P2.25 DEVELOPMENT OF A STOCHASTIC CLOUD-RADIATION PARAMETERIZATION

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1. INTRODUCTION

Scientists have long been aware that there is a need for a numerical description of radiative transfer through media with statistically distributed parameters (Stephens 1984, Ramanathan et al. 1989b, and Stephens et al. 1991). Stochastic radiative transfer modeling has recently been shown to be a promising approach to modeling the domain-averaged shortwave radiation fields that occur during scattered cloud conditions (Figure 1, Lane et al. 2002, Lane 2000, Lane and Somerville, 2003). The stochastic model distributes clouds in a clear sky according to the statistics of the cloud field and then calculates the ensemble-averaged radiation field.

A parameterization of the stochastic approach to modeling cloud-radiation interactions is being developed using archived data from the Atmospheric Radiation Measurement (ARM) Program's Clouds And Radiation Testbed (CART) sites. Cloud fields at the ARM Southern Great Plains site are characterized using long time-series data from the year 2000. Information about the cloud fields such as cloud height, thickness, and optical properties will be input to the stochastic model. The output shortwave radiation fields will be evaluated using observations. One benefit of the stochastic approach is the ability to calculate more realistic heating rates. The impact of these heating rates on model dynamics will be investigated using a single-column model.

2. DATA

In earlier studies, a novel method for investigating cloud spatial and physical properties using ground-based observations is presented. That research focused on low-level scattered clouds. In the current project, continuously sampled data from the Atmospheric Radiation Measurement Program (Stokes and Schwartz 1994) are used to study the physical and geometric characteristics of the cloud fields present over the Southern Great Plains site during one year. To date, information about the cloud field has been compiled for the three-month period from January to March. The characteristic cloud base height, cloud top height, cloud fraction, cloud liquid water path, cloud size and cloud spacing are assembled in histograms. The spatial characteristics will be compared with those obtained by other remote sensing techniques, and from *in situ* photographic analysis. The data analysis will focus on providing the stochastic model with information similar to that calculated in an Atmospheric General Circulation Model (AGCM).

The base height for each cloudy layer present during 2000 is taken from two sets of observations. The Belfort Laser Ceilometer (BLC) has high spatial resolution, but the laser is attenuated fairly low in the atmosphere (~12 km). The BLC cloud base heights are binned in 100-meter increments, and the number frequency of reported base heights are shown in Figure 2. This value differs from the actual number of clouds present as the height of a single cloud may be measured more than once as it passes overhead. Additionally, the instrument does not sample the cloud field during the processing cycle. Cloud base height measurements are also taken from the Micropulse Lidar (MPL). Although the lidar has poorer height resolution, it is capable of observing high clouds such as cirrus. The two datasets are compared (not shown) and information from both will be used as input to the models described in section 3.

The MPL can also be used to determine a one-dimensional fraction by calculating the percentage of time that a cloud was detected relative to the entire time sampled. Hourly averages of cloud fraction are compiled in histograms from this time series (Fig. 3). It can be seen that on an hourly basis, completely overcast conditions are the most frequent when cloud is present. In the first three months of 2000, the average cloud fraction was 0.64. January and March were cloudy about 75% of the time while in February clear sky was present 66% of the time. In a previous study, several instruments, including the BLC, the Micropulse Lidar, Multifilter Rotating Shadowband Radiometer (MFRSR), and human observer reports of cloud fraction were compared. In all cases, the cloud fraction determined from measurements was less than the estimated cloud fraction from the observer. This difference in overhead and all-sky fraction has been reported by Bretherton et al. (1995).

The wind speed measured at the ARM SGP site is combined with the cloud base height information to give an indication of the size of the overhead clouds. The MFRSR, a narrow field-of-view radiometer, is used to calculate how long the direct normal beam is blocked by a cloud. Multiplying the time the sun was obscured by the wind speed at the base-height of the cloud yields information about the cloud size. The ~8°

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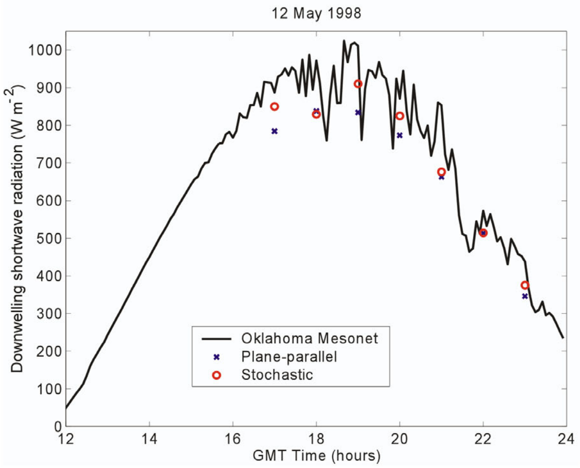

Fig. 1 Results from initial study showing performance of stochastic model versus a typical plane-parallel model and observations.

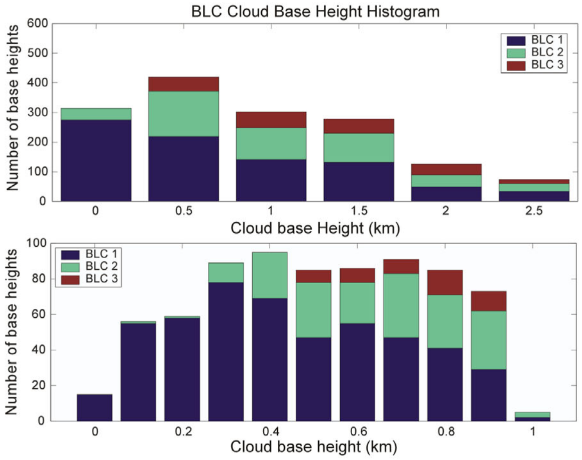

Fig. 2 Cloud base height histograms for the entire range detected by the BLC and for the bottom kilometer. The peak height in the first cloudy layer occurs around 300 m, while for the second cloudy layer the peak occurs near 400 m.

field-of-view traces a path, or chord, from the leading edge to the trailing edge of the cloud (Figure 4). At a characteristic height of 800 m, the aperture radius is 57 m (Iqbal 1983).

The data is normalized by the most proximate clear day signal, to determine a transmission ratio. The transmission ratio threshold is chosen to identify cloudy segments of the signal, with an average threshold of 0.9. The resulting cloud chords are compiled in a probability frequency distribution. Previous results indicate that the statistics gathered at the Central Facility are well correlated (with a phase shift) over the rest of the facility. This result suggests that averaging a single station over long time-periods yield similar results to averaging over multiple horizontally distributed stations for shorter times. It is, therefore, possible to obtain robust statistics describing the cloud field from point measurements given enough time.

3. MODELS

3.1 *Stochastic Model*

Stochastic radiative transfer theory is derived from linear kinetic theory and utilizes the line-statistics. The description of the cloudy atmosphere is statistical (Malvagi et al. 1993). For this study, we employ statistics for a mixture of cloud and clear sky. The distribution of each material is described by the chord lengths that are randomly selected from predetermined chord- length distributions. In this case, the chord lengths are determined from observations as indicated above, but the shape of the distribution is assumed to be Markovian. The cloudy material differs from clear sky in the liquid water content, and radiative properties. The probability distribution function that dictates the apportioning of cloud is constant throughout the layer. 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 (Byrne et al. 1996) is comprised of a spectral radiative transfer model and a model atmosphere. The spectral band model is based on the exponential–sum fitting scheme of Wiscombe and Evans (1977). The current version of the stochastic model has 38 unequally spaced spectral bands, which range in wavenumber from 2500 cm^{-1} to 50000 cm^{-1}. In each band up to two absorbing gases are allowed, depending on the wavelength. The two prime absorbers are water vapor and ozone, although carbon dioxide and molecular oxygen are included as well.

In order to calculate the radiative transfer in a realistic atmosphere, the model is initialized with profiles of pressure, temperature, moisture, carbon dioxide and ozone. In previous work, the profiles were taken from McClatchey's climatological values (McClatchey et al. 1972) for midlatitude summer. In the current project, the atmospheric profiles will be taken from the single-column model described below. The stochastic model atmosphere is currently divided into 32 layers, with a reflective surface, but no surface parameterizations. The model is applied to an area of approximately 250-km by 250-km. The cloud field characteristics that are pertinent to the calculation of spectral transmittance, such as cloud base height, cloud top height, cloud water amount, effective radius and cloud fraction are taken from the SGP observations and ingest on an hourly basis.

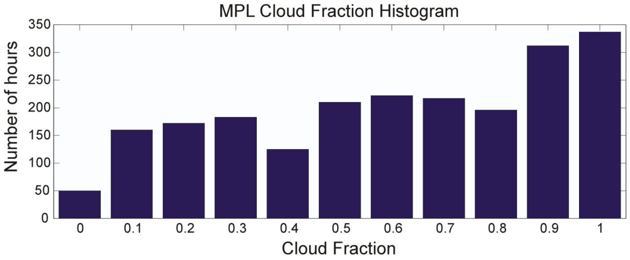

Fig. 3 Cloud fraction histograms from MPL data. The peak in the distribution is for overcast skies when clouds occur.

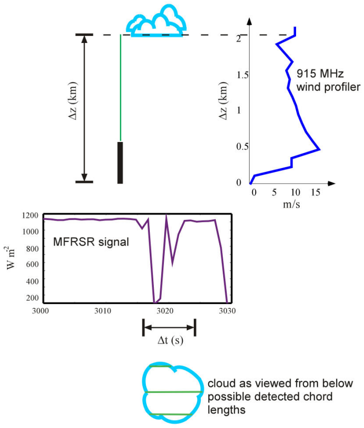

Fig. 4 Schematic illustrating the use of multiple instruments to determine a horizontal cloud scale and cloud spacing.

A discrete-ordinate method is used to solve the radiative transfer equation, with an approximate iterative technique. The model outputs the spectral and broadband intensity averaged over an ensemble of cloudy scenes. The result is not specific to a single location within the grid. In addition, pathlength information for both clear and cloudy sky is computed.

3.1 *Single-column Model*

The single-column model (SCM) developed at the Scripps Institution of Oceanography by Iacobellis and Somerville (1991 a,b) will be used in this study 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. The SCM requires a set of initial values of prognostic variables such as temperature and humidity. The time-dependent output of the SCM includes profiles of moisture and temperature, clouds, cloud-radiative properties, diabatic heating terms, surface energy balance terms, and hydrologic cycle components. The SCM, as used in this study, contains a complete set of parameterizations that is typical of contemporary AGCMs. 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 feedback to the surrounding environment. This allows for detailed study of the physical processes occurring within the column. 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. This information will be more limited than the observational dataset used for the preliminary development of this algorithm.

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 will be used to make this determination as being employed as a testbed for the evolving parameterization. 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. For example, on 12 May 1998 there is a broken cloud field present for several hours (see Figure 1). The SCM does produce some cloud on (Figure 5), however the predicted optical depth of the cloud is so small that it is ignored in the shortwave radiation calculation (Figure 6). This is an example of when the stochastic representation of the cloud field might improve the realism of the SCM.

For this preliminary study, the SCM is run with the Fouquart and Bonnel (1980) shortwave radiation routine. This is the same plane-parallel model that was run in stand-alone mode for comparison to the stochastic model previously. The first stage of the comparison will be providing the single-column model with the same hourly cloud field characteristics as those that were observed during 2000. The solar heating rate from both models will be used to diagnose the impact of the stochastic radiation code would have on the SCM. The next step will be to ingest the output radiation fields along with the cloud fields into the SCM. The final step will be to try to couple the two models.

4. CONCLUSIONS

Initial comparisons of the stochastic model with a typical two-stream shortwave model indicated that stochastic shortwave radiative transfer theory is a promising approach for representing the influence of macroscale cloud field structure on the radiation. The stochastic technique is now being extended as a parameterization that would be incorporated in a current AGCM.

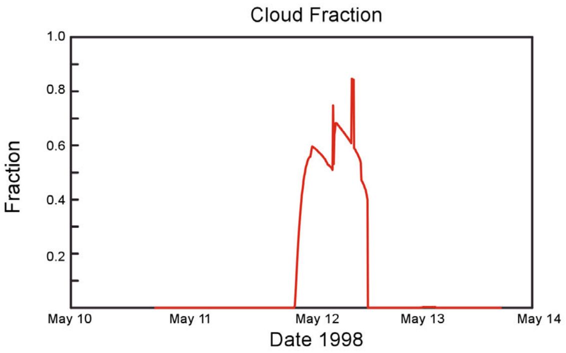

Fig. 5 Prognostic cloud fraction produced by the single-column model for 12 May 1998. Scattered cloud cover was observed for several hours before and after solar noon.

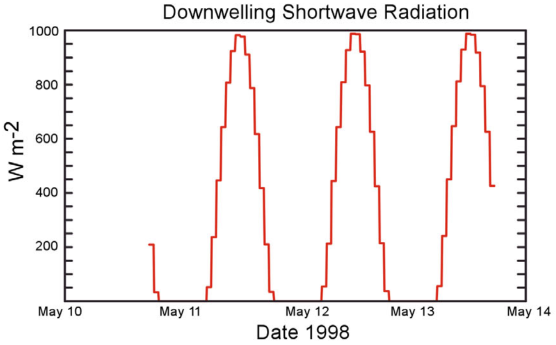

Fig. 6 Downwelling shortwave radiation calculated by the single-column model for 12 May 1998. Even though the model produces a cloud fraction, the optical depth is so small that the SCM ignores it in the radiative transfer calculation.

Extension of the parameterization to one appropriate for a global model can be achieved in part by incorporating the North Slopes of Alaska and the Tropical Western Pacific CART sites. The equatorial pacific has long time periods when broken clouds are prevalent, and the improvement in the modeled radiation field due to the stochastic approach may be more significant for this area than at the SGP site. The arctic site frequently has stratus and cirrus occurring in layers, with macroscale variability occurring in one or multiple layers. As the parameterization develops longer time periods, such as a year, will be utilized. Additionally, the stochastic model will be modified to incorporate modern ice parameterizations and cloud overlap, so that all cloud types and conditions may be included in the project.

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