Author’s response for the manuscript titled
„Exploring the footprint representation of microwave radiance observations in an Arctic limited-area data assimilation system”

First of all, the authors would like to thank the comment of the Anonymous Referee #1! We considered the comments and revised the manuscript accordingly. All the changes have been highlighted in the manuscript to ease the evaluation of the changes. In this letter, the answers are written after each reviewer’s comments (with blue colour).

Sincerely,

Máté Mile

On behalf of all authors

Radiance assimilation usually assumes point observations, which is fine for global NWP models, while for high resolution regional NWP models (and future high resolution global NWP models), the footprint size is too large and the footprint operator needs to be considered together with observation operator (RTM). The manuscript provides a comprehensive analysis and discussion on how such footprint operator can be developed and used. I have just one question and one suggestion.

Question: why the grided brightness temperature averaging is a straightforward one? is it possible to apply spatial response functions of AMSU/HMS channels? The standard deviation of OmB seems overestimated if the spatial response functions are not considered.

Indeed, this aspect is partly discussed in the conclusion section. In the current implementation, the footprint operator aims a near equidistant sampling inside the FOV in order to match (or come close to) the model horizontal resolution. However, as the reviewer suggests, such sampling approach with equal-weight averaging does not take into account the antenna pattern of the employed microwave instruments.

In order to consider the antenna pattern in the footprint operator, we have started to test two approaches. One idea is to apply weighted averaging keeping the implemented sampling and ensuring larger contributions for the operator points near the bore-sight and less weights towards the edge of the IFOV. See an example figure below showing the AMSU-A footprint operator points with the assigned weights of the averaging.

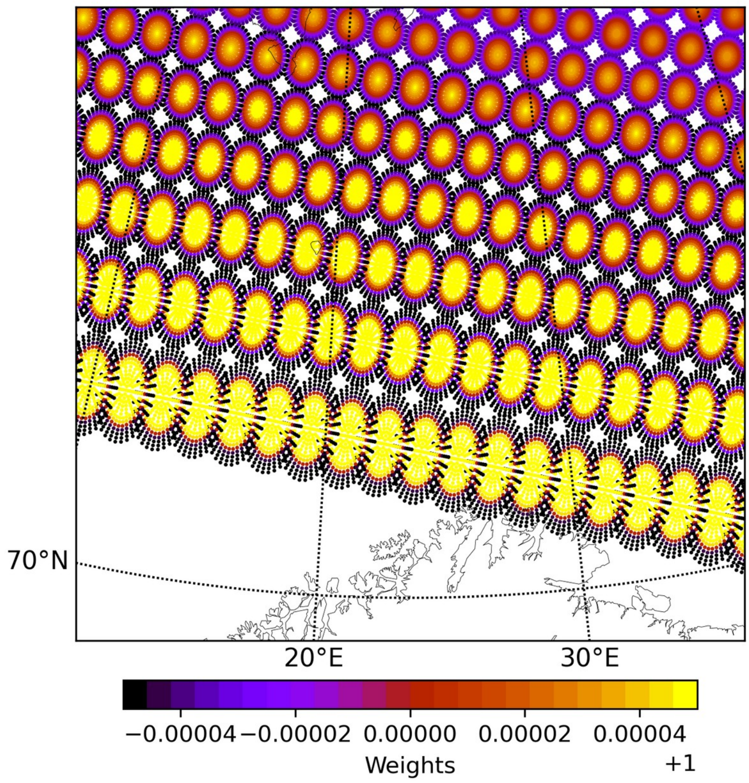

Figure 1. Taking into account radiance antenna pattern by weighted footprint operator points inside the AMSU-A IFOVs.

The statistics of OmB (observation minus background) departures were collected comparing the equal-weight and the weighted averaging footprint operator performance using MHS radiance observations. On the figure (figure 2.) below, this comparison can be seen for a statistics of a short period suggesting that the representation of the antenna pattern (i.e., the weighted averaging approach) is less meaningful and provides very similar reduction in OmB standard deviation than the equal-weighting approach. This approach is still under evaluation and the assigned weights might not be fully appropriate for the antenna response.

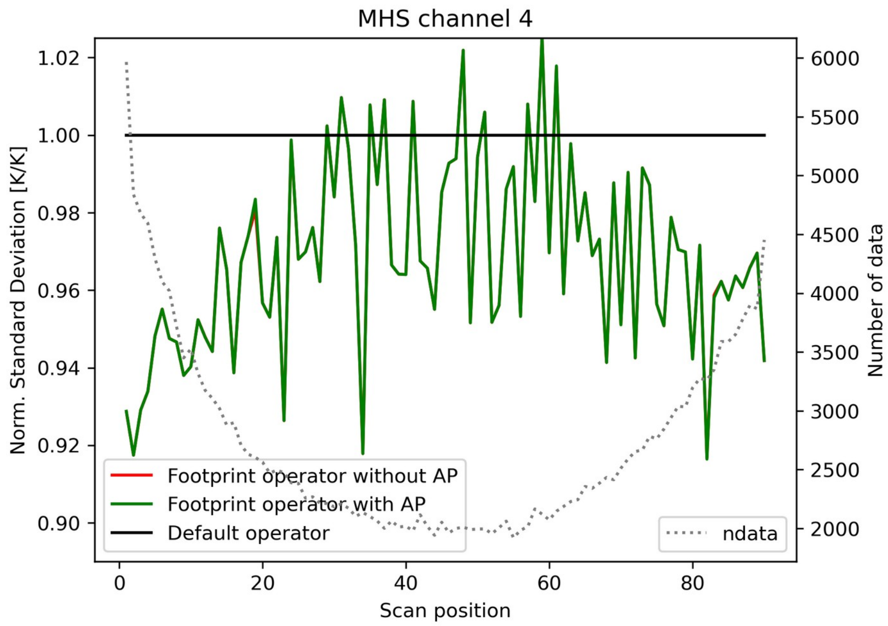

Figure 2. The standard deviation of OmB departures of MHS footprint operator normalized by the default radiance observation operator using radiance data from MHS channel 4. Here, we compare the footprint operator with (red line) and without (green) the antenna pattern representation with the weighted average approach.

Additionally, it’s worth mentioning that the MHS footprint representation (in the figure above for both runs) covers the effective FOV area and therefore not comparable with the results of Figure 17. in the manuscript.

Another idea is to keep every footprint operator point equally important (i.e., equally-weighted), but to apply oversampling near the bore-sight and to have fewer and fewer points towards the edge of the FOV. It would result in a certain representation of the antenna pattern by taking into account model information with larger relative weight or importance near the bore-sight. On the figures below, the different sampling strategy can be compared for AMSU-A and MHS pixels.

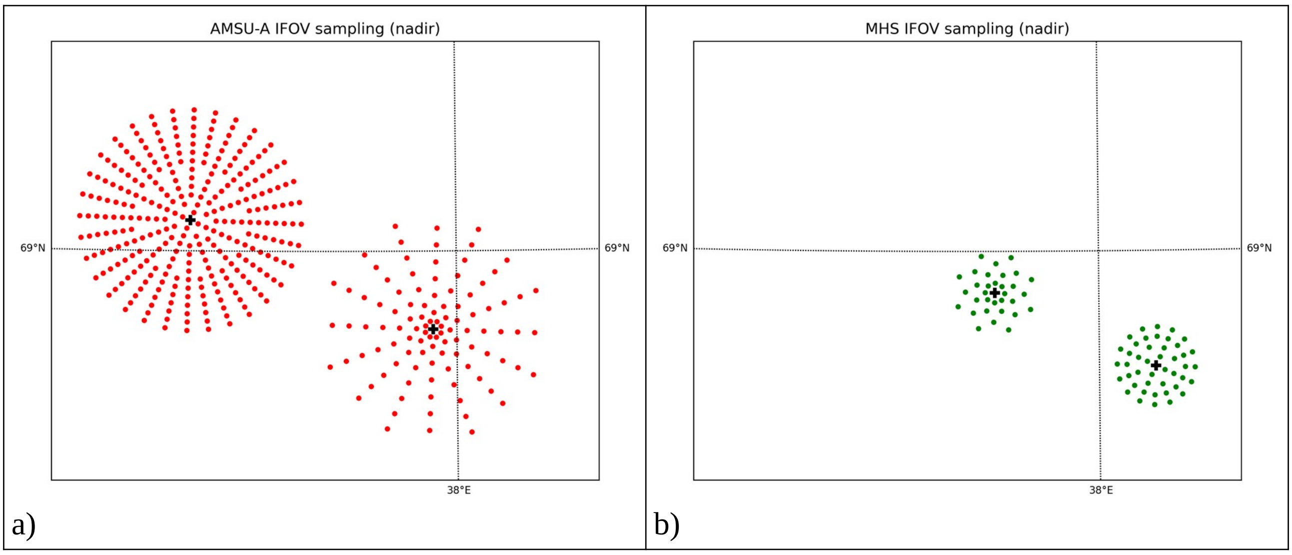

Figure 3. Different sampling in the microwave footprint operator. Figure a) shows AMSU-A pixels with the sampling used in the manuscript (left pixel) and a different more dense sampling scheme around the bore-sight (right pixel). Figure b) shows the same, however, new sampling is on the left and original sampling from the manuscript is on the right for MHS pixels.

The impact of this new and different sampling shows no further reduction in the standard deviation of OmB departures (not shown). However, this scheme needs further evaluation since the number of operator points are also changed.

These above-mentioned findings are preliminary and experimental ones, therefore, we have not incorporated them into the revised version of the manuscript. There is an ongoing work that will study an optimized version of the microwave radiance footprint operator with improved runtime performance and accuracy in an observing system experiment. In the current revised manuscript we have extend the conclusion with one sentence to explain this a bit further.

One suggestion: it worth noting a related research using high spatial resolution AHI observation for studying the IR sounder sub-footprint moisture variation, Di et al. (2021) found that the current IR sounders (such as CrIS, IASI, GIIRS etc.) with spatial resolutions between 12 and 16 km have typical average sub-footprint brightness temperature variations (BTVs) between 0.8 and 1.5 K over land, a 1 K variation in 6.25 μm water vapor absorption band corresponds to a 10% – 20% upper tropospheric moisture variation depending on the atmospheric humidity. Such sub-footprint BTVs, without being accounted for, may introduce additional uncertainties in quantitative applications *such as radiance assimilation. Their study provides another evidence on the needs of footprint operator in data assimilation for high resolution NWP models.*

Di, Di, Jun Li, Zhenglong Li, Jinlong Li, Timothy J. Schmit, and W. Paul Menzel. "Can current hyperspectral infrared sounders capture the small scale atmospheric water vapor spatial variations?." Geophysical Research Letters 48, no. 21 (2021): e2021GL095825.

Thank you for this reference that is certainly relevant for the subject. It is now mentioned in the Introduction section of the revised manuscript.