P1.17 USE OF IN-SITU OBSERVATIONS OF ARCTIC CLOUDS TO UNDERSTAND IMPACTS OF MIXED-PHASE CLOUDS ON SINGLE-SCATTERING: PROPERTIES: APPLICATIONS TO CLIMATE MODELS

Greg M. McFarquhar and Gong Zhang

University of Illinois at Urbana-Champaign, Urbana, IL

1. INTRODUCTION

Although regions at poles are especially sensitive to climate change, large uncertainties in the response of the Arctic to climate perturbations exist. Complex feedback mechanisms involving sea ice, snow cover, and clouds must be better understood and characterized before large disagreements between general circulation model (GCM) simulations can be reduced and future predictions of climate change refined. A lack of comprehensive measurements of ice-ocean-atmosphere processes and cloud and radiation properties previously prevented research progress on feedback mechanisms. Recent observations obtained during the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE) Arctic Clouds Experiment (ACE) and during the Surface Heat Budget of the Arctic Ocean Experiment (SHEBA) can now be used to enhance our understanding of Arctic climate (Curry et al 2001).

For Arctic clouds, Shupe et al. (2001) showed that retrieval techniques for all-ice and all-liquid clouds could be used only 34% of the time, suggesting mixed-phase clouds were present at other times. Understanding the properties of mixed-phase clouds is therefore critical for the Arctic environment. These properties feedback on radiative budgets because modeled radiative properties of mixed-phase clouds differ substantially from those composed exclusively of liquid particles (e.g., Sun and Shine 1995). Using direct measurements of single-scattering cloud properties from a cloud integrating nephelometer, Gerber et al. (2000) illustrated such differences finding larger values of asymmetry parameters (g) for mixed- and liquid-phase clouds than for ice-phase clouds. Not only do cloud radiative properties depend on the relative amounts of the phases, but also on their manner of spatial mixing (Sun and Shine 1994; Rotstayn et al. 2000).

The purpose of this study is to use in-situ measurements obtained during SHEBA to examine the nature of phase mixing and the contributions of water and ice to mixed-phase single-scattering and microphysical properties. The roles of water and ice in determining energy balance for this region are determined from radiative transfer simulations performed using the calculated single-scattering properties.

Corresponding author address: Greg M. McFarquhar, University of Illinois, Dept. of Atmospheric Sciences, 105 S. Gregory Street, Urbana, IL, 61801-3070, mcfarq@atmos.uiuc.edu

2. IN-SITU OBSERVATIONS

During SHEBA, the National Center for Atmospheric Research C-130 aircraft flew through ice-phase, liquid-phase, and mixed-phase clouds over the Arctic. Although not as many cases of mixed-phase clouds were observed as originally anticipated, a number of in-situ observations in mixed-phase clouds were obtained and are used to examine the microphysical characteristics of mixed-phase clouds. For this study, a mixed-phase cloud observation is defined to occur whenever both liquid and ice are detected in the same in-situ sampling period. Since this definition depends on the temporal and spatial averaging period, an averaging period of 30 s is used for the analysis presented here. The spatial mixture of phases can have a substantial effect on the properties of the mixed-phase clouds.

Following Cober et al. (2001), data from different instruments are used to identify cloud phase. Images from two-dimensional (2D) probes and SPEC Inc.'s Cloud Particle Imager (CPI) are first examined and a phase (mixed, liquid, or ice) and particle characterization (drizzle, rain, needles, dendrites, irregular, semi-circular ice) is assigned to each period. Such analysis can be ambiguous at times because between 5 and 40% of non-circular ice crystals appear circular and about 10% of particles that should be circular are not due to probe optics, distortion and phoretic effects. In addition, since most small ice crystals are quasi-spherical (e.g., Nousiainen and McFarquhar 2003), it is difficult to distinguish whether small particles are ice or liquid, meaning that mixed-phase periods might not be differentiated from ice-phase periods.

Data from other probes are hence used to help the final phase assessment. Cober et al. (2001) found that FSSP distributions were truncated at 30 μm with a peak at approximately 15 μm for liquid clouds, whereas broader distributions and number concentrations below 15 cm^{-3} typically existed for glaciated clouds. For temperatures below –4°C, the Rosemount icing detector (RICE) has a linear response to LWC, and an absence of a signal from the RICE suggests that the cloud is ice-phase; the signal strength can also be used to estimate the LWC and identify periods of supercooled water.

To estimate the relative importance of water and ice in the properties of mixed-phase clouds and to determine the mass and single-scattering properties of such clouds, number concentrations of all sizes and phases of cloud particles must be determined. For large particles, 2D probes can be used to determine particle phase and estimate the number concentrations of particles;

information about the observed habits from the CPI can be used to identify particle shapes, which are used to determine mass diameter relationships that are used to estimate ice mass content. Since 2D probes may underestimate small particle concentrations (Baumgardner and Korolev 1997), the detection of small particle concentrations is problematic. Although FSSP data cannot typically be used quantitatively for glaciated conditions (Gardiner and Hallett 1985), FSSP data can probably be used to describe size distributions in mixed-phase clouds because mixed-phase clouds sampled during SHEBA had low IWCs, meaning that the ice should not be substantially interfering with forward scattering from cloud droplets. Comparison with bulk liquid estimates from the RICE ensures that reasonable concentrations are available.

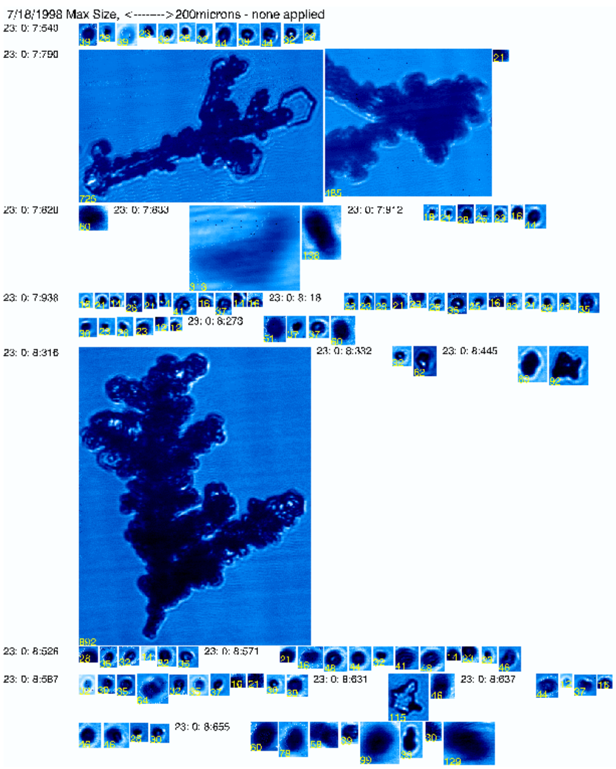

Figure 1: Observations of cloud particles made by CPI in mixed-phase cloud during flight of NCAR C-130, July 18, 1998. Observations made during time period where ice dominated mass concentrations.

3. OBSERVATIONS OF MIXED-PHASE CLOUDS

Figure 1 shows an example of ice crystals measured by the CPI in a mixed-phase cloud sampled July 18, 1998 during SHEBA. The larger non-spherical crystal images combined with a response from the RICE categorically showed that this was a mixed-phase cloud. Estimates of ice mass from mass-diameter relationships applied to the 2D data number concentrations and of liquid mass from the RICE and FSSP data showed that the cloud mass was dominated by the ice at this time. However, approximately 2 minutes later during the flight, the C-130 penetrated a portion of the cloud dominated by liquid, where only one large ice crystal was seen by the CPI in approximately a 45 second time period. Relatively few ice crystals were also seen in the 2D data. Examples of crystal images for this time period are shown in Figure 2.

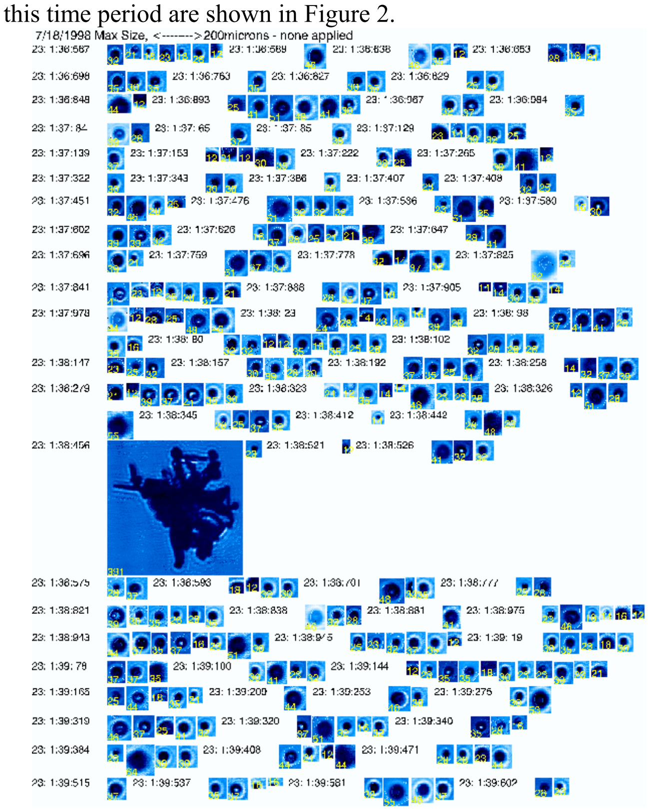

Figure 2: As in Fig. 1, except observations made during time period when water dominated mass concentrations.

For all 30 s time periods where mixed-phase clouds occurred during SHEBA, the ratio of the liquid water content to the total water content was calculated. Figure 3 shows the frequency distribution of these liquid water ratios; there was an insufficient statistical database to stratify the relationship by temperature. It is seen that mixed-phase clouds are dominated by contributions from the liquid water for most periods. There are also some instances, presumably when the cloud is rapidly glaciating, where the mass contents are dominated by ice. There are relatively few time periods where there are approximately equal contributions from water and ice. Similar results were found when data collected by the Canadian National Research Council Convair-580 during FIRE ACE were examined. Cober et al. (2001) found similar conclusions when a larger data base of mixed-phase clouds was examined.

4. IMPLICATIONS FOR RADIATIVE TRANSFER

Although many large-scale models now have prognostic equations for both water and ice, there are still some models that use a single prognostic variable for cloud water, and separate the mass content into water and ice using a temperature dependent liquid water fraction. In-situ observations (e.g., Moss and Johson 1994) have bee used to develop many of these relationships. The nature of the assumed temperature dependences can significantly impact the simulation of climate as Gregory and Morris (1996) found that the radiation budget of the UK Meteorological Unified model depended on the temperature range over which mixed-phase clouds were assumed to exist. Sun and Shine (1994) also showed that not only do cloud radiative properties depend on the relative amounts of the phases, but also on their manner of spatial mixing.

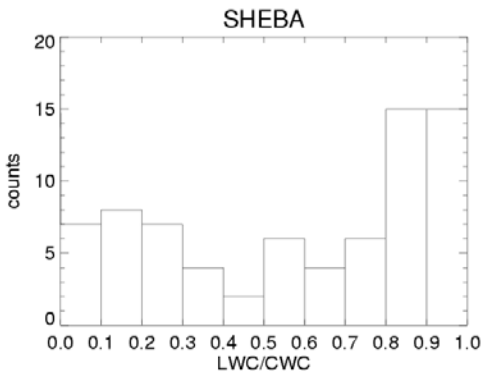

Figure 3: Frequency of occurrence of fraction of liquid in mixed-phase clouds, where fractions computed by averaging liquid and ice size distributions over a 30 s in-cloud time periods (based on data acquired by NCAR C-130 during SHEBA).

At the meeting results it will be shown how in-situ data collected during SHEBA are used to determine how the mixing of phases in both space and by particle size affects the mean scattering properties of the observed clouds. The mean scattering properties of mixed-phase clouds are derived by weighting the single-scattering properties of idealized ice crystals and water droplets according to observed number concentration and scattering cross-section. A plane-parallel radiative transfer model is then used to show that differences in cloud radiative forcing can be significant when single-scattering properties derived from temperature-dependent liquid water fractions are used as inputs to these models instead of scattering properties based on the observed distributions.

5. SUMMARY

Although there are still relatively few in-situ observations of mixed-phase clouds in the Arctic, analysis of data collected during SHEBA offers some clues as to the microphysical and single-scattering properties of these clouds. Further in-situ observations, coincident with lidar, radar, and radiometer data, are needed to better characterize the nature of these properties in the context of the physical processes that lead to the production and dissipation of these clouds.

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