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Analyzing the multipath of GPS time series to study snow properties

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Analyzing the multipath of GPS time series to study snow properties

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Abstract

Thousands of Global Positioning System (GPS) receivers worldwide record signals sent by satellites to infer how each receiver (and the ground they are attached to) moves over time. The motion of GPS receivers are used for many purposes, including studying tectonic deformation and changes in Earth's shape caused by surface loading. In this project, reflected wave arrivals contained within the multipath signal of GPS time series are extracted and analyzed to advance understanding of snow properties in mountainous regions of Montana/Idaho, USA. Analyzing reflected signals in GPS series has the potential to reveal properties of local snowpack, such as height, water content, snow surface temperature, dielectric properties, and density. Improving our ability to monitor physical characteristics of snowpack and how they evolve over space and time is essential as properties of snow are key to understanding the slippage of one layer on another, which impacts avalanche hazard. Moreover, snowpack monitoring provides information about availability of water resources and snow hydrology. This project focuses on analyzing the ray paths and attenuation of reflected GPS signals, also using reflections to infer properties of snow. Traditionally, to study snow properties, one must manually dig a snow pit to study the snowpack and/or use expensive remote-sensing technologies (e.g. InSAR). However, digging snow pits can be dangerous due to avalanche risk as well as costly and time inefficient. Relatively low-cost GPS stations that are now widely deployed worldwide present new opportunities to study snow properties, including in developing nations with fewer financial resources. We will use GPS interferometric reflectometry (GPS-IR) software developed by Kristine Larson (CCAR) to infer snow depth data from GPS multipath. Results will be validated with nearby instruments, such as Snow Telemetry (SNOTEL) and a co-located weather station, as well as by visiting the site in person to measure snow properties manually.

Introduction

Seasonal snow plays a crucial role in Earth's environment and ecosystem, from regulating temperature of the Earth's surface to replenishing freshwater resources in rivers and reservoirs in many regions of the world. Snow is an essential resource for the planet. However, snow fall also bring hazards like avalanches, which may impact human society gravely. Many people die or have their houses and facilities destroyed by avalanches each year.

In developing countries, there are very few resources and there is not much funding to mitigate natural hazards. Snow avalanches are one of those natural hazards that I have witnessed in Nepal personally, and which has affected many families. My motivation for this research was to investigate research methods that are low cost and efficient to study the snowpack and snow properties, with a long-term goal to apply the knowledge in developing countries to predict avalanche prone areas.

First step to studying the snowpack is finding out the height of snow accumulated each day. In this research we investigated previously conducted research on using low-cost GPS stations to extract the multi path data from GPS signals to calculate the snow height. We will be using Kristine Larson's methodology and software (GNSS-IR) to extract the snow height from GPS data records.

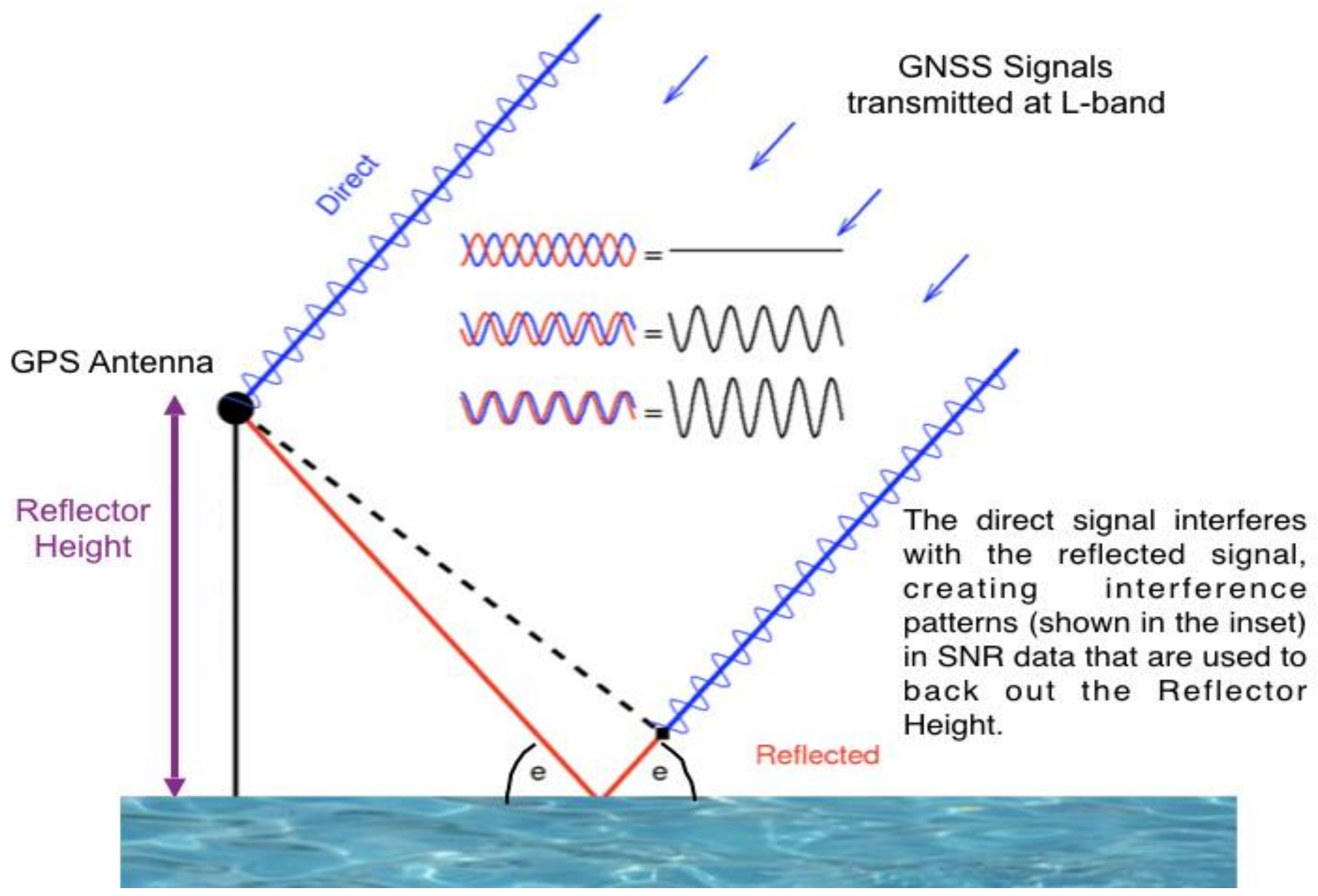
During my study, I looked primarily into select GPS stations in Idaho and Montana to extract the snow height for the year of 2020. I was interested to study this area because I had done field work here in summer 2020, installing GPS stations and weather stations. I would like to apply this methodology to extract temporal changes in snow height at the field stations in the future.

Summer 2020 Fieldwork at Selway, Idaho. Installing GPS stations and weather stations.

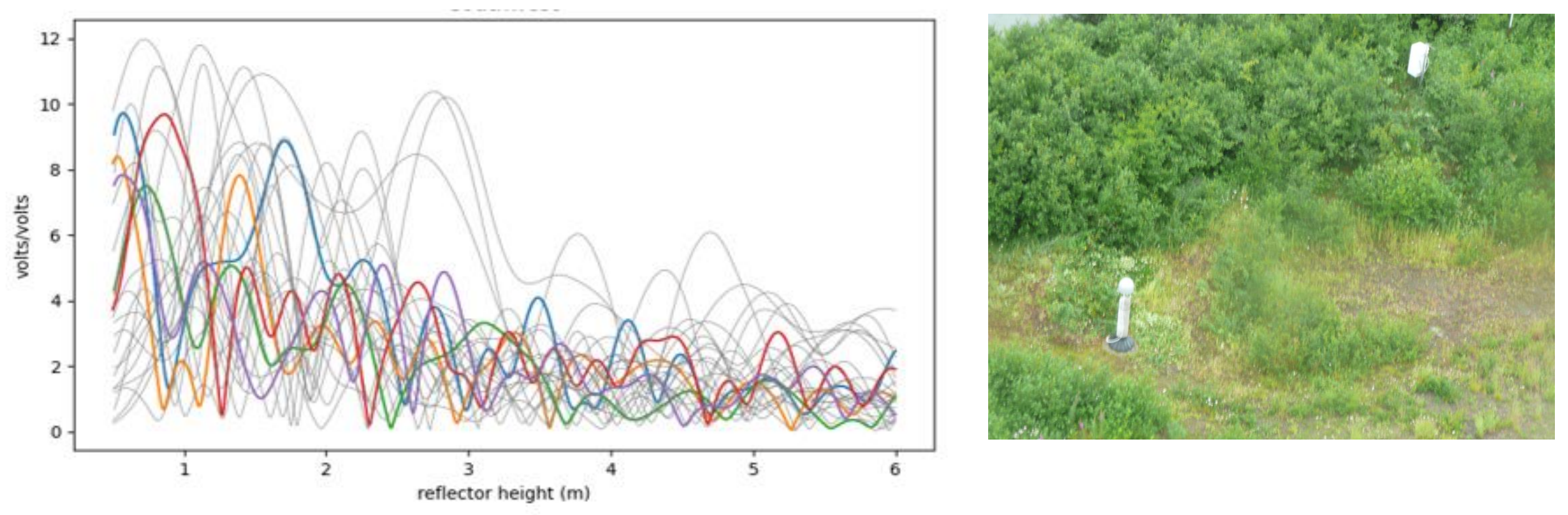
Methods

- Selecting a GPS station for snow-height analysis:
  - GPS site area has flat land around with no obstruction like trees and mountains.
  - Periodogram has strong, consistent peaks when computing reflector height on single day.
  - Assess satellite elevation angles, frequencies, and azimuth with respect to the GPS station.

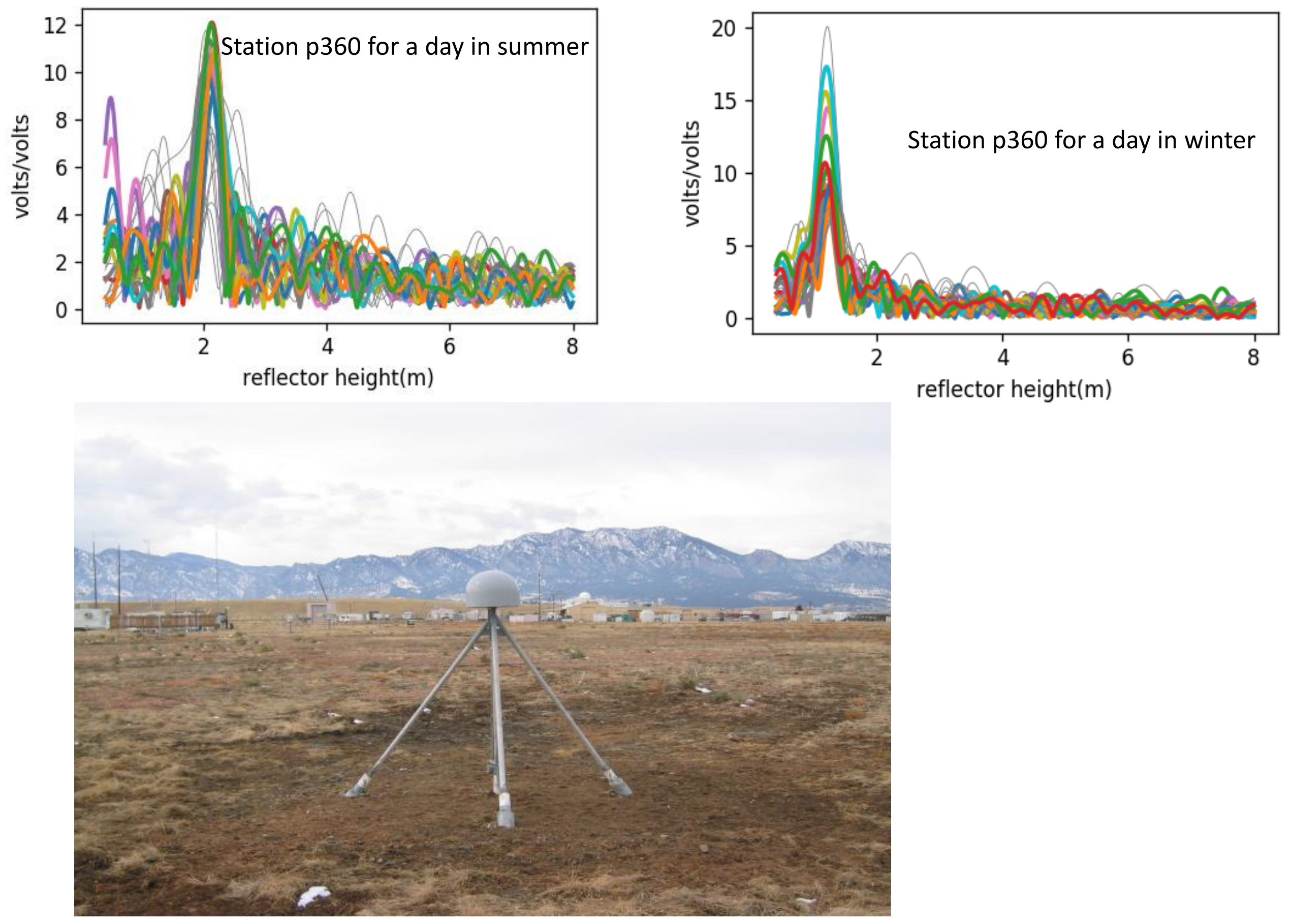
- Estimating snow height using the GNSS-IR software (Larson et al. 2012):
  - Select the GPS station you want to work with to compute its snow height.
  - Separate the daily signal-to-noise ratio (SNR) data file by rising and setting satellite tracks.
  - Generate Lomb-Scargle periodograms (LSP) for satellite signals received between elevation angles of about 5 ° to 30 °.
  - Estimate the average height of the antenna above the bare soil using summertime data.
  - Estimate snow depth for each day by subtracting LSP antenna height from the bare soil height.
  - Extract the mean snow height for each day and plot it on a timeline.



The direct signal interferes with the reflected signal, creating interference patterns (shown in the inset) in SNR data that are used to back out the Reflector Height.

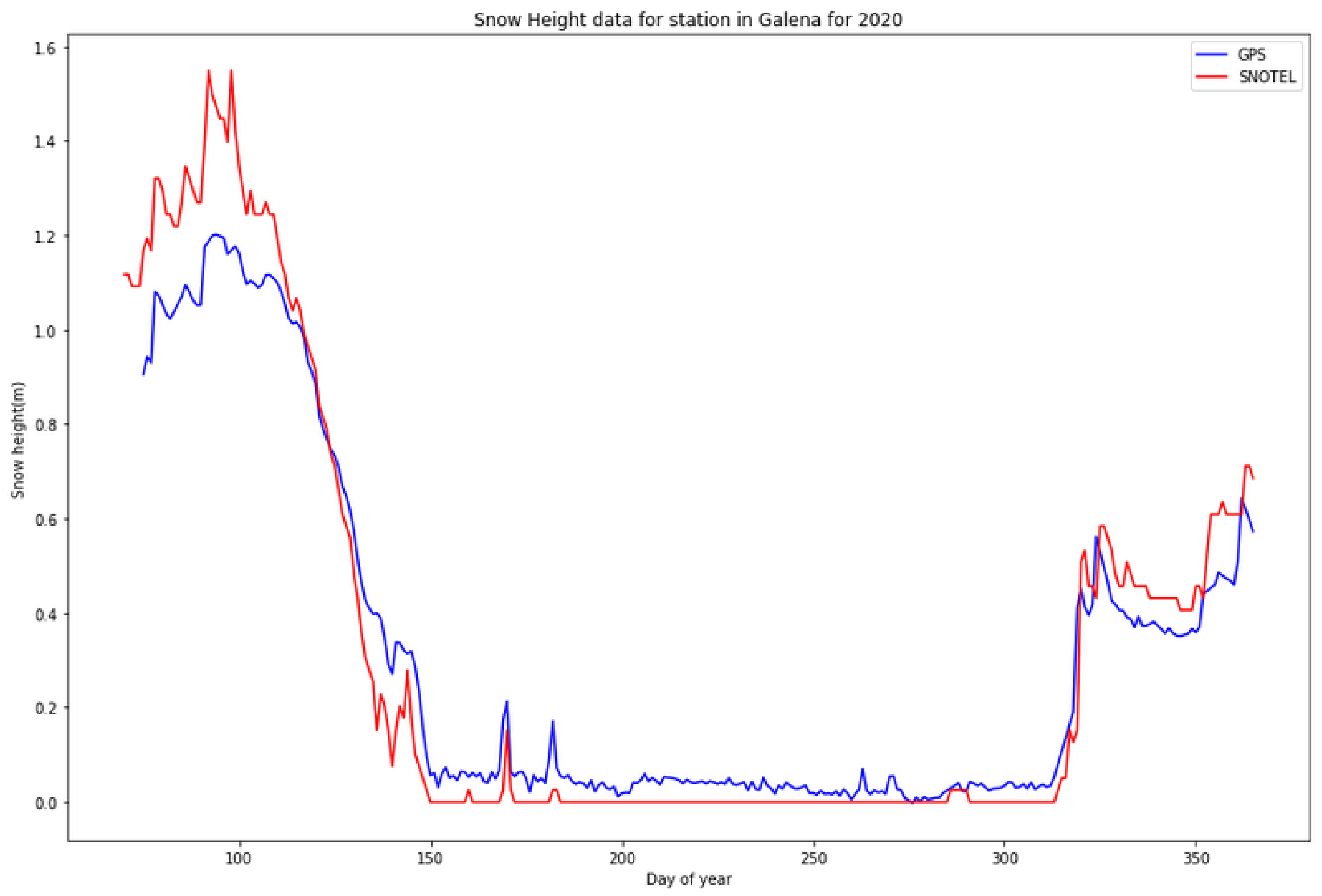


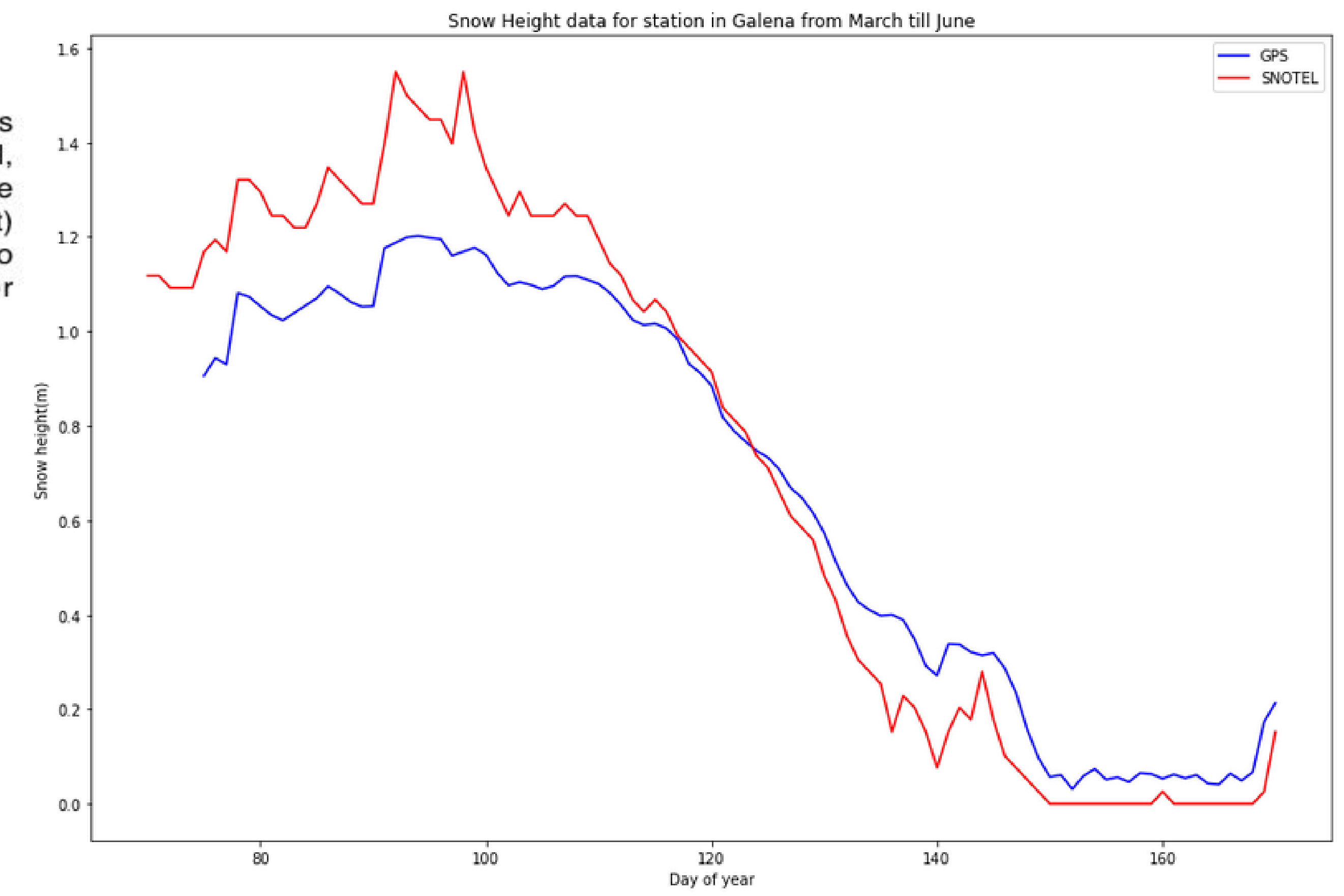
The above periodogram shows station that has various peaks that are not constant and is not a good station overall. The GPS station it corresponds to is also at a place where there is a lot of obstacles.

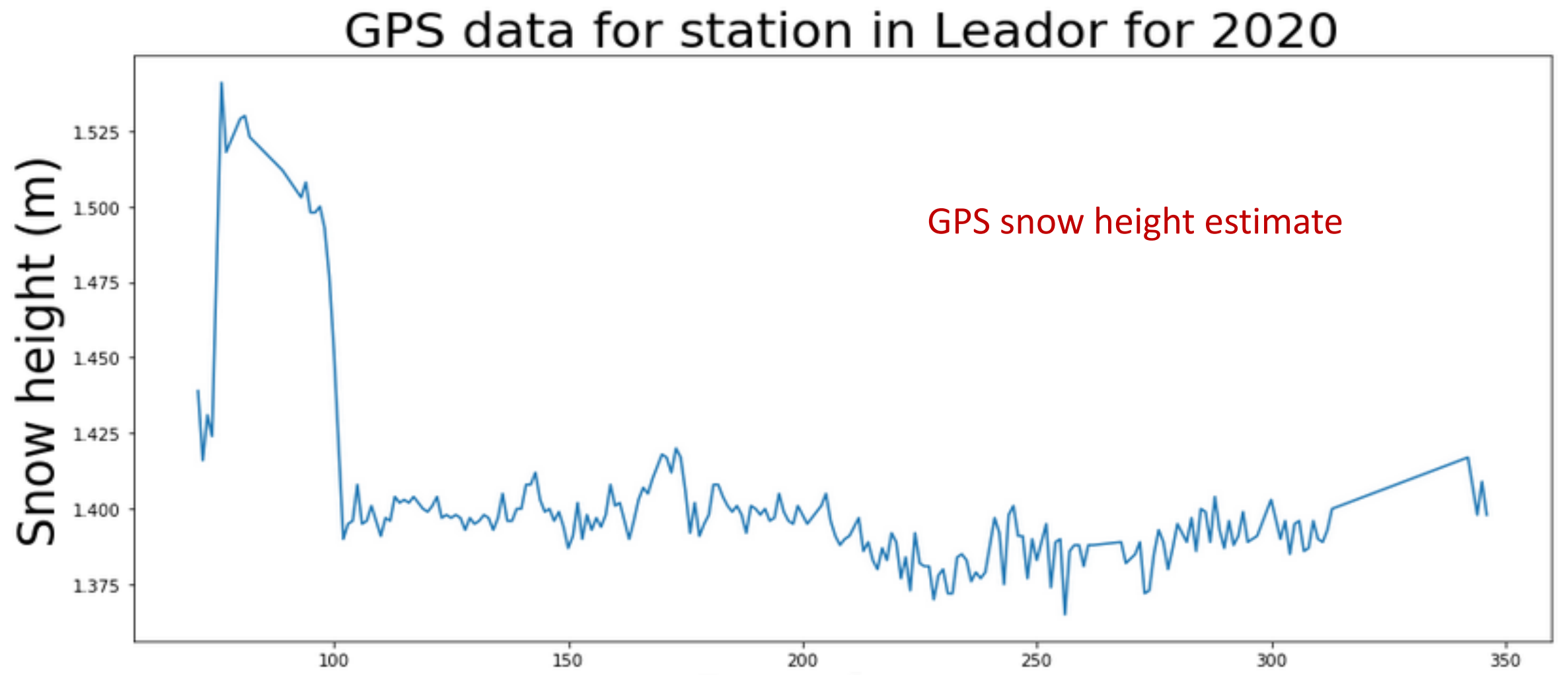


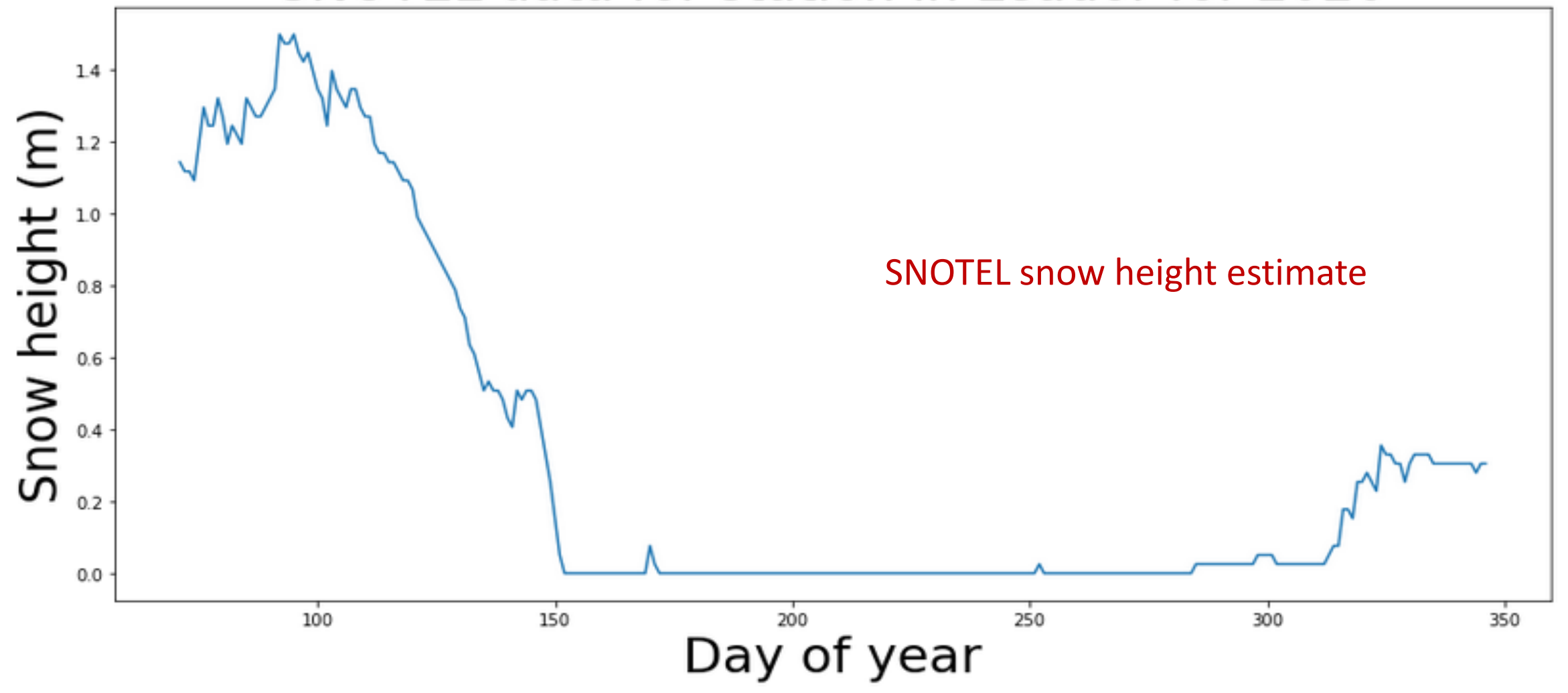
Consistent peak and one large peak can be seen this is periodogram. This signifies good data is available for this station. Moreover the GPS station the periodogram corresponds to is in a flat, horizontal surrounding

Results









Analysis

From the result, we can see that the reflector height extracted from the GPS and the snow height extracted from the SNOTEL matches the trend of the seasonal snowpack height.

Station in Galena was one of the stations that had better results than the others. This is because the station lies in a very flat horizontal surface and there were no obstructions on the site. Moreover, this station was the closest in proximity with the SNOTEL, which we are using for an independent comparison. The proximity of the SNOTEL to the GPS station affects the results, since snow pack can vary significantly between different mountain ranges. I have provided comparisons between 4 months of snow accretion through to snow ablation months in the year 2020 for Galena and a year-long snow height for the year 2020. The bare soil reflector height is constructed during summertime and it came out to be 1.9 meters. To find the snow height daily, I subtracted daily estimated reflector heights from 1.9 meters.

On the Snow Height data for station in Galena from March till June, we can see that the GPS station records 1.4 meters as the maximum reflector height and the SNOTEL records a maximum of 1.6 meters of snow height. The difference of 0.2 meters reflects a combination of error in the GPS and SNOTEL measurements of snow height, as well as spatial variations in snow height between the two stations.

Station Leador has a trendline for the reflector height that follows that of the corresponding SNOTEL-estimated snow-height data. However, there are many missing data points, especially in the months of March and April. The missing data in the springtime may be due to the station receiving too much snow such that the GPS receiver becomes buried under the snowpack, as the station elevation is high and in a mountainous area.

Even though we strategically selected stations that are primarily located in horizontally flat surroundings, station P358 is situated in a slightly hilly slope that I hypothesized would not make a big difference in the beginning. However, when I compared the results with stations that are on very flat land with this station, it can be noticed that the data has less quality to extract snow height and

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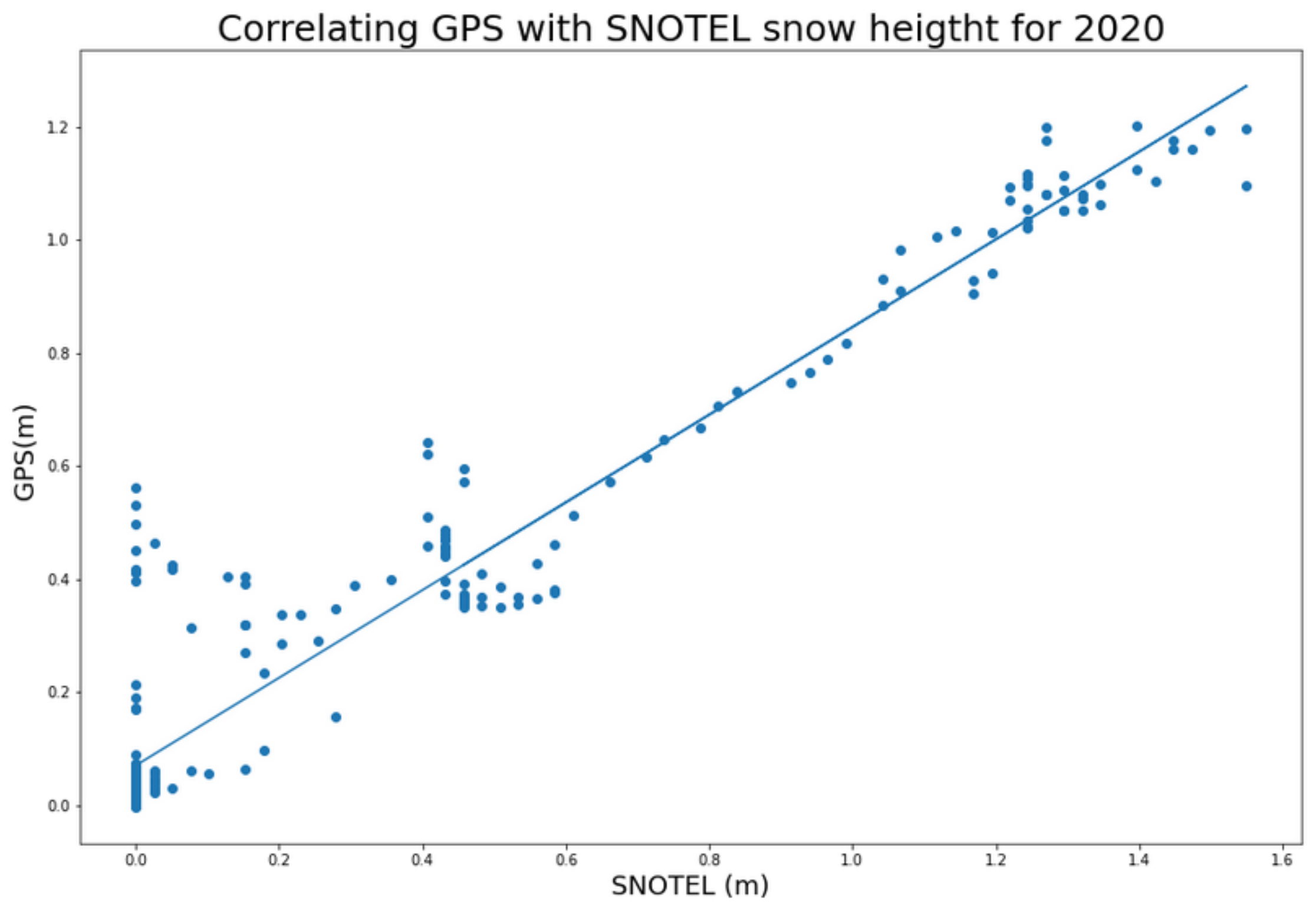

Pearson Correlation coefficient tells us that there is a strong linear correlation between SNOTEL and GPS snow height

Future works

I would really like investigate more in this method and apply it in different stations. Larson et al. (2012) mention that the GPS multipath method works well for PBO stations that have choke rings and that are located in very flat areas. I selected stations in this study that are well suited for this methodology. However, I would like to expand more and see how this method can be manipulated and tweaked to work on different stations that may not be in a perfect setting of flat land or stations where there may be obstructions, like mountains. I am interested to explore the data further.

Moreover, my goal is to apply this methodology to another set of GPS stations in Selway, Idaho. I assisted with installing and gathering data for the Selway GPS network in summer 2020. I aim to compare the GPS estimates of snow height with actual snow heights measured by digging snow pits in the field during the winter months.

Another route we could go in this research is that we can apply different models mathematically to estimate snow bulk density from the snow height timeline of each day to estimate the snow water equivalent (SWE), with the goal of quantifying the water supply in a particular area.

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