Evidence that most Florida anvil crystals derive from mid-tropospheric aerosols

Ann Fridlind, Andy Ackerman, and Eric Jensen
NASA Ames Research Center

Dave Stevens
Lawrence Livermore National Lab

Donghai Wang
NASA Langley Research Center

Andy Heymsfield and Larry Miloshevich
National Center for Atmospheric Research

Mike Poellot
University of North Dakota

Chuck Wilson
University of Denver

Cindy Twohy
Oregon State University

Darrell Baumgardner
Universidad Nacional Autonoma de Mexico

Tim VanReken, Tracey Rissman, Tomtor Varutbangkul, Rick Flagan, and John Seinfeld
California Institute of Technology

Haf Jonsson
CIRPAS

July 18 updraft case study

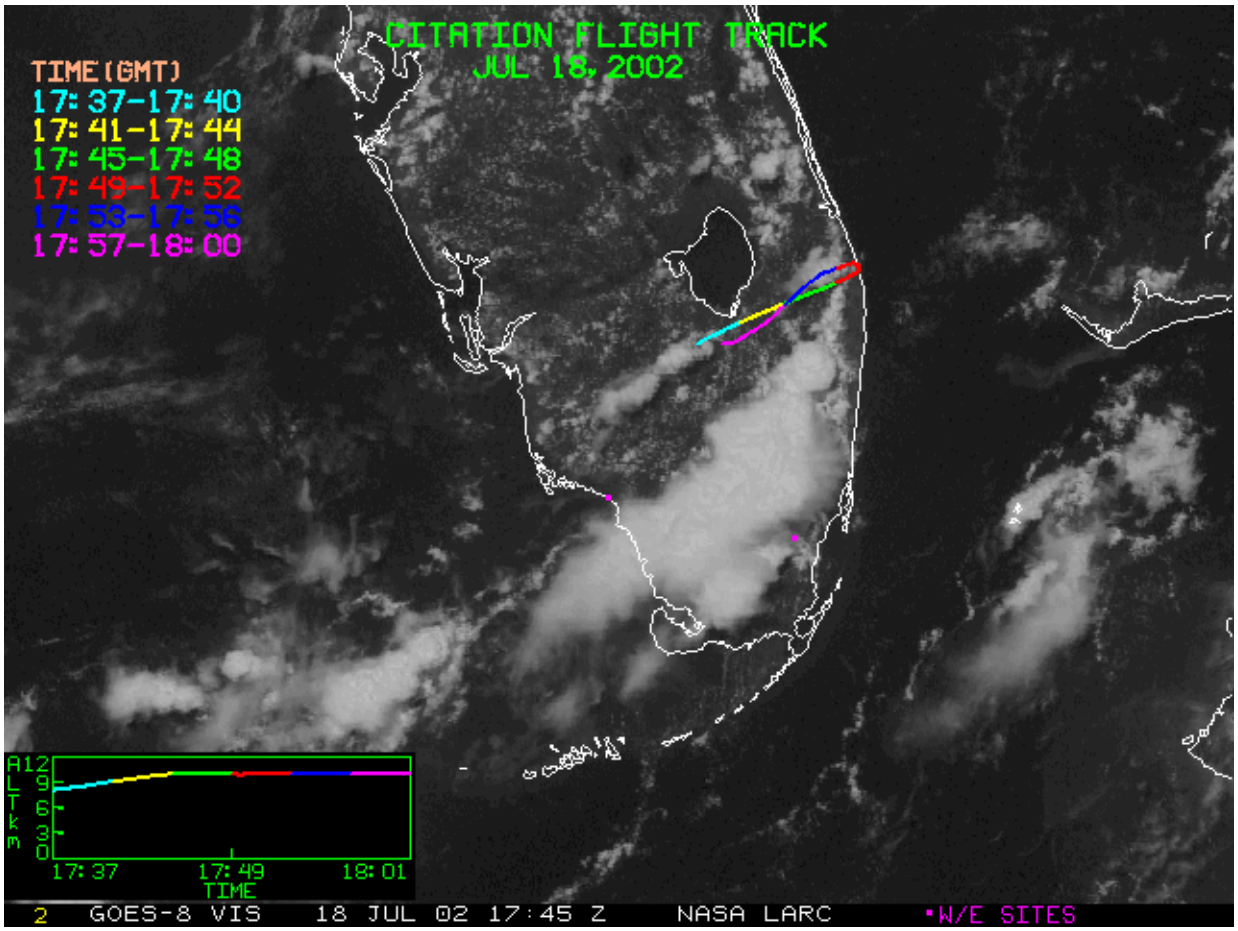
- Unique measurements by the Citation aircraft at -34°C (10 km)
  - highest updraft traversed by aircraft (>24 m/s)
  - highest particle numbers measured at -34°C (>200 cm^{-3})
  - highest liquid water content measured at -34°C (~0.3 g m^{-3})

- Scientific questions
  - are most anvil crystals homogeneously nucleated droplets?
  - where are the cloud condensation nuclei coming from?
  - how are aerosols influencing anvil properties?

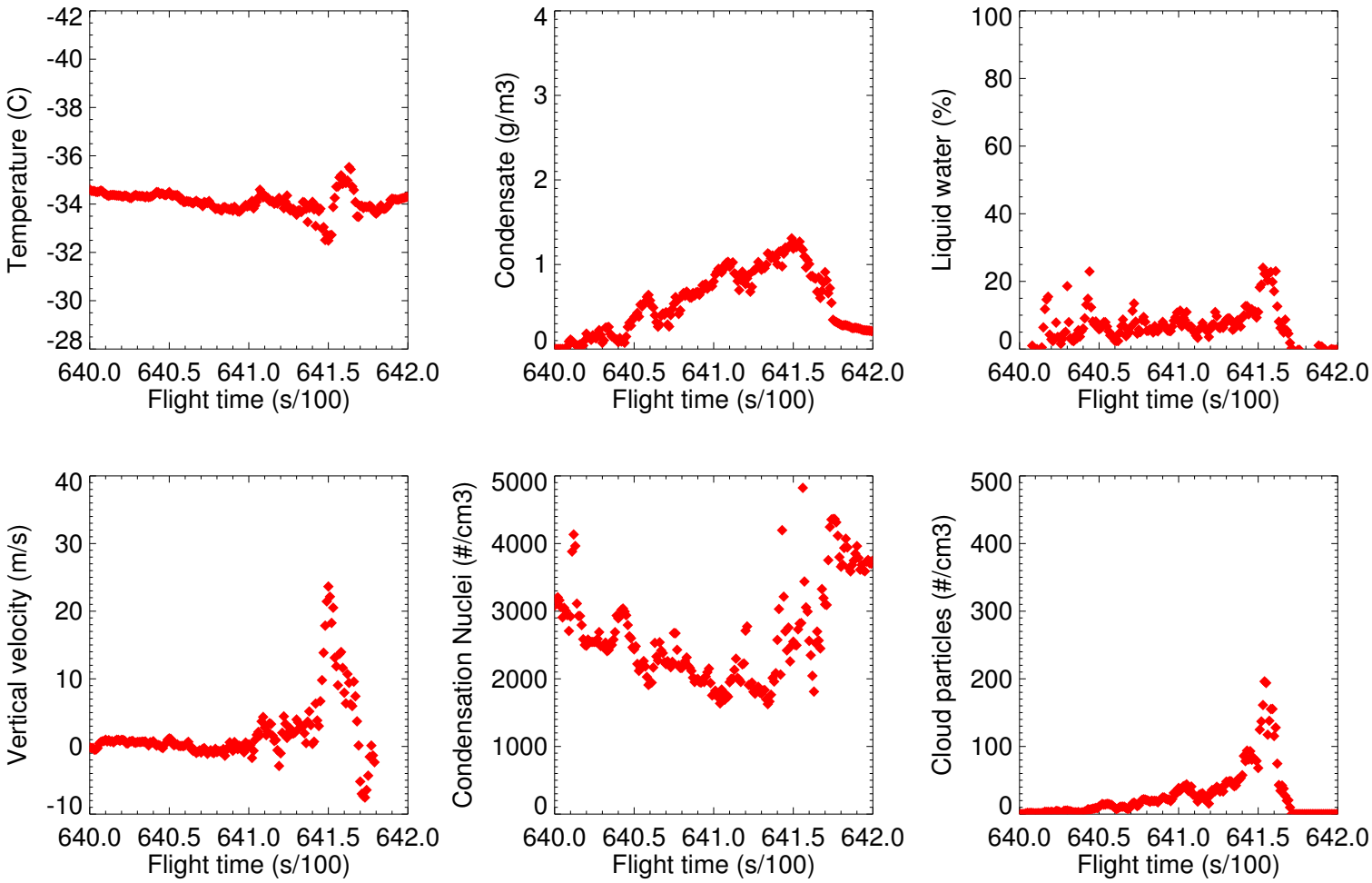
CRYSTAL FACE field experiment

Variable	WB-57 (above 12 km)	Citation (7-12 km)	Otter (below 4 km)
Aerosol number	X	X	X
Aerosol size distribution	X		X
Aerosol composition			X
Aerosol ice nuclei		X	
Cloud particle number	X	X	X
Cloud particle size distribution	X	X	X
Cloud ice residual composition	X	X	
Cloud crystal habit	X	X	
Cloud condensed water	X	X	X
Cloud phase		X	
Cloud scattering/asymmetry	X	X	
Meteorological data	X	X	X
Radiative fluxes	X		X
Tracers	X		X

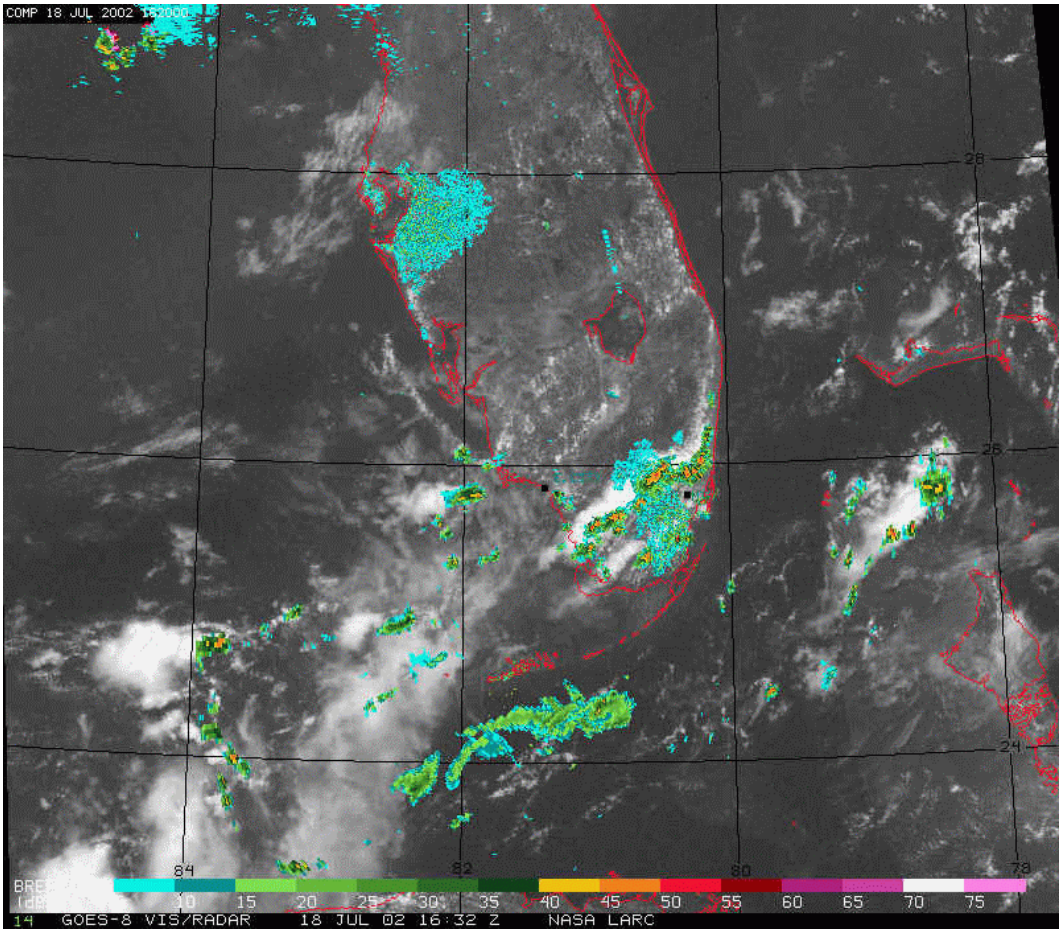
July 18 case study



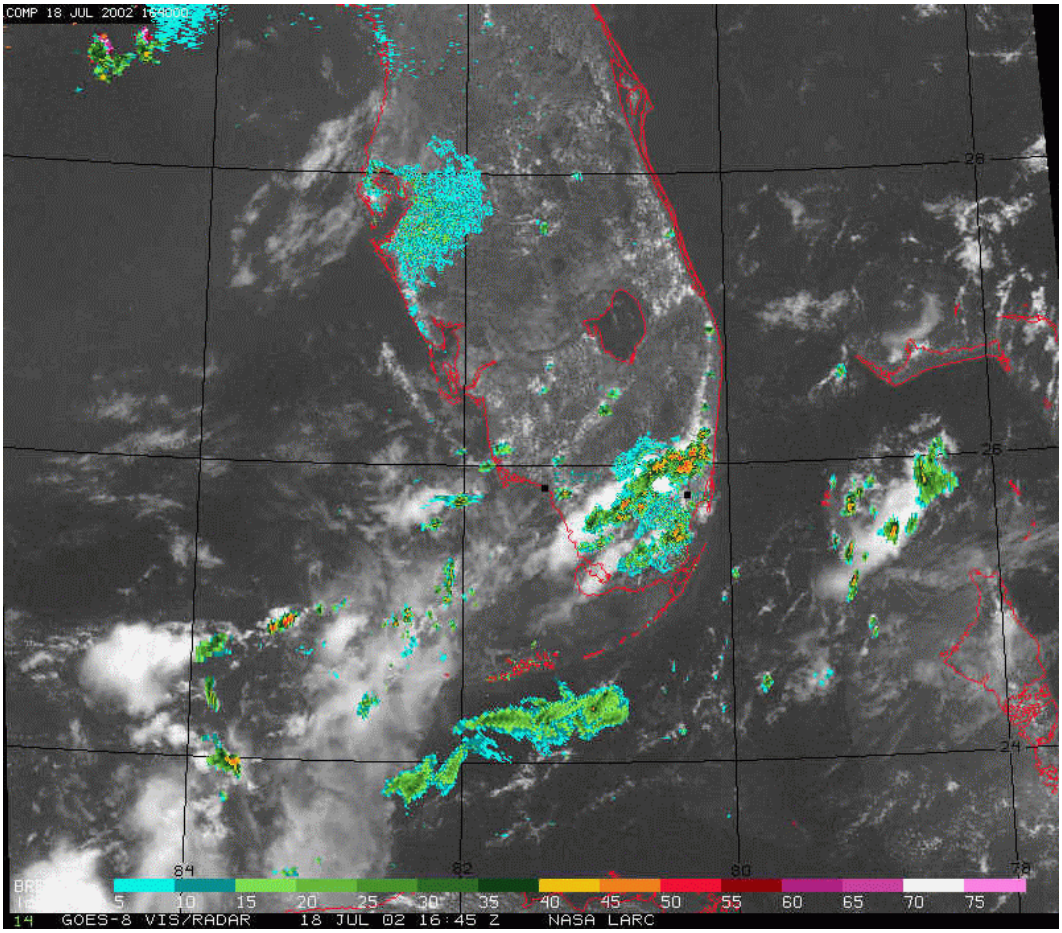
Updraft properties observed by the Citation



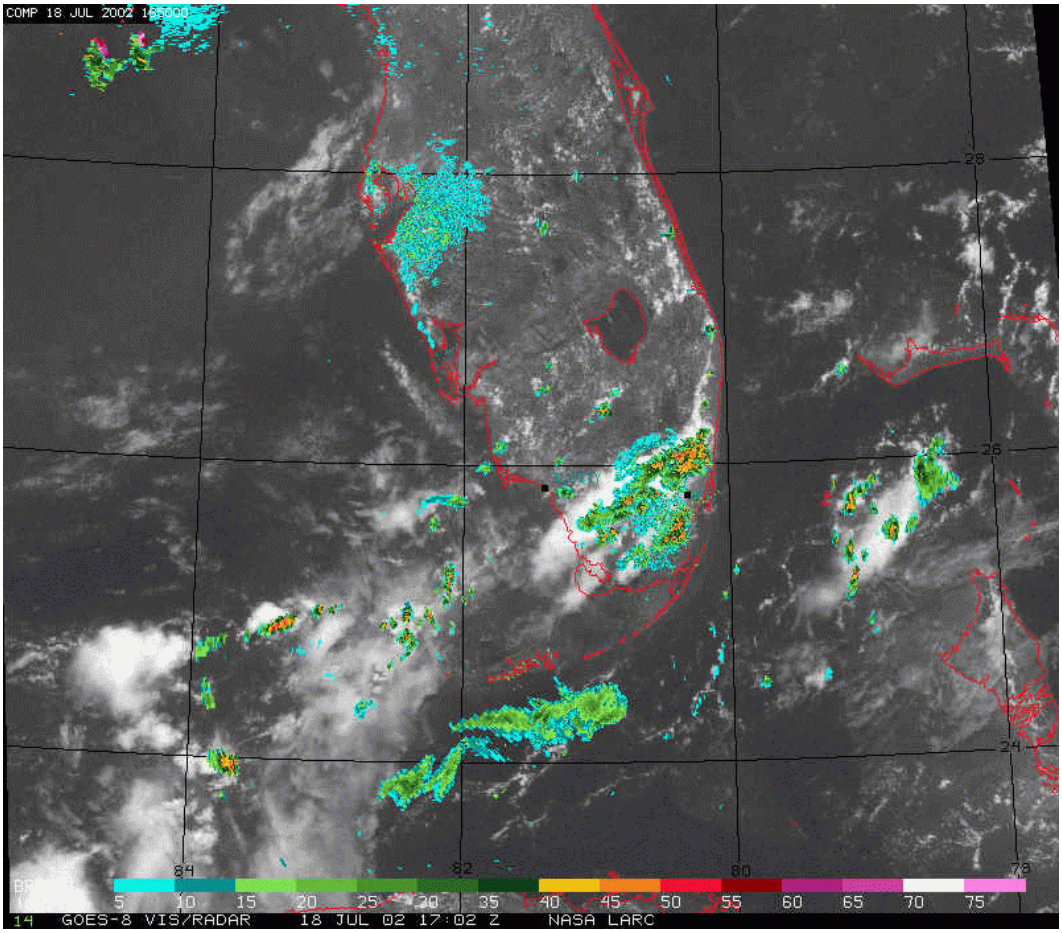
July 18 case study



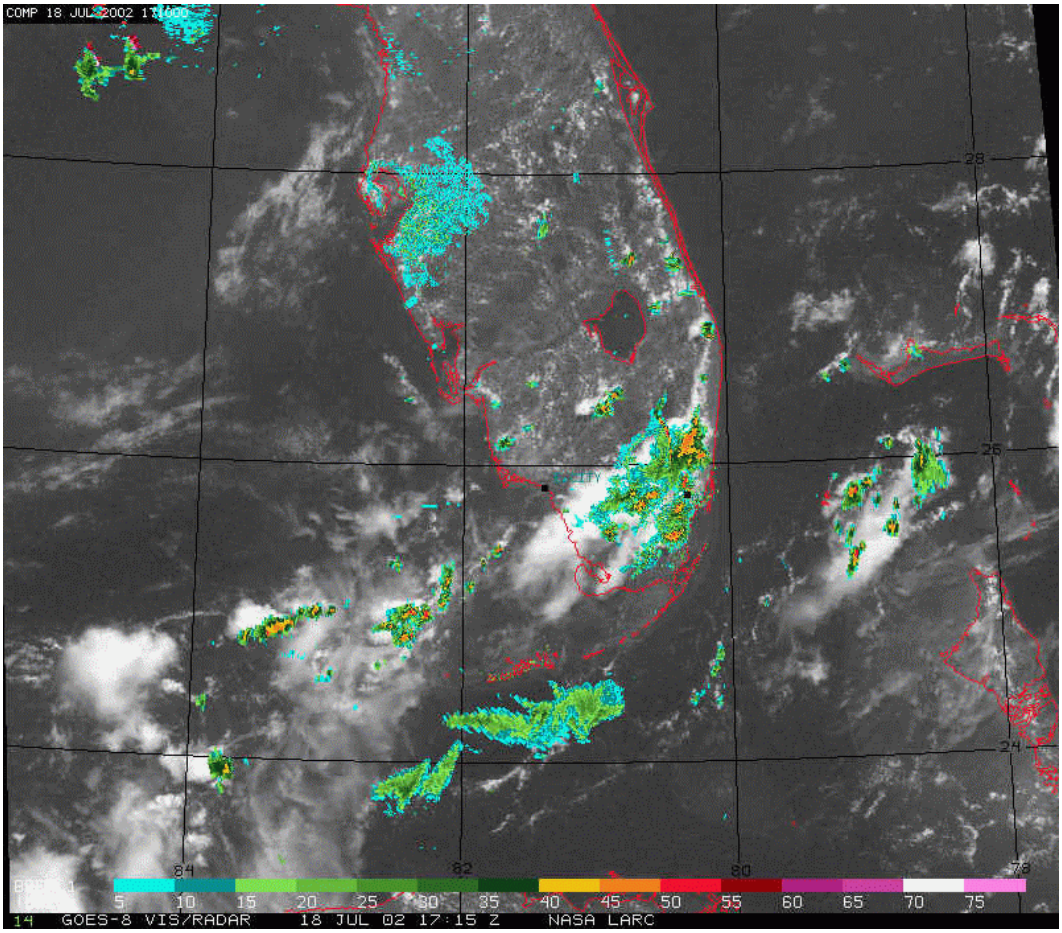
July 18 case study



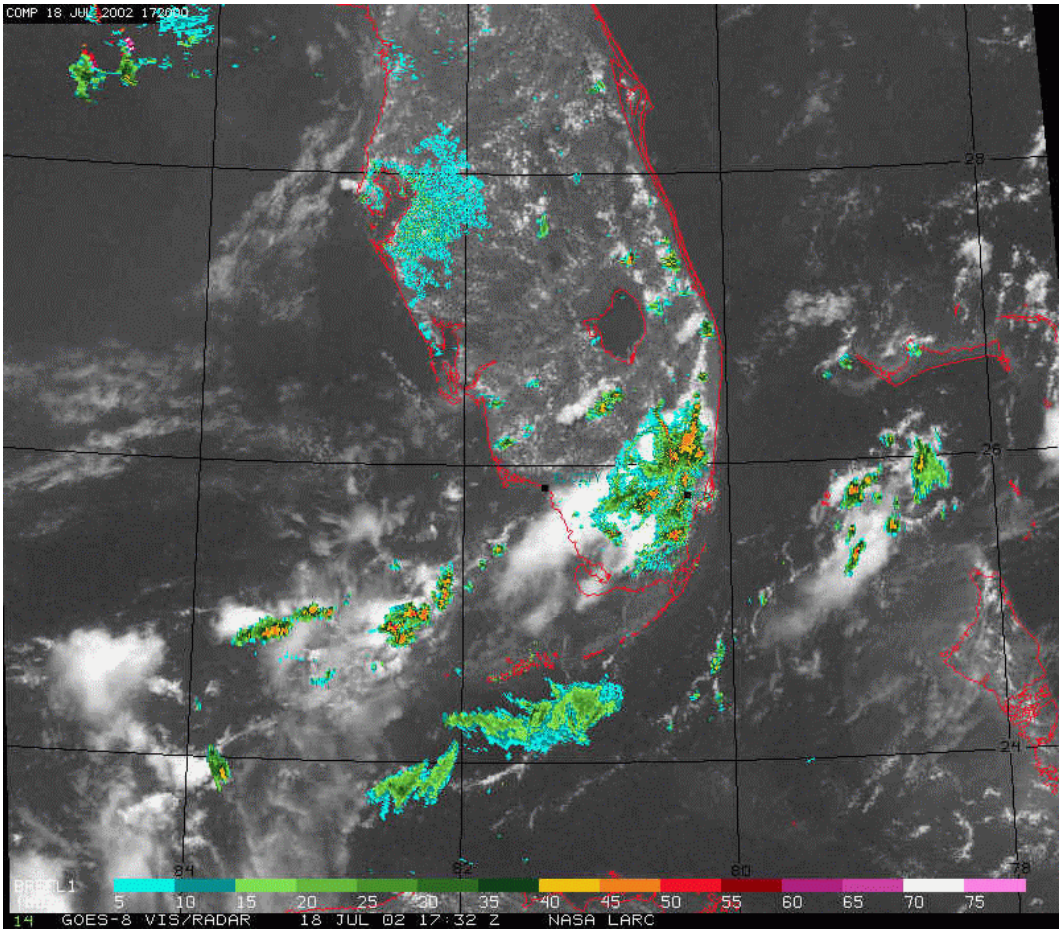
July 18 case study



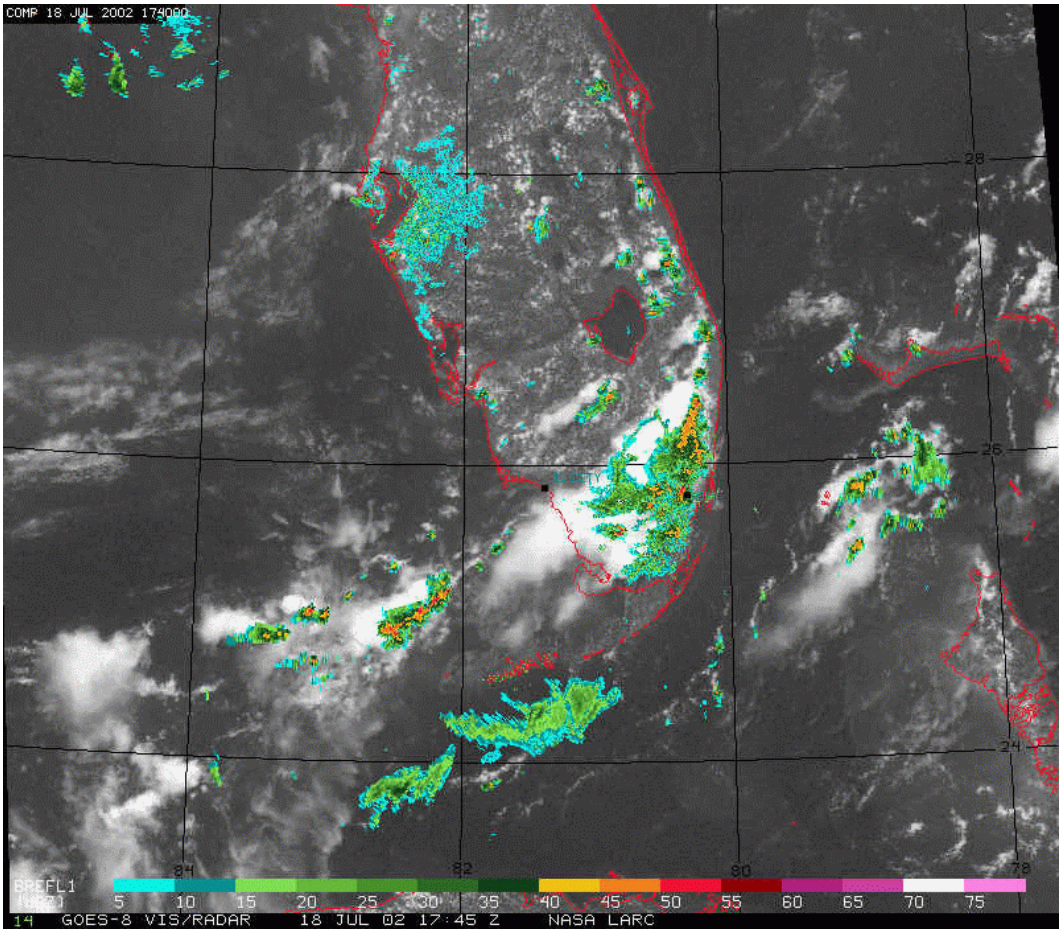
July 18 case study



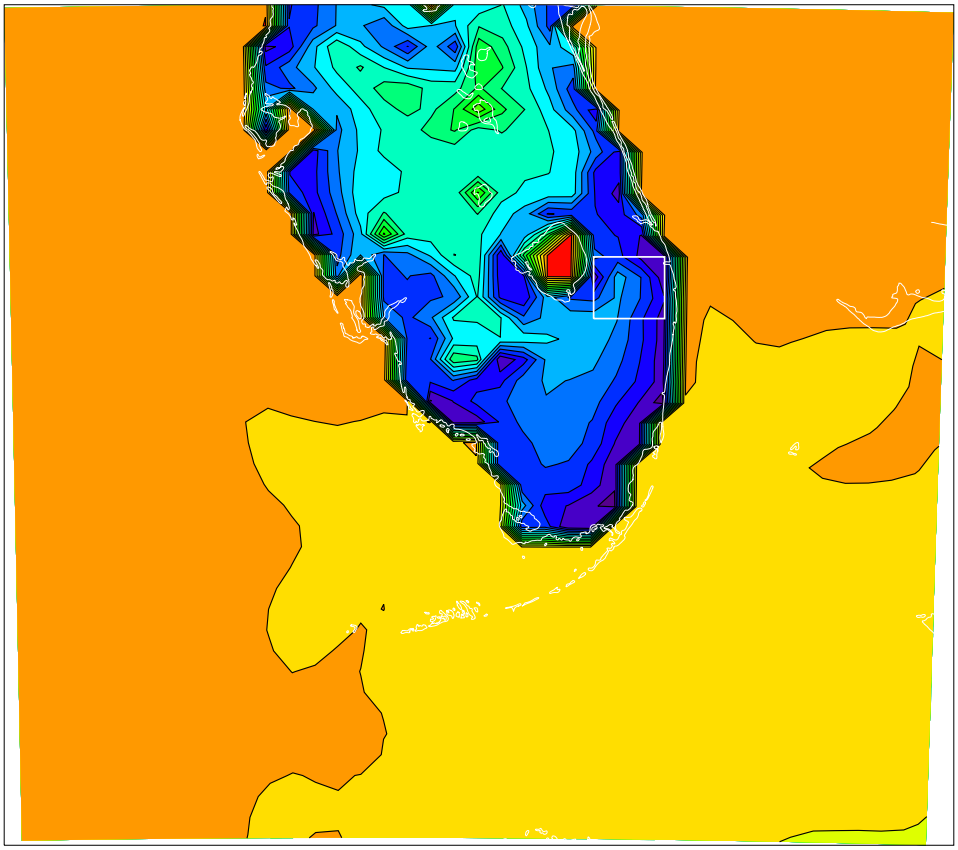
July 18 case study



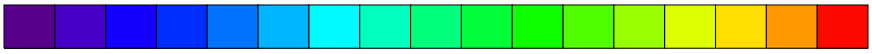
July 18 case study



Assimilated surface fluxes: ARPS model



Contour color min,max,delta: -1.600e-01, 1.000e-02, 1.000e-02



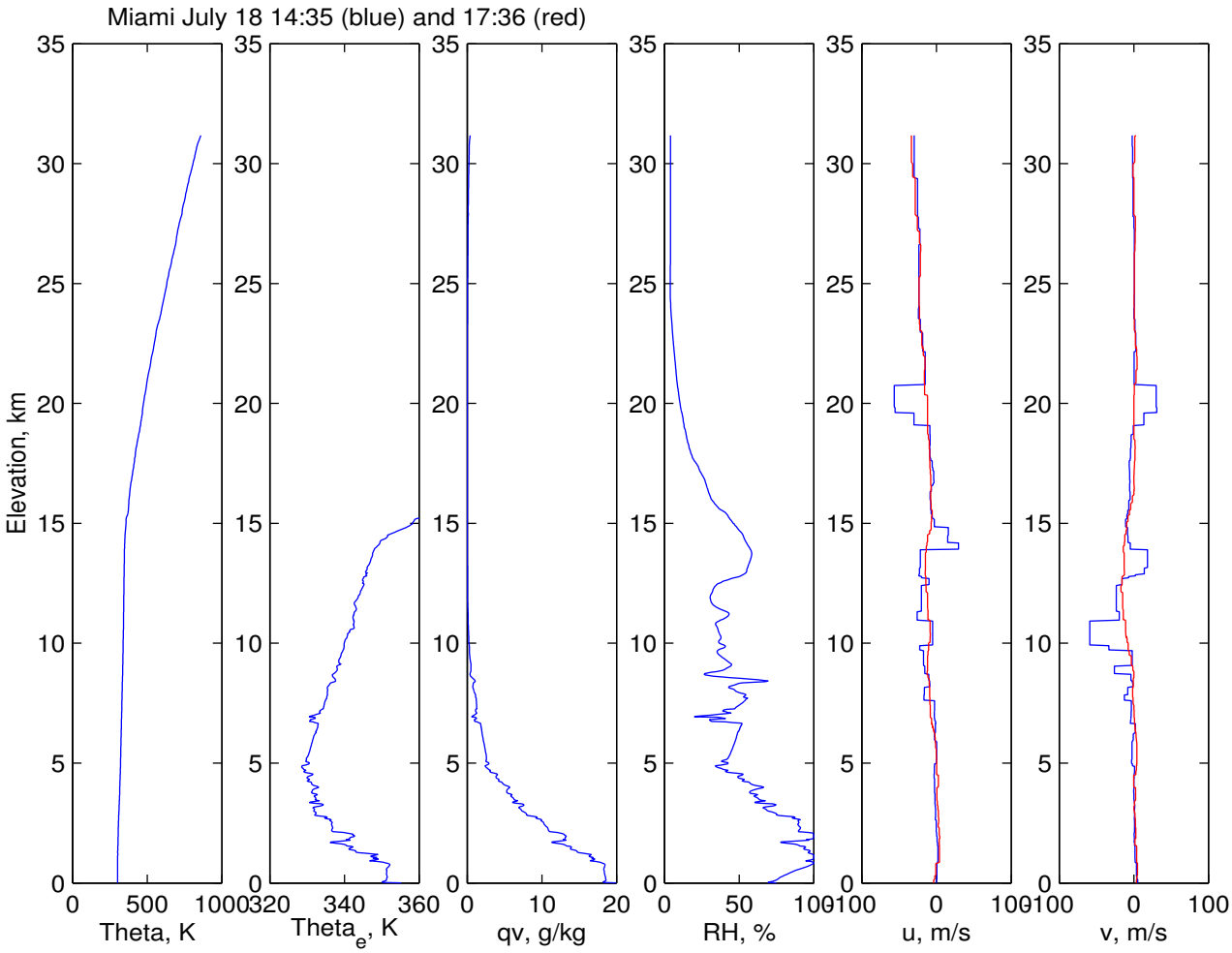
DHARMA model description

- Domain resolutions (48 x 48 x 24 km)
  - dx = 500 m, dz = 375 m (96 x 96 x 64 grid, 16 procs)
  - dx = 250 m, dz = 187.5 m (192 x 192 x 128 grid, 512 procs)
- Dynamics (dt = 5 s)
  - large-eddy simulation (Stevens and Bretherton, 1996)
    - Smagorinsky subgrid parameterization
    - sponge layer above 20 km
    - 3rd-order advection
  - open boundary conditions
    - observed sounding (constant)
    - assimilated surface fluxes (varying)

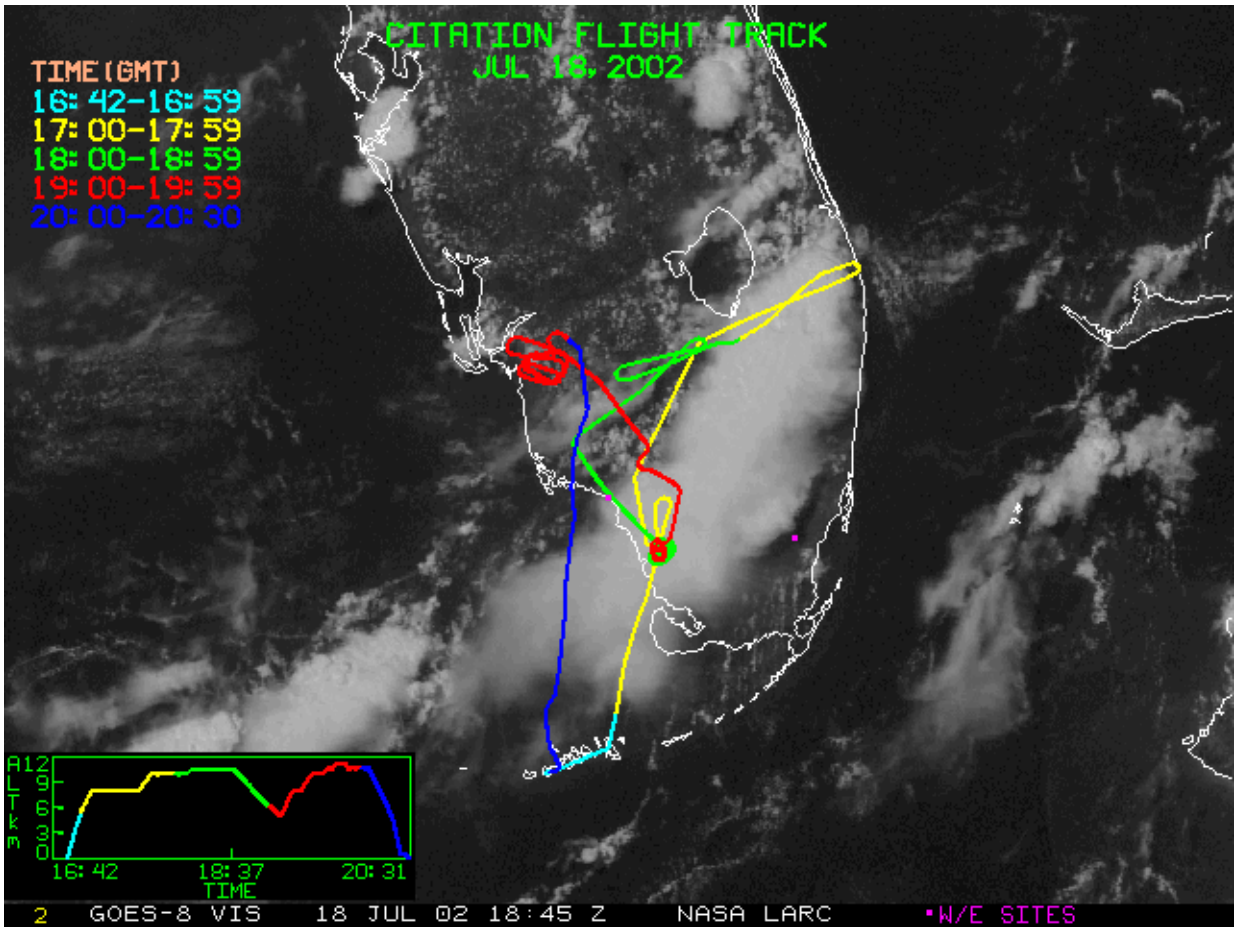
DHARMA model description

- Microphysics (minimum dt = 0.2 s)
  - 16 mass bins
    - aerosols (10 nm - 1 um diameter)
    - liquid (2 um - 1 cm diameter)
    - ice (2 um - 1.5 cm diameter)
  - aerosol activation and freezing
  - condensation and evaporation
  - coagulation
  - collision-induced and spontaneous breakup
  - sedimentation
  - homogeneous drop freezing
  - ice nuclei (immersion and deposition/condensation modes)
  - Hallett-Mossop rime splintering

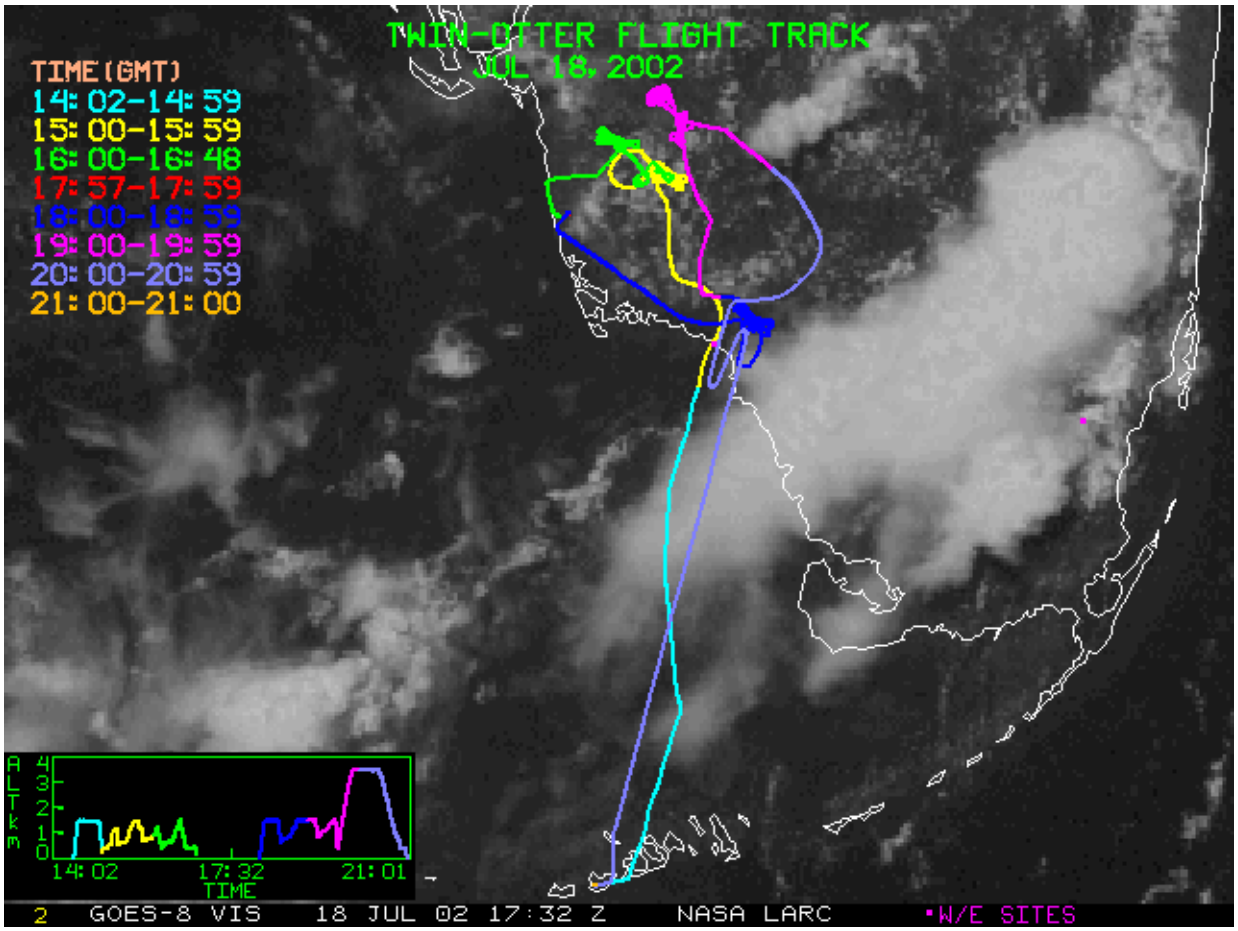
Assimilated meteorology: Miami sounding



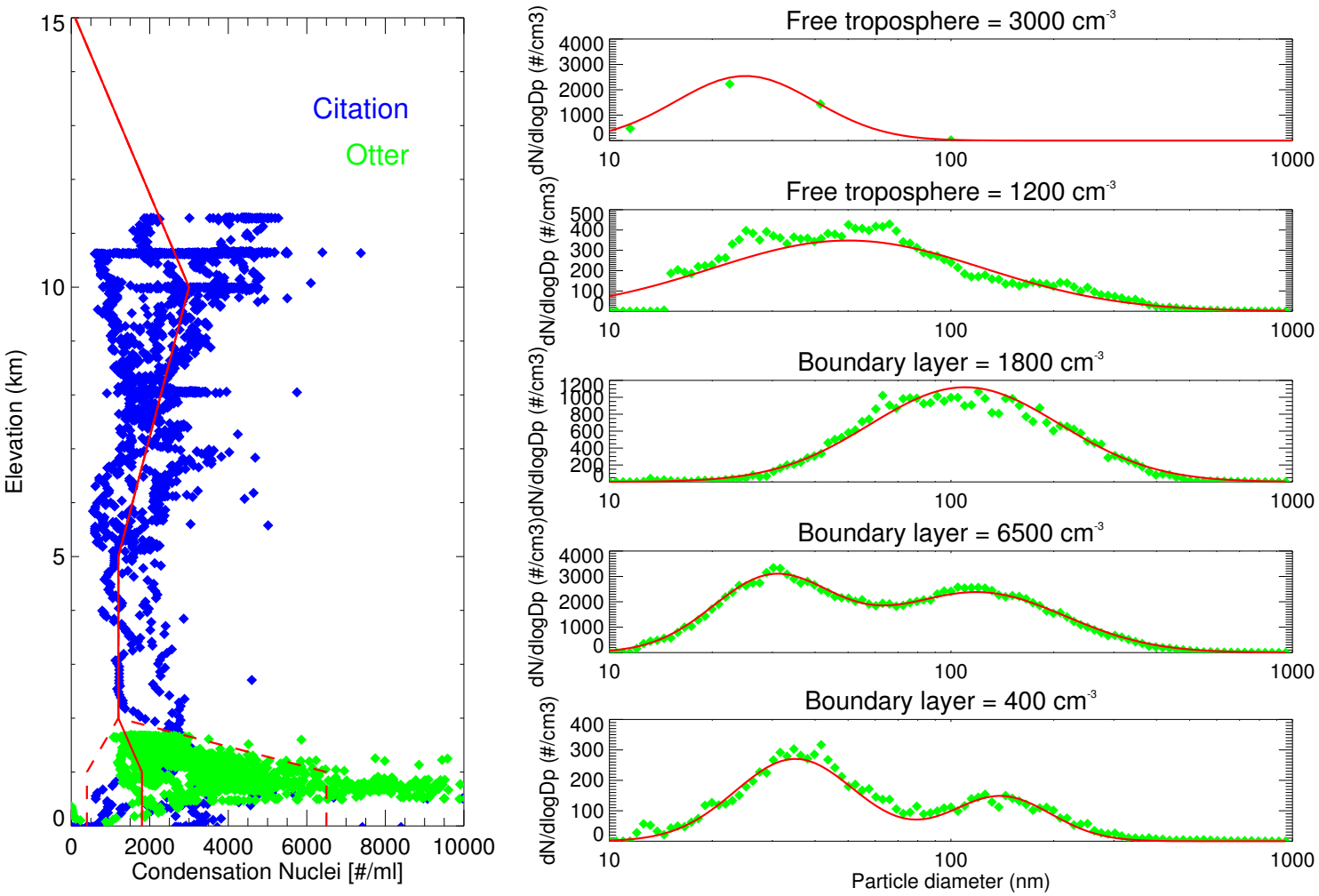
July 18 case study



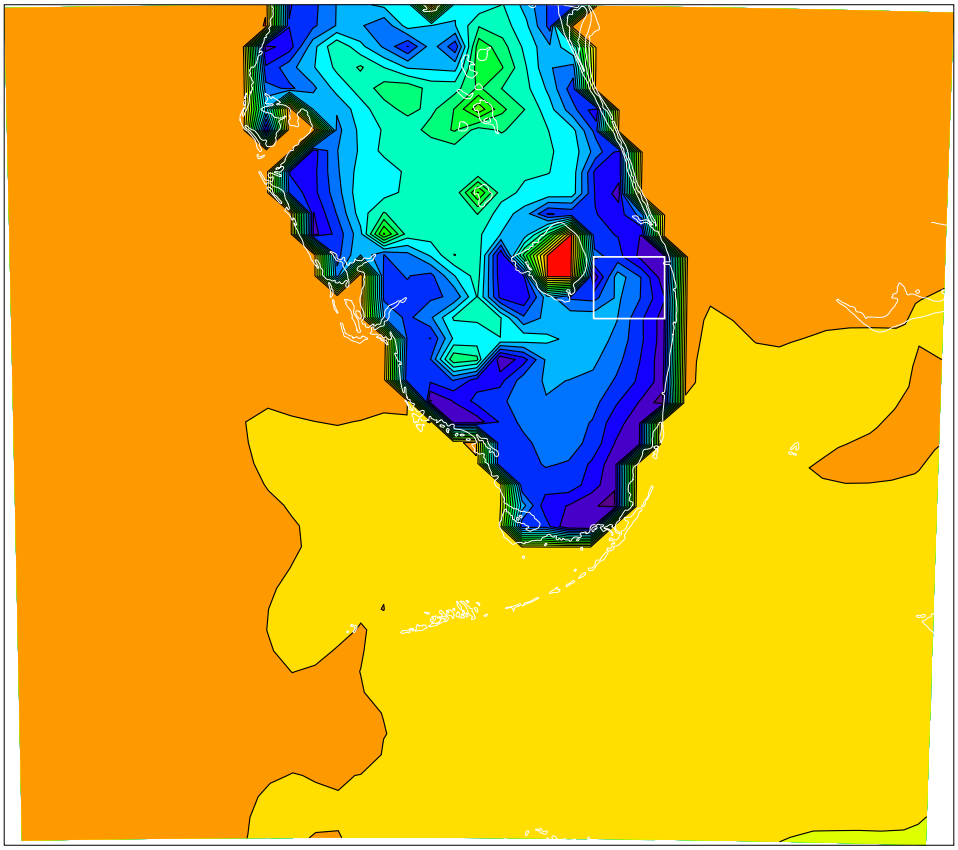
July 18 case study



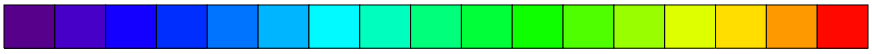
Assimilated aerosol profiles: Aircraft data



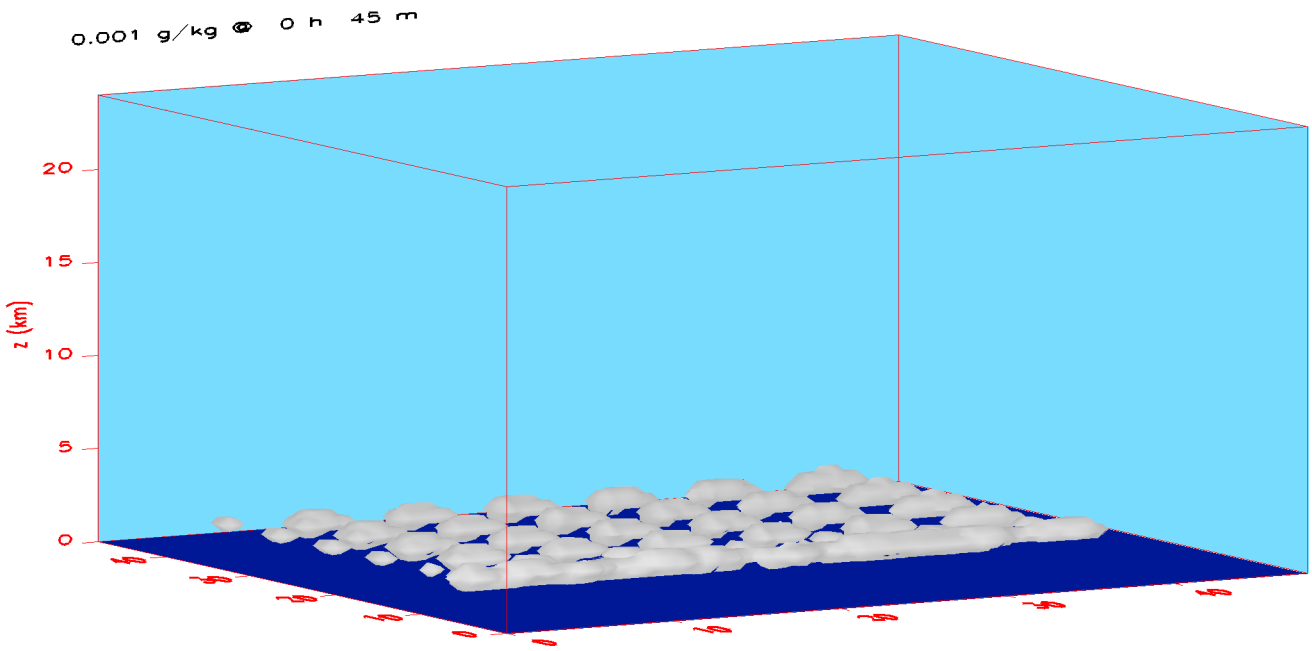
Assimilated surface fluxes: ARPS model



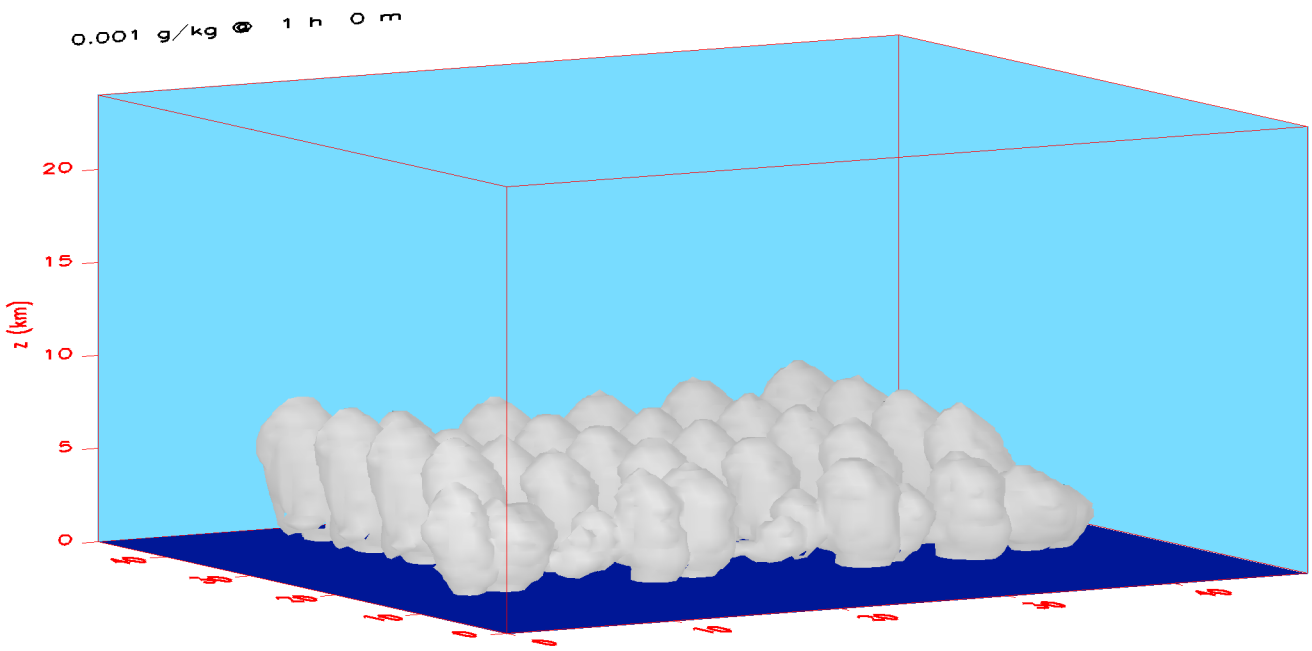
Contour color min,max,delta: -1.600e-01, 1.000e-02, 1.000e-02



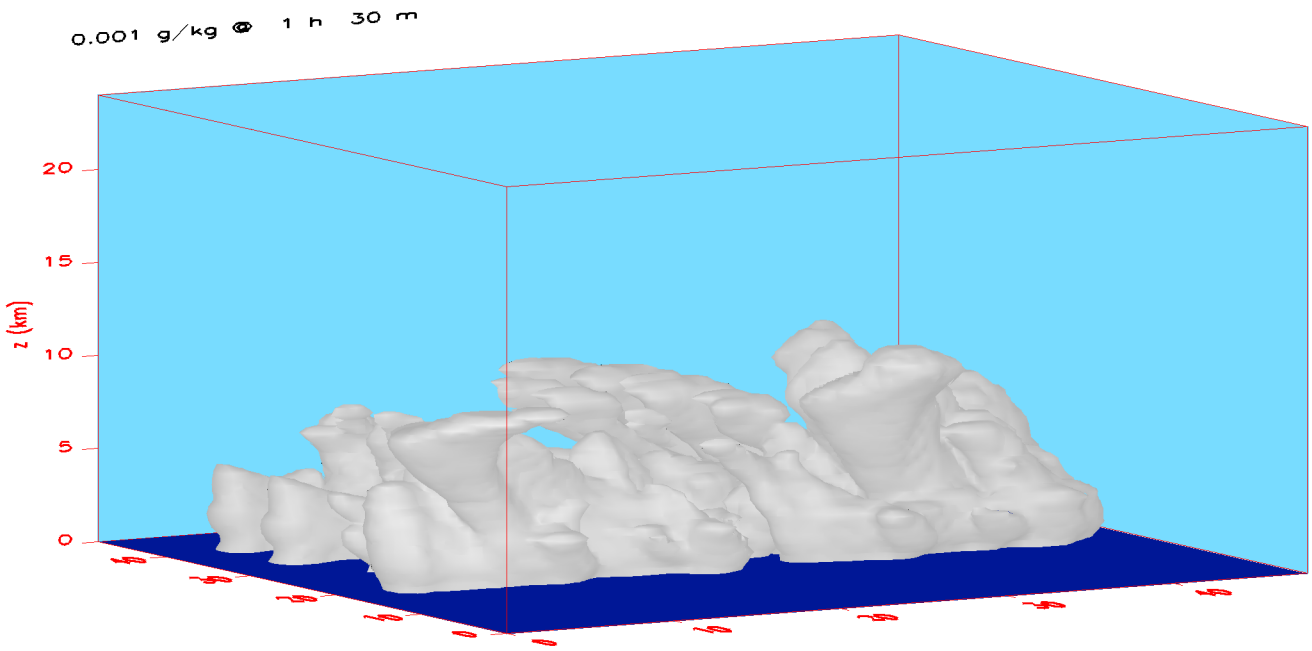
Modeled cloud isosurface



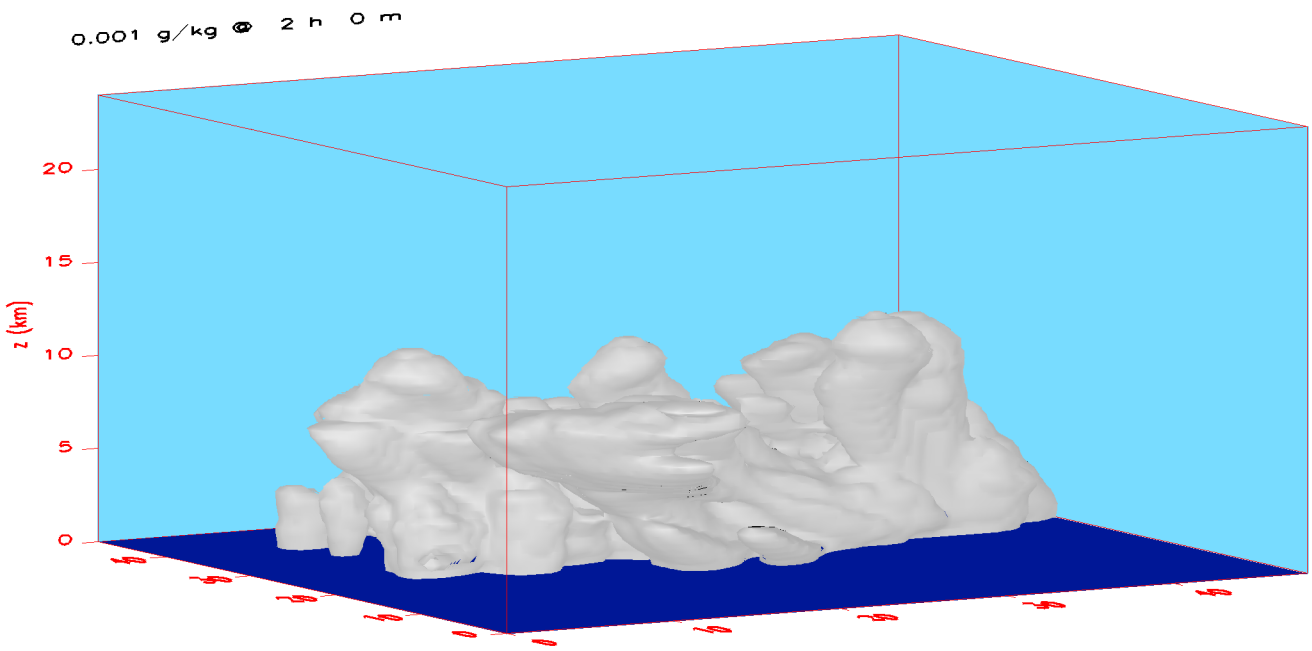
Modeled cloud isosurface



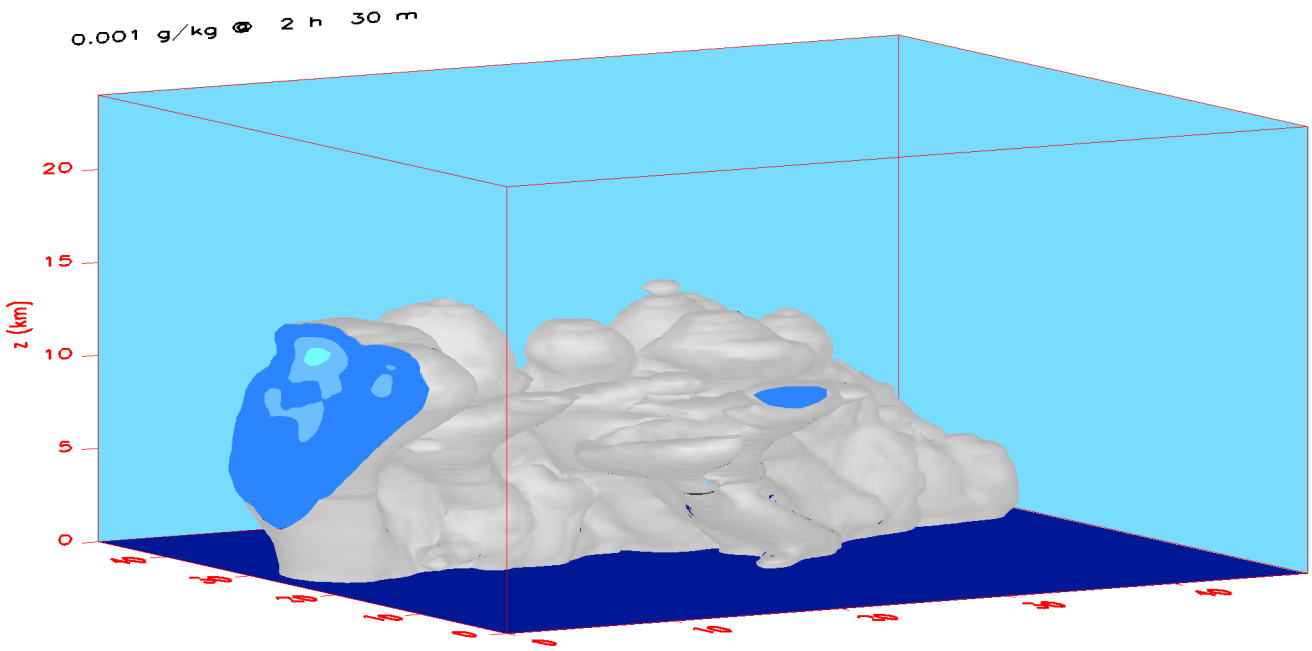
Modeled cloud isosurface



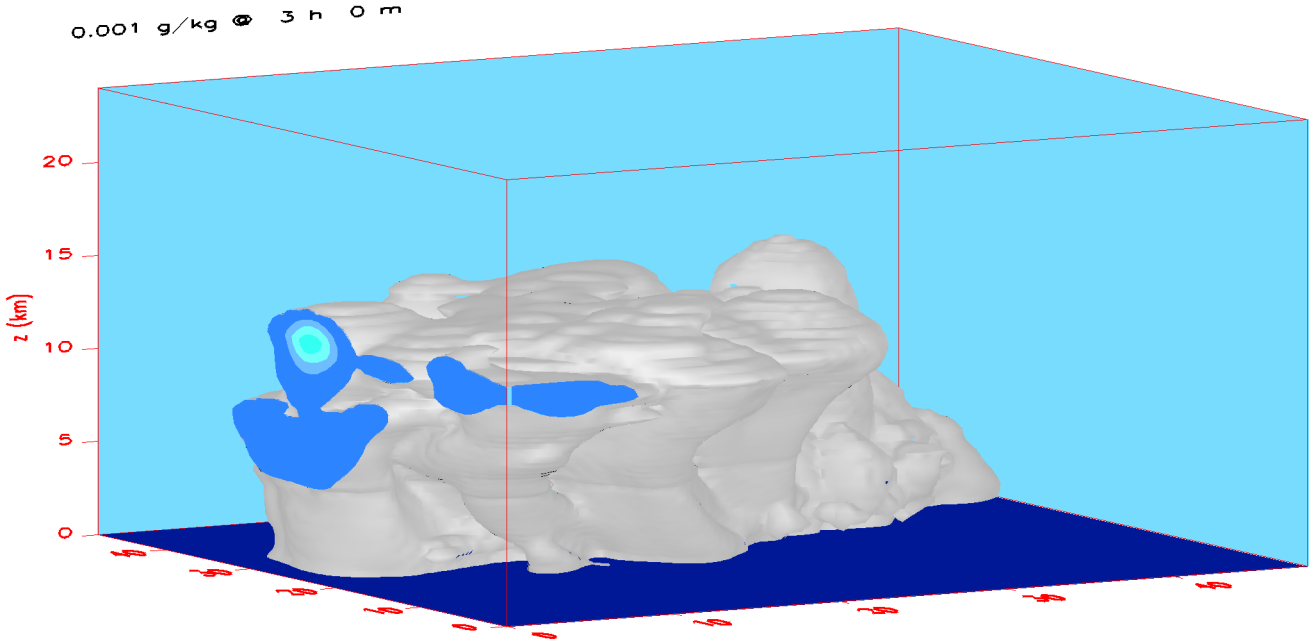
Modeled cloud isosurface



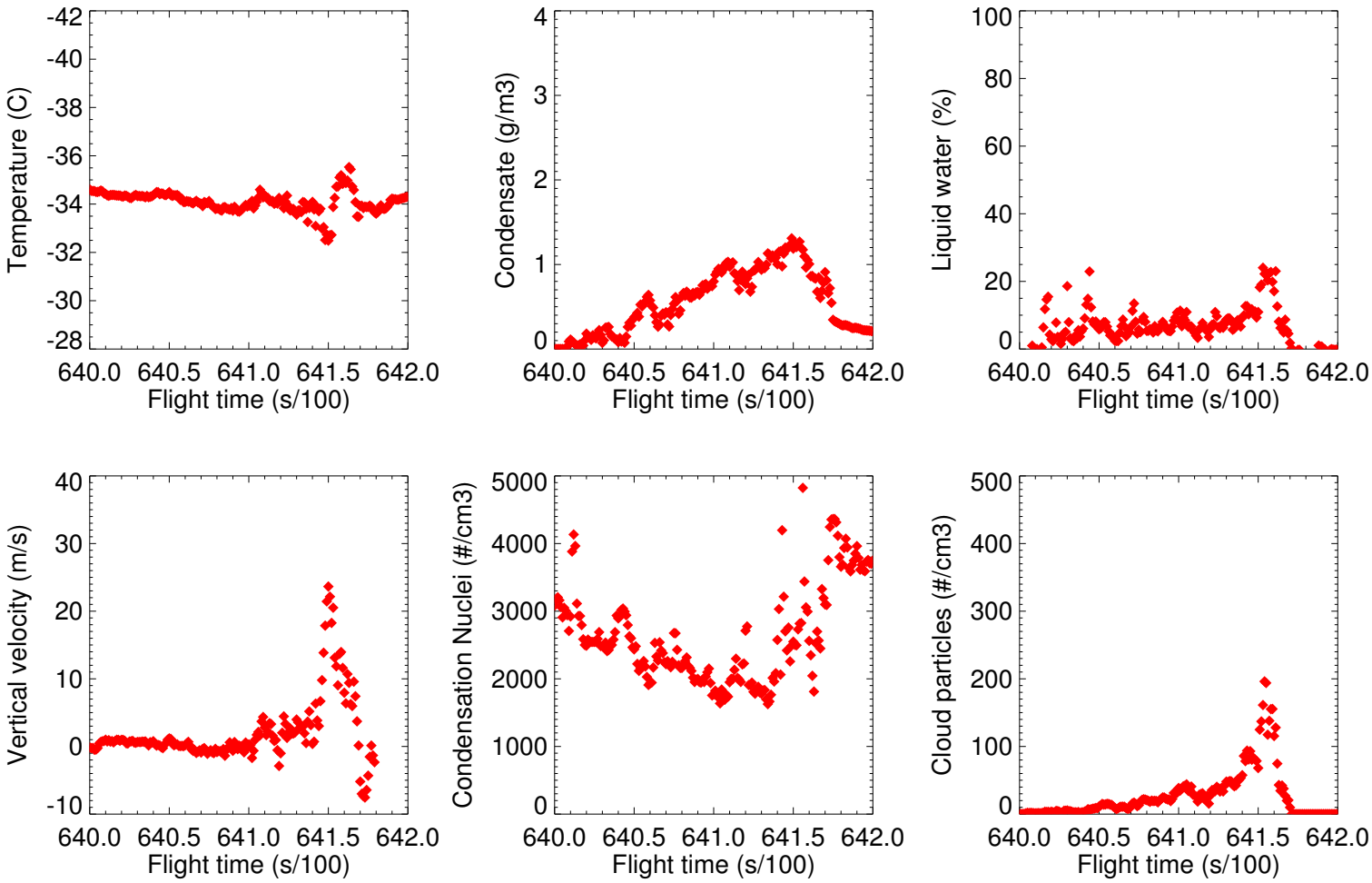
Modeled cloud isosurface



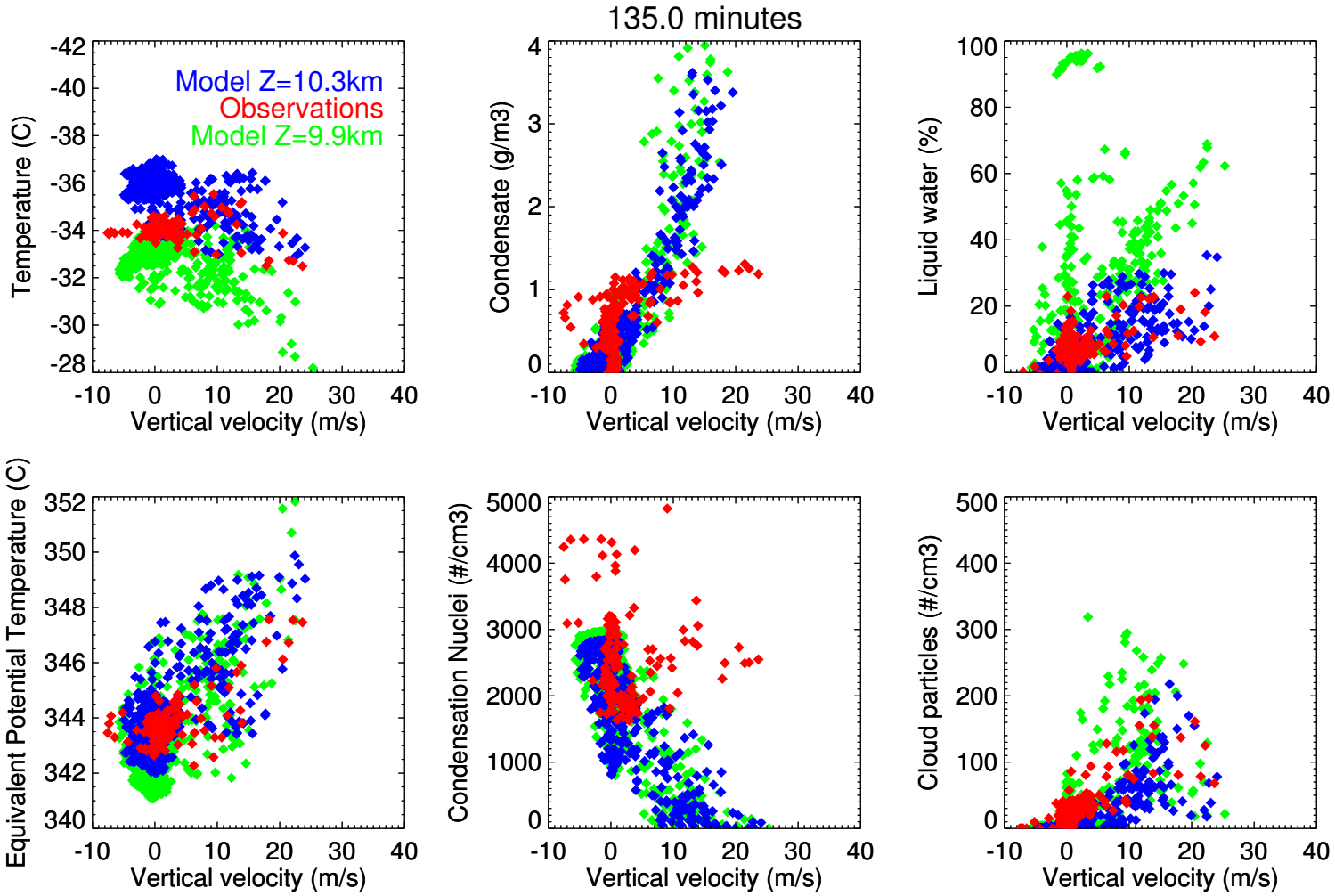
Modeled cloud isosurface



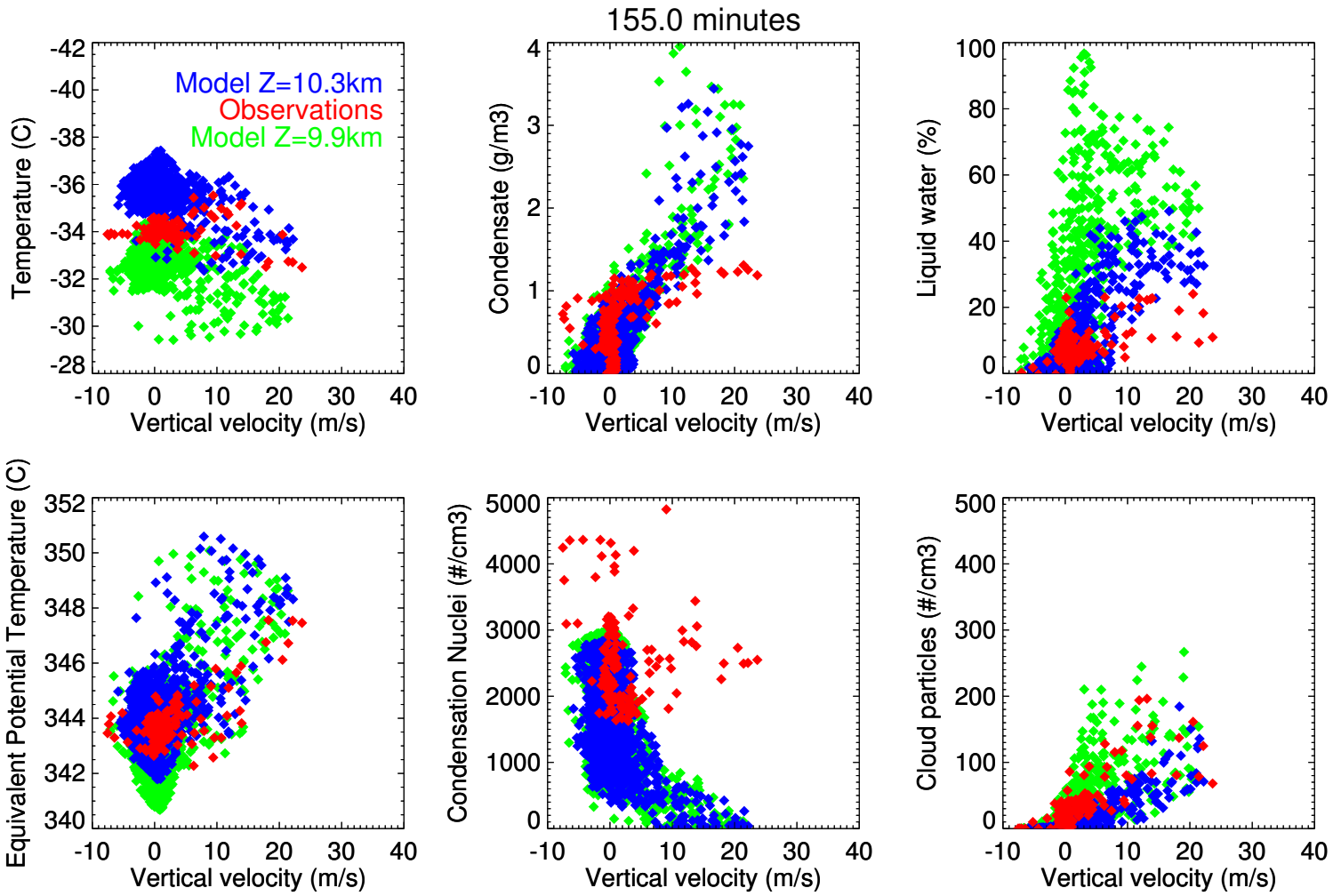
Updraft properties observed by the Citation



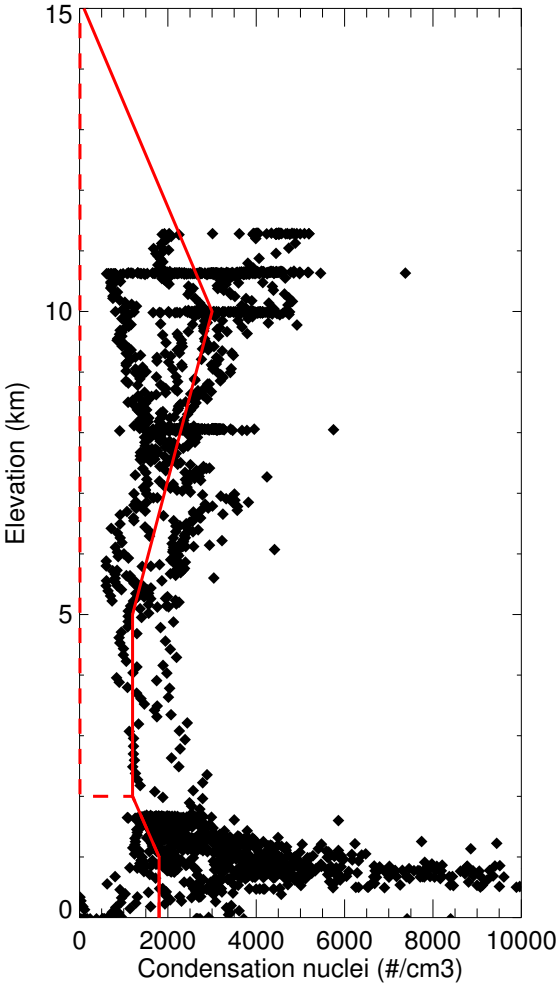
Comparison of modeled updraft properties with observations



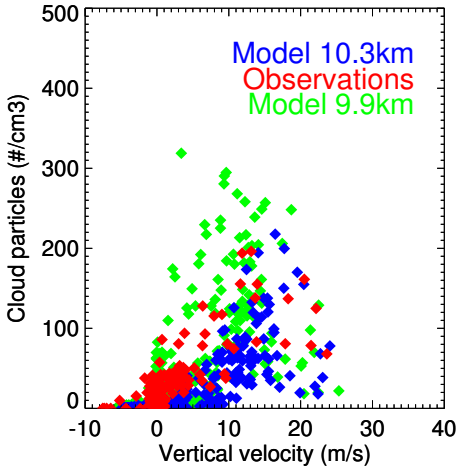
Comparison of modeled updraft properties with observations



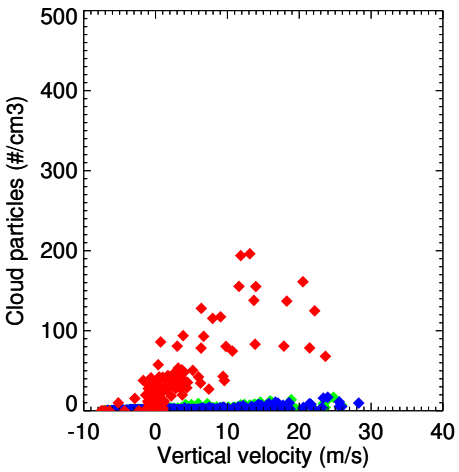
Sensitivity of modeled particle number to free troposphere aerosols



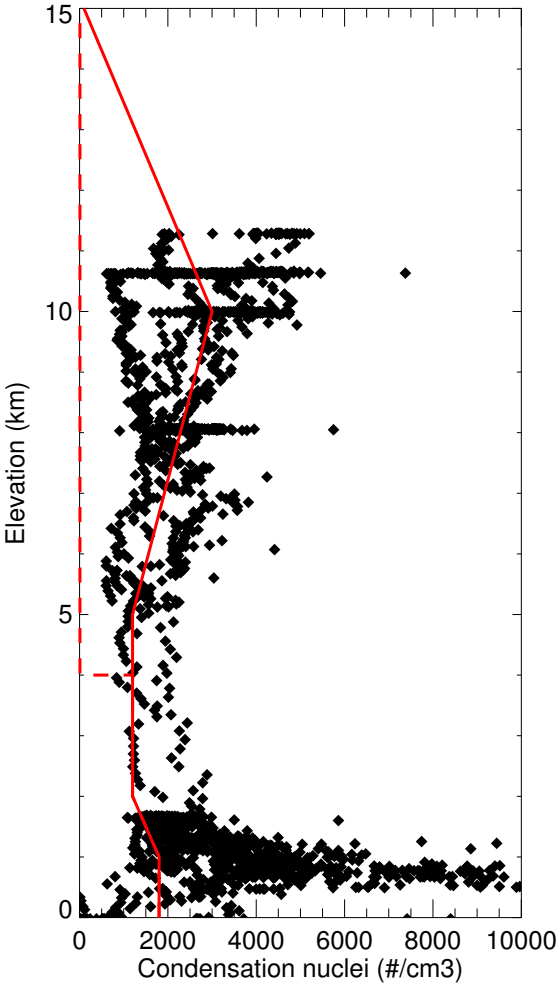
All FT aerosols (solid profile)



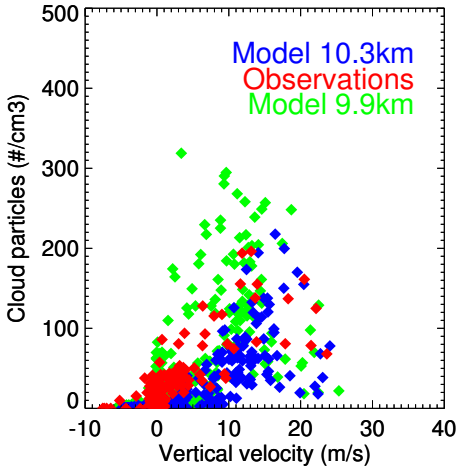
No FT aerosols > 2 km (dashed profile)



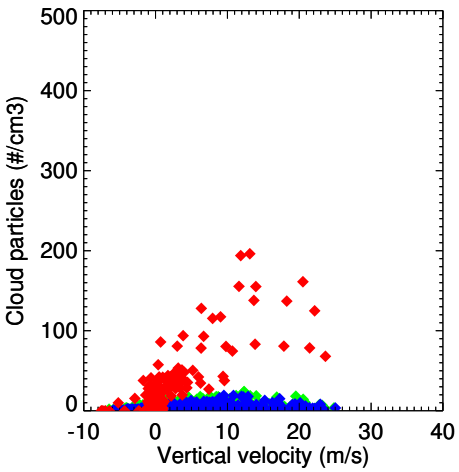
Sensitivity of modeled particle number to free troposphere aerosols



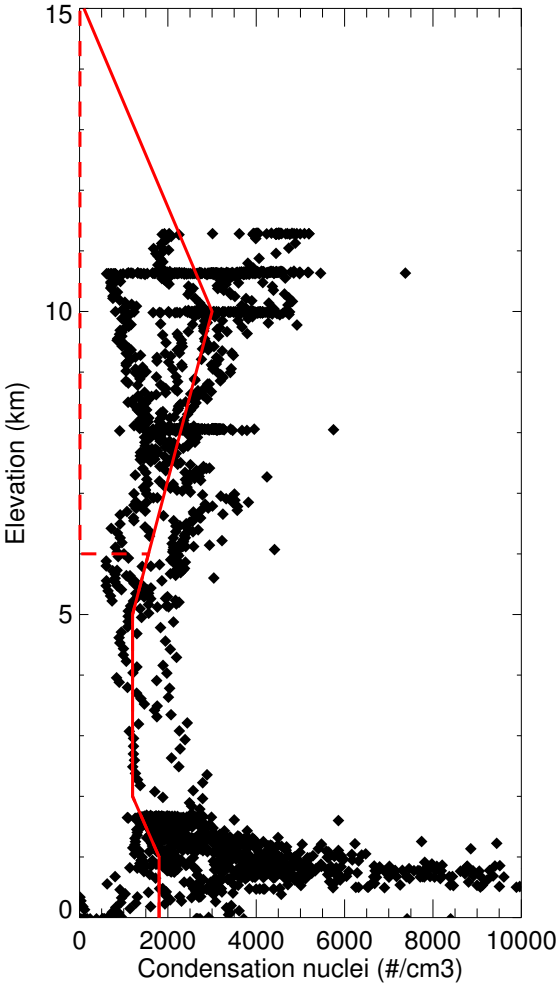
All FT aerosols (solid profile)



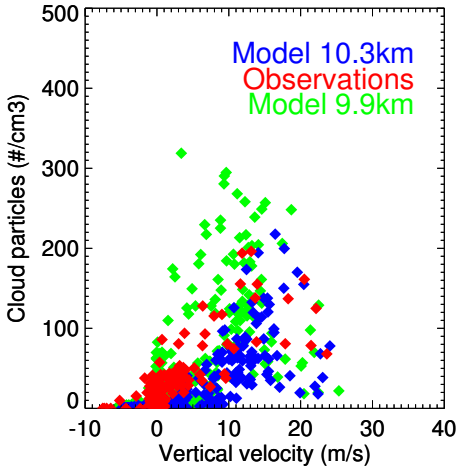
No FT aerosols > 4 km (dashed profile)



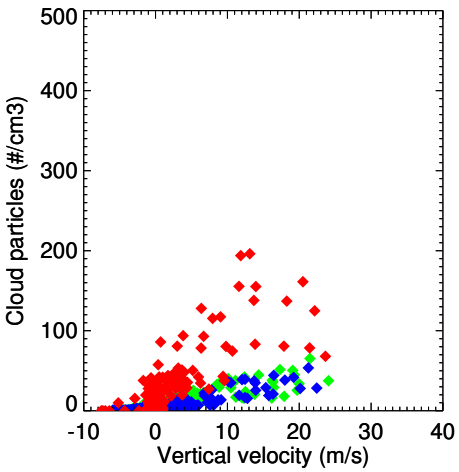
Sensitivity of modeled particle number to free troposphere aerosols



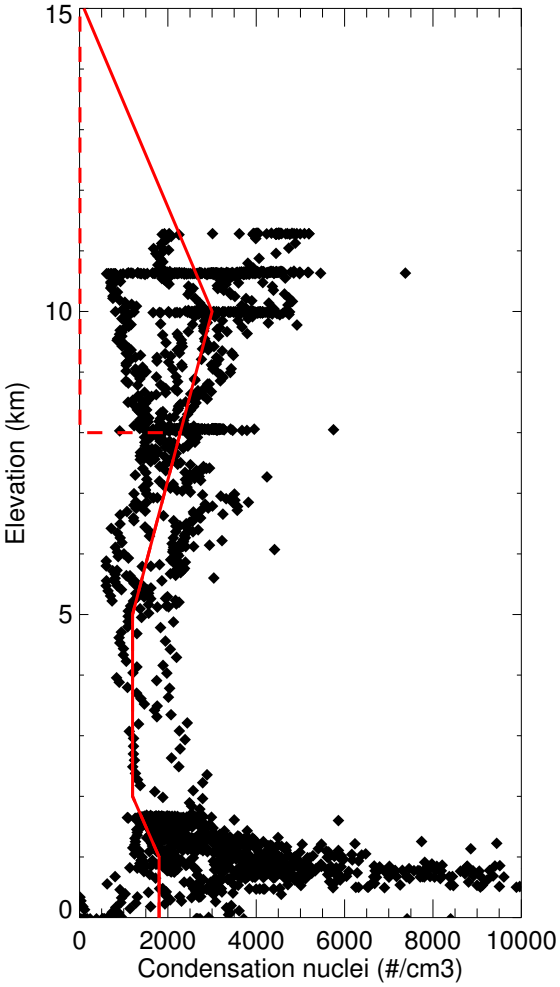
All FT aerosols (solid profile)



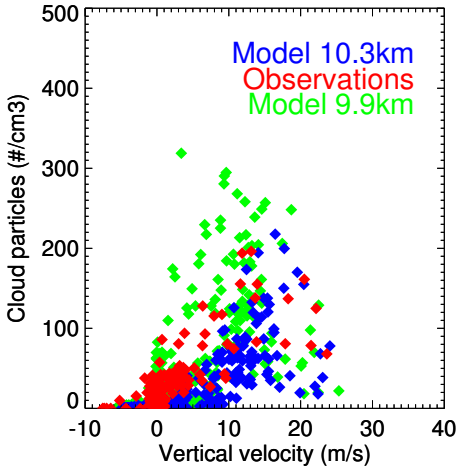
No FT aerosols > 6 km (dashed profile)



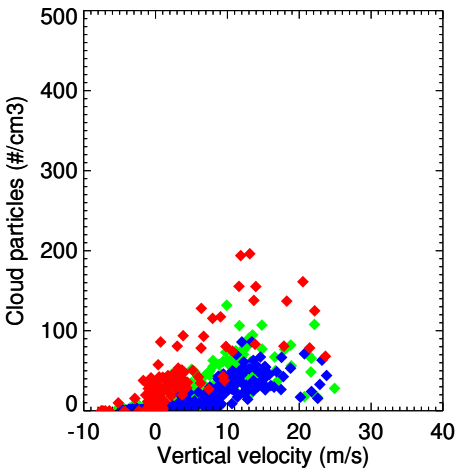
Sensitivity of modeled particle number to free troposphere aerosols



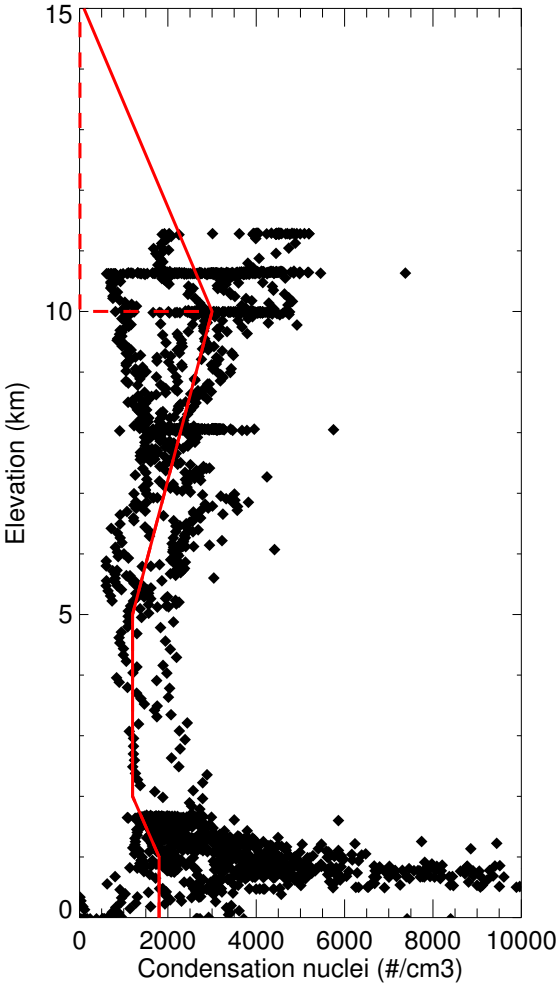
All FT aerosols (solid profile)



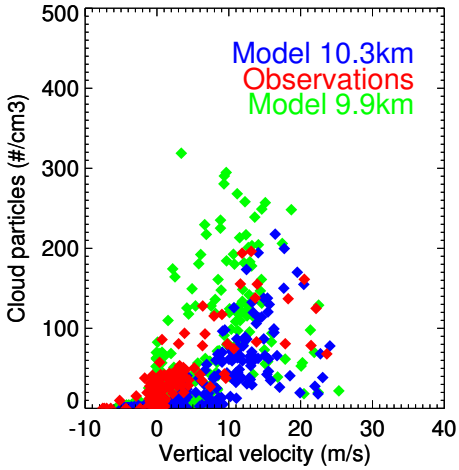
No FT aerosols > 8 km (dashed profile)



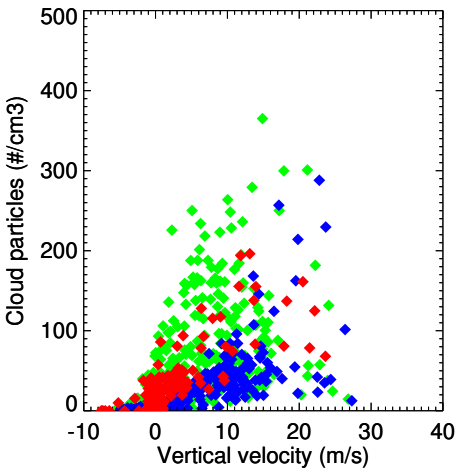
Sensitivity of modeled particle number to free troposphere aerosols



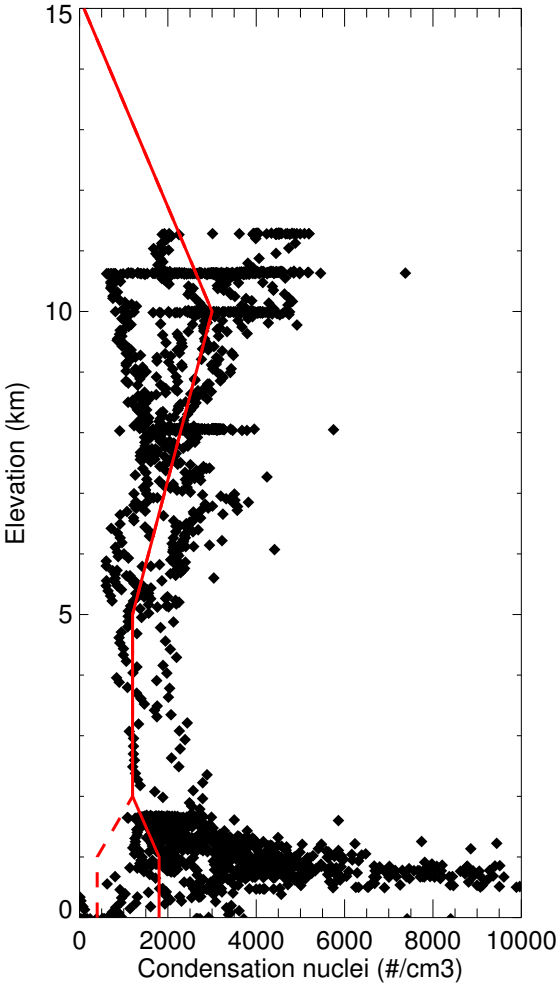
All FT aerosols (solid profile)



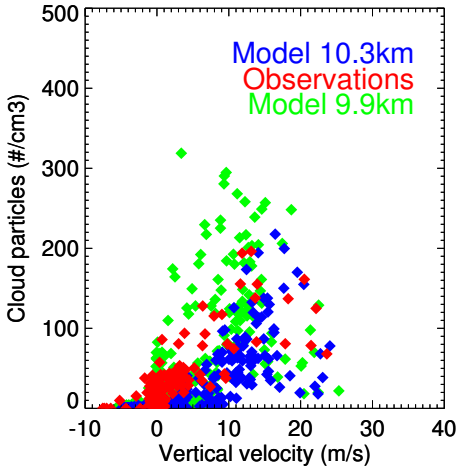
No FT aerosols > 10 km (dashed profile)



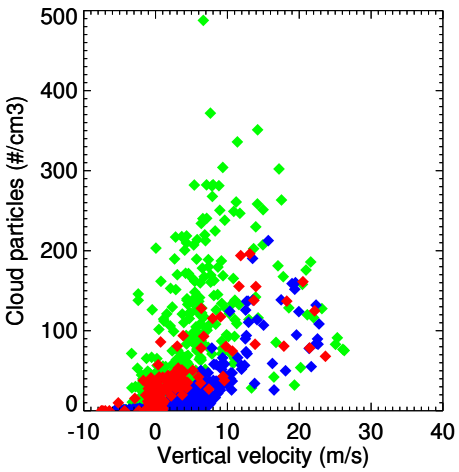
Sensitivity of modeled particle number to boundary layer aerosols



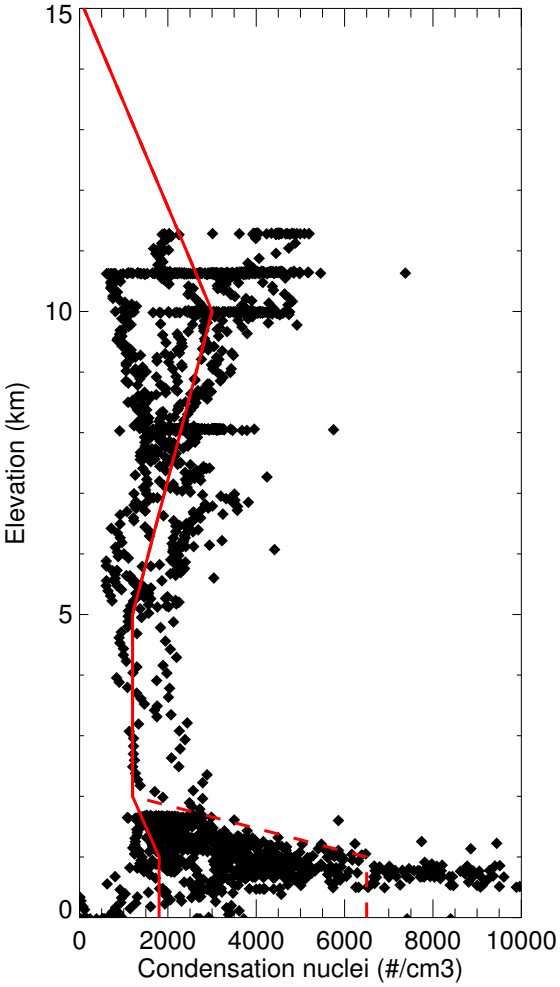
BL N=1800/ml (solid profile)



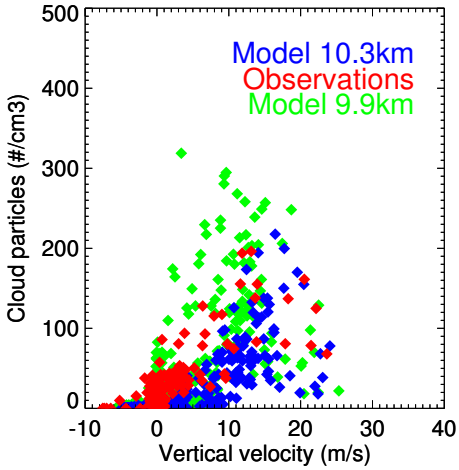
BL N=400/ml (dashed profile)



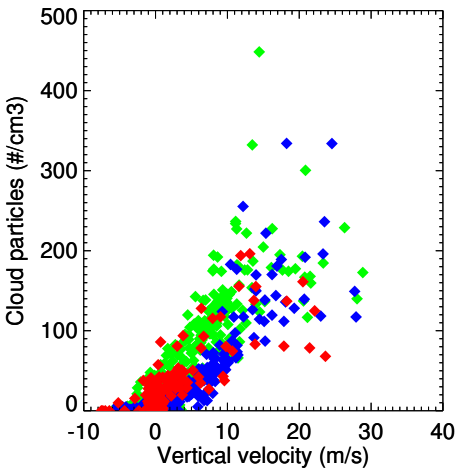
Sensitivity of modeled particle number to boundary layer aerosols



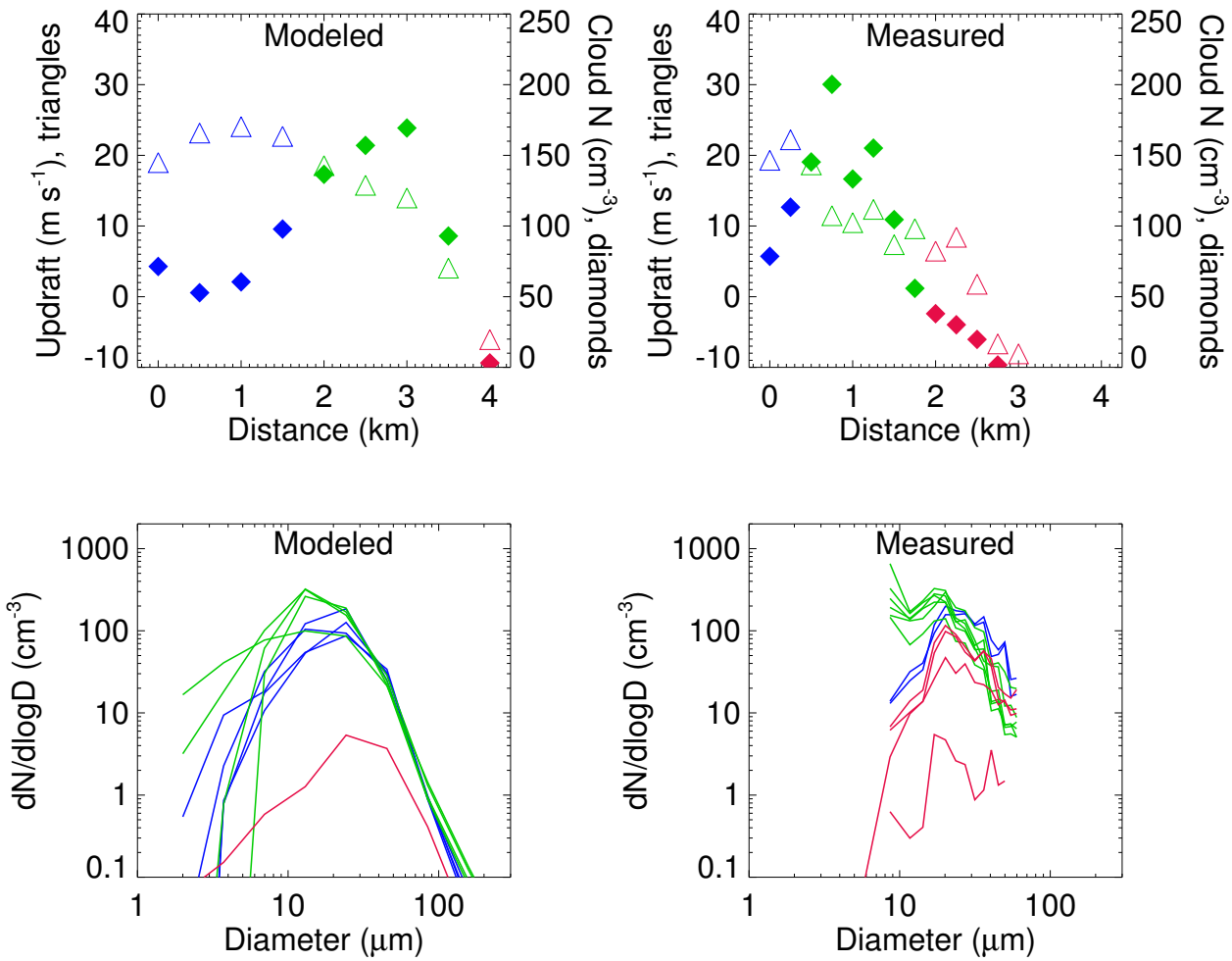
BL N=1800/ml (solid profile)



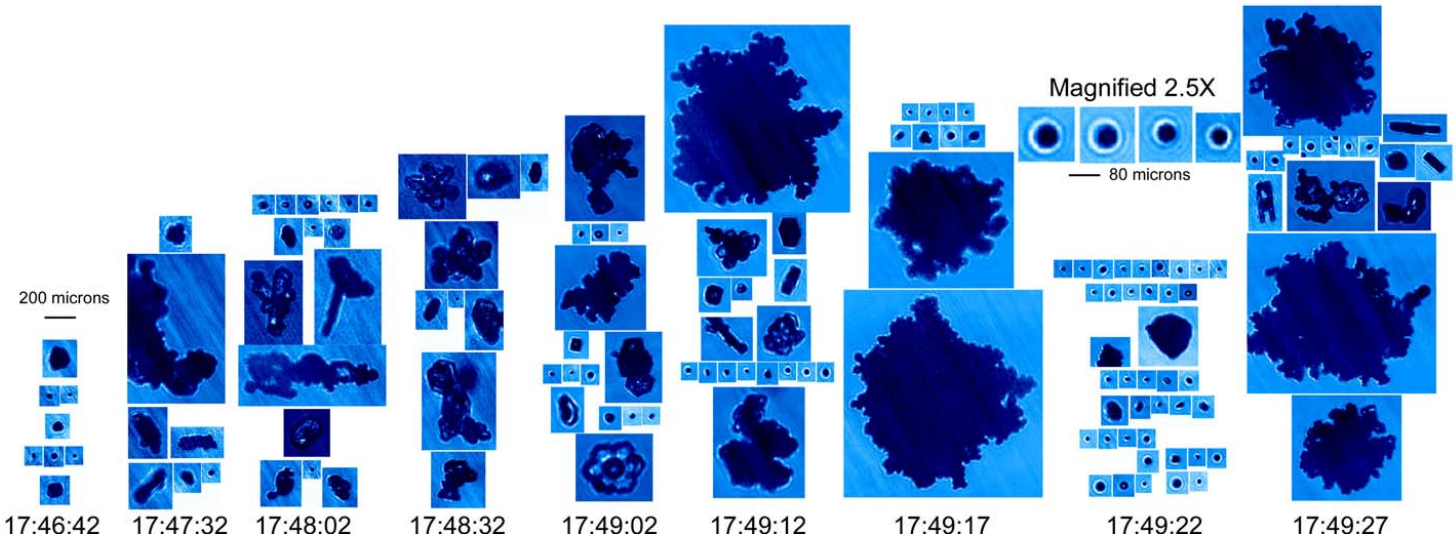
BL N=6500/ml (dashed profile)



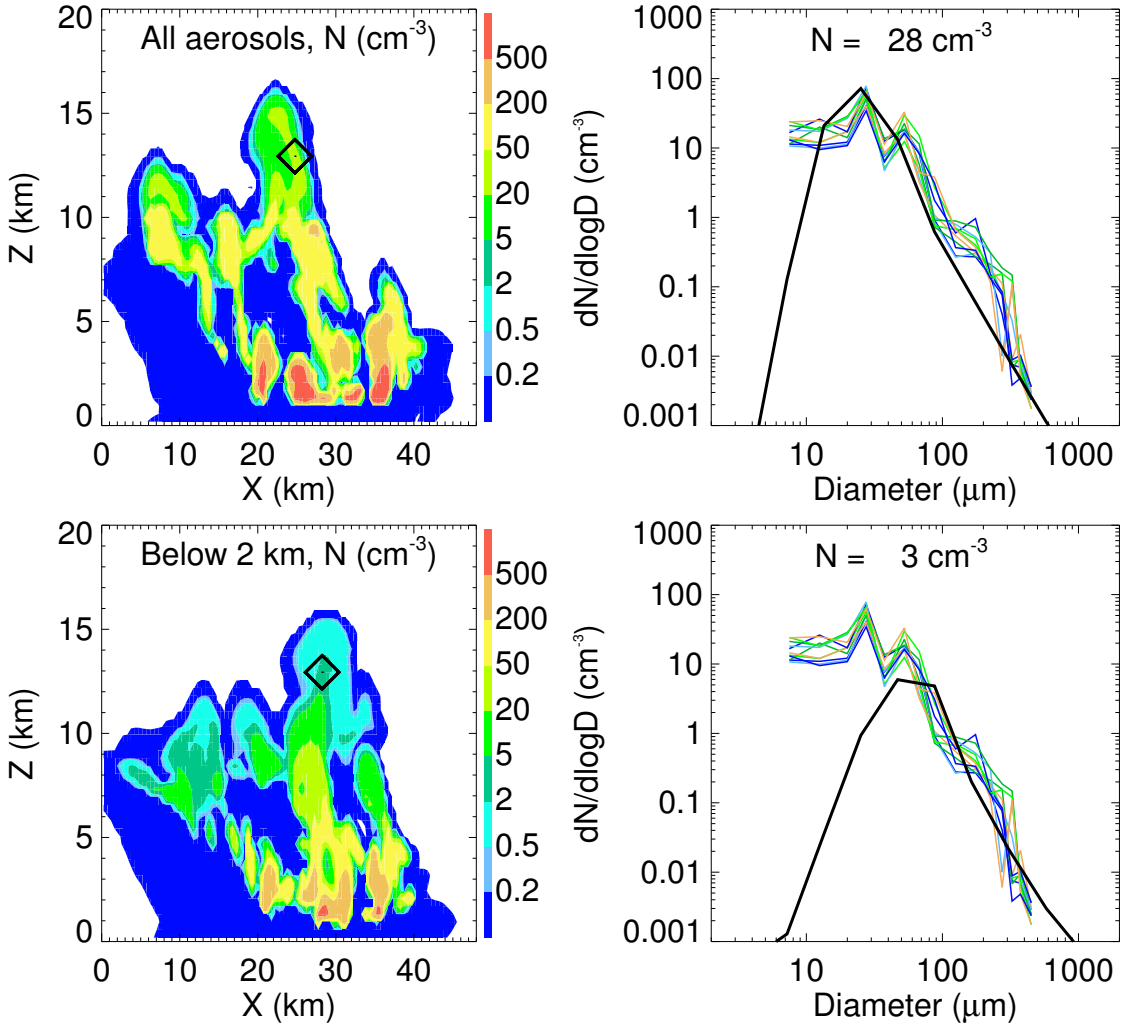
Modeled versus observed size distributions traversing the core



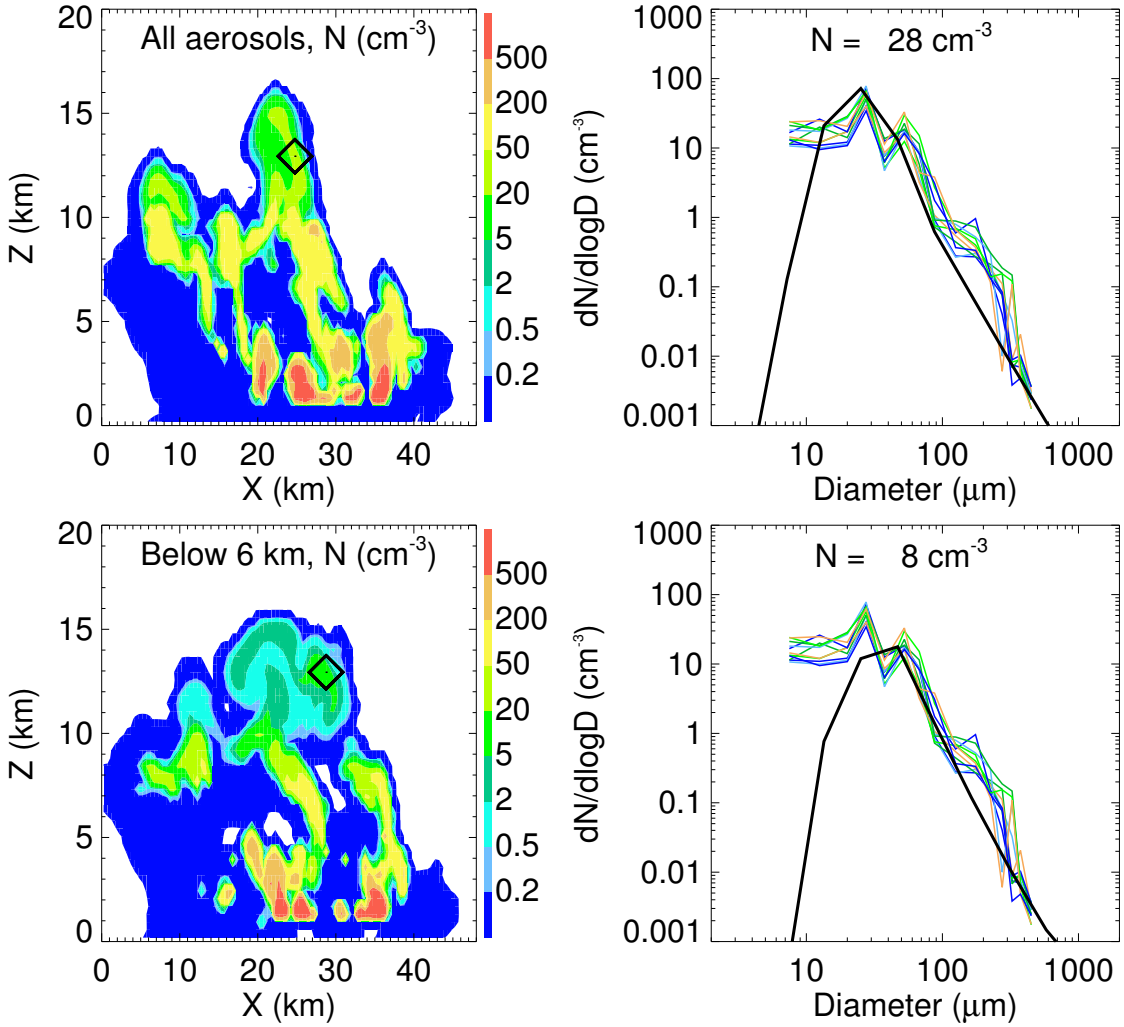
Cloud particle images



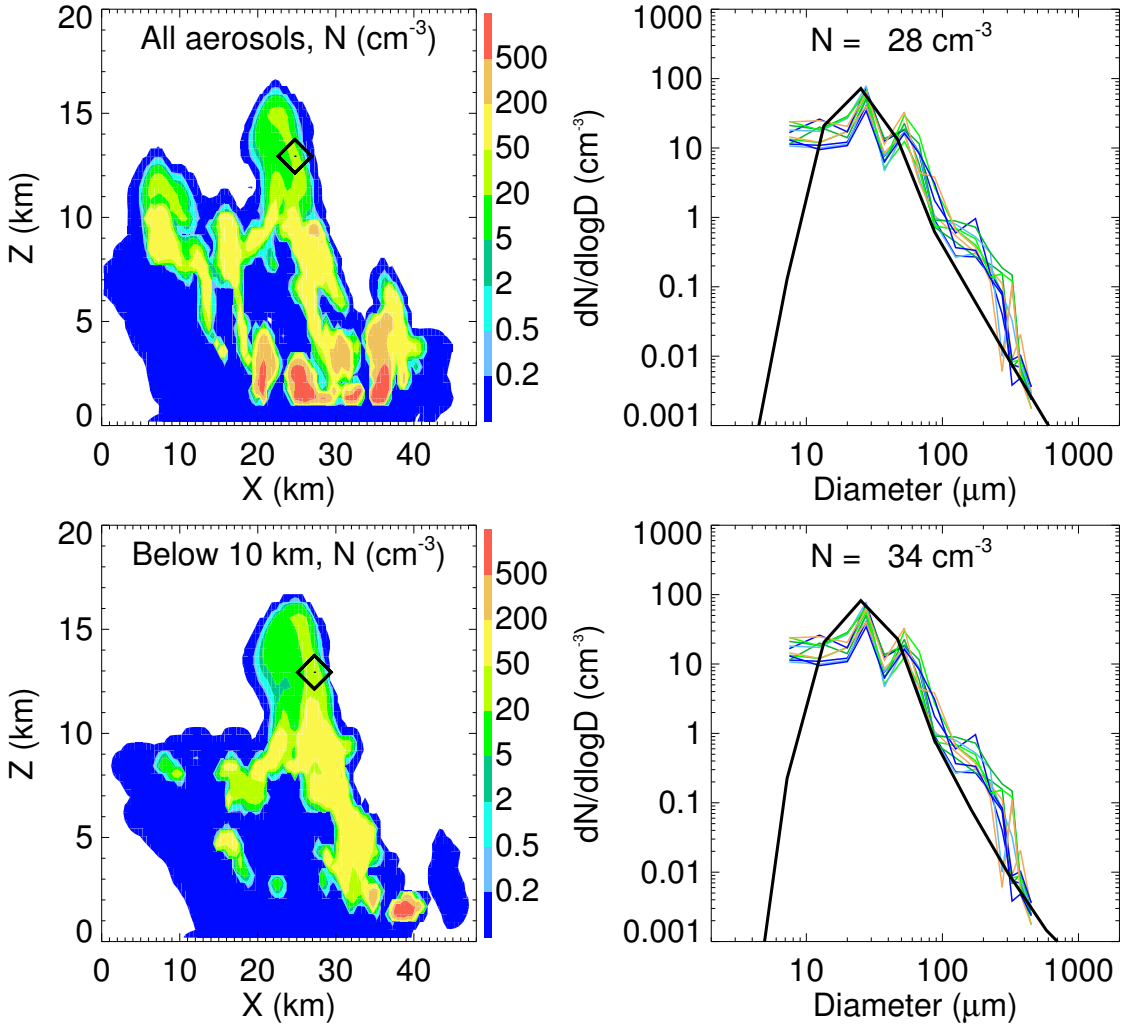
Sensitivity of modeled anvil particles to free tropospheric aerosols



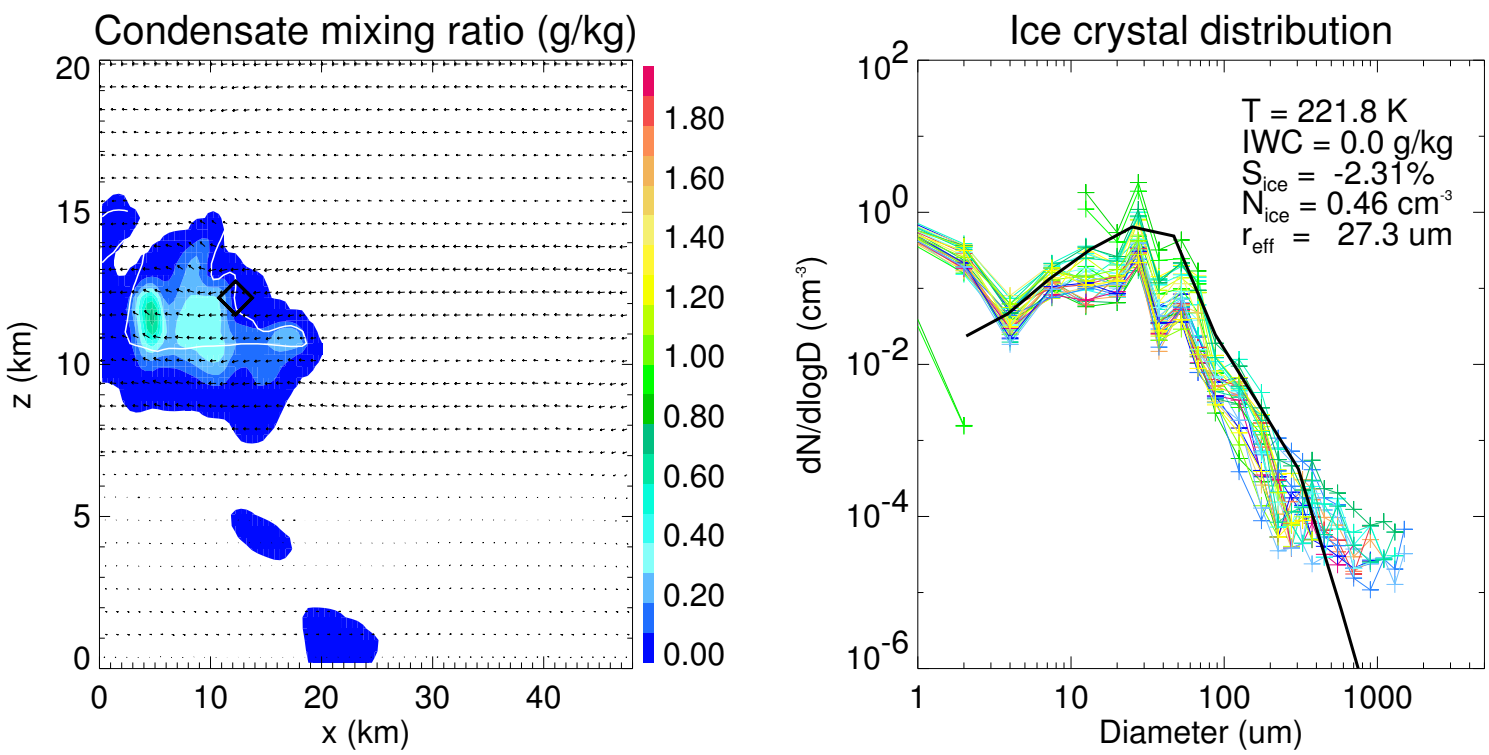
Sensitivity of modeled anvil particles to free tropospheric aerosols



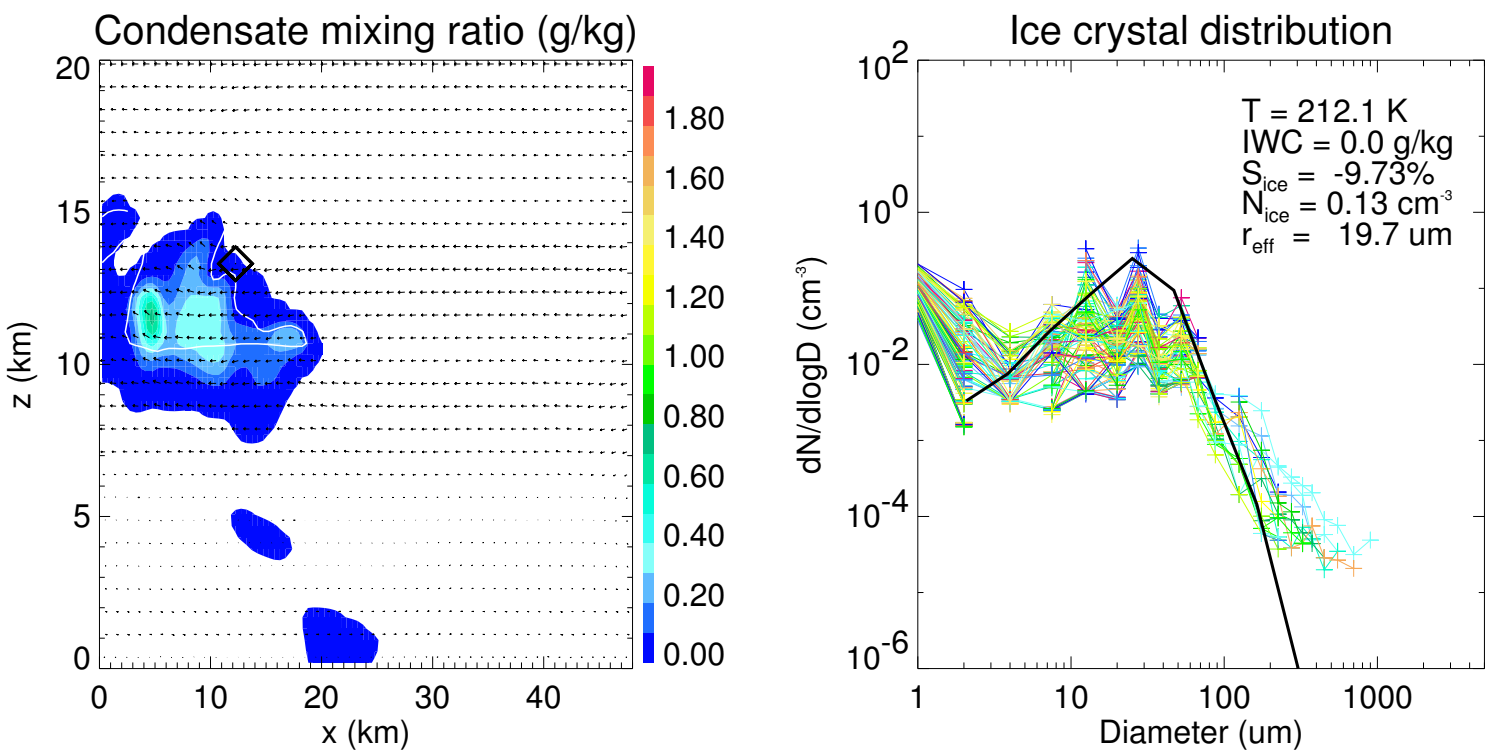
Sensitivity of modeled anvil particles to free tropospheric aerosols



Comparison of modeled anvil size distributions with observations



Comparison of modeled anvil size distributions with observations



Conclusions

- Which aerosols are most anvil crystals forming on?
  - aerosols below 2 km are insufficient
  - aerosols entrained above 10 are not a significant source
  - aerosols entrained between 6 and 10 km contribute most
- Three lines of evidence
  - number of droplets observed in the updraft core
  - peak numbers and small sizes in the core entrainment zone
  - size distribution peak and numbers of anvil ice crystals

Acknowledgments and future work

- Acknowledgements
  - NASA's Earth Science Enterprise
  - NOAA, NSF, DOE, ONR, and the USWRP
  - Jamie Smith, Brian Toon, Ed Zipser, Tim Garrett, Dan Cziczo

- Future work
  - anvil formation on July 3, 11, 16, 19, 21, 28, 29
  - meteorological conditions, supersaturation, aerosols, dust
  - anvil evolution (radiative fluxes)