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ETO Lidar Studies of Cirrostratus Altocumulogenitus: Another Role for Supercooled Liquid Water In Cirrus Cloud Formation

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ABSTRACT

Cirrus clouds have traditionally been viewed as cold, wispy or stratiform ice clouds, typically displaying optical phenomena such as haloes. A composition entirely of hexagonal ice crystals, of one habit or another, seems implicit in the definition of cirrus. Supercooled cloud droplets could only have a transitory existence in cirrus, since the concentrations of ice nuclei (IN) measured by various techniques (at the surface or in the lower troposphere) indicate an enormous number of IN that should be active at cirrus cloud temperatures. Reports of aircraft icing at cirrus cloud altitudes (itself a poorly defined criterion) were generally not well documented in the literature (for recent surveys see Rangno and Hobbs 1986 and Sassen et al. 1989a), and in view of the accepted ~-35° to -40°C threshold for "instantaneous" homogeneous nucleation, such reports do not appear to have altered the prevailing convention of viewing cirrus as exclusively ice clouds.

In light of recent instrumented aircraft and polarization lidar studies of cirrus clouds, however, it is clear that highly supercooled cloud droplets can sometimes be a component of cirrus clouds. The question of the prevalence of supercooled liquid water (SLW) in cirrus has implications for climate research, for it has been shown theoretically that thin SLW layers at the base of elevated cirrus clouds can have a relatively significant impact on radiation transfer through the cloudy atmosphere (Sassen et al. 1985). It remains to be determined if SLW is present abundantly enough in cirrus to play a significant role in the planet's radiation balance, or is merely a curious, infrequent occurrence.

To help evaluate this issue, the University of Utah polarization lidar FIRE Extended Time Observations (ETO) of cirrus clouds are being utilized to compile, among other parameters, a climatological record of SLW clouds associated with and within cirrus. Although our program is ongoing, and a proper assessment of the growing data base is in the future, on the basis of the observations collected so far it is appropriate to define the various modes of occurrence of SLW in cirrus clouds. (Note that the "definition" of cirrus clouds could seemingly exclude SLW-containing clouds as cirrus, but, as a former National Weather Service meteorological technician, my classification of cloud types is based on the "standard" visual appearance of clouds, with supporting all-sky photography.)

Figure 1 illustrates four distinct modes of the occurrence of SLW connected with cirrus cloud development identified from polarization lidar observations. Before discussing this figure, however, it is important to note that SLW (as used here) refers to the supermicron-sized cloud droplets measurable by in situ aircraft probes, which are shown by the stippled areas in Fig. 1. Thus ice nucleation at temperatures less than about -35° to -40°C likely involving the homogeneous freezing of haze particles (shown as dots in Fig. 1) is not considered here (see the companion paper by Sassen, Dodd and Starr). The existence of SLW clouds associated with cirrus can potentially impact radiative transfer to a much more significant extent than haze particle effects, and clearly affect attempts to evaluate satellite-viewed scenes containing high clouds (see, e.g., Wielicki et al. 1989).

Three of the modes have been described previously—the incorporation of supercooled altocumulus (and associated virga) into deepening cirrostratus (Sassen et al. 1989b), and the formation of SLW layers at the base of deep convective cirrostratus and orographic cirrus wave clouds (Sassen et al. 1989a). The cirrus cloud generation mechanism shown at the top of Fig. 1 involves the glaciation of a supercooled altocumulus cloud layer (essentially without ice particle "seeding" from higher cirrus), which can produce a fairly extensive cirrostratus cloud with cloud tops at or near the previously water-saturated layer. The resulting cloud is termed cirrostratus altocumulogenitus in recognition of the generation mechanism. The initial altocumulus glaciation may result from cloud top penetration into temperatures cold enough to promote homogeneous cloud droplet freezing, or according to the entrainment/drop evaporation mechanism proposed by Hobbs and Rangno (1985), for example. It is uncertain at this time whether significant additional ice nucleation occurs after altocumulus glaciation, or whether the cirrostratus ice particles are capable of persisting for long periods until complete sedimentation occurs and the altocumulus may again form to repeat the sequence. It is important to note that the precipitating ice crystals frequently, if not typically, display laser backscattering properties indicating horizontally oriented planar ice crystals, which minimizes the ice crystal fall speeds. Horizontally oriented plate crystals with diameters up to about 0.5 mm display terminal velocities in the 10-20 cm s^{-1} range (see Sassen 1980), such that periods of ~2 h are required for crystals to sediment through a 1.0-km depth, even without considering the large-scale ascent rate. Cirrostratus altocumulogenitus clouds typically appear to have cloud thicknesses on the order of a few kilometers.

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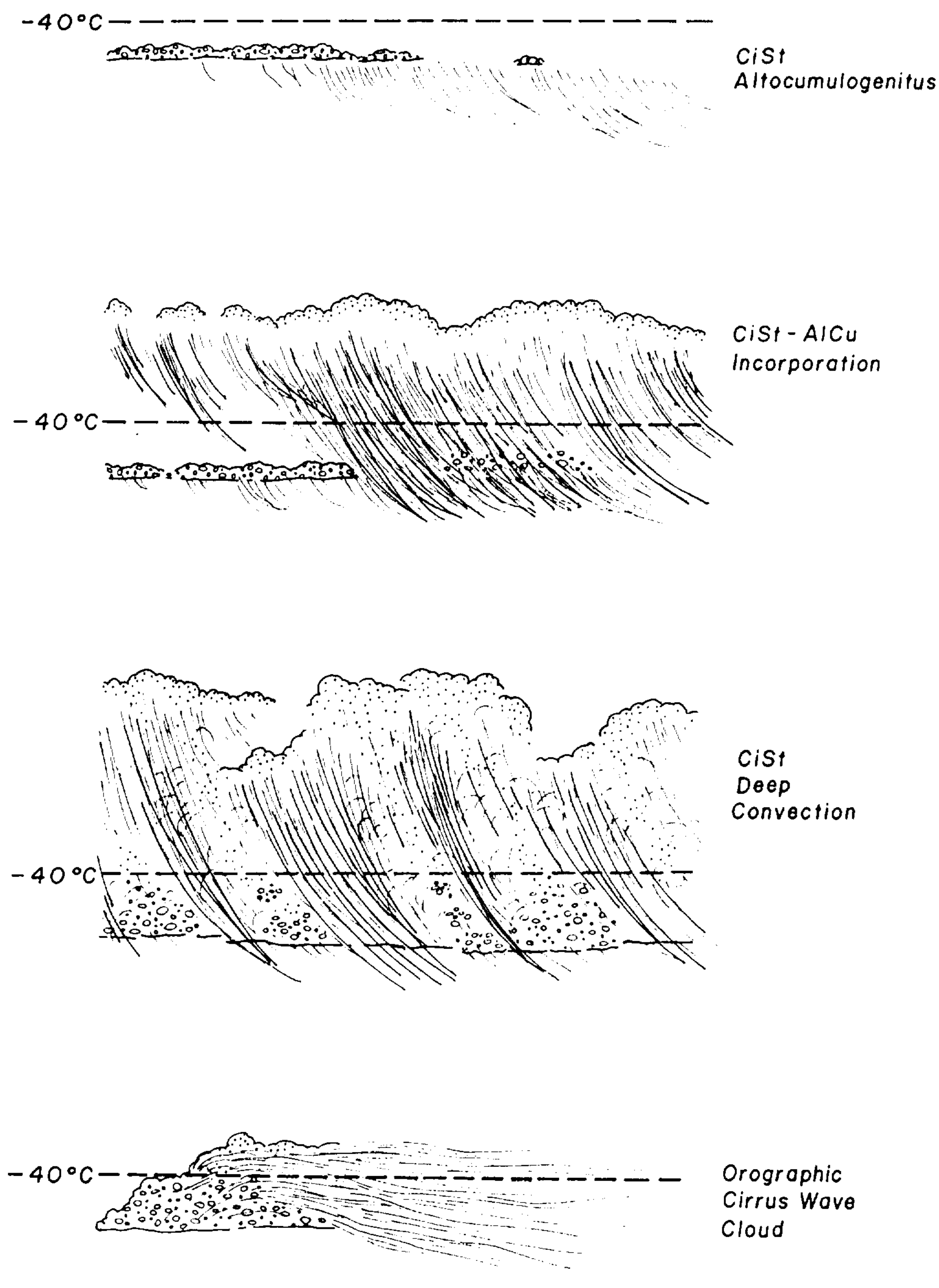

Fig. 1 *Schematic view of four modes of occurrence of supercooled cloud droplets (stippling using open circles) connected with the development of various cirrus types. Horizontal scales can vary from tens to hundreds of kilometers: typical vertical scales are a few kilometers for the top and bottom types, and up to several kilometers for the middle two cases.*

References

Hobbs, P. V., and A. L. Rangno, 1985: Ice particle concentrations in clouds. *J. Atmos. Sci.*, **42**, 2523-2549.

Rangno, A. L., and P. V. Hobbs, 1986: Deficits in ice particle concentrations in stratiform ice clouds with top temperatures ≤-30°C? Preprints, 23rd Conf. on Radar Meteorology and the Conf. on Cloud Physics, Snowmass, CO, Amer. Meteor. Soc., 20-23.

Sassen, K., 1980: Remote sensing of planar ice crystal fall attitudes. *J. Meteor. Soc. Japan*, **58**, 422-429.

Sassen, K., K. N. Liou, S. Kinne and M. Griffin, 1985: Highly supercooled cirrus cloud water: Confirmation and climatic implications. *Science*, **227**, 411-413.

Sassen, K., D. O'C. Starr and T. Uttal, 1989a: Mesoscale and microscale structure of cirrus clouds: Three case studies. *J. Atmos. Sci.*, **46**, 371-396.

Sassen, K., C. J. Grund, J. Spinhirne, M. Hardesty and J. M. Alvarez, 1989b: The 27-28 October 1986 FIRE IFO cirrus case study: A five lidar overview of cloud structure and evolution. *Mon. Wea. Rev.*, **117** (in press).

Wielicki, B. A., J. T. Suttles, A. J. Heymsfield, R. M. Welch, J. D. Spinhirne, M.-L. C. Wu, S. K. Cox, D. O'C. Starr, L. Parker and R. F. Arduini, 1989: The 27-28 October 1986 FIRE IFO cirrus case study: Comparison of radiative transfer theory with observations by satellite and aircraft. *Mon. Wea. Rev.*, **117** (in press).