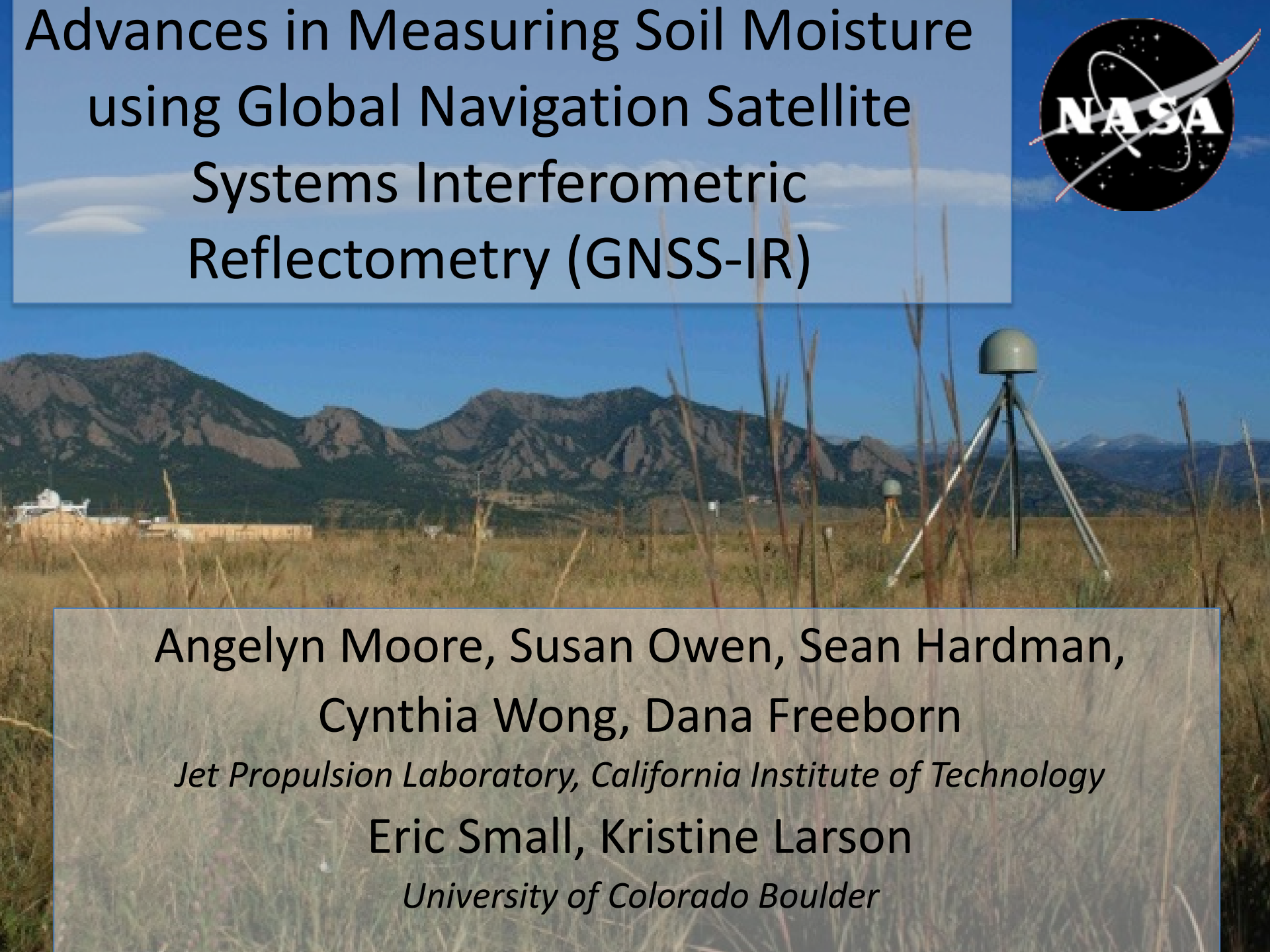
Advances in Measuring Soil Moisture using Global Navigation Satellite Systems Interferometric Reflectometry (GNSS-IR)



Angelyn Moore, Susan Owen, Sean Hardman, Cynthia Wong, Dana Freeborn

Jet Propulsion Laboratory, California Institute of Technology

Eric Small, Kristine Larson

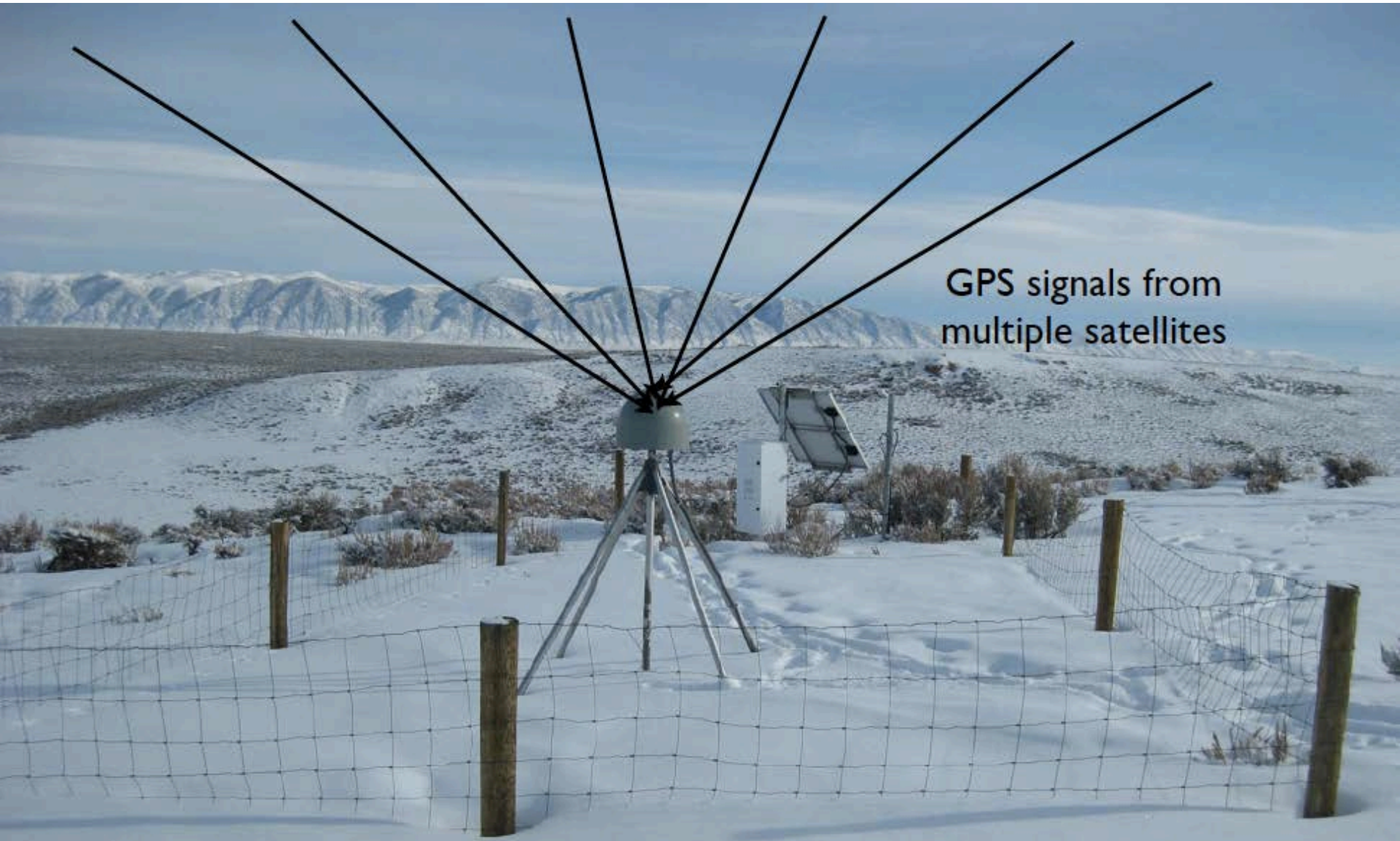
University of Colorado Boulder

Outline

- GNSS Interferometric Reflectometry (GNSS-IR)
- The soil moisture product
- Soil moisture in the presence of varying vegetation
- The vegetation index product
- CU PBO-H2O prototype portal in western U.S.
- CU-JPL NASA project to enable global expansion

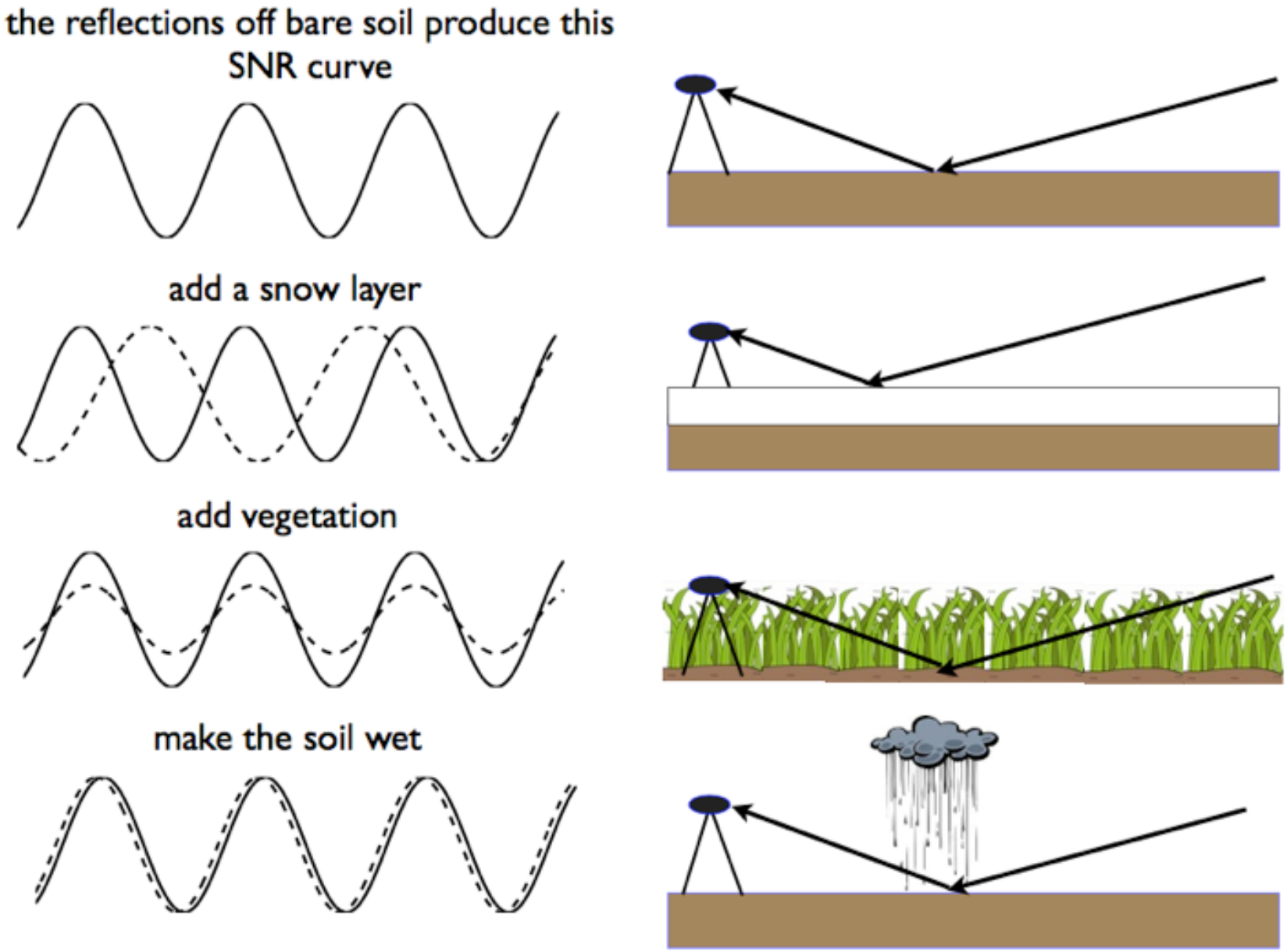
Why do this with GPS receivers?

- 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).
- Ground sensors are needed both for assimilation and satellite validation.
- Daily estimates (or better – SMC 12 hr).
- It's cheap.



"normal" people measure the distance between multiple satellites and the antenna (in the gray dome) and they estimate the antenna position (X, Y, Z or latitude/longitude/height).

We use the interference pattern created by the direct and reflected signal power to infer changes in the reflecting surface.

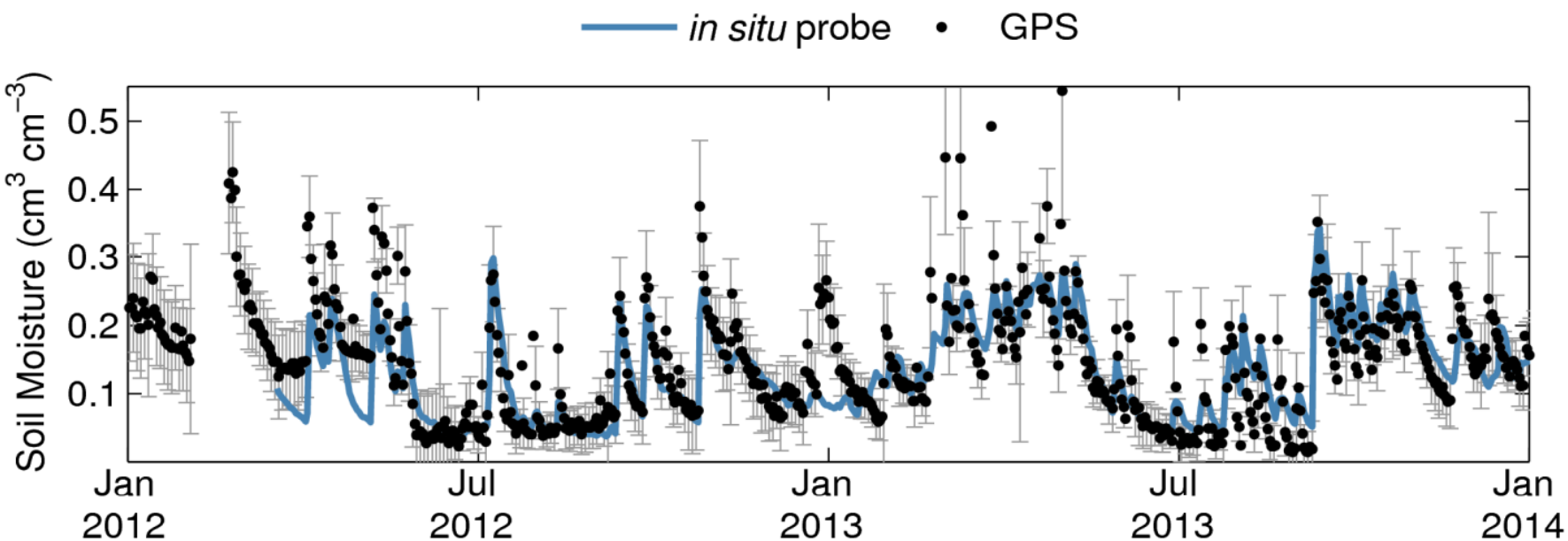


Larson et al., 2008; Larson et al., 2009; Larson and Small, 2014

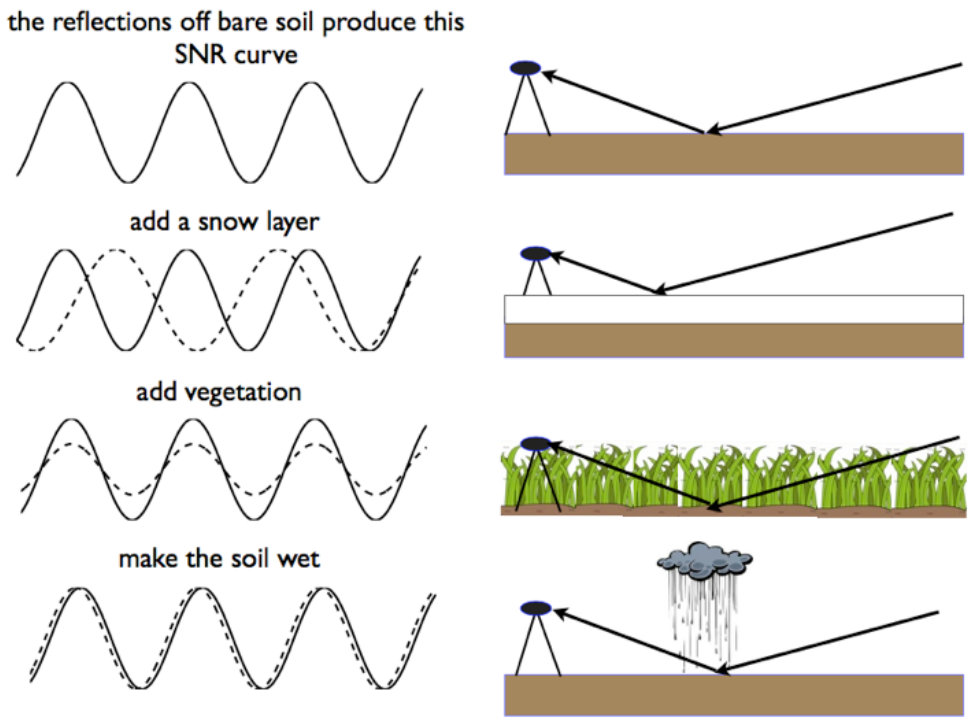
Soil moisture

- Soil moisture product represents an average over ~300m^2
- Compares well with measurements in 0-5 cm and 5-10 cm depths

Marshall, CO



Remember this?



Situation is complicated with more than one of these varying.

"All three GPS interferogram metrics (effective reflector height, phase, and amplitude) are affected by soil moisture in the top 5 cm of the soil"

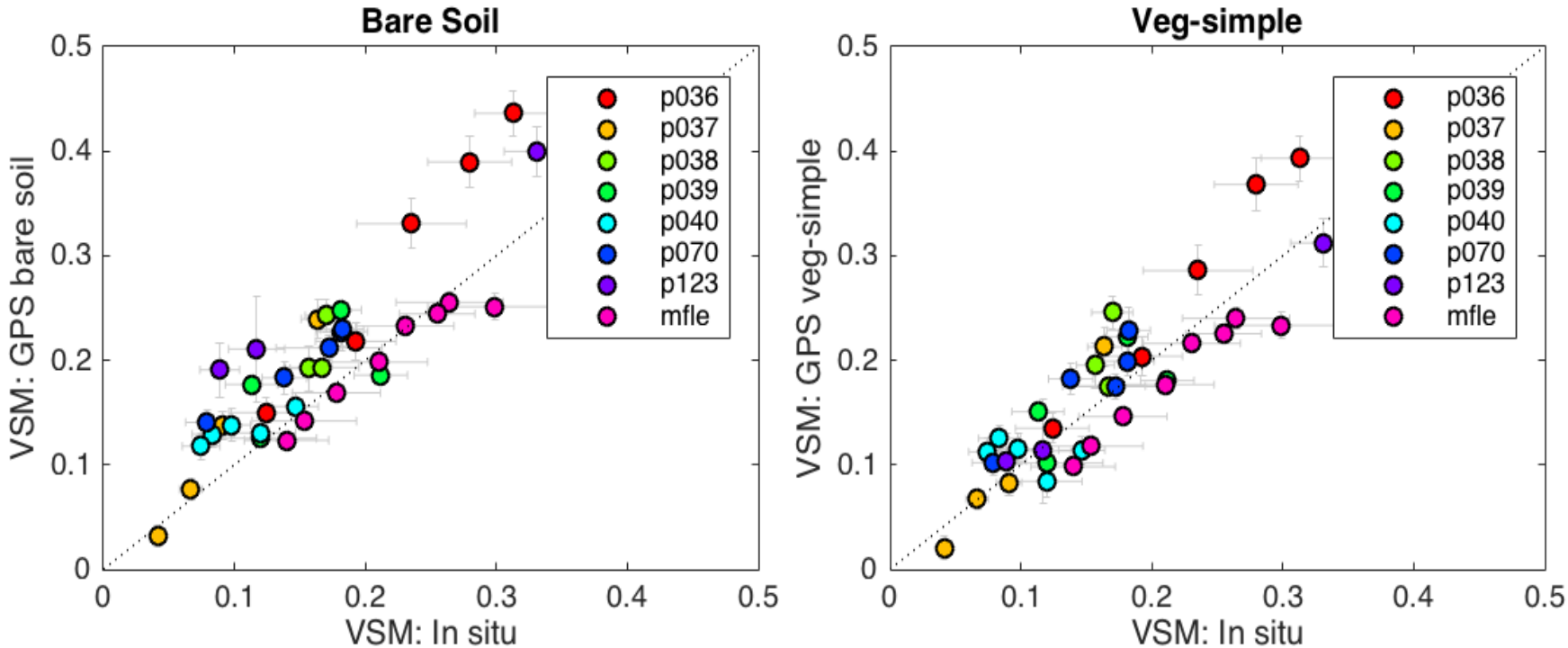
Small, E. E., Larson, K. M., Chew, C. C., Dong, J., & Ochsner, T. E. (2016). Validation of GPS-IR soil moisture retrievals: Comparison of different algorithms to remove vegetation effects.

Chew, C. C., Small, E. E., Larson, K. M., & Zavorotny, V. U. (2015). Vegetation sensing using GPS-interferometric reflectometry: theoretical effects of canopy parameters on signal-to-noise ratio data. IEEE Transactions on Geoscience and Remote Sensing, 53(5), 2755-2764.

GNSS-IR Soil Moisture Validation

Validation at PBO site

~25 theta probe measurements per site

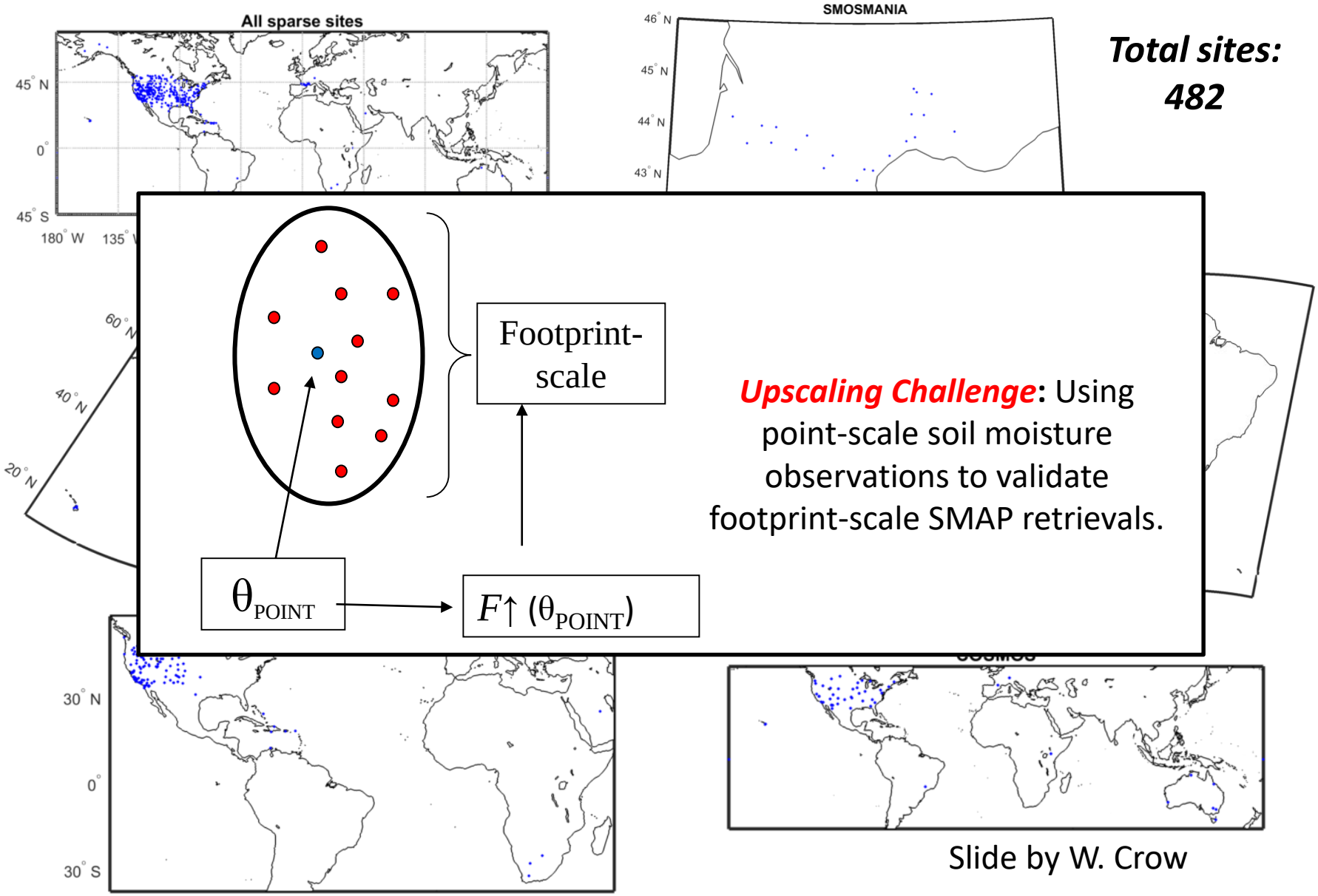


With adjustment for vegetation, RMSE < 0.04 m^3/m^3

→ sufficient for satellite validation

Small et al. 2015

GPS-IR compared to SMAP with other sparse networks



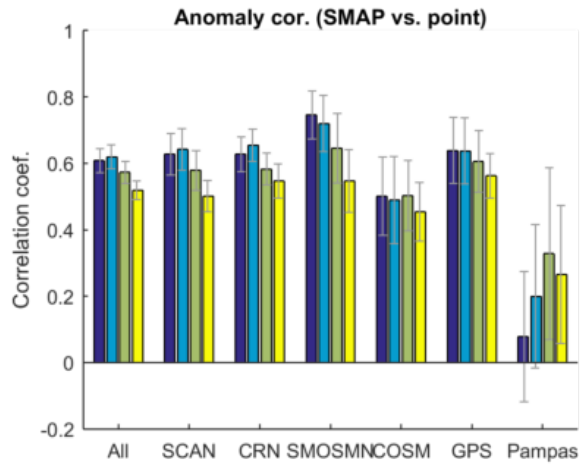
Total sites: 482

***Upscaling Challenge*: Using point-scale soil moisture observations to validate footprint-scale SMAP retrievals.**

Slide by W. Crow

L2 SM_P (stratified by sparse network)

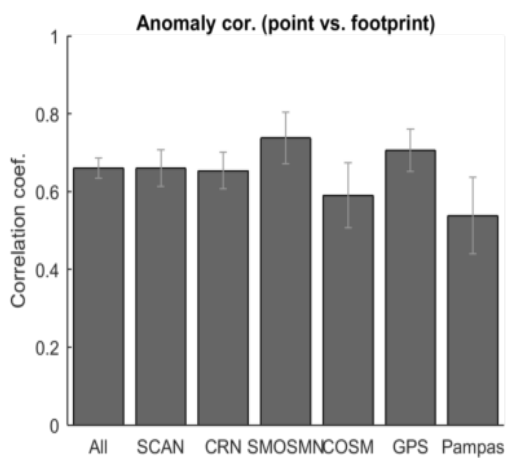
GPS compares with SMAP as well or better as other sparse networks



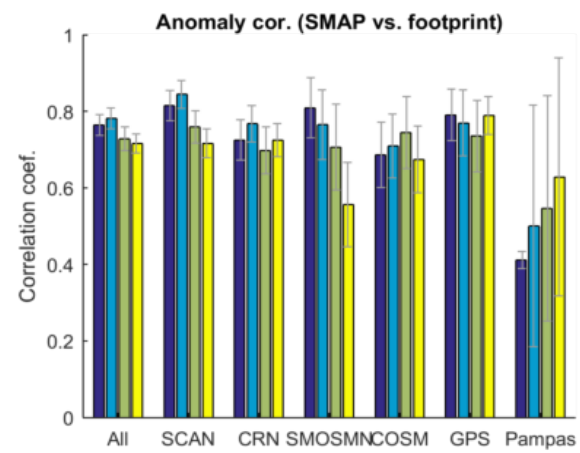
No TC - Point versus SMAP (degraded by *both* ground errors and SMAP errors)

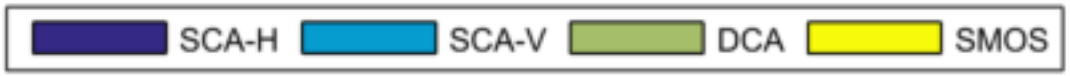
Point versus Truth

SMAP versus Truth



TC-based Decomposition

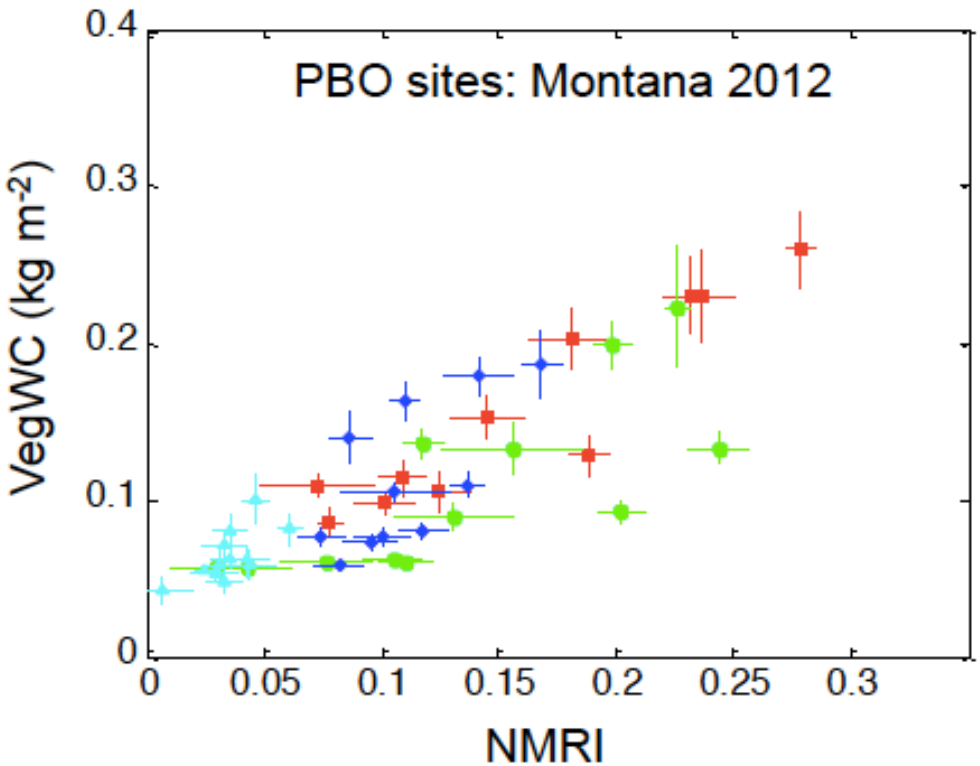


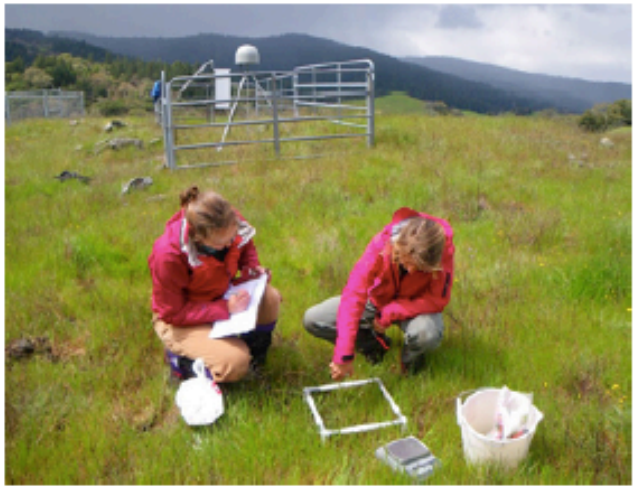


Slide by W. Crow

GNSS-IR Vegetation Index

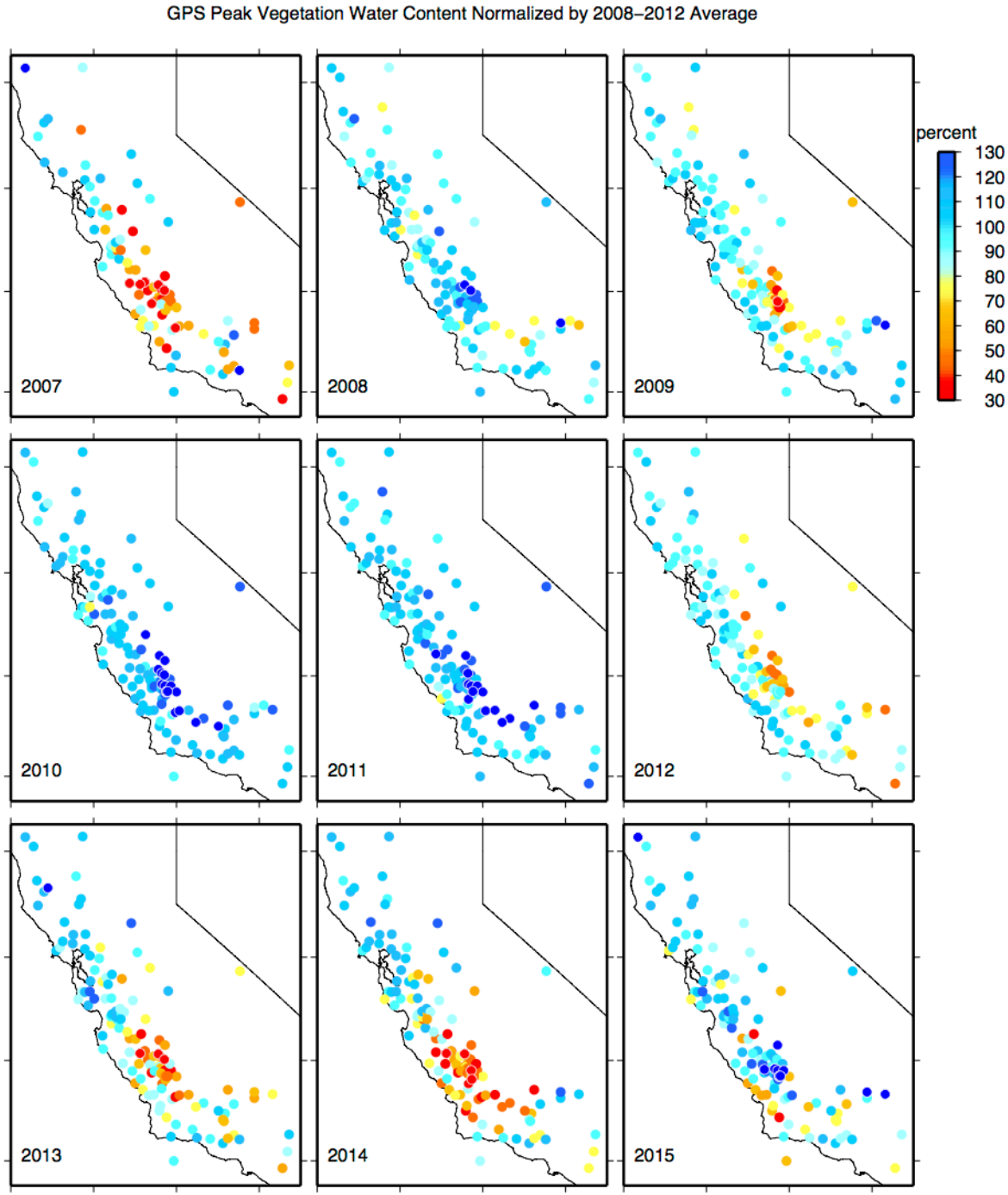
- Optical methods (NDVI) have ~weekly resolution and focus on "greenness"
- GNSS-IR NMRI is estimated daily and is related to water content, height and structure.



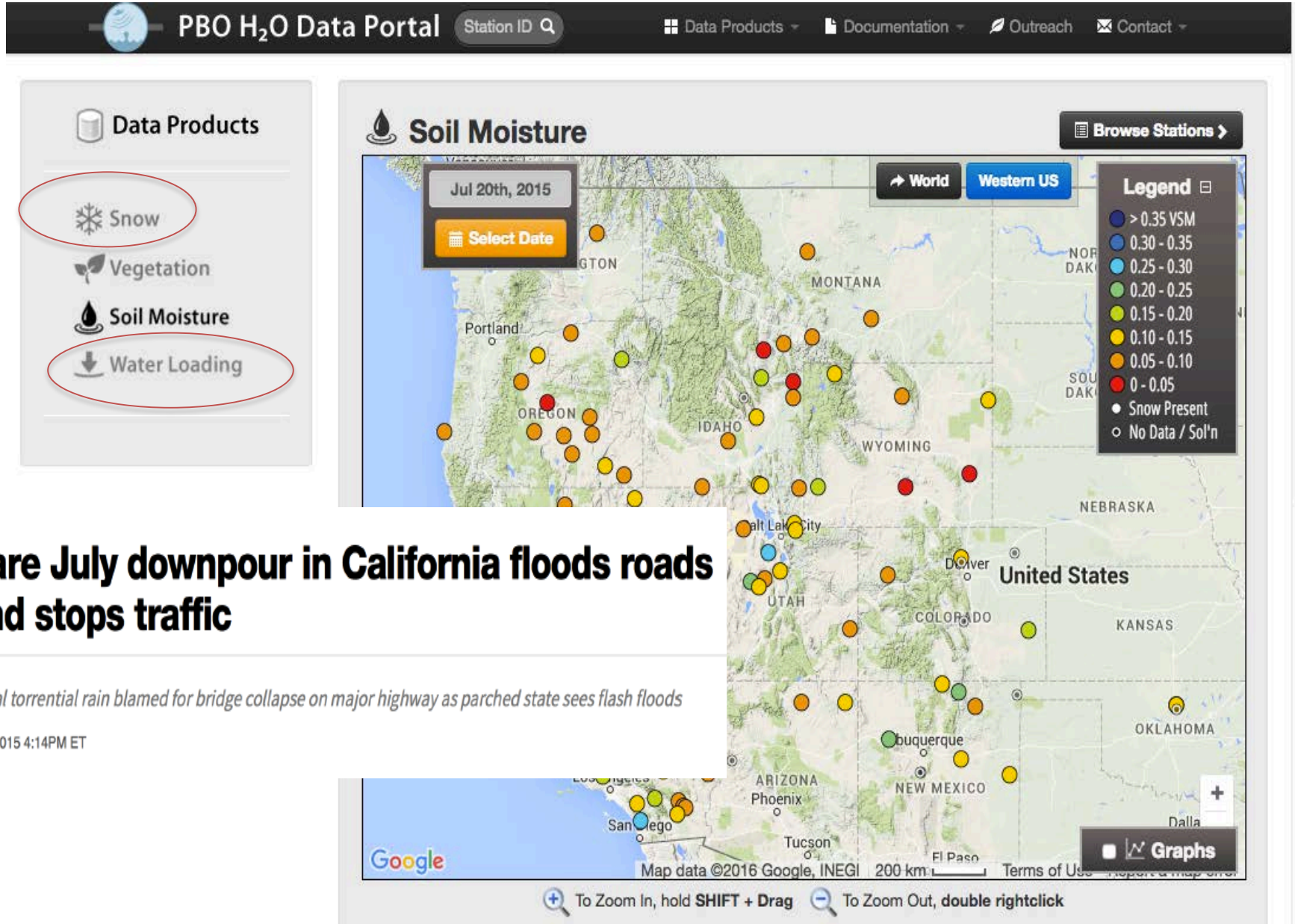


Normalized Microwave Reflection Index (Small, Larson and Smith 2014)

Map view of vegetation product in California



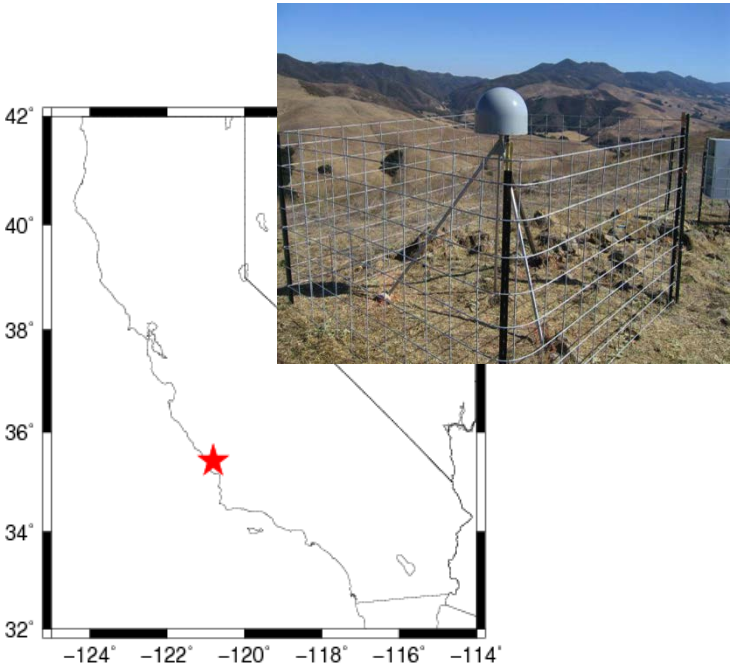
PBO H_2O Data Portal



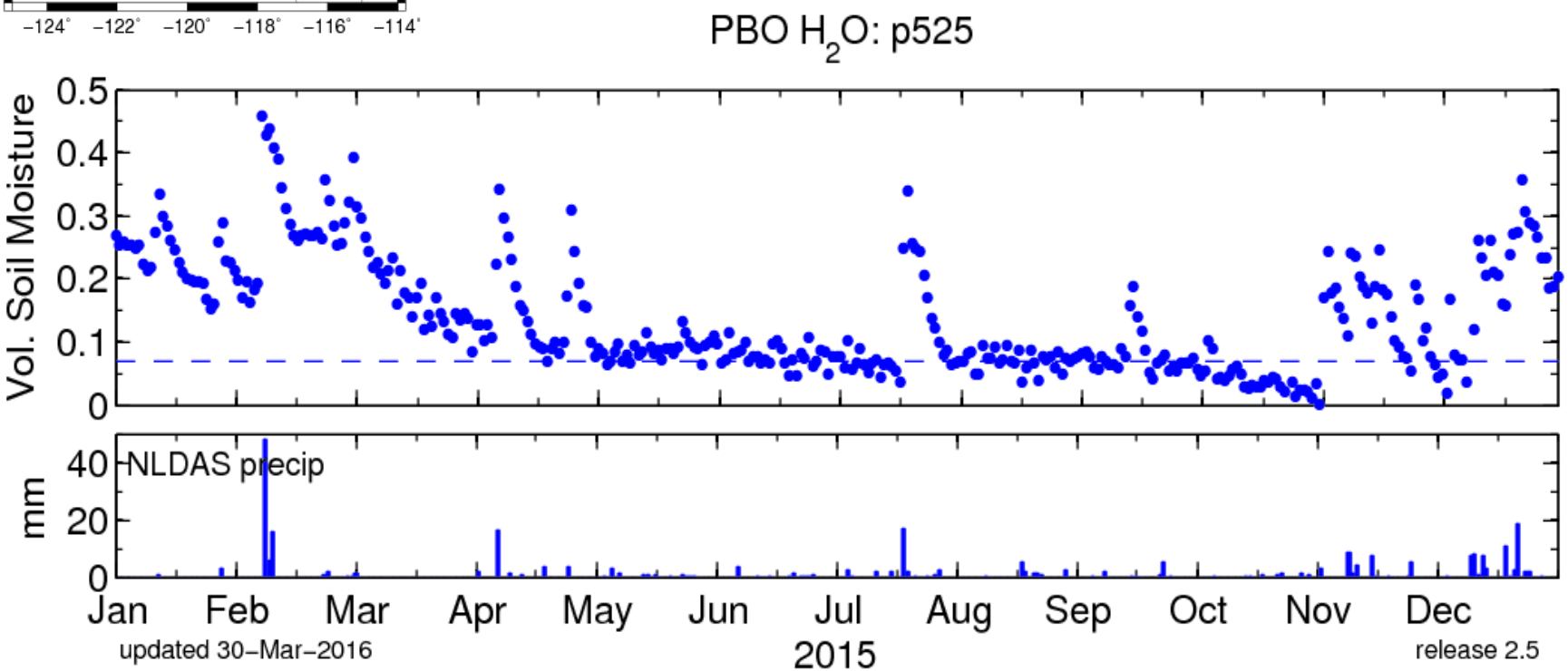
Rare July downpour in California floods roads and stops traffic

Unusual torrential rain blamed for bridge collapse on major highway as parched state sees flash floods

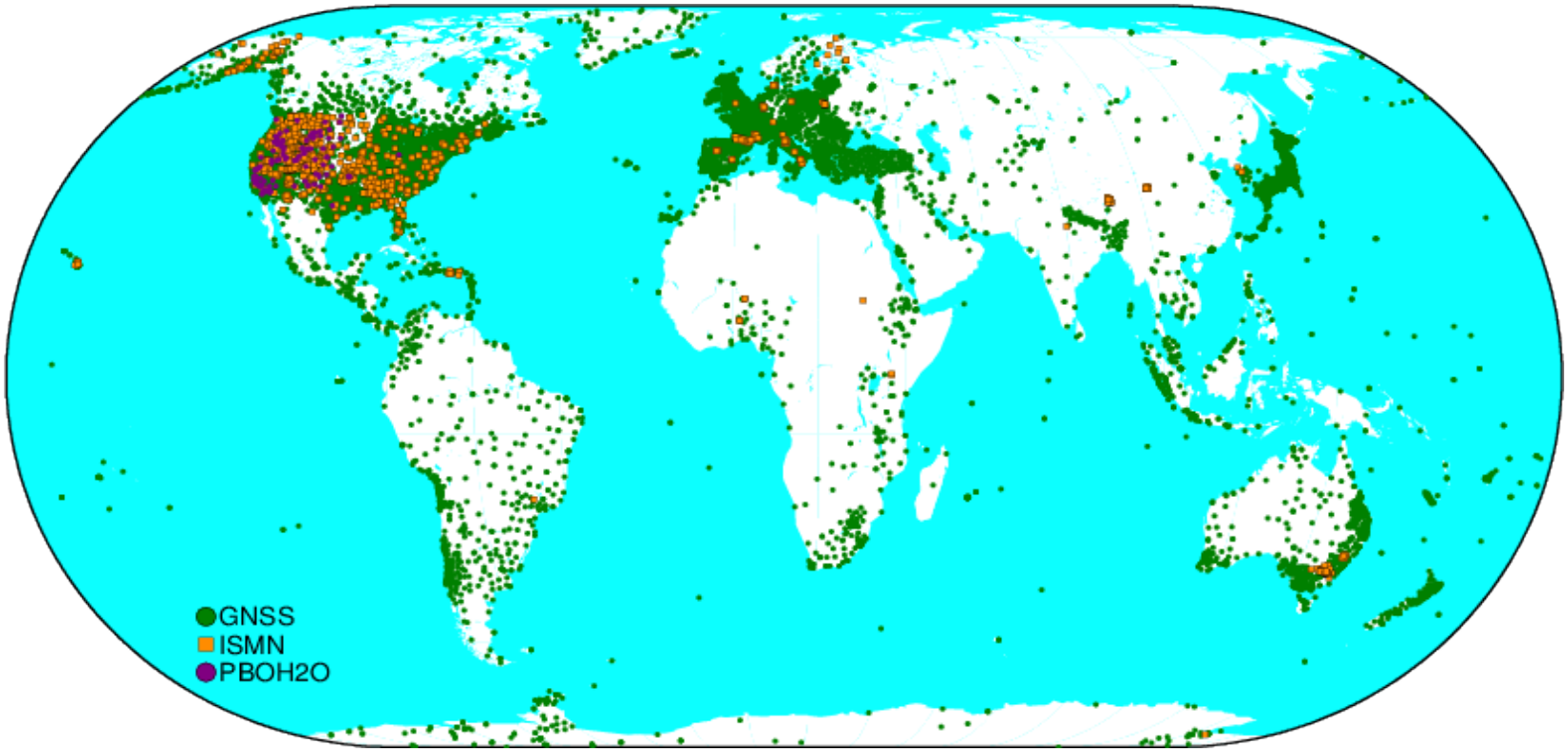
July 20, 2015 4:14PM ET



GNSS-IR Soil Moisture Timeseries



From Regional to Global



International Soil Moisture Network

Public GNSS sites

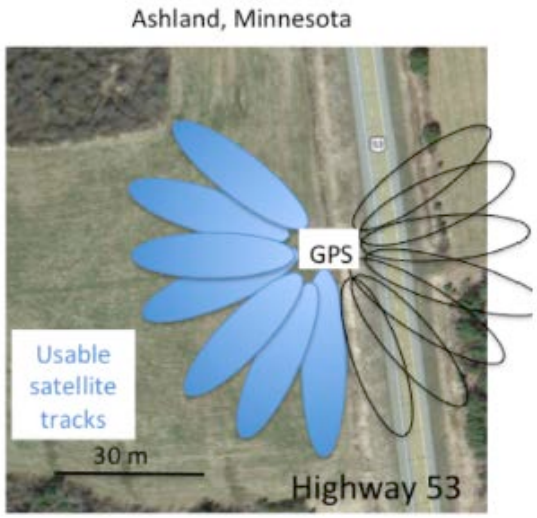
PBO H2O pilot project

The PBO-H_2O prototype was purpose-built for the largely homogenous PBO network, but there are many more subnetworks available.

From Regional to Global

To achieve the generalization and scalability required for global operations, CU and JPL are funded by the NASA Earth Science Technology Project for a 2 year project 2015-2017 to:

- Integrate the prototype system into the Apache OODT IT framework
- Develop technology to automatically evaluate sites for suitability for GNSS-IR products
- Develop technology to automatically configure the system according to site characteristics



Conclusions

- GNSS-IR measures soil moisture fluctuations with accuracy (RMSE < 0.04 cm^3/cm^3) [Small et al. 2016], over an area ~300m^2, in the 0-5 cm depth range
- Algorithms have been developed to measure soil moisture in the presence of variable vegetation [Small et al. 2016]
- A prototype western-U.S. system is currently available (google "PBO H_2O")
- An long-term record can be generated for any station with the appropriate data archived
- JPL and CU are working toward generalizing the system to accept global GNSS stations