Aerosol Indirect Forcing on Congestus and Deep Convective Clouds in the Tropics

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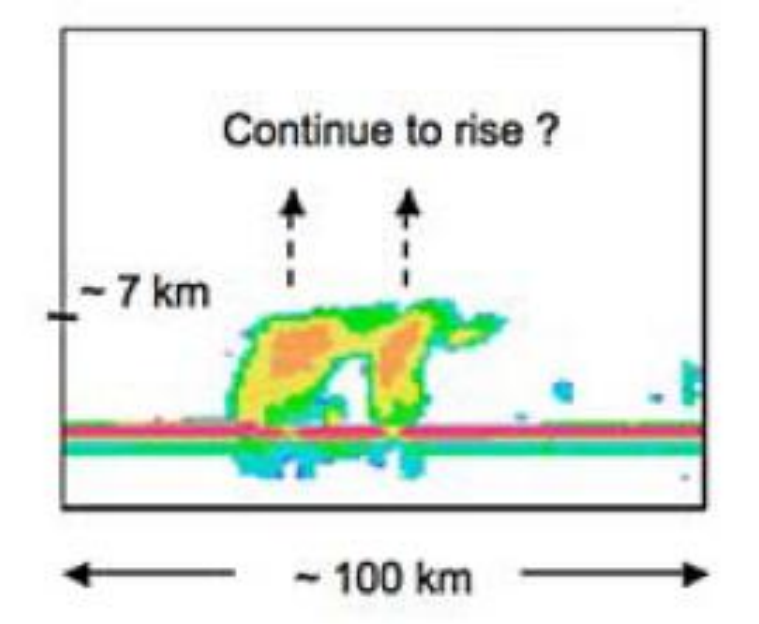
Image Source: CRYSTAL-FACE website

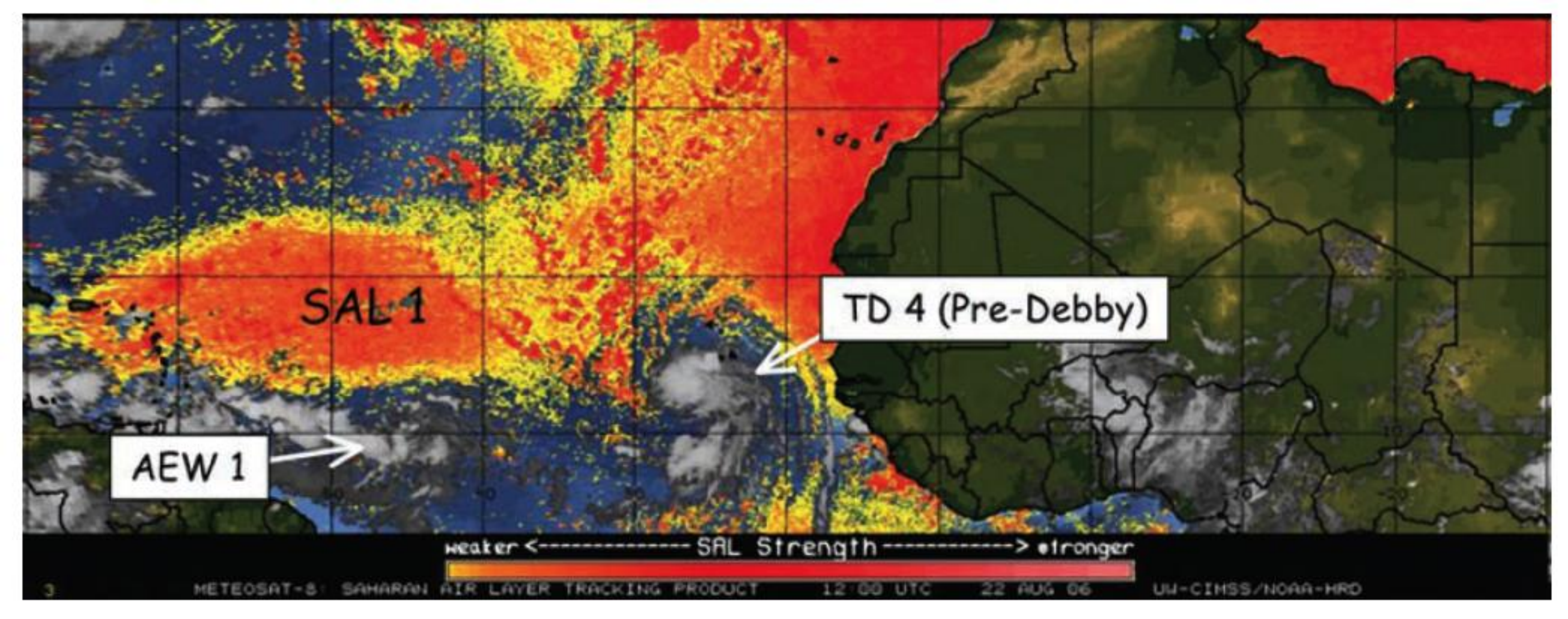
Goals

- To investigate the microphysical and dynamical response of congestus and deep tropical convective clouds to variations in aerosol concentration (CCN, IN, and combinations of both)
- Improve our understanding of Saharan Air Layer (SAL) on tropical cyclones and tropical clusters
- Improve representation of ice processes within our model
- Assess our dust transport / lofting module



- Terminal versus transient congestus
- Dynamical response to aerosol indirect forcing
- Role of entrainment – aerosol ingestion, dilution of mass fluxes

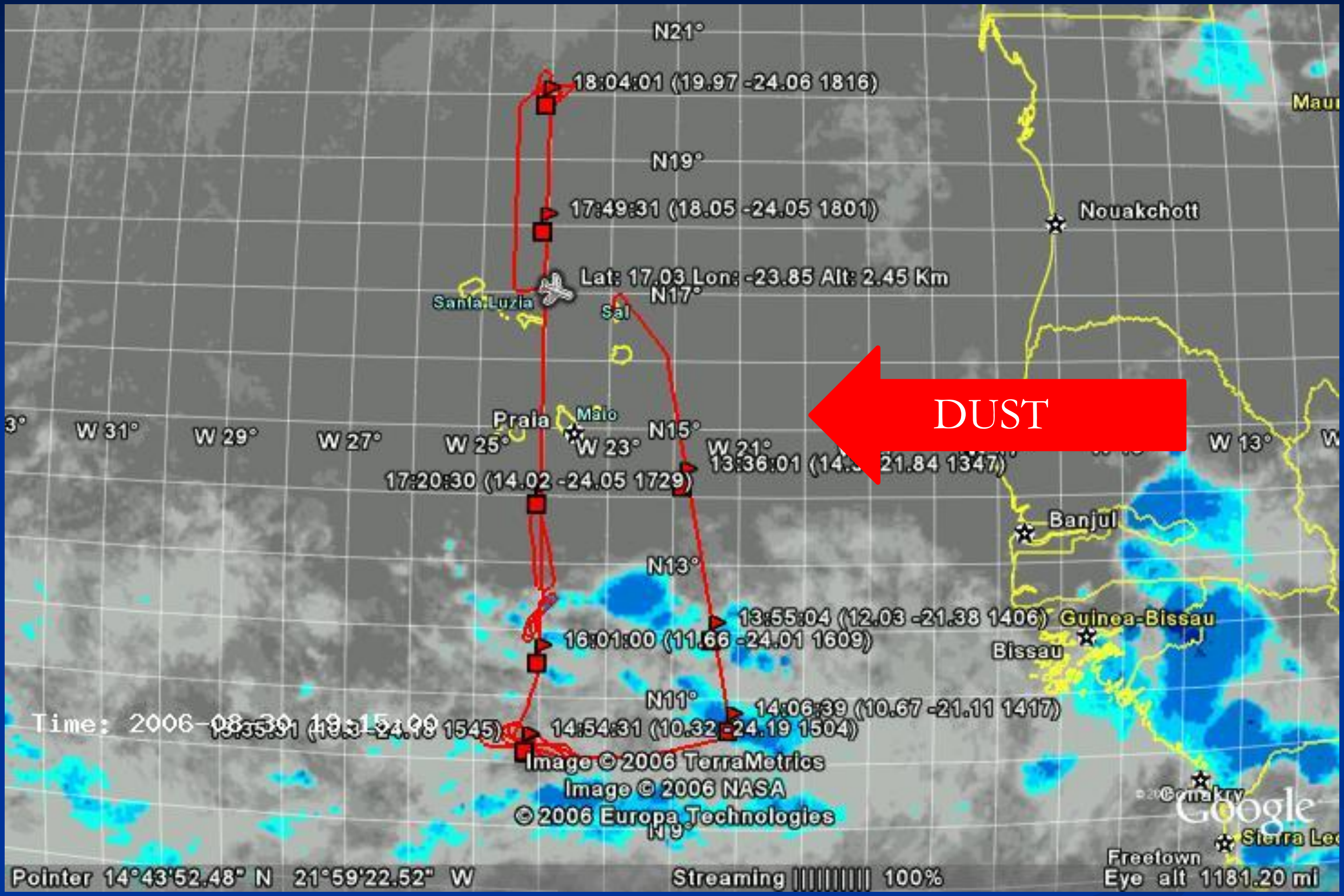
Top left image: Luo et al 2009; Bottom image (CRYSTAL-FACE field campaign)



GOES satellite imagery of tropical depression Debby on 23 August 2006 (after Zipser et al 2006)

Forcing associated with bulk environmental conditions (dry, warm, stable) of the SAL versus aerosol indirect forcing associated with dust?

Range of convective conditions



Locations of dropsondes in NAMMA on 30 August 2006

Trimodal Approach

- As the tropical atmosphere is never far from radiative convective equilibrium (RCE) => suitable framework to study tropical convection
- Conduct large-domain (10,000km), long-term (100 days) cloud-resolving simulations under a RCE framework

Cloud Resolving Model

- RAMS model developed at CSU
- 2 Moment bulk microphysics – bin-emulating
- Aerosol Scheme (Saleeby and Cotton, 2004)

$$N_{activated} = N_{available} F_{activation}$$

- Smaller cloud droplets are nucleated from CCN as a function of temperature, vertical velocity, CCN number concentration, and aerosol mean diameter
- Heterogeneous and homogeneous ice processes

Model Setup

- 2D model grid
  - 1 km grid spacing
  - 10,000 km in zonal direction
  - Variable grid spacing in the vertical
- Time period: 100 days
- Periodic lateral boundary conditions
- Oceanic boundary with fixed SST (300K)
- Initialized using TOGA-COARE sounding with zero mean wind
- Convection initiated with randomized perturbations to potential temperature field

Experiment Setup

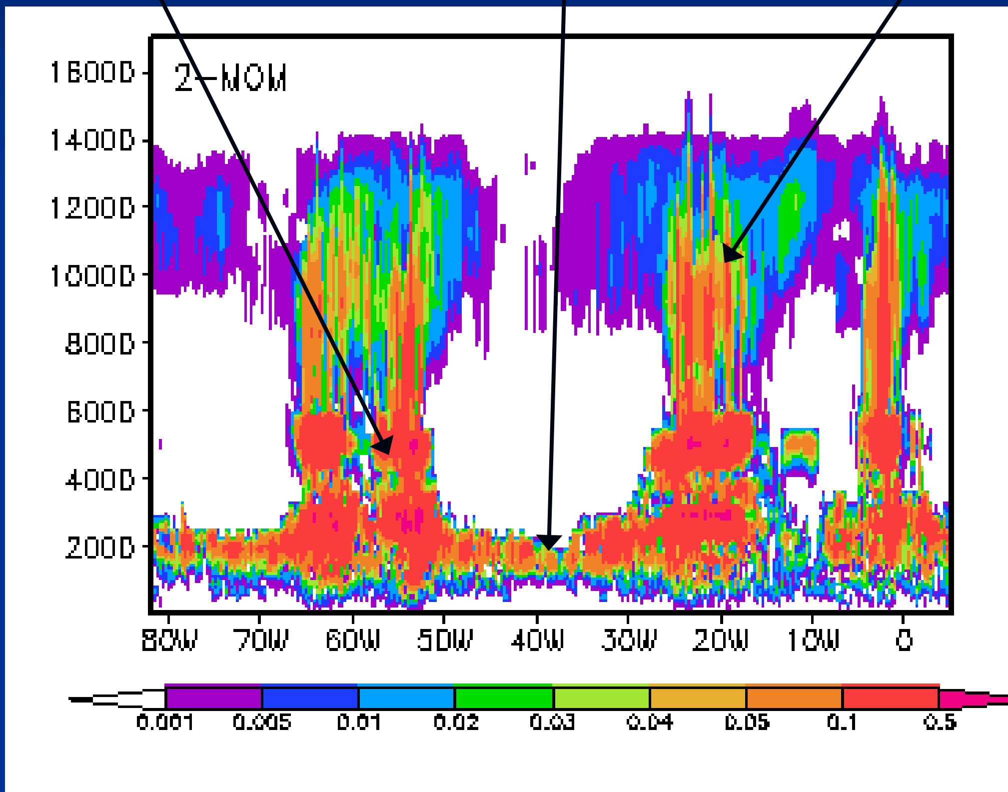
- Conduct the Control Run with clean background CCN concentrations (25 cc^{-1})
- Allow CONTROL simulation to reach RCE (60 days)
- Sensitivity tests:
  - Restart CONTROL simulations and run the simulations for another 40 days
  - Introduce aerosol layer between 2 and 4 km AGL
  - Experiments: 100, 200, 400, 800, 1600 and 3200 cc^{-1}
  - Aerosol layer updated each time step

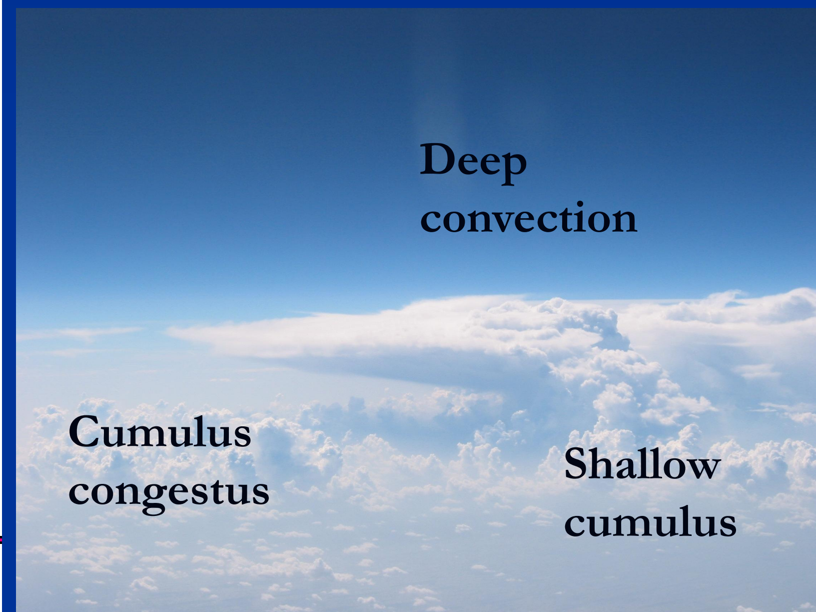
Tri-modal Distribution

Cumulus Congestus

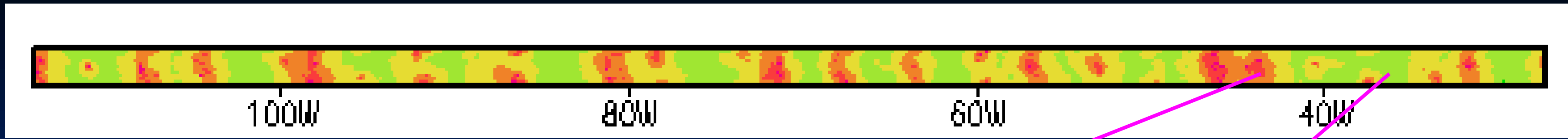
Deep convection

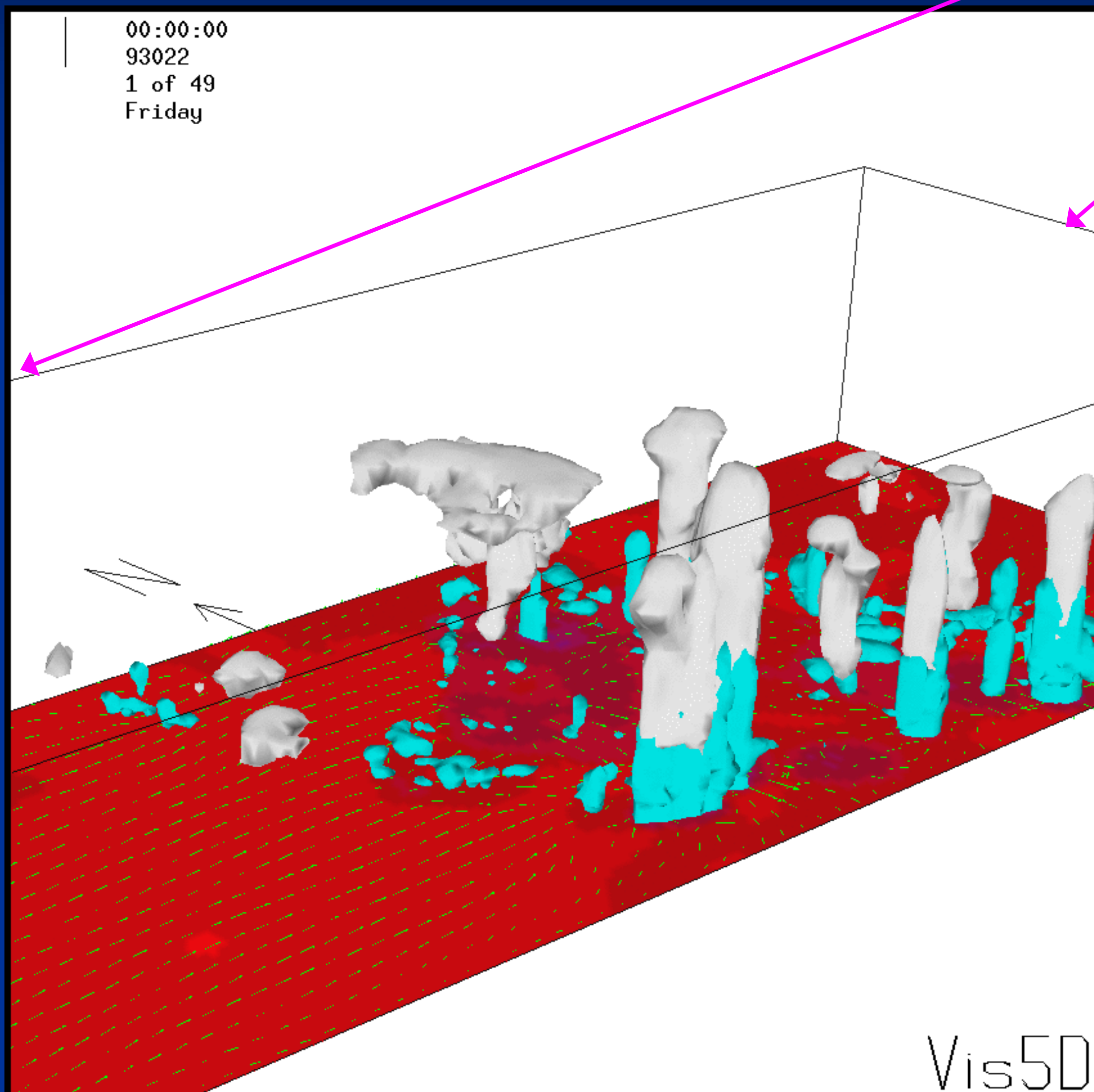
Shallow convection





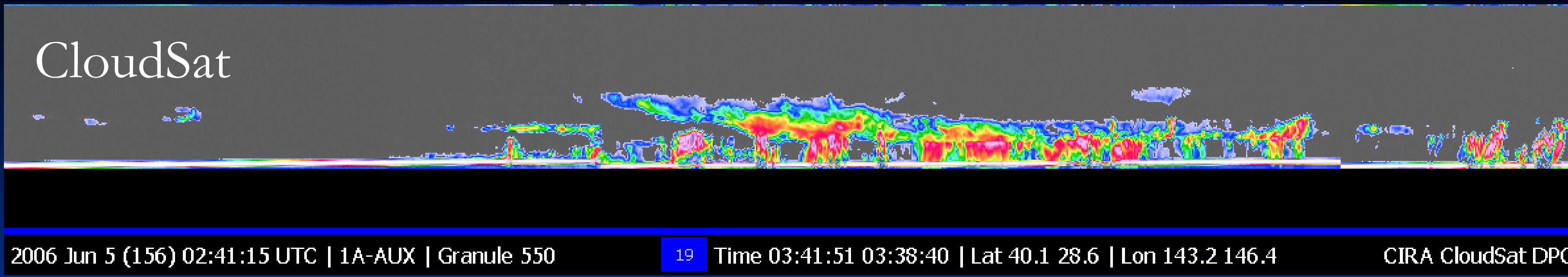
A vertical cross-section of the mean cloud water + cloud ice field for the Control experiment (left) and an image of the tri-model distribution observed during NASA's CRSTAL-FACE field campaign

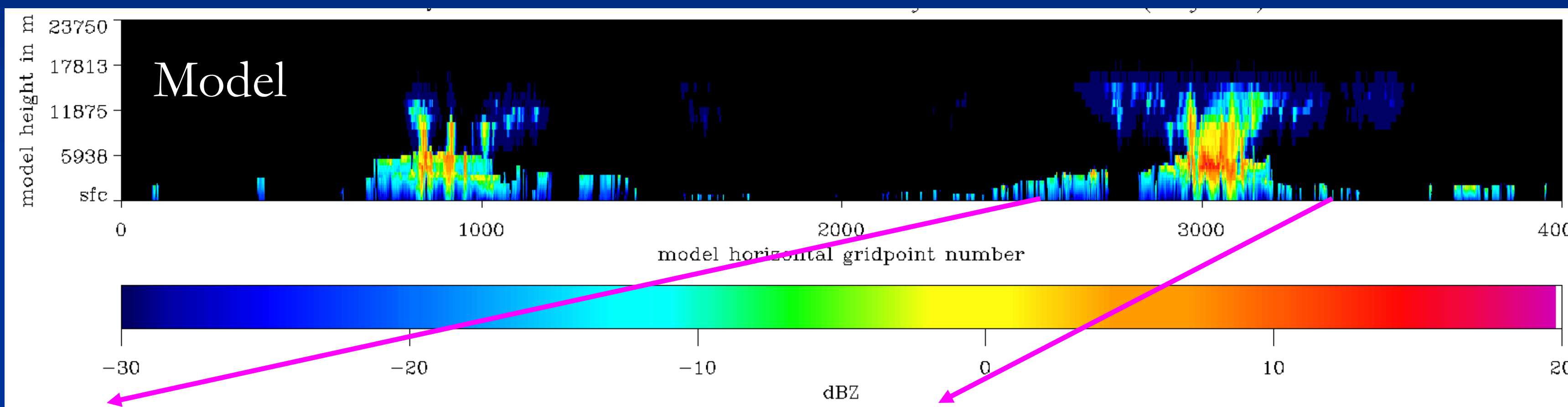


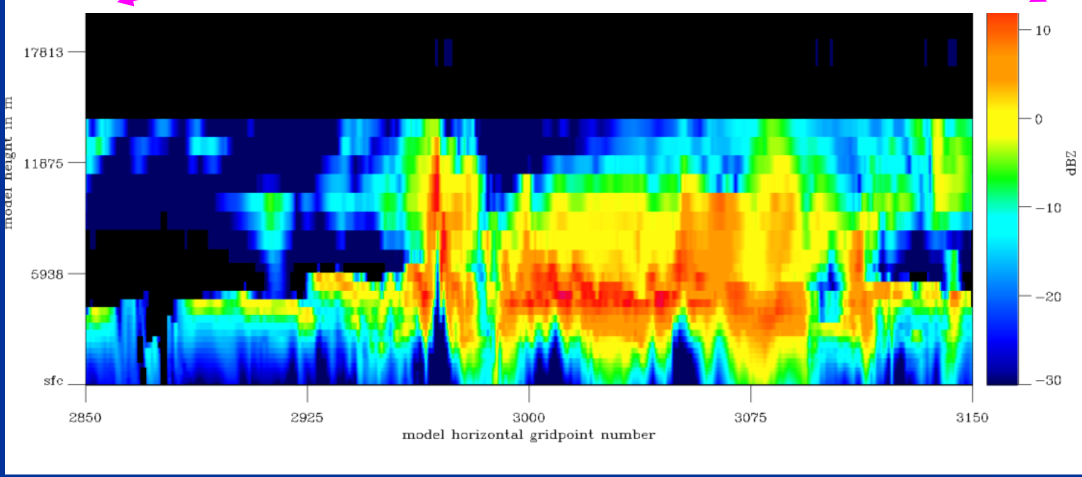


Convective development

Time interval: 1 hour
White: total ice with 0.1 g/kg isosurface shown
Blue: liquid water with 0.1 g/kg isosurface shown
Shading: temp at the surface (blue to red => cooler to warmer)
Wind vectors (green) at the surface





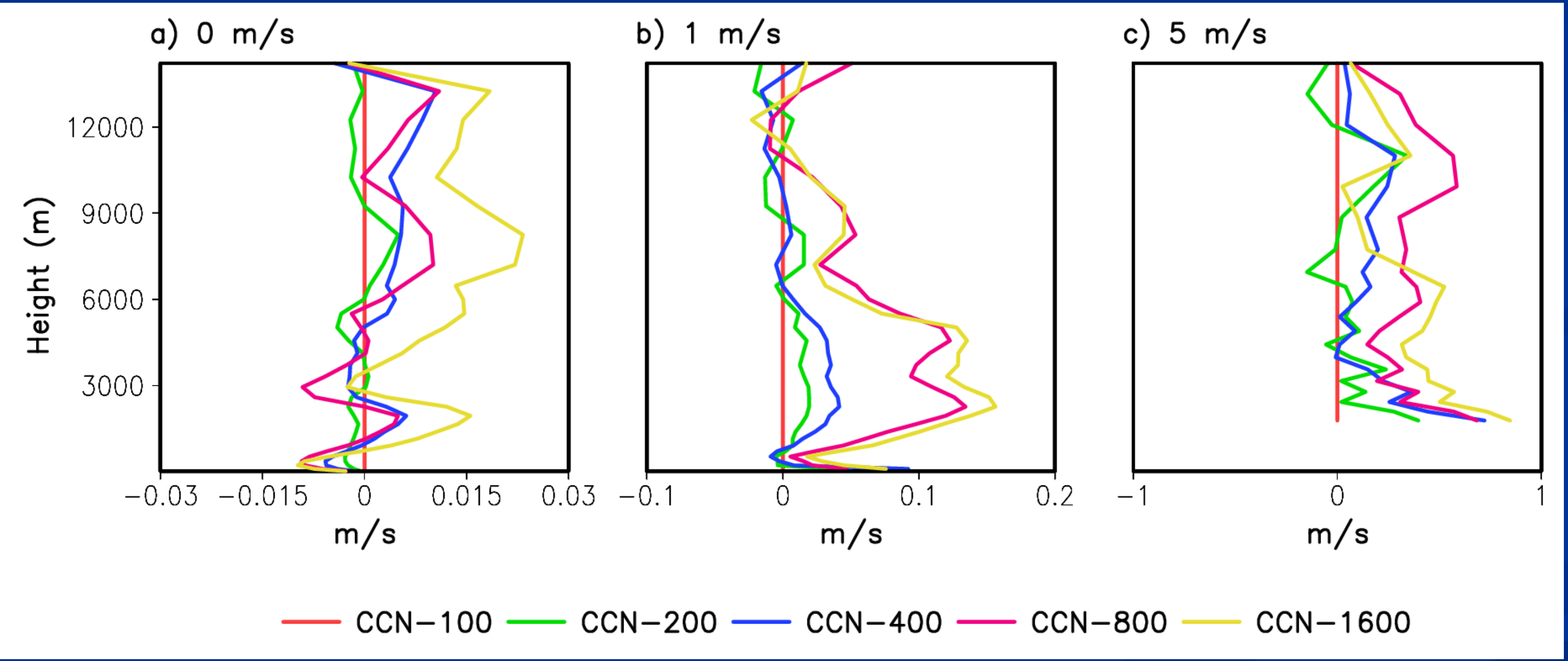


Tri-modal distribution

CloudSat data (top) and radar simulator data (mid and bottom)

Dynamic Response

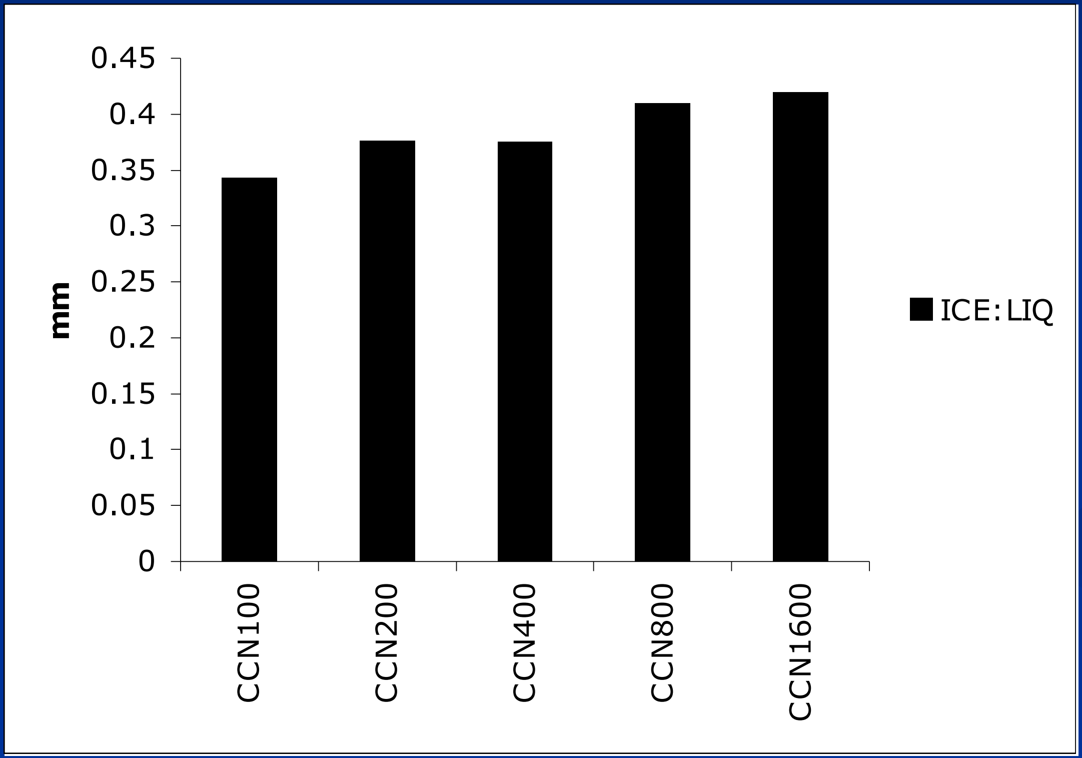
- Enhanced CCN concentrations => stronger updrafts



Temporally and spatially-averaged updraft strength represented as a difference from the Control experiment for various updraft thresholds

Reference: van den Heever et al 2011

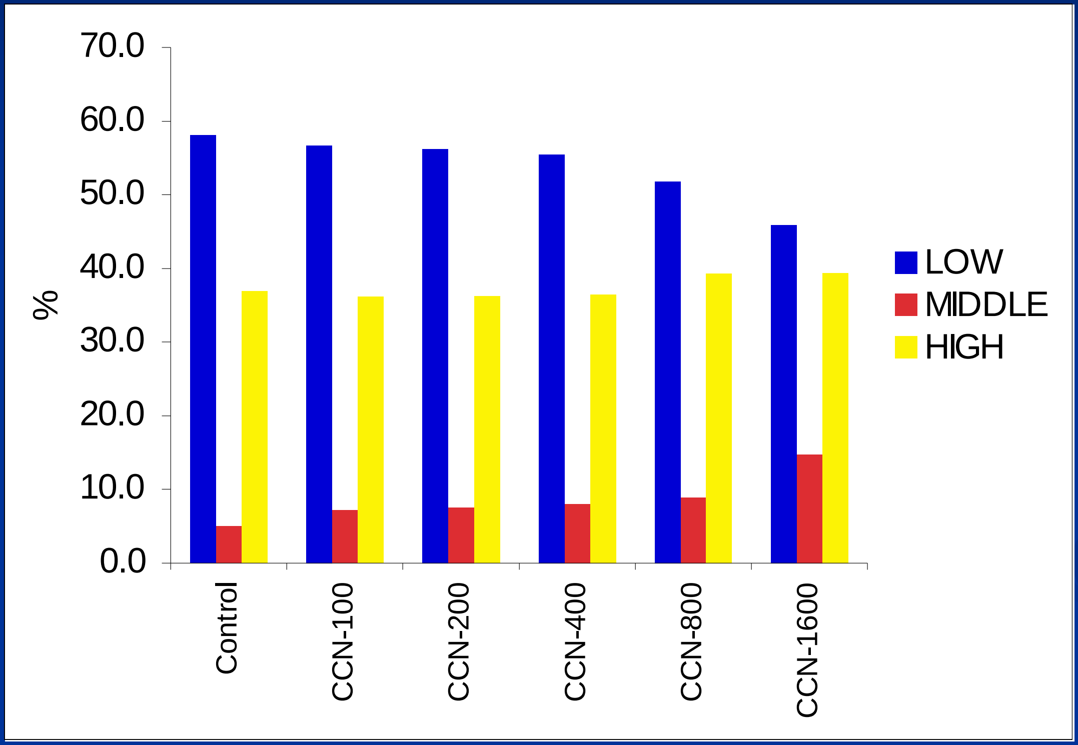
Ice:Liquid Ratio



Temporally- and horizontally-averaged vertically-integrated ice : liquid water ratios

- Enhanced CCN concentrations:
  - increased ice : liquid water ratio (20%)
  - Important radiative and remote sensing implications

Cloud Regime Frequency



Frequency occurrence (%) of low (<4km), middle (4-7km) and high (>7km) cloud for each CCN experiment

- Enhanced CCN concentrations
  - reduce low-level cloud frequency (~20%)
  - enhanced mid-level (~50%) and upper-level (~6%) cloud frequency

Precipitation Contribution (%) by Cloud Regime

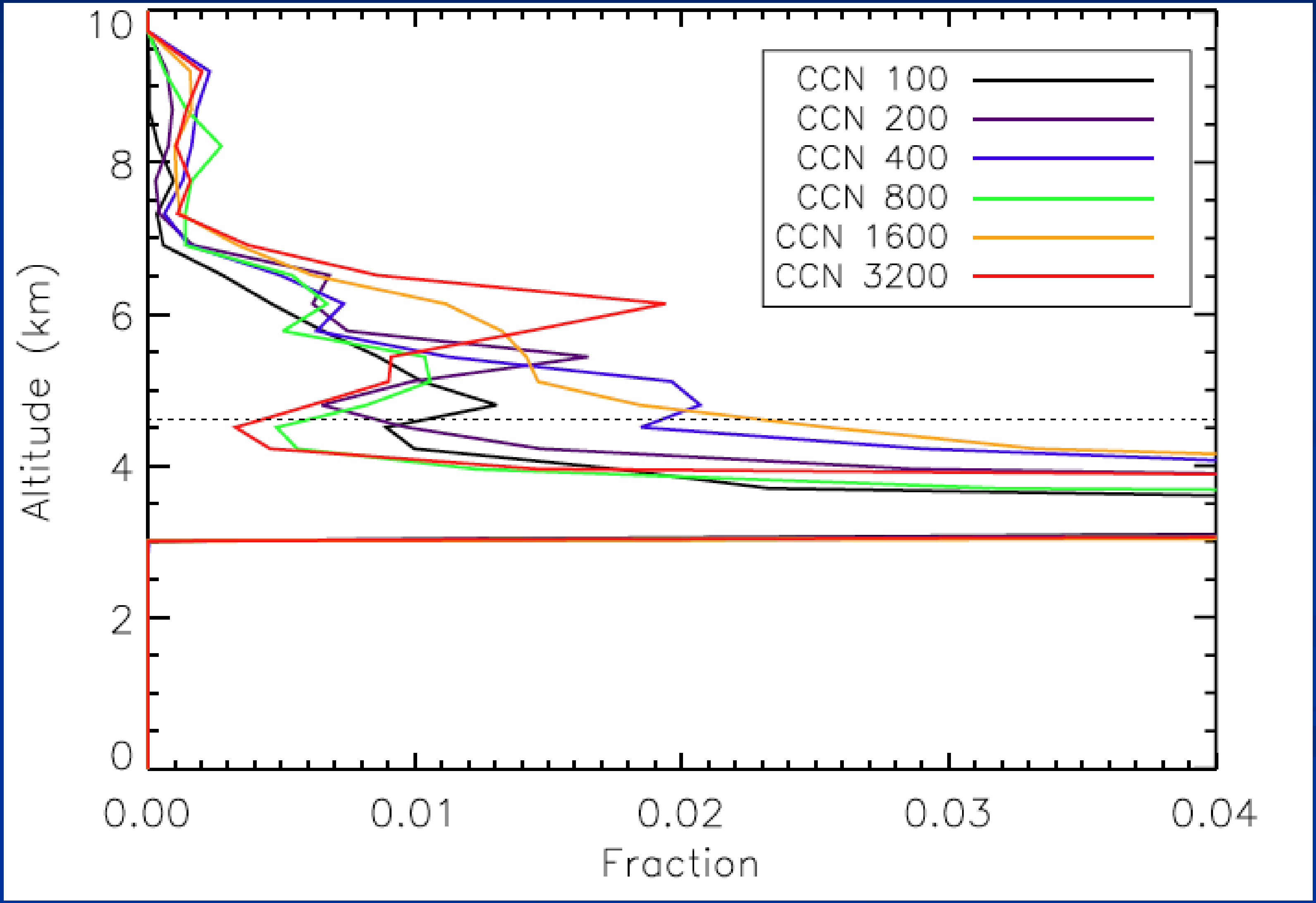
Cloud Type	CCN-100	CCN-200	CCN-400	CCN-800	CCN-1600
Low	12.3	10.8	9.4	6.9	4.8
Middle	9.3	8.6	8.8	9.0	9.7
High	78.4	80.5	81.7	84.0	85.4

~60%

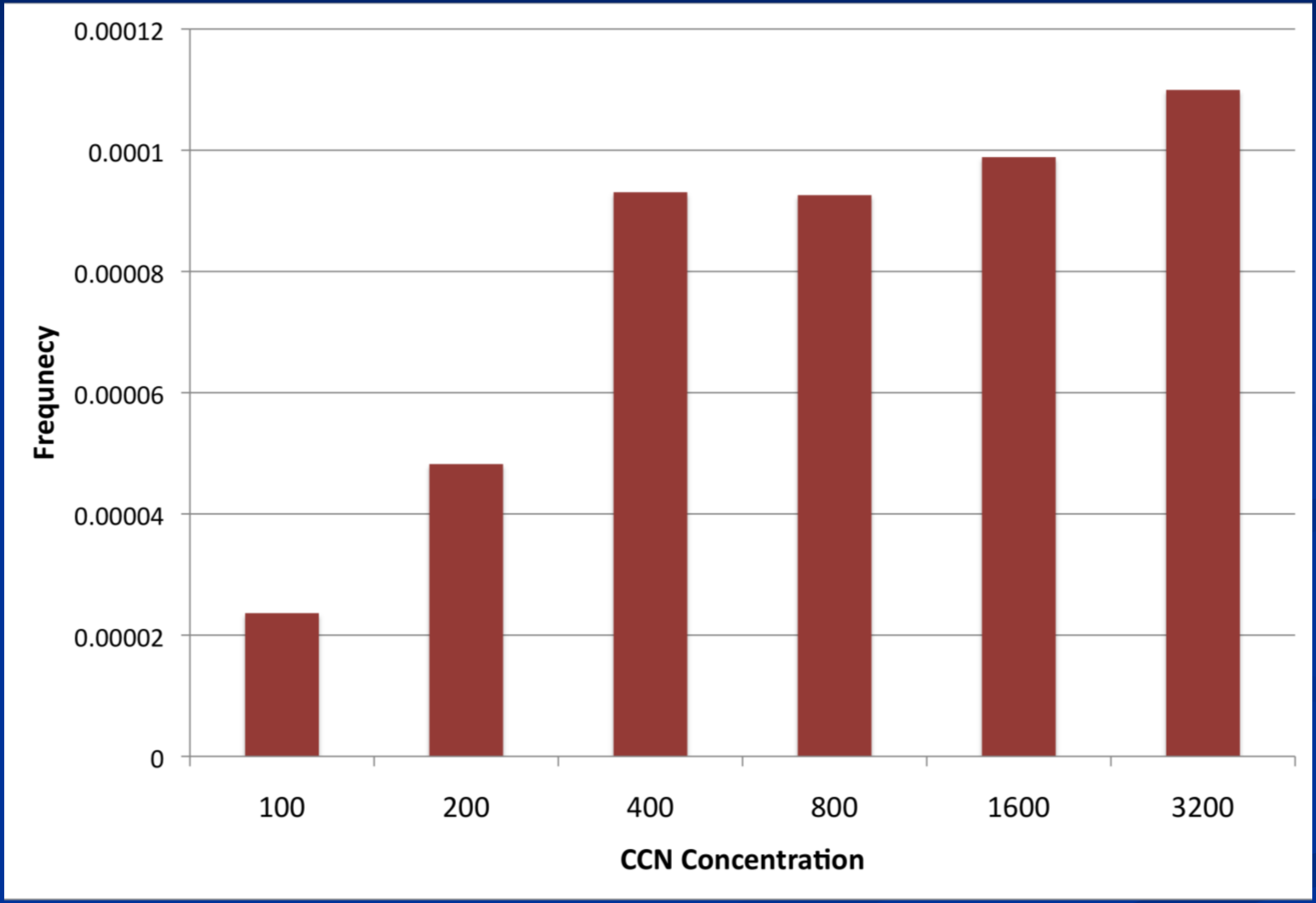
~13%

~10%

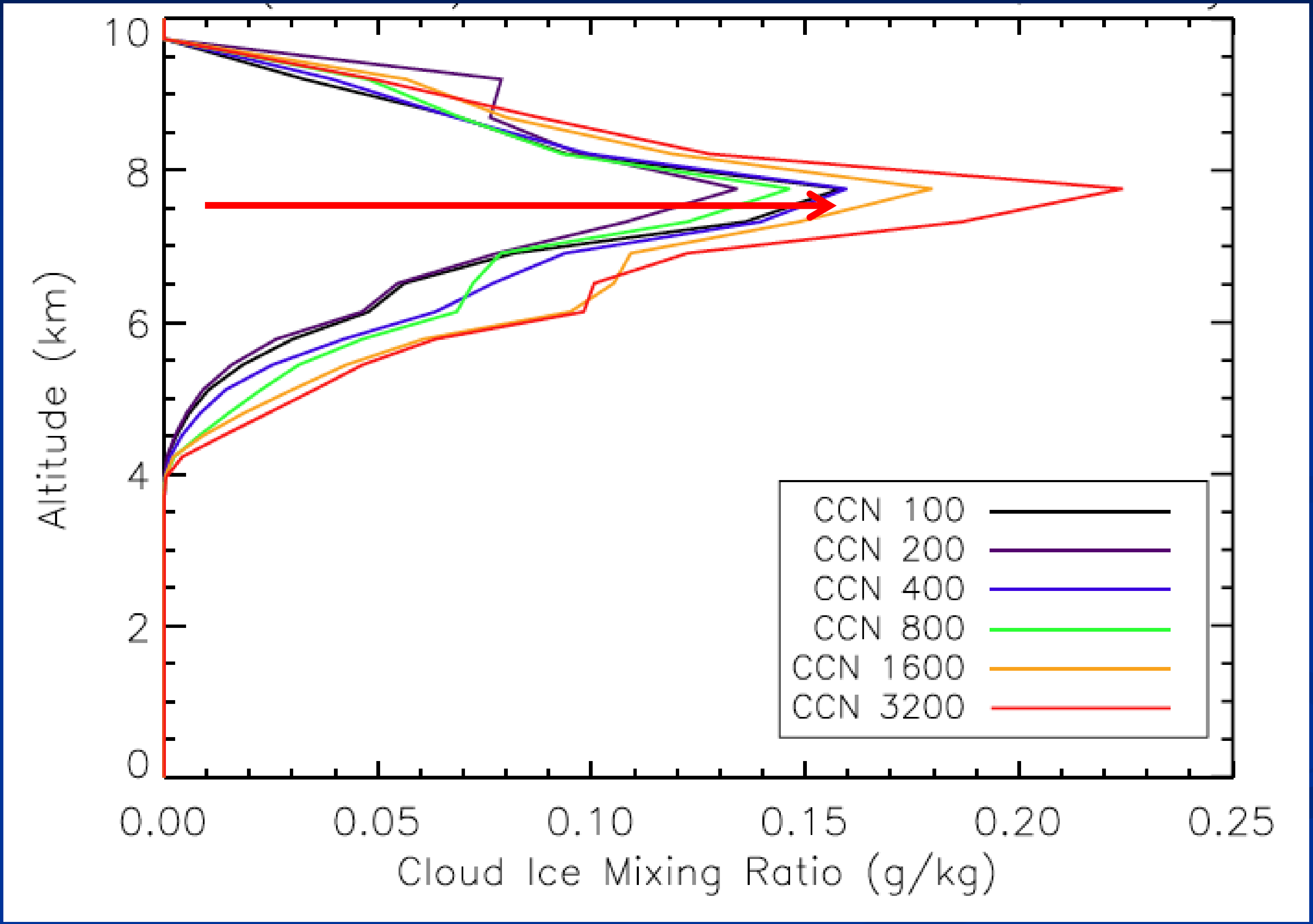
Cloud top frequency (3 -9 km)



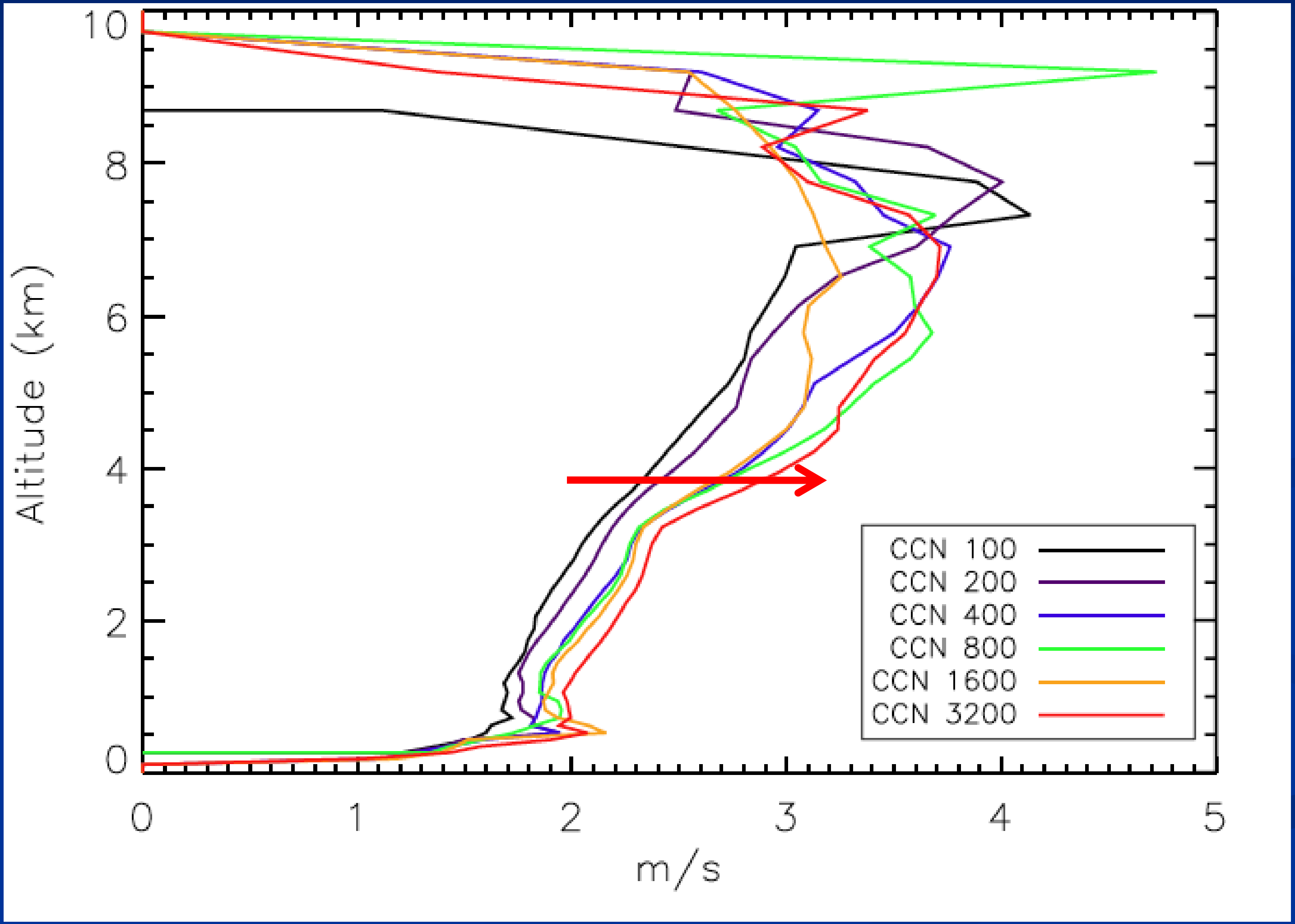
Cloud Top Frequency 7 – 9 km



Average Cloud Ice Mixing Ratio



Average W (> 1 m/s)



ICE-T Measurements

- Environmental variables – vertical wind profiles
- Vertical velocity => convective mass flux
- Secondary ice processes / splintering
- Other ice processes (riming rates)
- Initial IN concentrations and subsequent ice crystal number concentrations and diameters
- Cloud droplet number concentration and sizes
- CCN, GCCN and IN characteristics and concentrations
- Vertical profiles of these aerosols (esp dust)
- Precipitation rates
- Changes in characteristics below and above FL