Icing Risk Detection and Avoidance

Supercooled liquid water freezes on contact, presenting serious icing hazards to drones, helicopters and other aircraft. As a consequence, military and commercial flights are often curtailed or precluded from flying in weather conditions when the risk of actual or potential icing risk can impact the asset. The lack of icing data causes mission stoppage even in cases where the risk of icing is low. Better measurements will reduce uncertainty allowing for higher mission completion rates and more productive use of assets. We discuss recent ground and aircraft-based microwave radiometer observation and analysis and its potential for icing risk identification at 20 mile or more standoff distance.

Ground-Based Observations

Temperature and liquid water density retrievals from ground-based G-band (170-183 GHz) radiometer observations of a Colorado upslope winter storm are shown in Figures 2 and 3. Liquid water density up to 0.6 gm^{-3} at temperatures as low as -8 ^{o}C is seen, identifying moderate to heavy icing risk.

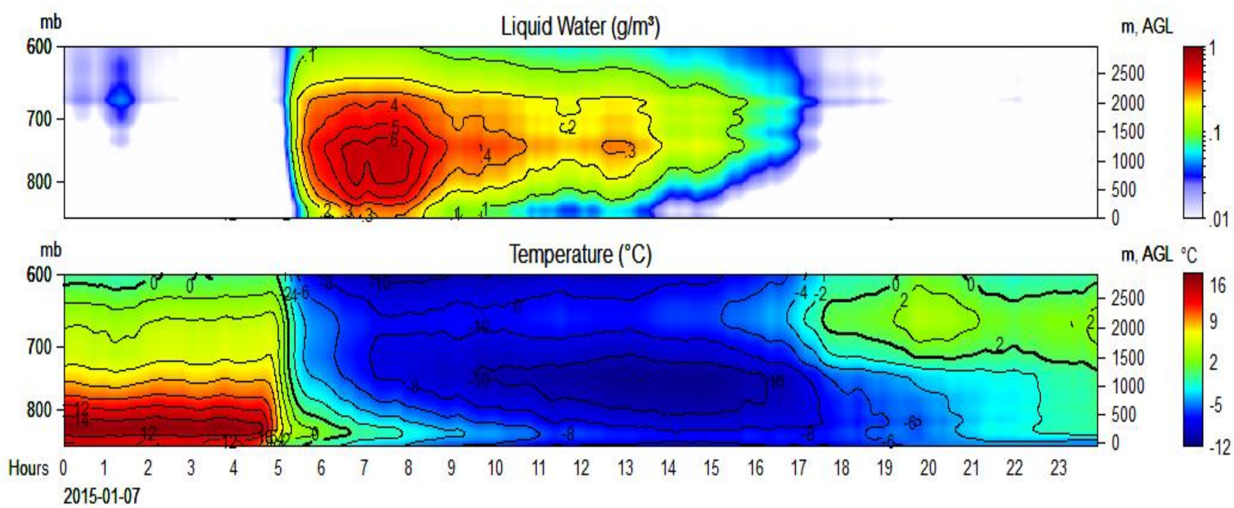

Figure 1. Radiometer air temperature and liquid (supercooled) density measurements.

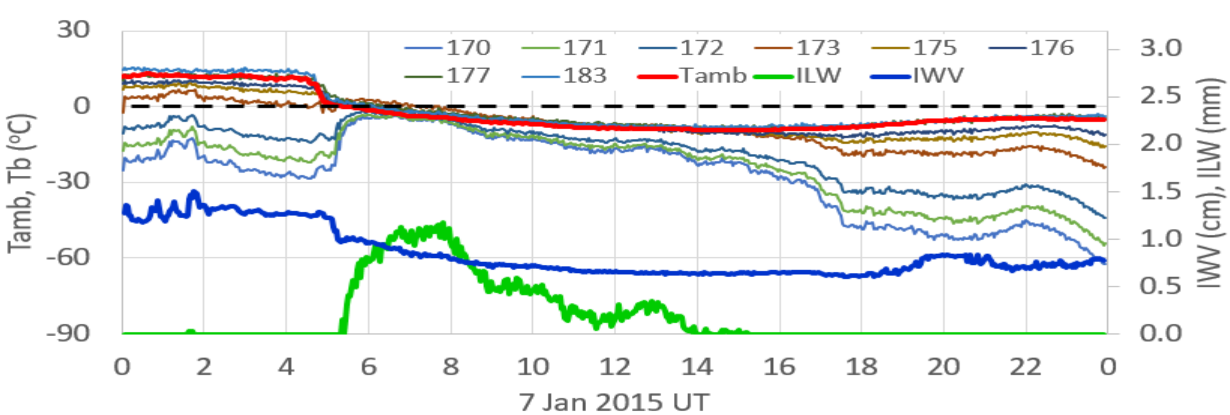

Figure 2. Radiometer ambient and brightness temperatures (Tamb, Tb), and integrated liquid water and water vapor (ILW, IWV) measurements. The black dashed line marks freezing temperature.

Airborne Sensor

A commercial multifrequency G-band microwave profiler (MP-G) mounted in the forward baggage compartment of a cloud seeding aircraft, is shown in Figure 3. The baggage compartment door is outfitted with a microwave radome for side-looking radiometer observation.

Figure 3. Side-looking aircraft-based G-band microwave radiometer and radome (insert).

Flight Observations in Cloud

Side-looking brightness temperature (Tb) observations in subfreezing liquid and ice cloud conditions, and flight altitudes, are shown in Figures 5 and 6. Temperature was ~15 °C on the runway during takeoff (2:55-3:07 UT) and landing (4:40-4:45 UT), and approximately -4 °C during level flight (3:25-4:25 UT). The radiometer looked upward during right turns and downward during left turns at the indicated elevation angles.

The second 10 °C right bank field of view shows colder Tb's identifying lower icing risk than the first. Colder Tb's for the first 20 °C right bank identifies lower icing risk than the second. Level flight fields of view identifying lower icing risk (Tb expansion) are marked with green arrows, with higher risk (Tb compression) marked with red arrows.

Downward looking left bank Tb's for the lower frequency channels would show ground temperature (~15 °C) with no liquid in the field of view. Instead, they converge at 0 °C identifying near freezing liquid in the field of view, consistent with marginal icing risk.

Additional aircraft-based G-band radiometer observations of supercooled cloud liquid and ice, complemented by wing camera images are consistent with results shown above[1].

[1] Ware et al, 2017.

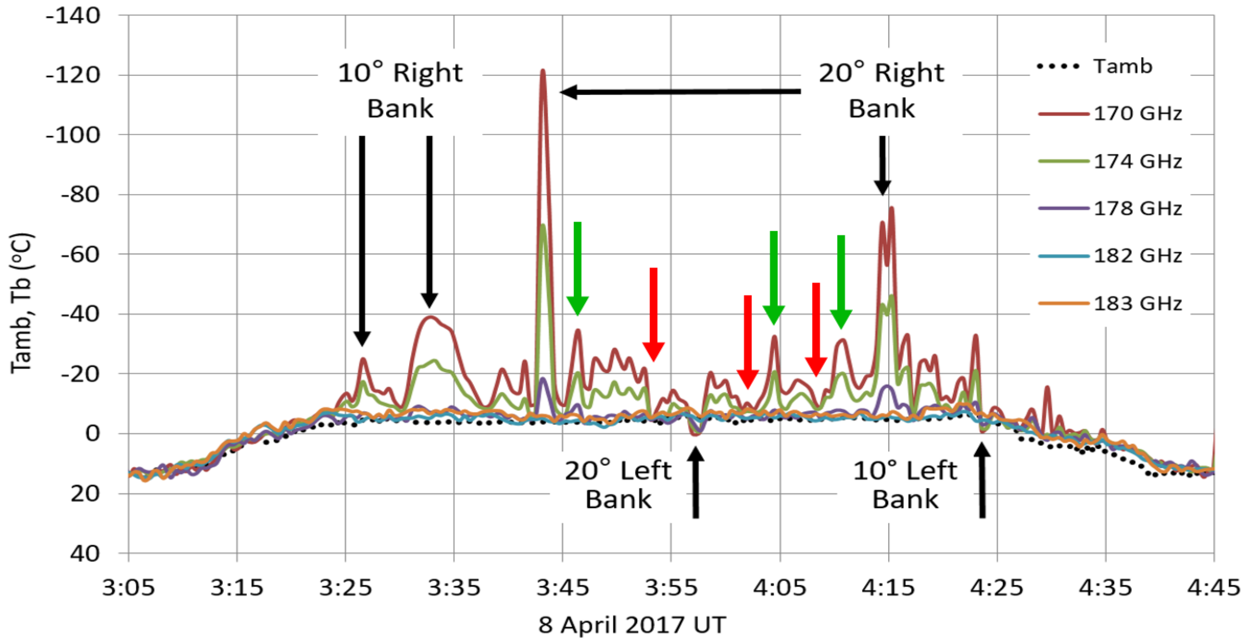

Figure 4. In flight side-looking ambient (Tamb) and brightness (Tb) temperatures. High and low icing risk flight paths are identified by red and green arrows.

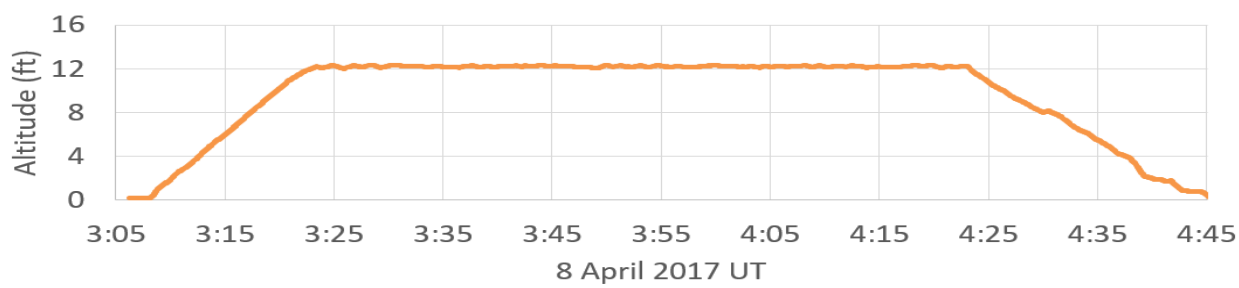

Figure 5. Flight altitude.

Downward looking left bank Tb's for the lower frequency channels would show ground temperature (~15 ºC) with no liquid in the field of view. Instead, they converge at 0 ºC identifying near freezing liquid in the field of view, consistent with marginal icing risk.

Additional aircraft-based G-band radiometer observations of supercooled cloud liquid and ice, complemented by wing camera images are consistent with results shown above[2].

Simulations

A three-dimensional radiative transfer model was used to determine the feasibility of a forward-viewing passive sensor for remotely detecting hazardous icing conditions[3]. The analysis shows 160-185 GHz dependencies on the liquid water content, cloud distance and temperature in good agreement with aircraft observations. The authors conclude that compact radiometer systems to detect and range supercooled liquid are feasible.

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[2] Ware et al, 2017.

[3] Adams and Boback, 2017.

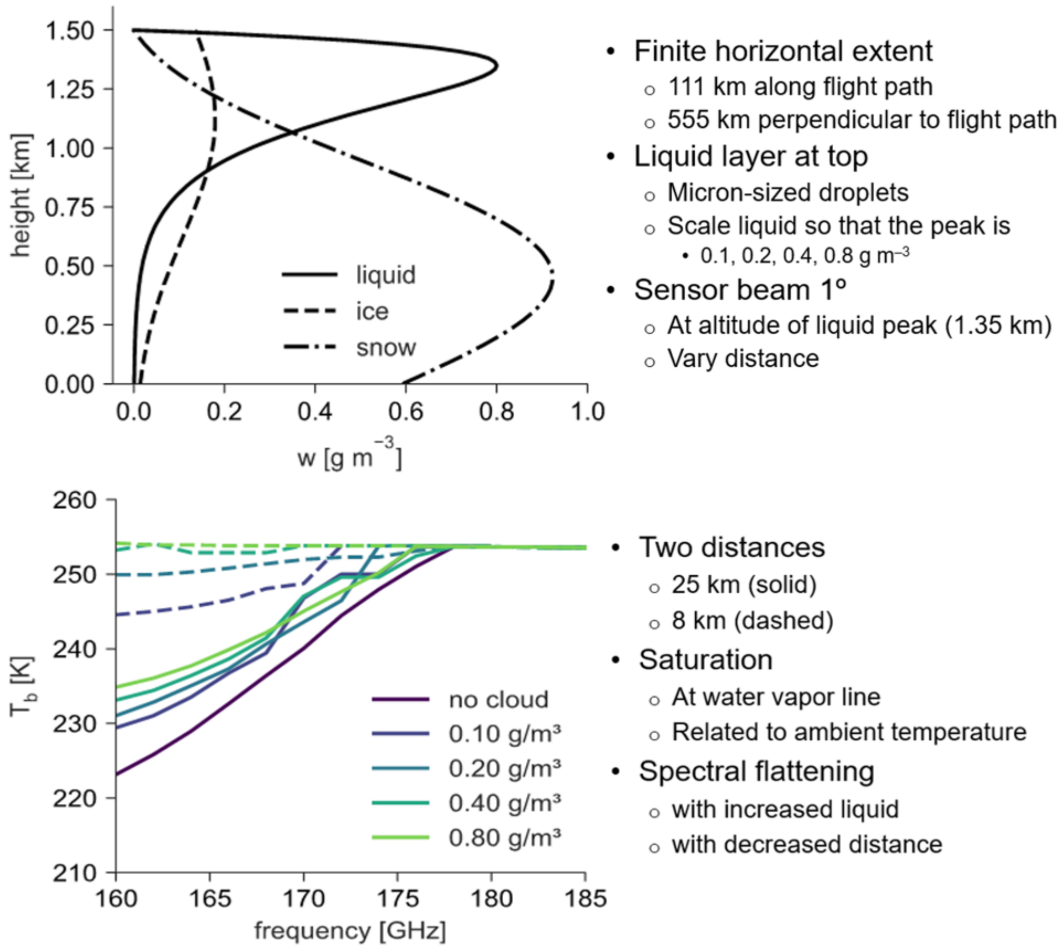

Figure 6. Simulated horizontal supercooled liquid observations[3].

Small SWaP

The aircraft-mounted G-band radiometer shown in Figure 4 is similar to the size and shape of a country mailbox. However, equivalent performance can be obtained with a cellphone-sized radiometer. Radiometrics is currently developing a small SWaP (size, weight and power) G-band radiometer design for use on drones and other aircraft under US Navy SBIR subcontract.

Discussion

Side scanning MP-G observations in horizontal, upward and downward directions show multichannel Tb compression when liquid water resides in the radiometer field of view, in contrast with Tb expansion in the absence of liquid water. Cloud and clear air in the radiometer field of view was confirmed by coordinated wing camera photos. In addition to identification of liquid water via Tb compression, compressed Tb values converge to the liquid water physical temperature. Thus, multifrequency G-band Tb observations provide liquid water range, density and temperature information essential for icing risk identification.

In summary, flight data and simulations demonstrate capability for supercooled liquid range and density determination via G-band radiometry. The sensor package can be reduced to cell phone size.

References

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