

**AN OBSERVATIONAL STUDY OF THE MICROPHYSICS OF ALTOSTRATUS  
CLOUDS**

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## OBJECTIVE:

Mixed phase clouds are colloidally unstable. This is because a cloud that is saturated with respect to liquid water is highly supersaturated with respect to ice. Therefore ice particles in a mixed phase cloud tend to grow at the expense of liquid droplets. The process by which a cloud changes from liquid to ice is called glaciation (Pruppacher and Klett 1997, p. 53). Therefore the question arises: How long can mixed phase clouds persist in a mixed phase state?, or alternatively, How fast does glaciation of clouds occur?

Field observations have demonstrated that glaciation can occur rapidly, i.e. within minutes, in the tops of cumulus turrets (Hobbs and Rangno 1985). In contrast, glaciation appears to proceed much more slowly in Arctic stratus clouds. In fact, both field observations (Pinto 1998) and numerical simulations (Harrington et al. 1999) suggest that Arctic stratus may sometimes reach an equilibrium in which the ratio of ice to liquid remains constant. This is possible because as ice particles grow, they tend to fall out of cloud, and then they can no longer deplete cloud liquid water. If the rate of formation of new ice crystals balances the rate of sedimentation of ice crystals, then the cloud can achieve an equilibrium. Both Pinto (1998) and Harrington et al. (1999) state that the rate of glaciation is highly sensitive to the concentration of ice-forming nuclei (IFN).

The present paper is concerned with the glaciation rate of altostratus clouds. The military desires better forecasts of altostratus because these clouds can impede visibility during military operations.

Hobbs and Rangno (1985) state that glaciation of altostratus and altocumulus clouds can require several hours, in contrast to the rapid glaciation of cumulus turrets. However, the aircraft measurements of Hobbs and Rangno (1985) (and those of Pinto 1998) were not Lagrangian measurements. That is, their aircraft transects did not drift with the horizontal wind so as to subtract out advective effects. With non-Lagrangian measurements, it can be difficult to determine whether an observed change in cloud properties occurs because the aircraft has observed temporal variations of a single patch of cloud or because the aircraft has sampled a horizontally varying cloud.

We will examine Lagrangian aircraft measurements obtained from a mixed phase altostratus cloud observed on November 11, 1999 during the CLEX-5 field experiment. The background of this case study is described in more detail in another paper in these conference proceedings (Fleishauer et al. 1999). We find that the rate of glaciation in this cloud was slow, and that by some measures, the cloud in fact de-glaciated.

## RESEARCH ACCOMPLISHED:

What was the glaciation rate of the November 11 altostratus cloud?

The answer is not obvious *a priori* because the glaciation rate probably depends strongly on the number of ice-forming nuclei near the cloud, and little is known about the concentration of IFN at mid altitudes over continents. One can imagine two scenarios.

First, if the IFN concentration is sufficiently large, a liquid cloud may be entirely converted to ice and only then dissipate either through precipitation or entrainment. Alternatively, if the IFN concentrations are small, a cloud may retain considerable liquid water until the moment it finally dissipates.

The November 11 cloud was sampled by an aircraft that executed racetrack-shaped flight patterns at various altitudes. Little, if any, ice was present in the top of the November 11 cloud. However, ice did exist in the base of and beneath the cloud. Therefore we compare the amount of ice measured in two racetracks near cloud base, separated in time by about half an hour. (The later and earlier racetracks are numbered 2 and 7 respectively in Fleishauer et al. 2000.) The altitude of the later racetrack was about 100 m lower than that of the earlier racetrack. Since the aircraft used a Lagrangian sampling strategy, both racetracks intercepted the same column of air. Therefore the observed changes in ice amount reflect temporal and not horizontal spatial changes.

We have analyzed data on ice obtained by two instruments: the Cloud Particle Imager (CPI) and the 2D-C probe. The CPI takes in-situ digital photographs of ice particles (Lawson and Jensen 1998). The 2D-C probe records the shadows of ice particles as they pass in front of an array of photodiodes (Baumgardner 1989).

The ice crystal measurements may be summarized as follows. Both the CPI and 2D-C find that the number concentration of ice particles and the ice water content slightly *decrease* between the two racetracks. Therefore, if glaciation rate is defined as either the change in number concentration of ice crystals or the change in ice water content, then the cloud, instead of glaciating, actually de-glaciates. However, the liquid water content also decreases during this time, so that the ratio of liquid to ice water content, for example, stays roughly constant within the (large) uncertainty of the measurements. What we can say with a fair degree of certainty is that for the Nov. 11 case, the process of glaciation (or de-glaciation) has a timescale longer than 40 minutes. The cloud was sampled until minutes before its disappearance, and considerable liquid water remained in cloud even at the end of sampling.

Since cirrus was observed above the altostratus cloud that we sampled, one might hypothesize that the seeder-feeder process was responsible for the fact that the altostratus cloud was mixed phase and that it persisted in a mixed phase state. That is, one might suppose that the ice present in the altostratus originated as ice fallout from the cirrus cloud above. However, neither the CPI nor the Forward Scattering Spectrometer Probe (FSSP) observed hydrometeors falling into the top of the altostratus during the two times when the aircraft flew above the altostratus cloud. These two times occurred when the aircraft first approached the cloud from above and performed a spiral descent, and midway through sampling when the aircraft executed an above-cloud racetrack. Despite the failure to observe seeder crystals, one might argue that ice had fallen into the top of the altostratus cloud before the aircraft arrived, and that the possible de-glaciation we observed occurred because the seeder process ceased as soon as the aircraft arrived. However, the cirrus clouds, as recorded on flight video, appear to be high, thin, and

without virga. The possibility that precipitating crystals from the cirrus cloud could have survived the long fall through subsaturated air to the altostratus cloud is remote.

#### CONCLUSIONS AND RECOMMENDATIONS:

We have sampled a mixed phase altostratus cloud and have found that the rate of glaciation was slow, and that by some measures, the cloud was in fact de-glaciating. We speculate that the cause of the slow or non-existent glaciation was low concentration of ice-forming nuclei (IFN), coupled with the fact that ice particles tend to sediment rapidly after they have grown sufficiently large by vapor diffusion. This hypothesis must remain speculative, since we did not measure IFN concentration.

We cannot establish that the cloud we sampled is representative of continental altostratus in general. To do so, more measurements would be required.

#### ACKNOWLEDGMENT:

This work was supported by the Department of Defense Center for Geosciences/Atmospheric Research Agreement #DAAL01-98-2-0078.

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