Development of a stochastic convection scheme

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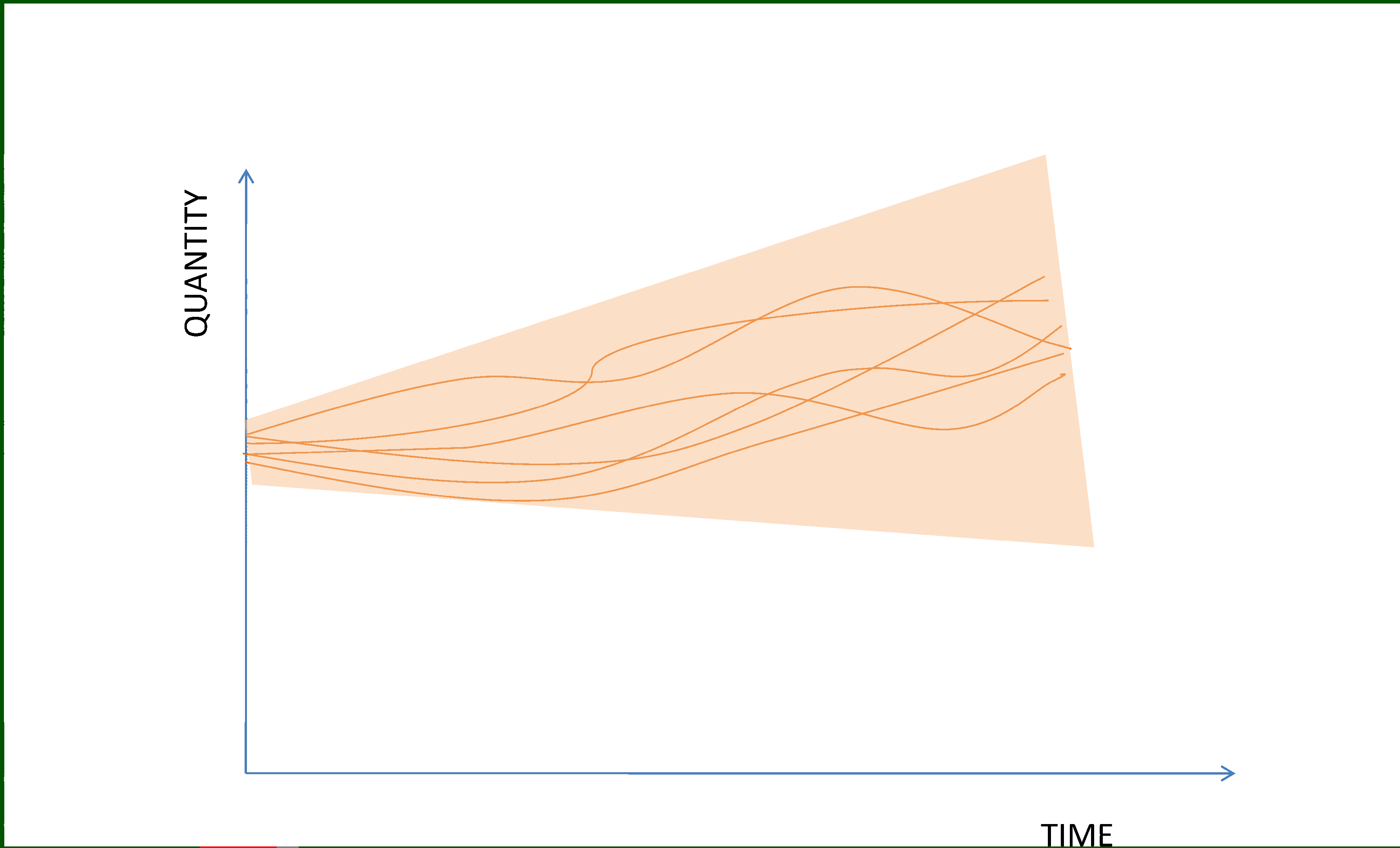
Outline

- 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.

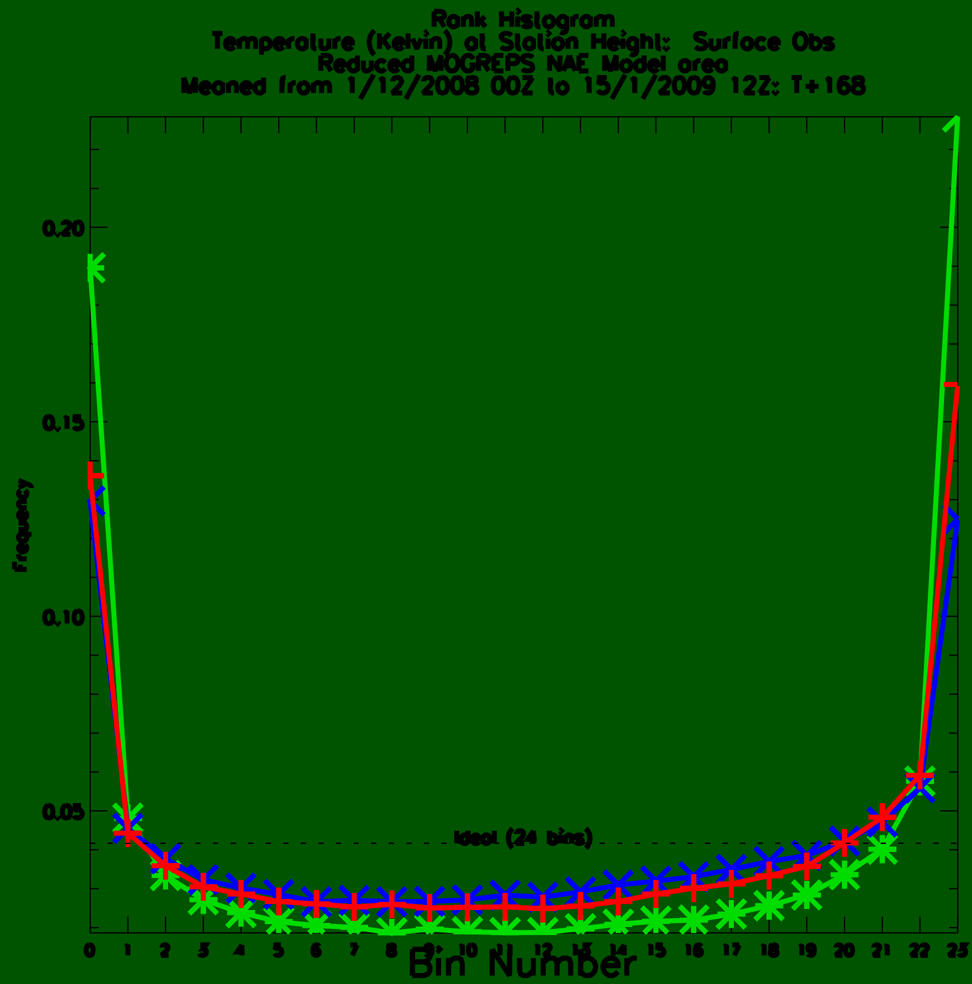
Ensemble Forecasting & Stochastic Paramterisation

- 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:
  $\dot{\mathbf{E}}_j(\mathbf{X}, t) = \mathbf{A}(\mathbf{E}_j, \mathbf{X}, t) + \mathbf{P}(\mathbf{E}_j);$
  $\mathbf{E}_j(\mathbf{X}, 0) = \mathbf{I}(\mathbf{X}) + \mathbf{D}_j(\mathbf{X})$
- 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: better forecast of variability

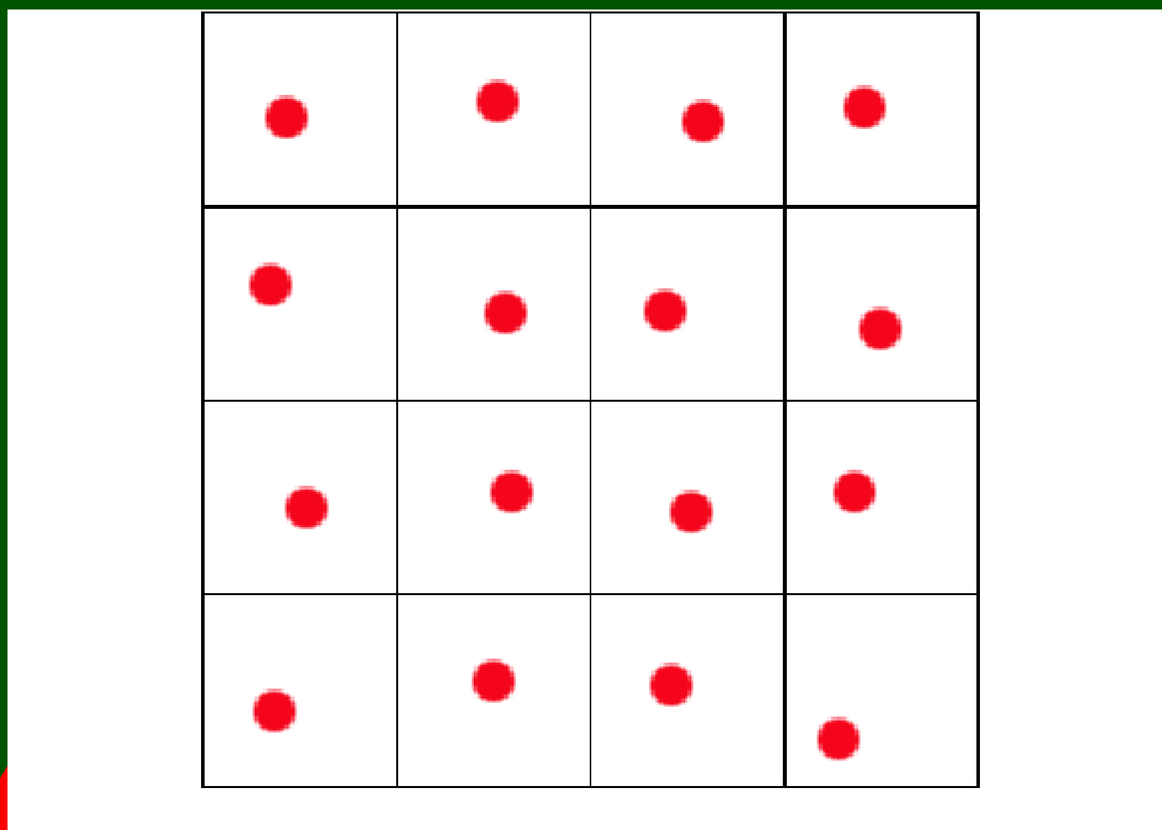


Rank Histograms of surface temperature



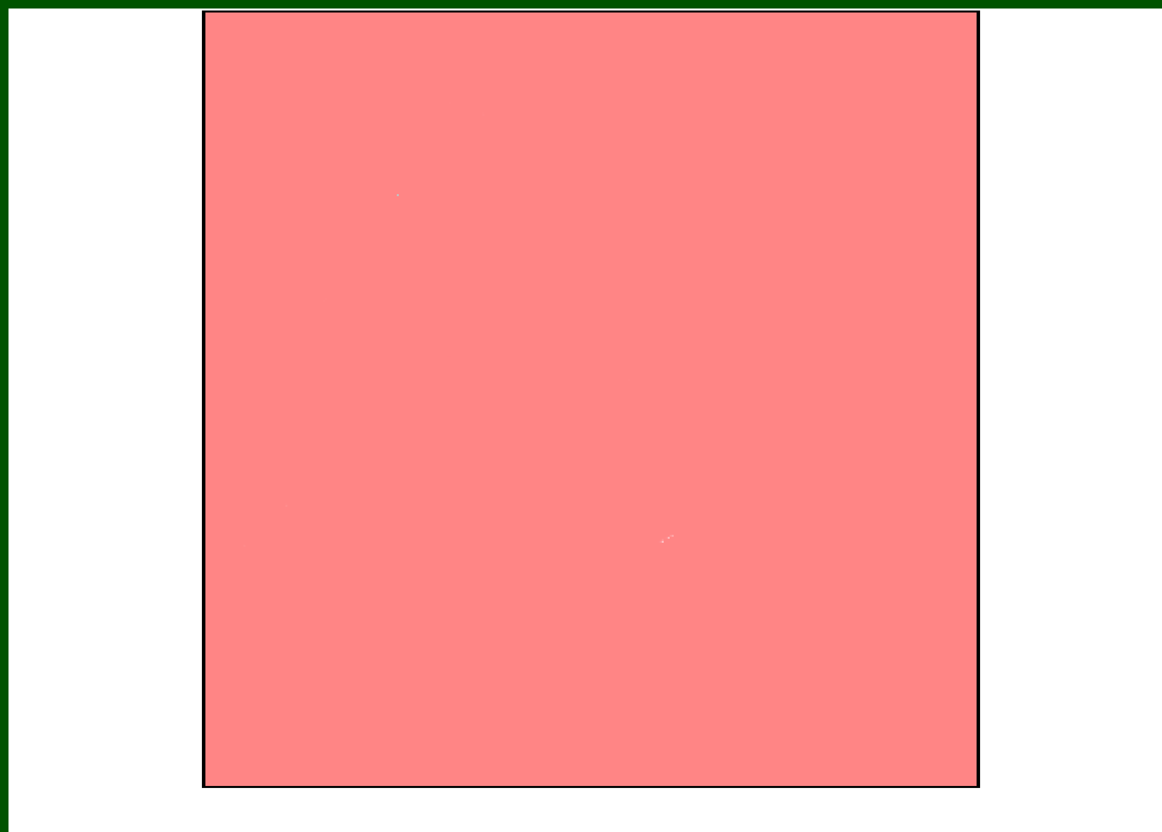
Conventional convective parameterisation

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



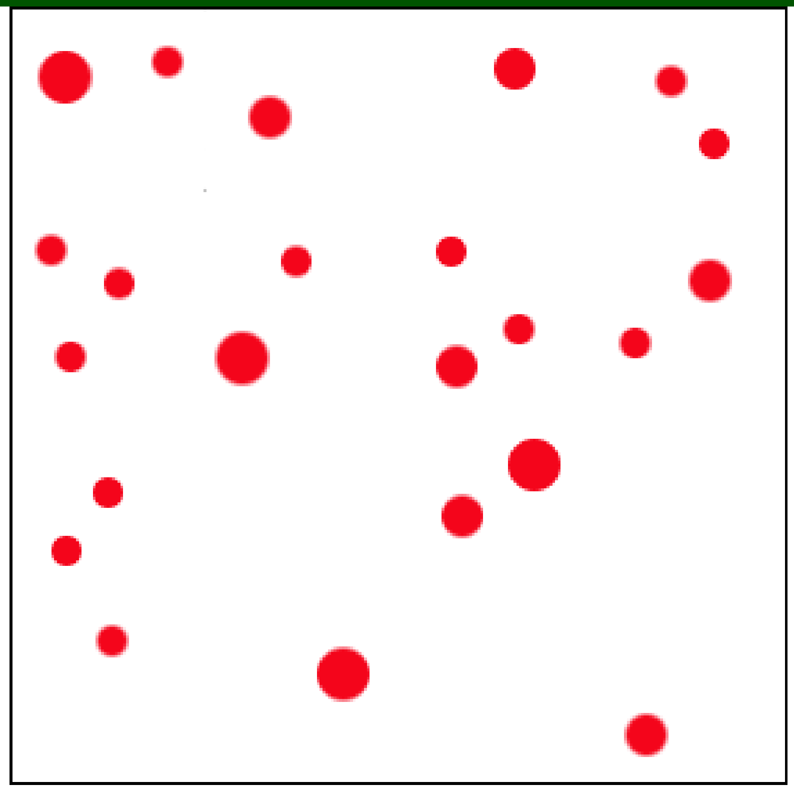
Conventional convective parameterisation

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



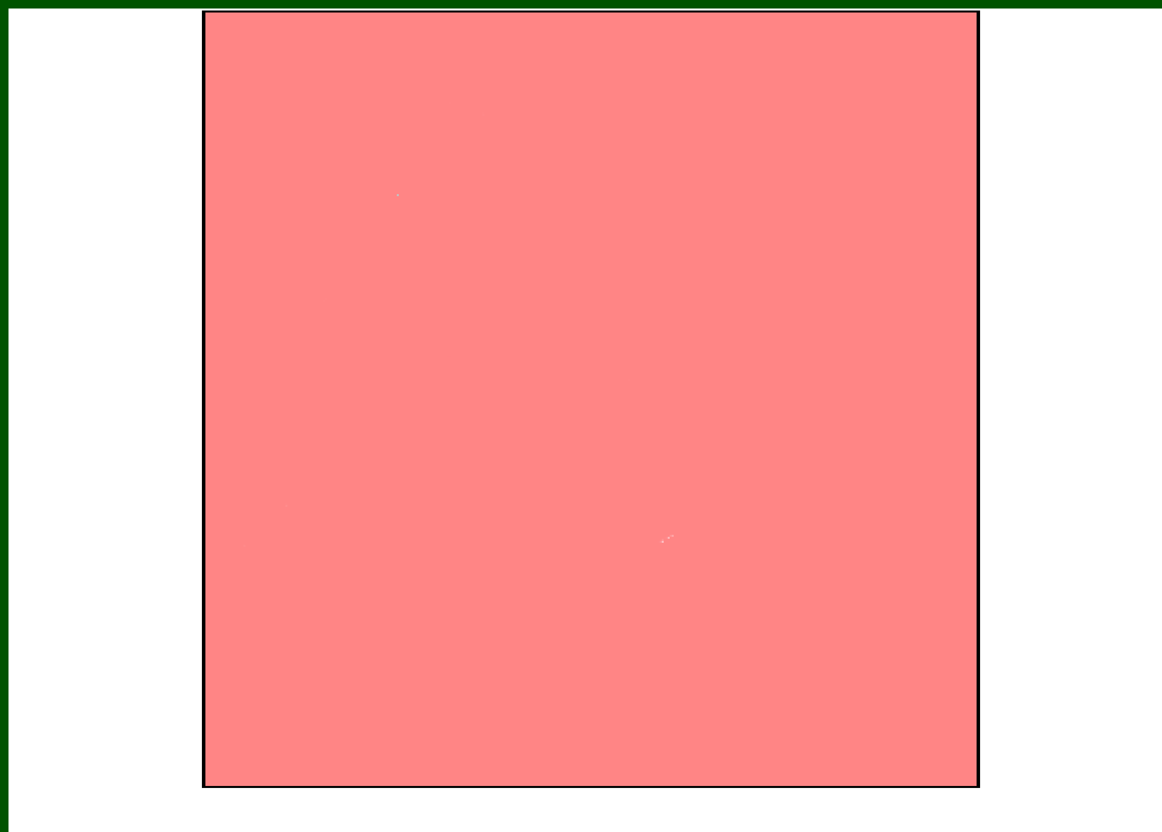
Stochastic parameterisation

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



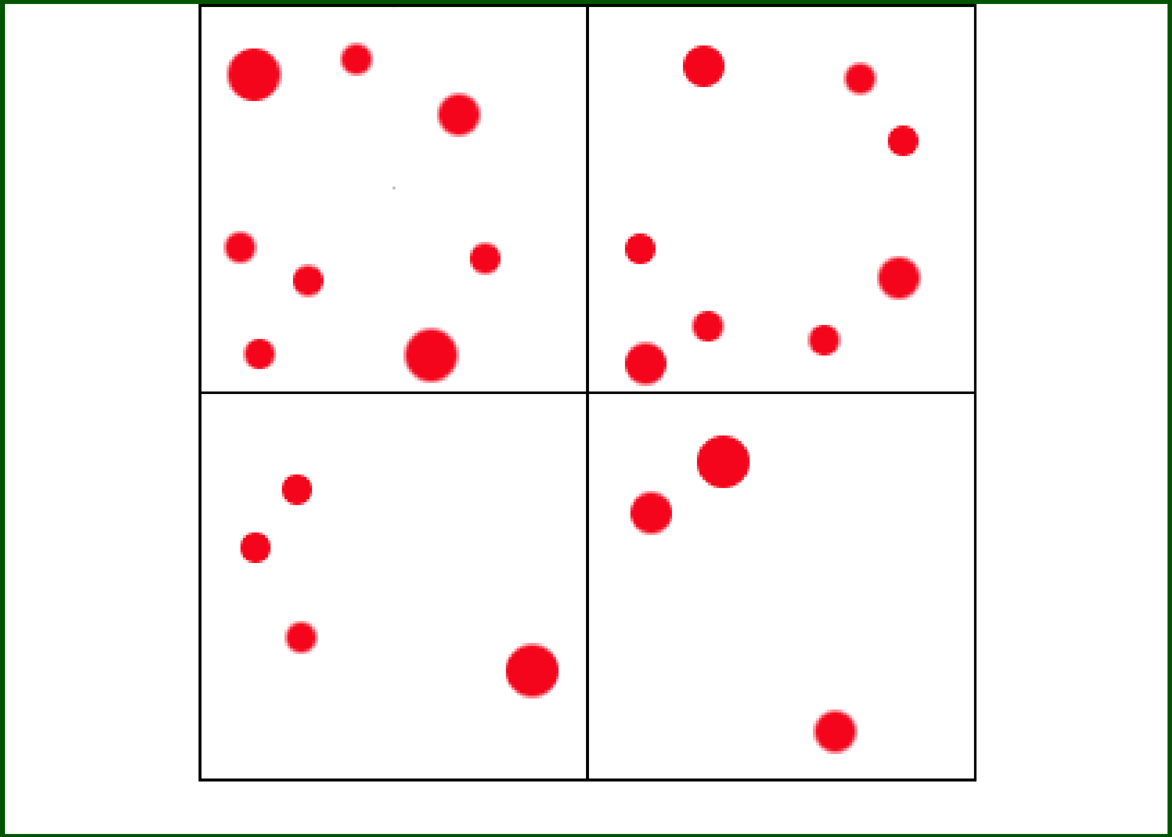
Effect of Paramterisation

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



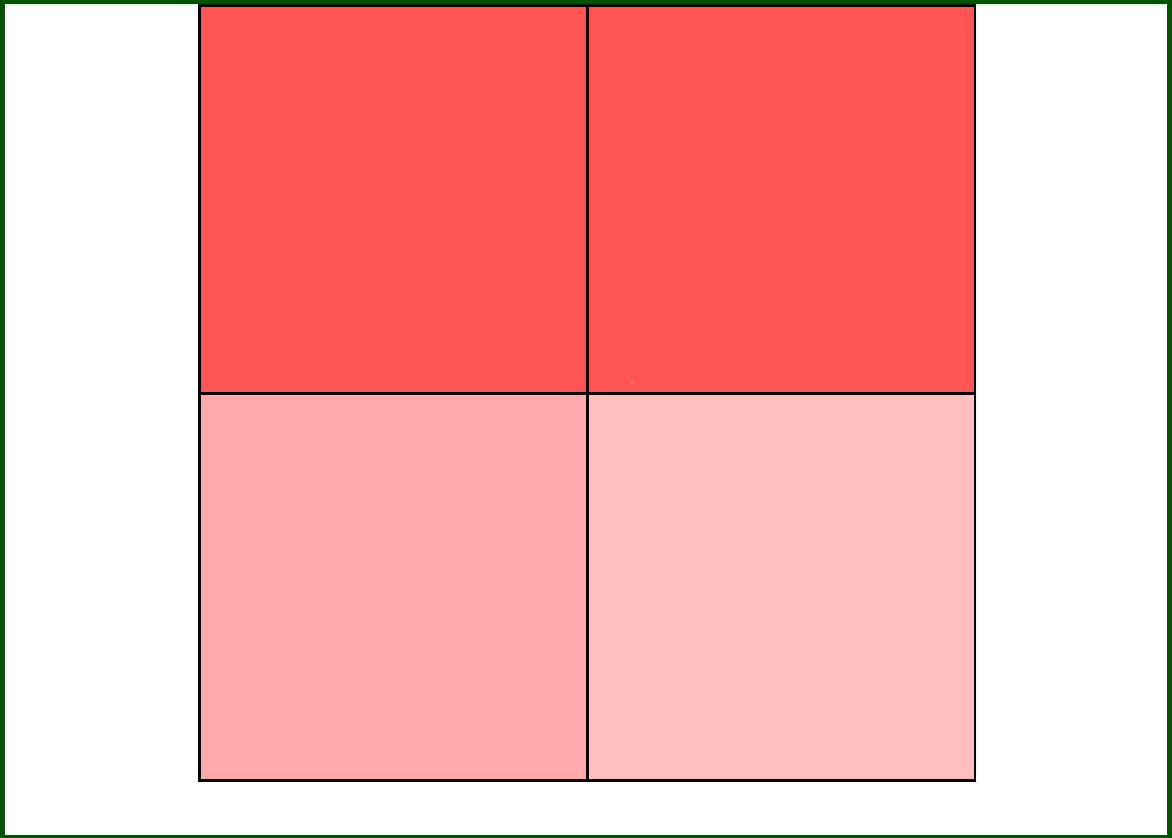
Stochastic Parameterisation

But for a smaller gridbox ...

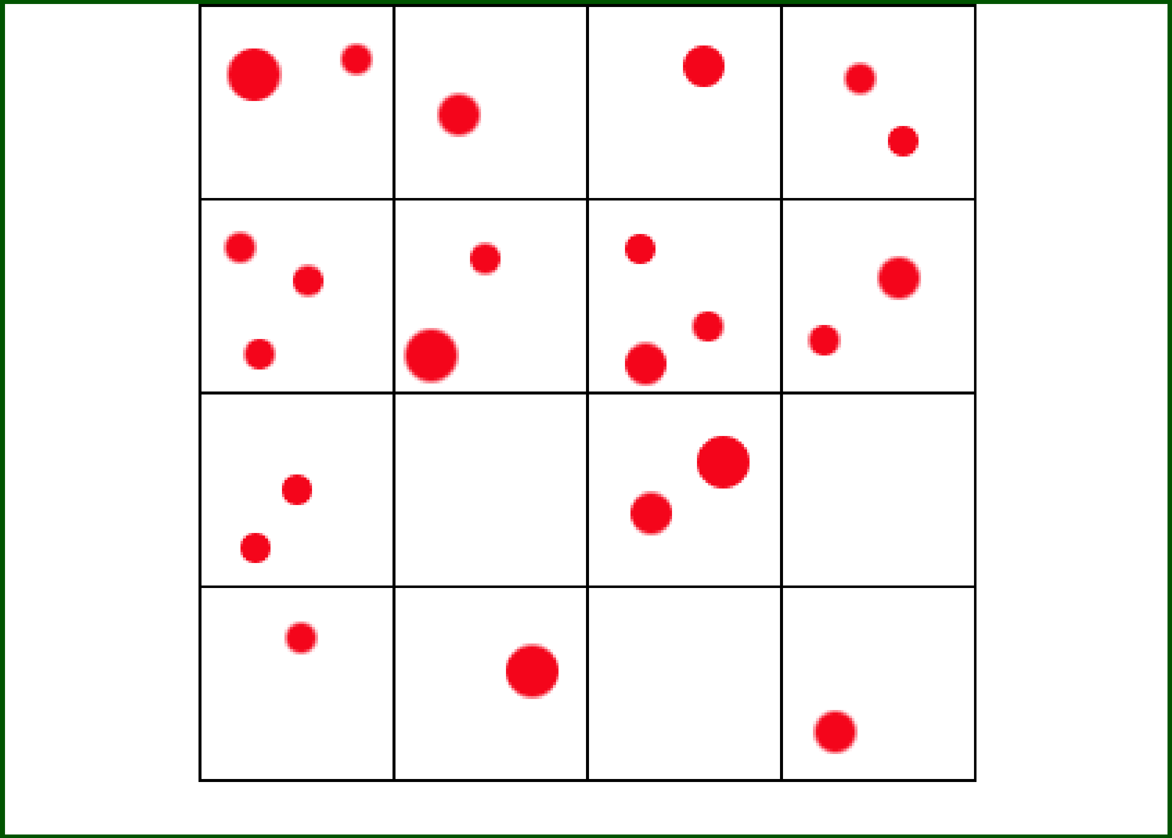


Effect of Paramterisation

The scheme allows some convective variability:



Stochastic Parameterisation



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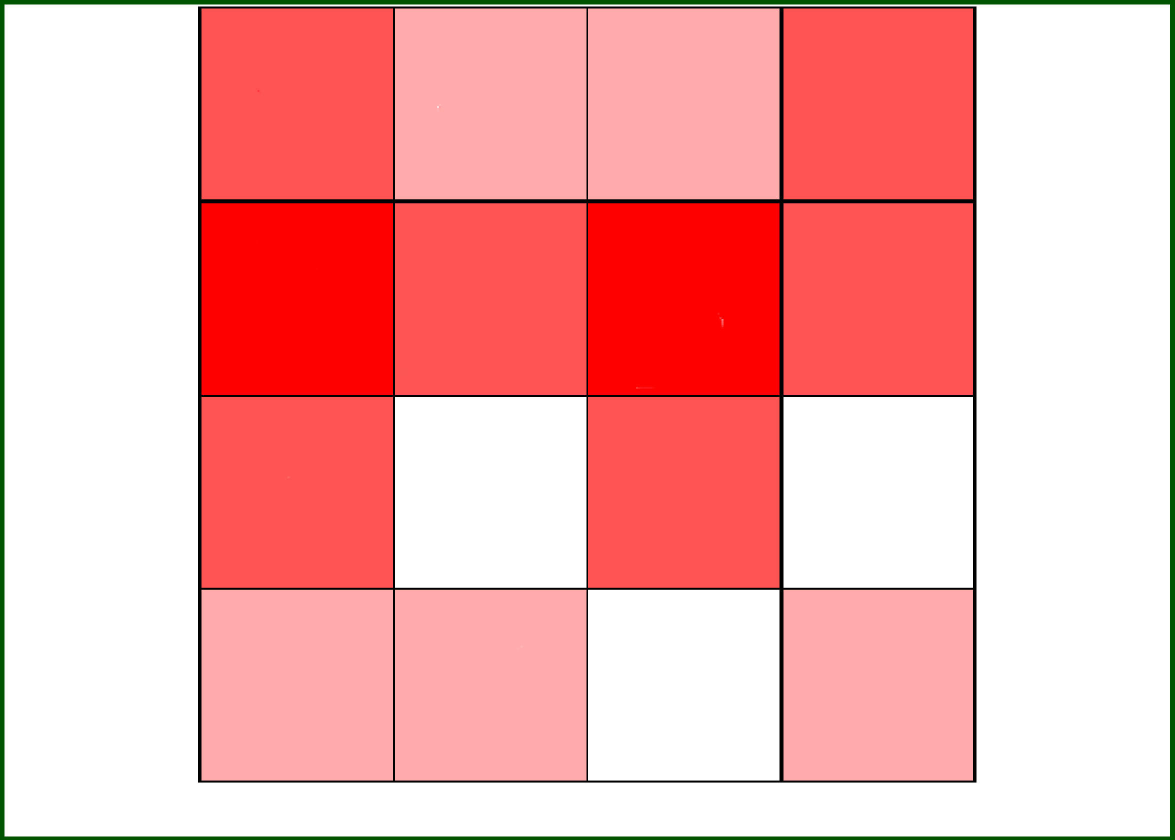
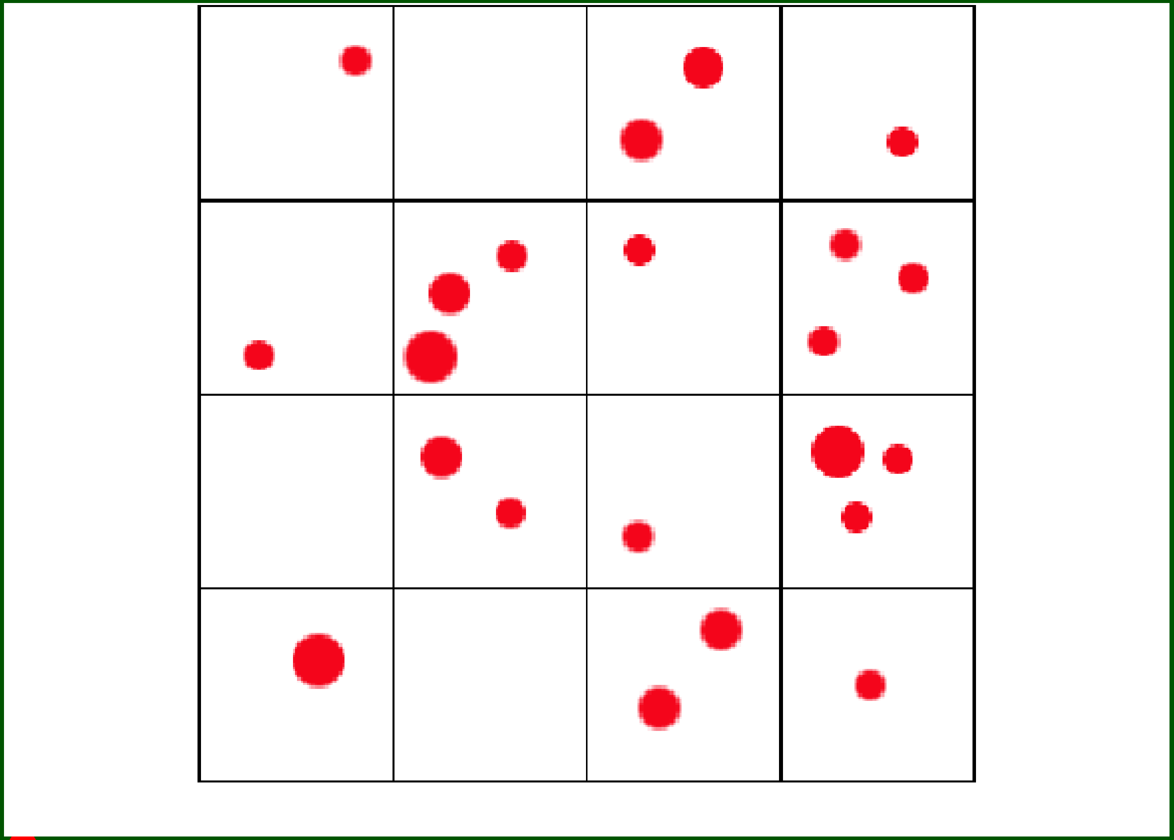
Effect of Paramterisation

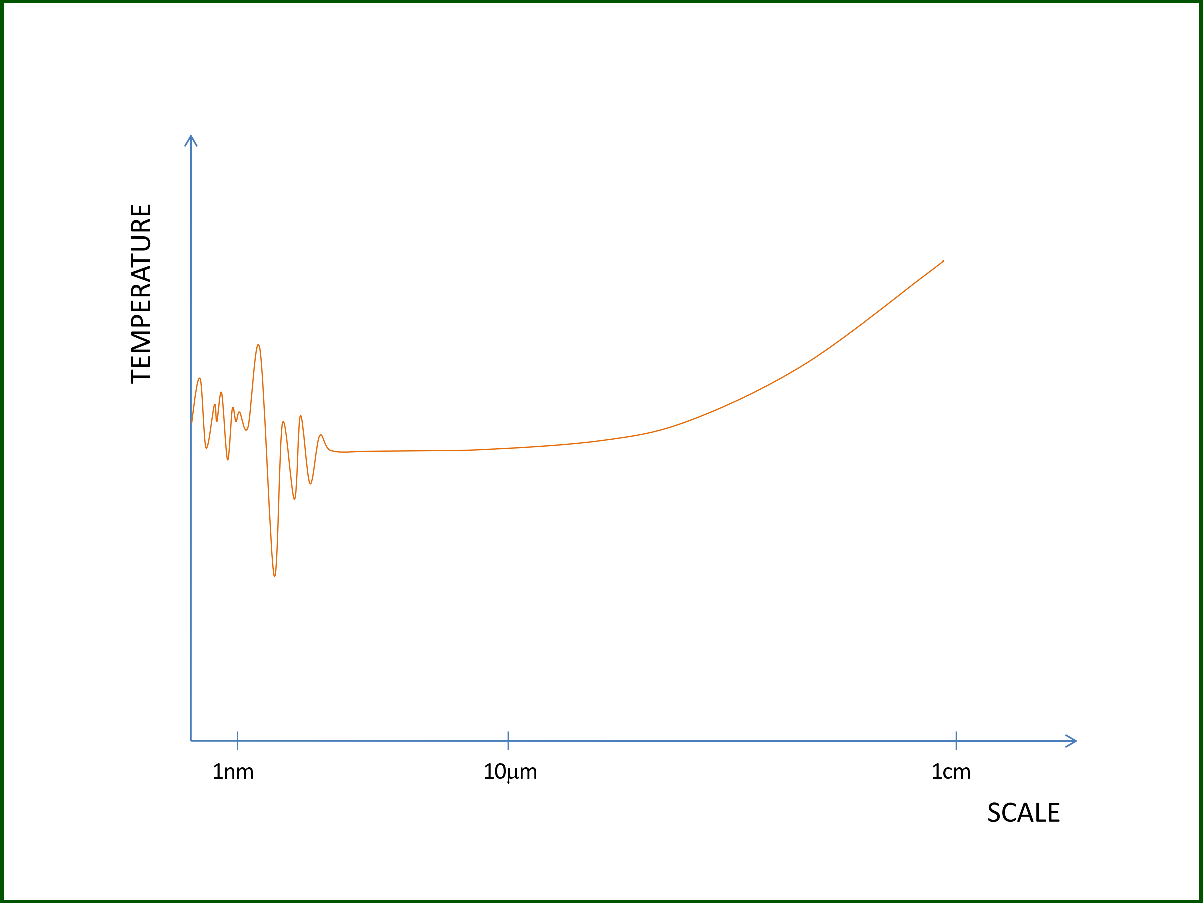


The real world

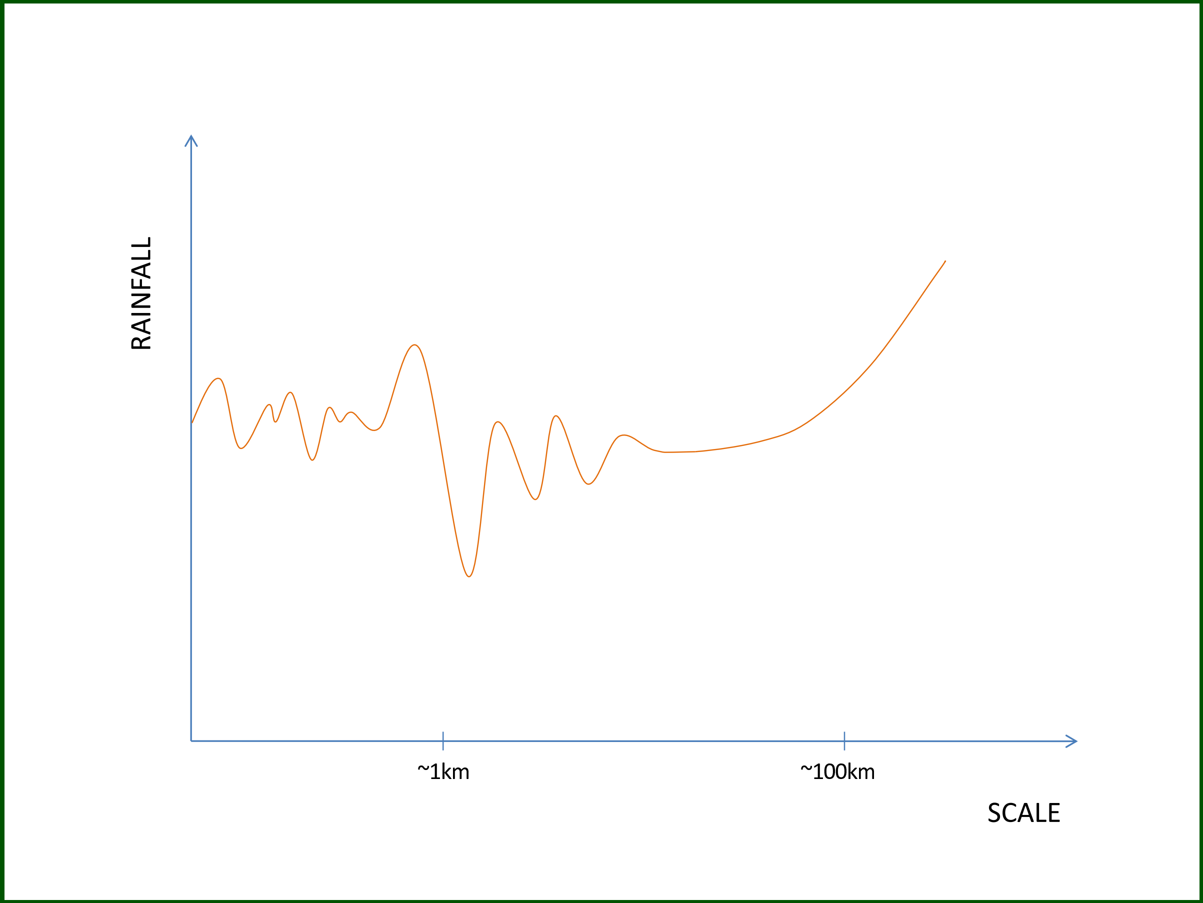
The distribution will be different in reality, but the *variability* will be similar.



Scale separation: thermodynam-ics



Scale separation: rainfall



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Convection parameterisation schemes

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

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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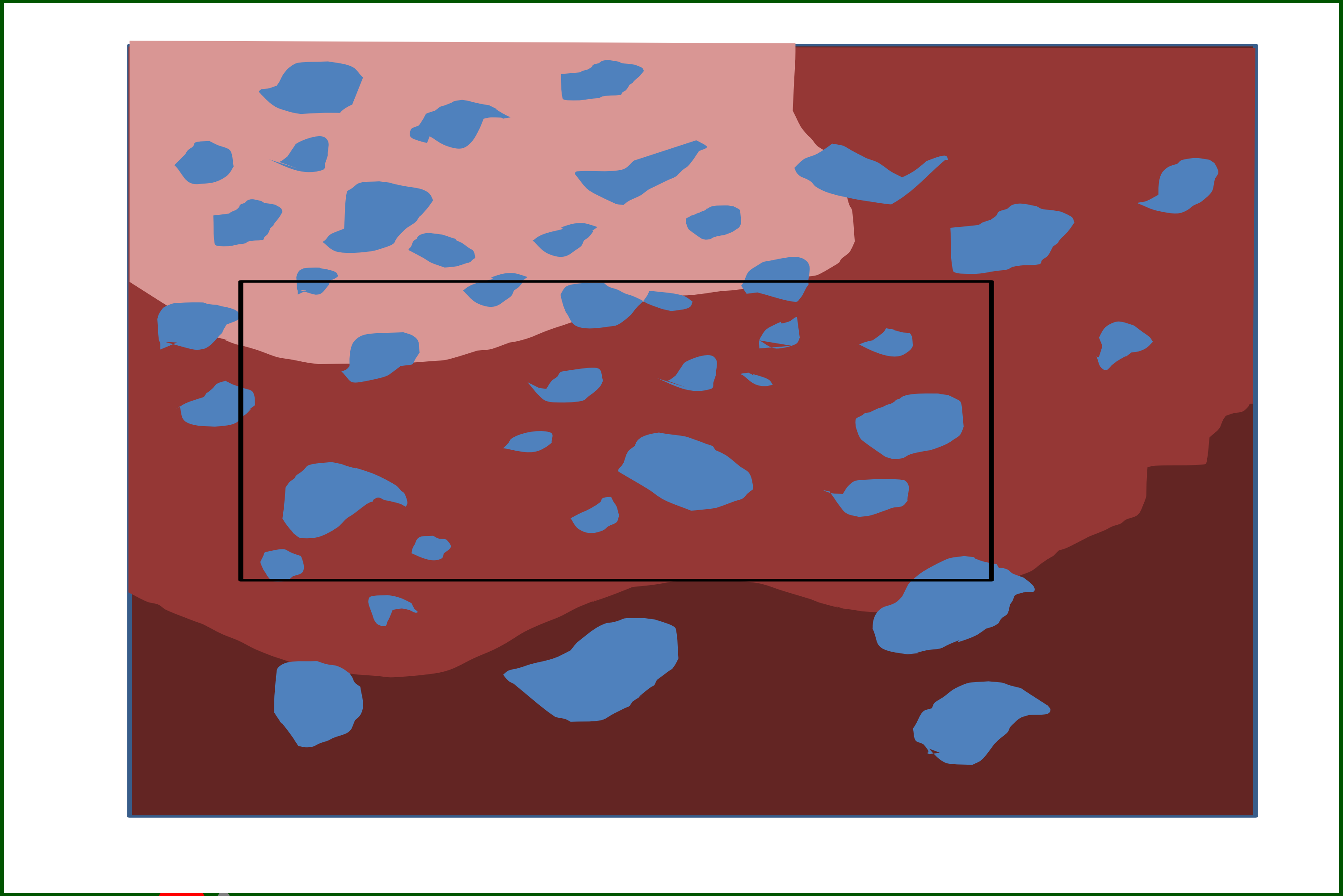
Plant Craig scheme: Averaging area



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

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

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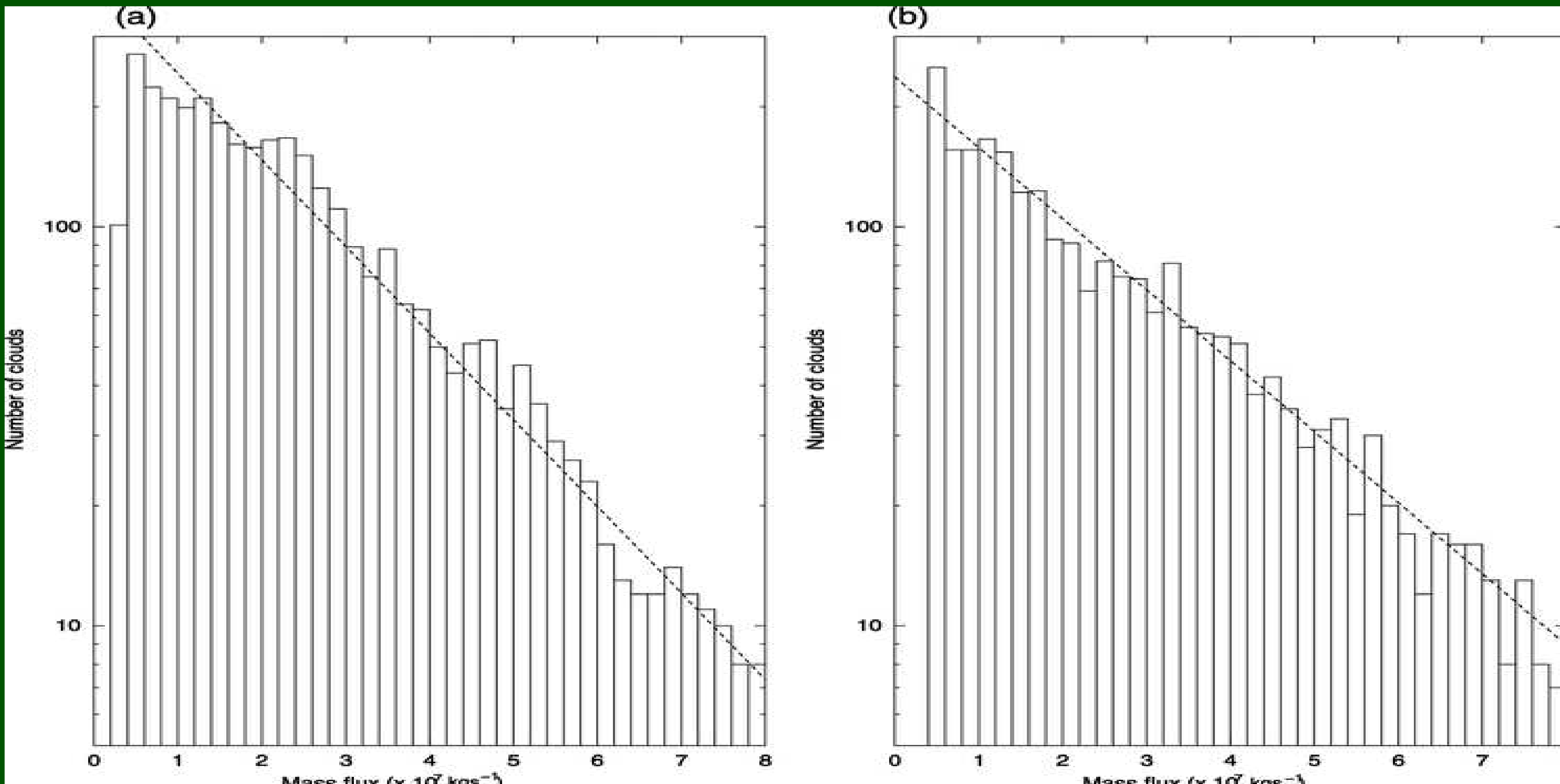
Exponential distribution in a CRM

Cohen, PhD thesis (2001)



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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,

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

leading to the following distribution for total mass flux:

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

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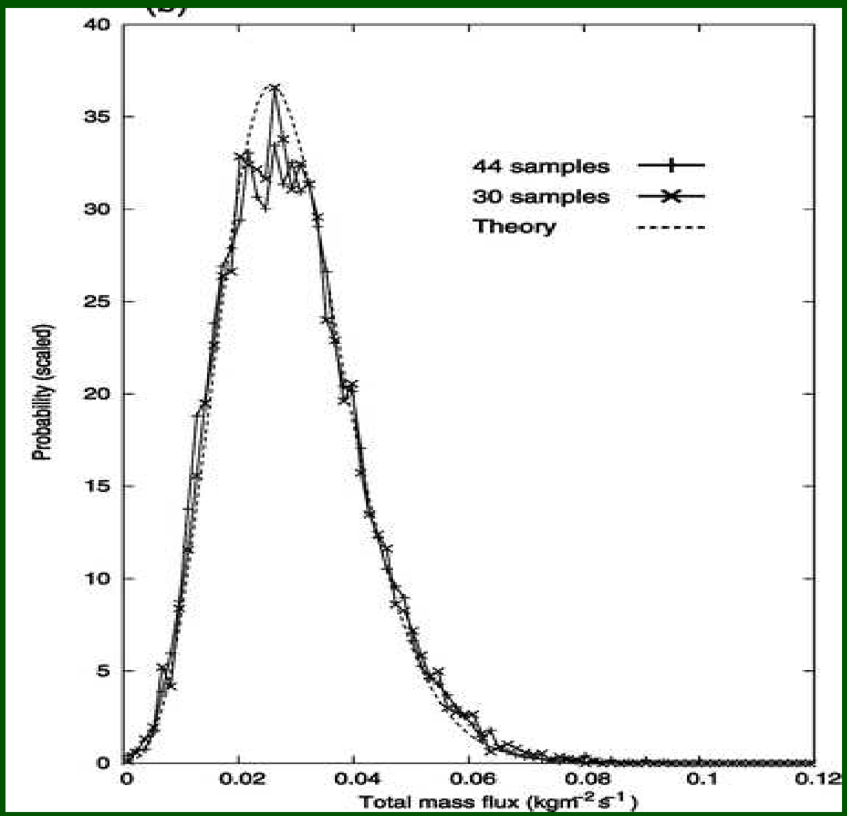
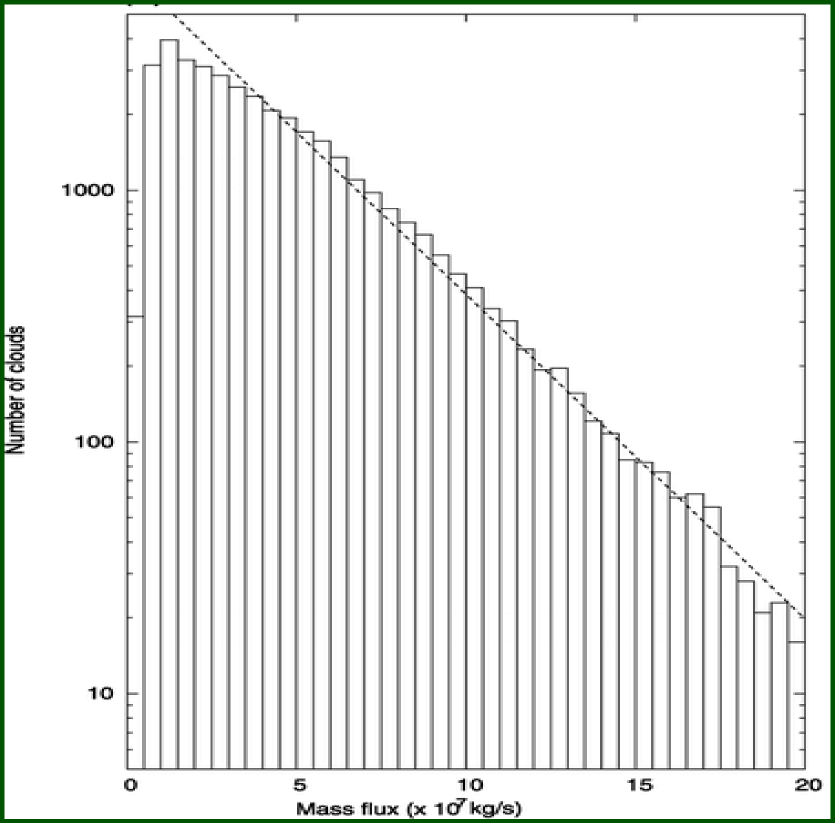
PDFs of mass flux in an SCM





- 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.

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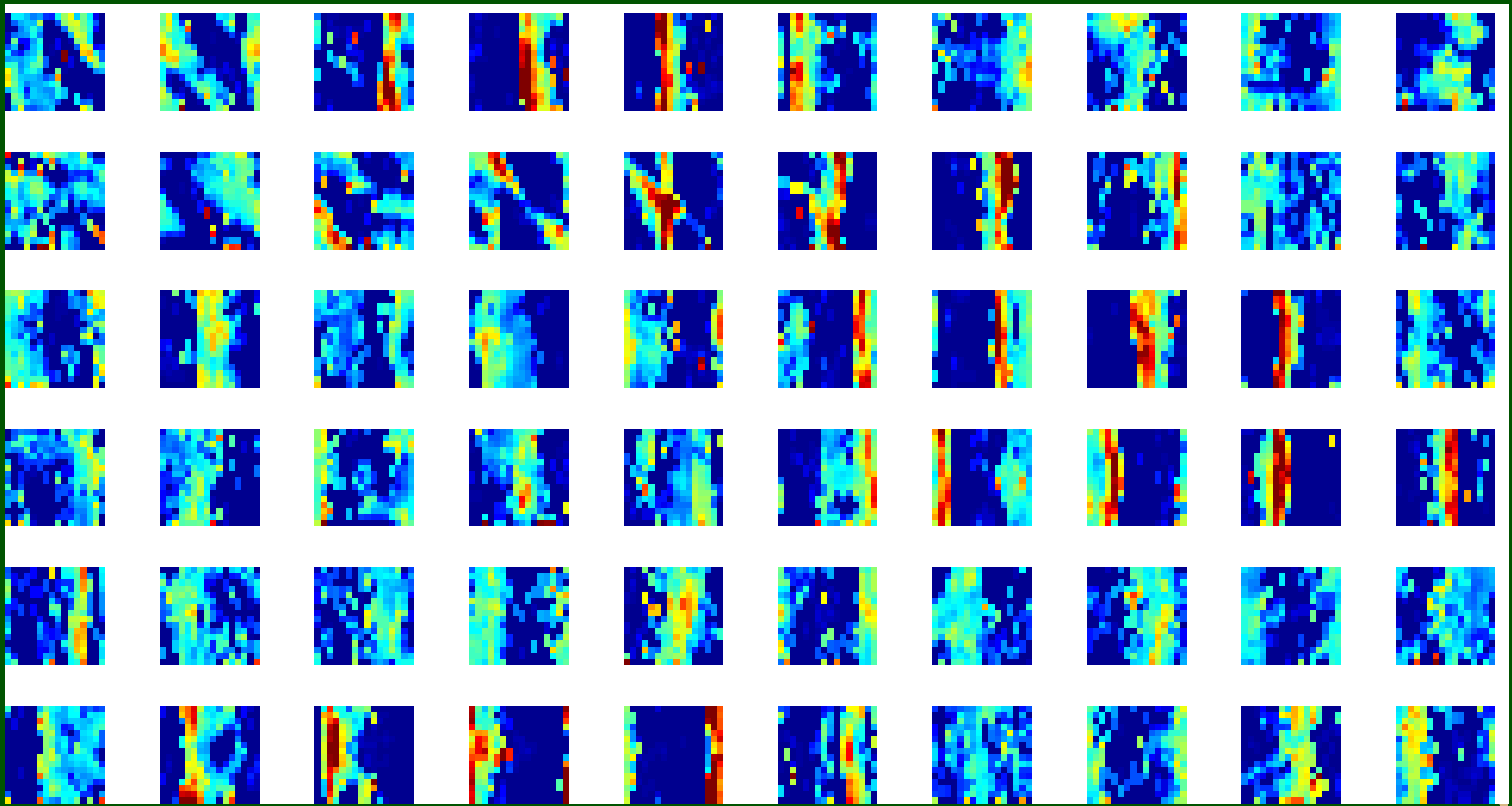
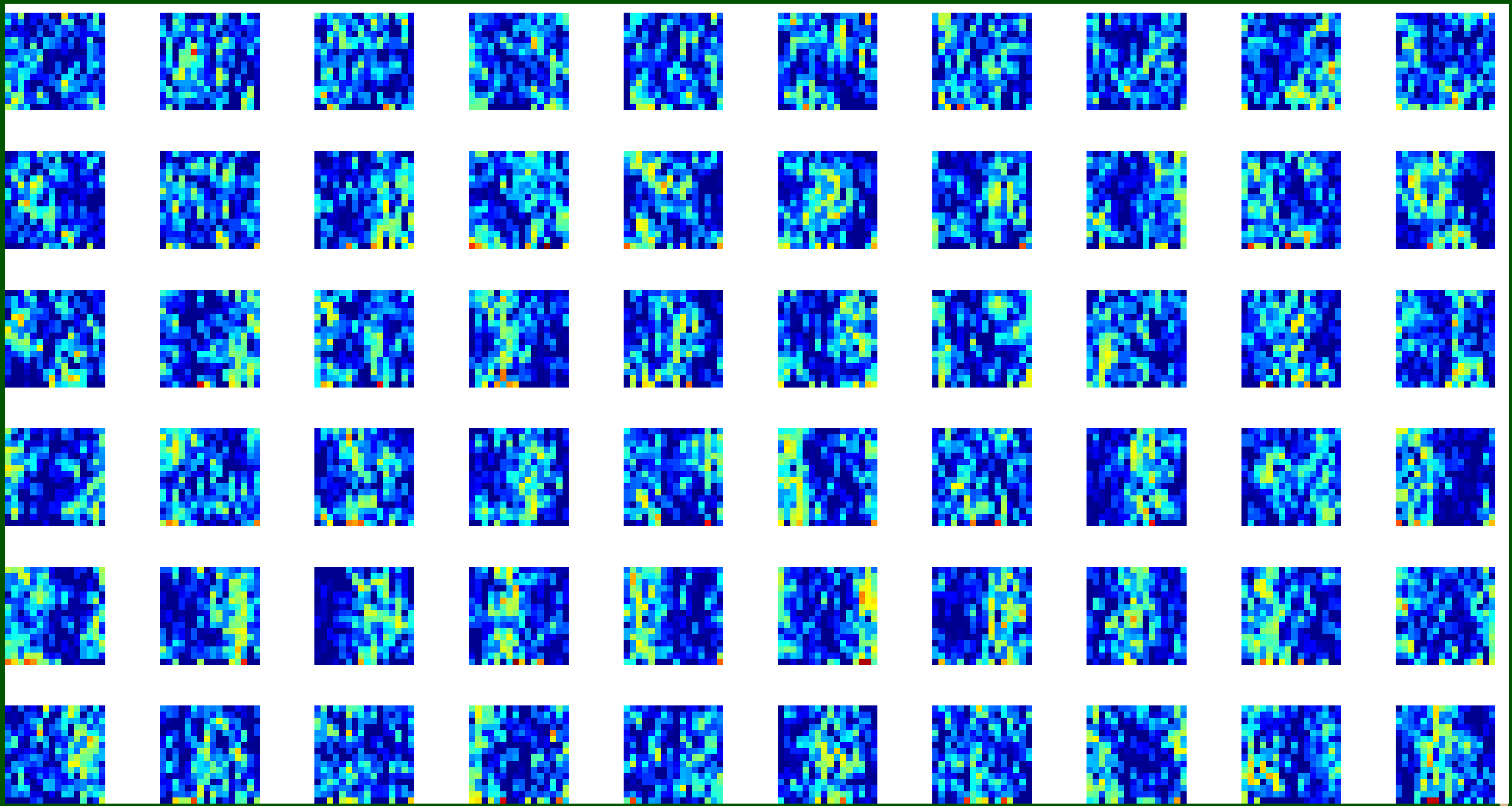
Rainfall snapshots: Gregory Rowntree scheme



animation

Rainfall snapshots: Kain Fritsch scheme



animation

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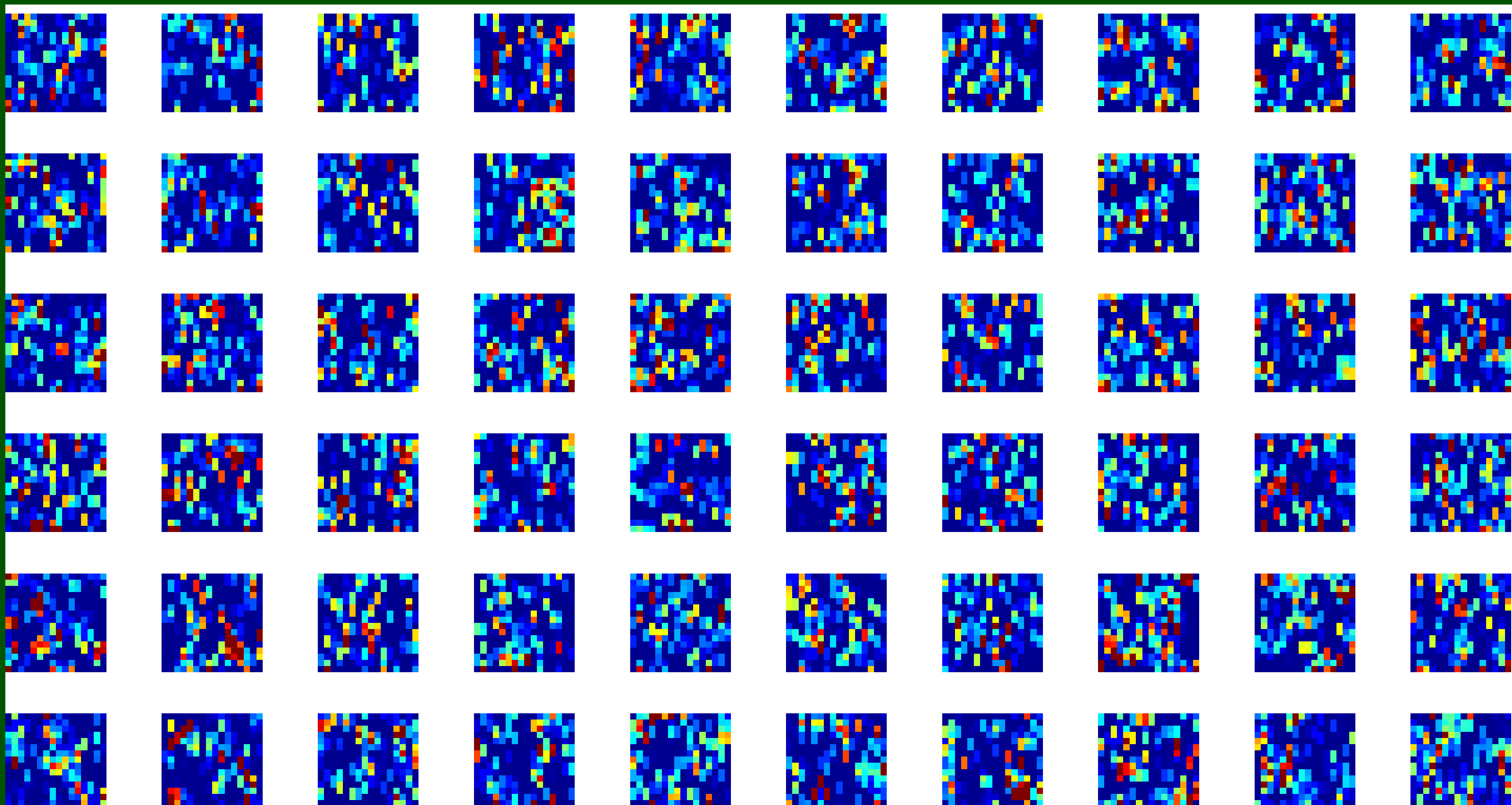
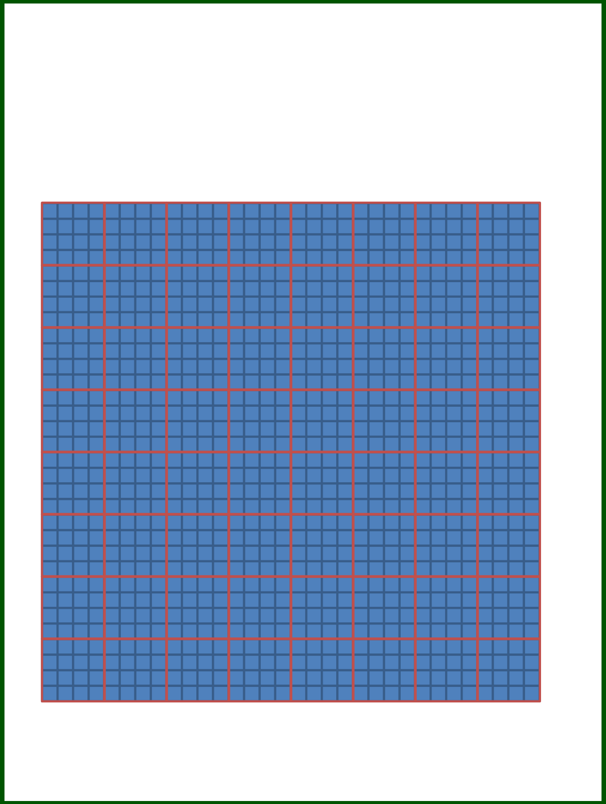
Rainfall snapshots: Plant Craig scheme



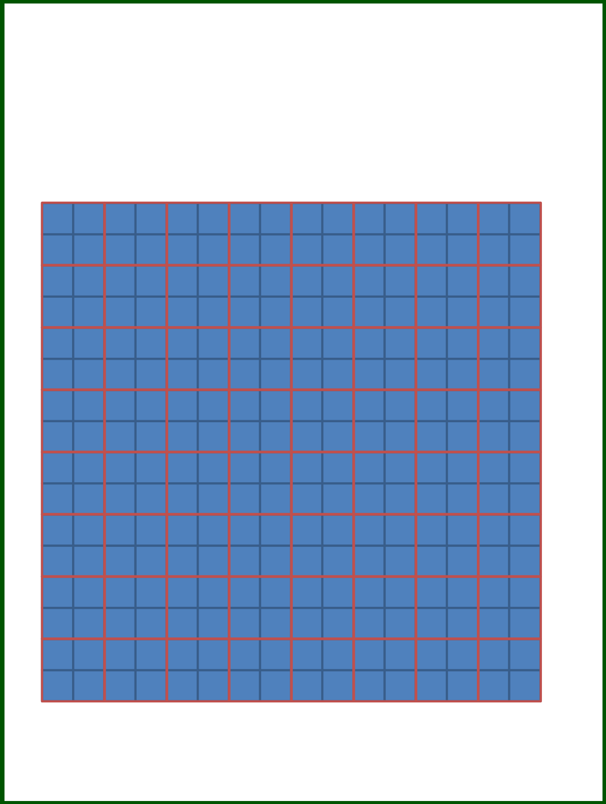
animation

Model grid division

16km

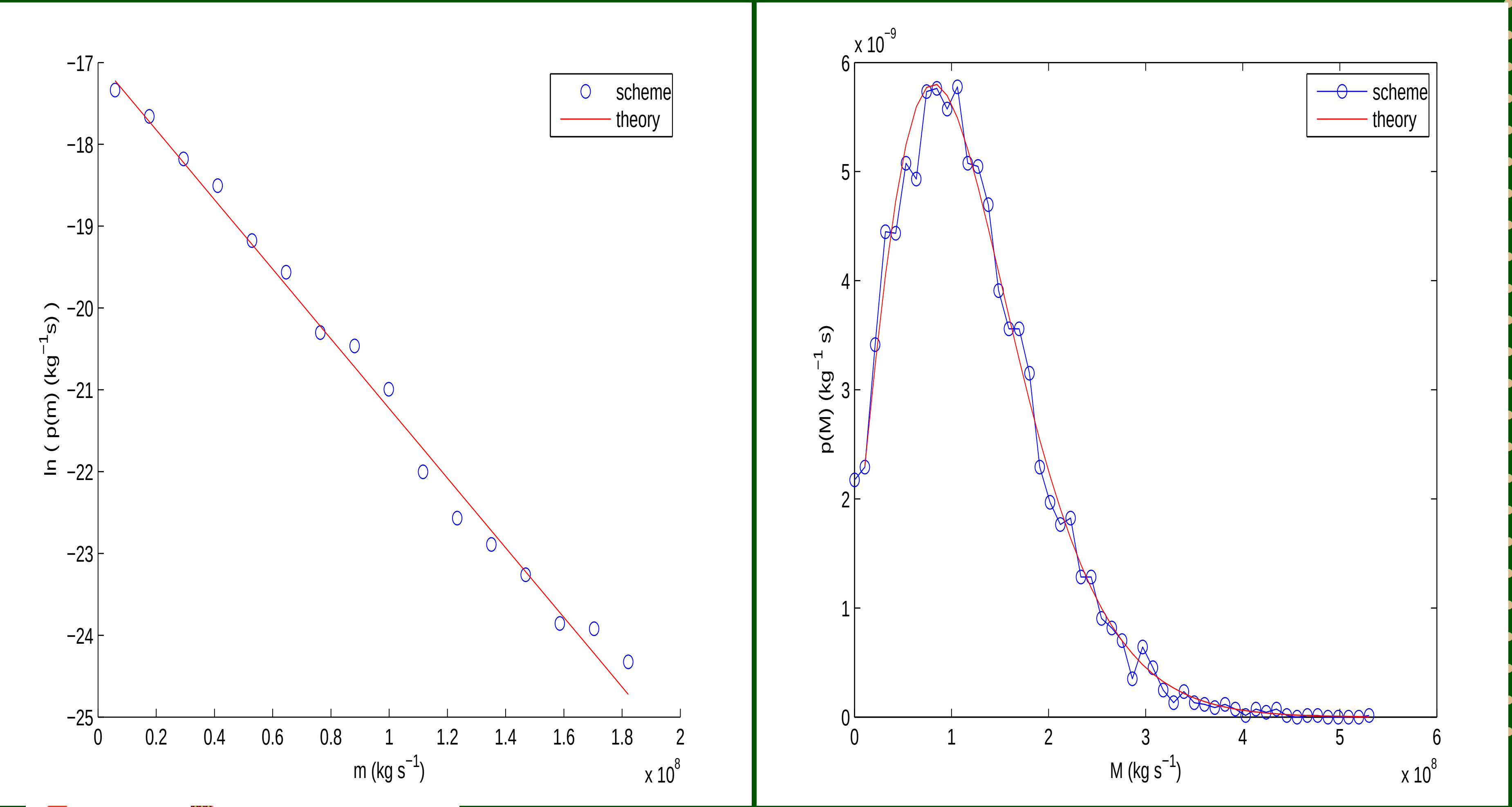


32km



PDFs of m and M for maximum averaging

Averaging area: $480\,\mathrm{km}$ square.
Averaging time: 50 minutes.



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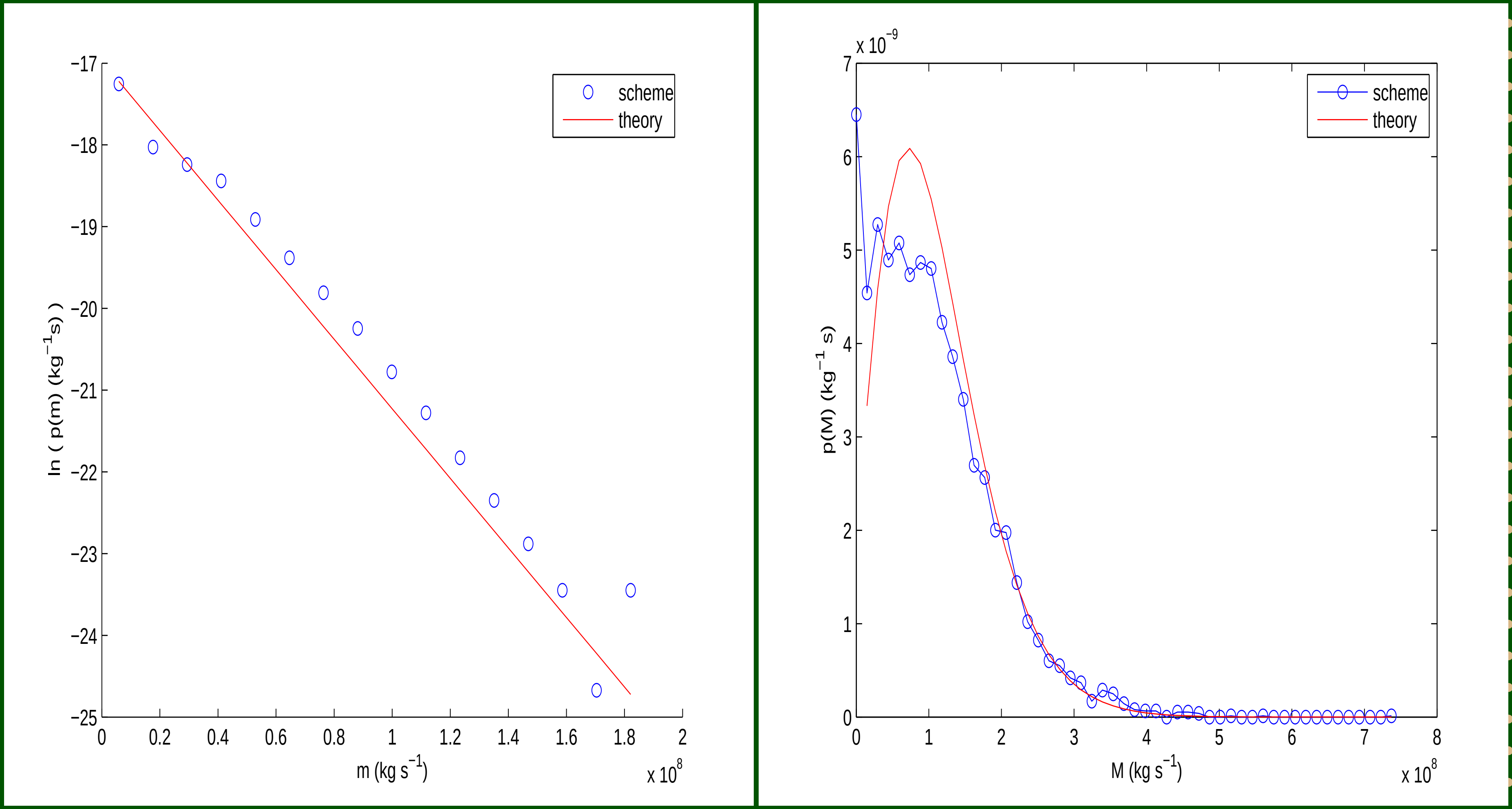
PDFs of m and M for no averaging



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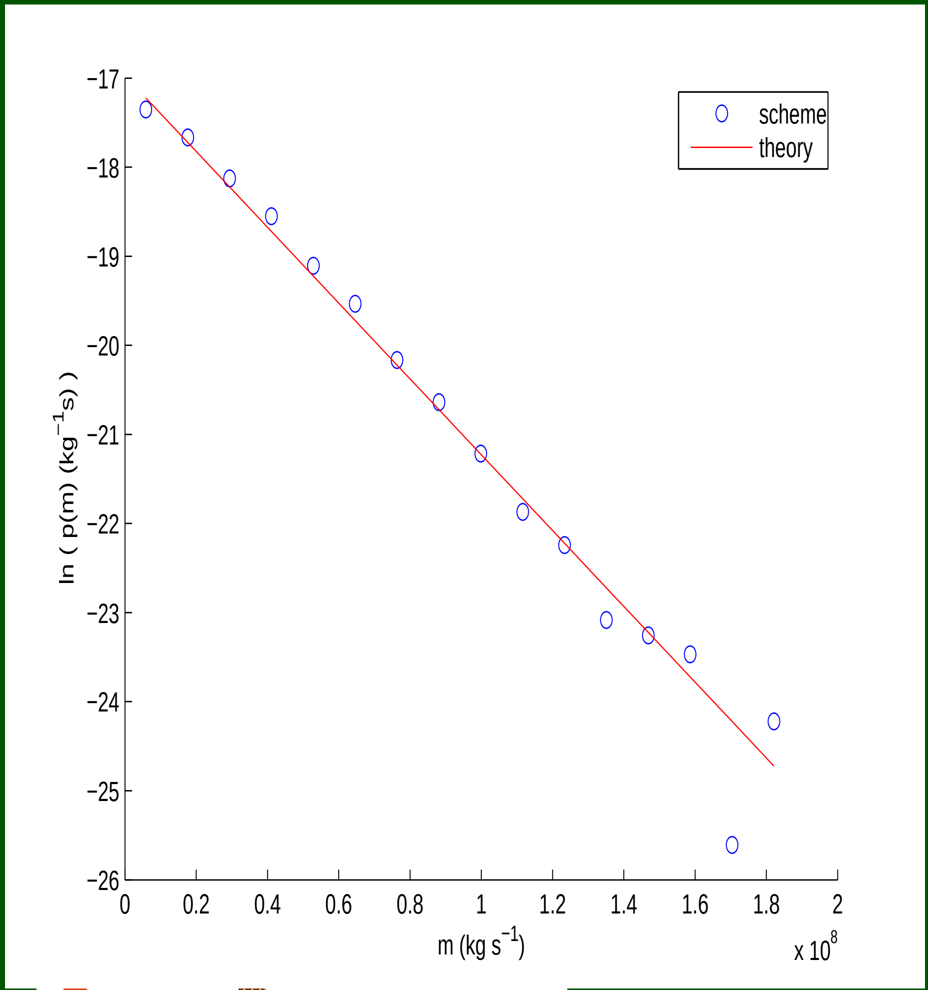
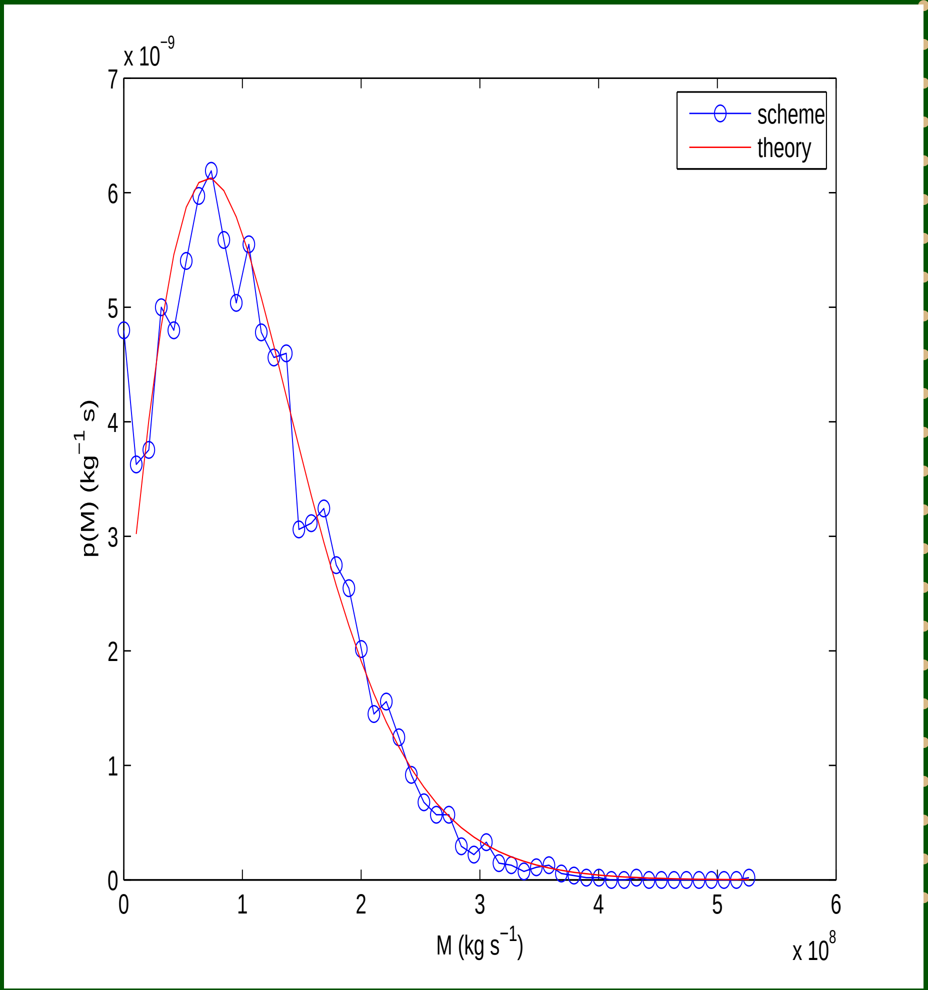
PDFs of m and M for intermediate averaging

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

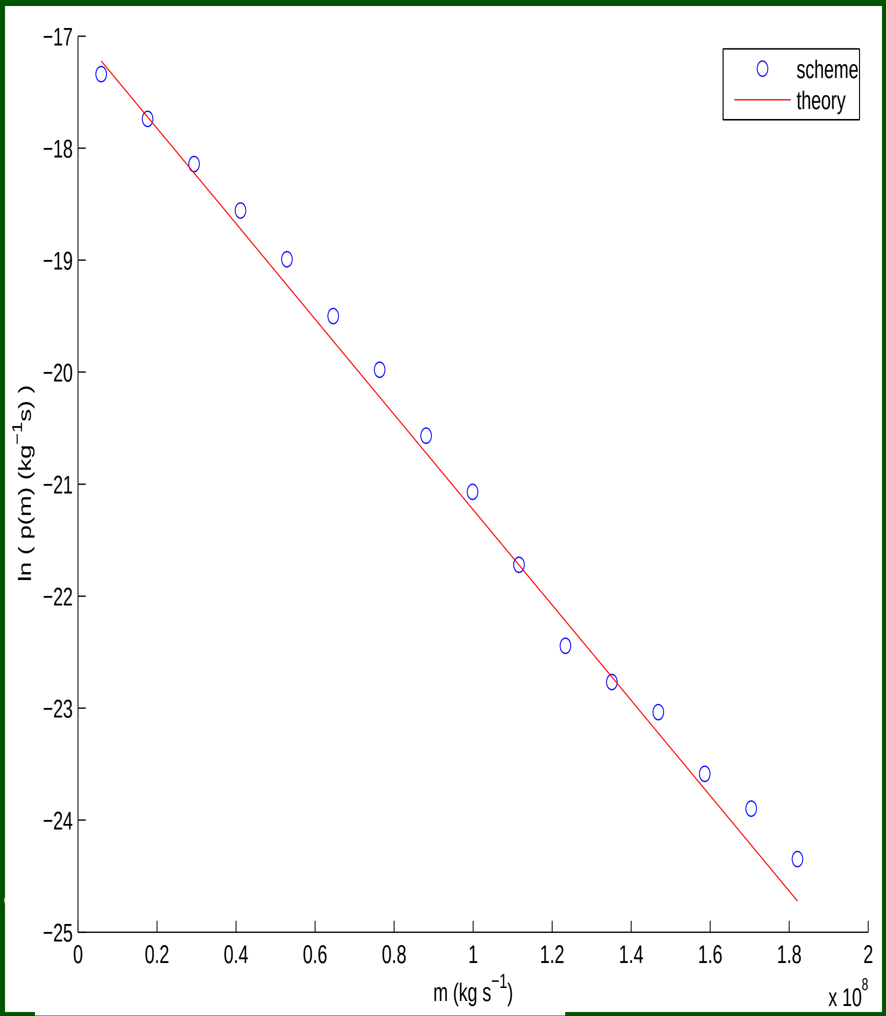
Averaging time: 50 minutes.

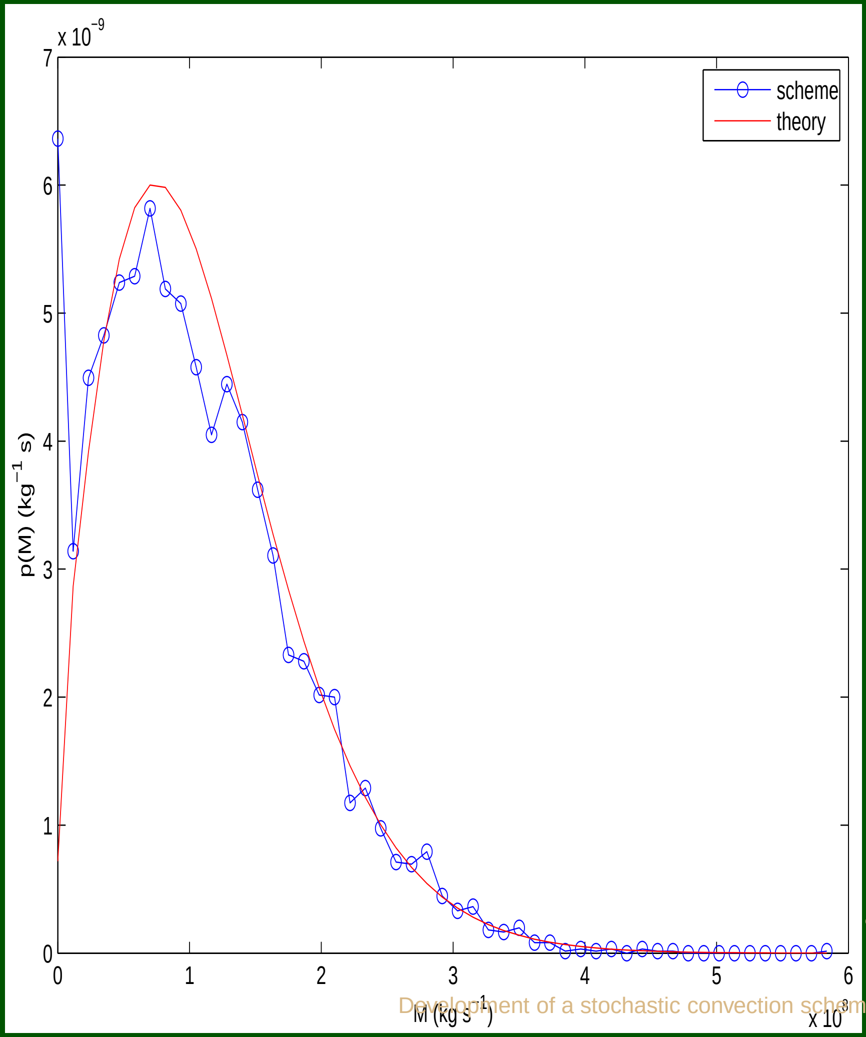




PDFs of m and M for less averaging

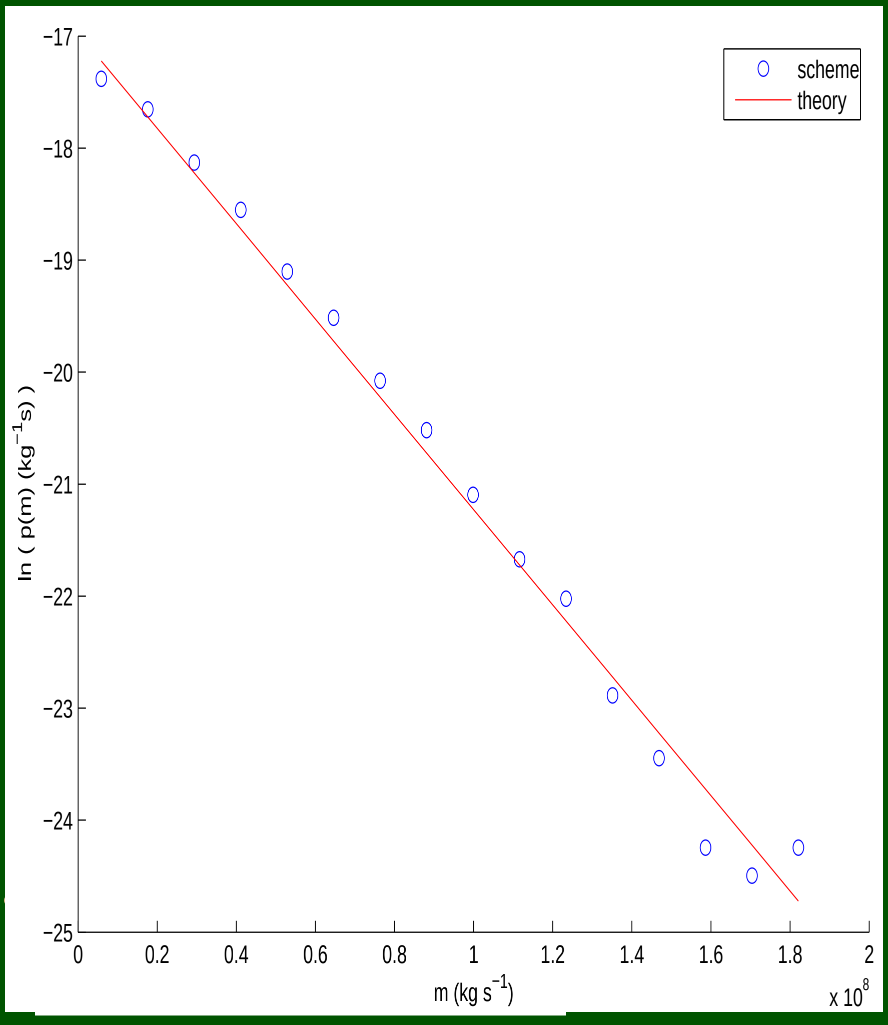
Averaging area: $96\,\mathrm{km}$ square.
Averaging time: 50 minutes.

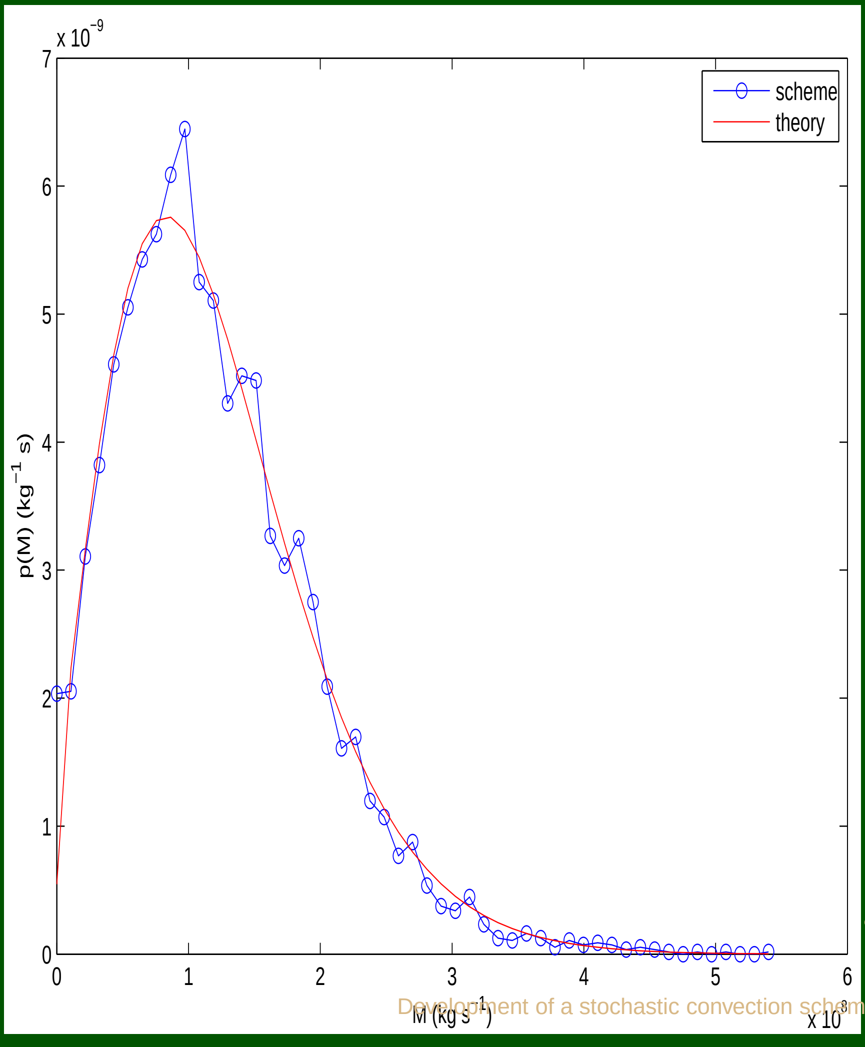




PDFs of m and M for 10 K/day cooling

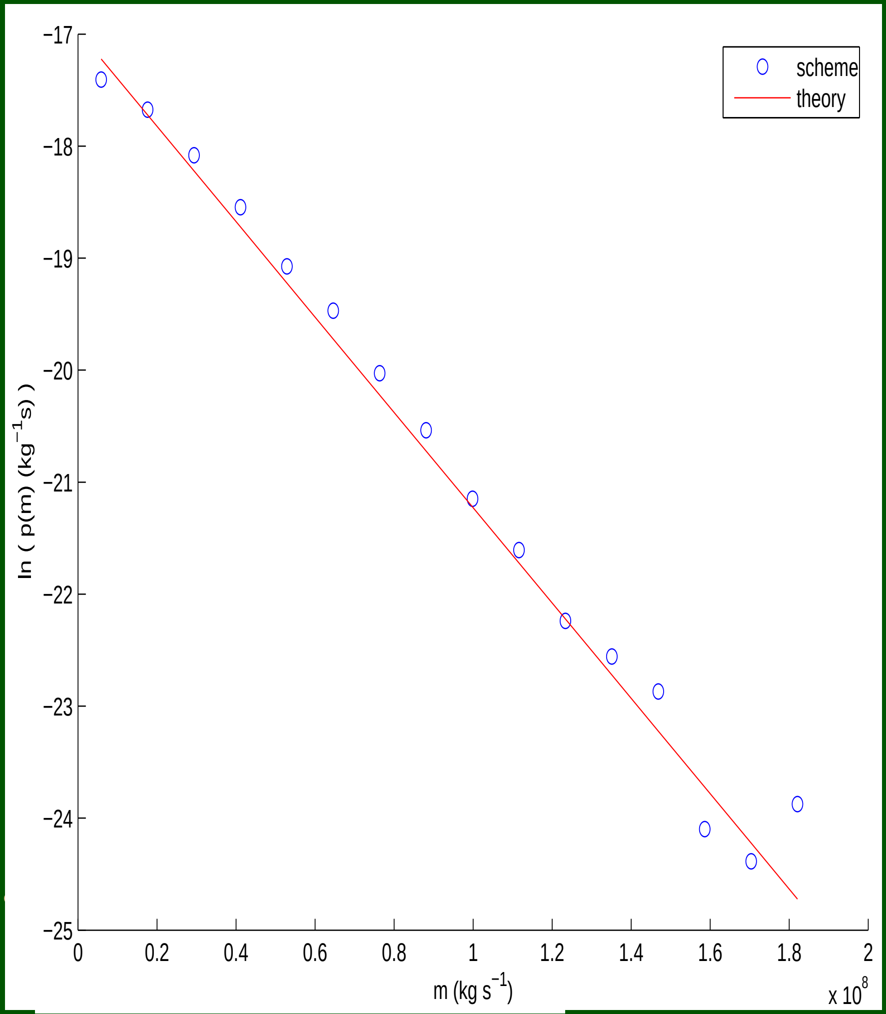
Averaging area: $160\,\mathrm{km}$ square.
Averaging time: 40 minutes.

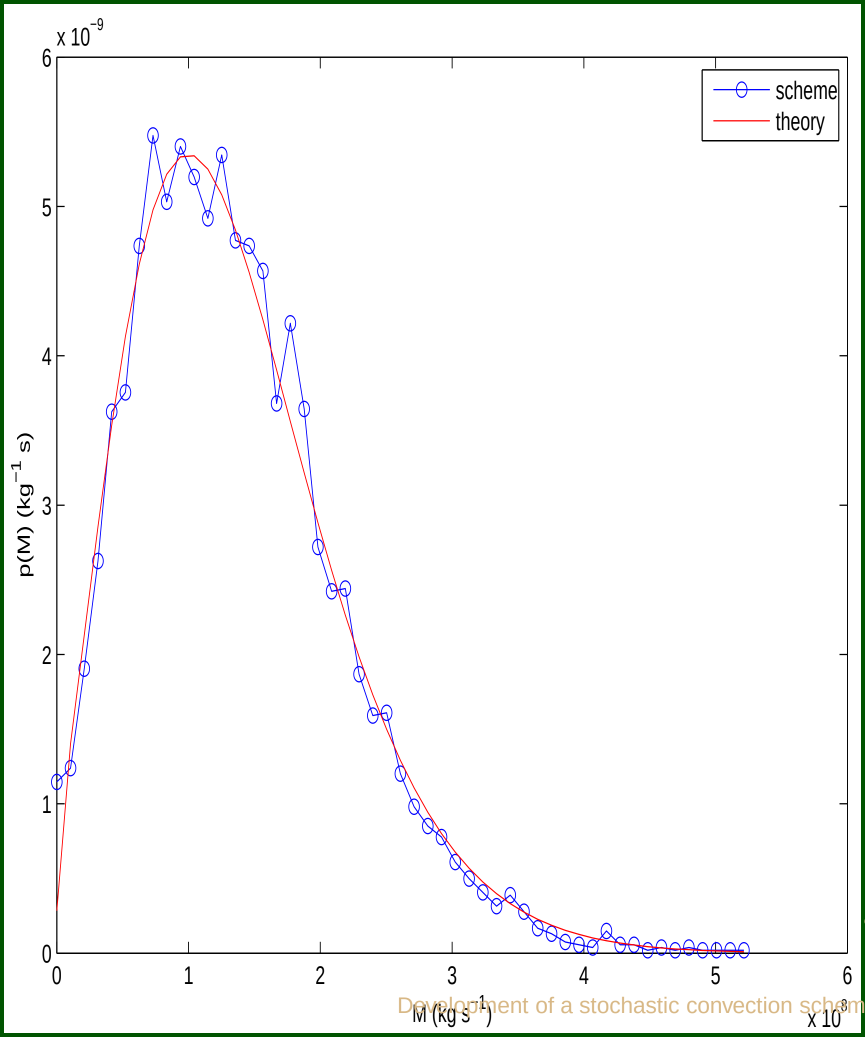




PDFs of m and M for 12 K/day cooling

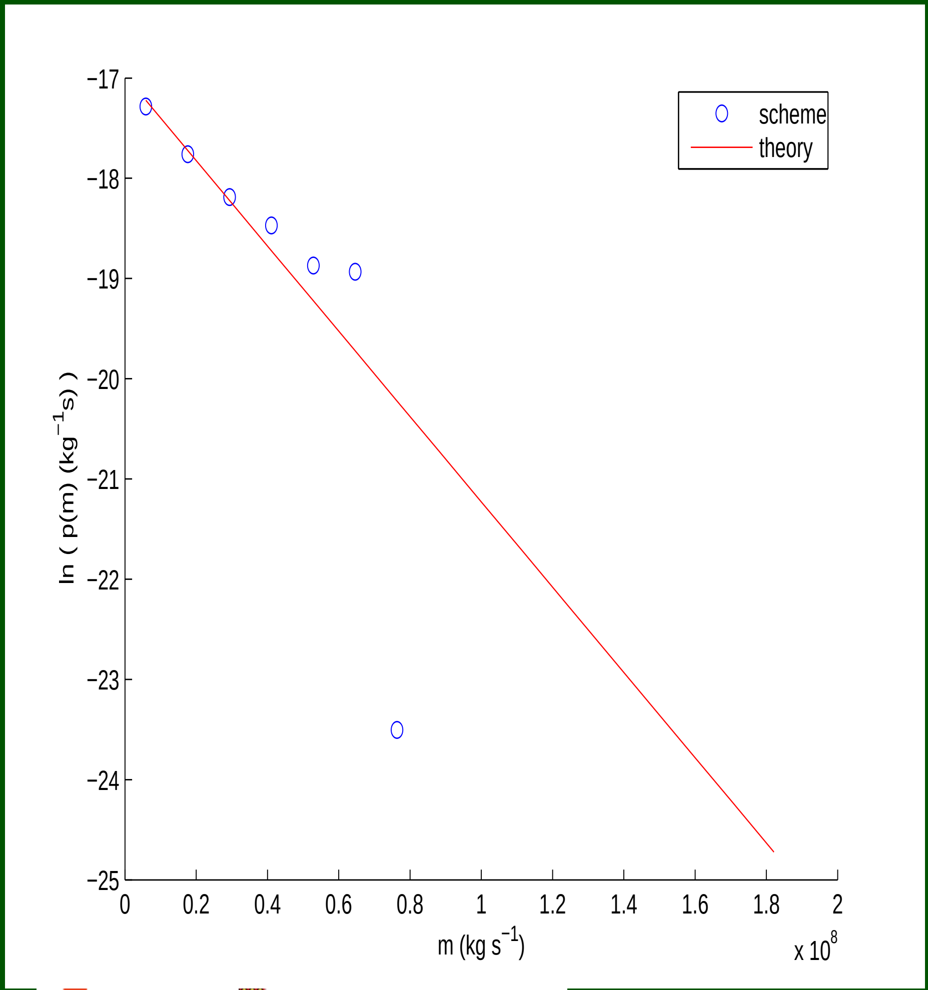
Averaging area: $160\,\mathrm{km}$ square.
Averaging time: 33 minutes.

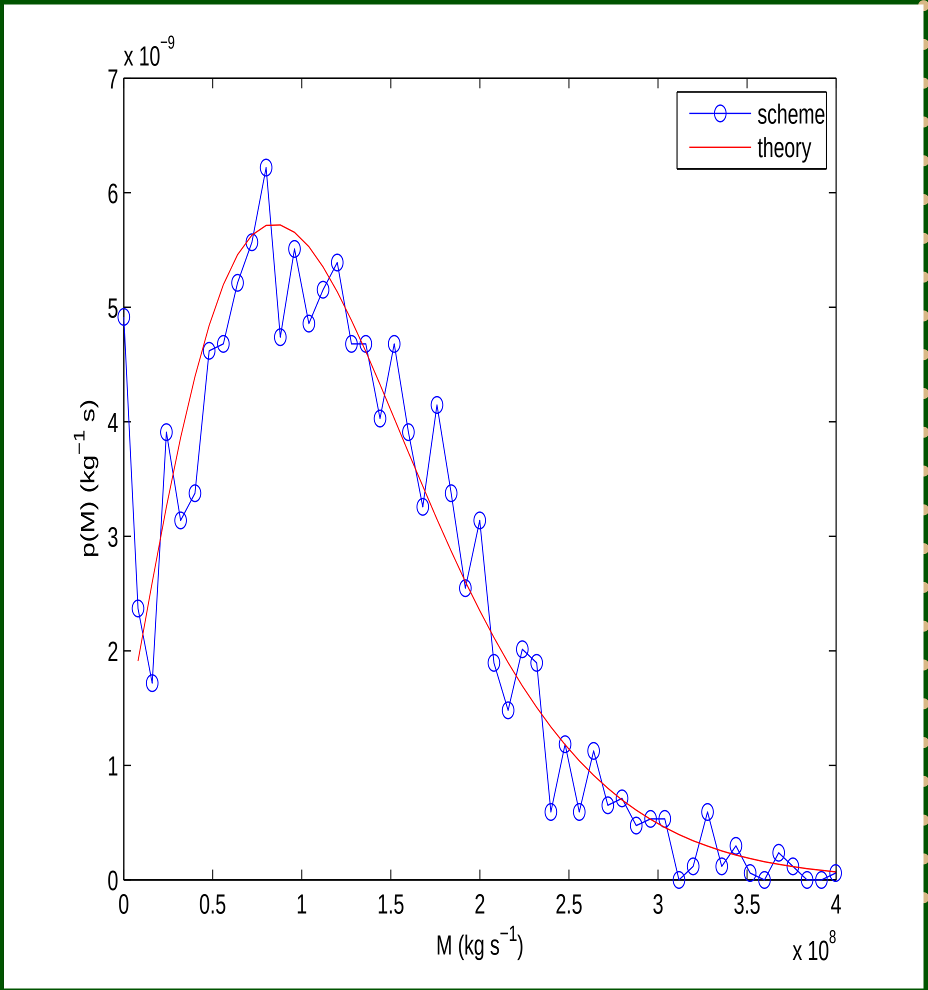




PDFs of m and M for 16 km

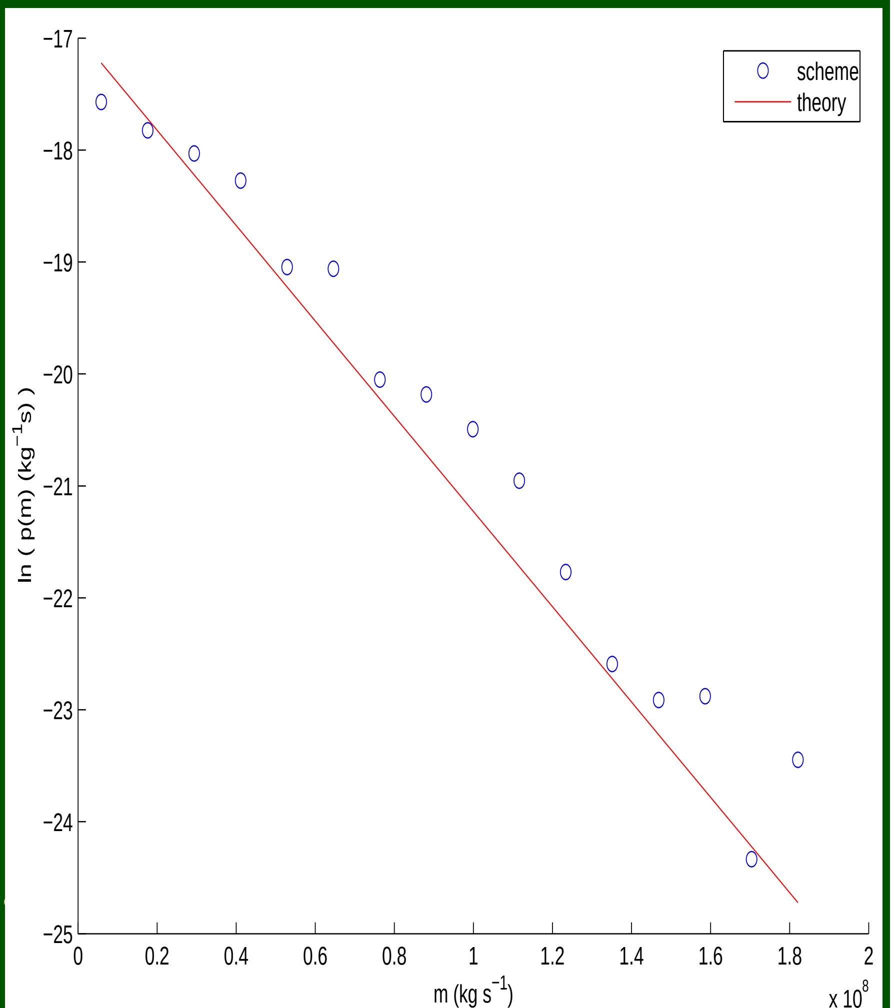
Averaging area: $144\,\mathrm{km}$ square.
Averaging time: 67 minutes.

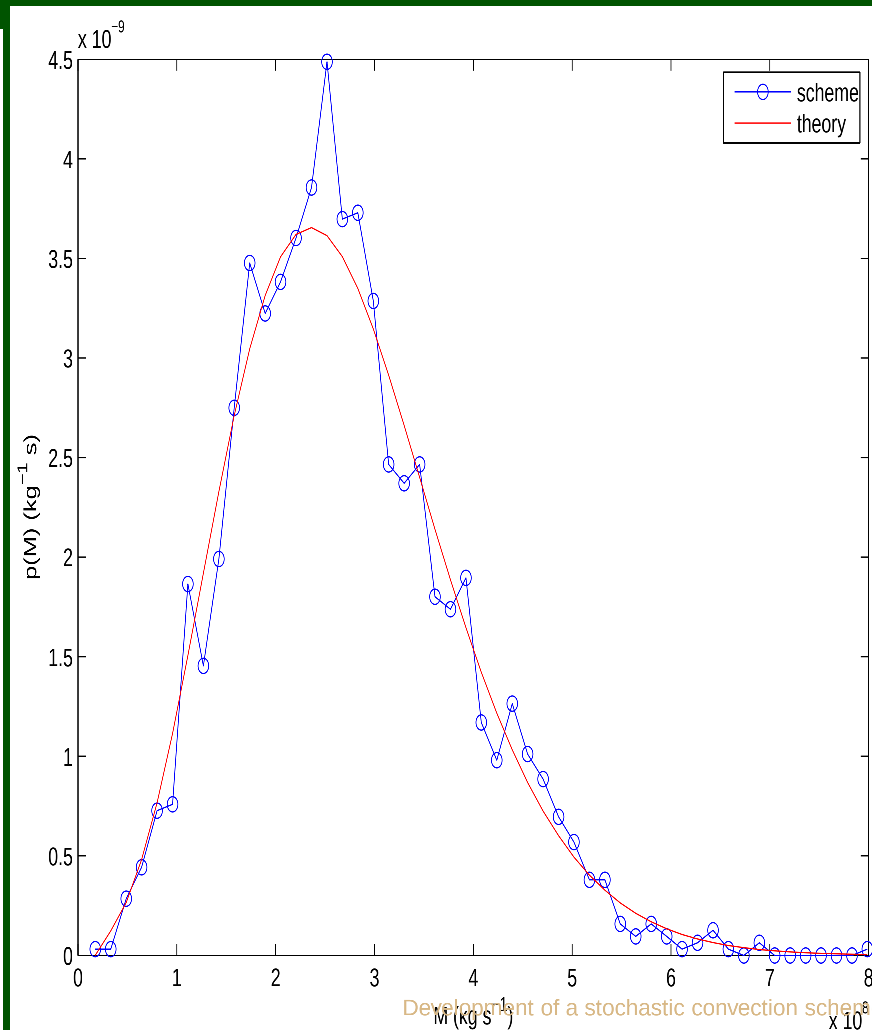




PDFs of m and M for 51 km

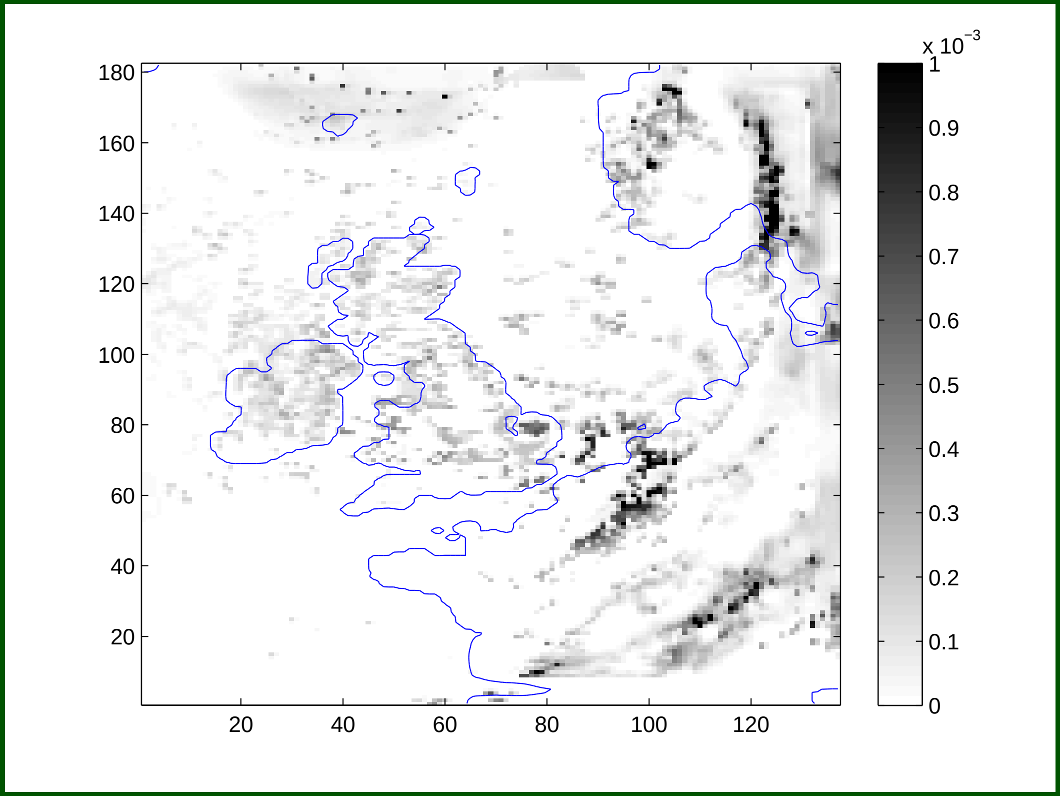
Averaging area: $152\,\mathrm{km}$ square.
Averaging time: 51 minutes.



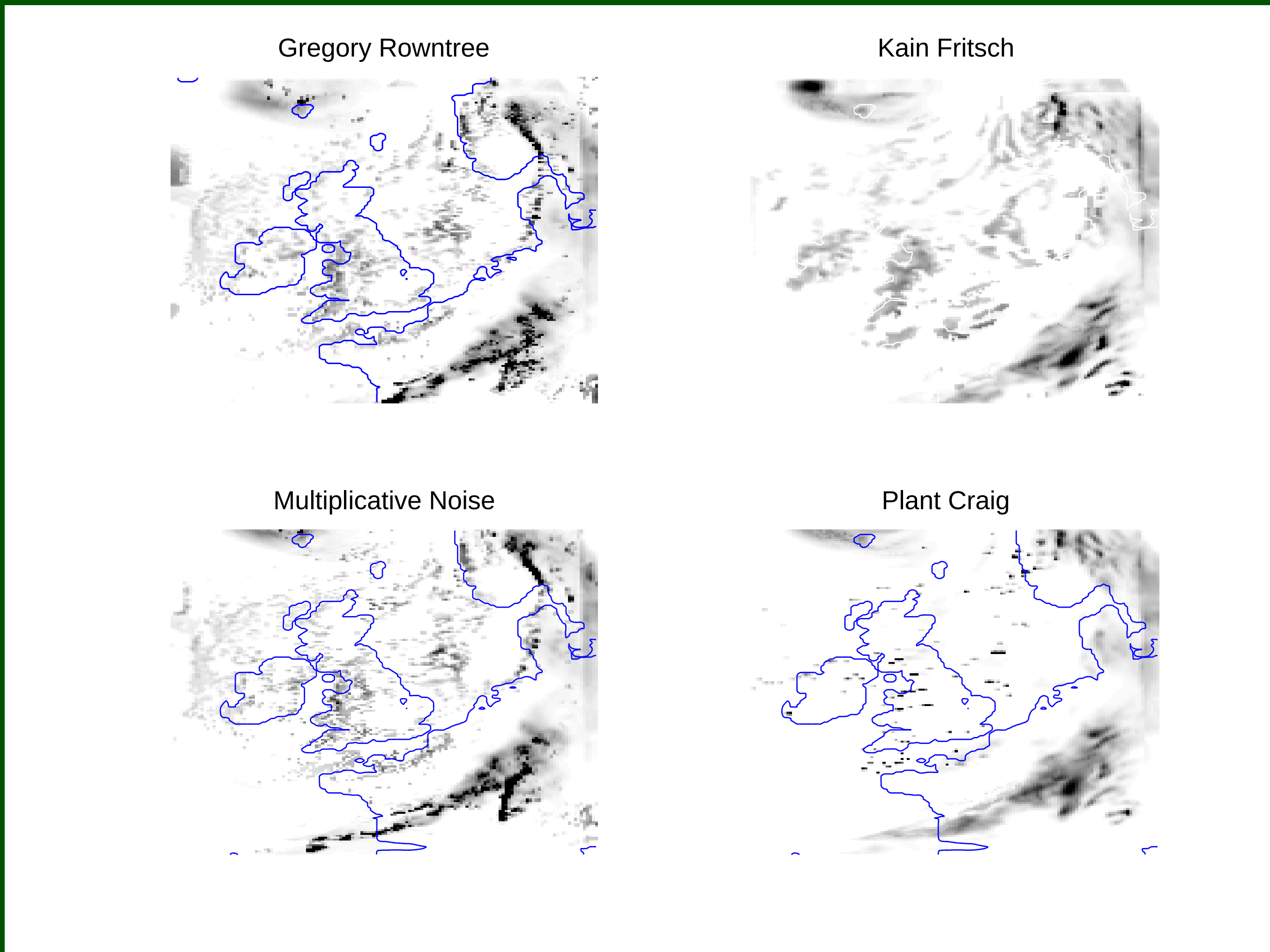


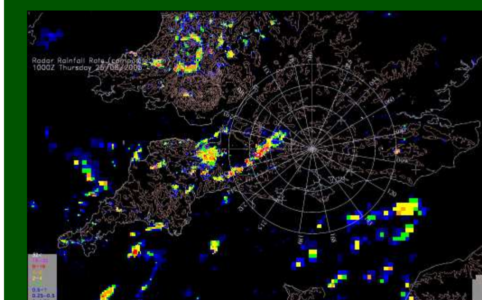
Case study: CSIP IOP18

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

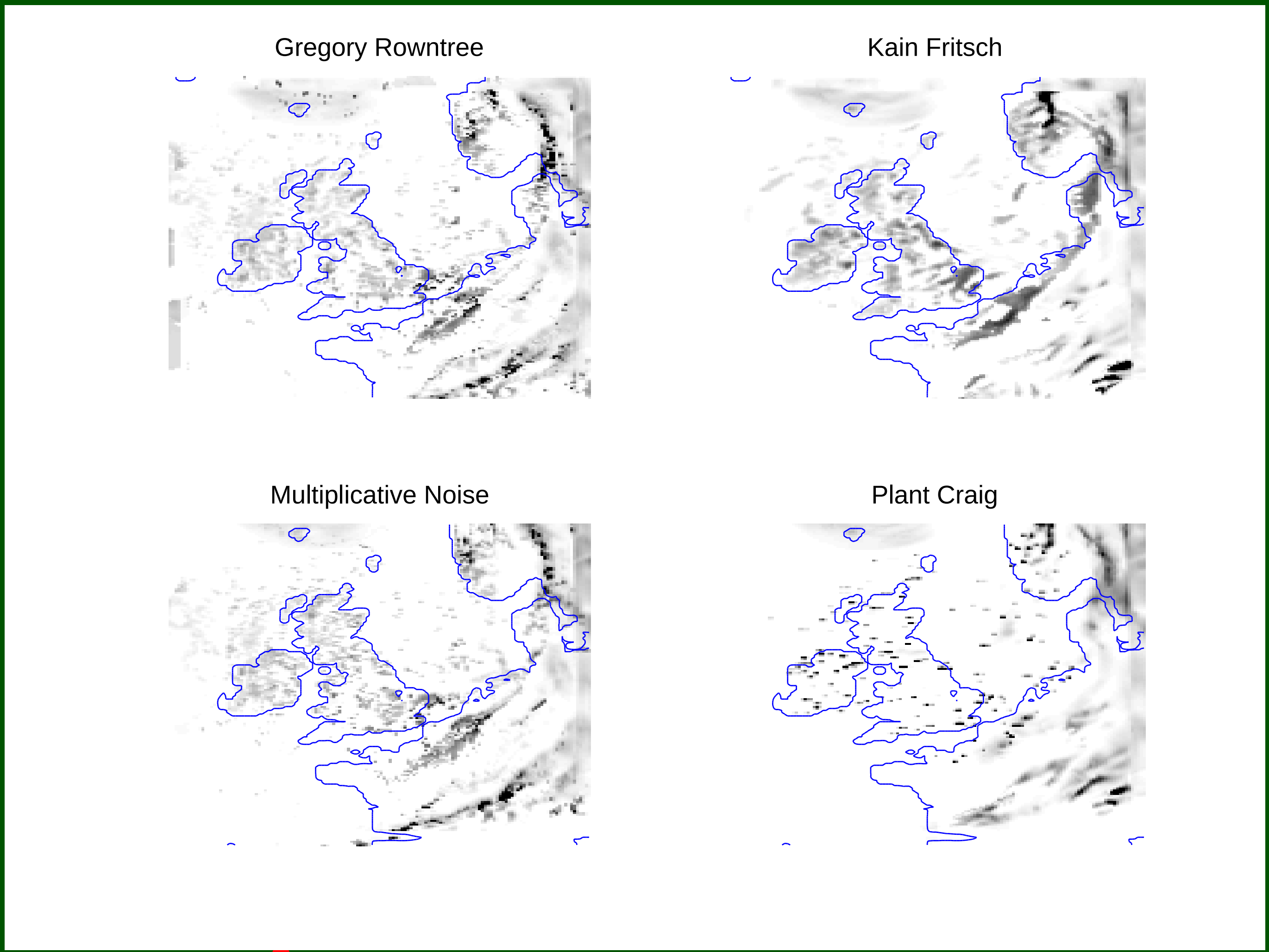


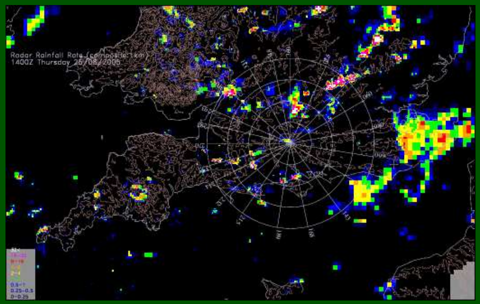
Comparison between models and rainfall radar: 1000Z





Comparison between models and rainfall radar: 1400Z





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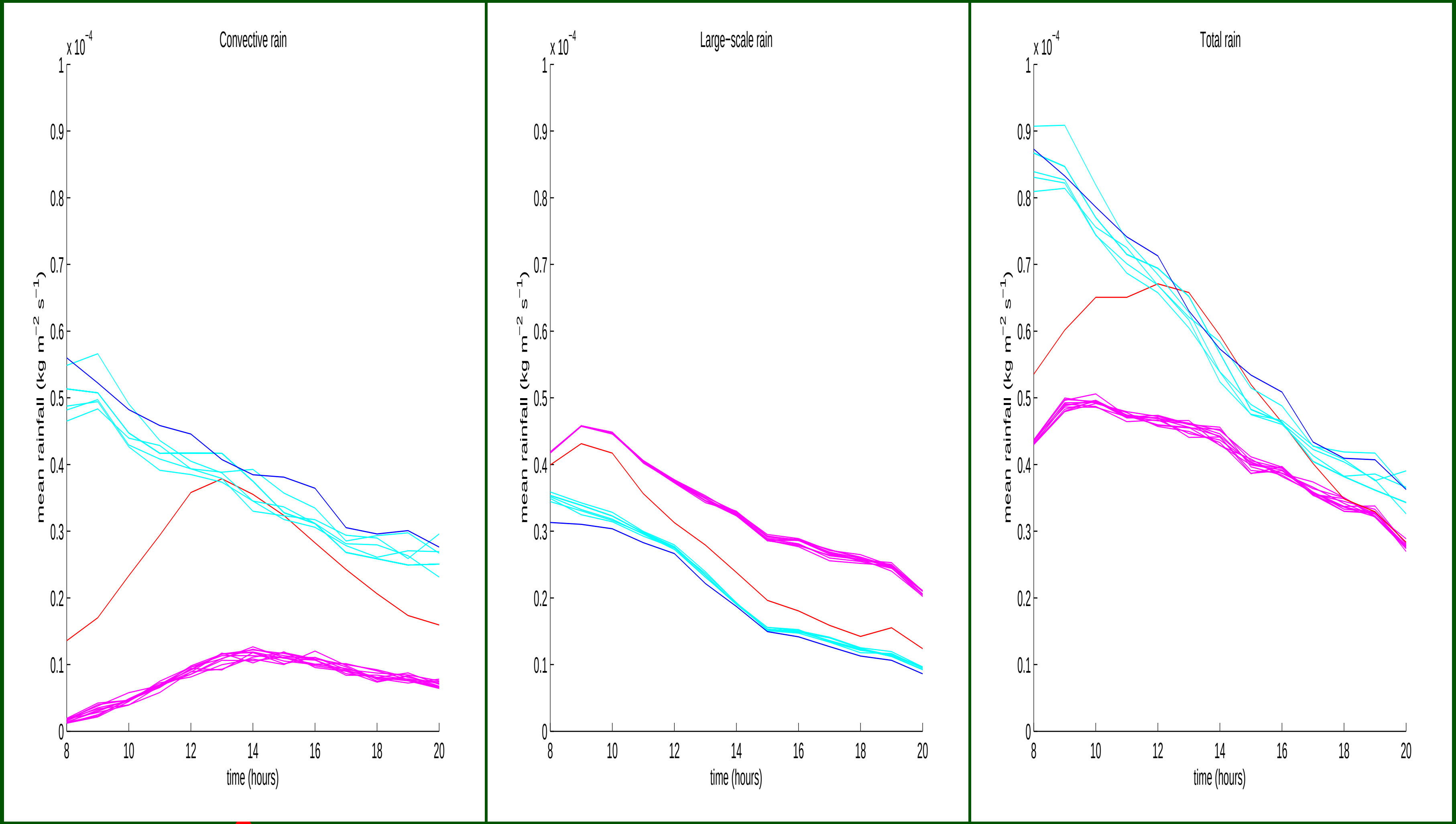
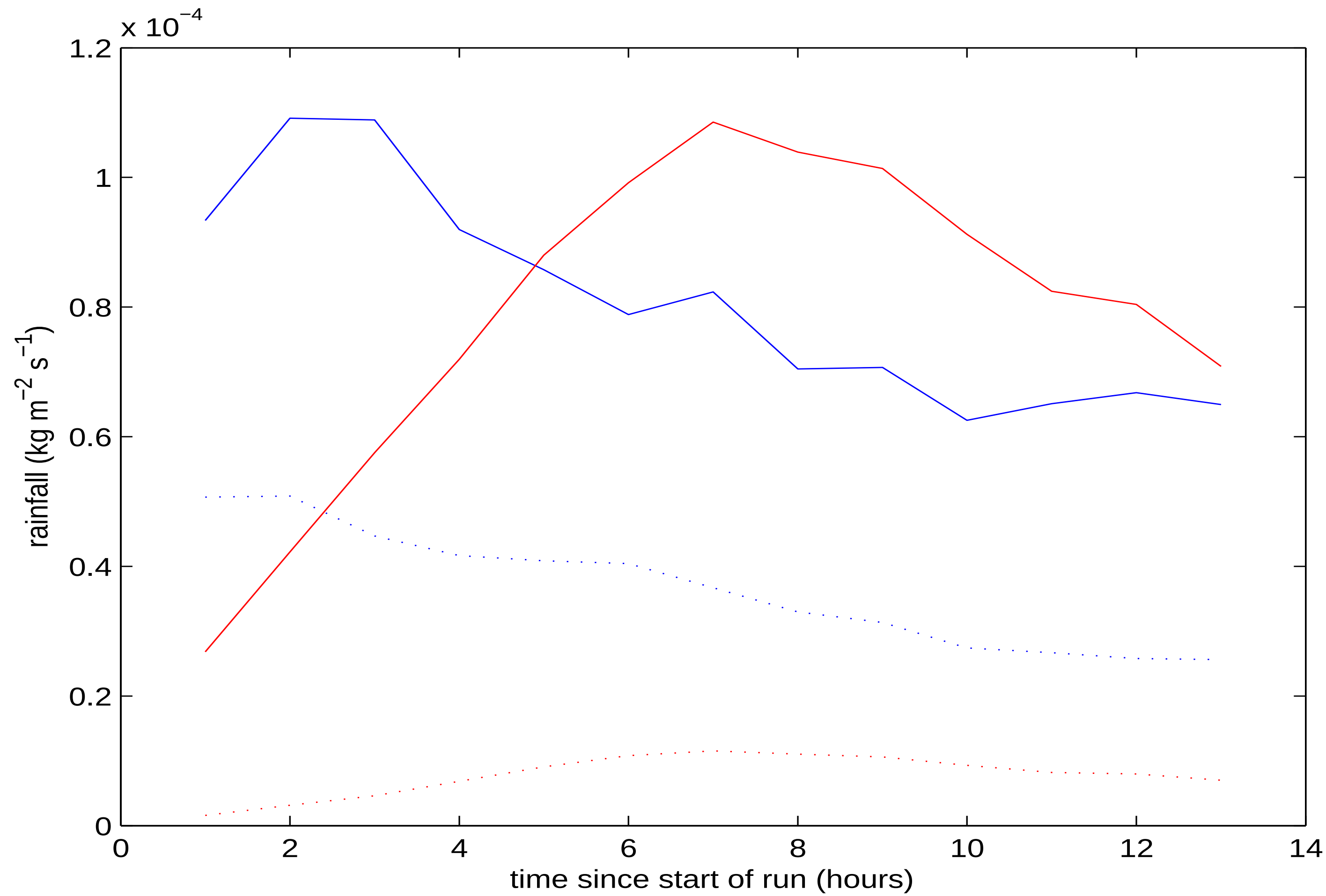
Average rainfall against time for different models



RMS of rainfall against time for two stochastic models

red – Plant Craig; blue – Multiplicative Noise

full line – RMS convection; dotted line – mean convection



Current 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.

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Possible future work

- Select extreme events from a data set and investigate whether or not the characterisation of the high rainfall tail is improved by including the Plant Craig scheme.
- Run convection schemes “offline”, driven with coarse-grained dynamics, and investigate their characterisation of the variability of the rainfall.

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 scheme behaves sensibly in a mesoscale setup, and is ready to be implemented in an ensemble prediction system. Some work needs to be done to increase the convective fraction of the rainfall when using the scheme.