Department of Meteorology

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Modeling the interactions between tropical convection and large-scale dynamics

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Motivation

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The weak-temperature gradient (WTG) approach *(Sobel and Bretherton (2000))* has been proved to be a useful framework for modelling the interactions between convection and the large-scale.

The WTG approach has been used to couple a CRM/SCM to a reference reservoir column: reference column model (*Sobel and Bretherton (2000) ; Raymond and Zeng (2005) and many others)*

- The region to simulate is small in comparison with its surroundings
- The surroundings do not vary in response to the WTG-derived circulation.

We used the WTG approach to couple two columns of the CRM: coupled-column model

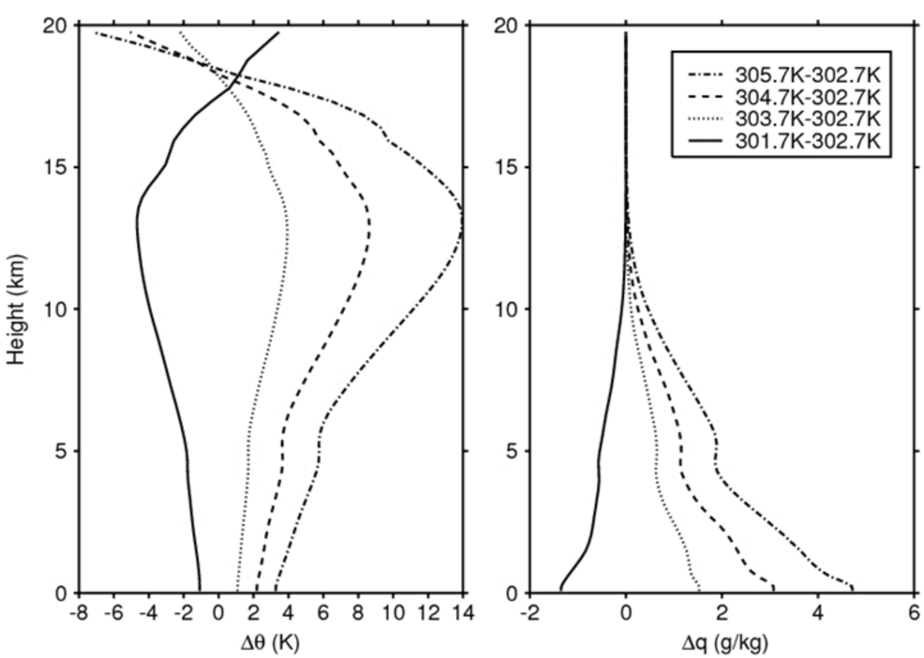
- The two columns are allowed to vary in response to the WTG-derived circulation
- This system is energetically closed in contrast to the reference column system
- It is proposed as a methodology for studying the influence on local convection of changes on local and remote forcing

Outline

- Model setup and control simulation
- Coupling methodology
- Reference column model
  ✓ Sensitivities to the coupling timescale
  ✓ Sensitivities to the initials conditions
- Coupled columns model
- Sensitivity to surface forcing
- Transition from supressed to active convection
- Summary

Model description and control run

- CRM based on the LEM at version 2.4 of the Met Office
- $Y \times Z = 128 \times 20$ km
- Resolution: $\Delta Y = 0.5$ km and 60 levels in the vertical
- Fixed radiation profile: 1.5 k/d from $0 - 12$ km and decreases linearly to 0 K/d at 15 km
- $U = 5$ m/s and $V = 0$ m/s



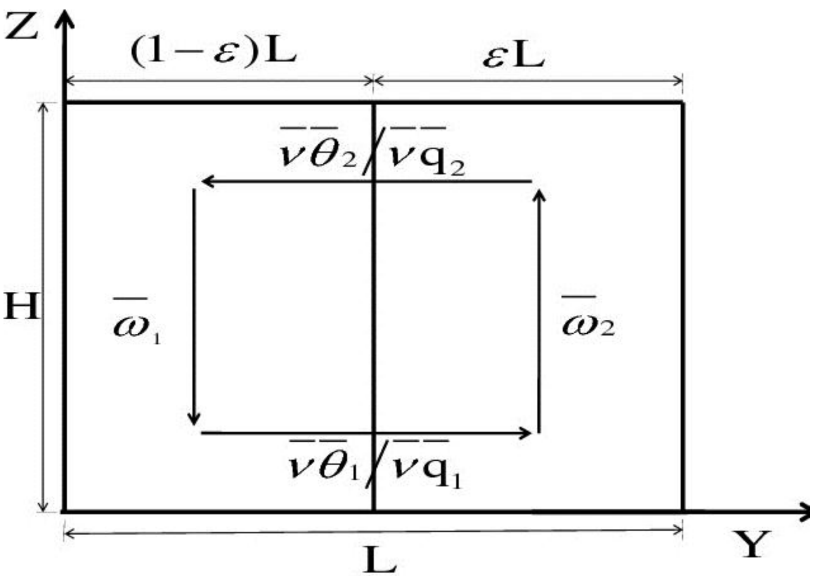
The control run has an

SST $= 302.7$ K (**control run**)

Mean rain rate: 4.77 mm/d

Evaporation: 4.80 mm/d

Coupling methodology :
The weak-temperature gradient approach



Two-column formulation

$\overline{\theta_1}$ and $\overline{\theta_2}$ are forced to remain close to each other using the WTG vertical velocity derived from:

$$\overline{\omega_2}\frac{\partial\overline{\theta_2}}{\partial z}-\overline{\omega_1}\frac{\partial\overline{\theta_1}}{\partial z}=\frac{f(z)}{\tau}\left(\overline{\theta_2}-\overline{\theta_1}\right)$$

and

$$\varepsilon\overline{\omega_1}+(1-\varepsilon)\overline{\omega_2}=0$$

Two-column configuration

$$\overline{\omega_1}=\frac{\varepsilon}{1-\varepsilon}\overline{\omega_2}$$

and

$$\overline{\omega_2}=-\frac{1}{\tau}\frac{\overline{\theta_1}-\overline{\theta_2}}{\frac{\varepsilon}{1-\varepsilon}\frac{\partial\overline{\theta_1}}{\partial z}+\frac{\partial\overline{\theta_2}}{\partial z}}$$

Reference column configuration

It is recovered from the coupled-column approach in the limit of $\varepsilon\to 0$. Hence

$$\omega_1\to 0$$

and

$$\overline{\omega_2}=\frac{1}{\tau}\frac{\overline{\theta}-\overline{\theta}_{ref}}{\frac{\partial\overline{\theta}}{\partial z}}$$

Reference column model

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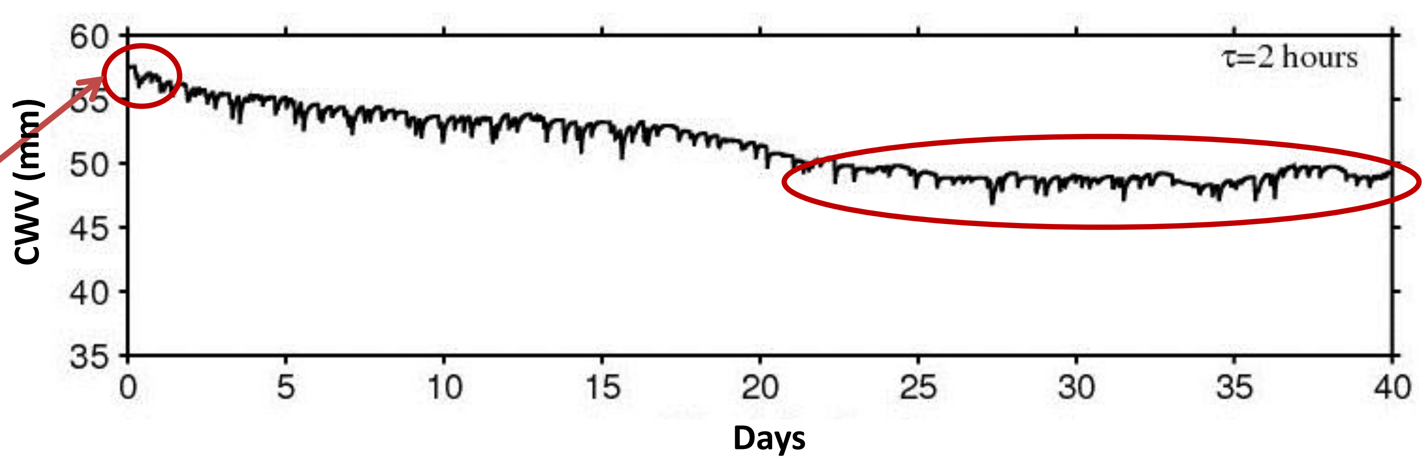
The reference column is defined with RCE profiles from the control run

The test and the reference columns have the same surface forcing

τ =2hr. It corresponds to a spacial scale of 360 km

Starts from the mean value obtained in the control run



Dry equilibrium state

Mean rain rate: 1,99 mm/d.

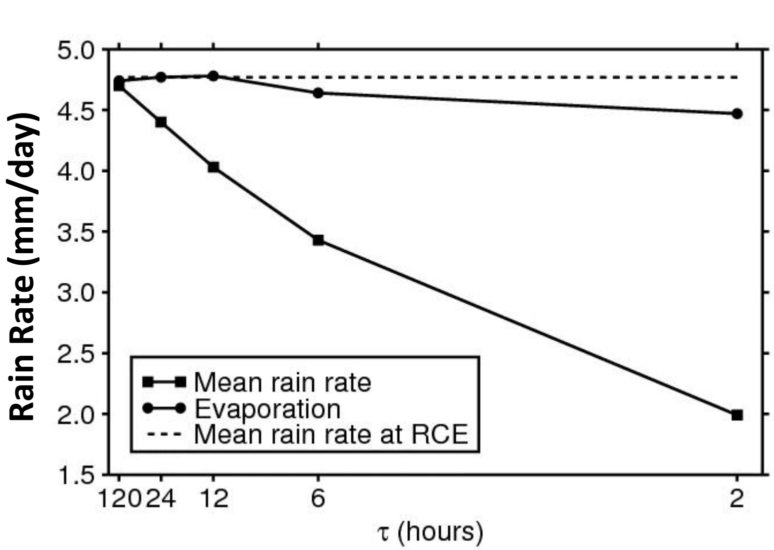
Evaporation: 4.47 mm/d

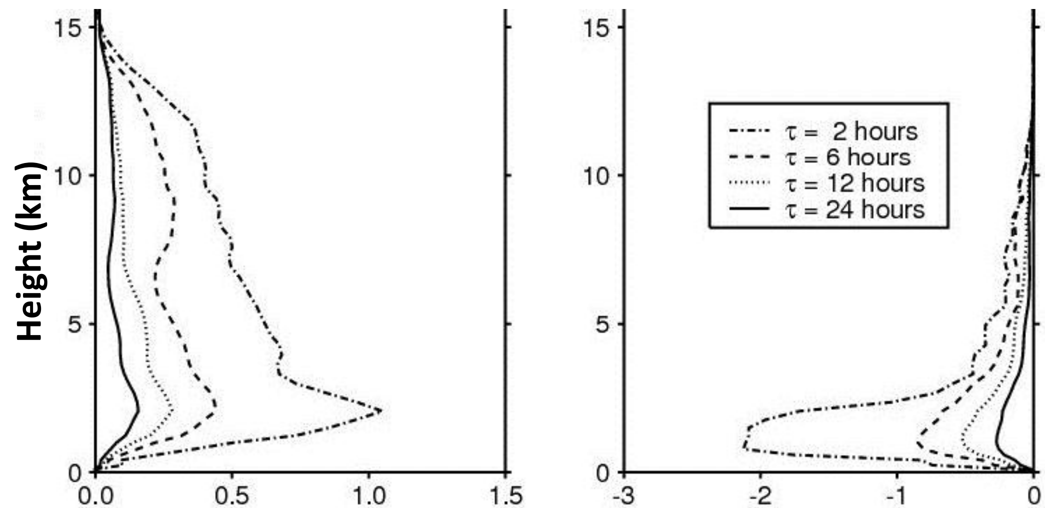
Dry equilibrium state with reduced precipitation compared to the RCE reference state

Reference column model:

Sensitivities to the WTG coupling timescale

$\boldsymbol{\tau} =$ 2, 6, 12, 24 and 120 hours. For Gravity waves of mean speed 50m/s, they correspond to a spacial scale of 360, 1080, 2160, 4320, 21600 km respectively.



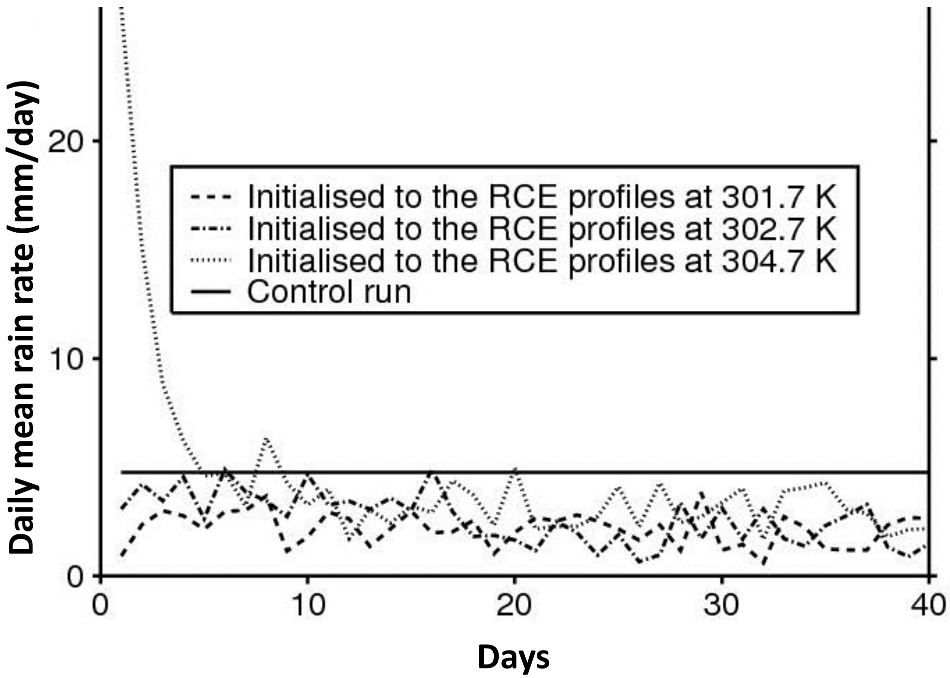


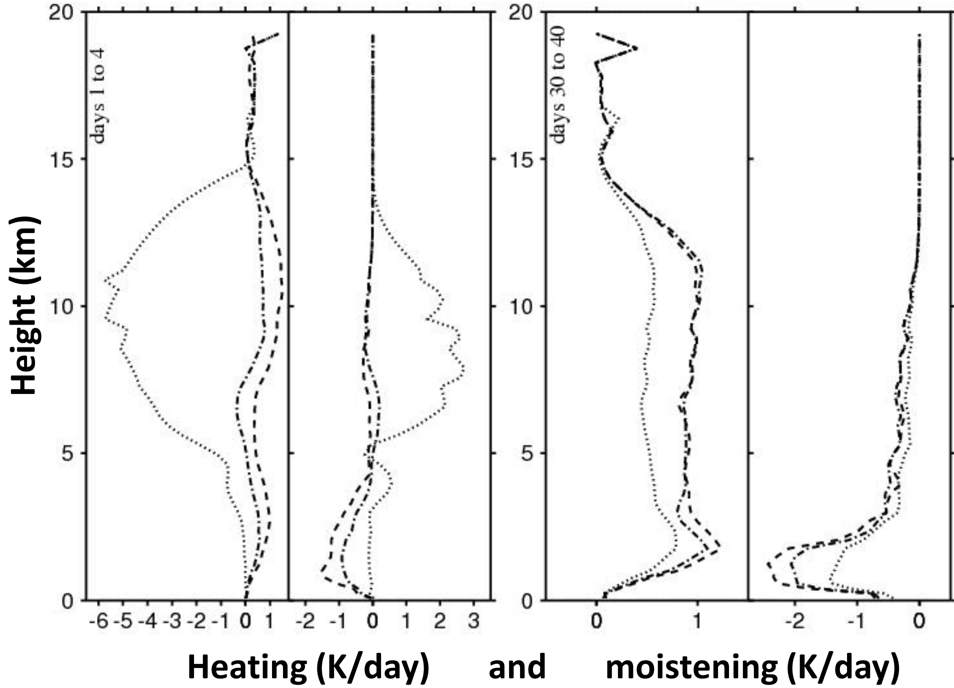
Heating (K/day) and moistening (K/day)
from the large-scale circulation

The strength of the circulation decreases with WTG adjustment rate $1/\tau$

Reference column model:

Sensitivity to the initial conditions



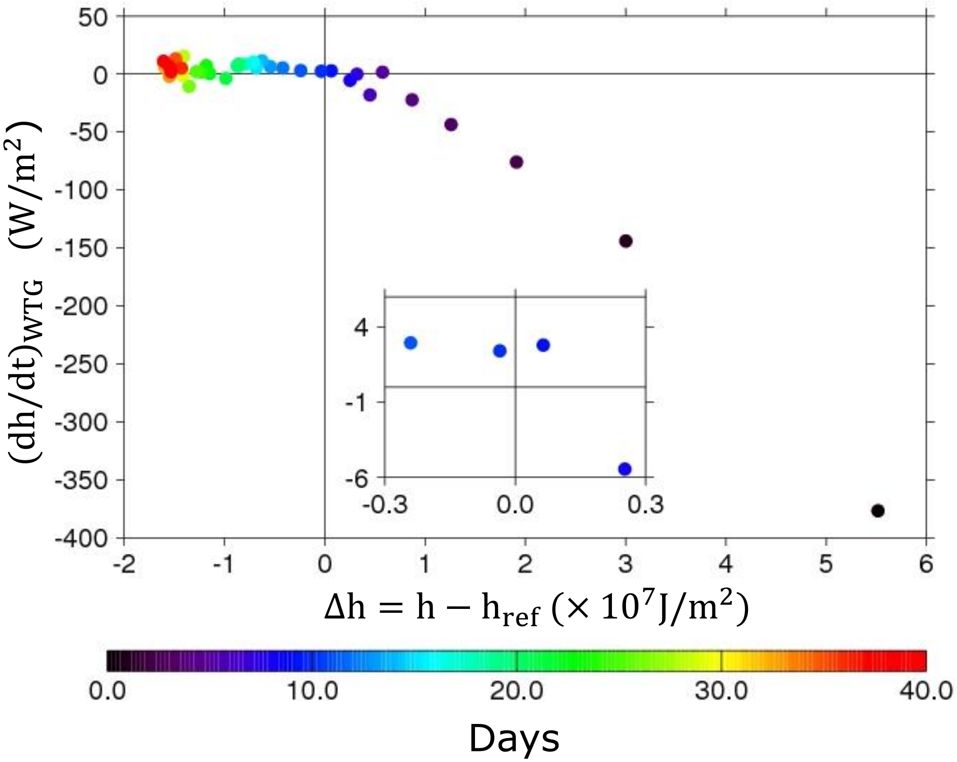


Over days 1 to 4 of the simulation initialised with RCE profiles at 304.7 K

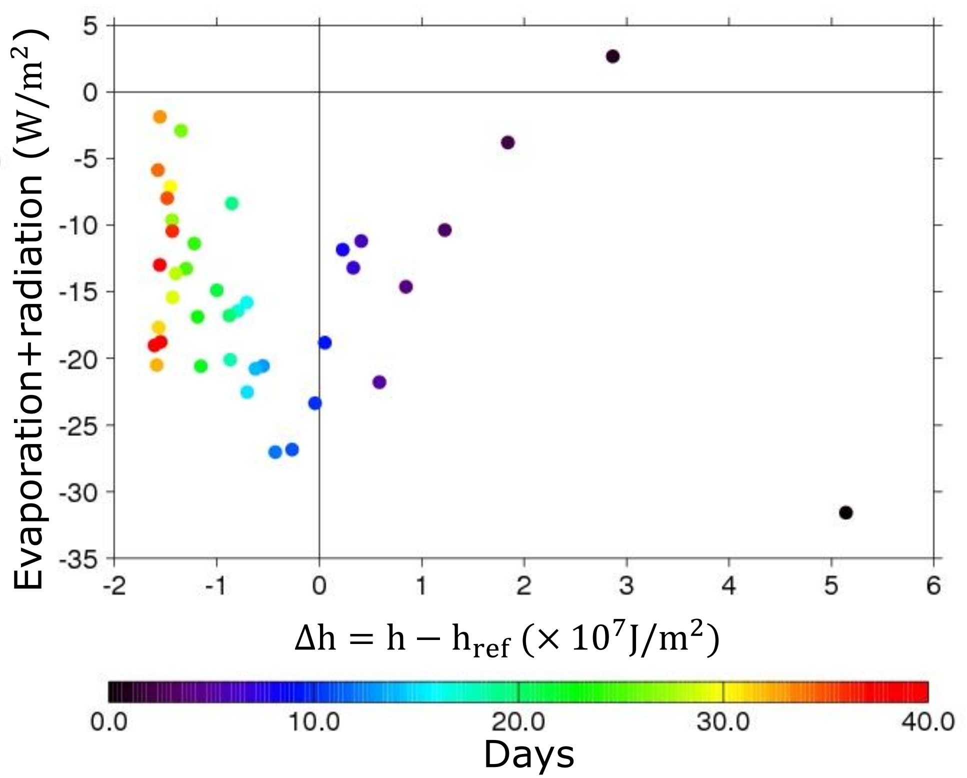
$$C_p \int_{surf}^{Z_{top}} \rho \left(\frac{\partial \overline{T}}{\partial t} \right)_{WTG} dz = -177.16 \ W/m^2 \quad \text{and} \quad L_v \int_{surf}^{Z_{top}} \rho \left(\frac{\partial \overline{q}}{\partial t} \right)_{WTG} dz = 91.20 \ W/m^2$$

Hence, energy is extracted from the test column

Why the test column cannot sustain a large-scale ascent?



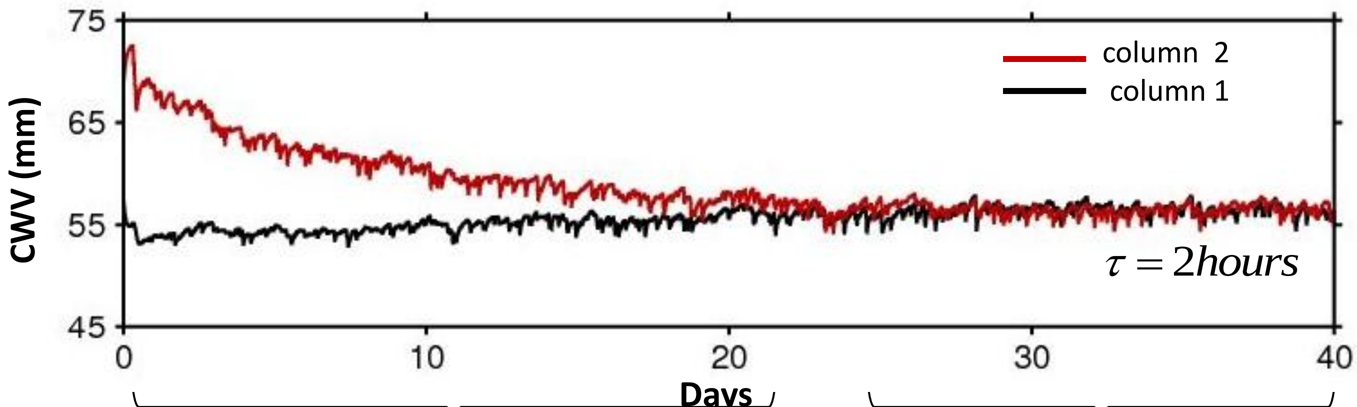
At day 10, the import of moist static energy into the test column by the WTG circulation is not enough to balance the reduction in surface evaporation



Coupled Columns Model

Column 1 and 2 are initialised to the RCE profiles at 302.7K and 304.7K.

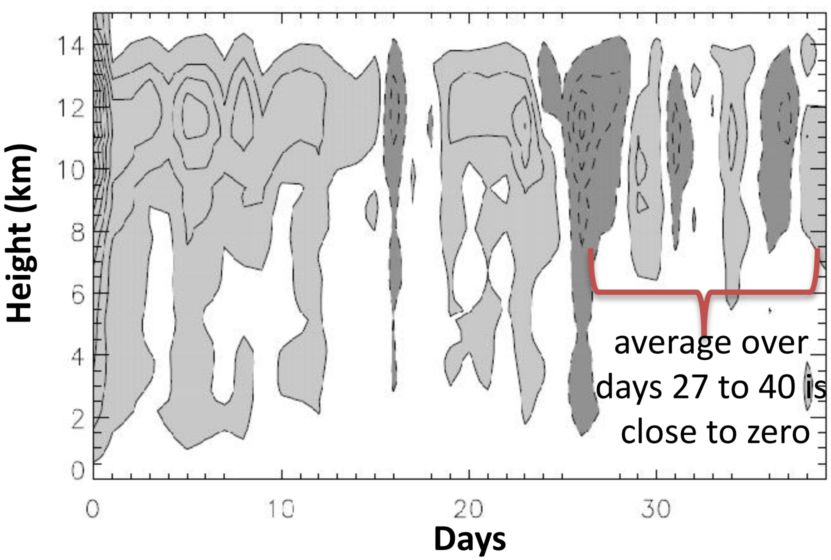
Both columns has the same surface forcing



The strength of the WTG circulation decreases

There is o time mean WTG circulation from day 27

Daily-mean WTG vertical velocity in column 2



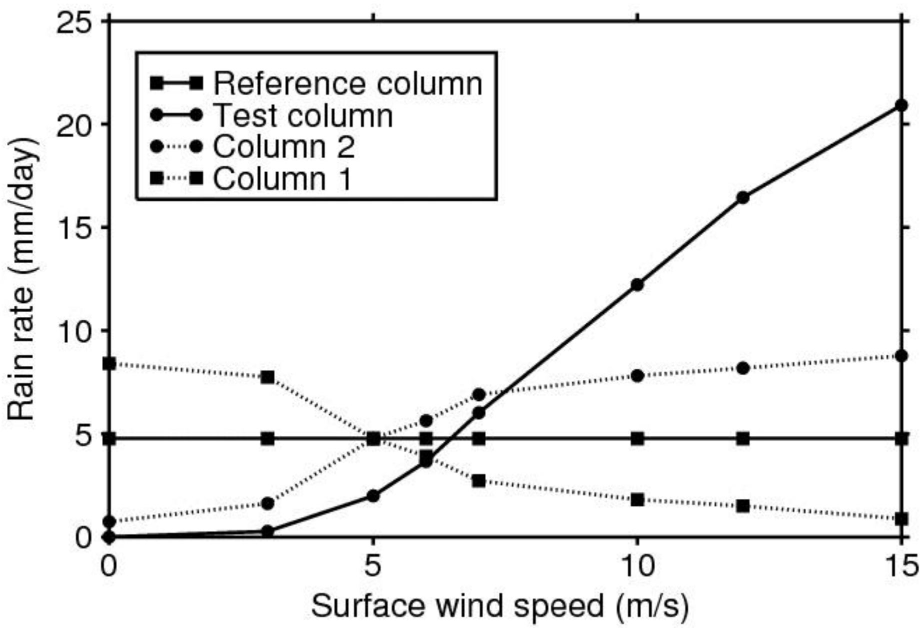
Equilibrium state with no time-mean WTG circulation.

Same results for $\boldsymbol{\varepsilon} = 0.1$, and $\boldsymbol{\varepsilon}=0.01$ with a much longer timescale of adjustment

Sensitivity to surface conditions

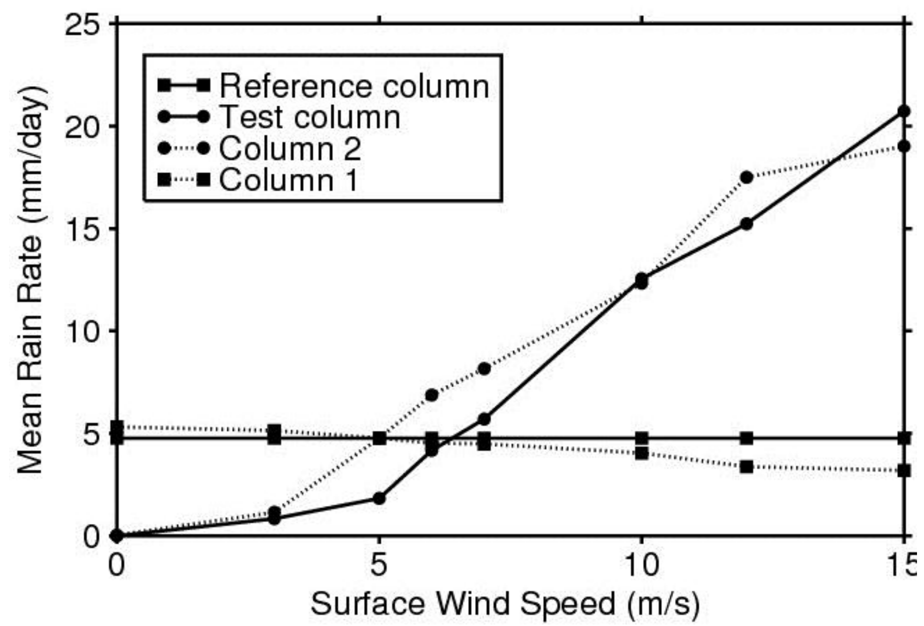
We changed U in the test column, or else in column 2.

For $\varepsilon = 0.5$ and $\tau = 2$ hr



The coupled-column system shows a much weaker sensitivity to surface forcing

For $\varepsilon = 0.1$ and $\tau = 4$ hr



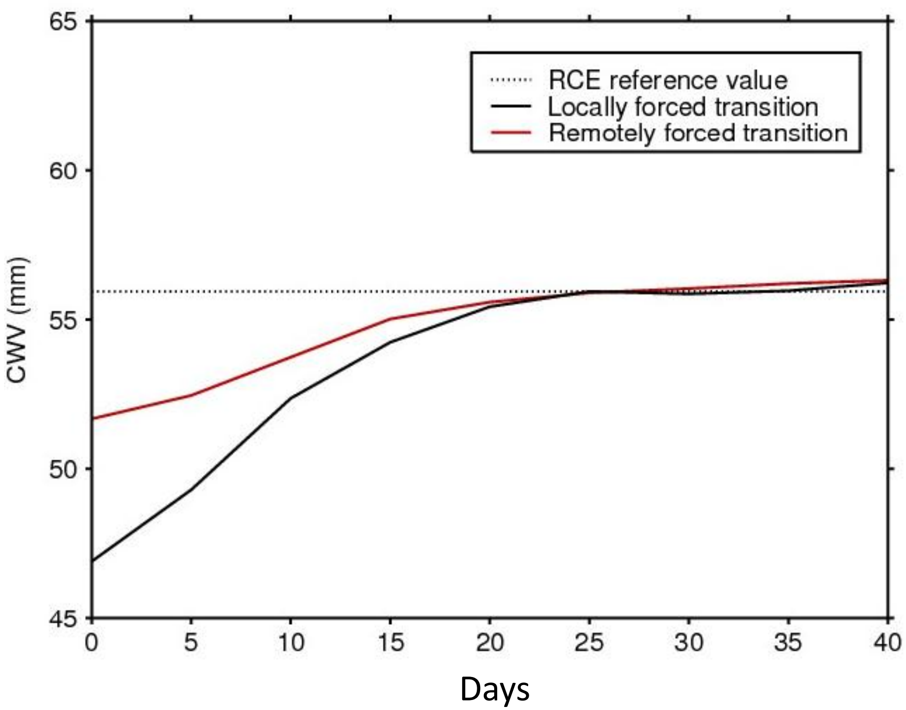
Note the differences between the systems for small changes in surface forcing

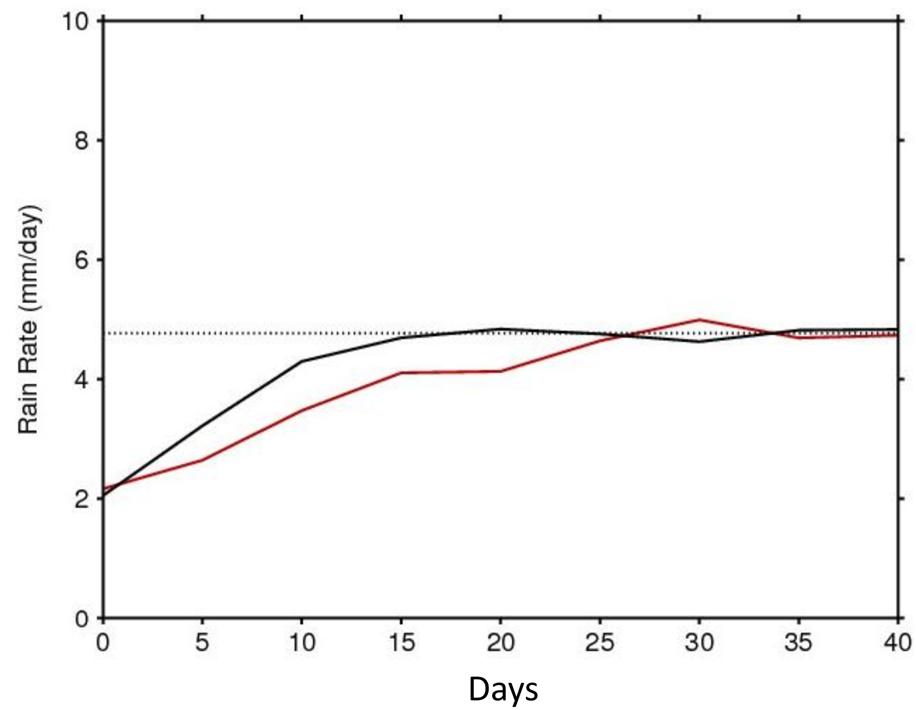
Differences in sensitivity remain for small changes in the surface forcing

Transition from supressed to active convection

$\Delta SST = 1$ K with column 1 colder than column 2. The derived large-scale circulation suppresses convection in column 1 relatively to column 2. The transition is then Forced in two ways:

1. **Local forcing**: by increasing the SST in column 1 to the value in column 2
2. **Remote forcing**: by decreasing the SST in column 2 to the value in column 1





The timescale of adjustment of CWV is similar in both cases. However, the time scale of adjustment of precipitation is much shorter in the case of locally forced transition

Summary

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- Under uniform conditions , the reference column simulations produce and equilibrium state with **large-scale descent in the simulated column**.

- Under uniform surface forcing, the coupled-column system reaches an equilibrium with **no time-mean WTG circulation even for large difference in column areas.**

- Even for **large difference in column areas**, the coupled-column configuration **behaves differently** from the reference column configuration for the cases of uniform surface forcing and small changes in surface forcing.

- As future work, the coupled-column column configuration will be used as a methodology for studying the transition from shallow to deep convection caused by changes in local and remote forcing under the WTG approximation.