The study of the characteristics of tropical thin cirrus and its radiative impacts

Joonsuk Lee[1], Andrew E. Dessler[1], Ping Yang[1], Bo-Cai Gao[2], and Steven Platnick[3]

[1]Texas A&M University, College Station, TX, [2]Naval Research Laboratory, Washington, D.C., [3]NASA Goddard Space Flight Center, Greenbelt, MD

1. Introduction

Thin cirrus clouds are frequently observed over the tropical regions. They absorb longwave radiation and reflect shortwave radiation. This property can lead to the net positive cloud radiative forcing resulting in local heating. In this study, the optical depth of tropical thin cirrus clouds and its frequency of occurrence are derived from the MODIS level-2 cirrus reflectance. Also, the cloud radiative forcing is simulated using the retrieved optical depth of thin cirrus clouds and atmospheric vertical profile from AIRS.

2. Retrieval of optical depth

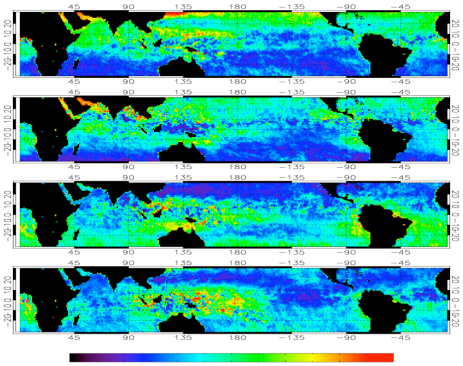
For an optically very thin layer, the reflectance is mostly contributed by single-order scattering events (Yang et al., 2001), which are related to the optical depth, τ, via,

$$\tau = r_c \frac{4\cos\theta_s \cos\theta_v}{P(\Theta)\tilde{\omega}}, \qquad (1)$$

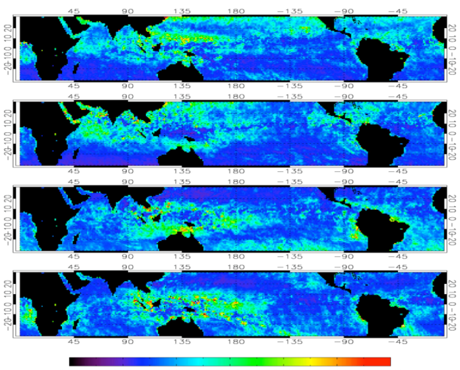
where r_c is the cirrus reflectance, $P(\Theta)$ is the phase function, Θ is the scattering angle, $\tilde{\omega}$ is the single scattering albedo, and θ_s and θ_v are the solar and satellite zenith angles, respectively (Dessler and Yang, 2003). The cirrus reflectance, r_c, is available from the MODIS level-2 MYD06 products.

To remove the effect of reflection from the surface or from thick clouds in the mid and upper troposphere, this calculation is confined to cloud-free pixels, as indicated by the MODIS cloud mask algorithm, and over the ocean where the surface reflectance is small.

The errors are introduced in the measured r, in the conversion from r to r_c, and r_c to τ. Dessler and Yang (2003) estimated that the detection threshold of this method is 0.02, and that the accuracy of the measurement is plus/minus a factor of two.



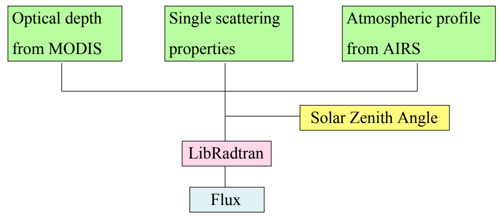
The fraction of "clear-sky" observations for 1°×1° boxes that have detectible thin cirrus (optical depth exceeds 0.02) for each season (Spring, Summer , Autumn, and Winter from top to bottom panel). The fraction of observations shows the seasonal variations.

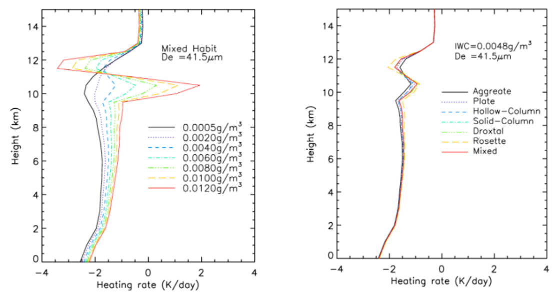


The optical depth of tropical thin cirrus for the pixels flagged as "clear-sky" by MODIS for each season (Spring, Summer, Autumn, and Winter from top to bottom panel). The optical depth is averaged over 1°×1° boxes, same as in fraction of observations. The pattern of optical depth is very similar to that of fraction of observations.

3. Simulation of cloud radiative forcing

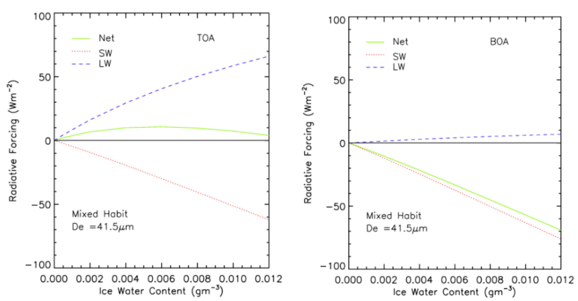
We use the Libradtran radiative transfer code (Mayer and Kylling, 2005) to simulate a radiative flux, atmospheric heating rate, and cloud radiative forcing. The background gaseous absorption properties are taken into account on the basis of the correlated k-distribution method. The single scattering properties of cirrus clouds including the extinction efficiency, single-scattering albedo and asymmetry factor are parameterized with respect to the effective particle size (2.0~3100 μm) and wavelength (0.2~100μm). The cloud radiative forcing is calculated on the 1° × 1° boxes in the tropical region between 30°N and 30°S. The solar zenith angle from MODIS is averaged on the same 1° × 1° boxes and the monthly averaged atmospheric vertical profile from AIRS is used. In this model, thin cirrus clouds are inserted from 10 to 12km layers.





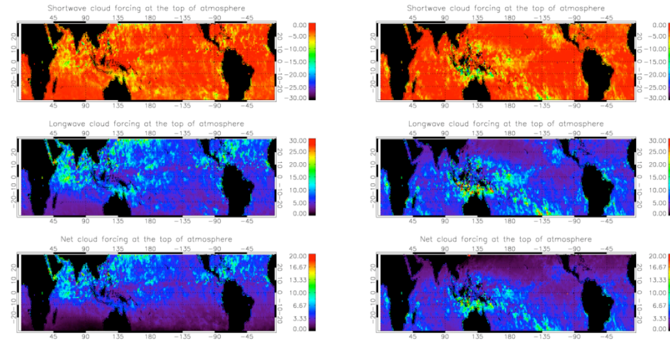
(a) (b)

Atmospheric radiative heating rate with respect to (a) ice water content and (b) particle habit. Clouds cause significant heating and cooling in the cloud layer. The heating rate is not very sensitive to ice particle habit.



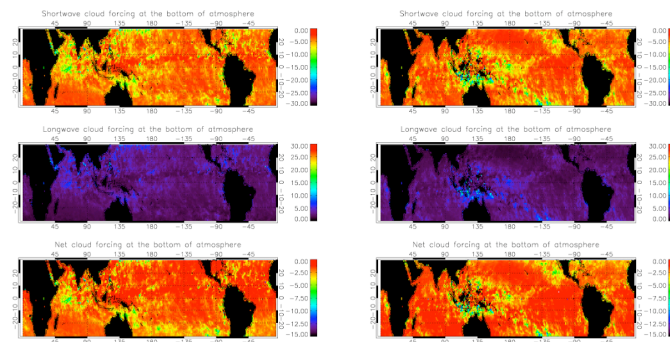
(a) (b)

Cloud radiative forcing at (a) the top of atmosphere and (b) bottom of atmosphere. Ice cloud causes a small net warming at TOA while net cooling occurs at BOA.



(a) (b)

Cloud radiative forcing at the top of atmosphere for (a) June 2005 and (b) December 2005. As shown in the sensitivity study, thin cirrus clouds have a net positive cloud radiative forcing at the top of atmosphere, because absporption of longwave radiation by thin cirrus clouds is larger than the reflection of shortwave radiation at the top of atmosphere.



(a) (b)

Cloud radiative forcing at the bottom of atmosphere for (a) June 2005 and (b) December 2005. Thin cirrus clouds have a net negative cloud radiative forcing at the bottom of atmosphere. The warming by thin cirrus clouds is small at the bottom of atmosphere due to the small optical depth.

4. References

Dessler, A. E., P. Yang, 2003: The distribution of tropical thin cirrus clouds inferred from Terra MODIS data. *J. Climate*, 16, 1241-1247.

Mayer, B. and A. Kylling, 2005: The libRadtran software package for radiative transfer calculations-description and examples of use, *Atmos. Chem. Phys.*, 5, 1855-1877.

Yang, P., B.-C. Gao, B. A. Baum, W. Wiscombe, Y. Hu, S. L. Nasiri, A. Heymsfield, G. McFarquhar, and L. Miloshevich, 2001: Sensitivity of cirrus bidirectional reflectance in MODIS bands to vertical inhomogeneity of ice crystal habits and size distributions. *J. Geophys. Res.*, 106, 17267-17291.