The Ultra-Wideband Software-Defined Microwave Radiometer For Ice Sheet Subsurface Temperature Sensing: Results from 2017 Campaigns

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Motivation and Outline

- The ultra-wideband software defined microwave radiometer (UWBRAD) measures Earth emissions from 0.5- 2 GHz to demonstrate remote sensing at these frequencies
  - Ice sheet internal temperatures
  - Sea ice thickness
  - Land surface applications (e.g. soil moisture)
  - Sea salinity
  - Supported under NASA 2013 Instrument Incubator Program; project concluded 3/31/18
- UWBRAD was deployed in airborne observations of the Greenland ice sheet in Sept 2016 and Sept 2017
  - Also observed land and sea scenes during transit to/from Calgary, Canada
- Outline
  - Review of UWBRAD
  - 2017 Campaign Description and Data
  - Application examples
  - Conclusions

Ultra-wideband software defined radiometer (UWBRAD)

- UWBRAD operates 0.5–2 GHz to demonstrate radiometric use of these bands
- Requires operating in unprotected bands, so interference a major concern
- Addressed by sampling entire bandwidth (in ~ 88 MHz channels) and implementing real-time detection/mitigation/use of unoccupied spectrum

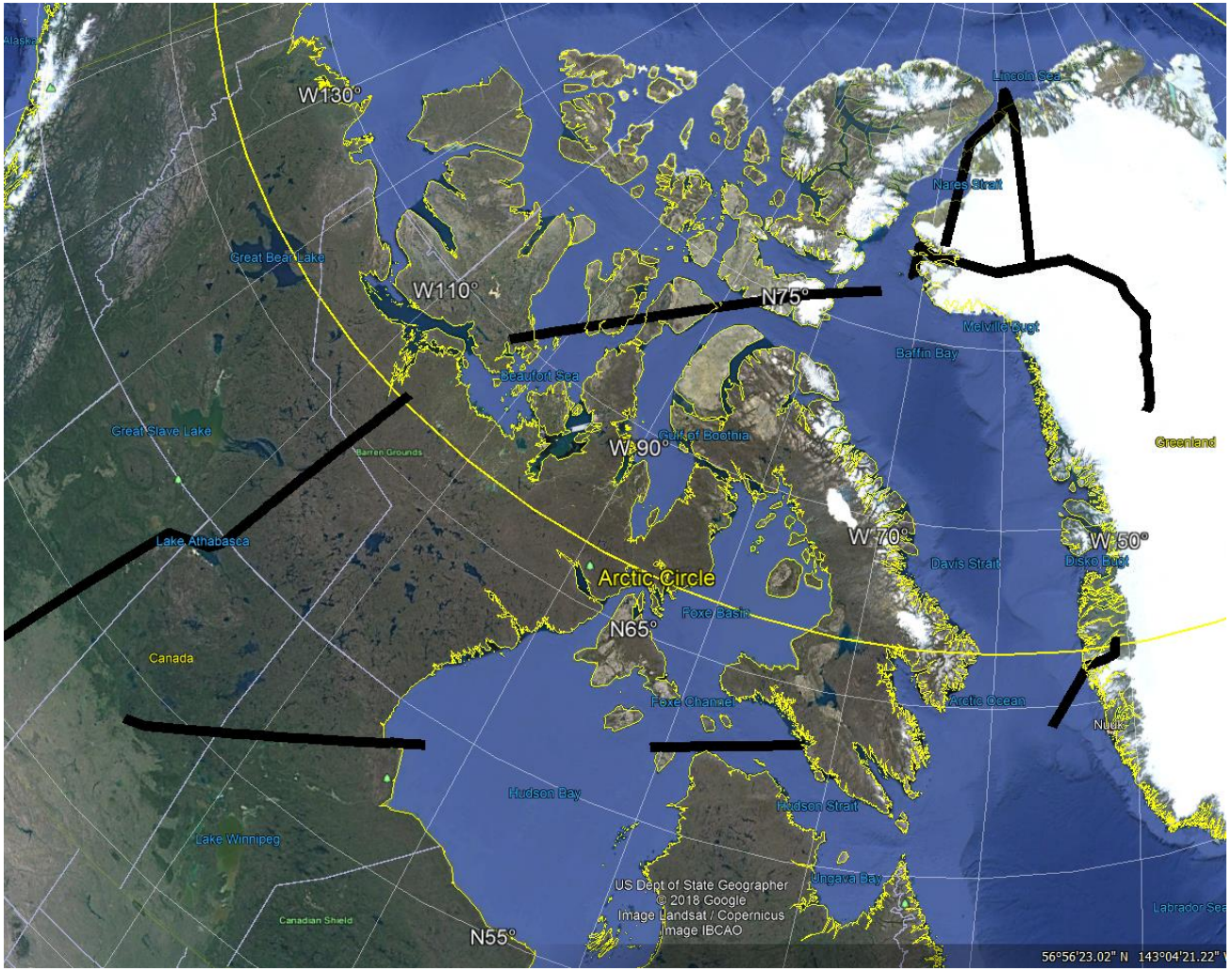
Freq (GHz)	0.5-2 , 12 x ~88 MHz channels
Polarization	Single (Right-hand circular)
Observation angle	Nadir
Spatial Resolution	1.2 km x 1.2 km (1 km platform altitude)
Integration time	100 msec
Ant Gain (dB) /Beamwidth	11 dB 60°
Calibration (Internal)	Reference load and Noise diode sources
Calibration (External)	Sky and Ocean Measurements
Noise equiv dT	0.4 K in 100 msec (each 100 MHz channel)
Interference Management	Full sampling of 100 MHz bandwidth in 16 bits resolution each channel; real time “software defined” RFI detection and mitigation
Initial Data Rate	700 Megabytes per second (10% duty cycle)
Data Rate to Disk	<1 Megabyte per second

UWBRAD Instrument

- Three subsystems:
  - Radiometer front end and downconversion modules
    - Front end modified between Sept 16 and Sept 17 campaigns to improve resistance to high RF power inputs and electrostatic discharge
  - Digital backend
    - 3 computers hosting 2 ADC cards each to sample 4 channels by each computer, 1 control computer
    - Each data acquisition computer computes data spectra and performs real time RFI flagging and removal
    - RFI filtering also can be performed in post-processing
  - Antenna
    - 0.5-2 GHz conical spiral design with near constant gain over frequency
    - Deploys from “periscope” system

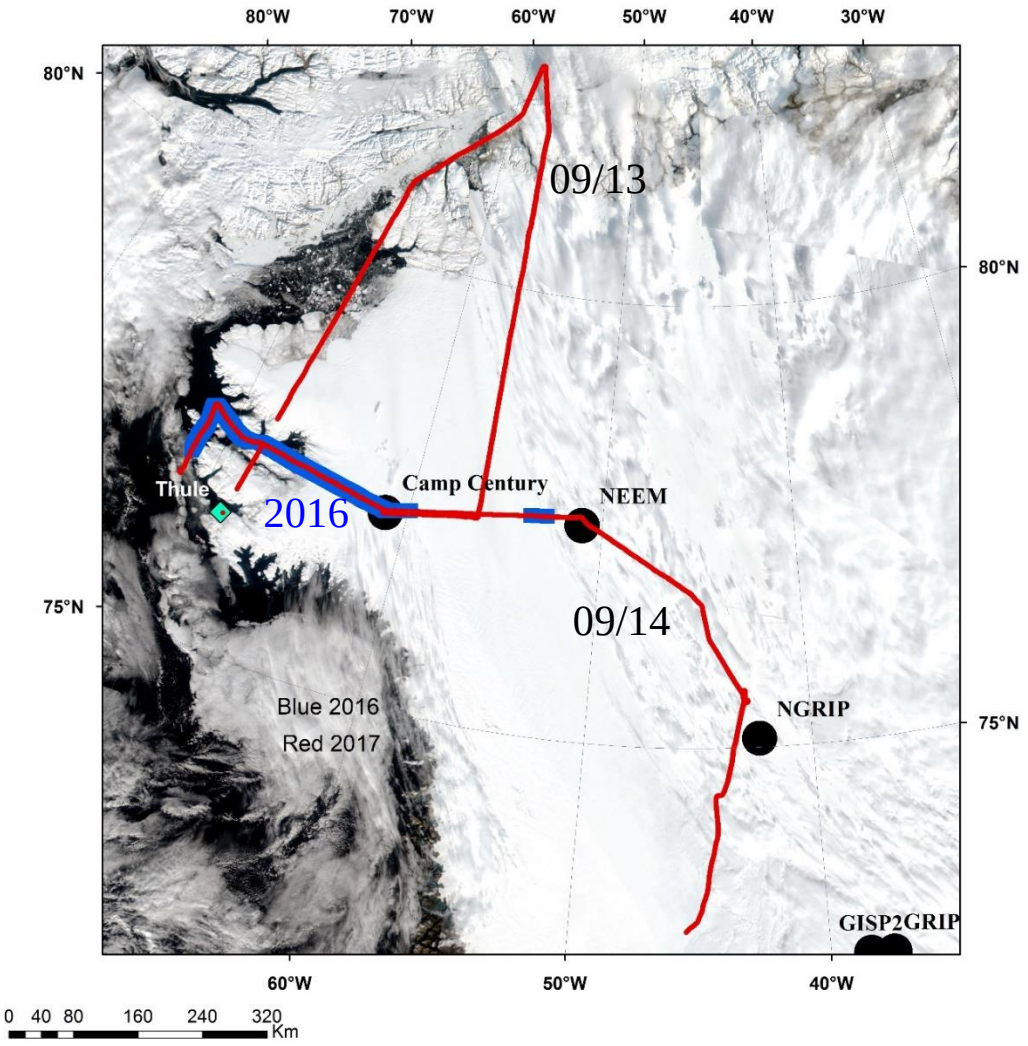
Summary of 2017 Flight Paths

- Datasets include
  - Greenland ice sheet
  - Sea ice in Nares Straits
  - Devon ice cap
  - Canadian northern latitudes
  - Sea surface
  - Firn aquifer regions



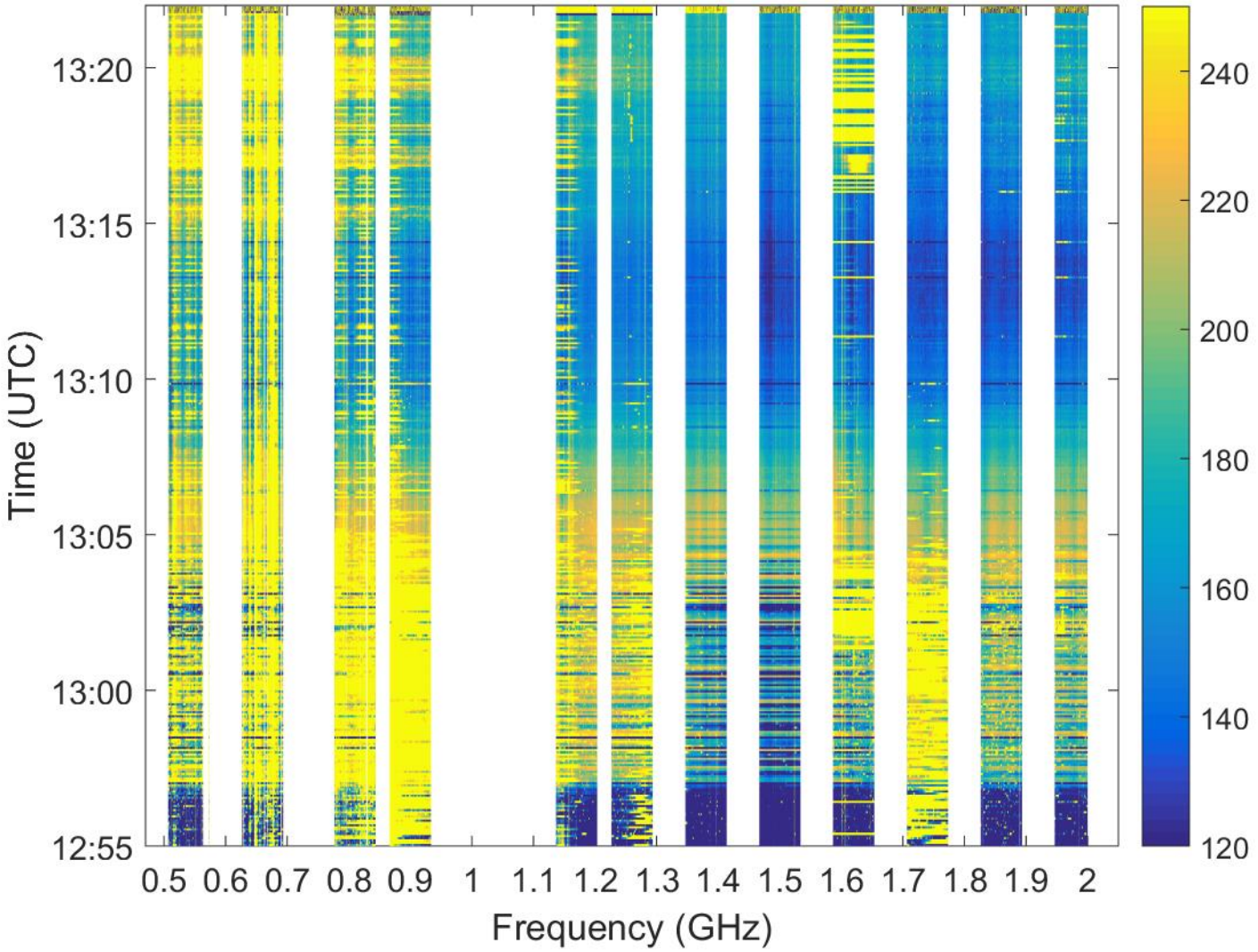
Zoom on September 13 and 14 Flight Paths

- **September 14th:**
  - overlapped 2016 flight path from Thule to Camp Century
  - covered NEEM and NGRIP core sites
- **September 13th:**
  - overlapped portion of September 14th path
  - provided coverage of sea ice in the Nares strait and Arctic Ocean
- 2017 data shown in what follows is current data release
- Data available at: http://www2.ece.ohio-state.edu/~johnson/uwbrad.html



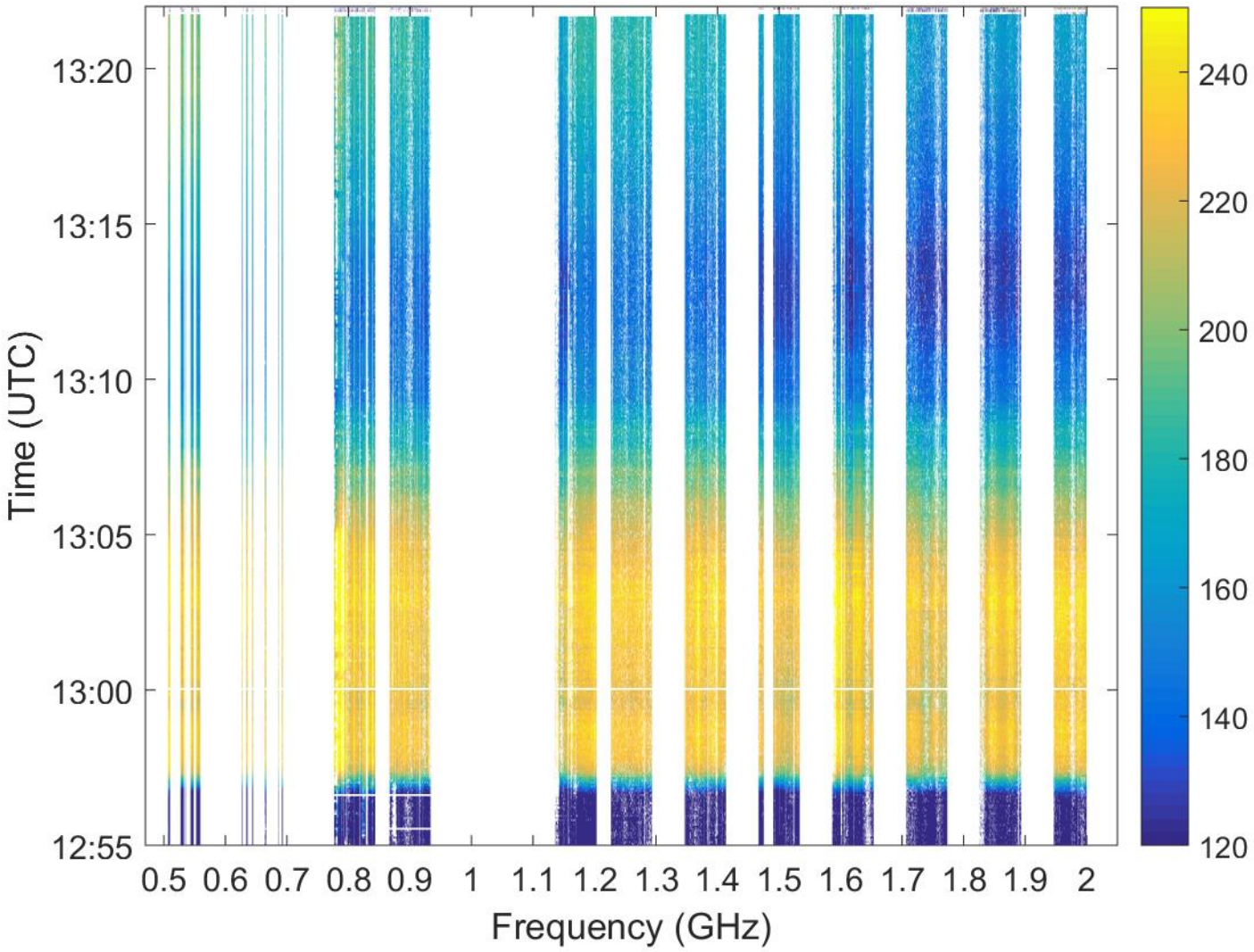
Full UWBRAD Spectra/RFI Processing

- Extensive RFI across spectrum, even in Greenland

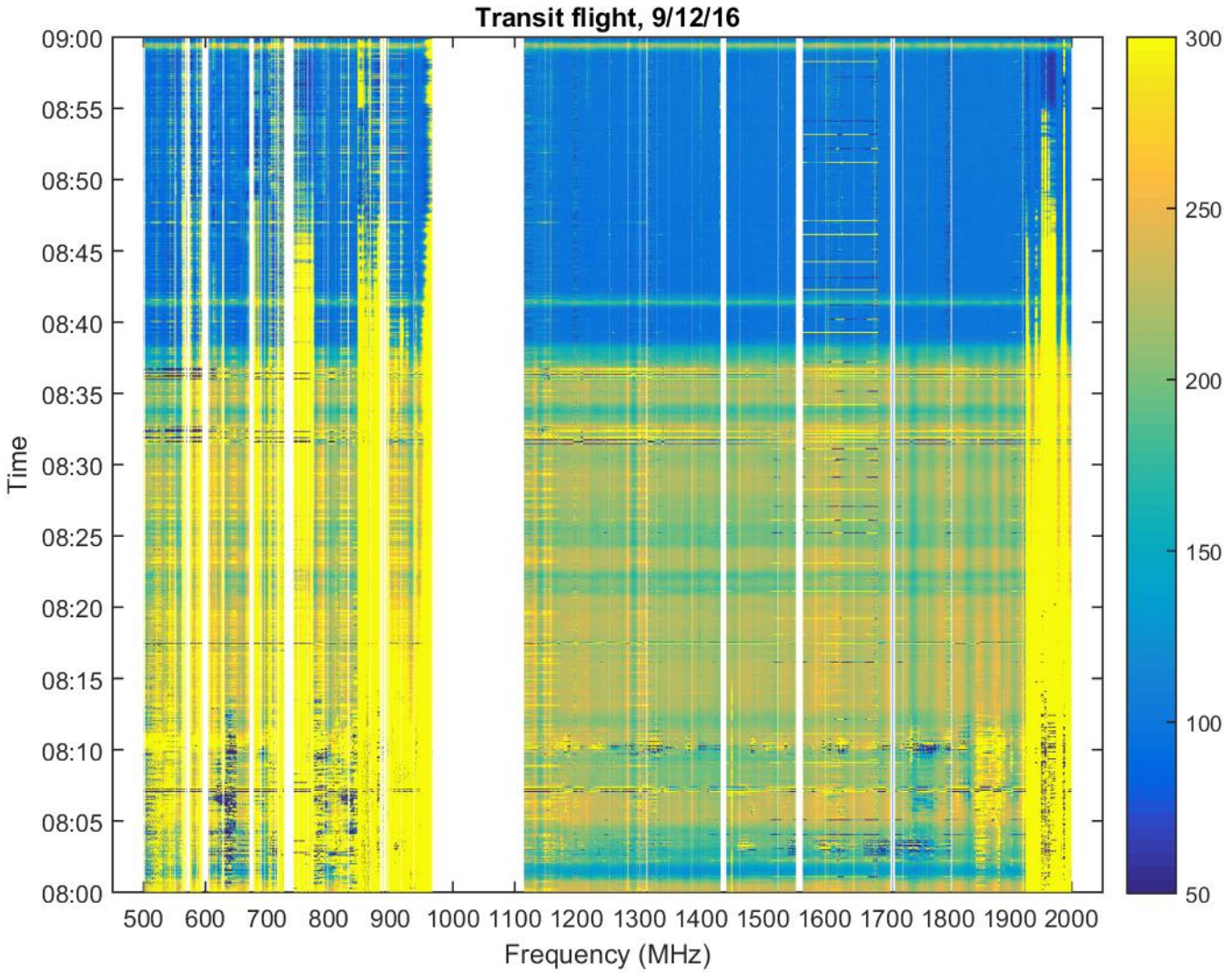


Full UWBRAD Spectra/RFI Processing

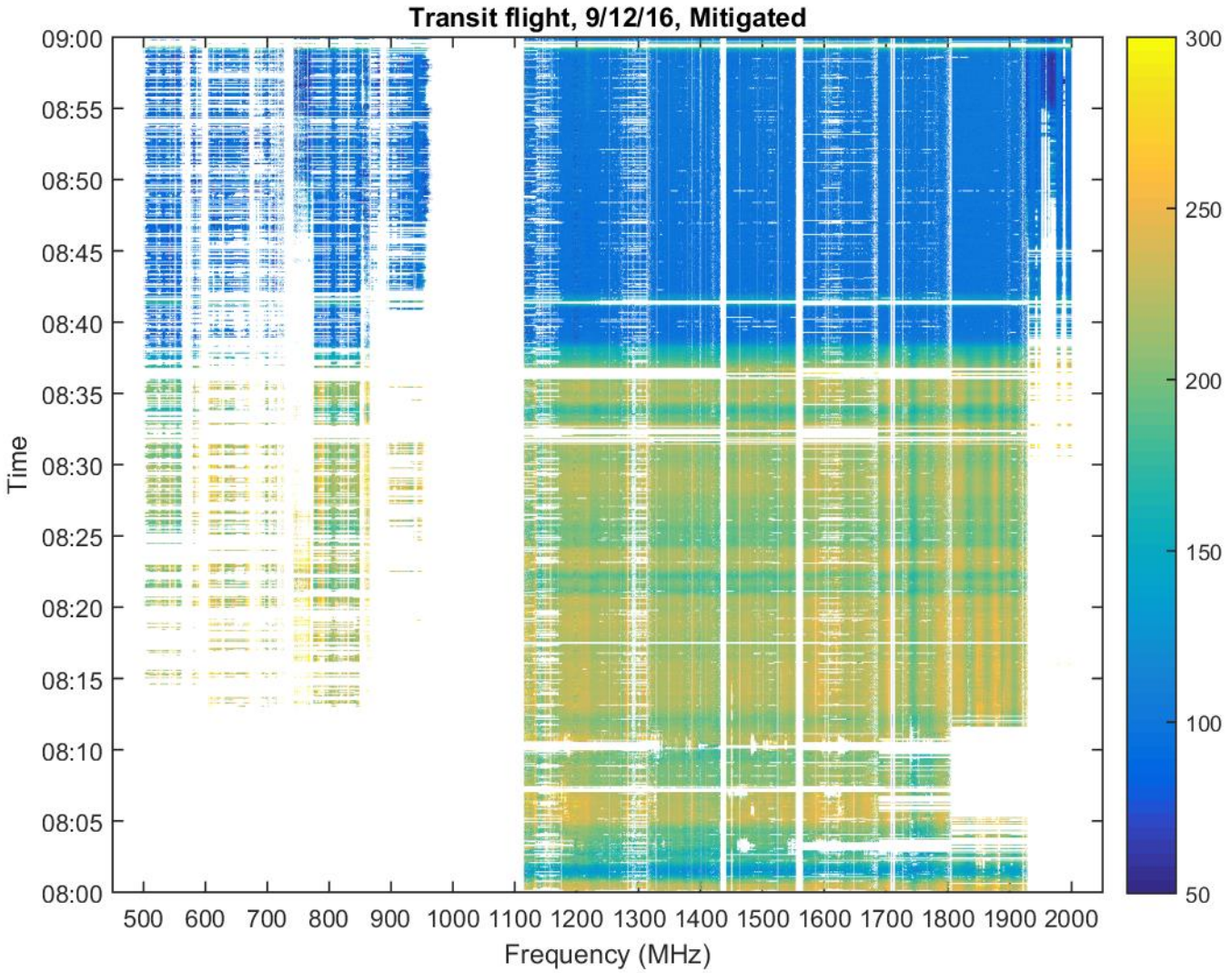
- Extensive RFI across spectrum, even in Greenland
- Pulse, Cross-frequency, and kurtosis detectors flag try to flag out corrupted parts of spectrum
- Appear to eliminate much RFI
- Large swaths of bandwidth lost in some cases
- Some evidence of RFI remaining



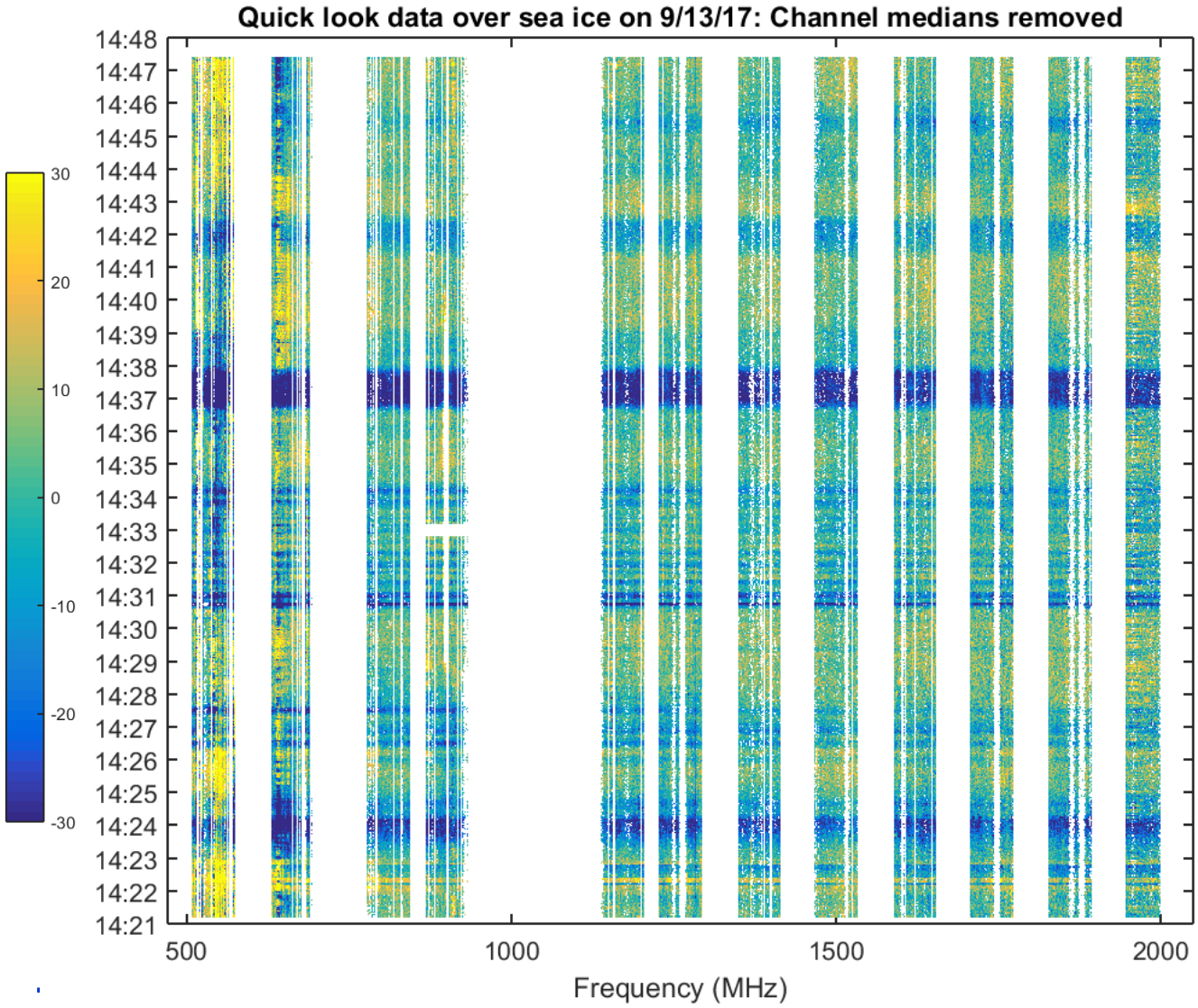
Transit Flight Examples



Transit Flight Examples

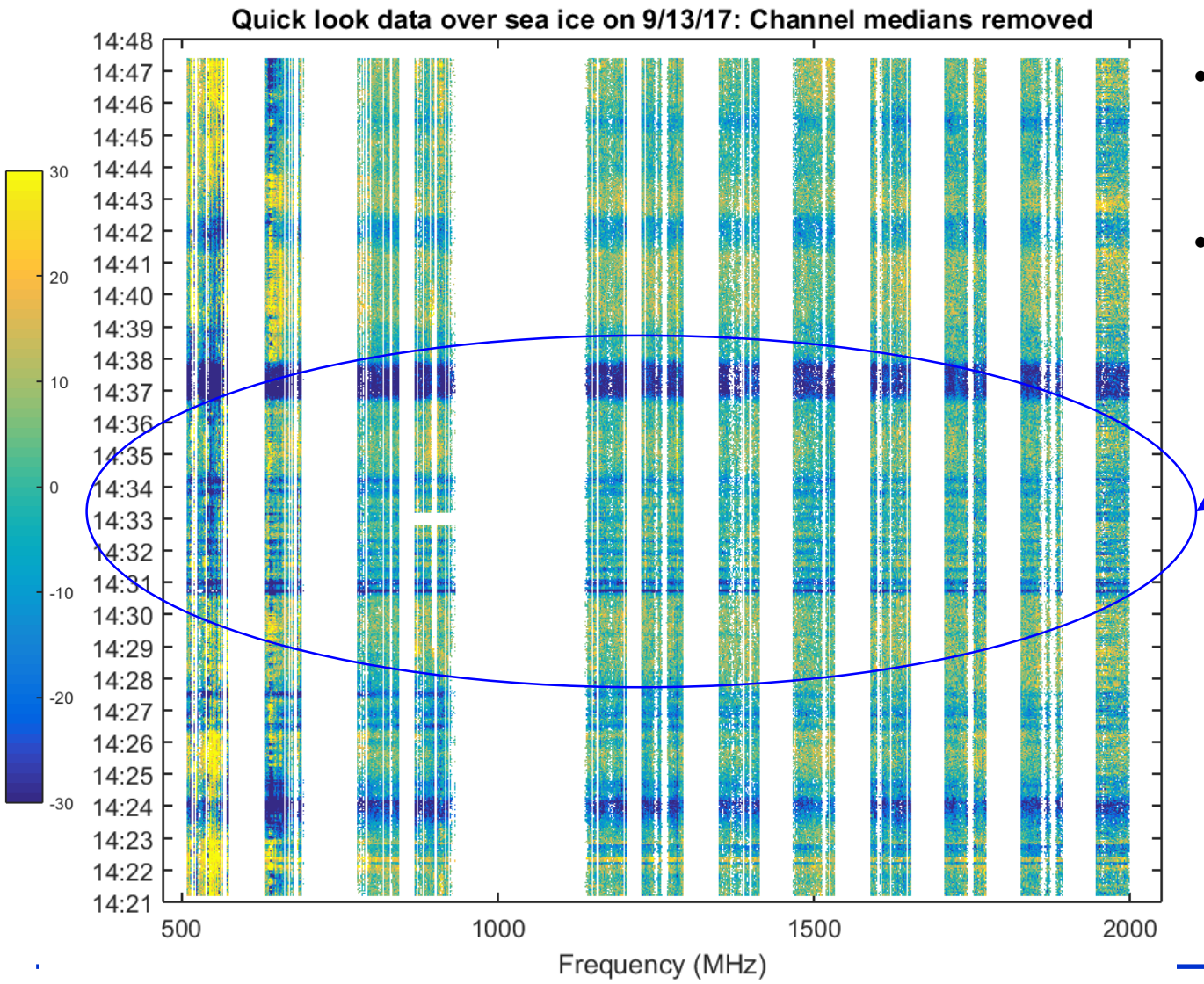


September 13th: Full Spectrogram



- Removing channel medians to highlight spectral variations

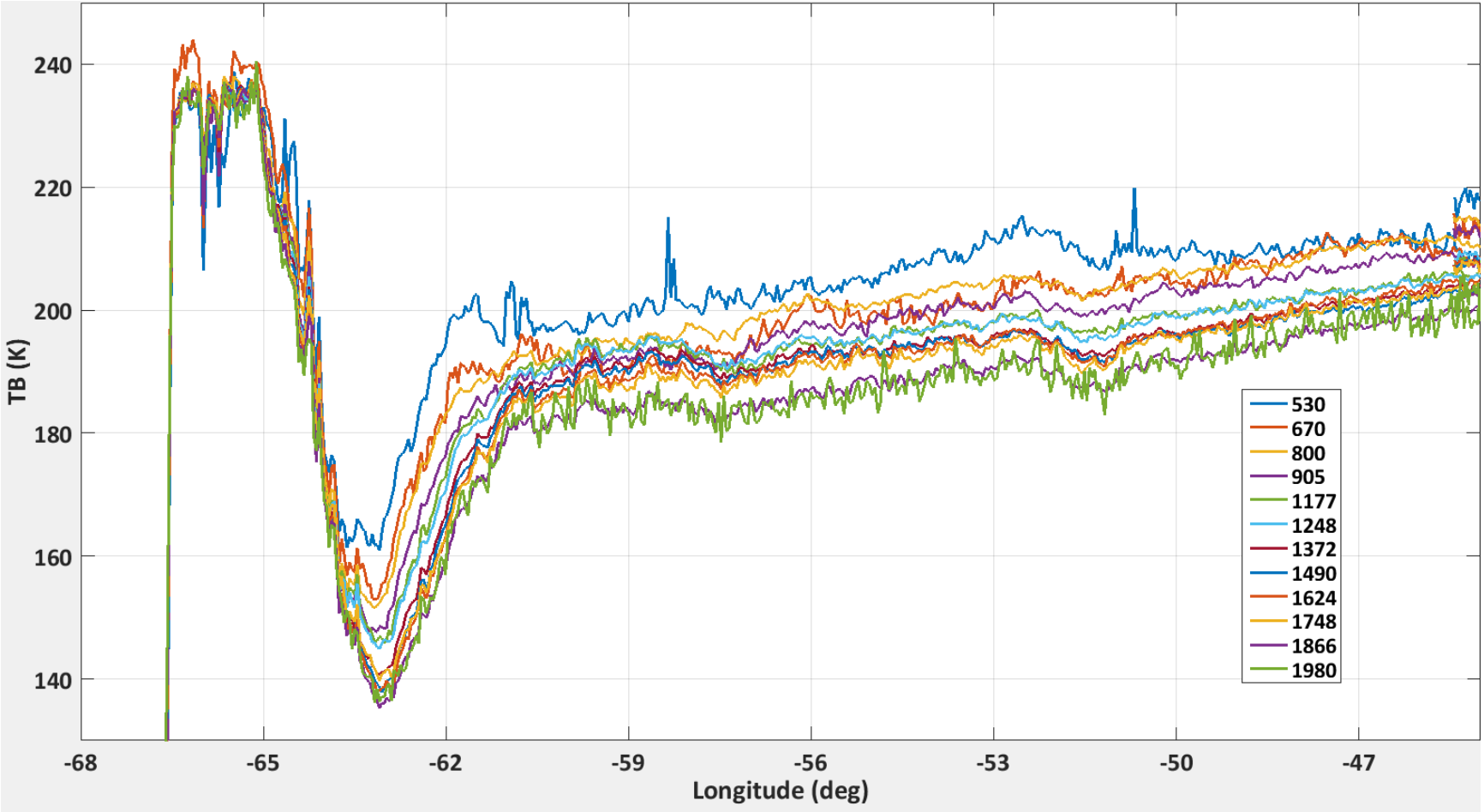
September 13th: Full Spectrogram



- Nares strait flight includes sea ice overpasses
- No immediate evidence of oscillatory features

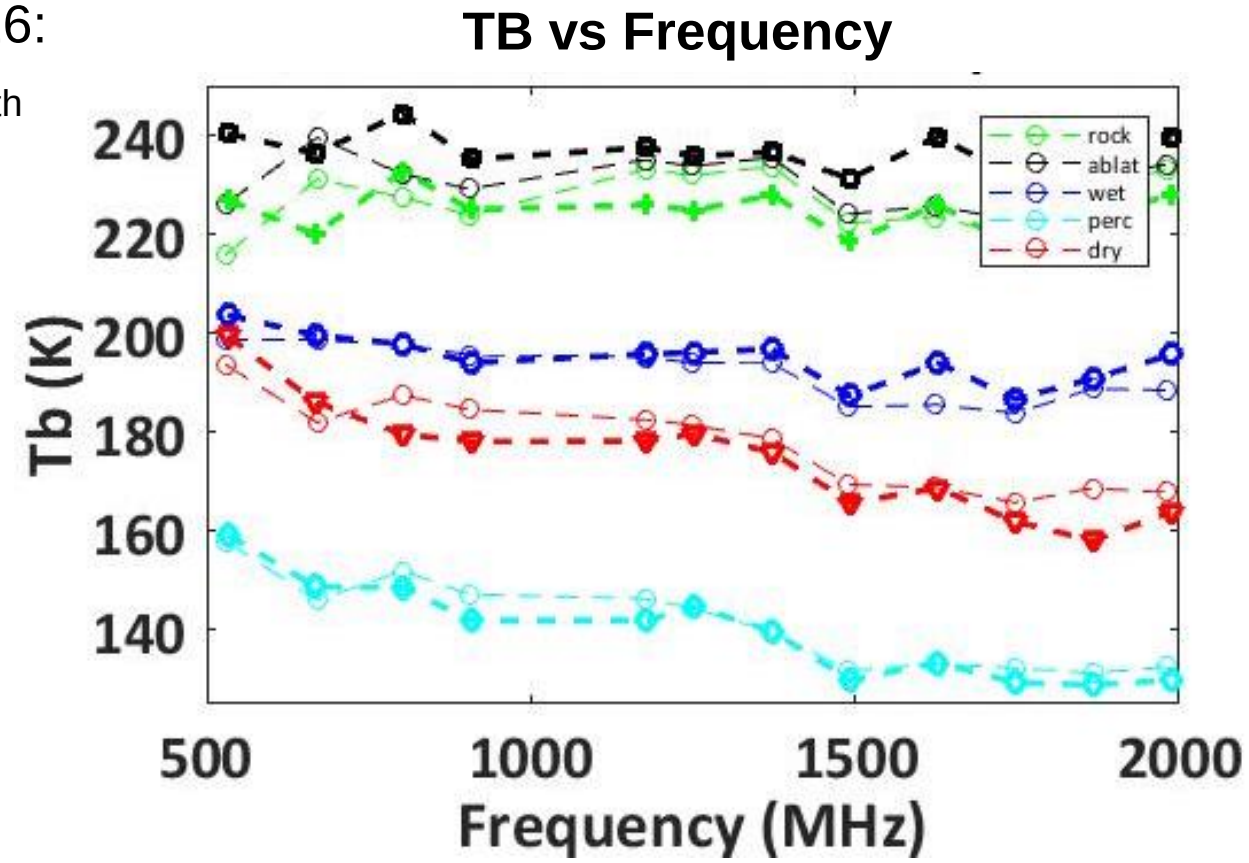
Results: September 14th

- Transition from ocean scene to rocky shore to percolation region into dry portion of ice sheet



September 14th: Ice Sheet Spectra

- Reasonable consistency between 2017 and 2016:
  - Some mismatch in flight path and possible temporal variability
  - Data still impacted by RFI contributions at some channels

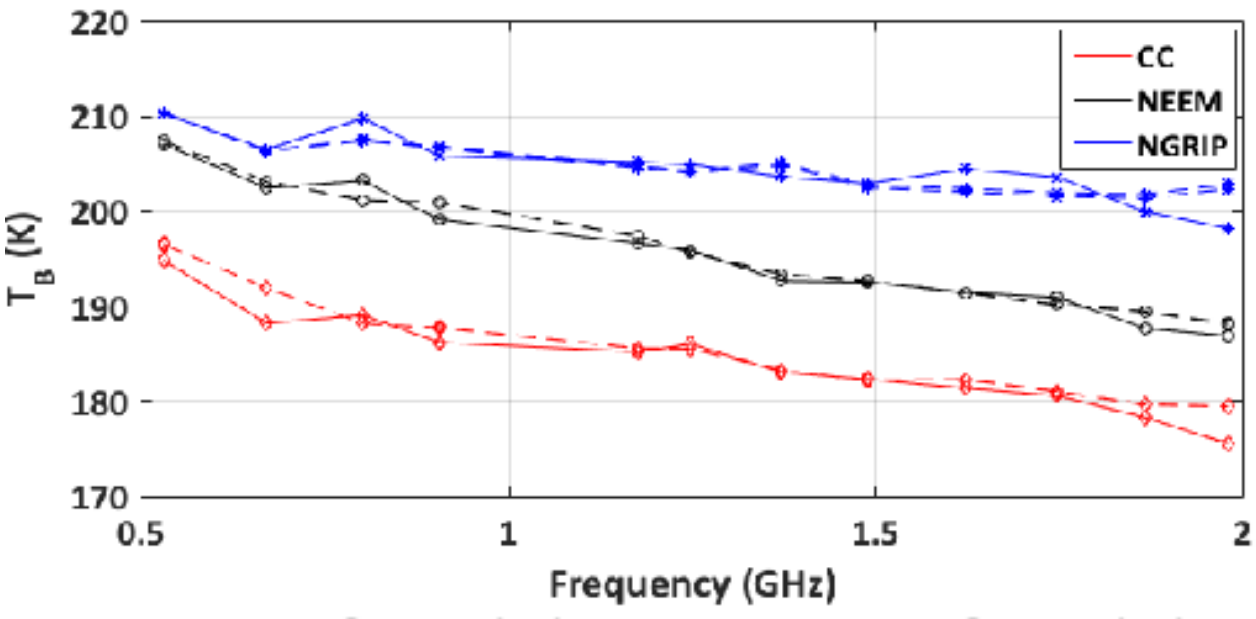


2017: Thick 2016: Thin

Retrieval Performance

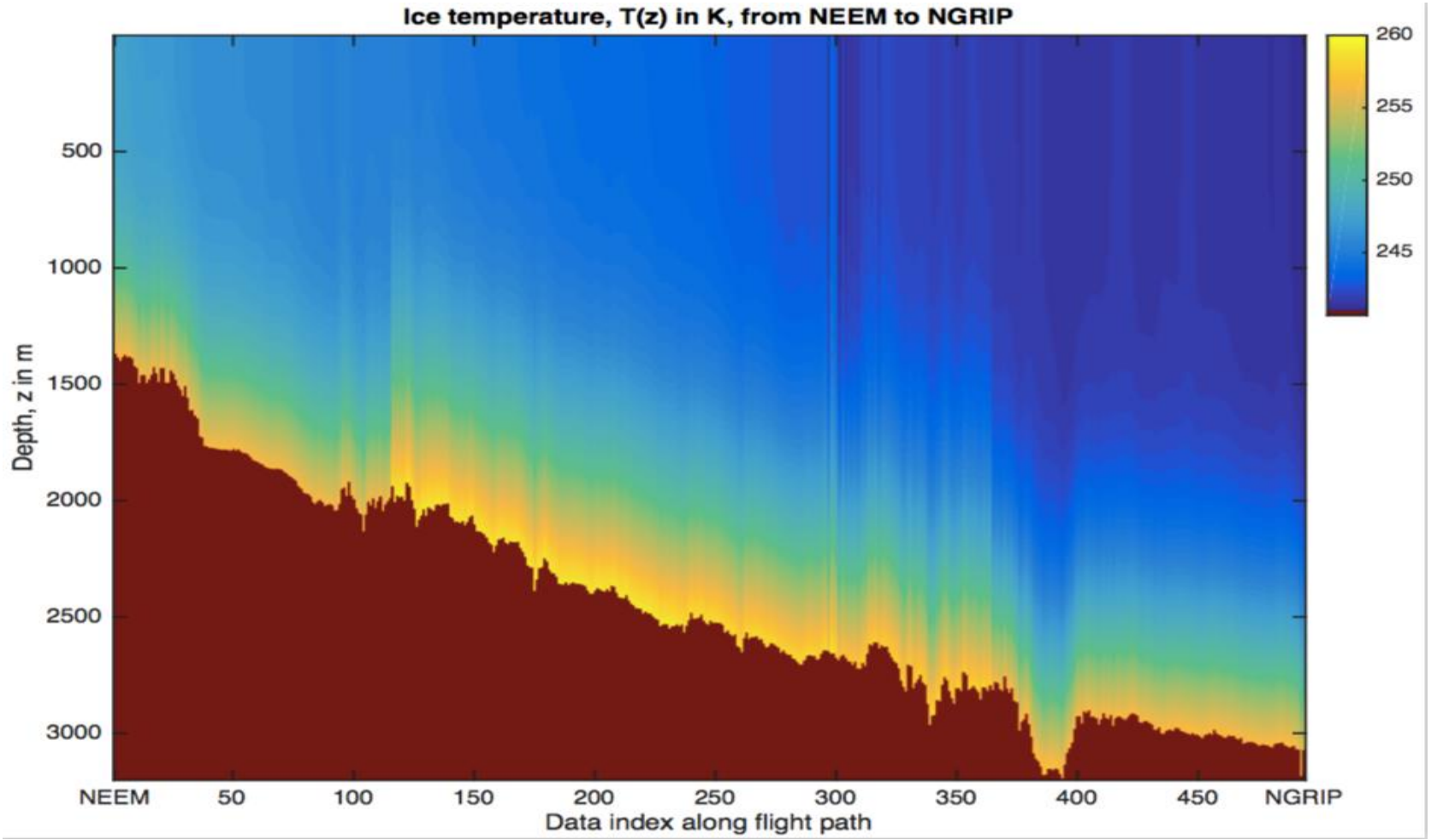
- Retrieval uses a parametrized model of the temperature profile and “tunes” parameters to get best fit between forward model and UWBRAD observations
- Forward model uses a “partially coherent” layered medium Monte Carlo simulation to describe upper firn effects combined with a “cloud model” for emission from lower portions of ice sheet
  - Requires description of nuisance density fluctuation parameters
  - Retrieval can be ill posed when density fluctuations are strong; can be addressed by invoking a-priori assumptions on density fluctuations
  - Also invoking a-priori knowledge on surface temperatures
- Examples of current forward model/retrieval performance

Model/measurement comparisons for the Camp Century, NEEM, and NGRIP borehole sites



Temperature Profile Retrievals

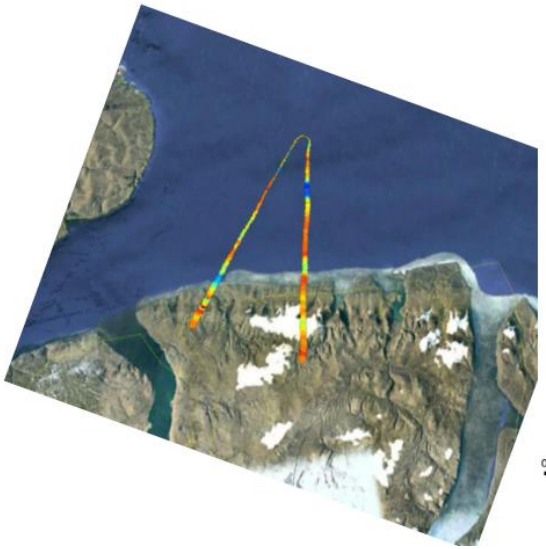
- Temperature profile retrievals along flight line between NEEM and GRIP boreholes possible after using in-situ borehole temperatures to constrain density parameter space

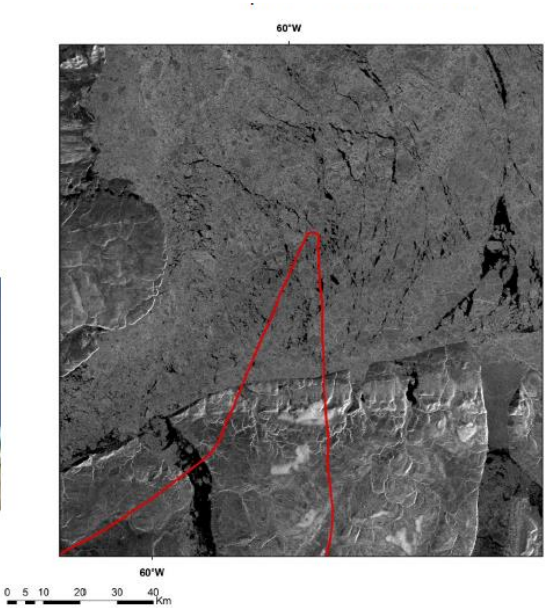


Application Example: Arctic Sea Ice

Sep 13th flight included measurements of sea ice in Northern Greenland

UWBRAD Tb over Sea Ice





Sentinel over Sea Ice

Photo collected during the UWBRAD flight

Tb variations appear consistent with changes in apparent ice concentration in Sentinel image.

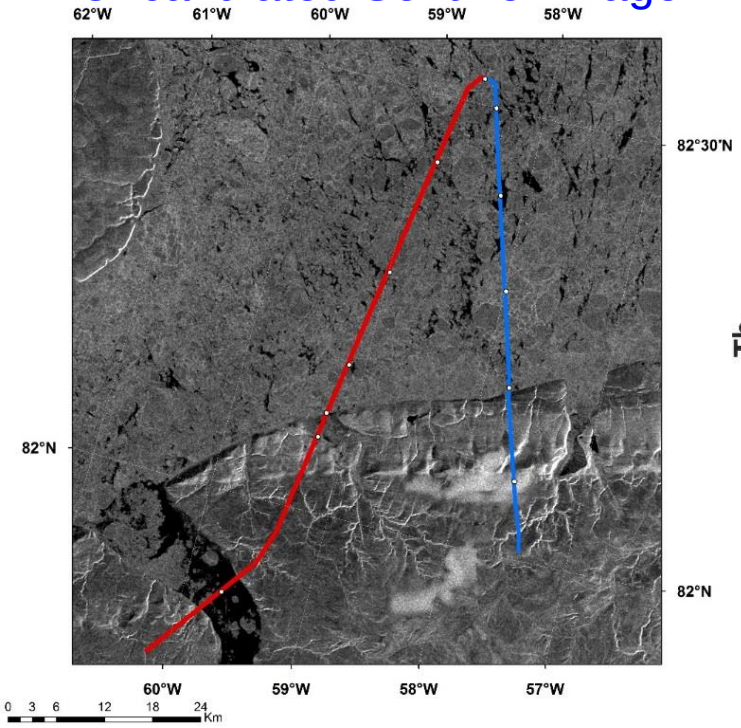
September 13th : Sea Ice

Sentinel SAR and UWBRAD Comparison:

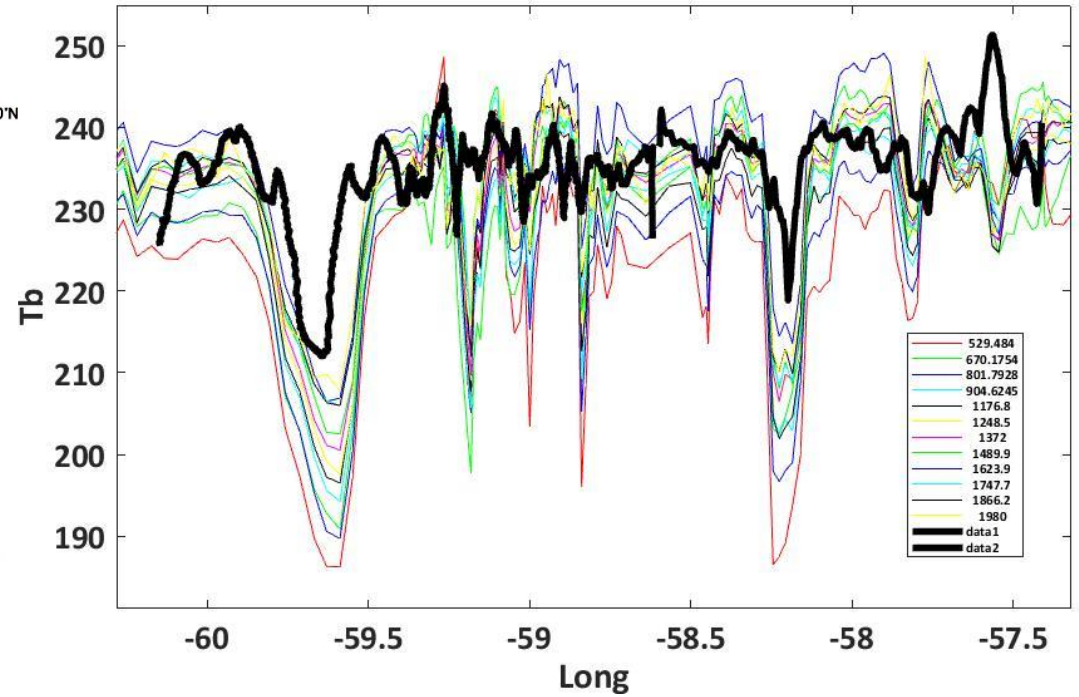
σ_0 is offset and scaled for overlay onto UWBRAD data.

$\sigma_0 = 40 \log_{10} \sigma$, σ is the calibrated pixel value

Uncalibrated Sentinel Image



1A IW beam HH
acquired on 9/13/17 at 20:50:15



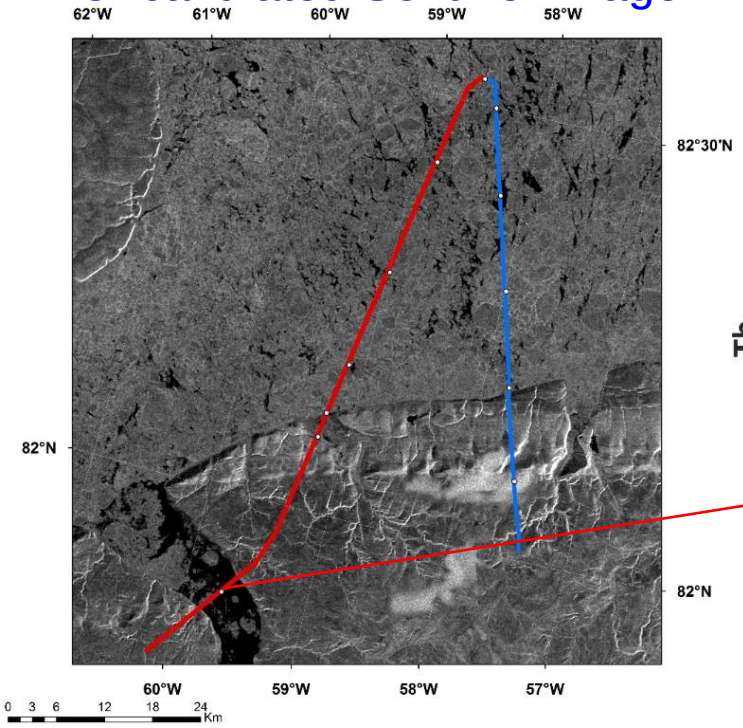
SAR and UWBRAD data are well correlated

September 13th : Sea Ice

Sentinel SAR and UWBRAD Comparison:

Low Tb corresponds to low sigma as expected over smooth water or very thin sea ice

Uncalibrated Sentinel Image



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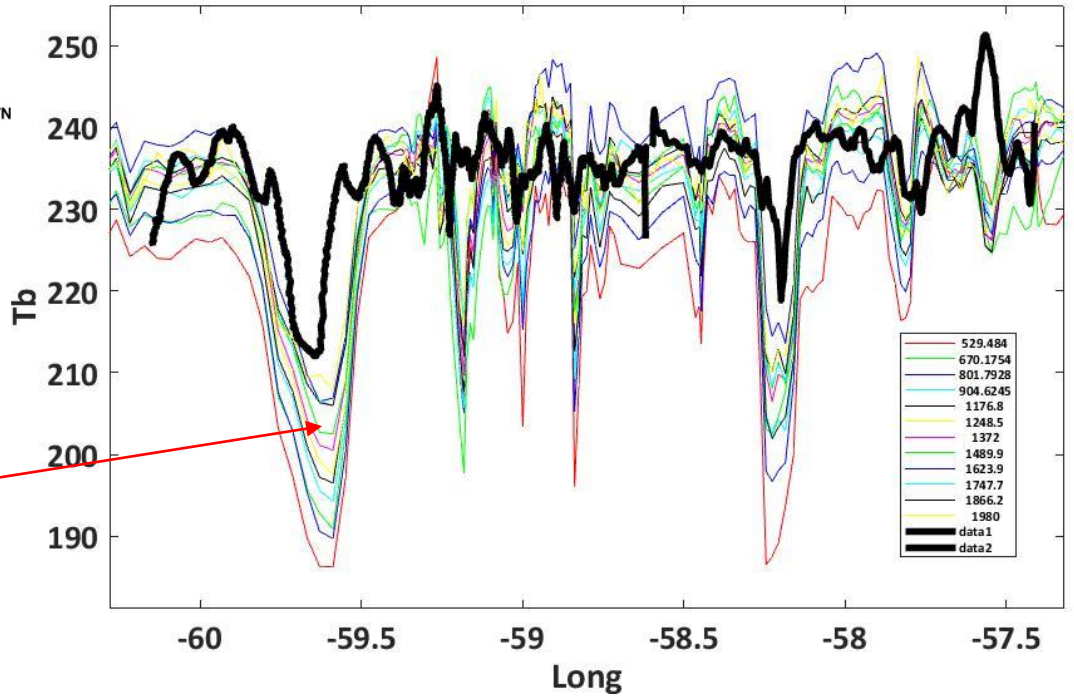

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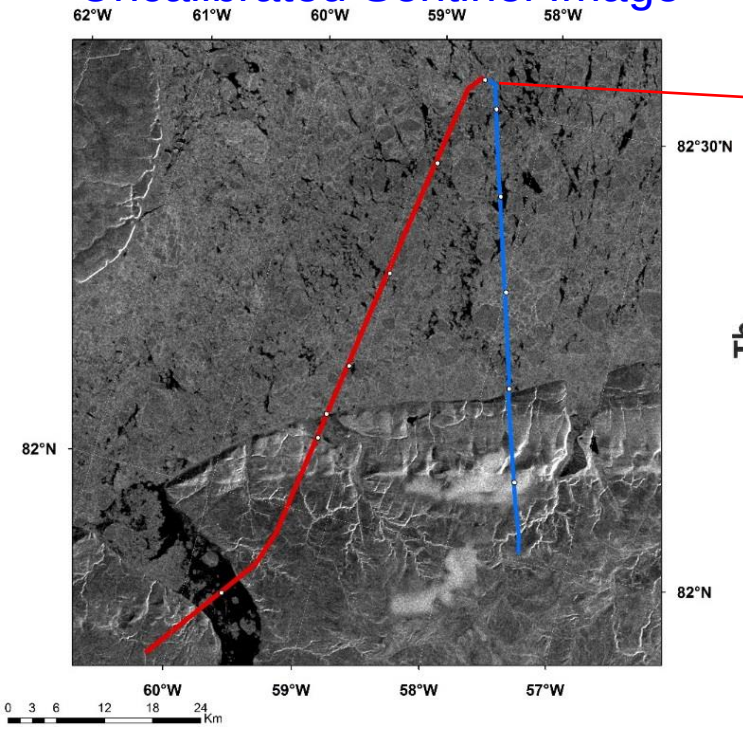
September 13th : Sea Ice

Sentinel SAR and UWBRAD Comparison:

Both data sets increase over sea ice where scattering increases backscatter but increased transmissivity increases Tb

Uncalibrated Sentinel Image



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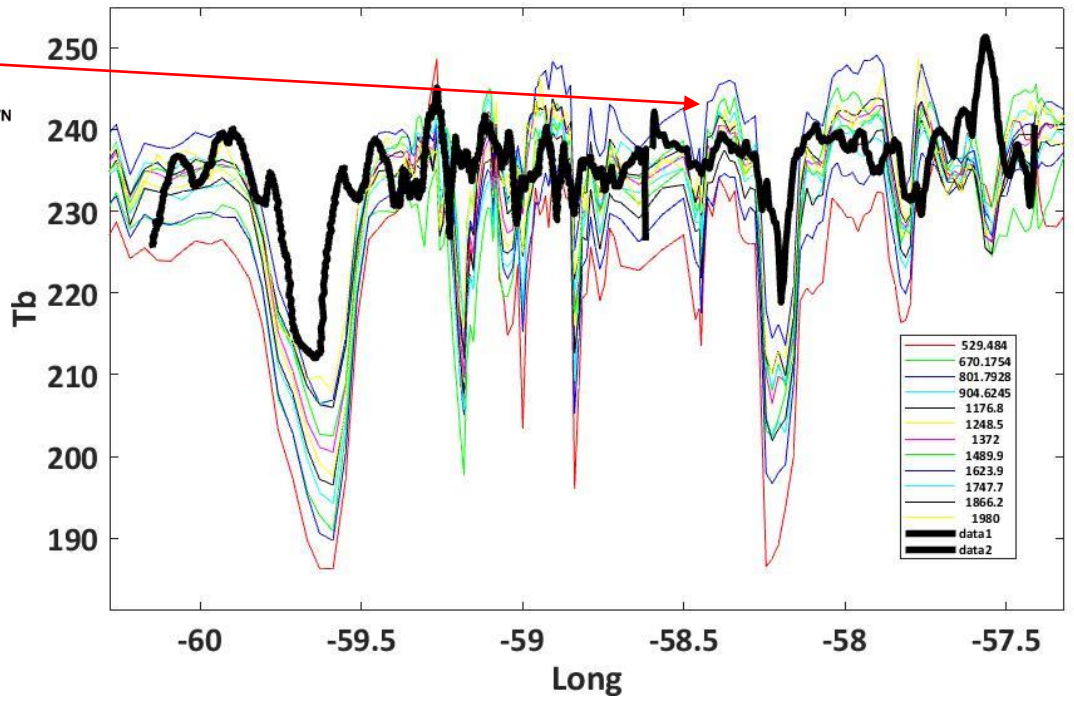


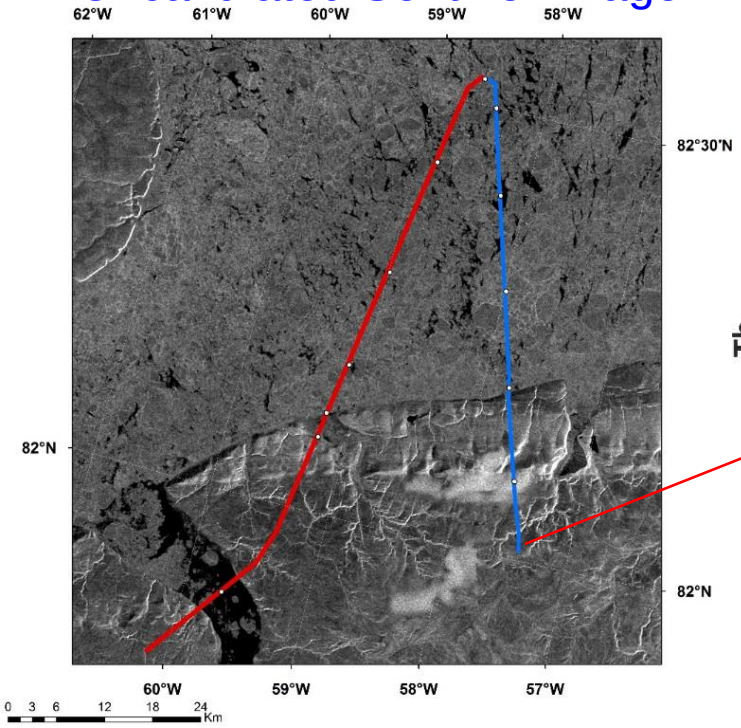
SAR and UWBRAD data are well correlated

September 13th : Sea Ice

Sentinel SAR and UWBRAD Comparison:

The relation is negatively correlated over the small ice cap at the southern end of the blue leg

Uncalibrated Sentinel Image



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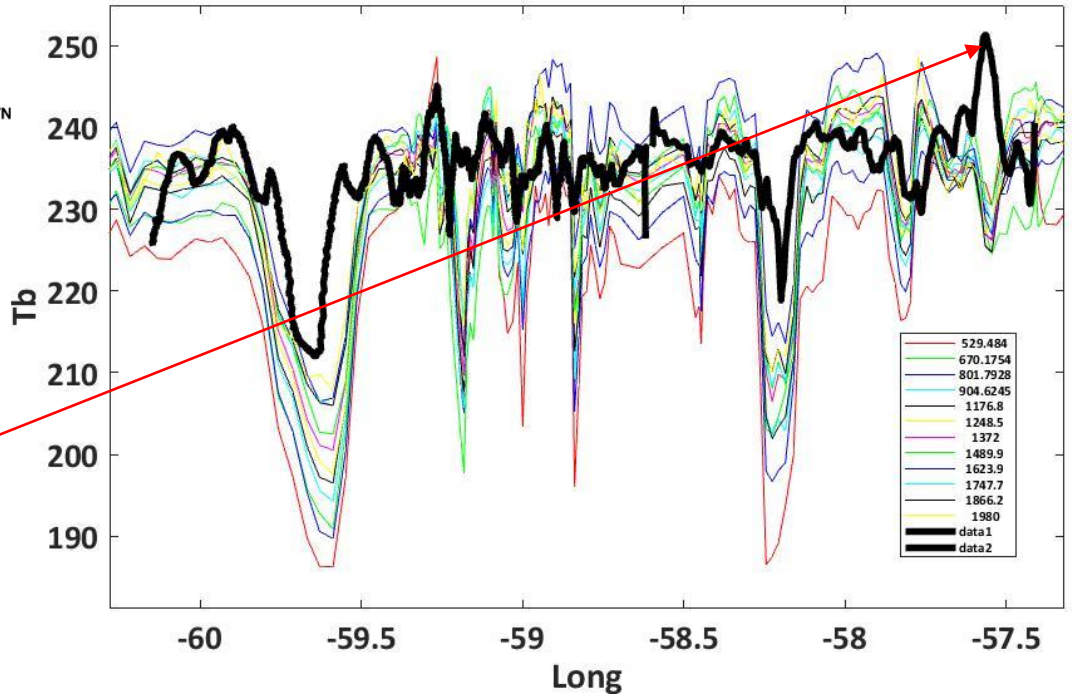
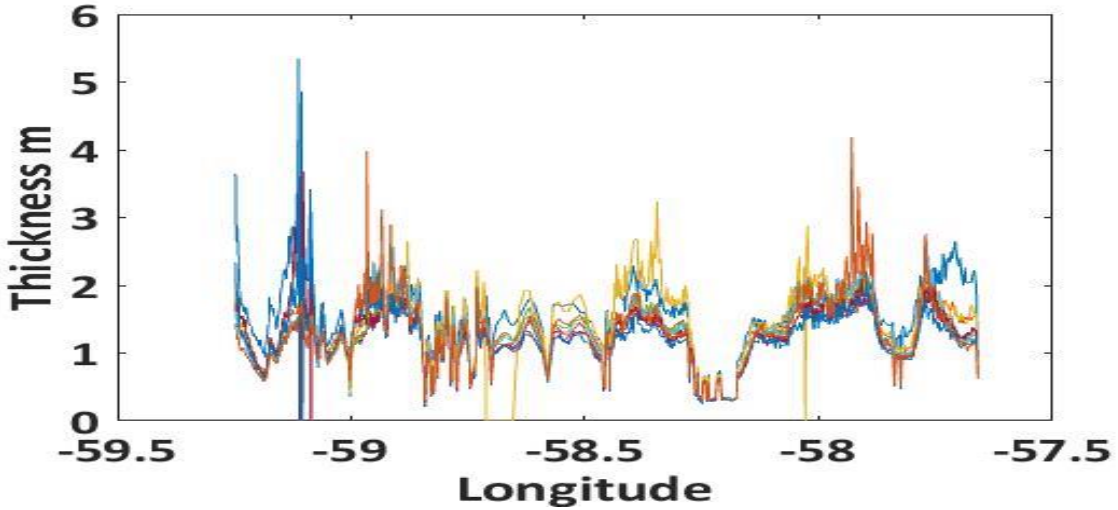


SAR and UWBRAD data are well correlated

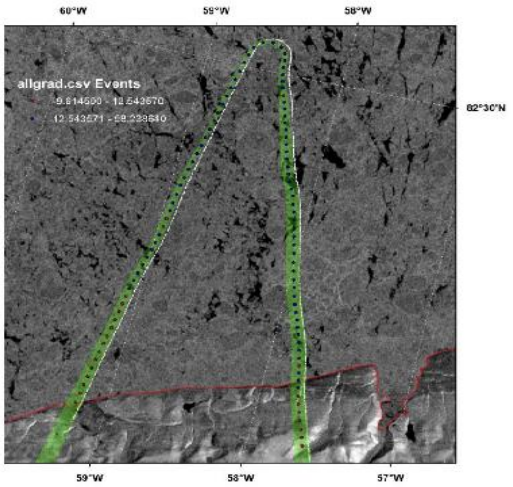
UWBRAD Retrievals of Sea Ice Thickness

- Remote sensing of sea ice thickness currently possible either with L-band radiometry or CryoSat altimetry
  - L-band good for ~ 10-50 cm thickness, altimetry for > 2 m thickness
  - Both perform poorly for crucial 50-200 cm thickness range
- Use of lower frequency radiometry expected to improve sensitivity to thickness for 50-200 cm
- Initial thickness retrieval performed for each frequency channel
  - some differences between channels but general trends indicative of ice properties
  - Emission and retrieval models being improved from this dataset
- Proposal submitted to NSF to participate in MOSAiC Campaign

UWBRAD Retrieved Ice Thickness in Lincoln Sea



Flight path over Lincoln Sea Ice



Conclusions

- UWBRAD 2016 and 2017 campaigns have obtained an extensive airborne dataset of 0.5- 2 GHz microwave thermal emissions for a variety of Earth scenes
  - Greenland ice sheet, sea ice, open ocean, boreal forest

- Data collected demonstrate expected correlations between UWBRAD spectra and geophysical thermal emission both for the ice sheet and for sea ice

- Results demonstrate the potential of 0.5-2 GHz microwave radiometry for use in a variety of remote sensing applications
  - Growing international interest in the use of 0.5-2 GHz radiometry for a variety of applications

- Preparing for deployment in Antarctica November 2018 under support of Italian Antarctic National Program; spaceborne proposal to ESA's EE10 program also submitted by CNR

- Recent/upcoming 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," to appear, TGRS, 2018.
  - S. Tan et al, "Physical models of layered polar firn brightness temperatures from 0.5 to 2 GHz" IEEE JSTARS, vol. 8, pp. 3681-91, 2015.