# Heating Rates in Mid-Latitude Cirrus Cloud Calculated from Retrieved Cirrus Microphysical Properties

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## Introduction

Cirrus clouds affect the surface and top-of-atmosphere energy budgets strongly through albedo and greenhouse effects, and can produce large local variations in atmospheric heating with heating at cloud bottom and cooling at cloud top (Liou 1986; Webster and Stephens 1980). Starr and Cox (1985) found that radiative modulation of local buoyancy through horizontal structure affects the structure and bulk properties of cirrus. Ackerman et al. (1988) have indicated that heating rates in tropical anvils are more sensitive to the assumed ice water content (IWC), but also are affected by the vertical distribution of IWC and the anvil thickness. The studies of heating rates in cirrus clouds were mainly based on limited observational data. The Atmospheric Radiation Measurement (ARM) Program data stream provides our capability to study this problem based on a more reliable large dataset. Cirrus IWC and size profiles can be retrieved from lidar, radiometer, and radar measurements (Matrosov et al. 1992; Mace et al. 1998; Wang and Sassen 2002a). The lidar-radar algorithm is applied to Raman lidar and millimeter wave cloud radar (MMCR) measurements at Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site and generated ~1000 hrs of cirrus cloud microphysical properties (Wang and Sassen 2002a, 2002b). Based on this dataset and a broadband radiative transfer model (Fu et al. 1997, 1998), heating rates in midlatitude cirrus cloud are calculated. The dependencies of cloud layer mean heating rates and the maximum difference within cloud layer on cirrus ice water path (IWP), absorption optical depth, and layer mean size are provided.

## Mid-Latitude Cirrus Cloud Microphysical Property Dataset

The lidar-radar algorithm combines extinction coefficient ($\sigma$) profile derived from Raman lidar measurements and MMCR radar reflectivity (Ze) profile to retrieve IWC and general effective radius ($D_{ge}$) profiles. Sensitivity studies showed the algorithm has good tolerance for the measurement errors in $Z_e$ and its parameterization error, and the accuracy of IWC is strongly dependent on the accuracy of $\sigma$ and its parameterization. The parameterization of $\sigma$ as a function of IWC and $D_{ge}$ has good accuracy (Fu 1996). The Raman lidar is one of the best instruments to measure cirrus extinction coefficient profiles. Therefore, the combination of the Raman lidar and MMCR generates reliable cirrus microphysical properties. This algorithm is applied to SGP CART measurements during November 1996 and November 2000. The statistics of cirrus microphysical and radiative properties are discussed in detail by Wang and Sassen (2002b).

## Heating Rate Profile

A broadband radiative transfer model (Fu et al. 1997, 1998) is used for heating rate calculations. To incorporate vertical inhomogeneity of cirrus microphysical properties, we use 100 m vertical resolution within 15 km above surface in the model. Temperature profiles are derived from a combination of radio sonde and model results.

## The Statistics of Heating Rates

Cirrus clouds are optically and geometrically thin, so it is difficult for general circulation models to simulate the vertical structure of cirrus property and heating rate profiles. Therefore, we only examine the statistics of layer mean heating rates and the maximum differences of heating rates within cloud layer (see Figures 1 - 8).

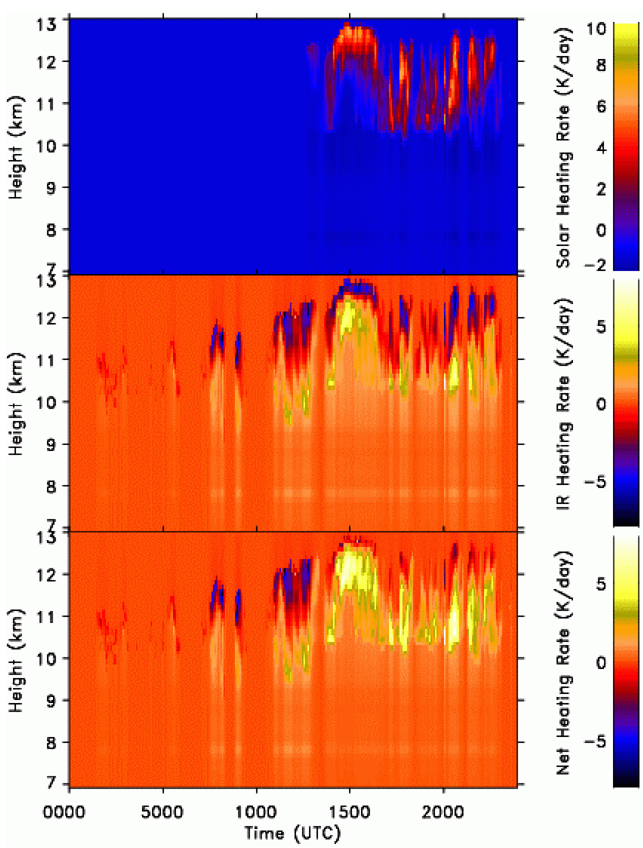


**Figure 1**. An example of net (cloudy sky – clear-sky) infrared (IR) and solar heating rate profile on October 15, 1998.

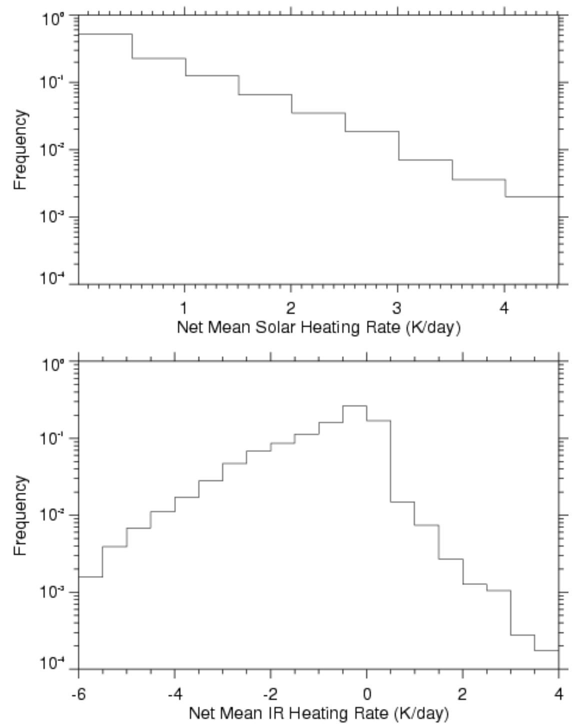


**Figure 2**. Frequency distributions of net mean solar and IR heating rate.

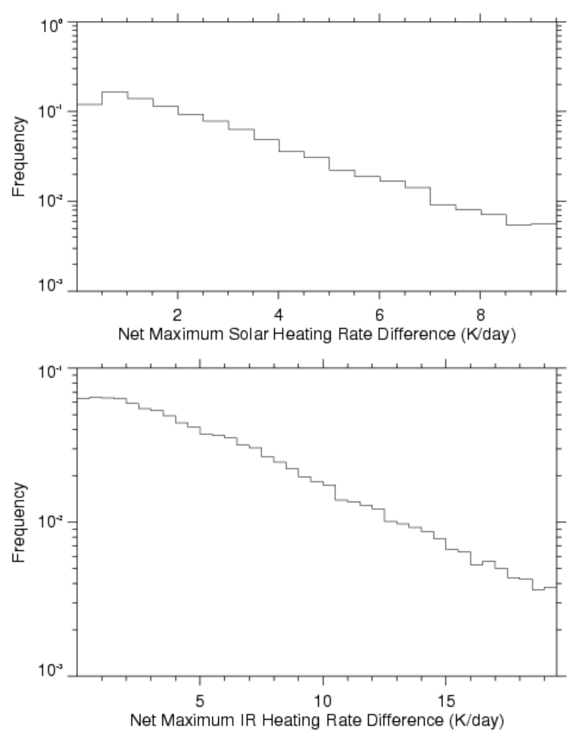


**Figure 3**. Frequency distributions of net maximum solar and IR heating rate differences within cirrus cloud layer.

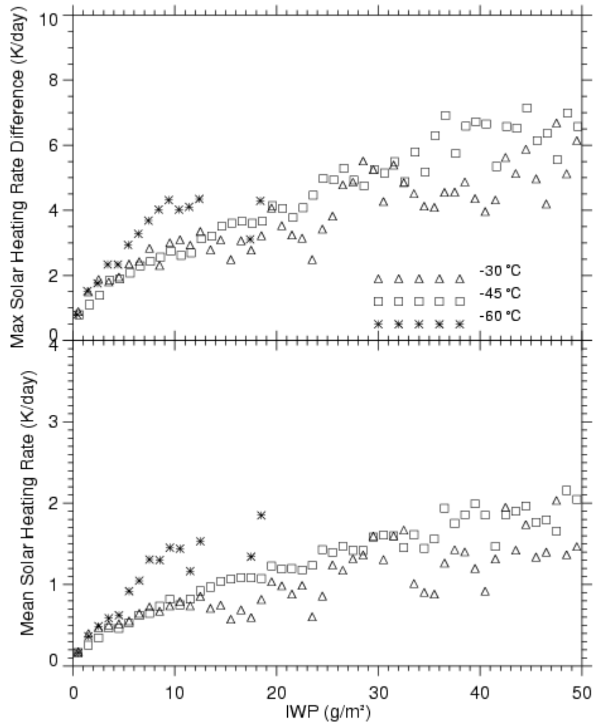


**Figure 4**. Solar heating rates as functions of IWP and midcloud temperatures. The mean values for midcloud temperatures -30°, -45°, and -60°C are calculated within 10-degree bin.

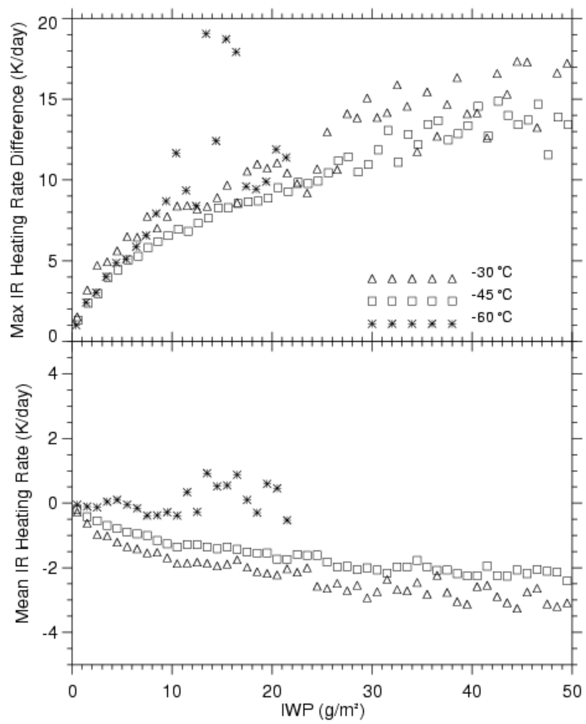


**Figure 5**. As in Figure 4, except for IR heating rates.

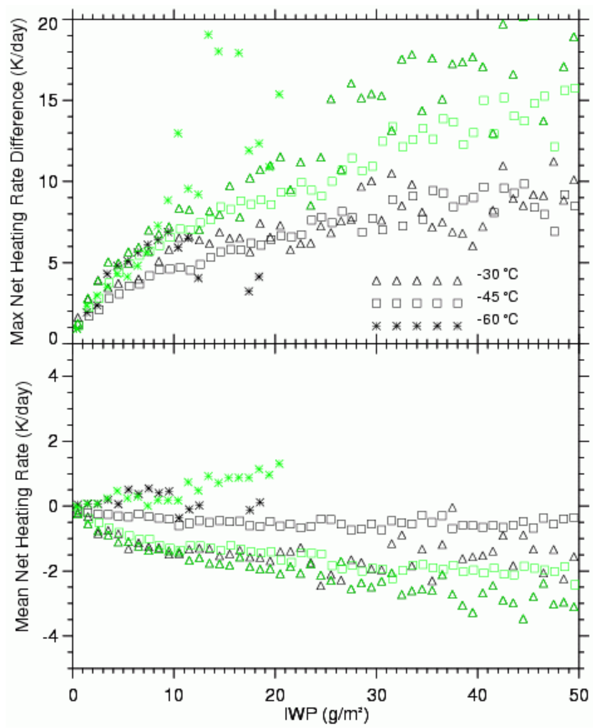


**Figure 6**. As in Figure 4, except for Net heating rates. Black symbols are for daytime and green symbols are for night time (zero solar heating rates).

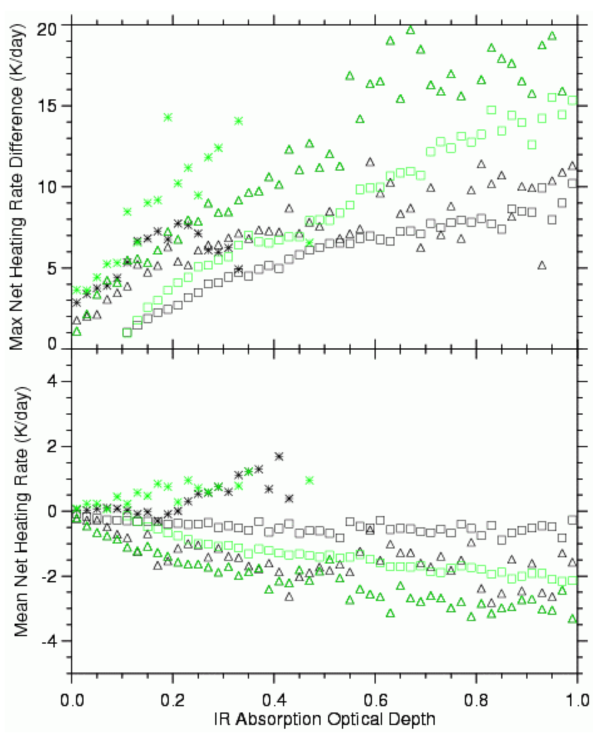


**Figure 7**. As in Figure 6, except for the dependency on IR absorption optical depth.

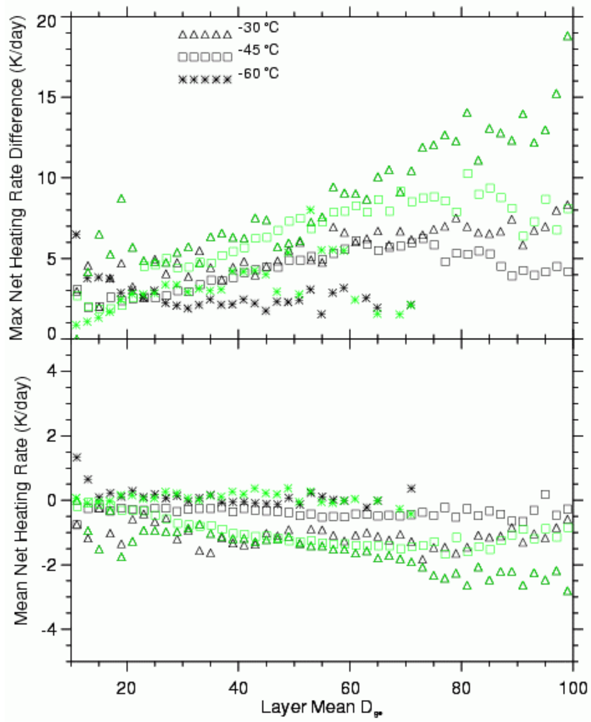


**Figure 8**. As in Figure 6, except for the dependency layer mean $D_{ge}$.

## Summary

1. Layer mean solar and IR heating rates are small for cirrus with low IWP (IWP <5 g/m$^2$), but the difference of heating rates in the cloud layer is up to 1 K/day.

2. Mean solar heating rates warm the clouds, and mean IR heating rates cool the clouds, except for cold cirrus clouds.

3. The layer mean heating rates and the maximum difference of heating rates in the cloud layer depend on the IWP.

4. The midcloud temperature dependencies are not very strong except for cirrus cloud layer.

5. The magnitude of the maximum difference within cloud layer is very significant compared to the layer mean heating rates. These radiative forcings may play an important role in regulating cirrus microphysical and radiative properties (Starr and Cox 1985).

6. There are significant differences in net heating rates between day and night, which are mainly caused by different effects of solar and IR radiation. These differences may be the result of differences in cirrus properties.

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