Progress report and instructions on the use of cellular automata deep convection in ALARO and HarmonEPS.

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Introduction

This documentation describes the current status and plans of the cellular automata deep convection scheme in ALARO, and for EPS use in HarmonEPS. The first part of the documentation describes some experiences with the scheme in HarmonEPS for a summer time-period. In the second part I have added some technical information on how to setup and use the scheme.

The scientific method of the scheme is described in Bengtsson et al. 2013. The idea is that the self-organizational characteristics of the cellular automata allow for lateral communication between adjacent numerical weather prediction (NWP) model grid boxes and add additional memory through added cell history to the deep convection scheme. (By cell history I refer to cells with a given pre-described 'lifetime', being incrementally reduced by 1 each time step where the rules are not met, in contrast to going directly from 1 to 0). The cellular automata acts in two horizontal dimensions, with finer grid spacing than the numerical weather prediction model. There is a random initialization of cellular automaton cells, and a random seeding of new cells at each time-step. The random numbers are generated with uniform distribution on the finer grid with a value between 0 and 1.

The scheme has been slightly updated since Bengtsson et al. 2013, such that the cellular automaton now receives the value 1 if the random number exceeds 0.5 in regions where convective available potential energy (CAPE) exceeds 300 J/kg each time-step (as opposed to 600 J/kg), and the pre-described lifetime is furthermore modified to be a function of CAPE according to:

L=min(CAPE\alpha,NLIVES)

where alpha is set to 20 J/kg, and NLIVES is 30. This means that the larger the CAPE value is in a model grid-box, the longer the cellular automata cells can stay active in that grid-box, with a maximum value of NLIVES. With a model time-step of 60 s, it means that if the cellular automata cell would lose a life each time-step, a value of NLIVES=30 corresponds to a lifetime of 1800 s.

Experiment in HarmonEPS:

The version of HarmonEPS used for this study is 37h1.2 and the setup is as follows: The domain is setup over central Europe, and is 1350 x 1125 km. The horizontal resolution is 2.5 km, and the number of vertical levels is 65. The control member is using 3D-variational data assimilation, with 6 hour cycling. The other members use the ECMWF upper air downscaled upper air forecast as an initial field every 12 hours, but its own surface data assimilation. The reference experiment uses 22 members; 10 members plus 1 control run which uses AROME physics, and 10 members plus 1 control run which uses 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. In order to avoid a cold start in HarmonEPS, the two control members uses a spin-up period of 3 weeks, which are then used as the starting field for all ensemble members.

The experiment using cellular automata is only applied in members with ALARO physics since deep convection is explicitly resolved in AROME. Thus, this experiment use only 10+1 members. The experiment use the same perturbed boundaries for the same members as the reference run, where all members are included. This way, only the cellular automata implementation contributes to the difference between a member in the reference and the experiment. The test period is 10 of June, 2012 to 21 of June, 2012 for the following results, however the intention is to finish the entire test period until the 28th of june, 2012. The forecast length is 36 hours.

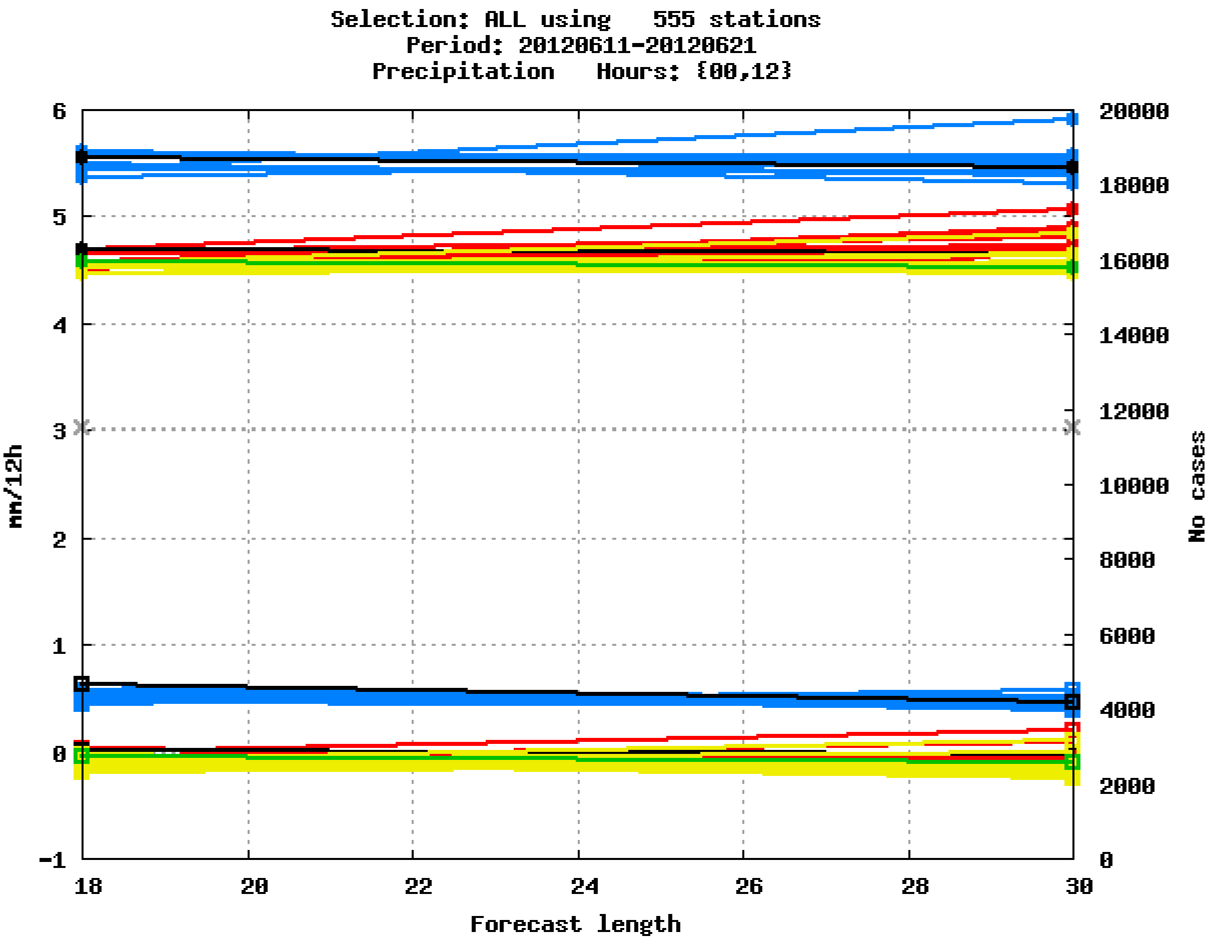


Figure 1. Root Mean Square Error (RMSE) and bias of 12 hour accumulated precipitation for the full time-period for all 20+2 members in the reference experiment, and the 10+1 members in the experiment with the CA scheme. Blue – AROME reference members, Red – ALARO reference members, Yellow – ALARO CA experiment members.

Figure 1 show the Root Mean Square Error (RMSE) and bias of 12 hour accumulated precipitation for the full time-period for all 20+2 members in the reference experiment, and the 10+1 members in the experiment with a stochastic parameterization of deep convection. The verification of precipitation is for the test period between 10 of June, 2012 to 21 of June, 2012, and the 12 hour accumulated precipitation verified is the forecasts initialized at 00 and 12 UTC between 30-18 and 18-06 forecast lengths. The precipitation field is verified against 555 synop stations (rain gauges).

In the plot the AROME members of the reference experiment are shown in blue, whereas the ALARO members of the reference experiment are shown in red, this way it is easier to distinguish the 10+1 members that can be compared with the CA scheme experiment (yellow). The control forecasts are shown in black for the reference experiments, and in green for the CA-experiment. It is clear that the two different physics options (AROME and ALARO) in the reference experiment have a different bias, and the RMSE and bias of the ensemble members are clustered into two parts, where the difference between each member come from the perturbed boundary conditions. Such difference in bias between half of the ensemble members is also motivation to avoid multi-physics ensembles, the ensemble may give good spread but for the wrong reason. It can also be seen that when comparing the reference ALARO members with the CA-scheme experiment (red vs yellow), the RMSE is reduced using the new parameterization for most ensemble members, including the control member, indicating an improvement in total precipitation in a deterministic sense using the CA-scheme.

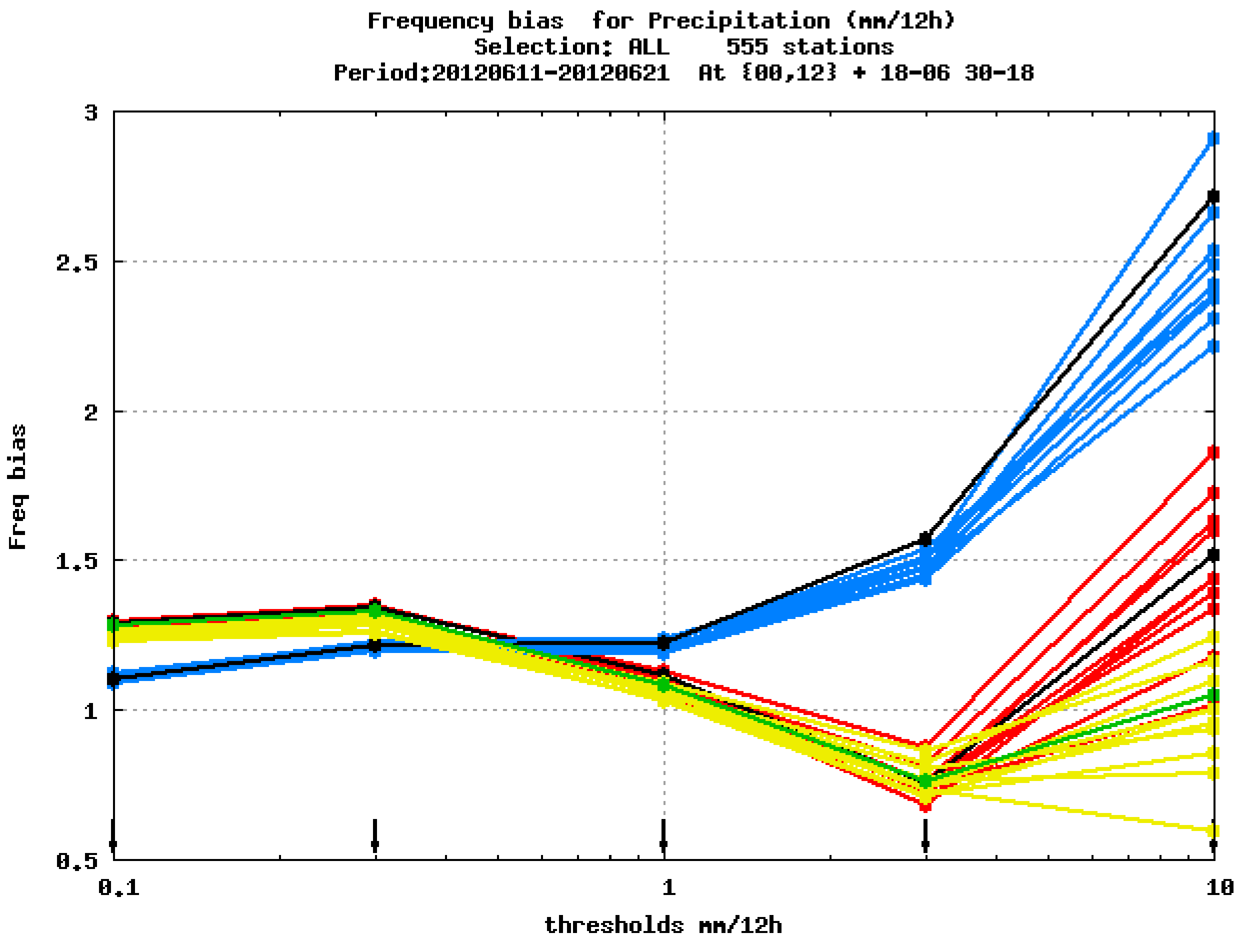


Figure 2: Frequency bias of 12 hour accumulated precipitation for the full time-period for all 20+2 members in the reference experiment, and the 10+1 members in the experiment with the CA scheme. Blue – AROME reference members, Red – ALARO reference members, Yellow – ALARO CA experiment members. Black – reference control for AROME and ALARO, and green is the control experiment in the CA-experiment.

Figure 2 shows the Frequency bias, in the Frequency bias, the desirable value for bias is 1, indicating an unbiased forecast where the event is forecasted exactly as often as it is observed. It can be seen that for small amounts of precipitation the AROME members (blue lines) are closer to 1 than the ALARO members with and without the cellular automaton scheme (red and yellow lines). However, for amounts over 3 mm in 12 hours there is a large overprediction of precipitation in AROME, perhaps a consequence of using explicit treatment of deep convection at 2.5 km horizontal resolution. Such an overprediction of precipitation, although not as distinct, can also be seen in the reference ALARO members (red lines) for amounts over 6-7 mm in 12 hours. The new parameterization (yellow lines) seem to reduce this overestimation, although it reduces it too much for large amounts, and instead an underprediction of large amount of precipitation can be seen using the cellular automata scheme in some of the members.

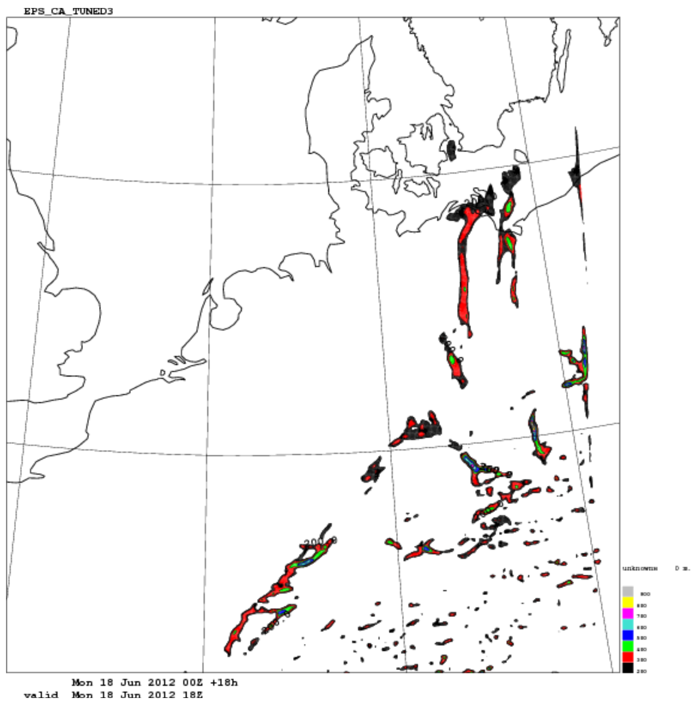


Figure 3: CAPE (J/kg) field on 2012-06-18, at 18UTC

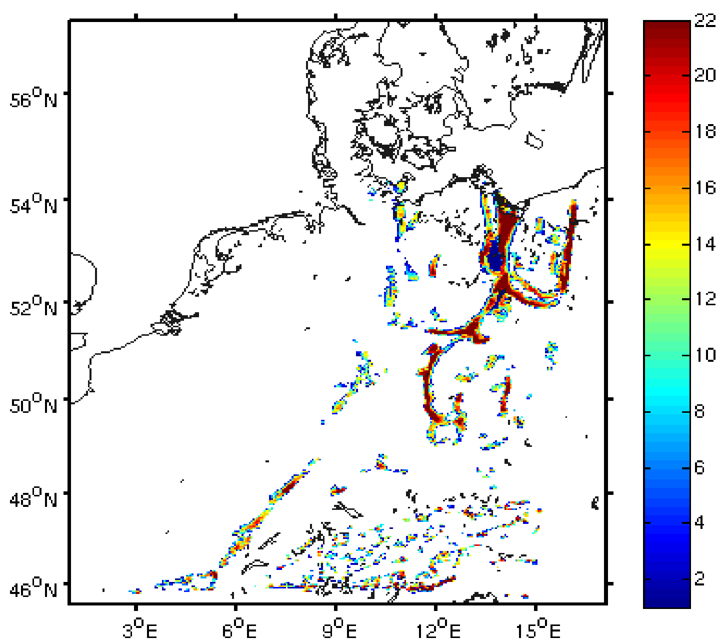
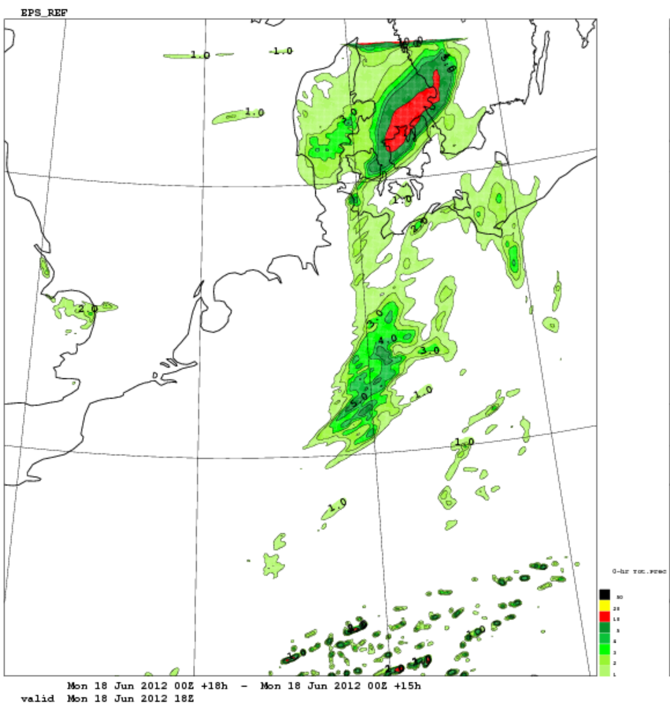


Figure 4: CA lifetime field on 2012-06-18, at 18UTC for the control member.

This can be understood by taking a closer look at the CA implementation, and how different regimes (high CAPE values, and strong moisture convergence), are influenced by the scheme. Figure 3 shows the CAPE values for 2012-06-18, at 18 UTC, and Figure 4 shows the corresponding CA field (lifetime values which range from 0-30, see below for technical discussion). It is clear that the CA is active in regions where CAPE overcomes a certain threshold, although, the cellular automata rules make it possible for cells to stay “alive” even though CAPE is below the given threshold. The impact on the precipitation field can be seen in Figure 5, and a quite clear connection to the CAPE field is visible. The scheme is doing what it is intended to do in these situations, and running 11 members with different evolution of the cellular automata would increase the spread of the scheme, and generate more possible convective responses to a given large scale state.



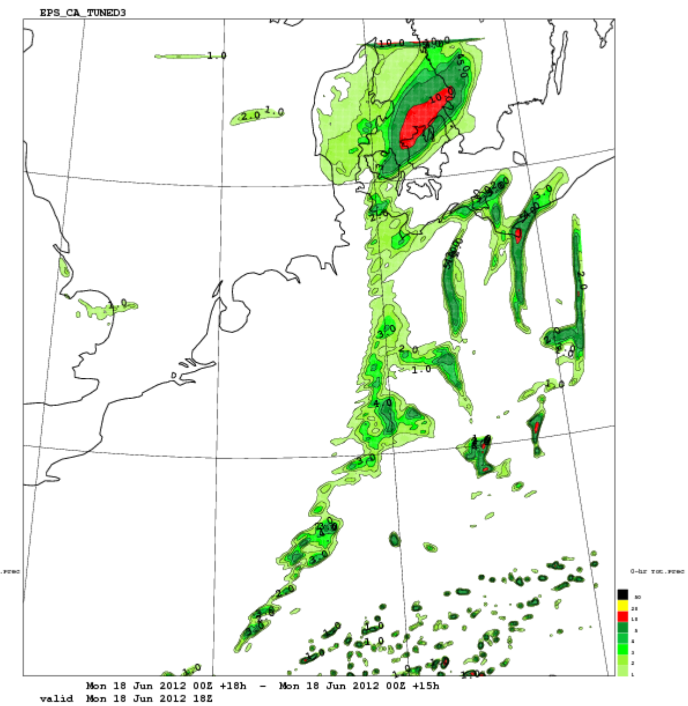


Figure 5: 3 hour accumulated precipitation valid at 18 UTC on 2012-06-18. Left reference ALARO, right ALARO + CA. (Both control members of HarmonEPS).

However, following equations 7 and 8 in Bengtsson et al. 2013, it can be seen that a consequence of the implementation strategy (relaxing a new ca-updraft mesh-fraction onto the original updraft mesh-fraction over a time-scale “tau”), the updraft mesh-fraction will be reduced in regions where the CA field is 0. Figure 6 show the RMSE and bias as a time-series of the experiment for the reference AROME (blue), reference ALARO (red) and CA-scheme (yellow). It is in particular on 2012-06-20 where the RMSE is reduced in the CA-experiment compared with the reference. A closer look at the impact on precipitation for this case show a reduction in large amount of precipitation over 12 hours over the south-east region of the domain (Figure 7). This is because the updraft mesh-fraction that was originally present as a consequence of moisture convergence is now reduced, since there were low values of CAPE. In terms of RMSE, and frequency bias (Figures 1, 2 and 6) it appears that this reduction of precipitation is appropriate, although it is very difficult to know exactly how much should be reduced before looking at radar or other high resolution precipitation observations.

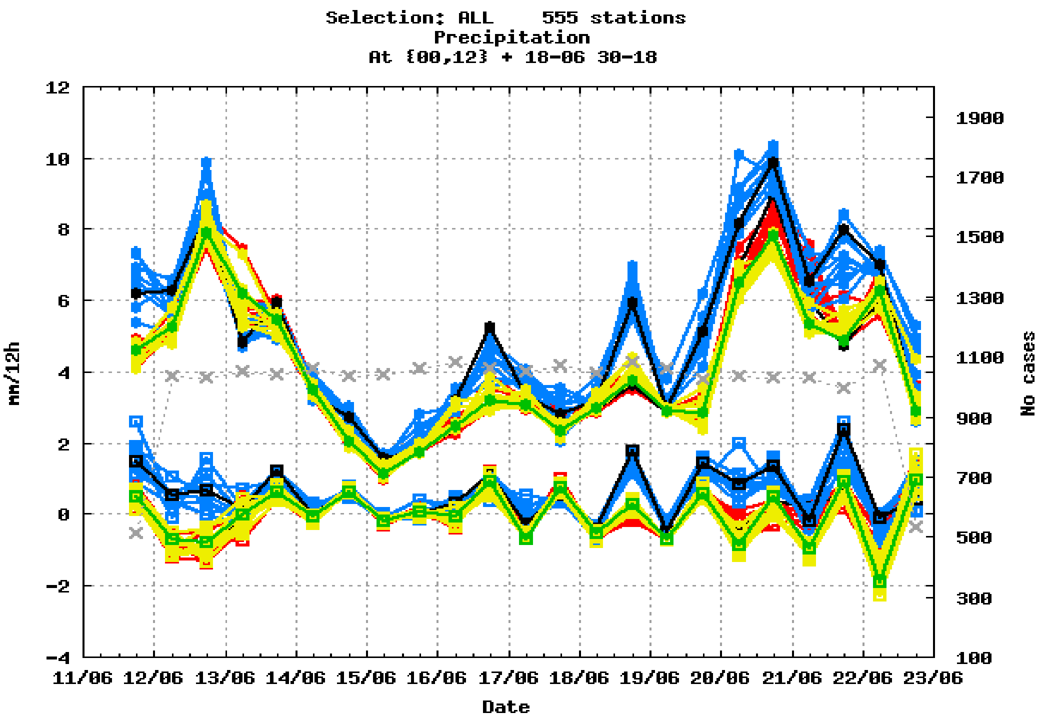


Figure 6: Timeseries of RMSE (top) and Bias (bottom) of 12-hour accumulated precipitation. AROME members in blue, ALARO reference in red and ALARO+CA in yellow. Green curve is control member of CA-experiment, and black curves are control members from the reference experiment.

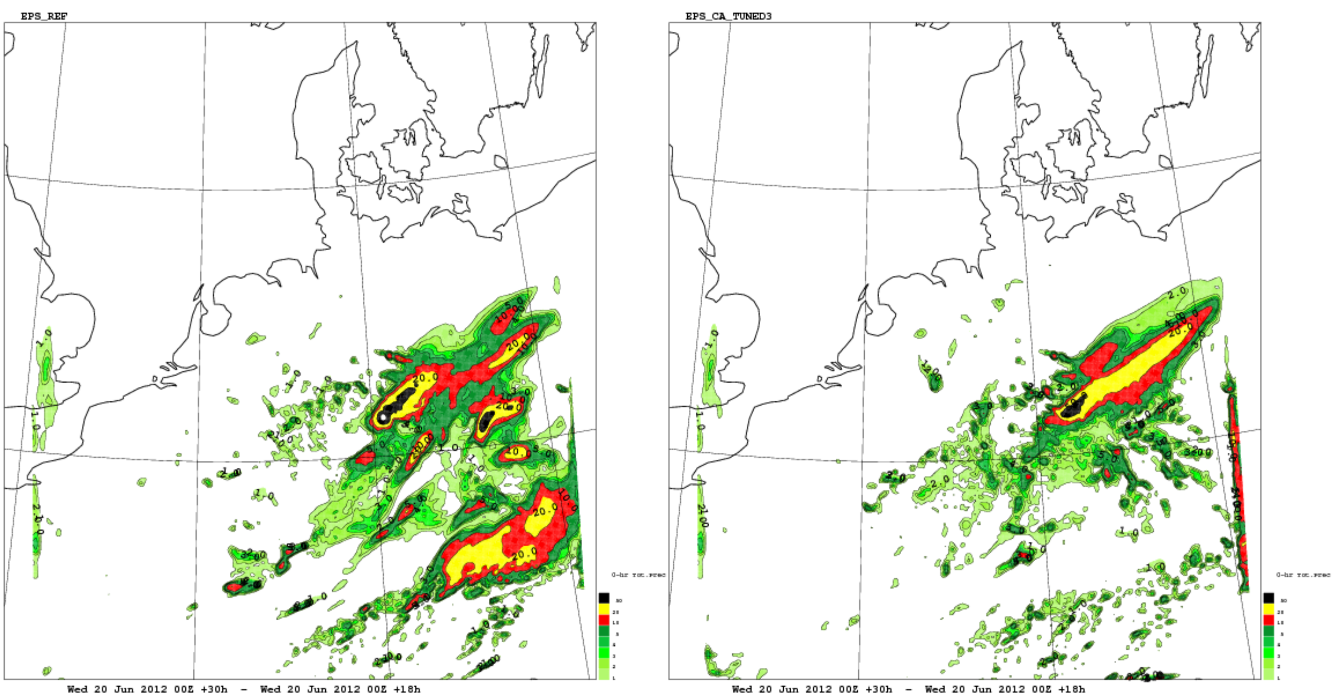


Figure 7: 12 hour accumulated precipitation valid at 06 UTC on 2012-06-21 Left reference ALARO, right ALARO + CA. (Both control members of HarmonEPS).

To sum up, when CAPE values are high, the scheme does what it is intended to do, however due to a consequence of the implementation method, where CAPE is not present, but an updraft-mesh fraction is present due to moisture convergence, precipitation will be reduced.

Due to the decrease of some erroneously large amounts of precipitation in all ensemble members with the CA-scheme, the ensemble spread is reduced comparing ALARO members with ALARO+CA members (Figure 8). This is of course not a desirable feature of a stochastic scheme in an EPS, even though this reduction can be understood and often results in a better skill.

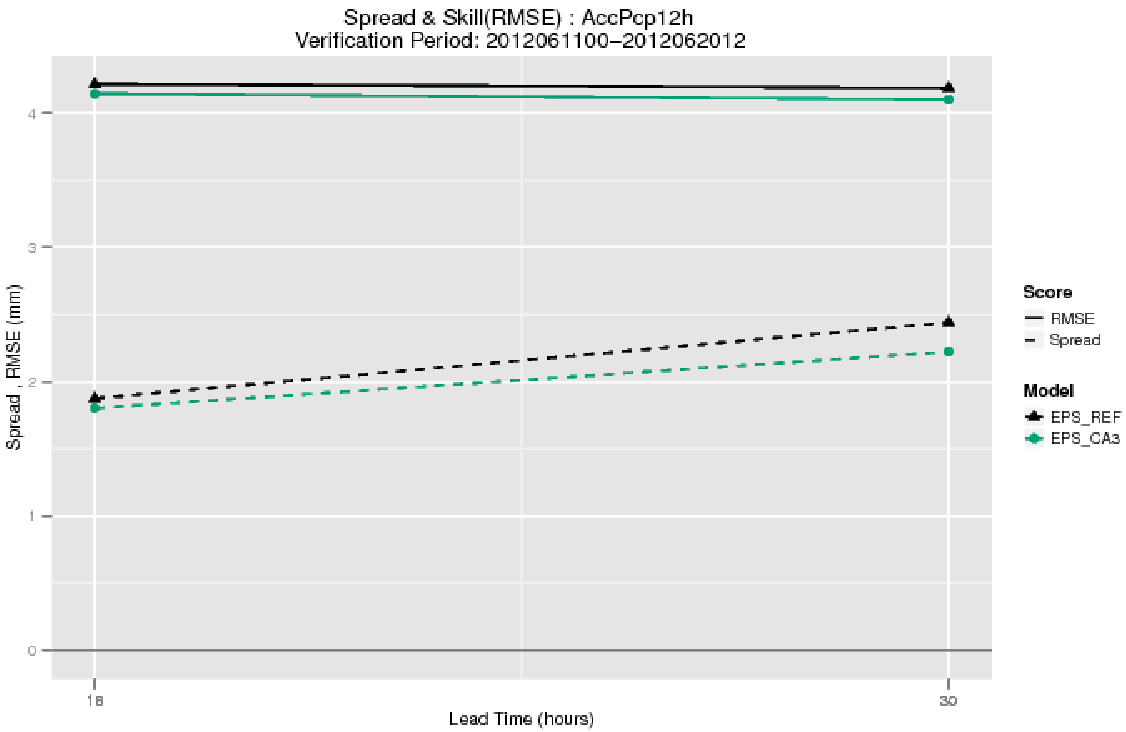


Figure 8: Spread and RMSE of 12 hour accumulated precipitation, black curve is the 10+1 ALARO members in the reference, and the green curves are the 10+1 members of the ALARO+CA experiment.

At present, I think the best way around this is to also constrain CA activity to moisture convergence (as well as CAPE). This way the scheme will mostly influence precipitation when CAPE values are high, and otherwise leave the forecast as it was. This way the scheme would target the more extreme chaotic type convective events. Such an implementation will most likely influence the present results, such that the witnessed reduction of the overestimation of large amounts will no longer be present, however, it could potentially lead to a larger spread associated with events constrained by large CAPE, which is really the desired outcome of using a stochastic parameterization of deep convection.

Further analysis of the behavior of the scheme will also include OPERA radar data and gridded precipitation observations such as EOBS.

Reference:

L. Bengtsson, M. Steinheimer, P. Bechtold and J.-F. Geleyn. 2013. A stochastic parametrization for deep convection using cellular automata. Q. J. R. Meteorol. Soc. DOI:10.1002/qj.2108

Source code

The latest version of the code is available in **harmonie-38h1.2,** however it is possible to use from cycle 37h1.1 with some modifications to the code therein. Please contact lisa.bengtsson@smhi.se in order to get the correct modifications if you work in a cycle earlier than 38h1.2.

Given the above results, it is likely that a new version of the scheme, using moisture convergence as a constraint, will be included shortly.

The main routines for controlling the cellular automata are located here and are written by Martin Steinheimer at ECMWF with some minor updates:

/src/arp/control/cuconvca.F90
/src/arp/module/yoe_cuconvca.F90

The main routine for coupling to the 3MT deep convection scheme is located here:

/src/arp/phys_dmn/accvud.F90

Namelist

The namelist variables for the cellular automata are controlled under NAMCA, with some tuning parameters controlled under NAMPHY0. For coupling with deep convection in ALARO, these are the recommended values for cycle 38h1.2 (an explanation of the options follows below):

```
NAMCA=>{
  'LCUCONV_CA' => '.TRUE.,',
  'LCA_ADVECT' => '.FALSE.,',
  'LCA_GLOBAL' => '.FALSE.,',
  'LCA_TEST'   => '.FALSE.,',
  'LCA_RANTROP' => '.TRUE.',
  'LCA_SMOOTH' => '.FALSE.,',
  'CA_PROB' => '\'WIND\',',
  'RCA_SEEDPROB' => '0.5,',
  'NFRCASEED' => '1,',
  'NLIVES' => '30,',
  'NSPINUP' => '1000,',
  'NFERTYRS' => '30,',
  'LCA_EXTRACT' => '.FALSE.,',
 },

NAMPHY0={
...
'NCATAU' => '2000.,',
'NCAPEMAX' => '300.,',
}
```

The namelist options are:

LCUCONV_CA: main switch for activating the CA scheme

LCA_GLOBAL: switch for a CA which is initialized over the entire domain
LCA_TEST: switch for initialize CA at single point
LCA_RANTROP : switch for random coupling of CA to deep convection (concerns initialization) . Setting this switch to TRUE means that if a randomly generated number in a gridbox exceeds RCA_SEEDPROB, and there is CAPE larger than NCAPEMAX in the same gridbox, CA cells get initialized with the value 1.

Note: if all of the initialization switches above are FALSE, CA cells are initialized with the value 1 in gridboxes where CAPE is larger than NCAPEMAX, and the lifetime, L, is set to

L=MIN((PCAPE(JLON)/20.),NLIVES)

RCA_SEEDPROB: Probability of random seeding for CA
LCA_SMOOTH: switch for smoothing CA on large scale grid

NTESTPROC: set on which processor the single point should lie (if LCA_TEST = TRUE)
NTESTGP: set which gridpoint the single point is on (if LCA_TEST = TRUE)

CA_PROB: switch to choose rules used to evolve the CA in time. Options are **GOL** for “Game Of Life”, **WIND** for a probabilistic CA that takes the wind field at 850 hpa into account, so the CA is more likely to produce new cells downwind. Lastly, **NOWIND** for equal probabilities upwind and downwind.
CA_WIND: switch to choose CA-wind (real/idealized, if CA_PROB = WIND)
NDXUNREAL: set X component of unreal wind
NDYUNREAL: set Y component of unreal wind

CA_FORC: switch to choose type of convective forcing (only ECMWF)

NFRCASEED: switch to choose frequency of seeding new cells in CA
NLIVES: switch to choose maximum number of lives
NFERTYRS: switch to choose max number of steps a cell can be fertile

Note: For rules according to GOL, NFERTYRS must equal NLIVES.

NSPINUP : set number of spin-up cycles for CA pattern

LCA_ADVECT: switch for "kind of" semi-Lagrangian advection (not working in ALARO yet)
LCA_ADVTEST : switch for advection test (CA only evolved first 5 steps, not working in ALARO yet)

LCA_EXTRACT : switch for extraction of CA fields (to plot output)
Note: in a HARMONIE experiment, make sure to copy the extracted fields from the working directory before archiving so they don't get removed each cycle.

LCA_NBDEBUG : switch for neighbour debug output

NCATAU: Time-scale, and tuning parameter of the system, for its implications see Bengtsson et al. 2013.
NCAPEMAX: CAPE values above this threshold level gets initialized with CA-cells.

Ensemble experiment:

In order to use the CA scheme in HarmonEPS, simply use the suggested namelist settings above, together with the ensemble member number:

'**NENSFNB**' => $ENV{ENSMBR},

This means that the CA is initialized with different random numbers for each member.