Using GNSS Signals to Measure Soil Moisture, Vegetation Water Content, Snow Depth, Water Levels, Permafrost, and Volcanic Plumes



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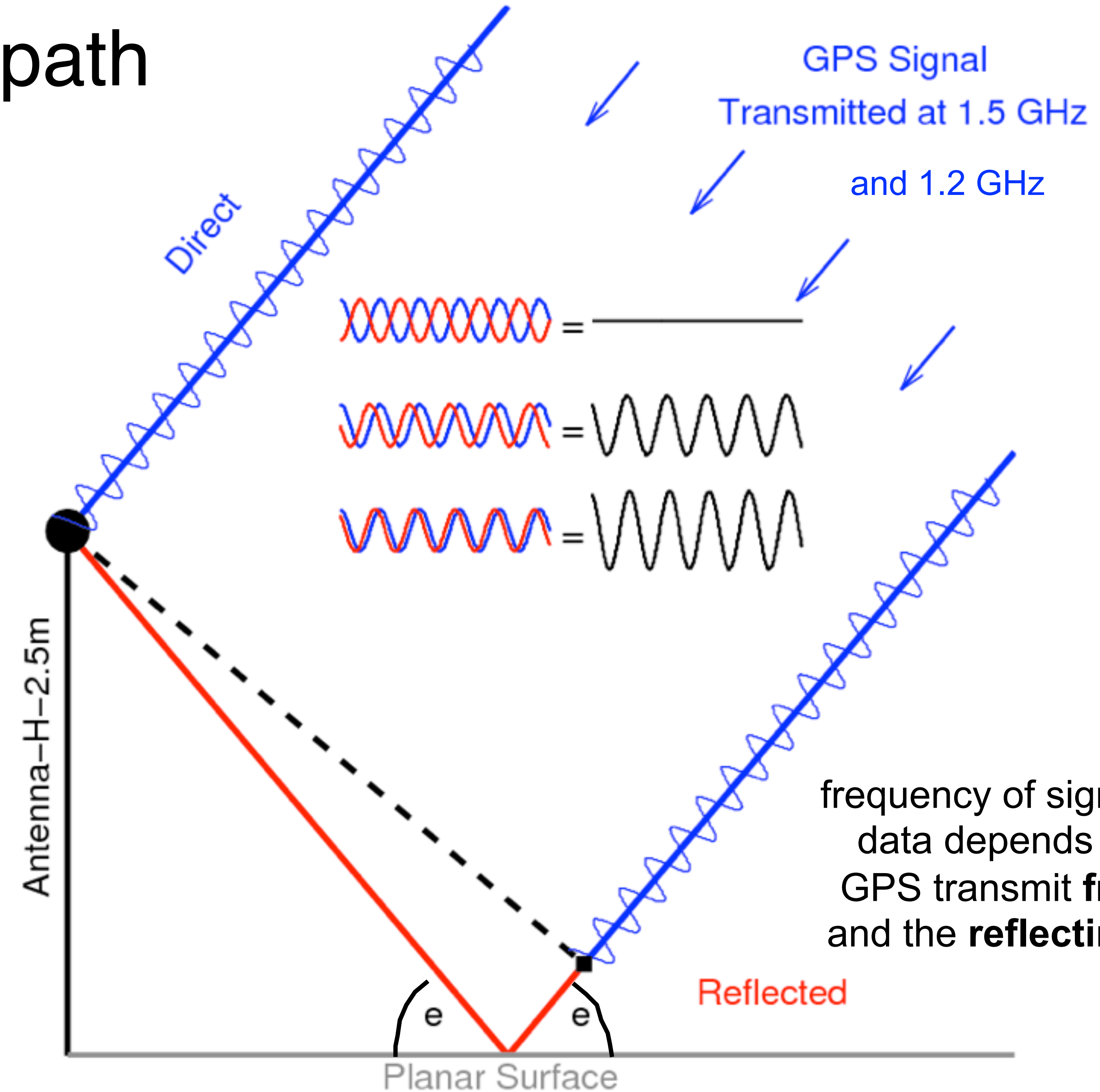
Outline

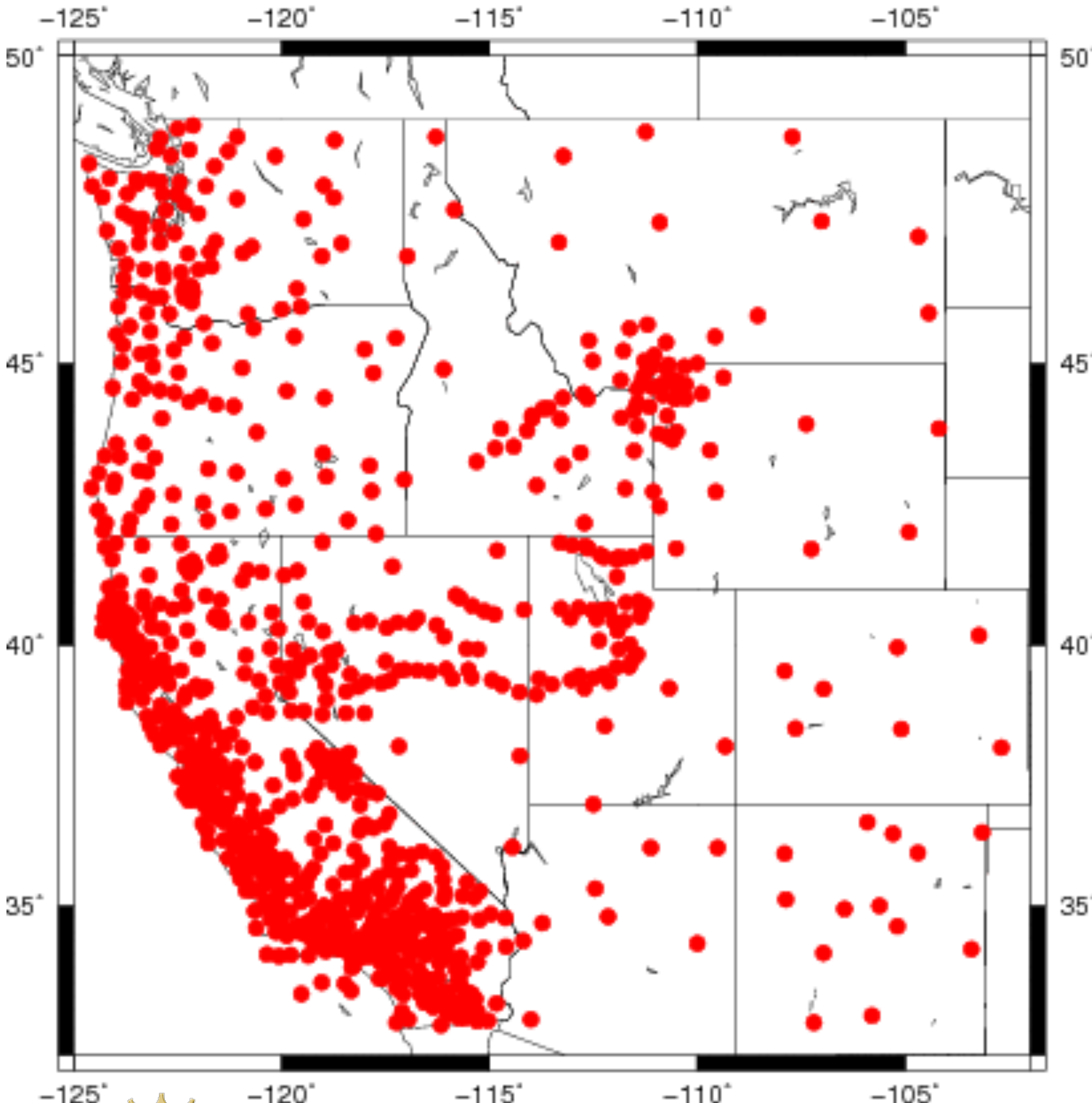
- Multipath
- Ground-based reflectometry
  - Snow
  - Soil Moisture
  - Vegetation Water Content
  - Water Levels
  - (Cryosphere)
- Volcanic Plume Sensing

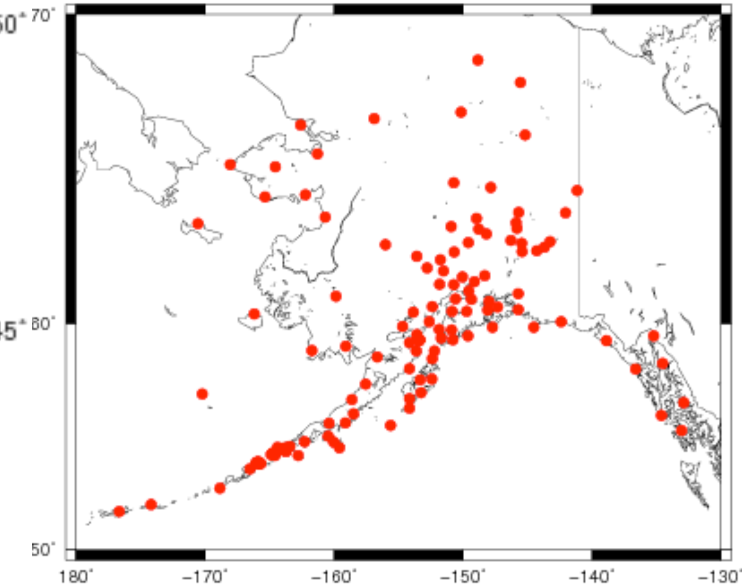
Multipath



frequency of signal strength data depends on **H**, the GPS transmit **frequency**, and the **reflecting medium**

EarthScope Plate Boundary Observatory (PBO)



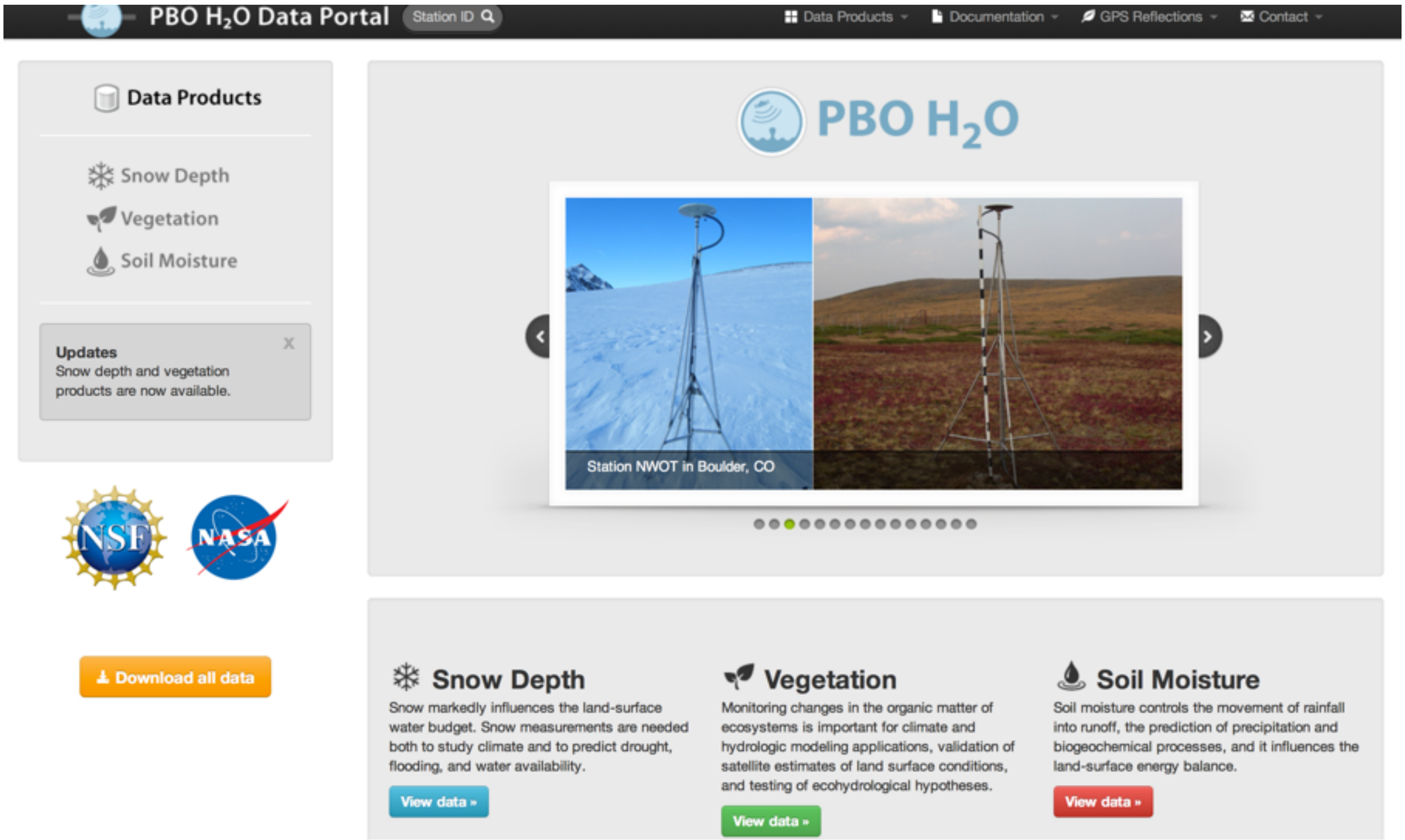


A network of 1100 continuously-operating GPS receivers - deployed to measure ground motions from plate tectonics, earthquakes, and volcanos.

Data are freely available (often in real-time) and are used by geoscientists and surveyors.

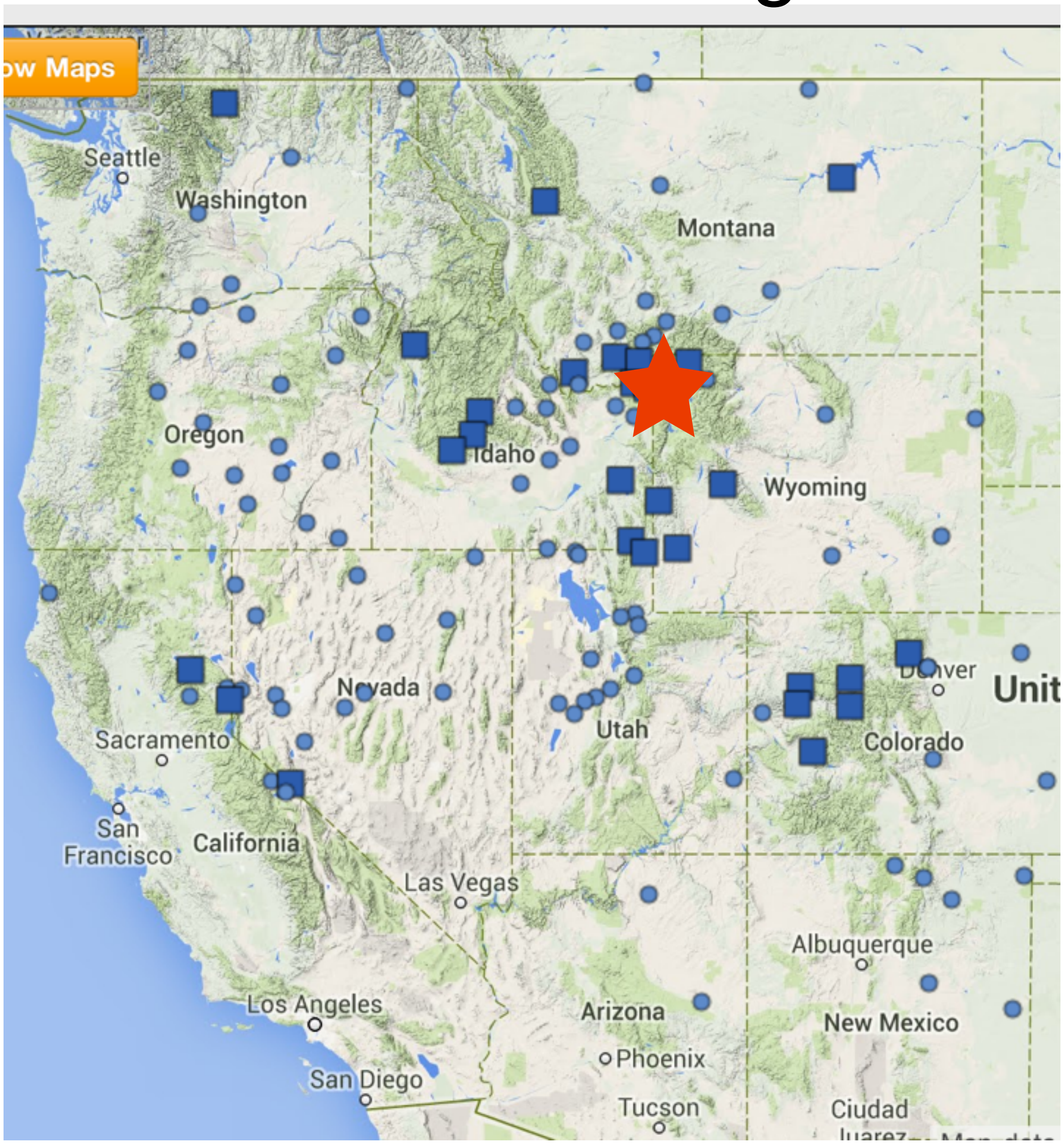
PBO H_2O

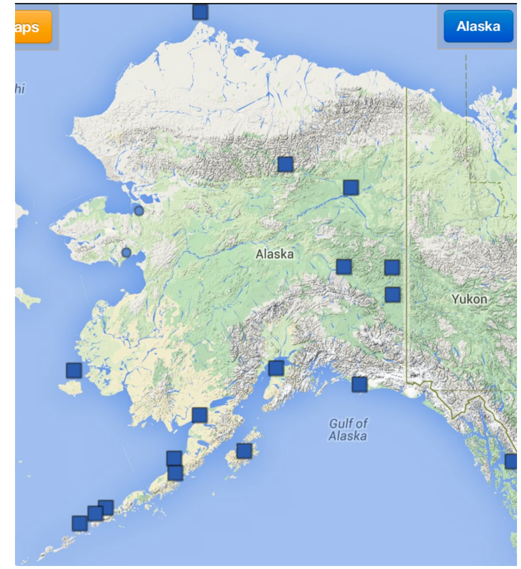
Using GPS reflection data from NSF's Plate Boundary Observatory (PBO) to study the water cycle

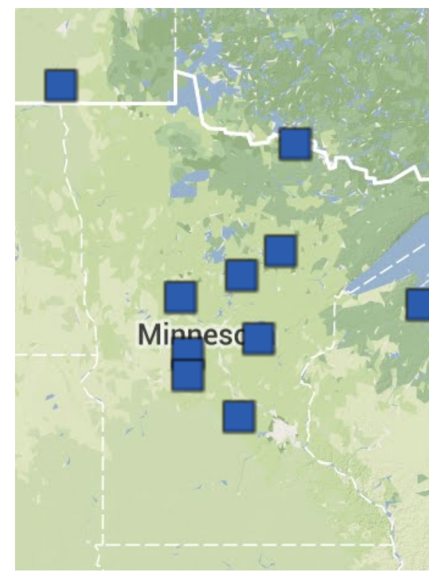


http://xenon.colorado.edu/portal

Measuring Snow

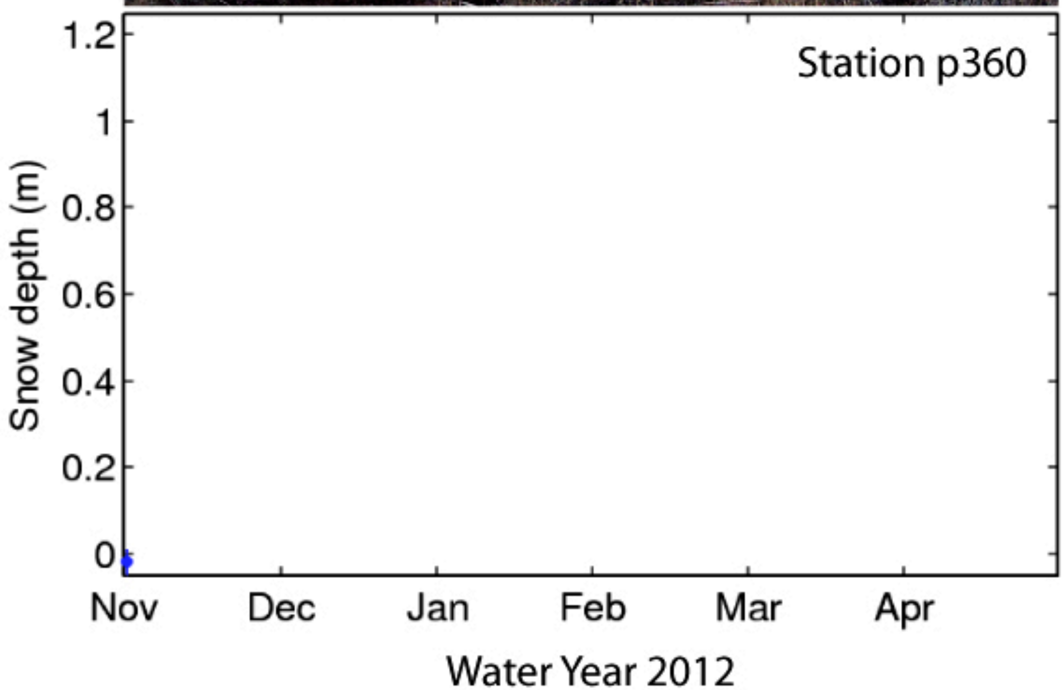


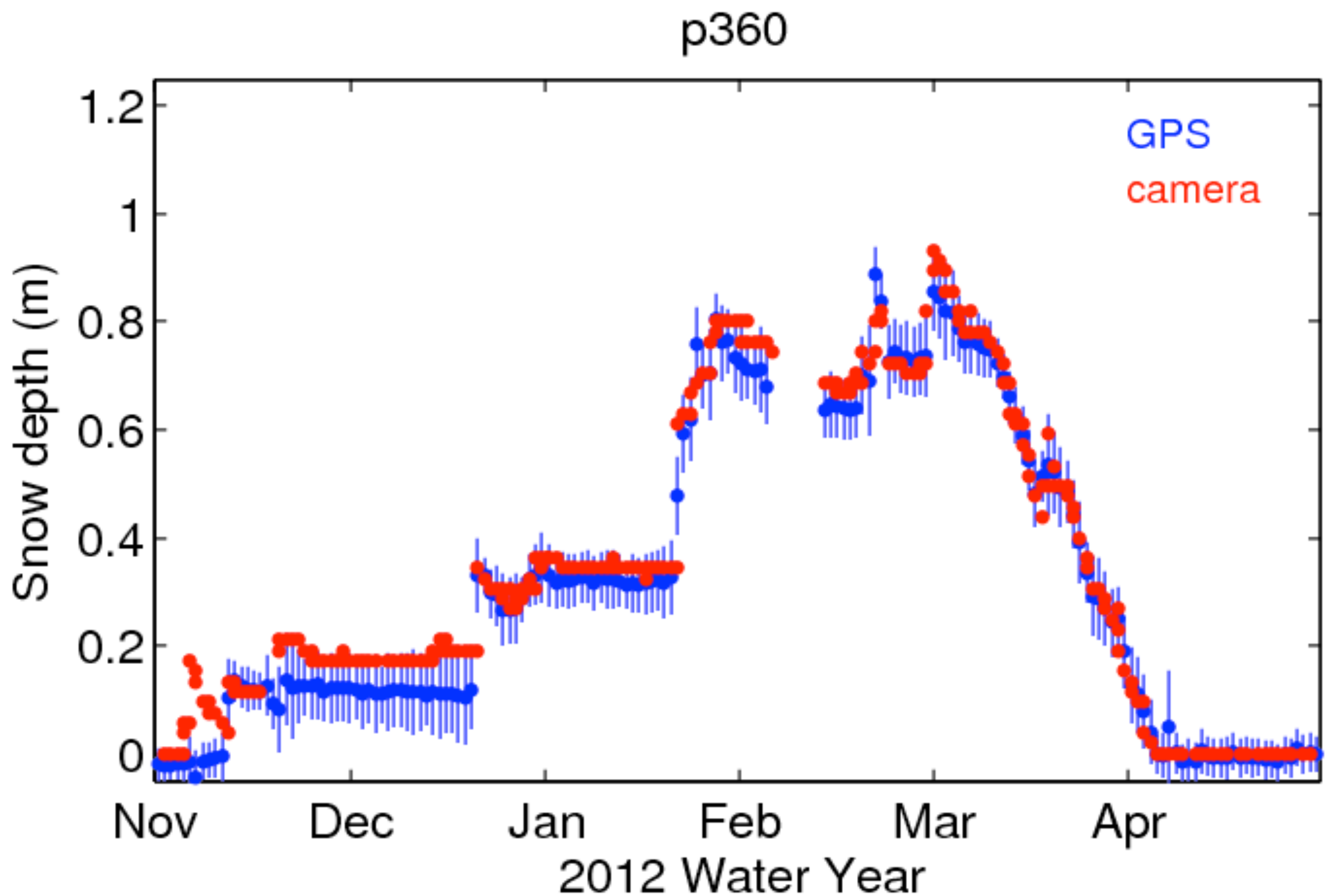




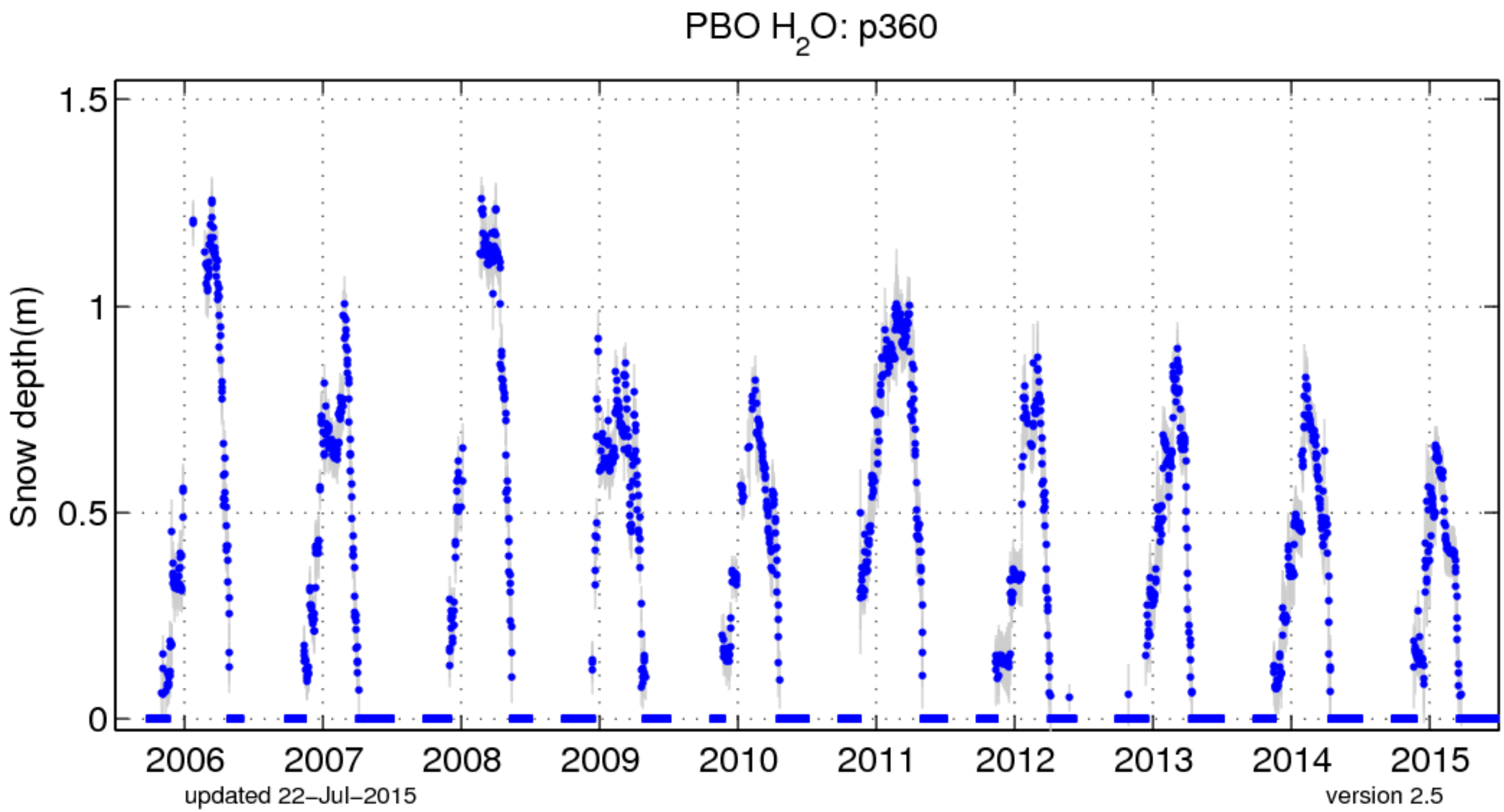
PBO H_2O

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

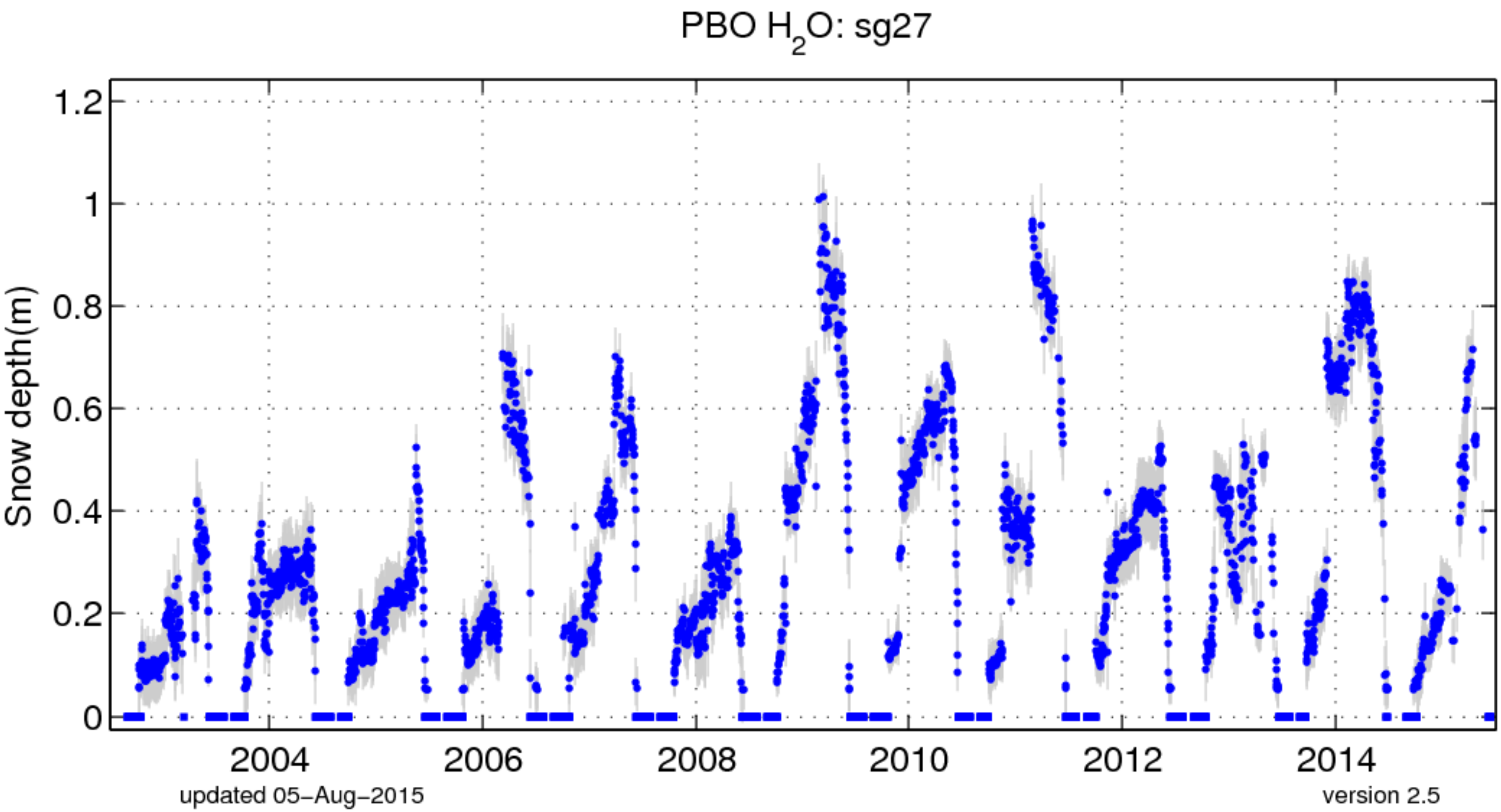

p360
GPS
camera
Snow depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
Nov
Dec
Jan
Feb
Mar
Apr
2012 Water Year

Snow Climatology

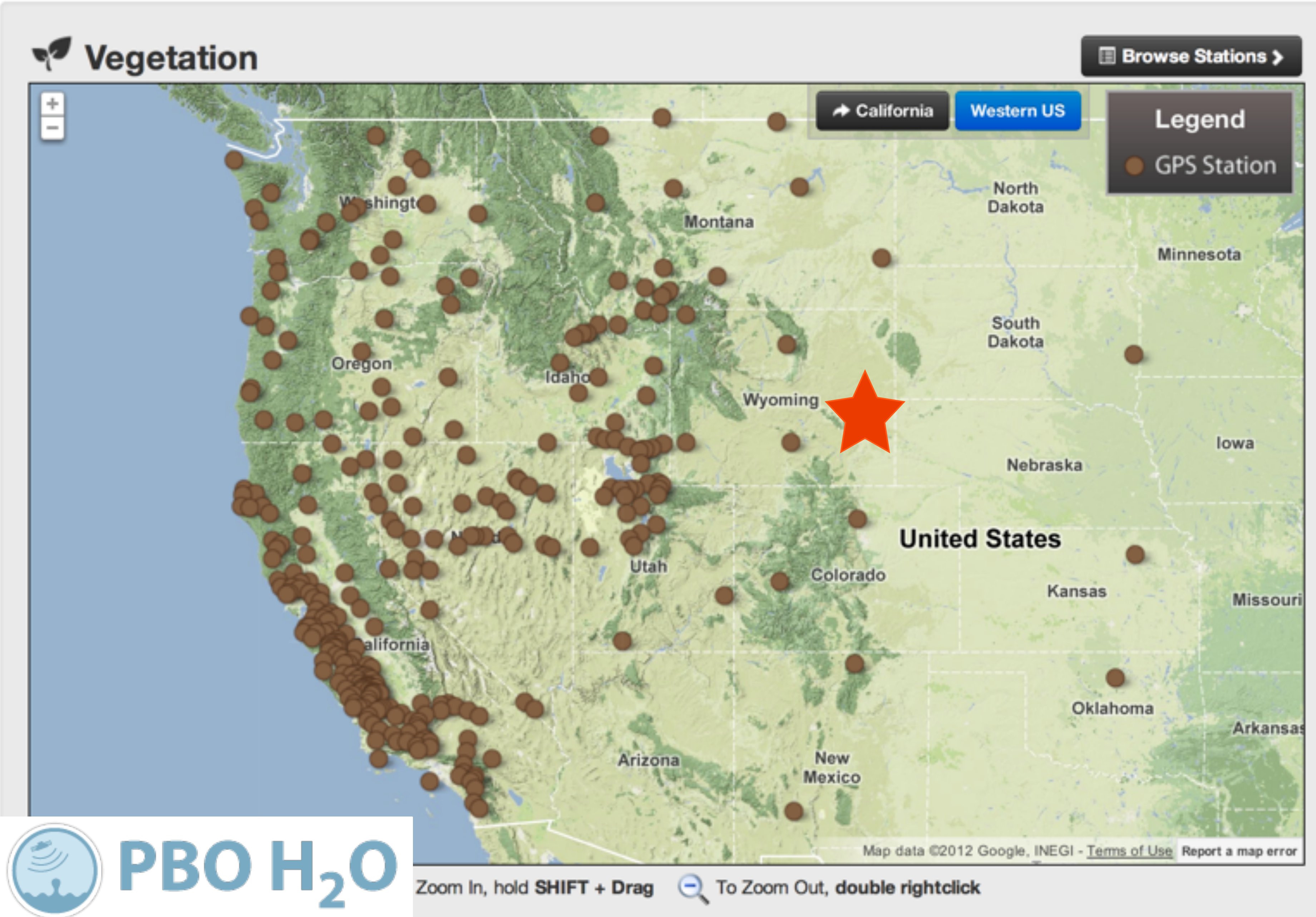


Note: we also provide a SWE product

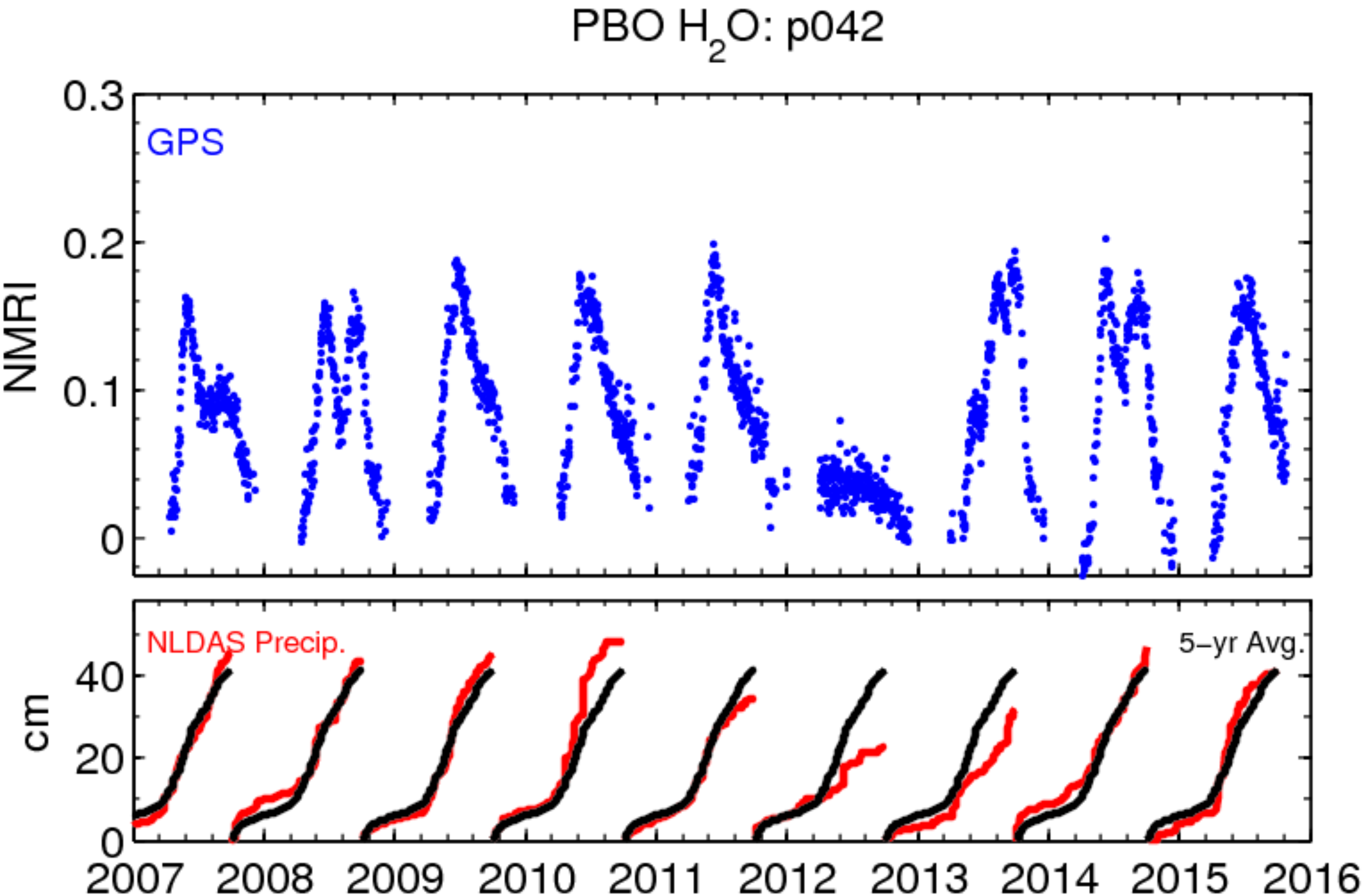
Barrow, Alaska



Monitoring Vegetation Water Content



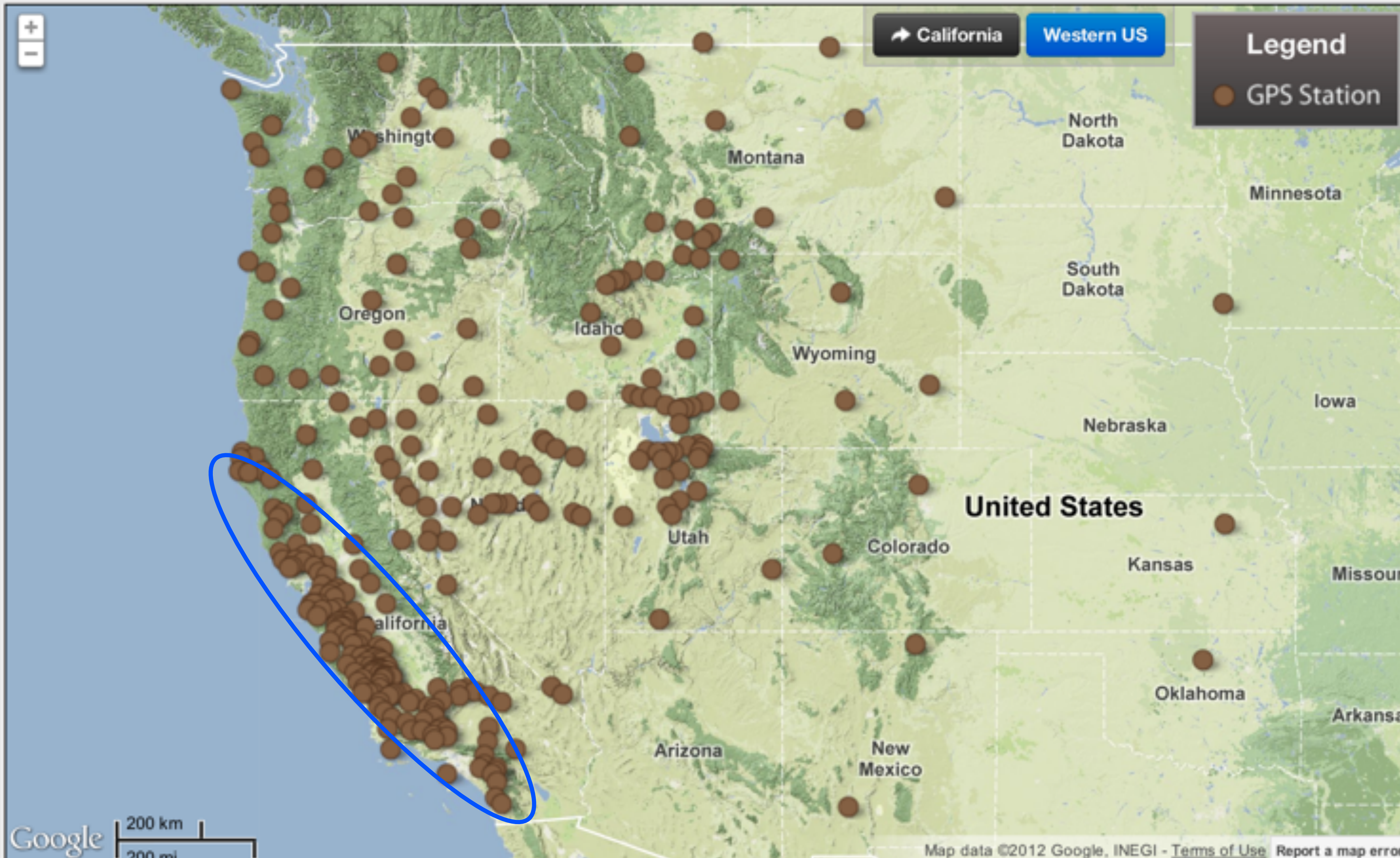
PBO H_2O



PBO H_2O: p042
GPS
NMRI
0.3
0.2
0.1
0
NLDAS Precip.
5–yr Avg.
cm
40
20
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

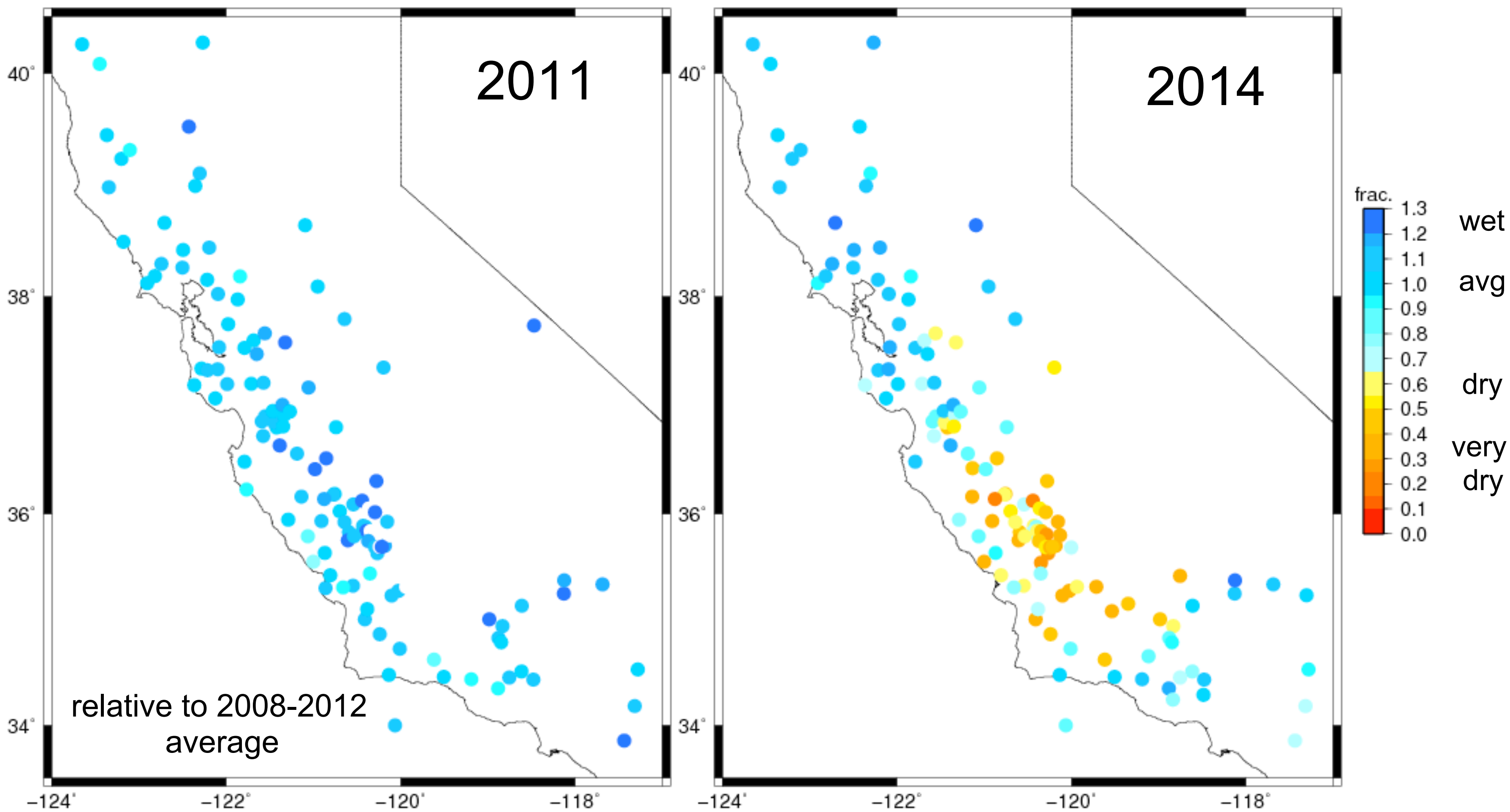
Vegetation

Browse Stations

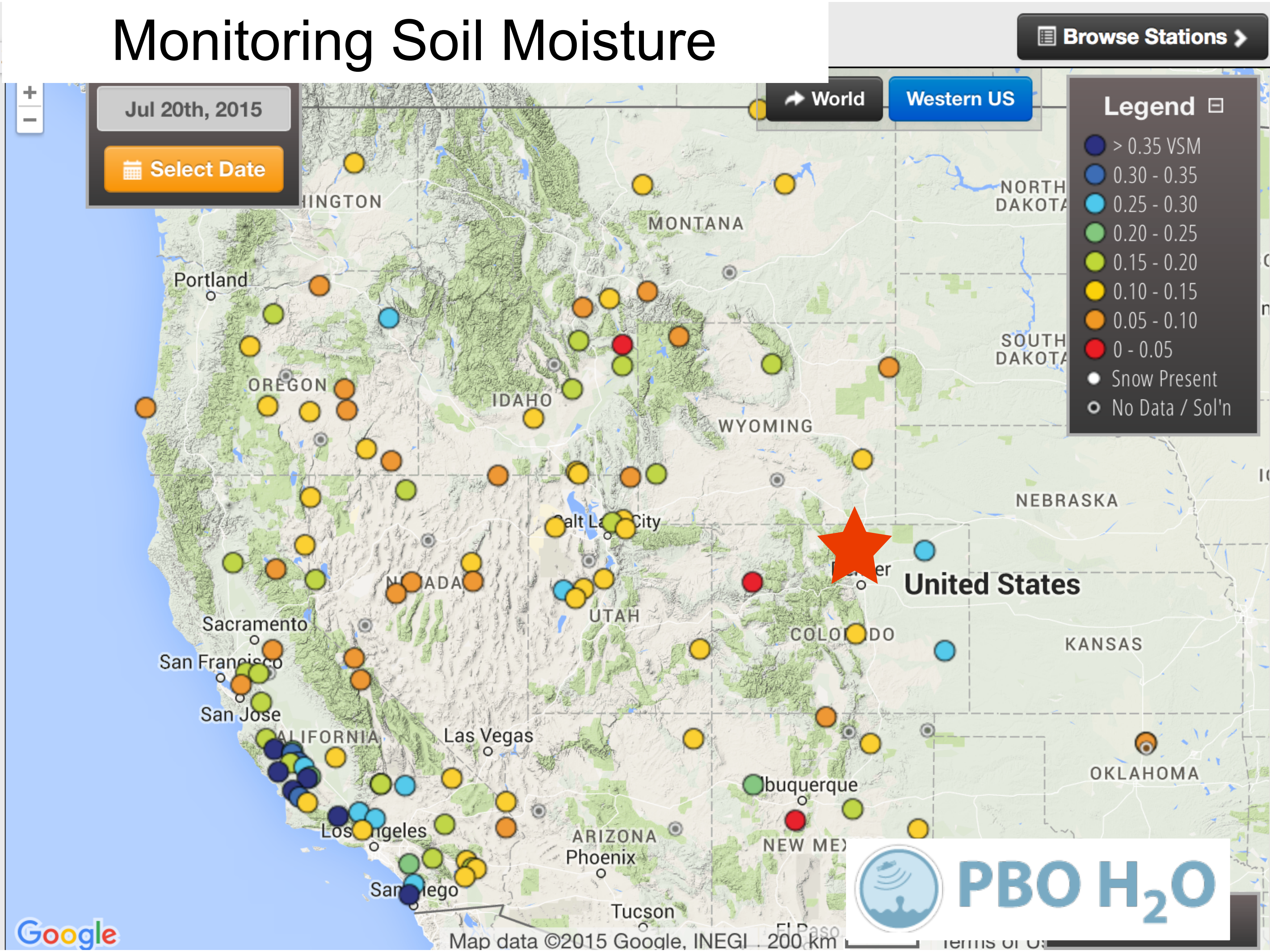


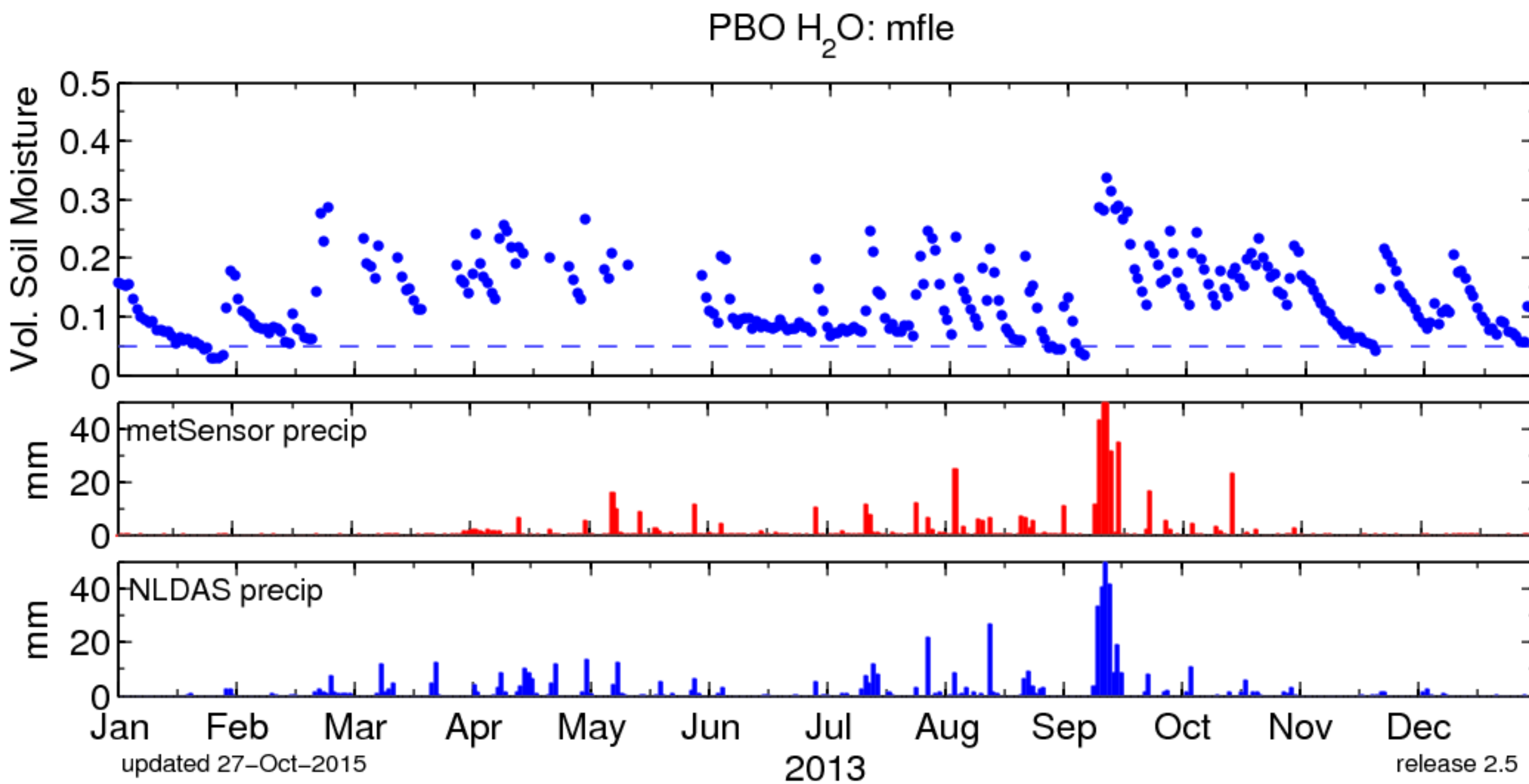
To Zoom In, hold **SHIFT + Drag** To Zoom Out, **double rightclick**

Peak Vegetation Water Content

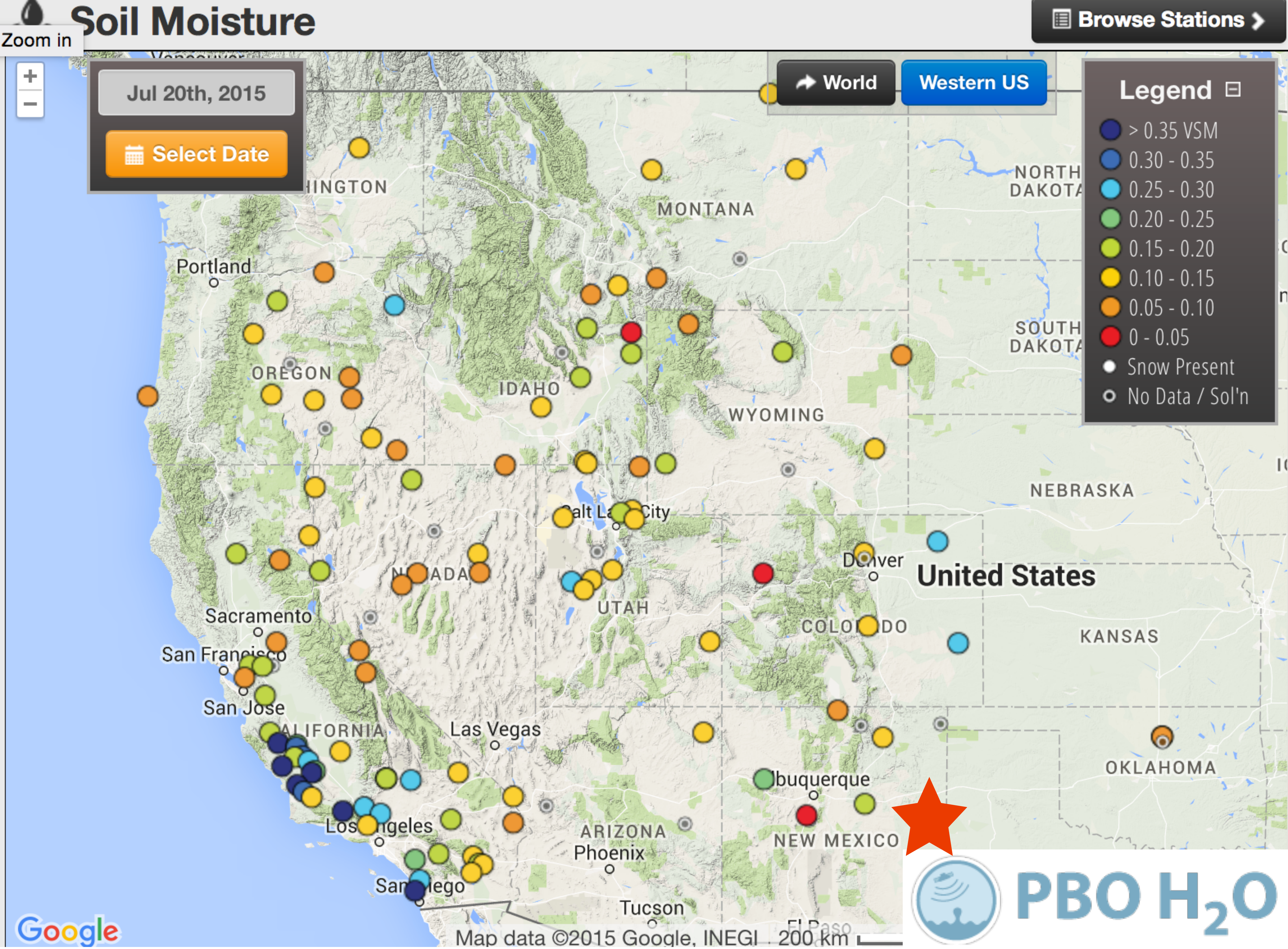


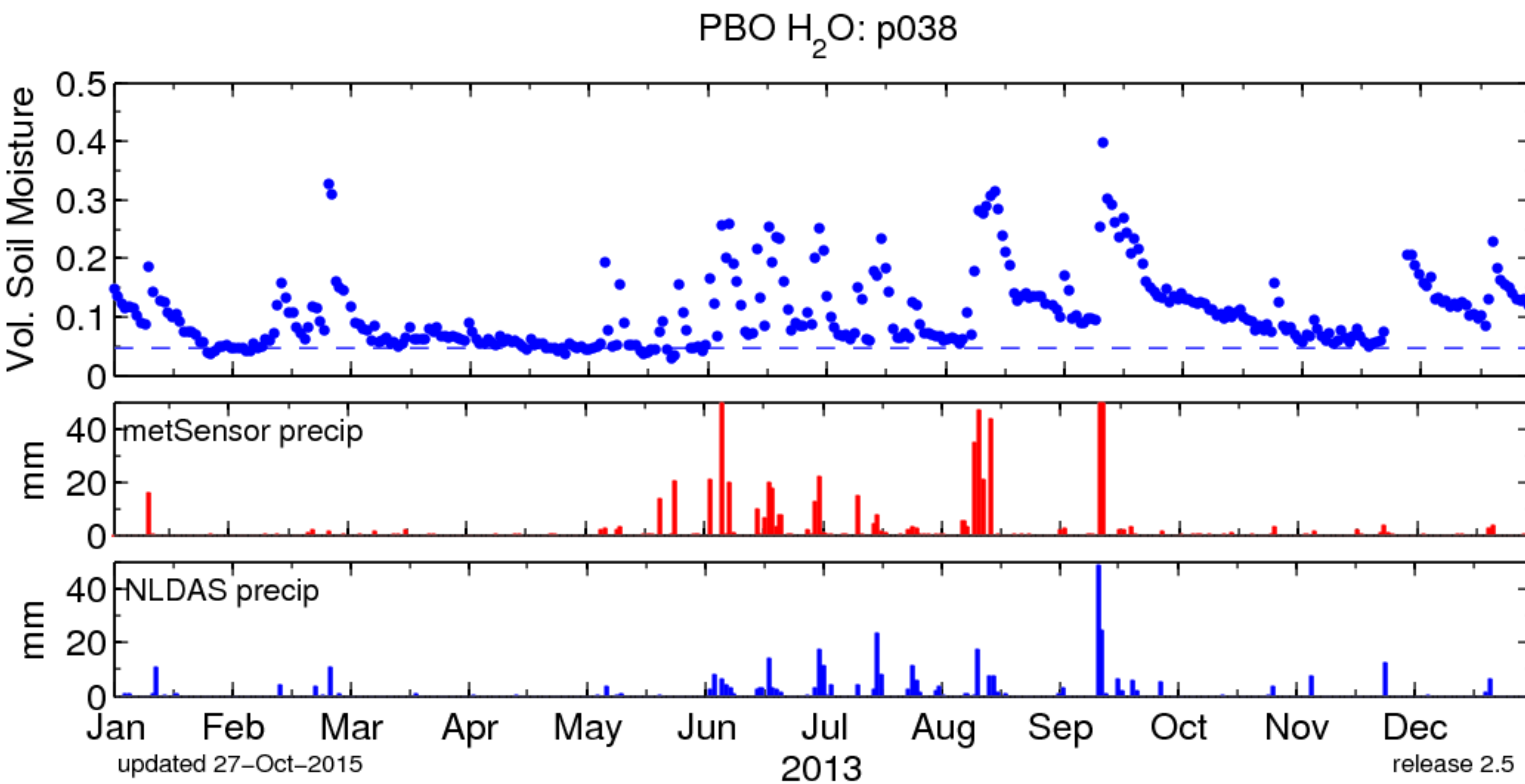
Monitoring Soil Moisture





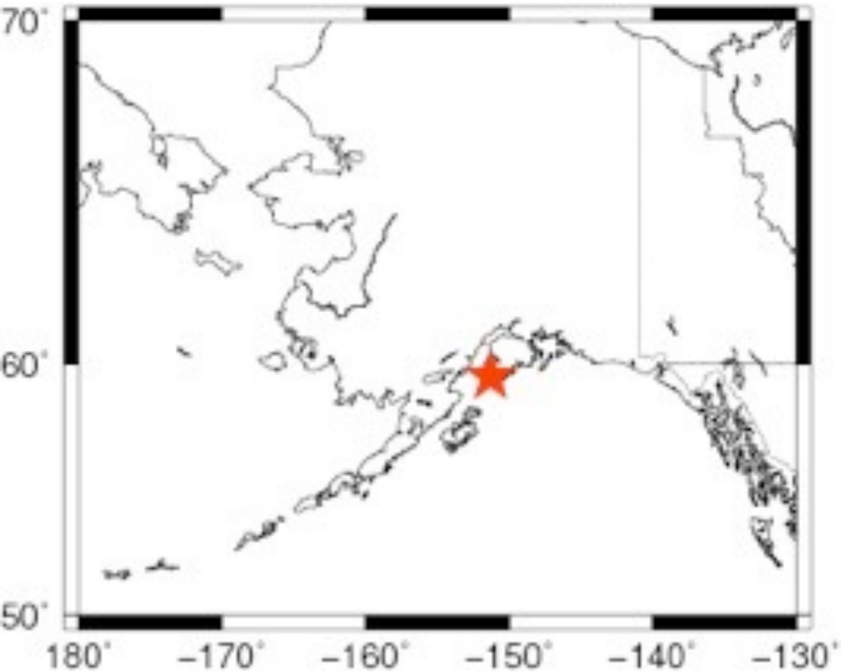
PBO H2O: mfle
Vol. Soil Moisture
0.5
0.4
0.3
0.2
0.1
0
metSensor precip
mm
40
20
0
NLDAS precip
mm
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
updated 27−Oct−2015
2013
release 2.5


Soil Moisture
Zoom in
Browse Stations
Jul 20th, 2015
Select Date
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
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
Portland
OREGON
IDAHO
WYOMING
NEBRASKA
UTAH
COLORADO
KANSAS
OKLAHOMA
United States
Sacramento
San Jose
Las Vegas
ARIZONA
Phoenix
NEW MEXICO
Tucson
PBO H2O
Map data ©2015 Google, INEGI 200 km
Google



PBO H_2O: p038
Vol. Soil Moisture
0.5
0.4
0.3
0.2
0.1
0
metSensor precip
mm
40
20
0
NLDAS precip
mm
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2013
updated 27-Oct-2015
release 2.5

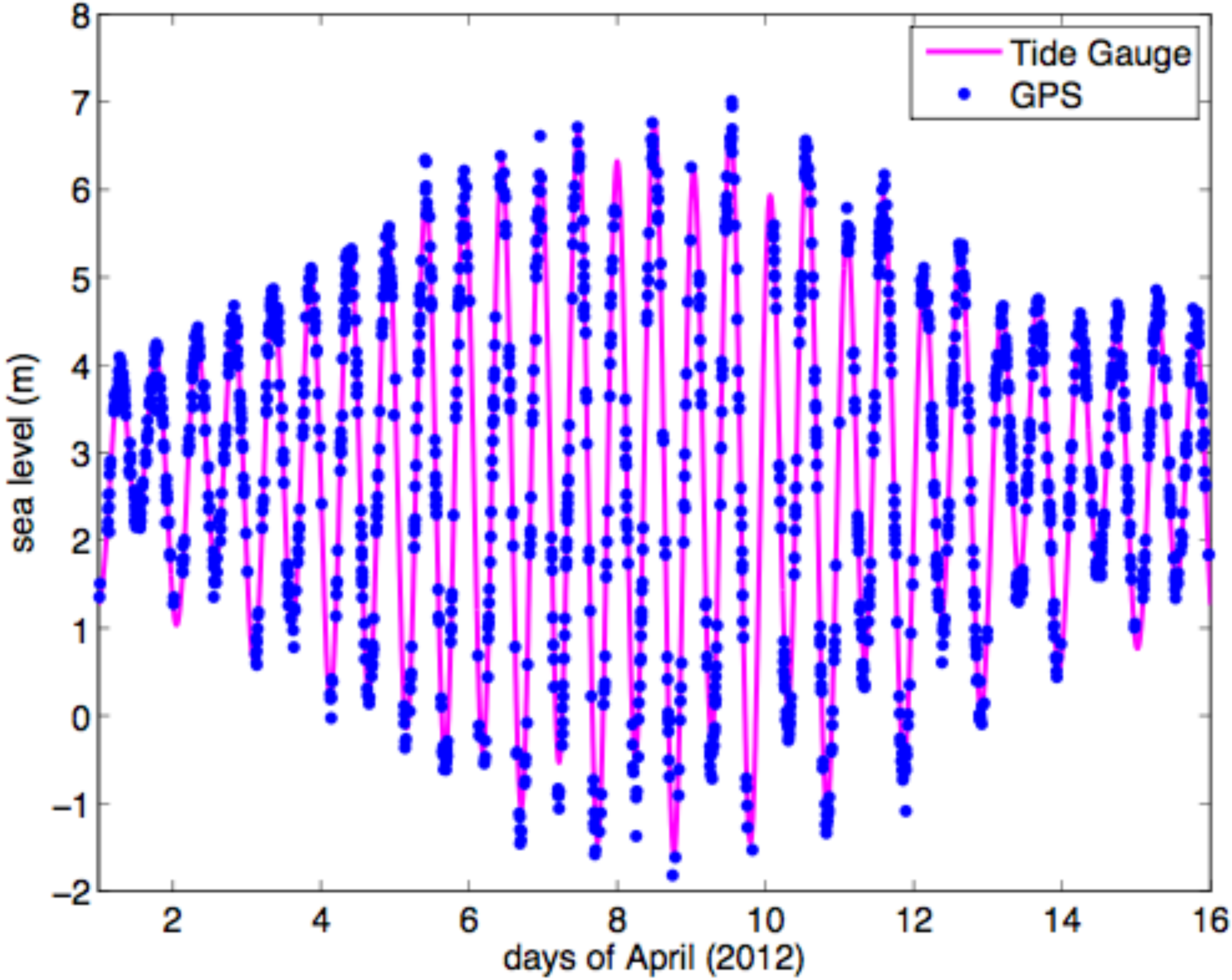
What else can you do with reflected GPS signals?



Kachemak Bay, Alaska

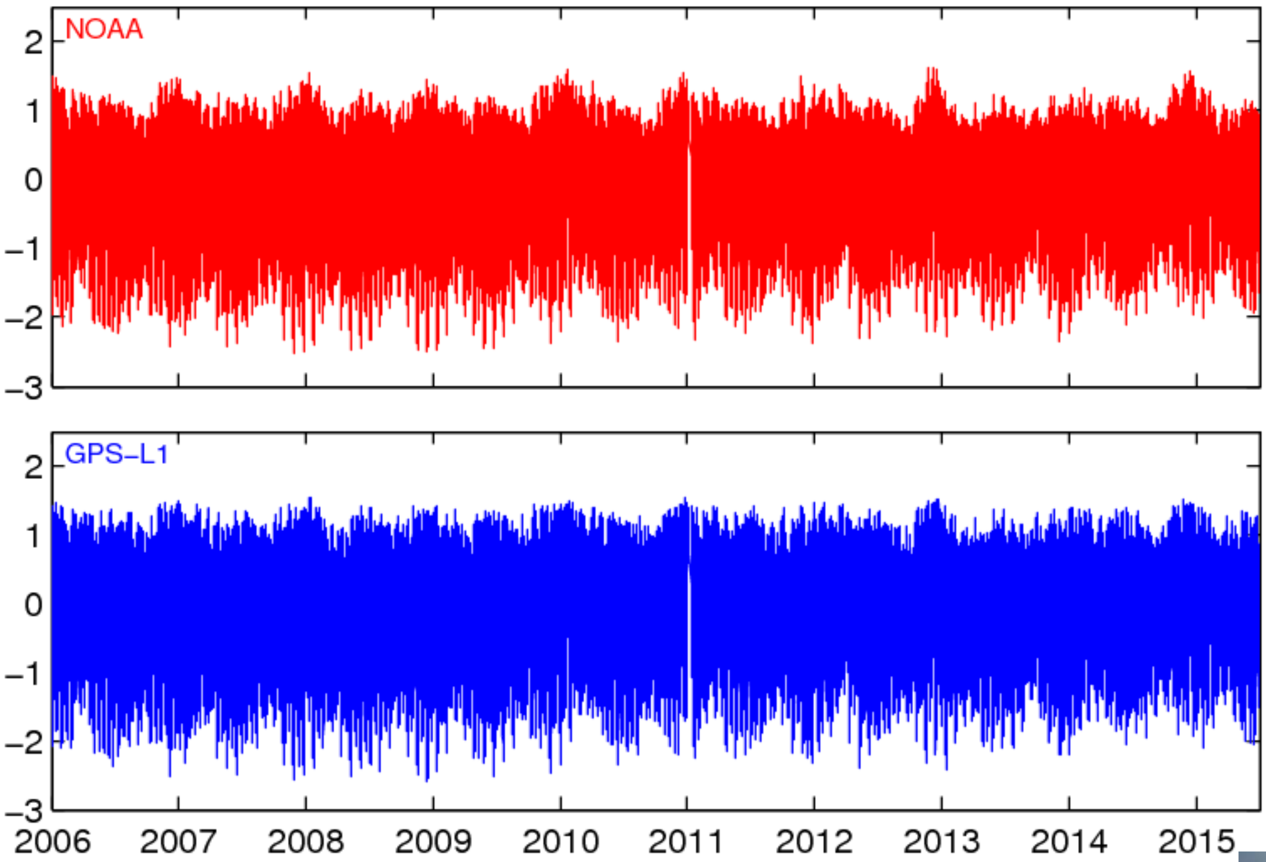
GPS site installed by Jeff Freymueller
University of Alaska at Fairbanks

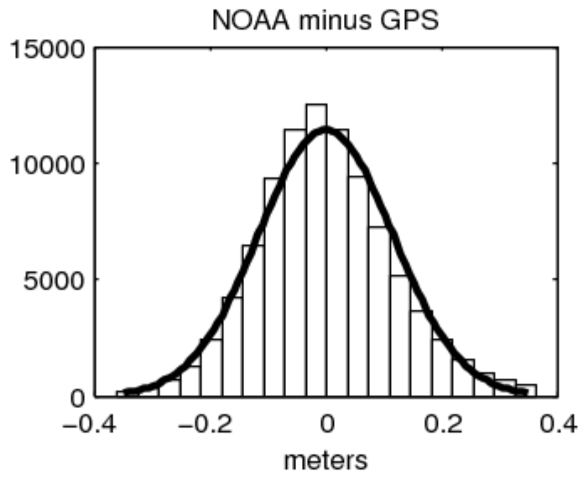
Comparison between GPS and ‘Real’ Tide Gauge



Larson et al., The Accidental Tide Gauge, *IEEE GRSL*, 2013

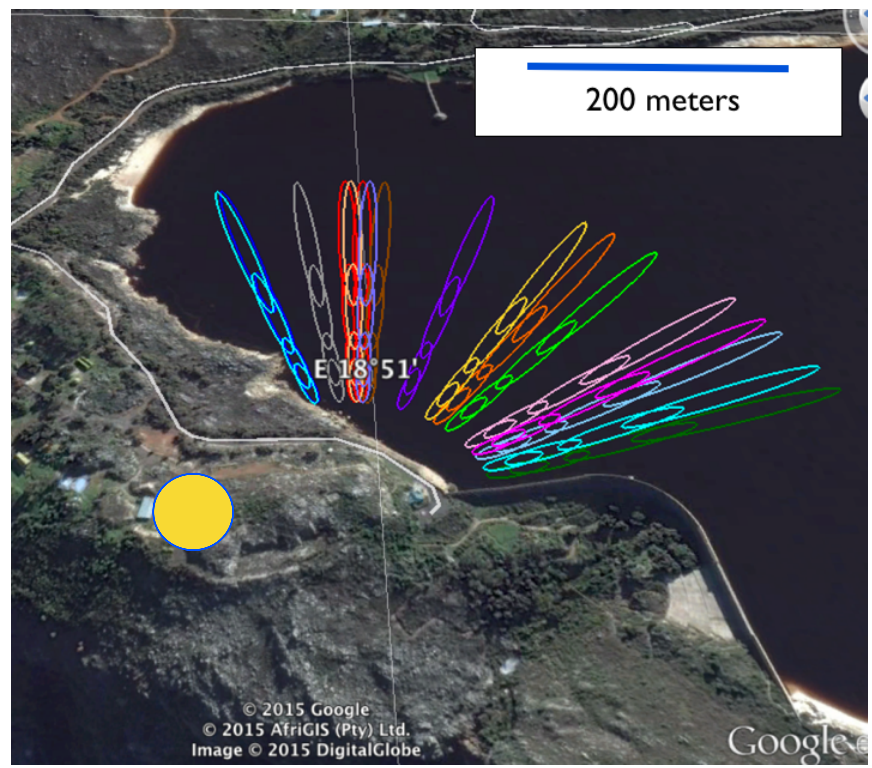
Friday Harbor, Washington, USA



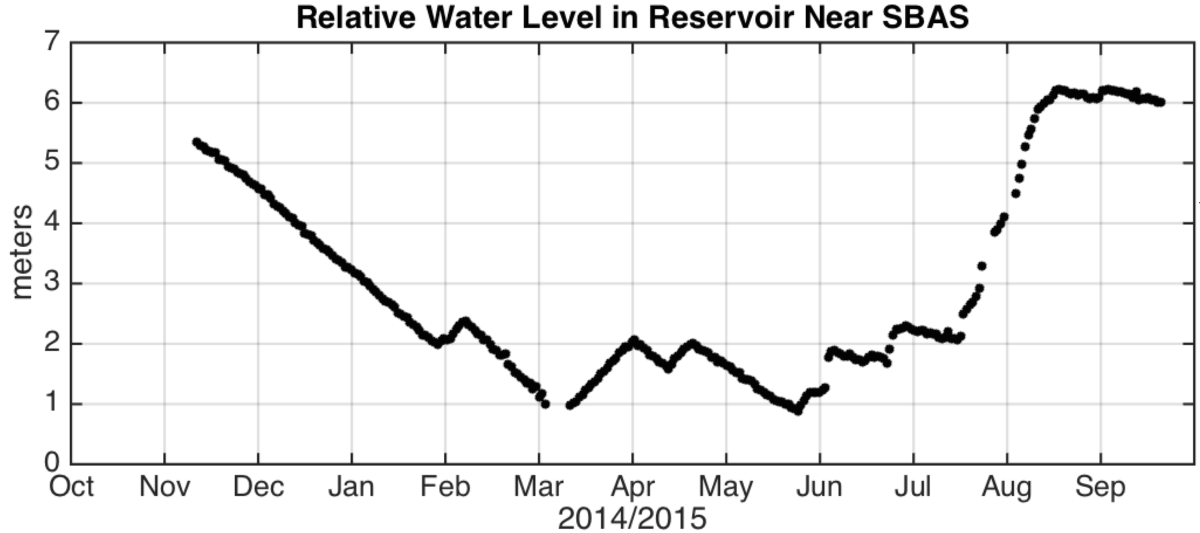


Fit to tidal coefficients: 7.5 cm for NOAA, 8.4 cm for GPS

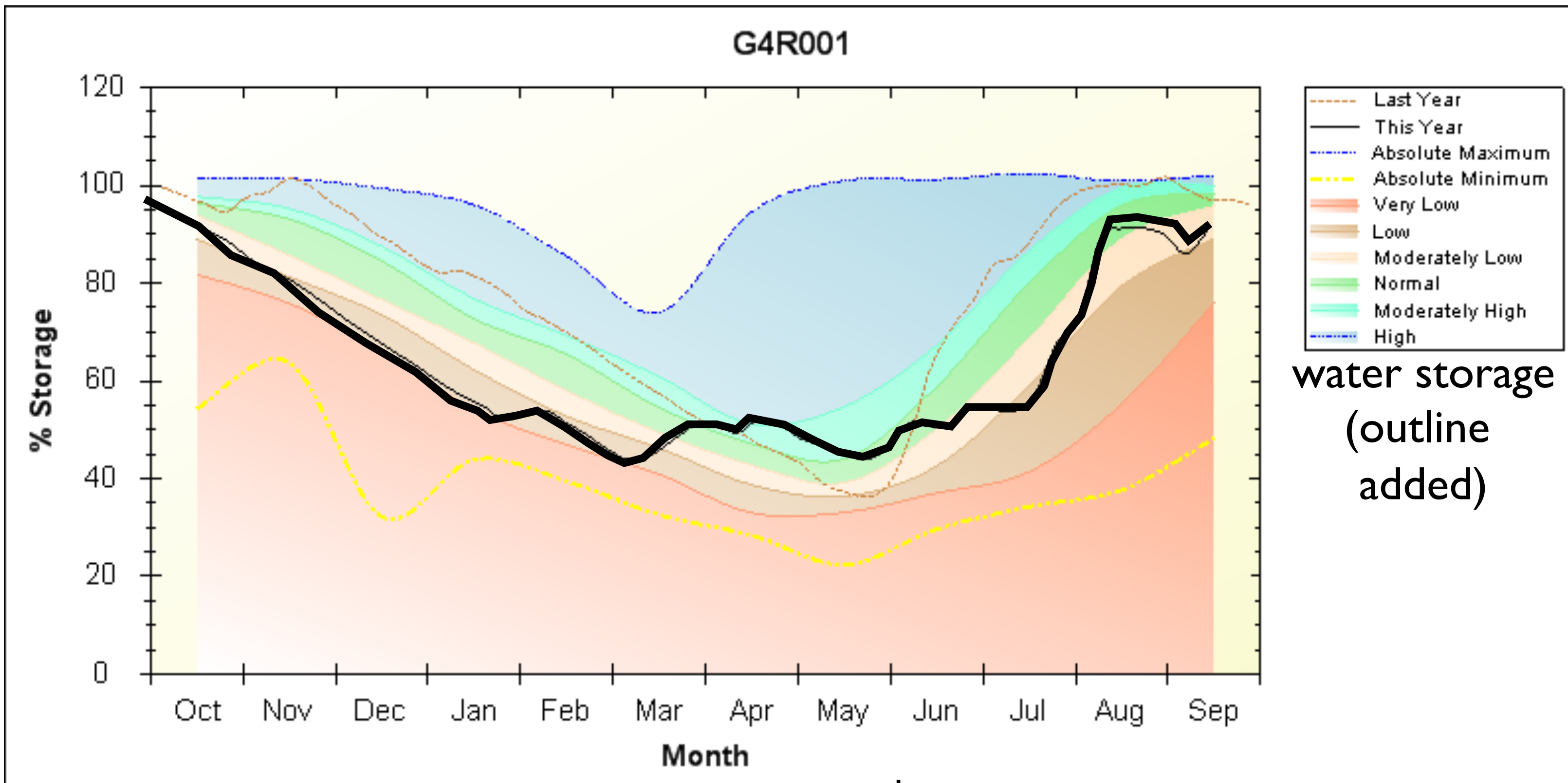
Steenbras Dam, Republic of South Africa



GPS Data courtesy of Trignet



GPS derived water level

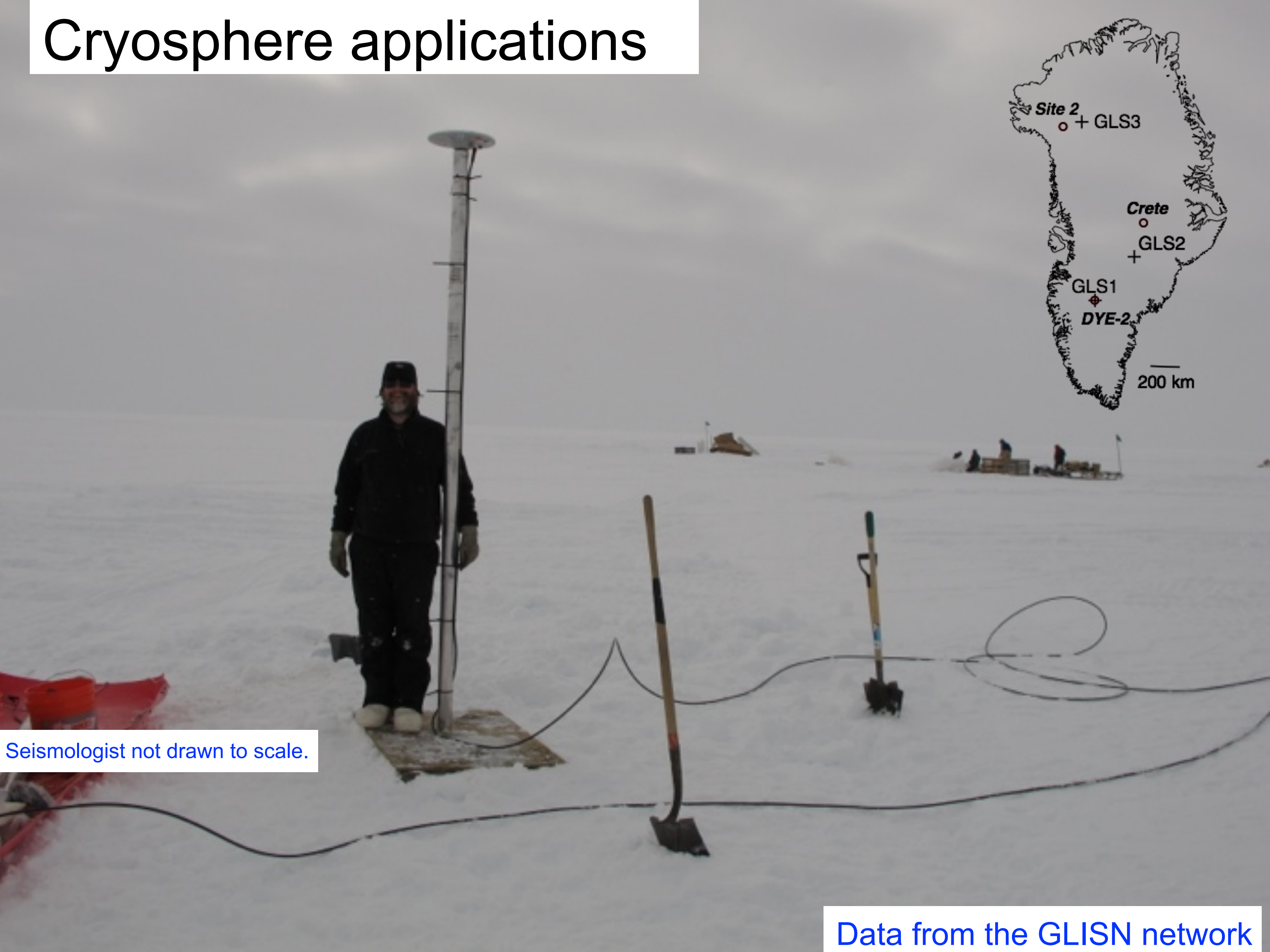


water storage (outline added)

water storage data:

https://www.dwa.gov.za/Hydrology/Weekly/percentile.aspx?station=%20G4R001

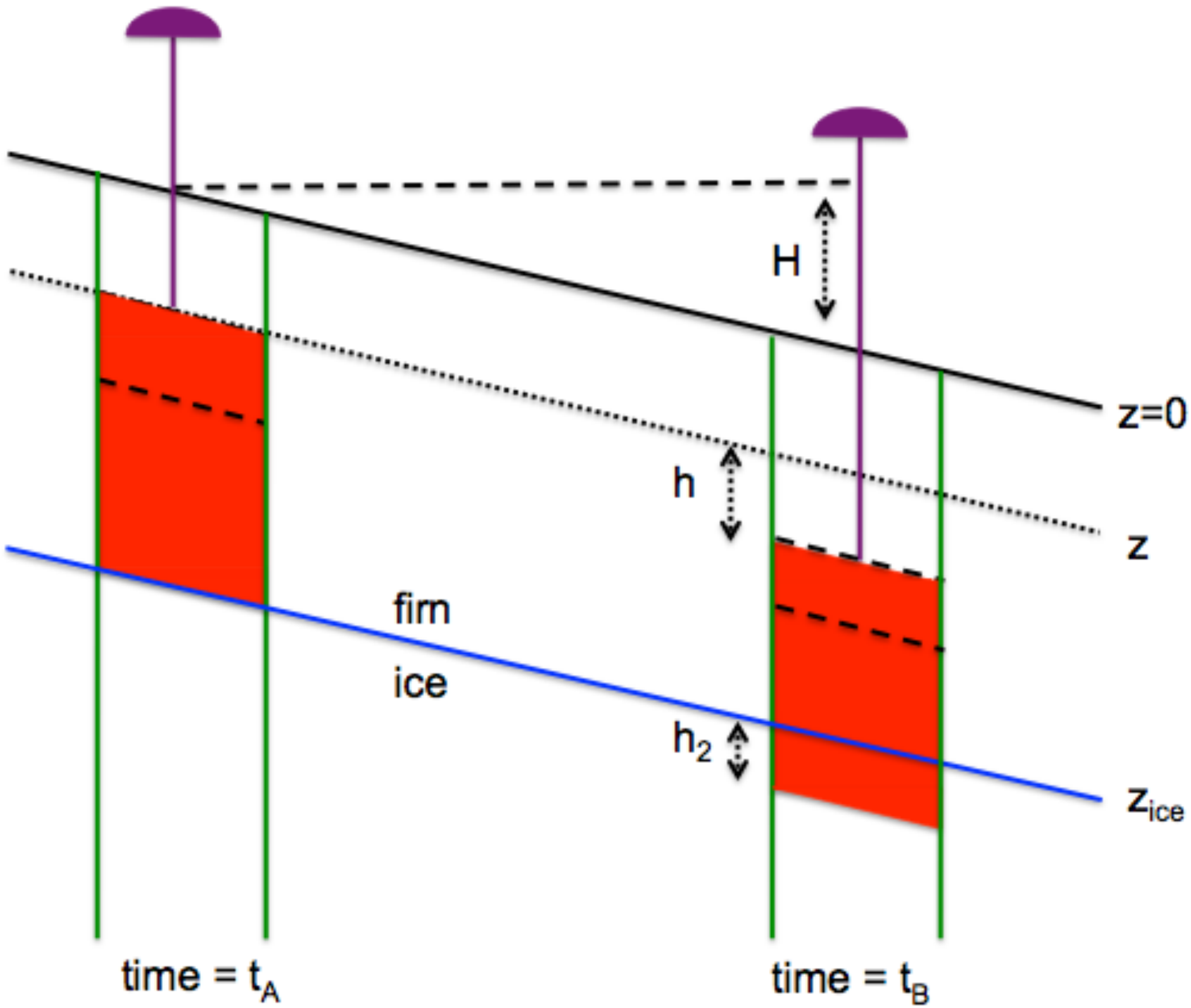
Cryosphere applications



Seismologist not drawn to scale.

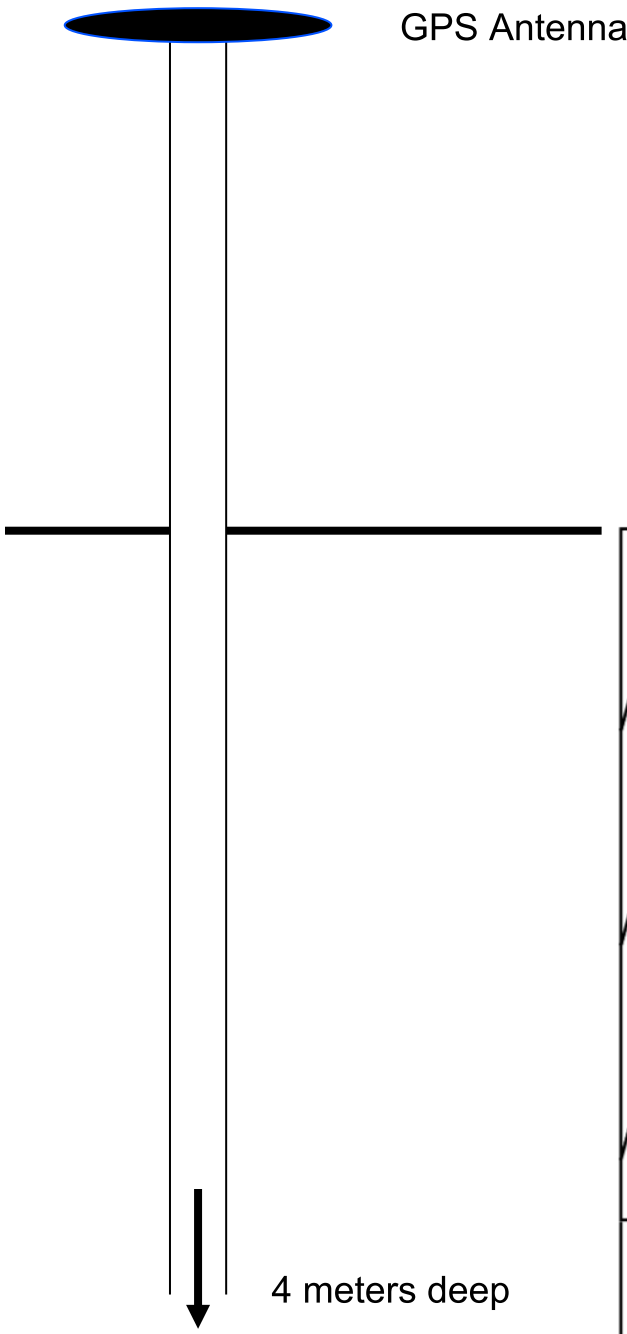
Data from the GLISN network

On an ice sheet, you can infer firn density

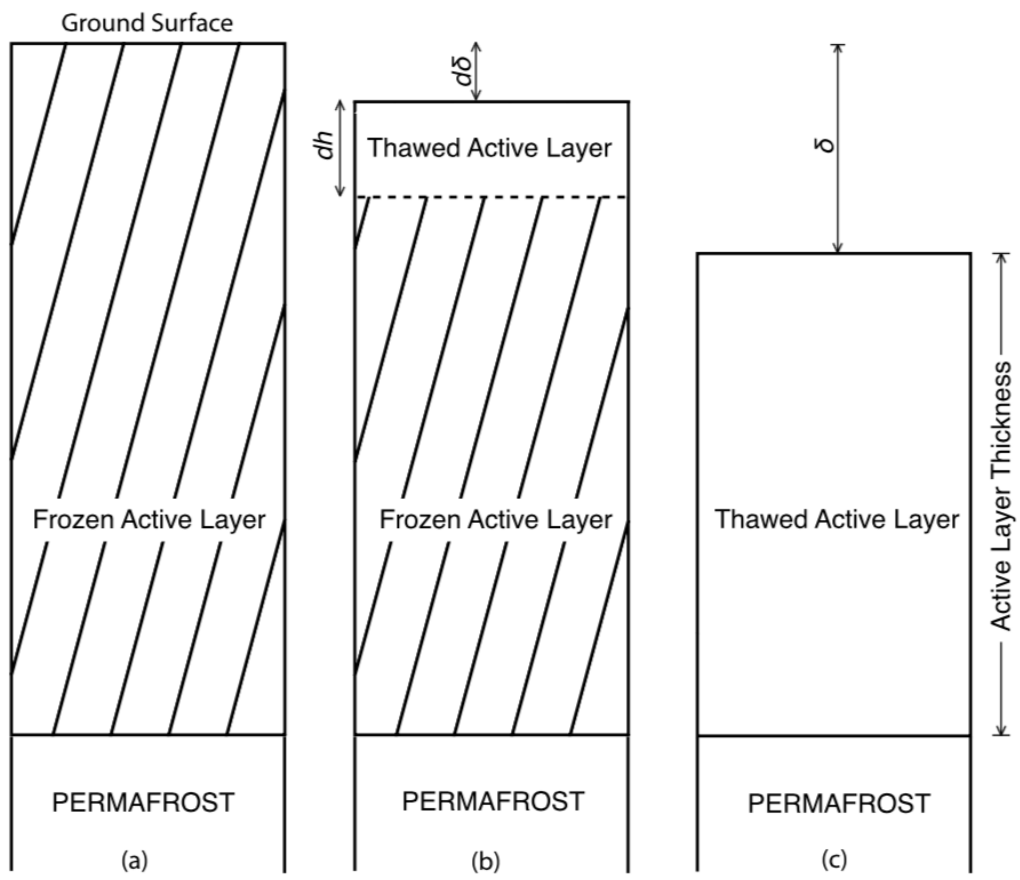


Larson, Wahr, Kuipers Munneke, 2015.

On permafrost, you are sensitive to changes in the active layer

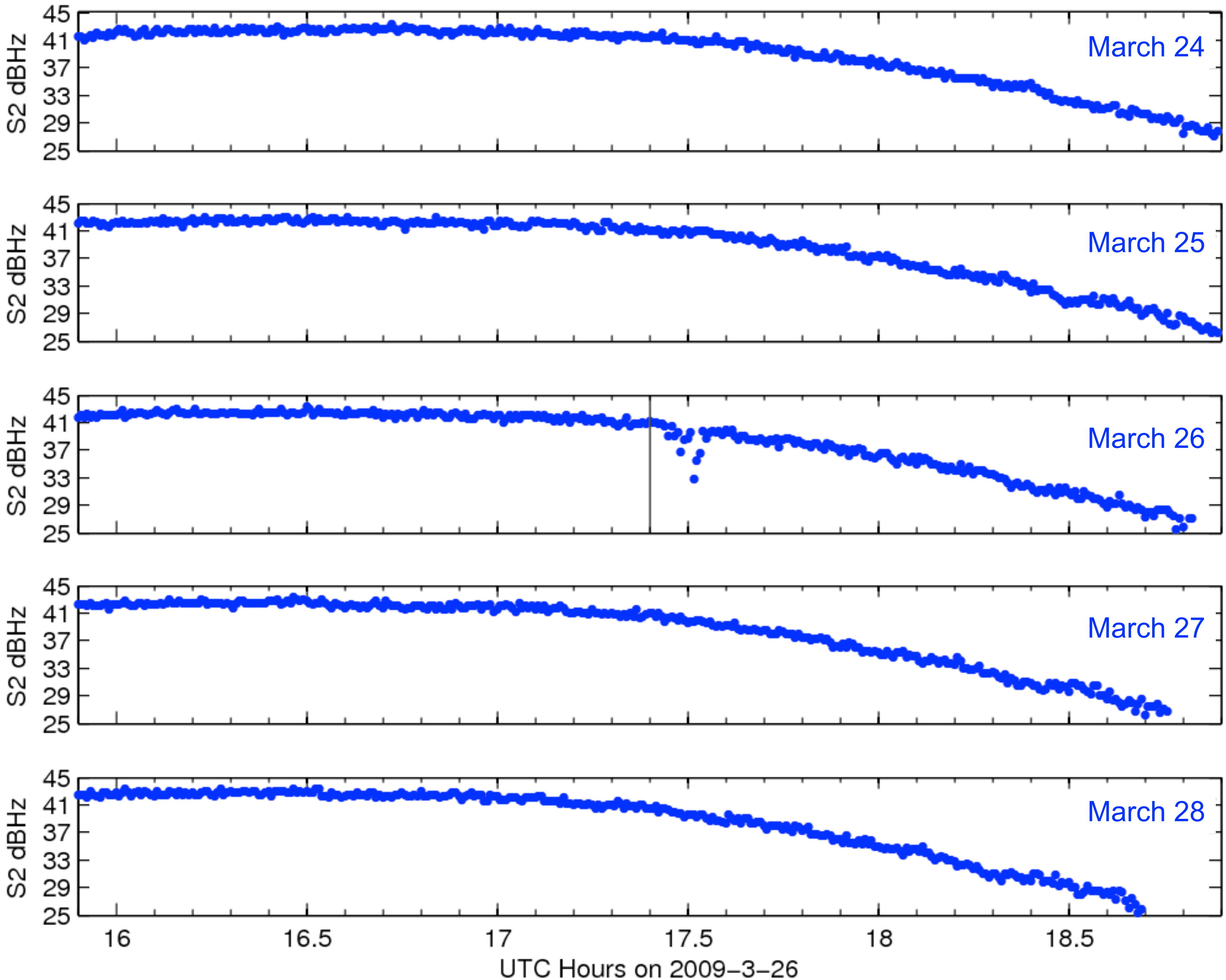


Active Layer Thickness ~50 cm at Barrow



Plume Sensing: Mt Redoubt, Alaska

SNR Data for Mt. Redoubt, Alaska

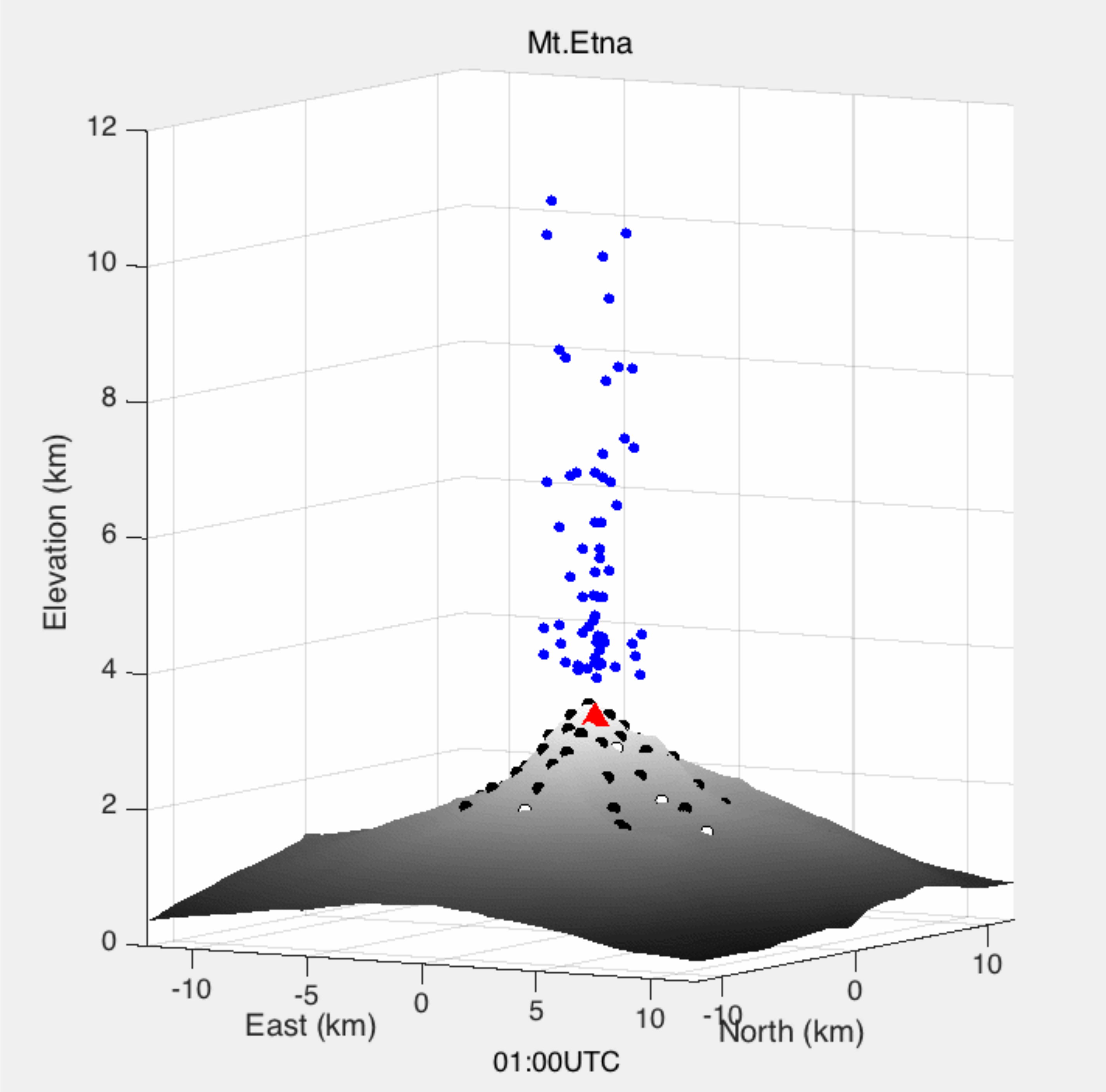


GPS site installed by Jeff Freymueller, UAF

Larson, A new way to detect volcanic plumes, GRL, 2013

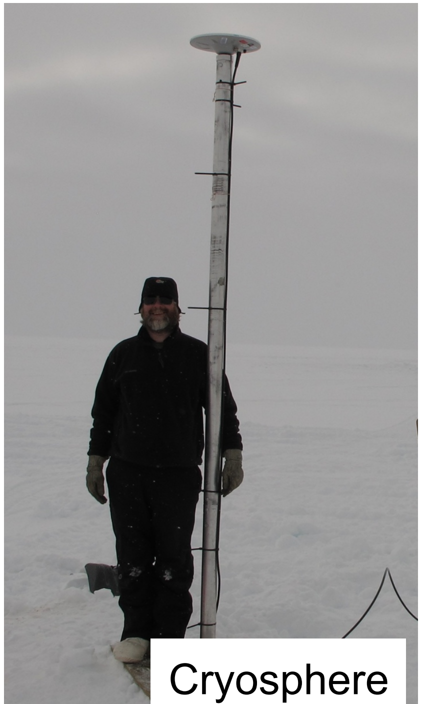
Why are these data valuable?

Any information about the timing, ascent rate, and height of a volcanic plume is useful for volcano ash dispersion models, which are used to make decisions about global airline routes and closure of airports.

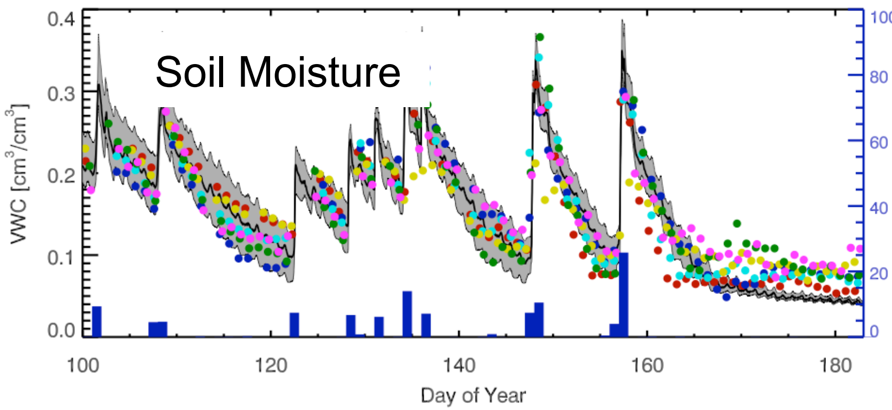


Mt.Etna
Elevation (km)
12
10
8
6
4
2
0
-10
-5
0
5
10
East (km)
-10
0
10
North (km)
01:00UTC

New Applications for GNSS: Validation of satellite sensors, *in situ* data for climate and sea level studies; water management, drought/flooding mitigation; permafrost monitoring; hazards assessments for airports.



>>>Increases stakeholders in GNSS networks<<<

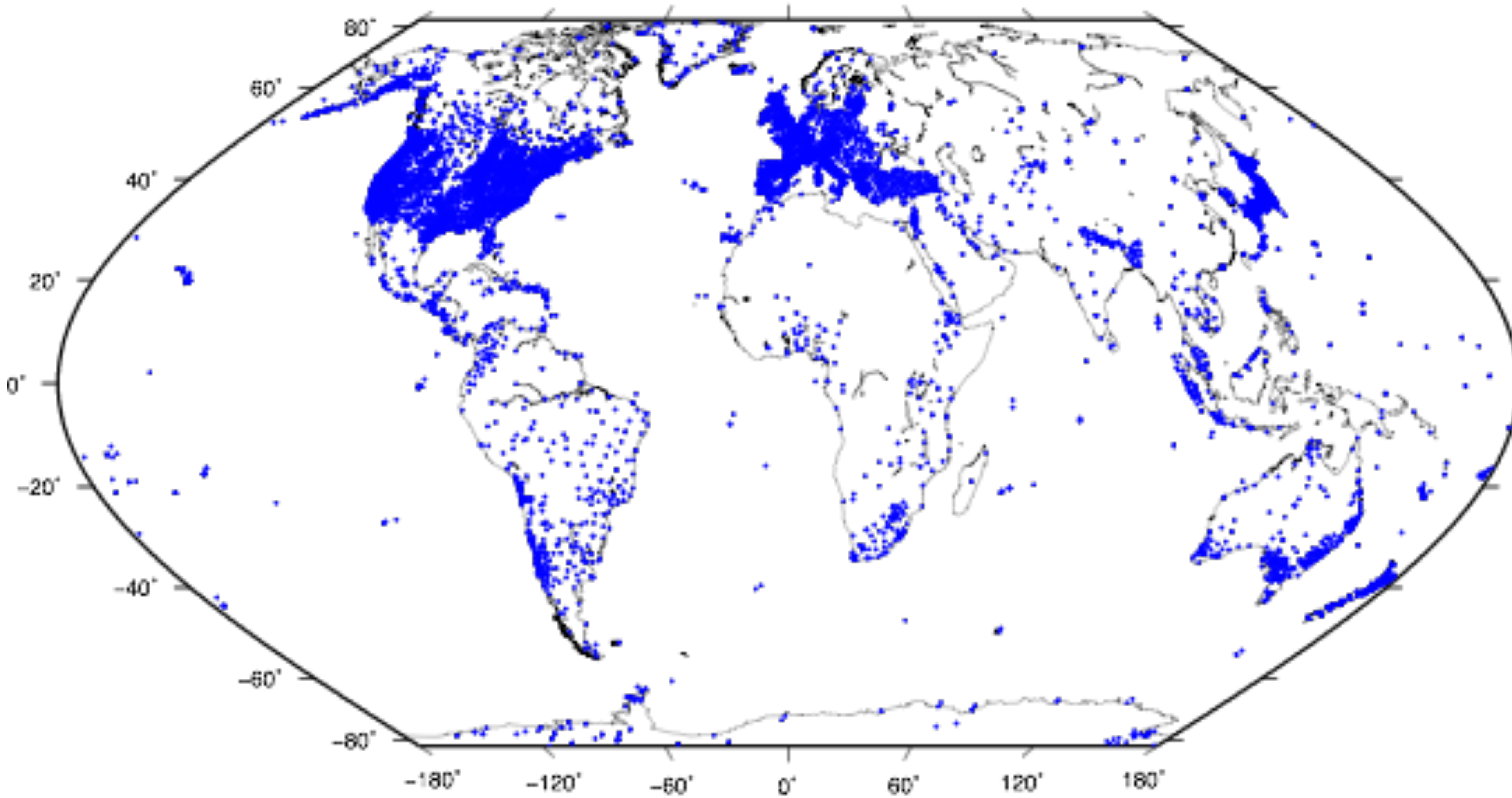


Take Home Messages

- The environmental products shown here were derived entirely from GPS data - no ancillary instrumentation was needed; existing instrumentation was used.
- There is no reason this could not be done with GLONASS, Beidou, and Galileo.
- New GNSS sites could be installed to take advantage of GNSS reflectometry.

Acknowledgements

- Eric Small, Valery Zavorotny, John Braun, Felipe Nievinski, Penina Axelrad, Ethan Gutmann, Clara Chew, Sarah Evans, Praveen Vikram, Evan Pugh, Bill Smith, John Kimball, Brian Hornbuckle, Tyson Ochsner, Jobie Carlisle, Mark Williams, Matt Jones, Mesa County (CO) Surveyors, Jeff Freymueller, John Wahr, Simon Williams, Karen Boniface, John Pratt, Andria Bilich, Minnesota DOT, RSA Trignet.
- NSF GEO: Climate and Large-Scale Dynamics, Physical and Dynamic Meteorology, Hydrologic Sciences, EarthScope, Instrumentation and Facilities, Education and Outreach.
- NASA: Earth Surface and Interior, Natural Hazards, AIST, and Terrestrial Hydrology.
- UNAVCO maintains the EarthScope PBO sites with funding from NSF.


80°
60°
40°
20°
0°
-20°
-40°
-60°
-80°
-180°
-120°
-60°
0°
60°
120°
180°