Exploring a microwave radiance footprint operator in regional data assimilation systems

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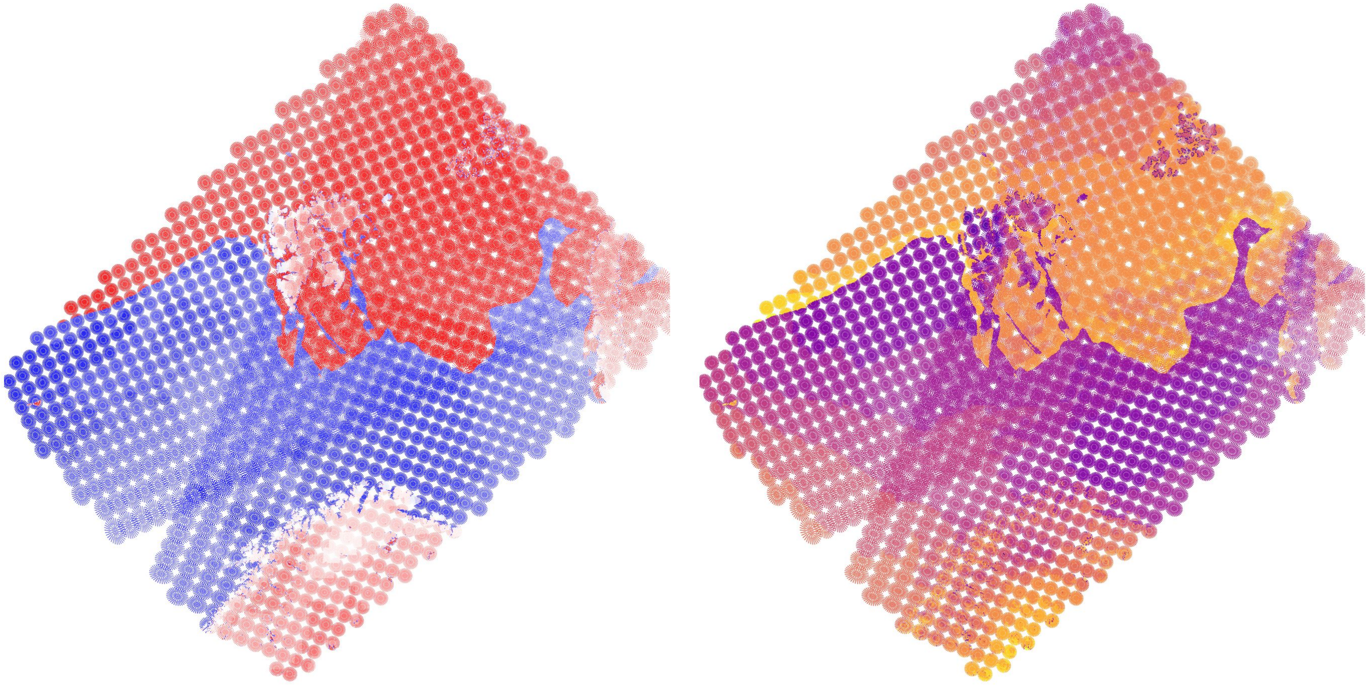

Motivation

Radiance data assimilation in high-resolution limited-area models **is challenging**

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Limited coverage

DA scheme (3D-Var)

Complex bias correction

Point observations

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Outline

Footprint operator in general

Data and models

The actual implemented radiance footprint operator

A case study

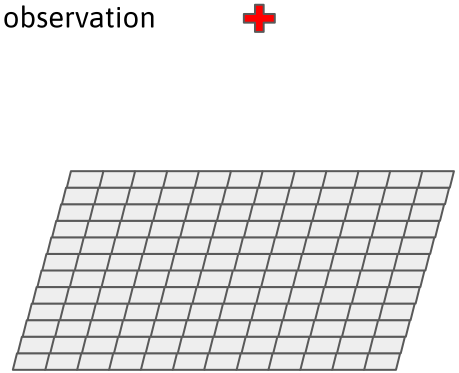
Statistics and forecast verification

Future plans and summary

The radiance footprint operator

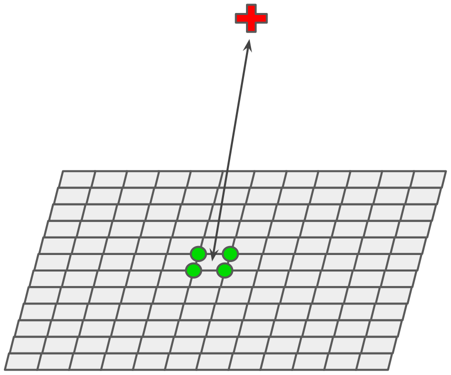
Single observation

Model grid



The radiance footprint operator

Interpolation



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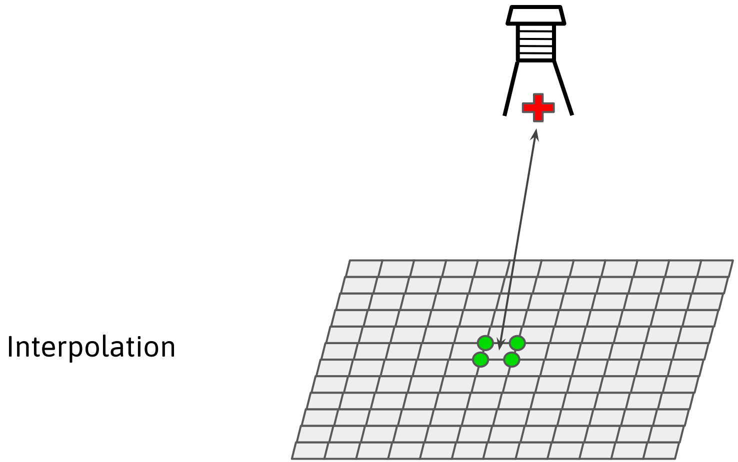

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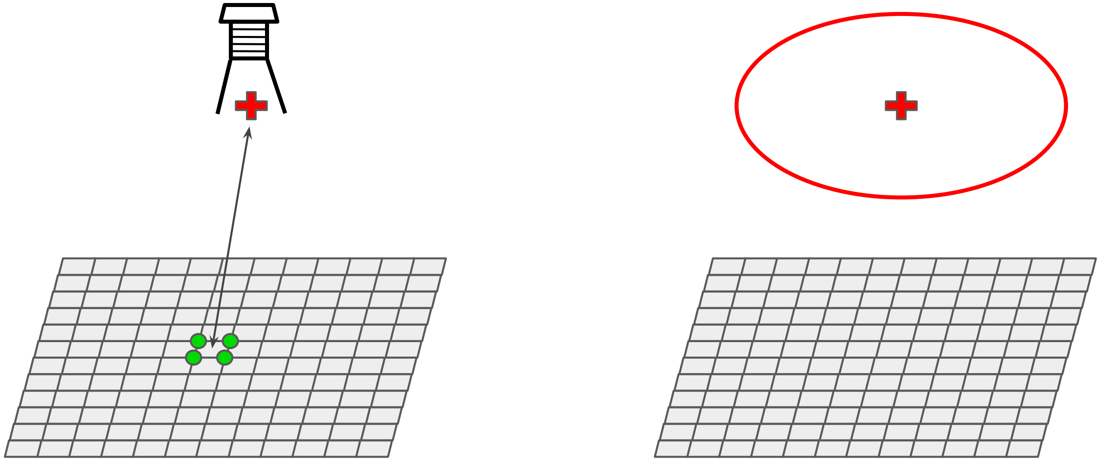

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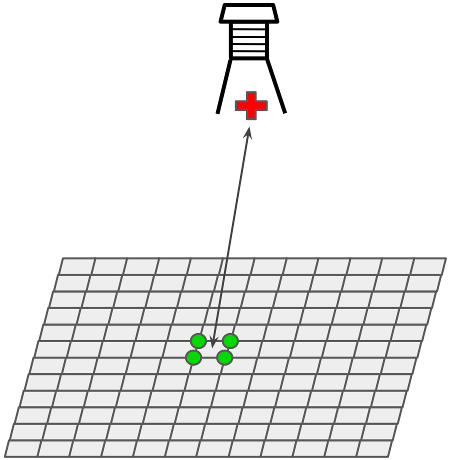
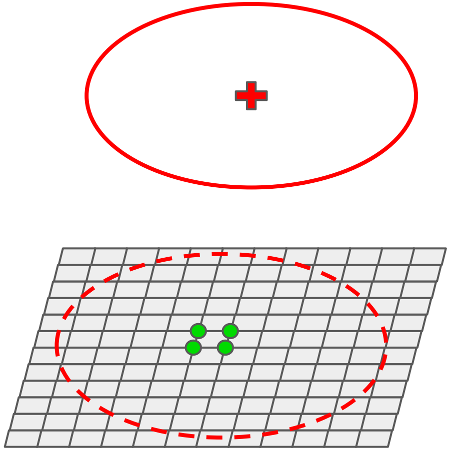
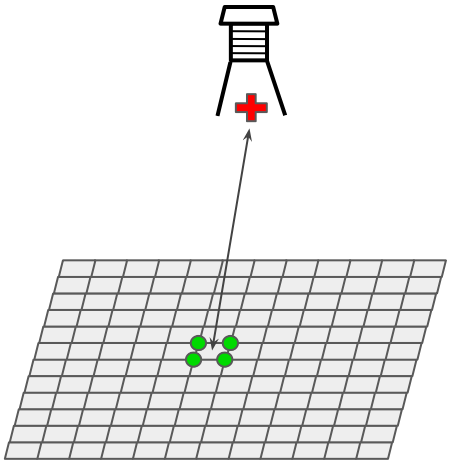


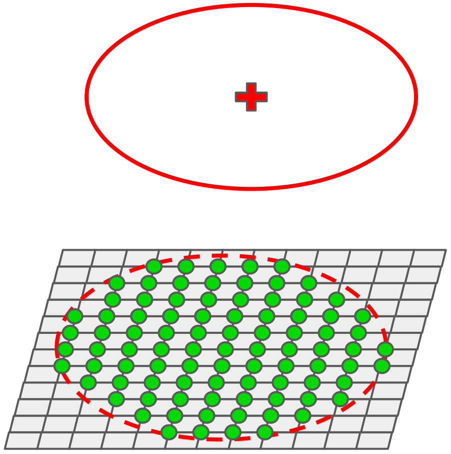


Interpolation?

The radiance footprint operator



Interpolation



Averaging
model quantities

Footprint operator

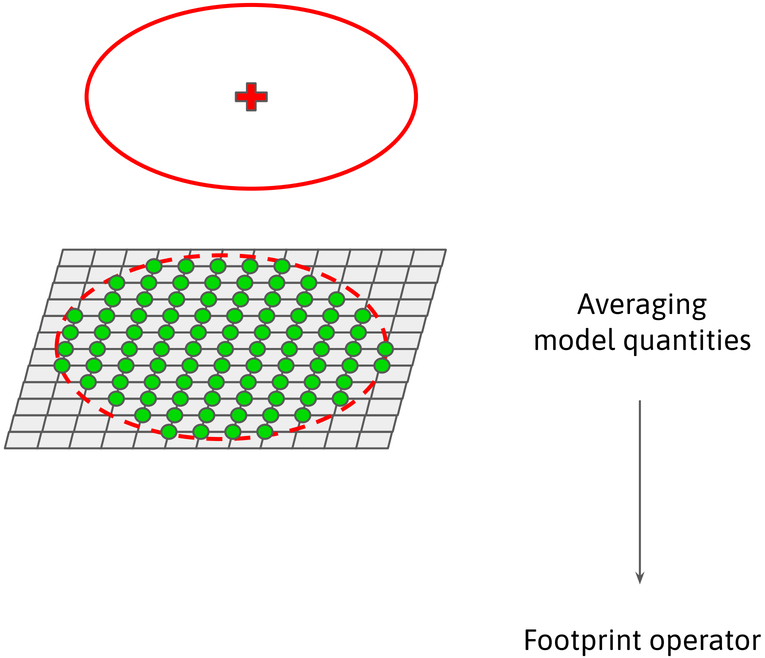
The radiance footprint operator

The idea of radiance footprint operator **is not new**, for example

Duffourg et al. (2010)
infrared radiances for convective-scale DA

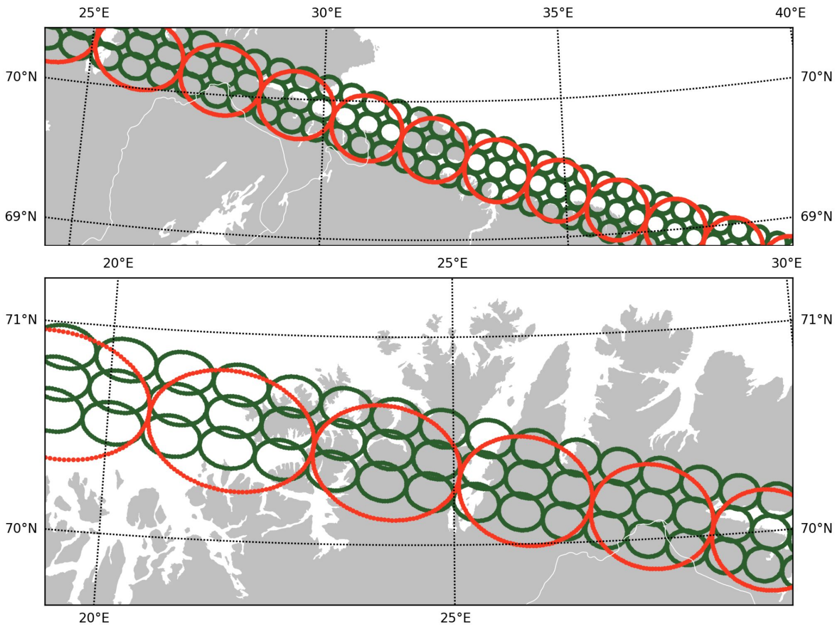
Kleespies (2009)
aggregation of model surface quantities

In this talk, **microwave, cross-track scanning** sensors and footprint operator are examined in a clear-sky framework.



AMSU-A and MHS radiances

AMSU-A IFOV size **48-147 km** (nadir-edge)
MHS IFOV size **16-53 km** (nadir-edge)



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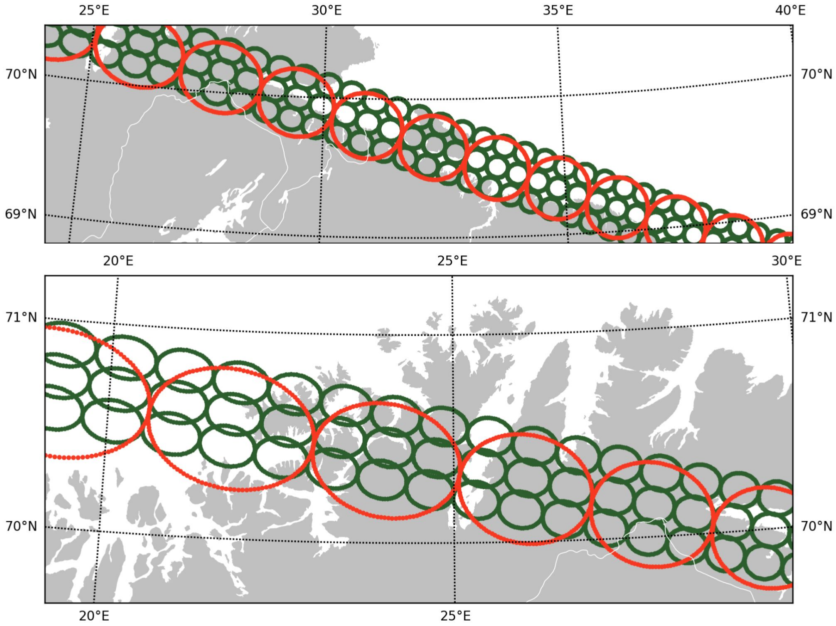
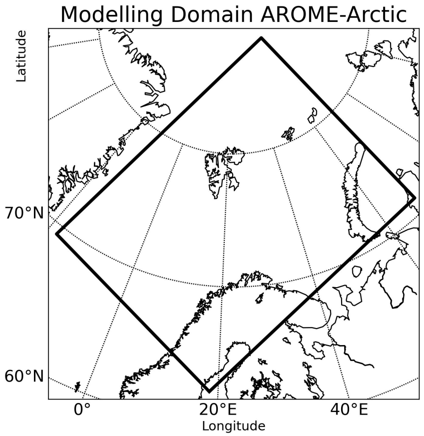


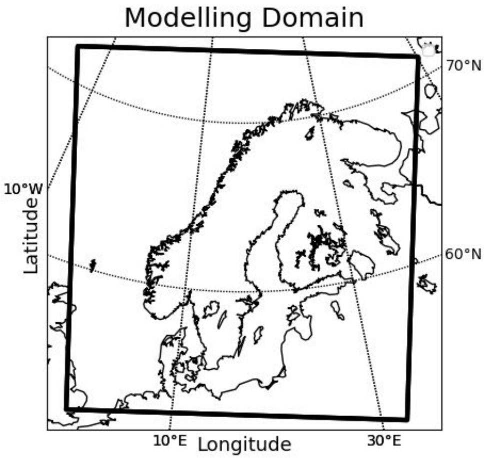
AROME-Arctic

HARMONIE-AROME core
2.5 km horizontal resol.
3D-Var scheme
CONV, AMV, SCATT, RAD

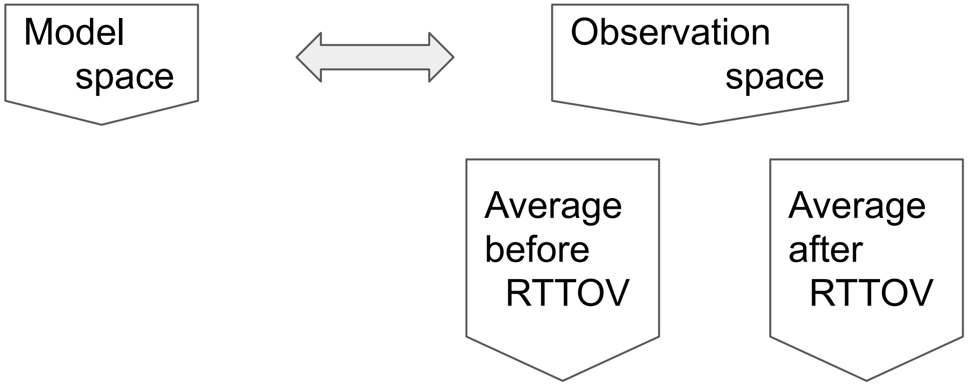


MetCoOp

HARMONIE-AROME core
2.5 km horizontal resol.
3D-Var scheme
CONV,AMV,SCATT,
RADAR, GNSS, RAD



Implementation



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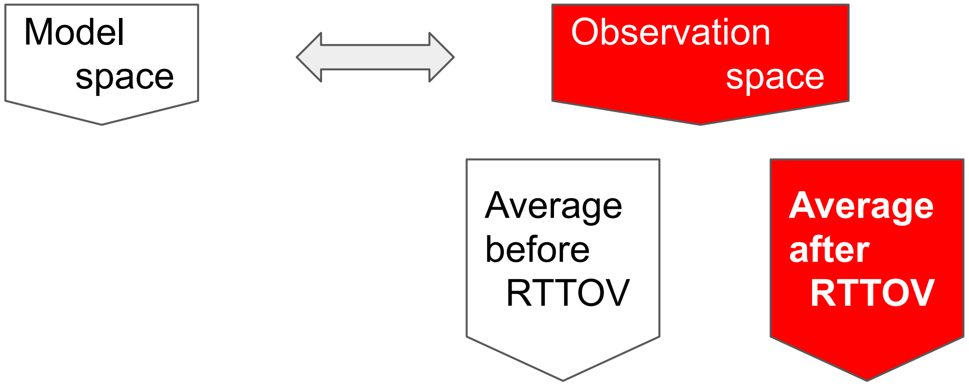
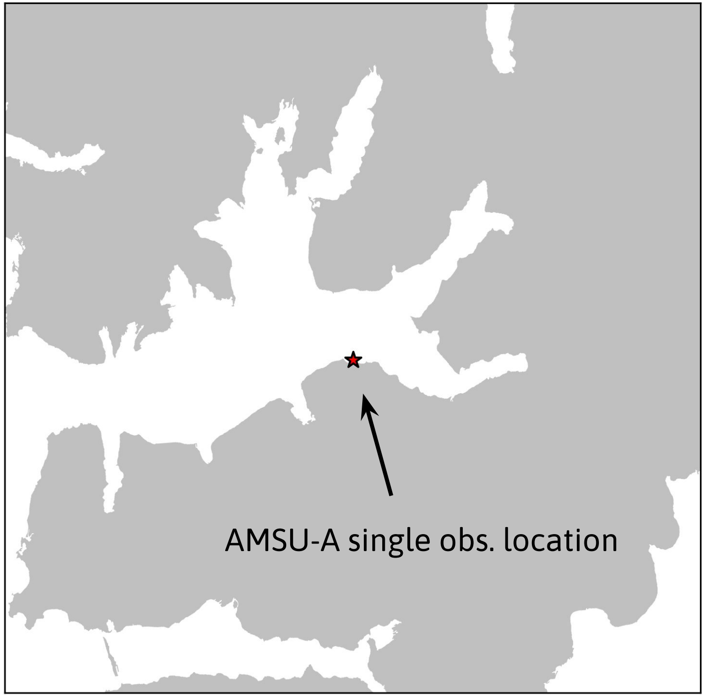


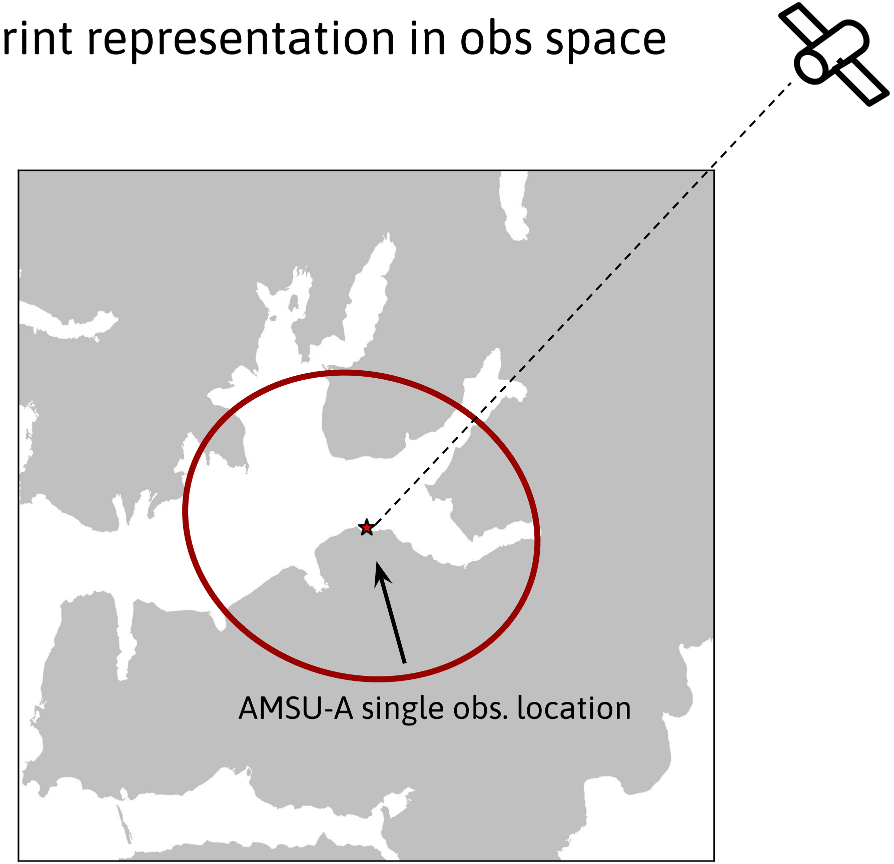
Footprint representation in observation space (using many interpolated model profiles) and averaging the simulated Tb after RTTOV simulations

Footprint representation in obs space



Svalbard, Isfjorden area

Footprint representation in obs space



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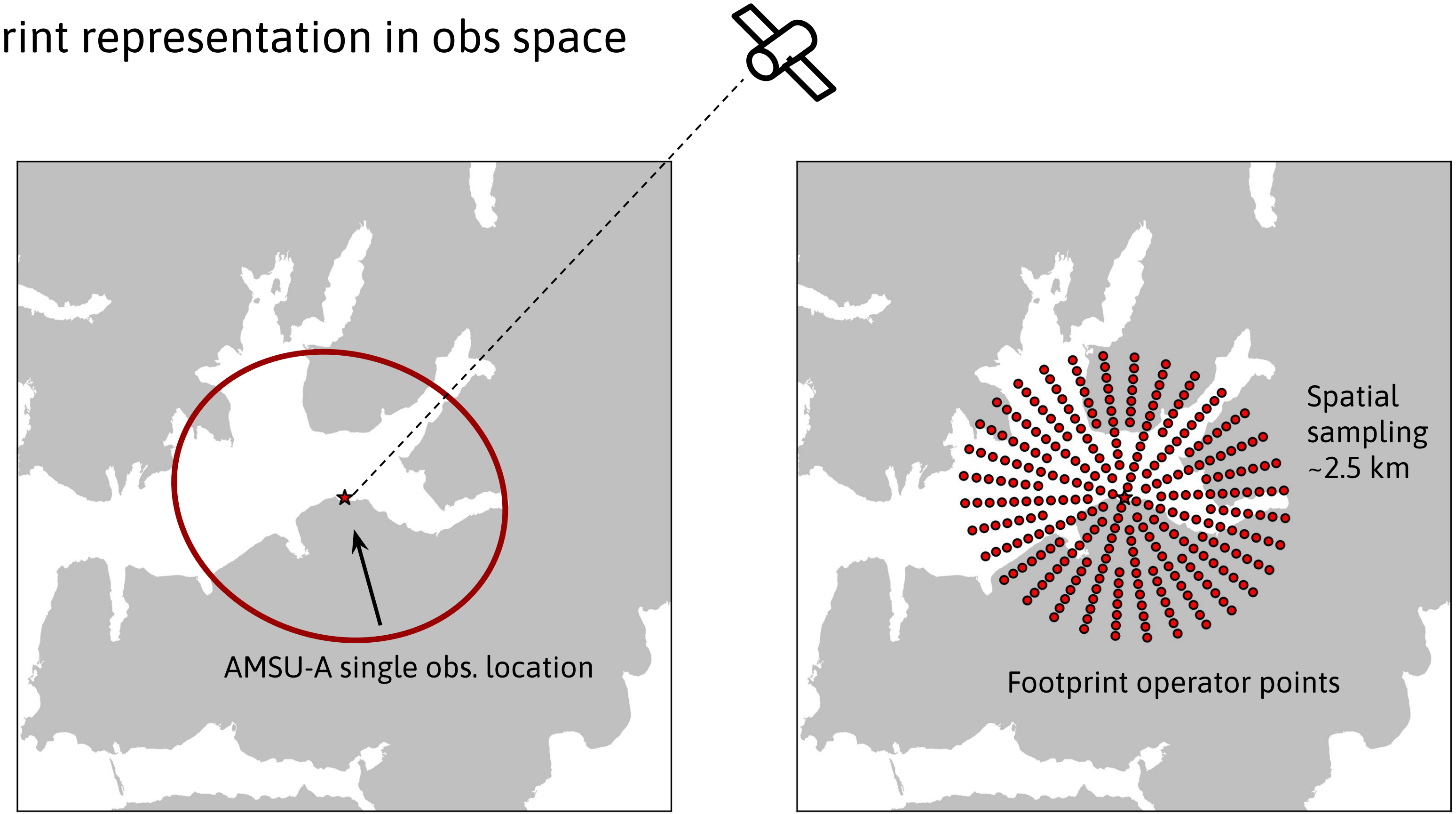

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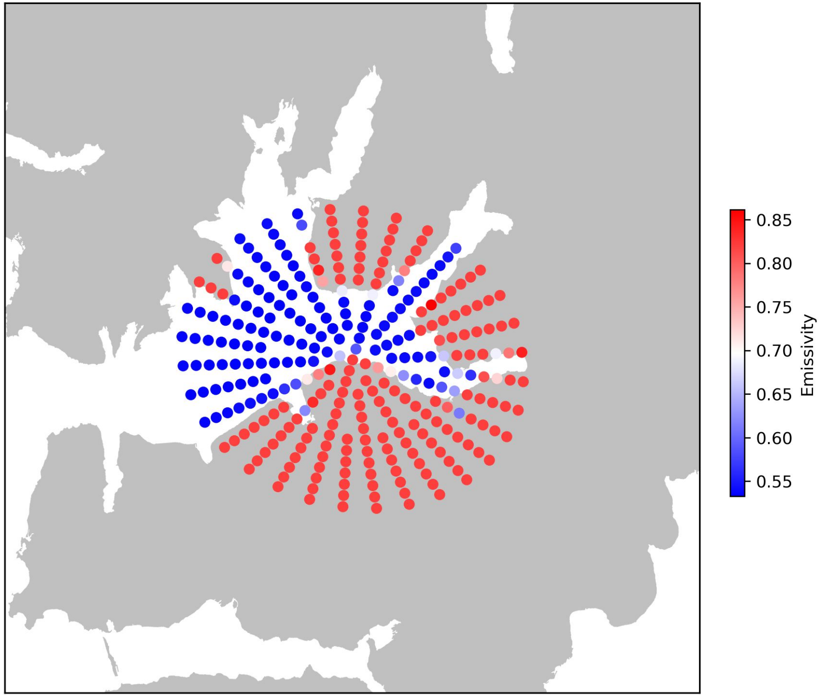
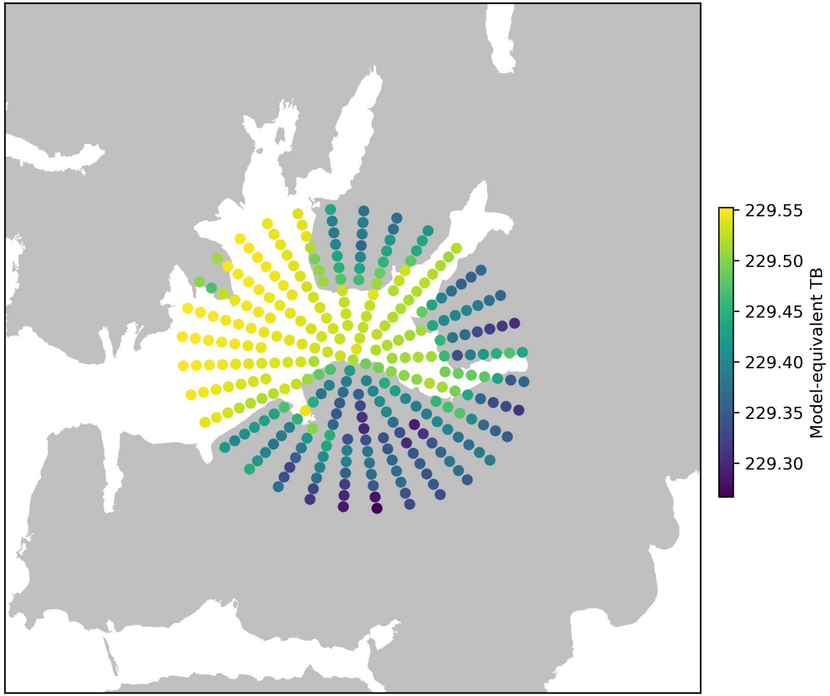
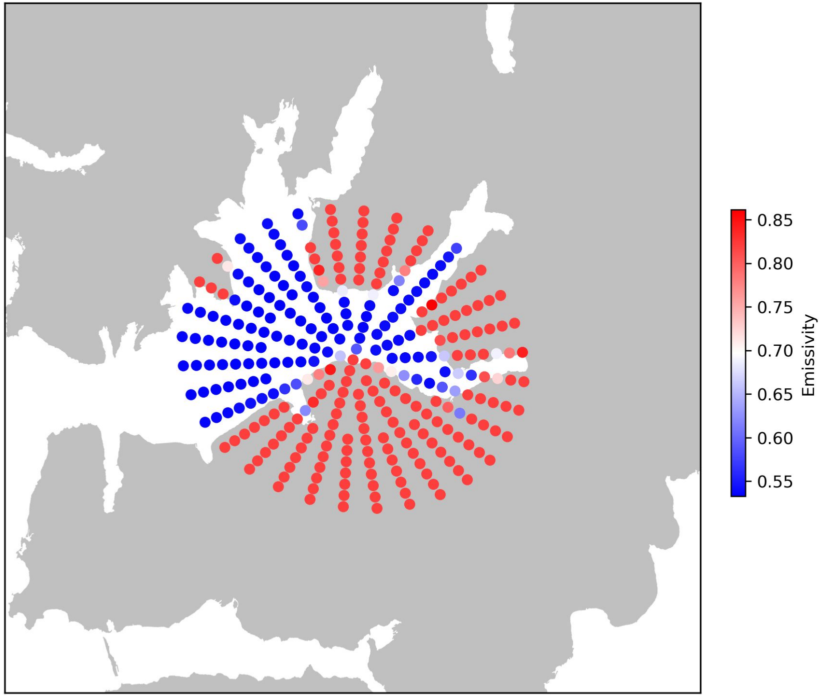


Retrieved emissivity for each footprint operator point independently.

Footprint representation in obs space



Simulated brightness temperature for each footprint operator point



Retrieved emissivity for each footprint operator point independently.

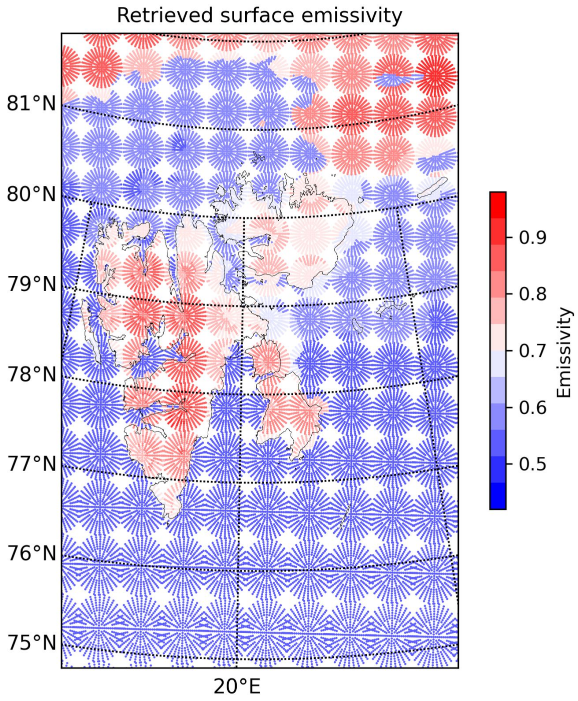
Retrieved emissivity in the footprint operator

Open ocean: Fast Microwave Water Emissivity Model (version 4)

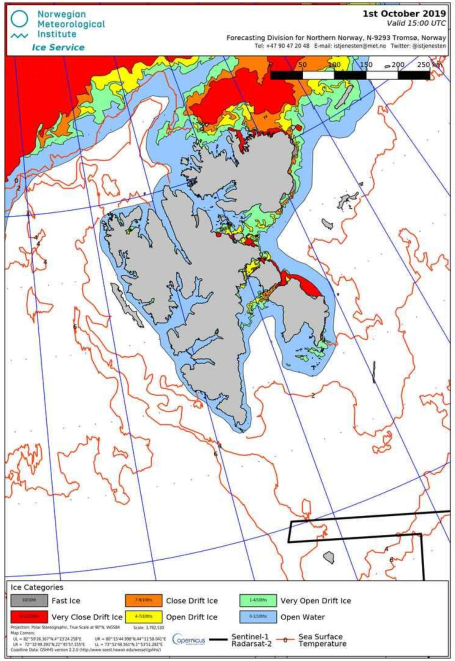
Over land: dynamic emissivity retrieval (Karbou et al., 2006)

Over sea ice: (Karbou et al., 2014)

Retrieved emissivity values are stored in the ODB (extended)



AMSU-A channel 6



Sea-ice chart of MET Norway

TL and AD footprint operators

The footprint operator calls the default radiance observation operator (Note, it depends on the choice of implementation).

The adjoint footprint operator is basically the transpose of the linear averaging operator.

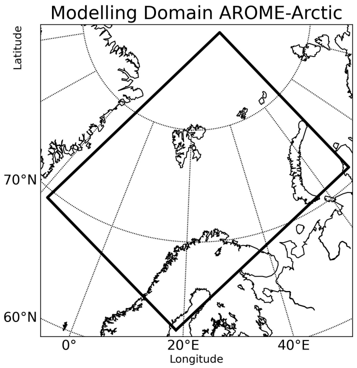
Adjoint identity	**Footprint operator results**
$< \mathbf{H}(\delta x), \delta y >$ =	-2.42733557586264723 2E+01
$< \delta x, \mathbf{H}^T(\delta y) >$ =	-2.42733557586265362 7E+01
Relative error =	2.63452844568811480 8E-15
The difference is	11.9 times machine precision.

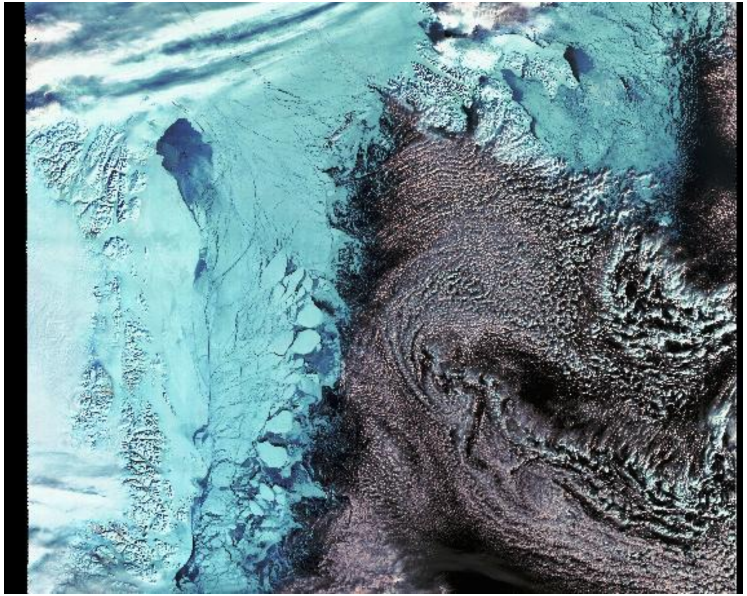
Table 1. The results of the adjoint identity test for the footprint operator using NOAA-19 AMSU-A satellite radiances in the analysis of 9UTC, 20 March, 2020. $\mathbf{H}$ is the linear and $\mathbf{H}^T$ is the adjoint footprint operator, $<,>$ is the inner product, x and y are vectors of the space.

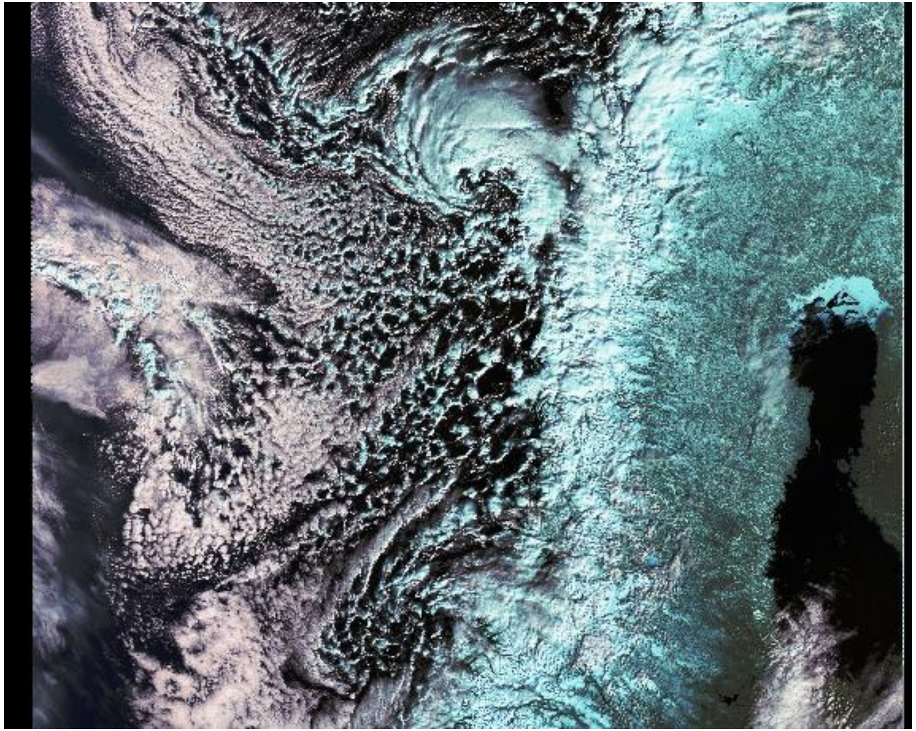
The footprint operator is more relevant where the **variability** in model fields is considerable and also comparable with the observation error

A case study

sub-footprint variability

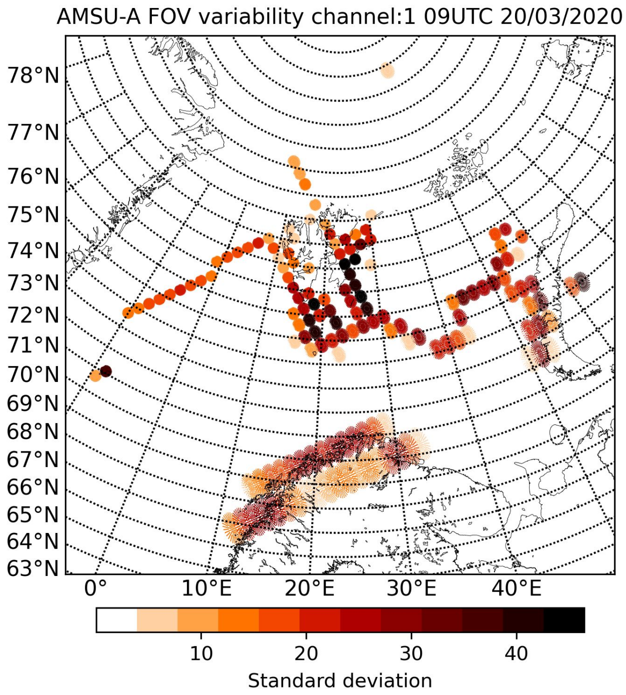




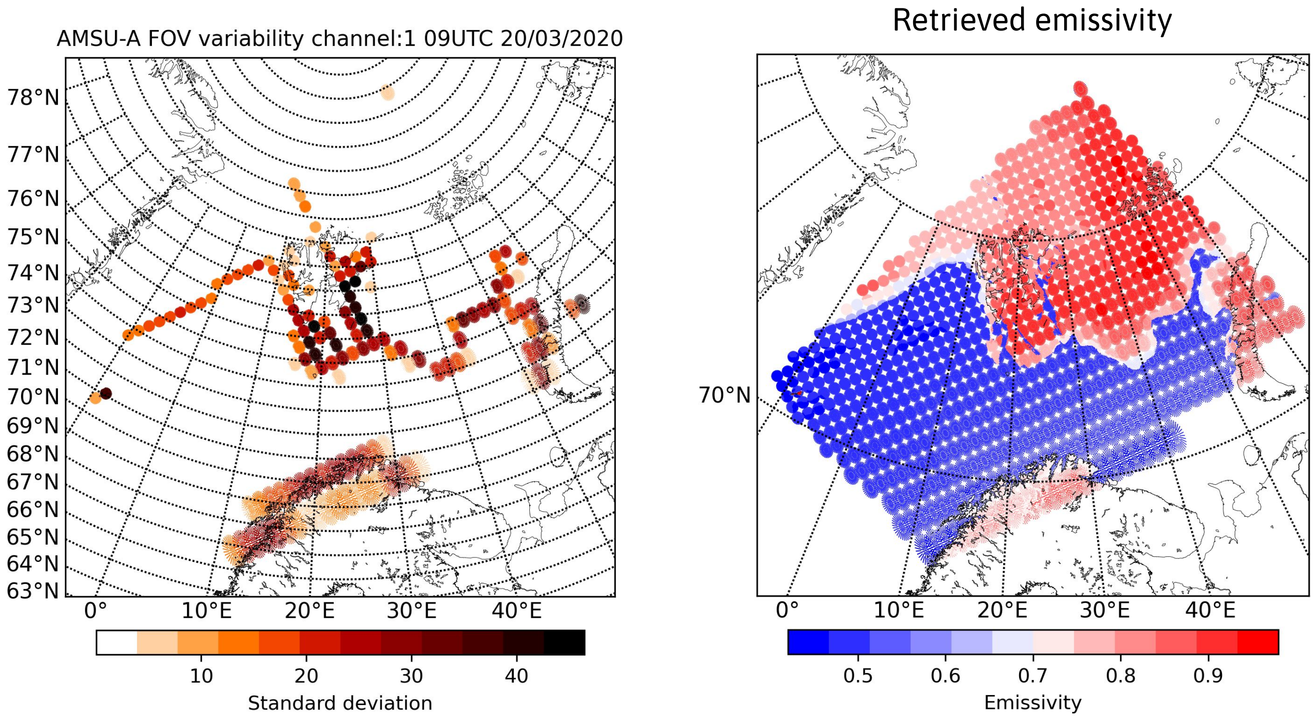


Copernicus Sentinel data 2020, processed by European Space Agency

A case study
Sub-footprint variability

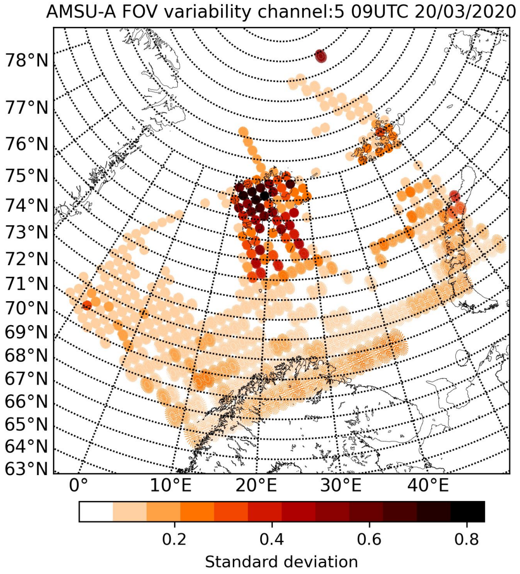


A case study
Sub-footprint variability

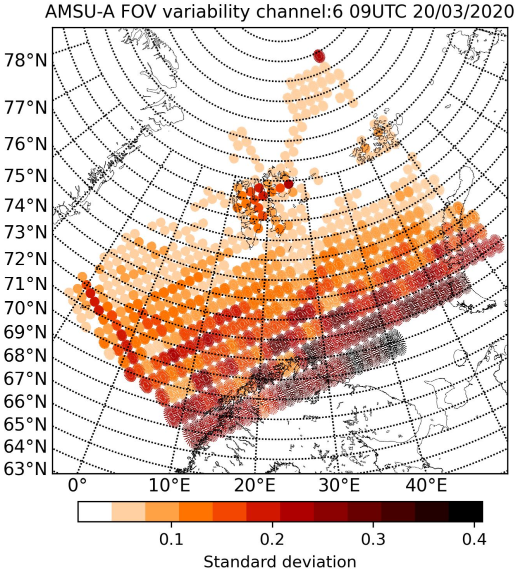


A case study
Sub-footprint variability

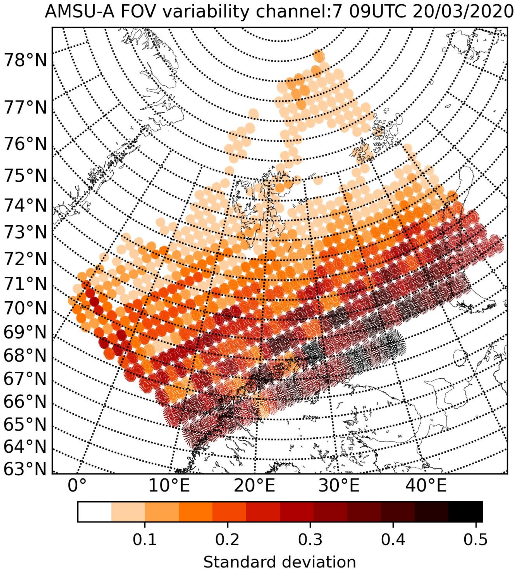
AMSU-A channel 5



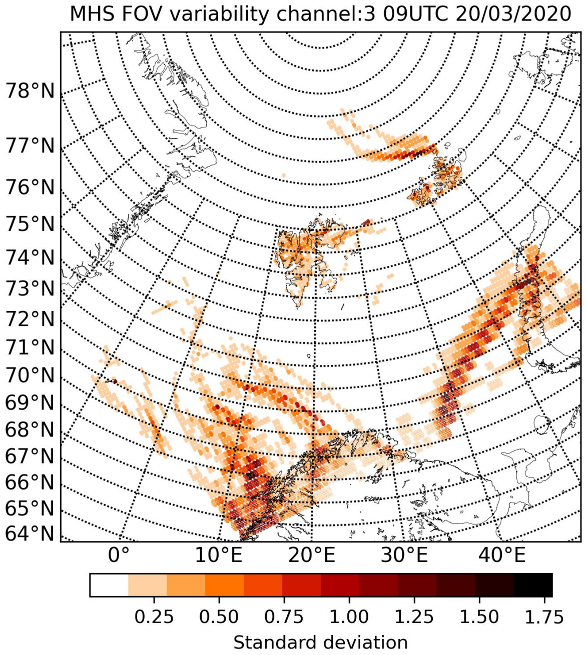
AMSU-A channel 6



AMSU-A channel 7

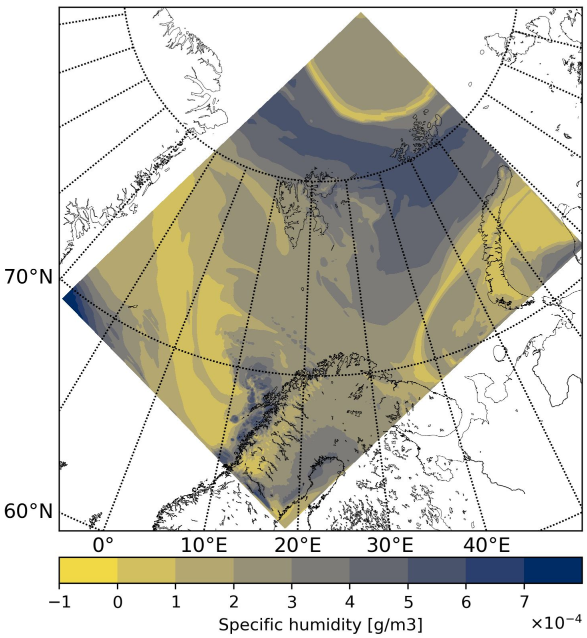


A case study
Sub-footprint variability

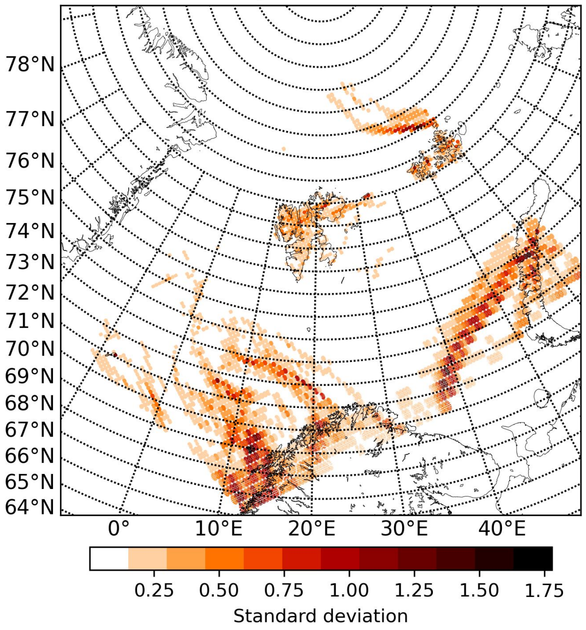


A case study
Sub-footprint variability

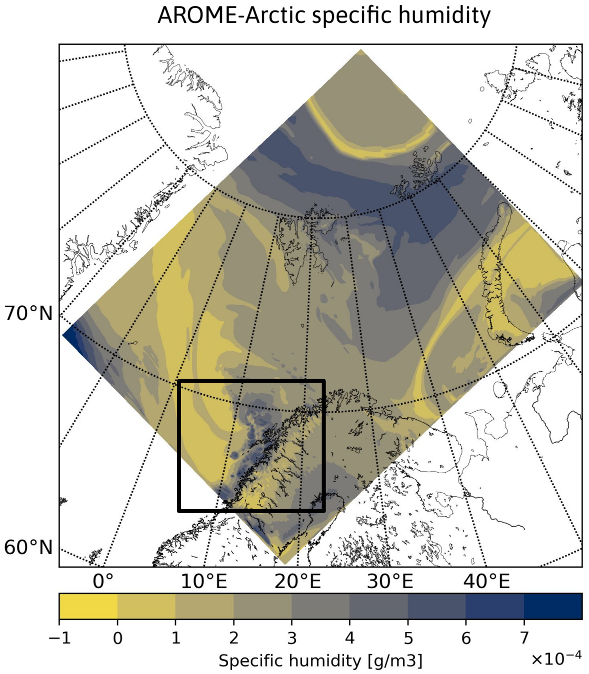
AROME-Arctic specific humidity

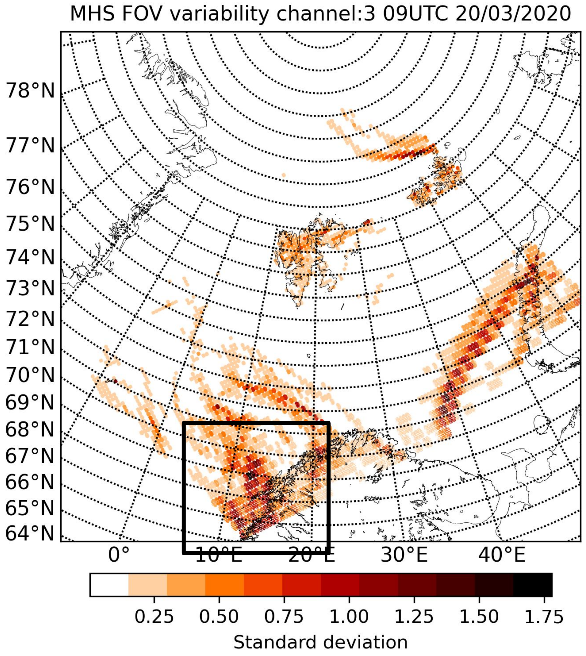


MHS FOV variability channel:3 09UTC 20/03/2020



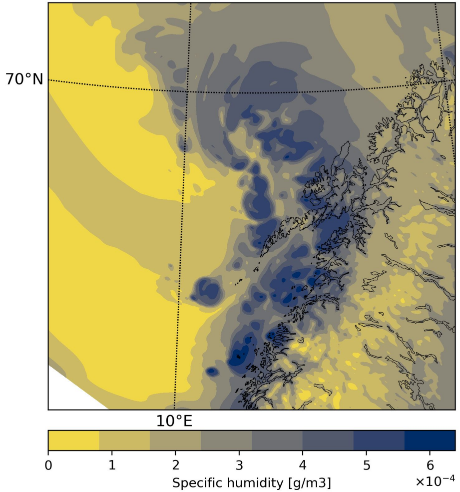
A case study
Sub-footprint variability

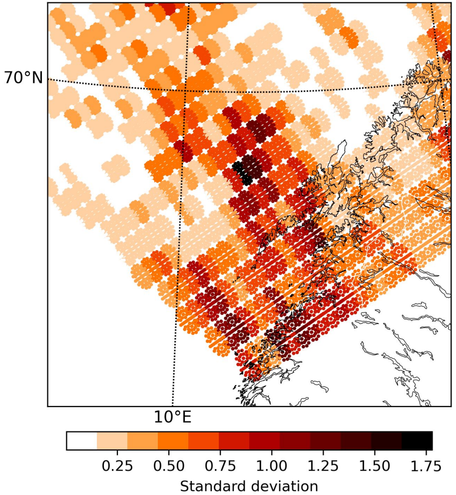




A case study
Sub-footprint variability

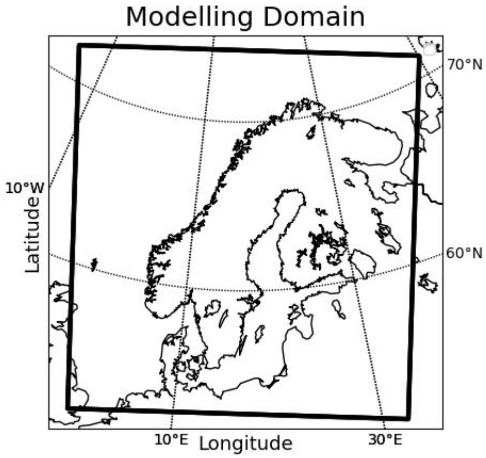
Copernicus Sentinel data 2020





The use of the footprint operator is potentially more beneficial

Radiance footprint operator
Observing system experiments



Spin-up period: 1-31 January, 2021

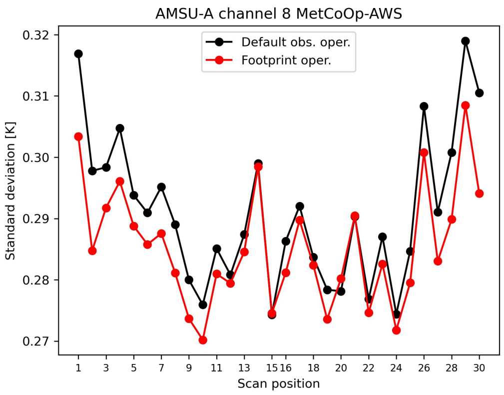
Verification period: 1-28 February, 2021

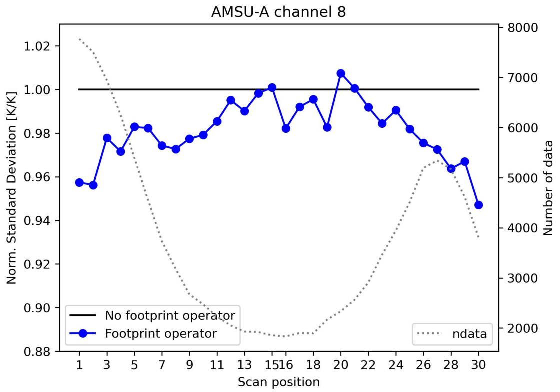
AMSU-A pixels near the edges of the swath are active

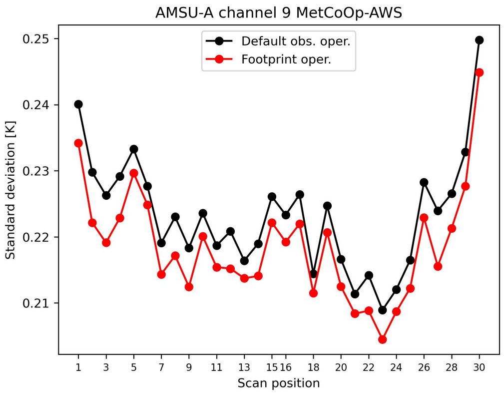
Assimilated observations: SYNOP, AIREP, TEMP, PILOT, BOUY, SCATT, AMSU-A (no MHS and IASI)

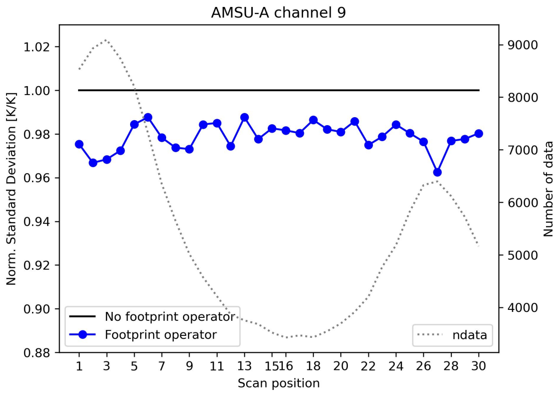
Verification: normalised RMSE diff. (90% confidence) between the default and the footprint observation operator experiment - positive/negative values denoting positive/negative impact of the footprint operator

Radiance footprint operator Departure-based statistics





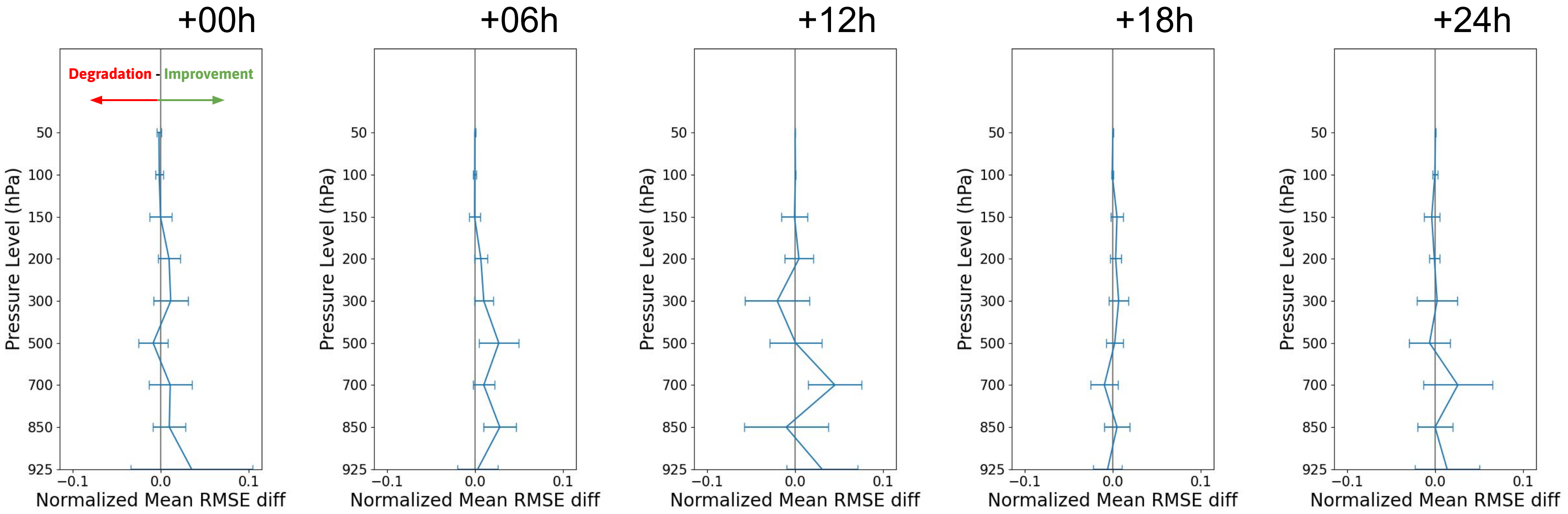




Radiance footprint operator Observing system experiments

Overall impact: neutral

Verification of temperature forecasts initialized at 06 UTC



Further plans

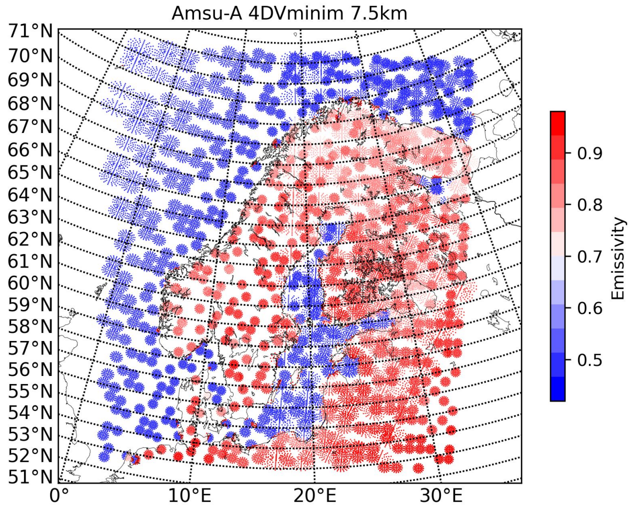
Preliminary results, more impact studies

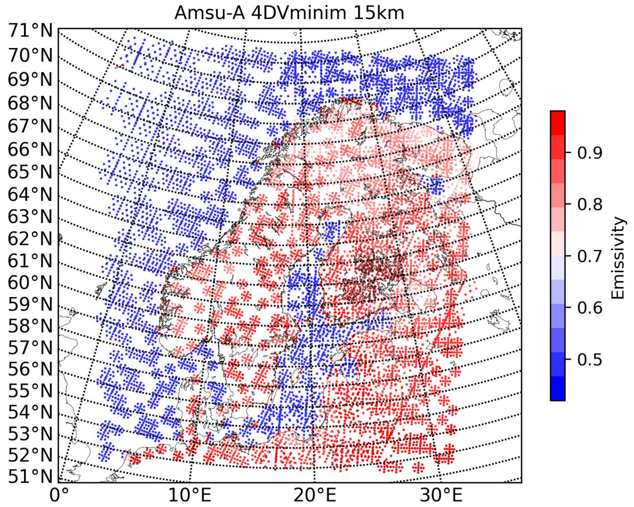
Multi-resolution 4D-Var with varying footprint operator sampling in the HR trajectory and LR minimisation runs

Optimization work, comparing different solutions

Footprint operator + Slant-path operator (Bormann et al., 2017; Shahabadi et al., 2020)

Taking into account the antenna pattern during the averaging (currently boxcar filter is used)





Summary

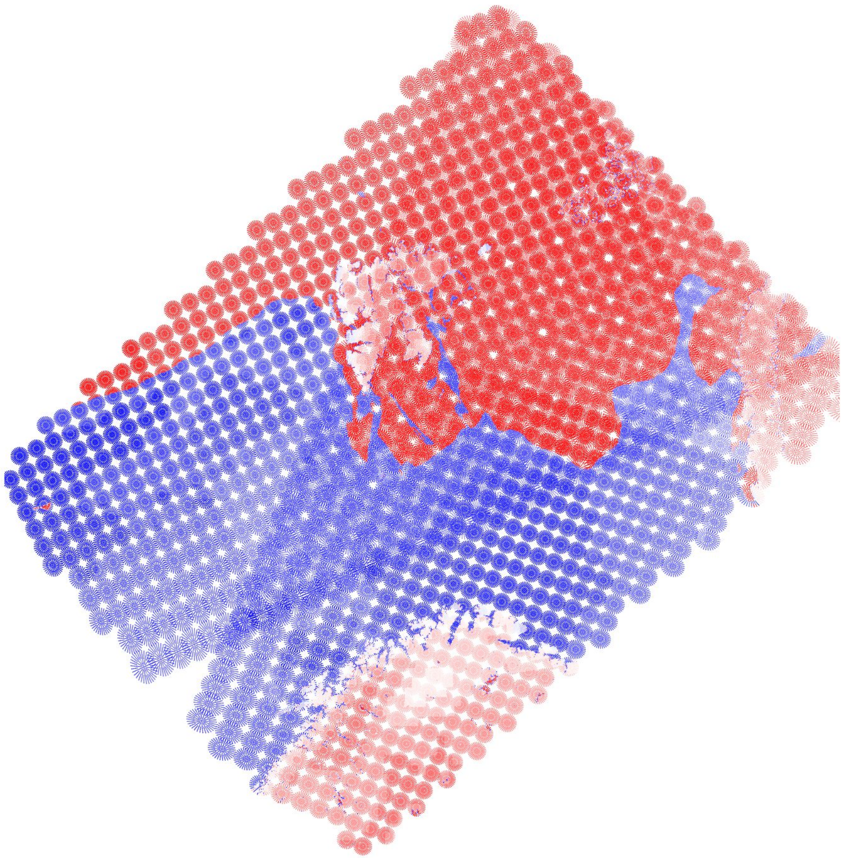
In high-resolution DA, the use of the footprint operator is relevant and improves spatial representation of the satellite data

Benefit is expected where the variability is large

Footprint operator reduces O-B standard deviation and has promising impact on LAM forecasts

Thank you for your attention!

Questions?



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