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Science of 10-km Resolution L-band Radiometry, JPL, October 10-12, 2023

Ice Sheet Liquid Water Content Retrieval with L-band and Multi-Frequency Radiometry

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2) University of Montana

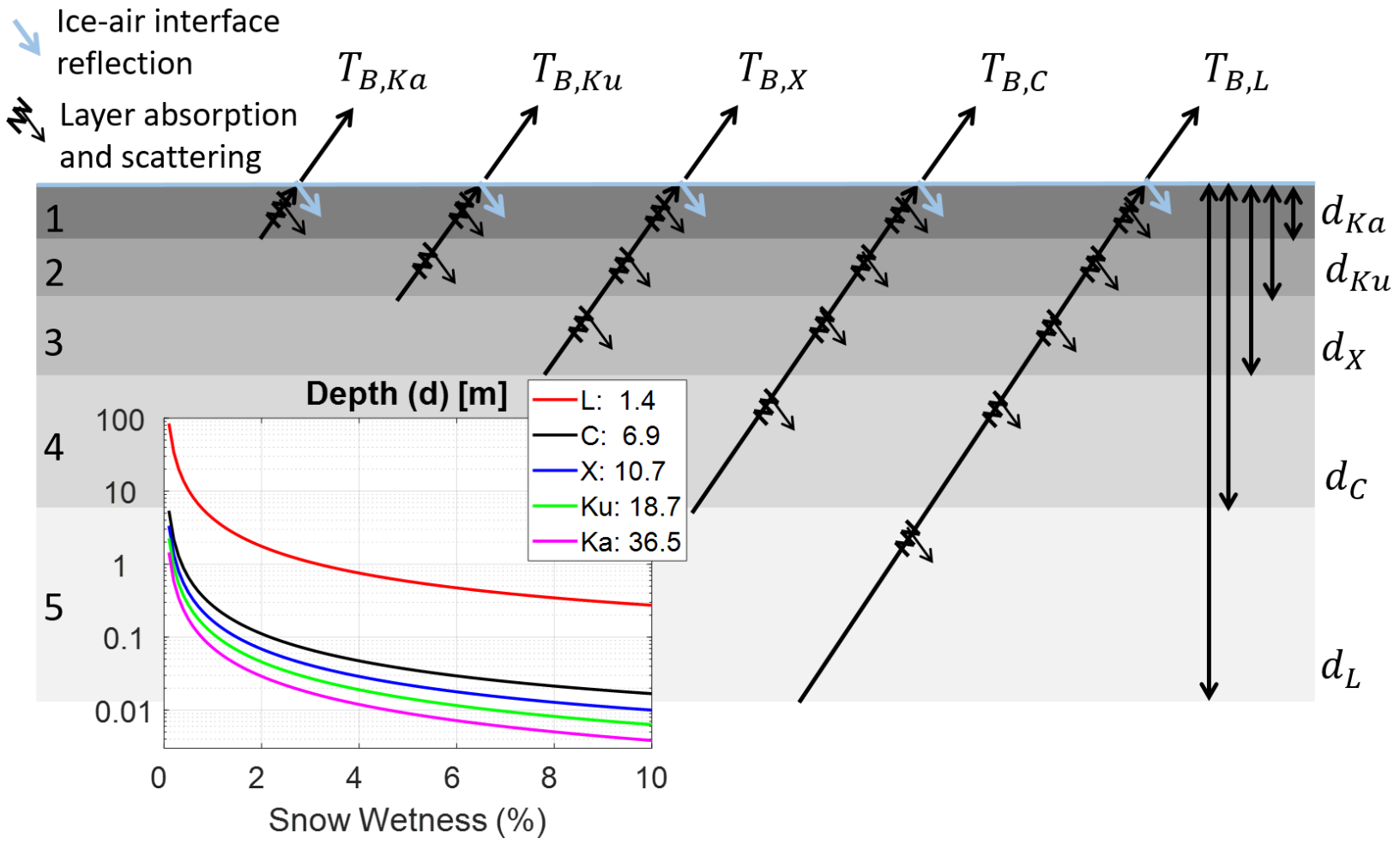
3) University of Calgary

4) Cooperative Institute for Research in Environmental Sciences (CIRES)

5) Geological Survey of Denmark and Greenland (GEUS)

6) NOAA Geophysical Fluid Dynamics Laboratory

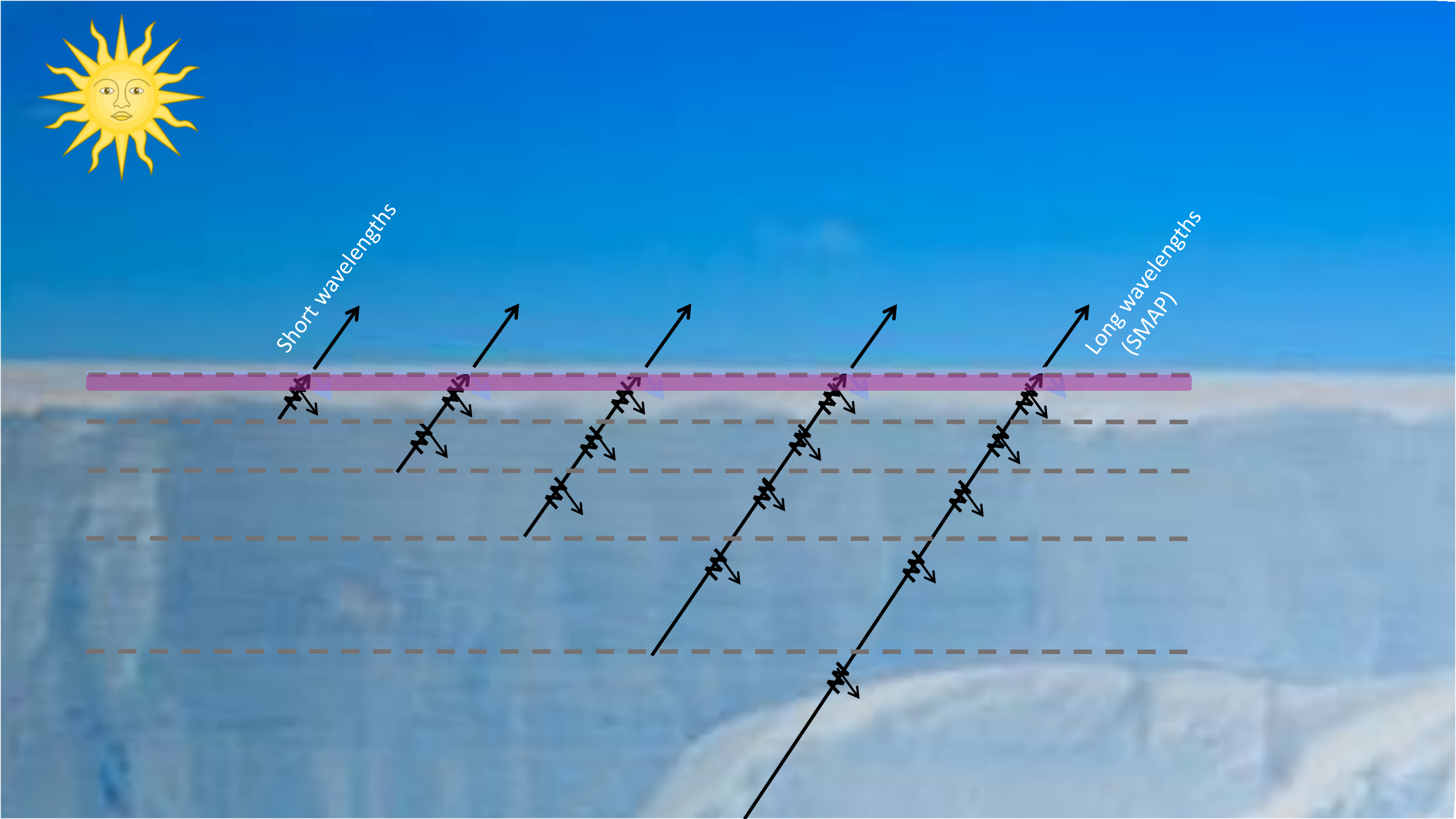
Multi-Frequency Origination Layer Thickness

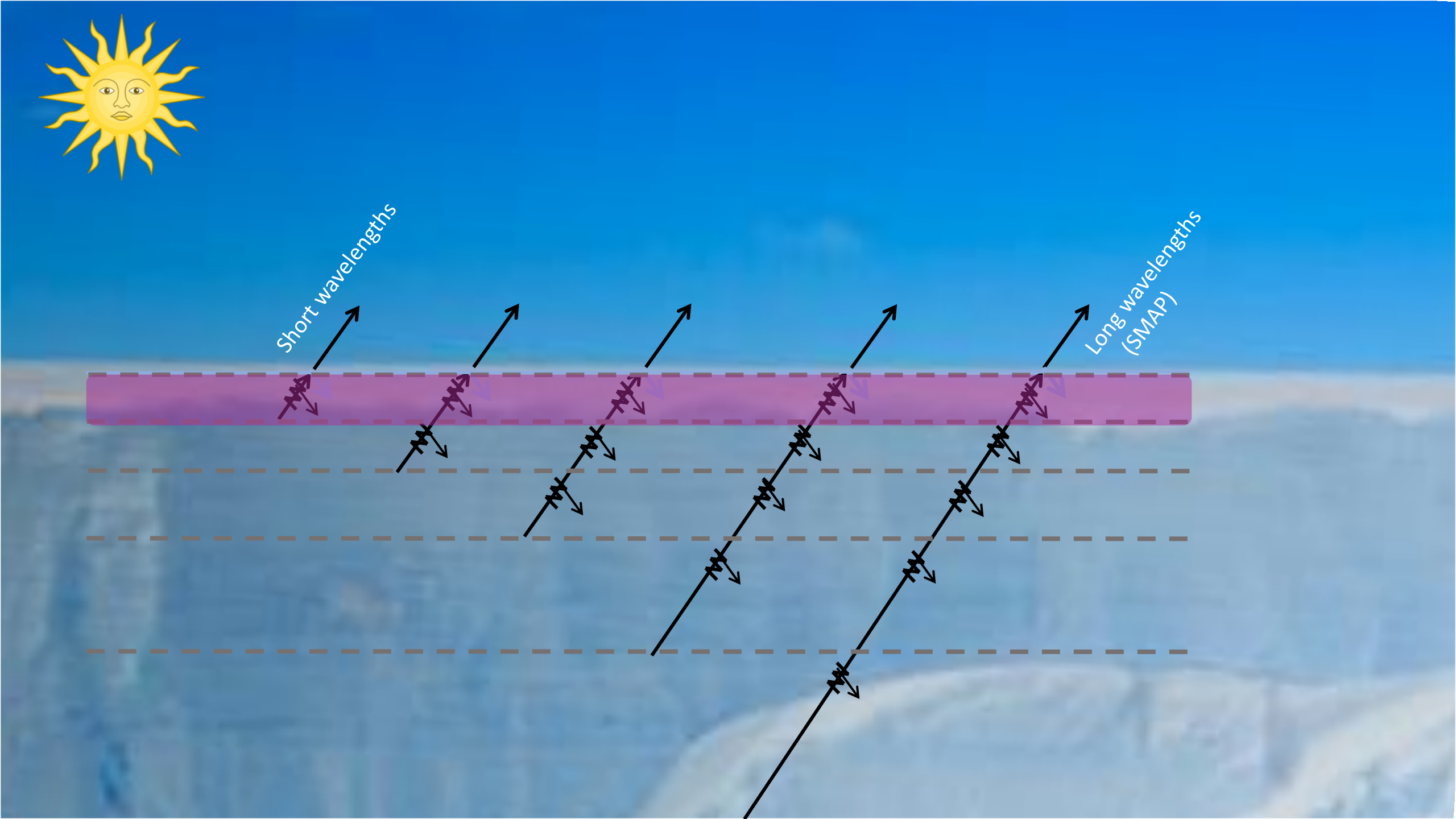


Radiation originated at various layers of ice sheet may propagate to the surface (depending on the frequency) through all layers, and is reflected at the air-ice sheet interface (depending on the frequency)

=>

The measured thermal emission has a variable origination layer thickness as a function of frequency


Short wavelengths
Long wavelengths
(SMAP)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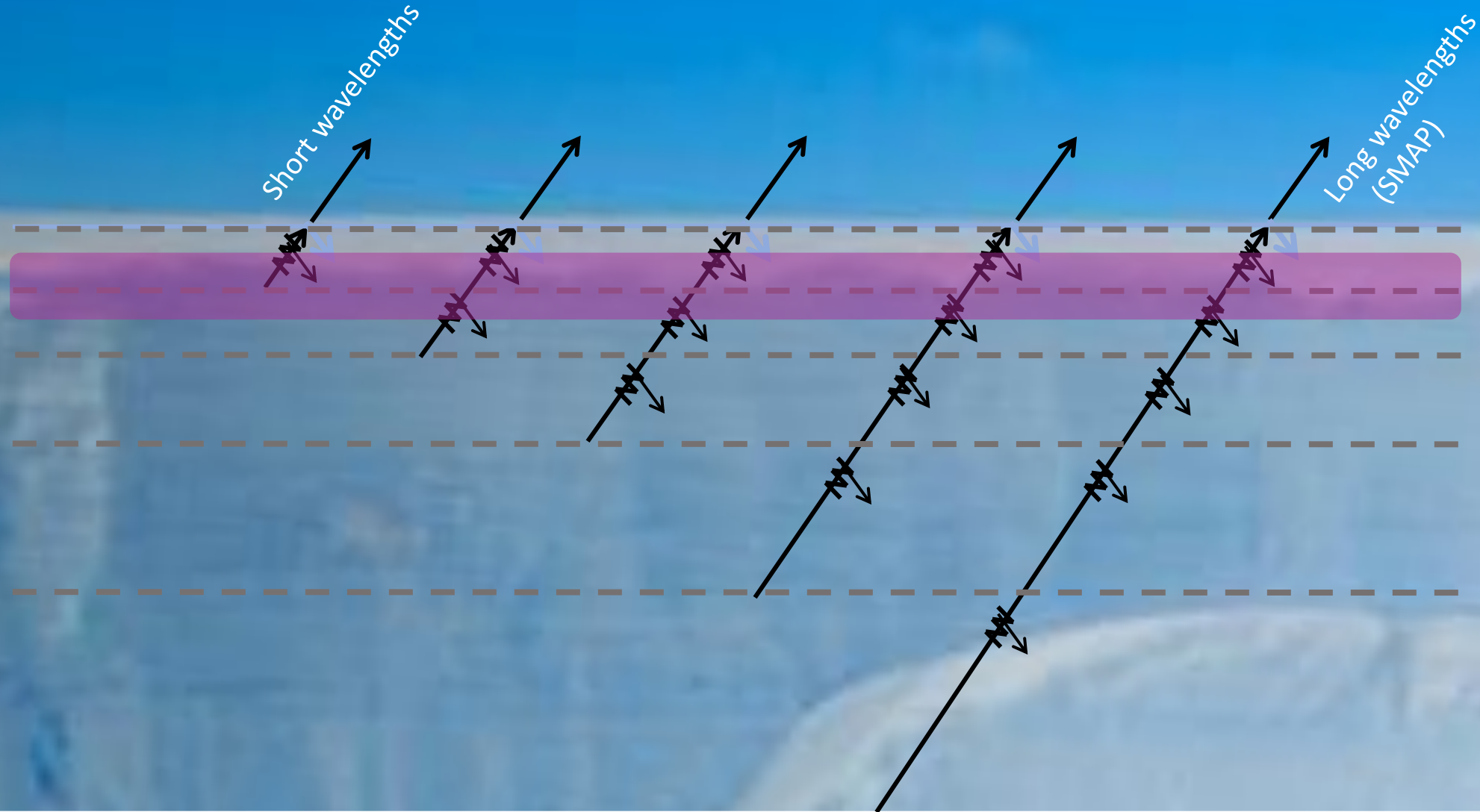
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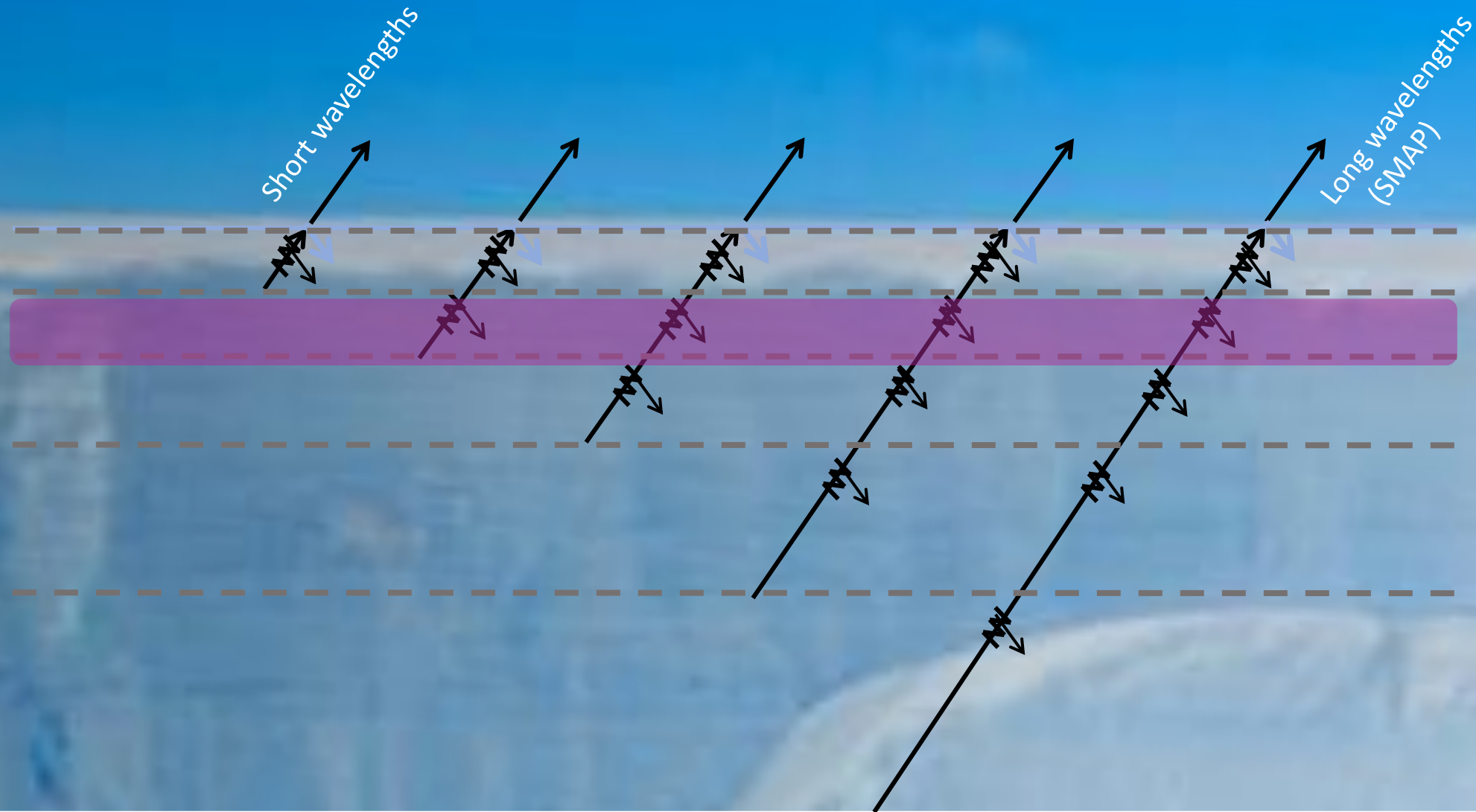
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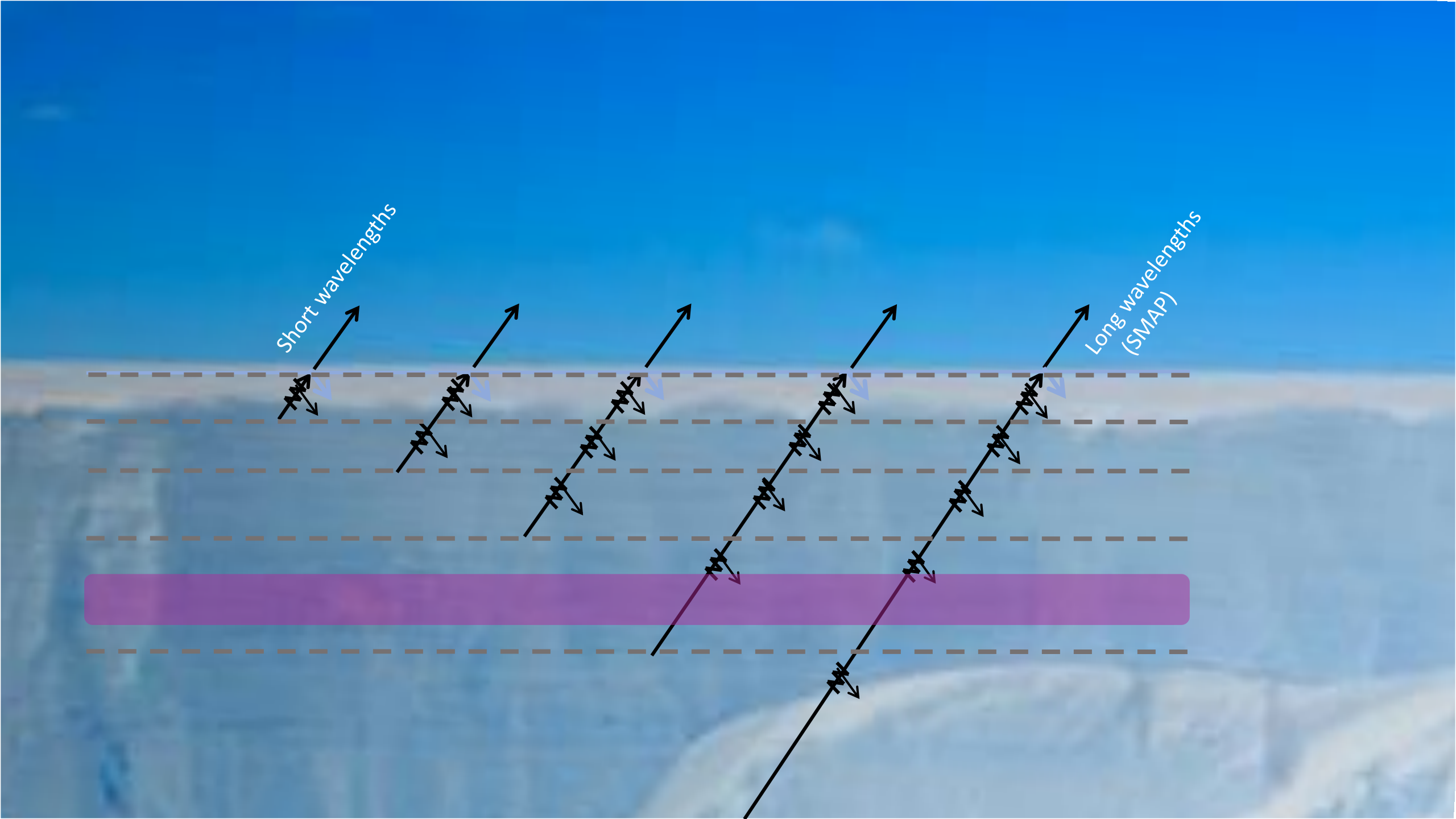
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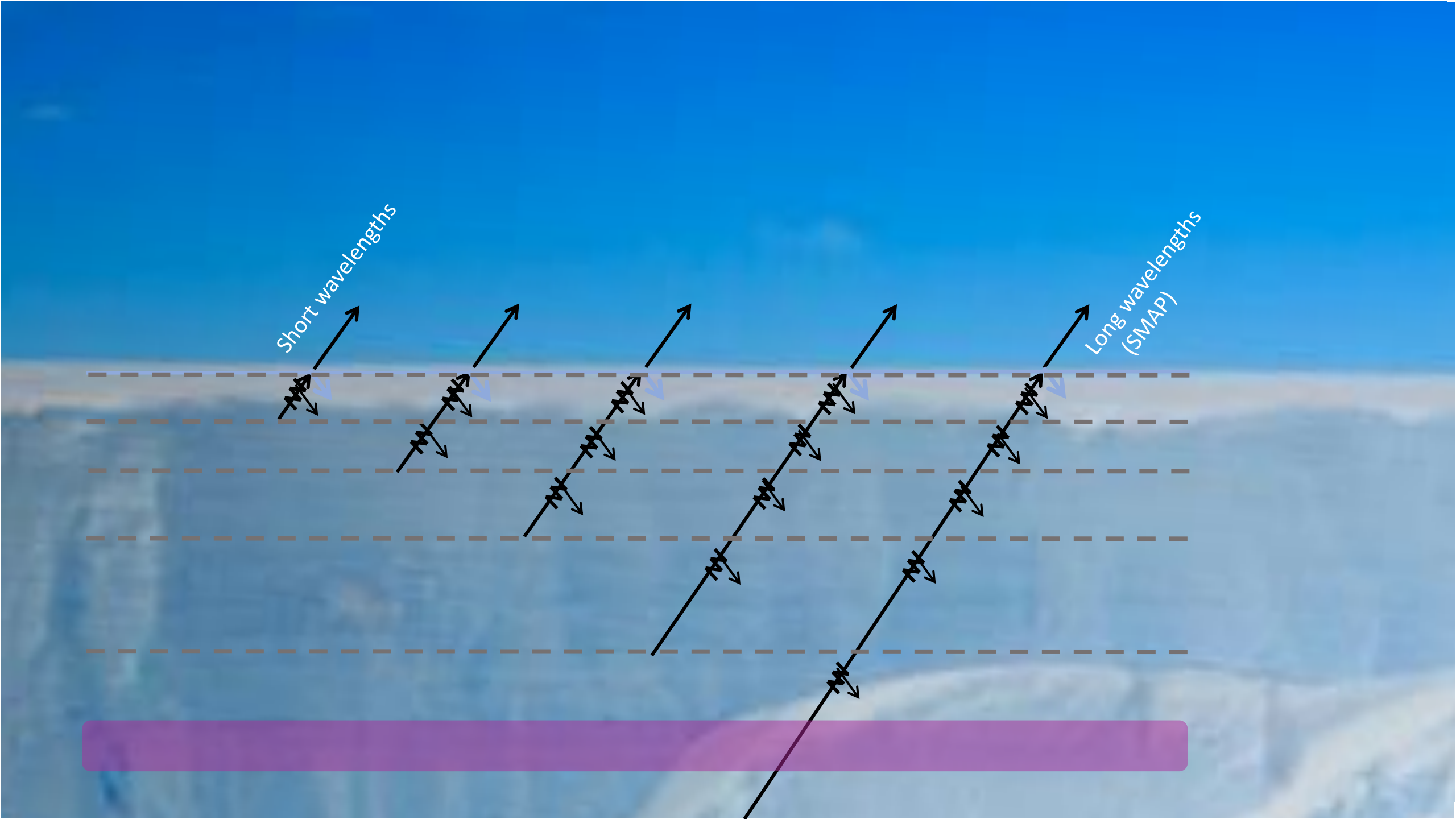
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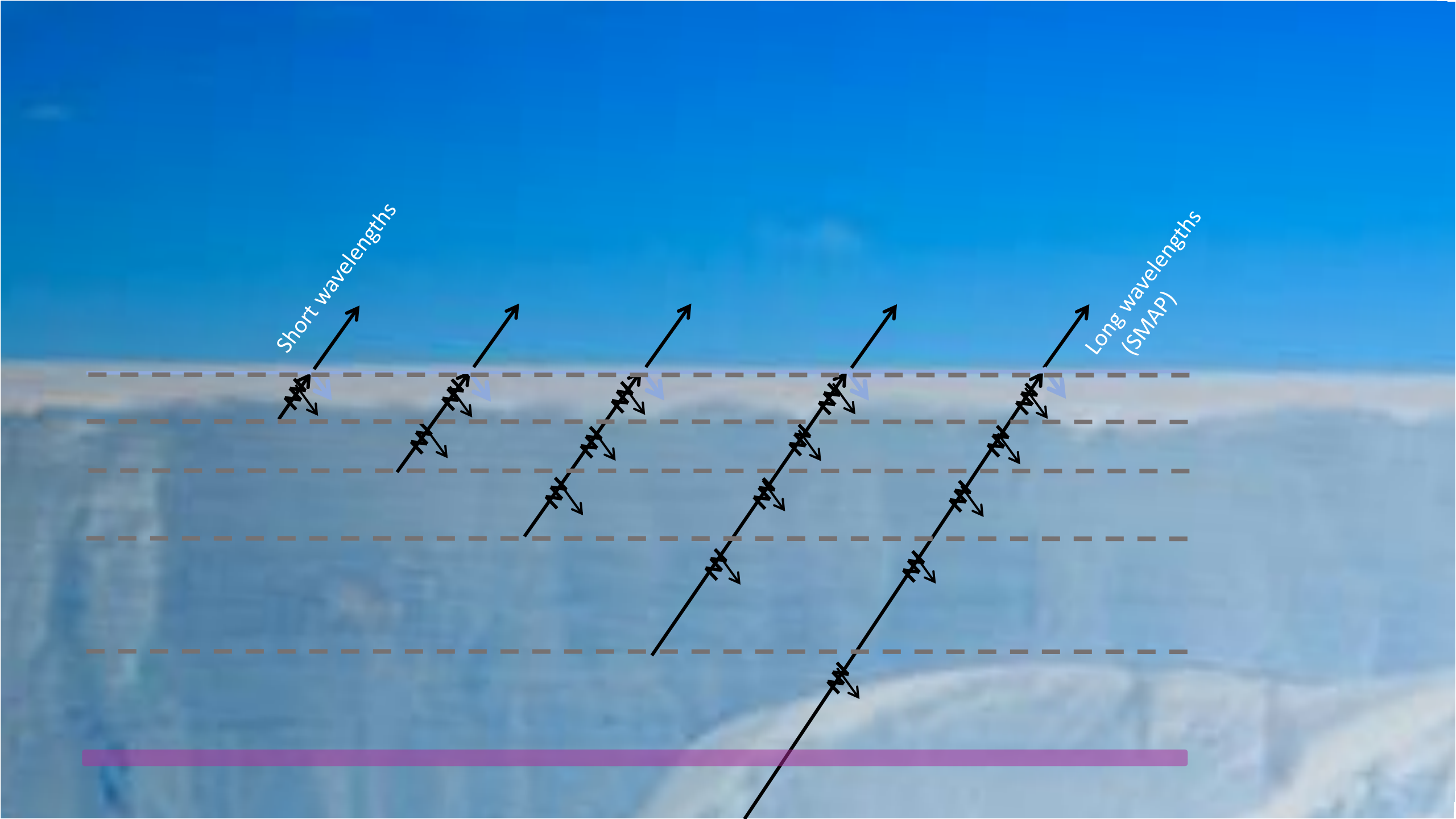
Short wavelengths
Long wavelengths
(SMAP)

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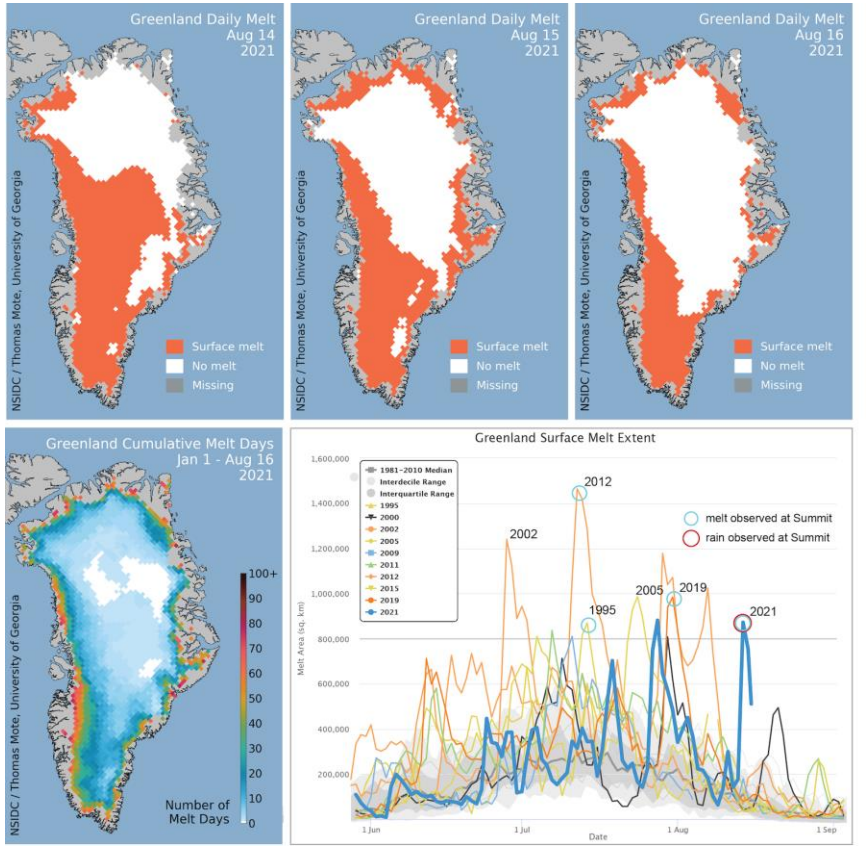
Microwave Record on Melt Detection

- Traditional passive microwave approaches use 19 and/or 36 GHz
  - "+" Long time series
  - "+" Sensitive to near-surface dielectric constant change
  - "-" Sensitive to snow grain metamorphosis
  - "-" Sensitive to atmospheric effects
  - "-" Do not see beyond the immediate surface, limits the information to surface
- Studies show several meters deep meltwater infiltration is commonplace, not measurable with 19/36 GHz techniques
- Lower frequencies enable snow wetness retrieval deeper in the ice sheets
  - e.g., Mousavi et al., 2021; 2022; Houtz et al., 2020
- Use of 6.9 and 10.7 GHz and a combination of 1.4 GHz with higher frequencies almost nonexistent in the past
- Optical and active microwave can provide high-resolution surface melt information but often with limited temporal resolution (limited by either overpass timing or clouds)



Greenland today, NSIDC 36.5 GHz melt product

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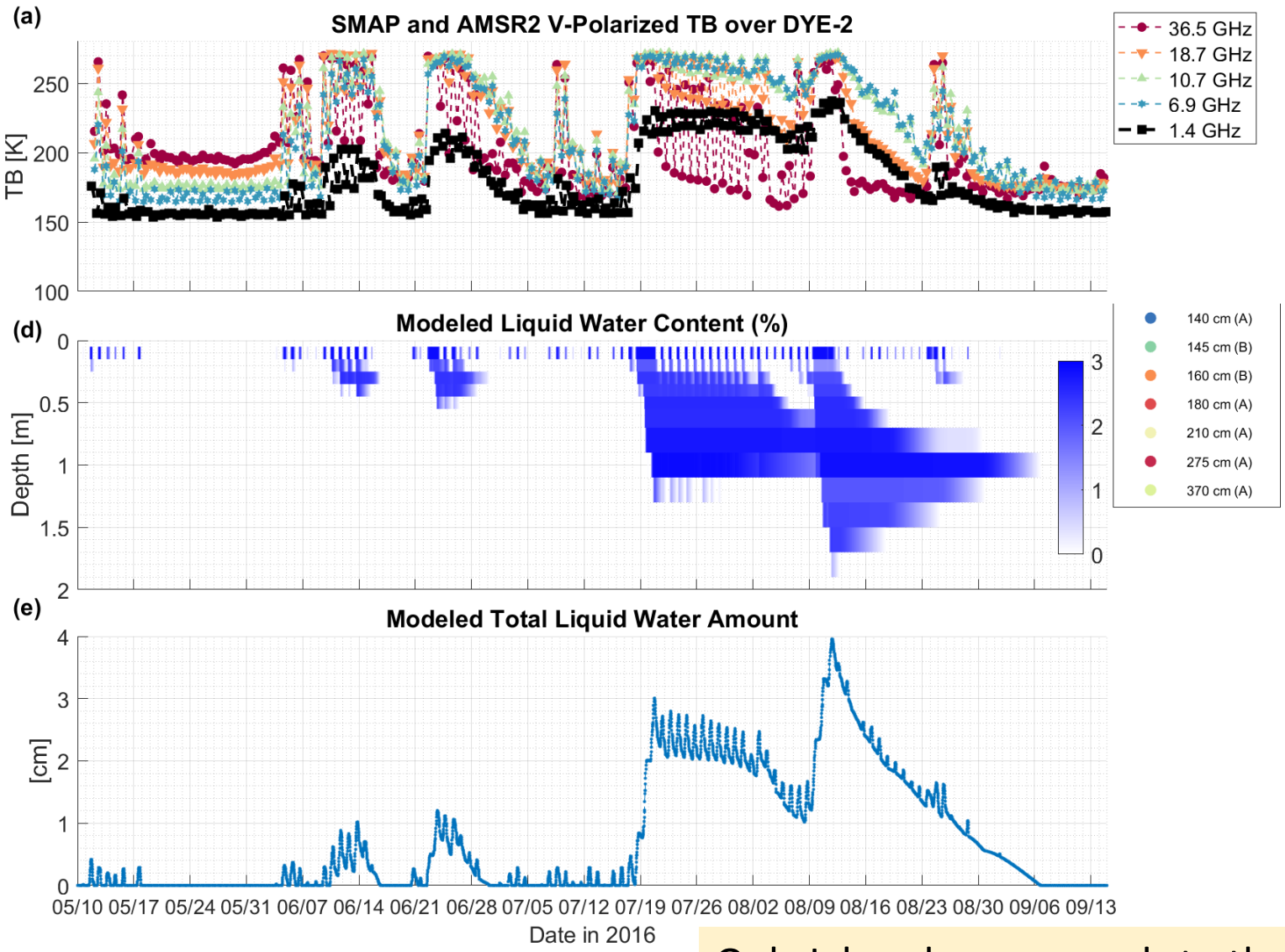
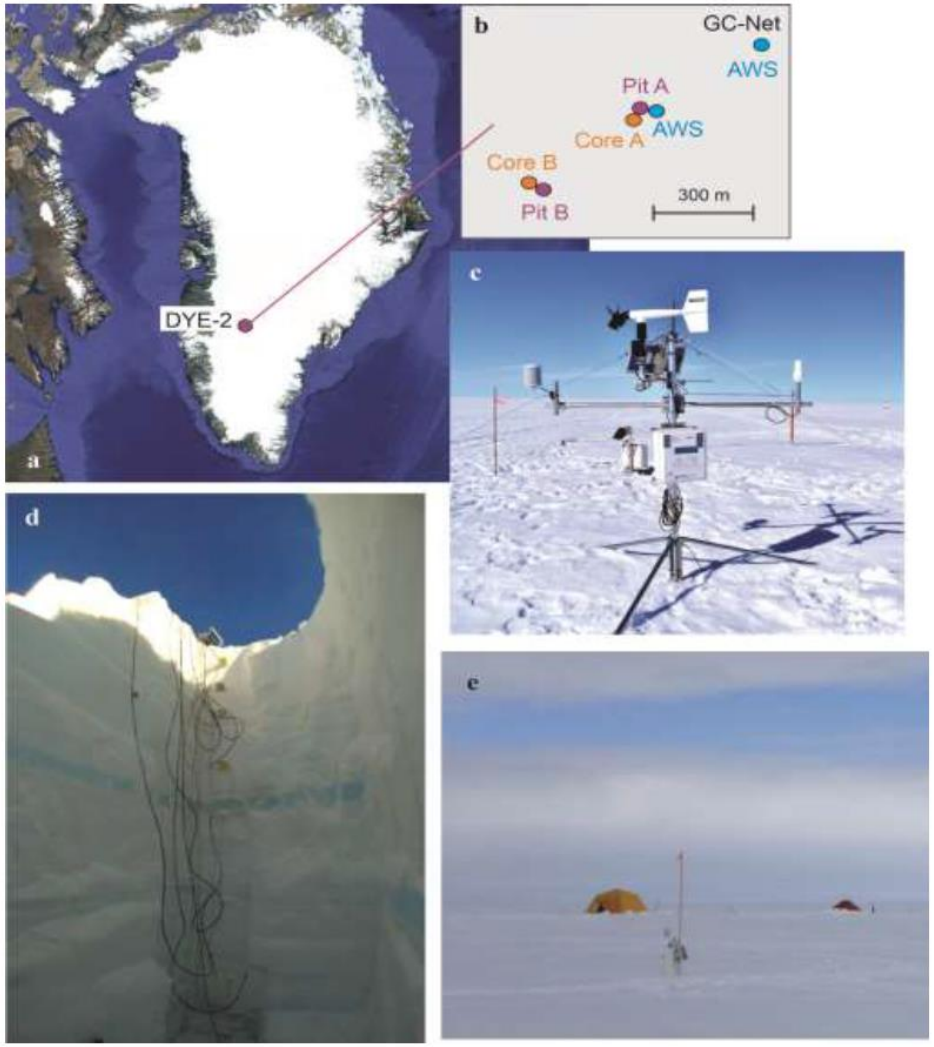
L-band is Sensitive to Total Meltwater Amount



In situ melt measurements at DYE-2 in 2016



Only L-band corresponds to the total meltwater, other frequencies saturate

Colliander, Mousavi et al. (2022)

Samimi, Marshall et al. (2021; 2022)

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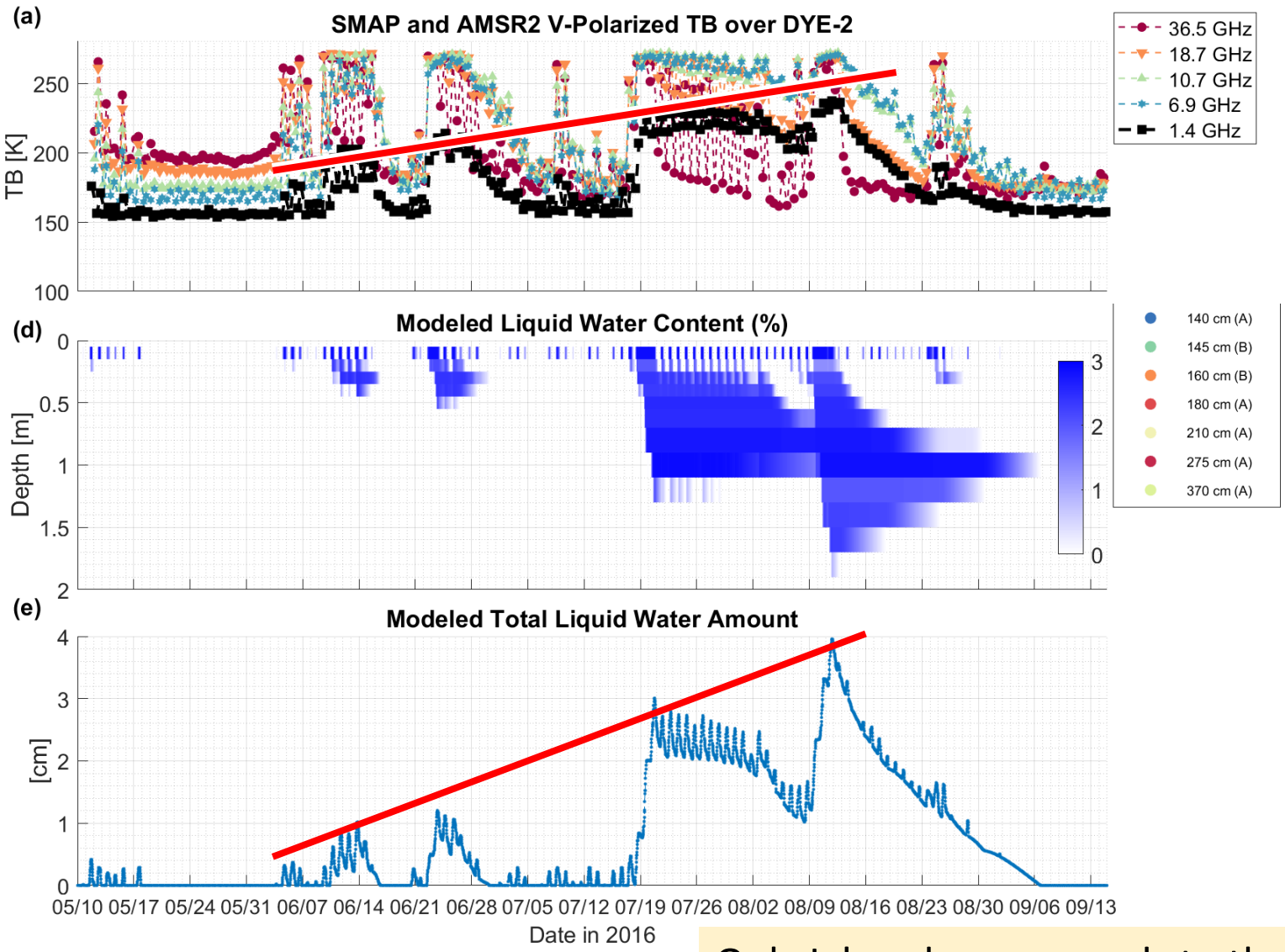

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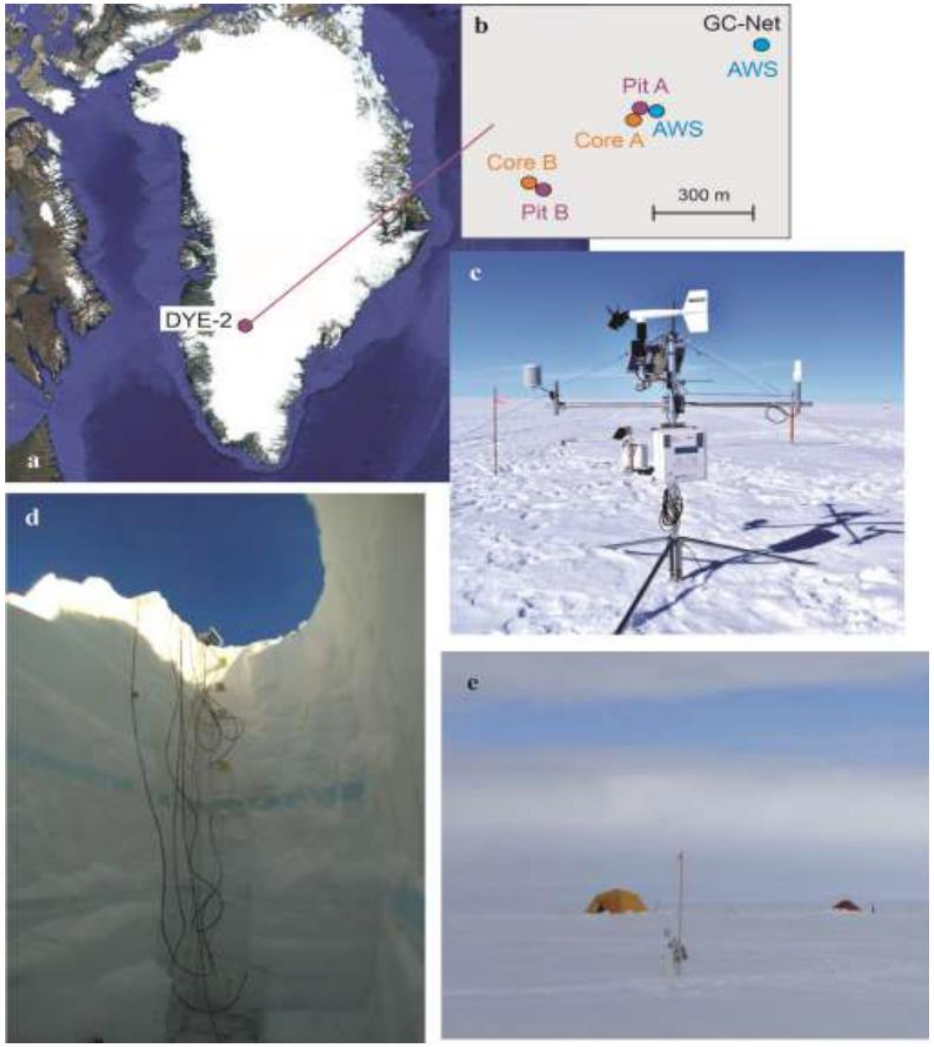

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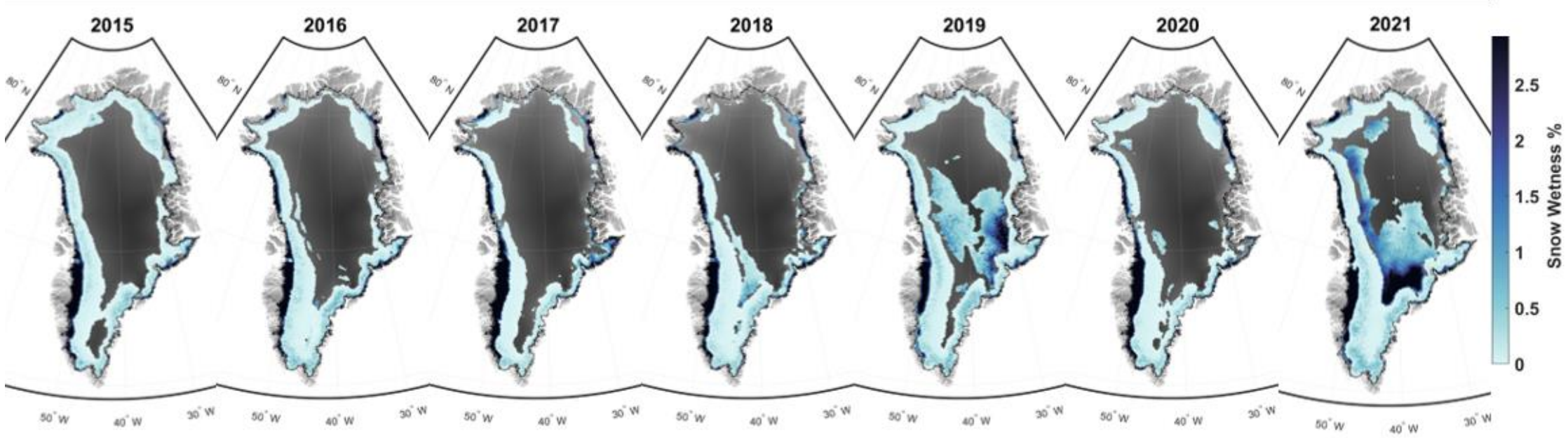
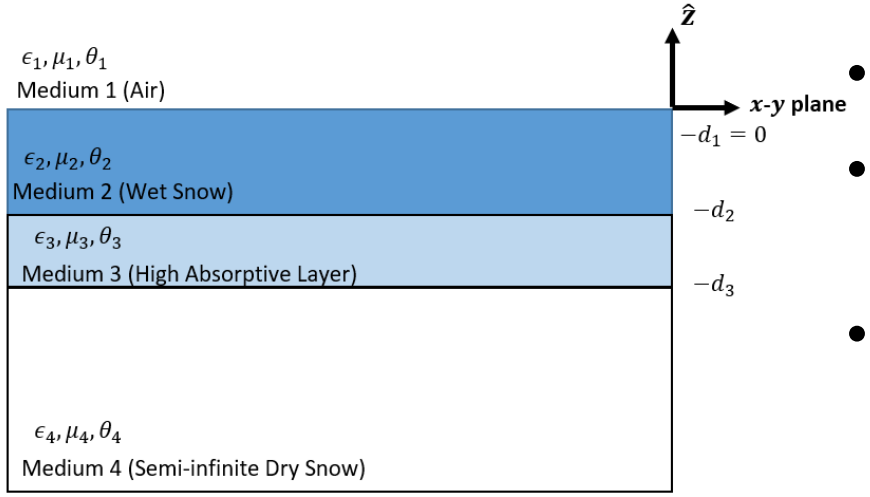
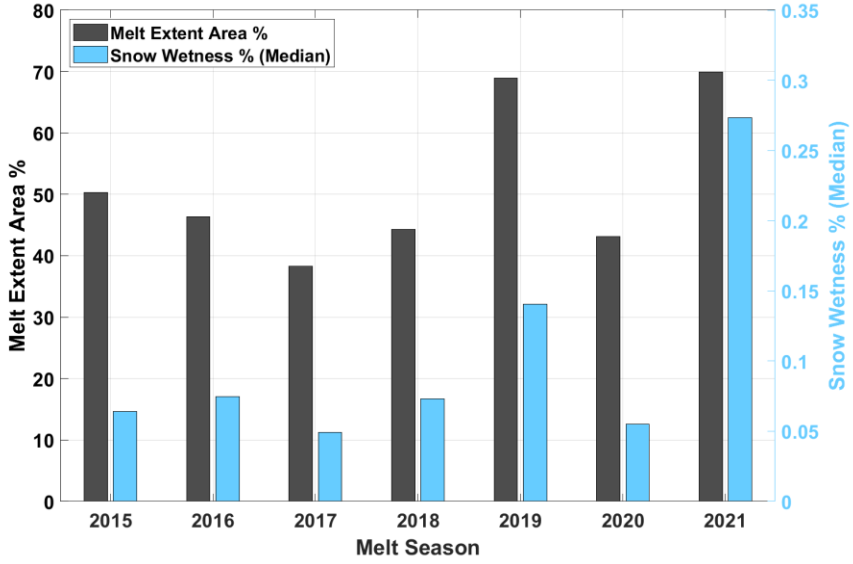
L-band Meltwater Retrieval





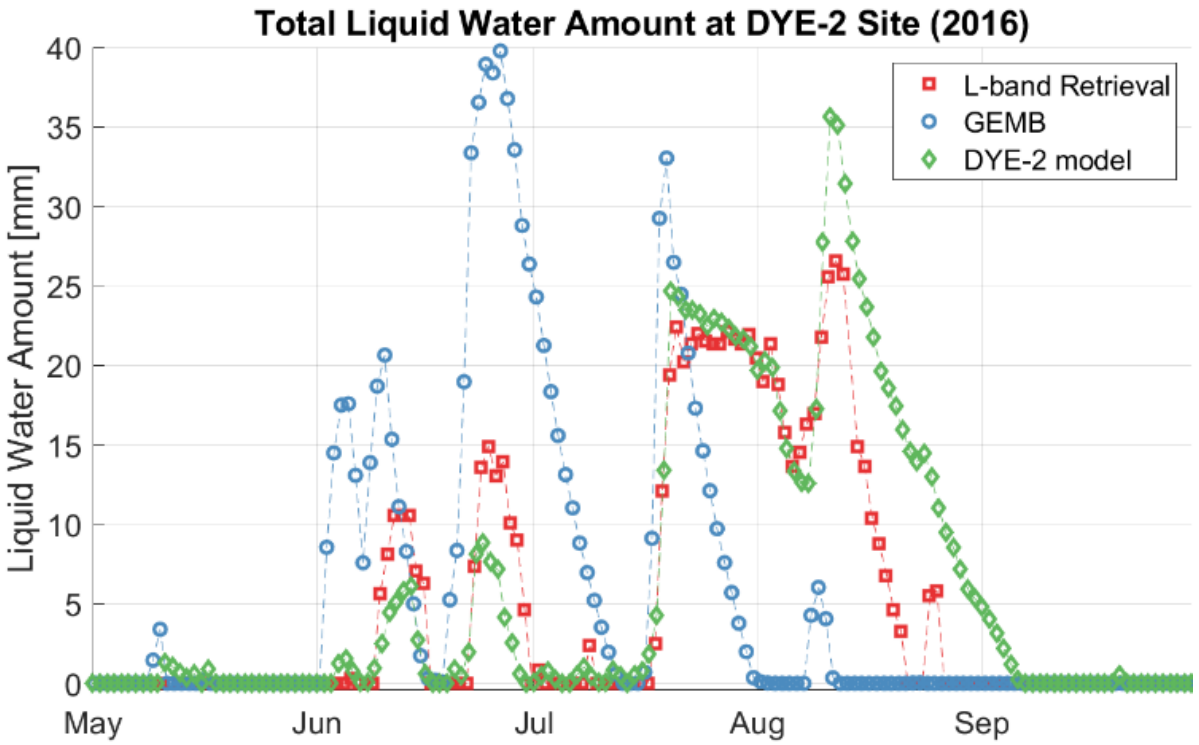
- Simple four-layer EM model
- Tune EM parameters during frozen and melt season
- Retrieve Liquid Water Content (LWC) by matching with observations each day

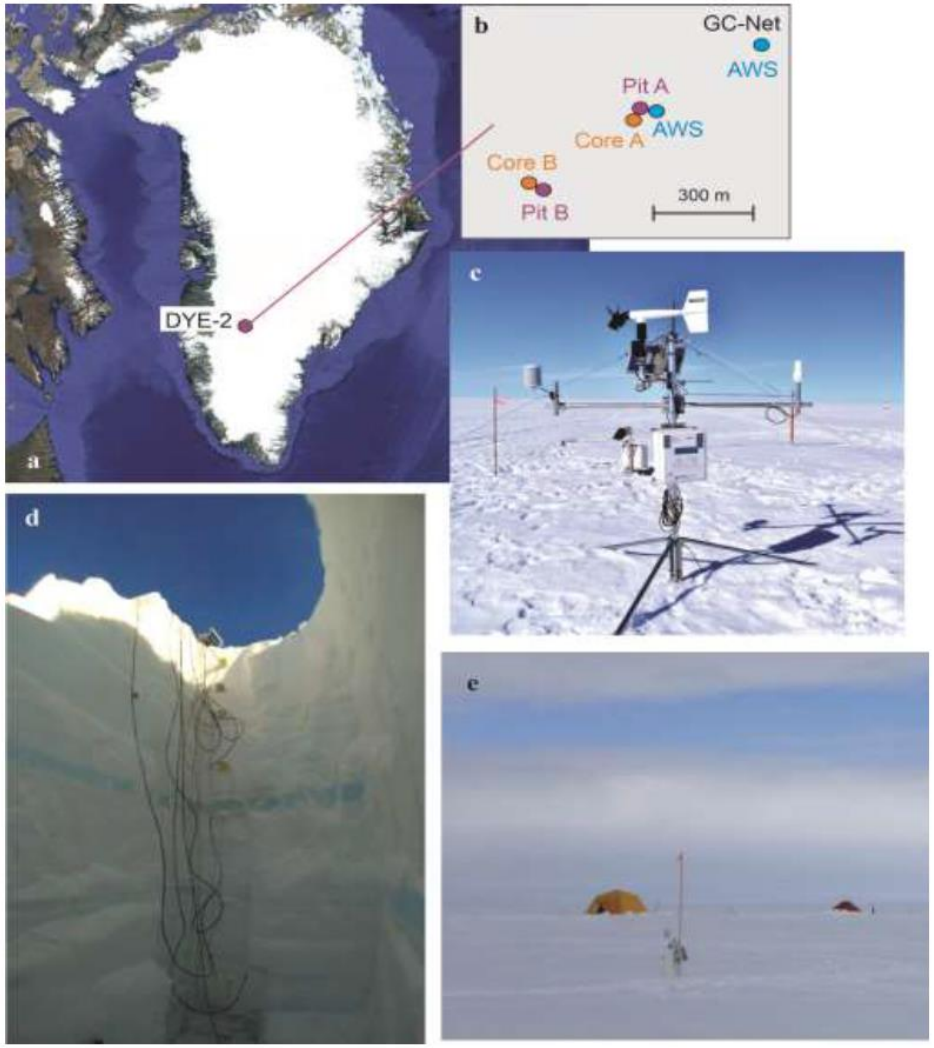


Mousavi, Colliander et al. (2021)

Station Measurements

- Liquid Water Content from subsurface temperatures
  - Local energy and mass balance model forced with sub-surface temperature and meteorological data

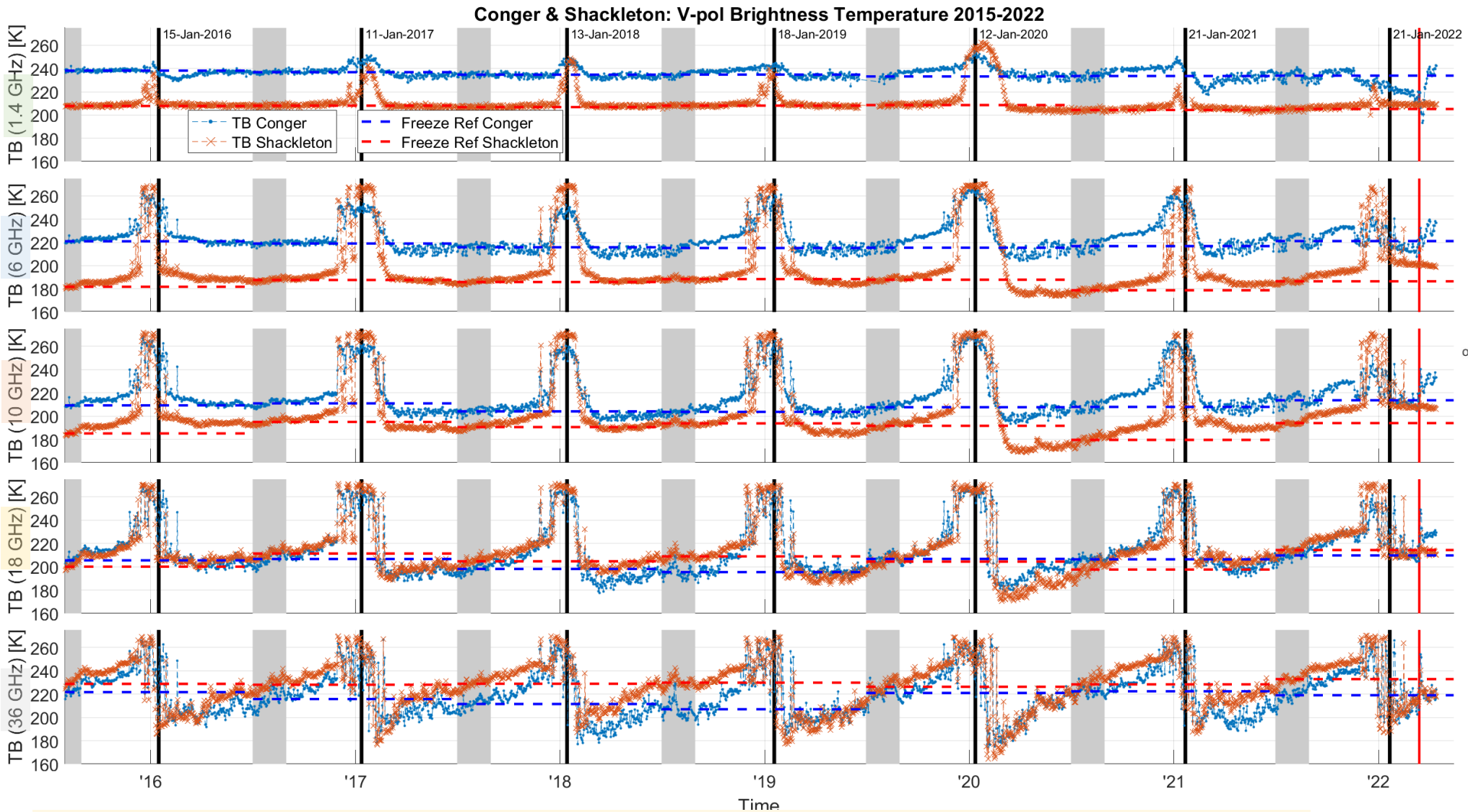


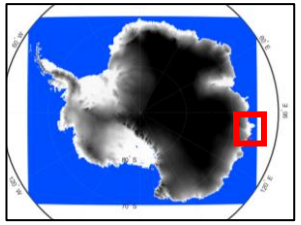


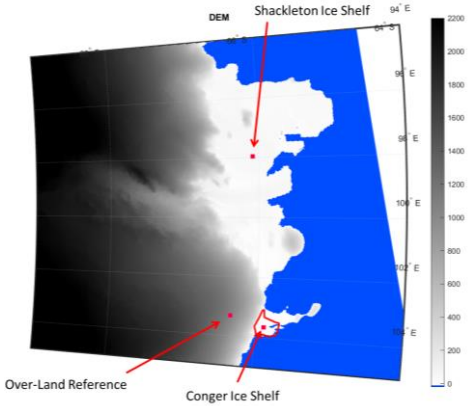
In situ melt measurements at DYE-2 in 2016 by Shawn Marshall (U. Calgary)

Colliander et al., 2022; Samimi et al., 2021; Mousavi et al., 2021; Gardner et al., 2023

Shackleton Ice Shelf



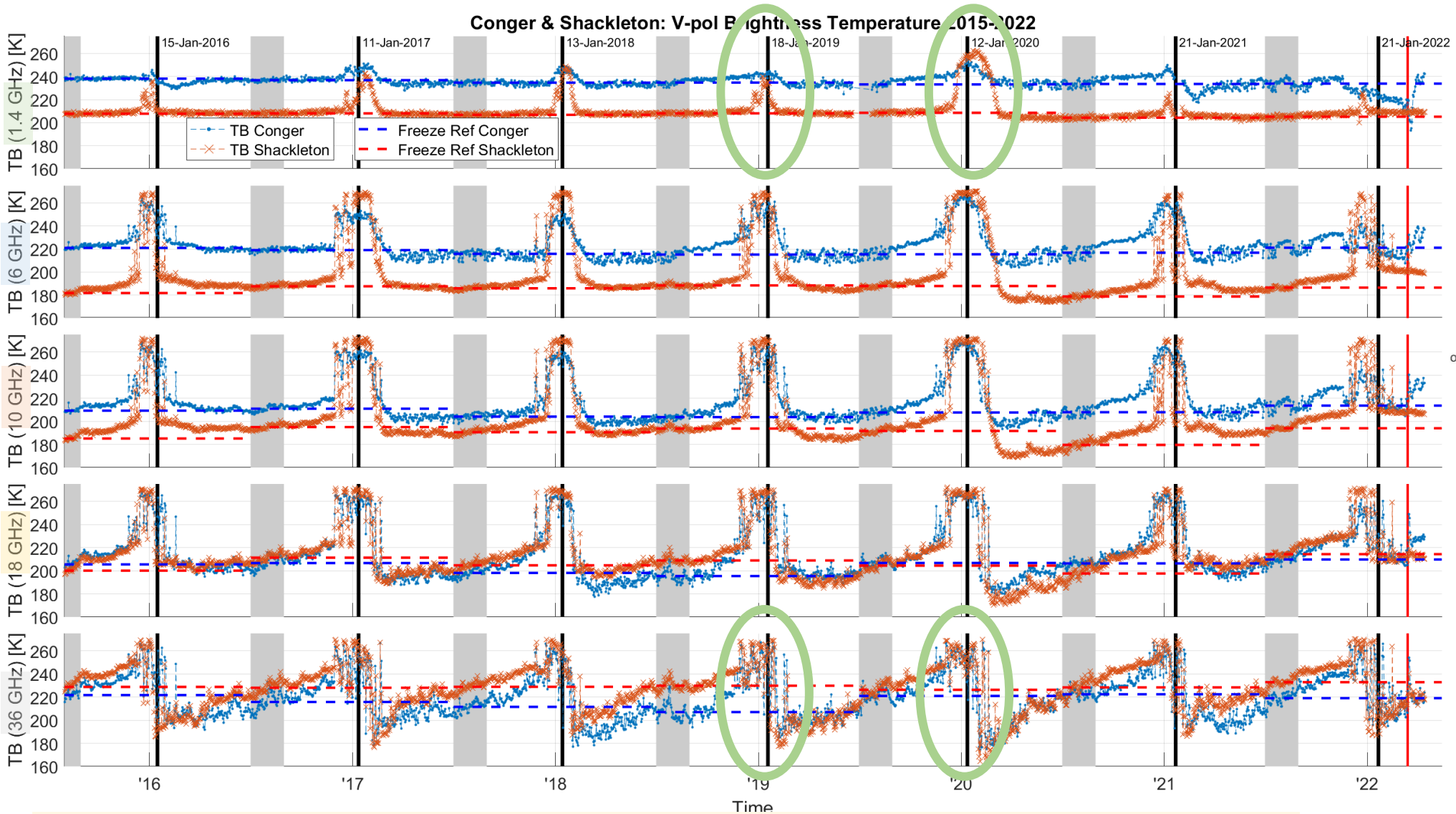


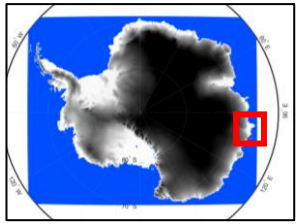


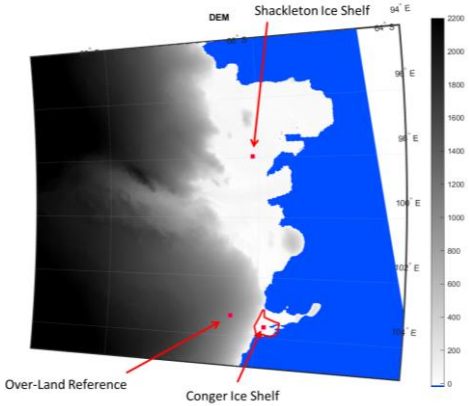
L-band signature reveals the range of meltwater generation, while the lower frequencies saturate and give only binary information

Colliander et al. (2022). AGU

Shackleton Ice Shelf







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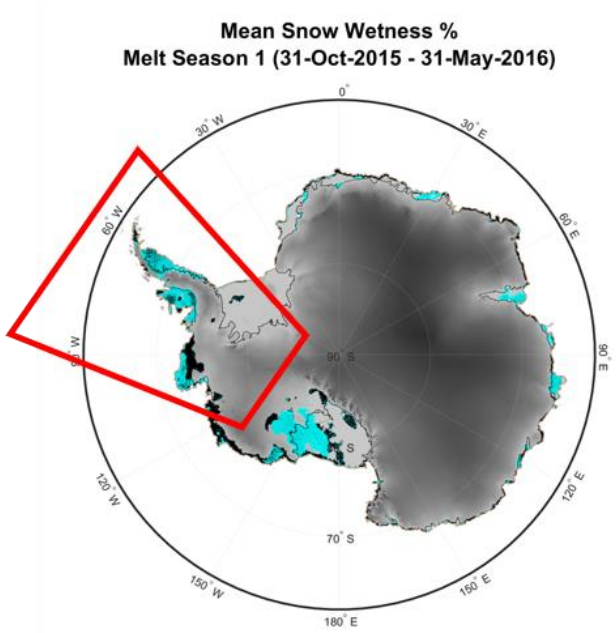
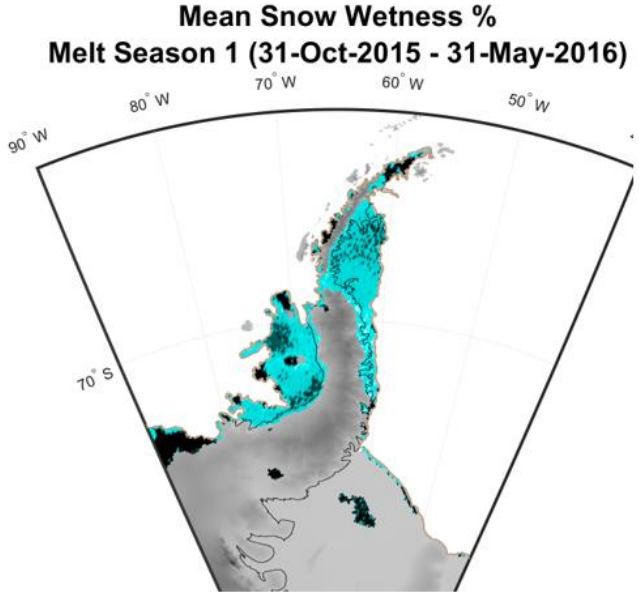
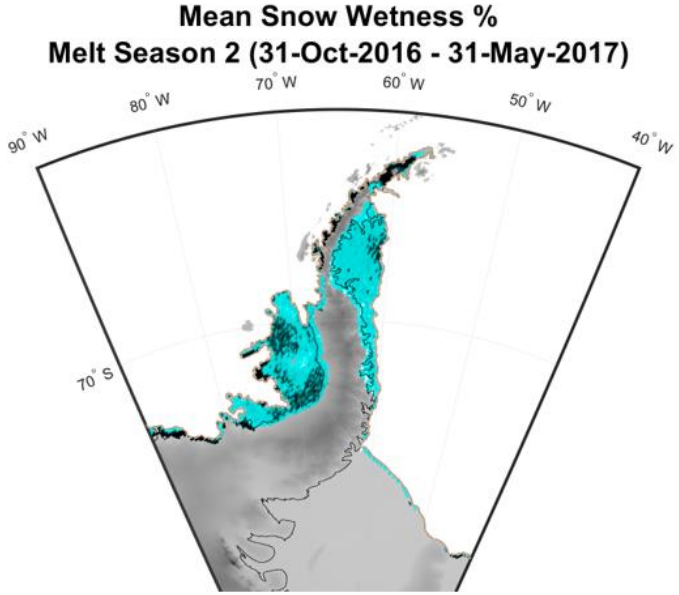
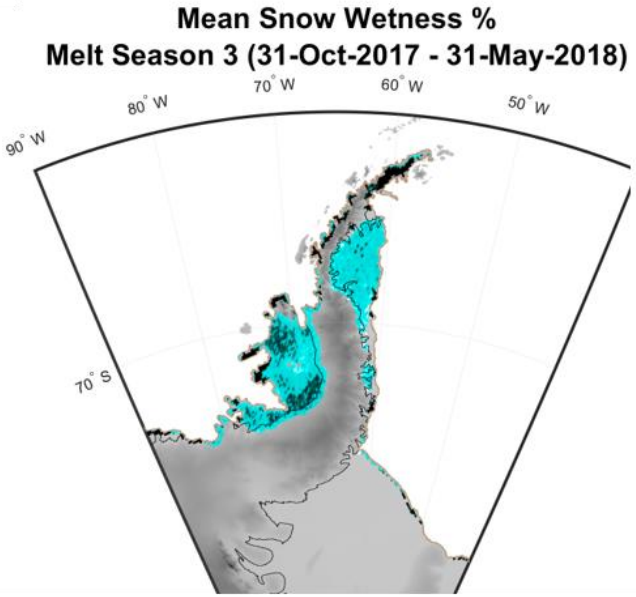
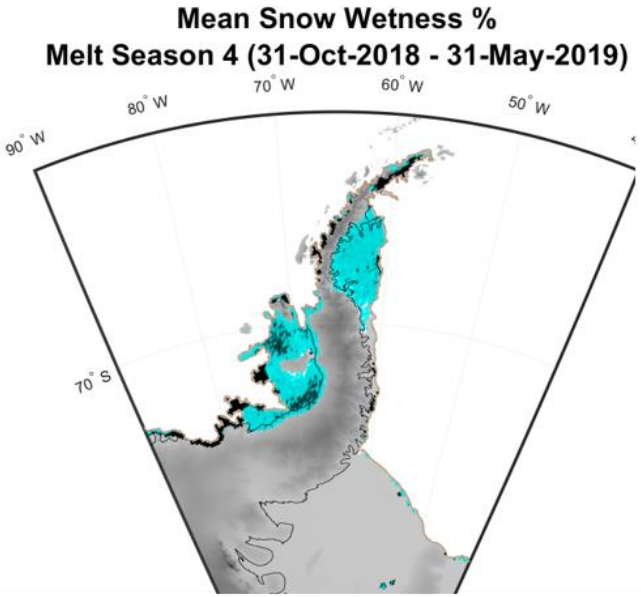
L-band Meltwater Retrieval

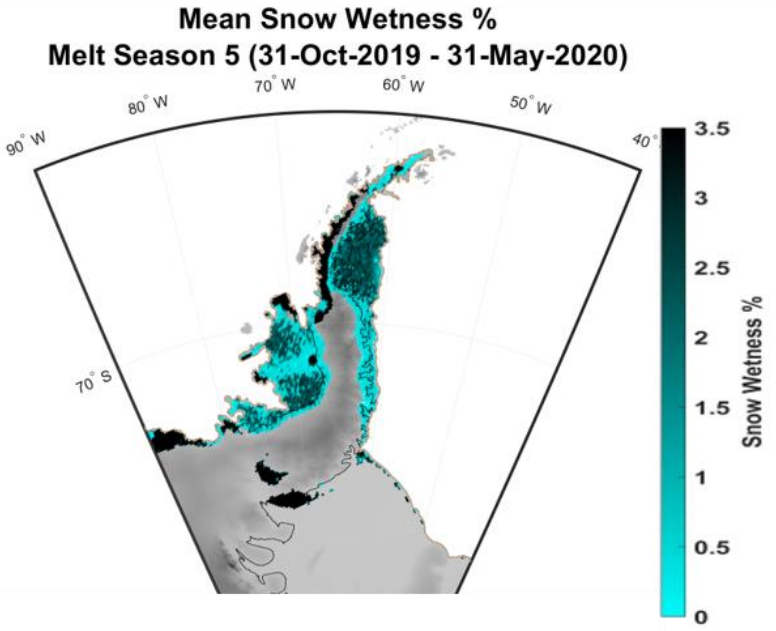












Mousavi, Colliander et al. (2022)

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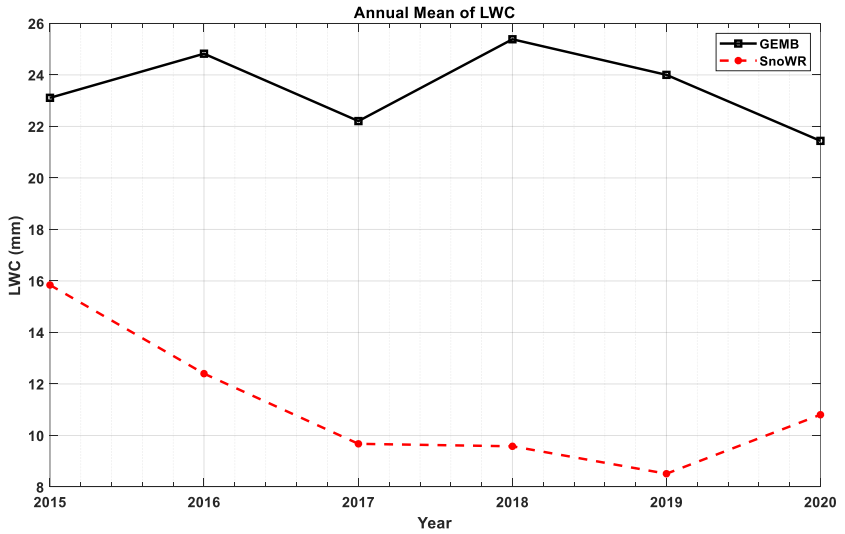
L-band Retrieval Comparison to Modeled Meltwater

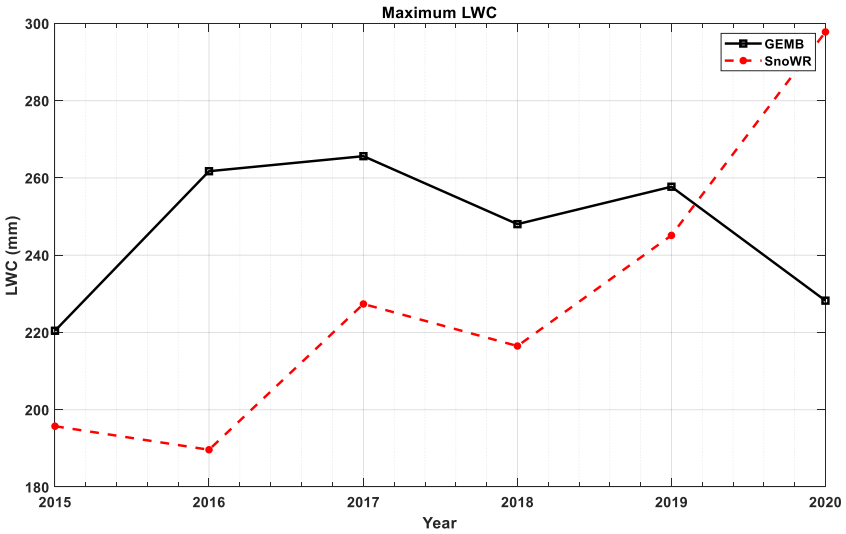
Completely independently retrieved and modeled LWC values show remarkable correspondence.

	ISSM-GEMB		SnoWR Algorithm	
Melt Season	LWC Ave (mm)	LWC Max (mm)	LWC Ave (mm)	LWC Max (mm)
2015	23.11	220.44	15.84	195.72
2016	24.82	261.73	12.40	189.63
2017	22.20	265.63	9.67	227.37
2018	25.38	248.03	9.57	216.48
2019	24.00	257.72	8.51	245.13
2020	21.43	228.23	10.80	297.78

Annual Mean LWC



Maximum LWC



Retrieval based on Mousavi, Colliander et al. (2021)

ISSM Glacier Energy and Mass Balance (GEMB) model by Nicole-Jeanne Schlegel, JPL

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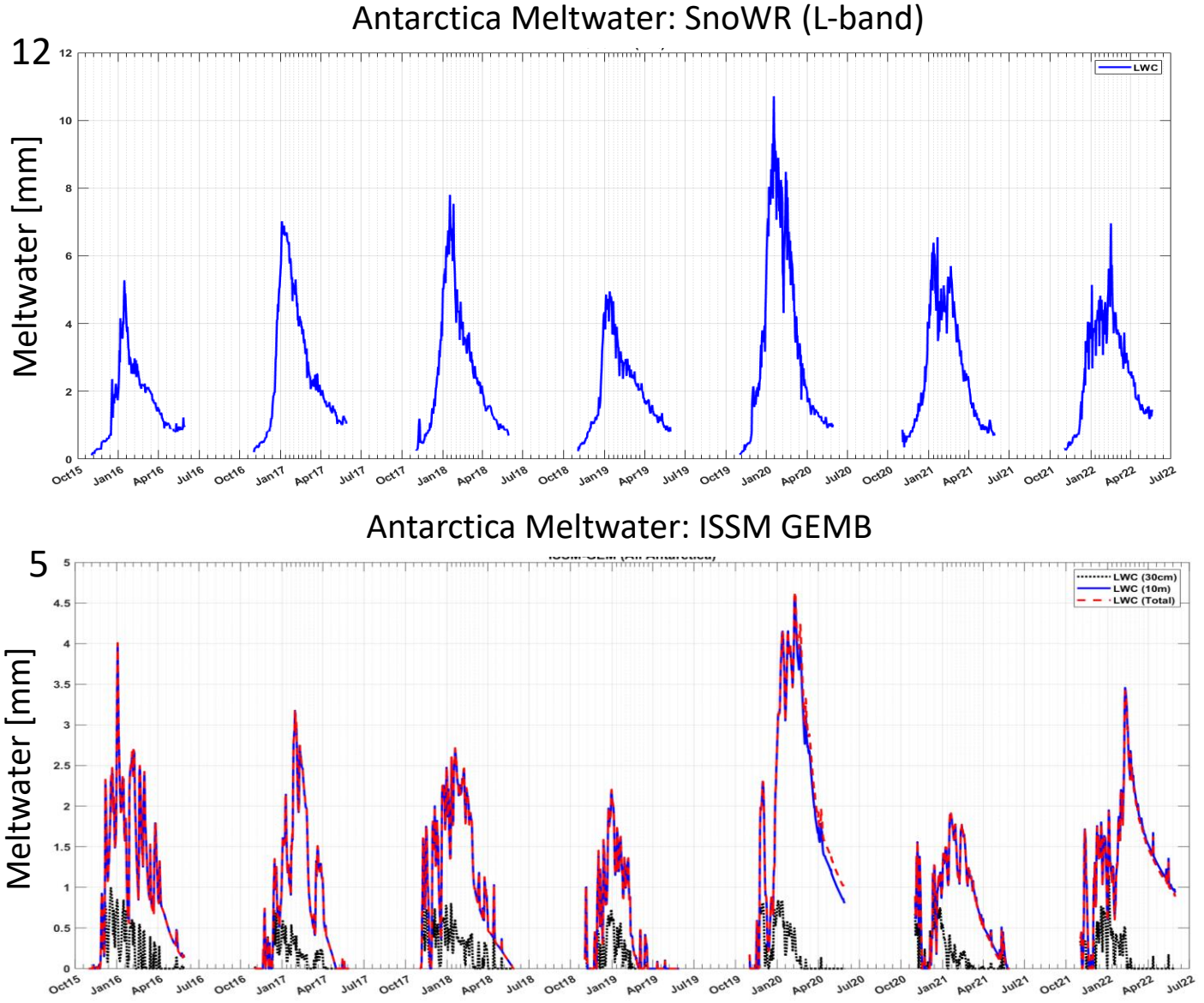
L-band Retrieval Comparison to Modeled Meltwater

- Evolution of retrieved and modeled Antarctica meltwater
- Temporal evolution matches well – peaks very well aligned
- L-band less sensitive to small melt amounts early in the season in the surface (black lines in bottom plot)

L-band retrieval corresponds to the evolution of the total modeled LWC.



Mousavi, Colliander, et al. AGU Fall Meeting 2022

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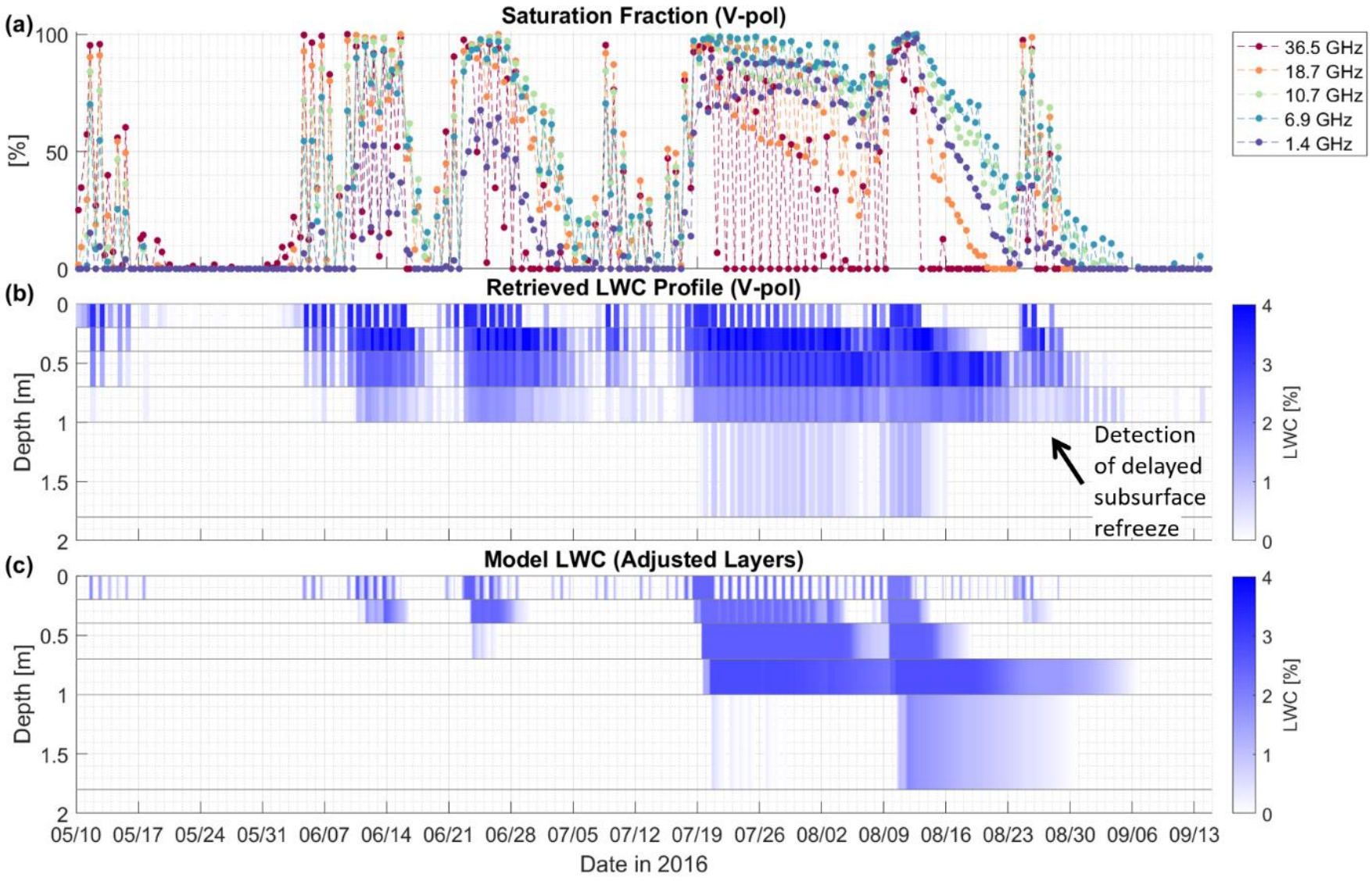
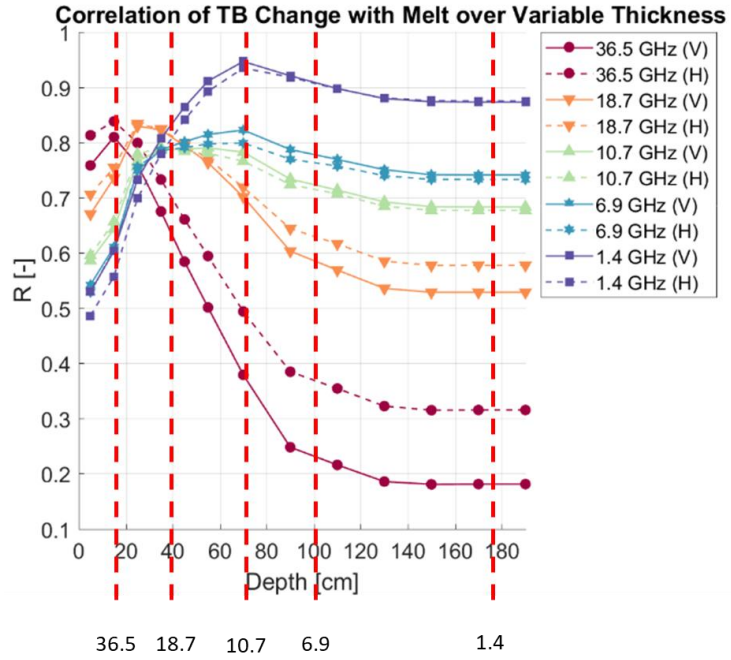
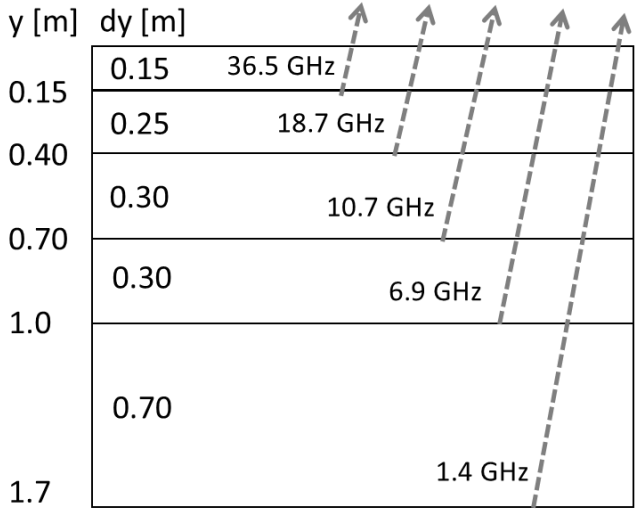
Melt Profile Retrieval at One Location







Colliander et al., GRL (2022)

Layered Meltwater Detection for Greenland

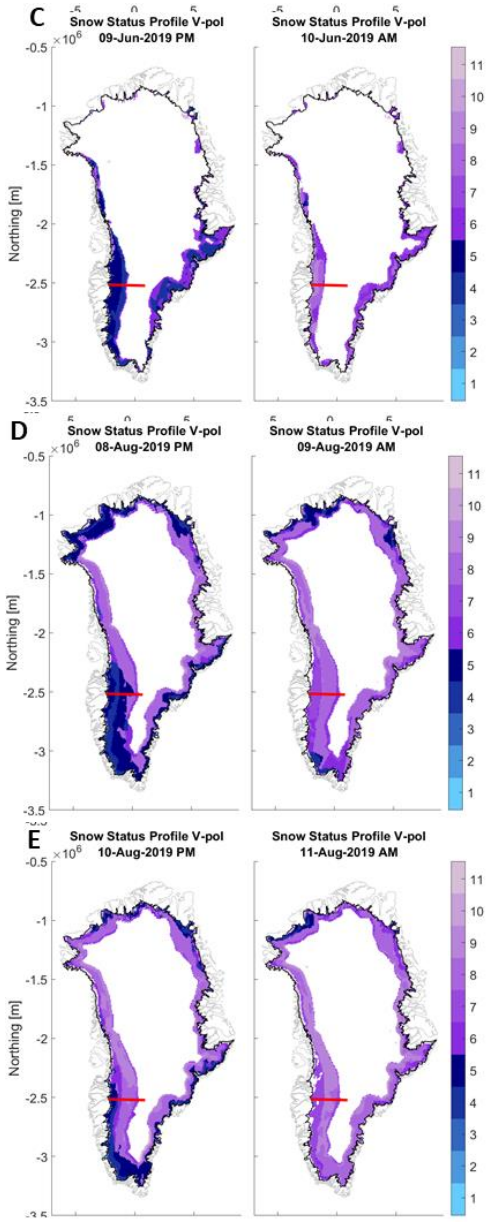
- Normalize TB for each with respect to the winter level (Jan and Dec) and summer max

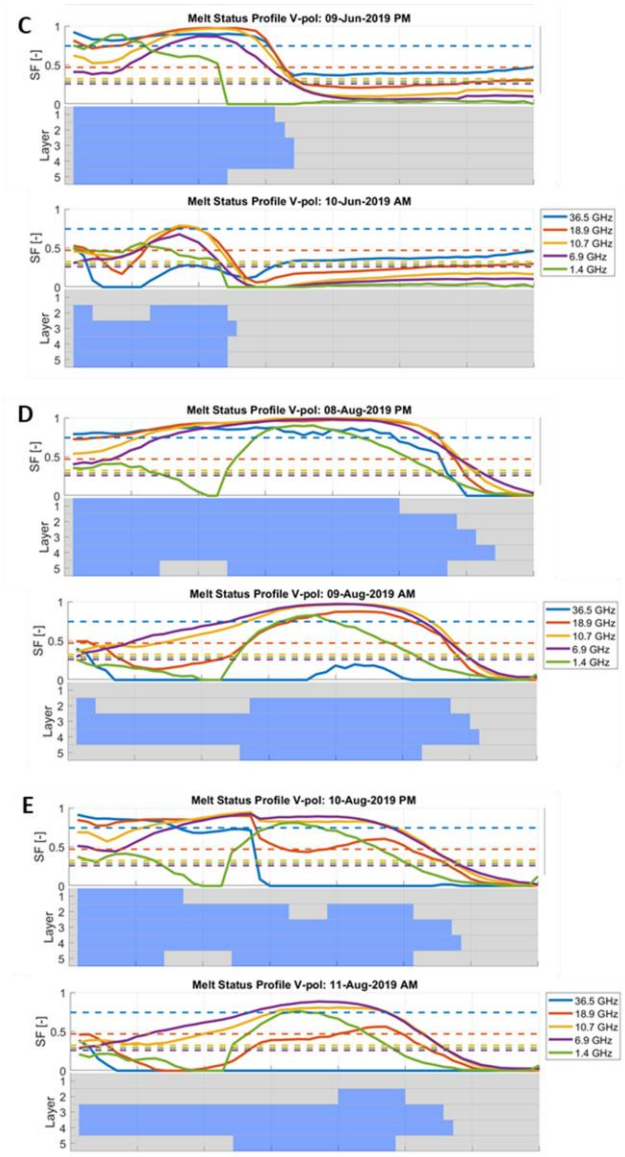
$$SF_p(f) = \frac{T_{B,p}(f) - T_{B,p}^{frozen}(f)}{T_{B,p}^{max}(f) - T_{B,p}^{frozen}(f)}$$

- Threshold based on TB variability of the winter reference

		Melt Scenarios										
Layer	Freq	1	2	3	4	5	6	7	8	9	10	11
1	36.5											
2	18.9											
3	10.7											
4	6.9											
5	1.4											

	Melt water
	Melt water or no melt water
	No melt water





Colliander et al. (2023).

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Layered Snow Status

		Melt Scenarios										
Layer	Freq	1	2	3	4	5	6	7	8	9	10	11
1	36.5											
2	18.9											
3	10.7											
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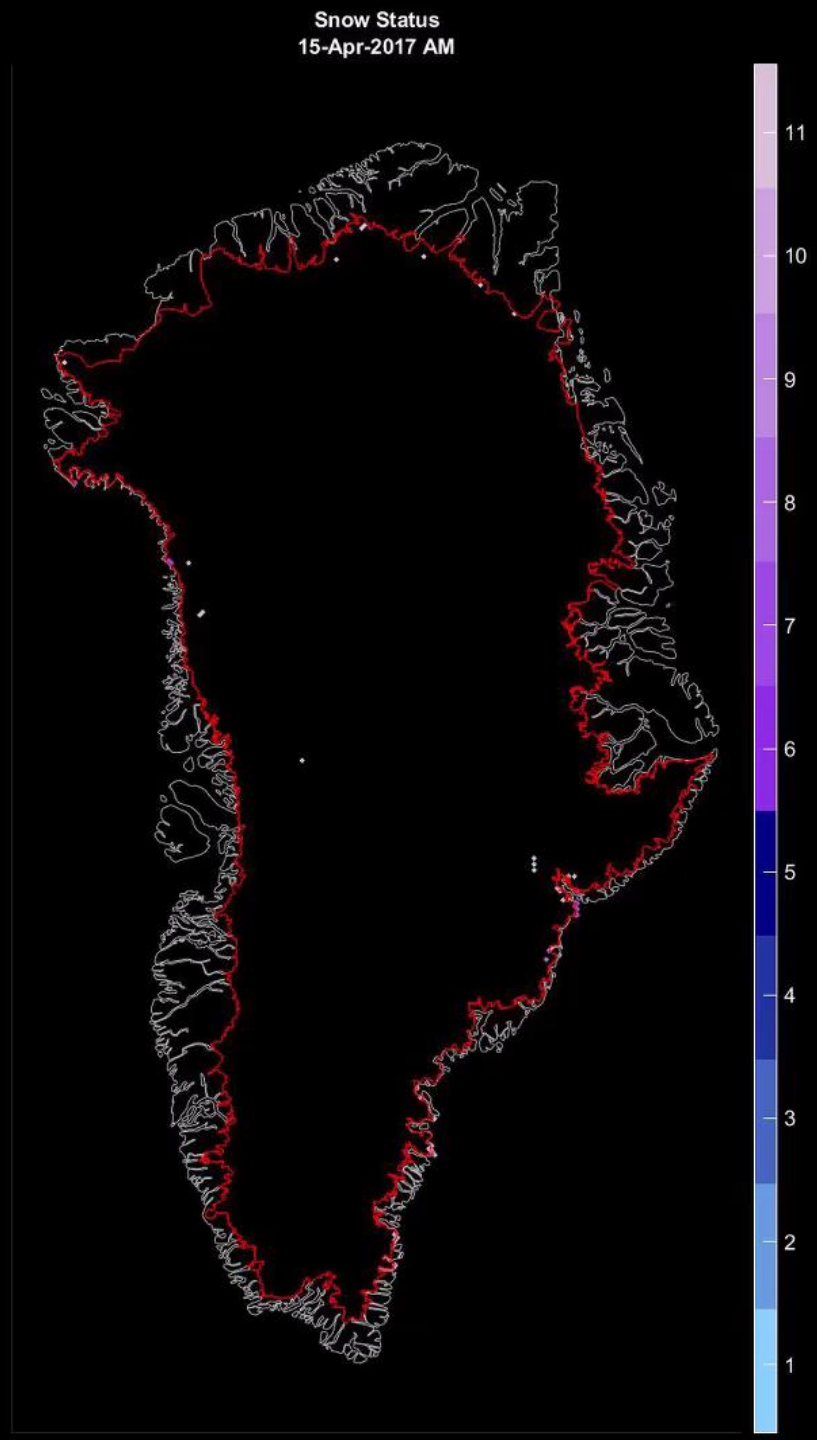

Summary

- L-band radiometry is the only frequency band able to retrieve meltwater amounts, not just the melt status
- The first comparisons to in situ and model results look promising
- Spatial and temporal differences between the high and low frequencies are very significant
  => lower frequencies needed to capture the melt amount and total melt status while the higher frequencies can inform on the depth of surface process