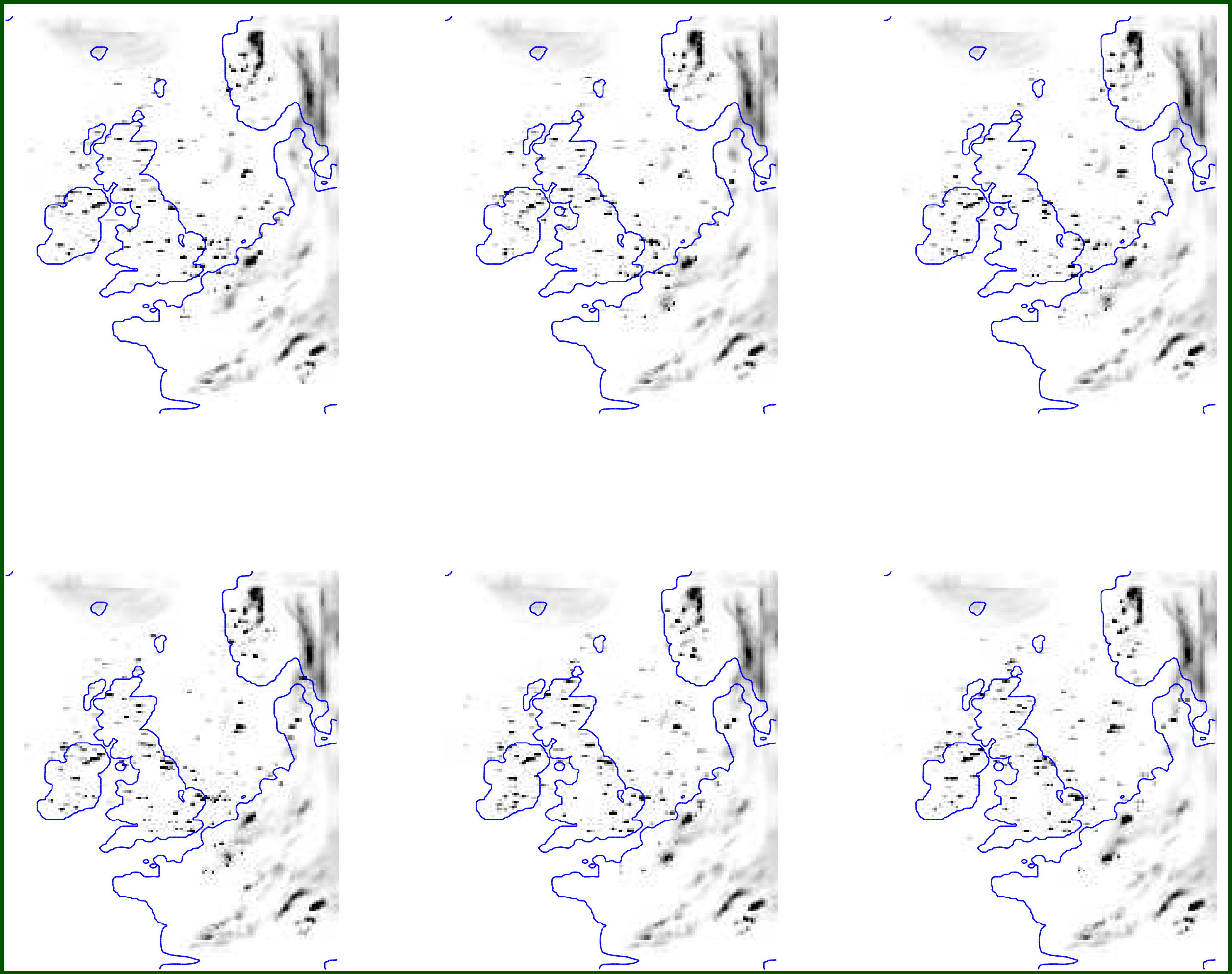
Development of a stochastic convection scheme

R. J. Keane, R. S. Plant, N. E. Bowler, W. J. Tennant

Mini-ensemble of rainfall fore-casts



Outline

- Overview of stochastic parameterisation.
- How the Plant Craig stochastic convective parameterisation scheme works and the 3D idealised setup.
- Results: rainfall statistics.
- A look at the Plant Craig scheme in a mesoscale run.
- Conclusions and future work.

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Ensemble Forecasting & Stochastic Paramterisation

- Single Deterministic Forecast:
  $\dot{\mathbf{E}}_0(\mathbf{X}, t) = \mathbf{A}(\mathbf{E}_0, \mathbf{X}, t) + \mathbf{P}(\mathbf{E}_0);$
  $\mathbf{E}_0(\mathbf{X}, 0) = \mathbf{I}(\mathbf{X})$
- Ensemble of Deterministic Forecasts:
  $\dot{\mathbf{E}}_j(\mathbf{X}, t) = \mathbf{A}(\mathbf{E}_j, \mathbf{X}, t) + \mathbf{P}(\mathbf{E}_j);$
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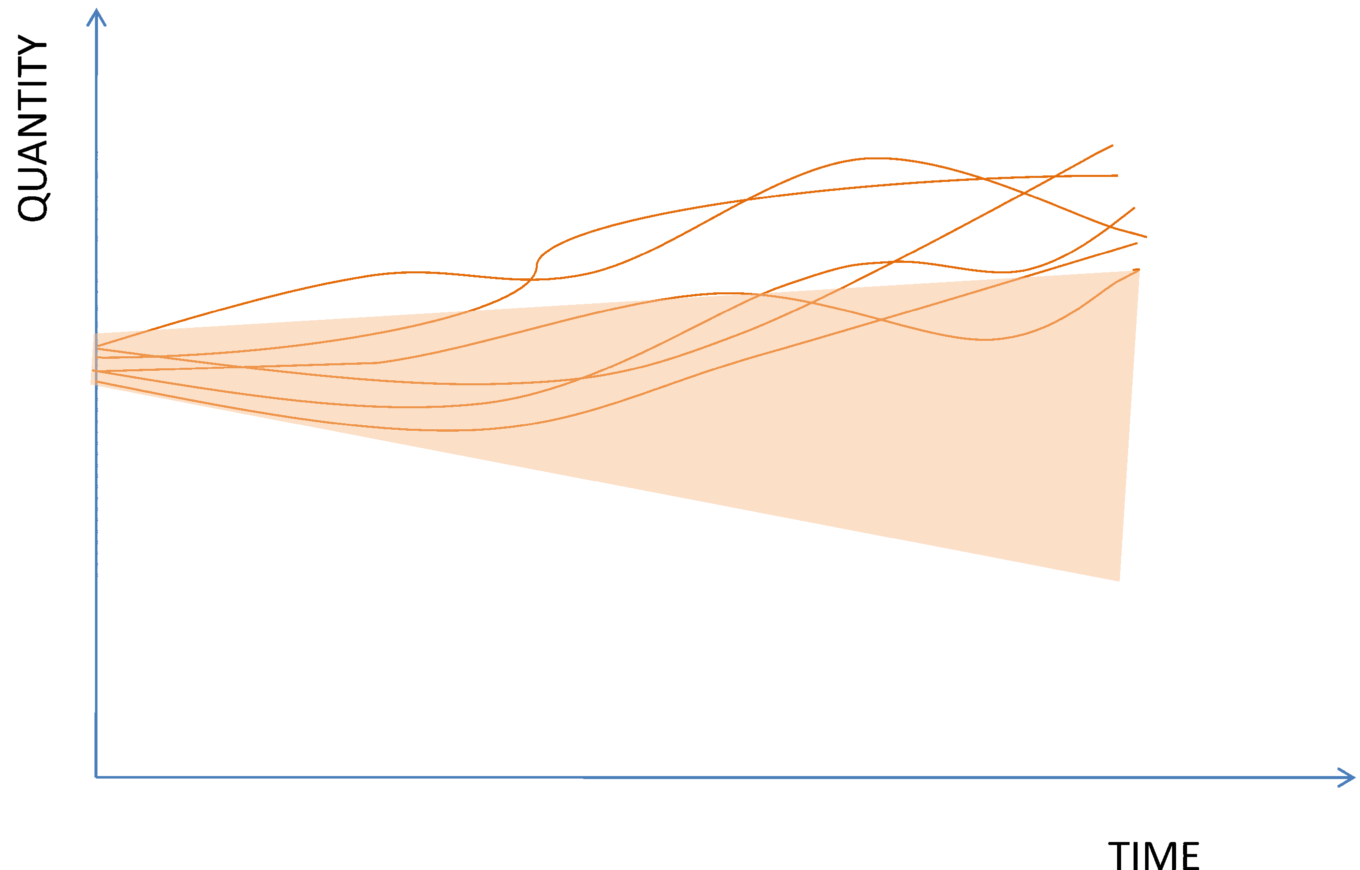
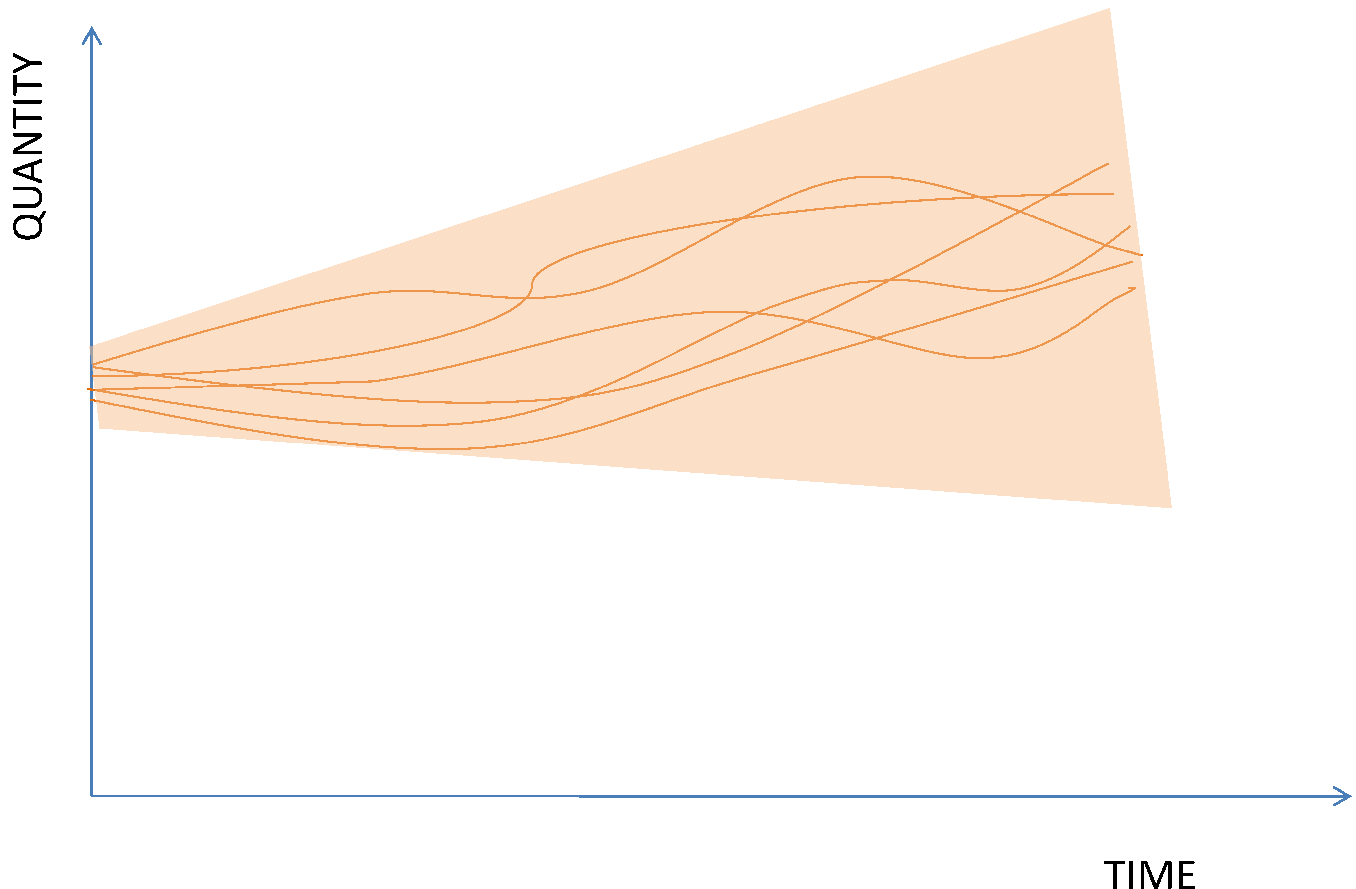
- Ensemble of Stochastic Forecasts:
  $\dot{\mathbf{E}}_j(\mathbf{X}, t) = \mathbf{A}(\mathbf{E}_j, \mathbf{X}, t) + \mathbf{P}_j(\mathbf{E}_j, t);$
  $\mathbf{E}_j(\mathbf{X}, 0) = \mathbf{I}(\mathbf{X}) + \mathbf{D}_j(\mathbf{X})$

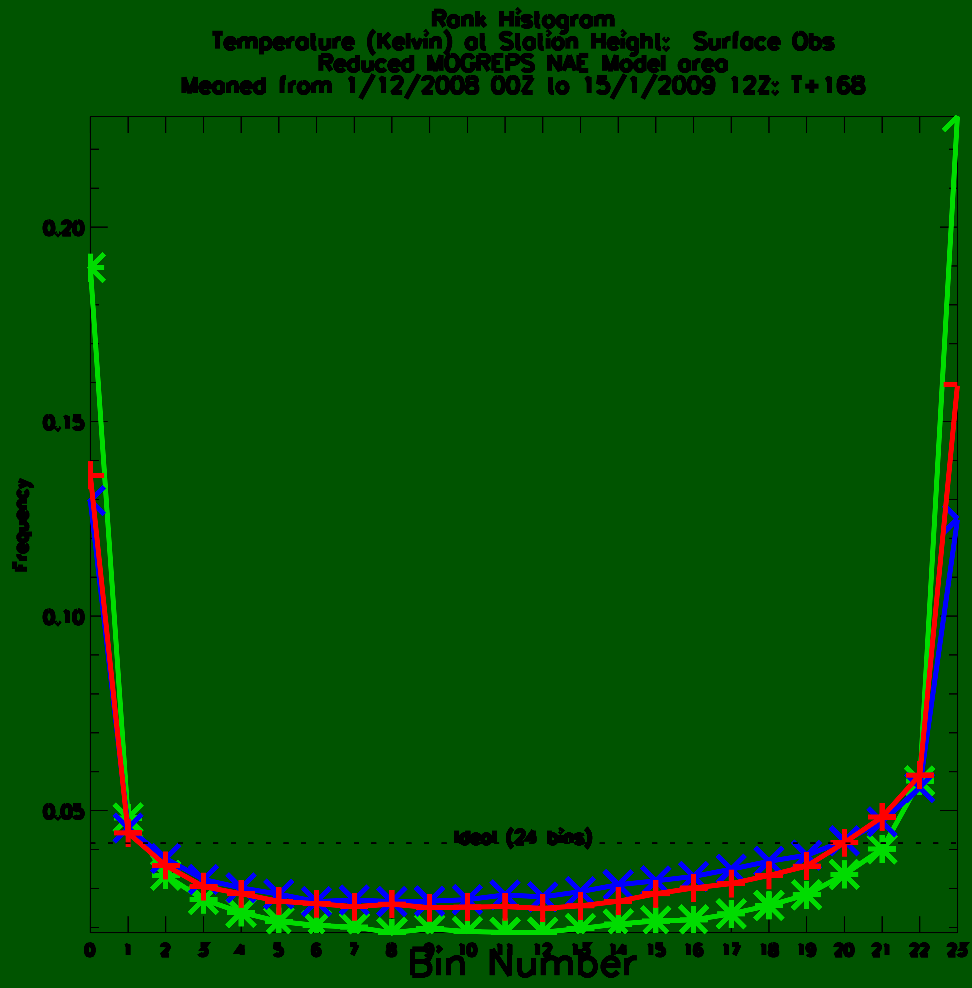
How stochastic parameterisations may improve ensemble forecasts: noise-induced drift



How stochastic parameterisations may improve ensemble forecasts: better forecast of variability



Rank Histograms of surface temperature



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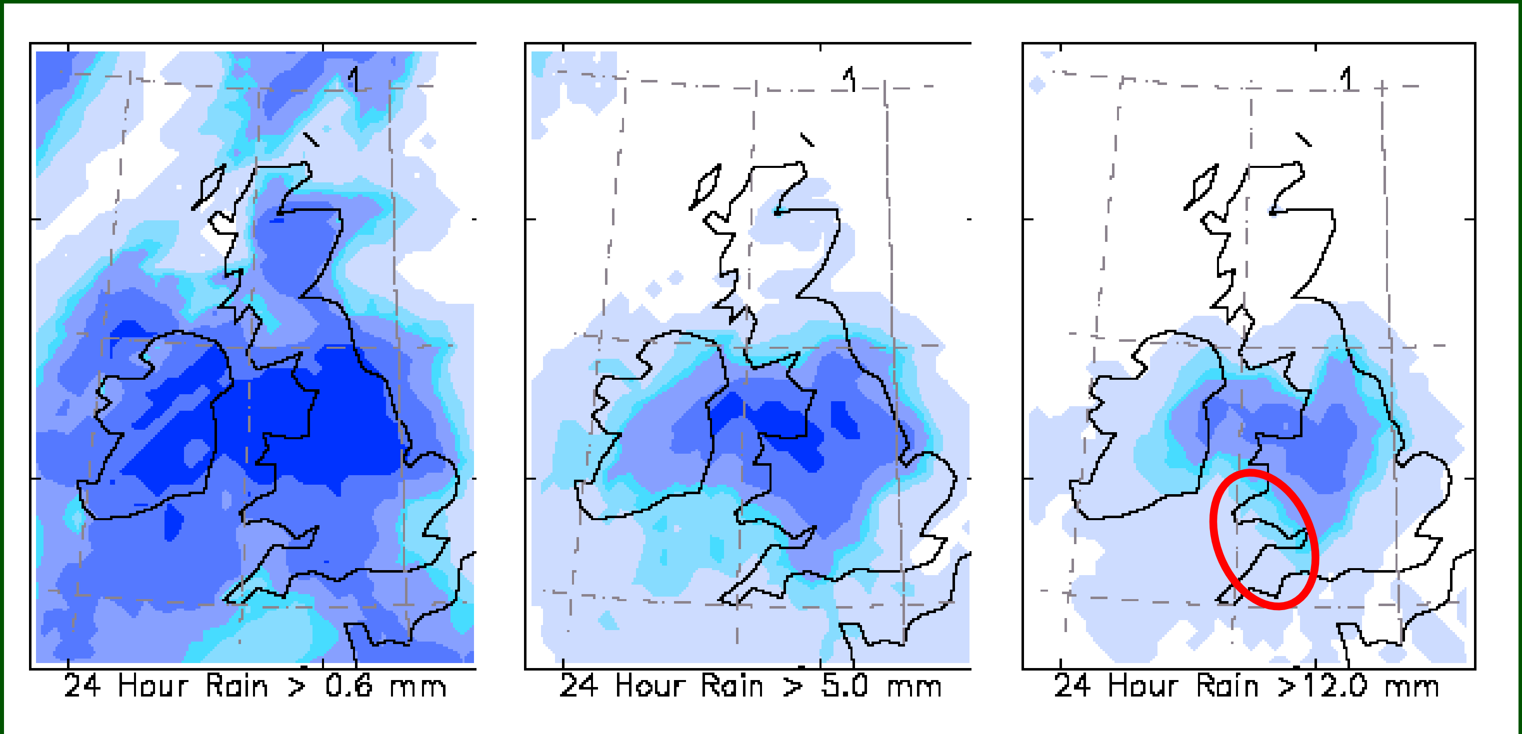
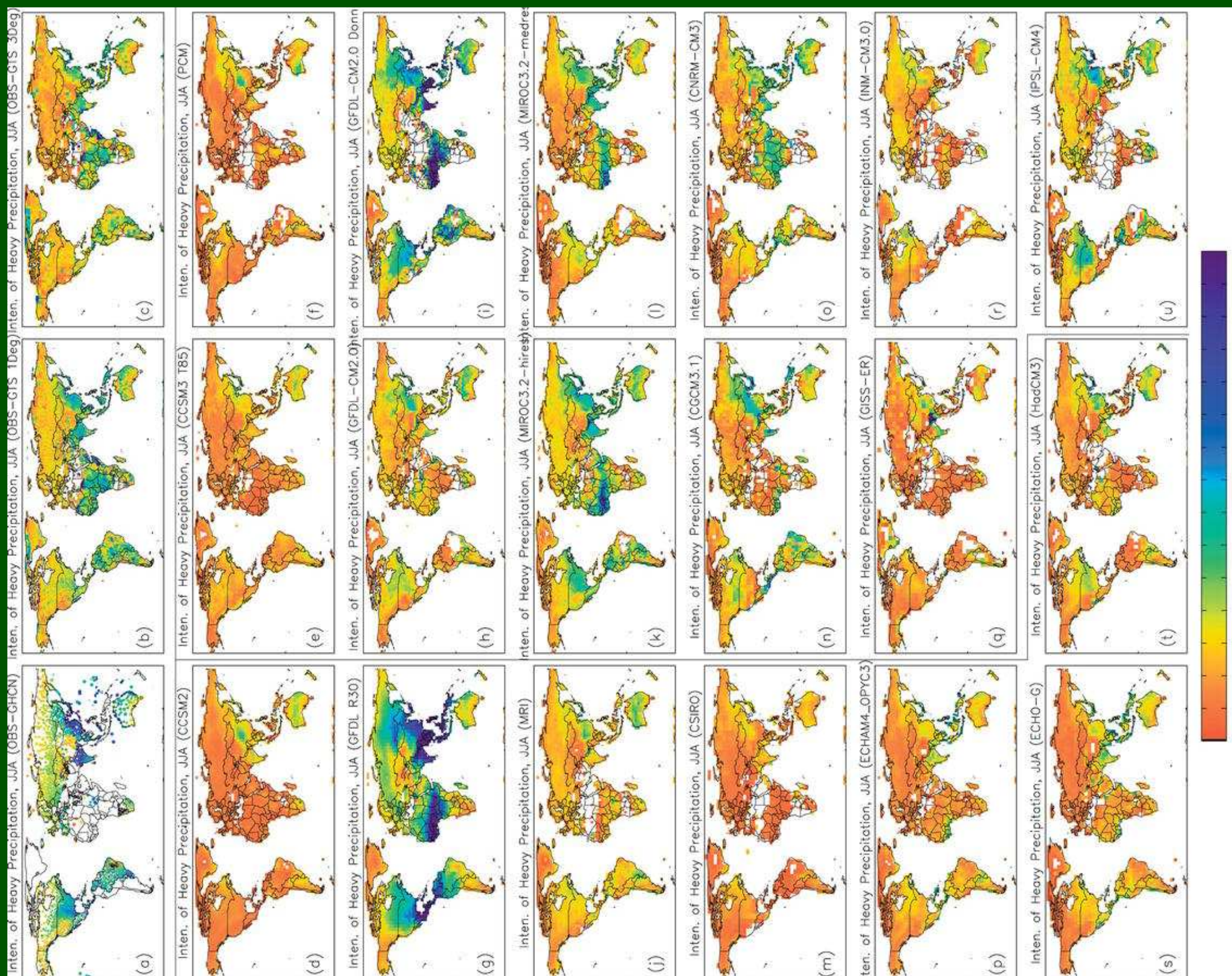
Heavy Rain Devon and South Wales 6th June 2009

Ken Mylne, 4th SRNWP workshop on Short Range Ensemble Prediction Systems, 2009.



Climate modelling of heavy pre-cipitation

Sun et. al. J. Clim. 2006



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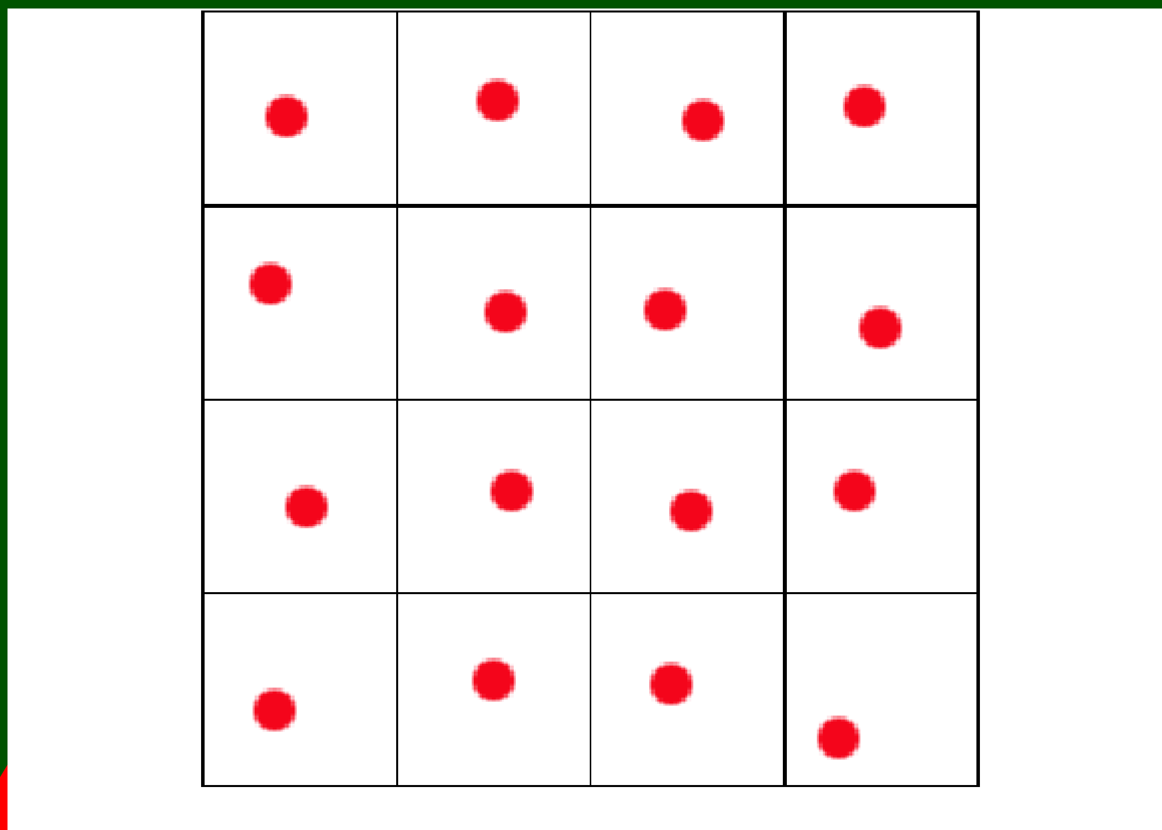
Conventional convective parameterisation

For a constant large-scale situation, a conventional parameterisaion models the convection independently of space:



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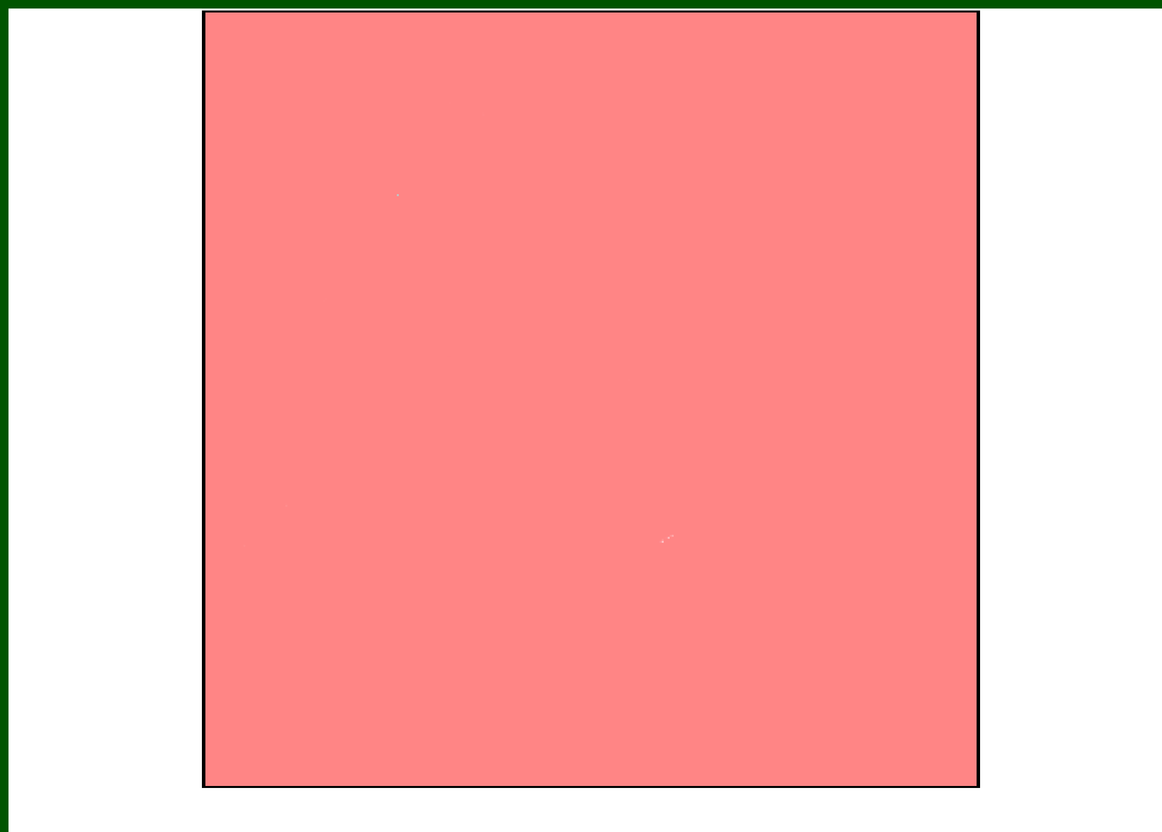
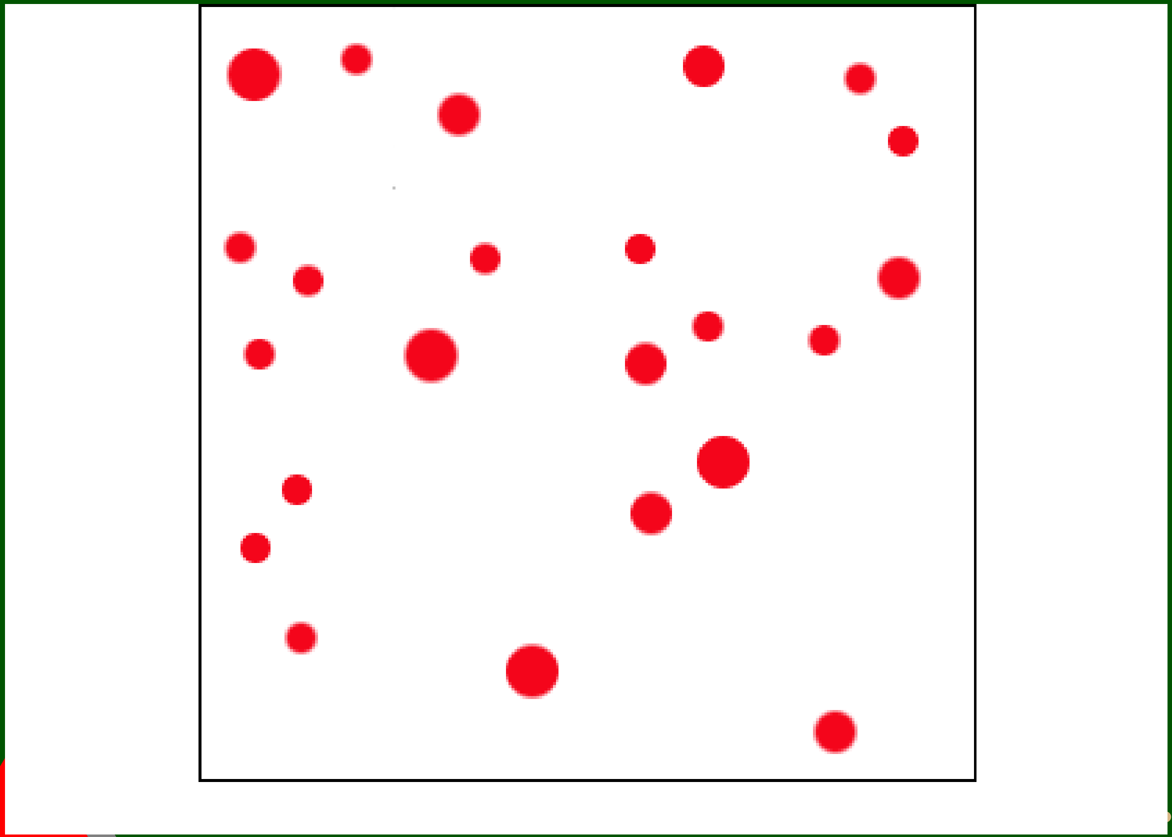
Conventional convective param-eterisation

This leads to a uniform, mean value of convection whatever the grid box size:



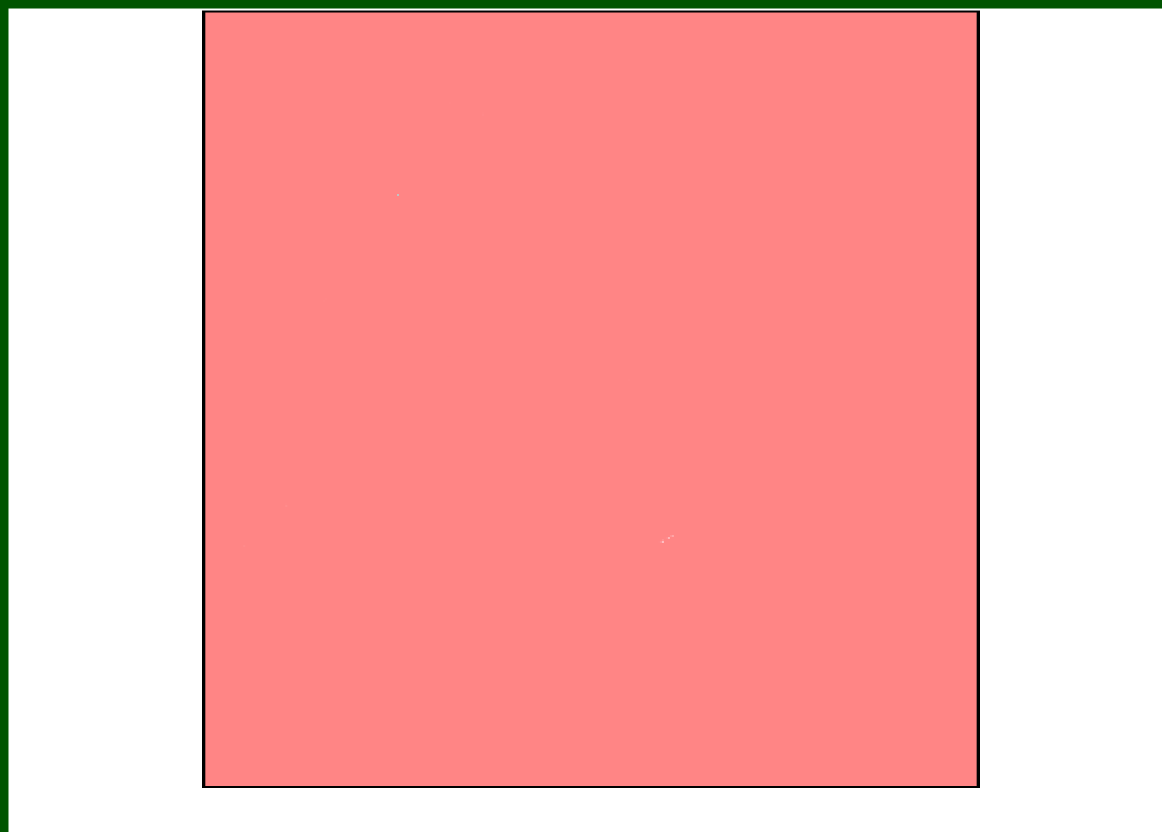
Stochastic parameterisation

A stochastic scheme allows the number and strength of clouds to vary consistent with the large-scale situation:



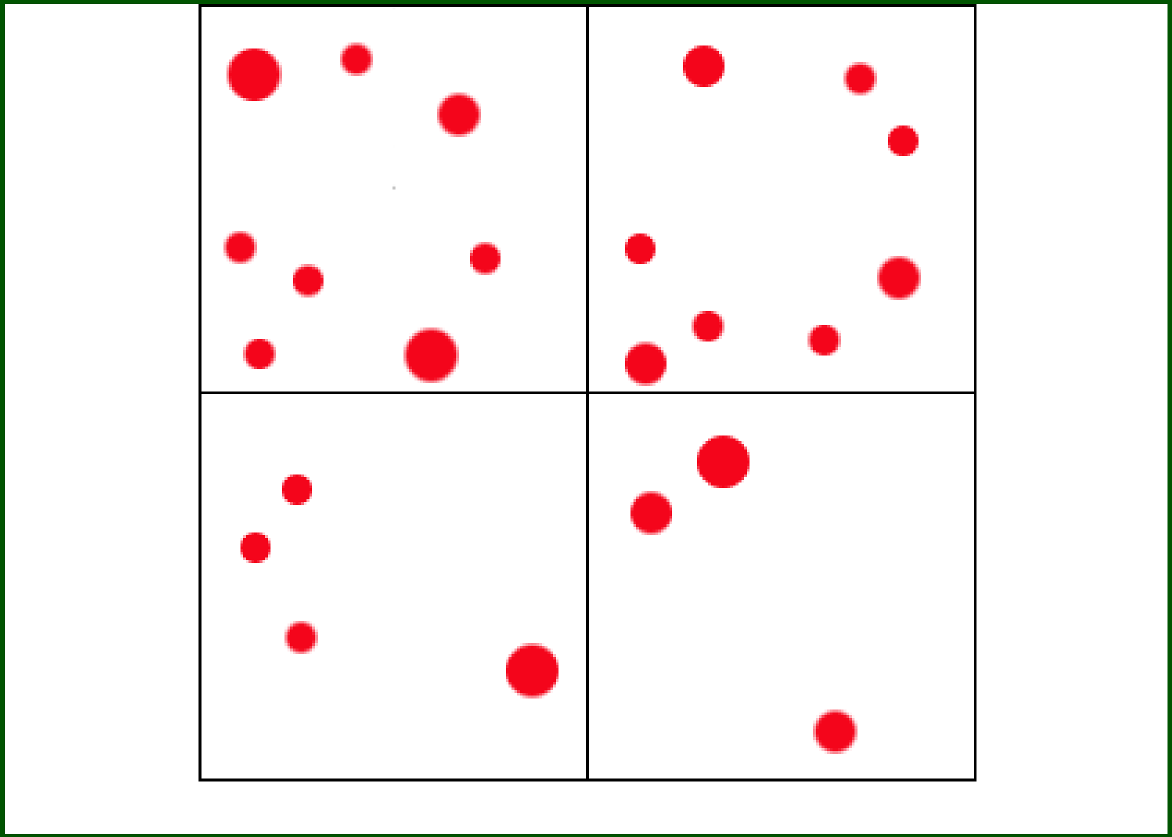
Effect of Paramterisation

Of course, this has no effect if the grid box is large enough:



Stochastic Parameterisation

But for a smaller gridbox ...



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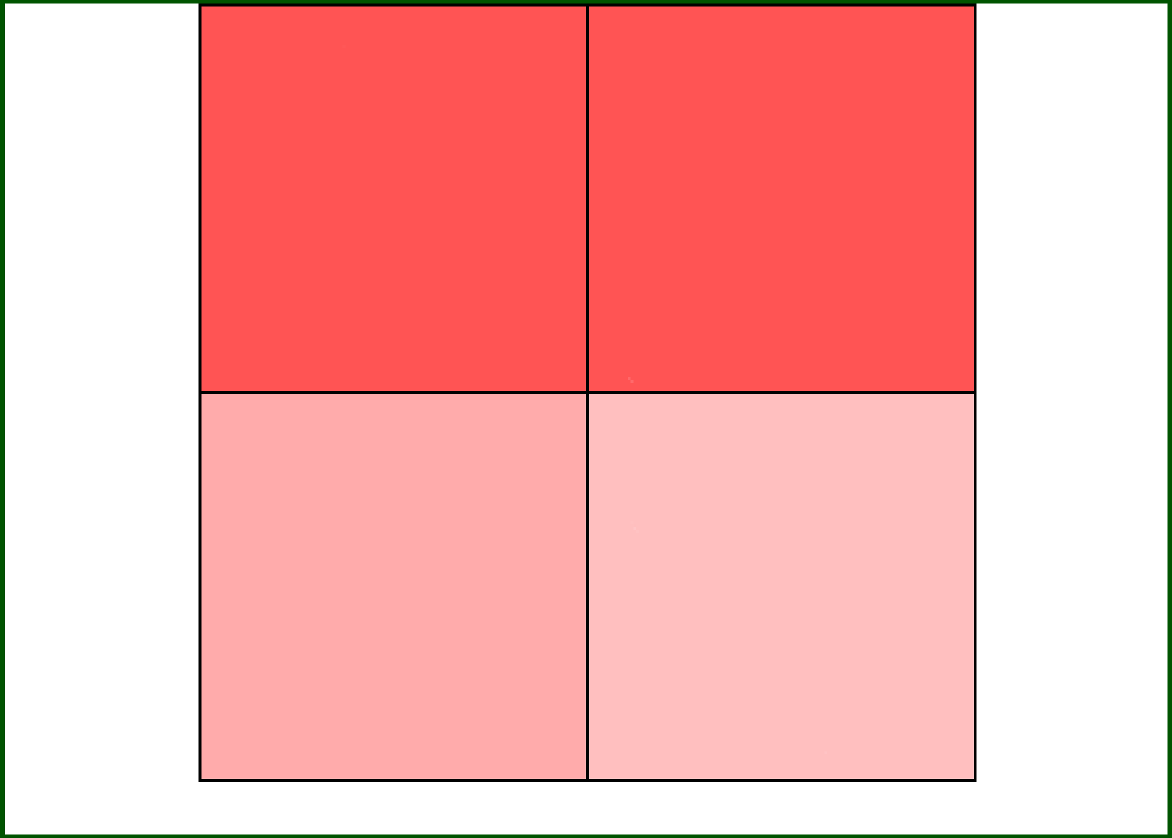
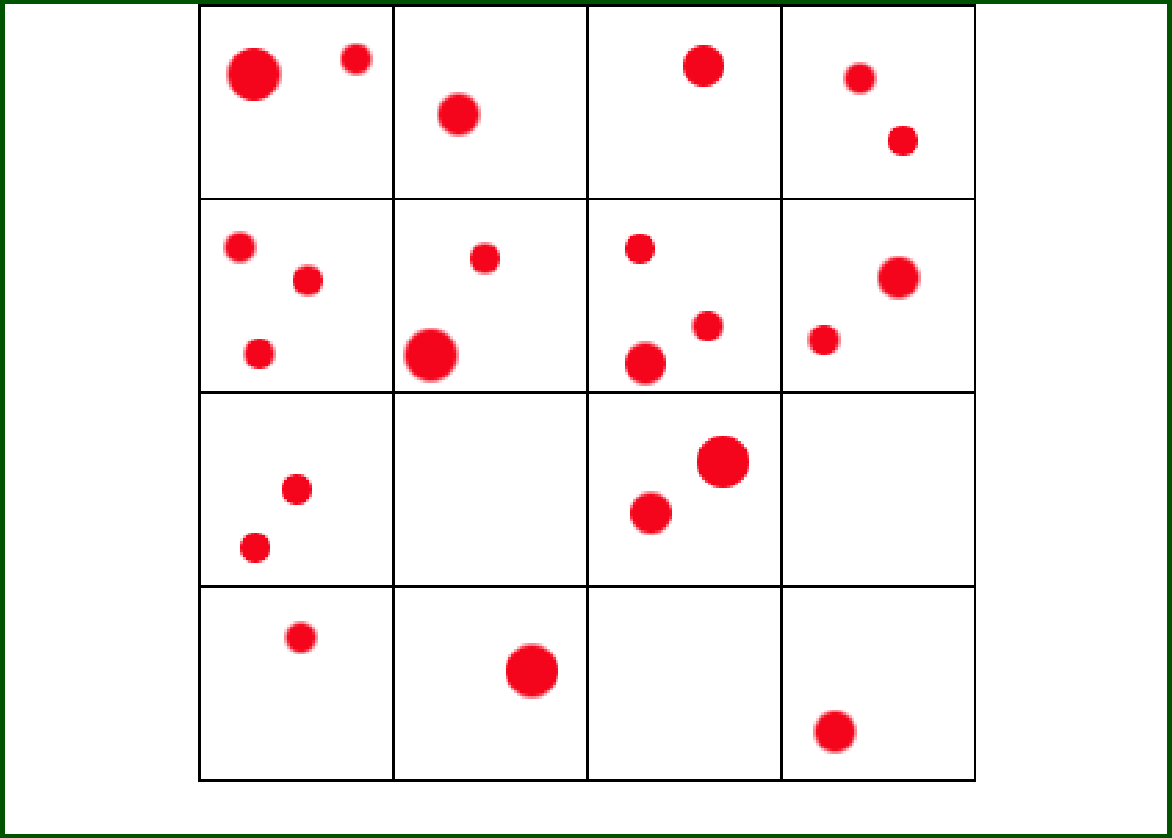
Effect of Paramterisation

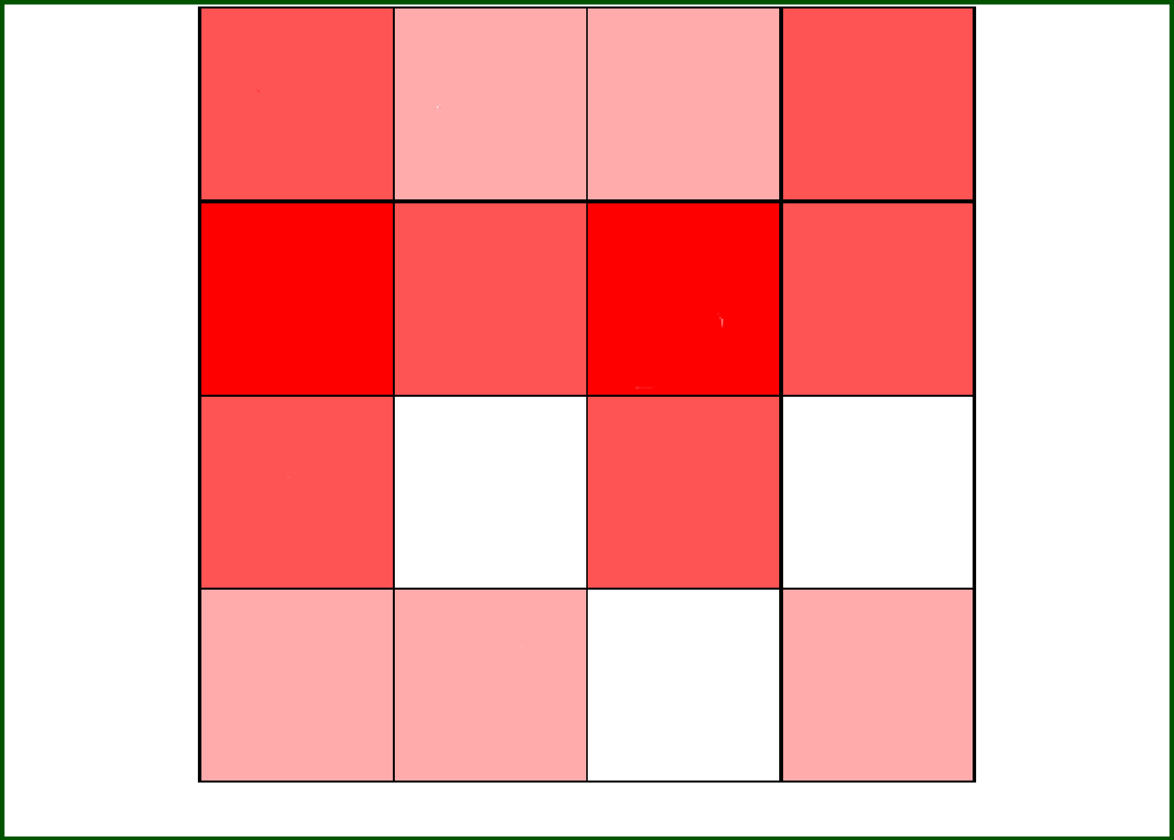
The scheme allows some convective variability:



Stochastic Parameterisation

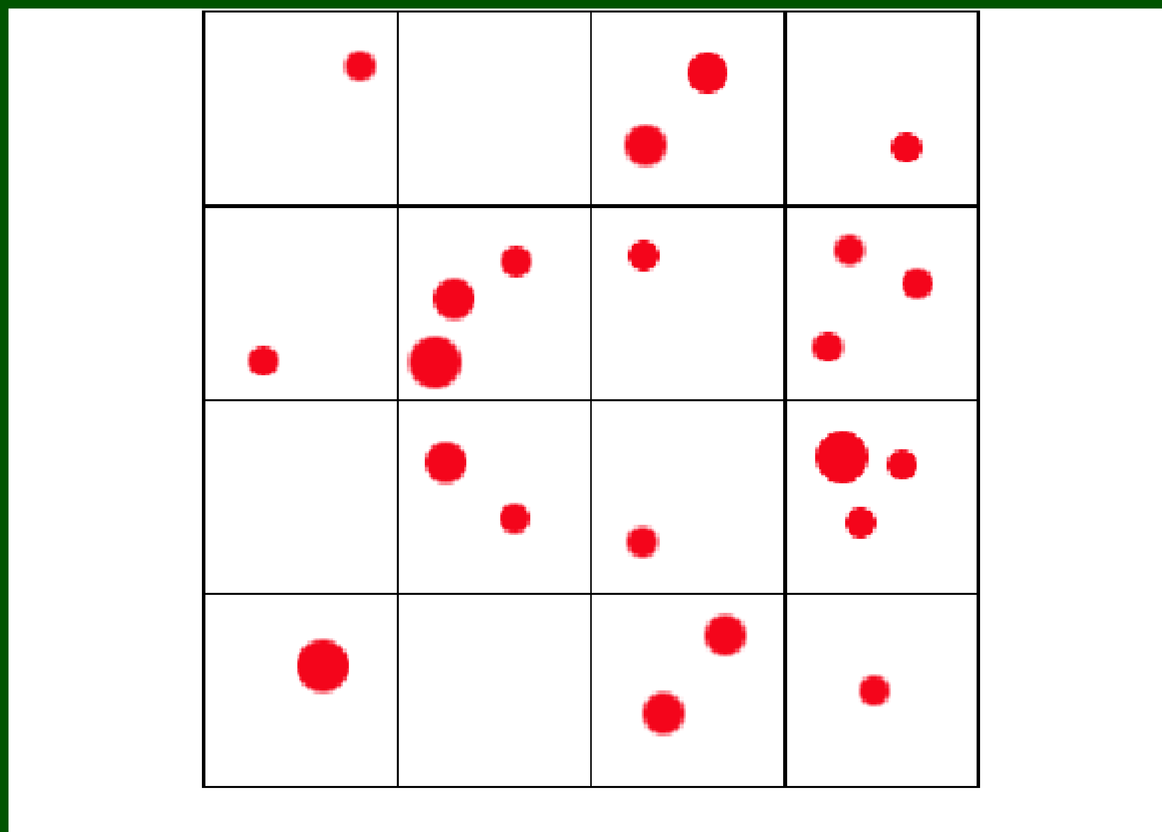


Effect of Paramterisation



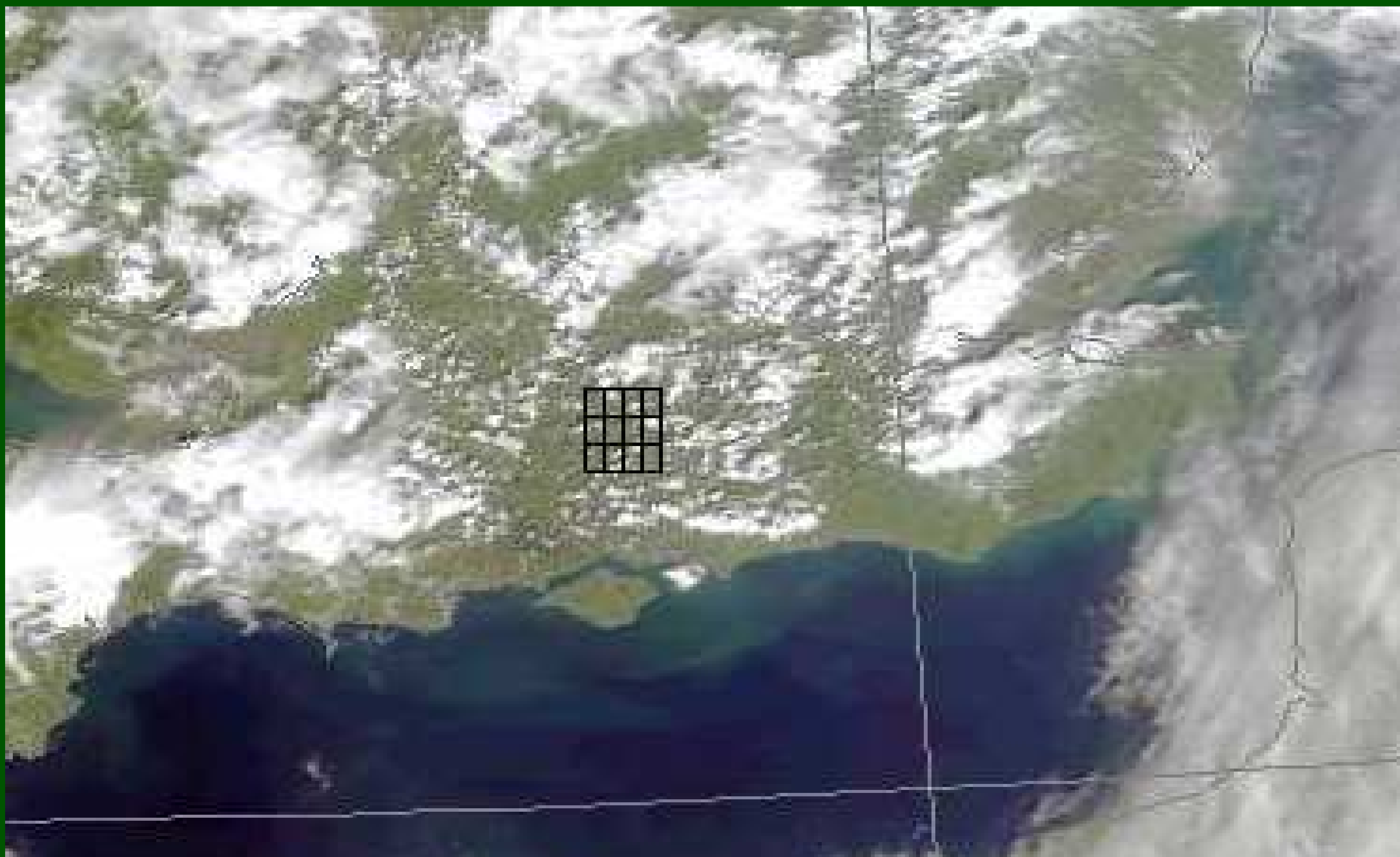
The real world

The distribution will be different in reality, but the *variability* will be similar.



Satellite image example

NERC SRS, Dundee, 15/06/09 13:32.



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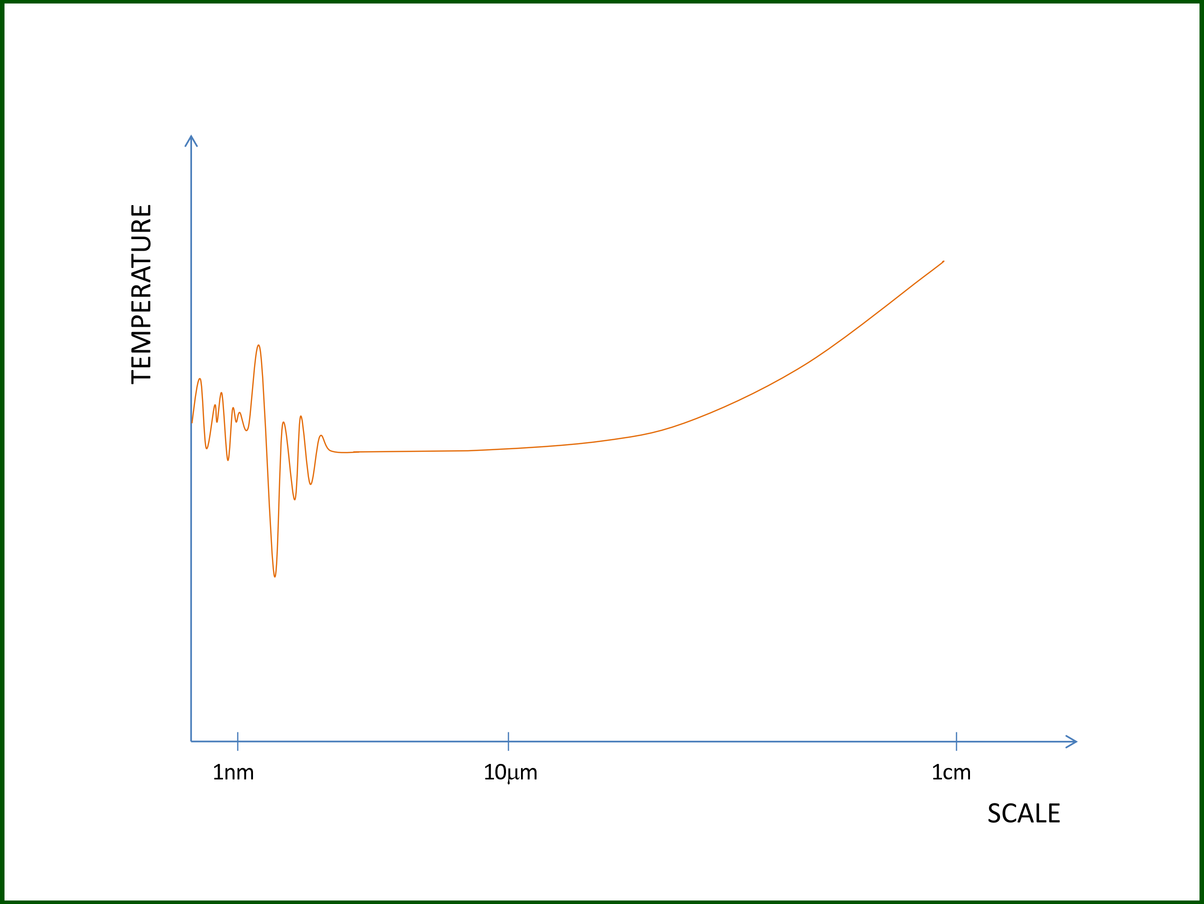
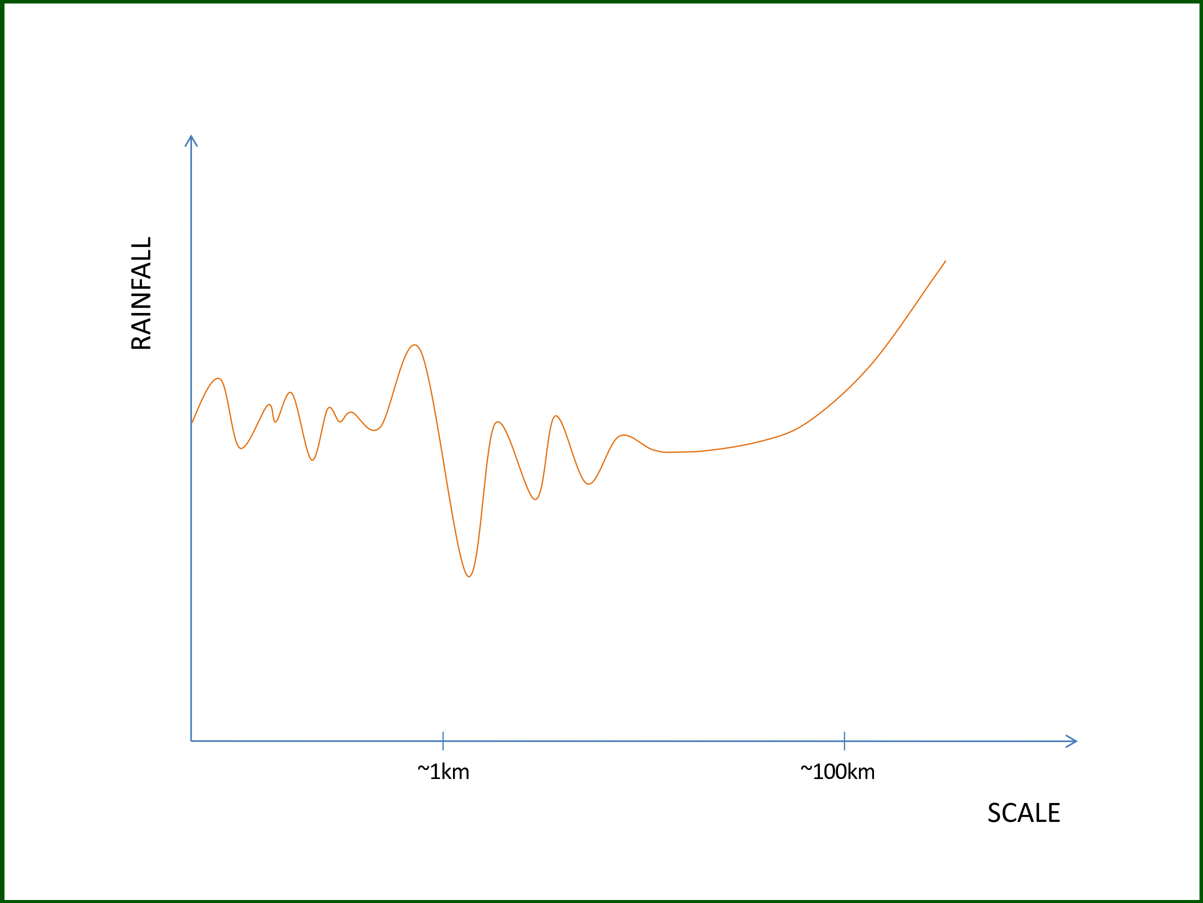
Scale separation: thermodynam-ics



Scale separation: rainfall



Convection parameterisation schemes

- Trigger function
- Mass-flux plume model
- Closure
- Examples
  - Gregory Rowntree (UM standard)
  - Kain Fritsch
  - Plant Craig (based on Kain Fritsch)

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Plant Craig scheme: Analogies

Statistical Mechanics	**Convection**
Particle	Cloud
Energy per particle	Mass flux per cloud m
Number of particles	Number of clouds N
Ensemble average energy	Ensemble average mass flux $\langle M \rangle$
Temperature	Ensemble mean mass flux per cloud $\langle m \rangle$
Entropy	Ensemble mean number of clouds $\langle N \rangle$

Plant Craig 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 (Cohen-Craig theory).
- Draw randomly from this distribution to obtain cumulus properties in each grid box.
- Compute tendencies of grid-scale variables from the cumulus properties.

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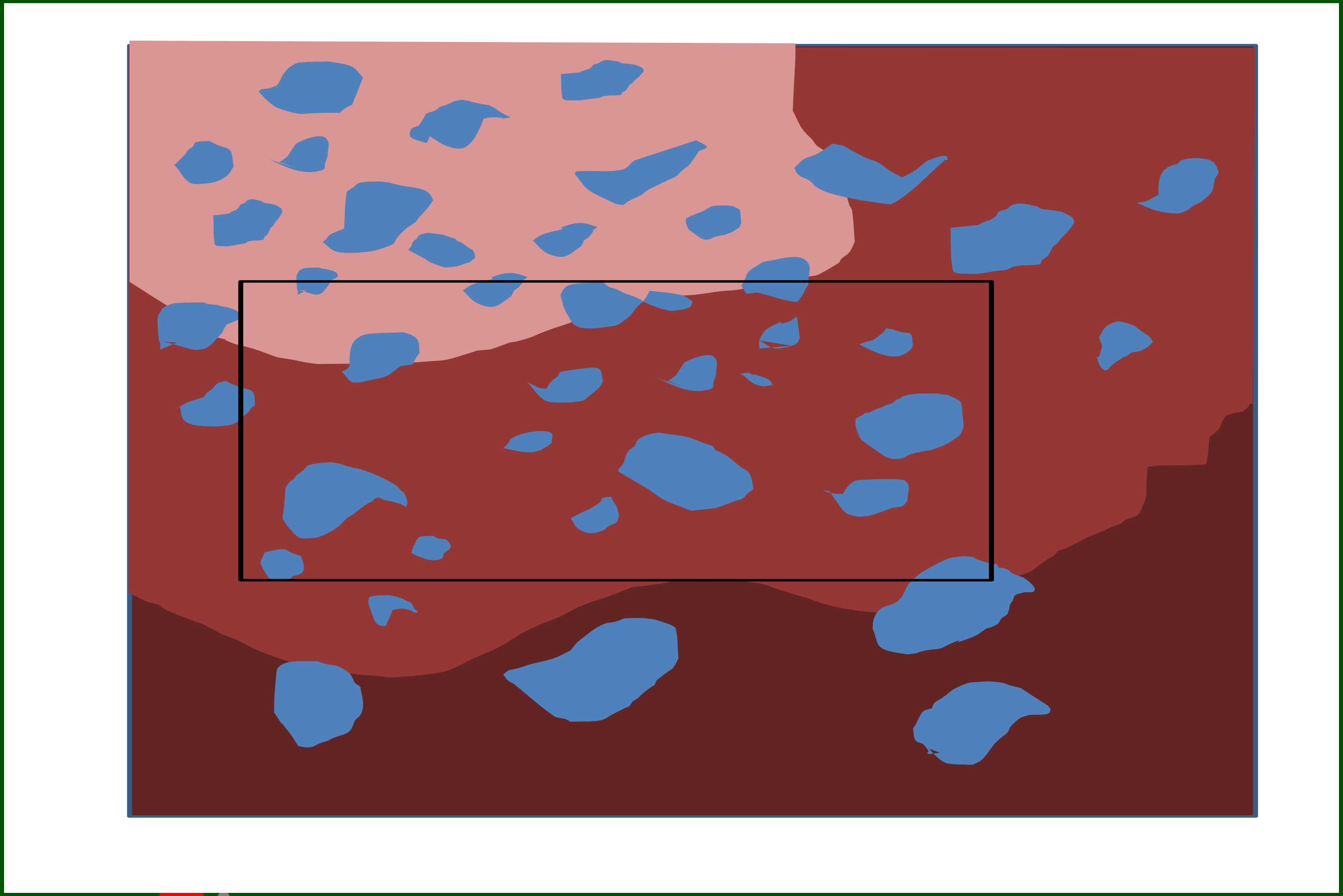
Plant Craig scheme: Averaging area



Plant Craig scheme: Probability distribution

Assuming a statistical equilibrium leads to an exponential distribution of mass fluxes per cloud:

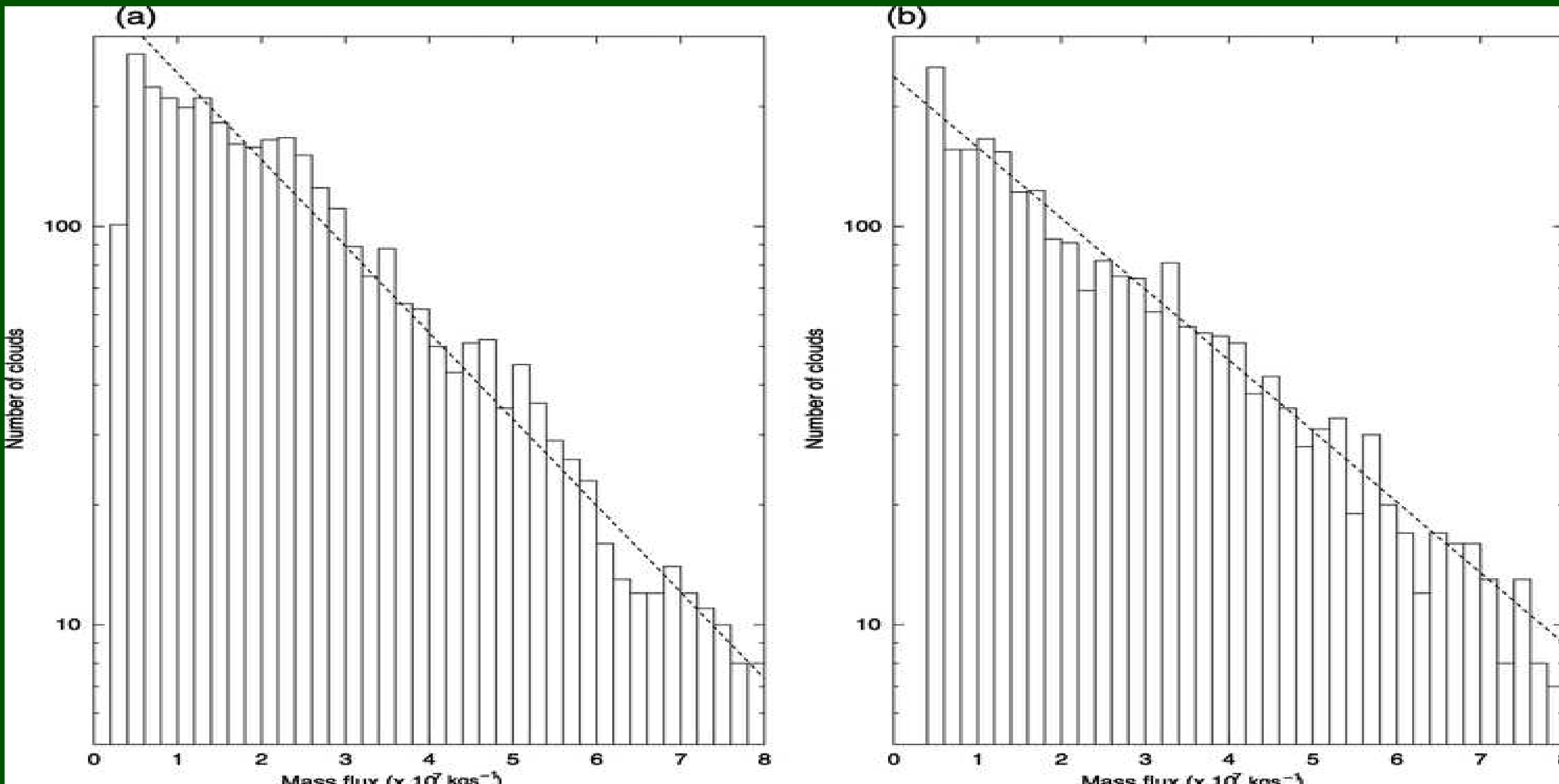
$$p(m)\mathrm{d}m = \frac{1}{\langle m \rangle} \exp\left(\frac{-m}{\langle m \rangle}\right) \mathrm{d}m.$$

So if $m \sim r^2$ then the probability of initiating a plume of radius r in a timestep $\mathrm{d}t$ is

$$\frac{\langle M \rangle 2r}{\langle m \rangle \langle r^2 \rangle} \exp\left(\frac{-r^2}{\langle r^2 \rangle}\right) \mathrm{d}r \frac{\mathrm{d}t}{T}.$$

Exponential distribution in a CRM

Cohen, PhD thesis (2001)



Ensemble Forecasting & Stochastic Paramterisation

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PDF of total mass flux

Assuming that clouds are non-interacting, $p(m)$ can be combined with a Poisson distribution for cloud number,

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

leading to the following distribution for total mass flux:

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

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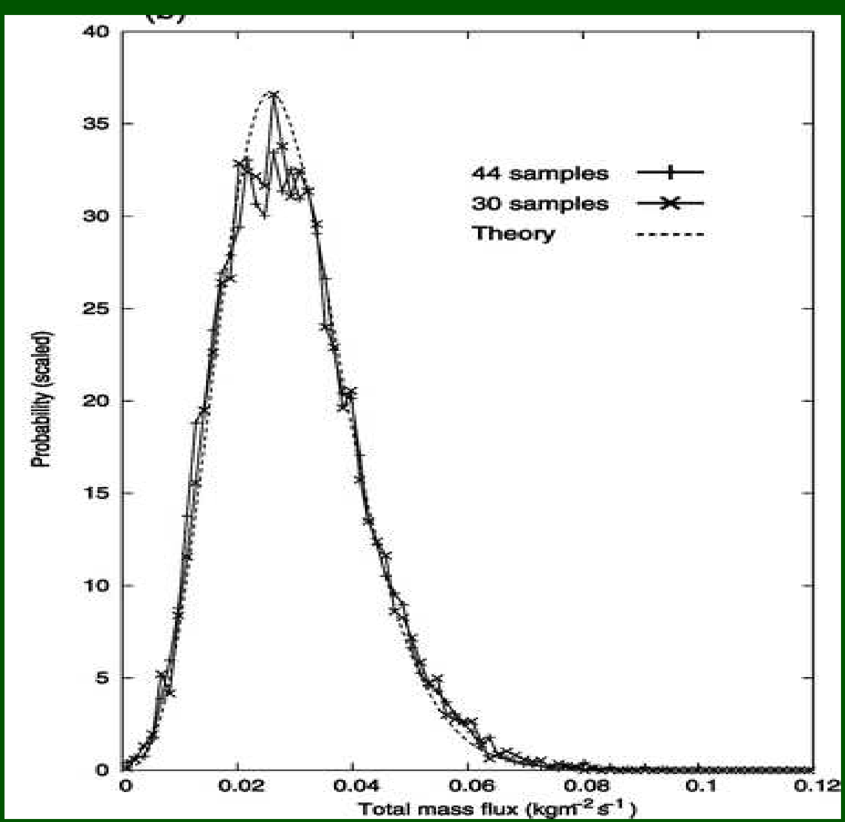
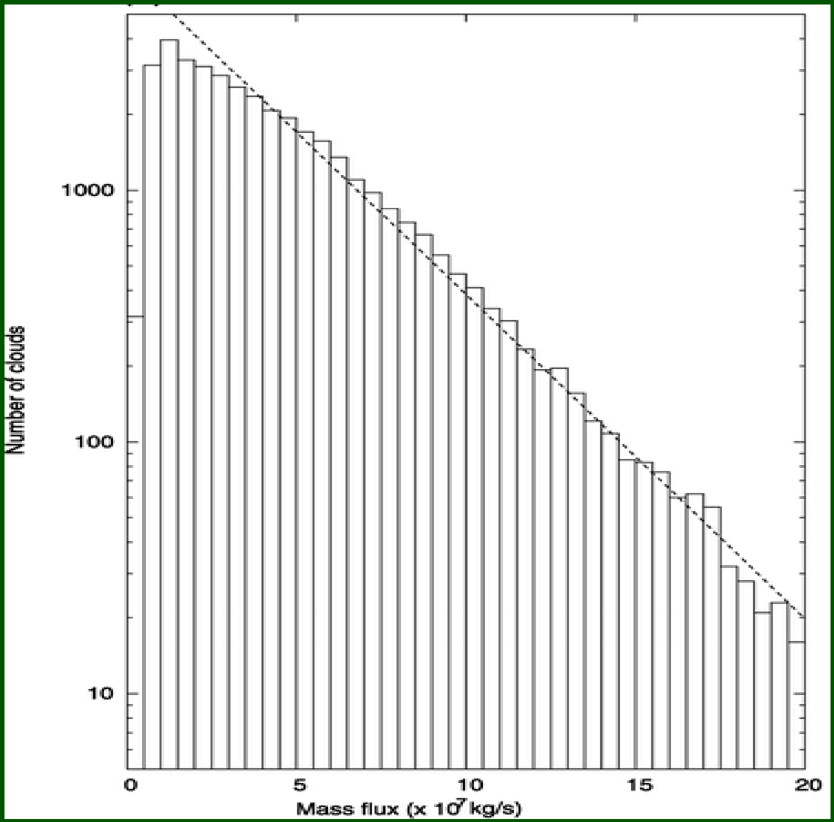
PDFs of mass flux in an SCM



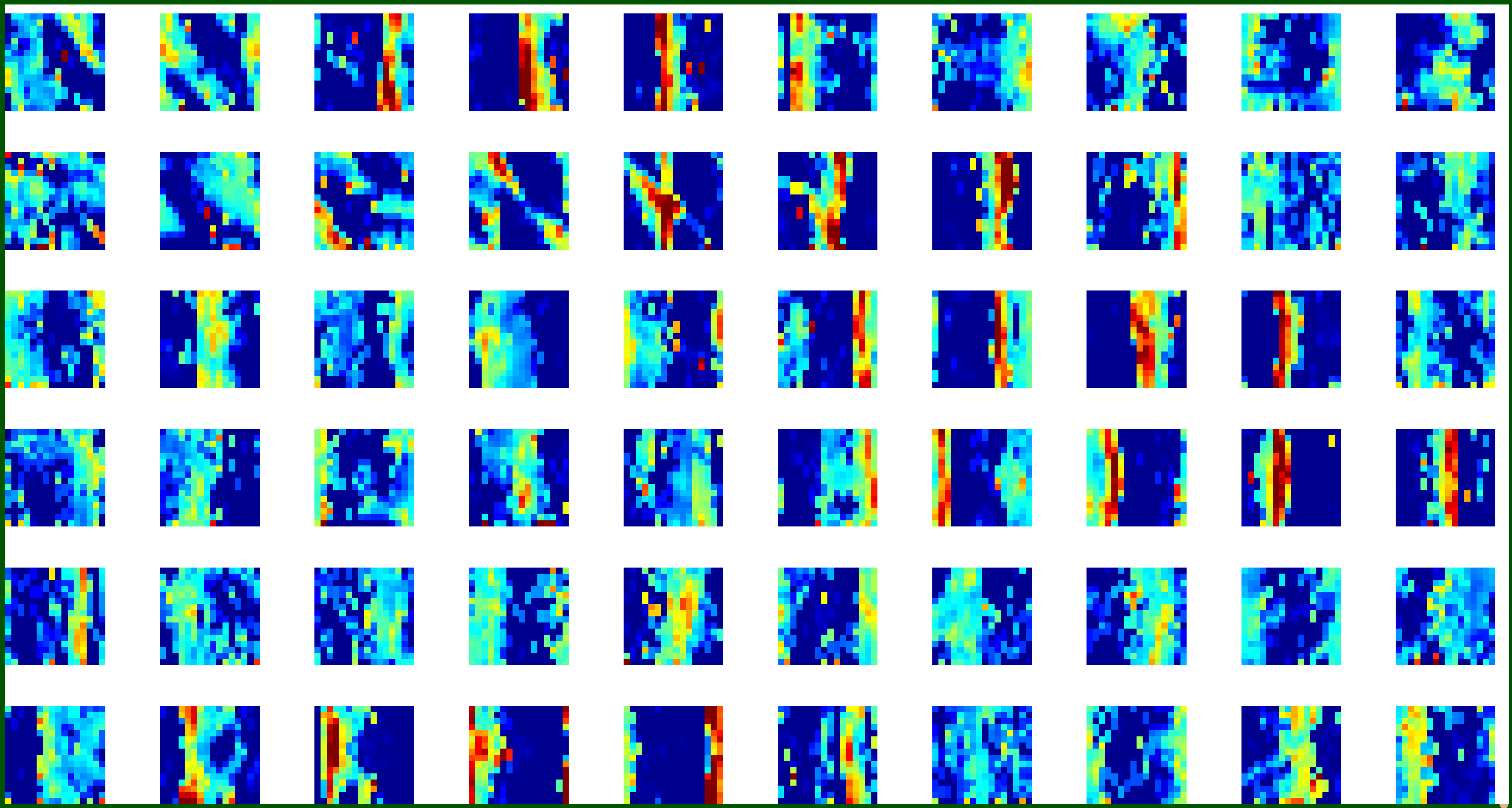


- Plant & Craig, JAS, 2008

3D Idealised UM setup

- 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.
- Targeted diffusion of moisture is applied.
- The grid size is 32 km.

Rainfall snapshots: Gregory Rowntree scheme



animation

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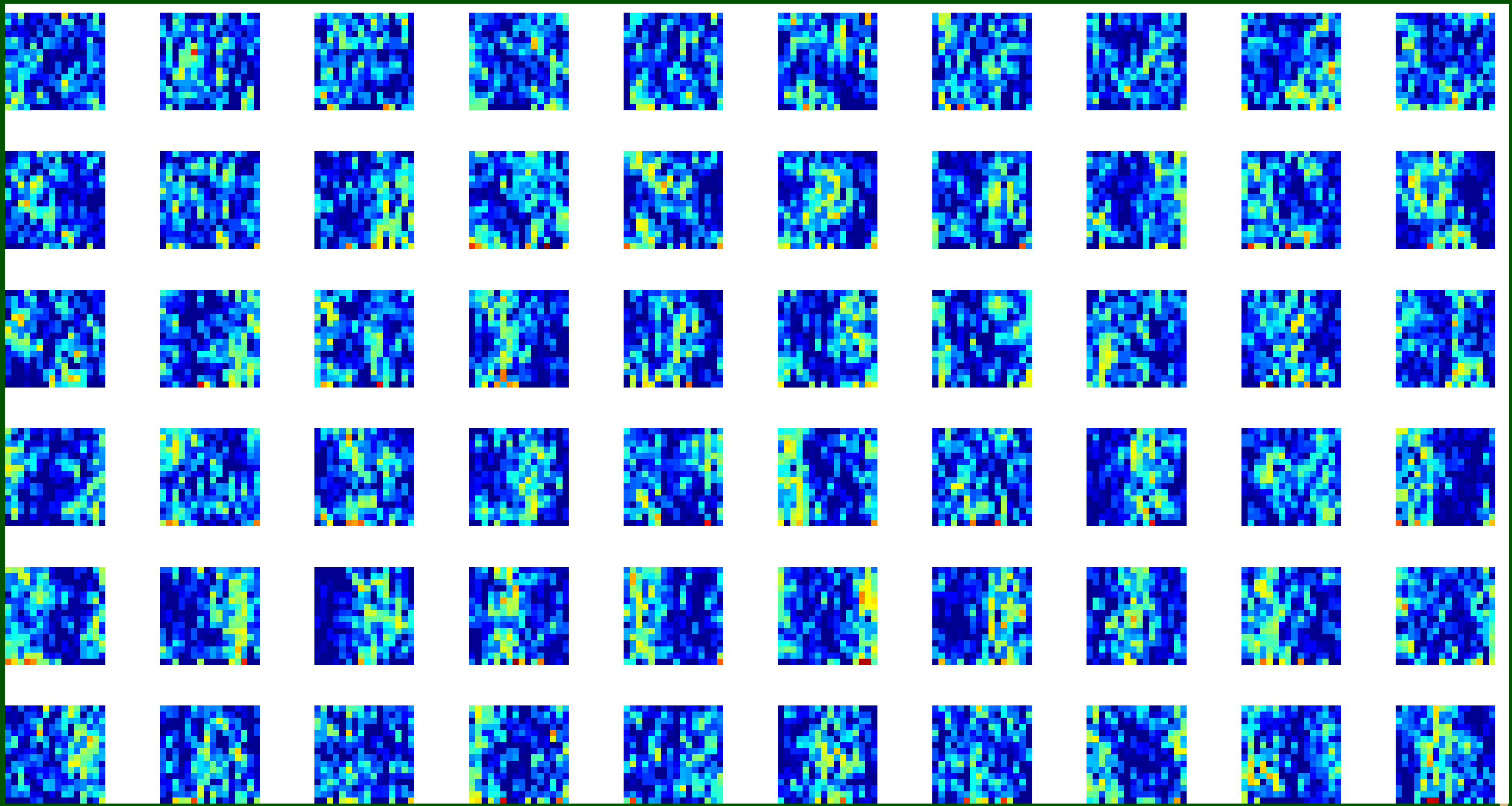
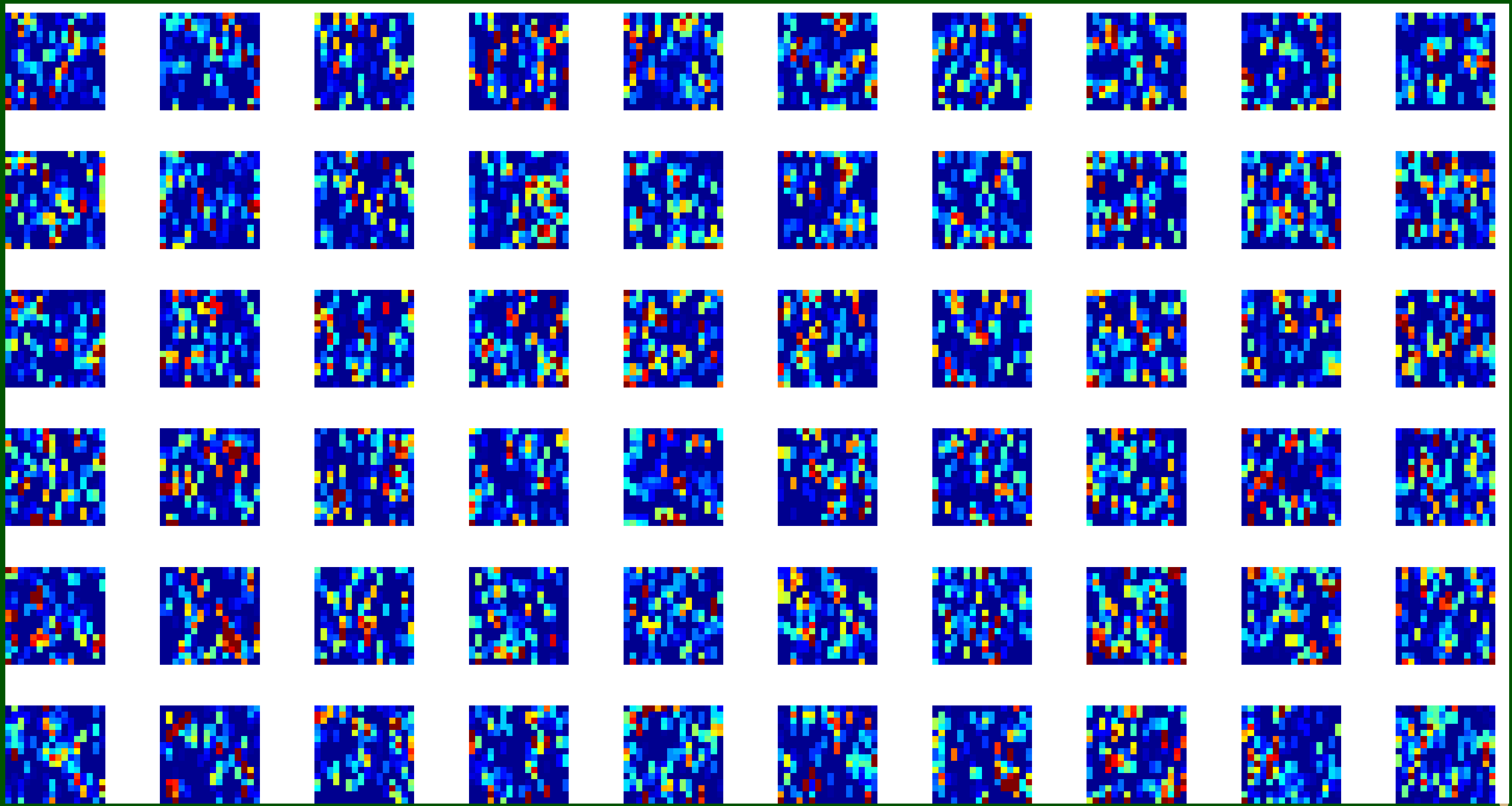
Rainfall snapshots: Kain Fritsch scheme



animation

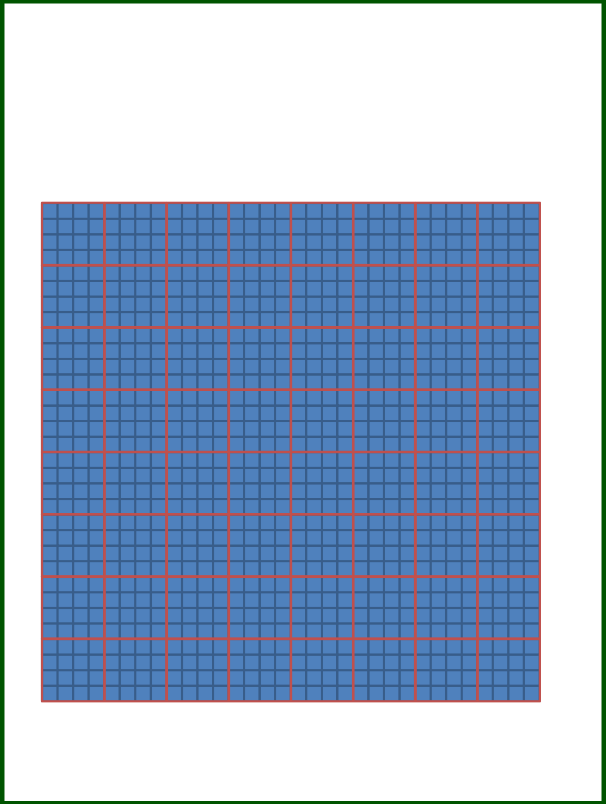
Rainfall snapshots: Plant Craig scheme



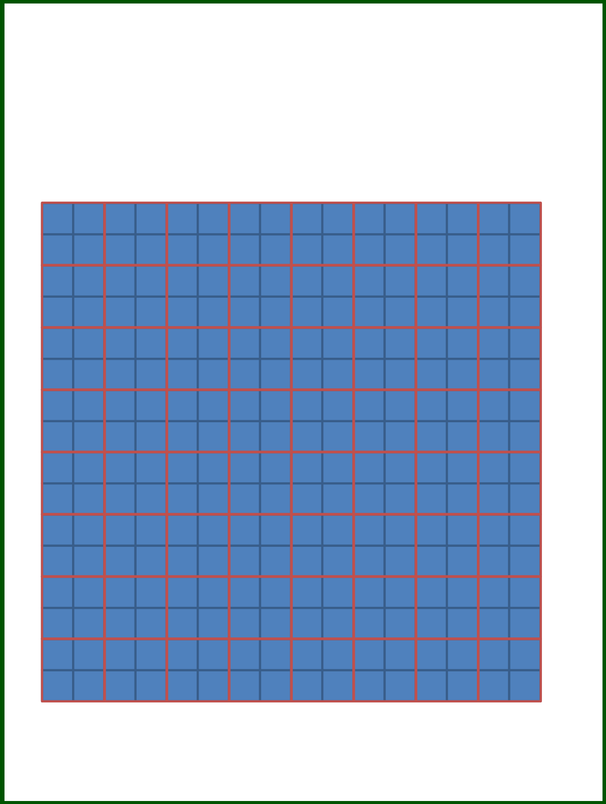
animation

Model grid division

16km



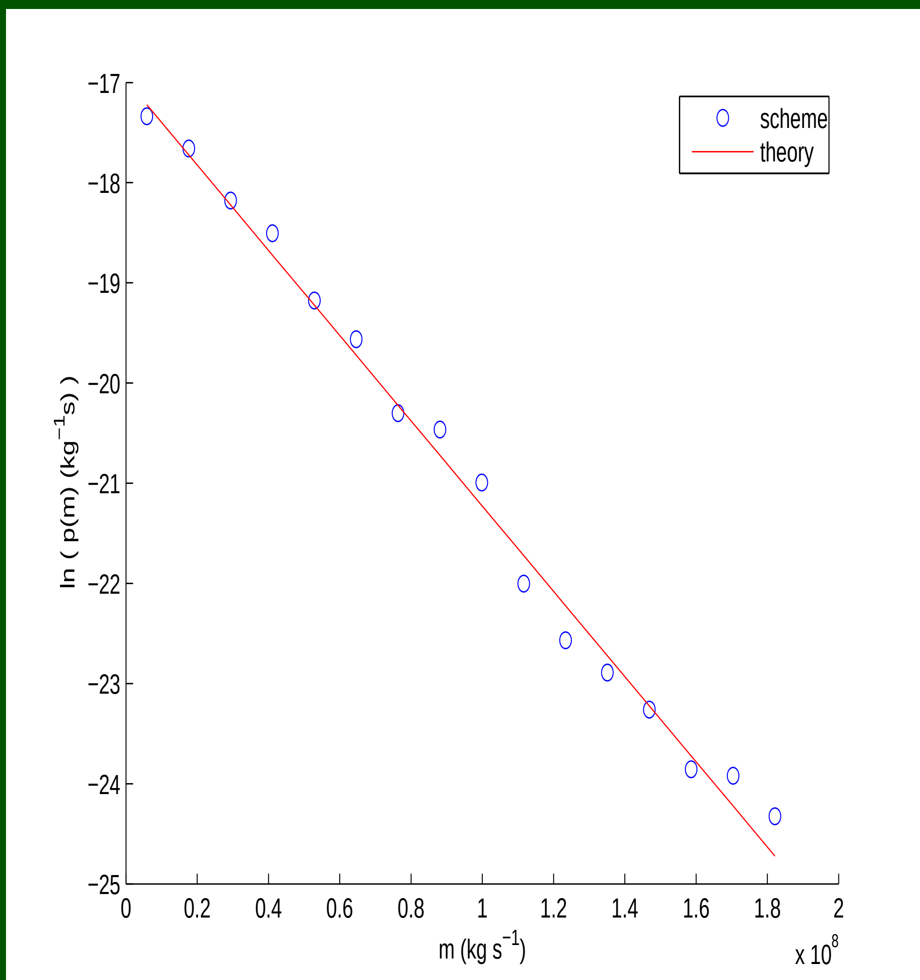
32km

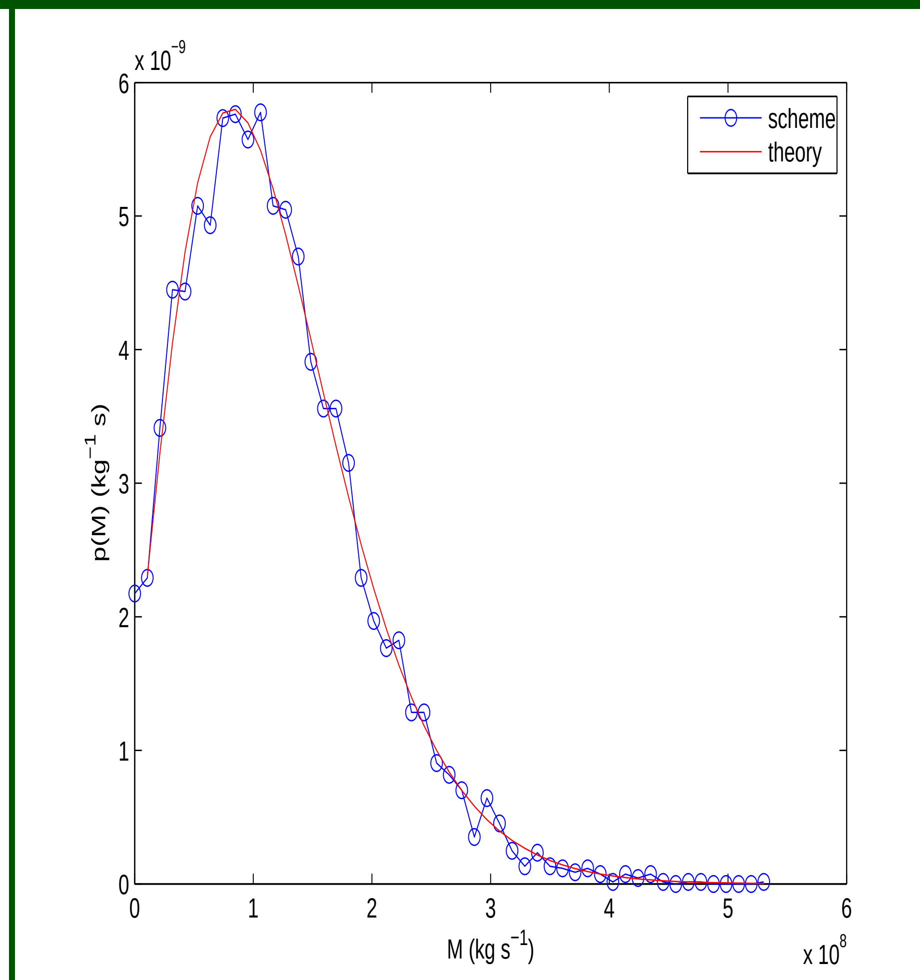


PDFs of m and M for maximum averaging

Averaging area: $480\,\mathrm{km}$ square.

Averaging time: 1 hour.





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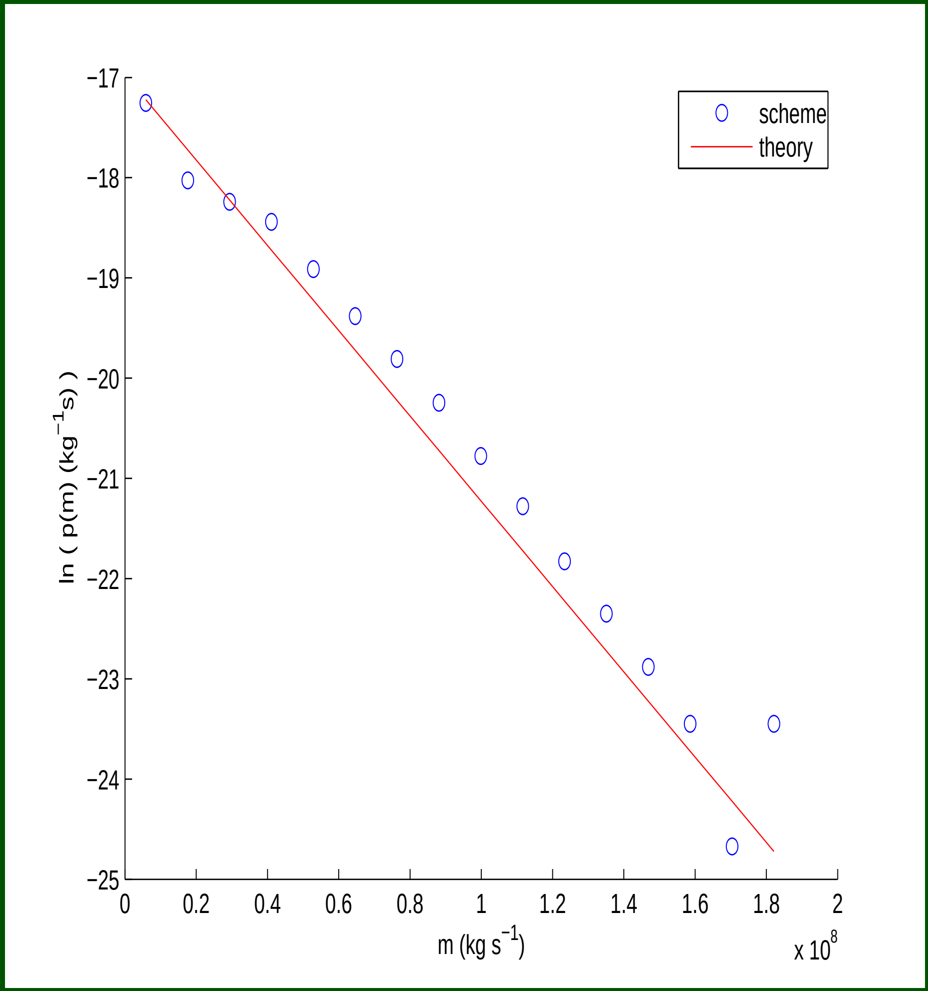
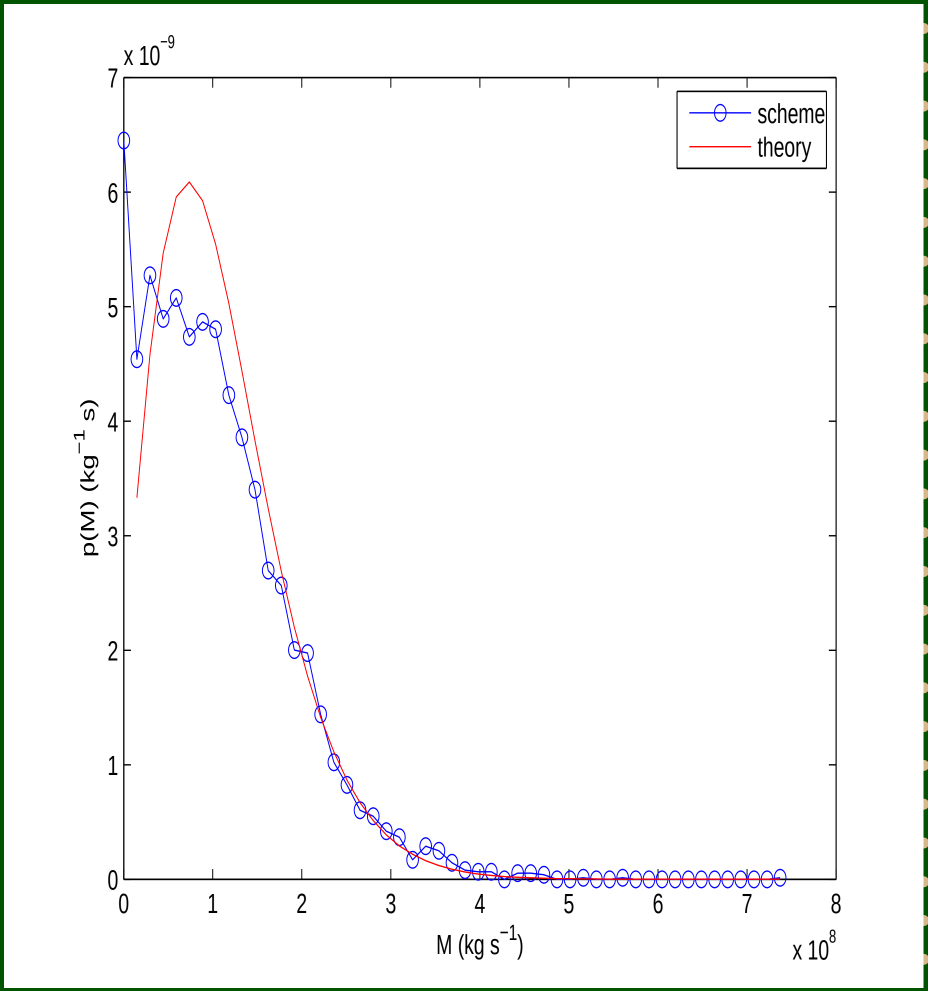
PDFs of m and M for no averaging





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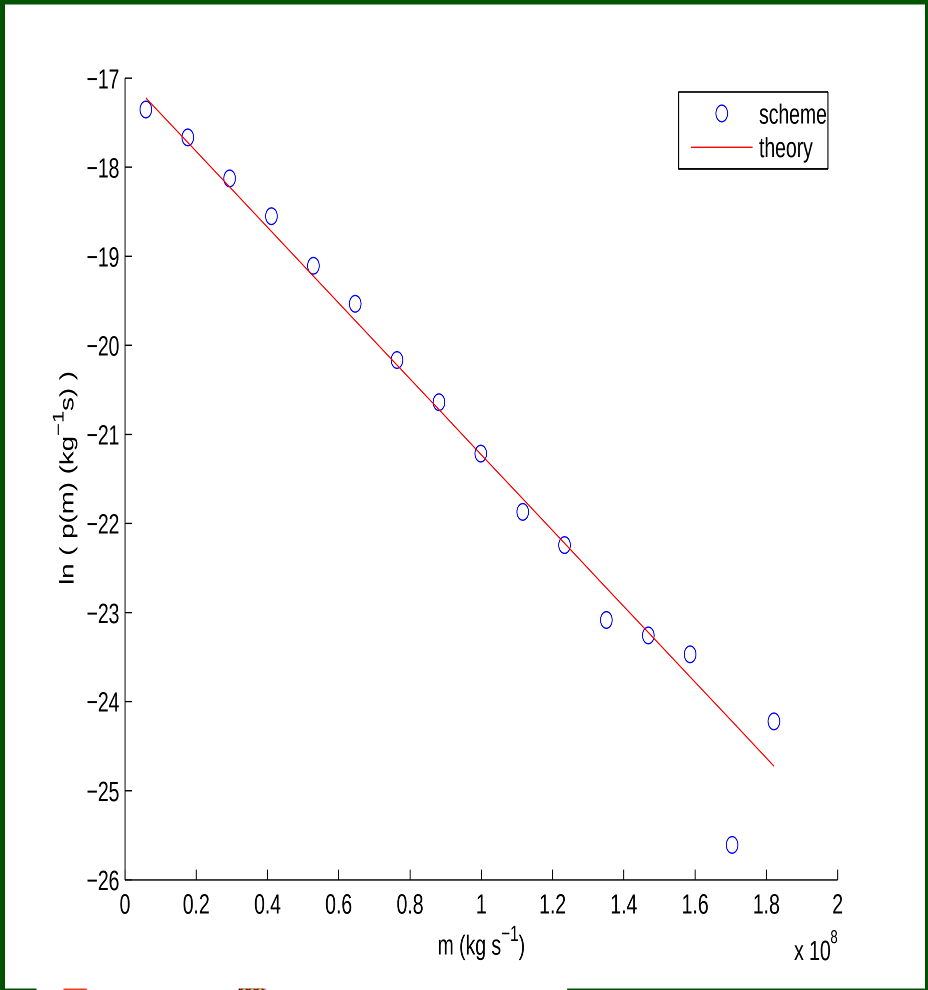
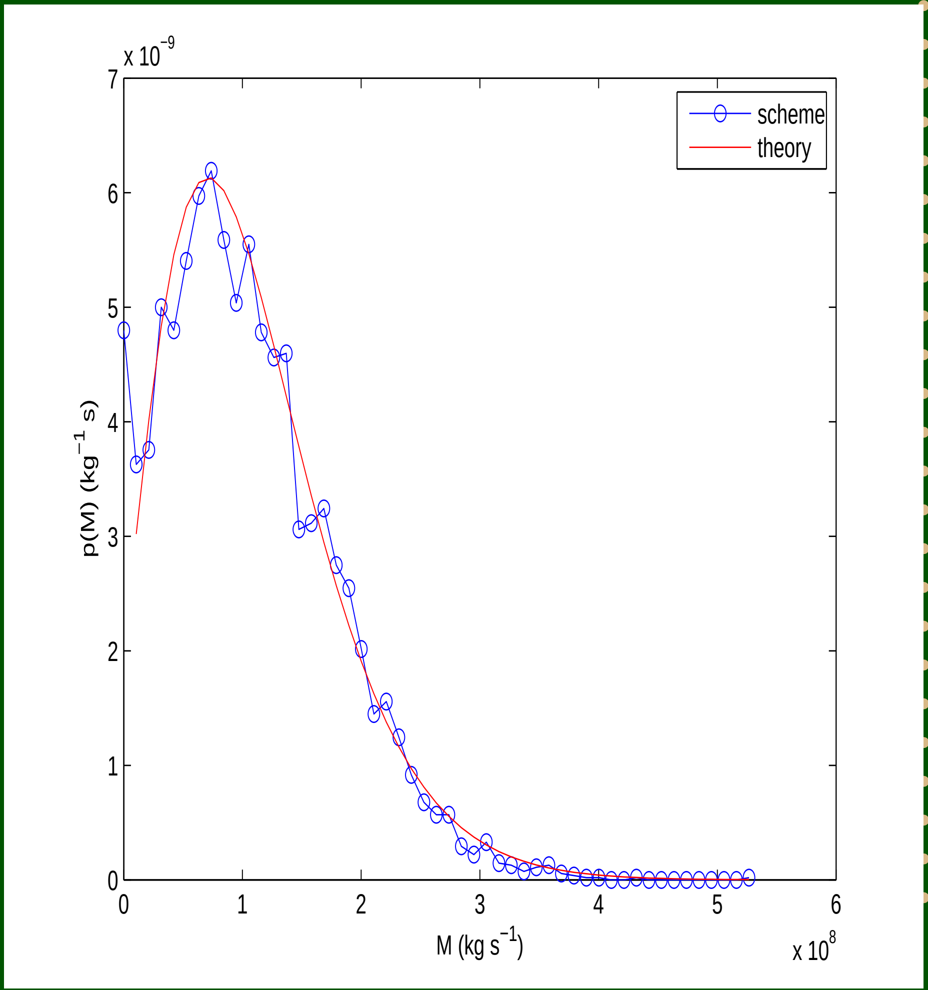
PDFs of m and M for intermediate averaging

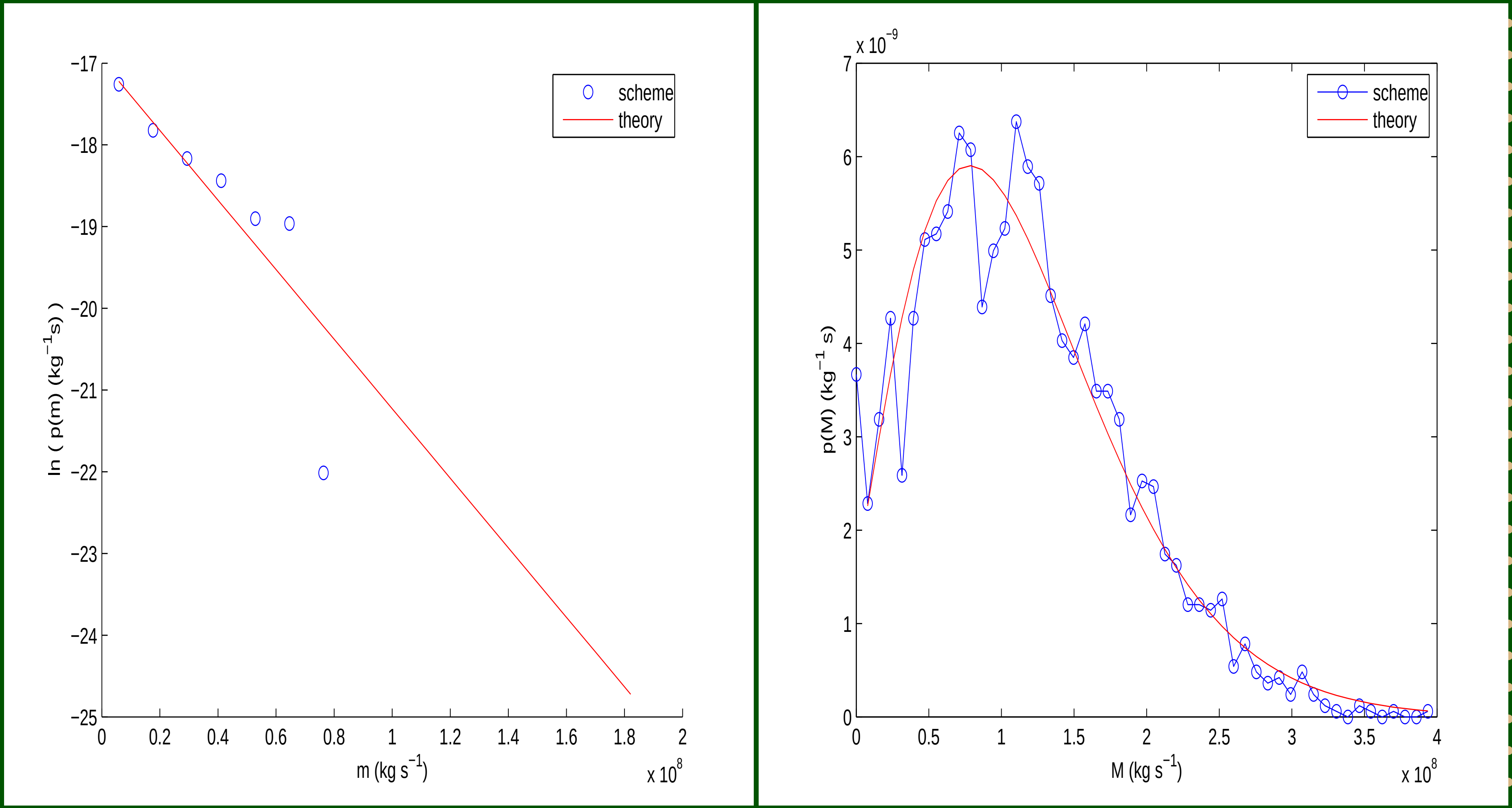
Averaging area: $160\,\mathrm{km}$ square.

Averaging time: 1 hour.

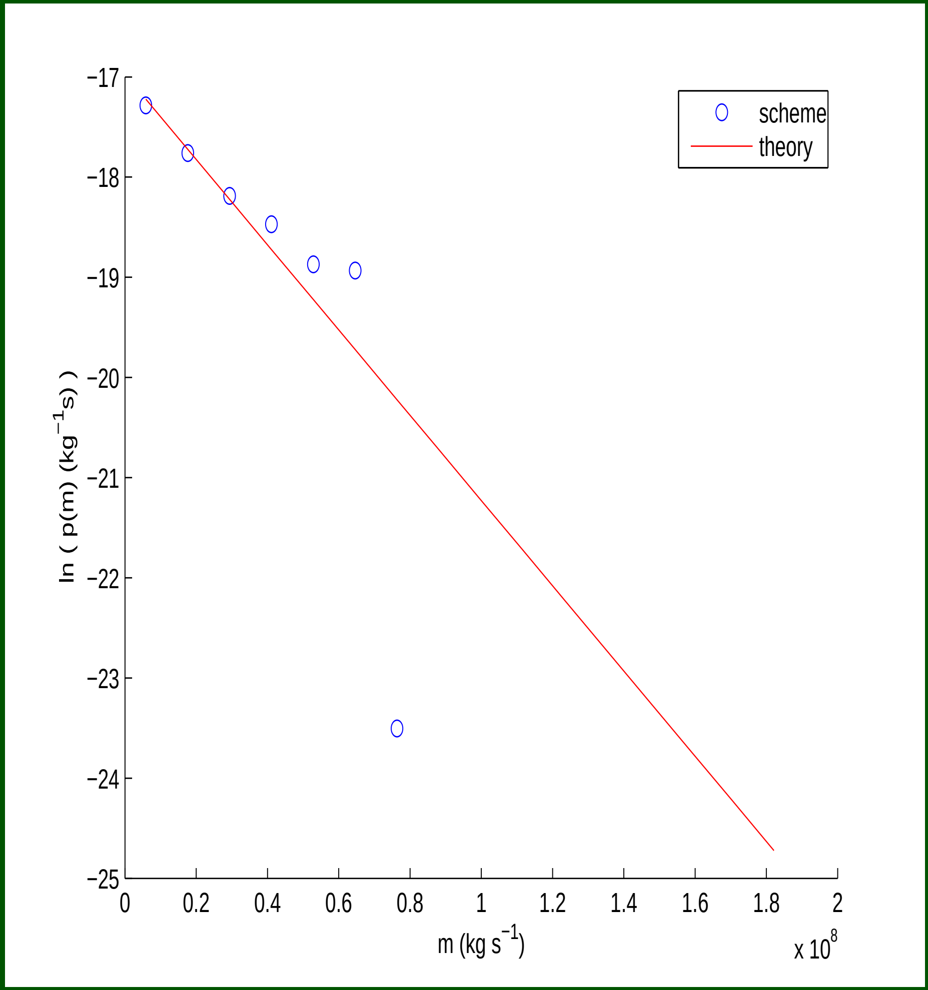


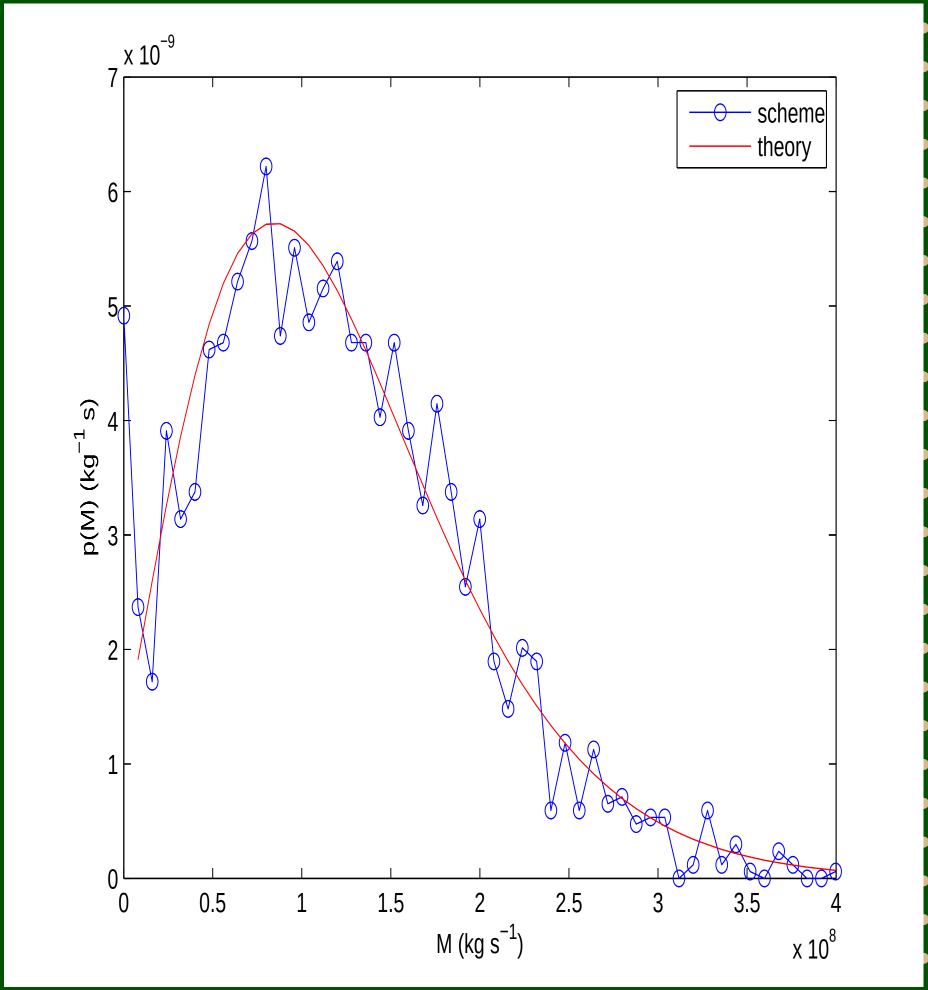


PDFs of m and M for 16 km (no averaging)



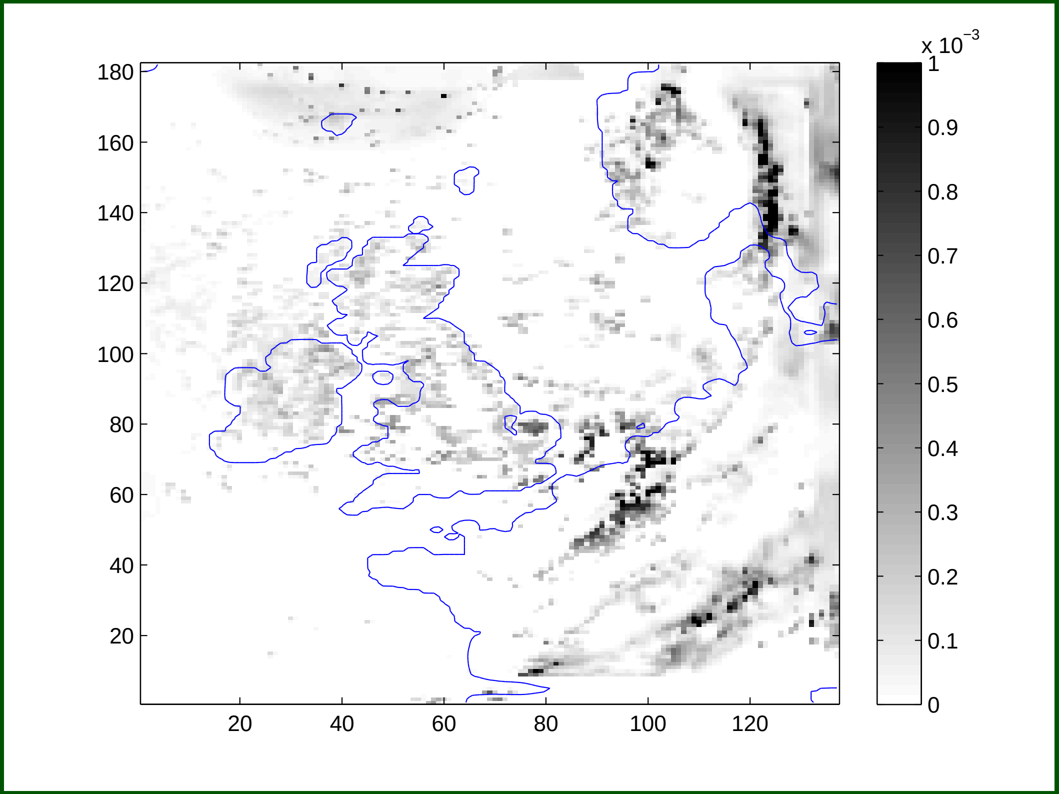
PDFs of m and M for 16 km (intermediate averaging)



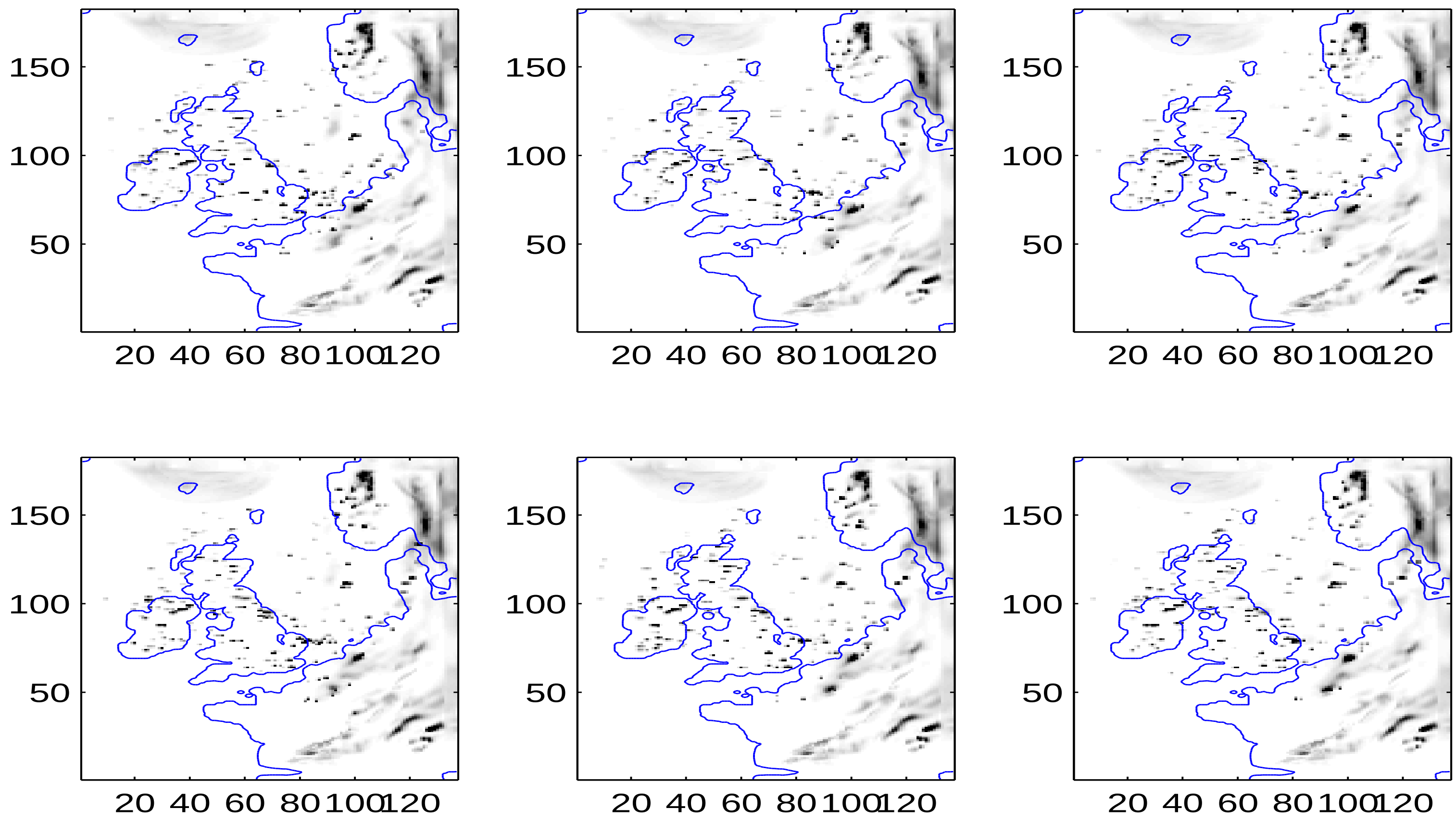


Case study: CSIP IOP18

- Starts at 25th August 2005, 07:00.
- 12 km grid with 146×182 grid points.

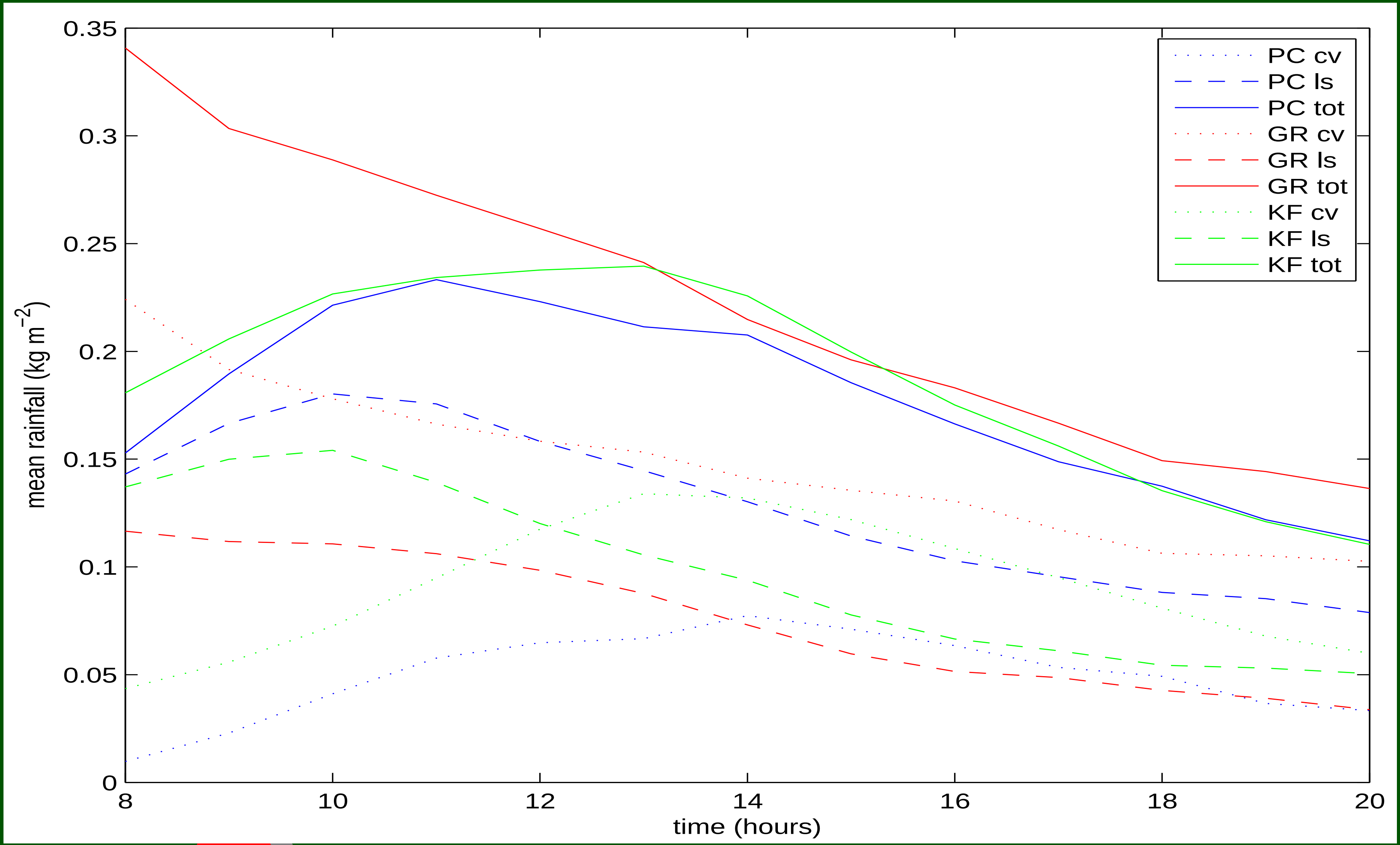


Ensemble of 6 runs using PC scheme



Development of a stochastic convection scheme – p.42/45

Rainfall against time for each of three schemes



Future work

- Implement the PC scheme in MOGREPS, to determine its impact on variability.
- Run on NAE domain (~ 20 km), for one Summer month.
- Compare with existing GR run and deterministic version of PC.
- Look at the effect of the scheme, and its stochastic nature, on the variability of the ensemble and the spread-error relationship.

Conclusions

- The convective variability in the scheme is according to the Cohen Craig theory, and is not due to spurious noise from the large-scale.
- An averaging area of roughly 160 km is required to effect this.
- The statistical behaviour of the scheme is correct at different resolutions, although the amount of averaging required may vary.
- The scheme behaves sensibly in a mesoscale setup, and is ready to be implemented in an ensemble prediction system.