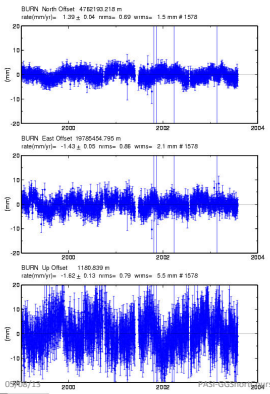
GAMIT Modeling Aspects Lecture 03

Thomas Herring
tah@mit.edu

Dominate Error Sources

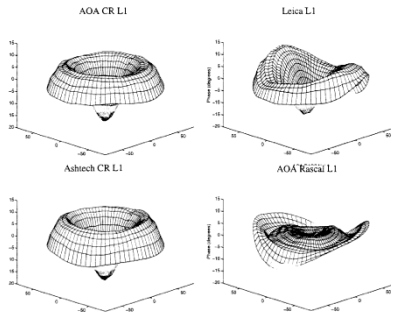
- "One-sided" geometry increases vertical uncertainties relative to horizontal and makes the vertical more sensitive to session length
- For geophysical measurements the atmospheric delay and signal scattering are unwanted sources of noise
- For meteorological applications, the atmospheric delay due to water vapor is an important signal; the hydrostatic delay and signal scattering are sources of noise
- Loading of the crust by the oceans, atmosphere, and water can be either signal or noise
- Local hydrological uplift or subsidence can be either signal or noise
- Changes in instrumentation are to be avoided



Time series for continuous station in (dry) eastern Oregon

Vertical wrms 5.5 mm, higher than the best stations. Systematics may be atmospheric or hydrological loading, Local hydrolology, or Instrumental effects

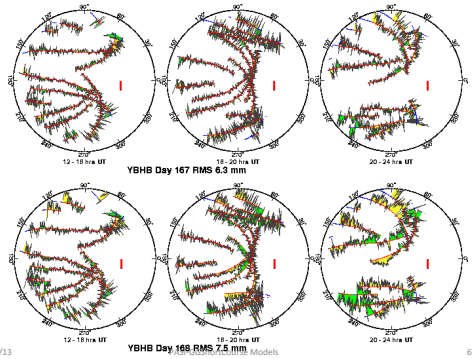
Antenna Phase Patterns

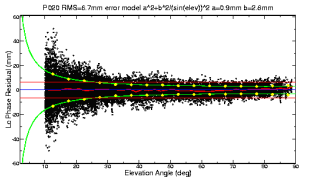


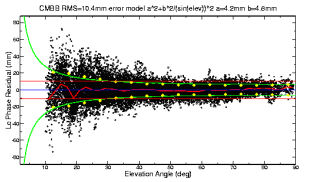
Modeling Antenna Phase-center Variations (PCVs)

- Ground antennas
  - Relative calibrations by comparison with a 'standard' antenna (NGS, used by the IGS prior to November 2006)
  - Absolute calibrations with mechanical arm (GEO++) or anechoic chamber
  - May depend on elevation angle only or elevation and azimuth
  - Current models are radome-dependent
  - Errors for some antennas can be several cm in height estimates
- Satellite antennas (absolute)
  - Estimated from global observations (T U Munich)
  - Differences with evolution of SV constellation mimic scale change
  - Recommendation for GAMIT: Use latest IGS absolute ANTEX file (absolute) with AZ/EL for ground antennas and ELEV (nadir angle) for SV antennas
  - (MIT file augmented with NGS values for antennas missing from IGS)

Multipath and Water Vapor Can be Seen in the Phase Residuals

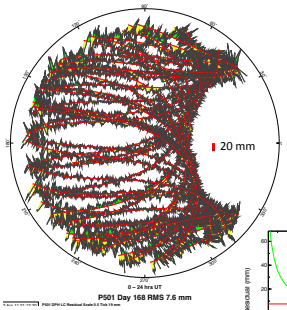






Top: PBO station near Lind, Washington.

Bottom: BARD station CMBB at Columbia College, California



Sky plot of phase residuals

Nature of data quality can be assessed by plots of phase residuals as a "sky plot" or as function of elevation angle.

Red line below is residuals averaged with elevation angle (used in later plots)

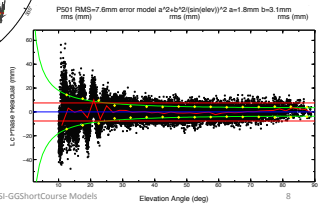
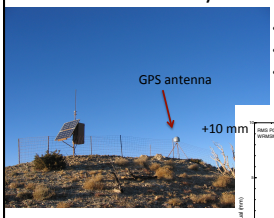
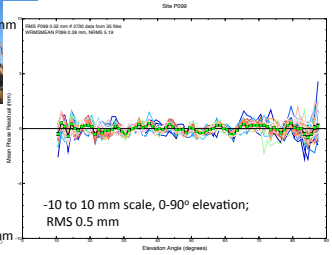


Plate Boundary Observatory (PBO) Site P099



- 30-days of data, different color lines
- Mean shown in green
- Note the ground is rough and drops away from site.

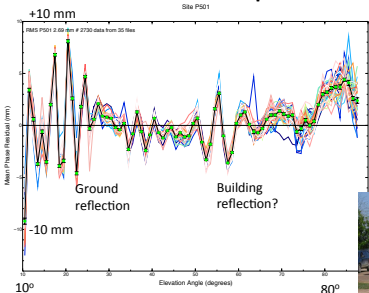


Position RMS 0.7 mm horizontal, 2.7 mm vertical (site in Nevada).

Plot generated *sh_plot_elmean*

-10 to 10 mm scale, 0-90° elevation; RMS 0.5 mm

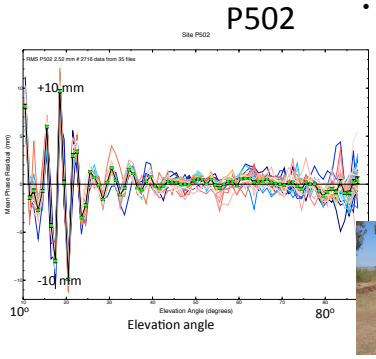
Example P501



- Example of ground reflection and building

Color are different days; and symbols with error bars are mean.
RMS 2.7 mm (5 times worse then P099).

P502

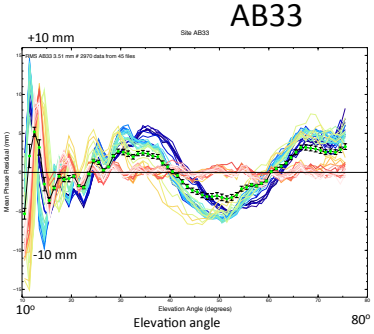


- Strong Ground reflection

Large ground reflection.
RMS 2.5 mm

Monitor to see how it changes as ground conditions change

AB33



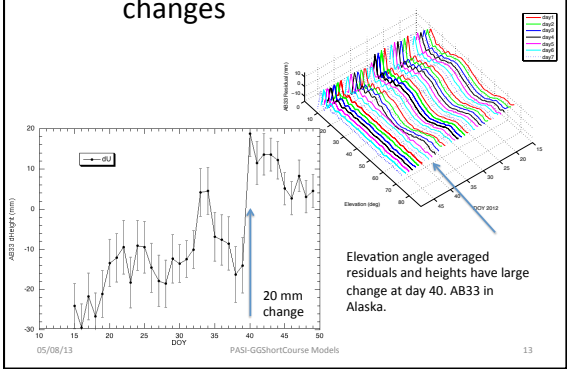
Time variable signals. Alaskan site.

Reason for time dependence not clear (maybe vehicle)

Colors span a 30-day interval. Site height changes when residuals change

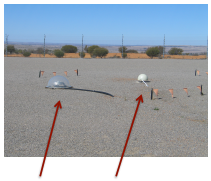
Time series and changes

Height changes correspond to residual changes



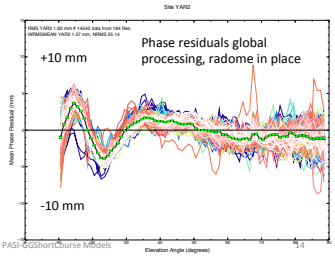
Elevation angle averaged residuals and heights have large change at day 40. AB33 in Alaska.

Yarragadee, Australia

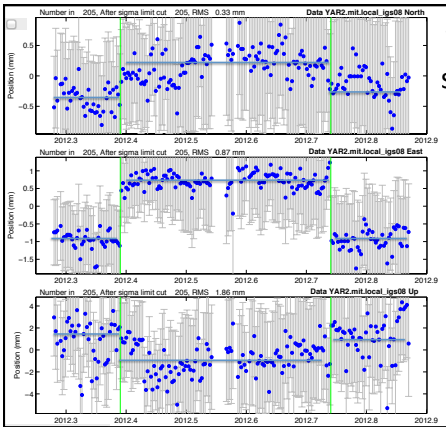


YAR3 (~1.5 m pillar not shown)

- YAR2: clear radome removed to test effect on position
- YARR has some tracking issues during this test
- YAR3: Pillar mounted site



Time series



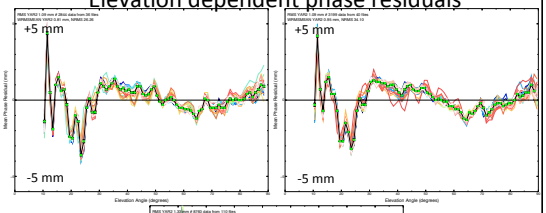
Estimates
NORTH
+0.41 -0.45
± 0.07 mm

EAST
1.68 -1.74
± 0.07 mm

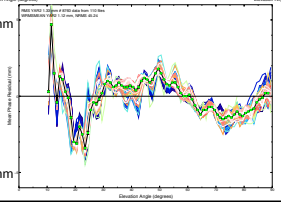
Up
-2.10 + 1.64
± 0.48 mm

RMS
NE 0.25 mm;
Up 1.7 mm

Elevation dependent phase residuals



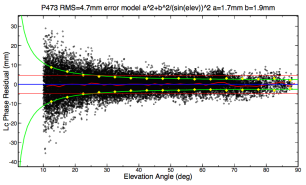
With (top before, and after) and without radome (differences right: Loss of YARR)

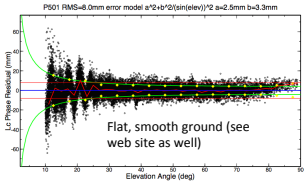


Residuals from YAR2, YARR and YAR3 analysis. High frequency from YAR3 site

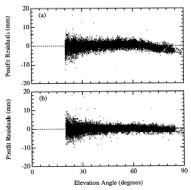
RMS:
Radome 1.1 mm
No-radome 1.3 mm

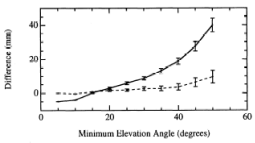
More examples





Flat, smooth ground (see web site as well)



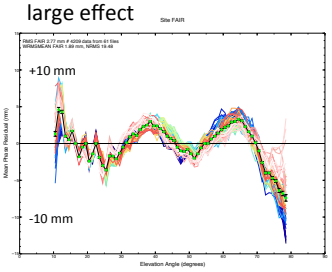


Left: Phase residuals versus elevation for Westford pillar, without (top) and with (bottom) microwave absorber.

Right: Change in height estimate as a function of minimum elevation angle of observations; solid line is with the unmodified pillar, dashed with microwave absorber added

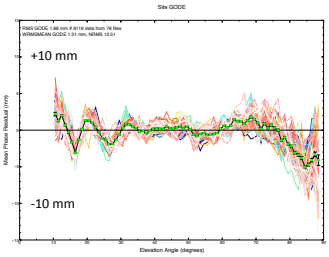
Fairbanks, Alaska

- Large residuals at GPS site.
- Radome removed but no large effect

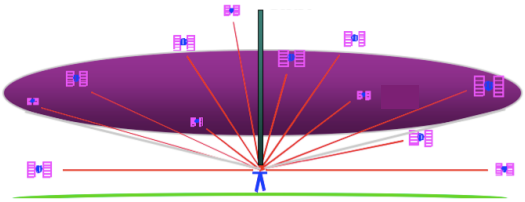


GGAO (GODE)

- Again removal of radome had little effect on systematic residual pattern



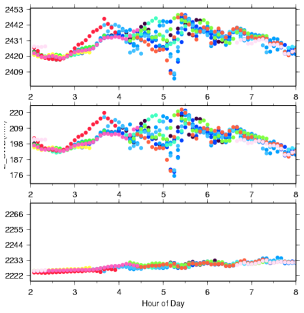
Atmospheric Delay



The signal from each GPS satellite is delayed by an amount dependent on the pressure and humidity and its elevation above the horizon. We invert the measurements to estimate the average delay at the zenith (green bar).

(Figure courtesy of COSMIC Program)

Zenith Delay from Wet and Dry Components of the Atmosphere



Colors are for different satellites

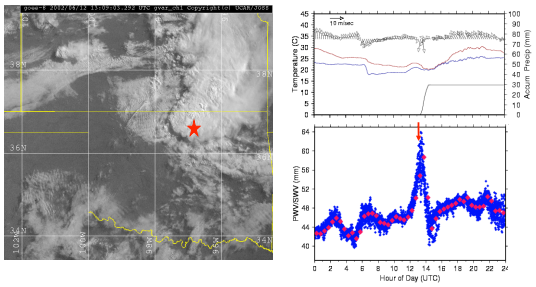
Total delay is ~2.5 meters
Variability mostly caused by wet component.

Wet delay is ~0.2 meters
Obtained by subtracting the hydrostatic (dry) delay.

Hydrostatic delay is ~2.2 meters; little variability between satellites or over time; well calibrated by surface pressure.

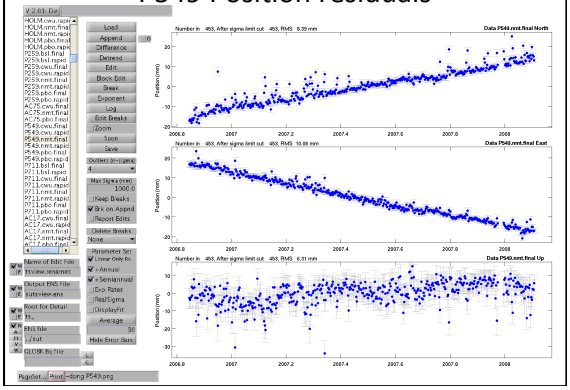
Plot courtesy of J. Braun, UCAR

Example of GPS Water Vapor Time Series



GOES IR satellite image of central US on left with location of GPS station shown as red star. Time series of temperature, dew point, wind speed, and accumulated rain shown in top right. GPS PW is shown in bottom right. Increase in PW of more than 20mm due to convective system shown in satellite image.

P549 Position residuals

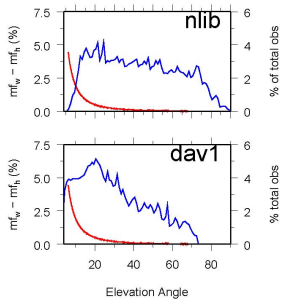


Effect of the Neutral Atmosphere on GPS Measurements

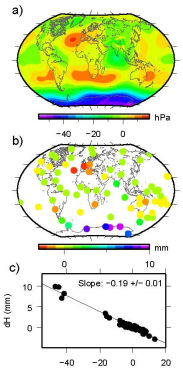
Slant delay = (Zenith Hydrostatic Delay) * ("Dry" Mapping Function) +
(Zenith Wet Delay) * (Wet Mapping Function) +
(Gradient Delay NS) (Gradient Mapping Function) * Cos/Sin(Azimuth)

- To recover the water vapor (ZWD) for meteorological studies, you must have a very accurate measure of the hydrostatic delay (ZHD) from a barometer at the site.
- For height studies, a less accurate model for the ZHD is acceptable, but still important because the wet and dry mapping functions are different (see next slides)
- The mapping functions used can also be important for low elevation angles
- For both a priori ZHD and mapping functions, you have a choice in GAMIT of using values computed at 6-hr intervals from numerical weather models (VMF1 grids) or an analytical fit to 20-years of VMF1 values, GPT and GMF (defaults)

Mapping function effects



- Mapping functions differ and this means hydrostatic and wet delays are coupled in the estimation.
- Example: Percent difference (red) between hydrostatic and wet mapping functions for a high latitude (dav1) and mid-latitude site (nlib). Blue shows percentage of observations at each elevation angle. From Tregoning and Herring [2006].



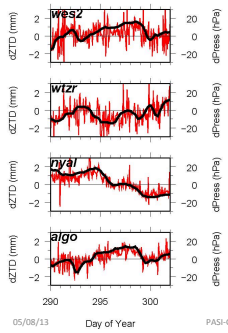
Effect of surface pressure errors

a) surface pressure derived from "standard" sea level pressure and the mean surface pressure derived from the GPT model.

b) station heights using the two sources of a priori pressure.

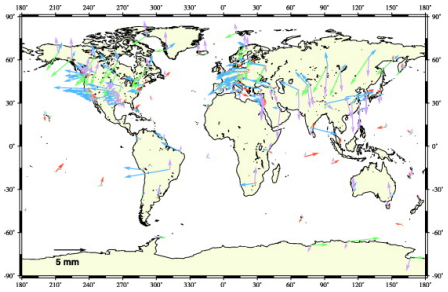
c) Relation between a priori pressure differences and height differences. Elevation-dependent weighting was used in the GPS analysis with a minimum elevation angle of 7 deg.

Short-period Variations in Surface Pressure not Modeled by GPT



- Differences in GPS estimates of ZTD at Algonquin, Ny Alessund, Wettzell and Westford computed using static or observed surface pressure to derive the a priori. Height differences will be about twice as large. (Elevation-dependent weighting used).

Annual Component of Vertical Loading



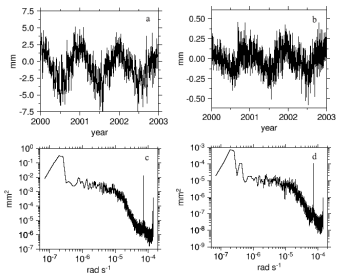
Atmosphere (purple) 2-5 mm

Water/snow (blue/green) 2-10 mm

Nontidal ocean (red) 2-3 mm

From Dong et al. J. *Geophys. Res., 107*, 2075, 2002

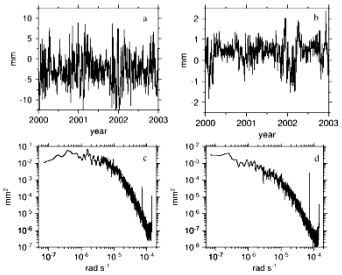
Atmospheric pressure loading near equator



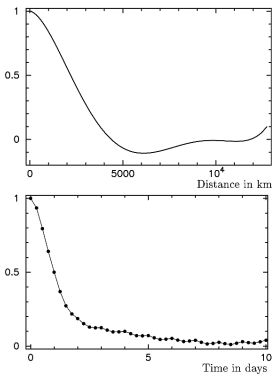
Spectral peaks at diurnal and semi-diurnal frequencies are S1/S2 "tidal" loading. (Thermal "tide" effect).

Vertical (a) and north (b) displacements from pressure loading at a site in South Africa. Bottom is power spectrum. Dominant signal is annual. From *Petrov and Boy* (2004)

Atmospheric pressure loading at mid-latitudes



Vertical (a) and north (b) displacements from pressure loading at a site in Germany. Bottom is power spectrum. Dominant signal is short-period.



Atmospheric delay correlation

- Spatial and temporal autocorrelation of atmospheric pressure loading (functions for mid-latitude site Algonquin, Canada).

From Petrov and Boy, *J. Geophys. Res., 109,* B03405, 2004

GAMIT Options for Modeling the Troposphere and Loading

- For height studies, the most accurate models for a priori ZHD and mapping functions are the VMF1 grids computed from numerical weather models at 6-hr intervals.
- For most applications it is sufficient to use the analytical models for a priori ZHD (GPT) and mapping functions (GMF) fit to 20 years of VMF1.
- For meteorological studies, you need to use surface pressure measured at the site to compute the wet delay, but this can be applied after the data processing (sh_met_util), and it is sufficient to use GPT in the GAMIT processing
- For height studies, atmospheric loading from numerical weather models (ATML grids) should also be applied. (ZHD and ATML are correlated, so don't use one set of grids without the other)

Summary

- For individual locations in regional network, atmospheric delay modeling, multipath and the stability of monumentation are usually the largest error contributors
- For survey mode measurements, set-up errors can also be large
- The other largest uncertainty and the way results are viewed can arise from the reference frame realization.