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	2020 (The first year of the project)
Project Title:	Development of consistent HarmonVar-EPS system
Computer Project Account:	spseboja
Principal Investigator(s):	Jelena Bojarova
Affiliation:	SMHI
Name of ECMWF scientist(s) collaborating to the project (if applicable)	…… ……
Start date of the project:	November 2019
Expected end date:	October 2022

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)			18MCPUs	3.3MCPUs
Data storage capacity	(Gbytes)				

Summary of project objectives (10 lines max)

The objective of the project is to develop, validate ad perform final tuning of the HarmonieVAR-EPS system on its optimal performance from both probabilistic and deterministic points of view. This include choice of an optimal approach for generation of initial conditions perturbations (BRAND/EDA/LETKF/FORCING); advancing the scheme to the Hybrid 4DVar/Hybrid 4DEnVar levels; customizing covariance localisation by further development of vertical, space-scale and time dimensions; validation of the performance of the scheme through numerical efficiency of the scheme, probabilistic and deterministic verification scores. The first year plan includes the selection of "best-choice" initial perturbation generaton scheme and further development of HARMONIE Hybrid 4DVar environment.

Summary of problems encountered (10 lines max)

The main problem encountered during the project was a development of instabilities in the HARMONIE EnVar system that were leasing to the numerical explosion of the Forecast runs. A special study was conducted (Nils Gustafsson, SMHI) to understand the reason of such instabilities and what remedy could be used to tackle them. These numerical instabilities were track down to a particular geographic location in the vicinity of Sogn Fjörd in Norwegian Mountains associated with extremely steep orography. HybridEnVar scheme with only 10 ensemble members (this extremely small ensemble size was chosen to save the resources) and linear grid used in HARMONIE setup amplified the problem which to some extend is always present in HARMONIE system.

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

The restricted HybridEnVar system with FORCING and LETKF initial perturbations will be conducted and the performance of the system will be evaluated using deterministic and probabilistic scores. The results will be compared with restricted HybridEnVar BRAND and HybridEnVar EDA systems taking into account computational efficiency of the systems. Small 10 members ensemble size will be used to perform these experiments in order to save the computational resources. In parallel the Hybrid 4DVAR and the Hybrid 4DEnVar schemes will be further developed including advanced covariance localisation options. The "best-choice" initial perturbation scheme with at least 20 ensemble members will be used for the final tuning of the HarmonieVar-EPS system on its optimal performance.

List of publications/reports from the project with complete references

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……
……

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.

The main objective of the first year of this project is the selection of the “best-choice” methodology for the generation of initial perturbations. Two weeks period during the second half of Jule 2019 was selected to evaluate the performance of HARMONIE Hybrid EnVar system with different ensembles of initial perturbations. This period was selected because several convective precipitation systems have passed over Scandinavia at this time. Harmonie DKCOEXP domain centred around Denmark has been chosen for this experiments. The domain is smaller than the operationally used MetCoOp domain and has relatively inhomogeneous orography. This allows to evaluate important features of the system and at the same time to save computational resources. It turned out that an ensemble of 11 members (10 members ensemble plus control) considered for this study is too small to demonstrate the full potential of the HybridEnVar system. An additional experiment with 21 ensemble members (20 ensemble members + control) using “BRAND-EPS” initial perturbations (randomization of the B-matrix covariance in the ensemble mode) was performed using national quotas. Standard verification scores show significant improvements in the HybridEnVar performance when a larger size ensemble is used. Nevertheless, we have decided to keep the small, 11 members ensemble size following the plan, to compare the ensemble methodologies between themselves. Then a larger, at least 21 members ensemble size, will be used to tune the “best-choice” HarmonVar-EPS system on its optimal performance.

HARMONIE HybridEnVar experiment with 11 ensemble members (“BRAND-EPS” methodology) has developed instabilities that have exploded during the forecast run started at 2019 06 26 03:00 while the baseline 3DVAR run has completed without problems . A separate study using national quotas was conducted (Nils Gustafsson et al) to understand the reason of the this behaviour and what remedy should be used to stabilize the run. The crash was tracked back to a specific geographic location in the vicinity of Sogn Fjörd in Norwegian mountains that is associated with a very steep and inhomogen orography. A false convection was produced that have induced extremely heavy katabatic winds. Under certain weather conditions HARMONIE system often produces such instabilities that die out without leading to explosion. 3DVAR data assimilation system with a homogeneous isotropic increments smooths the initial state. On contrary HybridEnVar system “sees” the orography and produces flow- and orography- dependent increments. The initial state includes a linear combination of ensemble perturbations. When several ensemble members have experienced instabilities at the same time the feature might be amplified in the solution to a level that leads to a forecast explosion. The following actions have helped to stabilize the system :
1) larger ensemble size allows to smooth out numerical instabilities;
2) quadratic or cubic grid allows to reduce numerical instabilities; by default HARMONIE system is using a linear grid where the only linear terms in the forecast model are represented correctly
3) a “restricted” minimization when the analysis increments are restricted to certain scales helps to avoid noise amplification on small scales.
In addition reduced time step might be needed to stabilize the system.

It is worth to mention that the study has shown an ability of the HARMONIE model to represent mountains waves correctly. In particular when cubic or quadratic grid were used the small scale numerical noise has disappeared and a stationary mountains waves have been established. A separate case study using the WRF model on the same domain using the same resolution has been performed. Despite of quite different dynamical solutions both models have provided consistent description of mountain waves, even through the HARMONIE representation of the mountain waves is somewhat smoother. The manuscript intended for a peer-reviewed scientific journal describing results of this study is in preparation. As well as a short paper on mountain waves and a numerical noise is being published in a popular science journal of the Swedish Meteorological Society (“Polarfront”) .

One should take into account that a proper implementation of quadratic or cubic grid keeping the same spectral resolution as in case of a linear grid requires decreased grid-distance (from 2.5 to 1.67 for quadratic grid and to 1.25 for cubic grid). This leads to a large increase of computational costs. To maintain the instabilities and carry the experiments we have selected a restricted minimization approach. The analyses increment affects the largest 100 1D-waves (of 320 available) and keeps the shorter waves unchanged extracting them from the short range HARMONIE forecast. The restricted minimization was extensively tried in the HARMONIE 3DVAR system with encouraging results (Bojarova and Gustafsson, 2019). The restriction of the extended control vector representing the ensemble weights has been recently implemented into the HARMONIE forecasting system.

Hybrid EnVar BRAND-EPS and HybridEnVar EDA experiments have been conducted using the restricted minimization. The meteorological validation of the system performance still need to be done. The technical verification shows that Hybrid EnVar EDA system produces somewhat lower spread of ensemble that Hybrid EnVar BRAND-EPS. The quality of the control member forecast are quite similar, however HybridEnVar BRAND-EPS draws closer to observations. The contribution from the ensemble part to the solution is stronger for HybridEnVar BRAND-EPS. The convergence to the solution is slightly slower for HybridEnVar BRAND-EPS even if HybridEnVar BRAND-EPS achieves lower absolute minimum of cost function. Both systems may experience a degenerate behaviour of the convergence when the step in the line search approaches the machine precision. The properties of the convergence are slightly improved when a larger ensemble size is used.