An Evaluation of Cirrus Parameterizations Using Southern Great Plains Data

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Parameterization of cirrus in large-scale models is a challenging problem for a number of reasons. Among the most important of these has been the lack of quantifiable tests of parameterization results. However, the necessary testing can now be carried out using the data stream from the Atmospheric Radiation Measurement Program (ARM) Southern Great Plains (SGP) site. Our approach to this problem is to use meteorological data from the Mesoscale Analysis and Prediction System (MAPS) assimilated analysis to force ice water content parameterizations used in climate models. We then derive optical properties from the ice water content (IWC) profiles using radiative parameterizations. The optical properties serve as input to a solar radiative transfer code. The computed downwelling irradiances at the surface are then compared to observed irradiances as a test of the parameterization validity. In this study, we use three IWC parameterizations proposed by Heymsfield and Donner, Stephens, and Slingo and Slingo. The radiative parameterizations are due to Ebert and Curry and Sun and Shine. The study period ranges from November 1, 1994, to April 30, 1995, and uses all daytime cirrus that occurred in isolation from other cloud decks. The 70 to 80 cirrus cases used in this study represent a significant improvement in the data base available for cirrus studies.

Cirrus events at the SGP site are identified using the micropulse lidar (MPL) data, radiosonde profiles, and satellite imagery. We define cirrus clouds as any cloud having a base temperature colder than -20°C. The meteorological forcing required to drive the parameterizations are determined from both radiosonde data and MAPS mesoscale model output. The Heymsfield-Donner (HD) model is strongly dependent on thermodynamic profiles and large-scale vertical velocity. The Stephens model depends only on cloud temperature, while the Slingo and Slingo (SS) model uses a profile of typical IWC values at 1% supersaturation. For each cirrus case, all three parameterizations are used to produce estimates of cloud location and IWC. Each seems to do a reasonable job of predicting cloud location, but the IWC values vary considerably. A detailed analysis of the resulting distributions has not yet been carried out, but will be used to identify systematic variations.

The radiative parameterization developed by Ebert and Curry (EC) requires effective radius and ice water content as input and produces cloud optical properties, such as optical depth, as output. An effective radius for the ice crystals is determined using temperature-dependent size distributions by Heymsfield and Platt. The Sun-Shine parameterization requires only the specification of liquid water content. Surface fluxes of solar radiation are computed from a delta-two-stream radiative transfer model that incorporates these cloud optical properties. The final step in the process is the computation of the surface shortwave cloud forcing (model cloudy solar flux - model clear sky solar flux) for each of the parameterizations for each case, which are then compared to the observed solar forcing (observed cloudy solar flux - clear sky solar flux).

The results to date are intriguing, but not definitive. Using the EC scheme, all three parameterizations significantly underestimate the observed forcing. HD produces the smallest forcing, presumably because it produces the smallest IWC profiles. The Stephens model produces the largest forcing, but still much less than the observed forcing. We suspect that the problem here may be that the HP size distributions have too large a mean radius, which in turn results in too large a solar transmission. The Sun-Shine model, on the other hand, results in a considerable over-estimate of the cloud forcing for both Stephens and SS. The HD values are very close on average but exhibit large scatter.

The next step in our research is to try to assess the reasons for the mismatched forcings and the large scatter. We are currently working on two approaches to retrieving cirrus optical depth and ice water path from the ARM data. These values will be compared to the parameterized values in order to identify systematic errors. We also intend to segregate the cases by synoptic classification and use mesoscale model simulations to examine the relationships at finer horizontal scales. We are optimistic that this methodology can lead to a significant improvement in our understanding of cirrus forcing and parameterizations.