# Remote Sensing of Ice Sheet Internal Temperatures and Sea Ice Thickness with the Ultra-Wideband Software-Defined Microwave Radiometer (UWBRAD)

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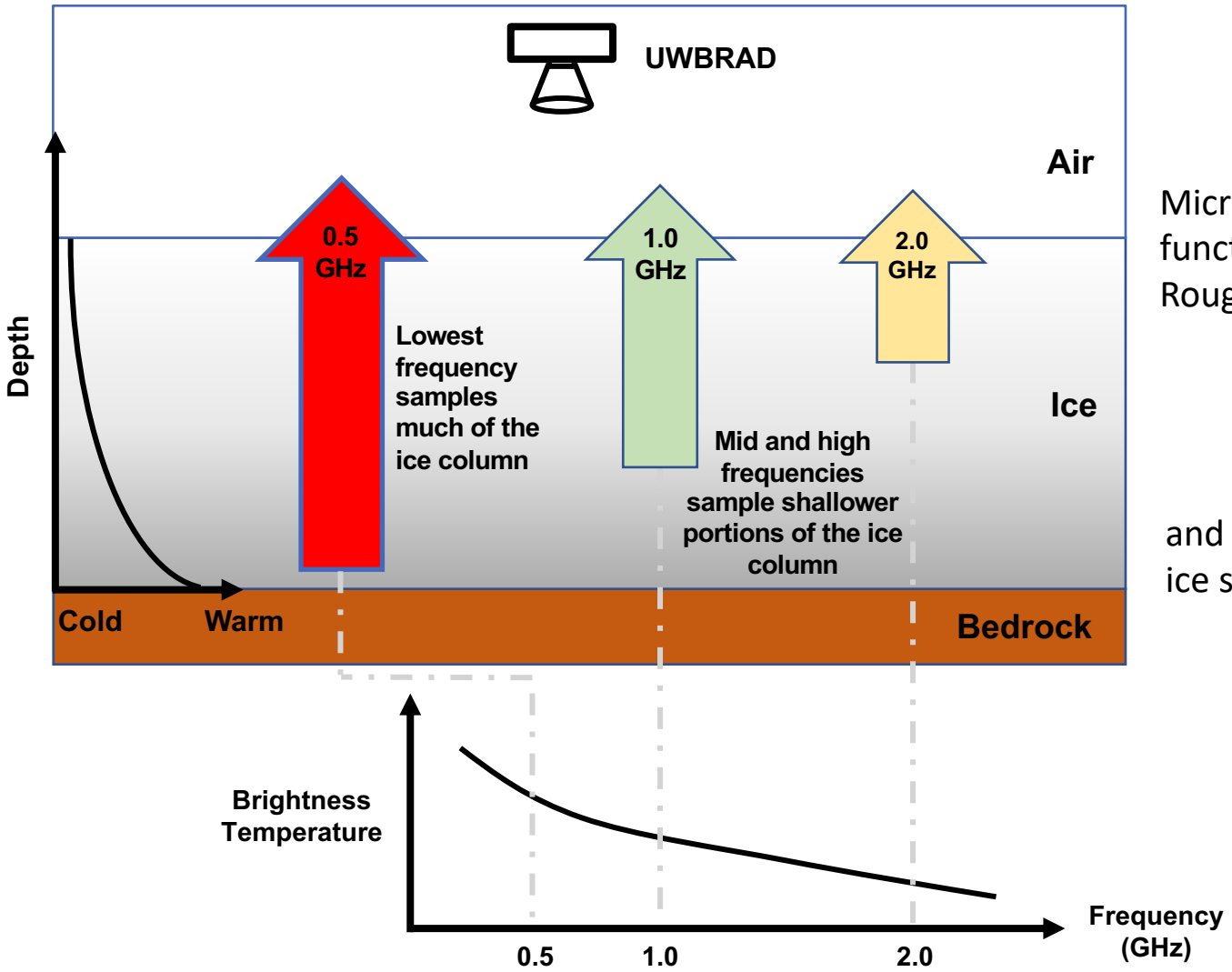
# Motivation and Outline

- Ice sheet internal temperatures and sea ice thickness (0-2 m) are two parameters of key interest that at present are difficult to remotely sense
- The ultra-wideband software defined microwave radiometer (UWBRAD) was designed under the 2013 IIP program to address these challenges
  - Measures Earth thermal emissions from 0.5- 2 GHz to remotely sense ice sheet internal temperatures and sea ice thickness
- UWBRAD was deployed in airborne observations of the Greenland ice sheet in Sept 2016 and Sept 2017; the latter also included sea ice measurements
  - Also deployed in Antarctica Nov-Dec 2018 under support of Italian Antarctic National Program and NASA Cryospheric Science Program and
  - A preliminary concept for space deployment has also been developed (the CryoRad Mission)
- Outline
  - Review of UWBRAD
  - Antarctic Campaign Overview
  - Results
  - Conclusions

# UWBRAD Measurement Concept

UWBRAD was designed for retrieving the internal temperature of ice sheets



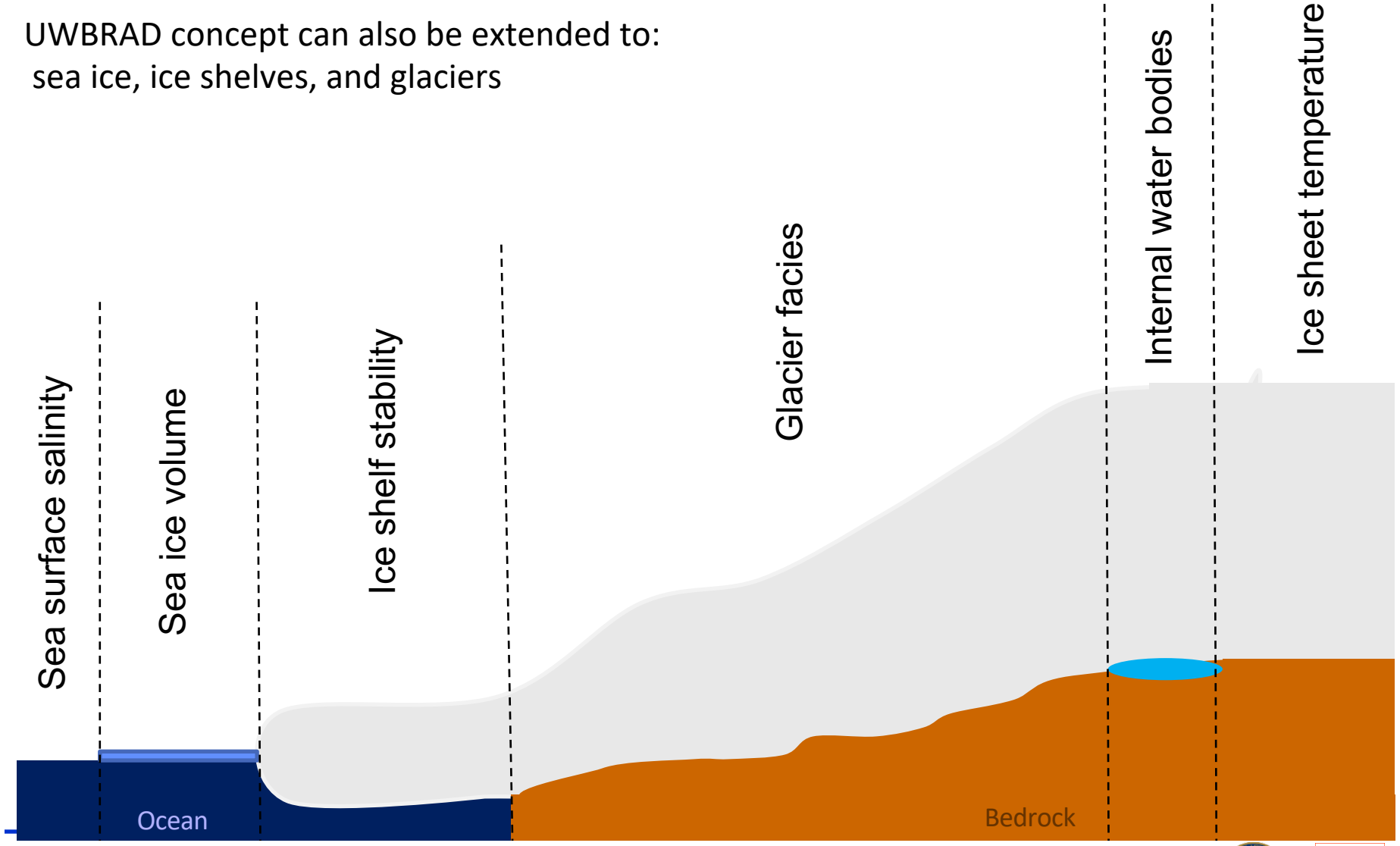

Microwave Emission is an explicit function of physical temperature. Roughly:

$$T_b = e\, T_{physical}$$

and is well suited to retrieve ice sheet temperature

# UWBRAD Measurement Concept

UWBRAD concept can also be extended to:
sea ice, ice shelves, and glaciers

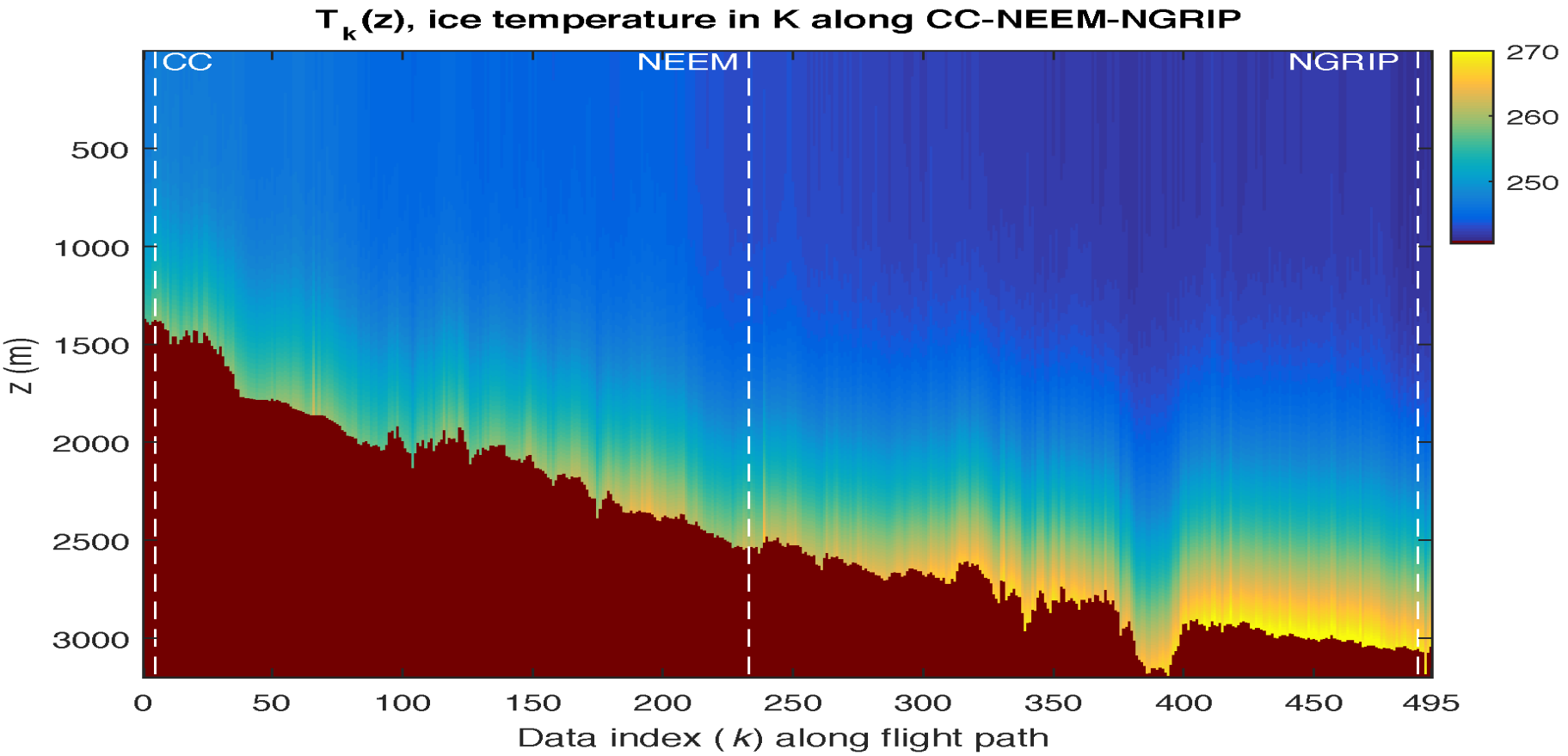


# UWBRAD Instrument

- Measures Earth thermal emissions in 12 ~ 88 MHz channels from 500- 2000 MHz
  - Each channel further resolved into 512 frequency sub-channels
  - Allows measurement of spectral properties of ice sheet and sea ice thermal emission
  - Traditional L-band radiometry measures only 1400-1427 MHz
- Single circularly polarized antenna observing at nadir
  - Antenna deployed in flight from “periscope” system
- System operates outside spectrum protected for microwave radiometry so algorithms to detect and remove radio frequency interference required
- Deployed aboard Ken Borek DC-3T Basler Aircraft in Greenland flights
- Deployed aboard Twin Otter Aircraft in Antarctica

# Temperature Profile Retrievals

- Temperature profile retrievals along flight line between NEEM and GRIP boreholes possible after using in-situ borehole temperatures to constrain density parameter space

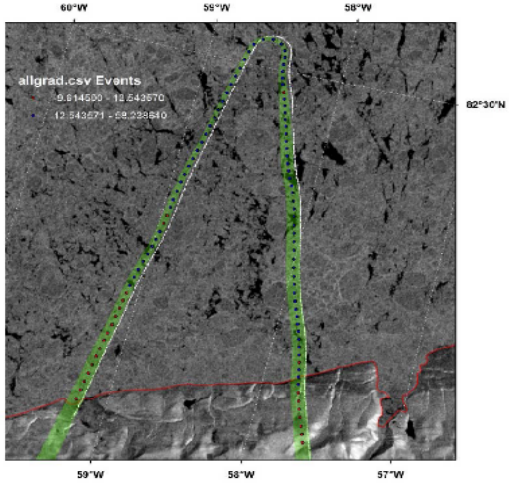


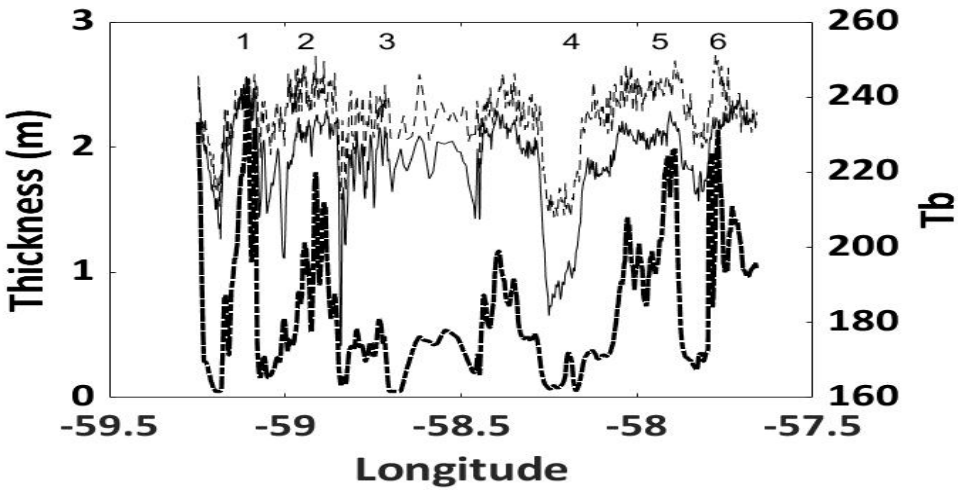

- Combining with a 0.5-1.5 GHz radar would constrain density parameters without need for ancillary data

# UWBRAD Retrievals of Sea Ice Thickness

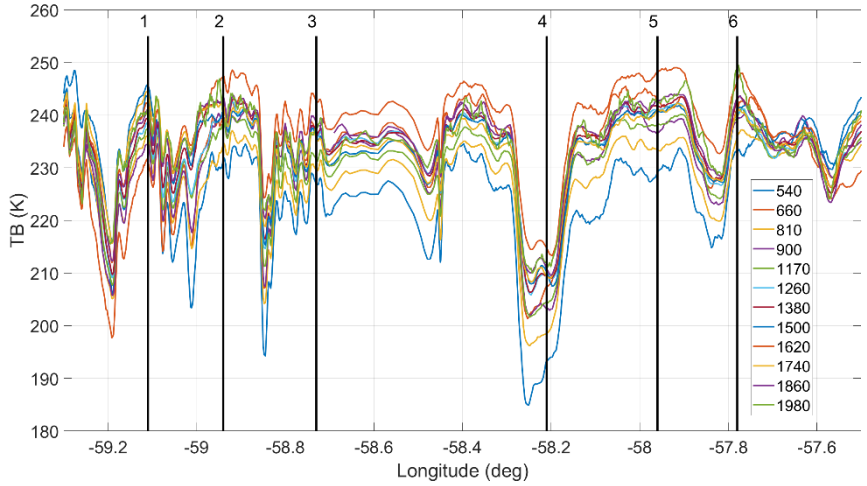
- Lower frequencies of UWBRAD should improve thickness sensitivity for 50-200 cm thicknesses
- Model for sea ice thermal emission developed for SMOS extended to 500-2000 MHz range and applied to retrieve thickness and salinity through best fit to UWBRAD spectra
- Results show thicknesses in the 20-220 cm range in this portion of the Lincoln Sea
- Unfortunately no reliable “ground truth” information for comparison, but results seem reasonable
- Team will deploy ground-based UWBRAD in upcoming MOSAIC campaign for further development

Flight path over Lincoln Sea Ice



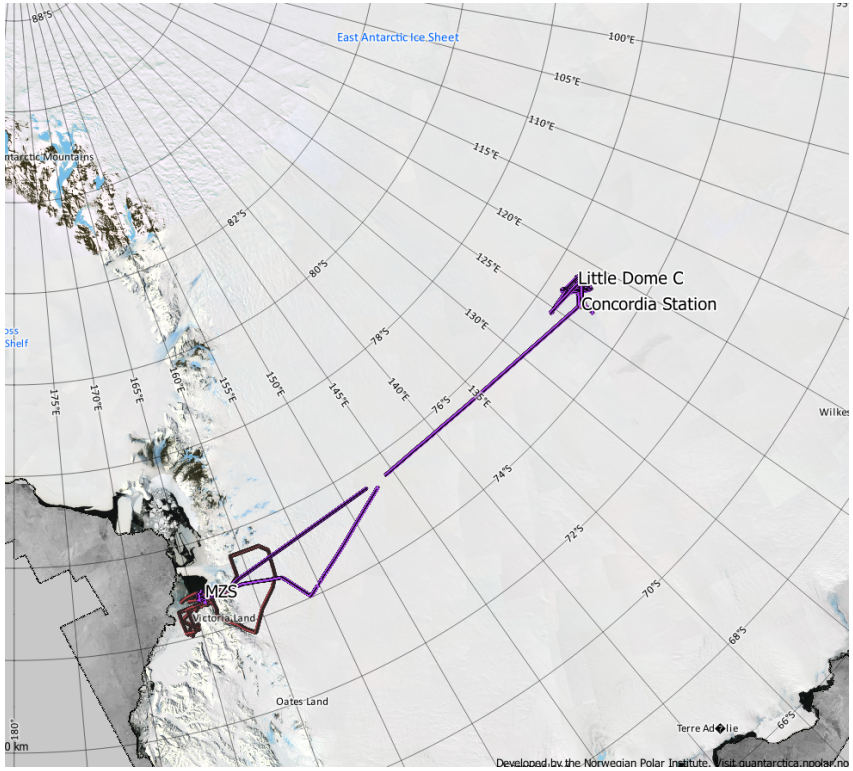




UWBRAD Brightness Temperatures



# 2018 Antarctic Campaign

- A campaign was carried out Nov-Dec 2018 as part of the 34th expedition of the Italian Antarctic Program; also supported by NASA Cryosphere program
- Campaign goals were the estimation of ice temperature profiles over the East Ice Sheet and sea ice volume estimation.
- Secondary targets: characterization of glaciers, ice shelves, blue ice
- UWBRAD deployed on a Twin Otter
- Flights over coastal sea ice, ice shelves, polynya, outlet glaciers, and transit over the ice sheet from Mario Zucchelli station to Concordia station
- 4 flights for a total of almost 5000km (the original plan was 7500km, shortened due to bad weather and strong katabatic winds)
- Extensive ground truth and ancillary datasets acquired



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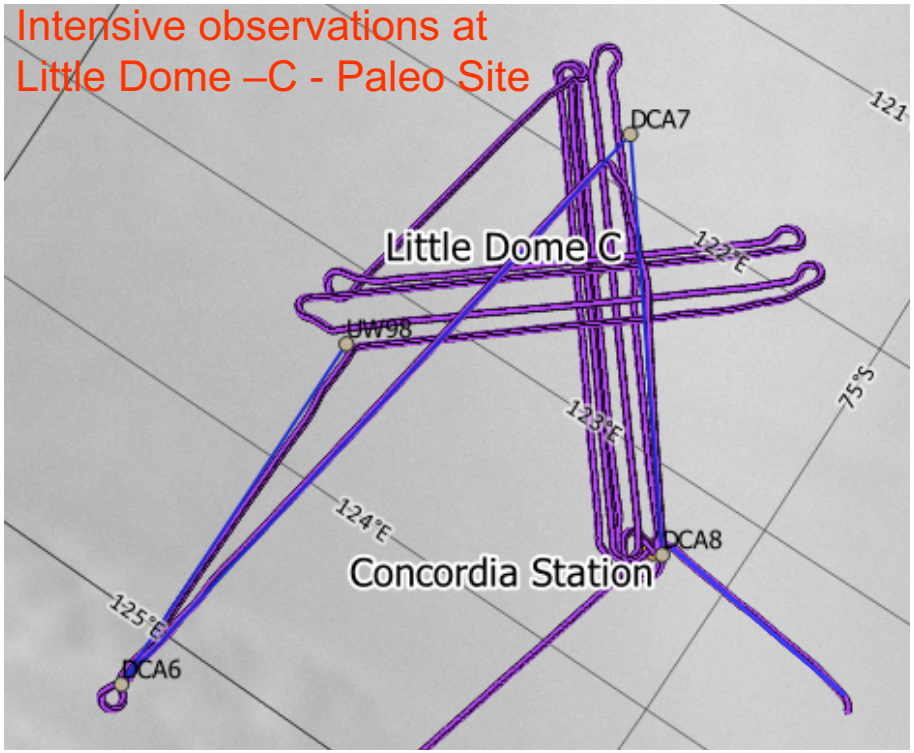

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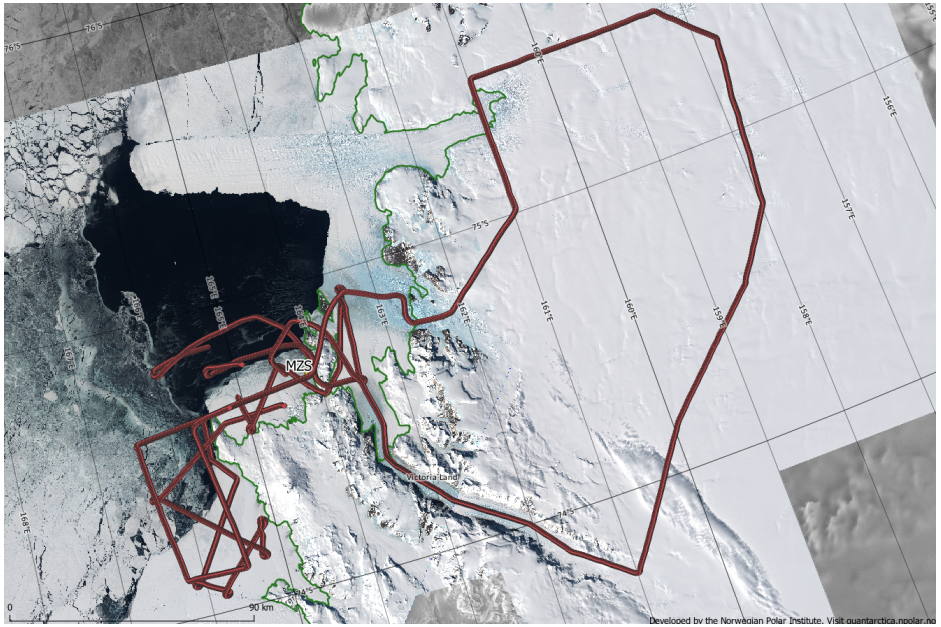
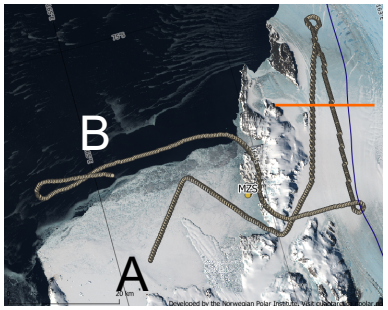
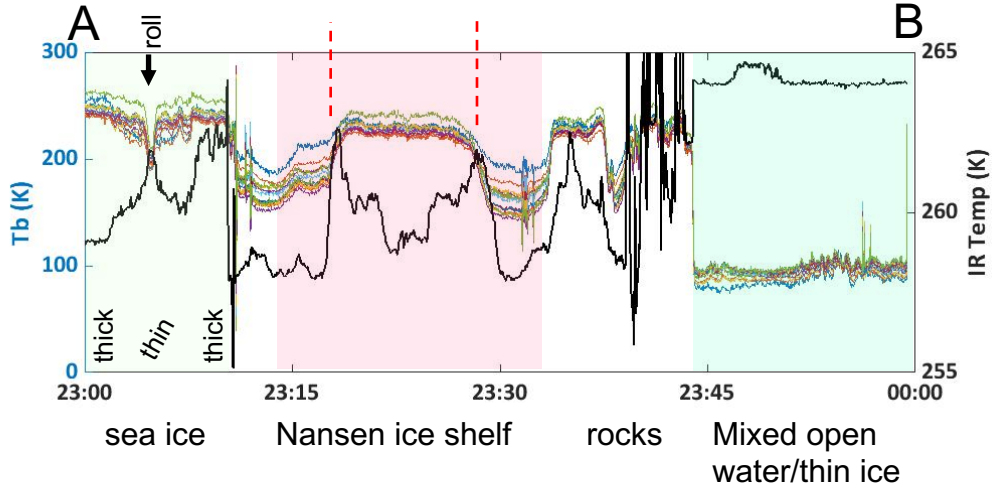


# Sea Ice Datasets

Antarctica

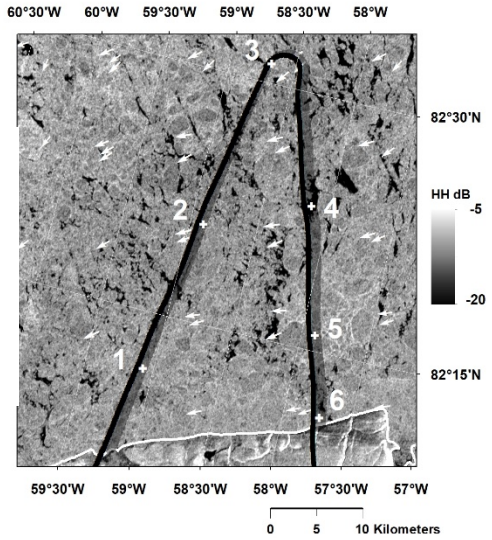


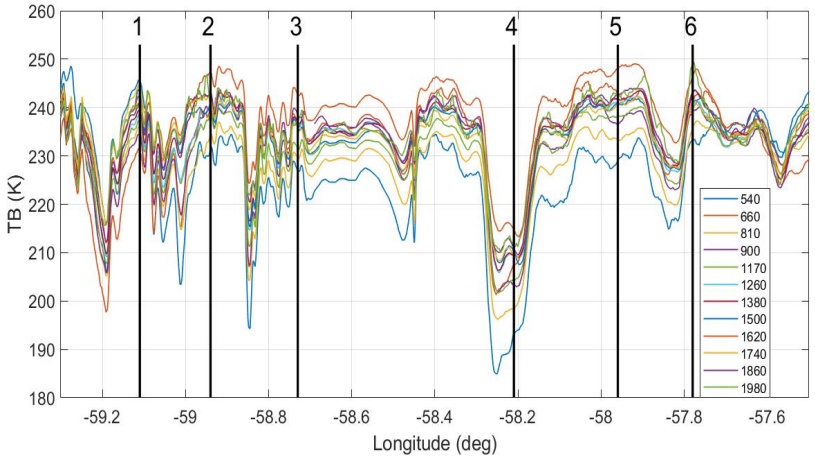




UWBRAD Tb over Terra Nova Bay sea ice portion of the Nov 24, 2018 flight.

Similar Tb levels (high) for thick ice.

Greenland

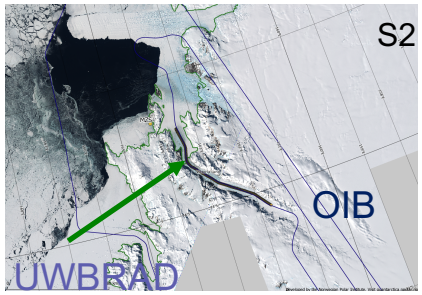


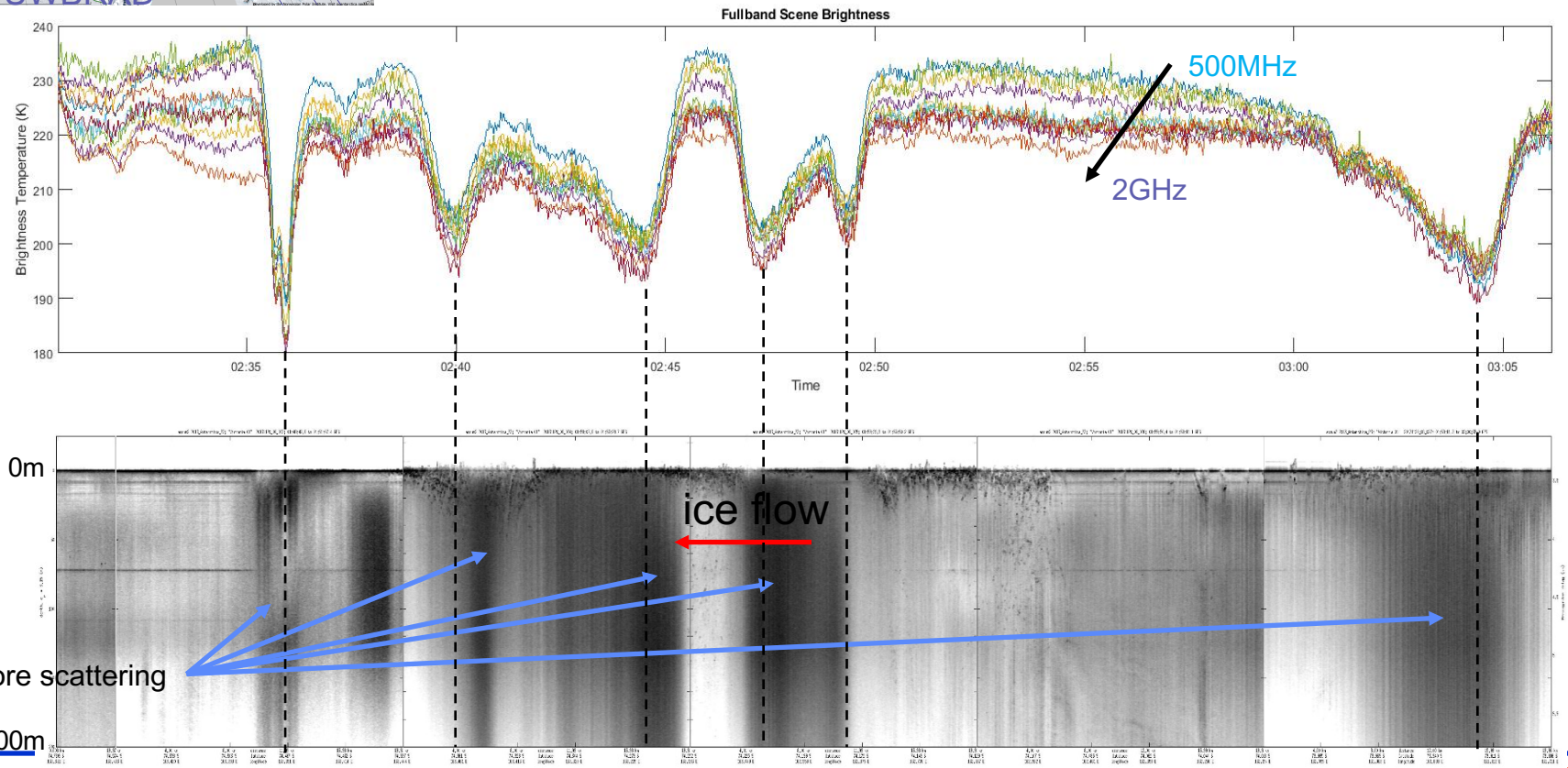

Tb over the Lincoln Sea. Warm temp retrieved as multiyear ice.
Cool Tb correspond to new, thin ice.

- Thickness retrievals for Greenland dataset reported in Jezek et al, "Remote Sensing of Sea Ice Thickness and Salinity with 0.5-2 GHz Microwave Radiometry", TGRS, accepted, 2019.

# Priestley Glacier: New Science?



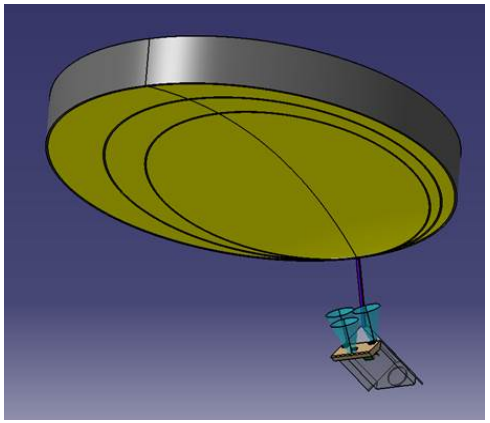

Comparison with the OIB 2013 Accumulation Radar, 565-885 MHz shows Tb signal decreasing in areas with greater scattering; TB spectral signatures also vary

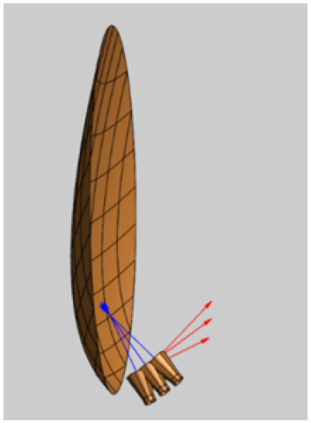



ice flow ~150m/yr

# CryoRad Mission Formulation

- CryoRad mission formulated for monitoring cryospheric processes using 0.4– 2 GHz radiometry by UWBRAD Team (PI: Giovanni Macelloni of IFAC)
- Science products:
  - sea ice thickness in the range 0-2 m
  - sea surface salinity
  - soil freeze /thaw state
  - ice sheet temperature 0-4000 m+
    ice sheet aquifers (water )+
    ice shelf stability
  - soil moisture
  - vegetation biomass





- Large Deployable Antenna (~ 10m)
- 3 feeds for 3 swaths –40 Km each

- Nadir viewing geometry, 120 km swath
- Foot Print : Max 40 Km (P-band) -8 Km ( S-band)
- Accuracy 1 K, sensitivity < 0.5 K
- Orbits: Not sun synchronous
- Revisit time <5 days at 60˚ , 3 days at 70 ˚

# Conclusions

- UWBRAD campaigns have obtained an extensive airborne dataset of 0.5-2 GHz microwave thermal emissions for the Greenland and Antarctic ice sheets and for sea ice
  - Also open ocean, boreal forest

- Results demonstrate the potential of 0.5-2 GHz microwave radiometry for sensing internal ice sheet temperatures and sea ice thickness
  - Paper on sea ice thickness sensing accepted; paper on ice sheet temperature retrieval in preparation for submission, analysis of datasets continuing
  - Growing international interest in the use of 0.5-2 GHz radiometry for a variety of applications
  - Recent project under NASA THP with WiBAR team (R. DeRoo) on snow sensing
  - Preparing for deployment of system on tower in the MOSAiC sea ice campaign (NSF)

- Proposals for additional deployments and for spaceborne mission continuing
  - CryoRAD submitted by IFAC to ESA's EE10 program

- Recent publications:
  - K. Jezek et al, "500-2000 MHz brightness temperature spectra of the Northwestern Greenland ice sheet," TGRS vol. 56, pp. 1485-96, March 2018.
  - M. Andrews et al, "The Ultra-Wideband Software Defined Microwave Radiometer: Calibration, RFI Processing, and Initial Campaign Results," TGRS vol. 56, pp. 5923-5935, 2018.
  - K. Jezek et al, "Remote sensing of sea ice thickness and salinity with 0.5-2 GHz microwave radiometry," accepted by TGRS, 2019.