Introduction

The purpose of this note is to give background information prior to the design of Version 1 of the MetCoOp Convective Permitting Ensemble Prediction System (MetCoOp-CPEPS). Version 1 will most likely undergo modifications before the system gets operational.

We build Version 1 on existing components in the HARMONIE system. When MetCoOp-CPEPS get operational the deterministic AROME-MetCoOp will stop. Therefore todays deterministic AROME-MetCoOp and the control run(s) in MetCoOp-CPEPS should be as similar (i.e. integration domain, model output, resolution and lead times) as possible to ensure a smooth transition for down stream users.

Why a convective permitting ensemble prediction system (CPEPS)?

The last decade weather forecasting has moved towards detailed forecasts in time and space (i.e. yr.no/smhi.se). Furthermore, a complete forecast should include a most likely forecast, how certain this forecast is and probabilities for other outcomes. The predictability and uncertainty on small spatial and temporal scales therefore need to be addressed.

The predictability of the atmosphere is limited since small-amplitude errors grow with time. The error growth rates are higher for small scale phenomena than for synoptic systems and high resolution EPS is therefore needed to predict the uncertainty in the fine scale details of the forecast. There are also important examples (i.e. the extreme weather Nina January 2015) that the development of the synoptic situation can be highly unpredictable only one day ahead.

Expected lead times for skillful forecasts is limited by the spatial/temporal scales and the phenomena of interest. However, the synoptic situation in combination with local forcing (i.e. coast-lines, topography, and land-use contrasts) may further control small scale features which open up for added value behind 1-2 days lead time from a CPEPS.

MetCoOp-CPEPS configuration and perturbations.

The design of MetCoOp-CPEPS start from AROME-MetCoOp with respect to integration domain, resolution, lead times, choice of physics etc.

It is recommended from HIRLAM system manager that MetCoOp-CPEPS employ cycle 40 of HARMONIE. Harmonie-40h1.1.alpha.1 was released in January 2015 and next alpha/beta-version is to be released in May 2015. The Cycle is at the moment undergoing meteorological and technical testing and further development. Release of Cy40h1 is planned for October 2015. Meteorological tests so far indicate that Cy38h1.2 and Cy40alpha have similar forecast quality. Current status of ALARO1+SURFEX in Cy40h1 is that it is not fully implemented and thus not tested at all (Cy38h1.2 support ALARO1).

The strategy for initial and lateral boundary conditions/perturbations can either be based on ECMWF-ENS or ECMWF-HIRES. The latter via so-called Scaled Lagged Average Forecasting (SLAF).

Initial perturbations can be calculated (and scaled) as the difference between the control forcing (ECMWF-ENS control or latest ECMWF HIRES) and the member forcing and added on the top of the assimilation of the control run in MetCoOp-EPS. A more simple approach is a pure downscaling (no assimilation in MetCoOp-EPS).

The approach with ECMWF-ENS is the traditional choice. However, recent results presented on HIRLAM ASM indicate that SLAF is an equally good choice (or even better). SLAF give more spread and particular in the upper atmosphere as ECMWF-ENS is not designed for optimizing the time window we need.

Ensemble data assimilation (EDA) is another possibility to account for initial uncertainty. This is however not fully tested yet, but can be a possibility at a later stage. In addition AEMET is testing LETKF that also can be an option at a later stage (Cy42 or later)

If lateral boundary conditions (and perturbations) are taken from different IFS-ENS members a "member-selection-method" should be considered (i.e. as used in COSMO; choose a particular sub set of IFS-ENS members, based on clustering, to increase ensemble spread).

The Harmonie system allows for a multi-physics approach with AROME and ALARO physics. Multi-physics results in better objective verification scores, but do require slightly more CPU resources in operational runs (~10%) in addition to invested resources in code knowledge and proper down stream use.

In cycle 40 surface perturbations (LPERTSURF) and SST perturbations (LPERTSST) are options which should be explored. Several other physical perturbation-schemes are under development; SPPT (AEMET), CA (SMHI, only ALARO), cloud mask perturbations (KNMI), parameter perturbations. There is also work on surface and initial perturbations (MET). These methods should be considered when available.

CPU use:

Number of members and forecast length are limited by available CPU. At Frost 328 nodes are available while 315 nodes are available at Vilje. However, these numbers are for MetCoOp and SMHI in total (Frost), and for MetCoOp and MET-Norway in total (Vilje), which mean that if MetCoOp use all available nodes, national models have to wait. AROME-MetCoOp use today approximately 45min at Vilje. If MetCoOp-CPEPS use ~60min the forecasts will be available 15min later than today (cut-off time kept on 1hr and 15min).

Lead times: A compromise between needs is to use different lead times for different members (i.e. a few members to +66hr, while the rest of the members to e.g. +36hr).

Time step: Today AROME-MetCoOp at Vilje make use of a 60s timestep, while backup-runs at Byvind uses 75s (have used both 60s and 90s earlier). Based on the Byvind experiences a run with 90s time step use approximately ¾ of the time used when applying 60s. It was the "de-aliasing upgrade" last summer that made it possible to increase the time step to 90s. Byvind-runs with 90s works ok, but crashed for the "Nina/Egon" case (reduced to 75s and worked). In the future a cubic grid will probably make it possible to increase the time step.

Cut off for observations is today 1hr and 15min and is already considered as short. A further reduction in the cut-off time is possible, but the impact should be investigated carefully.

Delivery time of AROME-MetCoOp today is approximately 2hr and 5min after cycling-time. Down stream users as i.e. duty forecasters are eager to receive new forecasts as early as possible.

Reduced model output is tested on Frost (model dumps only every 3hr) but did not result in large savings (~3-4%)

Duplication of control runs on both Frost and Vilje should be avoided and we should accept a decrease in forecast quality on those cycles one of the HPCs is unavailable.

User needs

This summary is based on a few interviews with users at SMHI and MET-Norway. The user needs diverge. In connection with severe weather, duty forecasters do seek uncertainty information for the short term forecasts. The main sources are consistency between model cycles, differences between available deterministic models and subjective judgments of the weather situation. GLAMEPS and IFS-ENS play a less important role, but are used. Duty forecasters wish that MetCoOp-CPEPS will give information about areas with large uncertainty. This includes the uncertainty of vertical profiles (i.e. for aviation purposes). Another concern is the realism of the ensemble spread. Duty forecasters wish that systematic model errors are addressed in model development and/or post-processing.

Today, PmP (SMHI) and api.met.no/Yr.no (MET-Norway) requires data two days and +66hr ahead, respectively. There is also a concern about resources that needs to be used for maintaining post-processing if a multi-physics approach is chosen. Based on experience the duty forecasters find it challenging with multi-model/physics EPSs that show a clustering behavior.

At MET-Norway a few ocean/wave models are partially forced with AROME-MetCoOp, while SMHI don't use AROME-MetCoOp as forcing (cover to small area).

Post-processing?

Only a limited set of CPEPS-members per cycle is possible. MetCoOp-CPEPS will most likely show too little spread and each realization will constitute systematic errors. Post-processing is a way to address these deficiencies. Post-processing is also necessary for down stream product generation.

Both SMHI and MET-Norway will do post-processing, but most likely with slightly deviating focus/interest (i.e. training data, products). A common operational post-processing might therefore be suboptimal except for methods that add data (i.e. lagging). However, common development and maintenance of post-processing methods could be beneficial. This could either be organized within MetCoOp or as a separate program between SMHI and MET-Norway.

CPEPS experiences at MET-Norway and SMHI

SMHI has positive experiences with HARMONIE-EPS for wind-power prediction purposes (i.e. ensemble mean add value compared to control run) but experience also too little spread. HARMONIE-EPS with multi-physics as also been used to investigate case studies on extreme precipitation.

At MET-Norway a down-scaling of IFS-ENS has been operational for a few years. A northern domain is used in winter for polar low predictions and a southern domain for convection in summer. In addition, for the Sochi winter Olympic Games 2014 HarmonEPS was set up to run in real time on Vilje, with 13 members (Arome). The control ran 3DVar and each member had surface assimilation cycle. IFS-ENS was used on boundaries and as initial perturbations (added to the 3DVar control analysis).

For MetCoOp a multi-physics setup similar to the Sochi-experiment has been evaluated on a mid-European domain. In general, multi-physics give better objective scores. A horizontal resolution of 2,5km vs 3,1km was also compared and indicates that except for precipitation there is similar quality between the resolutions. These results are before any post-processing is done (with the exception of a simple height adjustment for temperature). More results will be presented in Karlstad.

Backup

A traditional back-up is not possible with MetCoOp-CPEPS. However, members will be distributed on Frost and Vilje. Downstream users need to handle variations in available members. The system configuration should ensure at least that (1) there are always a long forecast available and (2) we avoid cold starts of any of the EPS members.

Infrastructure

With an EPS-system with a limited number of members there will most likely not be a dramatic increase in *input*-data put to the HPC's. Observations is similar, but lateral boundary data from IFS-ENS has half spatial resolution (1/4 of data points) and is only available every 3rd hour. However, ECMWF-ENS will most likely be available hourly soon. LBC input data will then be up to twice as large as today. If we use SLAF the data amount will be similar to todays.

Getting model data output from the HPC's to SMHI and MET-Norway might be a bottle neck. Each institute should consider disc and storage needs.

Testing of new system configurations/model updates.

In the pre-operational phase of MetCoOp-EPS we still need to run AROME-MetCoOp which implies that for the preoperational runs the entire HPC's are not available for testing. Furthermore, when MetCoOp-CPEPS replace AROME-MetCoOp, testing of new versions of the model system will still be demanding.

Summary and suggestions for MetCoOp-CPEPS Version 1

Several EPS-configurations has been tested on Frost/Vilje, but still there are uncertainties with respect to what we can afford operationally. We believe a more efficient setup can be found, but there are also an uncertainty of CPU-use of Cy38h1.2 (which is used in the testing) compared to Cy40. To suggest a few alternative configurations we have assumed that we can use approximately 60min at Frost/Vilje, which is 15min more than today.

Discussion themes in Karlstad:

1. Initial and lateral boundary conditions/perturbations. ECMWF-ENS, SLAF or down-scaling?
2. Multi-physics, AROME only or AROME and ALARO physics? Other physical perturbations?

3. Lead times. Should all members have equal lead time?
4. What is an appropriate time step?
5. Choice of model resolution. 2,5km or 3,1km?
6. What is necessary model output?
7. What is acceptable cut-off time, and what is acceptable delivery time?

8. Post-processing. Common or not, how to go on?
9. How do we promote MetCoOp-EPS to users and make use of feedback?
10. Backup?

11. How do we handle pre-operational phase including both AROME-MetCoOp and MetCoOp-EPS on the HPCs?
12. How do we handle further model- and model system development?

Based on the preliminary tests a few "realistic" configurations are suggested bellow. What we end up with can of course deviate from this. An even number of members should be chosen to get symmetry for the perturbations. An experience from GLAMEPS is that we should omit the oldest control-run when lagging.

Alt 1: 2,5km	**Cntrl AROME**	**AROME mb**	**Total**
Frost	1 x +66hr	5 x +36hr	246hr
Vilje		2 x 66hr, 1 x 36hr	168hr
Lagging	1 x 60hr	4x60hr, 12x30hr	1cntl + 16mb

Alt 2: 2,5km	**Cntrl AROME**	**AROME mb**	**Cntrl ALARO**	**ALARO mb**	**Total**
Frost	1 x 66hr	2 x 36hr	1 x 36hr	2 x 36hr	246hr
Vilje		1 x 66hr, 1 x 36hr		2 x 36hr	174hr
Lagging	1 x 60hr	2x60hr, 6 x 30hr	1 x 30hr	8 x 30hr	2cntl +16 mb

Alt 3: 3,1km	**Cntrl AROME**	**Members AROME**	**Total**
Frost	1 x 66hr	1 x 66hr, 6 x 36hr	348hr
Vilje		2 x 66hr, 3 x 36hr	240hr
Lagging	1 x 60hr	6 x 60 + 18 x 30hr	1cntrl + 24 mb