Soil Moisture, Snow, and Vegetation Sensing Using GPS Receivers

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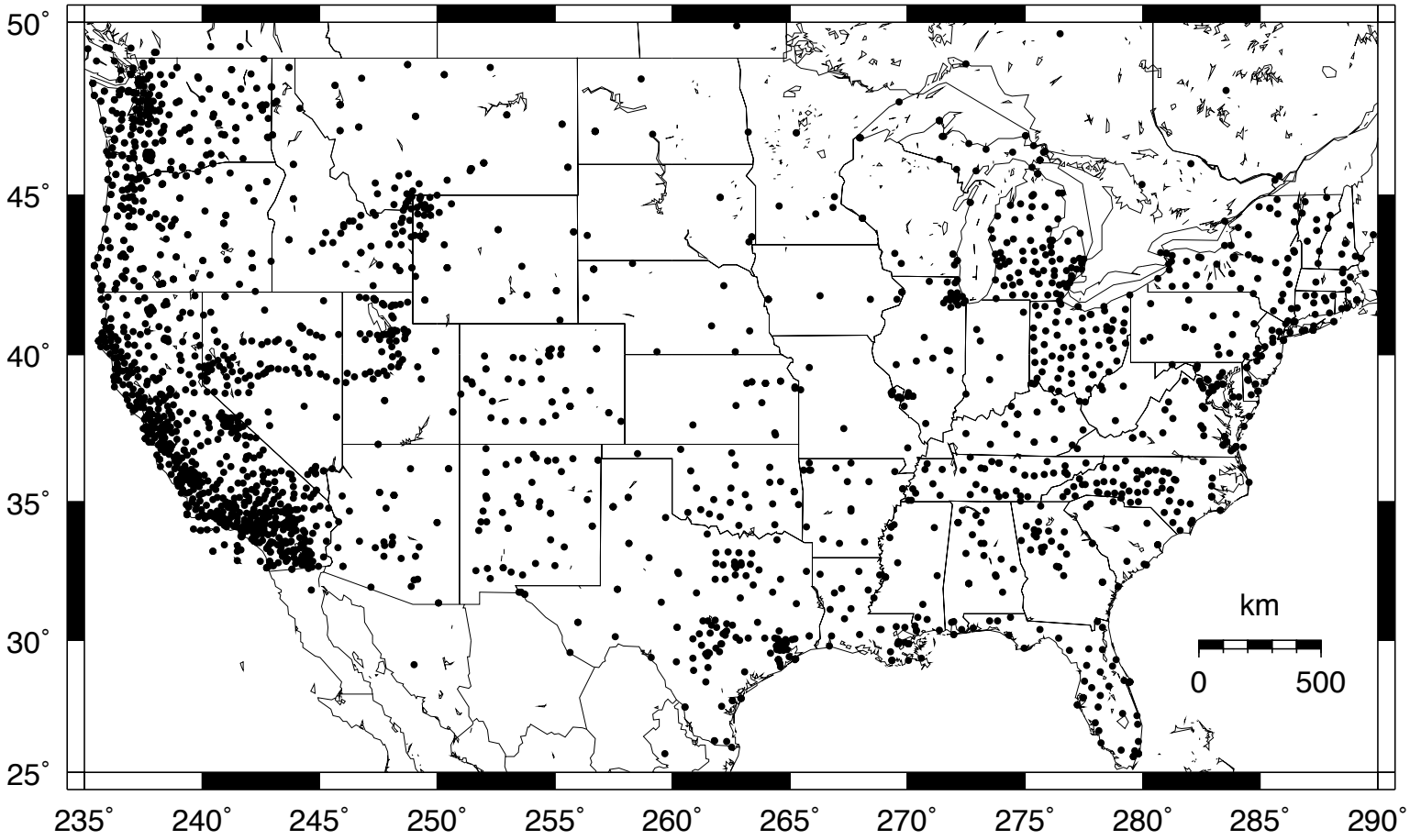
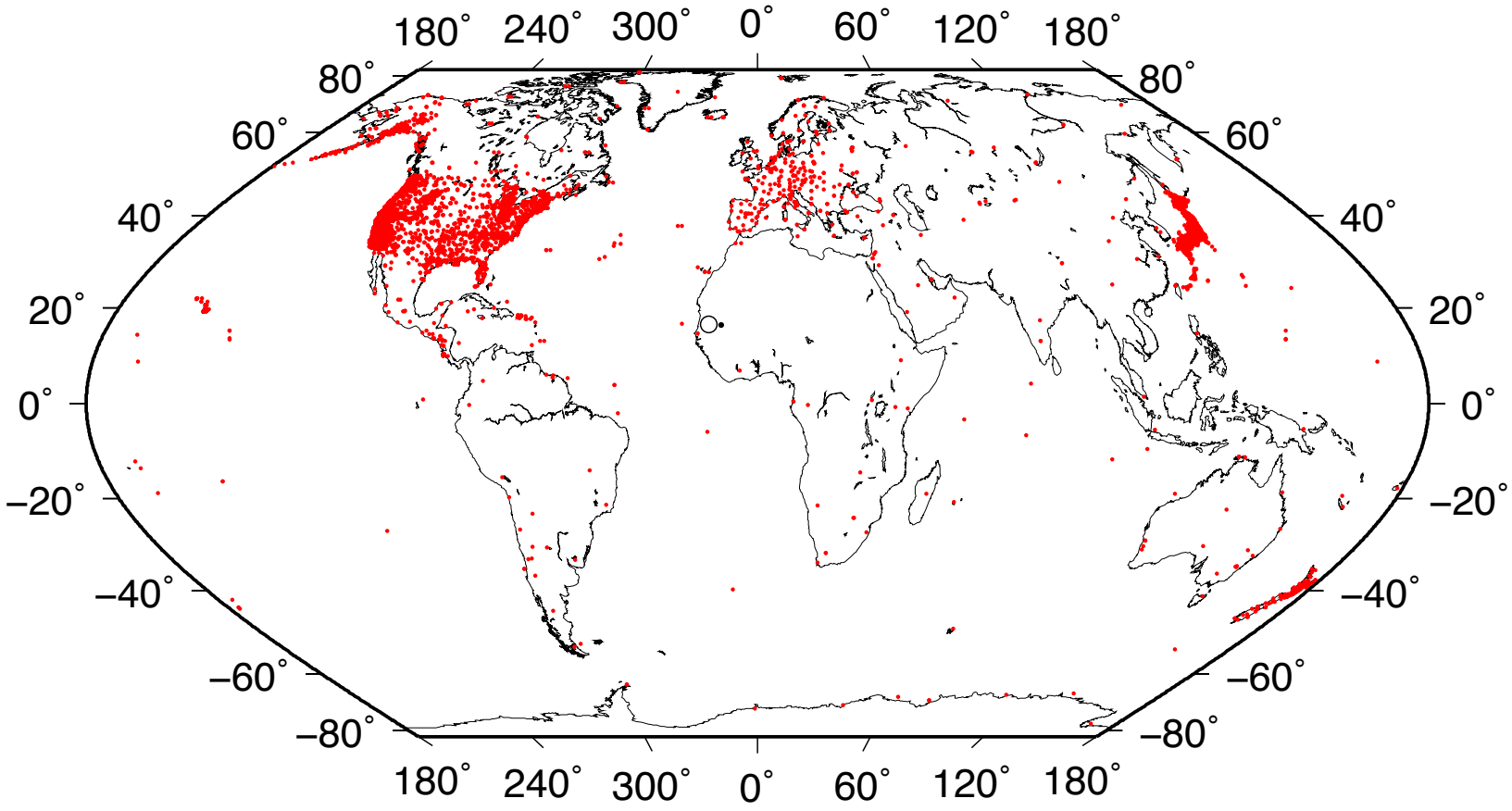
Outline

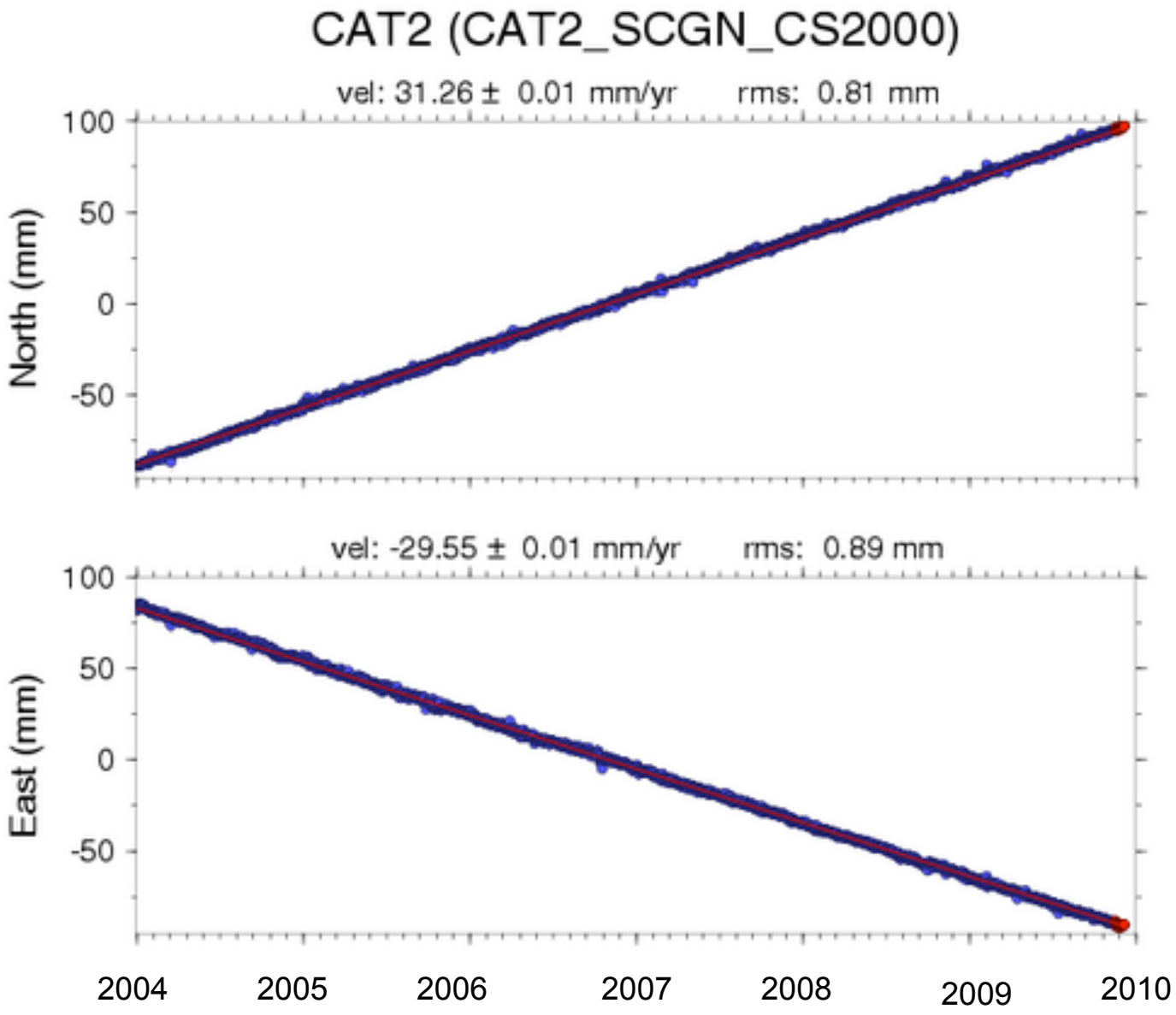
- Multipath in geodetic applications
- Multipath signature in geodetic data
- Multipath results using geodetic receivers:
  - Soil Moisture
  - Snow Depth
  - Vegetation Water Content

Continuously-Operating Geodetic GPS Receivers ~2 years ago



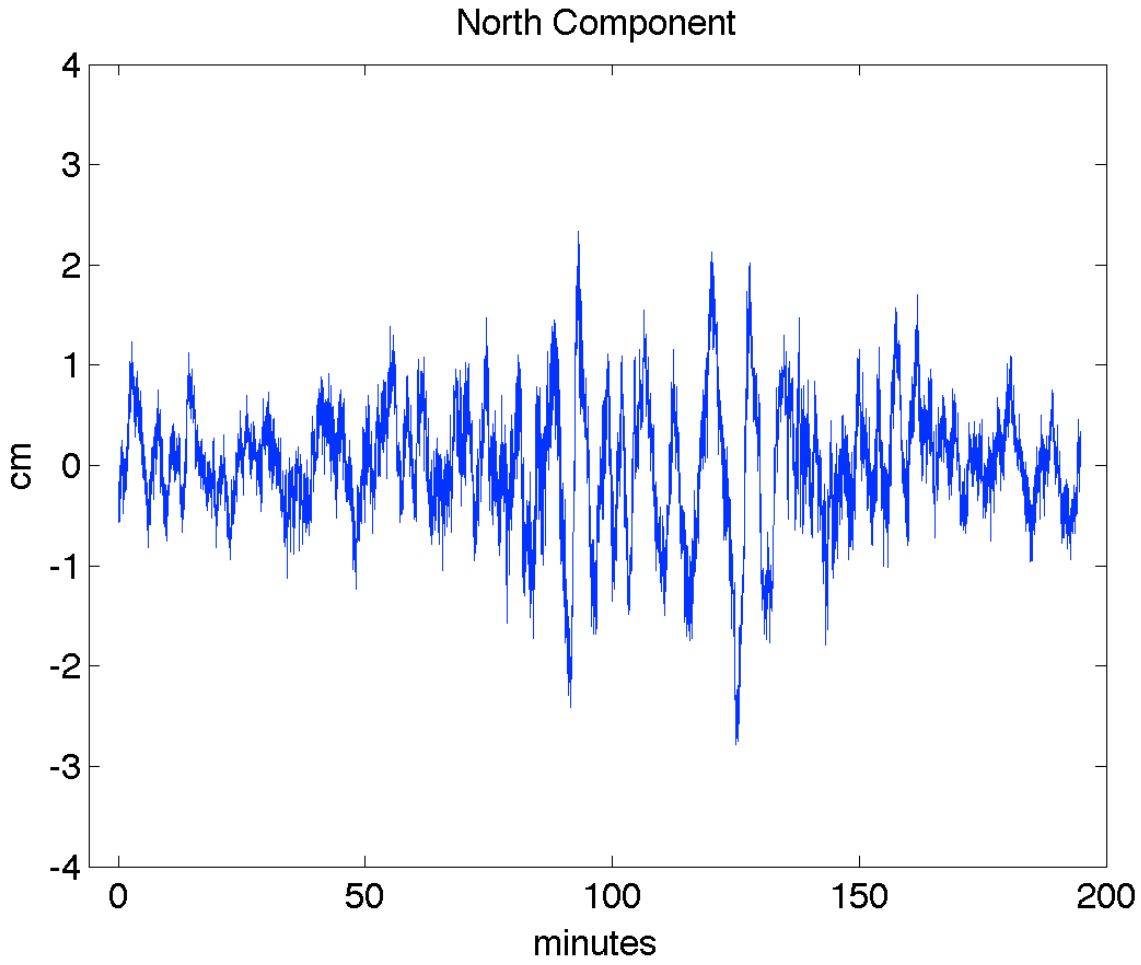

180°
240°
300°
0°
60°
120°
180°
80°
60°
40°
20°
0°
−20°
−40°
−60°
−80°

Results for plate motions: no multipath modeling



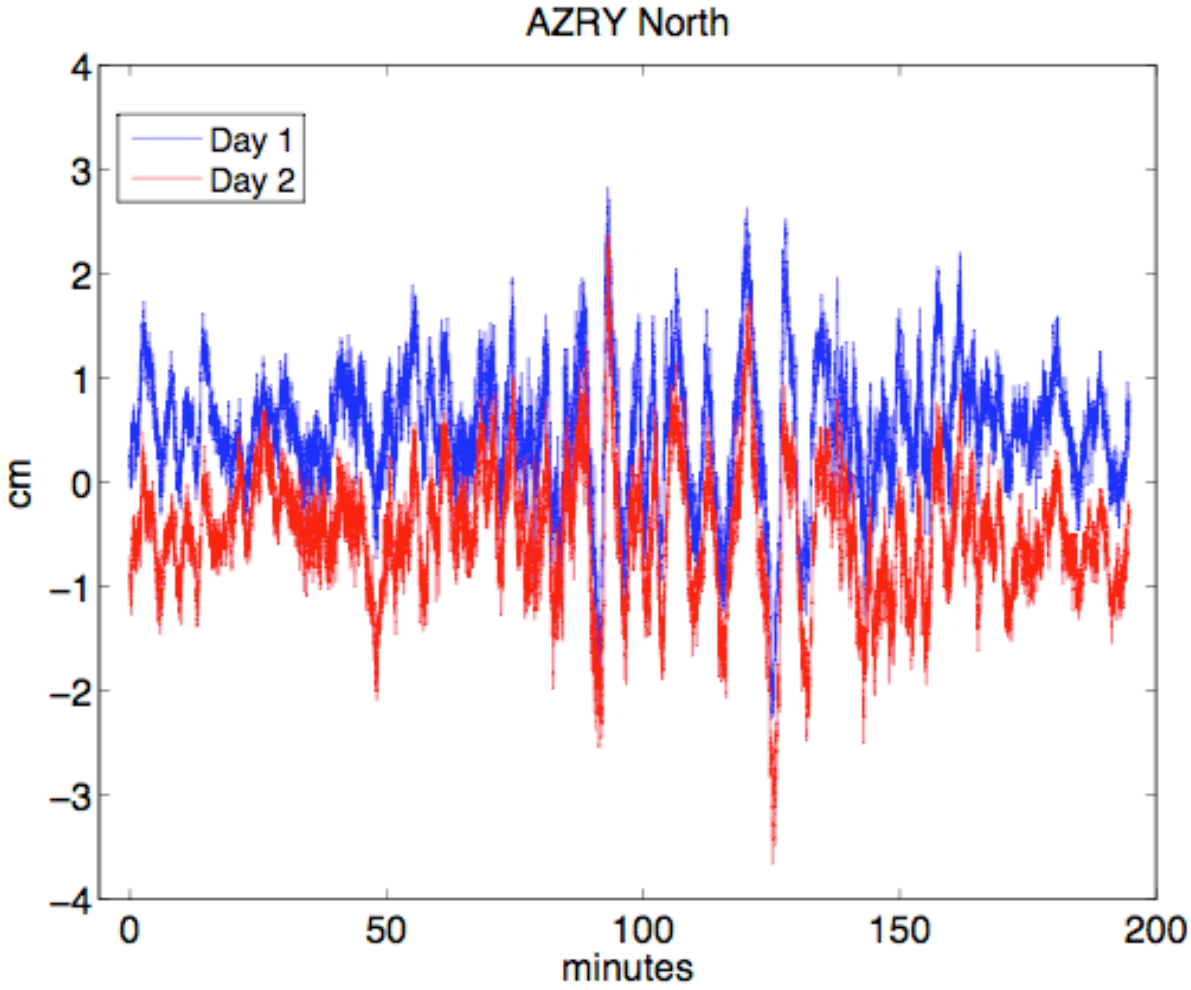
source: PBO website

but if you look at higher temporal sampling



Larson, Bilich, and Axelrad, Improving high-rate GPS precision, JGR. 2007

use “yesterday” to correct “today”

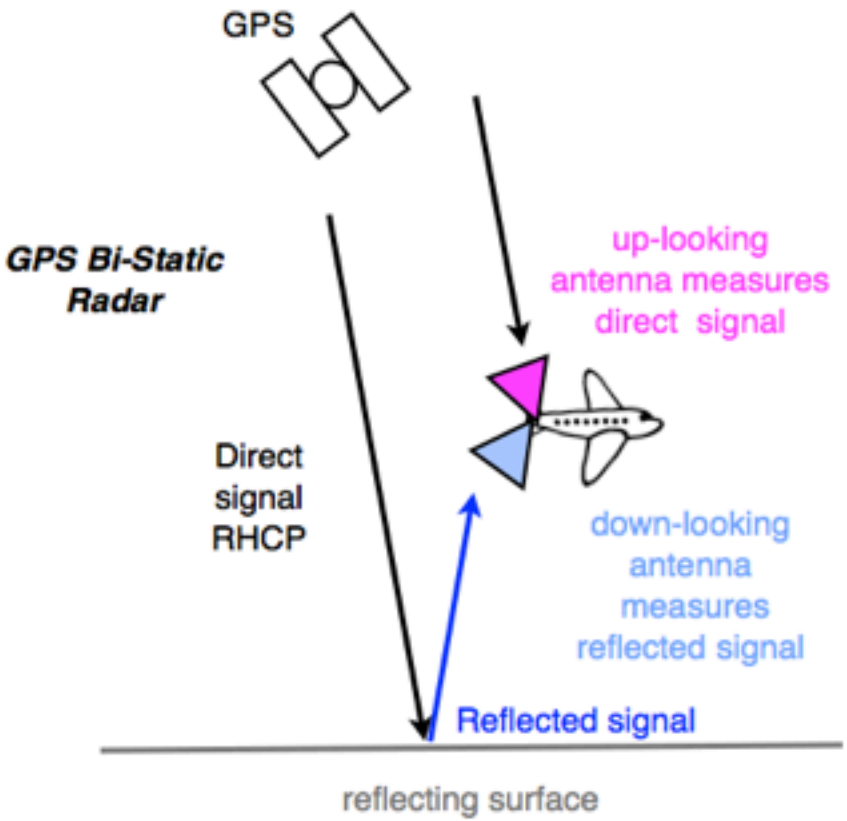


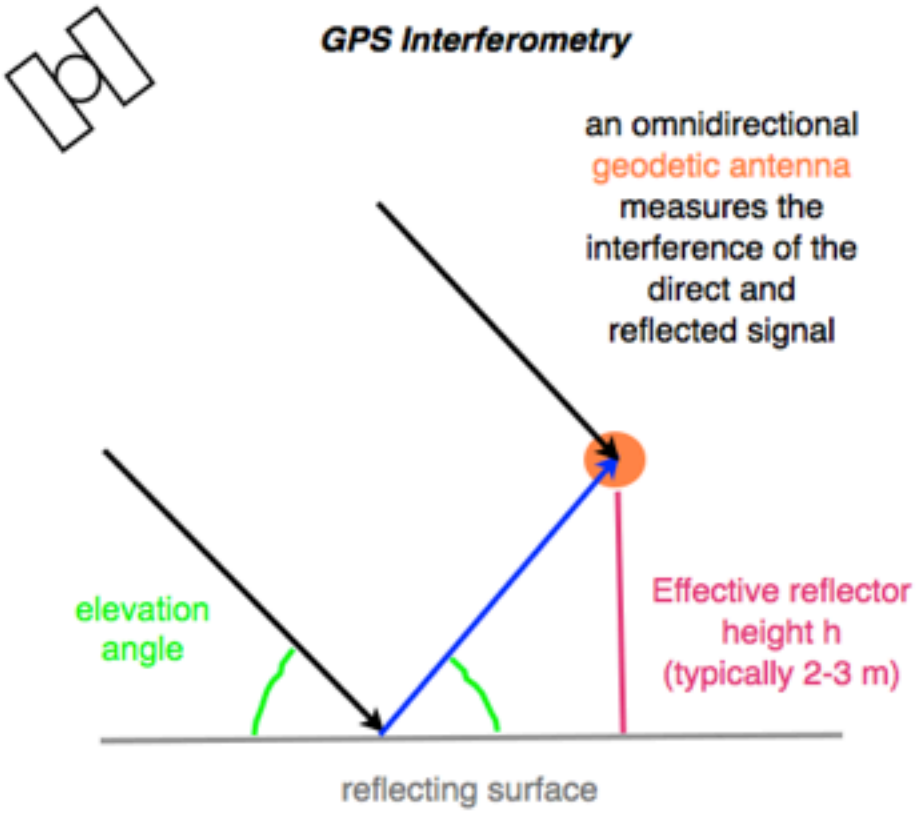
Choi et al., Geophysical Research Letters, 2004.

but is yesterday really like today?

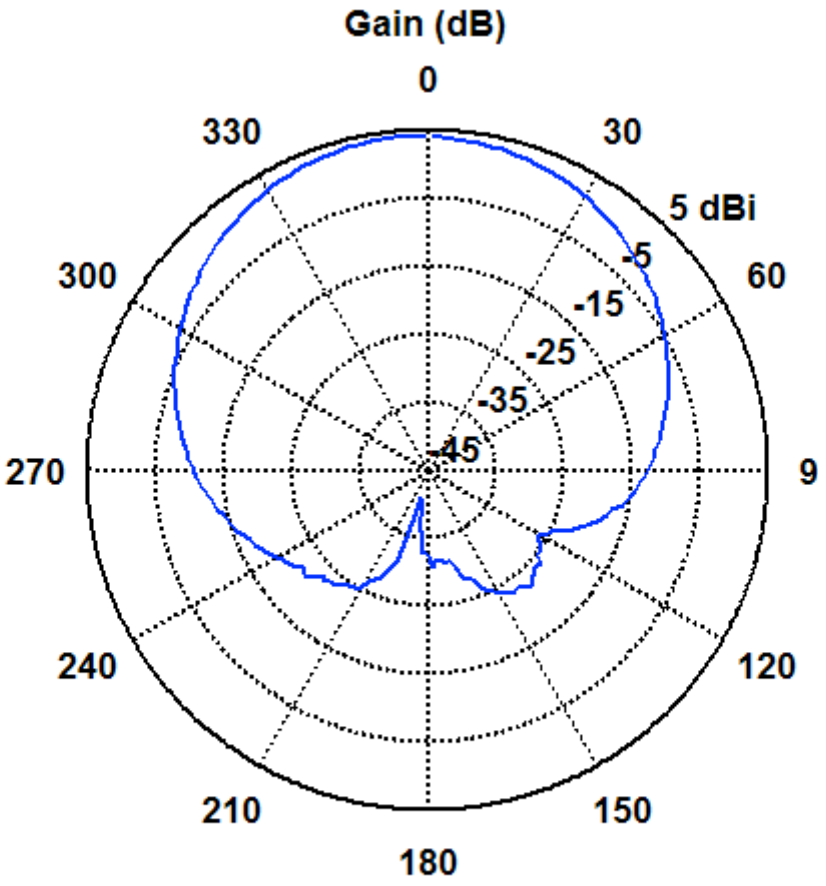
the question:

- Data collected from geodetic-quality GPS receivers are clearly sensitive to reflected signals.
- Can those same GPS receivers be used to measure soil moisture, snow, and vegetation changes?

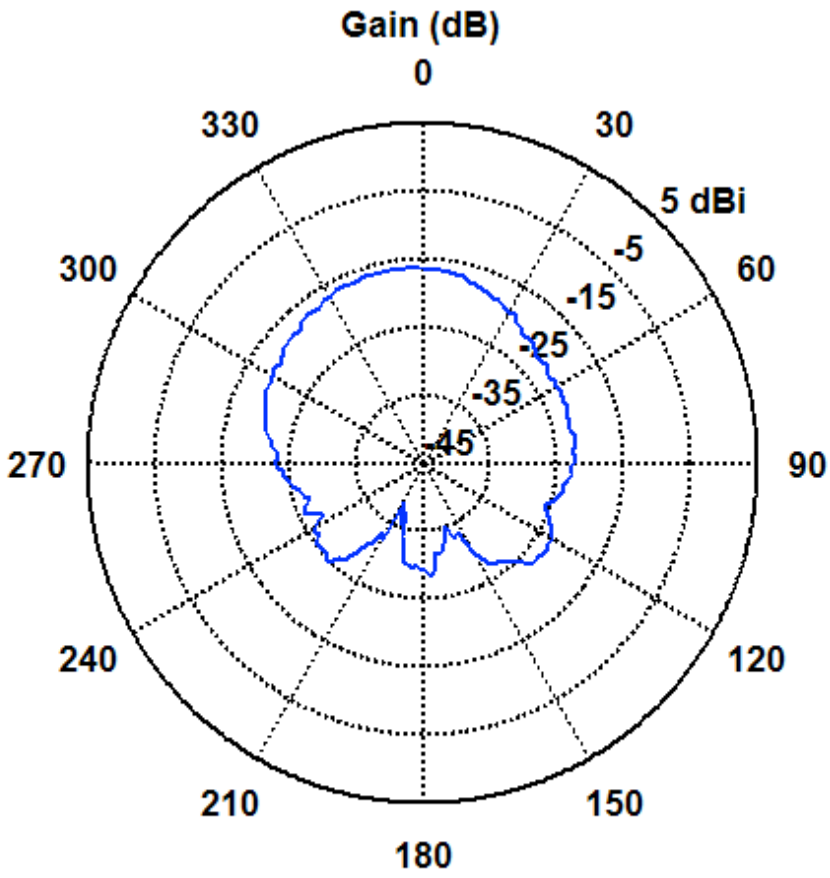

GPS
GPS Bi-Static Radar
up-looking antenna measures direct signal
Direct signal RHCP
down-looking antenna measures reflected signal
Reflected signal
reflecting surface


GPS Interferometry
an omnidirectional geodetic antenna measures the interference of the direct and reflected signal
elevation angle
Effective reflector height h (typically 2-3 m)
reflecting surface

the difficulty



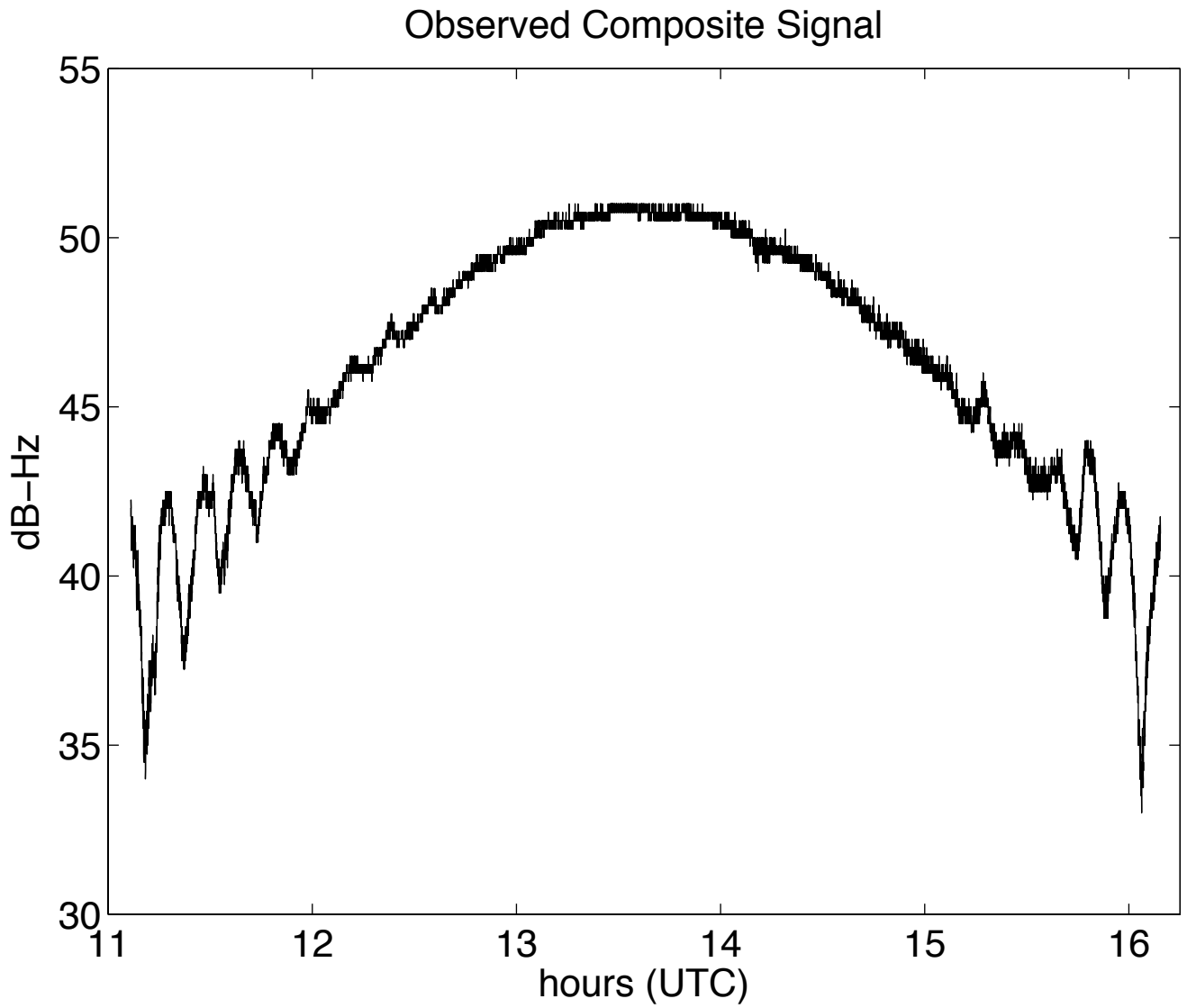
Right-Hand Circularly Polarized



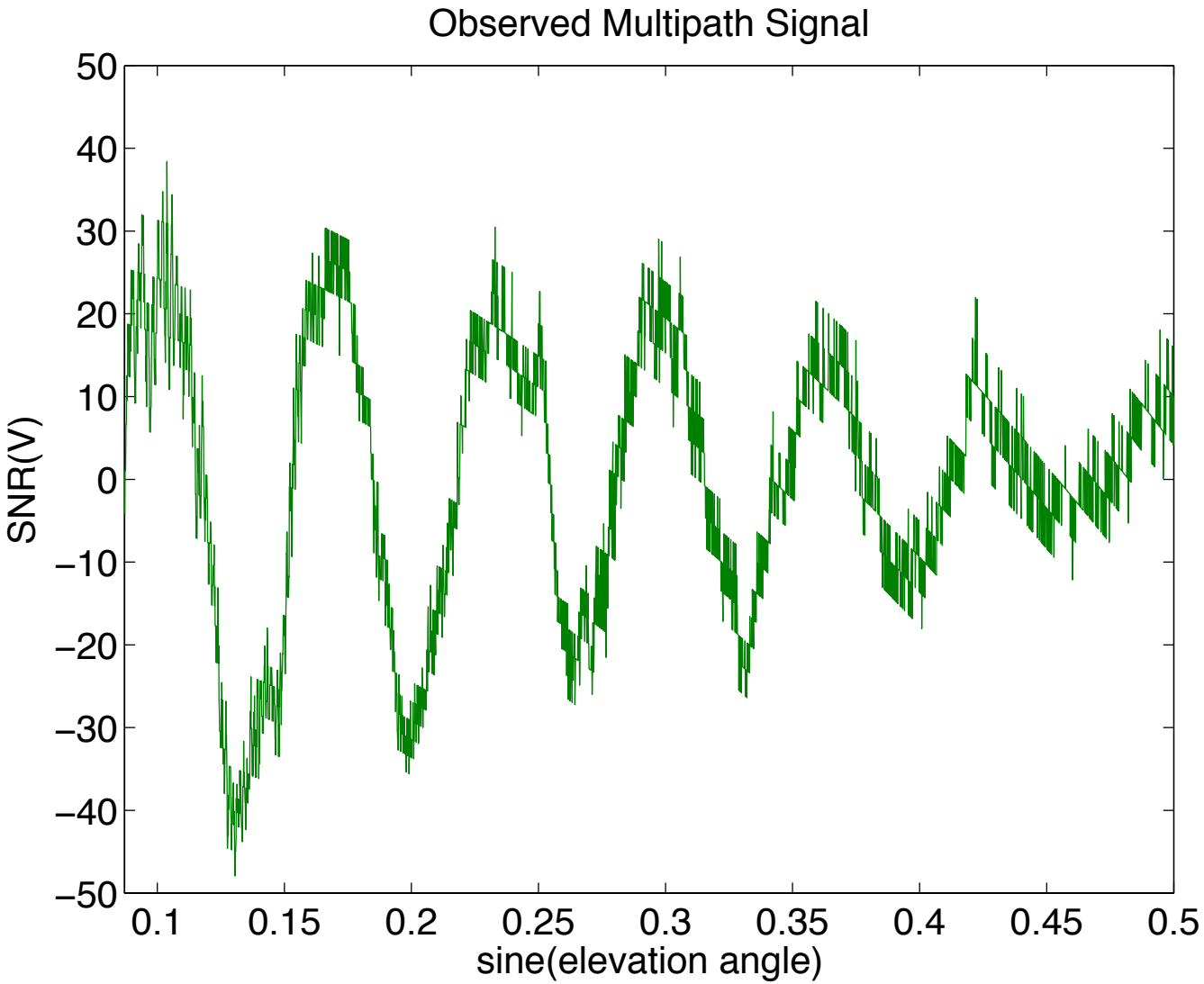
Left-Hand Circularly Polarized

Figures courtesy of Felipe Nievinski

instead of pseudorange or carrier phase observables (or residuals), use Signal Power (SNR)



the “reflected” signal



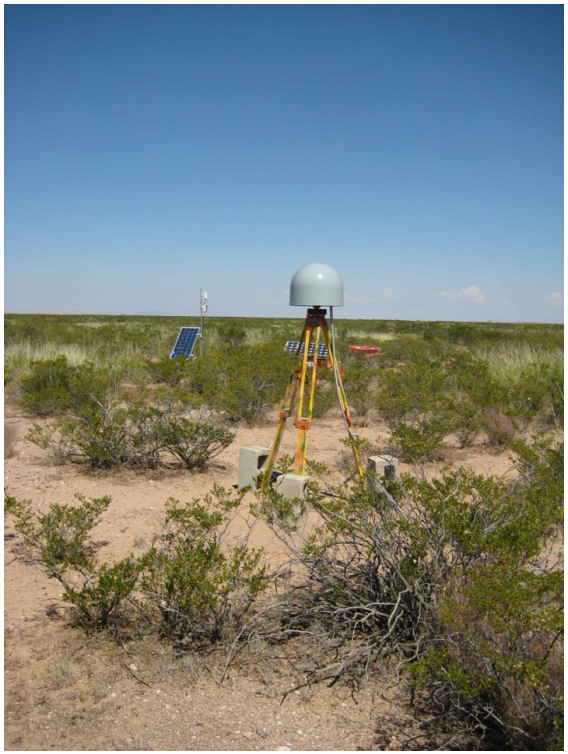
Changes in these oscillations (frequency, amplitude) are related to changes in the ground.

three scientific applications

soil moisture

snow

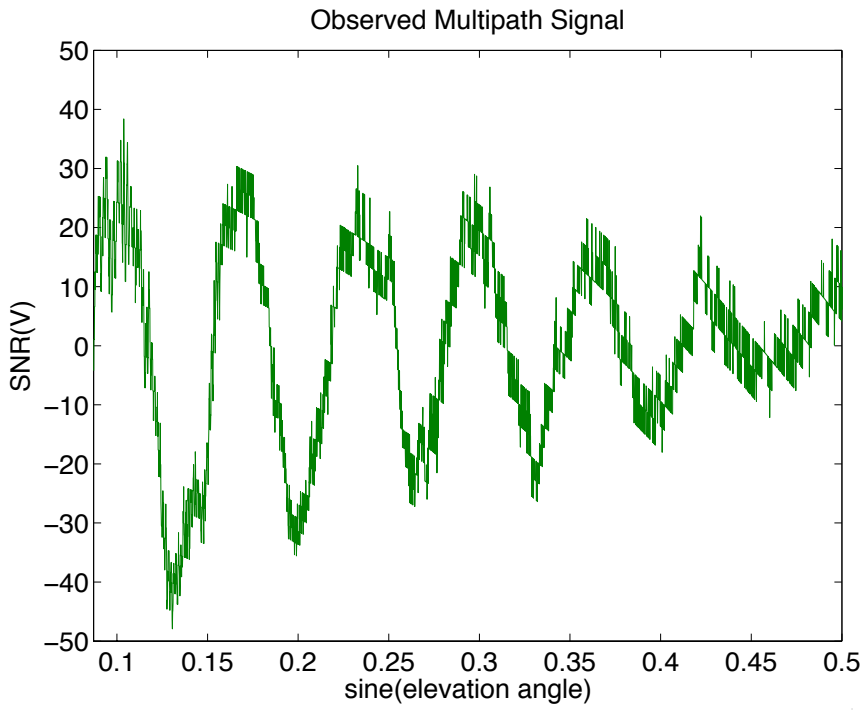
vegetation



soil moisture

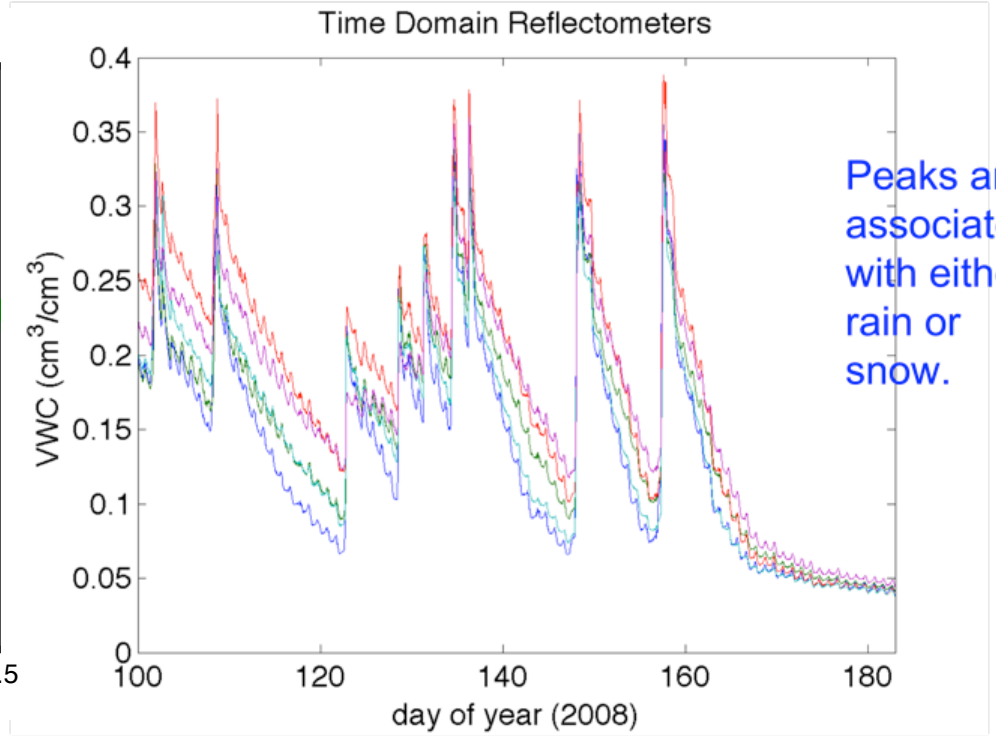
- We buried 10 time domain reflectometers - 5 at 2.5cm and 5 at 7.5 cm
- And collected GPS SNR data from L2C satellites using a Trimble NetRS (geodetic) receiver and choke-ring antenna.

GPS data

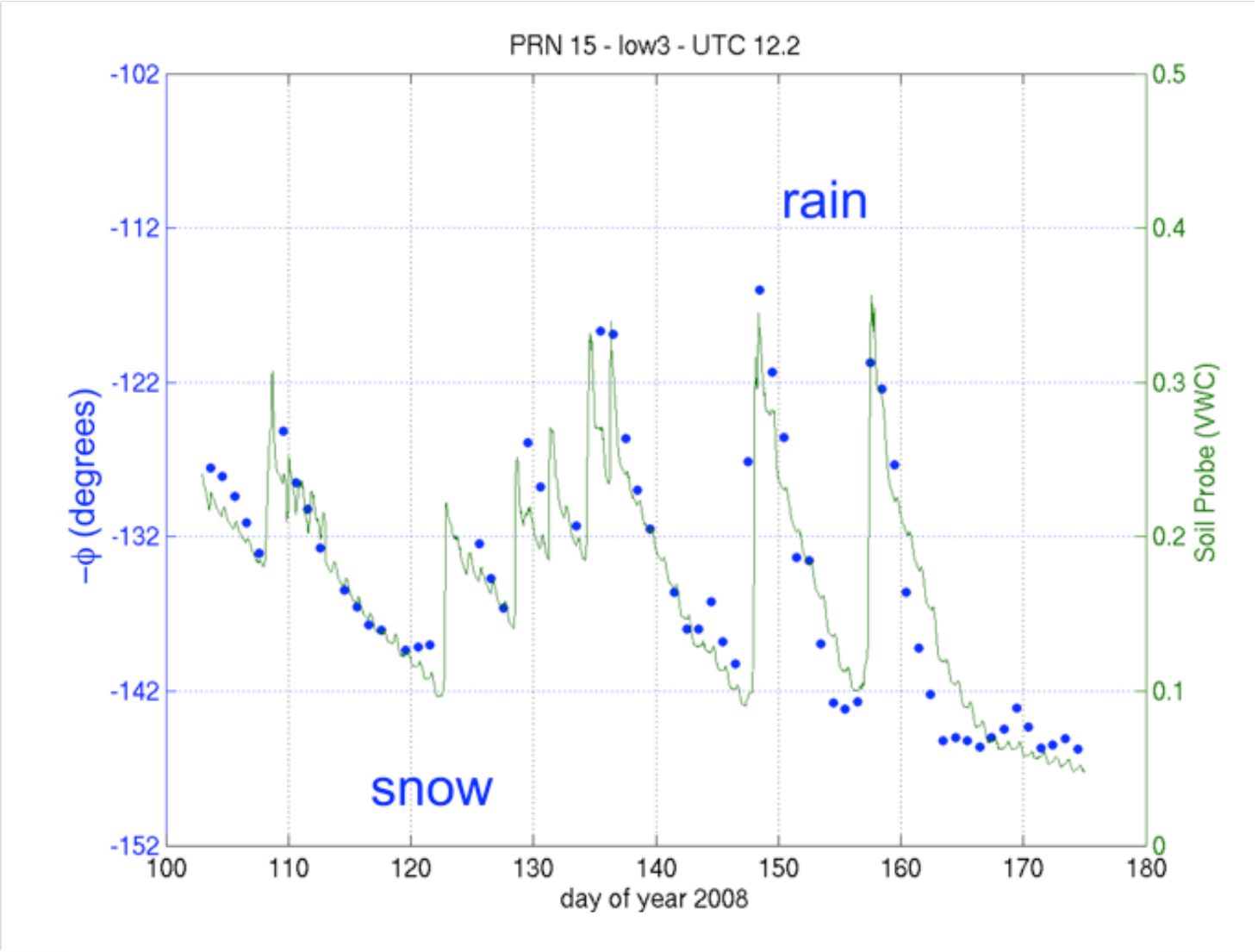


SNR: fixed frequency; estimated amplitude and phase offset

TDR data

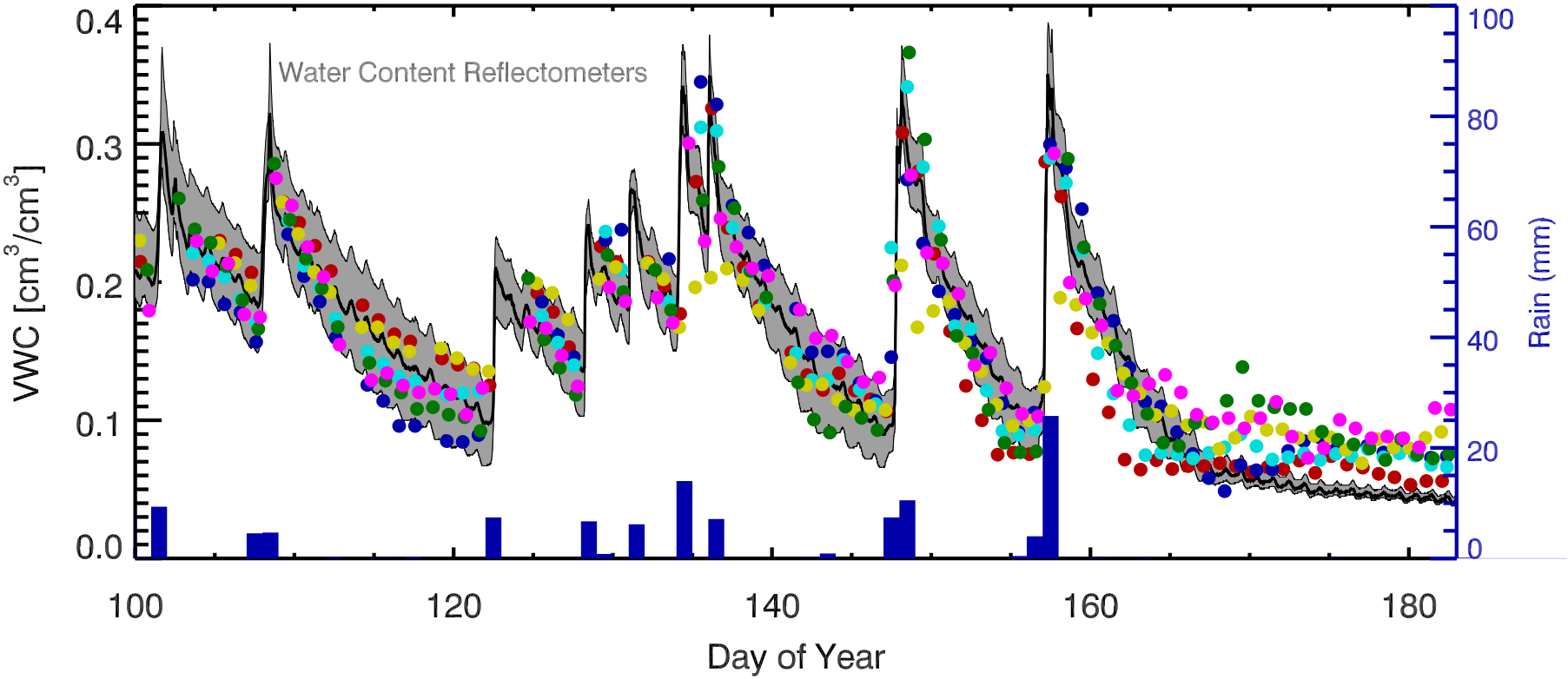


How does ϕ relate to volumetric water content (VWC)?



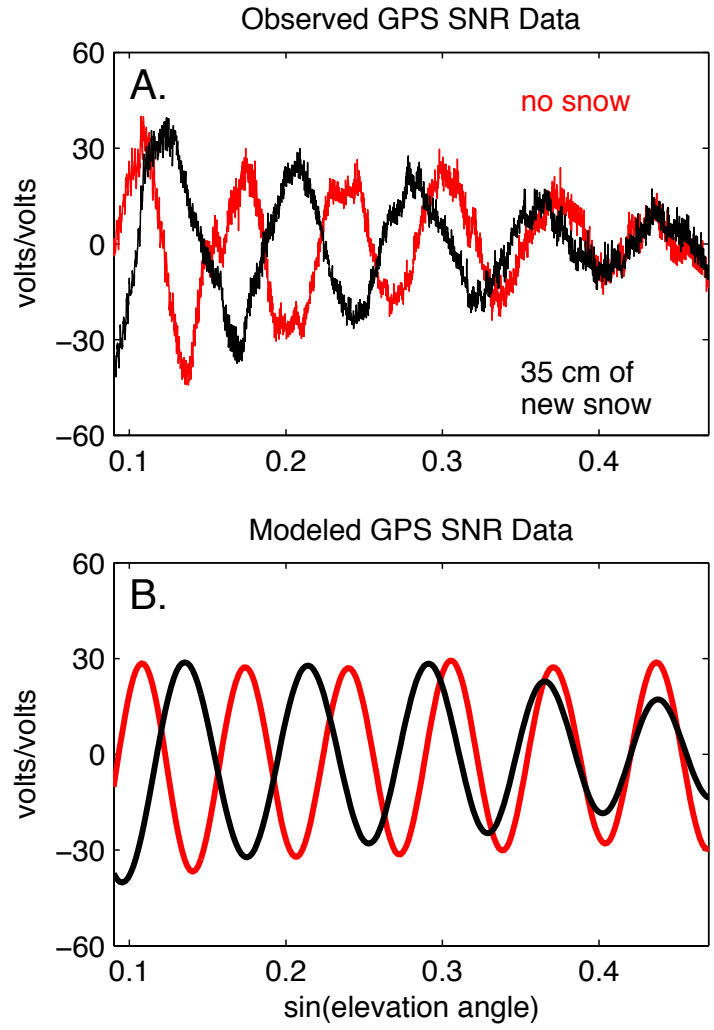
We later demonstrated that “reflector height” also corresponds well with VWC

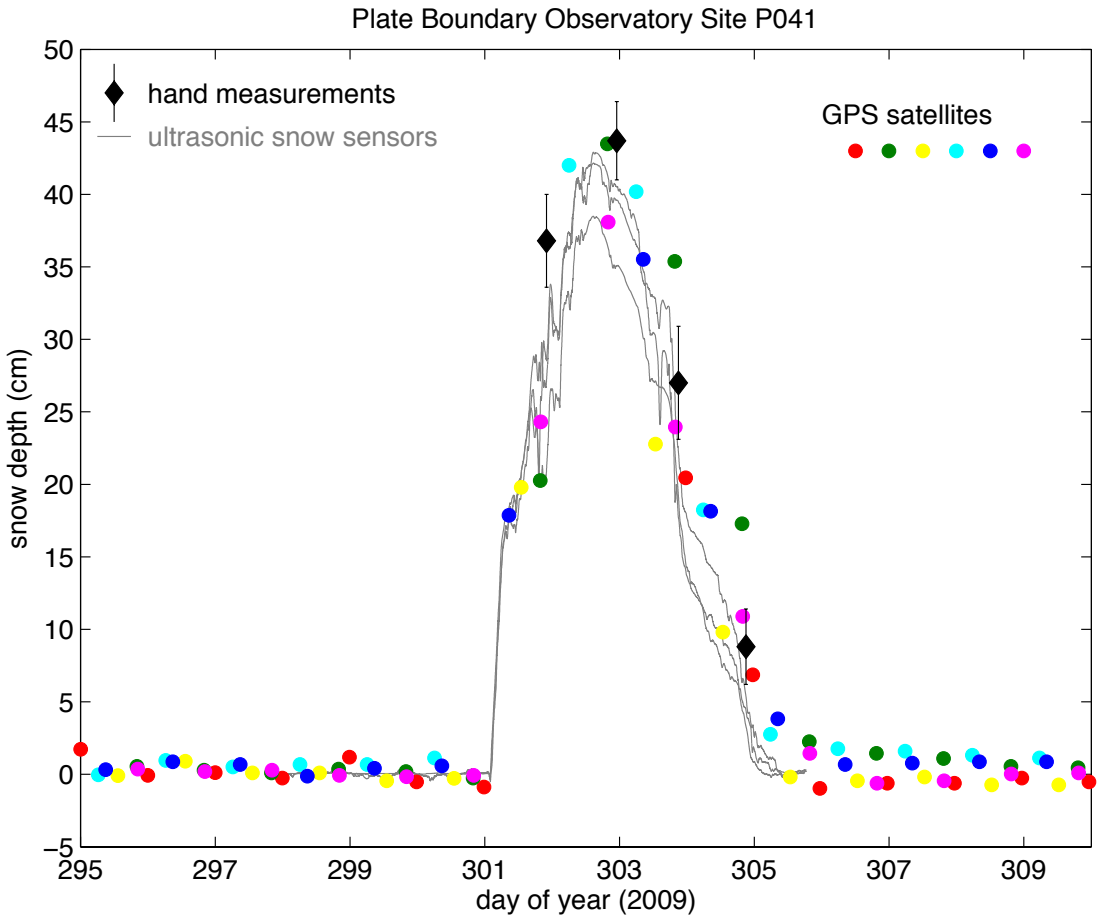
initial results



Larson, Small, Gutmann, Braun, Zavorotny, and Bilich, Use of GPS receivers as a soil moisture network for water cycle studies, *Geophys. Res. Lett.*, 2008

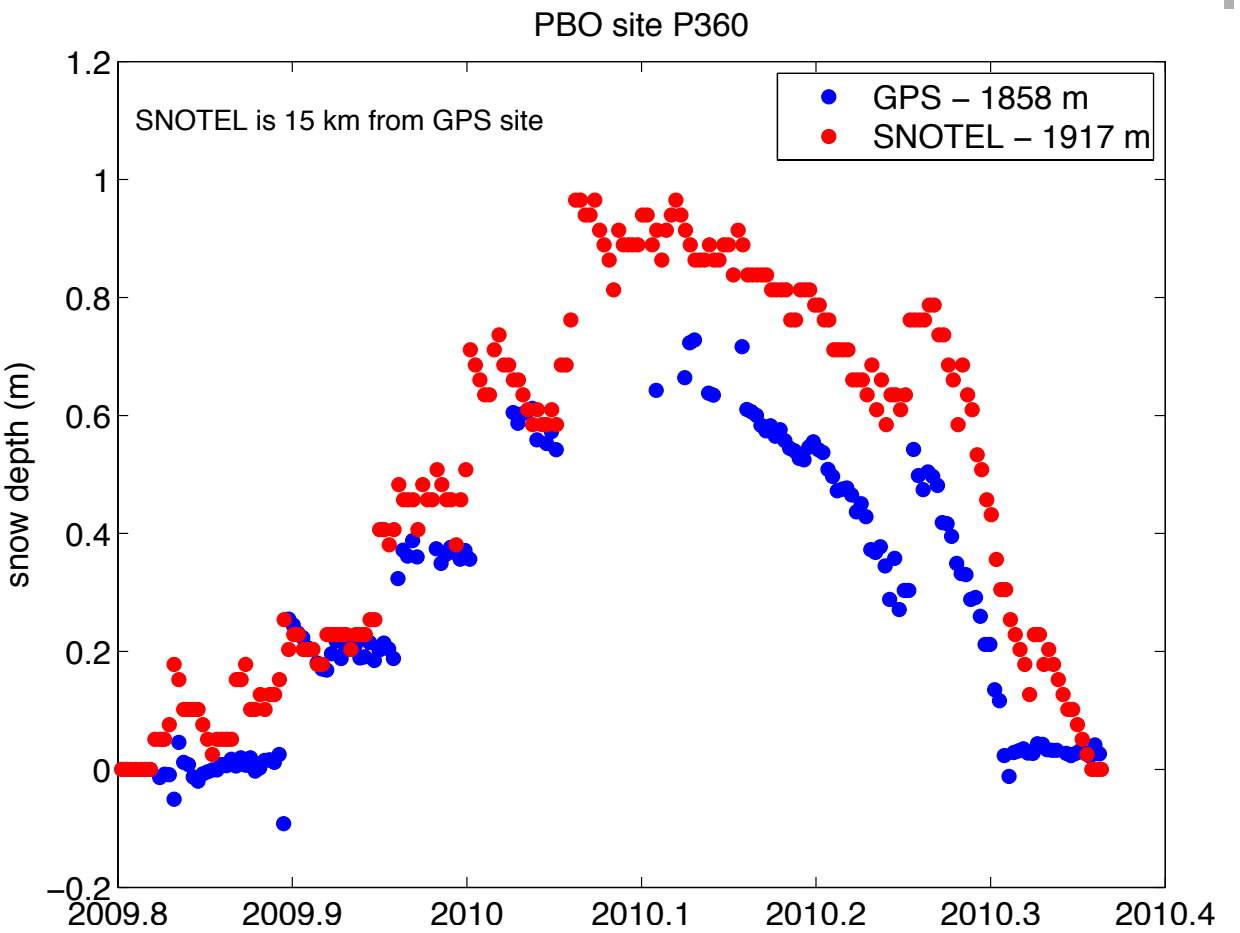
GPS Snow Sensing

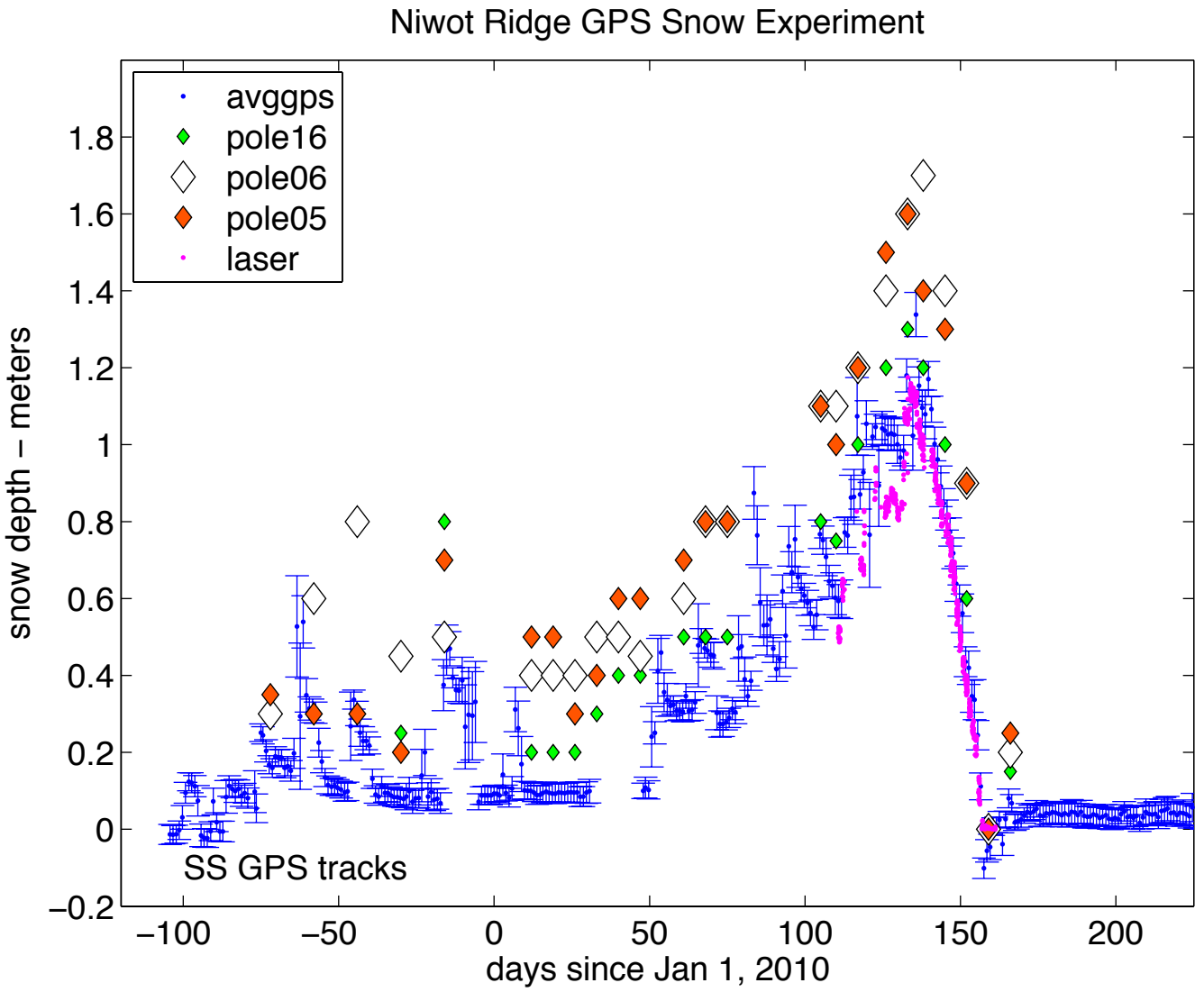




Larson, Gutmann, Braun, Zavorotny, Williams, and Nievinski, Can we measure snow depth with GPS receivers?, *Geophys. Res. Lett.*, 2009

Plate Boundary Observatory Site P360




Niwot Ridge GPS Snow Experiment
avggps
pole16
pole06
pole05
laser
snow depth – meters
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−100
−50
0
50
100
150
200
days since Jan 1, 2010
SS GPS tracks

GPS Vegetation Sensing

PBO site in Parkfield, CA

in addition to SNR data, multipath can also be observed in the geodetic observables - i.e. MP1

$$P1 = R + I/f_1^2 + M1 + \varepsilon_{p1}$$

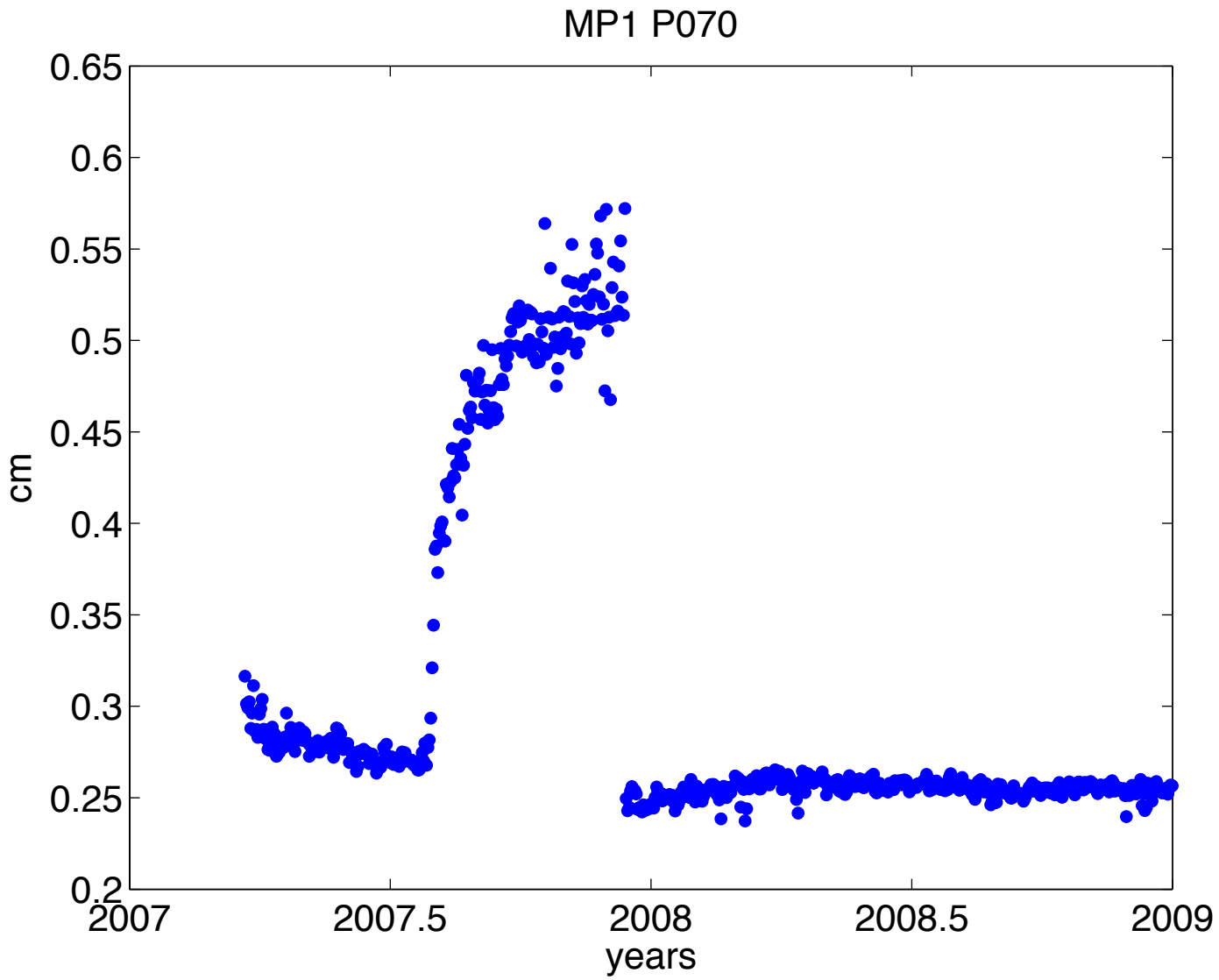
$$\lambda_1 L1 = R - I/f_1^2 + N_1\lambda_1 + \varepsilon_{\phi 1}$$

$$\lambda_2 L2 = R - I/f_2^2 + N_2\lambda_2 + \varepsilon_{\phi 2}$$

$$MP1 = P1 - 4.09L1\lambda_1 + 3.09L2\lambda_2$$

$$MP1 = M1 + N + \varepsilon_{p1}$$

how do geodesists typically use mean RMS

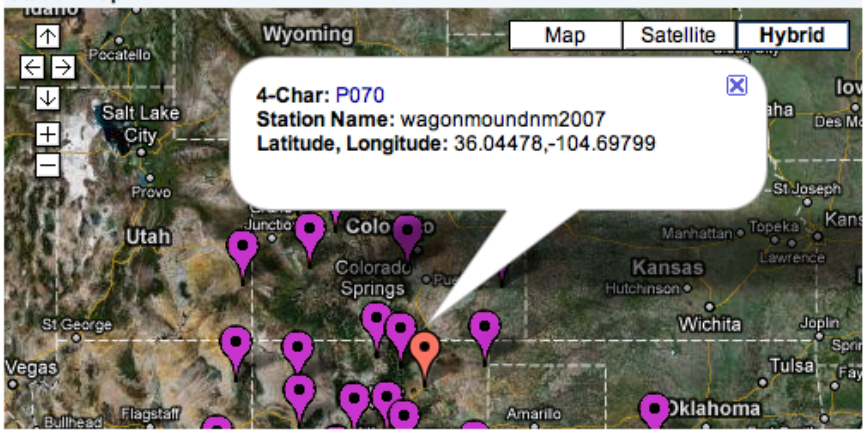


GPS Station: p070 - Overview

Overview | Data Products | State of Health | Equipment | Network | Education and Outreach | Reports | Photos | Additional Information

4-Char:	P070
Station Name:	wagonmoundnm2007
Station Installation Date:	2007-03-21 00:00:00
Monument Installation Date:	2007-03-21 00:00:00
Station Status:	Installed
Project:	PBO
Region:	East
Latitude, Longitude:	36.04478, -104.69799
Elevation:	1884.511 m / 6183 ft
Monument Type:	DDBM
Location (City, State):	WAGON MOUND, NM
Group(s):	PBO GPS

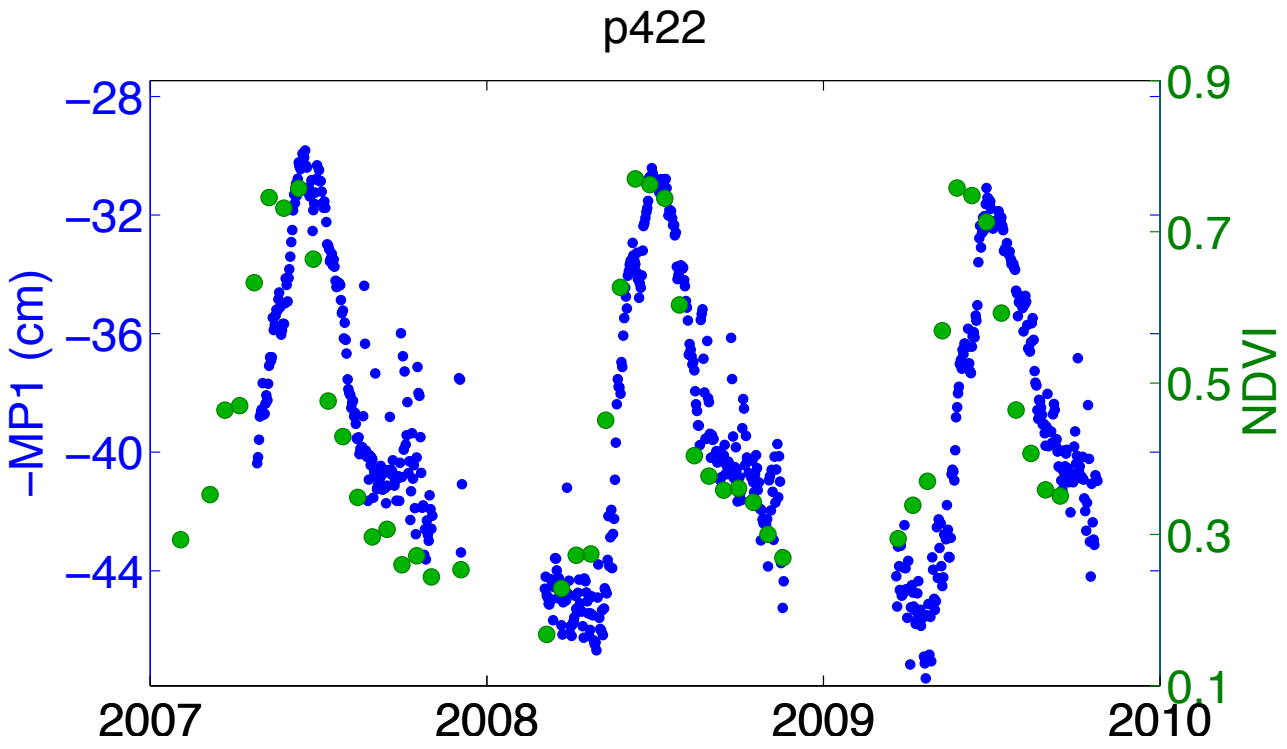
Station Map



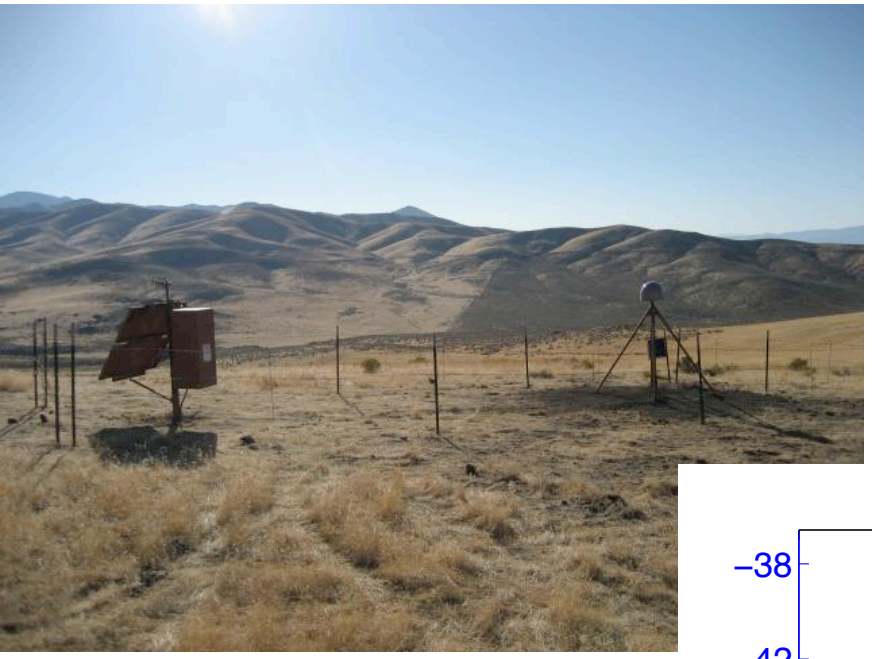
Station Equipment

Equipment	Model	Serial Number	Date Installed
Receiver	NETRS	4413233097	2007-03-21
Antenna	TRM29659.00	4623A16423	2007-12-13
Radome	SCIT	0923	
CDMA	CDMA MODEM W/LAN	00134989FCD8	2007-03-21

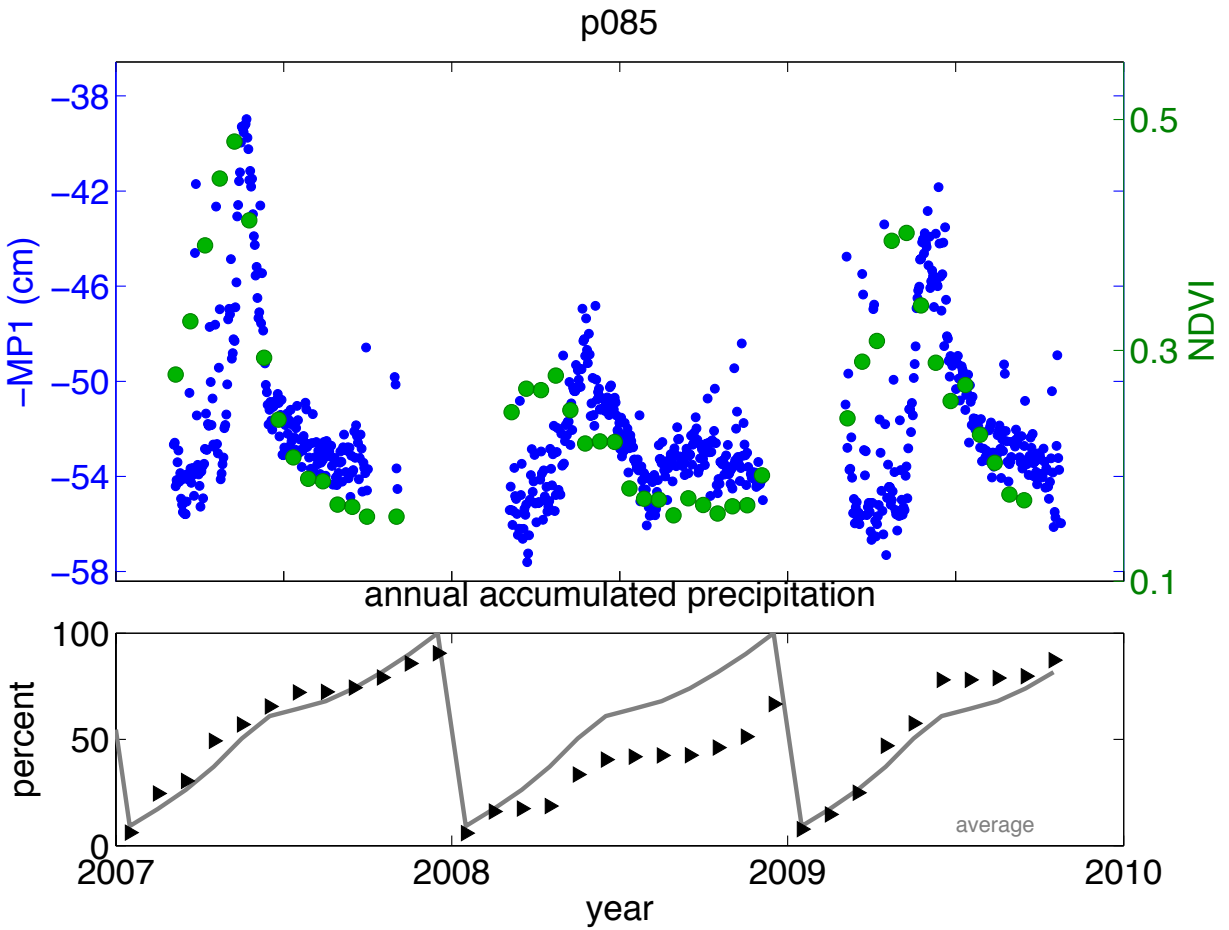
Foothill, Idaho
P422



Small, Larson, and Braun, Sensing Vegetation Growth With Reflected GPS Signals, *Geophys. Res. Lett.,* 2010.

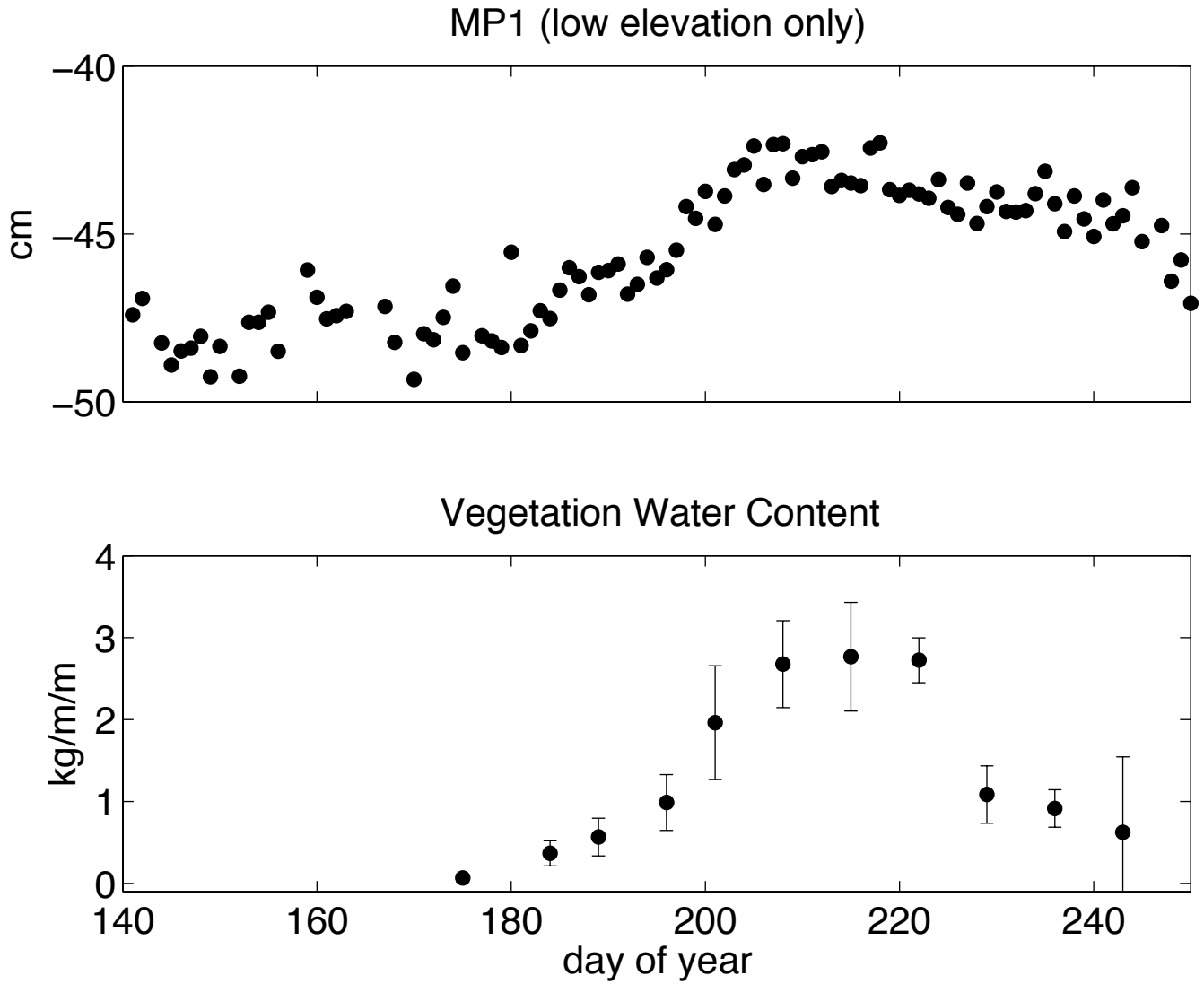


Battle Mountain, Nevada P085



Munson Farm Experiment

comparison with *in situ* data



Small et al., 2010.

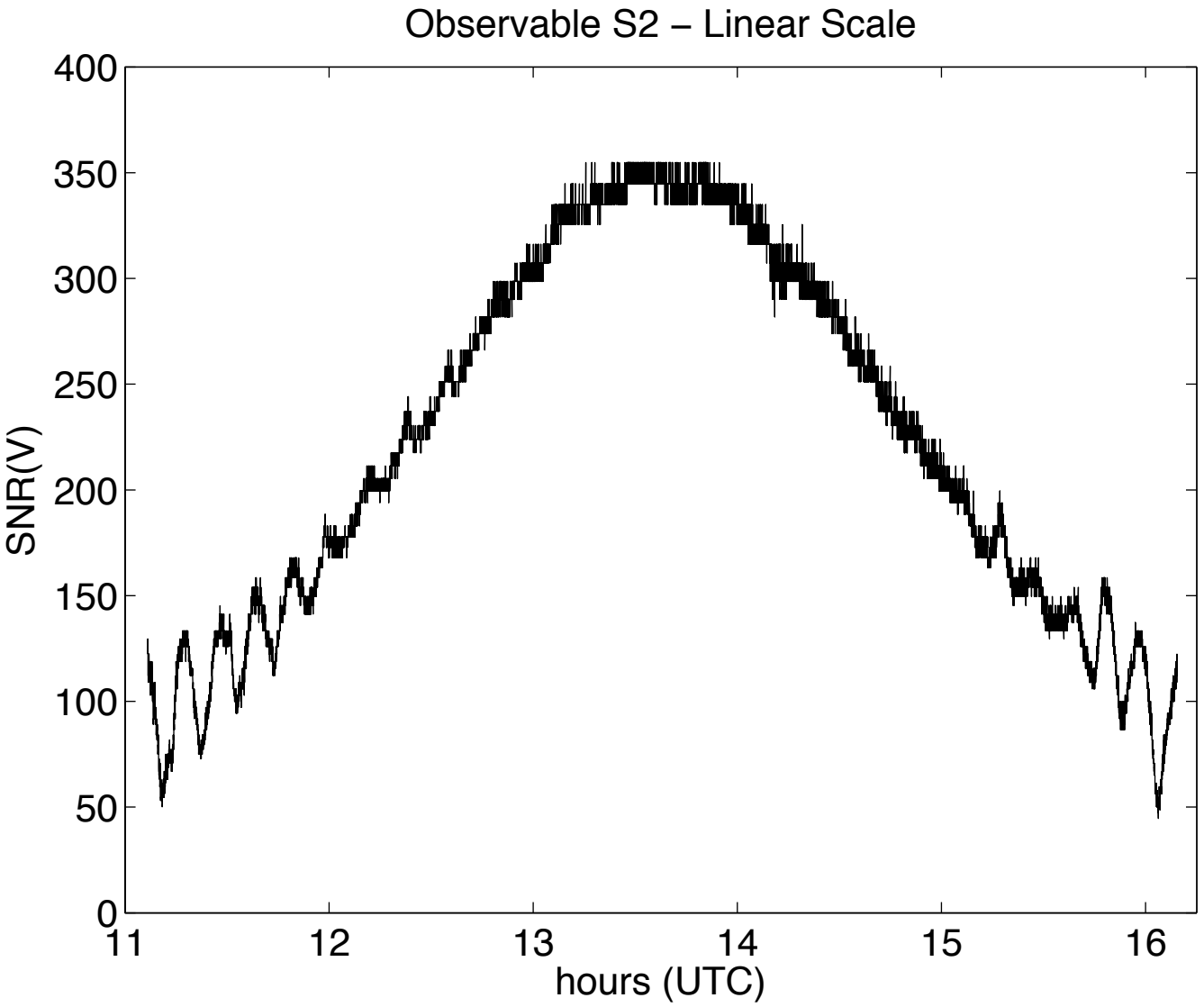
Conclusions

- expand the use of an existing GPS network to new communities (hydrology, ecology, atmospheric sciences, cryosphere, water management)
- provide data products to improve weather prediction and climate studies
- potential validation network for new environmental satellite missions, especially SMOS, SMAP, Desdyni.

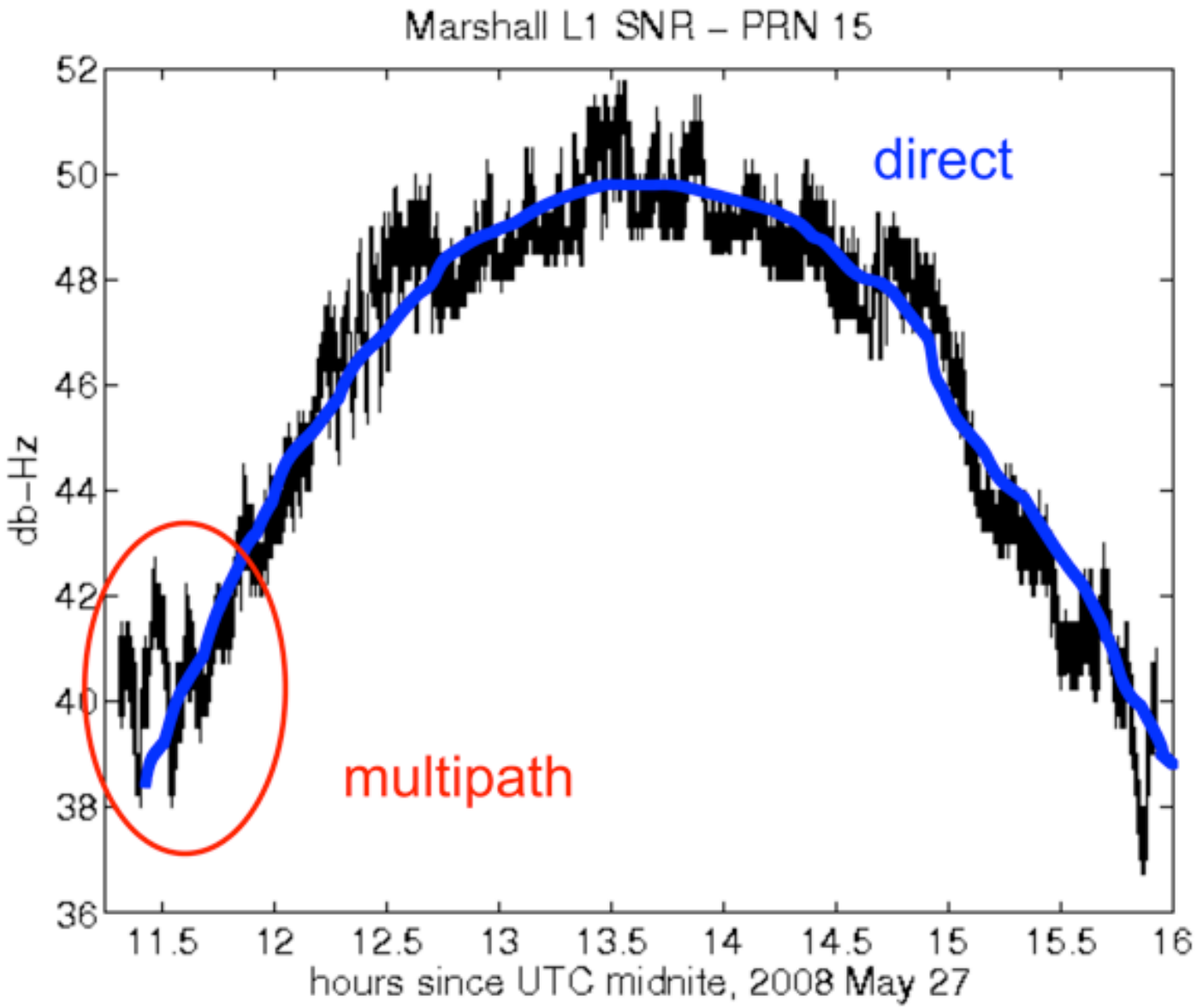
Acknowledgements

- NSF AGS and EAR (0740515 and 0935725)
- CU Seed Grants
- Andria Bilich, Penina Axelrad, and Bob Munson
- Plate Boundary Observatory
- UNAVCO, esp. Mike Jackson, Fred Blume, Chuck Meertens, Jim Normandeau, Dave Maggert, Lou Estey, and Sarah Doelger.

SNR - Linear Scale



L1 SNR Trimble NetRS



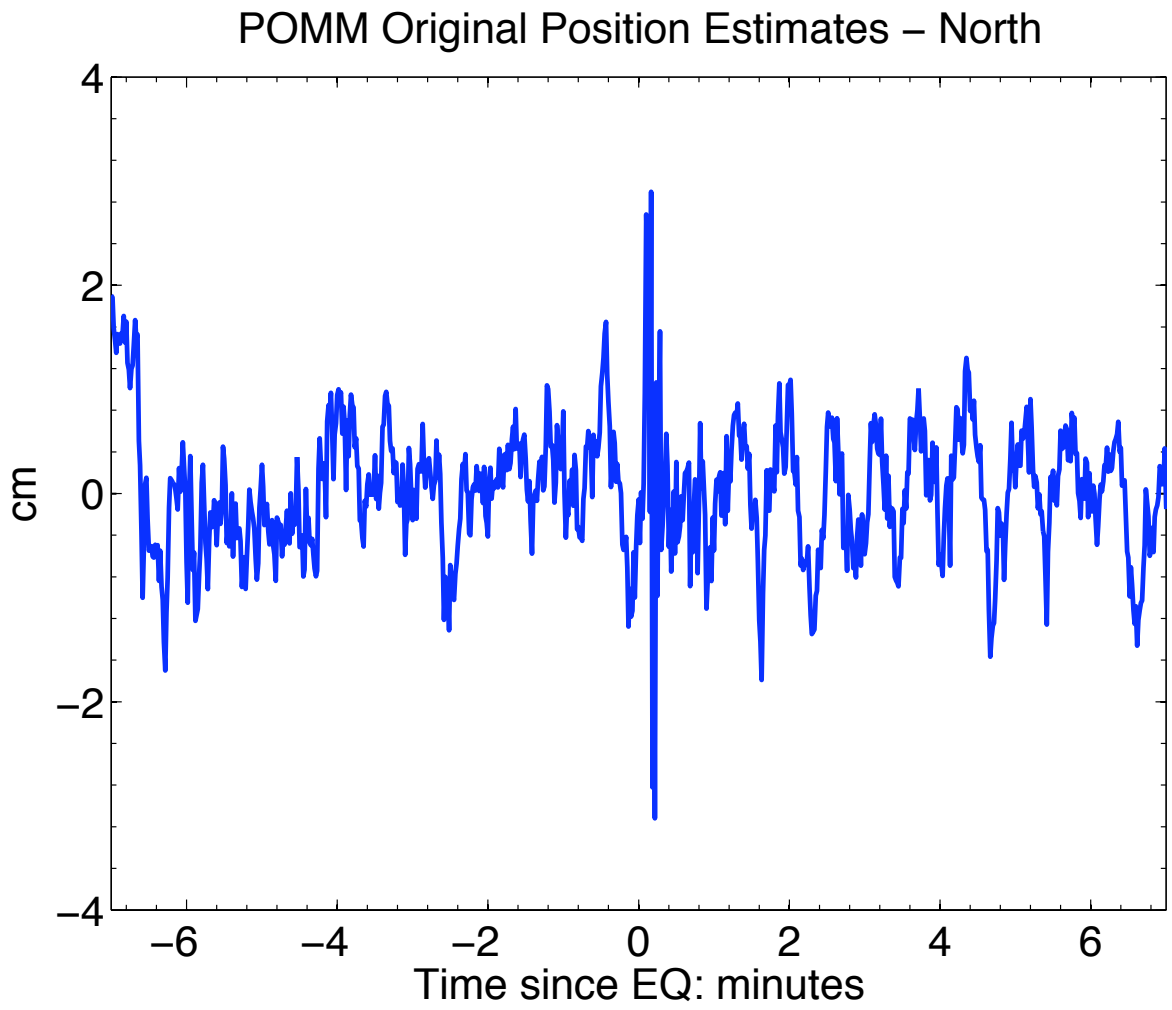
What can we compare MP1 variations to?

NDVI: Normalized Difference Vegetation Index

ratio of spectral reflectance in the near-infrared and red regions, i.e. how green it is.

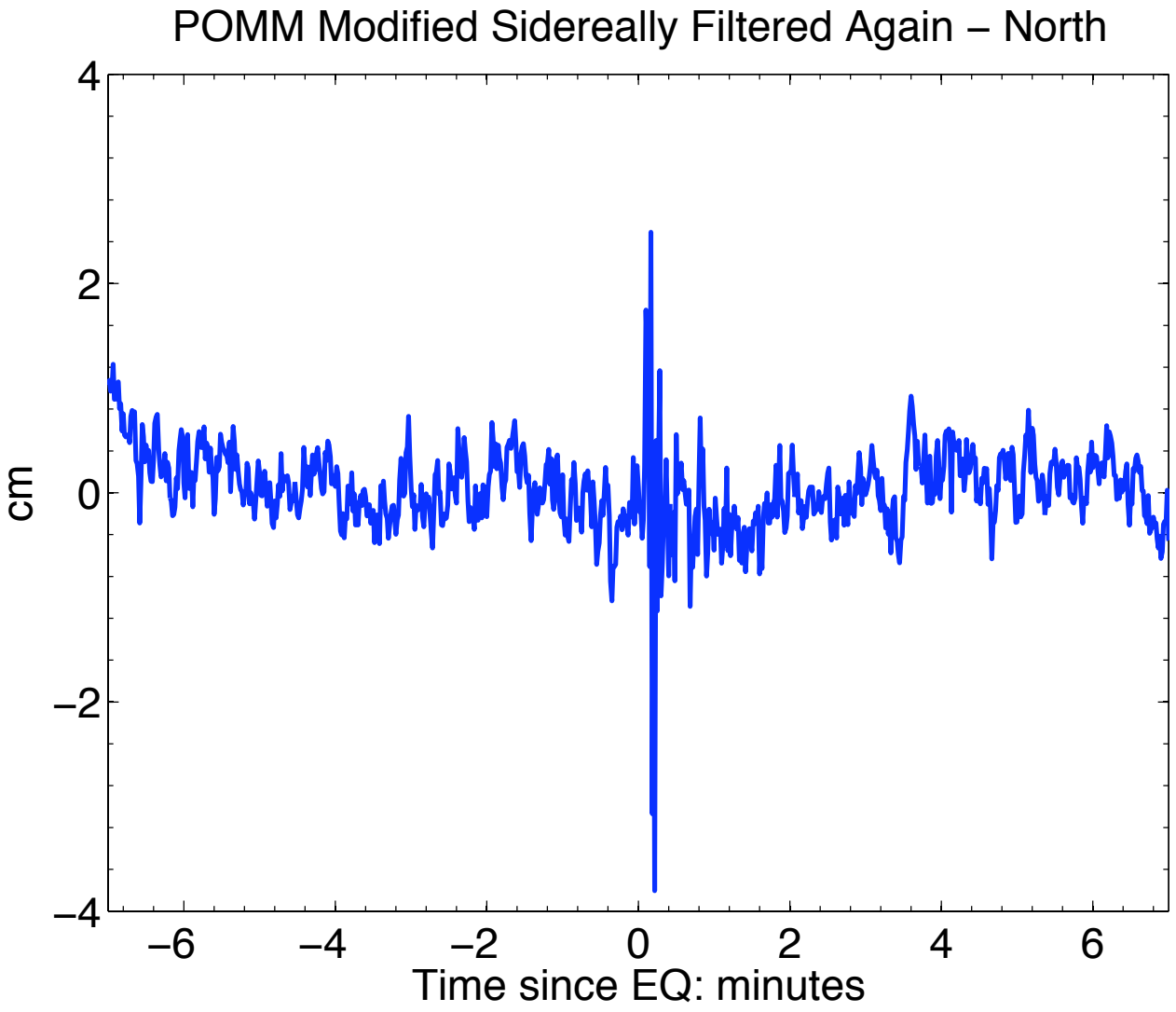
NDVI MODIS: every 16 days, 250 m by 250 m pixel

example:



Larson, unpublished 1-Hz GPS records from the Parkfield earthquake

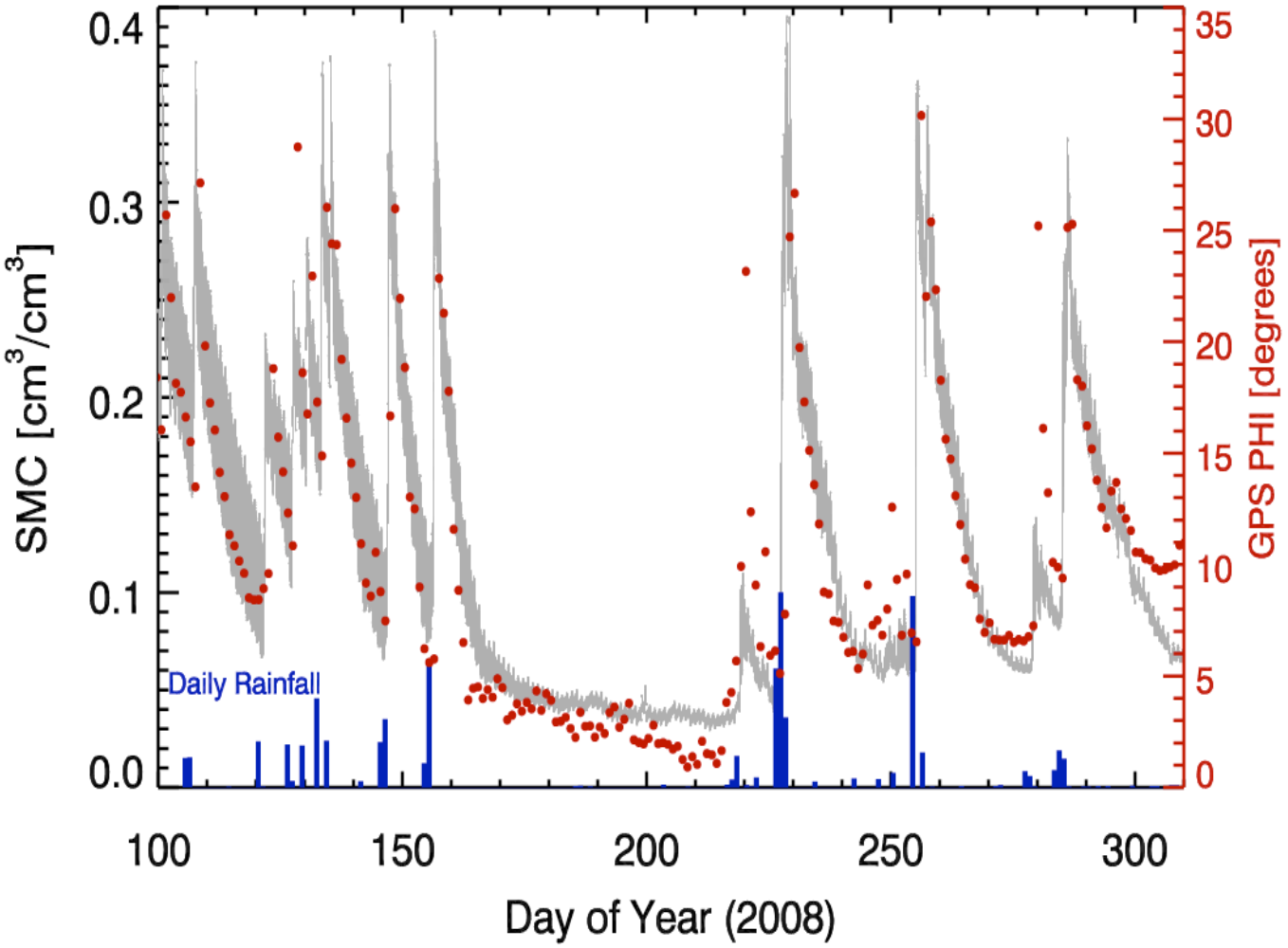
1-hz time series with multipath removed



Agnew and Larson, Finding the Repeat Times of the GPS Constellation, *GPS Solutions*, 2007

Water Content Reflectometers

GPS



Larson, Small, Gutmann, Braun, Zavorotny, and Bilich, GPS Multipath and Its Relation to Near-Surface Soil Moisture Content, *IEEE J-STARS*, 2010