P2.6 INVESTIGATION OF SHORTWAVE RADIATIVE TRANSFER AT THE ARM CART SITES USING A MULTIPLE LAYER STOCHASTIC MODEL

Dana E. Veron*, Jaclyn Secora and Michael Foster

Rutgers University, Department of Environmental Sciences

1. INTRODUCTION

A stochastic cloud-radiation model has been shown to do a good job of representing the domain-averaged shortwave fluxes when evaluated using observations. One year of continuously sampled cloud property observations from all three Atmospheric Radiation Measurement (ARM) Program's Cloud and Radiation Testbed (CART) sites (Southern Great Plains, Tropical Western Pacific, and North Slope of Alaska) are analyzed and then input into the model on an hourly basis. We compare the output from the multiple cloud layer stochastic model to that of the single-cloud layer version of the model previously used. The output radiation fields will be evaluated using plane parallel model output and independent observations. These results will form the basis for a shortwave cloud-radiation parameterization that will incorporate the influence of the stochastic approach on the calculated radiative fluxes. Initial results utilizing the stochastic approach in a single-column model will be shown.

2. DATA

Previously, a novel method for investigating cloud spatial and physical properties using ground-based observations was presented (Lane et al., 2002). We use continuously sampled data from the Atmospheric Radiation Measurement Program (Stokes and Schwartz, 1994) to study both the physical and geometric characteristics of the cloud fields over all three research sites, the Southern Great Plains (SGP), Tropical Western Pacific (TWP) and the North Slope of Alaska (NSA). An in-depth discussion of the analysis for all three sites during the one year period of January through December 2000 has been presented in a previous study (Lane-Veron and Secora, 2004), and will be summarized below. The characteristic cloud base height, cloud thickness, cloud fraction, cloud size, effective radius and optical depth have been analyzed and when possible, compared to other available measurements (not shown). The data analysis will focus on providing the stochastic model with information similar to that calculated in an Atmospheric General Circulation Model.

* *Corresponding author address:* Dana E. Veron, Rutgers, The State University of New Jersey, Department of Environmental Sciences, 14 College Farm Road, New Brunswick, NJ 08901-8551; Veron@envsci.rutgers.edu

2.1 *Cloud Base Height*

Every cloud and radiation parameterization uses cloud base height (CBH) to indicate the vertical position of clouds. Figure 1 shows and overview of our analysis of the observed CBH field at the 3 ARM sites during 2000. The data is taken from the Belfort Laser Ceilometer, which has high spatial resolution as compared to a lidar, but is unable to observe higher clouds, such as cirrus. The histograms in Figure 1 show the variability of CBH over the whole year, and that the NSA and TWP sites tend to have cloud bases lower than 500 meters. Below, monthly mean CBH is shown. The NSA site has the lowest clouds most of the year and the SGP site has the most variable cloud base height field.

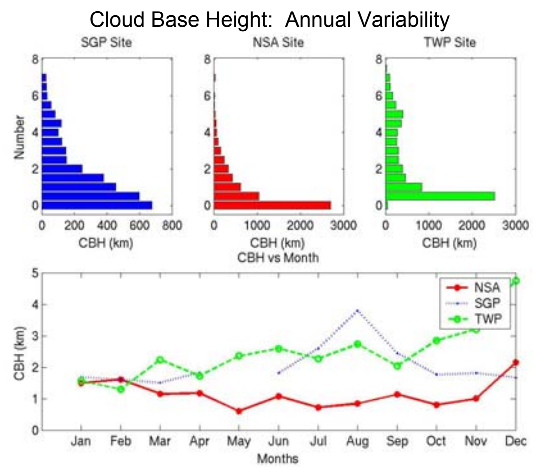

Figure 1. Histograms of cloud base height at each ARM CART site (top) and monthly mean cloud base height (bottom) during the year 2000

2.2 *Effective Radius*

The stochastic model calculates a volume optical depth using information about cloud thickness, horizontal extent, liquid water path and the droplet effective radii (r_{eff}). The Dong et al., 1997 retrieval is used to calculate r_{eff}. Figure 2 shows histograms of r_{eff} at all three sites and, below, the monthly mean values. The r_{eff} at the NSA site tends to be the largest of all three sites in the winter/spring (January-April) and the smallest in the late summer (July-September). The TWP site tends to have a consistent r_{eff} close to 5μm throughout the year.

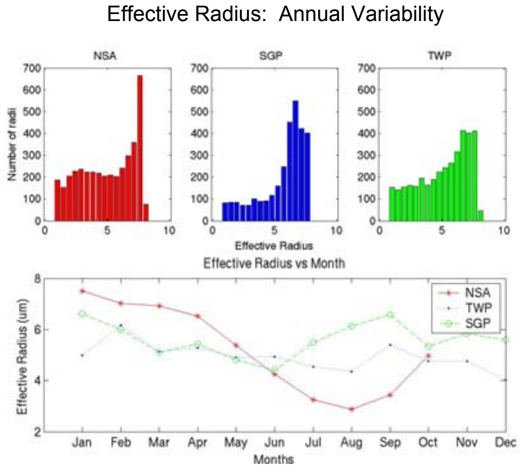

Figure 2. Histograms of effective radius at each ARM CART site (top) and monthly mean effective radius (bottom) during the year 2000

2.3 *Chord Length*

The stochastic model represents the geometry of the cloud field through a probability distribution of chord lengths. The chord length is computed by combining the wind speed at the height of an observed cloud and the amount of time the cloud is overhead to yield information about the cloud size. As seen in Figure 3, the chord lengths at the SGP site are more variable than those at the other two sites. The TWP and NSA sites tend to have small clouds, often less than about 200 meters.

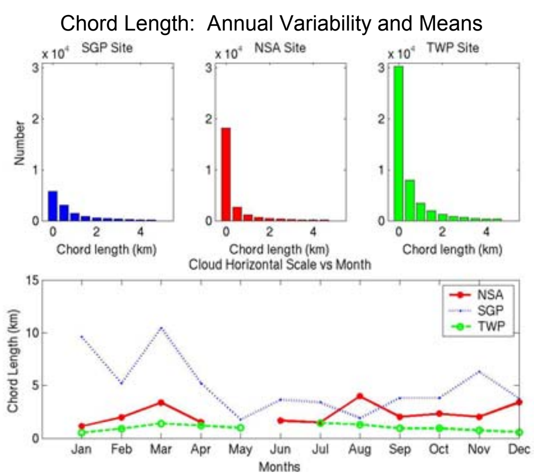

Figure 3. Histograms of chord length at each ARM CART site (top) and monthly mean chord length (bottom) during the year 2000

3. MODELS

The observations described above are provided on an hourly basis to a single layer and multiple layer stochastic shortwave radiative transfer model. The resulting domain-averaged downwelling radiation is compared and evaluated against observations to determine the utility of the stochastic approach. Model runs are performed hourly for all three sites for all of 2000.

3.1 *Stochastic Model*

The stochastic model (Byrne et al. 1996) used in this study is comprised of a spectral radiative transfer model based on the exponential–sum fitting scheme of Wiscombe and Evans (1977) and a model atmosphere. There are 38 unequally spaced spectral bands, which range in wavenumber from 2500 cm^{-1} to 50000 cm^{-1}. Each band contains up to two absorbing gases, primarily water vapor and ozone, although carbon dioxide and molecular oxygen are also used.

The model is initialized with profiles of pressure, temperature, moisture, carbon dioxide and ozone taken from McClatchey's climatological values (McClatchey et al. 1972) for the appropriate season. The model atmosphere is divided into 32 layers, with a reflective surface. The model is applied to an area of approximately 250-km by 250-km, roughly equivalent to each of the CART sites (Lane-Veron and Somerville, 2004).

For this study, Markovian statistics for a mixture of cloud and clear sky are used. The distribution of each material is described by the chord lengths that are randomly selected from predetermined chord-length distributions – in this case distributions that were determined from observations as described in section 2.3. The cloudy material differs from clear sky in the liquid water content, and radiative properties. In general, the clouds occupy a fractional volume of the model layer. It is possible to have multiple layers of clouds, but there is no correlation in placement of the clouds between layers.

The stochastic model is not appropriate for all cloudy situations. It is expected that the stochastic model will have the greatest influence when the cloud size is similar to the scale of a photon mean free path. Therefore, an important step in this process will be determination of when a stochastic cloud and radiation parameterization is appropriate, and how to identify these situations in an AGCM environment. The single-column model (see below) will be used to make this determination

3.2 *Single-column model*

The single-column model (SCM) developed at the Scripps Institution of Oceanography by Iacobellis and Somerville (1991 a,b) is employed to investigate the influence of the stochastic cloud-radiation routine on the atmospheric heating rates. The single-column model can be envisioned as one column of an atmospheric general circulation model and is used as a testbed for cloud-radiation parameterizations (Randall et al. 1996). The SCM is an appropriate environment for this development as it currently contains the fractional cloud cover model used in most modern AGCMs and will provide the same information about the state of the atmosphere to the new parameterization that an AGCM would. The SCM requires a set of initial values of prognostic variables such as temperature and humidity which are provided from an analysis of observations from the Southern Great Plains ARM CART site. The SCM, as used in this study, contains a complete set of parameterizations that is typical of contemporary AGCMs.

4. RESULTS

We present results for two runs of the stochastic model, one on the single layer version and another on the multiple layer version. The single layer stochastic radiative transfer model only accounts for one layer of clouds in the atmosphere. We use the cloud information for the bottom-most layer of clouds. The multiple layer version of the model can account for up to three layer of clouds.

Figure 4 shows a comparison between the single layer model and multiple layer model as compared to observations of down-welling solar radiation (DWSR) for fall (September, October, November) 2004. At the NSA and TWP sites, the multiple layer model does a better job of reproducing DWSR. At the SGP site, the single layer model does a better job.

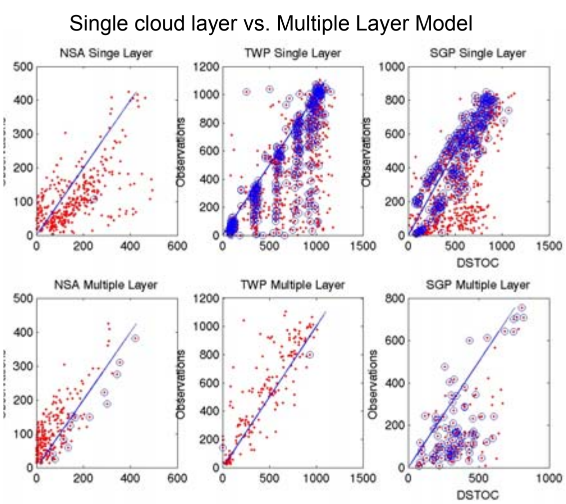

Figure 4. Single Layer Stochastic model vs Observations at each of the three ARM CART sites (top) and Multiple Layer Model vs Observations (bottom). Figures shown are from Fall 2000.

Preliminary studies have shown that frequently, the SCM either calculates clear sky or a large cloud fraction with extremely small optical depth when low-level broken cloud fields are present. To expand on this result, the single-column model is run at all three CART sites for the year 2000. The SCM is spun up for 12 hours and then run 24 hours. Then the start time of the model is shifted by six hours and the process begun again. All model results are an average of 4 SCM runs. For this study, the SCM is run with the Fouquart and Bonnel (1980) shortwave radiation routine. Initially, the SCM is allowed to predict cloud properties. Then the cloud properties described in section 2 are introduced into the SCM on an hourly basis. The resulting radiative fluxes at all model levels are compared to those of the stand-alone stochastic model. Surface fluxes are compared to observations. The solar heating rate from both models will be used to diagnose the impact of the stochastic radiation code would have on the SCM. Initial results indicate that the model clouds fields are very sensitive to the humidity forcing variables (not shown).

4. FUTURE WORK

Additional analysis of the stand-alone stochastic model results are necessary to ascertain why the single-layer stochastic model consistently performs better at the Southern Great Plains site, while the multilayer model, which is physically more realistic, performs better in the tropics and the polar regions. Cluster analysis is being explored as a method for determining objectively when stochastic radiative transfer is an improvement on current radiation schemes and when it is unnecessary.

Ultimately, the stochastic radiative transfer model will be coupled to the single-column model as a replacement for the current shortwave radiation parameterization. However, before this step is taken, the single-column model will be forced with the radiative fluxes determined during the offline stochastic runs with the multilayer model to investigate the possible impact of the stochastic approach on model dynamics.

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