

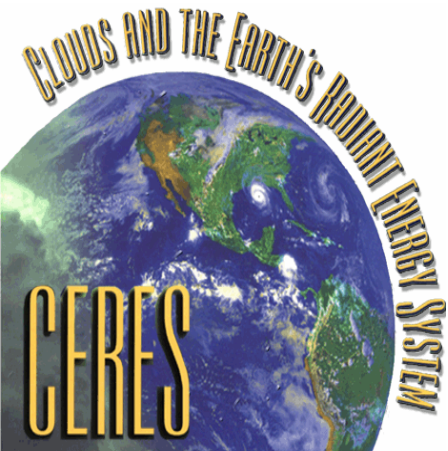
Effect of Invisible Clouds on Radiation Energy Budget

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Introduction

Invisible clouds in this study mean super-thin clouds which cannot be detected by MODIS but are classified as clouds by CALIPSO.

These sub-visual clouds may exist globally and may have effects on Earth-atmosphere radiation budget, remote sensing of aerosols, and retrieval of surface skin temperature.

What is the global coverage of these thin clouds? Any geo-location dependence? Can climate models neglect these clouds?

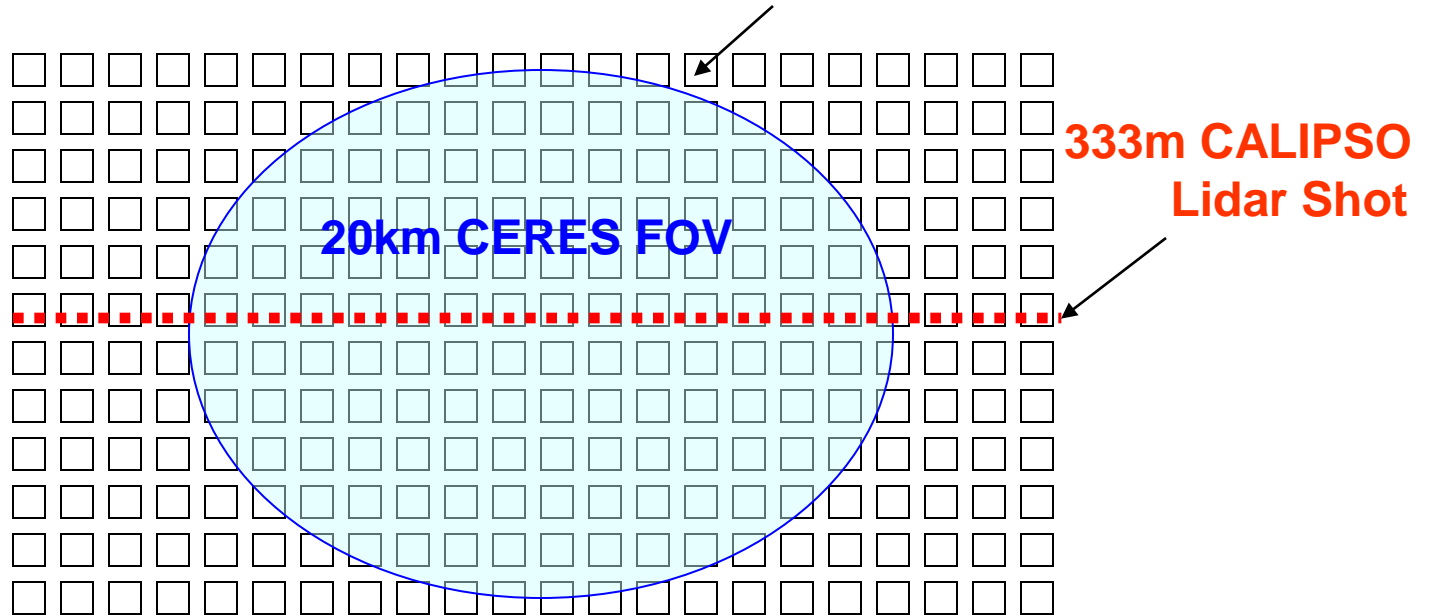
What are the infrared and shortwave radiation effects of these clouds?

In this study, 4-month CCCM data (Jul 06, Oct 06, Jan 07, Apr 07), which merges CERES, MODIS, CALIPSO, and CloudSat measurements, are analyzed.

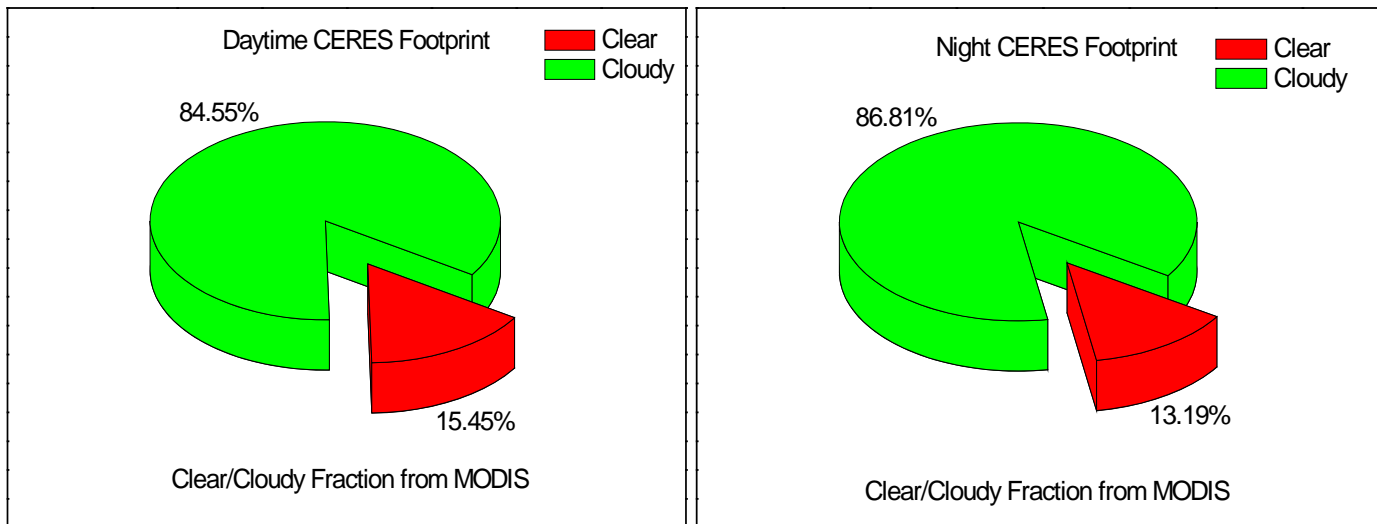
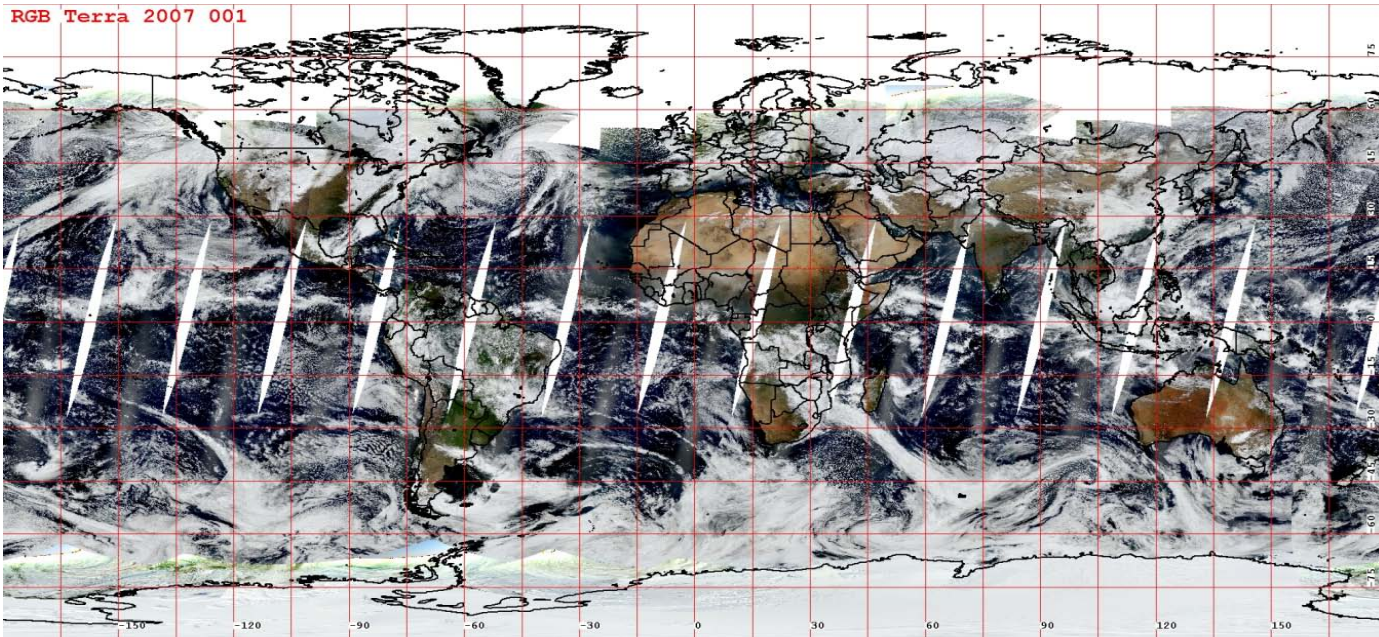
Method and Data

4-month CCCM data

1km MODIS Pixel

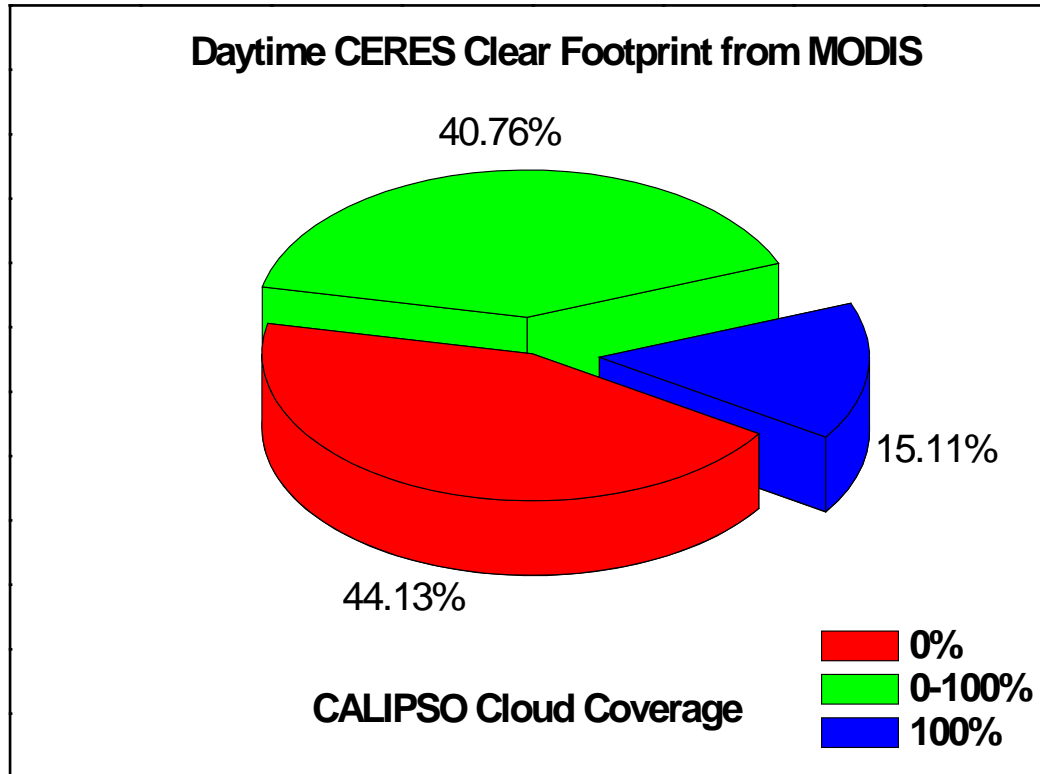


Invisibly cloudy CERES FOVs:
MODIS clear & CALIPSO cloudy

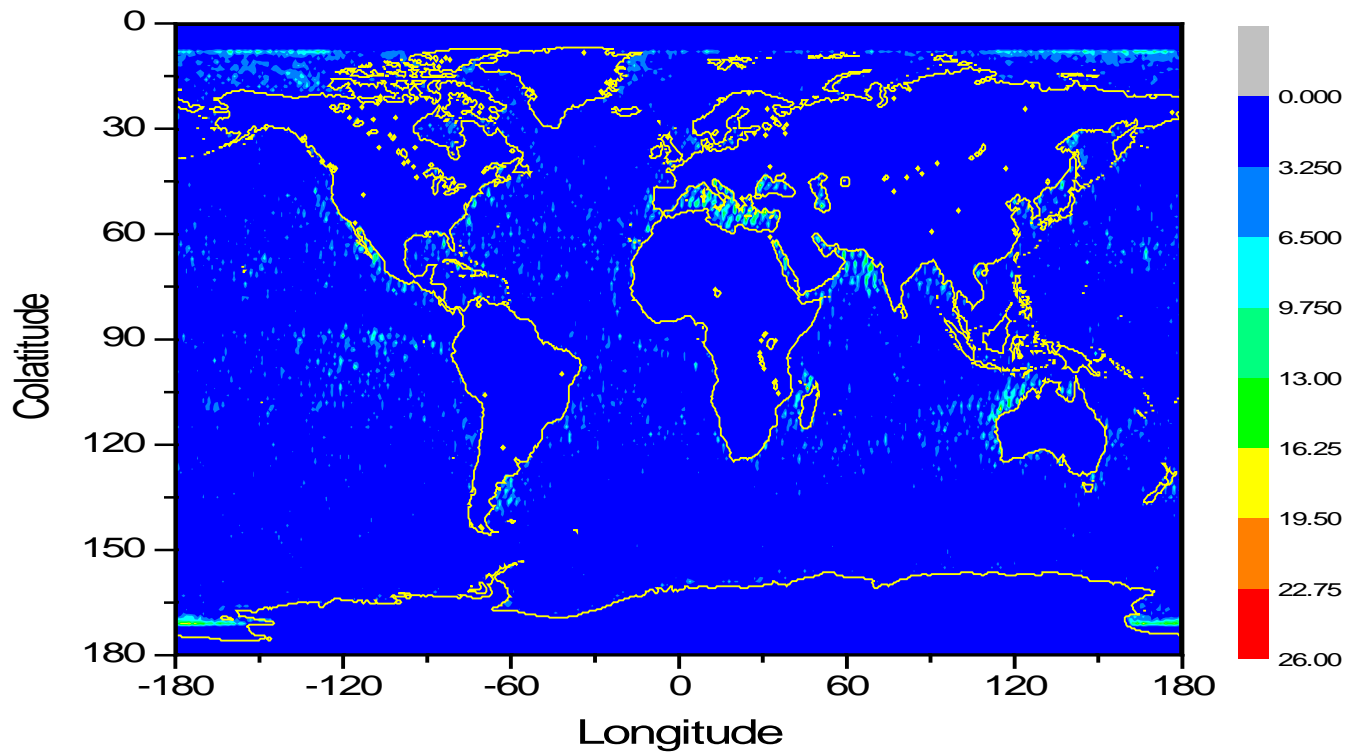


MODIS-derived 4-month clear percentage of CERES FOVs

Daytime Radiation Effect

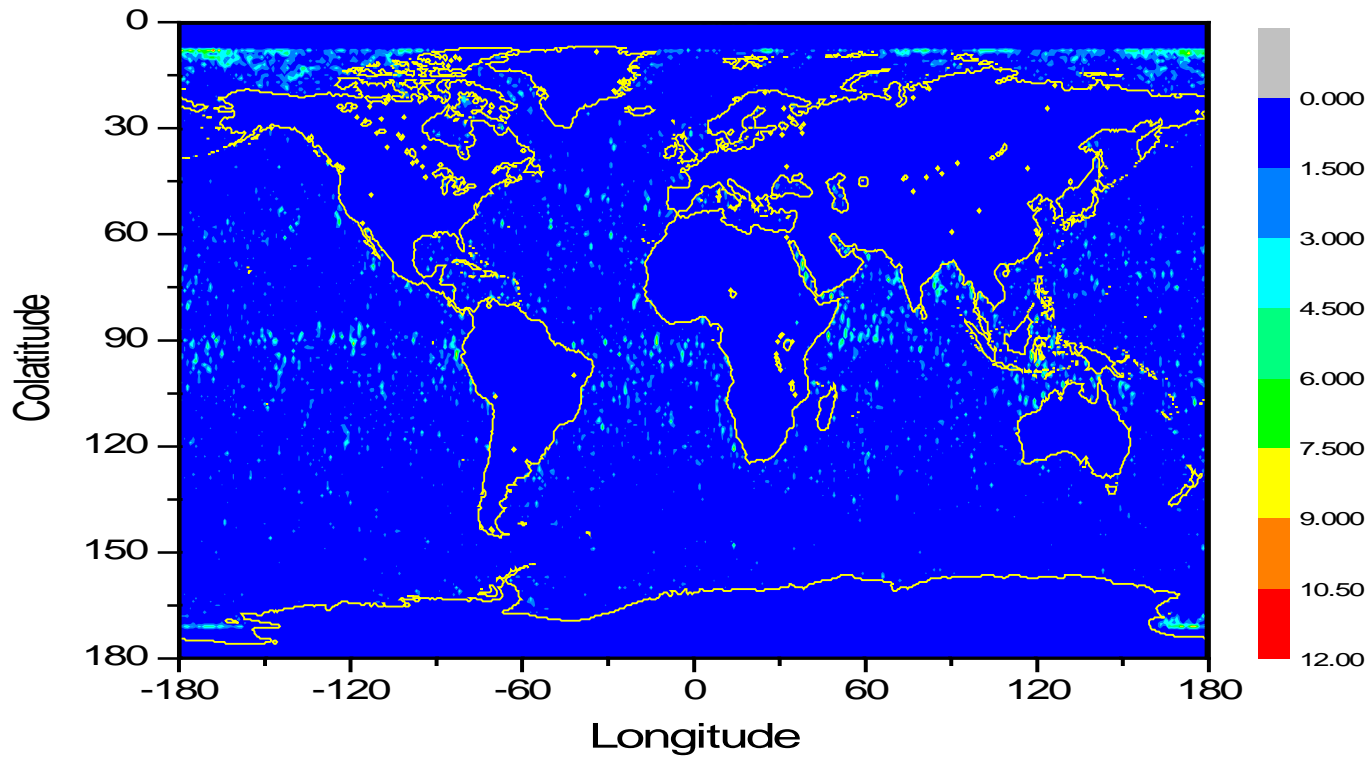


CALIPSO-derived 4-month cloudy percentage in
MODIS-clear CERES FOVs



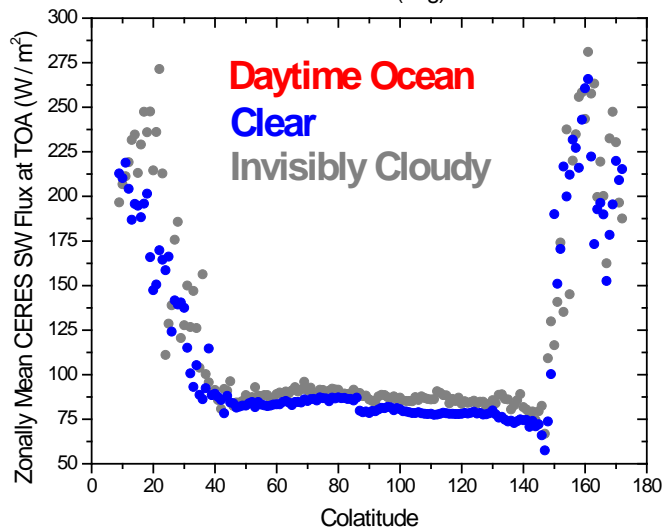
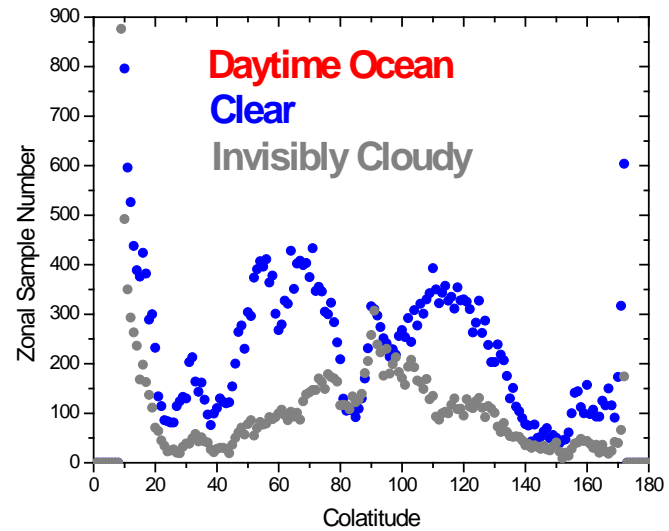
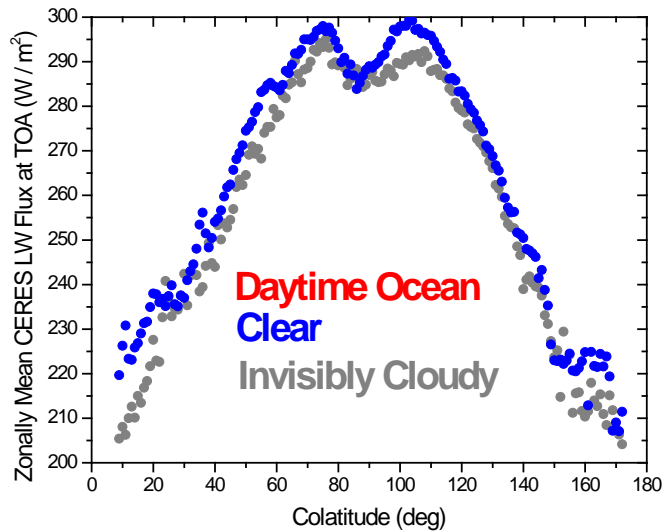
Daytime Purely Clear Sampling

CERES FOVs of MODIS clear & CALIPSO clear



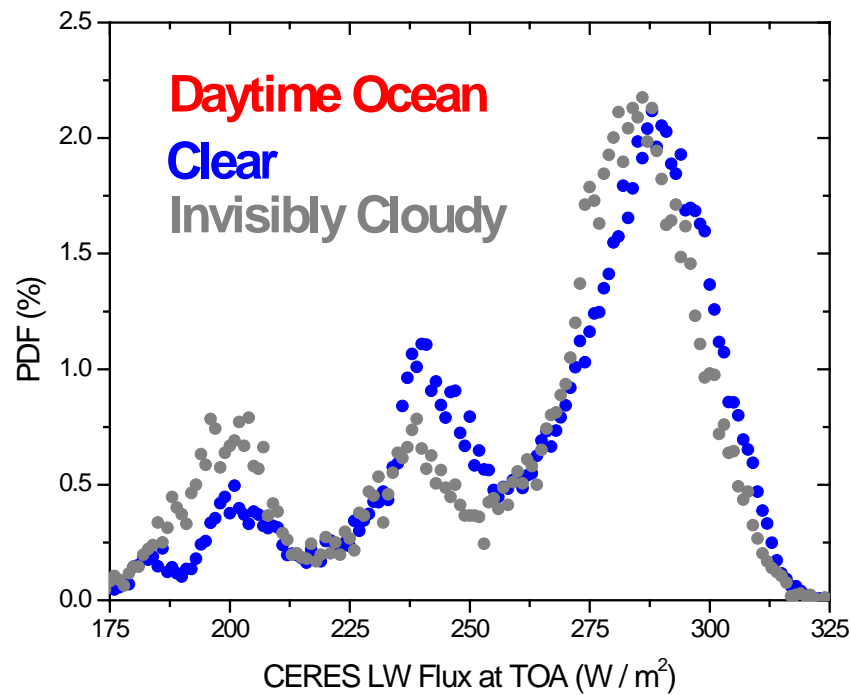
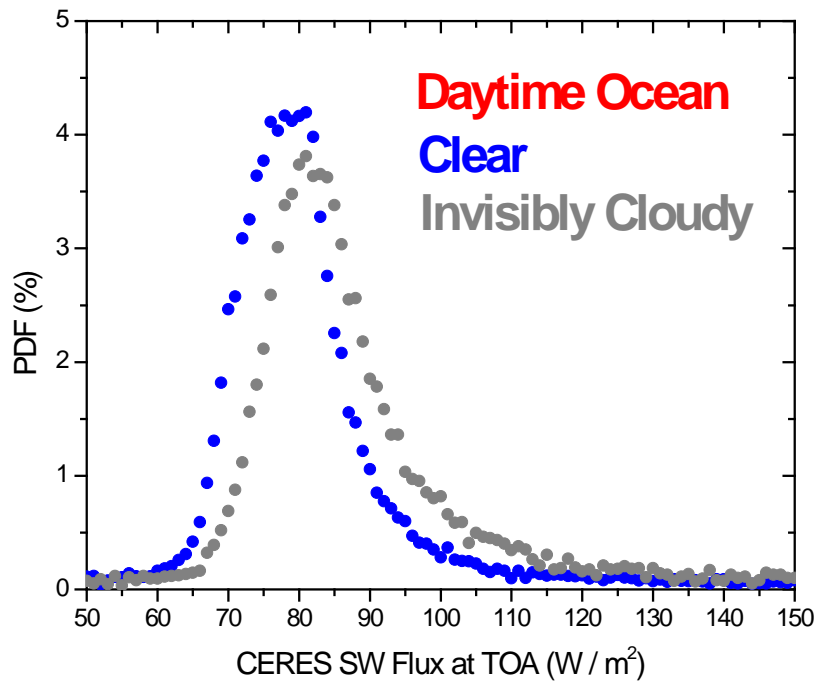
Daytime Invisibly Cloudy Sampling

CERES FOVs of MODIS clear & CALIPSO overcast

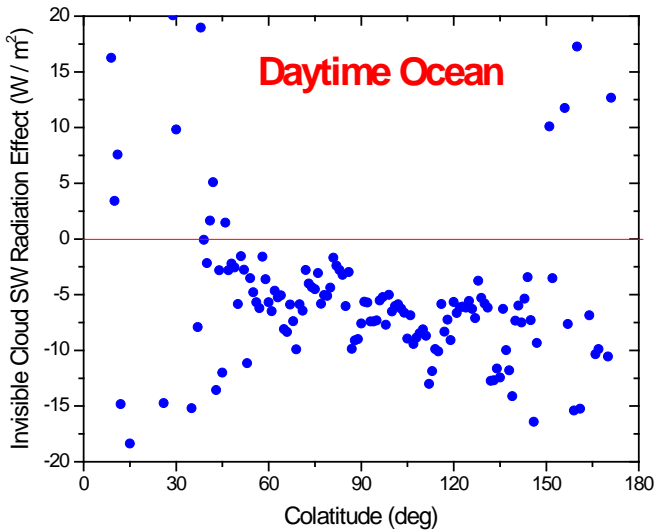
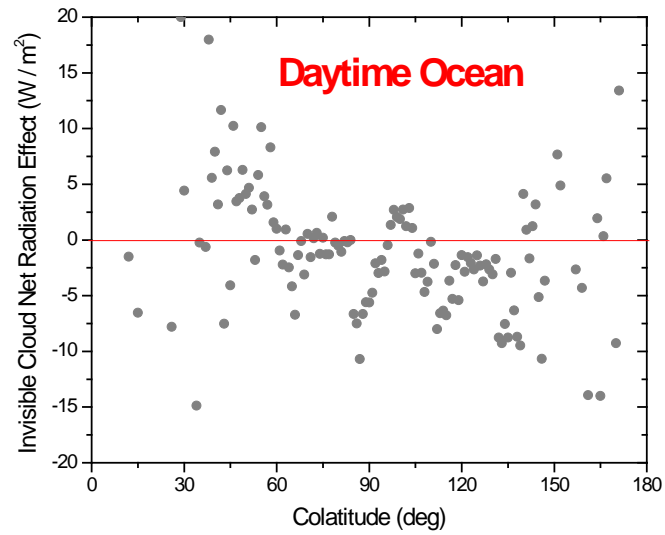
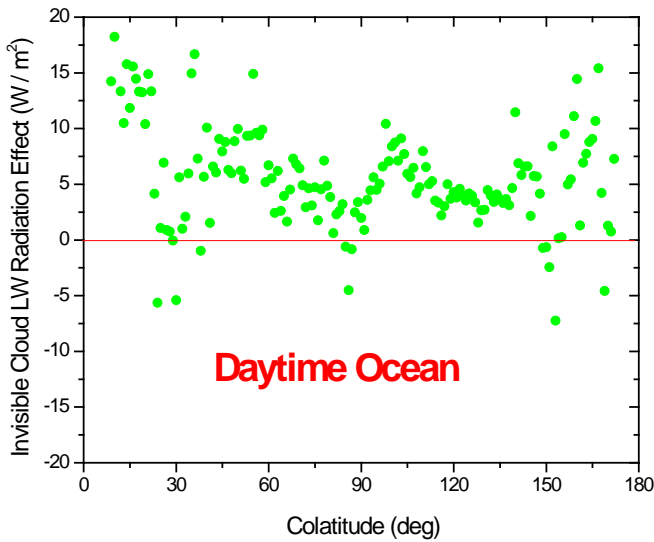


Up to 10 Wm(-2) warming/cooling effect could be seen in mid-latitude and subtropical zones!

Ocean daytime zonally mean LW and SW flux



Ocean daytime zonally mean flux distribution

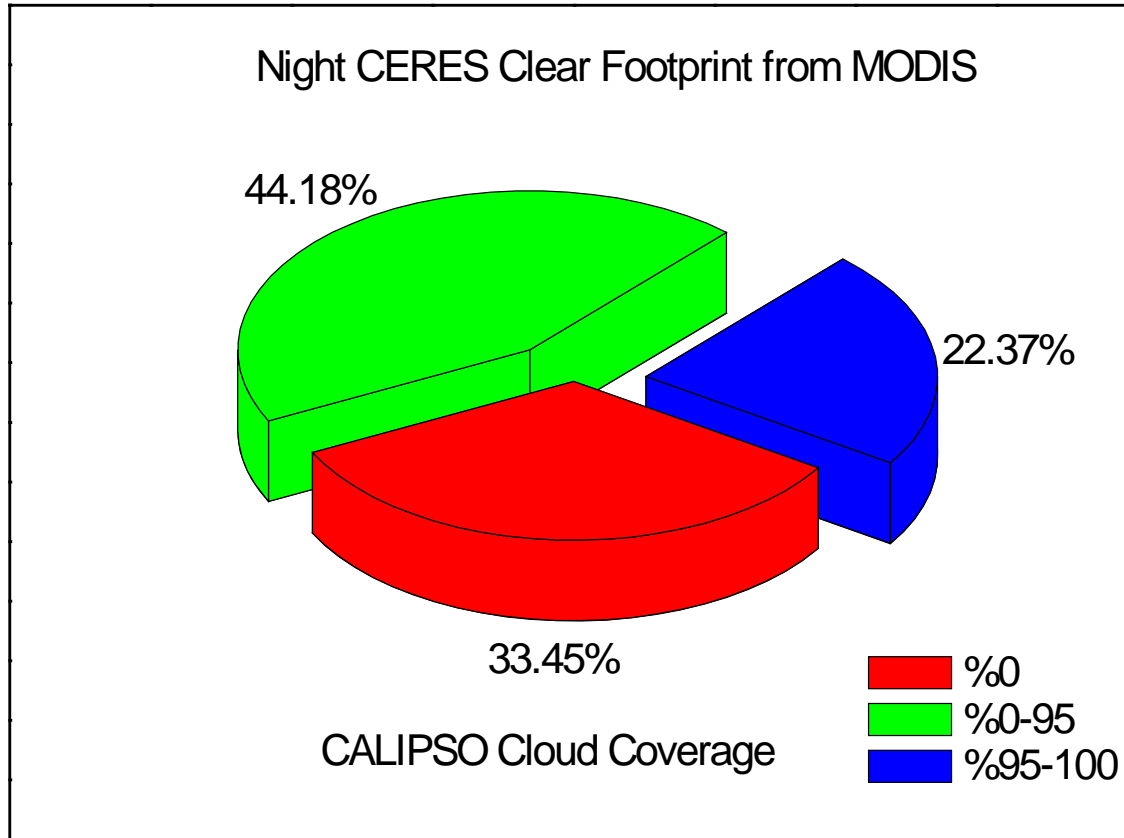


$$\frac{\int_0^{\pi} \alpha S_0 \cos \theta d\theta}{2 \int_0^{\pi} d\theta} = \frac{\alpha S_0}{\pi}$$

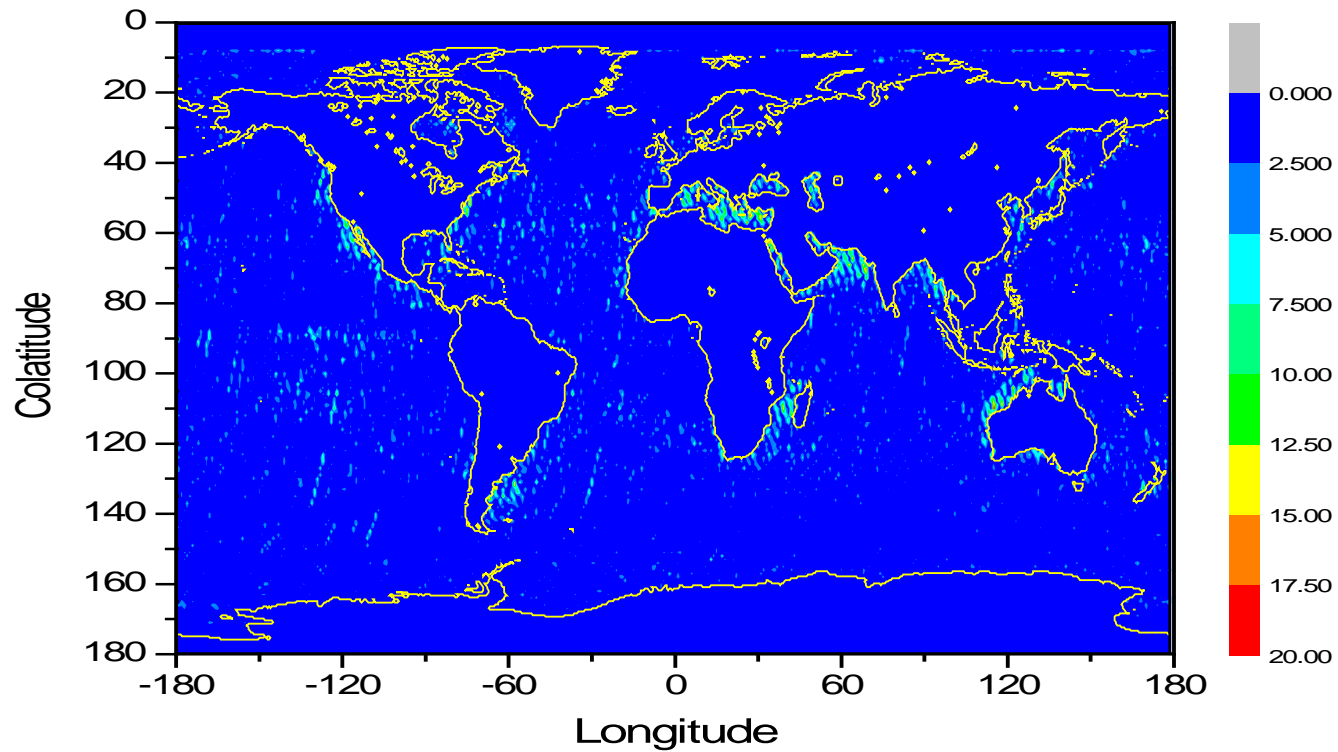
Roughly, diurnal mean SW radiation effect is ~1/3 of the instantaneous value, i.e. ~3 Wm(-2) cooling effect.

Ocean daytime zonally mean instantaneous invisible cloud radiation effect

Night Radiation Effect

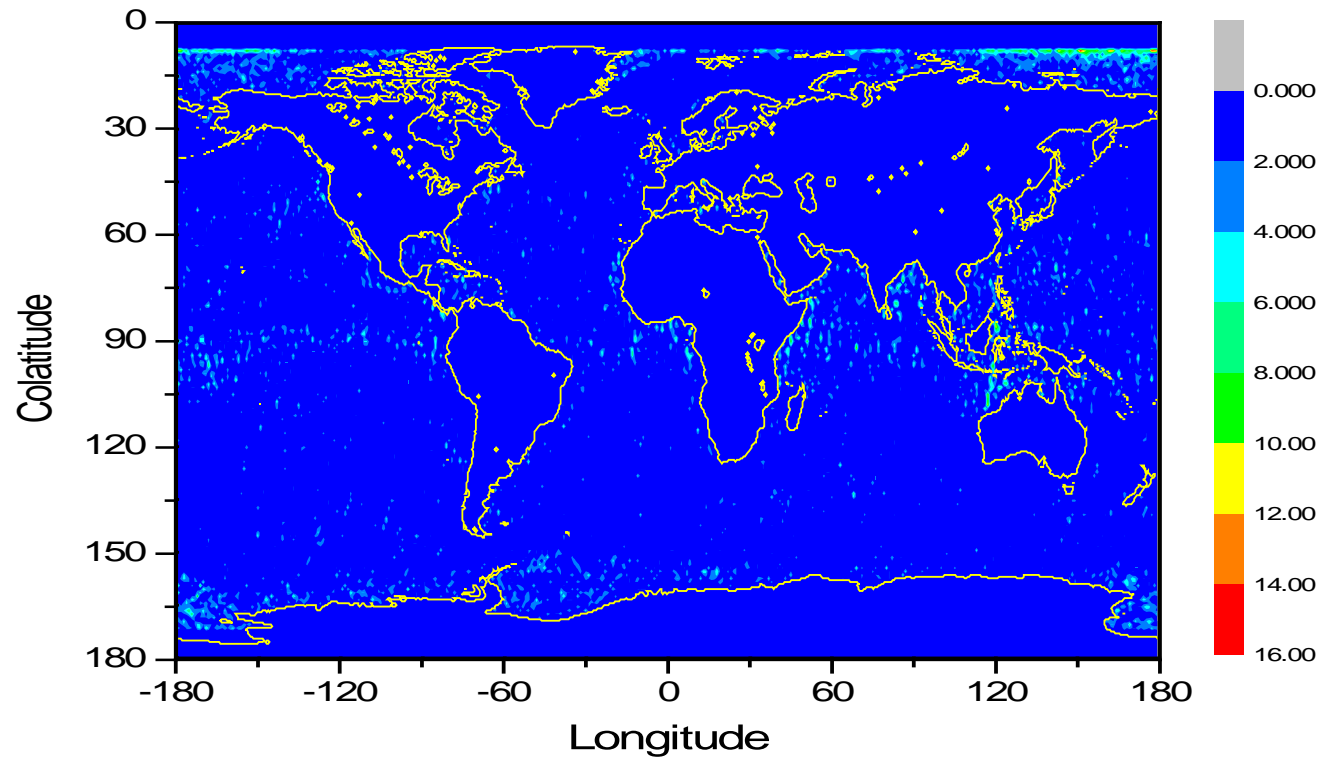


CALIPSO-derived 4-month cloudy percentage in MODIS-clear CERES FOVs



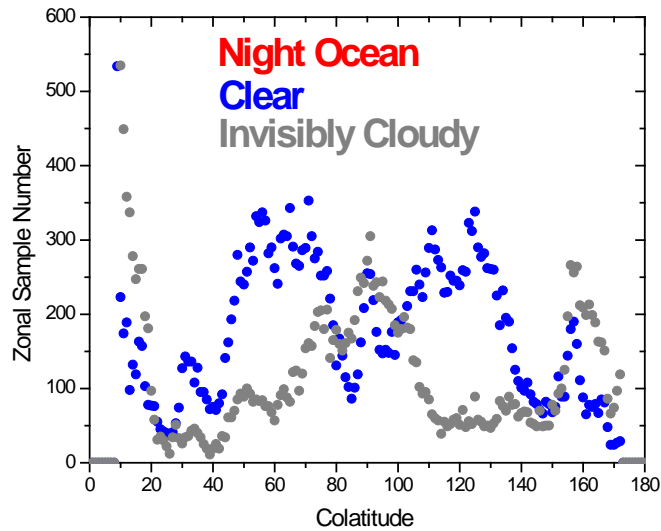
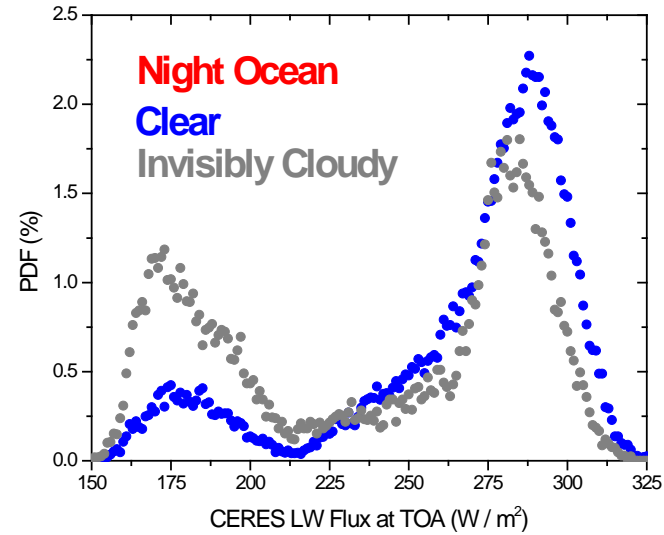
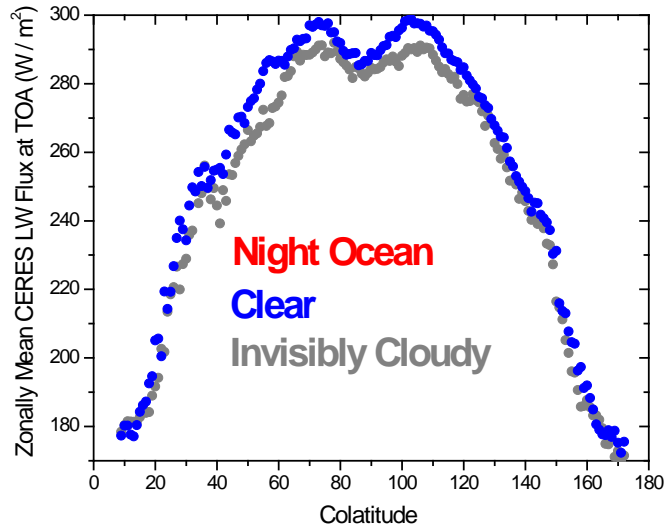
Night Purely Clear Sampling

CERES FOVs of MODIS clear & CALIPSO clear



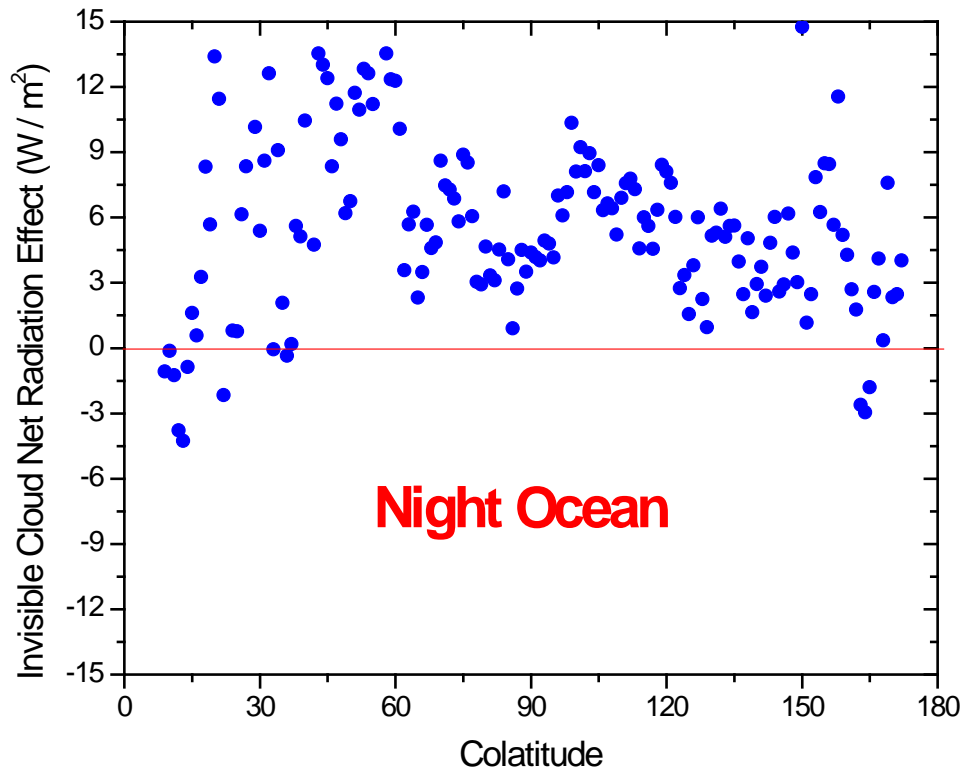
Night Invisibly Cloudy Sampling

CERES FOVs of MODIS clear & CALIPSO overcast



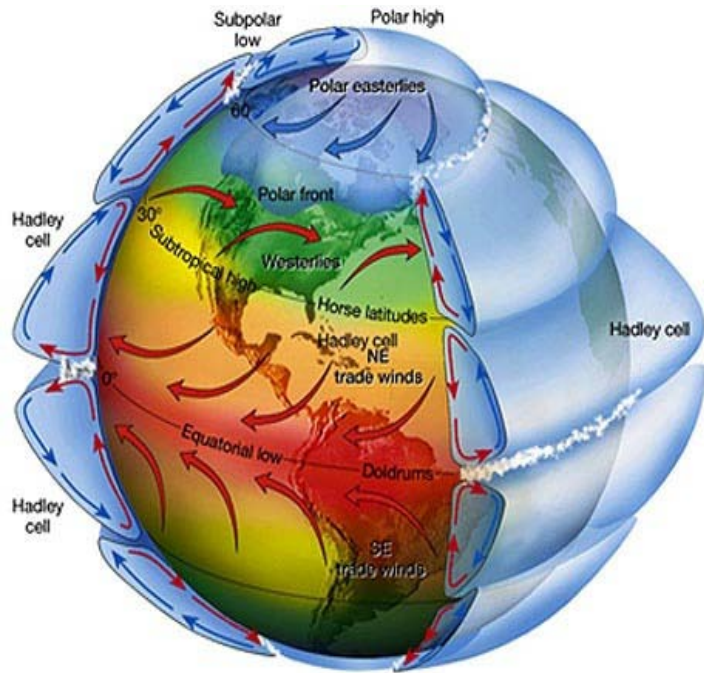
Up to 10 Wm^{-2} warming effect could be seen in mid-latitude and subtropical zones!

Ocean night zonally mean clear/cloudy LW flux data



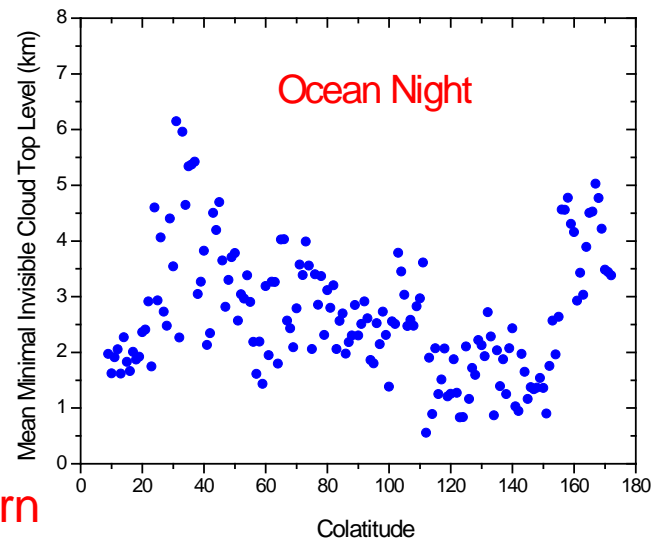
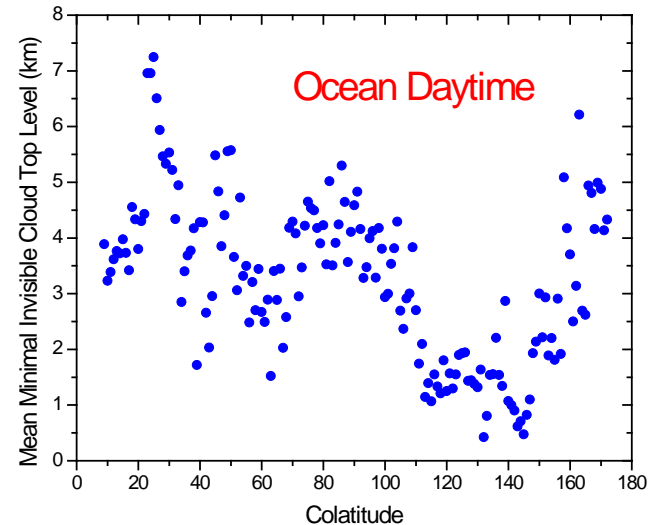
Ocean night zonally mean instantaneous invisible cloud radiation effect

Correlation of Minimal Cloud Height with Transition Zones



Daytime Lowest-level invisible clouds correlate with the transition zones between Hadley Cells, and Hadley and Mid-Latitude Cells, where air flows upward or downward.

Invisibly clouds are very probably new-born clouds at ITCZ or dying clouds at subtropical high zones



Effect on MODIS Aerosol Product

Statistics of matched and mismatched cases

CALIPSO Cloud Fraction Bins

		0.0	0.0-0.5	0.5-1.0	1.0
MOD04	0.0	14.92%	0.23%	0.29%	4.30%
Cloud	0.0-0.5	0.67%	0.04%	0.04%	0.56%
Fraction	0.5-1.0	2.00%	0.17%	0.19%	2.58%
Bins	1.0	4.00%	0.51%	0.71%	68.81%

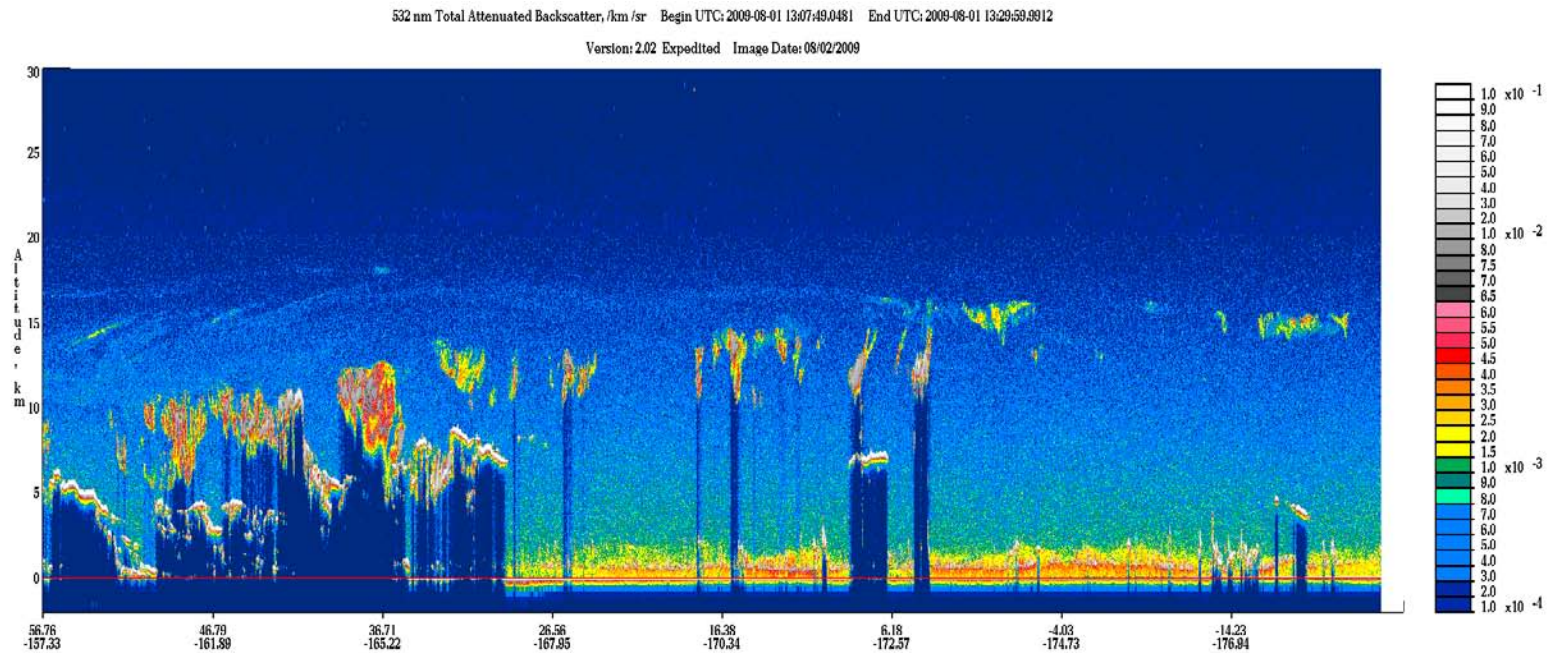
Total 1km x 1km region number: 219897

Comparison of MODIS and CALIPSO cloud masks on 1km x 1km pixels

Conclusion

1. Up to 50% of MODIS-derived clear-sky scenes are actually covered by invisibly thin clouds.
2. Invisibly thin clouds could account for $\sim 7.5 \text{ Wm}^{-2}$ instantaneous regional cooling effect at SW in daytime. These clouds have an instantaneous regional warming effect of $\sim 6 \text{ Wm}^{-2}$ at LW, day and night.
3. Regional diurnal mean radiation effect of invisibly thin clouds is $\sim 3 \text{ Wm}^{-2}$ net warming. Global total radiation effect is $\sim 0.2 \text{ Wm}^{-2}$ net warming from only the MODIS-clear regions.
4. Invisible clouds play important roles in regional and global radiation energy budget, because of their significant net warming effect. It can also seriously affect the aerosol product from MODIS and other passive measurements. Intensive measurements and studies should be performed for these global warming clouds.

5. This study only estimates the radiation effect of invisible clouds over MODIS-clear CERES FOVs. These clouds also widely exist over MODIS-cloudy scenes. Their global warming effect could be much larger than $\sim 0.2 \text{ Wm}^{-2}$.



The authors thank Seiji Kato for providing CCCM data and Bing Lin for useful discussions