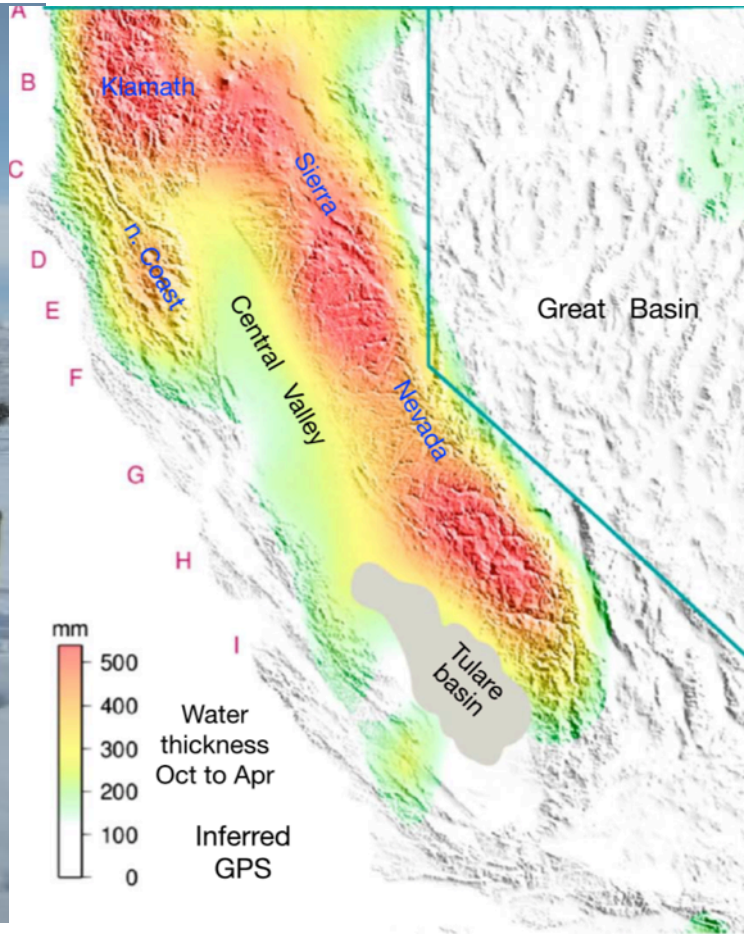
Innovating with EarthScope to Study the Water Cycle



Kristine M. Larson
http://kristinelarson.net

EarthScope: Anticipated Results

- Unravel the structure, evolution and dynamics of North America
- Probe the behavior of active fault systems
- Study details of earthquake nucleation and rupture process
- Advance understanding of natural hazards
- Explore the inner workings of volcanoes and magmatic processes leading to eruption.
- …

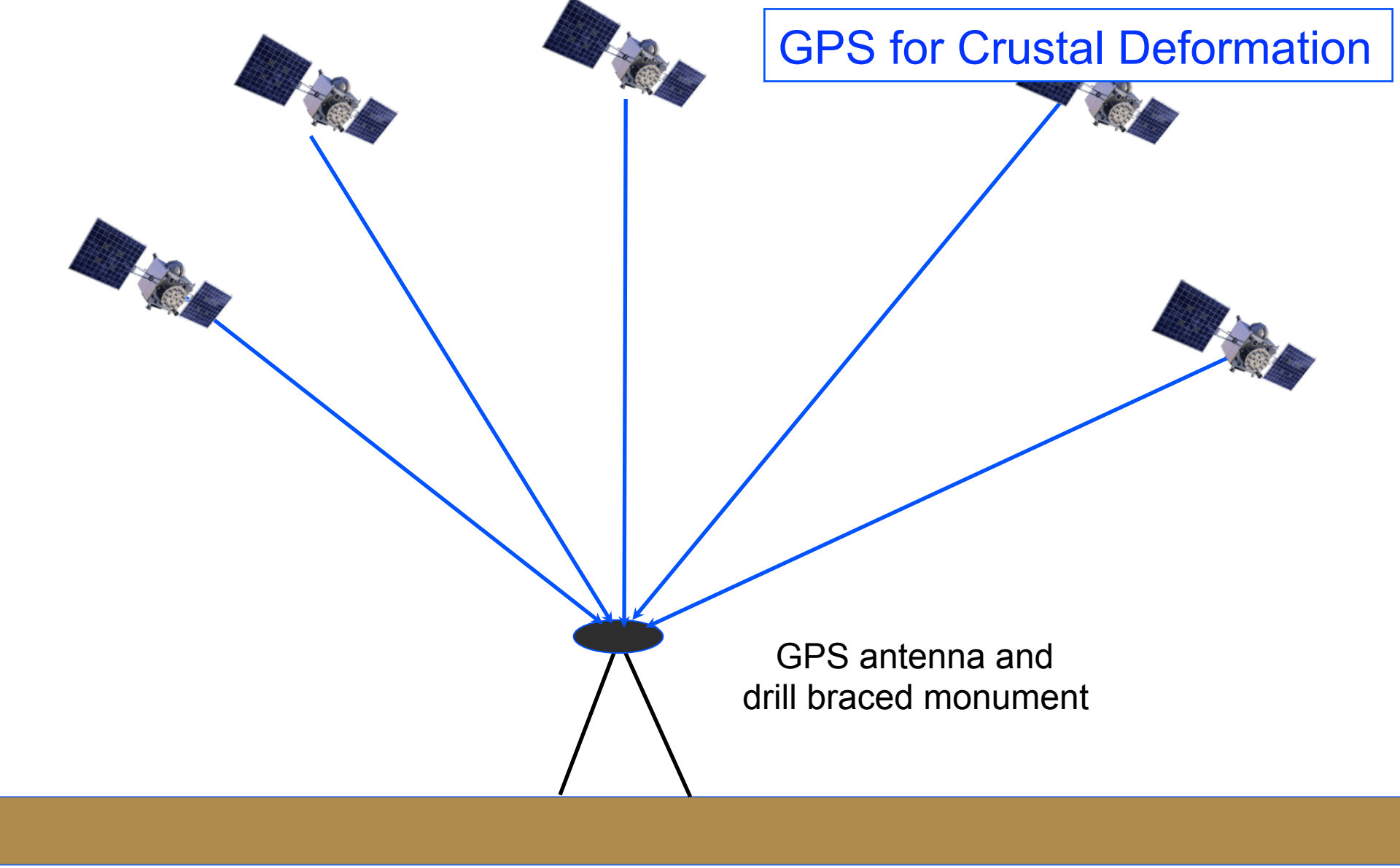
No mention of the water cycle

EarthScope Working Group, 2001

EarthScope & the Water Cycle

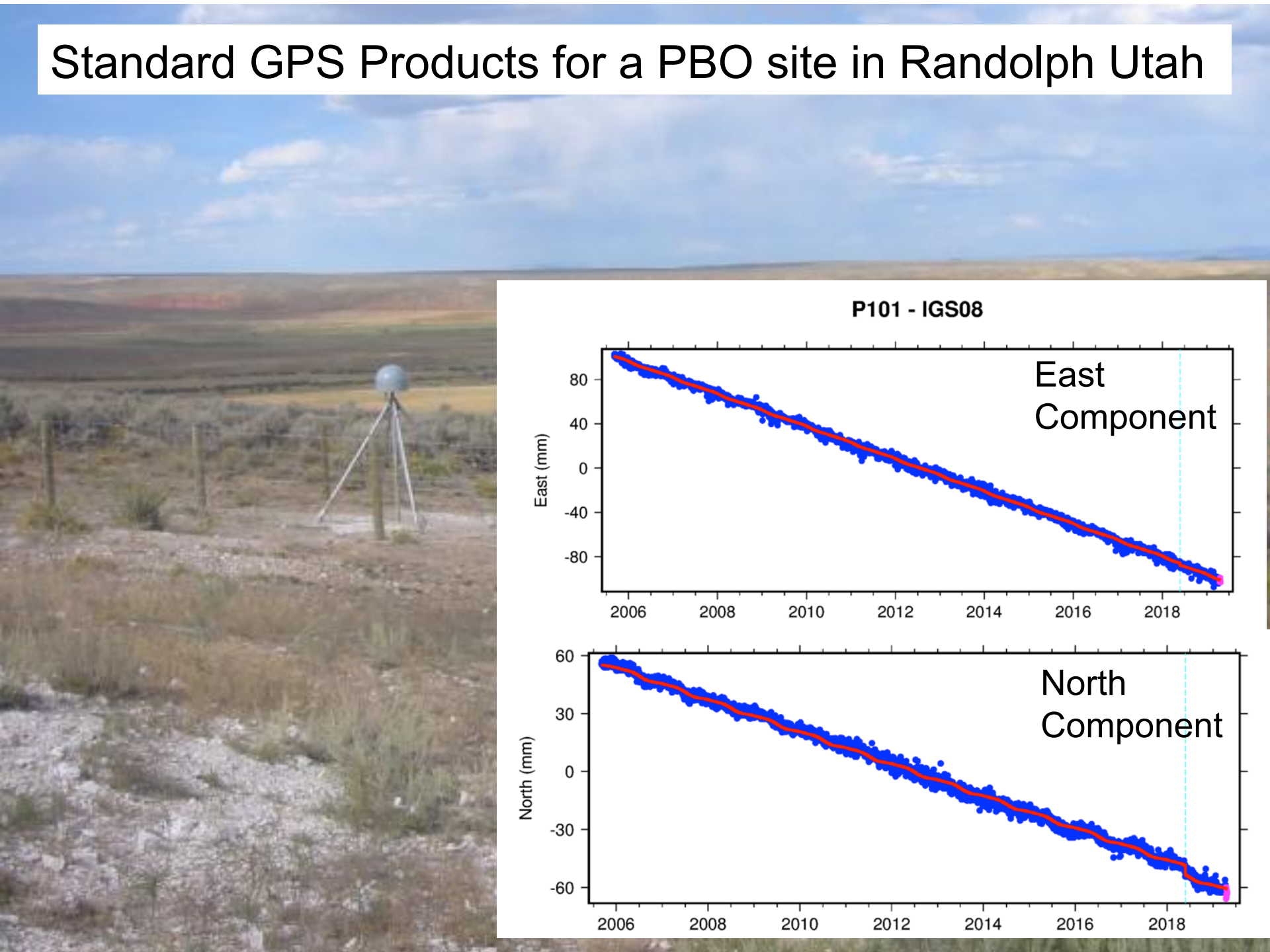
- What does a GPS site traditionally measure and how is that related to anything that a hydrologist would want to know?
  - Total water storage
  - Ground water changes
- GPS Reflectometry and Hydrology
- Unexpected Outcomes

GPS for Crustal Deformation

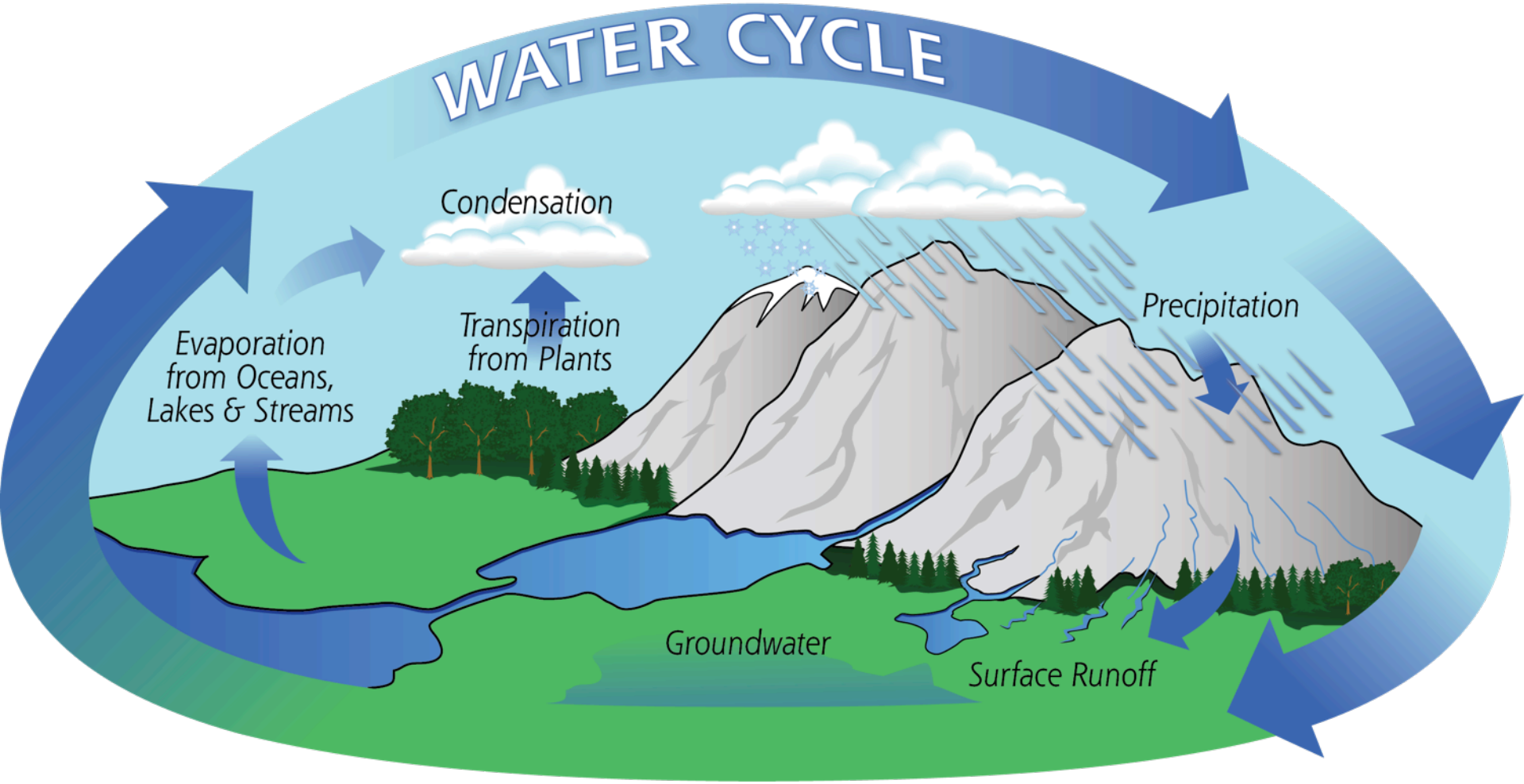


Ranging data from multiple satellites are used to estimate site positions every day.

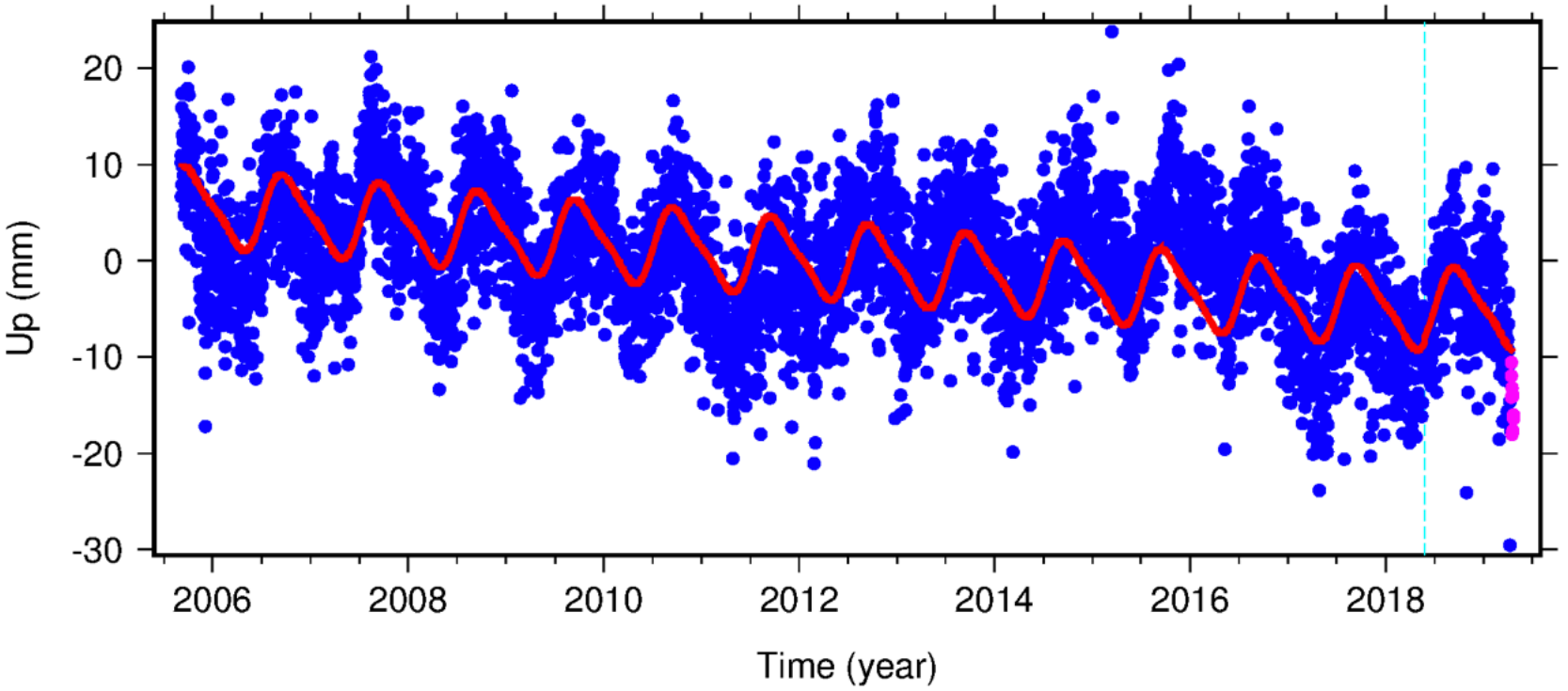
Standard GPS Products for a PBO site in Randolph Utah



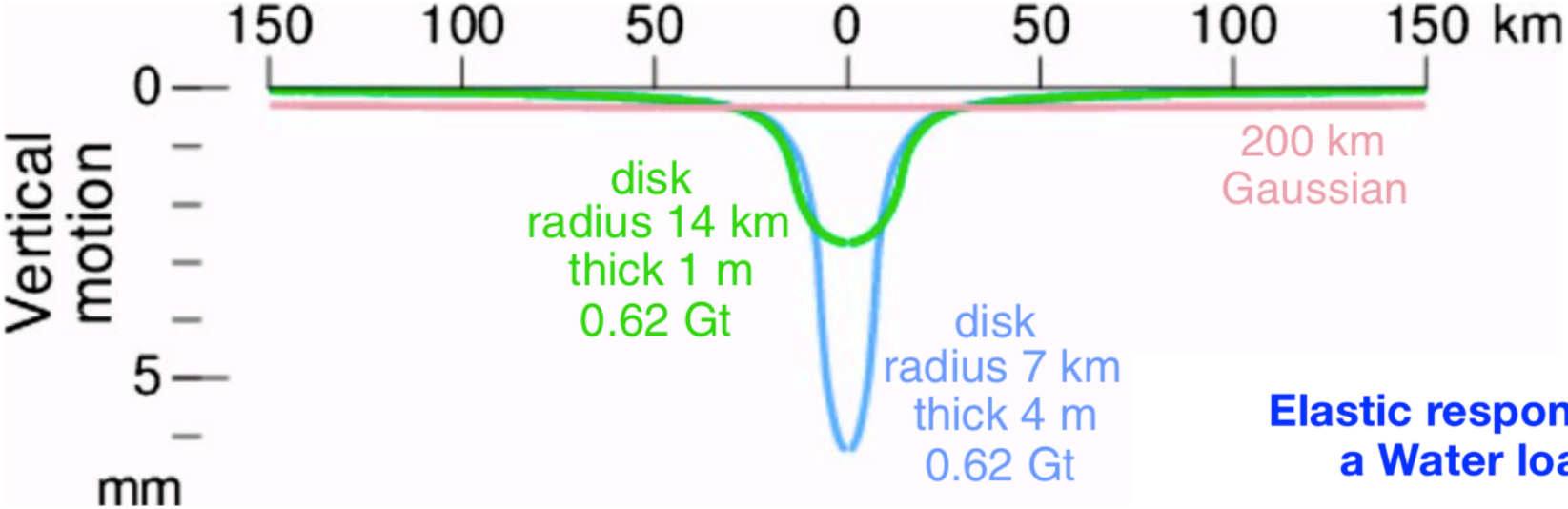
What do climate scientists want to know?



But the vertical coordinate time series are clearly showing something a little more interesting…



Think of your GPS site as a kind of scale

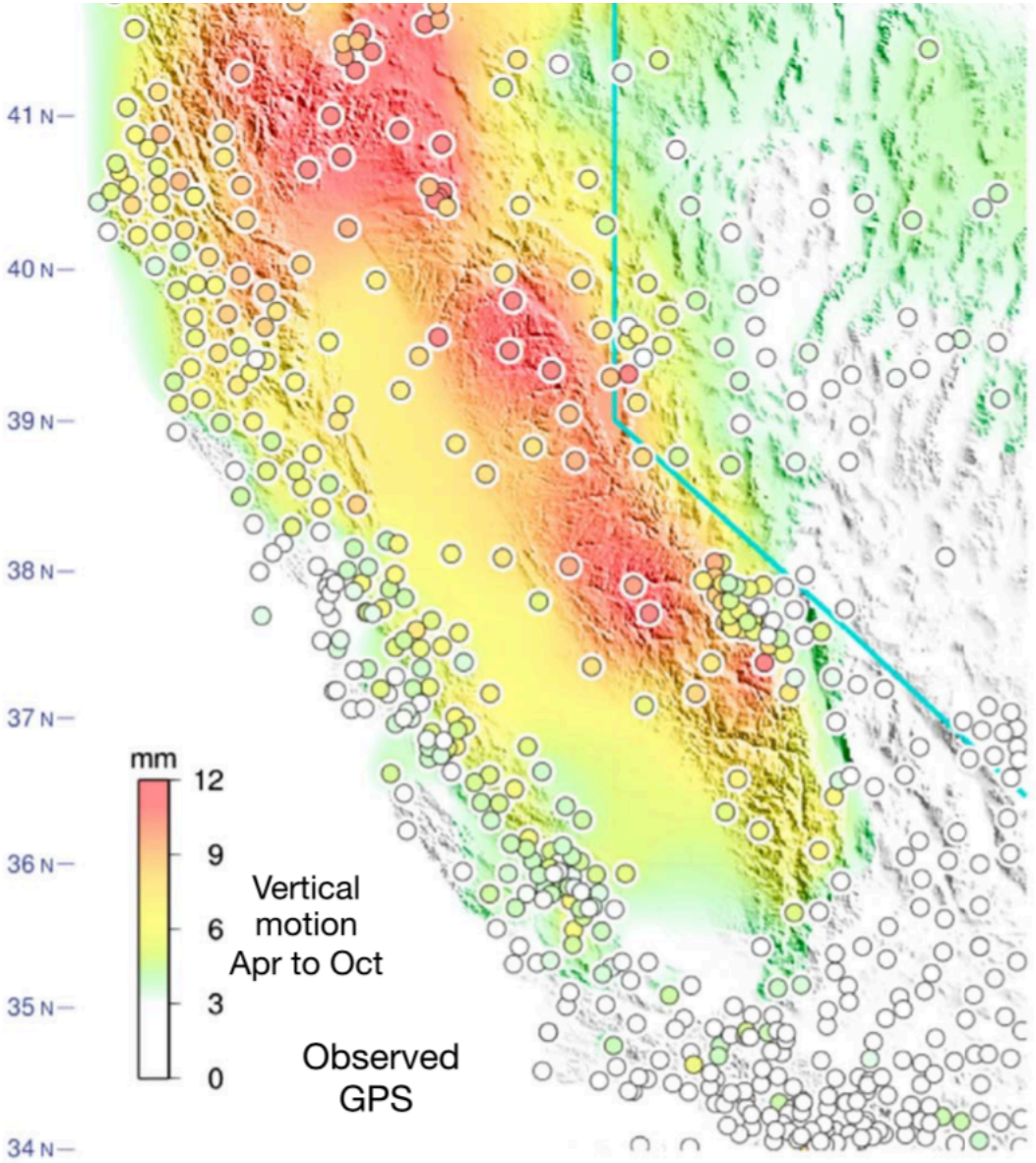


Argus et al. 2014

Elastic response to a Water load

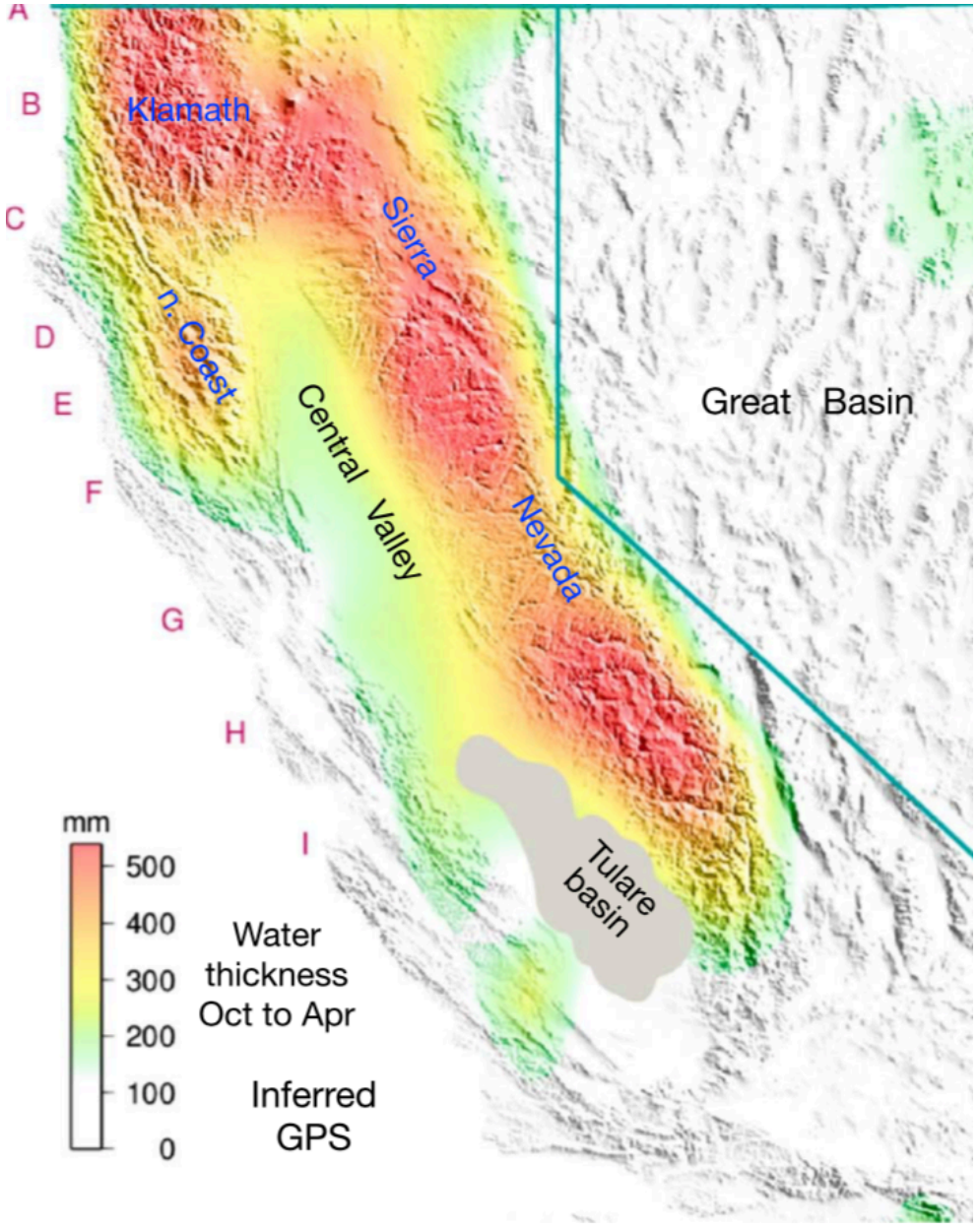
Mountains subside in elastic response to a snow or water load

1. Use GPS sites to estimate seasonal vertical deformation



Argus et al. 2014

2. Invert to measure water storage changes



Argus et al. 2014

Longer-term GPS vertical displacements tell you about the effects of severe drought

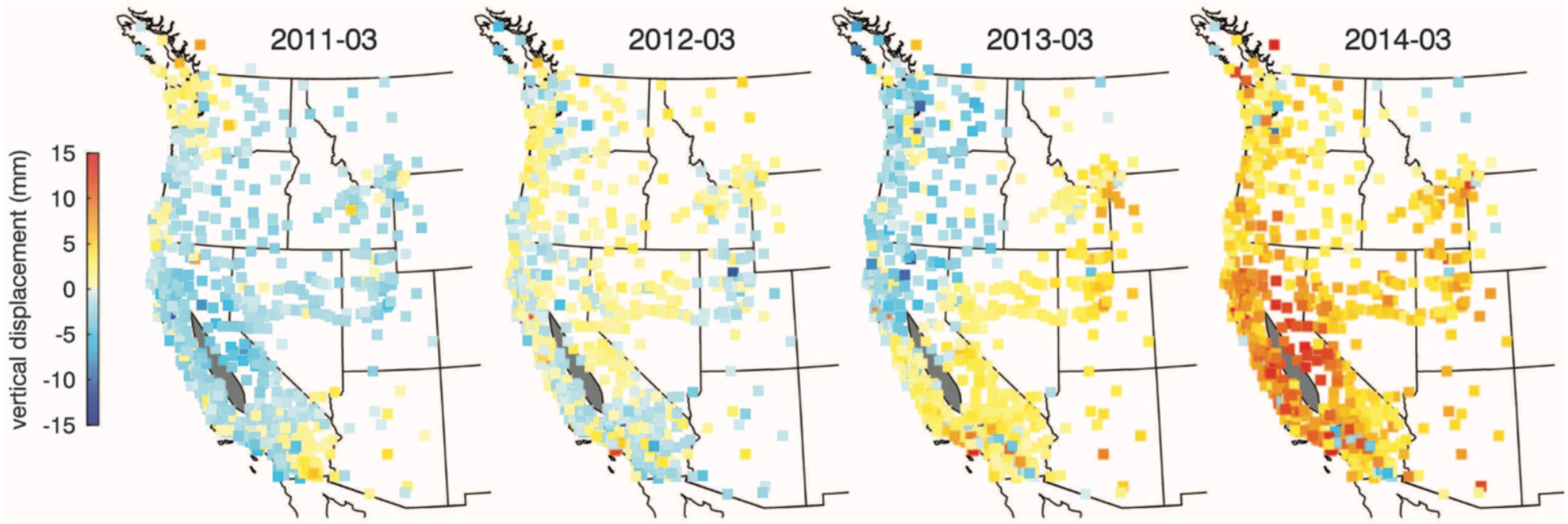


Fig. 2. Maps of vertical GPS displacements. Spatial distribution of displacements from the time series in Fig. 1, from 1 March 2011 through 2014. Uplift is indicated by yellow-red colors and subsidence by shades of blue. The gray region is where stations were excluded in the Central Valley of California.

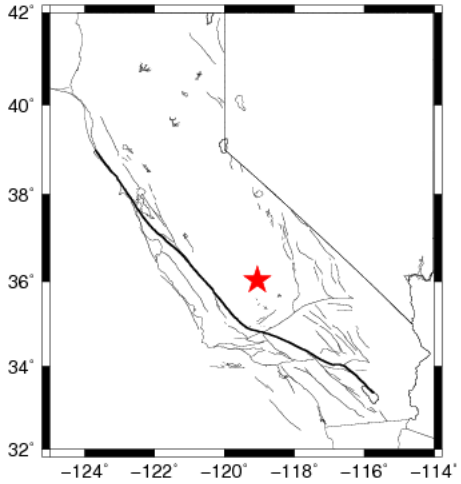
Borsa et al 2014

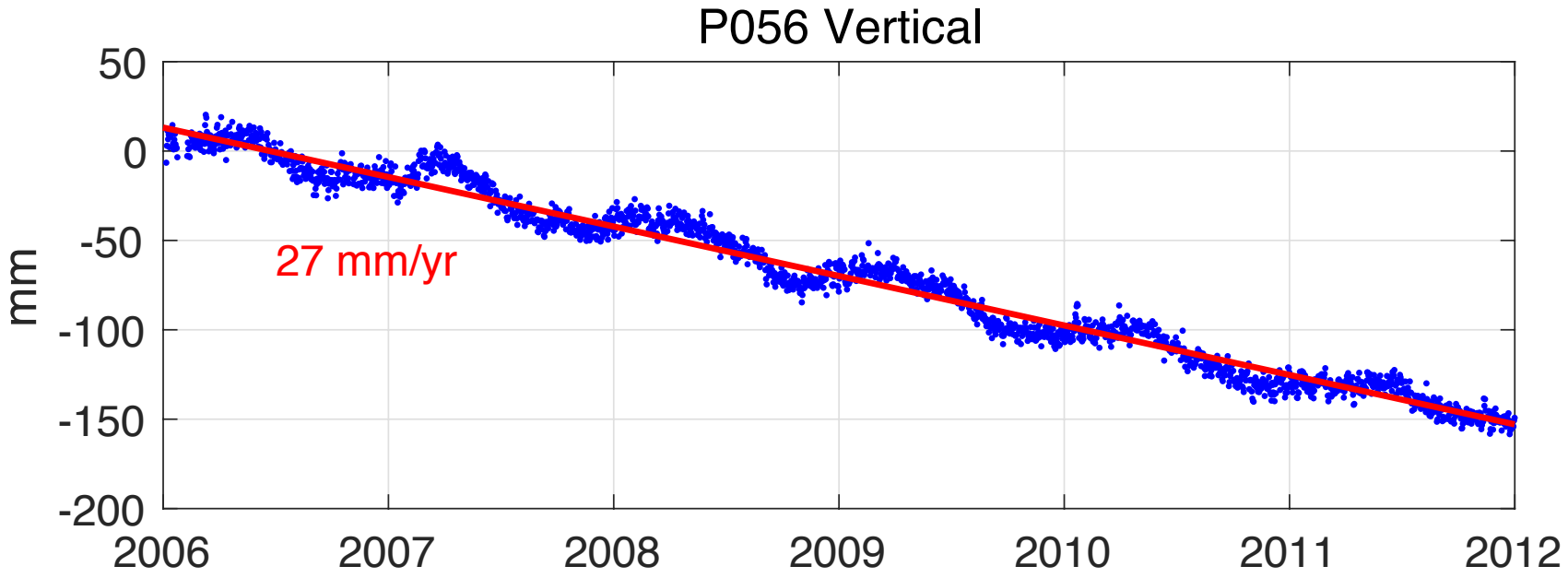
Effect of ground water changes

Porous response to Groundwater change

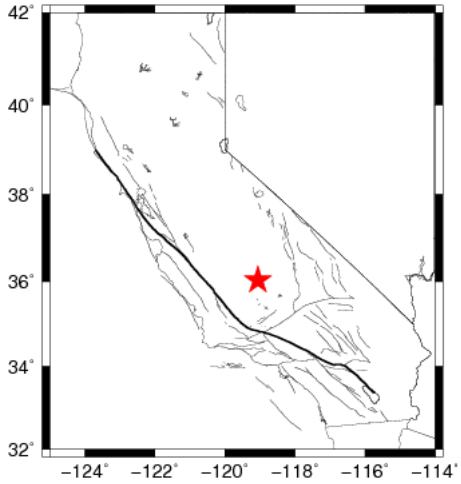
Aquifers expand as groundwater fills the pores between the silts, sands, and gravels comprising the aquifer

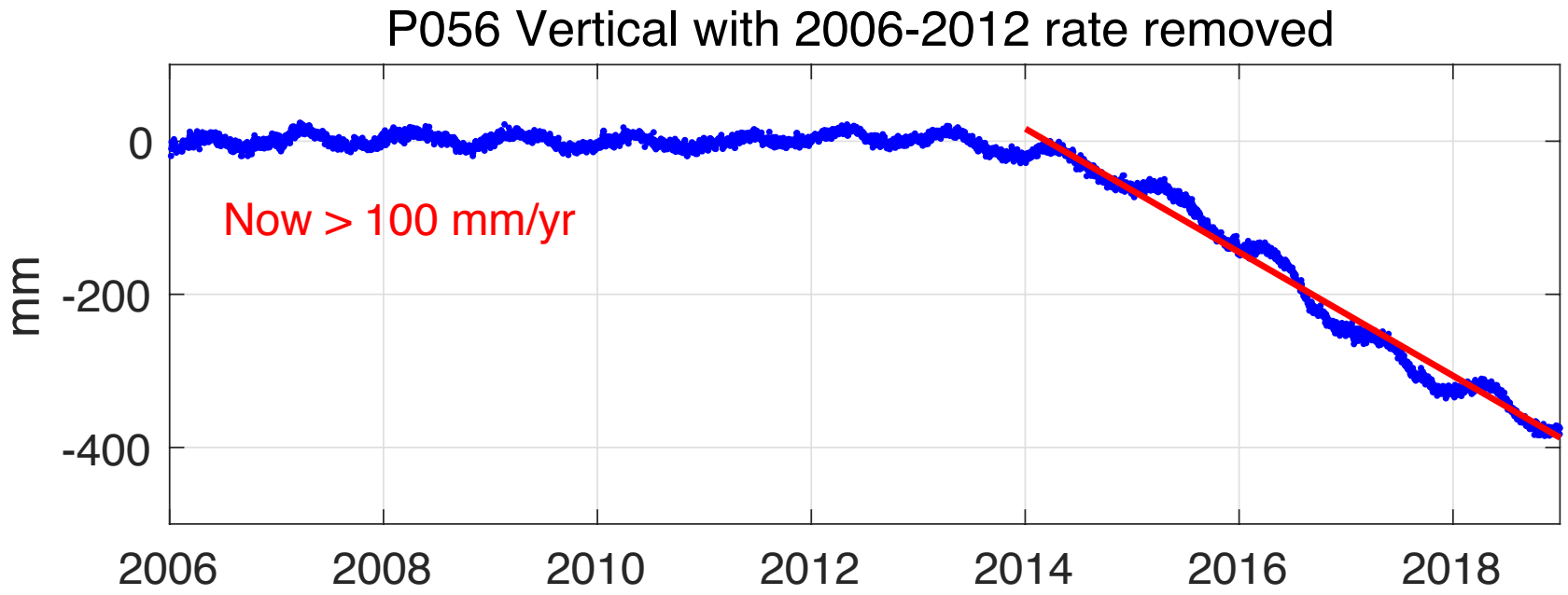
P056, Porterville, 2006-2012





P056, Porterville, 2006-2019

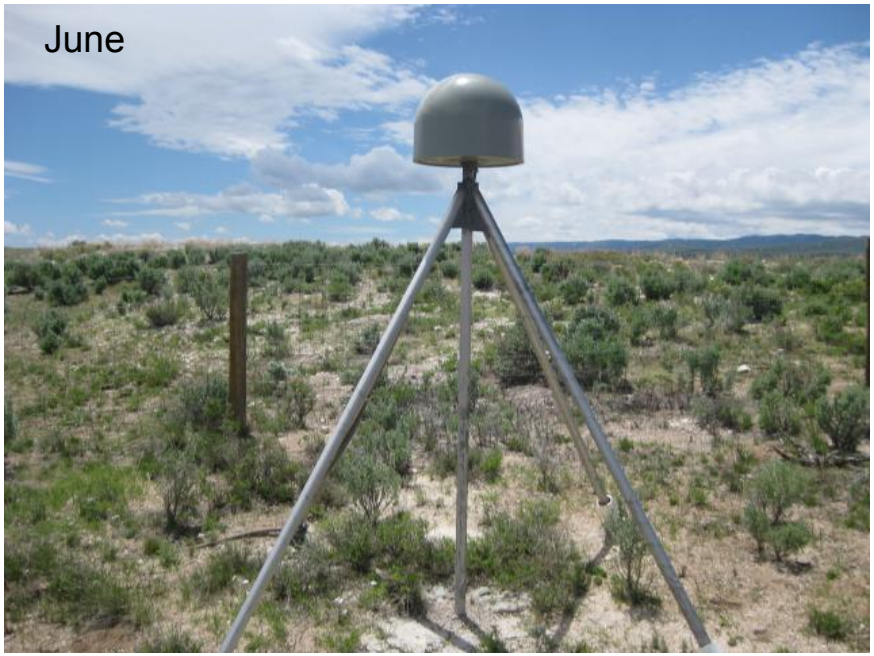


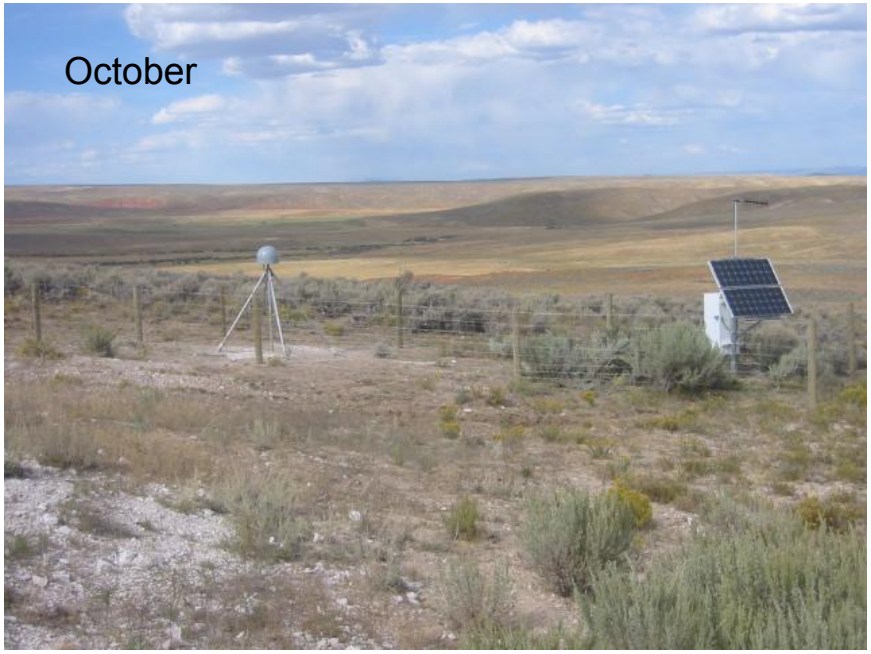


Take home messages

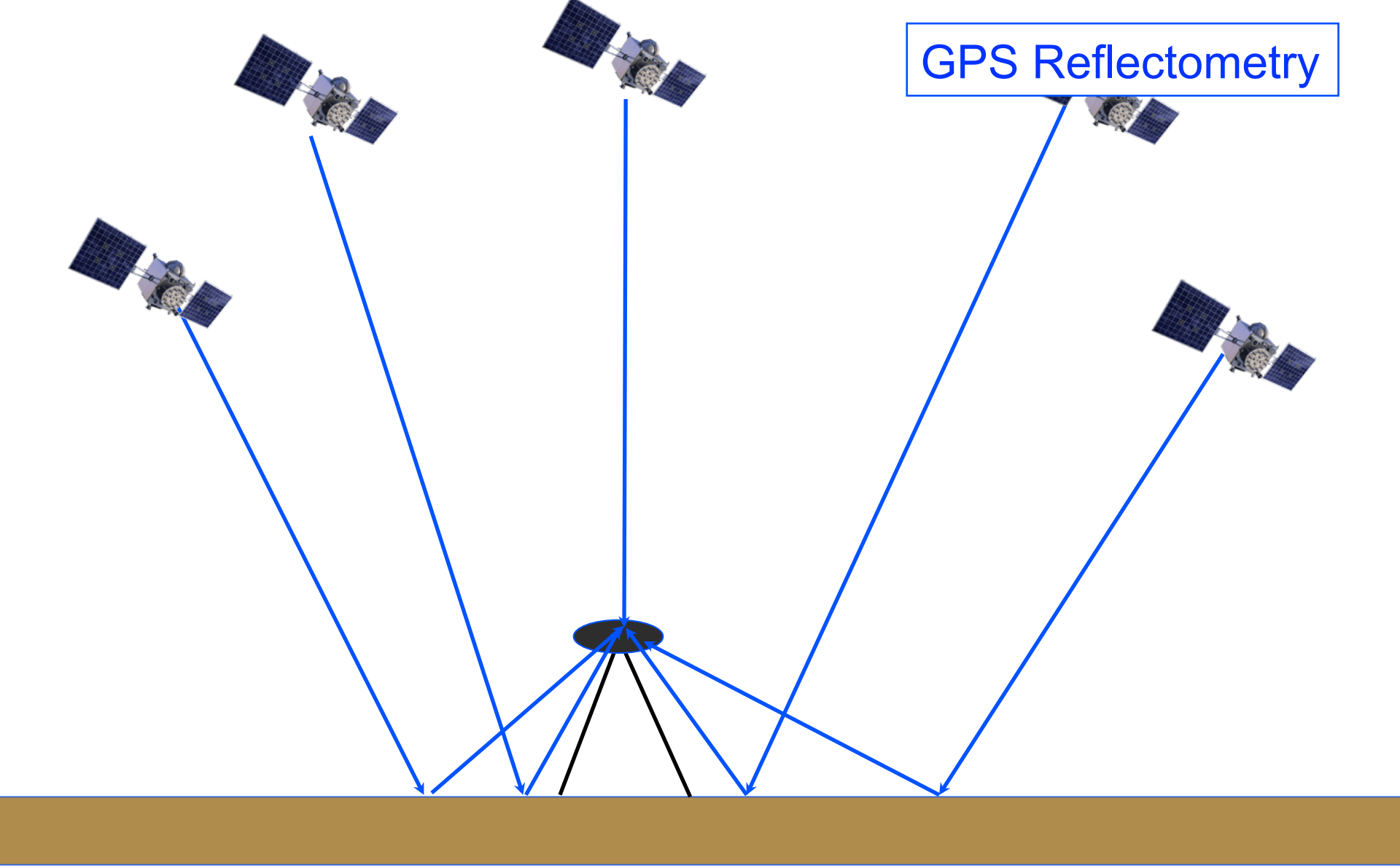
- Large GPS arrays such as PBO can provide terrestrial water storage information at unique spatial and temporal scales.
- Understanding the interaction between GPS and hydrologic processes ultimately leads to better positioning products for tectonic studies.

Can we learn anything about the surface below a GPS antenna?





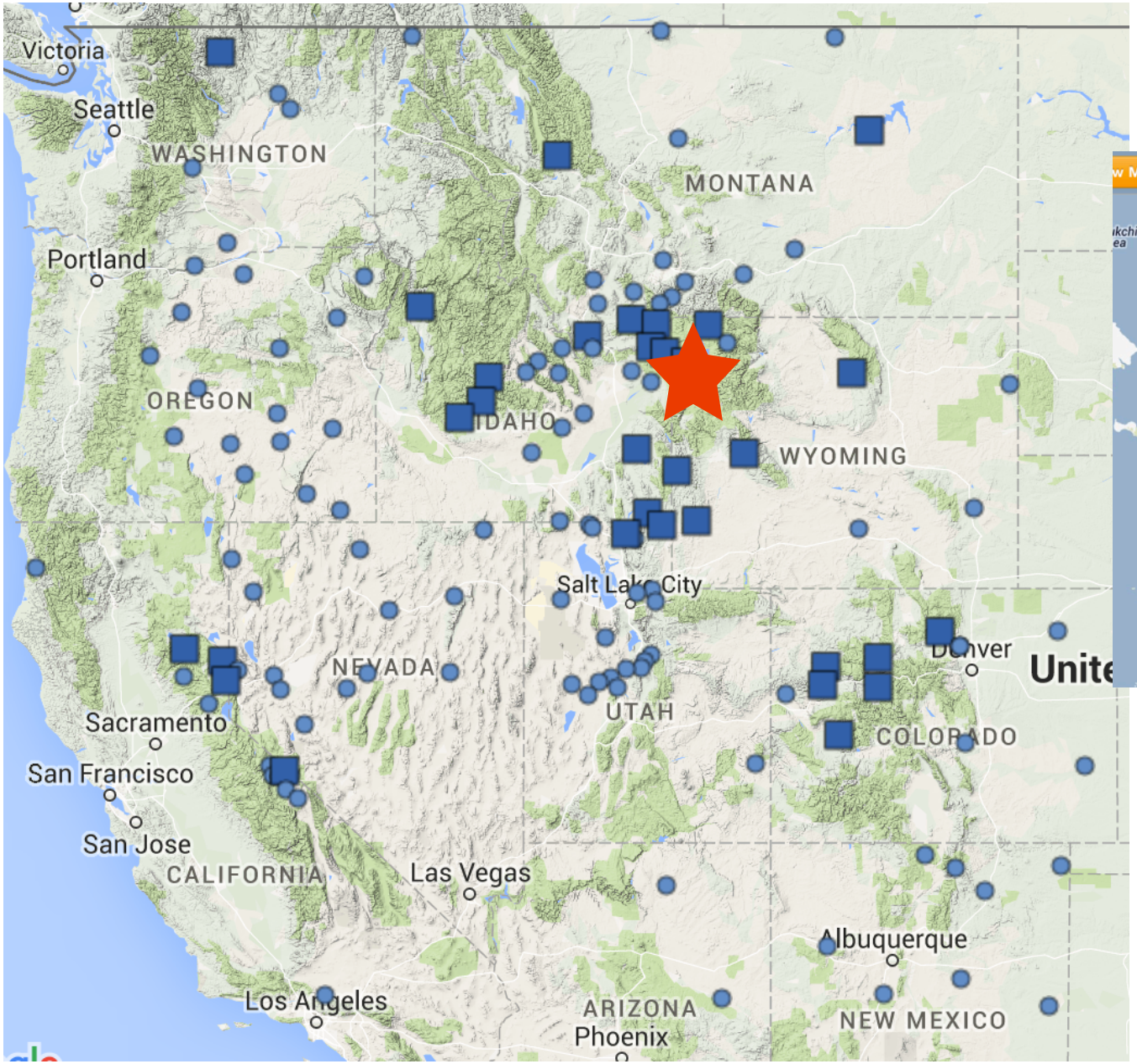
PBO Site P101

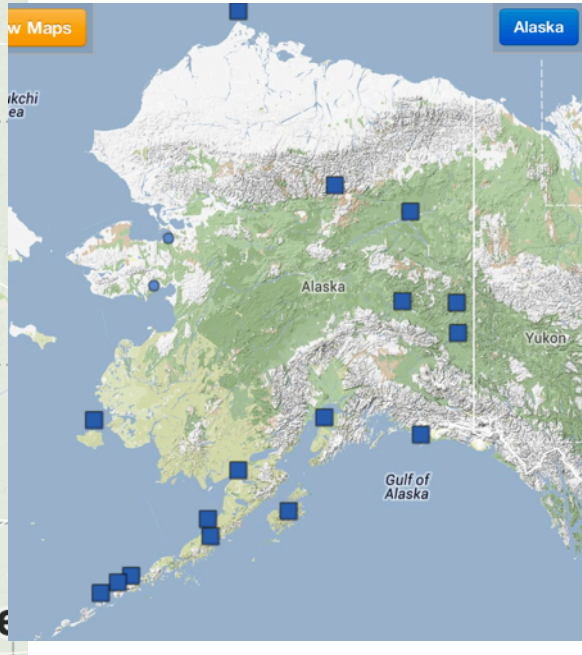


Ignore the positioning data – use the reflected signals to turn each GPS site into a bistatic radar.

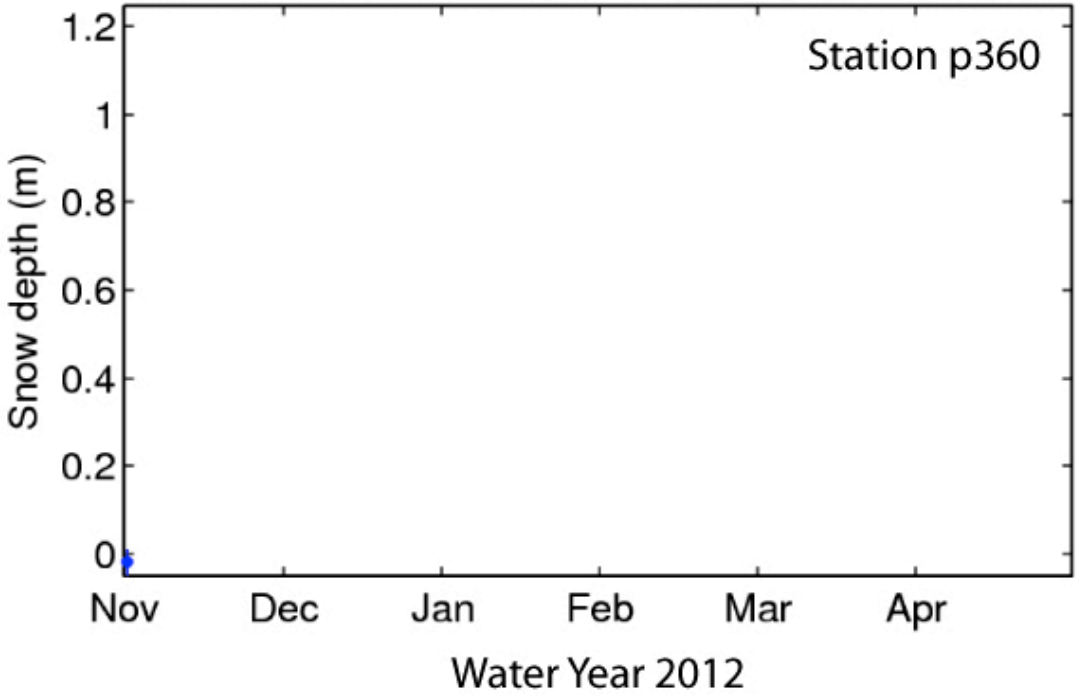
Snow Depth and SWE

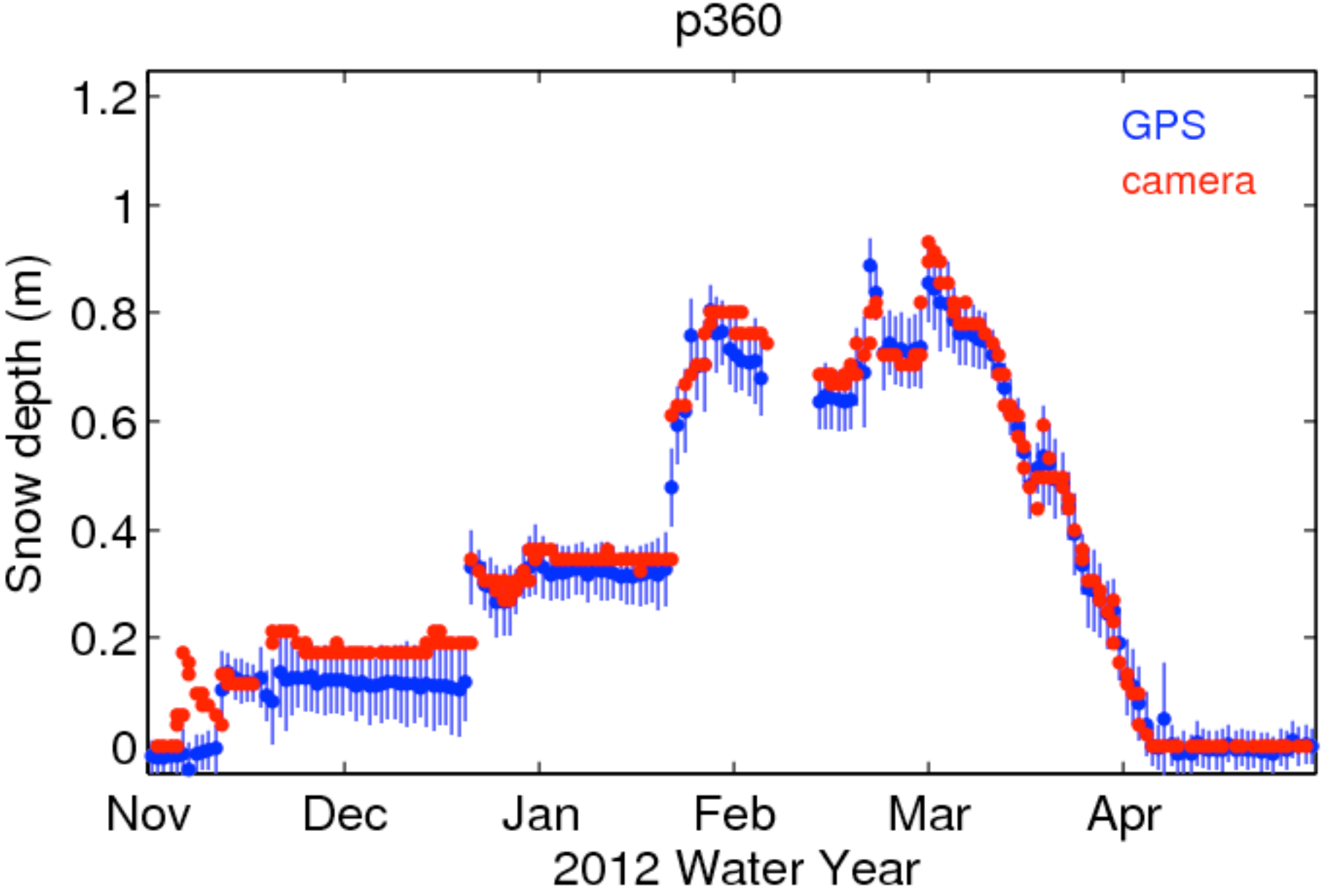
PBO H_2O



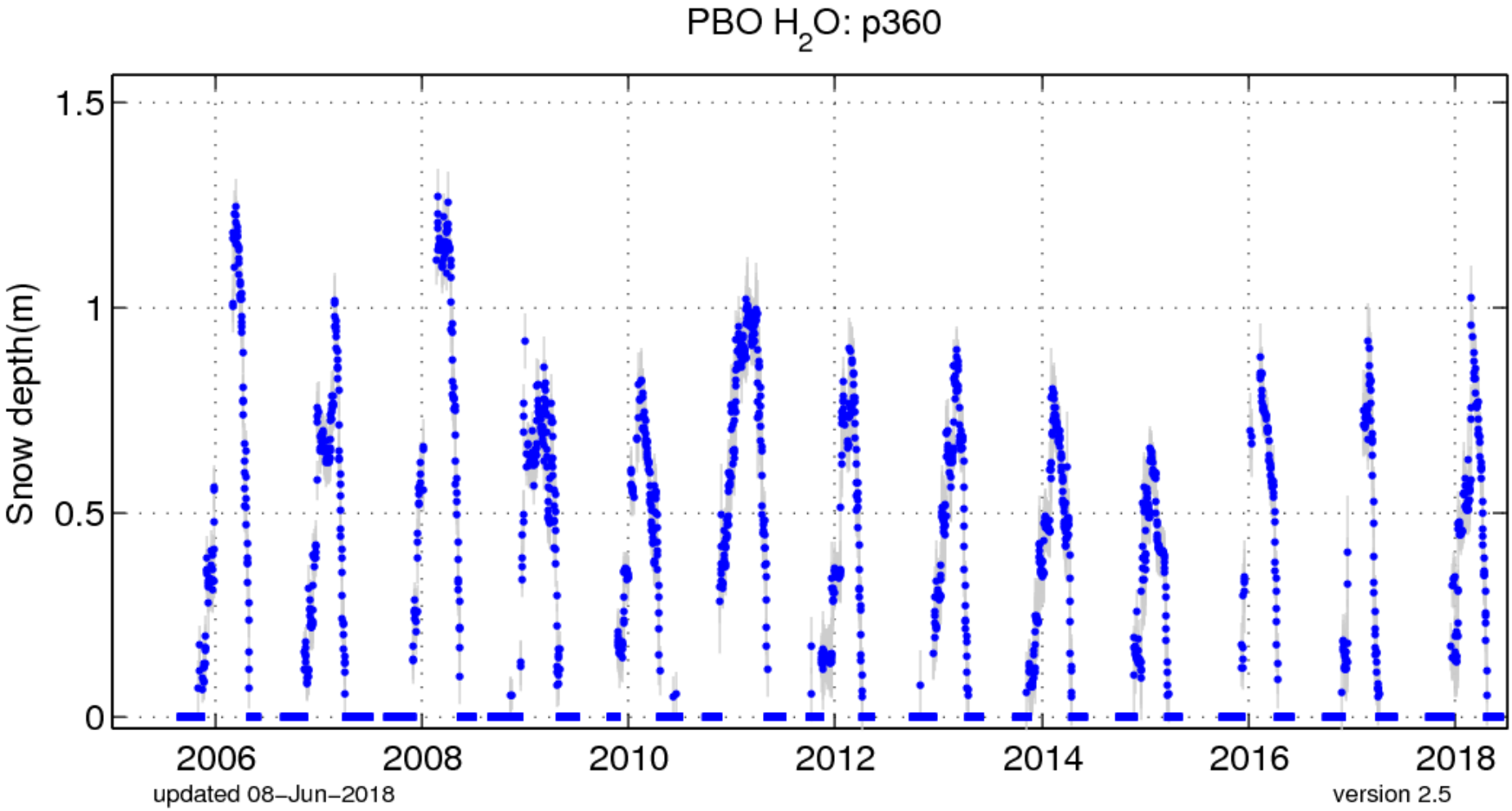


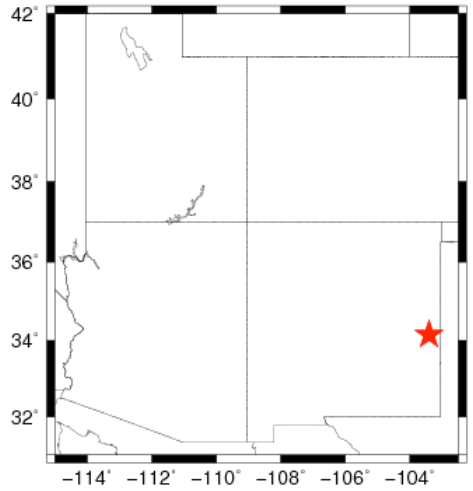

P360 08:21:28 2012/05/07


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

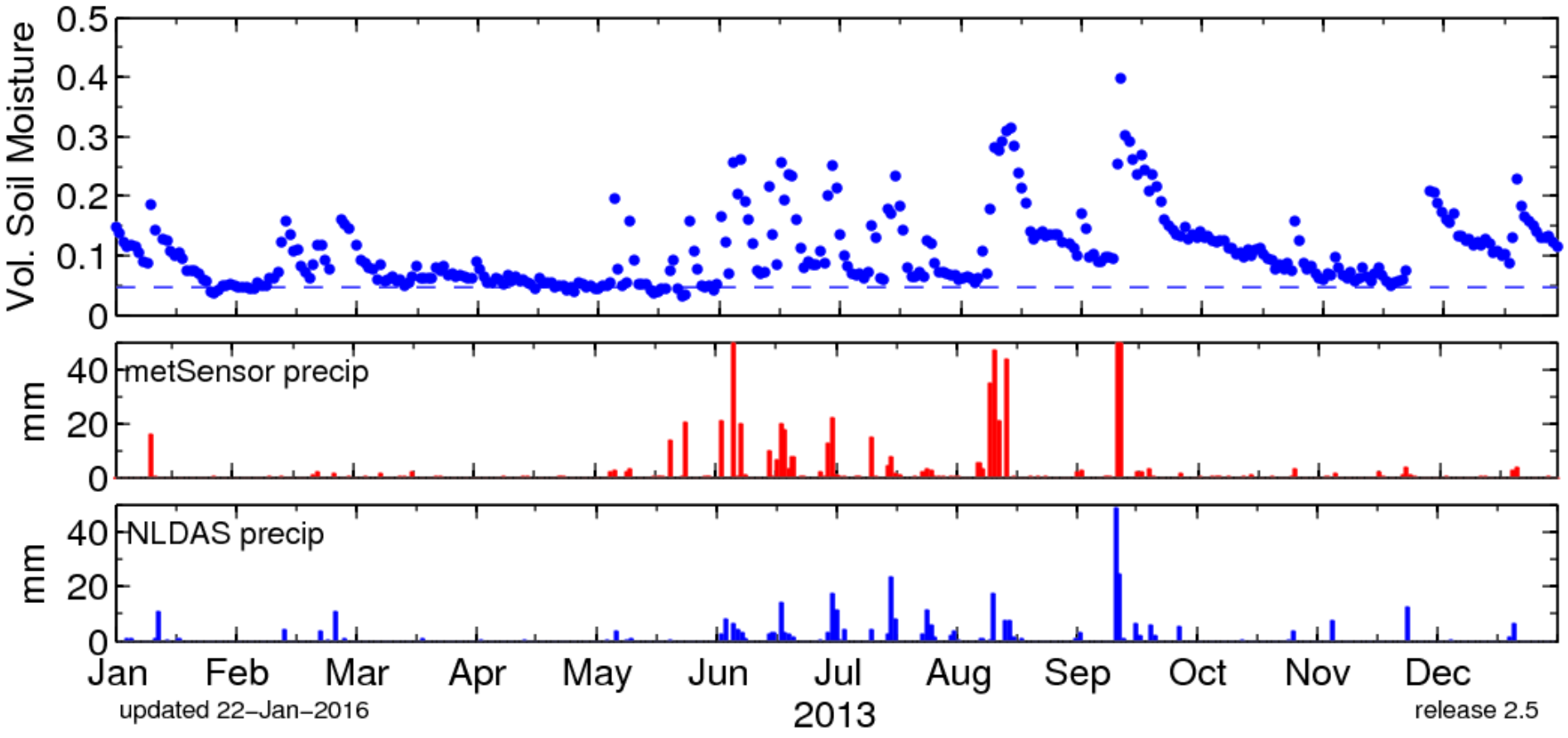
Snow Climatology





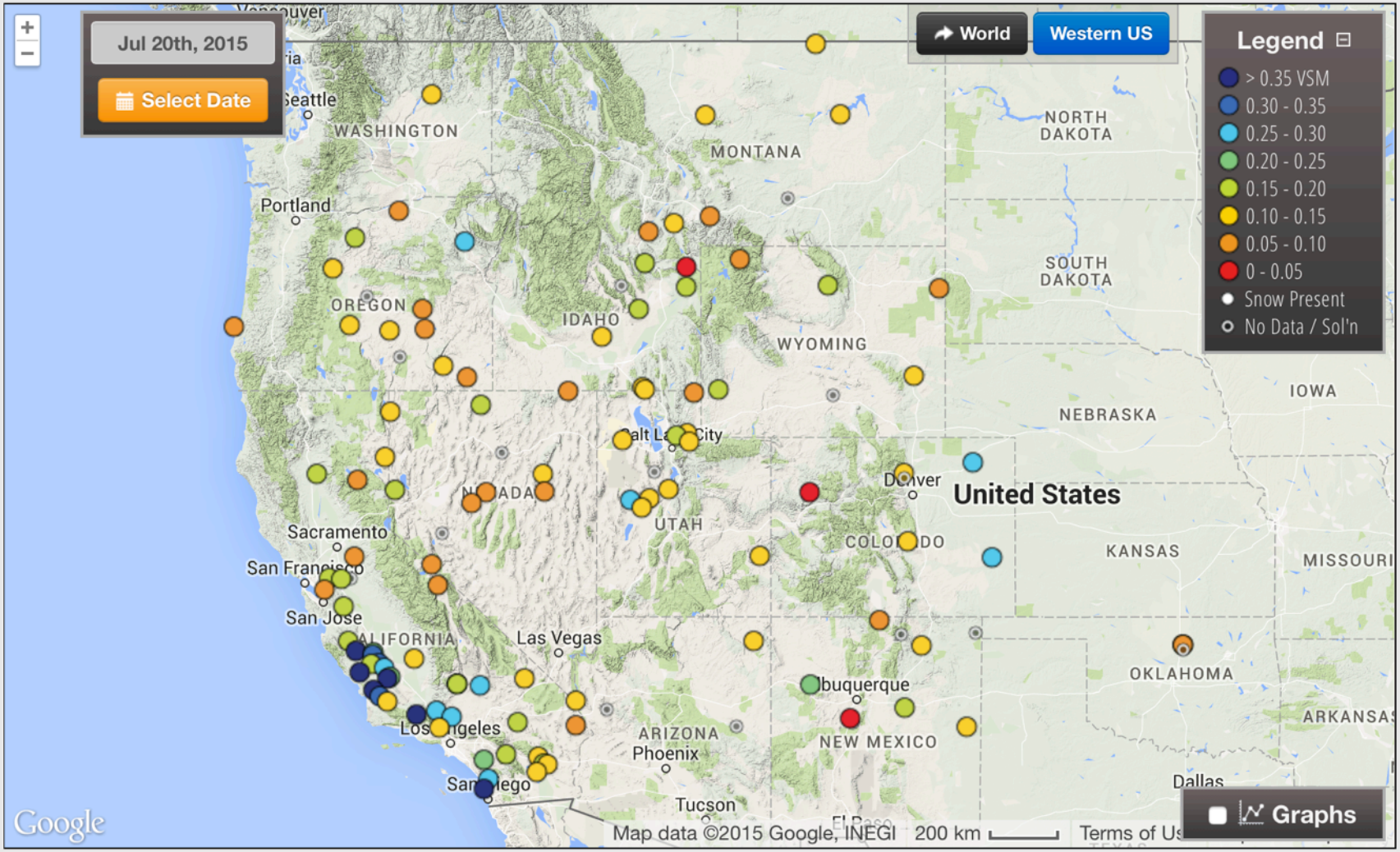
Soil Moisture

PBO H_2O: p038

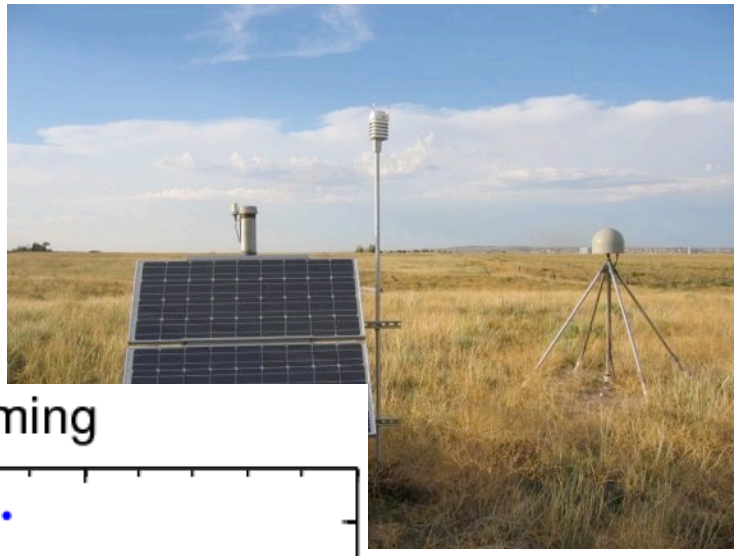


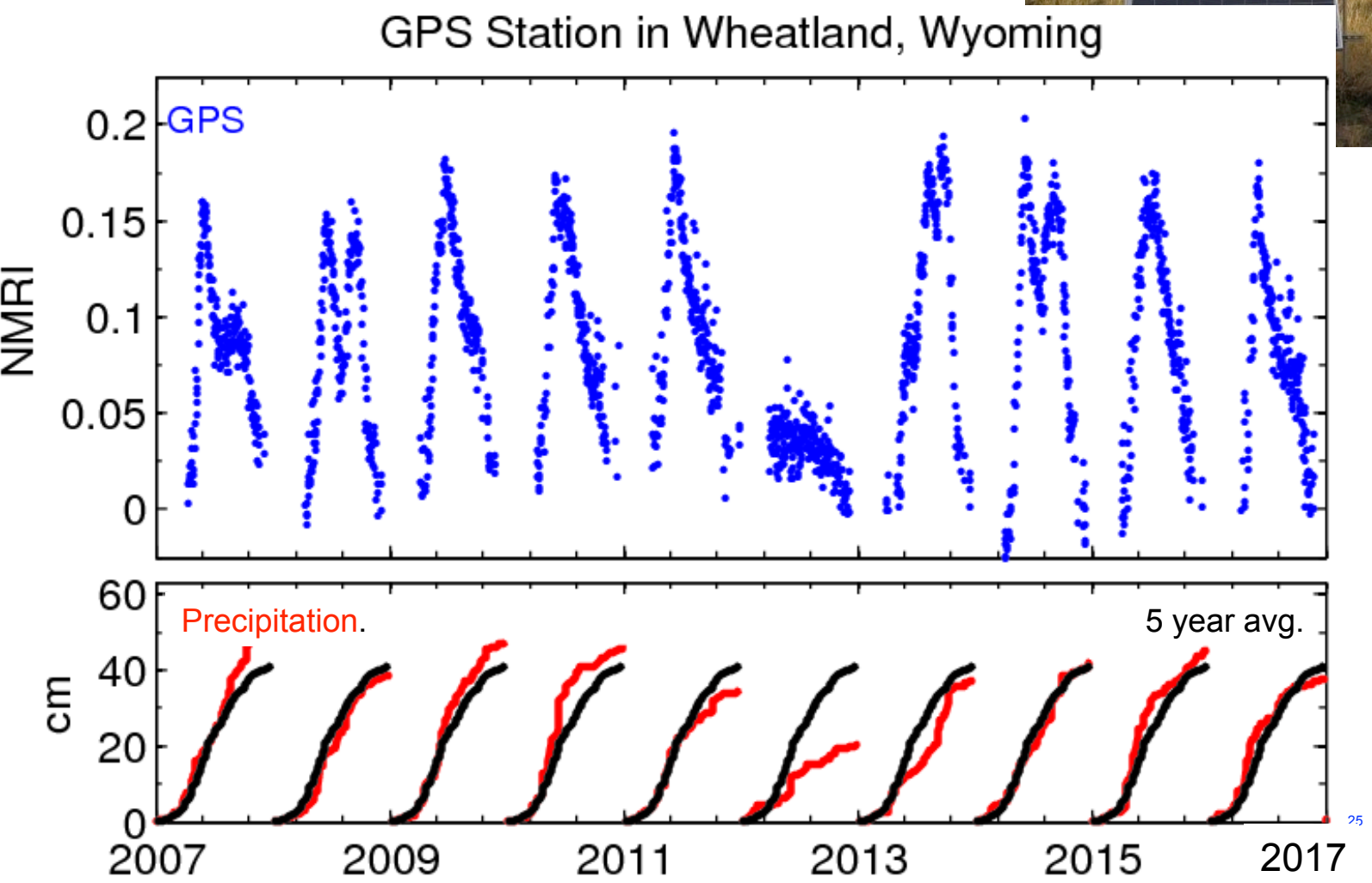
PBO H_2O

Soil Moisture

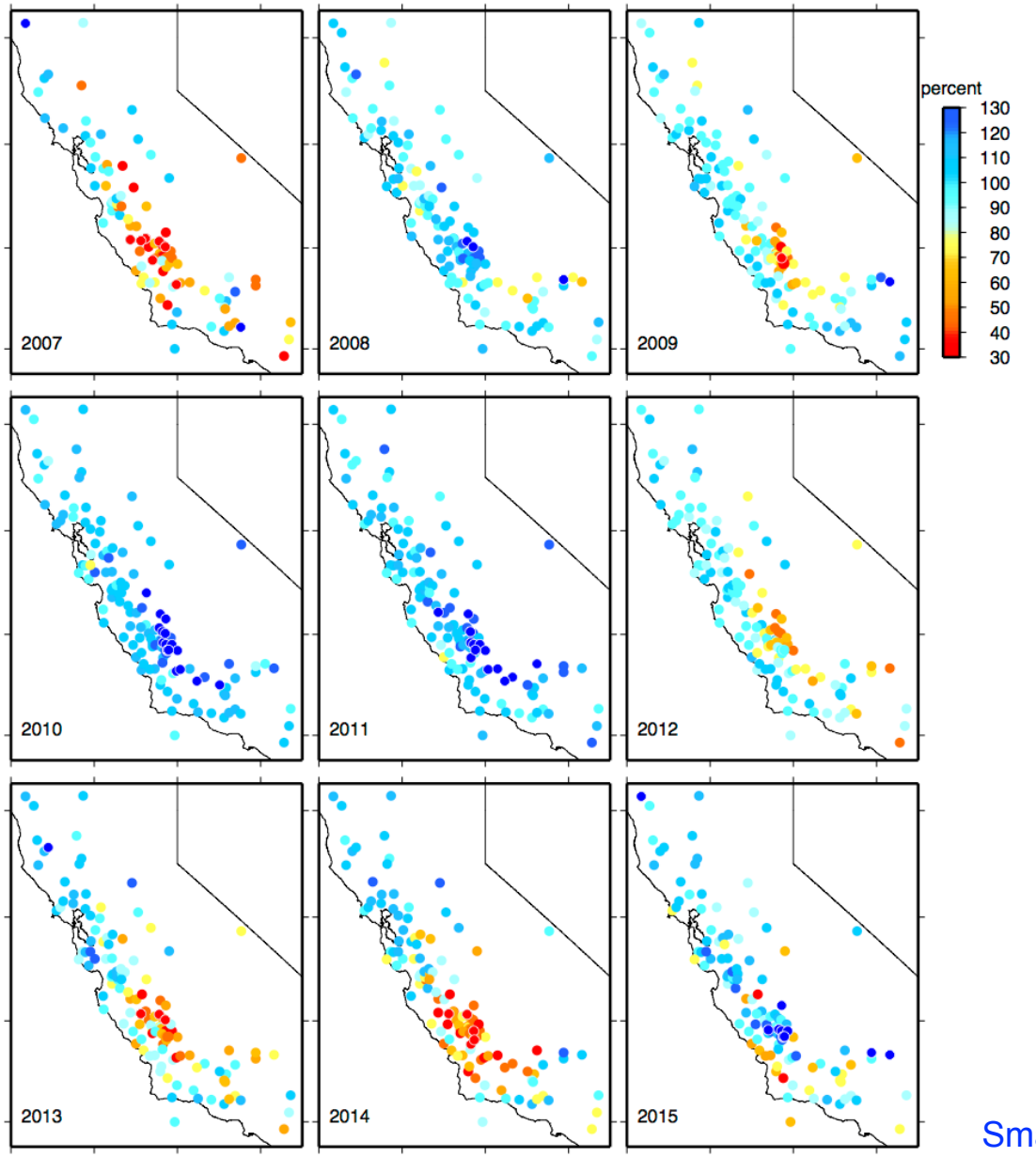


Vegetation Water Content





California Vegetation Water Content: 2007-2015



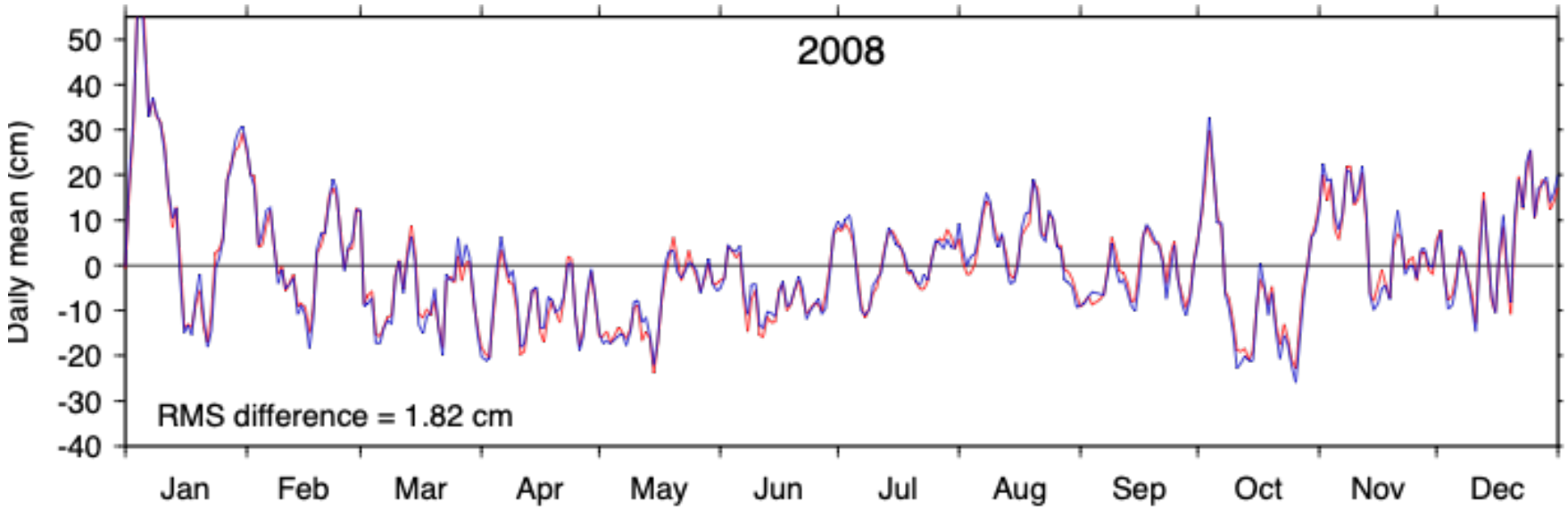
Small et al. 2018

Unexpected Outcomes of EarthScope Water Cycle Research

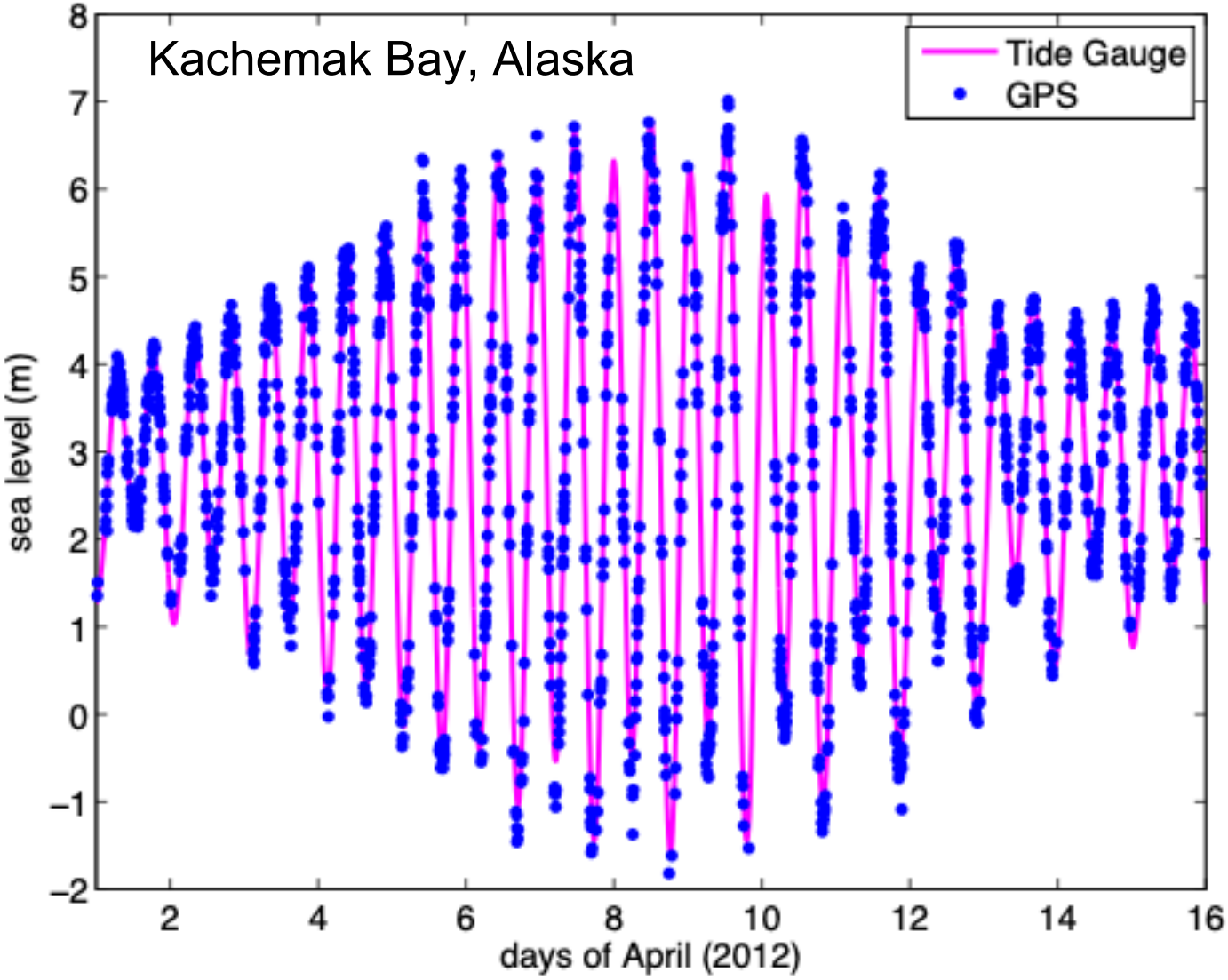
Water Levels

PBO Site SC02, Friday Harbor, Washington

Comparison between GPS tide gauge and NOAA tide gauge



PBO led directly to the development of a new kind of tide gauge

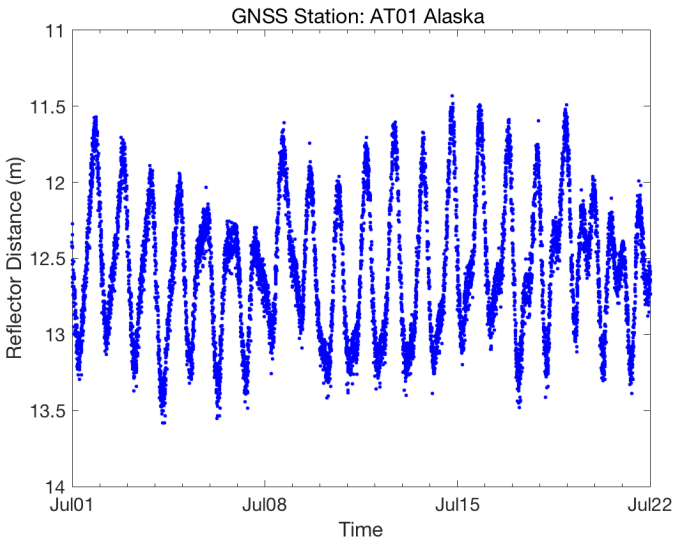


GPS Data: Jeff Freymueller

Advantages of a GPS tide gauge:

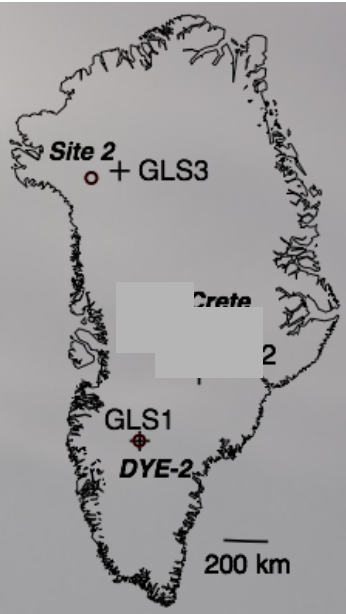
No parts in the water, doesn't require a pier, and you know the vertical land motion.

Today: GPS + Europe + China + Russian Systems



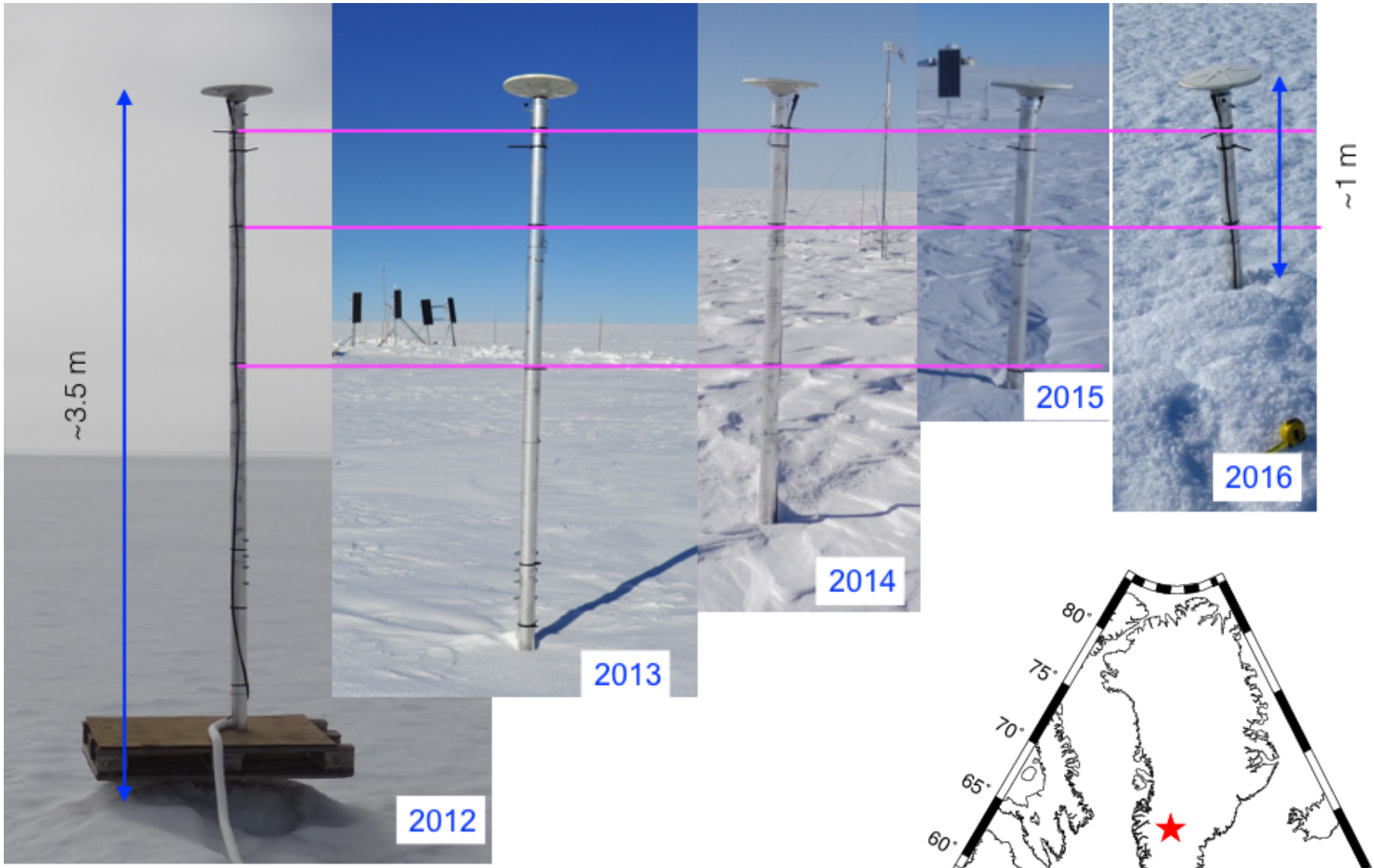
Alaska Ocean Observing System
UNAVCO

Ice Sheets

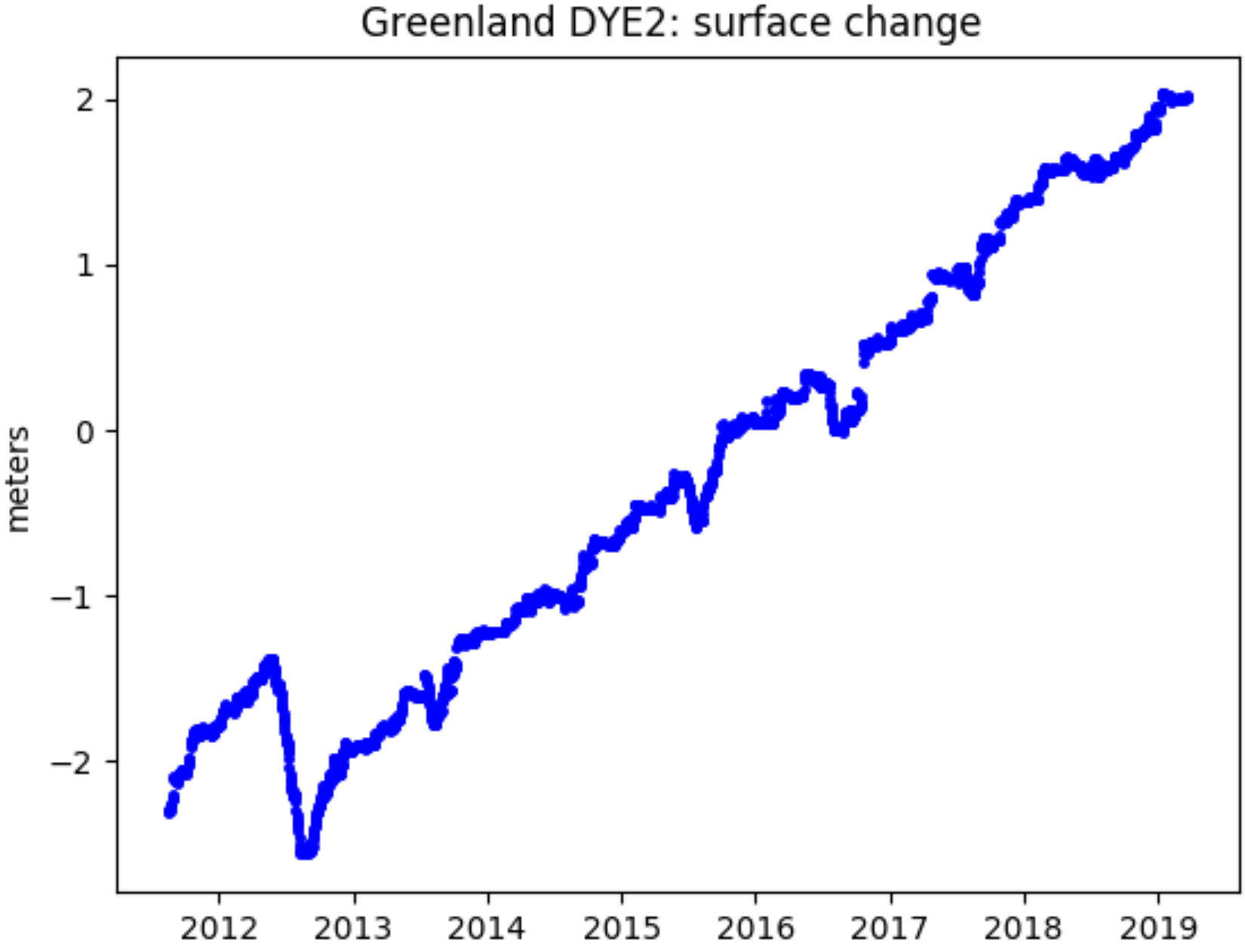


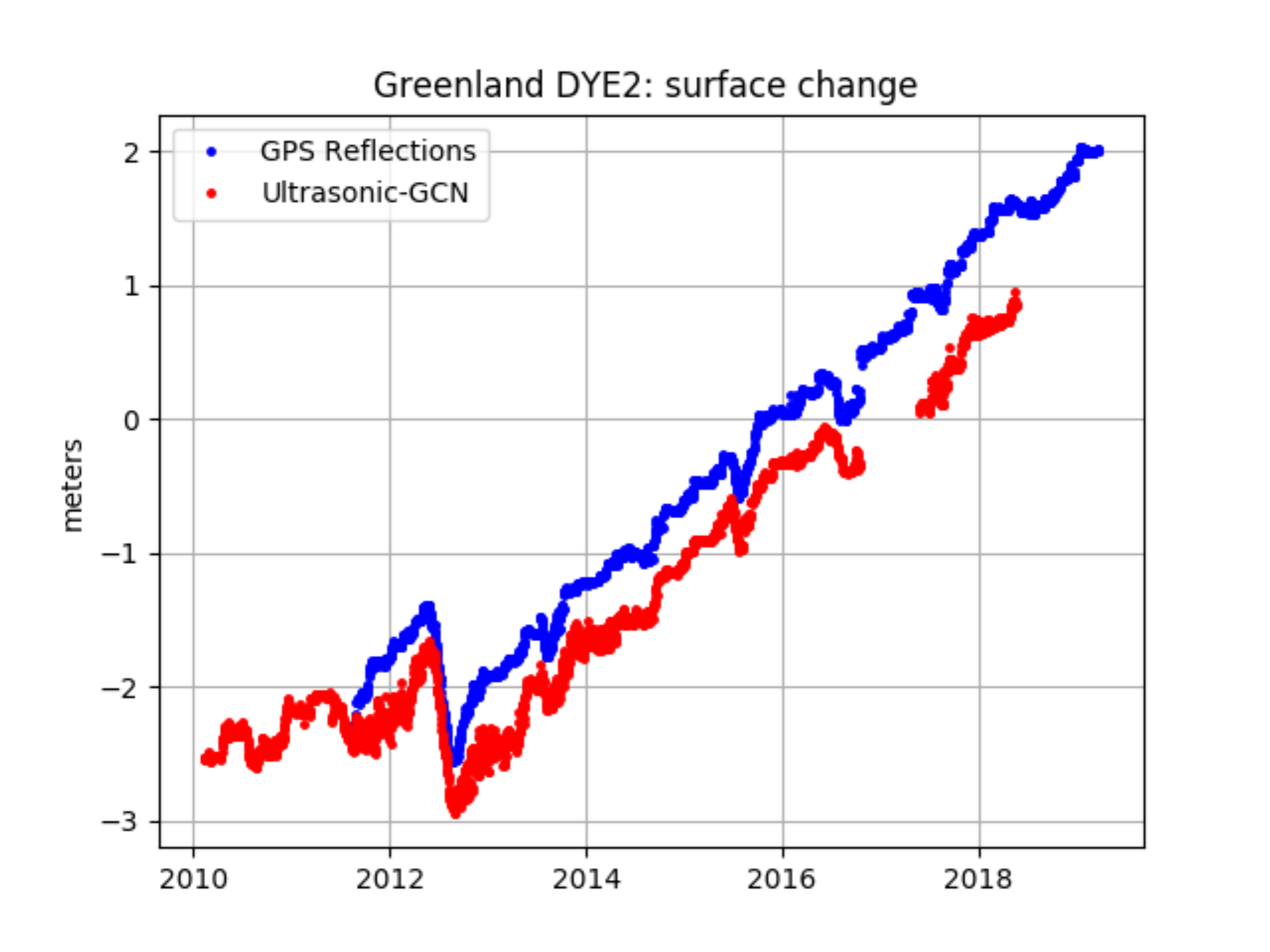
GLISN network

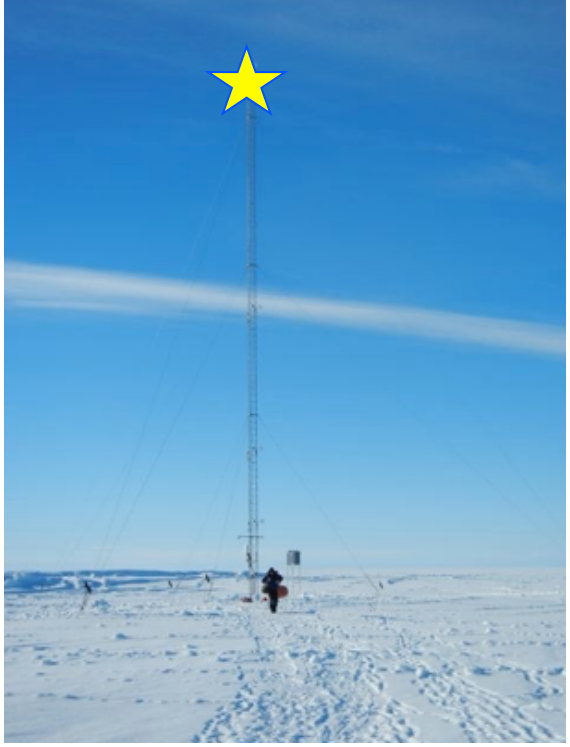
Dye2, Greenland



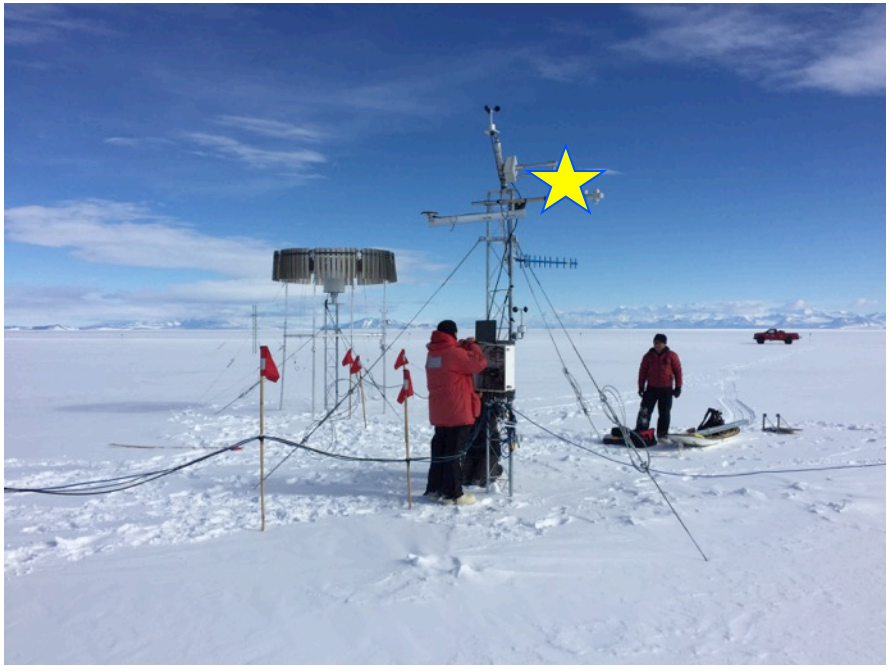
Photos: IRIS

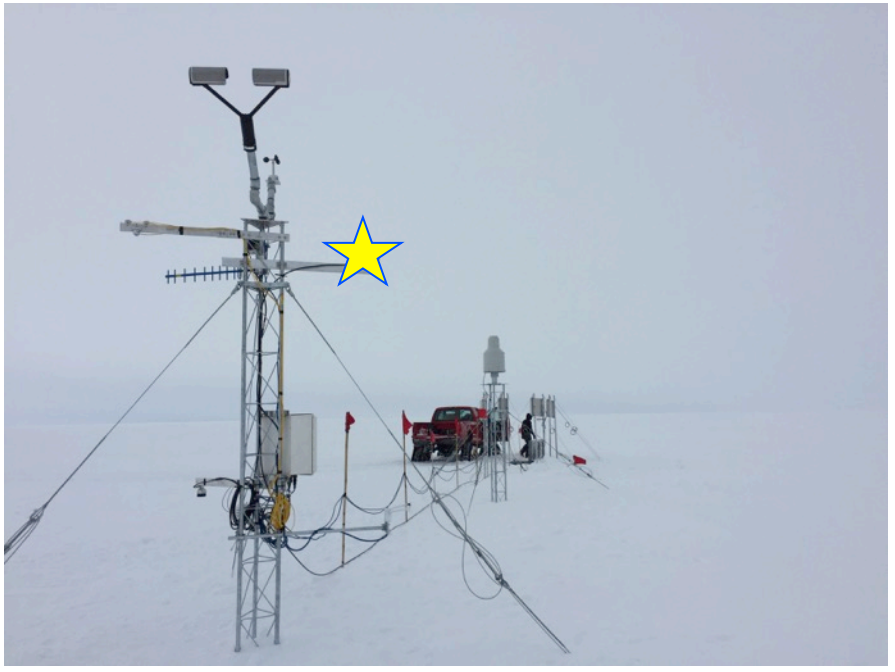

Greenland DYE2: surface change
meters
2
1
0
−1
−2
2012
2013
2014
2015
2016
2017
2018
2019


Greenland DYE2: surface change
GPS Reflections
Ultrasonic-GCN
meters
2
1
0
−1
−2
−3
2010
2012
2014
2016
2018



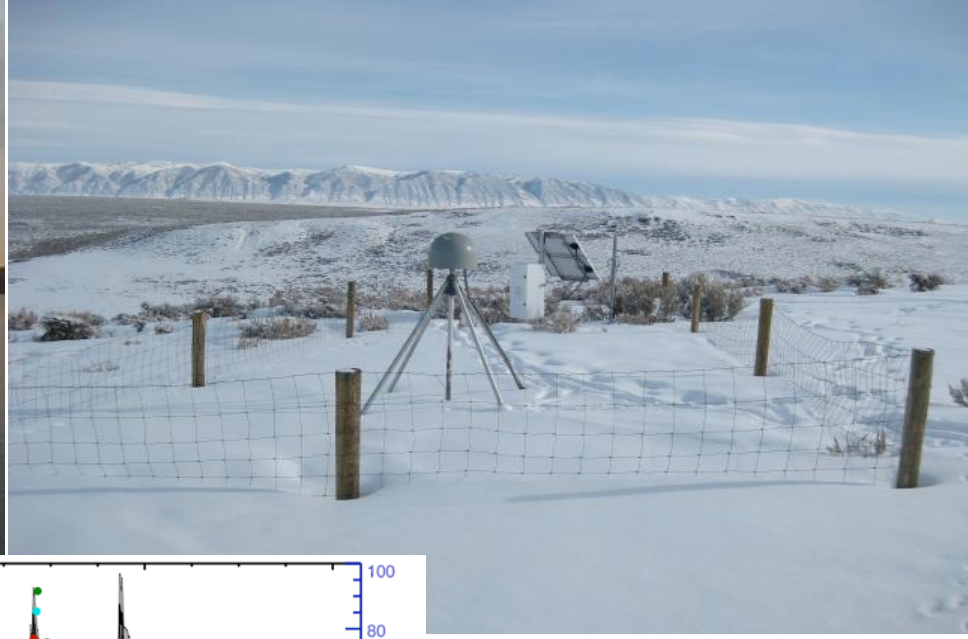
Antarctica: GPS Reflectometry Sites on the Ross Ice Shelf and Thwaites Glacier

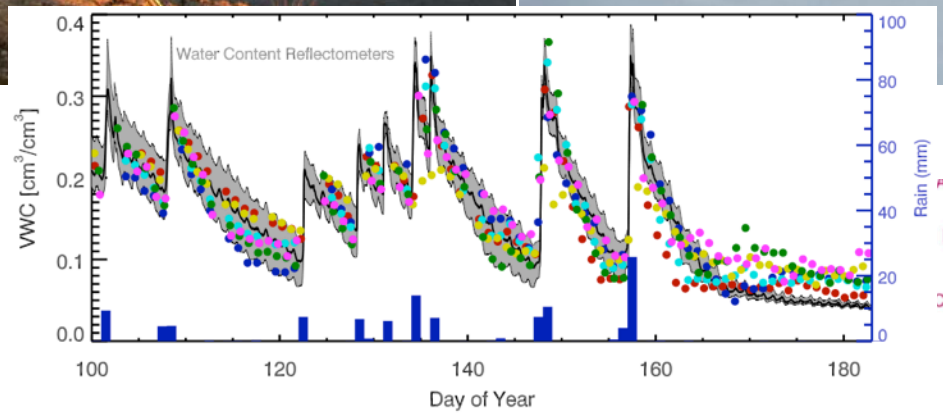


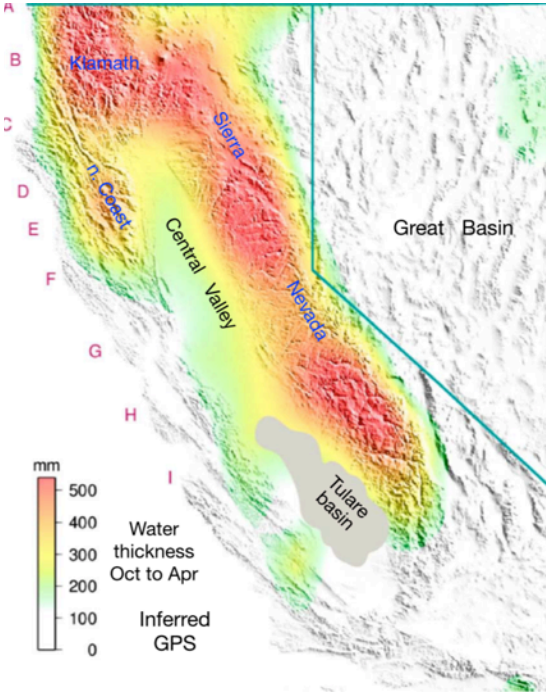


Transformative - Interdisciplinary Science from EarthScope

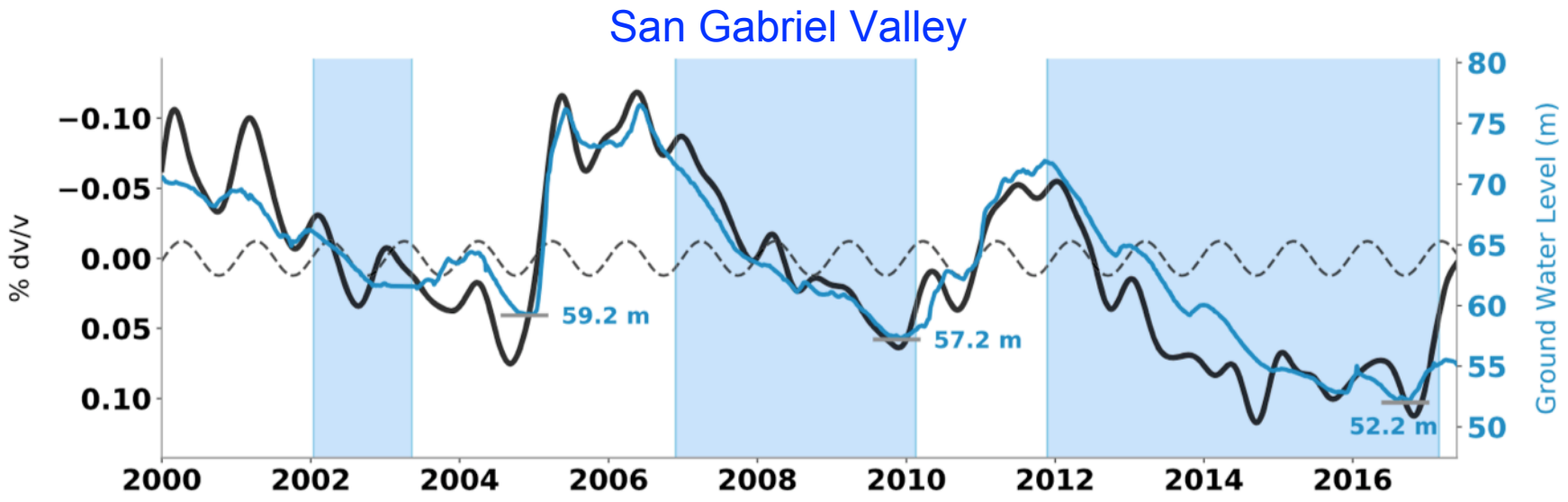
- Importance of Global Geodetic Infrastructure
- EarthScope's Open Data Policy.
- State of the art instrumentation and archiving systems.
- Outcomes:
  - Terrestrial water storage estimates at unprecedented temporal and spatial scales.
  - In Situ Hydrologic and ecological data for climate scientists and water managers.
  - A tide gauge that is tied to our terrestrial reference frame (and that has no parts in water).
  - A new snow (and firn compaction) sensor for cryosphere sciences.
  - Cal/val data for satellite missions (SMAP, SMOS, IceSat2, SWOT).




Water Content Reflectometers
VWC [cm³/cm³]
Rain (mm)
Day of Year
0.0
0.1
0.2
0.3
0.4
0
20
40
60
80
100
100
120
140
160
180


Klamath
Sierra
N. Coast
Central Valley
Nevada
Great Basin
Tulare basin
mm
500
400
300
200
100
0
Water thickness Oct to Apr
Inferred GPS

Hydrology Research with USArray Data



Clements and Denolle, 2018