Capturing convection's sensitivities in a plume scheme

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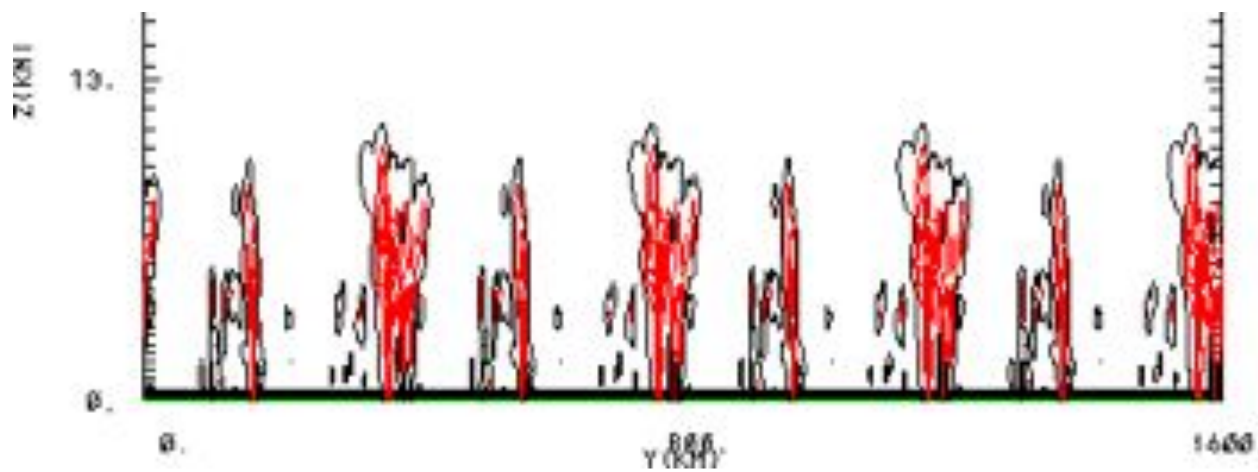
Harvard, Oct 17 2009

(personal) historical moment

- Two very old ideas, fiiinally coming to fruition?

1. 1995: study convection sensitivities
   - inhibition vs. bulk instability (CAPE) controls
   - sensitivities at equilibrium (as opposed to hot-bubble triggered storms)

- 1997: learned cloud model (Clark-Hall)



- Hated the technical side (scripts and queues and mass stores, oh my!)
- Methodology new -- "parameterized large-scale dynamics," not just LS "forcing" – but feeble
- Salvage writeup in 2004

- Proposed mo better with Stefan
  - RESULTS IN PRESS just last week
  - w/in days of Zhiming's very complementary work

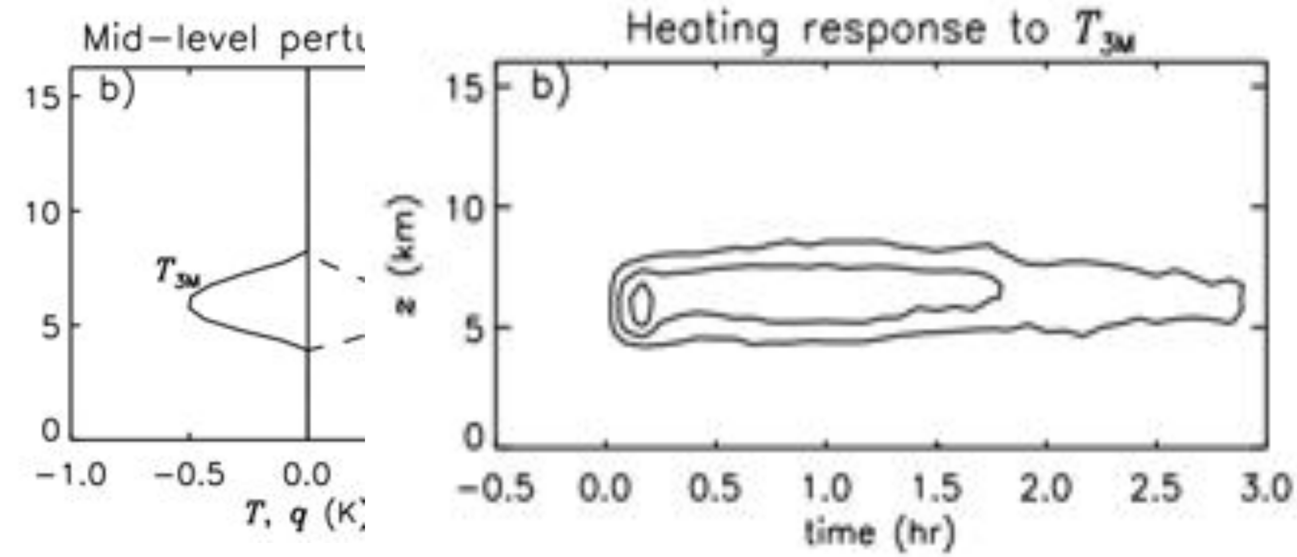
- *A rich suite of important sensitivities to guide parameterization is in hand!*

T&M 2009 and Kuang 2009

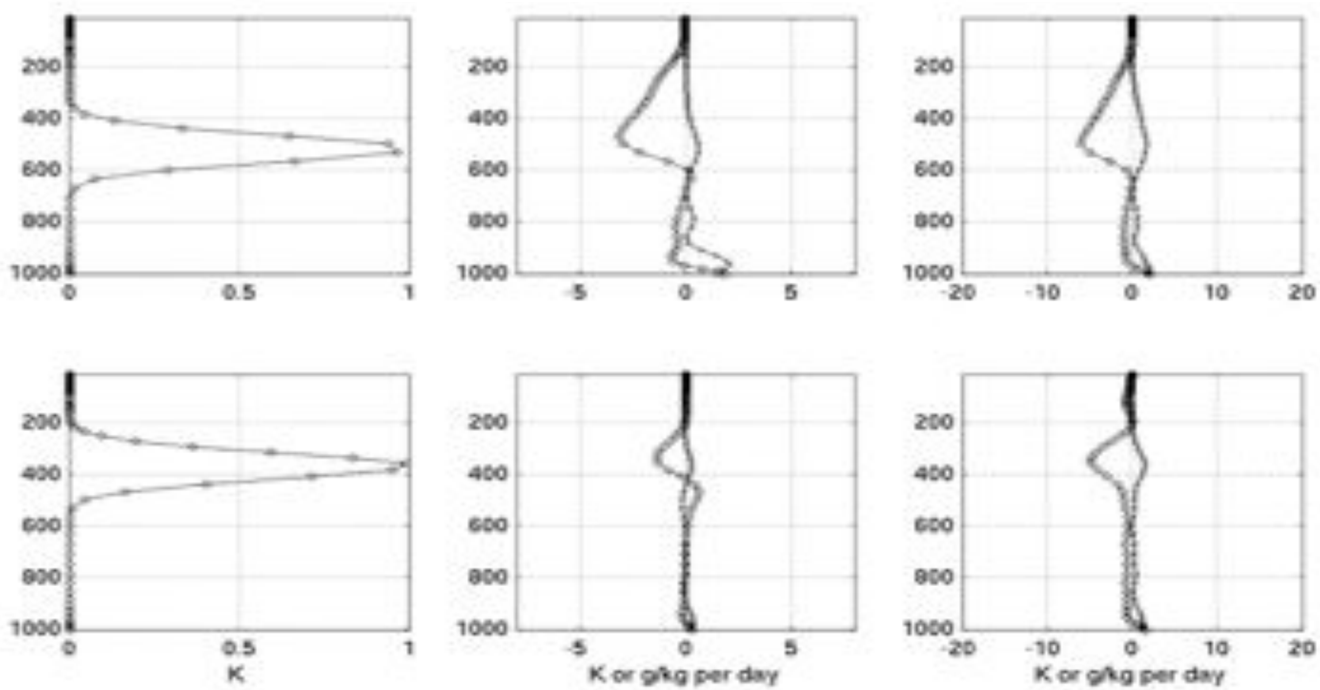
- Want *Q'* = { Q1'(p), Q2'(p) } as functions of thermo. sounding anoms *S* = { T'(p), qv'(p) }
- Method 1: direct, but from, not in eqm.
  - stimulus → response: create S', watch Q'(t)
  - ensemble for stat. robustness (48 in T&M)
- Method 2: inverse: uses (requires) linearity
  - S' = **F** Q' , Q' perturbed via forcing: *in* equilibrium
  - time is the statistical dimension: sustain Q'
  - Magical multilinearity: Q' = $\mathbf{F}^{-1}$ S'
  - S'(t) = S'(0) exp($\mathbf{F}^{-1}$t) can be compared to Method 1

Responses to midlevel T’

Method 1: stimulus and response ensemble mean (T&M 2009)

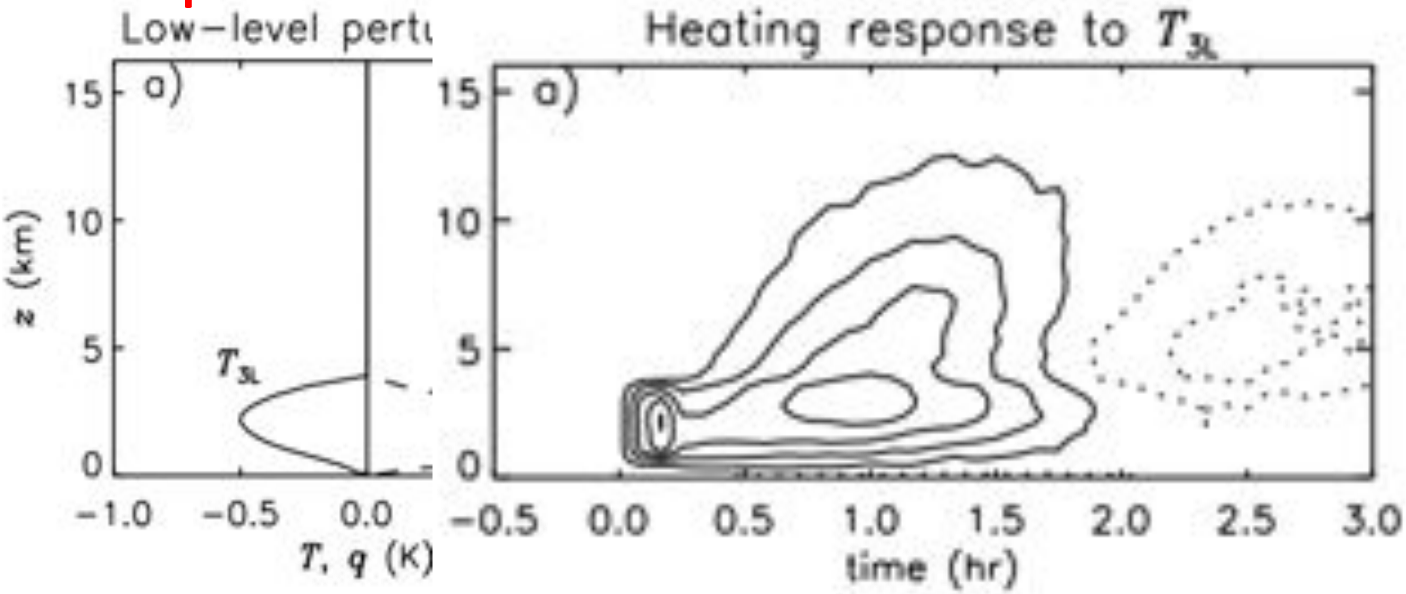


Method 2: Matrix inversion from long maintained forcing perturbations (Kuang 2009)



Responses to low level T'

Method 1: stimulus and response ensemble mean (T&M 2009)



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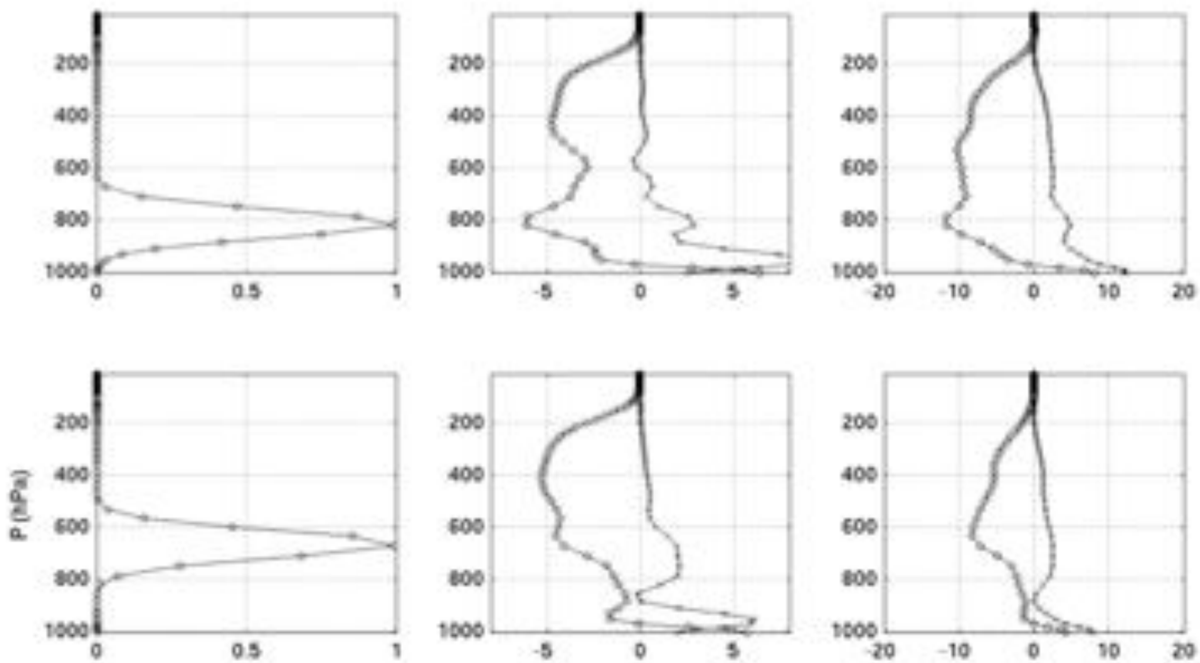
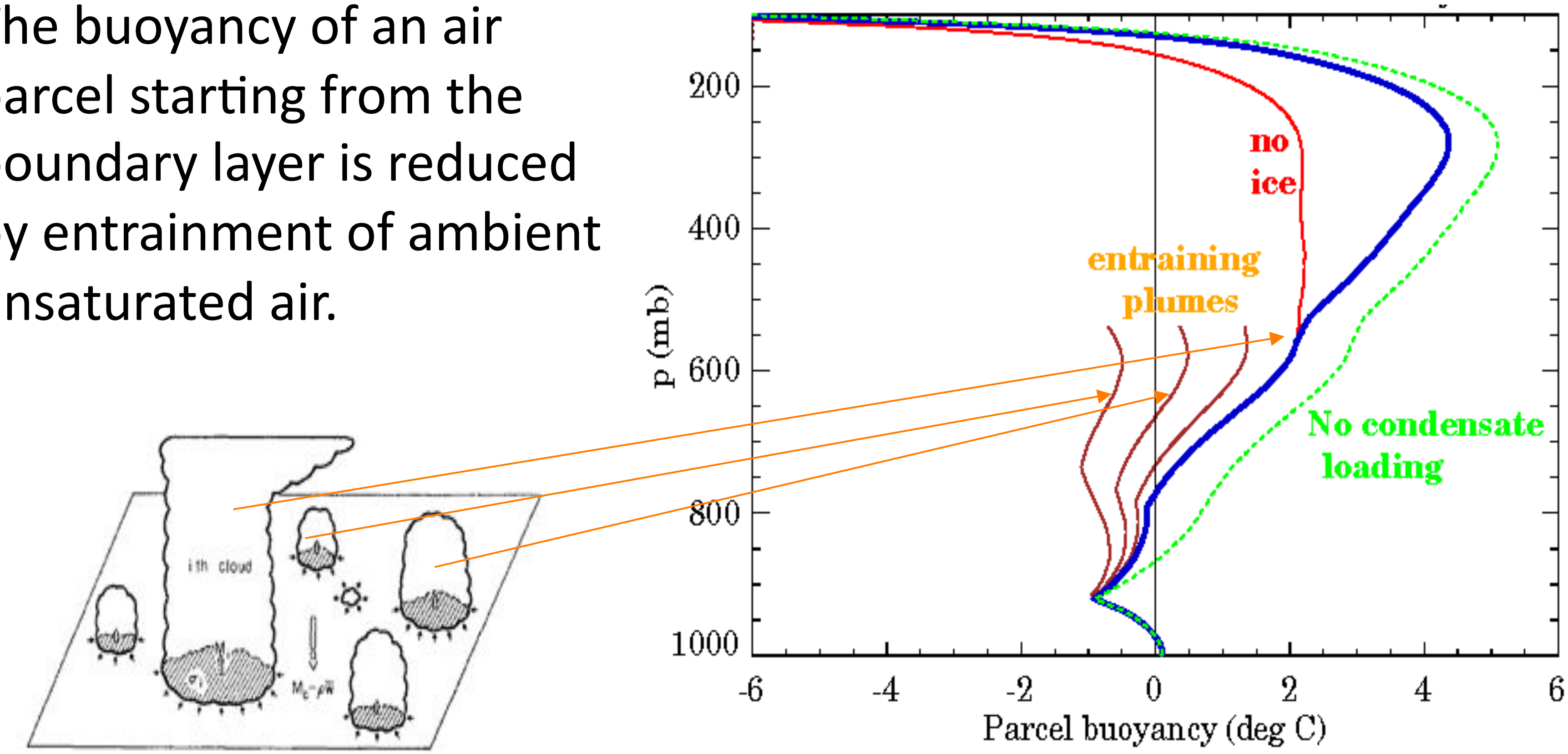


(personal) historical moment

- Two very old ideas: 2
- Parameterization idea from Y2K in Hawaii
  - Trying to devise buoyancy calcs for lifted air (w/ mixing etc. – thanks Dave R for codes) that can explain congestus clouds in obs. soundings
  - Impossible with usual entrainment treatments!
    - lower trop buoyancy weak – dilution kills it
    - upper trop buoyancy strong – hard to stop plume at midlevels without a lot of mixing
      - deny latent heat of freezing? maybe... sorta hokey though

Simple (constant) entrainment

COARE mean sounding: The buoyancy of an air parcel starting from the boundary layer is reduced by entrainment of ambient unsaturated air.



Arakawa and Schubert 1974

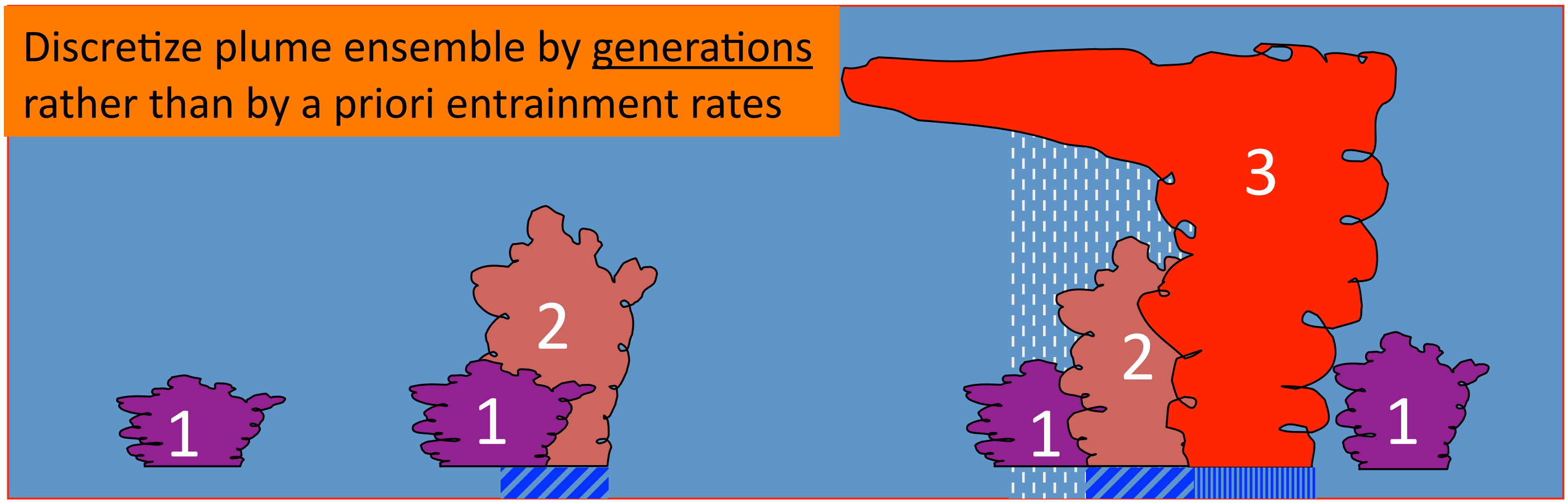
An Idea

- cloud **fields** are **organized**.
- Congestus may happen by entraining previous/ neighbor clouds as a low level boost, THEN starting to dilute with “env” to lose buoyancy at midlevels.

Contention:

The taller clouds aren't subject to less mixing, they just have a *positional* advantage

Yes to entrainment, but sometimes of non-average air



- All plumes entrain strongly. First clouds entrain clear air, so they provide needed sensitivity to qv, but are typically shallow.
- Later convection may entrain air pre-moistened by prior clouds.
- This gives deep clouds an indirect q dependence, but opens up questions of cloud-field organization.

This slide is about 10 years old! (Y2k)

Progress (decadal)

- Key sticking points passed this year
  - Steady state assumption
    - everything is a mass *flux*
      - no ‘area’ or ‘mass’ or ‘time’ to confuse me
      - just plumbing: plug detrainment from plume i into ent i+1
  - Picked up a specific, published, closed, *GCM implemented* entraining-detraining plume (Bretherton et al. 2004; Park&Breth 2009)

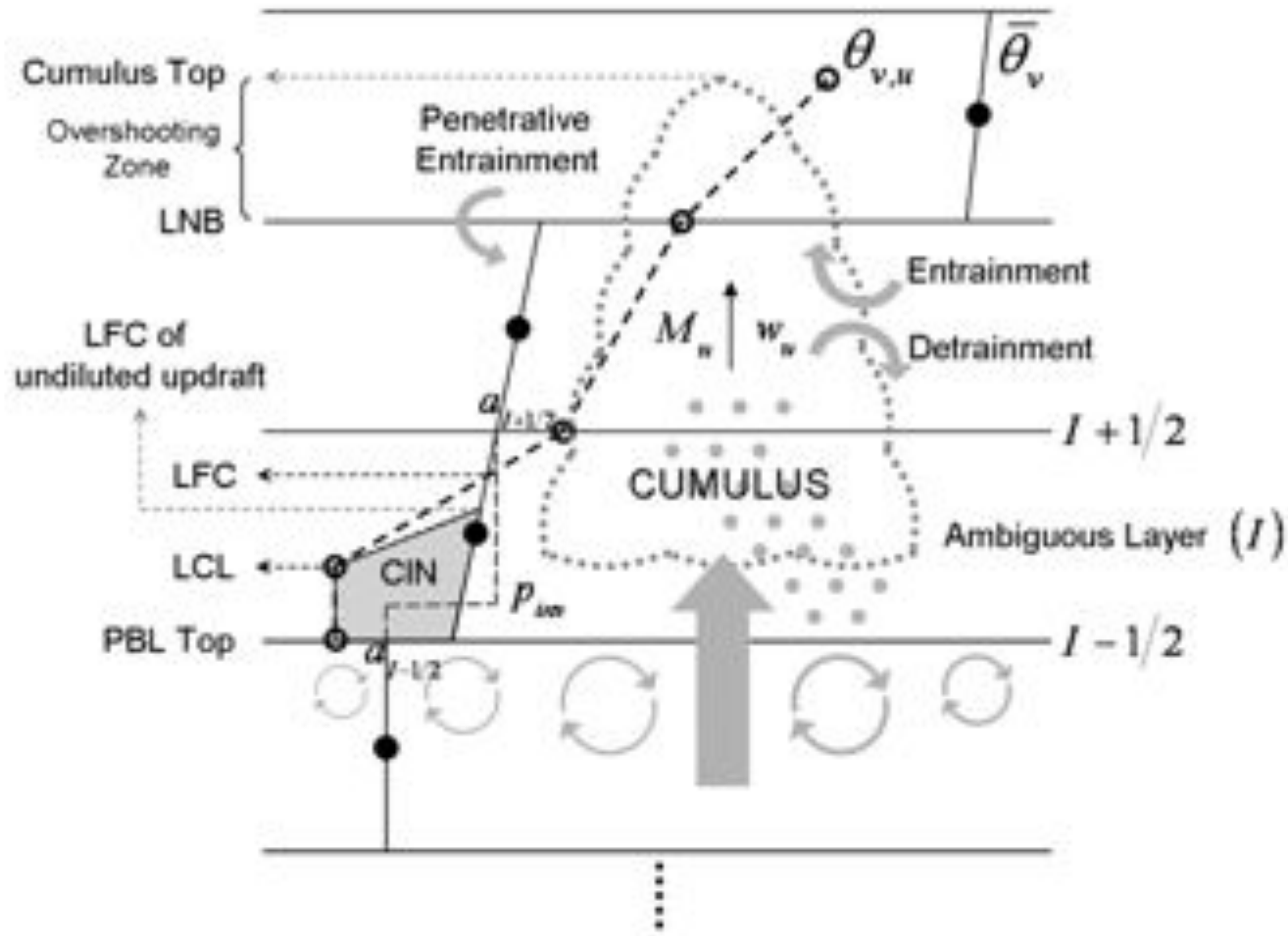
Steady state assumption: rad!

- "Unbiased", if not locally accurate

- Game-changer for tractability
  - prognosis = what arrays to define & carry in memory across time, how to decommission memory objects, how to conserve variables (open sys) -- ???

  - steady plume: conserve mass, mse, qtot, integrating upward to solve a timeless function of height
    - D/Dt ➔ w d/dz

Park, S., and C.S. Bretherton, 2009: The University of Washington Shallow Convection and Moist Turbulence Schemes and Their Impact on Climate Simulations with the Community Atmosphere Model. *J. Climate*, ***22, 3449–3469.***



ic structure of UW shallow cumulus scheme describing vertical evolution of a bulk cumulus updraft and

Gory details are happily all worked out!

Code tuned globally and optimized for performance.

Can I leverage it?

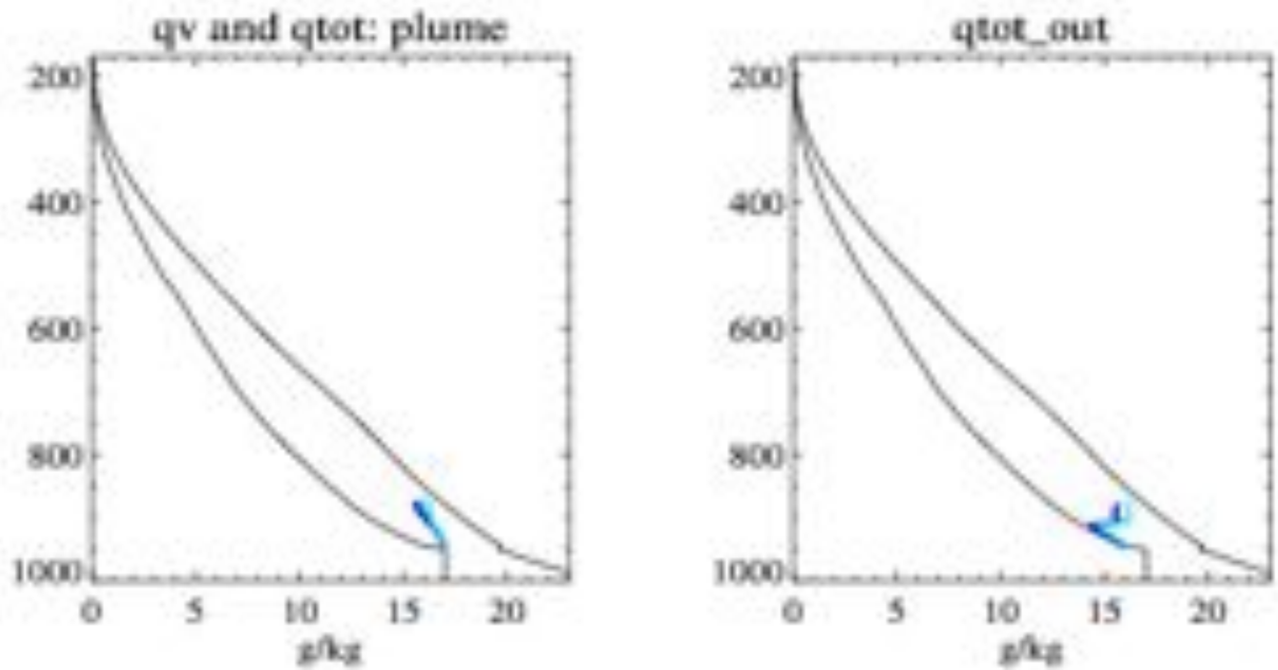
Details aside (til Seattle next week)

– I just wrap a loop around the plume computation, and pass plume i's detrainment (mass flux and thermo. properties) into the in-box for mixing for plume i+1

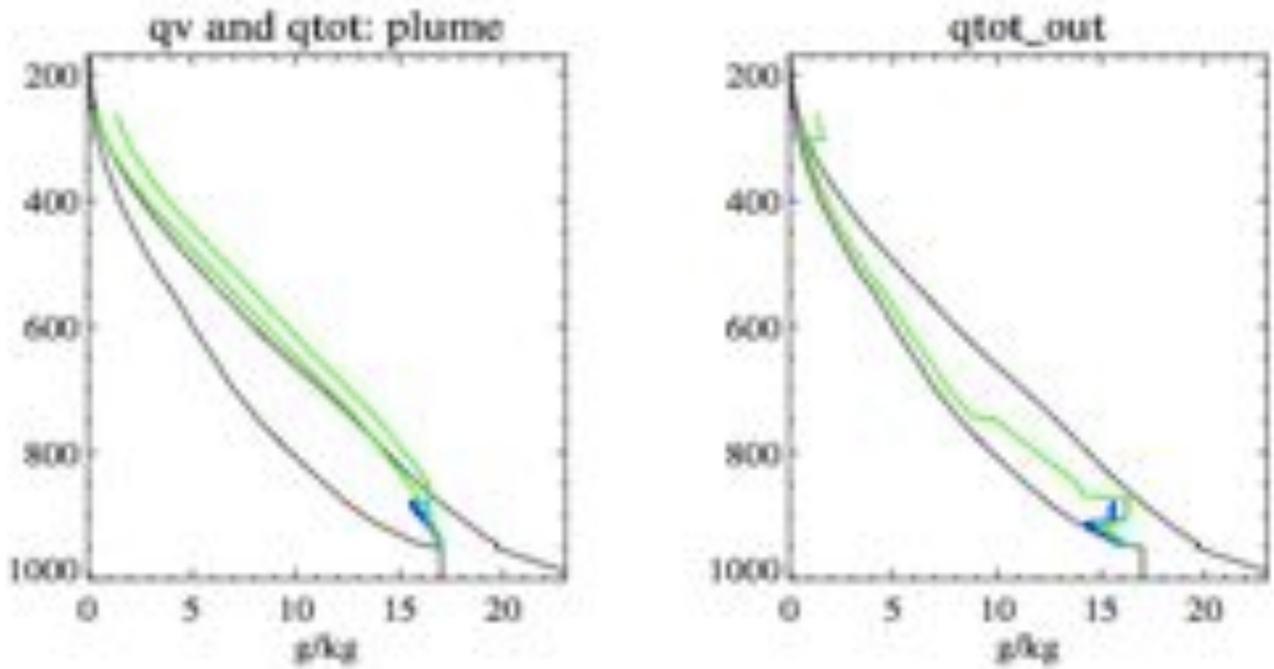
– After 1st plume, closure hinges on plume-plume interaction probabilites (overlap, or **organization**).


‘Organization’
Org = 1
Org = 0

$0 < org < 1$



qv and qtot: plume
qtot_out
200
400
600
800
1000
0
5
10
15
20
g/kg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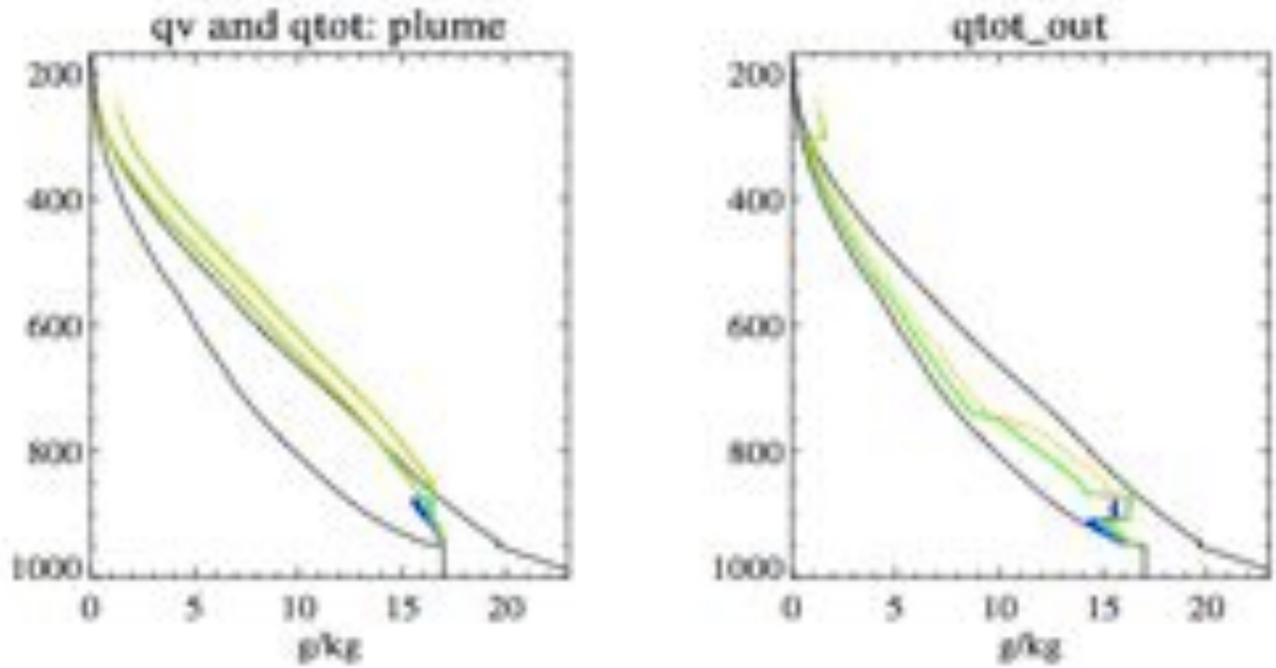

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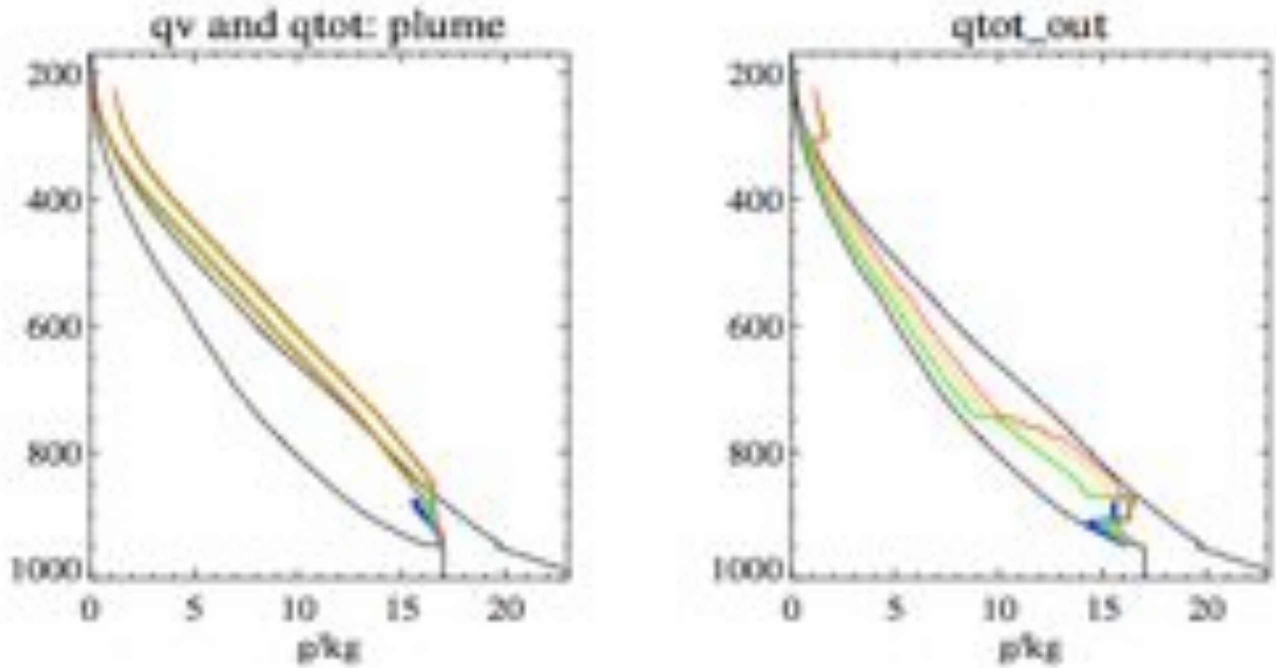

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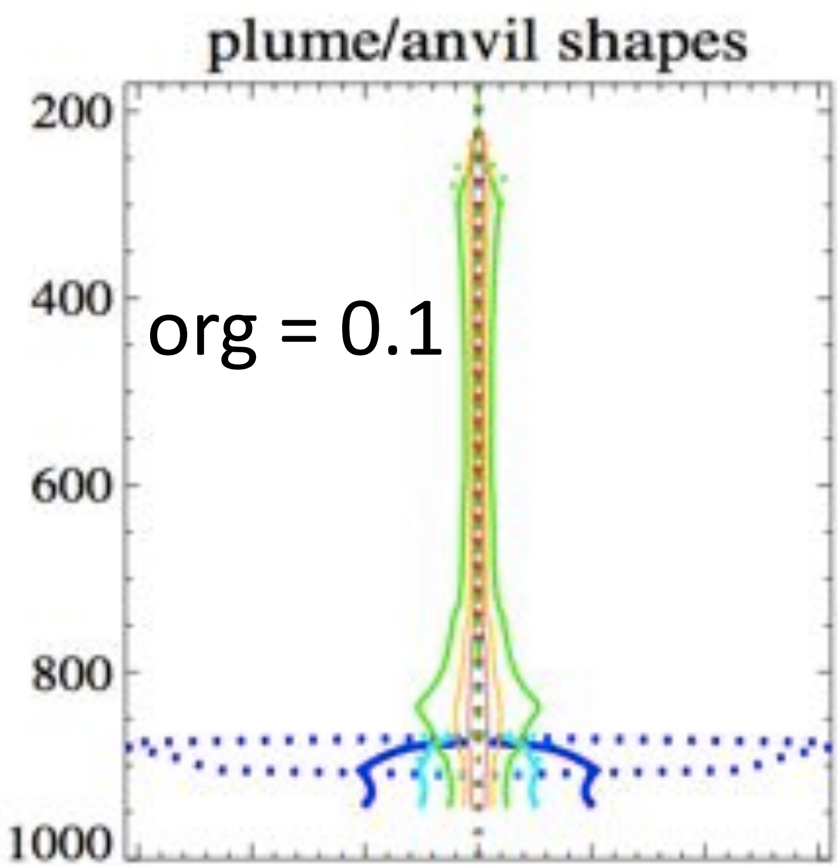
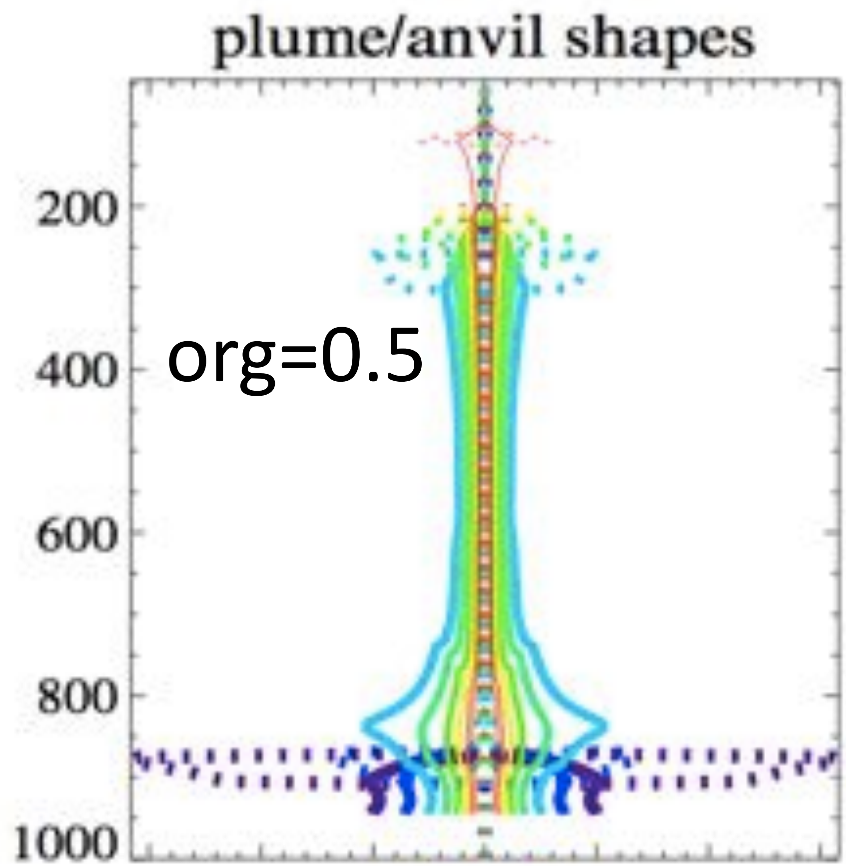
Effects of organization (= overlap)

in a given sounding with fixed assumptions

- Have M(p), w(p), so width(p) = $(M/\rho w)^{1/2}$





Effects of organization (= overlap)

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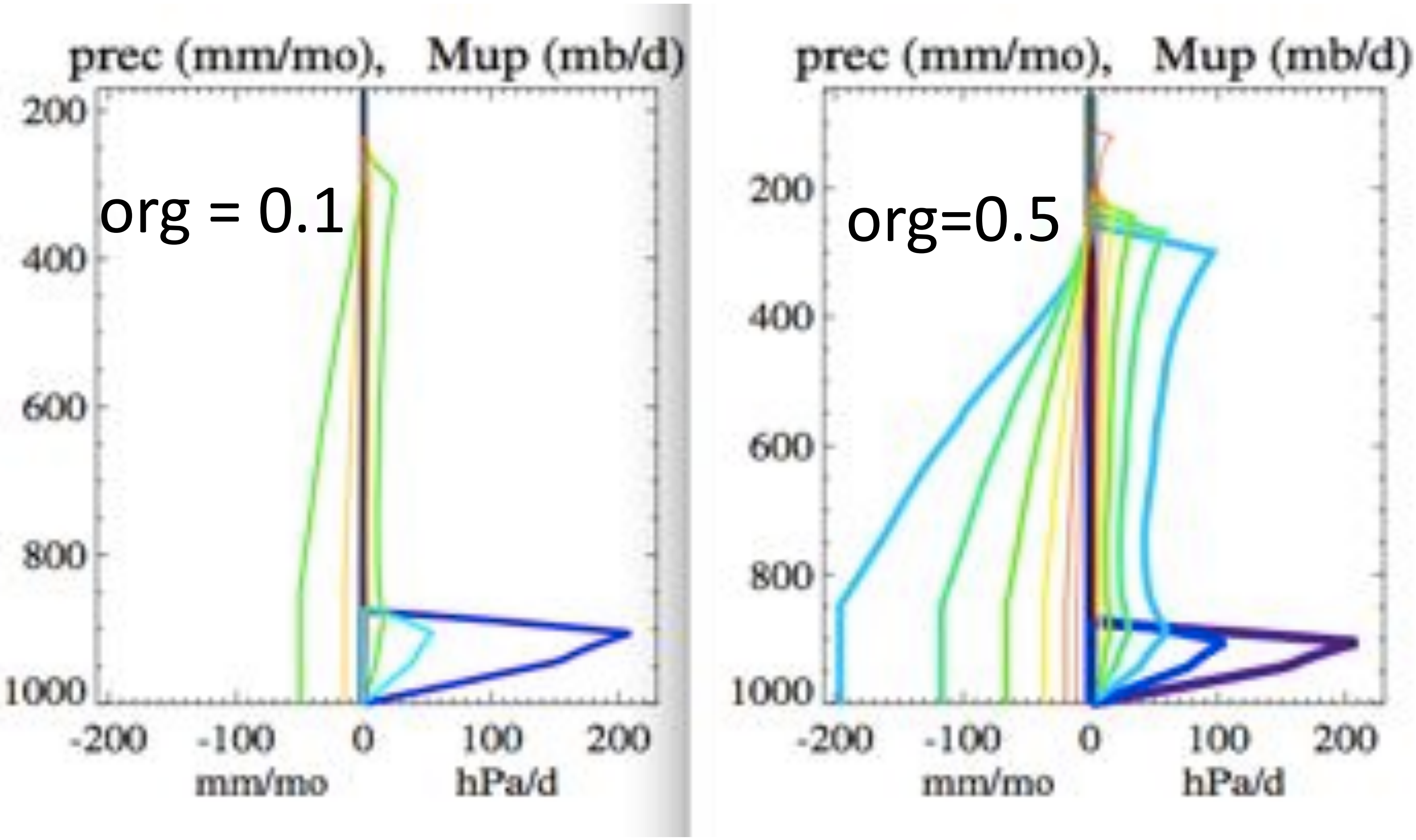
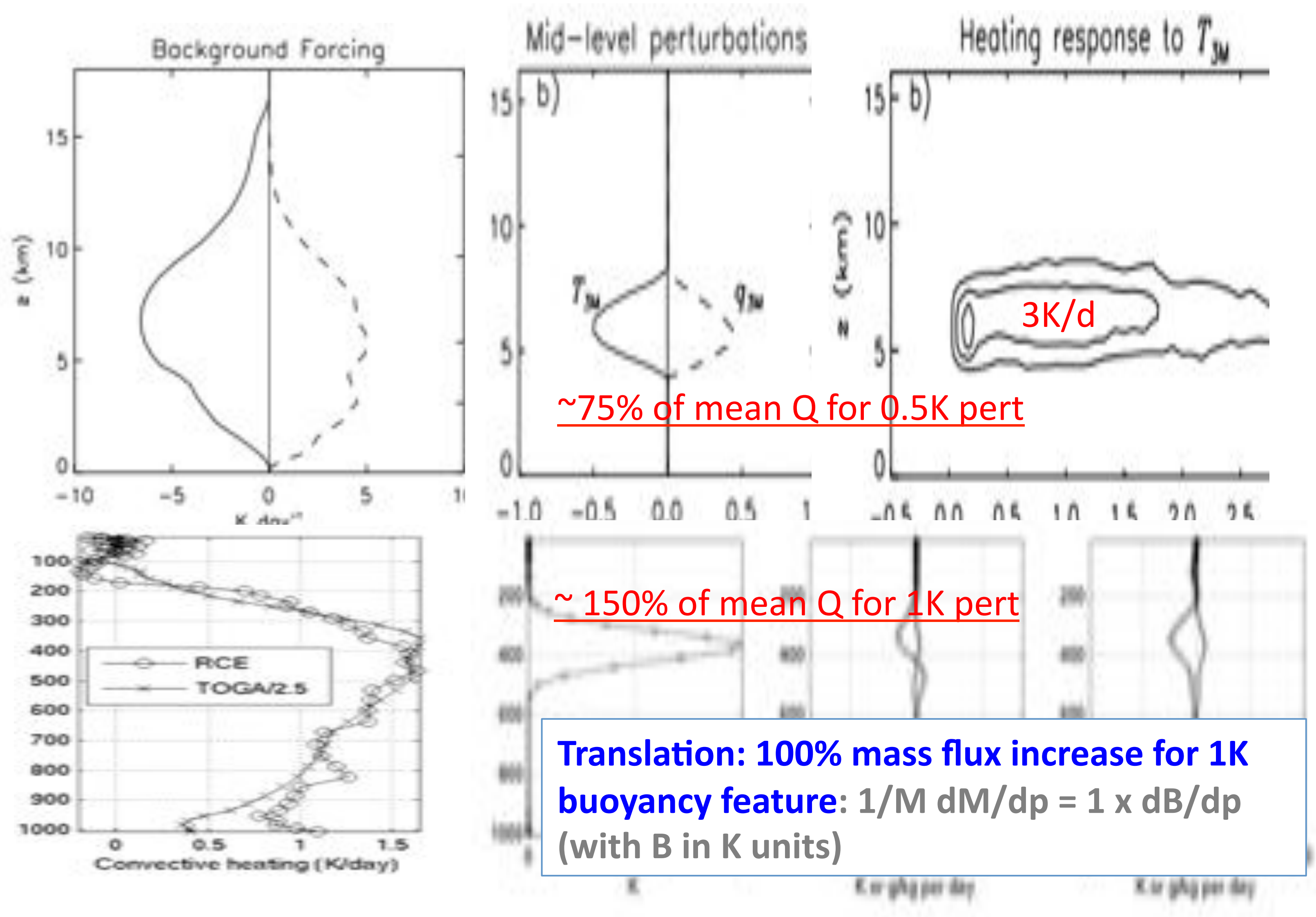


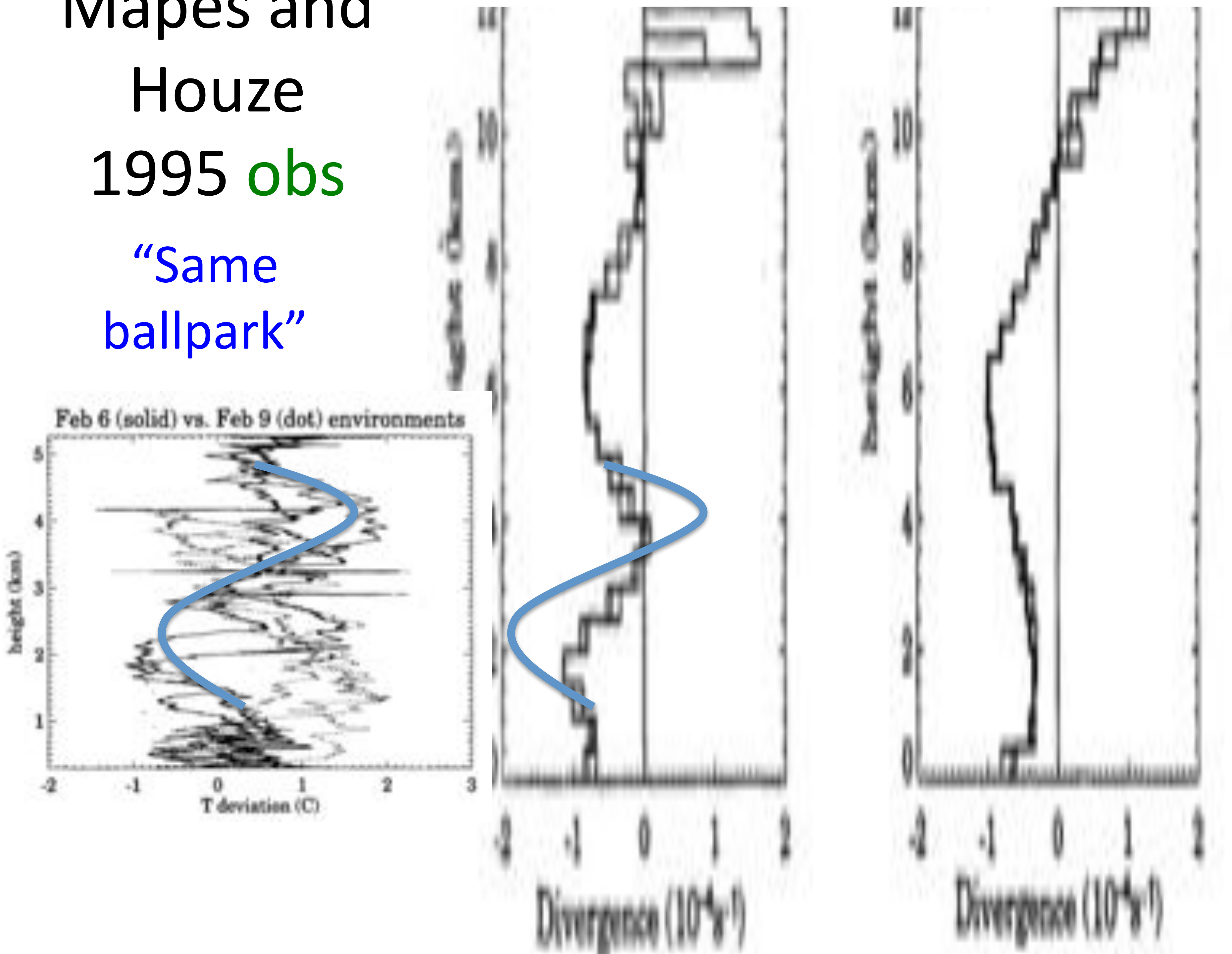
Back to sensitivities: constrain plumes?



Translation: 100% mass flux increase for 1K buoyancy feature: 1/M dM/dp = 1 x dB/dp (with B in K units)

Mapes and Houze 1995 obs

"Same ballpark"



Gravity Waves, Compensating Subsidence and Detrainment around Cumulus Clouds

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(Manuscript received 20 August 1987, in final form 16 June 1988)

Mechanism of dB/dz driven inflow

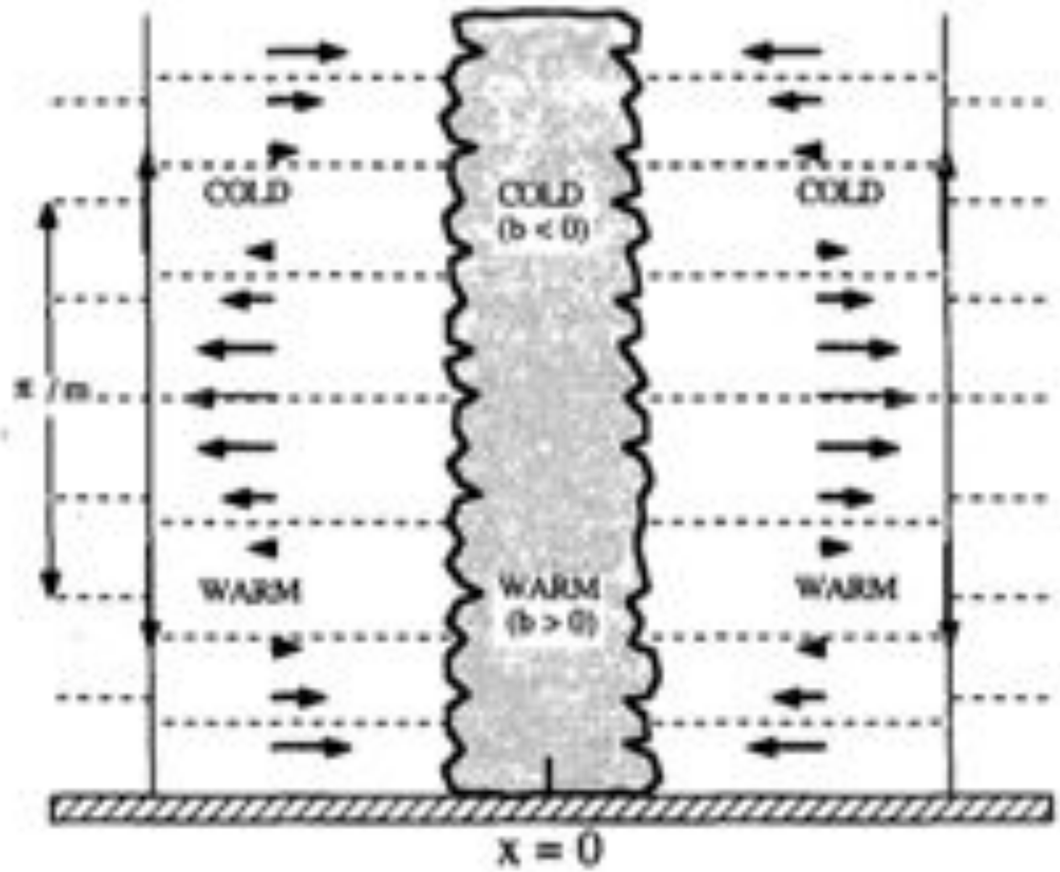

FIG. 6. The response to an idealized cloud maintaining a sinusoidal buoyancy perturbation in an atmosphere of uniform stratification.

Emanuel scheme mixing

Recent Modifications of the Emanuel Convective Scheme in the Navy Operational Global Atmospheric Prediction System

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Marine Meteorology Division, Naval Research Laboratory, Monterey, California

(Manuscript received February 21, 2003, in final form November 24, 2003)

DOI: 10.1175/1520-0493(2004)132<1254:RMOTEC>2.0.CO;2

undilute parcel buoyancy gradient plus a mixing term that depends on the vertical pressure depth of the model layer as in the following equation [Eq. (1) in EZ99].

$$\frac{\delta M_i}{M_b} = \frac{|\delta B_i| + \Lambda \delta p_i}{\sum_{j=1}^{N} (|\delta B_i| + \Lambda \delta p_j)}. \qquad (1)$$

Here δM_i is the mass flux of undilute air from the cloud source level that mixes with the environment at level i (mixing cloud

Based on the preceding considerations, a preliminary alternative treatment was adopted in NOGAPS for the mixing cloud mass flux in the Emanuel scheme. In this approach the undilute parcel buoyancy gradient in (1) is replaced with the undilute parcel buoyancy. Thus

$$\frac{\delta M_i}{M_b} = \frac{|B_i| + \Lambda \delta p_i}{\sum_{j=1}^{N} (|B_j| + \Lambda \delta p_j)}. \qquad (4)$$

Emanuel scheme mixing change

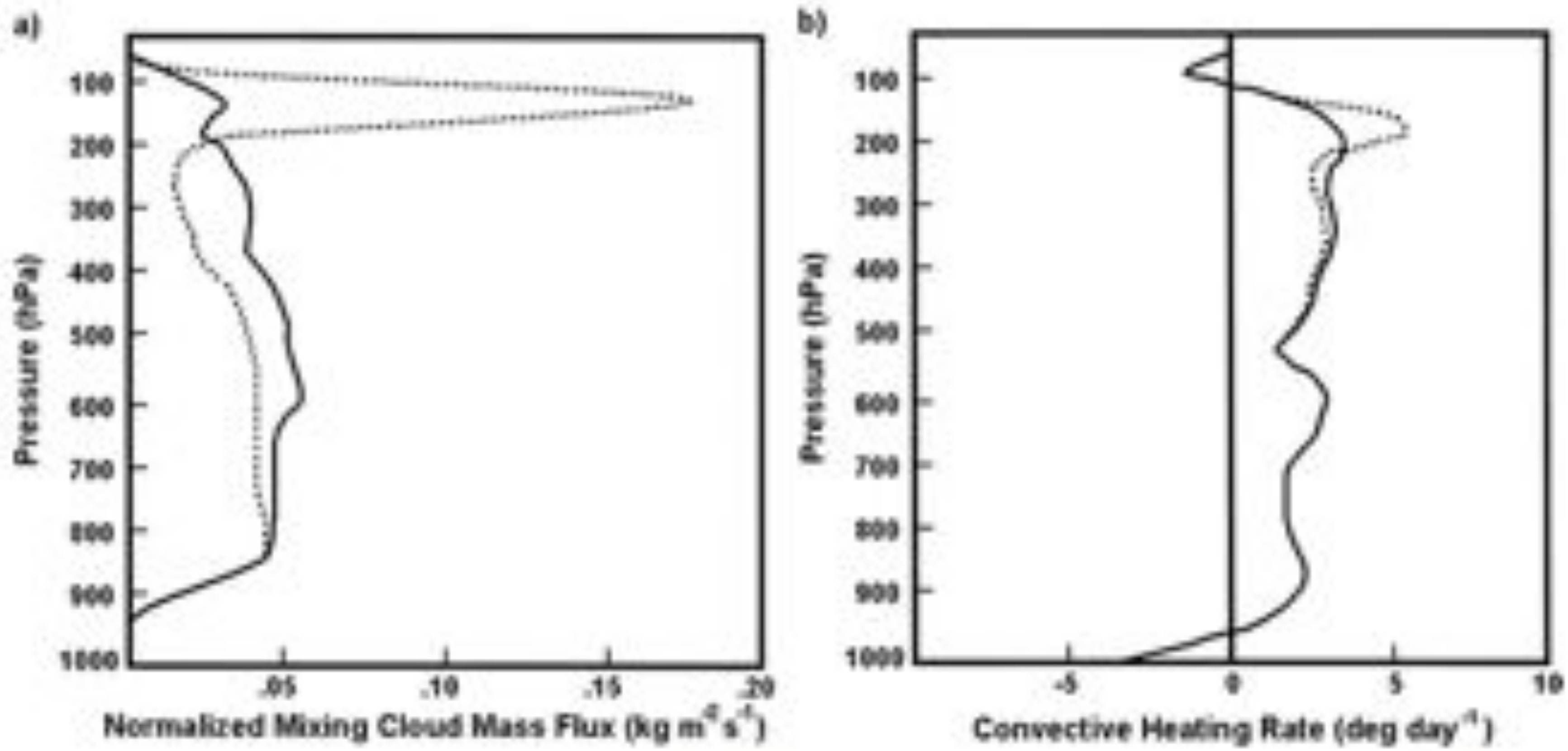

Fig. 5. (a) Mean mixing cloud mass flux profile (kg m^{-2} s^{-1}) and (b) mean convective heating profile (°C day^{-1}) predicted by the Emanuel scheme (dashed line) and the Emanuel scheme with modified mixing parameterization using (4) (solid line) in semiprognostic tests for 1 Nov–31 Dec 1992 for the TOGA COARE IFA region

Large-scale (strategic) goals

- Subgrid assumptions exist to serve GCMs, not other way round!
- Evade familiar old entrainment dilemma
  - make conv. sensitive to dryness but not overdilute
- Manage shallow to deep transition better
  - continuous, contingent
    - e.g. diurnal cycle developmental delay
    - stats of transition probability, in larger-scale waves

Summary

- Sensitivities of convection now well mapped w/CRMs, in / near equilibrium
  - 2 studies, different methods, similar results
    1. Wonderfully (multi)linear
       - but not deterministic, and background dependent
    2. Vertically local part: anomalies are damped
       - e.g. mass flux bump ~100% of bkgd. for ~1K T bump
         » implies net entrainment - net detrainment couplet
    3. Nonlocal*: low level* anomalies affect *deep* convection
       - "effective inhibition layer" ~ 4km deep
       - q' has more upward impacts than T'
       - nonlocal part stronger when background convxn is weaker

Summary

- Sensitivities of convection now well mapped in CRMs, in / around equilibrium
- Re yesterday (is the MJO a moisture mode?)
  - Sensitivity to T' and q' about equal, for T'/q' ratios appropriate to waves (vertical displacements)
    - This disp.-like ratio of T' to q' is in fact observed for high frequency fluctuations
    - Joint 'moisture-stratiform insty' (Kuang 2008)
  - For lower freq (MJO), q' is relatively much bigger
    - *MJO convection anomalies dominated by q'*

Summary

- Param’z’n idea finally coming to fruition: interacting plumes
  - wrapped Breth et al. plume in a loop (offline, IDL) & can close the problem in pretty satisfying terms, I think – details on request (not written up)
  - several parameters to tune – but sensitivity work gives many relevant pieces of information
  - opens door to ‘organization’ of convection as a meaningful part of GCM phenomenology


help wanted (avail. immed.)
Miami
ROSENSTIEL SCHOOL