3D experiments with a stochastic convective parameterisation scheme

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Introduction

Stochastic parameterisation schemes improve the spread of ensembles of weather forecasts. For a given grid-scale model state, the entire distribution of possible subgrid-scale states, consistent with the grid-scale state, is sampled probabilistically. This enables a stochastic scheme to capture the variability in the paramterised quantity better than a conventional scheme: in a conventional scheme, a mean subgrid-scale state is always assumed, even if the real behaviour of the parameterised quantity can vary far from this mean.

Overview of the Plant-Craig (PC) stochastic convection scheme

Methodology

- Obtain the large-scale state by averaging resolved flow variables over both space and time.
- Obtain $\langle M \rangle$ from CAPE closure and define the equilibrium distribution of m (Craig & Cohen, 2006)
- Draw randomly from this distribution to obtain cumulus properties in each grid box.
- Compute tendencies of grid-scale variables from the cumulus properties.

Probability distribution of cloud mass flux

Assuming a statistical equilibrium,

$$p(m)\mathrm{d}m = \frac{1}{\langle m \rangle} \exp\left(\frac{-m}{\langle m \rangle}\right)\mathrm{d}m.$$

- m is the mass flux per cloud and $\langle\rangle$ denotes an ensemble mean.
- Cloud-resolving model (CRM) simulations suggest that, with homogeneous, steady large-scale forcing, interactions between clouds can be ignored (Cohen & Craig, 2006).

$p(m)$ can then be combined with a Poisson distribution for cloud number N,

$$p(N) = \frac{\langle N \rangle^N \mathrm{e}^{-\langle N \rangle}}{N!},$$

leading to the following distribution for total mass flux M:

$$p(M) = \left(\frac{\langle N \rangle}{\langle m \rangle}\right)^{1/2} \mathrm{e}^{-(\langle N \rangle + M/\langle m \rangle)} M^{-1/2} I_1 \left(2\sqrt{\frac{\langle N \rangle}{\langle m \rangle}M}\right).$$

- I_1 is a modified Bessel function of the first kind.
- $\langle M \rangle = \langle N \rangle \langle m \rangle$ is obtained from the CAPE closure; $\langle m \rangle$ is pre-defined according to CRM results.
- The PC scheme yields these distributions correctly in single column model experiments (Plant & Craig, 2008)
- The distributions are observed in cloud-resolving model experiments. (Cohen & Craig, 2006).

Both results are obtained in radiative-convective equilibrium, i.e. in the absence of variation in the large-scale forcing.

3D idealised UM experiments

Setup

- The Met-Office Unified Model is used, with the PC convection scheme.
- Radiation is represented by a uniform cooling.
- Convection, large scale precipitation and the boundary layer are parameterised.
- The domain is square, with bicyclic boundary conditions.
- The surface is flat and entirely ocean, with a constant surface temperature imposed.
- Horizontal diffusion, vertical diffusion of θ and targeted diffusion of moisture are applied.

PDFs of cloud mass flux

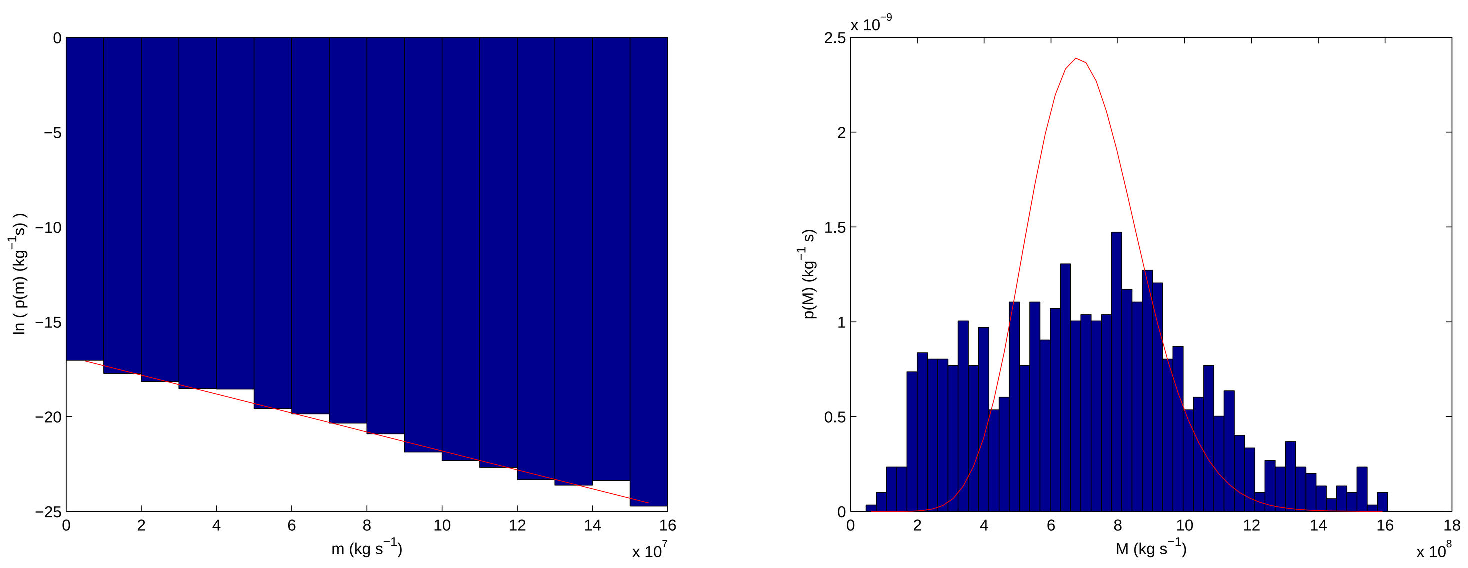

Figure 1: Histograms of $p(m)$ and $p(M)$, with the theoretical curve plotted in red.

- $p(m)$ agrees well with the theory.
- $p(M)$ is not according to the theory, suggesting that the non-interacting assumption does not apply in the PC scheme.
- The PDF of number of clouds follows $p(N) = \exp(-N/\langle N \rangle)/\langle N \rangle$ (figure 2).
- Combining this with $p(m)$ also does not yield the observed distribution, again suggesting that the clouds interact strongly and that there is organisation in the rainfall pattern.

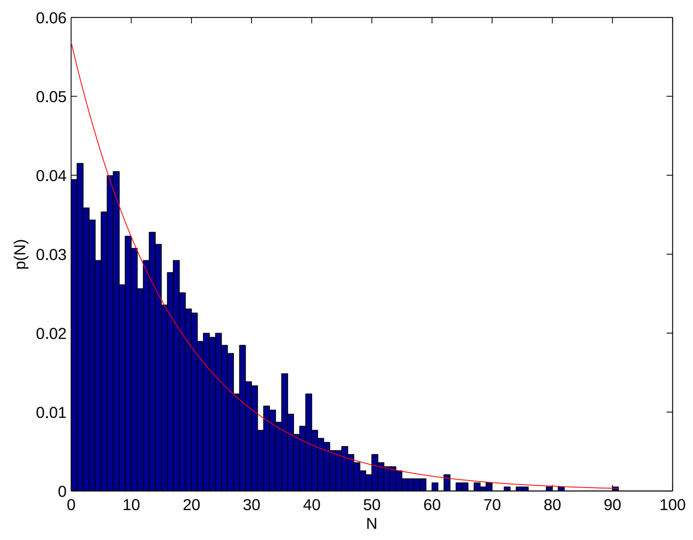

Figure 2: Histogram of cloud number, with a suggested theoretical curve plotted in red.

- There is some hint of organisation in the rainfall pattern for the PC scheme (figure 3, left), suggesting that the non-interacting theory cannot be expected to apply. The Gregory-Rowntree (GR) conventional scheme yields much stronger organisation in the same setup (figure 3, right).

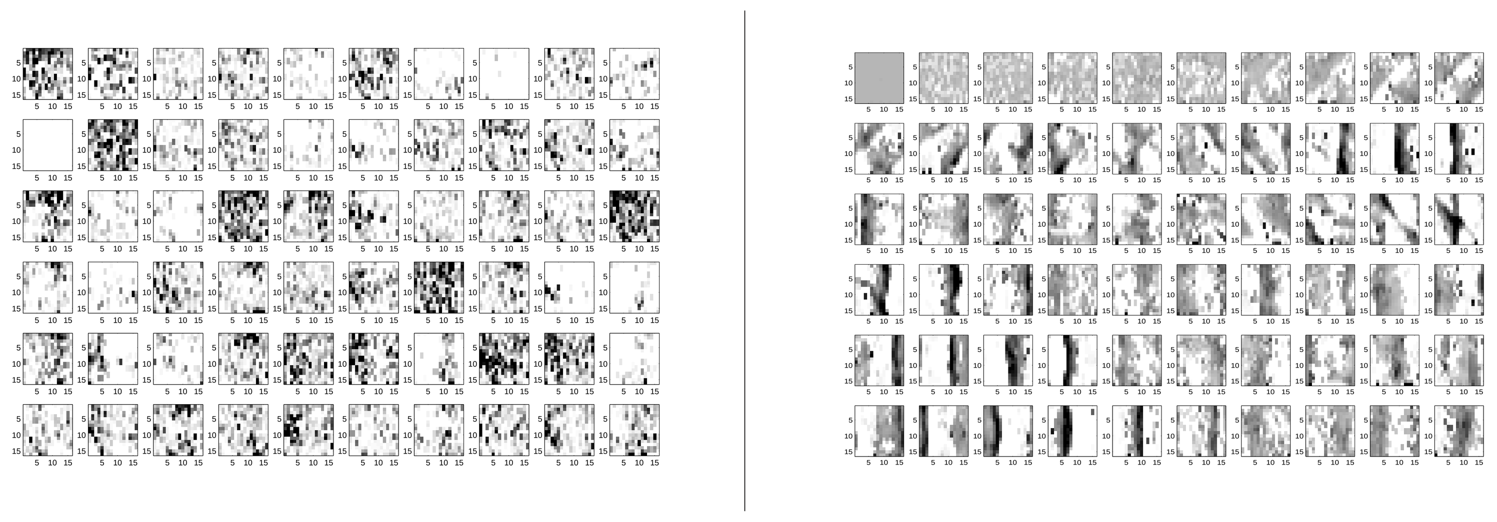

Figure 3: Time series of snapshots of rainfall pattern in PC scheme (left) and GR scheme (right). The greyscale is up to $10^{-3}\,\mathrm{kgm^{-2}s^{-1}}$.

Case study: CSIP IOP18

- An ensemble of six mesoscale runs was performed using the PC scheme in the UM, varying the random selection of clouds (identical initial and boundary conditions).
- Snapshots of rainfall are plotted in figure 4. The overall pattern is similar amongst the ensemble members, but the precise location of convective storms varies.

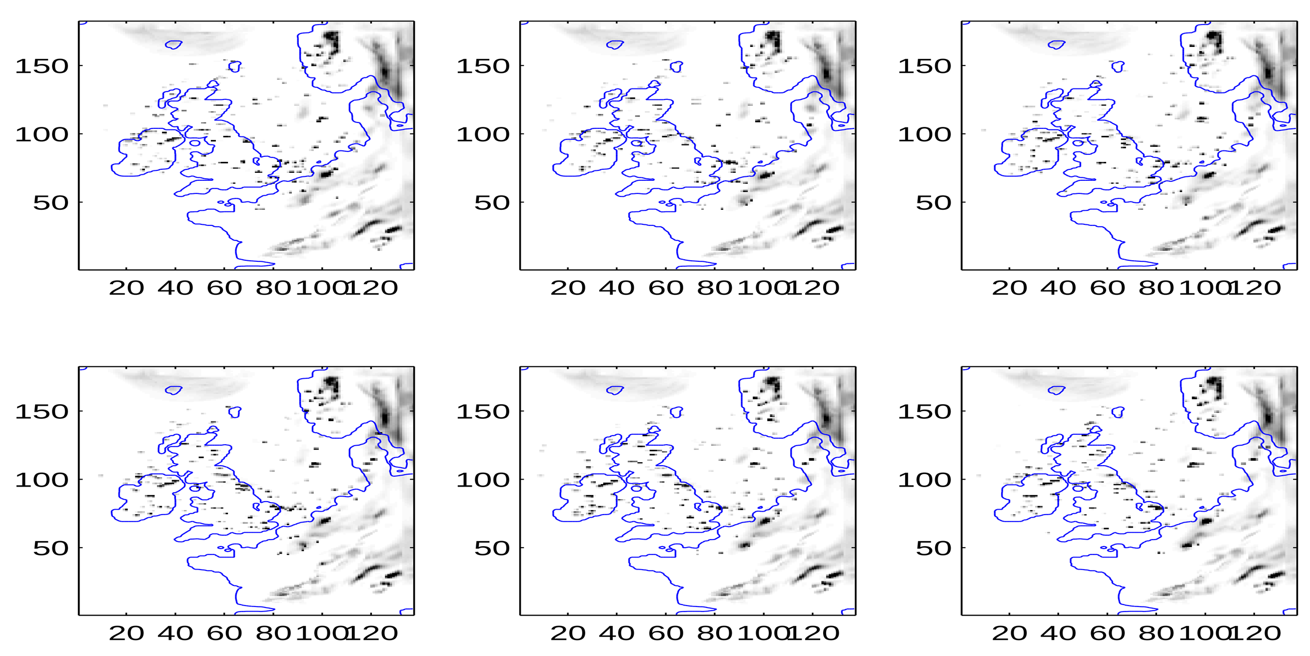

Figure 4: Snapshots of total rainfall for each ensemble member. The greyscale is up to $10^{-3}\,\mathrm{kgm^{-2}s^{-1}}$.

Root-mean-square deviation from the mean

- The RMS deviation of total rainfall is accounted for mostly by the convective rain.
- The mean value of total rainfall is accounted for mostly by the large-scale rain.

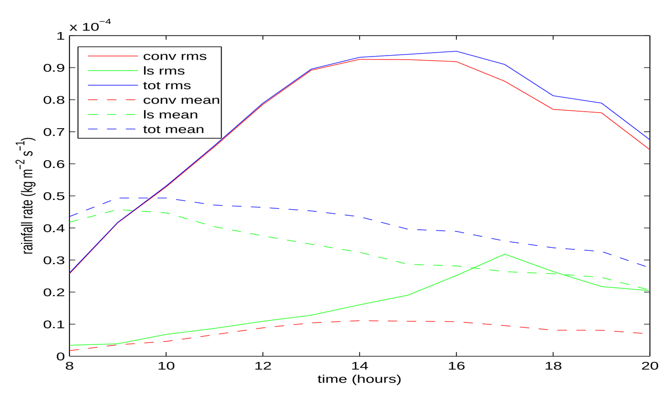

Figure 5: Averaged rainfall as a function of time.

Comparison with Gregory-Rowntree (GR) conventional scheme

- The PC scheme produces 19% of its rain as convective rain, whereas the figure for the GR scheme is 67%.
- There is some difference in total rainfall which reduces as the models 'spin up'.
- The difference between the PC ensemble runs is smaller than the difference between the two schemes.

Conclusions

- **The scheme yields the correct distribution of individual cloud mass flux.**
- **The distribution of total mass flux is not as according to non-interacting theory, suggesting that there is some organisation of cloud structure in the scheme.**
- **The scheme yields considerable convective variability in the simple ensemble case study; the overall convective rainfall behaviour is sensible.**

References

Cohen, B. G. & Craig, G. C. (2006). Fluctuations in an equilibrium convective ensemble. part II: Numerical experiments. *J. Atmos. Sci.*, **63**(8), 2005–2015.

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