Study of the radiative effect of thin cirrus clouds using CERES, MODIS and AIRS data

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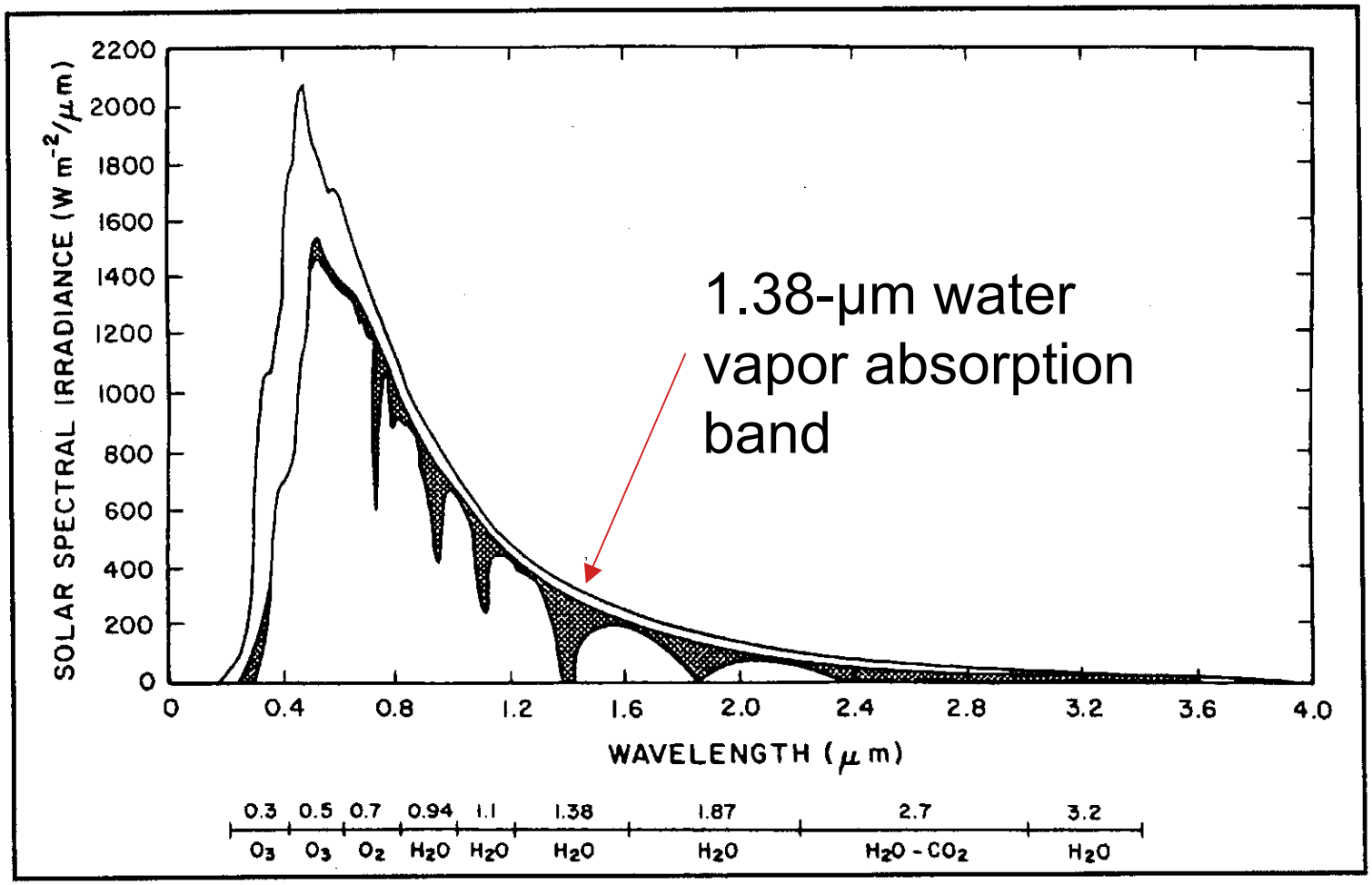
- Motivation

  Frequent occurrence of tropical thin cirrus clouds

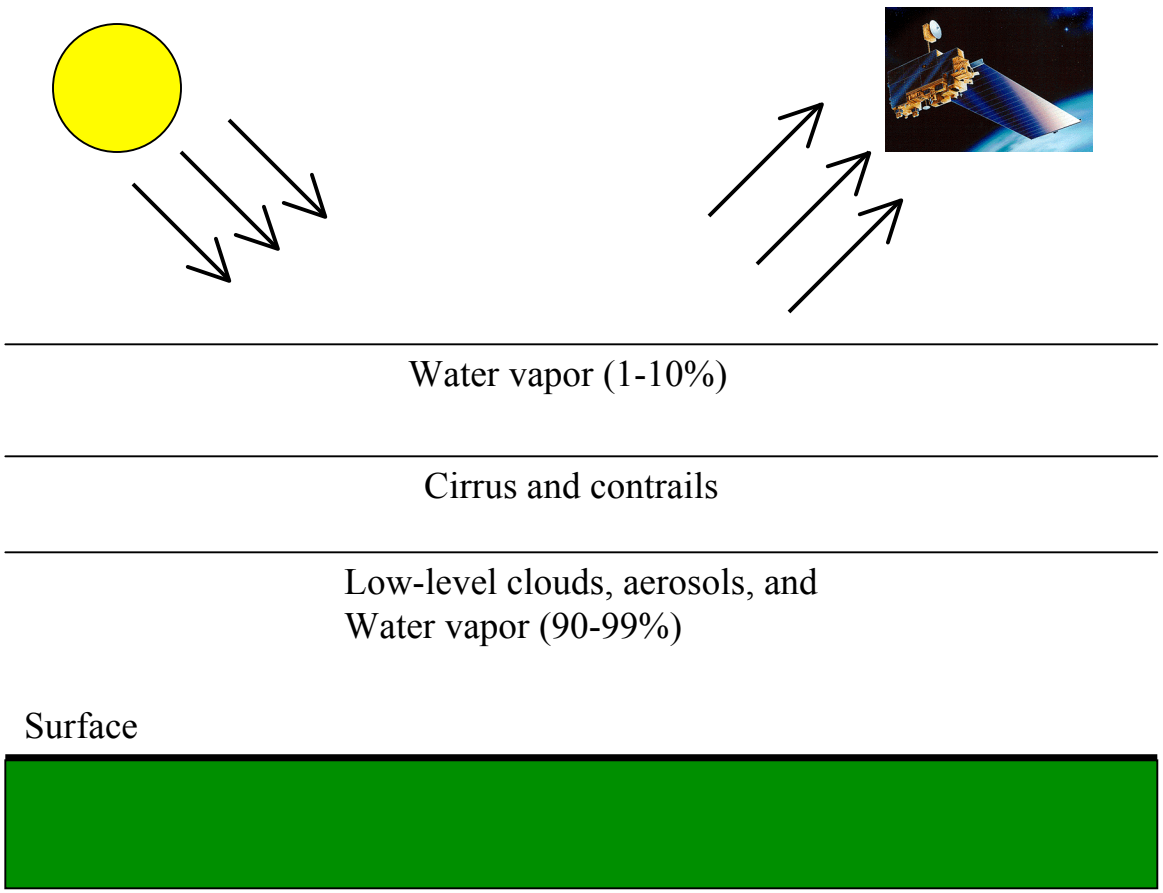
  - Seasonal coverage of thin cirrus clouds is more than 50% near the central region of the warm pool in the western Pacific (Prabhakara et al., 1993).
  - Cloud occurrence at Nauru as measured by lidar reveals that high clouds occur on average 44% of the time (Comstock and Ackerman, 2002).

- Objectives

- Detection and retrieval of sub-visible cirrus in “clear-sky” region using MODIS 1.38 μm channel
- Potential contamination of CERES “clear-sky” nighttime FOVs by thin cirrus
- Comparison between the CERES measurements of outgoing longwave radiation (OLR) and AIRS-based simulation of OLR under clear sky conditions

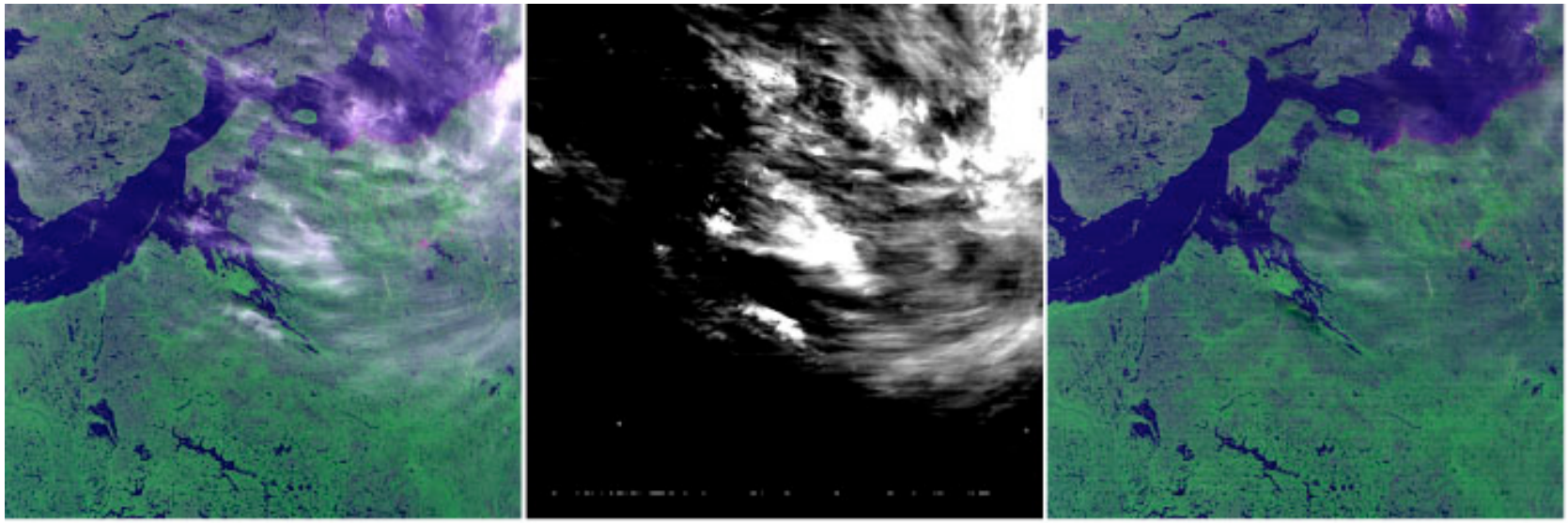


Adapted from Liou, 1980: An Introduction To Atmospheric Radiation


Water vapor (1-10%)
Cirrus and contrails
Low-level clouds, aerosols, and
Water vapor (90-99%)
Surface

MODIS Cirrus Correction

Uncorrected Image **Cirrus Image (1.38 μm)** **Cirrus Corrected Image**



Gao, B.-C., P. Yang, W. Han, R.-R. Li, and W. Wiscombe, 2002: An algorithm using visible and 1.38-μm channels to retrieve cirrus cloud reflectances from aircraft and satellite data. *IEEE Trans. Geosci. Remote Sens.*, 40, 1659-1668.

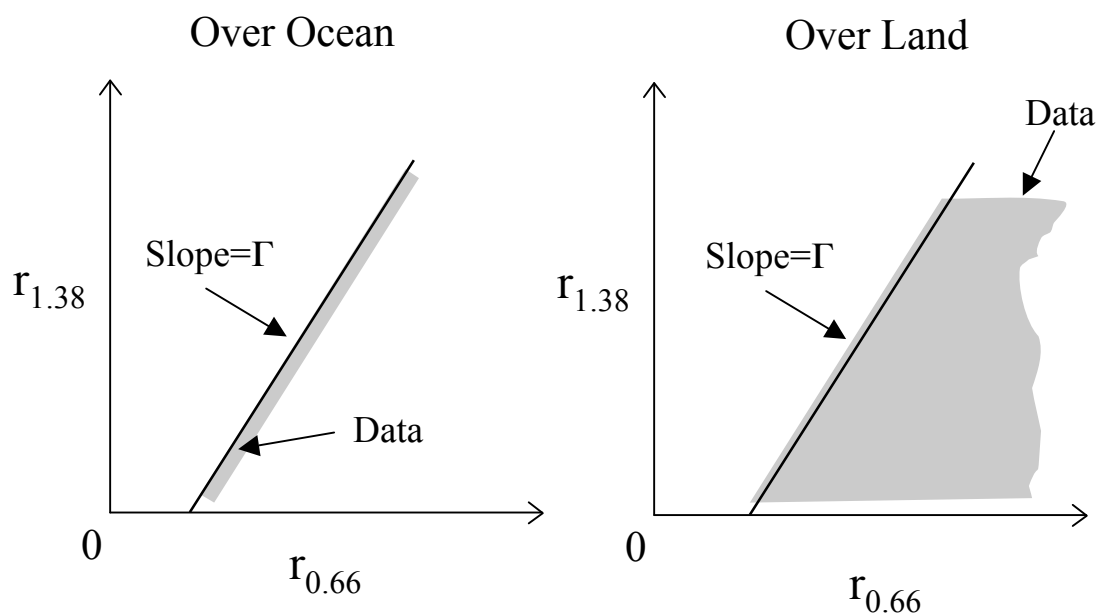
Deriving Cirrus Reflectance

True or isolated visible cirrus reflectance:

$$r_{c,0.66}(\mu_0, \phi_0, \mu, \phi) = \frac{r_{1.38}(\mu_0, \phi_0, \mu, \phi)}{\Gamma}$$

Gao, B.-C., P. Yang, W. Han, R.-R. Li, and W. Wiscombe, 2002: An algorithm using visible and 1.38-μm channels to retrieve cirrus cloud reflectances from aircraft and satellite data. *IEEE Trans. Geosci. Remote Sens.*, 40, 1659-1668.

Derivation of Γ



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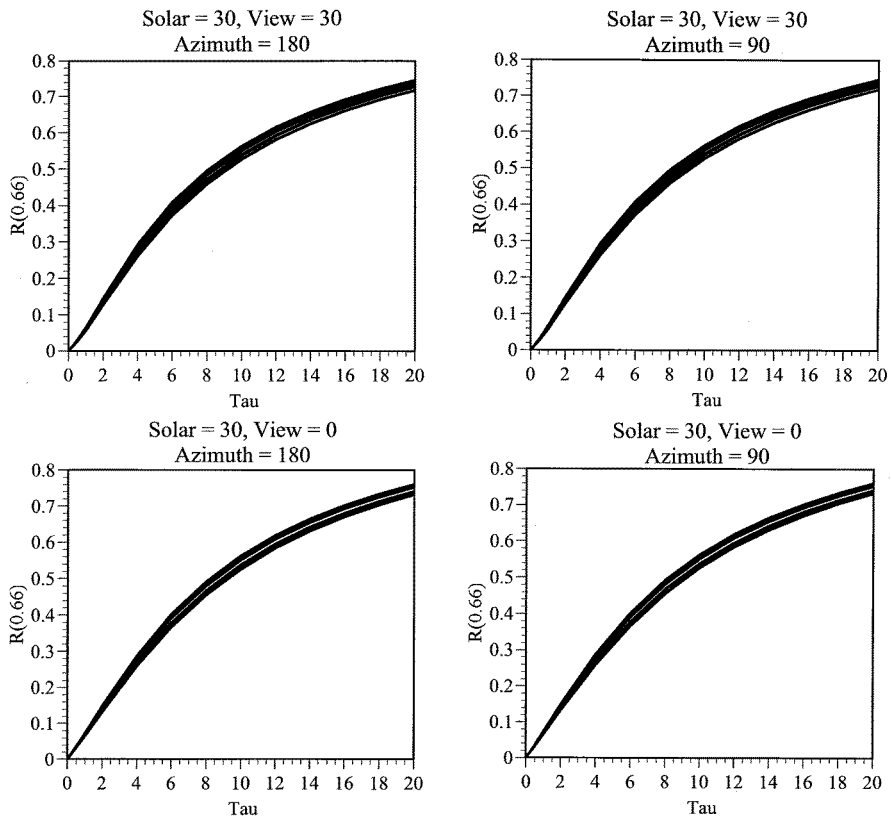
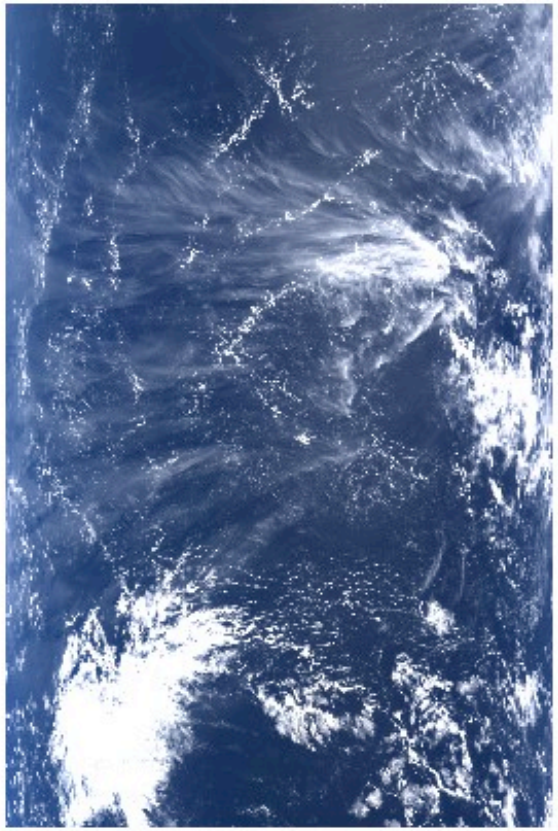
Sample Look-up Tables

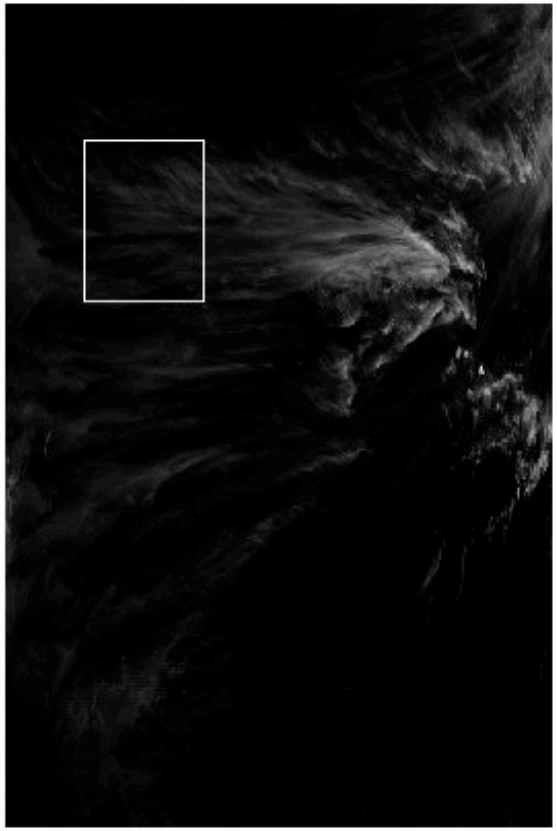


Meyer, K., P. Yang, and B.-C. Gao, 2004: Optical thickness of tropical cirrus clouds derived from the MODIS 0.66 and 1.38-um channels. *IEEE Trans. Geosci. Remote Sens.* 42, 833-841

MODIS RGB Image

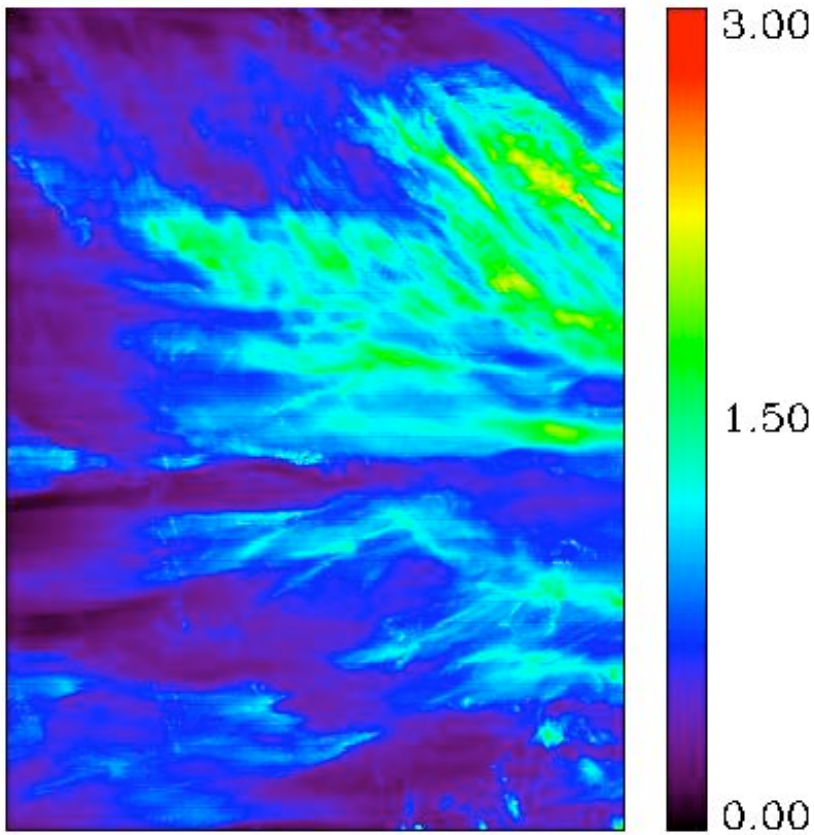


MODIS 1.375-μm Image



Meyer, K., P. Yang, and B.-C. Gao, 2004: Optical thickness of tropical cirrus clouds derived from the MODIS 0.66 and 1.38-um channels. *IEEE Trans. Geosci. Remote Sens.* 42, 833-841

Retrieved Optical Thickness



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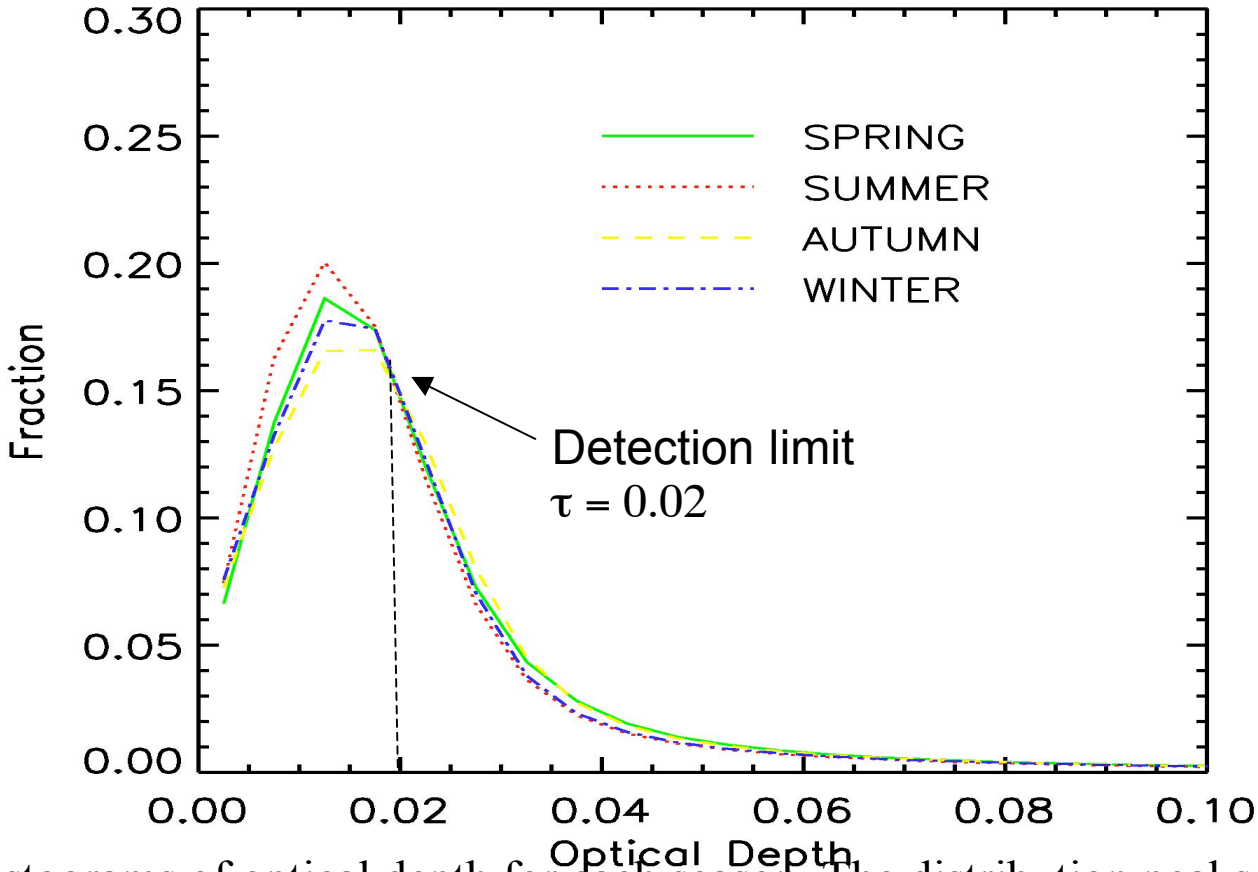
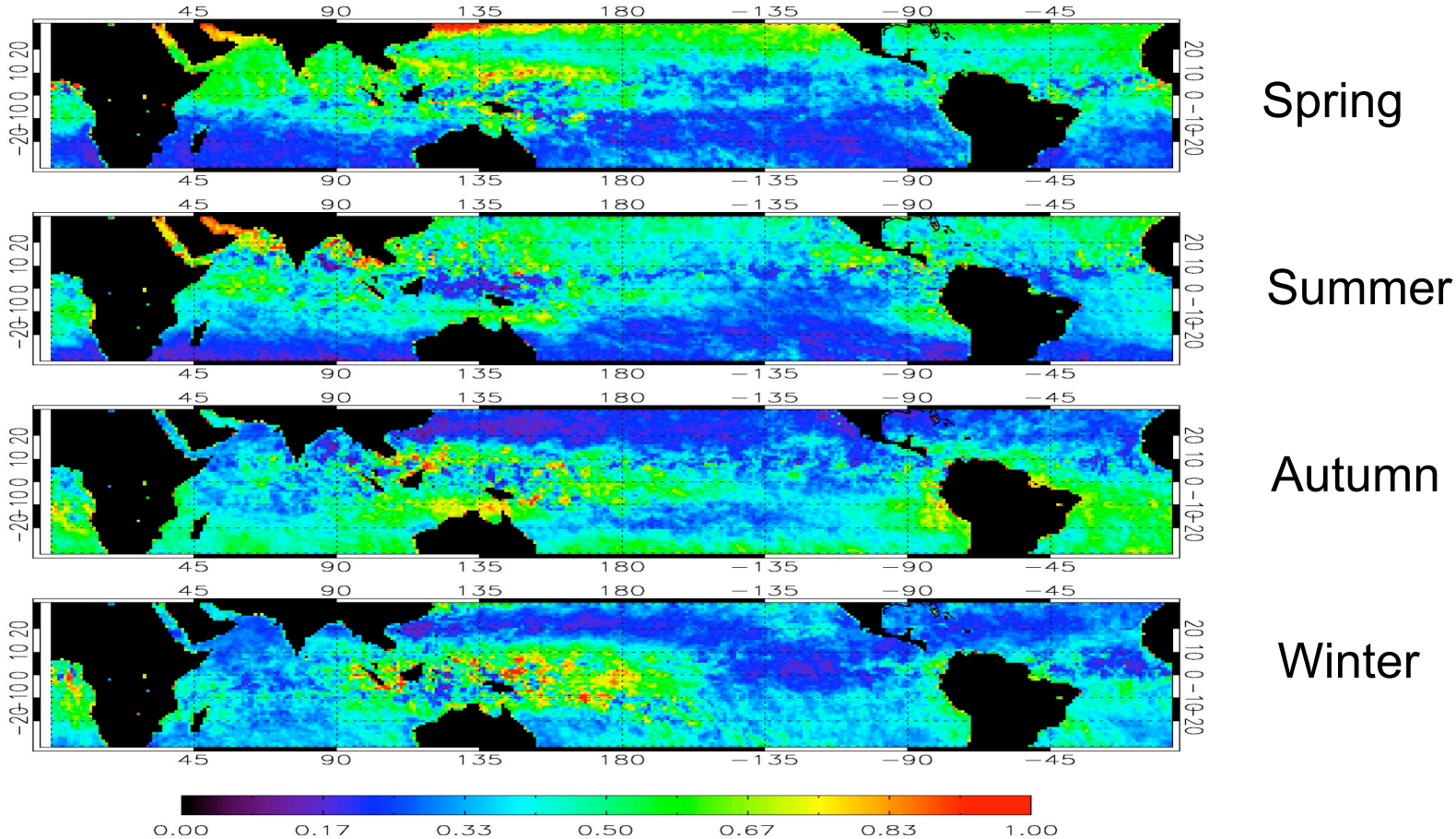


Histograms of optical depth for each season. The distribution peaks strongly at low optical depth. Using τ=0.02 as a detection limit, 44%, 39%, 47%, and 44% of the observations flagged as cloud-free have detectible thin cirrus clouds for spring, summer, autumn, and winter, respectively.

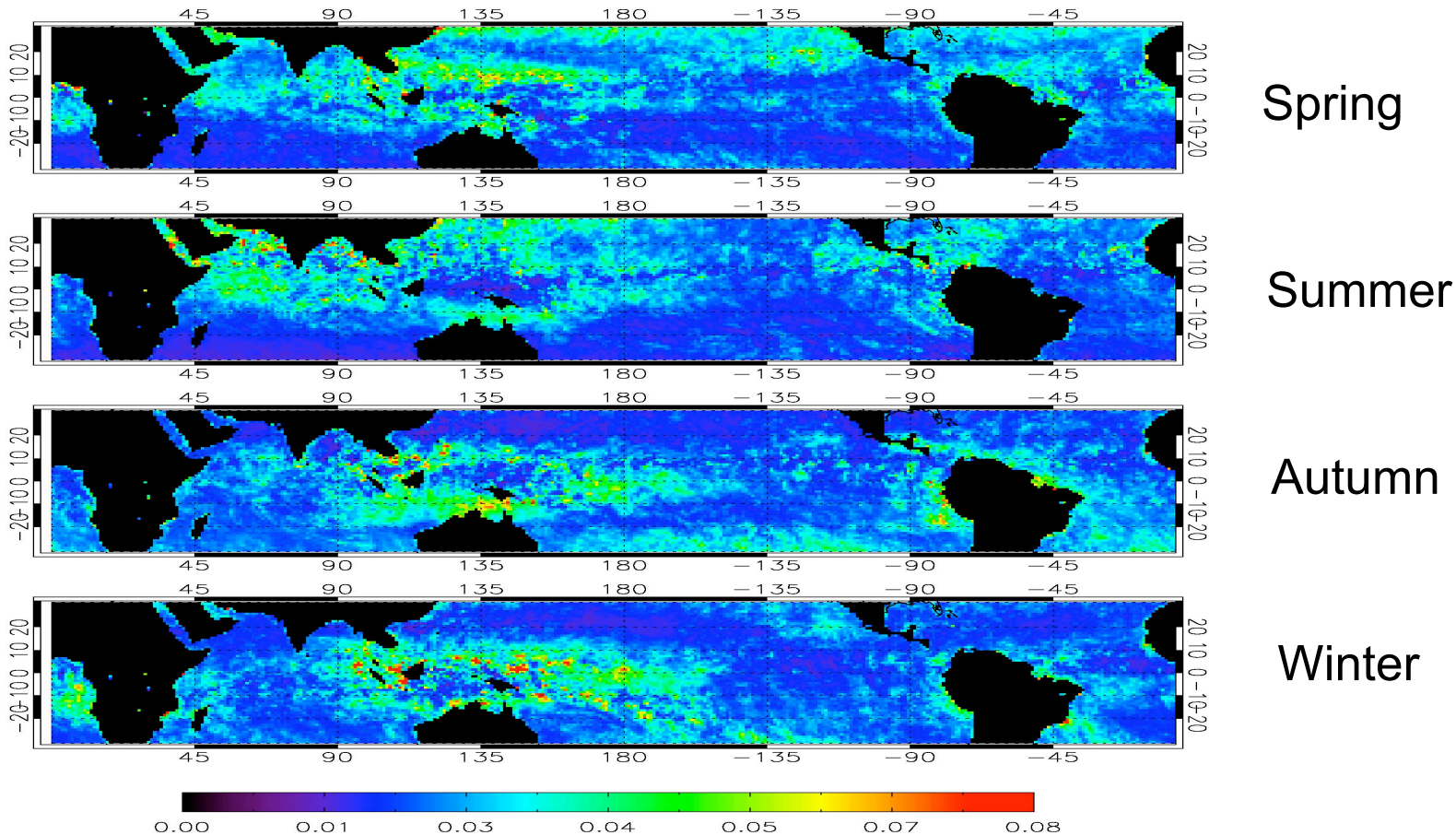
(Dessler and Yang, J. Climate, 16, 1241-1247, 2003)

Cloud Fraction



The fraction of "clear-sky" observations for 1°×1° boxes that have detectable 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 along with deep convective regions.

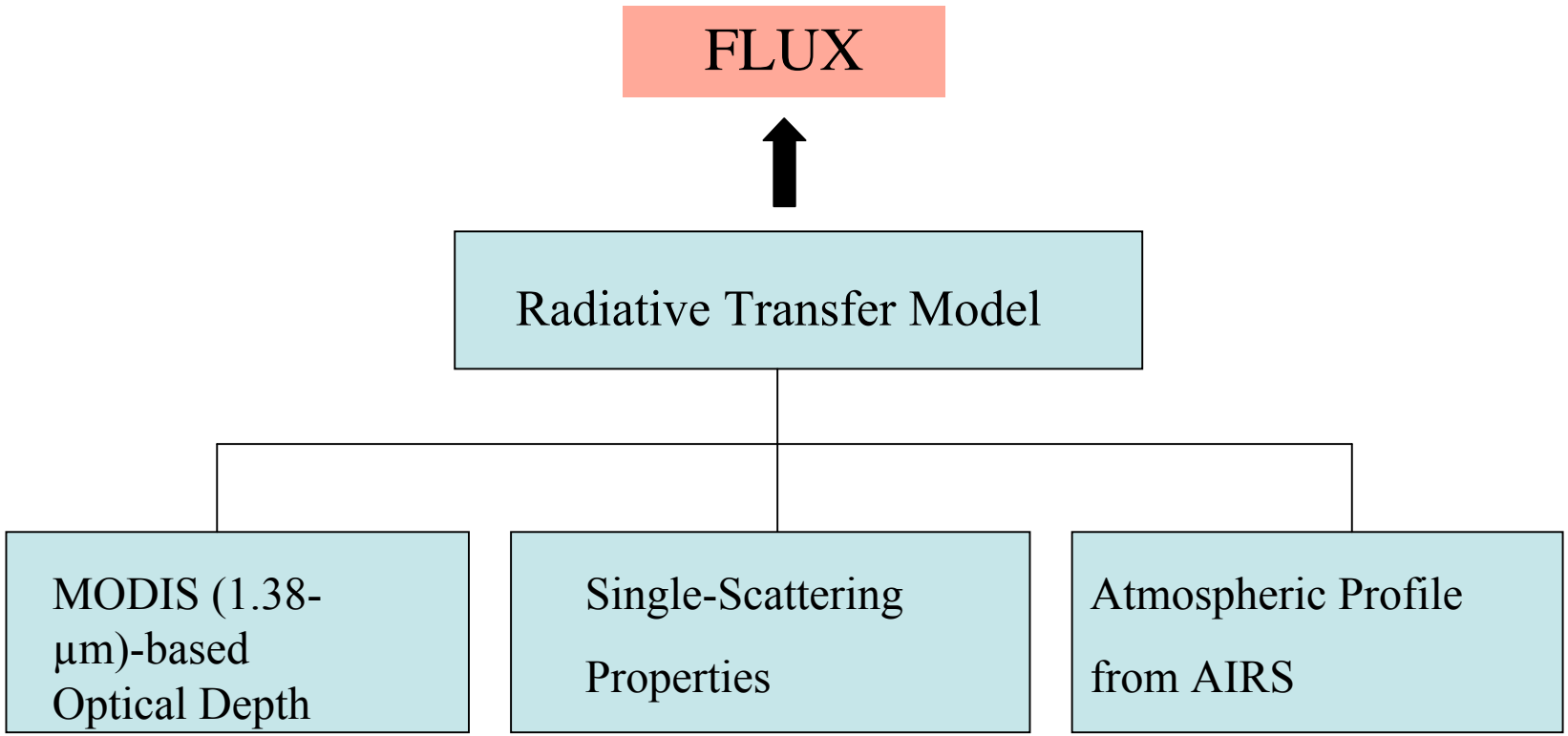
Cloud Optical Thickness



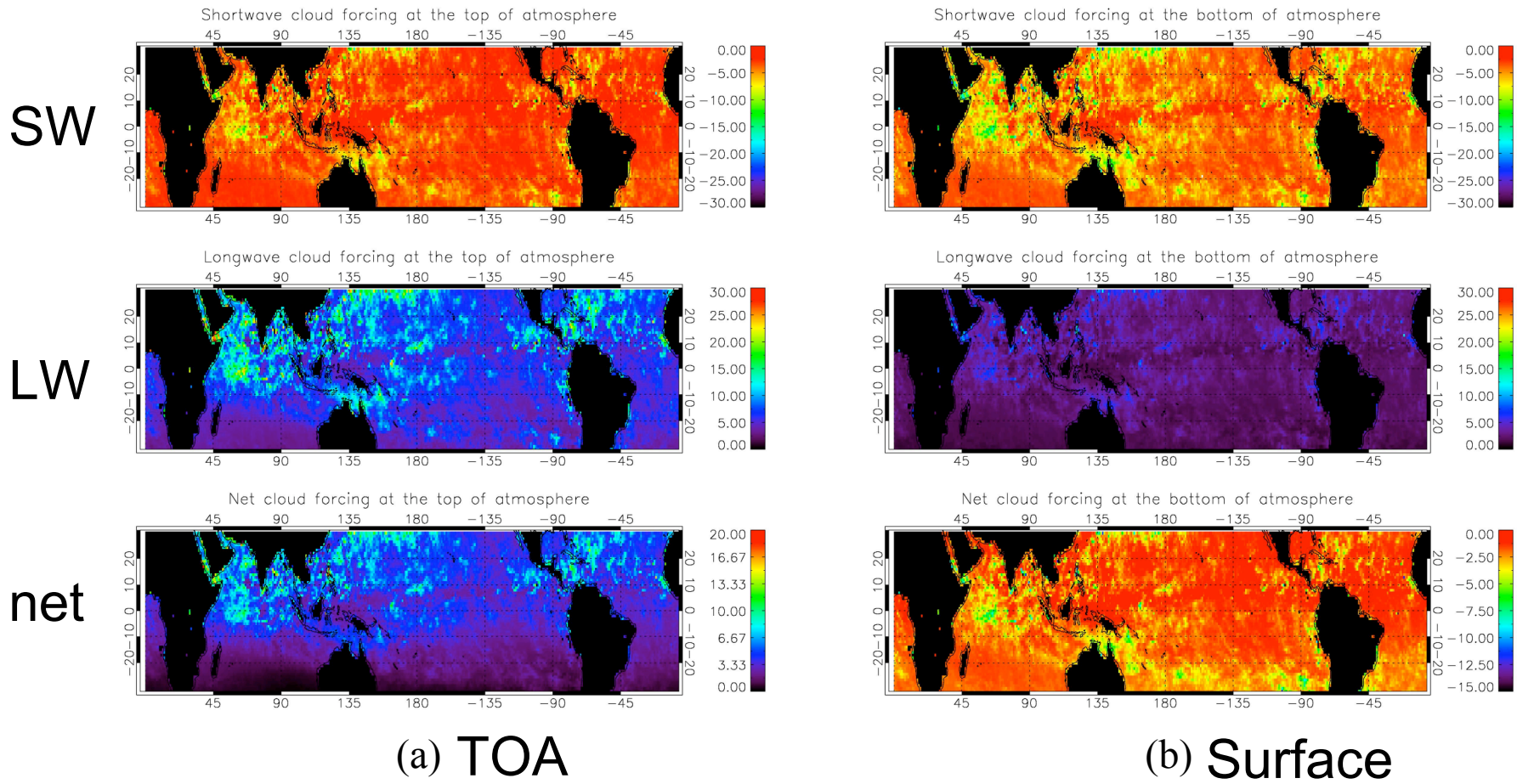
The optical depth of tropical thin cirrus for the pixels flagged as "clear-sky" by MODIS for each season (Spring, Summer, Autumn, and Winter from top to bottom panel). The optical depth is averaged over 1°×1° boxes, same as in fraction of observations. The pattern of optical depth is very similar to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

Sub-visible cirrus under “clear-sky” conditions

- Radiative Forcing



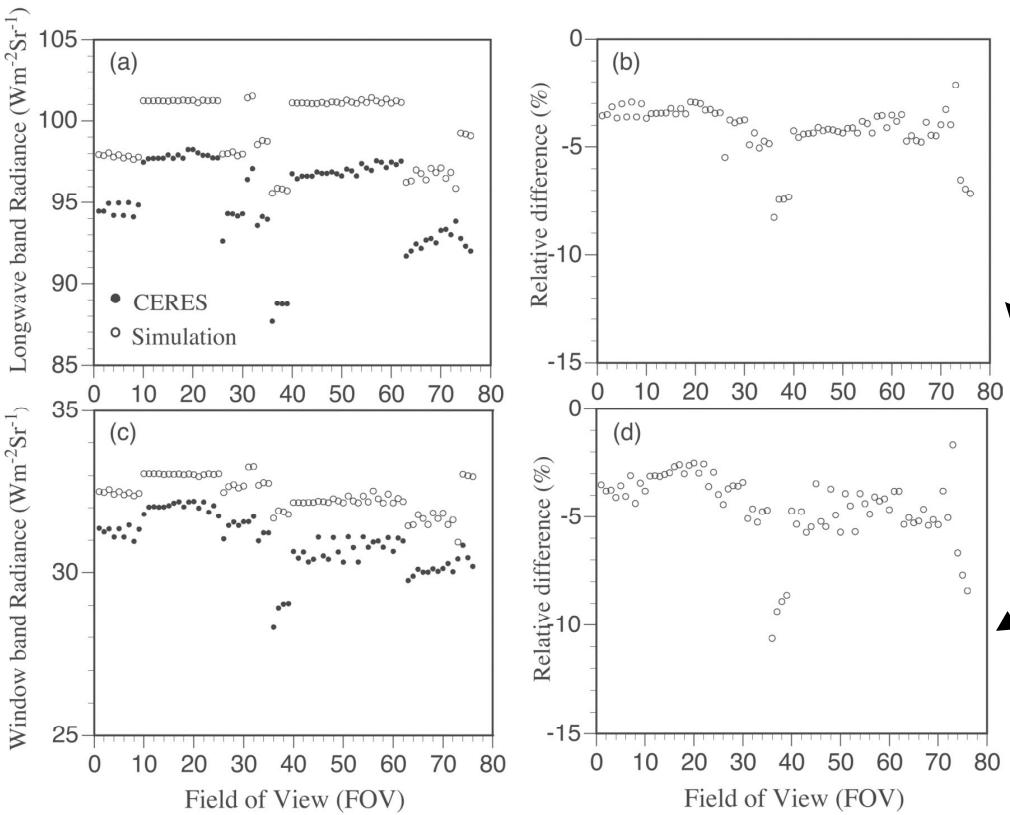
CRF of sub-visible cirrus June 2005



(a) TOA (b) Surface

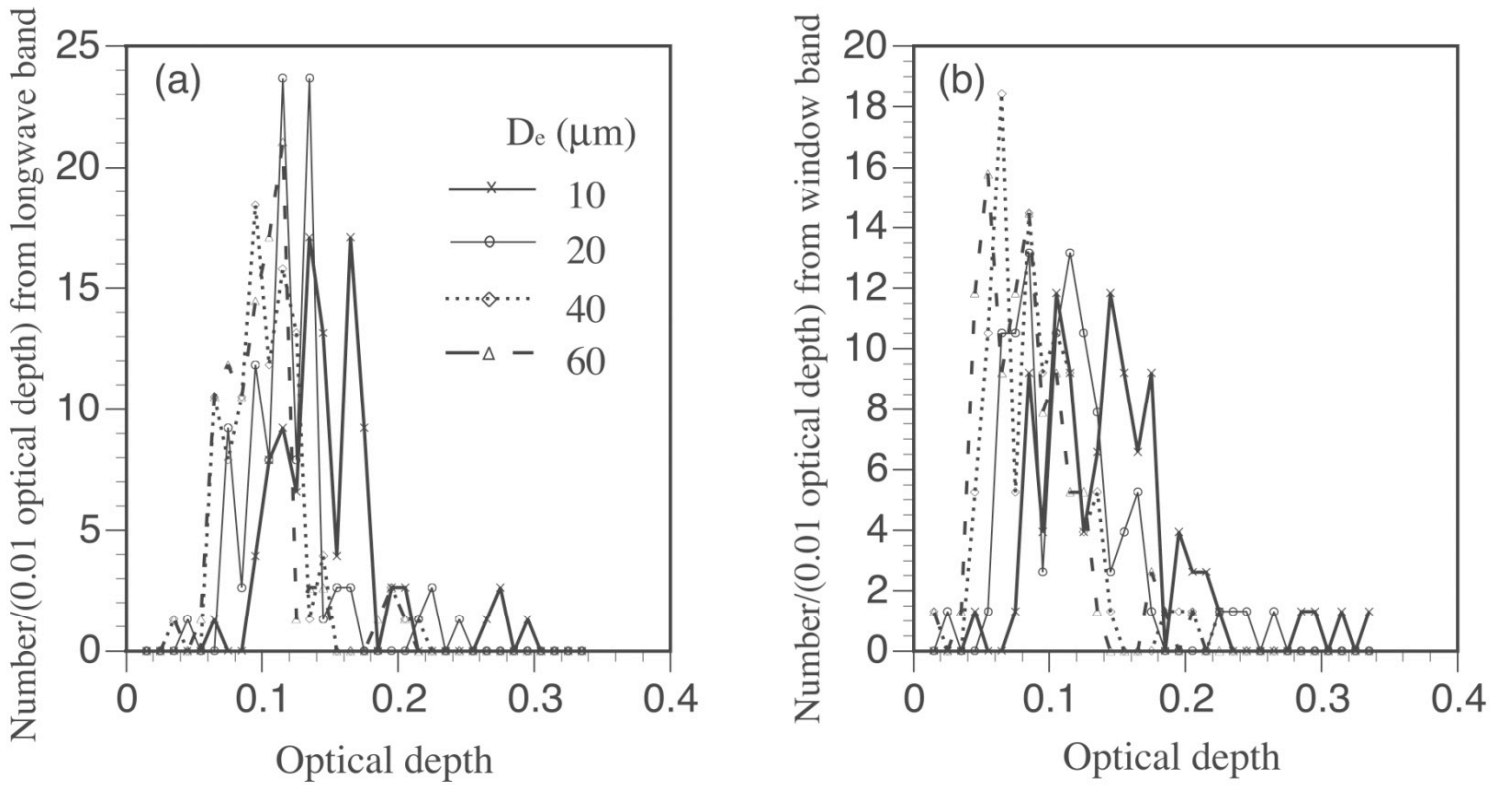
Cloud radiative forcing (a) at the top of atmosphere and (b) at the surface for **June 2005**. As shown in the sensitivity study, thin cirrus clouds have a net positive cloud radiative forcing at the top of atmosphere and a net negative forcing at the bottom of atmosphere.

Potential Contamination of CERES "Clear-Sky" FOVs by Thin Cirrus



- Over CERES "clear-sky" FOVs, CERES OLR is lower than simulated OLR by
  - ~4.2% (longwave)
  - ~4.5% (window)

Lee, Y. K., P. Yang, Y. Hu, B. A. Baum, N. G. Loeb, and B.-C. Gao, 2006: Potential nighttime contamination of CERES clear-sky field of view by optically thin cirrus during the CRYSTAL-FACE campaign. J. Geophys. Res. Vol. 111, No. D9, D09203 10.1029/2005JD006372

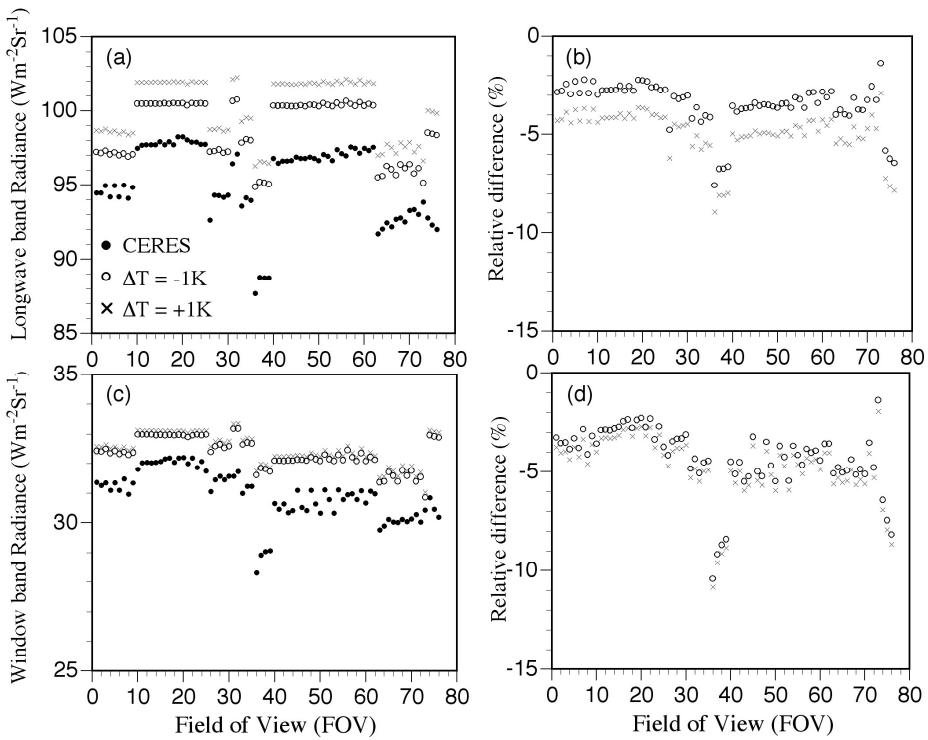


Distribution of the optical depths of thin cirrus clouds retrieved from the difference of observed and simulated radiances by assuming various effective particle sizes. Panel (a): results based on the longwave band data; panel (b) results based on the window band data.

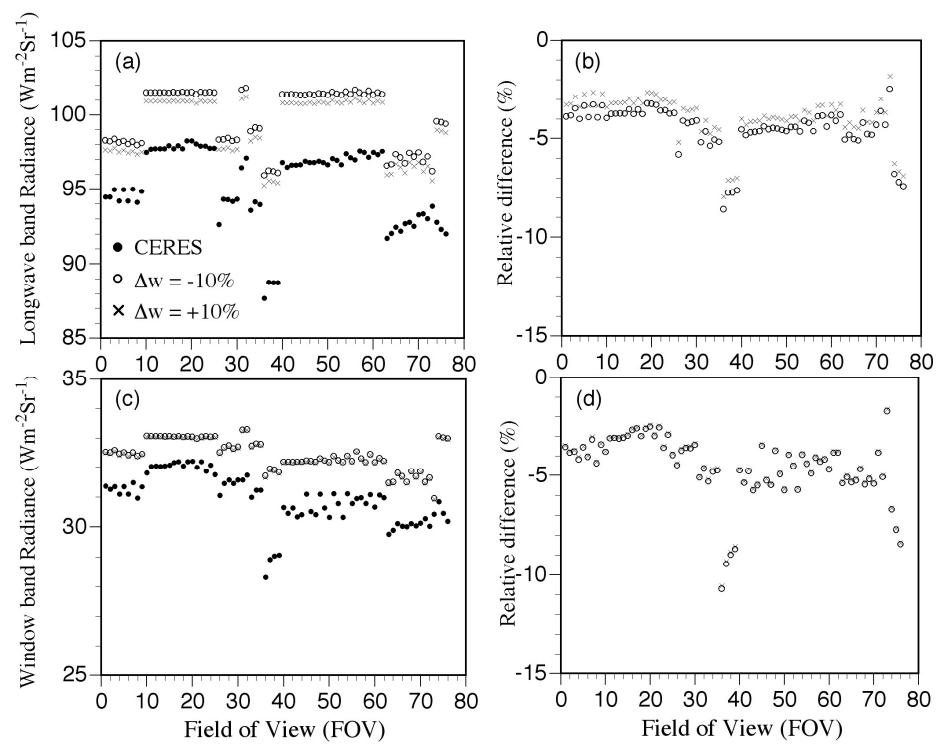
Lee, Y. K., P. Yang, Y. Hu, B. A. Baum, N. G. Loeb, and B.-C. Gao, 2006: Potential nighttime contamination of CERES clear-sky field of view by optically thin cirrus during the CRYSTAL-FACE campaign. J. Geophys. Res. Vol. 111, No. D9, D09203 10.1029/2005JD006372

Potential Contamination of CERES "Clear-Sky" FOVs by Thin Cirrus

- Sensitivity study



atmo temperature profile $\pm 1K$



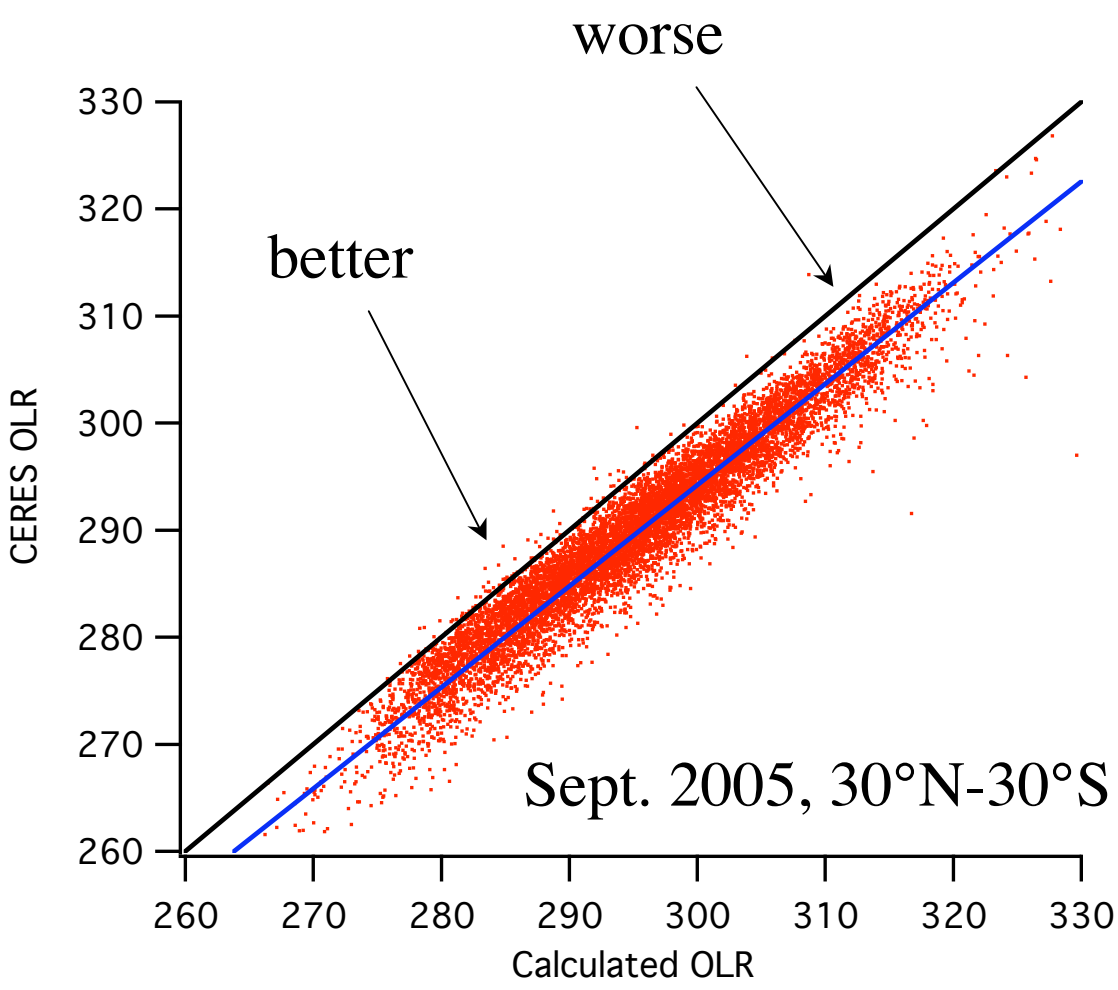
atmo water vapor $\pm 10\%$

CERES OLR *VS.* AIRS OLR

- Methodology
  - Use CERES Aqua SSF edition 2a data
  - Consider those CERES measurements where > 96% of the collocated MODIS cloud-mask measurements are clear
  - Combine with AIRS measurements within ~20 km of the CERES measurement
  - Calculate TOA flux from CERES surface skin temperature and AIRS profiles of q, T, and O_3
  - Nighttime, ocean, March and September 2005

Model

- Chou et al., 2001: A Thermal Infrared Radiation Parameterization for Atmospheric Studies. NASA Tech. Memo. 104606, vol. 19, 1-55.
- The infrared spectrum (0~3000 cm^{-1}) is divided into 9 bands and a subband, in total 10 bands
- Using the Air Force Geophysical Laboratory HITRAN data base (1996 version)
- The parameterization includes the absorption due to major gaseous absorption (water vapor, CO_2, O_3) and most of the minor trace gases (N_2O, CH_4, CFC's) as well as clouds and aerosols.
- The gaseous transmission function is computed either using the k-distribution method or the table look-up method.
- Accuracy: within 1% of the high spectral-resolution line-by-line calculation
- In this calculation, band 9 (1900~3000 cm^{-1}) is excluded to match with CERES TOA flux band (50~2000 cm^{-1}). The flux at 30 km between 1900 and 2000 cm^{-1} is 0.9 Wm^{-2} using tropical atmosphere.
- Vertical atmospheric profiles from AIRS are used, including temperature, water vapor, and ozone profile
- Atmosphere is divided into 100 layers from surface to 100 km and the AIRS profiles are interpolated at each level.



CERES=0.96 calc + 8

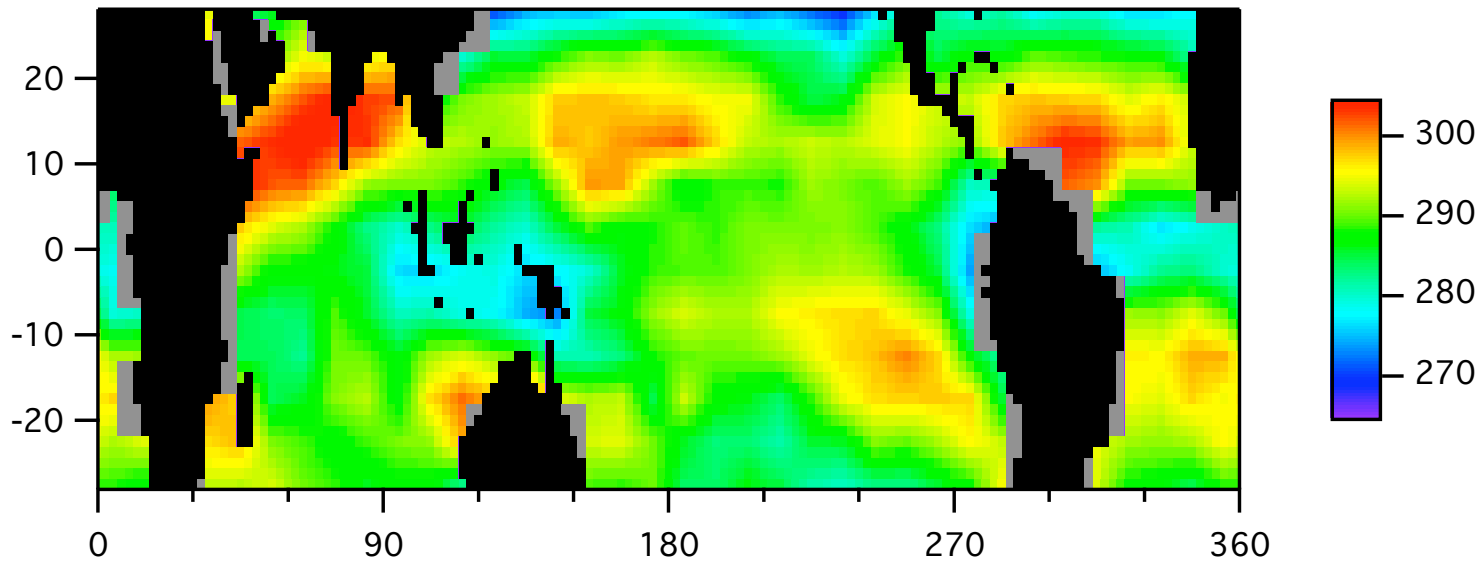
Avg. difference
4.7 W/m^2

Standard deviation
2.3 W/m^2

Previous Work

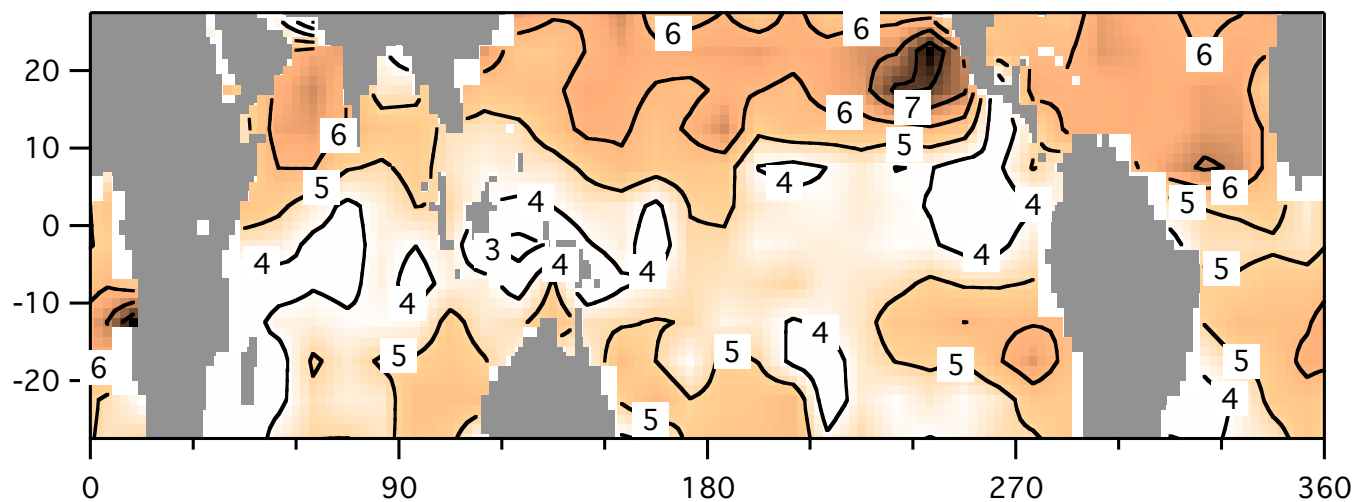
Paper	model - measurement (W/m^2)	notes
Ho et al., 1998	2-4	estimated 30N-30S from Fig. 2 for March and Sept.
Collins and Inamdar, 1995	2-6	difference is a function of RH
Inamdar and Ramanathan, 1994	0.5 (st. dev. = 9)	20N-20S, all months of 1985

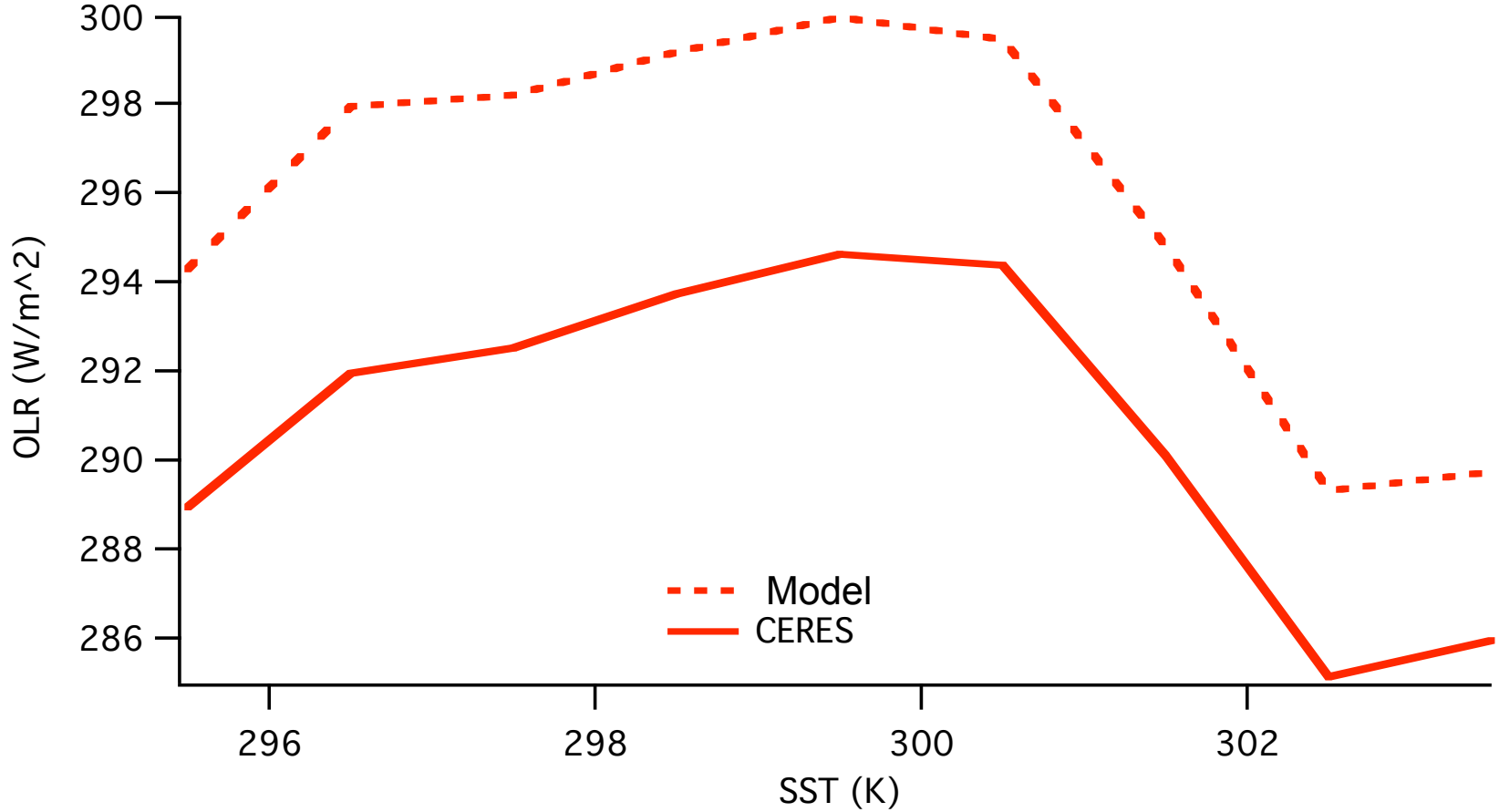
Clear-sky OLR



March 2005

model - meas.





data from 9/05

Compare to 299 to 303 K

303 K OLR
289.3 W/m^2

299 K OLR
297.7 W/m^2

ΔOLR
-8.4 W/m^2

Surface T	2.0
Lower Trop T	2.8
Upper Trop T	0.6
Lower Trop q	-7.9
Upper Trop q	-6.3

Lower Trop = 1000-500 hPa, Upper Trop = 500-100 hPa

data from 9/05

Compare to 295 to 299 K

299 K OLR
297.7 W/m^2

295 K OLR
285.3 W/m^2

ΔOLR
12.4 W/m^2

299 K to:	295 K	303 K
Surface T	8.3	2.0
Lower Trop T	9.7	2.8
Upper Trop T	4.8	0.6
Lower Trop q	-7.6	-7.9
Upper Trop q	-3.2	-6.3

Lower Trop = 1000-500 hPa, Upper Trop = 500-100 hPa

data from 9/05

Conclusions

- The radiative effect of sub-visual thin cirrus clouds is significant
- OLR calculated using AIRS measurements agrees with CERES measurements within ~5 W/m^2
  - Agreement best in the deep tropics and worst in the subtropics
- We are also studying the mechanisms that regulate clear-sky OLR
- T and q are the most important factors
  - T dominates below 298 K, q dominates above

Ongoing Work

- Investigation of the radiative forcing of ice clouds using MOD06/MYD06 (collection 5), AIRS and CERES data

Yang, P., L. Zhang, G. Hong, S. L. Nasiri, B. A. Baum, H.-L. Huang, M. D. King and S. Platnick, 2007: Differences between Collection 4 and 5 MODIS ice cloud optical/microphysical products and their impact on radiative forcing simulations, *IEEE Trans. on Geosci. and Remote Sensing* (in press)

Hong, G., P. Yang, B.-C. Gao, B. A. Baum, Y. X. Hu, M. D. King and S. Platnick, 2007: High cloud properties from three years of MODIS Terra and Aqua Data over the Tropics, *J. Appl. Meteor.* (in press)