Representation of model uncertainty in a convection permitting EPS - HarmonEPS

Inger-Lise Frogner

and the HIRLAM EPS and predictability team

Reading, November 2017

What is HarmonEPS?

HarmonEPS is the convection permitting EPS of the HIRLAM consortium, a EPS built around the ALADIN-HIRLAM system

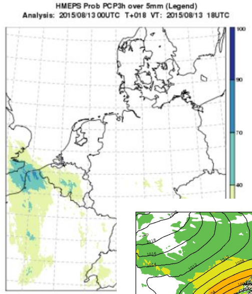
Configurations:

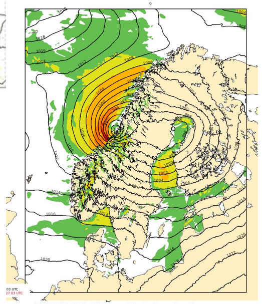
- Arome (+Alaro in earlier cycles)
- 10 - 20 members
- 2.5 km
- 3D-Var
- SURFEX
- ~54h
- With or without lagging
- Different choices for perturbations

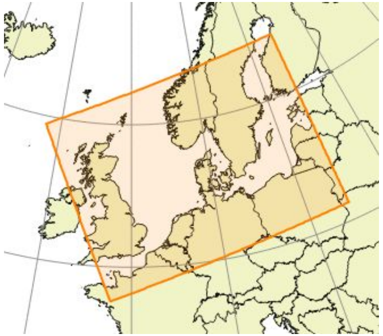
Nested in IFS ENS or IFS high. res. (SLAF)
Operational systems:

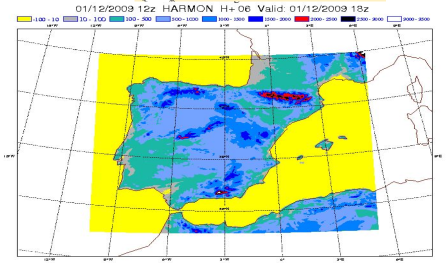
- MEPS (MetCoOp EPS, Sweden, Finland and Norway)
- COMEPS (Denmark)

Systems under development in Spain, The Netherlands, Belgium and Ireland (next presentation)









What is HarmonEPS?

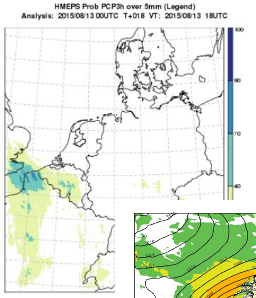
A variety of perturbations are available, or is being developed:

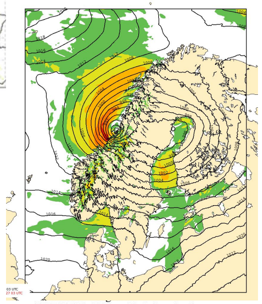
- Initial condition uncertainty
  - Perturbing with ENS:
    HarmonEPS ANA + (ENS mbr - ENS control)
  - EDA
  - LETKF

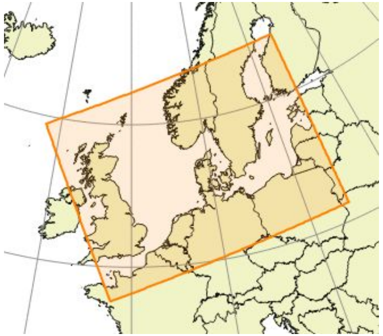
- Lateral boundary conditions
  - ENS at the boundaries
  - SLAF: Differences between ECMWF high res. with different ages

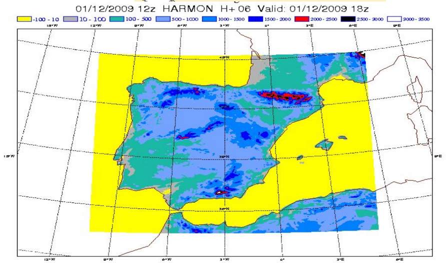
- Surface perturbations (from Meteo France)

- Model error representation - this talk



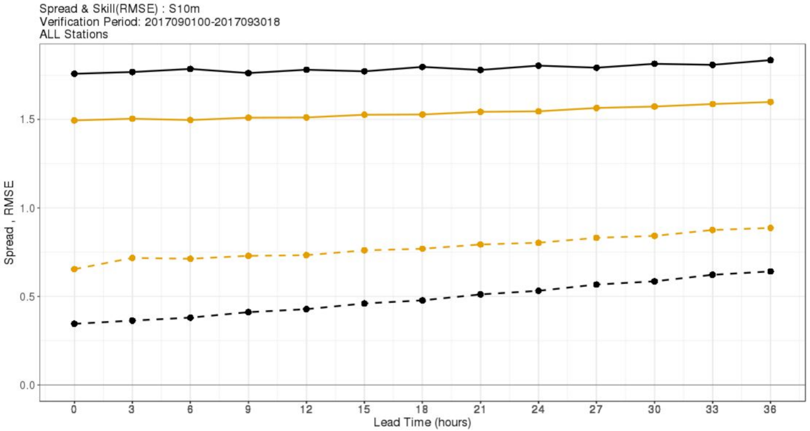




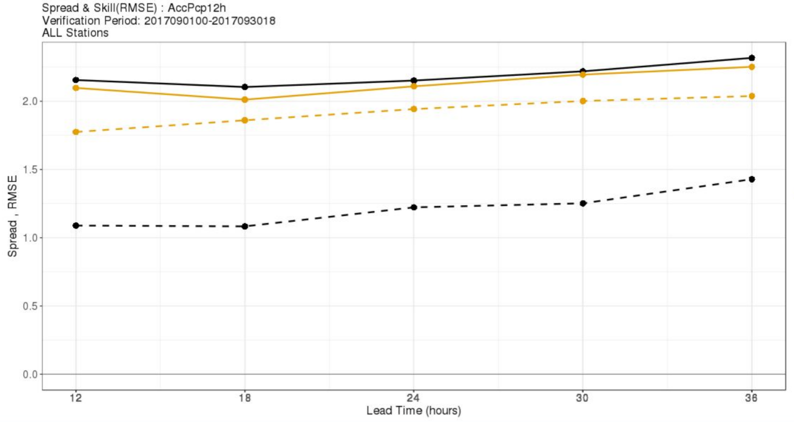


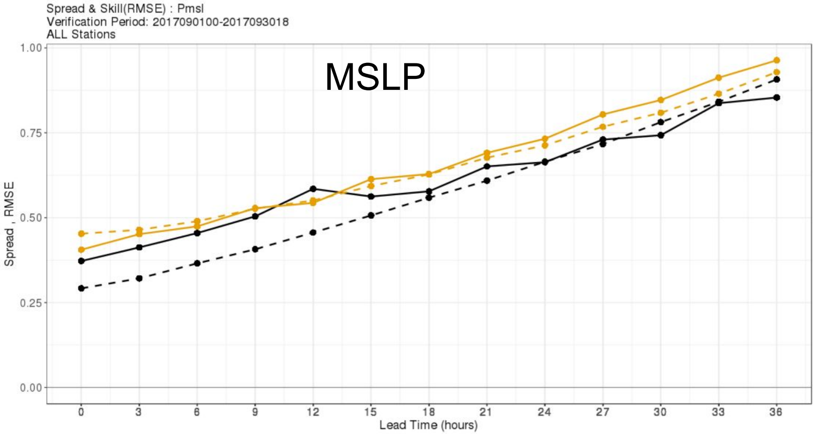
Example of operational MEPS vs EC ENS, September 2017

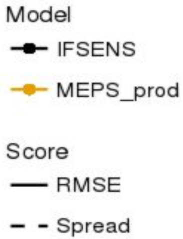
10m wind speed



12h accumulated precipitation







Representing model error in HarmonEPS

- Tested, or is being tested or developed in HarmonEPS:
    - **Multi-model** (Arome and Alaro)
    - **Multi-physics** (Different combinations of schemes for turbulence, microphysics and radiation)
    - **SPPT**
    - **RPP** (Randomly Perturbed Parameters - constant in time and space)
    - **SPP** (Stochastically perturbed parameterizations - varying in time and space)
    - **Cellular automata** stochastic deep convection scheme in Alaro

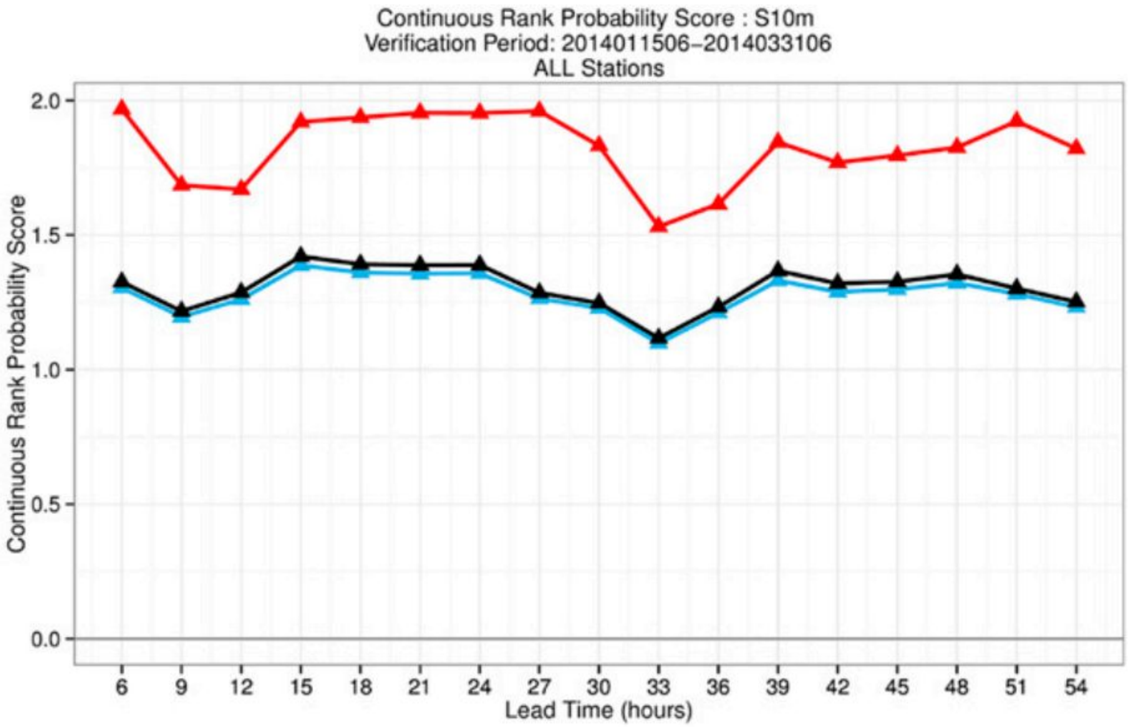
Short about effect of multi-model in GLAMEPS

A motivation for early work on model error in HarmonEPS

2.5 months in winter 2014 - Sochi Olympics

GLAMEPS is Multi-model

GLAMEPS consists of 4 equally sized sub-ensembles, two Alaro and two Hirlam



CRPS 10m wind speed

-Full GLAMEPS 54 members

-Subset of GLAMEPS with 12+1 members from the two HIRLAM sub-ensembles (26 members)

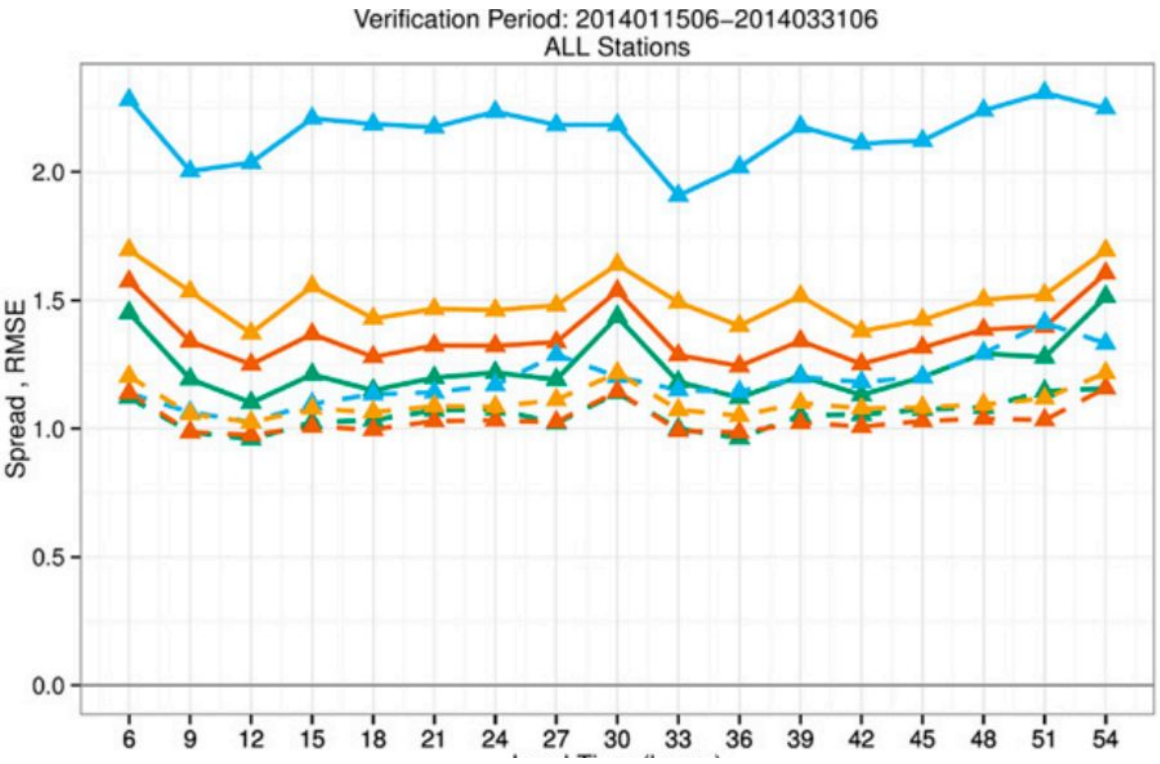
-Subset of GLAMEPS with 6+1 members from all four sub-ensembles (28 members)

Number of sub-ensembles matters more than the number of members

Frogner et al 2016: https://doi.org/10.1175/WAF-D-16-0048.1

Multi-model - calibrated

GLAMEPS consists of 4 equally sized sub-ensembles, two Alaro and two Hirlam



Spread/skill 10m wind speed

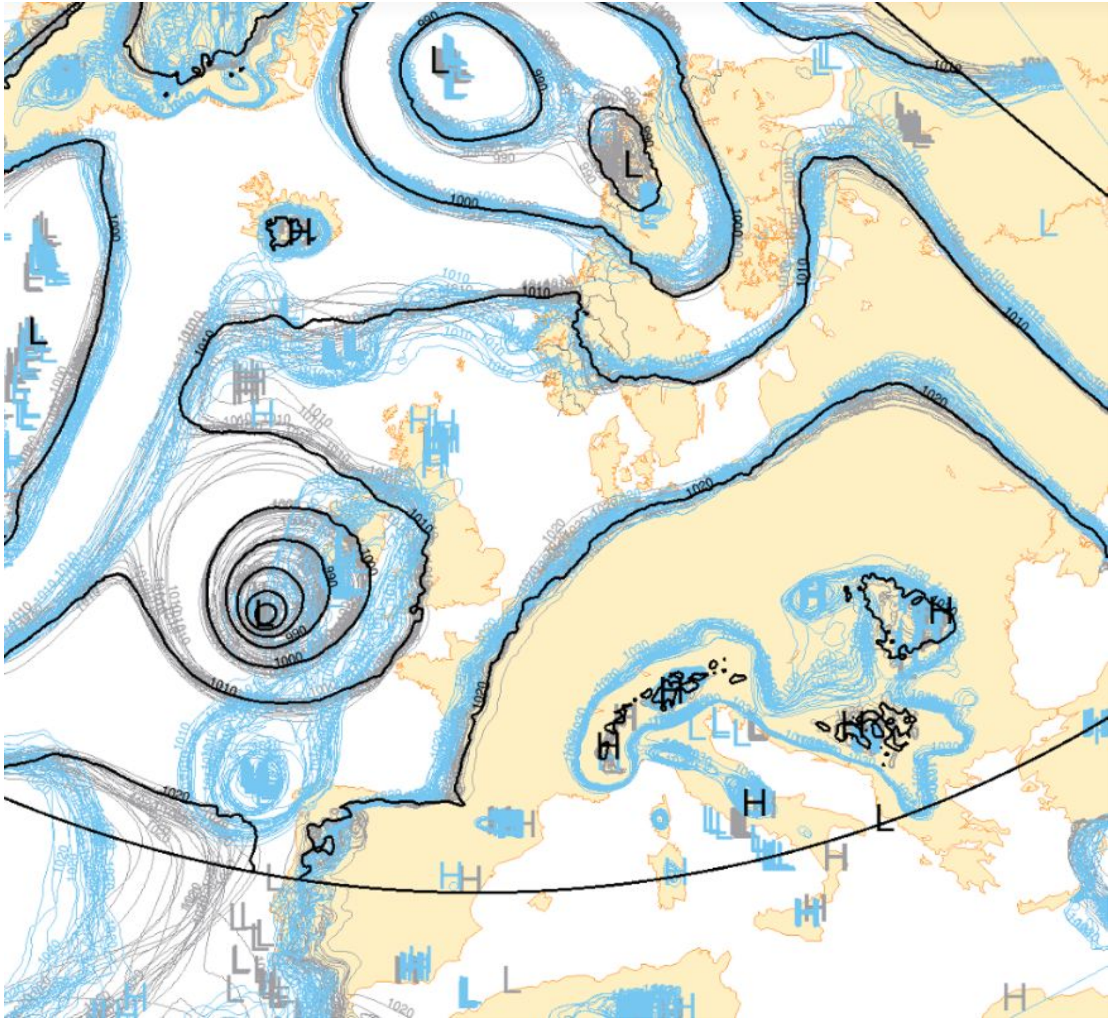
-Full GLAMEPS 54 members
-Full GLAMEPS 54, *calibrated*

-Subset of *calibrated* GLAMEPS with 12+1 members from the two HIRLAM sub-ensembles (26)

-Subset of *calibrated* GLAMEPS with 6+1 members from all four sub-ensembles (28)

Number of members matters after calibration. Multi-model still beneficial after calibration and bias removal

Frogner et al 2016: https://doi.org/10.1175/WAF-D-16-0048.1



GLAMEPS showed clear clustering according to model in the Ophelia storm

__ EC high res
__ members sub-ensemble 1 and 2
__ members sub-ensemble 3 and 4

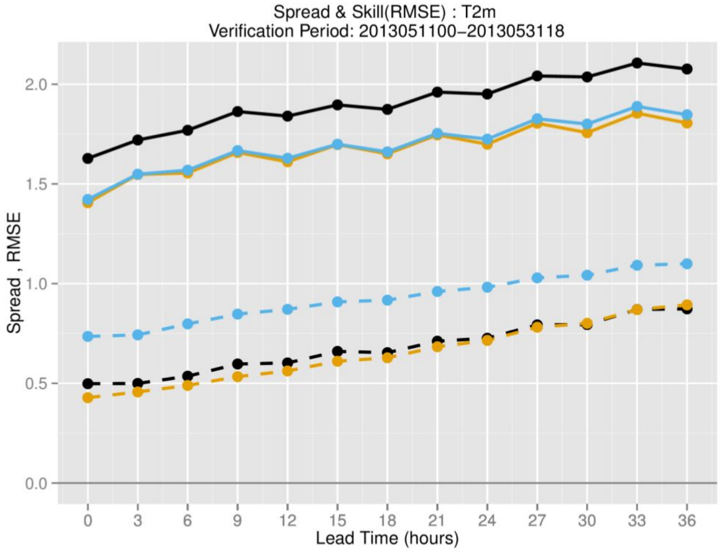
“Multi”-model in HarmonEPS (Arome and Alaro)

Experiment period: 20130511-20130531

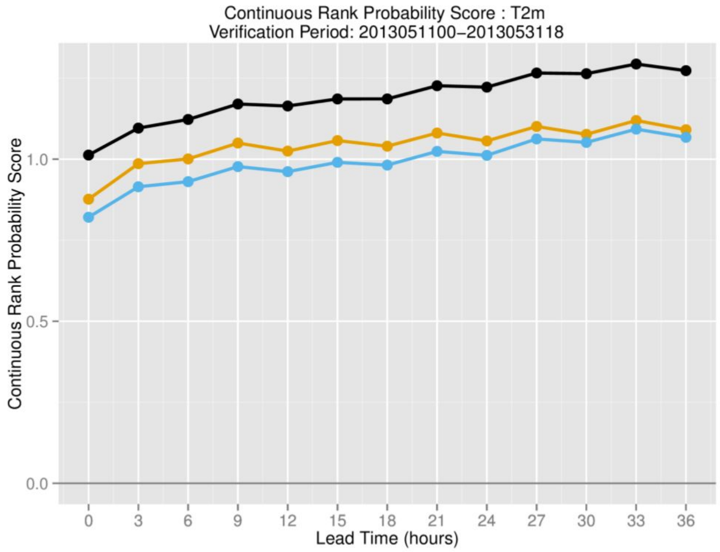
Multi-model: Arome and Alaro 11 member ensembles

T2m

Spread and skill



CRPS



Score

RMSE

Spread

--- Model 1

--- Model 2

--- Multi-model

Model 1 clearly inferior to model 2

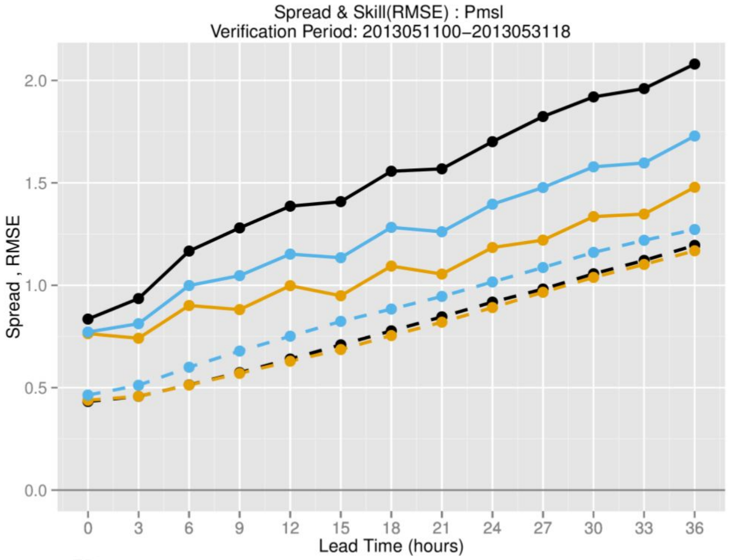
But still mainly better scores for multi-model

Martin Ridal and Inger-Lise Frogner

Multi-model: Arome and Alaro
11 member ensembles

Mslp

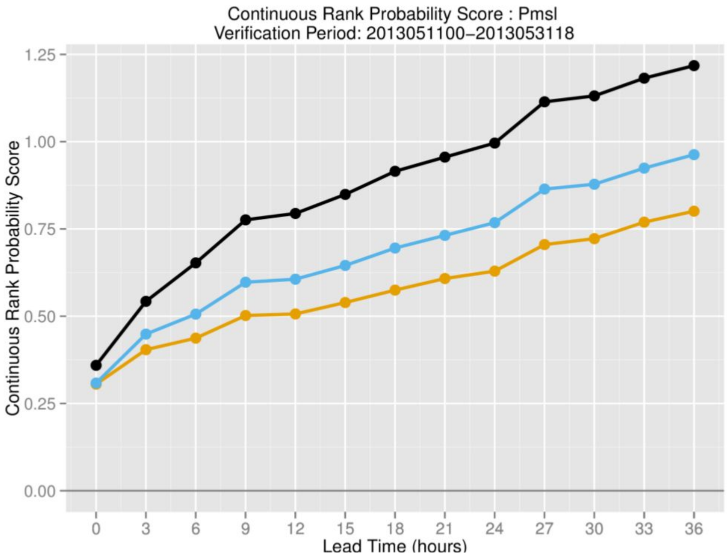
Spread and skill



Score
RMSE
Spread

--- Model 1
--- Model 2
--- Multi-model

CRPS

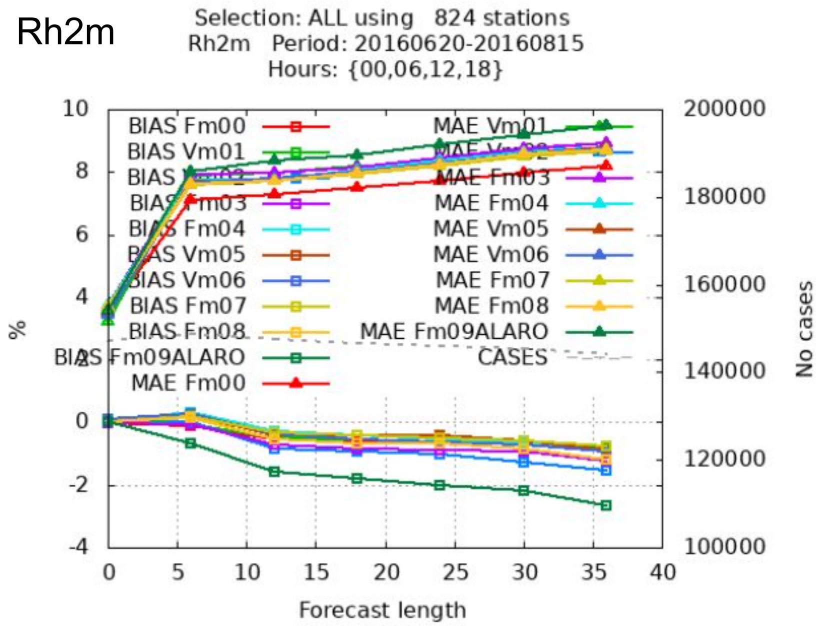


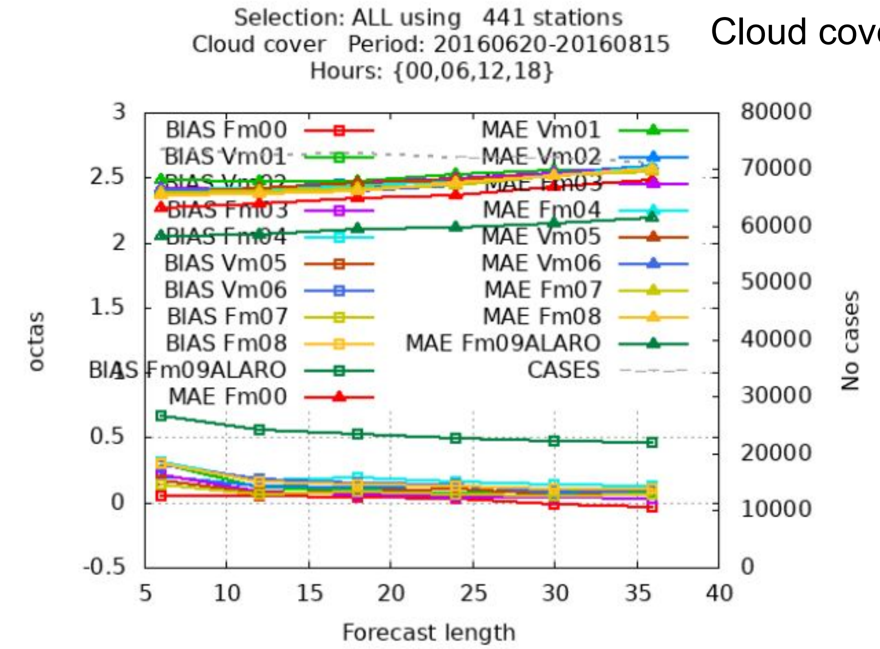
Model 1 clearly inferior to model 2
Worse scores for multi-model

Martin Ridal and Inger-Lise Frogner

Examples of MAE and bias for individual members

Rh2m





Cloud cover

_____ Alaro
_____ Arome

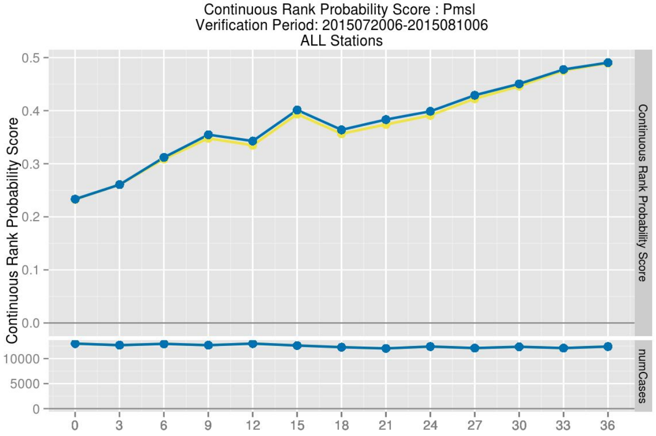
Clearly different behaviour of Arome and Alaro - different climate in the two models

Bjorn Stensen

Multi-physics with different parameterizations in HarmonEPS (Arome)

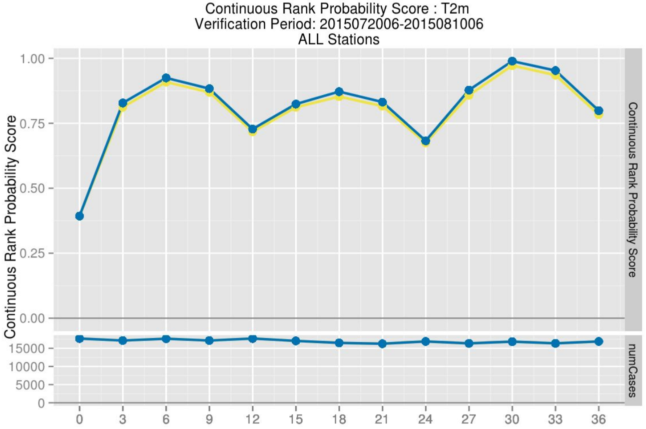
- Experiment period 3 weeks in summer 2015: 20150720-20150810
- Different settings and combinations of schemes for turbulence, microphysics and radiation in the members
- One or two changes in each member
- Same choice for each member for every run

CRPS



Pmsl

T2m



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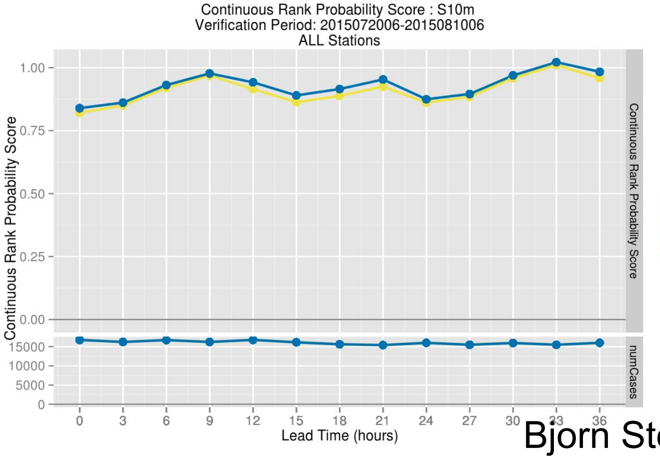
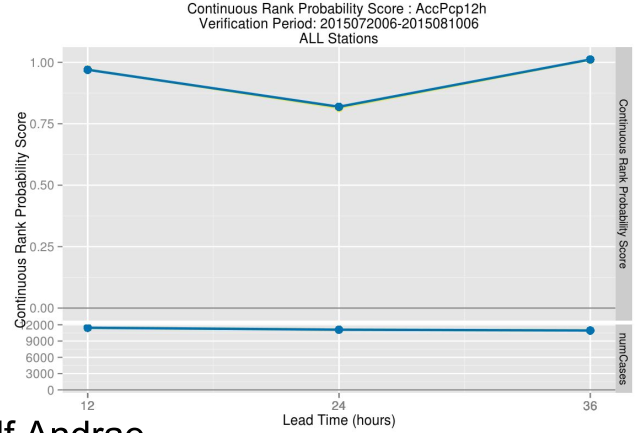
Multi-physics

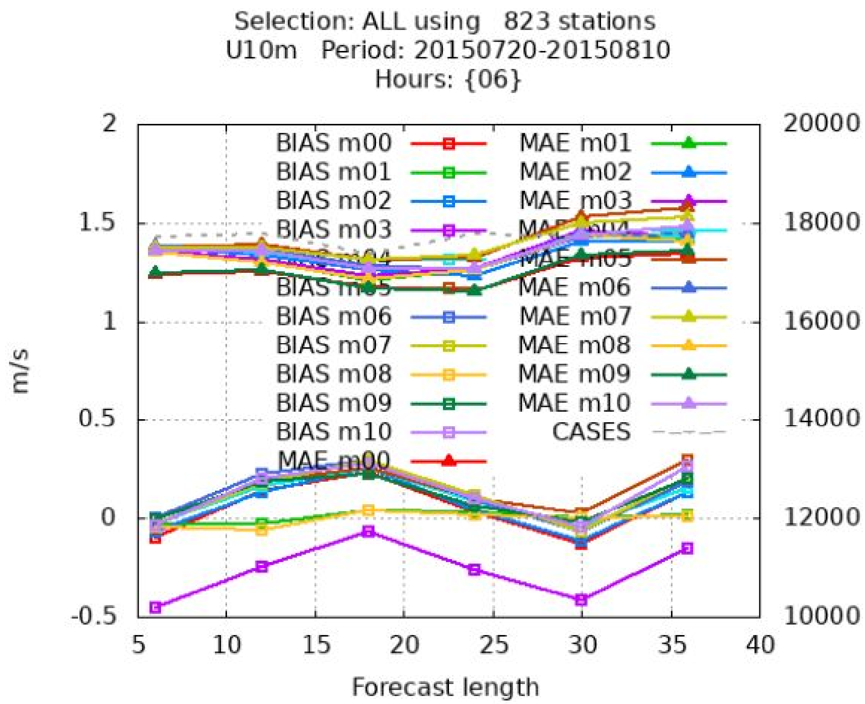


S10m

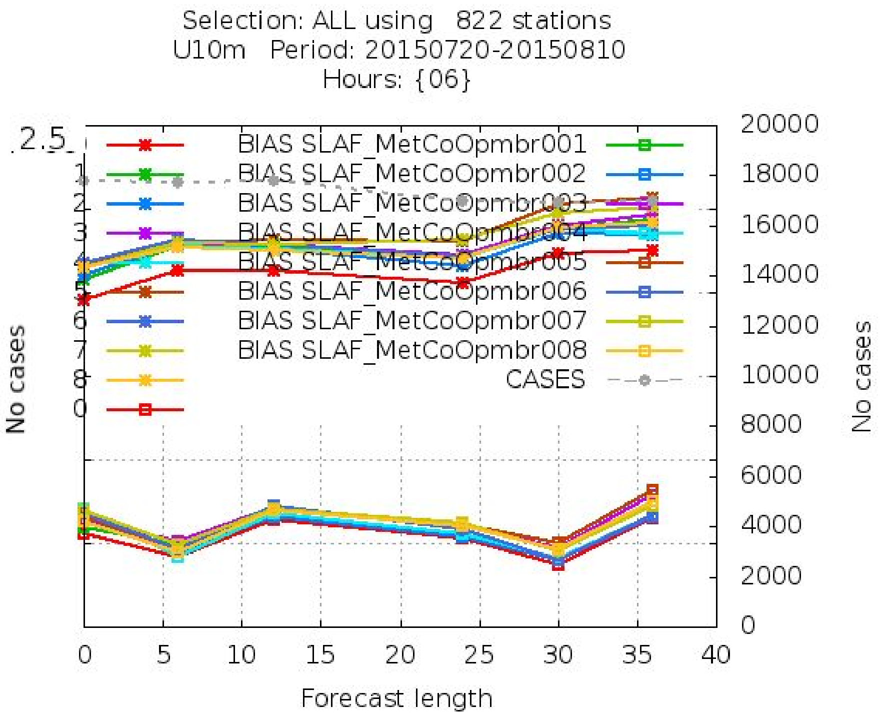
12hPcp



Bjorn Stensen, Lisa Bengtsson, Ulf Andrae



Multi-pysics



Single physics

Bjorn Stensen, Lisa Bengtsson, Ulf Andrae

Representing model error by multi-model or multi-physics

- Scores improved by multi-model/multi-physics, if models are of ~same quality
- The improved skill of multi-model is seen also after calibration and bias removal
- Suggests that the improved performance of multi-model goes beyond the effects of error cancellation and that it accounts for more basic aspects of model uncertainty

BUT:

- Members cluster
- Different biases/model climates in the members can be a problem - calibration needed
- It is hard to maintain a multi-model system
- A multi-physics system is maybe easier
  - but different members with different settings will always have the same characteristics
  - Typically make use of older schemes that probably are inferior to the newest

SPPT and parameter perturbations (towards SPP):

- **SPPT** is available in HarmonEPS (1 pattern, 3 at ECMWF)

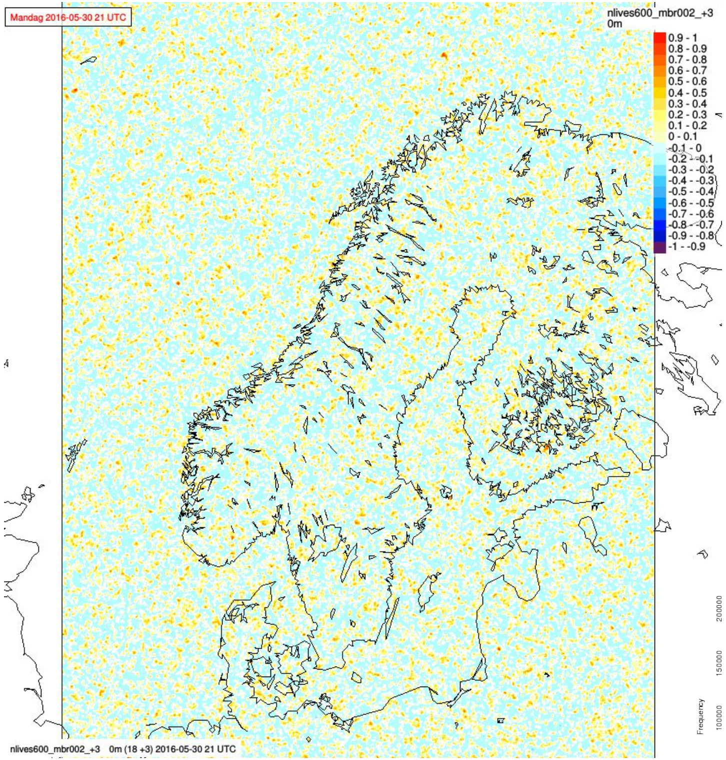
- **RPP** (Randomly perturbed parameters) - our first attempt at perturbing parameters by stochastically varying the parameter for each member and each cycle, but kept constant in time and space

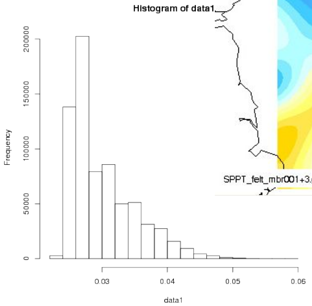
- **SPP** - Stochastically perturbed parameterizations is being developed in HarmonEPS
  - So far tested for one parameter
  - Normal distribution for parameter - log-normal as in IFS to be implemented shortly
  - IFS framework for SPP is being implemented in HarmonEPS
  - As RPP - but varying in time and space according to a 2D random pattern
    - we have tested two pattern generators: CA and SPPT
  -

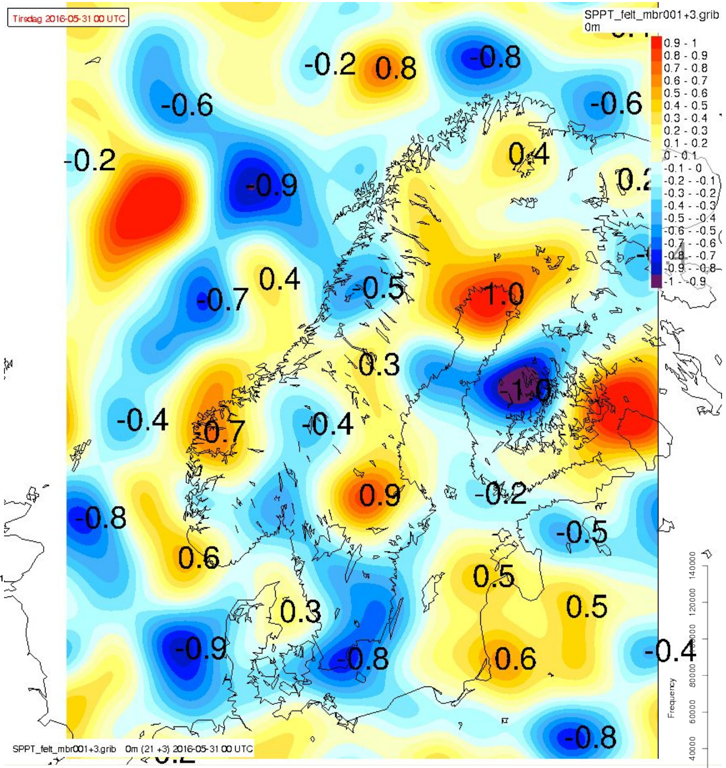
Examples of patterns used:

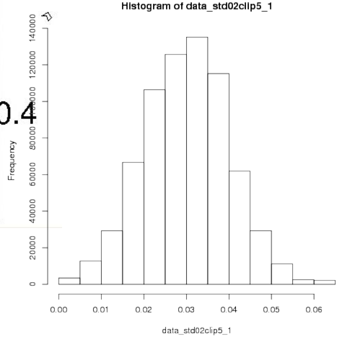
CA-pattern

SPPT-pattern (Temporal scale: 8h, Spatial scale: ~200km)









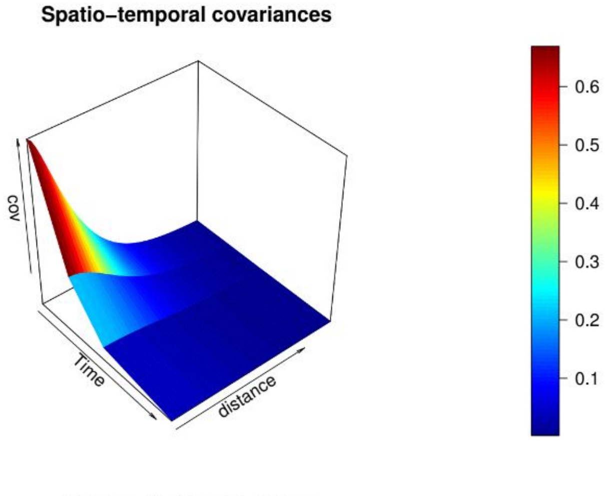
A third option: SPG - Stochastic Pattern Generator

Advantages with SPG:

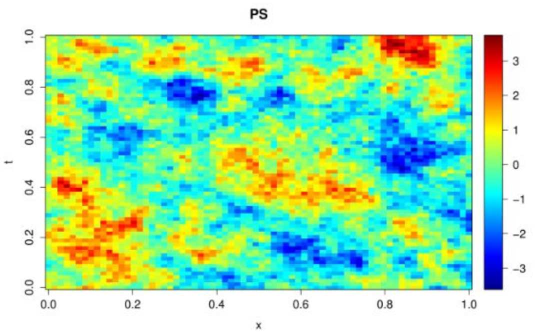
- Designed for limited area
- Easily tunable spatial and temporal length scales
- Fast computations
- proportionality of scales: In reality, longer spatial scales ‘live longer’ than shorter spatial scales, which ‘die out’ quicker.

Implemented in Arome cy38 by Mihály Szűcs, in HarmonEPS cy40 by Ole Vignes (ongoing)

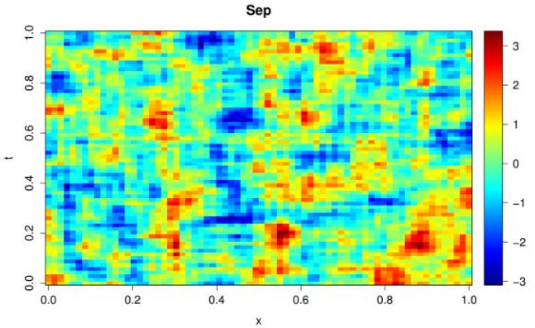
M. Tsyrulnikov and D. Gayfulin



Ranges: t=0...12 h, r=0...750 km



Non-separable correlation model



Separable correlation model

SPPT and parameter perturbations (towards SPP):

Experiments:

- SPPT

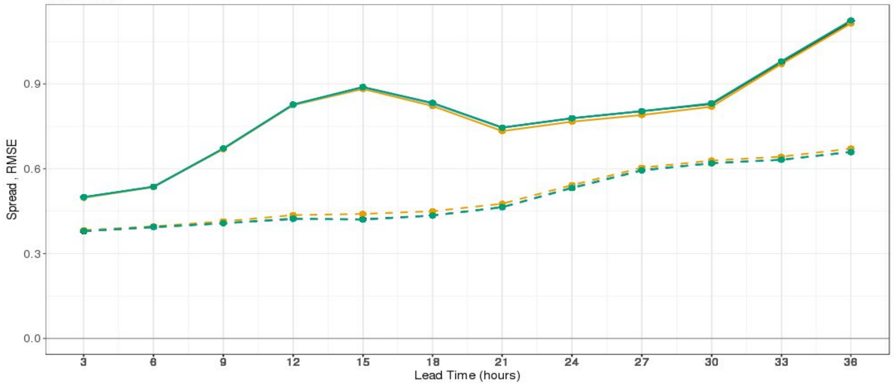
- Perturbed parameter - VSIGQSAT - a parameter that allows lower relative humidity for (low) clouds to form
    - RPP - Stochastically varying, but kept constant in time and space
    - "SPP-CA" - Coupled to CA-pattern generator to allow for spatio-temporal correlations (not shown)
    - "SPP" - Coupled to SPPT-pattern generator to allow for spatio-temporal correlations

- Compared to a reference with no perturbation of VSIGQSAT

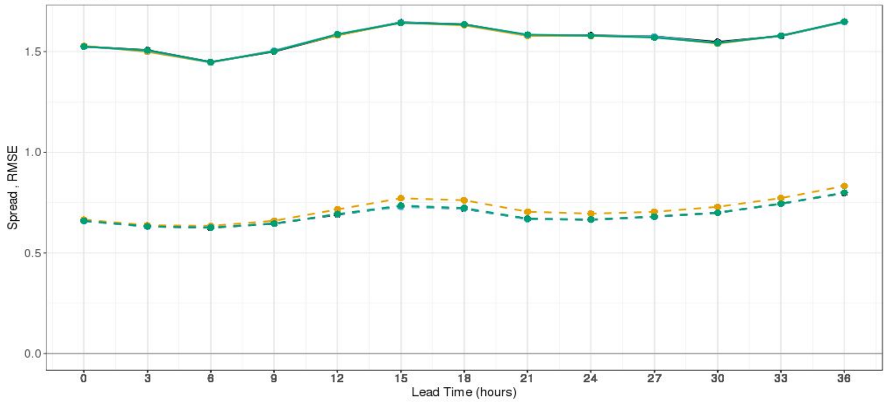
SPPT implementation in HarmonEPS by Alfons Callado, RPP/SPP implementation by Ulf Andrae

Spread and skill, 2016053000 - 2016061500

Pmsl

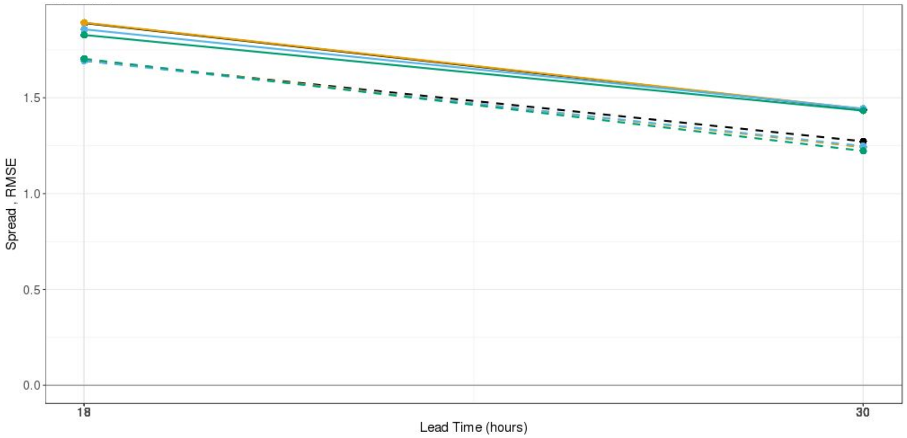


S10m



REF
SPPT
Varying in time/space (SPP)
Constant time/space (RPP)

AccPcp12h



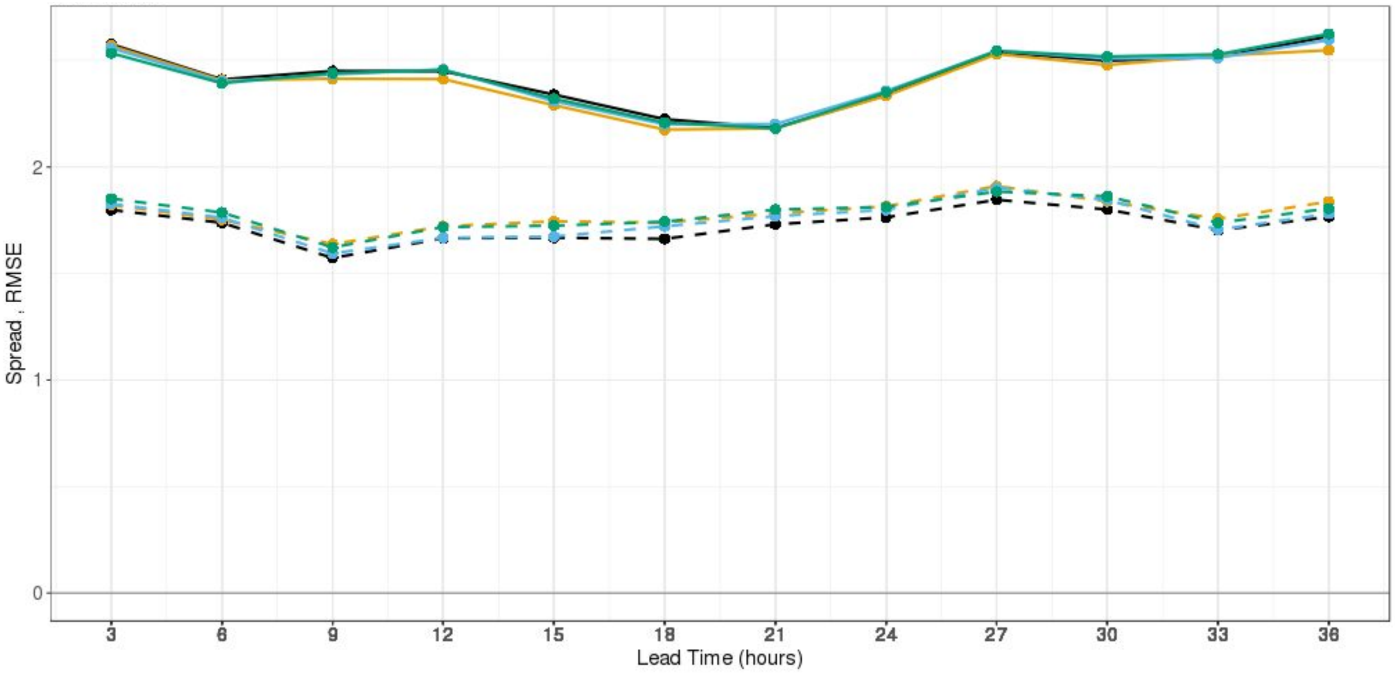
Negligible impact of perturbing VSIGQSAT

Positive, but small, impact on spread from SPPT

Ulf Andrae and Inger-Lise Frogner

Spread and skill, 2016053000 - 2016061500

Low clouds



Small positive impact on spread from perturbing VSIGQSAT ~ same as from SPPT

RPP better than SPP

SPPT slightly better RMSE

REF
SPPT
Varying in time/space (SPP)
Constant time/space (RPP)

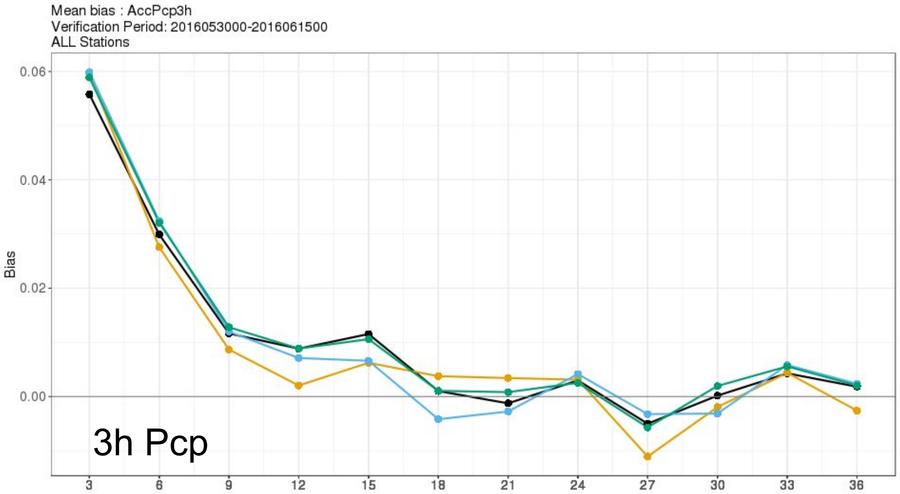
Ulf Andrae and Inger-Lise Frogner

Mean bias

Less precipitation with SPPT

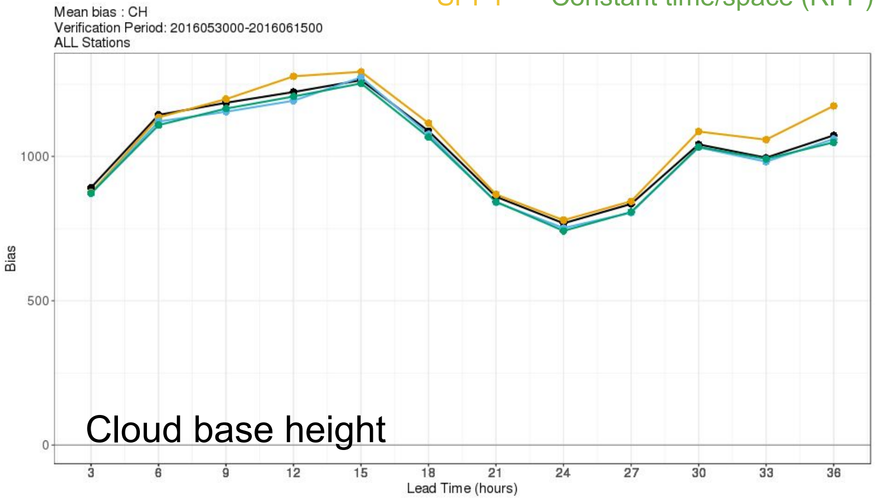
Higher cloud base with SPPT

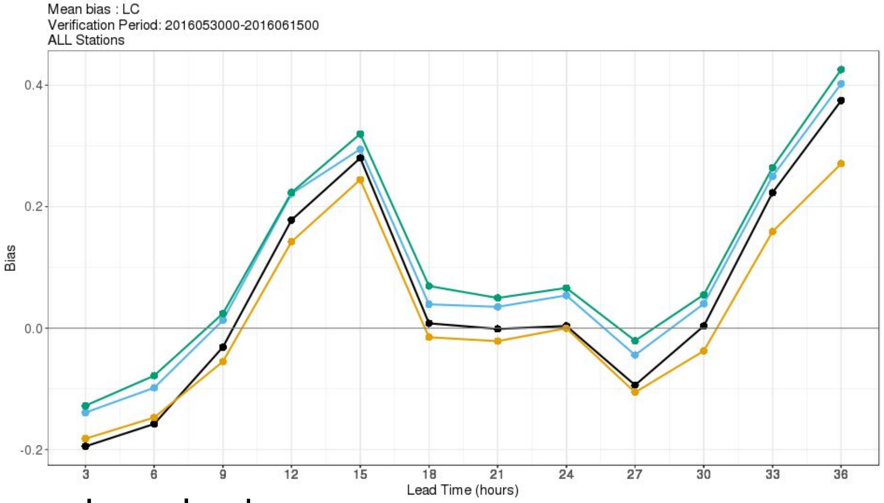
Less low clouds with SPPT, more low clouds with perturbing VSIGQSAT



REF Varying in time/space (SPP)

SPPT Constant time/space (RPP)

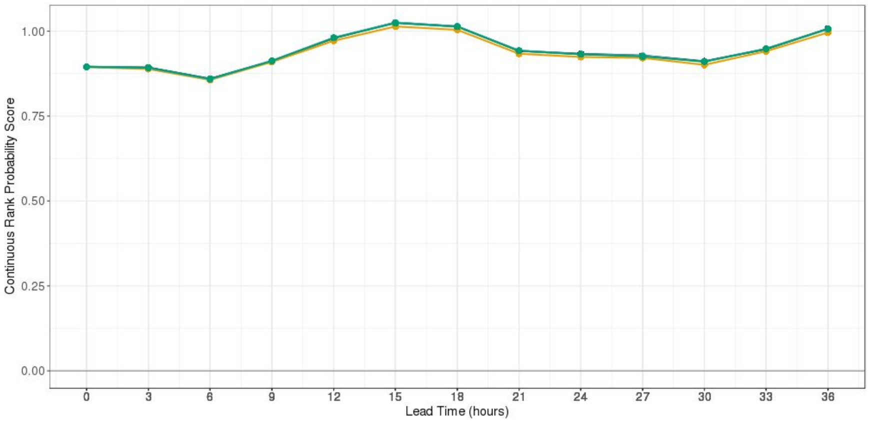




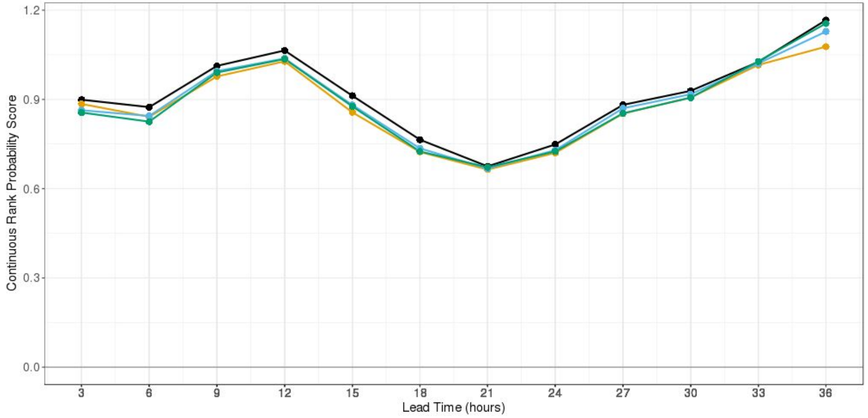
Low clouds

CRPS

S10m



Low clouds



REF Varying in time/space (SPP)
SPPT Constant time/space (RPP)

Small, positive impact of SPPT on S10m (and other parameters)

Very little impact of perturbing VSIQSAT except for cloud related parameters where there is a small, but positive, impact of the same order as SPPT

Ulf Andrae and Inger-Lise Frogner

AROME-EPS SPPT impact

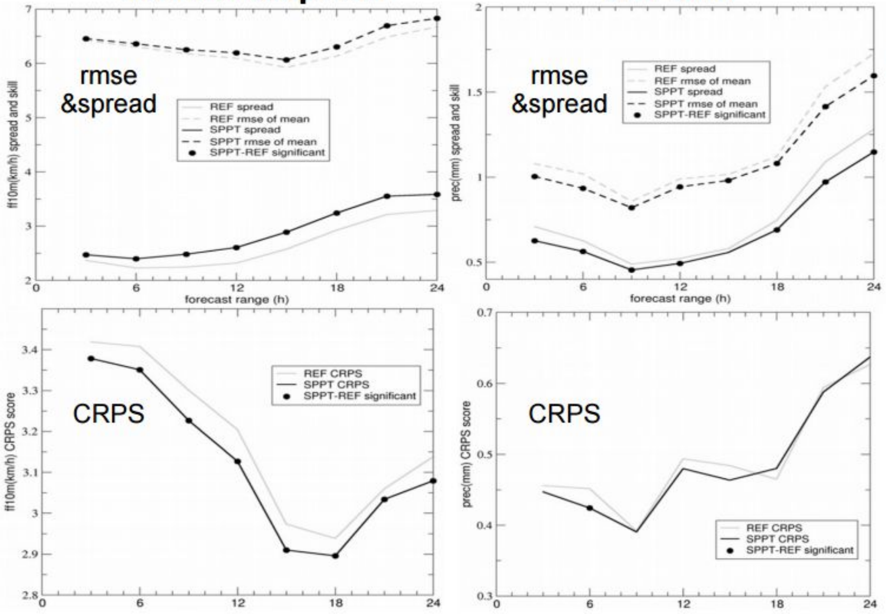
- adds beneficial spread to low-level T, HU, wind, cloudiness
- small but robust improvement of performance measures (Brier, ROC, etc)
- mostly neutral impact on precip, undesirable drying effect

caveat : *'in an underdispersive ensemble, anything that adds spread will improve scores'*

From F. Bouttier,
ECMWF Annual seminar 2017

SPPT
very good for
underspread
wind

10m windspeed | **6-h rain**



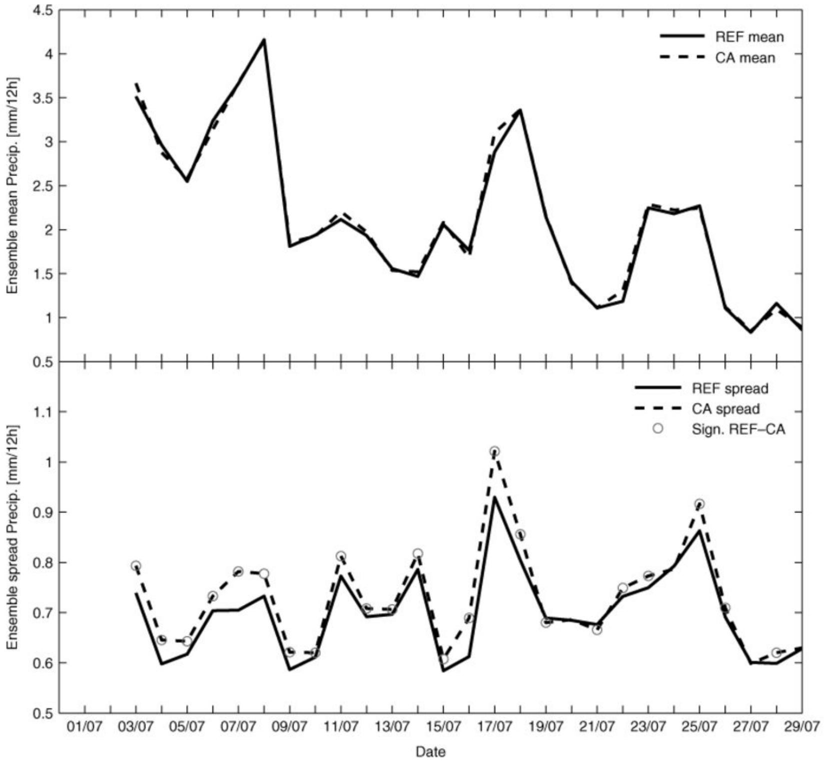
(Bouttier 2012)

SPPT
decreases
precip spread
by drying
effect.

neutral impact
on scores.

Cellular automata

Lagged ensemble, Alaro, 5.5 km



12 h accumulated precipitation
___ REF
----- CA

Ensemble mean

Ensemble spread

Bengtsson et al 2013 *doi:10.1002/qj.2108*

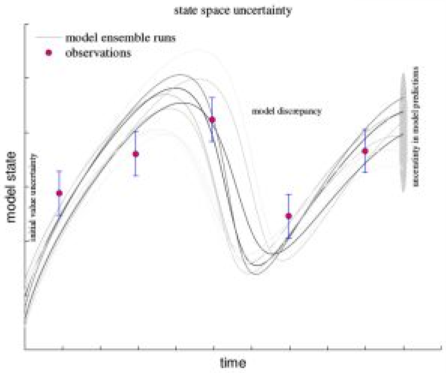
Further work on upper air perturbations in HarmonEPS:

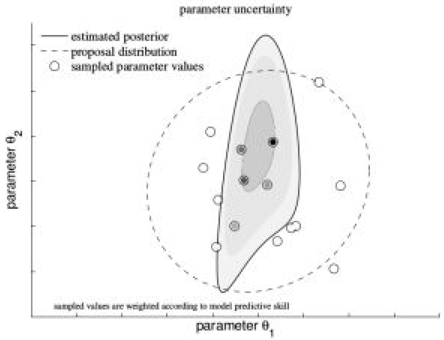
- Continue to develop SPP in HarmonEPS
  - Technical implementation work
  - Include more parameters
- Study closer the effect of the different perturbations, looking into spatial and temporal scales of the pattern, test new pattern generator (SPG), comparing RPP and SPP with SPPT
- Use tendencies as a diagnostic tool
- Look more into SPPT settings
- Estimate uncertain parameter values, and pdf's, in Harmonie-Arome by use of **EPPES** (Ensemble Prediction and Parameter Estimation System) in HarmonEPS

Parameter estimation

In practice

1. Draw a set of parameters from the distribution $N(\mu, \Sigma)$
2. Run an ensemble of forecasts with these (sub-sets of) closure parameter values
3. Evaluate runs
   - Criterion can be chosen freely, e.g. temperature bias at 1000 hPa
   - Determines which parameter sub-sets work best
4. Update proposal distribution $N(\mu, \Sigma)$
5. Draw a new set of parameters and repeat





Representing model error in the grey zone?

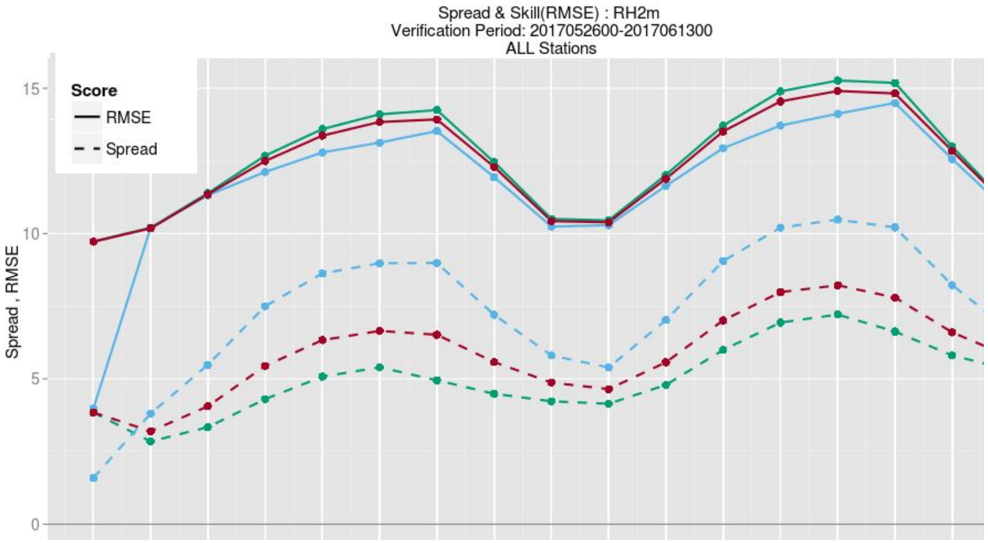
- **Multi-model and multi-physics**, including calibration, will probably do the work - but hard to maintain and clustering of the members makes it harder to use for the forecasters
- **SPPT:**
  - Less convincing results for convection permitting EPS (but can probably be improved)
  - Previous talk: “current stochastic model uncertainty representations very dependent on tendencies from the deep convection scheme” - can explain why it is not so good for convection permitting EPS?
- **SPP:**
  - Able to focus on the processes you want, so should work for all resolutions, including the grey zone
- **Stochastic parameterizations** (like CA) should also work as demonstrated by use in Alaro with 5.5 km horizontal resolution

And don’t forget the surface ...

- Perturbed parameters in MEPS are roughness, albedo, SST, soil temperature, soil wetness, LAI
- The perturbations has a typical length scale of 150 km and may be either multiplicative or additive.
- Improves the scores, especially for T2m and RH2m

Surf pert off
Surf pert on
Surf pert on, surf assimilation all members

Spread and skill - Rh2m



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Thank you

Physic settings for each member

Mbr000: Arome ref.

Mbr001: $HARATU = TRUE$. Turbulence scheme based on the scheme in the RACMO model. (new mixing length, new stability functions)

Mbr002: $LOCND2 = FALSE$. Switch off microhysics option for separate ice-phase representation (Ivarsson, 2010).

Mbr003: $EDMF(CMF\_CLOUD = DIRE) + HTURBLEN = DEAR$. "Direct" cloud scheme coupled to the mass-flux in EDMF (instead of the "statistical" cloud scheme), and alternative mixing length in the CBR scheme (Deardorff (1977).

Mbr004: $EDKF(CMF\_UPDRAFT =' RAHA')$. Eddy diffusion mass-flux scheme with (Rio et al. 2008 and 2010) mass-flux formulation. ("Direct" cloud scheme)

Mbr005: $EDKF$. Eddy diffusion mass-flux scheme with (Kain-Fritsch) mass-flux formulation. ("Direct" cloud scheme)

Mbr006: $ACRANEB2$. ACRANEB2 radiation scheme in AROME.

Mbr007: $LGRSN = TRUE + LLCRIT = TRUE$. Convert graupel to snow more efficently in microphysics scheme, and more efficient precipitation from shallow convective cumulus in cold conditions.

Mbr008: $LOCND2 = FALSE + HARATU = TRUE$.

Mbr009: $ACRANEB2 + EDKF$.

Mbr010: $'RLWINHF' =' 0.7.'$. Inhomogeneity factor for cloud-representation in a grid-box in radiation scheme switch to 0.7.

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Parameter estimation

Ensemble Prediction and Parameter Estimation System (EPPES)

- Consider closure parameters as a Gaussian distribution with some mean μ and covariance matrix Σ
  - μ : parameter value that performs best on average
  - Σ : how much the optimal value varies due to evident modeling errors