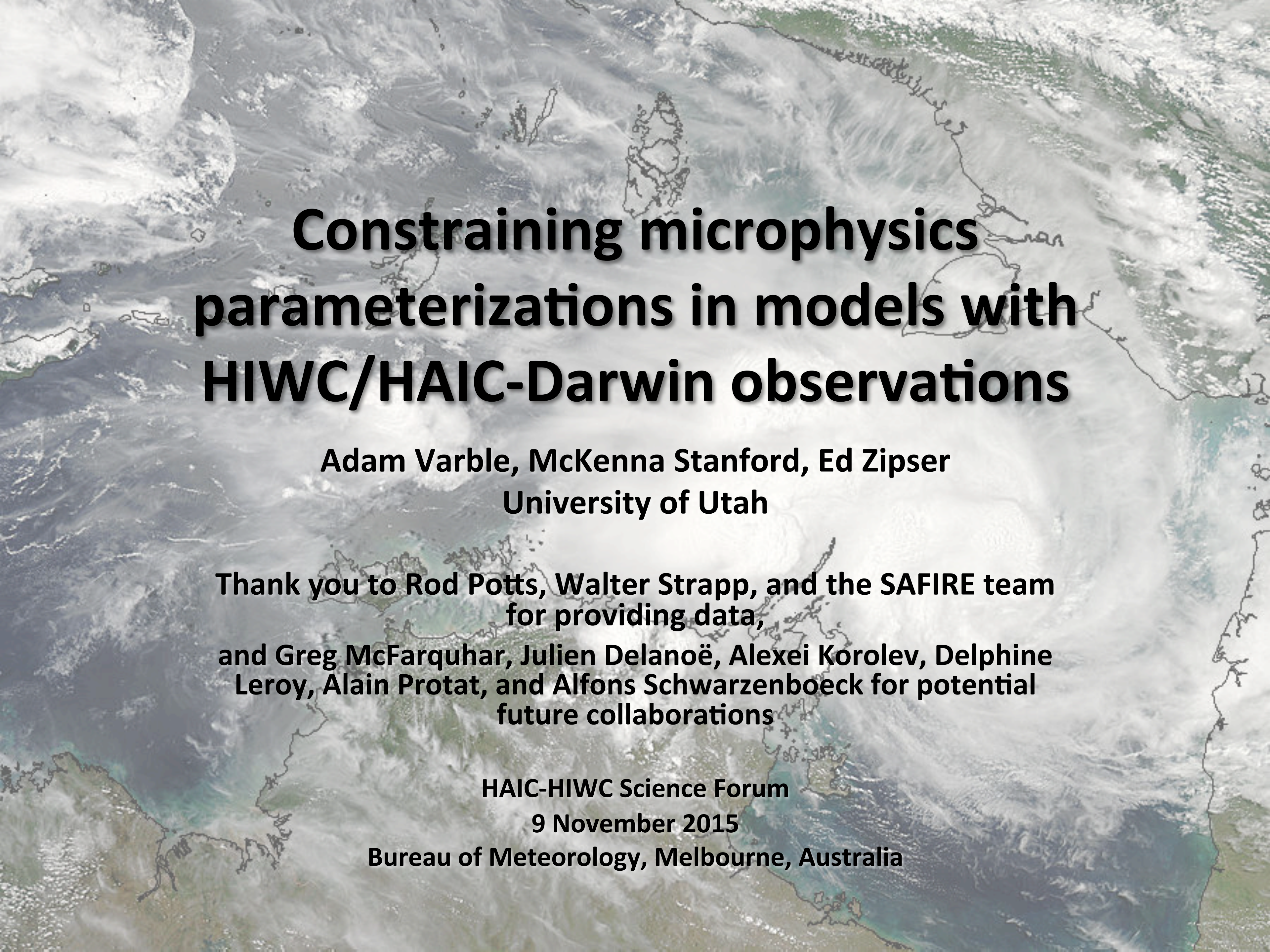


Constraining microphysics parameterizations in models with HIWC/HAIC-Darwin observations

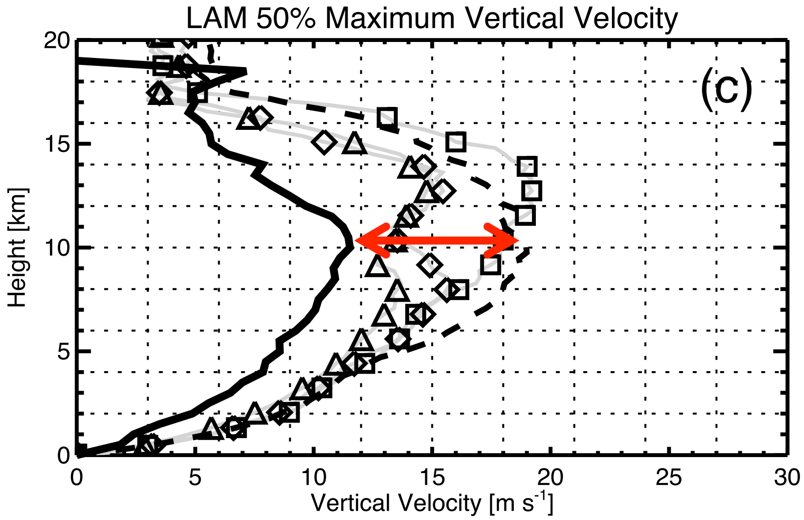
Adam Varble, McKenna Stanford, Ed Zipser
University of Utah

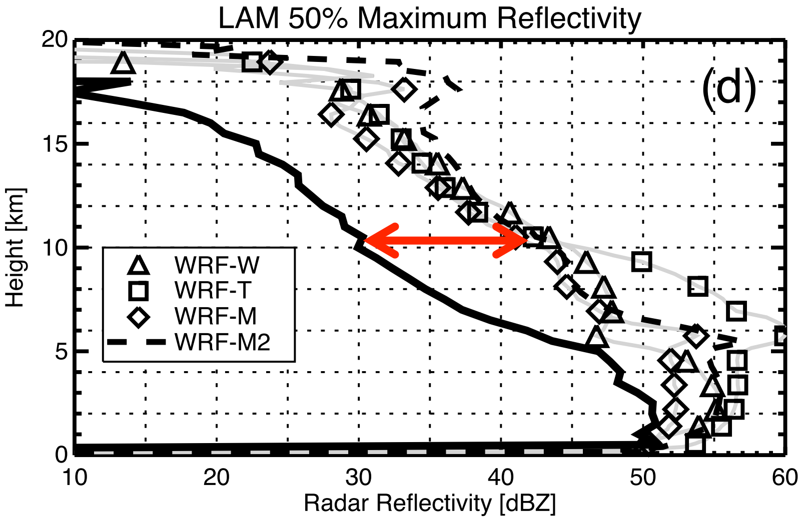
Thank you to Rod Potts, Walter Strapp, and the SAFIRE team for providing data,
and Greg McFarquhar, Julien Delanoë, Alexei Korolev, Delphine Leroy, Alain Protat, and Alfons Schwarzenboeck for potential future collaborations

HAIC-HIWC Science Forum
9 November 2015
Bureau of Meteorology, Melbourne, Australia

Current Focus is on Comparing Observed and Simulated Convective Updraft Properties

<u>Why?</u> Models have difficulty reproducing observed convective reflectivity and retrieved vertical velocity, which leads to cloud and precipitation biases that impact weather and climate prediction, but detailed observations that could help to improve models are not common. Convective updrafts are the location where very high IWC originates, and modeling helps to understand how ice properties evolve through non-measureable processes.





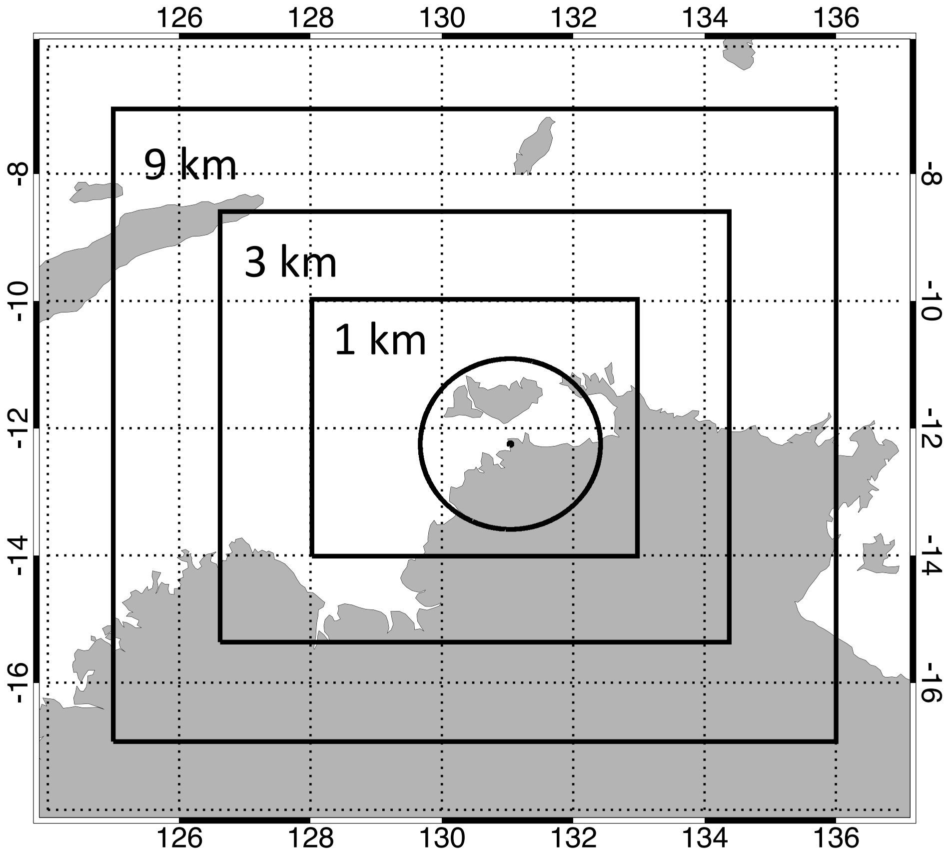
Flight 23 Simulation Setup

WRF V3.6.1

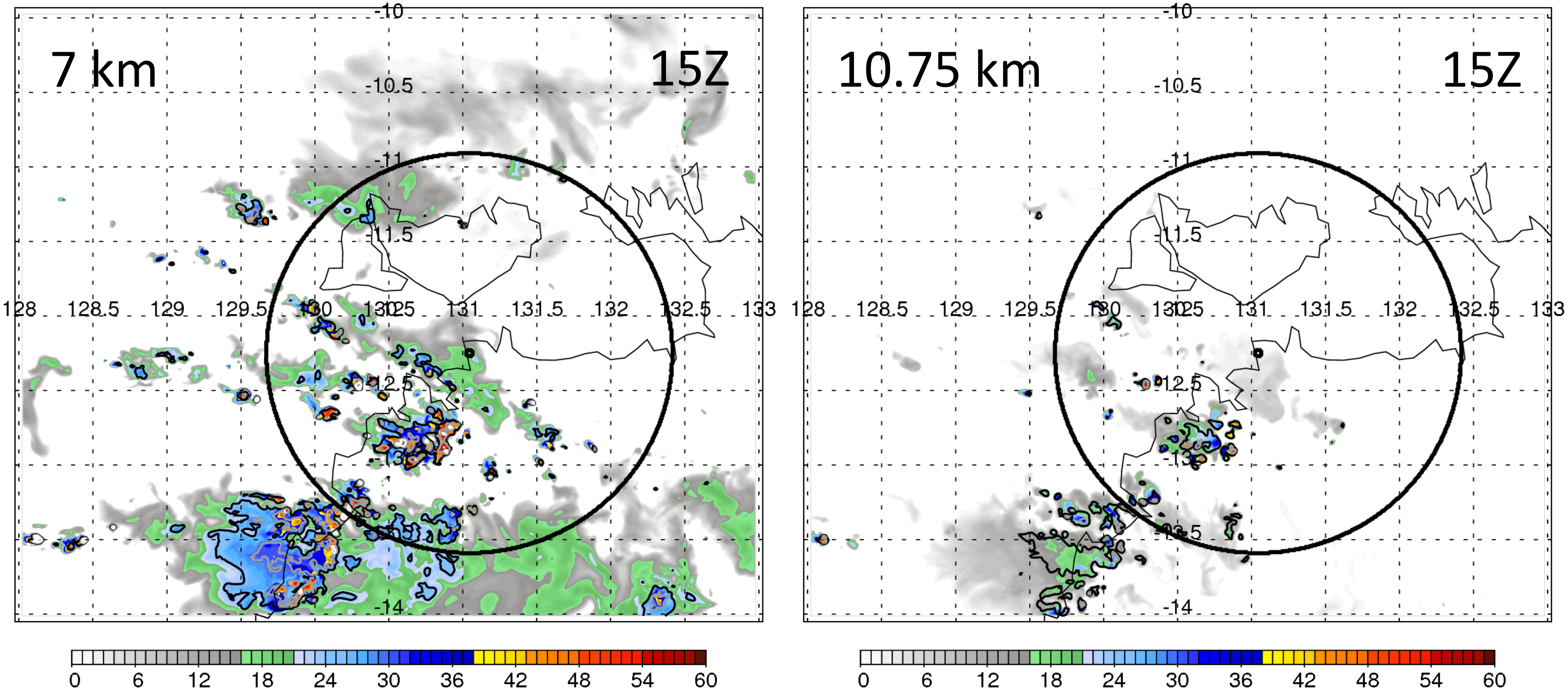
3 nested domains (9, 3, 1 km; 92 vertical levels) forced by ACCESS-R 12-km analyses

Thompson bulk microphysics, which has a sophisticated snow representation

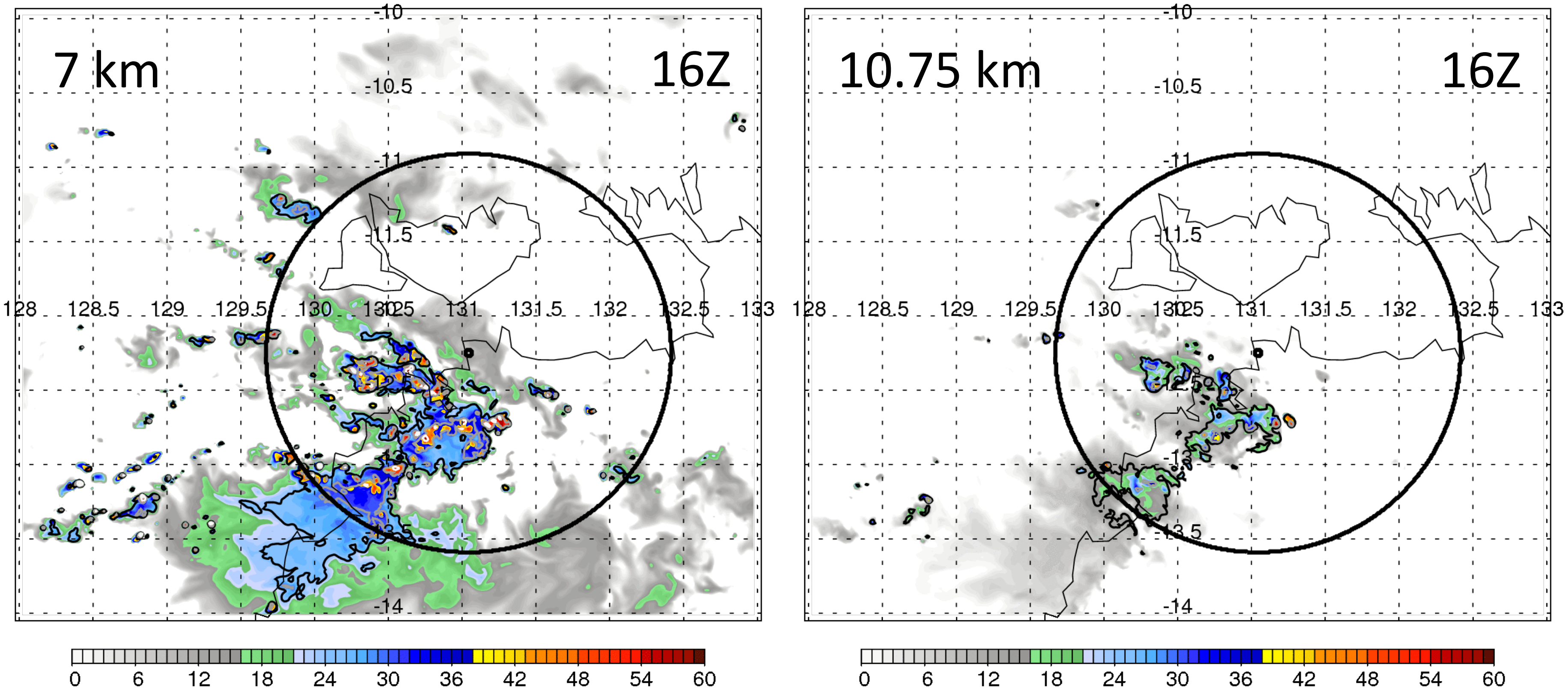
Initialized at 0Z 18 February and run through 6Z 19 February



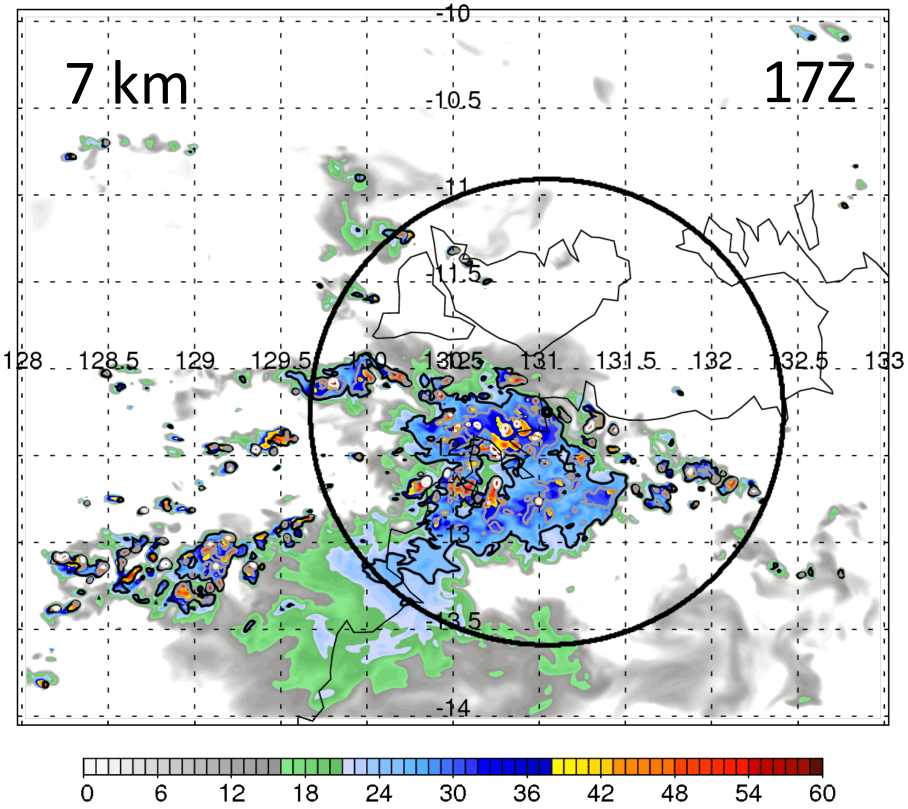
Production of High IWC and low dBZ

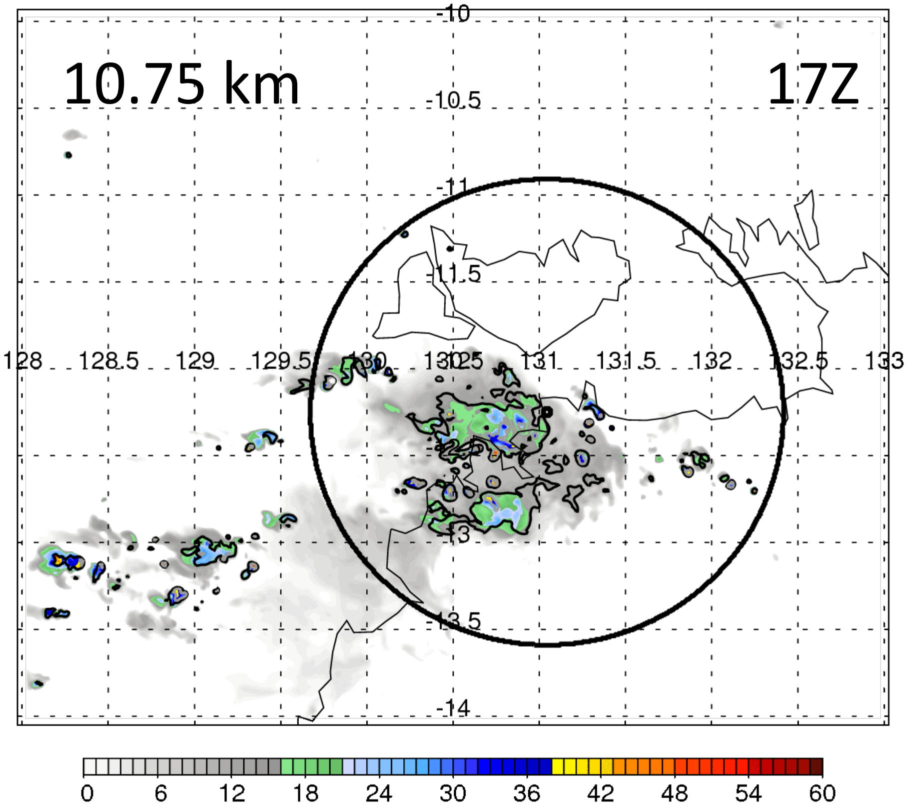


Production of High IWC and low dBZ

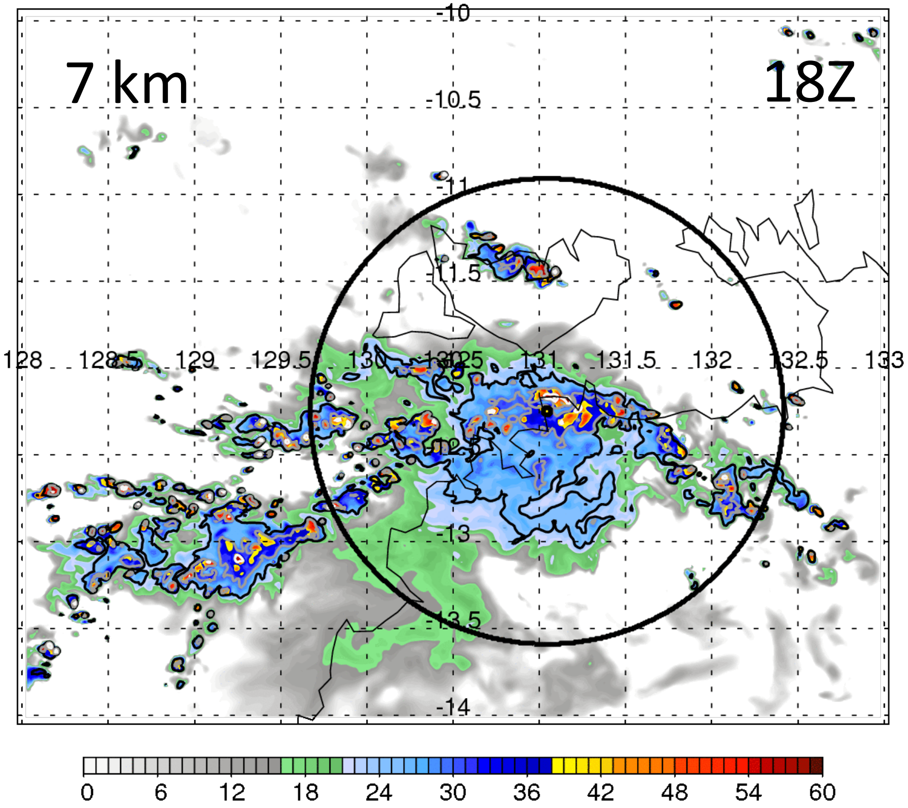


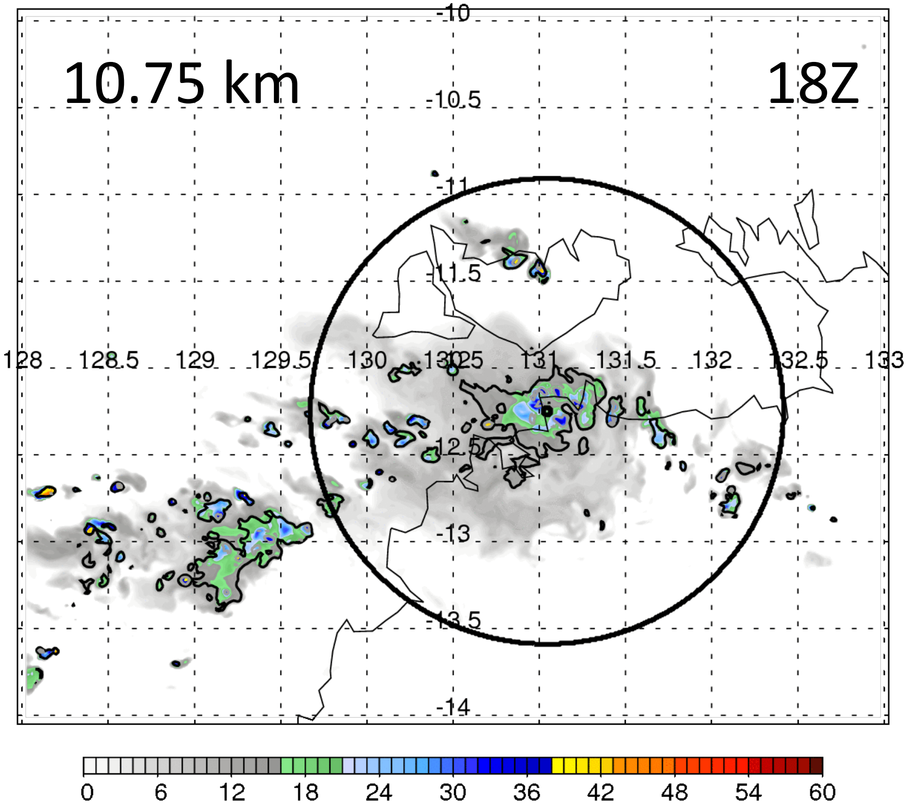
Production of High IWC and low dBZ



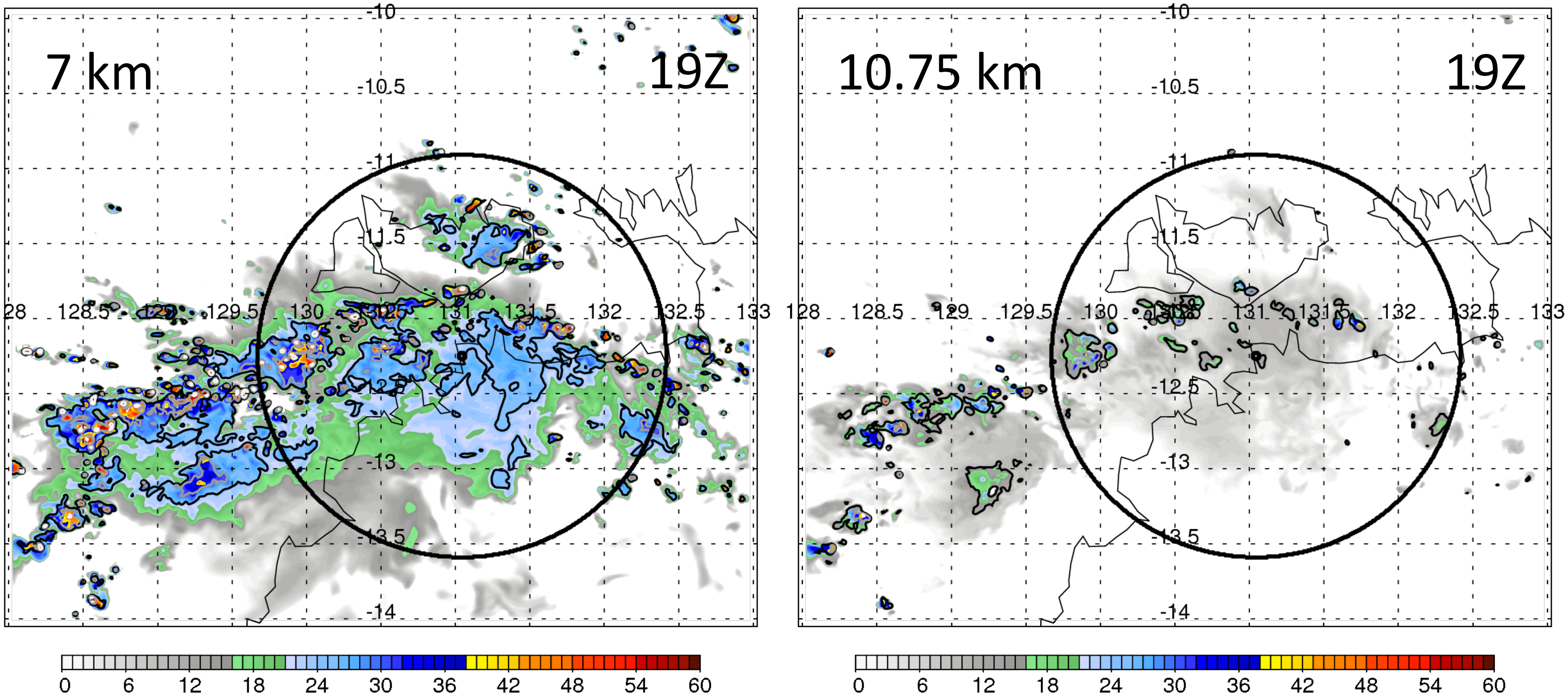


Production of High IWC and low dBZ

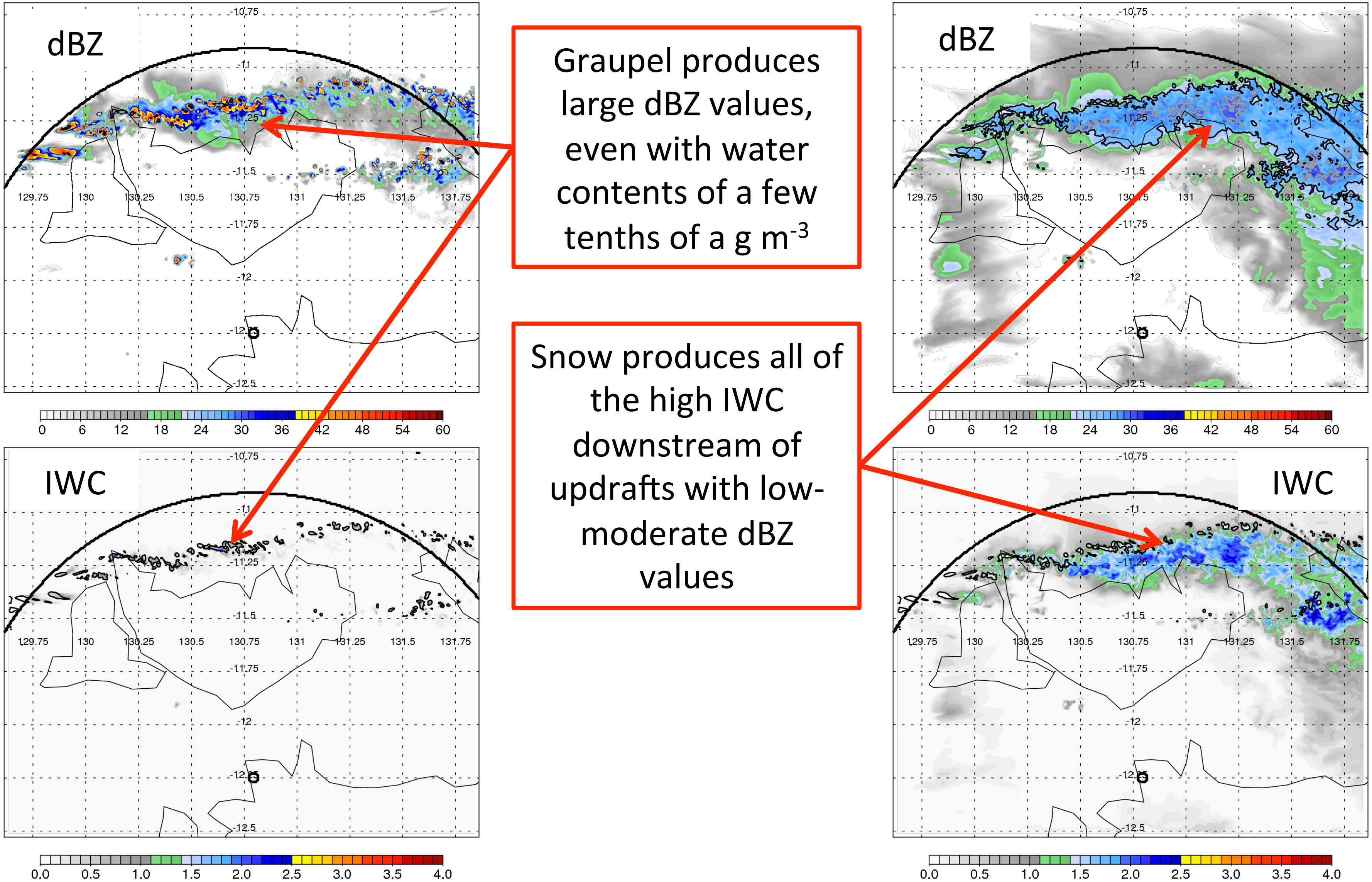




Production of High IWC and low dBZ



Graupel (left) vs. Snow (right) at 7-km Altitude



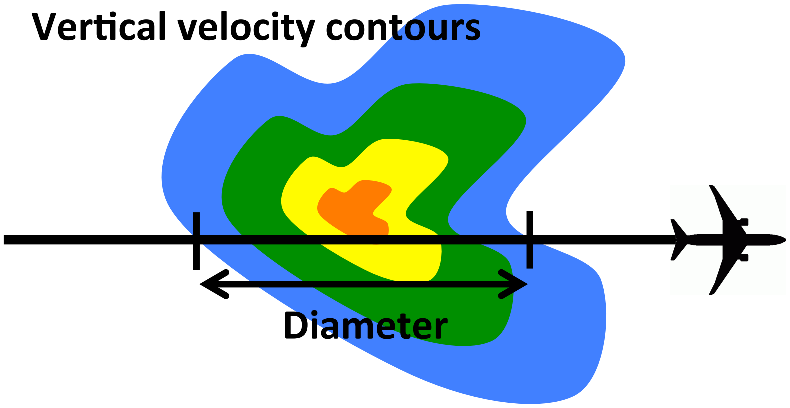
Graupel produces large dBZ values, even with water contents of a few tenths of a g m^{-3}

Snow produces all of the high IWC downstream of updrafts with low-moderate dBZ values

Methodology

Fly pseudo-flight tracks through the model and define updrafts as at least 500 m (333 m grid spacing) or 1 km (1 km grid spacing) of continuous 1 m s^{-1} upward motion

- Degrade flight observations (IKP, vertical air motion) to 333 m and 1 km to match model grid spacing and define updrafts in same manner



Variables
- Average and peak vertical velocity
- Diameter
- Mass Flux
- Average and peak TWC

Where applicable
- Average and peak reflectivity

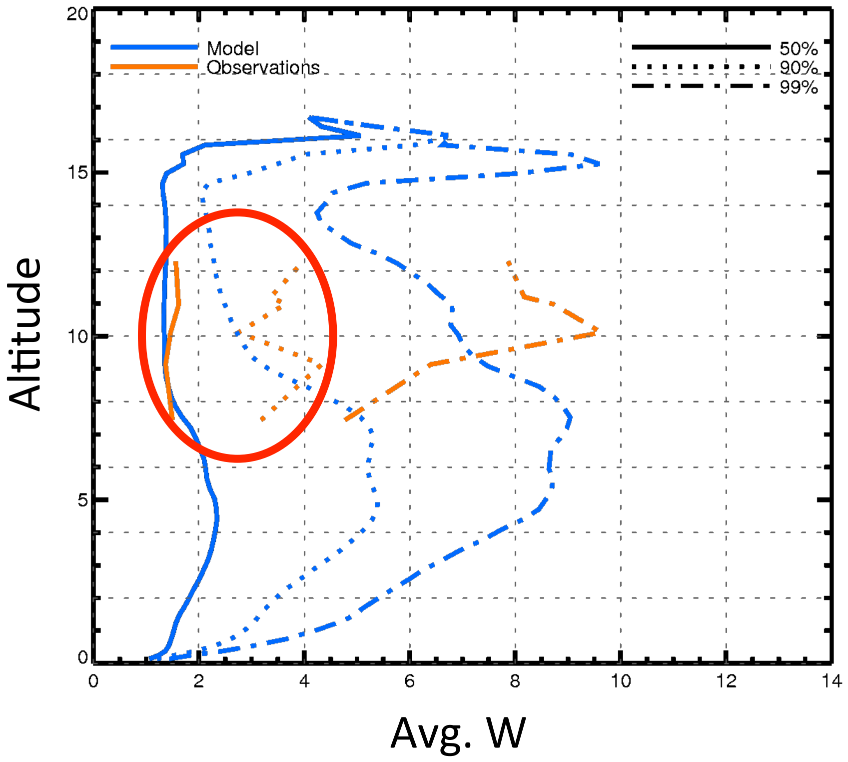
Future
- Number concentration
- Mass mean diameter

Models
- Hydrometeor breakdown and process rates

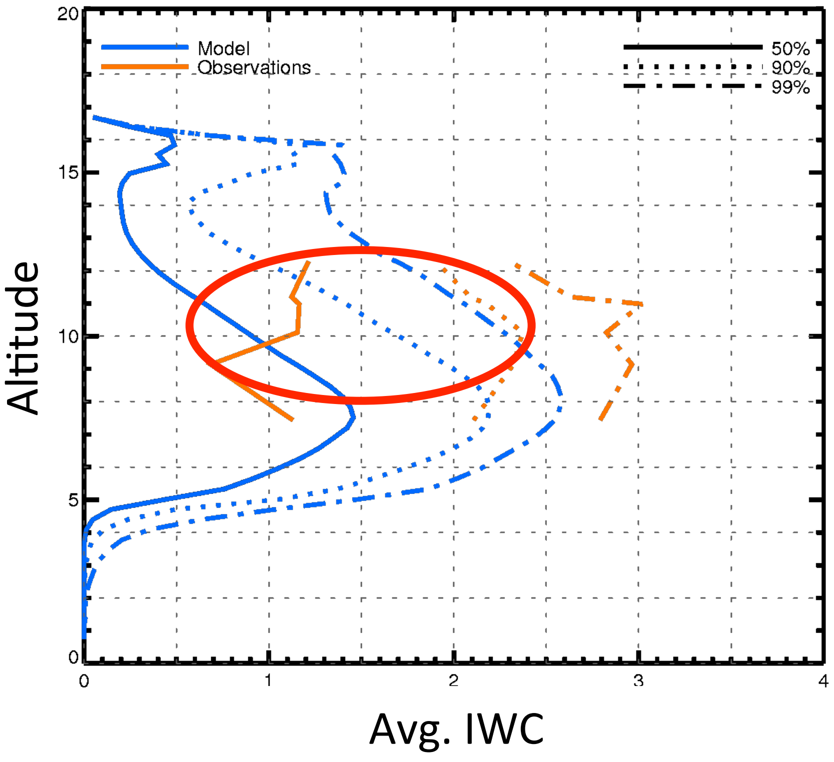
How do observed and simulated values of updraft vertical velocity and IWC compare?

Tends to be higher IWC in observed than simulated updrafts at cold temperatures, but observations are from all events whereas simulated values are from Flight 23 alone

50th, 90th, and 99th Percentiles

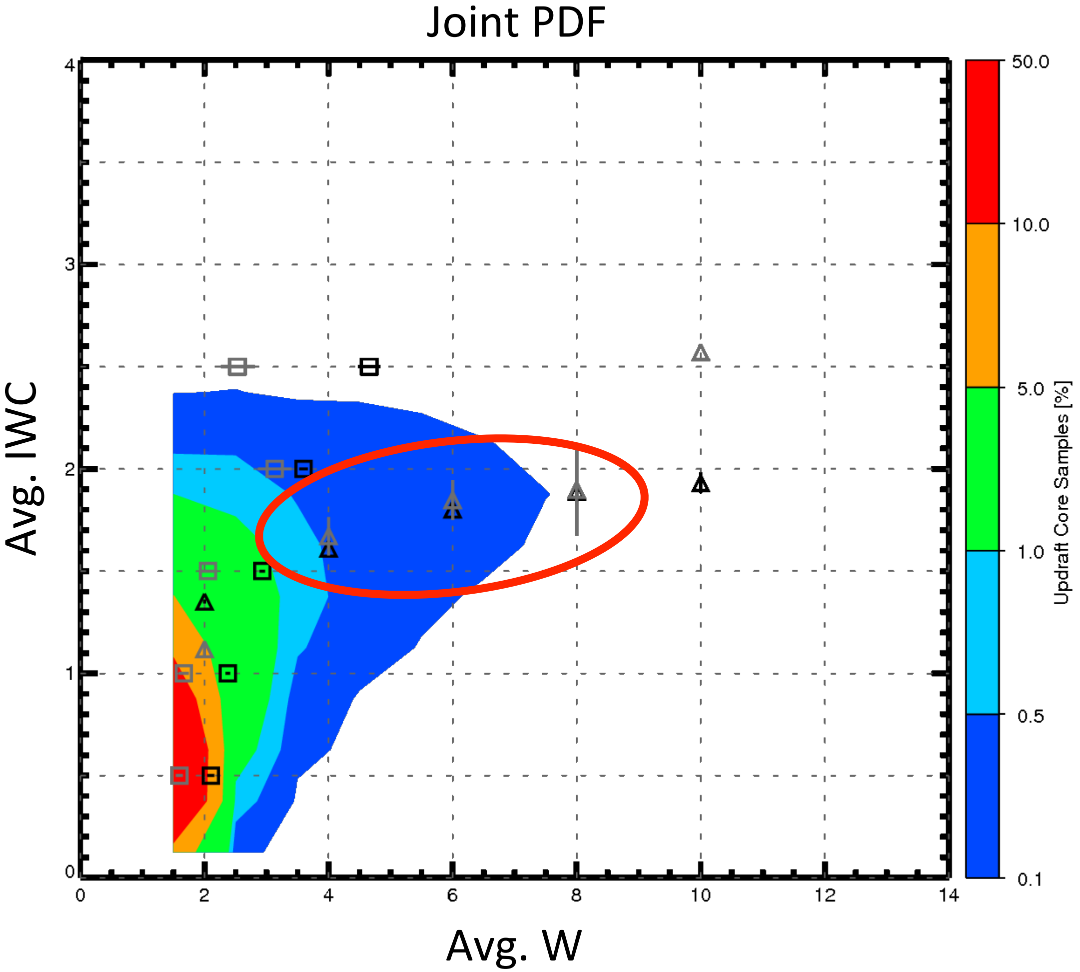


50th, 90th, and 99th Percentiles



Comparison of observed and simulated convective updraft properties at -30 to -40°C

- Remarkably good agreement at degraded resolution
- IWC and vertical velocity do not depend much on updraft width
- Good correlation between IWC and vertical velocity with leveling off of IWC at larger vertical velocities



Other events that we are currently simulating

1. **Flight 6 (Jan. 23)** in Joseph Bonaparte Gulf: decently long transects of 2 g m^{-3} with spikes to over 3 g m^{-3}, 3 temperatures (-30 to -50°C)

2. **Flight 10 (Jan. 29)** near Gove just off coast: 3 temperature levels (-30 to -50°C) through same area, decent transects of 2 g m^{-3} with spikes over 3 g m^{-3}, updraft exceeding 20 m s^{-1}

3. **Flights 12-13 (Feb. 2-3)** tropical low in Joseph Bonaparte Gulf: decent 3 g m^{-3} segments with one spike over 5 g m^{-3}, primarily between -20 and -40°C; little lightning so not avoiding "intense" areas

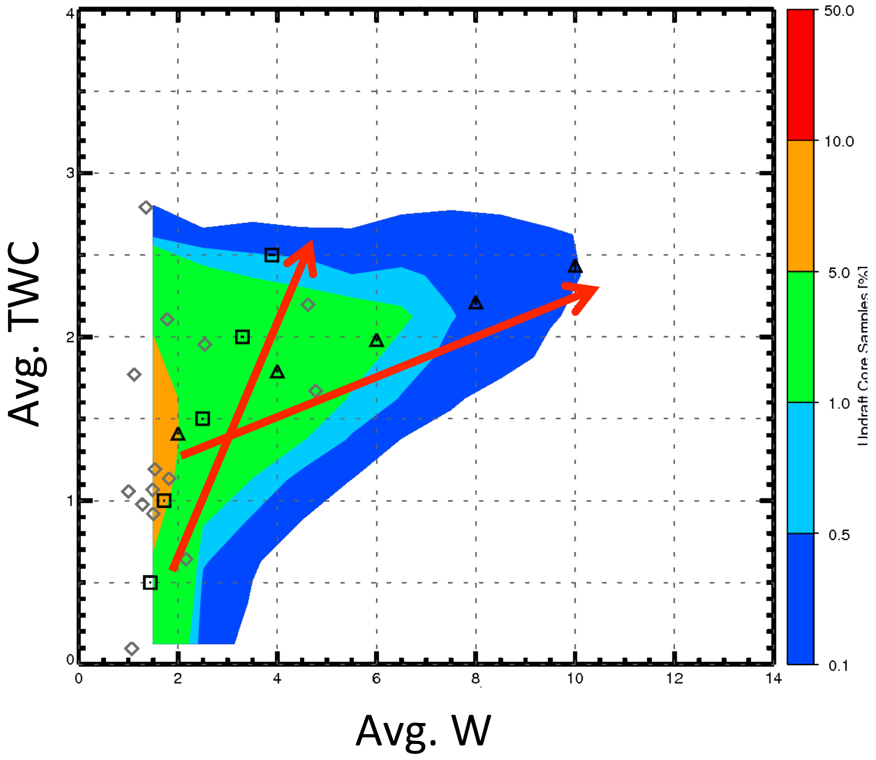
4. **Flight 16 (Feb. 7)** squall northwest of Broome: flying at -40°C along the convective line where it had decayed enough to avoid lightning and graupel with up to 50 km segments averaging 2 g m^{-3} with occasional spikes to 3 g m^{-3}

- Expecting similar statistics with the primary difference in events being the depth of intense updrafts with high IWCs
- Will test other popular bulk microphysics schemes as well

What about -10°C?

- Good agreement of increasing TWC with vertical velocity
- But, as cloud ice/snow water content decreases with increasing vertical velocity in the simulation

Joint PDF



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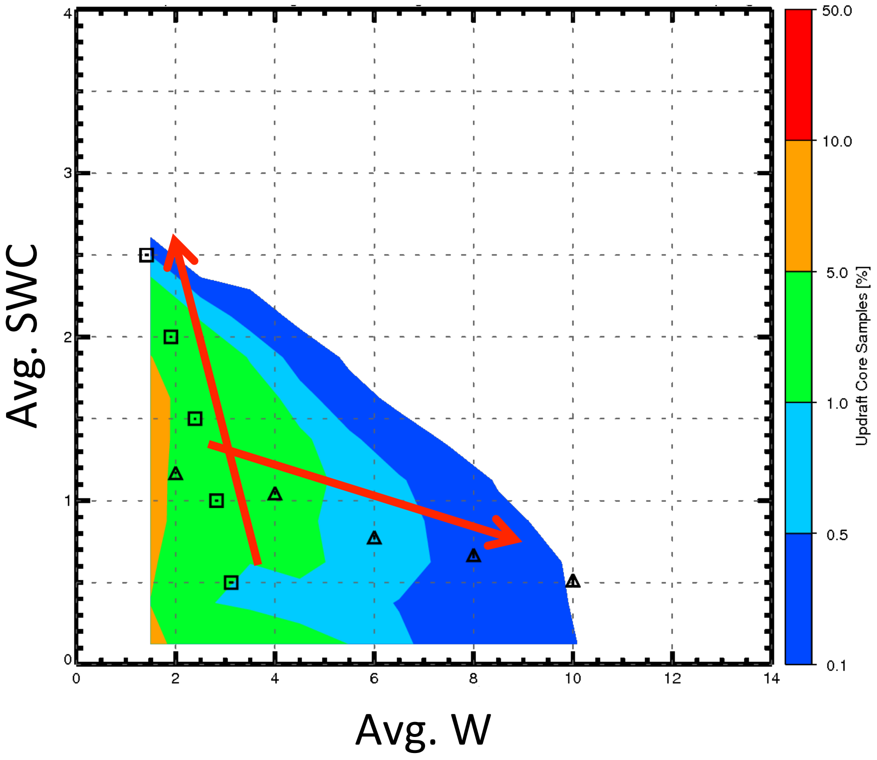
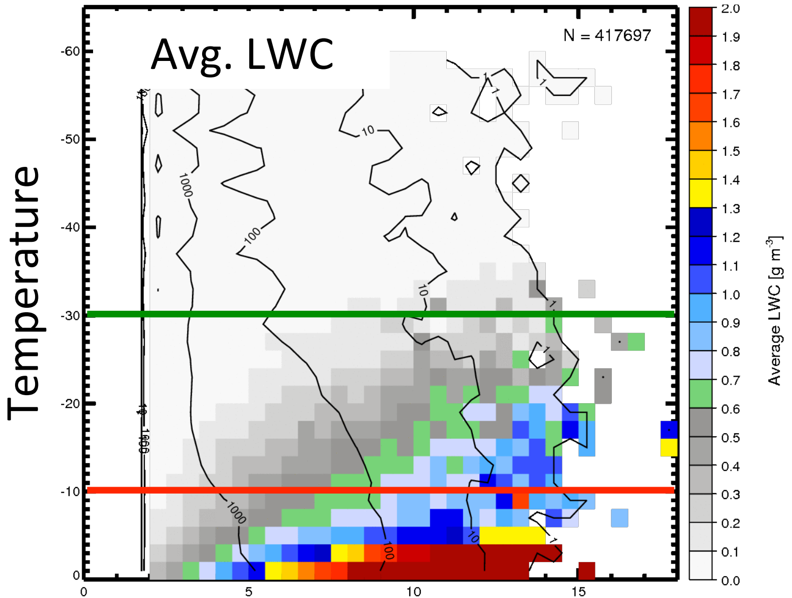
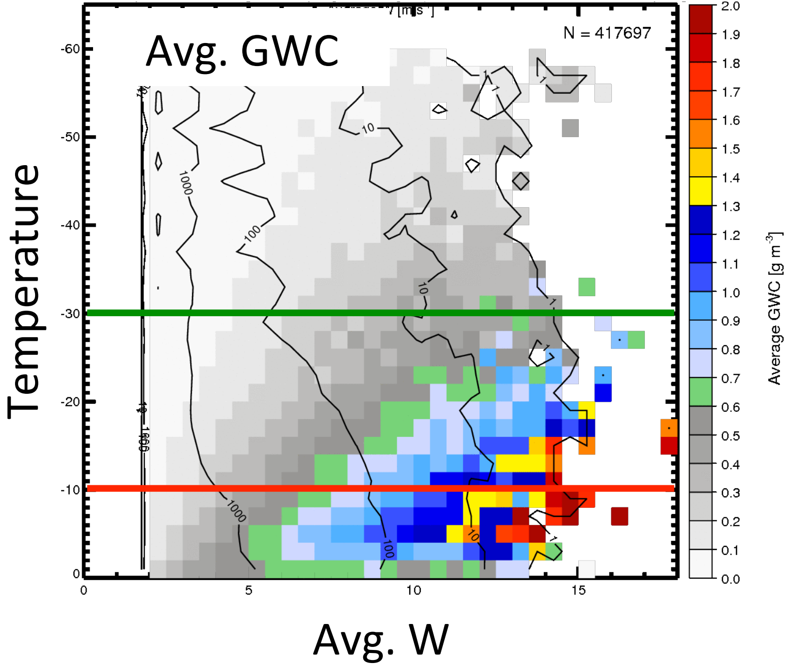
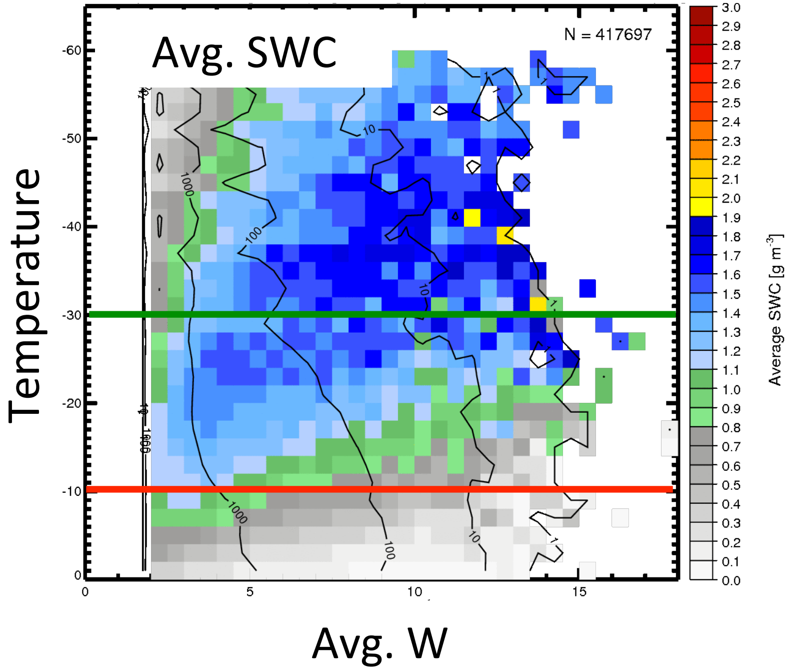


Too much simulated liquid (upper left) and graupel (lower left) prevents high IWC dominated by small ice (lower right) at warm temperatures



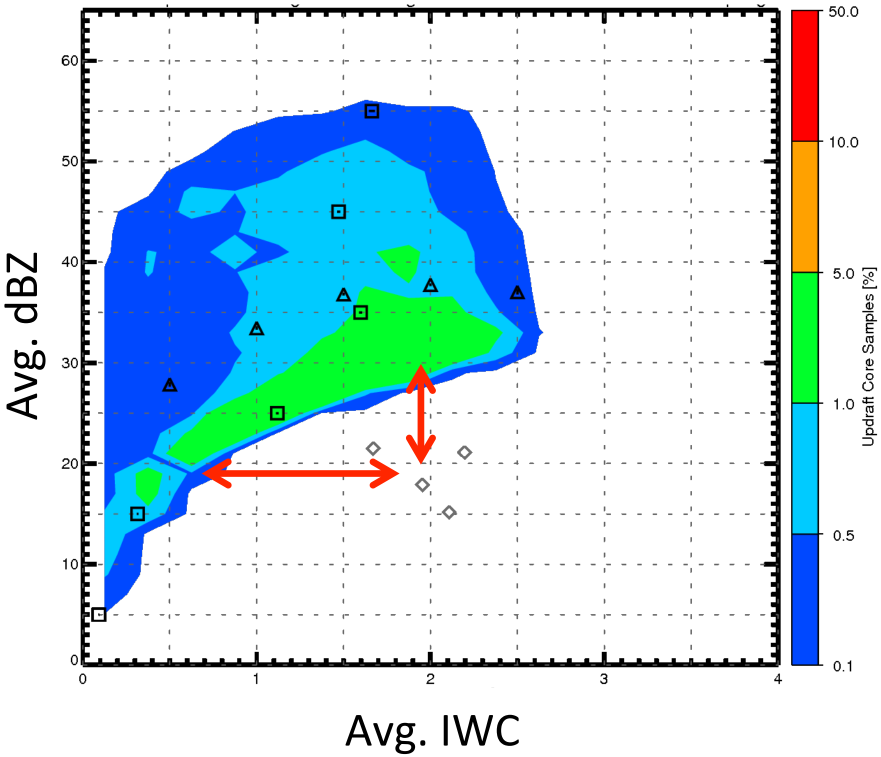




Problems in model phase and ice type partitioning at -10°C

For a given updraft size and strength, there are no simulated updrafts that have the same properties as the ones observed during the 18 February flight

Joint PDF



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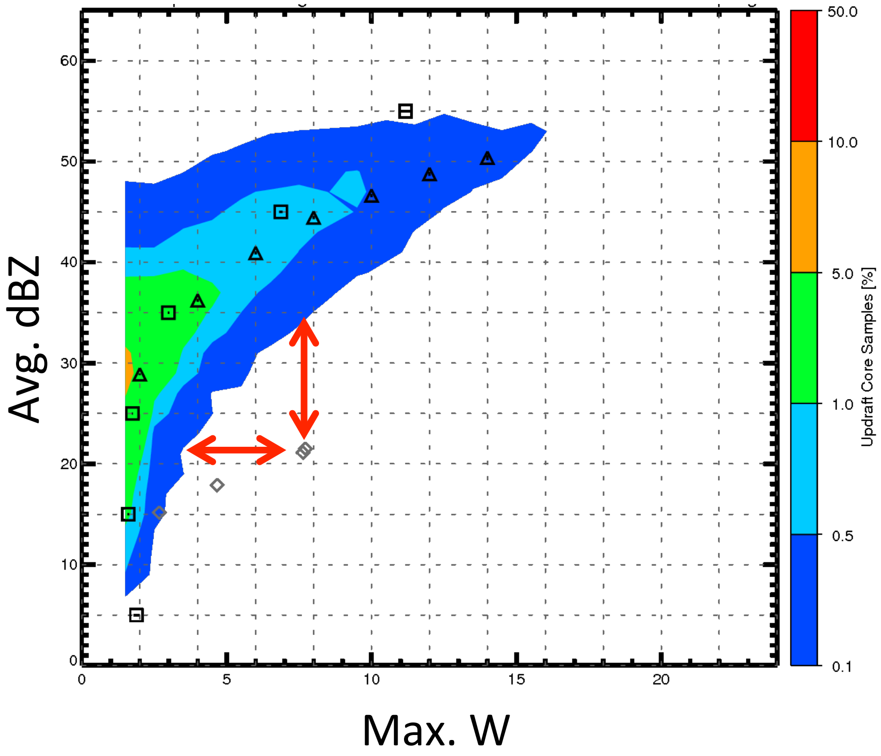
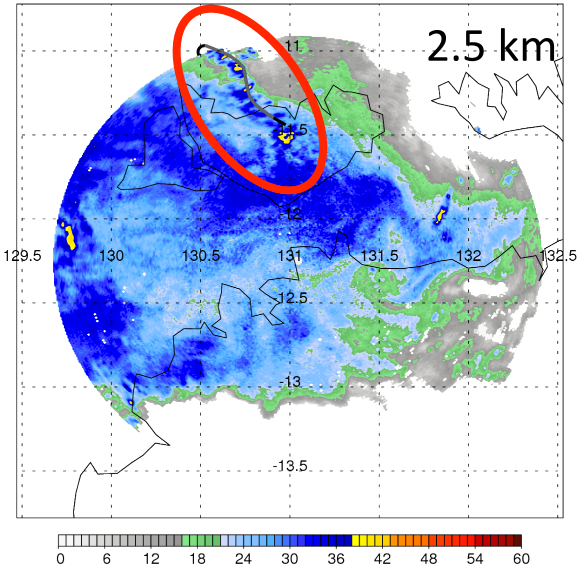


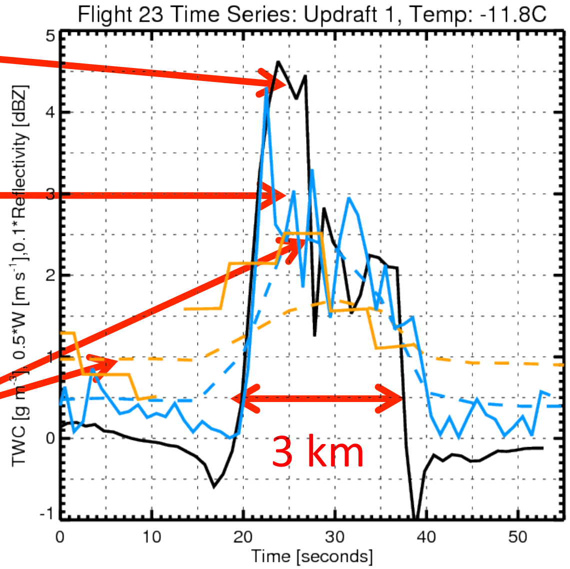
Observed Updrafts at -11.8°C

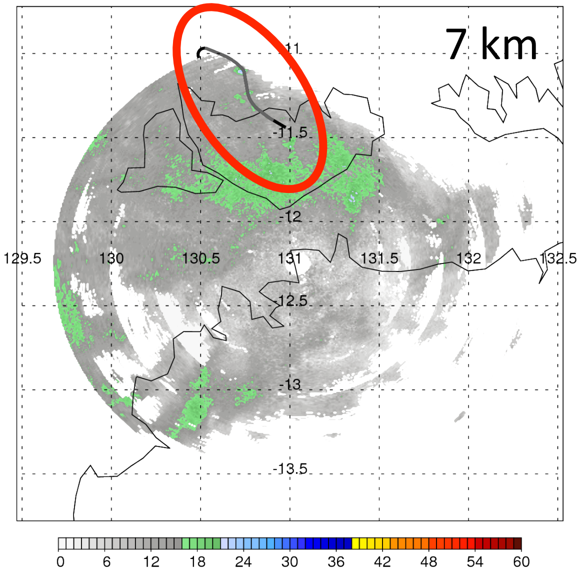


9 m s^{-1} peak
6 m s^{-1} average

4 g m^{-3} peak
2 g m^{-3} average

Change from
10 dBZ to 25 dBZ

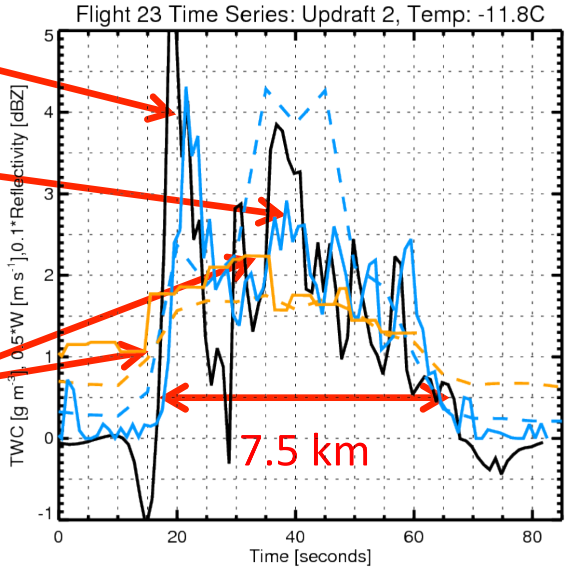




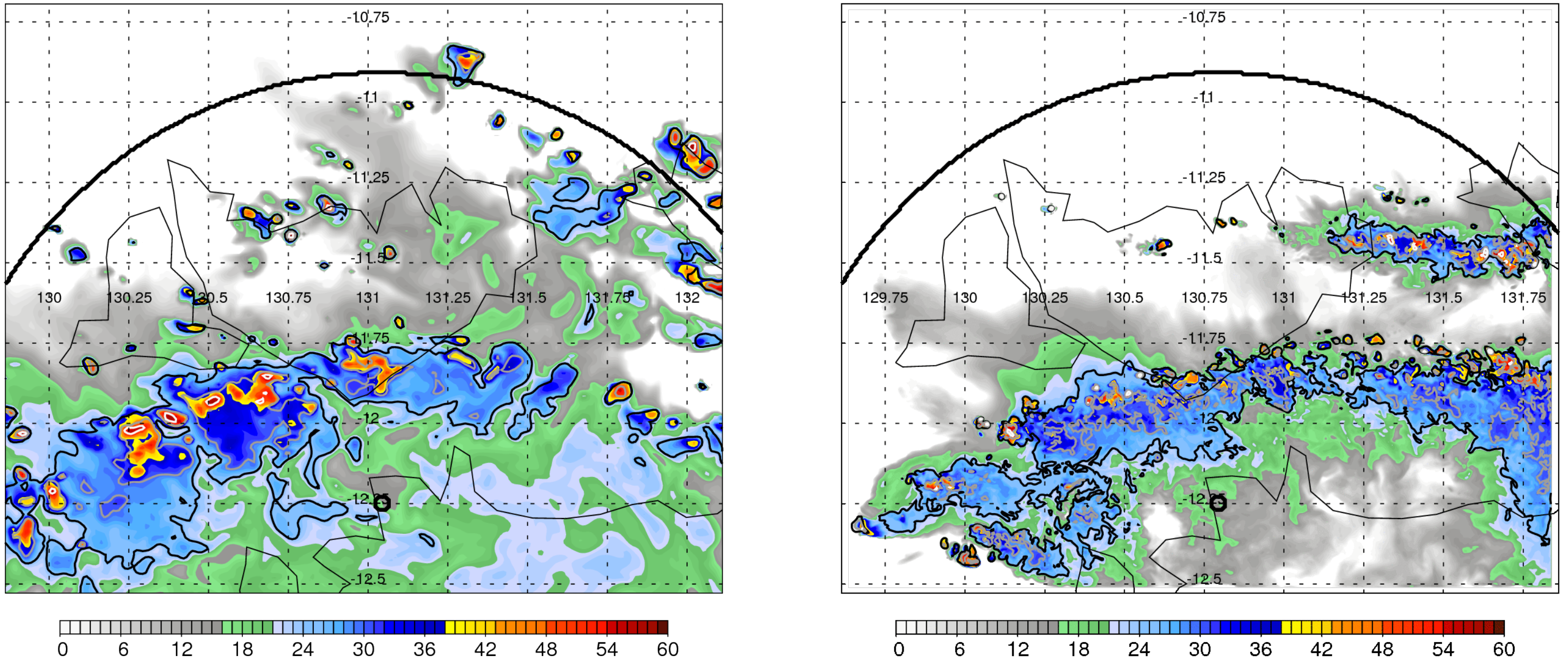
10 m s^{-1} peak
4 m s^{-1} average

4 g m^{-3} peak
2 g m^{-3} average

Change from
10 dBZ to 22 dBZ



High Resolution Inner Domain



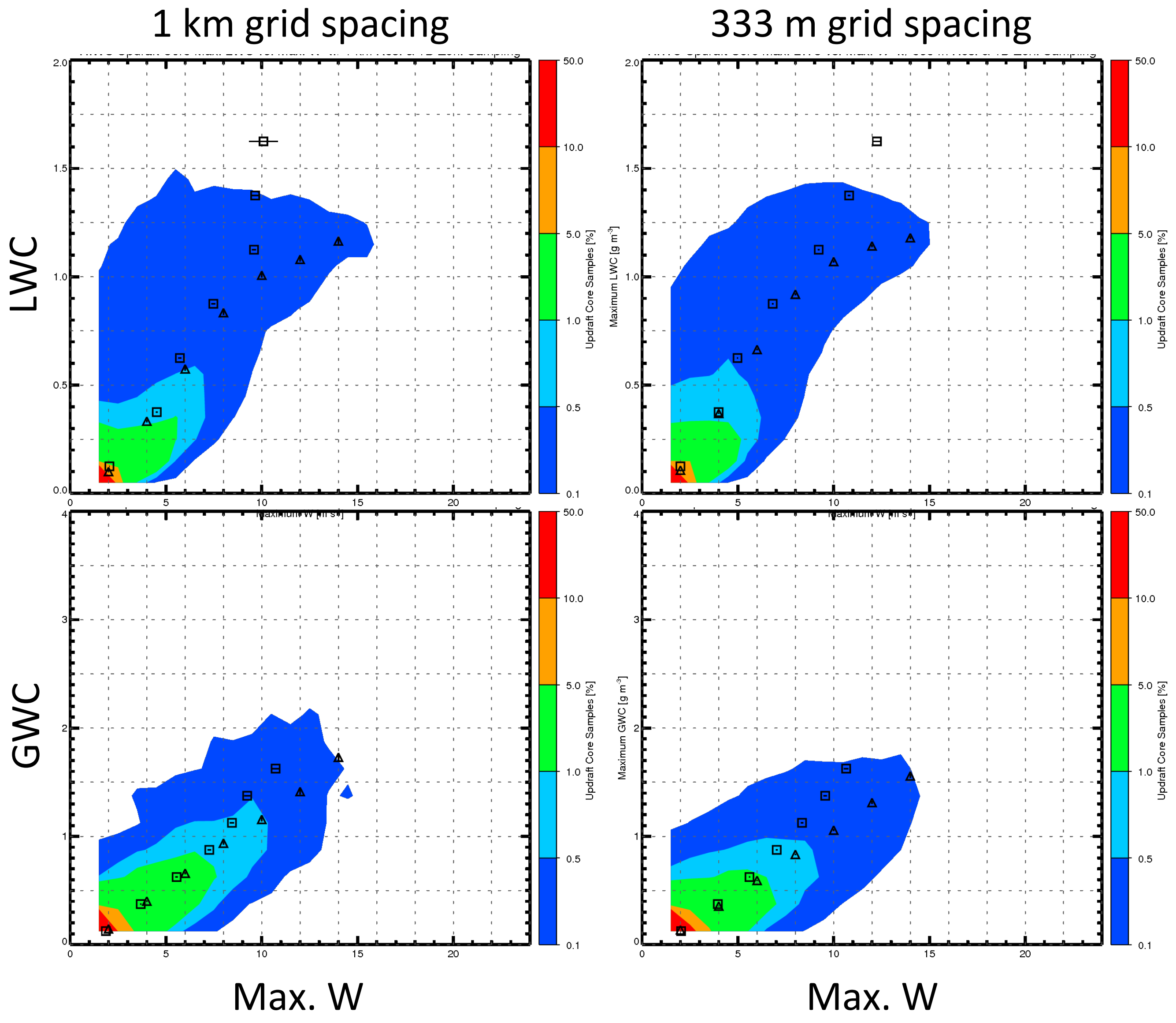
240 km by 200 km size with 333 m horizontal grid spacing and 183 vertical levels

Forced with 1-km grid spaced WRF output between 12Z 18 and 0Z 19 February

Better resolves updraft dynamics and mixing

1 km vs. 333 m model horizontal grid spacing

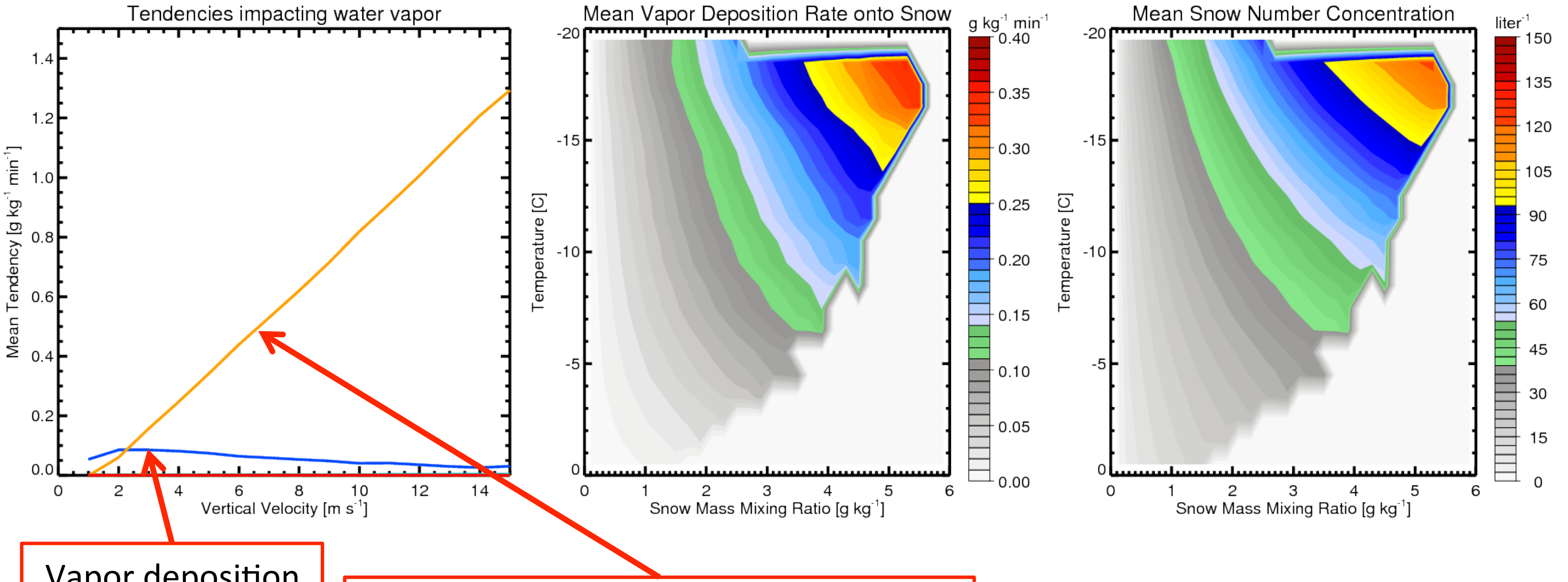
Convective updraft statistics look similar for both model resolutions suggesting that the primary problem may lie in the microphysics parameterization rather than the grid resolution


1 km grid spacing

333 m grid spacing

Why is there so much liquid and graupel in simulations?

(1) Supersaturation is not efficiently removed in updrafts stronger than 1 m s^{-1}, which leads to liquid droplets and riming. This could be the result of insufficient snow number concentrations.

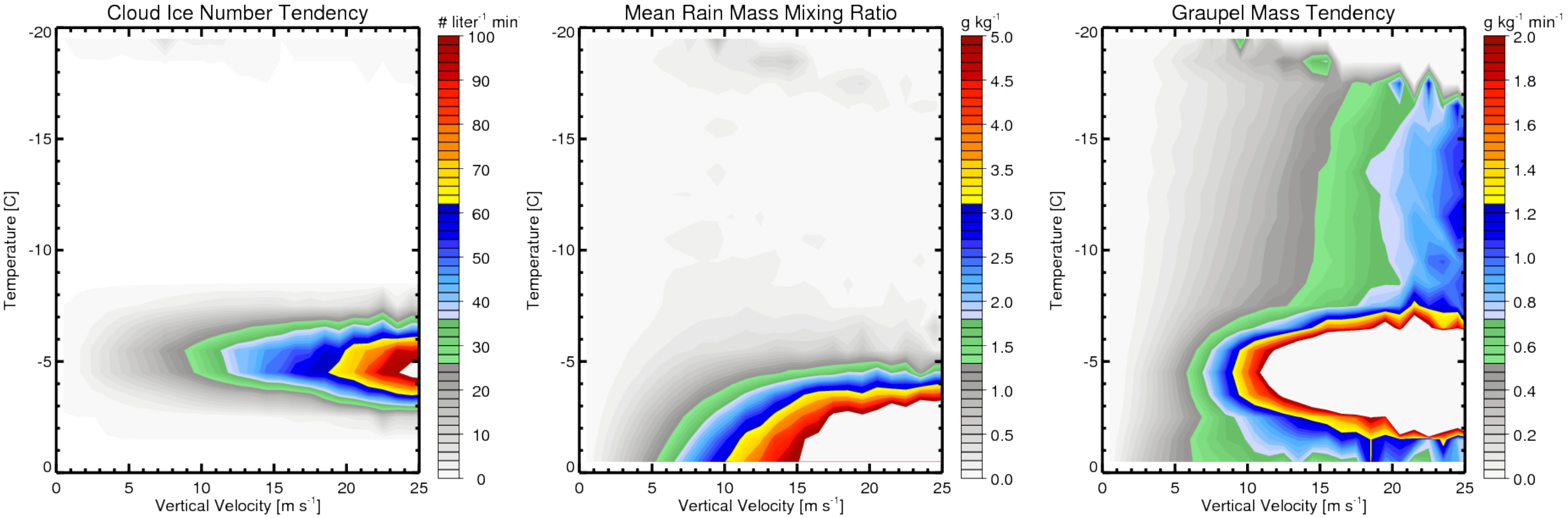


Vapor deposition onto snow

Supersaturation w.r.t. liquid after ice processes, but before condensation

Why is there so much liquid and graupel in simulations?

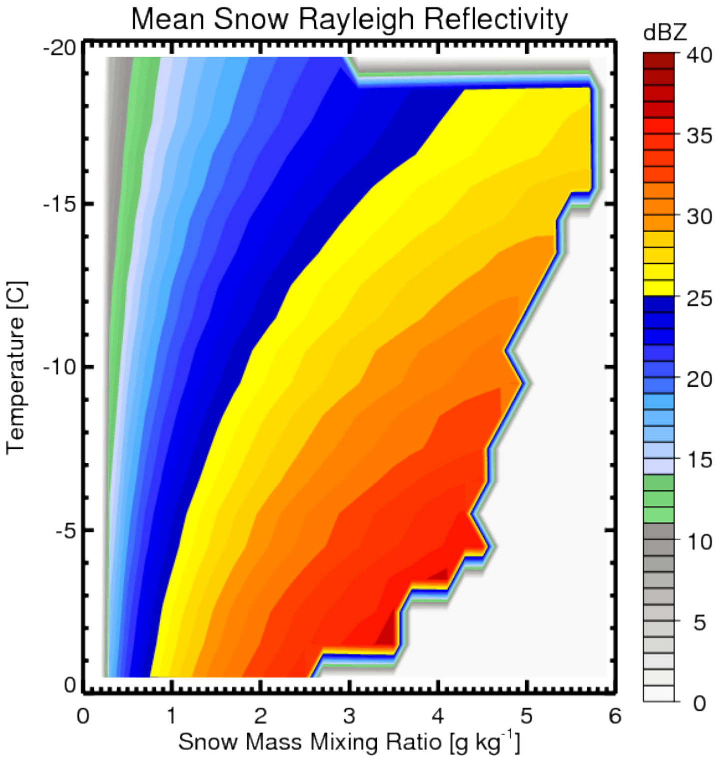
(2) Ice splinters in updrafts with vertical velocities exceeding 5 m s^{-1} are quickly consumed by liquid (primarily rain) being lofted in the updraft leading to graupel production



Additional issues in bulk microphysics schemes

Prescribed size distributions given predicted mass and temperature work well in stratiform precipitation, but not for situations with production of large numbers of ice particles at warm temperatures

- Ultimately need to predict number concentrations (i.e., a 2-moment scheme), but these do not guarantee 100's L^{-1} at warm temperatures, so there is a problem in typical representation of mixed-phase microphysics in this region
- Mass-diameter and gamma PSD fits are also needed, perhaps with flexibility to be able to handle the vastly different environments of convective drafts and stratiform regions



More observational validation needed

- A measure of ice size (reflectivity or MMD) in addition to bulk mass, number (uncertain), and vertical velocity is crucial to highlighting problems in simulations
- Estimating upper bounds on LWC and graupel mass could be useful for showing that most TWC is in smaller sized ice, which the model struggles to do at warm temperatures and only does at cold temperatures because it is diagnosed that way
- 0 to -10°C region is where mixed phase interactions often determine properties of ice being lofted to colder temperatures in updrafts with relatively low reflectivity, but it is also where models perform worst, so Cayenne data will be crucial

Next Steps

1. Finish simulating other key observed events
2. Analyze convective downdrafts and high IWC regions like updrafts
3. Validate simulations with all possible observations (RASTA, PSDs, TWC, winds, geostationary satellite) – coupling of more than two independent measurements exposes model issues
    - Cayenne data is crucial because of lack of warm observations in Darwin and longer wavelength radar data
4. Explore realistic pathways for increasing ice number concentrations and decreasing LWC and graupel at warm temperatures in simulations
    - Analyze impacts on mesoscale cloud and precipitation structure
5. Explore sensitivity of simulations to ice properties (size distribution, fall speeds) and ice processes (rime splintering, collection, etc.)
    - Implement a PSD parameterization based on HIWC/HAIC measurements with Greg McFarquhar
6. Analyze the life cycle of simulated "mesoscale" regions of high IWC at cold temperatures including their relation to updraft dynamics and ice sedimentation/divergence