Simultaneous Observation of Cool Cloud Liquid by Ground-Based Microwave Radiometry and Icing of Aircraft

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ABSTRACT

An example of measurement of liquid water in a cool cloud deck by microwave radiometry and simultaneous observation of icing of aircraft is given. Implications in use of microwave radiometers for warning of icing conditions, and in weather-modification application, are discussed. The liquid in the cloud is shown to be supercooled by supporting evidence from the National Weather Service radiosondes at Denver, Colorado.

A dual-channel microwave radiometer, utilizing the frequencies 21 and 32 GHz, has been in operation at the Weather Service Forecast Office (WSFO), Stapleton Airport, Denver, Colorado during 1978–79. The radiometer is a remote sensing system that operates continuously and unattended. By measuring emission from the vapor and liquid that are in a vertical antenna beam, independent observations of total precipitable water vapor and integrated liquid water in the zenith are provided for the WSFO. Microwave radiometers do not respond to ice in clouds, or to dry snow. The basic principles and techniques of microwave radiometry are discussed, for example, by Kraus (1966); they are essentially those used in radio astronomy. The equipment and calibration of the equipment used here are discussed by Guiraud *et al.* (1979), and Snider *et al.* (1980). The absorption coefficient of liquid water, as a function of temperature is also discussed in the latter reference.

On the morning of 15 February 1979, following a clear and relatively warm night, a heavy cloud deck moved in at 0600 MST accompanied by a decrease in surface temperature to well below freezing. The surface temperature is plotted in the first (top) panel of Fig. 1, and the cloud conditions are indicated in the fourth panel (second from bottom).

Upon appearance of the cloud deck overhead, the liquid channel of the radiometric system began indicating significant liquid water above the observing site at the airport as shown in the third panel of Fig. 1. The amount of liquid in the column overhead varied between 0.1 and 0.3 mm during the remainder of the day. Shortly after the onset of observation of the liquid, reports of icing of aircraft were received from the Flight Control Center at the airport as indicated in the fifth panel of Fig. 1.

It is tempting to conclude that the liquid being observed was supercooled. We have been able to confirm that such was indeed the case by examining

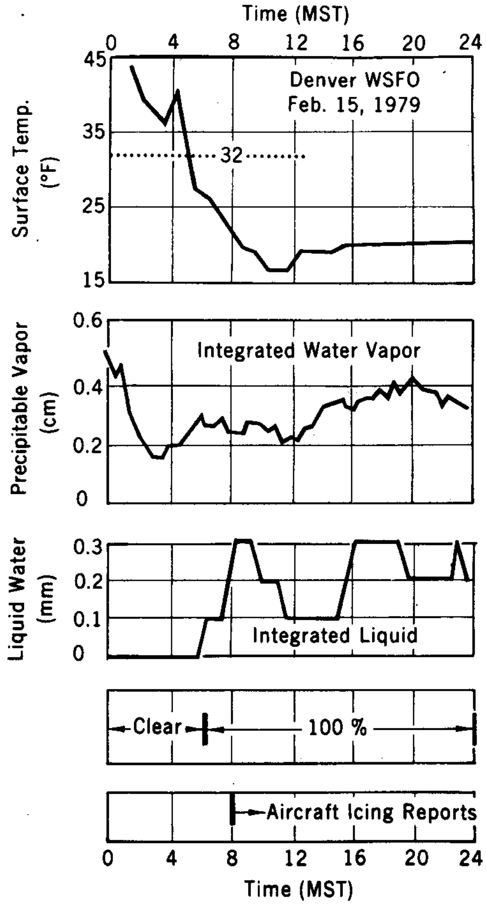

FIG. 1. Five panel plots indicating the surface temperature, precipitable water vapor, overhead liquid water, cloud cover and icing conditions on aircraft, measured at Stapleton Airport, Denver on 15 February 1979. The second and third plots are data measured by microwave radiometer.

the radiosonde data preceding and during the event. The temperature and relative humidity profiles to ~500 mb at Denver for 0500 and 1700 MST on 15 February, are plotted in Fig. 2. The 0500 profiles are indicative of the clear warm night mentioned above. But the 1700 profiles show the cloud deck still persisting between ~2300 and 3000 m altitudes. There is a considerable temperature inversion over that interval of height, amounting to ~7°C. The temperatures over the interval containing the cloud deck vary from about −14 to −7°C. Indeed the entire 1700 profile does not exhibit a temperature above −7°C. We conclude therefore that the liquid in the cloud deck (at least that measured at 1700 h in Fig. 1) was supercooled. Since the integrated liquid (at 1700 h) amounts to ~0.3 mm over a cloud deck of 700 m thickness, the mean density of the supercooled liquid was ~0.45 g m^{-3}; at present the errors to this estimate are unknown.

In weather-modification experiments, a major decision to be made is which cloud to seed, and when. It is felt by some leading weather modifiers that the presence of clouds containing liquid with temperature below 0°C constitutes a favorable condition for the seeding operation. Microwave radiom-

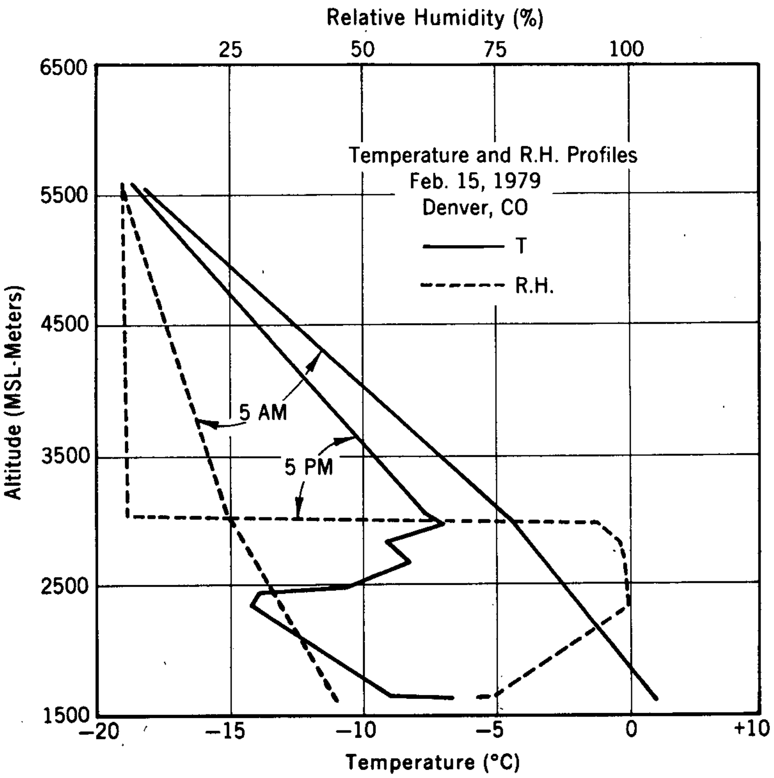

FIG. 2. Temperature and relative humidity profiles measured by NWS radiosondes at Stapleton Airport at 0500 and 1700 MST on 15 February 1979.

etry identifies a cloud containing liquid since clouds formed of ice only do not generate any signal in microwave radiometers but clouds containing both liquid and ice do produce a signal in the radiometers. It is suggested, therefore, that monitoring of clouds for liquid in this way would be of considerable benefit in weather modification. It is, of course, also desirable to measure the temperature in the cloud by remote sensing or other means to assure that the liquid is supercooled.

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