The Study of Melting of Snowflakes in the Atmosphere

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ABSTRACT

The phenomena of melting of snowflakes in the atmosphere have been studied by analysis of surface weather observation, laboratory experiment, theoretical calculation, and field observation.

Analysis was made of the relationship between forms of precipitation and surface meteorological elements. The occurrence frequency of snow increased with decreasing air temperature and relative humidity. That of sleet and rain increased with increasing temperature and relative humidity. With increasing precipitation intensity, in this case, sleet rather than rain frequently occurred. These results suggest that the melting of snowflakes in the atmosphere is influenced not only by air temperature but also by relative humidity and precipitation intensity. The precipitation intensity is probably associated with snowflake size or density, and according to Gunn and Marshall (1958) snowflakes of larger size become dominant as precipitation intensity increases. It is presumed that sleet is likely to form at high intensity of precipitation because large snowflakes melt slowly.

In the experiment, the melting process of snowflakes was observed in a vertical wind tunnel in an airstream of 5.5 °C in temperature and of 100 cm sec^{-1} in velocity. The examination revealed that no break-up of snowflakes took place in melting and that the melted water did not accumulated on the snowflake surface but percolated into the inside. The percolation may be due to capillary action. By the above result, a micro-physical model was proposed of a snowflake in melting. Using the model, an empirical formula for the melting rate of snowflakes, which is expressed as the rate of decrease in radius R by melting, was obtained to give the relation $dR/dt = -\varepsilon \tilde{a} (K\Delta T + L_V D \Delta\sigma)/L_f \rho_i R$. The coefficient ε is an adjustable parameter to bridge the gap between experiment and theory, and evaluated as 1.75. $\tilde{a}$ is the ventilation coefficient of spheres, K the thermal conductivity of air, L_V the latent heat of vaporization of water, D the coefficient of molecular diffusion of water vapor in air, ρ_i the density of the snowflake, $\Delta\sigma$ the difference between water vapor density of airstream and equilibrium water vapor density on the snowflake surface, and ΔT the temperature difference between snowflake and ambient airstream.

Using the empirical formula as a basic equation, simulation of melting of snowflakes in the atmosphere was made to estimate the effects of air temperature, relative humidity, and snowflake size and density on the process of melting; the effect of relative humidity and snowflake size and density in particular was noted in this simulation. The results indicated that the fall distance for the onset of melting below freezing level increased with decreasing relative humidity and that the fall distance for

the completion of melting increased with decreasing relative humidity and with increasing snowflake size and density. If the air below freezing level is subsaturated, say 50 %, snowflakes reach the ground in unmelted condition, even at a warm surface air temperature of 5 °C. If it is saturated, snowflakes begin to melt from just below freezing level. Snowflakes of ordinary size, with equivalent diameter 1-4 mm in raindrop, completed melting within several hundred meters below freezing level. Large snowflakes with diameter 5-6 mm in raindrop did not complete melting as far as 1 Km below freezing level. The fall distance for the completion increased further with decreasing relative humidity.

The fall distance for the onset of melting is explained in terms of wet-bulb temperature of snowflakes. With decreasing relative humidity, the wet-bulb temperature of snowflakes decreased and snowflakes which would have a wet-bulb temperature below 0 °C do not melt. The fall distance for the completion is interpreted by the heat capacity of snowflakes and latent heat due to evaporation of water vapor from the snowflake surface; large snowflakes with large heat capacity melt slowly and a large amount of evaporation of water at low relative humidity suppresses the melting rate.

To verify the result of simulation, field observation has been carried out of snowflake water content, fall velocity, mass, and cross-sectional area under various conditions of surface air temperature and relative humidity. The results showed that fall velocity and liquid water content of snowflakes were dependent on surface air temperature above 0 °C, relative humidity, and snowfalke mass. Fall velocities increased with increasing air temperature and relative humidity. Increase in velocity was greater with snowflakes of smaller mass. At surface air temperatures above 1 °C, fall velocities were almost constant with respect to snowflake mass. These findings show a different tendency from the results of Magono (1953) and Langleben (1954) which were obtained mainly about non-melted snowflakes. The water content in snowflakes was highest at the highest surface air temperature of 1.8 °C. In the case of the same air temperature, it increased with increasing relative humidity and in the case of the same air temperature and relative humidity, it increased with decreasing snowfalke mass. These observations agree well with the result of simulation.

It is concluded that the melting process of snowflakes is under the control of (1) heat transfer from the ambient air to the snowflakes, (2) latent heat accompanying the phase change of water vapor on the snowflake surface, (3) heat capacity of snowflakes. The factors important in the process are air temperature, relative humidity, and snowflake size and density.

The present study will contribute to the clarification of bright-band formation in radar meteorology. It will also be useful for predicting the precipitation form and snow accretion in routine weather forecast.