Alertness

Improved assimilation of scatterometer winds at Met Norway (the supermodding method)

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Introduction and motivation

In the Arctic region the conventional observations are very sparse, hence not enough to build an accurate high resolution initial condition of limited-area NWP systems. By this fact the non-conventional observations play even more important role in data assimilation, but the way such data is usually employed is conservative and suboptimal. One objective of the ALERTNESS (Advanced models and weather prediction in the Arctic: Enhanced capacity from observations and polar process representations) project is an improved use of observations by taking into account the observation footprint in the observation operator.

The observation as point measurement is taken into account in data assimilation. However, remote sensing observations like for example scatterometer winds are representative on an area of wind vector cells. The basic aim is to establish a "model-state-aggregation" method called supermodding primarily for scattermeter observations which computes model equivalents in data assimilation representing the footprint area and more importantly to avoid correcting unconstrained small scales.

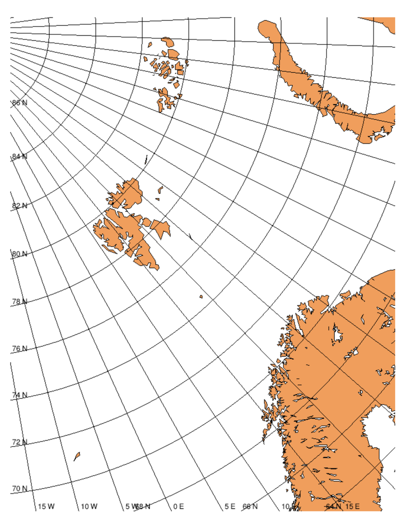
This study addresses spatial structures simulated by models which cannot be observed by the observing system. Without a strong ocean coupling, limited-area model may not do better over the ocean, since no information is available for the initialization of the small scales (Stoffelen et al., 2020). Our hypothesis is that the representation of the observation footprint is only one aspect, and we argue that lack of adequate forcing like 4D observations, high-resolution boundary conditions and physical constraints, also determine the scales one can analyse deterministically in a limited-area domain over the open ocean. In this study, we further elaborate on the footprint operator proposed by Marseille and Stoffelen (2017) in a mesoscale DA system with focus on scatterometer winds and taking into account the small spatial scales of the NWP model.

AROME-Arctic model and ASCAT scatterometer observations

The AROME-Arctic model is running with 2.5 km horizontal grid spacing and using 65 vertical levels up to 10 hPa over the high-latitude model domain, which is displayed in the figure below.

The lateral boundary conditions (LBCs) in the AROME-Arctic model are provided by the global ECMWF/IFS (Integrated Forecasting System) model at TCo1279 spectral resolution (around 9 km grid distance). Regarding the observation set, the operational AROME-Arctic DA system (Müller et al.,2017b) uses all available conventional and numerous satellite observations including ASCAT scatterometer data.

The scatterometer instrument on board polar-orbitting satellites is designed to measure wind speed and direction by backscattered radar signals from ocean waves. The scatterometer wind measurements are determined on a grid of Wind Vector Cells (WVCs). The observation footprint of scatterometer measurements corresponds to the size of the WVCs used for actual wind calculation. In this study, the ASCAT coastal product with 12.5 km distance between adjacent observations along and across the swath is considered. The effective resolution of scatterometer wind products is typically twice the sampling distance, i.e., around 25 km for the coastal product (Marseille and Stoffelen, 2017).



The limited-area domain of AROME-Arctic

The supermodding observation operator of the AROME assimilation system

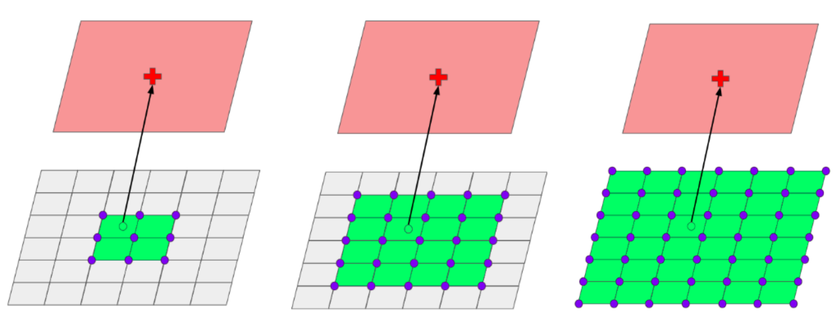
The applied incremental variational analysis can be obtained by searching for the minimum of cost function described by (1) and (2) below

$$J(\delta x) = \frac{1}{2}(\delta \mathbf{x}^T \mathbf{B}^{-1} \delta \mathbf{x}) + \frac{1}{2}(\mathbf{d} - \mathbf{H}(\delta \mathbf{x}))^T \mathbf{R}^{-1} (\mathbf{d} - \mathbf{H}(\delta \mathbf{x})) \qquad (1)$$

$$\nabla J = (\mathbf{B}^{-1} + \mathbf{H}^T \mathbf{R}^{-1} \mathbf{H}) \delta \mathbf{x} - \mathbf{H}^T \mathbf{R}^{-1} \mathbf{d} \qquad (2)$$

where **B** and **R** are the background-error and the observation error covariance matrix respectively. **H** is the linearised observation operator and $\mathbf{H}^T$ stands for its adjoint version. δx is the increment and **d** represents the innovation, i.e., the difference between the observation vector and its model counterpart projected to observation space by the nonlinear observation operator. In its recent implementation of the observation operator, it does bilinear horizontal interpolation using 4 or 12 neighbouring grid-points, which is considered as an accurate solution for most of the conventional observations, but scatterometer observations are representative of an area about three times the size of a WVC.

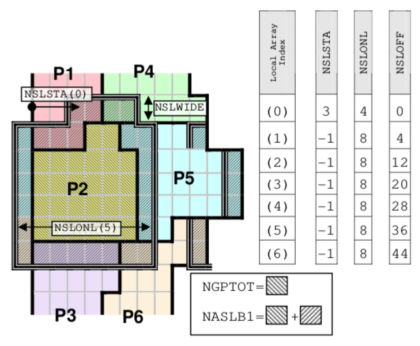
Supermodding aims to improve the spatial representation of the observation by averaging the model counterpart and therefore ignoring the correction of small unobserved and unconstrained scales in DA. This approach was implemented for scatterometer data in the observation operator of the variational assimilation scheme (schematic figure below illustrates the approach). For the purpose of this study, the size of averaging in model space (called the *supermodding size* hereafter) can be easily changed to test the impact of avering in the observation operator.



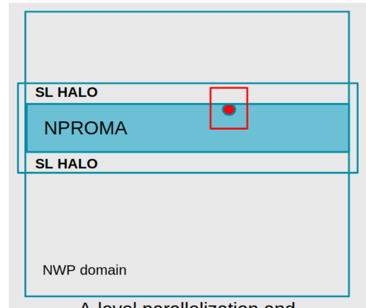
Schematic figure showing the supermodding observation operator with different supermodding size. The red cross indicates the observation with a certain footprint (pink area), blue dots show the selected grid points for the computation of the observation model-equivalent, and the green area indicates the $H(x_b)$ itself computed by the observation operator

A technical point of the implementation

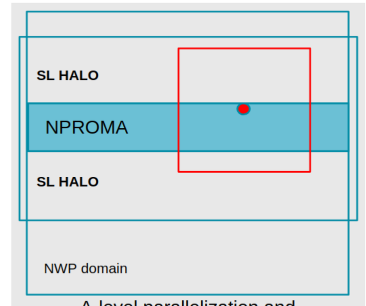
The AROME source code is developed to be able to run it in High Performance Computing facilities. In order to run the supermodding method (i.e. averaging model fields using large number of grid-points) on a massively parallel processing, the currently used parallelization for observation operator had to be extended. The so called Semi-Lagranian (SL) computation halo protects dynamical core's trajectories during model integration to not go out from computation blocks. This approach is also used for observation operator, but horizontal interpolation does not require significant SL halo size. To be able to access large number of neighbouring grid-point, the size of the SL halo was extend for supermodding. The schematic figure about this technical issue can be seen on figures below.



ECMWF IFS documentation about SL halo in CY40r1



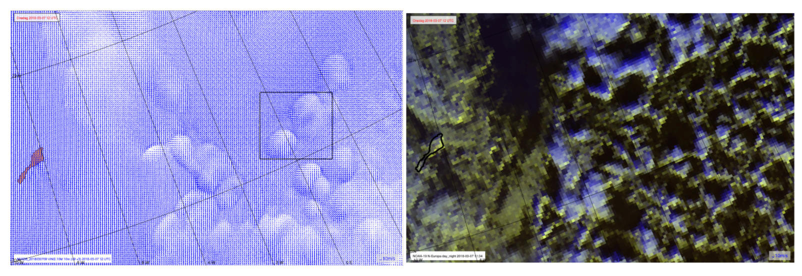
A-level parallelization and horizontal interpolation



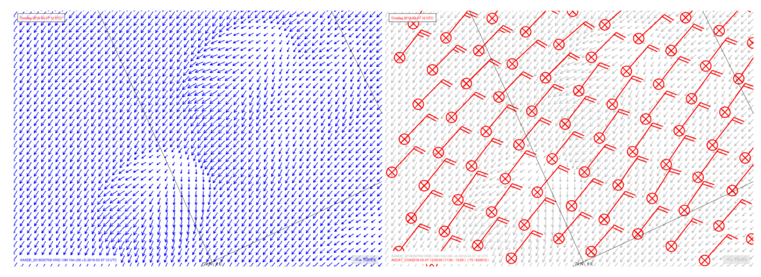
A-level parallelization and supermodding

An idealised experiment with ASCAT supermodding assimilation

The concept of supermodding can be best explained through a case study where all available ASCAT observations were assimilated without other operationally used observations in AROME-Arctic. The case study analysed here is 1200 UTC, 7th of March, 2018, where the AROME-Arctic model shows small-scale phenomena (convection in this case) which are not observed by the ASCAT instrument. Figures (on the left) below display wind vectors of AROME-Arctic and the corresponding AVHRR satellite image indicating that convection was present near Jan-Mayen island. A smaller subdomain is highlighted (figures on the right) to demonstrate the resolution gap between AROME and ASCAT products.

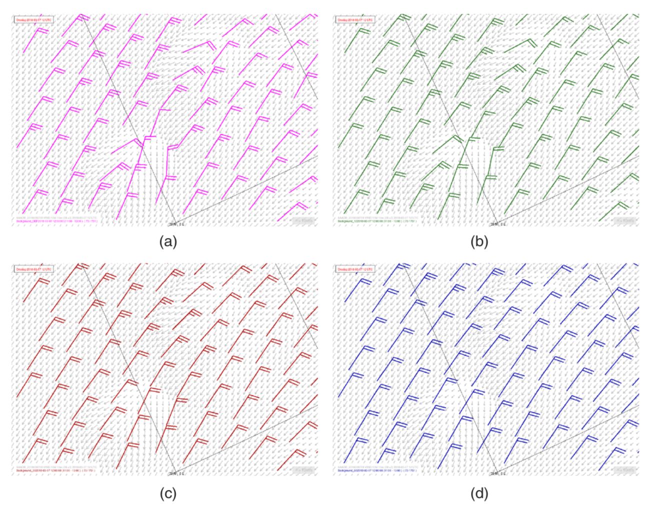


The 10 m wind field (blue wind vectors) of the AROME-Arctic 3-hr forecast and NOAA-19 AVHRR day/night satellite image at 1200 UTC on 7 March 2018

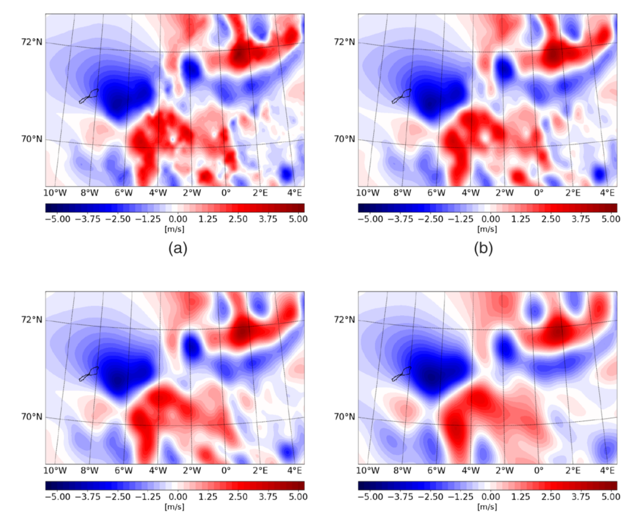


Over the boxed area from Figure on the left the 10 m wind field (blue wind vectors) of the AROME-Arctic 3-hr forecast and the wind field (red wind barbs) of the ASCAT coastal product at 1200 UTC on 7 March 2018.

To diagnose the supermodding operator, figures (below) illustrate an intermediate step of the assimilation procedure when model information is projected to observation space (i.e., the $H(x_b)$). From these figures, it is clear that default ASCAT assimilation as a point observation compares and corrects small-scale model information with ASCAT measurements, but which cannot be observed by the satellite instrument. This is still the case when representing the ASCAT footprint (12.5 km supermodding), while 30 km and more apparently 60 km supermodding constrains the larger scales of the AROME-Arctic background and avoids any correction on the smallest scales, by construction. Figures (on the right) show wind u-component analysis increments for a slightly larger subdomain comparing the same four assimilation configurations. It shows how increments are reshaped by the supermodding observation operator in order to correct the larger scales by the use of ASCAT observations..



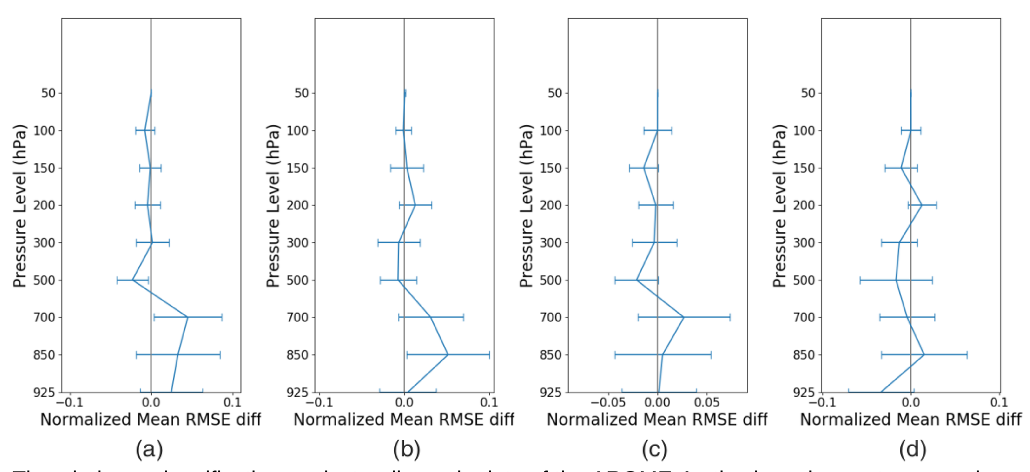
(a) The interpolated AROME-Arctic background to ASCAT location (magenta wind barbs), (b) the 12.5 km supermodding of AROME-Arctic background to ASCAT location (green wind barbs), (c) the 30 km supermodding of AROME-Arctic background to ASCAT location (dark red wind barbs), and (d) the 60 km supermodding of AROME-Arctic background to ASCAT location (blue wind barbs).



The analysis increments of the AROME-Arctic 3D-Var wind u-component using ASCAT (a) with horizontal interpolation, (b) with 12.5 km supermodding, (c) with 30 km supermodding, and (d) with 60 km supermodding, all at model level 65 at 1200 UTC on 7 March 2018

The observing system experiment

AROME-Arctic experiments were carried out with all operationally used observations, and the only difference between them was the applied observation operator (horizontal interpolation for use as point observation or supermodding with various sizes).
The normalised differences in RMSE scores are shown and indicate the added value of supermodding near 700-850hPa with 30 and 60 km sizes for +12h AROME wind speed forecasts.



The wind speed verification against radiosonde data of the AROME-Arctic observing system experiment (period 05 February to 31 March 2018); normalized RMSE difference (90% confidence) between the reference and (a) the supermodding 30 km, (b) the supermodding 60 km, (c) the supermodding 100 km, and (d) the supermodding 225 km

Conclusion and Outlook

- To analyse 4D structures deterministically by an assimilation method, sufficient data samples are required. In the case of insufficient sampling, distorted dynamical structure and the problem called aliasing (Nyquist, 1928) occur, leading to corrupted analysis structures and short-range forecasts. Nyquist (1928) suggests oversampling by a factor of two in all dimensions to prevent the generation of artificial waves (Moiré effect). By the use of ASCAT coastal products in the IFS global DA, De Chiara et al. (2019) arrived at an optimum of 62.5 km superobbing of ASCAT winds, which comes close to the Nyquist criterion, i.e., half the distance of the deterministic resolution (which is ~150 km). Following the same logic, but in high-resolution DA, the supermodding method can be utilised to neglect the correction on unconstrained small scales larger than the effective resolution of the ASCAT winds.
- Figures of idealised case study illustrate that the AROME-Arctic model simulates small-scale phenomena which are not necessarily observed by the ASCAT coastal product, which is due to phenomena being likely out of phase (at the wrong location and/or time) and/or because the ASCAT resolution is too coarse to resolve these.
- In the verification against radiosonde observations, supermodding showed both improvement and degradation depending on the chosen supermodding sizes. The use of 30 km supermodding size has mostly positive impact on wind speed and temperature forecasts (not shown here) initialised at 1200 UTC in the lower troposphere. The use of 60 km supermodding showed statistically significant positive impact in wind speed at the 850 hPa level, in temperature at 700 and 850 hPa levels (not shown), and in geopotential height at 500 hPa (not shown) without observed degradation of the forecasts initialised at 1200 UTC compared to the default ASCAT assimilation. Further increasing supermodding size in the assimilation system seems more detrimental than beneficial.
- In conclusion, the DA of scatterometer observations in the AROME-Arctic model can be improved by the use of the supermodding method. However, the supermodding method with too large averaging sizes can introduce representation error and can remove true model variance as well.

References

De Chiara, G., Stoffelen, A., Lin, W., Portabella, M., Vogelzang, J. and Isaksen, L. (2019) Evaluation of ASCAT superobbing products for NWP data assimilation. A Joint Satellite Conference presentation; available at: https://ams.confex.com/ams/JOINTSATMET/meetingapp.cgi/Paper/360735.

Marseille, G.-J. and Stoffelen, A. (2017) Toward Scatterometer winds assimilation in the mesoscale HARMONIE model. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10, 2383–2393.

Müller, M., Homleid, M., Ivarsson, K.-I., Køltzow, M.A.Ø., Lindskog, M., Midtbø, K.H., Andræ, U., Aspelien, T., Berggren, L., Bjørge, D., Dahlgren, P., Kristiansen, J., Randriamampianina, R., Ridal, M. and Vignes, O. (2017b) AROME-MetCoOp: a Nordic convective-scale operational weather prediction model. Weather and Forecasting, 32, 609–627.

Nyquist, H. (1928) Certain topics in telegraph transmission theory. Transactions of the American Institute of Electrical Engineers, 47, 617–644. https://doi.org/10.1109/T-AIEE.1928.5055024.

Stoffelen, A., Vogelzang, J. and Marseille, G.-J. (2020). High resolution data assimilation guide. EUMETSAT NWP SAF Documentation, version 1.3. https://nwp-saf.eumetsat.int/site/download/documentation/scatterometer/reports/High_Resolution_Wind_Data_Assimilation_Guide_1.3.pdf