Sensing Snow Depth over the Arctic Sea Ice Using GPS Interferometric Reflectometry

Tyler Landsparger

Mentors: Dhiman Mondal, Pedro Elosegui, John Barrett, Chet Ruszczyk
Outline

I. Objectives

II. Techniques and Mathematics

III. First Investigation (Snow on solid ground)

IV. Second Investigation (Ocean tides)

V. Third Investigation
   (MIT SIDEx Arctic stations)

VI. Implications

VII. Acknowledgments
Primary Objective: Advance an existing software program to directly extract reflector heights from GPS reflection data.

Scientific Objective: Remotely measure changes in snow depth on the Arctic sea ice over time. Snow accumulation is an important parameter in determining how much sea ice melts in the summer.
Techniques

- I used a software package called “gnssrefl” for my investigations and advanced it further by adding code of my own.

Link to images and software: (Larson, https://github.com/kristinemlarson/gnssrefl)
**Mathematics Involved**

**Signal-to-Noise Ratio (SNR) function**

\[
\text{SNR}(\theta) = A(\theta) \sin \left( \frac{4\pi H_R}{\lambda} \sin \theta + \phi \right)
\]

- **SNR(\theta)** = Signal-to-noise ratio in terms of the elevation angle (dB-Hz)
- **\(\theta\)** = Elevation angle (degrees)
- **\(\lambda\)** = GPS band wavelength (0.19 m for L1)
- **\(H_R\)** = Reflector height (m)
- **\(\phi\)** = Phase constant (can typically be ignored)
- **\(A(\theta)\)** = Amplitude of SNR data (dB)

**Period of the SNR function**

\[
\text{Period(SNR)} = \frac{\lambda}{2h} = P_{SNR}
\]

Solve for \(H_R\).

\[
\frac{\lambda}{2P_{SNR}} = H_R = h
\]

**Reflector Height (H_R)**
First Investigation: Measuring Snow Depths
(Stationary Station and Reflector)

This investigation helped me to calibrate and improve my understanding of SNR and GPS-IR.

Sample “dry day” data: May 11, 2020

1.93 m dry height – 1.53 m snow height = 0.40 m of snow

March Blizzard of 2021: March 15, 2021
Second Investigation: Monitoring Ocean Tides
(Stationary station, moving reflector)

This investigation showed that GPS-IR can be used to observe changes in ocean tides over time.

Hour 0-582 mean: -0.249 m
Hour 0-582 RMS: 0.338 m

Hour 582-768 mean: 0.161 m
Hour 582-768 RMS: 0.334 m

Sudden shift on July 22 (0.4 m offset)

Cause: 7.8 magnitude earthquake
• Sites studied: SX12 and SX13

• Days analyzed: DOY 62-64, 2021 (March 3-5, 2021)

• Stations located on drifting Arctic sea ice off the northern coast of Alaska.

• The ice is always moving, so the receivers are also always moving.
  • The rate of ice and station movement is not constant.

• Reflector height measurements with a high amount of scattering were expected due to the stations’ motion.
Third Investigation: MIT Arctic SIDEx GPS sites

SX13

rms = 1.243
Third Investigation: MIT Arctic SIDEx GPS sites


rms = 1.609
Third Investigation: MIT Arctic SIDEx GPS sites

sx12 Reflector Heights, Days 62-64, 2021

- Day 62
- Day 63
- Day 64
Third Investigation: MIT Arctic SIDEx GPS sites

sx13 Reflector Heights, Days 62-64, 2021

- Day 62
- Day 63
- Day 64

SX13
Summary & Implications

• We collected and analyzed data from multiple GPS receiver sites.

• These investigations reproduced the results of previous studies.

• Early Arctic sea ice GPS-IR results have been surprising, but promising. Station motion may only have a negligible impact on measuring reflector heights based on these results.

• Further investigation is required to verify GPS-IR’s viability for sensing snow depths on drifting Arctic sea ice.
Acknowledgments

• Thank you to Dr. Dhiman Mondal, Dr. Pedro Elosegui, Dr. John Barrett, and Dr. Chet Ruszczyk for guiding me through this project and teaching me how to perform scientific research.

• Thank you to Linnea Wolniewicz, MIT Haystack Observatory, and the rest of the MIT REU interns for their support while conducting this research.

• Thank you to NSF for funding my project and those of my colleagues!