# Idealized simulations of the diurnal cycle of deep convection using the new Met Office Cloud-Resolving Model (MONC)

1. **Look at the memory properties in the deep convection**
2. **Investigate if the variability in the main state is important for the memory**
3. **Determine on what space and timescale we do have memory**

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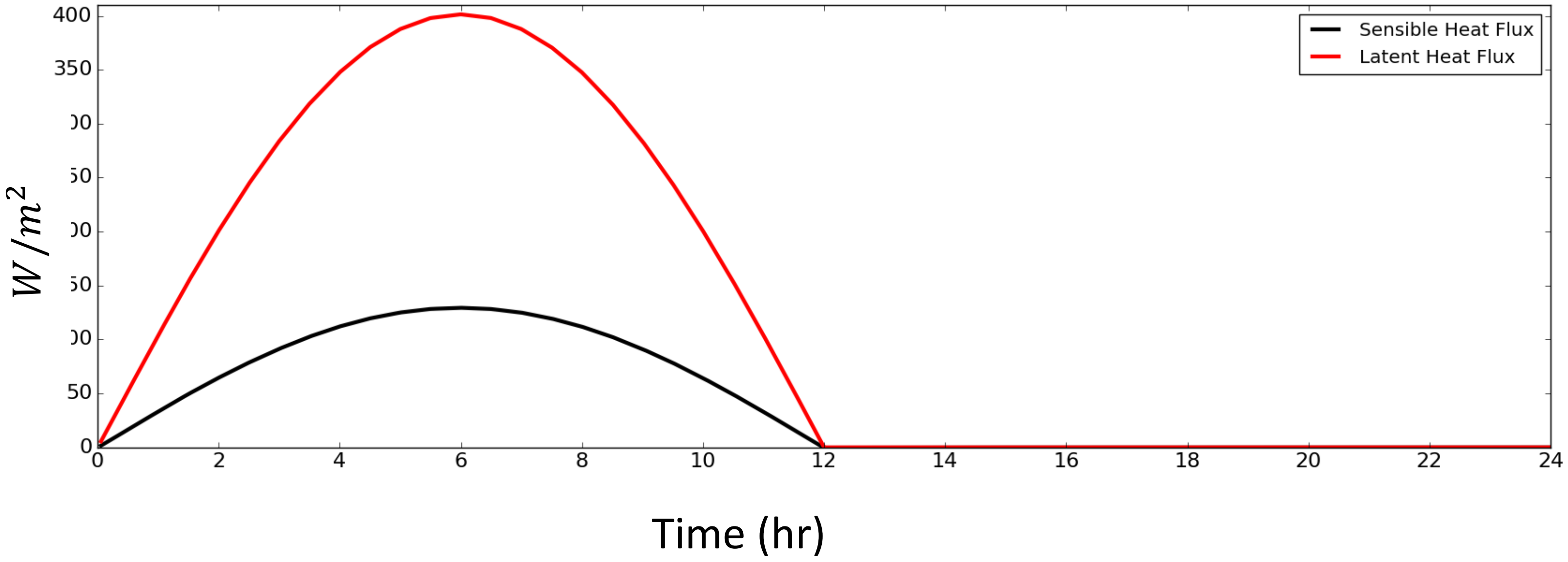
CPPC: Met Office, Exeter, UK, 15-19 July 2019

# MONC configuration

| | |
|---|---|
| **Model dimensionality** | **3D** |
| **Domain size** | $100 \times 100\ km$ |
| **Horizontal resolution** | 200 m |
| **Number of vertical levels** | 99 |
| **Vertical resolution** | On a stretched grid with more levels near the surface |
| **Model top** | 20 km |
| **Newtonian damping layer** | $\tau = 0.0001$, $Z_d = 15\ km$ and $H_d = 2.5\ km$ |
| **Wind shear imposed** | None ($u, v$ relaxed to $0\ m/s$ to with $\tau = 2\ h$) |
| **Coriolis** | Zero |
| **Boundary conditions** | Bi-periodic, rigid lid |
| | |

# Setup and forcing are based on the EUROCS case study




**Control simulation**

Peak SHF =130 $w/m^2$, LHF= 400 $w/m^2$

RC is prescribed:
$-1.75K/d$ from 0-12km, then decreases linearly with height to $0K/d$ at 15km

Different **strengths of surface forcing**

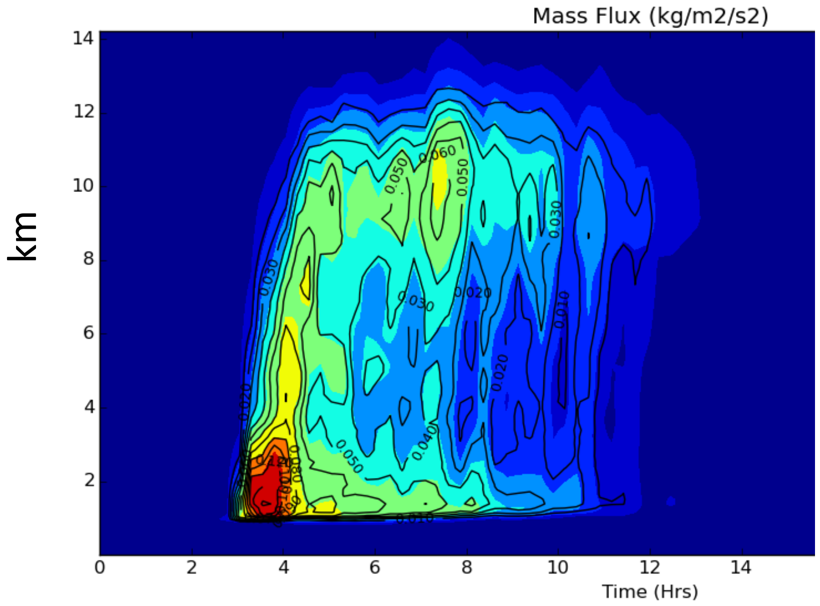
**Weakly forced simulation: 0.5*Control**
Peak SHF =65 $w/m^2$
Peak LHF= 200 $w/m^2$
RC=$-0.875\ K/d$

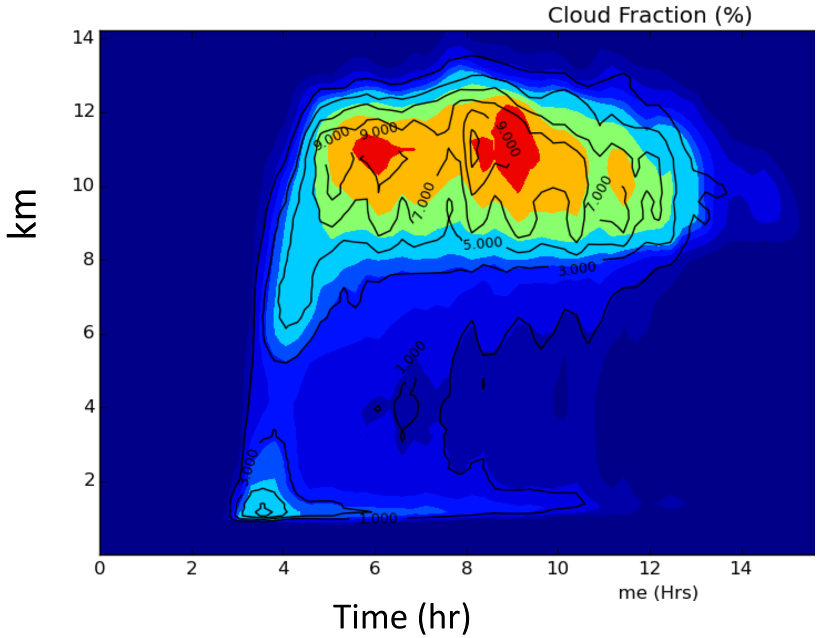
**Strongly forced simulation: 1.5*Control**
Peak SHF =195 $w/m^2$
Peak LHF= 600 $w/m^2$
RC=$-2.625\ K/d$

- Most of the simulations are performed over 10 forcing cycles to ensure statistically significant results
- Most of the results presented are the composites over 9 forcing cycles, after the first forcing cycle has been removed

# Evaluation on multi forcing cycles

## Control simulation



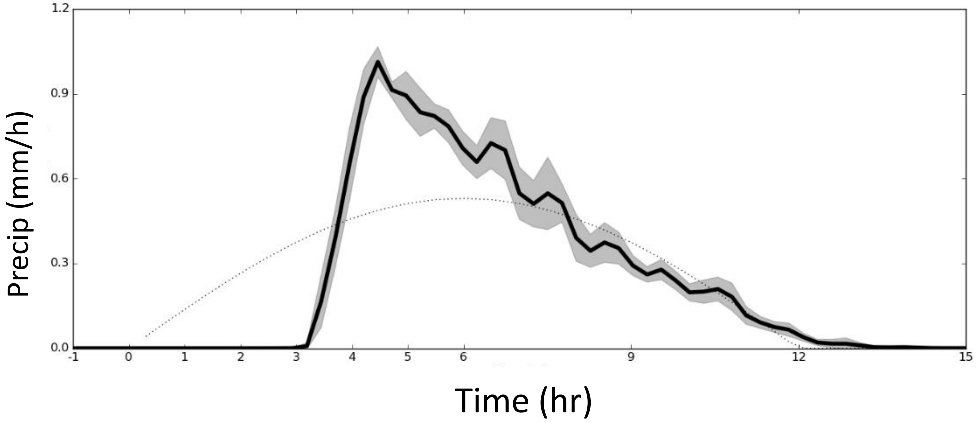




ACu ($q_l$ $or$ $q_i > 10^{-5} kg/kg$ and $w > 0\ m/s$)

BCu or Cloud cores (ACu, $\theta_v' > 0\ K$)

Triggering ~ 3h

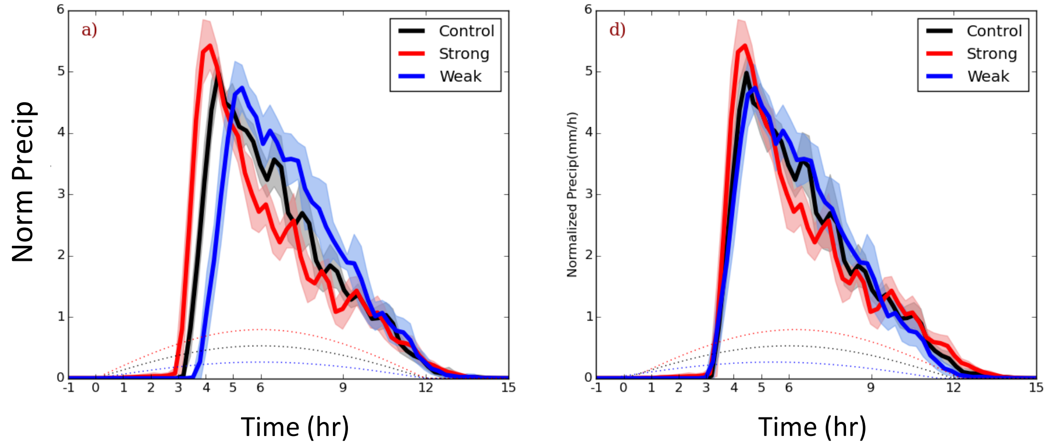
Triggering =rapid intensification of convection with deep convective cloud top emerging rapidly into the upper troposphere




Rainfall occurs too early after triggering=Early morning precipitation peak

# Timing of convection for different strengths of surface forcing



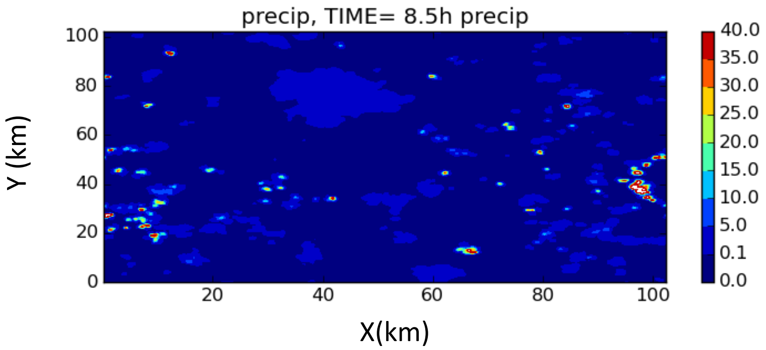


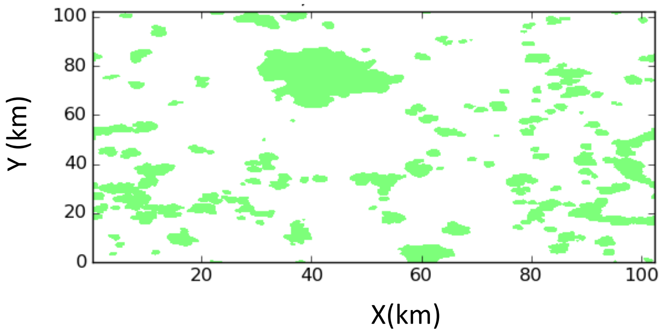

- MRR= 0.1mm/h (weak), 0.2mm/h (control), and 0.3 mm/h (strong)
- MF and cloud fraction increases with the strength of surface forcing
- Time of triggering increases with decreasing forcing
  - Triggering is at 2.75h (strong), 3h (control), and 3.5h (weak).

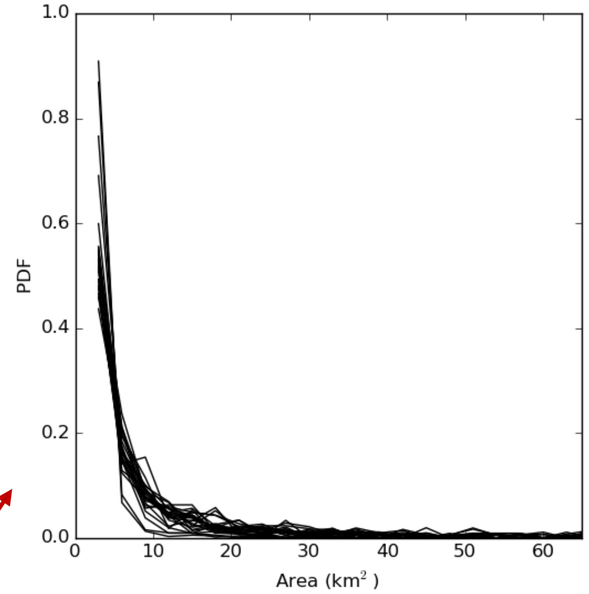
After triggering: regardless of the strength of surface forcing

- deep convective cloud top emerges rapidly into the upper troposphere
- The rate of growth of cloud top is very similar
  - Rainfall occur too early after triggering
  - Precipitation peaks almost at the same time: about 1.5h after triggering

# Evolution of rainfall events




2D surface precipitation (15 minutes output frequency)

A grid point $(i, j)$ is masked as cloudy if $precip_{i,j} \geq 0.5 \times \overline{< precip >}$
Cloudy grid points are classified in clusters (rainfall events)

PDF of $A_i$ (4-12h)

The distribution is very broad.

Number of rainfall events is $N$
Area of each rainfall event $A_i = n_i \Delta x \Delta y$

Average radius $\bar{R} = \sqrt{\bar{A}/_\pi}$ and standard deviation of radii $\sigma_R$

# Evolution of rainfall events

Evolution of $\bar{R}$ can be divided into three stages:

## Growing stage(3-5h):

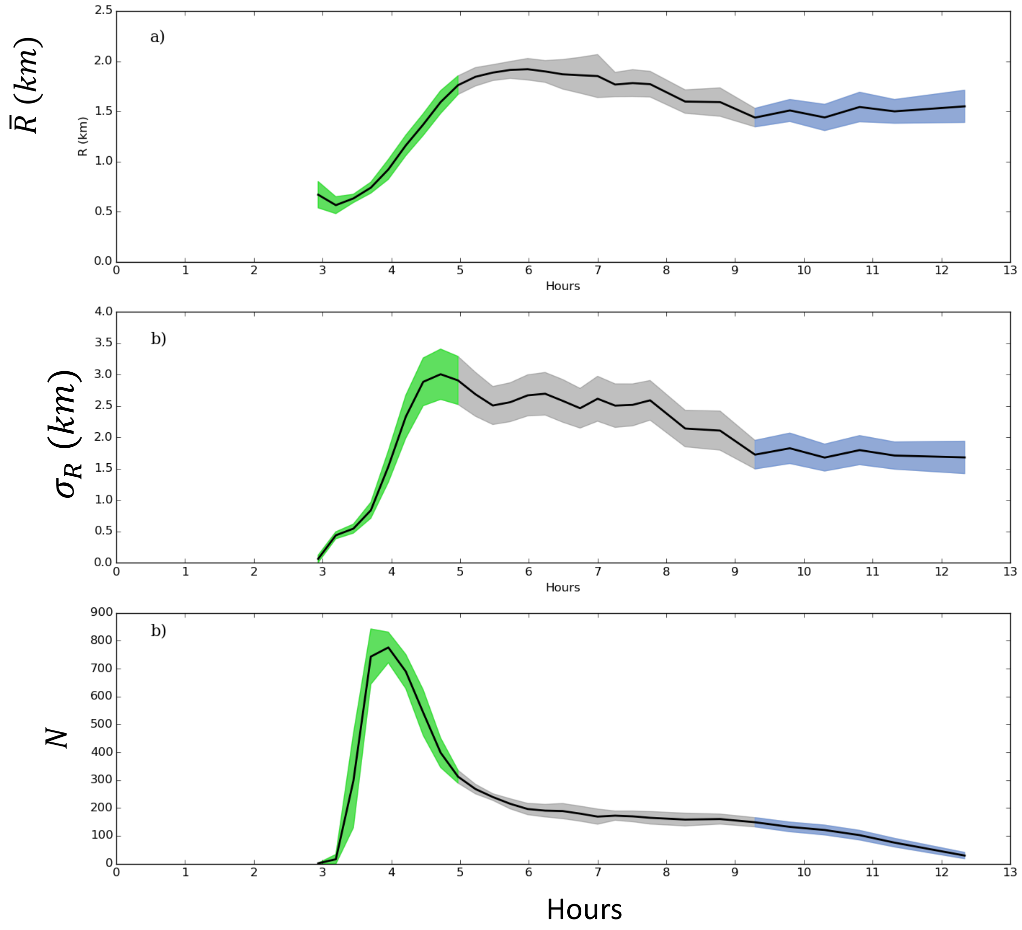
- marked with a gradual growth of $\bar{R}$
- $N$ peaks at 4h (~1h after triggering)
- Between 4-5h $N$ decreases rapidly while $\bar{R}$ is increasing

## Mature stage(5-9h):

- $\bar{R}$ adjusts from its peak value to a smaller value
- $N$ is decreasing

## Steady stage (9-12h):

- $\bar{R}$ is almost constant
- $N$ continues to decrease and reaches 0 when precipitation stops




$\bar{R}$ does not vary substantially with time, away from triggering

Time-evolution of the total MF is mainly caused by variations in the cloud statistics (number), rather than changes in the characteristics of the clouds (radius).

# Sensitive to the strength of the forcing?

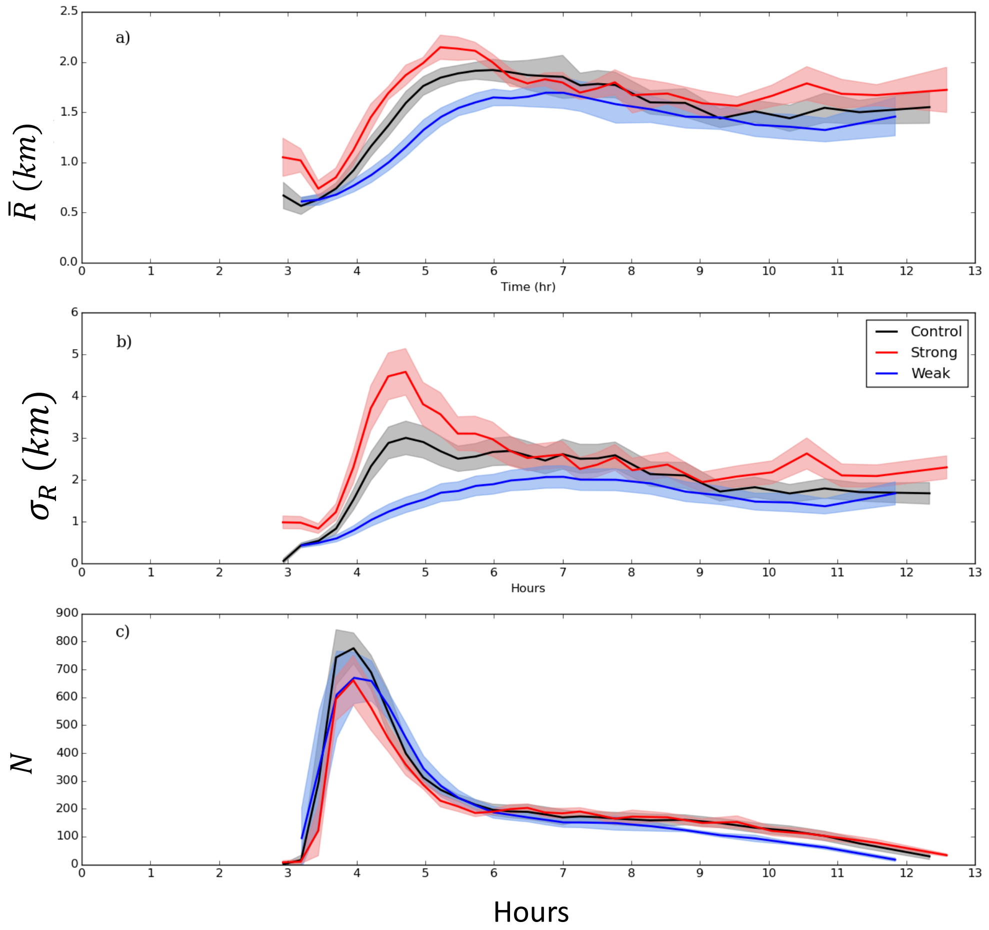
The mean MF per cloud increases with the strength of SF

Growing stage:

- Clear size dependence
  - $\bar{R}$ and $\sigma_R$ increase with the strength of surface forcing
- $N$ peaks 1 hour after triggering (for all cases)

Mature and steady stages

- No clear separations

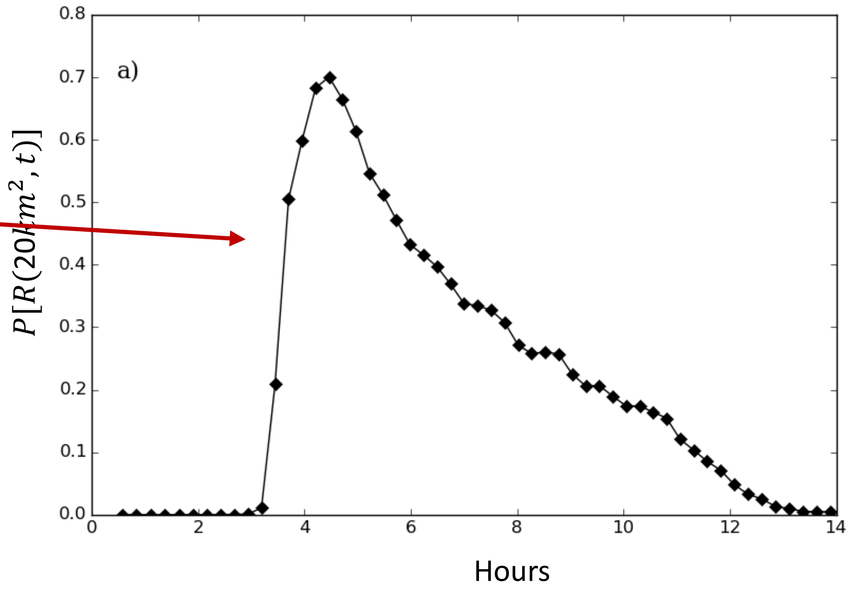


# Convection depends on its own history?

Evaluation of convection within a given area A

Each area A is considered to have rain if its precip is $\geq 0.5 \times \overline{< precip >}$

Conditional probability of finding rain within a $20km^2$, $P[R(20km^2, t)]$




Persistence of rainfall events: $P[R(A,t)/R(A,t-\Delta t)]$

Minimum persistence: 0

Maximum persistence: $P[R(A,t)]$

For random distributions, the conditional probability of finding persistent rainfall by random chance:

$P^2[R(A,t,\Delta t)]$=$P[R(A,t)] \times P[R(A,t-\Delta t)]$

There is no memory if $P[R(A,t)/R(A,t-\Delta t)] \sim P^2(R(A,t,\Delta t)$

There is memory if $P[R(A,t)/R(A,t-\Delta t)] \neq P^2(R(A,t,\Delta t)$

Memory function $M[R(A,t,\Delta t)]$= $\dfrac{P[R(A,t)/R(A,t-\Delta t)] - P^2[R(A,t,\Delta t)]}{P[R(A,t)]}$

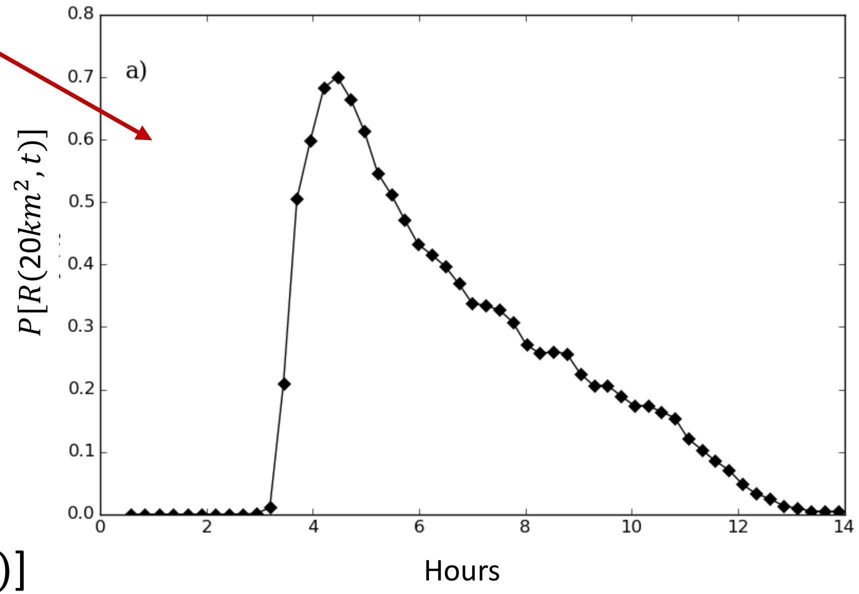
# Convection depends on its own history?

No convective memory if $P[R(A,t)/R(A,t-\Delta t)] \sim P^2(R(A,t,\Delta t)$

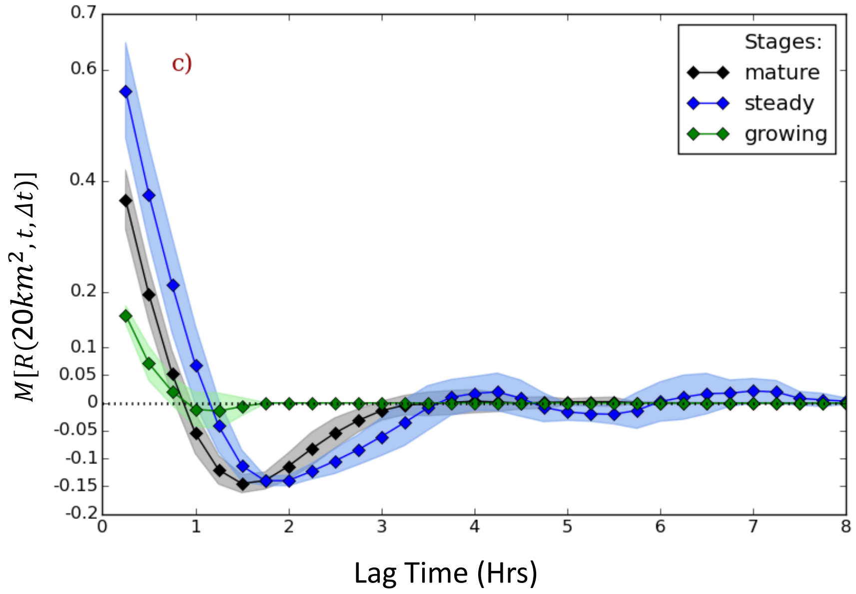
There is memory if $P[R(A,t)/R(A,t-\Delta t)] \neq P^2(R(A,t,\Delta t)$

Memory function $M[R(A,t,\Delta t)] = \dfrac{P[R(A,t)/R(A,t-\Delta t)] - P^2[R(A,t,\Delta t)]}{P[R(A,t)]}$

$P[R(20km^2,t)]$




$M[R(20km^2,t,\Delta t)]$




## Growing stage (3-5h):

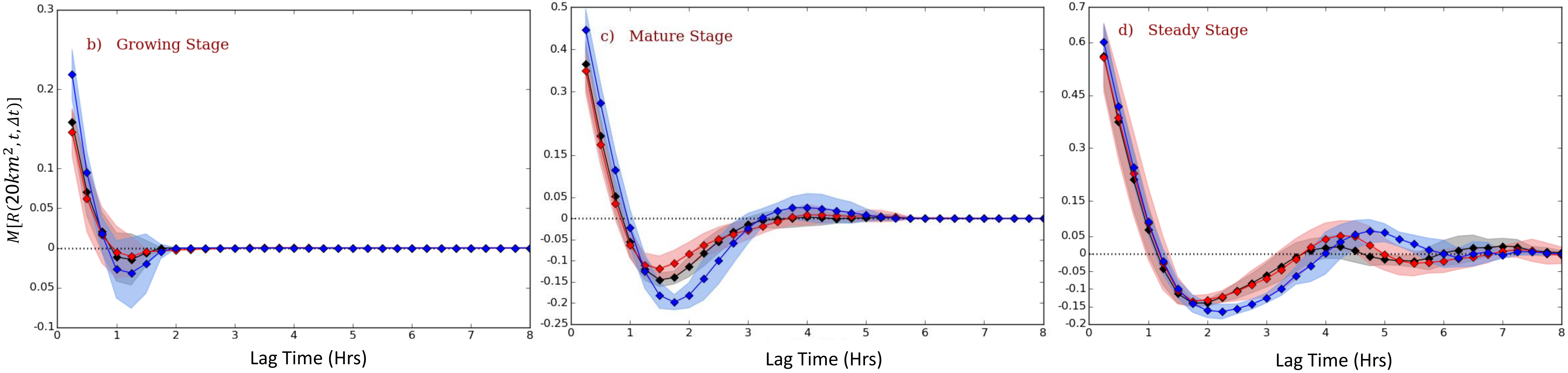
- Newly developing rainfall events are more likely to persist for half an hour or so

## Mature (5-9h) and steady (9-12h) stages:

- Very similar memory functions
- Convection depends its history over the previous 3 hours
- Depending on the most recent history:
    - *It is more likely to rain where it was already raining or*
    - *rainfall events are more likely to be suppressed if they have been active for few hours already*

# Convection depends on its own history?

## $M[R(A,t,\Delta t)]$ sensitive to the strength of surface forcing?




$M[R(A,t,\Delta t)]$ shows a weak sensitivity to the strength of surface forcing

- Weak: rainfall events decay less rapidly and are suppressed more strongly

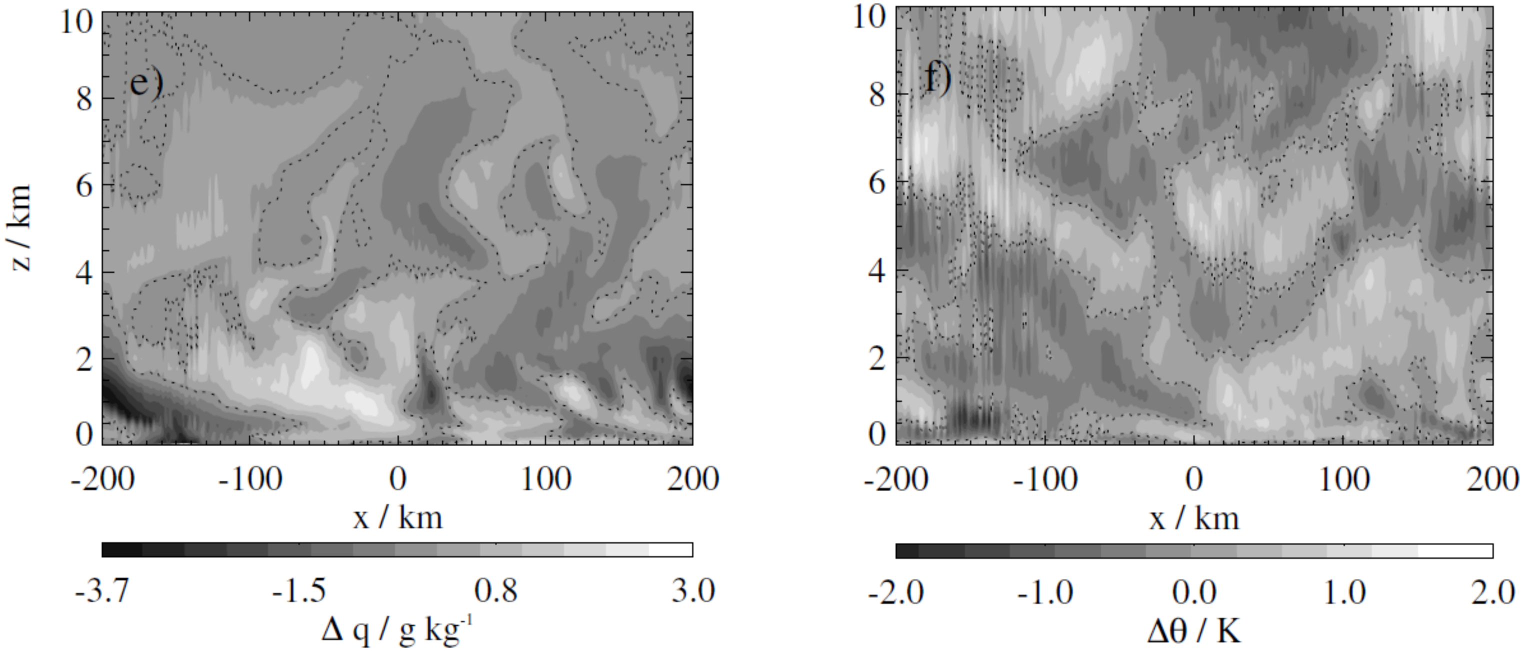
## $M[R(A,t,\Delta t)]$ sensitive to $A$?

- Very similar memory functions for $\mathrm{A} < 10 \times 10\ km^2$
- A significant reduction when $\mathrm{A} \geq 10 \times 10\ km^2$ and
- $M[R(A,t,\Delta t)] \approx 0$ for $\mathrm{A} \geq 25 \times 25\ km^2$

# Memory attributed to the initial thermodynamic fluctuations

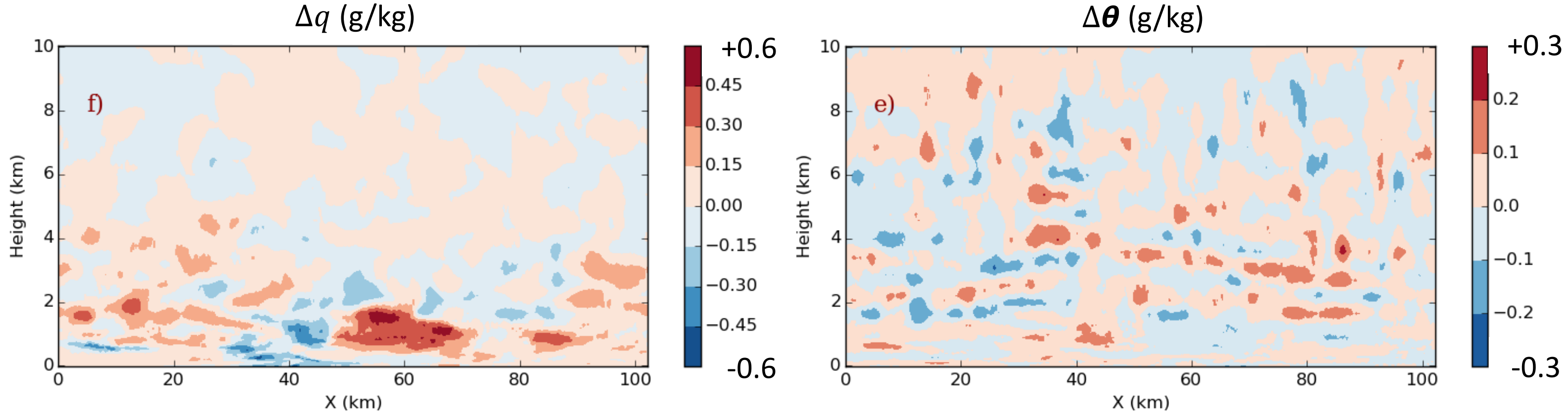


Study of Stirling and Petch [2004]
Onset of precip changes by several hours
And rainfall amount is increased by 70 %




In our study:

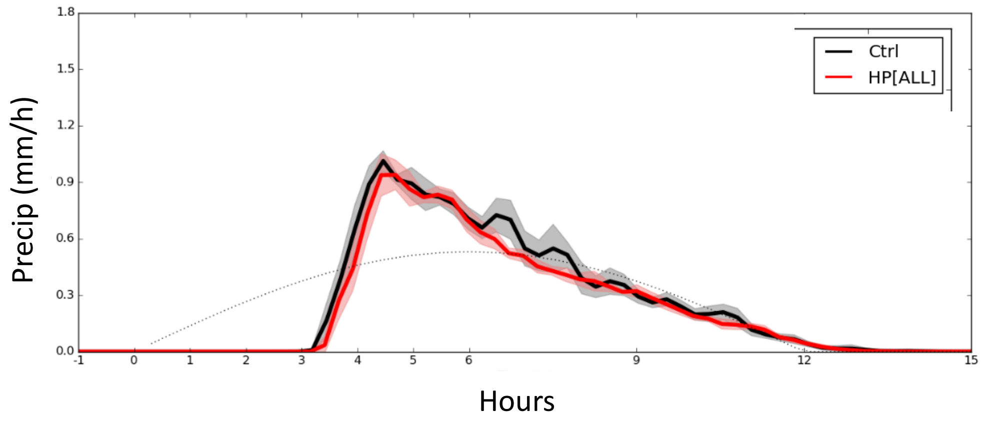
Thermodynamic fluctuations at the start of the next diurnal cycle




The amplitudes of $\Delta\theta$ and $\Delta q$ are at least 6 times smaller
Do they influence the evolution of convection on the next day?

# Memory attributed to the initial thermodynamic fluctuations

1- We applied "homogenization perturbations" of $\theta$ and $q$ (without changing the domain mean state) at all vertical levels between 15-24h



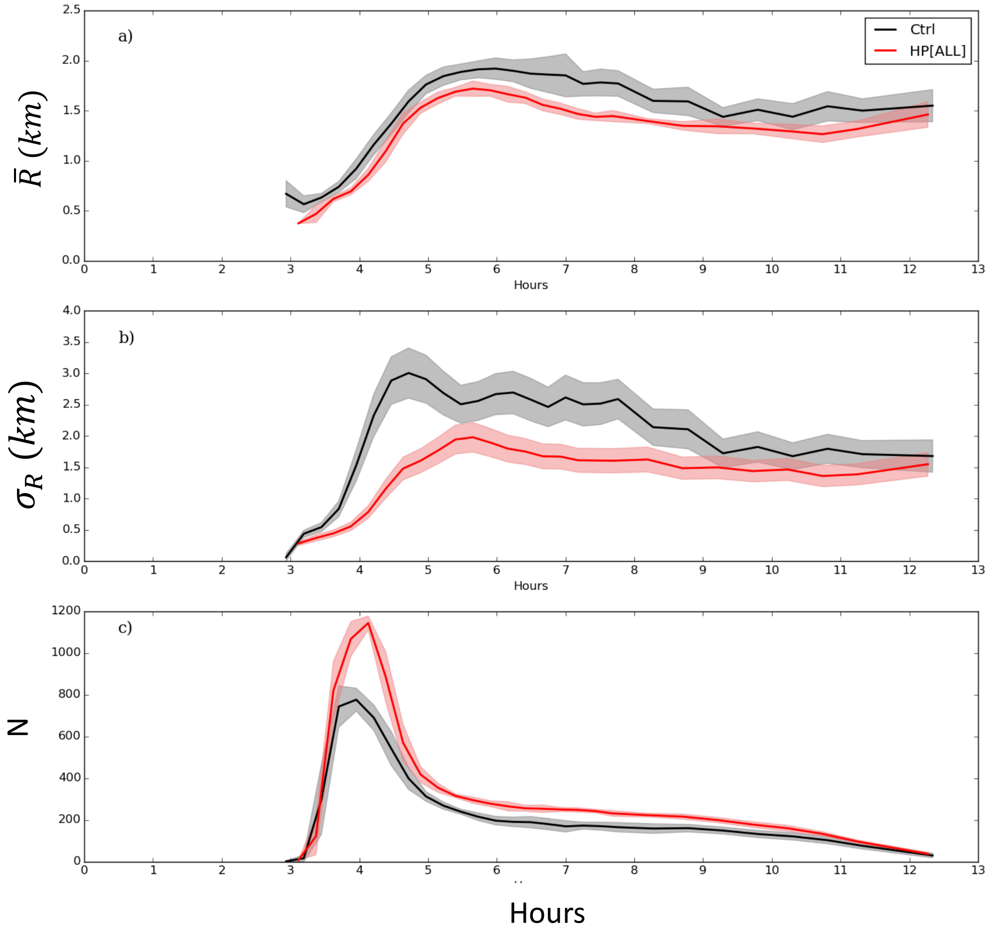

Following "homogenization perturbations":

- precipitation peaks at the same time
- Convection intensity is reduced by 10%
  (Mean rain rate= 0.18mm/h compared to 0.2mm/h in the control simulation)

# Thermodynamic fluctuations have a significant impact of the evolution of rainfall events

## Following homogenization perturbations

- Clear separations in the evolution of rainfall events
- $\sigma_R$ is narrower and $\bar{R}$ is smaller
- $N$ is increased (up to 450)
- Recovery time is over 6hours (3-9h)
- Convection intensity is reduced by 10% and N is increased
    - Rainfall events are less intense



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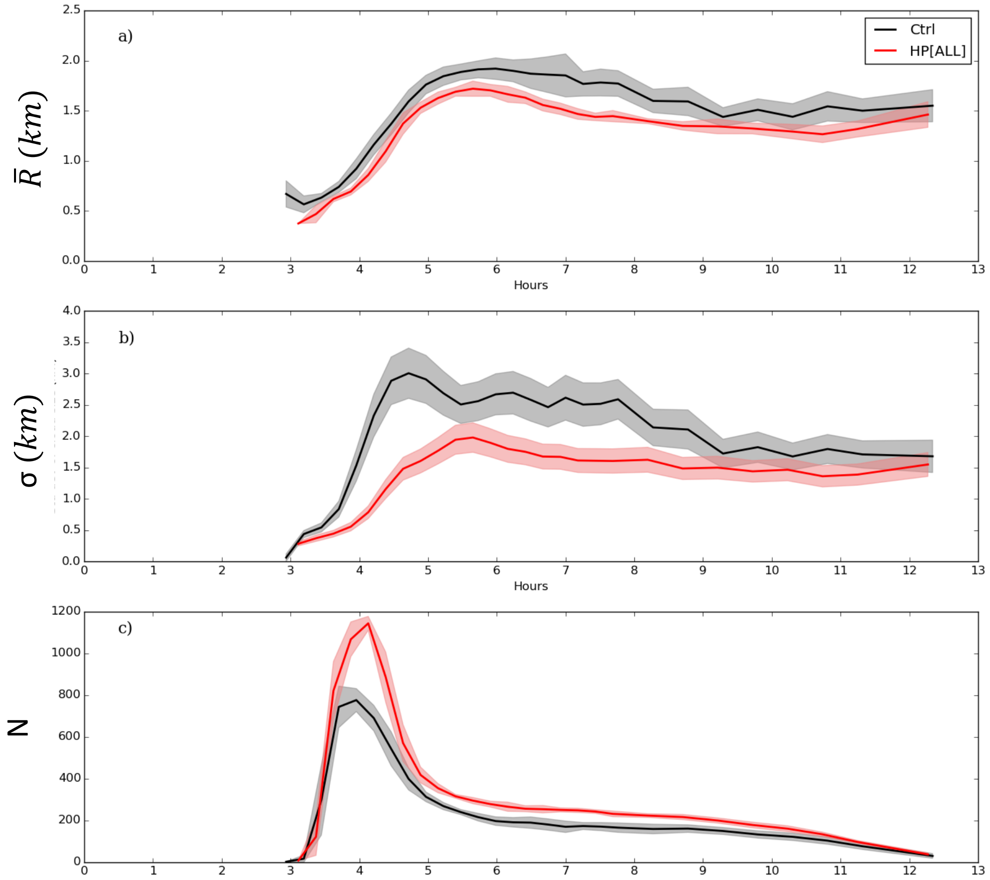
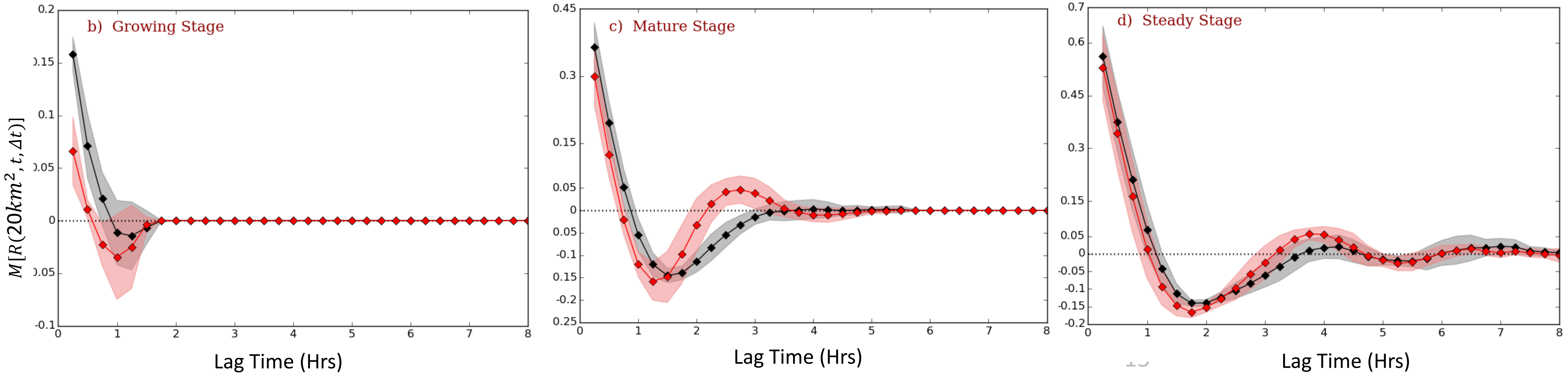
- $N$ is increased (up to 450)
- Recovery time is over 6hours (3-9h)
- Convection intensity is reduced by 10% and N is increased
  - Rainfall events are less intense
    - Decay more rapidly
    - Recover more rapidly (an hour earlier)

## Homogenization perturbations below 4km or above 4km

- $\Delta\theta$ and $\Delta q$ below 4km appear to contribute as a primary storage of convective memory

*(Confirms the results of Stirling and Petch [2004] and Colin et al. [2019])*



# Summary

- We produced the Diurnal cycle experiment that focuses on the triggering of deep convection.
- Morning precipitation maxima (*rainfall occurs too early after triggering*)

- Rainfall events become relatively larger with increasing strength of surface forcing
- Time-evolution of convection is mainly caused by variations in $N$, rather than changes in $\bar{R}$

The memory function depends on $A$. Within a 20 $km^2$

- Newly developing rainfall events are more likely to persist for an 0.5h.
- Depending on the most recent history of convection
  - It might be more likely to precipitate where it was already precipitating or
  - Rainfall events might be more likely to be suppressed if they have been active for few hours already

Thermodynamic fluctuations at the start of the next diurnal cycle have

- A little impact on the timing and intensity of convection
- A significant impact of the evolution of rainfall events
  - N decreases (up to 450 reduction), R and $\sigma_R$increase
  - Rainfall events are more intense, thus decay and recover more slowly
  - The contributions from $\Delta\theta$ and $\Delta q$ mostly resides in the lowest 4 km.

# Questions

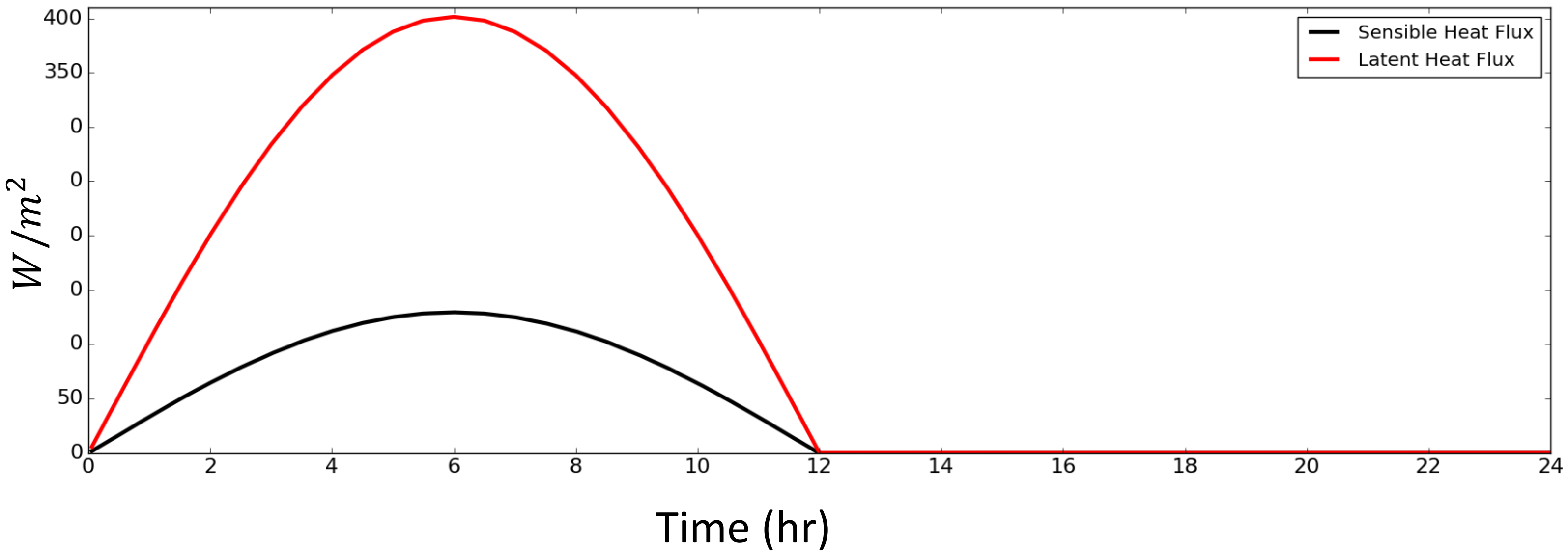
# objectives

**Our interest is to look at the memory properties: the memory in the deep convection**

**Want to see if the variability in the main state is important for the memory**

**I want to know on what space and time the memory is important**

# Setup and forcing are based on the EUROCS case study




**Control simulation**

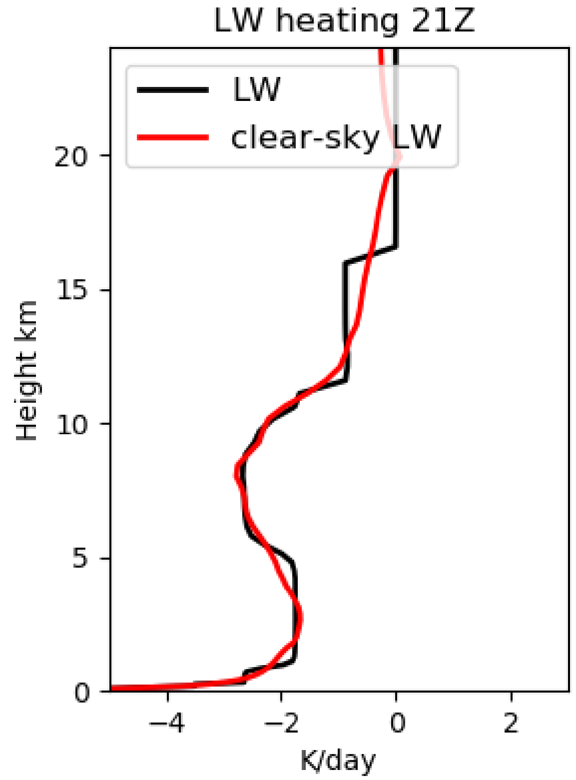
Peak SHF =130 $w/m^2$, LHF= 400 $w/m^2$

RC is prescribed:

$-1.75K/d$ from 0-12km, then $0K/d$ at 15km

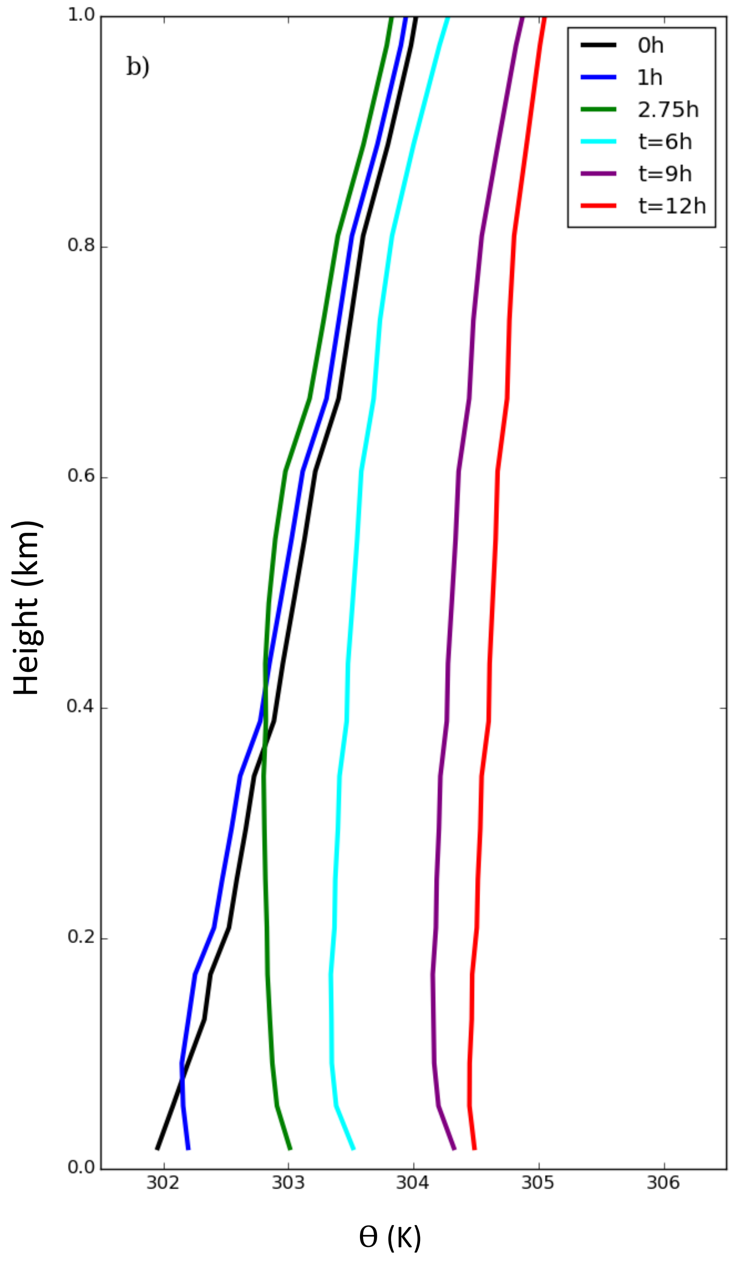
*Additional cooling at night (12-24h)*

$-3K/d$ at 0 km decreases to 0 $K/d$ at 1 $km$



# Evolution of the boundary layer

**Control simulation**

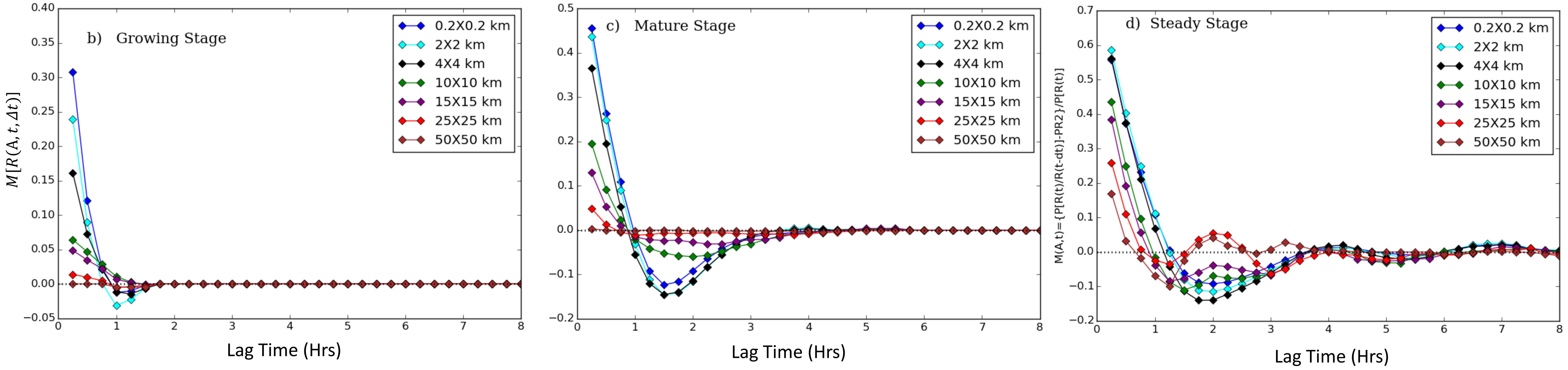



**Evolution of the BL**

- At sunrise: the near surface is at its coolest state and the BL is stable
- Near surface temperature is increasing
- BL depth is increasing: 100m at 1h to 800m at 12h
- Warmest state at sunset
- Surface forcing is off between 12-24h
  - Free troposphere cools down uniformly
  - Below 1km: the column cools more rapidly
- At 24h
  - Stability structure of the free troposphere is maintained close to that at 0h
  - The BL is stable

# Convection depends on its own history?

Does $M[R(A,t,\Delta t)]$ sensitive to the A?




The amplitudes of $M[R(A,t,\Delta t)]$ decrease with increasing A

Growing stage:

No convective memory when $\mathrm{A} \geq 25 \times 25\ km^2$

Mature stage:

- Very similar memory functions for $\mathrm{A} < 10 \times 10\ km^2$
- A significant reduction when $\mathrm{A} \geq 10 \times 10\ km^2$ and
- No convective memory when $\mathrm{A} \geq 25 \times 25\ km^2$

Steady stage

- $M[R(A,t,\Delta t)]$ shows different sensitivity for $\mathrm{A} \geq 15 \times 15\ km^2$
  - Rainfall events are a little bit enhanced and
  - There is convective memory even within area $\geq 25 \times 25\ km^2$



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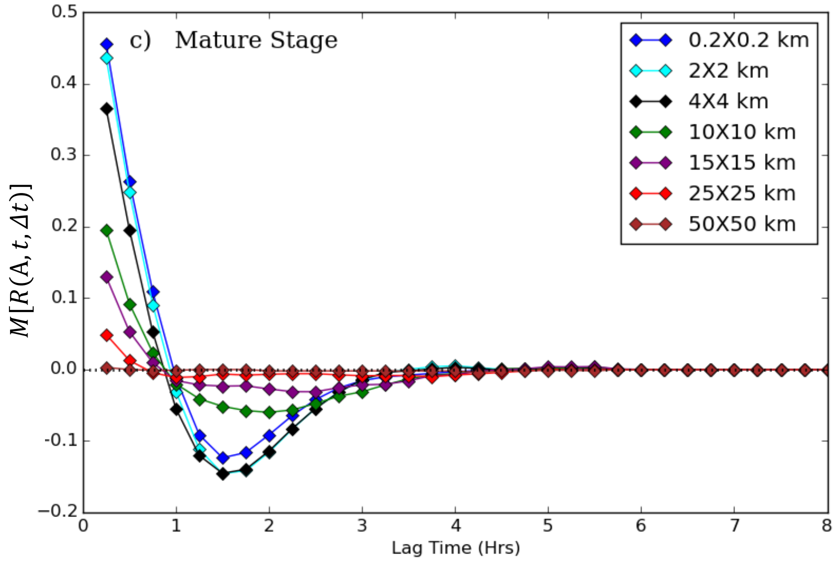
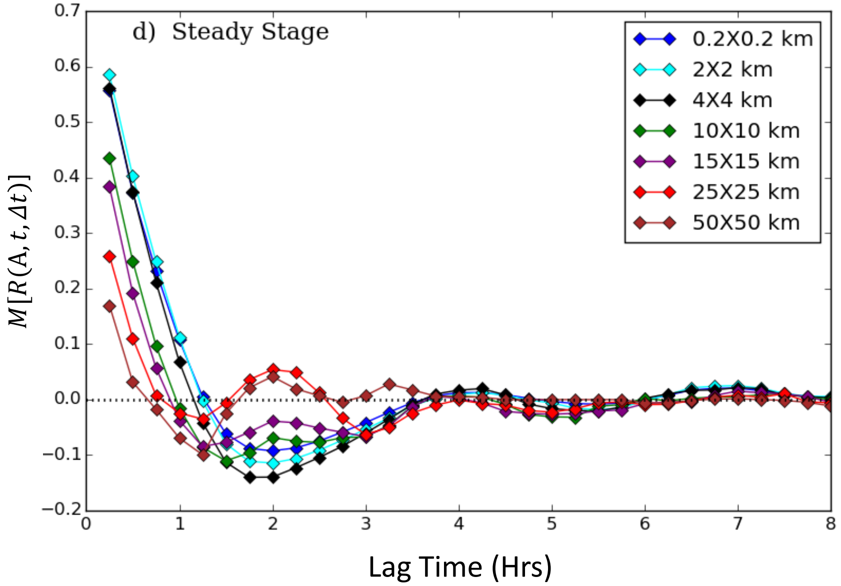
Analysis of $M[R(A,t,\Delta t)]$ reveals to evaluate current convection using information from previous behaviour of convection we needs to know the size of the area within which convection is evaluated and its life cycle are



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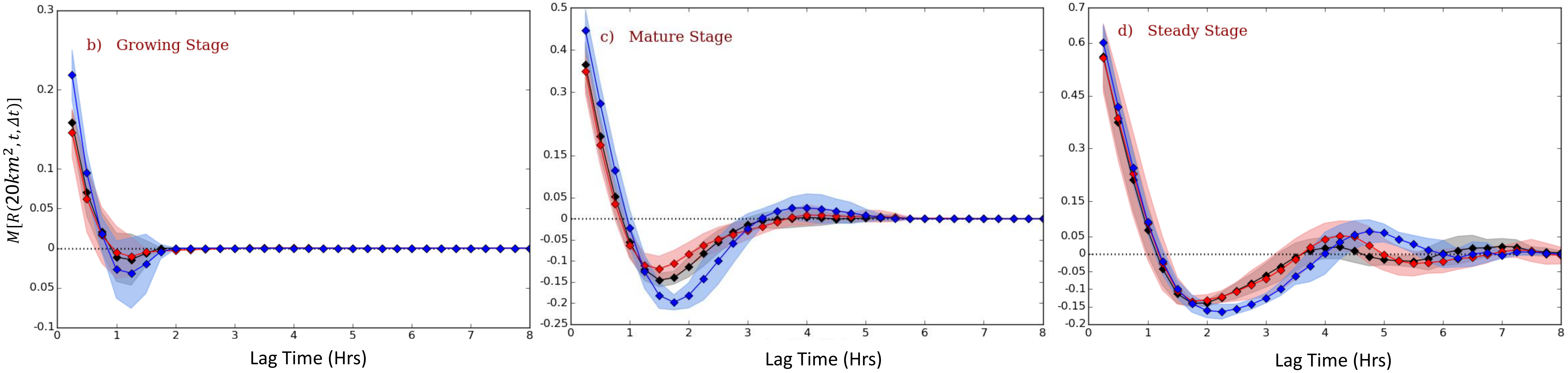


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- Weak: rainfall events decay less rapidly and are suppressed more strongly



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