Department of Meteorology

Cloud-Resolving Model simulations with one and two-way couplings via the weak-temperature gradient approximation

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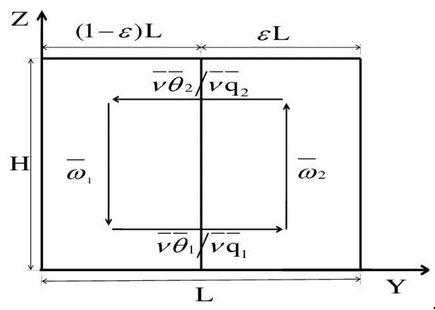
1. Introduction

A CRM is coupled to a reference column using the **weak-temperature gradient** (WTG) approach. Under uniform surface forcing, a large-scale circulation with descent in the test column develops no matter the choice of the relaxation profile and the initial conditions. This is similar to the equilibrium state found in some other studies, but not all.

Two columns of the CRM are fully coupled. This configuration is energetically closed in contrast to the reference column configuration. No mean large-scale circulation develops over uniform surface forcing, regardless of the relative area of the two columns. For columns of very different areas, the coupled-column approach behaves very similarly to the reference column approach. Differences in the behaviour do however remain for small changes in the surface forcing.

2. Coupling methodology



Two-column formulation

Coupled-column approach

$$\overline{\omega}_2 = -\frac{1}{\tau}\frac{\overline{\theta}_1 - \overline{\theta}_2}{\frac{\varepsilon}{1-\varepsilon}\frac{\partial\overline{\theta}_1}{\partial z} + \frac{\partial\overline{\theta}_2}{\partial z}}$$

Reference column approach

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

$$\overline{\omega}_1 \to 0$$

and

$$\overline{\omega}_2 = \frac{1}{\tau}\frac{\overline{\theta} - \overline{\theta}_{ref}}{\frac{\partial\overline{\theta}}{\partial z}}$$

$$\overline{\omega}_2 \frac{\partial\overline{\theta}_2}{\partial z} - \overline{\omega}_1 \frac{\partial\overline{\theta}_2}{\partial z} = \frac{1}{\tau}\left(\overline{\theta}_1 - \overline{\theta}_2\right)$$

and

$$\overline{\omega}_1 = -\frac{\varepsilon}{1-\varepsilon}\overline{\omega}_2 = 0$$

3. Model description

The Met Office Large Eddy

Model at version 2.4

- $Y \times Z = 128 \times 20$ km and $Y = 500$ m
- Fixed sea surface temperature (SST)
- Fixed radiative cooling profile
- Fixed wind speed $\mathrm{U} = 5$m/s

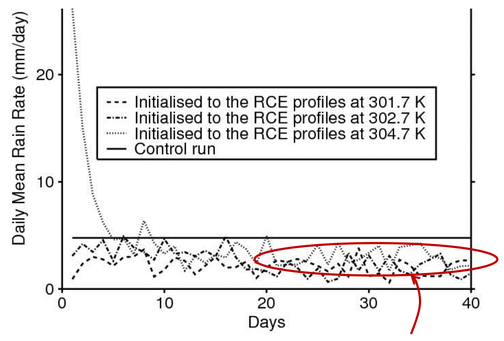
Radiative-convective simulations

- The model is run for different SST
- The **control integration** has an SST of 302.7 K
- The profiles at equilibrium of the control integration are used to define the reference column profiles in the reference column experiments

4. WTG calculations over uniform surface conditions

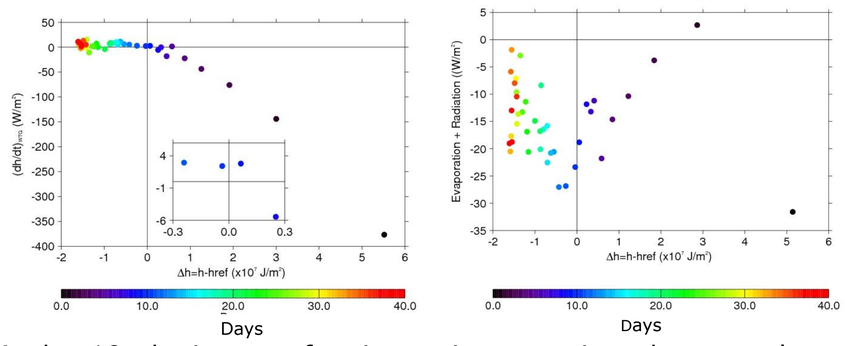
$SST = 302.7$ K and $U = 5$ m/s in both columns and $\tau = 2$ hr.

Reference column approach



A dry equilibrium with suppressed convection

Why the test column can not sustain large-sale ascent?

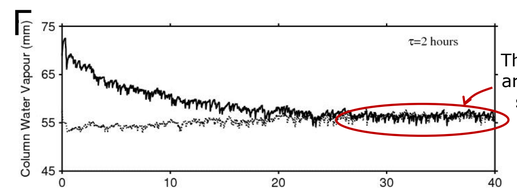


At day 10, the import of moist static energy into the test column by the WTG circulation is not enough to balance the reduction in evaporation

Coupled-column approach

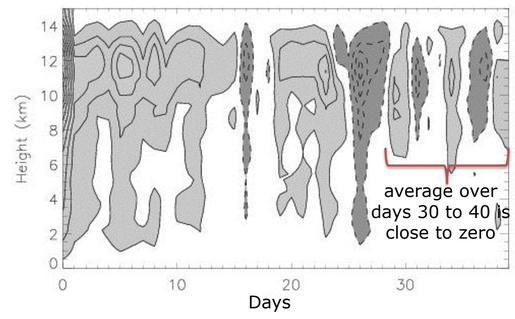
Column 1 and 2 are initialised to the RCE profiles at 302.7 and 304.7 K respectively.

$\varepsilon = 0.5 \quad \overline{\omega}_2^{WTG} = -\overline{\omega}_1^{WTG}$



The two curves are indistinguishable from day 30

Daily-mean large-scale vertical velocity in column 2

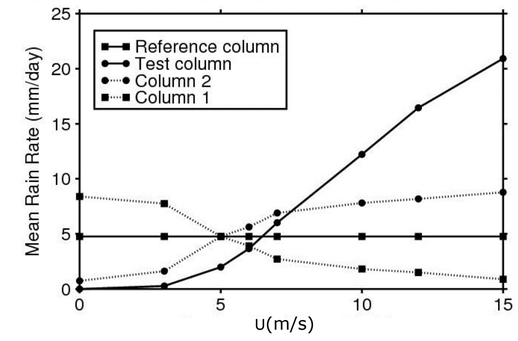


Same results for $\varepsilon = 0.01$, but with a longer timescale of adjustment

4. WTG calculations over non-uniform surface conditions

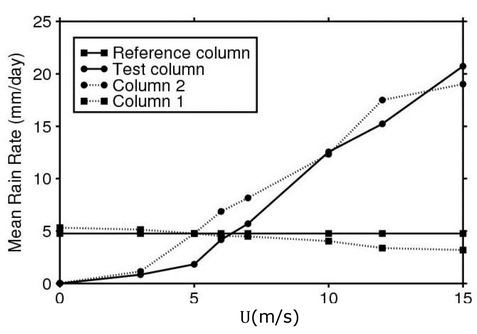
We changed U in the test column, or else in column 2.

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



The two systems behaves very similarly for large changes in the surface forcing

5. Transition from shallow to deep convection

6-Summaries

•A WTG circulation with descent in the test column is a robust result of the reference column simulations performed under uniform conditions. This situation is associated with net transport of moist static energy into the test column by the WTG circulation with a small compensating reduction in surface evaporation.

•Under uniform surface forcing, the coupled-column system reaches an equilibrium with no time-mean WTG circulation even for small ε. However, the timescale of adjustment of the columns increases as ε approaches zero.

•In the limit of $\varepsilon \to 0$ the sensitivity of the coupled-column system to the difference in surface forcing is very similar to that in the reference column system. However, differences in sensitivity remain for small changes in the surface forcing.

References

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Acknowledgments

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