Linking Cloud-Radiation Parameterization Performance to Large-Scale Dynamics

D.E. Veron
College of Marine Studies, University of Delaware
Newark, Delaware

M. Foster
Rutgers, The State University of New Jersey
New Brunswick, New Jersey

Abstract

Parameterization of cloud-radiation interactions in an atmospheric general circulation model using a stochastic approach allows for a statistical representation of cloud field geometry. Previous work indicates that the stochastic approach to cloud-radiation parameterization performs better than typical plane-parallel algorithms in situations where the horizontal cloud fraction is between 0.2 and 0.8. However, this does not completely describe the physical situations when a stochastic approach to modeling cloud-radiation interactions is appropriate. Cluster analysis has been applied to data of the atmospheric state, cloud physical, and dynamical characteristics, and radiative transfer model results to determine the situations in which an atmospheric general circulation model would make best use of a stochastic cloud-radiation parameterization. Preliminary results from the ARM Climate Research Facility (ACRF) Tropical Western Pacific (TWP) locale indicate that situations involving deep convection may benefit the most from a stochastic approach.

Introduction

A cloud climatology has been developed at all three ACRF locales (Ackerman and Stokes 2003) using continuously sampled, ground-based observations from the year 2000 (Veron and Secora 2006). This data set was developed in preparation for running a stand-alone stochastic radiative transfer model (Lane et al. 2002; Lane-Veron and Somerville 2004) for all daylight cloudy hours. The climatology was developed using observations of cloud base height, cloud thickness, cloud horizontal scale, cloud fraction, droplet effective radius, and cloud optical depth. Results from these annual runs have been used to develop a stochastic corrective term that can be applied in most plane-parallel atmospheric general circulation models (AGCM; Veron et al. 2006).

One key to the successful application of a stochastic cloud-radiation parameterization in an AGCM is an objective determination of when the influence of cloud geometry on the radiation field should be accounted for and when it should be ignored. Simple comparisons of model output and dynamical variables have given us some insight into this process. For example, initial comparisons have indicated that the stochastic approach is most appropriate with cloud fraction less than 0.8. Although the stochastic model performs well in very low cloud fraction situation (e.g. < 0.2), it is not worth the additional computational expense in comparison to a modern plane-parallel cloud-radiation routine. In addition, the performance of the stochastic parameterization is sensitive to the geometrical thickness of model clouds, as well as the amount of liquid water present (Veron and Secora 2006). However, these simple comparisons do not yield insight to which dynamical situations in an AGCM would produce cloud fields that would require the use of a stochastic cloud-radiation parameterization. For this purpose, cluster analysis (e.g. Jakob et al. 2005; Gordon et al. 2005) is being explored as an objective tool for determination of appropriate use of a stochastic cloud-radiation parameterization.

Development of Clusters

One way to improve our understanding of the stochastic approach to cloud-radiation modeling is to separate the range of observed cloud fields into dynamical regimes and look at individual regime properties. However, since the stochastic approach is going to be applied as a parameterization to model cloud fields from an AGCM, it is important that this division be made objectively. Several trial cluster sets have been developed using the K-MEANS algorithm (Anderson 1973; Jakob and Tselioudis 2003) with data from the aforementioned Southern Great Plains (SGP) cloud climatology. This approach follows previous work done by Jakob et al. (2005) and Gordon et al. (2005). The clusters are derived from 3-hourly histograms that are built on 15-minute average observations of cloud fraction, cloud base height and liquid water path from the central facility and the four boundary facilities. The data are grouped into ten cloud base height and ten liquid water path bins. Our analysis is restricted to histograms, which contain four or more members.

The 3-hourly data for the year 2000 are grouped into four cloud regimes by applying the k-means clustering algorithm to mean cloud fraction, cloud base height and cloud liquid water content for the SGP site. Figure 1 shows the frequency distributions as a function of cloud base height and cloud liquid water path. Times without cloud were eliminated from the clusters. Values of cloud fraction, cloud base height, and cloud liquid water content were all converted to a scale varying linearly from 0 to 1. The frequency of the cluster occurrence is equal to the number of elements in a cluster divided by the total number of elements. Four clusters were chosen because that appeared to be the maximum number of clusters with distinct cloud properties.

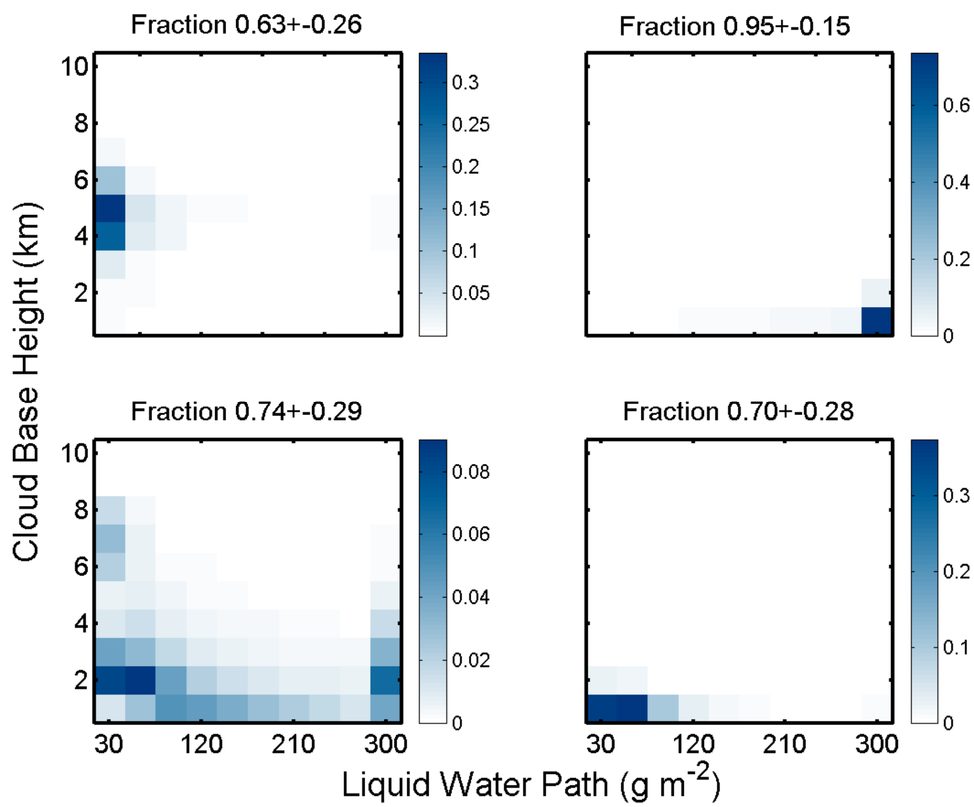

Figure 1. Frequency distribution of cloud base height versus cloud liquid water path for each of the four clusters.

Table 1 indicates the cluster centroids for the entire data set (year 2000, for all five stations). Conditions with completely clear sky occurred 70% of the year and were not included in this analysis. The last two columns in the table indicate some additional cloud properties for the clusters. Cluster 1 is composed of mid-level, low-water clouds (alto-stratus1); Cluster 2 (overcast) contains geometrically and optically thick clouds with very high cloud fractions. Cluster 3 (mixed) contains a mixture of high-level clouds, probably cirrus, along with a range of low-level clouds with varying cloud water contents. Cluster 4 contains a mix of low- to mid-level clouds with relatively large optical thickness. However, additional dynamical information will be brought to bear on the data sets for better identification of the regimes.

Table 1. Mean properties by cluster number. The last two columns are cloud properties not used in the cluster analysis.

Cluster #	Mean LWP (g m-2)	Fraction (%)	Mean CBH (km)	Mean CTH (km)	Mean Tau
1	35	63	4.128	5.789	6.615
2	504	95	0.51	3.4905	29.6187
3	149	74	2.07	3.6909	16.9212
4	49	70	0.655	2.9849	20.6796

One of the concerns in using observed cloud properties is whether the clouds observed at a single point (such as the heavily instrumented Central Facility) is representative of the entire site. As can be seen in Table 2, for clusters 3 and 4 there is little variation in the relative frequencies of occurrence among the five stations. For clusters 1 and 2 the relative frequency of occurrence is low, but varies as a function of station.

Table 2. Frequency of occurrence of each cluster type as a function of location.

Station #, Cluster #	B1	B4	B5	B6	C1	All Data
1	0.11	0.08	0.04	0.05	0.09	0.07
2	0.09	0.18	0.18	0.23	0.15	0.17
3	0.64	0.56	0.63	0.59	0.63	0.61
4	0.15	0.18	0.15	0.13	0.13	0.15

Application of Clusters to Radiation Fields

The separation of the data by regime is applied to downwelling shortwave radiation data, observed and modeled. A single-column model (Iacobellis and Somerville 1990) is forced with a constrained variational analysis (Zhang et al. 2001; Xie et al. 2004) dataset from the ACRF SGP site and employs the Tiedtke (1993) cloud parameterization. The data from the Veron and Goris (2006) climatology has already been input into a stochastic radiative transfer model (Lane-Veron and Somerville 2004) for all of 2000 at the three ACRF sites (Veron et al. 2006). The difference between observations and model results is assessed as a function of cluster (Figure 2). As expected, the stochastic model underpredicts the domain averaged downwelling shortwave radiation (DWSR) for cluster 2, with high fraction, and cluster 3, with mixed and possibly overlapped clouds. The stochastic model performs reasonably well for clusters 1 and 4. Note that on average, the stochastic model performs better than the standard plane-parallel routine in the single-column model for all but overcast conditions (Table 3).

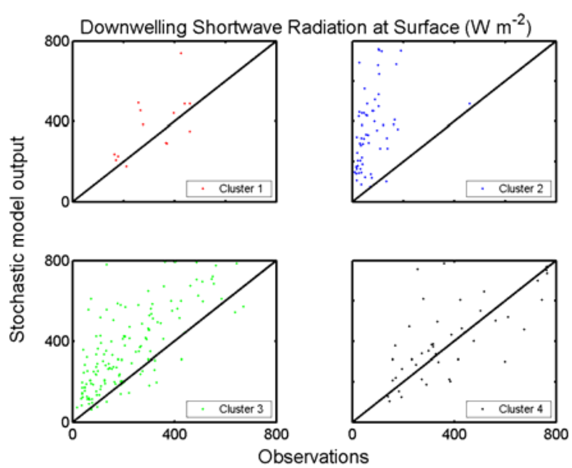

Figure 2. Comparison of stochastic model DWSR to observed from ARM solar infrared station network.

Table 3. Average difference between modeled downwelling shortwave radiation and observations by cluster.

Cluster #	Obs-DSTOC	Obs-SCM
1	93.80	74.54
2	284.19	251.21
3	155.40	185.06
4	50.02	136.40

Conclusions

A cluster algorithm has been applied at the ACRF SGP site using continuously sampled, ground-based data. Four major regimes have been identified using cloud base height, cloud fraction, and liquid water path annual data from the year 2000. The regimes are present at the Central Facility and the boundary facilities, but not in the same frequencies. Further studies will indicate the presence of a given regime at multiple stations at a given time.

The regimes derived in this analysis are being used to assess performance of a shortwave radiative transfer model.

Contact

Dana E. Veron, College of Marine Studies, University of Delaware, 114B Robinson Hall, Newark, DE 19716. dveron@udel.edu, (302) 831 4842.

References

Ackerman, TP, and GM Stokes. 2003. “The Atmospheric Radiation Measurement Program.” *Physics Today* 56:38-44.

Gordon, ND, JR Norris, CP Weaver, and SA Klein. 2005. “Cluster analysis of cloud regimes and characteristic dynamics of midlatitude synoptic systems in observations and a model.” *Journal of Geophysical Research* 110.

Jakob, C, G Tselioudis, and T Hume. 2005. “The radiative, cloud and thermodynamic properties of the major tropical western Pacific cloud regimes.” *Journal of Climate* 18:1203-1215.

Jakob, C, and G Tselioudis. 2003. “Objective identification of cloud regimes in the Tropical Western Pacific.” *Geophysical Research Letter* 30:2082.

Lane, DE, K Goris, and RCJ Somerville. 2002. “Radiative transfer through broken cloud fields: Observations and model validation.” *Journal of Climate* 15(20):2921-2933.

Lane-Veron, DE, and RCJ Somerville. 2004. "Stochastic theory of radiative transfer through generalized cloud fields." *Journal of Geophysical Research* 109.

Tiedtke, M. 1993. "Representation of clouds in large-scale models." *Monthly Weather Review* 121:3040- 3061.

Veron, DE, J Secora, and M Foster. 2006. "Application of a stochastic correction to modern shortwave radiation parameterizations." *Journal of Geophysical Research*, in preparation.

Xie, S, RT Cederwall, and M Zhang. 2004. "Developing long-term single-column model/cloud system resolving model forcing data using numerical weather prediction products constrained by surface and top of atmosphere observations." *Journal of Geophysical Research* 109.

Zhang, MH, JL Lin, RT Cederwall, JJ Yio, and SC Xie. 2001. "Objective analysis of ARM IOP data: Method and sensitivity." *Monthly Weather Review* 129:295–311.

Bibliography

Anderberg, MR. 1973. Cluster Analysis for Applications. Academic Press, 359 pp.

Iacobellis, S, and RCJ Somerville. 1991a. "Diagnostic modeling of the Indian monsoon onset. Part I: model description and validation." *Journal of Atmospheric Science* 48:1948-1989.

Iacobellis, S, and RCJ Somerville. 1991b. "Diagnostic modeling of the Indian monsoon onset. Part II: budget and sensitivity studies." *Journal of Atmospheric Science* 48:1948-1989.

Veron, DE, and J Secora. 2006. "Development of a 1-year cloud climatology for the ARM CART Sites." *Journal of Climate*, in preparation.

Veron, DE, CP Weaver, and F Veron. 2005. "Stochastic radiative transfer on RAMS cloud fields." *IEEE Transactions of the Geosciences Remote Sensing*, in preparation.