Evaluating the CoMorph Parameterization using idealised simulations of the two-way coupling between convection and large-scale dynamics

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Introduction

We present a new methodology to test the interactions of convection schemes with their larger-scale environment. In this study, a single-column model (SCM) using the new Met Office convection scheme, CoMorph, and the new Met Office NERC Cloud Model (MONC) used as a Cloud-Resolving model (CRM) are coupled to damped-gravity wave (DGW) derived large-scale dynamics. The coupled models are used to investigate convective responses to stimulus forcings under the influence of interactive large-scale dynamics. We show results from the SCM using CoMorph, demonstrating that its behaviour is now very similar to that of the CRM.

Model description

Models	MONC	SCM
Dimension	3D	1D
Wind	None; (u, v) relaxed to (5,0)m/s	
Rad Cool	-1.5 K/d (0-12 km) decreases to 0 (16 km)	
Radiative-Convective Equilibrium (RCE) simulations		
$\bar{P}_{RCE}$(mm/d)	4.22	4.27
$\bar{E}_{RCE}$ (mm/d)	4.20	4.26

Parameterized large-scale dynamics

A combination of the momentum and thermodynamic equations.

$$\frac{\delta}{\delta p}\left(\varepsilon \frac{\delta\bar{\omega}}{\delta p}\right) = \frac{\kappa^2 R_d}{\bar{p}^{RCE}}\left(\bar{T}_v - \bar{T}_v^{RCE}\right)$$

$\bar{\omega}$ induces source or sink terms to θ and q budgets

$$\left(\frac{\delta\theta}{\delta t}\right) = \cdots + \bar{\omega}\frac{\delta\bar{\theta}}{\delta p} \quad \text{and} \quad \left(\frac{\delta q}{\delta t}\right) = \cdots + \bar{\omega}\frac{\delta\bar{q}}{\delta p} + \max\left(\frac{\delta\bar{\omega}}{\delta p}, 0\right)\left(\bar{q}^{RCE} - \bar{q}\right)$$

Experimental design

$$\left(\frac{\partial T}{\partial t}\right)_{pert} = \frac{A_T}{\tau} Sin\left(\frac{z - H/2}{H/2}\right) \quad \text{and} \quad \left(\frac{\partial q}{\partial t}\right)_{pert} = \frac{A_T}{\tau}\left(\frac{z}{h}\right)^2 Exp\left[2\left(1 - \frac{z}{h}\right)\right]$$

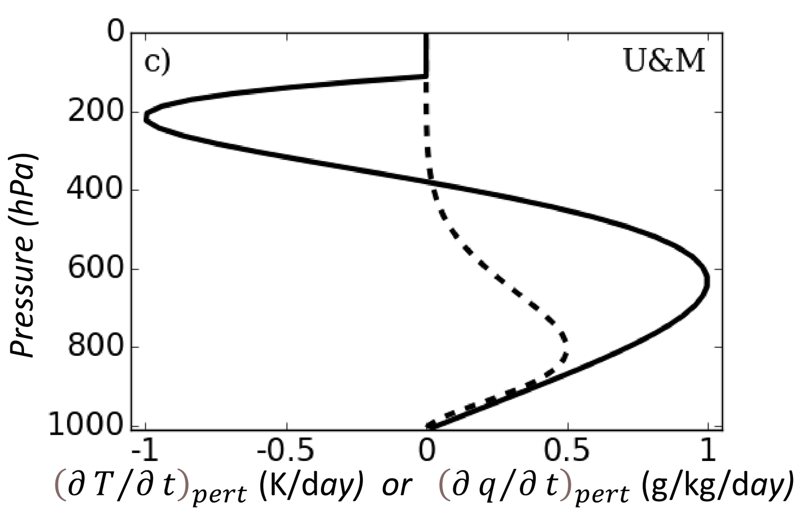

Fig.1 Examples of stimulus forcings acting to enhance convection:
$A_T = +1$ **K/d** enforces a less stable column (solid curve)
$A_q = +0.5$**g/kg/d** enforces a moister column (dotted curve)

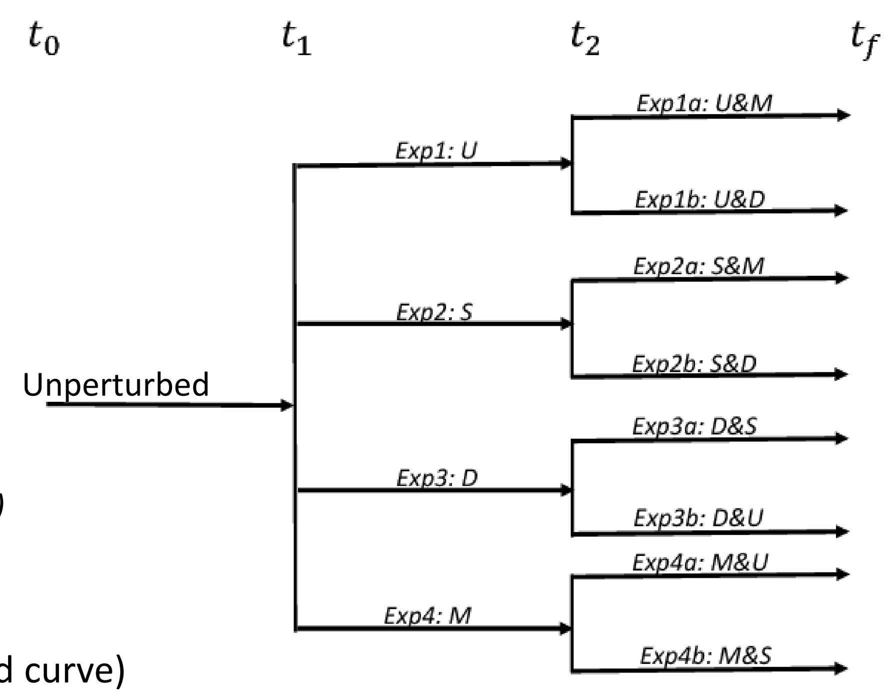

Fig2. Full range of possible combination of perturbations

Approach to equilibrium

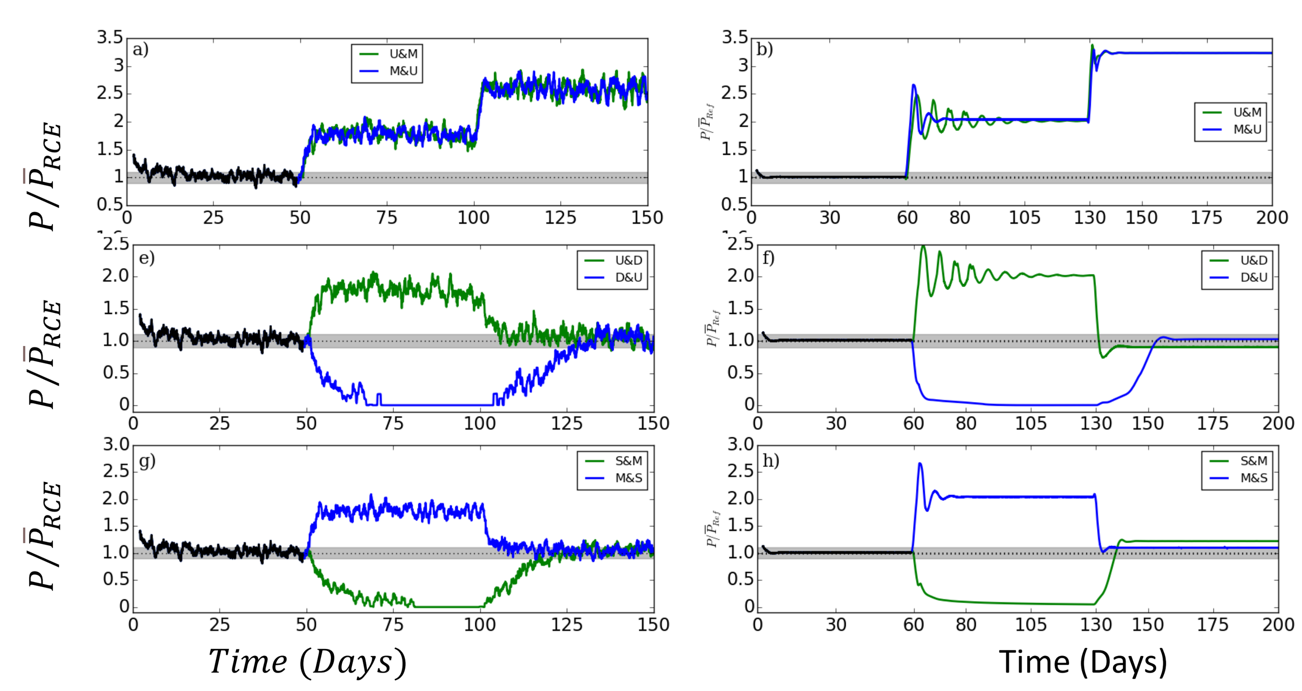

Fig.3 Timeseries of normalized precipitation rate ($P/\bar{P}_{RCE}$)

Vertical profiles

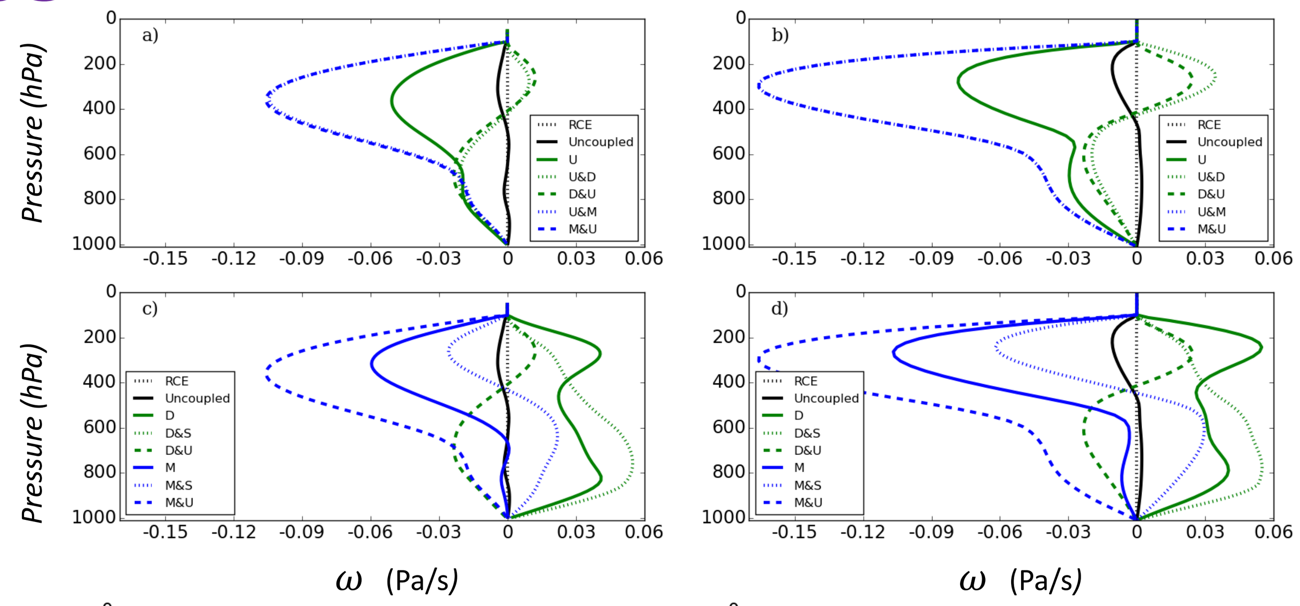

Fig.4 Profiles of the large-scale pressure velocity $\bar{\omega}$

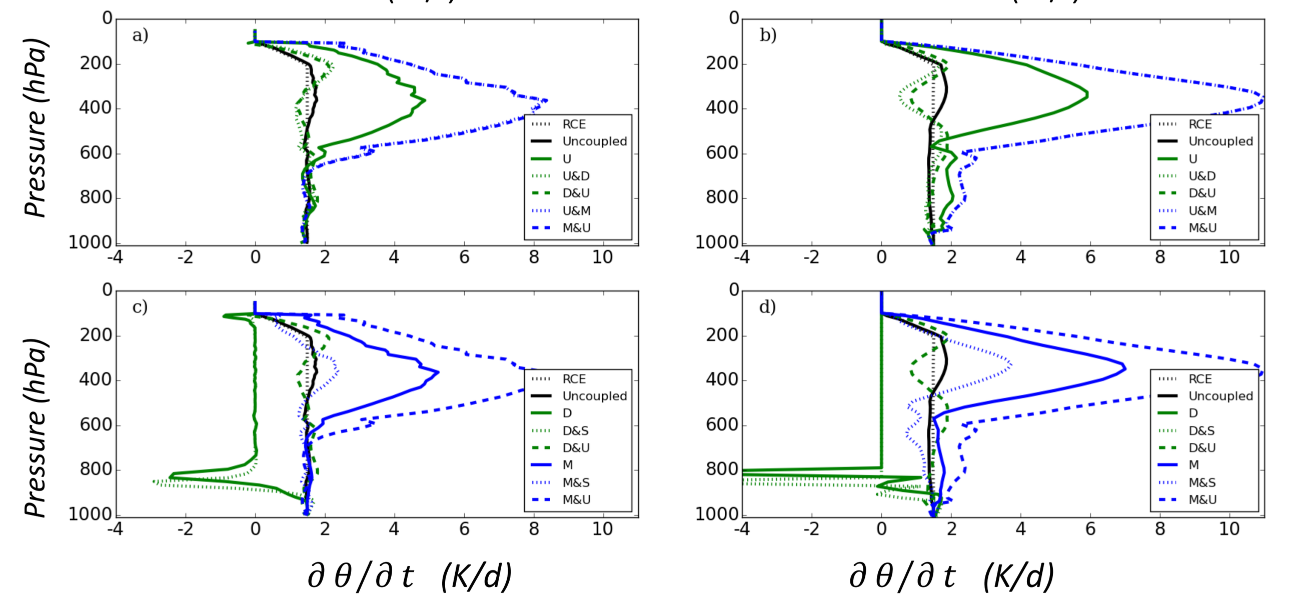

Fig.5 Profiles of the sum of heating rates in MONC and the sum of heating rate from parameterized physics in the SCM

Response as a function of the strengths of moistening stimuli

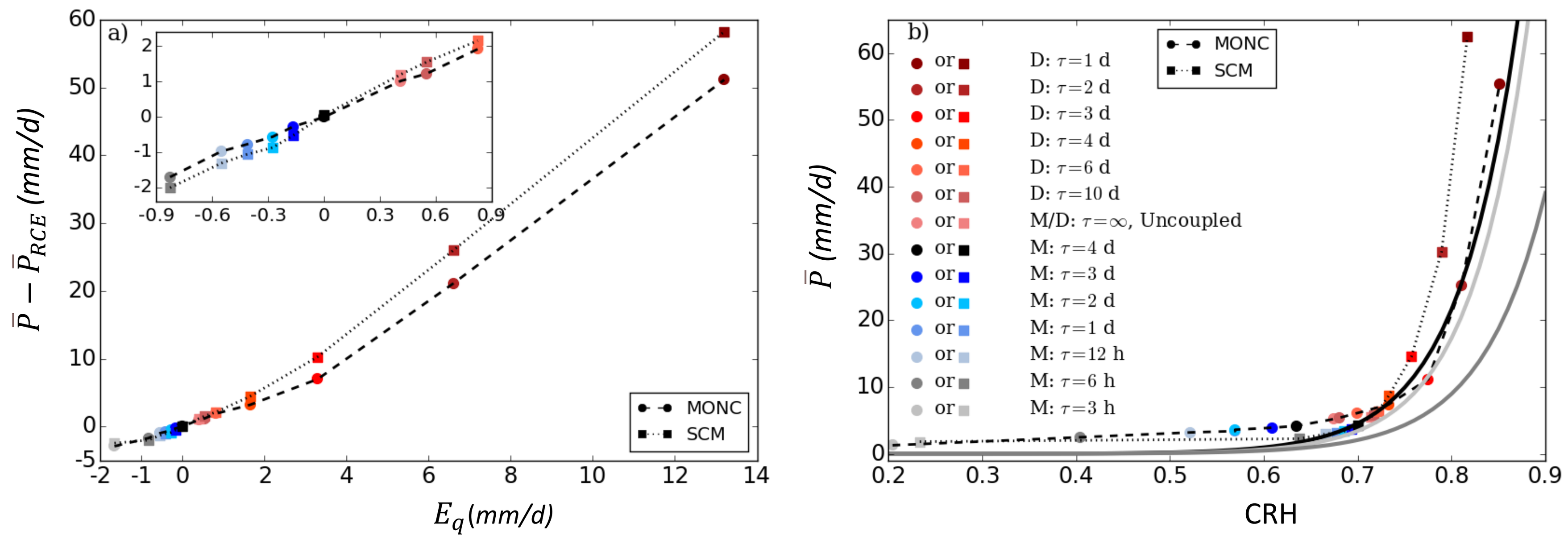

Fig.6 a) Scatter plots of $\Delta\bar{P} = (\bar{P} - \bar{P}_{RCE})$ and $E_q = \int\left(\frac{\partial q}{\partial t}\right)_{pert} dp/g$. b) scatter plots of $\bar{P}$ versus CRH. The solid black, grey and silver curves are those derived using (SSMI) observations over the tropical oceans (Bretherton et al. 2040 and Rushley et al. 2018)

Conclusions

- For stimuli acting to enhance convection
  - The SCM adjusts to a new equilibrium with stronger responses
  - The SCM responses are faster, followed by damped oscillations
- For stimuli acting to suppress convection
  - The SCM adjusts to a dry equilibrium that is similar to that in the CRM, but its transient convective responses are markedly too fast *(CoMorph parameterized physics are not quite effective in capturing the long-term convective memory found in the CRM simulations)*
- Convective rainfall in the SCM is relatively insensitive to a combination of stimuli acting to enhance and suppress convection simultaneously, in agreement with the CRM.
- Convective responses in the SCM are very similar to those in the CRM for moistening up to 0.83 mm/d, and above which they are stronger.
- Both models simulate a monotonic increase of precipitation with CRH and correctly capture the observed CRH threshold
- Above the threshold, the increase of precipitation with CRH is more abrupt in the SCM than in the CRM and observations *(CoMorph parameterized physics do not appropriately capture the precipitation-CRH relationship as the CRH increases passes its threshold)*

Reference

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2. C. Bretherton, M. Peters, and L. Back. Relationships between water vapor path and precipitation over the tropical oceans. *J. Clim.*, **17**, 1517:1528,2004.
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