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Modeling the interactions between tropical convection and large-scale dynamics

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Interactions between convection and LS dynamics

New approaches:

- Super-Parameterisation of Randall et al. (2003)
- Diabatic Acceleration and REscaling (DARE) of Kuang et al. (2005)
- Earth Simulator Centre and CASCADE project

Recently:

Weak Temperature Gradient approach of Sobel and Bretherton (2000)

- SCM coupled to a reference column (Sobel and Bretherton (2000))
- CRM coupled to a reference column (Raymond and Zeng (2005), Perez et al. (2006))

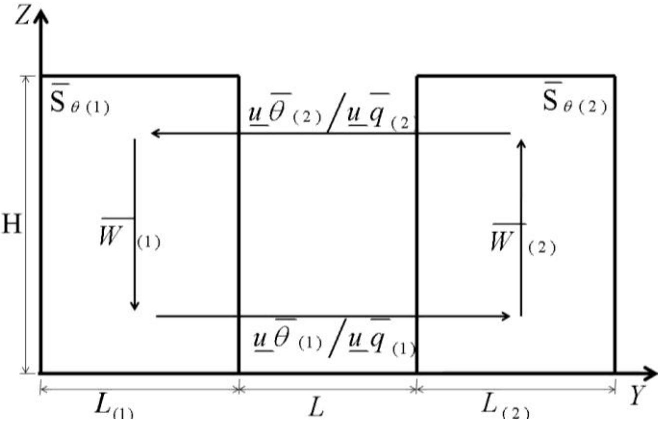
Outline

- Coupling methodology
- Model setup and control simulation
- Reference column model
- ✓ Can Large-scale circulation develops in a homogeneous environment?
- ✓ Sensitivities to the Gravity waves time scale
- ✓ Sensitivities to initials conditions
- Coupled columns model
- Summaries
- Future work

Model setup

- The Met Office large Eddy Model (LEM) at version 2.4 is used.
- Domain size: $Y \times Z = 128 \times 20km$. Horizontal resolution: $0.5km$
- Prescribed cooling: 1.5K/day from the surface to 12km, reducing linearly to 0K/day at 15km
- $\overline{V} = 0m/s$ and $\overline{U} = 5m/s$
- Coriolis force is zero
- Model initialised with data from the TOGA-COARE field experiment from the western Pacific warm pool
- Model run for 40 days with sea surface temperature (SST) ranging between 301.7 and 305.7K
- The radiative-convective Equilibrium (RCE) profiles obtained with SST of 302.7K (**control run**) are used as reference profiles in the reference column model. Mean rain rate of 4.77 mm/day compared to 4.80 mm/day of surface evaporation.

Weak Temperature Gradient (WTG) calculations



Two-column formulation

The WTG vertical velocities:

$$\overline{\omega}_{(1)} = \frac{\overline{\theta}_{(1)} - \overline{\theta}_{(2)}}{\tau\left(\frac{\partial\overline{\theta}_{(1)}}{\partial z} + \frac{\partial\overline{\theta}_{(2)}}{\partial z}\right)}, \quad \overline{\omega}_{(2)} = -\overline{\omega}_{(1)} \quad \text{with} \quad L_{(2)} = L_{(1)}$$

τ is related to $\chi = \frac{1}{2}L_{(1)} + L + \frac{1}{2}L_{(2)}$

The tendencies of $\theta_{(1)}$ due to large scale circulation: $\frac{\partial\overline{\theta}_{(1)}}{\partial t} = \overline{\theta}_{(1)}\frac{\partial\overline{\omega}_{(1)}}{\partial z} - \frac{\partial\overline{\omega}_{(1)}\overline{\theta}_{(1)}}{\partial z}$

Assumptions:

1- $\partial\overline{\theta}/\partial z \gg 1K/km$ 2- Horizontal flow with no shear

3- Large-sale circulation do not advect condensate

Heat and moisture budgets:

$$\sum_{i=1,2}\left\{SHF_{(i)} + C_p\int_{surf}^{Z_{top}}\rho\left[\left(\frac{\partial\overline{T}_{(i)}}{\partial t}\right)_{\mu} + \left(\frac{\partial\overline{T}_{(i)}}{\partial t}\right)_{rad} + \left(\frac{\partial\overline{T}_{(i)}}{\partial t}\right)_{WTG}\right]dz\right\} = 0$$

and

$$\sum_{i=1,2}\left\{E_{(i)} - P_{(i)} + L_v\int_{surf}^{Z_{top}}\rho\left(\frac{\partial\overline{q}_{(i)}}{\partial t}\right)_{WTG}dz\right\} = 0$$

Reference Column Model

θ and q are specified in one of the column (reference column).

Heat and moisture advected out of the other column (test) is not received by the reference one: **The budgets are not strictly closed.**

The test column is initialised with profiles from the reference one.

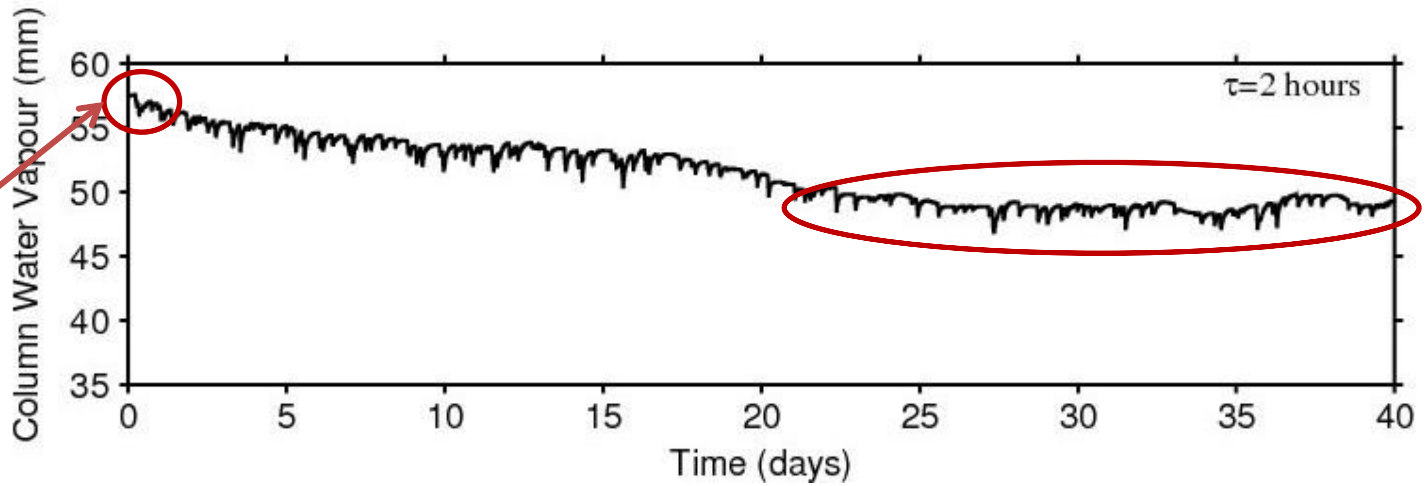
Both columns as the same SST of 302.7K: Uniform boundary.

τ = 2, 6, 12, 24 and 120 hours. For Gravity waves of mean speed 50m/s, they correspond to χ= 360, 1080, 2160, 4320, 21600 km.

The reference column model is run for 40 days.

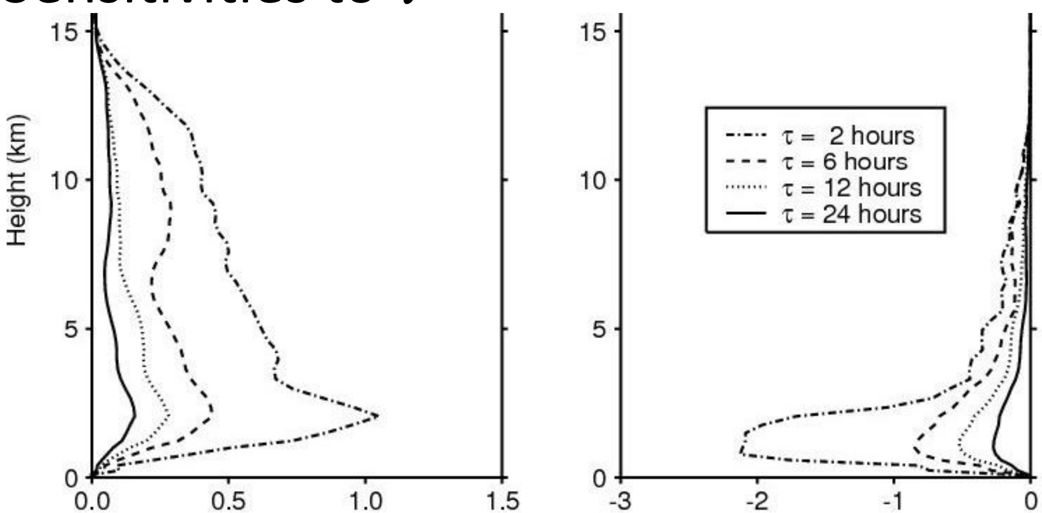
Can Large-scale circulation develops in an homogeneous environment?

Starts from the mean value obtained in the control run



Quasi-steady state

Sensitivities to τ



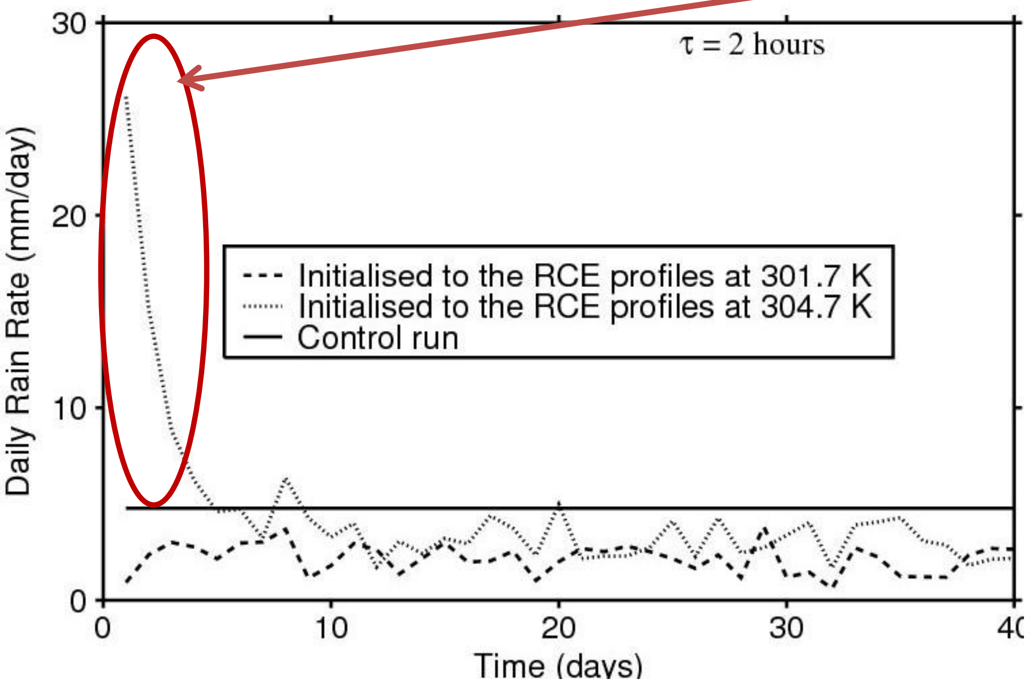
Heating (K/day) and moistening (K/day) from the large-scale circulation for different τ

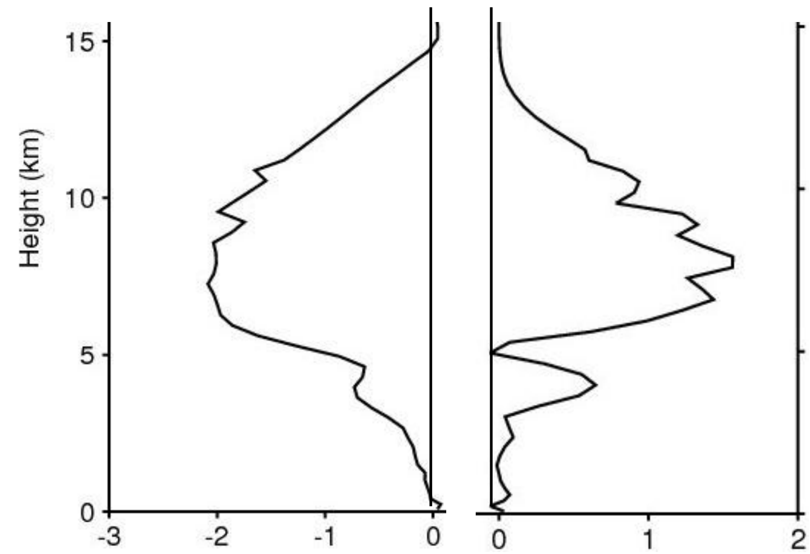
Experiments	Mean rain rate (mm/day)	Evaporation (mm/day)
Control run	4.77	4.80
$\tau = 120$ hours	4.70	4.74
$\tau = 24$ hours	4.40	4.77
$\tau = 12$ hours	4.03	4.78
$\tau = 6$ hours	3.43	4.64
$\tau = 2$ hours	1.99	4.47

Mean rain rate increases with τ

Sensitivity to the initial conditions

Average from days 1 to 4





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

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

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

The result is insensitive to the initial conditions.

Energy is extracted from the system hence the strength of the initial LS circulation decreases

Coupled Columns Model

The profiles in neither column are specified

Heat and moisture advected out of one column (test) is equal to that received by the other column: **The budgets are closed.**

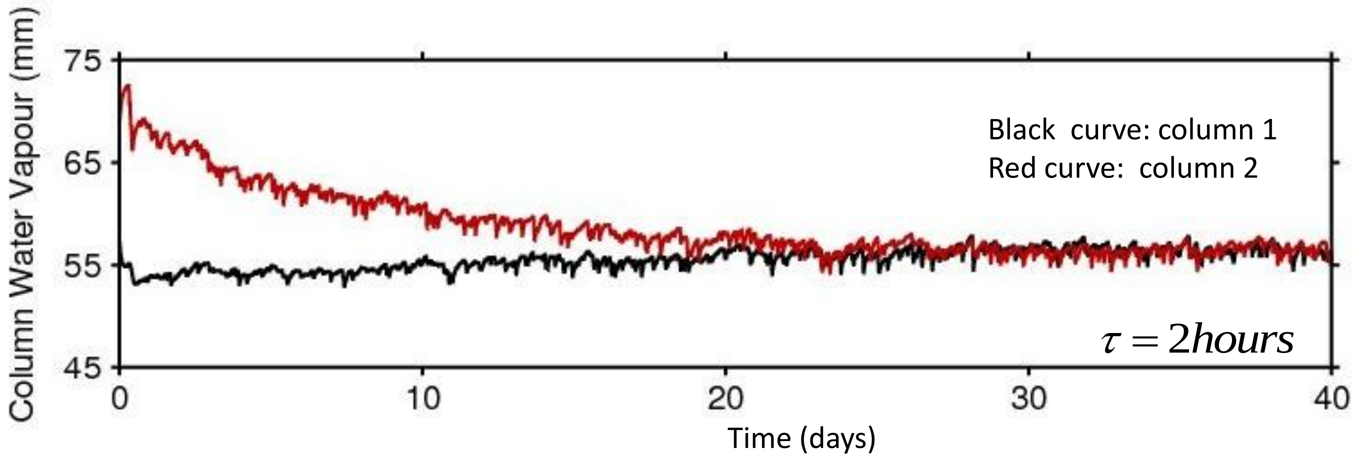
The coupled columns model is more **realistic** and has not been studied before.

Key experiments from the reference column model are performed in the coupled column model.

Column 1 and 2 are initialised to the RCE profiles at 302.7K and 304.7K. Both columns has the same SST of 302.7K: **Uniform boundary.**

The coupled columns model is run for 40 days.

Coupled Columns Model



The model tries to maintain the initialised large-scale circulation

The two columns adjust to almost the same state which in turns is very similar to the equilibrium state obtained in the control run.

	Mean rain rate (mm/day)	Evaporation (mm/day)
Control run	4.77	4.80
Column 1	4.72	4.73
Column 2	4.85	4.77

The adjustment time scale of the coupled columns model decreases as τ increases.

Summaries

Reference column model

- This model has a unique final state with descent in the test column which does not depend on how it has been initialised.
- The mean rain rate increases with the length scale of LS circulation
- The rate of changes of evaporation is negligible hence, precipitation variations is mainly controlled by large-scale horizontal moisture advection.

Coupled columns model

- This new model cannot sustain LS circulation no matter the strength of the initial circulation. Hence, **large-scale circulation with descent in the test column is an artefact of the reference column approach.**
- The shorter the value of τ, the longer the time required by the model to adjust to an equilibrium with no large-scale circulation.

Future Work

- ✓ Examine the equilibrium response of the coupled columns model to inhomogeneous SST.
- ✓ Understand how two-way interactions between convection and LS circulation influence the transition from shallow to deep convection.
- ✓ Compare the 2D and 3D simulations.
- ✓ Use of an interactive radiation scheme and an interactive surface

Thank you