Characterising The Effects of Parameterised Convection by Their Linearised Responses

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Introduction

Convection parameterisations in global models typically do not agree with each other. Understanding those different and unique characteristics of convection schemes would be essential to improve the ability to better represent convection in global models. However, testing schemes directly in climate models, or against observational case studies, typically has not been able to separate good and bad schemes or assumptions.

This study evaluates convection parameterisations currently used in popular models with single column model (SCM) simulations under idealised radiative-convective equilibrium (RCE) conditions by evaluating their responses to perturbations. These SCM RCE simulations are used to construct linear response functions as in Kuang (2010), in which the convective tendencies in new equilibrium status under small heating or moistening perturbation forcing applied at a specific vertical level are examined in a linear response framework. Convective sensitivities in each model are compared with reference values derived using cloud resolving model (CRM) by Herman and Kuang (2013).

Model Setup & Experimental Methods

- Standard conditions: No rotation, SST=28ºC, U surface wind=4.8 m/s. Fixed radiation (-1.5K/d), T and q relaxation in stratosphere
- Use **matrix inversion technique** proposed by Kuang (2010) in which convective tendencies are determined using

Forcing → Response

$$\frac{d\mathbf{x}}{dt} = \mathrm{M}\,\mathbf{x}$$

Convective tendencies:
dT/dt (convective heating/cooling)
dq/dt (convective moistening/drying)
etc.

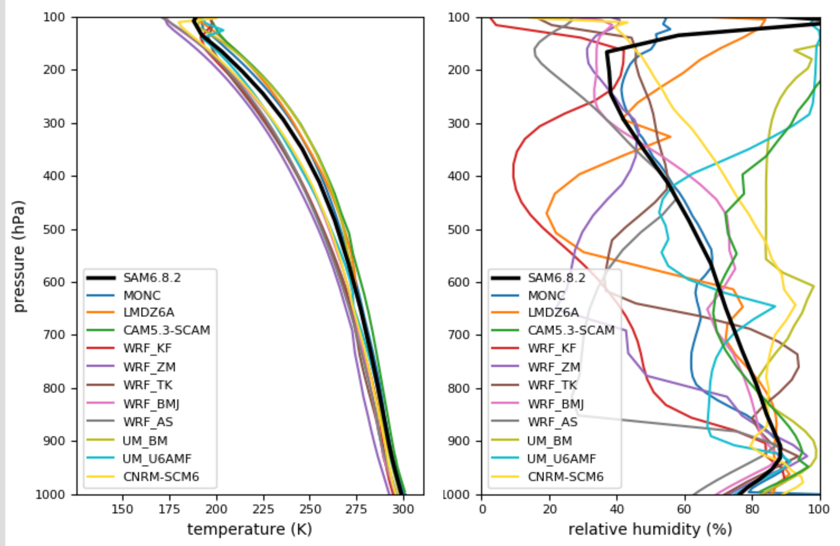
Environmental conditions:
T (temperature)
q (humidity)
etc.

Models & Schemes

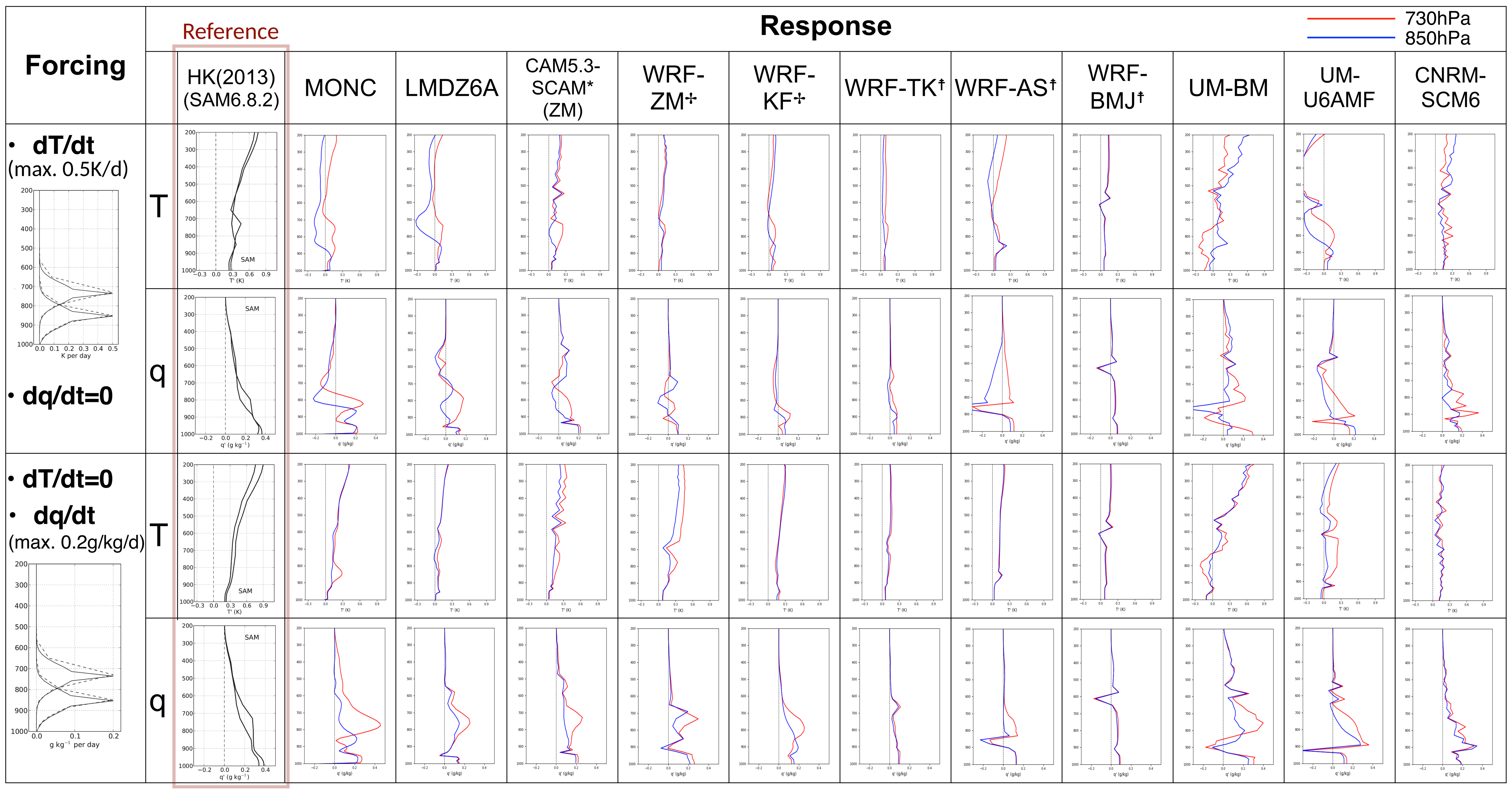
Model		Convection scheme	PBL scheme
SAM6.8.2		N/A – Cloud Resolving Model	
MONC		N/A – Met Office's NERC Cloud Model	
LMDZ6A (SCM)		Modified Emanuel scheme + cold pool parameterization (Grandpeix and Lafore 2010, Rio et al. 2013)	Eddy diffusion (Yamada, 1983) + mass-flux representation of thermals (Rio et al. 2010)
CAM5.3-SCAM (SCM)		Zhang-McFarlane deep convection / UW shallow convection scheme	Moist Turbulence scheme (Bretherton and Park, 2009)
WRF (SCM)	ZM	Zhang-McFarlane	YSU (Hong, Noh and Dudhia, 2006)
	KF	Kain-Fritsch	
	TK	Tiedtke	
	AS	New Simplified Arakawa-Schubert	
	BMJ	Betts-Miller-Janjic	
UM (SCM)	BM	Betts-Miller	Lock et al. (2000)
	U6AMF	UM 6A Mass Flux scheme	
CNRM-SCM6		PCMT (Piriou et al. 2007, Guérémy 2011)	Cuxart et al. (2000)

Mean State Profiles

- RCE columns of temperature (left) and relative humidity (right) for all models are shown below:



Results



* random noise applied, all U = 5m/s, SST=29ºC, ✢ dT/dt = 0.2K/d, † dT/dt=0.2K/d, dq/dt=0.1g/kg/d

Discussion

- Responses of all models generally do not resemble the reference, even responses of the two high resolution cloud resolving models are quite different (SAM6.8.2 and MONC).
- Responses of humidity (q) disagreed more with references than responses of temperature (T).
- A few models display kinks around 900hPa, which could be related to the boundary layer schemes.
- A few models display wiggly responses (CAM5.3-SCAM, UM & CNRM), which could be related to the internal processes in the respective models.
- Betts-Miller scheme in WRF and UM show very different responses, while Zhang-McFarlane scheme in WRF and CAM5.3-SCAM display fairly similar responses.
- Linear response function is a useful tool to characterise convective parameterisations and could help identify deficiencies in the schemes.
- The mean state alone shows wide variation in relative humidity, and this is what deviates most from the reference in the perturbation experiments too.

Future Plans

- Evaluate convective microstate memory (Colin et al. 2019), e.g., cold pools, in a convection scheme for better representation of organisation effect.
- Conduct further tests using different large-scale forcings (e.g., vertical velocity, etc.).
- Complete linear response functions (i.e. forcing all model levels) and use them to identify flaws in and eventually improve convection schemes.
- Test the modified schemes in global models.
- Apply the linear response function method to verify phenomena that are poorly simulated in climate models.
- Investigate causes of different RH outcomes and refine experiments with similar initial RH in the mean state - RH (or initial condition) sensitivity test in SCM.

REFERENCES

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