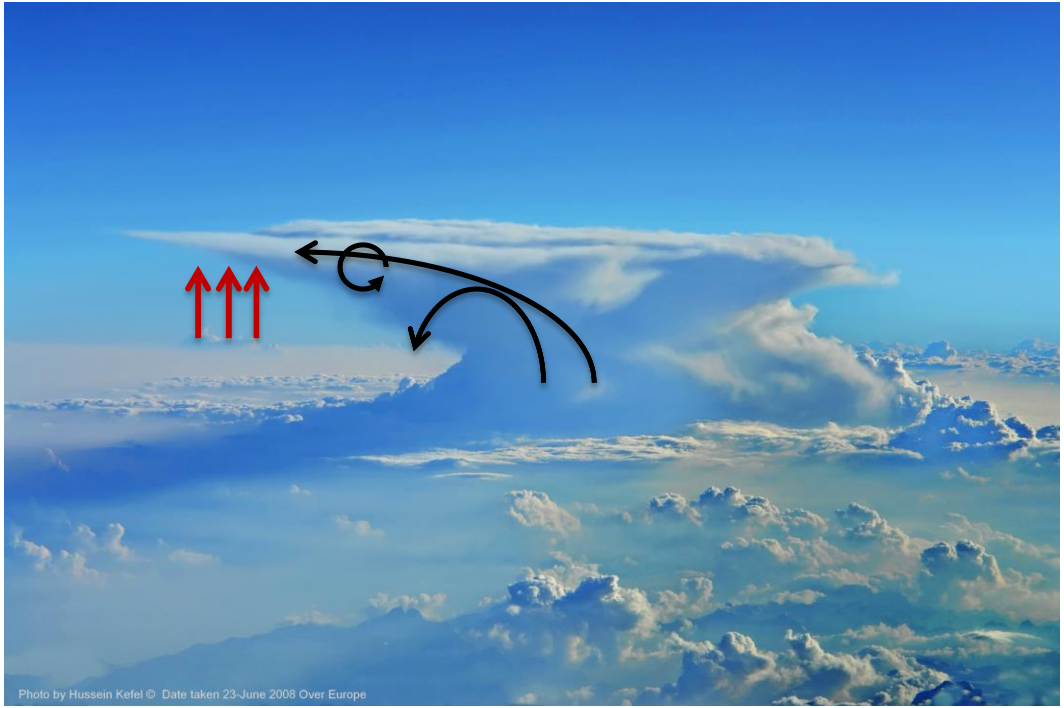
Lifecycles of ice crystals detrained from deep convection

Eric Jensen, Sue van den Heever, Sarah Woods, Bernd Kärcher



- What is the origin of ice crystals in aged anvil cirrus?
  - Persistent ice crystals detrained from convective cores?
  - Deposition growth of small crystals detrained from cores?
  - Nucleation of new ice crystals driven by waves or small-scale convection?

- Approach: track growth/sublimation-sedimentation-advection lifecycles of individual ice crystals detrained from deep convection

Pacific Oxidants, Sulfur, Ice, Dehydration, and cONvection experiment (POSIDON)

- A WB-57F mission in Guam in October 2016

Eric Jensen (NASA/ARC) and Ru-Shan Gao (NOAA/ESRL)

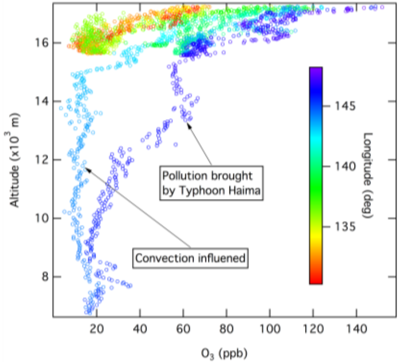
Objectives:

1. Investigate low O_3 values in the western Pacific upper troposphere
2. Investigate the transport and chemistry of sulfur species
3. Assess the validity of global model predictions of sulfur species and aerosols
4. Compare properties of convectively-generated anvil cirrus and in situ cirrus

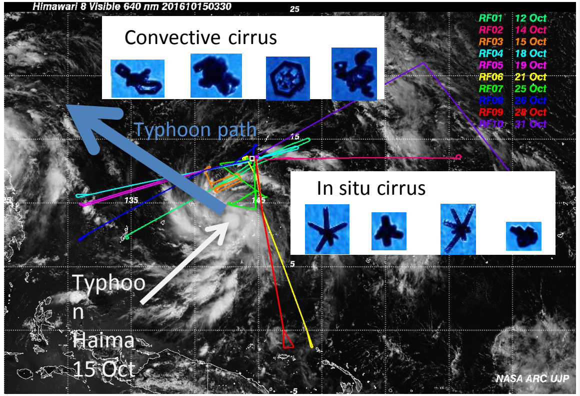
WB-57F Payload: SO_2, O_3, H_2O, total H_2O, WAS, MMS, ice shapes/sizes, PANTHER, aerosol

Balloon Payload: O_3, H_2O, Aerosol

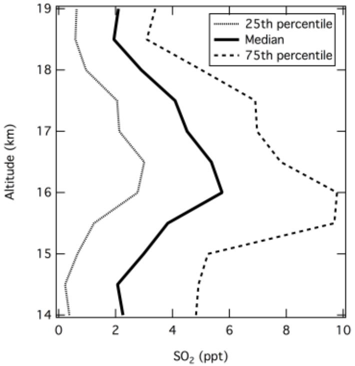
A) TTL O_3 profiles indicate both convective transport of clean maritime and polluted air



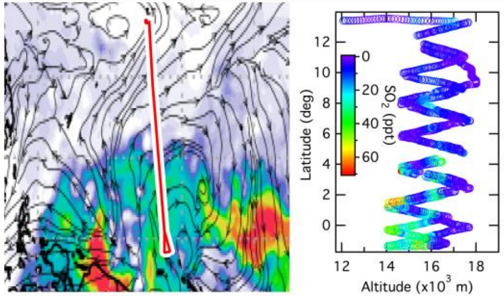
D) Flight paths on visible image showing movement of typhoon



B) Measurements indicating relatively low TTL SO_2

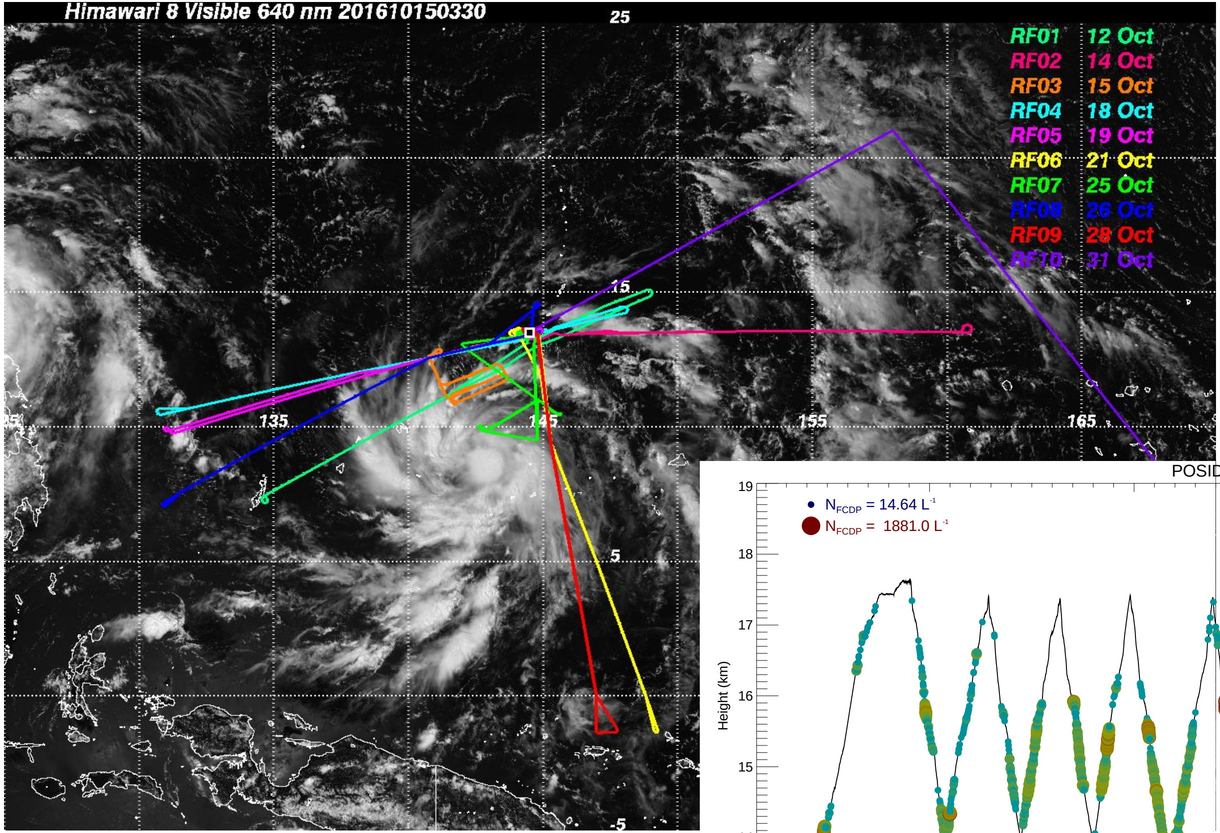


C) Sampling of volcanic SO_2 plume in the TTL forecast by GEOS5 chemical transport model



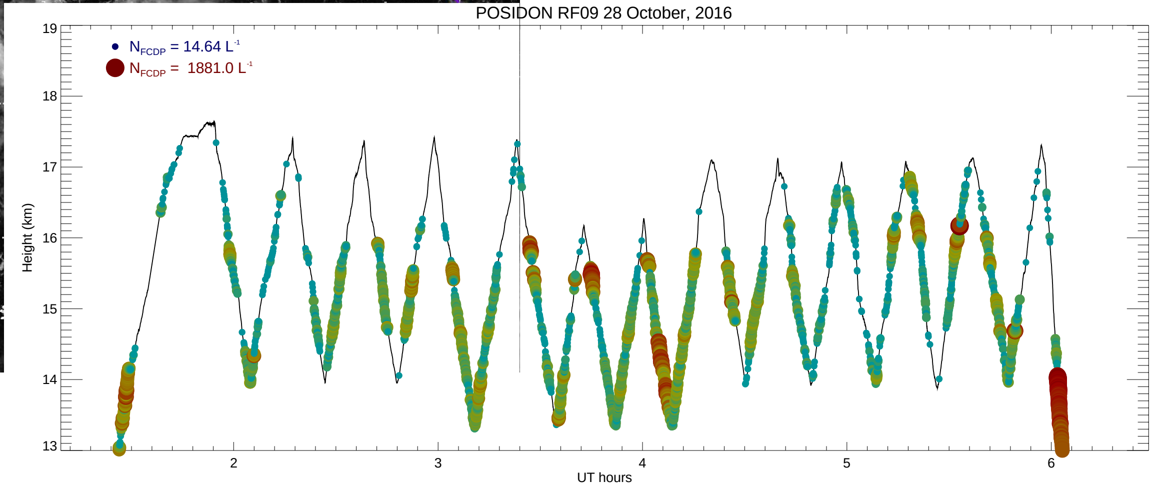
- ➔ Survey of TTL ozone concentration, including impacts of pollution and tropical cyclones (A)
- ➔ Characterization of TTL SO_2 concentration and comparison with GOES5 forecasts, including background values and pollution/volcano plumes (B,C)
- ➔ Extensive sampling of TTL gases and ice detrained from deep convection (D)
- ➔ Comparison of convective anvil cirrus and in situ TTL cirrus (D)

POSIDON flight paths

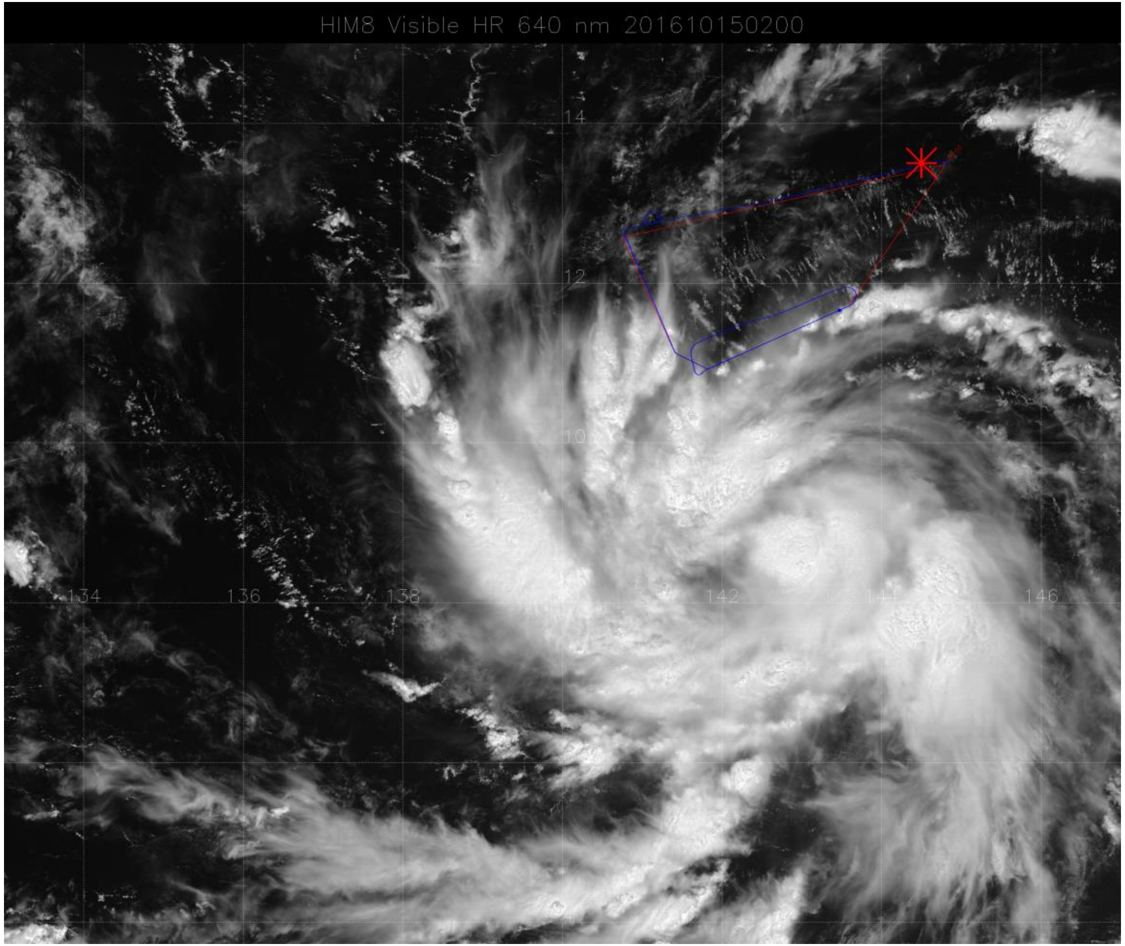


Two types of flights:

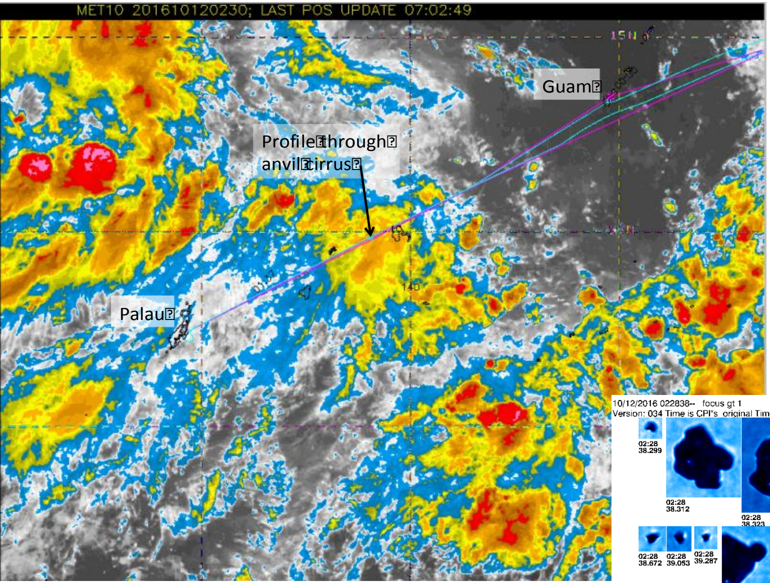
1. Out-and-back survey flights
2. Convective detrainment or residual plume

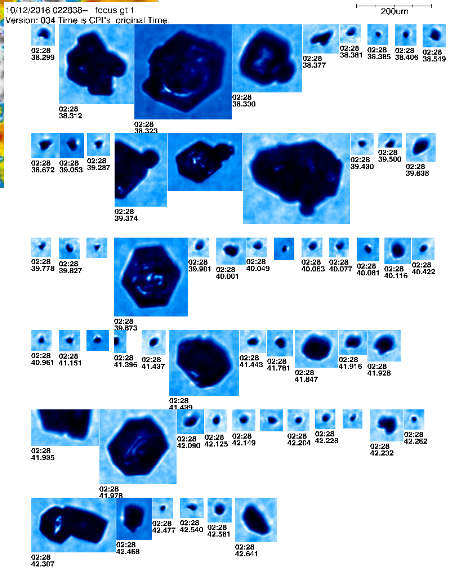


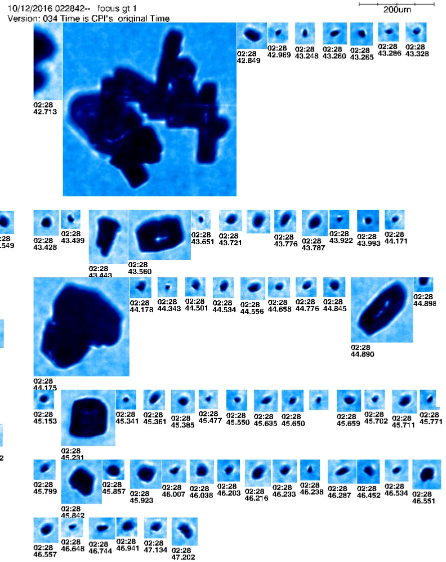
RF03: Typhoon Haima detrainment sampling

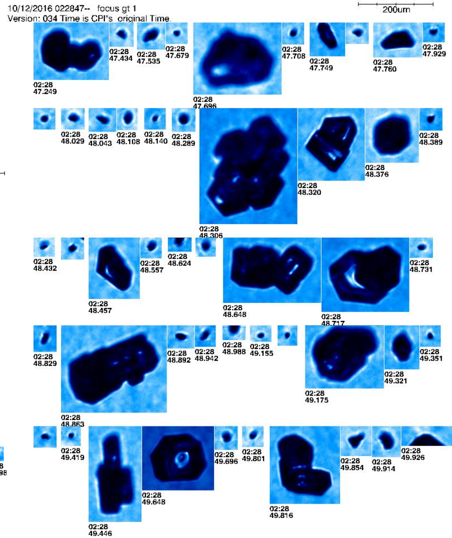


4. TTL cirrus: habits of in anvil cirrus

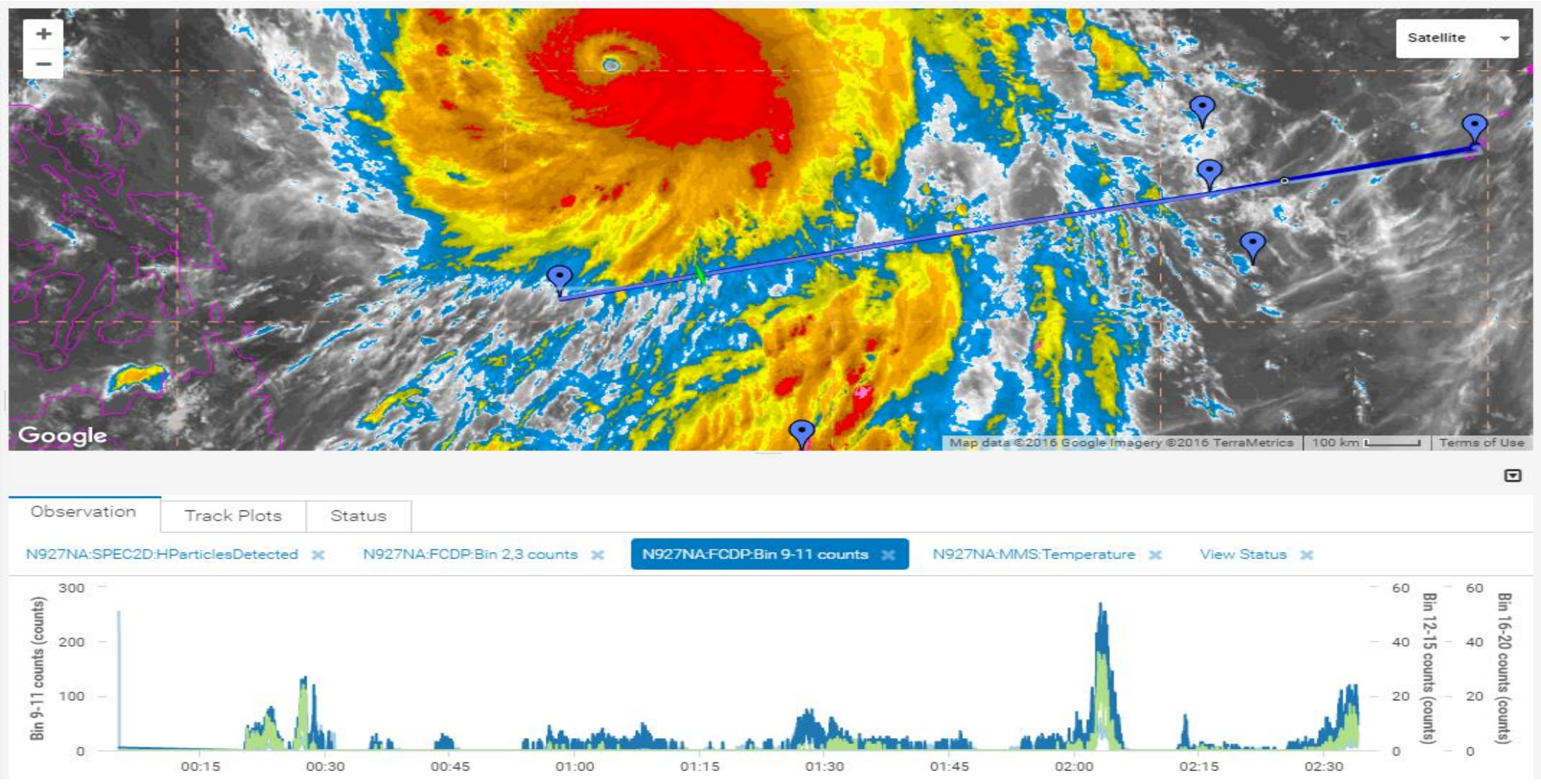




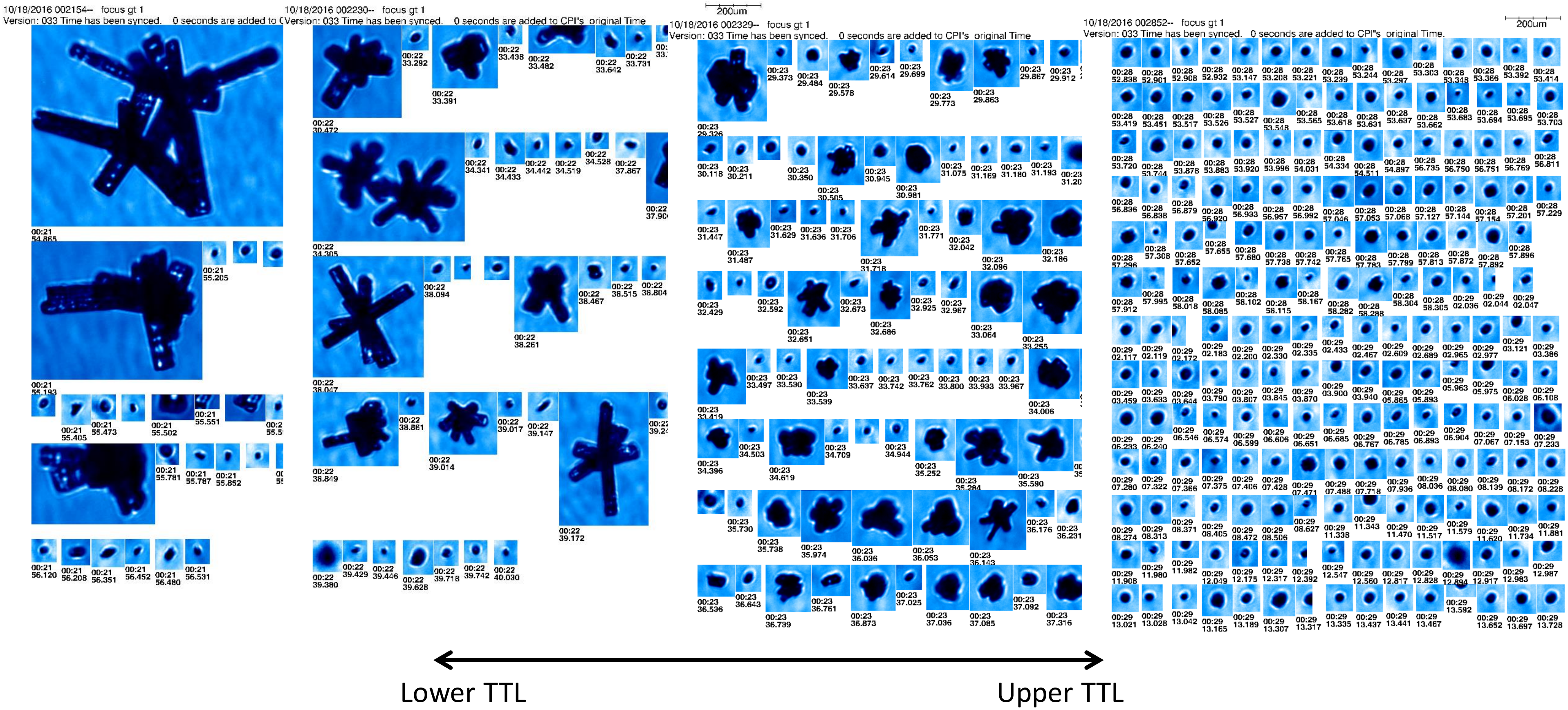


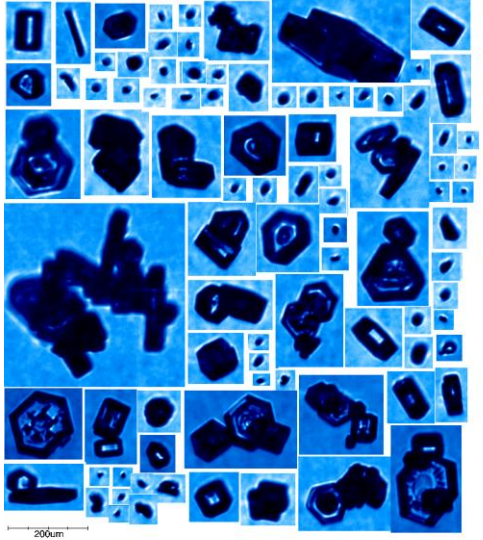


4. TTL cirrus: habits of convective and in situ cirrus ice crystals



4. TTL cirrus: habits of in situ cirrus ice crystals



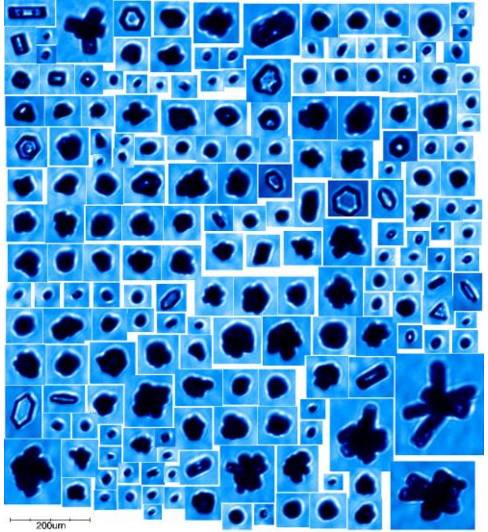


CPI Sample Images:

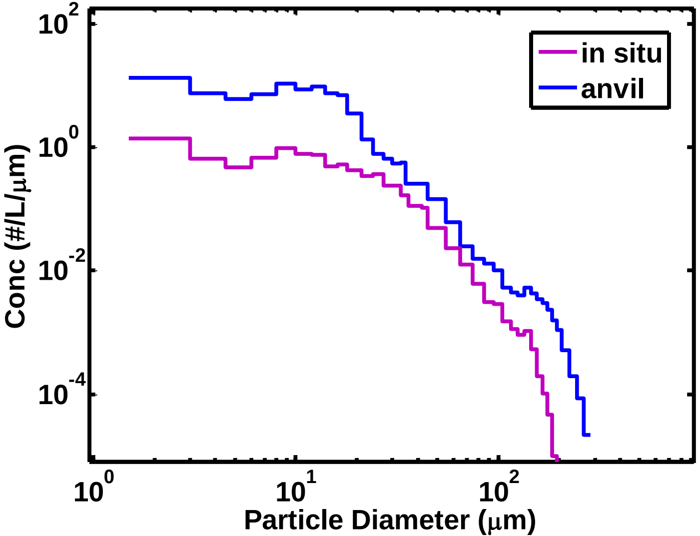
200 µm

Anvil

In situ



FCDP and 2D-S Composite PSD



Anvil TTL Cirrus

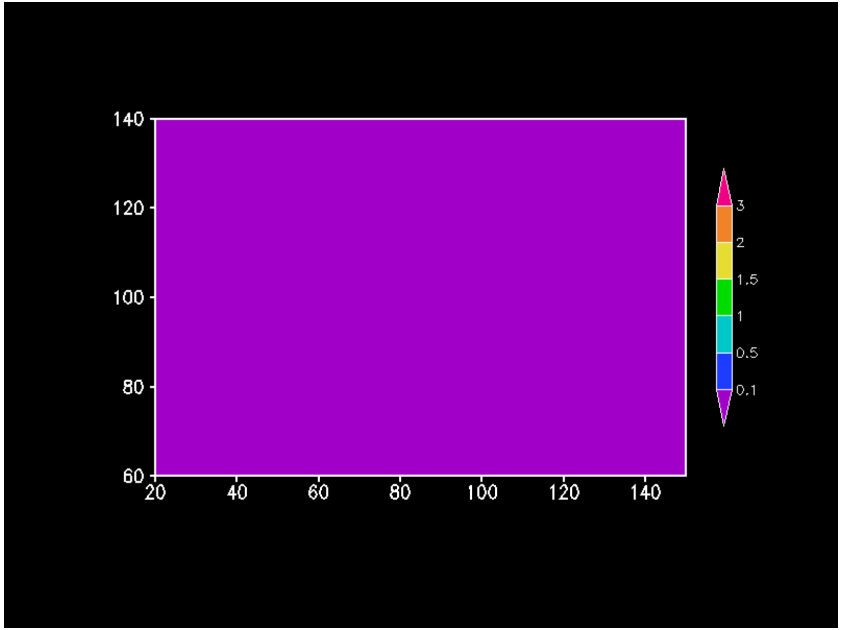
- Aggregates
- Larger particles
- Higher concentrations
- Columns, plates, irregulars, quasi-spheroids

In Situ TTL Cirrus

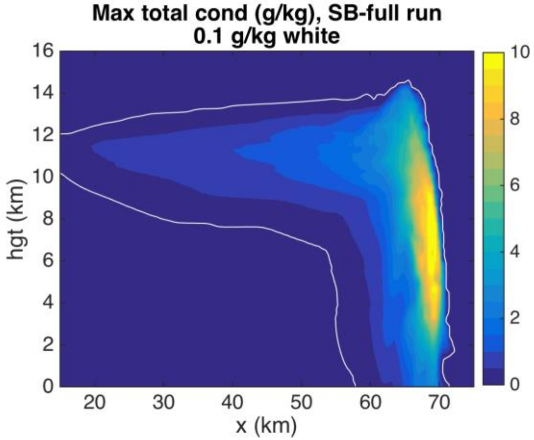
- No aggregates
- Fewer large particles
- Lower concentrations
- Columns, plates, irregulars, quasi-spheroids, & budding and bullet rosettes

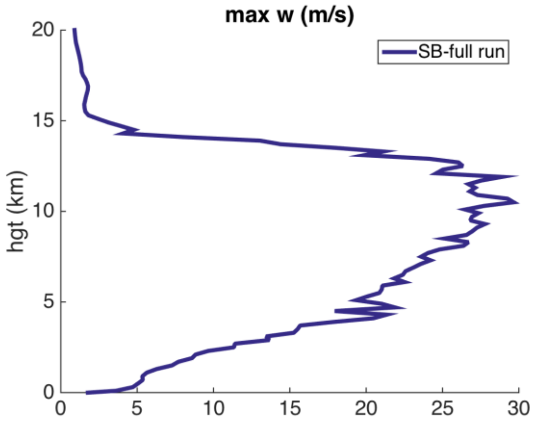
S. Woods and P. Lawson

Storm Characteristics

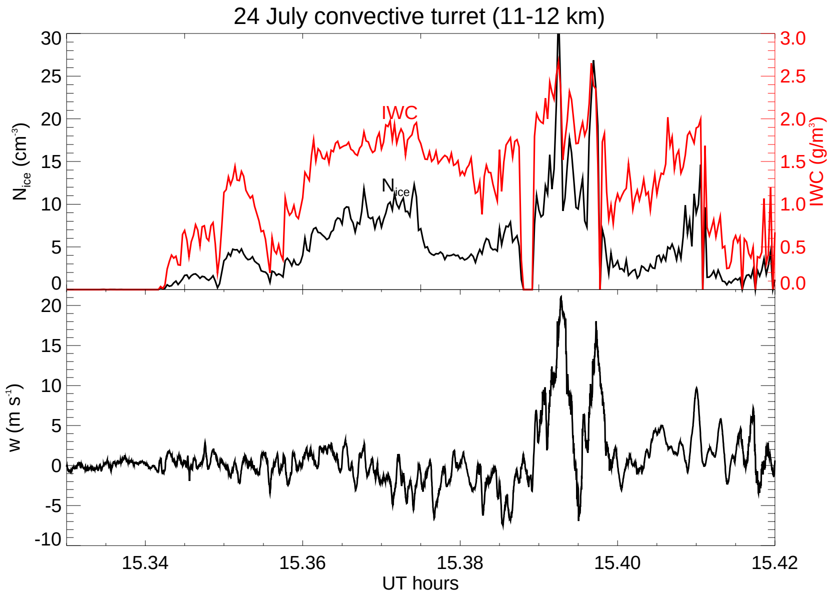


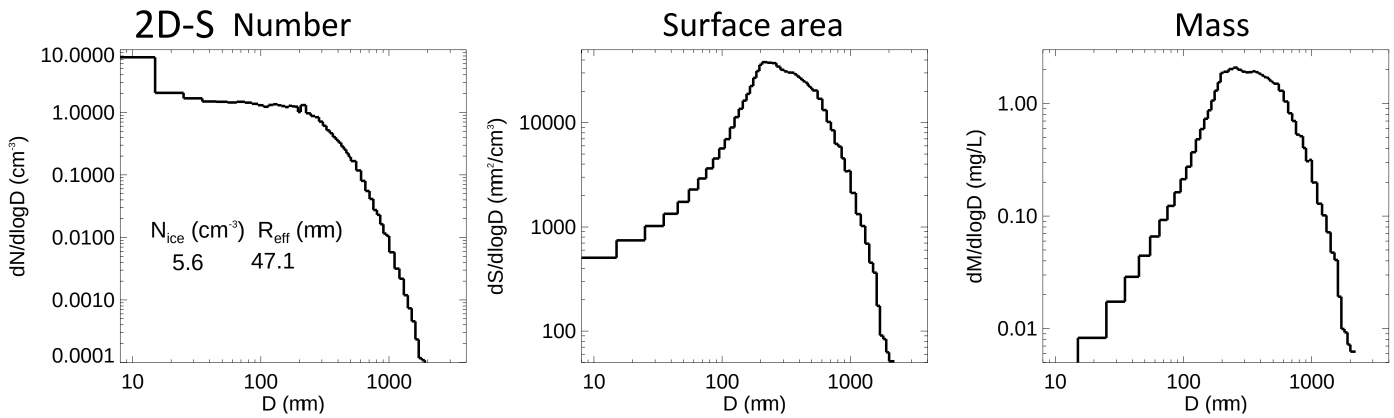
Plan view of ice water path (mm, shaded) and vertical velocity at 9.7 km (black contours, 5 and 10 ms^{-1})





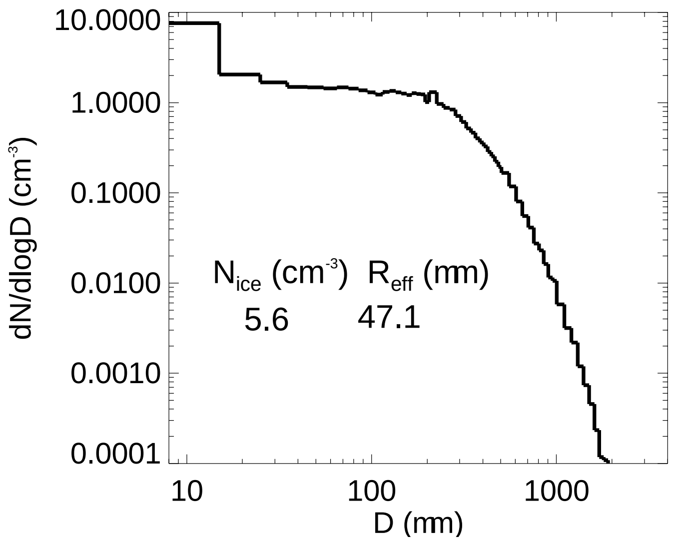
TC-4 DC-8 transit through convective core at 12 km



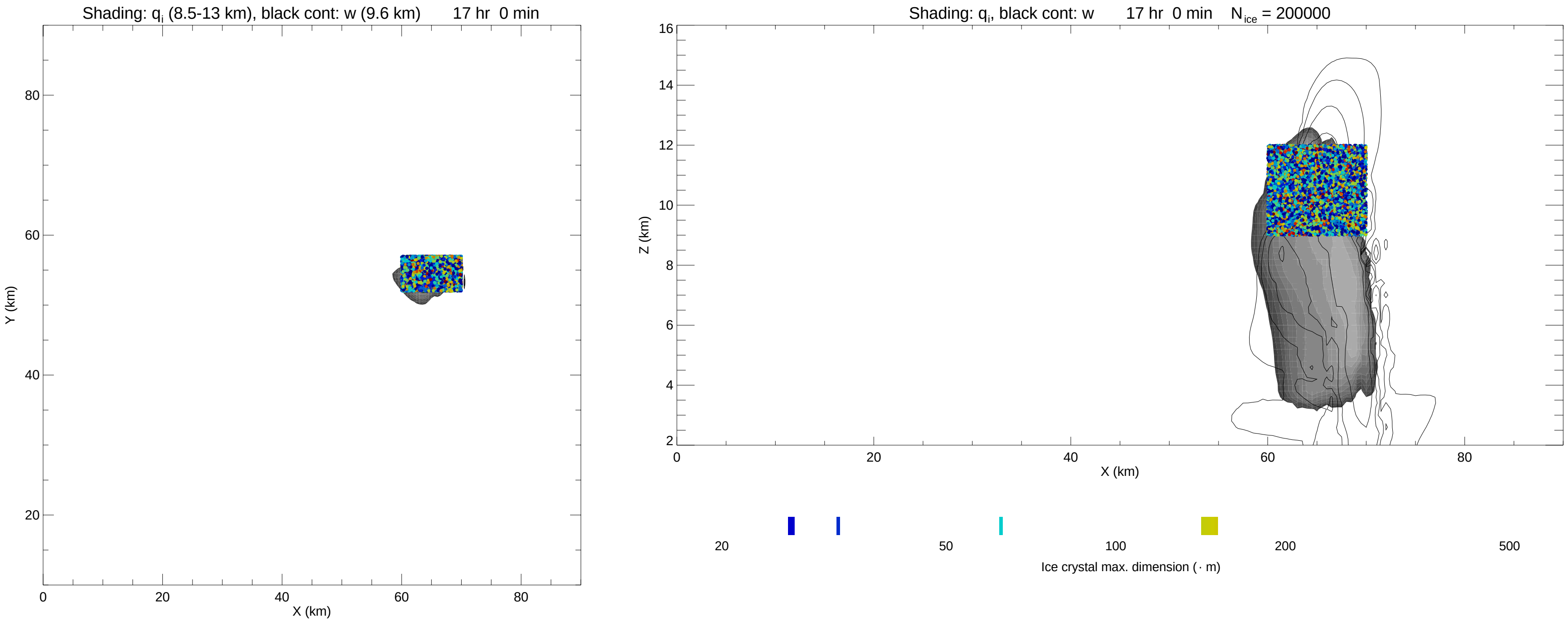


Tracking advection, sedimentation, and growth of ice crystals detrained from deep convection

- Ice crystal size distribution initialized with TC-4 convective core 2D-S size distribution
- Fallspeed parameterization from Mitchell and Heymsfield [2005] used (need to try Westbrook et al. fall speeds)
- Assume bullet rosettes with aspect ratio of individual bullets set to 5
- Ice crystals started in upper part of convective core (9–12 km)
- Sub-stepping used for ice growth/sublimation (1-sec time step)



Anvil ice crystal growth-sedimentation trajectories



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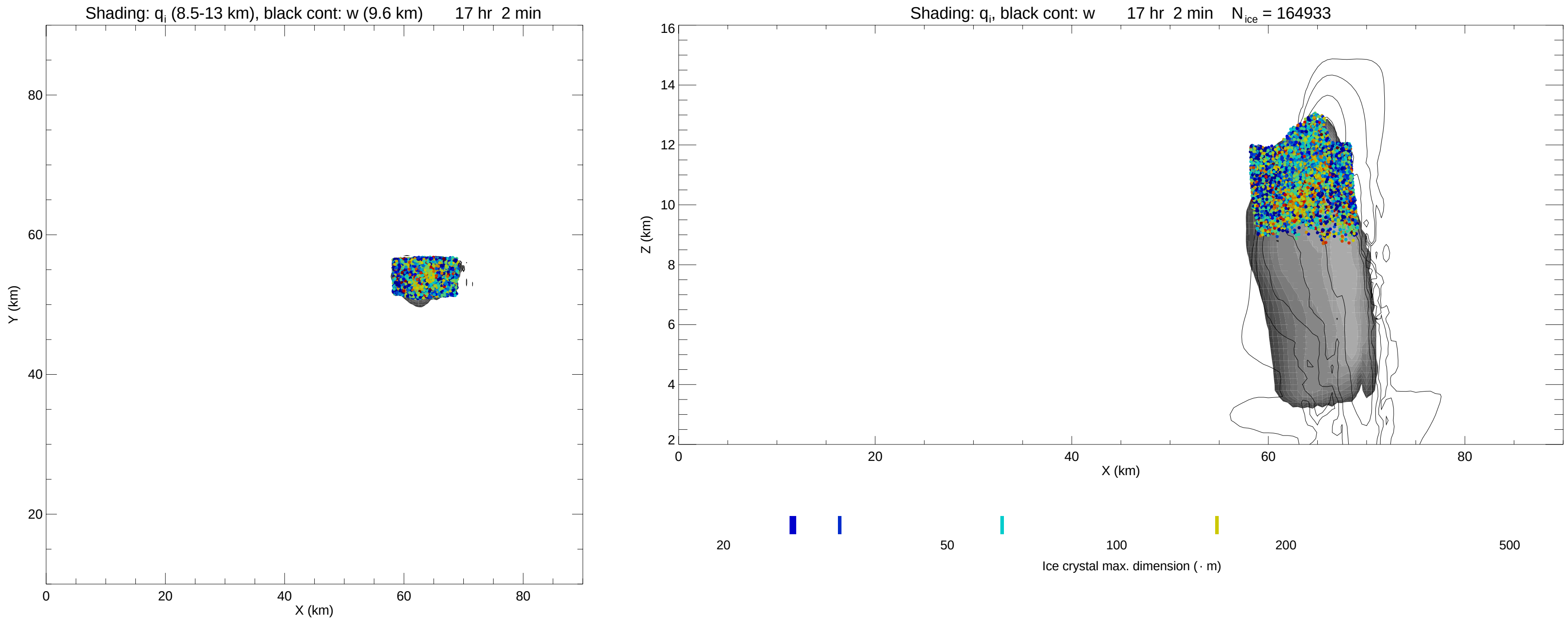

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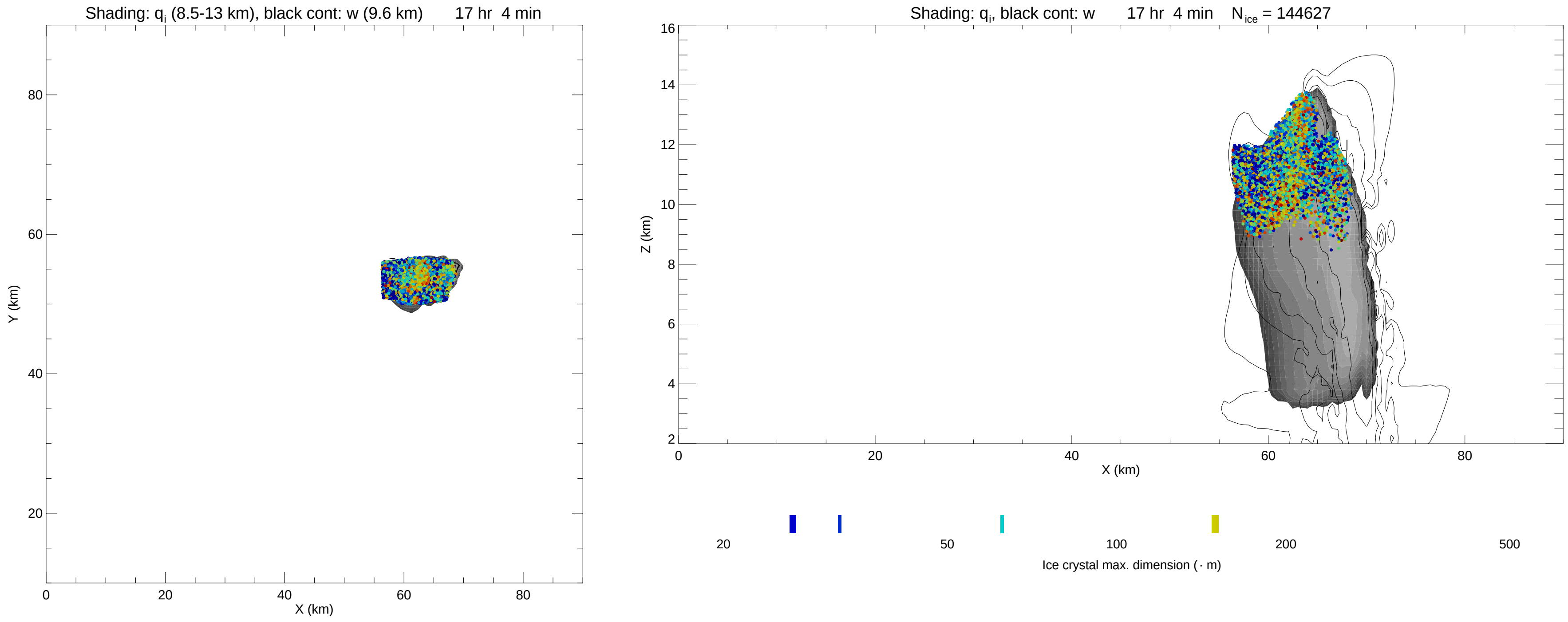

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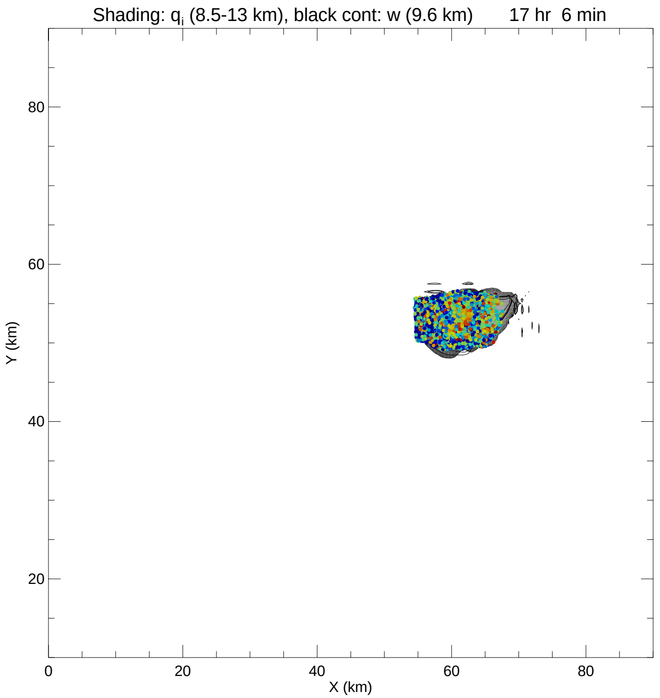

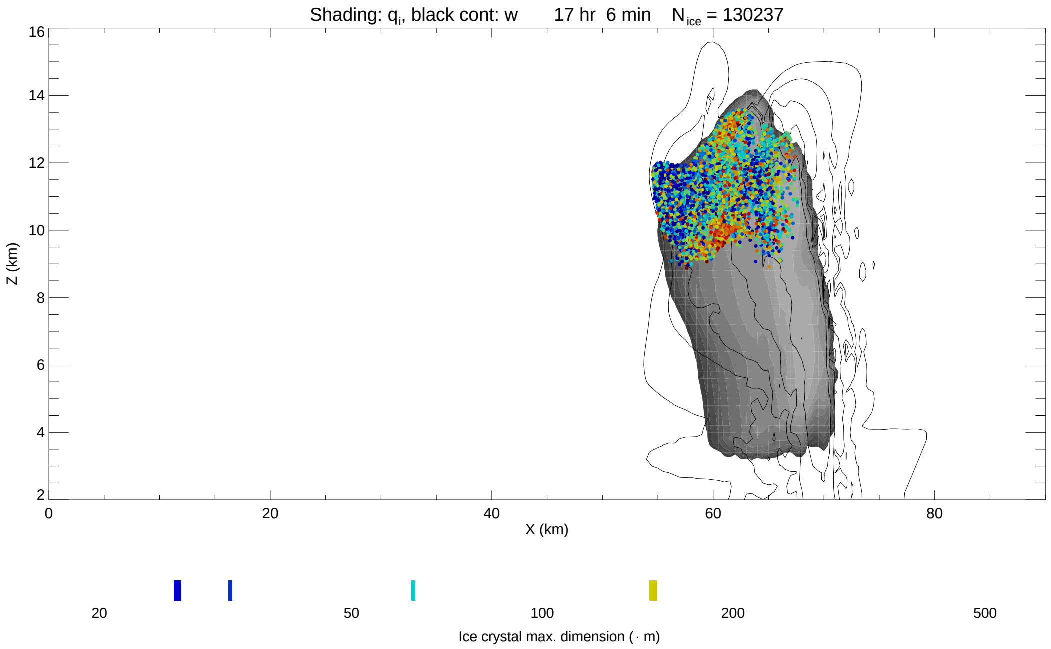

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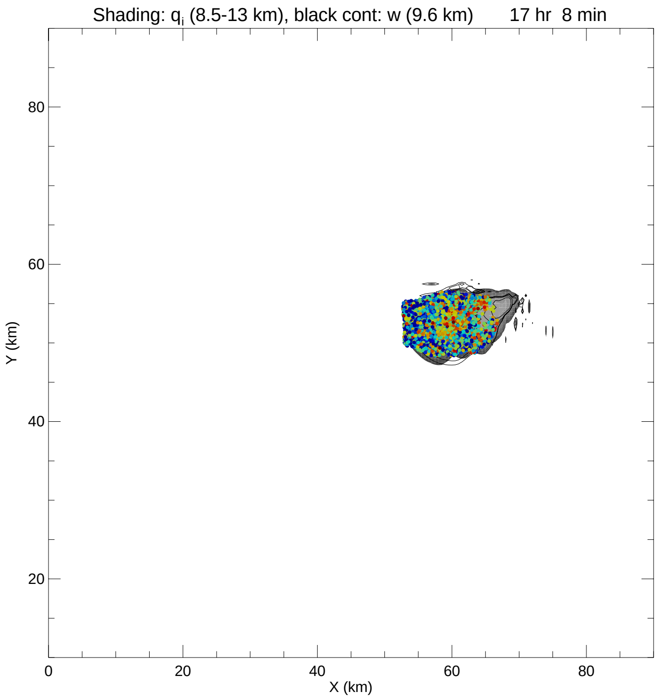

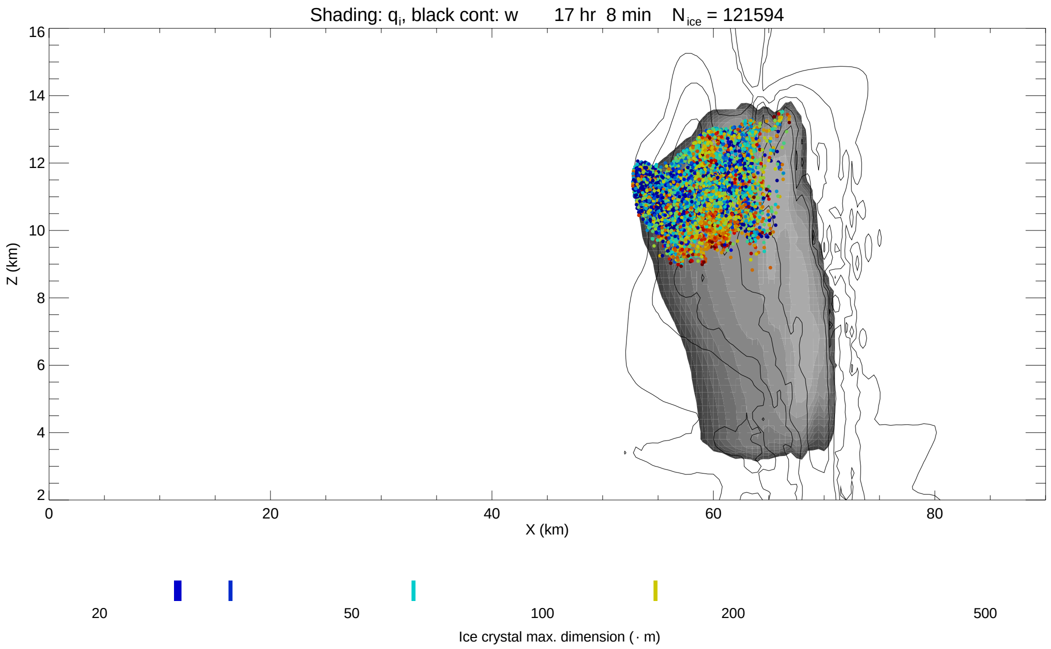

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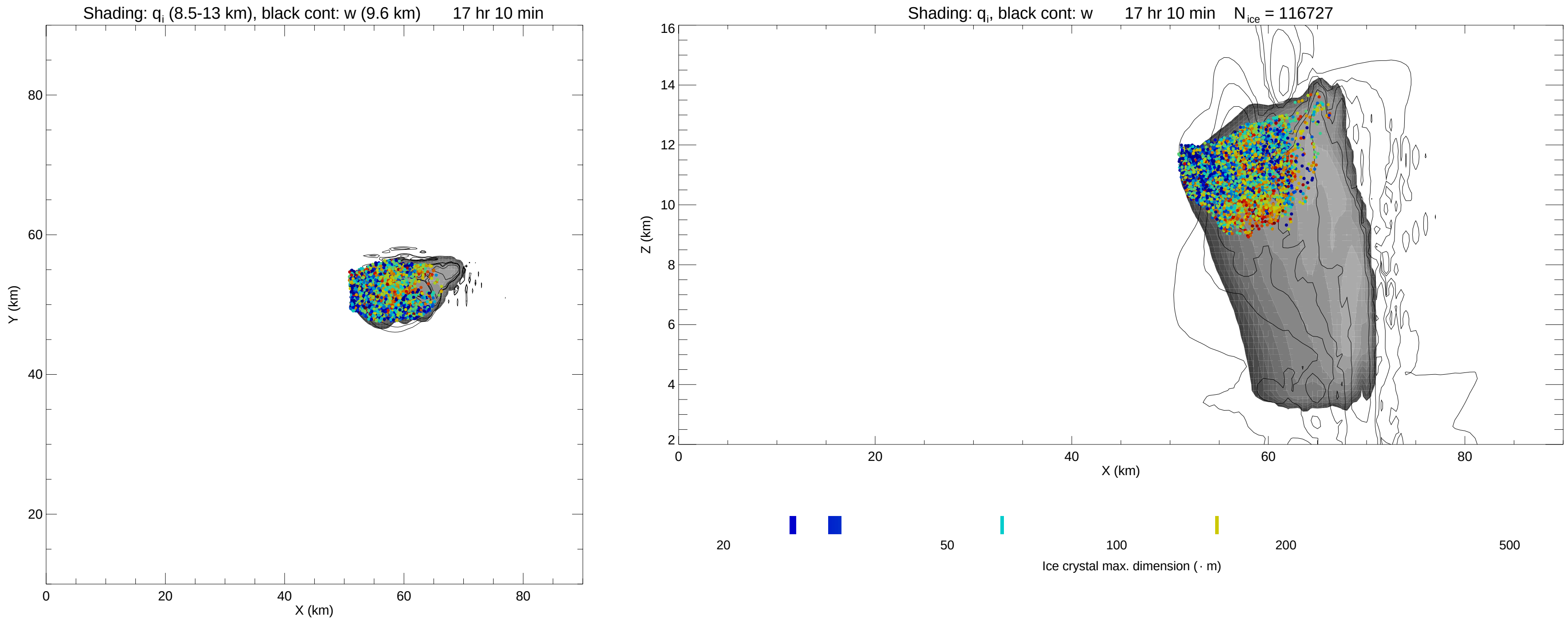

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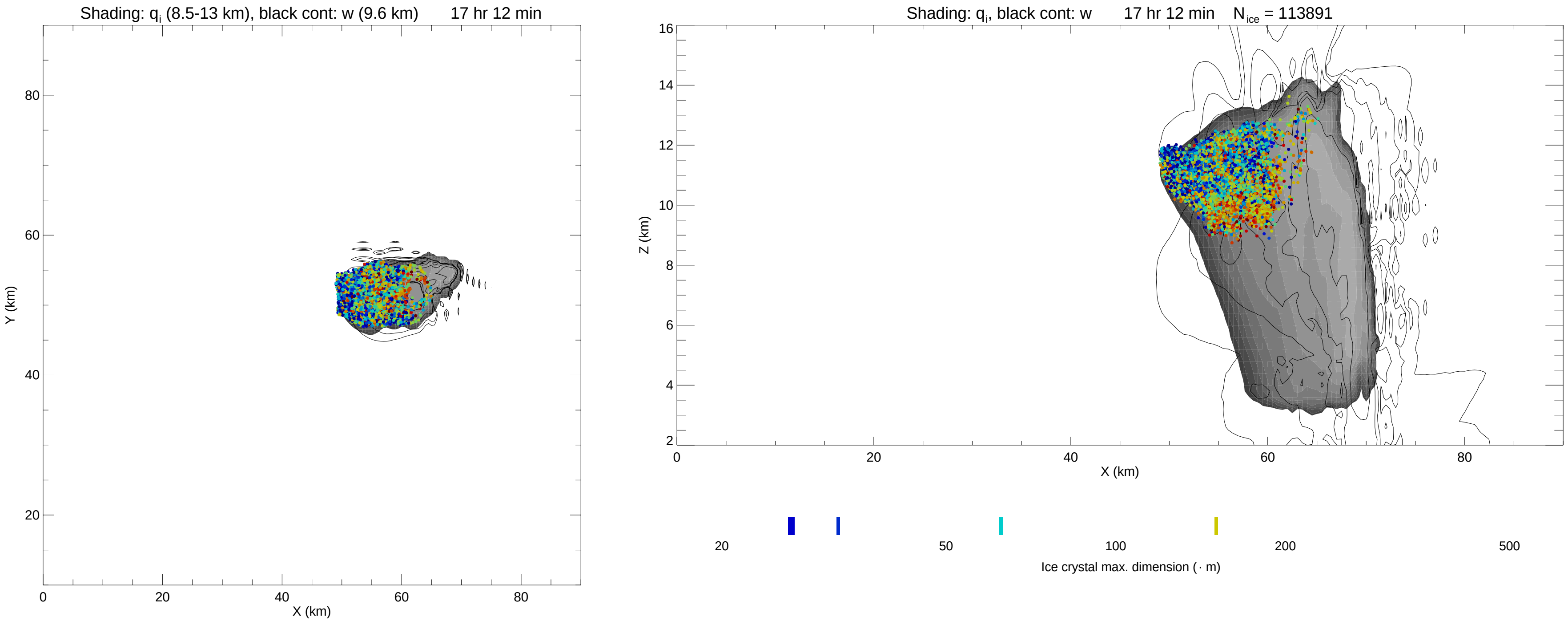

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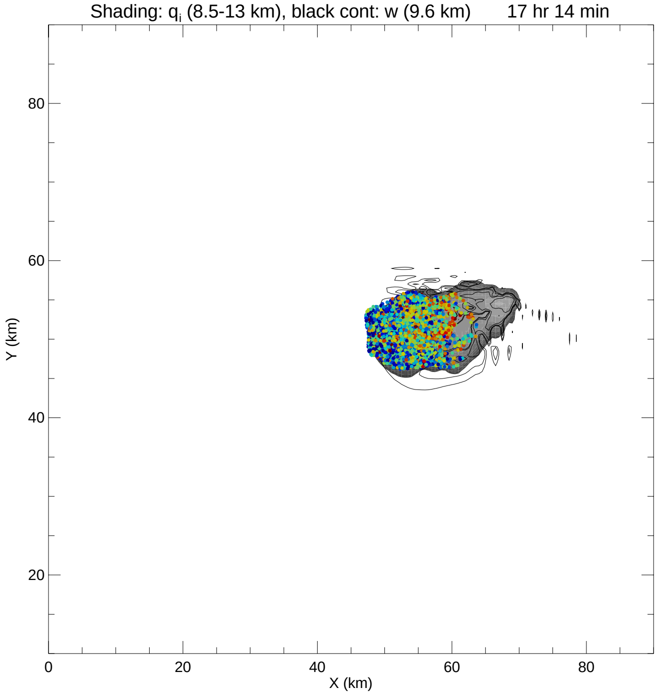

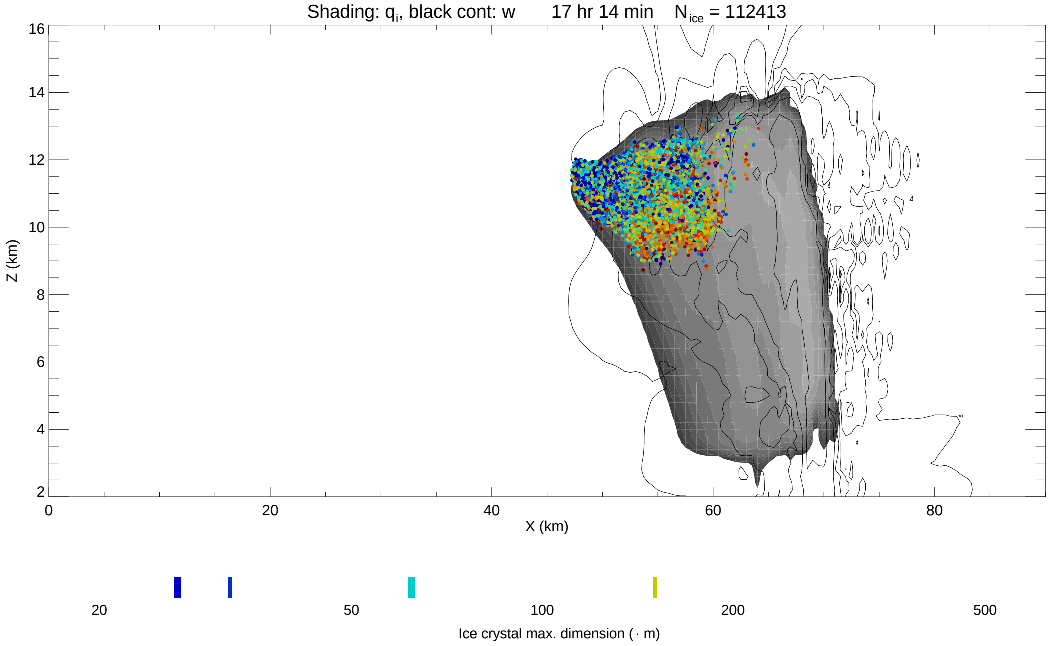

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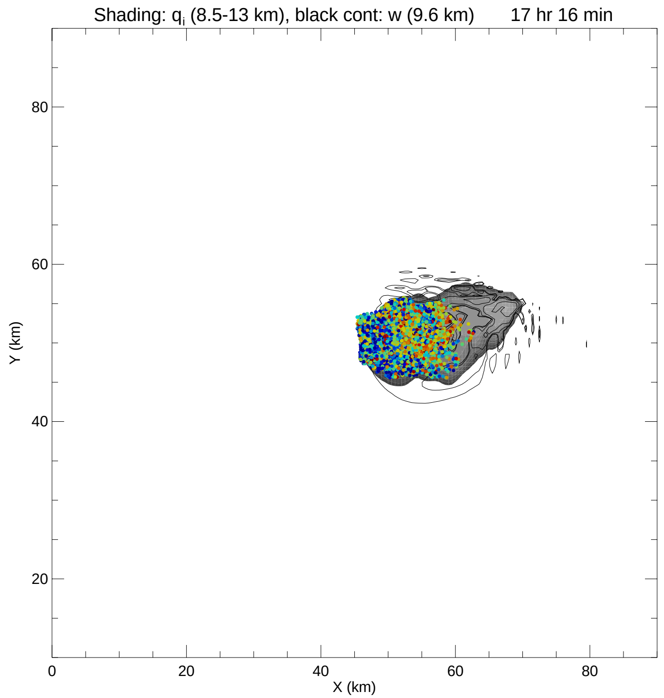

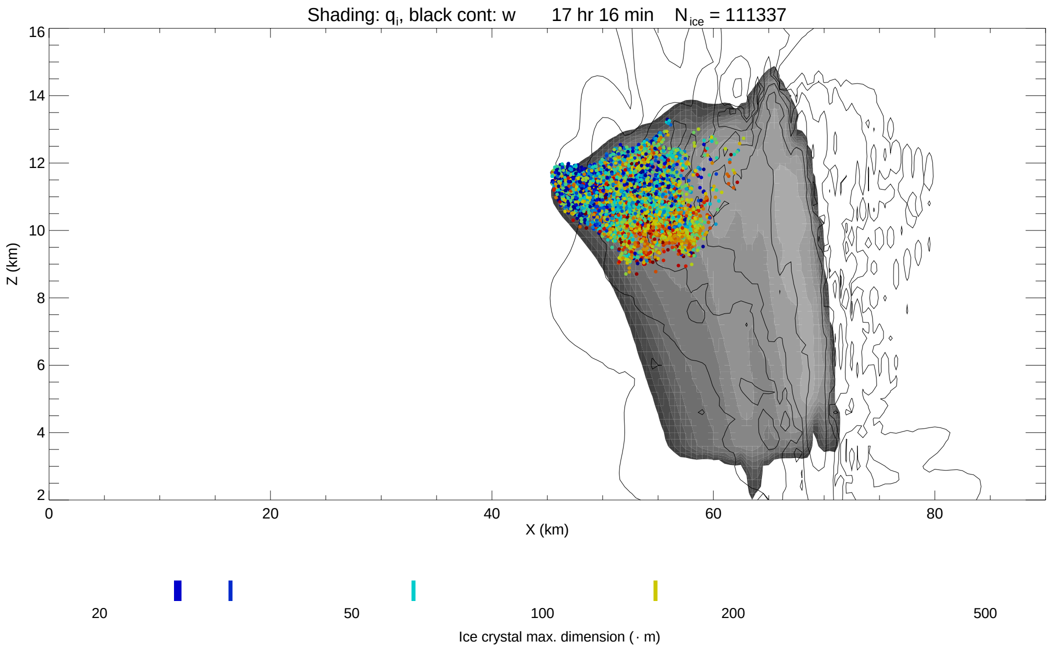

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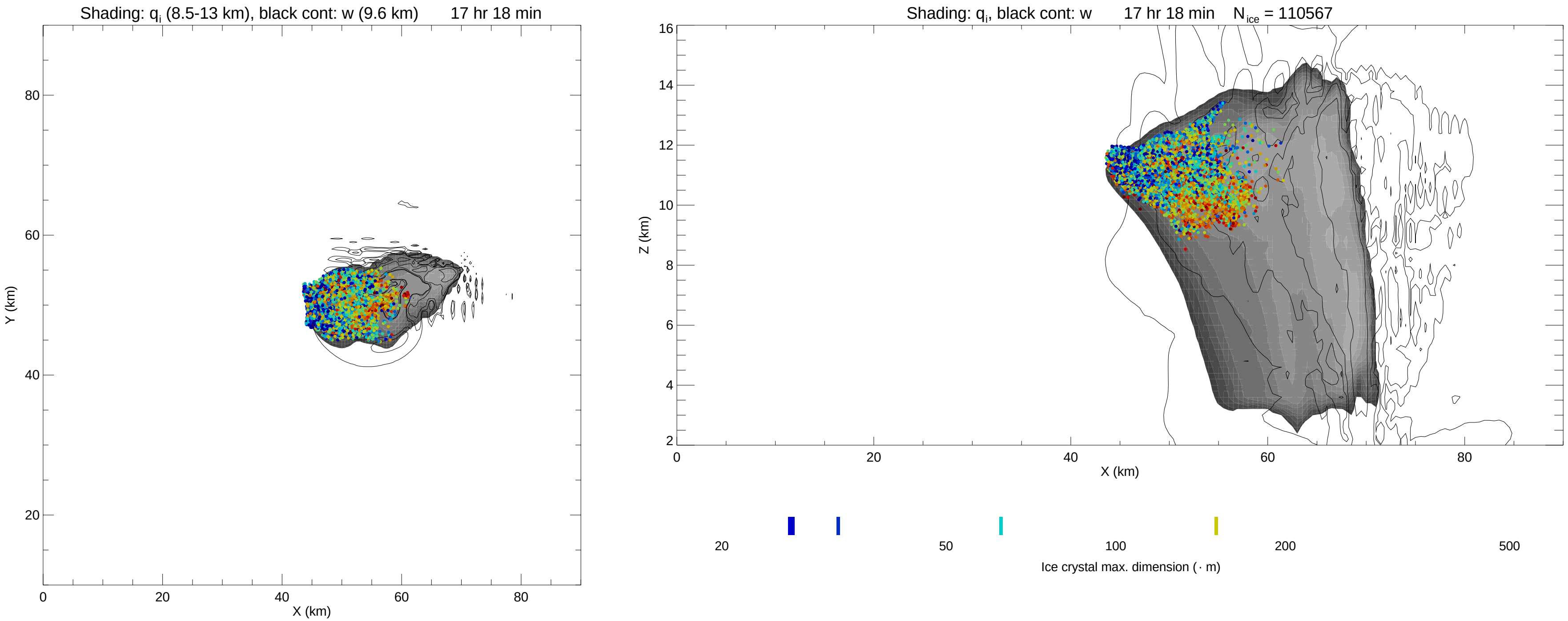

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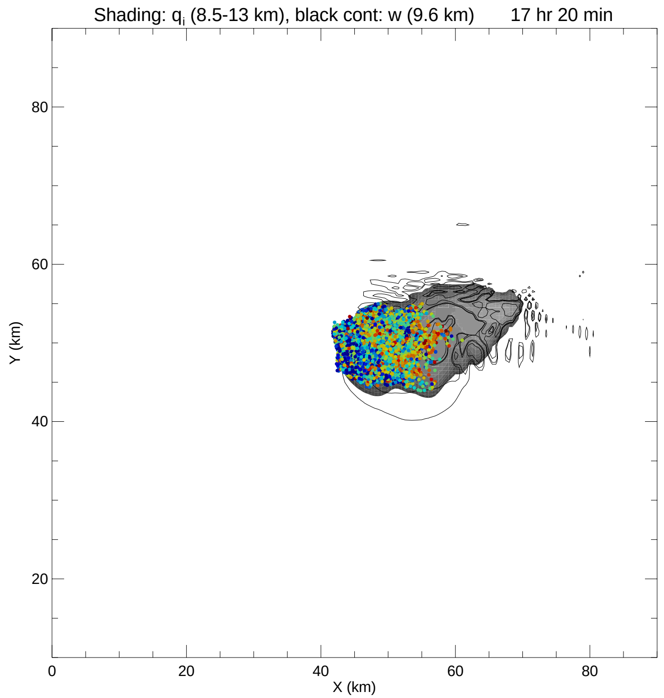

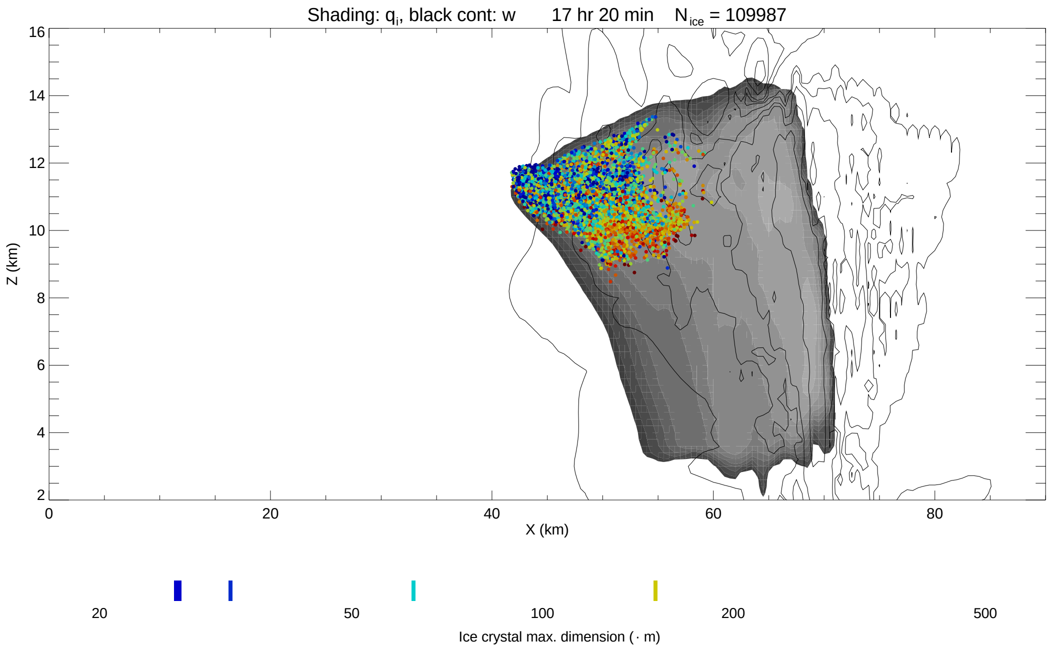

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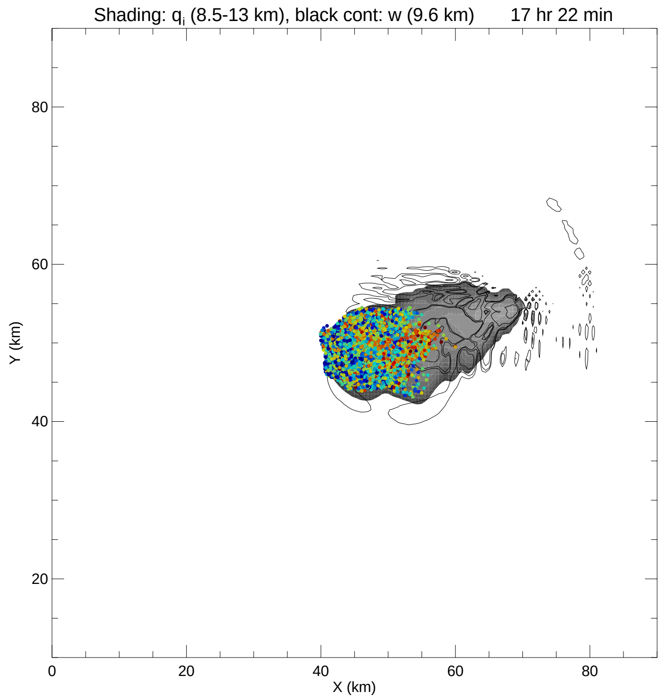

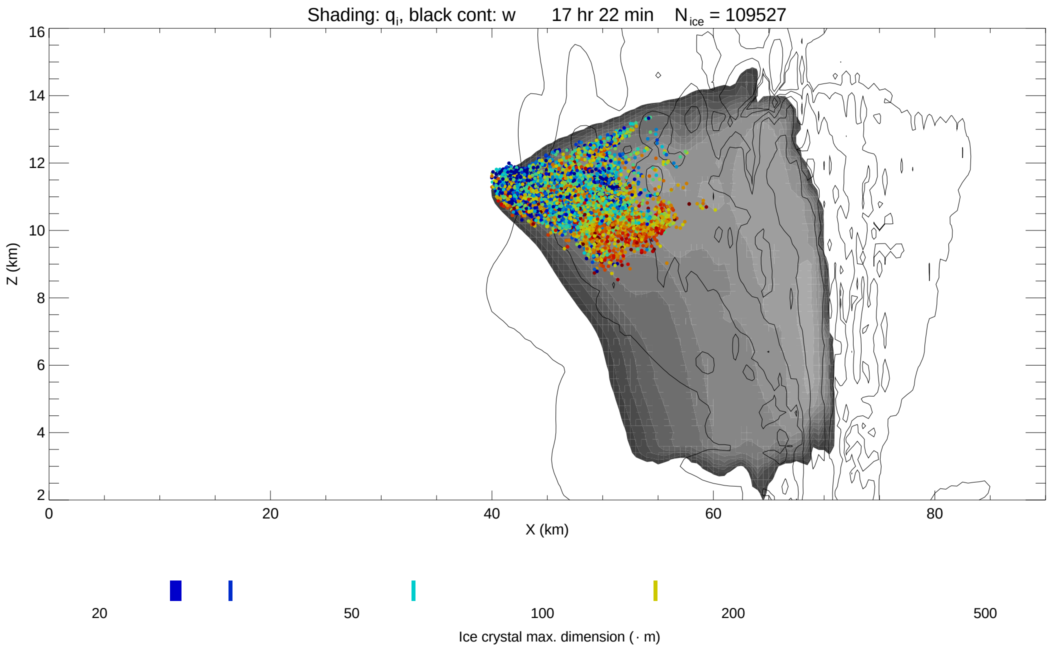

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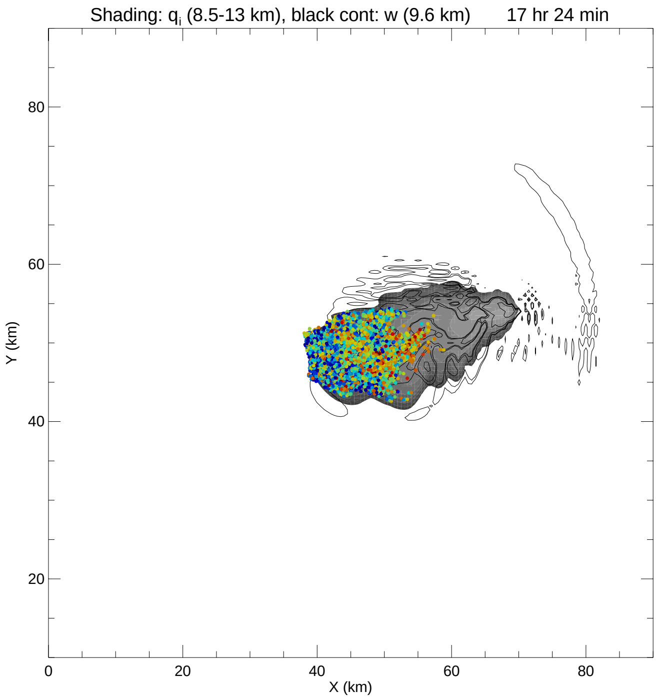

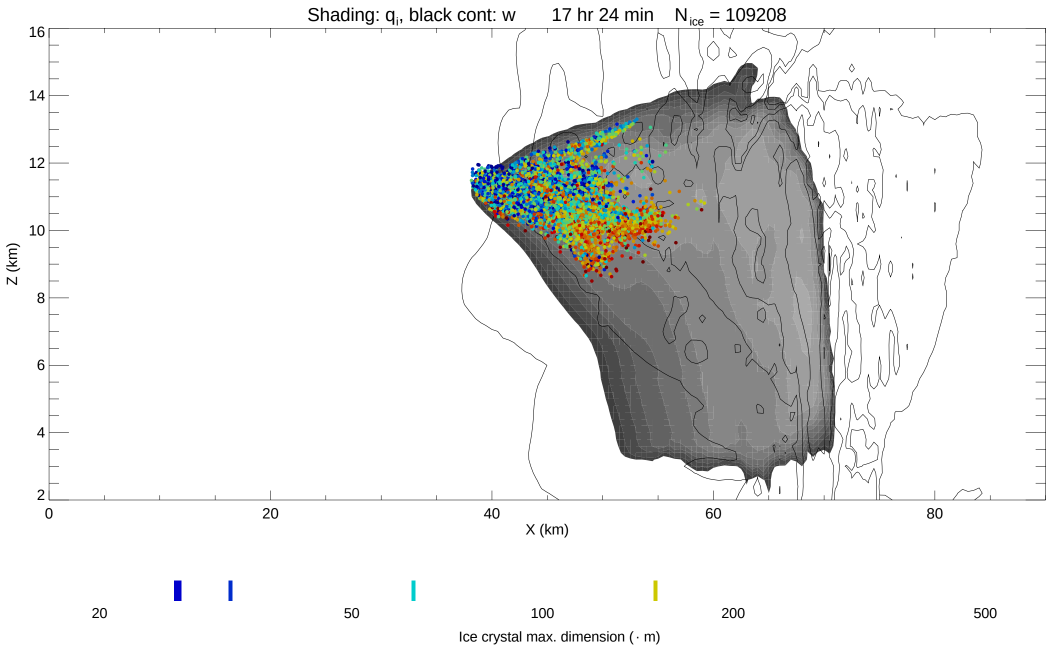

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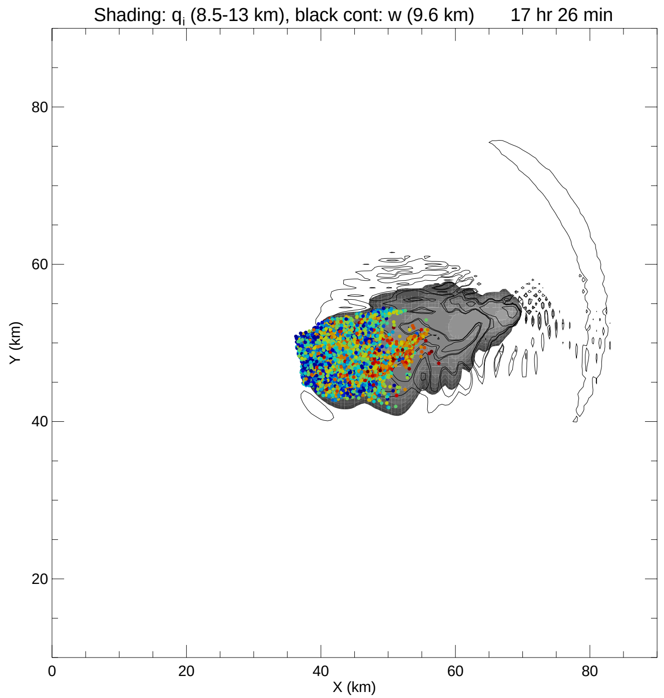

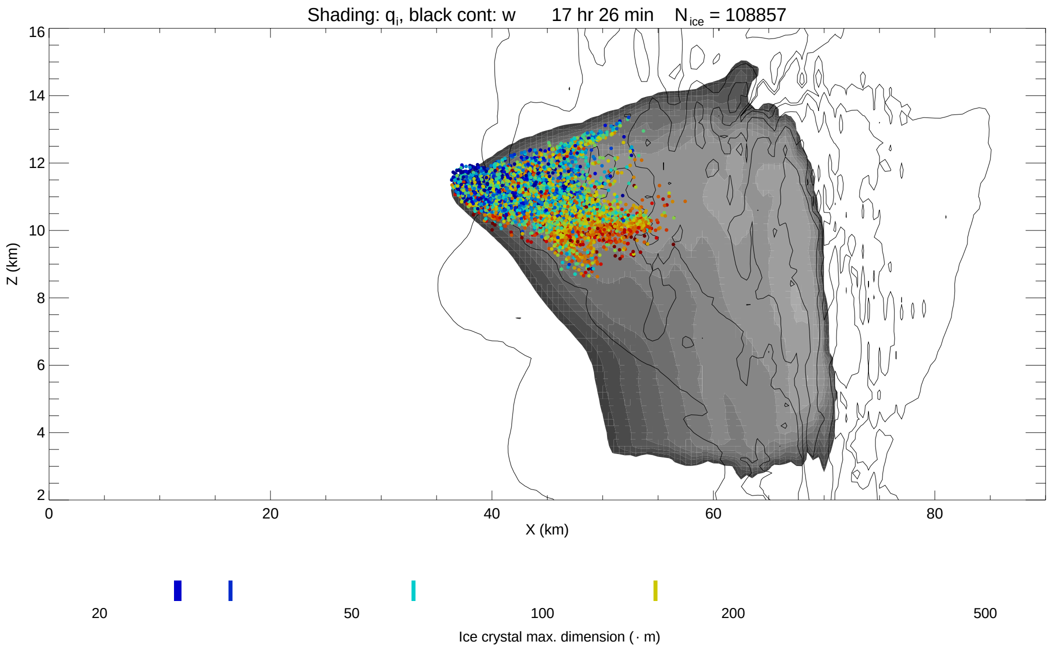

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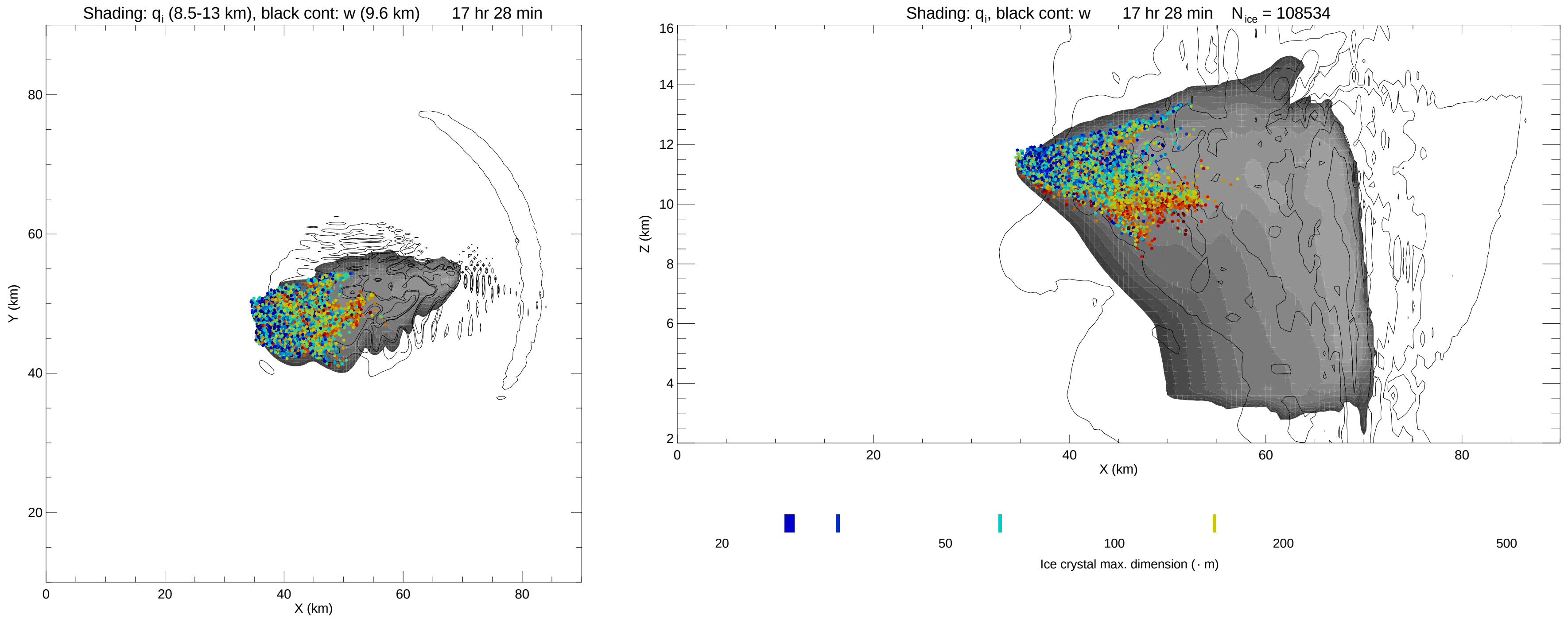

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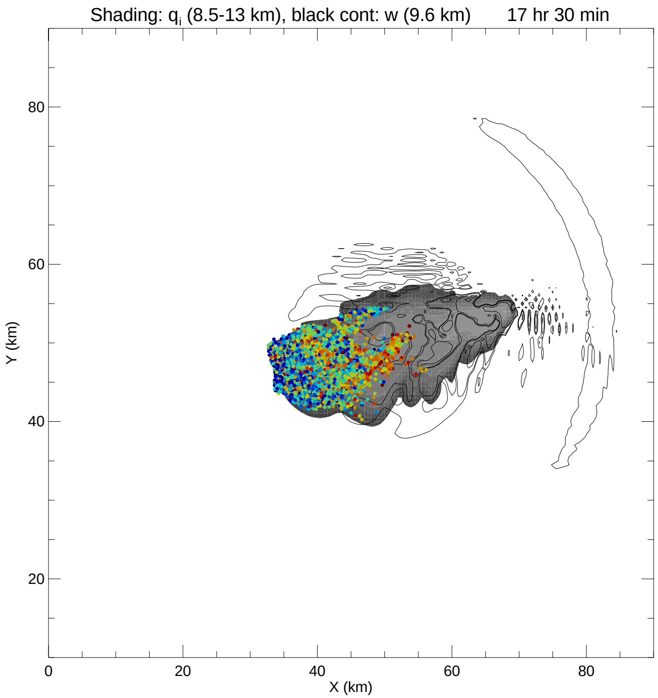

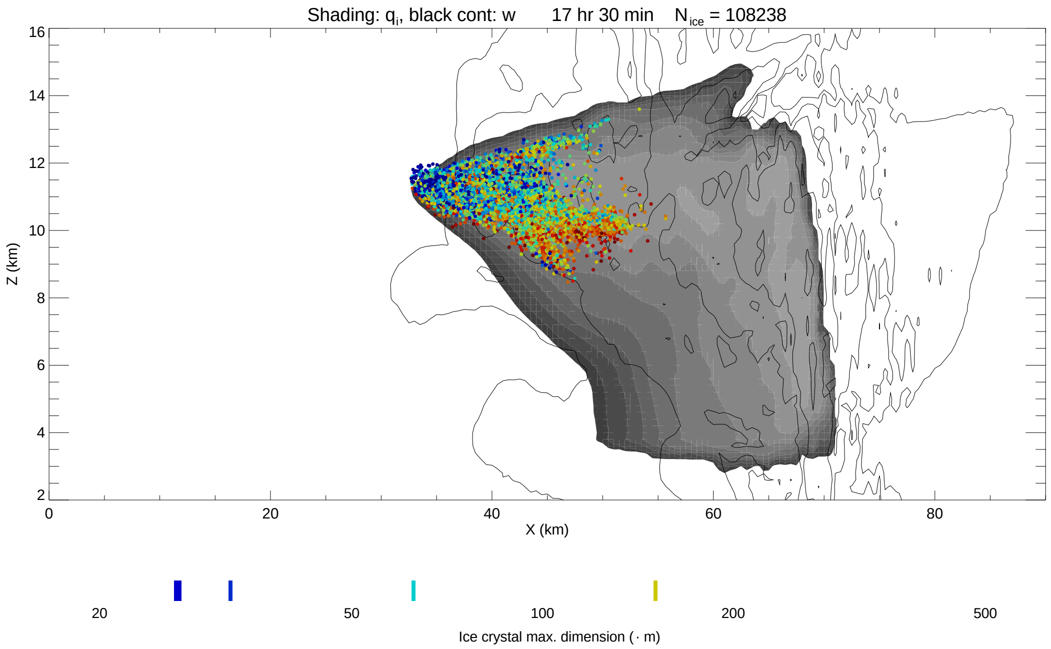

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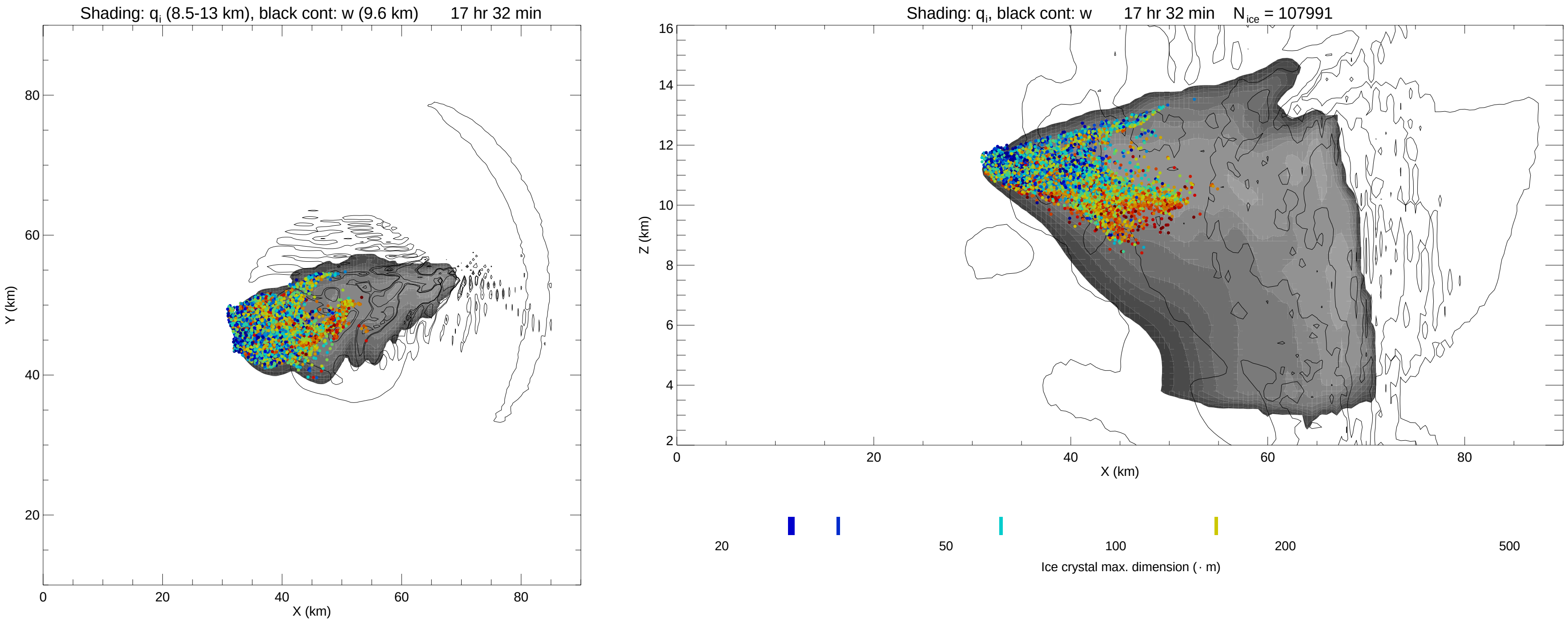

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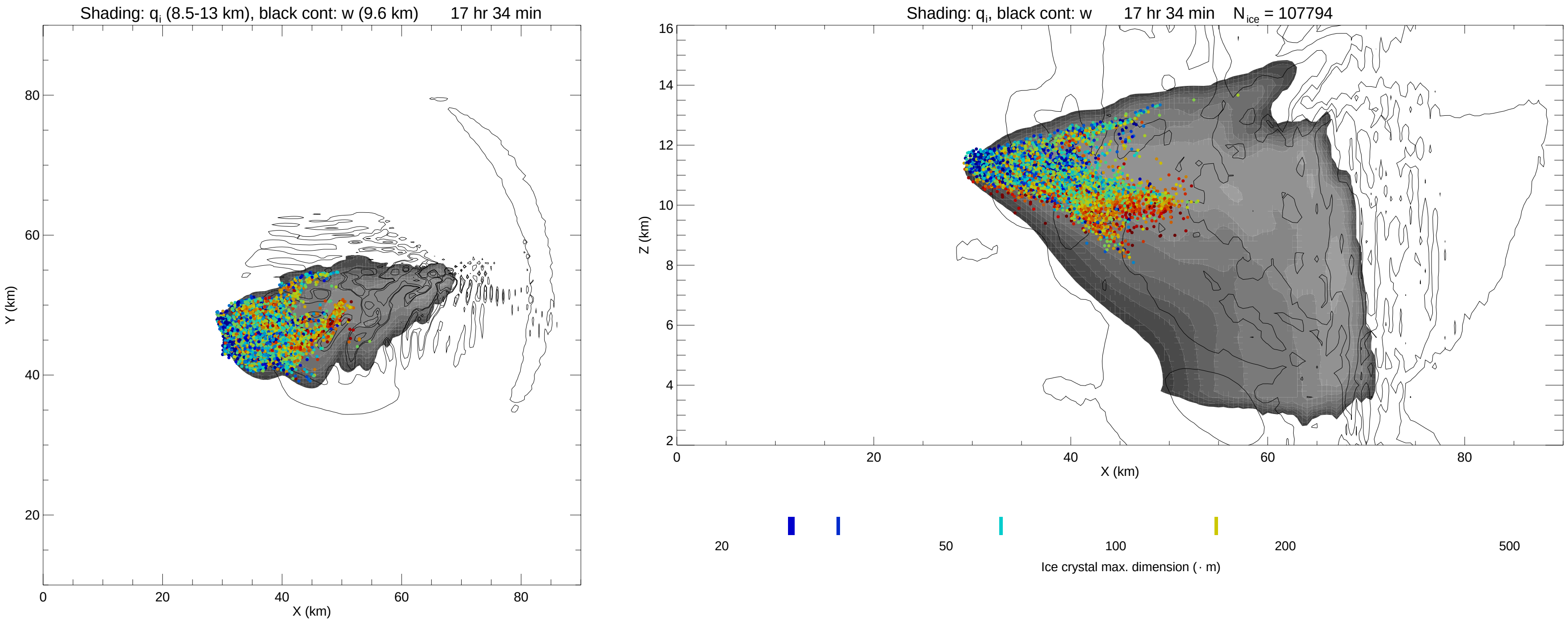

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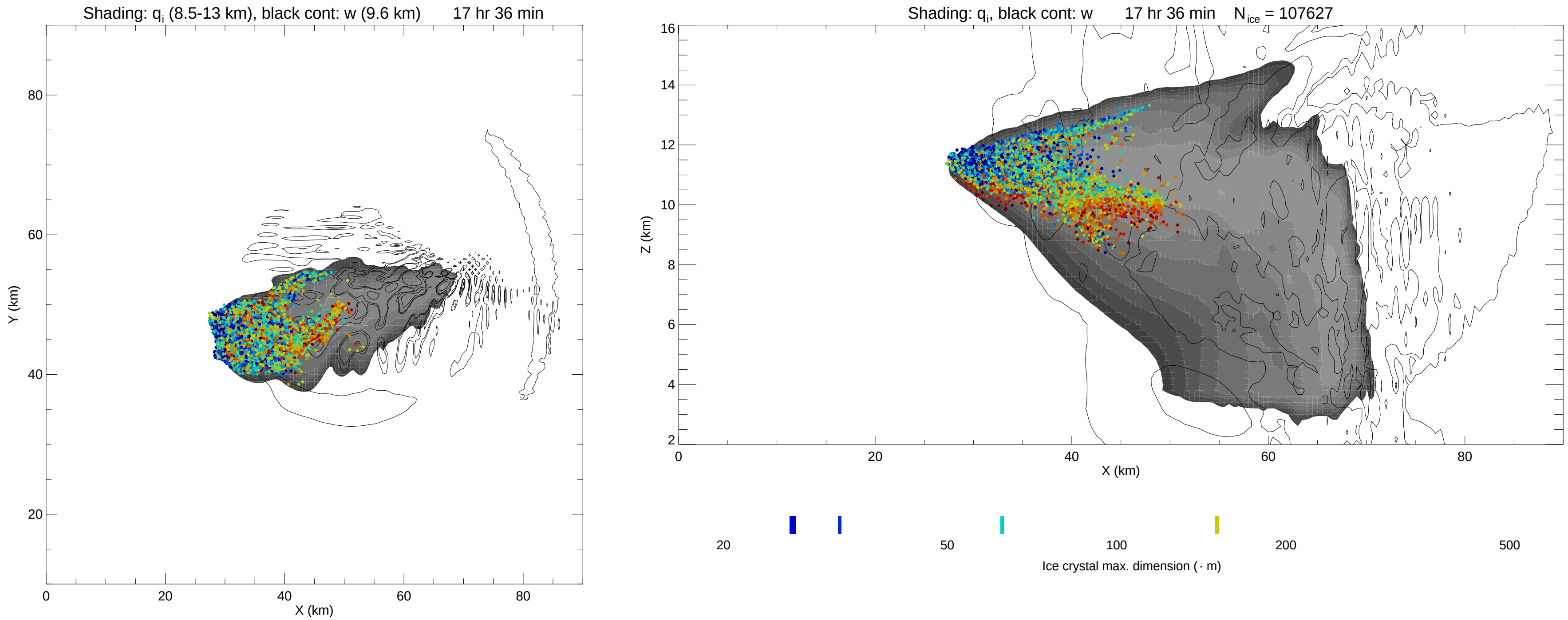

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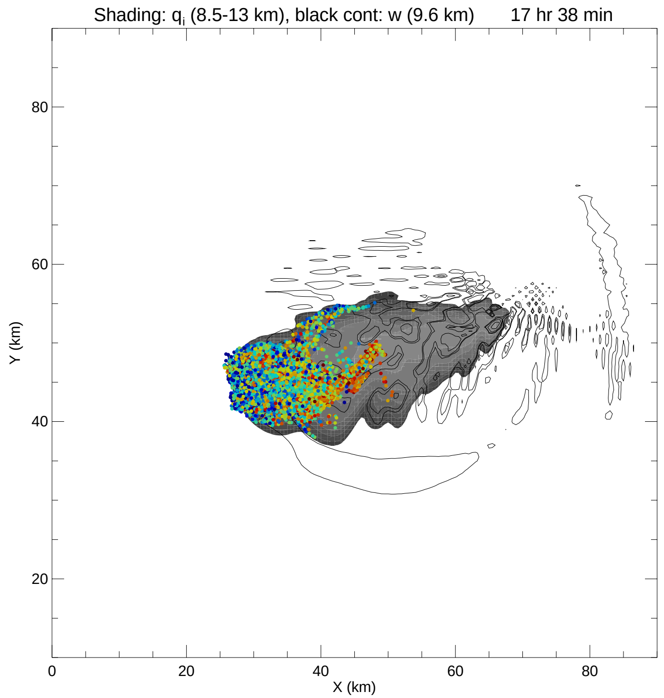

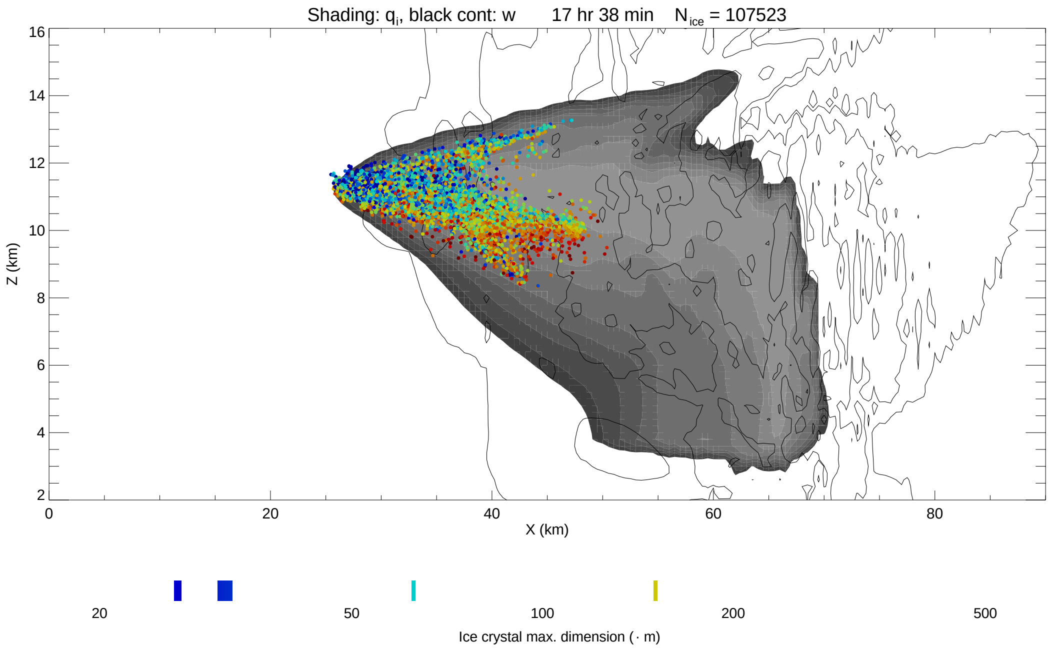

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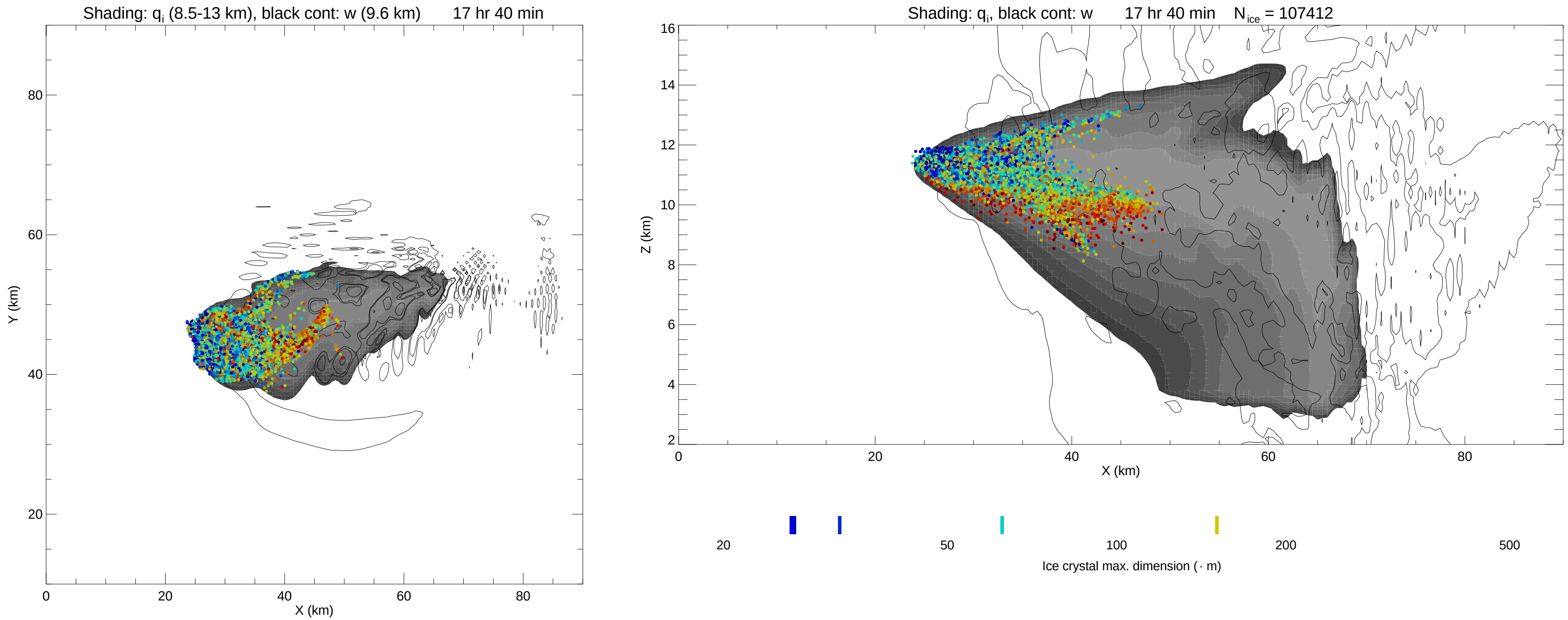

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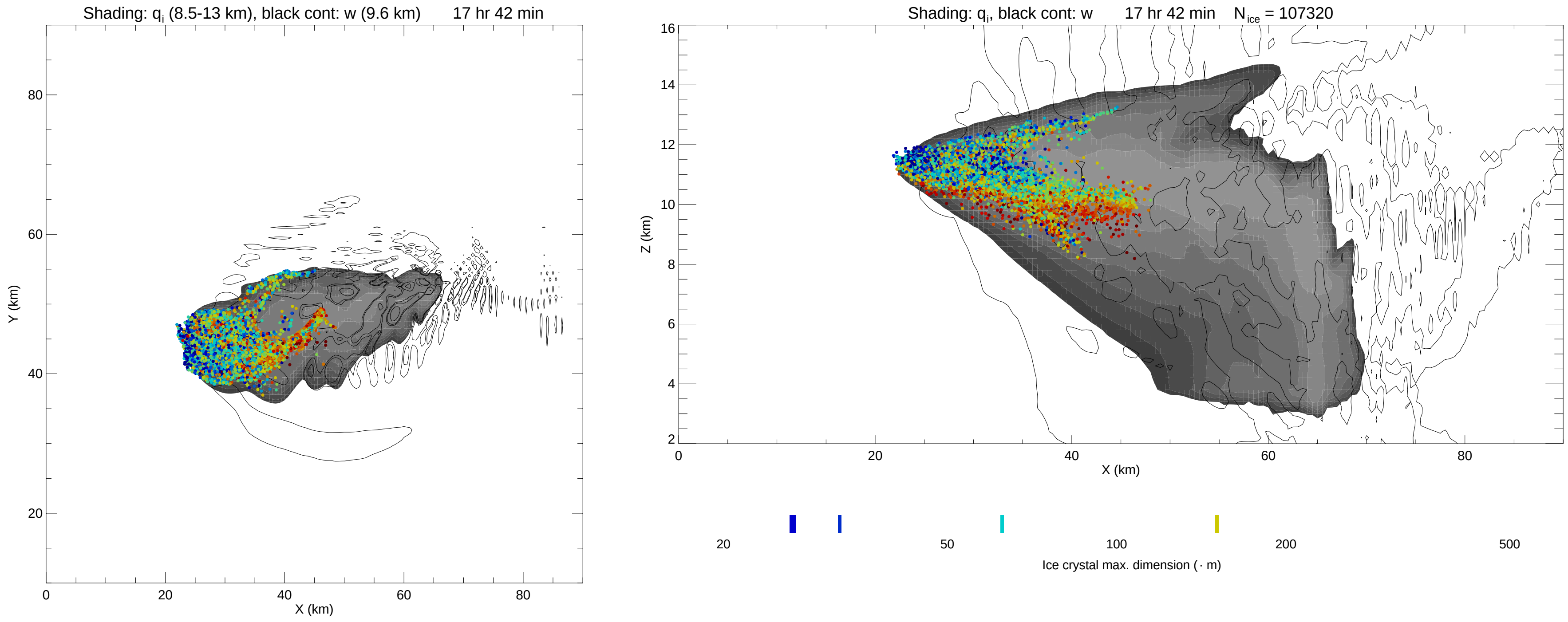

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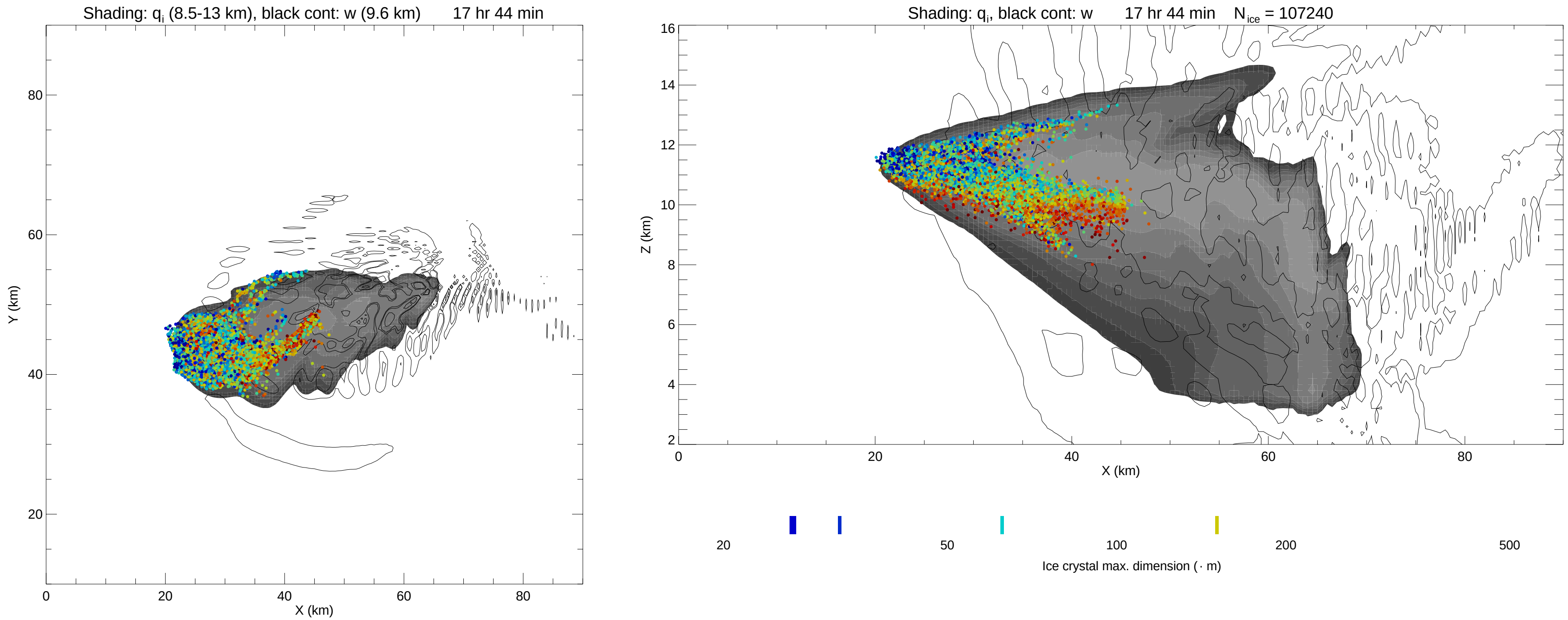

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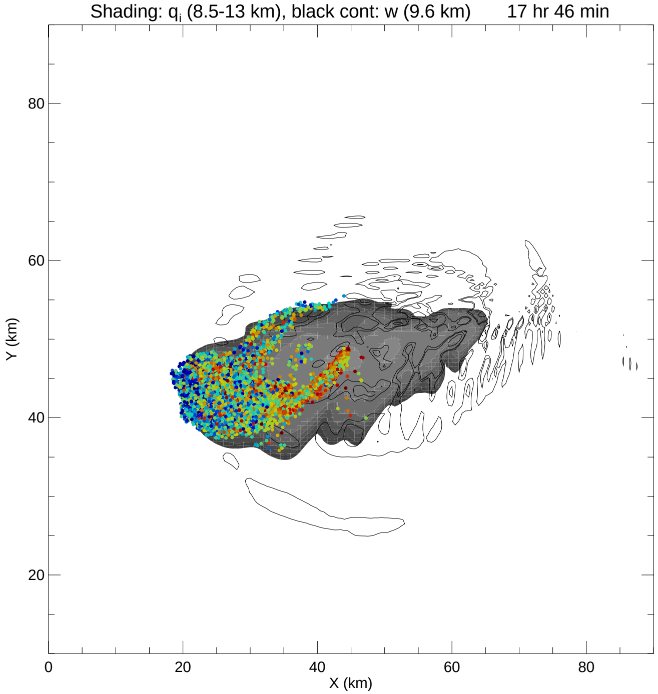

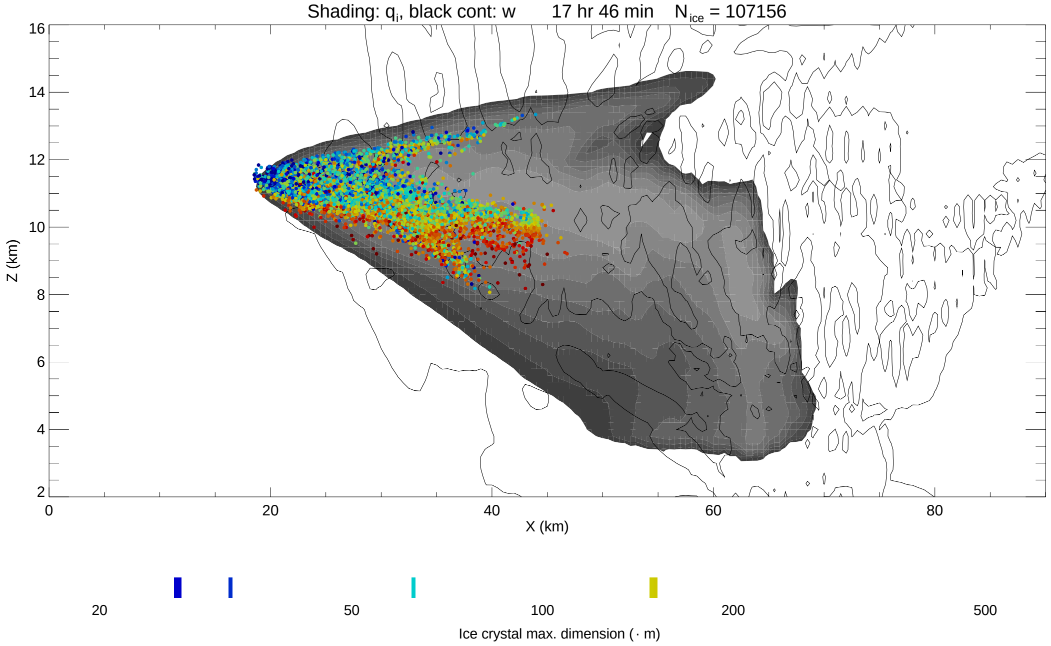

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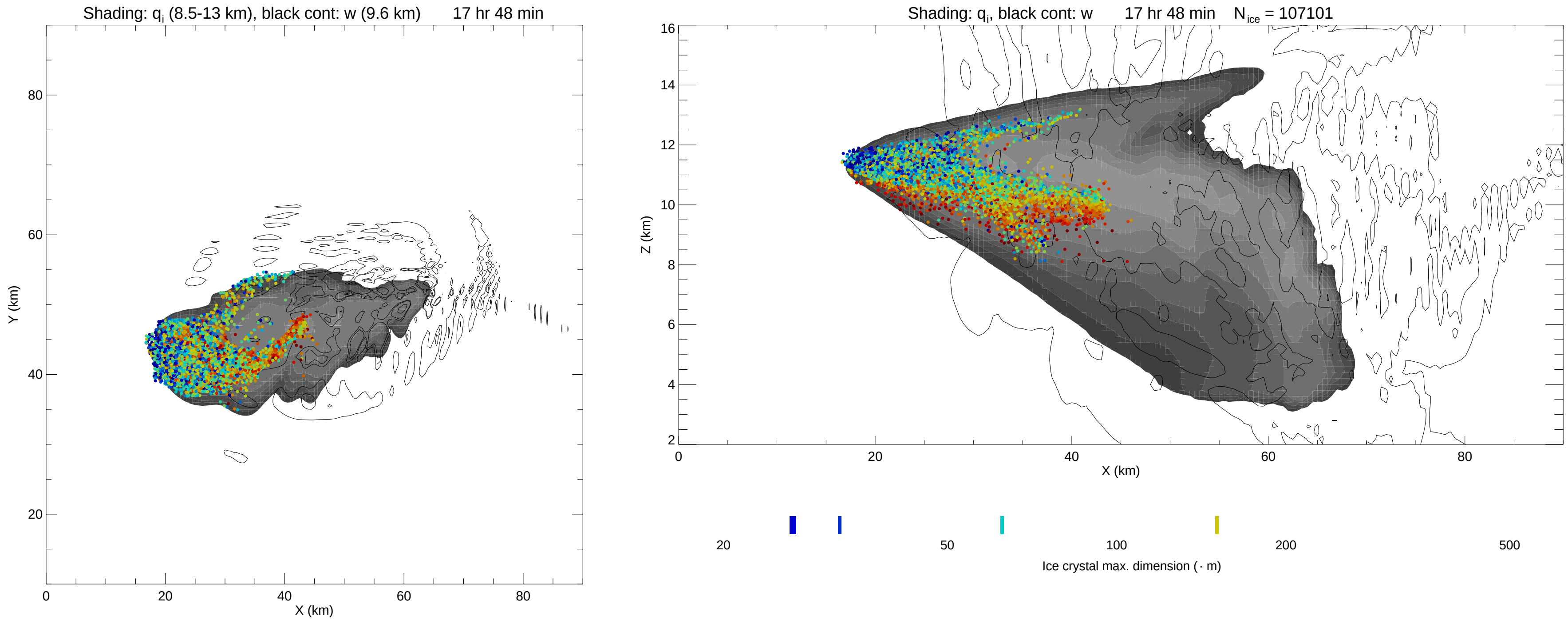

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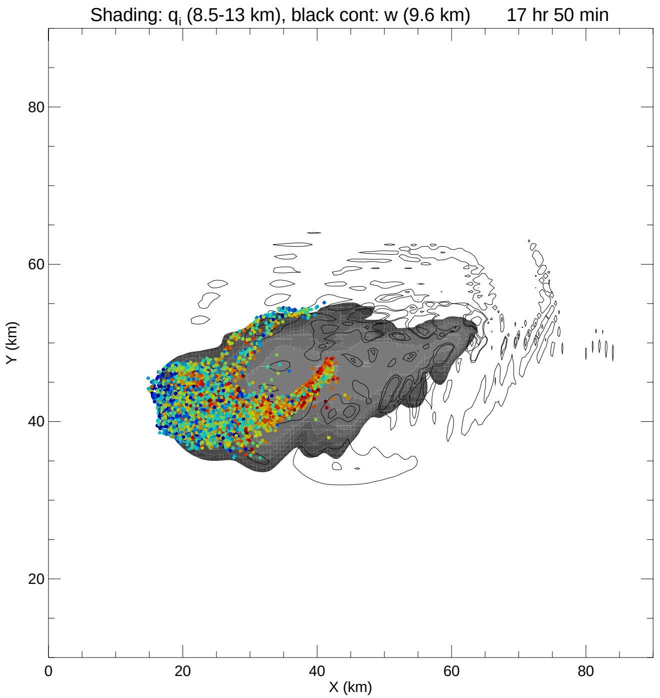

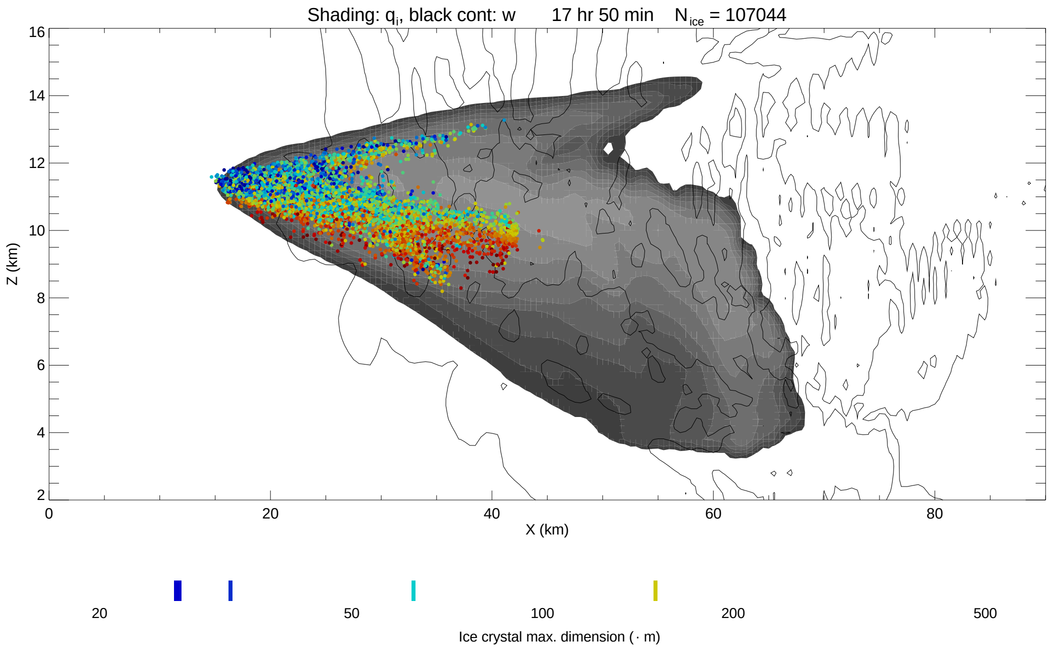

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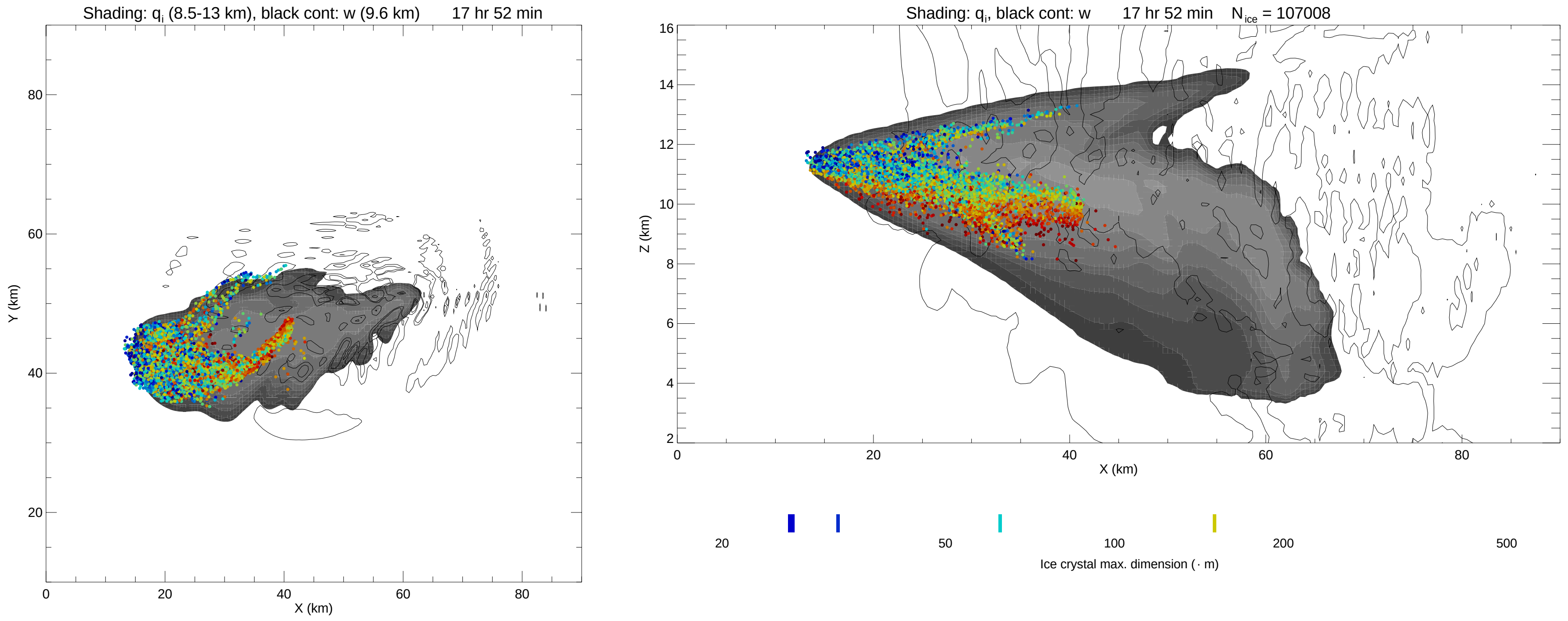

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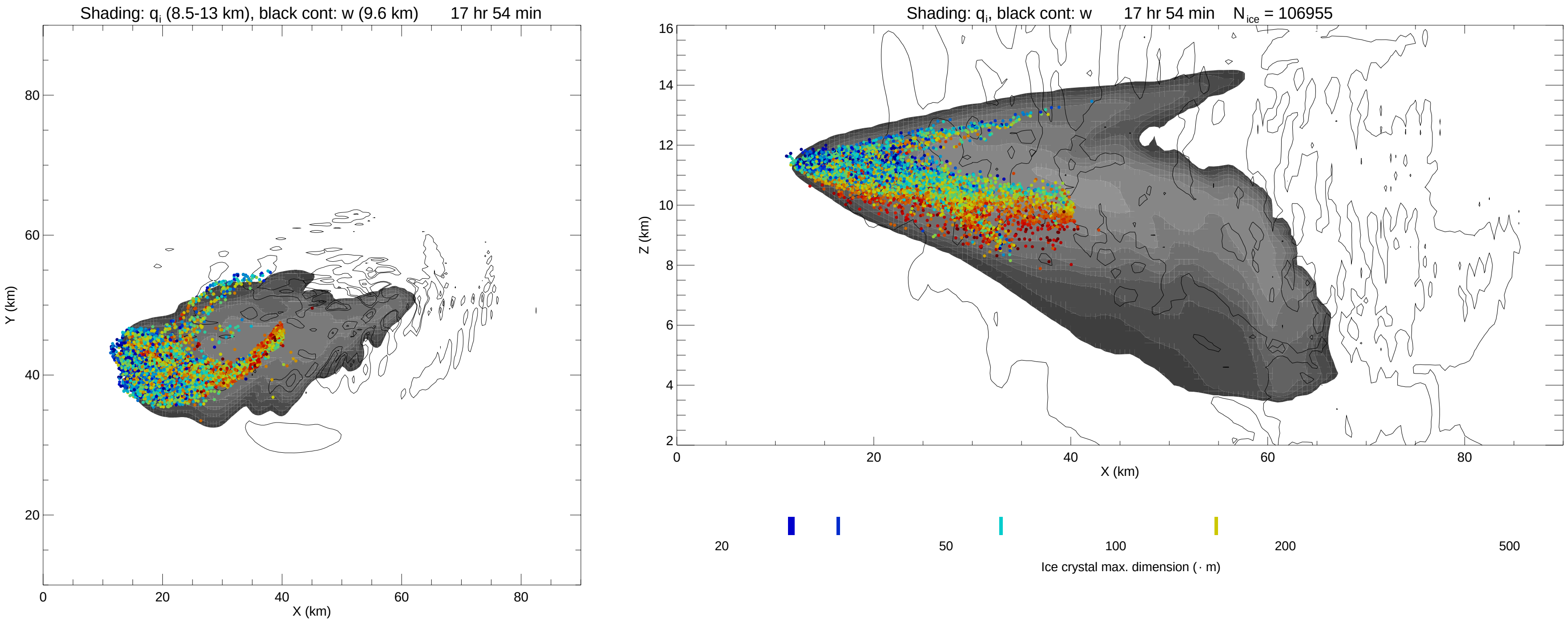

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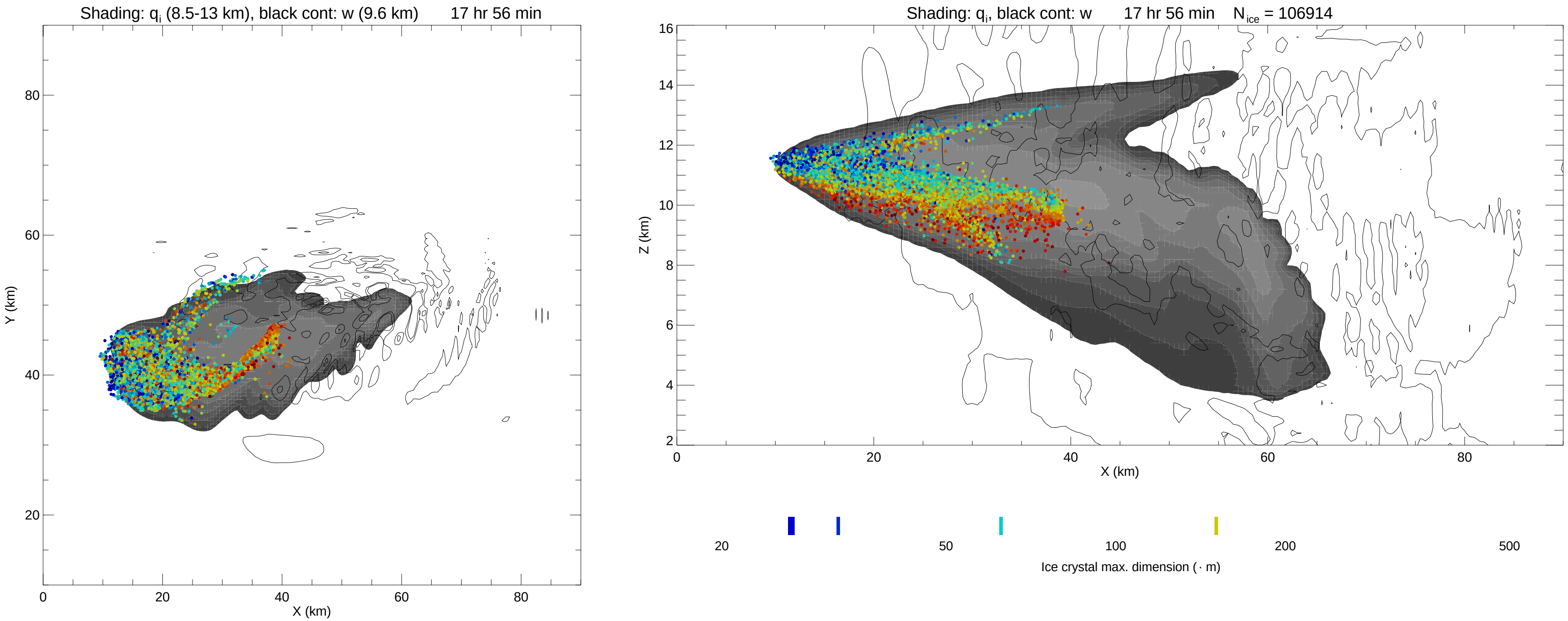

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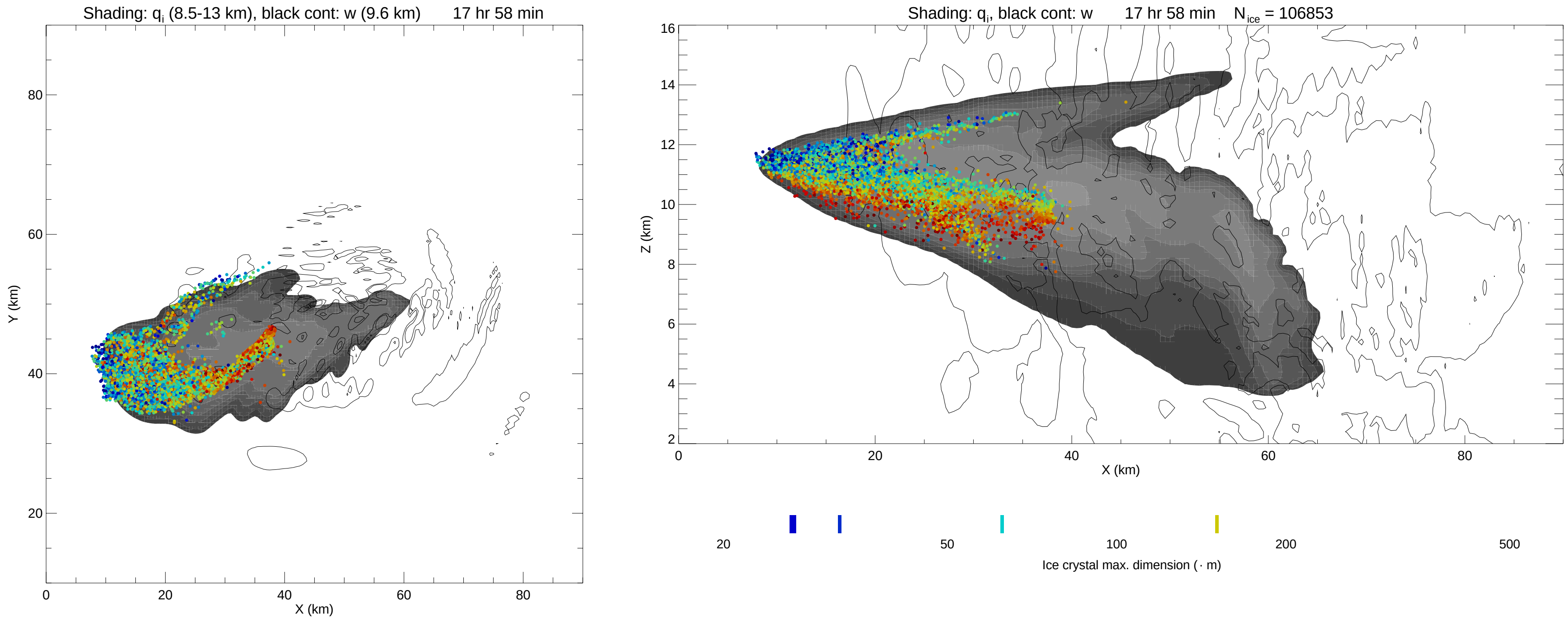
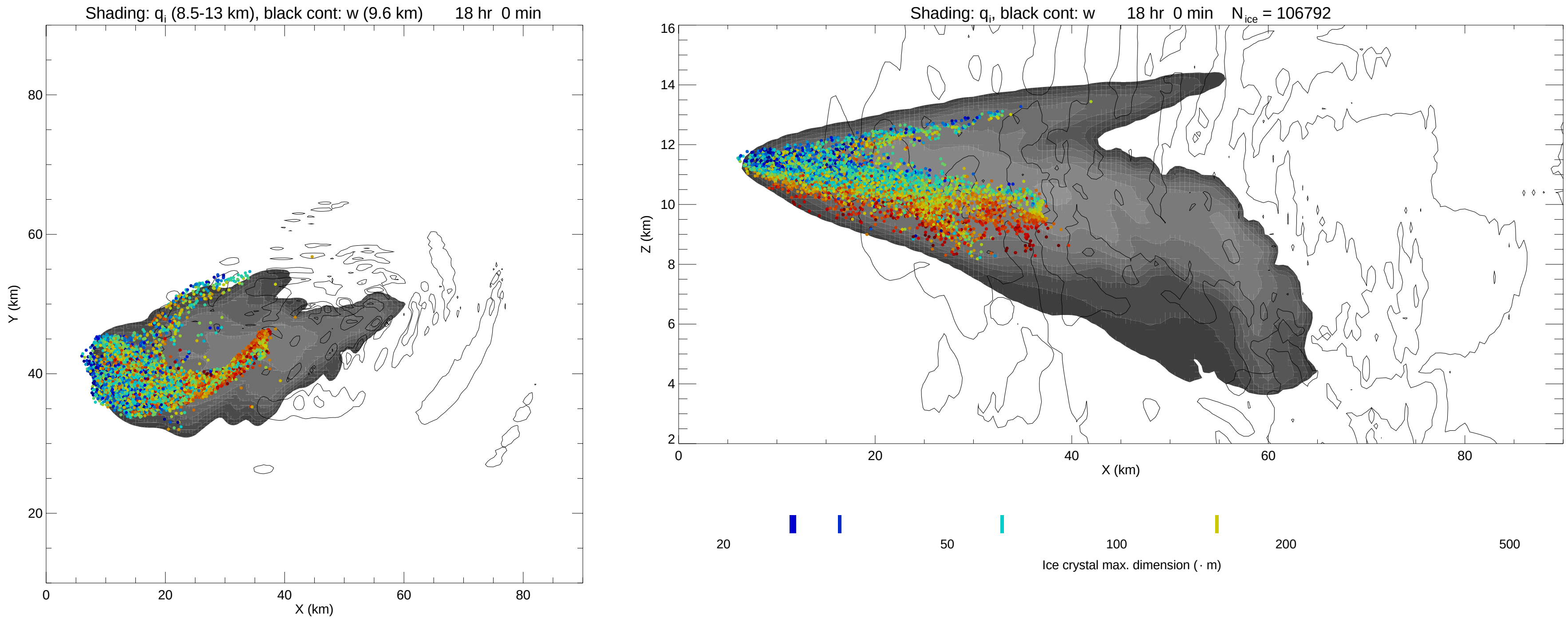
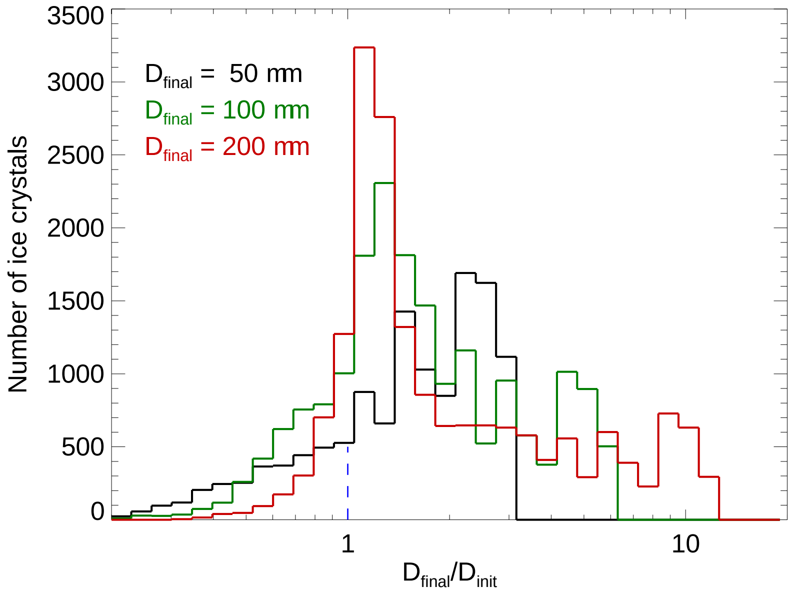


Anvil ice crystal growth-sedimentation trajectories



Statistics of ice crystal growth/sublimation



- Frequency distributions of ice crystal final max. dimension (1800h) divided by initial max. dimension (1700h) are shown for ice crystals with D_{final} near 50, 100, and 200 µm.
- Most of the ice crystals grew by deposition of vapor, which is consistent with the predominance of bullet rosettes in aged anvils.

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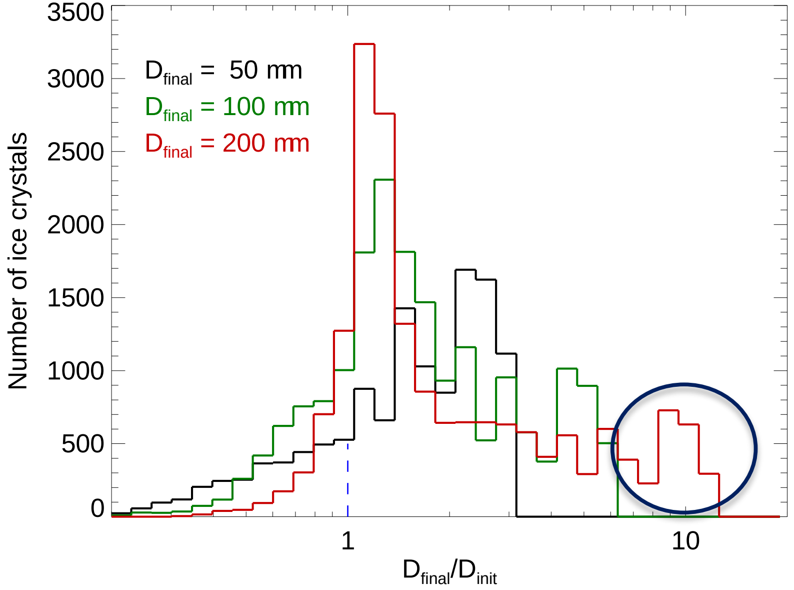

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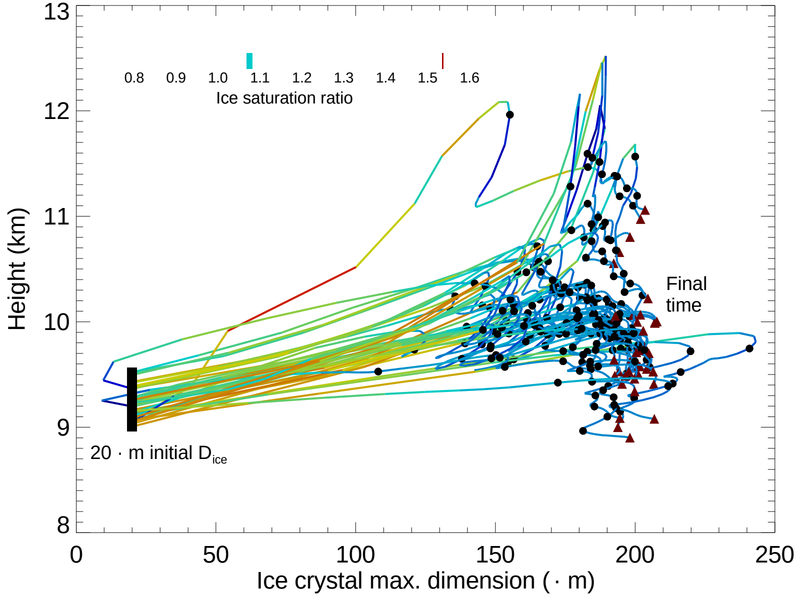

Most of the ice growth occurred in first 10 min inside supersaturated convective core.

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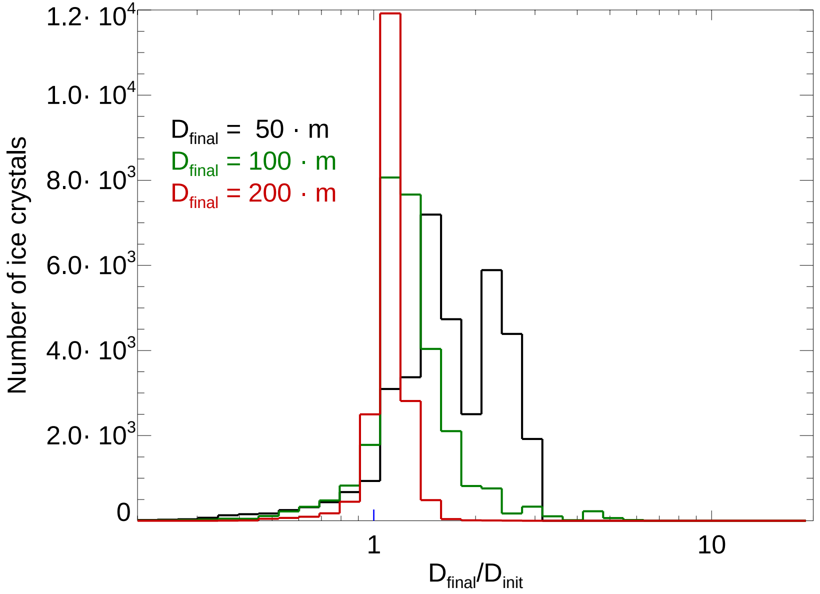
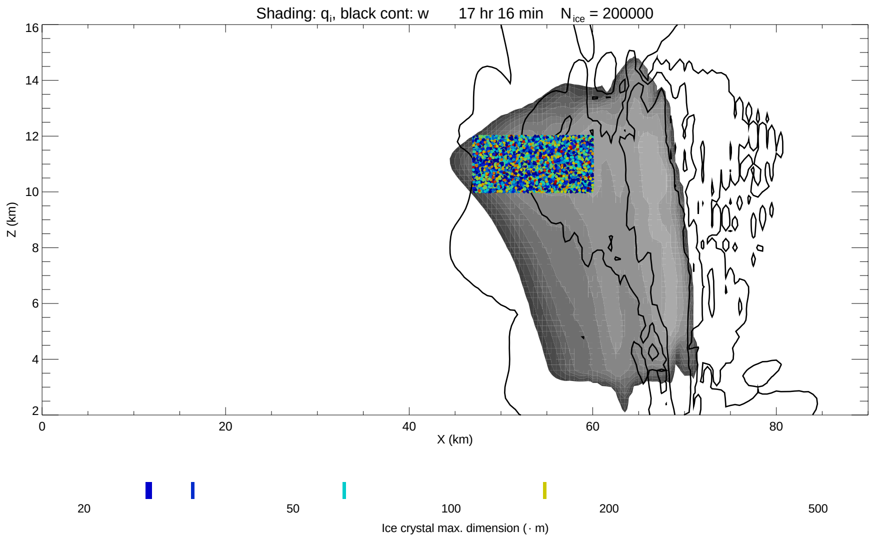


Most of the ice crystals still grew by vapor deposition at modest supersaturations (5–10%)

Re-run simulation with ice crystals initialized at later time and outside convective core



Summary and next steps

- Preliminary ice-crystal tracking simulations seem to support hypotheses based on observed ice habits:
    1. Large aggregates near convective cores do not persist
    2. Ice growth in anvil produces bullet rosettes

- Redo cloud-resolving model simulation using higher spatial resolution, higher cloud top, and longer duration

- Evaluate sensitivities to assumed ice habits and corresponding capacitances and fall speeds.