P3.1 EVALUATING A STOCHASTIC SHORTWAVE RADIATION ROUTINE USING A SINGLE-COLUMN MODEL

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1. INTRODUCTION

The stochastic approach to modeling shortwave radiative transfer through a cloudy layer that has large-scale inhomogeneities in cloud properties (e.g., cloud size and spacing) allows for more physically real cloud scenes without huge computational expense. We are developing an empirical stochastic cloud-radiation parameterization from numerous stand-alone calculations that can be used in modern atmospheric general circulation models. The stand-alone model performs well in predicting downwelling shortwave fluxes at the surface when evaluated using independent observations for low, broken cloud fields have low liquid water paths and cloud fraction between 0.2 and 0.8. Results from coupling of the SIO single-column model with the stochastic model will be shown and compared with the new cloud-radiation parameterization.

2. SINGLE-COLUMN MODEL

The single-column model (SCM) developed at the Scripps Institution of Oceanography by Iacobellis and Somerville (1991 a,b) is used in this study to investigate the new stochastic cloud-radiation parameterization. The SCM has a similar horizontal domain as that of an AGCM grid cell, but the dynamic and radiative processes in the column do not feed back to the surrounding environment. This allows for detailed study of the physical processes occurring within the column, which makes the single-column model a good testbed for the evolving parameterization (Randall et al. 1996).

The SCM is a particularly appropriate environment for this development as it contains a fractional cloud cover model (Fouquart and Bonnel 1980) similar to that used in most modern AGCMs and will provide the same information about the state of the atmosphere to the new parameterization. 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 site. The SCM, as used in this study, contains a complete set of parameterizations that is typical of contemporary AGCMs.

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.

2.1 *Single-column model runs*

Initially, the SCM is run at the Atmospheric Radiation Measurement Program's (ARM; Stokes and Schwartz, 1994) Southern Great Plains (SGP) site for the year 2000 with the Tiedtke (1993) prognostic cloud scheme. The SCM was forced with observational data from the ARM SGP site, using the variational analysis technique of Zhang and Lin (1997) and Zhang et al. (2001). The SCM was run in ensemble mode with a run-length of 24-hours after an initial 12-hour spin-up period. The runs were performed at 6-hour intervals and then averaged together. This series of simulations is designated as the control.

The second set of simulations, again run in ensemble mode for the year 2000, is performed where most of the cloud properties such as cloud base height, cloud thickness, cloud fraction, liquid droplet effective radius, and liquid water path are taken from a cloud climatology developed from continuously sampled data from the ARM SGP site. Cloud spatial and physical properties are derived from ground-based observations following Lane et al. (2002). An in-depth discussion of the cloud property analysis for all three ARM Cloud and Radiation Testbed (CART) sites during the one-year period of January through December 2000 has been presented in a previous study (Veron and Secora, 2005).

Figure 1 compares the prognosed cloud fraction using the Tiedtke (1993) scheme and observed cloud fraction at the ARM SGP site for June 2000.

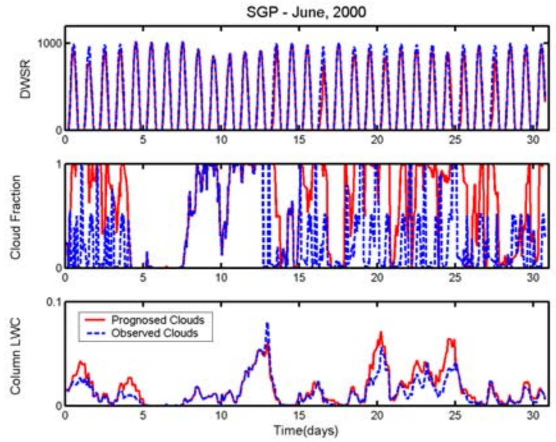

Figure 1. Comparison between single-column model runs using the Tiedtke (1993) cloud parameterization (dashed blue) and using observed values of cloud fraction, base height, droplet effective radius, and liquid water path (red) for a) downwelling shortwave at the surface b) cloud fraction and c) column liquid water content.

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In general the downwelling shortwave radiation at the surface calculated by the single-column model for each series of runs agrees fairly well. It can be seen in Figure 1b that the prognostic cloud scheme often produces larger cloud fraction than that observed by the Micropulse Lidar that was used in developing the cloud climatology (Veron and Secora, 2005). The liquid water content from the prognostic scheme is also higher than that observed. Figure 2 shows that the clouds that are calculated by the Tiedtke scheme are both too high and too persistent, leading to frequently overcast days. The stochastic model is not appropriate in overcast and very high liquid water content situations (Lane-Veron and Somerville, 2004).

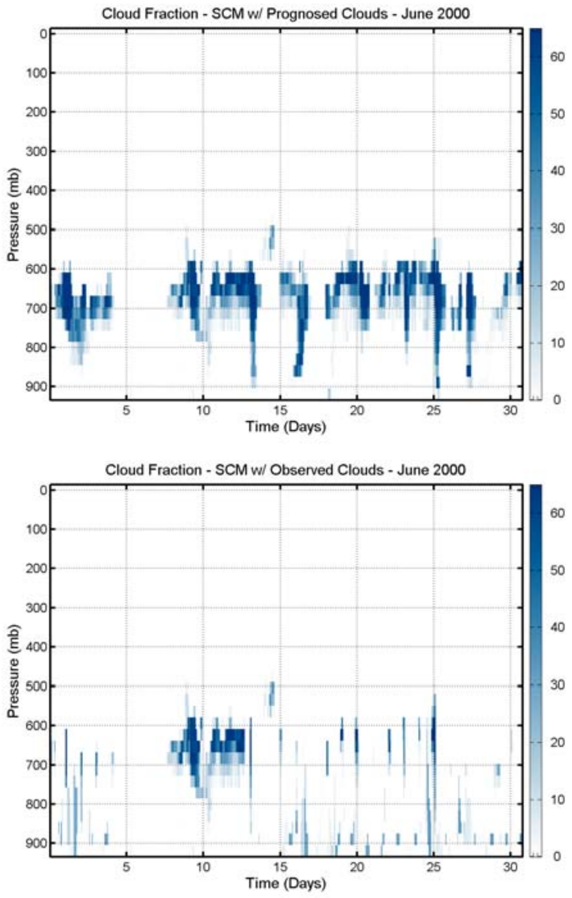

Figure 2. Contour plot of cloud fraction from SCM runs using prognosed clouds (above) and observed clouds (below). The cloudy period around day 10 is similar in both as there was a gap in the observations and so the computed cloud properties were used.

3. STOCHASTIC MODEL

The stochastic model (Byrne et al. 1996, Lane-Veron and Somerville, 2004) used in this study is an approximate radiative transfer model that uses Markovian statistics to describe the distribution of clouds in a AGCM grid cell. The model calculates the impact of this statistical cloud field on the domain-averaged, ensemble-averaged radiation field. 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 Veron and Secora (2005). In general, the clouds occupy a fractional volume of the model layer and differ from clear sky in the liquid water content and radiative properties. It is possible to have multiple layers of clouds, but there is no correlation in placement of the clouds between layers.

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 (Veron and Secora, 2005). The TWP and NSA sites tend to have small clouds, often less than 200 meters in horizontal extent.

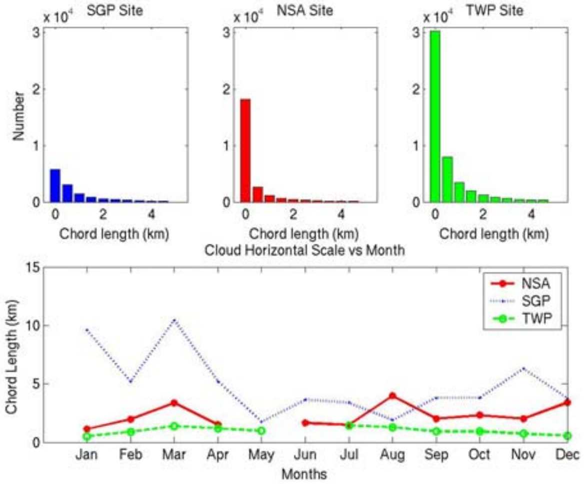

Figure 3. Annual distribution of cloud chord length as a function of location (top) and shown as a monthly mean (bottom).

3.1 *Stochastic Model Simulations*

The stochastic model has 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).

The cloud properties from the climatology (Veron and Secora 2005) provided on an hourly basis to a multiple layer stochastic shortwave radiative transfer model for all of 2000. The resulting domain-averaged downwelling radiation is evaluated against observations to determine the utility of the stochastic approach. An additional set of simulations are performed where the cloud properties from the Tiedke (1993) parameterization are provided as input to the stochastic model. As the SCM does not currently calculate chord length, the observed chord lengths are used for both sets of simulations.

Figure 4 shows the downwelling shortwave radiation predicted by the stochastic model plotted against observations for the NSA site for all of 2000. The color-coding indicates the amount of liquid water path measured by the microwave radiometer. Note that the stochastic model performs best when the liquid water paths are low, such as when broken clouds or mixed-phase clouds are present.

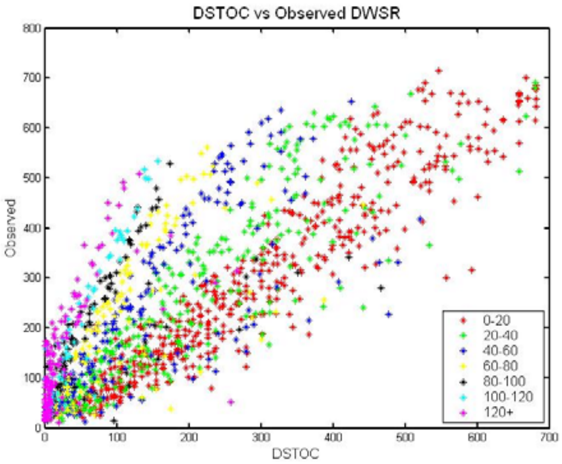

Figure 4. Scatter plot of downwelling shortwave radiation at the surface predicated by the stand-alone stochastic model versus independent observations at the ARM North Slope of Alaska site for the year 2000.

Similar comparisons have been done at the other ARM CART sites as well. The stochastic model performs best when the cloud fraction is less than 70% (not shown).

3.2 *Coupled Model Runs*

The stochastic shortwave radiative transfer model has now been coupled to the single-column model in place of the shortwave cloud-radiation parameterization. The coupled model runs provide insight into the impact of the stochastic approach on the single-column model dynamics, especially on the shortwave heating rates. However, the coupled model simulations require too much computational time to be considered for use in an AGCM. Therefore the results of these simulations have been characterized using cluster analysis for used in the new parameterization.

4. PARAMETERIZATION DEVELOPMENT

The stochastic cloud-radiation parameterization will functionally add a term to the standard plane-parallel shortwave radiation calculation that will be ignored in low cloud fraction (< 0.2) and high cloud fraction (>0.7) situations. The value of the term is dependent on dynamical situation and global location. For example, for situations where low-level, mid-fraction clouds occur, the stochastic term will decrease the amount of downwelling shortwave radiation reaching the surface relative to that predicted by the plane-parallel calculation alone (not shown).

5. FUTURE WORK

Further evaluation of the coupled SCM-stochastic model runs is required to refine the stochastic cloud-radiation parameterization. Additional testing of the parameterization is required in both the SCM and in an AGCM. Current research is underway using a regional scale model to investigate the link between large-scale dynamical fields and the sub-grid scale chord lengths required by the stochastic model (Veron et al., 2005). The ability of the stochastic model to represent mixed-phase clouds is also being investigated (Veron and Brodie, 2005).

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