SOME OBSERVATIONS ON THE CHARACTER OF SNOW

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ABSTRACT

Typical snowfalls in eastern Canada and the northeastern United States are associated with complex and deep weather systems. Attempts to apply the ice crystal habit characterization of Nakaya, and Magono and Lee, to determine the temperature and humidity regimes where the snow originates often fail due to these complexities.

Precipitation in the polar regions occurs in and beneath well-stratified layers, which are much less complex and permit more direct comparison of snow crystal type to the temperature-humidity regime. Many of these precipitation events occur in conjunction with clouds that approximate the conditions at the leading edge of midlatitude warm fronts, although the cloud is only a few hundred meters above the surface. It has been possible to calculate the growth rate of primary ice crystals in these conditions from fundamental concepts. Additional cases have been observed where ice crystal optical phenomena have been quite precisely associated with ice crystal type and temperature-humidity regime. Analysis of polar ice crystal falls indicate that there is sufficient and continuous production of small, plate-type crystals that can survive falls through layers below.

Introduction

The crystal habit of falling snow is a well-studied subject. The historic photographs made by Bentley and the classification of frozen precipitation particles proposed by Schaefer in 1955 are often used to characterize the nature of mesoscale storms. Nakaya's (1954) relationship among temperature, relative saturation and crystal habit, and Magono and Lee's (1966) extension of Nakaya's diagram are useful in cloud physics when a cloud-forming layer is examined. In some cases, haloes and other optical effects can be used to quite precisely identify the ice crystal type, temperature and saturation in thin cloud layers (Hogan 1984, Hobbs 1974, Humphreys 1940, Kobayashi 1961).

Typically, in the northeastern United States and in eastern Canada, snowfalls are more complex, with mixtures of aggregates and individual crystals falling from several layers. This presents a difficult problem in estimating or defining the snow formation or growth processes from observations on the ground. The leading edge of a typical warm front poses a more tractable situation for study. It has been hypothesized by Schaefer (1950) that warm frontal precipitation arises from crystals descending from cirrostratus, which grow and aggregate while falling through warmer moister layers below. A study of the nature of the crystals found in the leading edge of cirrus could be applied to determining whether they achieve sufficient sedimentation rates to survive descent to more moist layers.

The ice crystal clouds which are found a few hundred meters above the South Polar plateau are formed in temperature-humidity regimes quite similar to midlatitude cirrus (Hogan 1975, Kikuchi and Hogan 1976, Sato et al. 1981). The ice crystals precipitating to the surface a few hundred (or fewer) meters below should then approximate the crystals precipitating into the moister lowers in a midlatitude warm front. A stationary surface observer on the polar plateau can then sample precipitating crystals from several clouds in a reasonably short time period.

These ice crystal clouds form as the air is forced to rise along the gentle slope of the polar plateau. Interestingly the slope of the ice cap is quite comparable to that of a midlatitude warm front.

The South Pole Station is a good site for such observations, as the terrain is extremely smooth, and wind velocities are generally less than 7 m/s at the surface when these thin ice clouds are present. There is a complete meteorological observation station, including radiosonde facilities at the South Pole Station. During the duration of this study, a slow-rising radiosonde was launched each day, in addition to the two synoptic launches. This slow-rising sonde provided a detailed profile of the temperature and saturation in the lowest kilometer, where the cloud and descending ice crystals were confined. The conventional hygrometer used in U.S. rawinsondes is relatively inaccurate when used to define ice-saturation at temperatures below -20°C. A small amount of dry ice was attached to the sonde, and the ice-saturated region was delineated by visual observation of beginning and cessation of a persistent ice cloud trailing from the dry ice.

A complete description of the experimental technique and data analysis can be found in Townsend (1985). Some of the more important results are summarized here.

The experiments were conducted during January 1983. The surface temperatures during the times of collection varied from -28 to -36°C. The "moist" layer above, in which the ice crystals formed, varied in temperature from -25 to -35°C.

Growth rates for plate-type ice crystals were calculated using the basic equation of Byers (1965) and the varying thickness method of Auer and Veal (1970). These growth rates were applied in combination with the ice crystal fall speeds of Yagi (1970) to determine the distance of fall accompanying the growth to 110 μm diameter, a previously observed maximum for single plate-type crystals. The temperatures, saturations and fall distances available were determined from the rawinsonde data.

The fall distances required for a thin, constant-thickness plate to grow to 110 μm diameter are given in Table I. These fall distances are based on the typical conditions of T = -30°C and P = 620 mb.

Hexagonal plate crystals can grow large enough to fall a few hundred meters in a very thin saturated layer, according to this calculation. Examination of replicas of suspended hexagonal ice crystals collected during the experiments yield the size distribution given in Table II, which is based on 796 crystals collected on two days when ice clouds approximating cirrostratus where observed. Figure 1 shows the crystal radius vs. fall distance for the same two days.

Table I. Fall Distance Required to Grow to 110 μm Diameter.

Saturation Ratio, with respect to ice	Total Fall Distance (Meters)
1.05	67
1.10	34
1.15	23
1.20	17
1.25	14
1.30	11
1.35	9

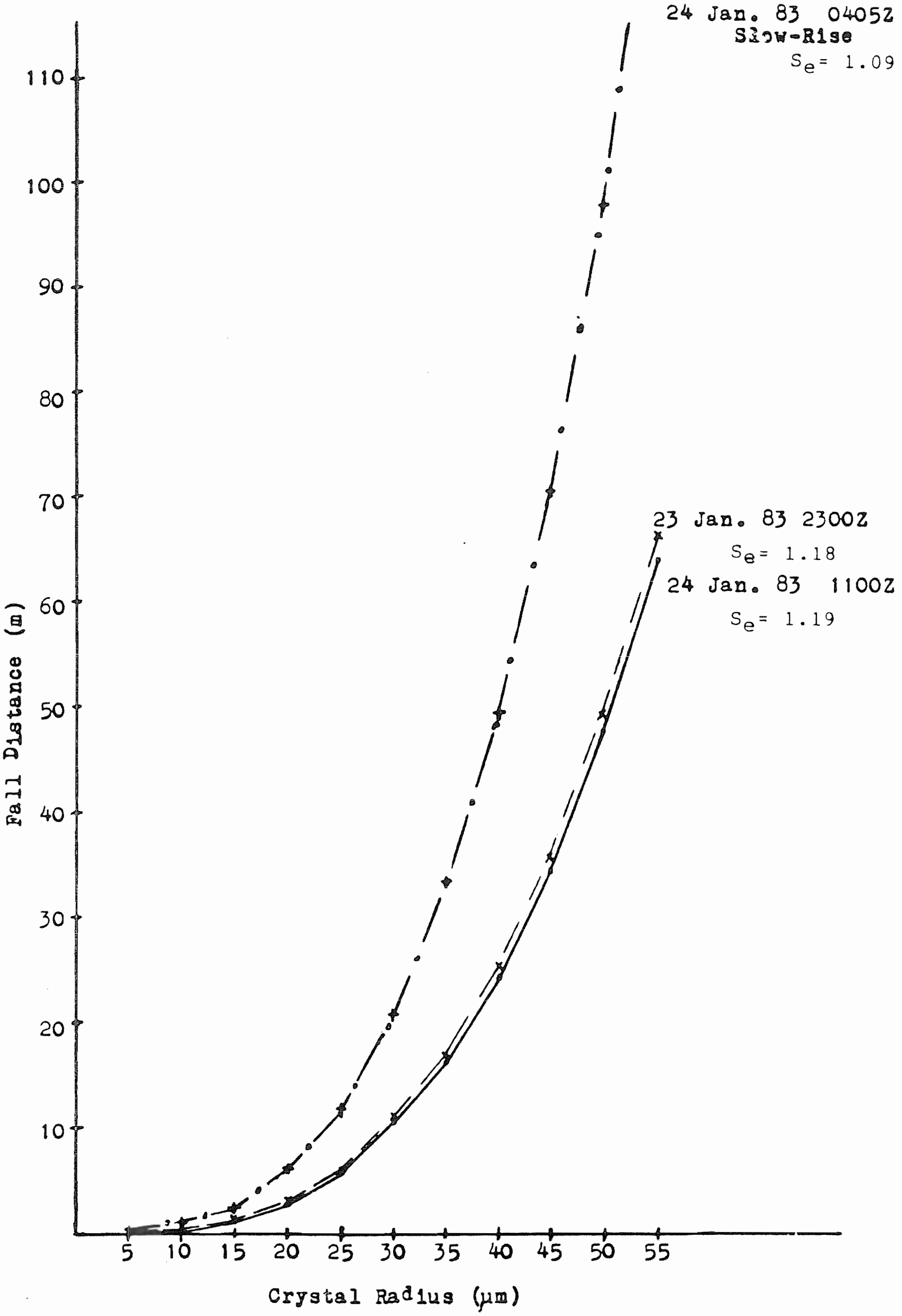

Figure 1. Plot of theoretical growth of varying thickness crystals for three cases during 23 and 24 January 1983. The polar sky had an appearance similar to midlatitude cirrostratus during this period.

Table II. Size Distribution of Suspended Hexagonal Ice Crystals for 23-24 January 1983, When Skies Had Moderately Thick Overcast Similar in Appearance to Cirrostratus.

Center Diameter of Size Interval (μm)	Percent Hexagonal Plate Crystals in Diameter Interval [Rounded to Whole Number]
10	12
20	28
30	20
40	16
50	6
60	7
70	3
80	2
90	1
100	1

Calculation of the fall distance required to produce 66% of these crystals, lying in the 20- to 40-μm-diameter size classes (i.e. 15 to 45 μm diameter interval) using the temperatures of the accompanying radiosonde ascent, show that only 20 to 60 m of fall through ice-saturated air would be sufficient.

It is interesting to note that only a small fraction of the crystals are in the 10-μm-diameter size class. Special attention was given to properly sample for small crystals, and the absence indicates that the growth is indeed rapid, with the 10-μm crystals probably falling from the lower few meters of the cloud. Crystals of 50 μm or greater diameter have a tendency to thicken or grow into columnar-type crystals. That is, they are still present and probably constitute a much greater portion of the precipitating mass, but they constitute a smaller number of crystals than the thin-plate-type crystals.

Discussion

Large equivalent amounts of water and great single-storm snow depths are produced by warm frontal precipitation in the northeastern United States and eastern Canadian provinces. These snowfalls often have cloud base temperatures of only a few degrees below freezing, and much of the moist lower air may be warmer than -20°C, where few natural particles are active ice nuclei. These warm fronts often produce heavy falls along long trajectories, which would be expected to deplete the number of particulate nuclei.

At temperatures of -30°C or colder, large concentrations of small, plate-like ice crystals often form even in pristine south polar air, with few particulate nuclei. These crystals may form on usually poor nuclei, such as sea salt as found by Kumai (1978), or perhaps by homogeneous nucleation if a relatively high saturation ratio occurs. Thin or triangular plate-type crystals are indicators of homogeneous nucleation according to Schaefer.

Braham (1967) showed that larger crystals could survive kilometer distance falls in apparently clear air. Braham and Spiers Duran (1967) found partially evaporated bullet crystals, indicative of formation at cirrus temperatures in clear air below. Heymsfield (1973) observed cirrus crystals at a maximum of 2.5 km below clouds.

The air near the surface at the South Polar plateau is cooler than the air above but generally not ice saturated. The larger number concentrations of plate-type ice crystals observed in this study, suspended in air near the surface, indicates a good cold survival for the 15-45 μm diameter plates. This would indicate that, in addition to the "cirrus-type" bullet and columnar crystals often associated with seeding lower warmer cloud layers, many thin plate crystals are also formed in cold layers -25°C or less in temperature. These crystals are capable of surviving falls at low temperature or in marginally ice saturated conditions and are also potential nuclei for lower warmer clouds, facilitating continued precipitation of large numbers of snow flakes.

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