Significance and Impact of High-Resolution Variational Assimilation of Satellite Microwave Radiances over Various Surfaces

Swapan Mallick [a], Magnus Lindskog [a] and Stéphanie Guedj [b]

[a] *Swedish Meteorological and Hydrological Institute (SMHI), SWEDEN*

[b] *The Norwegian Meteorological Institute (Met-No), NORWAY*

SMHI

Meteorologisk institutt

INTERNATIONAL TOVS WORKING GROUP

International TOVS Working Group

ITSC-25: Goa, INDIA, 8-14 May 2025

OUTLINE:

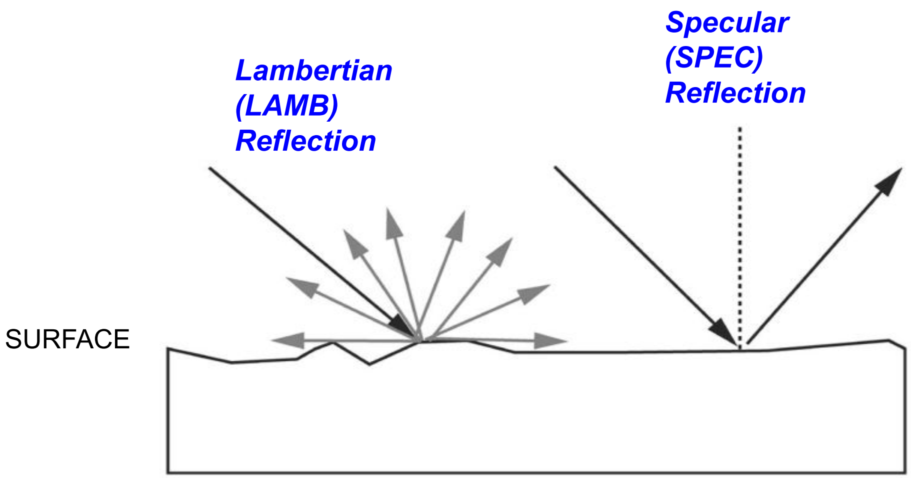
- The **objective** of this study is to extend the work of **Bormann et al. (2017)** by utilizing low-peaking MW data assimilation across various surfaces and under different atmospheric conditions.
- **Instrument:** The Advanced Microwave Sounding Unit (**AMSU-A**).
- The study expanded to analyze the assumptions of reflection over **land, snow, and sea-ice**, thereby enhancing the application of microwave radiance.
- In addition, this study examines simulation results across **different weather seasons** to capture varying atmospheric conditions.
- Multiple experiments using **3D-Var** assimilation across various seasons assess the impact of Lambertian (**LAMB**) and specular (**SPEC**) reflections.
- Surface emissivity is dynamically retrieved using the **RTTOV** model and **window channels**.

Advanced Microwave Sounding Unit (AMSU)

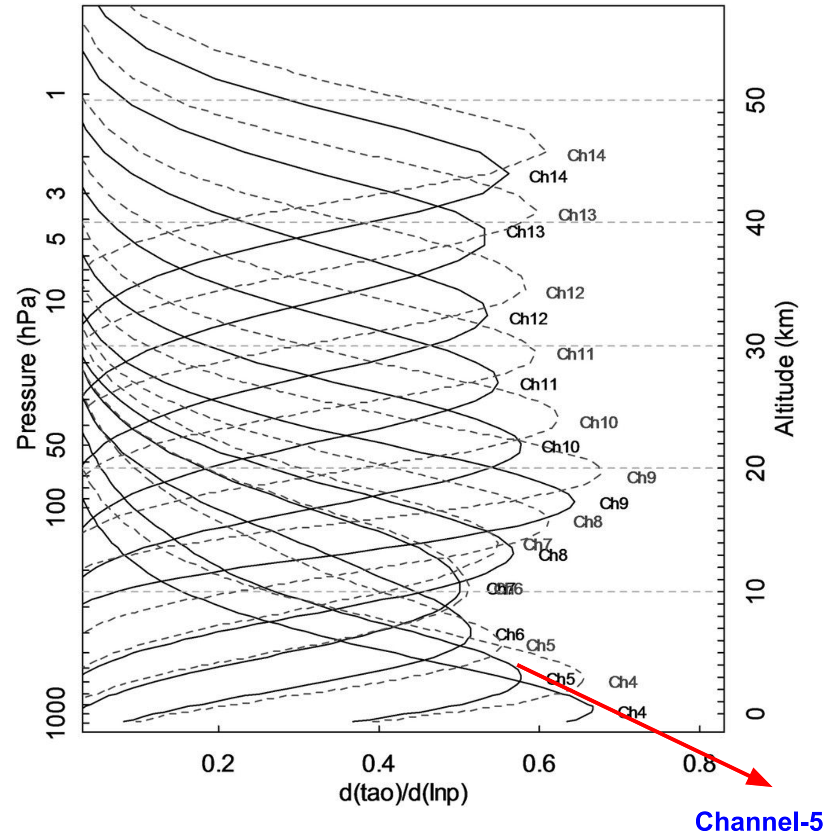
The Advanced Microwave Sounding Unit (AMSU-A), a 15-channel microwave sounder designed primarily to obtain temperature profiles in the upper atmosphere and to provide a cloud-filtering capability for tropospheric temperature observations.

- ➔ 15 channel microwave sounder (AMSU-A) with a frequency range of 15-90 GHz.
- ➔ Provides atmospheric temperature and humidity measurements from the surface up to 40 km.
- ➔ IFOV size of about 48 km near nadir.
- ➔ Near global coverage twice per day.
- ➔ Utilization period 1998-2027.

Advanced Microwave Sounding Unit (AMSU)



@ Guedj et al, 2010



Weighting functions of AMSU-A atmospheric temperature channel (4–14) at near nadir (1.67°, solid lines) and limb scan positions (48.33°, dashed lines).

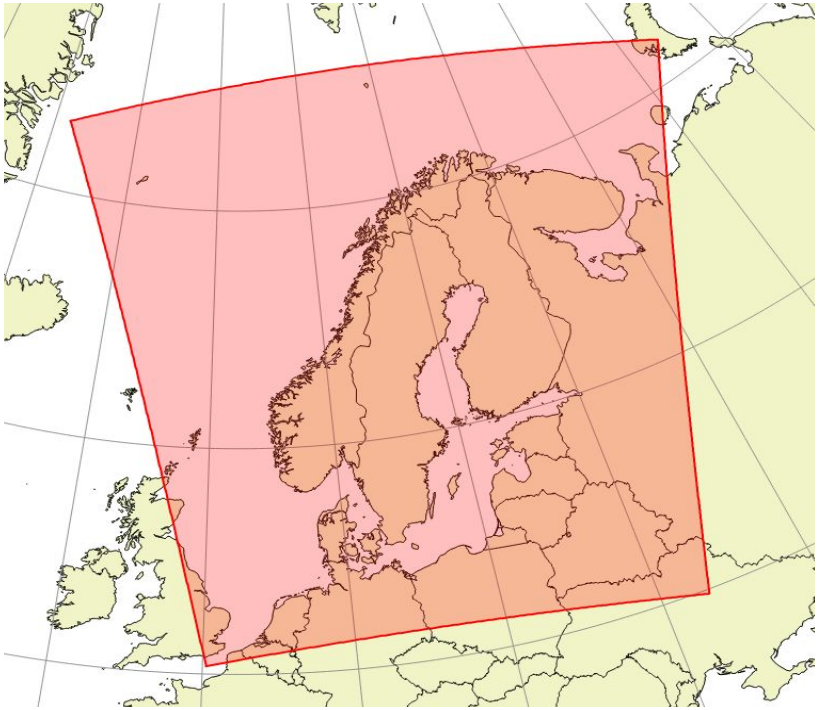
@ https://doi.org/10.1175/JTECH-D-13-00134.1

Experiment Setup: MetCoOp

- An operational cooperation between the **Swedish**, **Norwegian**, **Finnish**, **Estonian** and **Latvian** weather services.
- Regional system (HARMONIE-AROME) for high resolution NWP. Horizontal grid-distance 2.5 km, 65 vertical levels.
- Ensemble-system with 30 ensemble-members.
- Forecasts are produced each hour up to 66 h on 3 HPCs.
- NWP-based nowcasting suite for forecasts up to 12 h.
- **3D-Var data assimilation** with conventional types of obs., radar, GB GNSS ZTD, Mode-S EHS, satellite based ASCAT, MW and IR radiances used (still clear-sky approach).

@ https://metcoop.smhi.se

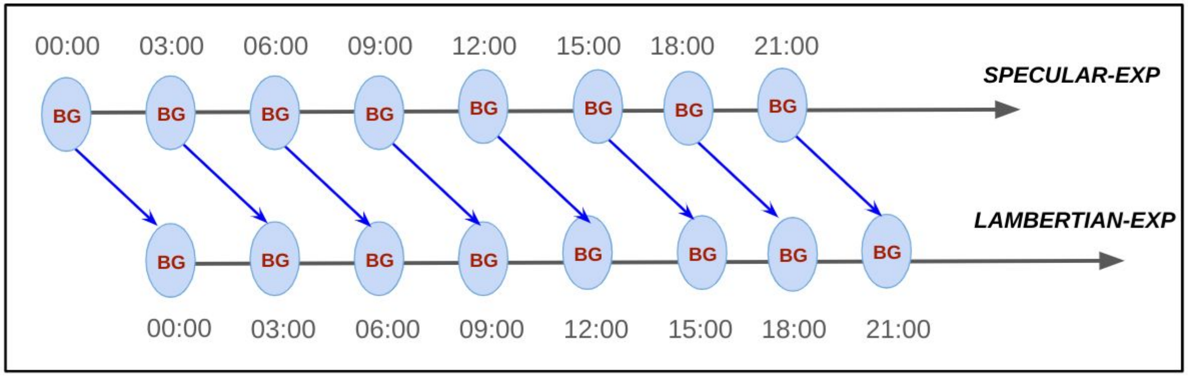
Model domain



Experiment Setup:

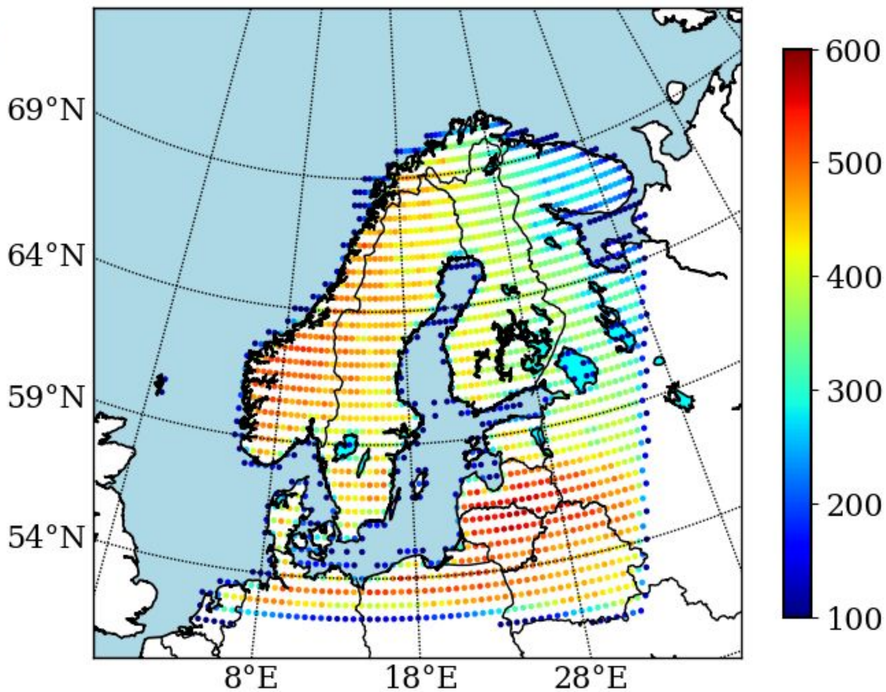
SL.	MONTH 2024	Days	Experiment
1.	JANUARY, 2024	1-30	SPEC, LAMB
2.	APRIL, 2024	1-30	SPEC, LAMB
3.	JUNE, 2024	1-30	SPEC, LAMB
4.	FEB, 2025	1-28	SPEC, LAMB

Both **Lambertian** and **Specular** have the same configuration; however, their emissivity differs.



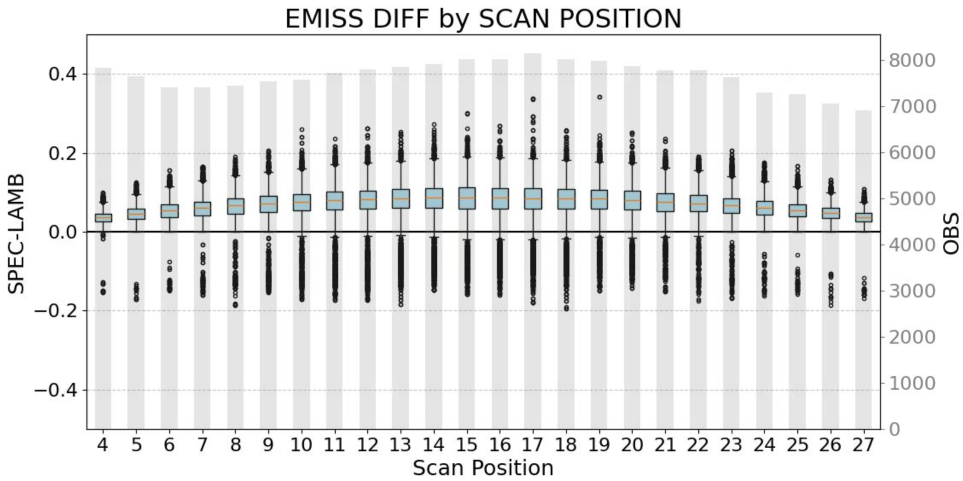
Impact over Land: January 2024

AMSU-A Channel-5
Observation Count



The number of observations for each grid box (0.5 x 0.5) and the data available over LAND for the entire month of January 2024, as well as for all assimilation cycles.

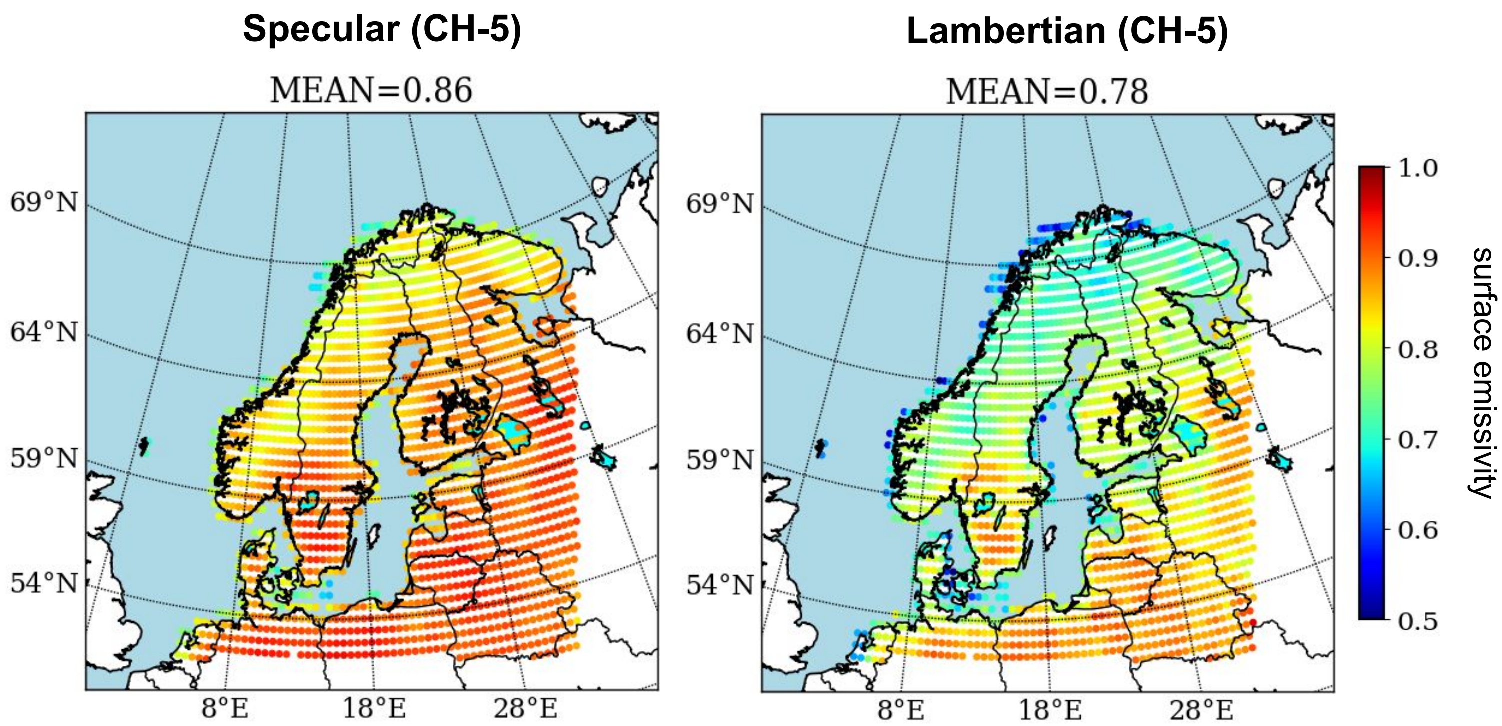
Differences in surface emissivity calculated using specular and Lambertian experiments for various scan positions during January 2024



=> The Lambertian effect is a function of zenith opacity, which influences the spectral shape of the retrieved surface emissivity.

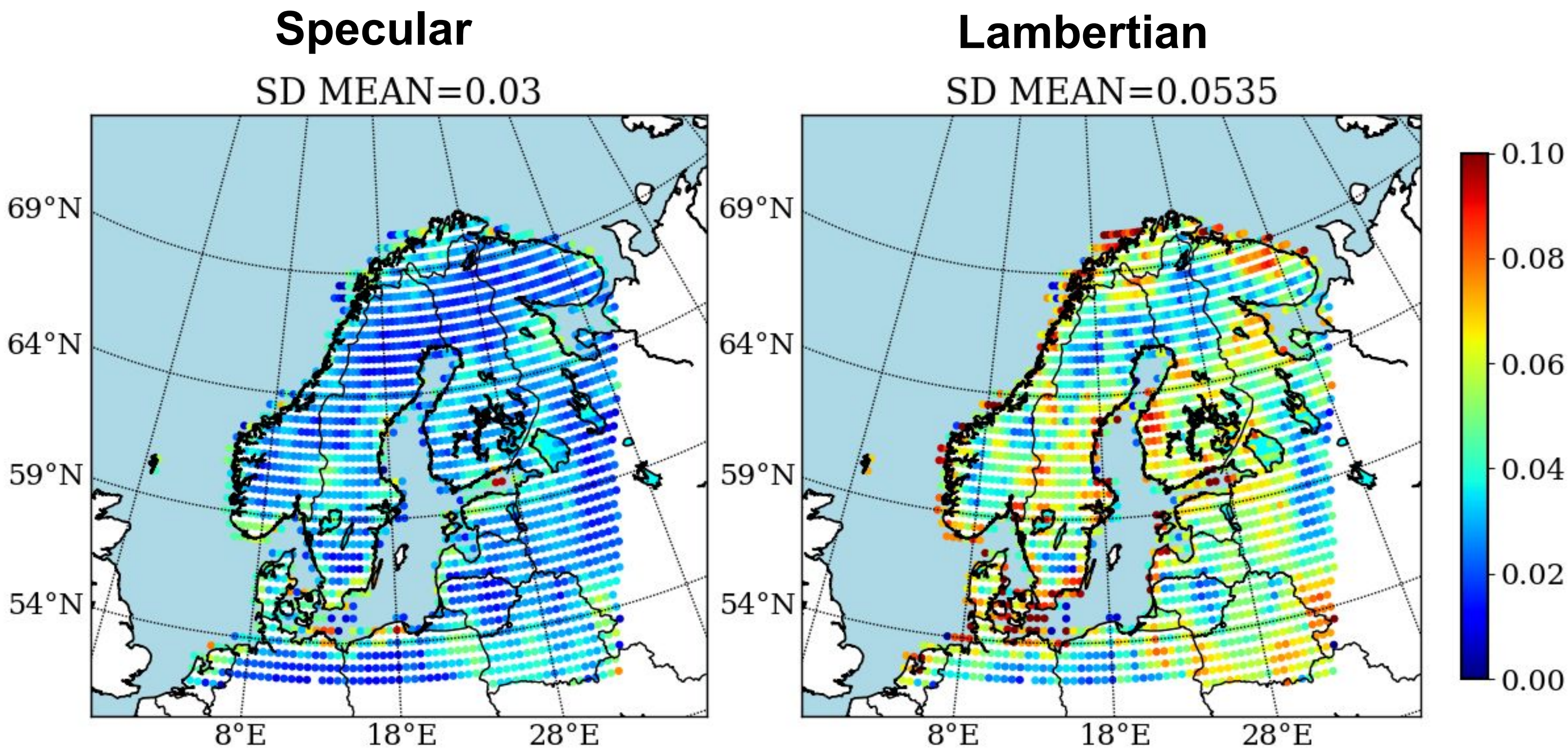
Impact over Land: January 2024

Surface emissivities calculated at AMSU-A (Channel-3) were used as input for RTTOV.



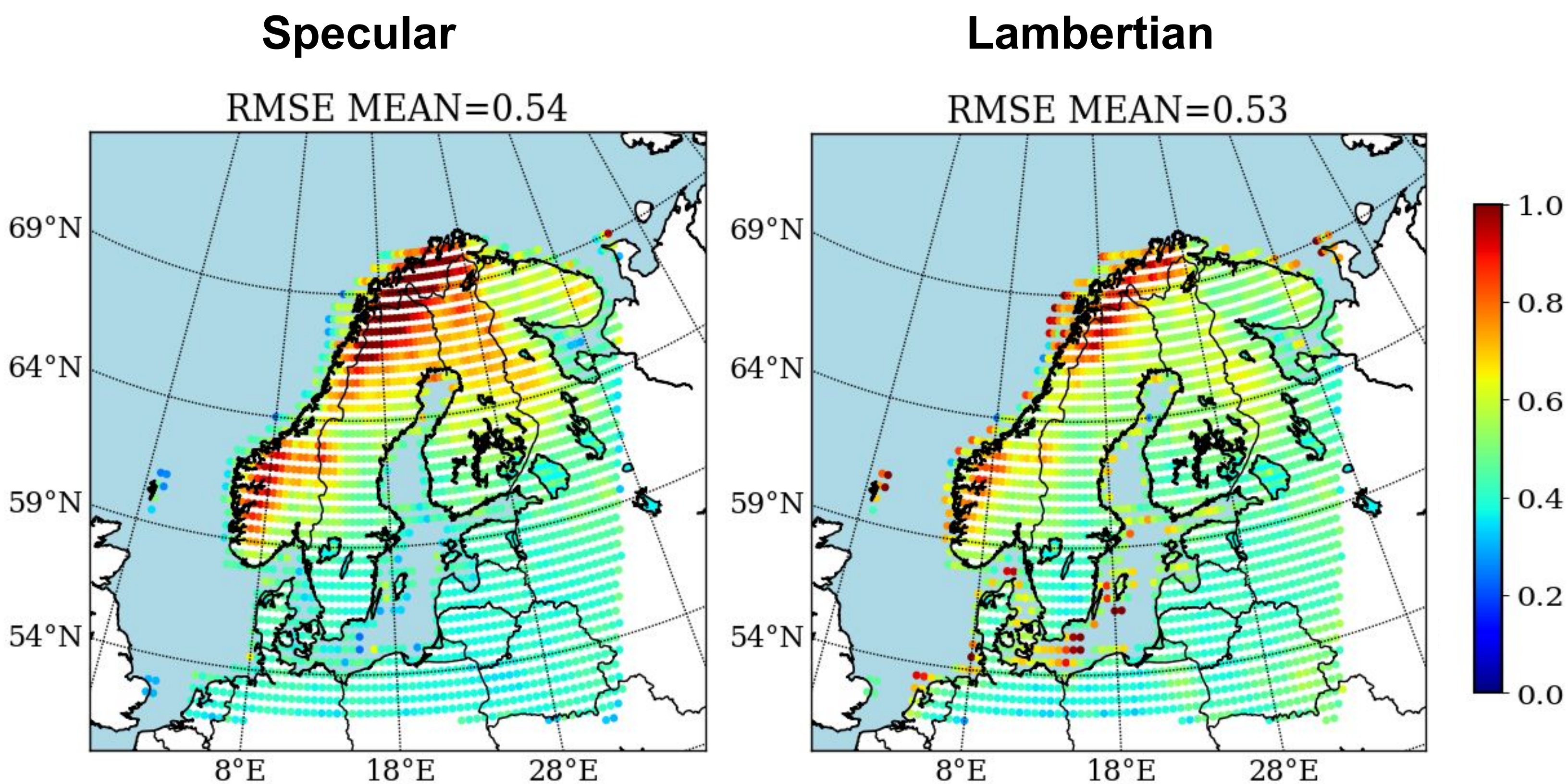
Spatial distribution of gridded (0.5x0.5) mean surface emissivity from AMSU-A (Channel-5) and from two different scenario Lambertian and Specular reflection.

Impact over Land: January 2024



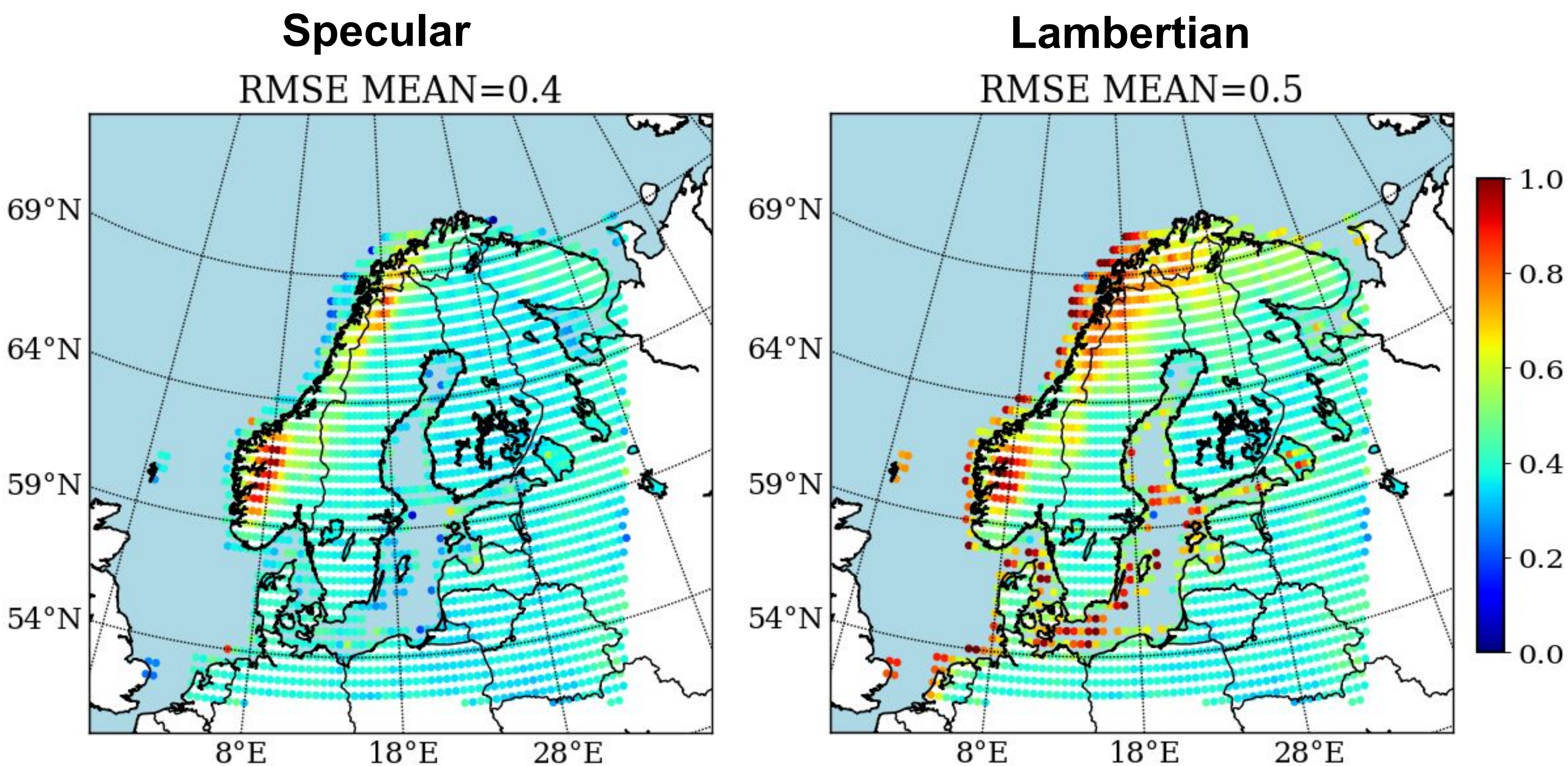
The spatial distribution of the gridded (0.5x0.5) standard deviation (SD) of retrieved emissivity for two different scenarios—Lambertian and specular reflection—of AMSU-A channel 5 is presented. The image clearly indicates that the uncertainty in emissivity is significantly higher in Lambertian reflection, whereas in specular reflection, the standard deviation (uncertainty spread) is much lower and more uniform.

Impact over Land: January 2024



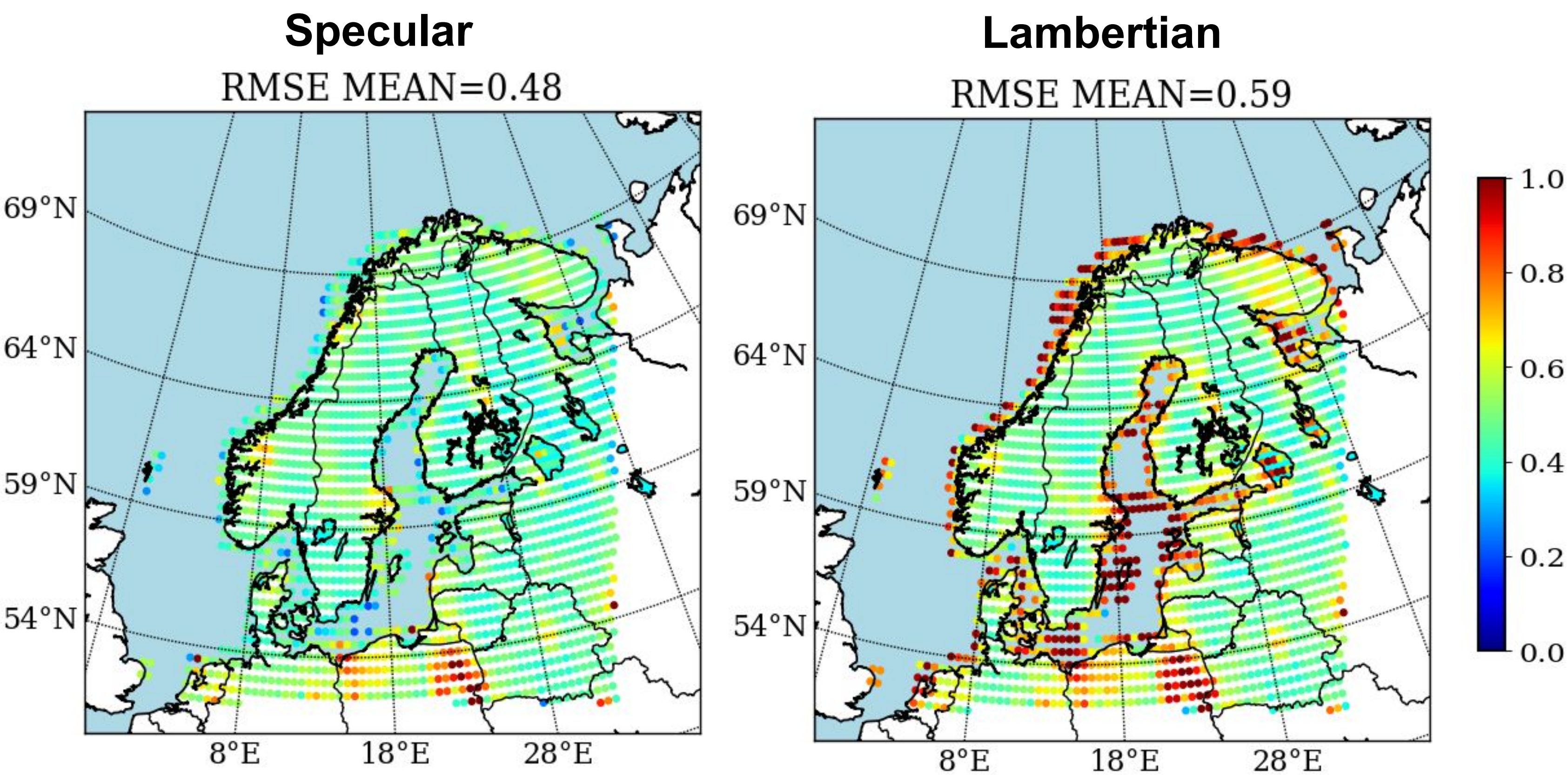
Spatial distribution of gridded (0.5x0.5) root mean square error (RMSE) of brightness temperature (in K) for two different scenario Lambertian and Specular reflection before bias correction of AMSU-A channel-5.

Impact over Land: April 2024



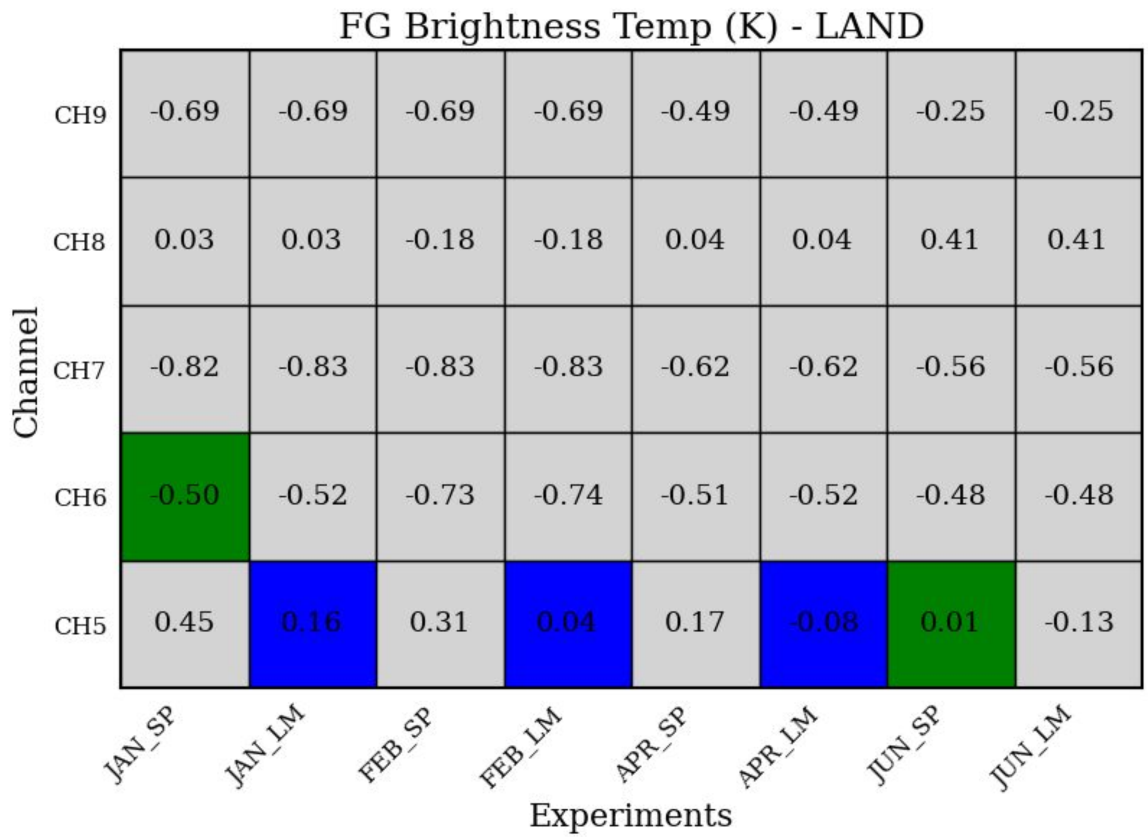
Spatial distribution of gridded (0.5x0.5) root mean square error (RMSE) of brightness temperature (in K) for two different scenario Lambertian and Specular reflection before bias correction of AMSU-A channel-5.

Impact over Land: June 2024



Spatial distribution of gridded (0.5x0.5) root mean square error (RMSE) of brightness temperature (in K) for two different scenario Lambertian and Specular reflection before bias correction of AMSU-A channel-5.

Impact over Land



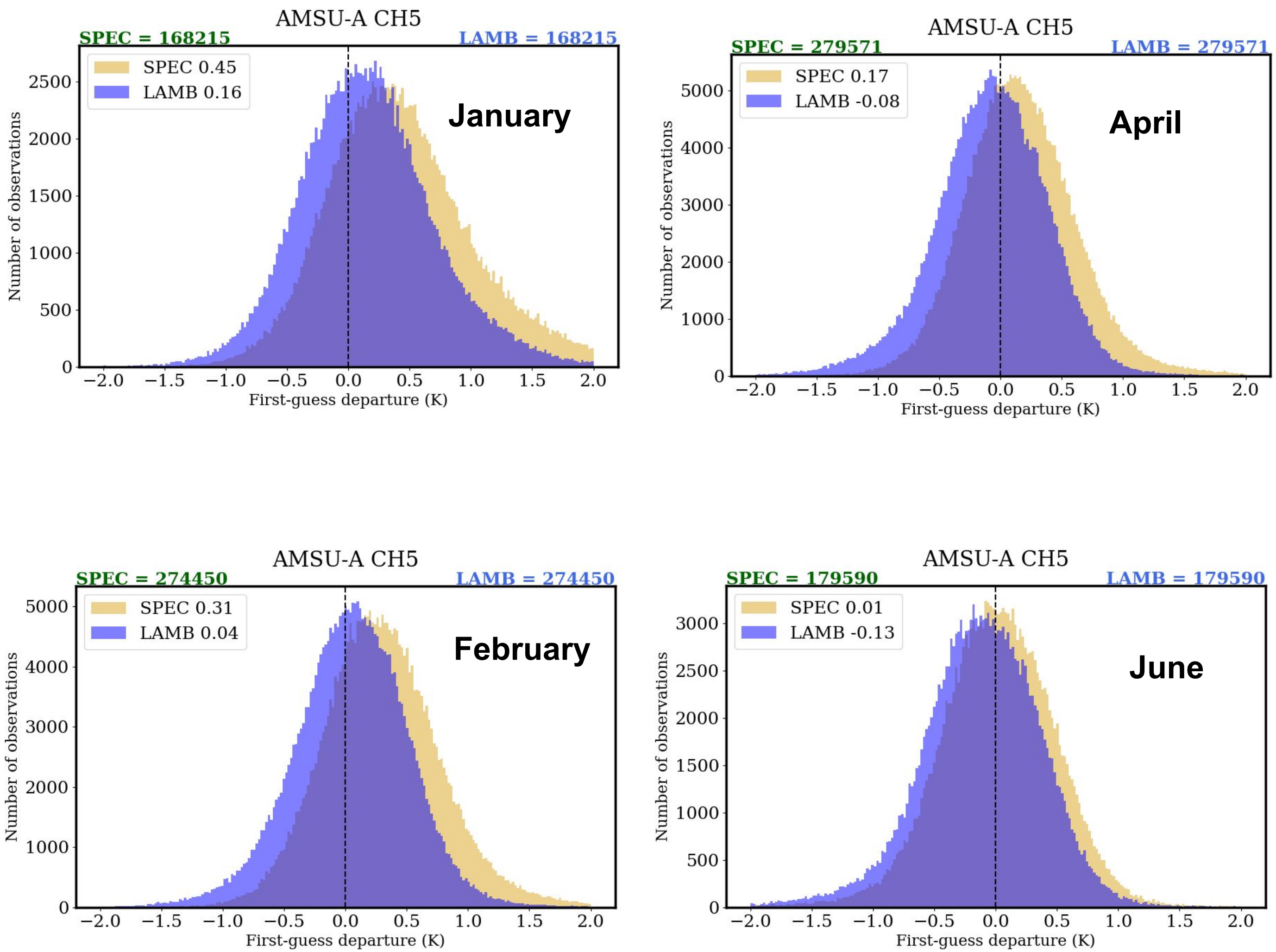
First-guess departure (FG) of brightness temperature (k)

Specular better

Neutral

Lambertian better

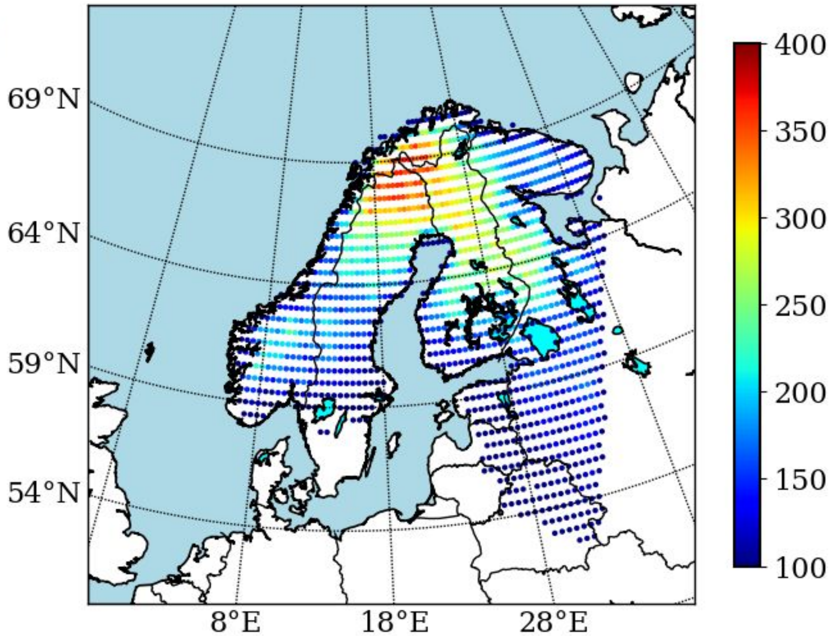
First-guess departure (FG) of brightness temperature (k)

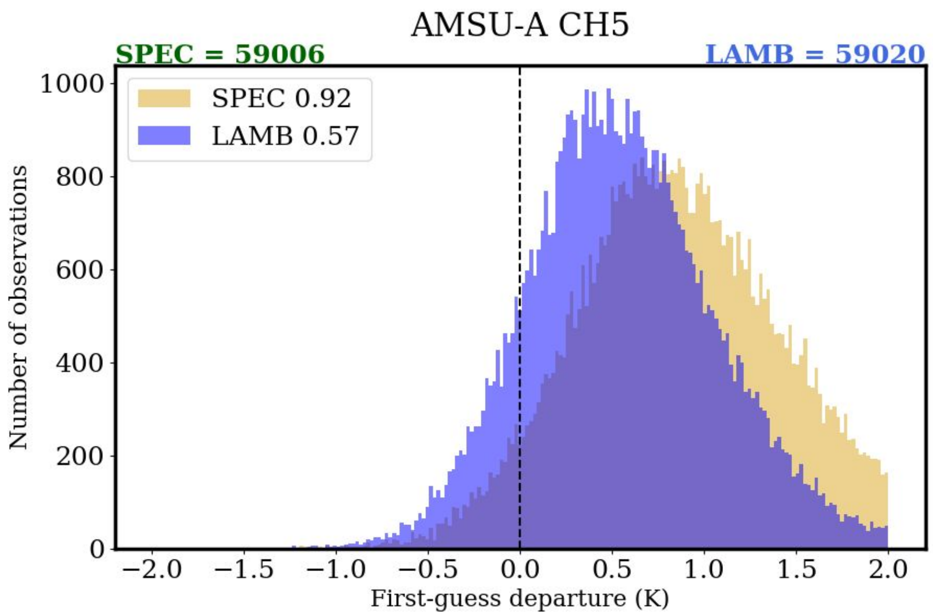


First-guess departure (FG) of brightness temperature (k)

Impact over Snow: January 2024

AMSU-A Channel-5
Observation Count

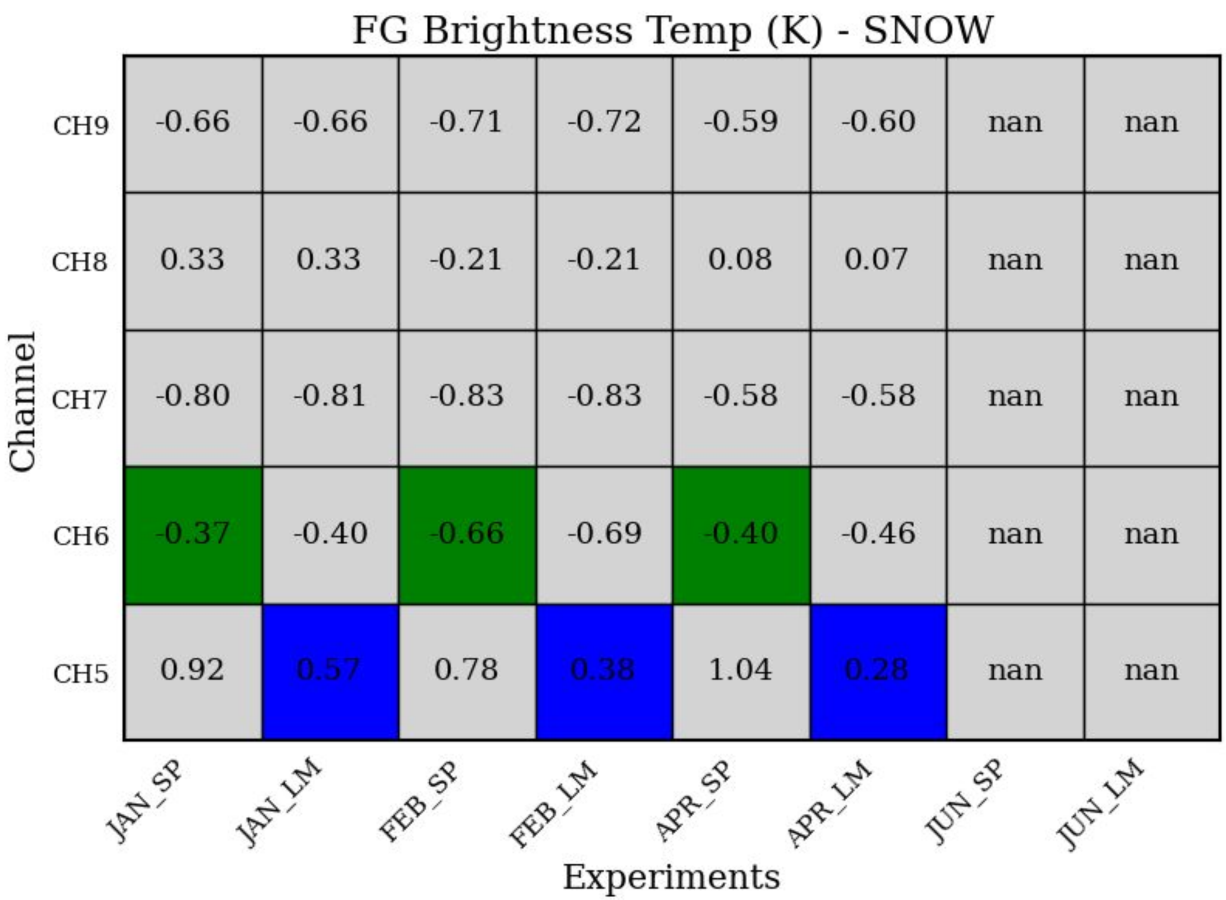




First-guess departure (FG) of brightness temperature (k)

The number of observations over each grid box (0.5 x 0.5) and the available over Snow for the entire month of January 2024, as well as for all assimilation cycles.

Impact over Snow



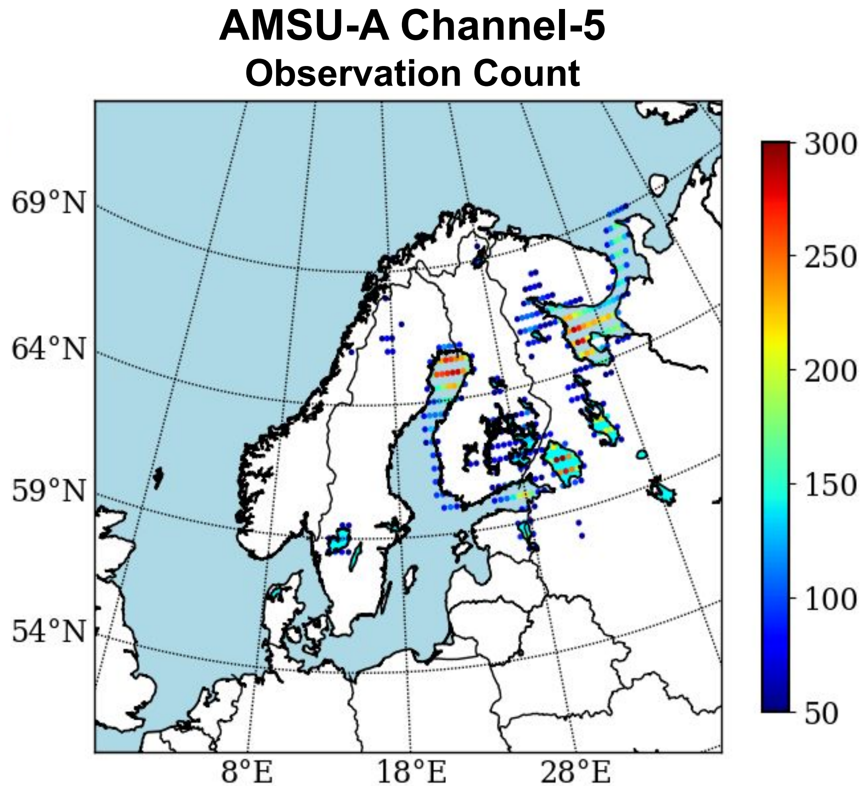
First-guess departure (FG) of brightness temperature (k)

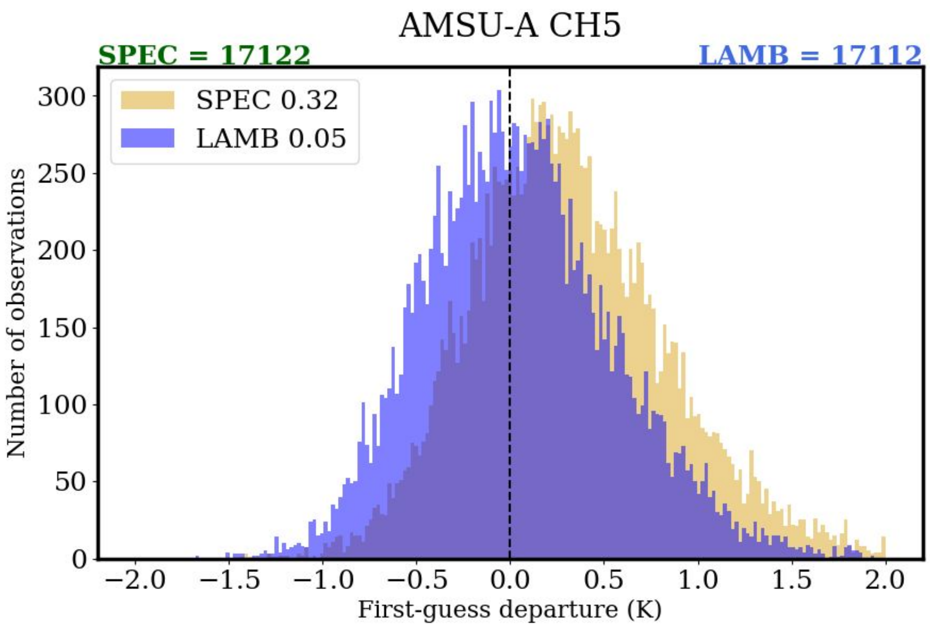
Specular better

Neutral

Lambertian better

Impact over Sea-Ice: January 2024

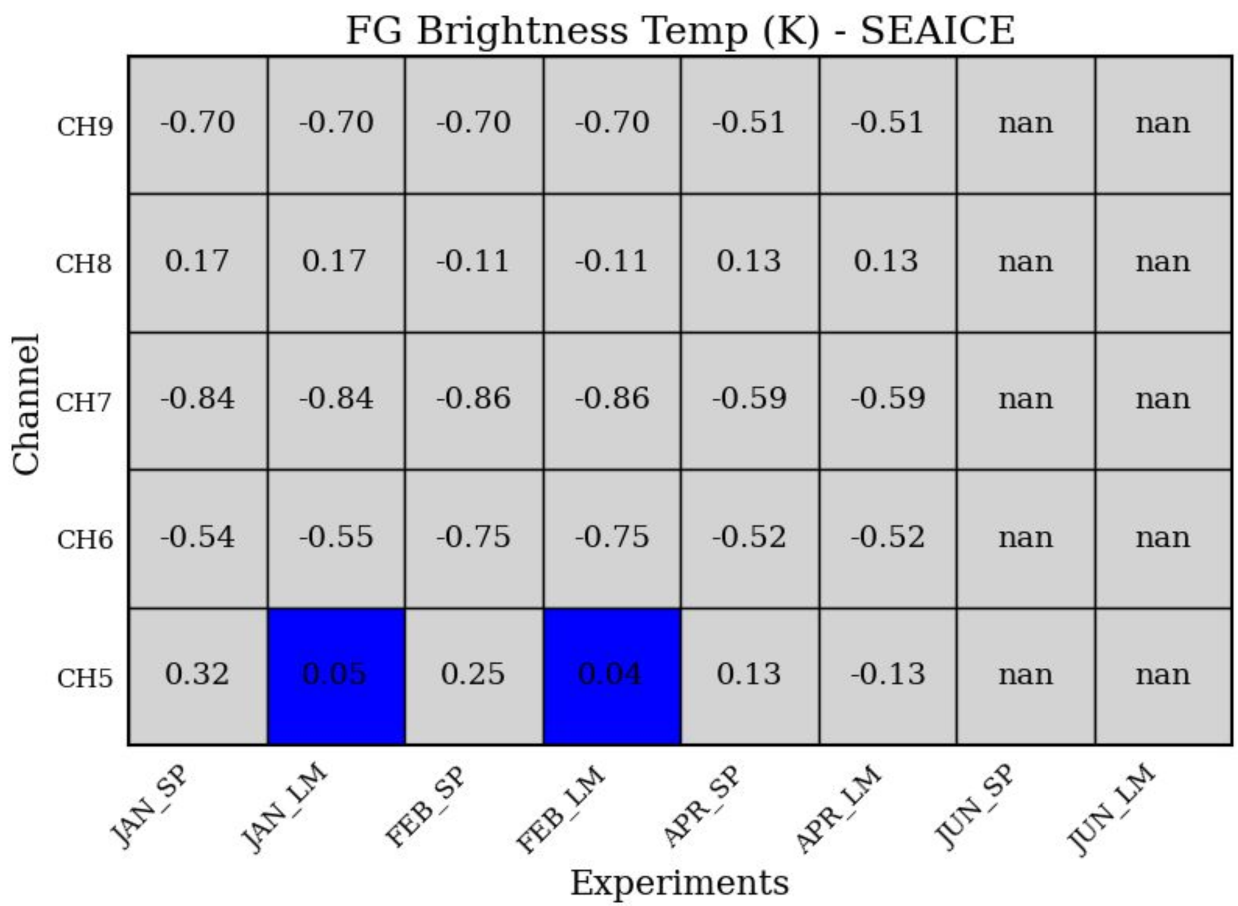




The number of observations over each grid box (0.5 x 0.5) and the available over Sea-Ice for the entire month of January 2024, as well as for all assimilation cycles.

First-guess departure (FG) of brightness temperature (k)

Impact over Sea-Ice



First-guess departure (FG) of brightness temperature (k)

Specular better

Neutral

Lambertian better

Summary:

- During the winter months (January and February), the specular reflection method exhibits a higher root mean square error (RMSE) in terms of BT than the Lambertian method over land. In the summer months, the specular reflection method outperforms the Lambertian reflection method over land.
- During the winter months, the background error in brightness temperature (K) is consistently positive over snow-covered areas for both the LAMB and SPEC experiments.
- Uncertainty in surface emissivity, measured in terms of standard deviation (SD), is higher in Lambertian reflection. In contrast, specular reflection exhibits a much lower and more uniform standard deviation, indicating a narrower spread of uncertainty.
- A more in-depth study will explore the significance of the weighted mean of various types of reflection on different surfaces and across different seasons.

Acknowledgments: This research was supported by the

European Space Agency (ESA) project:

- Performance Evaluation of Arctic Weather Satellite Data (No. 4000136511/21/NL/IA).

and

The Swedish National Space Agency (SNSA) project:

- Consistent Air-Ice-Sea Data Assimilation of Satellite Observations (CAISA) (No: 2021-00085).

Reference:

- Bormann et al. 2017 https://doi.org/10.21957/qyh34roht
- S. Guedj, et al. 2010, https://doi: 10.1109/TGRS.2009.2036254.
- https://space.oscar.wmo.int/instruments/view/amsu_a

Thank you for your attention !