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(2/2), 2022(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	19731742.57 (98%)	20000000	106,766 (0.5%)
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.

Summary of problems encountered (10 lines max)

The evaluation of improved atmospheric forcing in the coupled ocean-sea ice system has been postponed due to technical reasons (porting issues of the ocean-sea ice system). Some difficulties were noticed concerning the slow HPC (cca) and archived data (ECFS), however, no major problems were encountered so far. For example, at the end of 2021, archived (observations and LBCs) data have not been used from MARS in order to run the experiments faster.

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

The implementation of radiance footprint operator is going to be validated further and extended for multiple instruments. It is planned to apply a radiance footprint operator for Arctic Weather Satellite (AWS) products in the frame of an ESA project. After the completed implementation and scientific validation of the footprint operator, observing system experiments are going to be carried out in order to compare its performance with the default radiance observation operator.

List of publications/reports from the project with complete references

Mile, M., Azad, R., Marseille, G.J. (2022): Assimilation of Aeolus Rayleigh-clear winds using a footprint operator in AROME-Arctic mesoscale model. Geophysical Research Letters, 49, e2021GL097615. https://doi.org/10.1029/2021GL097615

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 original idea for the footprint operator implementation was to apply averaging in model space in order to fully replace horizontal interpolation in the radiance observation operator. However, it has several drawbacks for example the satellite footprint cannot be represented properly in model space (see an illustration below) and it would not take into account non-linear effects of the radiance observation operator. On the other hand, the footprint calculation in observation space uses many interpolated model profiles and multiple calls of the radiative transfer model which makes the operator more appropriate and computationally more expensive as well. This second solution was also considered and started to be investigated in the special project. Single observation experiments using the model space based footprint operator have been shown in the previous report but in this report we are discussing the preliminary results of the footprint operator in observation space.

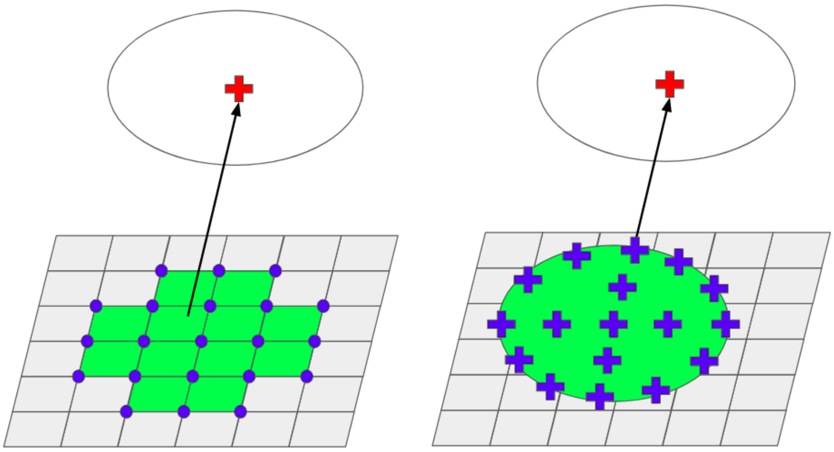


Figure 1. The schematic figure of footprint representation in model space (left) and in observation space (right) in comparison with a radiance observation (red cross) and the corresponding FOV ellipse.

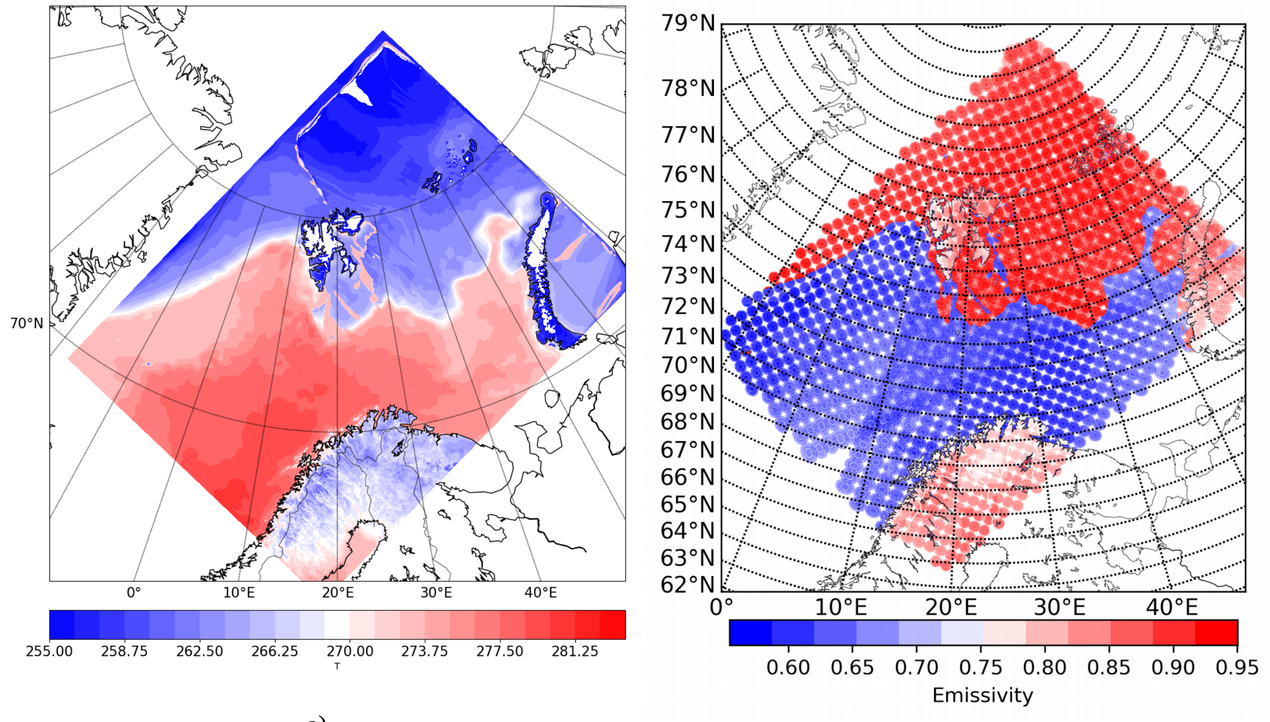
The footprint observation operator in observation space is based on the structure of 2D GOM arrays in the common source code. There are similar already existing examples like RADAR, GPS RO, and GNSS SPD observations in the variational assimilation system of limited-area models.

A dedicated subroutine was implemented in the setup level of the assimilation code (mkglobstab) in order to retrieve additional geolocations around the actual observation location forming the FOV ellipse i.e., the satellite footprint. It utilises the characteristics of the assimilated satellite instrument (scanning geometry, azimuth, satellite altitude) and aims to match the sampling of the footprint operator points with the horizontal resolution of the model. The observation information is read from the ODB during this footprint setup subroutine. The point observation based radiance observation operator was extended with the functionalities of 2D GOM arrays which can be activated by a namelist switch keeping the default operator beside the new footprint operator in the source code. The code was prepared for such a development in many subroutines, but not in all. The implementation was started and explored in cy43h1.2 using an Arctic domain (AROME-Arctic model configuration).

Initially, microwave radiances of AMSU-A instrument were tested. The model variability is not particularly large for temperature sensitive radiance data like AMSU-A, but this instrument has the largest footprint size among the operationally assimilated radiance data of AROME-Arctic model. Later, AMSU-B and infrared radiances are going to be tested as well. For the time being, only clear-sky radiances are assimilated in AROME-Arctic and all-sky assimilation is an ongoing research.

During the implementation of the radiance footprint operator, the emissivity is one particularly important (and challenging) parameter for the successful radiance assimilation. By the use of the footprint operator, emissivity is determined for each operator points (at many geolocations around the observation location) meaning that different surface conditions inside the FOV area can be taken into account during the computation of simulated brightness temperatures.

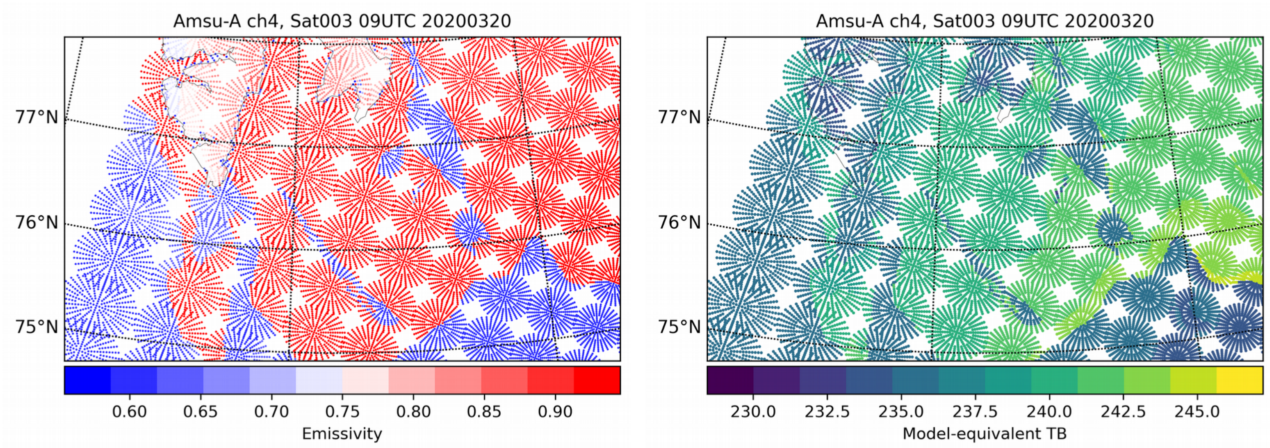
A case study is shown here in order to demonstrate the retrieved emissivity of the footprint operator. In Figure 2., the surface temperature of the AROME-Arctic model is plotted at 09UTC, 20th of March, 2020 and can be compared with the emissivity calculated by the footprint operator for Metop-A and NOAA-19 AMSU-A satellite radiances.



a) b)

Figure 2. The AROME-Arctic surface temperature (left) and the retrieved emissivity by the footprint operator for Metop-B, and NOAA-19 AMSU-A radiances at 09 UTC, 20th of March, 2020.

It can be seen that the footprint operator enables to describe better surface properties and might help to better model sub-footprint processes, heterogeneity in radiance data assimilation instead of using the default (point based) observation operator. In Figure 3a., the area from south of Svalbard is highlighted (from Figure 2b) for the retrieved emissivity (Figure3a) and also for model-equivalent brightness temperatures of AMSU-A channel 4 (Figure3b), 5 (Figure3c), and 6 (Figure3d).



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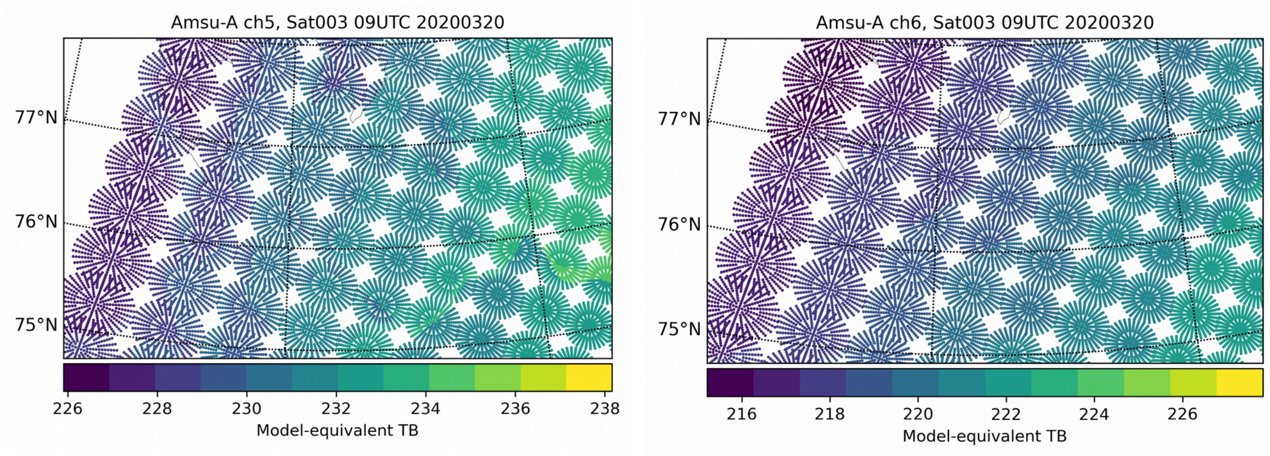

c) d)

Figure 3. A zoomed area near south of Svalbard (from Figure 2.); Retrieved emissivity (3a), simulated brightness temperatures of AMSU-A channel 4 (3b), channel 5 (3c), and channel 6 (3d) by the radiance footprint operator. Observations from Metop-B satellite at 09 UTC, 20th of March, 2020.

In Figure 3, the footprint operator points are more apparent and it can be seen that FOV ellipses and the corresponding footprint sizes are elongated close to the scan edge (on the left side of each sub-Figure). The simulated brightness temperatures are also plotted on Figure 3. for low- and high-peaking AMSU-A channels showing a detailed view by the use of footprint operator.

The development of the radiance footprint operator is still ongoing and needs extensive validation and testing, therefore, more results can be expected in the final report of the spnomile special project.

2 – Implementation of Aeolus footprint operation in AROME-Arctic

An Aeolus Rayleigh-clear footprint operator has been implemented in AROME-Arctic data assimilation system as well. The footprint operator is able to reduce the standard deviation of observation minus background departures and to slightly improve AROME forecasts. This study has been published and summarized by Mile et al. (2022).