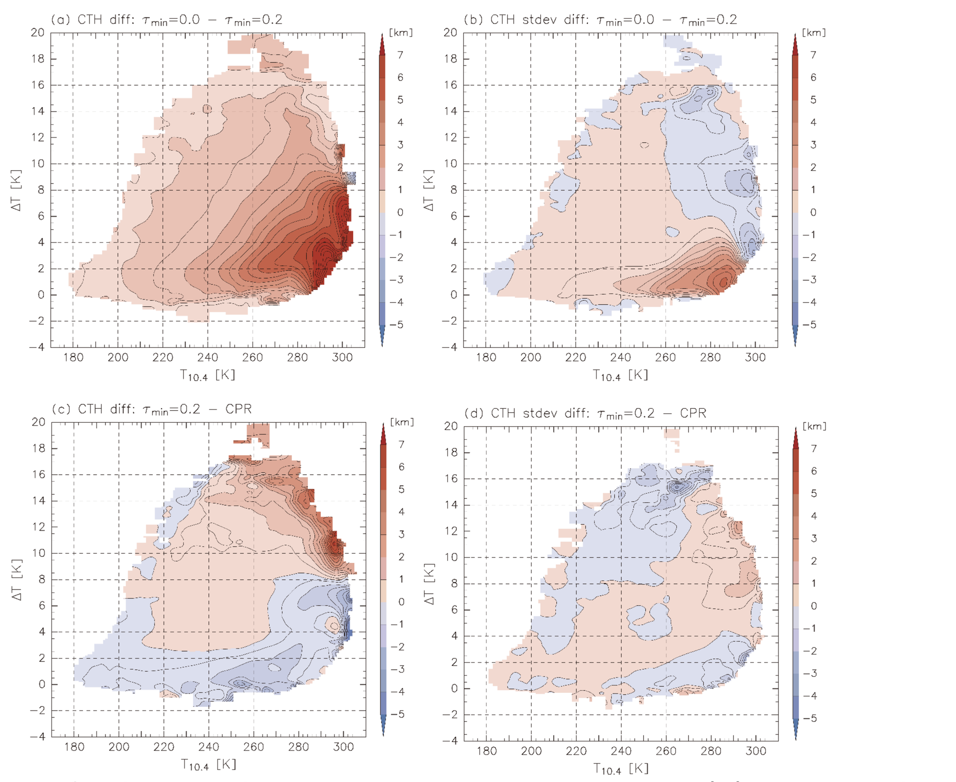
Our products (with CPR) are accessible from http://database.rish.kyoto-u.ac.jp/arch/ctop/index_e.html.

Hamada, A., N. Nishi, 2010: *J. Appl. Meteor. Climatol.*, **49**, 2035-2049.
Inoue, T., 1985, *J. Meteor. Soc. Japan*, **63**, 88-99.

Appendix



Estimates (heavy solid lines) and standard deviations of samples (±1σ, dashed lines) along the vertical lines in the LUT (Fig. 3) at (a)–(c) $T_{10.4}$ = 250 K and (d) $T_{10.4}$ = 275 K. The distribution of the cloud-top heights of the samples used for the estimation (within 5 K from $T_{10.4}$ shown in each figure) is also shown by orange dots and the natural logarithm of the probability density ($K^{-1}km^{-1}$) is shown by thin contours. Contour interval is 0.25 (only over -2.25). (a) Observations by the CPR, (b) observations by the CALIOP (τ_{min} = 0.0), and (c) observations by the CALIOP (τ_{min} = 0.2).



Difference of values in the same position in two LUTs. (a) Estimated cloud-top height (CTH) (km) when τ_{min} = 0.0 minus that when τ_{min} = 0.2. (b) Similar to (a) but for the standard deviation of the samples (km). (c) Estimated CTH (km) when τ_{min} = 0.2 minus that from the CPR. (d) Similar to (c) but for the standard deviation of the samples (km). Contour interval is 0.5 km.