Comparing convective memory in different schemes with imposed fixed RCE state

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The "diagnostic" assumption

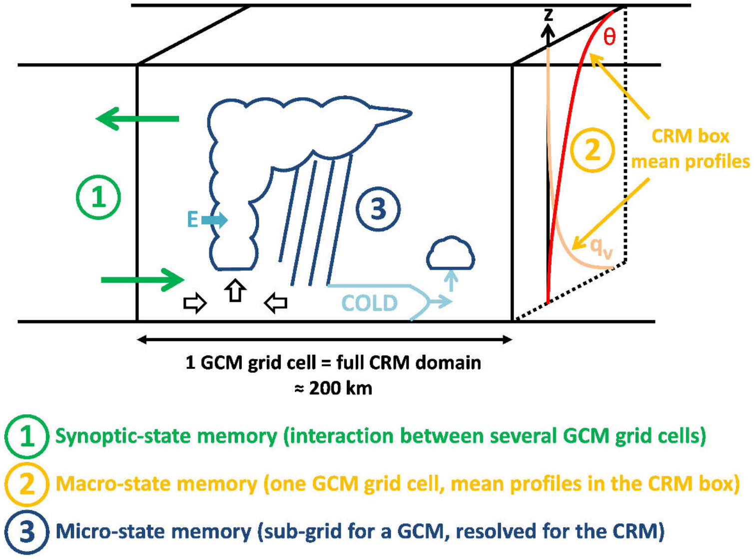
- We usually assume that $$C(x,t)=f[\xi(x,t)]$$

  with C = convective activity at position x, at time t

  ξ = environmental large-scale conditions, at (x,t)

- It's a natural hypothesis for
  - Traditional parameterisations
  - Observations analysis: to generalise relationships
- Valid as long as scales are large enough
- But less valid with increasing resolution

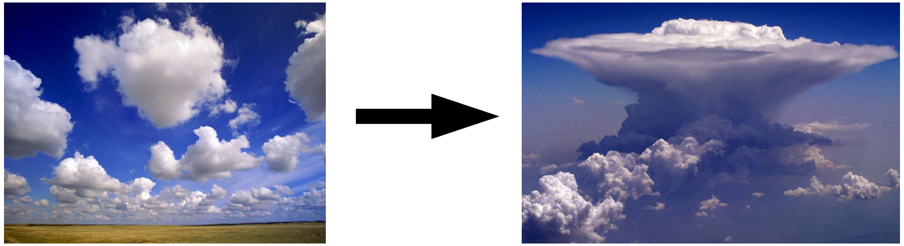
→ How to do beyond this problem ?

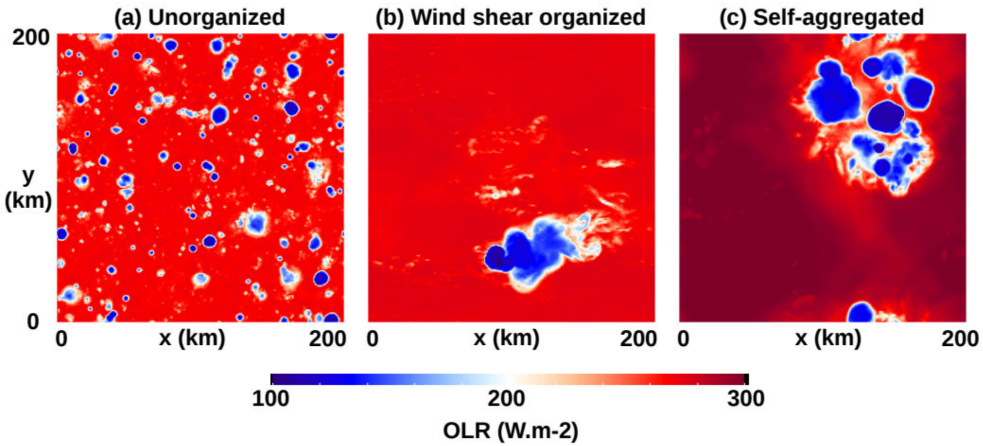


Colin et al 2019

Convective memory

- There is memory when, for given large-scale conditions (macrostate), convection depends on its own history (microstate).
- Many processes can contribute to memory (cold pools, energy cycle, varying entrainment, etc...)
- Memory related to small-scale processes comes from MSE structures (thermodynamics, humidity) at low levels (*Colin et al 2019*).
- It increases with spatial organisation
- *Daleu et al 2020*: convective memory is only important for scales smaller than 25 km for disorganised convection over land
- Already added in many models. But no consensus ?





Colin et al 2019

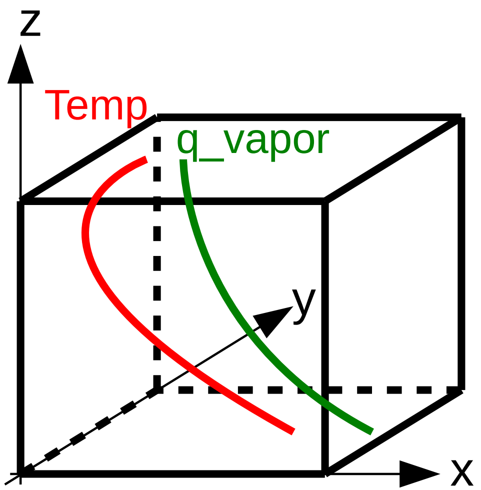
Questions

- We want to isolate and study small-scale (unresolved) memory, without being affected by large-scale influence.

$$C(x,t)=f[\xi(x,t)]$$

- To what extent convection is determined by anything else than large-scale state variables (thermodynamic variables, winds) ?

→ use of a fixed large-scale state setup



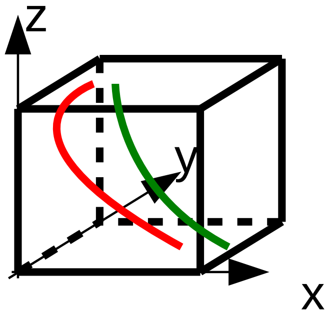
Idealised CRM simulations: method

- WRF model in RCE over ocean
- Domain: 200 km * 200 km
- Resolution = 1km : deep convection is resolved
- Interactive radiation, boundary layer scheme active
- SST = 302 K
- No rotation
- Doubly periodic boundary conditions

- We add a relaxation term (strong nudging) on mean (T,q,u,v) values, towards target profiles computed from the RCE state : we can control the large-scale state.

  → a bit like WTHG (instead of WTG)

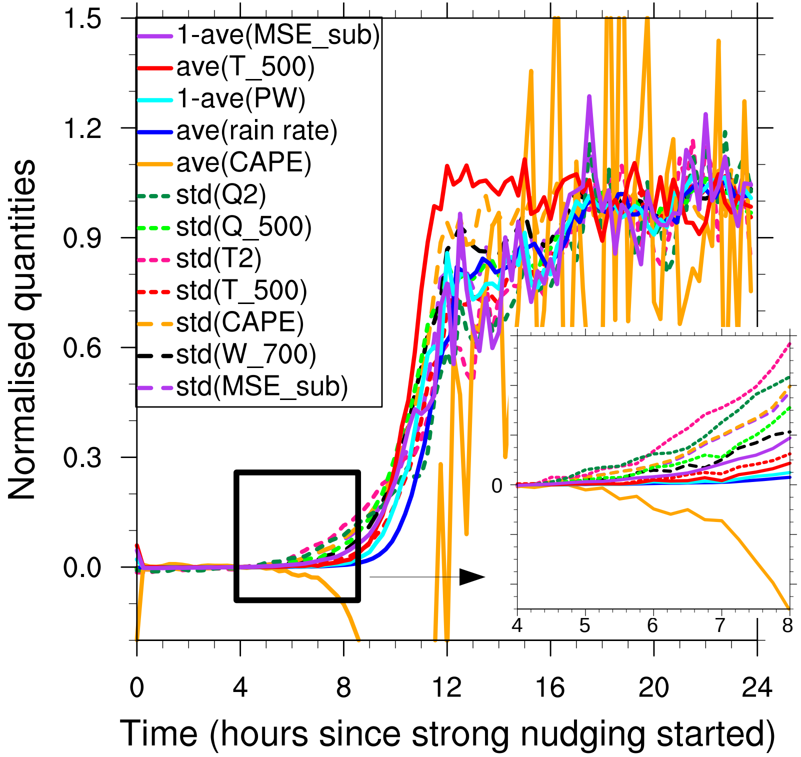
$$\frac{\partial u}{\partial t} = -\frac{1}{\tau}\left(\overline{u} - \overline{u}_{target}\right)$$

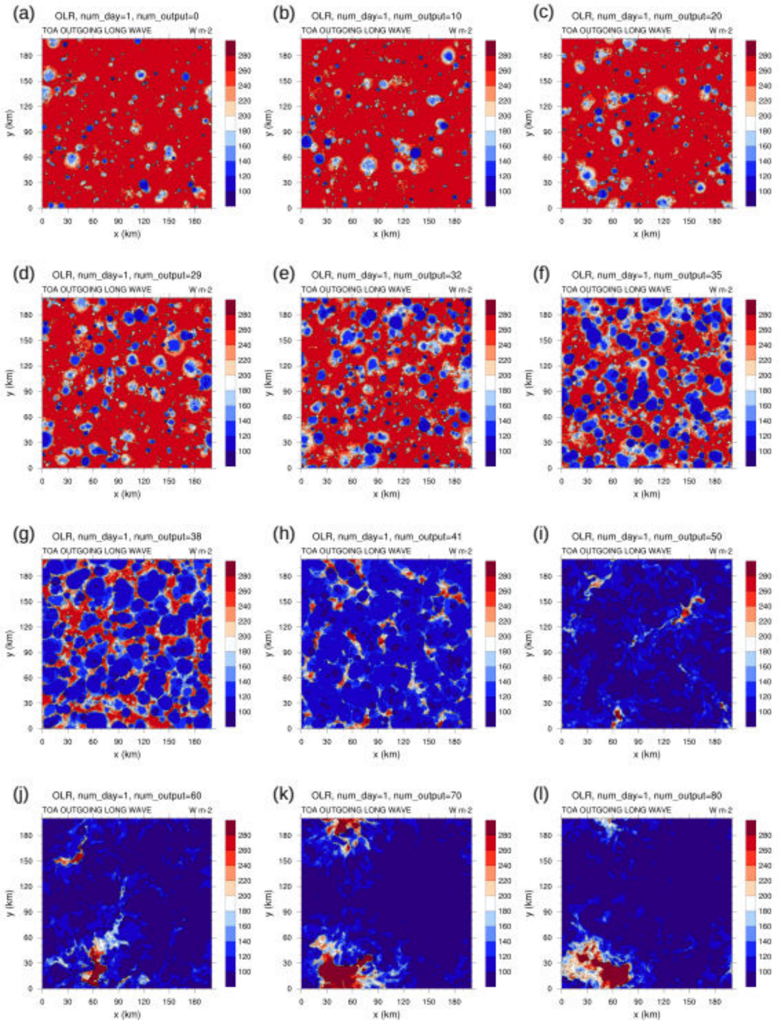


- We repeat the experiments on ~ 10 members

Idealised CRM simulations: results

- The situation is unstable
- 2 cases: exponential growth, or exponential decay





Colin and Sherwood 2021 (in revision)

Predator-prey model of convection

Model with 3 variables, including 2 prognostic ones (with memory).

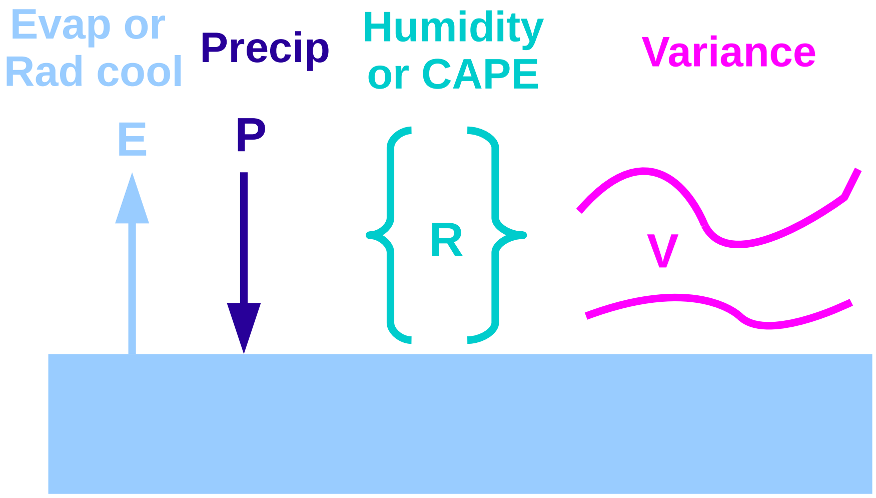
$$\frac{\partial R}{\partial t} = E - P$$

$$\frac{\partial V}{\partial t} = -\alpha_{damp} V + \alpha_{Vp} P + \varepsilon_V$$

$$P = \alpha_p R V \varepsilon_P$$

- Predator: V (microstate)
- Prey: R (macrostate)

→ Roel Neggers's decentralised approach?



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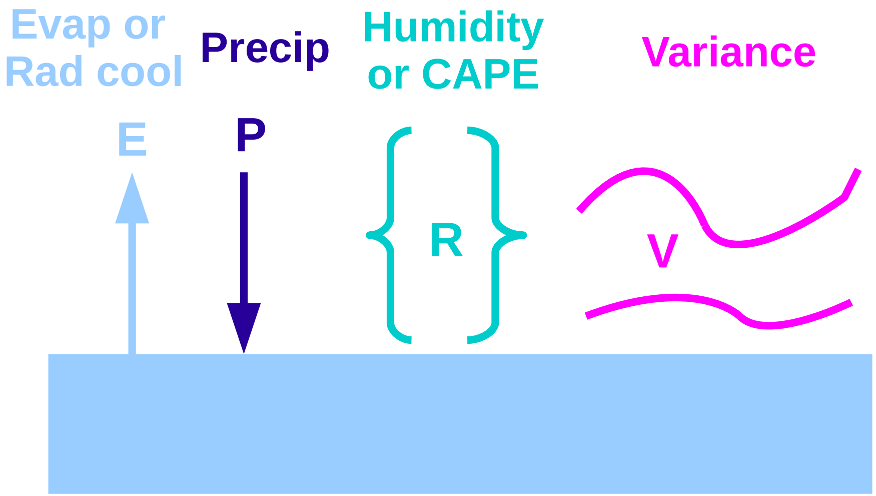
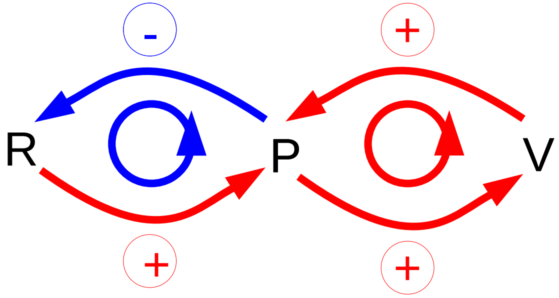
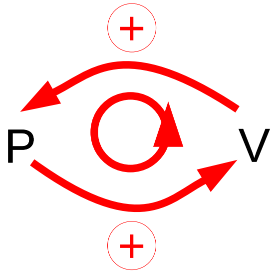


- Control simulations (RCE)



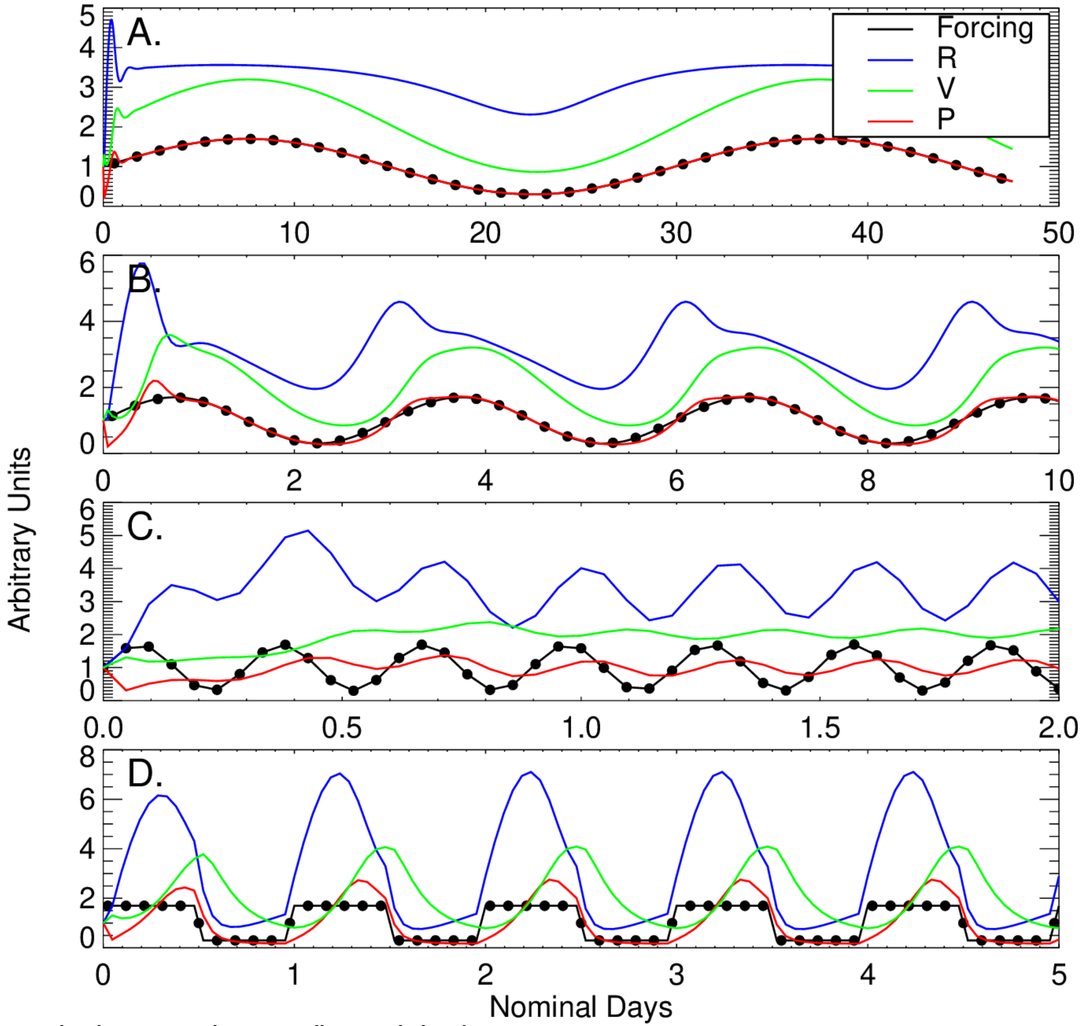
Stable

- Fixed large-scale state (macrostate) $\frac{\partial R}{\partial t} = 0$



Unstable

Predator-prey model of convection: large-scale waves



Colin and Sherwood 2021 (in revision)

- Forcing by a periodic wave
- Quasi-equilibrium for long and medium scales.
  P is in phase with the forcing (since R is leading, V is lagging)
- For smaller scales, P lags the forcing
- For a “diurnal cycle” forcing, R peaks around noon, P peaks in the afternoon
- NOTE: The lag relationships between R, V, P can also be detected in ARM observations.

Idealised SCM simulations: method

- Question: Are the previous behaviours also found in GCMs ?

- LMDZ, WRF, CAM models in SCM : RCE over ocean ("convective playground")
- We can test different parameterisations (e.g., WRF), and different versions of a scheme (e.g., LMDZ)

- We impose a fixed large-scale state (instead of nudging). Two methods are possible:
  - Fixing all large-scale variables input to the scheme, leaving free only the variables which represent small-scale structures ($\delta T_{wak}, \delta q_{wak}, \sigma_{wak}, D_w$ in LMDZ)
  - Fixing only (T,q,u,v), as in the CRM, towards target profiles computed from the RCE state

- General strategy:

  1. Let each model and configuration find its RCE state
  2. Computing the target profiles to be imposed from that RCE state
  3. Simulation under fixed large-scale conditions

- Be mindful if convection is not triggered with the target profile

Idealised SCM simulations: method

Courtesy of Yi-Ling Hwong

Input scheme variables
(large-scale state, macrostate)

	KFETA	NTIEDTKE	NSAS	BMJ	CAMZM	GF
T	x	x	x	x	x	x
TH	x			x	x	
QV	x	x	x	x	x	x
QC		x	x			
QI		x	x			
P	x	x	x	x	x	x
U	x	x	x		x	x
V	x	x	x		x	x
W	x	x	x			x
RHO	x	x	x	x		x
DZ8W	x	x	x	x	x	x
PI	x	x	x	x	x	x
HFX		x	x		x	x
QFX		x	x		x	x
PBLH			x		x	
KPBL				x	x	x
HT					x	x

But also:
- NTIEDTKE: rthften, rqvften (total advective potential temperature and moisture tendencies)
- CAMZM: TKE_PBL, z, CLDFRA, MAVAIL (soil moisture availability), Psfc, TSK, U*

Idealised SCM simulations: first results

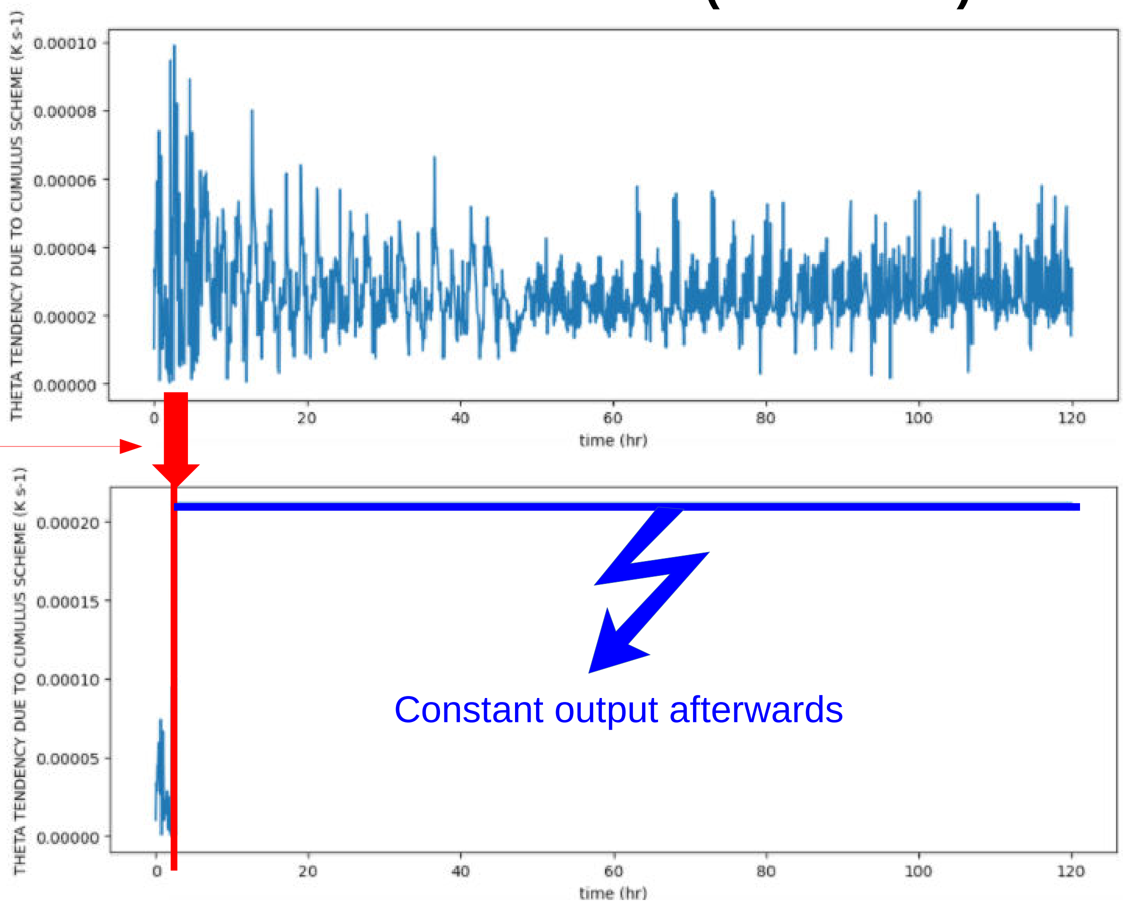
Convective Theta tendencies

WRF - New Tiedtke (NTIEDTKE)

RCE (CTRL)

We start to impose the large-scale state at that time

Fixed large-scale state



This scheme leads to constant output under fixed large-scale conditions: no memory

Courtesy of Yi-Ling Hwong

Conclusion

1. Method using RCE but with imposed fixed large-scale state (fixed to the RCE values).

2. CRM: exponential growth or decay of convection. The RCE state is unstable here, so the large-scale state is not sufficient to predict convective evolution (memory).

3. Predator-prey model: a positive feedback via small-scale heterogeneities, a negative feedback via the large-scale mean state.

4. This simple model with memory captures reasonably well the effects of large-scale waves on convection.

5. This configuration in SCM is still being tested. But it could become an additional SCM test to guide parameterisation development: are they sensitive to anything else than large-scale mean profiles (in particular to convective history)?

References

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Just South of Darwin, Australia

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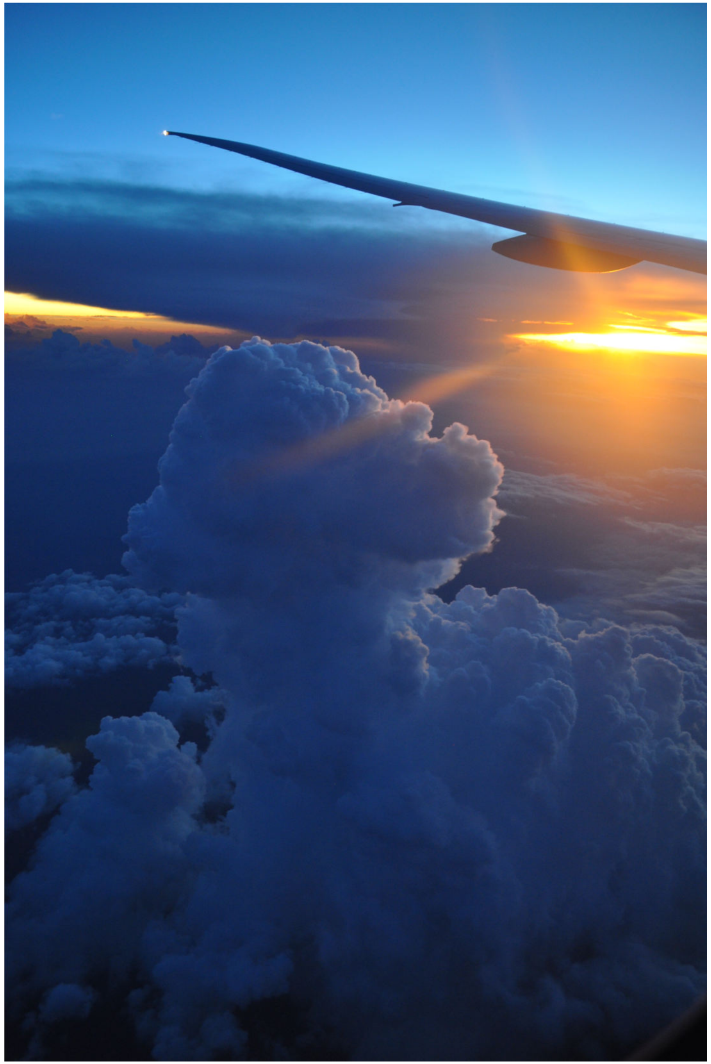
Maxime Colin

Just South of Darwin, Australia



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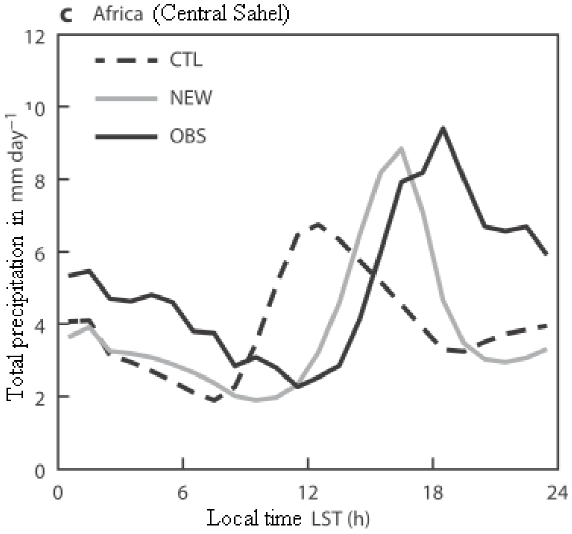
Extra slides

Some issues in GCMs

- It rains too often, too little (*Stephens et al 2010, Hourdin et al 2020*)
- Diurnal cycle (*Rio et al 2009, Bechtold et al 2014*).
- A challenge: capturing a realistic spatial organisation of convection.
- Weak entrainment leads to a better mean state, but high entrainment leads to better variability.



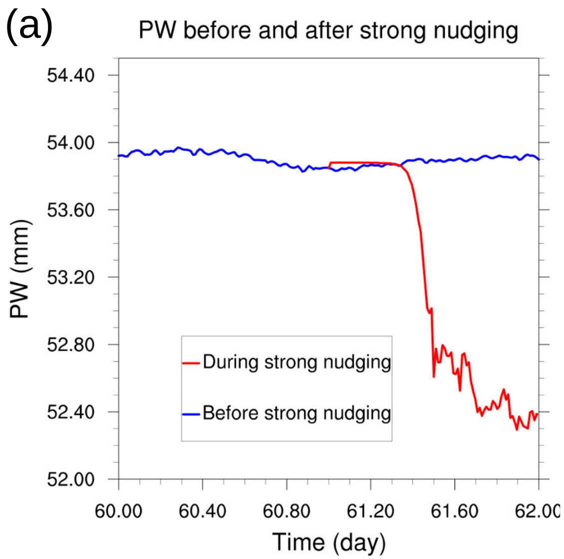
Bechtold et al 2014

- Despite important improvements...

→ Invitation to rethink some aspects of convection

Idealised CRM simulations: results

- The situation is unstable
- 2 cases: exponential growth, or exponential decay
- Nudging is very effective for 6-8h, but fails afterwards
- Impact of nudging terms
- Instability which grows from low-level thermodynamic variances



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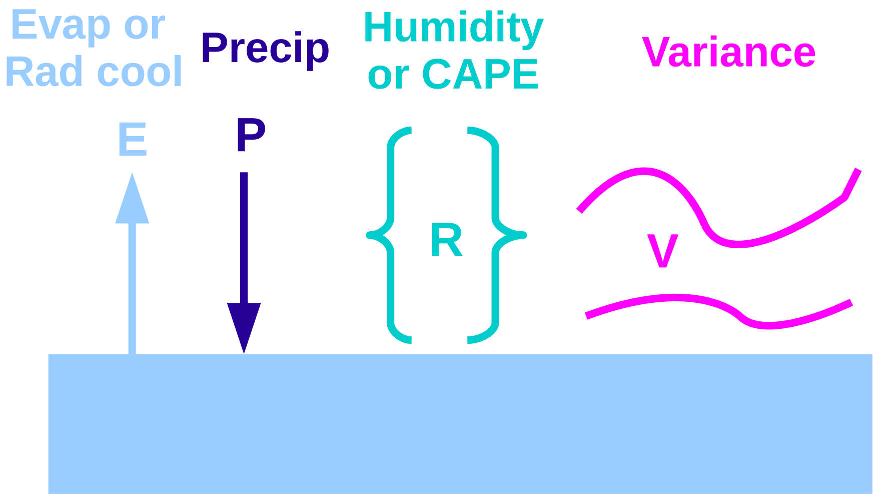


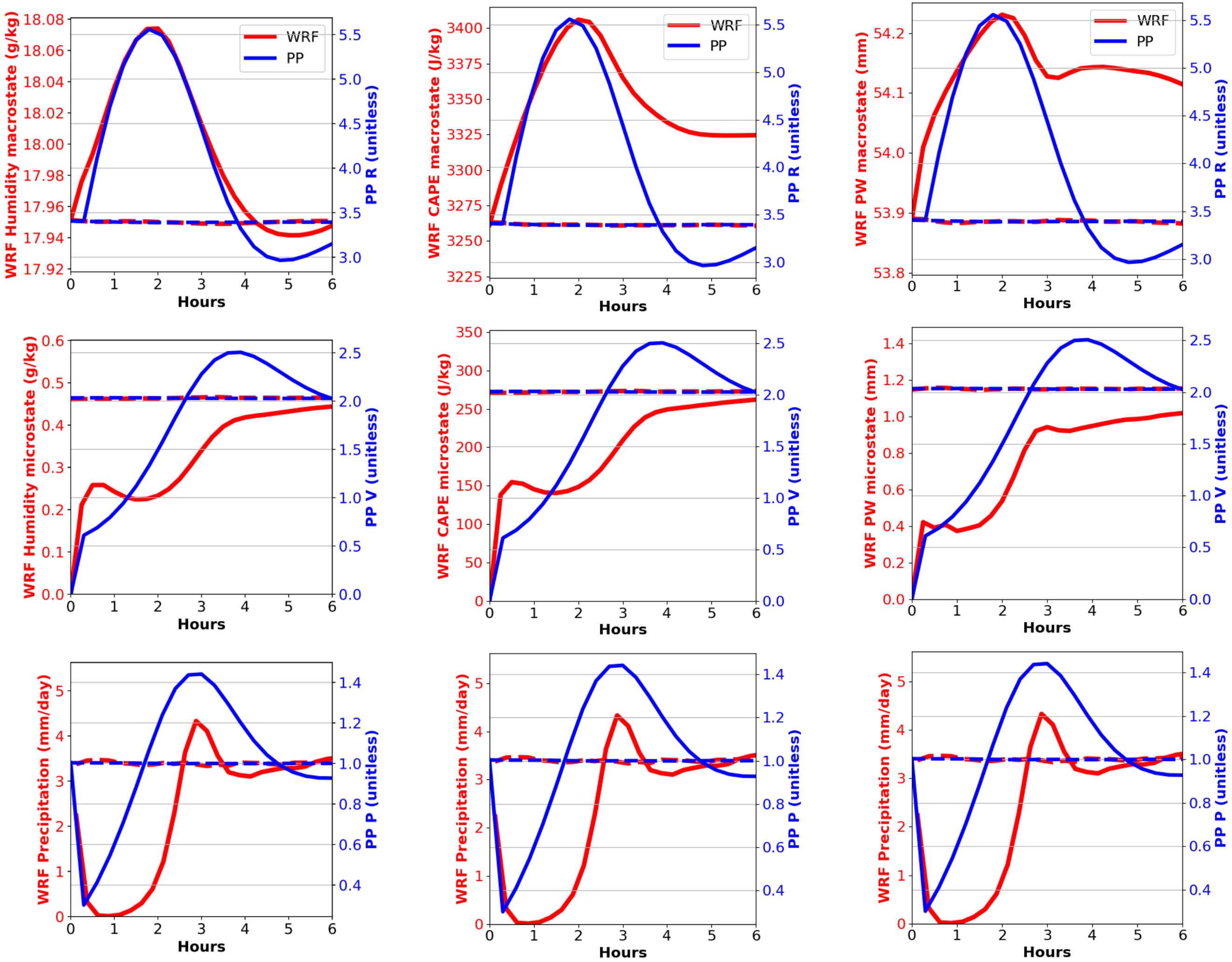
- Under fixed large-scale conditions:

  $\frac{\partial R}{\partial t} = 0$ so two equations remain

  $\frac{\partial V}{\partial t} = \alpha_{Vp} \alpha_P (R_0 - R_{RCE}) V$ $\rightarrow$ exponential solution

- The predator-prey model captures several CRM behaviours:
  - Oscillations after homogenising
  - Fixed large-scale state

Predator-prey model of convection with memory



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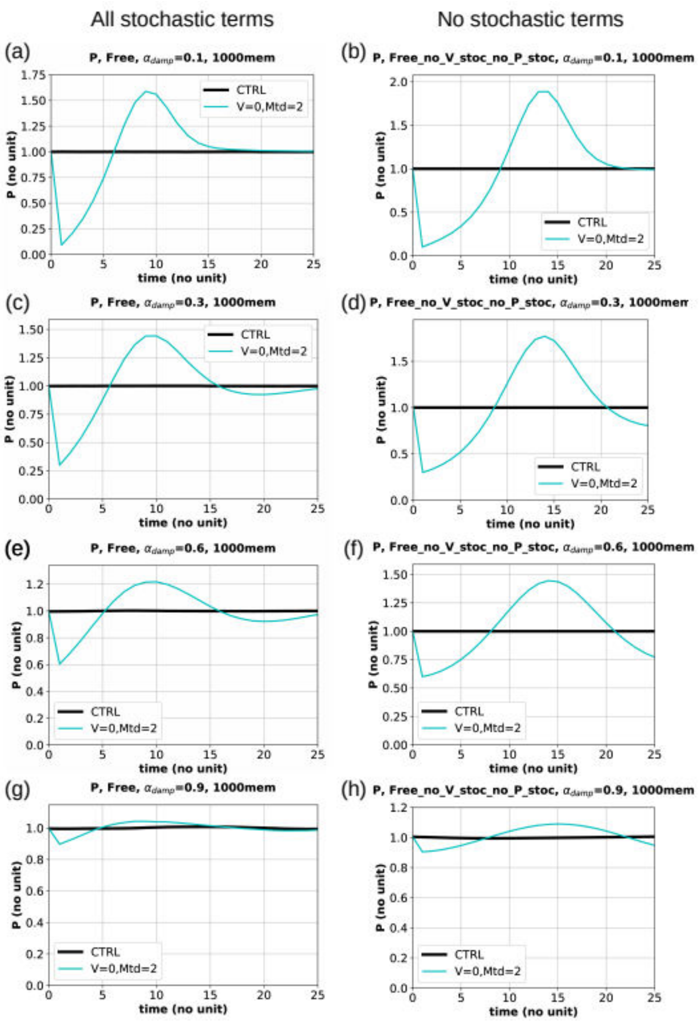

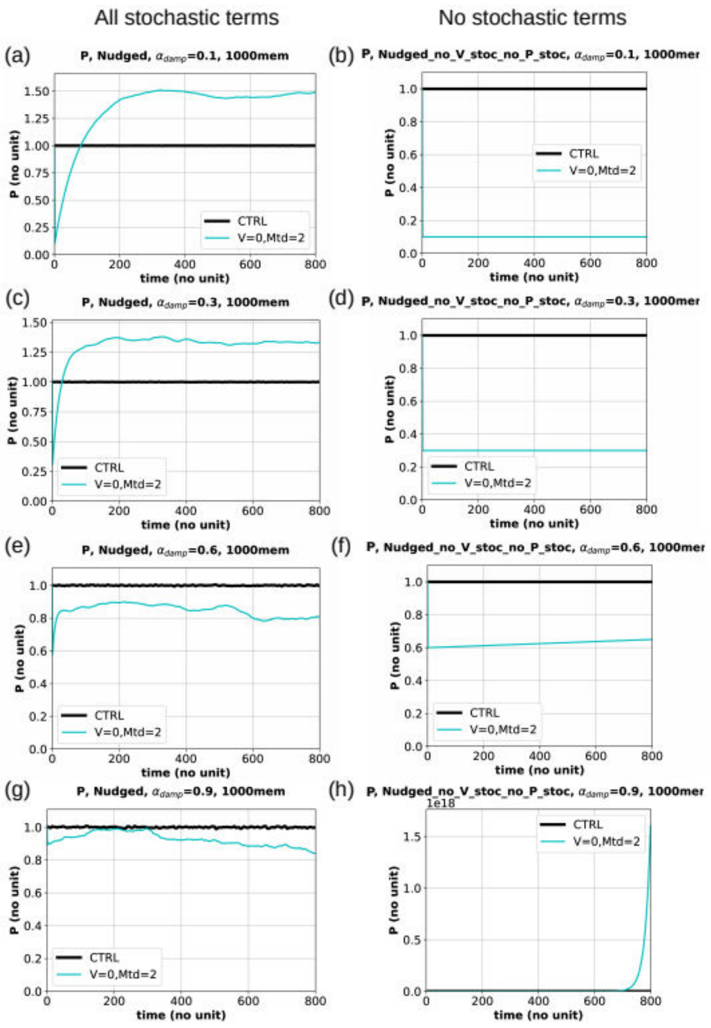

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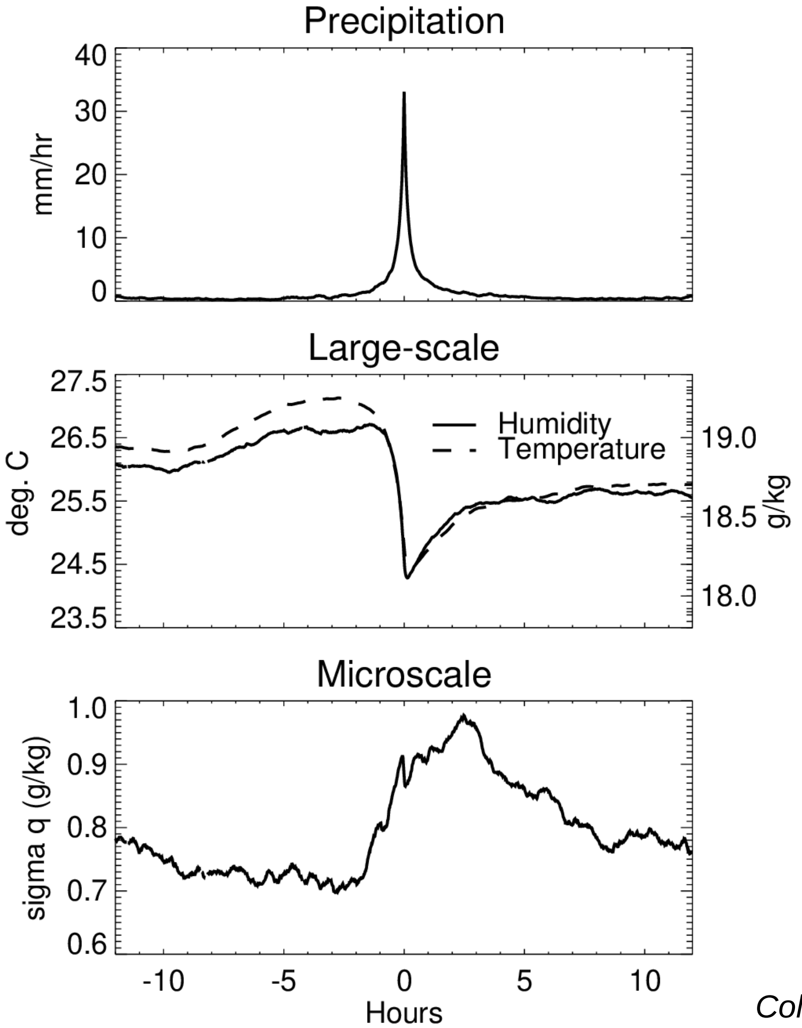
Predator-prey model of convection: observations



- The lag relationships between R, V, P can also be detected in ARM observations.

Colin and Sherwood 2021 (in revision)

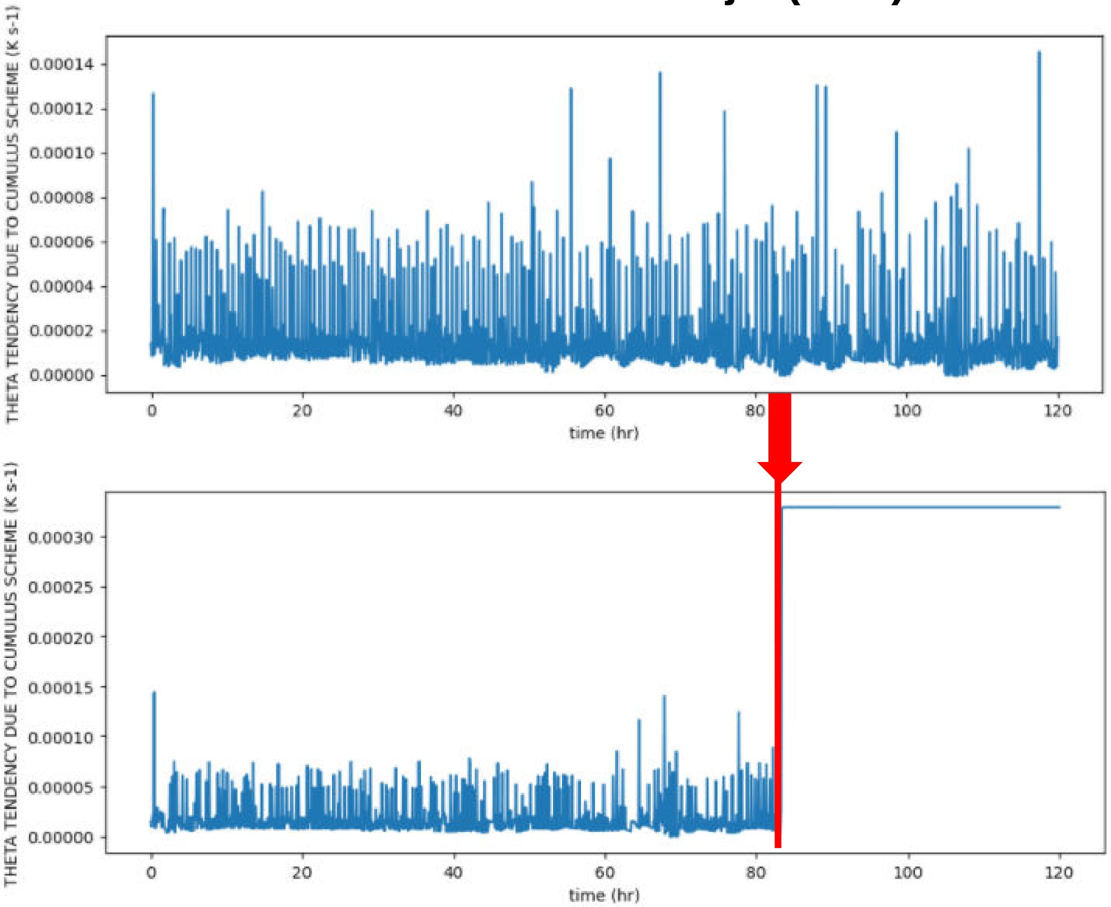
Idealised SCM simulations: first results

Convective Theta tendencies

RCE (CTRL)

Fixed large-scale state

WRF - Betts-Miller-Janjic (BMJ)



Courtesy of Yi-Ling Hwong

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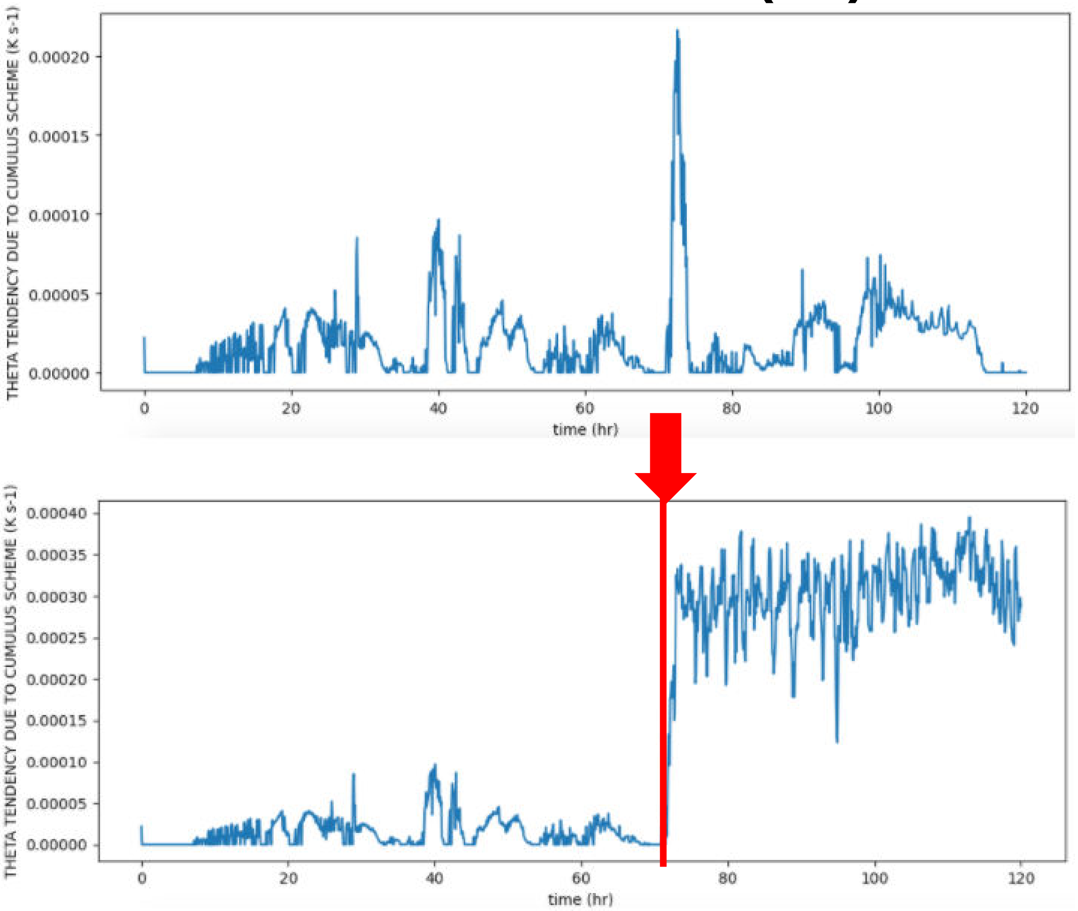
Fixed large-scale state

WRF - Grell-Freitas (GF)

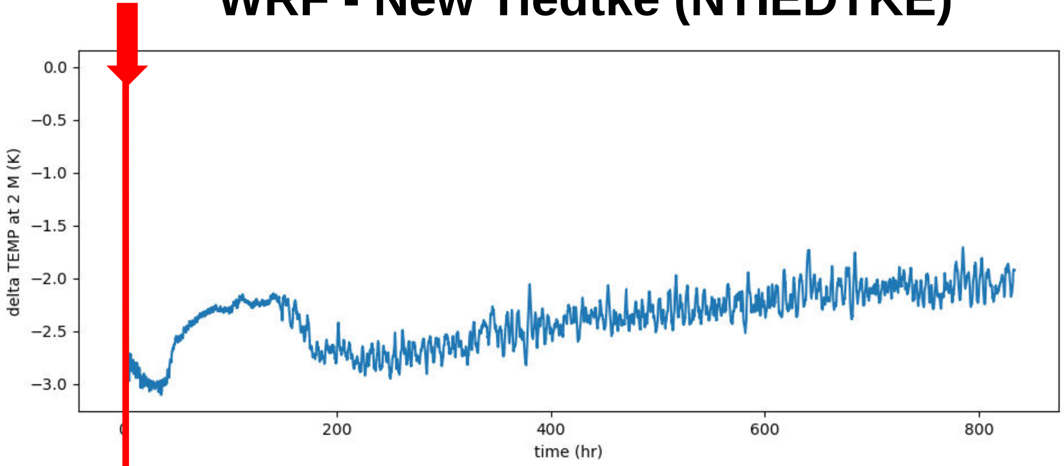


Courtesy of Yi-Ling Hwong

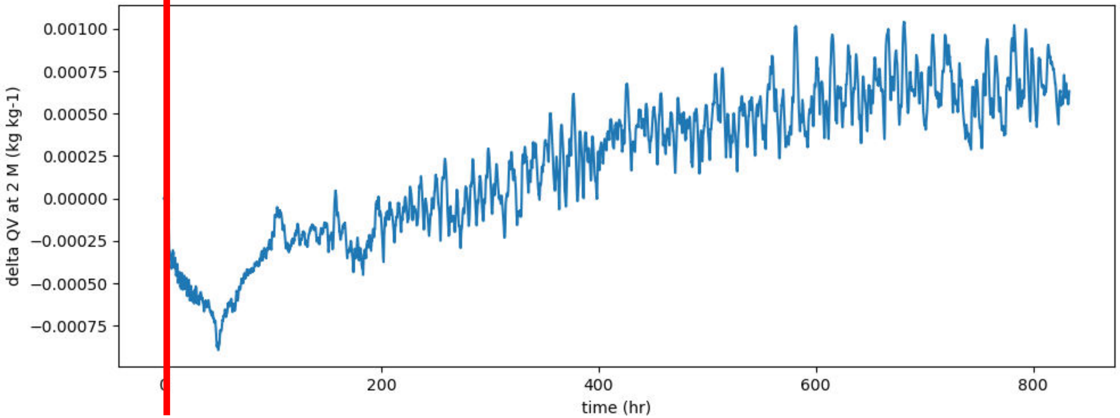
Idealised SCM simulations: first results

WRF - New Tiedtke (NTIEDTKE)

δT2 (Fixed large-scale state - RCE)



δQ2 (Fixed large-scale state - RCE)



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