Entrainment

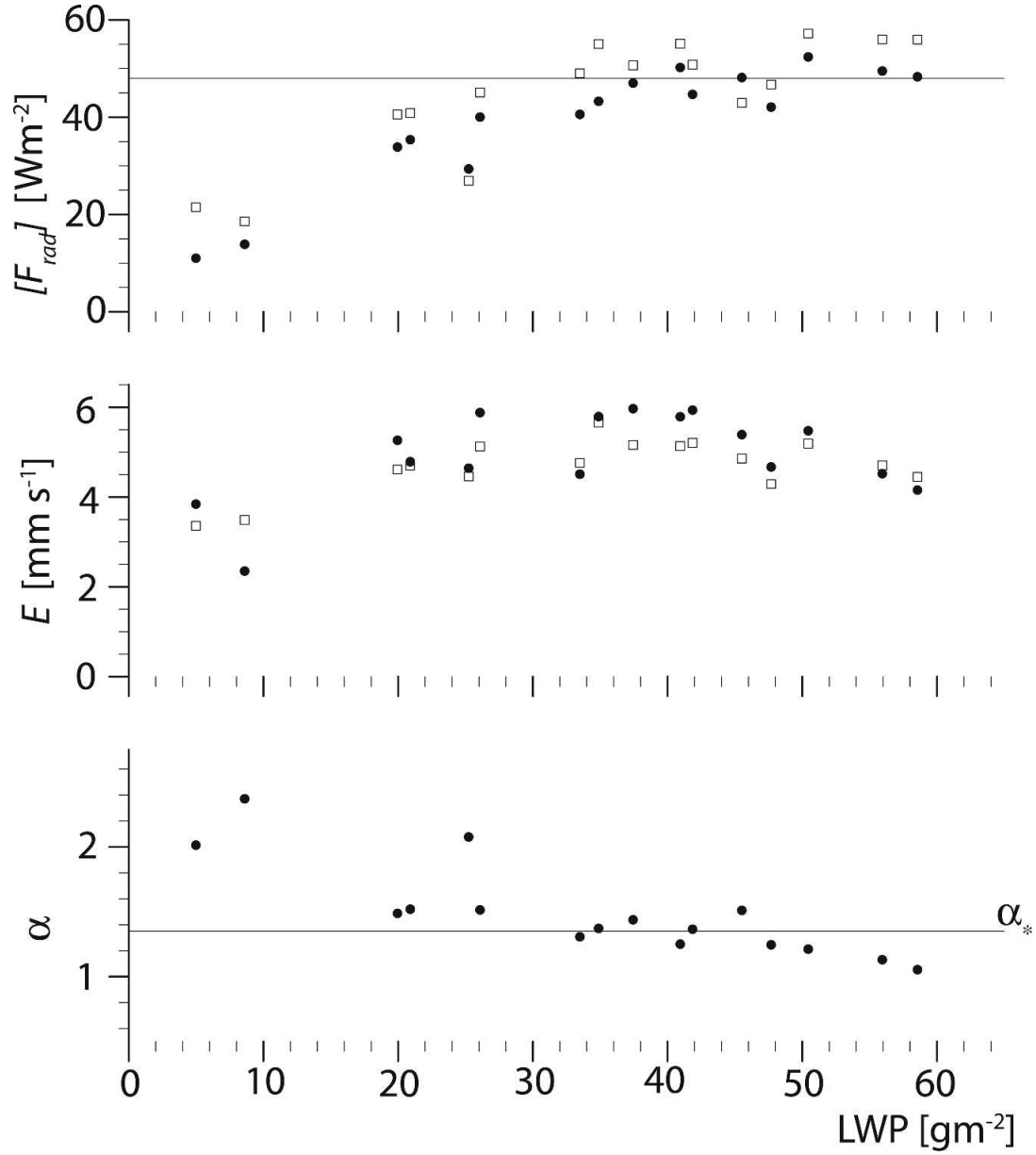
- Into what structure?
  - boundary layer (vertical delineation)
  - tropospheric region (horizontal delineation)
  - “cloud” or up/downdraft (curvilinear delineation)
- Glimpses from radar data + 3D model
  - Arctic stratus
  - tropical deep convection
- How models can help/be helped

Boundary-layer clouds

- Sc cloud-top entrainment rate primarily controlled by cloud-top radiative cooling (Stevens et al., 2005)

  $\alpha = E\,\Delta\theta_l / F_{rad}$

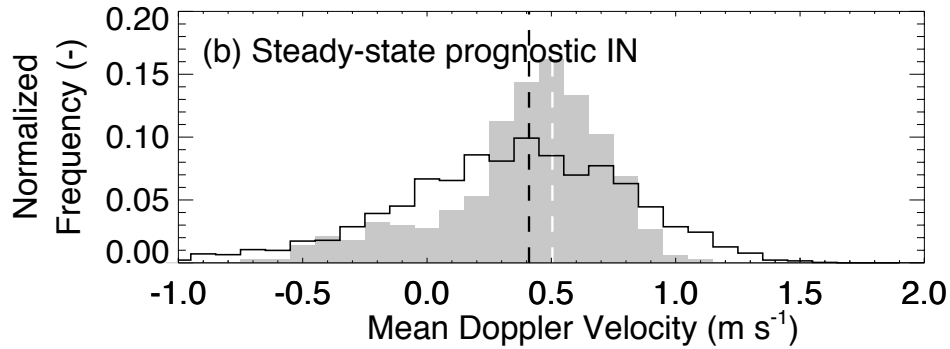
- But microphysics plays a role (Bretherton et al., 2007; Ackerman et al., 2009)



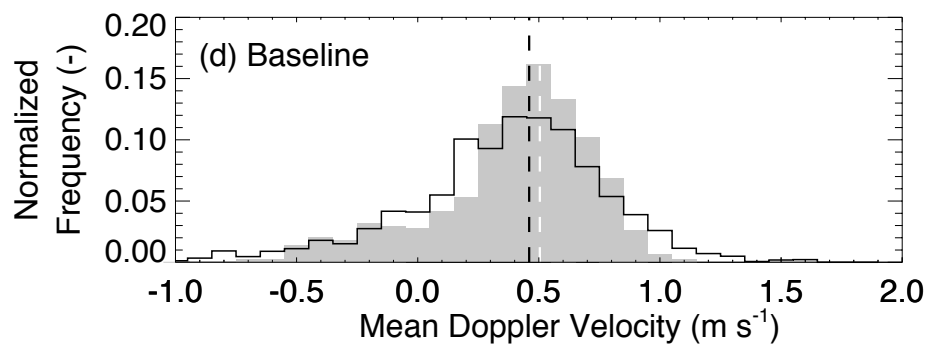
Evidence in Doppler velocities?

- Mixed-phase Arctic Sc case (Fridlind et al., in review)
- Relevant signal is in vertical wind speeds
- Microphysics plays some role in relationship of Doppler velocity to wind speed

entrainment = 0.17 cm/s



entrainment = 0.13 cm/s

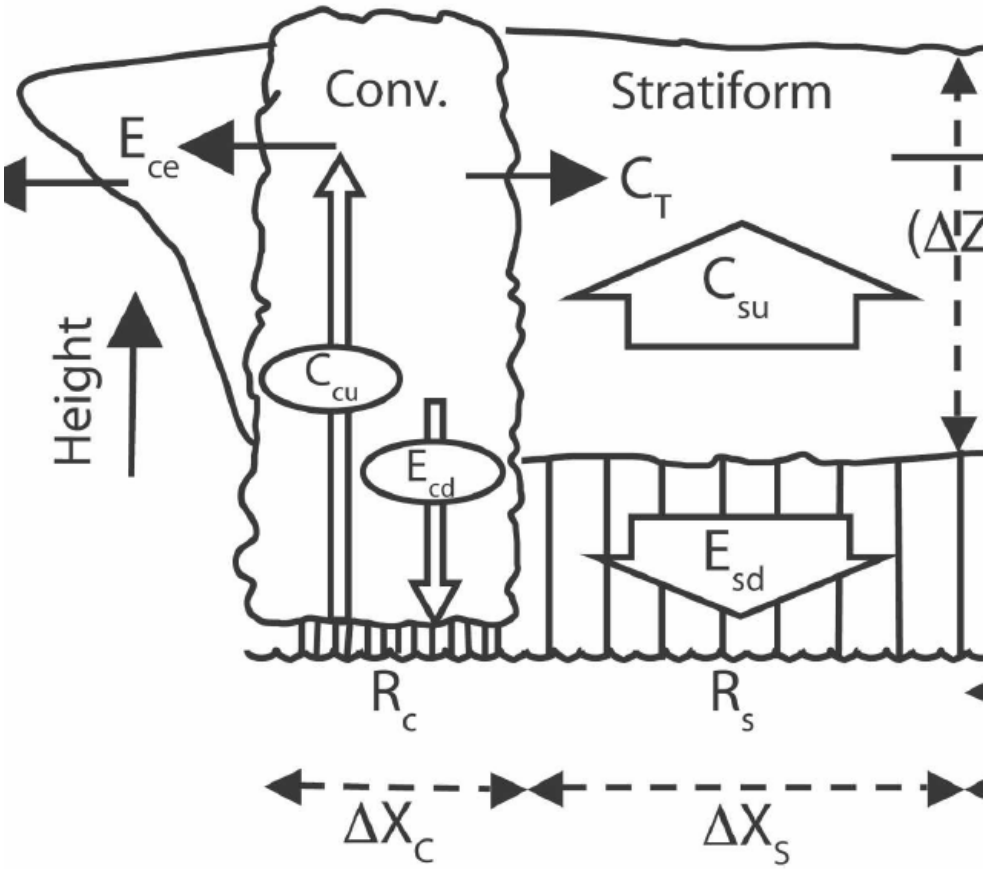


Tropical deep convection

- Water budget equation (Houze et al., 1980)

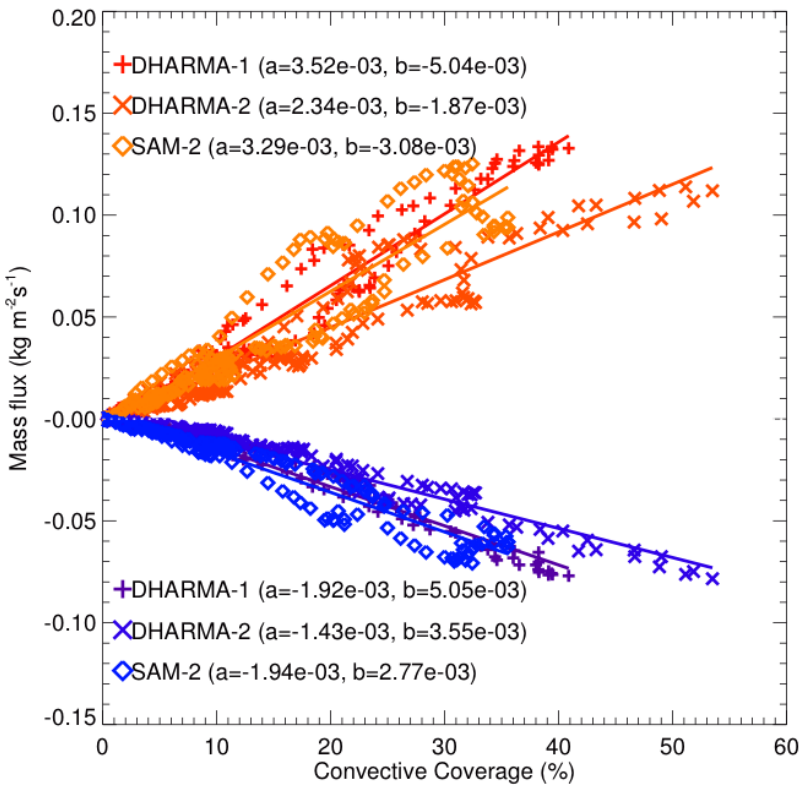
  $C_{cu} = R_c + E_{cd} + E_{ce} + C_T$

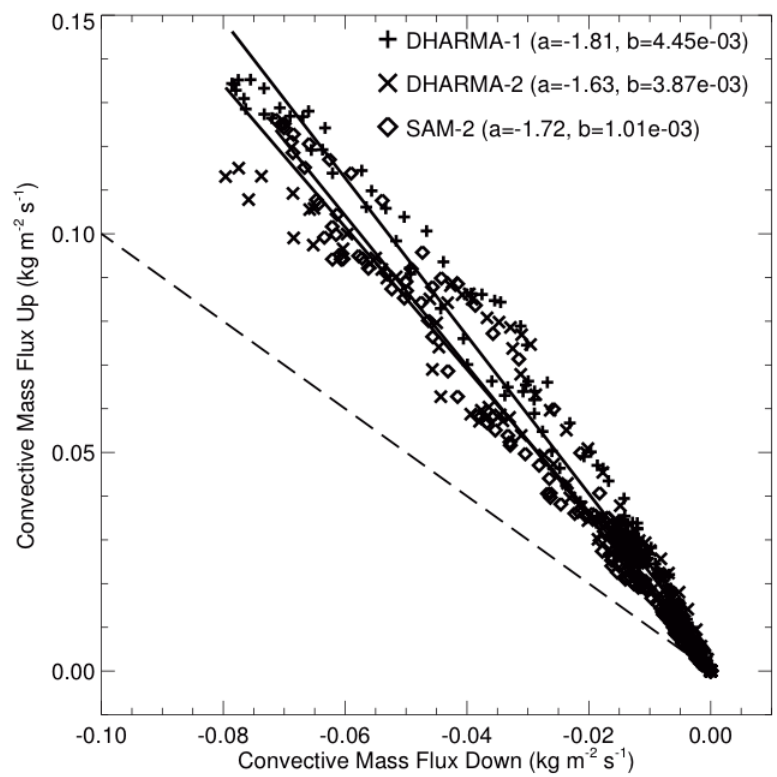
- Horizontal delineations of the atmosphere with two detrainment terms



Tropical deep convection

- Vertically averaged up/down mass fluxes roughly proportional to convective area and one another, thus detrainment proportional to convective area (Mrowiec et al., in preparation)





How can models/theory help/be helped?

- Modelers do not need something all the time, but uncertainty vital
  - focus on limited conditions
  - well-defined structures easiest
  - could start with unique conditions (even mixed-phase Sc)
- Boundary-layer (horizontal delineation)
  - need to link vertical winds and thermodynamic structure to entrainment rate (theoretical, models need help)
  - forward modeling, test sampling requirements under controlled conditions, etc. (can still help here; e.g., a guess what drizzle might look like when embedded in a field with well defined turbulence properties)
- Vertical and curvilinear delineations
  - can separate features of vertical velocity or other structures (e.g., remove gravity wave contributions to vertical mass fluxes)
  - limited more by theoretical definition? or more open to observational definition and interpretation?