Limitations of the equilibrium assumption between convection and the forcing

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1. Motivation

Convective systems are a major contributor to global circulations of heat, mass and momentum. However, as convective processes occur on scales smaller than the grid, parameterisation schemes are used in large-scale numerical models.

Current parameterisations require a statement of equilibrium between the large-scale forcing and the convective response. This assumption is valid for radiative-convective equilibrium (RCE) where the convective system fluctuates about a mean response. These fluctuations have been explained by theory.

We discuss the fluctuations that occur in response to a time-varying forcing.

2. Method & model set-up

A Cloud Resolving Model (the Met Office LEM) is forced with time-varying surface fluxes, based on observations of the diurnal cycle over land. However, in order to investigate the sensitivity of equilibrium assumptions to the forcing timescale, runs are compared in which the length of the 'cycle' has been artificially altered (here we focus on 3 and 24 h).

The model set-up is similar to Stirling and Petch (2004). It is first run to equilibrium with constant surface fluxes simulating noon conditions. The run is continued for a further 12 cycles with time-varying forcing. A constant tropospheric cooling is applied to balance the moist static energy.

The simulations presented here are 3D with 1km resolution in a 64km x 64km domain.

3. Equilibrium and non-equilibrium

Figure 1 shows that the overall strength of the convection is almost independent of timescale, but that for shorter timescales, the response over a single cycle is much more variable.

Questions arising:

•Is this due to the fluctuations inherent in a convective system (i.e. natural variability) ?

•Can theory be used to explain these fluctuations?

•Is the theory valid regardless of the forcing timescale?

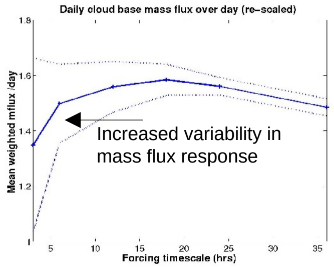


Figure 1 Mean and standard deviation of the mass flux integrated over a forcing cycle, as a function of forcing timescale.

4. Theory of fluctuations about equilibrium

Cohen and Craig (2006), hereafter CC06, present a theory for the fluctuations of an ensemble of convective clouds. This assumes:

•equilibrium with the large-scale forcing,

•clouds are point-like, non-interacting and randomly distributed in space.

The normalised variance of total mass flux M is then described by:

$$\frac{\langle(\delta M)^2\rangle}{\langle M\rangle^2} = \frac{2}{\langle N\rangle}$$

M total mass flux
N total number of clouds

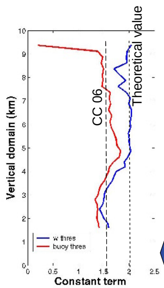
$$\text{Constant term} = \frac{\langle(\delta M)^2\rangle}{\langle M\rangle^2}\times\langle N\rangle = 1.56 \quad -(1)$$

CC06 showed that this theory was approximately valid in RCE with prescribed radiative cooling and constant surface temperature.

5. Testing theory for surface driven RCE setup

It is not immediately apparent that this theory is valid for other model setups. Here the model is forced by constant surface fluxes (balanced by large-scale cooling). Figure 2 shows the variation with height of the 'constant term' from equation 2. Two different 'cloud' definitions are used.

• The buoyancy definition consistently underestimates the theoretical value and the value from the w definition.



• Both definitions are closer to theory higher in the atmosphere, above the minimum in the moist static energy.

• Using a buoyancy threshold results are independent of the strength of the forcing.

Figure 2 Value of constant term (equation 1) for surface-flux-driven RCE setup. Blue line is for cloud definition of w >1 m/s. Red line is for clouds that are buoyant, upward-moving and moist. Dashed lines are included for comparison.

6. Fluctuations for time-varying forcing

The variance between cycles is calculated for each point within the cycle. Values of the constant term can be used to compare the variability to that which would occur about an equilibrium state.

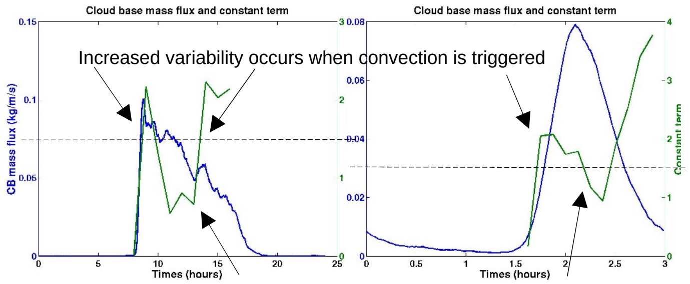


Figure 3 Variation in constant term with time for (a) 24h and (b) 3h forcing timescale, at 3.4km. Dashed line shows value of constant term from surface-flux-driven RCE run, figure 2.

7. Conclusions

The theory of CC06 explains fluctuations about equilibrium in idealised experiments of both ocean and land-based convection. For time-varying land-based convection, given the time-varying ensemble-mean response <M>, normalised fluctuations are smaller than those that would occur at equilibrium. Thus, to parameterise time-varying convection over land, the focus should be on understanding the ensemble-mean response.

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Cohen, BG and Craig, GC. 2006. Flucuations in an equilibrium convective ensemble. Part II Numerical Experiments. *Quart. J. Roy. Met. Soc.* **63**,2005-2015. Stirling, AJ and Petch, JC. 2004. The impacts of spatial variability on the development of convection. *Quart. J. Roy. Met. Soc.* **130**, 3189-3216.