A Convection Scheme for CAM6

AMWG Meeting

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AMP. CGD. NCAR

- Some important ‘features’ (possibly) associated with convection scheme
  - Double ITCZ
  - Unrealistic timing and intensity of convective precipitation (e.g., diurnal cycle)
  - Too rapid transition from stratocumulus to cumulus along the subtropical transect
  - Biases of water vapor & clear sky LW radiation (?)
  - Too strong subtropical high in summer (?)
  - Too strong hydrological cycle (?)
  - Monsoon
  - Lack or weak MJO
  - Climate sensitivity of cirrus clouds
  - Many other features since ‘convection’ is the ‘pump’ of the atmospheric circulation

- Limitations in Current Convective Parameterizations

I. Convective updraft does not have a time memory

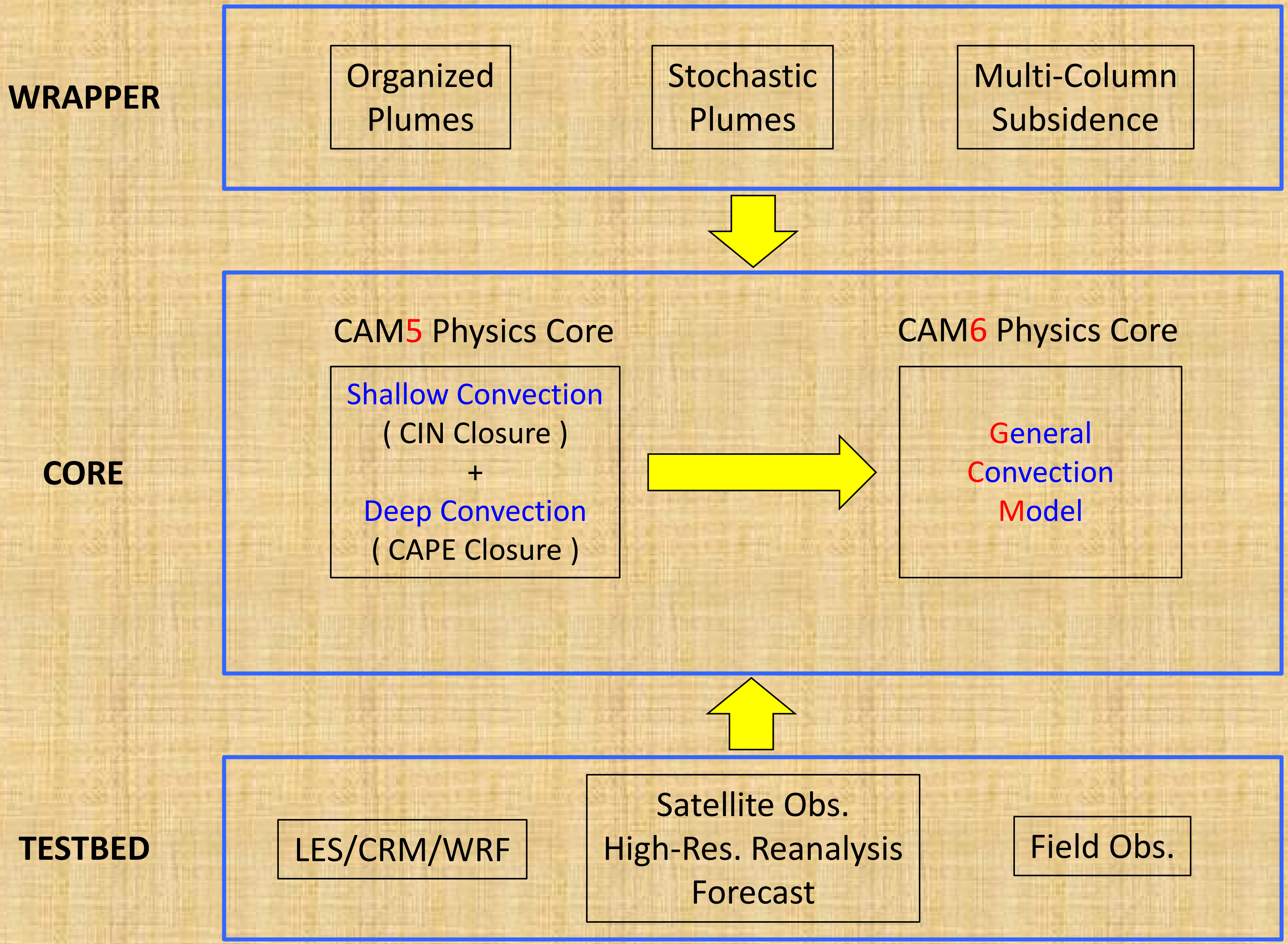
: Quasi-steady convective updraft plume

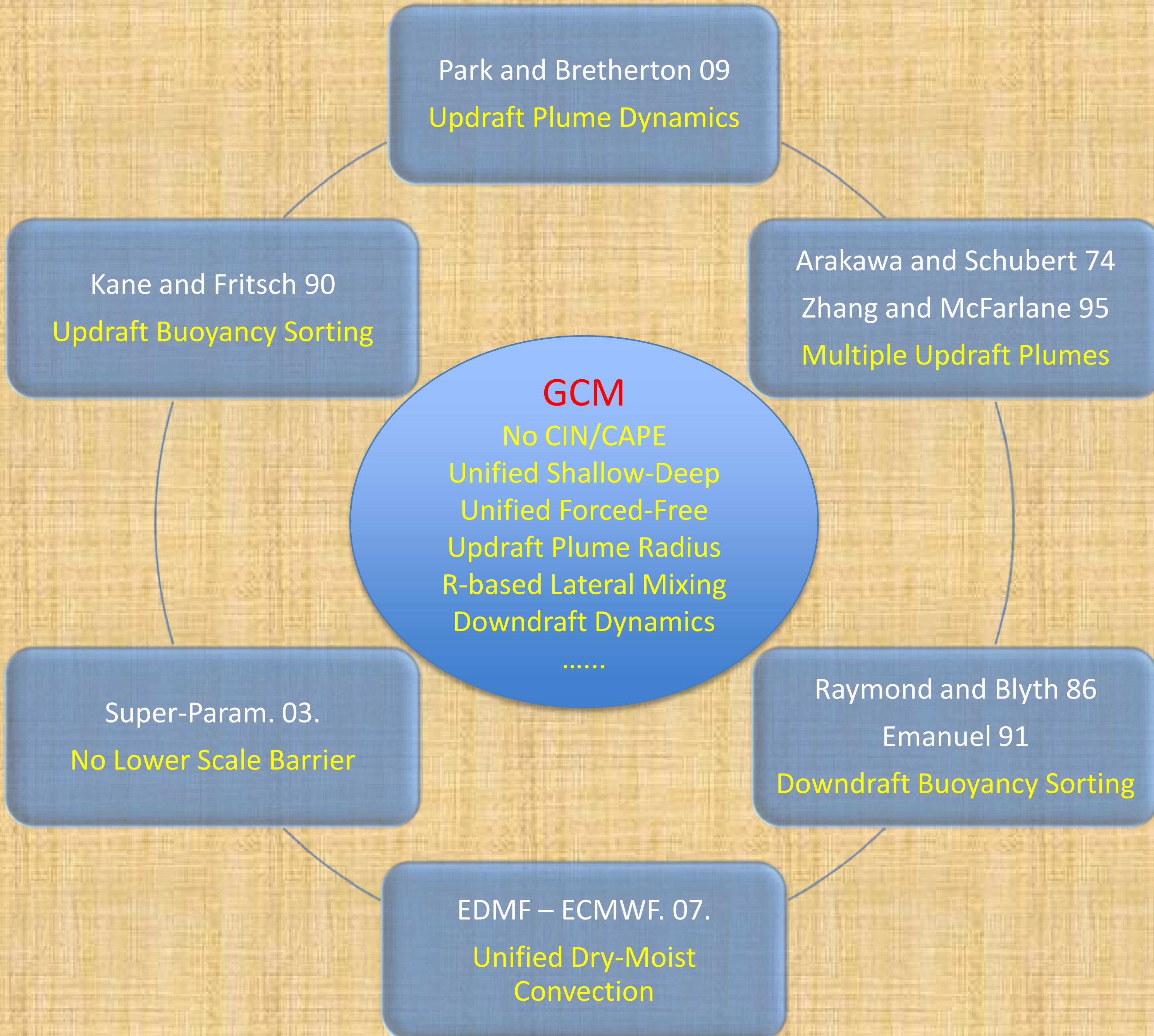
II. Compensating subsidence entirely exists within the same column as the convective updraft

: a << 1 (a : convective updraft fractional area)

III. Other 'tangible' parameterization issues

1. Unified treatment of '*shallow*' and '*deep*' convection
2. Unified treatment of '*dry*' and '*moist*' convection
3. Unified treatment of '*forced*' and '*free*' convection
4. Treatment of *downdraft dynamics*
5. Parameterization of *lateral mixing*
6. 2-moment *cumulus microphysics interacting with aerosols*
7. The *vertical overlap of convective cloud* for radiation, evaporation of precipitation, and wet scavenging of aerosol


WRAPPER
Organized Plumes
Stochastic Plumes
Multi-Column Subsidence
CORE
CAM5 Physics Core
Shallow Convection
(CIN Closure)
+
Deep Convection
(CAPE Closure)
CAM6 Physics Core
General Convection Model
TESTBED
LES/CRM/WRF
Satellite Obs.
High-Res. Reanalysis
Forecast
Field Obs.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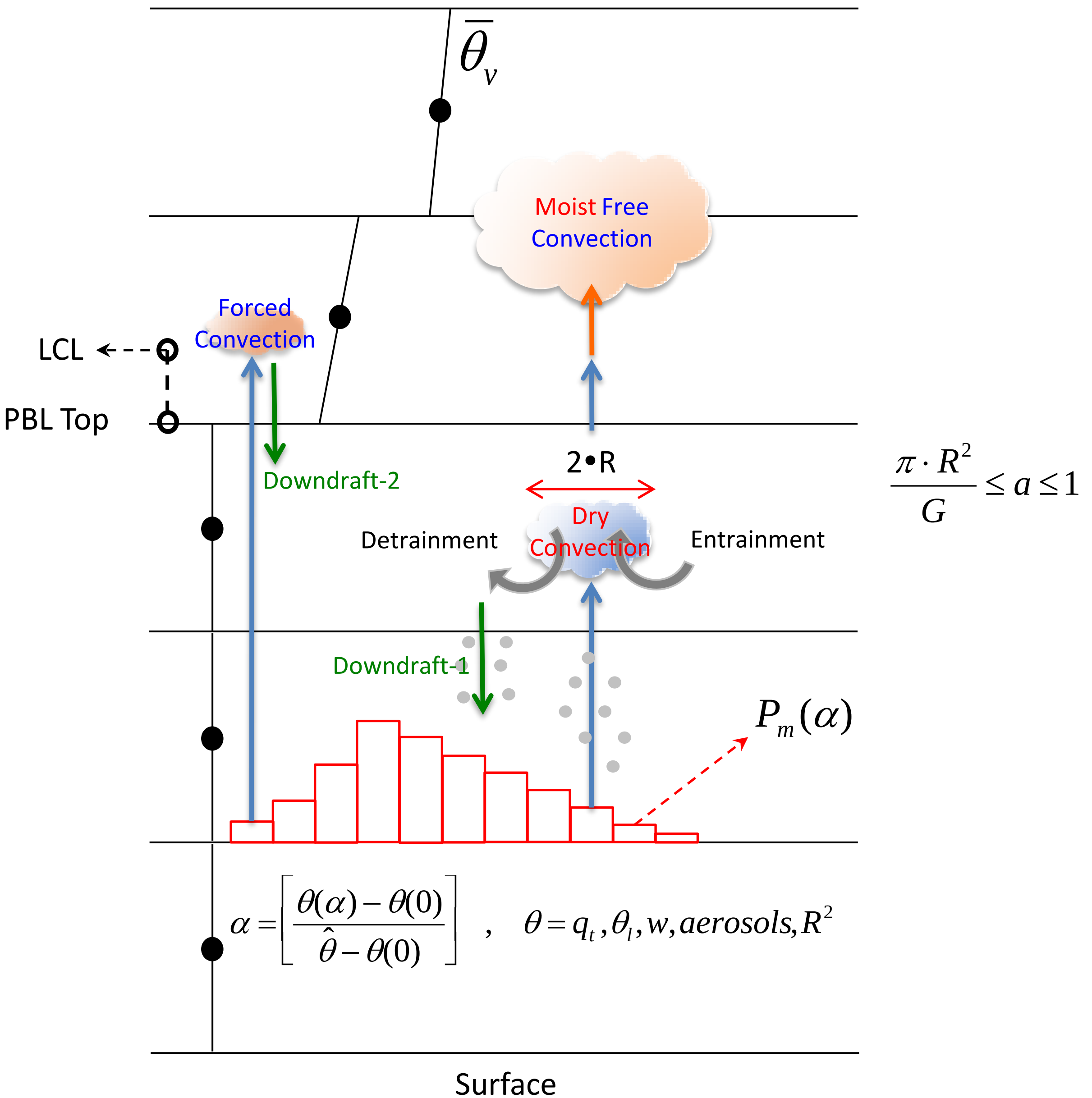
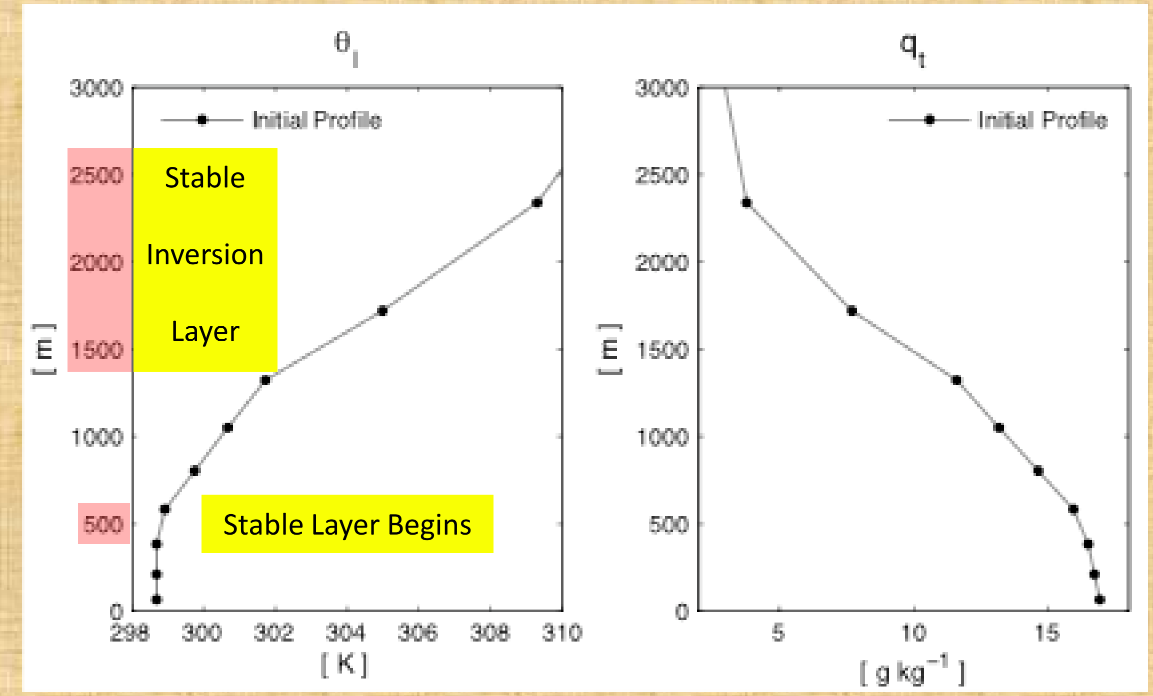
……

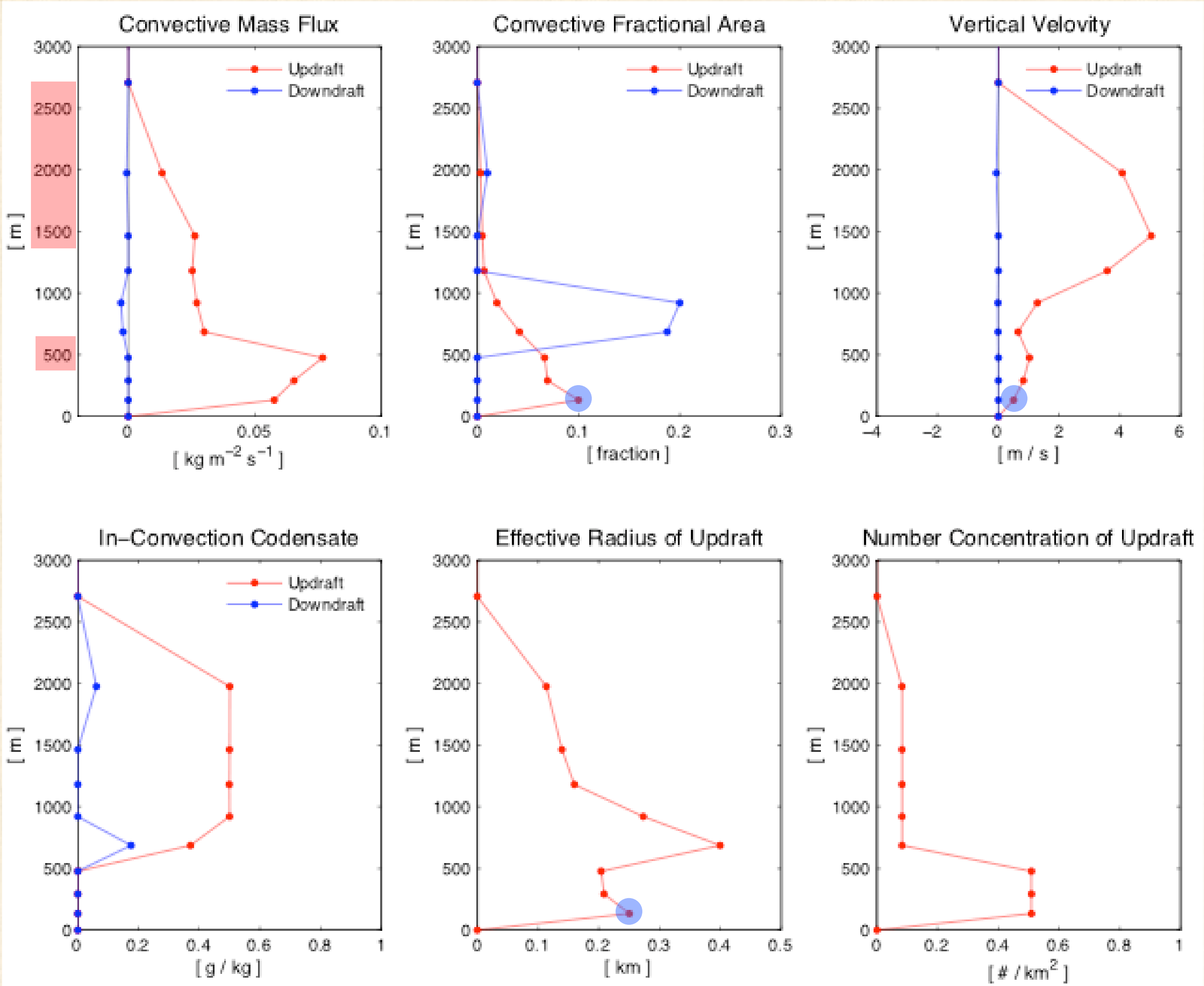
General Convection Model



Sample Initial Profile

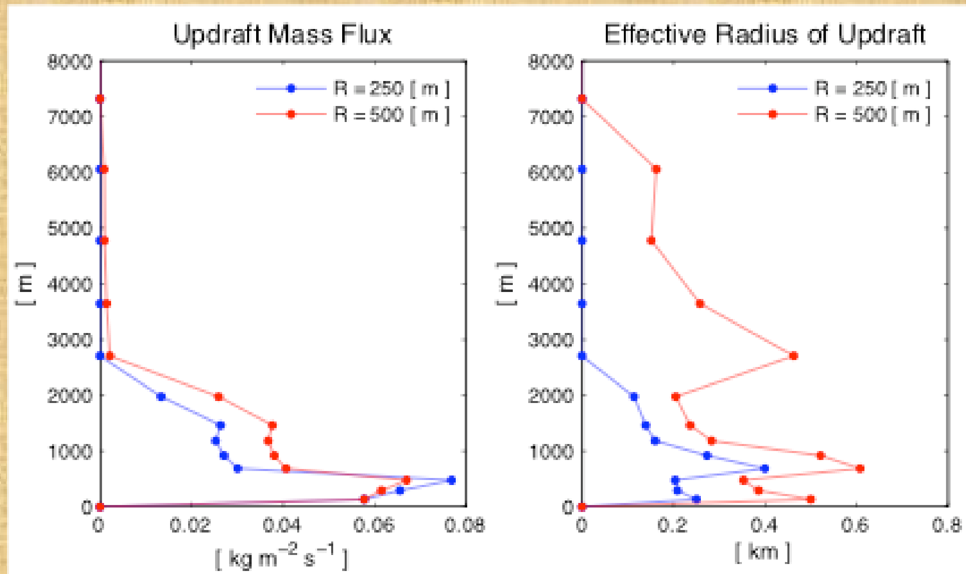


$a_u = 0.1, \quad w_u = 0.5 \text{ [m s}^{-1}\text{]}, \quad R_u = 250 \text{ [m]}$

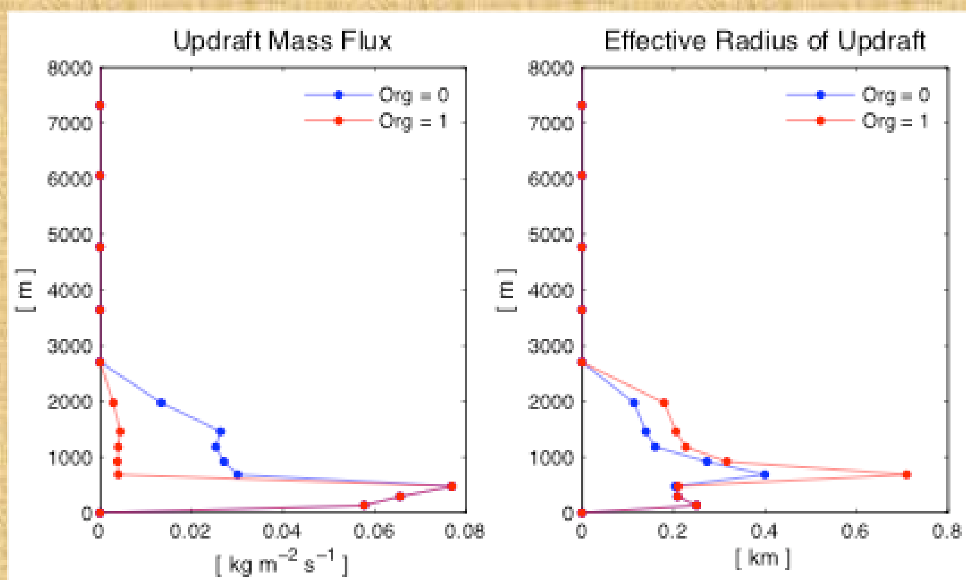


Transition from Shallow to Deep Convection

Sensitivity to Plume Radius



Sensitivity to Organization



" Breaking the Cloud Parameterization Deadlock "

by David Randall, Marat Khairoutdinov, Akio Arakawa, Wojciech Grabowski. BAMS. 2003.

We should be asking ourselves: *Is it really possible to parameterize all of this complexity with quantitative accuracy?* Work on cloud parameterizations for large-scale models began about 40 years ago (Fig. 8). Collectively, we, the authors of this paper, have been working on the problem for almost a century. Are we having fun yet? Definitely yes. Cloud parameterization is a beautiful, important, infinitely challenging problem, and we continue to be fascinated and excited by it. We and the other members of our research community have made important progress, of which we should be proud, and we have no doubt that progress will continue. Nevertheless, a sober assessment suggests that with current approaches the cloud parameterization problem will not be "solved" in any of our lifetimes.

Sungsu Park wants to prove that
he is investing his whole life to something that is worthwhile to do.

Major Remaining Issues in the Parameterization of Convection

I. Unified Treatment of Shallow and Deep Convection

II. Unified Treatment of Dry and Moist Convection

III. Unified Treatment of Forced and Free Convection

IV. Treatment of Downdraft Dynamics

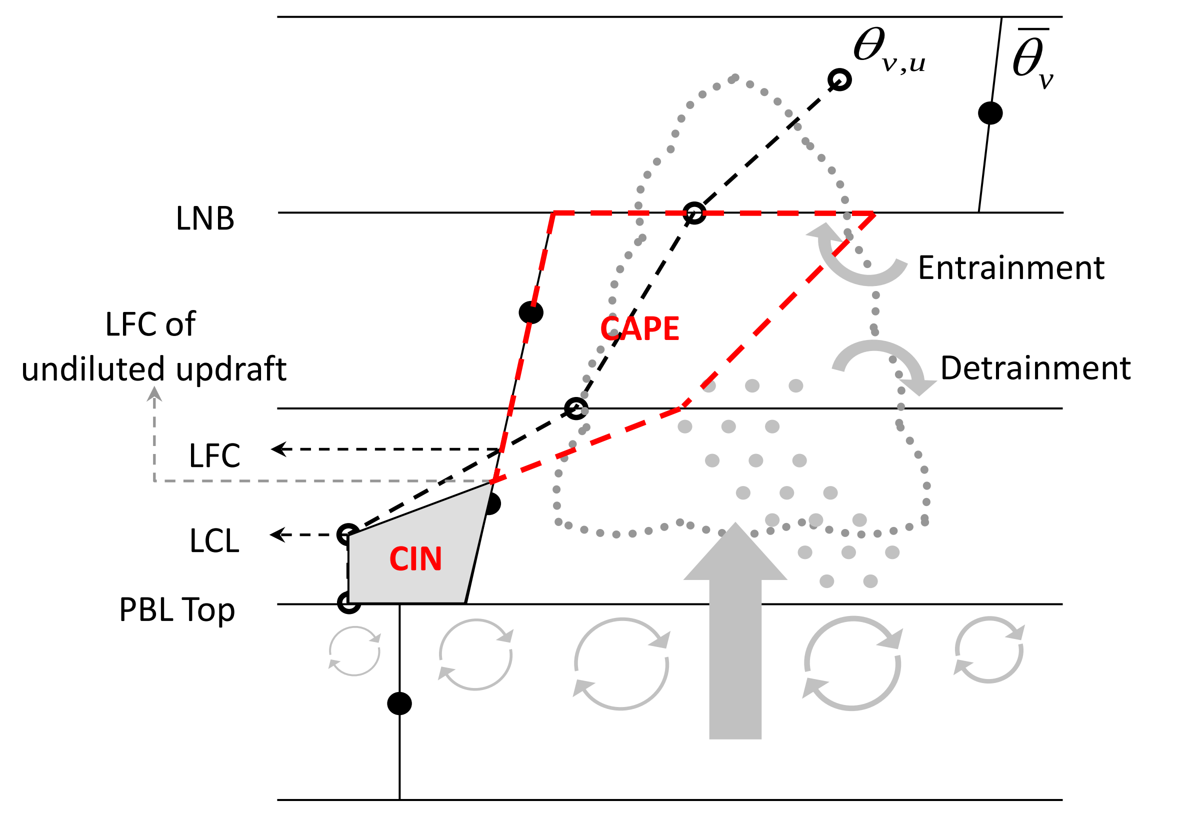
I. Parameterization of Lateral Mixing

II. Convection across the Scale Barrier

III. Cloud Overlap for Microphysics, Radiation, and Aerosol Wet Deposition

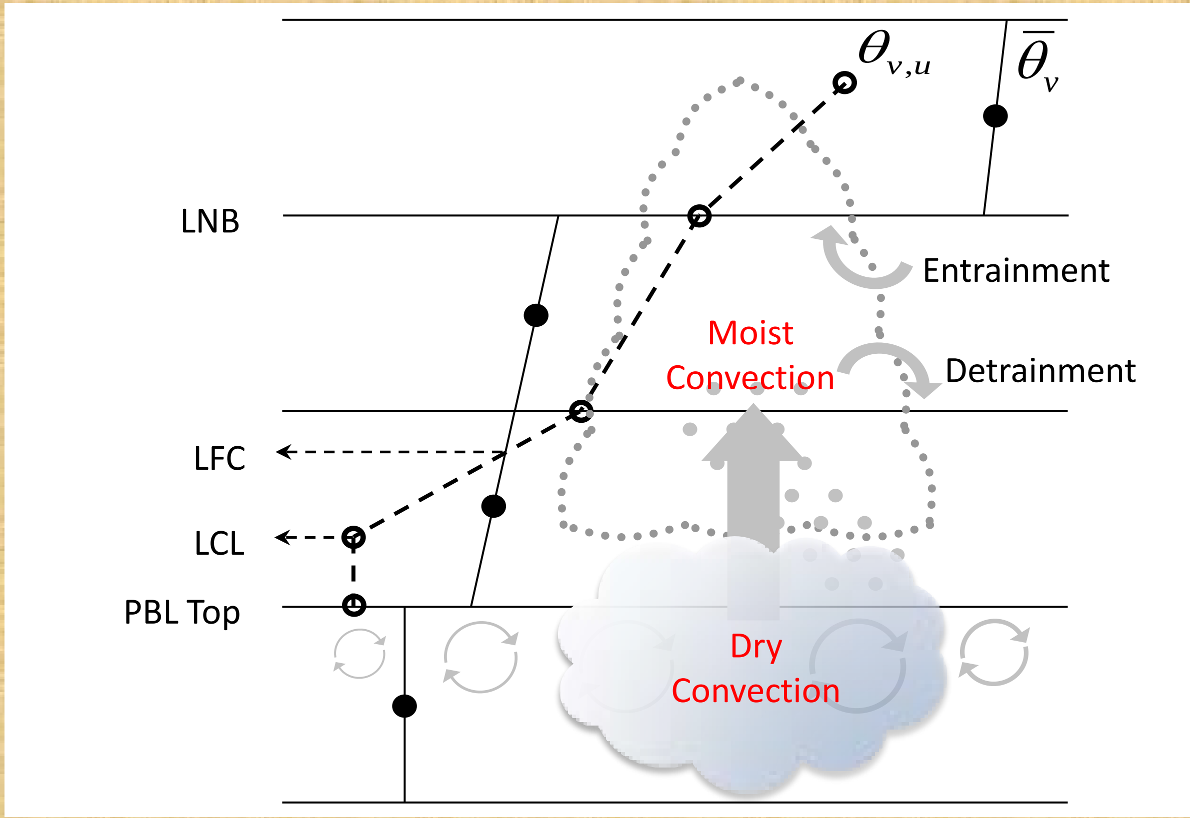
IV. Microphysics interacting with Aerosols

Unified Treatment of Shallow and Deep Convection



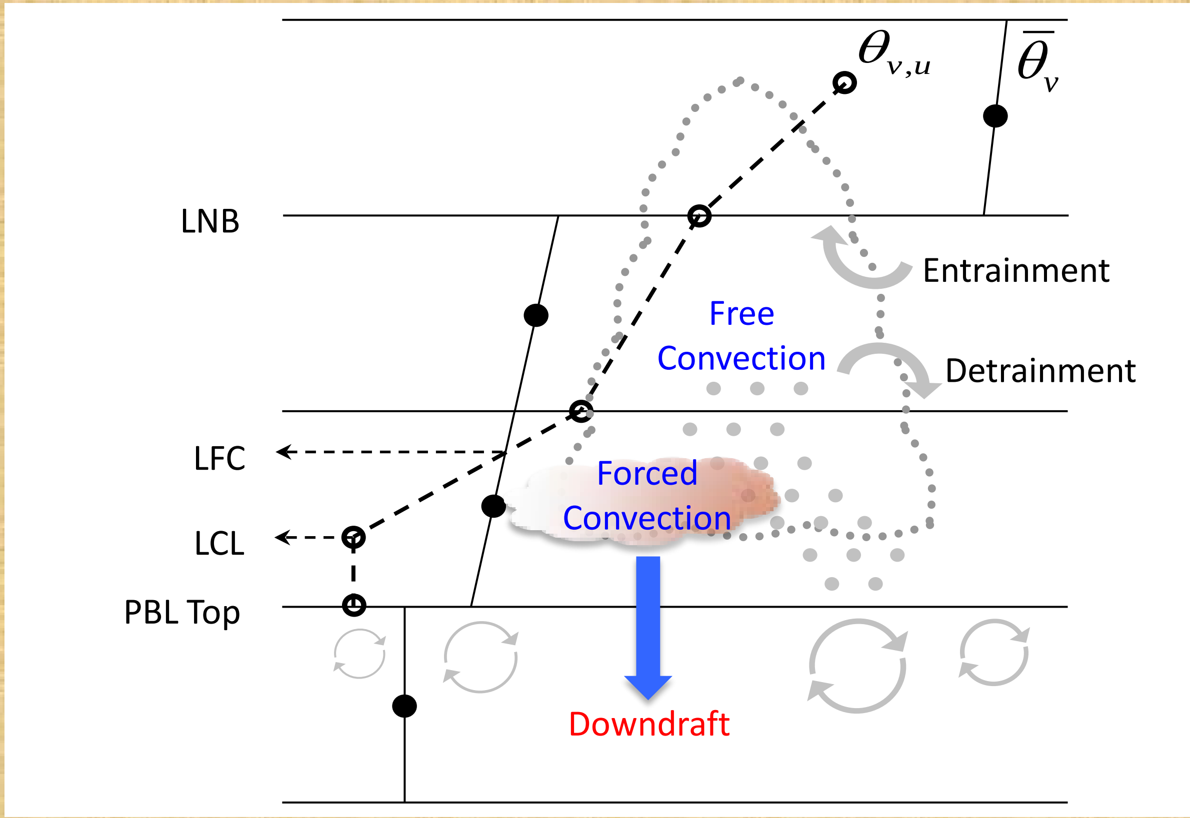
- Cloud *base* mass flux is computed from CIN for shallow and CAPE for deep convection.
- However, convection embryo should not know what is happening in the upper air (where CAPE is computed) before it reaches there. This issue of ' *the violation of time history* ' also arises to CIN closure when the convection rises from the lower PBL.
- *The real convection scheme*
    1. should not have any closures based on CIN/CAPE.
    2. should resolve different sizes of shallow (small R) and deep (larger R) convection.

Unified Treatment of Dry and Moist Convection



- *Cumulus* (i.e., moist convection) *is merely a visualization* of dry convection from below. There is no reason why the god assigns different physics on the dry and moist convection.
- However, in the CAM4, dry convection is incompletely treated in the PBL scheme (e.g., no non-local transport) while moist convection is treated in the convection scheme.
- *The real convection scheme*
  1. should be able to treat both the dry and moist convection in the same way.

Unified Treatment of Forced and Free Convection



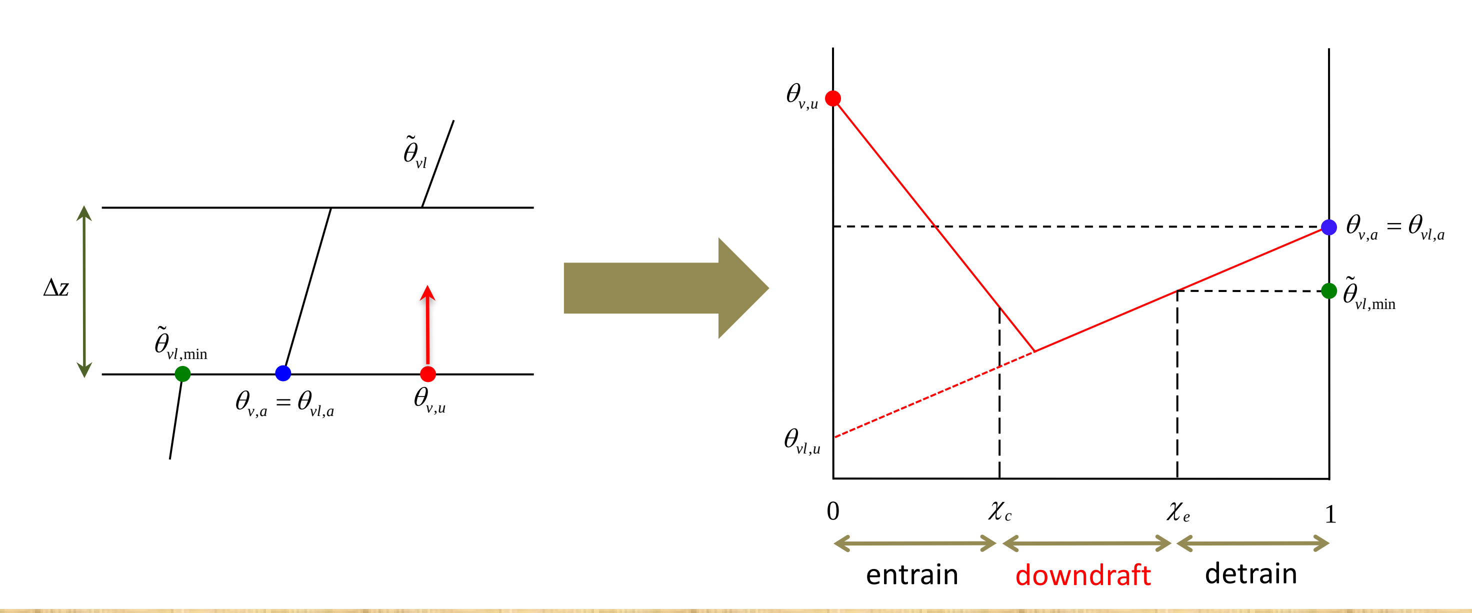
- Current convection schemes can only handle free convection. Weak convection with negative buoyancy near the PBL top (e.g., forced convection) cannot be handled.

- *The real convection scheme*
    1. should be able to treat forced convection,
    2. which requires general treatments of '*multiple plumes*' and '*downdraft dynamics*'.

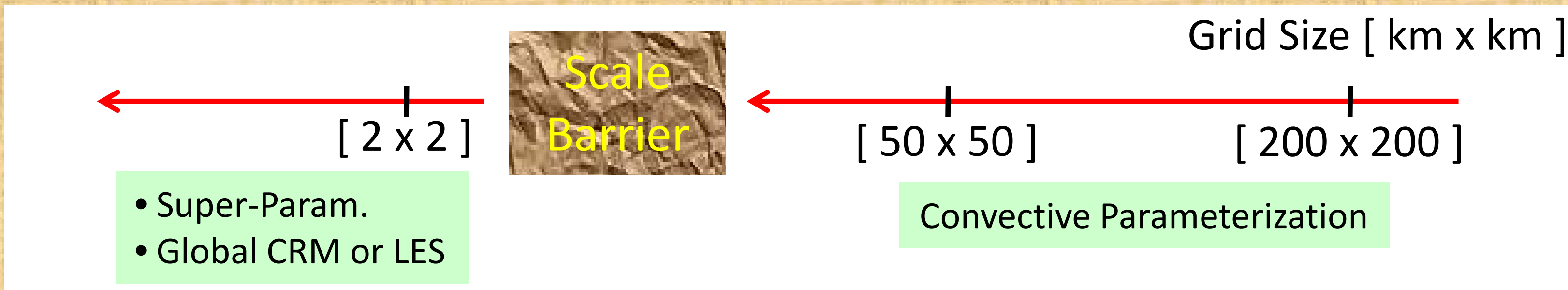
Treatment of Downdraft Dynamics

- Treatment of downdraft in most convection schemes is highly uncertain.
  In the CAM deep convection, downdraft is
  1. generated at level of the minimum MSE at a fixed fraction of updraft mass flux.
  2. independent of evaporation of precipitation.

- *The real convection scheme*
  1. should be able to simulate the evaporation of precipitation within downdraft.
  2. should be able to treat multiple sources of downdraft (e.g., '*forced convection*', '*mixing between saturated and unsaturated airs*').

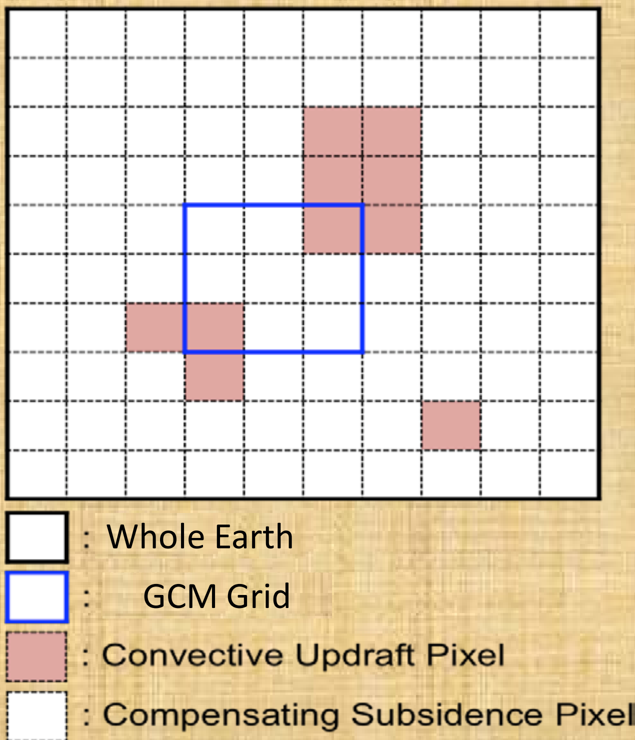


Convection across the Scale Barrier



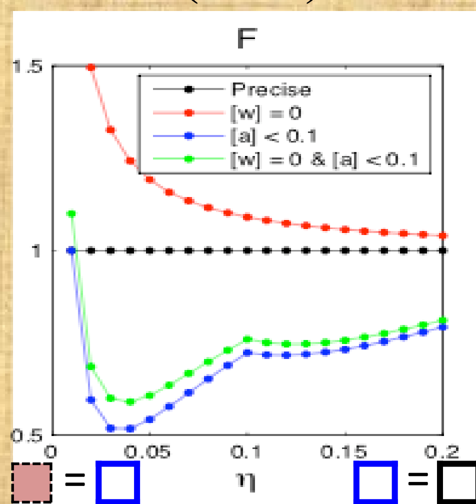
$$\overline{w'\theta'} = \overline{[w^*\theta^*]} + \overline{[w][\theta]} - \overline{w}\,\overline{\theta}$$

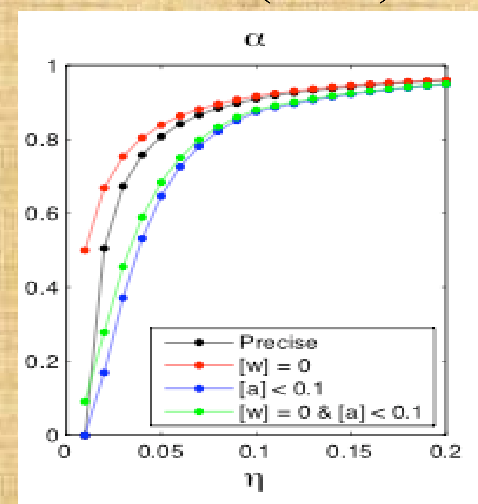
Convection — Advection



$$F = (C + A)/F_{true}$$

$$\alpha = C/(C + A)$$





- *The real convection scheme*
  1. should allow finite 'updraft/downdraft' fractional area.
  2. should allow multi-column distributions of compensating subsidence.

Parameterization of Lateral Mixing

• The most robust findings on the lateral mixing rate of a single updraft plume came from the laboratory and field experiments in the 1950s :

$$\varepsilon_0 = \frac{c}{R} \qquad R: \text{Radius of Plume}$$

• However, all the existing convection schemes do not use this because

1. they do not compute R,
2. they are aiming at simulating the mixing rate of ensemble-mean updrafts instead of an individual single plume.

• Current parameterizations of ensemble-mean mixing rate are highly uncertain, incomplete, and physically non-attractive. To make things worse, the behavior of convection is highly sensitive to the parameterization of lateral mixing rate.

• *The real convection scheme*

1. should be able to simulate plume radius R of individual plume,
2. should be able to treat multiple plumes with different R.

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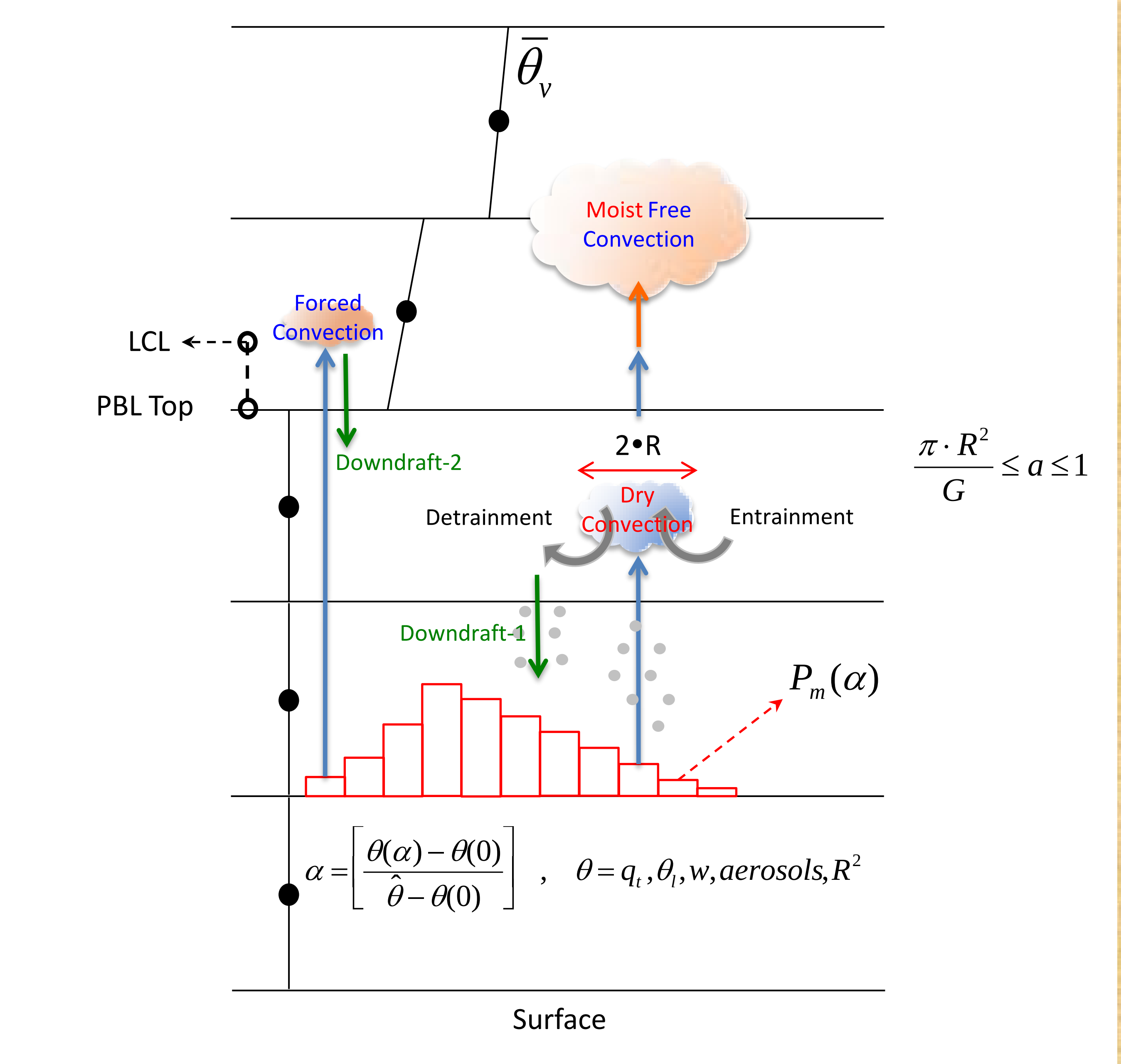
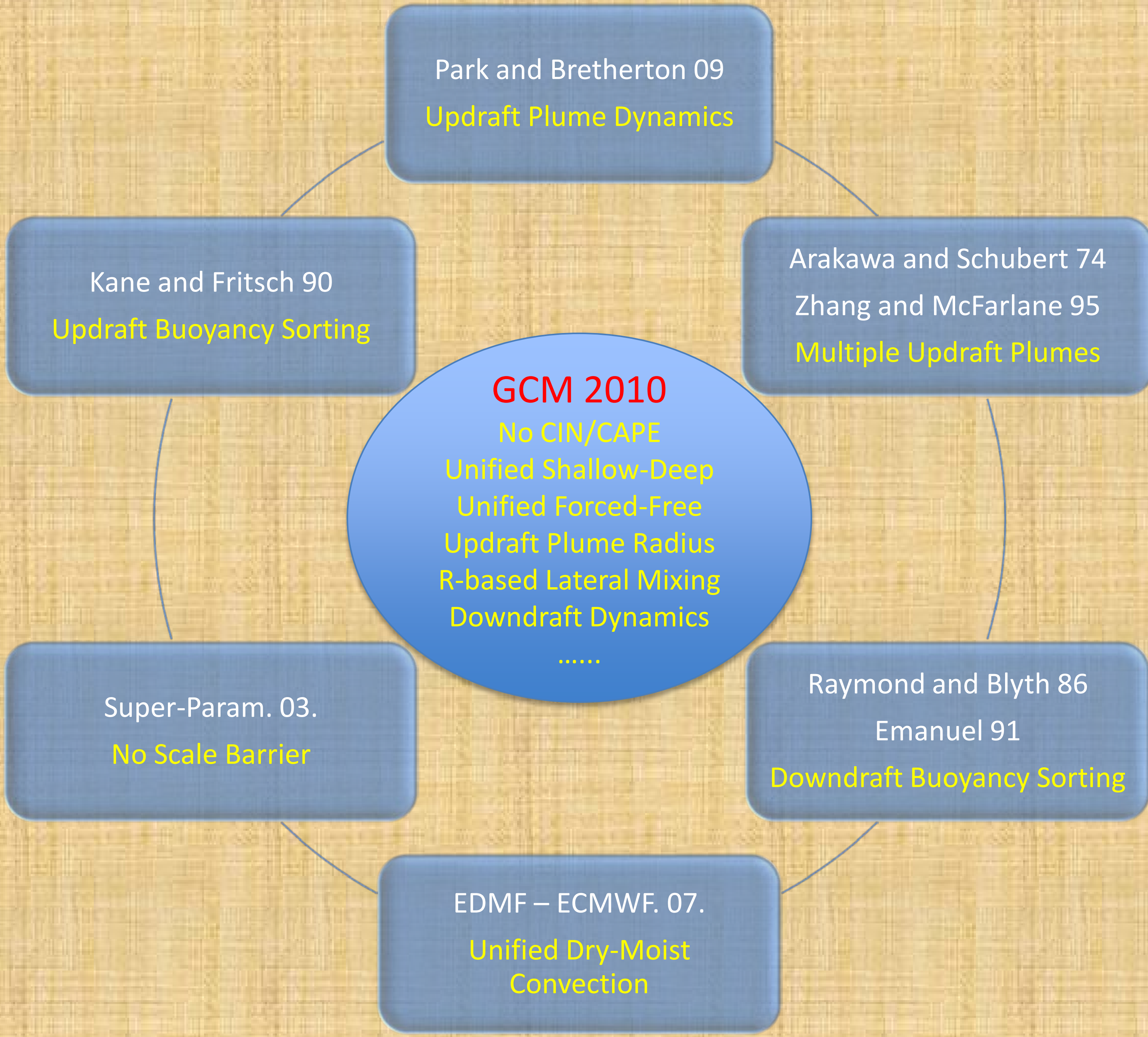
General Convection Model (Park 2010)

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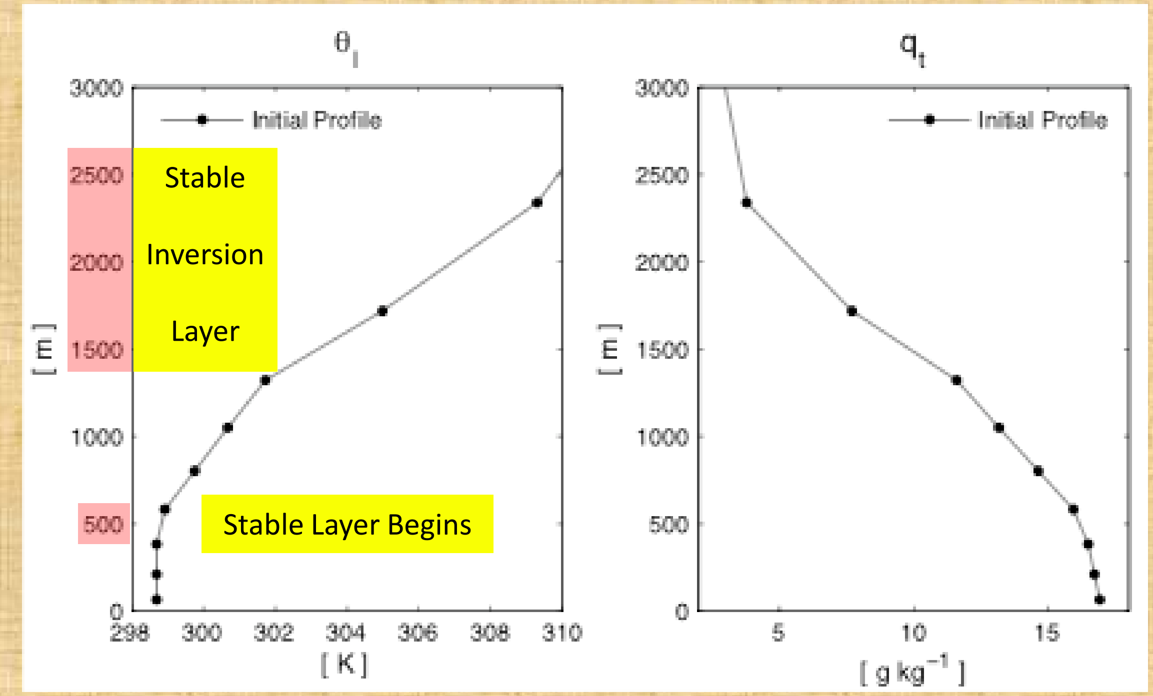

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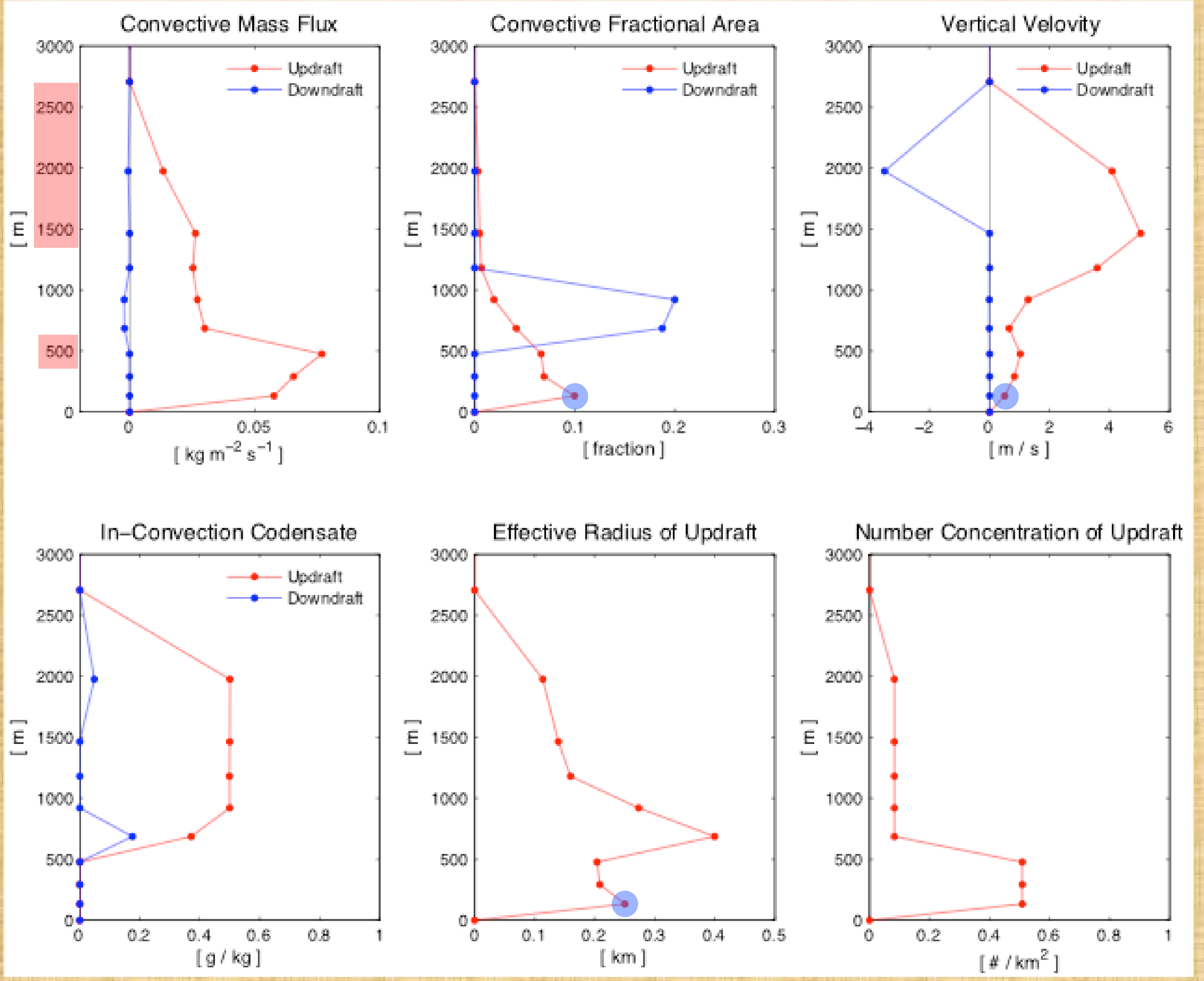

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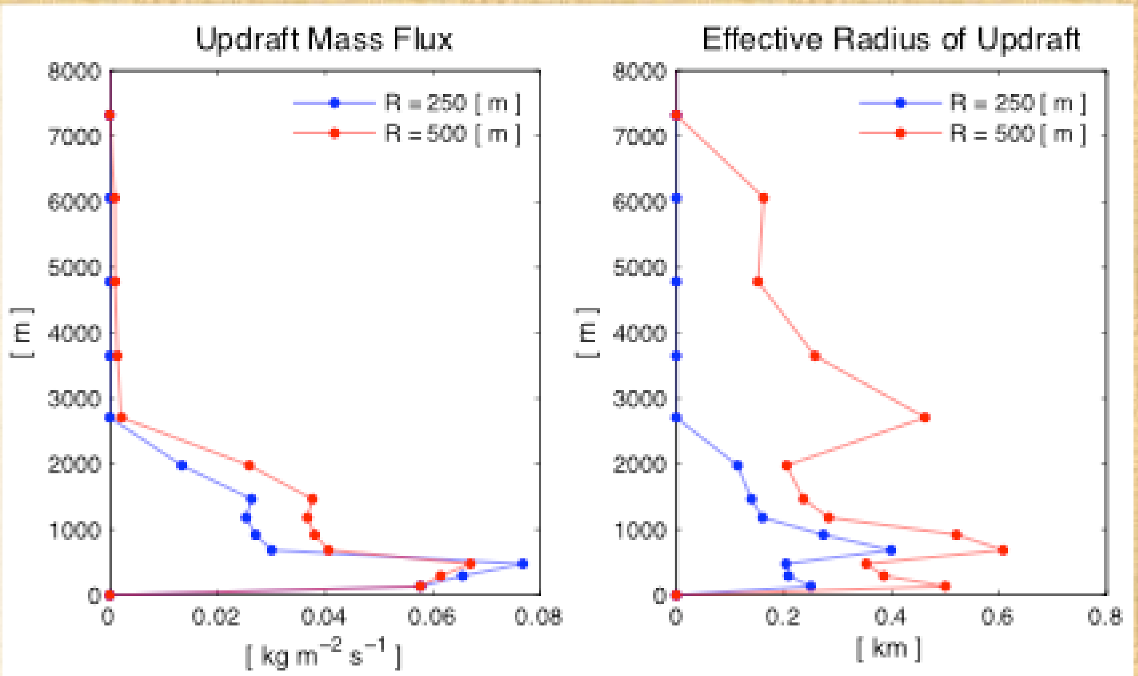

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