Computation of Domain-Averaged Irradiance with a Simple Two-Stream Radiative Transfer Model Including Vertical Cloud Property Correlations

S. Kato
Center for Atmospheric Sciences
Hampton University
Hampton, Virginia

Introduction

Recent development of remote sensing instruments by Atmospheric Radiation Measurement (ARM?) Program provides information of spatial and temporal variability of cloud structures. However it is not clear what cloud properties are required to express complicated cloud fields in a realistic way and how to use them in a relatively simple one-dimensional (1D) radiative transfer model to compute the domain averaged irradiance. To address this issue, a simple shortwave radiative transfer model that can treat the vertical cloud optical property correlation is developed. The model is based on the gamma-weighted two-stream approximation (Barker 1996). It separates the domain into clear and cloudy columns and computes radiation in the both columns (Kato 2003). The model can treat horizontally inhomogeneous overcast clouds as well as broken cloud fields with realistic cloud overlap feature. Inputs to the model are the vertical profile of cloud fraction, cumulative cloud fraction computed from the top of the atmosphere, and vertical profile of the conditional probability of cloud occurrence, which is the probability of the cloud occurrence in other computational layers provided that clouds are present at a given layer. The model is tested against a Monte Carlo model. A comparison shows that the model is capable to compute domain averaged irradiance of complicated cloud fields that are generated cloud resolving models.

Model Description

The earlier model (Kato 2003) assumes that random cloud overlap for clouds that are not directly illuminated by direct radiation. To account for the vertical correlation of clouds in the cloudy column, a variable expresses the vertical correlation C is introduced such that

$$C = \sum_{j=1}^{i=1} \eta_{ij} \frac{\bar{\tau}_j}{\bar{\tau}_i},$$

where $\bar{\tau}_i$ and $\bar{\tau}_j$ is the mean optical thickness of *i*th and *j*th layer, respectively. The layer with *j* = 1 is at the top of the atmosphere and the index increases with decreasing the altitude. The coefficient η is

$$\eta_{ij} = \sum_{j=1}^{i} \left[P(z_j \middle| z_i) - A_j \right],$$

where $P(z_j | z_i)$ is the probability of cloud occurrence in the *j*th layer when clouds are present in the *i*th layer and A is the cloud fraction. The difference $P(z_j | z_i) - A_j$ is, therefore, the departure of the cloud overlap probability between *j*th and *i*th layers from that of the random overlap.

It is then assumed that the domain averaged irradiance $\overline{F}$ at the bottom of two layers is

$$\overline{F} = \left(1 + \frac{C_{\overline{\tau}_u}}{\nu \mu_0} \right) \int_0^\infty P(\tau; \overline{\tau}, \nu) \exp(-C_\tau / \mu_0) F d_\tau,$$

where P is a gamma distribution expressing the distribution of optical thickness, ν is a shape parameter of the distribution and subscript *u* indicating the upper layer.

Results

Cloud fields used for intercomparison of radiation codes in Climate Models Phase III (Barker et al. 2003) were used to test the algorithm. The cloud fraction, optical thickness, and value of C for the one case are shown in Figure 1 and Figure 2. The above algorithm is included in the algorithm given by Kato (2003). The correlation of cloud properties is considered in computing the direct irradiance, diffuse irradiance, and both. Computed heating rates indicate that the agreement with Monte Carlo results is better than the plane parallel random overlap approximation (Figures 3 and 4). However, including the correlation in computing both direct and diffuse irradiances does not necessarily improve the result compared with the heating rate computed using the correlation in computing either the direct or diffuse irradiance. This indicates that improvement of irradiance profile computations depends on cloud type.

Conclusions

1. While C expressing the vertical correlation of cloud position depends on cloud type, using the coefficient improves radiation computation for deep convective type clouds.

2. Because the coefficient C can be derived from observed cloud fields, it can express a realistic cloud fields using cloud fraction and cumulative cloud fraction in computing domain averaged irradiance by a 1D radiative transfer model.

3. Improvement of irradiance profile using C depends on cloud type.

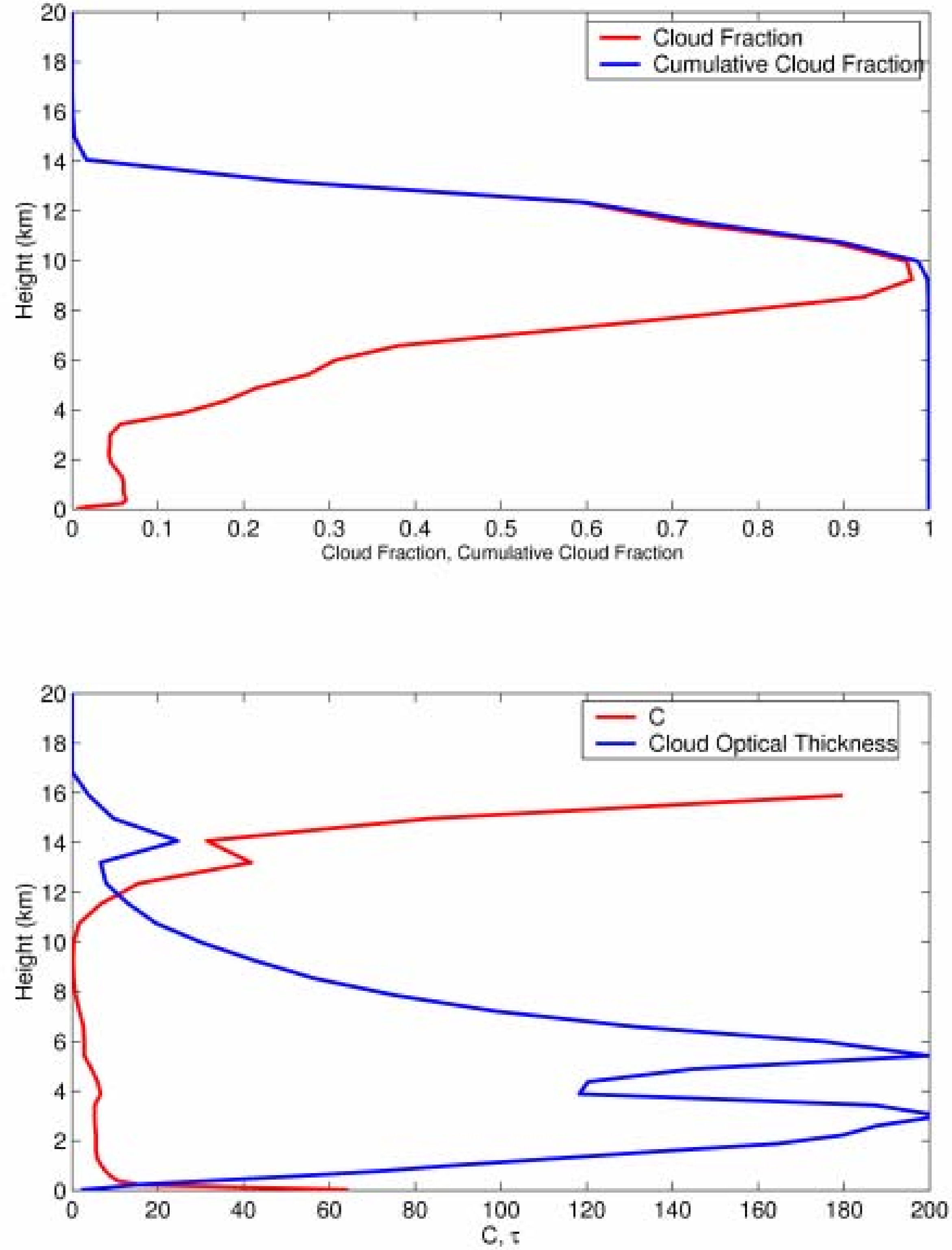

Figure 1. Vertical profile of the cloud fraction (top), optical thickness, $P(z_j | z_i)$, and $P(z_j | z_i) - A_i$ (bottom) for GATE B case.

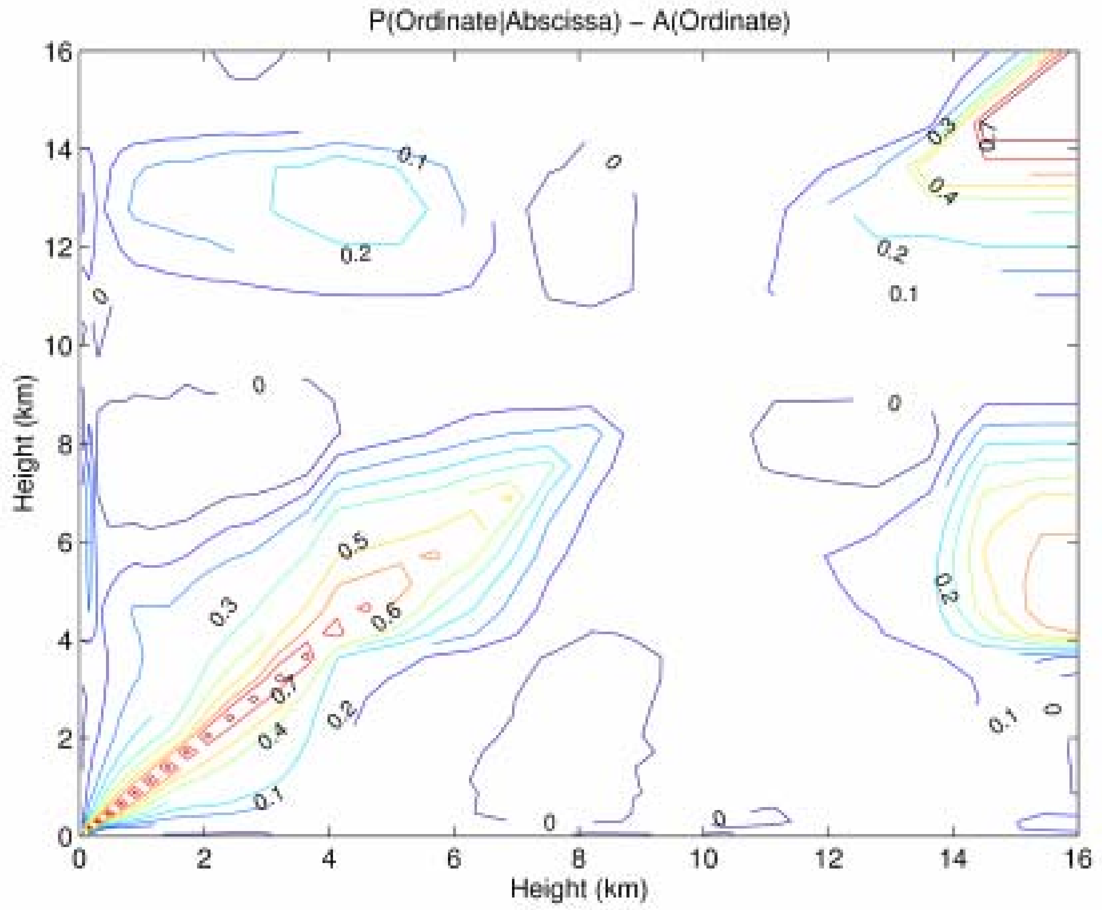

Figure 2. Value of $P(z_j | z_i) - A_j$ for GATE B case.

Corresponding Author

Seiji Kato, s.kato@larc.nasa.gov, (757) 864-7062

References

Barker, H. W., 1996: A parameterization for computing grid-averaged solar fluxes for inhomogeneous marine boundary layer clouds. Part I: Methodology and Homogeneous Biases. *J. Atmos. Sci*., **53**, 2289-2303.

Barker, H. W., et al., 2003: Assessing 1D atmospheric solar radiative transfer models: Intercomparison and Handling of Unresolved Clouds. *J. Climate*, in press.

Kato, S., 2003: Computation of domain-averaged shortwave irradiance by a one-dimensional algorithm incorporating correlations between optical thickness and direct incident radiation. *J. Atmos. Sci*., **60**, 182-193.

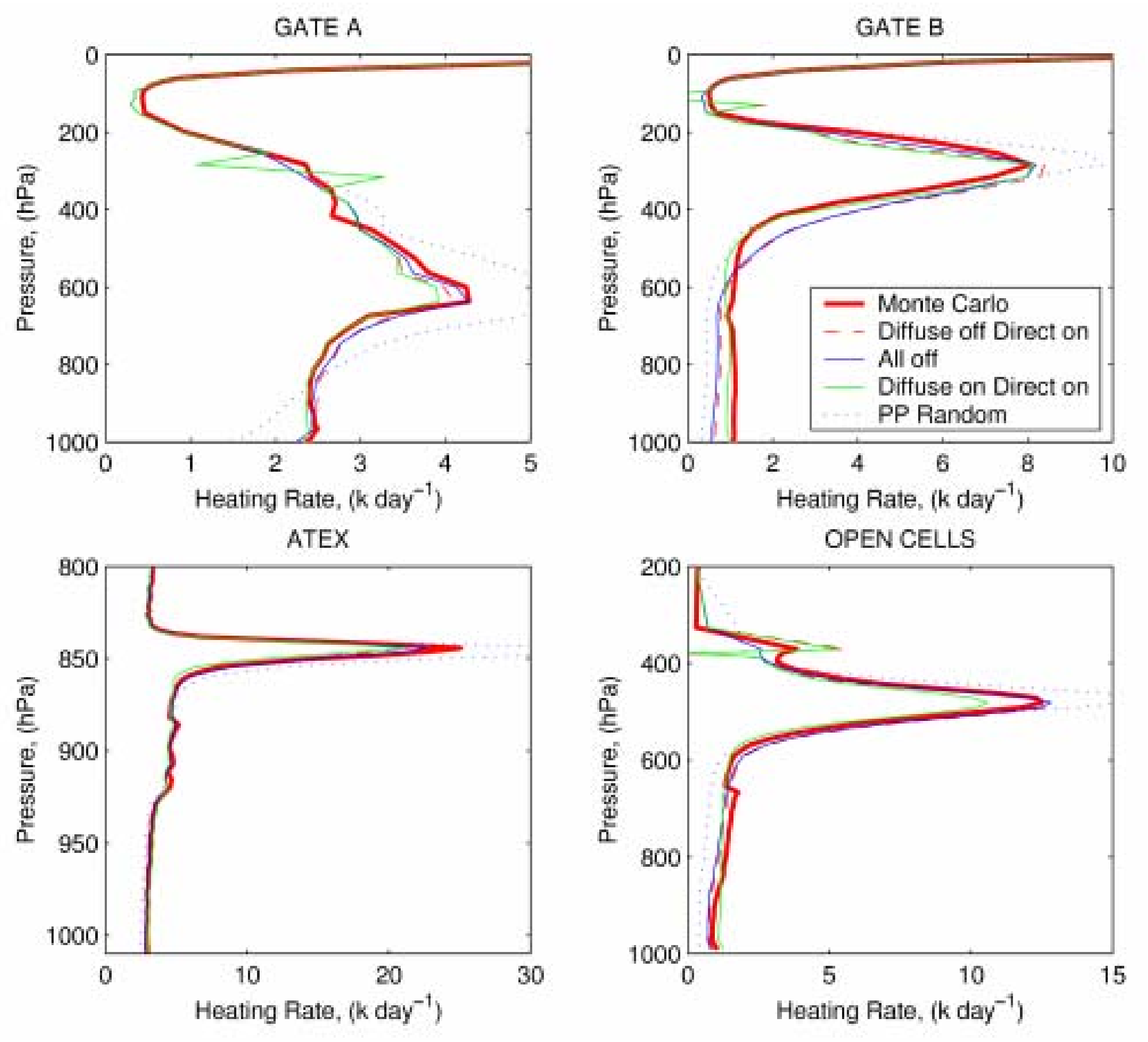

Figure 3. Heating rate profile at the solar zenith angle of 0 degree.

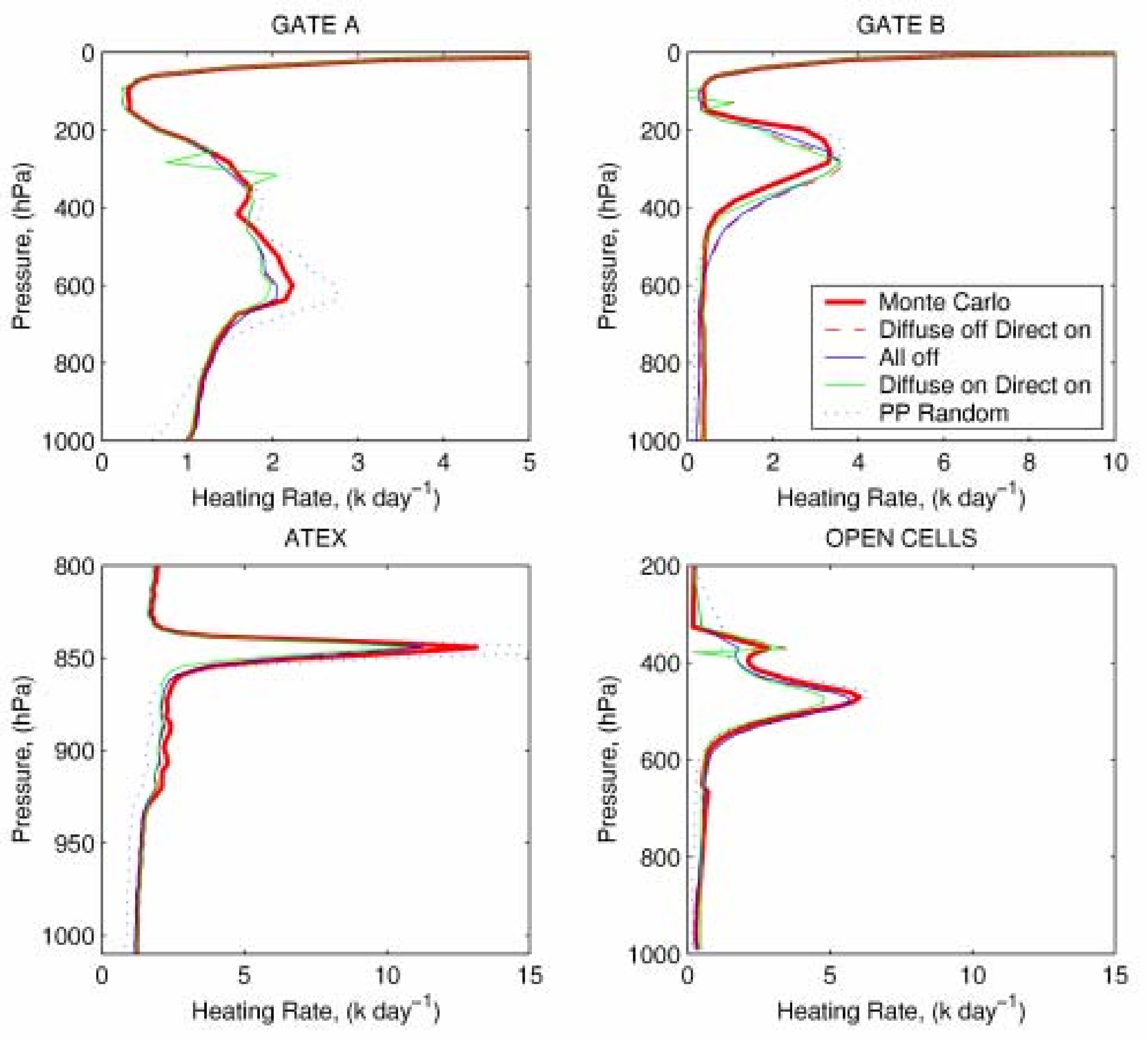

Figure 4. Heating rate profile at the solar zenith angle of 60 degree.