What's quasi-equilibrium all about?

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Why is convection important?

Focus on deep convection

- Major transport of heat, moisture and momentum.

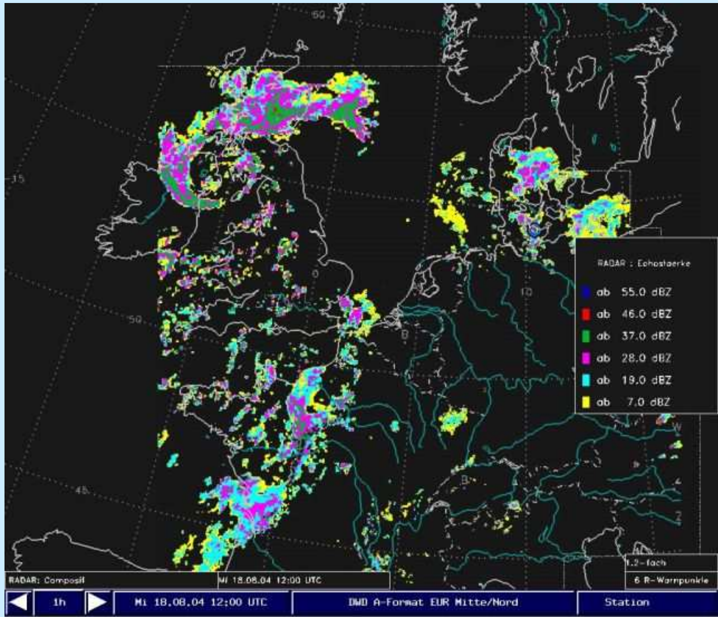

Cumulonimbus

Fair weather cumulus


Focus on this!

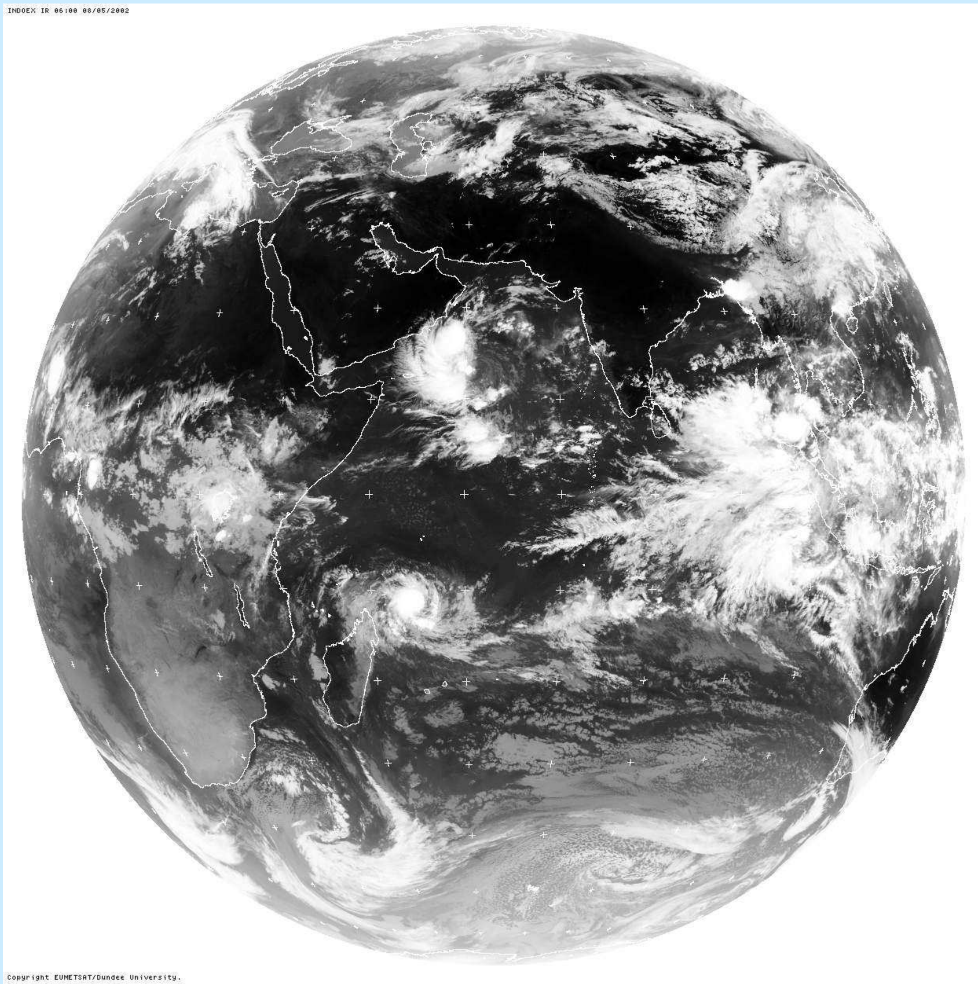
What is deep convection?

- Develop on organised, long-lived systems such as squall lines and MCSs.



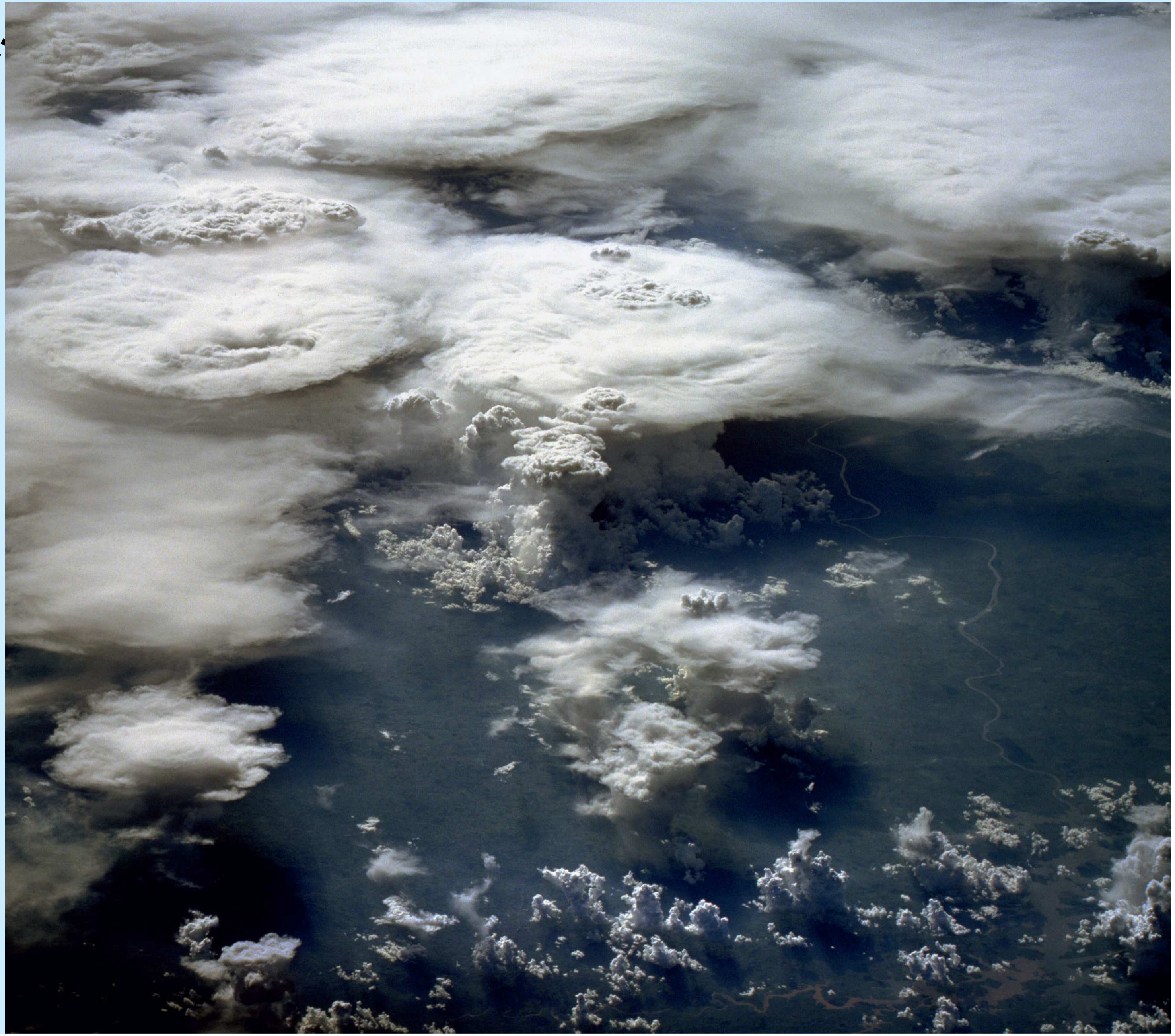
What is deep convection?

- Provide energy to large-scale circulations eg Hadley cell.
- Convection interacts and modulates MJO.



What is deep convection?

- Effects the radiation budget of the earth.



Convection meets NWP

- Convective systems are a major contributor to global circulations of heat, mass and momentum
- Representation depends on scale of model

  High resolution models explicitly resolve clouds

  Large scale models require parameterisation

- Parameterisations represent the mean effect of the sub-grid scale cloud process on the large scale flow

- For validity this requires assumptions to be made about the mean convection

Parameterisation basics

Arakawa and Schubert (1974)

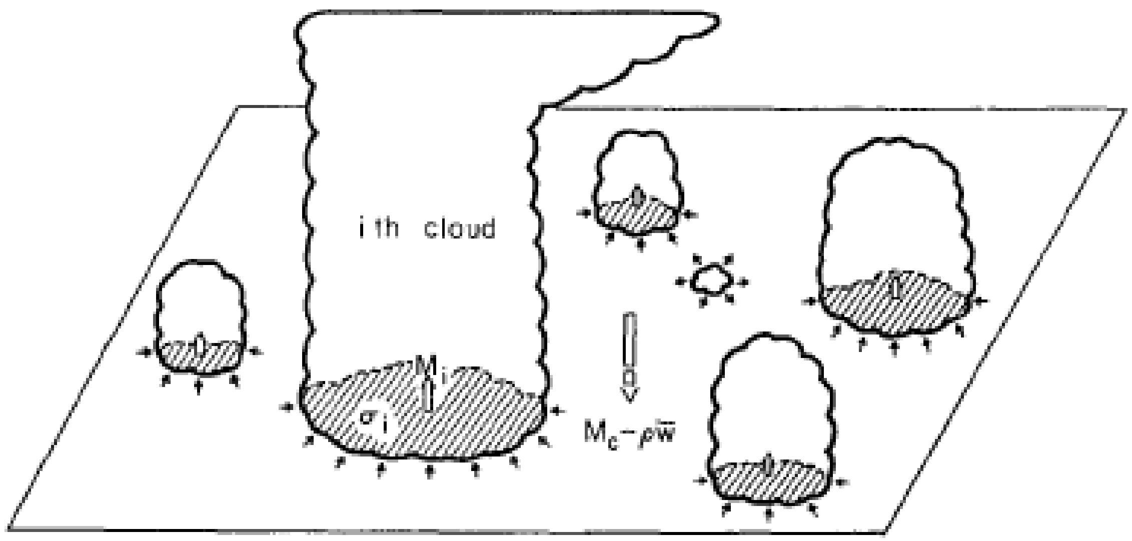


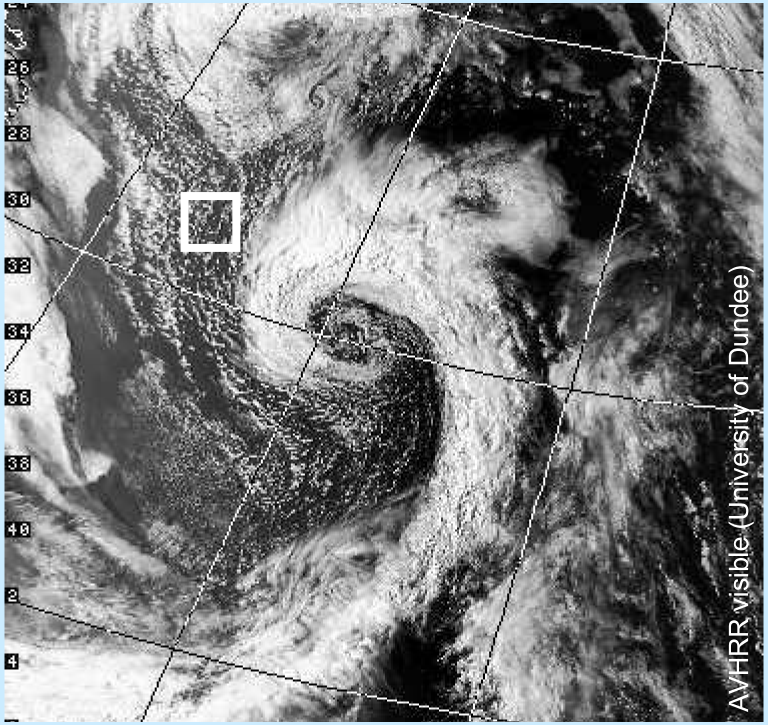
FIG. 1. A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

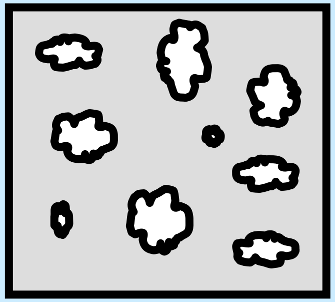
$$\tau_{adj} \ll \tau_{ls}$$

Key assumption

The assumptions

- Scale separation in time and space between cloud processes and large scale flow
- Convection acts on smaller and faster scales than the large scale flow





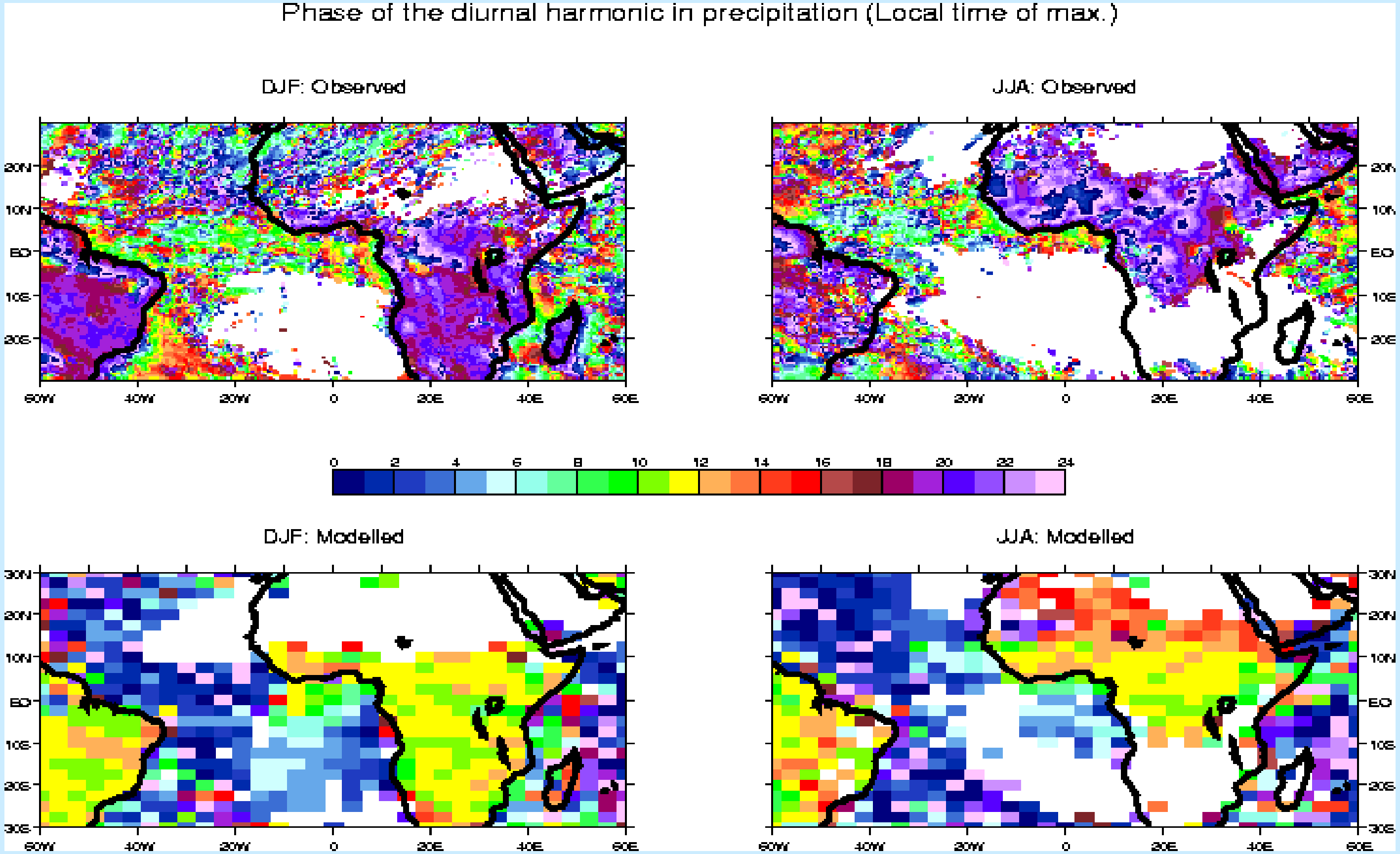
- Convective ensemble

- Analogous to the equation of state

  $p=\rho RT$

Motivation

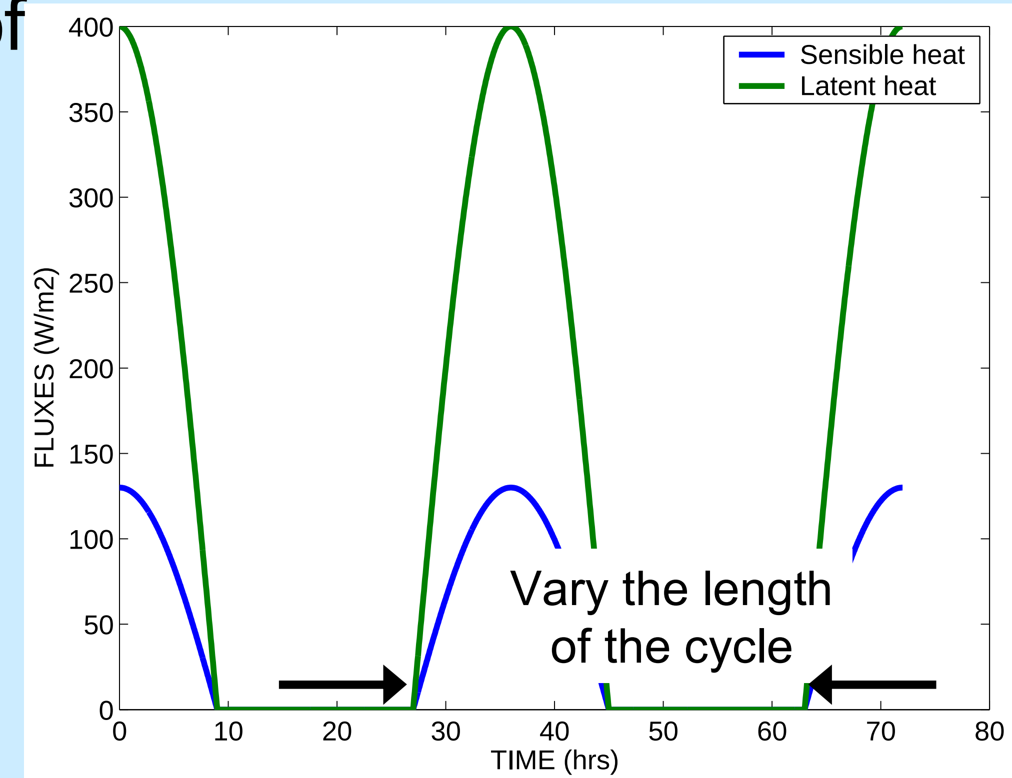
➢Model compared to observations (Yang & Slingo 2001)



➢Longer systematic life cycle…memory?

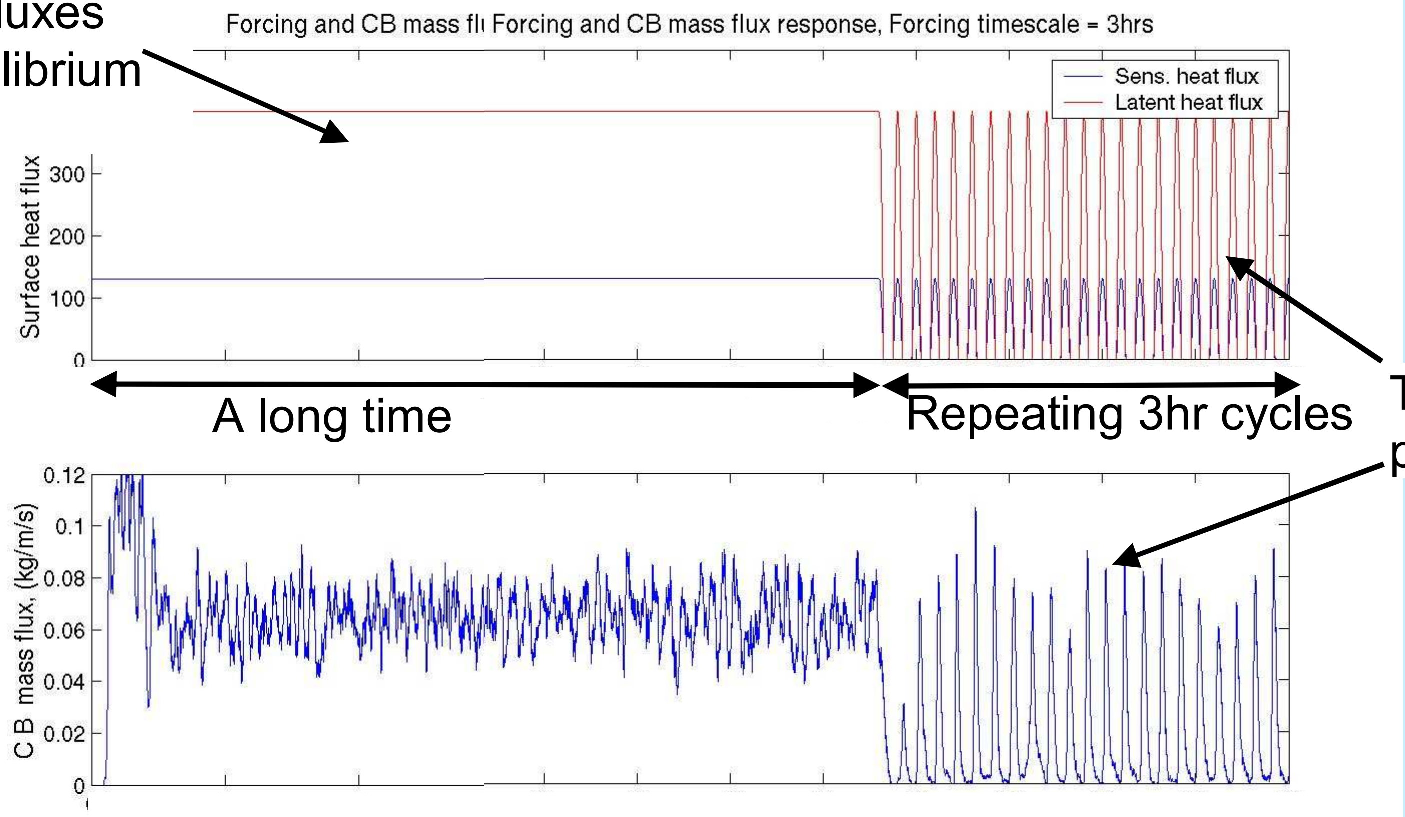
Large eddy models setup

- LEM run as a CRM explicitly resolves cloud-scale dynamics but parameterises sub-grid processes
- Largest eddies are responsible for majority of transport so are explicitly resolved
- Initialised with profiles of θ and q_v
- Non-rotating, no wind shear
- 1 km resolution
- Balanced in terms of moist static energy



Control run

Control run: Applying constant surface fluxes until equilibrium achieved

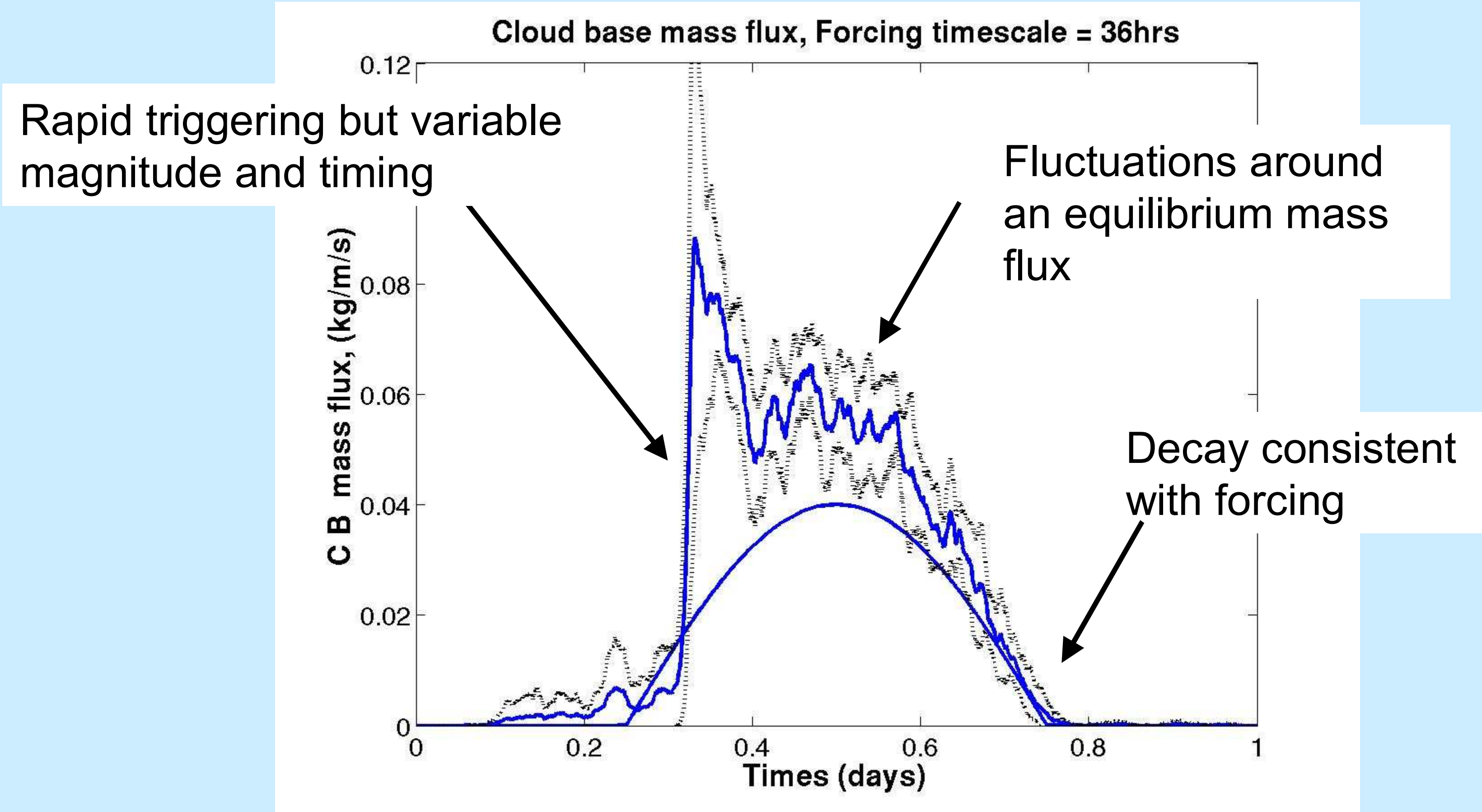


Time-varying portion of run

Initial convective response is strongly influenced by the control run. It was found a portion of ~ 6hrs need to be removed. This suggests 'memory' within the system.

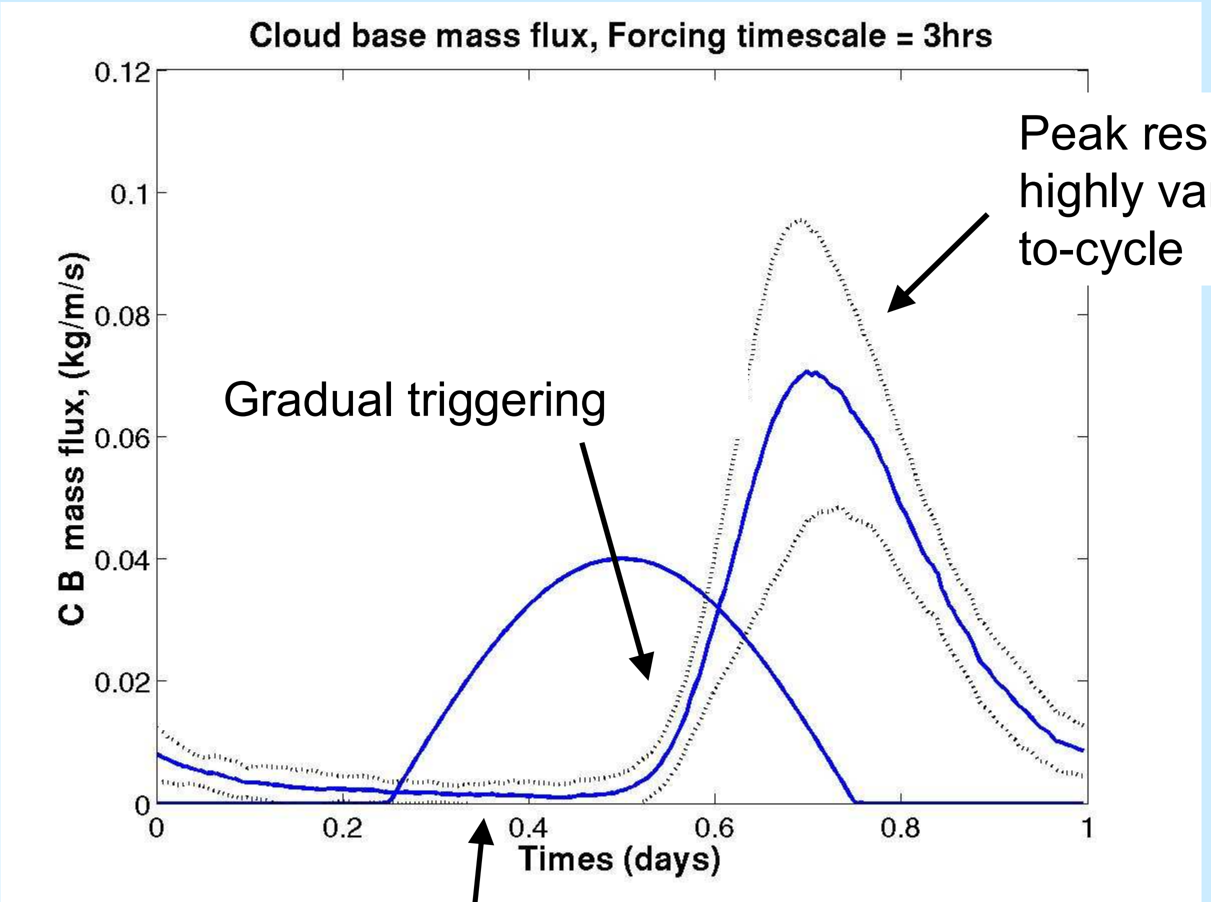
Equilibrium response

Long timescale - 36 hrs



Non-equilibrium response

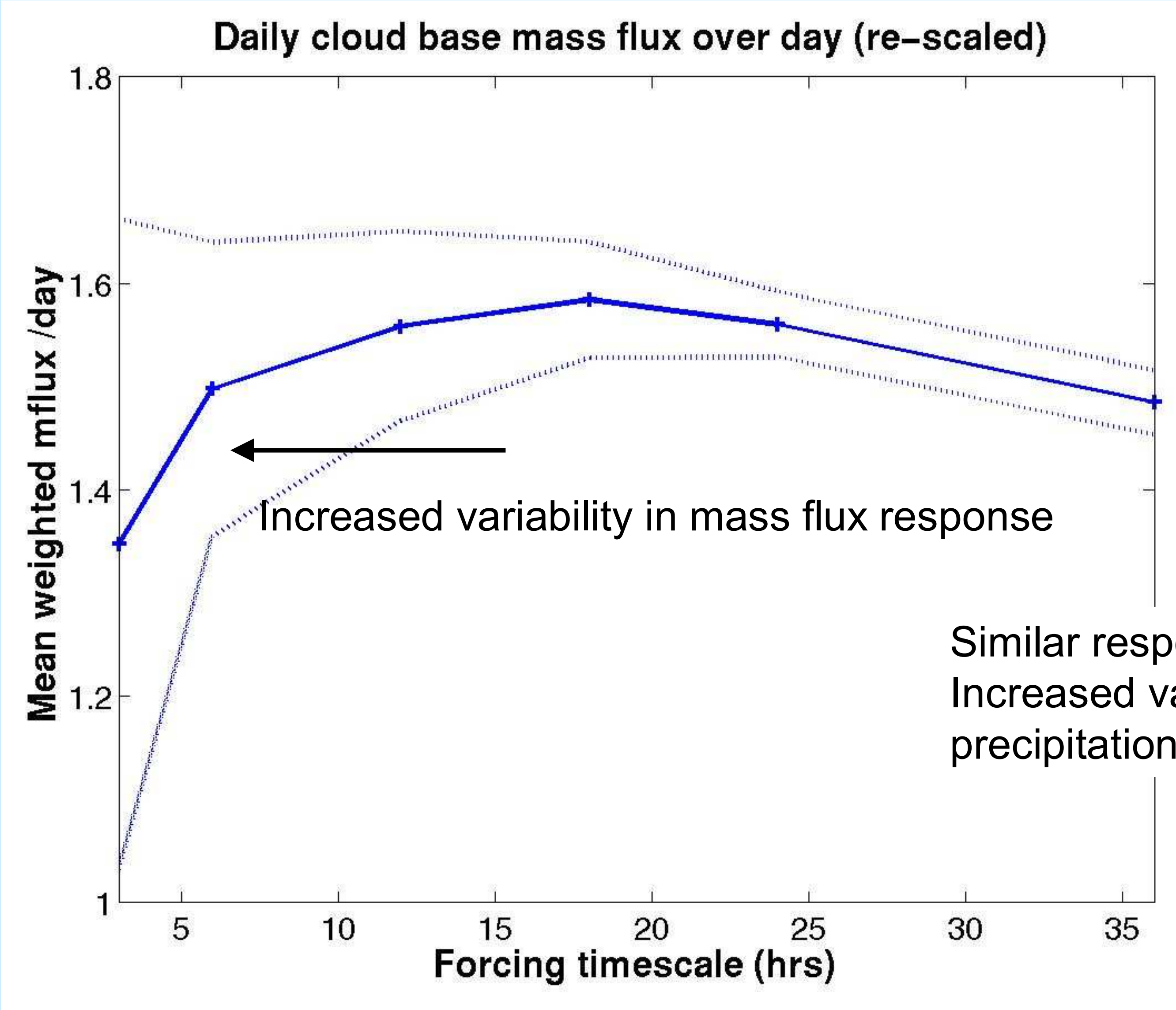
Short timescale - 3 hr



Peak response highly variable cycle-to-cycle

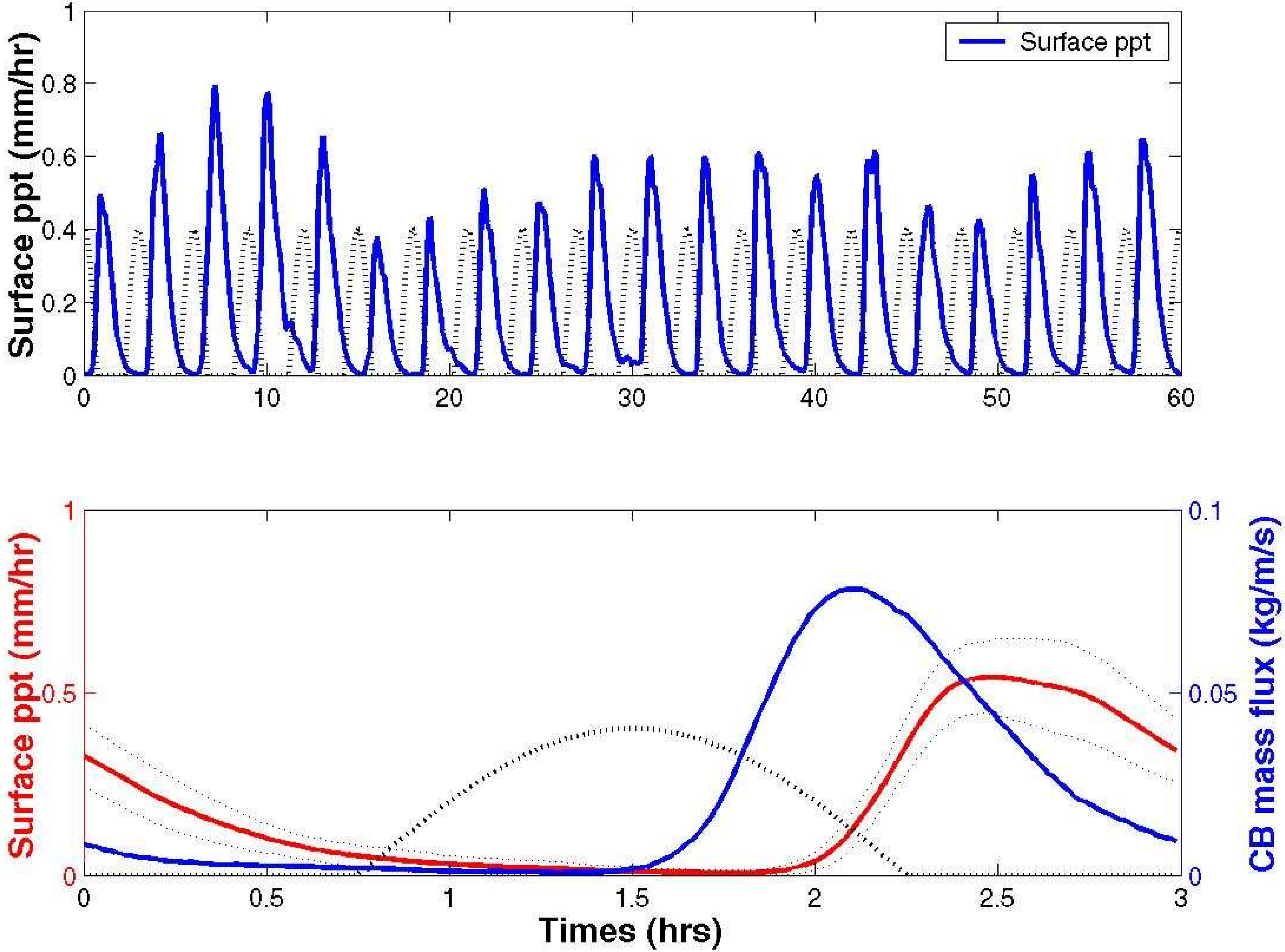
All times show convective activity

Effect of forcing timescale



Similar response for precipitation. Increased variability in mean total precipitation per cycle.

Control run


Surface ppt
Surface ppt (mm/hr)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
Surface ppt (mm/hr)
CB mass flux (kg/m/s)
0
0.5
1
0.05
0.1
0
0.5
1
1.5
2
2.5
3
Times (hrs)

Diurnal cycle depends on…

Khairoutdinov and Randell (2006)

- Localised solar heating due to surface
- Sea-breezes
- Cold pools and gust fronts ←
- Dry lines ←
- Horizontal convective rolls

Stirling and Petch(2004)

- Earlier rain events ←
- Land use
- Soil moisture
- Cold pools in boundary layer ←
- Humidity of free troposphere ←

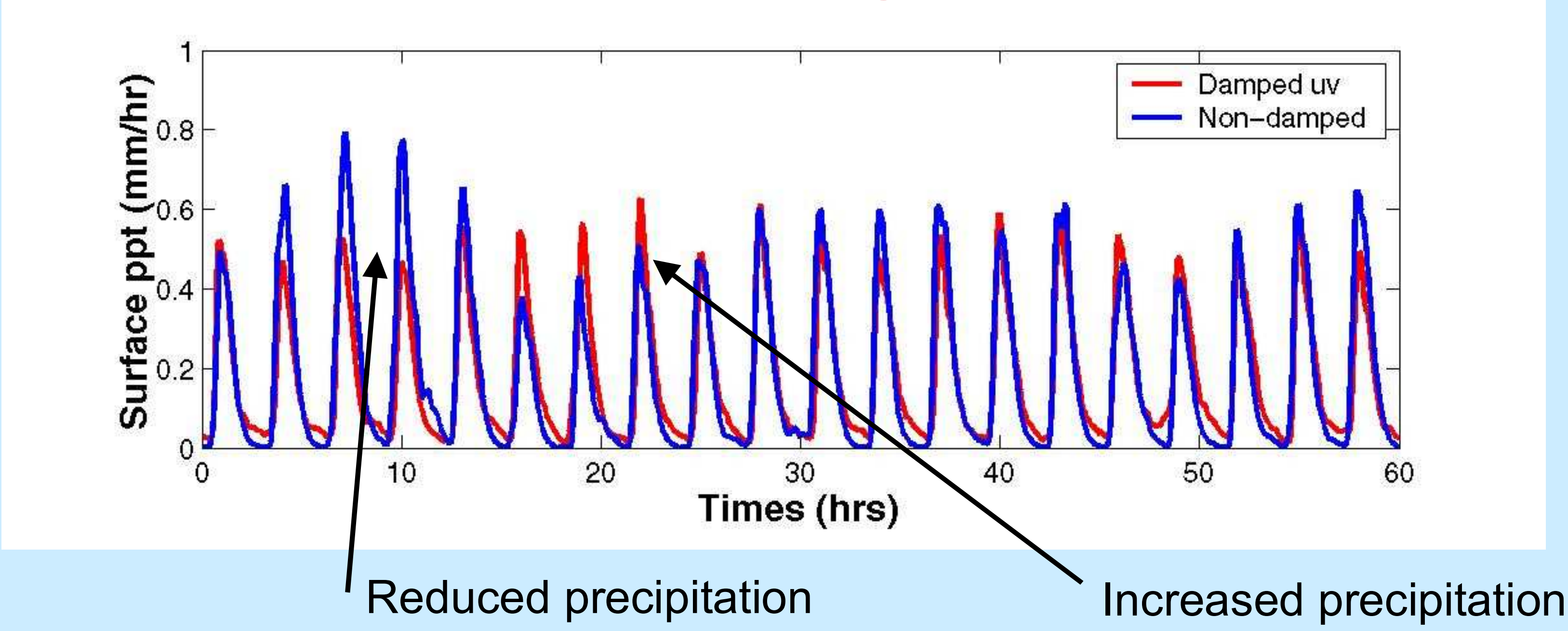
Experimental set up

- Perturb key thermodynamic variables by damping them back to the horizontal mean
- Damp on the convective timescale ~ 15 mins
- Investigate effect on variability in 3 hr run

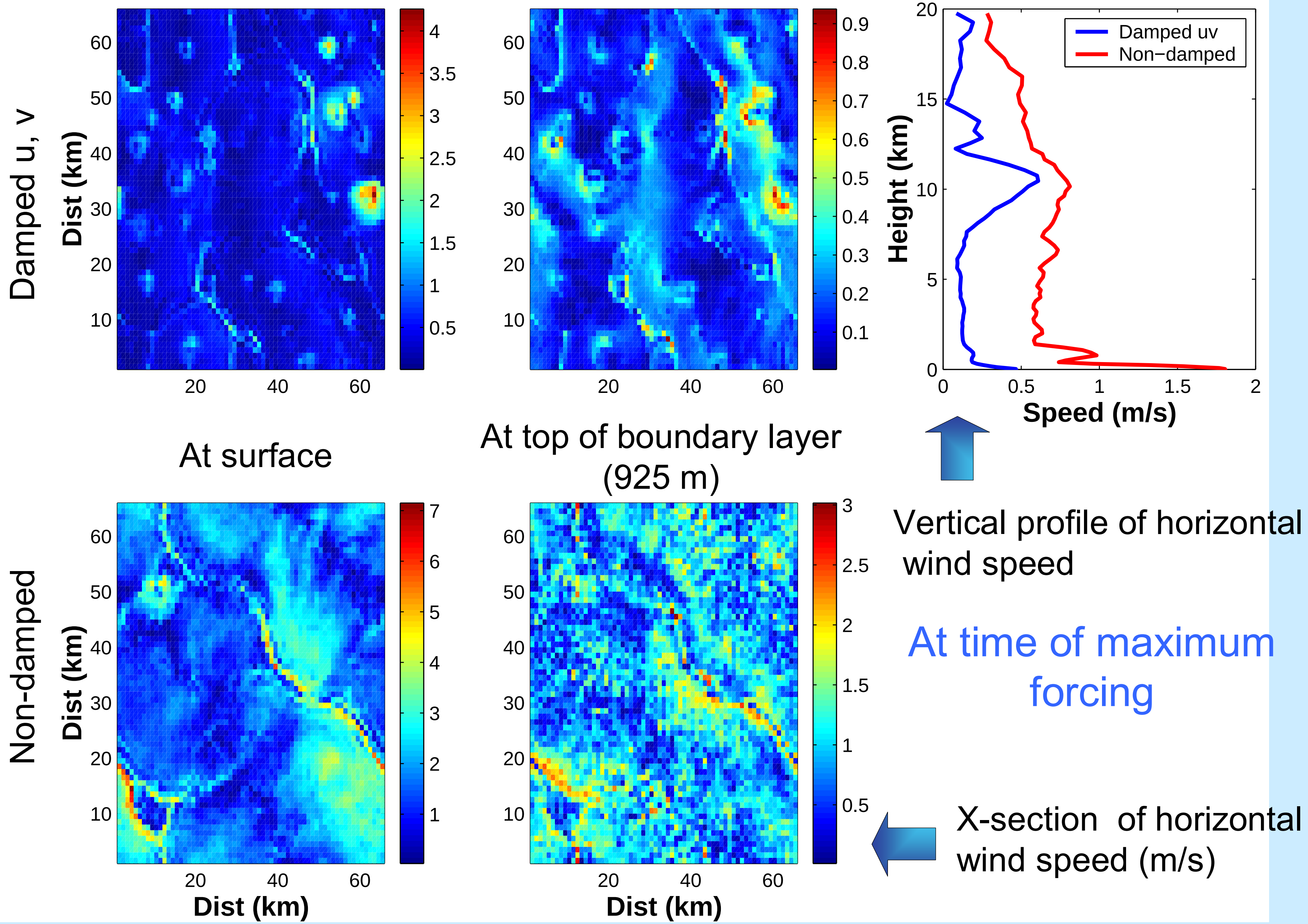
Variables to damp

- Horizontal winds, u, v
- Vertical wind, w
- Moisture, q_v
- Temperature, θ

Damping u, v

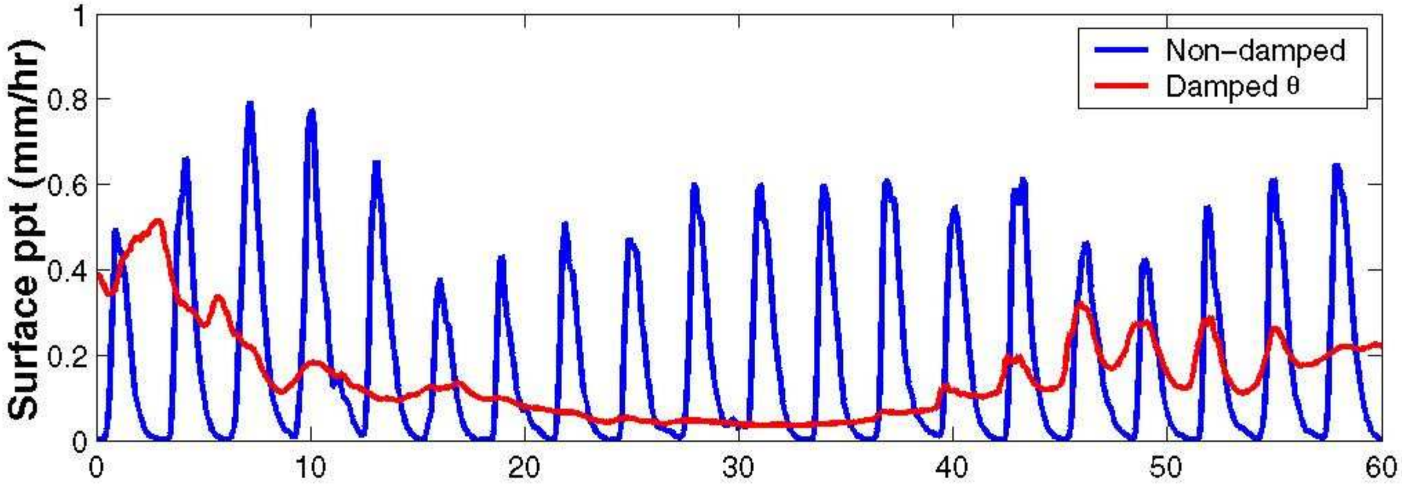


- Damping u, v reduces the variability in the precipitation where the variability was stronger.
- It increases the variability where it was weaker.

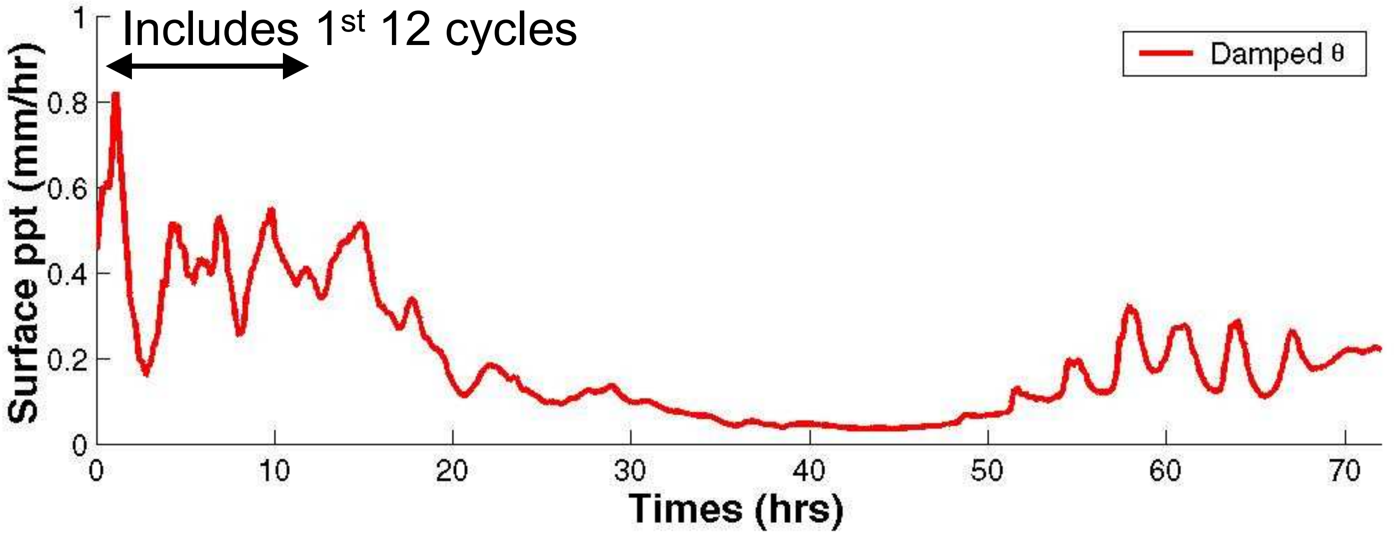


Damped u, v
Non-damped
Dist (km)
At surface
At top of boundary layer
(925 m)
Height (km)
Speed (m/s)
Damped uv
Non−damped
Vertical profile of horizontal wind speed
At time of maximum forcing
X-section of horizontal wind speed (m/s)

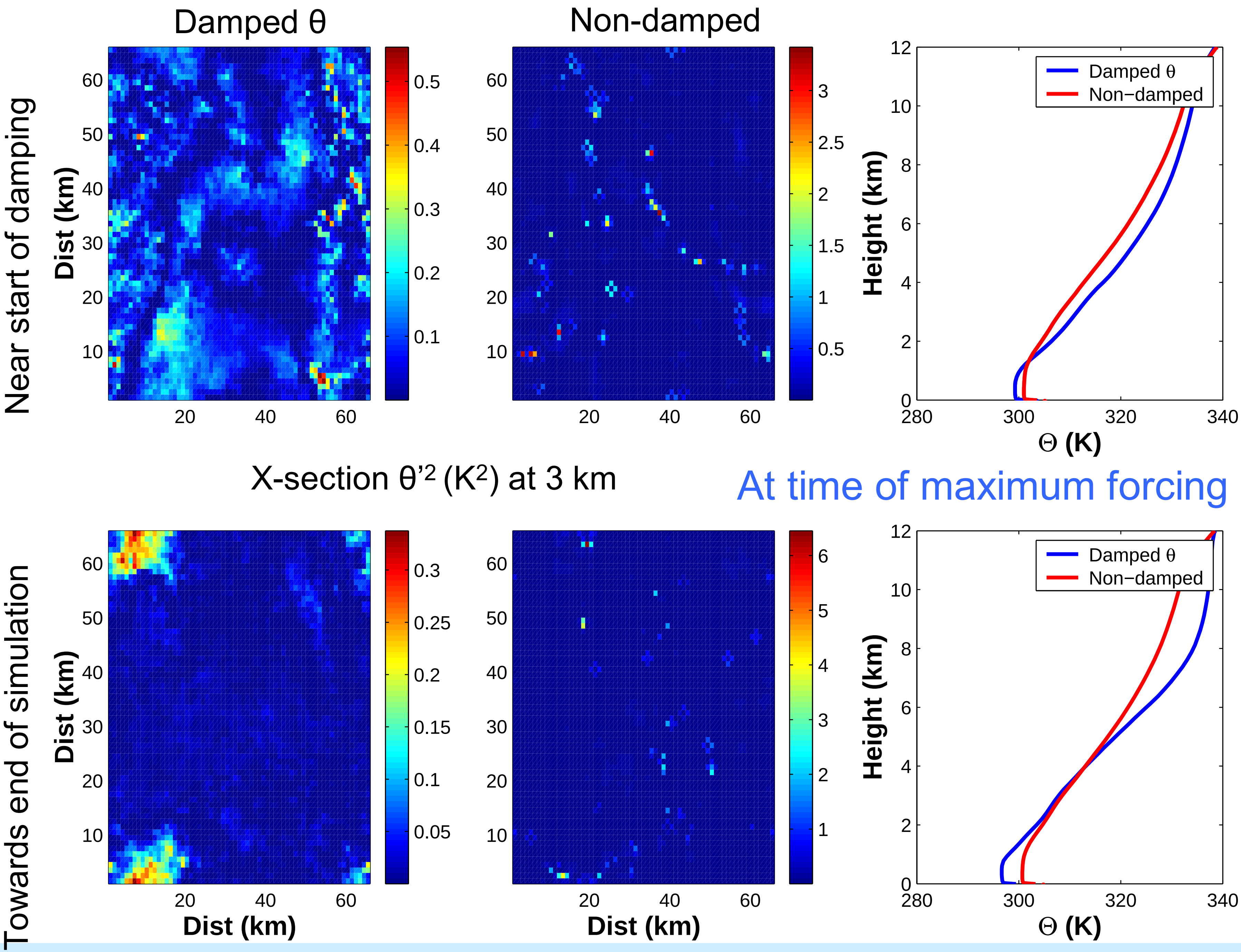
Damping θ



Non−damped
Damped θ
Surface ppt (mm/hr)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60

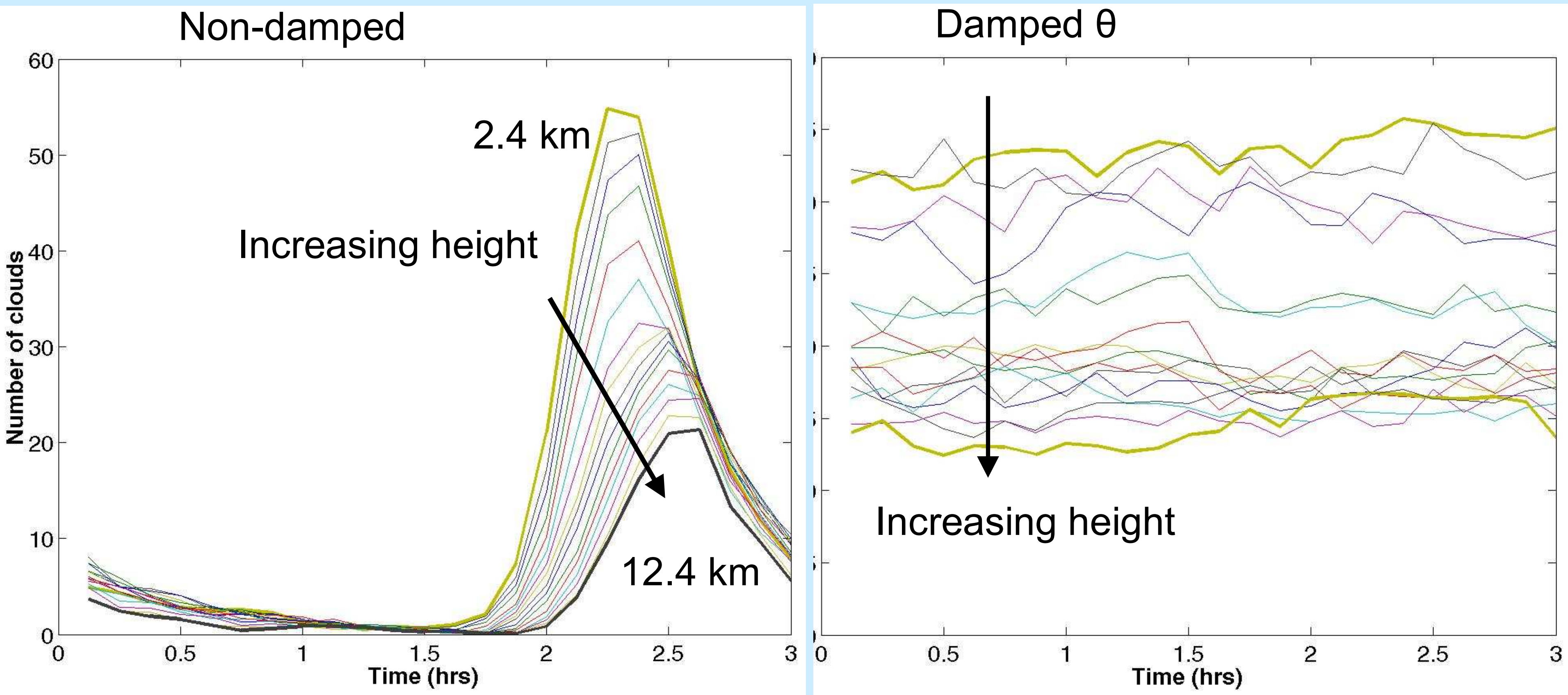


Includes 1st 12 cycles
Damped θ
Surface ppt (mm/hr)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
Times (hrs)


Damped θ
Non-damped
Near start of damping
Dist (km)
Height (km)
Θ (K)
Damped θ
Non−damped
X-section θ'2 (K2) at 3 km
At time of maximum forcing
Towards end of simulation
Dist (km)
Dist (km)
Height (km)
Θ (K)
Damped θ
Non−damped

Cloud distribution

Mean number of clouds



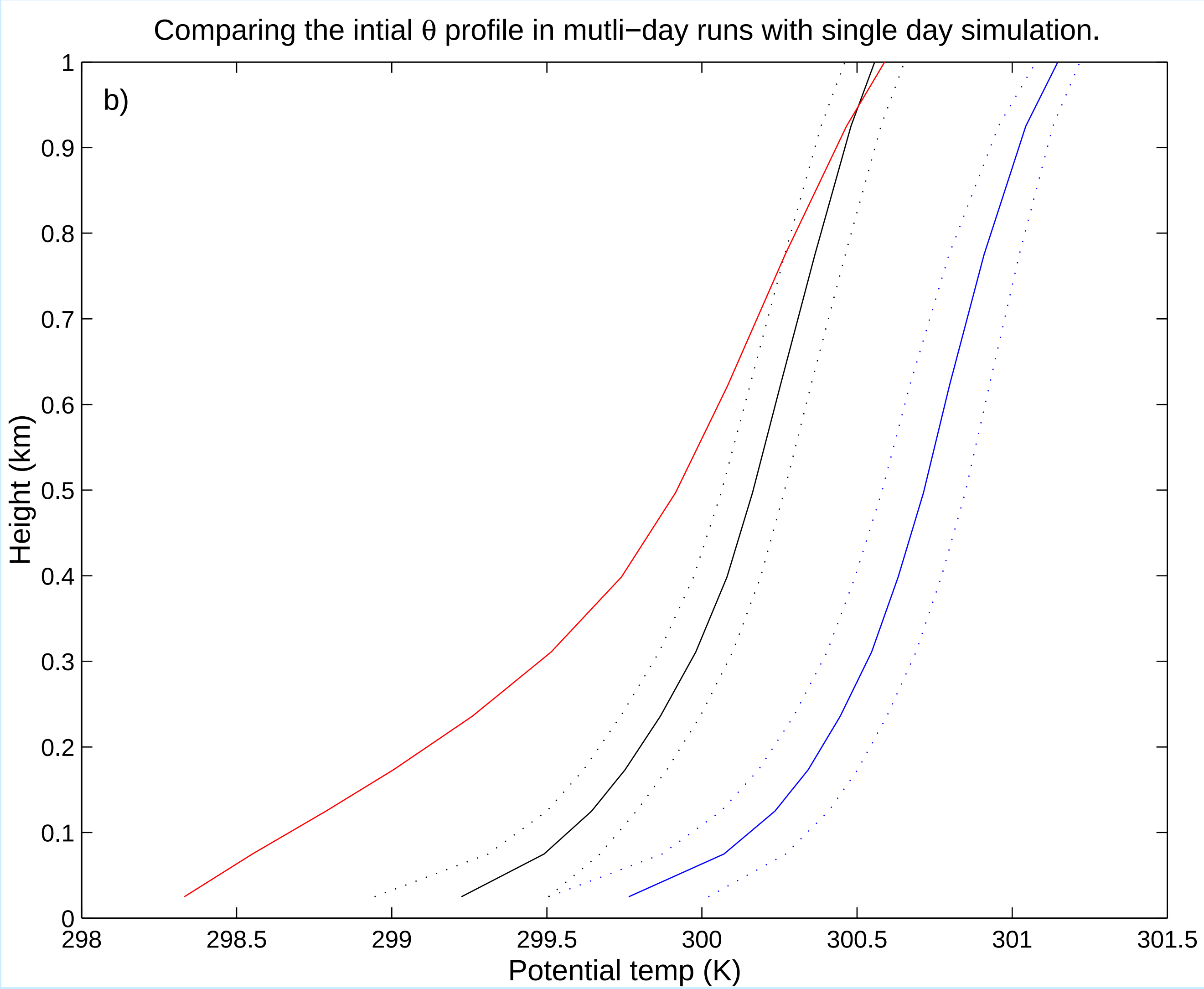
Clouds defined as buoyant, moist and upward moving

Conclusions

- Including convective parameterisations in numerical models is essential.
- However results suggest that making an equilibrium assumption might not always be valid.
- At short forcing timescales the convection is not a direct function of the forcing.
- The time-history of the system affects the current amount of convection. The system has an element of memory.
- Experiments are starting to consider what variables may cause this memory.
- u, v and θ are initial suggestions but experiments need to be carefully constructed.

Discussion points

- How do we make a parameterisation that works for all forcing timescales eg. $\tau_{adj} \leq \tau_{ls}$
- What key variables provide the memory in the convective system?
- At what height do they have greatest effect?
- Is their spatial variability also a key factor?


Comparing the intial θ profile in mutli−day runs with single day simulation.
b)
Height (km)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
298
298.5
299
299.5
300
300.5
301
301.5
Potential temp (K)