An assessment of IceBridge airborne data quality over Arctic sea ice via comparison with in situ measurements gathered in the Beaufort Sea

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The ICEX experiment

• In March 2011 a 9 km long survey line was established near the US Navy ICEX2011 ice camp in the Beaufort Sea

• The survey line was strategically located to cover a wide range of Arctic ice types

• Goal: The primary goal of the ICEX experiment was to provide an assessment of the remaining errors associated with aircraft-derived snow depth and sea ice thickness as a function of ice type

- First-year ridge
- Multiyear ice
- Refrozen lead
- Undeformed first year ice
An operation IceBridge (OIB) P-3 aircraft overflight of the survey line was conducted on the 23rd March 2011 from an altitude of ~465 m.

- 16 passes over the survey line in total
- This analysis is based on the straightest overflight: pass 5
Overview

• For my AGU talk I focused on the science results from ICEX
• The aim of this talk is to outline the technical aspects of the radar analysis
• There are four topics I will cover:
  • Timing errors
  • Radar cross section of corner reflectors
  • Waveform artifacts
  • Grating lobes
Timing errors
Unique feature on the sea ice surface at 25.93 s (Due to distinct ice block)

The same unique feature on the sea ice surface seen at 10.93 s in snow radar

Flat sea ice surface

Undulating sea ice surface

Reference time
No lead visible in DMS image

Pulse limited radar footprint

Comparison echogram - DMS image: original data

Undulating sea ice surface
Hypothesis for the cause of the timing error

- Between segment #1 and #2 the time signal used by the GPS navigation system switched from GPS to UTC time.
- A 15 second correction had been applied to all of the segments to convert from GPS time to UTC time, on the assumption that all the segments are locked into GPS time.
- For segments #2 to #8 the time signal is already UTC time so the time signal therefore gets ‘over corrected’. As a result the data in segments #2-#8 are 15 seconds behind the correct time.
Correcting the snow radar timing error

• The time signal used to sync the snow radar echograms with the navigational data was -15 seconds in error over the majority of the 20110323 flight, including the ICEX survey area

• This resulted in a geolocation error of ~1575 m (for an average aircraft velocity of ~105 m/s)

• The 15 second timing error also resulted in incorrect aircraft altitude corrections being applied to the echograms resulting in the undulating ice surfaces seen in uncorrected snow radar echograms

• We contacted CRESIS on this issue and they corrected the snow radar dataset for the 20110323 flight
Corrected Data
Corrected Data

Ku band radar: 20110323-01-161.mat

Flat sea ice surface

Corrected Snow radar: 20110323-04-084.mat

Flat sea ice surface
Flat sea ice surface

Lead feature visible in DMS image

Comparison echogram - DMS image: **corrected** data

Feature: predicted lead
Lat: 73.024960
Lon: -146.757114

Pulse limited radar footprint

200 m
Radar cross section of corner reflectors
Radar Cross Section (RCS) for trihedral corner reflector

\[ \sigma_{max} = \frac{\pi l^4}{3\lambda^2} \]

- \(\sigma_{max}\) = maximum radar cross section
- \(l\) = length of edge of reflector aperture
- \(\lambda\) = radar wavelength
CRYOVEX survey

Ku Radar: 20110415-02-121.mat

distinct radar reflectors

Snow Radar: 20110415-01-158.mat

distinct radar reflectors
**Ku-band radar**

\[ \lambda \approx 2 \text{ cm} \]

- CRYOVEX
  - \( L = 1.4 \text{ m} \)
  - RCS = 10057

- ICEX
  - \( L = 0.9 \text{ m} \)
  - RCS = 1830

**Snow radar**

\[ \lambda \approx 10 \text{ cm} \]

- CRYOVEX
  - \( L = 1.4 \text{ m} \)
  - RCS = 402

- ICEX
  - \( L = 0.9 \text{ m} \)
  - RCS = 73
Waveform artifacts
Ramp pass calibration

- Ramp passes over airfields can be used to constrain the average flat surface radar response.

- The airfield ramps are flat, smooth and free of snow, making them ideal surfaces for calibration.
The average ku-band radar waveform

Average waveform constructed from 224 waveforms over ramp passes from the 2011 IceBridge Arctic campaign.

Trailing subsidiary peak 23.60 ns after main lobe -13.1 dB below main lobe.
Leading `sidelobe'
2.10 ns before main lobe
-17.3 dB below main lobe

Trailing `sidelobe'
1.95 ns after main lobe
-11.2 dB below main lobe

The average snow radar waveform

Average waveform constructed from 941 waveforms over ramp passes from the 2011 IceBridge Arctic campaign
Grating lobes
(Observed in DC8 flights)
Grating lobes

- The aircraft velocity divided by the radar PRF determines the spacing of the pulse locations.
- If this spacing (d) is greater than half the wavelength of the carrier frequency secondary lobes (grating lobes) can start to induce angular ambiguities in post-processed radar data.
Multiple caused by grating lobe

PRF = 2000 Hz
velocity = 128 m/s
x = 81 m
Multiple caused by fore grating lobe

PRF = 2000 Hz

velocity = 105 m/s

x = 99 m

Multiple caused by aft grating lobe