SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2021
Project Title:	Operationalization of SPP and further improvements of EDA, boundary and surface perturbation in MEPS
Computer Project Account:	spseandr
Principal Investigator(s):	Ulf Andrae
Affiliation:	SMHI
Name of ECMWF scientist(s) collaborating to the project (if applicable)	None
Start date of the project:	2020-01-01
Expected end date:	2022-12-31

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	16M	10.1M	16M	8.0M
Data storage capacity	(Gbytes)	30000	>60000	60000	>90000

Summary of project objectives (10 lines max)

The aim of the project is to improve ensemble related components in the MetCoOp ensemble system MEPS. In the first part we have focused on the possibility to derive new background error statistics for our 3DVAR setup using ensemble members from MEPS and the sensitivity to different components in the perturbation chain. We have also studied that impact of different perturbations on the moisture balance in the system.

Summary of problems encountered (10 lines max)

The general feeling is that the throughput of experiments on cca has become slower both due to slower MARS retrievals and longer queuing times on cca. The slow access to data on ECFS is also always a challenge.

Summary of plans for the continuation of the project (10 lines max)

- Continued investigations of background error sensitivity to different perturbations and boundaries with emphasis on extended usage of ECMWF EDA data.
- Longer runs and sensitivity studies with Stochastically Perturbed Parameterizations scheme (SPP)
- Improvements of surface perturbation aspects as outlined in the project application.

List of publications/reports from the project with complete references

None

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

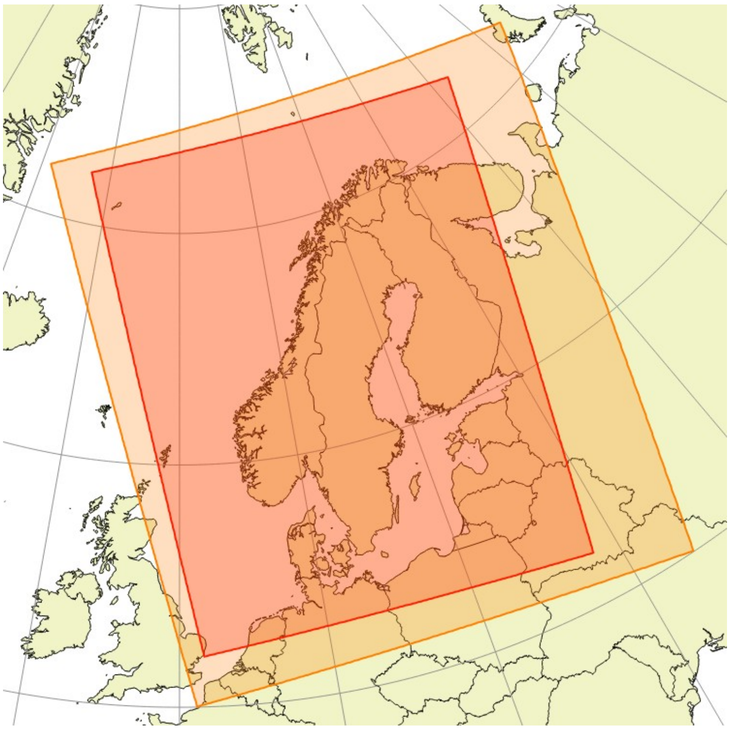

Figure 1: New operational domain for MEPS in orange and the domain used for the experiments described in red.

Introduction

The MetCoOp ensemble (MEPS) serves the participating countries (Estonia, Finland, Norway, Sweden) with high resolution ensemble forecasts over the domain shown in Figure 1. MEPS is based on HarmonEPS developed within the the ACCORD consortium (Frogner et.al. 2019). A redesigned setup for MEPS was introduced in operations in February 2020. The new ensemble is based on Ensembles of Data Assimilation (EDA), using members from IFSENS on the boundaries and is running in a continuous mode as described in Andrae et.al. (2020). The upgrade also involved a new larger domain shown in Figure 1, improving mainly precipitation forecasts for systems propagating from south or south east.

After one year in operations our experience is that most of earlier problems with excessive precipitation and cloud cover during the first hours are gone. This is thanks to more balanced and reduced initial perturbations. We also maintain an added skill compared to IFSENS for most surface parameters except MSLP with the new system. The ensemble though still suffers from a dry bias in near surface and boundary layer relative humidity. The first part of the report addresses this dry bias and the connection to moist perturbations in general and the soil water perturbations in particular.

The new larger domain requires a new set of background error statistics (BES) for the data assimilation and it is normally a costly procedure to generate representative statistics for all seasons. A lot could be gained if (pre) operational data from the ensemble forecasts could be used and it would also allow us to explore a more continuous update of statistics representing “errors of the day”. The second part of this report consists of a deeper analysis of the possibilities to use the ensemble directly for the generation of BES.

Controlling the dry bias

It has been reported from operational setups with HarmonEPS that perturbed members tend to dry compared to the control, and some of the members may even become unphysically dry, as shown in Figure 2. The drying of perturbed members is illustrated in Figure 3, which shows the bias for relative humidity at 2 m (RH2M) for the different ensemble members and the control for an experiment with HarmonEPS run for the period 1 to 15 June.

Soil moisture (WG) perturbations as well as upper air humidity perturbations were pointed out as possible suspects, and a number of experiments has been carried out to investigate the causes of the drying of the ensemble members and to propose a solution. The experiments were carried out by running nine different experiments with HarmonEPS for the period 1 to 15 June 2019 where the effect of WG perturbations, humidity perturbations, surface assimilation as well as ensemble of data assimilation (EDA) were investigated. For most of the experiments Cycle 40 was used, but for the two EDA experiments we applied Cycle 43.h2.1.1. The experiments are briefly described in Table 1.

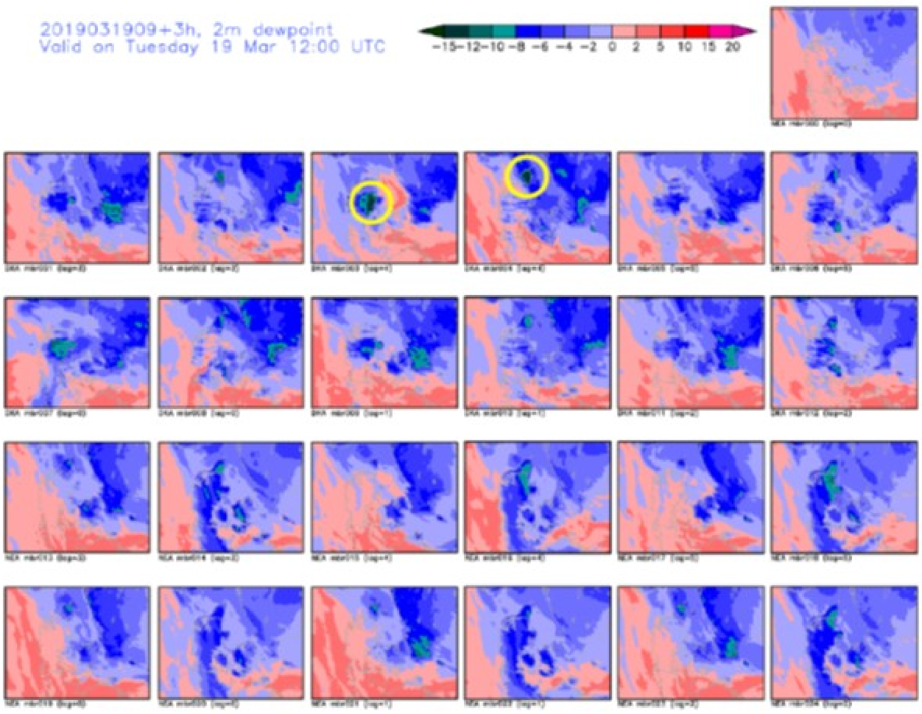

Figure 2: Dew point temperature in 2m from the setup at DMI on 3 March 2019 for control and ensemble members. The perturbed members are generally dryer than the control, and some members become extremely dry over limited areas, shown by the yellow circles. Courtesy Henrik Feddersen, DMI.

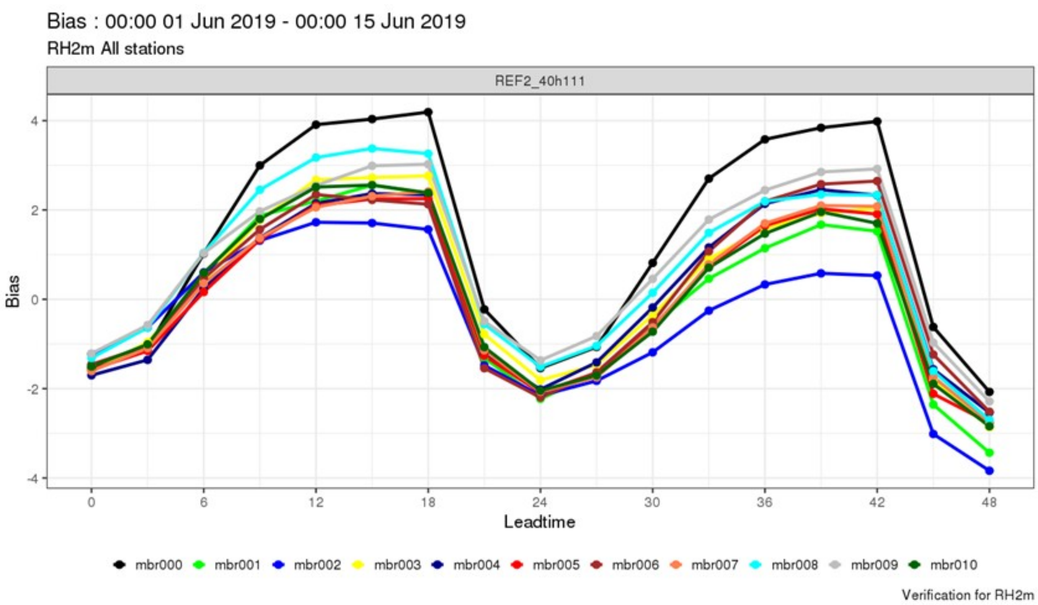

Figure 3: Bias for RH at 2m for HarmonEPS run from 1 to 15 June 2019. Control run is black.

The RH2M bias for all experiments except for the two on EDA are shown in Figure 4. While turning off the surface assimilation of the perturbed members reduces the drying, turning off the perturbations of soil moisture seems to solve the problem, also when surface assimilation of members is retained. Turning off the perturbations of humidity has only a minor impact on the drying, and the impact of EDA is negligible (not shown). These results indicate that the perturbations of soil moisture is the main cause of the drying of the perturbed members, and a possible solution to the problem is to turn these perturbations off. However, as shown in Figure 5, turning off or reducing the soil moisture perturbations reduces the spread of the ensemble considerably and slightly increases the root mean square error. In other words, this is not an adequate solution to the problem.

Table 1: Experiments with HarmonEPS

HarmonEPS Experiments	
CY40	
REF2_40h111	Reference experiment
SPP_SPPT_2_cp	Surface assimilation of ensemble members turned off
SPP_SPPT_2_cp_NoWGpert	Surface assimilation of ensemble members turned off. No perturbation of soil moisture.
REF2_40h111_PertWG_Sigma005	Reduced standard deviation of perturbations of soil moisture from 0.1 to 0.05
REF2_40h111_NoQpert	Turned off perturbations of humidity in PertAna. Soil moisture perturbations on.
REF2_40h111_NoQpertLBC	Turn off perturbations of humidity in LBC. Soil moisture perturbations on.
REF2_40h111_NoQWGpert	Turned off humidity perturbations in both PertAna and LBC. Turned off soil moisture perturbations
CY43h2.1.1	
CY43h211_NoEDA	Ensemble of data assimilation (EDA) not applied. Soil moisture perturbations turned off.
CY43h211_EDAon	EDA turned on. Soil moisture perturbations turned off.

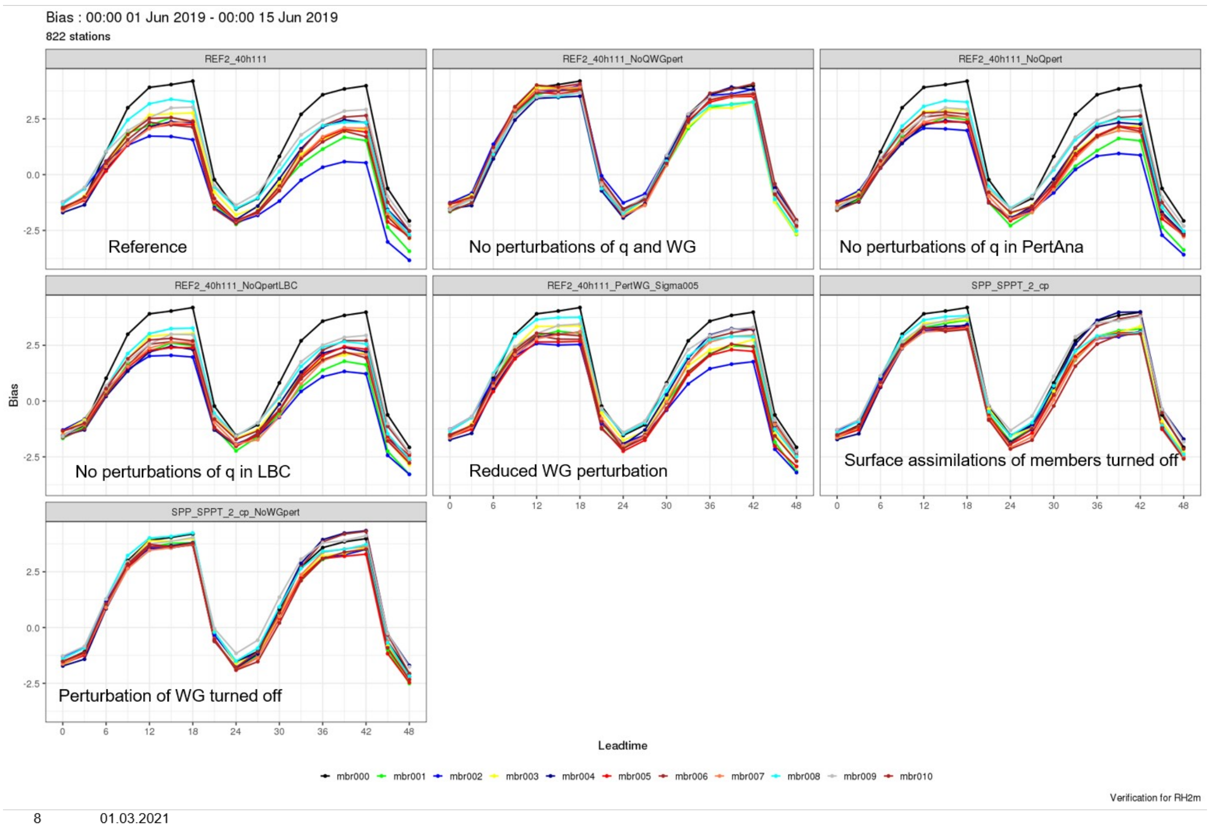

Figure 4: Bias of control and perturbed member for RH2M for the experiments shown in Table 1, except for the two experiments on EDA.

A better solution of this problem could be to adjust the soil moisture perturbations, rather than to do an overall reduction or discontinue them. If soil moisture is perturbed to values above field capacity, this will not affect transpiration, and hence not increase the humidity of the near surface air. Figure 6 shows soil wetness index (SWI) for the control run and a perturbed member at 6 hour lead time, where a SWI value above 1 indicate that field capacity is exceeded. The figure shows that WG has been perturbed above field capacity over parts of the model domain, and this is the case for most of the perturbed members (not shown). Since perturbations above field capacity will not increase e.g. the evaporation whereas those below wilting point will we will have an asymmetric response and these results indicate that perturbing WG above field capacity is the main cause of the observed drying of the ensemble members. In the next experiments we plan to perturb SWI instead of soil moisture, and constrain the perturbed values to be between 0 (wilting point) and 1 (field capacity).

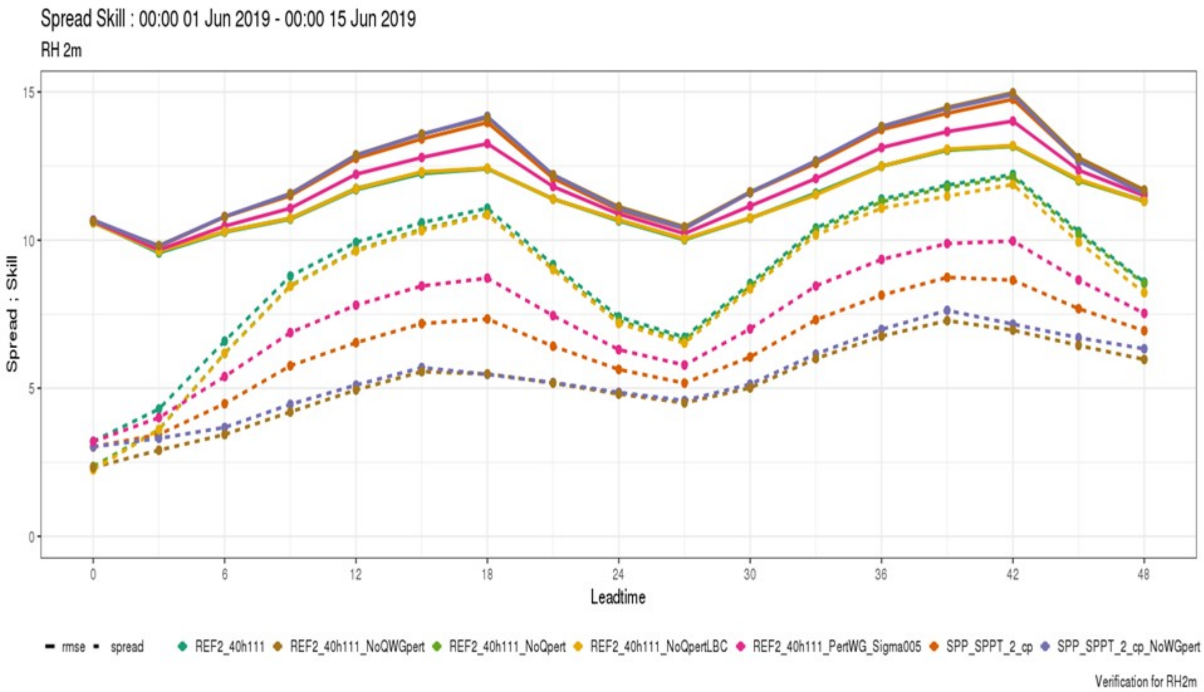

Figure 5: Root mean square error and spread for RH2M for all experiments shown in Table 1, except for the two on EDA.

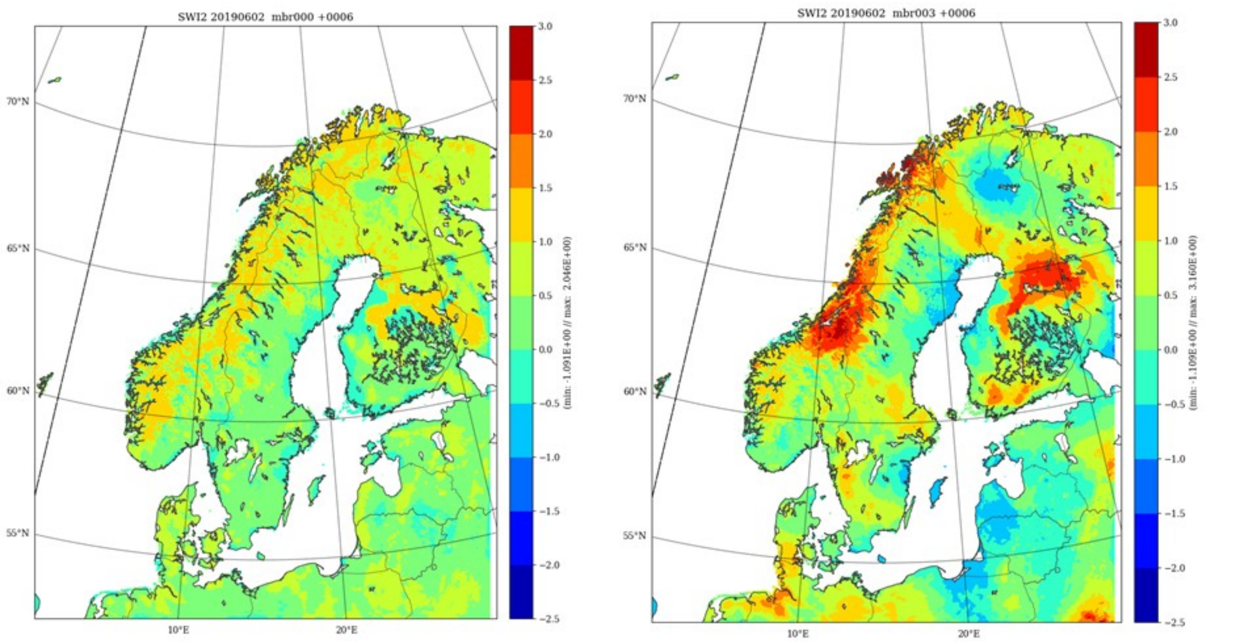

Figure 6: Soil wetness index for control (left) and member 3 (right) at 6 hour lead time.

Data assimilation friendly perturbations

The current operational statistics has been derived using a four member EDA setup driven by the ECMWF EDA system on the boundaries for a winter and summer period. BES for the new setup were derived from 6h forecasts over the period of 14th of May to 29th of November 2019 and were used for a single observation experiment and compared with a similar setup using the operational BES. It's clear from Figure 7 that the new statistics spread the increment over larger horizontal scales and thus prevent the resulting analysis from representing smaller scale features. To investigate the source of the larger scales further a series of experiments were performed. In these experiments we study the impact of different perturbation components:

- **Boundaries**: The usage of EDA (STREAM=ELDA) or IFSENS boundaries.
- **PertAna**: Inclusion of extra perturbations derived as the scaled difference between the used IFSENS/ELDA member and the control.
- **LSmix**: Mixing of ECMWF large scale information prior to the analysis.
- **Surfpert**: The sensitivity to the scale of the surface perturbations.

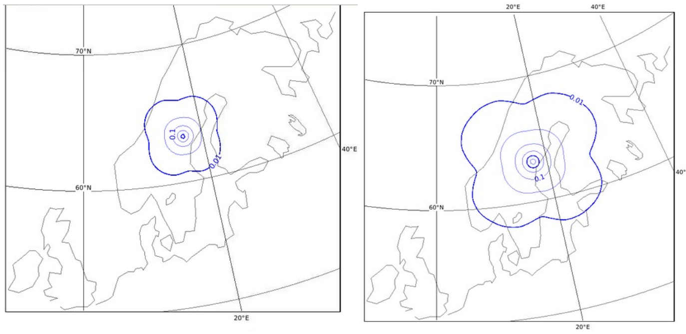

Figure 7: Temperature increment for a 1K warmer observation inserted at 500hPa. Left: operational BES, right: new BES.

For each of the experiments listed in table 2 we run EDA using conventional observations only with subsequent forecasts up to 6h for August 2019 using a four member ensemble over the smaller domain shown in Figure 1. New BES were derived for each of the experiments and the characteristics in terms of the energy at different horizontal scales as well as the vertical correlations compared. The findings, presented as the spectral density for vorticity at level 60, Figure 8, and the vertical correlation for humidity, Figure 9, can be summarized as follows:

- PertAna with IFSENS gives much more energy on larger scales whereas with ELDA the difference is smaller suggesting that the spread is much larger in IFSENS compared to ELDA. PertAna also introduces wider correlations in the vertical.

- LSMIX constrains the setup in the sense that without it the applied perturbations are given more freedom to evolve and thus gives more energy on the larger scales

- The operational statistics still has the smallest energy on the largest scales but it's based on different periods and more cases and does not include the surface perturbations.

It was only found a small near surface sensitivity to the horizontal scale of the surface perturbations (not shown). The results suggest that with the current setup data from MEPS is not suitable for generation of new BES. The difference in our methodology compared to other centres using EDA for their generation of background error statistics is that in MEPS we propagate all perturbations to the next cycle whereas in the other cases there is a clear separation between perturbations for data assimilation and ensemble purposes. A short two weeks test where we cycle neither the surface perturbations nor the result of PertAna shows as expected a reduced spread for near surface variables (not shown). What is interesting though is that the dry bias is reduced, Figure 10, which suggests that the accumulative effects of e.g. the surface perturbations are problematic.

IFSENS has recently been updated and now runs on the same number of levels as the EDA suite which helps to reduce possible differences in the capability to resolve vertical structures. In addition ECMWF has agreed to output forecast data from the EDA suite with 1h frequency up to 18h. This allows us to make a cleaner comparison of the impact of the boundaries.

Conclusions and outlook

In this report we've described activities related to the performance of the MetCoOp ensemble MEPS. We have shown that the dry bias in the ensemble can be controlled by either switching off the soil water perturbations or by not cycling them. The impact of various perturbations on the characteristic scales of the background error statistics used in the data assimilation has been investigated. We conclude that currently data MEPS cannot be used for generation of such statistics and we will investigate the impact and feasibility of a separation of perturbations for data assimilation purposes from those used to create a skilful ensemble. Work will continue, supported by this special project, to address these questions.

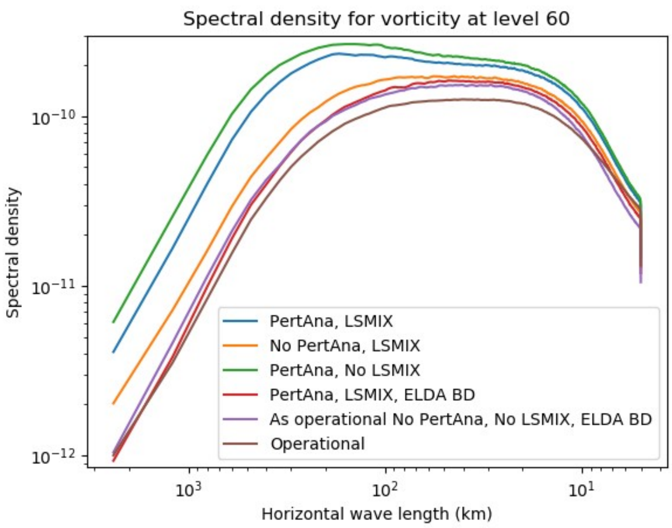

Figure 8: Spectral density for vorticity at level 60 for the background error statistics generated from the experiments in table 2.

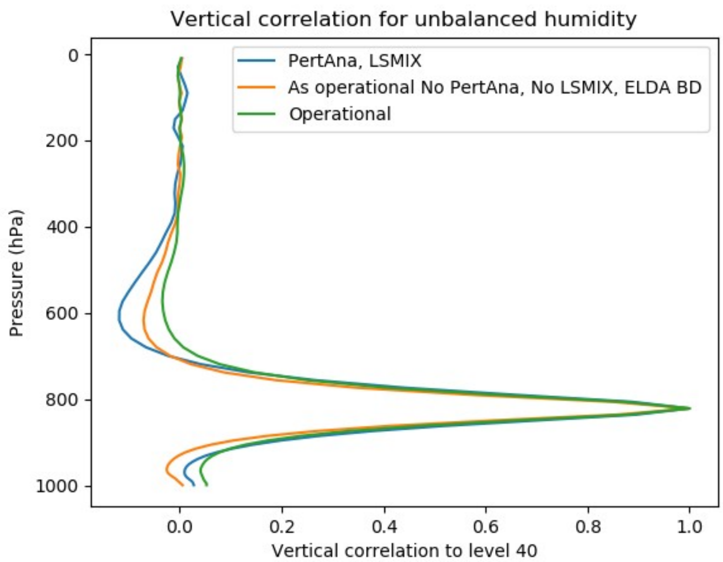

Figure 9: Vertical correlation to level 40 for the background error statistics generated from some of the experiments in table 2.

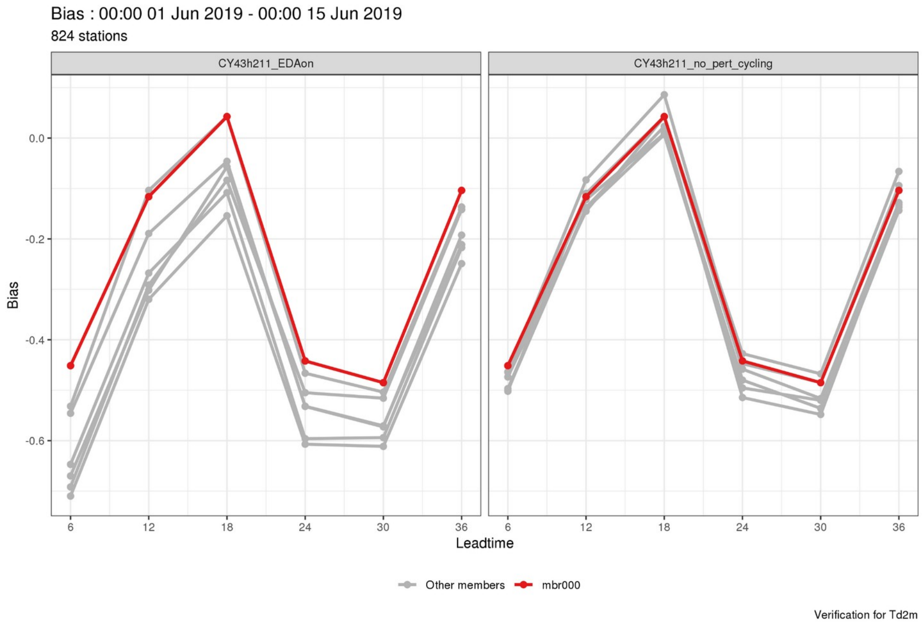

Figure 10: Bias for Dew point temperature at 2 meters for 1-15th of June 2019 with cycled perturbations (left) and non-cycled perturbations (right).

Table 2: Perturbation sensitivity experiments

	Boundaries	**PertAna**	**LSmix**	**Surfpert scale**
Operationally used	IFS ELDA	No	No	0km (off)
ELDA, no PertAna, no LSMIX	IFS ELDA	No	No	150km
ELDA boundaries	IFS ELDA	Yes	Yes	150km
MEPS like	IFSENS	Yes	Yes	150km
No PertAna	IFSENS	No	Yes	150km
No LSMIX, no PertAna	IFSENS	No	No	150km
50km surface pert	IFSENS	Yes	Yes	50km
No LSMIX	IFSENS	Yes	No	50km

References

Andrae, U. et.al, 2020, A continous EDA based ensemble in MetCoOp, ALADIN-HIRLAM Newletter Nr 14, 189-198

Frogner, I., Andrae, U., Bojarova, J., Callado, A., Escribà, P., Feddersen, H., Hally, A., Kauhanen, J., Randriamampianina, R., Singleton, A., Smet, G., van der Veen, S., and Vignes, O. (2019). HarmonEPS—The HARMONIE Ensemble Prediction System. *Weather and Forecasting* 34, 6, 1909-1937, https://doi.org/10.1175/WAF-D-19-0030.1