

*EESS (active) Radar Techniques
Focused on Cryosphere Work
- Or -
RFI, Cryosphere, Radar remote sensing
from low to high frequency*

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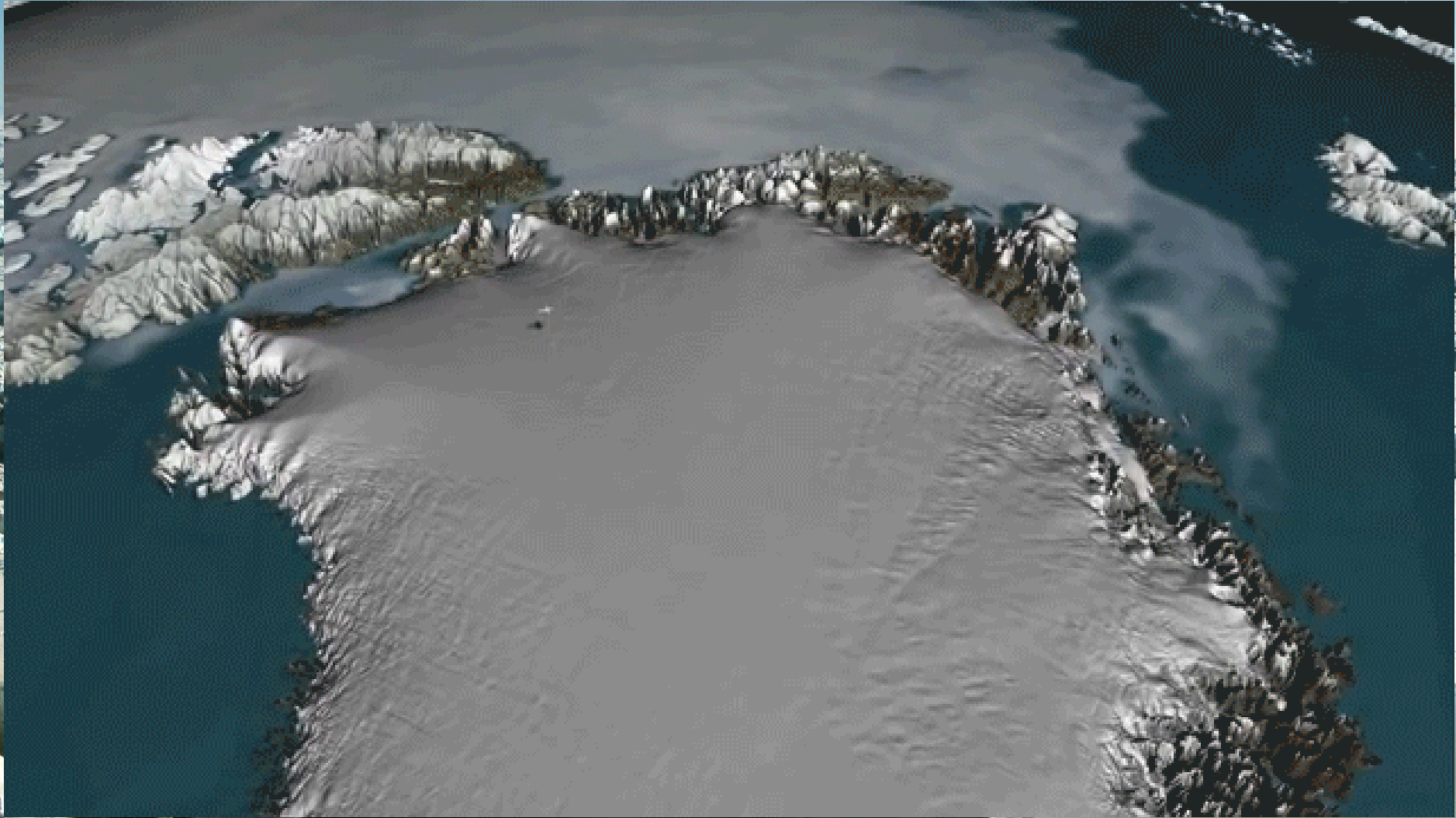
Canadian Space Agency Agence spatiale canadienne



acknowledged for
contributing the
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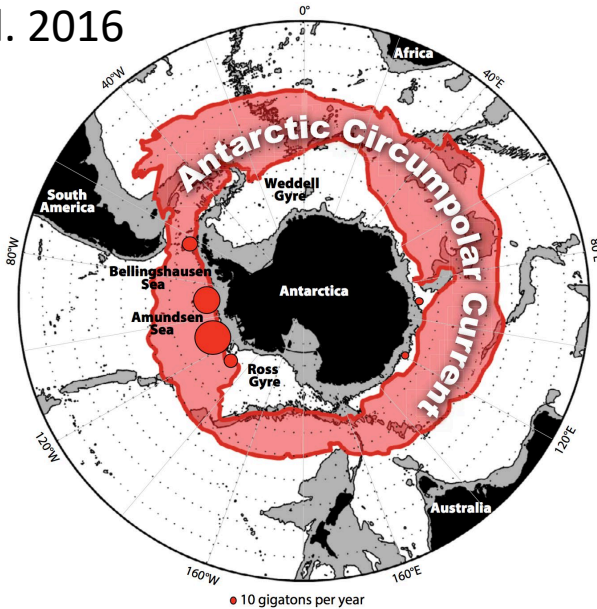
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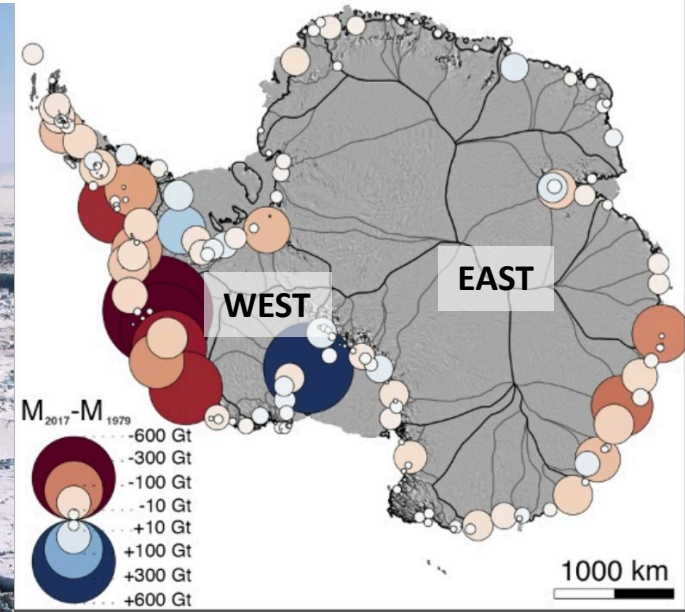


Ice sheet loss from a warmer ocean

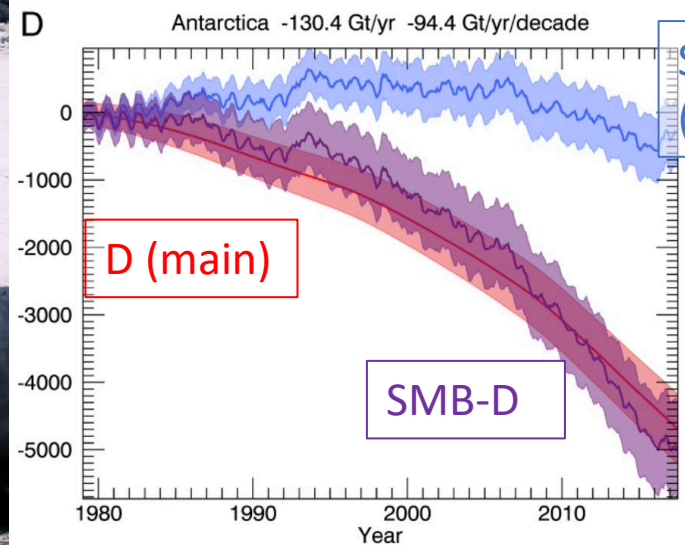
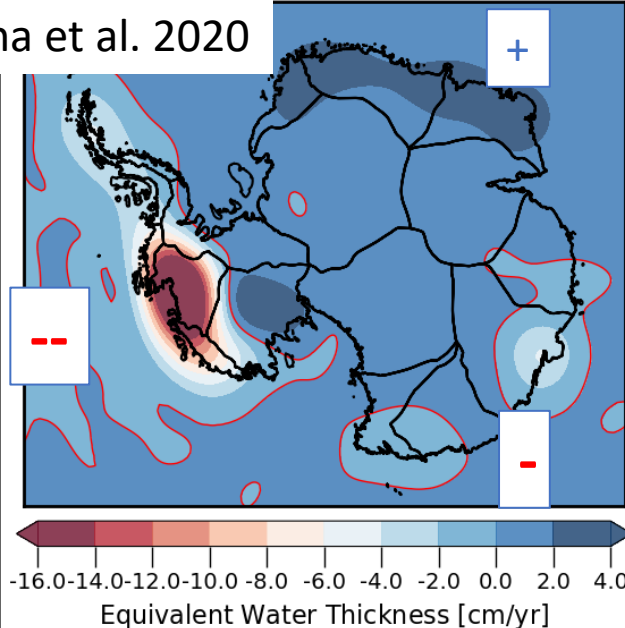
Gille et al. 2016

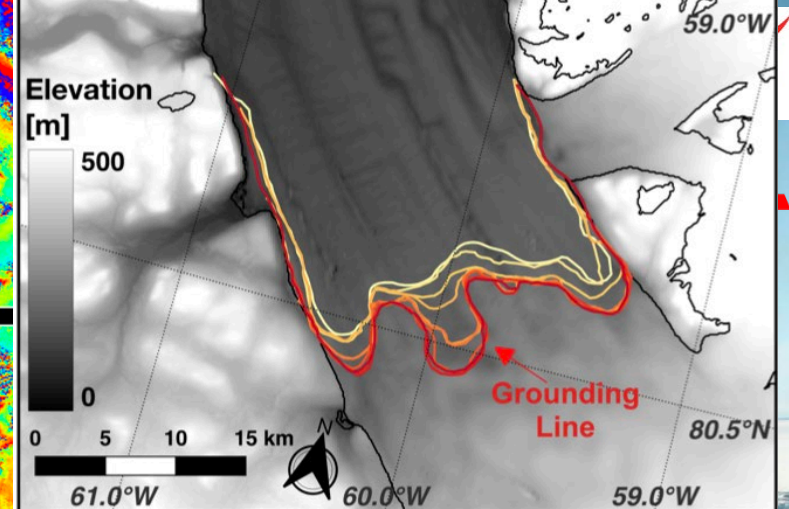
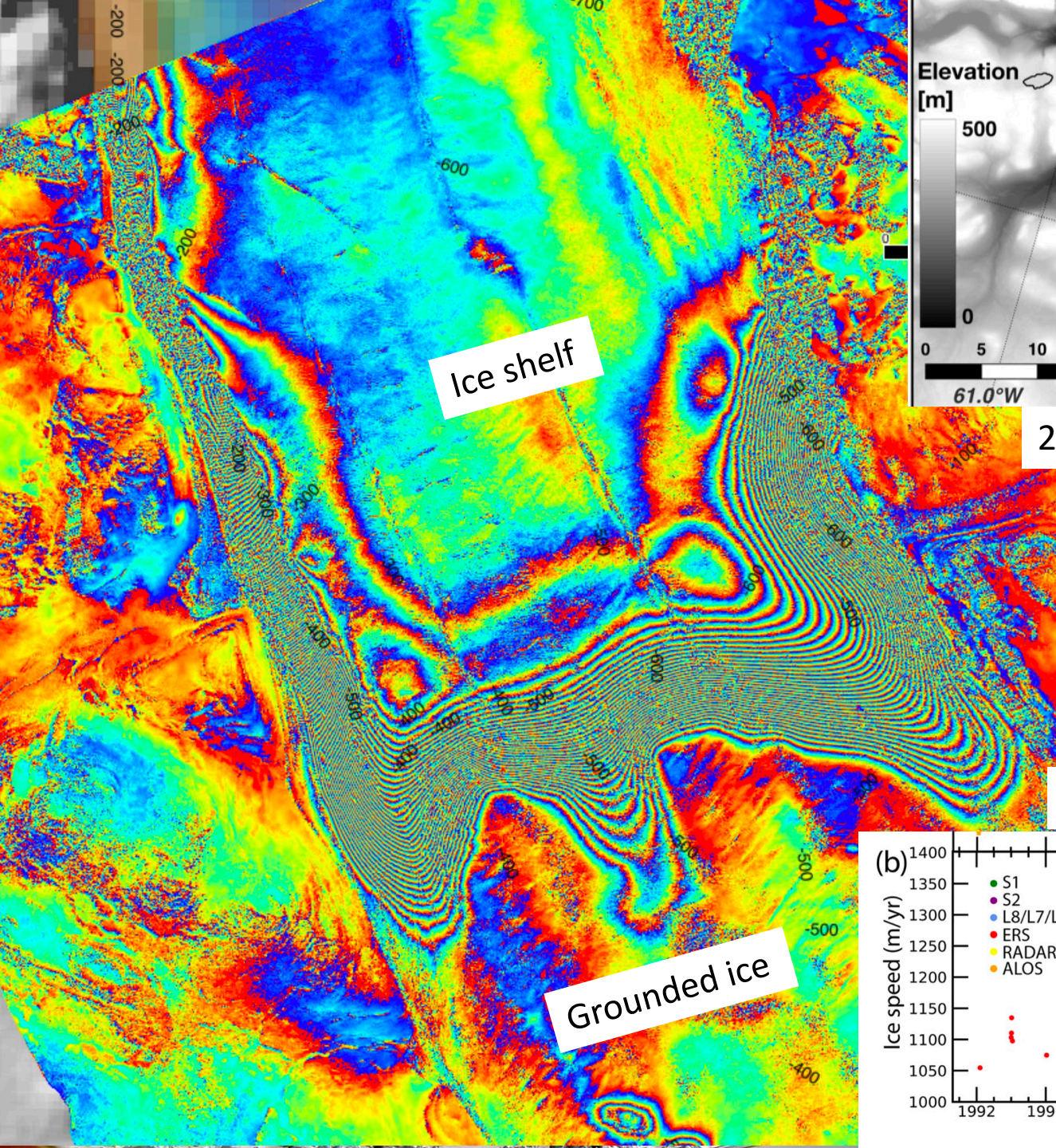


Rignot et al. 2019



Velicogna et al. 2020

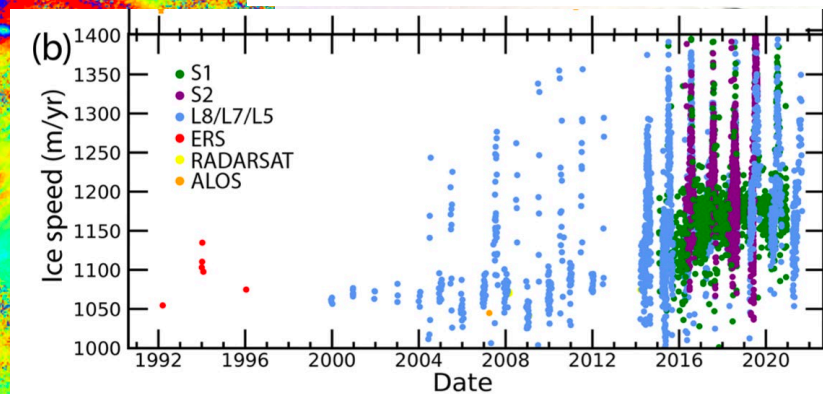




2018-2023, 7-km GL retreat



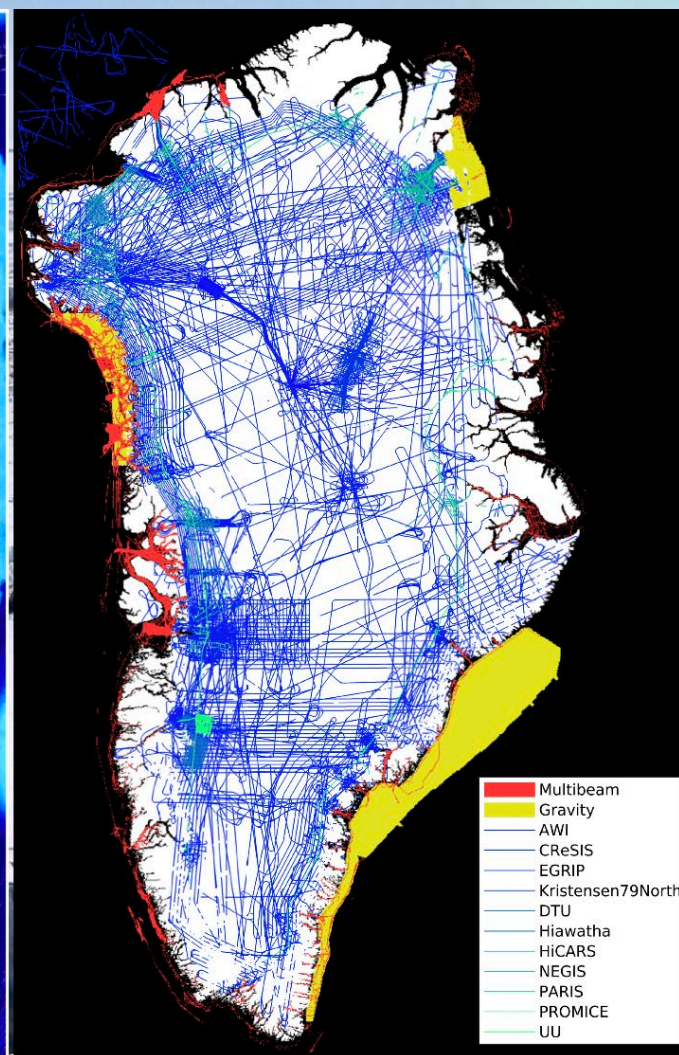
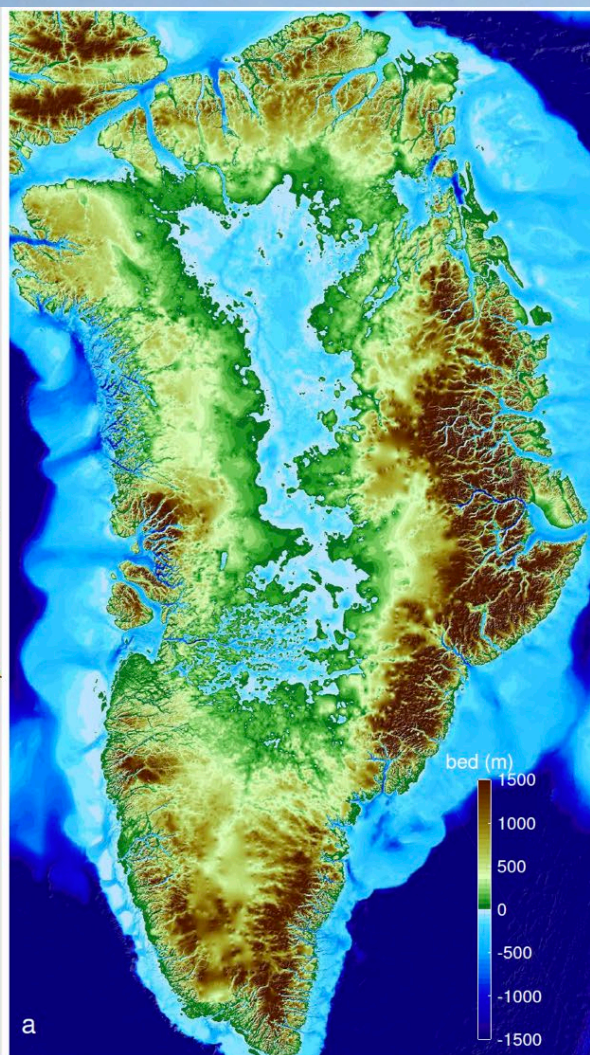
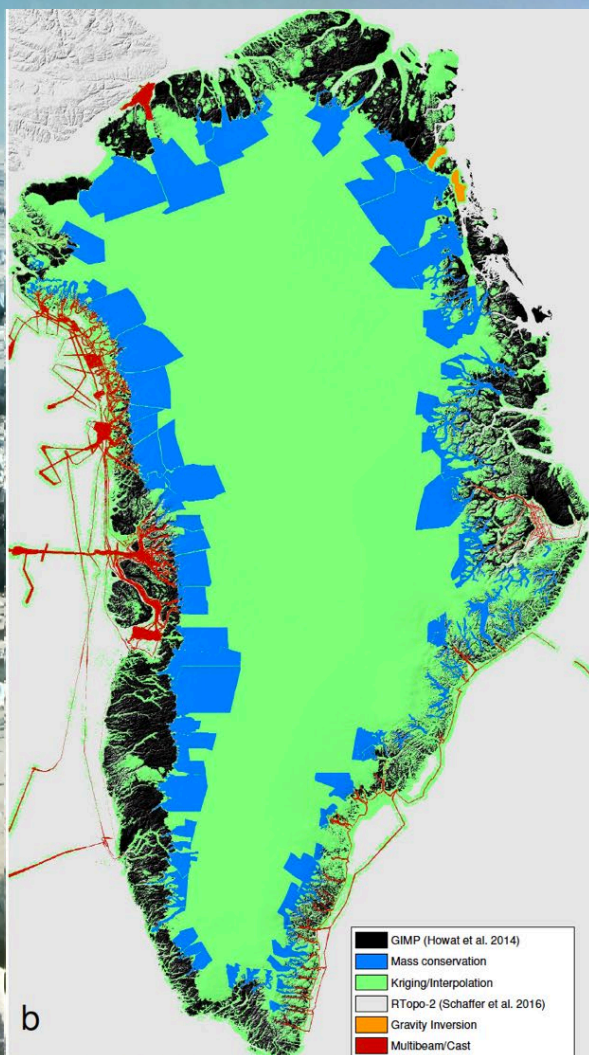
2018-2023 Glacier Speedup



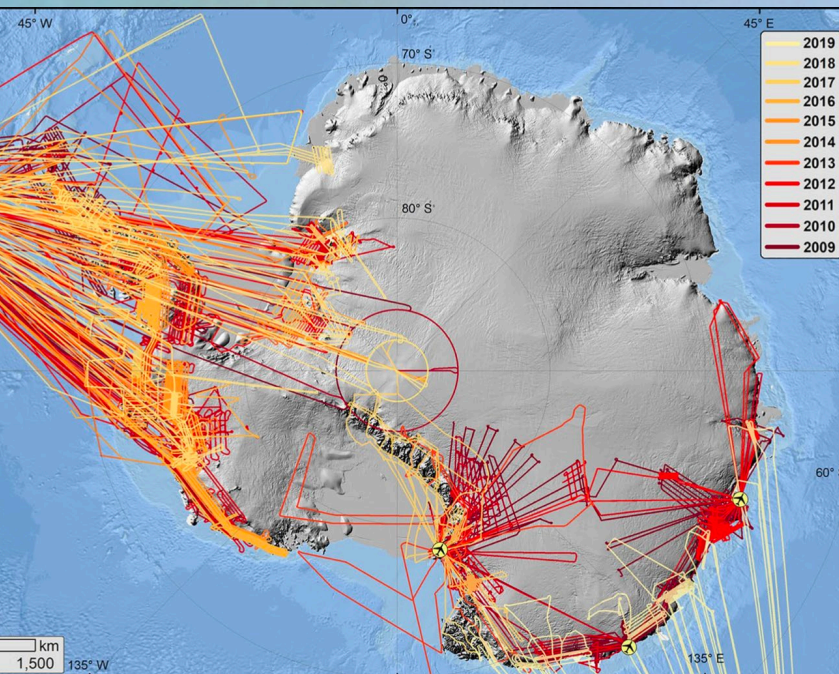
RFI and the Cryosphere

- “Lower” frequencies are “better”
- Max RFI at P-band (Biomass) because of SOTR.
- High/variable at L-band (NISAR, ALOS PALSAR) but ok with filtering
- Moderate at C-band (Sentinel-1, Harmony), but ok with routine checks
- Less problematic, but not immune, at X-band (TerraSAR, ICEYE), case by case mitigation

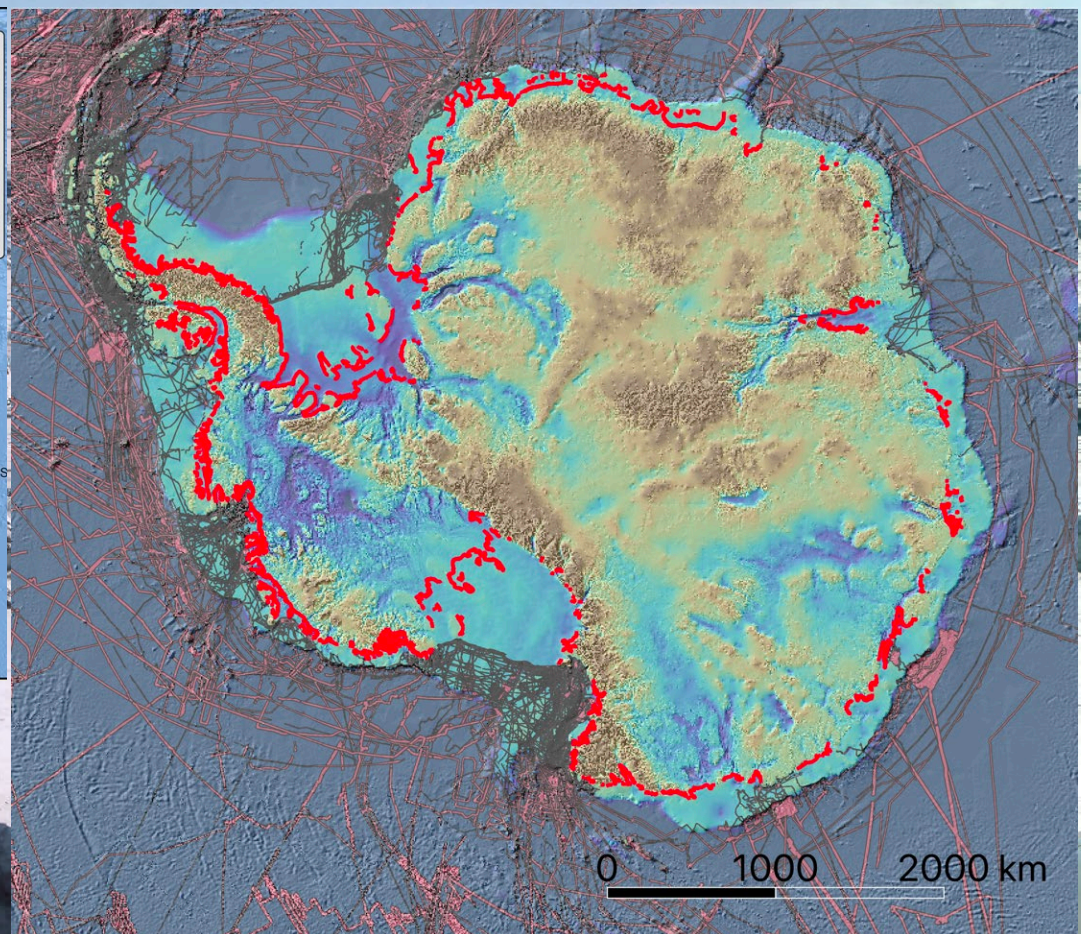
Bed/bathymetry Greenland: OMG 2015-2020 + OIB 2009-2019 + others = IBCAO Version 5



Bed and bathymetry, Antarctica: OIB 2009-2019 (no OMG) + others = IBCSO Version 2

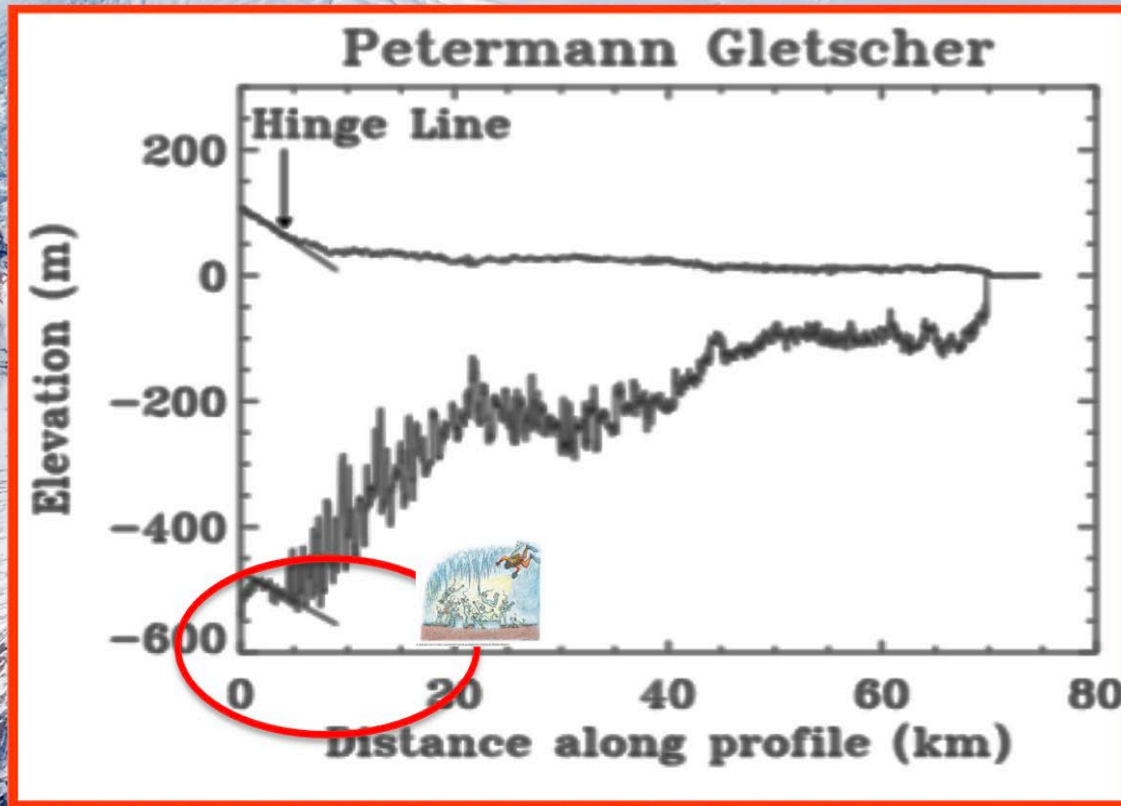


MacGregor et al., 2021



Dorschel et al., 2022
Morlighem et al., 2020

At the beginning ...



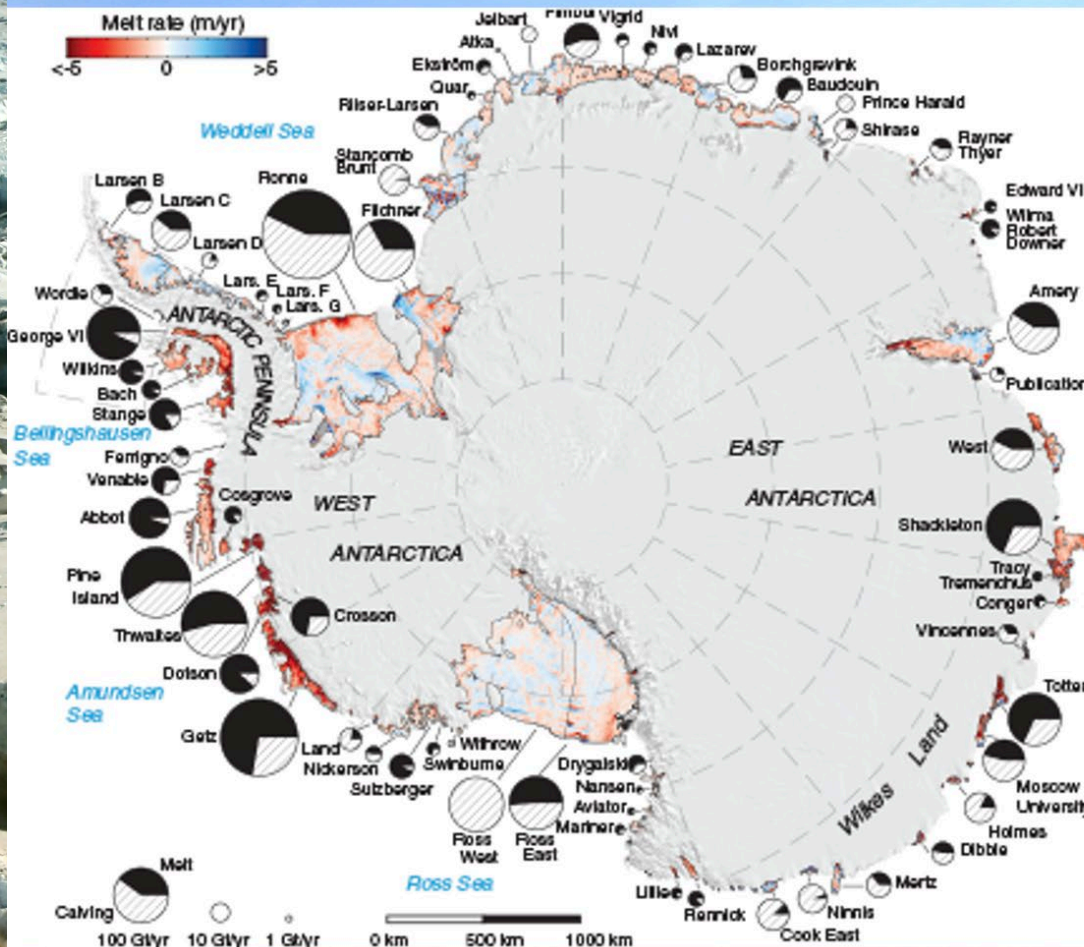


Ice shelf melting around Antarctica

E. Rignot, S. Jacobs, J. Mouginot, B. Scheuchl



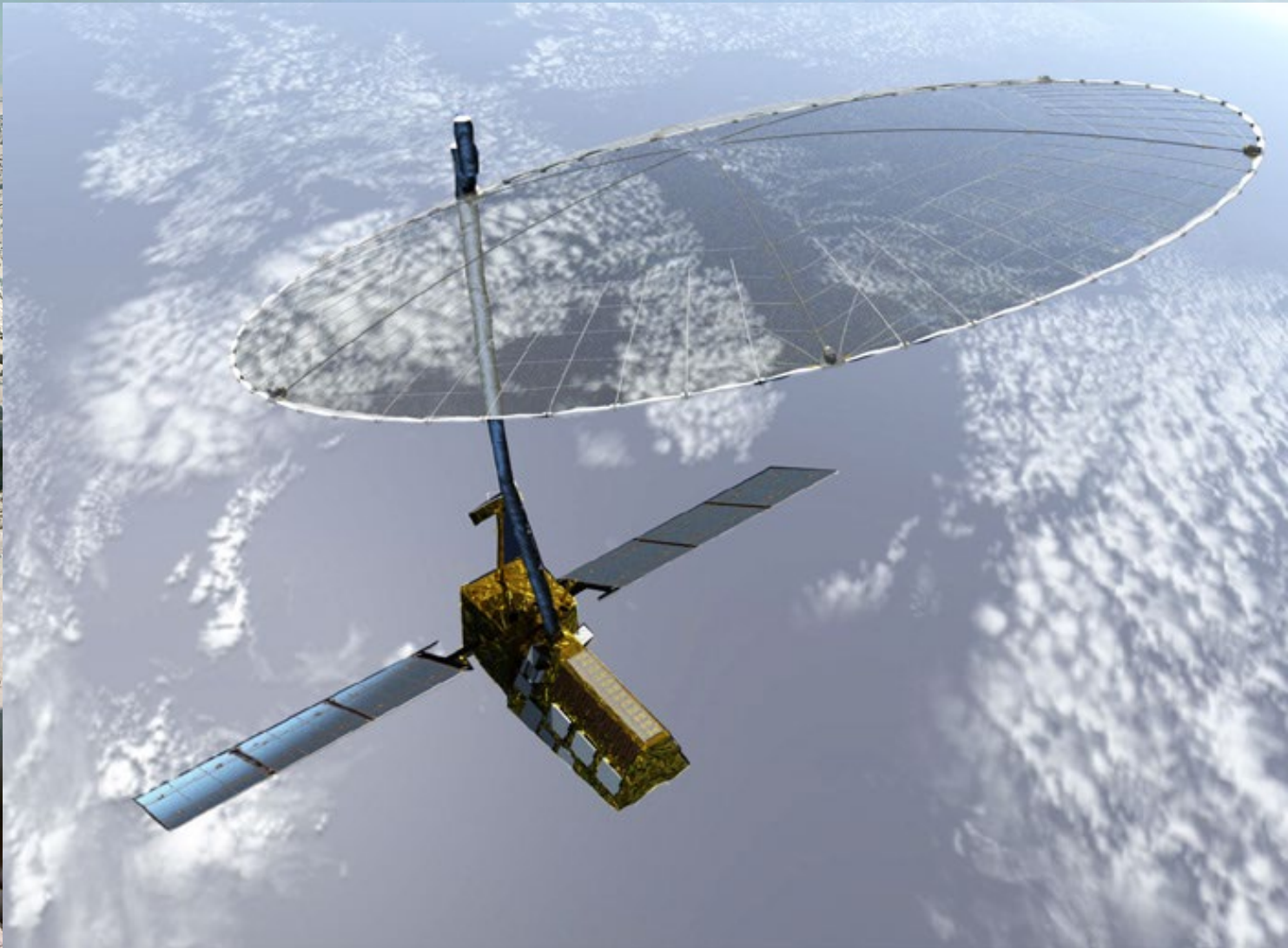
InSAR, OIB, RACMO, ICESat → Bottom melt rate



- Bottom melting ($1,325 \text{ Gt/yr}$) > calving ($1,089 \text{ Gt/yr}$)
- Cold-based, giant Ross, Filchner, Ronne ($2/3^{\text{rd}}$ area) → 15% of the melt.
- 10 warm-based (8% area) in West Antarctica → 50%.
- 6 East Antarctic ice shelves with undocumented ocean conditions exhibit similar high/melt ratios.
- Shifts in ocean circulation could tip large ice shelves from cold to warm and trigger massive losses.

NASA ISRO SAR Mission:

To study ice sheet dynamics
Launched July 30, 2025!





ESA BIOMASS mission: P-band (455 MHz), Left looking, 12 m antenna, launched in April 2025, 6MHz BW (25 m SR), 23-31° incidence, 60 km swath, 50 m spacing at 4 looks, 25-45 days ground track repeat.

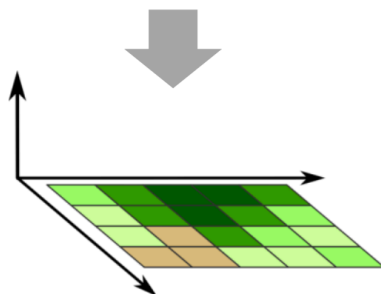
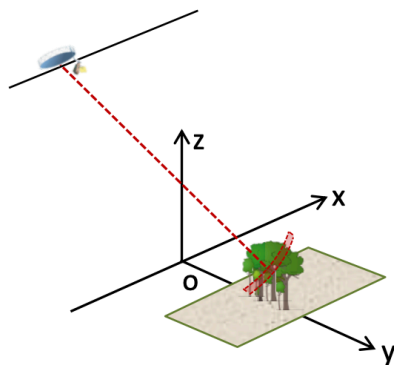
Biomass retrieval at 200 m spacing; secondary objectives over ice.

ESA/NASA joint investigation of cal/Val opportunities for ESA's Earth Explorer 7 Biomass mission within SOTR field-of-view

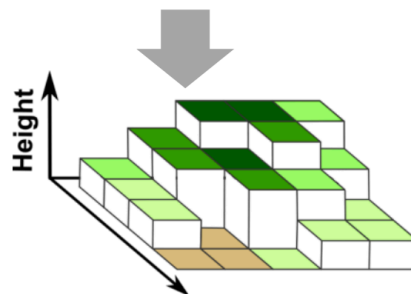
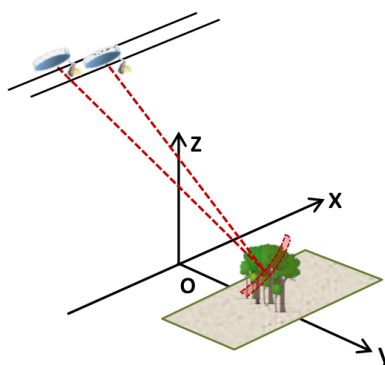
Commissioning phase, Tomo phase (14 mo, 3 day baseline), PolInSAR (4 years, 7 day baseline), possible to roll off to nadir geometry.

BIOMASS combines advanced techniques to enhance retrieval performances

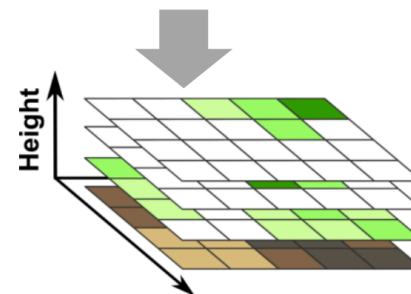
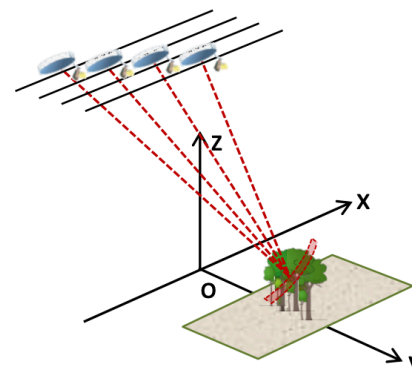
PolSAR
 (SAR Polarimetry)

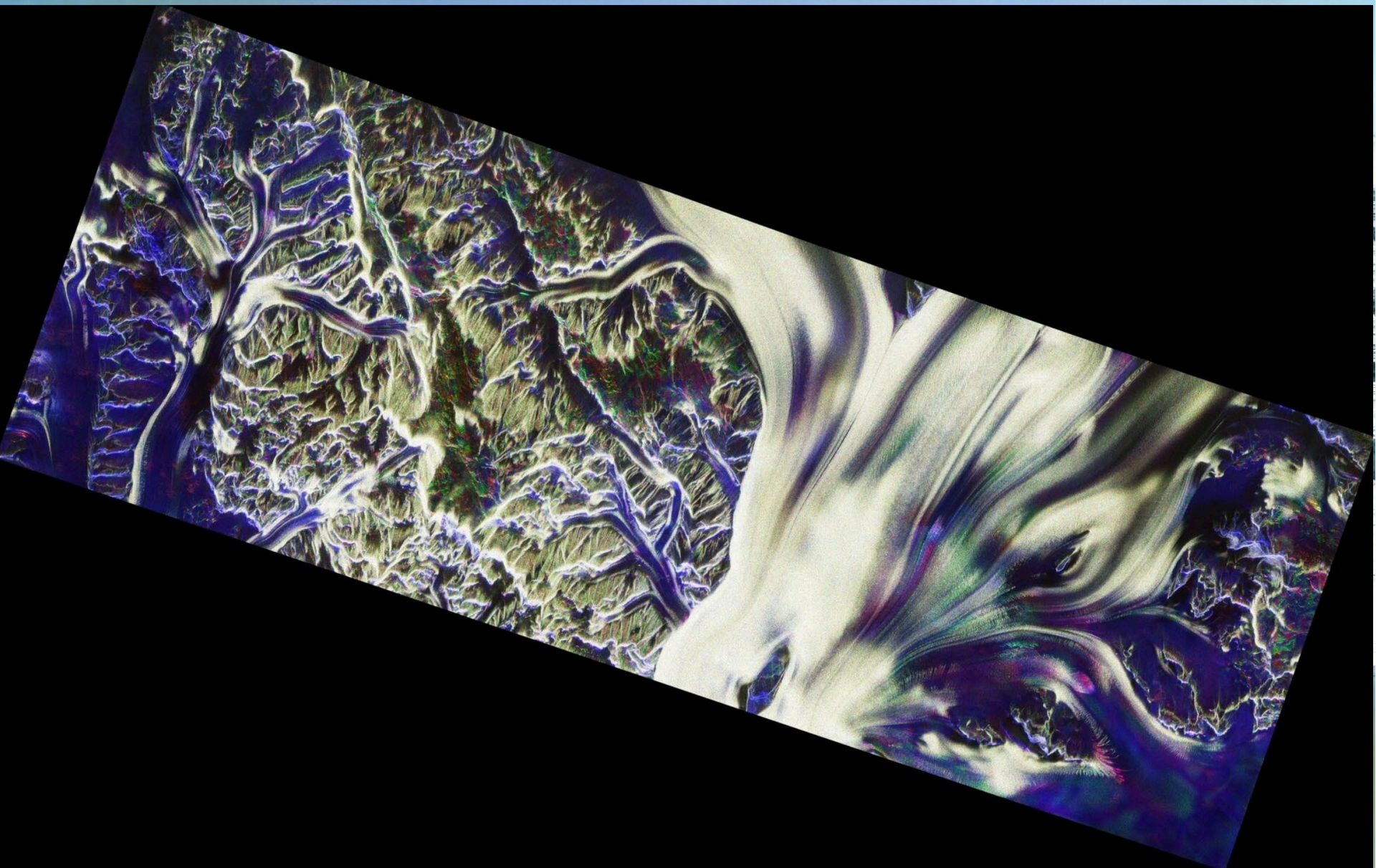


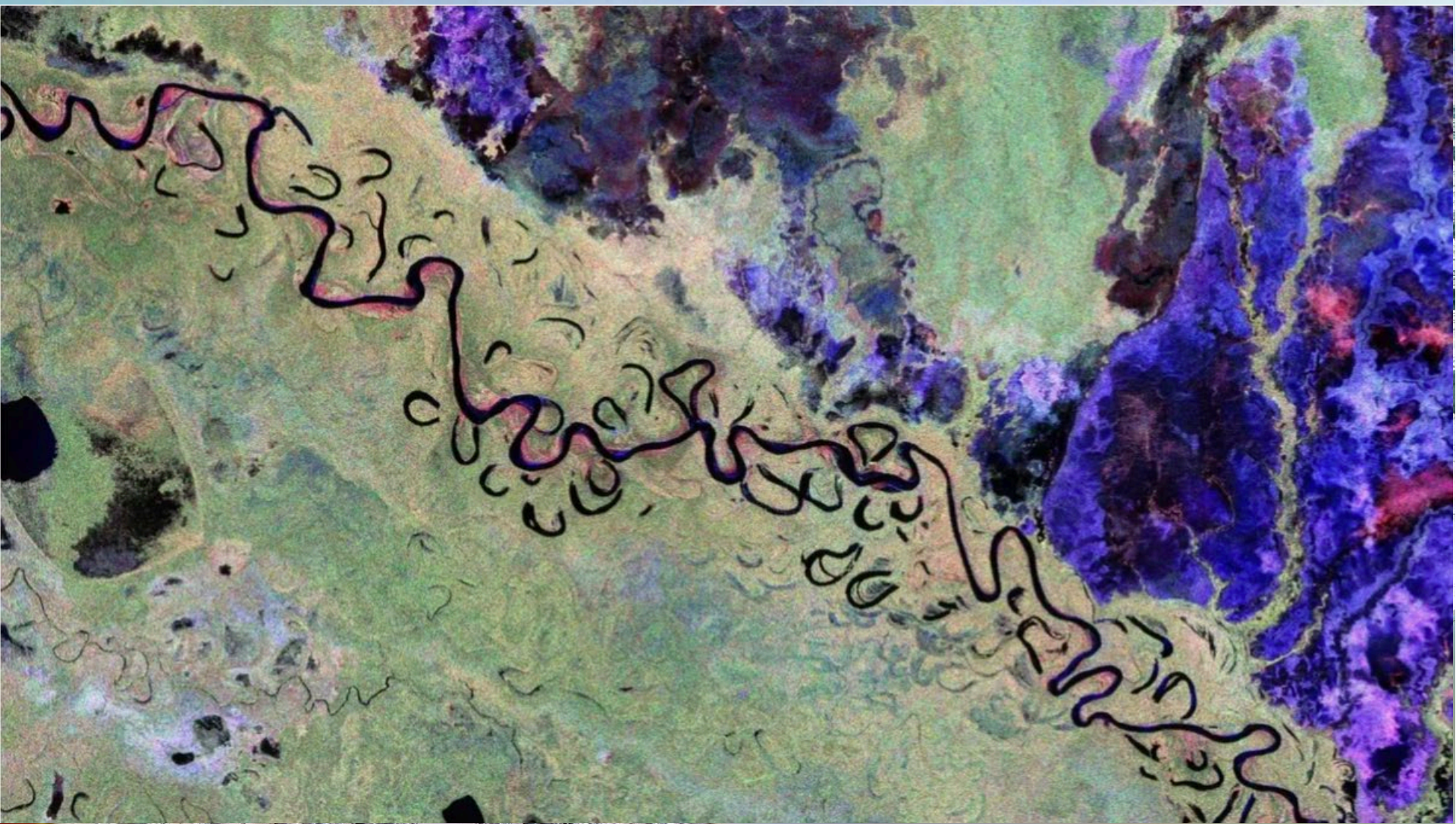
PolInSAR
 (Polarimetric SAR Interferometry)



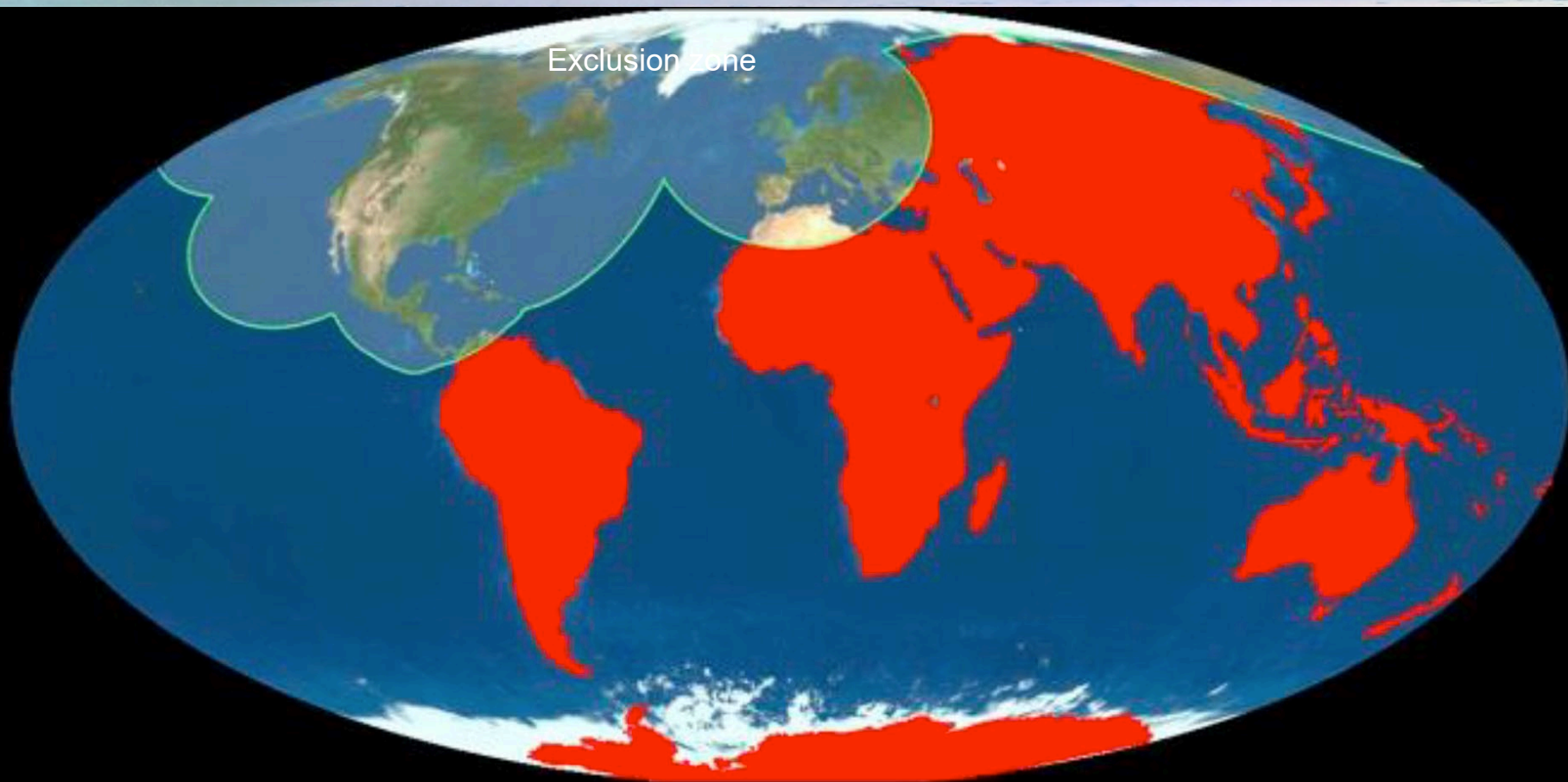
TomoSAR
 (SAR Tomography)







SOTR (Space Object Tracking Radar network) exclusion zone for Biomass orbit



- BIOMASS coverage is “subject to US DoD Space Object Tracking Radar (SOTR) restrictions... not allowed within line-of-sight... mainly exclude the North American continent and Europe.
- SOTR “restricts the imaging opportunities for Biomass **because of the potential interference on the SOTR operation by the Biomass transmit signal**,” and shows an acquisition mask with a green **SOTR line-of-sight boundary** inside which “no Biomass operations would be allowed.”
- **Greenland / Thule:** the **BMEWS/UEWR space-tracking radar at Pituffik (Thule)** is one of the U.S. SOTR sites (along with Clear, AK and RAF Fylingdales, UK). i.e. a **canonical SOTR location** inside the “no-operate (LoS) region.”
- SAR is low duty, low power (600 W Biomass → 7 mW on a 200 m pixel, 3.1 kW NISAR, ditto; speed is 7 km/s). Weather radar is 700 kW), Airport is 10 kW, Cell base is 50 W, and SOTR is many 10 MW.
- P-band (432–438 MHz region) is heavily allocated to **radio astronomy, military radars, and space services; but is immensely useful for science.**



Investigate possibilities for operation within exclusion zone

- The ITU-R Recommendation that is included in the ITU-R Radio Regulations (“incorporated by reference”) stipulates the following in its *recommends* 2:
 - “that spaceborne active sensors operating in the range 420-450 MHz not be put into operation within view of the terrestrial space object tracking radars listed in Table 2, **unless detailed analysis, on a case-by-case basis, to include consideration of the effects of the radars’ receiver processing upon unwanted SAR signals, and possibly field testing have been performed to confirm compatibility with the mutual agreement of the affected administrations**”
- https://www.itu.int/dms_pubrec/itu-r/rec/rs/R-REC-RS.1260-2-201709-!!!PDF-E.pdf
- Joint investigations requested to alleviate the current restriction to initially allowing “campaign-like” (time and area limited) covering North American Cal/Val sites (e.g. used for NISAR)
- Initial in-orbit tests could be carried out during commissioning phase and early phase E2

Due to current SOTR restrictions, the Biomass mission is focused on mainly (sub-)tropical forest areas. Additional inclusion of both temperate and boreal forest areas would complement L- and C-band SAR observations and would significantly reduce retrieval uncertainty in these areas (study report available).

Greenland (for Biomass secondary cryosphere objective; currently focused on Antarctica) would be the holy grail through the unique potential of P-band observations for detecting e.g. (low) ice velocities on the ice sheet.



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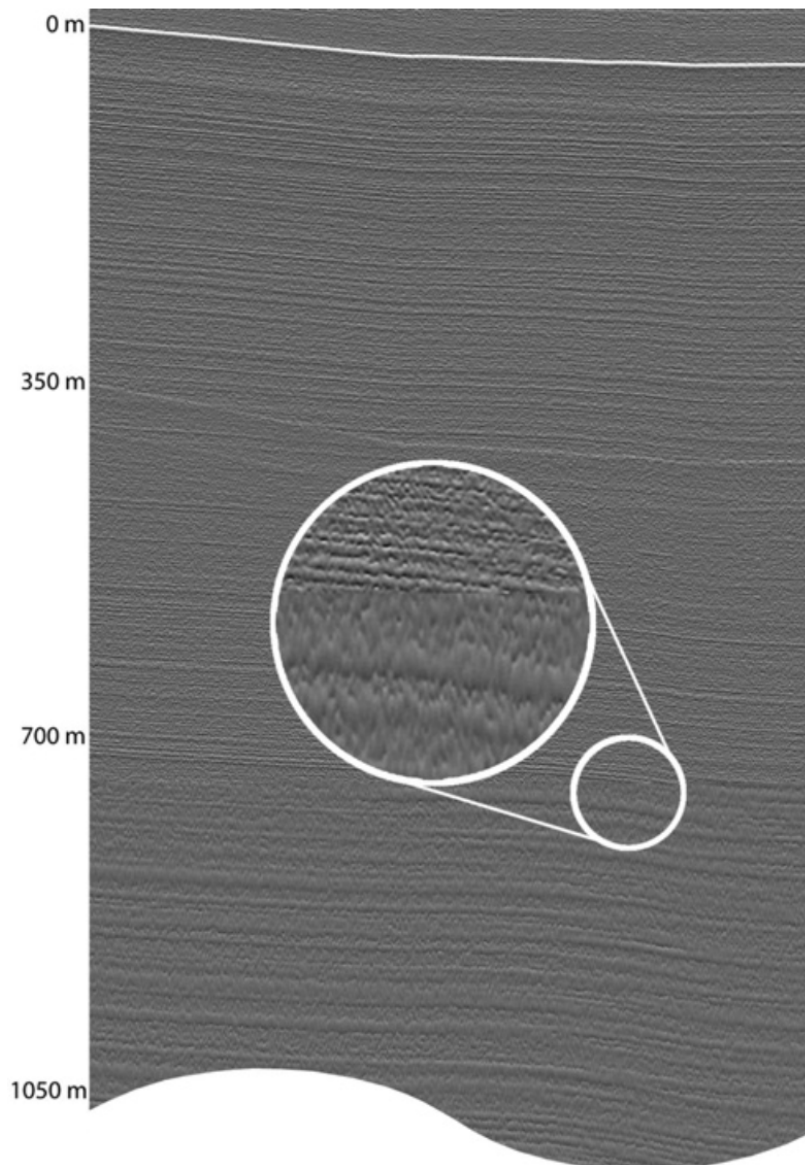



Figure 9 *Internal ice layers mapped in shallow/deep mode*
 In the zoomed inset the seam between the shallow and the deep windows is visible because two different bandwidths were used

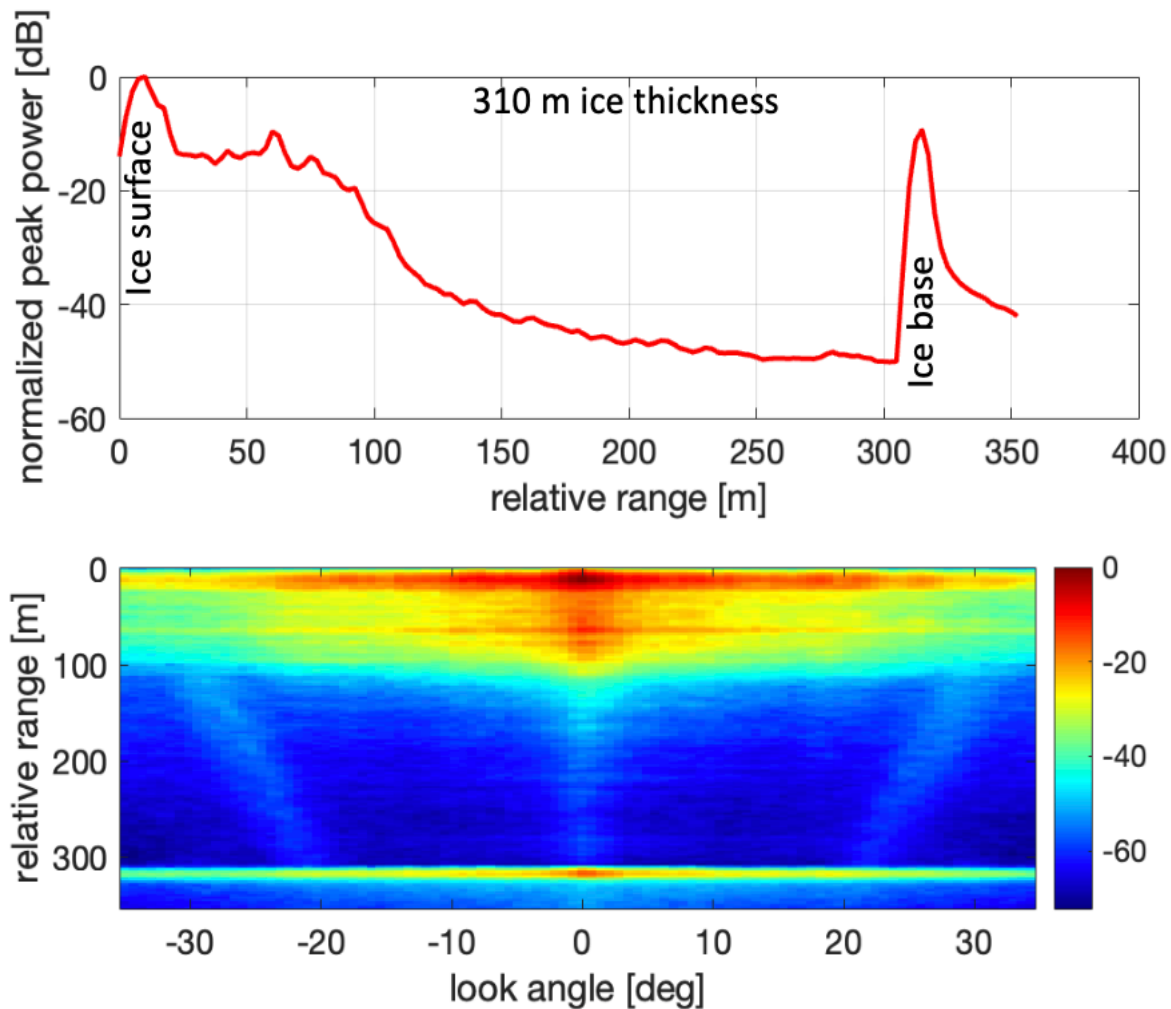


Fig. 2. Return waveform (top) and range-Doppler spectrum (bottom) based on airborne P-band ice sounding radar data from the Fimbul ice shelf in the Antarctic.

Conclusions

- InSAR critical for the cryosphere and polar science: ice motion + grounding line from a constellation ranging from L- to X-
- Radar sounding limited to sporadic airborne campaigns, no capability to repeat and measure changes, is a major impediment for cryosphere science (ice thickness, ice melt).
- STOR and other limitations restrict data acquisitions over the ice sheets where disturbances are negligible, commercial interest is zero, but potential for science discovery is large.

