Where does the memory of convection stem from? Why can it be useful for parameterizations?

D'où vient la mémoire de la convection ?
En quoi cela peut-il être utile pour les paramétrisations ?

Maxime Colin, Steven Sherwood

Sandrine Bony, Jean-Yves Grandpeix, David Fuchs, Olivier Geoffroy, Nidhi Nishant. Jason Evans

1) What is the "memory of convection"?

- Convective memory: how much similarity there is between the current convective state and the previous convective states.

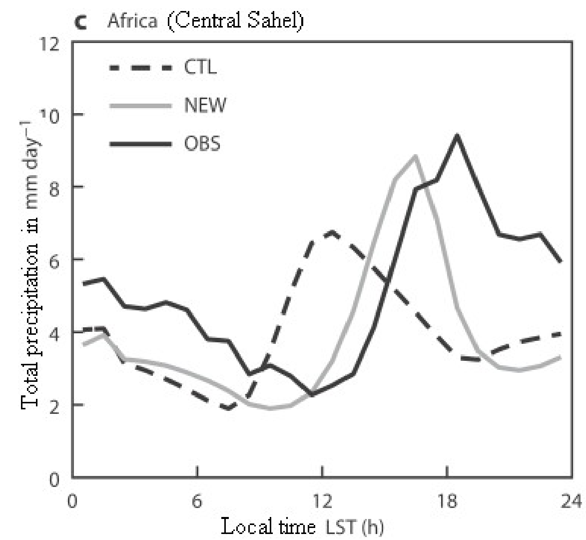
  → persistence of clouds in time !

  Convective state: strength and localisation of convection (precipitation...)

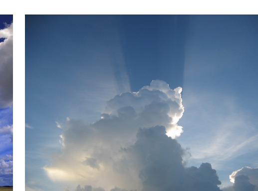
- GCM: we usually assume quasi-equilibrium convection (CAPE is released instantaneously: the response of convection is in phase with the solar forcing)

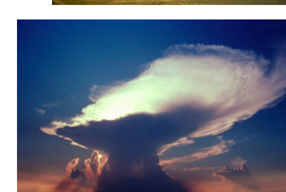
  In reality: non-equilibrium convection (ex: diurnal cycle)

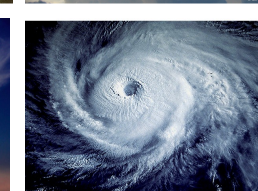
  Convective memory: the departure from equilibrium convection



From Bechtold et al 2013

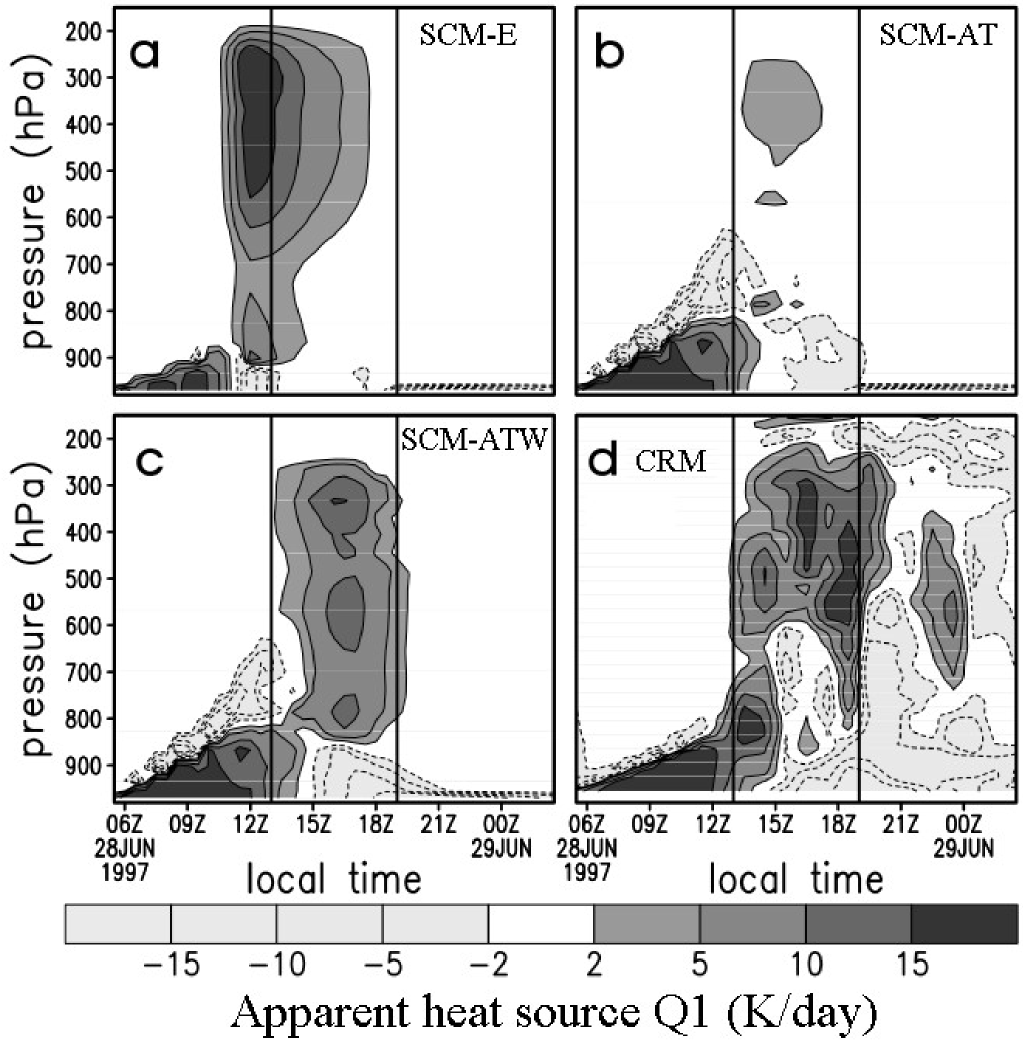






2) Why studying convective memory?

- 1st reason: it happens in real life!
- Diurnal cycle: delay in the response of convection.



From Rio et al 2009

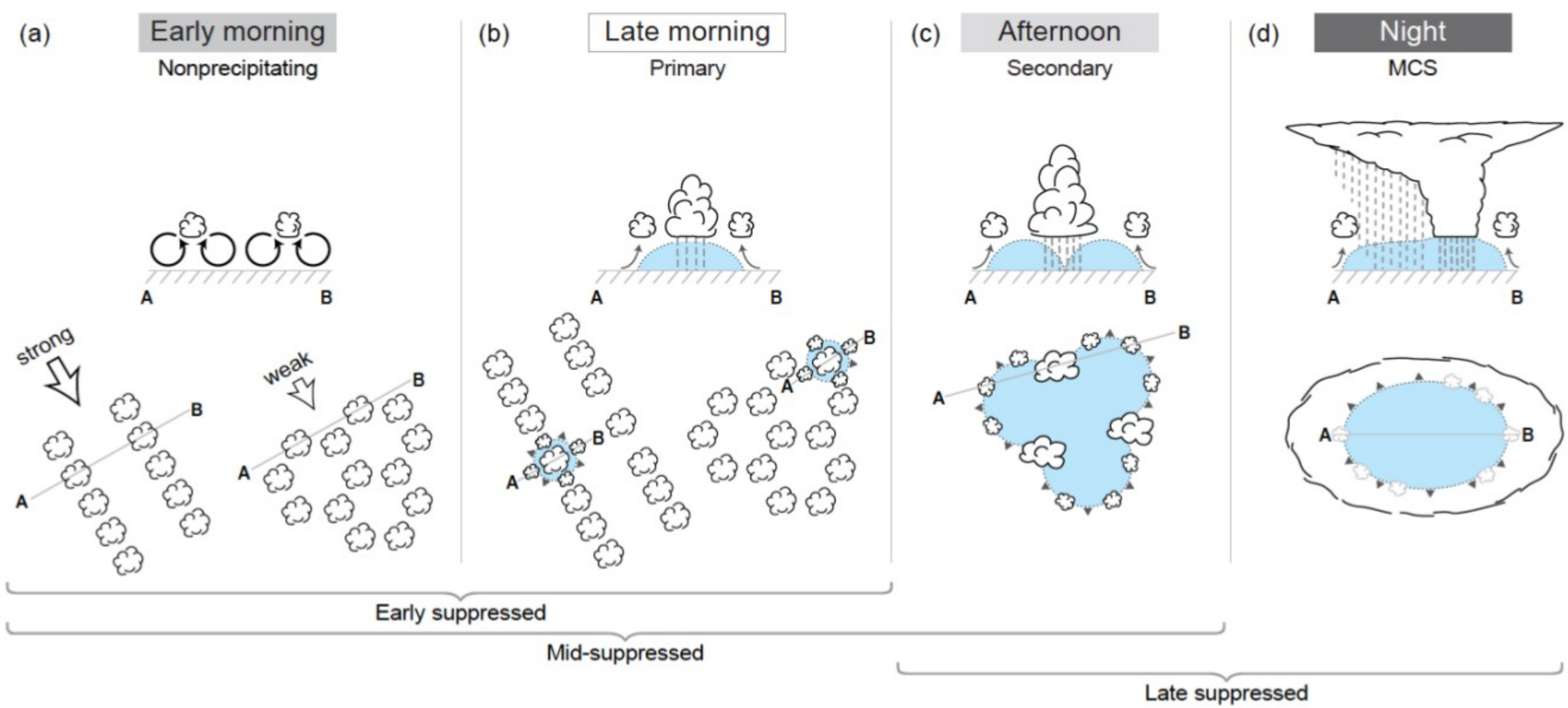
2) Why studying convective memory?

- There is spatial organisation of convection (MCS, cold pools, etc...)

  → influence on the future development of convection

  → Memory (inertia, persistence)

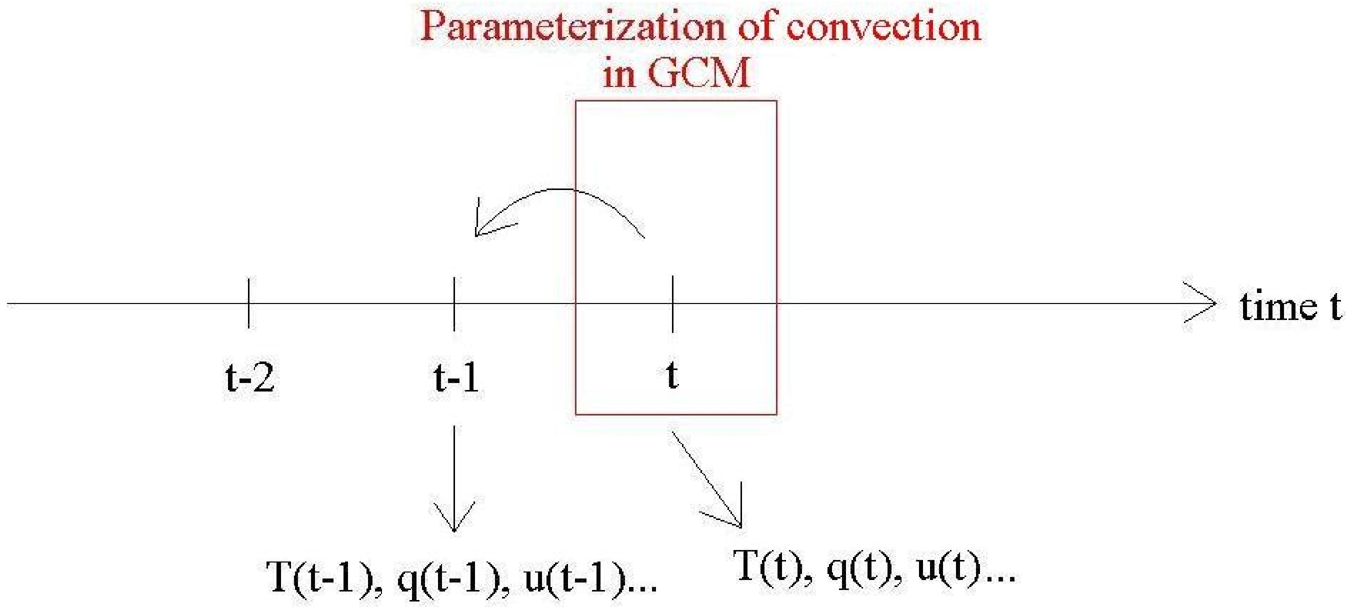
Credit: Business Insider Indonesia (picture taken in the US, Nebraska)



From Rowe and Houze 2015

2) Why studying convective memory?

- 2nd reason: a practical use for the parameterizations (Diagnosis of the issue in GCMs)



- Usually, parameterizations in GCMs use large-scale variables at instant t ONLY.
- But they do not look back in time.
- 2 types of parameterizations:
  - Physical (process-based),
  - Empirical (overall effects)

2) Previous studies about convective memory

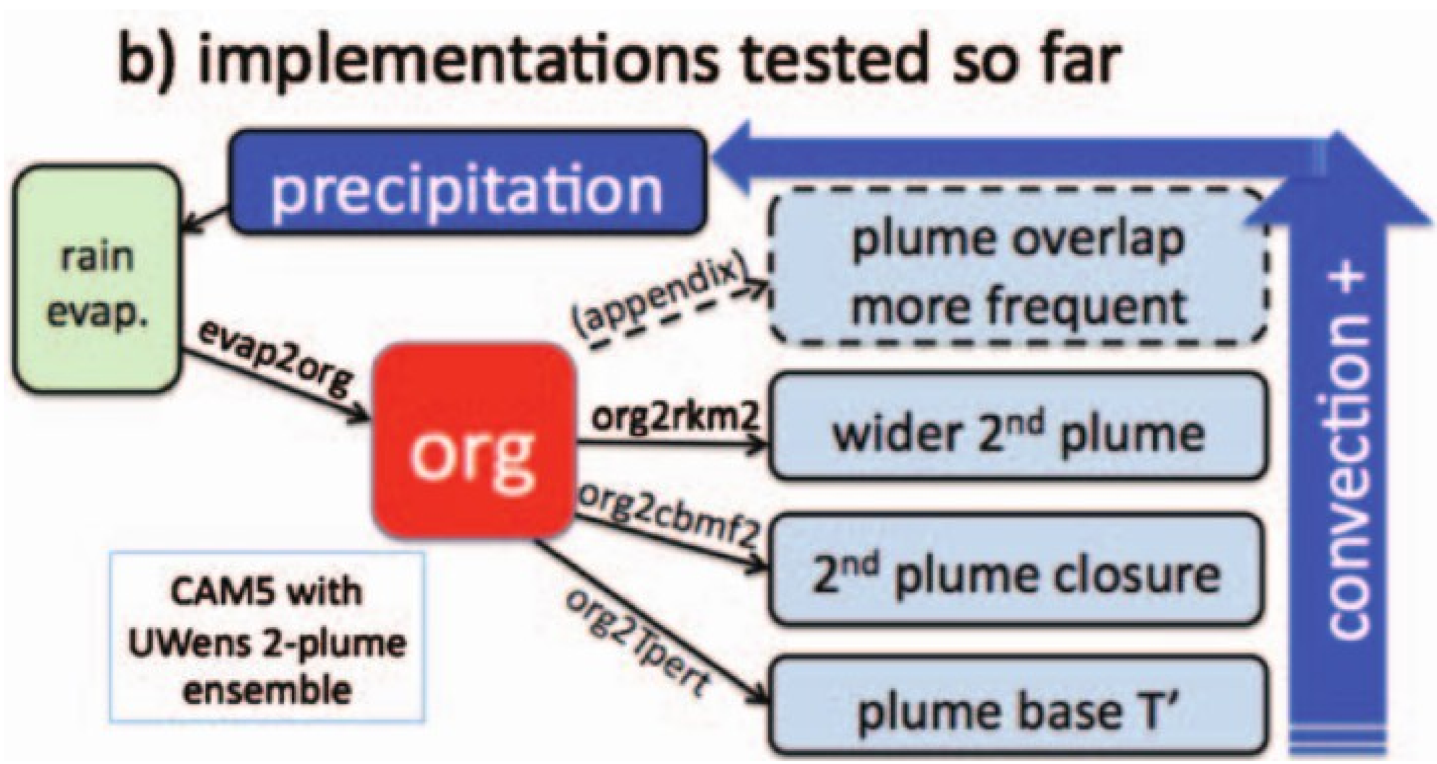
• Strong memory when cloud entrainment depends on rain evaporation prognostically [Piriou et al 2007]

• The organisation factor: prognostic variable: org

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

Source: rain evaporation [Mapes and Neale 2011]

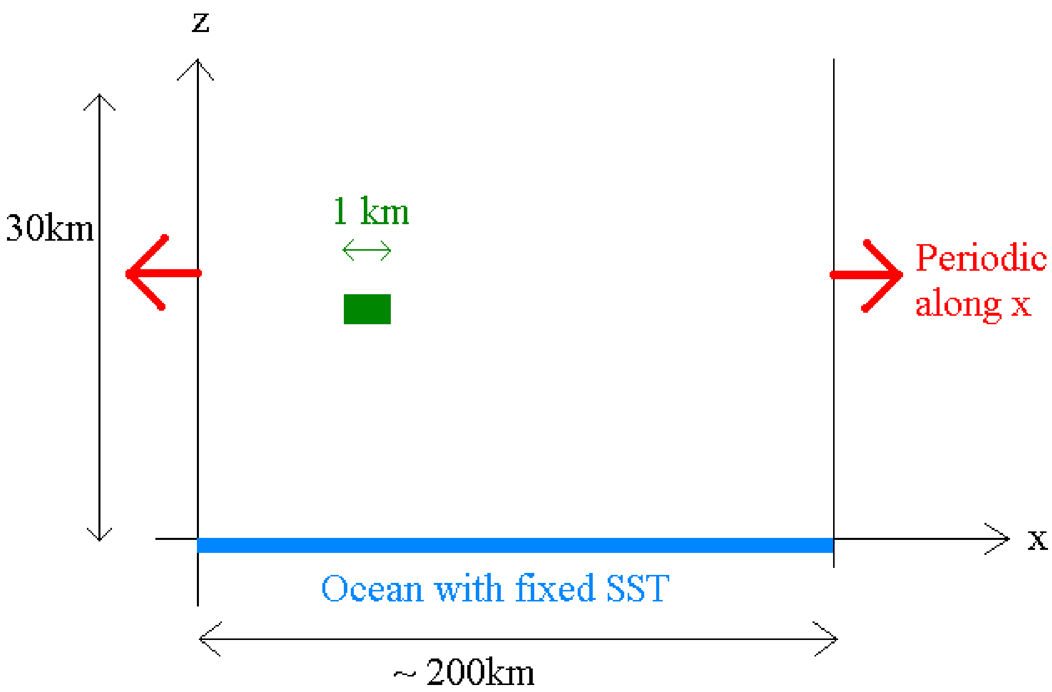
• But how to choose org based on physical arguments?



From Mapes and Neale 2011

3) Methodology

- CRM: 200km domain
- Model: WRF
- Idealised simulation
- Fixed SST
- Focus on convection: doubly periodic boundary conditions (along x and y)
- Resolution ~ 1km
- Run it to a statistical equilibrium (RCE)
- So far, 2D only...



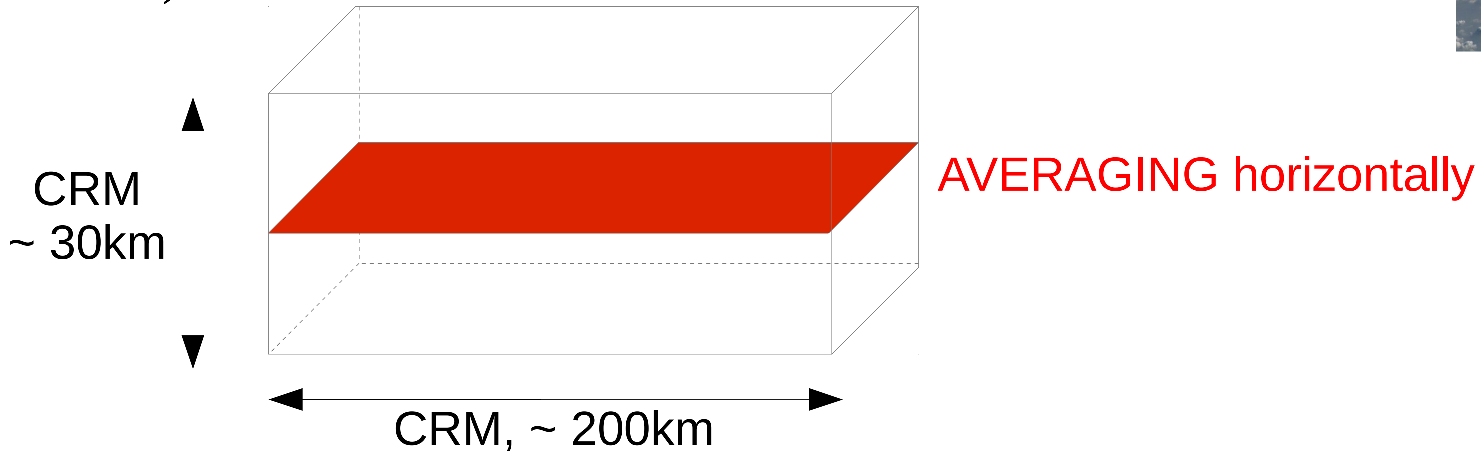
- No parameterization of convection

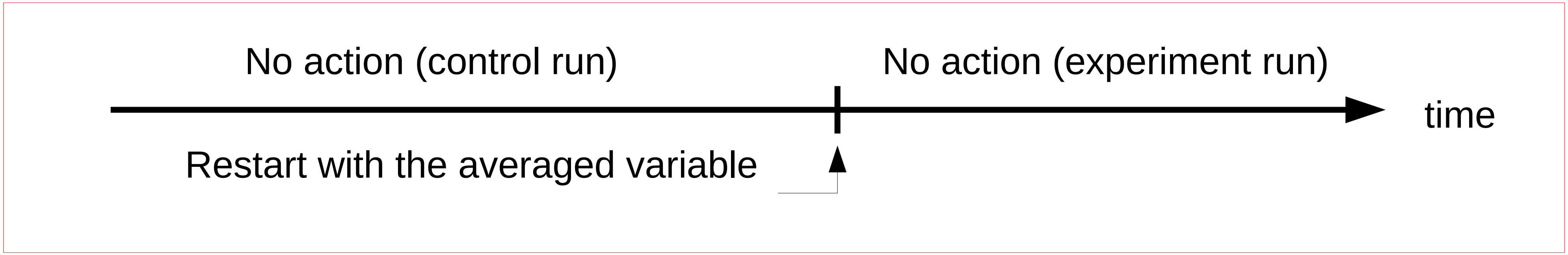
3) Methodology: experiment

Question: what is the variable that is the most important for convective memory?

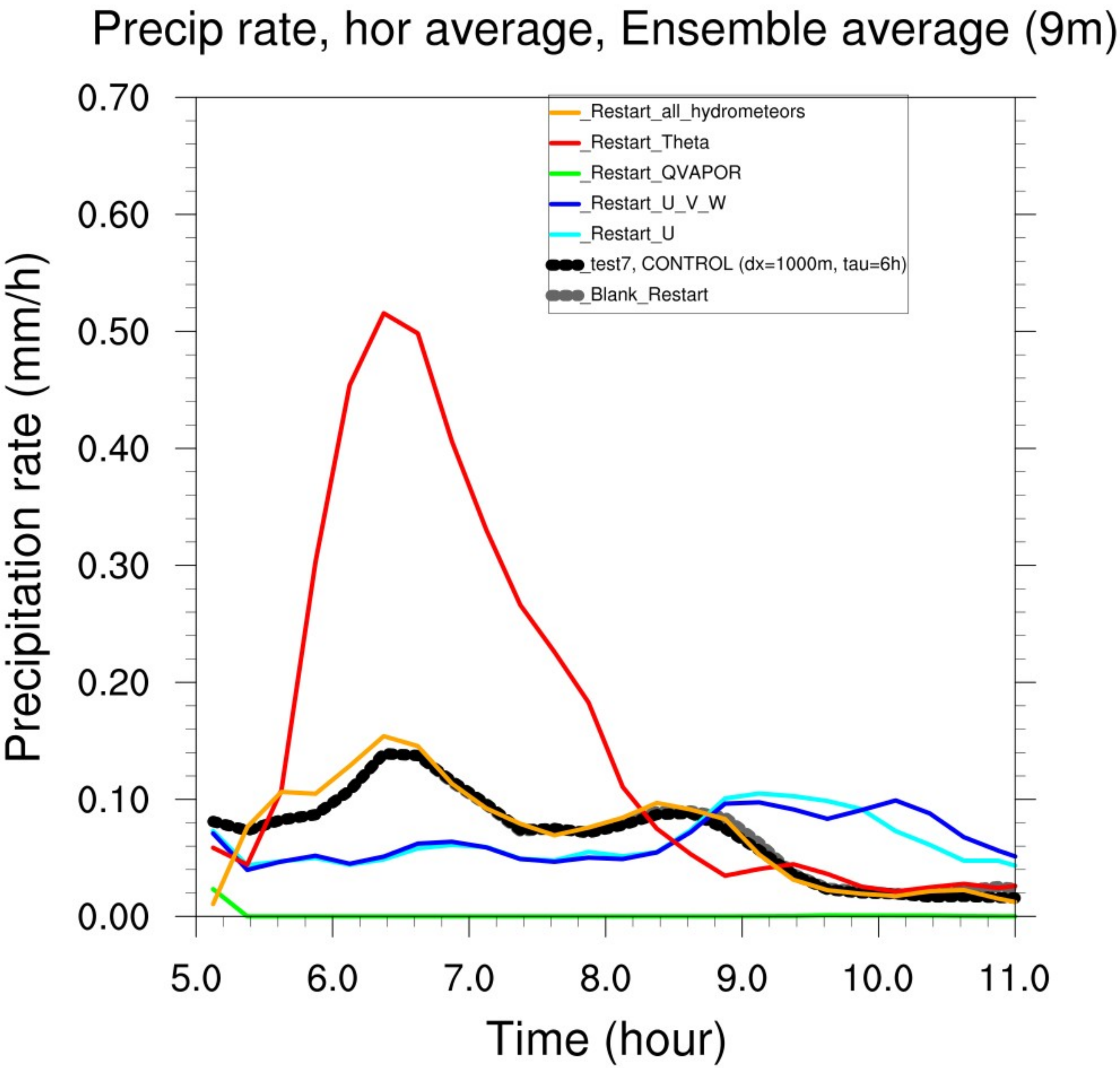
- If a variable is important for convective memory, killing variations should also kill convection.
- We pick one time step and one (or a few) variables.
- Averaging and restarting
- What is the effect on the convective state (recovery time scale)?

From Image Science and Analysis Laboratory,
Johnson Space Center





4) Results



Precipitation rate, 6h

Ensemble average

2 control runs: in black and grey
→ very similar

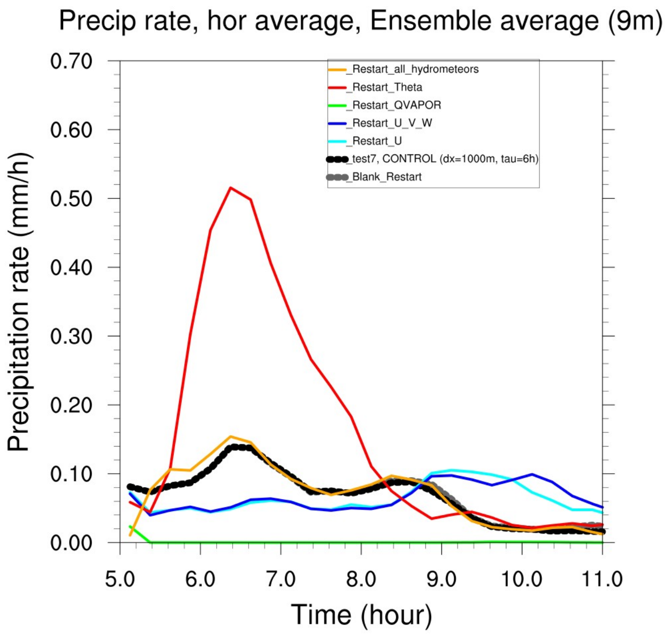
With 5 experiments.

Water vapour seems to be the most important!

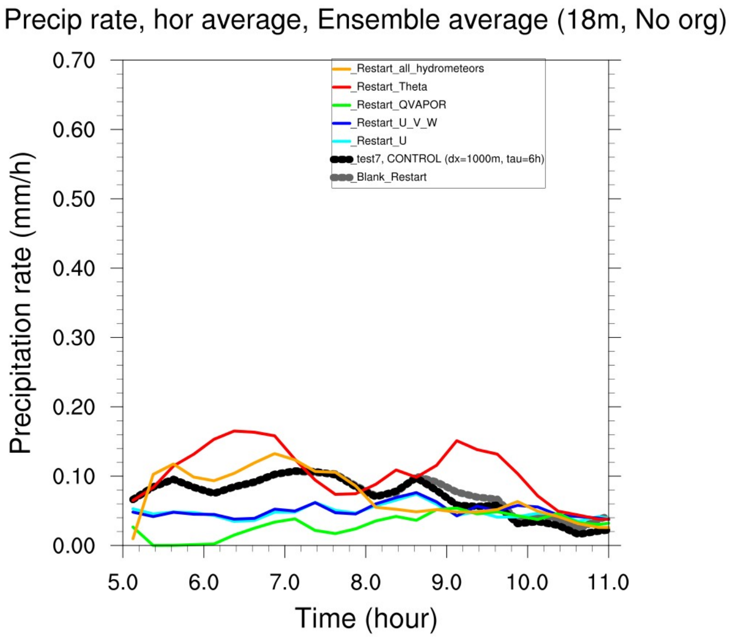
Temperature?

4) Results

NO ICE, WITH ORG

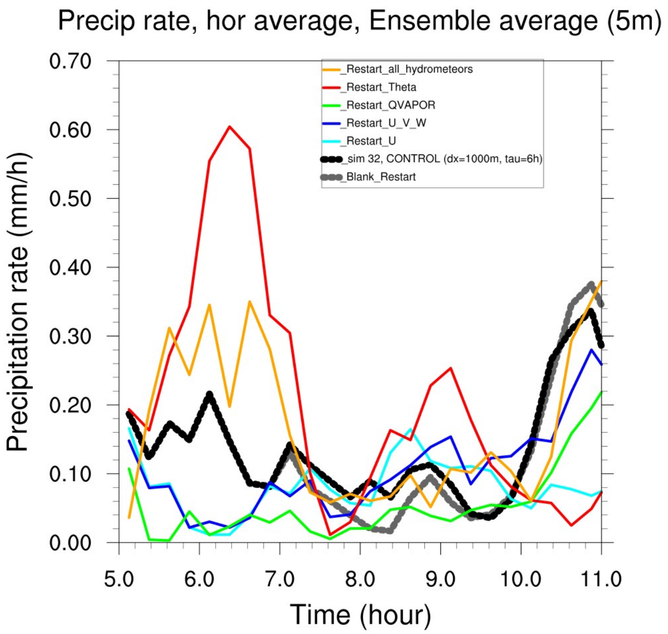


NO ICE, NO ORG

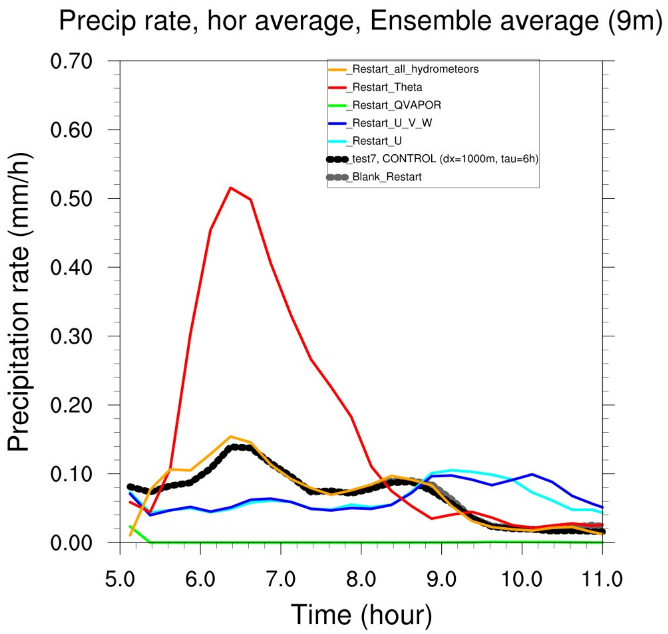


4) Results

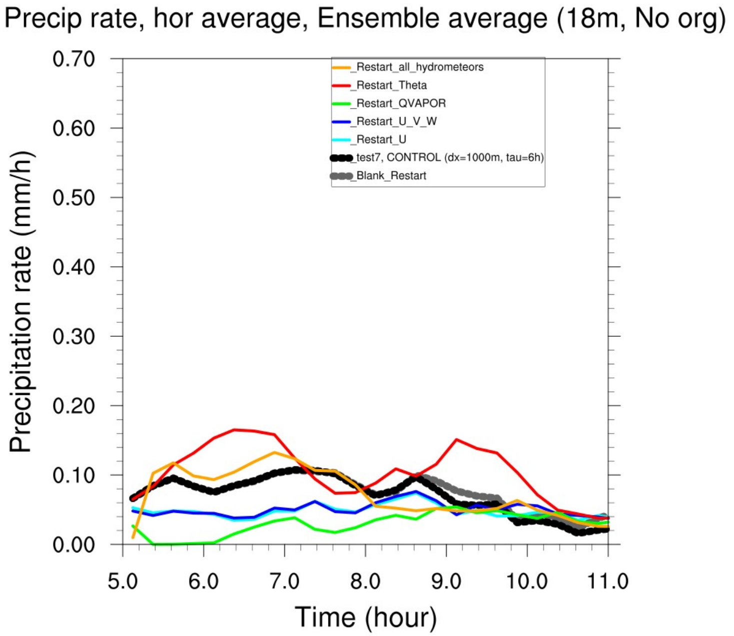
WITH ICE



NO ICE, WITH ORG



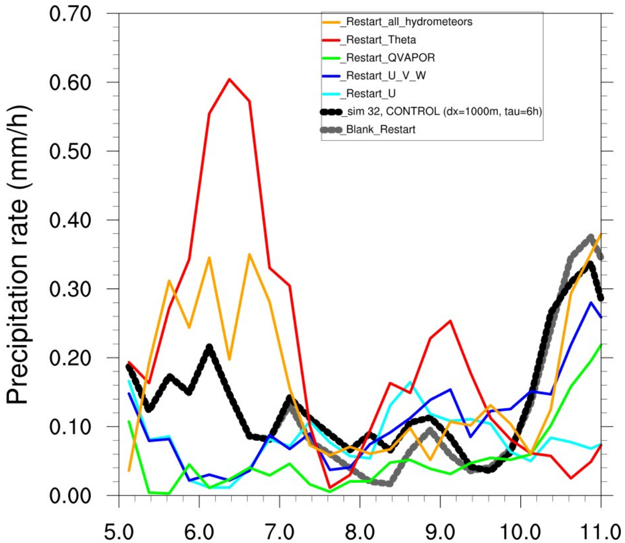
NO ICE, NO ORG



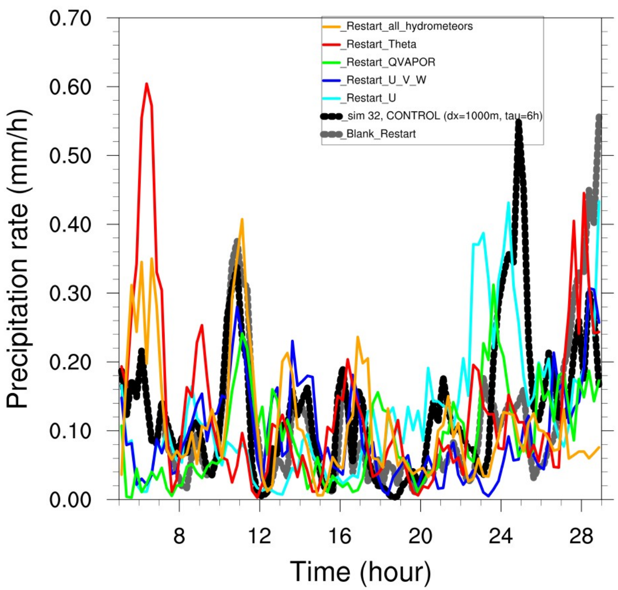
4) Results

WITH ICE

Precip rate, hor average, Ensemble average (5m)

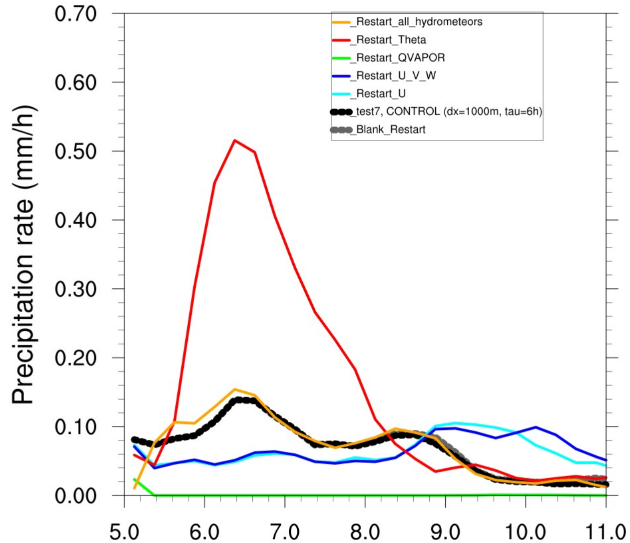


Precip rate, hor average, Ensemble average (5m)

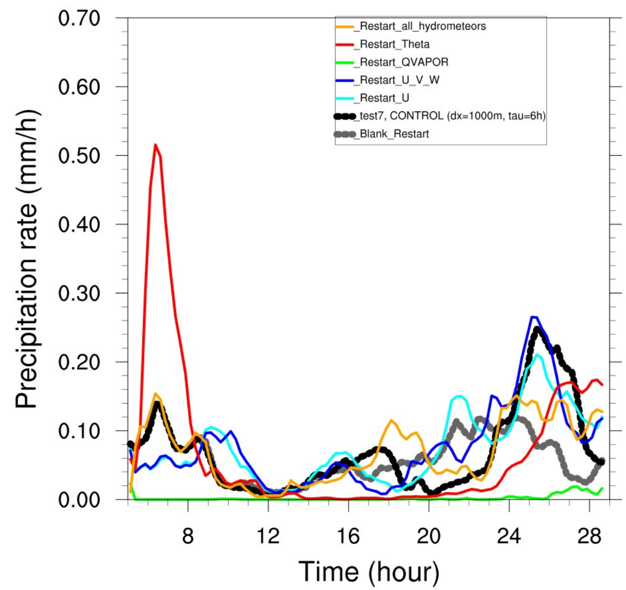


NO ICE, WITH ORG

Precip rate, hor average, Ensemble average (9m)

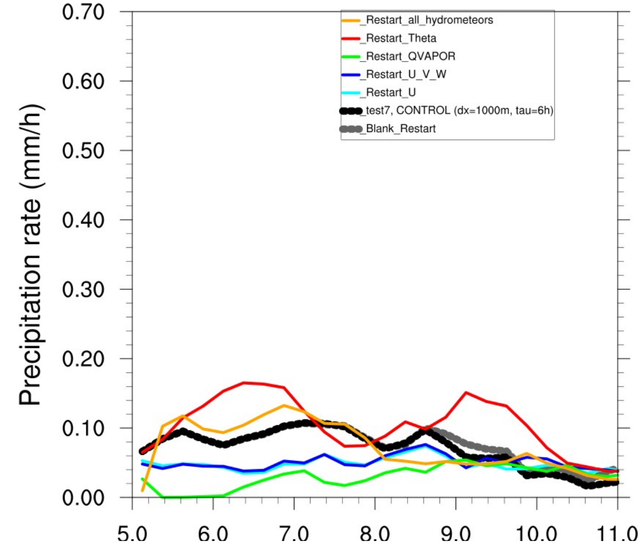


Precip rate, hor average, Ensemble average (9m)

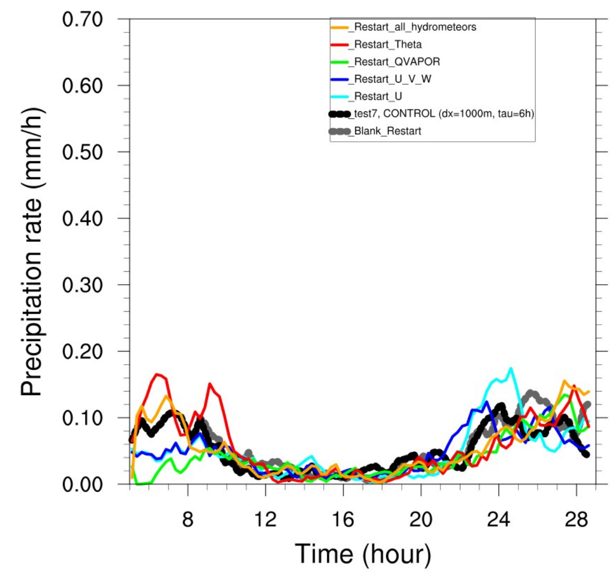


NO ICE, NO ORG

Precip rate, hor average, Ensemble average (18m, No org)

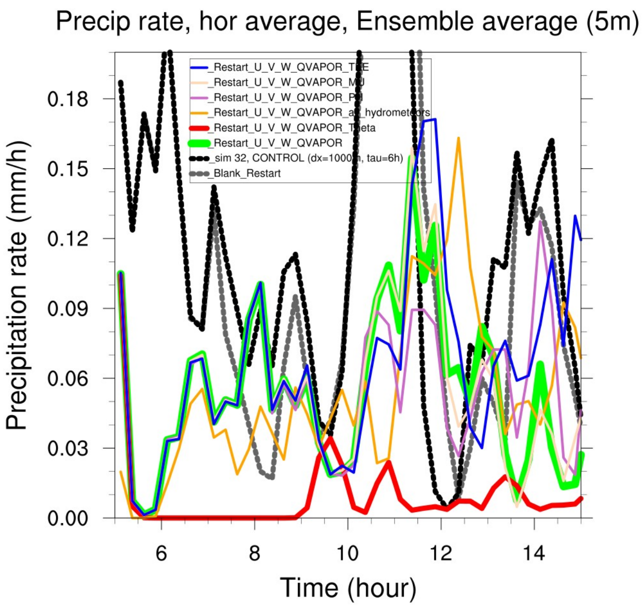


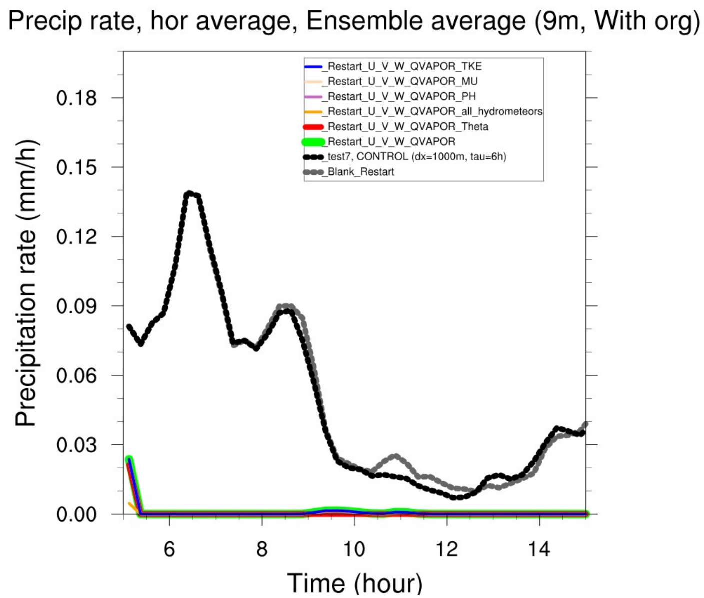
Precip rate, hor average, Ensemble average (18m, No org)

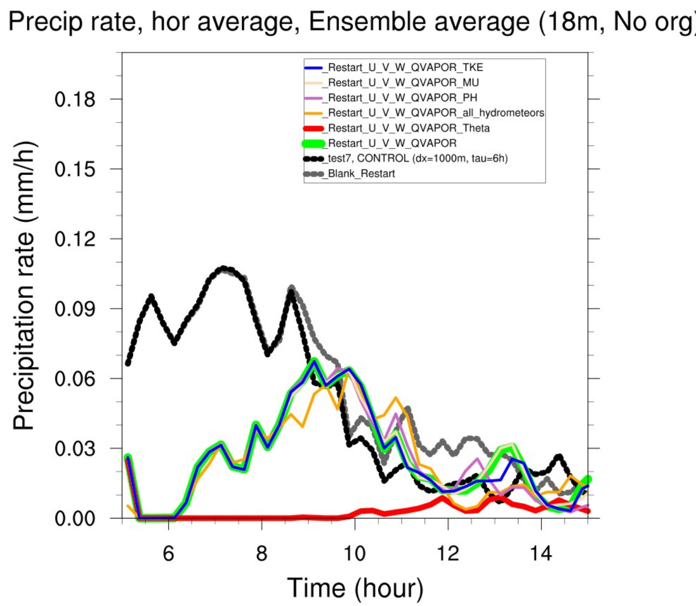


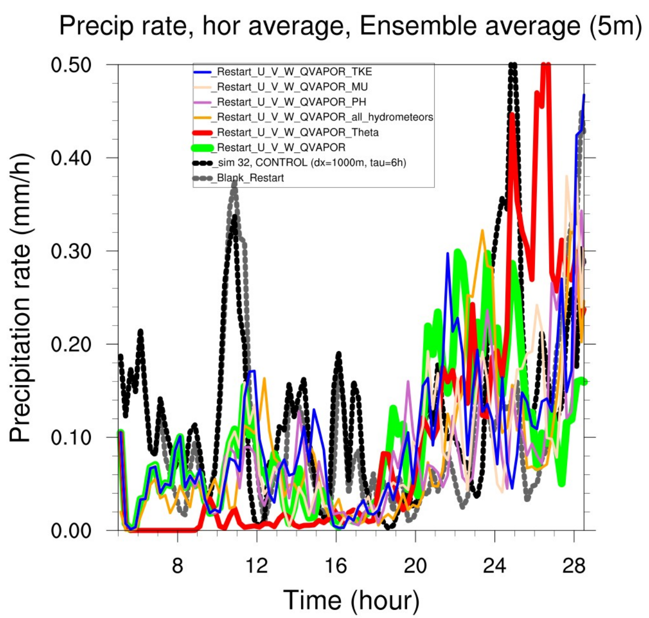
4) Results – part 2

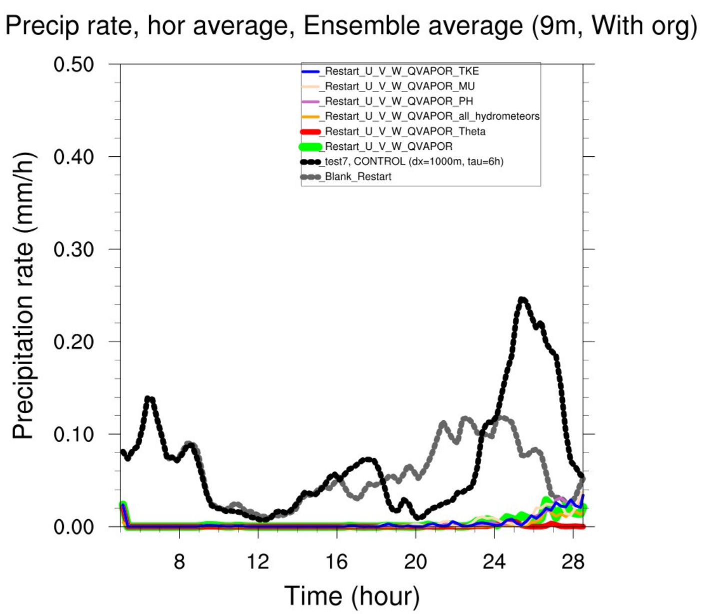
WITH ICE | NO ICE, WITH ORG | NO ICE, NO ORG

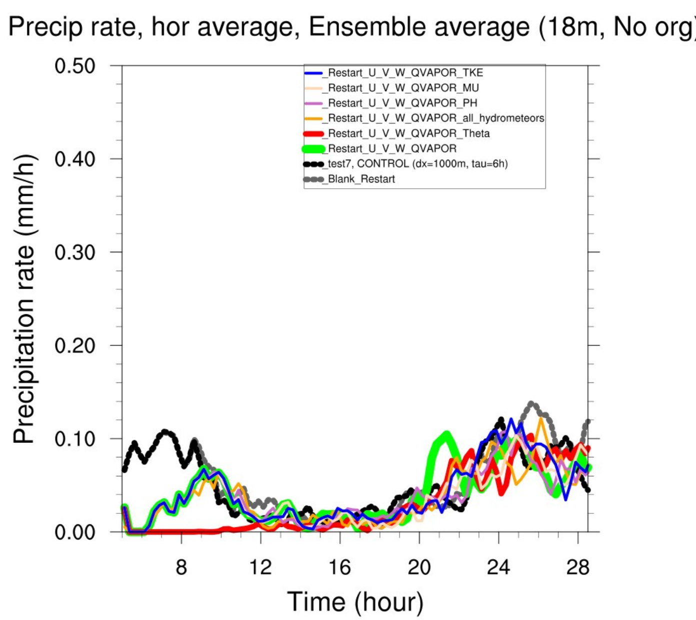












Perspectives

WRF in RCE

1. Go to 3D

2. Run averaging experiments on PBL / free troposphere only

3. Start from other equilibrium states (shallow convective case, etc)

LMDZ in RCE (1D, 3D?):

1. What is the impact of memory-related parameters/variables (cold pools, troposphere humidity) on the large-scale equilibrium profiles?

2. How LMDZ behaves compared to the results shown by WRF? Repeating similar experiments on variables describing the subgrid state

3. Effect of introducing a perturbation, such as drying of air in the free troposphere (sensitivity to tropospheric humidity)?

→ Which sources of memory in LMDZ? Interaction memory / large-scale ?

Conclusion

- Most convection schemes don't include enough memory.
  But which prognostic variable should we have to include memory?

- There could be a memory effect in:
  - The persistence of environmental conditions
  - The subgrid processes for fixed environmental conditions

- Our experiments get rid of subgrid variations of large-scale variables
  → we can compare the memory power of each variable...

- Results:
  - Water vapour: the main variable carrying memory for positive feedbacks
  - Potential temperature carrying memory of negative feedbacks
  - Then winds and potential temperature → enough information

- Issues with varying domain-mean profiles, diurnal cycle, 2D

Credit: community.allhiphop.com

1) What is the "memory of convection"?

- A phenomenon in equilibrium with its forcing loses memory.

- Out of equilibrium, we cannot predict the system purely based on its current state, we also need to know its history! Hysteresis!

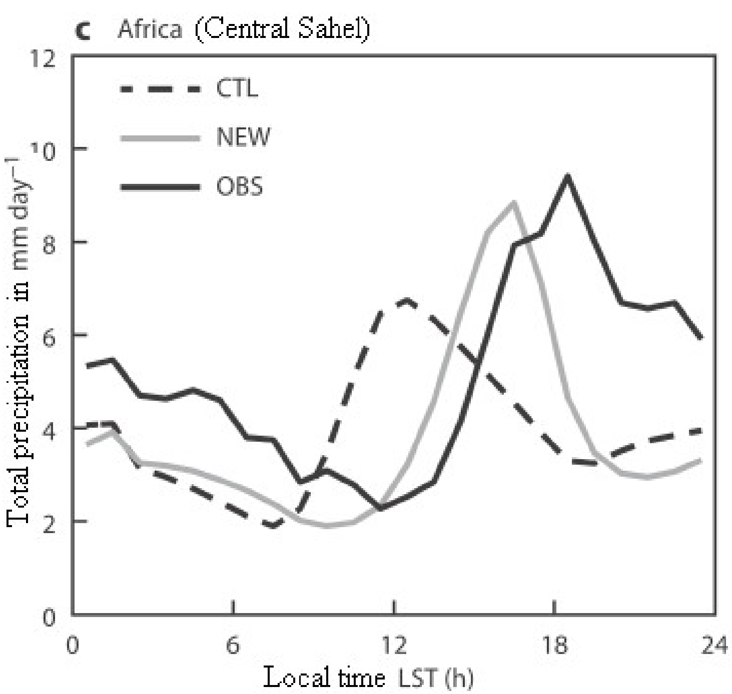
→ need for more prognostic variables

Convection does not only feel the current environmental grid-cell variables...

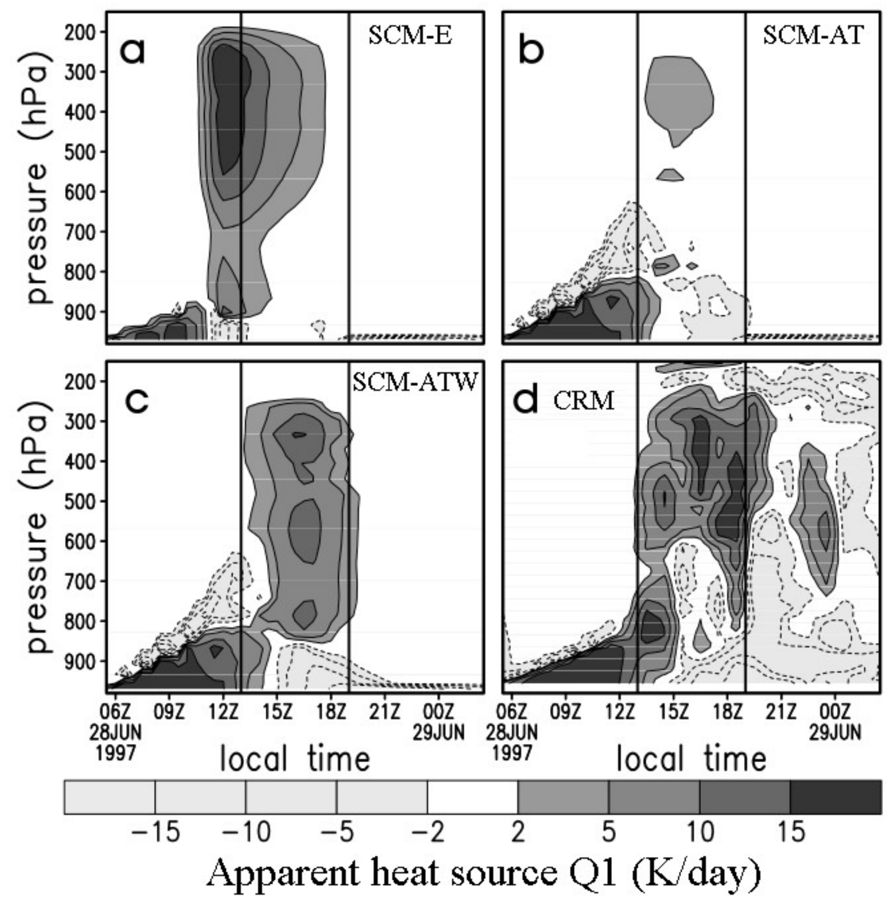



1) Motivation: Problems of convection in GCMs

- Diurnal cycle of convection (precipitation) could be represented better:



From Bechtold et al 2013

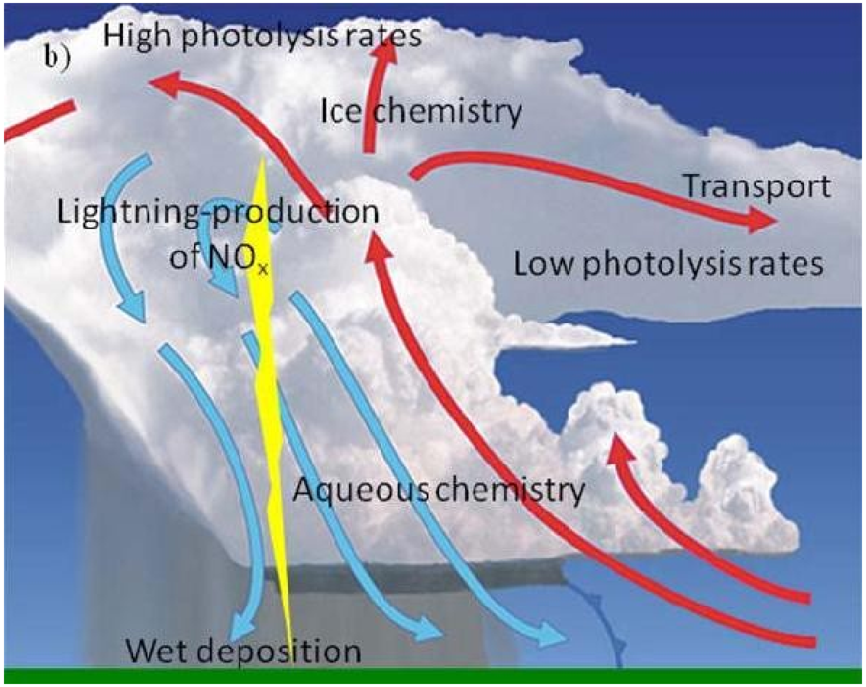


From Rio et al 2009

1) Motivation: Problems of convection in GCMs

- The reality of Spatial organisation of convection
  - Mesoscale Convective Systems / Cold pools
  - Organisation ► influence on the development of convection
    ► Memory (inertia, persistence)
- Convection does not only feel the current environmental grid-cell variables...

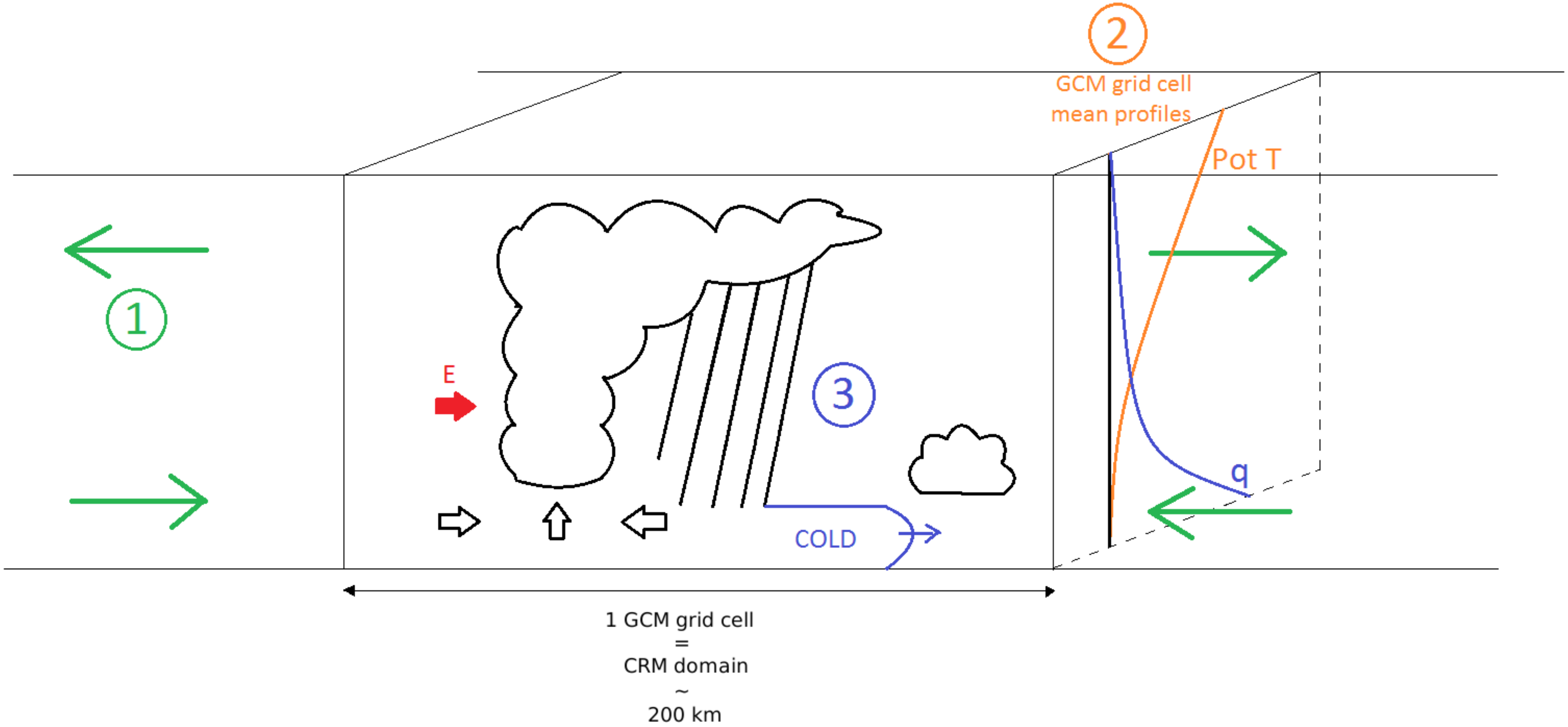
Credit: Business Insider Indonesia (picture taken in the US, Nebraska)



From UCAR and NOAA National Weather Service

3) What is the memory of convection?

- We focus on the memory due to SUBGRID-scale structures !



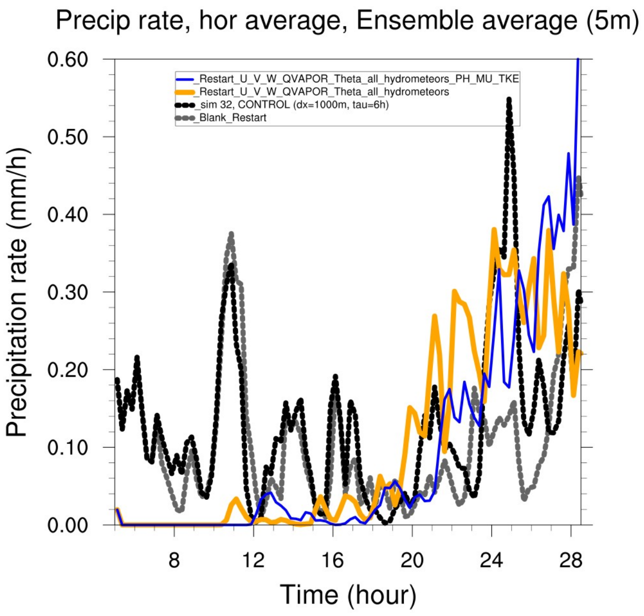
1 Large-scale memory (interaction between several GCM grid cells, CISK)

2 GCM grid cell memory (One grid cell, mean profiles in the box)

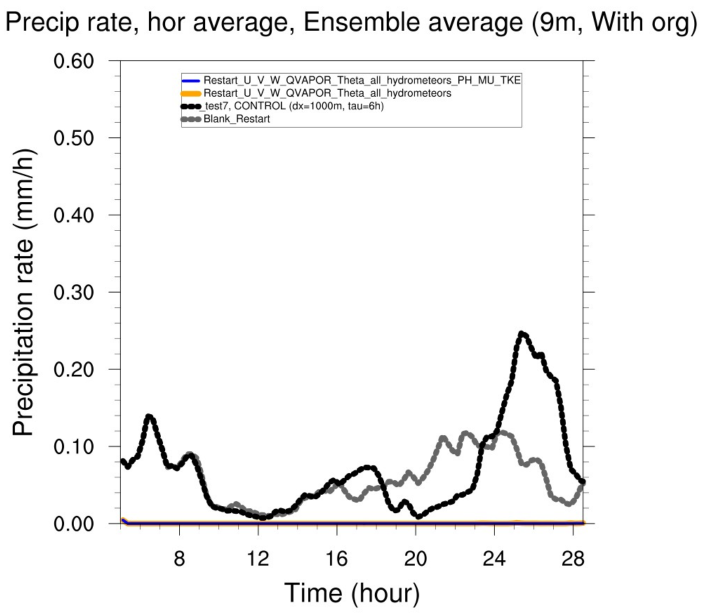
3 Small-scale memory (unresolved for a GCM, subgrid structures)

4) Results - part 3

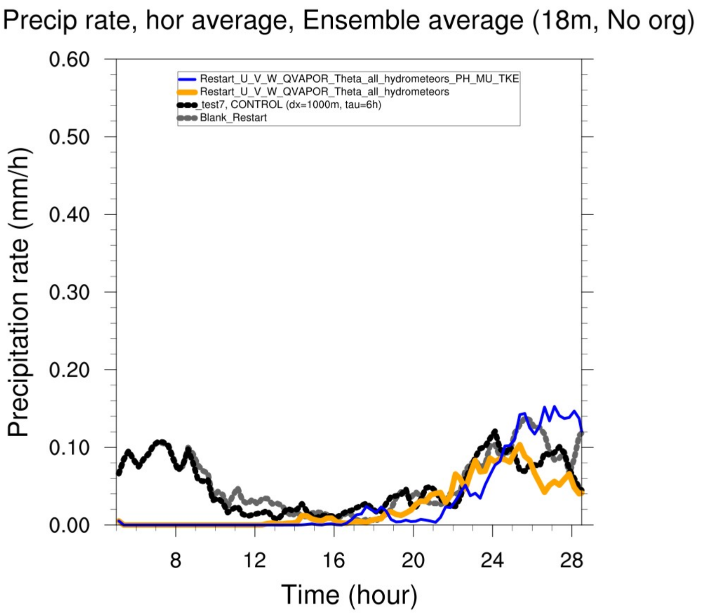
WITH ICE



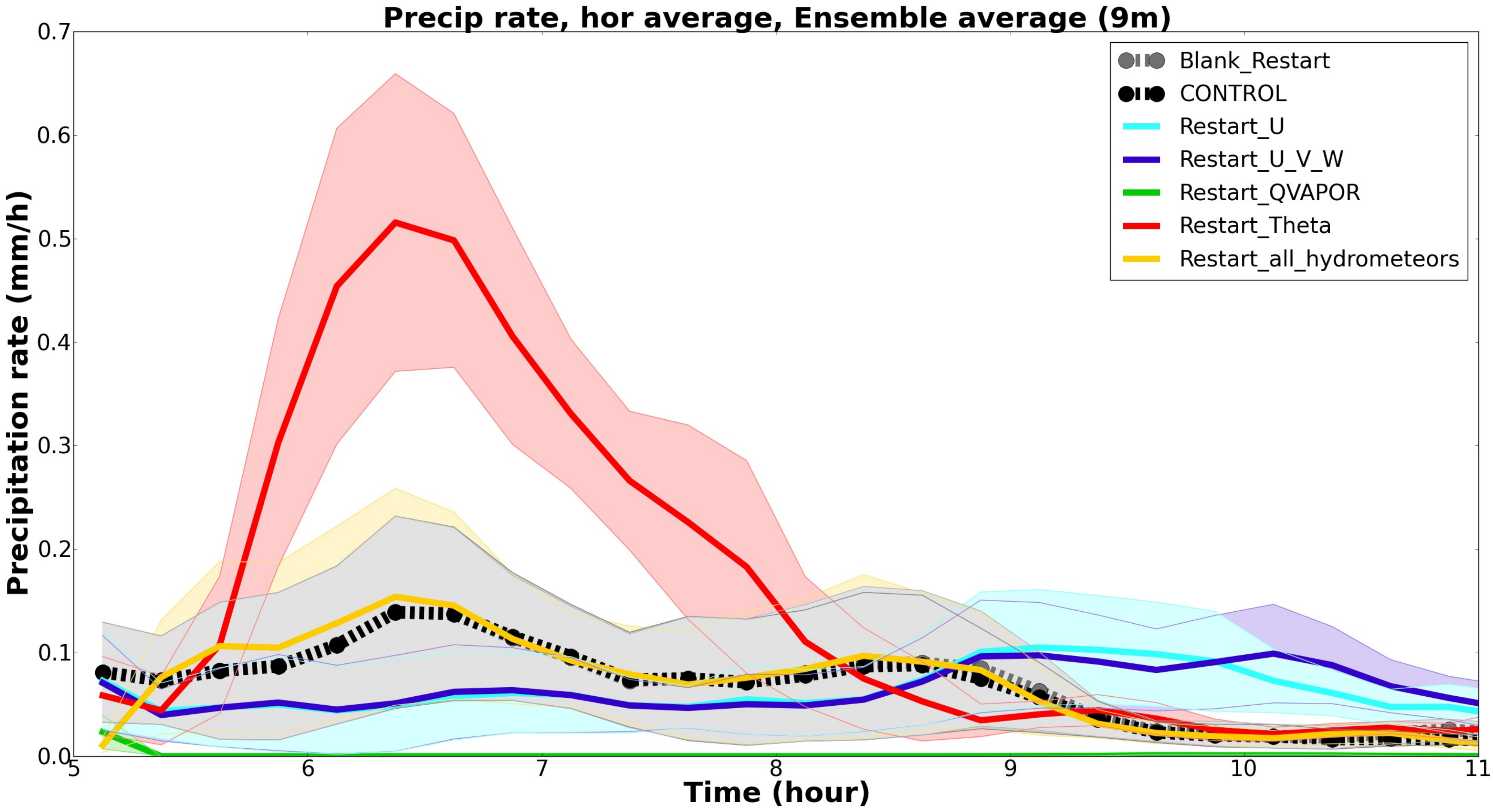
NO ICE, WITH ORG



NO ICE, NO ORG

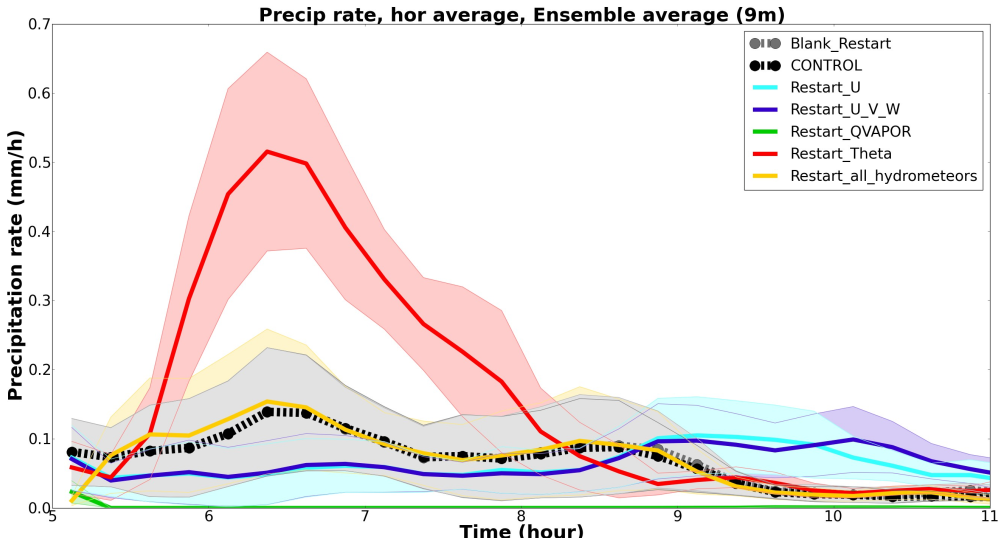


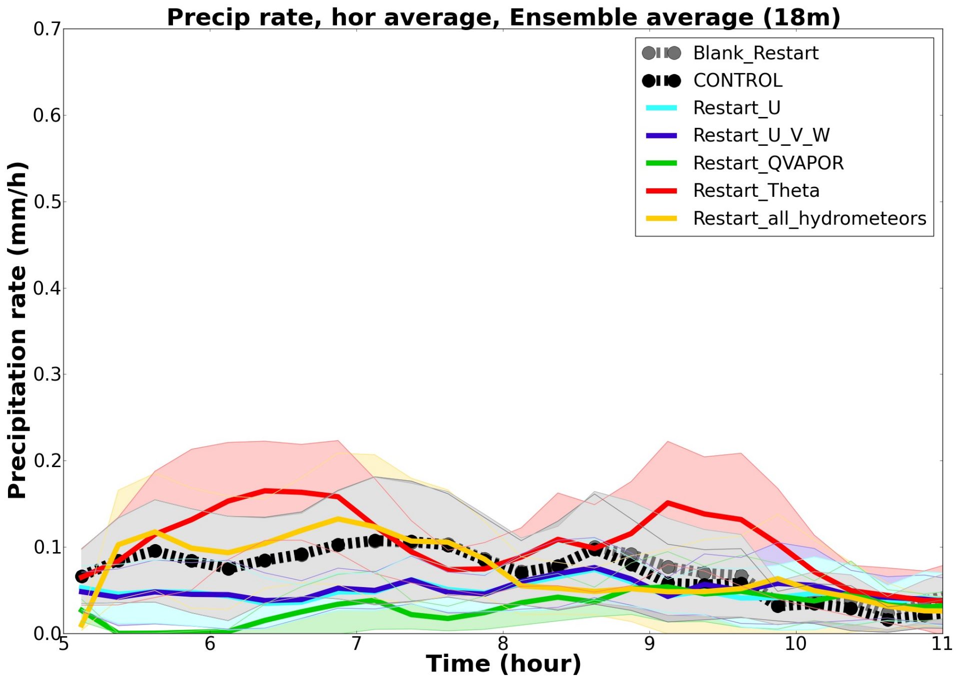
IV) Results



With error bars calculated as the standard error of the (ensemble-)mean

IV) Results


Precip rate, hor average, Ensemble average (9m)
Precipitation rate (mm/h)
Time (hour)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
5
6
7
8
9
10
11
Blank_Restart
CONTROL
Restart_U
Restart_U_V_W
Restart_QVAPOR
Restart_Theta
Restart_all_hydrometeors


Precip rate, hor average, Ensemble average (18m)
Precipitation rate (mm/h)
Time (hour)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
5
6
7
8
9
10
11
Blank_Restart
CONTROL
Restart_U
Restart_U_V_W
Restart_QVAPOR
Restart_Theta
Restart_all_hydrometeors

Plan at CCRC

Sets of Experiments

1. Homogenize [X1, X2, …]
   without nudging on domain-mean profiles

2. Homogenize [X1, X2, …]
   with strong nudging on the domain-mean profiles.

3. Swap regime forcing
   with strong nudging to the mean profile of a different regime

Cases:

- Deep convective
  - 2D
  - 3D
- Shallow convective

- Ice microphysics (Hong and Lim)
- Warm rain microphysics (Kessler)
  - Organised convection
  - Non-organised convection

➔ LES ?

Plan at LMD

1. What is the memory that LMDZ already has (scheme for cold pools)? Can we quantify it?

2. Can we apply the results of the first part to include more memory in the scheme (water vapour, etc...)? Does it improve convection?

AND / OR

3. How to propagate cold pools (in order to propagate convection)?

4. Dynamics of cold pool population (varying cold pool density).