MOIST DEEP CONVECTION

Why is deep-convection so special in the parameterisation trade? (1/2)

- Because such a parameterisation automatically requires some knowledge of the model's resolved tendencies (closure problem).
- Because it is a non-hydrostatic phenomenon that we try to parameterise in a hydrostatic-type framework (for the scales –above 10km- where we need such a parameterisation).
- Because trigger, maintenance and decay mechanisms are complex and difficult to control in an atmospheric state always at the edge of a yes/no behaviour.

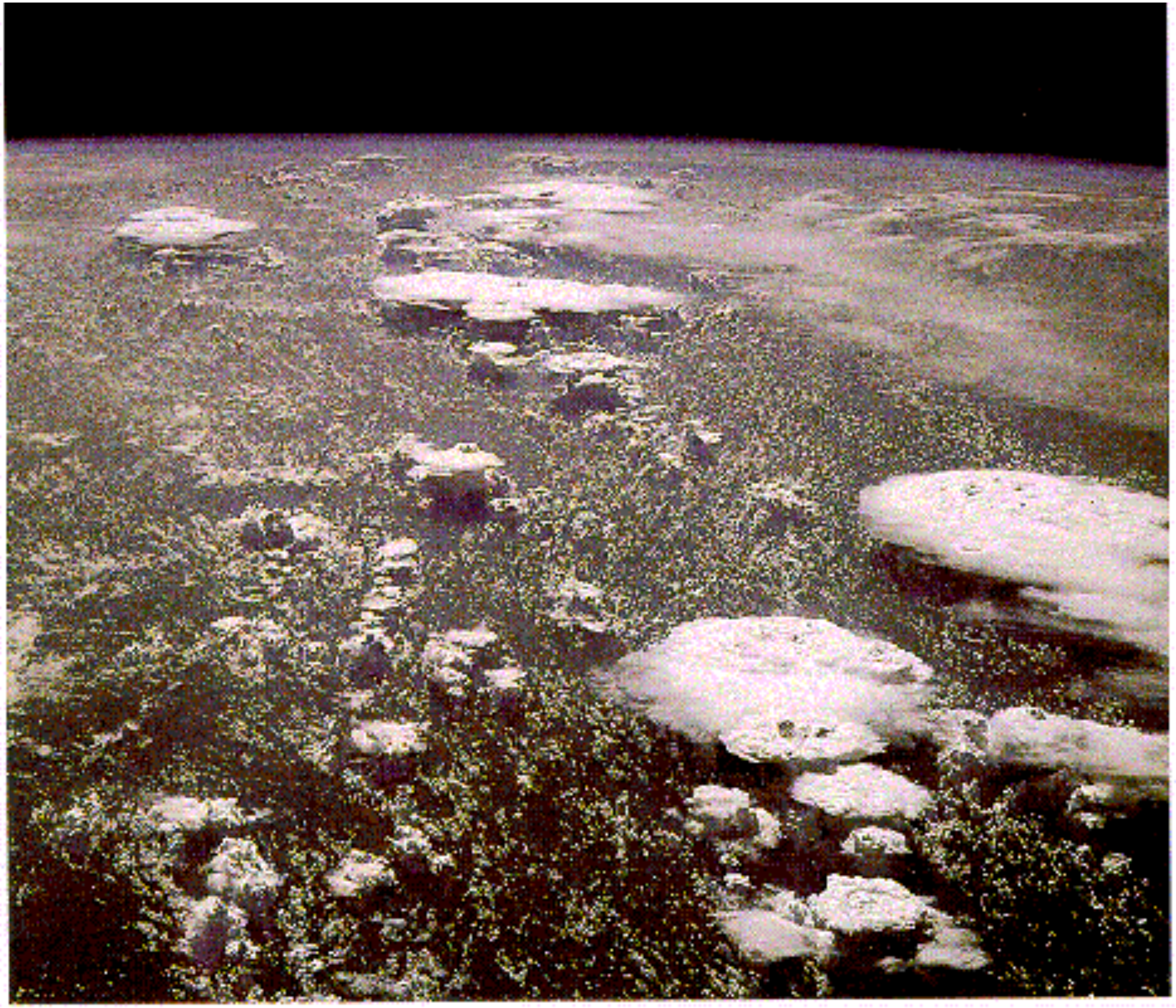
Why is deep-convection so special in the parameterisation trade? (2/2)

- Because the links and bridges with shallow convection, dry convection and slantwise convection are subtle and difficult to model.
- Because convective updrafts (and downdrafts) have their own life-cycles, that we should forecast or at least statistically simulate.
- Because '***visible***' convection seems like a local auto-organised process while its '***invisible***' influence and conditions of existence are very much of a large scale type.
- Because the conditions of interplay of this 'scale duality' are yet subject of heavy controversy!

Why do we need a parameterisation of deep-convection?

- Because for models that do not resolve the 1km scale, convection-associated clouds are clearly sub-grid and look like the result of an auto-organisation process.
- Because, without it, resolved microphysics of clouds and precipitation takes over the vertical stabilising role, but at the wrong scale with sometimes catastrophic consequences on the modelled atmosphere – grid point storms.
- Not because it helps maintaining the correct local vertical gradients of temperature and humidity but because it controls the intensity of large scale dynamical adjustment motions (Hadley cell, …)

Convection is multi-scale



Convection instabilities

There are 5 instabilities:

- CAPE (CIFK)
- CISK
- WISHE
- Saturation deficit
- Cold pools

Concepts (1)

CIFK: Conditional Instability of the First Kind:

"Precipitating convection is driven by vertical moist instability"

Source of energy:

CAPE: Convective Available Potential Energy

CIFK is a 1D process: no horizontal circulation taken into account.

Archimedes (287 av. JC), Espy (1841)

Lifting -> Buoyancy -> Upward force -> Lifting

Concepts (2)

CISK: Conditional Instability of the Second Kind:

"Precipitating convection is driven by low level's dynamical moistening"

Source of energy:

L * water vapor tendency due to humidity convergence

CIFK is a 2D or 3D process: positive feedback involves horizontal circulation

Charney, Eliassen, Kuo, Ooyama (1960-1970), GATE (1974), Bougeault (1985), etc.

Convergence -> water vapor -> condensation -> heating -> lifting -> convergence

Concepts (3)

WISHE: Wind Induced Surface Heat Exchange:

"Precipitating convection is driven by low level's physical moistening"

Source of energy:

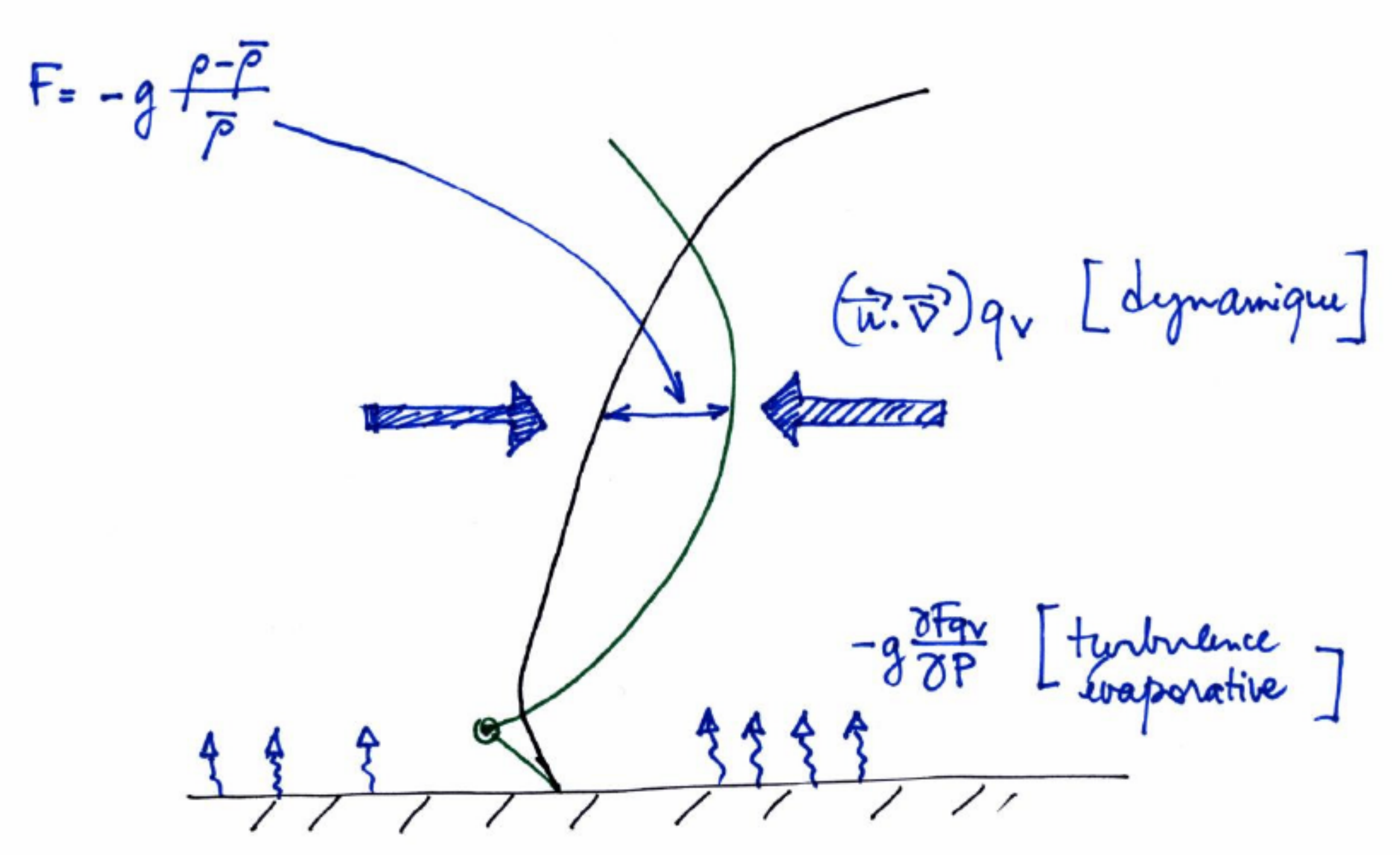
L * water vapor evaporation from surface

WISHE is a 2D or 3D process: positive feedback involves horizontal circulation. Important in Air-Sea interactions – cyclones;

Emanuel, Yano, Raymond (1984-1990)

Condensation -> heating -> lifting -> surface wind -> surface evaporation -> condensation

Combination of CIFK, CISK and WISHE



Concepts (4)

SATDEF: Saturation deficit:

"Precipitating Convection is favored if mid-tropospheric layers (between 2 and 5 km) are moist"

Source of energy:

Less evaporation within the drafts.

Redelsperger, Parsons, Guichard (2002)

Moister air in mid troposphere -> less evaporation in updrafts -> stronger updrafts -> higher clouds -> surface evaporation -> moistening of higher layers

Concepts (5)

Cold pools:

"Convective transition from shallow to deep involves a collective cloud mechanism, via uplifting by cold pools"

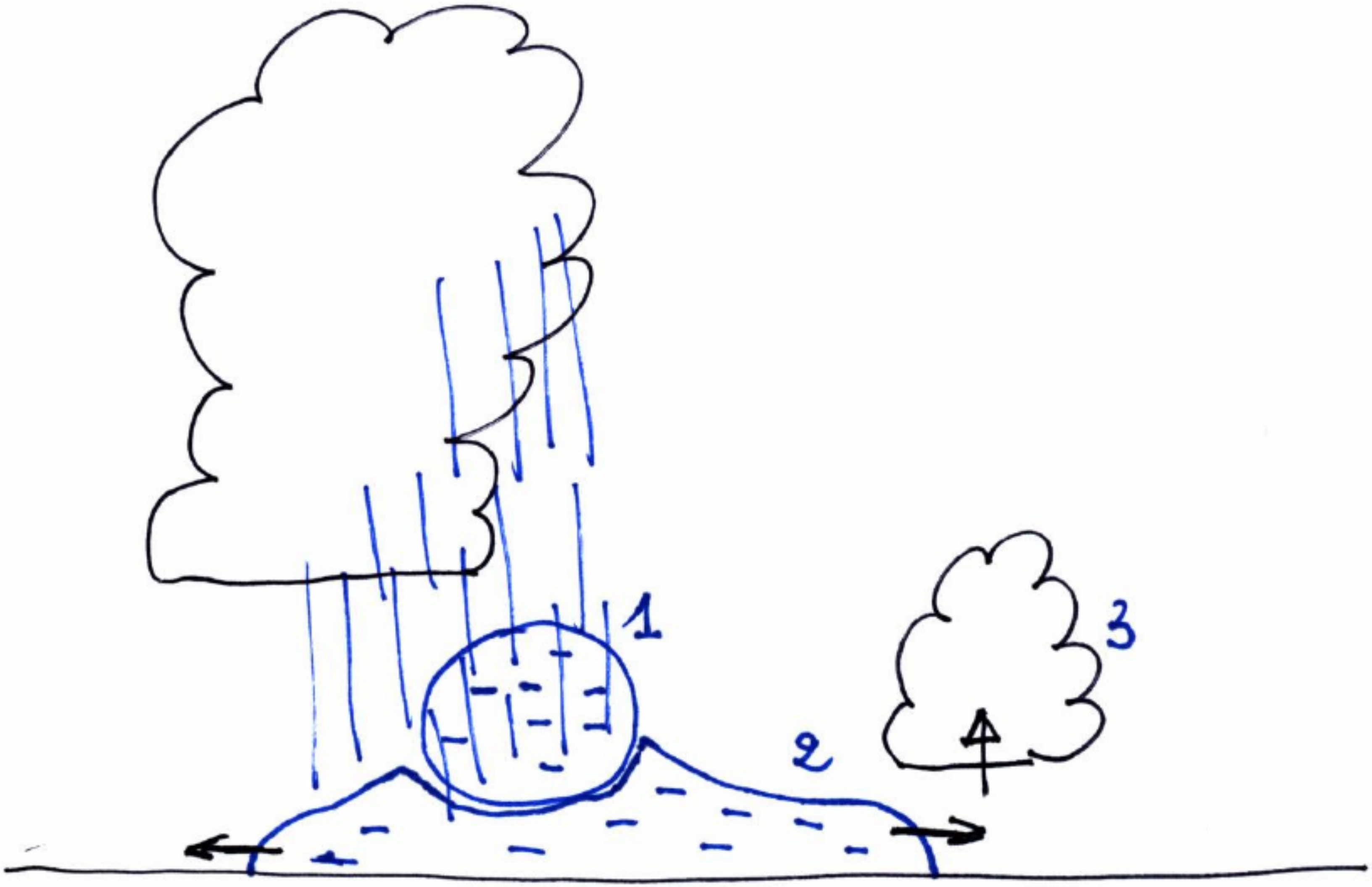
Source of energy:

Adiabatic lifting

Guichard et al. (2004), Khairoutdinov et Randall (2006)

Ascent -> precipitation -> evaporation of precipitation -> cold pool -> density current -> new ascent

Cold pools



The CISK vs. WISHE controversy

Static view (there is also a wave-propagation equivalent)

Conditional **I**nstability of the **S**econd **K**ind

? → Condensation → Buoyancy

More moisture

Where does the moisture comes from ?

Low level convergence

Updraft motion

Surface pressure drop

Wind **I**nduced **S**urface **H**eat **E**xchange

? → Condensation + Ascent → Balanced profile's maintenance

More available moisture

What determines the balanced profile ?

Stronger…

Sinking in dry regions ⇔ Radiation

Need of a return flow

The CISK vs. WISHE main difference

Conditional Instability of the Second Kind

? Condensation

Convection drives the 'large-scale' circulation

Surface pressure drop

Wind Induced Surface Heat Exchange

? Condensation + Ascent

More avai

maintenance

Stronger w

s ⇔ Radiation

Convection controls the 'large-scale' circulation

Need of a return flow

The truth seems to be situation- and scale dependent !

The Quasi-Equilibrium (QE) concept: history

- Whatever causality is at work, QE is verified at very large scale, but not necessarily below.
- Study of the phenomenology of convection led (Ooyama, 1971) to the concept of mass-flux formulation (**see later**) for parameterisation.
- This shifted the old problem of convective closure from budgets to complex questions about the dynamics of convective circulations.
- But the (misleading?) answer was to replace the search of an additional convective impact under given local circumstances by that of a full convective answer to a non-convective forcing.

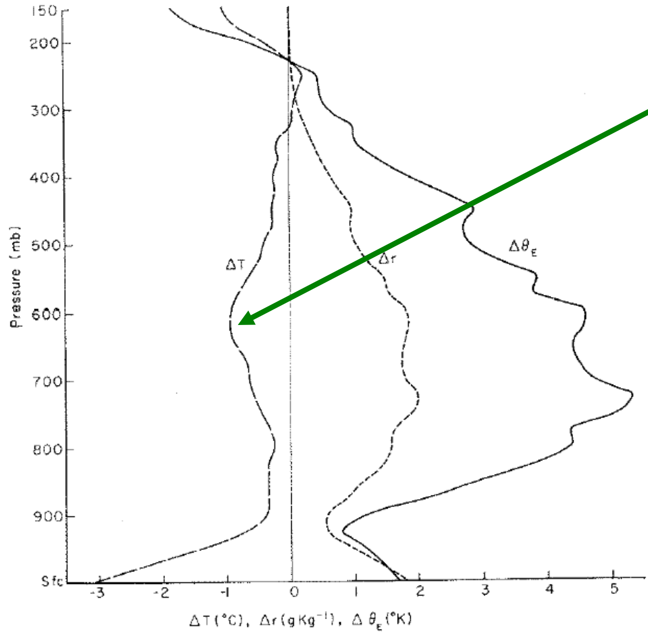
The Quasi-Equilibrium (QE) concept: controversy

- CISK idea of QE: convective circulations are determining the 'larger scale' vertical velocities that in turn force convection
- WISHE idea of QE: 'being in a lift, it is not because the counterweight goes down that you're going up'
- Anti-QE thinking (*20 years lost, they say*):
  - Scales are not separable (the 'invisible' part of convection is *at the scale of the Rossby radius of deformation*);
  - Forcing and answer to it are not really separable either (at least scale-dependent in a model where the return flow must be accounted for in the grid-box)!
  - There is no 'under-law' of convective regions dynamics that aggregates local behaviours to a simple balance.

QE and causality. Le Châtelier’s principle as an answer? (1/2)

- Chemical reactions QE: if the modification of some parameters does displace the equilibrium, other forces counteract the primary evolution, **but only partly**.
- Mapes (1997):
  - If convective heating follows cooling by adiabatic ascent (~WISHE in full QE meaning) the resulting effect will be cooling;
  - If convective heating precedes cooling by adiabatic ascent (~CISK in full QE meaning) the resulting effect will be heating.
- Test to be done by statistical differences between observations of active and non-active periods.

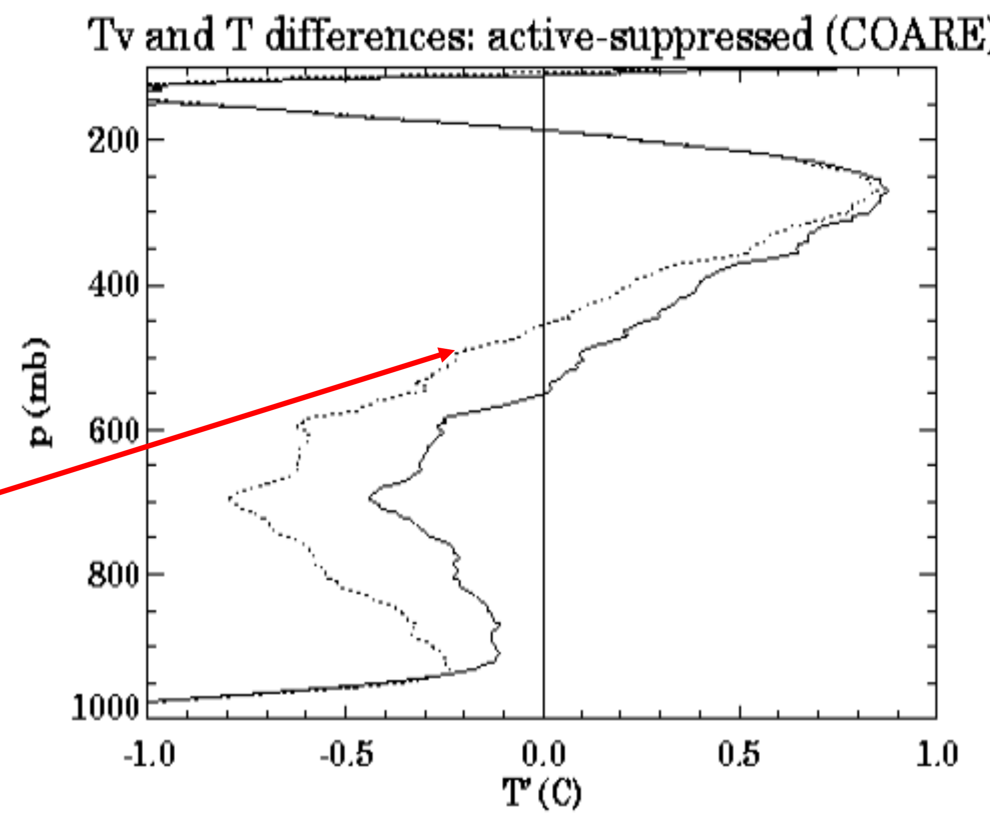
QE and causality. Le Châtelier's principle as an answer? (2/2)



300 Venezuelian soundings => ΔT<0 => WISHE wins (if QE exists)

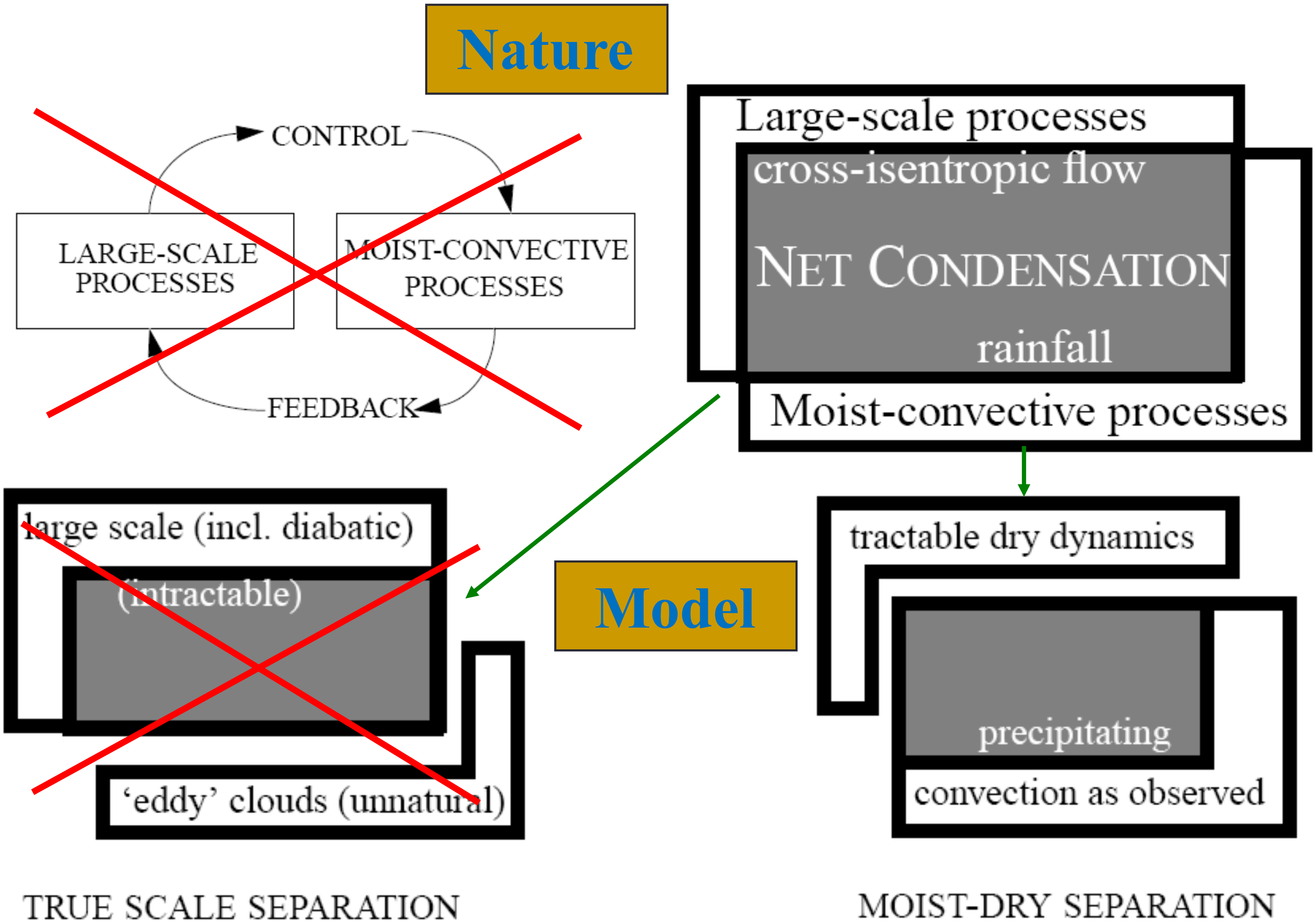
BUT

More mitigated results on TOGA-COARE (and GATE)



Is QE really usefull ?

QE => scale separation. Which concept to replace that?



Vertical velocity. Which representativeness? Which use?

For any conservative quantity ψ one may symbolically write

$$\underbrace{\frac{}{t} = u\frac{}{x} \quad v\frac{}{y} \quad \bar{\ }\frac{}{p}}_{\text{adiabatic}} \quad \underbrace{M_c\frac{}{p} + D(\ {}_c \quad)}_{\text{convective}}$$

adiabatic

convective

But $\quad |M_c| > |\bar{\ }| >> |\ {}_e = \bar{\ } + M_c|$

In other words, the computed large-scale vertical velocity is just the average of the (rare) cloud ascents and of a slightly sinking environment everywhere. Hence the large scale vertical advection term is dynamically meaningless (**but model-wise unavoidable**) and has to be compensated by a good estimate of the mass flux, slightly bigger thanks to surface evaporation (*back to WISHE*).

Thus, if QE is doubtful, the mass-flux parameterisation should never use the diagnosed large-scale vertical velocity as input.

What else do we have as input for the closure assumption?

- CAPE (**C**onvective **A**vailable **P**otential **E**nergy)
- CIN (**C**onvective **IN**hibition energy)
- Moisture convergence: a ‘good old concept’ first introduced by Kuo (1965, 1974) in order to get rid of convective adjustment.
- The Kuo-scheme:
  - ***Equations***: height independent time-scale for the return to a reference neutral ascent, separately in θ and q_v;
  - ***Closure***: humidity convergence (both of dynamical and surface evaporation origin) = rain fallout + moistening by detrainment;
  - A moist-adiabat for the ***cloud ascent***.

Basic picture of the ‘classical’ convection parameterization

Arakawa and Schubert 1974

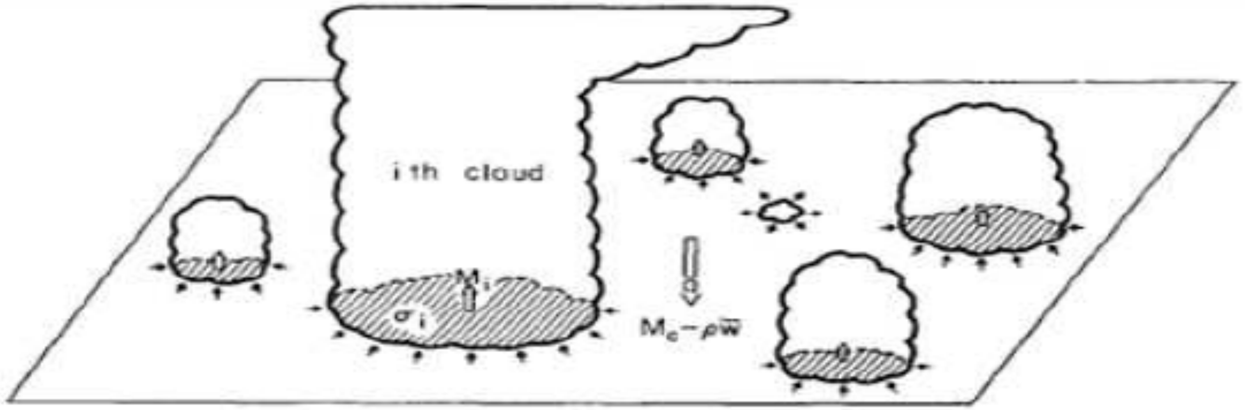
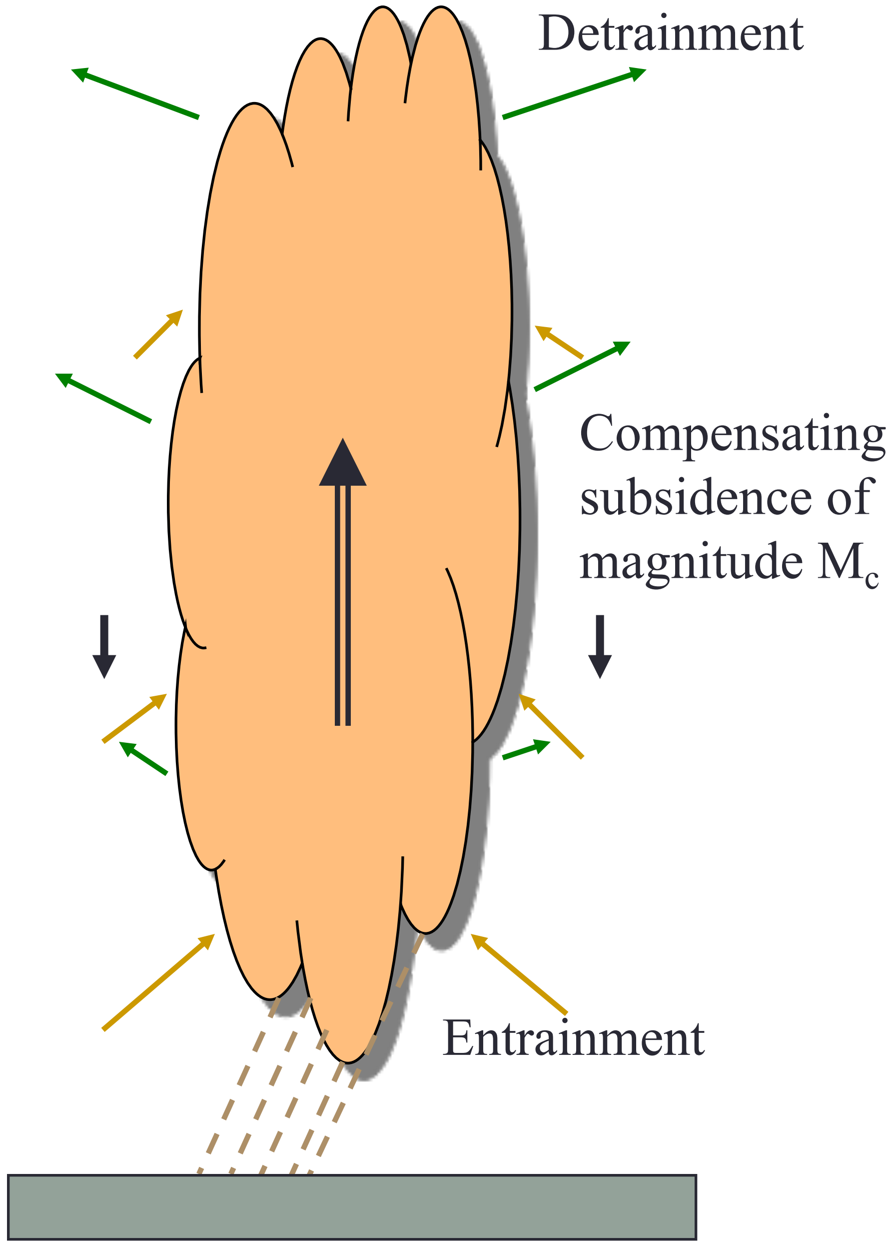


FIG. 1. A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

Scale separation in both space and time between cloud-scale and the large-scale environment ⇒ Convection characterised by ensemble of convective plumes within some area of tolerably uniform forcing.

The mass-flux approach



Hypotheses:

-steady cloud

-negligible updraft area

$$\frac{\bar{\ }}{t} = \frac{}{p}\left[M_c\left(\bar{\ } \quad {}_c\right)\right]$$

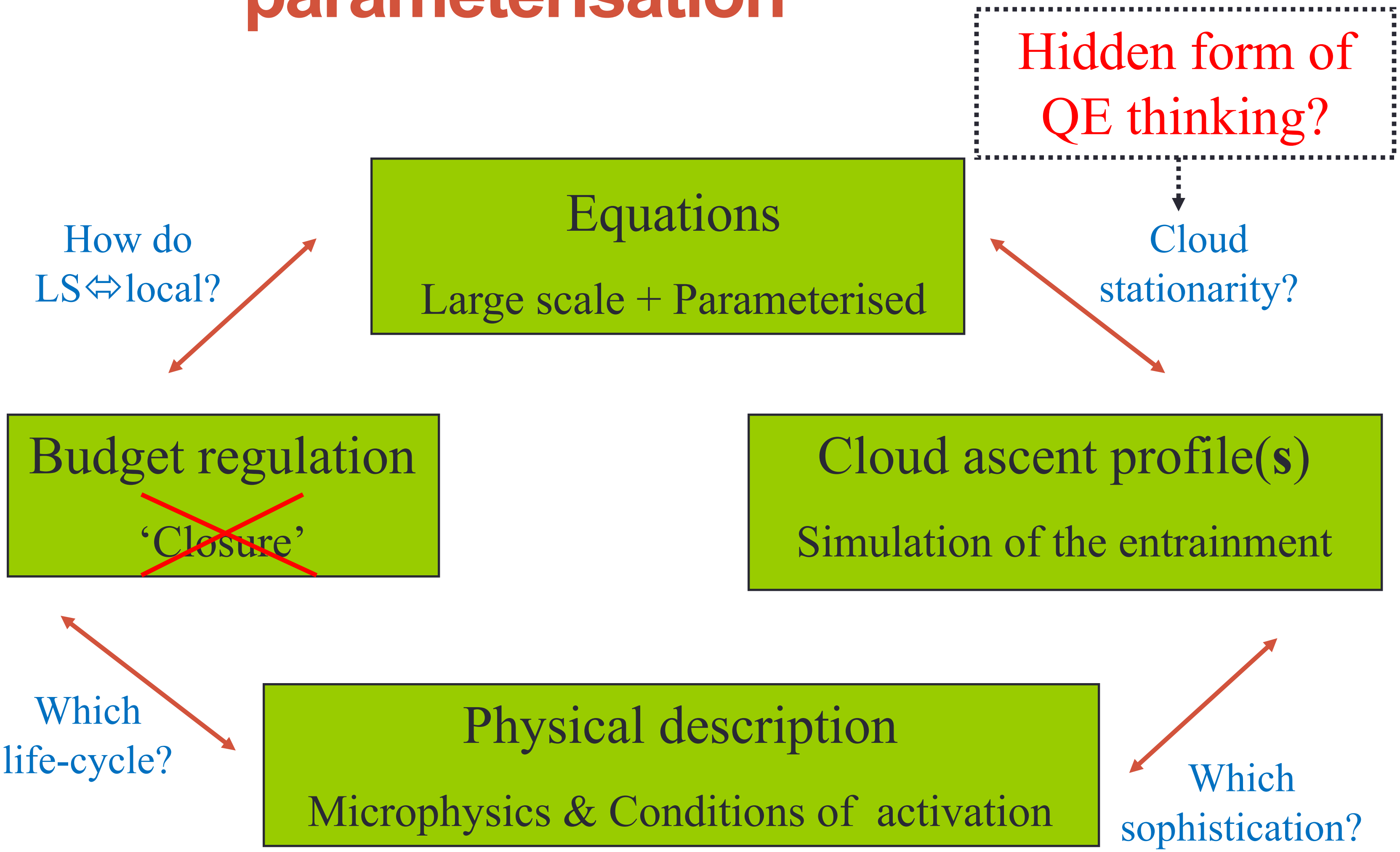
$$\frac{M_c}{p} = D \quad E$$

$$M_c \frac{{}_c}{p} = E\left({}_c \quad \bar{\ } \right)$$

Bulk approach

- The plumes do not interact directly, only with their environment $\Rightarrow$ If the plume equations are almost linear in mass flux then a summation over plumes will recover equations with the same form;
- So the ensemble of plumes can be represented as a single equivalent “bulk” plume => statistical assessment of the plumes’ population in the grid box.
- We get schemes based on Yanai 1973, Bougeault 1985..
- What happens when the model resolution increases – number of plumes in the grid box become less numerous and the statistical assessment does not hold any more: we enter the gray zone of moist deep convection.

Standard ingredients of a convective parameterisation



As conclusion for Lesson

- ***At the extreme opposite of the radiative transfer parameterisation, we did consider deep convection more as a problem of theory and classification than of equations and approximations. This view is surely exaggerated, be it only because of the many 'left-over' items. But, there is still a lot of truth into it. Here is the last refuge when believing 'parameterisation ≠ modelling'.***