VAISALA

WHITE PAPER

Freezing conditions identification with the Forward Scatter FD70

Breakthrough technology for world-leading accuracy

1 Freezing and icing as phenomena

Icing occurs under very specific atmospheric conditions where supercooled water comes in contact with cold surfaces. Icing is an operationally significant phenomenon as ice accretion can sometimes be heavy enough to bring down trees and powerlines, cause safety issues for aircraft, and make roads and pathways hazardous.

Icing is often caused by supercooled liquid precipitation, or freezing precipitation. Typically, freezing precipitation forms in the atmosphere by following a pattern of temperature changes in the right order. Precipitation often starts as snow in cold air, then melts as it falls through a warm air layer. As the droplets reach cold air again closer to ground, they become supercooled. It is possible for water droplets to exist below freezing and remain in liquid form in the absence of nucleus: These supercooled water droplets turn into ice as they strike surfaces that are close to or below freezing. Different icing conditions are characterized by different droplet sizes, the precipitation type and content, and the air temperature.

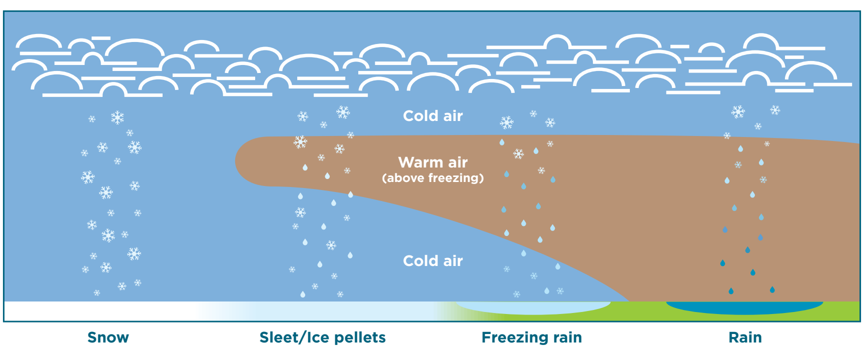

Figure 1. Development of winter precipitation

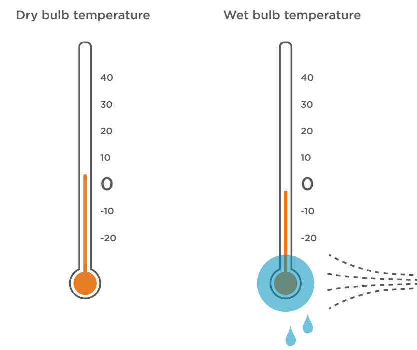

Figure 2. Dry bulb and wet bulb temperatures

Wet-bulb temperature

Wet-bulb temperature takes evaporative cooling into account which makes it more useful for identifying freezing and icing conditions. Instead of air temperature, wet-bulb temperature should be used to identify freezing conditions where precipitation might be supercooled. This is because freezing rain rarely occurs when the wet-bulb temperature is above freezing, but it can easily occur with air temperature above freezing.

2 Operational impact

Awareness of icing conditions is critical weather intelligence that drives decisions on appropriate actions to either mitigate the impact of icing or to alert those impacted by icing conditions to exercise caution. Whether it's in the aviation industry where icing conditions directly affect aircraft performance and ground operation safety, road weather where icing creates hazardous driving and walking conditions, or the energy sector where ice loading impacts everything from wind turbine performance to power transmission efficiency, awareness is essential to enable a proactive response.

Most automated weather observing systems struggle to identify these conditions, and human observation is typically necessary to validate the presence of icing. The groundbreaking technology in the Vaisala Forward Scatter Sensor FD70 enables automated weather observation platforms to accurately identify these conditions in real time in an autonomous operating mode. The FD70 even excels in extremely challenging mixed precipitation environments where both frozen and liquid droplets are present.

3 Conventional sensing technologies

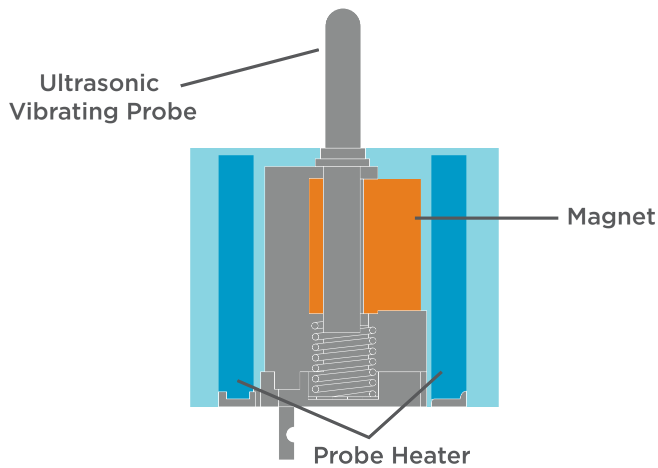

Figure 3. Ultrasonic Vibrating Probe

Ultrasonic vibrating probes

A freezing rain sensor utilizes the change in the mechanically-driven vibration frequency of a surface due to ice accumulation. Heating is then applied to de-ice the surface which restores the frequency back to its predetermined point. Sensor output in this method is binary — it is either icing or not icing. The frequency change profiles for both freezing rain and freezing drizzle are very similar. Therefore, the freezing rain sensor alone cannot distinguish between these two phenomena.

Reliable data from an additional sensor is necessary to differentiate freezing rain from drizzle and provide information about the precipitation rate. The sensor sensitivity depends upon the magnitude of frequency change, and these vibration-type freezing rain sensors are unable to sense very light drizzle (<0.2 mm/h). Snow does not cause this type of sensor to report freezing conditions, however a mixture of rain and snow frequently does.

Impedance-based sensors

Another type of freezing rain sensor employs impedance-based water and ice detection. In this method the conductivity of an ice or water layer is measured, and within a certain resolution, layer thickness can be derived. Reporting sensitivity and identification issues are similar to mechanically-driven vibration sensors.

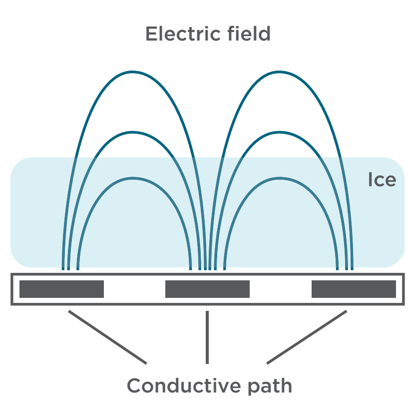

Figure 4. Impedance-based sensor

Impedance-based freezing sensors often miss light freezing drizzle and freezing fog. The sensor does not measure during the normal 10-minute de-icing heating cycle. The icing layer build-up takes time to develop, resulting in significant data reporting gaps.

Due to mechanical differences from vibration-type sensors, impedance-based sensors more often report ice layers during snow. Again, additional information is required to differentiate this ice layer from one formed by freezing rain, freezing drizzle or freezing fog.

Conventional optical sensors

Conventional optical sensors, either disdrometer or forward scatter, identify precipitation type based on residence time, scatter signal amplitude and air temperature. With scatter signal and residence time, small snowflakes look like drizzle droplets. Near 0°C, temperature information is not a reliable differentiator between freezing liquid, non-freezing liquid and frozen particles. These aspects make it difficult to identify present weather types in freezing and icing conditions, which is why conventional optical sensors are often complemented by freezing rain sensors.

4 Forward Scatter FD70: changing the paradigm

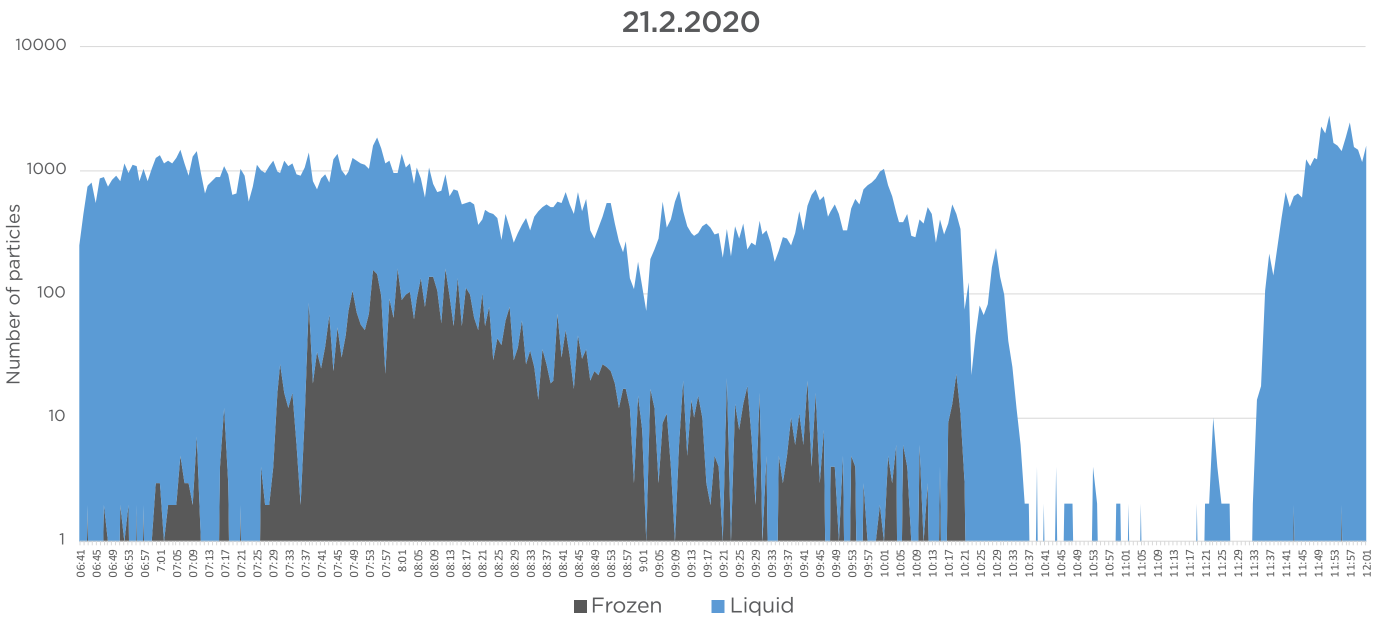

Figure 5. FD70 particle type identification based on single particle analysis by two receivers.

By employing two receivers coupled with thin light sheet transmission technology, the FD70 scans the particle from two angles. This detailed particle-by-particle analysis allows highly reliable frozen-liquid differentiation. The capability to differentiate between frozen and liquid particles—in addition to other precipitation identification—puts the FD70 present weather identification in a class of its own.

Figure 5 shows the FD70's ability to distinguish between frozen and liquid on a single particle basis. Here we show a period of about 200 minutes (07:00 – 10:20) where mixed snow and rain are clearly visible. The scatter signatures of several particles indicate that they are frozen; at the same time, there are many particles with liquid particle signatures. A human observer as well as high-resolution camera images confirmed the event (Figure 6) to be mixed rain and snow. After a short break at half past eleven, precipitation continued as drizzle and rain with practically no sign of frozen particles.

As seen from the example above, the FD70 can not only identify the present weather type, but the algorithm differentiates between frozen and liquid precipitation at the single particle level. This significantly improves the identification of light snow and light rain close to 0°C as well as the ability to accurately identify periods of mixed rain and snow, freezing drizzle and freezing rain.

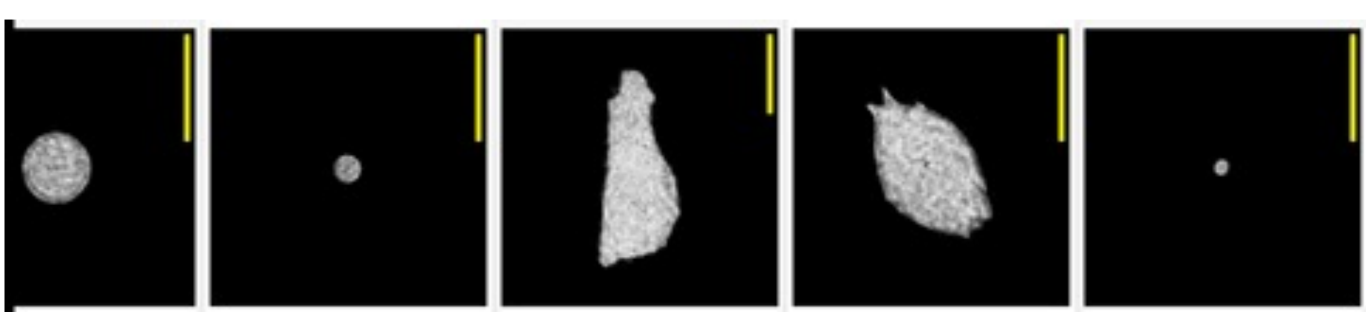

Figure 6. Particle images captured by high-resolution camera 08:04-08:05. The yellow line is 1 mm long. Both liquid (spherical) and frozen (irregular) particles are visible.

The present weather identification performance of the FD70 has been tested against various reference sensors and compared against human observations at numerous sites worldwide. One of the comparison tests was conducted at Helsinki-Vantaa airport for a period of three months, from January to March 2021, during which time, many challenging present weather conditions were encountered.

In general, a human observer cannot report rapid changes in present weather as fast as the sensor, or observe the start and end of an event as accurately. Also, subtle details such as distinguishing between mist/fog and drizzle can be tricky for human observers. (Note: Drizzle droplet diameter is larger than 0.2 mm). The FD70, however, can accurately and consistently determine droplet sizes.

It is unrealistic to expect a 100% match between a sensor and a human observer for present weather reporting. Differences often occur due to some of the above mentioned reporting discrepancies, which can be verified with high-resolution camera images.

Figure 7 covers one day of present weather reports by human observers and the FD70. From midnight to 16:00, both report snow (WMO code 71); the FD70 also reports a few one-minute events of mixed snow and rain (WMO code 67) and ice pellets (WMO code 74). The observer reports freezing drizzle at 16:15, reports snow from 16:35 to 17:10, and then continues reporting freezing drizzle until 22:20.

The FD70 reporting is a bit more varied. To understand whether it is correct, the events need to be examined in more detail. For example, reporting ice pellets (sleet) indicates the presence of a warm layer aloft where falling snow is melting and then freezing again. This re-freezing causes evaporative cooling above the surface, and likely the presence of supercooled water aloft, before it freezes again to form the ice pellets observed at the surface. These ice pellets are a possible prior indication of a coming freezing event.

When the observer first reports freezing drizzle, the FD70 reports a couple of minutes of mixed snow and rain. Also, during the second longer period when the observer is reporting freezing drizzle, the FD70 reports mostly mixed snow and rain or snow grains, with a few reports of freezing drizzle and freezing rain.

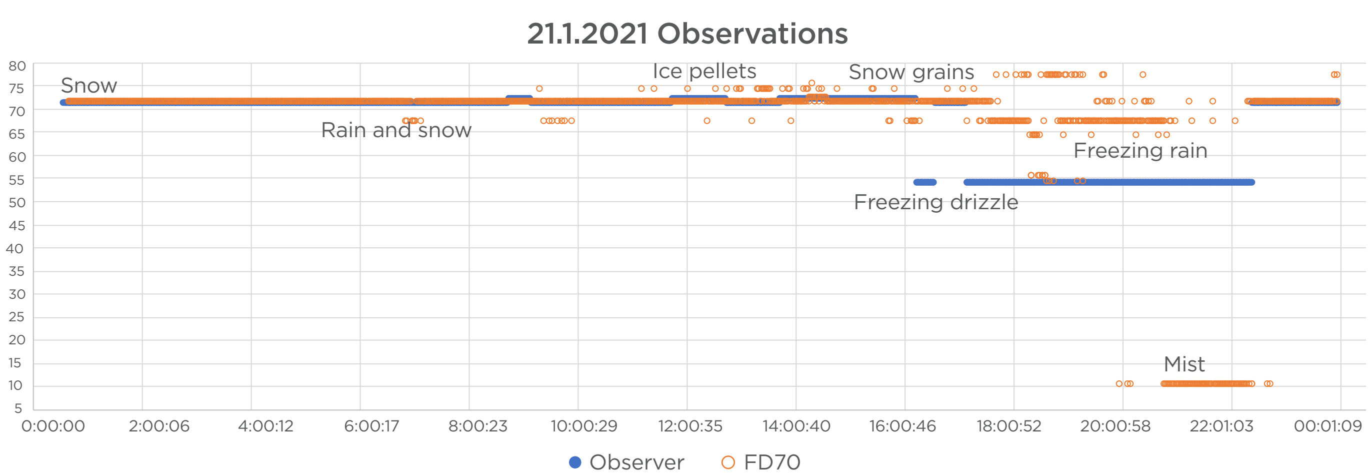

Figure 7. Present weather observations by human observer and FD70 on 21.1.2021.

High-resolution images captured during the event (Figure 8) reveal the presence of small, irregular particles mixed with spherical particles, i.e., snow or ice pellets mixed with liquid water. The air temperature during the event was between -5°C and -3.5°C.

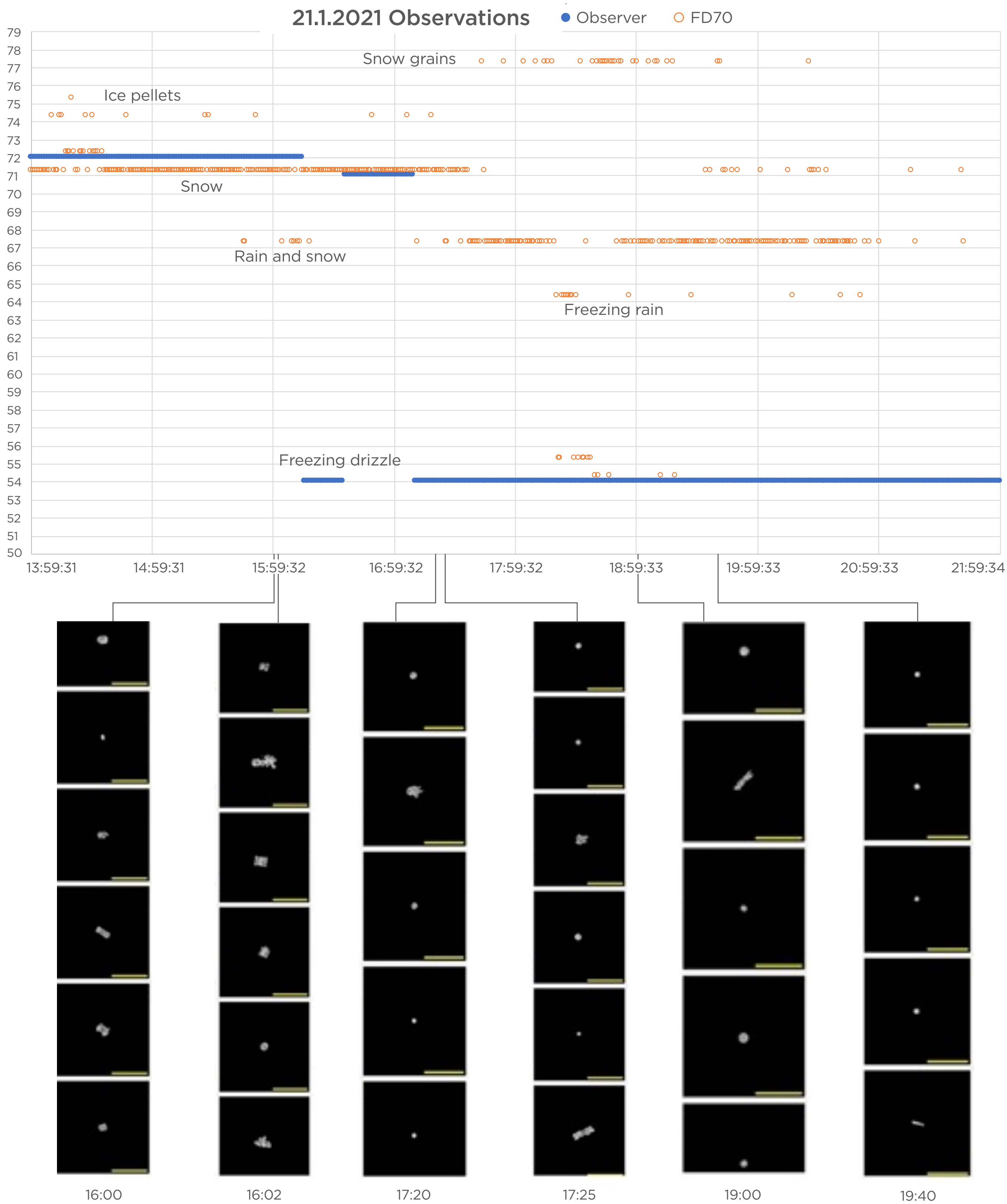

Figure 8. Zoom-in of Figure 7 data on freezing observations, including particle images captured by high-resolution camera on 21.1.2021. The yellow line is 1 mm long. Both liquid (spherical) and frozen (irregular) particles are present in the images.

The event undoubtably had freezing drizzle, and the high-resolution camera images confirm the FD70 observations of freezing drizzle mixed with frozen particles. The FD70's ability to examine every particle individually and identify liquid/frozen state makes the sensor's present weather identification very detailed. Overall, the comparison of results covering the three-month period show exceptionally high agreement between the FD70 and human present weather observations.

During the testing period, we examined the agreement of FD70 freezing conditions reporting during periods where human observers reported freezing drizzle. Here we accept as freezing identifications FD70 reports of freezing drizzle, freezing rain, freezing fog, mixed snow and rain (if wet bulb temperature is below 0°C) and mist (if wet bulb temperature is below 0°C).

Excluded are clear reports that are associated with the end of an event. Some scattered few minutes of snow reporting by FD70 that occur between freezing reporting are also excluded. These short periods of tiny snowflakes can go undetected by the observer, as discussed above and visualized by high-resolution camera images. Freezing conditions agreement between FD70 and the observer, during observer reported freezing drizzle, is above 92%. Similarly freezing rain agreement is above 97% as shown in Figure 9.

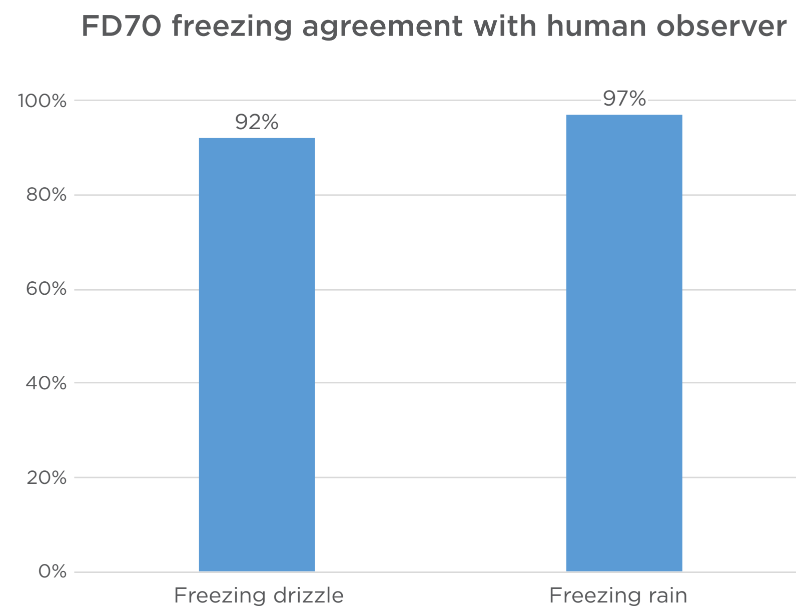

Figure 9. FD70 freezing agreement with human observer.

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