Analysis of the 23 April, 2021 plane crash in Arkansas from an icing perspective

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This document was prepared by Allyson Rugg from the Inflight Icing Team at NCAR to document the icing-focused analysis conducted for the fatal crash of a single-propeller general aviation aircraft at about 2150 UTC on 23 April, 2021. The purpose of this report is to characterize the microphysical conditions likely present around the aircraft's flight path to aid NTSB investigators in determining the cause of the accident. Satellite and radar observations are analyzed first, followed by model output from the 3-km operational HRRR model, and a special 1-km nest inside the HRRR which was run by the NOAA Global Systems Laboratory (GSL) for this accident.

Observations

Radar

Radar observations analyzed were from the Multi-Radar Multi-Sensor (MRMS) mosaic. Figure 1 (top) shows the low-level (0 - 4 km MSL) composite (maximum) reflectivity from the MRMS mosaic from 2150 UTC with the flight track shown in black and the location of the plane at 2150 marked with a red dot. The bottom of Fig. 1 shows the along-track cross section of MRMS reflectivity (shading), with temperature contours from the 1-km HRRR model in black and the flight track in red. Multiple radar scans were used to construct this cross section in order to show what was encountered by the aircraft as it travelled in real time. As a result, the radar data on the left-hand side of the plot comes from earlier scans than the data on the right-hand side.

The radar data in Fig. 1 suggest the plane took off below the leading anvil of an approaching convective system, then passed near a smaller convective cell about 120 km Southeast of takeoff. Reflectivity near the small convective cell was 15 to 25 dBZ (Fig. 1, bottom) and the plane was at temperatures between -5 and -16^{o}C, which are appropriate temperatures for airframe icing. Animation of the low-level composite (not shown) over time suggests the small convective cell was decaying at the time the plane flew near it, and this is consistent with the low composite reflectivity compared to the more widespread convection to the Southwest.

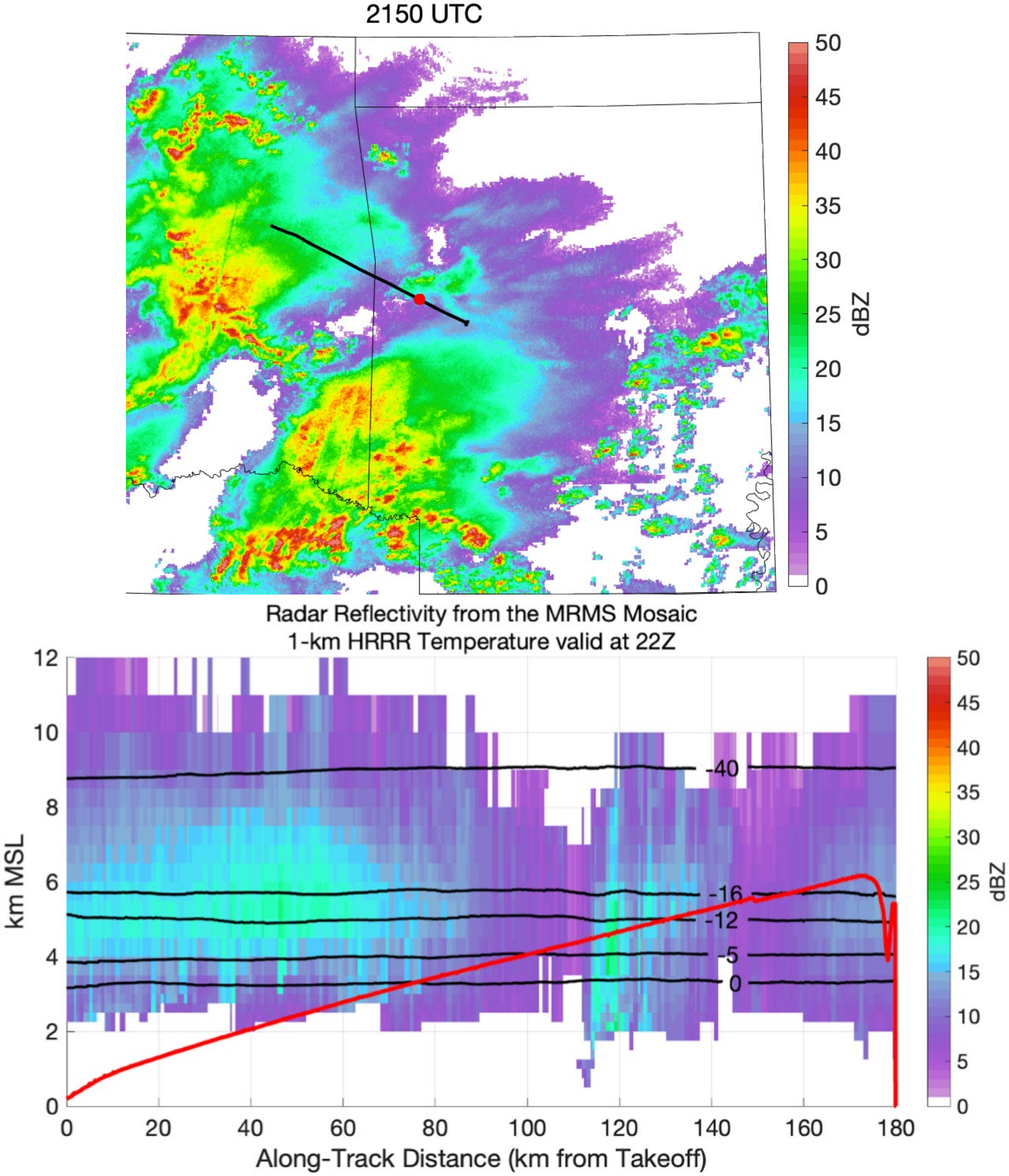

Figure 1: Top: Composite (maximum) reflectivity between 0 and 4 km MSL from the MRMS mosaic at 2150 with the flight track shown in black and the position of the plane at 2150 as a red dot. Bottom: along-track cross section of MRMS reflectivity with temperature contours from the 1-km HRRR nest (black lines) and the flight track in red.

Satellite

Satellite data analyzed were from the Advanced Baseline Imagery (ABI) on GOES-16. Data from 4 shortwave ABI channels (0.64, 1.37, 1.6, and 2.24 um) were combined into a red-green-blue (RGB) product called the “Day Icing RGB” which is shown in Fig. 2. The Day Icing RGB is designed to show cloud height, phase, and liquid particle size so that the more red indicates higher clouds, more green indicates large liquid drops or ice crystals of any size, and more blue indicates liquid phase. As such, the large orange cloud top in Fig. 2 is indicative of a high, thick, ice-dominated cloud top (orange = high green and red, low blue components). Thinner clouds appear more red, and lower ice and liquid clouds appear green and blue, respectively. Cyan areas (not many in Fig. 2) are indicative of supercooled large drops at cloud top. The large orange cloud deck in Fig. 2 is very typical of deep convection.

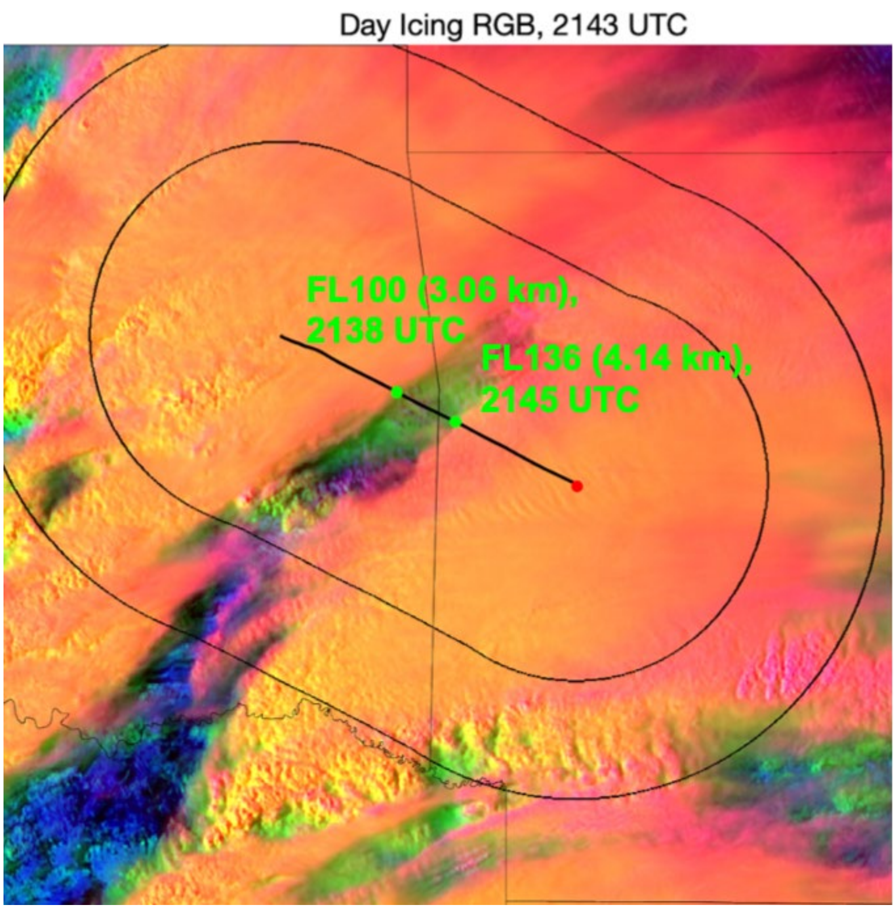

Figure 2: The Day Icing RGB from GOES-16 (shading) with the flight track in black, the crash site shown as a red dot, and green dots marking the altitude and time of two key points on the flight track. Black ovals around the flight track are 100 km (inner ring) and 100 statute miles (outer ring) from the flight track.

From a satellite perspective, this case is very similar to a flight from the In-Cloud ICing and Large-drop Experiment (ICICLE) into elevated convection in the Midwest on 23 February, 2019 (Rugg et al., in preparation). In addition to the large orange cloud deck, that ICICLE case also showed ripples in the cloud texture, which are also visible West of the crash site in Fig. 2.

During this ICICLE flight, conditions between -5 and -16°C were largely glaciated, with frequent high ice water content (HIWC, ice water content of at least 0.5 g m^{-3}) conditions. Pockets of supercooled liquid water (SLW) and freezing drizzle (FZDZ, drops between 100 and 500 um in diameter) were observed during the ICICLE case, especially in/near updrafts and at temperatures closer to -5°C. It is possible the plane in this crash encountered a similar pocket of SLW and/or FZDZ near the smaller convective cell seen in the radar imagery about 120 km from takeoff (Fig. 1), though the low composite reflectivity and decaying nature of the convective cell casts some doubt into this theory.

Model Output

Model output is consistent with inferences from radar, satellite, and parallels with the 23 February ICICLE case. Multiple forecasts from the 3-km operational HRRR valid at 2200 UTC were analyzed because models are notorious for misplacing or mistiming convection even if they get the general structure correct. Figure 3 shows 3, 2, and 1-hour forecasts (top to bottom), though longer lead times showed similar patterns. The columns of Fig. 3 show the maximum between flight levels 150 and 200 of (left to right): liquid water content (LWC), ice water content (IWC), mixed-phase total water content (TWC), and the maximum diameter of liquid drops (DMax). The flight track and crash site are marked with a black line and red dot, respectively, and the same 100-km and 100-mile rings from Fig. 2 are also shown in black. All liquid shown is supercooled, and mixed-phase TWC is defined as the sum of LWC and IWC where both were at least 0.01 g m^{-3}. The calculation of DMax follows methods from Tessendorf et al. (2021) and is defined as the 95th percentile of the model rain drop size distribution.

The various model forecasts show differences in the placement of condensate, but similar overall magnitudes and patterns which is typical of model forecasts. Only one forecast was run with the 1-km nest, and this is shown in Fig. 4. While the 3-km model shows considerable FZDZ (blue colors) Southwest of the flight, the 1-km HRRR shows very little. Otherwise, the 1-km model shows similar patterns to the 3-km results. The model runs all show IWC around 0.5 g m^{-3} near the flight track, but only small pockets of supercooled liquid, mostly to the Southwest of the flight track. This is consistent with radar imagery showing the strongest convection to the Southwest and knowledge of the similar ICICLE flight where SLW was found predominantly in updrafts.

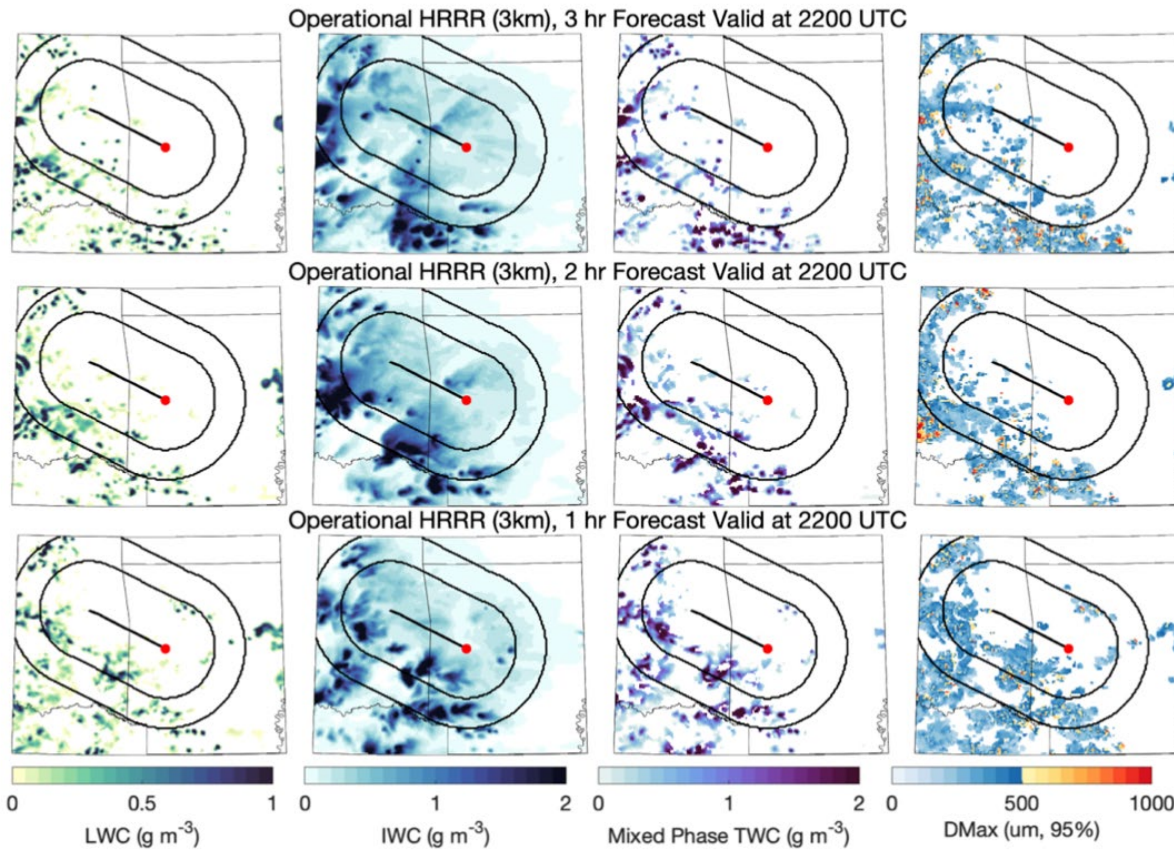

Figure 3: Maximum between FL150 and 200 of (left to right): LWC, IWC, mixed-phase TWC, and DMax from the 3-km HRRR valid at 2200 UTC. Flight track is shown in black with the crash site in red. The ovals around the flight track indicate a range of 100 km (inner ring) and 100 statute miles (outer ring) from the flight track.

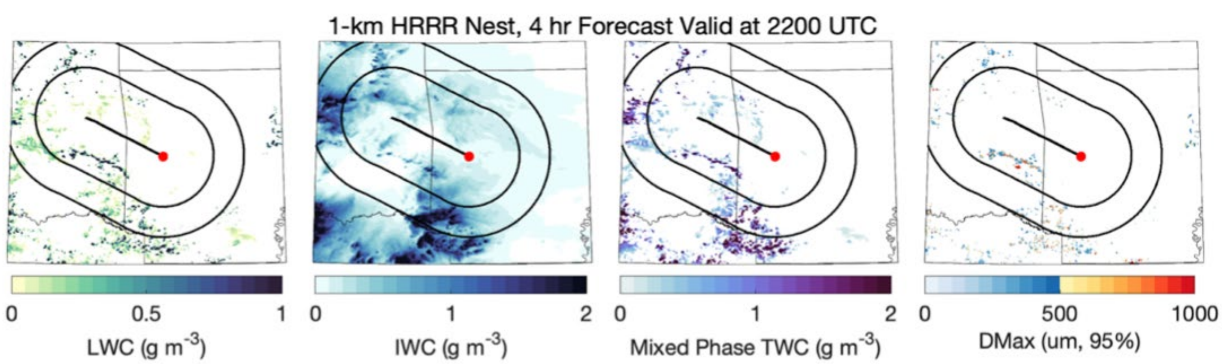

Figure 4: Similar to Fig. 3 but for the single forecast run with a 1-km nest.

In an attempt to account for uncertainty in the placement of convection in the model, the radar reflectivity simulated by the model at 4 km was compared to observed radar reflectivity at 4 km (MSL). The 4-km reflectivity was used because the model only provides reflectivity as a few vertical levels (e.g., 4 km, surface, and 0^{o}C), and of those levels 4 km is the most relevant for this case. Maximum observed reflectivity at 4 km was 21.5 dBZ, so all model points with a 4-km simulated reflectivity between 18 and 22 dBZ, temperature below freezing, and TWC of at least

0.01 g m^{-3} within 100 km or 100 statute miles were considered. If the 18 dBZ lower bound on the simulated reflectivity range is lowered, condensate decreases overall. Using these points, the distributions of the same condensate fields as Figs. 3 and 4 are shown in Figs. 5 (3-km HRRR) and 6 (1-km nest). For Fig. 5, points from all lead times available are shown, except the 0-hour diagnostic because of artifacts introduced by data assimilation. Regardless of model resolution and the choice of range (100 km or miles), less than half of points contained LWC of at least 0.1 g m^{-3} and a similar fraction contained IWC of at least 0.5 g m^{-3} (the lower bound on what is generally considered HIWC). Where mixed phase was found, over half of points contained TWC of at least 0.5 g m^{-3}, however, and over half of points contained FZDZ in the 3-km model, despite the low values of LWC.

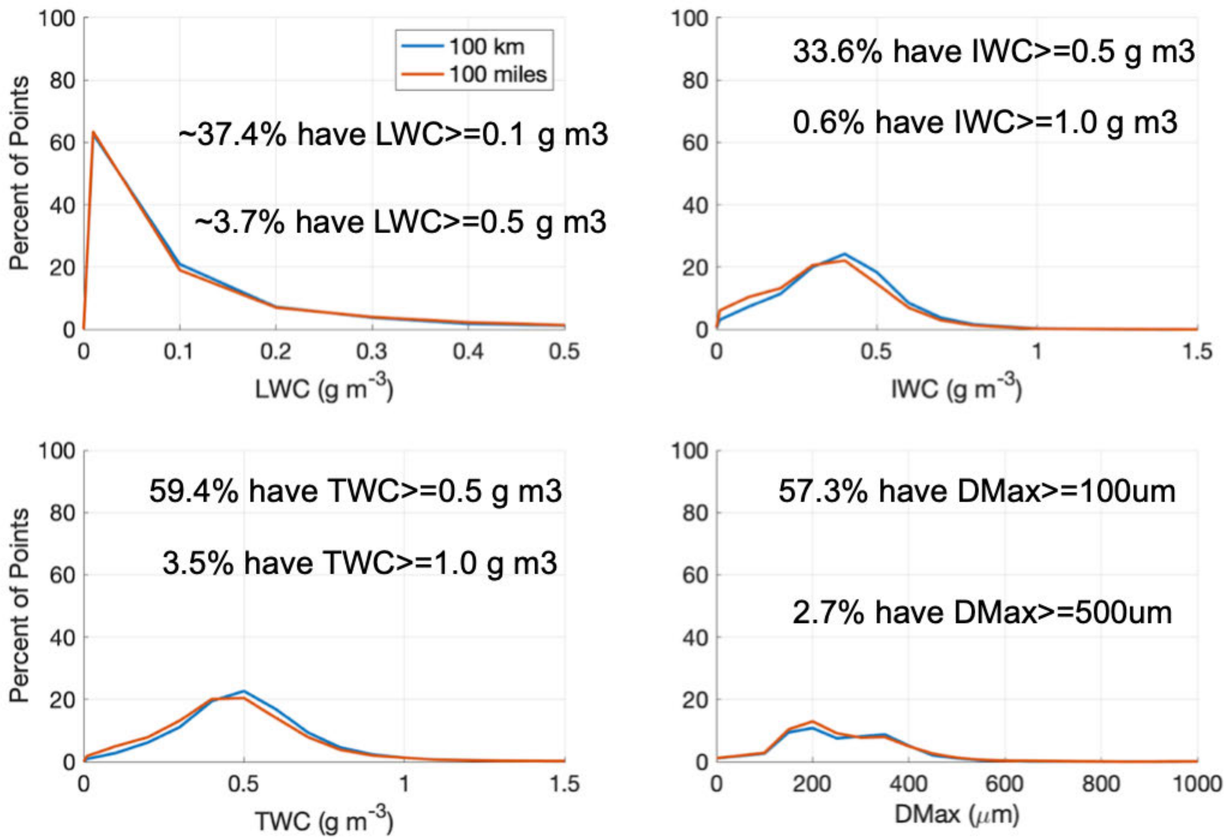

Figure 5: Distribution of (left to right, top to bottom): LWC, IWC, mixed-phase TWC, and DMax for points from all forecasts (except 0-hr) of the 3-km HRRR valid at 2200 UTC where 4-km simulated reflectivity was between 18 and 22 dBZ, temperature was below freezing, and TWC was at least 0.01 g m^{-3}. Blue and red curves show the distribution of points within 100 km and 100 statute miles of the flight track, respectively.

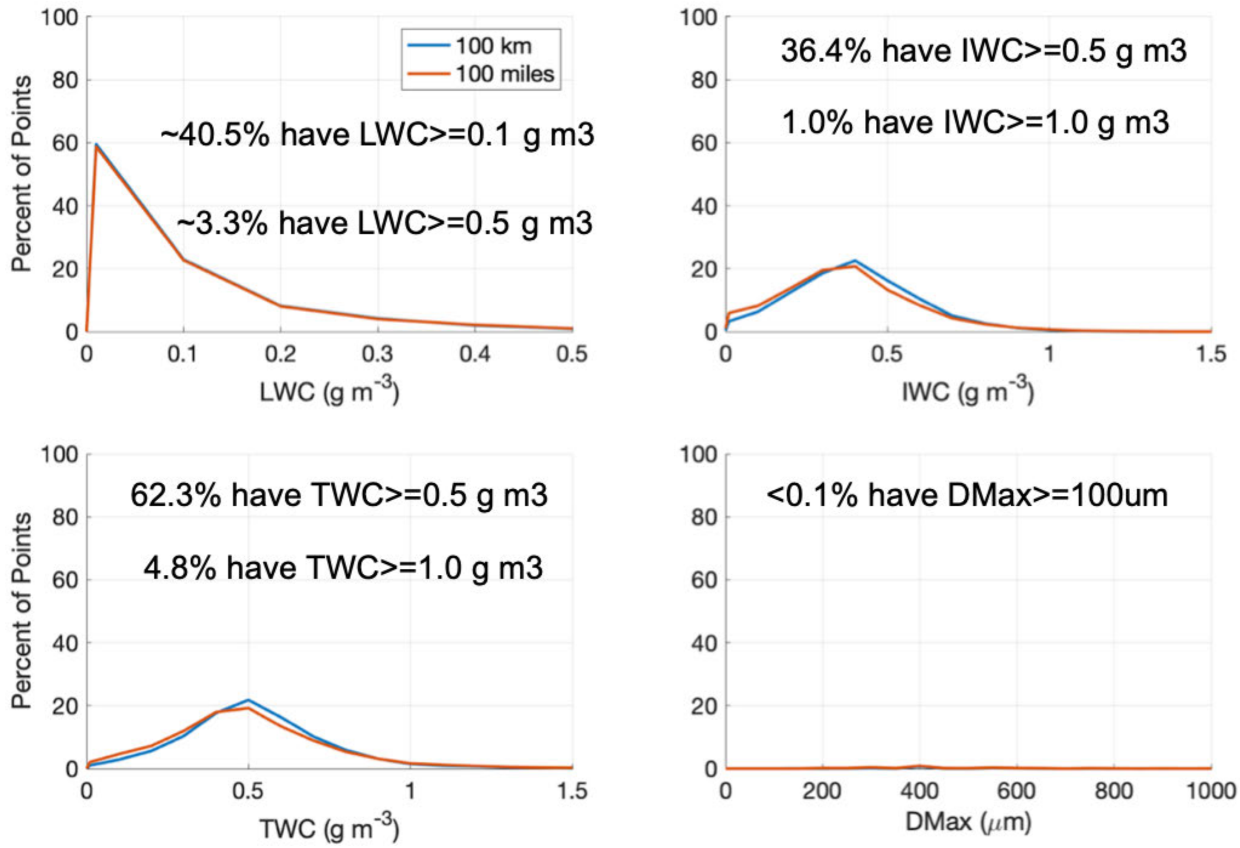

Figure 6: Similar to Fig. 5 but for the single 1-km nest forecast valid at 2200 UTC.

Summary

Generally, the conditions encountered were likely ice-dominated, possibly with pockets of mixed-phase. The liquid found in mixed-phase conditions could have been FZDZ, but probably had low LWC (below 0.1 g m^{-3}). HIWC (IWC ≥ 0.5 g m^{-3}) may also have been encountered. Unfortunately, the mixed phase conditions and convective nature of the system means there is a large degree of uncertainty in where the supercooled liquid was present and in what quantities.

References

Tessendorf, S., A. Rugg, A. Korolev, I. Heckman, C. Weeks, G. Thompson, D. Jacobson, D. Adriaansen, and J. Haggerty, 2021: “Differentiating Freezing Drizzle and Freezing Rain in HRRR Model Forecasts.” *Wea. Forecasting*, **36 (4)**, doi: 10.1175/WAF-D-20-0138.1.

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