Diurnal Cycle of Deep convection using MONC

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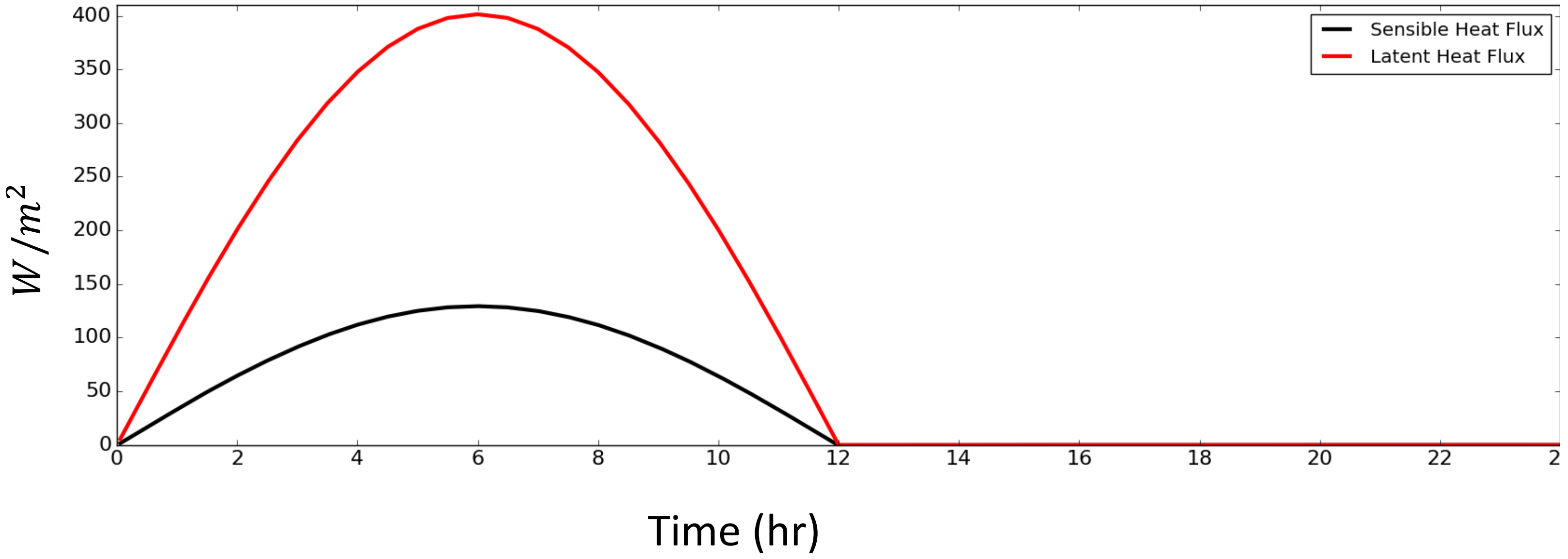
MONC- configuration

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



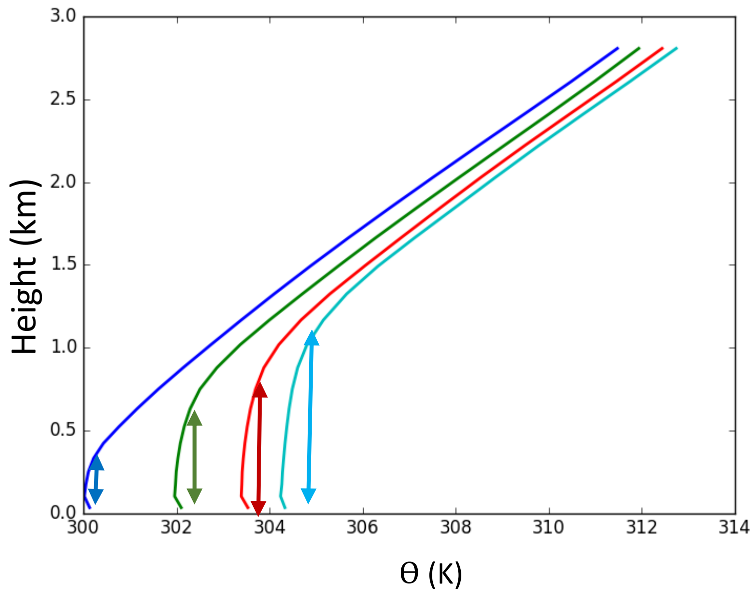
Control simulation

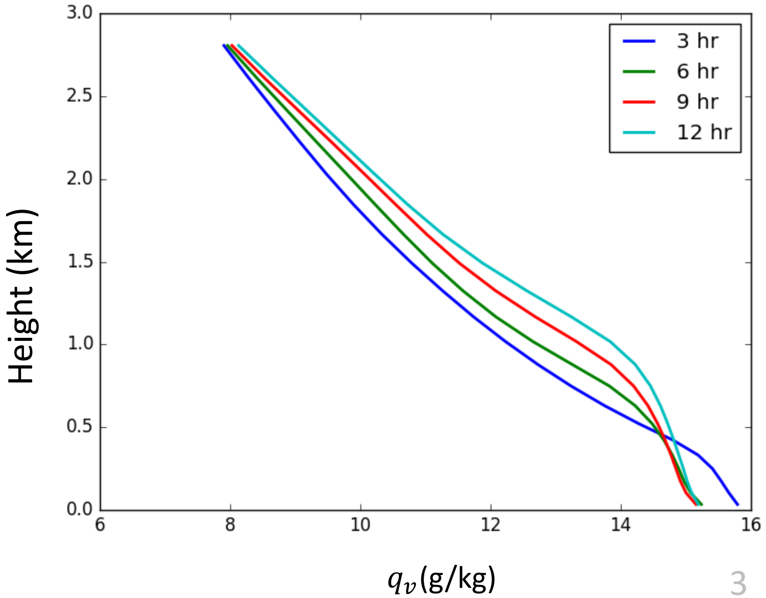
Peak SHF =130 w/m^2
Peak LHF= 400 w/m^2

Forcing time-scale: 24h

RC required to balance SHF+LHF over a 24h is prescribed:
$-2.2\ K/day$ from 0 to $7.5\ km$ then decrease linearly with height to $0\ K/day$ at 12 km

Evolution of the BL





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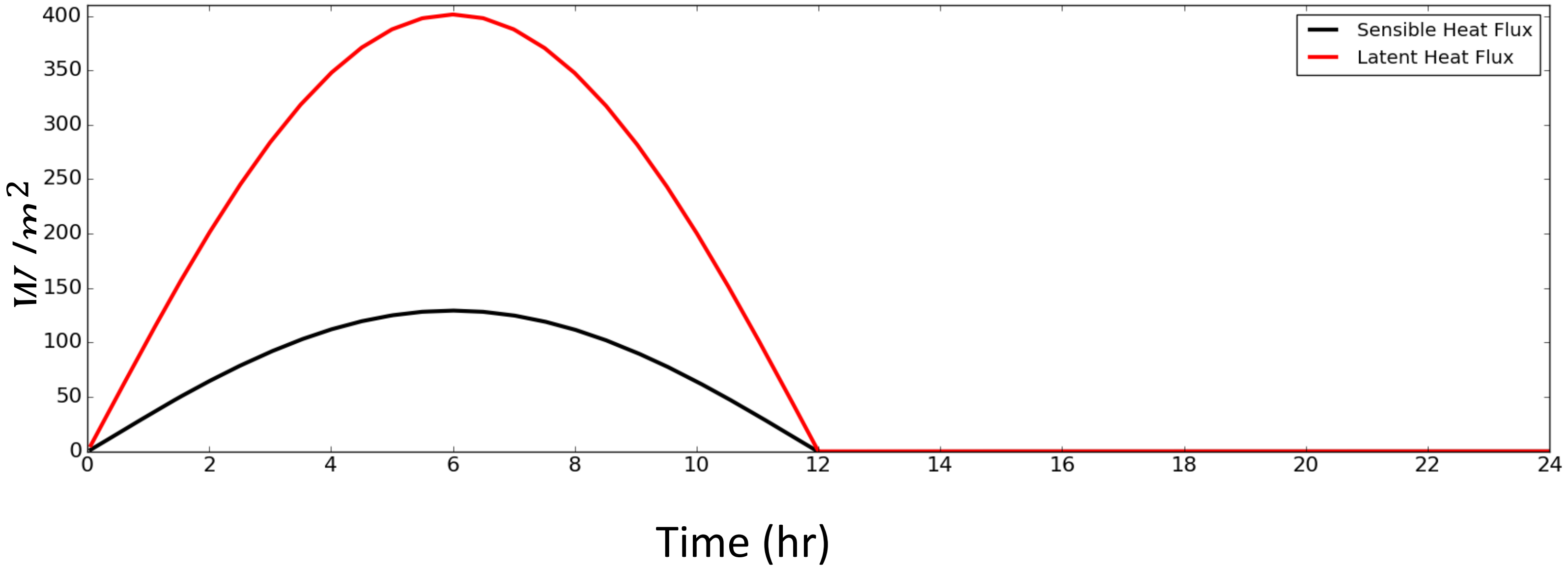

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Different **strengths of surface forcing**

Strong forcing
Peak SHF =195 w/m^2
Peak LHF= 600 w/m^2
RC=$-3.3\ K/day$

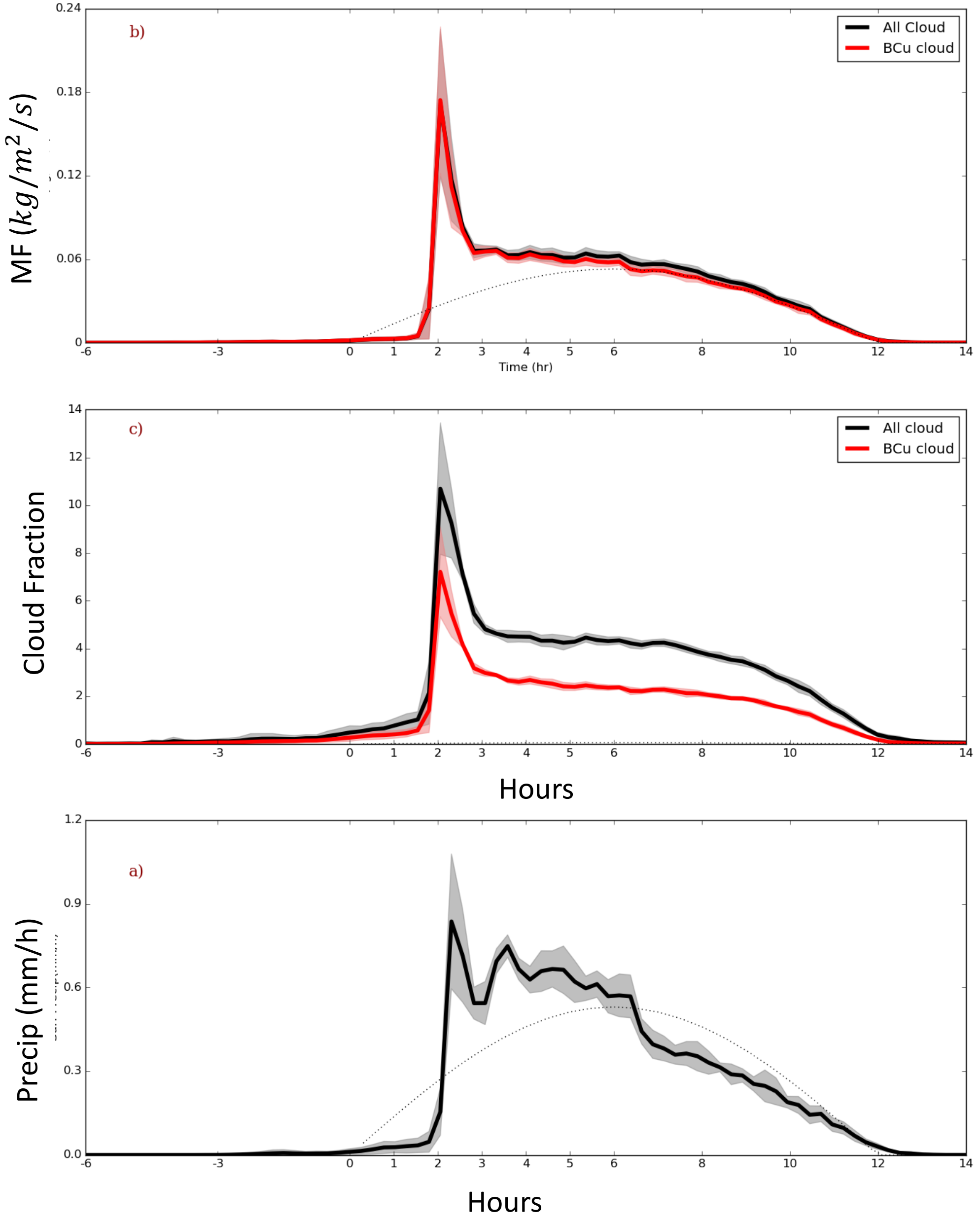
Weak forcing
Peak SHF =65 w/m^2
Peak LHF= 200 w/m^2
RC=$-1.1\ K/day$

Same Bowen ratio (~0.3) and forcing timescale (24 hrs)

Simulations are performed over several forcing cycles to ensure statically significant results and most of the results presented are the composites over 9 forcing cycles

Control simulations (over 10 forcing)

Composite timeseries over 9 forcing cycles (after the 1st forcing cycle has been removed)



- All cloud: $q_l \;\; or \; q_i > 10^{-5} kg/kg$
- BCu Cloud: $q_l \;\; or \; q_i > 10^{-5} kg/kg, \;$ w > 0m/s, and $\theta_v' > 0 \; K$

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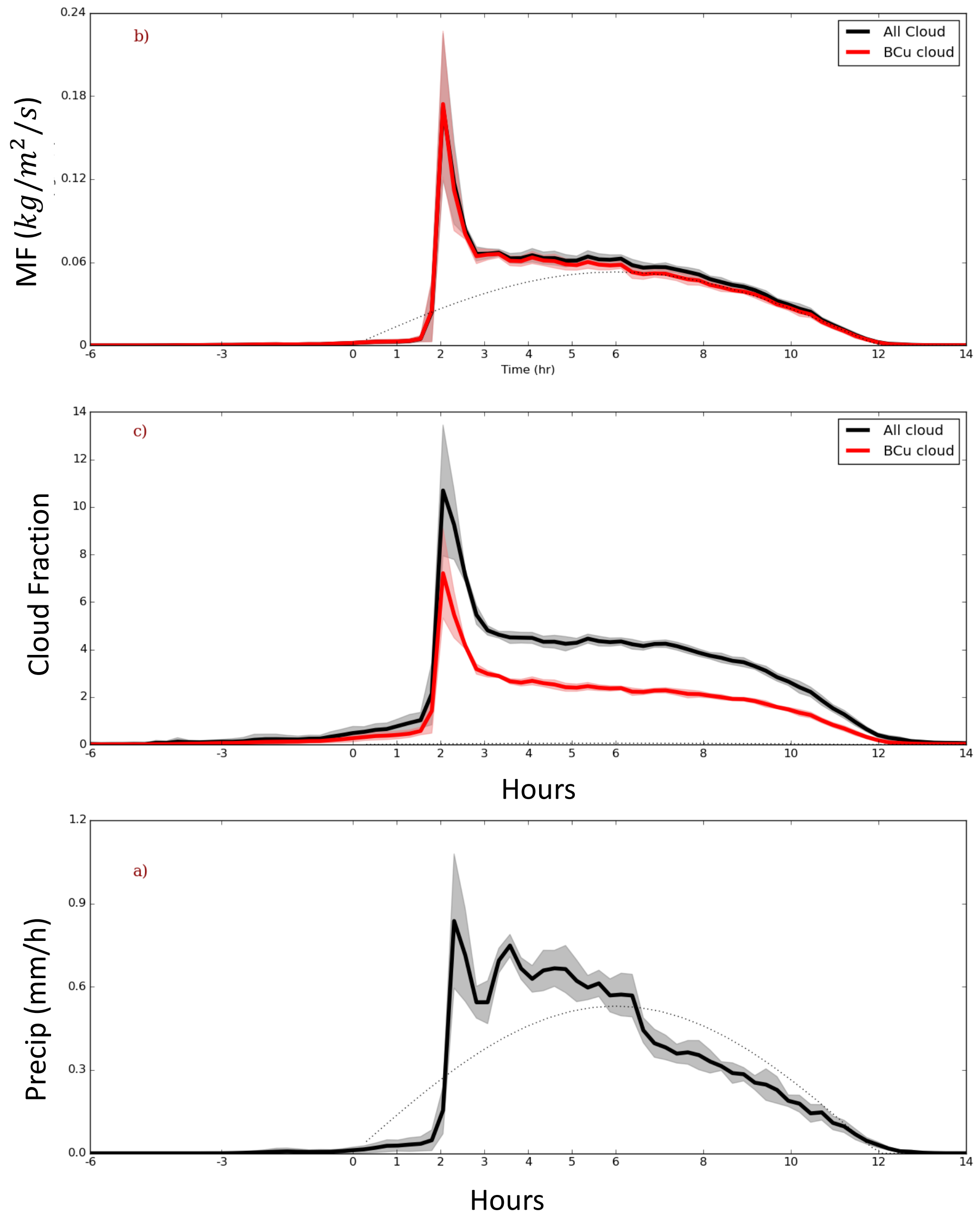

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- BCu Cloud: $q_l \;\; or \; q_i > 10^{-5} kg/kg, \;$ w > 0m/s, and $\theta_v' > 0 \; K$
  - $\sigma_{BCu} \sim 0.6 \times \sigma_{All}$ while $MF_{BCu} \sim MF_{All}$
    - *Most of the clouds which are not* $\theta_v' > 0 \; K$ *must be* $w < 0 \; m/s$
    - MF_{BCu} *is dominant source of mass flux*

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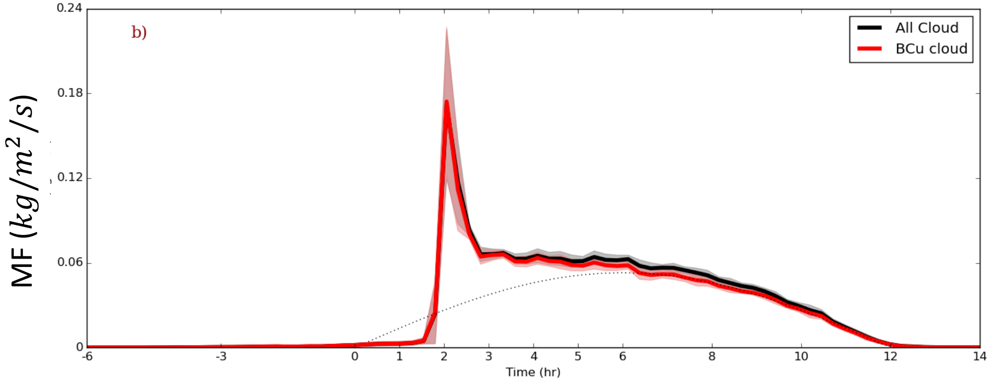

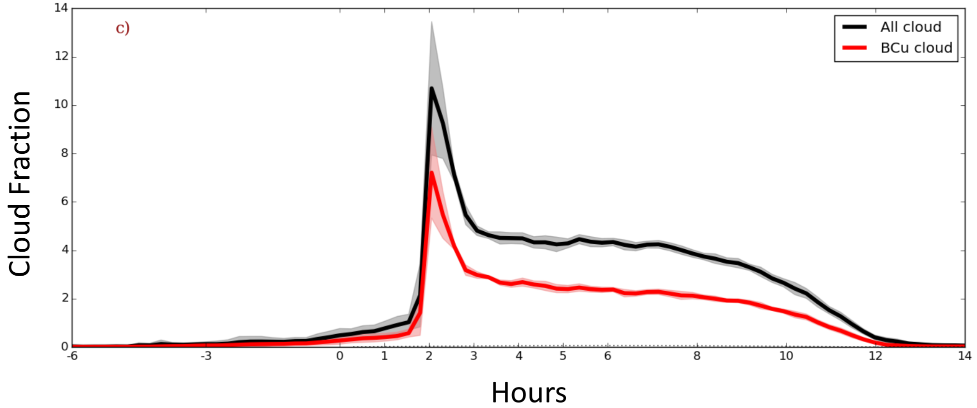

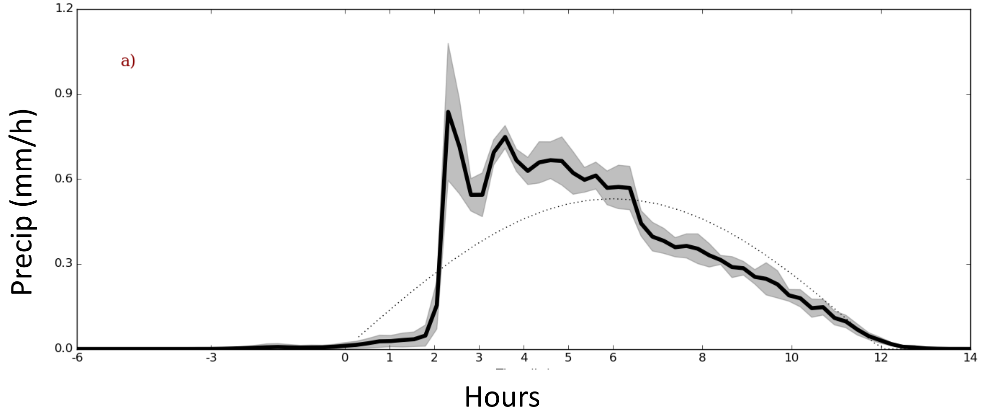

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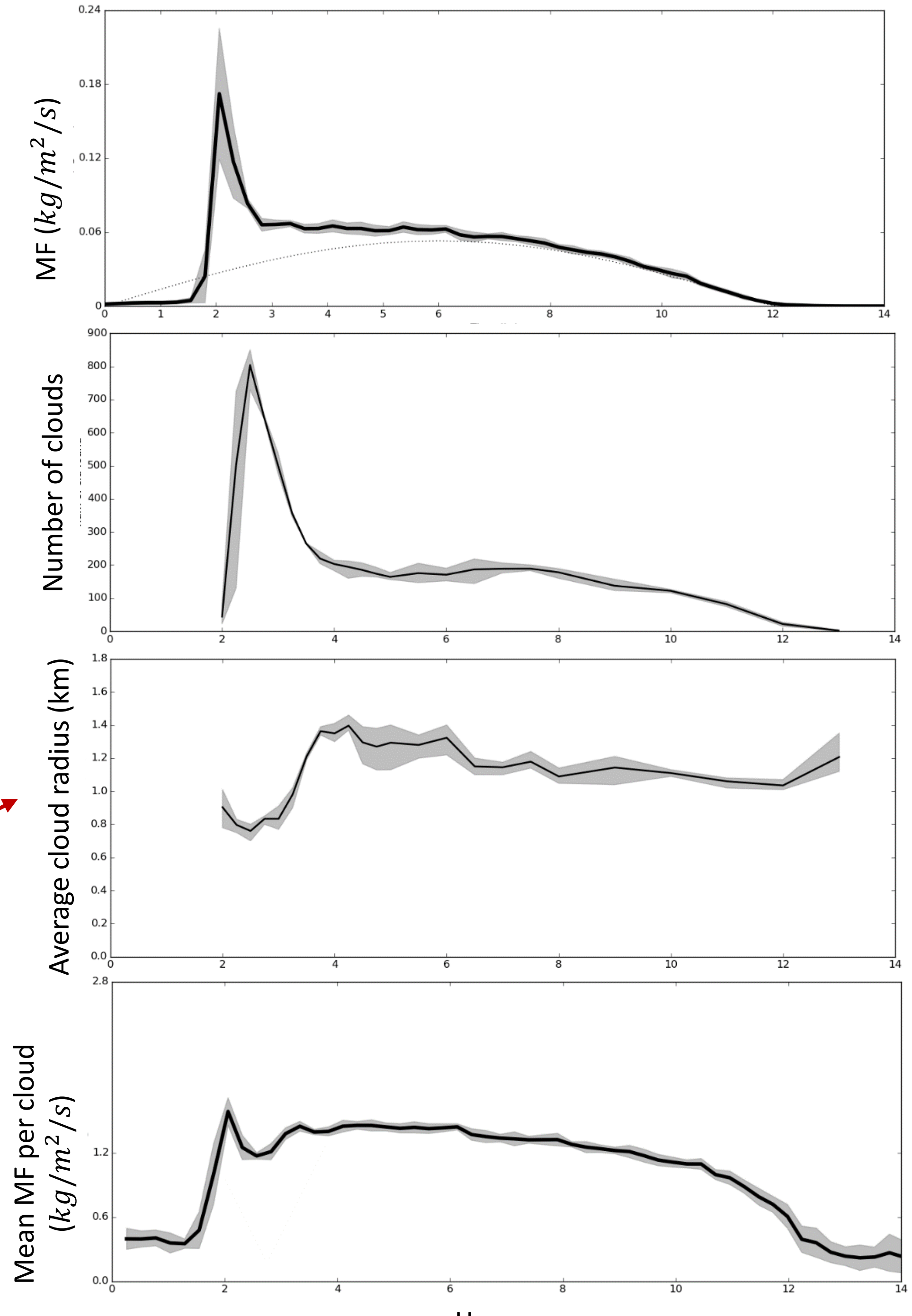
  - $\sigma_{BCu} \sim 0.6 \times \sigma_{All}$ while $MF_{BCu} \sim MF_{All}$
    - *Most of the clouds which are not $\theta_v' > 0\ K$ must be $W < 0 m/s$*
    - *MF_{BCu} is dominant source of mass flux*
  - Initial response of convection is seen as a strong "spike"
    - *The triggering of deep convection lags the start of surface forcing (about hour 2)*
    - *Triggering of deep convection (similar result with 100m hor res.)*
  - More variability on the precip timeseries
  - 2 onsets of precip, both leading surface flux maxima.
    - *1st maxima associated with the triggering of deep conv*
  - Away from triggering
    - *MF and σ follow the shape of surface forcing*
    - *Precip reaches a second maxima, then decreases gradually*

Control simulations

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

Do not vary substantially with time, away from triggering



Sensitive to the strength of the forcing?

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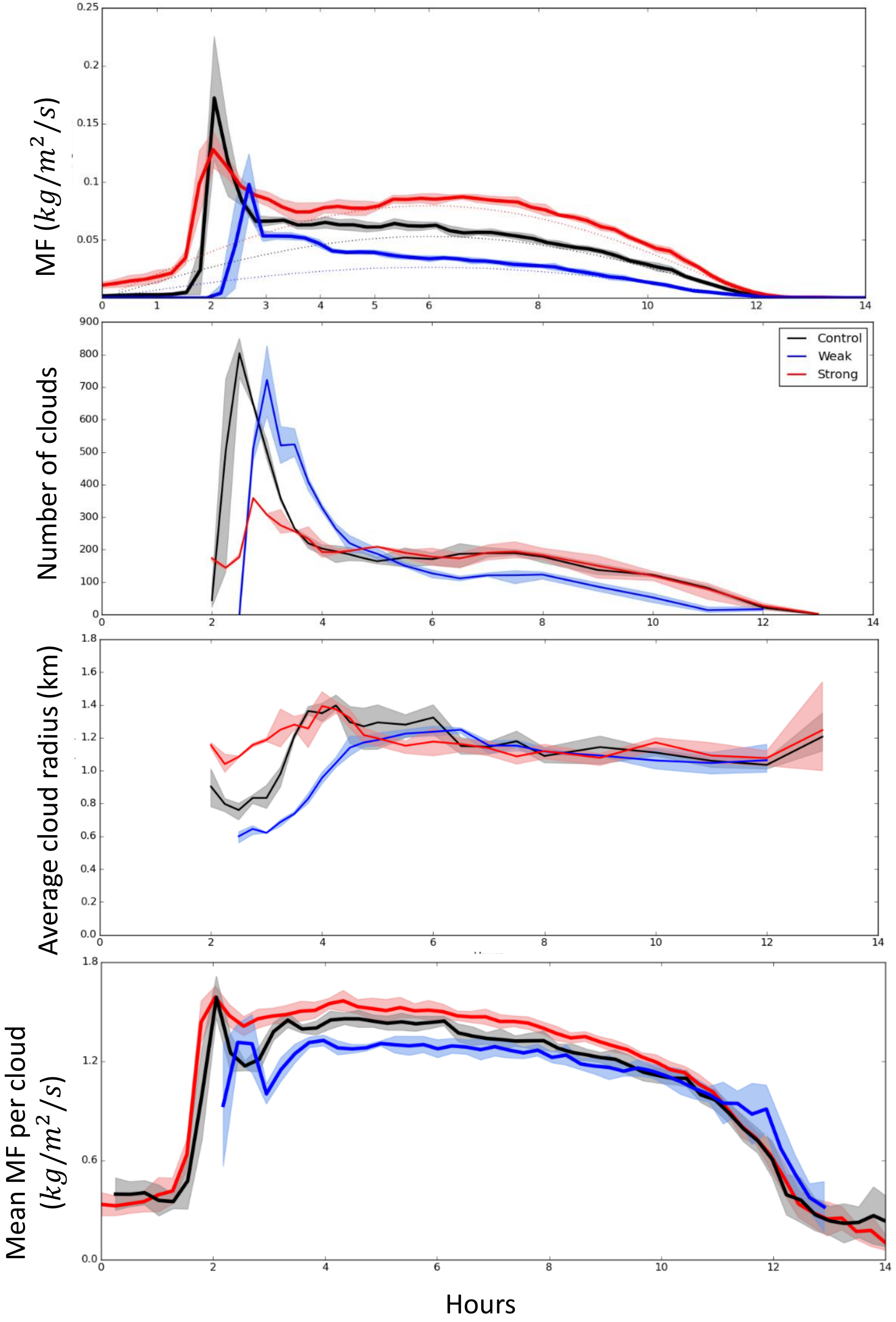
At triggering: strong forcing produces less numerous and relatively larger clouds

The triggering time is delayed in the weak forcing
The number of clouds is sensitive to the strength of the forcing

Independent on the strength of the forcing:

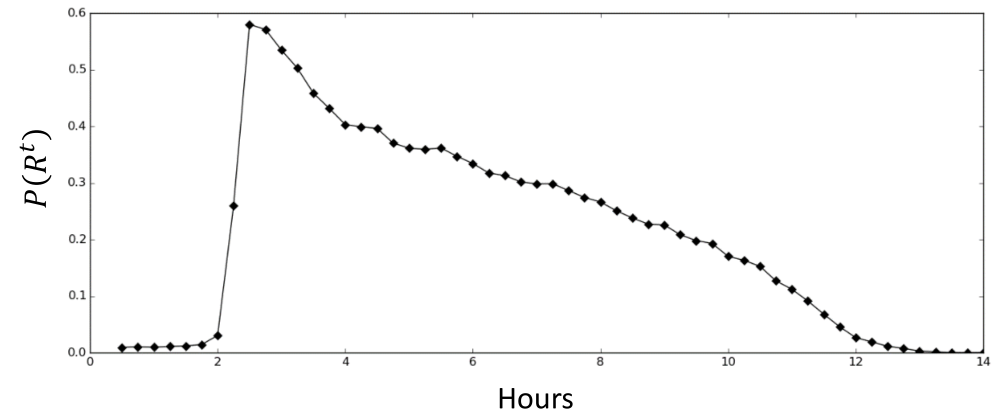
- Away from triggering cloud radius does not depend on the strength of the forcing
- Time-evolution of cloud base mass flux is mainly caused by variations in the number, cloud fraction, rather than changes in the cloud radius.

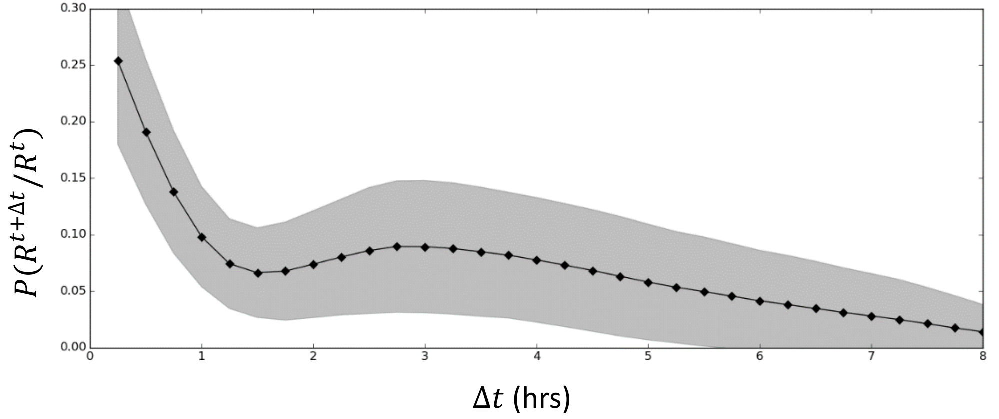


Convective memory?

A grid point (i, j) is considered to have produced precipitation if: $precip_{i,j} \ \geq 0.5 \times \overline{< precip >}$

Results obtained using 2D precipitation averaged on $4 \times 4\ km$ sub-domain





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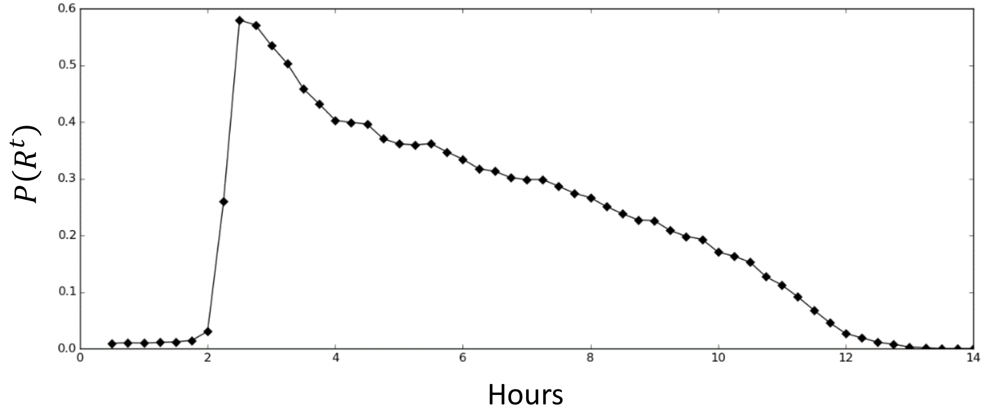
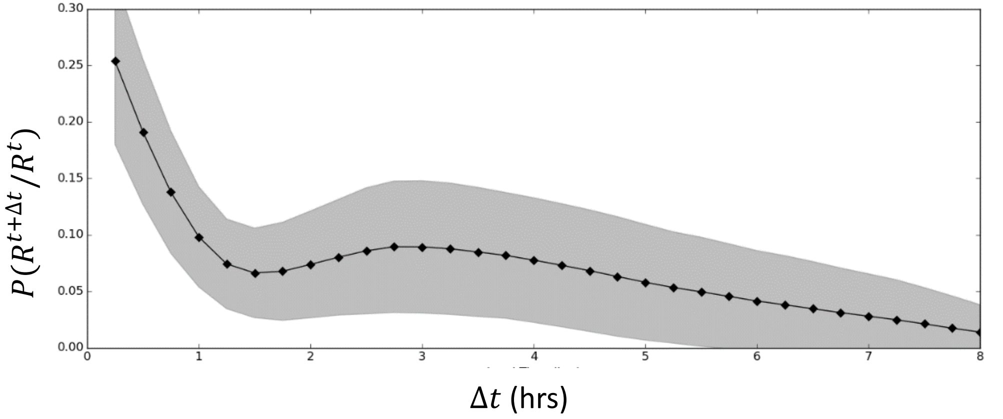
For random distributions: $P(R^{t+\Delta t}/R^t)$ =$P(R^{t+\Delta t}) \times P(R^t)$= $P\left(R^2\right)$

There is memory in the convective system if: $\boldsymbol{P(R^{t+\Delta t}/R^t)}$ **-**$\boldsymbol{P\left(R^2\right) \neq 0}$

The memory of convection at time t on convection at time $t + \Delta t$ will be evaluated using: $\{P(R^{t+\Delta t}/R^t)$ -$P(R^2)\}/P(R^t)$





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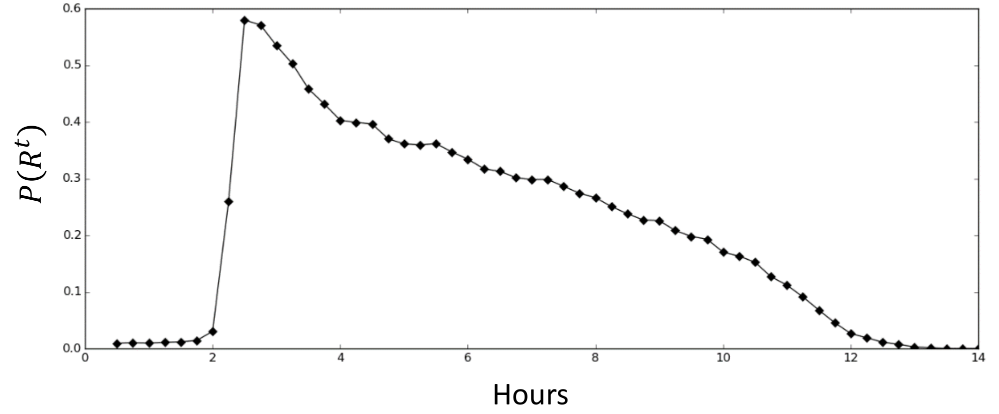
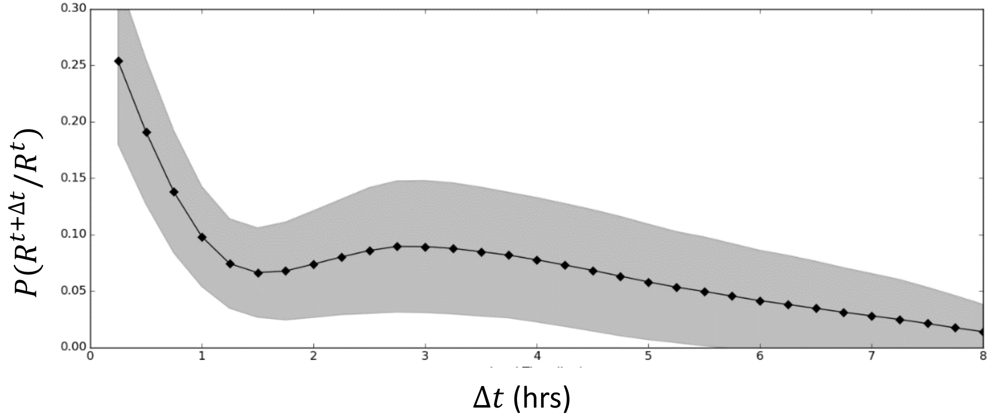
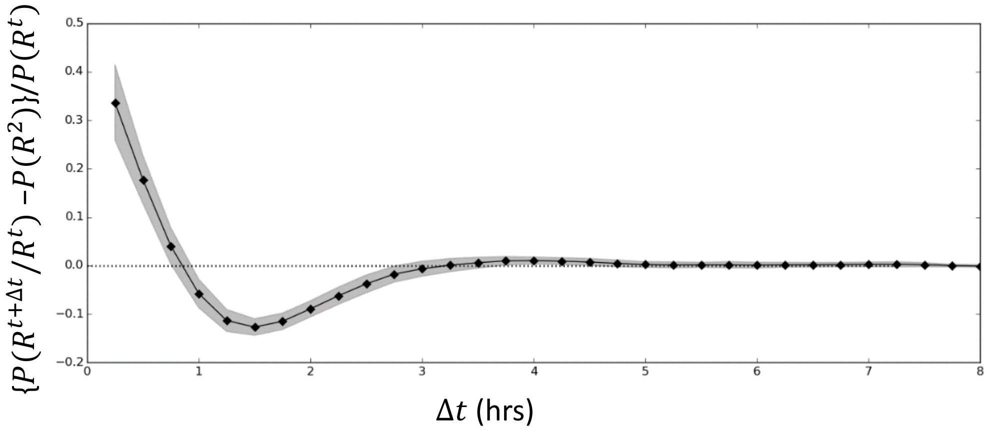
In 3 hours time, convective system will lots all the memory whether it is raining or not







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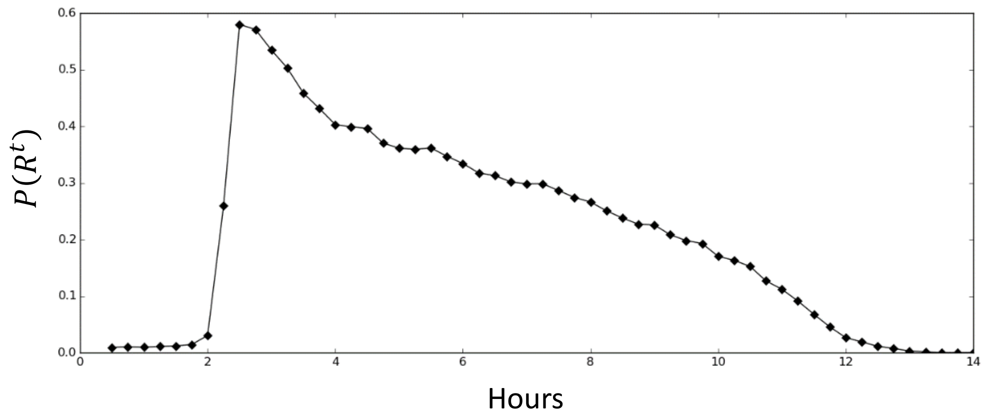

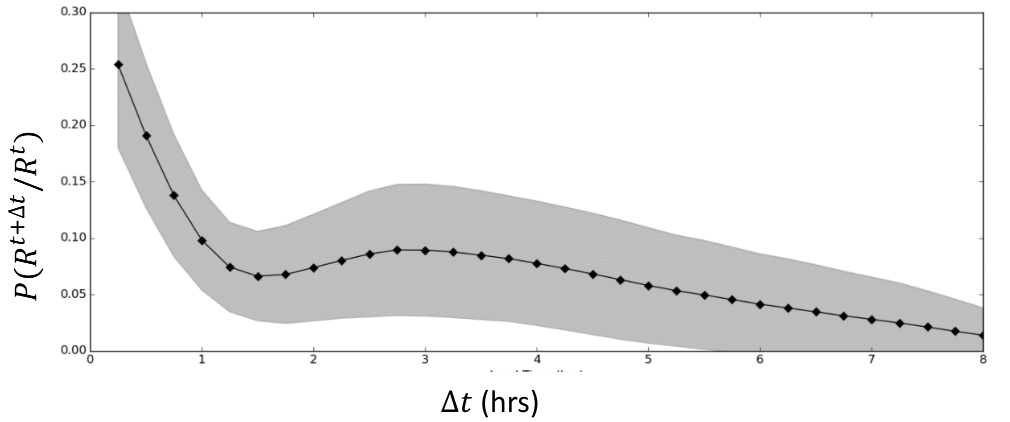

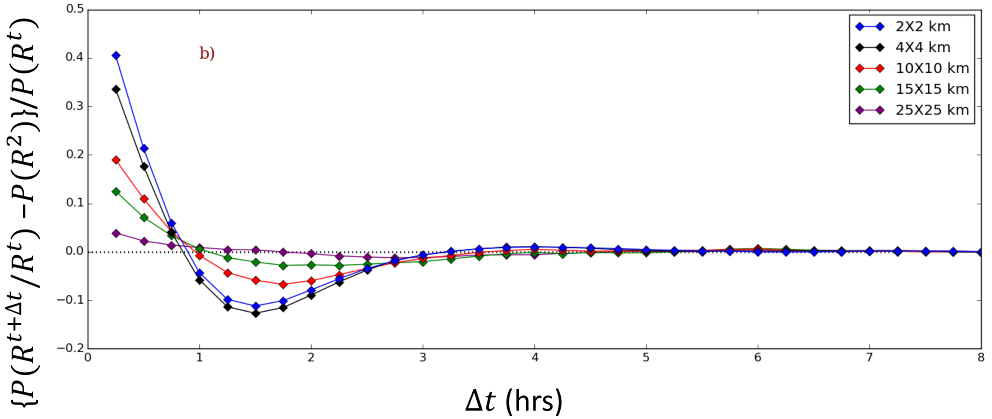

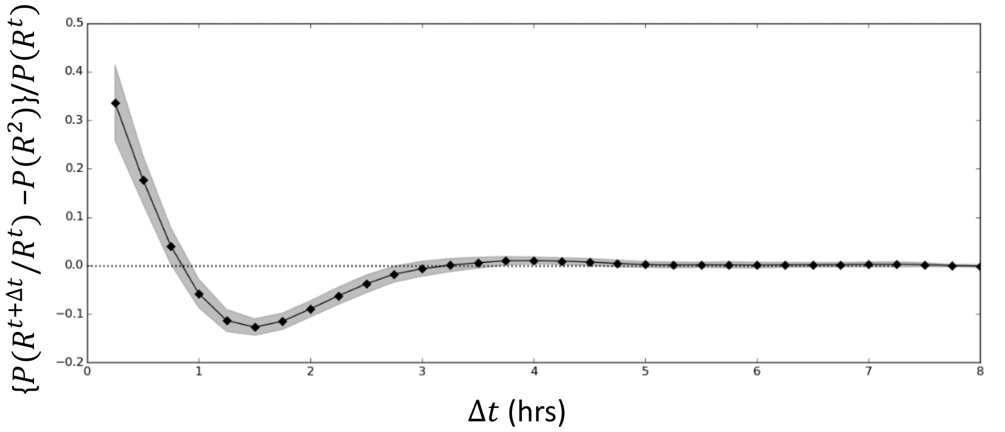

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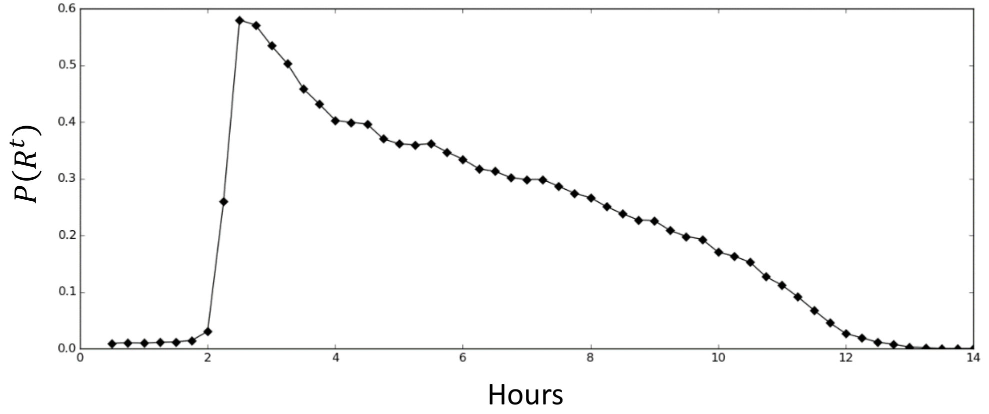

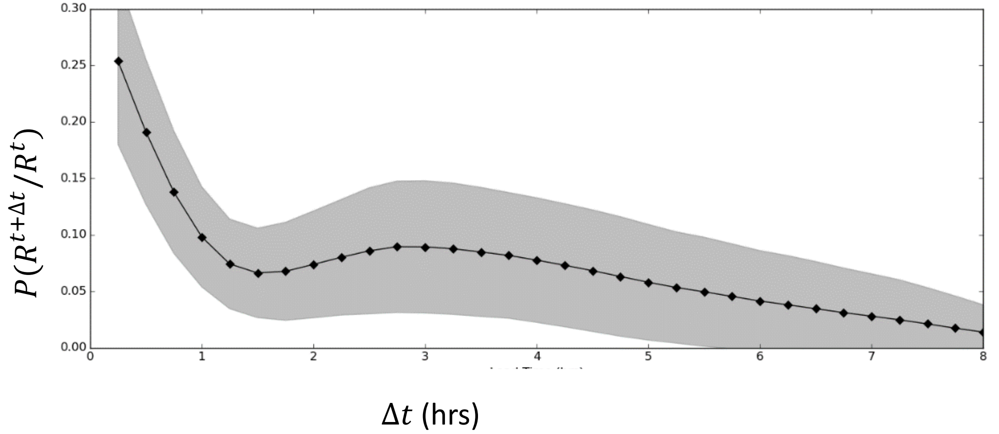

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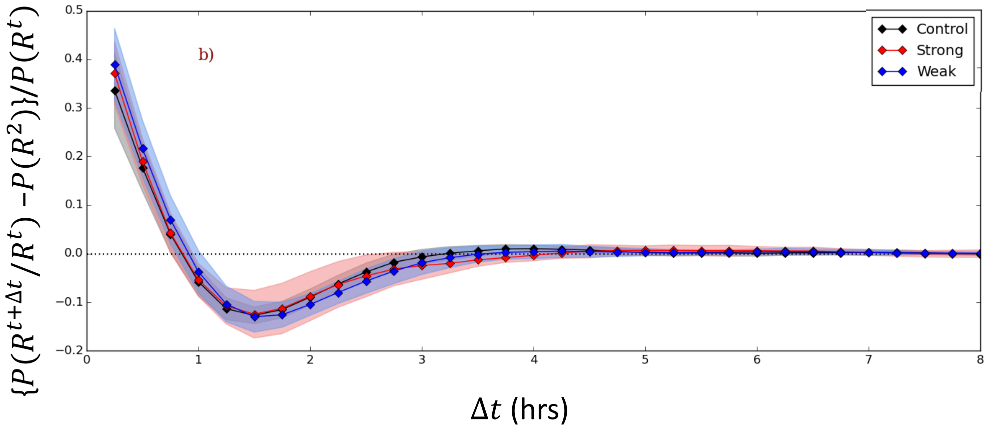

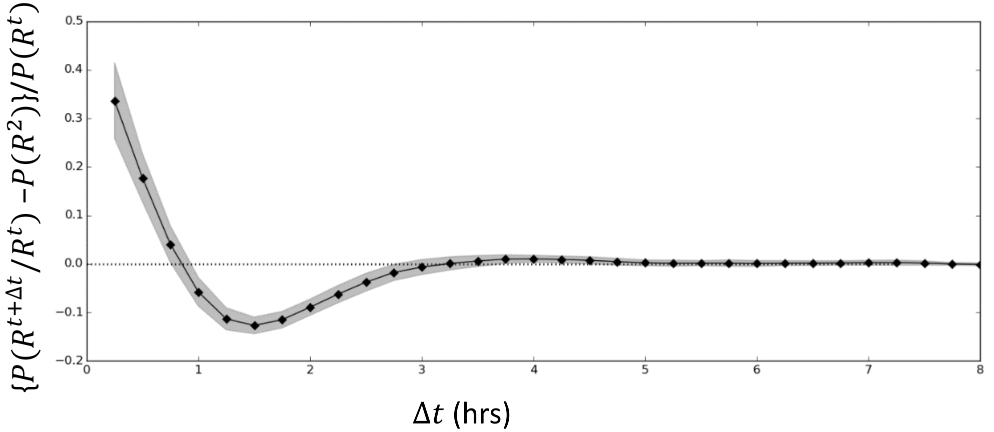

Memory attributed to the thermodynamic variabilities at night time

Experiment is the repetition of the control, but with the variability of θ and q_v removed at night time:

$$\frac{\partial \theta_{i,j}^{k}}{\partial t} = -\frac{1}{\tau}\left(\theta_{i,j}^{k} - \overline{\theta^{k}}\right) \text{ and } \frac{\partial q_{v_{i,j}}^{k}}{\partial t} = -\frac{1}{\tau}\left(q_{v_{i,j}}^{k} - \overline{q_v^{k}}\right)$$

Applied at all vertical levels with $\tau = 1\ h$

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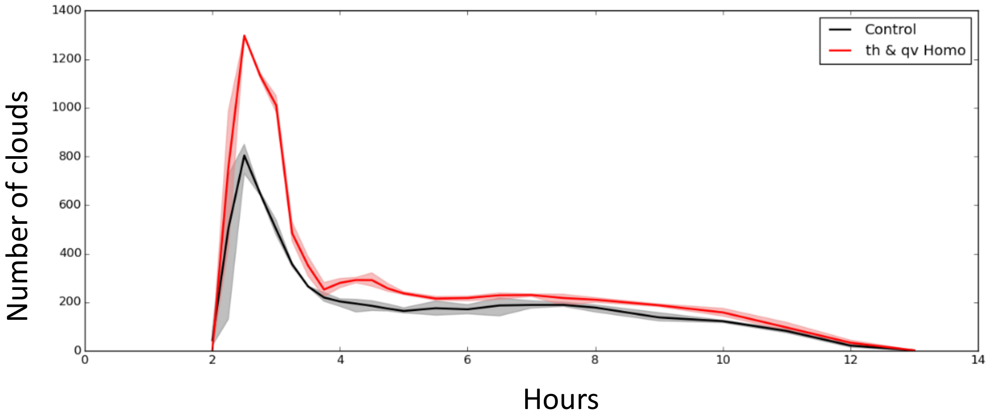
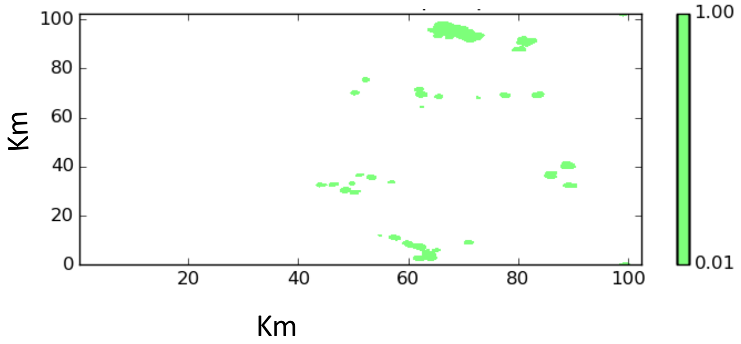
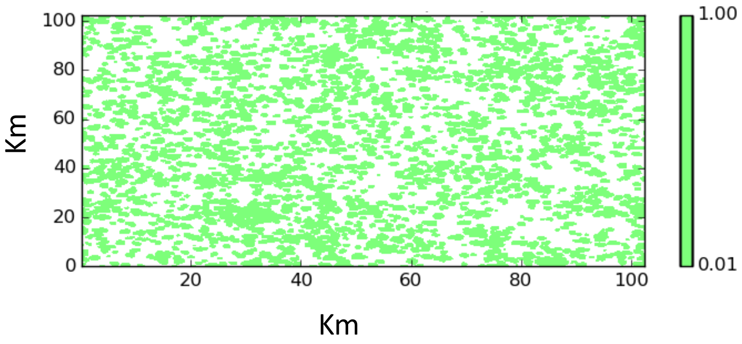
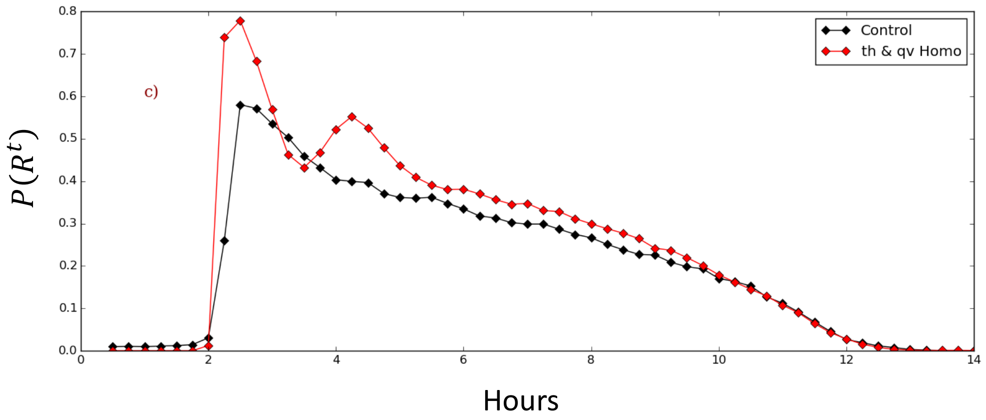


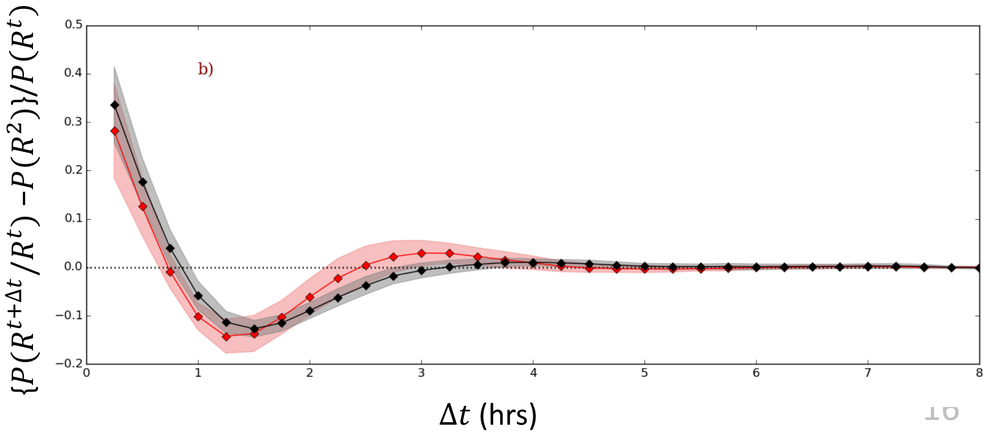
Control: Cloud, 2h



Relax: Cloud, 2h







When thermodynamics conditions are homogeneous

- At triggering: greater number of smaller clouds

- greater number of clouds and more chance of rain up to hour 10
- The memory timescale is a bit shorter

Summary

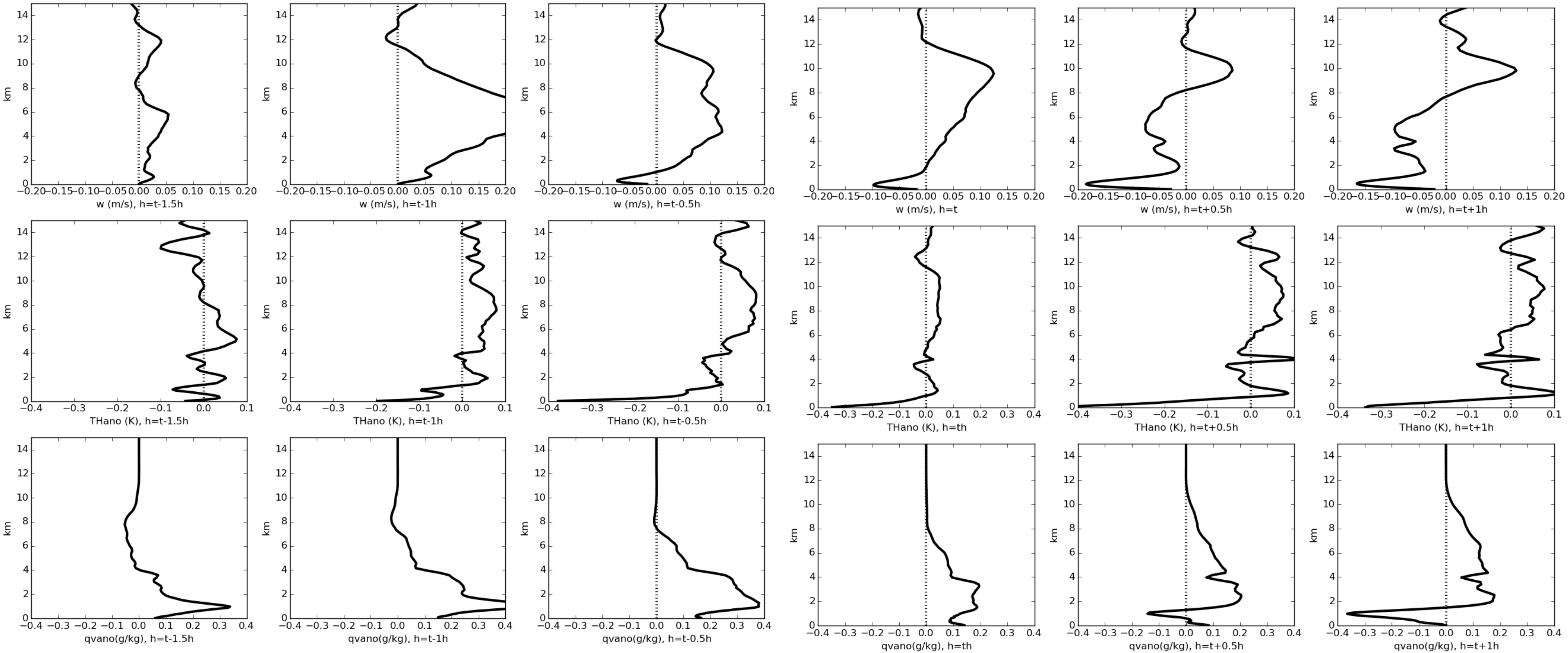
- We produced the Diurnal cycle experiment that focuses on the triggering of deep convection.

- In all our sims:
  - the onsets of precip lead surface flux maxima.
  - Cloud radius increases during the triggering phase, and remain almost steady away from triggering (independent on the strength of the forcing)
  - Time-evolution of convection is mainly caused by variations in the cloud statistics, rather than changes in the characteristics of the clouds (independent on the strength of the forcing).

- There is memory in the convective system
  - The memory timescale (about 3hours) is not sensitive to the strength of the forcing
  - we can change the memory in the convective system by homogenising θ and q_v at night time
    - Convective system takes about 10 hours to recover
      - Greater number of smaller clouds
      - More chances of rain

Diurnal Cycle – Next steps

1. How do thermodynamic and dynamic profiles change before and after rainfall?



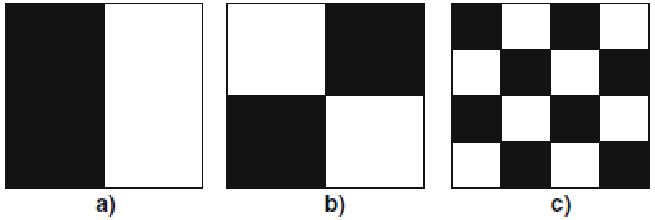
2. Writing up
3. The impact of surface heterogeneity on the diurnal cycle of convection

What is the impact of surface heterogeneity on the diurnal cycle of convection in a high resolution model?

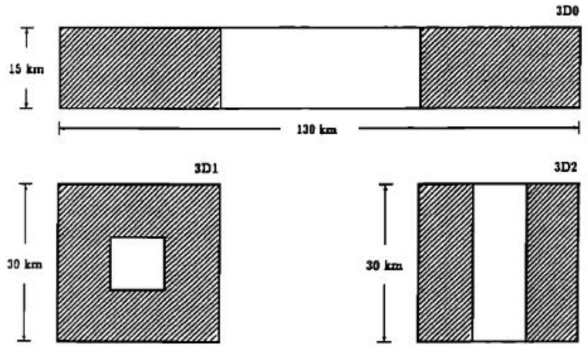
- Convection intimately linked to land surface via fluxes of sensible and latent heat.
- Many studies focussed on the boundary layer and its development (e.g. Courault et al. (2007), Avissar and Schmidt (2008), Kang and Bryan (2010)……) . Tend to be small domains.
- Not many on the impact on deep convection at high resolution. One example is Wu et al. (2015) but not very high resolution (2km). Applied small random perturbations with a correlation length scale to precipitation then used this to determine perturbations to H and L.

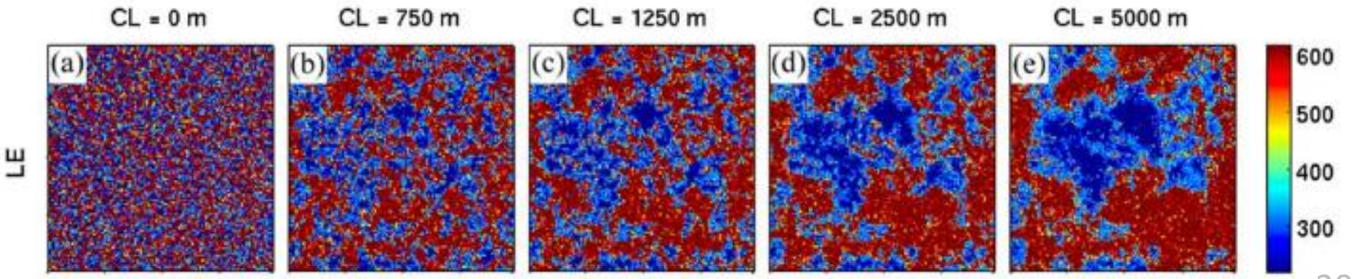
What is the impact of surface heterogeneity on the diurnal cycle of convection in a high resolution model?

- Many different ways to introduce heterogeneity: directly through latent and sensible heat flux, Bowen ratio, surface T gradients, vegetation types, soil moisture variations….
- Many possible patterns
- Many possible scales



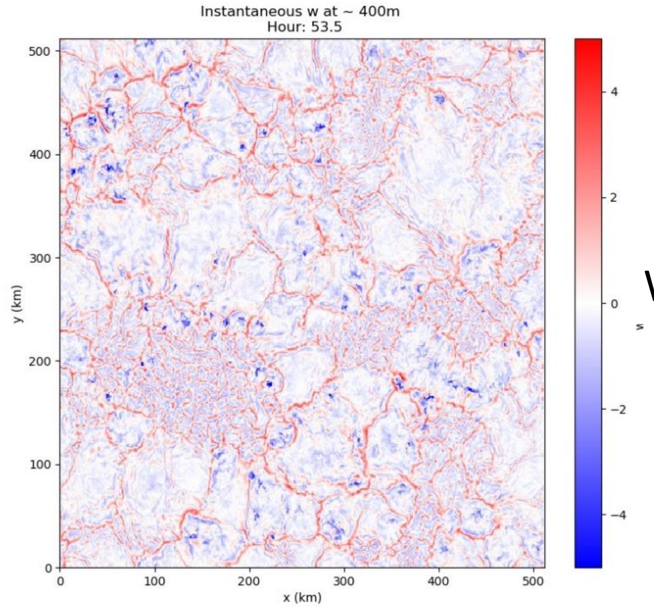
$$H(i) = H_0 + A\,sin\left(\frac{2\pi}{\lambda}\,i\Delta x\right)$$



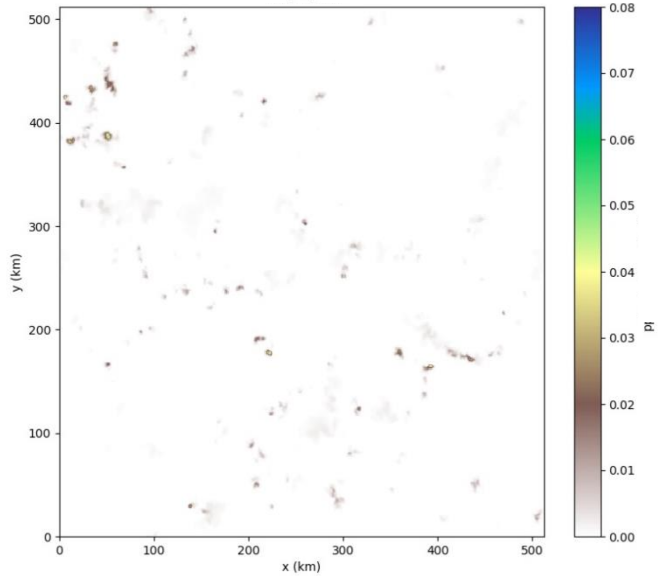


What is the impact of surface heterogeneity on the diurnal cycle of convection in a high resolution model?

- Idealised study in MONC
- Set up functionality to have spatially varying surface fluxes/temperature (using netcdf files as input)
- Idealised tests of impact of having spatially varying surface fluxes
    - Use idealised diurnal cycle setup (Initially no correction to energy balance)
    - Random perturbations? Patches? Sine wave? Correlation length scale?
    - Is there an impact on the convection? What is it?
    - Dependence on length scale, magnitude and timing
- Implement energy balance correction.



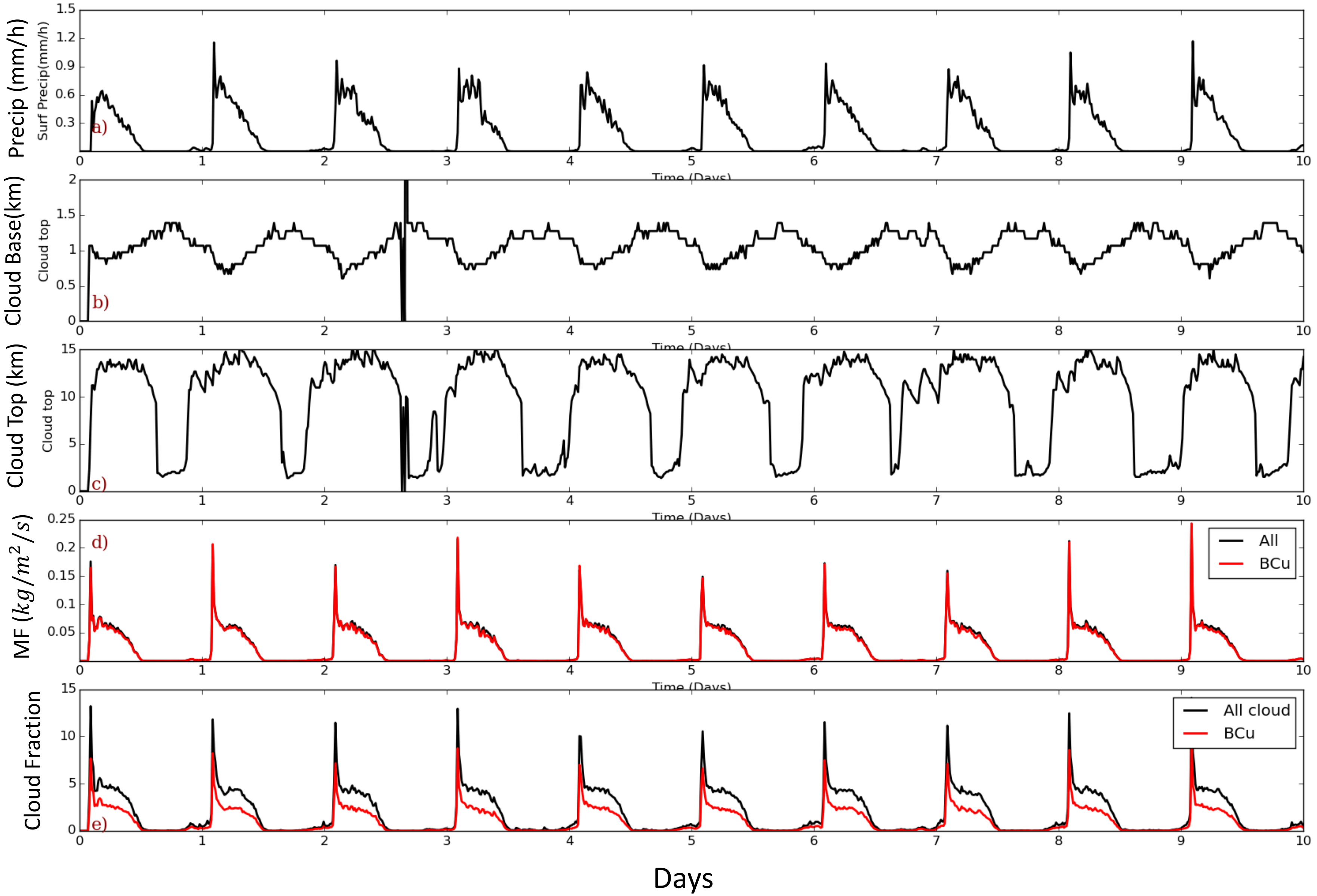
W (m/s)



Precipitation rate (kgm^{-2}s^{-1})

Questions

Simulations over 10 forcing cycles



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- Initial response of convection seen as a strong "spike"
- There is always cloud at night time in the domain (sometime deep) .
- Max precip not always associated with max of MF.

The characteristics of the convective response are not consistent day-to-day.