Stochastic cellular automata deep convection parameterization in HarmonEPS

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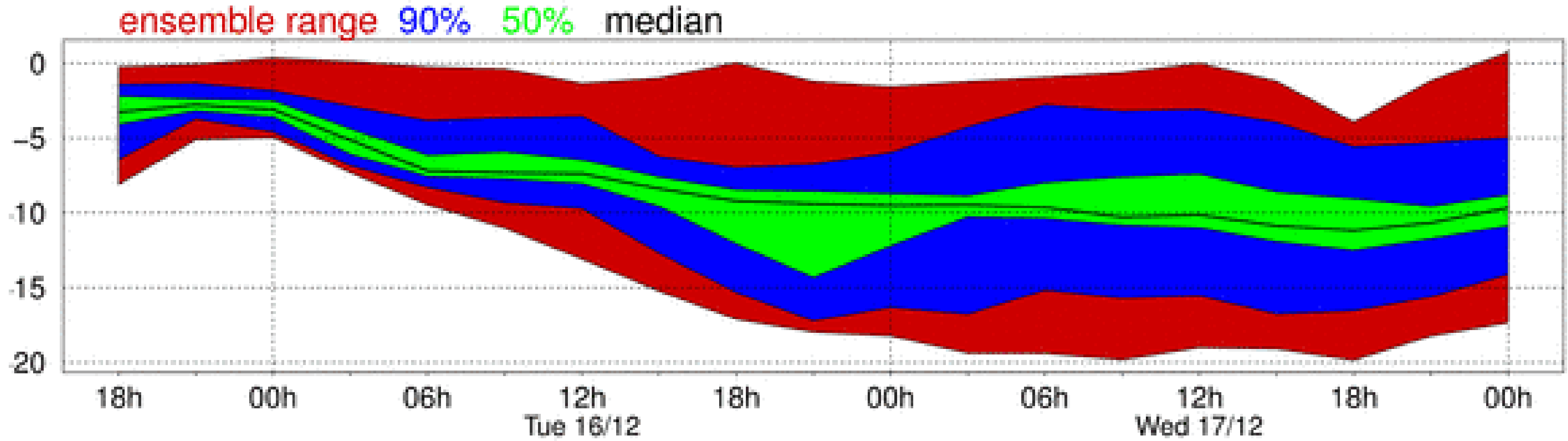
Acknowledgements to: Inger-Lise Frogner, Alex Deckmyn and Andrew, Alfons

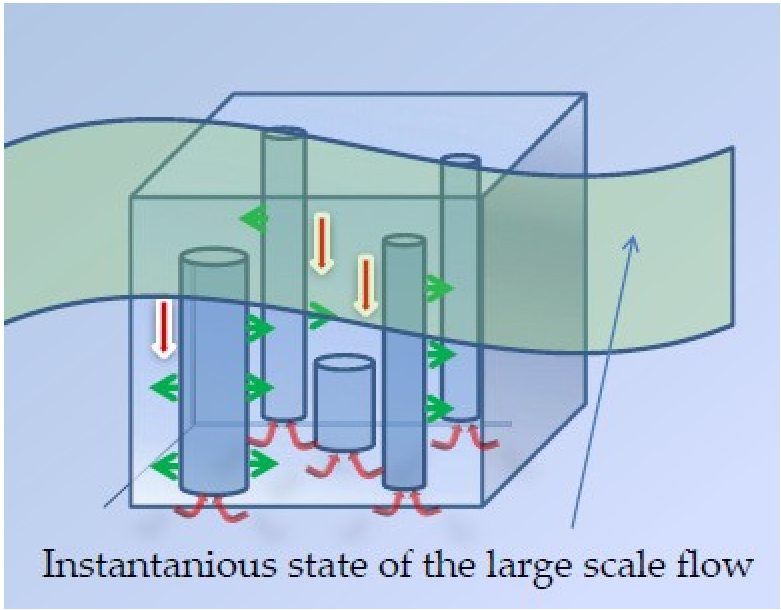
STOCHASTIC PARAMETERIZATION

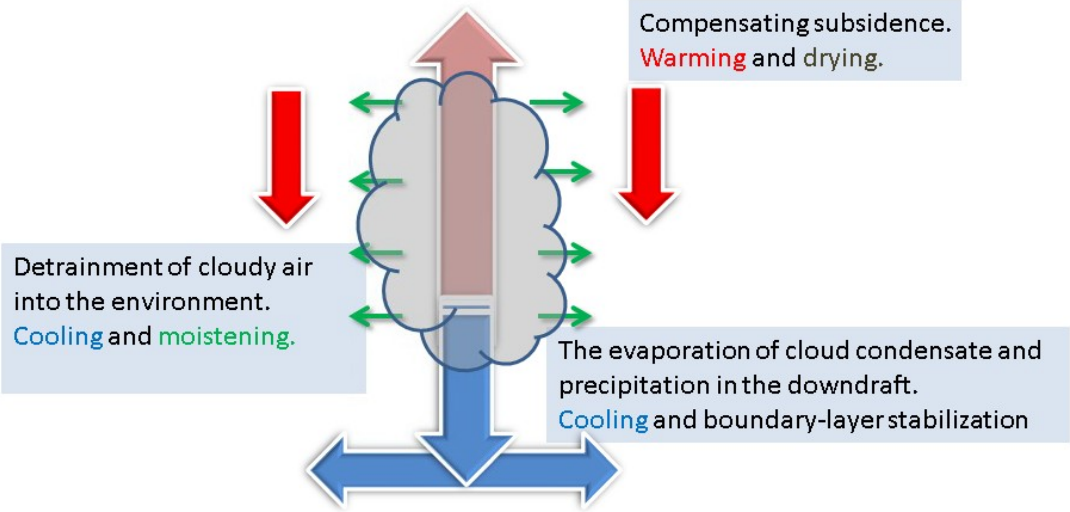
On the practical side: We need to deliver weather forecasts and climate projections which account for uncertainty in the model formulation as well as in the initial conditions.



STOCHASTIC PARAMETERIZATION

On the theoretical side: We need to consider the fact that a space-time average is not necessarily a good approximation to the average effect of many subgrid-scale processes that might occur in a grid-box.



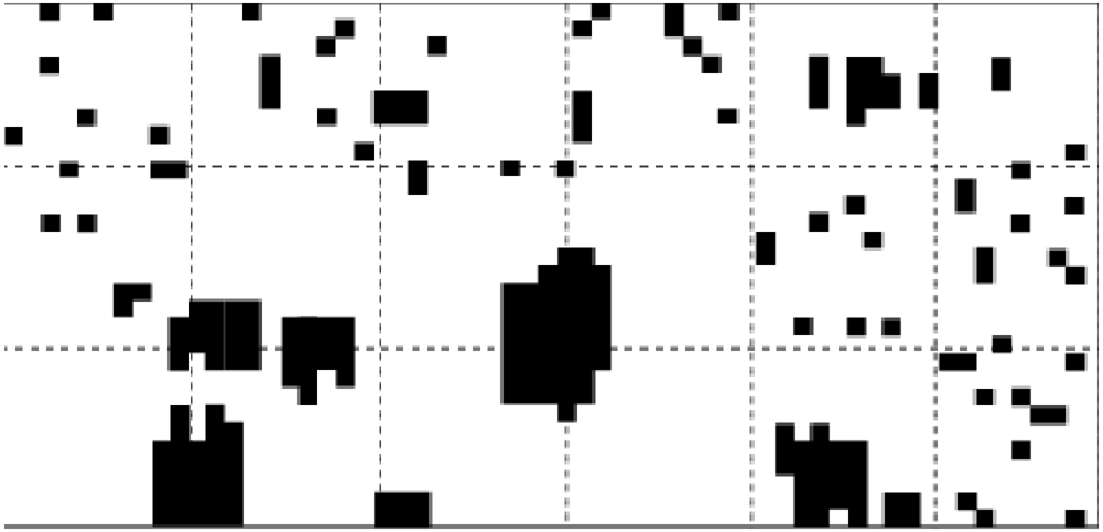


STOCHASTIC PARAMETERIZATION

- Need to describe the upward transport of heat, water vapour and momentum in terms of the grid column profile of wind, temperature and humidity - IMPOSSIBLE!
- Can only hope to represent the average effect of many cloud lifecycles
- Maybe use random numbers to mimic statistical fluctuation in cloud numbers and intensities?
- Spatial organization extends across many grid-boxes. How could we represent that? And does it matter to the forecast model?

USE OF CELLULAR AUTOMATA (CA)

A cellular automaton describes the evolution of discrete states on a grid, according to a set of rules based on the states of neighbouring cells at the previous time step.



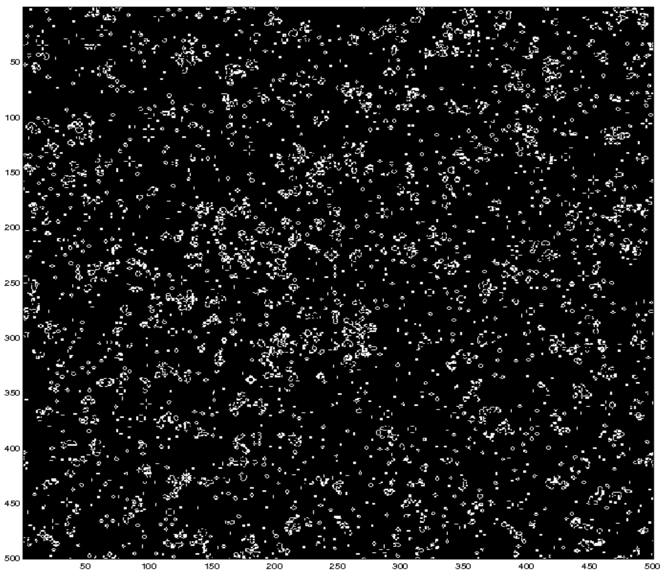
The idea to use a CA in weather models was first proposed by Palmer in 1997. Later tested in the ECMWF model as a pattern generator for a backscatter scheme.

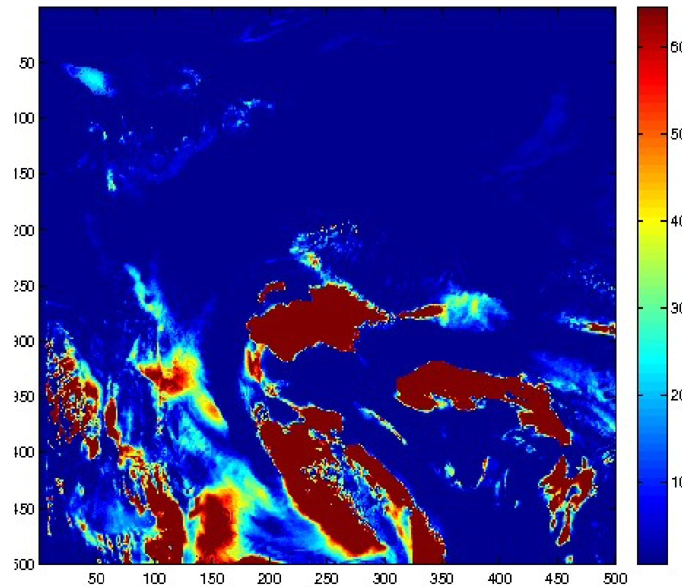
(Shutts and Palmer, 2004; Shutts, 2004; Berner et al., 2005, 2010)

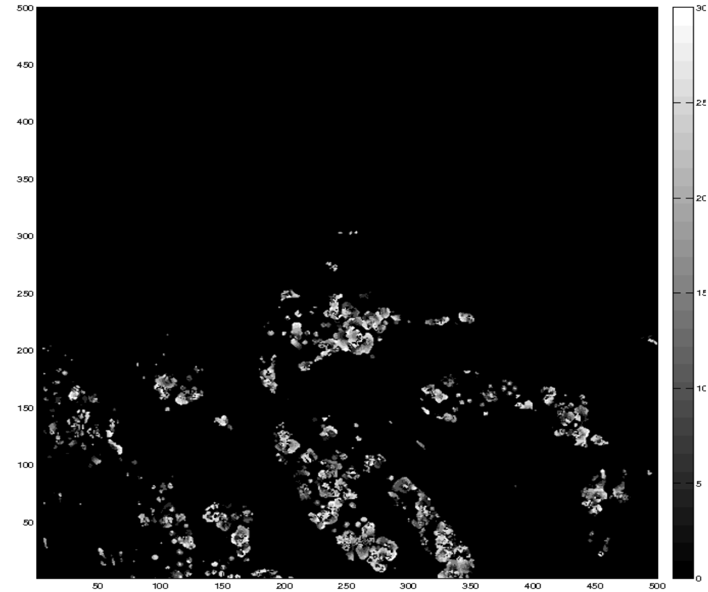
GOL field, continuous in time, active over whole domain

CAPE field

Final field with added “cell history”, new cells “seeded” where CAPE overcomes a threshold







- We introduce the use of CA within the deep convection param.
- Two-way coupled in convection scheme, constrained by physical quantities (such as CAPE and moisture convergence).
- Rules according to GOL, continuous in time, time and space scales on order of organized deep convection
- Horizontal communication - organization
- Memory – cell history

The deep convection closure

Updraft mass-flux: $$M_u = -\sigma_u \frac{\omega_u^*}{g}$$

Updraft vertical velocity: $$\frac{\partial \omega_u^*}{\partial t} = B + E\omega_u^{*2} - A\frac{\partial \omega_u^{*2}}{\partial p}$$

Updraft mesh-fraction:

$$\underbrace{\frac{\partial \sigma_u}{\partial t}\int (h_u - \overline{h})\,\frac{dp}{g}}_{\text{Storage term}} = \underbrace{L\int \sigma_u \omega_u^* \frac{\delta q_c}{g}}_{\text{Condensation}} + \underbrace{L\int MC\frac{dp}{g}}_{\text{Moisture convergence}}$$

Gerard et. al. 2009

Introducing the CA information

$$\frac{\partial \sigma_u}{\partial t} \int \left(h_u - \overline{h}\right) \frac{dp}{g} = L \int \sigma_u \omega_u^* \frac{\delta q_c}{g} + L \int MC \frac{dp}{g} +$$
$$\frac{\sigma_{CA} - \sigma_u}{\tau} \left(\int \left(h_u - \overline{h}\right) \frac{dp}{g} \right)$$

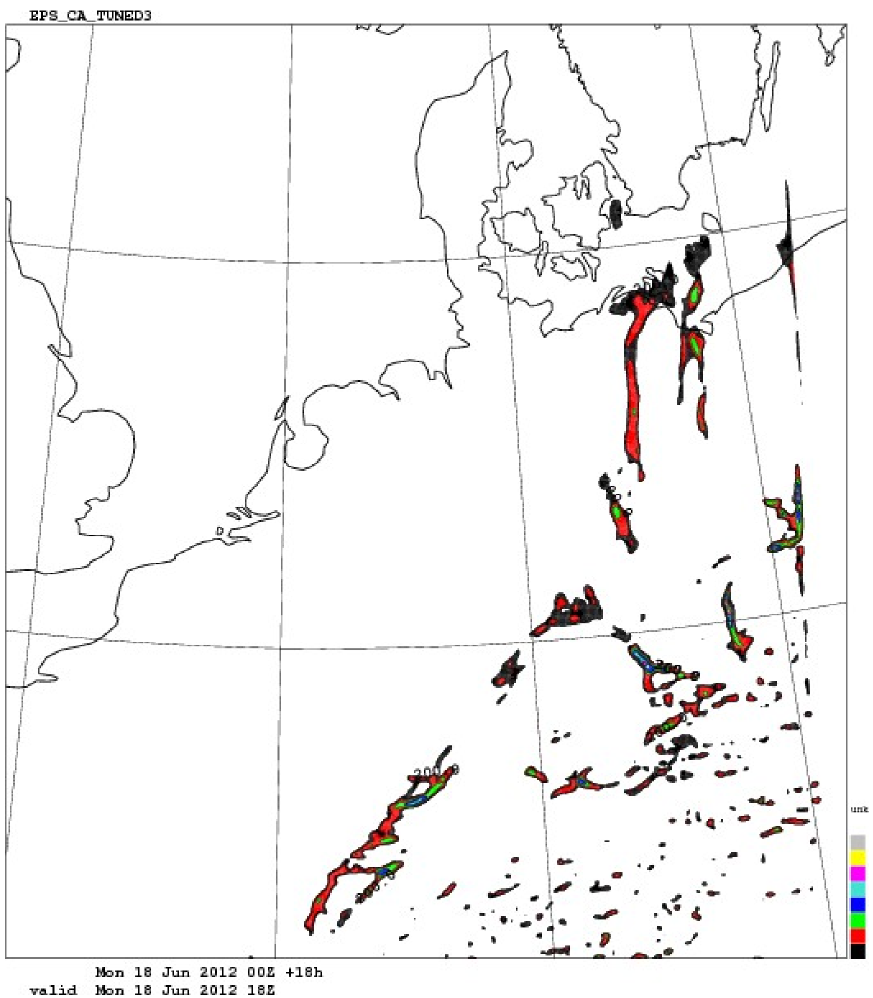
- Source and sink
- Mass conservation
- Stability
- “Meteorological sanity”
- Tau is a tuning parameter of the system.

THE ENSEMBLE PREDICTION SYSTEM (EPS)

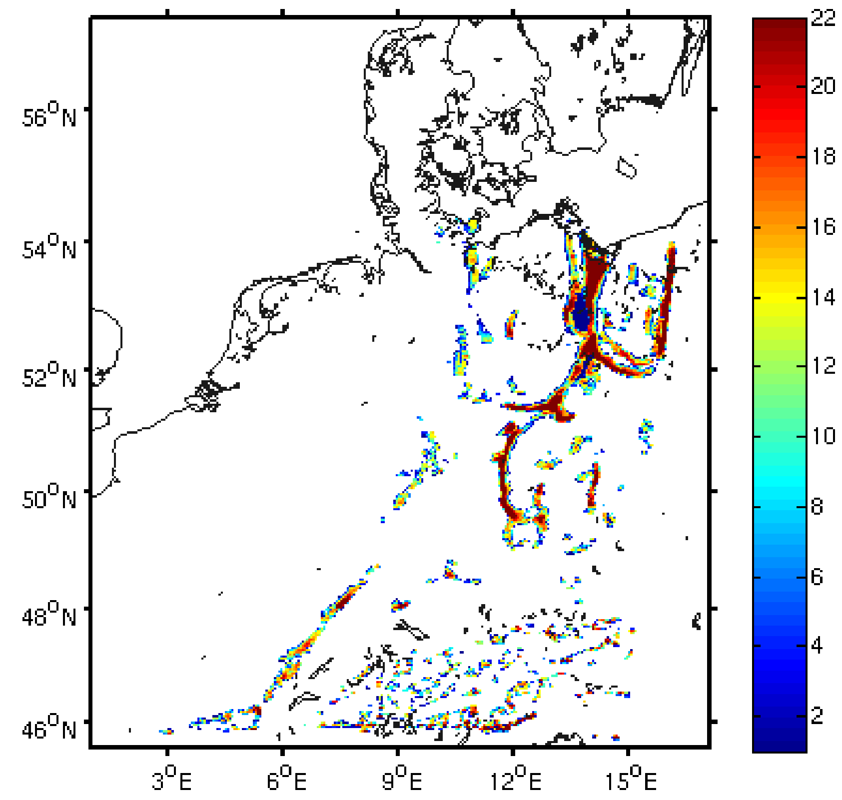
HarmonEPS:

- Non-hydrostatic dynamical core, grid-distance 2.5 km
- The control member is using 3D-variational data assimilation, with 6 hour cycling.
- The other members use the ECMWF down-scaled upper air forecast as an initial field every 12 hours. (own surface DA).
- 22 ensemble members; 10+1 with AROME physics, and 10+1 with ALARO physics.
- The perturbations come from the boundary conditions updated at 00 UTC and 12 UTC, where each member of HarmonEPS uses a member from the ECMWF EPS with 16 km horizontal resolution.
- PertAna.
- Test period is
  - 2012-06-10 to 2012-06-28 (18 days at 00 and 12 UTC) (Central Europe)
  - 2011-10-23 to 2011-11-07 (16 days at 00 and 12 UTC) (Spain+Portugal)

Example: CAPE and CA-field



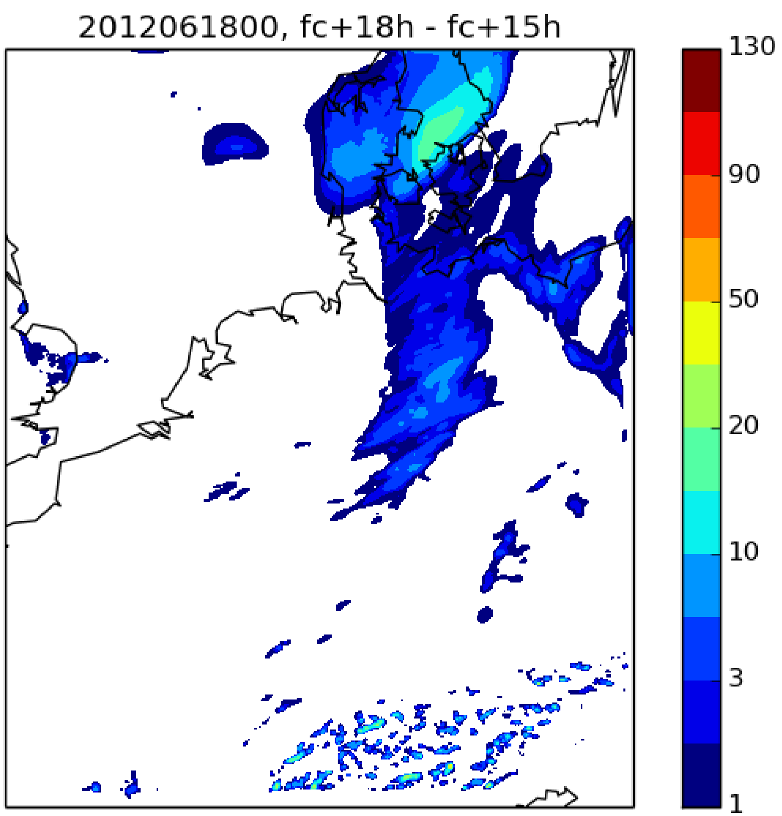
CAPE field



CA field

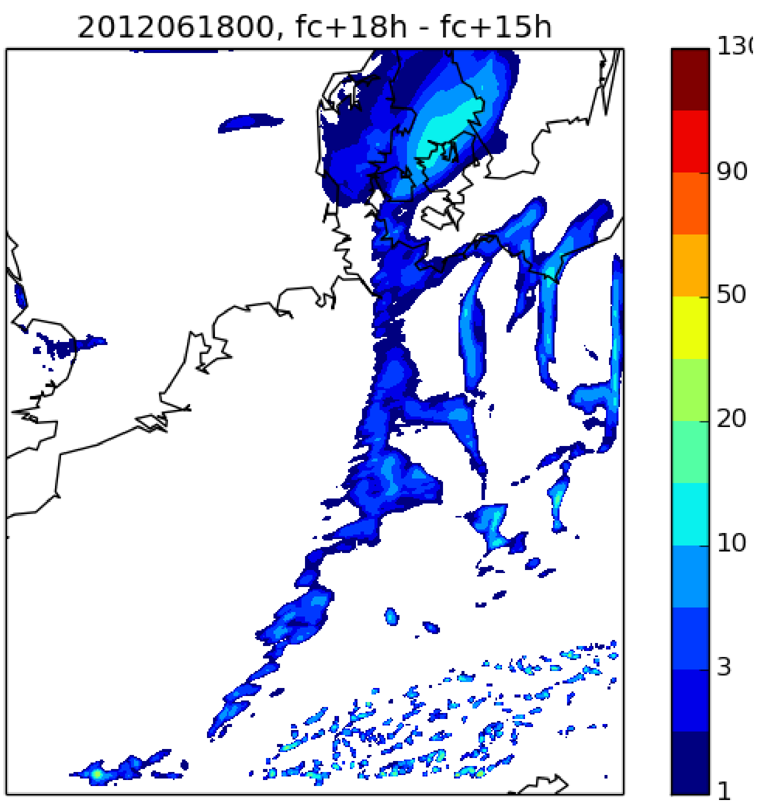
Valid 18 UTC, 2012 06 18.

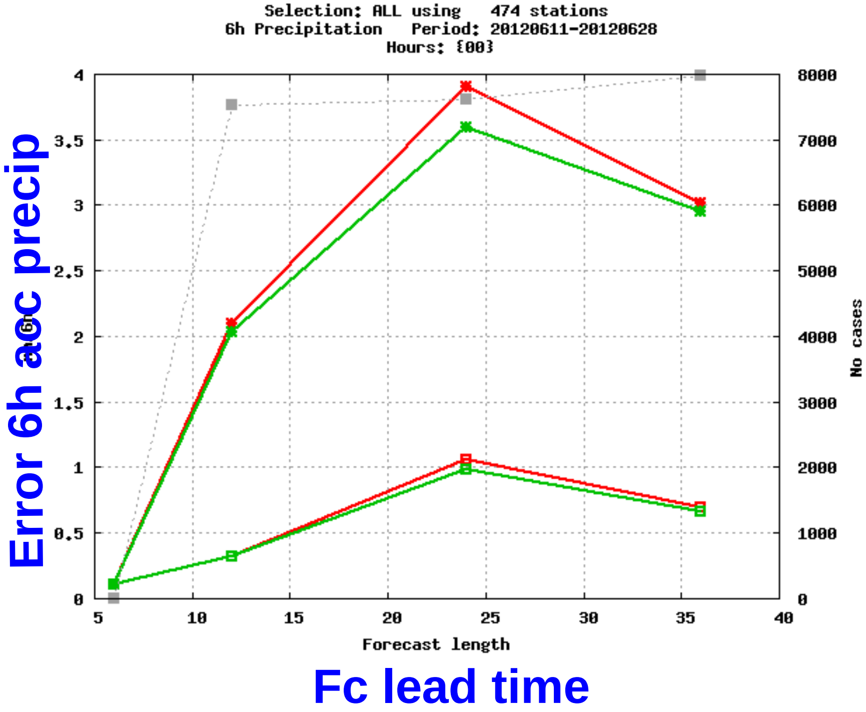
Example: 3h acc precipitation

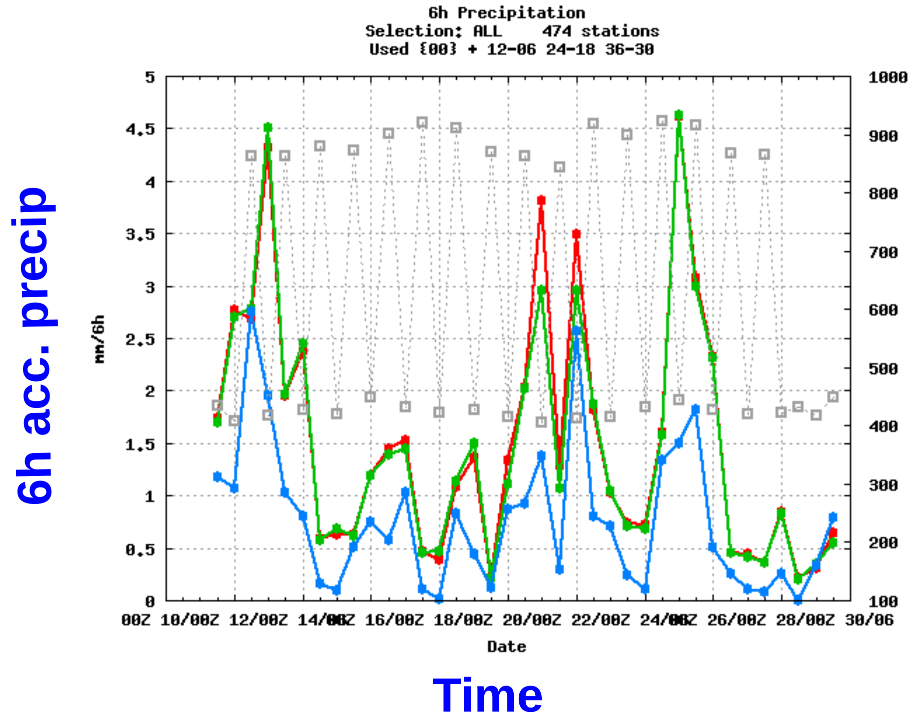


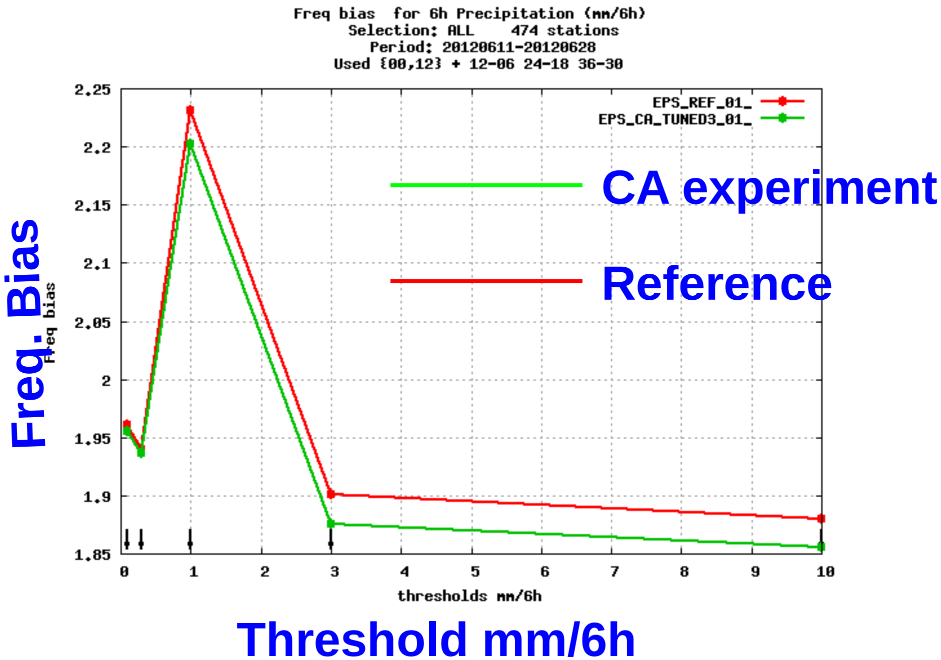
Reference

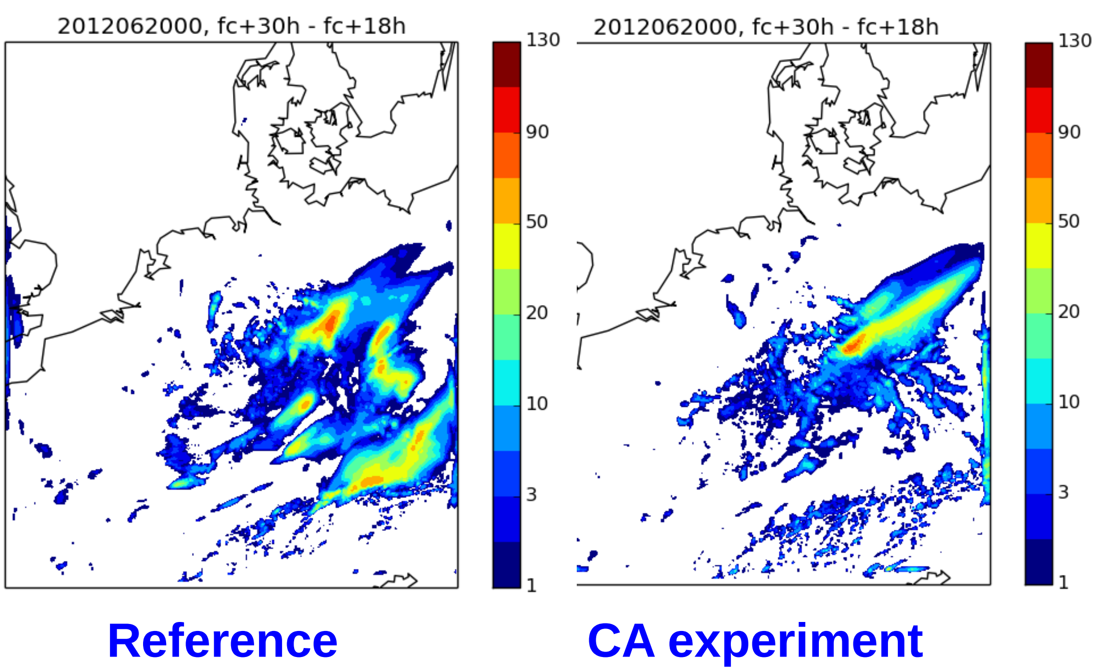
CA exp




Selection: ALL using 474 stations
6h Precipitation Period: 20120611-20120628
Hours: {00}
No cases
Forecast length
Error 6h acc precip
Fc lead time


6h Precipitation
Selection: ALL 474 stations
Used {00} + 12-06 24-18 36-30
mm/6h
No cases
Date
6h acc. precip
Time


Freq bias for 6h Precipitation (mm/6h)
Selection: ALL 474 stations
Period: 20120611-20120628
Used {00,12} + 12-06 24-18 36-30
EPS_REF_01_
EPS_CA_TUNED3_01_
Freq bias
thresholds mm/6h
CA experiment
Reference
Freq. Bias
Threshold mm/6h


2012062000, fc+30h - fc+18h
2012062000, fc+30h - fc+18h
Reference
CA experiment

Why this reduction in precipitation?

$$\frac{\partial \sigma_u}{\partial t}\int \left(h_u - \overline{h}\right)\frac{dp}{g} = L\int \sigma_u \omega_u^* \frac{\delta q_c}{g} + L\int MC\frac{dp}{g} + \frac{\sigma_{CA}-\sigma_u}{\tau}\left(\int \left(h_u-\overline{h}\right)\frac{dp}{g}\right)$$

$$\sigma_{\mathrm{b}}^{+}\sum_{l=1}^{N} f^{l}(h_{\mathrm{u}}^{l}-\overline{h}^{l})\Delta p^{l} - \sum_{l=1}^{N}\sigma_{\mathrm{u}}^{l-}(h_{\mathrm{u}}^{l}-\overline{h}^{l})\Delta p^{l}$$

$$= \sigma_{\mathrm{b}}^{+}\sum_{l=1}^{N} L^{l} f^{l}\omega_{\mathrm{u}}^{*l}\Delta t\,\delta q_{\mathrm{c}}{}^{l} + \sum_{l=1}^{N} L^{l} MC^{l}\Delta p^{l}\Delta t,$$

Why this reduction in precipitation?

$$\frac{\partial \sigma_u}{\partial t}\int \left(h_u-\overline{h}\right)\frac{dp}{g} = L\int \sigma_u \omega_u^{*}\frac{\delta q_c}{g} + L\int MC\frac{dp}{g} + \frac{\sigma_{CA}-\sigma_u}{\tau}\left(\int \left(h_u-\overline{h}\right)\frac{dp}{g}\right)$$

$$\sigma_{\mathrm{b}}^{+}\overset{\textcolor{red}{\mathrm{C}}}{\sum_{l=1}^{N} f^{l}\left(h_{\mathrm{u}}^{l}-\overline{h}^{l}\right)\Delta p^{l}} - \overset{\textcolor{red}{\mathrm{B}}}{\sum_{l=1}^{N}\sigma_{\mathrm{u}}^{l-}\left(h_{\mathrm{u}}^{l}-\overline{h}^{l}\right)\Delta p^{l}}$$

$$= \sigma_{\mathrm{b}}^{+}\overset{\textcolor{red}{\mathrm{D}}}{\sum_{l=1}^{N} L^{l} f^{l}\omega_{\mathrm{u}}^{*l}\Delta t\,\delta q_{\mathrm{c}}{}^{l}} + \overset{\textcolor{red}{\mathrm{A}}}{\sum_{l=1}^{N} L^{l} MC^{l}\Delta p^{l}\Delta t},$$

Why this reduction in precipitation?

$$\sigma_b^+ = \frac{B + A\Delta t}{C + D}.$$

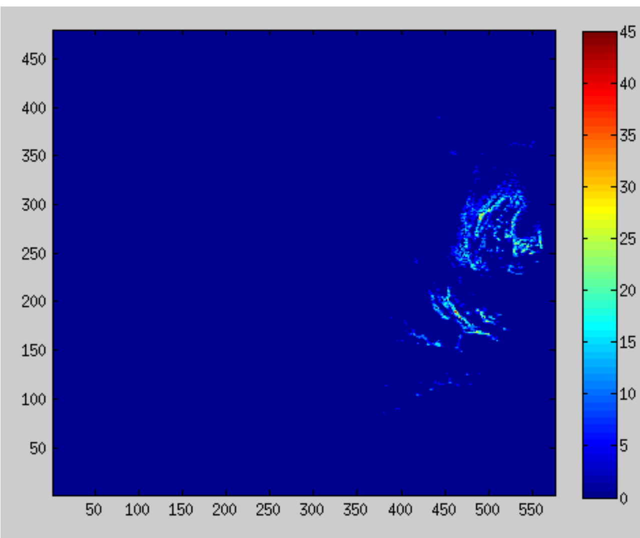
If sigma_ca is 0 sigma_b is reduced.

If sigma_ca is larger than 0 sigma_b may increase. (if sigma_ca is larger than the RHS of eq. 1)

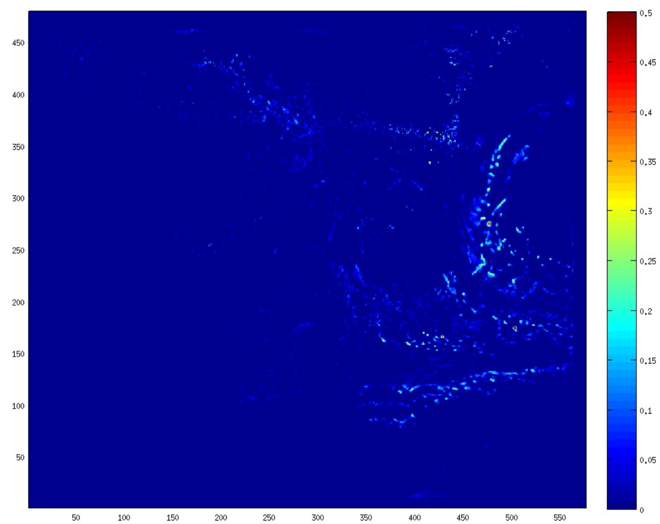
$$\sigma_b^+ = \frac{B + A\Delta t + \sigma_{CA}\dfrac{C\Delta t}{\tau}}{C + D + \dfrac{C\Delta t}{\tau}}.$$

Add sigma_ca explicitly?

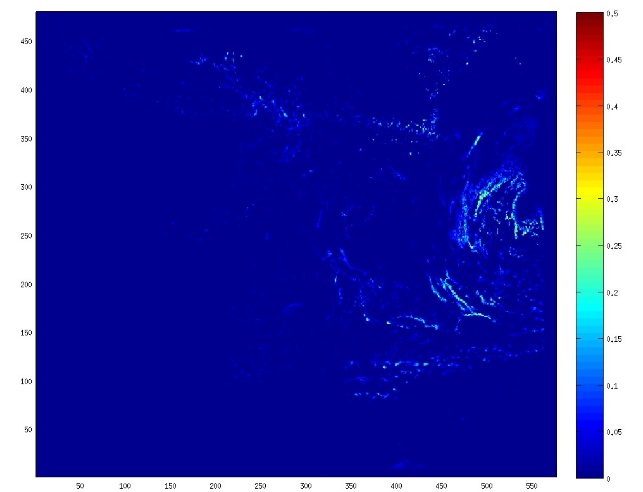
- sigma_b = sigma_b + sigma_ca



CA - field

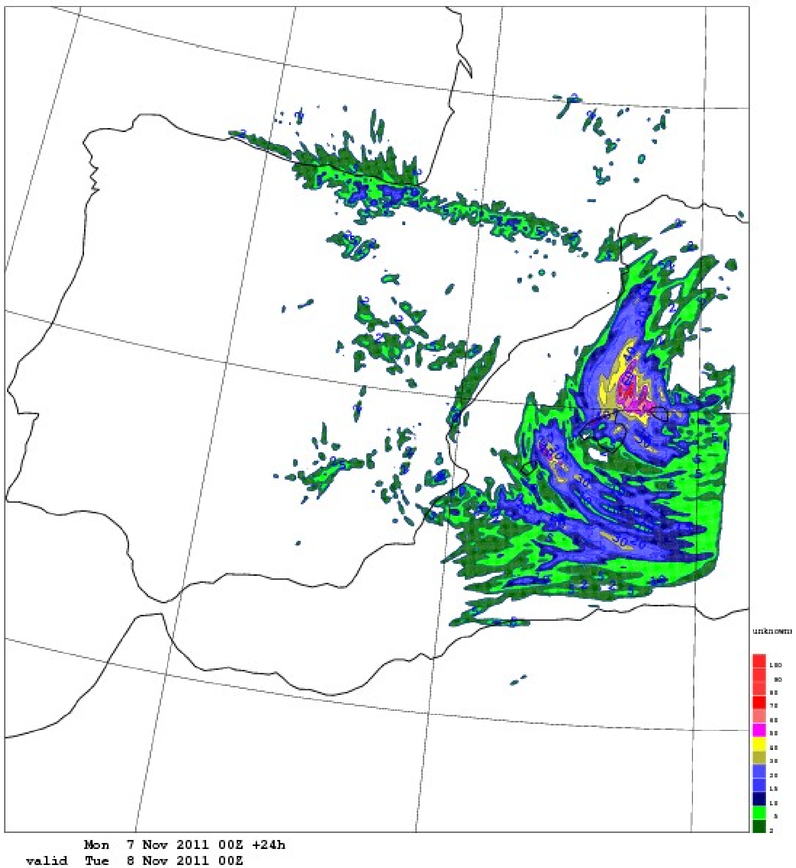


sigma_b
(updraft mesh-fraction)

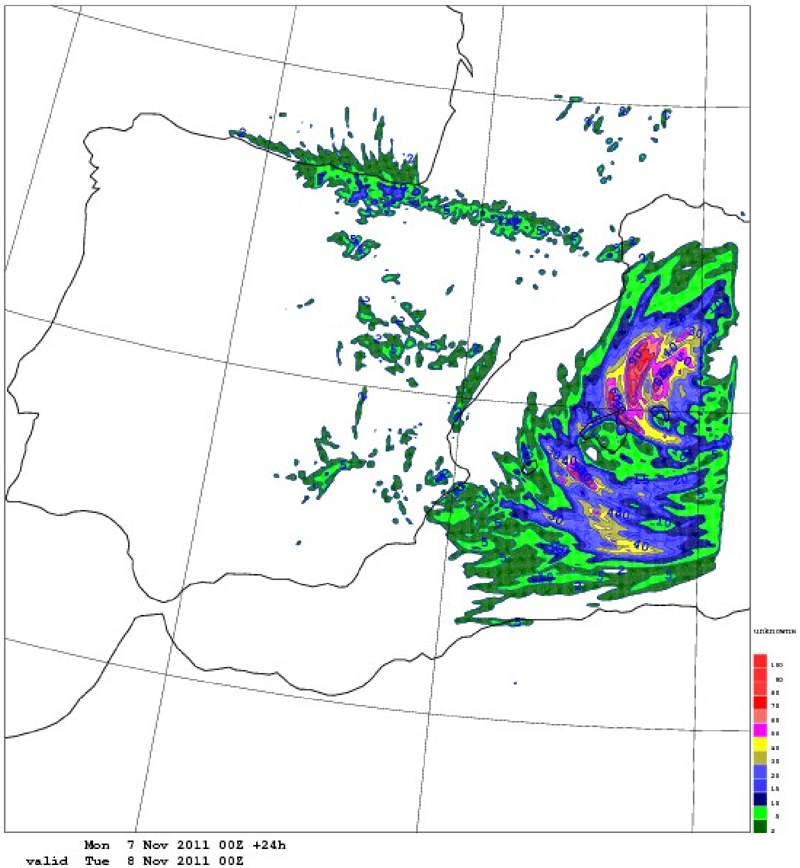


sigma_b + sigma_ca
(updraft mesh-fraction)

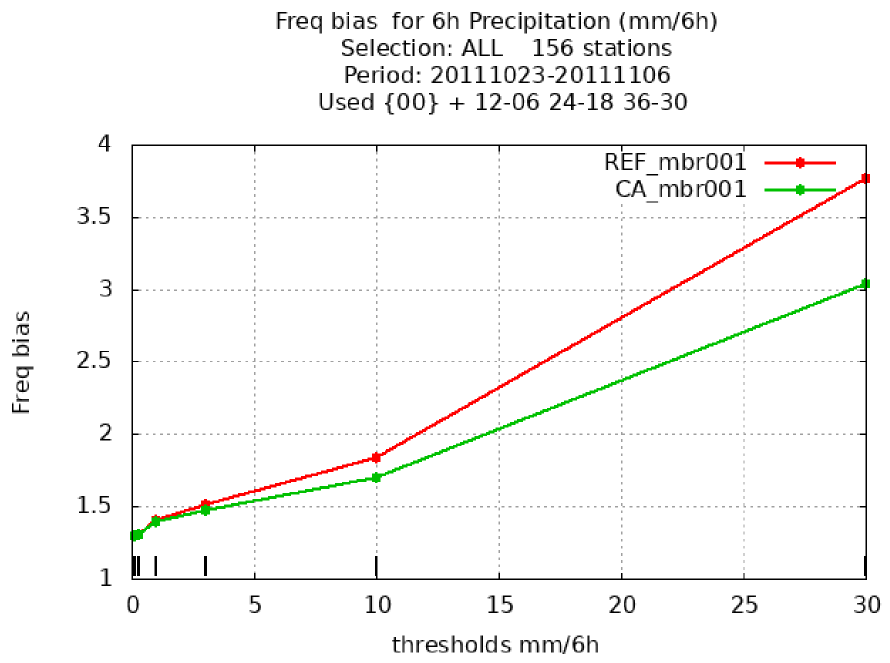
6 h subgrid precipitation



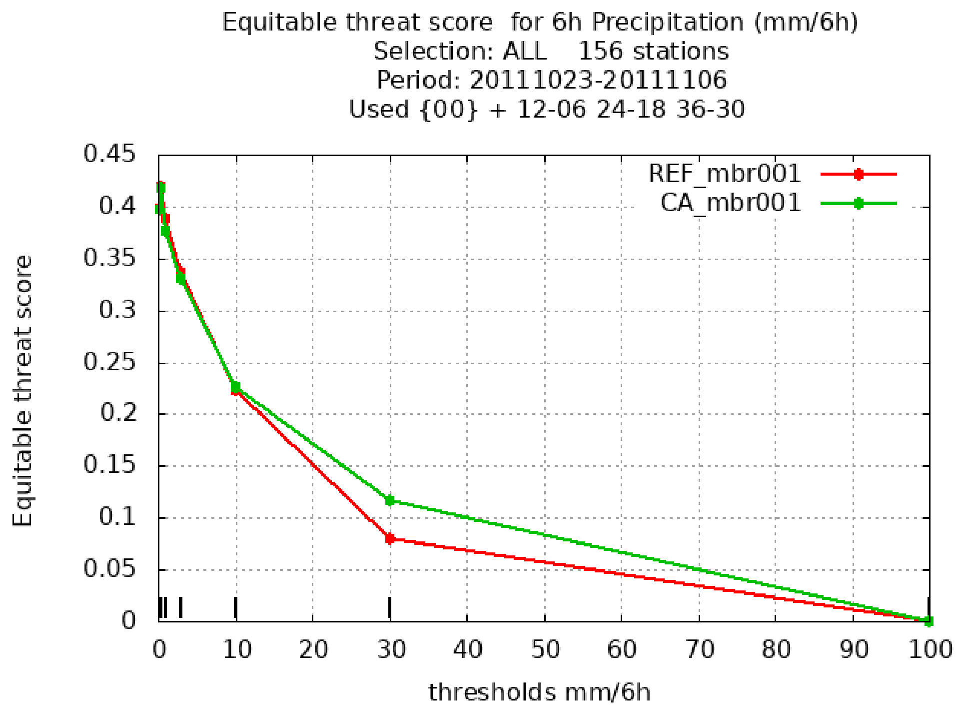
Reference



CA-experiment



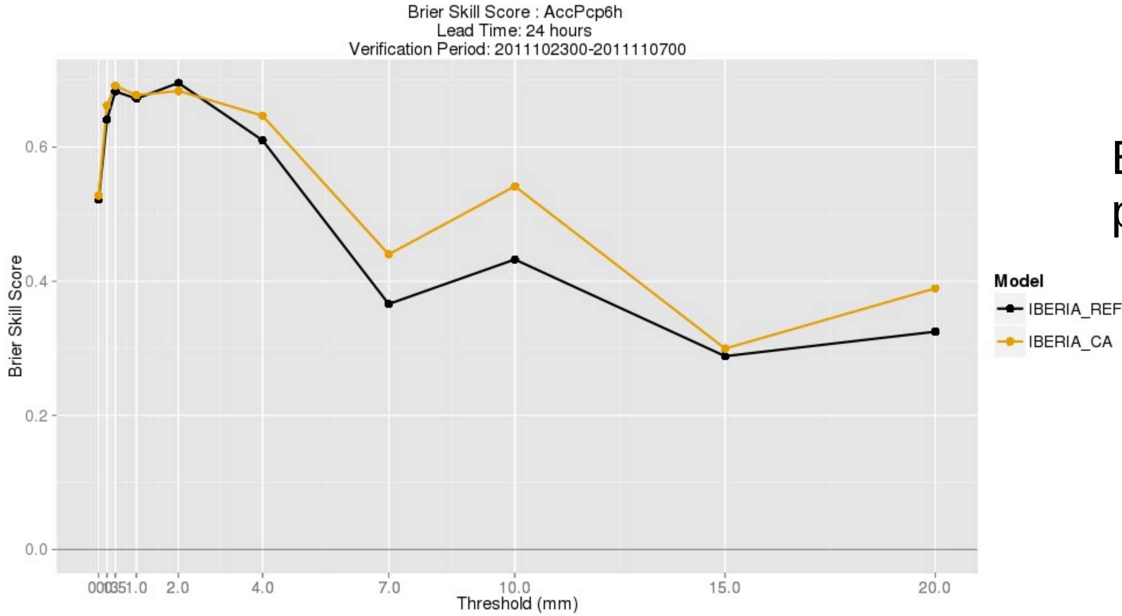
Frequency bias
6h acc precip



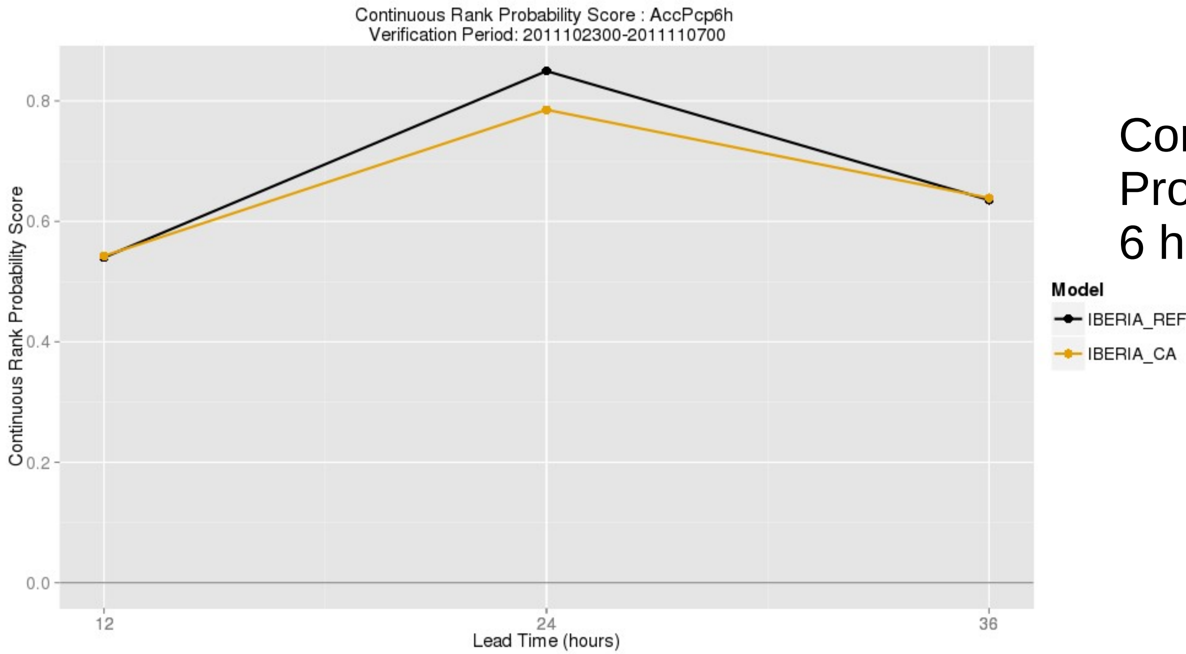
Equitable threat
score 6h acc precip

Possible Feedback Mechanisms

- If mesh-fraction goes to 1, sub-grid vertical velocity can be reduced.
- If sub-grid precipitation increases, resolved precip. is reduced.
- If mesh-fraction approaches 1 at 2.5 km horizontal resolution, CAPE in the column goes to 0.



Brier skill score, 6h precip, 24 h forecast.



Continuous Rank Probability Score 6 h acc precip.

CONCLUDING REMARKS

- The impact of the stochastic scheme in an Ensemble Prediction System is rather modest.
- For precipitation (6 and 12 h acc. Values), the deterministic skill is improved (Neutral for temp, wind, pressure, clouds – not shown).
- This improvement leads to a reduced ensemble spread.
- Probabilistic scores indicate that there is a positive impact with the scheme.
- Would like to look closer at 1h and 3h accumulated values using radar data to see impact on more convective time and space scales.

THOUGTS

- Some methods used in order to achieve more spread in EPS is to multiply total tendencies by random numbers, or running multi-model/multi-physics ensembles.
- It seems more physically sound to address uncertainty at the source, rather than multiplying total tendencies with random numbers, or getting spread from two or more different model biases.
- However, in this case, since the CA component is implemented in the already existing deep convection scheme, the impact is rather constrained by the large scale variables which are input to the parameterization.
- If the stochastic scheme improves the model bias by giving a better distribution of physical variables on the sub-grid scale (or other reasons), then the spread may be reduced, but for the right reason.