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

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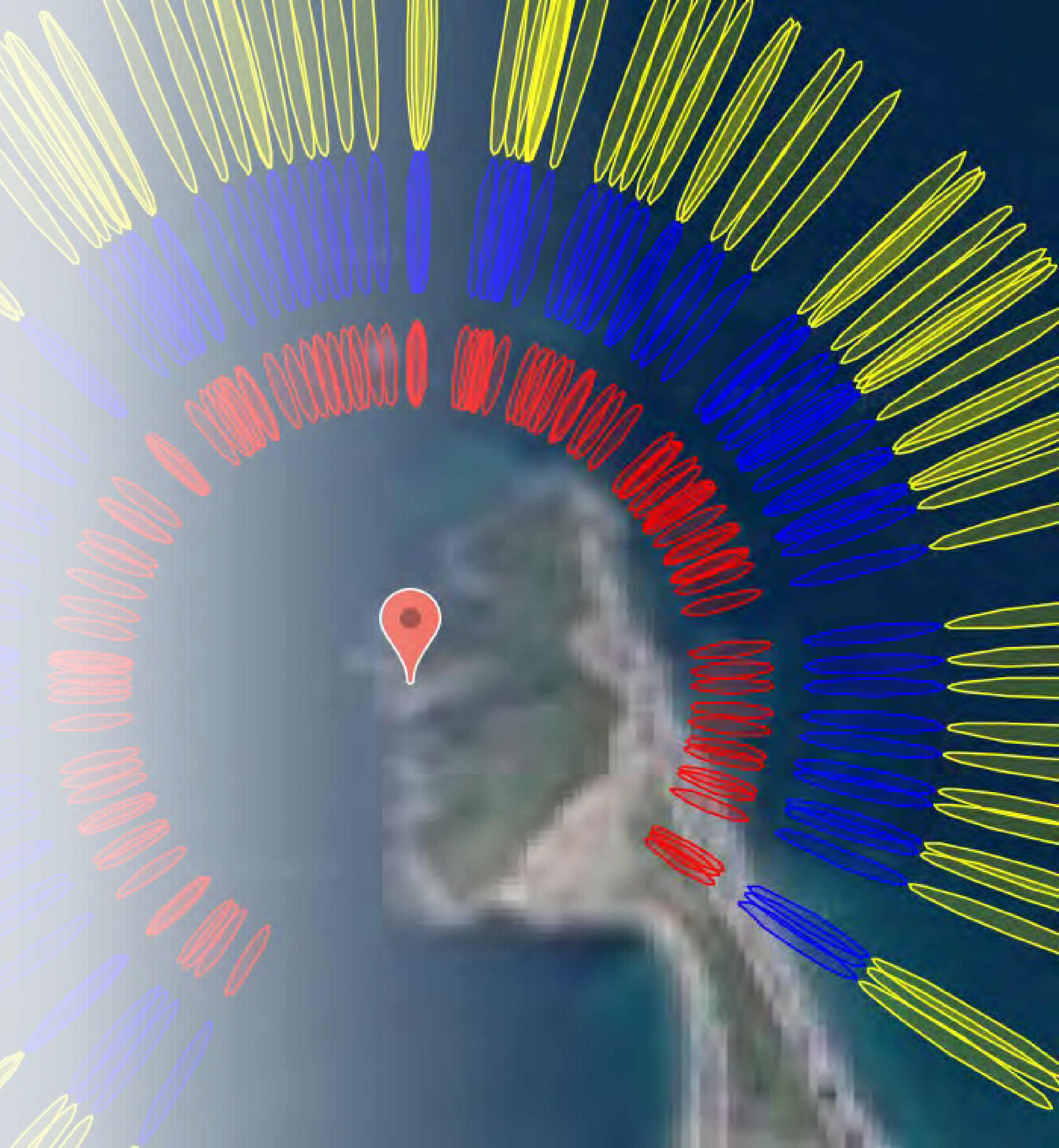

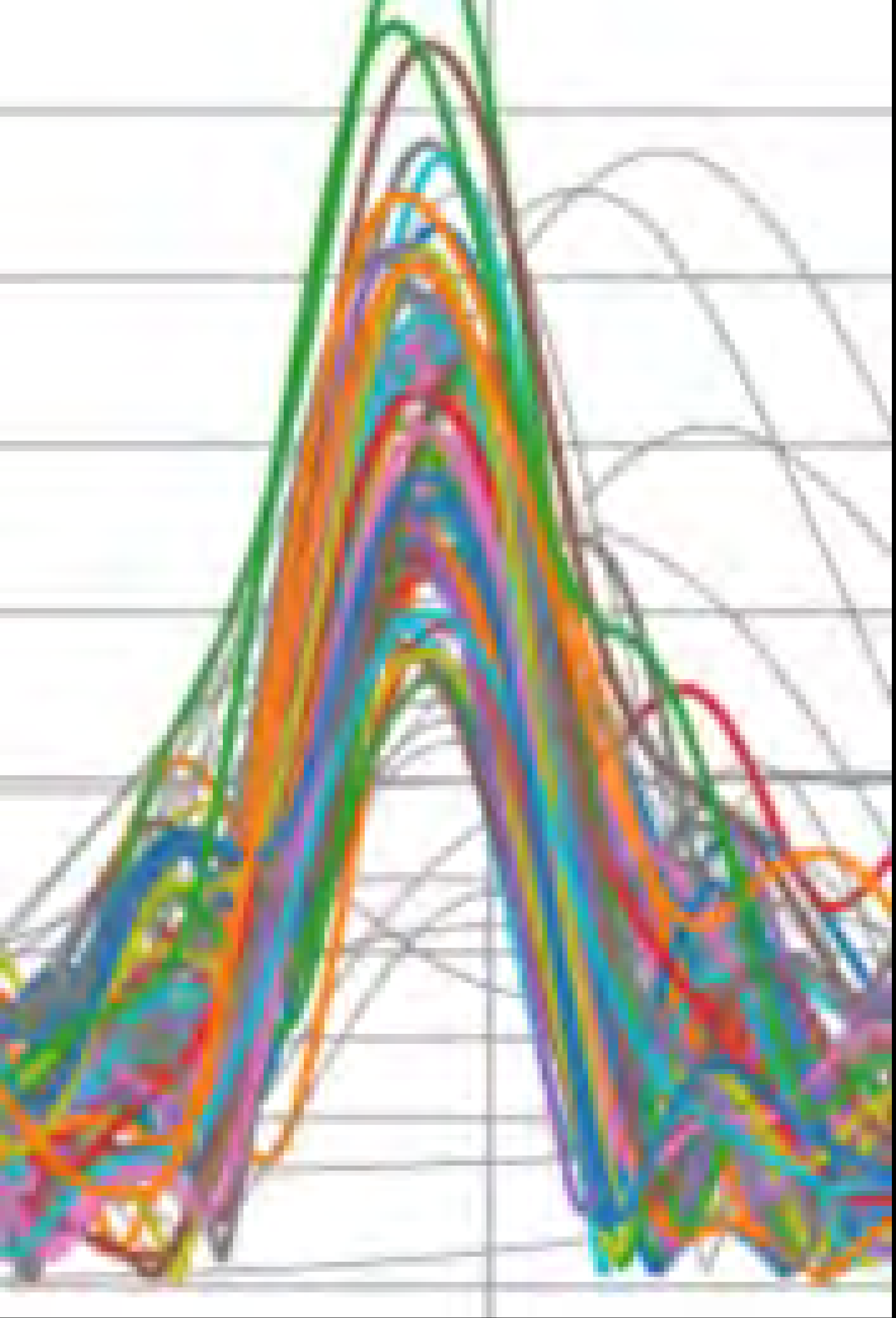

Outline

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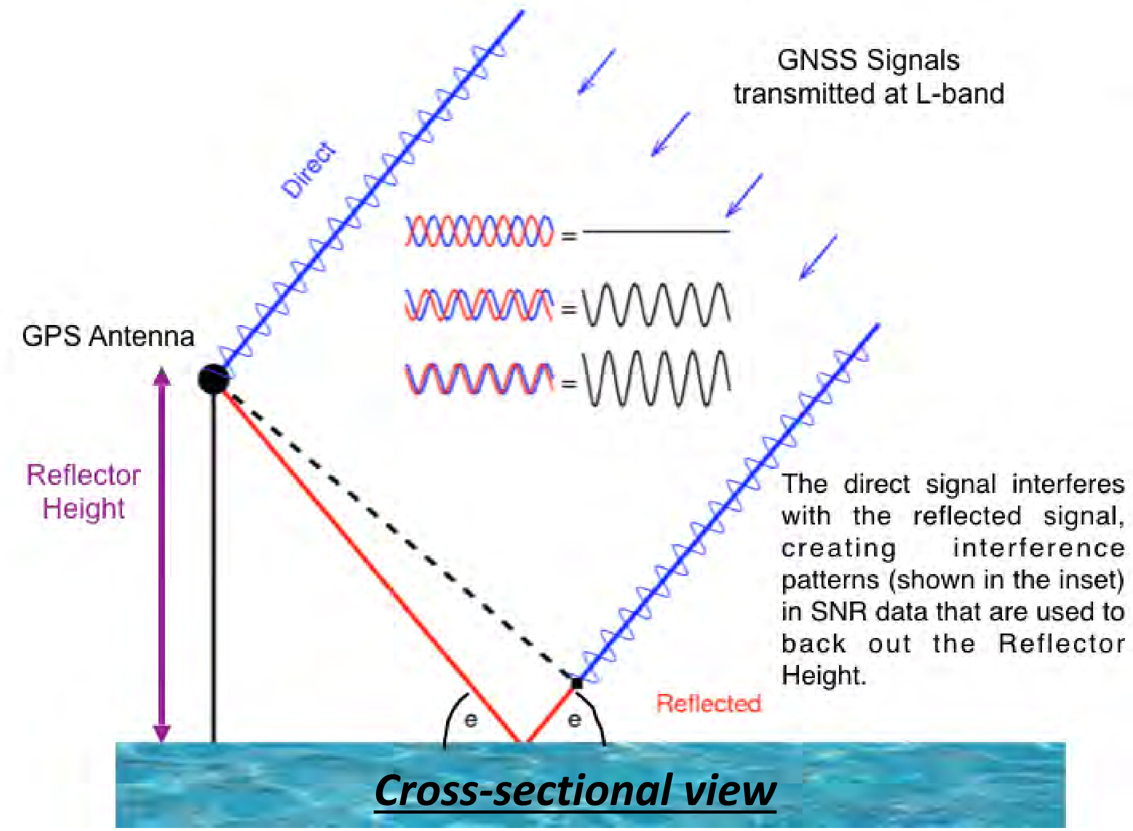
Primary Objective: Advance an existing software program to directly extract reflector heights from GPS reflection data.

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



Cross-sectional view

Reflector surface is an ellipse, ***not*** a point.

View from above

- 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

$$\mathrm{SNR}(e) = A(e)\sin\left(\frac{4\pi H_R}{\lambda}\sin e + \phi\right)$$

SNR(e) *= Signal-to-noise ratio in terms of the elevation angle (dB-Hz)*

e *= elevation angle (degrees)*

Lambda *= GPS band wavelength (0.19 m for L1)*

HR *= Reflector height (m)*

Phi *= Phase constant (can typically be ignored)*

A(e) *= Amplitude of SNR data (dB)*

$$B = \frac{4\pi h}{\lambda}$$

$$\frac{1}{B} = \frac{\lambda}{4\pi h}$$

$$\frac{2\pi}{B} = \frac{2\pi\lambda}{4\pi h} = \frac{\lambda}{2h}$$

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

Solve for H_R.

$$P_{SNR} = \frac{\lambda}{2h}$$

$$\frac{1}{P_{SNR}} = \frac{2h}{\lambda}$$

$$\frac{\lambda}{2P_{SNR}} = H_R = h$$

Period of the SNR function (P_{SNR})

$$\frac{\lambda}{2h} = P_{SNR}$$

Reflector Height (H_R)

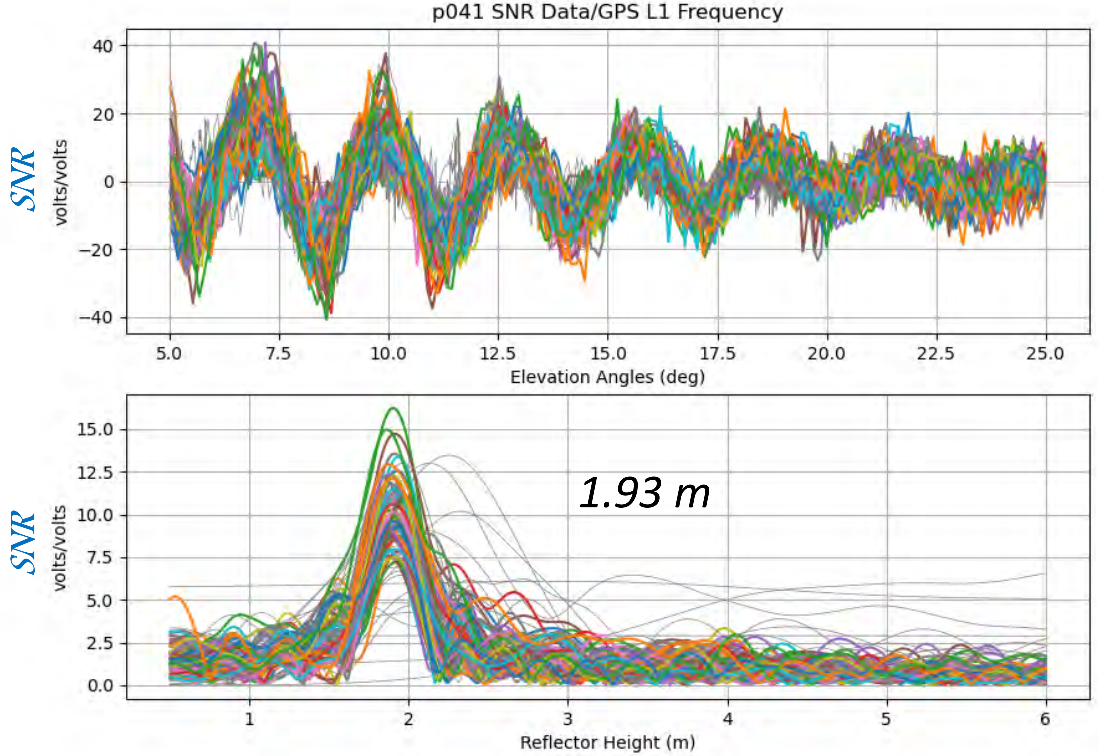
$$\frac{\lambda}{2P_{SNR}} = H_R$$

First Investigation: Measuring Snow Depths

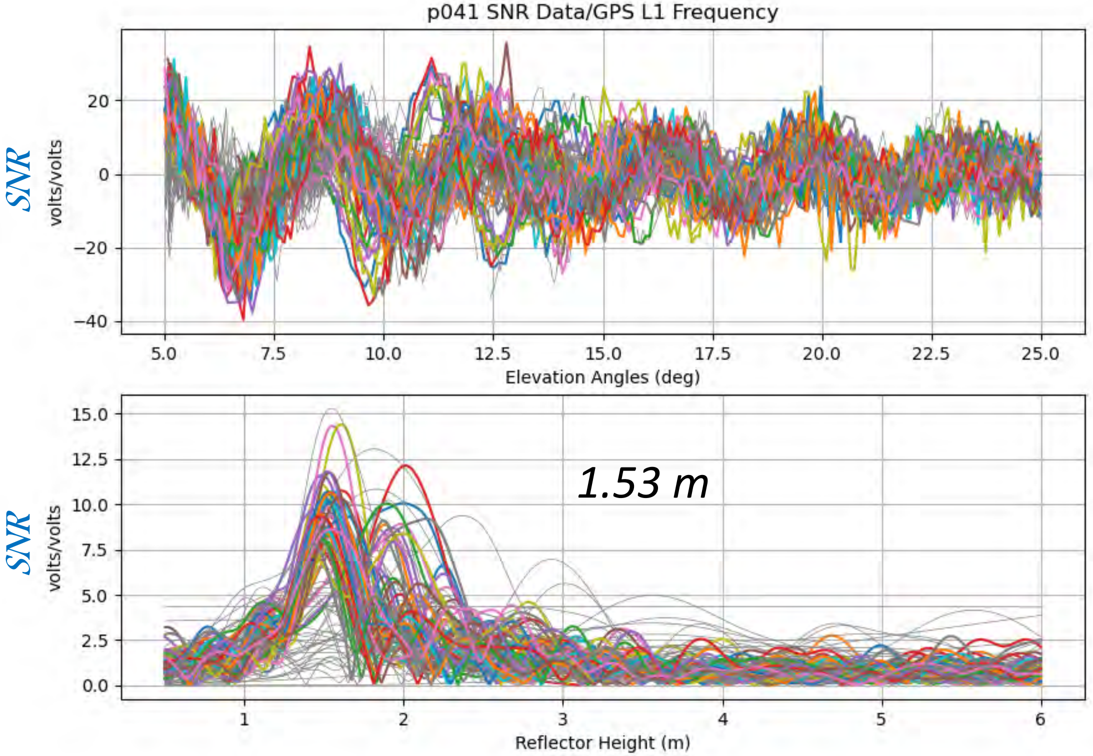
(Stationary Station and Reflector)

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

The investigated receiver



Sample "dry day" data: May 11, 2020



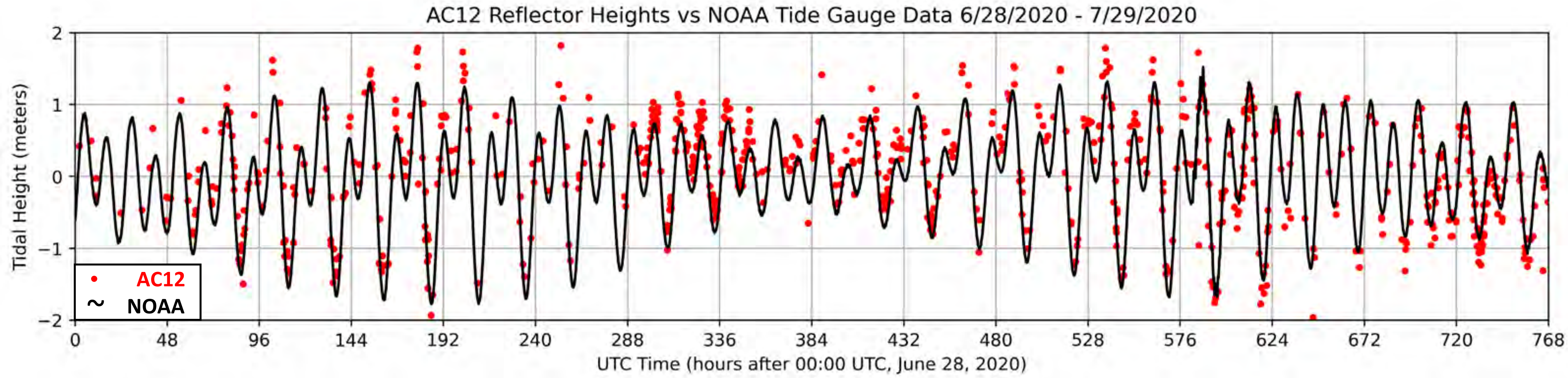
March Blizzard of 2021: March 15, 2021

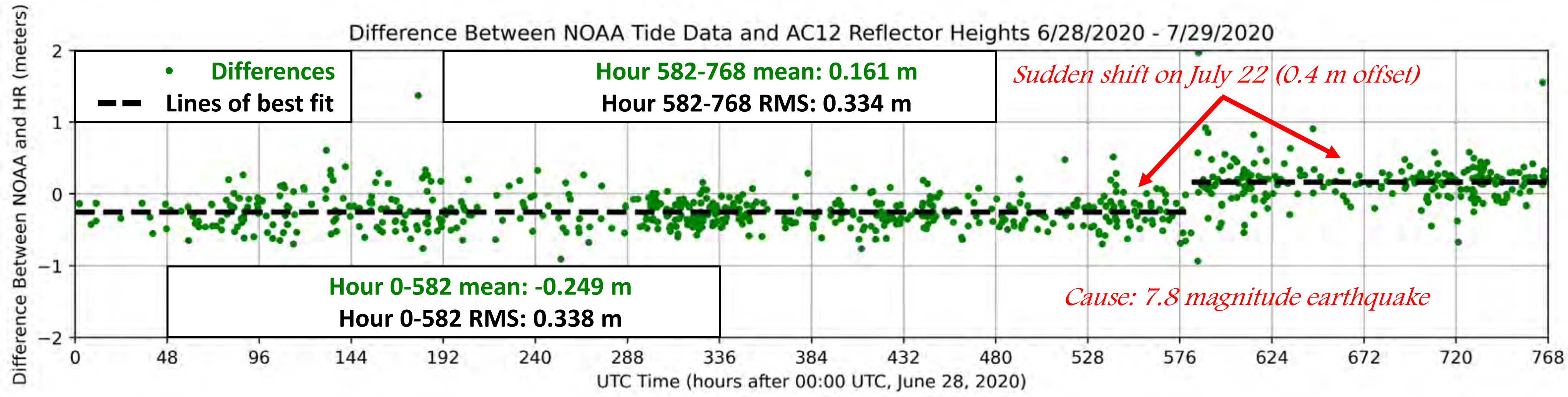
1.93 m dry height – 1.53 m snow height = 0.40 m of snow

Second Investigation: Monitoring Ocean Tides

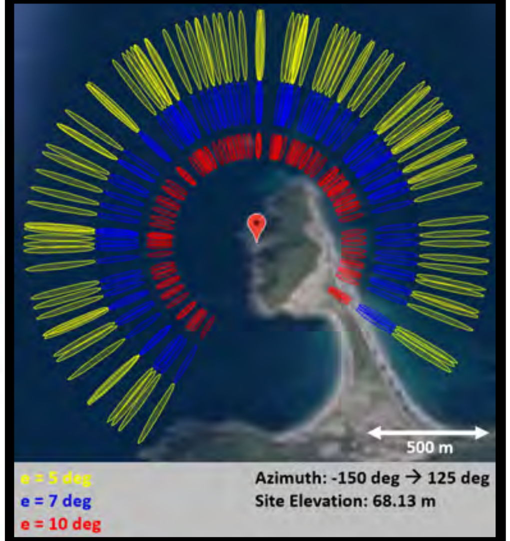
(Stationary station, moving reflector)

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





The investigated receiver

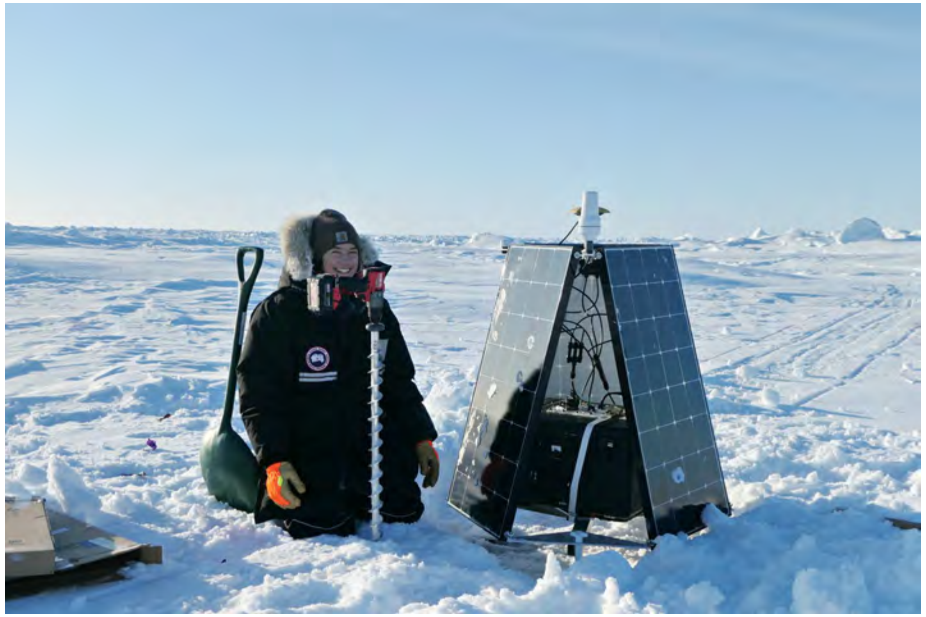


Third Investigation: MIT SIDEx, Arctic stations

(Moving station and reflector; Reflector stationary relative to station)

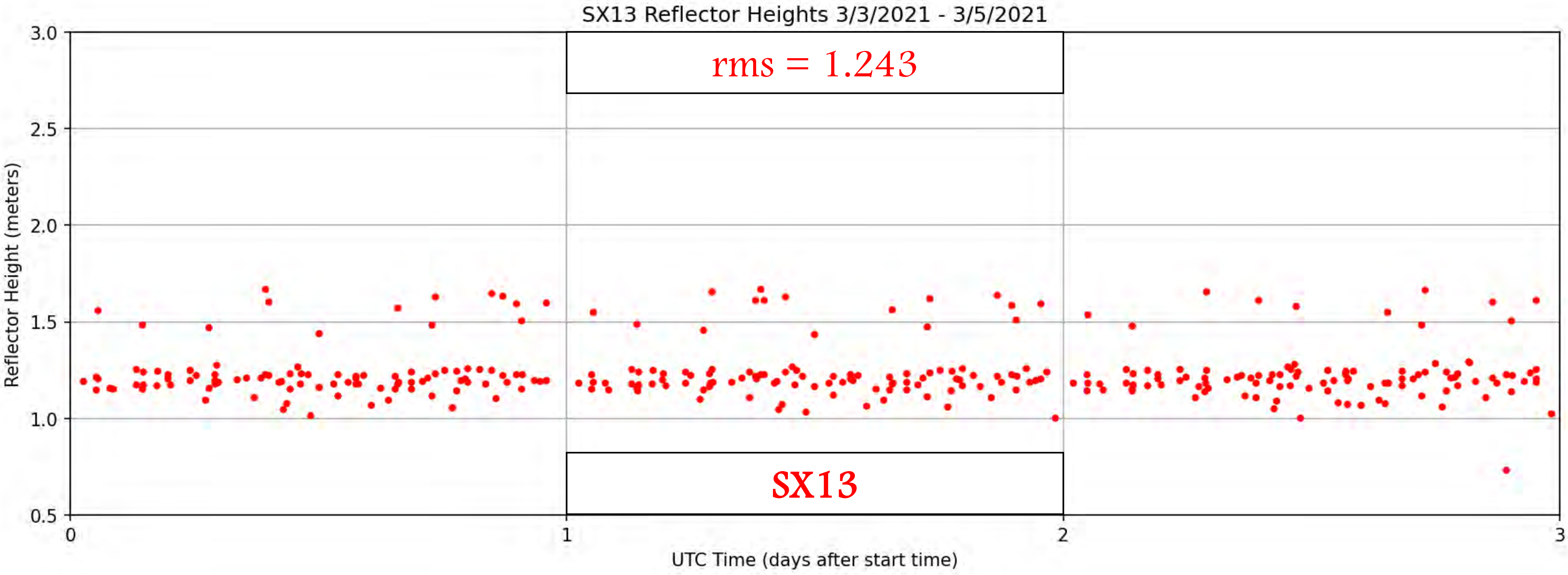
- Sites studied: SX12 and SX13
- Days analyzed: DOY 62-64, 2021 (March 3-5, 2021)
- Stations located on drifting Arctic sea ice off the northern coast of Alaska.

- **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.

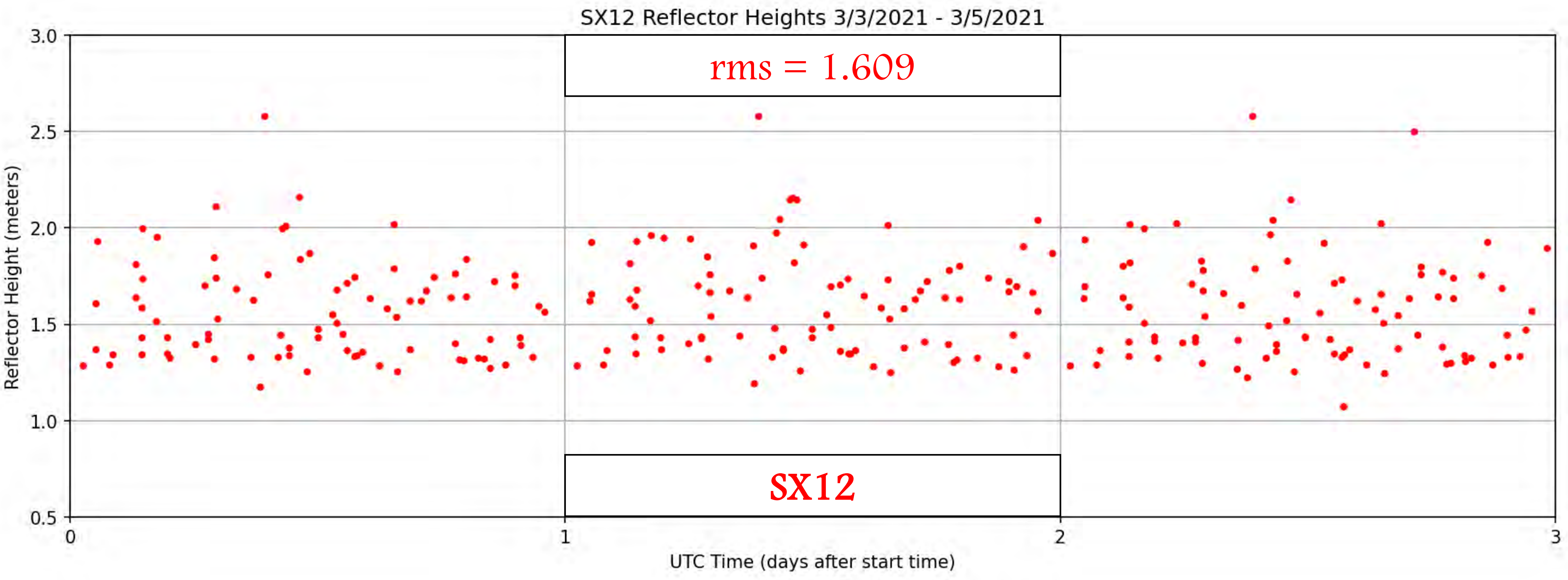


A SIDEx station

Third Investigation: MIT Arctic SIDEx GPS sites



Third Investigation: MIT Arctic SIDEx GPS sites



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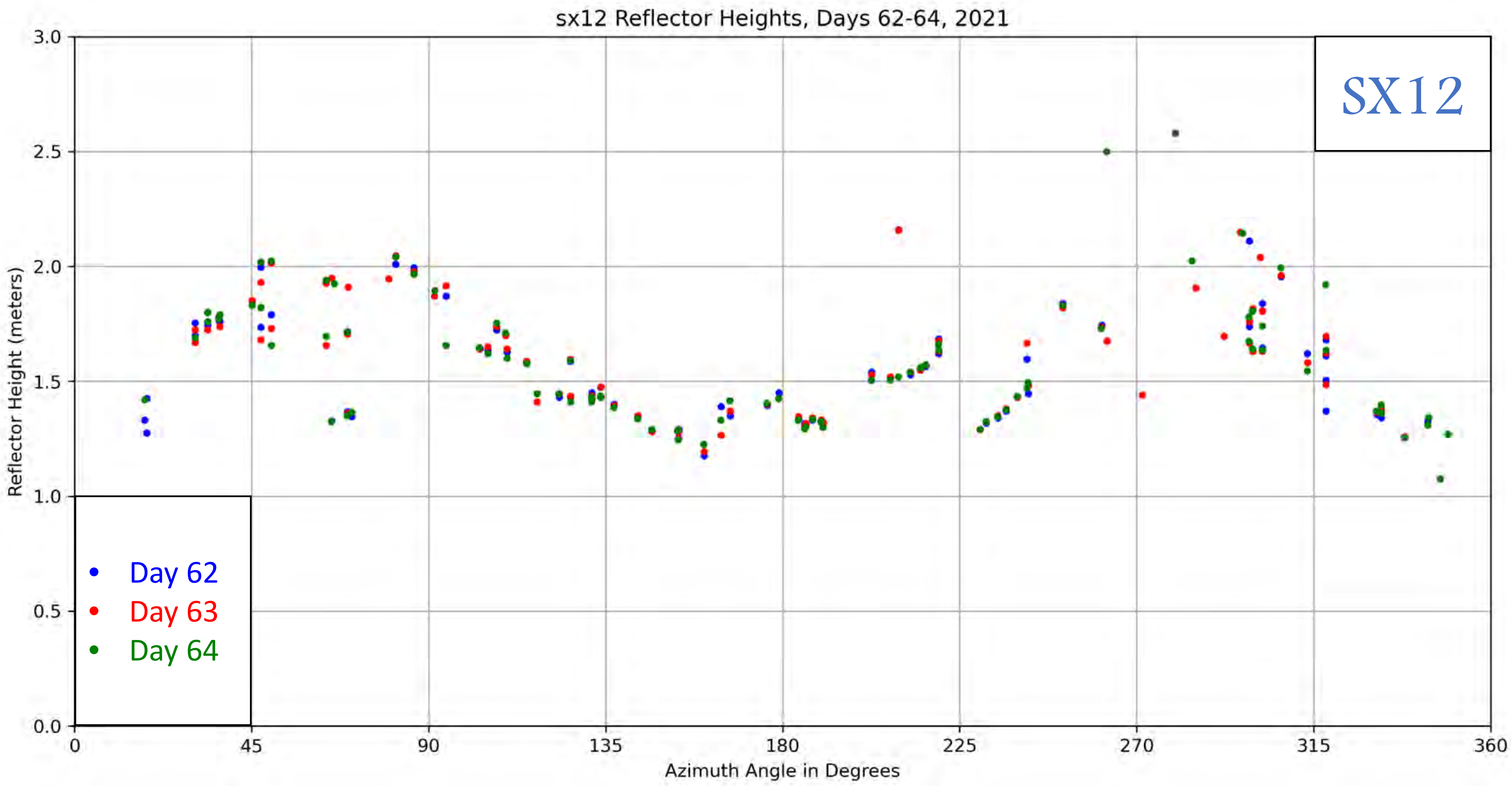

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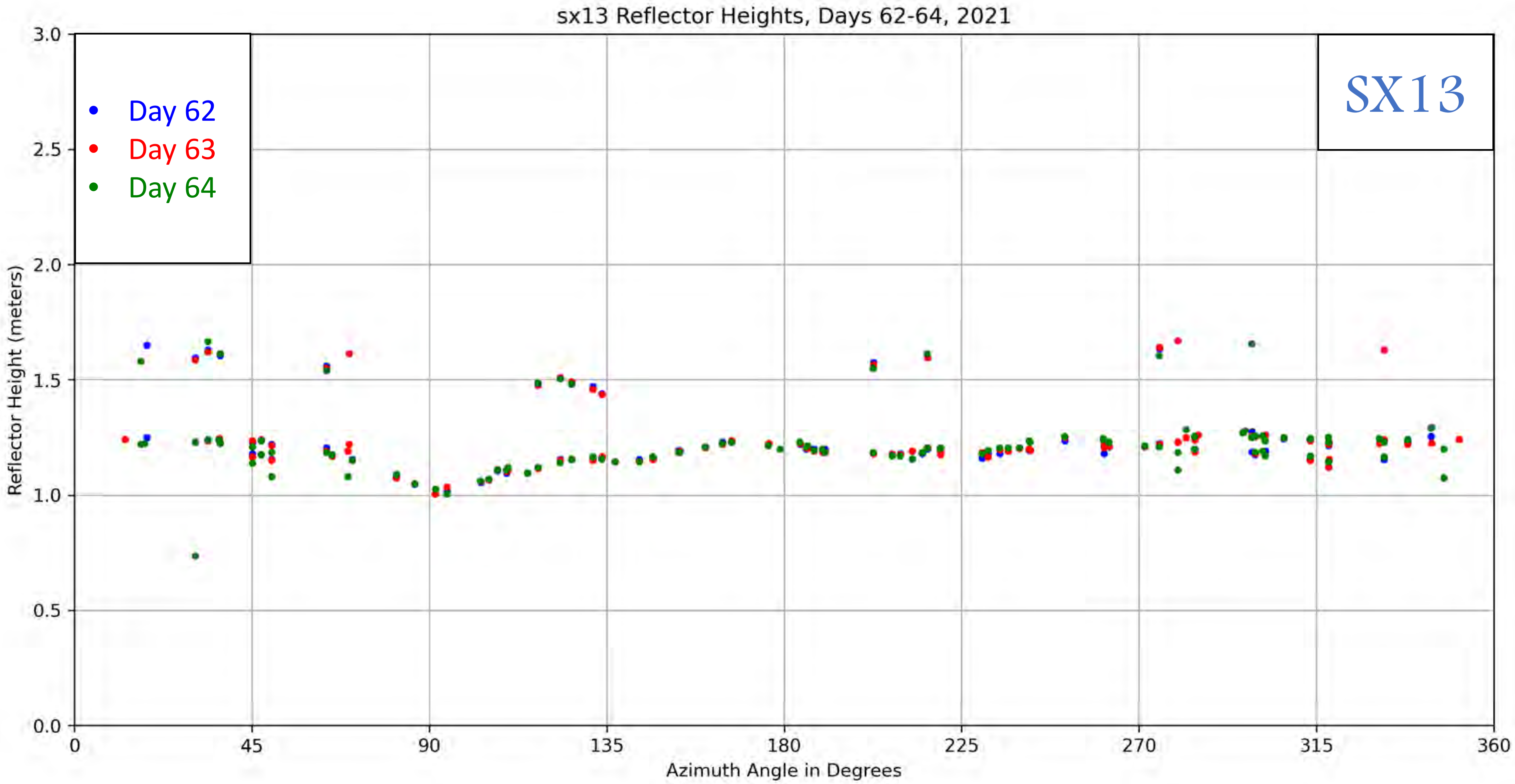

Summary & Implications

- 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.

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