Living Planet Symposium
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On the retrieval of ice sheet temperature in Antarctica by using SMOS observations

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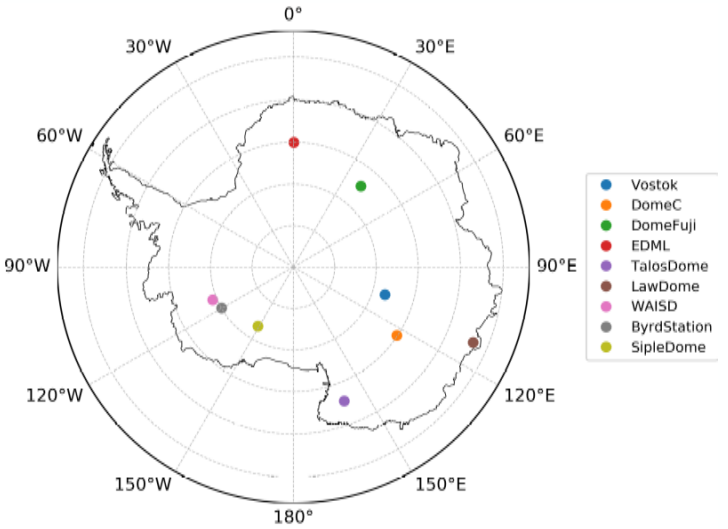
https://4d-antarctica.org

Ice sheet temperature in Antarctica from SMOS
Introduction

Context
Ice temperature essential to understand the Antarctic ice sheet evolution mainly because of its interaction with the ice flow

Problem
Ice temperature only provided by a few boreholes and glaciological models



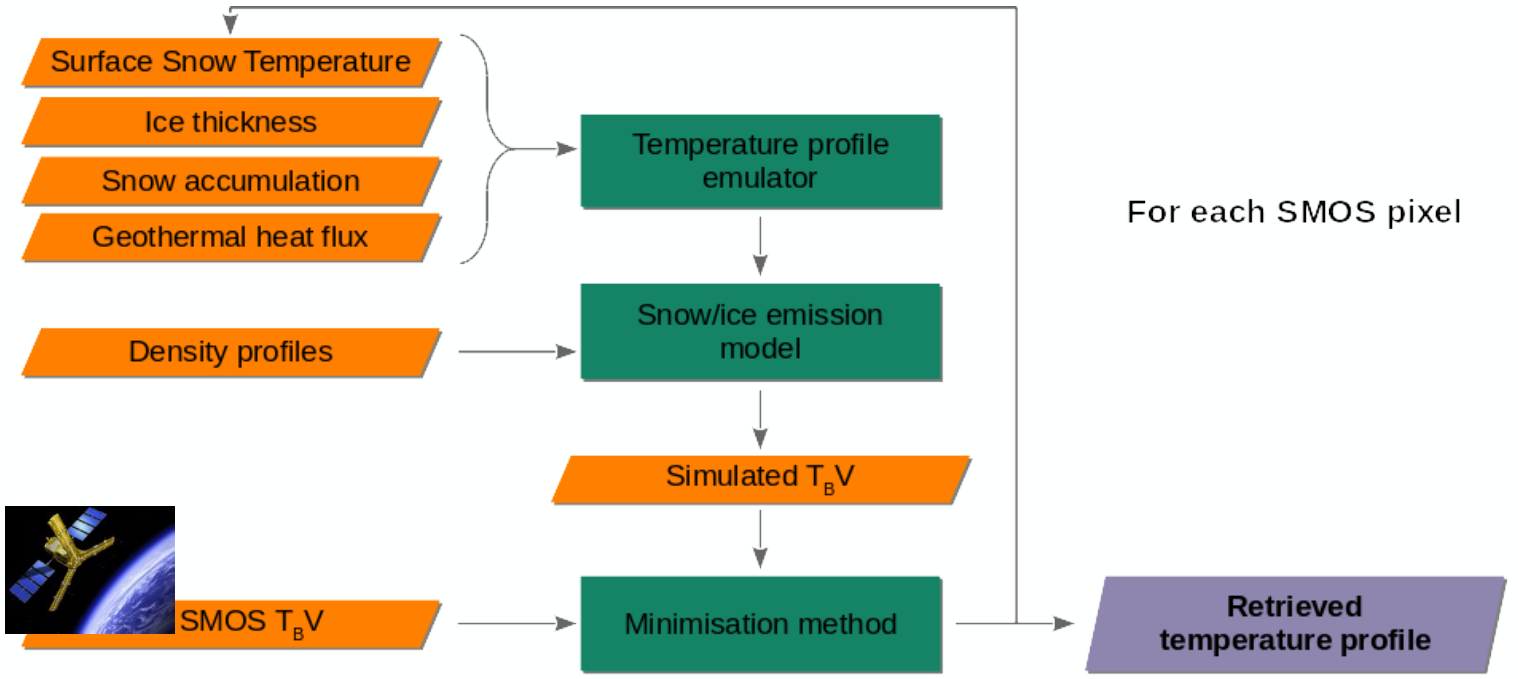
The SMOS satellite opportunity

Launch in 2009
Microwave radiometer: 1.4 GHz
Advantage: Sensitivity to the ice temperature several hundred meters in depth (Macelloni et al., 2016, 2019)

=> possibility for the first time to reach information about the ice sheet temperature in depth from satellite

Objective
Associate SMOS observations and a glaciological model to retrieve the ice temperature profiles

Ice sheet temperature in Antarctica from SMOS
Method – A Bayesian approach



Temperature profiles emulator

✓ 1D Robin glaciological model
(Robin, 1955)
- Easy and fast to use
- Valid in a limited area over the Plateau

✓ **GRISLI 3D glaciological model**
(Quiquet et al., 2018)
- Based on a DNN to make easy to use
- Force with past surface temperature (over 25 kyrs), derived from the average of 20 GRISLI runs.
- Valid where ice thickness > 1000 m

Minimisation method

✓ **Bayesian approach**
to search for the probability of each unknown to predict the SMOS T_B observations
(Markov Chain Monte Carlo (MCMC) method (DREAM), Laloy and Vrugt, 2012)

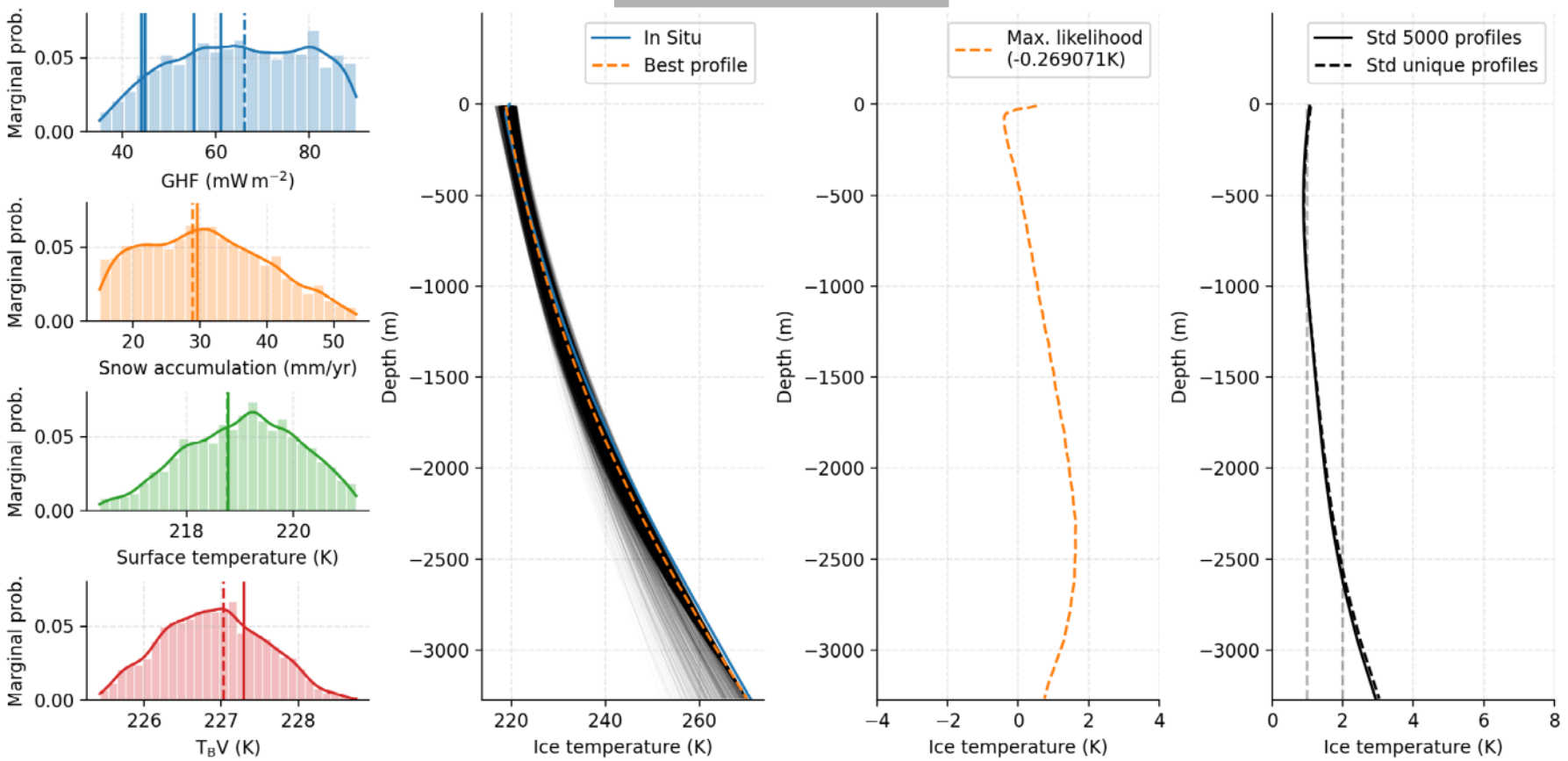
→ A set of equiprobable unknown geophysical parameters given the observations
=> a set of equiprobable temperature profiles

Ice sheet temperature in Antarctica from SMOS
A Bayesian approach – Example Dome C

Free parameter	Prior distribution	A priori sources	Standard deviation σ
Surface temperature	normal	Fréville et al., 2014	1.5 K
Snow accumulation	normal	Agosta et al., 2019	A priori * 0.5 mm yr^{-1}
Geothermal heat flux (GHF)	uniform	mean of 5 datasets	40 mW m^{-2}

Fixed Ice thickness
→ well-known

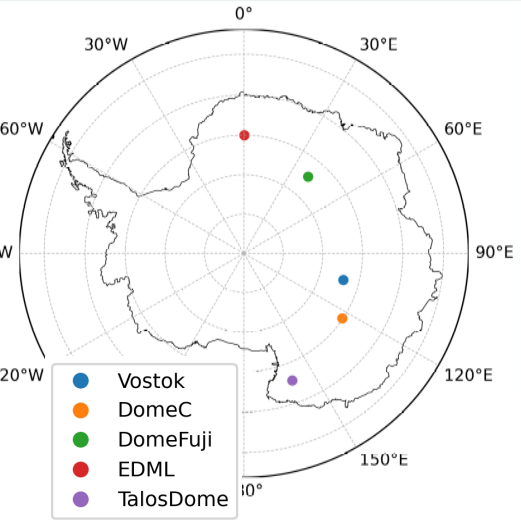
Dome C



✓ Good agreement with in situ measurements in upper part (< 1 K above 1500 m)

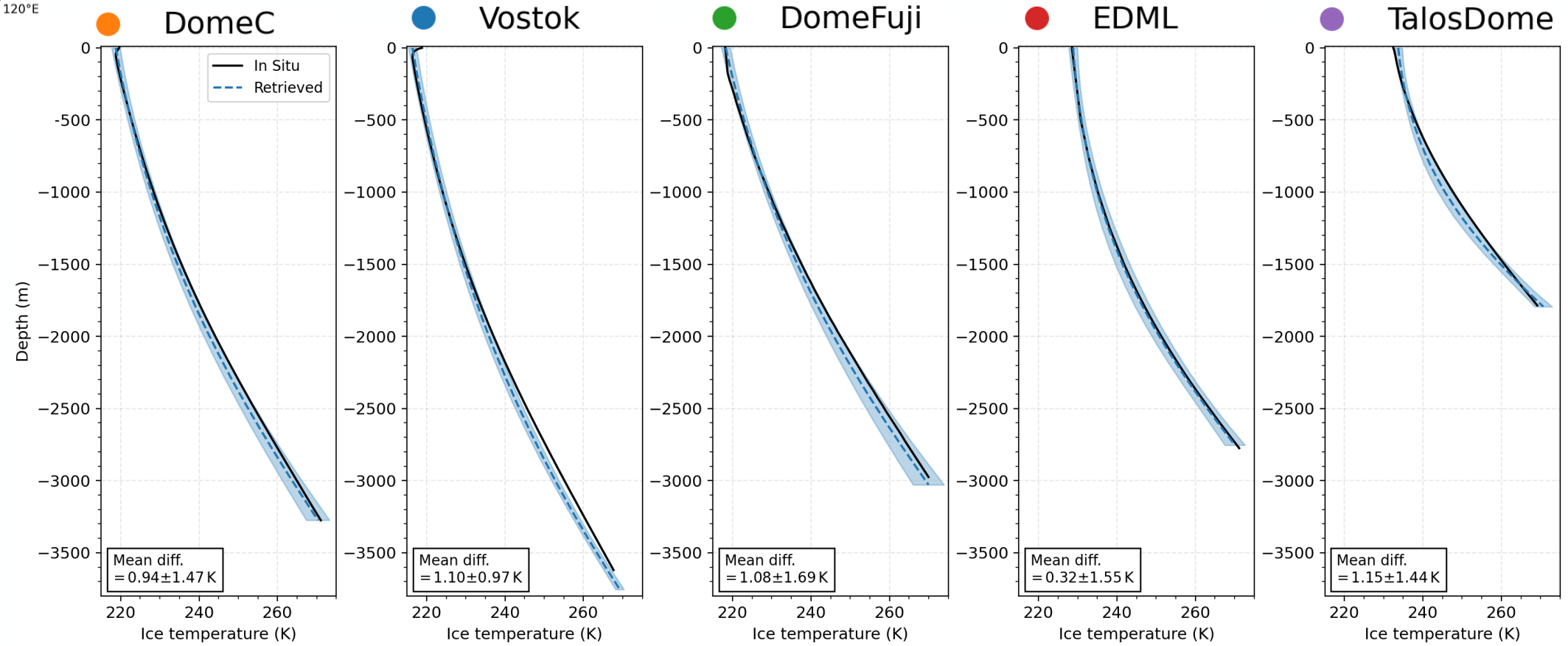
✓ Std > 2 K down to 2500 m
→ SMOS is more sensitive to the upper part of the ice sheet

Ice sheet temperature in Antarctica from SMOS
Comparison with in situ measurements

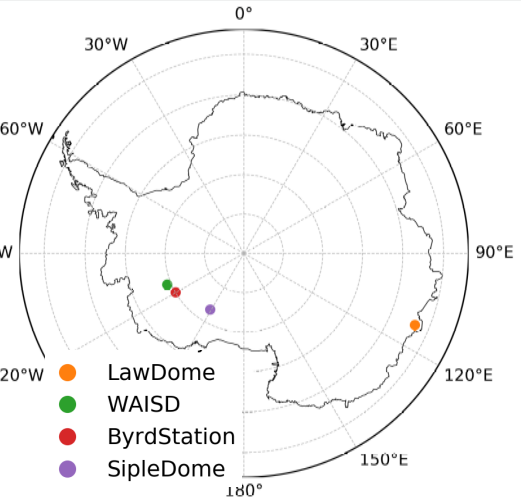


Plateau area

- ✓ Good agreement with in situ measurements
- ✓ Mean difference < 1.1 K (max = 2 K)
- ✓ Mean standard deviation < 1.7 K
- ✓ Larger std below 2000 m (~ 3-4 K at Dome C and Dome Fuji)

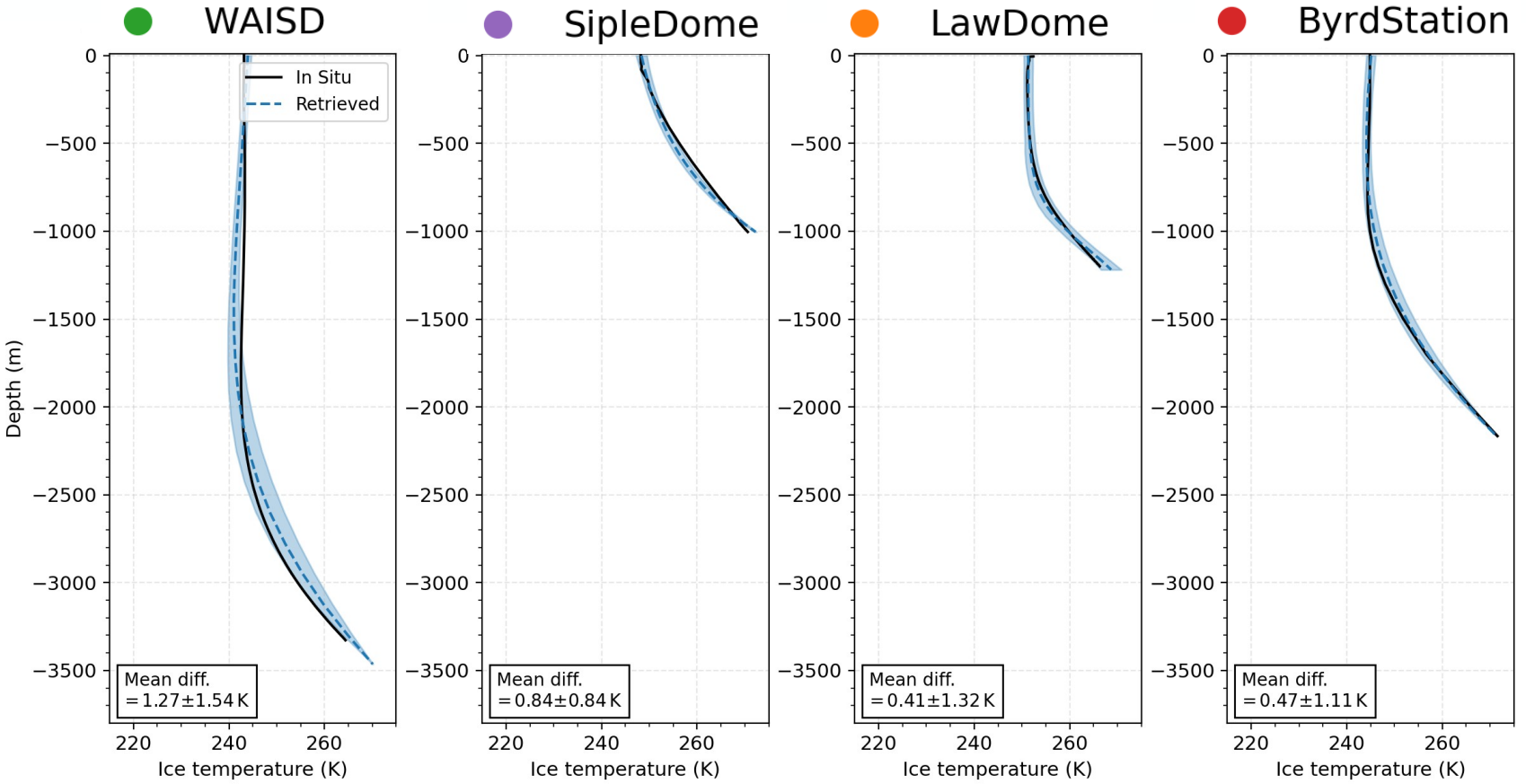


Ice sheet temperature in Antarctica from SMOS
Comparison with in situ measurements



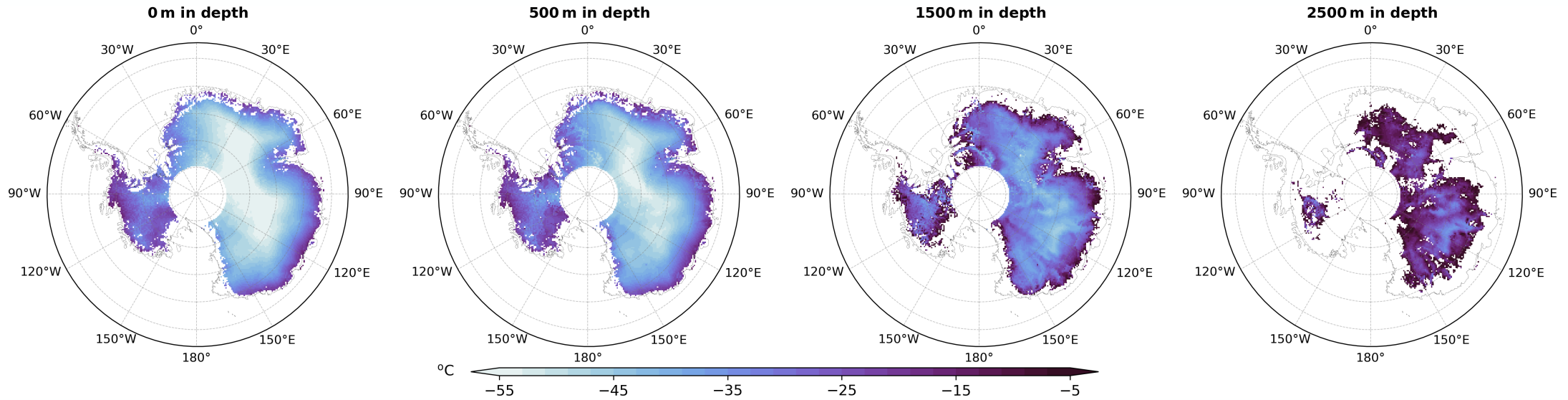
West and coastal area

- ✓ Good agreement with in situ measurements
- ✓ Mean difference < 1.3 K (max = 2 K)
- ✓ Low mean standard deviation (< 1.5 K), max ~ 4 K at WAISD



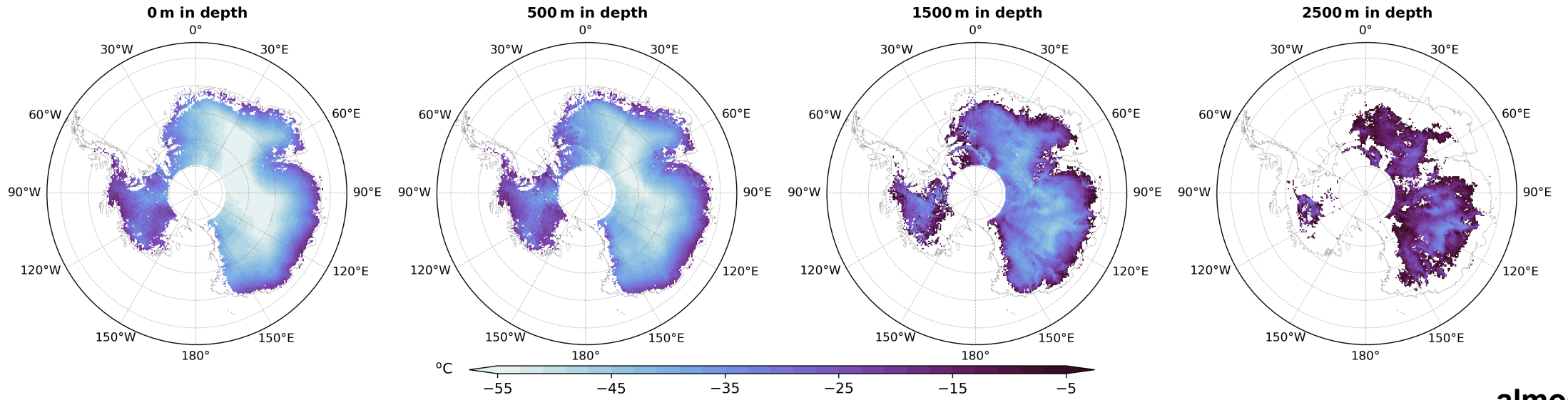
Ice sheet temperature in Antarctica from SMOS

Results – Temperature maps



GRISLI

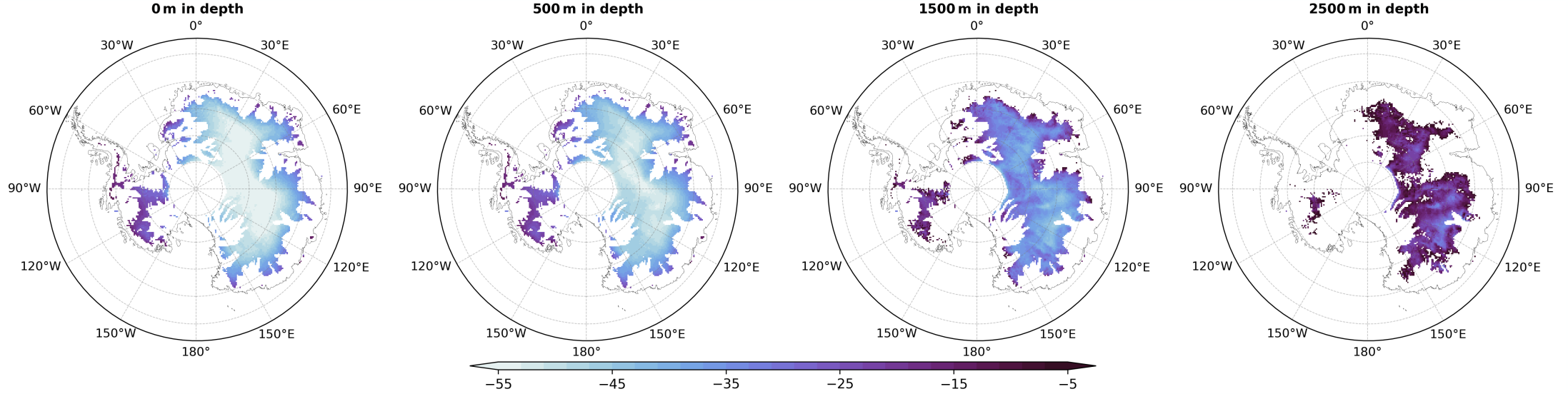
Ice sheet temperature in Antarctica from SMOS
Results – Temperature maps



GRISLI

9,377,000 km²

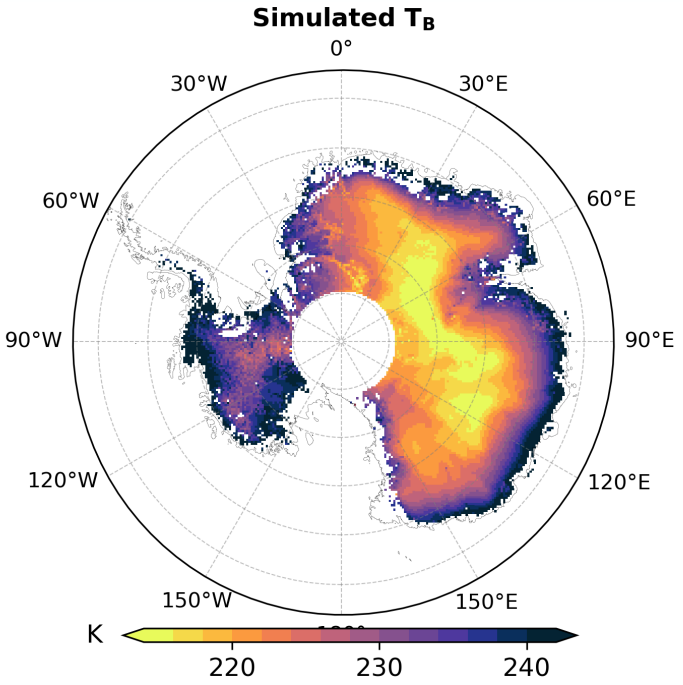
almost twice as much

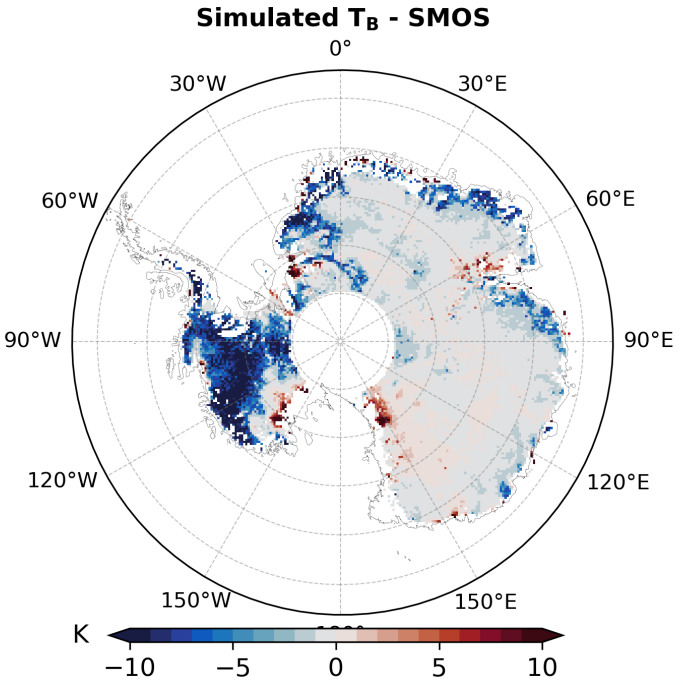


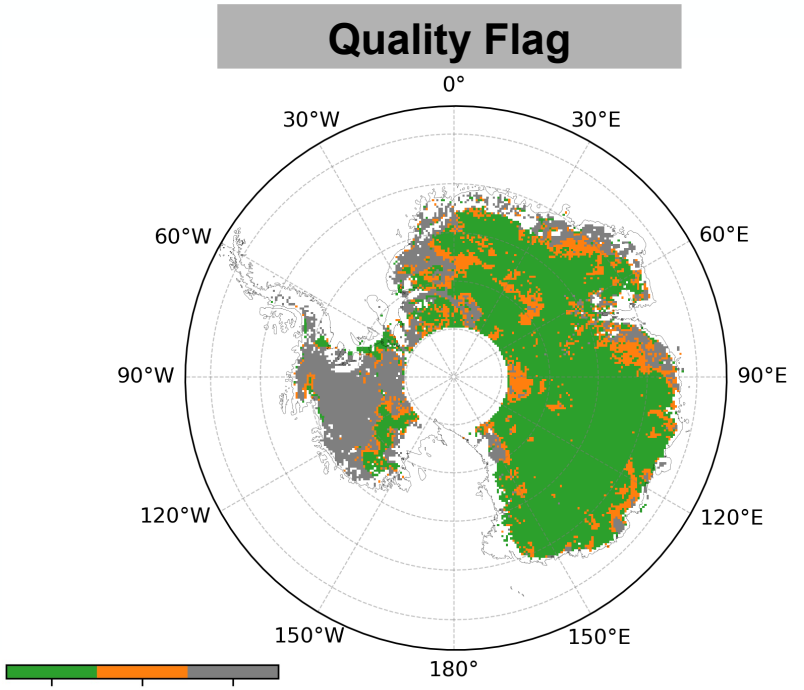
Robin

5,292,000 km²

Ice sheet temperature in Antarctica from SMOS
Results – Quality Flag







- ✓ Difference between simulation and SMOS usually < 1 K
- ✓ except over the West Antarctica suggesting issues in the snow/ice emission modelling
  → retrieval less reliable here

=> Quality Flag based on the difference between SMOS and simulations

2 – Doubtful → dif > 2 K

1 – Acceptable → dif < 2 K

0 – Good → dif < 1 K

Ice sheet temperature in Antarctica from SMOS
Conclusion

Results

✓ Algorithm based on a **Bayesian approach**
to combine the SMOS satellite observations with a glaciological model

✓ Validity area where **ice thickness > 1000 m** thanks to the 3D GRISLI emulator

✓ Retrieval provides **ice temperature, uncertainties and quality flag**

Perspectives

✓ Investigate the **electromagnetic modelling** over the West Antarctica

✓ Apply the methodology to the **Greenland** ice sheet

Long-term perspectives

✓ Using frequencies lower than the SMOS 1.4 GHz
in order to improve the retrieval close to the bottom

=> CryoRad mission concept: 0.5-2 GHz radiometer