Regime transitions in a parameterized world: where are/should the decisions be taken?

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Evolution of regimes

How does a GCM move between situations in which various processes is more or less important?

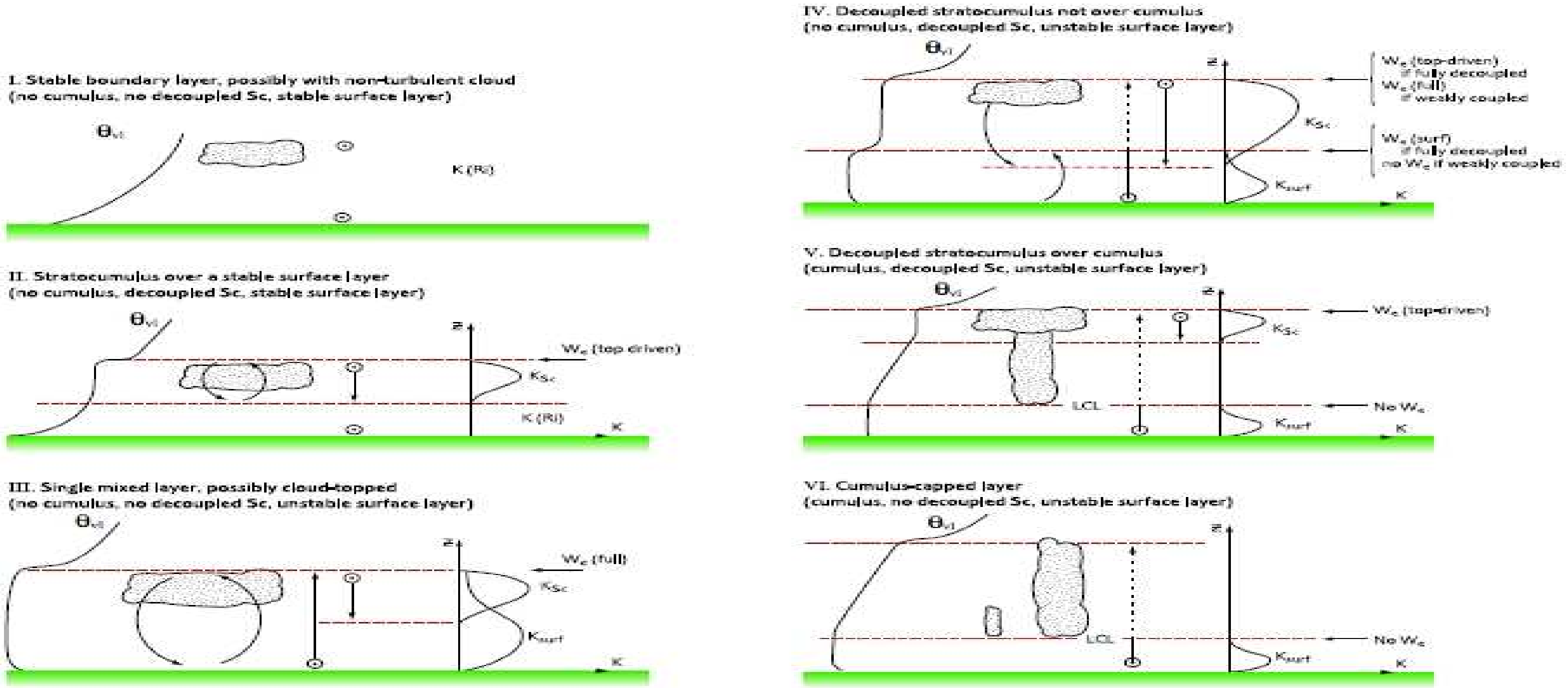
1. Complete separation of processes: only one active
2. Complete separation of the treatments but more than one may be active
3. Coupling processes through complex interactions
4. Coupling processes but with interactions only via an environment
5. Coupling processes outside of the GCM to derive an effective treatment of the combination

In practice, most GCMs are linking some things together in all of these ways!

I. Complete Separation

- Assume one process (or mode of behaviour) dominates
- Big advantage if modes often equilibriate and can be accurately described in isolation
- Desirable not to spend too long in marginal or intermediate regimes (else modes proliferate)
- Decision making process is essential for transitions
- Note decisions may be very sensitive to any noise in the model state around the time of transition

Boundary Layer Modes



- and 7th type (unstable shear-dominated introduced to improve morning transition)
- Stability decisions are very good against observations, other decisions much less so (Harvey et al 2014)

I. Complete Separation

Implications:

- Description of each mode should be as clean as possible: use idealized simulations
- Observations are best used to test the model by distinguishing the modes
- Observations must also flag-up “no mode assigned” or “multiple modes assigned”

II. Multiple processes

Multiple inter-related processes treated separately but each activated if each decision so dictates.
For example:

- Allow large-scale condensation if model state permits it
- Allow shallow convection if model state permits it
- Allow deep convection if model state permits it

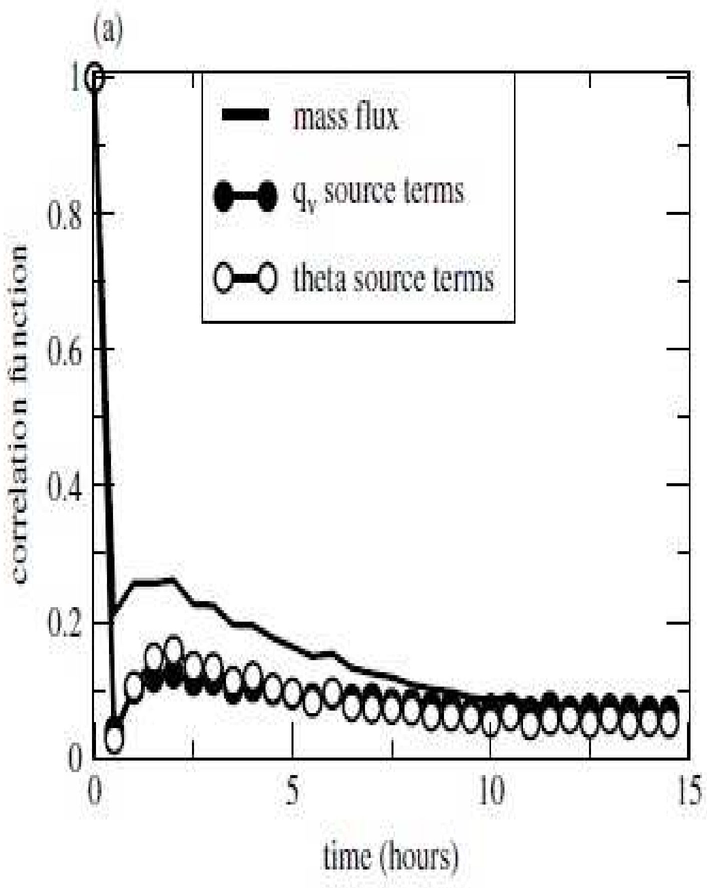
We face such situations in grey-zone regimes, when model dynamics is capable of acting but of course we do not control its decisions

II. Multiple processes

Implications:

- Still allows each process to be treated in isolation (which may or may not be desirable)
- Potential for double counting of a process
- The structure of the timestep matters
- Can very easily produce numerical artefacts
- Full model may not do what was intended

Artificial noise



(Stiller 2009)

- In a simple situation where we belong in a particular regime, it can be surprisingly difficult to stay there
- Convection schemes often produce on/off noise

Combining/unifying processes

Various approaches to unification in which processes are taken together:

- Interactions may be handled in complex ways
- Or relatively simply
- Or by effectively averaging to produce a simplified "effective" process

III. Complex interactions

Various attempts are being made to include cold pools explicitly in parameterization

- Likely an important transitional / organizational mechanism
- Updraft properties $\Rightarrow$ downdraft properties $\Rightarrow$ cold pool $\Rightarrow$ disturbed boundary layer $\Rightarrow$ modifies subsequent updraft triggering and/or properties $\Rightarrow$ ...

III. Complex interactions

Implications:

- We have to be cautious not to mistake complexity for sophistication
- e.g. if one of the links is weak then little or no value arises from dveloping many details elsewhere
- (Personally I worry about the downdrafts)
- Key issue: is the full system reasonably robust such that it reliably maintains the correct regime, or are there delicate sensitivites that we must learn and target?

IV. Interactions via environment

- Quasi-independent process types with simple mediation
- A good example is a spectral plume representation (Arakawa and Schubert 1974)
- The cloud types do not interact directly: only via their environment

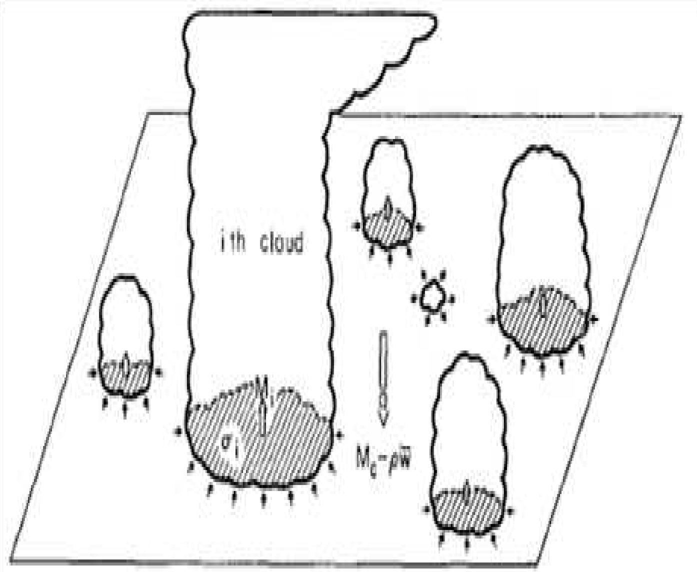
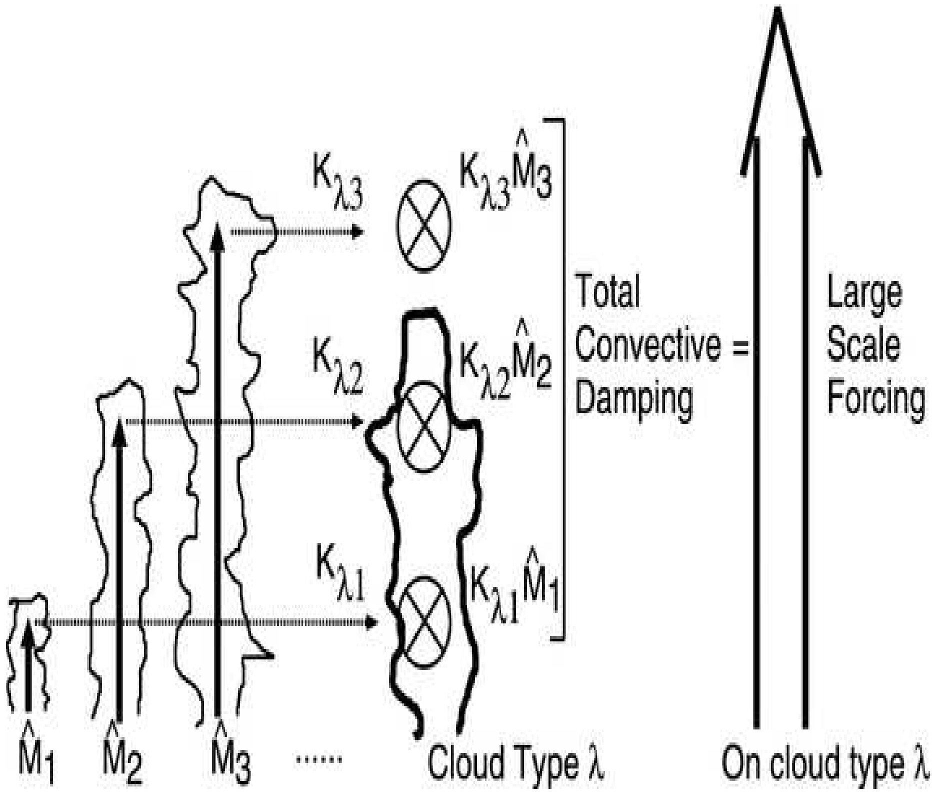


FIG. 1. A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

IV. Interactions via environment



$$\sum_j \mathcal{K}_{ij} M_{B,j} = F_i$$

- F_i is known from the GCM
- $\mathcal{K}_{ij}$ is known from the plume model
- Invert matrix $\mathcal{K}$ to get $M_{B,j}$

IV. Interactions via environment

Implications:

- If valid, improves on II in that the interplay between closely-related processes can be controlled
- e.g. interactions of deep and shallow convection treated self-consistently without concern for the sequencing
- But need to identify a environmental quantity that controls each interacting process to evaluate F and $\mathcal{K}$

V. Construct an effective process

- Sum over the spectrum to produce an effective “bulk” form
- Many examples in convection schemes...
- If the plume equations are linear in mass flux for each type, then bulk plume has equations with the same structural form

V. Construct an effective process

Implications:

- The big advantage is the simplicity whilst retaining the basic structure
- We can't easily observe the "effective" cloud!
- Entrainment/detrainment has to encode both the dynamics of an updraft *and* implicit assumptions about spectrum distribution
- Microphysics has to be built on effective, bulk variables
- Actually, important things are not linear

Summary

- How a model makes a regime transition must depend on how the regimes are represented by the model
- For .XOR. system everything hinges on the decision making, and instantly switch between equilibrium regimes
- If multiple processes involved, it is the way they couple that is likely most important during transitions
- The way we couple dictates how we need to improve the parameterizations: must look at full GCM not just one scheme!
- $\Rightarrow$ it may be entirely natural that focus in handling shallow $\longrightarrow$ deep transitions has been placed on entrainment, closure, representing cold pools etc

References

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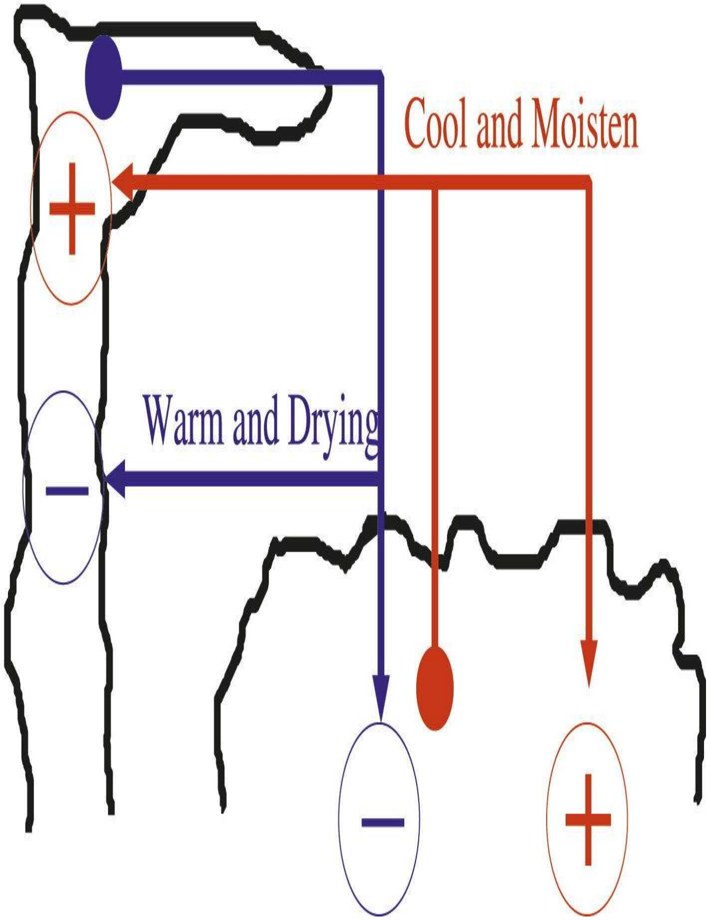
- Stiller (2009). Efficient moist physics schemes for data assimilation. II: Deep convection. *QJRMS*, **135**, 721–738.
- Yano and Plant (2012). Convective quasi-equilibrium. *RG4004*, **50**.

Extras, in case useful

IV. Interaction via environment



- Deep convection consumes instability and damps all convection types
- In some situations, shallow convection can pre-condition atmosphere for deep convection, giving +ve feedbacks

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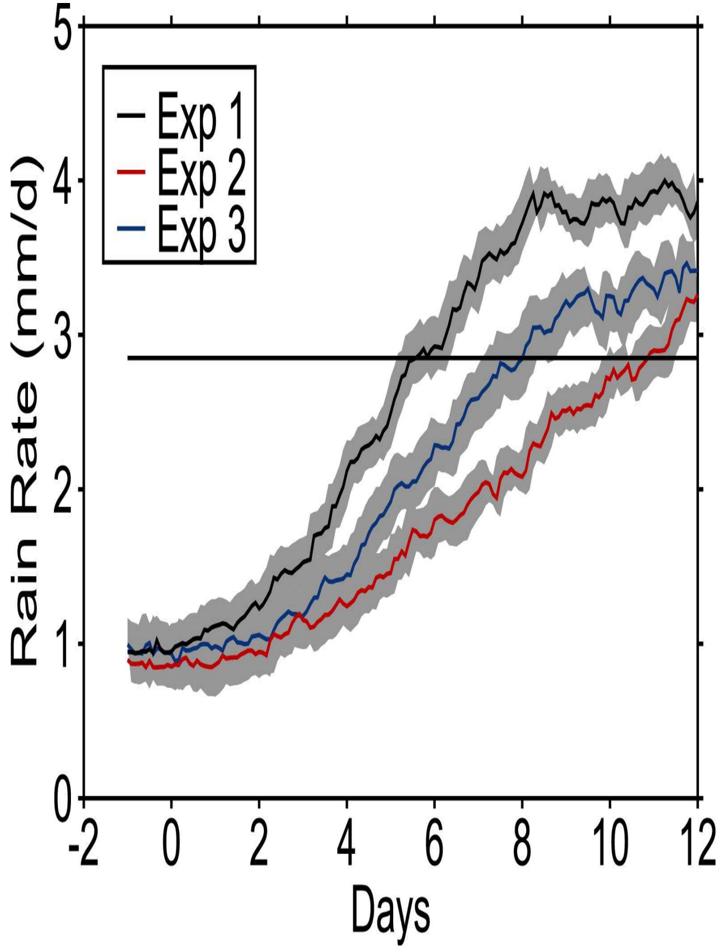
Transition mechanisms



- 2 columns coupled via WTG (Daleu et al 2014)
- Exp1: transition by increasing local SST
- Exp2: transition by reducing remote SST (removing suppressing circulation)
- Exp3: increase local and reduce remote SSTs