Ultra-Wideband Radars for Measurements Over Land and Sea Ice

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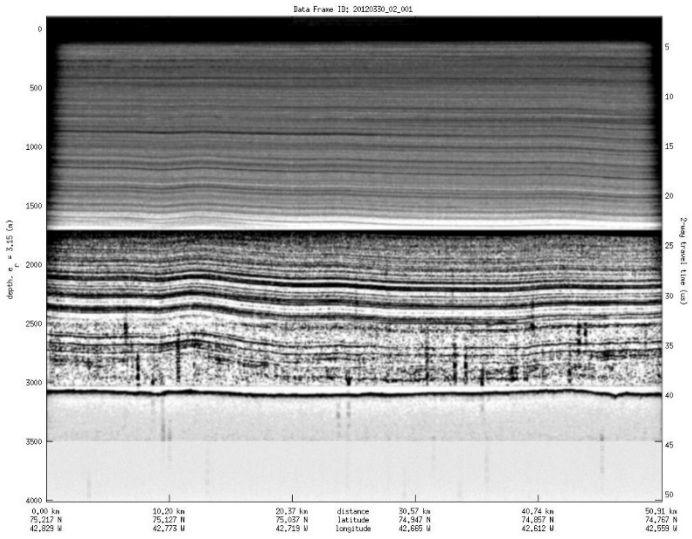
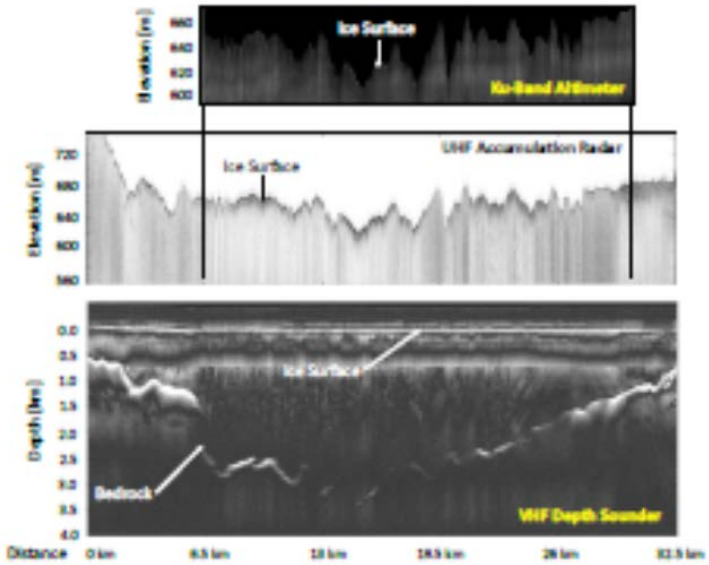
Outline

- Introduction
  - Dick Moore introduced me to UWB radars (FM CW) in 1979
- Systems Description
  - Antenna arrays
- Results
- Future plans
- Summary

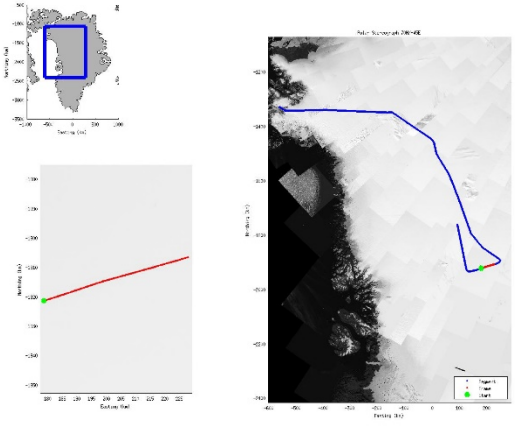


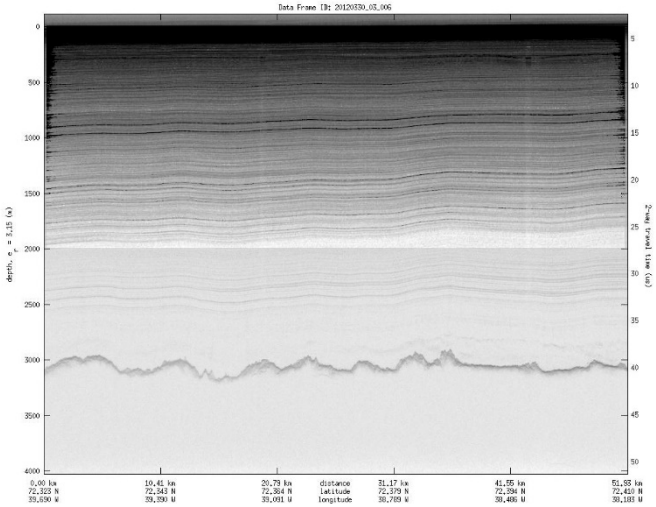


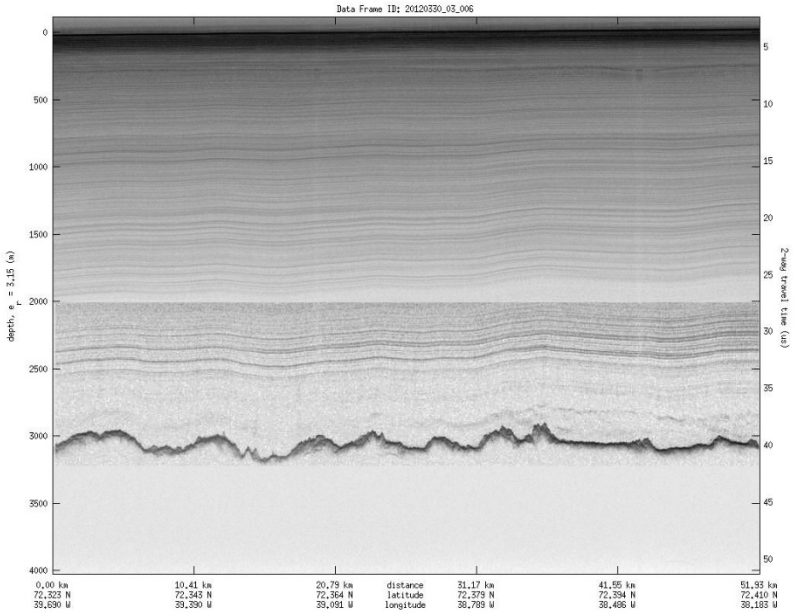
Introduction: why

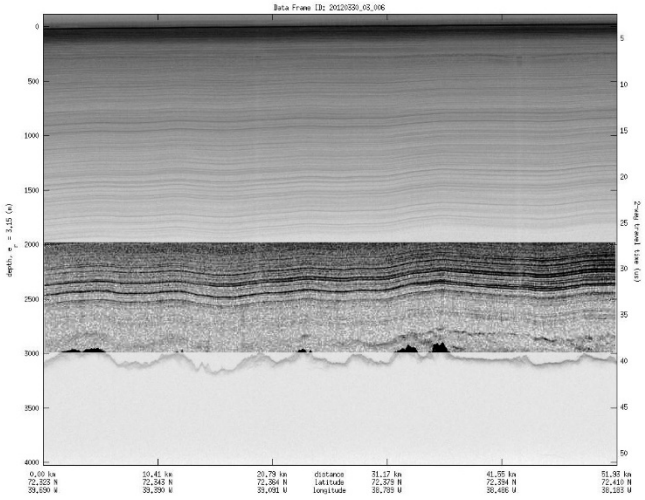
- **Radar sounding and imaging with ultra-wideband radars using large antenna arrays**
  - **Sounding of most challenging areas**
  - **High-altitude measurements**
    - **Large array**
  - **Mapping of internal layers with fine resolution**
    - **Near-surface layers with about 50 cm resolution**
    - **Layers near the bed with 50-200 cm resolution**
      - **Attenuation response of ice**
  - **Unambiguous determination of basal conditions**
  - **Estimating bottom melt rates of ice shelves**
  - **Optimum ice-core site selections**

Layers close to the bed



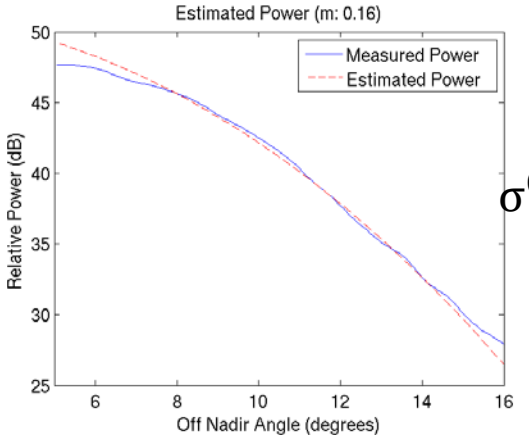






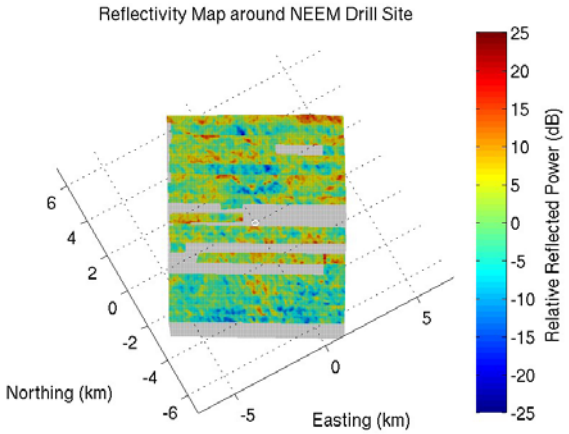
Basal Conditions: Multi-Frequency

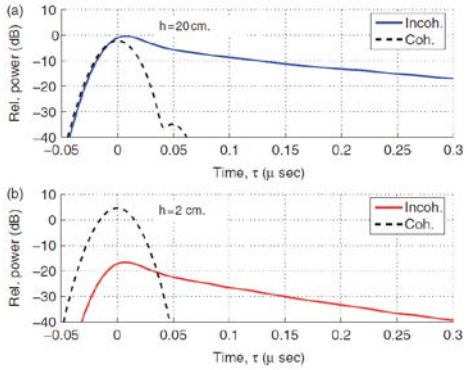
- Radar return from the ice bed depends on:
  - Dielectric contrast
  - Roughness
  - Ice loss
- Segment data in multiple bands:
  - Estimate roughness
  - Loss
  - Determine bed conditions



$$\sigma^0(\theta) = \frac{|\Gamma(0)|^2 e^{-\frac{tan^2(\theta)}{2s^2}}}{2s^2 cos^4(\theta)}$$

Blake, CReSIS Tech report 147





Niamsuwan et al, [2011] Waves in complex media., vol. 21, pp 184-197

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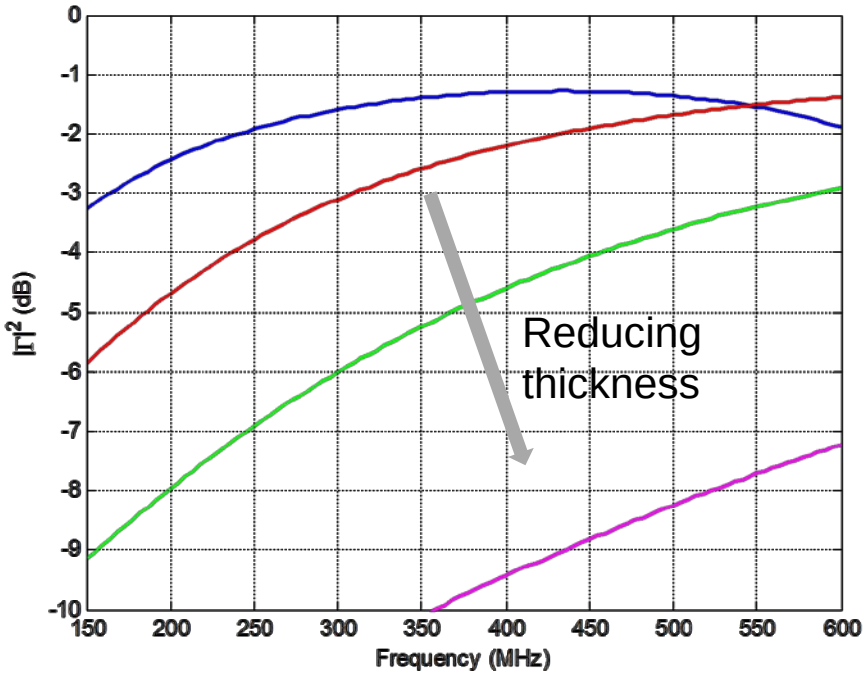
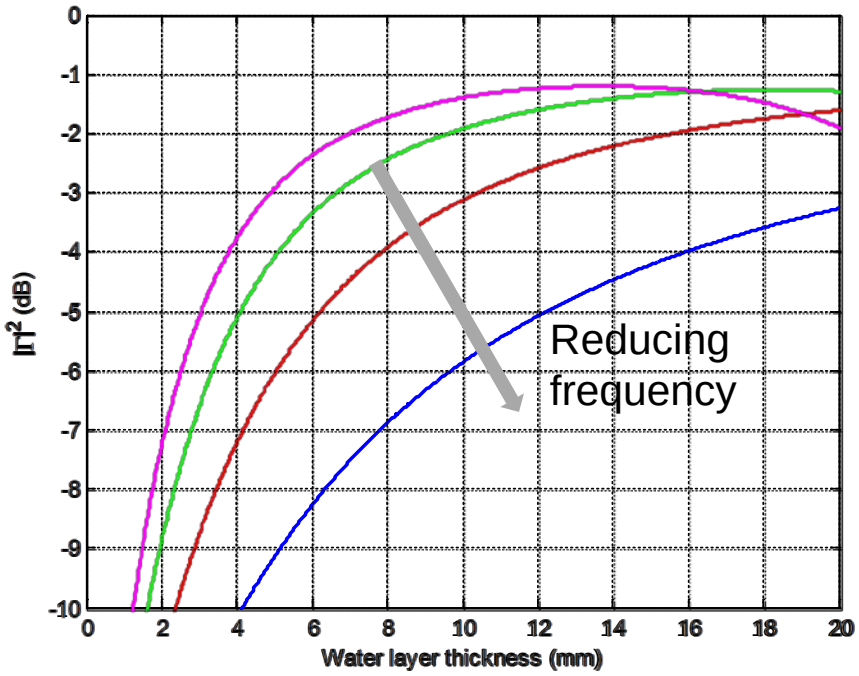
Reflection Coefficient at Ice-Water Interface

Frequency dependence



20 mm
10 mm
5 mm
1 mm

Water layer thickness dependence



150 MHz
300 MHz
450 MHz
600 MHz

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Radar Instrumentation

Instrument	Measurements	Frequency Range / Bandwidth	Power	Antenna	Aircraft
MCoRDS/I	Ice Thickness Internal Layering Image Bed Properties	150-600 MHz 450 MHz (190-450 MHz, 2013-2014 field season)	~4 kW 800 W	Slotted-Array Wing-Mounted Fuselage	Basler
Ultra wideband microwave radar	Surface Topography Near Surface Layering	2-18 GHz 16 GHz	200 mW	Vivaldi Array	DC-8 P-3 Twin Otter, Basler
	Snow on Sea Ice Surface Topography Near Surface Layering	Older versions (2-8 GHz and 12-18 GHz)	200 mW		DC-8 P-3 Twin Otter, Basler
Accumulation Radar	Ice Thickness and Layers	600-900 MHz 300 MHz	10 W	Dipole Array	P-3 Twin Otter
Temperate Ice Sounder	Ice Thickness	14 and 35 MHz 1 and 4 MHz	100 W	Loaded Dipoles	Small UAV

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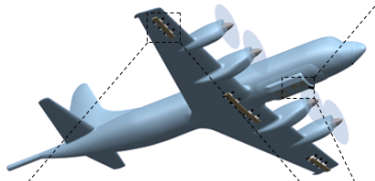
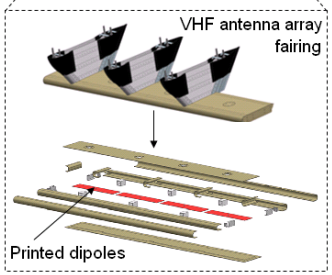
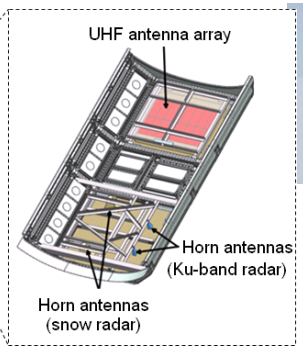
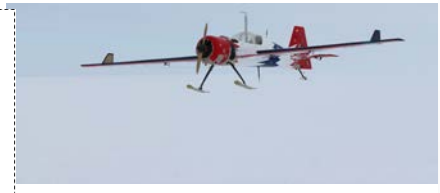
Background: Airborne Platforms

NASA P-3B

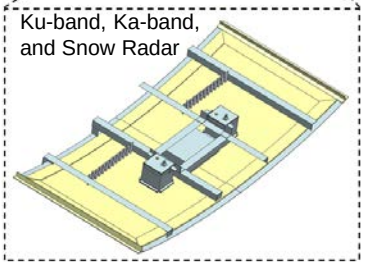


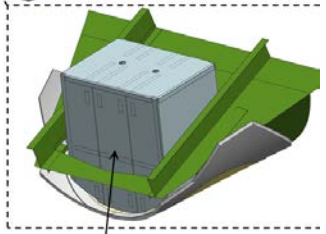




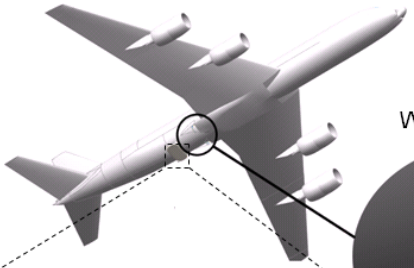


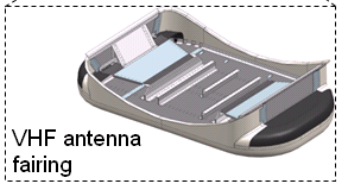
NASA C-130

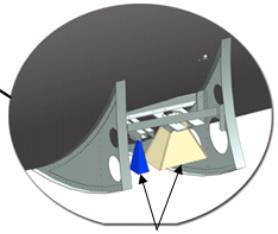




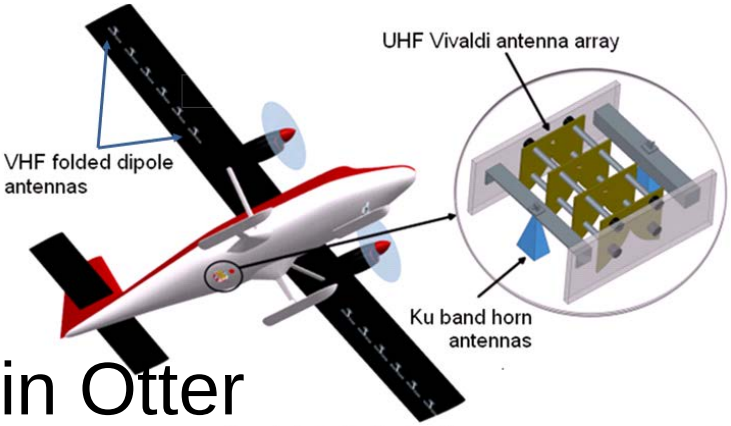
NASA DC-8





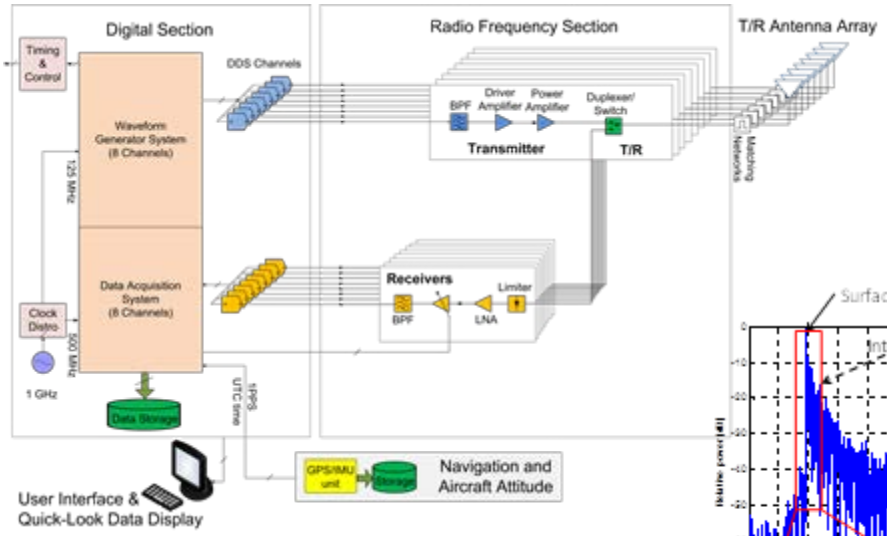


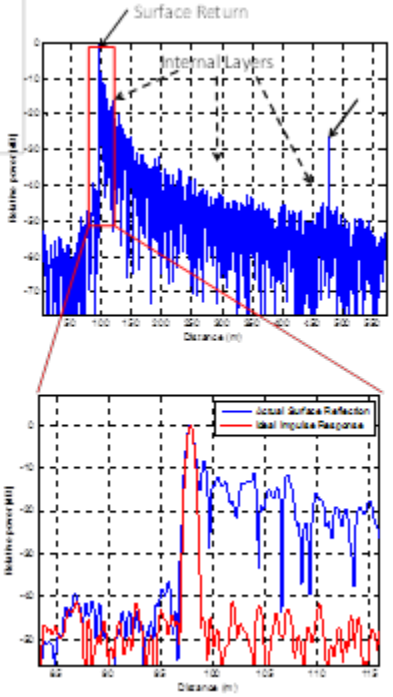
Basler

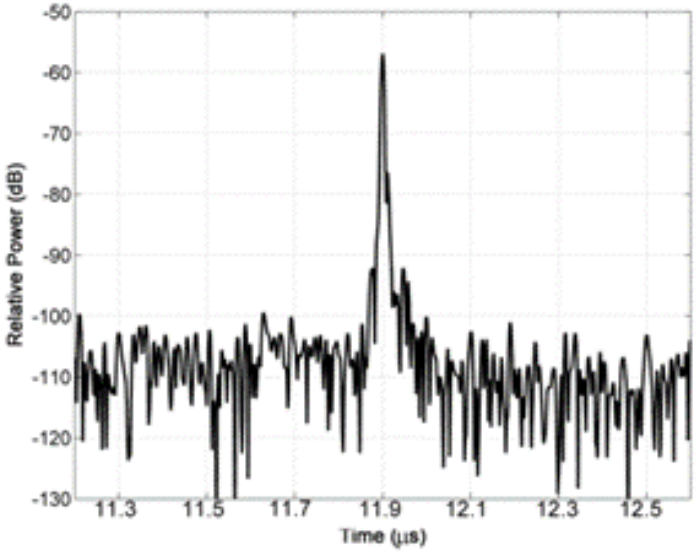


Twin Otter

2013 Configuration







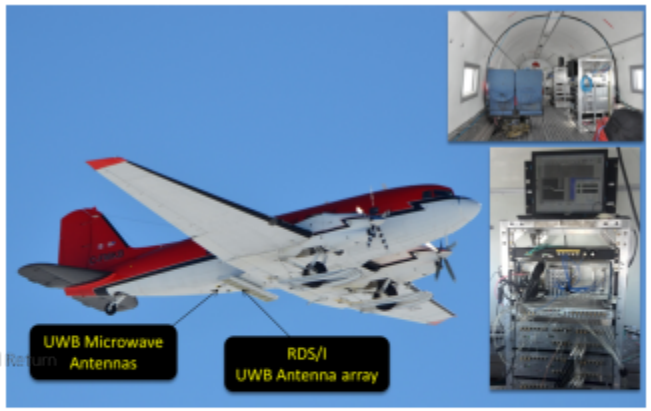
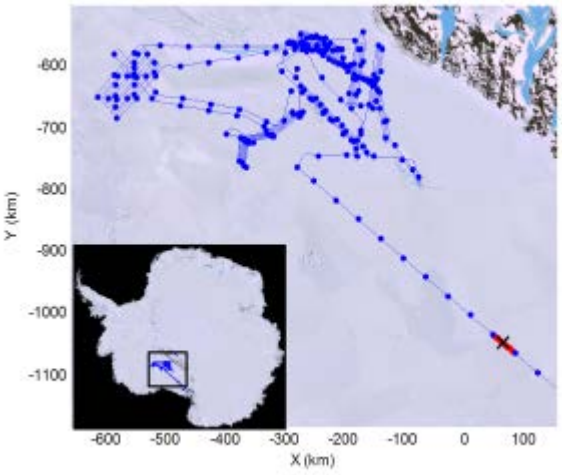


Figure 1. *Photograph of the BT-67 (EASLER) platform outfitted with the radar antennas. The inset shows a photograph of the inside of the cabin equipped with the instrument package (top) and a photograph of the radar electronics (bottom)*



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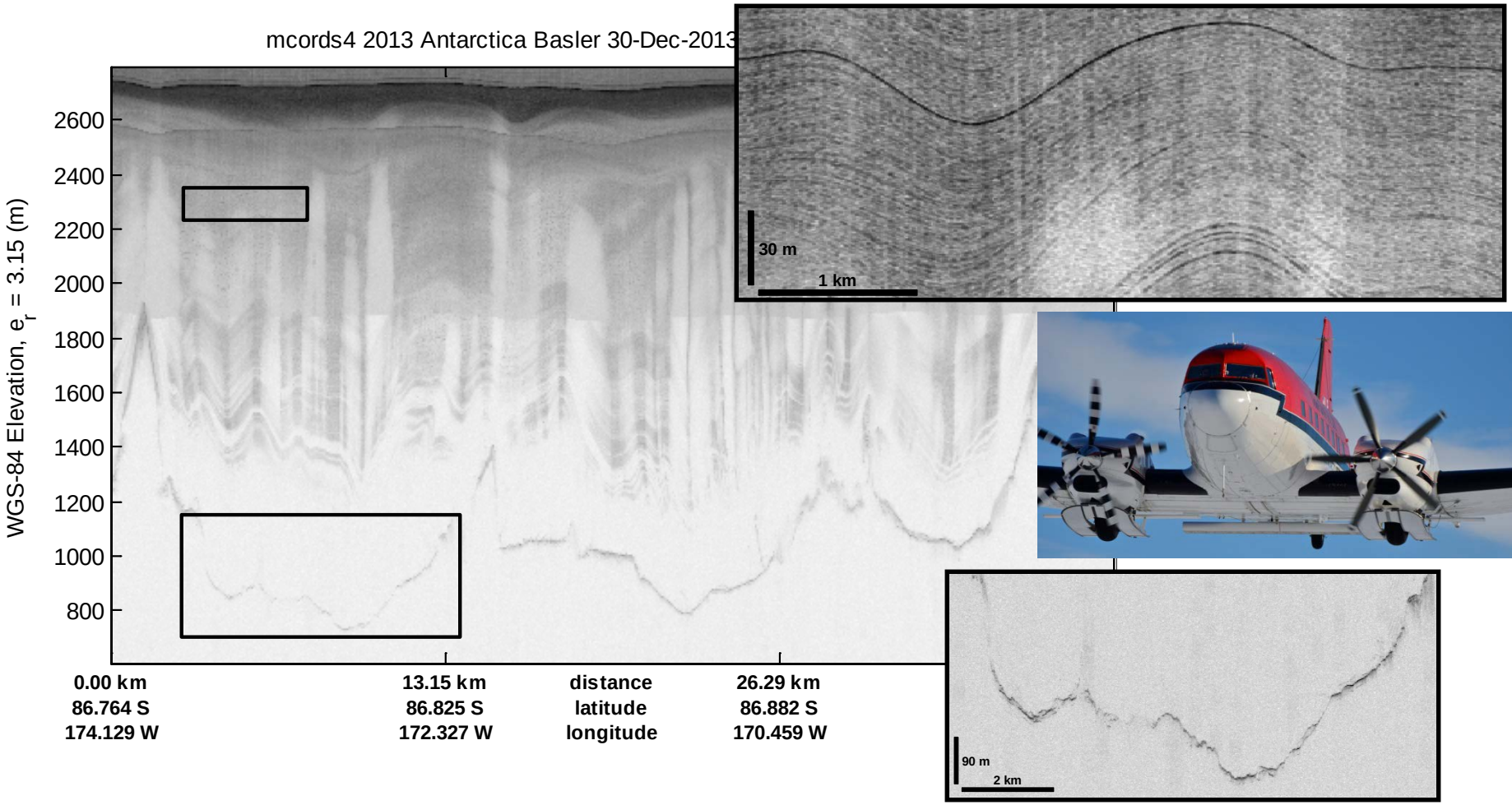
Basler 2013/14 Antarctica



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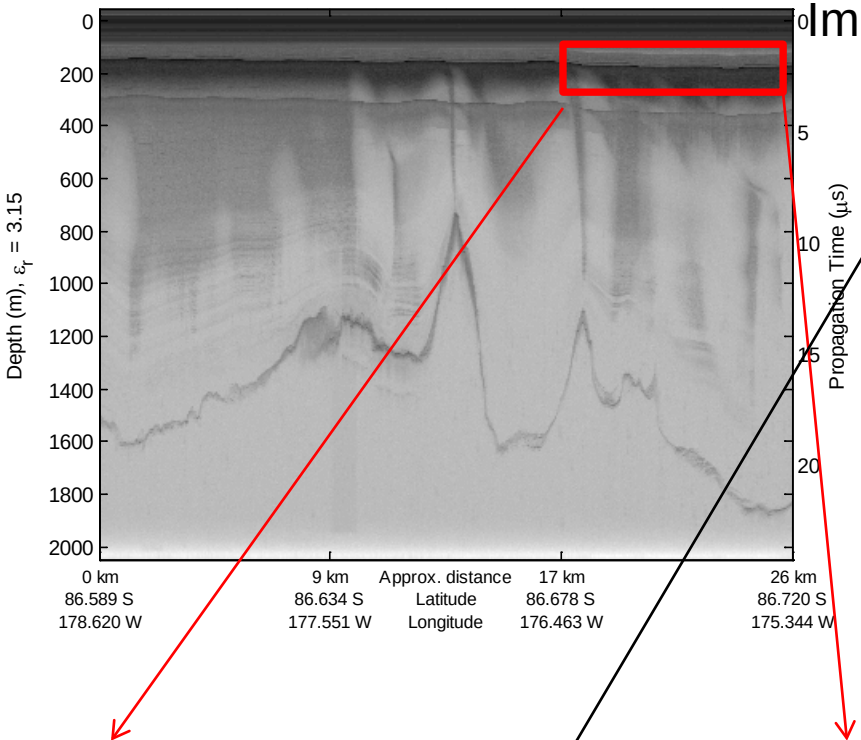
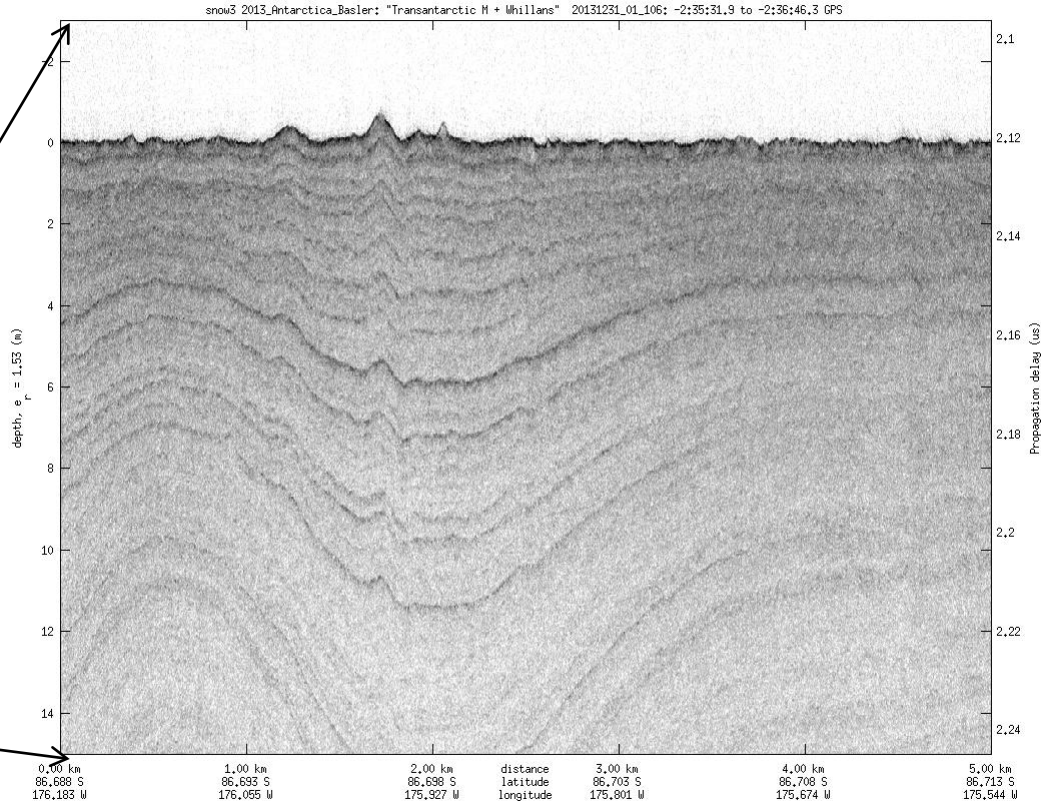
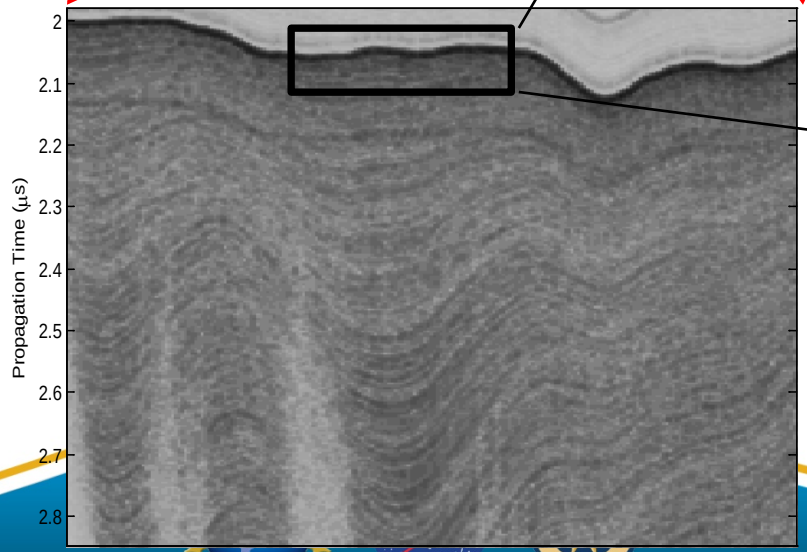
Correlation with Snow Radar

Imaging of in south of the Transantarctic Mountains







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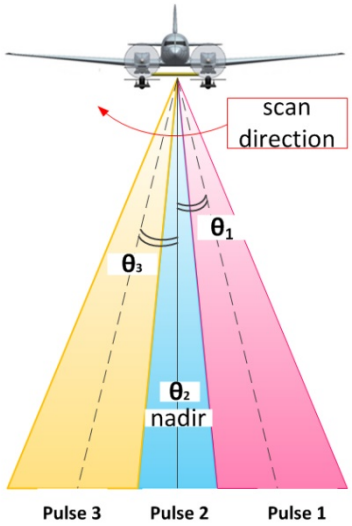
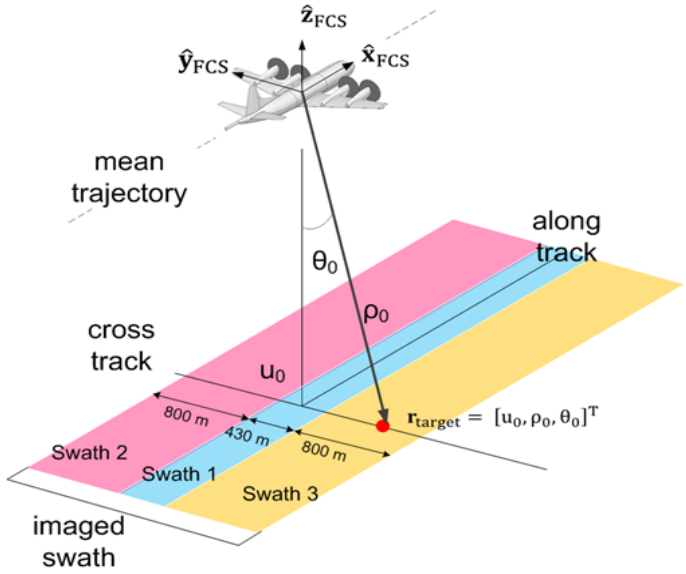
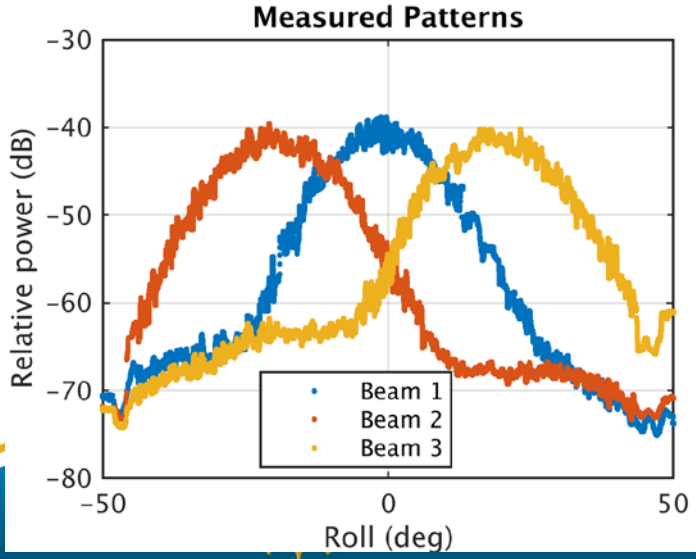
Multibeam, Wide Swath 3D Imaging

Transmit Beamforming





Tstumpf, 2015



Position of target is $\mathbf{r}_{target} = [u_0, \rho_0, \theta_0]^T$

u_0 zero Doppler position,
ρ_0 is range,
θ_0 is direction of arrival (DOA)

After SAR processing

u_0 = KNOWN,
ρ_0 = KNOWN,
θ_0 = UNKNOWN

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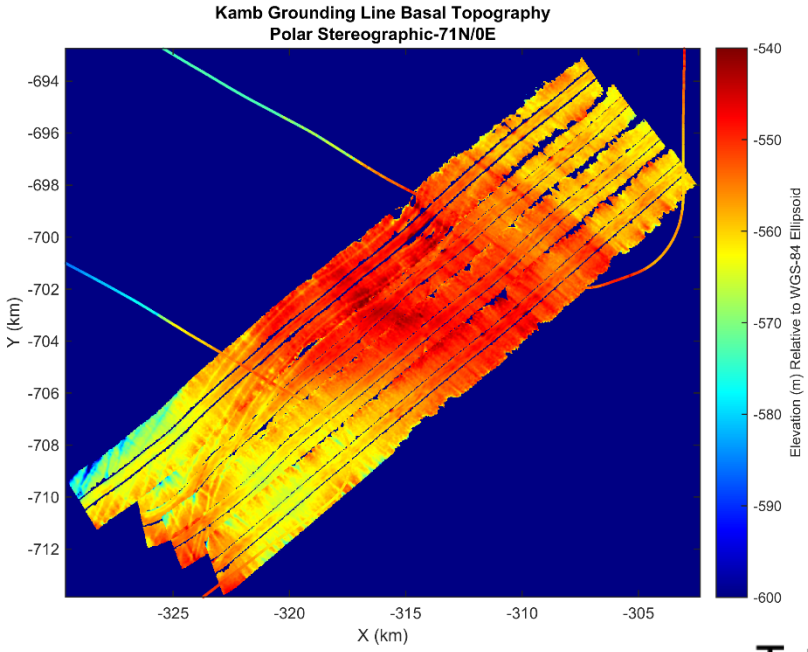
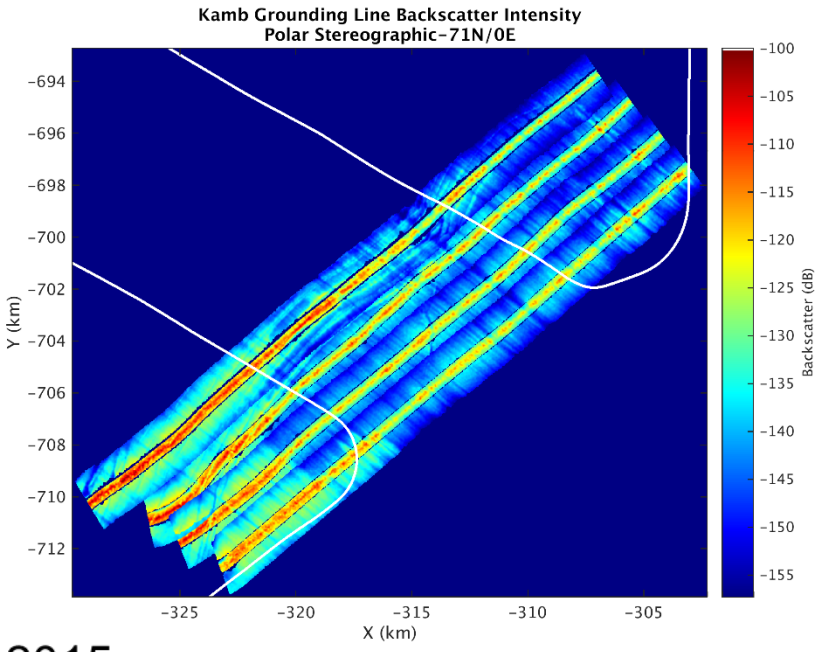
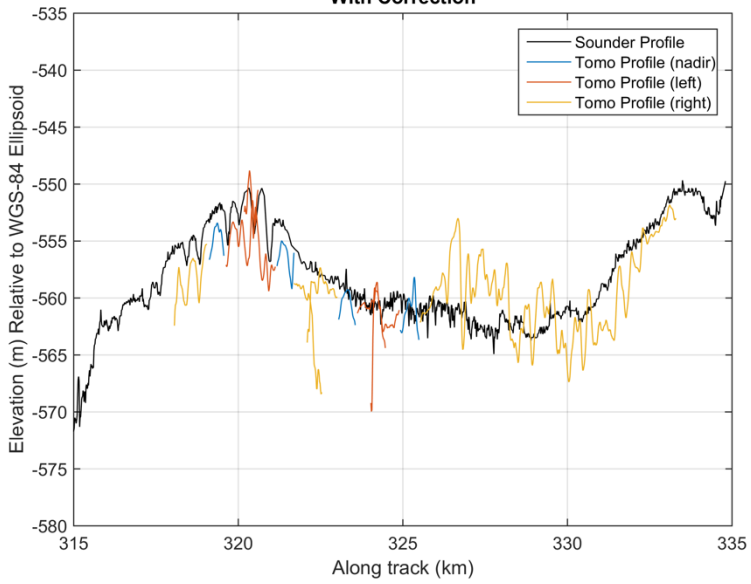
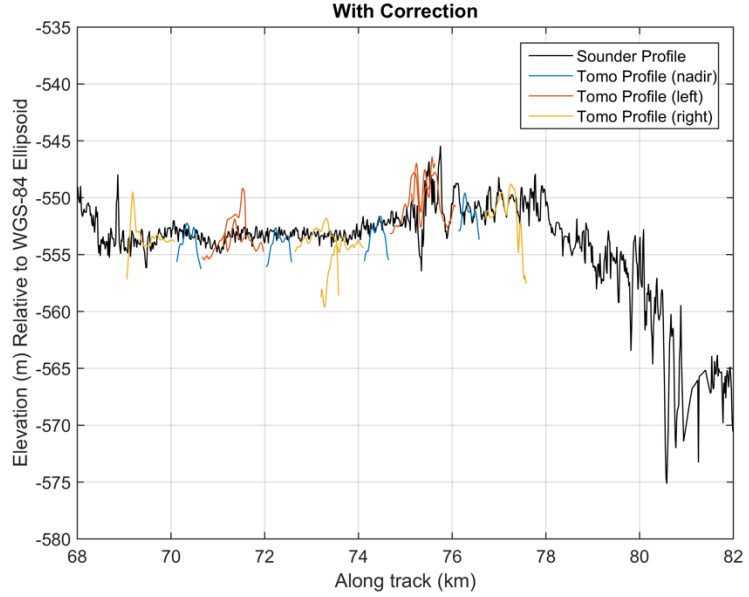


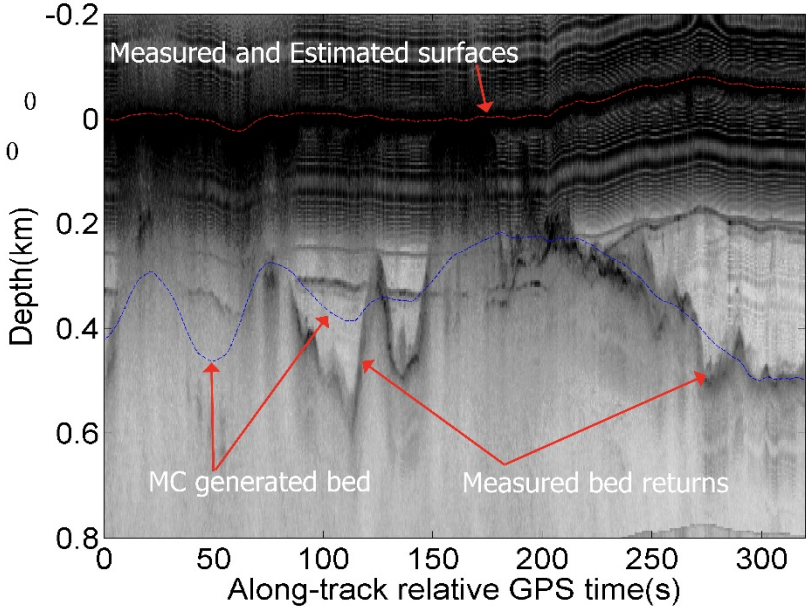


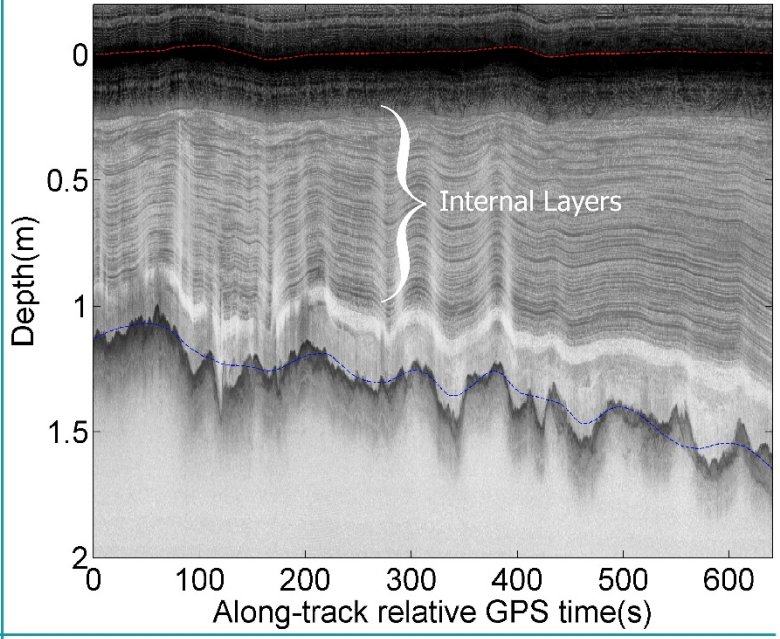
Tstumpf, 2015





Measured and MC-Generated Results





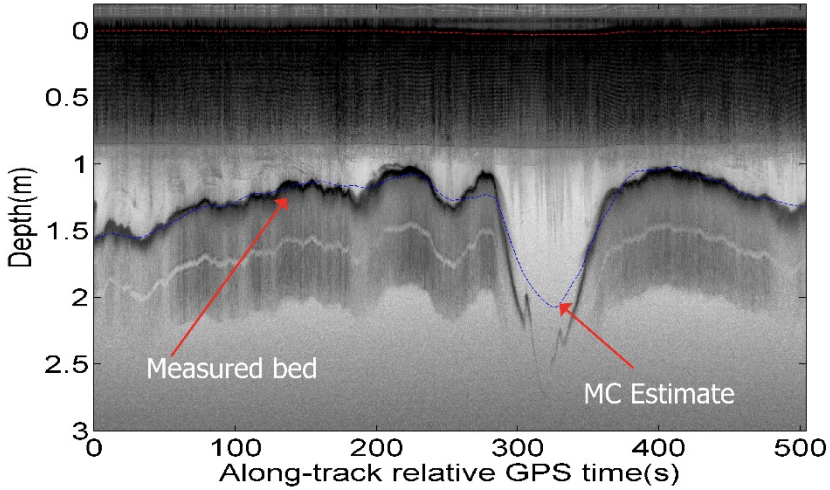
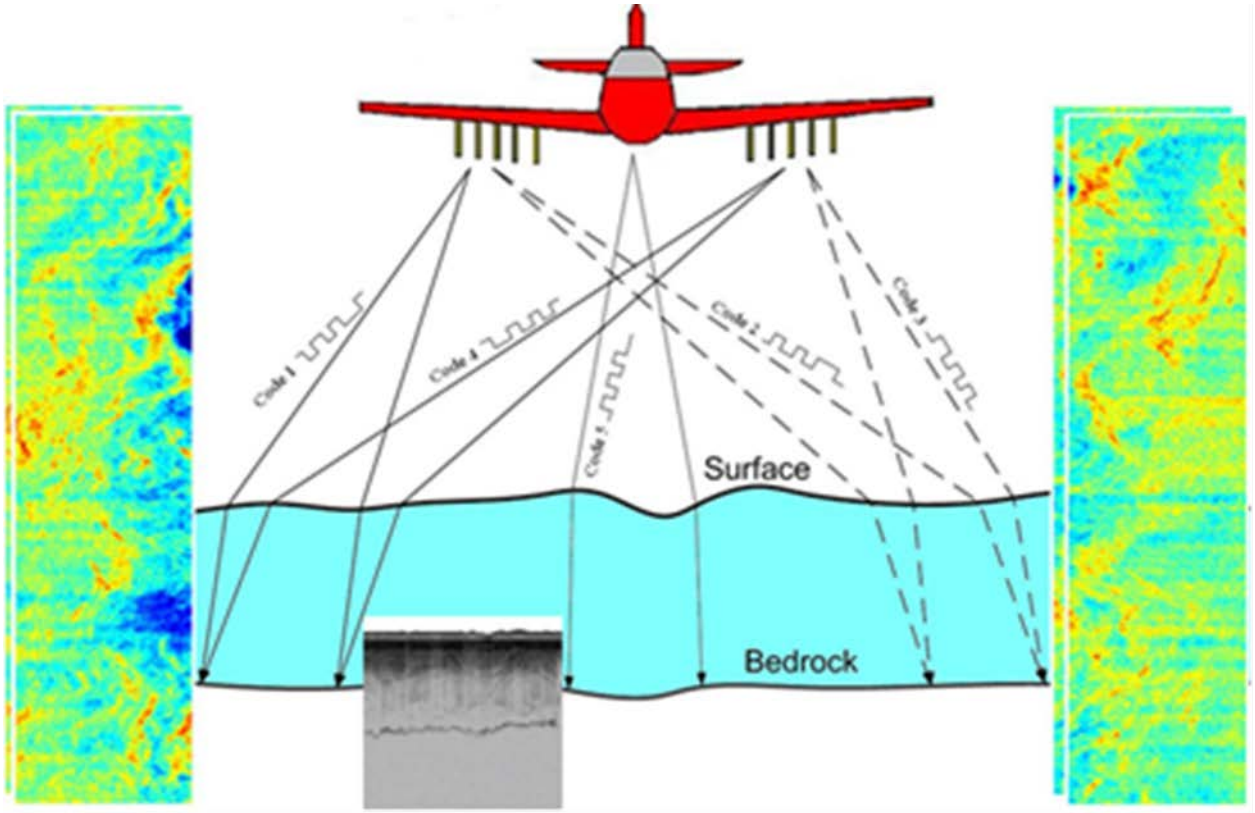


Figure 1 : Radar echograms of data collected on the Greenland ice sheet. These echograms show radar returns from the ice surface, ice-bed and internal layers. Ice thickness estimates generated from Mass-Conservation (MC) models are shown in these echograms with the surface in red and ice bed in blue. The comparisons clearly show there are large errors in estimated thicknesses for areas with complex bed topography with peaks and troughs. The errors are as large as 700 m (echogram on bottom left) for about 2.5 km thick ice, more than 25%.

In SAR +Tomography

Coded waveforms
3-7 transmit beams
8 transmit channels
9 *Receive beams*
24 receivers



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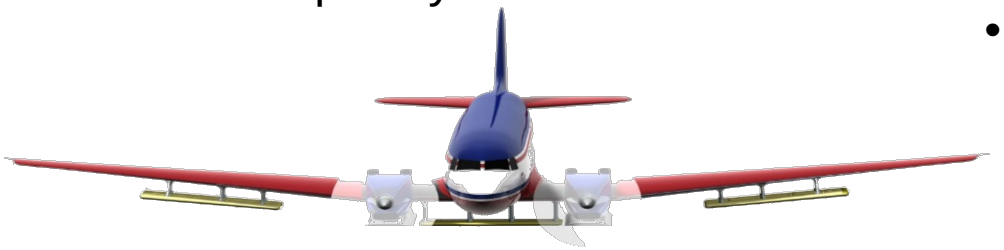
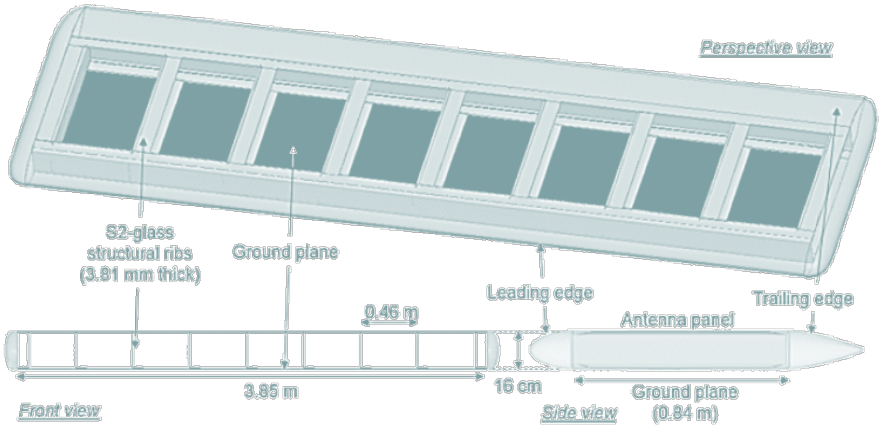
UWB MCoRDS/I

- Ice thickness measurements
- Fine resolution ice layering mapping with 33 cm vertical resolution
- Basal conditions retrieval based on multi-frequency measurements

- AWI Basler POLAR 5/6
- 3.85 m x 0.84 m x 0.16 m custom fiber glass fairing
- Three 8-element subarray with reconfigurable antenna polarization
- 150-600 MHz





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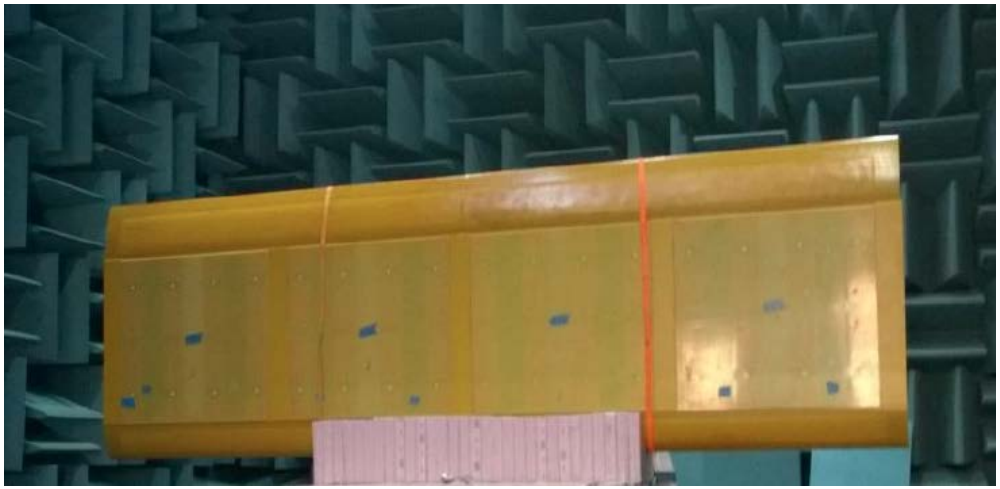
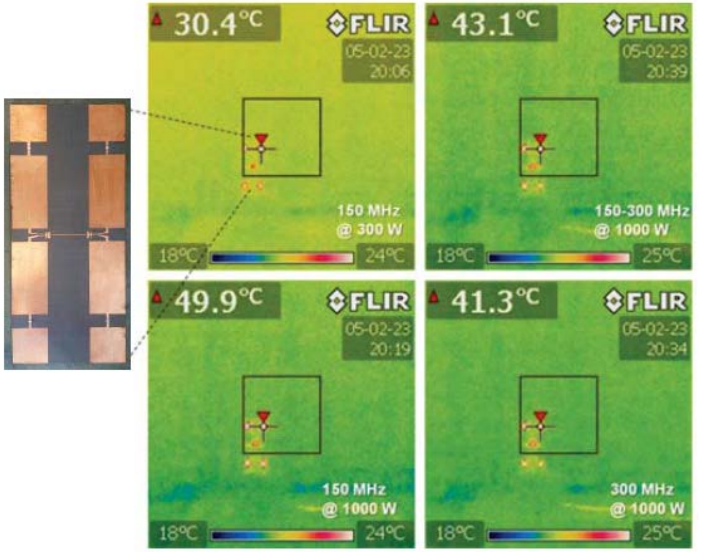
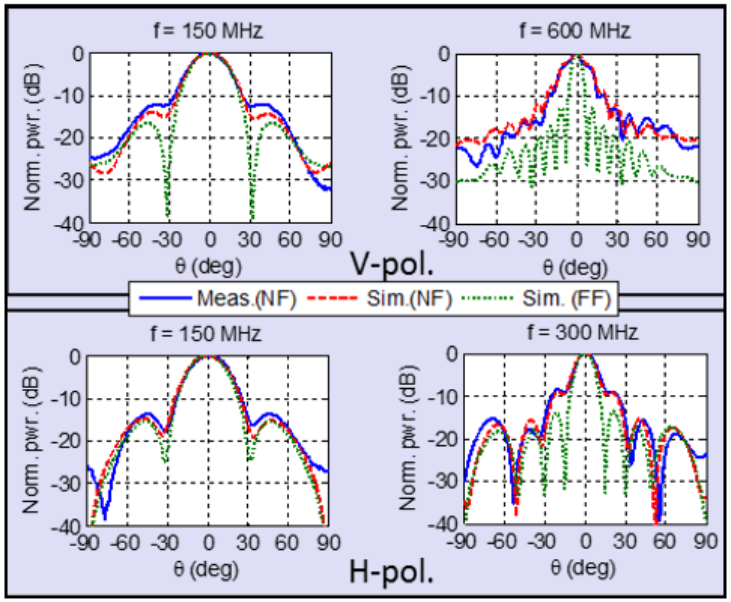
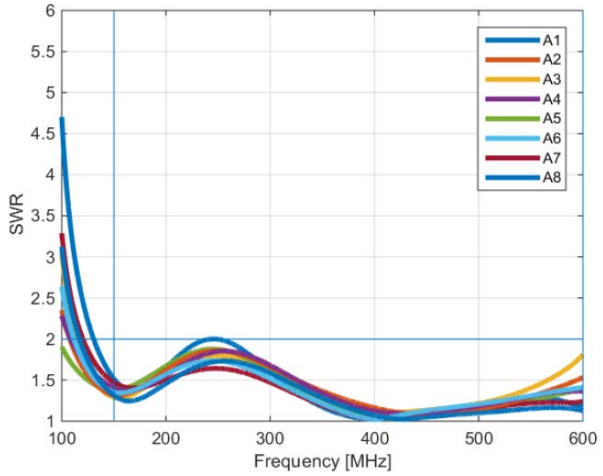
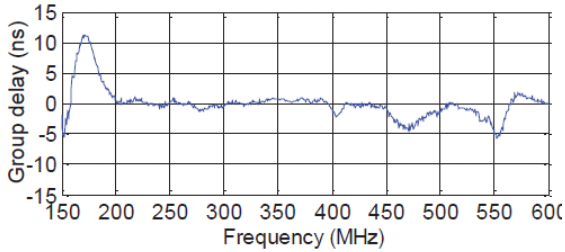
UWB antenna array characterizaton

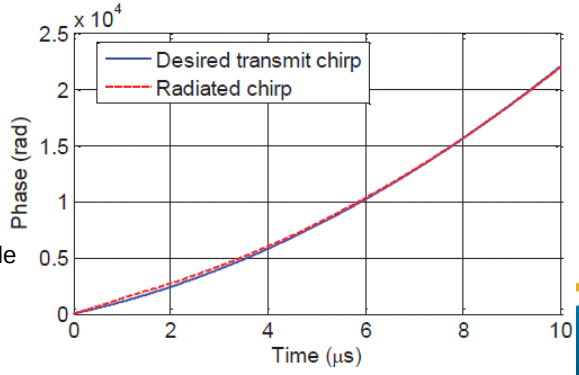






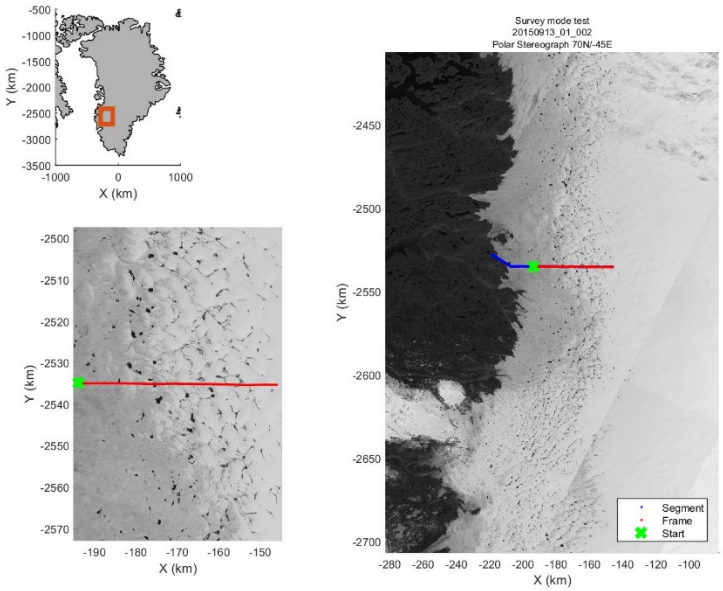


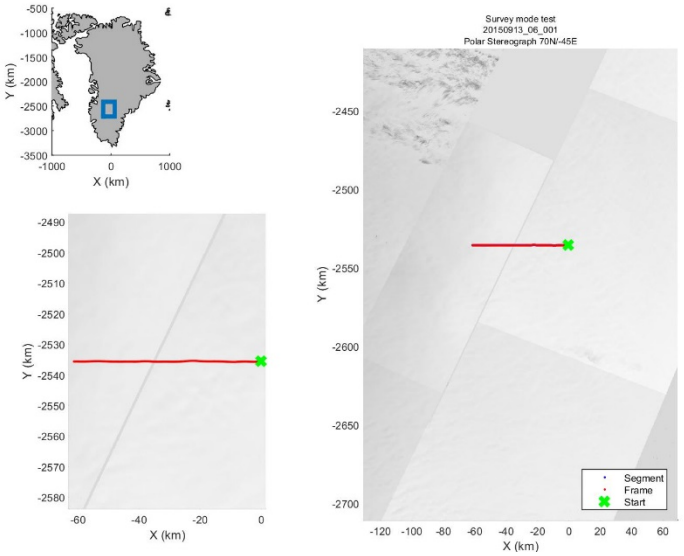


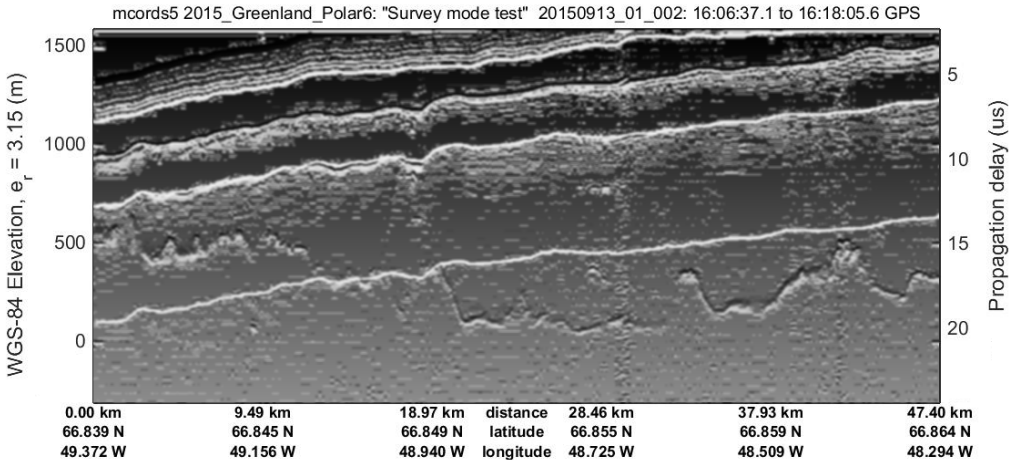


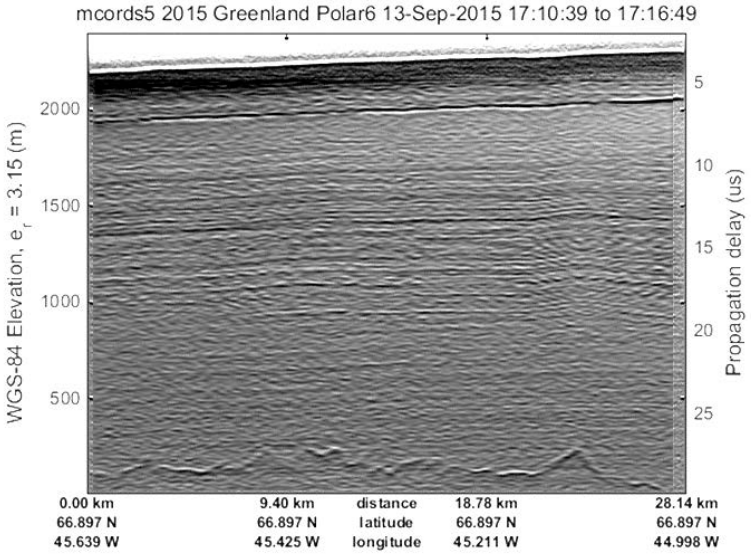
J.-B Yan et al., “A Polarization Reconfigurable Low-Profile UWB VHF/UHF Airborne Array for Fine Resolution Sounding of Polar Ice Sheets”, *IEEE Trans. Antennas Propagat.*, 2015

Sample results from Greenland test flight





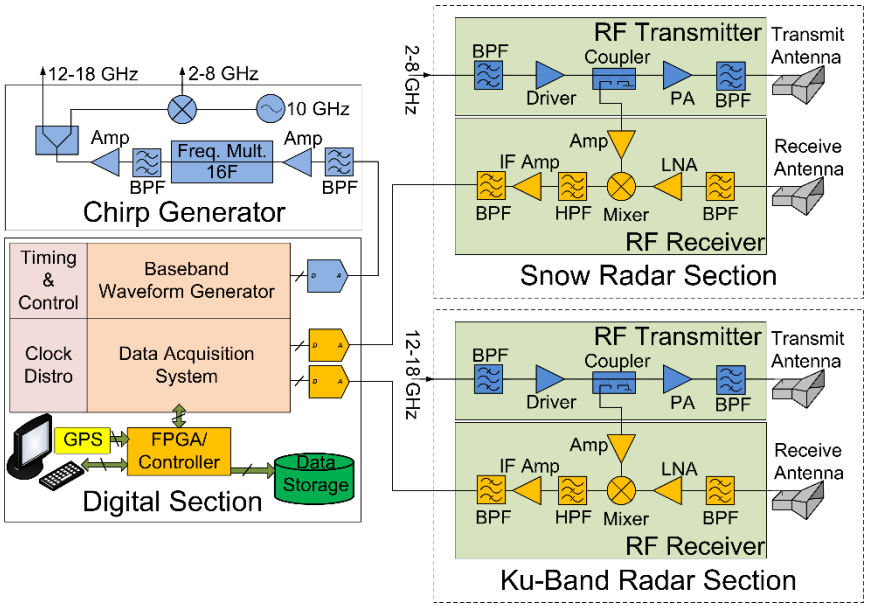




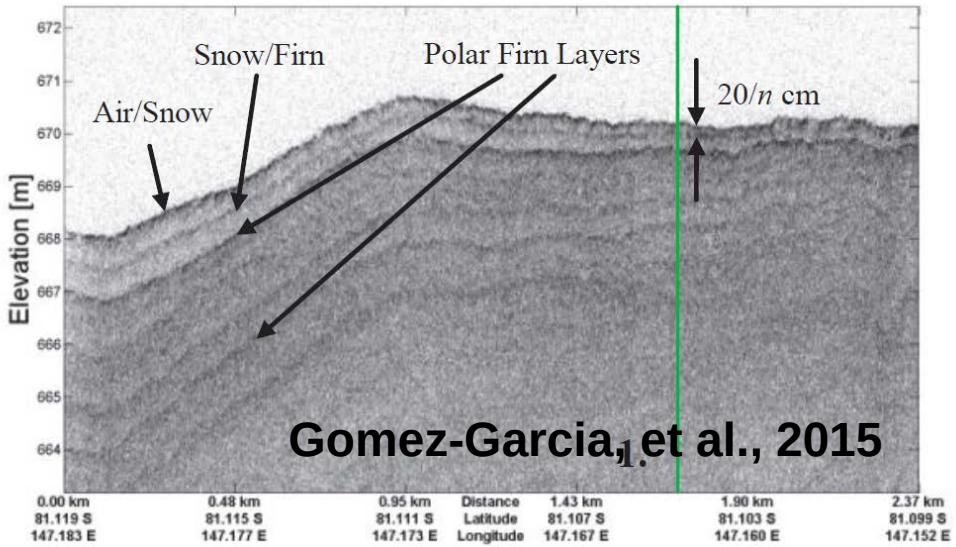
Instrumentation

Instrument	Measurement	Center Frequency	Bandwidth	Peak Transmit Power	Vertical Resolution
MCoRDS/I	Ice thickness Internal layering	375 MHz (150-600 MHz)	up to 450 MHz	6 kW	~38 cm
Ku-band Radar	Ice surface topography and internal layering	15 GHz (12-18 GHz)	up to 6 GHz	~200 mW	~4 cm
Snow Radar	Snow cover over sea ice and internal layering over glacial ice	5 GHz (2-8 GHz)	up to 6 GHz	~200 mW	~4 cm (~1.5 cm)
UWB Microwave Radar	Near Surface Internal Layers	10 GHz (2-18 GHz)	16 GHz	~200 mW	~1.5 cm

Results: Ku-Band Radar/Snow Radar



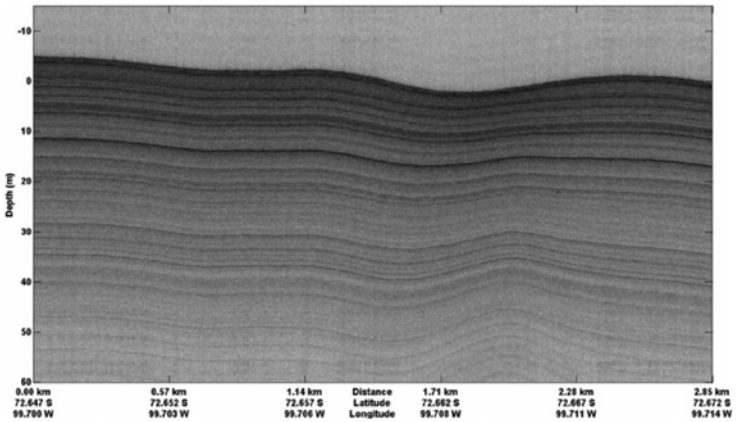
Ku-band Radar



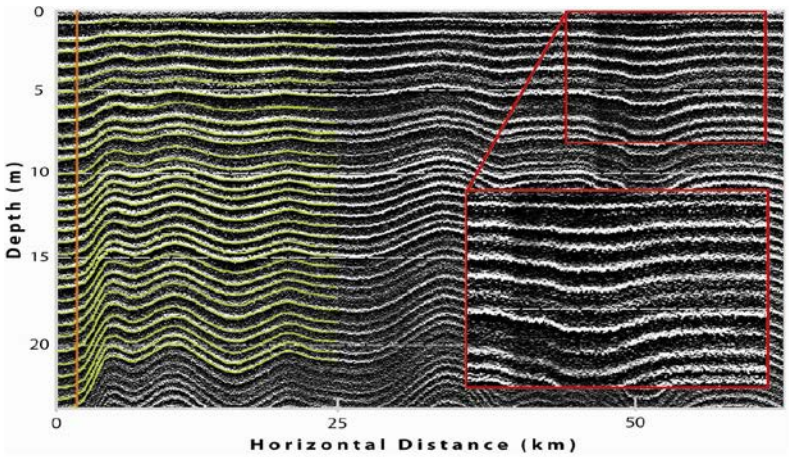
Gomez-Garcia, et al., 2015

2-8 GHz Snow Radar

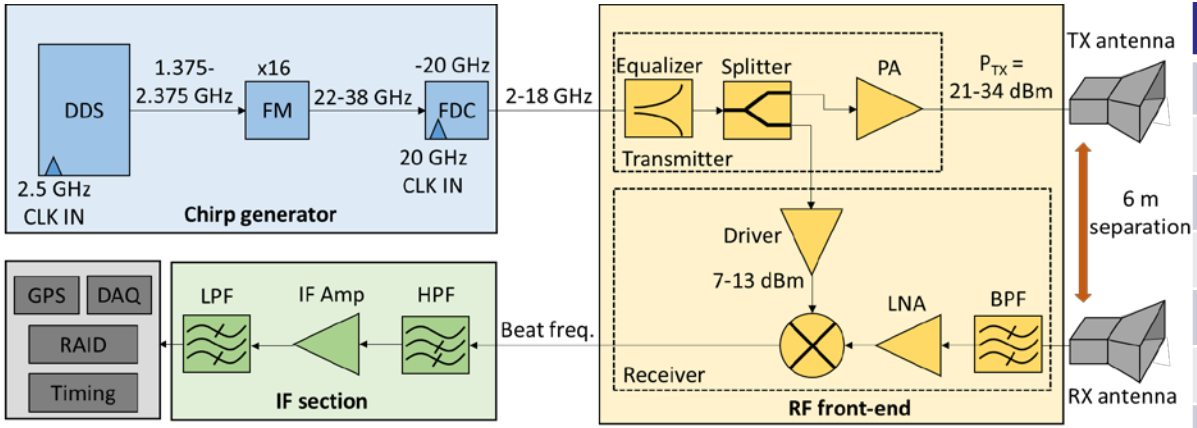
Panzer, et al., 2013



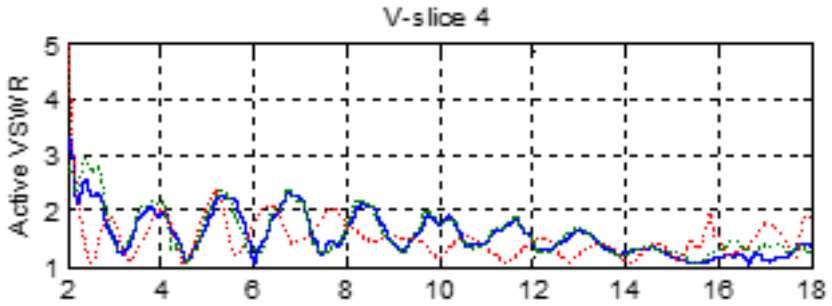
Medley, 2013

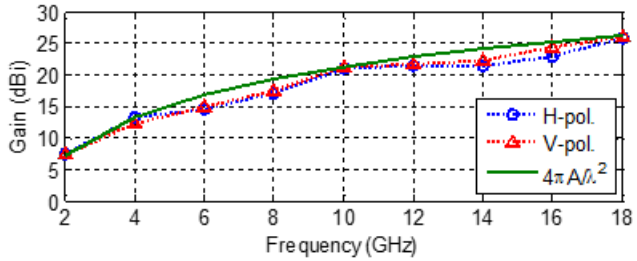


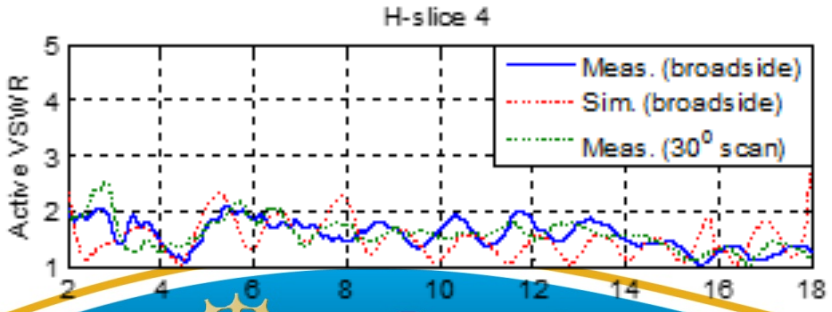
System specifications

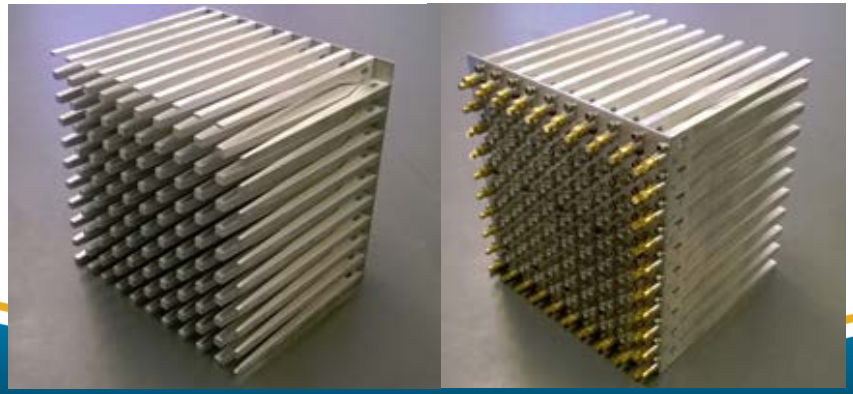


Parameter	Value	Unit
Frequency band	2-18	GHz
Bandwidth	16	GHz
Chirp length	240	µs
PRF	3.9	kHz
Transmit power	20-30	dBm
Antenna gain (array)	10-20	dBi
ADC sampling rate	125	MHz
ADC resolution	14	bit
Range resolution	0.94	cm



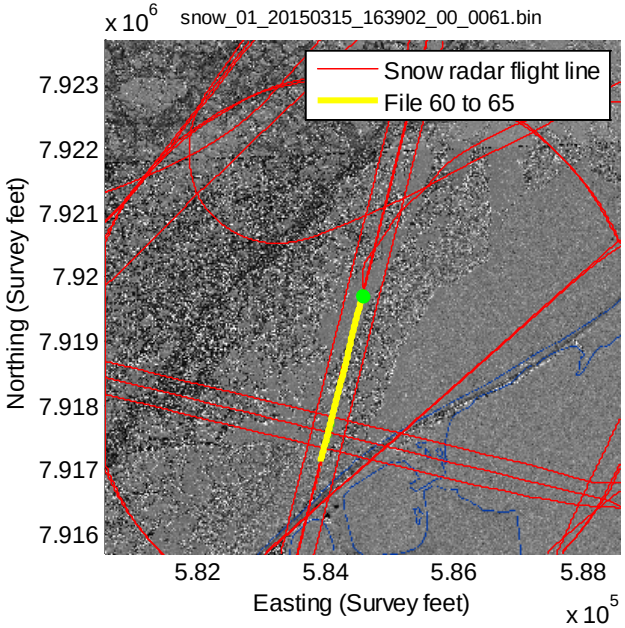


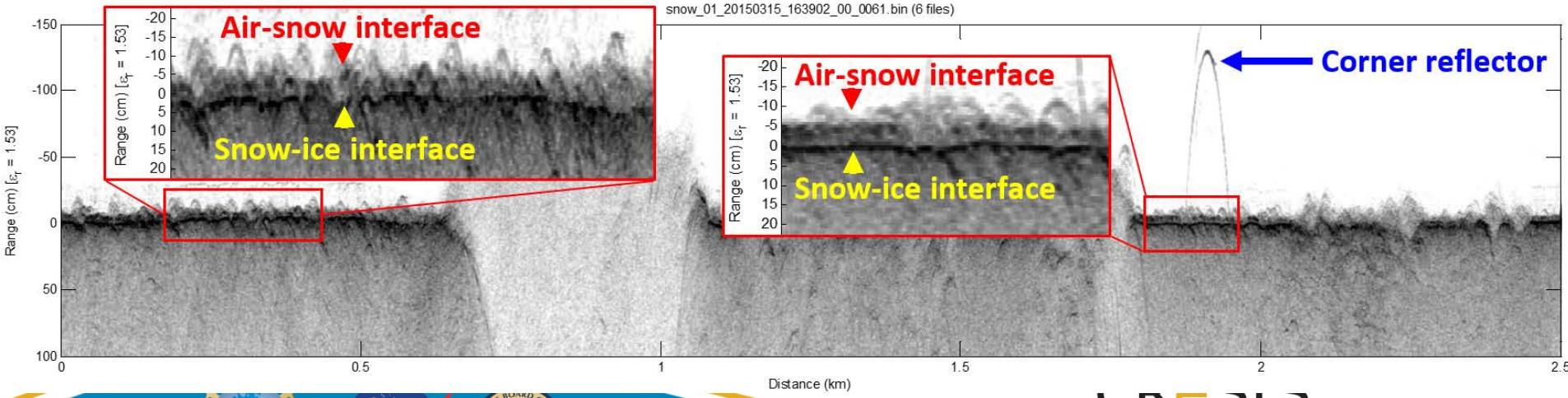




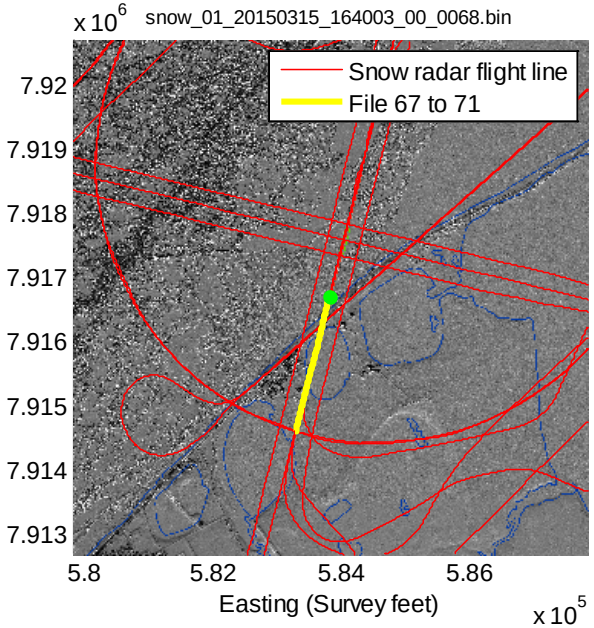
NSF NASA

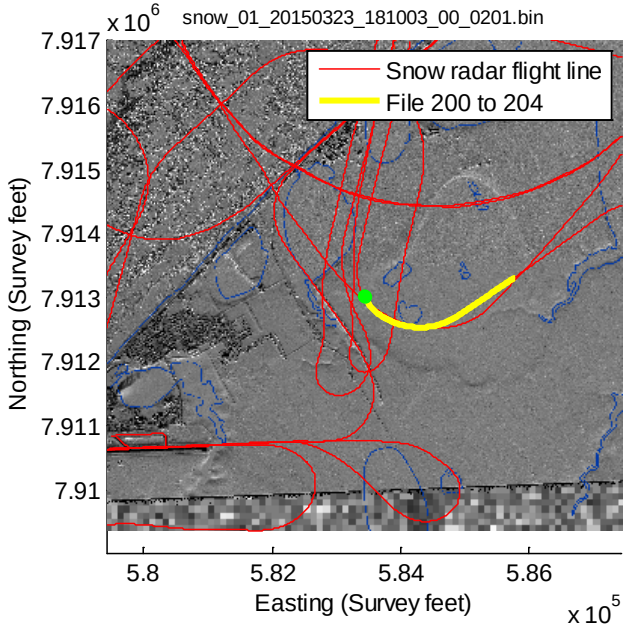
Sample Results over sea ice

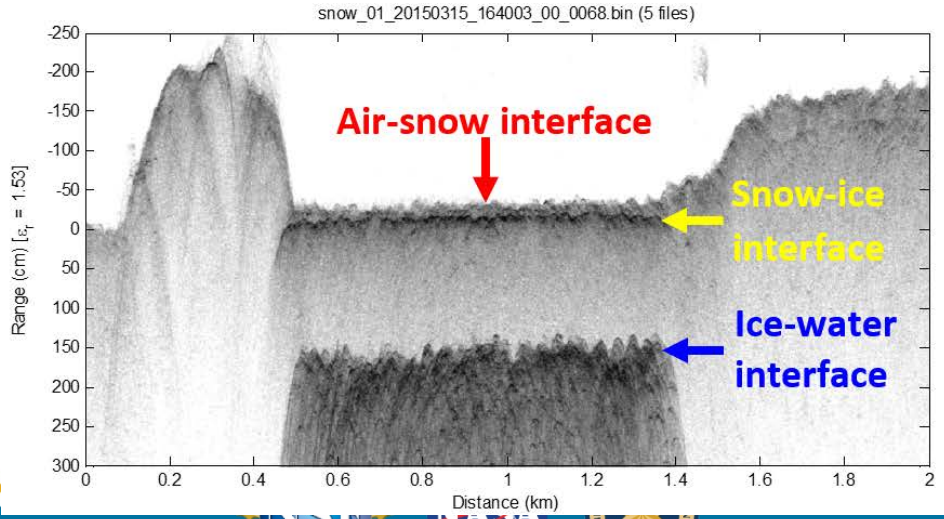


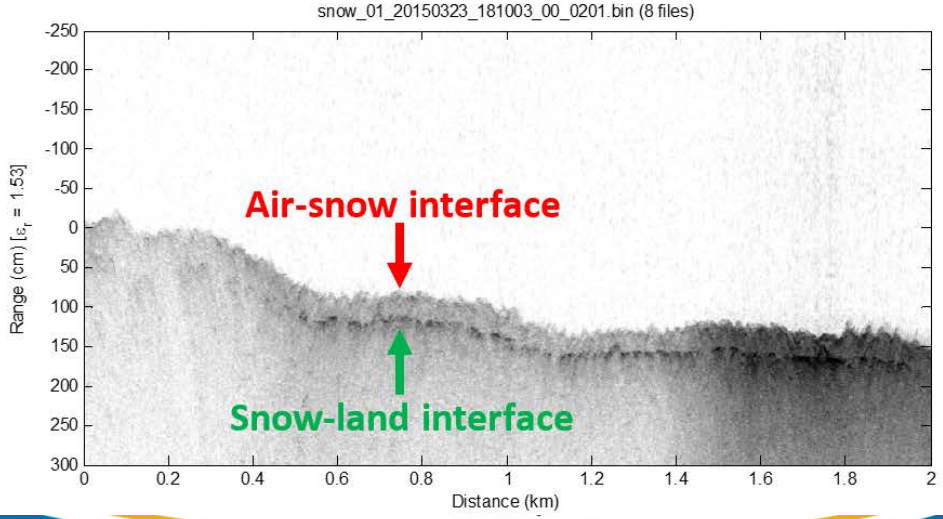


Sample Results over land



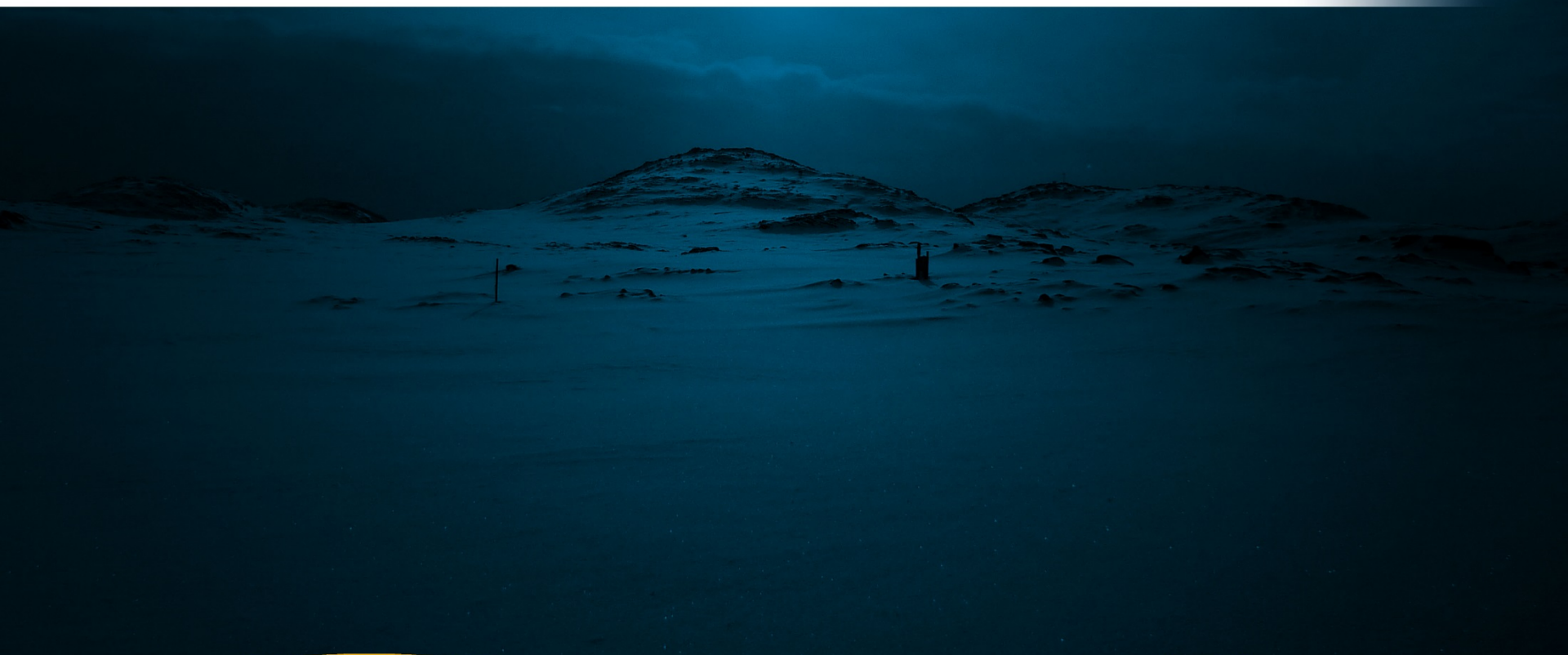






Summary

- We developed and demonstrated the application of Ultra Wideband Radars (UWB) for polar research:
  - Ice thickness and basal conditions
  - Mapping internal layers in firn and ice with fine resolution
  - 3-D topography of the ice bed and surface
  - snow accumulation rates
  - Thickness of snow over sea ice and land
- Future capabilities include fine range resolution of 2 cm and increased sensitivity.
- Other applications include detection of supraglacial lakes and ice shelves' bottom melt rates.



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