JPL CCS workshop
Science of 10-km L-band Radiometry
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Ice Sheet Temperature Retrieval

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ESA 4D Antarctica
ESA SMOS ESL
ESA 4D Greenland

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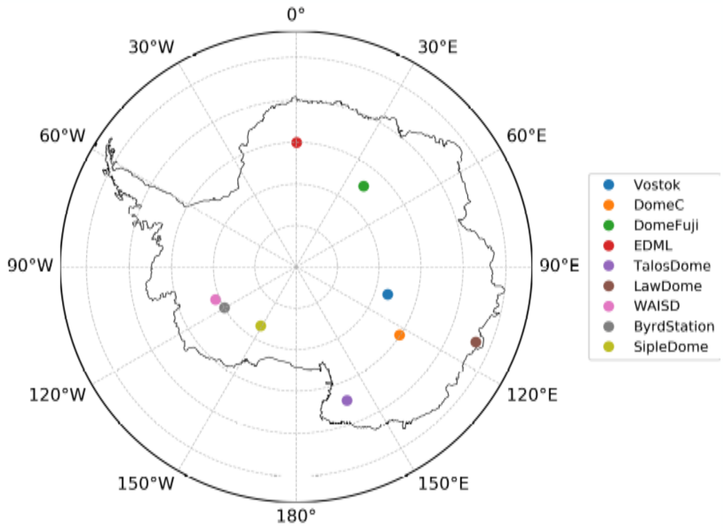
Ice sheet temperature in Antarctica from SMOS
Introduction

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



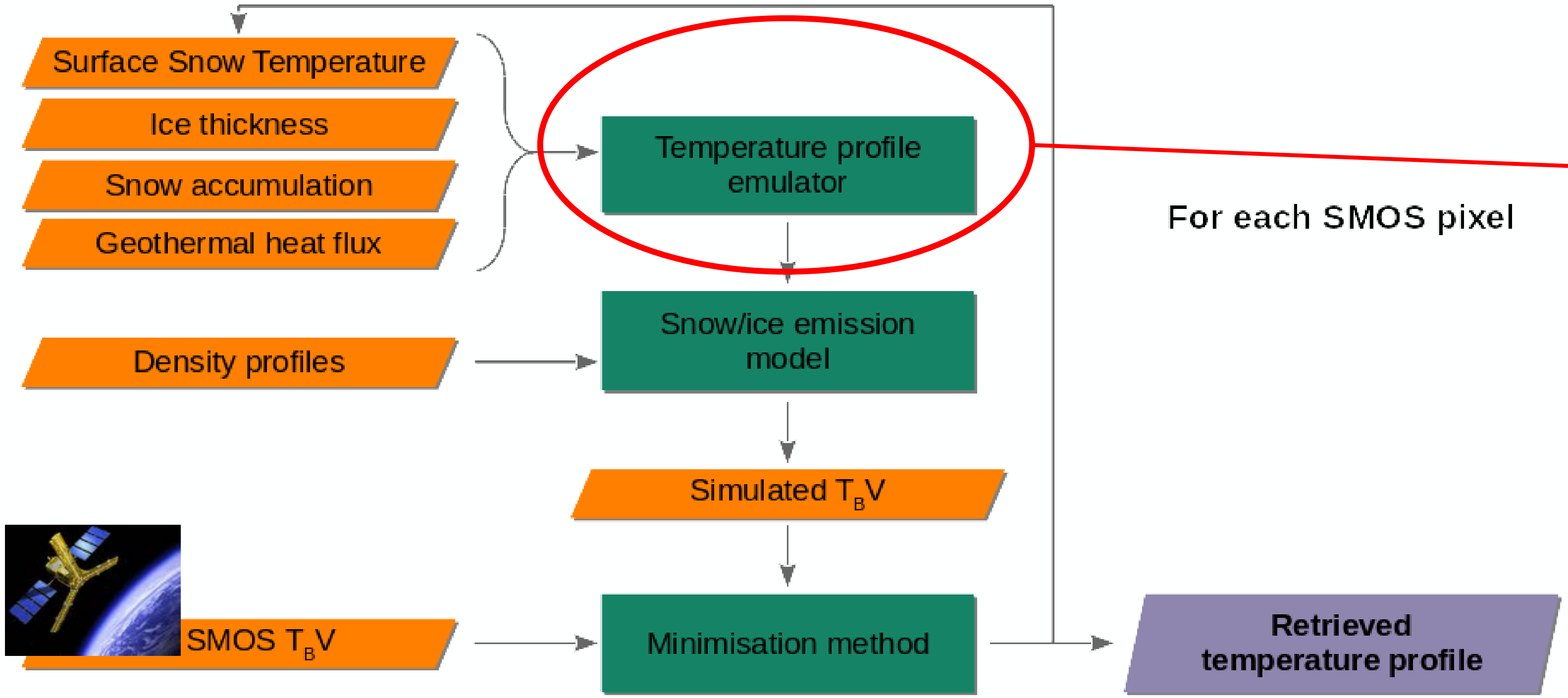
The L-band opportunity

SMOS / SMAP - Microwave radiometer: 1.4 GHz
High penetration in dry ice → Sensitivity to inner properties 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

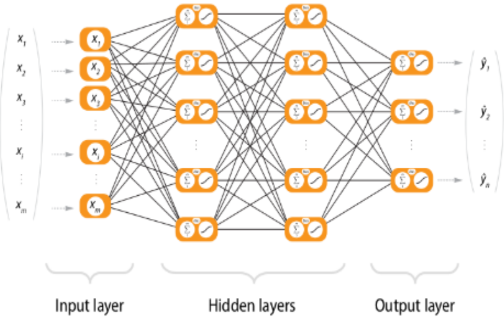


Temperature profiles emulator

GRISLI 3D glaciological model
(Quiquet et al., 2018)

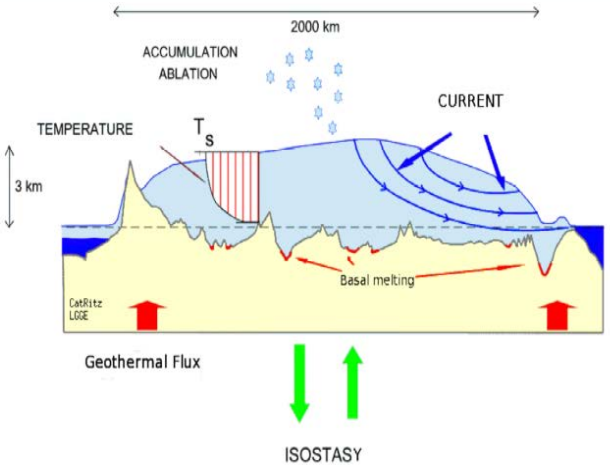
- Based on a DNN to make easy to use
- Forced with past surface temperature (over 25 kyrs)
- Derived from 20 GRISLI runs
- Valid where ice thickness > 1000 m

Input Parameters X from GRISLI
Ts, H, Ghf, acc
surface velocity
surface slope, …

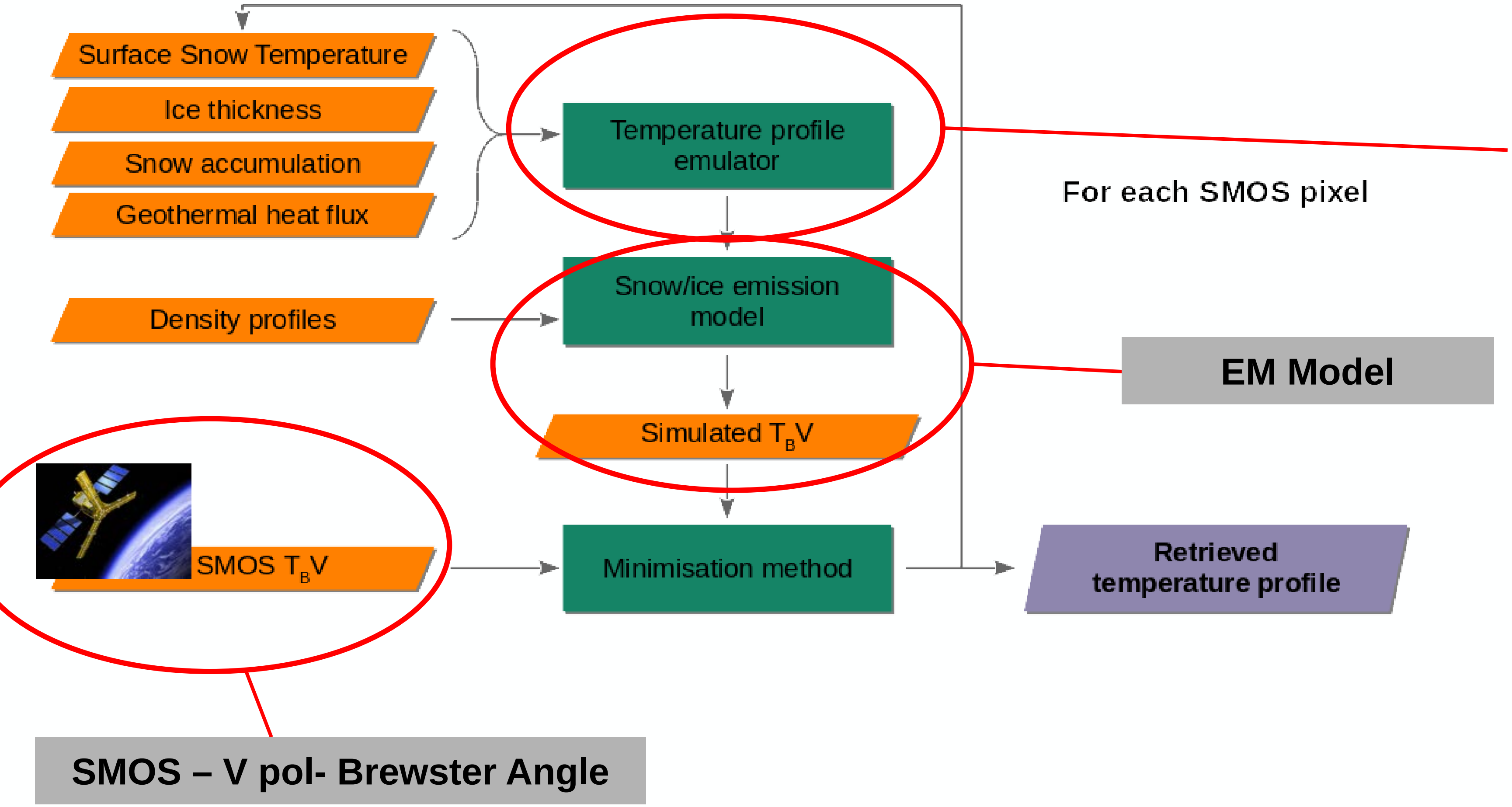


Predicted output ŷ
Temperature profiles

Optimized by comparison with GRISLI temperature profiles **Y**



Ice sheet temperature in Antarctica from SMOS Method



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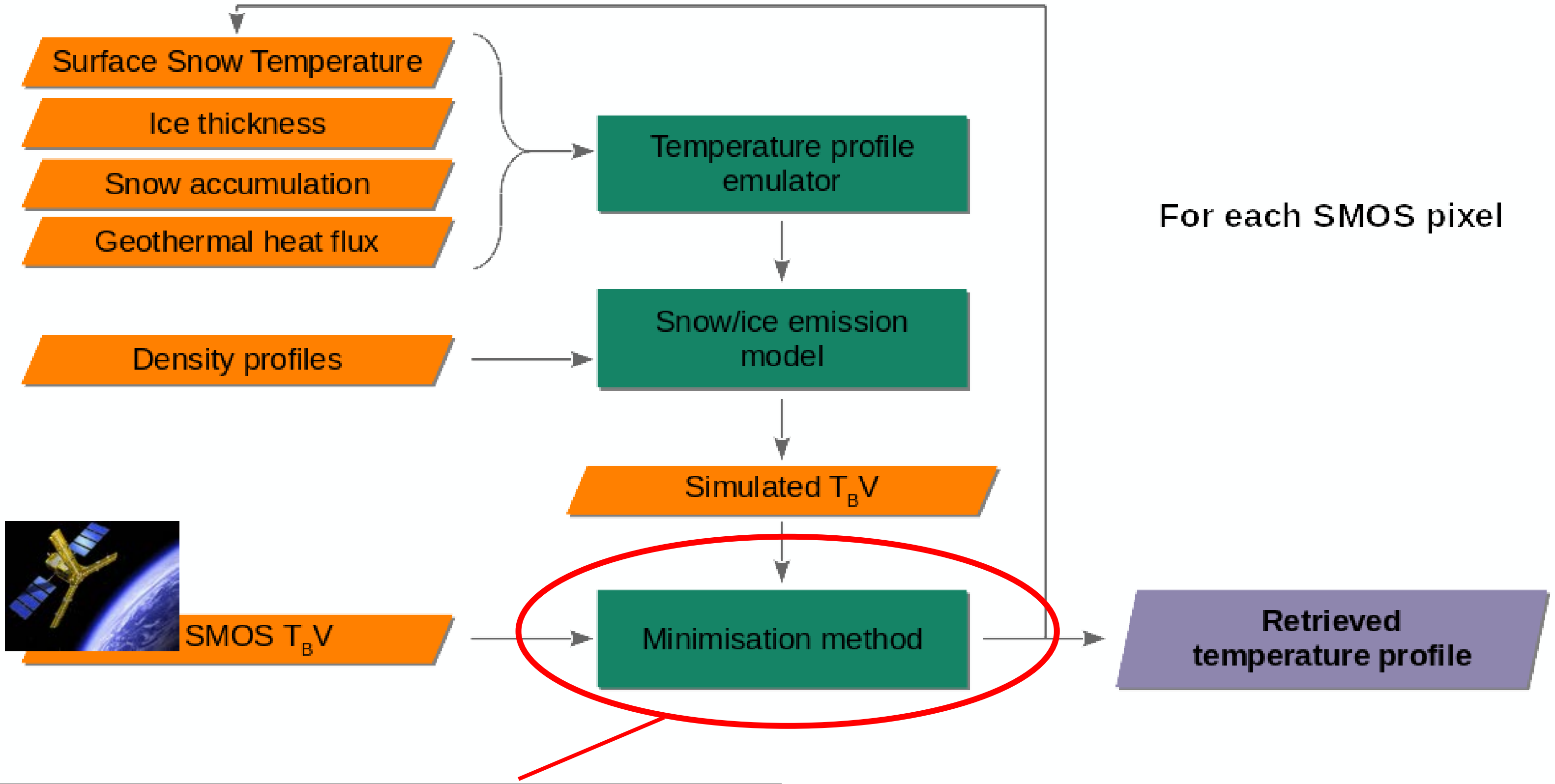

Temperature profiles emulator

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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)

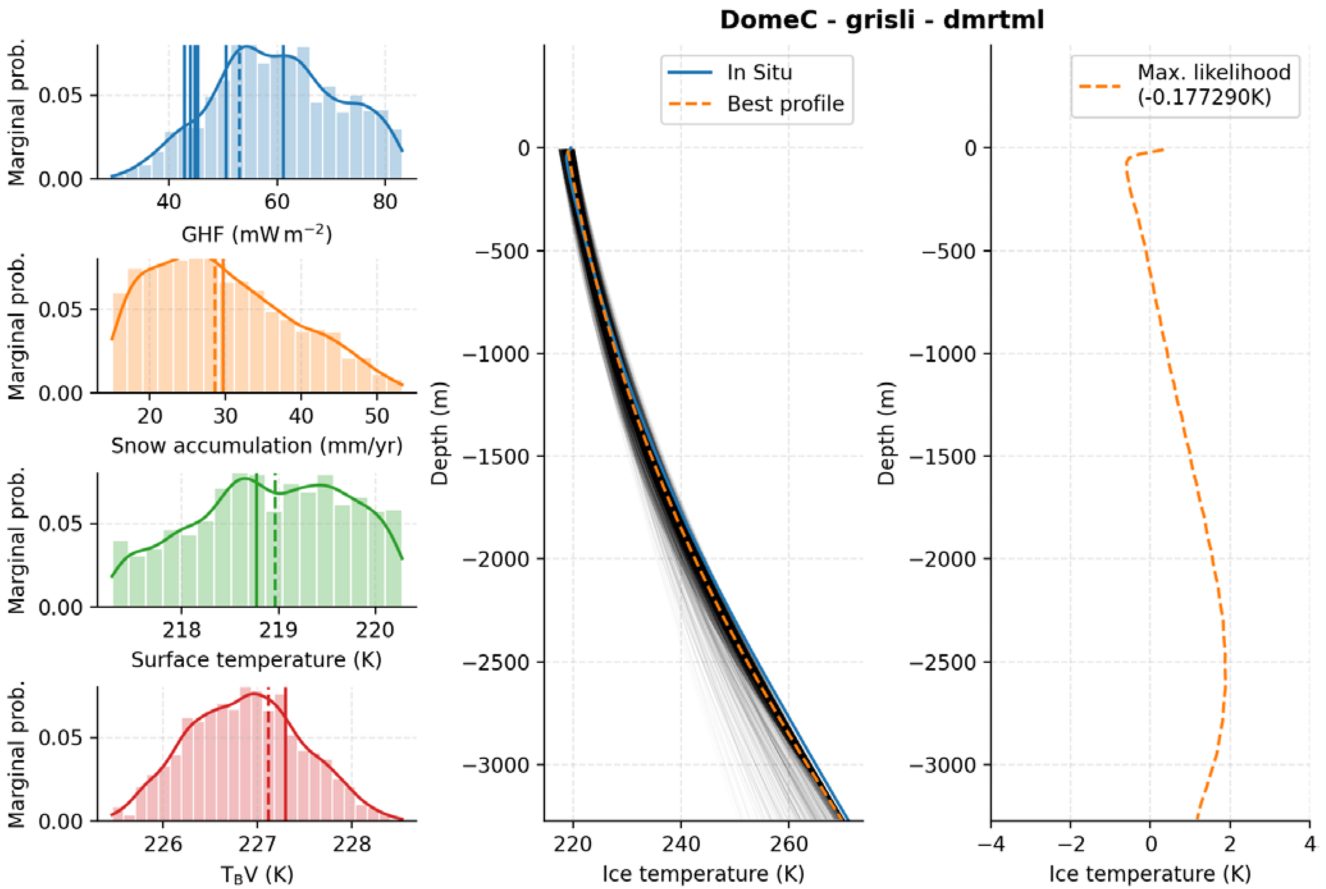
→ A set of equiprobable unknown geophysical parameters given the observations
=> a set of equiprobable temperature profiles

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)	multi-Gaussian	6 datasets**	~30 mW m^{-2}

Fixed Ice thickness
→ well-known

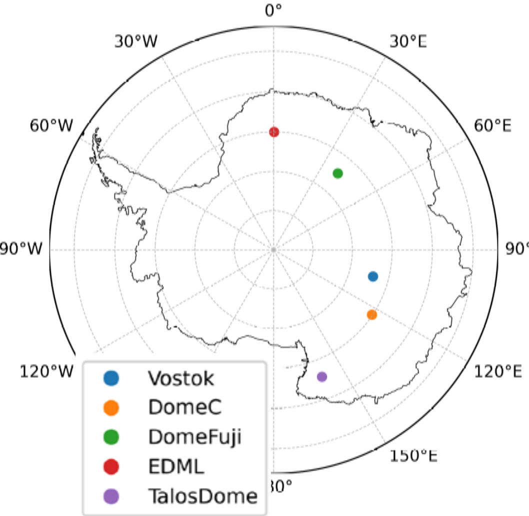
**Shapiro et al., 2004; Fox Maule et al., 2005 (version Puruker 2012); An et al., 2015; Martos et al., 2017; Shen et al., 2020; Stål et al., 2021



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

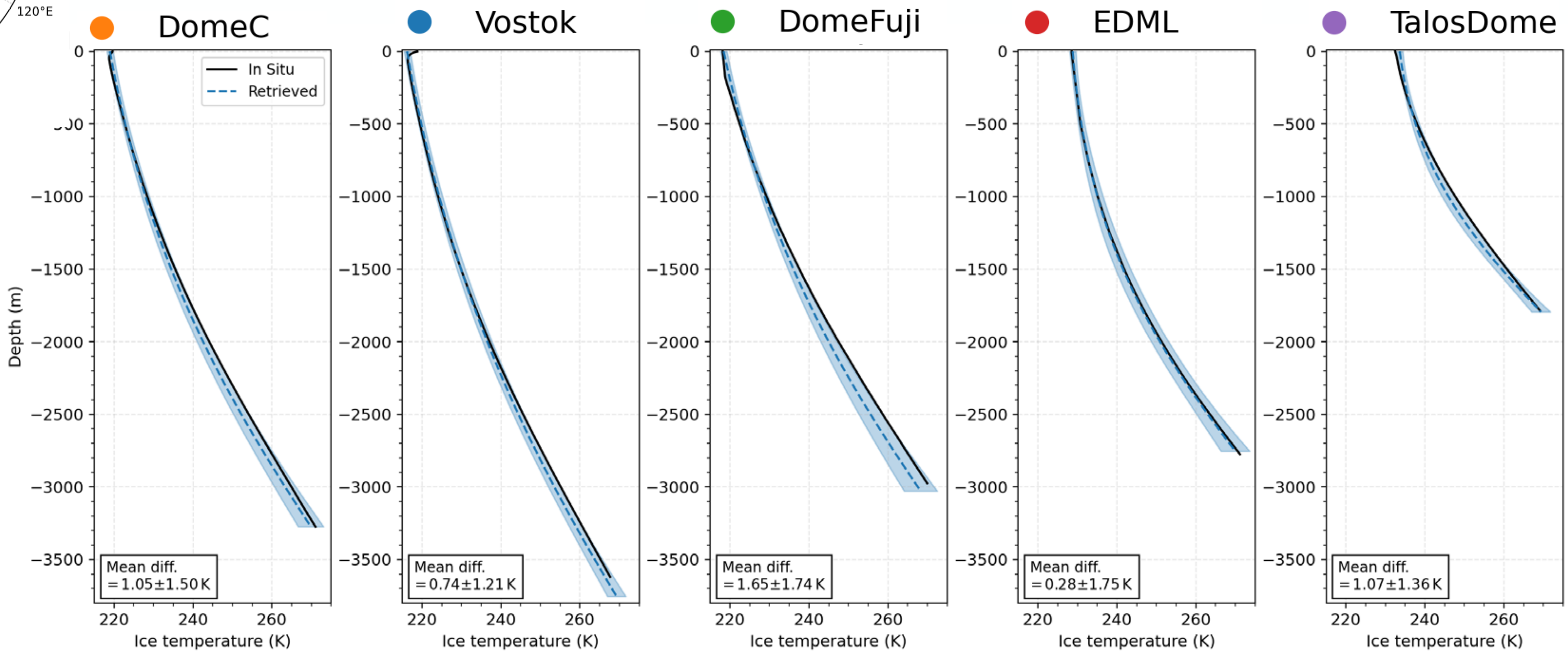
✓ Difference and std increase with the depth → SMOS is more sensitive to the upper part of the ice sheet

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

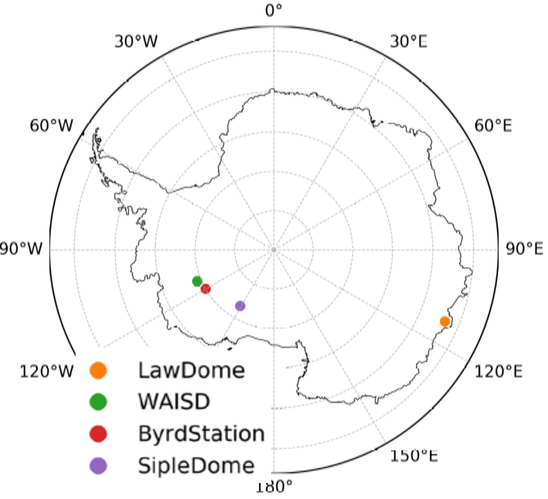


Plateau area

- ✓ Good agreement with in situ measurements
- ✓ Mean difference < 1.6 K (max = 2 K)
- ✓ Mean standard deviation < 1.7 K
- ✓ Larger std below 2000 m (~ 3-4 K at Dome C and Dome Fuji)

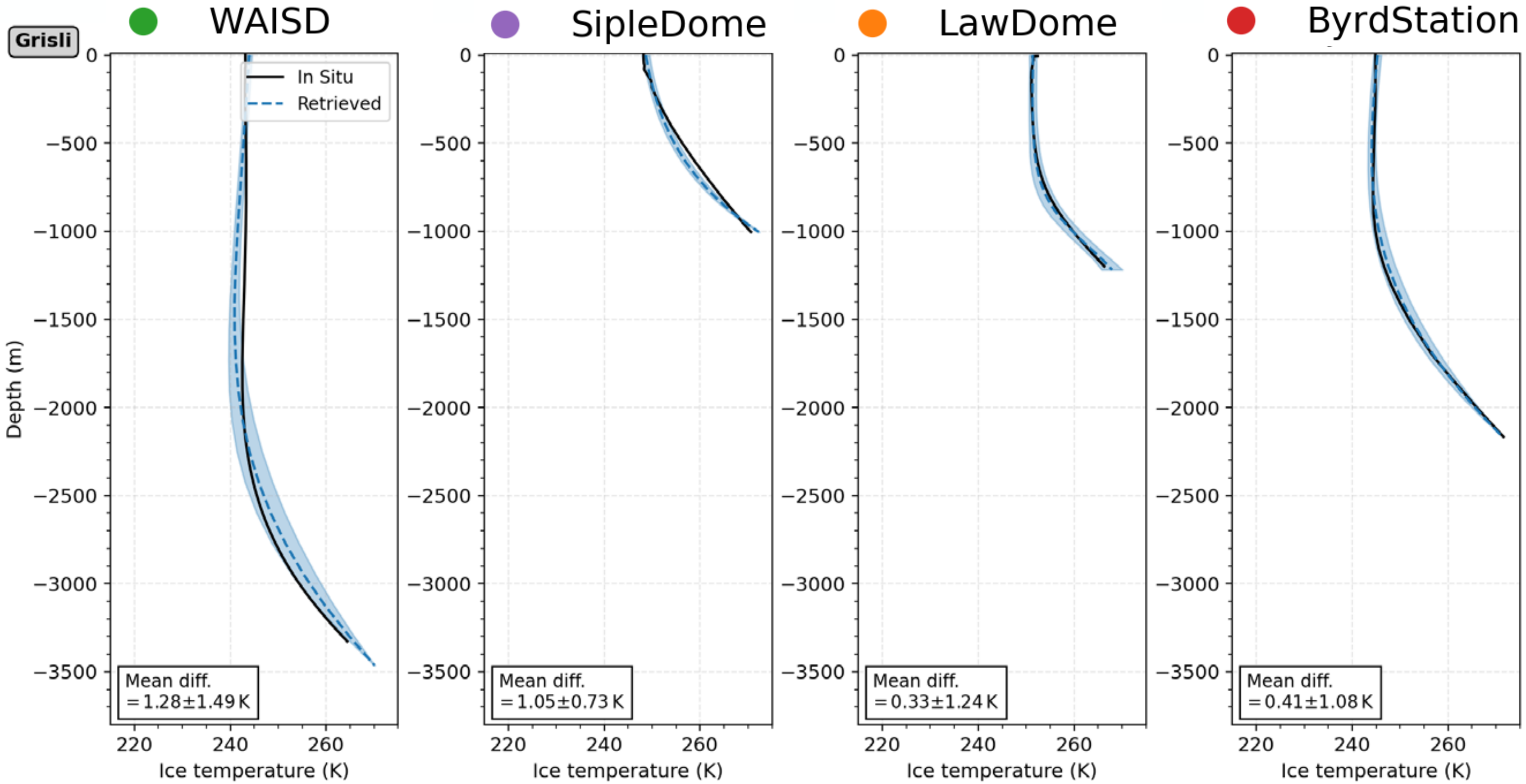


Ice sheet temperature in Antarctica from SMOS
Comparison with in situ measurements



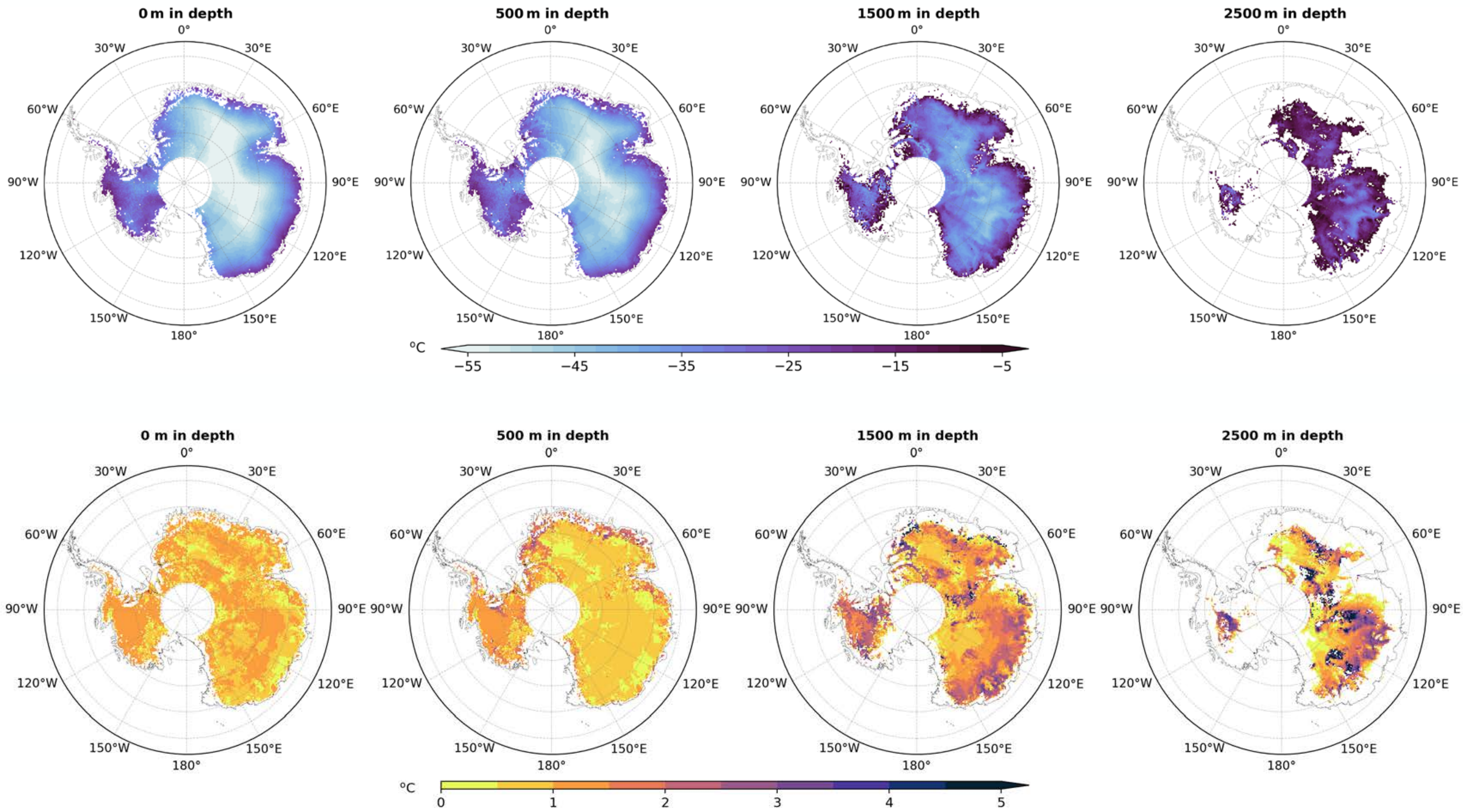
West and coastal area

- ✓ 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

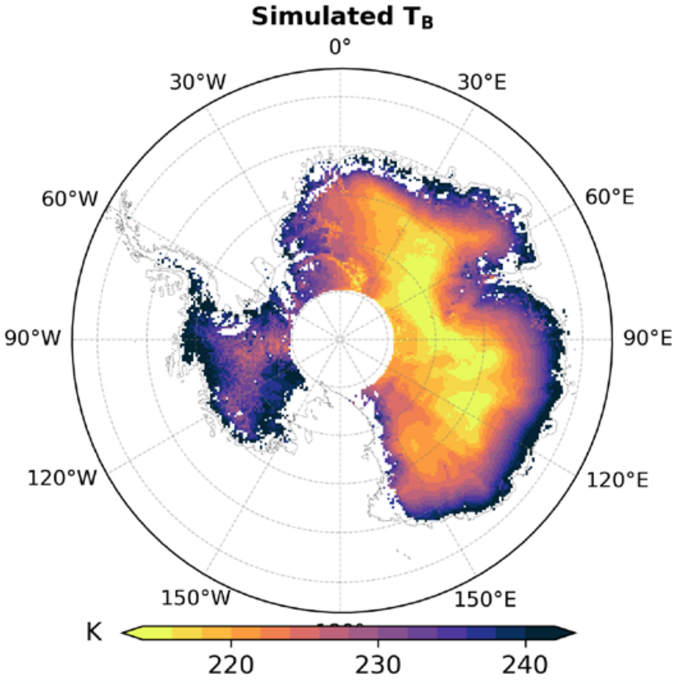
Results – Temperature maps

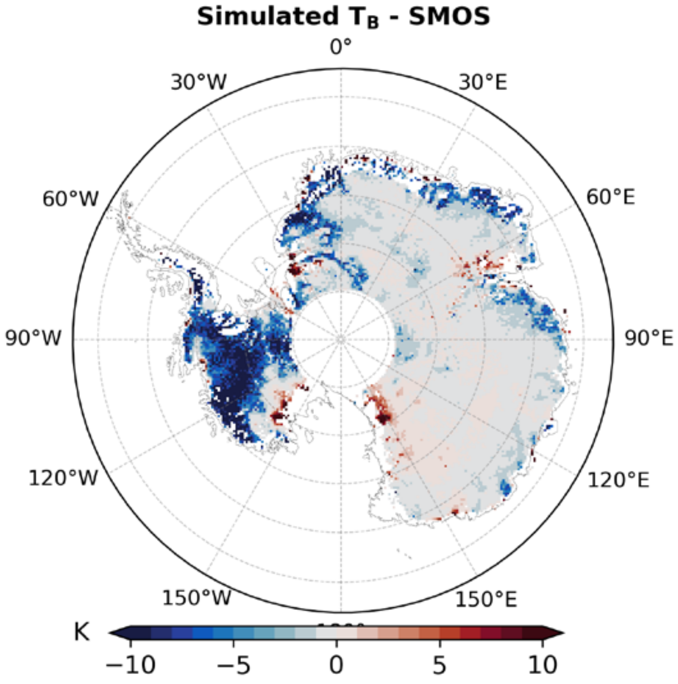


Ice temperature

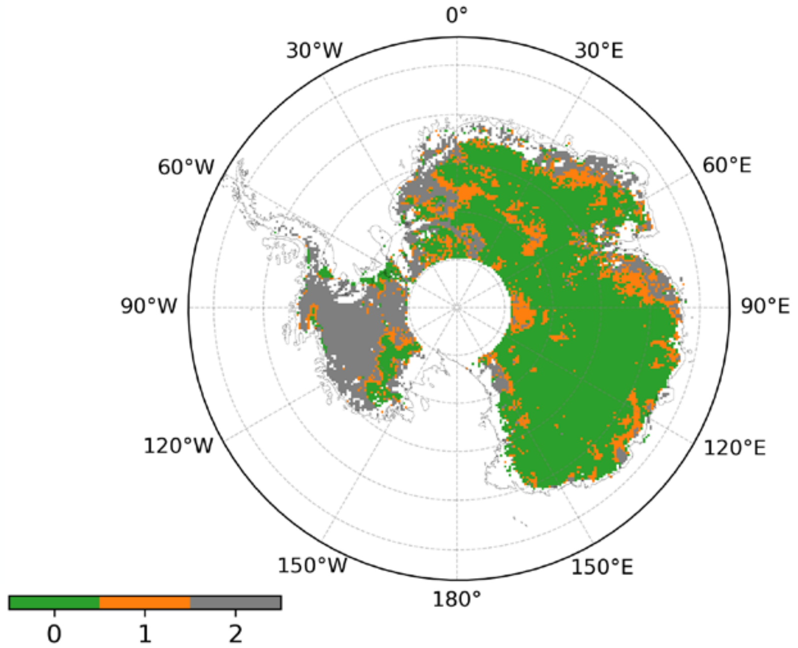
Standard deviation

Ice sheet temperature in Antarctica from SMOS
Results – Quality Flag





Quality Flag



2 – Doubtful → dif > 2 K

1 – Acceptable → dif < 2 K

0 – Good → dif < 1 K

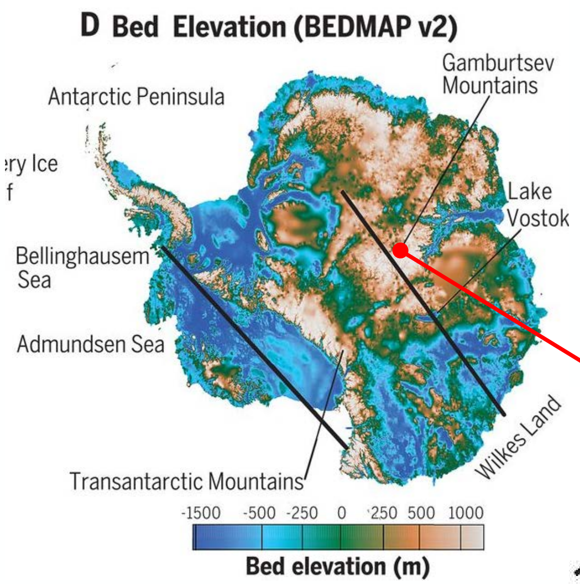
- ✓ Difference between simulation and SMOS usually < 1 K
- ✓ except over the West Antarctica suggesting issues in the snow/ice emission modelling

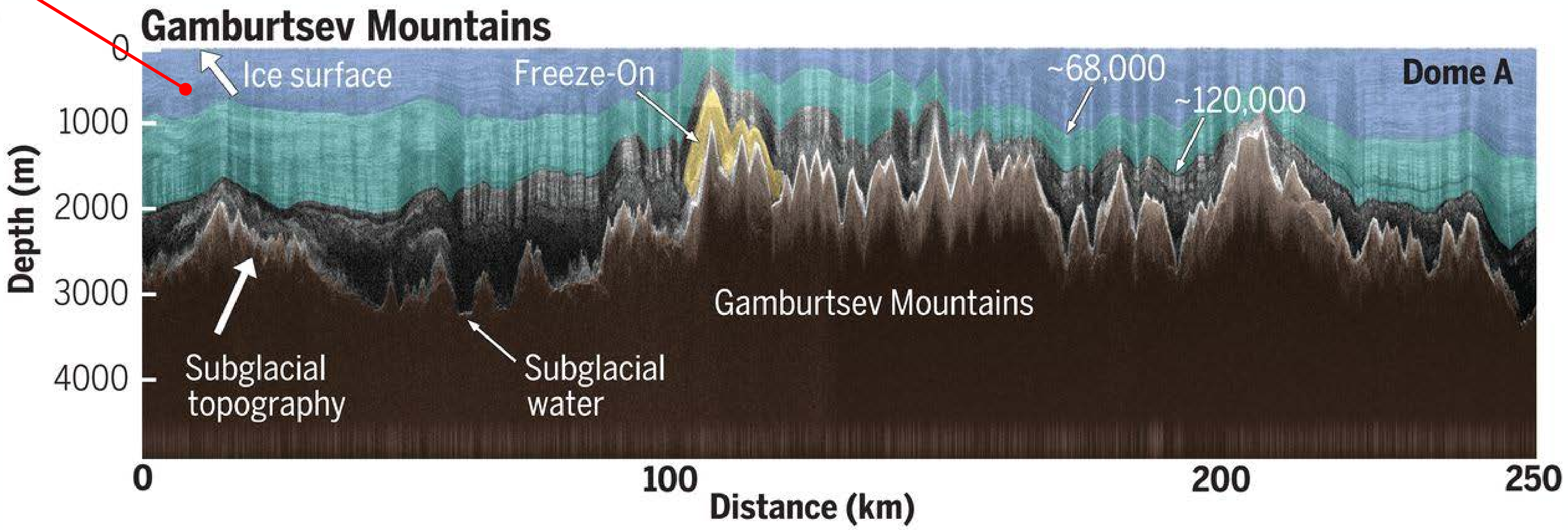
→ retrieval less reliable here

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

Ice sheet temperature in Antarctica from SMOS
Perspectives

Higher Resolution → 10 Km

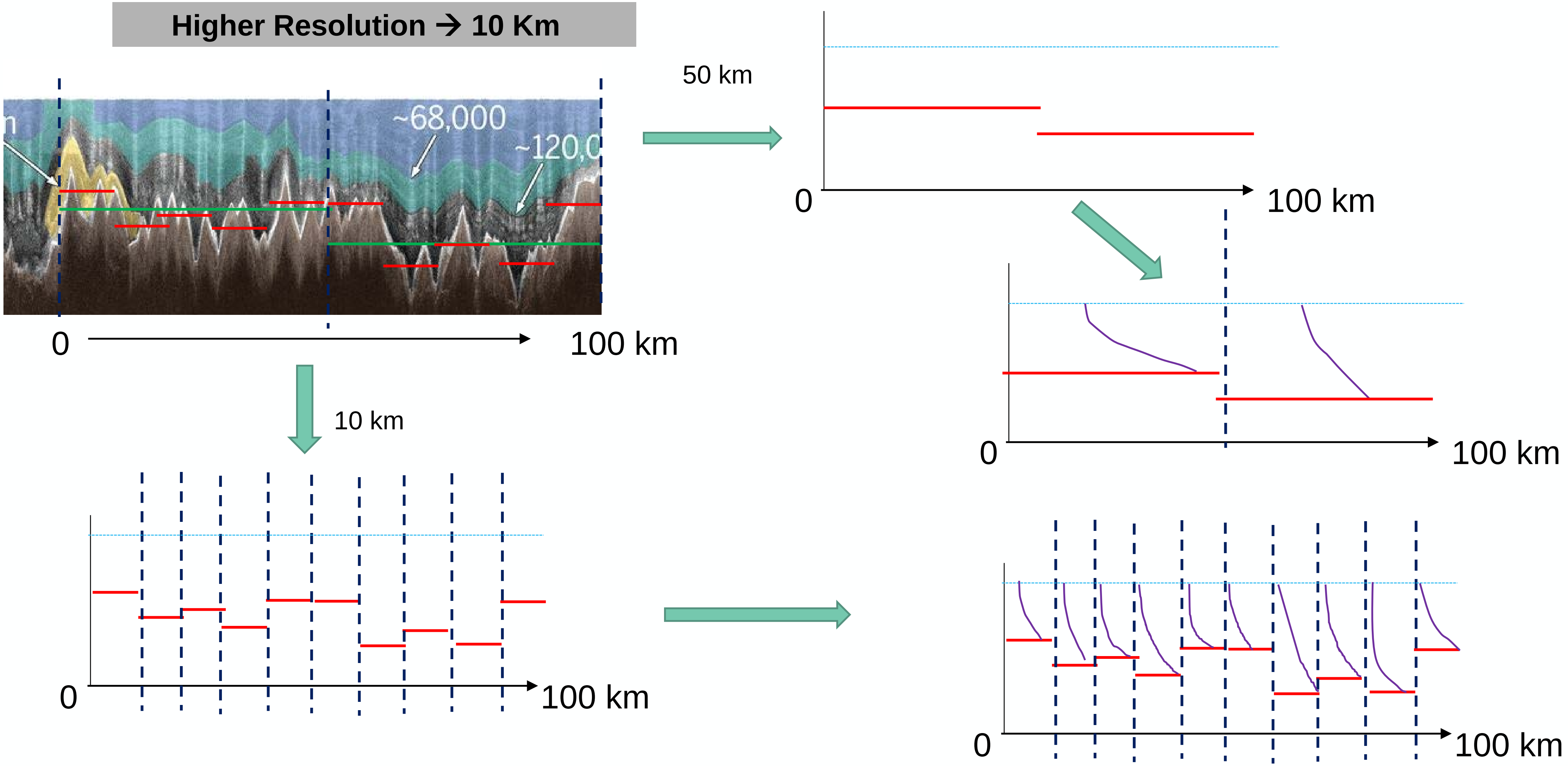




From Bell et al. (2020)

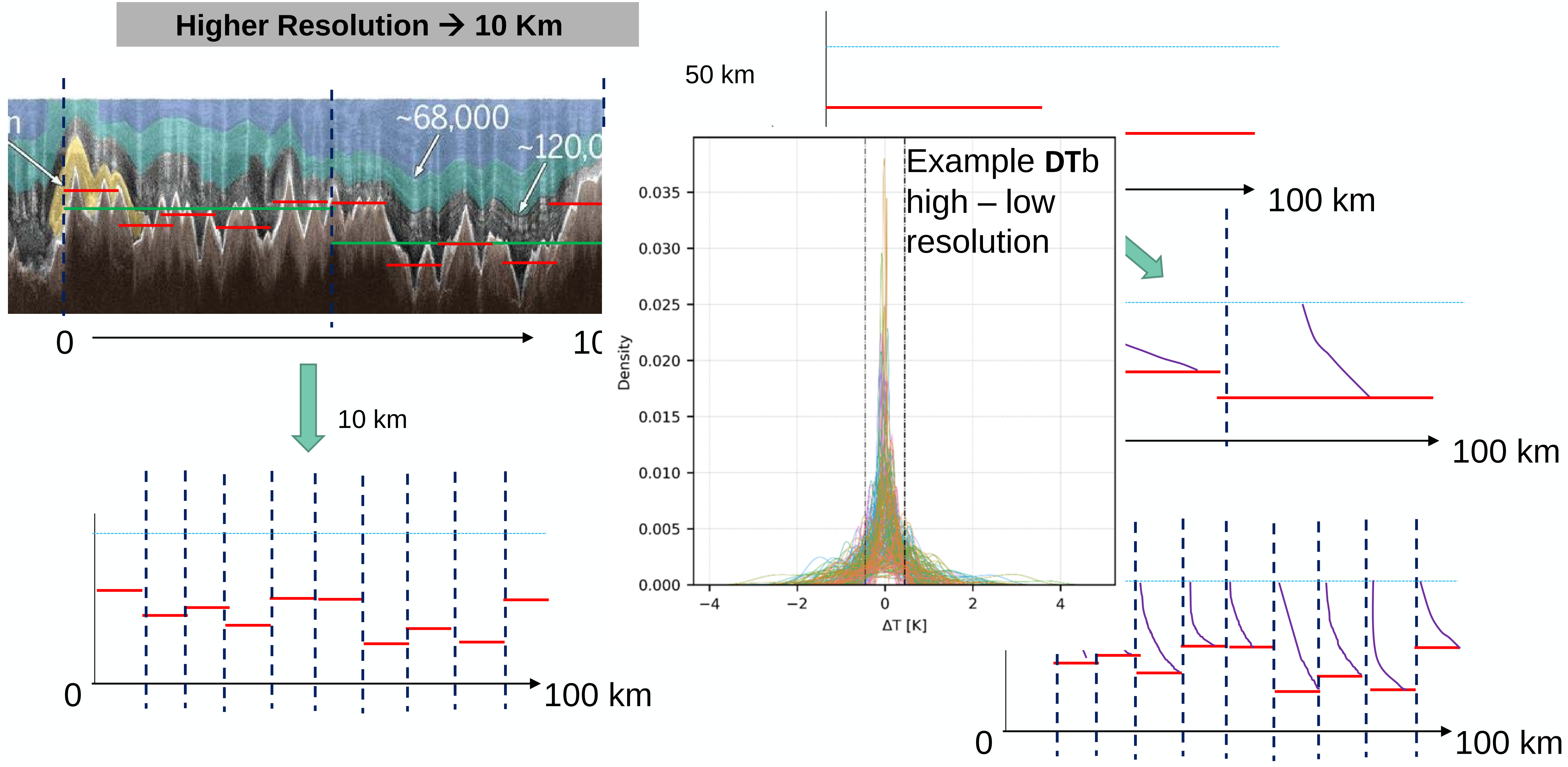
Ice sheet temperature in Antarctica from SMOS
Perspectives

Higher Resolution → 10 Km



Ice sheet temperature in Antarctica from SMOS
Perspectives

Higher Resolution → 10 Km



Ice sheet temperature in Antarctica from SMOS
Summary and Perspectives

Summary

- ✓ Using L-band radiometer and retrieval algorithm is possible **to provide information on ice sheet temperature profile → not available before (**only from few boreholes and models**)**
- ✓ Retrieval provides **ice temperature, uncertainties and quality flag**
- ✓ **Relevant for ice sheet rheology → ice sheet processes and stability → sea level raise**
- ✓ **Not developed close to the coast** (melting/complexity)
- ✓ Error increases close to the base (**for penetration depth limit**)

Short-term perspective – on going

- ✓ Investigate the **electromagnetic modelling** over the West Antarctica
- ✓ Apply the methodology to the **Greenland** ice sheet
- ✓ Couple results with geology community → GHF estimate from lithosphere processes

Long-term perspectives

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