



Making an Impact on Environmental Sciences with non-Traditional Applications of GPS Measurements:

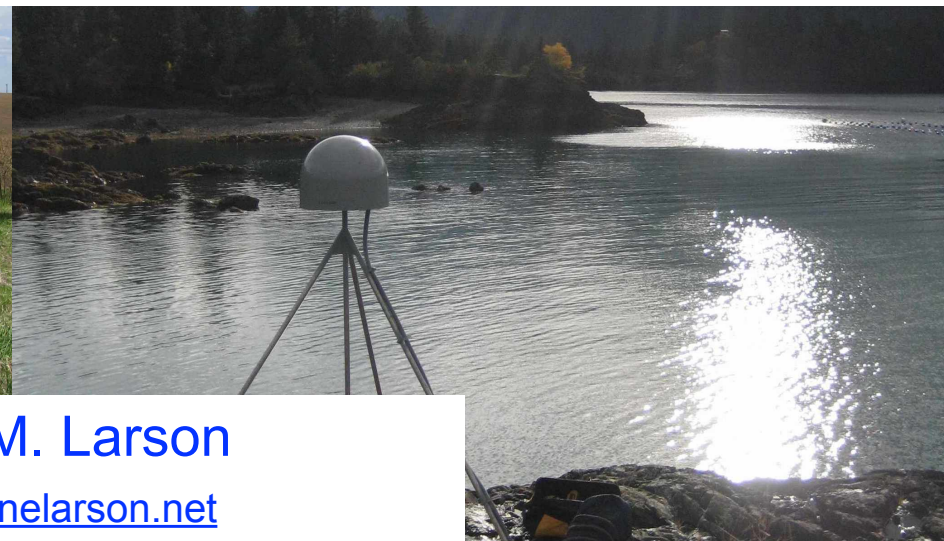


Kristine M. Larson

<https://kristinelarson.net>



Making an Impact on Environmental Sciences with non-Traditional Applications of GPS Measurements: Some Things I Learned While Developing Hydrogeodesy



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Outline

- What is GPS/GNSS Interferometric Reflectometry (GNSS-IR)?
- Applications
- How can we make new discoveries like GNSS-IR available to the Earth science community?

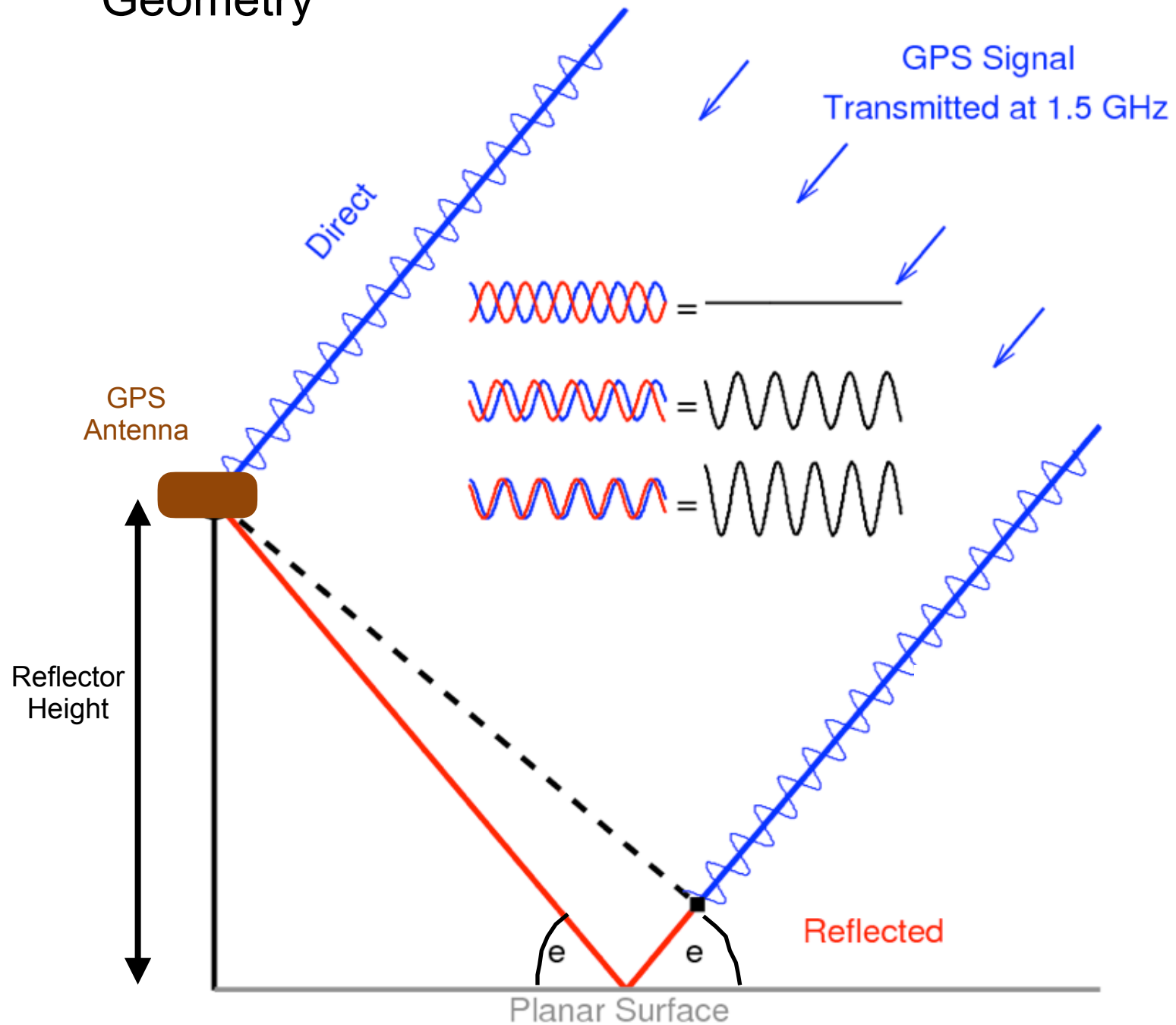
What is GNSS-IR?

GPS/GNSS interferometric reflectometry is a technique that turns a GNSS site into a bistatic radar.

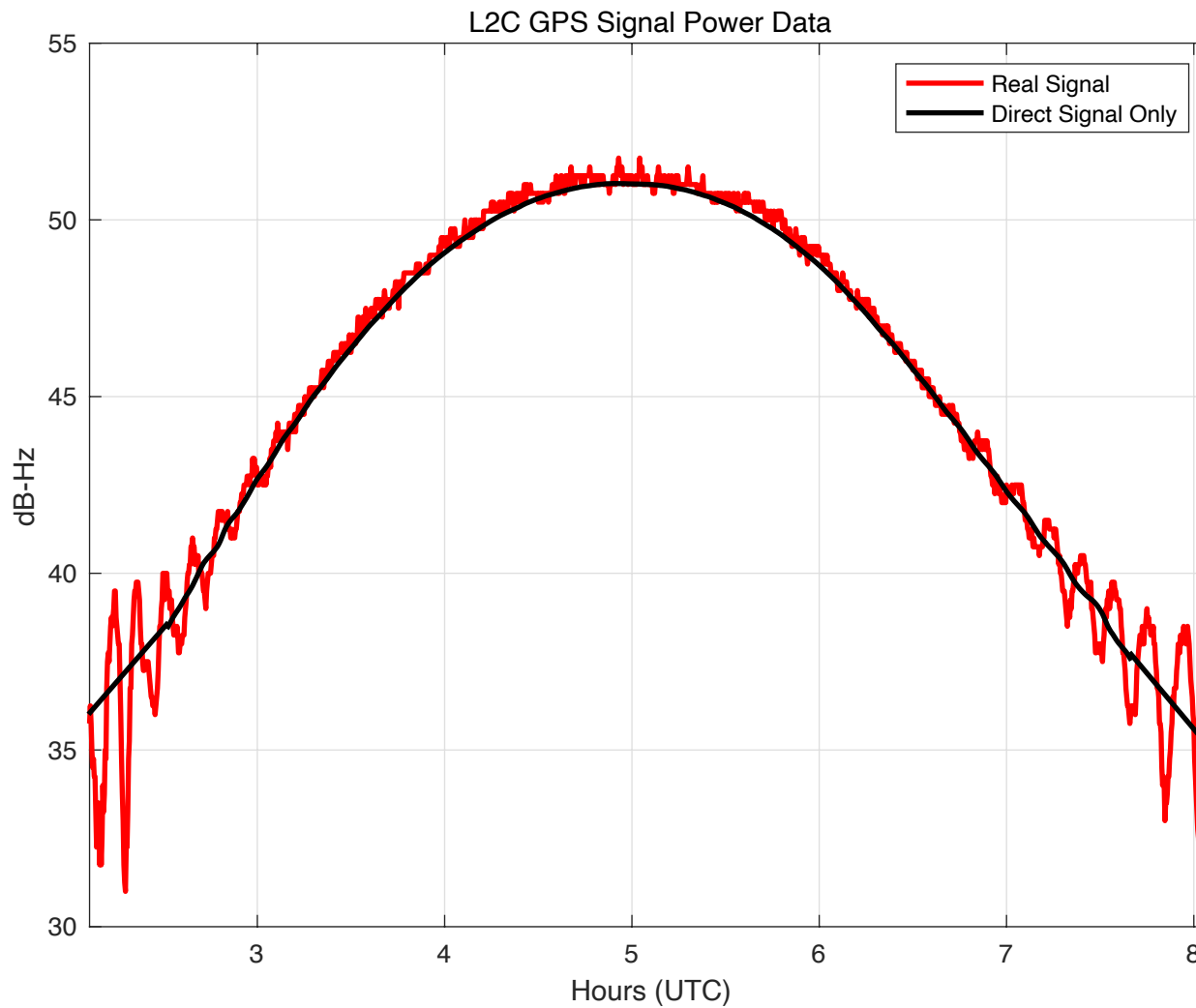
It uses low elevation angles and forward scatter (multipath) from planar surfaces near the antenna.

GNSS-IR uses consumer off-the-shelf GNSS instruments, usually geodetic-quality, with no modifications (i.e. the antennas are zenith pointing).

Geometry



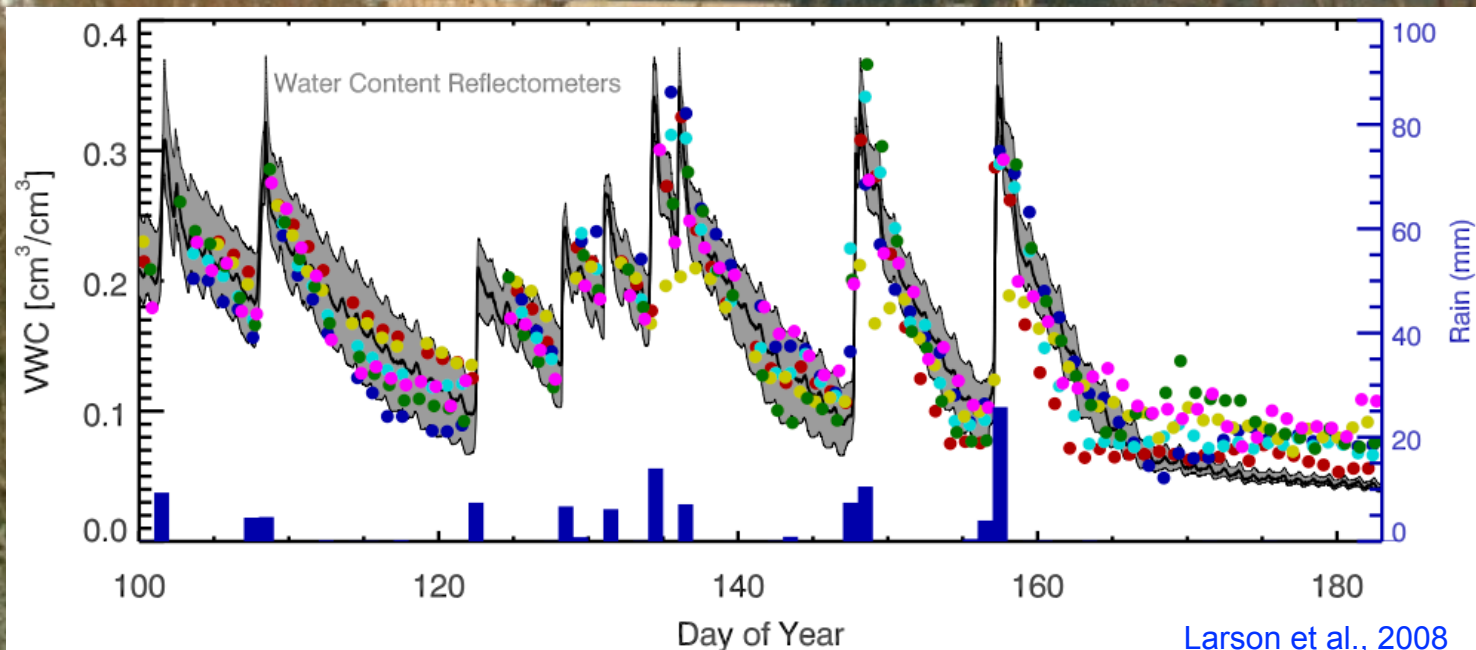
Example GNSS-IR observables



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

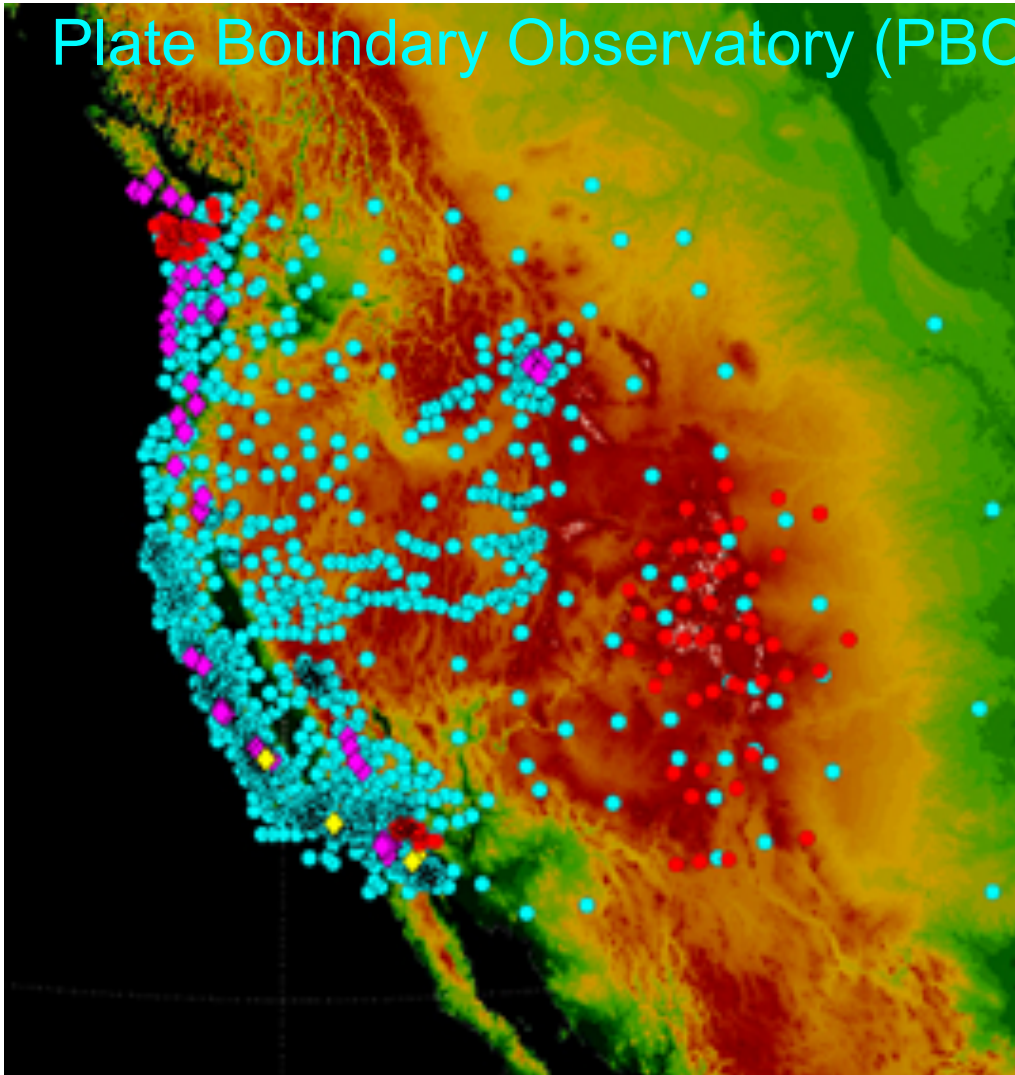
- Supplement other *in situ* sensors, many of which have very small footprints and/or are expensive to maintain.
- Satellites have very large footprints (and don't work well in some conditions).
- GNSS data are “inexpensive.”
- Ground sensors are needed both for assimilation and satellite validation.

We started trying to measure soil moisture in 2007, and had our first good result in 2008, followed by snow in 2009, vegetation in 2010

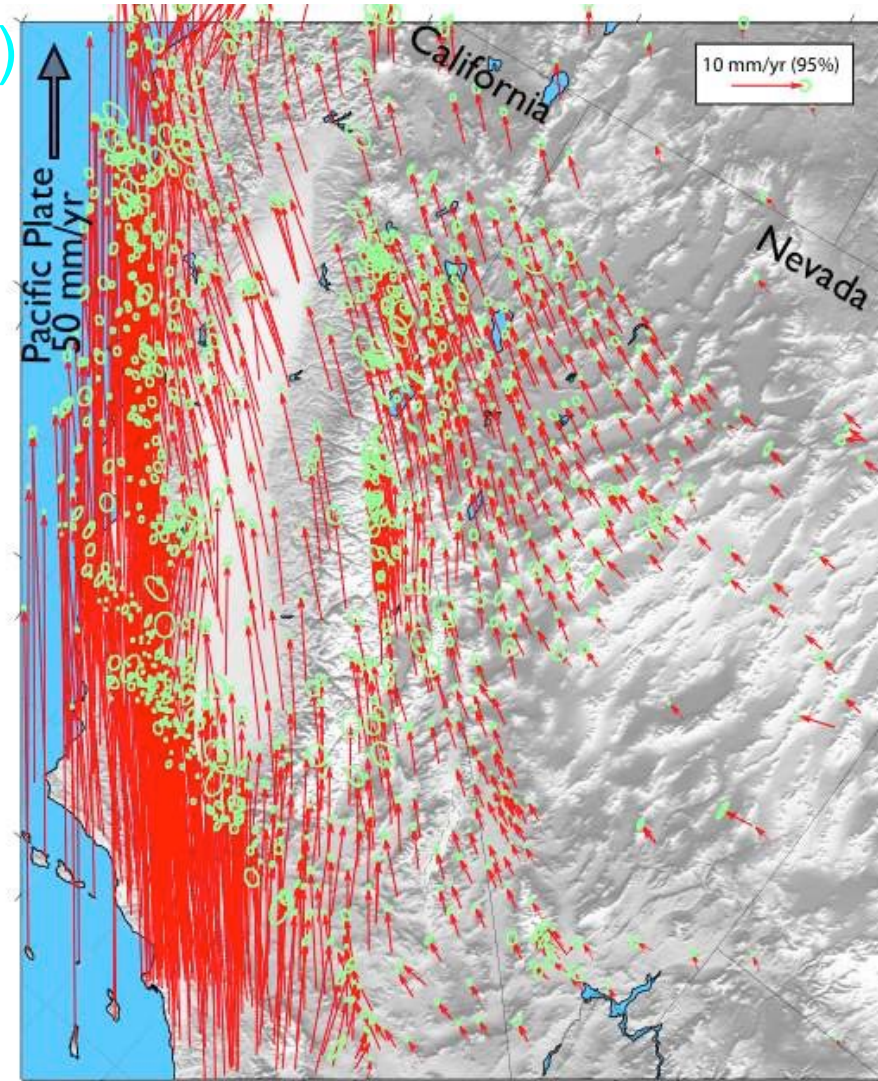


In 2012 we started PBO H₂O

Plate Boundary Observatory (PBO)



+150 stations in Alaska



Source: Bill Hammond



Soil Moisture

Started with 25 stations - ultimately used 150.

[Browse Stations](#)

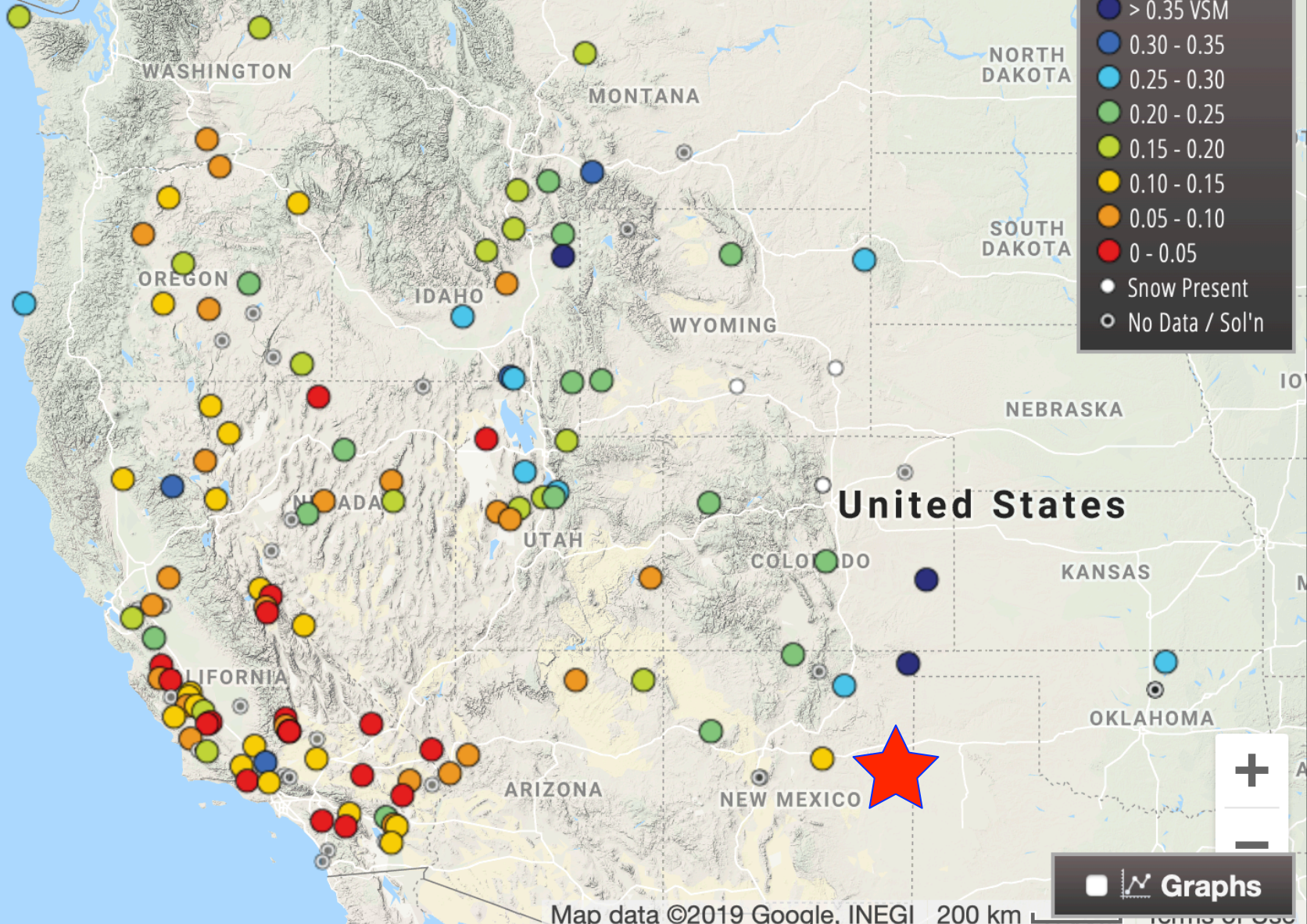
Daily Soil Moisture Maps

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



Google

Map data ©2019 Google, INEGI 200 km [Terms of Use](#)

[Graphs](#)



Soil Moisture

Started with 25 stations - ultimately used 150.

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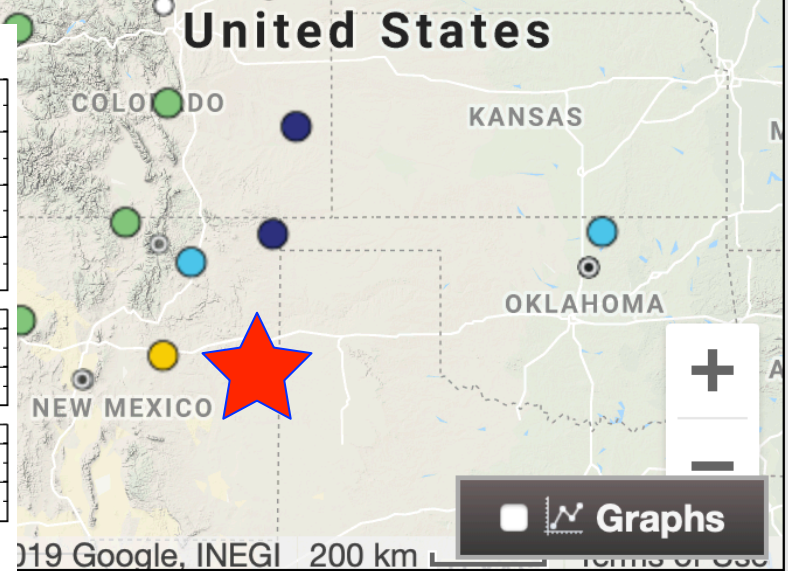
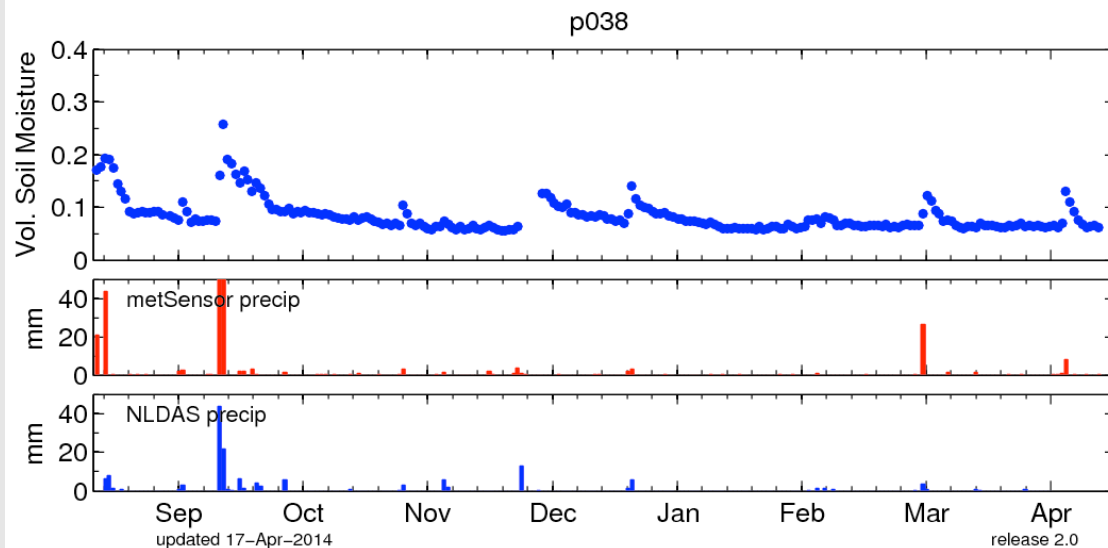
Daily Soil Moisture Maps

[World](#)

[Western US](#)

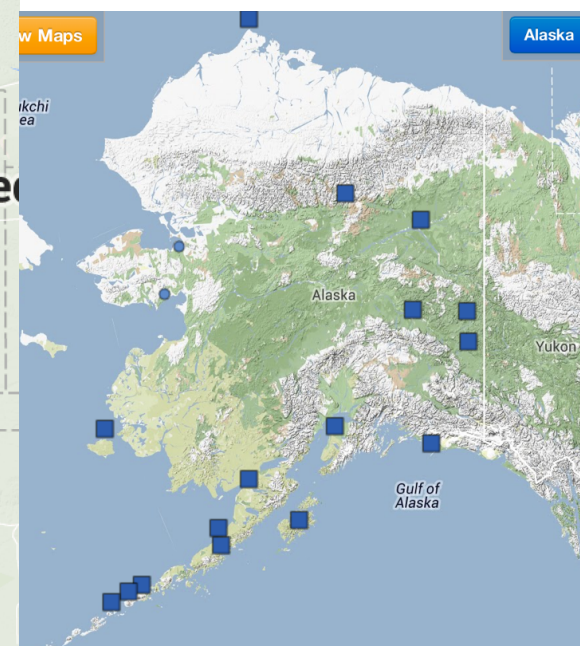
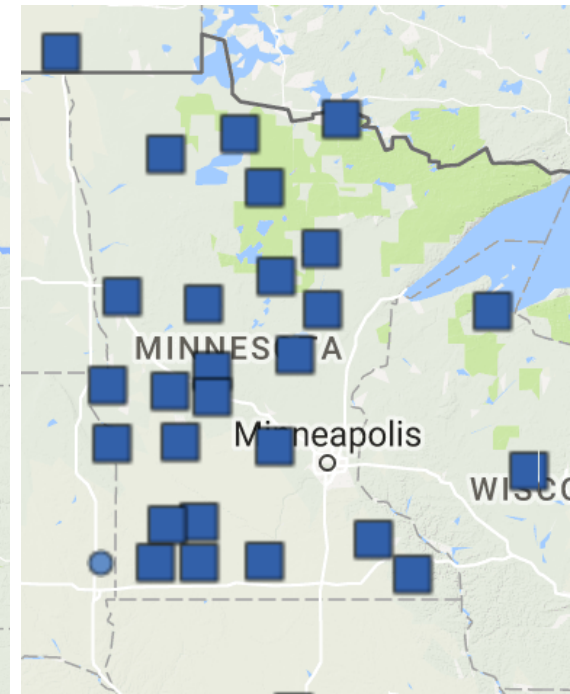
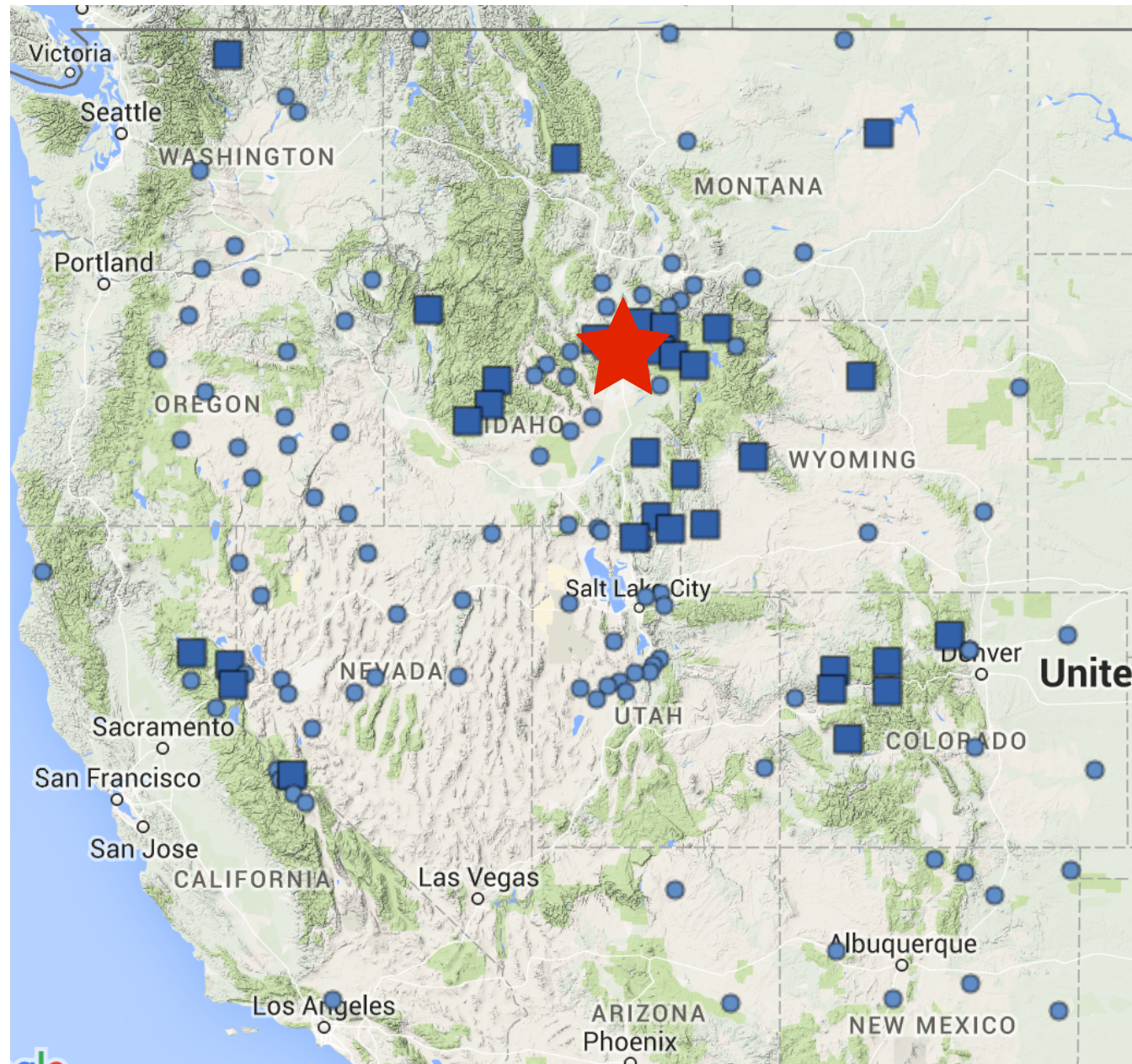
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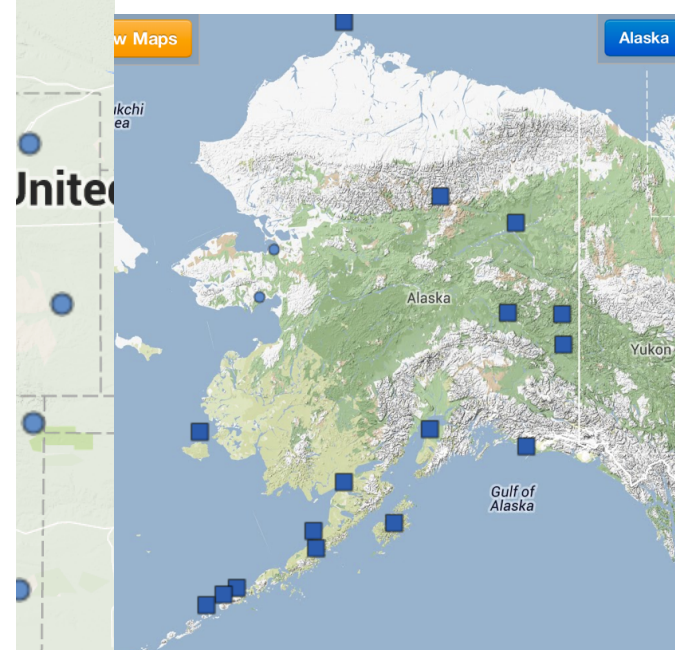
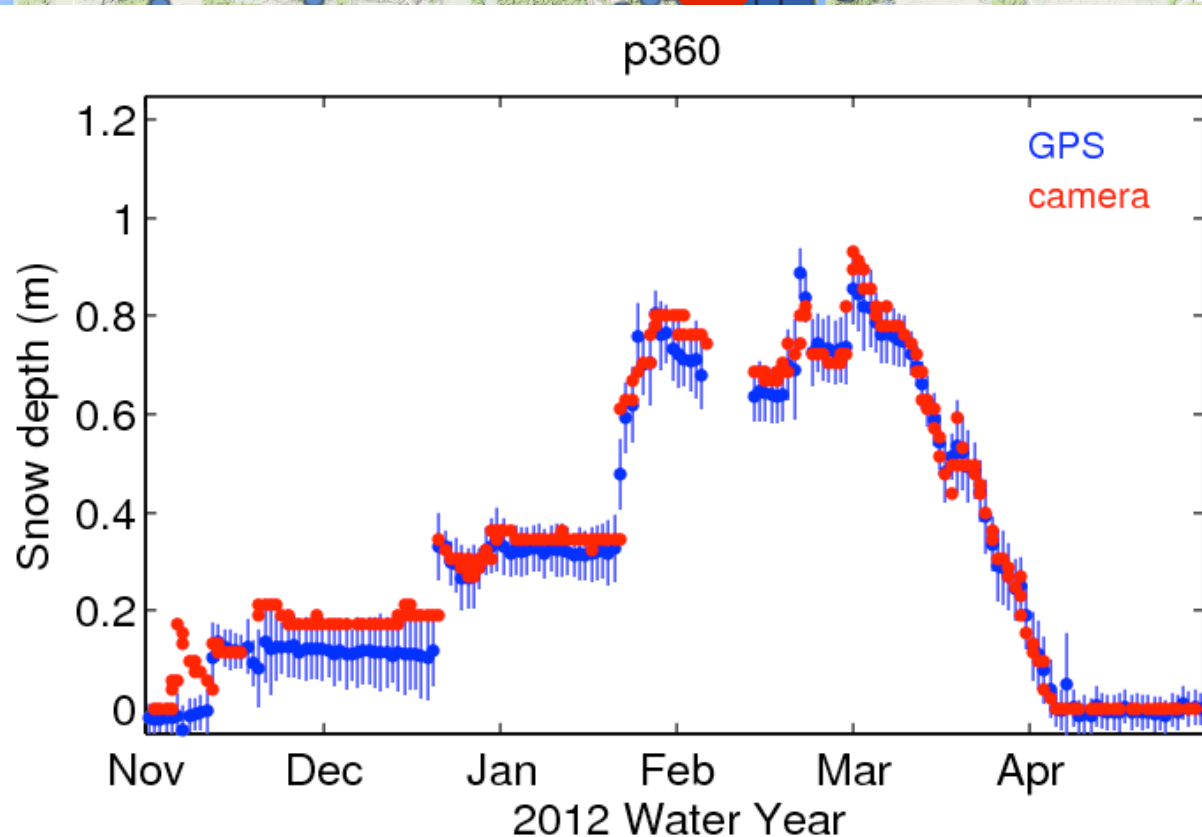
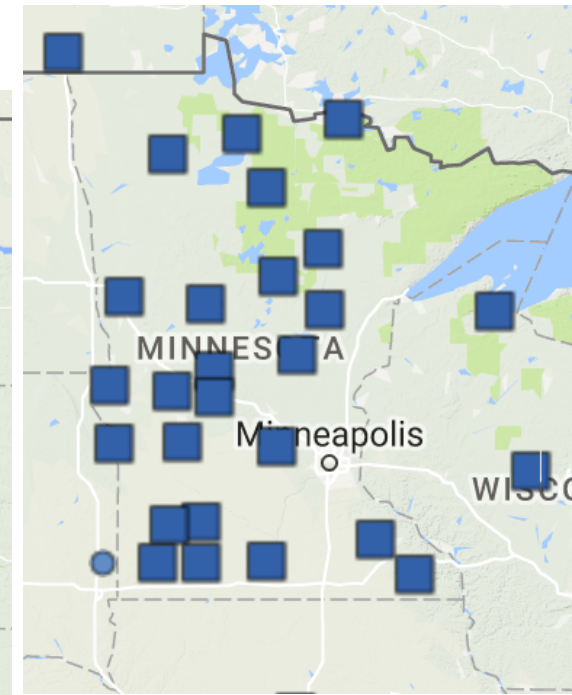
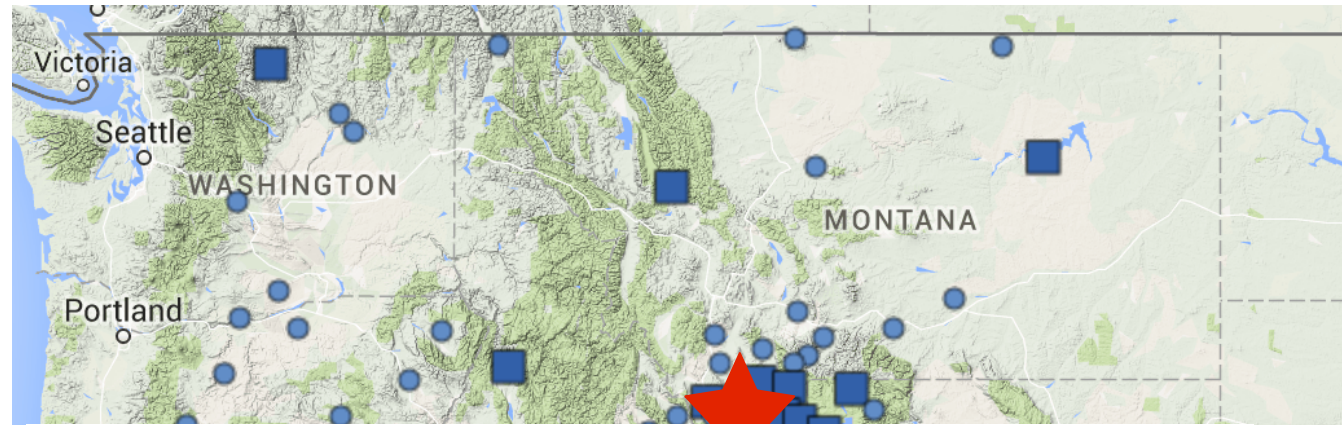


[Graphs](#)

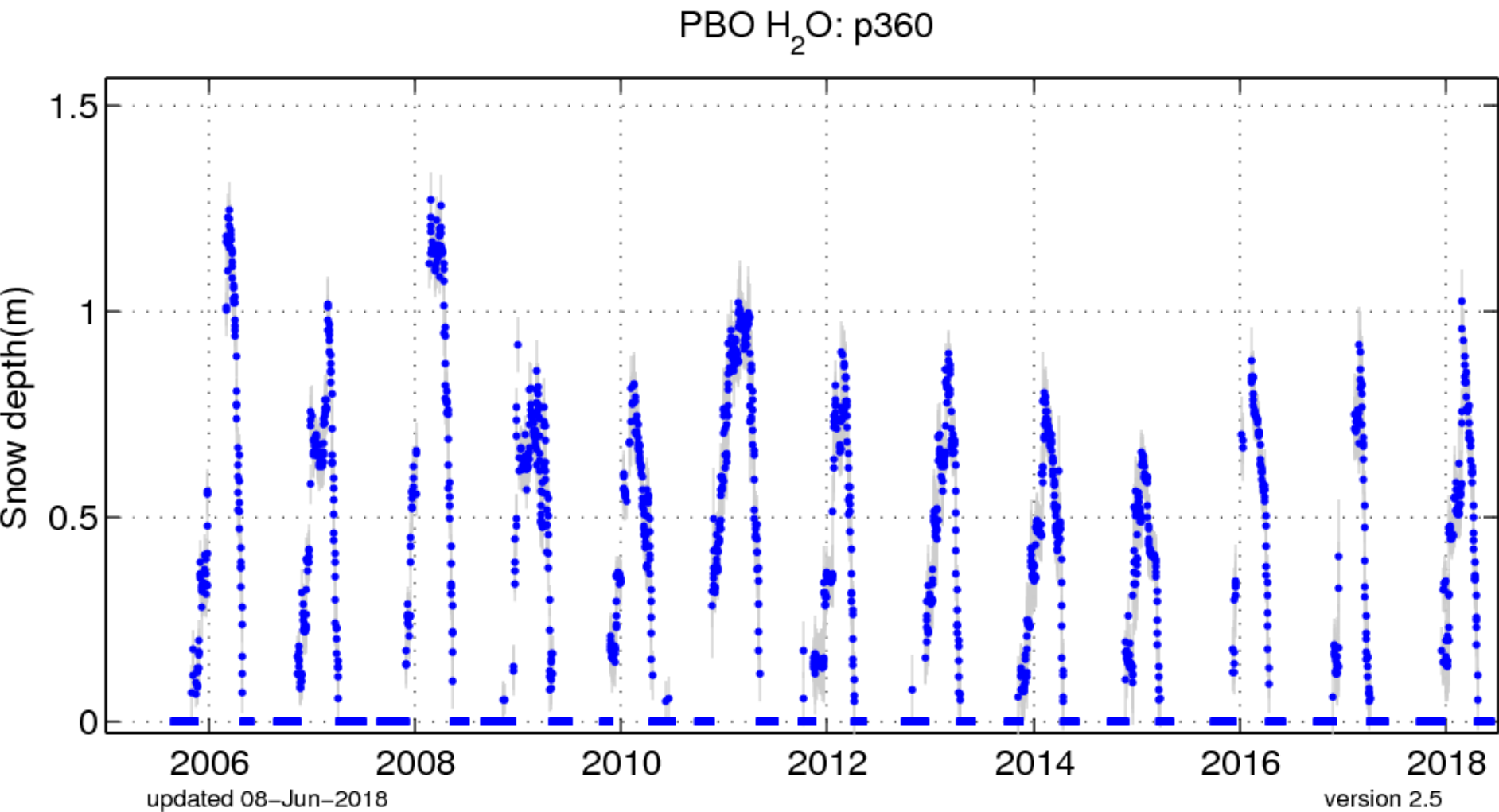
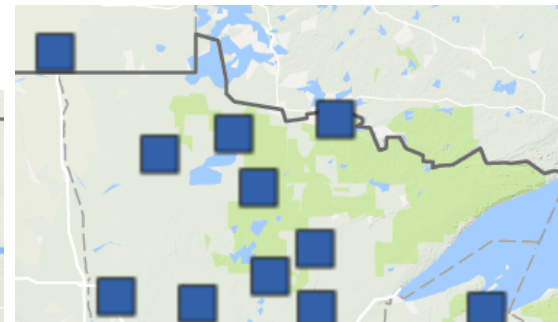
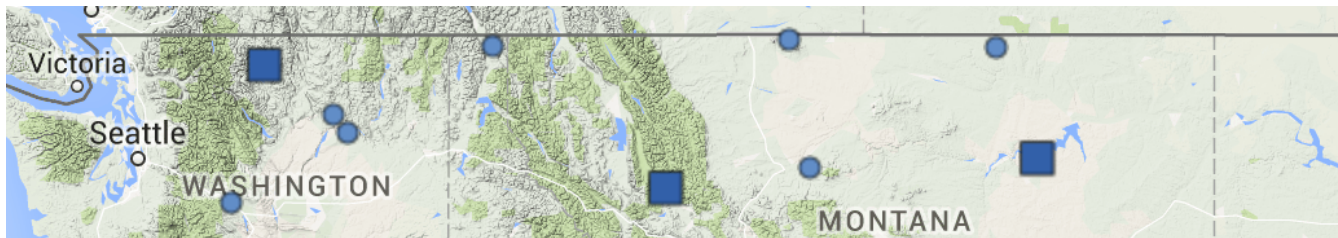
Snow Depth/Snow Water Equivalent



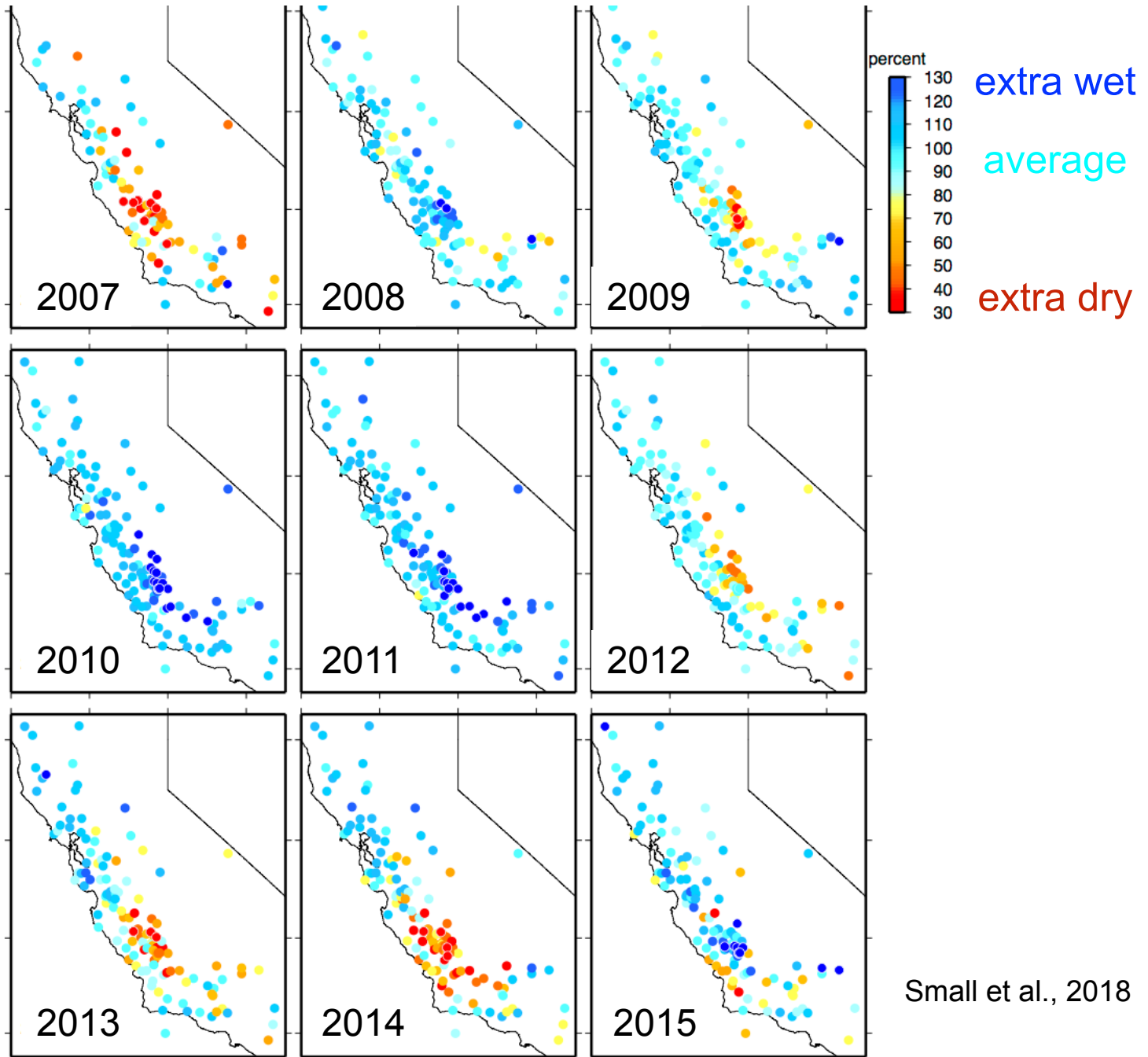
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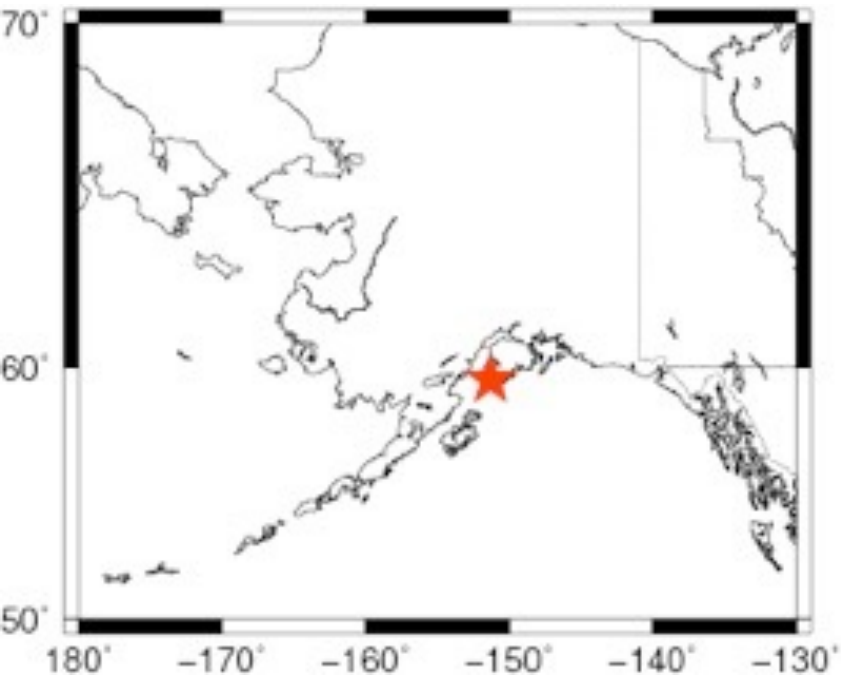
Snow Depth/Snow Water Equivalent



Normalized Peak Vegetation Water Content



Tides

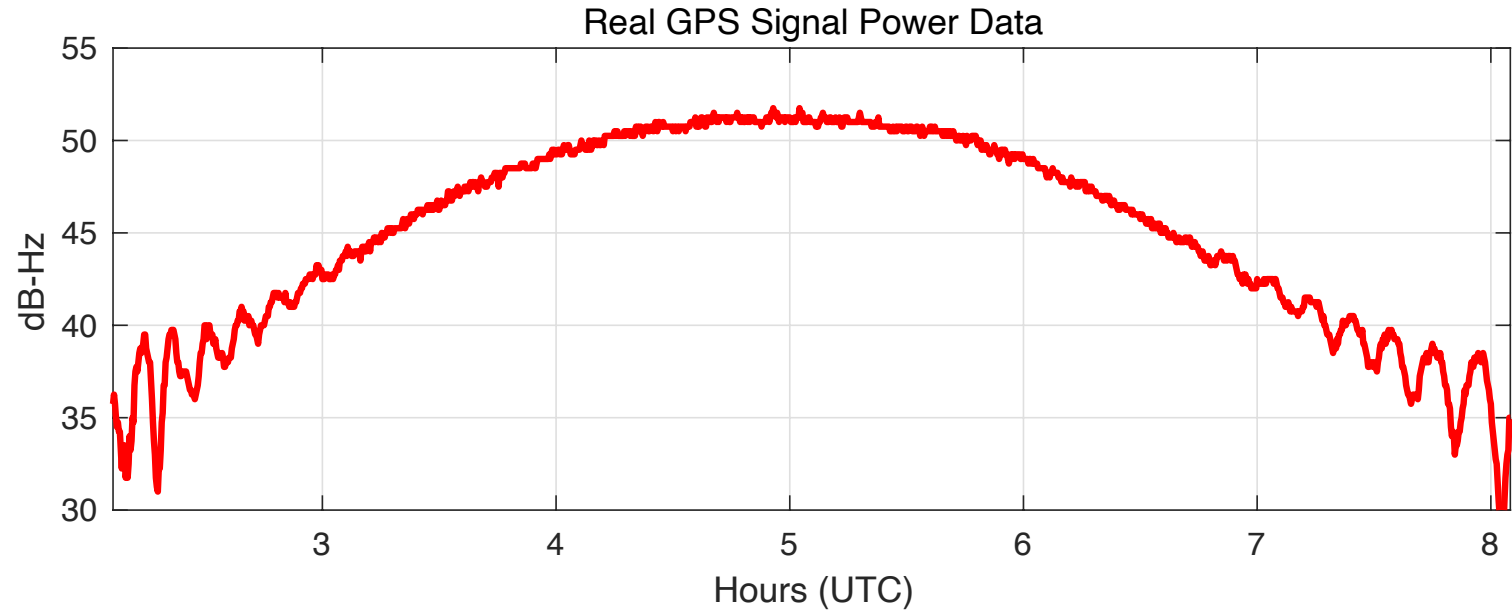


GNSS-IR measures
water levels in ITRF

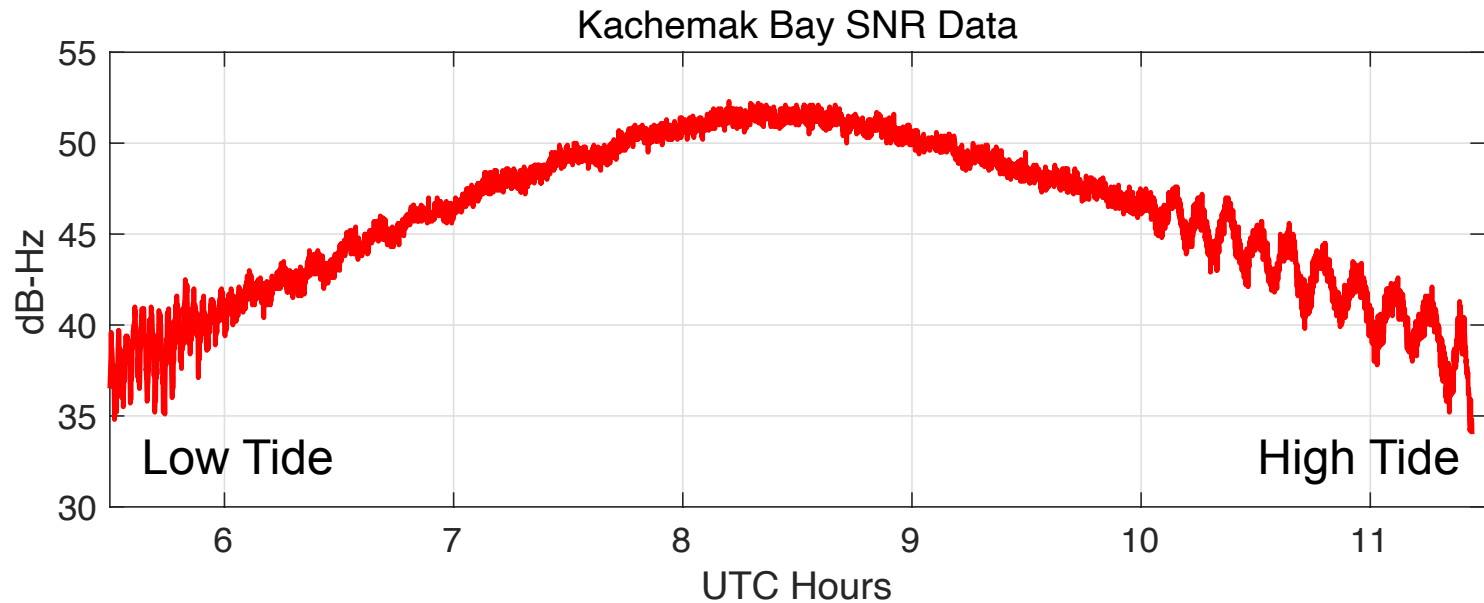
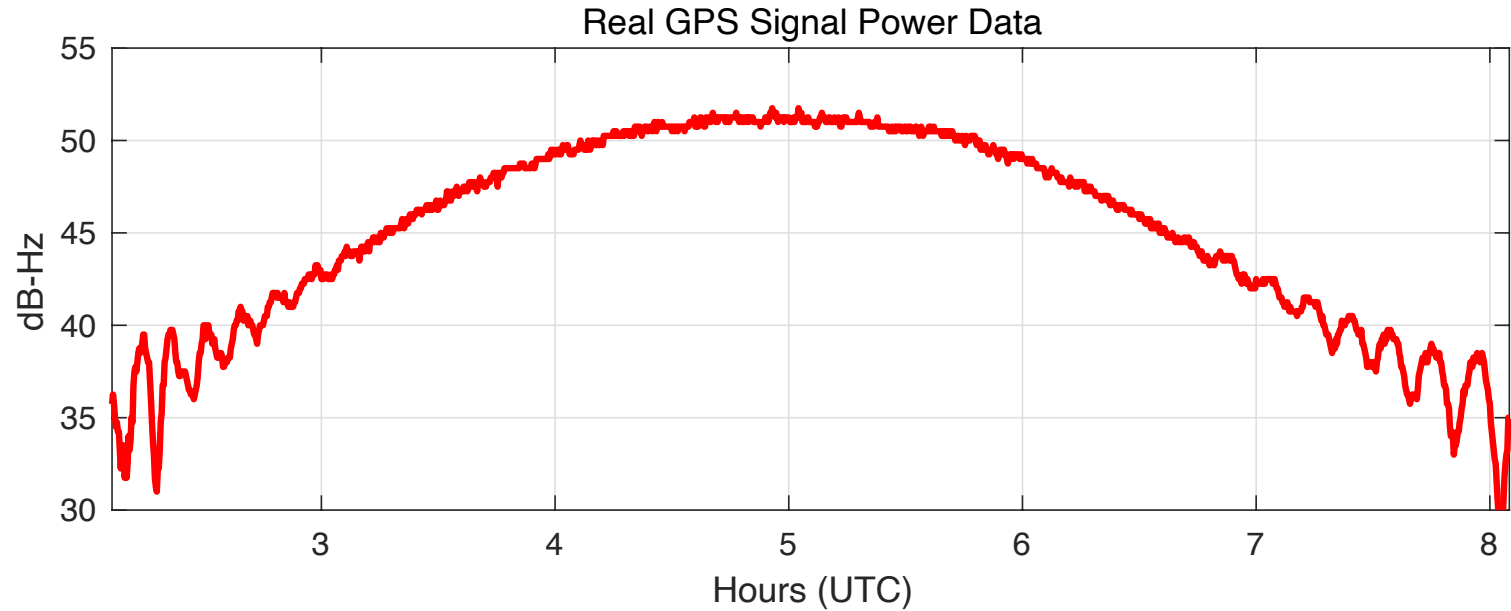
Kachemak Bay, Alaska



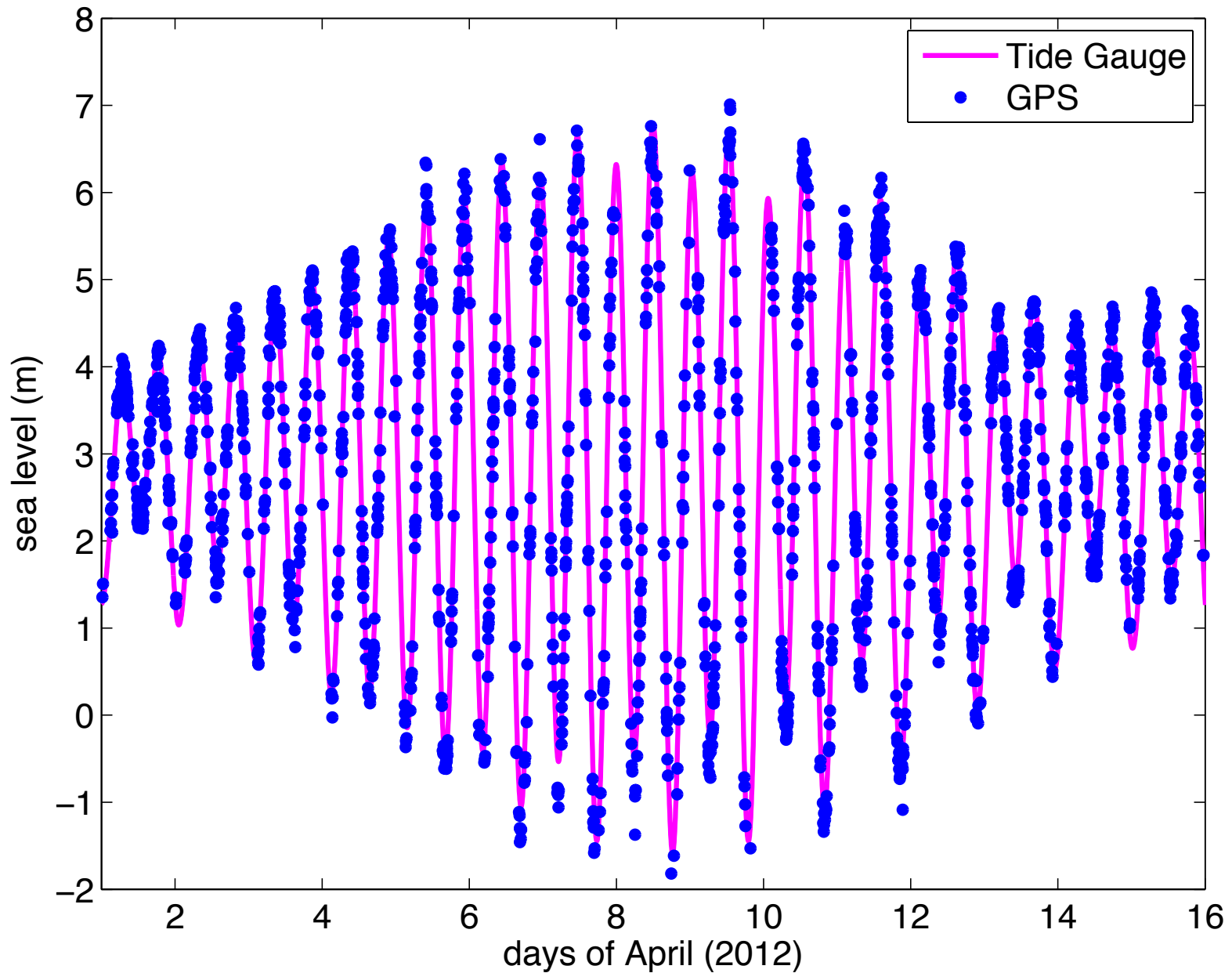
Typical SNR Data for a non-dynamic site, 2 meters tall



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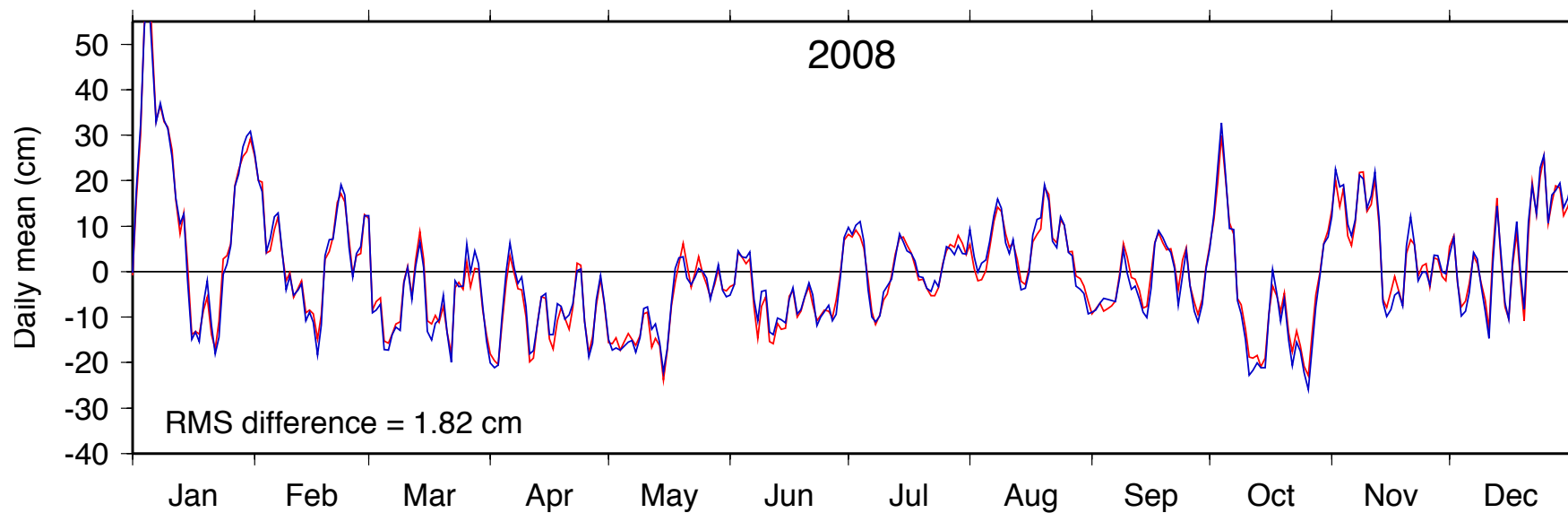


Comparison between GPS and 'Real' Tide Gauge

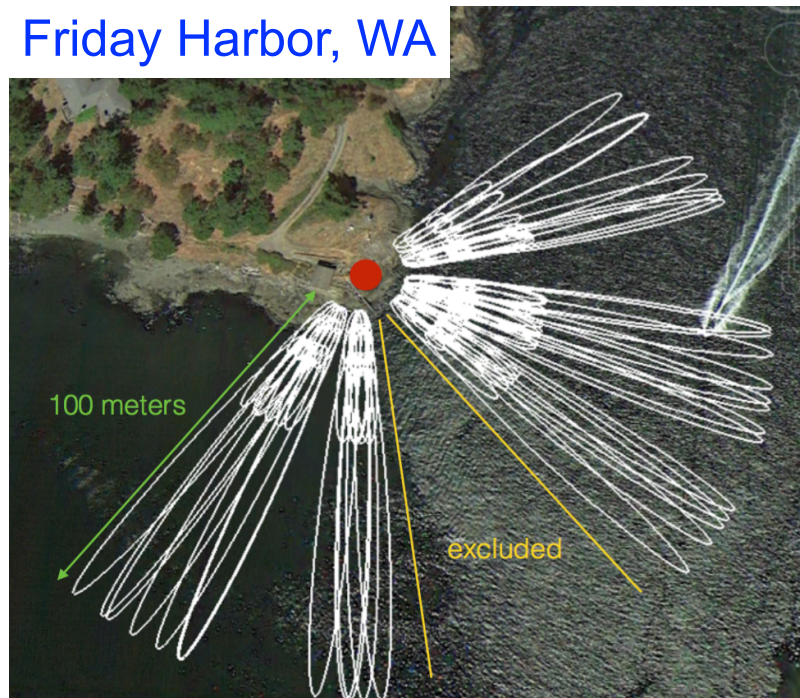


GPS Only

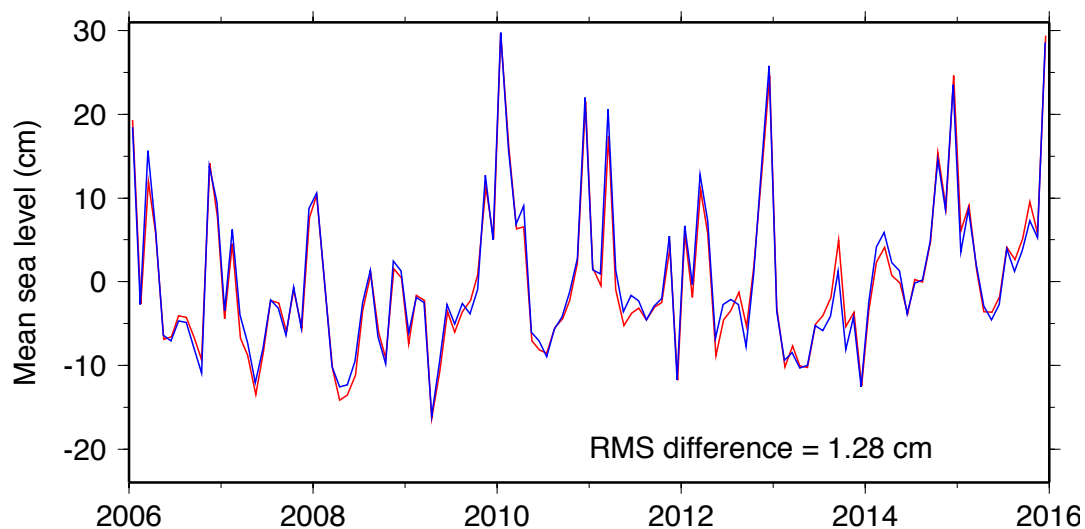
Daily Comparison with NOAA tide gauge



Friday Harbor, WA

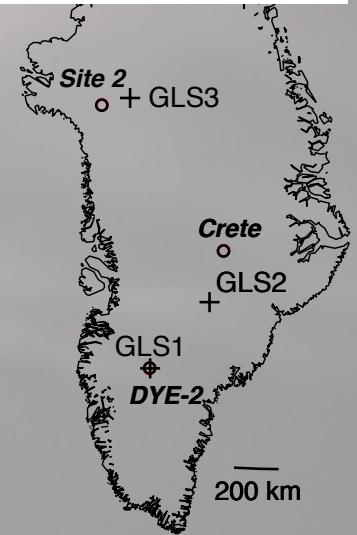


Monthly Comparison



Ice Sheets

GLISN network

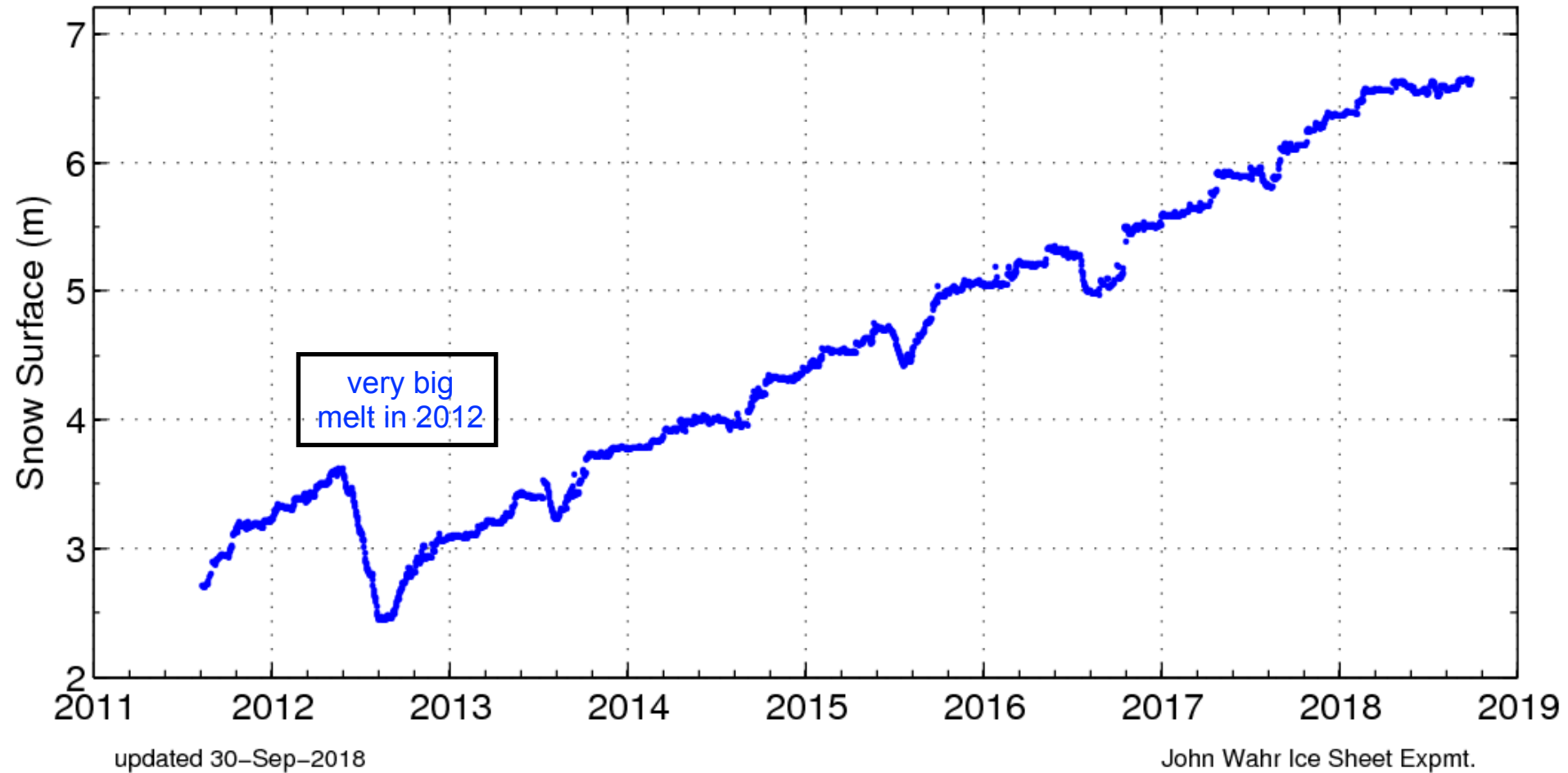


Seismologists?

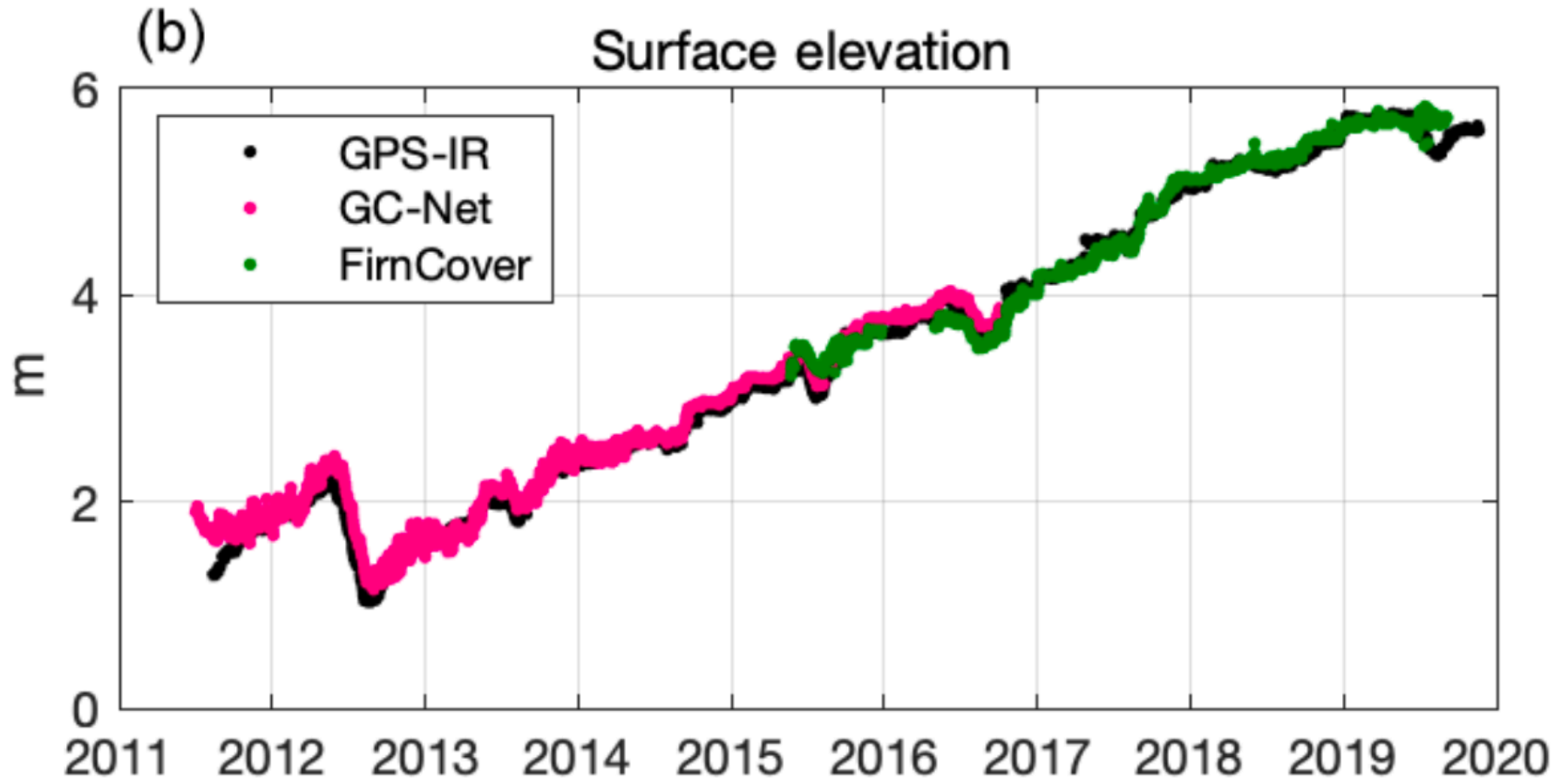
Larson et al., 2015

Dye 2, Greenland

Snow Surface, PBO H₂O: gls1

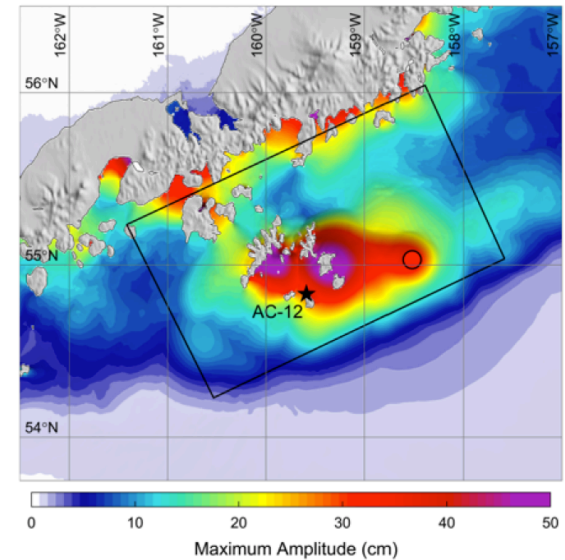


Comparison with Pingers

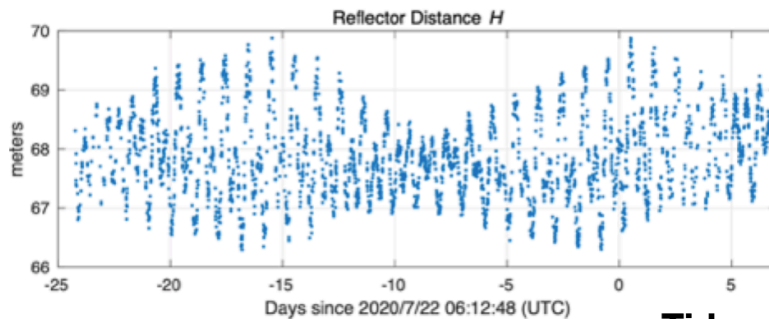
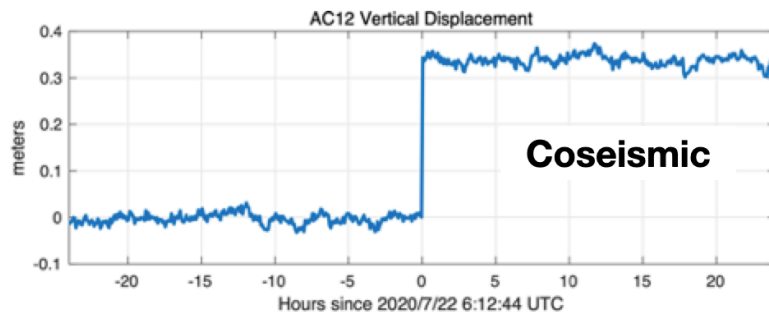
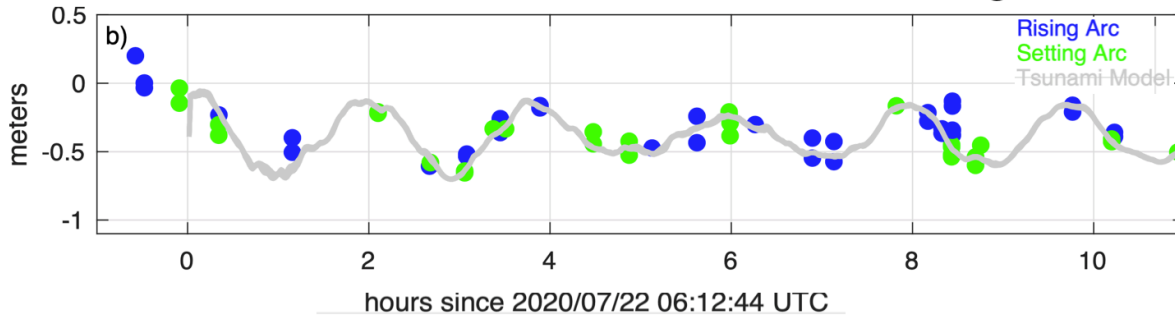


Shumagin Islands Earthquake Tsunami

Tsunami Model



Tsunami waves observed with reflected GPS signals

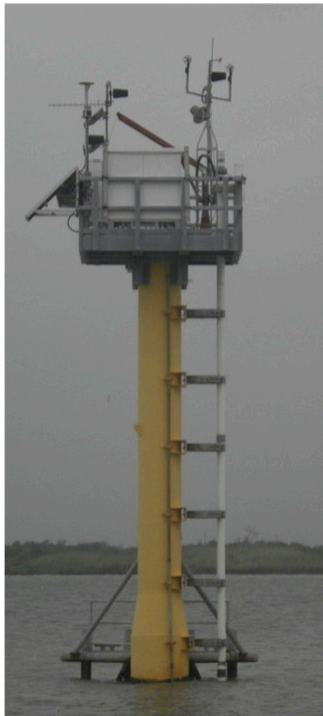


Tides

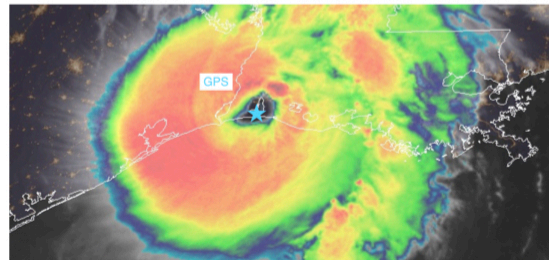
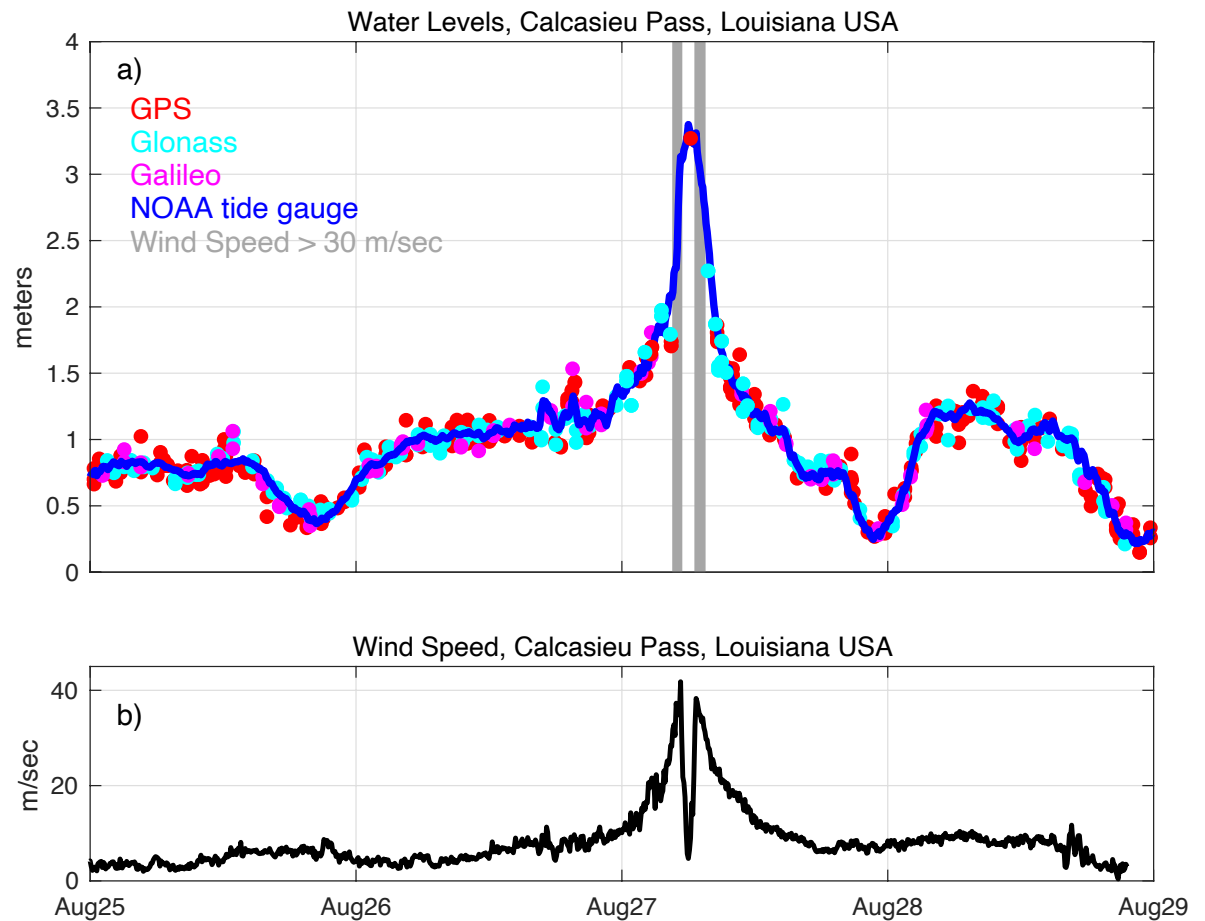
AC12, Chernabura, Alaska



Hurricane Laura Storm Surge



Water Levels Measured with
Reflected GPS Signals During
Hurricane Laura



<https://kristinelarson.net>

How were we able to go from an idea in 2007 to a full-scale, validated technique for soil moisture, snow, and vegetation water content at hundreds of sites in the western U.S. by 2017?



PBO H₂O



Valery
Zavorotny

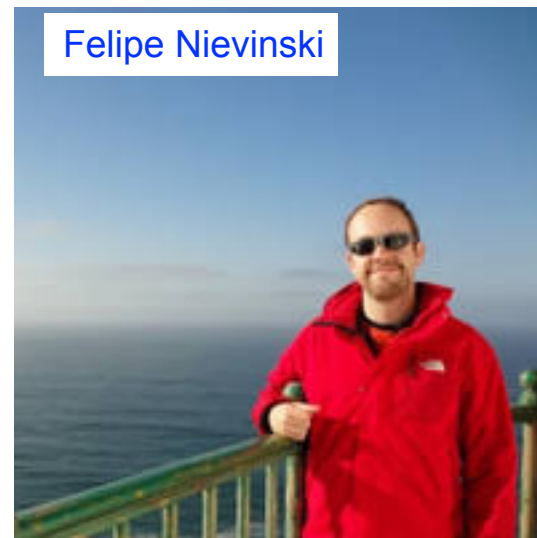
Eric Small

John Braun



Evan Pugh

Felipe Nievinski

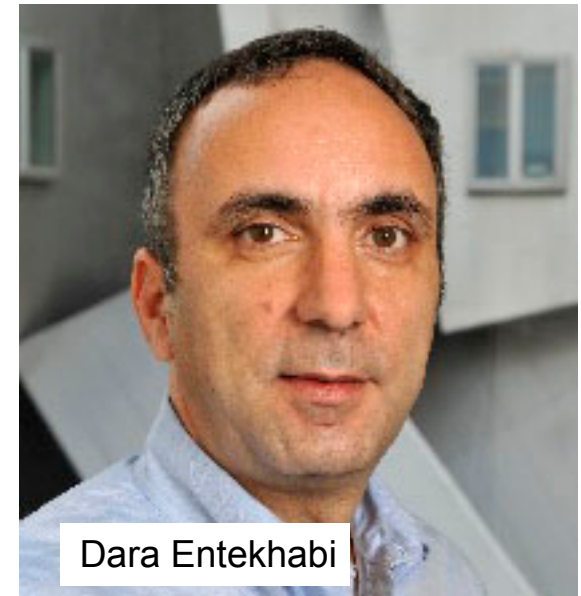


Clara Chew

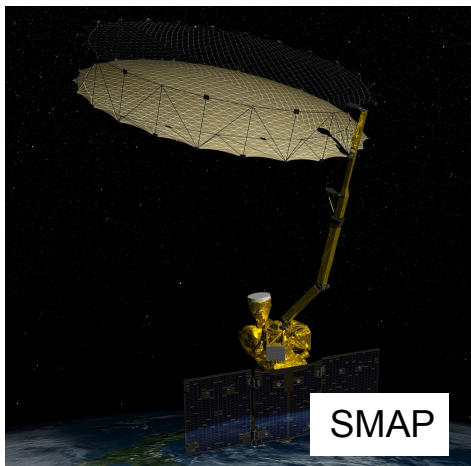




Jay Fein



Dara Entekhabi



SMAP

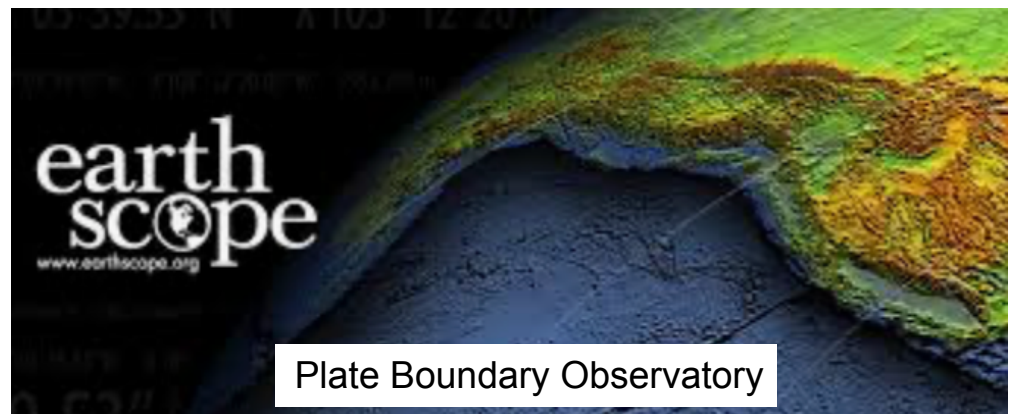


Plate Boundary Observatory

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- With very generous funding from NASA AIST, all its code was ported so that it could be run by JPL.
- While there is still interest in soil moisture, cryosphere/oceanographic applications are taking off.

My thoughts on this 14-year odyssey

- NSF and NASA do a great job of supporting PI-driven research. None of this research would exist without it.

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- No one reads the literature.
- Success is a double-edged sword.

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- Who are the potential GNSS-IR Users?

A lot of potential GNSS-IR users want the Amazon experience. Let's be honest - they all want it.



Kristine's GNSS-IR WebApp



Examples

Ross Ice Shelf, Antarctica:

☒ lorg ☐ phnx ☐ wly

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

Upload RINEX

 no file selected

Freq MinRH MaxRH MinElAng

L1 0.4 8.0 5.0

MaxElAng ReqAmp PkNoise

25.0 8 3.0

RINEX 2.11, 10 MByte limit, lowercase (gz or Z allowed), filename is sssd00.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
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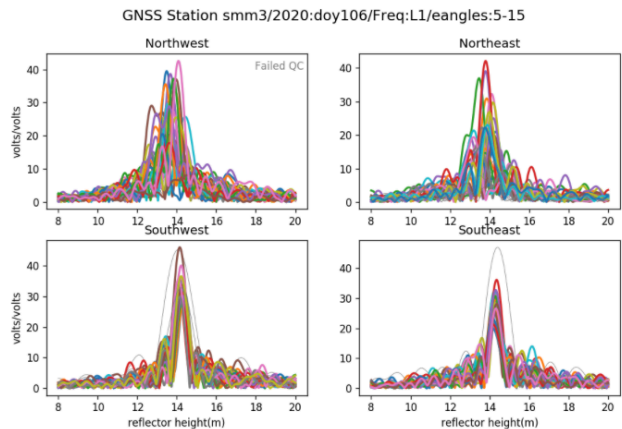
RINEX 2.11: UNAVCO, SOPAC, CDDIS, or SONEL.

RINEX 3: CDDIS

Return from the API

Reflection results will appear in 5-10 seconds:

Status:"finished"

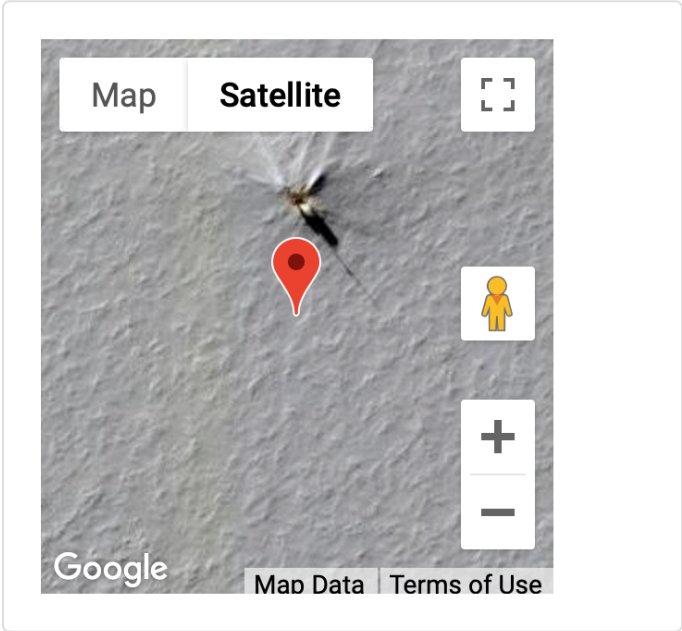


What should the answers look like?

Numerical Results

% Please acknowledge <https://gnss-reflections.org> when

%	Year	DOY	RefHt	Azim	fr	Hours	Sat	Ampl	pk2noise
%			m	deg		UTC		v/v	
%	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	2020	106	13.623	300	1	10.79	1	25.15	6.54
	2020	106	13.555	319	1	11.97	4	30.25	5.14
	2020	106	14.039	340	1	16.72	5	21.34	3.87
	2020	106	13.775	348	1	13.64	6	11.53	4.65
	2020	106	13.530	310	1	15.05	7	22.97	4.23
	2020	106	12.723	322	1	7.84	8	29.07	5.04
	2020	106	13.810	333	1	13.05	9	21.94	4.80
	2020	106	13.740	299	1	5.96	10	33.28	6.75
	2020	106	13.340	311	1	9.21	11	25.47	5.14
	2020	106	14.425	339	1	21.81	12	25.73	5.23
	2020	106	13.488	305	1	19.44	13	39.46	6.81
	2020	106	13.913	279	1	8.66	14	33.56	6.16



Station: smm3

Date: 2020-4-15

Latitude: 72.573

Longitude: -38.4702

Elevation (m): 3252.453

MSL (m): 3208.51



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- Environmental scientists have the necessary computational skills but have limited time to pick up something “new.”
- Open GNSS-IR source code package with really good documentation would make it easier for everyone.



**Kristine M.
Larson**

kristinemlarson

Follow

...

GPS/GNSS enthusiast,
geodesist, recovering
engineering professor

Open source python repository
on github:

snow, water levels, and soil moisture

[gnssrefl](#)

GNSS Reflections Code

● Python ☆ 18 🍴 10

<https://github.com/kristinemlarson/gnssrefl>

This effort is being supported by NASA

The Python Package Index (PyPI) is a repository of software for the Python programming language.



gnssrefl 0.0.24

```
pip install gnssrefl
```



A GNSS reflectometry software package

The Python Package Index (PyPI) is a repository of software for the Python programming language.



Search projects



gnssrefl 0.0.24

```
pip install gnssrefl
```



- UNAVCO has been contracted to make Jupyter Notebooks

- My hope is that by helping to build this open source software I will be able to engage the smaller community of GNSS-IR experts to maintain it in the future.

My mantra

Don't worry about the overall importance of the problem; work on it if it looks interesting. I think there's a sufficient correlation between interest and importance.

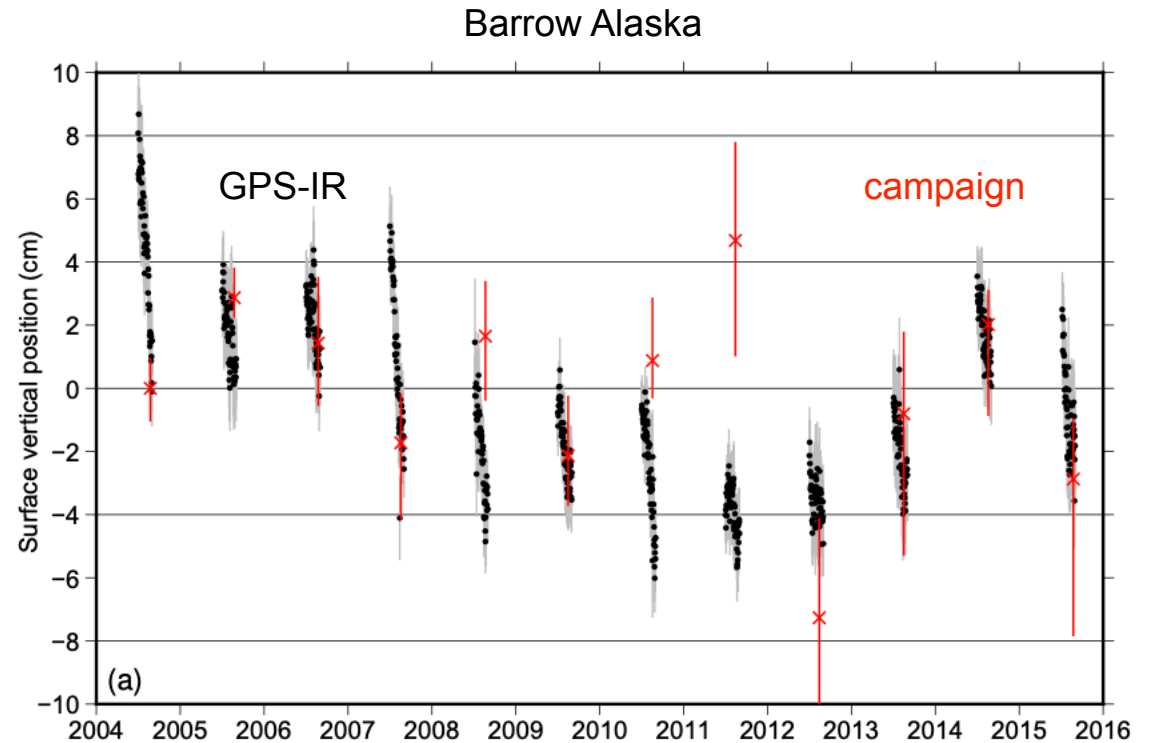
— David Blackwell

extra slides

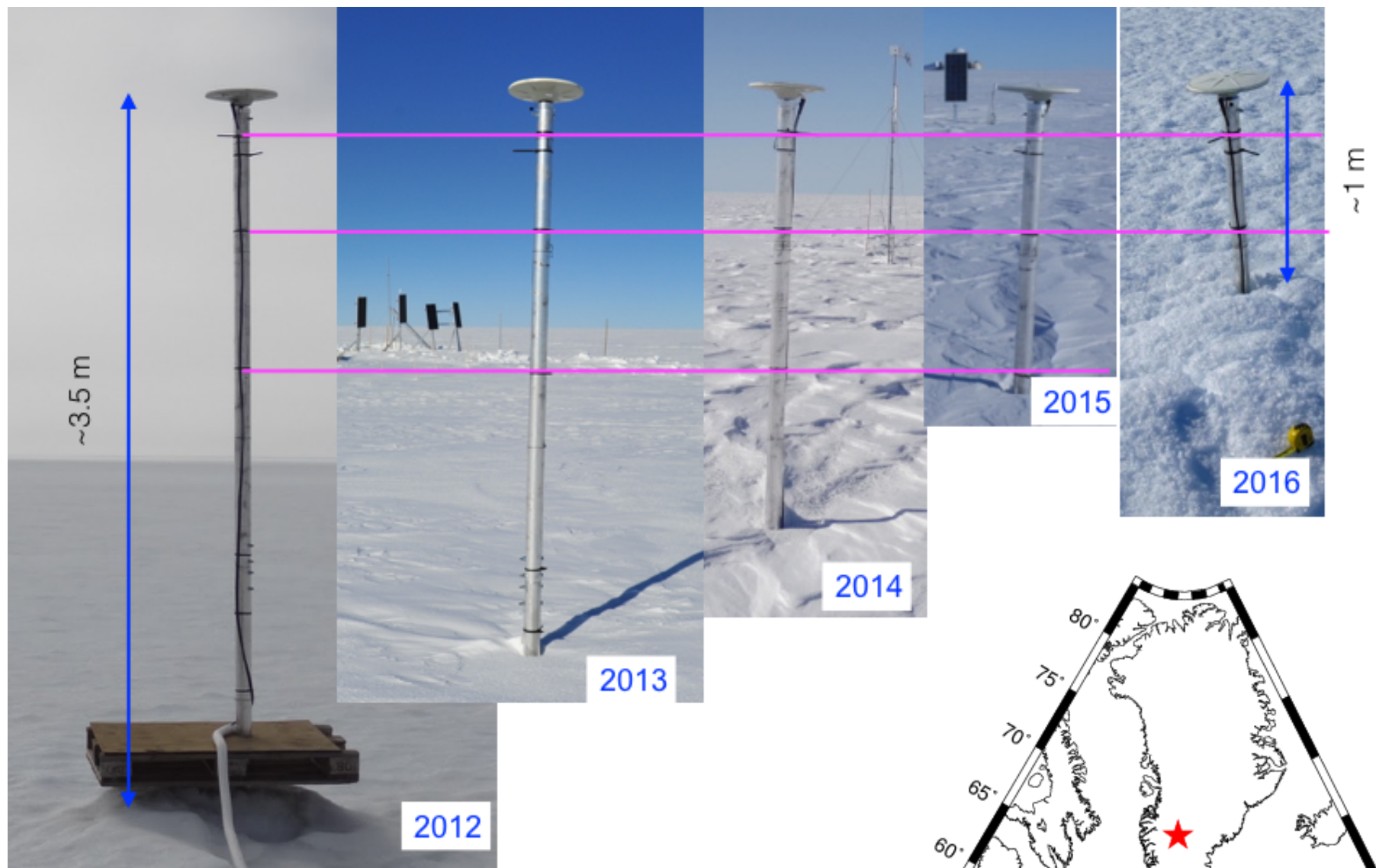
Permafrost Melt



Lin Liu, Univ. Hong Kong

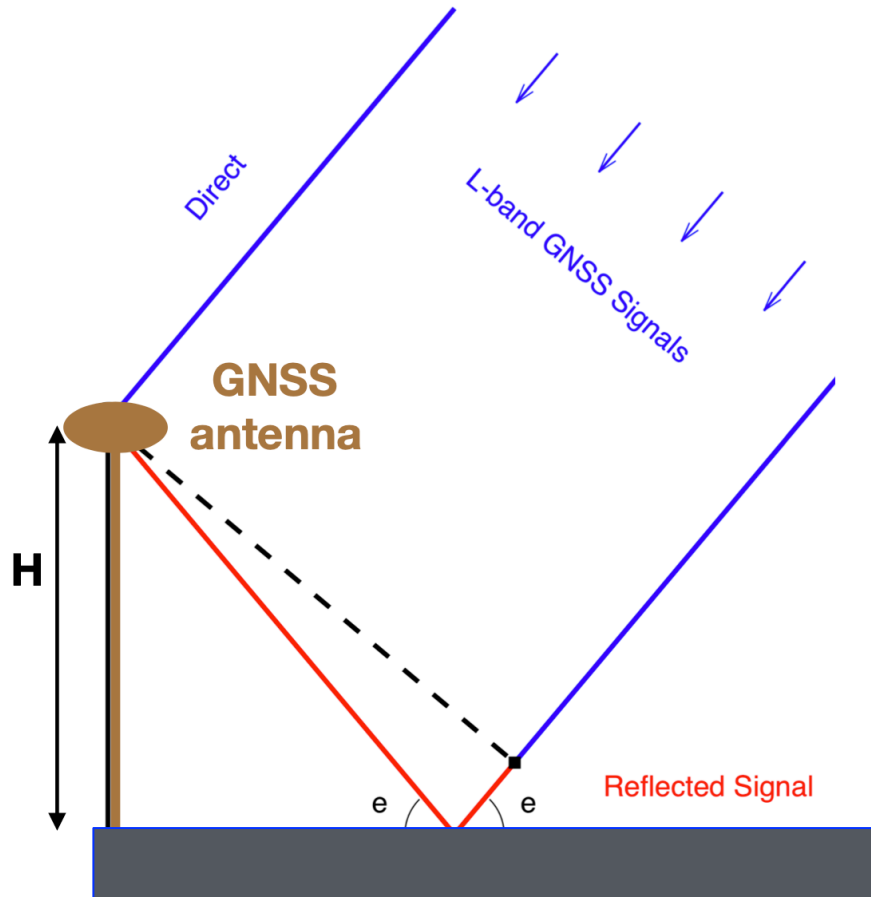


Liu and Larson, 2018

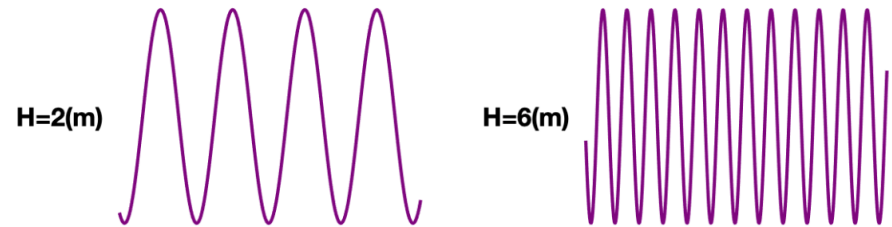


Acknowledgements: GLISN, IRIS, UNAVCO, Dean Childs.

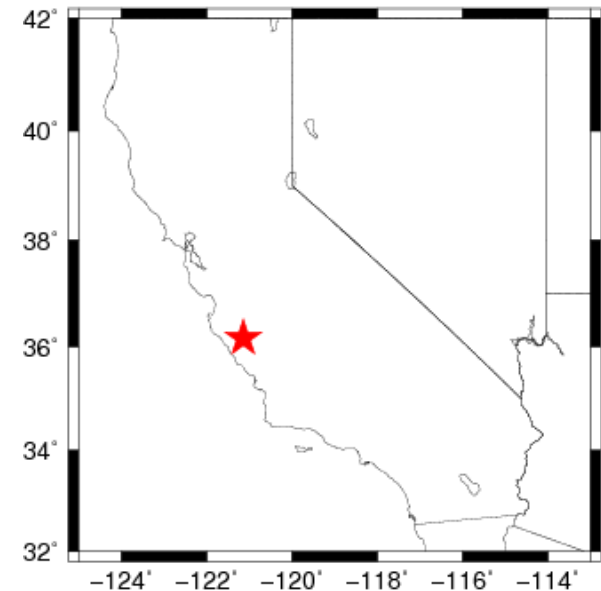
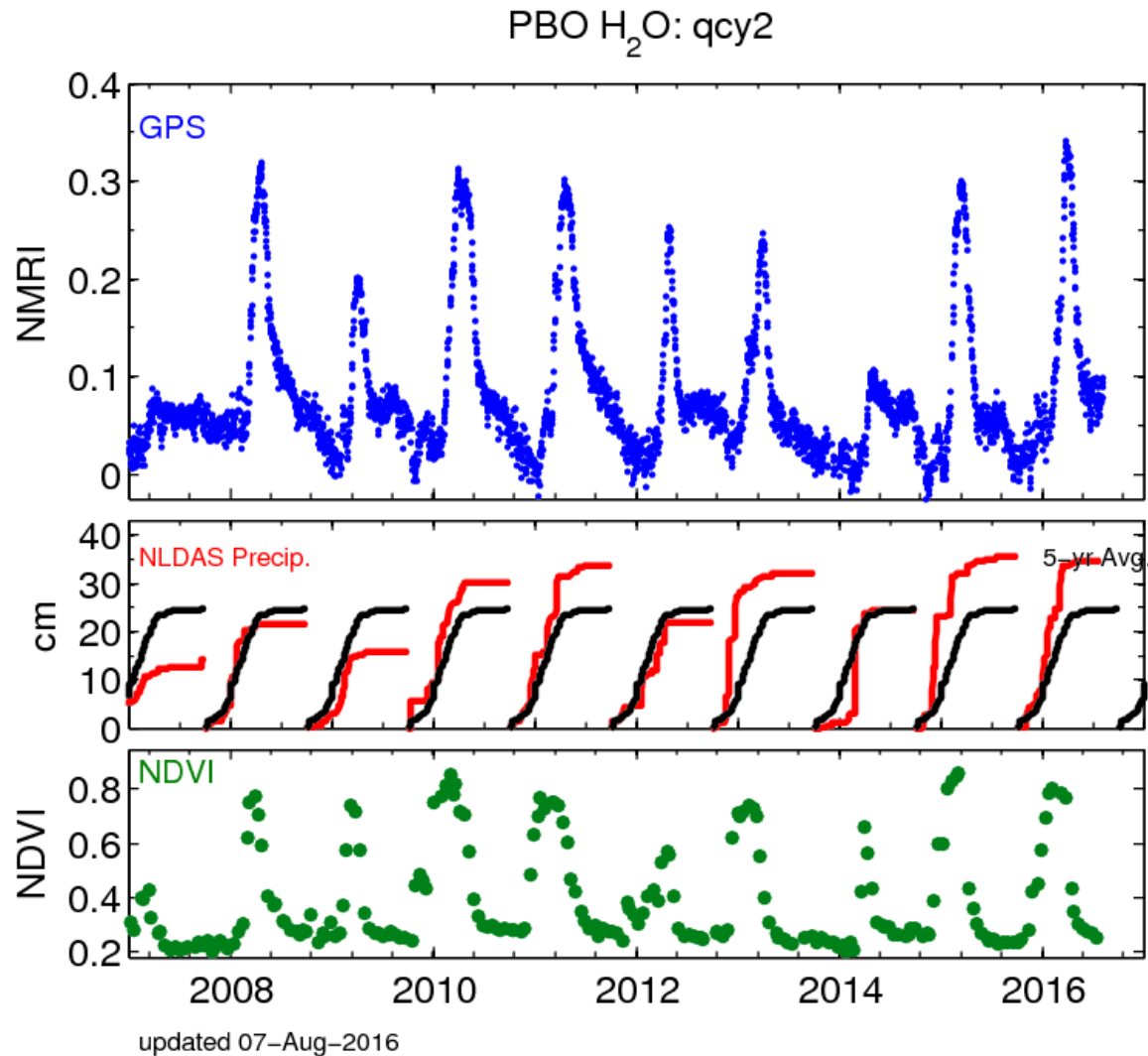
The frequency of the **interference pattern** created by the **direct** and **reflected** GNSS signals depends on H



the reflected signal also depends on the type of surface it is and its roughness



Vegetation Water Content

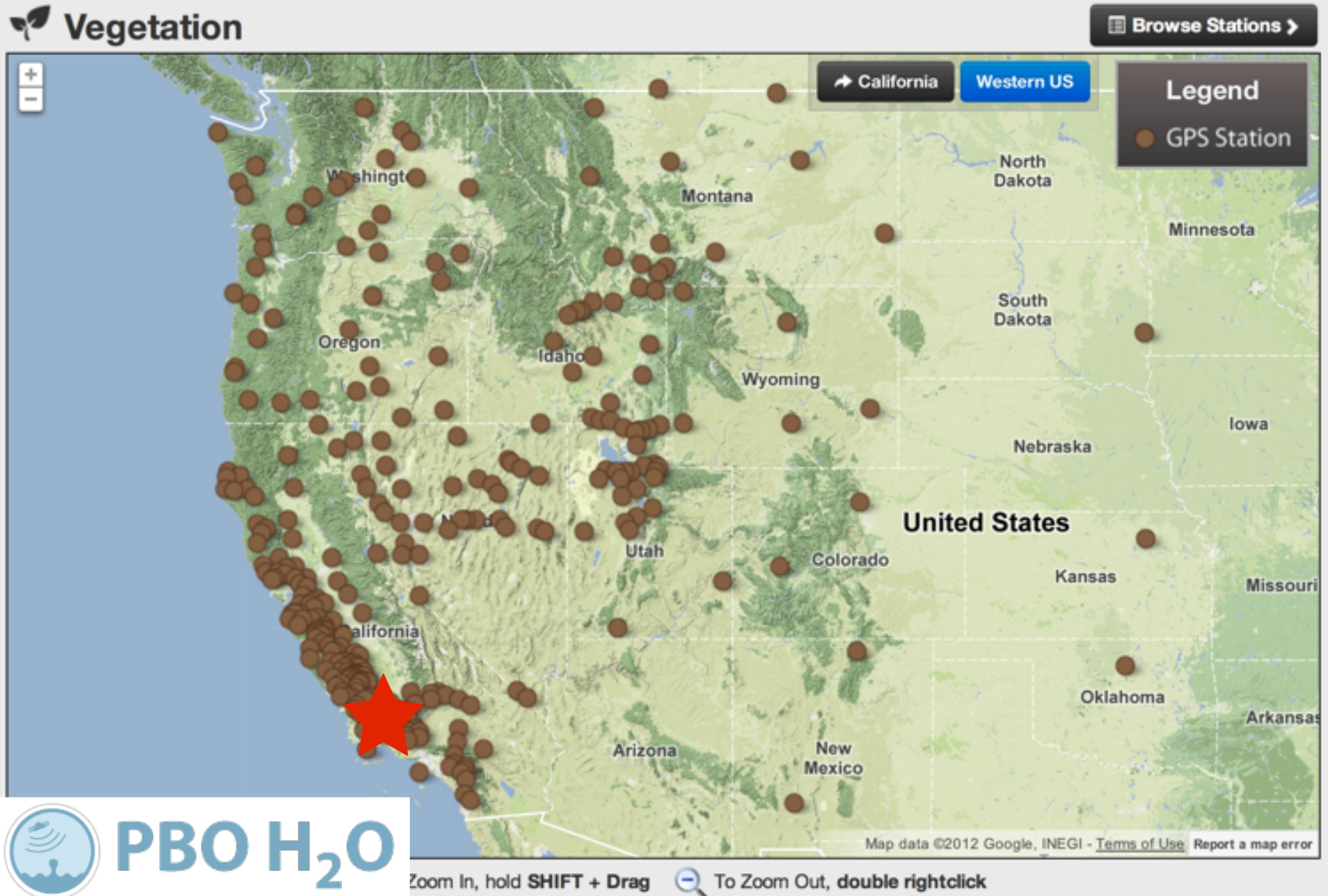


First Applications: Terrestrial Hydrology



- 2008 soil moisture: land-atmosphere interactions; runoff and infiltration; plant productivity.
- 2009 snow: timing and amount of runoff; influences climate.
- 2010 above-ground biomass: global carbon budget; influences climate.

Monitoring Vegetation



My son the 21 year old professional software engineer was willing to help me with javascript and provide feedback

