SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Testing and developing the HARMONIE data assimilation system at MET Norway
Computer Project Account:	spnorand
Start Year - End Year :	2018 - 2020
Principal Investigator(s)	Roger Randriamampianina
Affiliation/Address:	Norwegian Meteorological Institute (MET Norway) Henrik Mohns Plass 1 0371 Oslo
Other Researchers (Name/Affiliation):	Roohollah Azad, Mate Mile, Roel Stappers, Teresa Valkonen, Trygve Aspelien, Yurii Batrak, Ole Vignes, Mariken Homleid, Hilde Haakenstad, Rafael Johannes Grote

The following should cover the entire project duration.

Summary of project objectives

The objective of this special project is to support all data assimilation (DA) related activities at MET Norway. The tasks in the application involve five activities: 5-years hindcast, refinement of background error statistics, improvement of sea ice modelling, use of more satellite observations, and participation in OOPS development. These were the dominating DA topics at application time, while from 2018, we were also engaged in other external projects involving more topics like assimilation of Aeolus HLOS data (PRODEX), observation operator refinement and all-sky radiance assimilation (Alertness) and Copernicus regional reanalysis projects (C3S_322_Lot1 – European and C3S_D322_Lot2 – Arctic).

Summary of problems encountered

We reported a low priority queuing in 2018, but since then no specific problem was encountered.

Experience with the Special Project framework

We think the special projects are very well managed and controlled. It is very good that we receive regularly the status of the SBU usage. We experienced very high level support. The application procedure is clear and the reporting procedure is simplified but at the same time requests details about the outcome of the projects.

Summary of results

The spnorand project was used to complete with some experiments few data assimilation tasks which are connected to external research projects or internal developments. Since the tasks are not connected to each others, we report about them separately as follows:

1- Improvement of the microwave radiances assimilation

MET Norway is leading the Copernicus Arctic regional Reanalysis project. As part of the short development related to this project, in cooperation with Sigurdur Thorsteinsson from the Icelandic Meteorological Office (IMO), we performed few experiments aiming to improve the assimilation of microwave radiances over sea ice. The work consisted in the implementation of the use of the dynamical emissivity and Atlases, available in the IFS and ARPEGE/AROME system, with the microwave radiance assimilation in the Harmonie system. With help from Philippe Chambon and Florian Suzat from Meteo France, we succeed to test this approach with very good results. For example Figure 1 shows that activating the dynamical emissivity and use of Atlases allows the assimilation of more low peaking channels over sea ice and Greenland. This approach was first adapted to the Arctic reanalysis system, and later was added to the operational AROME-Arctic regional model. See *Thorsteinsson and Randriamampianina (2018)* for more details.

2- Implementation of the assimilation of Aeolus HLOS wind in Harmonie data assimilation

In framework of the PRODEX CAL/VAL project, we implemented the assimilation of the simulated HLOS wind data from ECMWF in the Harmonie-Arome data assimilation (DA). This consisted with adaptation of the reading and processing of the HLOS wind. We had to use the newest available cycle (CY43) for this task. This work was done in close collaboration with Meteo France colleagues. Figure 2 shows the processing of the Aeolus data in the Harmonie-Arome DA. It shows the HLOS wind before (bottom graph) and after (top graph) screening. In this example, the processing removed some low level winds below the jet stream due to too large background departure. The assimilation of the HLOS winds in Harmonie-Arome DA shows very promising positive impact, although the timeliness of this data is the reason why we couldn't yet use them in operational.

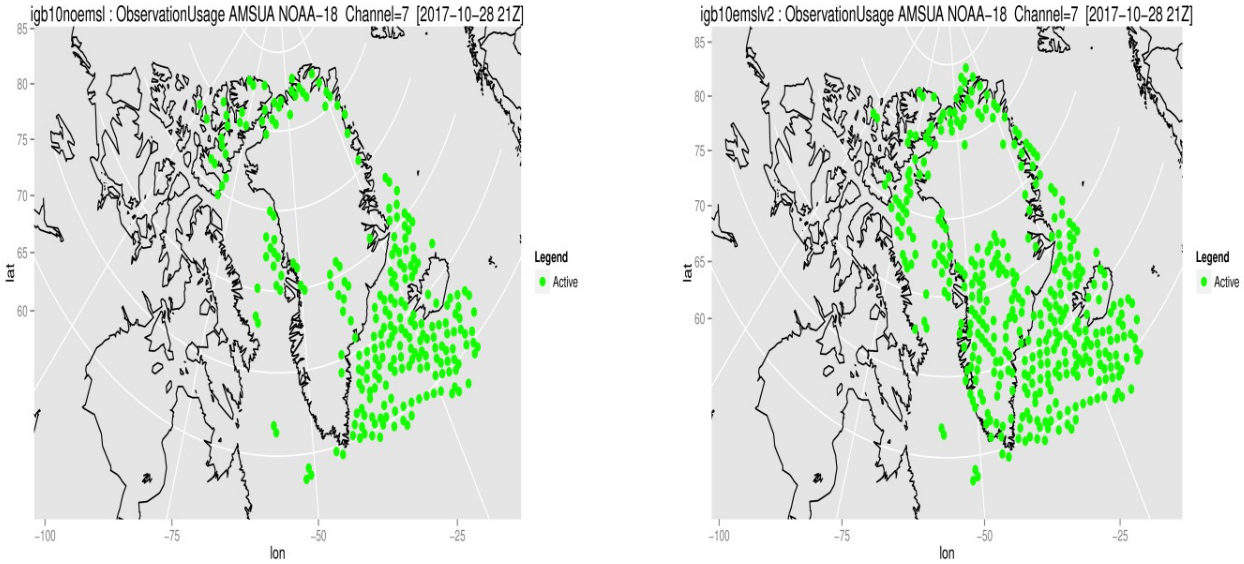

Figure 1. Active pixels from channel 7 (NOAA-18) without (left) and with (right) activating the use of dynamical emissivity and Atlases in Harmonie-Arome data assimilation.

3- Reporting the implementation of the AROME-Arctic data assimilation

Part of the used resource was applied to compute comprehensive verification scores for our earlier (implementation done in 2013-2014) observing system experiment (OSE) study, performed during the implementation of the AROME-Arctic model. We implemented a new verification tool which takes into account all active observations used in the data assimilation, including radiance data. A paper describing this study was published with acknowledgement to the special project spnorand (*Randriamampianina et al. 2019*). Example of results of the new implementation is shown on the figure 3 below, where verification against radiances is shown.

4- Supporting the Arctic OSE study

The last part of the resource was used to support an Arctic OSE. This study was done in the framework of the year of polar prediction (YOPP) programme, YOPP-endorsed Alertness (alertness.no) and APPLICATE (applicate.eu) projects, and performed during the special observation periods (SOP1 – winter, and SOP2 – summer) using data denial approach. This study took into account the global OSEs (full global – *Bormann et al. (2019)* and Arctic (*Laurence et al. (2019)*) as lateral boundary conditions (LBC). Use of the different global OSE results as LBC in the regional Arctic OSE, using the AROME-Arctic regional model, allowed us to compute the following relative impact of observations: 1) impact of the Arctic observations through the regional data assimilation; 2) impact of the Arctic observations through LBC; 3) the total impact of the observations due to their loss in both global and regional models; and 4) impact of the non-Arctic observations on the AROME-Arctic model. Table 1 describes all the performed experiments.

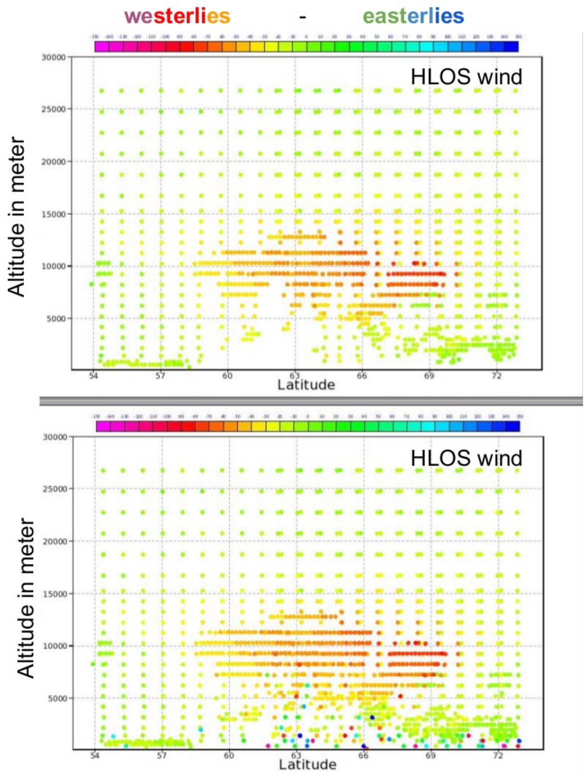

Figure 2. Processing of the simulated HLOS wind data in Harmonie-Arome DA before (bottom) and after (top) the data screening.

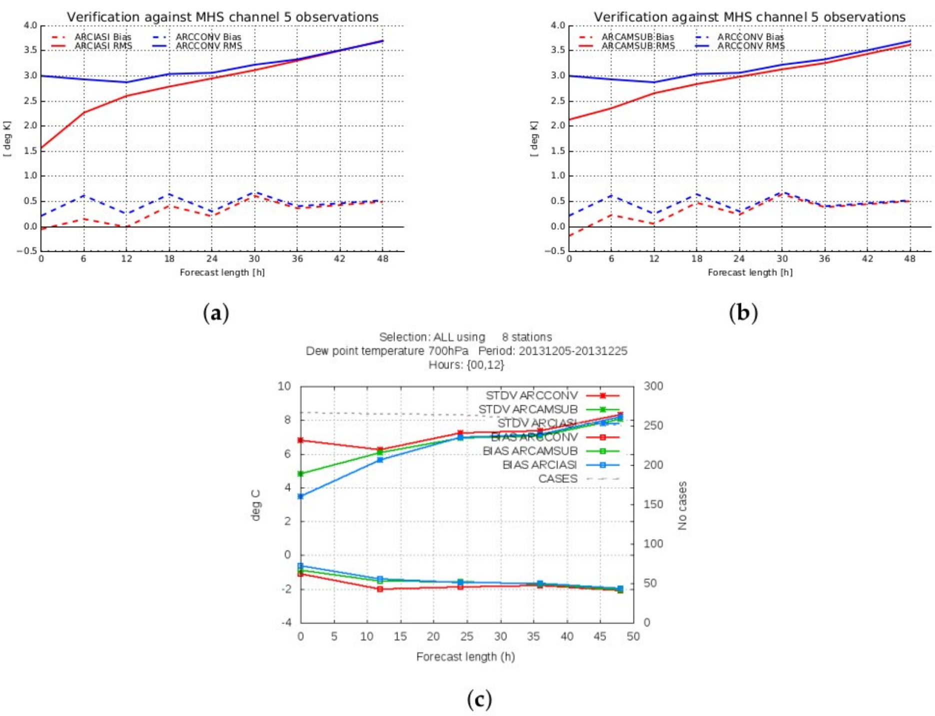

Figure 3: The verification against the AMSU-B/MHS channel 5 brightness temperature (a, b) and the verification against radiosonde observations (c). The horizontal axes in (a, b) show forecast lengths similar to the one in (c). The RMSE and the error standard deviation (STDV) are comparable. Note that channel 5 of the AMSU-B/MHS instrument picks at around 700 hPa depending on the water vapour in the air.

Global Experiments used as LBCs	Regional	Observation type

for the regional experiments	experiments	
Gall	Rall	All observations included
Gall	RnoXX	XX observations removed for SOP1: MW, MT, MH, IR, AM, CV, RS, PS, S1 XX observations removed for SOP2 : MW, IR, CV, AM
GnoXX (Arctic)	RnoXX	XX observations removed for SOP1: MW, MT, MH, IR, AM, CV, RS XX removed for SOP2: MW, IR, CV
GnoXX(Arctic)/GnoXX(global)	RnoXX	XX removed for SOP1: MW, IR, CV

Table 1. Summary of the experiments and naming. G = global NWP system, R = Regional NWP system, all = all observations, noXX = observation type XX is removed, SOP1 = YOPP Special Observing Period 1, SOP2 = YOPP Special Observing Period 2. MW = microwave radiances, MT = microwave temperature sensitive radiances, MH = microwave humidity sensitive radiances, IR = Infrared radiances, AM = Atmospheric Motion Vectors, CV = all conventional observations, RS = all radiosonde observations, PS = all surface pressure observations, S1 = all additional SOP1 observations. The Gall/Rall experiment indicates for example the regional experiments in which all observations are assimilated in regional DA, which uses as LBCs the global experiment in which all observations are used. GnoMW/RnoMW indicates the regional experiment used while no MW sensitive observations are used in either the regional nor north of 60N in the global DA.

Points 2) and 3) above are new in the literature. Point 4) is also interesting from the point of view Arctic activities planning and European observing system design strategies. Due to lack of computational resource, some of the experiments were performed with shorter period and the summer SOP study was done with fewer observation types compared to the winter one. Paper, with acknowledgement to spnorand, describing the main findings related to the points 1) – 3) above is now submitted to per review journal for publication (*Randriamampianina et al. 2020*). Figure 4 shows an example of the results from this study. Following are just few interesting findings from this study:
– For upper-air forecasts, the impact through the LBCs dominates, and for some observation types the forecast impact from denying the observations lasts throughout the forecast range when the observations are denied in the regional as well as the global system. In contrast, if observations are denied in the regional DA system only, the upper-air impact of the investigated observations is significant at most up to 12 hours for conventional observations while the significant impact is observed at longer forecast range in case of satellite observations. However, the impact on the surface fields is dominated by the impact through regional DA and significant impact on surface fields can last up to 36 hours (satellite microwave) and 48 hours (conventional observations).

– The present study suggests that a full assessment of the benefit from observations in a regional system should take into account the impact of observations in both the regional DA and in the global assimilation system that provides the LBCs. Past studies reported only one of those relative impacts, i.e. the impact of observations through regional DA, and these studies therefore underestimate the full observational impact.

Concluding remark

Most of the time, with few additional special projects, we are able to do what we are planning for the year, but in 2019 we faced serious computational resource problems. While spnorand could help a bit to complete the planned experiments, more was needed. This lead to some restriction to the planned study. See report 4 for more details.

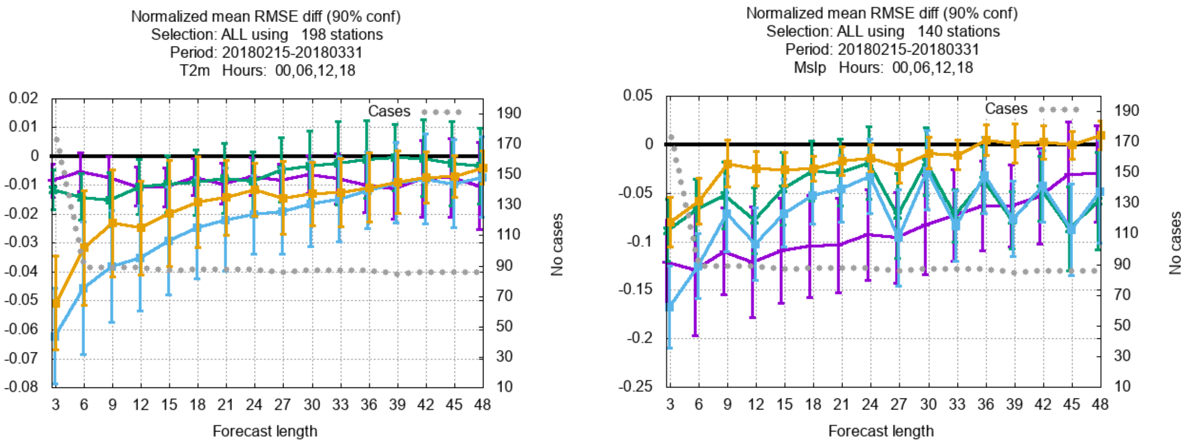

Figure 4: Difference in mean root mean square error (RMSE), normalized by the mean scores, of 2m temperature (T2m, left) and mean sea level pressure (Mslp, right) showing the impact of all Arctic conventional observations through regional data assimilation (orange), through LBC (green), total impact of Arctic observations (light blue), and impact of non-Arctic observations (purple) is thus shown in percents (e.g. from -8 to 2 percent in the left plot). Negative/positive values indicate positive/negative impact of observations on forecast skill. A 90% two sided statistical significance test is applied, and verification is against the 8 radiosonde stations in the AROME-Arctic domain. The number of cases for each lead time is shown by the dashed line and the right hand side y-axis.

List of publications/reports from the project with complete references

Thorsteinsson S and R Randriamampianina, 2018, Use of low peaking channels from ATOVS in regional data assimilation, 28th ALADIN Wk & HIRLAM All Staff Meeting 2018, 16-20/04/2018, Toulouse, France, available from:
http://www.umr-cnrm.fr/aladin/IMG/pdf/asm_20180416_sthrr_dynemisv4.pdf

Azad R, H Schyberg, R Randriamampianina, 2018, Aeolus Wind Data Assimilation and Cal/Val at MET Norway, Aeolus workshop, Darmstad, Germany.

Randriamampianina R, H Schyberg, M Mile, 2019, Observing System Experiments with an Arctic Mesoscale Numerical Weather Prediction Model. *Remote Sens.* 2019, *11*(8), 981; https://doi.org/10.3390/rs11080981

Randriamampianina R, Bormann N, M A Ø Køltzow, H Lawrenc, I Sandu, Zh Q Wang, Relative impact of observations on a regional Arctic numerical weather prediction model, 2020, Submitted Q. J. R. Meteorol. Soc.

Referred papers:
Bormann, N., Lawrence, H. and Farnan, J. (2019) Global observing system experiments in the ecmwf assimilation system.368ECMWFTechnicalMemorandum, 839.

Lawrence, H., Bormann, N., Sandu, I., Day, J., Farnan, J.andBauer, P. (2019)Useandimpactofarcticobservationsinthe396ecmwfnumericalweatherpredictionsystem.Q.J.R.Meteorol.Soc., 145, 3432–3454.

Future plans

Spnomile was used to complement some the works reported here, although it’s mainly for Mate Mile’s PhD study.
MET Norway together with the Nordic Meteorological institutes will be involved in preparation and planning of the small Arctic Weather Satellite (AWS). We (Magnus Lindskog (SMHI) is the principle investigator) are applying for special project to support the needed development work in this project. Since all our institutes are still involved in reanalysis projects the following year, we will need additional resources to do more research.