GNSS and Environmental Sensing

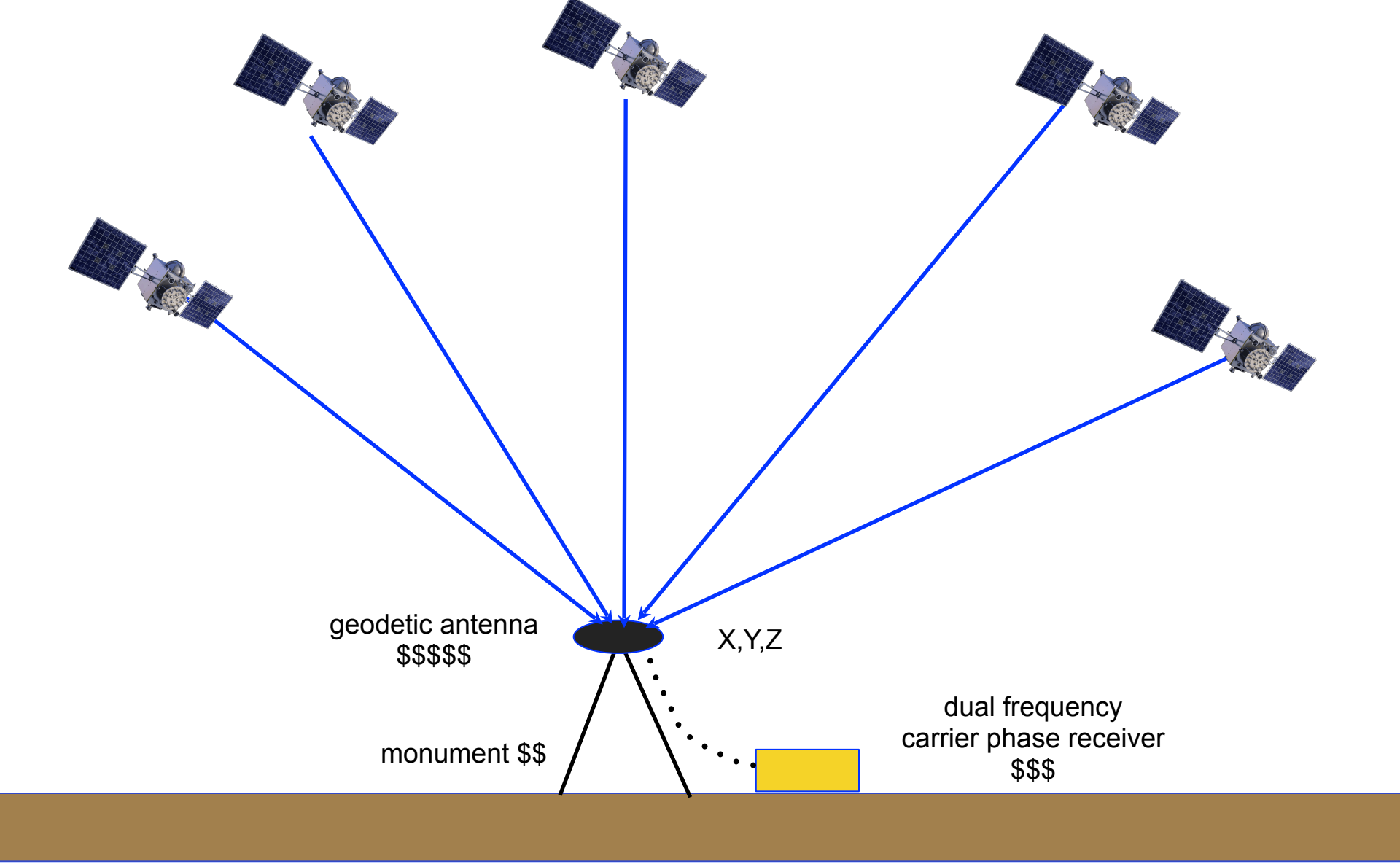
Kristine M. Larson

Professor Emerita

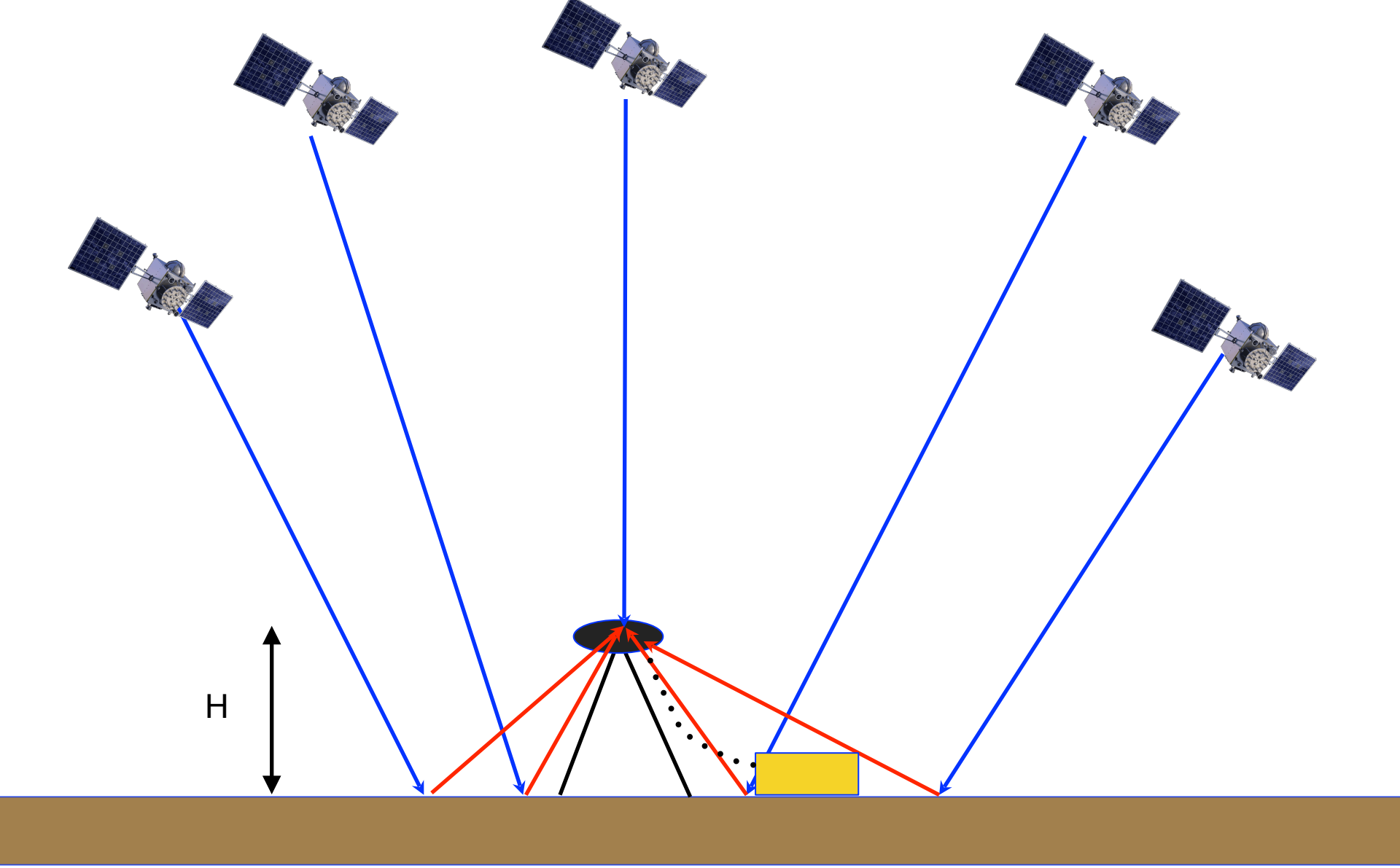
University of Colorado, Boulder

Outline

- Environmental Sensing with GNSS Interferometric Reflectometry (GNSS-IR)
- What can you do with GNSS-IR?
- New work

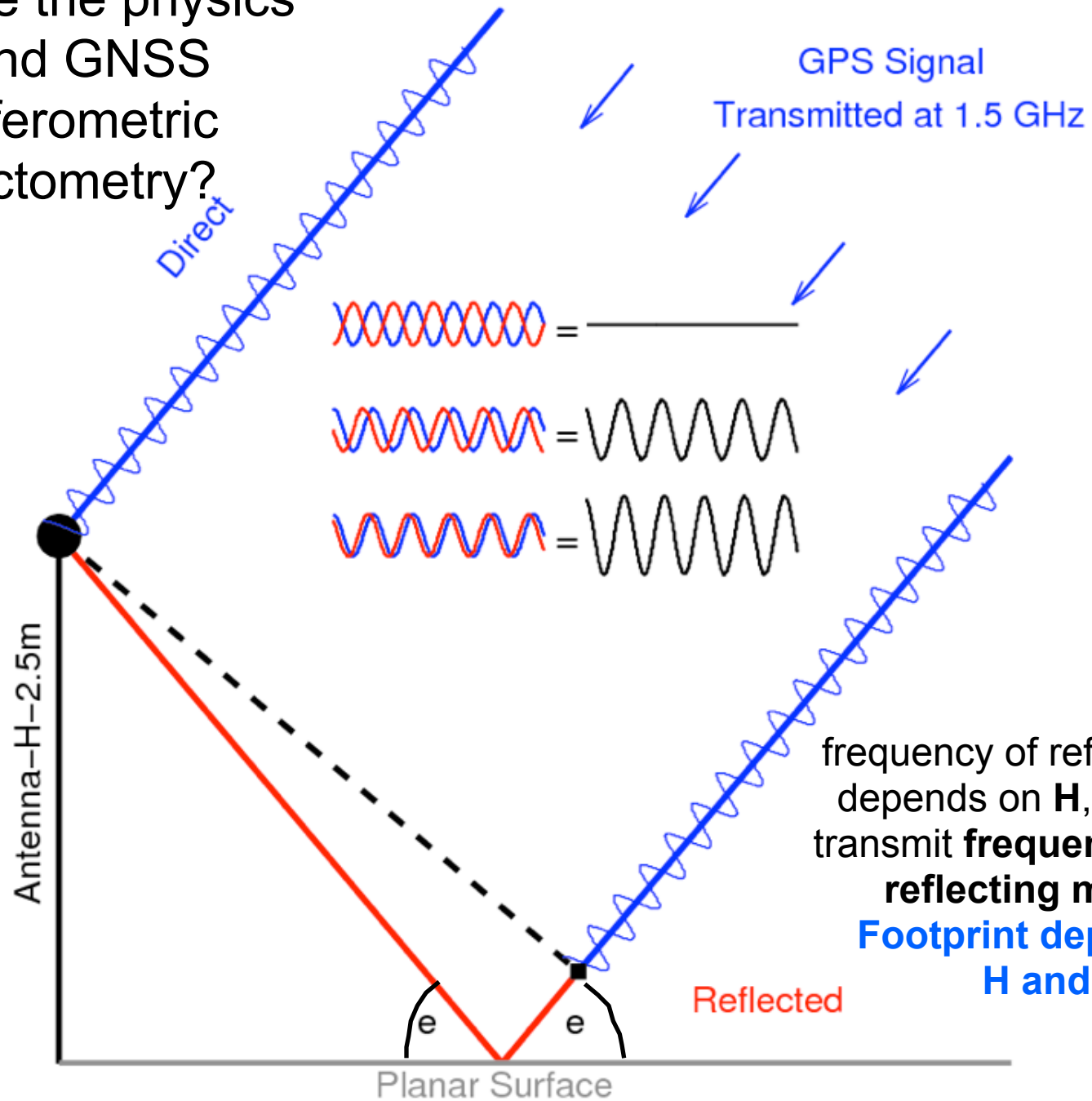


How I thought about GPS when I was a geodesist



How a reflections person sees the world

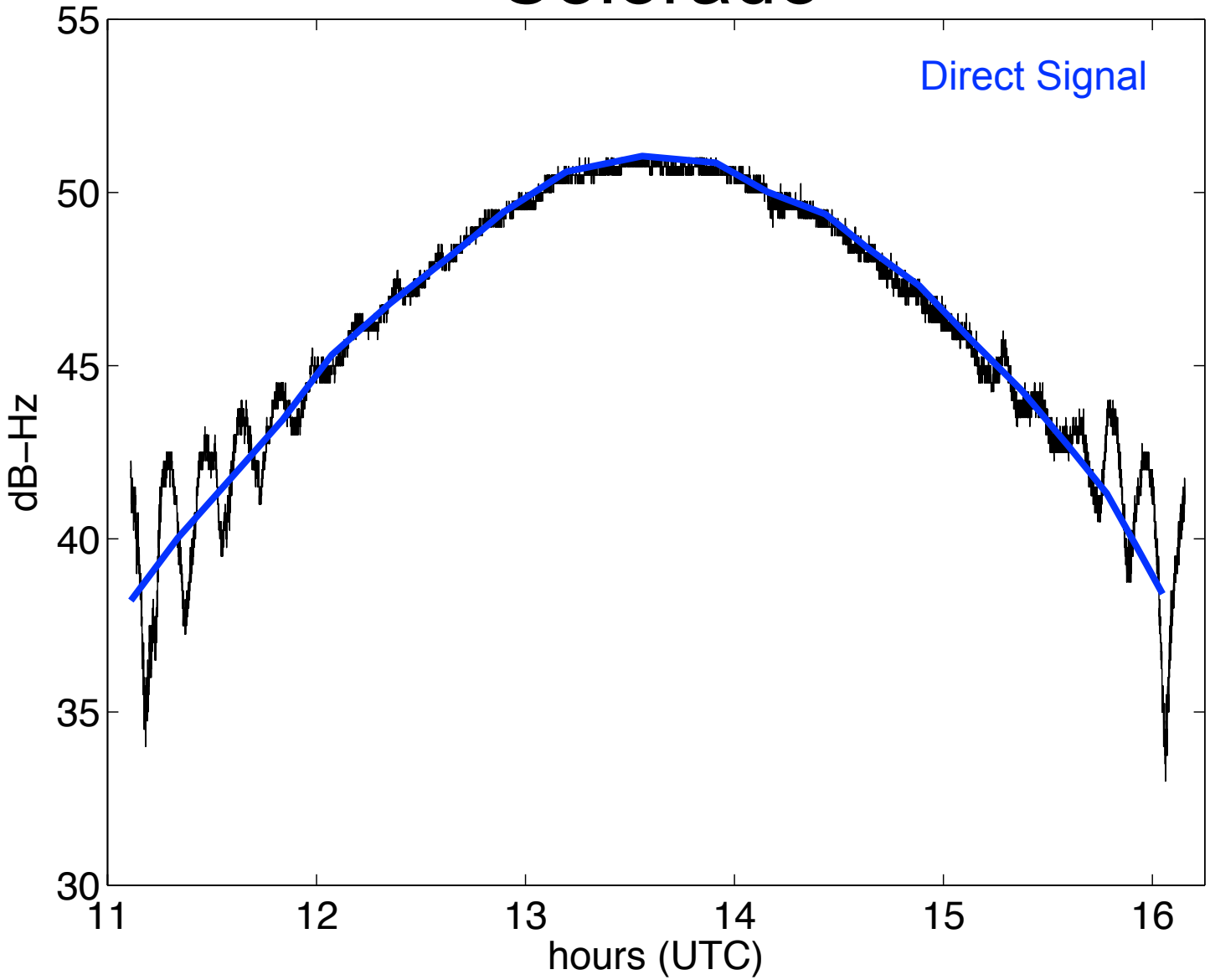
What are the physics behind GNSS interferometric reflectometry?



frequency of reflection data depends on **H**, the GNSS transmit **frequency**, and the **reflecting medium.**

Footprint depends on H and e.

L2C SNR data for Marshall, Colorado



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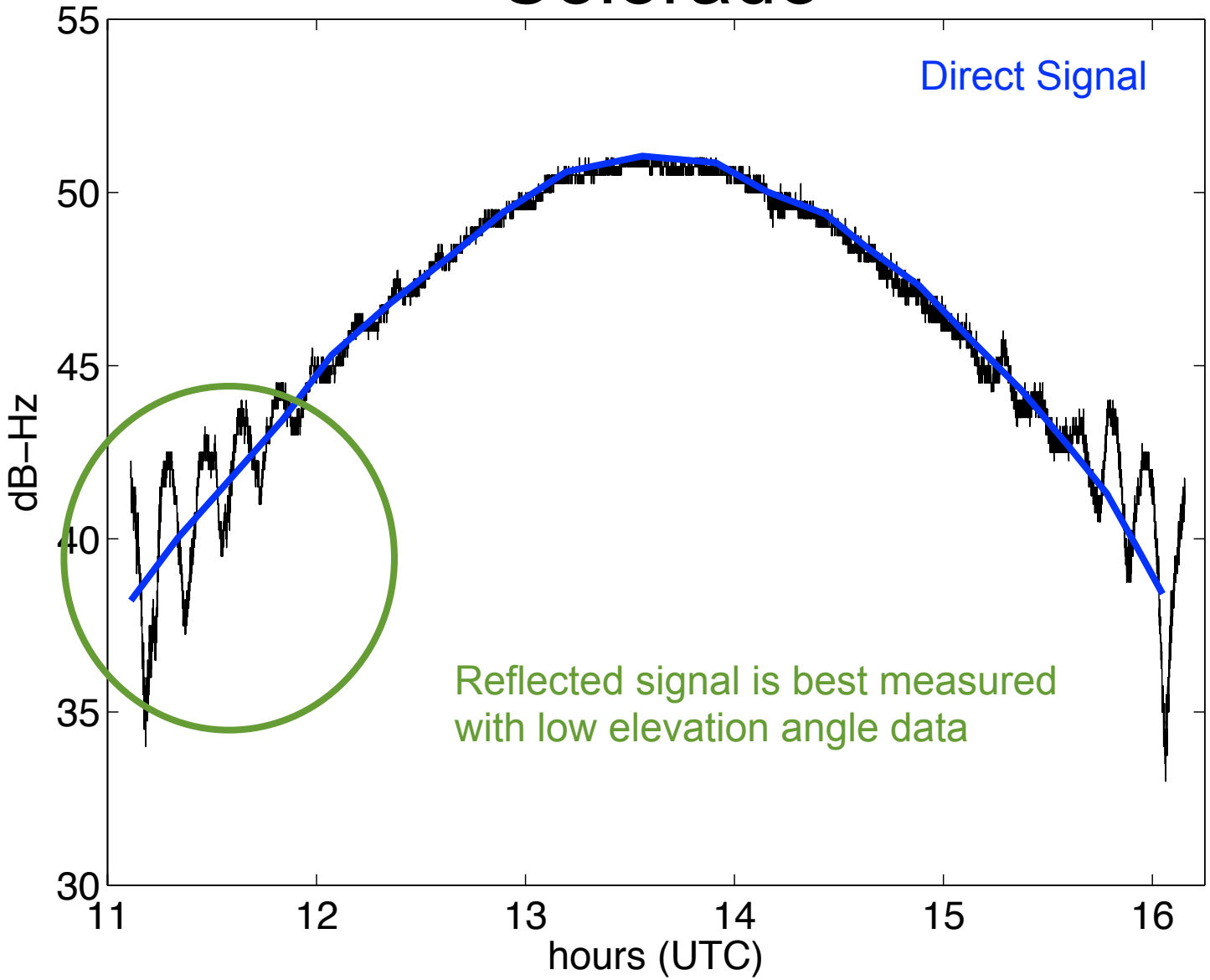

Why would you want to measure environmental signals with GNSS receivers?

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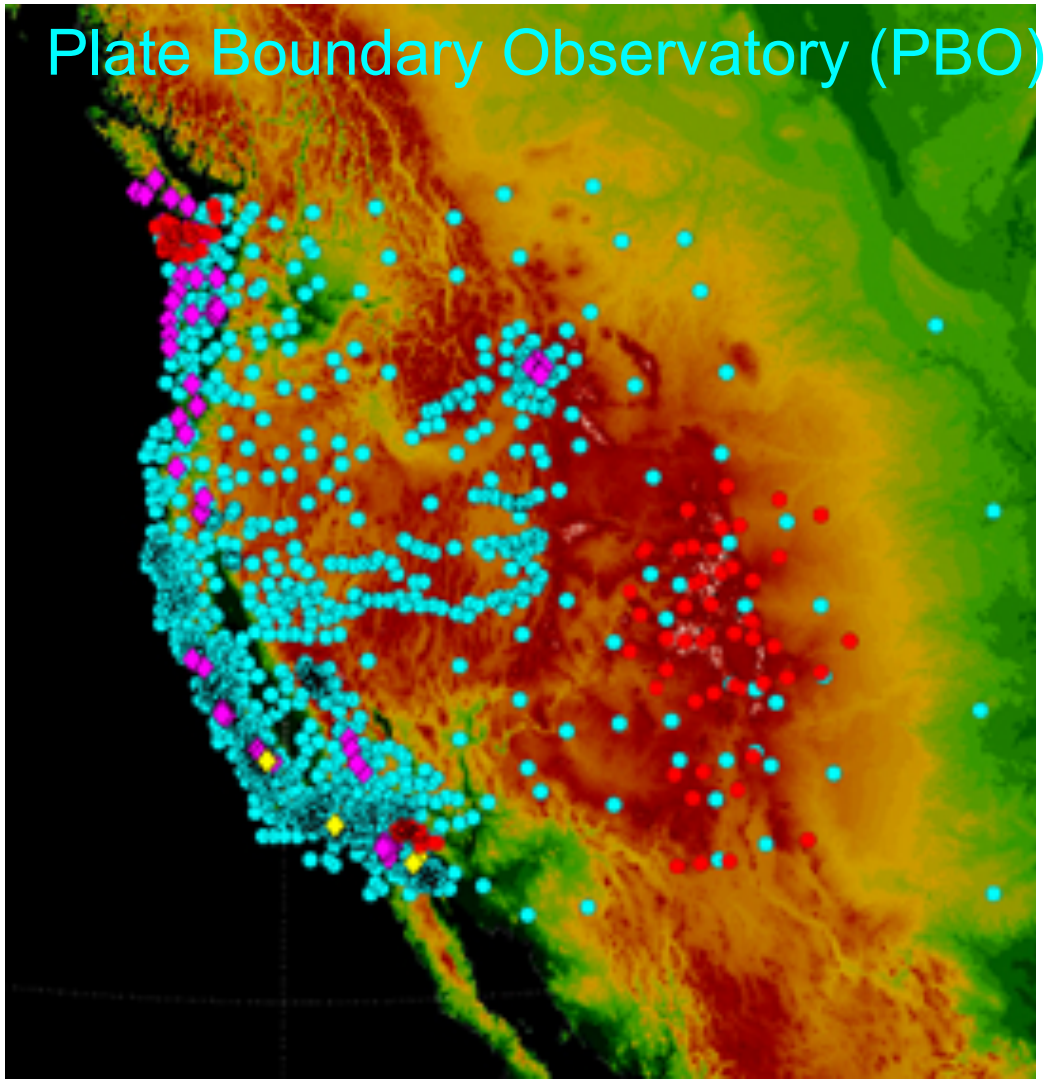
- Satellites have very large footprints (and don't work well in some conditions).
- GNSS data are very "inexpensive."
- Ground sensors are needed both for assimilation and satellite validation.

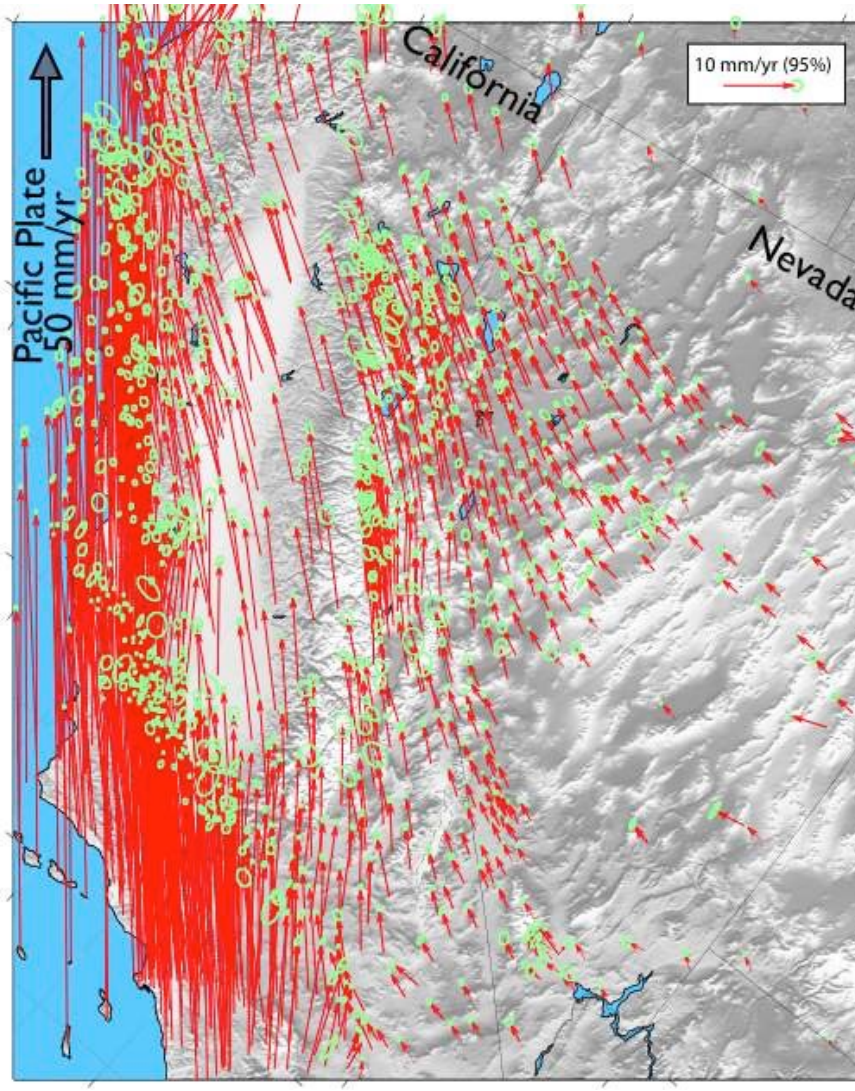
First Applications: Terrestrial Hydrology

- soil moisture: land-atmosphere interactions; runoff and infiltration; plant productivity.
- snow: timing and amount of runoff; influences climate.
- above-ground biomass: global carbon budget; influences climate.

Testing GNSS interferometric reflectometry

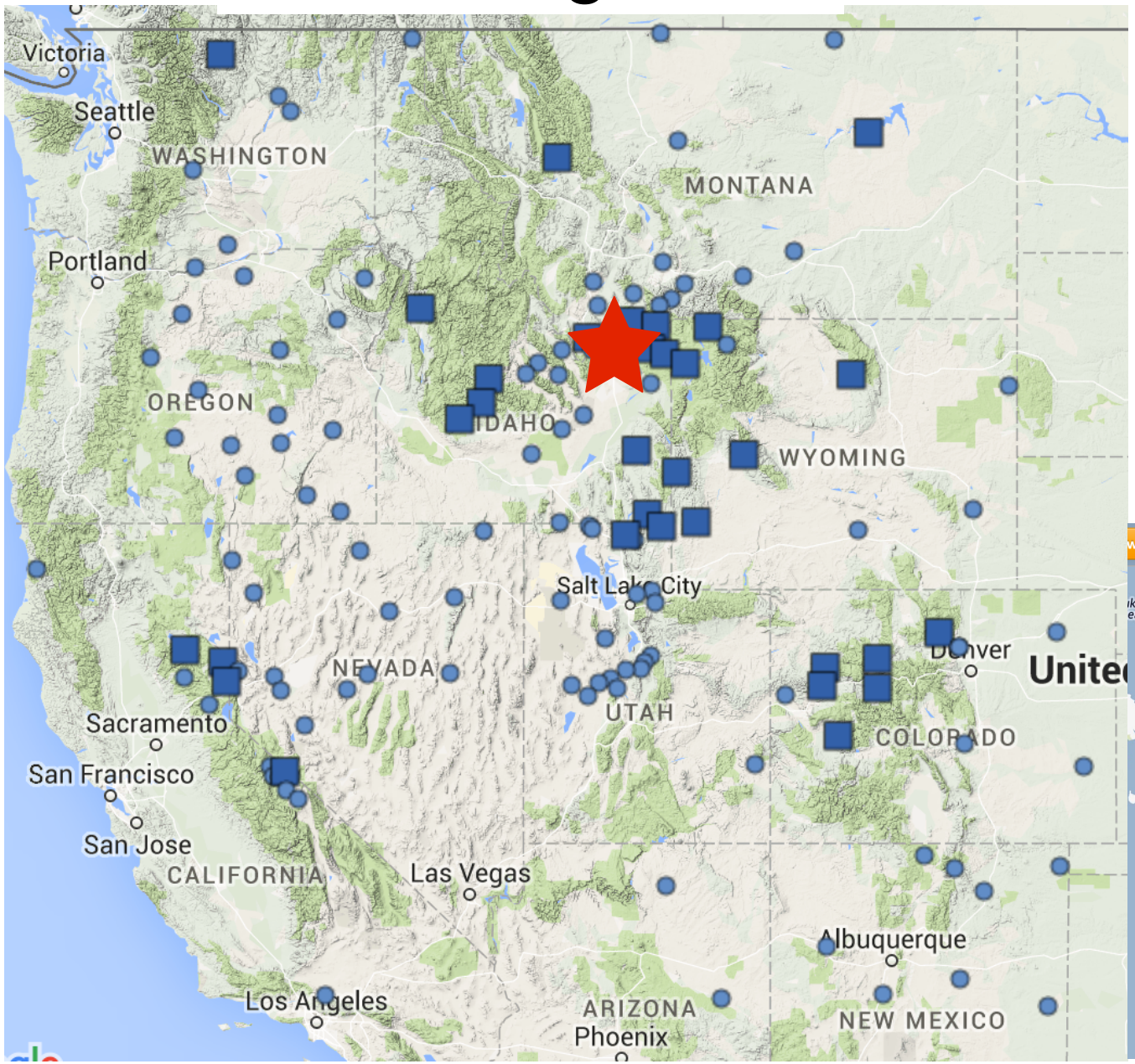


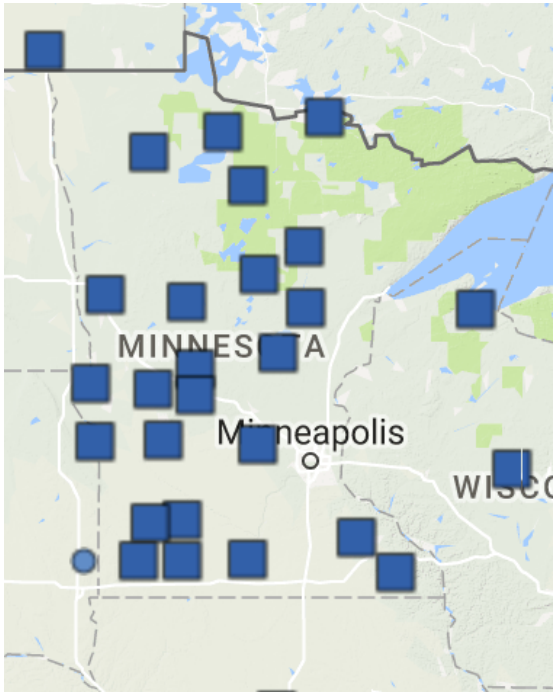
+150 stations in Alaska

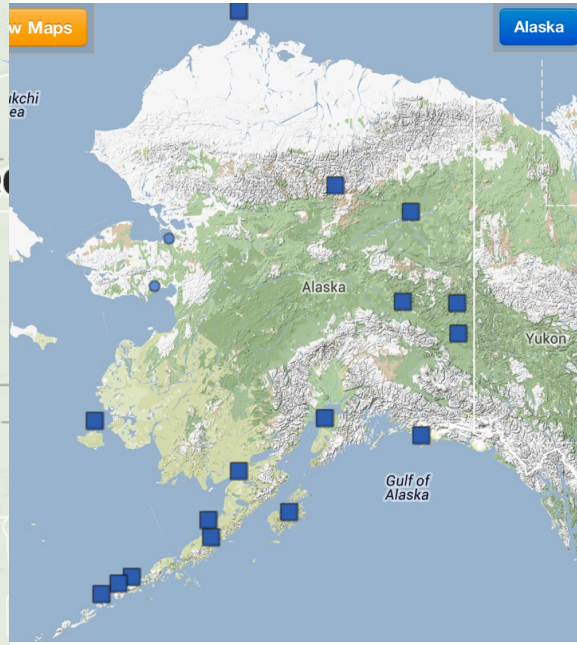


Source: Bill Hammond

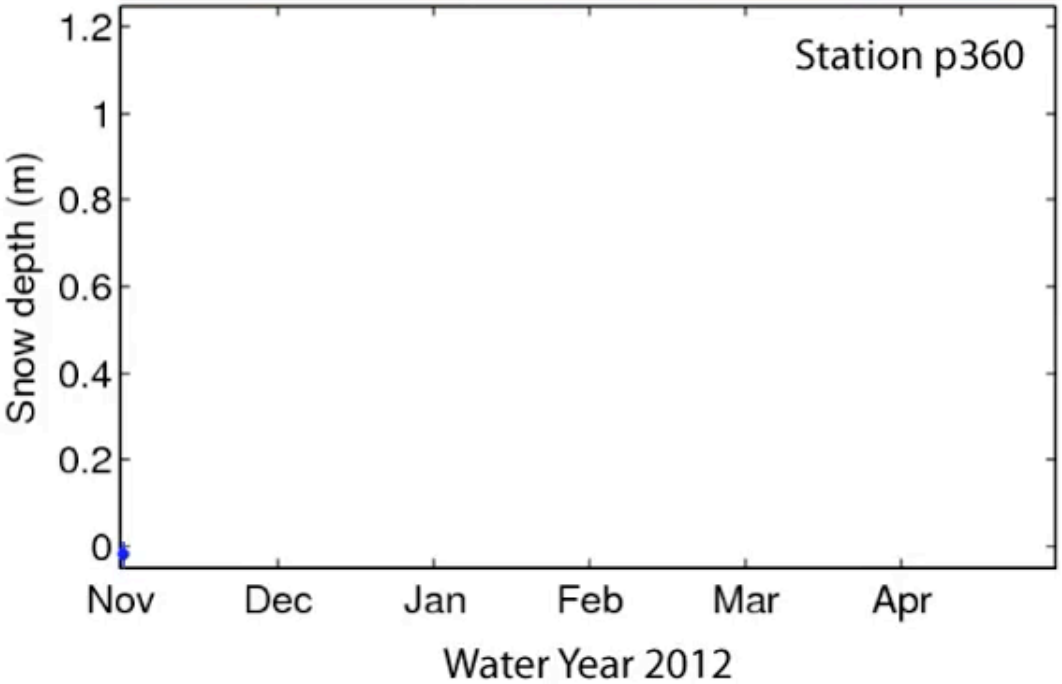
Monitoring Snow

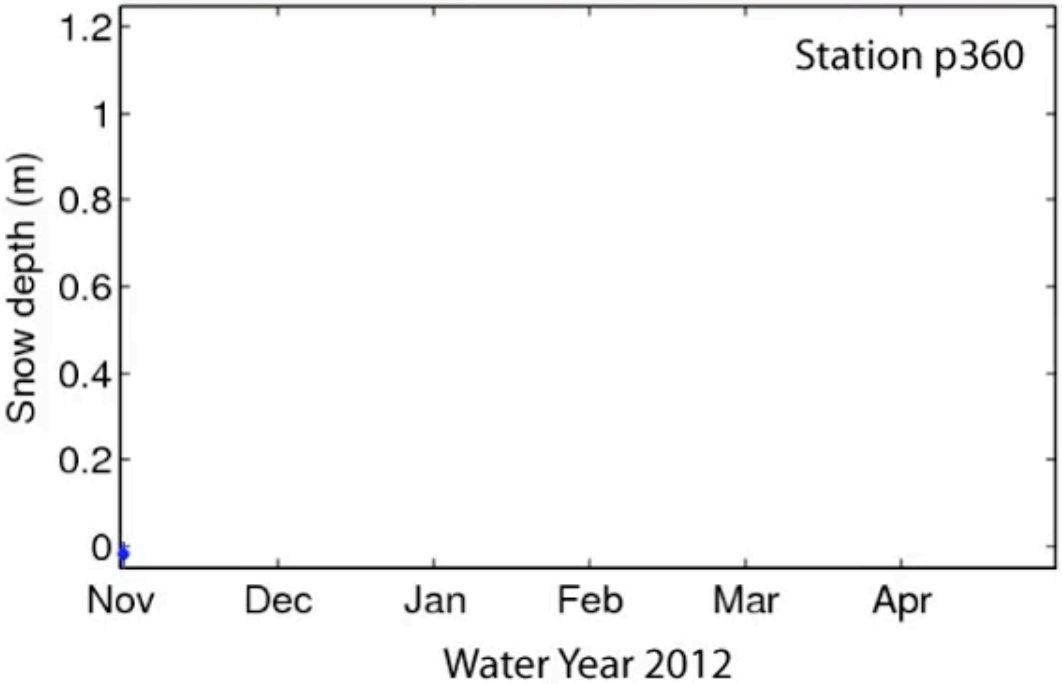






Installed a camera to take a picture of this stick every day


Station p360
Snow depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
Nov
Dec
Jan
Feb
Mar
Apr
Water Year 2012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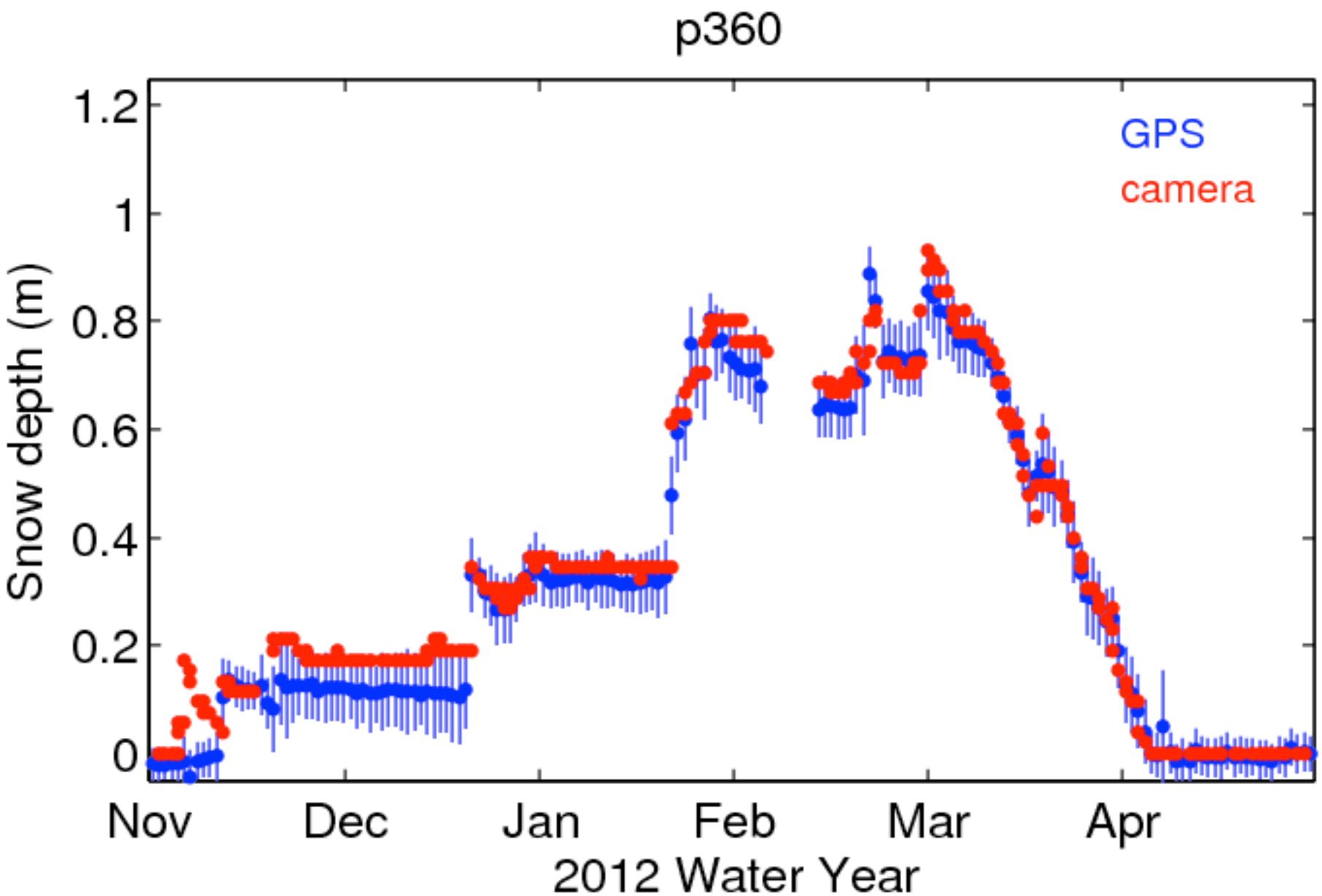
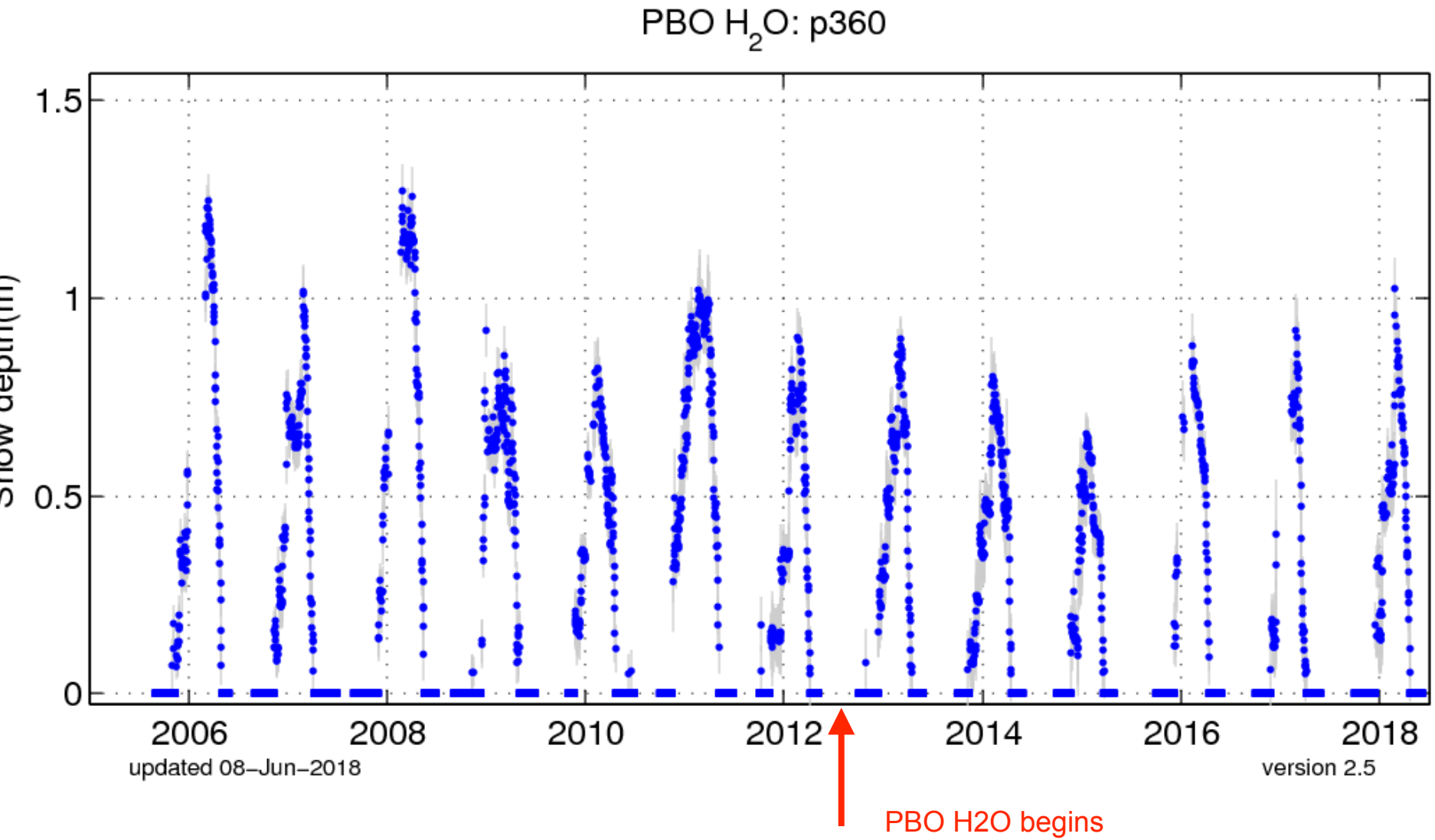
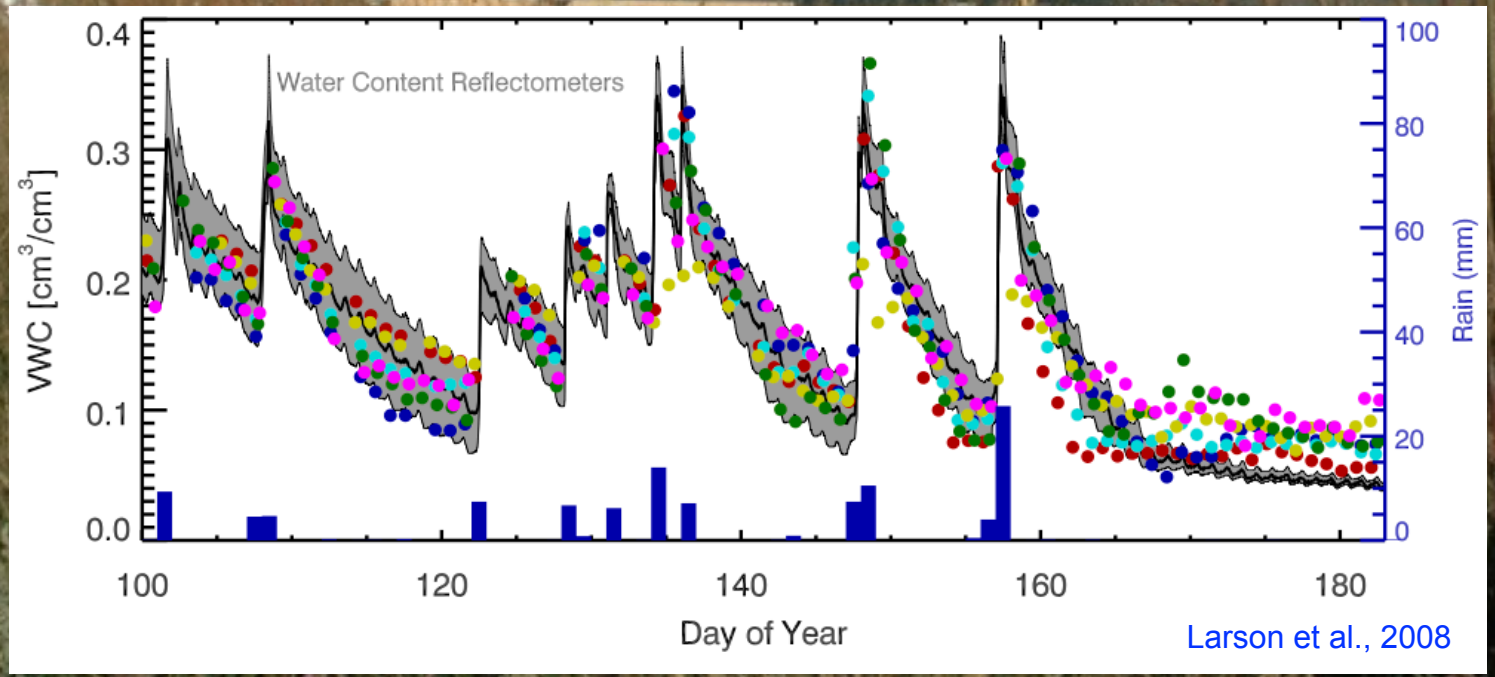

p360
GPS
camera
Snow depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
Nov
Dec
Jan
Feb
Mar
Apr
2012 Water Year

Snow Climatology



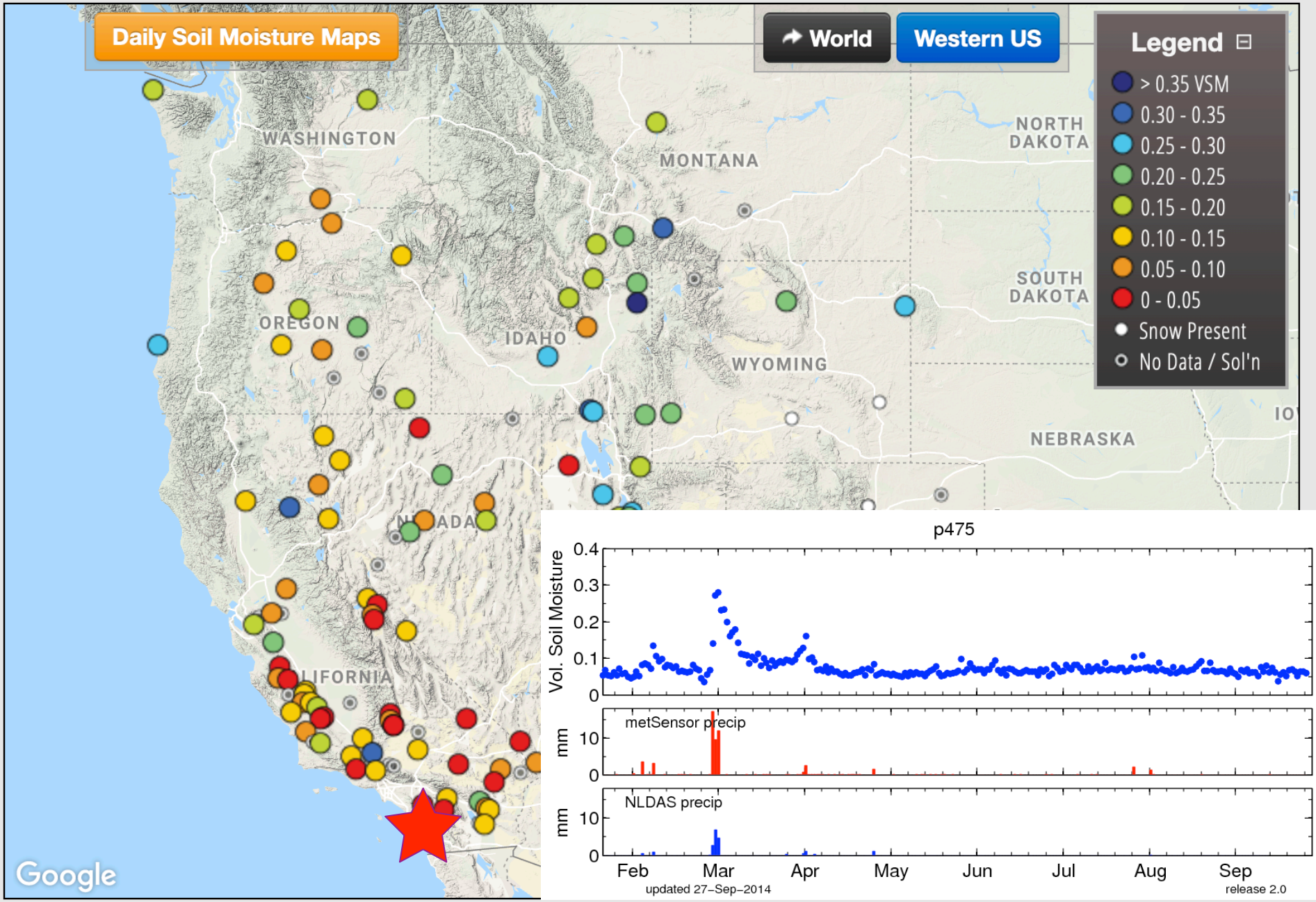
Soil Moisture



Larson et al., 2008

Soil Moisture

Browse Stations



Soil Moisture

Browse Stations

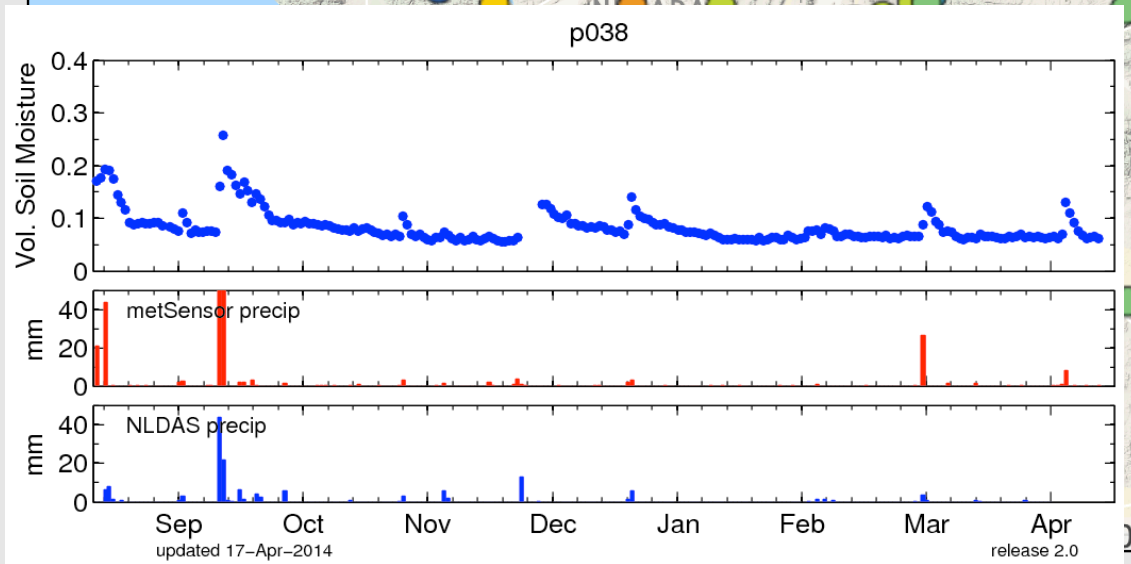
Daily Soil Moisture Maps

World | Western US

Legend

- > 0.35 VSM
- 0.30 - 0.35
- 0.25 - 0.30
- 0.20 - 0.25
- 0.15 - 0.20
- 0.10 - 0.15
- 0.05 - 0.10
- 0 - 0.05
- Snow Present
- No Data / Sol'n

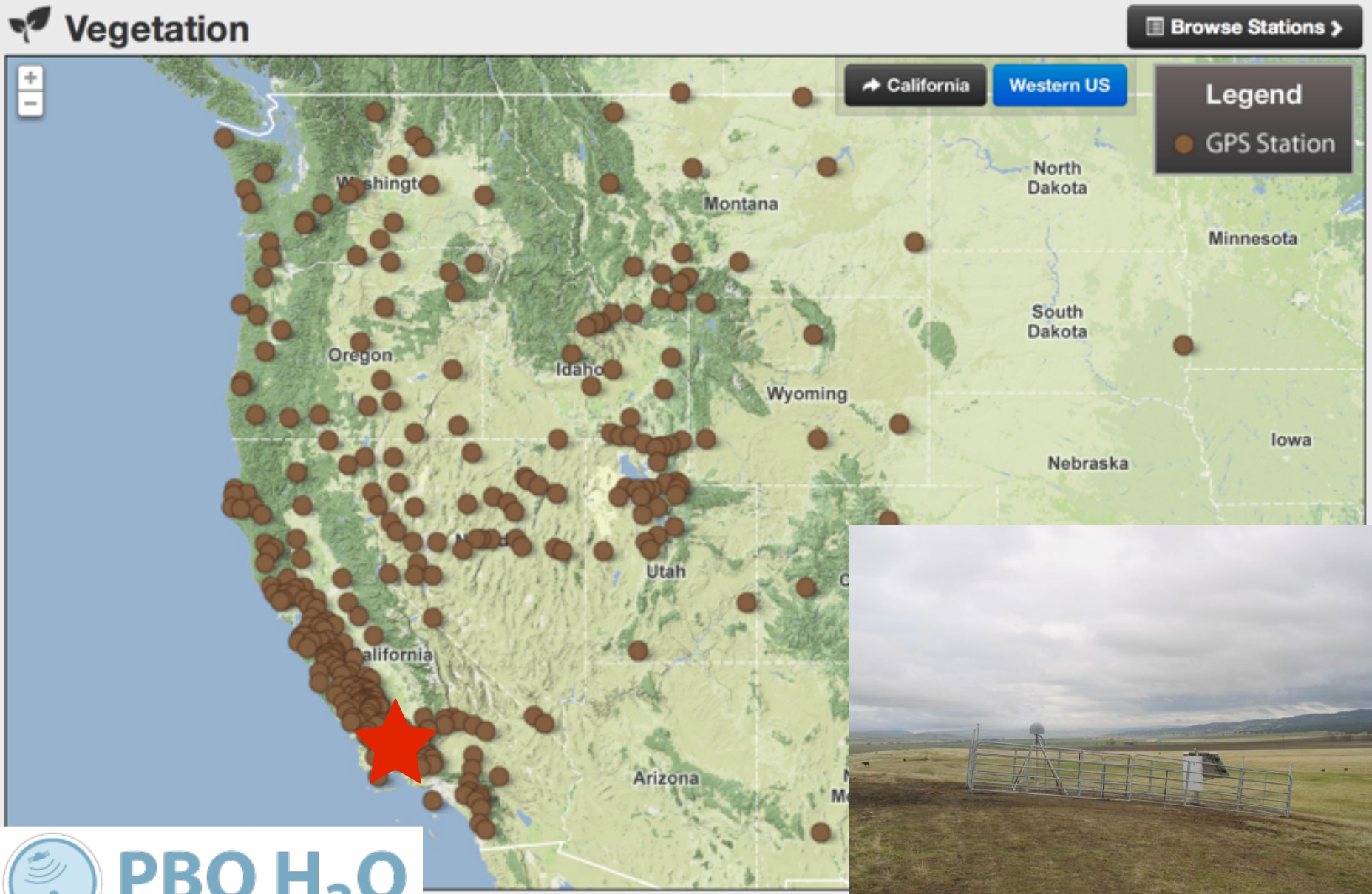
WASHINGTON
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
OREGON
IDAHO
WYOMING
NEBRASKA
United States
COLORADO
KANSAS
OKLAHOMA
NEW MEXICO



Graphs

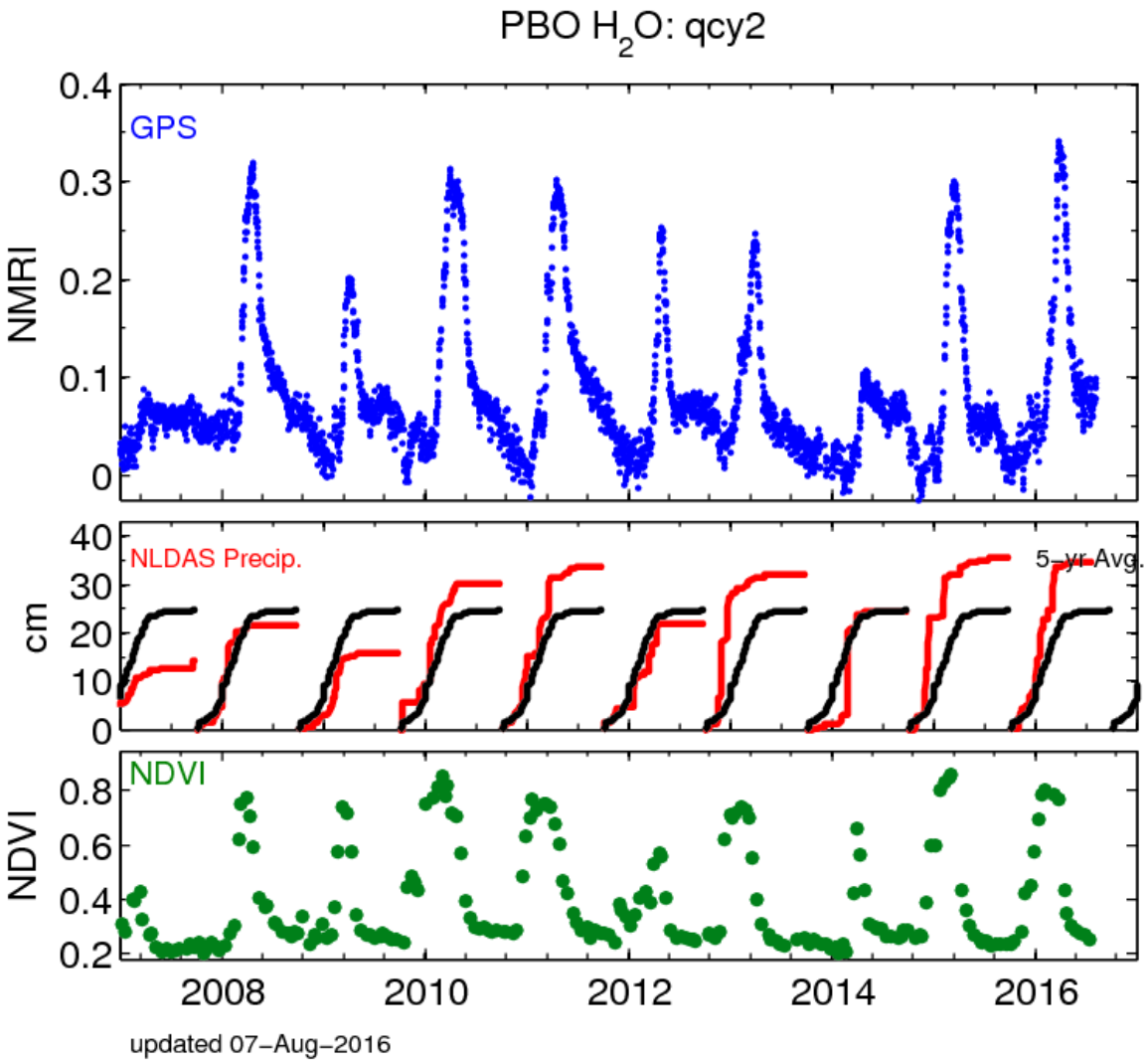
200 km

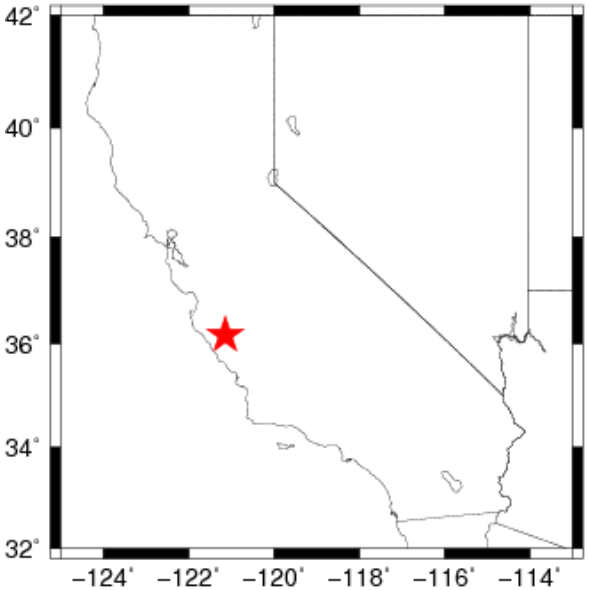
Monitoring Vegetation



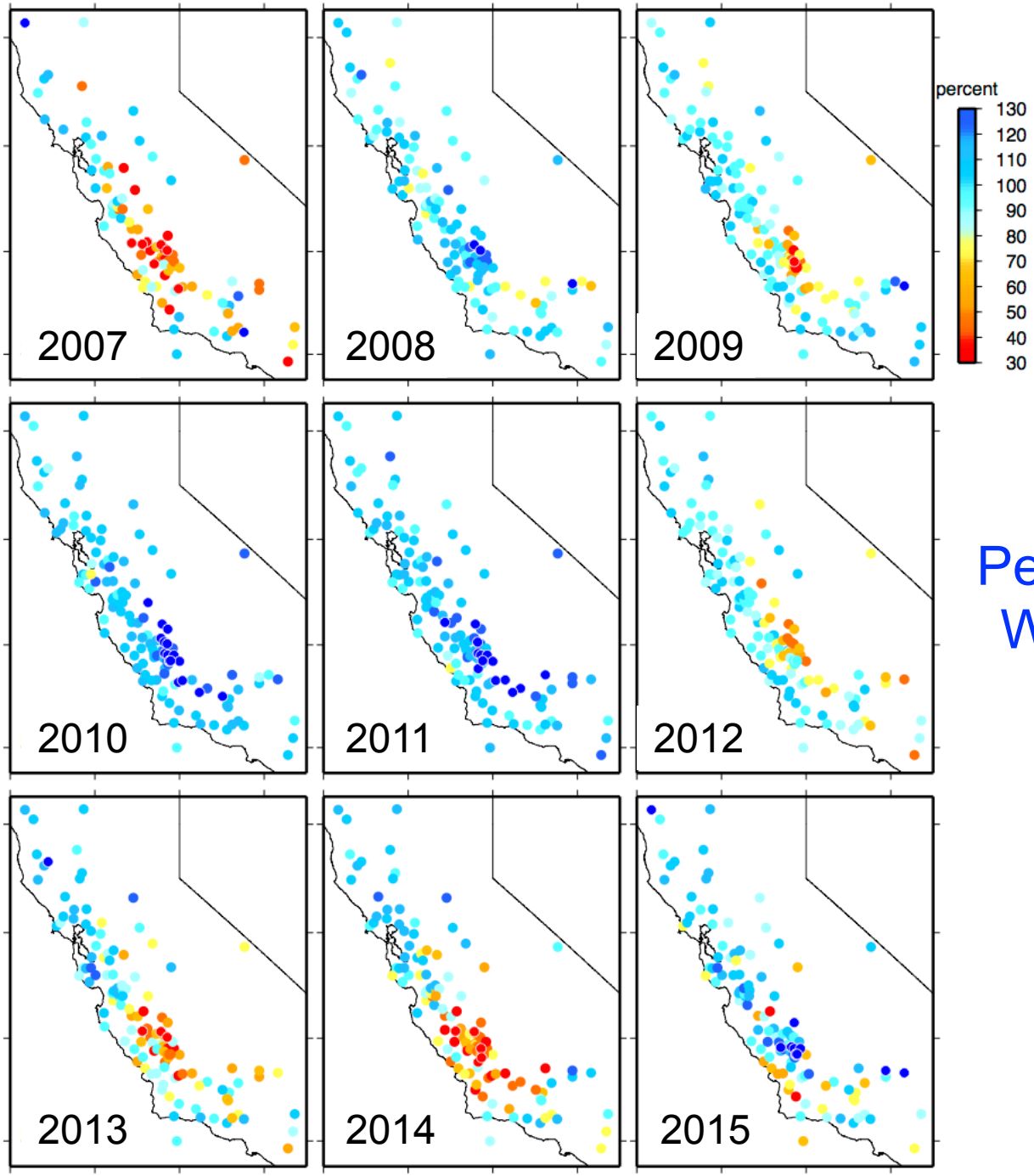
PBO H_2O

Vegetation Water Content





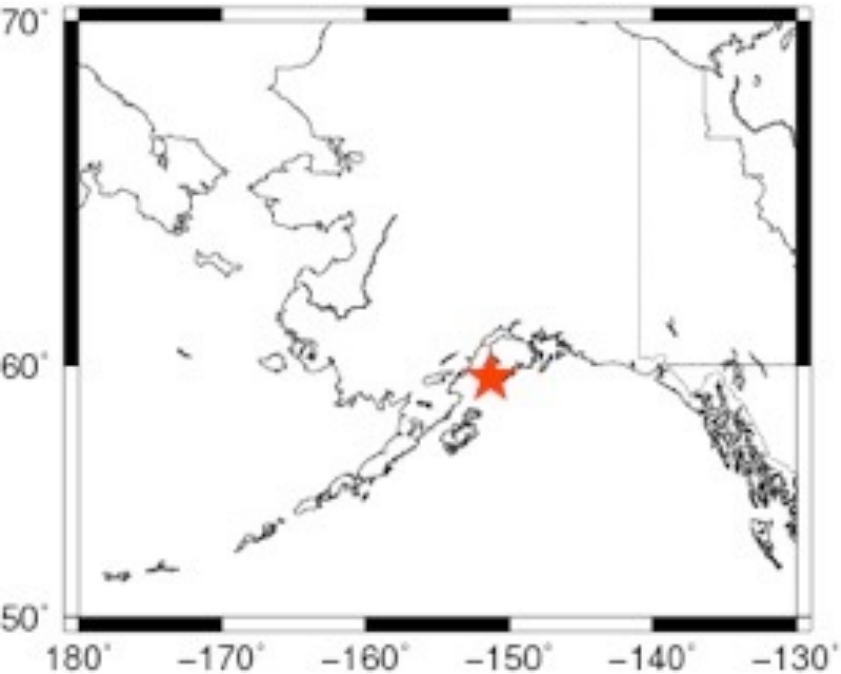
PBO H_2O Peak Vegetation Water Content Normalized by 2008–2012 Average



Normalized Peak Vegetation Water Content

More details:
Small et al.,
Remote Sensing, 2018

Sea Surface



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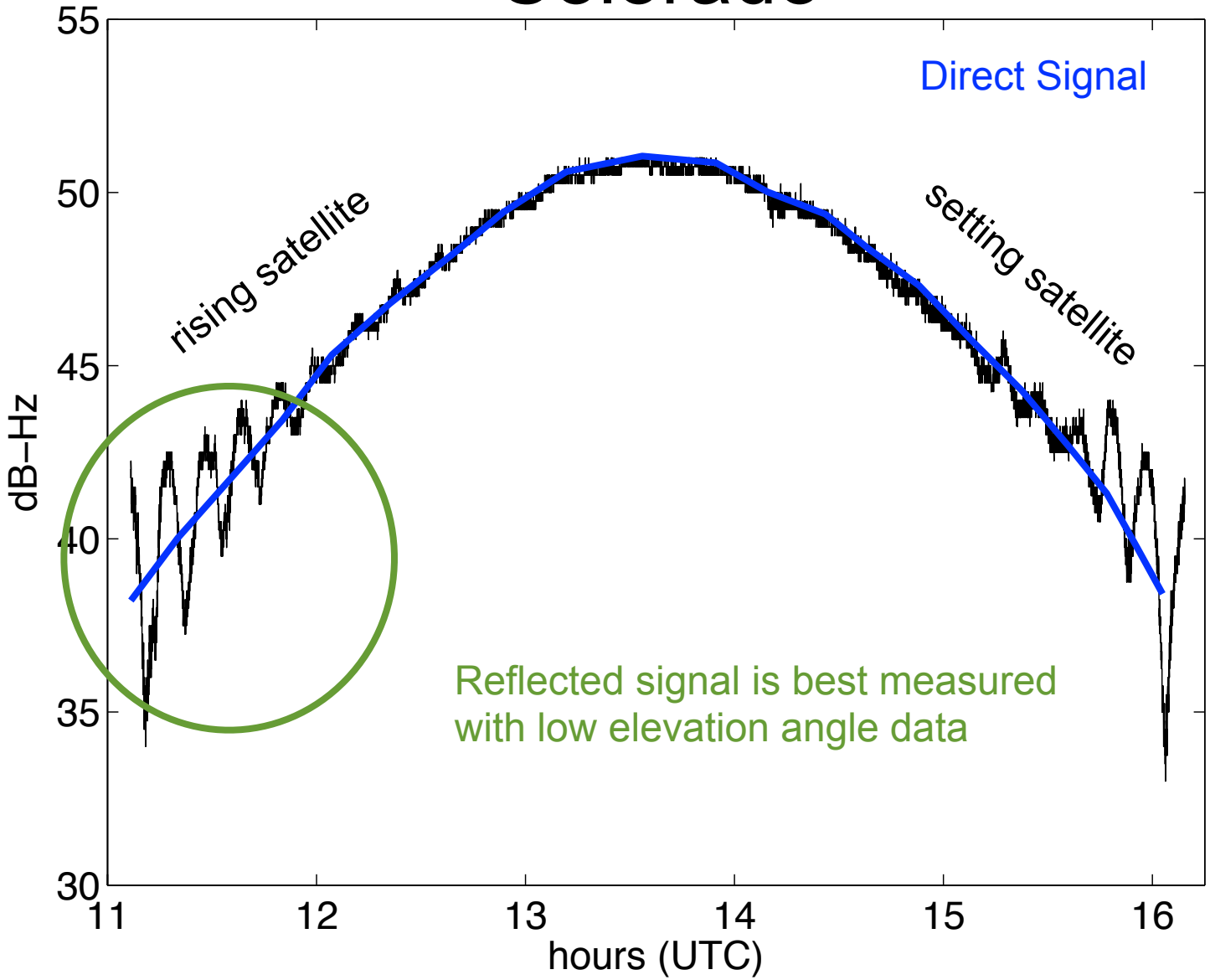
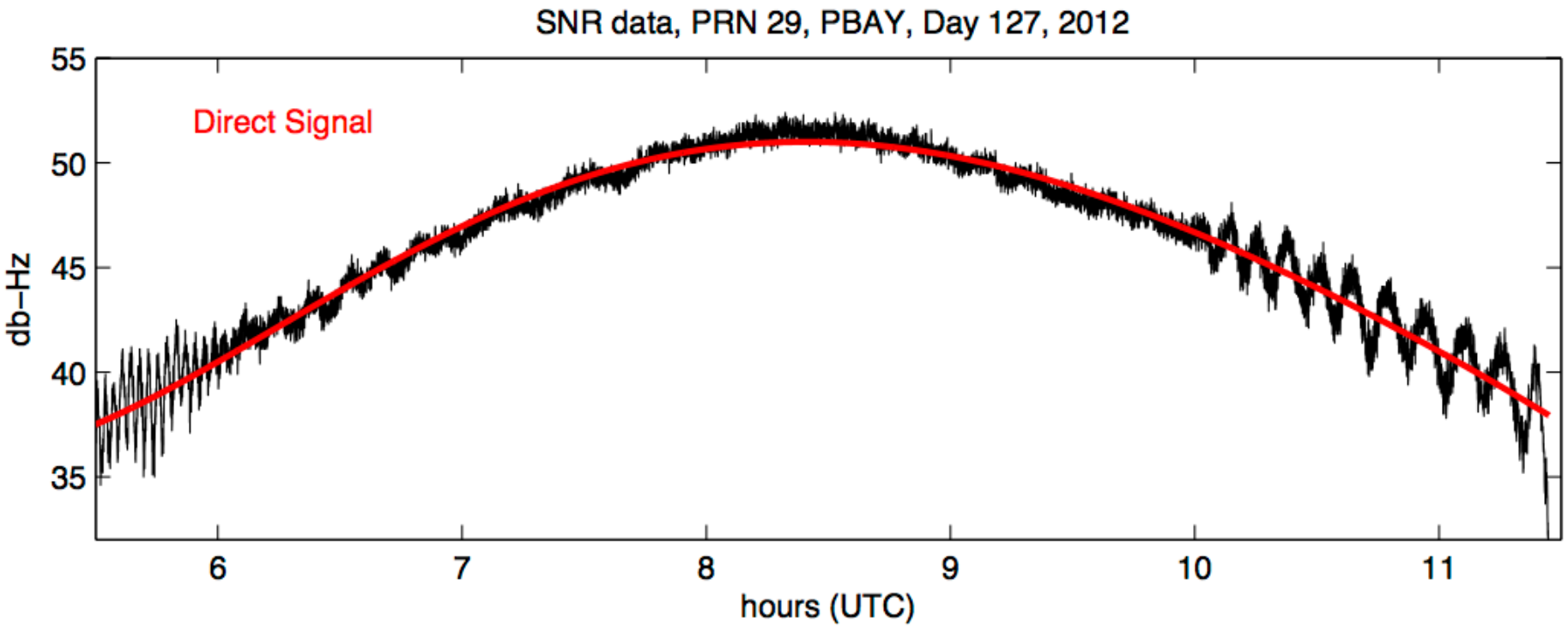


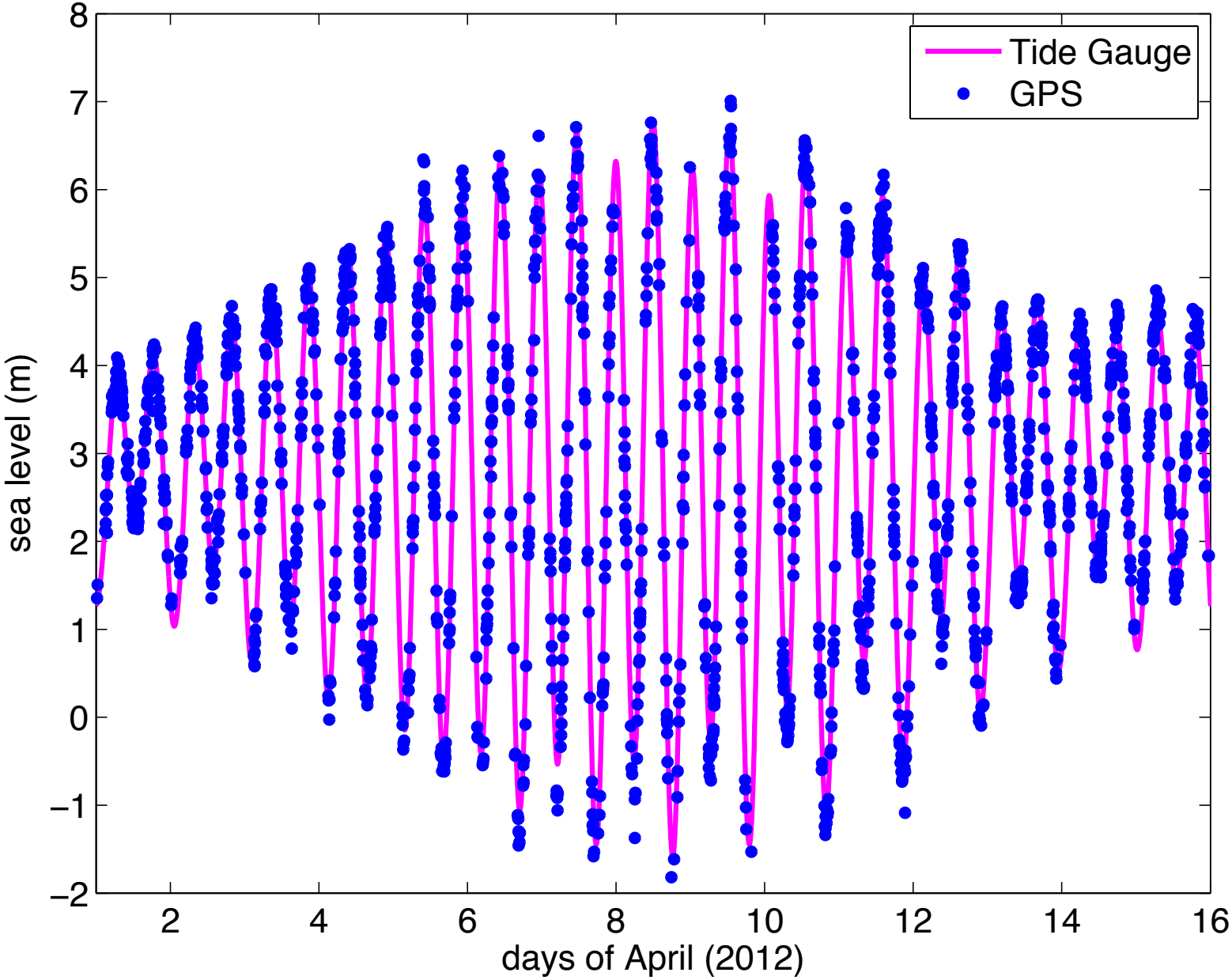
Kachemak Bay, Alaska



Low Tide

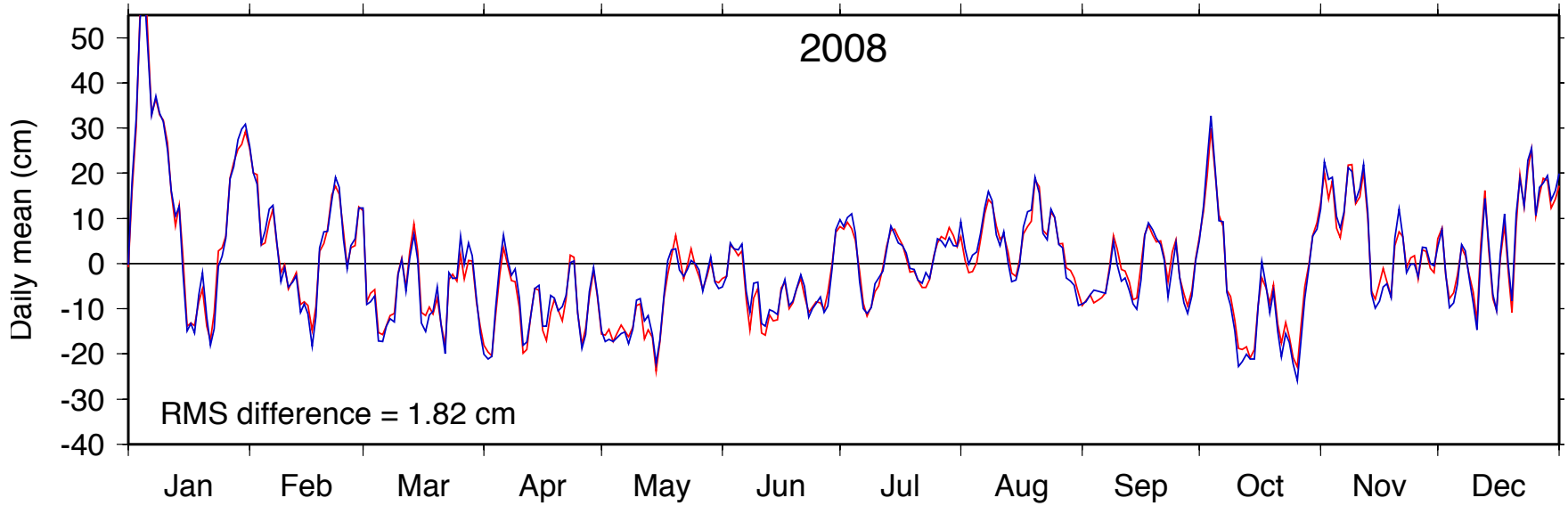
High Tide

Comparison between GPS and 'Real' Tide Gauge

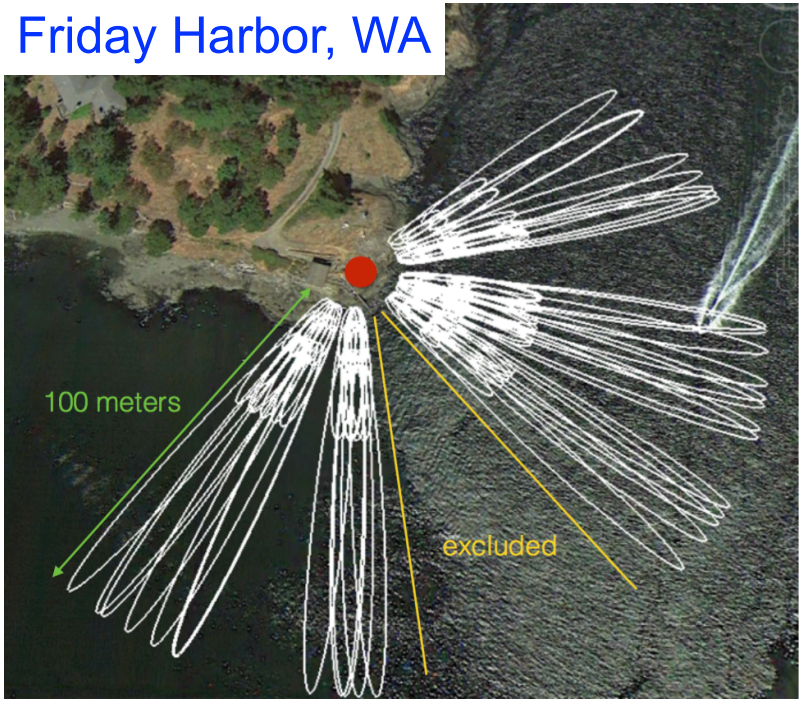


Larson, Ray, Nievinski, and Freymueller, The Accidental Tide Gauge, *IEEE GRSL*, 2013

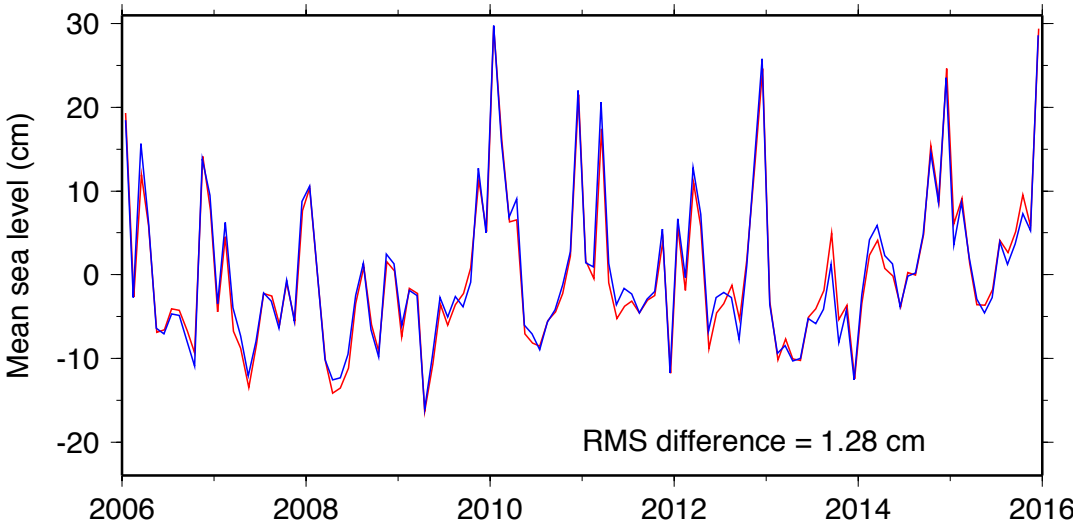
Daily Comparison with NOAA tide gauge



Friday Harbor, WA

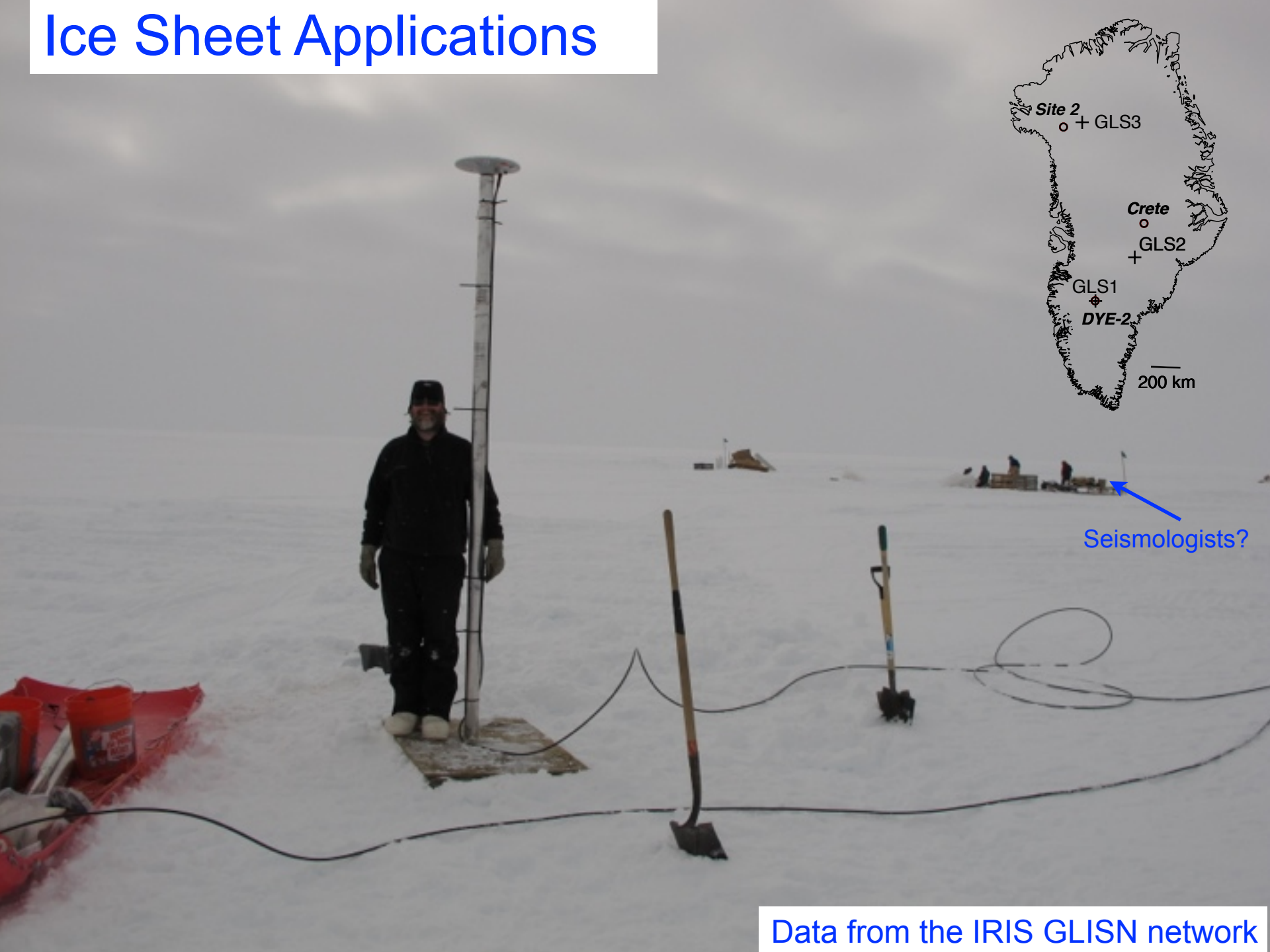


Monthly Comparison



Larson, KM, Ray, R. and SWP Williams, JOceanAtmTech, 2017

Ice Sheet Applications



Data from the IRIS GLISN network

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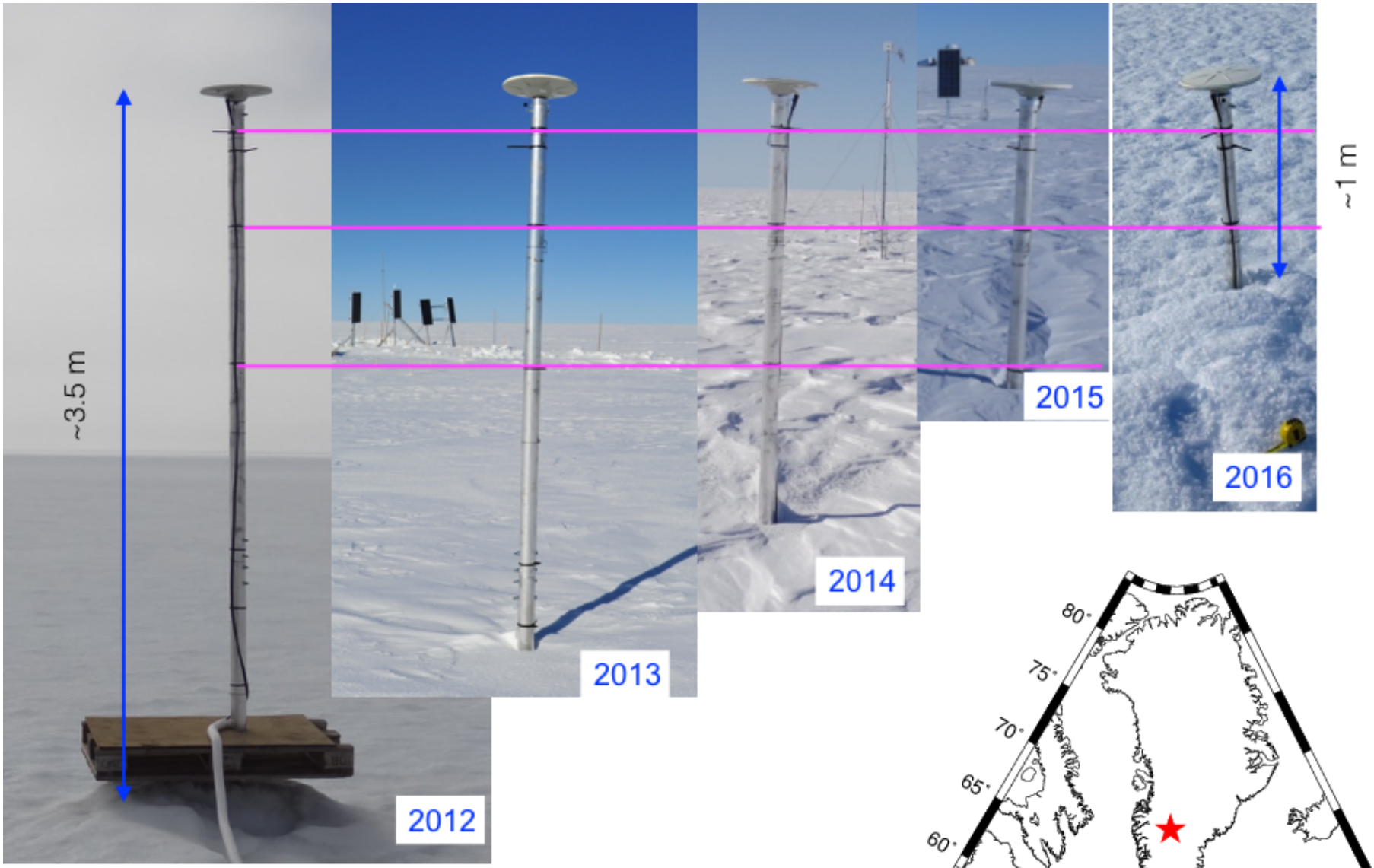
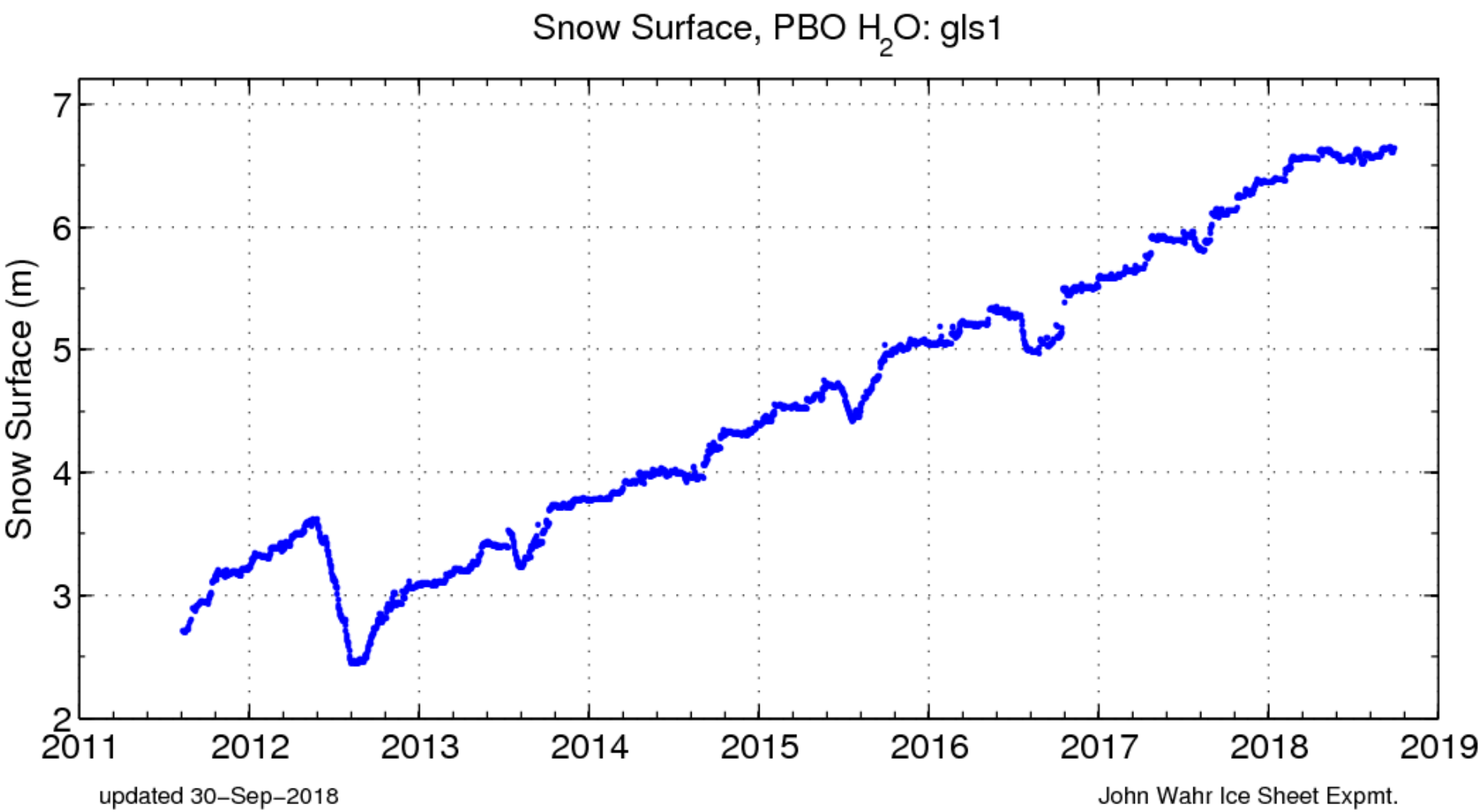
- Existing datasets can be analyzed.
- Measures the surface - does not significantly vary depending on the wetness of the snow.



Acknowledgements: GLISN, IRIS, UNAVCO, Dean Childs.

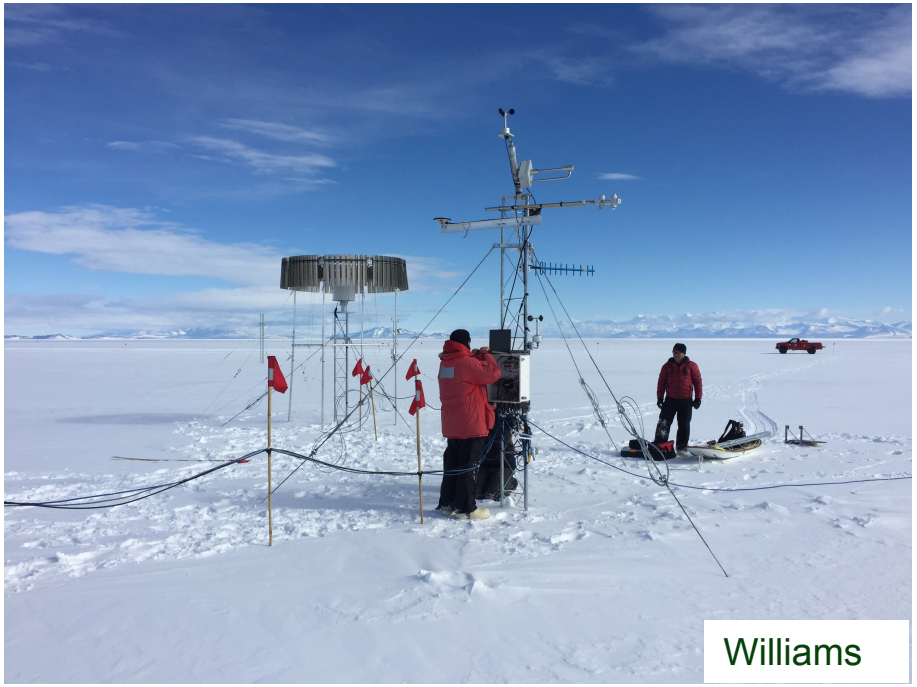
Dye 2, Greenland



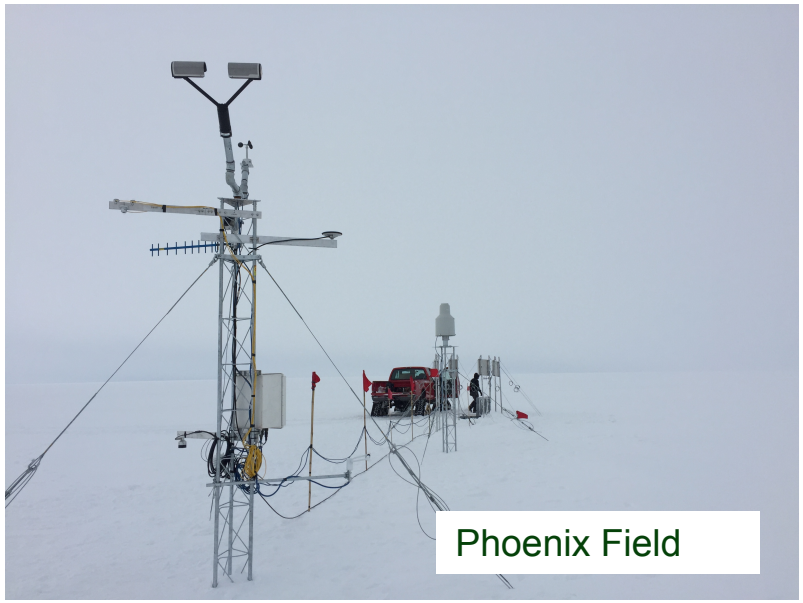
Some New Things

Deliberate GNSS-IR

Ross Ice Shelf, Antarctica

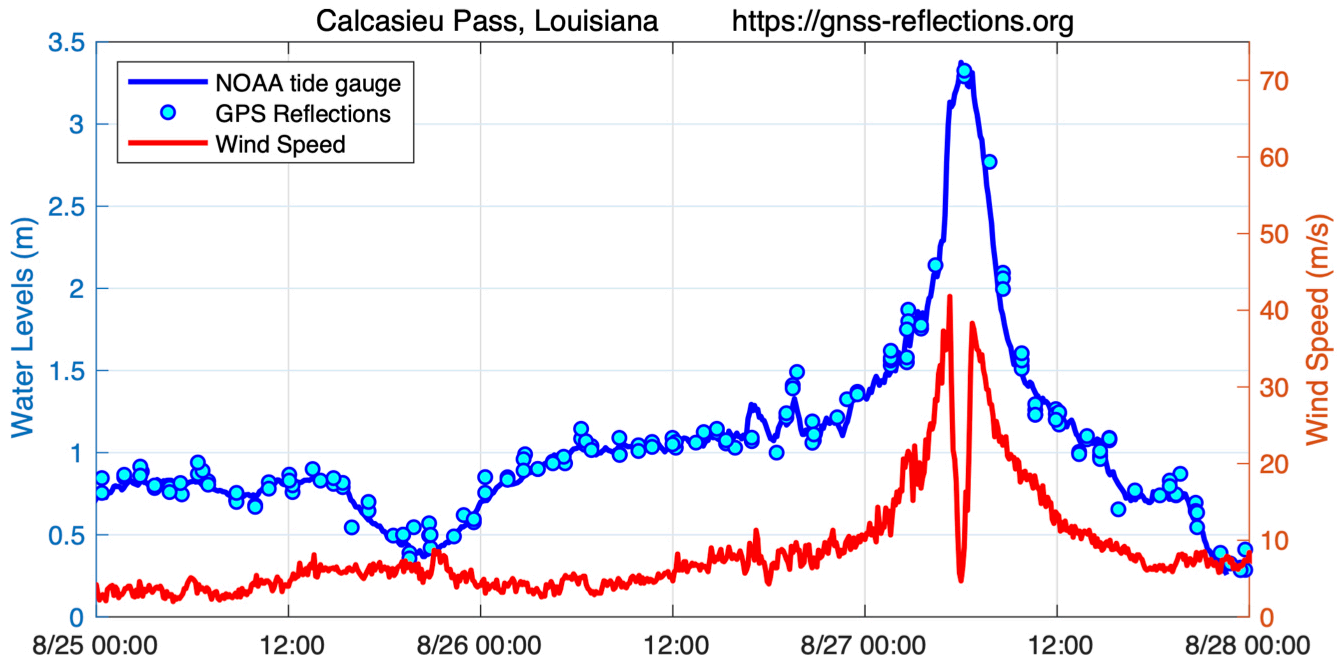


Williams

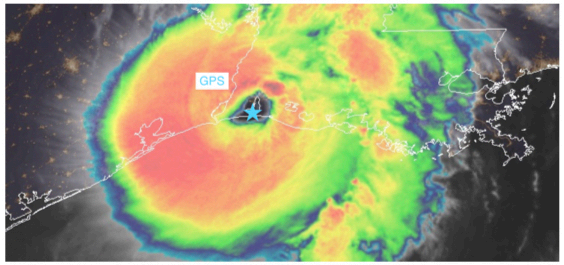


Phoenix Field

Hurricane Laura



Water Levels Measured with Reflected GPS Signals During Hurricane Laura

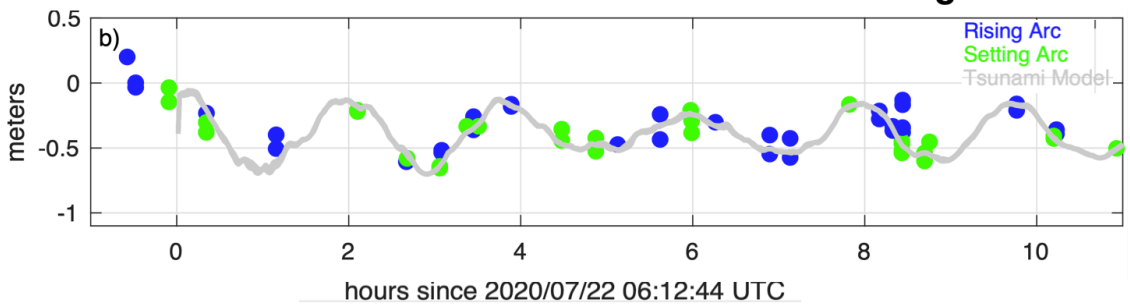


https://kristinelarson.net

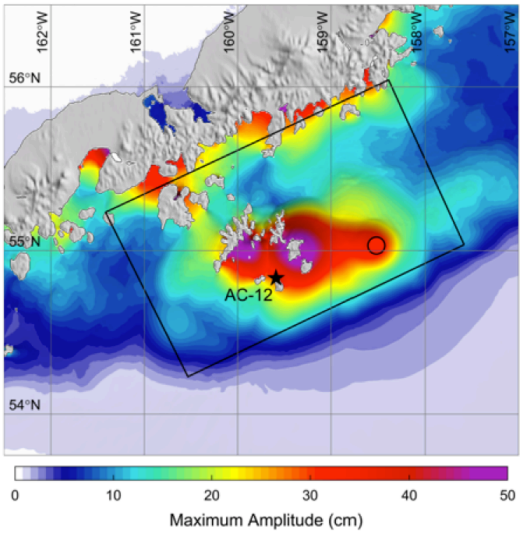
K.M. Larson, T. Lay et al., submitted to *Geophysical Research Letters*

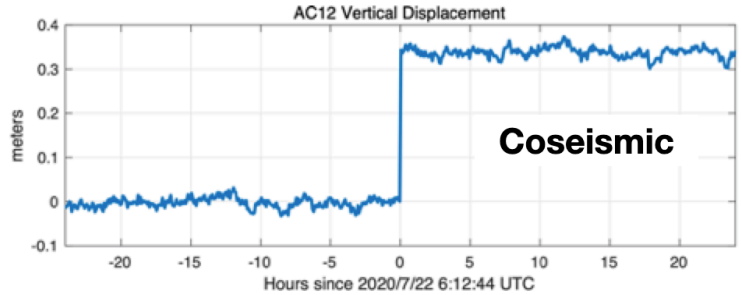
Tsunami - Shumagin Islands, Alaska

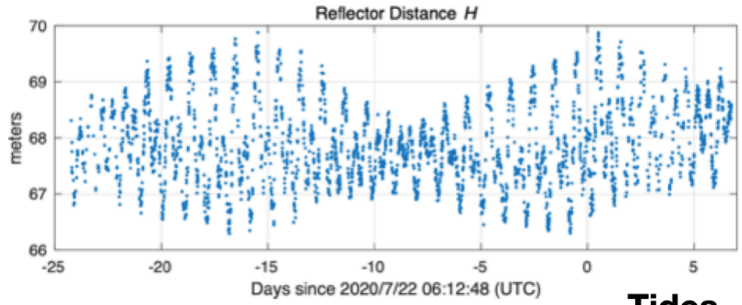
Tsunami waves observed with reflected GPS signals



Tsunami Model







Tides

AC12, Chernabura, Alaska

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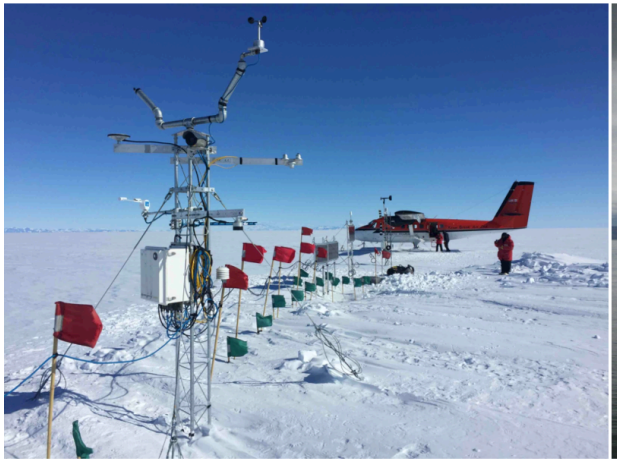
GNSS-IR Reflections Questions Geoid Calculator Reflection Zones Publications

https://gnss-reflections.org

Kristine's GNSS-IR WebApp



Examples

Ross Ice Shelf, Antarctica:
(•) lorg ( ) phnx ( ) wlly

Thwaites Glacier, Antarctica:
( ) khlr ( ) uthw ( ) lthw

Greenland:
( ) gls1 ( ) gls2 ( ) gls3 ( ) smm3

Soil Moisture/Snow:
( ) p360 ( ) p038 ( ) p041 ( ) p037

Water Levels:
( ) at01 ( ) sc02 ( ) mchn

Australia: L2C using RINEX3 files
( ) park ( ) mro1 ( ) kat1 ( ) mchl

Submit

Upload RINEX

Choose File no file selected

Freq	MinRH	MaxRH	MinElAng
L1	0.4	8.0	5.0

MaxElAng	ReqAmp	PkNoise
25.0	8	3.0

Submit

RINEX 2.11, 10 MByte limit, lowercase (gz or Z allowed), filename is ssssddd0.yyo and ssss is station name, ddd is day of year and yy is two character year. Upload must take less than 30 sec.

Analyze RINEX data from archives

Station	Year	DOY	Freq
p038	2019	200	L1

ReqAmp	MinRH	MaxRH	MinElAng
8	0.4	8.0	5.0

MaxElAng	Pk2Noise	RINEX
25.0	3.0	2.11

Submit

RINEX 2.11: UNAVCO, SOPAC, CDDIS, or SONEL.
RINEX 3: CDDIS

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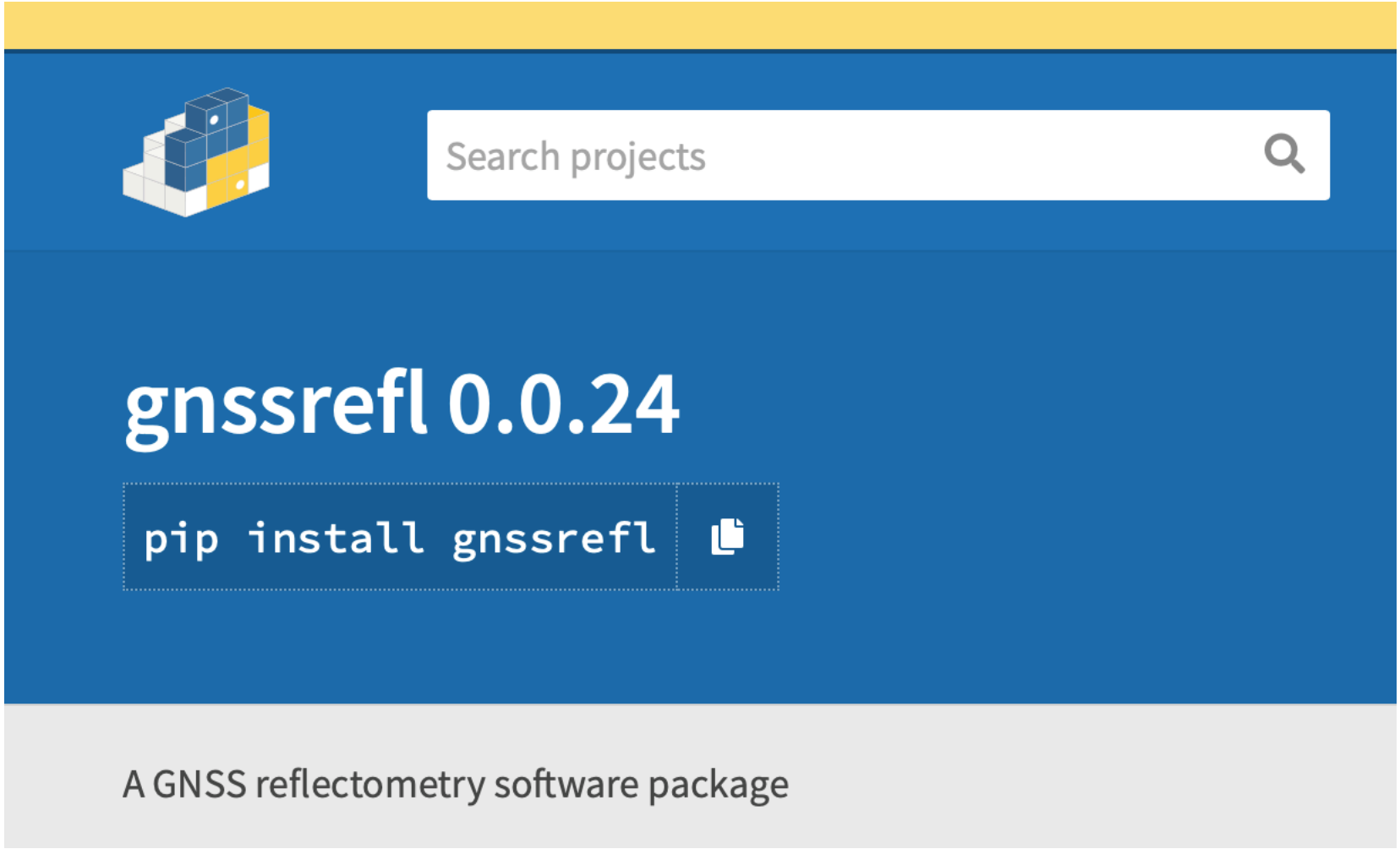
- Those that don't want to know what goes on under the hood (the Amazon experience). This category includes nearly all environmental scientists.
- Those that sort of want to know what is going on and are willing to install and use a modern programming language. Geodesists have these skills but are generally uninterested in measuring environmental signals.

Open source python:



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- Those that are keen to make GNSS-IR better.

If you are interested in using or improving GNSS-IR, please feel free to contact me!

kristinem.larson@gmail.com

https://kristinelarson.net

https://github.com/kristinemlarson

@funwithgps