University of Utah Research Update: Future Work

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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

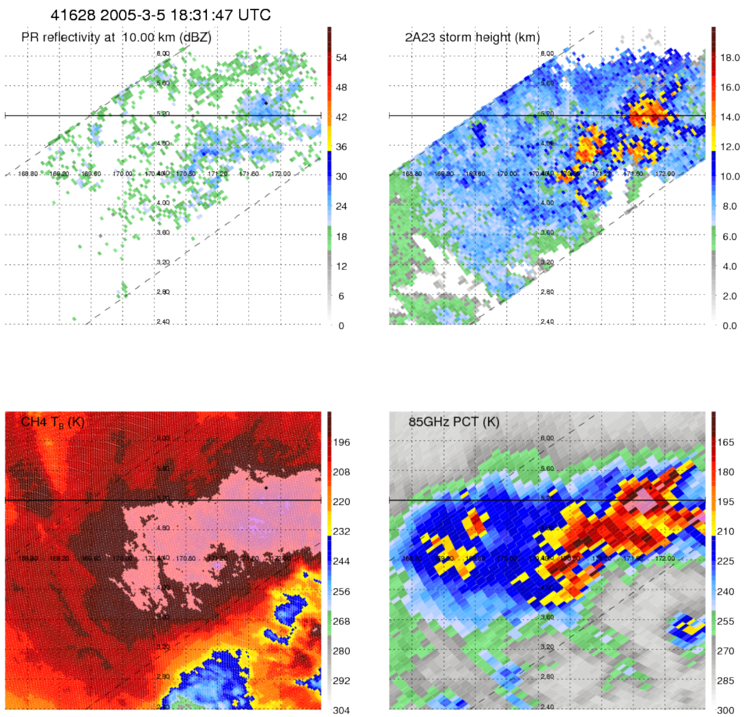
What produces such high concentrations of vapor grown ice particles?

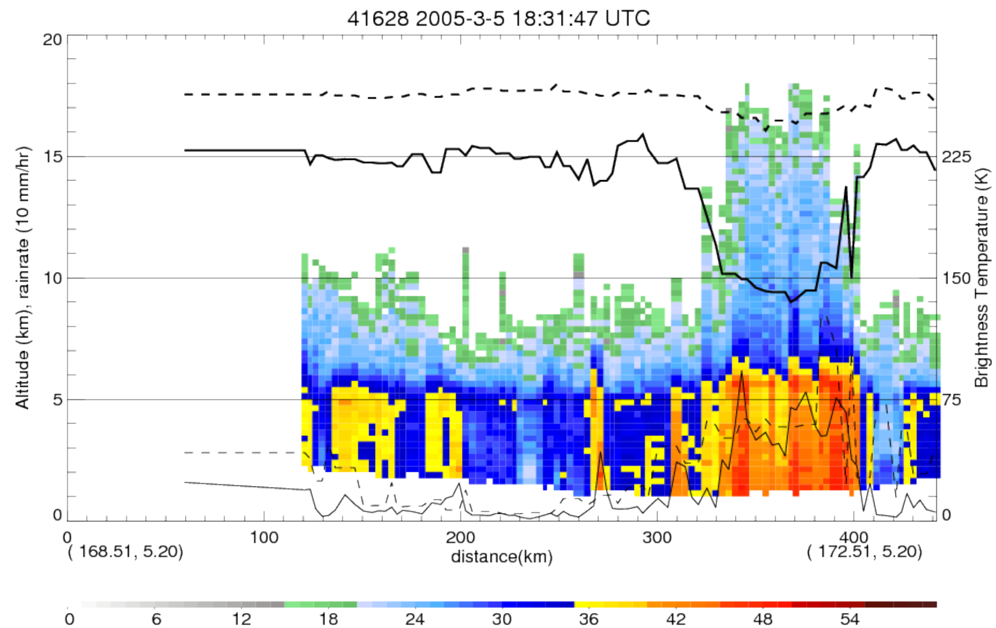
- Hallett-Mossop – peak rate of 350 splinters per mg of rime at -5°C
  - Lower rates at other temperatures bounded by -3°C and -8°C
- Lawson et al. (2015) Ice-T observations of growing isolated tropical congestus clouds
  - High LWCs with high dBZ depleted in 1 to 1.5 km and replaced by high IWC with low dBZ
  - Suggests raindrop fracturing as a key multiplication mechanism
    - Splinter production rate depends on size of drop (5 splinters for freezing 500 micron diameter raindrop)

TABLE 2. Mean values of the updraft-core measurements listed in Table 1 for each temperature region. Mean values are weighted by duration time. The equivalent radar reflectivity Z is calculated from the particle size distribution (Lawson and Zuidema 2009).

ICE-T updraft-core mean values											
Region	Temp (°C)	VAV mean ($m\,s^{-1}$)	VAV max ($m\,s^{-1}$)	VAV std dev ($m\,s^{-1}$)	VAV duration (s)	Drop concentration (cm^{-3})	LWC ($g\,m^{-3}$)	Liquid Z (dBZ)	Ice concentration (L^{-1})	IWC ($g\,m^{-3}$)	Ice Z (dBZ)
Cloud base	22	1.0	1.7	0.5	7	89	0.2				
All liquid	−3	9.5	14.9	3.1	16	58	3.5	37	0	0.00	0
First ice	−9	10.3	16.4	3.5	13	37	2.4	33	50	0.01	−31
Rapid glaciation	−15	7.4	11.2	2.2	9	22	0.3	−13	572	2.78	14

Are there large particles between 0 and -10°C in tropical oceanic convection?



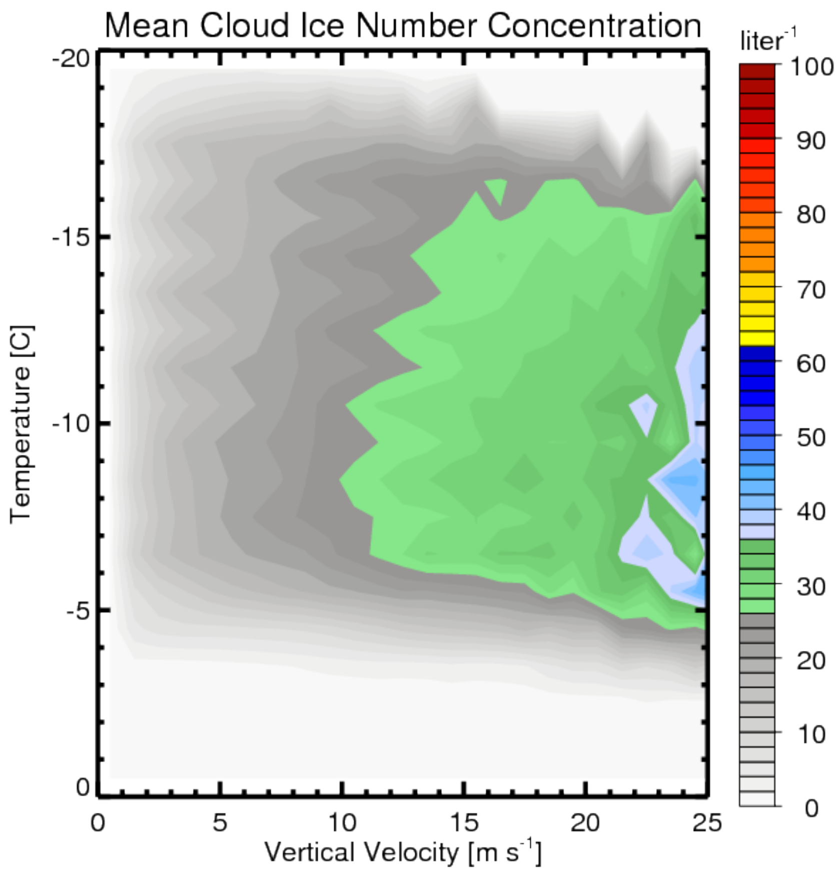


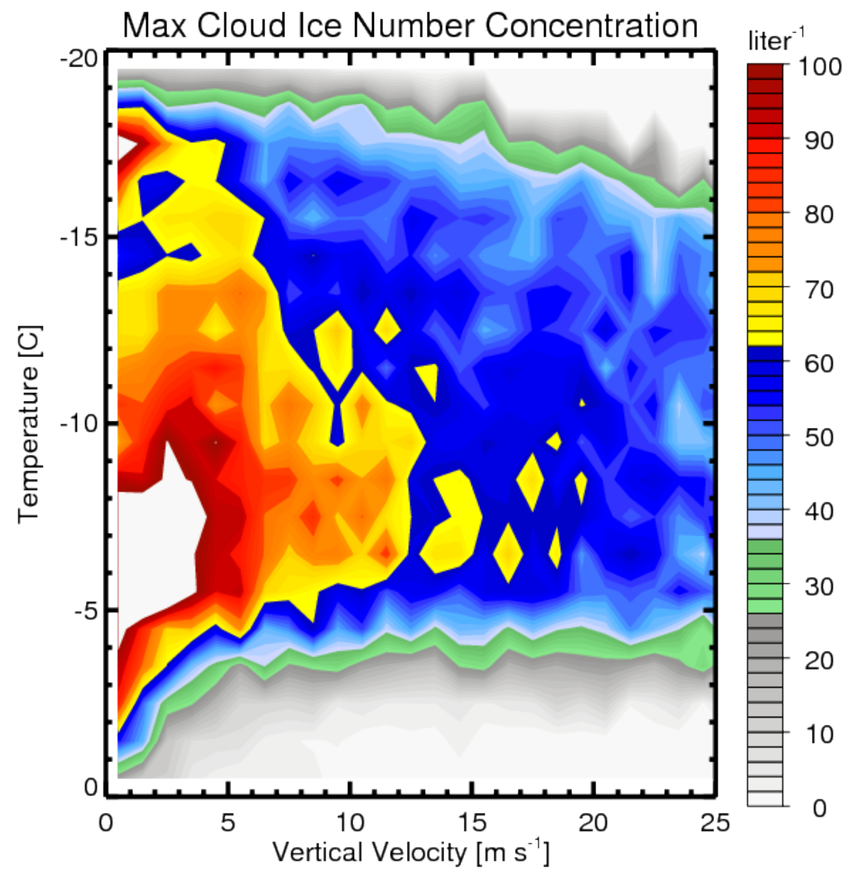
Worth noting that typical continental convection would not have as many raindrops or large cloud droplets being lofted for a given vertical velocity – would this limit ice multiplication in such systems? Is homogeneous freezing of cloud droplets important in such systems for producing high concentrations of small ice?

Fallout of Graupel or Raindrop Fracturing/Lack of Significant Graupel Production?

- Lack of lightning and dropoff in reflectivity suggests either lack of much graupel or rapid fallout of graupel
  - Updrafts of 5 to 10 m s^{-1} can largely cancel out raindrop terminal fall speeds and potentially keep them at relatively warm temperatures for a substantial length of time, perhaps enhancing the ice splinter production rate if fracturing is occurring
- Cayenne observations between 0 and -10C?
  - Any conditions with appreciable LWC? If so, what are cloud and rain droplet sizes and what does the radar data say about changes with height?
  - Different than ICE-T in that most of the sampled updrafts during HIWC/HAIC are mature or decaying – entraining of "environmental" ice

Simulated ice number concentrations





Problems in Models

1. Graupel size distribution produces high dBZ for even low GWC (e.g., 0.1 g m^{-3}) in simulations
2. Fate of lofted rain is becoming graupel, but is this realistic? Should it fracture or fall out faster? How is it removed so quickly without more large ice particles lofted?
3. Typical Hallett-Mossop parameterization (350 splinters per mg of rime peak at -5°C) is insufficient to produce 100s to > 1000 L^{-1} ice number concentrations in typical updraft cores – what additional mechanism is responsible for these observations?
4. Conversion of cloud ice to snow is based on ice size, but these categories have different assumed properties that produces inconsistencies

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Importance of Size Measurement