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
Results for plate motions: no multipath modeling

CAT2 (CAT2_SCGN_CS2000)

vel: 31.26 ± 0.01 mm/yr  rms: 0.81 mm

vel: -29.55 ± 0.01 mm/yr  rms: 0.89 mm

source: PBO website
but if you look at higher temporal sampling
use “yesterday” to correct “today”
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 Bi-Static Radar

Direct signal RHCP

up-looking antenna measures direct signal

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

Effective reflector height $h$ (typically 2-3 m)

elevation angle

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

Observed Multipath Signal

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

soil moisture  snow  vegetation
• We buried 10 time domain reflectometers - 5 at 2.5 cm 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

Observed Multipath Signal

SNR: fixed frequency; estimated amplitude and phase offset

TDR data

Time Domain Reflectometers

Peaks are associated with either rain or snow.
We later demonstrated that “reflector height” also corresponds well with VWC.
initial results

GPS Snow Sensing
Plate Boundary Observatory Site P360

SNOTEL is 15 km from GPS site

- GPS – 1858 m
- SNOTEL – 1917 m
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

\[
P1 = R + \frac{I}{f_1^2} + M1 + \epsilon_{p1}
\]

\[
\lambda_1L1 = R - \frac{I}{f_1^2} + N_1\lambda_1 + \epsilon_{\phi1}
\]

\[
\lambda_2L2 = R - \frac{I}{f_2^2} + N_2\lambda_2 + \epsilon_{\phi2}
\]

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

\[
MP1 = M1 + N + \epsilon_{p1}
\]
how do geodesists typically use mean RMS

MP1 P070

how do geodesists typically use mean RMS
GPS Station: p070 - Overview

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: 1864.511 m / 6183 ft
Monument Type: DDBM
Location (City, State): WAGON MOUND, NM
Group(s): PBO GPS

Station Map

4-Char: P070
Station Name: wagonmoundnm2007
Latitude, Longitude: 36.04478, -104.69799

Station Equipment

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comparison with *in situ* data

MP1 (low elevation only)

Vegetation Water Content

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.
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• UNAVCO, esp. Mike Jackson, Fred Blume, Chuck Meertens, Jim Normandeau, Dave Maggert, Lou Estey, and Sarah Doelger.
SNR - Linear Scale

Observable S2 – Linear Scale

SNR(V)

hours (UTC)
L1 SNR Trimble NetRS

Marshall L1 SNR – PRN 15

direct

multipath

hours since UTC midnite, 2008 May 27
What can we compare MP1 variations to?

NDVI: Normalized Difference Vegetation Index
decrease in the 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:

POMM Original Position Estimates – North

Larson, unpublished 1-Hz GPS records from the Parkfield earthquake
1-hz time series with multipath removed

POMM Modified Sidereally Filtered Again – North

Water Content Reflectometers