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?

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:
\[
\frac{\langle \delta M^2 \rangle}{\langle M \rangle^2} = \frac{2}{N} \quad \text{for surface driven RCE setup,}
\]

\[
\frac{\langle \delta M^2 \rangle}{\langle M \rangle^2} = \frac{1.56}{\langle N \rangle} \quad \text{for cloud-resolving RCE setup.}
\]

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.

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.

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.

Acknowledgements
LD is supported by NERC CASE award NER/S/A/2004/12408

References