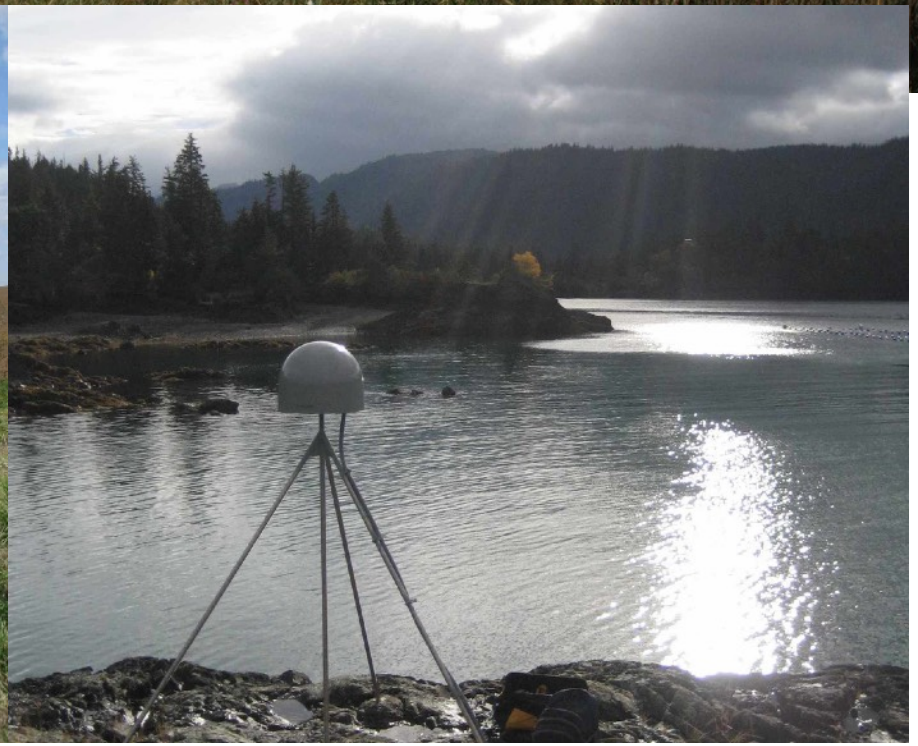
2023 GNSS-IR short course
Snow Accumulation



In the first hour

- We will focus on snow - both what I will call “seasonal snow” and snow accumulation on ice sheets.
- Both rely on measuring the reflector height RH, which is a primary output of gnssrefl.
- Please keep in mind that while we concentrate on RH, the amplitude of that retrieval also has information and is available to you should you want to investigate further.
- Unlike other *in situ* sensors, GNSS-IR measures a “large” footprint.
- We generally focus here on daily averages.

Good, Bad, Complex

- Snow on ice:
  - Good thing: rare to find buildings in Antarctica and Greenland that will obstruct your reflected signals (though it does happen)
  - Good thing: fairly traditional sampling intervals (15-30 seconds) usually work.
  - Good or bad thing: interpretation can be complex
- Seasonal snow:
  - Complicated: you have four kinds of surfaces: bare soil, bare soil with vegetation, new snow, compacted snow.
  - It does not directly measure SWE, which is generally the preferred quantity. SWE model is available to be ported.
  - Bad thing: Civilization

- If you are interested in measuring snow accumulation on ice, then you probably already know more than I do about ice sheets.
- Look to the published papers on this for information about what RH means on an ice sheet.
- You will likely need to think about compaction.
- Remember that this is a GNSS receiver - so you have access to *precise positioning* as well as GNSS-IR.

Constraints on snow accumulation and firn density in Greenland using GPS receivers

Kristine M. LARSON,[1] John WAHR,[2] Peter KUIPERS MUNNEKE[3]

GPS-derived estimates of surface mass balance and ocean-induced basal melt for Pine Island Glacier ice shelf, Antarctica

David E. Shean[1,2], Knut Christianson[3], Kristine M. Larson[4], Stefan R. M. Ligtenberg[5], Ian R. Joughin[1], Ben E. Smith[1], C. Max Stevens[3], Mitchell Bushuk[6], and David M. Holland[7,8]

Brief Communication: Update on the GPS reflection technique for measuring snow accumulation in Greenland

Kristine M. Larson[1], Michael MacFerrin[2], and Thomas Nylen[3]

Long-Term Snow Height Variations in Antarctica from GNSS Interferometric Reflectometry

by Elisa Pinat [1,*], Pascale Defraigne [1], Nicolas Bergeot [1,2], Jean-Marie Chevalier [1,2] and Bruno Bertrand [1]

Snow accumulation variability on a West Antarctic ice stream observed with GPS reflectometry, 2007–2017

M. R. Siegfried[1,2], B. Medley[3], K. M. Larson[4], H. A. Fricker[1], and S. Tulaczyk[5]

- Seasonal snow:
  - PBO H2O worked on this.
  - We computed snow depth and SWE for 250 sites for almost a decade. https://gnss-reflections.org/maps
  - We compared snow RH with “bare soil” RH.

Can we measure snow depth with GPS receivers?

Kristine M. Larson,[1] Ethan D. Gutmann,[2] Valery U. Zavorotny,[3] John J. Braun,[4] Mark W. Williams,[5] and Felipe G. Nievinski[1]

GPS snow sensing: results from the EarthScope Plate Boundary Observatory

Kristine M. Larson · Felipe G. Nievinski

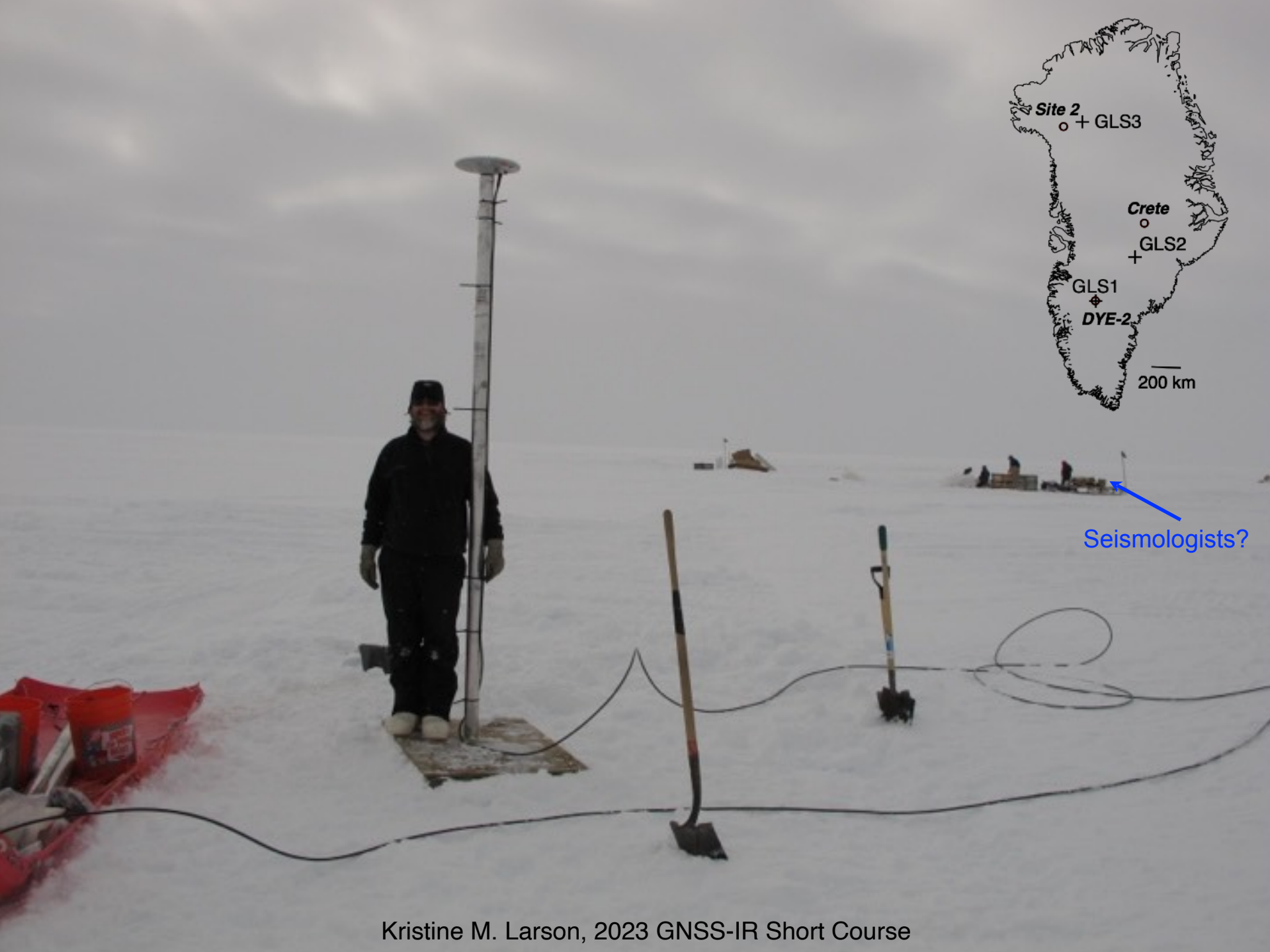
Snow depth, density, and SWE estimates derived from GPS reflection data: Validation in the western U. S.

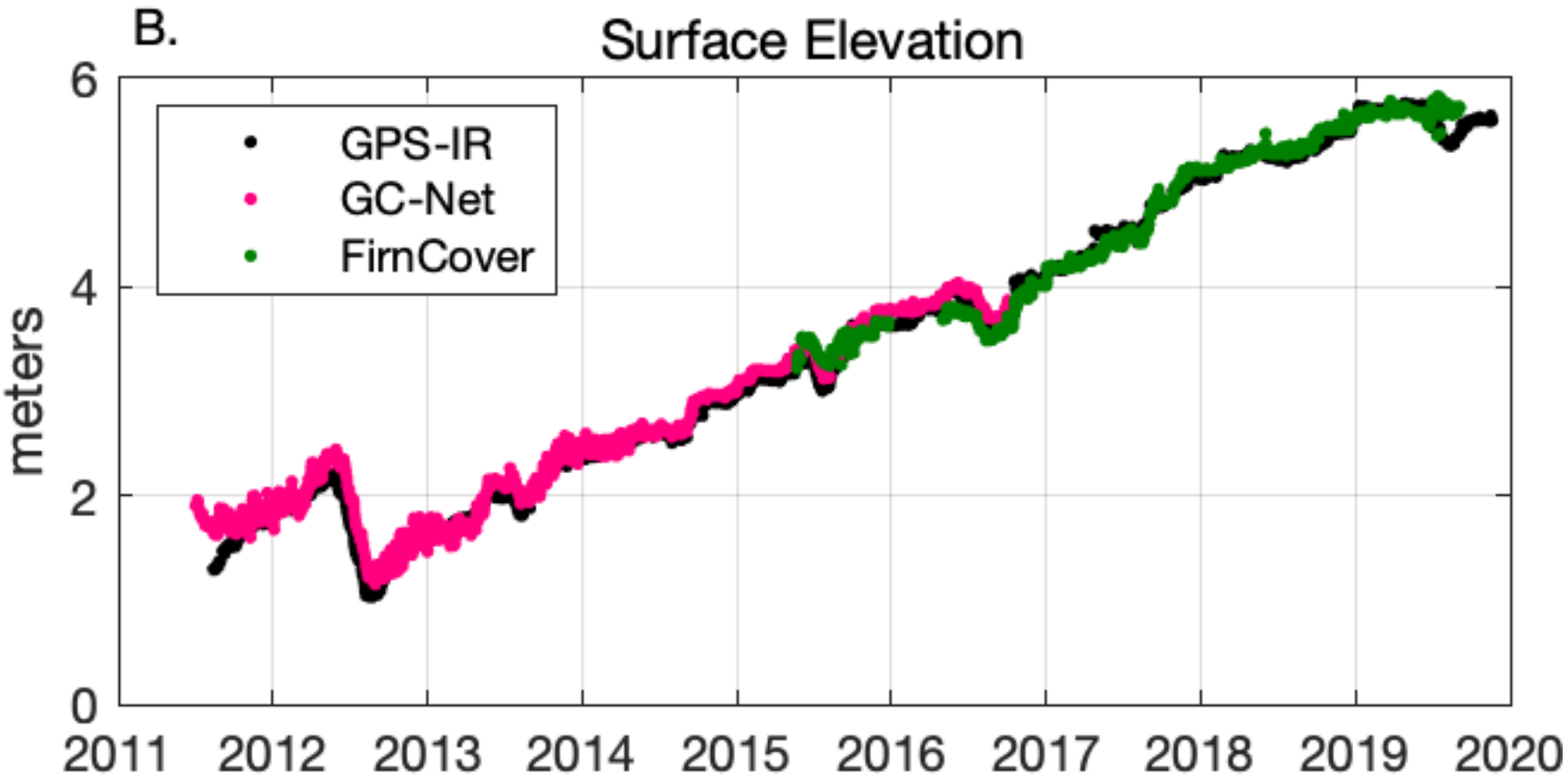
James L. McCreight[1], Eric E. Small[2], and Kristine M. Larson[1]

Inverse Modeling of GPS Multipath for Snow Depth Estimation—Part II: Application and Validation

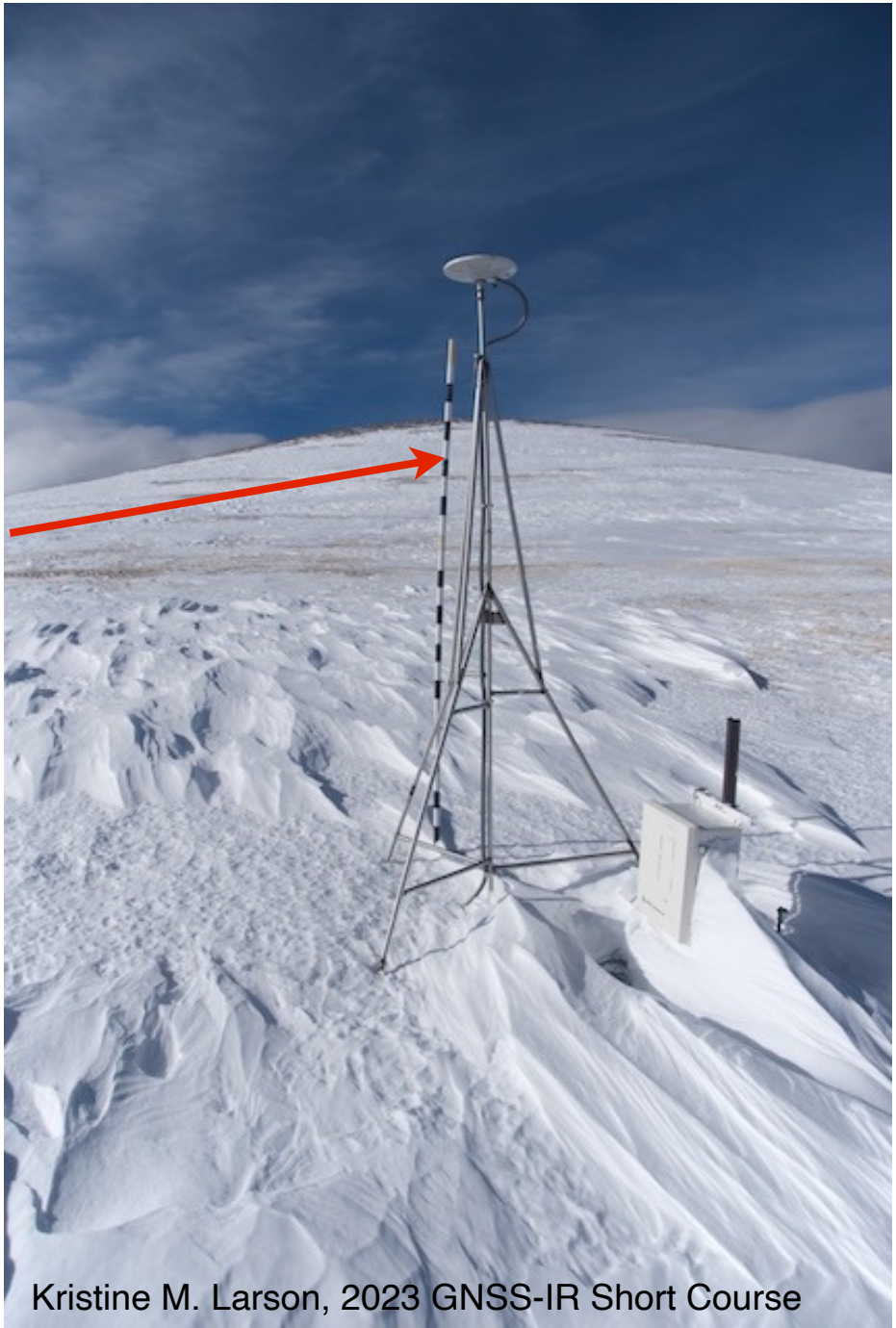
Felipe G. Nievinski and Kristine M. Larson

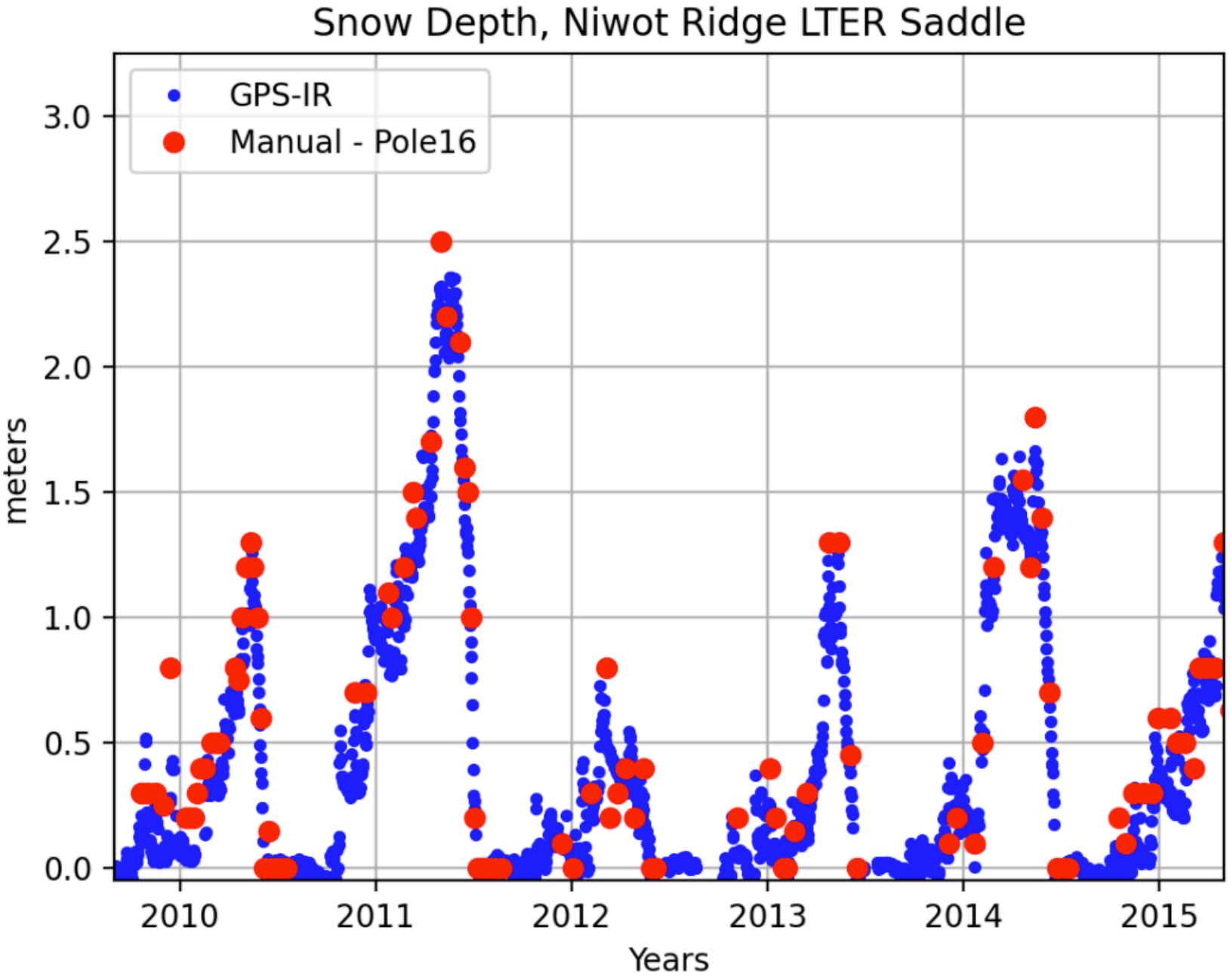
Does it work?


Site 2
GLS3
Crete
GLS2
GLS1
DYE-2
200 km
Seismologists?


B.
Surface Elevation
GPS-IR
GC-Net
FirnCover
meters
0
2
4
6
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

pole 16




Snow Depth, Niwot Ridge LTER Saddle
GPS-IR
Manual - Pole16
meters
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2010
2011
2012
2013
2014
2015
Years