Development of the Plant-Craig stochastic convection parameterisation scheme

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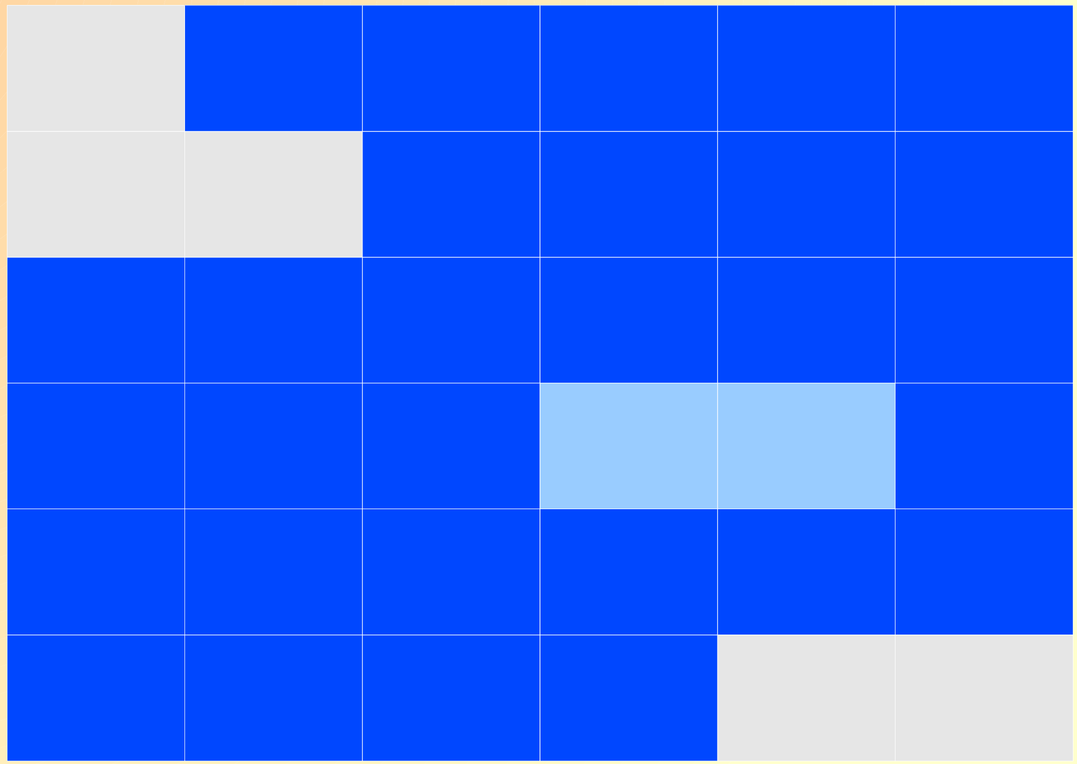
Outline

- Description of the Plant-Craig stochastic convection scheme.
- Verification of particular aspects of the scheme in an idealised setup.
- Implementation in COSMO
- Implementation in MOGREPS (UK Met Office)
- Implementation in ICON.

Convective Parameterization

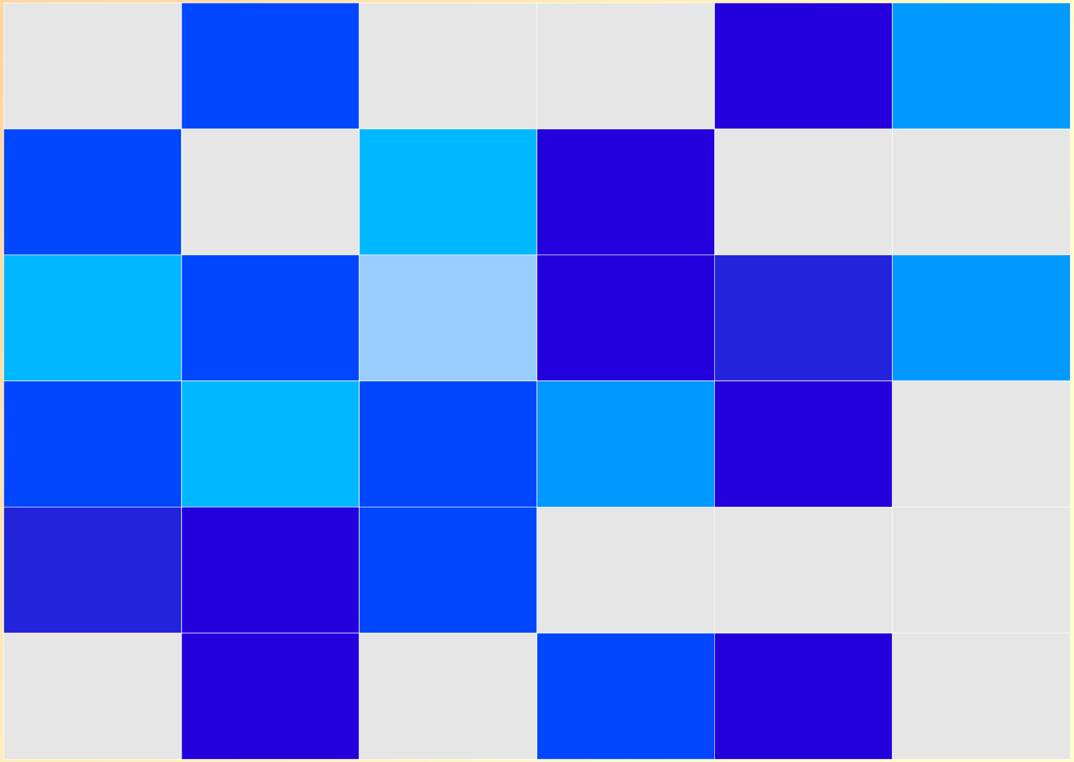
- Calculates the effect of the unresolved convection on the resolved temperature and moisture fields. Removes instability and produces convective precipitation as a bi-product.
- Commonly includes 3 components:
  - Trigger function.
  - Entrainment/detrainment calculation.
  - Closure.

Conventional convection scheme



The large-scale situation is constant over the area shown: convective variability is produced by the “binary” nature of the scheme's trigger function.

Stochastic convection scheme



The large scale situation is, again, constant over the area shown; convective variability is introduced by applying random noise to the input or the output of the scheme.

Plant Craig scheme methodology

- Obtain the large-scale state by averaging resolved flow variables in space (nearby gridboxes) and in time (previous timesteps).
- Obtain the mean total mass flux from CAPE closure and define an equilibrium PDF of mass flux per cloud, from Cohen-Craig theory verified by CRM simulations:

$$p(m)\,dm = \frac{1}{\langle m \rangle} e^{-m/\langle m \rangle}\,dm$$

- Draw randomly from this distribution to obtain the cumulus properties in the gridbox.
- Compute tendencies of grid-scale variables from the cumulus properties.

Advantages of the Plant Craig scheme

- Gives the same result as a conventional parameterisation, on larger scales at which the conventional parameterisation is valid.
- This is tested by comparing the mean state, over a large domain, of the Plant-Craig scheme with those of other schemes.
- Gives physically realistic variability close to the grid scale.
- Adapts automatically to different resolutions (down to ~7km!).

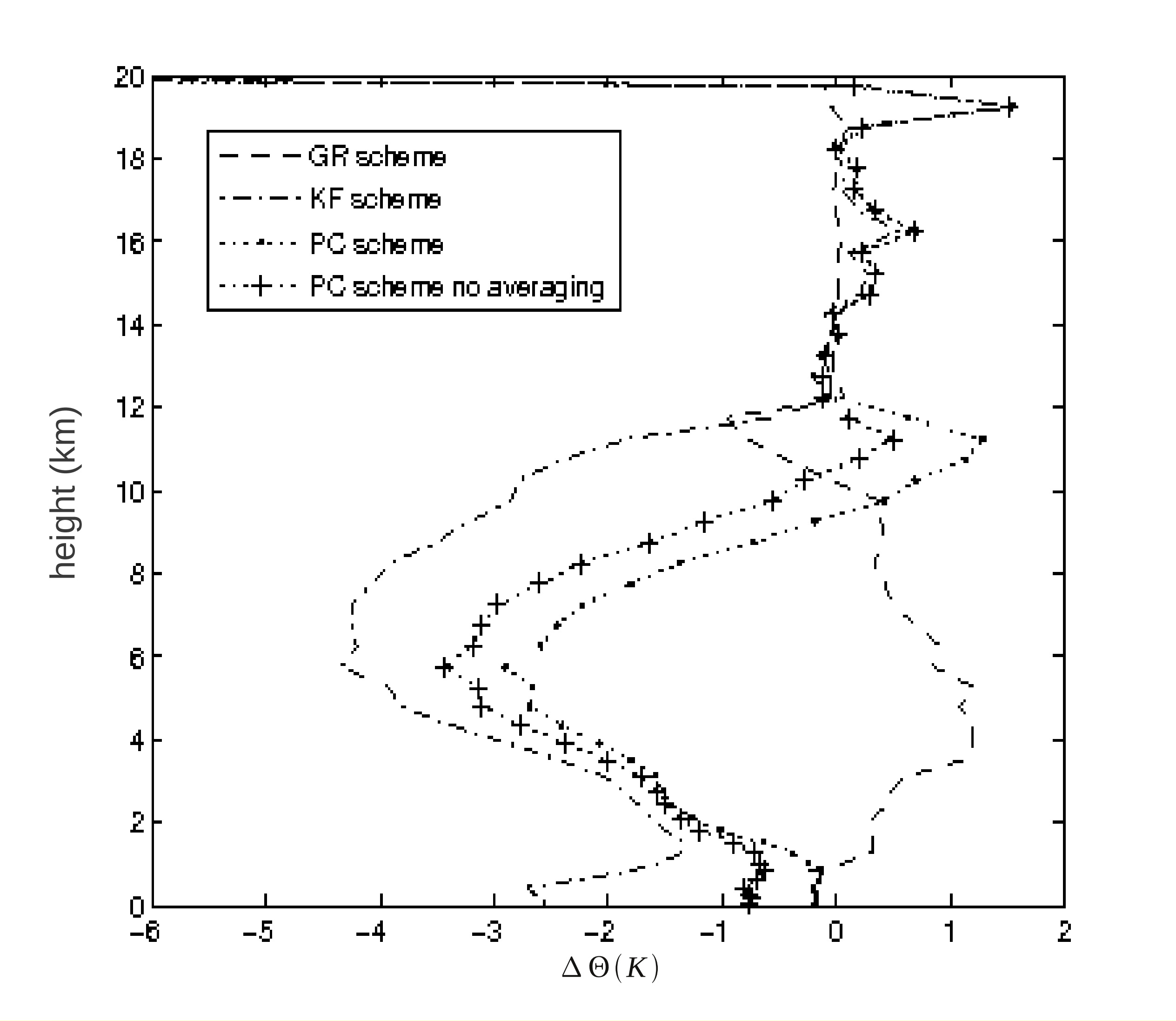
These are tested by comparing PDFs $p(\langle M \rangle, \langle m \rangle, M)\, dM$ predicted from Cohen-Craig theory (and verified by CRMs) with those from the Plant-Craig scheme, at a range of different scales and resolutions.

Radiative equilibrium experiment

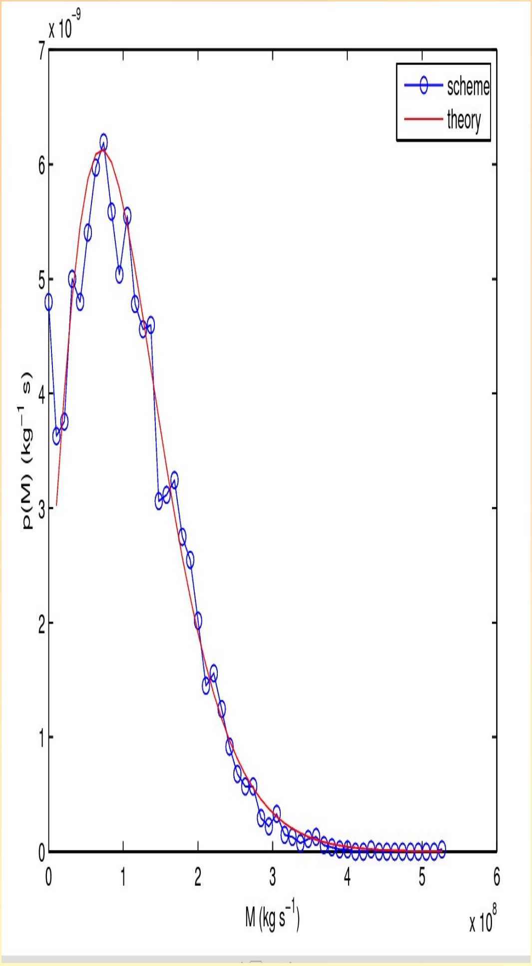
- UK Met Office UM used in idealised mode.
- Square domain, with bicyclic boundary conditions.
- Constant sea-surface temperature applied; the surface heat transfer is allowed to vary.
- Radiation is represented by a uniform imposed cooling profile.
- Grid lengths of 16km, 32km and 51km.
- The domain length is 512km.

Averaged potential temperature profile

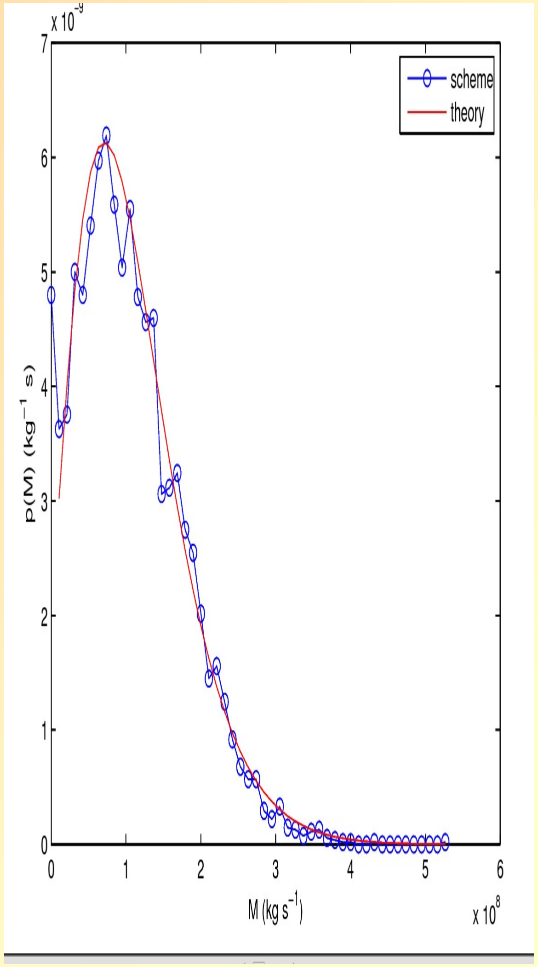
Potential temperature is meaned over the whole domain, for 3 different convection schemes. The corresponding profile for a CRM experiment is then subtracted.



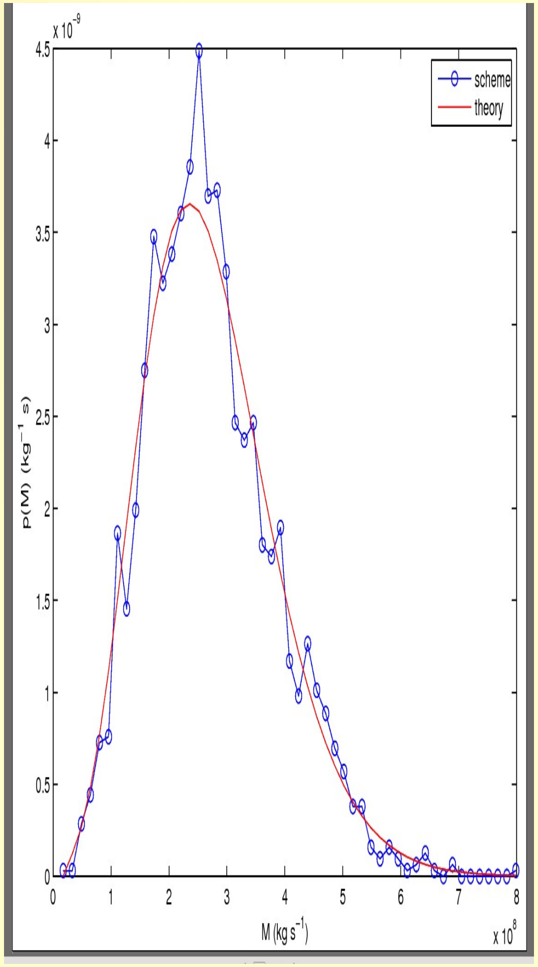
Comparison of actual PDF with Cohen-Craig theory for three different resolutions



16km



32km



51km

Rainfall PDFs

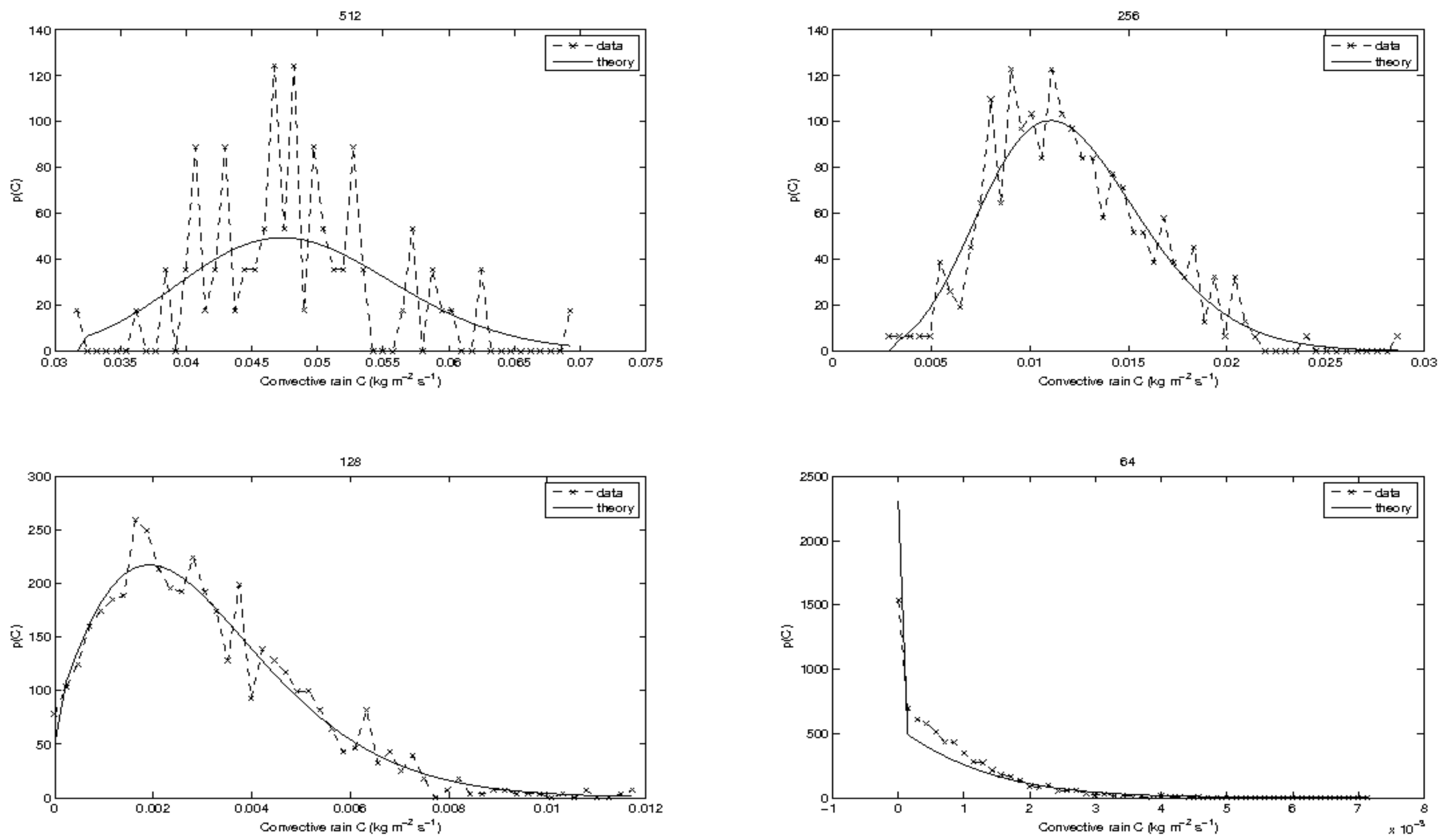
Assuming that convective rainfall *C* is a linear function of mass flux *M*, then a PDF of total rainfall can be derived, $p(C,\langle c\rangle,\langle C\rangle)dC$, with the same shape as the PDF of total mass flux.

This can then be compared with PDFs obtained from different schemes.

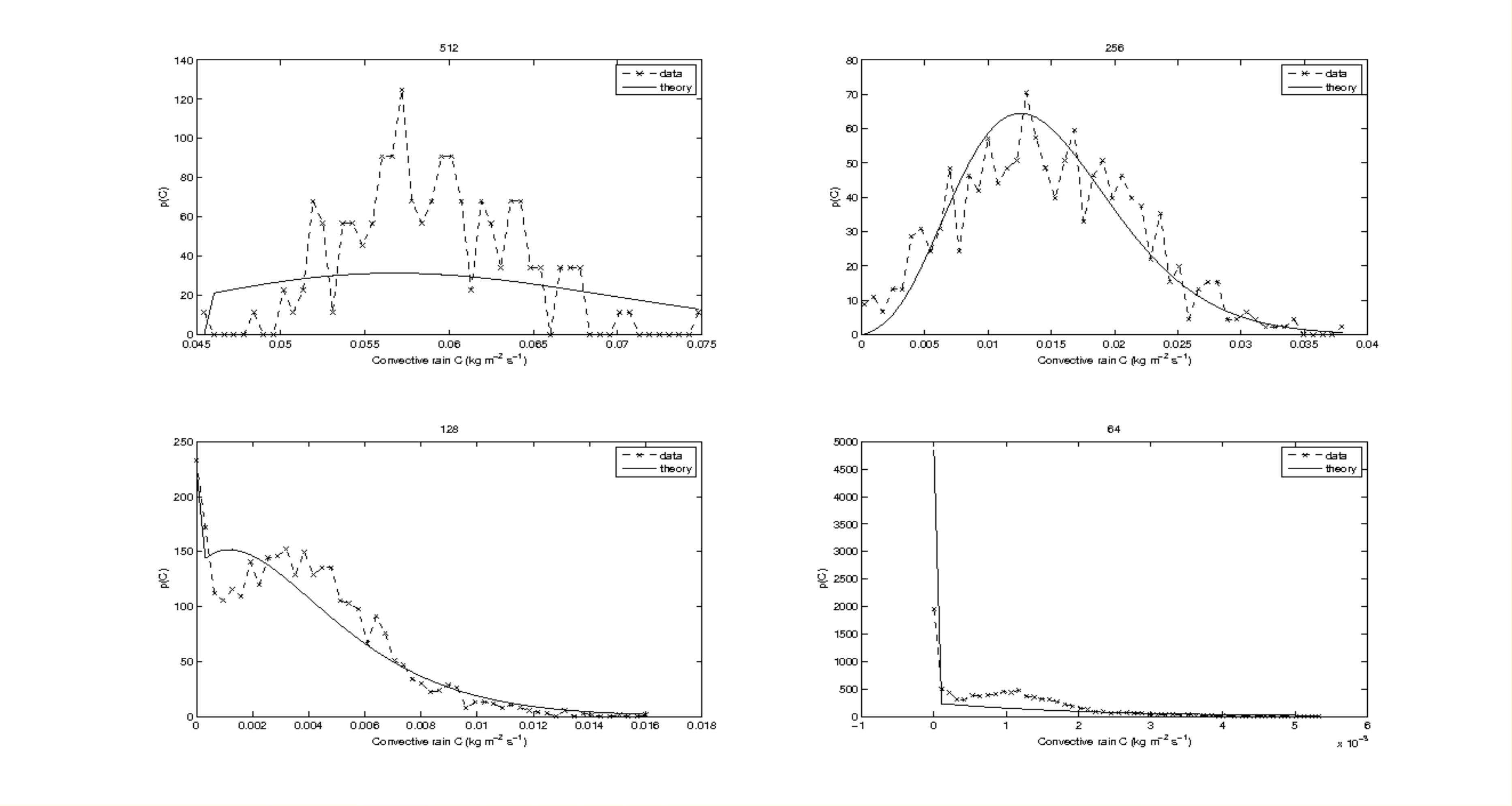
This can, of course, be done for different scales, by looking at the rainfall over different sizes (different numbers of gridboxes).

Because $\langle c\rangle$ is not known explicitly, it is fitted to give the best agreement, for **one** scale. This **same** value is then used for **all** the other scales.

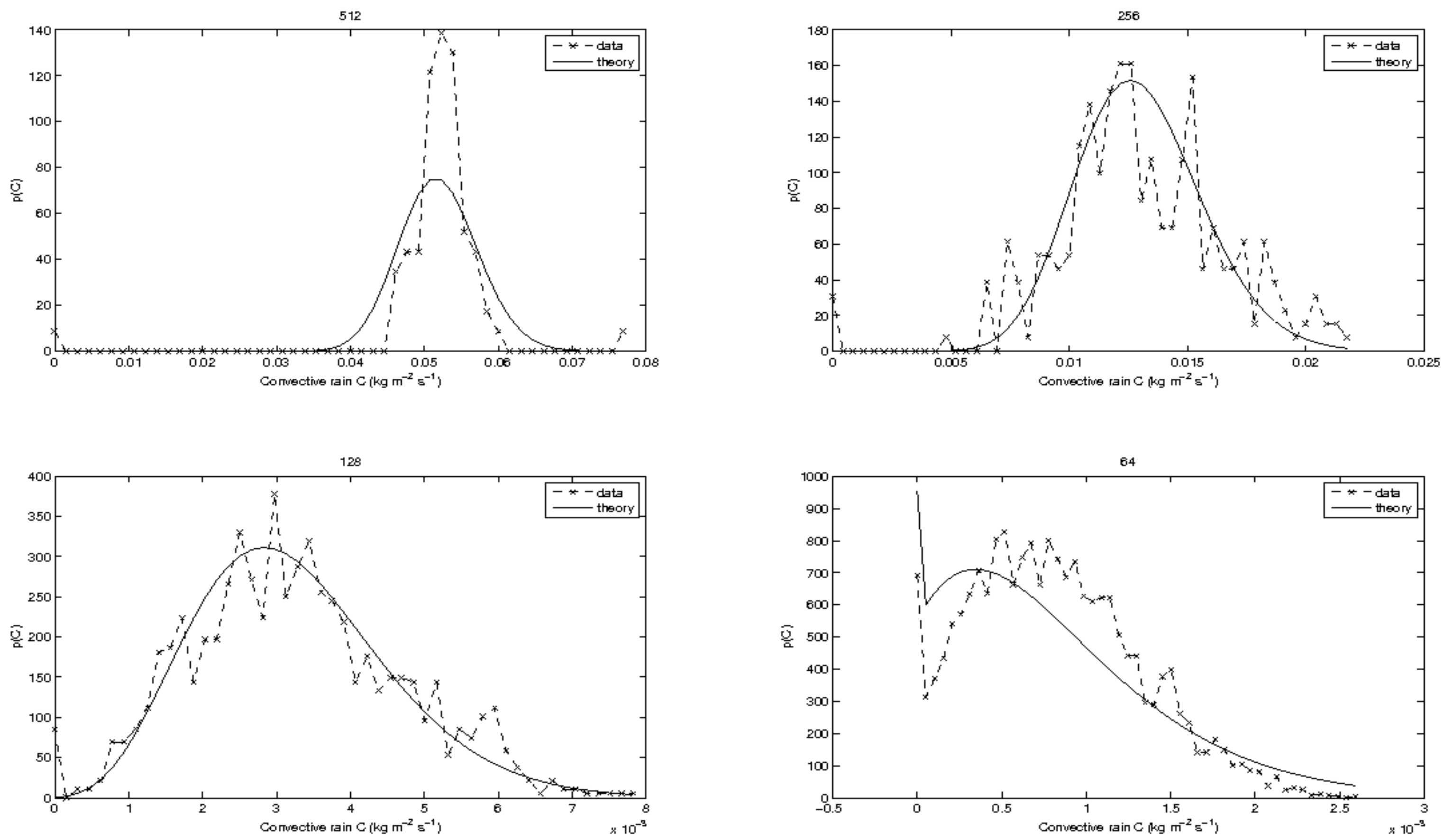
Rainfall PDFs for Plant-Craig scheme



Rainfall PDFs for Gregory-Rowntree scheme

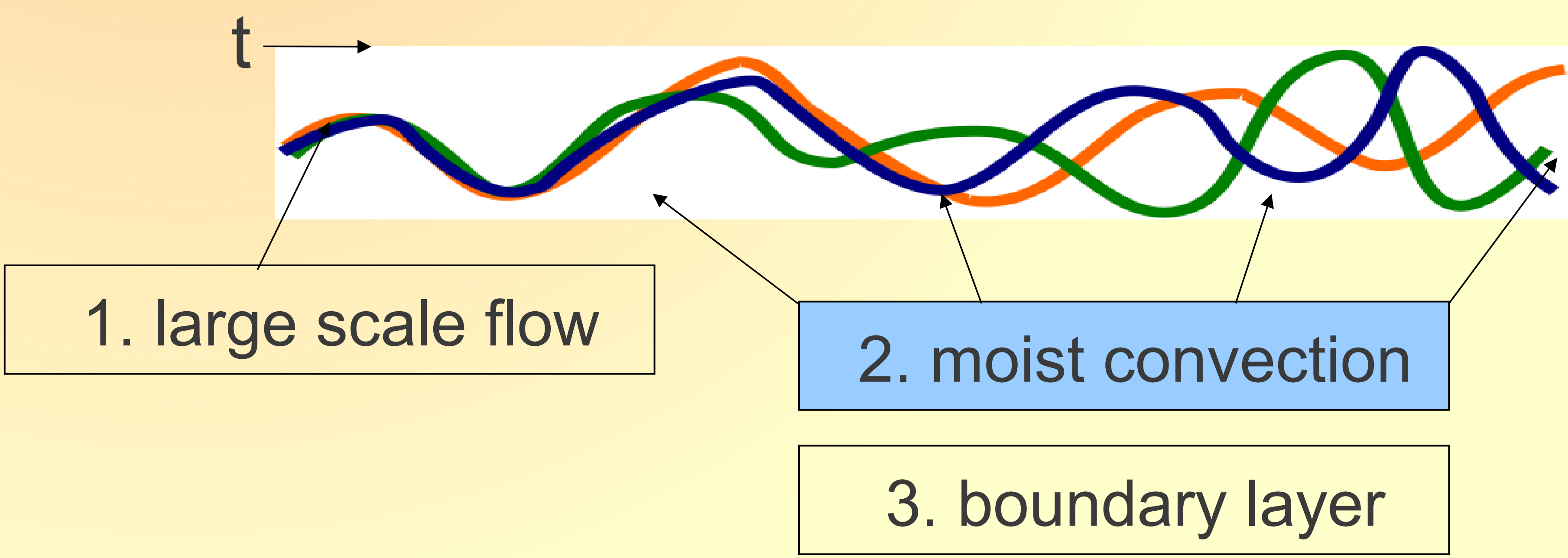


Rainfall PDFs for Kain-Fritsch scheme



Plant-Craig scheme in COSMO: the PANDOWAE project

- Study the roles of large and small scales on predictability of high impact weather, such as:



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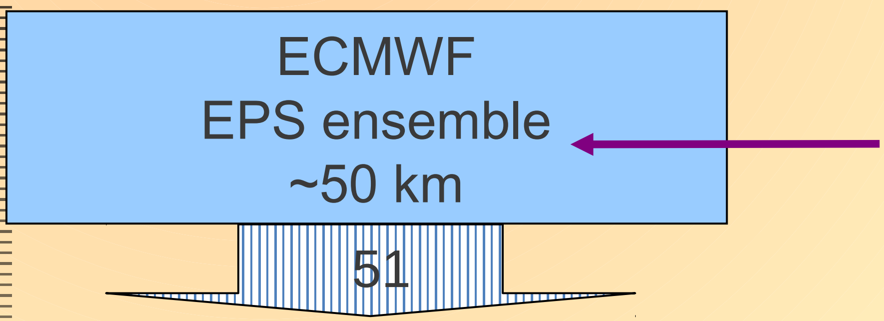
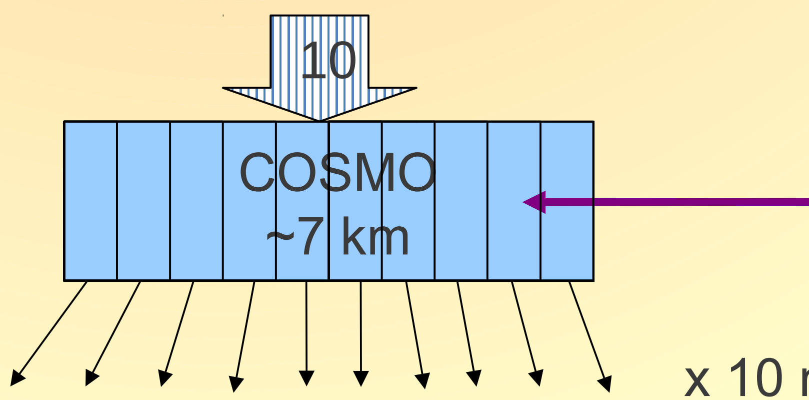
Ensemble forecast experiments



introduction of variability of the large-scale flow through initial and boundary conditions

10 members selected by
COSMO-LEPS clustering system (Molteni et al., 2001)



Each member drives 10 COSMO simulations with the Plant-Craig scheme

x 10 members

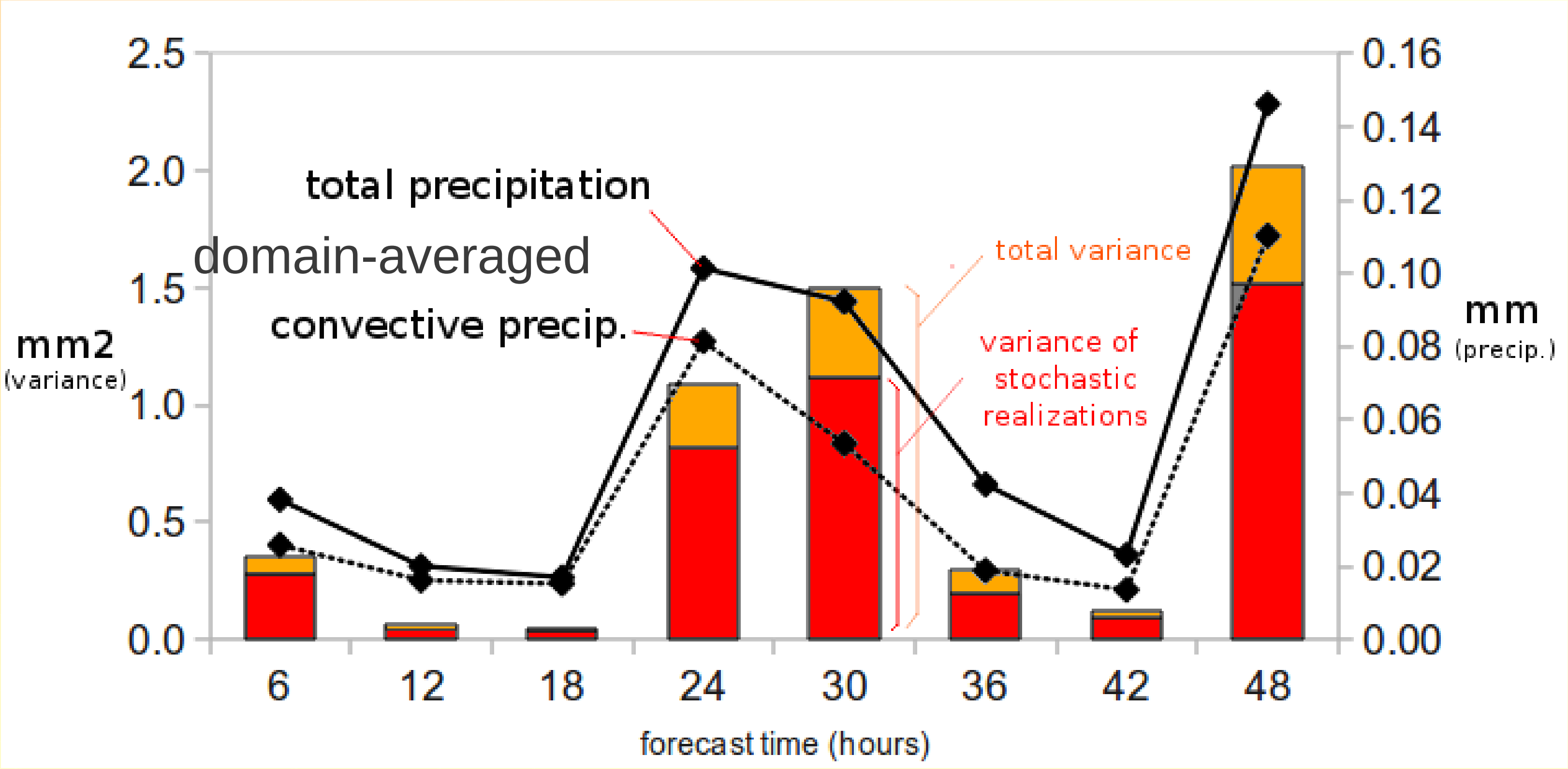
100 members

variability within group driven by 1 EPS member ("internal"), and total variability ("total")

Results

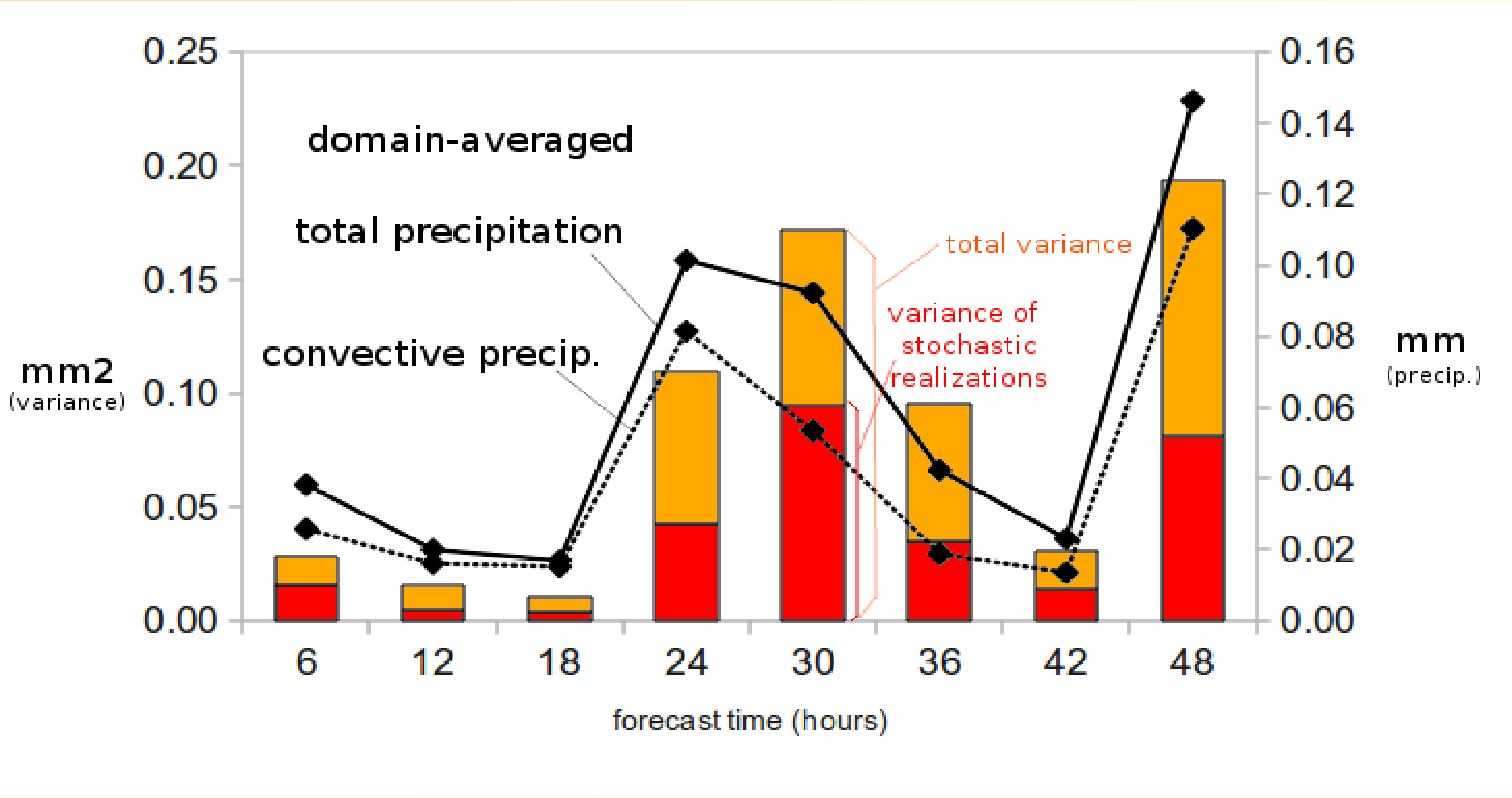
We have calculated the sample variance of 1 hourly rain accumulations for every grid point.

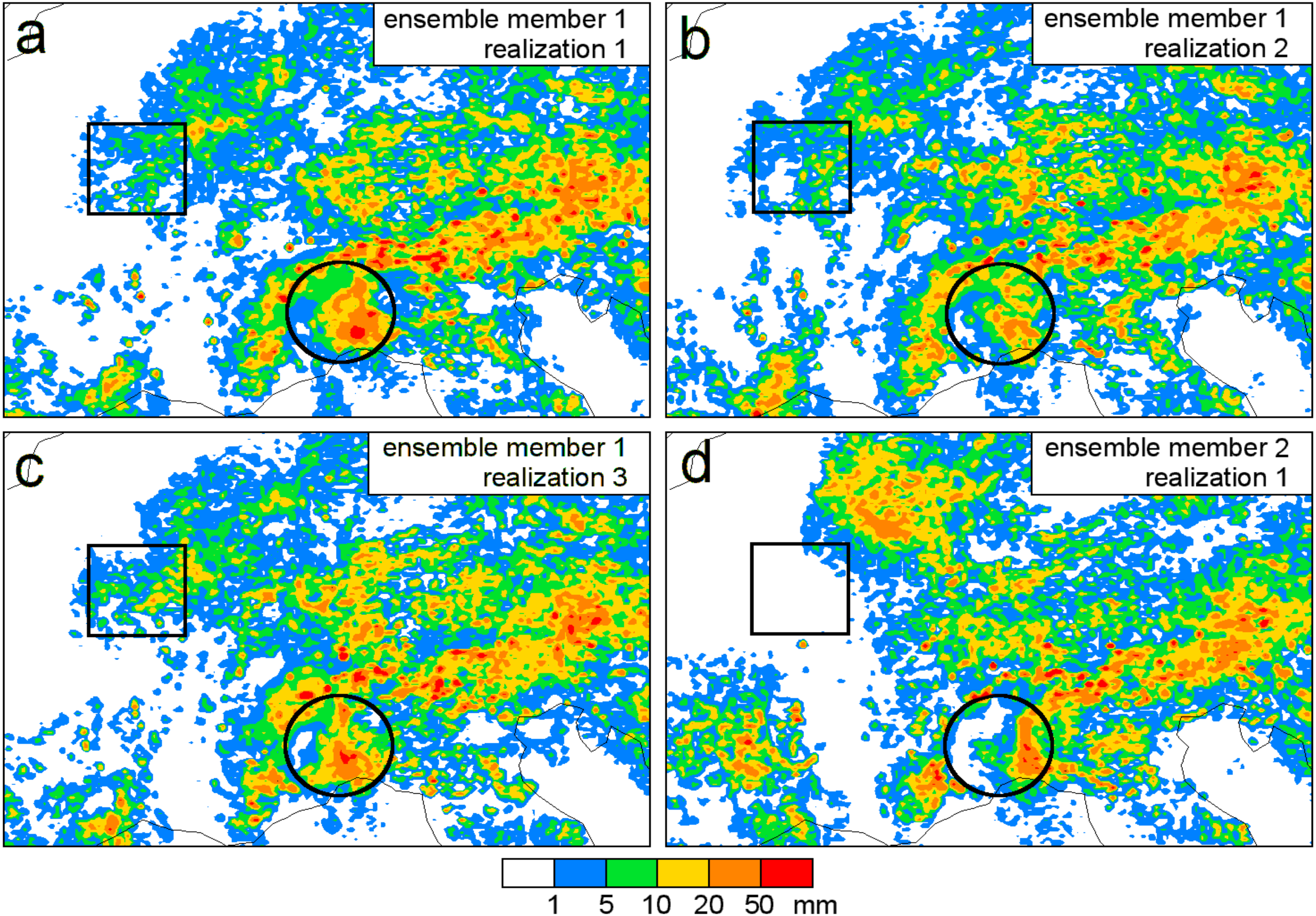
For a weakly-forced case:



Results

Sample variance smoothed over 5x5 grid points:

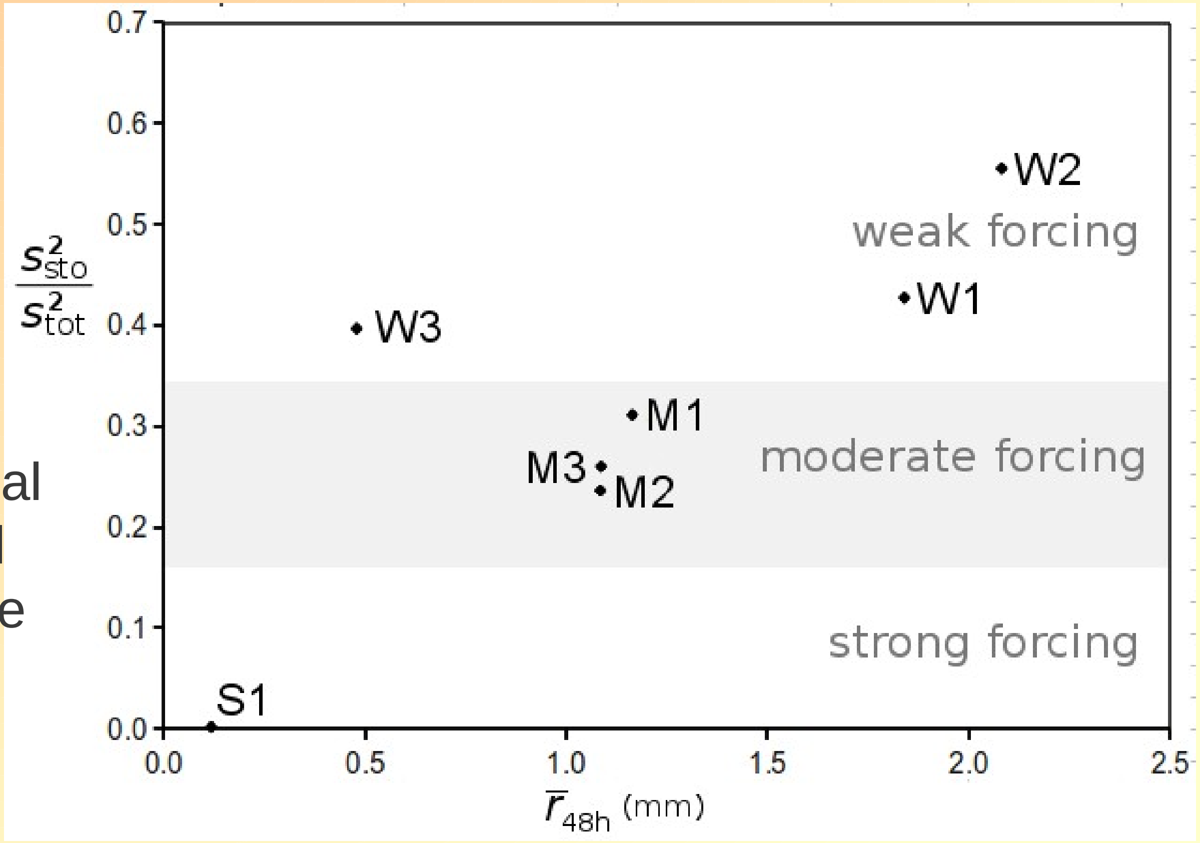




24 hour accumulated precipitation

Results

Ratio of internal to total variance

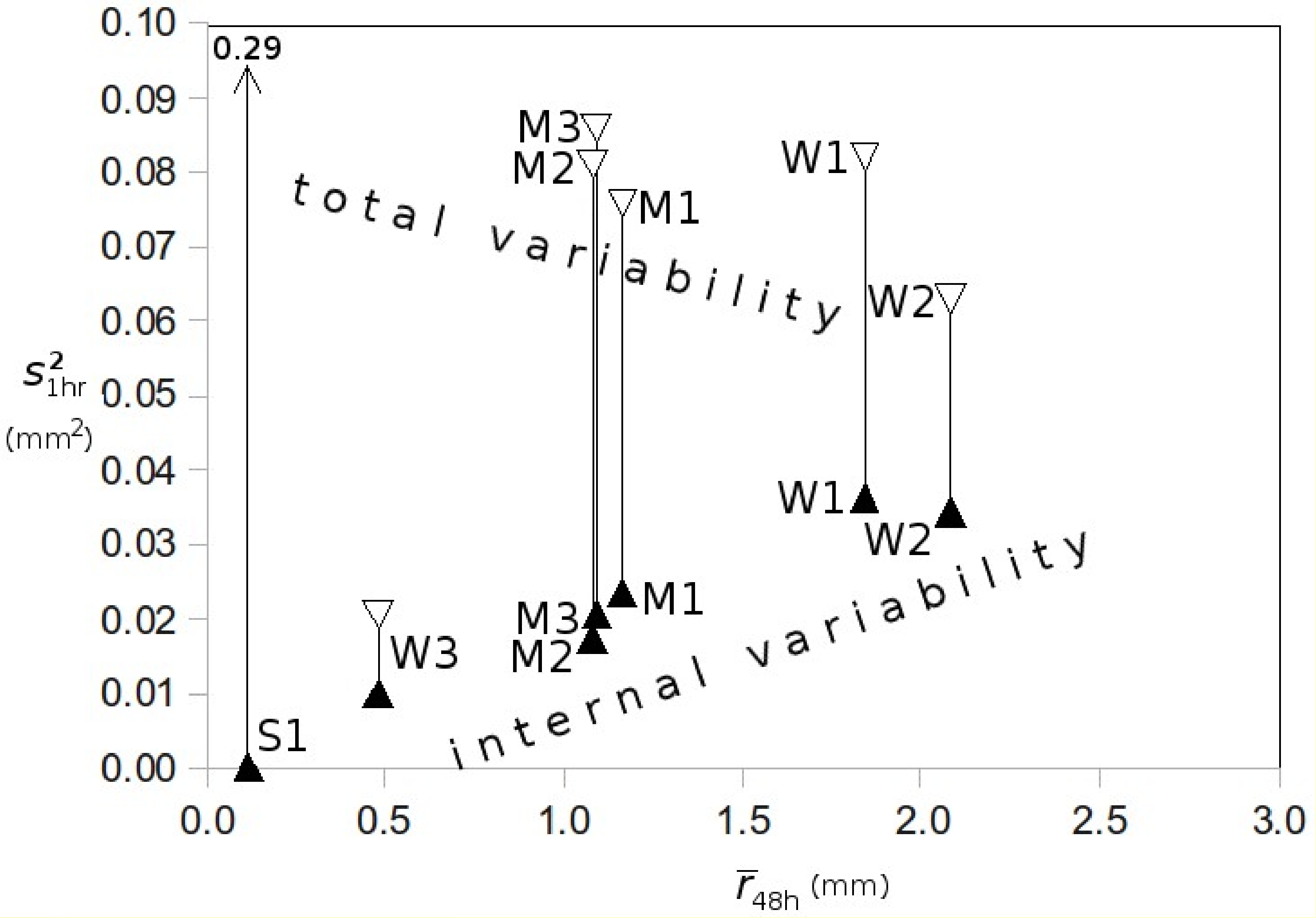


domain-averaged 48 h accumulated rain

Weakly-forced cases the internal Variance (i.e. of the stochastic scheme) Plays a relatively large role.

Results

variance

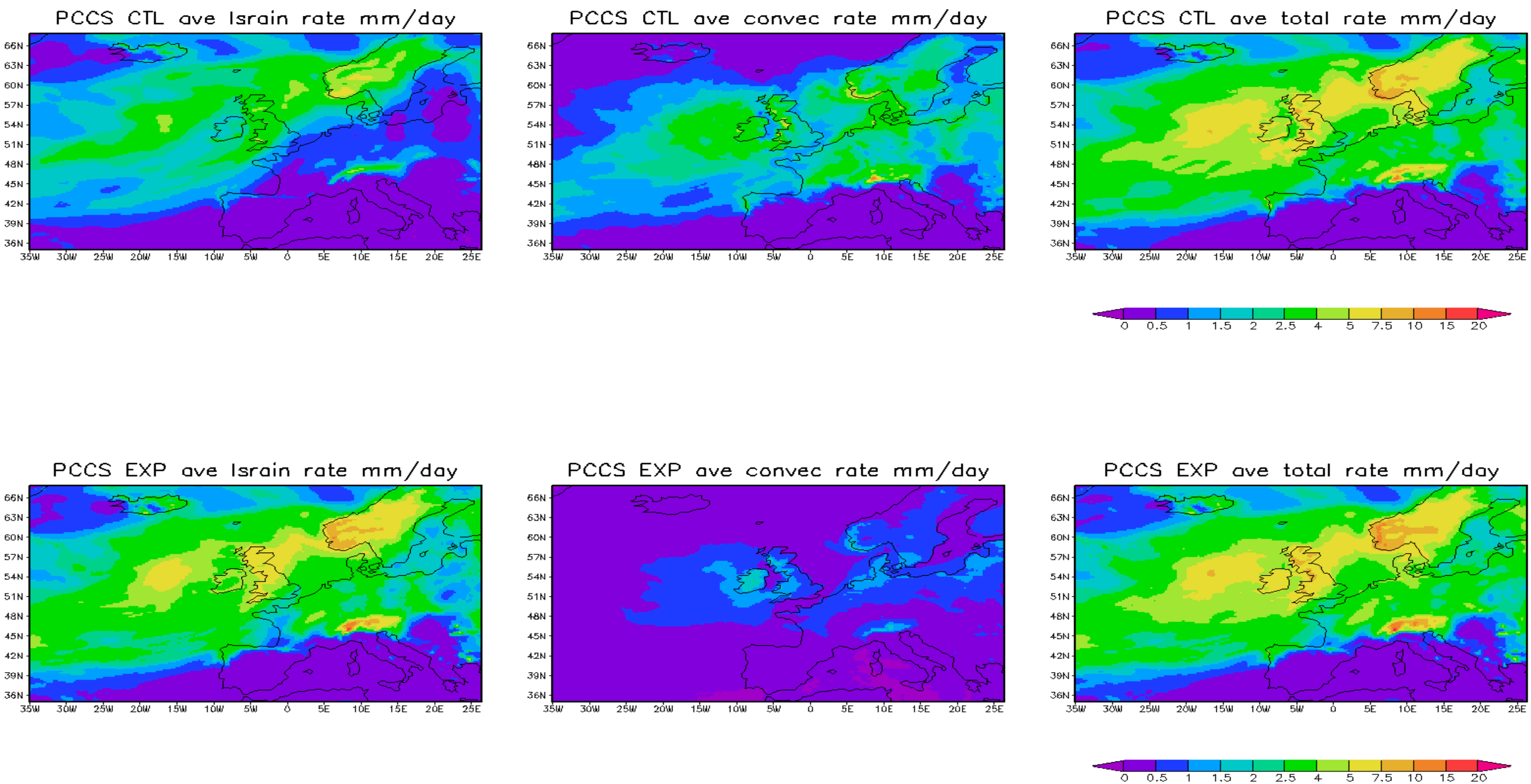


domain-averaged 48 h accumulated rain

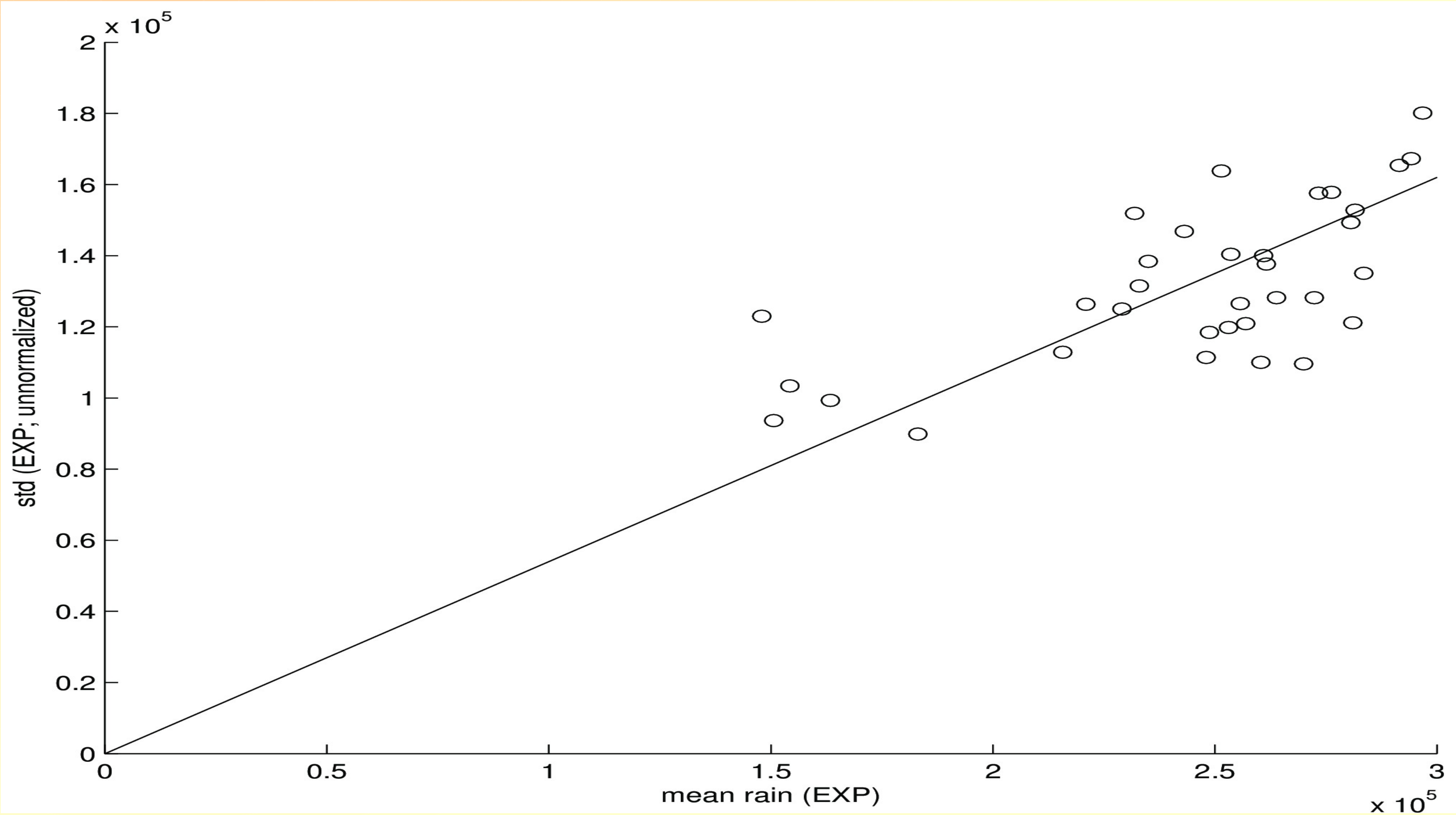
MOGREPS run

- UK Met Office 24-member limited area ensemble.
- The limited area is over Europe and the north Atlantic, driven by the Global model.
- The grid spacing is 24 km.
- Run for one month, July-August 2009.
- Forecasts twice daily, for 54 hours each.
- The standard (Gregory-Rowntree) convection scheme is replaced by Plant-Craig (and compared to the actual forecast done with Gregory-Rowntree).
- The actual forecast is labelled “CTL” and the Plant-Craig version is labelled “EXP”.

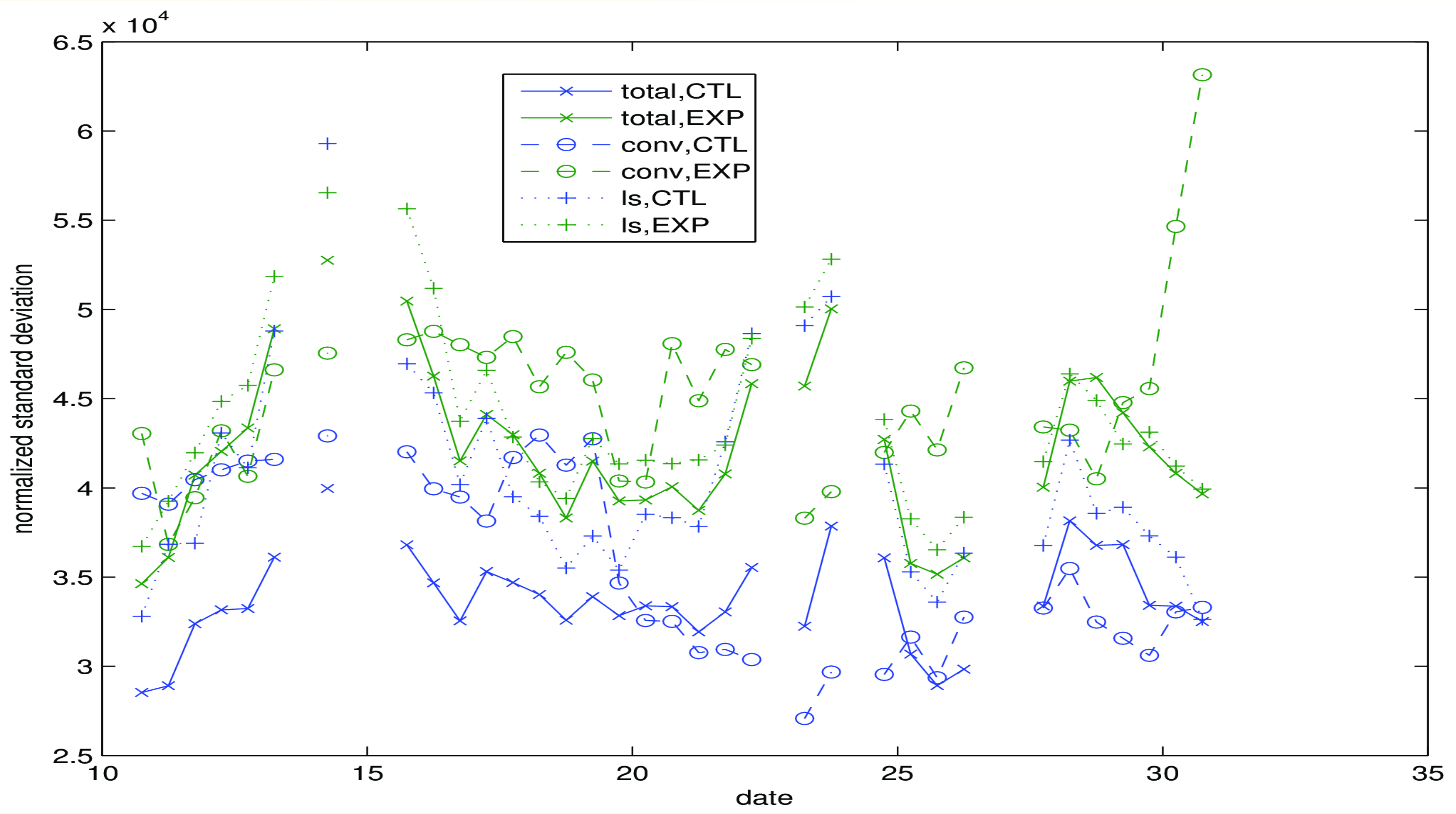
Climatology of the MOGREPS run



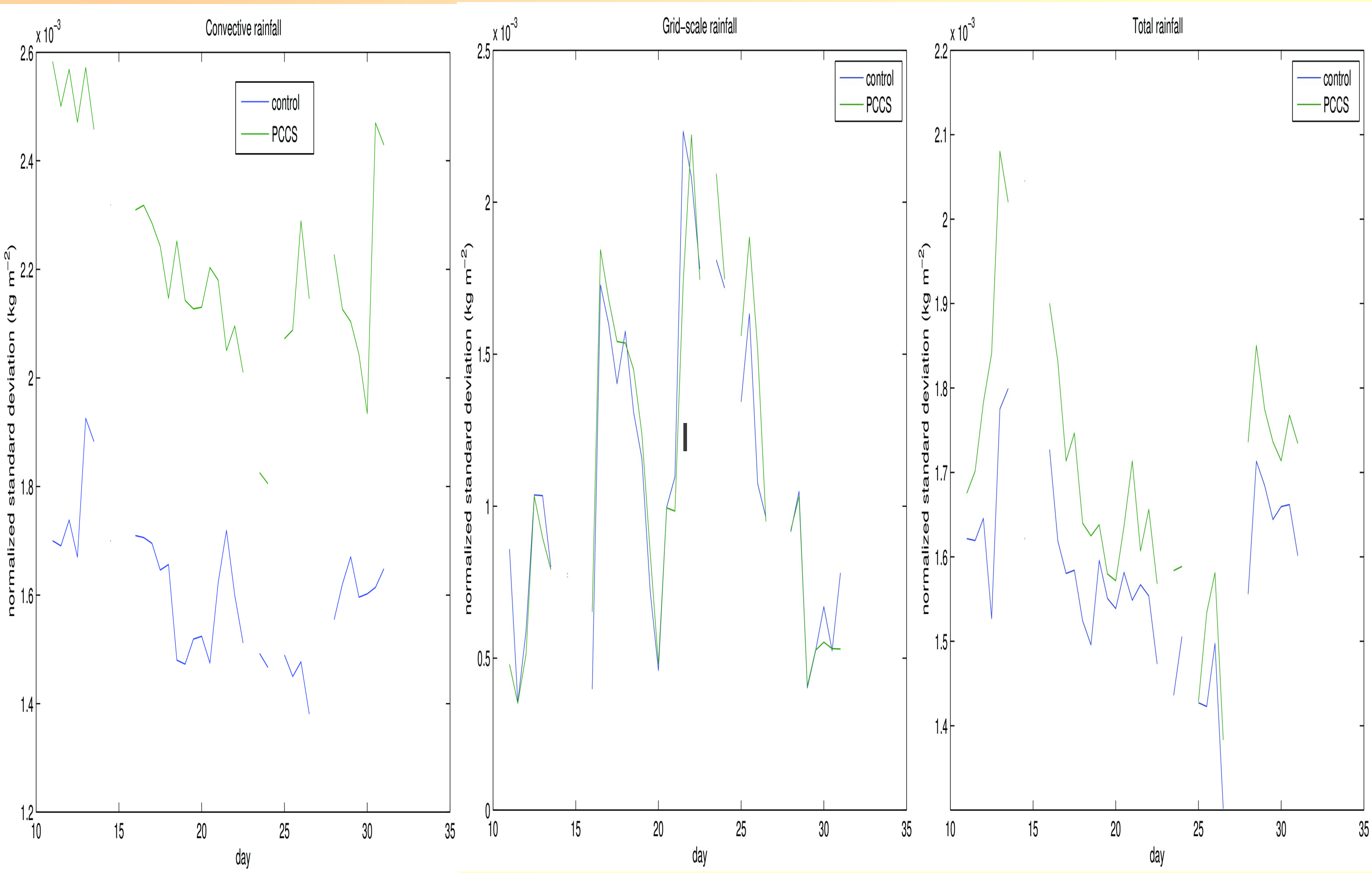
Standard deviation (across ensemble members; meaned over entire domain) of 2-day rainfall accumulation plotted against mean 2-day rainfall accumulation (both in mm)



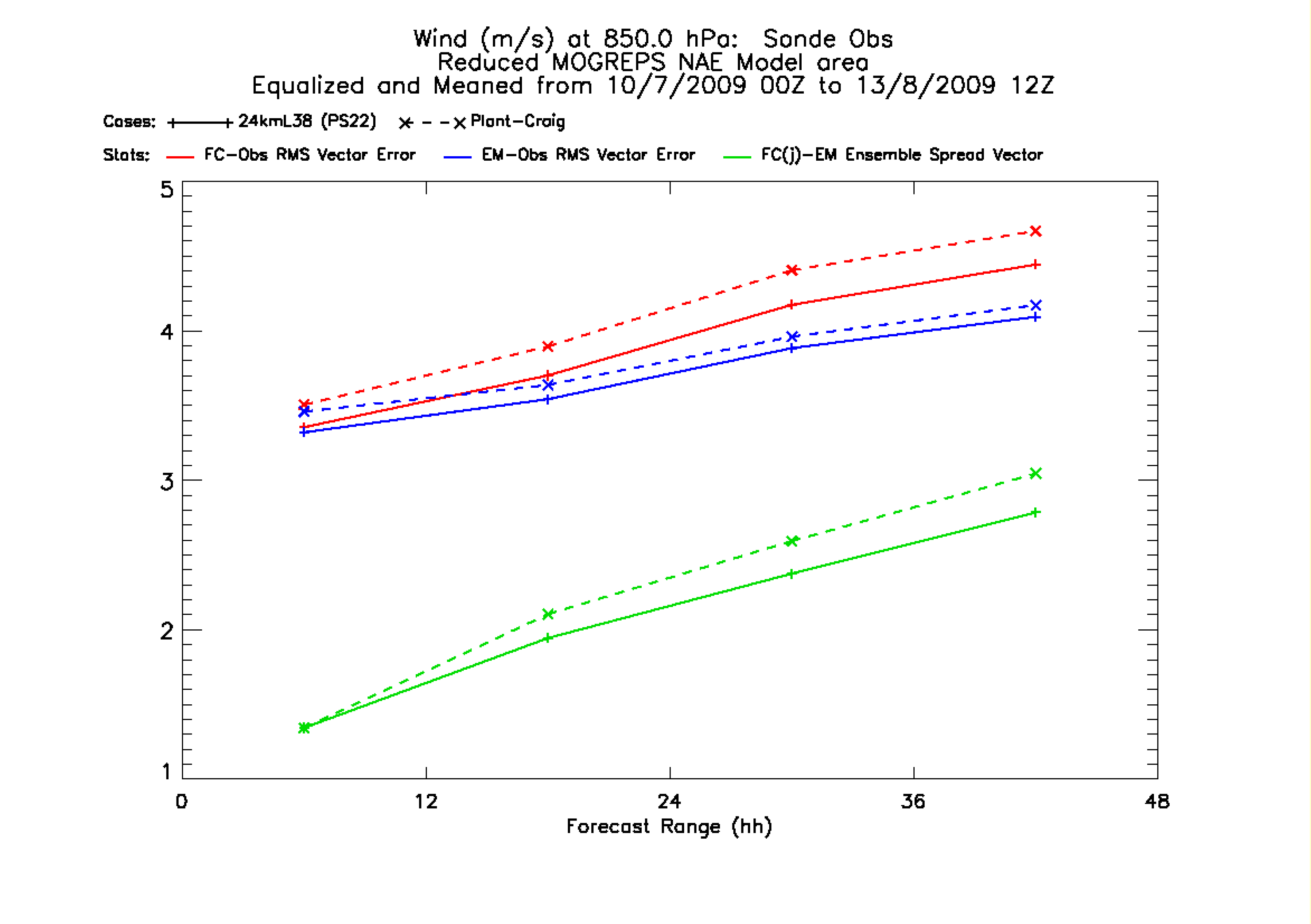
Timeseries of normalized standard deviation of rainfall accumulation, in mm



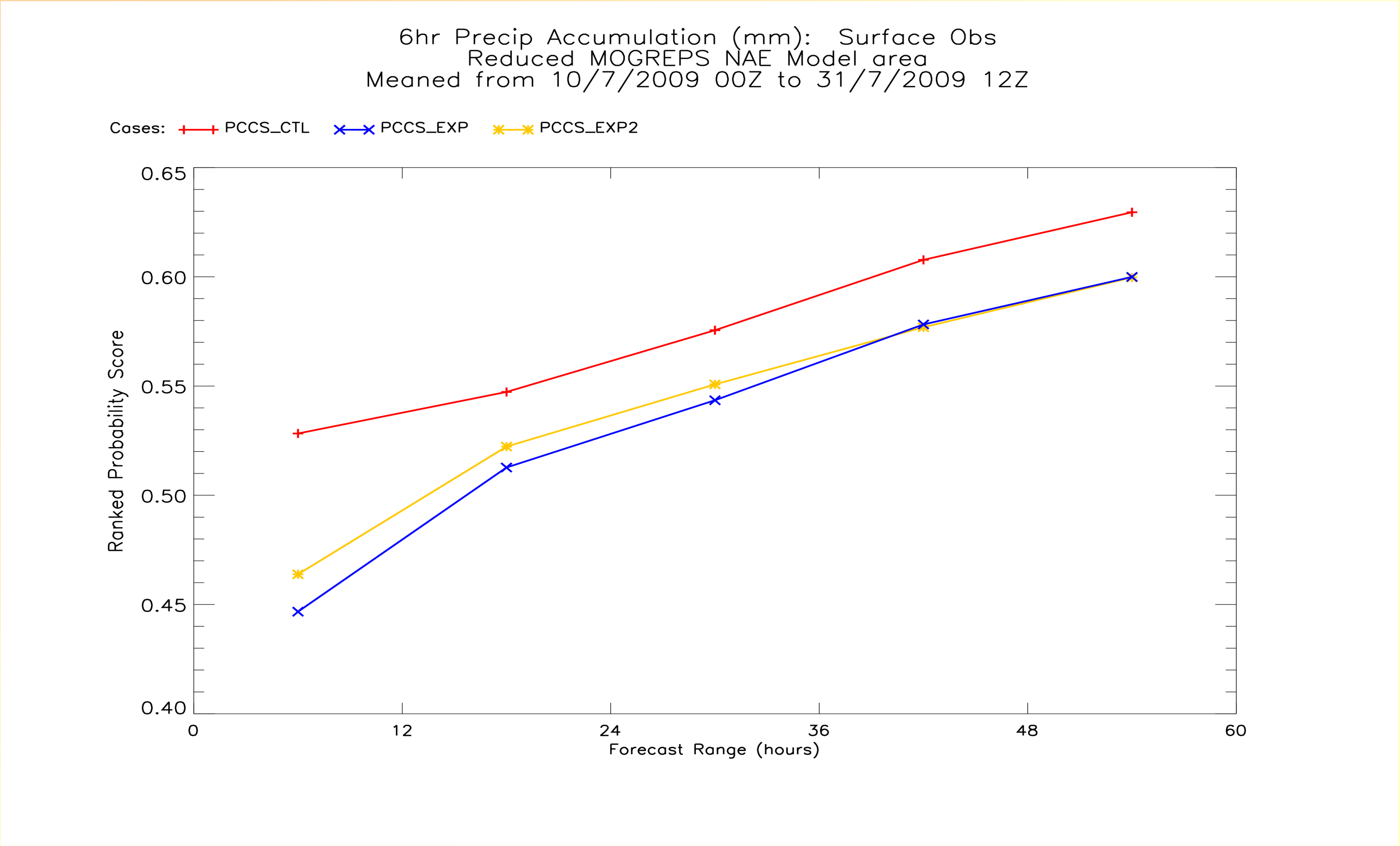
Normalized standard deviation of rainfall over 120 km blocks



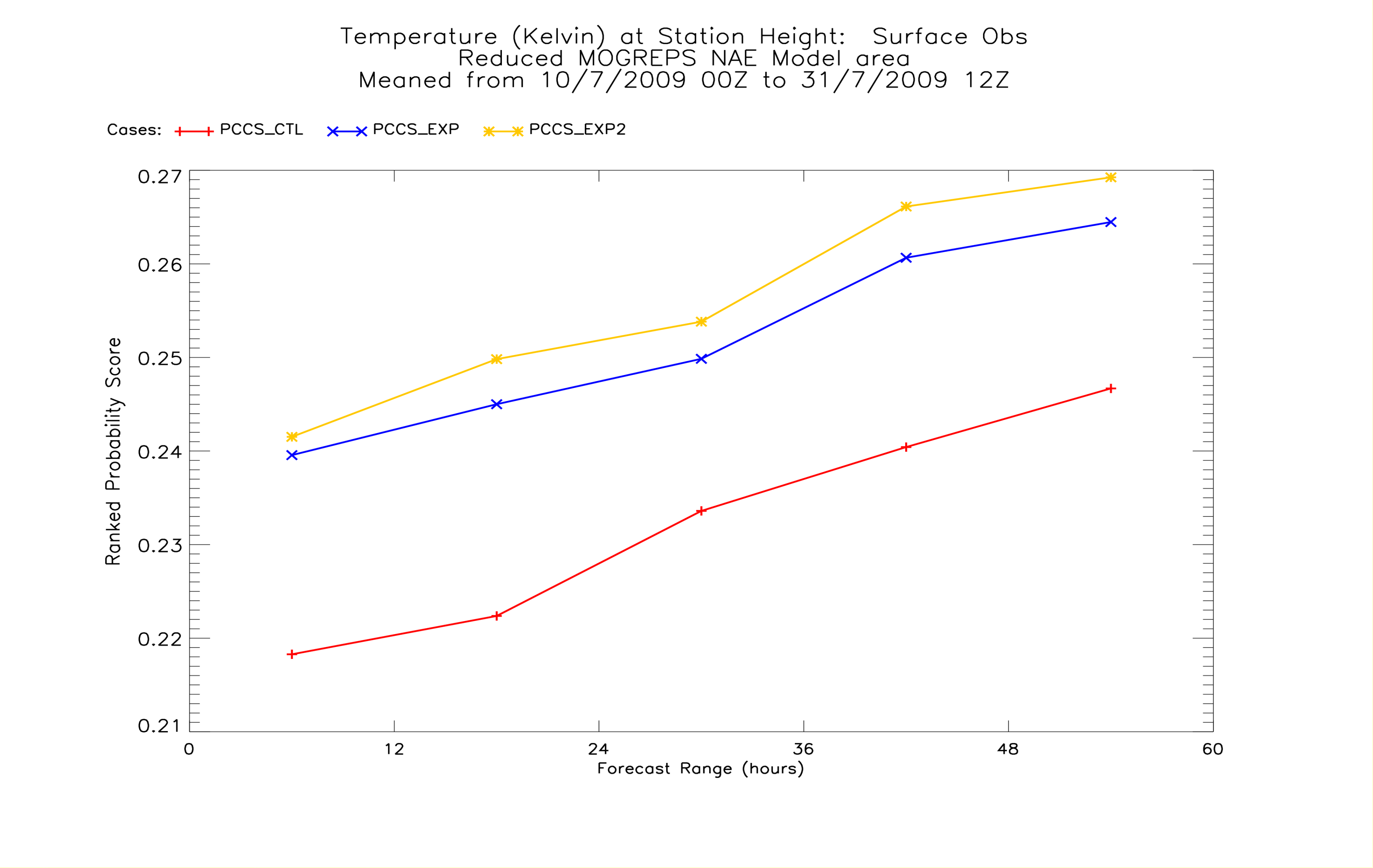
Spread and skill increases for MOGREPS run, using Plant-Craig compared with Gregory-Rowntree



Rank Probability Scores for Plant-Craig and Gregory-Rowntree: rainfall



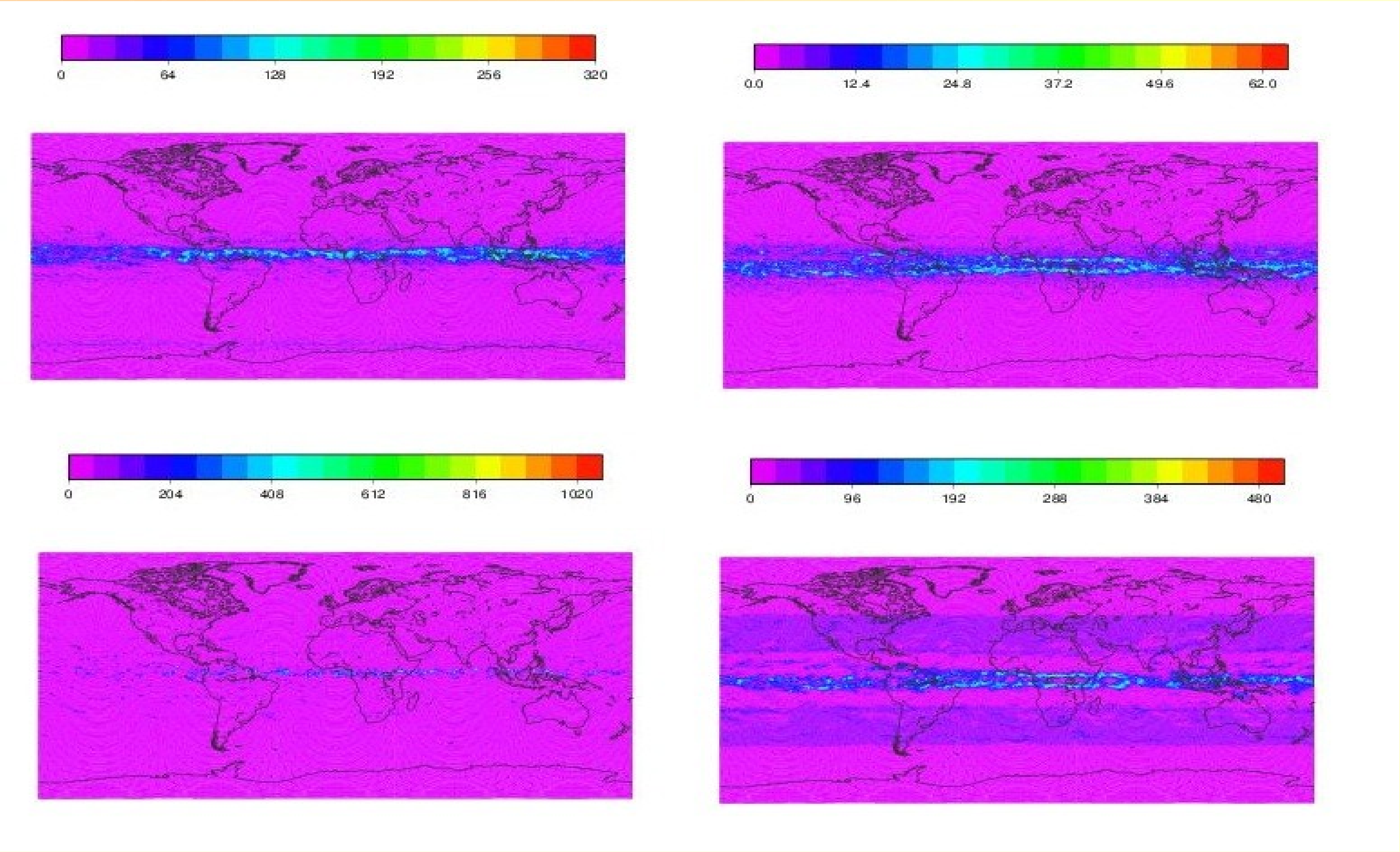
Rank Probability Scores for Plant-Craig and Gregory-Rowntree: temperature



Implementation in ICON

- The first step is to run Aquaplanet simulations in order to carry out tests of variable resolution and to investigate the effect of the stochastic scheme on the rainfall variability.
- The Plant-Craig scheme has been successfully implemented into ICON; current work is focussed on increasing its speed as it runs too slowly compared to the standard scheme.

Rainfall accumulations in ICON (after just 12.5 days!!) for Plant-Craig (left) and Tiedtke-Bechtold (right); convective rain on top and grid-scale rain on bottom



Conclusions

- The Plant-Craig scheme has been shown to better represent convective rainfall variability than conventional schemes.
- Stochastic schemes are likely to be most useful in weakly-forced cases, even when there is little convective precipitation.
- There is some evidence of upscale transfer of variability, and improvement on verification scores, suggesting that the Plant-Craig scheme has significant advantages over statistical downscaling.
- The scheme is currently being implemented into ICON, and is expected to properly handle variable resolution down to 7 km.