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(2/2), 2021(1/2)
Project Title:	Advanced assimilation of satellite observations and the impact of improved atmospheric forcing over a limited-area Arctic region
Computer Project Account:	spnomile
Principal Investigator(s):	Mile, M.
Affiliation:	Norwegian Meteorological Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	n/a
Start date of the project:	01/01/2020
Expected end date:	31/12/2022

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)	20000000	20353784.11 (101%)	20000000	6192599.45 (30%)
Data storage capacity	(Gbytes)	40000		40000	

Summary of project objectives (10 lines max)

The aim of the project is to improve the assimilation of radiance observations (focusing on spatial representativeness error) over high-latitudes, and to evaluate the impact of improved atmospheric forcing in a coupled ocean-sea ice model. It is planned to run AROME model at 2.5km resolution over an Arctic domain during selected periods and to develop a new observation operator taking into account satellite footprint in data assimilation procedure. The performance of AROME data assimilation will be assessed using specific data assimilation diagnostics and forecast verifications. Scientific studies of the new observation operator will focus on obtaining reduced error in data assimilation and providing more accurate analyses for AROME forecasts. In the next phase of the project, data assimilation developments will give an understanding of how an improved use of radiance data influence the coupled ocean-sea ice system as well.

Summary of problems encountered (10 lines max)

In 2020 and 2021, the implementation of radiance footprint operator has been continued and in parallel the supermodding operator of scatterometer observations was further tested as well. Some difficulties were noticed concerning the slow HPC (cca) and archived data (ECFS), however, no major problems were encountered so far.

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

The implementation of new observation operator was started and progressing with different implementation phases (from the most basic one towards a more advanced implementation stage). After each source code implementation phase, technical and scientific validation are done (i.e. single observation experiments with various radiance observations, data assimilation diagnostics, mono and parallel tests). The validation of the completely implemented method will be followed by the tuning of predefined data assimilation errors and the execution of observing system experiments. Additionally, special case studies, particularly interesting in the Arctic region, are going to be examined. At a later stage, the coupled ocean-sea ice system is going to be set up in ECMWF's HPC.

List of publications/reports from the project with complete references

Mile, M., Randriamampianina, R., Marseille, G.J., Stoffelen, A. (2021): Supermodding - a special footprint operator for mesoscale data assimilation using scatterometer winds. Q.J.R. Meteorol. Soc., https://doi.org/10.1002/qj.3979

Randriamampianina R., N. Bormann, M. A. Ø. Køltzow, H. Lawrence, I. Sandu, Z.-Q. Wang (2021): Relative impact of observations on a regional Arctic numerical weather prediction system, Q.J.R. Meteorol. Soc. https://doi.org/10.1002/qj.4018.

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 spnomile project was used to develop and study the following tasks:

1 – Development of new footprint operator for radiance instruments

The implementation of radiance footprint operator follows a similar idea of scatterometer supermodding operator (Mile *et al.*, 2021) i.e., averaging model grid-point information during the computation of $H(x_b)$. Apparently, radiance footprint operator is more complex which means that averaging is needed on all model levels with position dependent footprint sizes. Therefore, we decided to do the source code implementation gradually in various phases starting from a simplified footprint representation towards the most sophisticated footprint representation. In figure 1, the footprints of IASI instrument on AROME model levels (L65) are plotted which are going to be realized in the final implementation phase of the observation operator. It can be seen that the footprint size depends on the vertical and horizontal position of the observed pixel and the footprint (FOV) itself forms an ellipse.

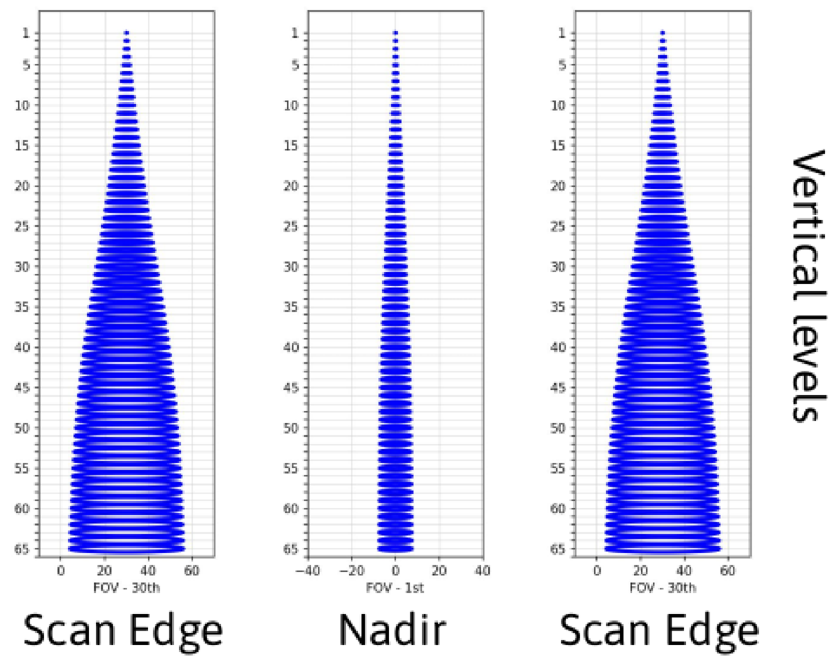

Figure 1. The schematic representation of IASI FOV ellipses on AROME-Arctic 65 vertical levels.

In the first phase of the implementation, the averaging operator without taking into account the vertically and horizontally varying footprint size was built for radiance observations. In figure 2, the analysis increment of a single observation experiment is shown for temperature and specific humidity control variables when radiance observation (IASI) was assimilated with this basic footprint operator. It is important to mention that the footprint size was constructed as a rectangular shape in this phase. The averaging size was chosen arbitrarily to 50km for all model levels (as shown schematically on the right figure). The increments are much smoother than the relatively sharp increments obtained by the default observation operator (not shown).

In the second implementation phase, the vertically changing footprint size was taken into account and tested. It means that the footprint is the smallest at the model top and gradually increases towards the lowest model level. The same single observation experiment was tested with this second footprint operator as well. In figure 3, the analysis increments can be seen when the averaging operator used 10km footprint size at the model top and 50km footprint size at the lowest model level. For the time being, these averaging sizes were chosen arbitrarily for demonstration purposes.

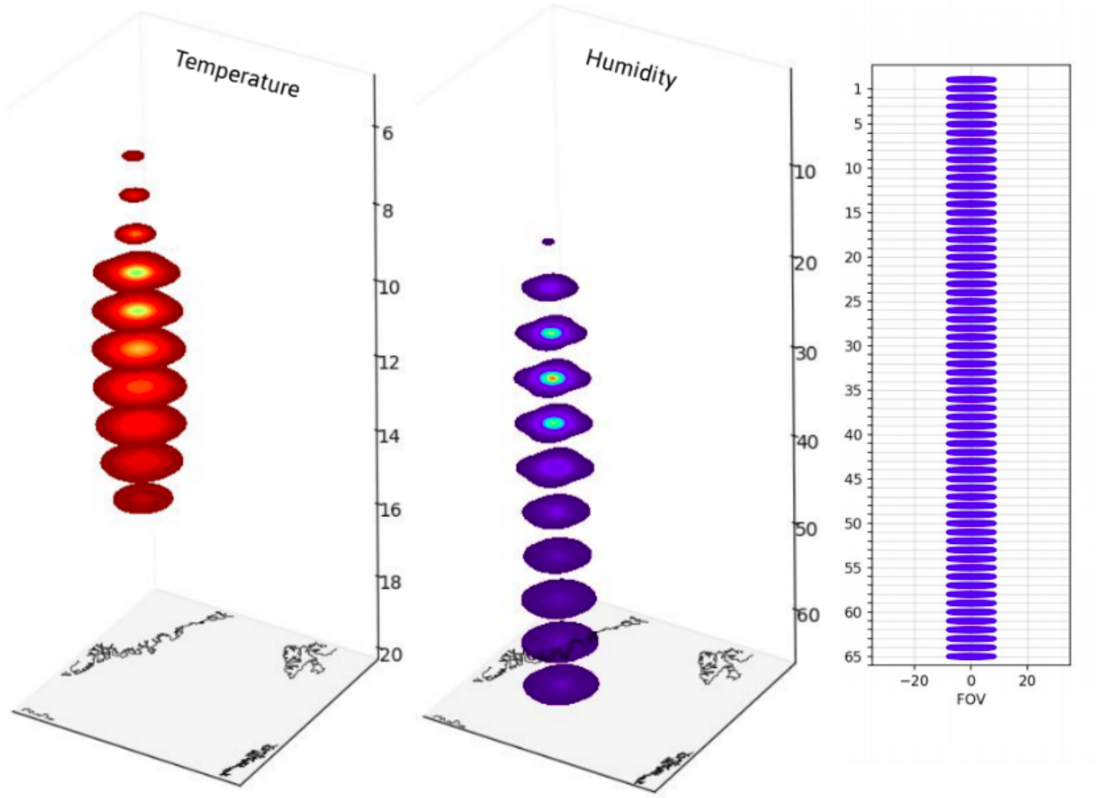

Figure 2. 3D-Var analysis increments using 1st implementation phase for temperature (left), specific humidity (middle) control variables at various model levels (z-axis) over the Lofoten archipelago. The analysis time is 2100UTC on 19 March 2018.

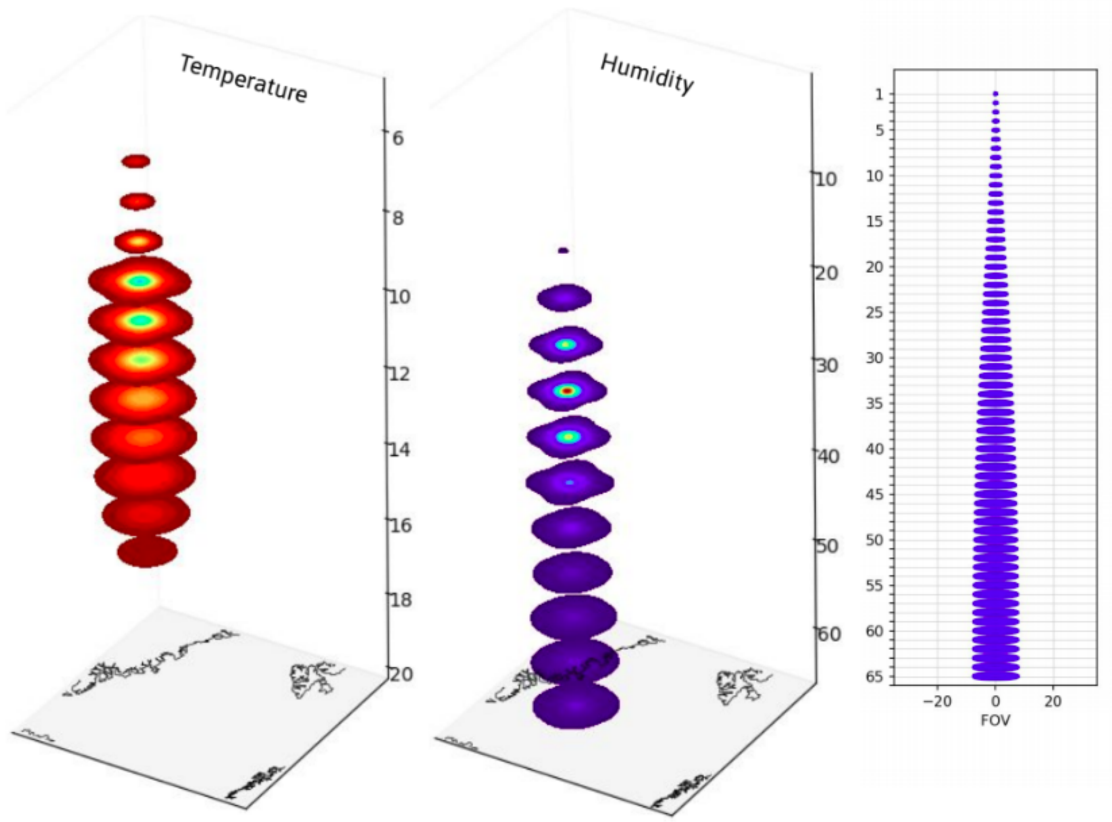

Figure 3. 3D-Var analysis increments using 2nd implementation phase for temperature (left), specific humidity (middle) control variables at various model levels (z-axis) over the Lofoten archipelago. The analysis time is 2100UTC on 19 March 2018.

In comparison with figure 2, it can be seen that for temperature variable the increments are less smoothed i.e., the footprint operator provides similar results (does averaging with fewer grid points) than the default interpolation operator.

In the final implementation phase (which is still ongoing), the complete footprint operator is planned to be implemented where the horizontal position of the observed pixel is also taken into account (see figure 1.). It means that footprint size is generally the largest at the satellite scan edge and near surface but the smallest at the model top in nadir viewing direction.

2 – Implementation of Aeolus footprint operation in AROME-Arctic

The already implemented footprint operator was also extended and tested for Aeolus HLOS wind observations. The Aeolus Rayleigh-clear winds are the results of averaging ~90km along the satellite track, therefore, in a high-resolution model like AROME, the use of a footprint operator for Aeolus Rayleigh-clear winds can be meaningful. A single observation experiment was carried out in order to demonstrate the impact of footprint representation on analysis increments which is shown in figure 4.

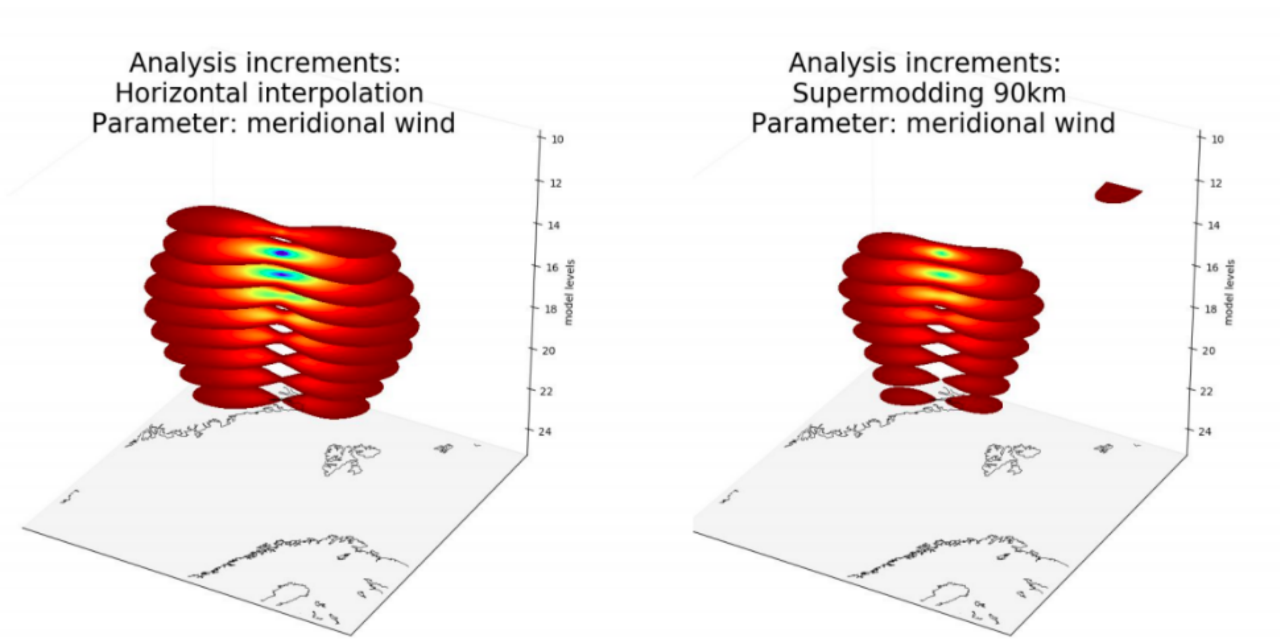

Figure 4. 3D-Var analysis increments of Aeolus (Rayleigh-clear) single observation in AROME-Arctic. The default observation operator using horizontal interpolation is on the left and the footprint operator with 90km averaging size is on the right. The analysis time is 0600UTC on 25 October 2019.

The single observation experiments and the footprint operator related source code developments (both radiance and Aeolus) consumed relatively small amount of SBUs in the special project so far. The HPC resources were mostly used for compilation and various minimization tasks without the requirement of large storage capacity.

3 – Assessment of inflated observation errors and reduced thinning with ASCAT scatterometer supermodding in AROME-Arctic

Beside the development of radiance and Aeolus footprint operators, the ASCAT scatterometer data assimilation were further tested concerning error tuning and reduced thinning with the supermodding observation operator. Although, it was not considered in the original proposal, but the supermodding or footprint operators might require the revision of pre-defined errors in data assimilation which is going to be important for radiance data as well. For this purpose, various observing system experiments were carried out with inflated observation errors and reduced thinning distances. All experiments were assimilating ASCAT (coastal products) scatterometer data with 60 km supermodding size which averaging size was found to be the most beneficial for ASCAT and AROME-Arctic (Mile *et al.*, 2021). In order to diagnose the performance of the different supermodding experiments, a diagnostic tool using passive (i.e., independent) scatterometer observations (Marseille *et al.*, 2016) was utilized. The OSCAT scatterometer observations were used from ScatSat-1 satellite with 25 km sampling. In figure 5, the result of passive OSCAT diagnostic is plotted for both wind components and for 10 different experiments including default ASCAT assimilation (orange), no ASCAT assimilation (grey), supermodding (60 km size) experiments with 50 km thinning (blue) and inflated observation errors (0.5, 1.0, 1.5, 2.0), and supermodding (60 km size) experiments with 5 km thinning (basically no thinning, red colour) and inflated observation errors (0.5, 1.0, 1.5, 2.0).

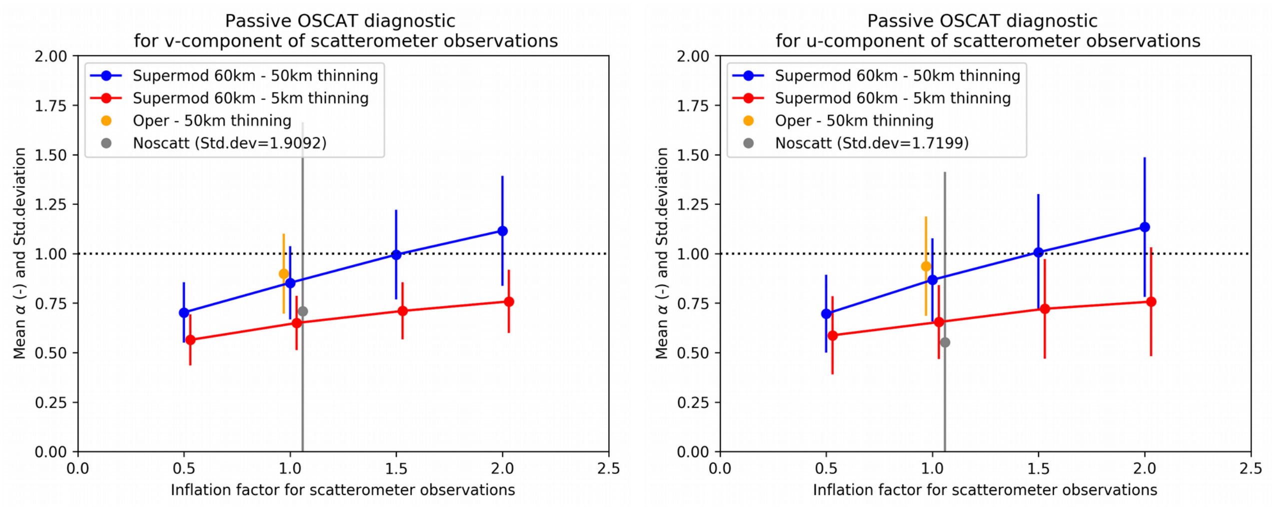

Figure 5. Diagnostic tool using passive OSCAT scatterometer observations for v- (left figure) and u-component (right figure) of wind. The mean alpha values and standard deviations as a function of inflated observation error are plotted . Diagnostic was run over the period 01-31 March, 2018.

The alpha value proposed by Marseille *et al.* (2016) provides an assessment of the data assimilation system performance. When the alpha value is close to 1, the data assimilation system is well-tuned. It can be seen that supermodding with 50 km thinning and no observation error inflation (1.0 sigmao coefficient) makes the assimilation system less optimal (than the operational with default ASCAT assimilation), but inflating the observation errors by a factor of 1.5 might improve the data assimilation system considerably. Additionally, this diagnostic suggests that reducing the thinning distance makes the assimilation system even less optimal with the supermodding operator. It is important to mention that ASCAT data were assimilated from Metop-A and Metop-B satellites which might require a more advanced error tuning when satellite constellations with no thinning might require specific error inflation in the assimilation system.

In order to evaluate the performance of the supermodding experiments, spatial variances (Vogelzang *el al.*, 2015) were utilized as well. The spatial variances were computed for (independent or passive) OSCAT data and for supermodding experiments with no (1.0) and 1.5 inflated observation errors. It can be seen in figure 6 that inflating the observation error by 1.5 factor makes the supermodding analyses closer to the independent OSCAT observations on all spatial scales between 50 and 1000 km.

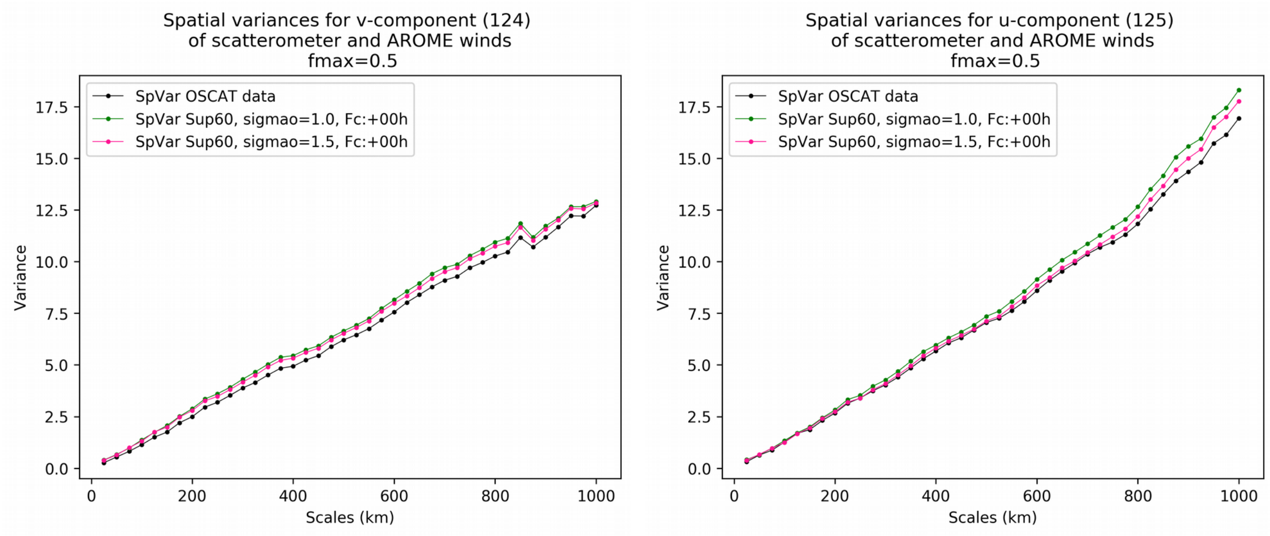

Figure 6. Spatial variances of OSCAT observations and interpolated AROME-Arctic analyses as a function of spatial scales. The variances were computed on the period of 01-31 March, 2018.

The scatterometer supermodding experiments with inflated errors and reduced thinning consumed the bigger part of the SBUs in the special project.

Additional references:

Marseille, G.-J., Barkmeijer, J., de Haan, S., Verkley, W.: Assessment and tuning of data assimilation systems using passive observations. Q.J.R. Meteorol. Soc. 142 , 3001-3014, 2016.

Vogelzang, J., King, G. P., and Stoffelen, A.: Spatial variances of wind fields and their relation to second-order structure functions and spectra. J.Geophys. Res. Oceans, 120, 1048-1064. doi:10.1002/2014JCO10239, 2015.

4 – Study the AROME-Arctic forecasting capabilities through observing system experiments

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. However, it's not firmly connected to the original proposal of spnomile special project, but this study delivered many important outcomes, which are important for the original objectives of the spnomile project as well. For example, it showed the value of globally assimilated observations in a limited-area model, AROME-Arctic. It is particularly important to determine which scales are actually determined well by the global model and the assimilated global observing system. More details about the results are discussed in Randriamampianina *et al.* (2020).