Impact of a stochastic parameterization of cumulus convection, using cellular automata, in Harmon-EPS

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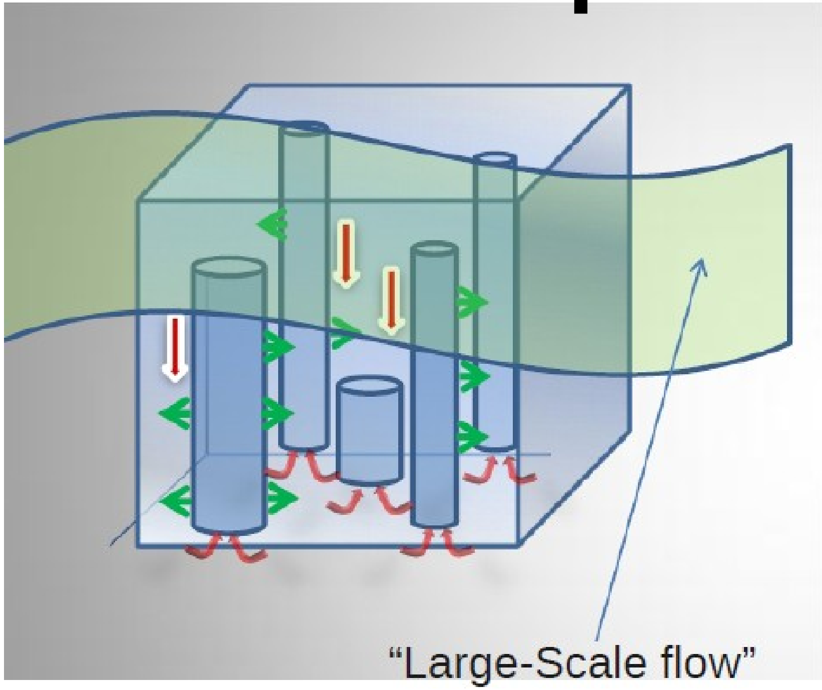
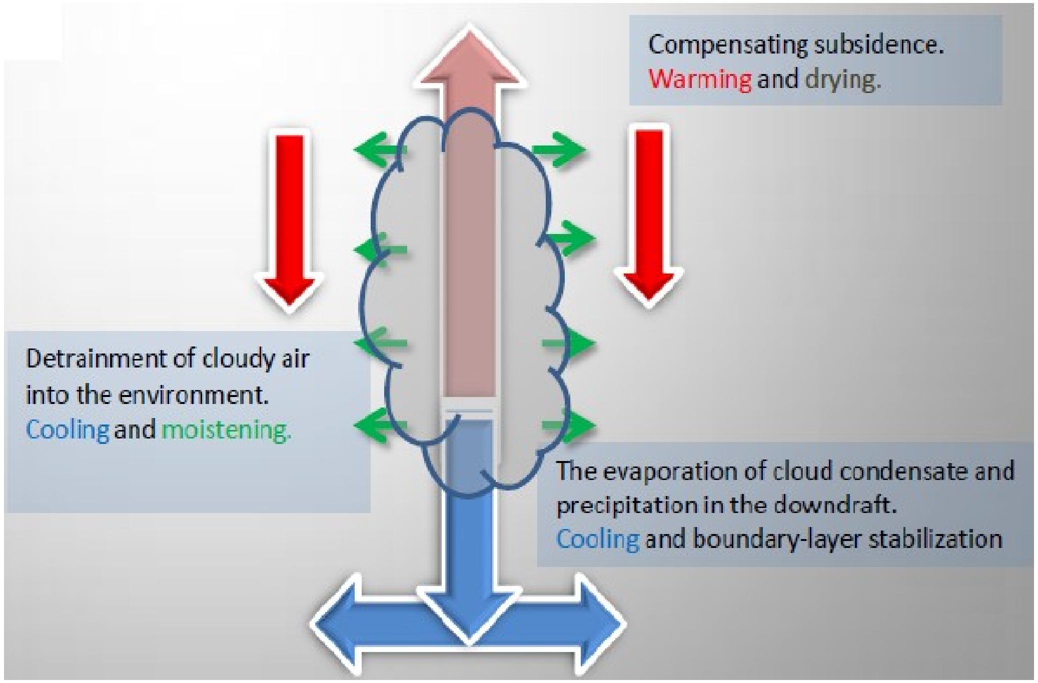
Acknowledgements: Jean-Francois Geleyn, Luc Gerard, Peter Bechtold, Inger-Lise Frogner, Martin Steinheimer, and Filip Vana

Outline of presentation

- **The cellular automata coupled to the 3MT deep convection scheme**
- **The meso-scale ensemble prediction system, Harmon-EPS**
- **Results**
- **Where to go from here...**

The challenge with cumulus parameterization


“Large-Scale flow”

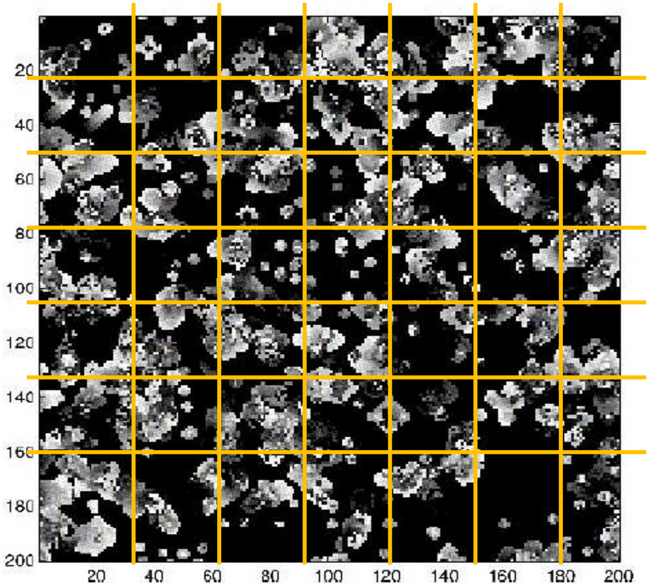

Compensating subsidence.
Warming and drying.

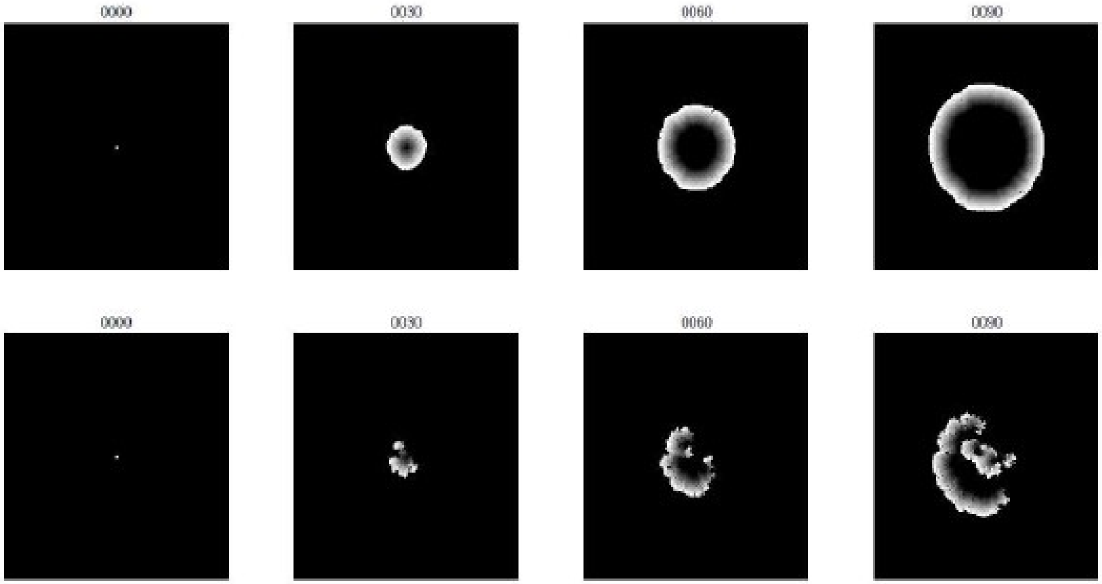
Detrainment of cloudy air into the environment.
Cooling and moistening.

The evaporation of cloud condensate and precipitation in the downdraft.
Cooling and boundary-layer stabilization

- Given a large enough area, ensemble effect of individual updrafts represented by one updraft.
- Quasi-equilibrium assumed at an instantaneous state, not obvious at increasing resolution.
- No horizontal transport (column physics).

Cellular Automata





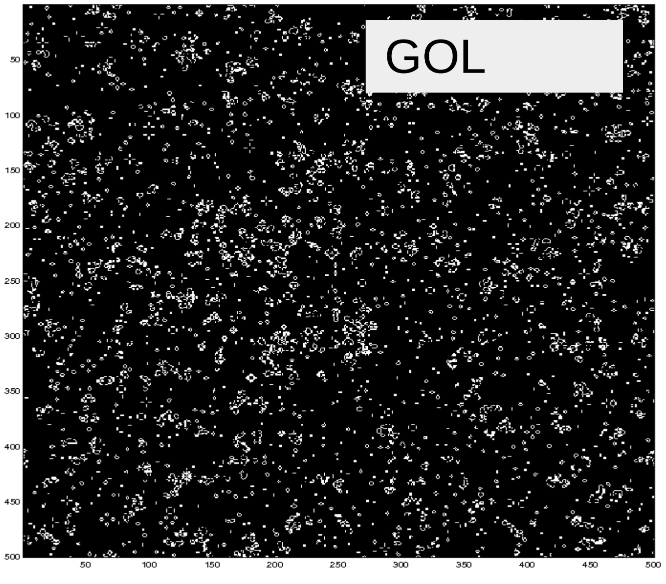
From Martin Steinheimer

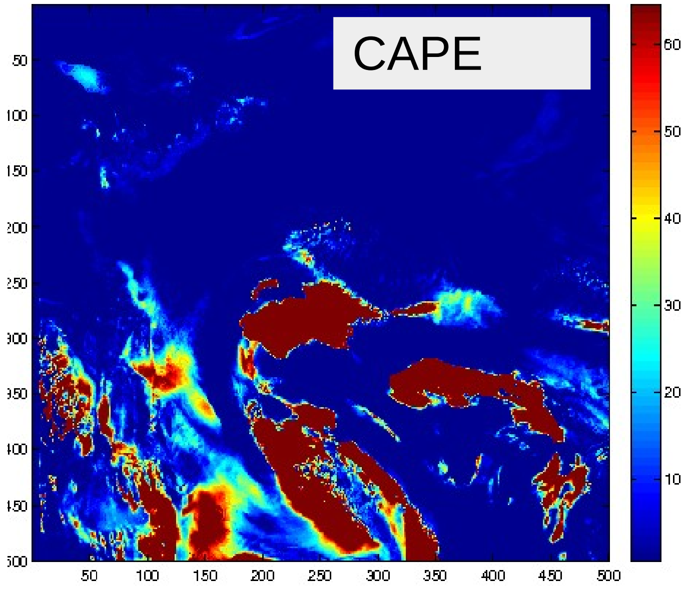
It possesses many qualities interesting for deep convection parameterization.

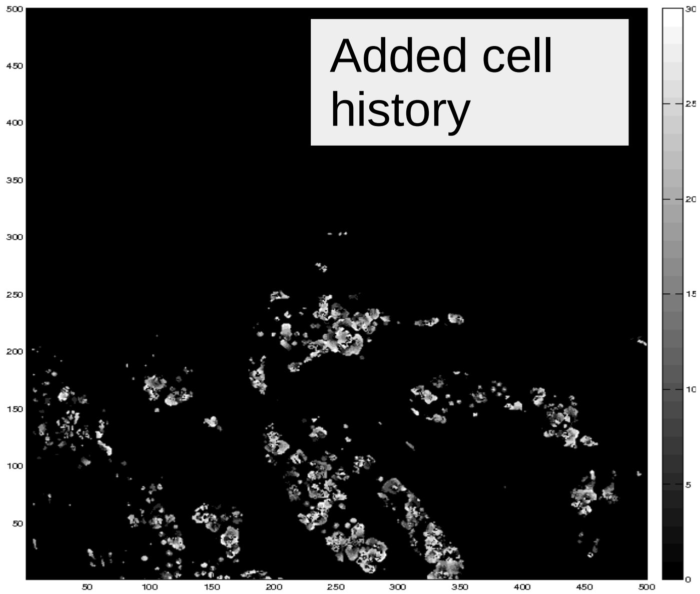
- Horizontal communication
- Memory
- Stochastisity

Stochastic parameterization of cumulus convection using cellular automata

- Can we use random numbers and self-organizational properties of cellular automata to mimic statistical fluctuation in cloud numbers and intensities?
- Can we allow for horizontal organization and communication between adjacent model grid-boxes in the cumulus parameterization?
- *Bengtsson, L., Steinheimer, M., Bechtold, P. and Geleyn, J.-F. (2013), A stochastic parametrization for deep convection using cellular automata. Q.J.R. Meteorol. Soc., 139: 1533–1543.*







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:

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

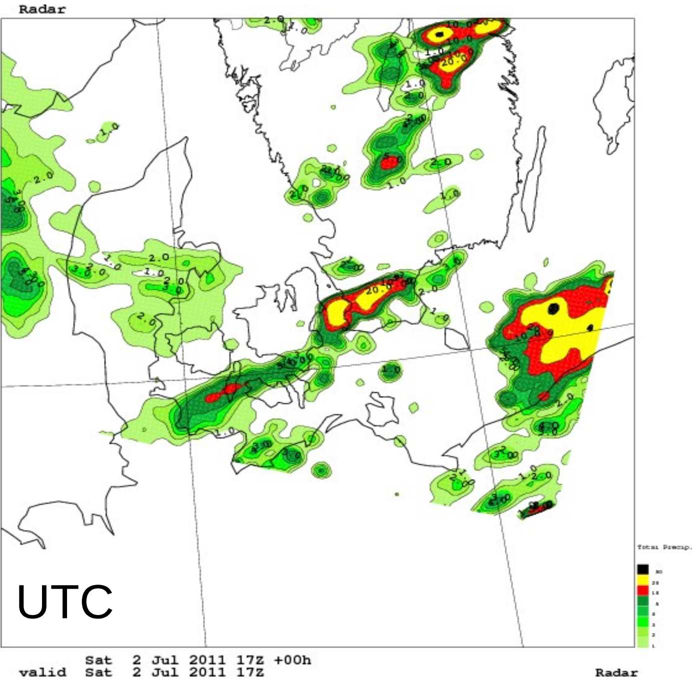
Luc Gerard et. al. 2009

Introducing the CA information

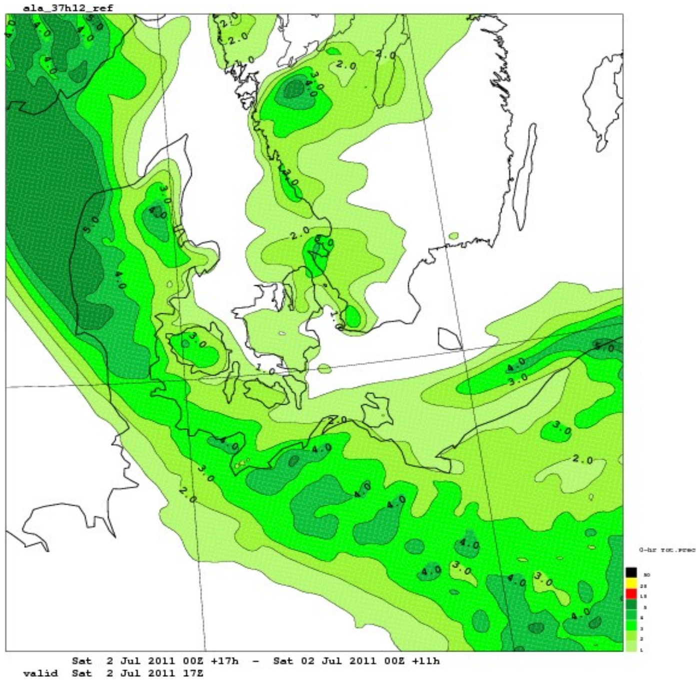
$$\frac{\partial \sigma_u}{\partial t} \int \left(h_u - \overline{h}\right) \frac{dp}{g} = L \int \sigma_u \omega_u^* \frac{\delta q_c}{g} + L \int MC \frac{dp}{g} + \\ \frac{\sigma_{CA} - \sigma_u}{\tau} \left(\int \left(h_u - \overline{h}\right) \frac{dp}{g} \right)$$

Bengtsson et. al 2013

Radar
6h acc.
Precip.
(mm)

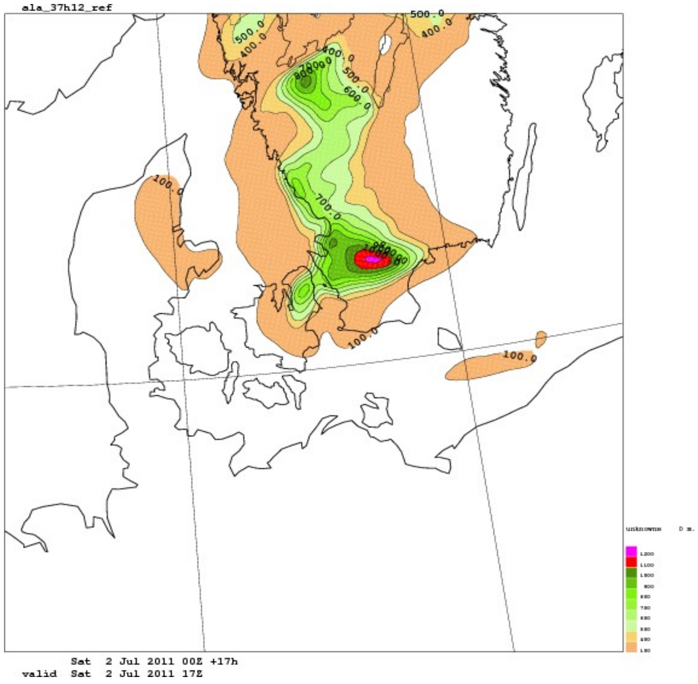


20110702 + 17 UTC

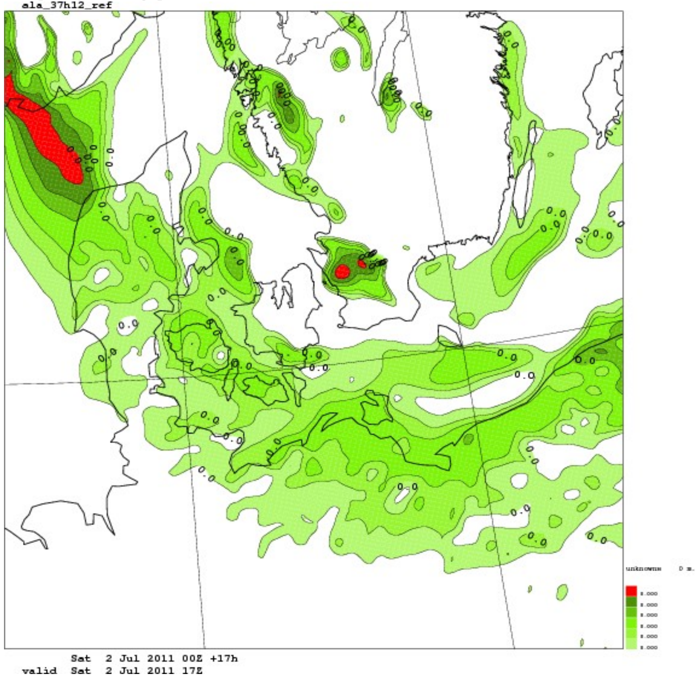


Reference.
6h acc.
Precip.
(mm)

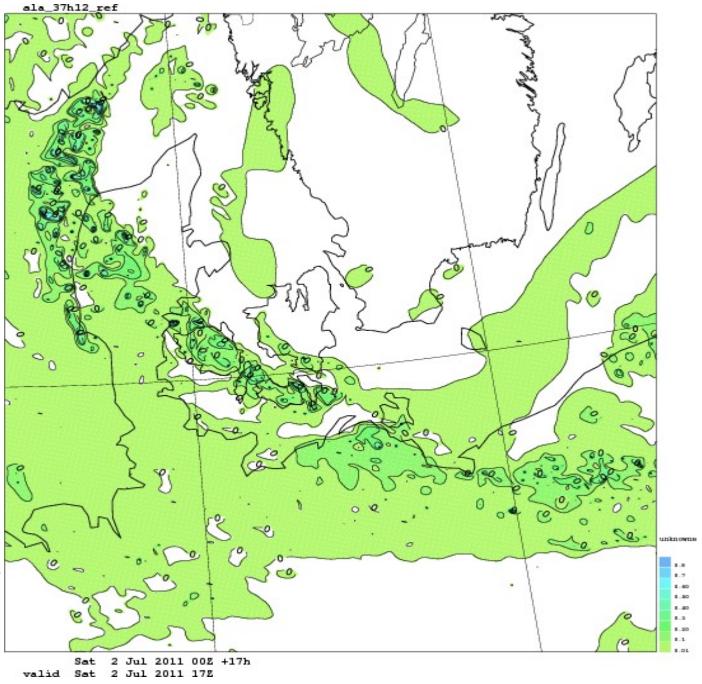
CAPE (J/kg)



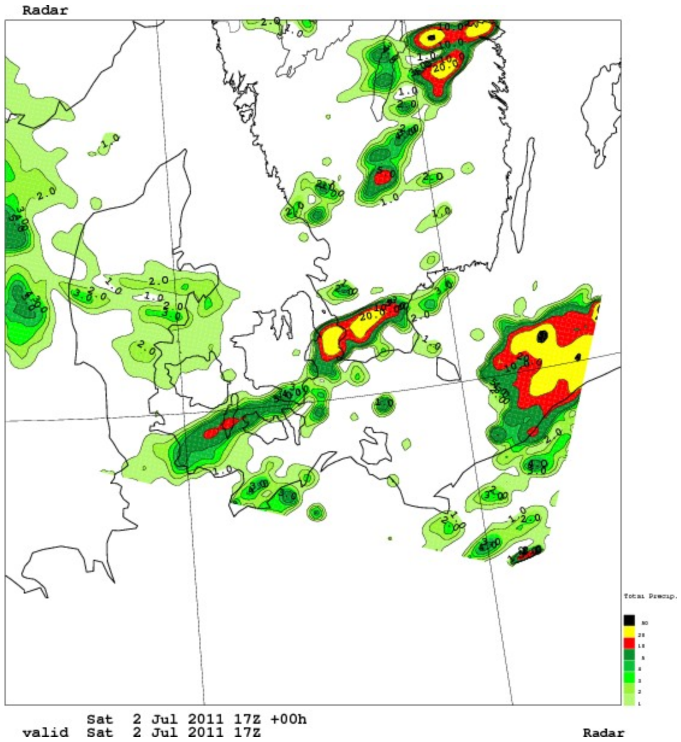
Moisture convergence
(kg/kg)



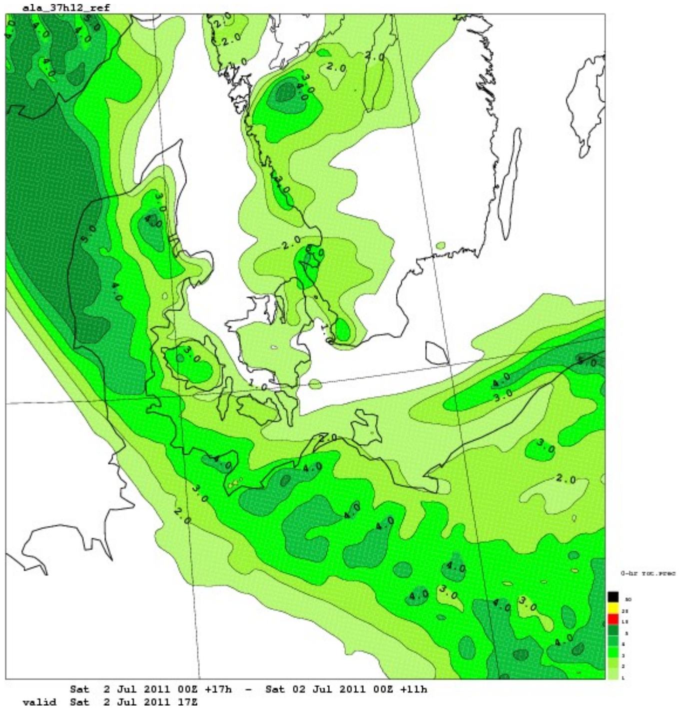
Updraft mesh-fraction



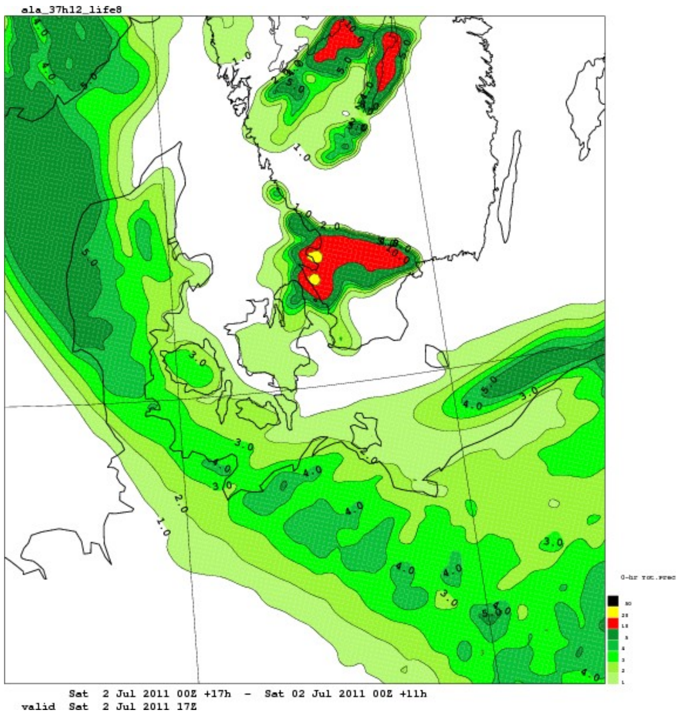
6h acc. Precip (mm).



Radar



Reference model



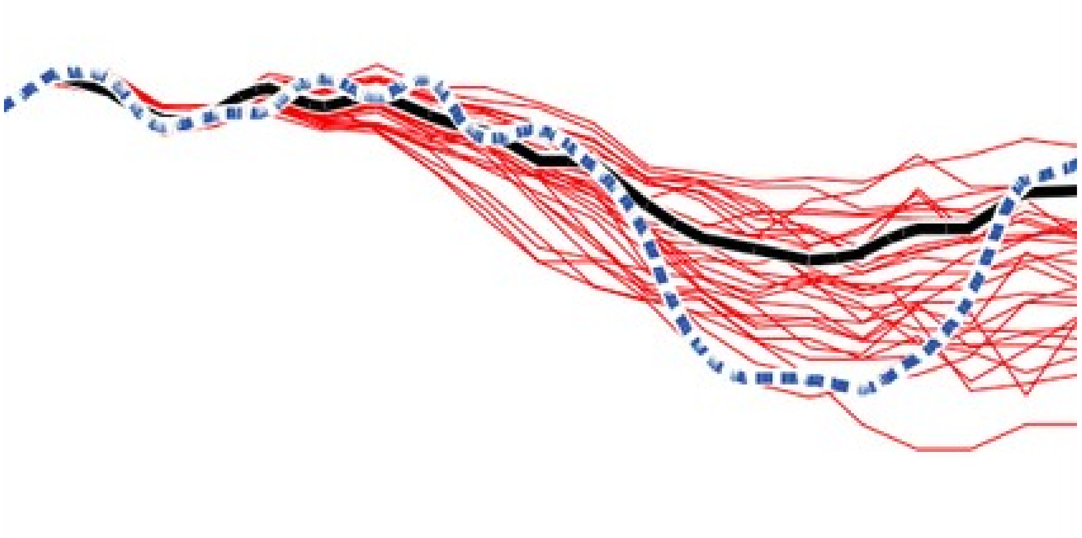
With CA implementation

20110702 + 17 UTC

Deterministic run, 5 km horizontal resolution

The question:

Can the proposed scheme, which was implemented ***with the aim to improve the description of a physical process,*** have an impact on the performance of the ***uncertainty estimates*** given by an ensemble prediction system?



Harmon-EPS

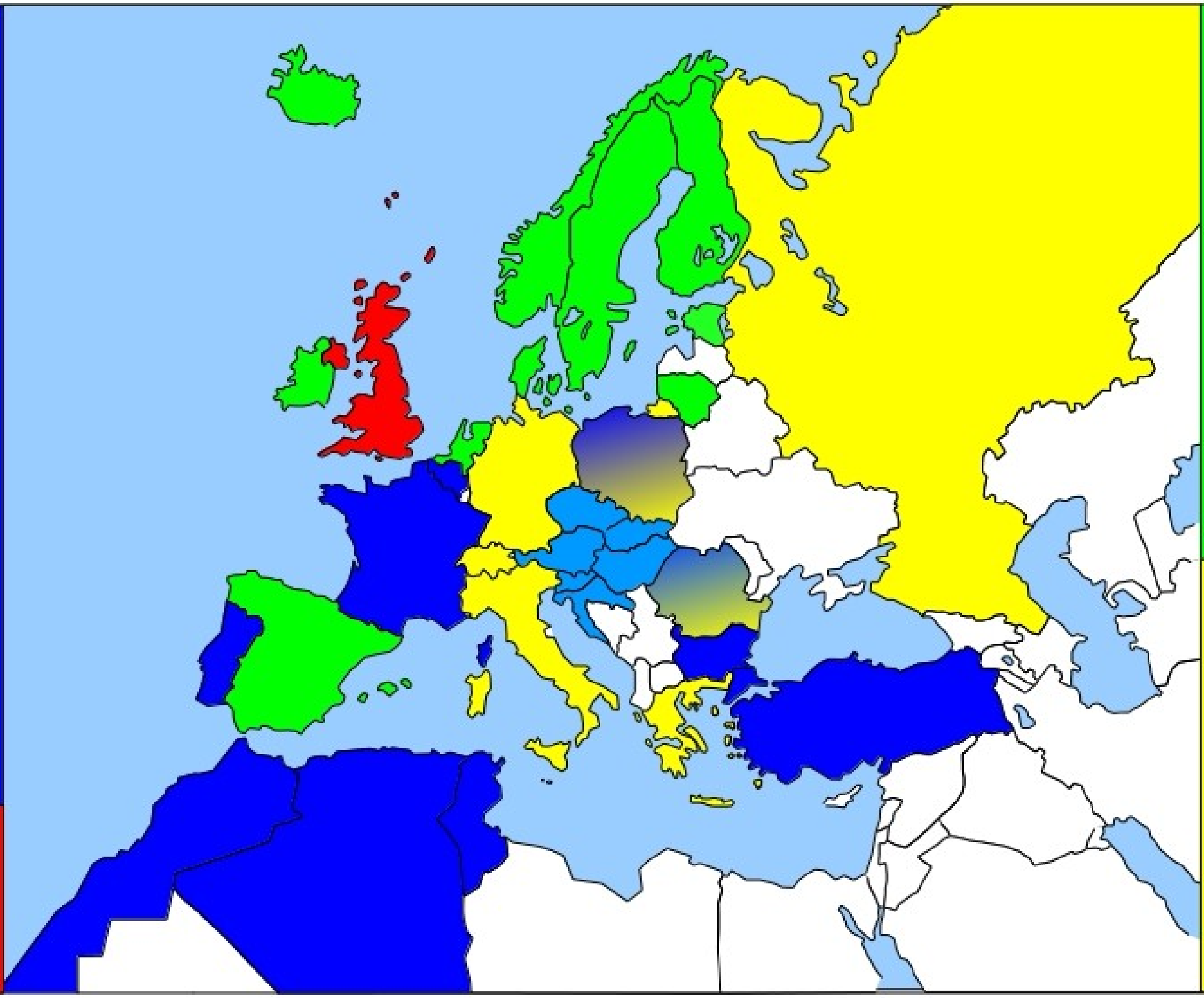
- An Ensemble Prediction System framework based on the HARMONIE model system.
- Collaboration on a framework for national weather centres in the HIRLAM-ALADIN consortia to set up a convective scale ensemble prediction system.
- The collaboration entails both research on initial/model error representation for short range ensemble prediction, as well as work on calibration, verification, and setting up a script system/scheduler to run large ensemble experiments.

SRNWP Consortia in Europe

ALADIN
Algeria
Belgium
Bulgaria
France
Morocco
Poland
Portugal
Tunisia
Turkey

Austria
Croatia
Czech Rep.
Hungary
Romania
Slovakia
Slovenia

UKMO
United Kingdom



HIRLAM
Denmark
Estonia
Finland
Iceland
Ireland
Lithuania
Netherlands
Norway
Spain
Sweden

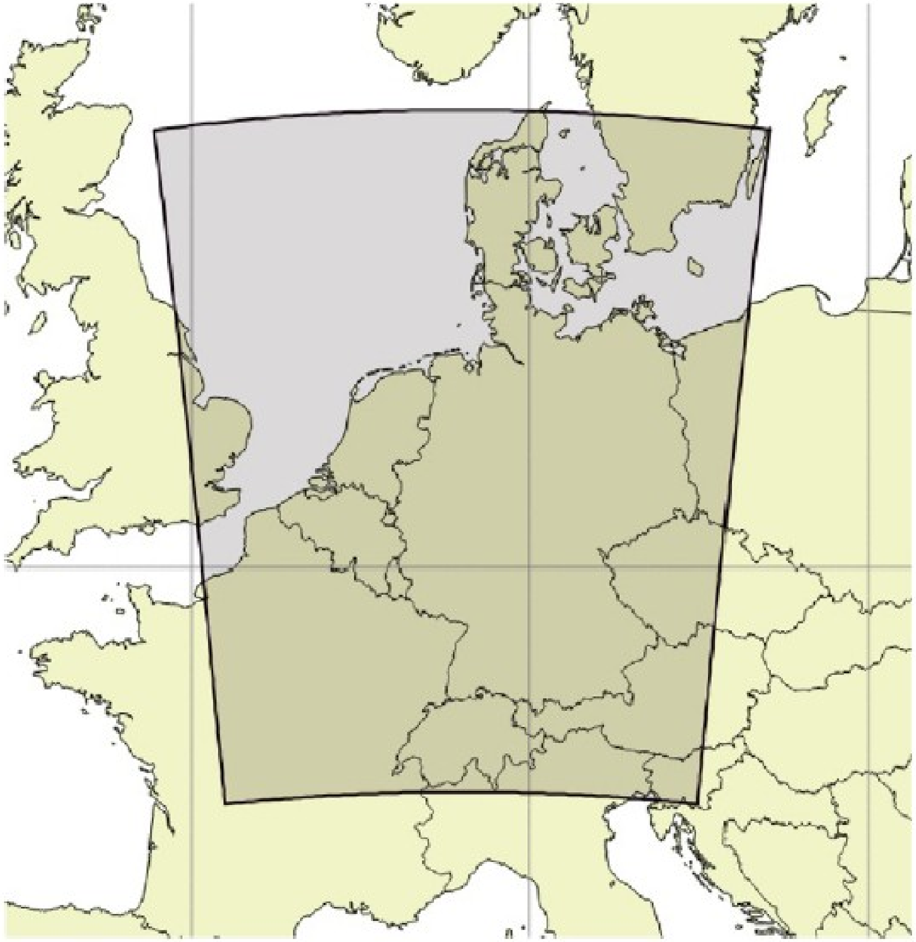
COSMO
Germany
Greece
Italy
Poland
Romania
Russia
Switzerland

Harmon-EPS

- Uses the ALADIN non-hydrostatic dynamical core, grid-distance 2.5 km.
- Physical “packages”; AROME, ALARO
- Perturbation options: Downscaled from ECMWF ENS, Scaled Lagged Average Forecast (SLAF), EDA with 3D-var tested, LETKF under development, and test with perturbation of initial state according to:

  IN = AN_c + k *(FG_c - FG_m)
- Model error representations:
  - Multi-physics: AROME/ALARO
  - Multi-physics schemes (turbulence, microphysics, convection, radiation, clouds)
  - SPPT (F. Bouttier et.al, Meteo-France)
  - Parameter perturbations and MSG cloud mask (Sibbo Van der Veen, KNMI)
  - Surface perturbations from Meteo-France EPS (F. Bouttier)
  - Cellular Automata

Experiment setup



- 18 day period June, 2012.

  36 h forecasts, initiated 00 and 12 UTC.

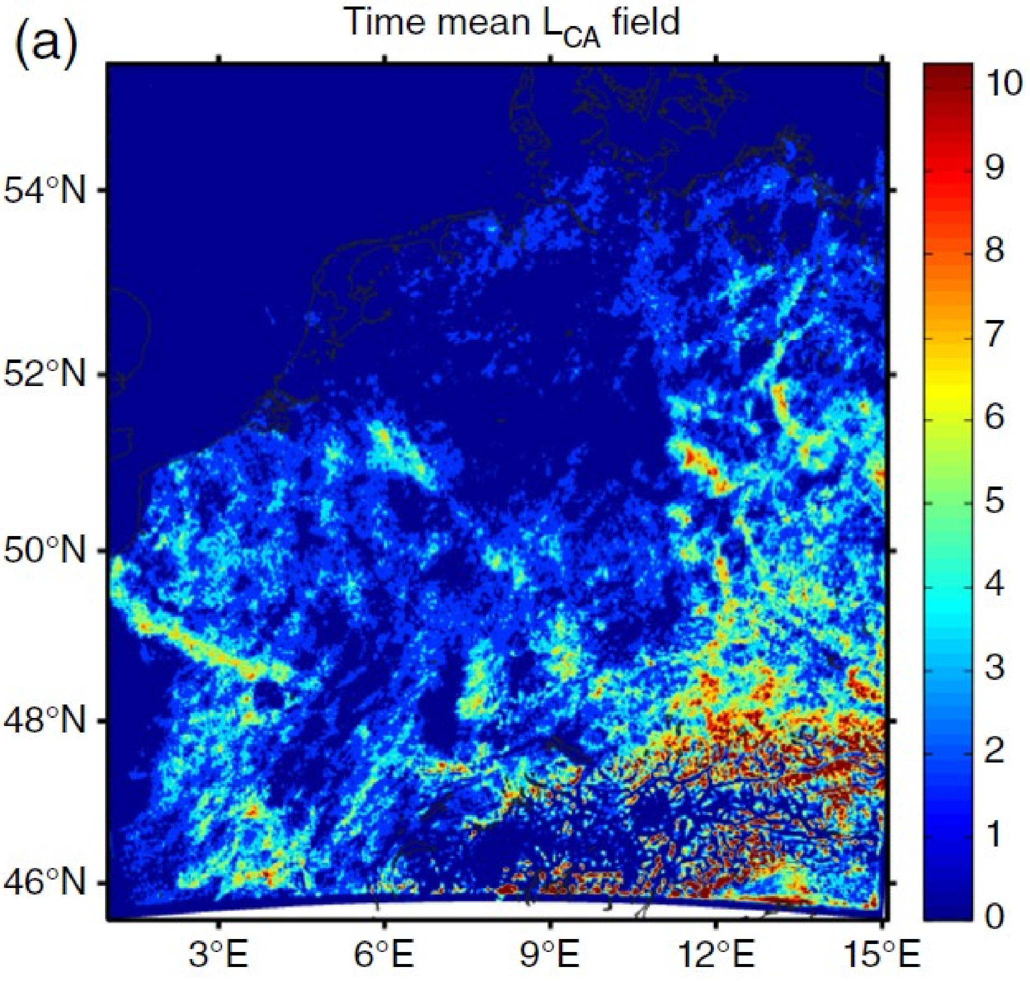
  The control member is using 3D-variational data assimilation, with 6 hour cycling.

  The perturbations come from the boundary and initial 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. (Courtesy of Martin Leutbecher, ECMWF). All perturbed members use their own surface data assimilation.

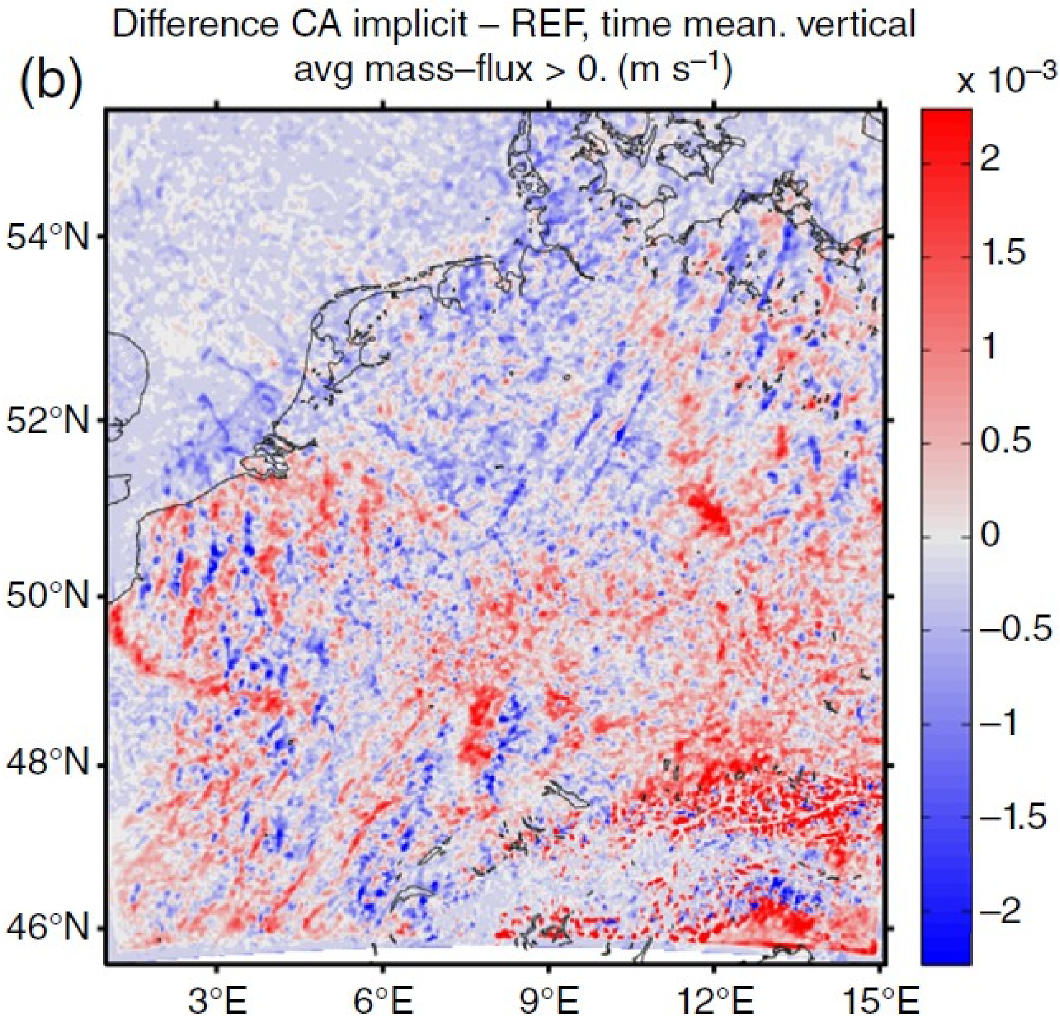
  The reference experiment uses only 10+1 members with ALARO physical parameterization.

  Te cellular automata (CA) experiment uses the exact same initial/lbc perturbations, but each member has a different random seeding in the initialization of new CA cells.

Hourly mean over 18 day period



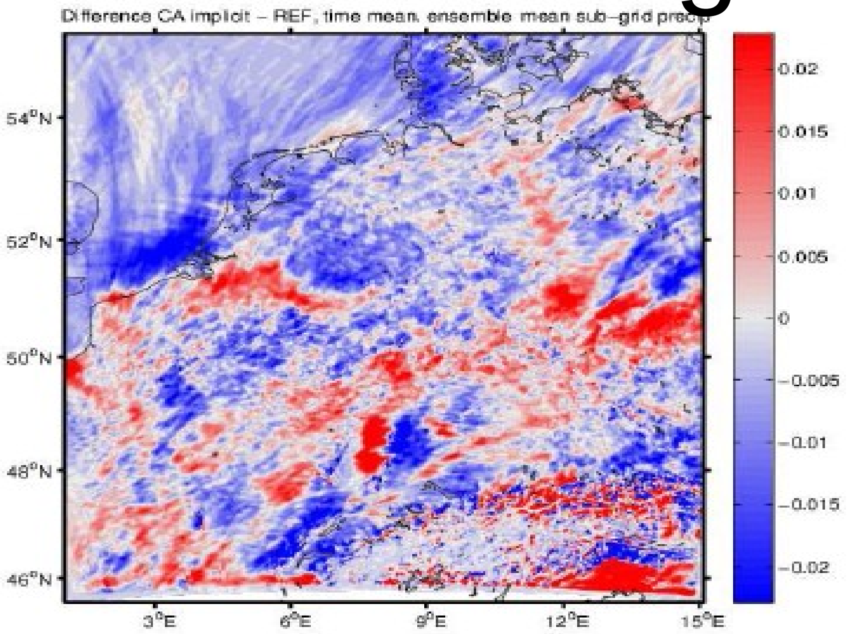
Cellular automata field “life-time”



Difference: CA –
Reference

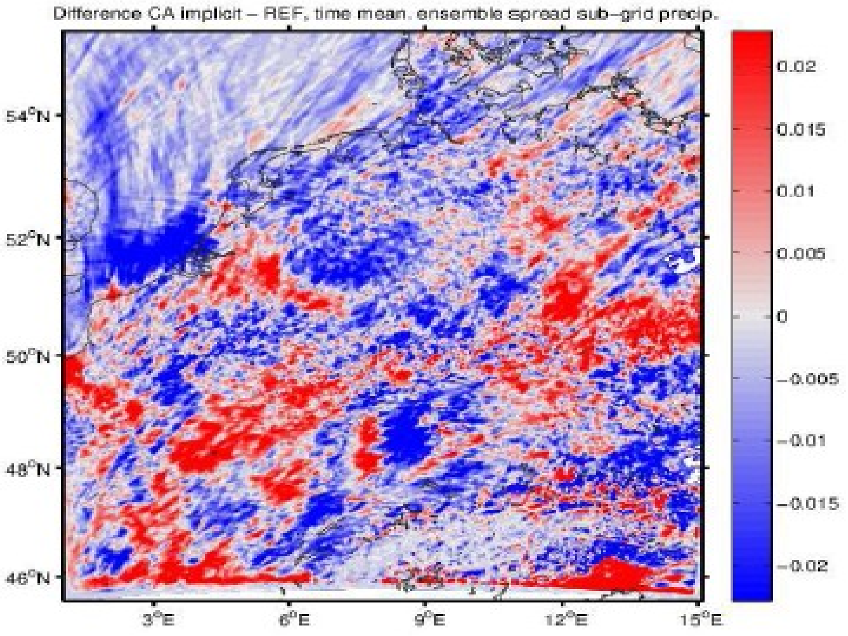
Vertical avg. mass-flux

6 h sub-grid precipitation



- CA – Reference

  Ensemble Mean

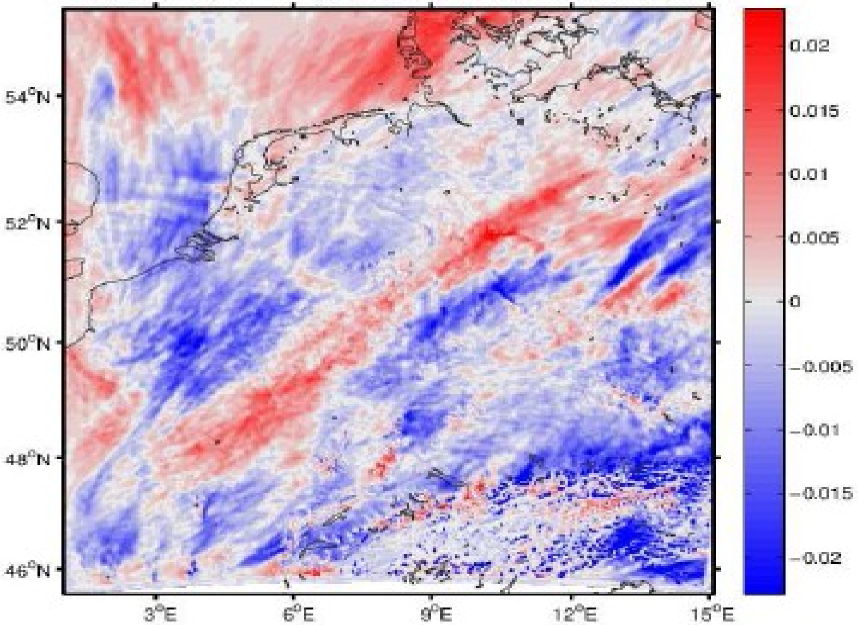


- CA – Reference

  Ensemble Spread

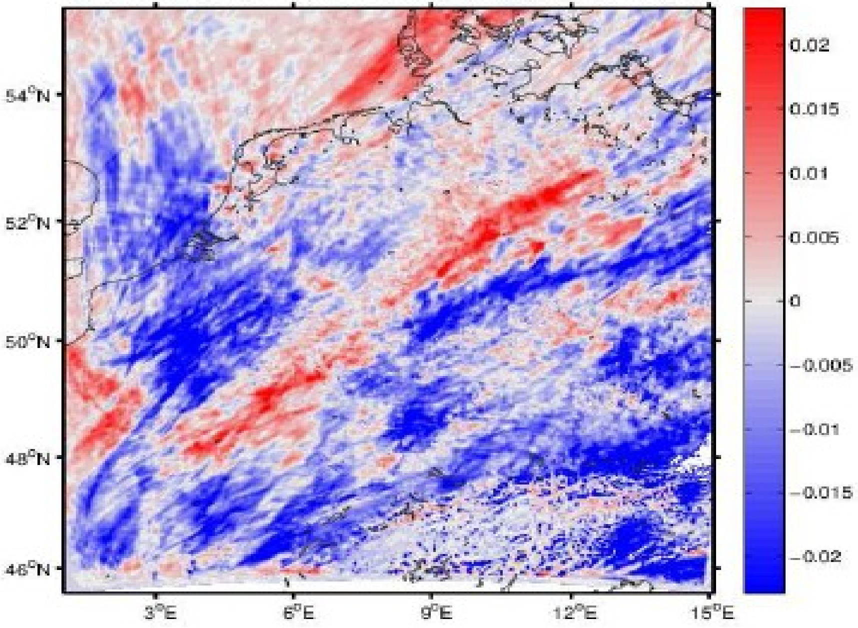
6 h resolved precipitation

Difference CA implicit – REF, time mean. ensemble mean resolved precip.

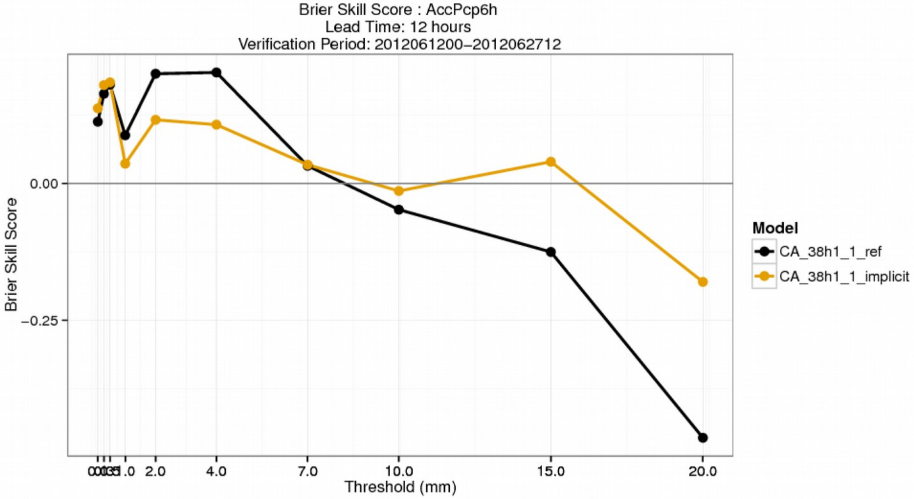


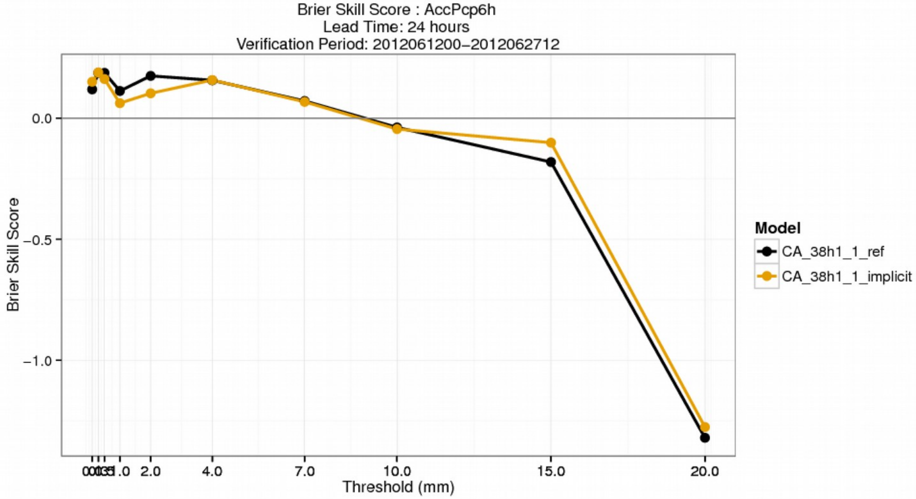
- CA – Reference Ensemble Mean

Difference CA implicit – REF, time mean. ensemble spread resolved precip.



- CA – Reference Ensemble Spread


Brier Skill Score : AccPcp6h
Lead Time: 12 hours
Verification Period: 2012061200–2012062712
Brier Skill Score
0.00
−0.25
2.0
4.0
7.0
10.0
15.0
20.0
Threshold (mm)
Model
CA_38h1_1_ref
CA_38h1_1_implicit


Brier Skill Score : AccPcp6h
Lead Time: 24 hours
Verification Period: 2012061200–2012062712
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7.0
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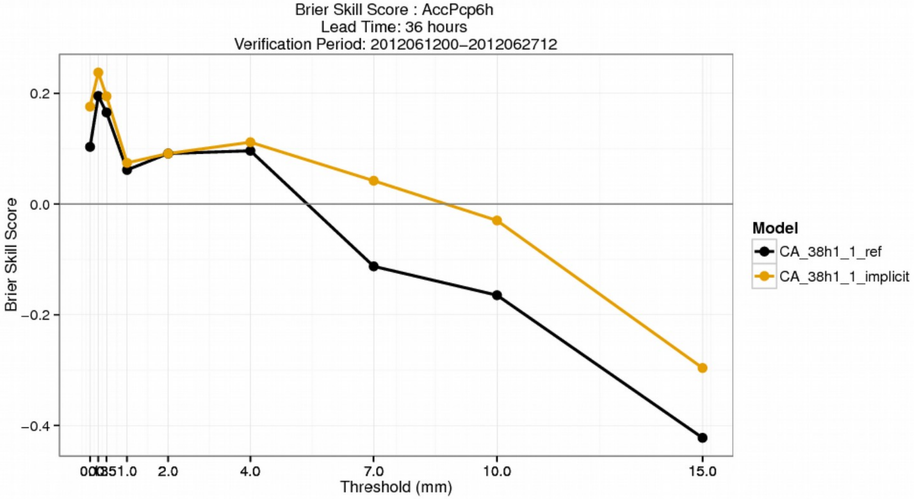
20.0
Threshold (mm)
Model
CA_38h1_1_ref
CA_38h1_1_implicit


Brier Skill Score : AccPcp6h
Lead Time: 36 hours
Verification Period: 2012061200–2012062712
Brier Skill Score
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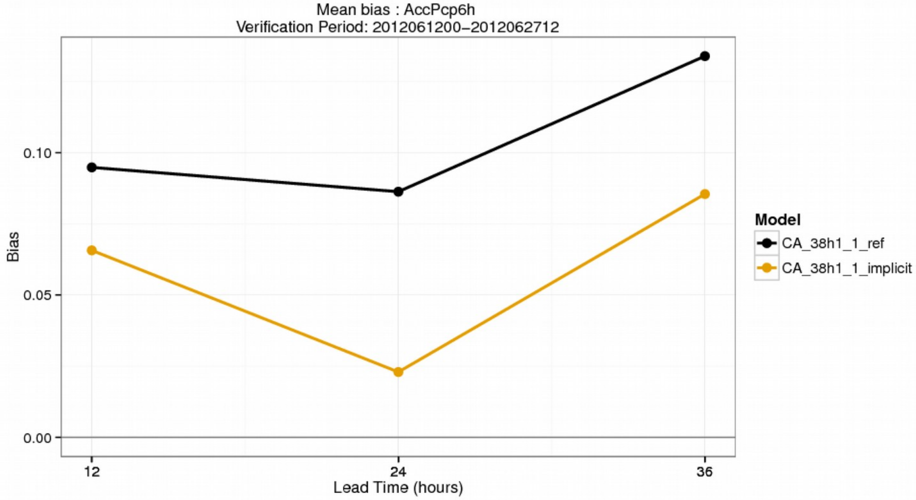
0.0
−0.2
−0.4
2.0
4.0
7.0
10.0
15.0
Threshold (mm)
Model
CA_38h1_1_ref
CA_38h1_1_implicit


Mean bias : AccPcp6h
Verification Period: 2012061200–2012062712
Bias
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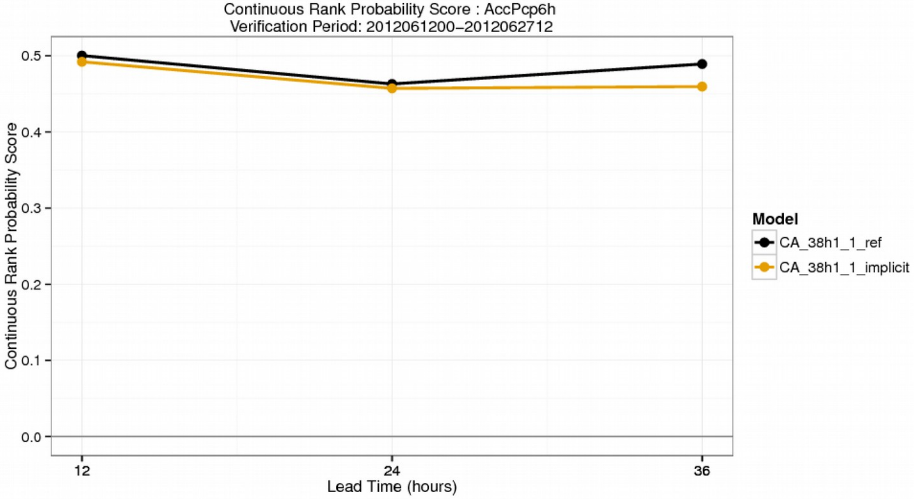
0.00
12
24
36
Lead Time (hours)
Model
CA_38h1_1_ref
CA_38h1_1_implicit


Continuous Rank Probability Score : AccPcp6h
Verification Period: 2012061200–2012062712
Continuous Rank Probability Score
0.5
0.4
0.3
0.2
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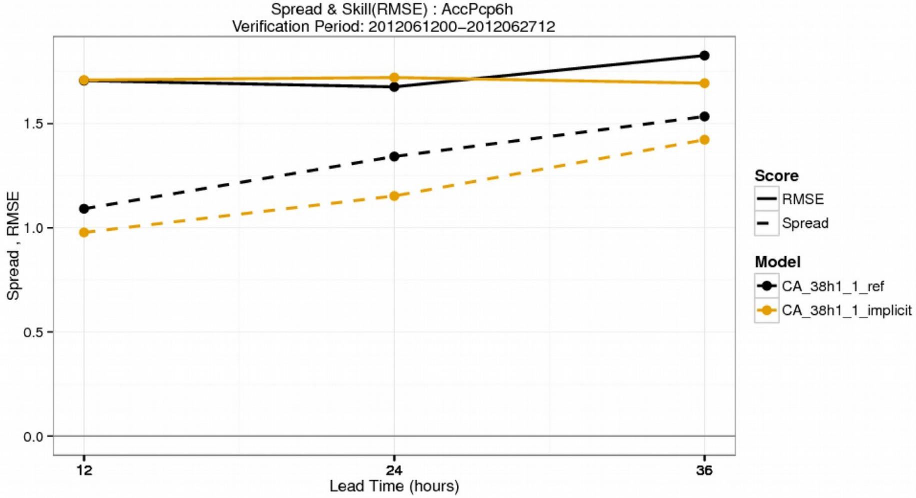
0.0
12
24
36
Lead Time (hours)
Model
CA_38h1_1_ref
CA_38h1_1_implicit


Spread & Skill(RMSE) : AccPcp6h
Verification Period: 2012061200–2012062712
Spread , RMSE
1.5
1.0
0.5
0.0
12
24
36
Lead Time (hours)
Score
RMSE
Spread
Model
CA_38h1_1_ref
CA_38h1_1_implicit

Take home message:

- The inclusion of the stochastic scheme increases the spread of convective precipitation, but the knock-on effects on large-scale precipitation mean that the approach overall reduces the spread in total precipitation.

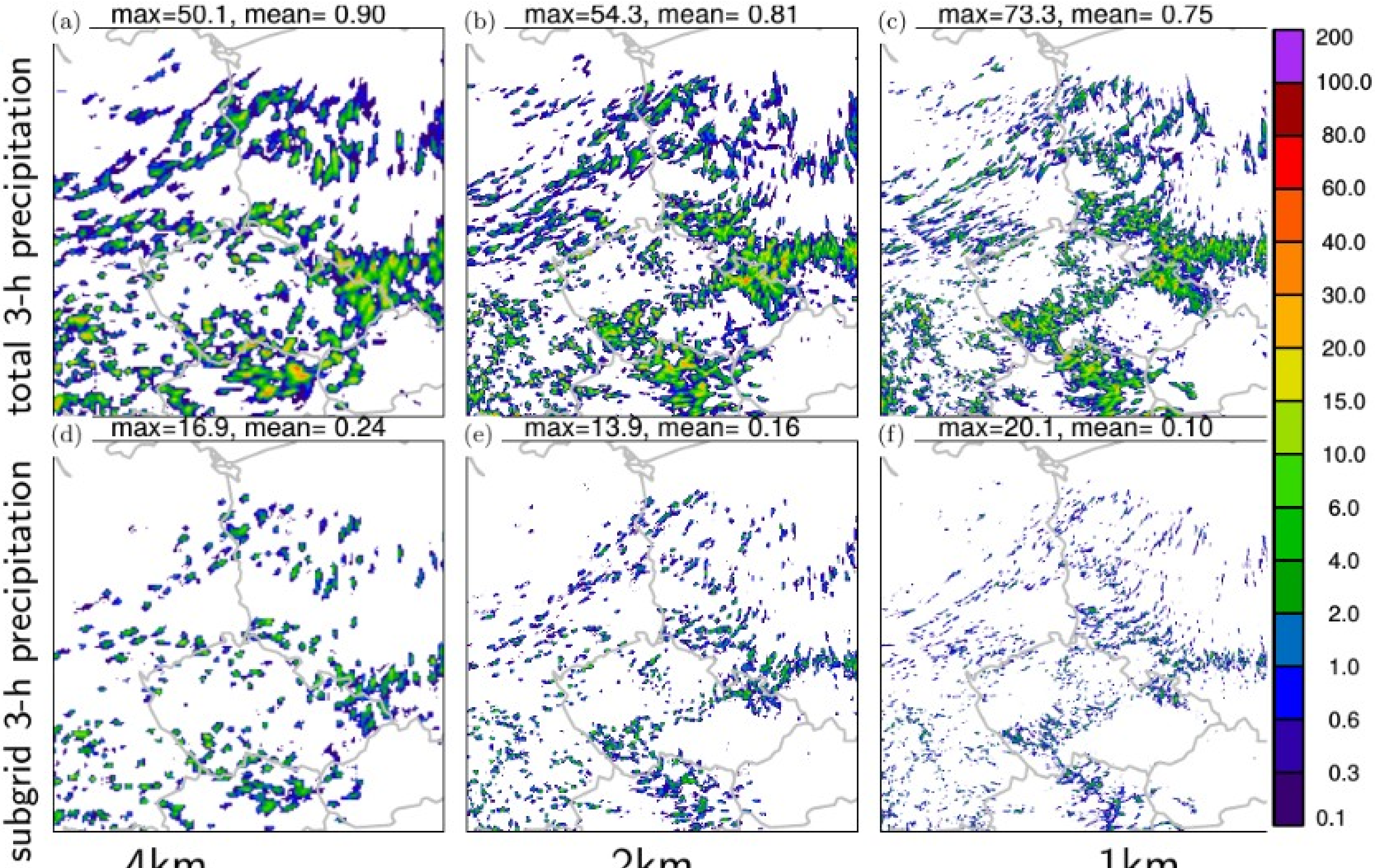
  -> A stochastic scheme on the sub-grid, does not automatically produce more spread.

- The scheme reduces the model bias in 6h acc. precipitation, which leads to a slightly improved ensemble forecast (more reliable), but not because of increased spread, but rather because of improved skill.

Discussion and future outlook

- The influence of the scheme seem confined to the sub-grid scale, no large impact on ensemble spread in the resolved variables, T, q, U, V
- Useful to have cellular automata at 2.5 km grid-spacing?
- Some recent results suggests even at 1 km the CA can have an impact on organization of deep convection.

Summer convection 2 July 2009 (3-hour precipitation at 18 UTC)



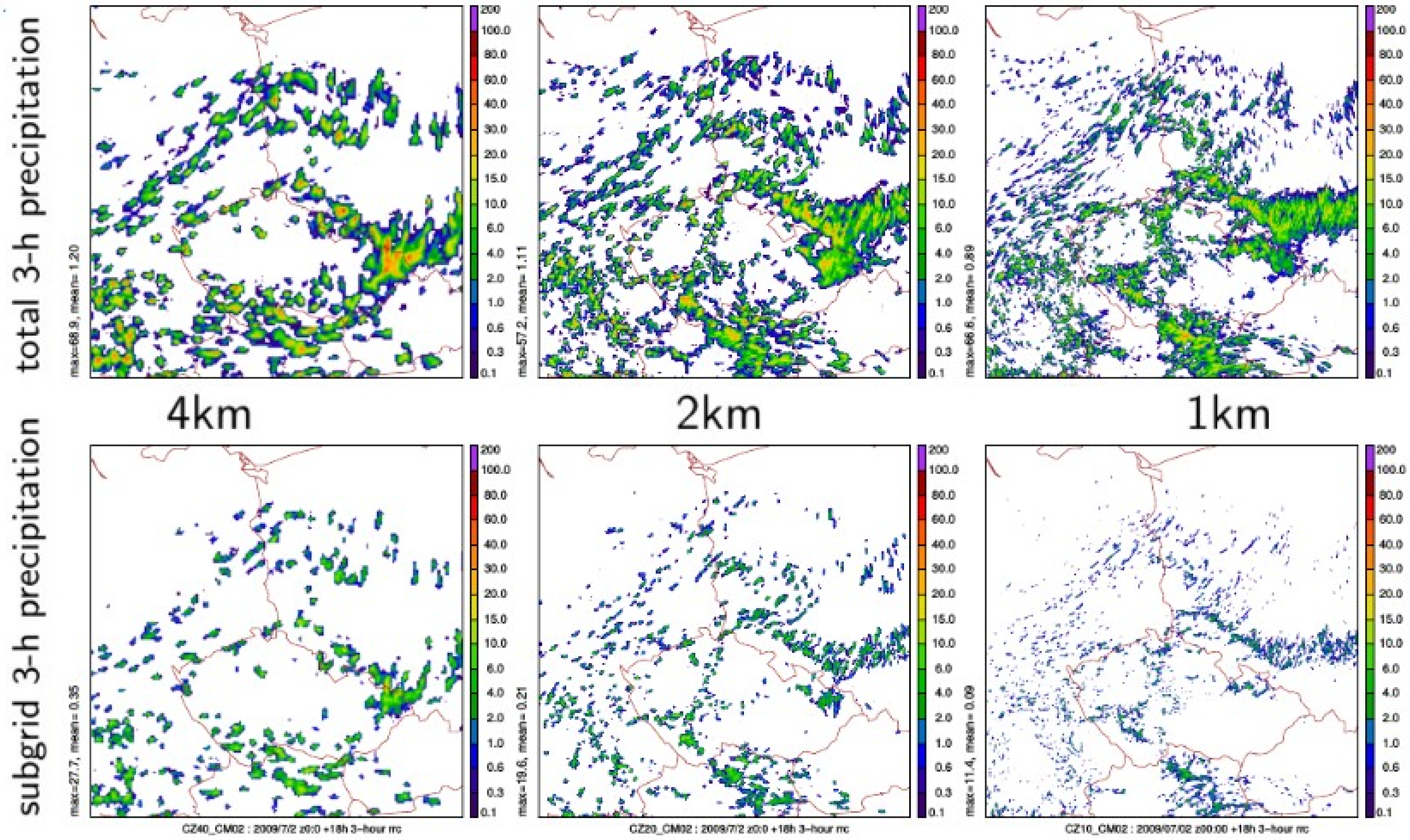
4km 2km 1km

Sub-grid part of precipitation is decreasing

Lack of meso-scale structure, precipitation areas are more “dotty”

Luc Gerard, Neva Pristov, HIRLAM-ALADIN ASM 2016

Summer convection 2 July 2009 (3-hour precipitation at 18 UTC)
Using Cellular Automaton and new horizontal momentum handling



Sub-grid part of precipitation is significantly reduced

Meso-scale structure is kept

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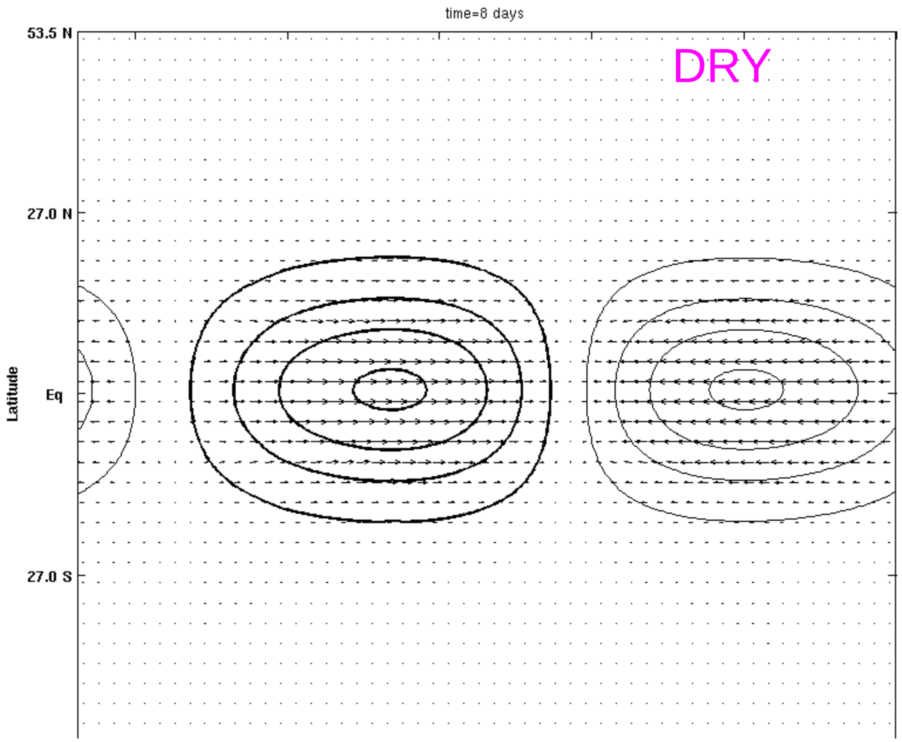
Discussion and future outlook

- In order to really understand the interaction with the dynamics, and “transfer of uncertainty” upscale, would like to study convectively coupled equatorial waves, with/without the cellular automata scheme.
- Recently received nice software from Peter Bechtold, ECMWF to filter out equatorial wave signal, and use OLR to study for instance the Kelvin wave mode... will probably be the next step.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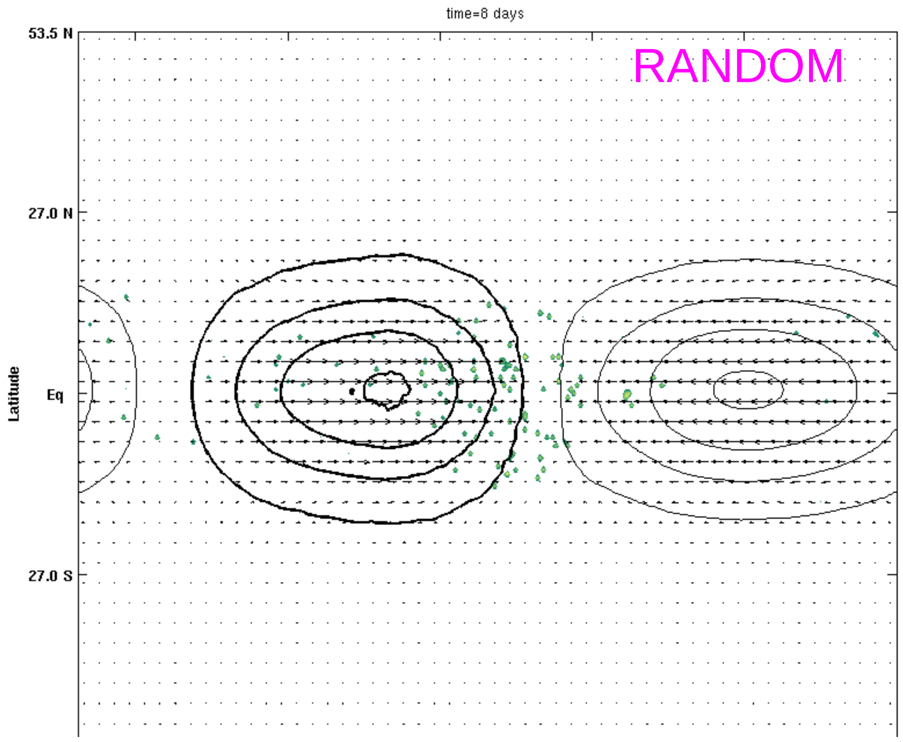
DRY
53.5 N
27.0 N
Eq
27.0 S
Latitude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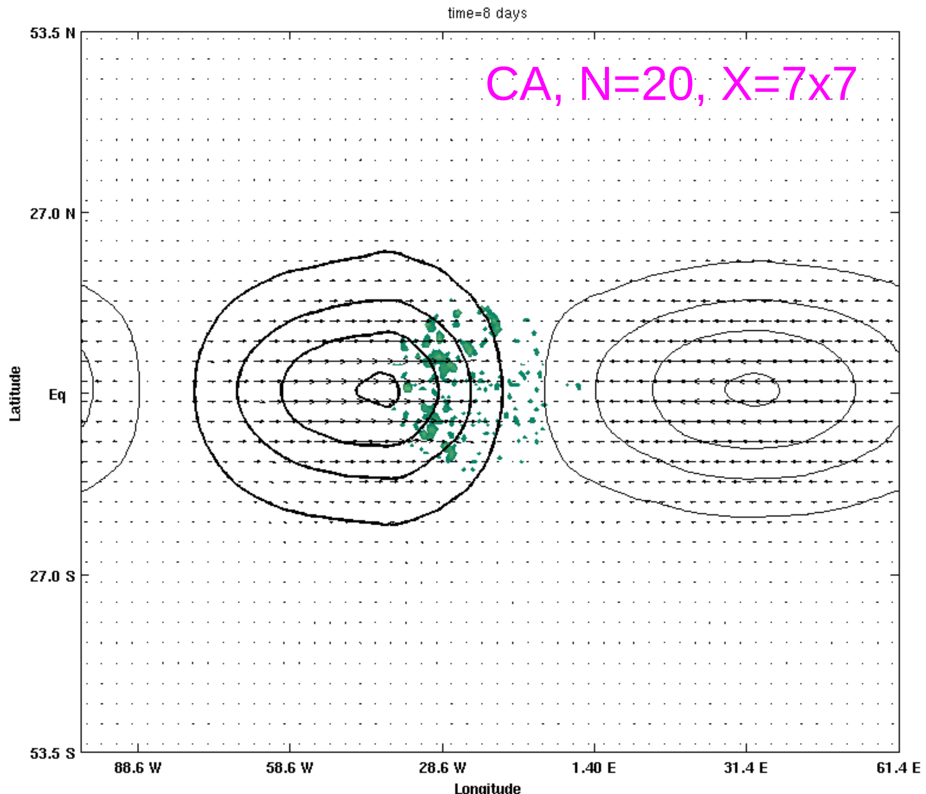
RANDOM
53.5 N
27.0 N
Eq
27.0 S
Latitude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CA, N=20, X=7x7
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27.0 N
Eq
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53.5 S
Latitude
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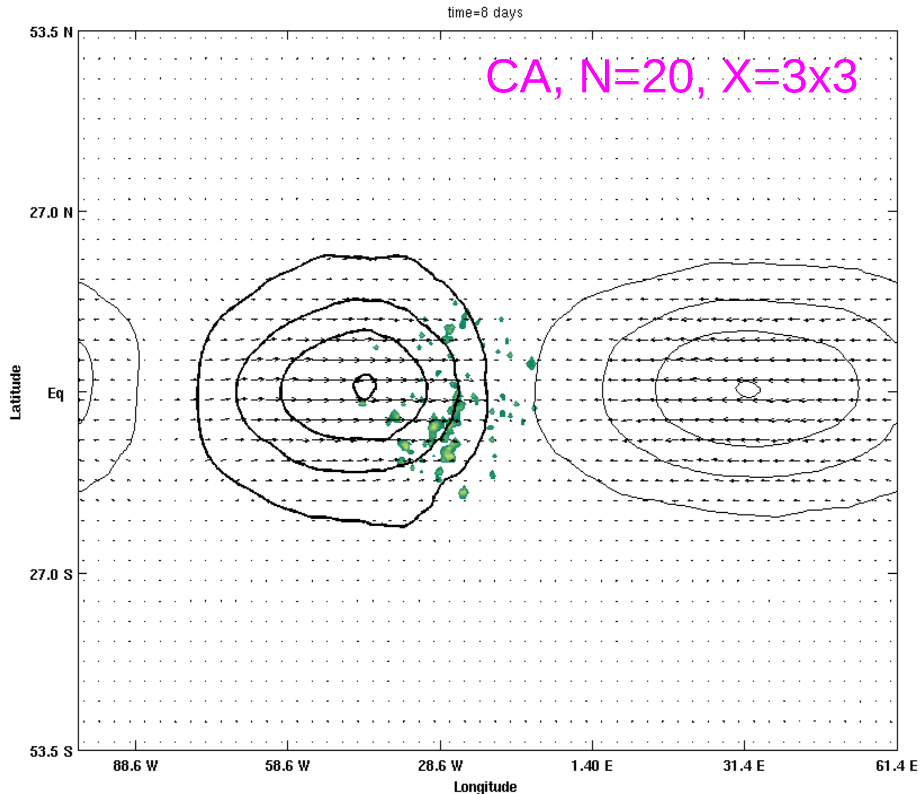
58.6 W
28.6 W
1.40 E
31.4 E
61.4 E
Longitude


time=8 days
CA, N=20, X=3x3
53.5 N
27.0 N
Eq
27.0 S
53.5 S
Latitude
88.6 W
58.6 W
28.6 W
1.40 E
31.4 E
61.4 E
Longitude

Thank you for your attention!