Convective parameterization

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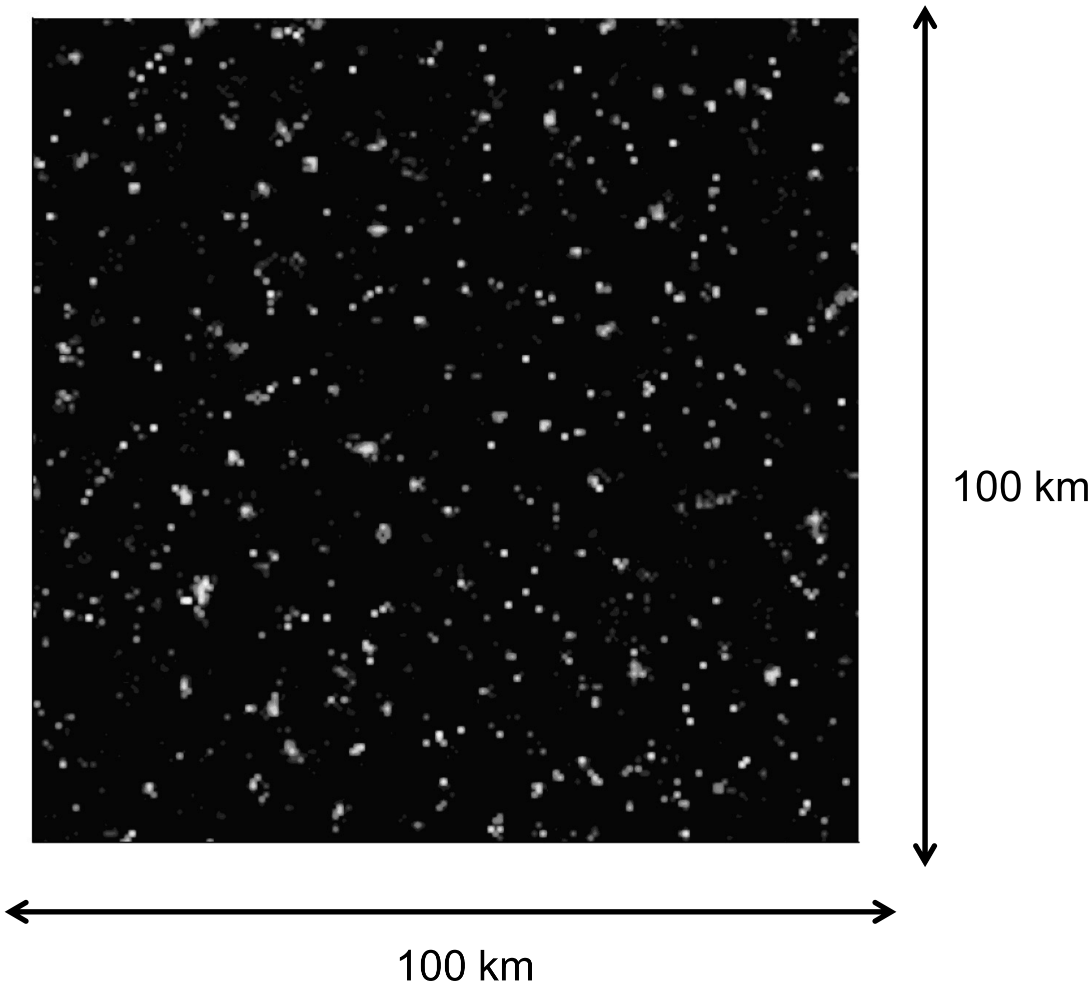
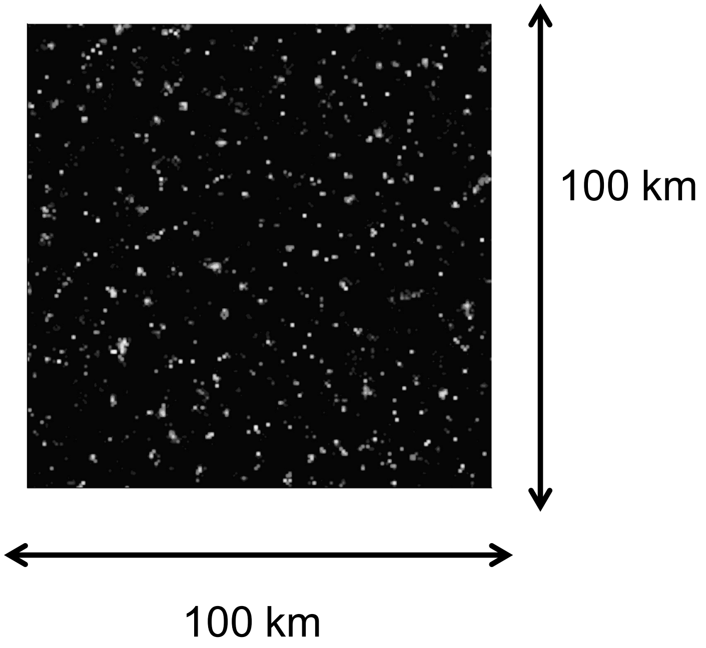
The issue

Convective clouds are smaller than grid spacing



The basic idea

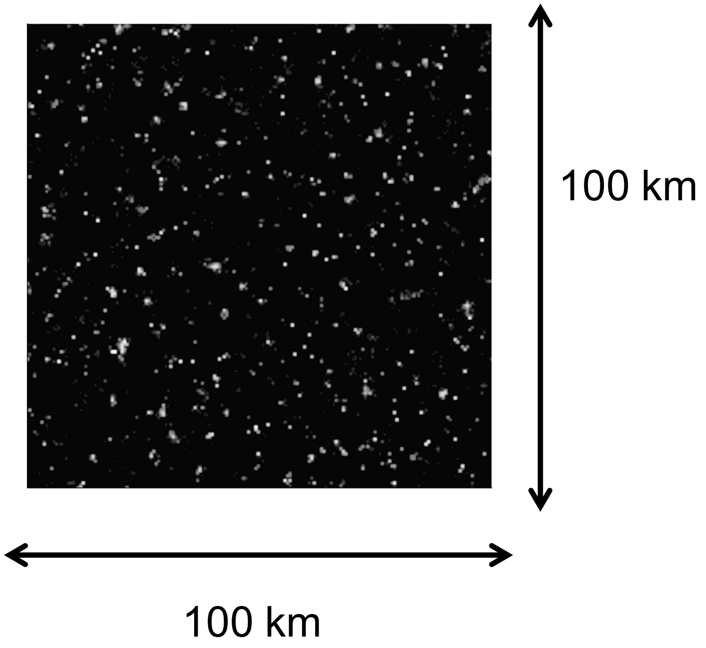
- Represent the statistical effects of convective clouds without representing all individual clouds



The basic idea

$$\frac{\partial \overline{\psi}}{\partial t} = -\frac{1}{\rho}\frac{\partial \rho \overline{u_i' \psi'}}{\partial x_i} + ...$$

$$\frac{\partial \overline{\psi}}{\partial t} = -\frac{\partial \overline{w' \psi'}}{\partial z} + ...$$



Outline

1. Job of a convection scheme
2. Type of convection schemes
   a. Adjustment scheme
   b. Mass flux scheme
3. The 3 ingredients of a mass flux scheme
4. Representation of organization

1. **Job of a convection scheme**
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1. Represent effects of convection on resolved large-scale flow

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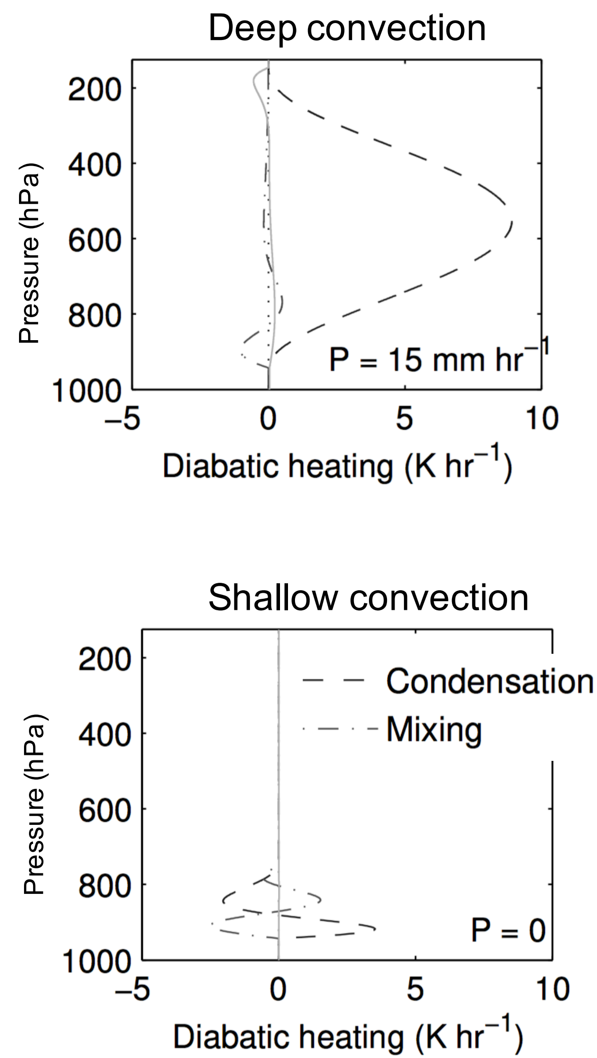
1. **Precipitation**

   - At the surface, how much where and when

   - Two sources of precipitation in a GCM:
     - Convective precipitation, from convection scheme, when grid box is not saturated
     - Stratiform (large-scale) precipitation, from microphysics scheme, when grid box is saturated

1. Represent effects of convection on resolved large-scale flow

1. **Precipitation**
2. **Heating, moistening and momentum**
   - Vertical profile, how much, where and when
   - Different convective clouds have different profiles



Bellon and Bony

1. Represent effects of convection on resolved large-scale flow

1. **Precipitation**
2. **Heating, moistening and momentum**
3. **Tracers**

1. Represent effects of convection on resolved large-scale flow

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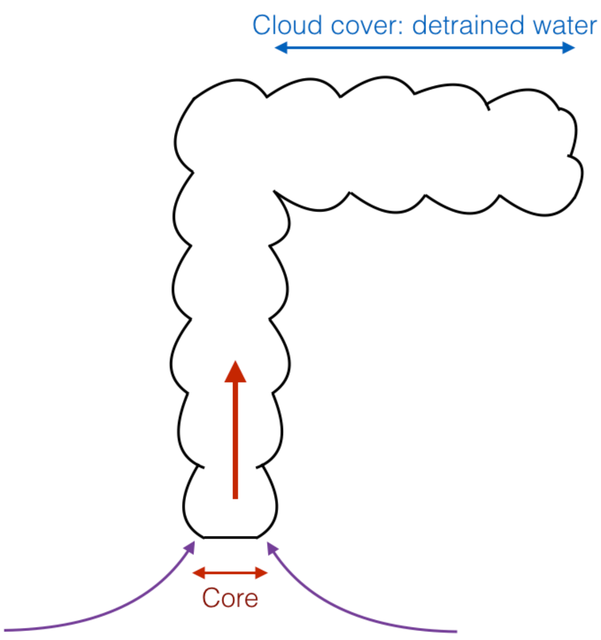
3. **Tracers**
4. **Cloud cover**

1. Represent effects of convection on resolved large-scale flow

1. **Precipitation**
2. **Heating, moistening and momentum**
3. **Tracers**
4. **Cloud cover**
   - NO !
   - Convection scheme only predicts updraft core
   - Passes relevant information to cloud cover scheme and radiation scheme



2. Type of convection schemes

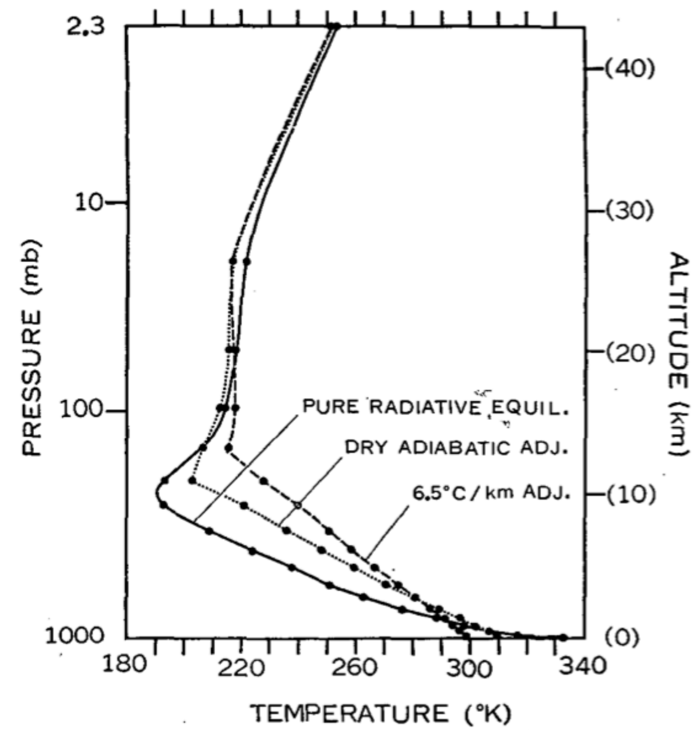
1. Job of a convection scheme
2. **Type of convection schemes**
   a. **Adjustment scheme**
   b. **Mass flux scheme**
3. The 3 ingredients of a mass flux scheme
4. Representation of organization

2a. Adjustment schemes

- Based on the idea of radiative convective equilibrium (Manabe and Stickler 1964)
- Relax temperature profile to a given moist adiabat (Manabe 1965, Betts and Miller 1986)

$$\frac{\partial \overline{\psi}}{\partial t} = \frac{\psi_{ref} - \overline{\psi}}{\tau} + \ldots$$

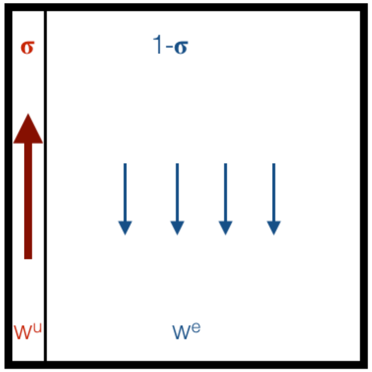
- Drawback: need to know reference state, atmosphere not in a RCE state
- Not used anymore



Manabe and Strickler (1974)

2b. Mass flux schemes

- Virtually all convection schemes
- Split a grid box in at least two parts:
  - the buoyant updraft where air goes up
  - The quiescent environment which is slowly subsiding



- The average of a variable ψ reads:

$$\overline{\psi} = \sigma^u \psi^u + (1 - \sigma^u)\psi^e$$

- Vertical eddy transport by convection:

$$\overline{w'\psi'} = \sigma^u \overline{w''\psi''}^u + (1 - \sigma^u)\overline{w''\psi''}^e + \sigma^u(1 - \sigma^u)(w^u - w^e)(\psi^u - \psi^e)$$

2b. Mass flux schemes

$$\overline{w'\psi'} = \sigma^u \overline{w''\psi''}^u + (1-\sigma^u)\overline{w''\psi''}^e + \sigma^u(1-\sigma^u)(w^u - w^e)(\psi^u - \psi^e)$$

- Assume:

$$\sigma^u << 1$$

$$w^u >> w^e$$

$$\psi^e = \overline{\psi}$$

- Give:

$$\overline{w'\psi'} = \sigma^u w^u (\psi^u - \overline{\psi})$$

$$\overline{w'\psi'} = \frac{M^u}{\rho}(\psi^u - \overline{\psi}) \qquad \text{with} \quad M^u = \rho\sigma^u w^u$$

2b. Mass flux schemes: some remarks

- If M^u and ψ^u are know, then vertical eddy transport by convection is known

$$\overline{w'\psi'} = \frac{M^u}{\rho}(\psi^u - \overline{\psi})$$

- If eddy transport is known, effect of convection on resolved flow is also known

$$\frac{\partial \overline{\psi}}{\partial t} = -\frac{\partial \overline{w'\psi'}}{\partial z} + ...$$

- **Mass flux approach is only valid for large (O(100 km)) grid boxes !**
- Simple and elegant: don't need to know area and vertical velocity

$$M^u = \rho \sigma^u w^u$$

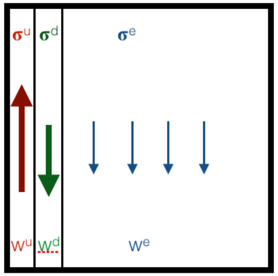
- Crux: maybe it is actually better to predict area and vertical velocity separately…

2b. Mass flux schemes: some more remarks

$$\overline{w'\psi'} = \frac{M^u}{\rho}(\psi^u - \overline{\psi})$$

- Two types of mass flux scheme:
  - bulk: replace all clouds by one pseudo bulk plume
  - spectral: use several plumes
- Generally the bulk approach is used
- But still distinguishes at least between shallow and deep convection
  - either the convection scheme decides between deep or shallow
  - or use two schemes, one for deep, one for shallow
- Generally a downdraft is also added

$$\overline{w'\psi'} = \frac{M^u}{\rho}(\psi^u - \overline{\psi}) + \frac{M^d}{\rho}(\psi^d - \overline{\psi})$$



3. The 3 ingredients of a mass flux scheme

1. Job of a convection scheme
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   a. Adjustment scheme
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3. **The 3 ingredients of a mass flux scheme**
4. Representation of organization

3. The 3 ingredients of a mass flux scheme

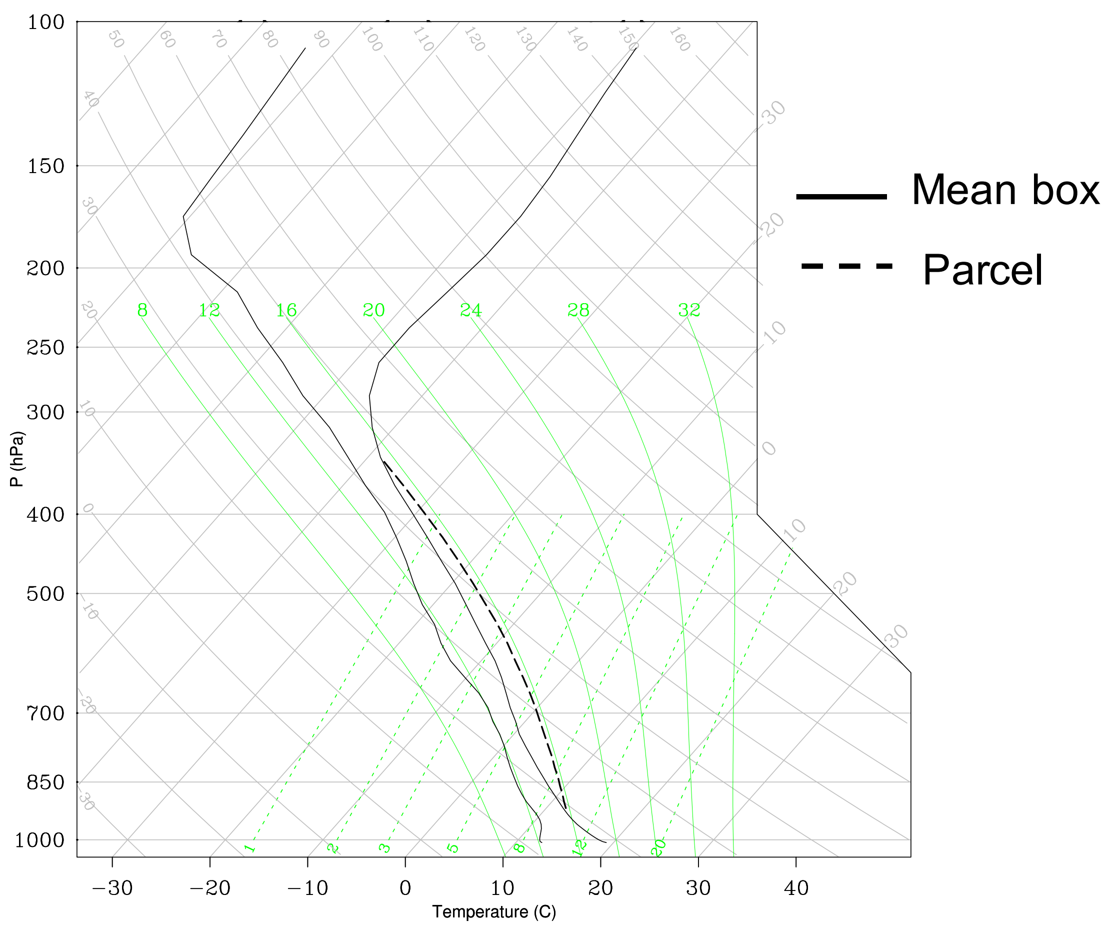
1. The trigger:
   Is convection happening ?

2. The closure:
   How much convection is happening ?

3. The cloud model:
   Predict vertical profile

3a. The trigger

- Parcel ascent: if atmospheric profile is unstable, convection is triggered
- Add some perturbation to derive parcel properties
- Can distinguish between shallow and deep convection based on cloud top height
- Some closures don't require a separate trigger



3. The 3 ingredients of a mass flux scheme

1. The trigger:
   Is convection happening ?

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   How much convection is happening ?

3. The cloud model:
   Predict vertical profile

3b. The closure: moisture convergence

- For long the traditional approach to close deep convection (e.g. Kuo 1974, Tiedtke 1989)

$$M_b^u \sim -\int_{z_b}^{z_t} \frac{\partial}{\partial x_i}(\rho q u_i)dz + F_E$$

- Over the tropics, precipitation almost equals moisture convergence
- Convection acts to consume the large-scale supply of moisture.
- Critic:
  - does not include “true” cause for convection (instability)
  - convergence is a consequence not a cause for convection
  - strong positive feedback

3b. The closure: moisture convergence

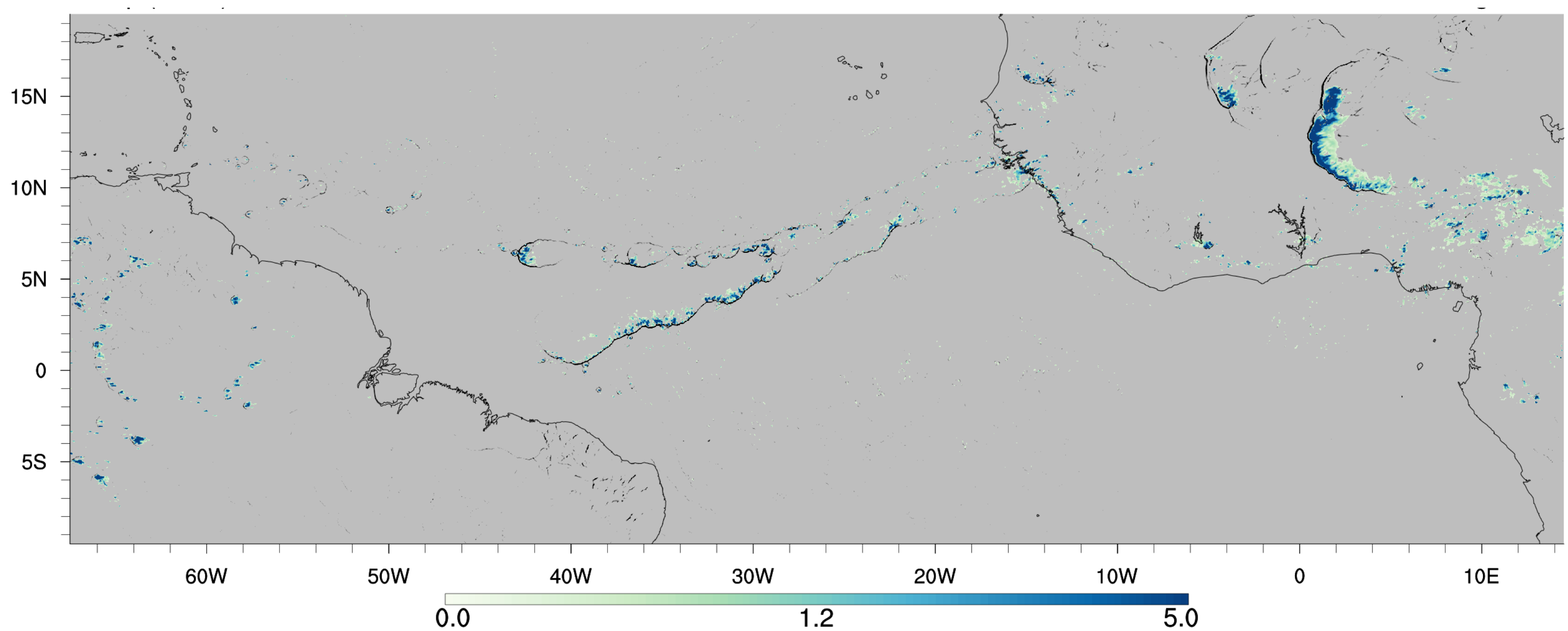


Figure M. Brueck, simulation D. Klocke

3b. The closure: CAPE

- Now the usual approach to close deep convection (e.g. Emanuel and Raymond 1993)

$$M_b^u \sim \frac{CAPE}{\tau}$$

- Convection acts to consume the large-scale supply of CAPE
- Assume convective quasi-equilibrium: convection responds quickly to change in the large-scale forcing, on a time scale much shorter than the temporal variations in the large-scale forcing itself
- Critic:
  - does not take into account convection resulting from forced ascent
  - Convective quasi-equilibrium not valid (e.g. diurnal cycle)

3b. The closure: CAPE

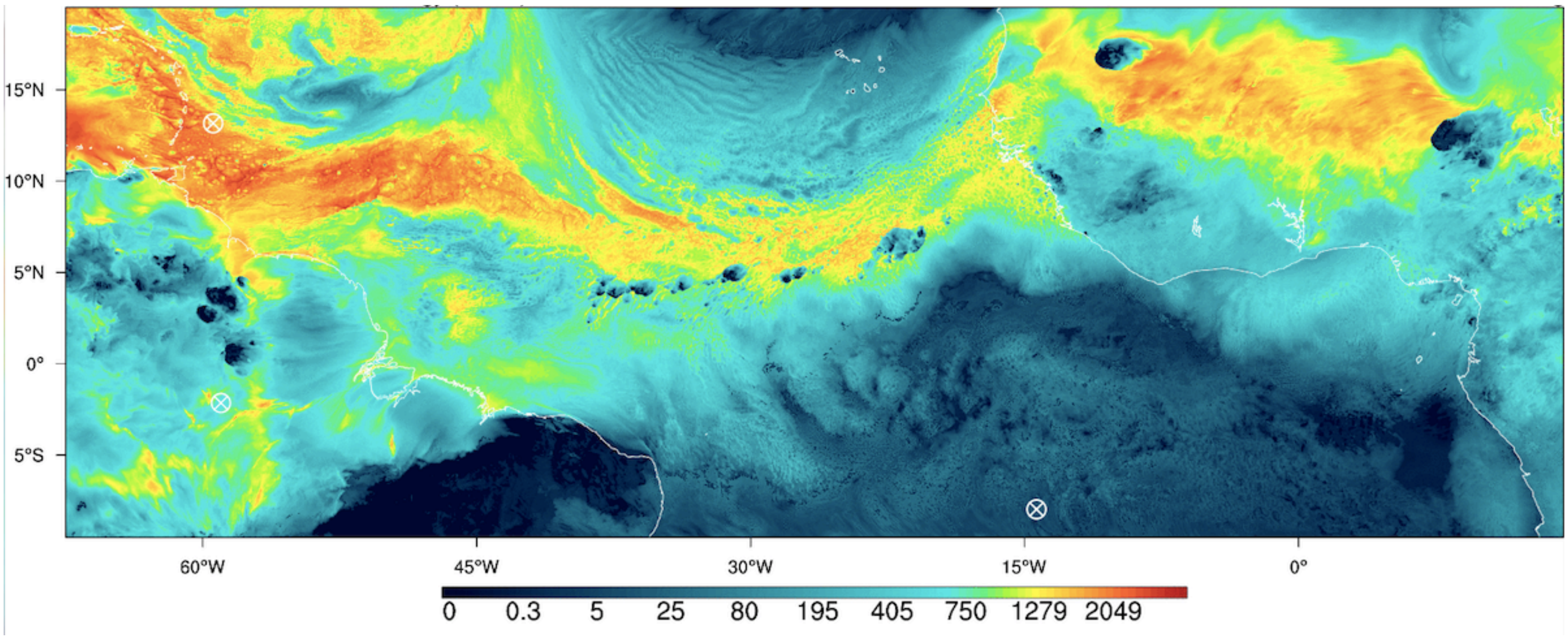
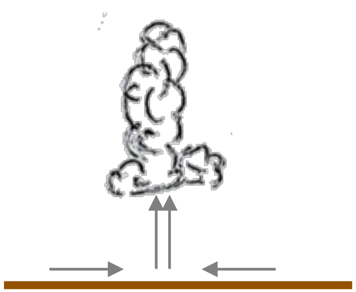


Figure M. Brueck, simulation D. Klocke

3b. The closure: Moisture convergence versus CAPE

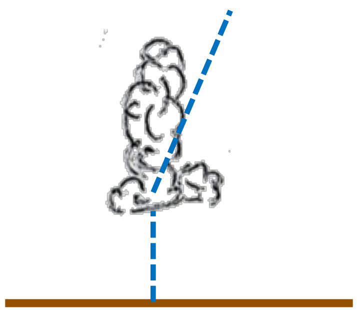
Dynamical view

- Convection happens where circulations converge



Thermodynamical view

- Convection happens in moist and/or unstable columns

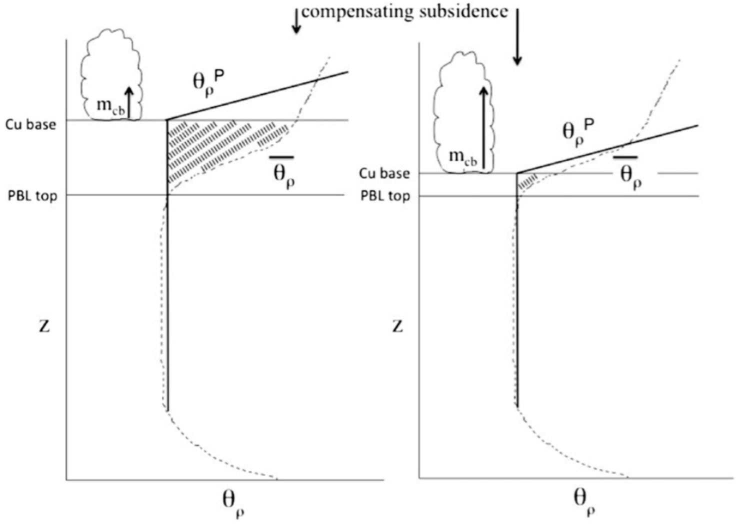


3b. The closure: boundary layer - based

- Use to close shallow convection and more recently deep convection (e.g. Park and Bretherton 2009, Rio and Hourdon 2008, Fletcher and Bretherton 2010)

$$M_b^u \sim W \exp(-\frac{CIN}{W^2})$$

- Maintain the base of the cumulus cloud at the top of the PBL
- No trigger needed
- Critic:
  - CIN is a small and noisy field



Fletscher and Bretherton (2010)

3. The 3 ingredients of a mass flux scheme

1. The trigger:
   Is convection happening ?

2. The closure:
   How much convection is happening ?

3. The cloud model:
   Predict vertical profile

3c. The cloud model

$$\frac{\partial \overline{\psi}}{\partial t} = -\frac{\partial \overline{w'\psi'}}{\partial z} + \ldots.$$

$$\overline{w'\psi'} = \frac{M^u}{\rho}(\psi^u - \overline{\psi})$$

- Need to know:

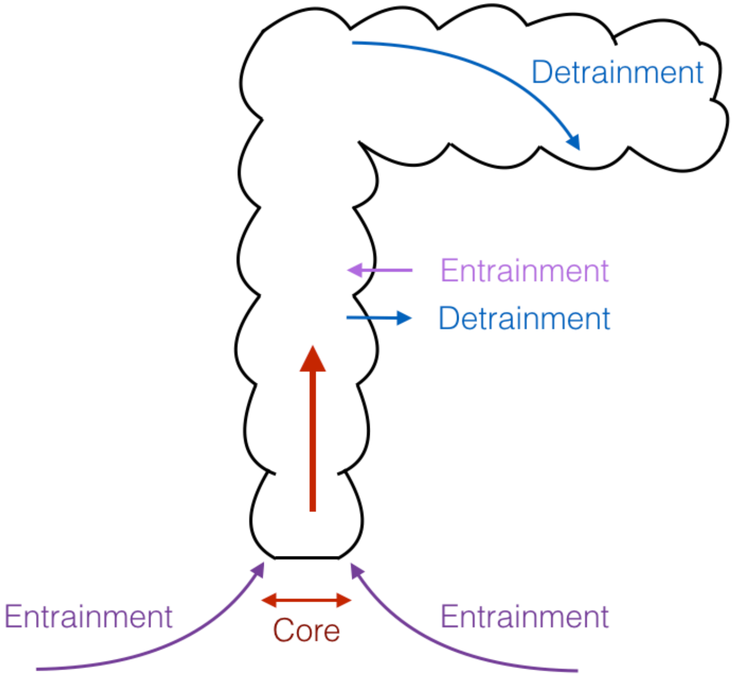
$$\frac{\partial M^u}{\partial z} = ??$$

$$\frac{\partial \psi^u}{\partial z} = ??$$

- Use the model of a bulk entraining-detraining plume

$$\frac{\partial M^u}{\partial z} = E - D$$

$$\frac{\partial M^u \psi^u}{\partial z} = E\overline{\psi} - D\psi^u + S$$



3c. The cloud model

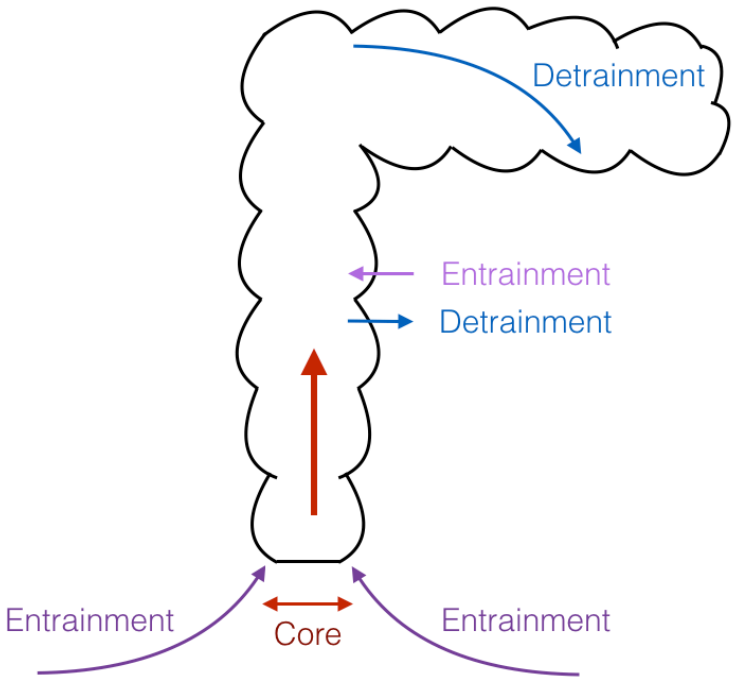
$$\frac{\partial M^u}{\partial z} = E - D$$
$$\frac{\partial M^u \psi^u}{\partial z} = E\overline{\psi} - D\psi^u + S$$

- Entrainment of environmental air increases the mass flux, as air mass is brought into the updraft

- Entrainment of environmental air cools and dries the updraft because the updraft is warmer and moister than its environment

- Ensuing changes in updraft properties leads to evaporation of cloud water

- The associated evaporative cooling reduces the buoyancy of the updraft and acts negatively on convection

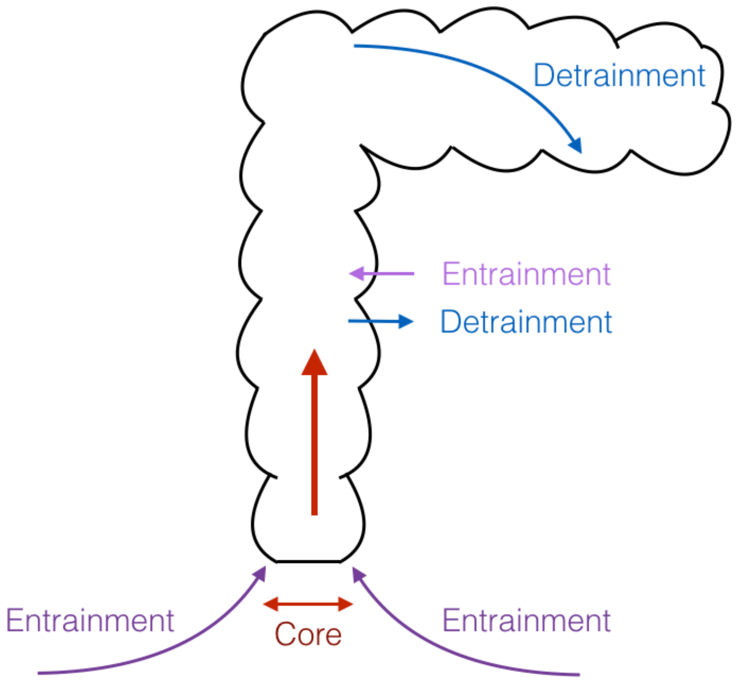


3c. The cloud model

$$\frac{\partial M^u}{\partial z} = E - D$$

$$\frac{\partial M^u \psi^u}{\partial z} = E\overline{\psi} - D\psi^u + S$$

- Detrainment of updraft air decreases the mass flux, as air is lost to the environment
- Detrainment of updraft air moistens and warms the environment because the updraft is warmer and moister than its environment
- This acts positively on the future development of convection



3c. The cloud model

$$\frac{\partial M^u}{\partial z} = E - D$$

$$\frac{\partial M^u \psi^u}{\partial z} = E\overline{\psi} - D\psi^u + S$$

- Define

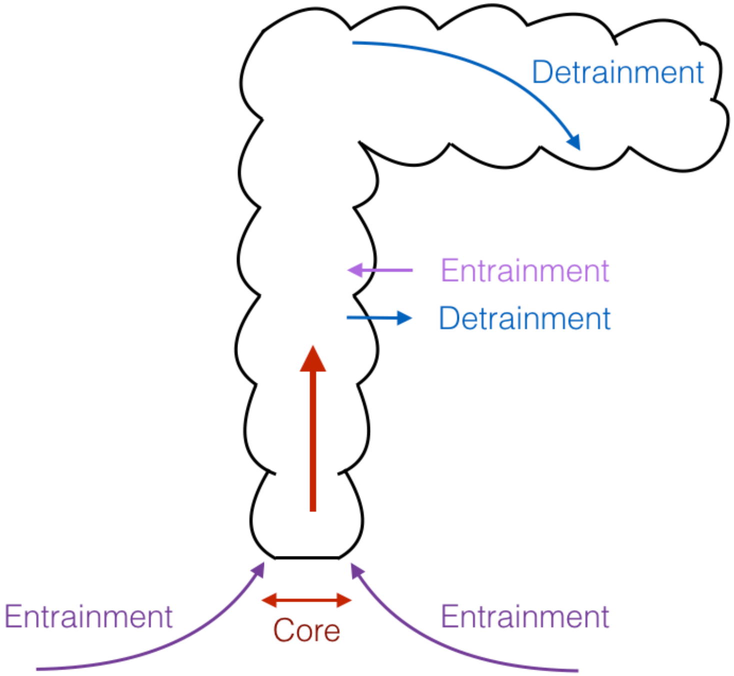
$$E \equiv \epsilon M^u$$

$$D \equiv \delta M^u$$

- Replace

$$\frac{\partial M^u}{\partial z} = M^u(\epsilon - \delta)$$

$$\frac{\partial \psi^u}{\partial z} = -\epsilon(\psi^u - \overline{\psi}) + S$$



It's magic !!!!

$$\frac{\partial\overline{\psi}}{\partial t} = -\frac{\partial\overline{w'\psi'}}{\partial z} + ...$$

$$\overline{w'\psi'} = \frac{M^u}{\rho}(\psi^u - \overline{\psi})$$

$$\frac{\partial M^u}{\partial z} = M^u(\epsilon - \delta)$$

$$\frac{\partial \psi^u}{\partial z} = -\epsilon(\psi^u - \overline{\psi}) + S$$

We only need to know entrainment and detrainment rates and we know effects of convection on resolved flow !!!!

Mmmhh......

We don't know entrainment and detrainment rates

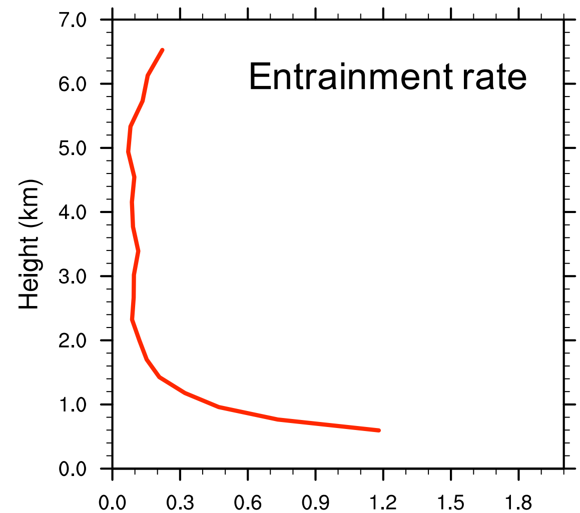
3c. The cloud model: entrainment and detrainment

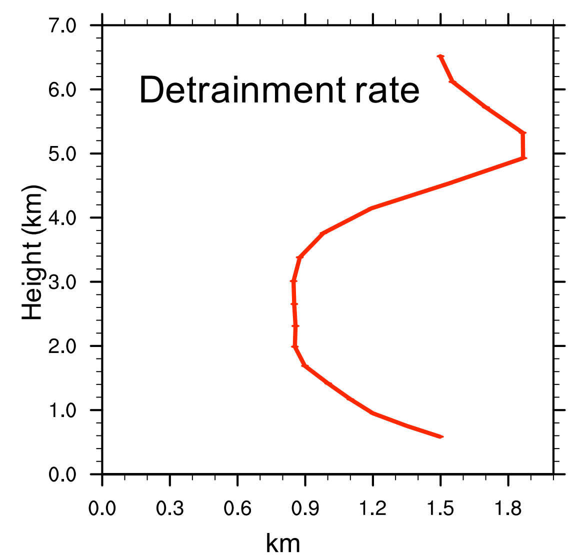
- Tuning knob of a convection scheme
  - Make shallow or deep convection
  - Make a single or a double ITCZ
  - Make or not a MJO
  - Shift precipitation patterns
  - Make it rain more or less

3c. The cloud model: entrainment and detrainment

- Tuning knob of a convection scheme
  - Make shallow or deep convection
  - Make a single or a double ITCZ
  - Make or not a MJO
  - Shift precipitation patterns
  - Make it rain more or less

- Various approaches but some few properties
  - Should vary vertically
  - Shallow convection has larger entrainment rates than deep convection
  - Entrainment rate depends on relative humidity





3c. The cloud model: microphysics

$$\frac{\partial M^u}{\partial z} = M^u(\epsilon - \delta)$$

$$\frac{\partial \psi^u}{\partial z} = -\epsilon(\psi^u - \overline{\psi}) + S$$

- Simple saturation-adjustment process
- Distinguish only liquid and ice based on temperature
- Simple autoconversion: convert a fraction of cloud water to rain and/or snow
- Snow can melt to rain
- Snow can sublimate
- Rain can evaporate, generally only below cloud base
- Snow and rain fall in the same grid box, no advection

4. Representation of organization

1. Job of a convection scheme
2. Type of convection schemes
   a. Adjustment scheme
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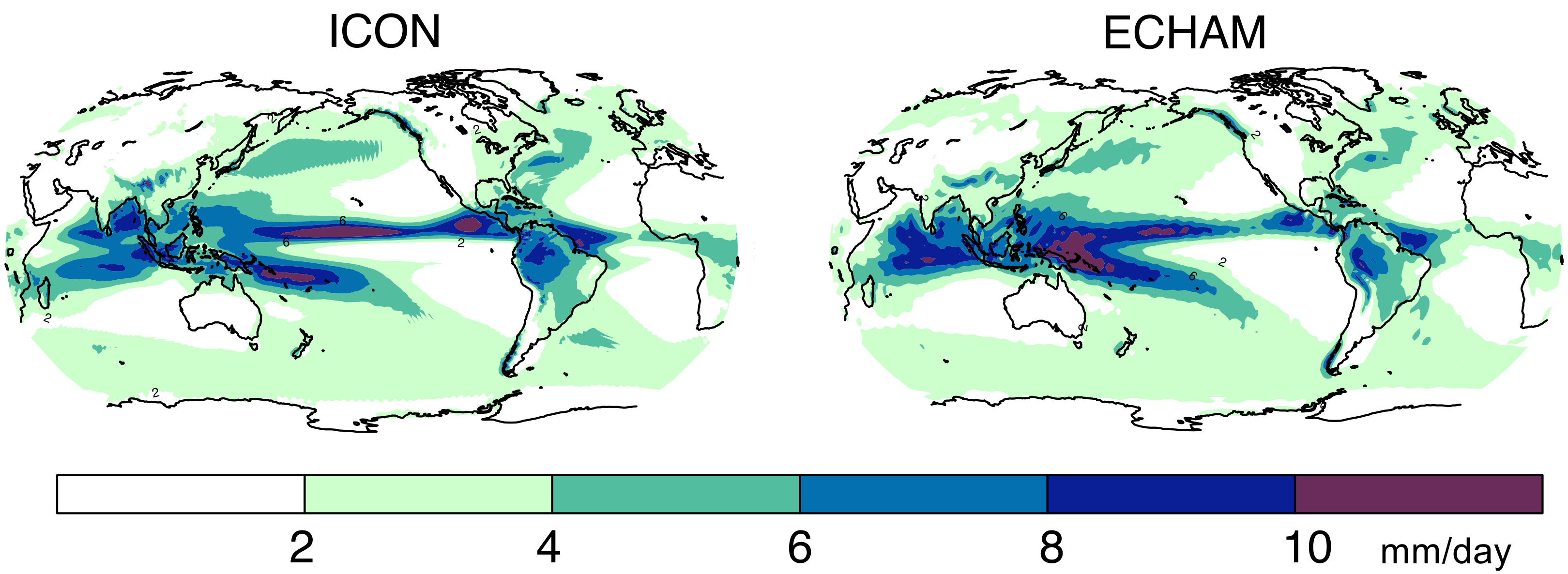
4. **Representation of organization**

4. Convective organization on larger scales

- On scales larger than the grid box, convective organization should happen spontaneously

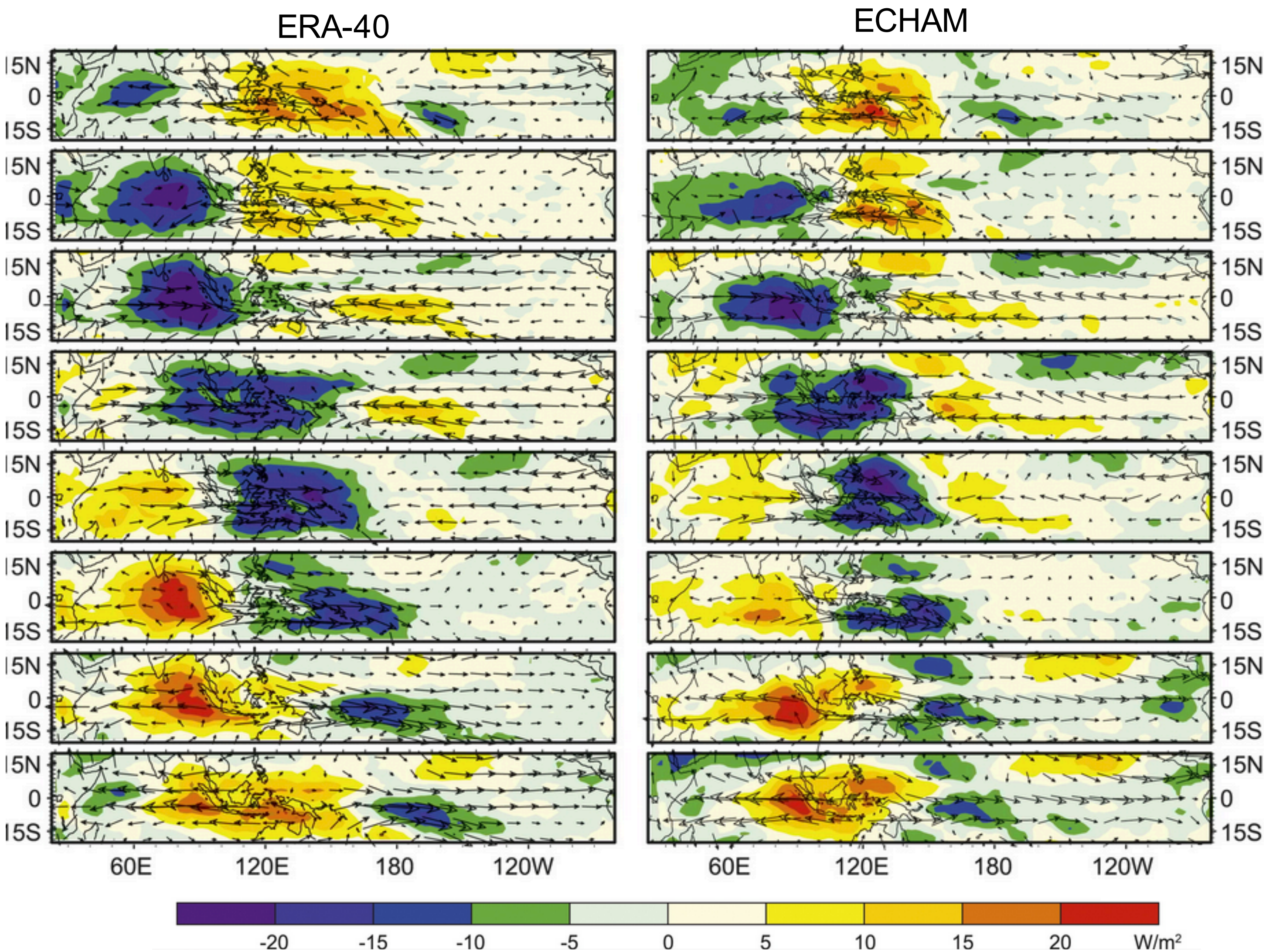
- Does convection organize on larger scales?

4. Convection can indeed organize on larger scales: ITCZ



Crueger et al. (2018)

4. Convection can indeed organize on larger scales: MJO



Crueger et al. (2018)

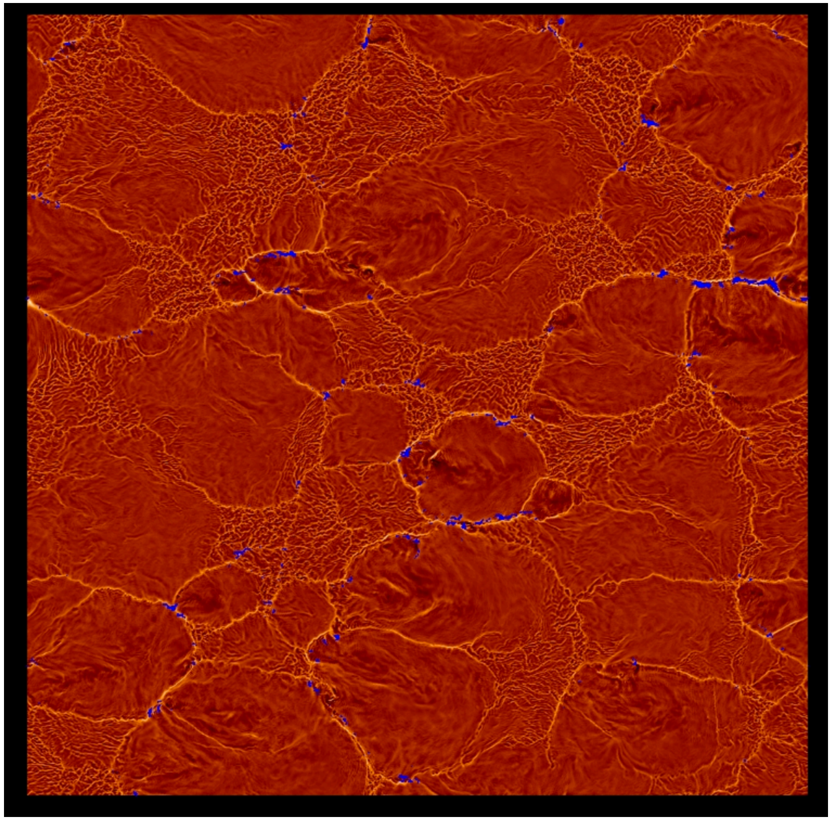
4. Convective organization on scales smaller than the grid spacing

- Convective parameterizations generally do not include a representation of organization

4. Representation of mesoscale organization: cold pools

1. Cold pools
   - Melting of hydrometeors and evaporation of precipitation generate cold pools
   - When cold pools collide, air forces to rise, preferential triggering location
   - Modify trigger function

$$M_b^u \sim W \exp(-\frac{CIN}{W^2})$$



Linda Schlemmer

4. Representation of mesoscale organization: cold pools

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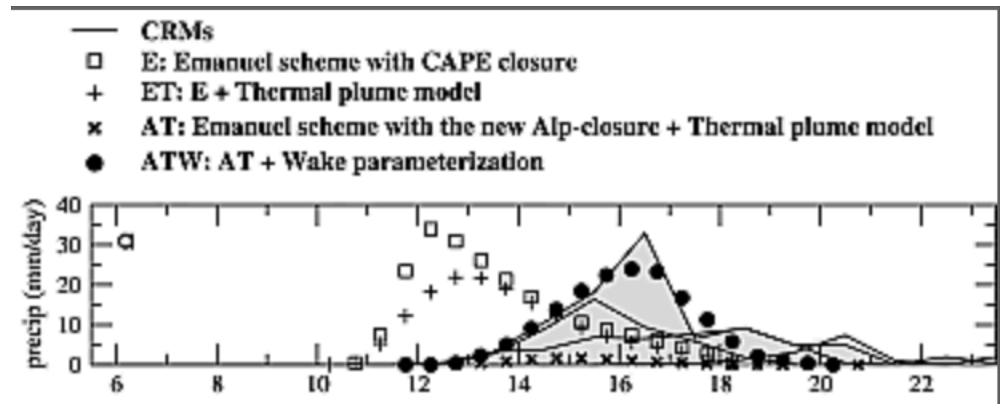
$$M_b^u \sim W \exp(-\frac{CIN}{W^2})$$

   - Diurnal cycle



Rio et al. (2009)

4. Representation of mesoscale organization: cluster size

1. Cold pools
2. Cluster size
   - Organized convective clusters are larger than isolated convective cells
   - Entrainment rate is inversely proportional to updraft's size
   - Modify entrainment rate (Mapes and Neale 2011, Hohenegger and Bretherton 2013)

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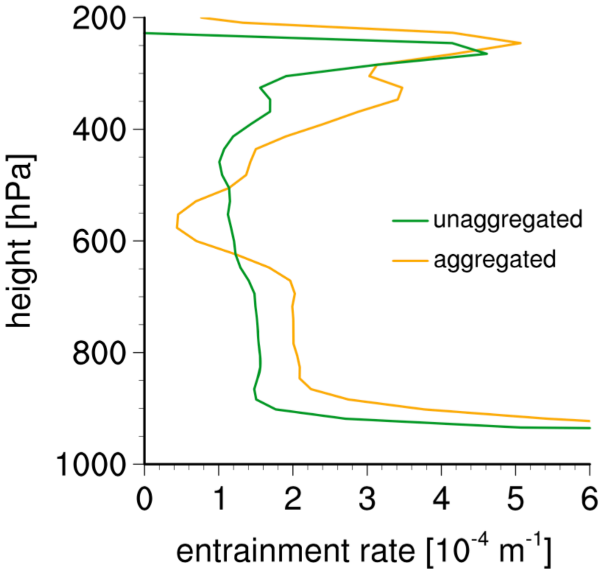
   - Doesn't seem to be backed up by convection-permitting simulations



Becker et al. (2018)

4. Representation of mesoscale organization: cluster size

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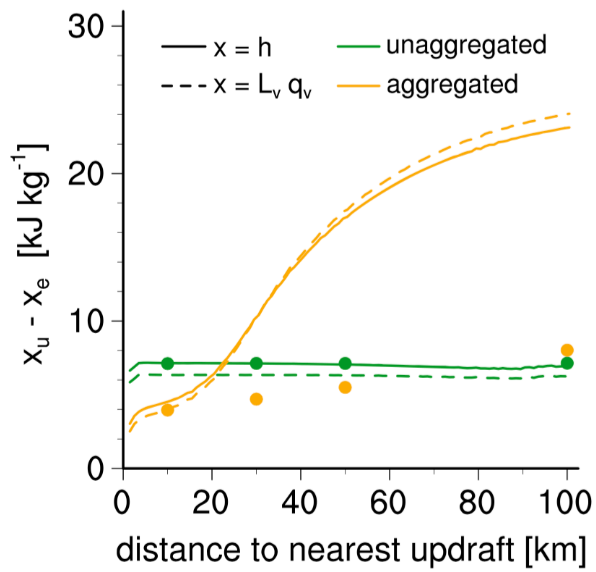
   - Organized convective clusters are larger than isolated convective cells
   - Entrainment rate is inversely proportional to updraft's size
   - Modify entrainment rate (Mapes and Neale 2011, Hohenegger and Bretherton 2013)
   - Doesn't seem to be backed up by convection-permitting simulations
   - Rather include a moist shell

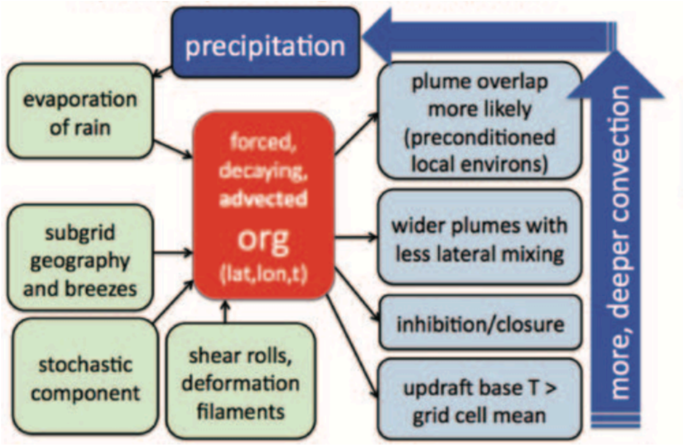


Becker et al. (2018)

4. Representation of mesoscale organization: org parameter

1. Cold pools
2. Cluster size
3. Org parameter (Mapes and Neale 2011)

$$\frac{d(org)}{dt} = S - (org)/\tau$$



Mapes and Neale (2011)

4. Representation of mesoscale organization: mesoscale heating

1. Cold pools
2. Cluster size
3. Org parameter
4. Mesoscale heating (Moncrieff and Liu 2006)
   - Organized convection has a different heating profile than isolated convection due to stratiform precipitation
   - Add mesoscale heating on tendency
   - Mesoscale heating proportional to convective heating

But should we include the effect of mesoscale organization?????

Conclusions

1. Job of a convection scheme
   - Represent the statistical effect of convection without representing individual clouds
2. Type of convection schemes
   - Mass flux approach
3. The 3 ingredients of a mass flux scheme
   - Trigger (yes/no), Closure (how much), Cloud model (vertical profile)
   - Entrainment and detrainment rates
4. Representation of organization
   - Not on the mesoscale, some aspects of large-scale organization captured