**A Study to Investigate Cloud Feedback Processes and Evaluate GCM Cloud
Variations Using Statistical Cloud Property Composites From ARM Data**

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Executive summary

The representation of clouds in Global Climate Models (GCMs) remains a major source of uncertainty in climate change simulations. Cloud climatologies have been widely used to either evaluate climate model cloud fields or examine, in combination with other data sets, climate-scale relationships between cloud properties and dynamical or microphysical parameters. Major cloud climatologies have been based either on satellite observations of cloud properties or on surface observers' views of cloud type and amount. Such data sets provide either the top-down view of column-integrated cloud properties (satellites) or the bottom-up view of the cloud field morphology (surface observers). Both satellite-based and surface cloud climatologies have been successfully used to examine cloud properties, to support process studies, and to evaluate climate and weather models. However, they also present certain limitations, since the satellite cloud types are defined using radiative cloud boundaries and surface observations are based on cloud boundaries visible to human observers. As a result, these data sets do not resolve the vertical distribution of cloud layers, an issue that is important in calculating both the radiative and the hydrologic effects of the cloud field. Ground-based cloud radar observations, on the other hand, resolve with good accuracy the vertical distribution of cloud layers and could be used to produce cloud type climatologies with vertical layering information. However, these observations provide point measurements only and it is not immediately clear to what extent they are representative of larger regimes. There are different methods that can be applied to minimize this problem and to produce cloud layering climatologies useful for both cloud process and model evaluation studies. If a radar system is run continuously over a number of years, it eventually samples a large number of dynamical and microphysical regimes. If additional data sets are used to put the cloud layering information into the context of large-scale dynamical regimes, such information can be used to study interactions among cloud vertical distributions and dynamical and microphysical processes and to evaluate the ability of models to simulate those interactions.

The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) program has established several Climate Research Facilities (ACRF) that provide continuous, long-term observations of clouds and radiation. ARM, with its overall goal of improving the treatment of radiation and clouds in climate models has provided unique observing systems for accelerating progress on the representation of cloud processes. In this project, six and a half years (January 1998 to June 2004) of cloud observations collected at the Southern Great Plains (SGP) Oklahoma ACRF were used to produce a cloud-type climatology. The climatology provides cloud amounts for seven different cloud types as well as information on the detailed structure of multi-layer cloud occurrences. Furthermore, the European Centre for Medium-Range Weather Forecasts (ECMWF) model output was used to define the dynamic regimes present during the observations of the cloud conditions by the vertically pointing radars at the SGP ACRF. The cloud-type climatology and the ECMWF SGP data set were then analyzed to examine and map dynamical conditions that favor the creation of single-layer versus multi-layer cloud structures as well as dynamical conditions that favor the occurrence of drizzle in continental stratus clouds. In addition, output from the ECMWF weather model forecasts

was analyzed with the objective to compare model and radar derived cloud type statistics, in order to identify the major model deficiencies in cloud vertical distribution and map their seasonal variations.

Project activities and accomplishments

The project included two primary goals. The first was to create a cloud type climatology over the Southern Great Planes site that will show how cloud vertical distribution varies with dynamic and thermodynamic regime and how these variations would affect cloud climate feedbacks. The second was to compare this climatology to clouds derived by a numerical model in order to identify the major model deficiencies in cloud vertical distribution and map their seasonal variations. The following two paragraphs summarize the project accomplishments with respect to those two goals.

Clouds in the ARM climatology were classified with respect to their altitude (low, middle, and high), vertical development, and the presence of multilayer clouds. It was found that single-layered cirrus, middle or low clouds were observed a total of 23% of the time that the MilliMeter Cloud Radar (MMCR) was operating, and multi-layer clouds were observed 20.5% of the time. Boundary layer clouds exhibit the strongest seasonal variability because of continental stratus associated with midlatitude frontal systems. Cirrus clouds are the most frequently observed cloud type and exhibit strong seasonal variability in cloud base height (higher cloud base during the summer months) and relatively constant cloud fraction. The majority of middle-level clouds are shallow with vertical extent less than 1 km. No strong seasonal cycle in the fractional coverage of multi-layer clouds is observed. Continental stratus clouds exhibit strong seasonal variability with maximum occurrence during the cold seasons. Non-drizzling stratus clouds exhibit a bimodal seasonal variability with maximum occurrences in the fall and spring, while drizzling stratus occur most frequently in the winter. Thermodynamic and dynamic variables from soundings and the European Centre for Medium-Range Weather Forecasts Model (ECMWF) analyses at the SGP site illustrate an interesting coupling between strong large-scale forcing and the formation of single-layered (no other cloud layer is present) continental stratus clouds. Single-layered stratus clouds (drizzling and non-drizzling) exhibit a strong correlation with upward vertical movement at the 500 mbar level and with strong northerly flow.

The results of the ECMWF model evaluation analysis indicate that cirrus and to a lesser extent middle level clouds are the major cloud types missing in the model simulations and that they are missing mostly as parts of multi-type rather than single-type structures. Boundary layer clouds are simulated at approximately the right amounts in the annual mean statistics, but this result comes from the model simulating too little boundary layer cloud in the winter and too much in the summer. Overall, the model forecasts miss about 11% of the total cloud amount, and most of the missing cloud occurs at time periods when multiple cloud types are present in the observations. The figure below shows the clouds observed by the SGP radar (red line) and those produced by the ECMWF model (black line) when only single type clouds are present (top panel) and when multi-type

clouds are present (bottom panel). It can be seen that the model produces the right amounts of single-type clouds but misses large amounts of multi-type clouds.

Publications

Tselioudis, G., and P. Kollias, 2007: Evaluation of ECMWF cloud type simulations at the ARM Southern Great Plains site using a new cloud type climatology. *Geophys. Res. Lett.*, **34**, L03803, doi:10.1029/2006GL027314.

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