ERTH 455 / GEOP 555
Geodetic Methods

– Lecture 9: Your Noise can be Your Signal; Getting Data –

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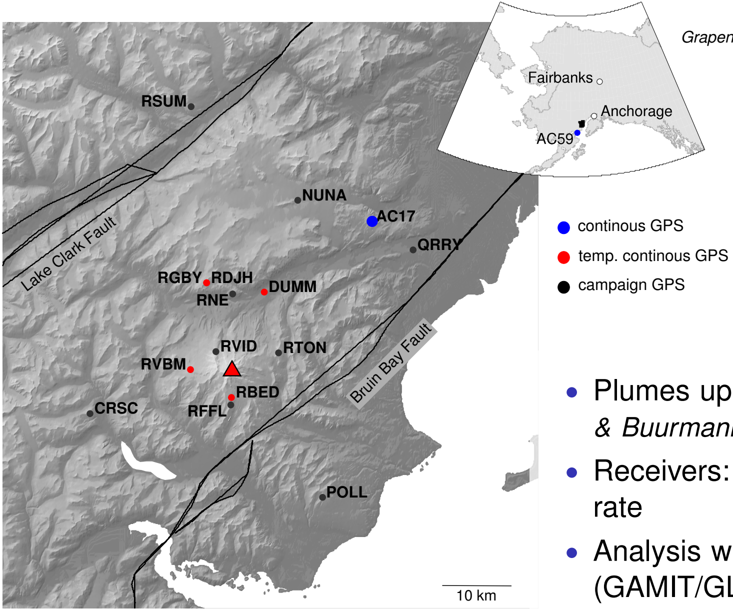
Phase Residuals

- Generally try to reduce phase residuals as much as possible.
- Are we making any assumptions in the processing?

Phase Residuals

- Generally try to reduce phase residuals as much as possible.
- Are we making any assumptions in the processing?
- YES! Remember all the troposphere, ocean load and other models?
- Worthwhile to investigate phase residuals for systematic ‘signals’!
- Might find new application for GPS!

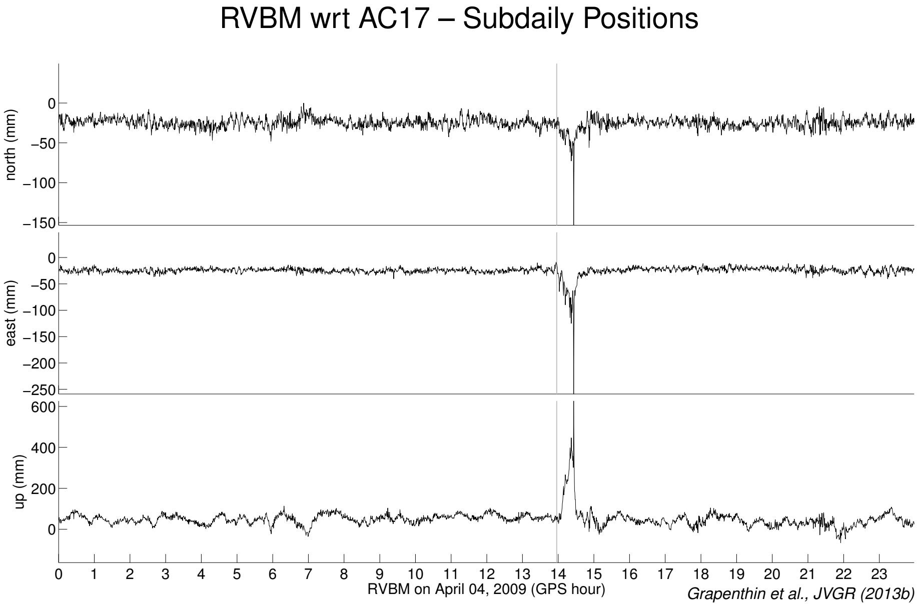
Phase Residuals: Volcanic Ash Detection



Grapenthin et al., JVGR (2013b)

- Plumes up to 18 km *(Bull & Buurmann, JVGR, 2013)*
- Receivers: 30 s sample rate
- Analysis with track (GAMIT/GLOBK)

Phase Residuals: Volcanic Ash Detection



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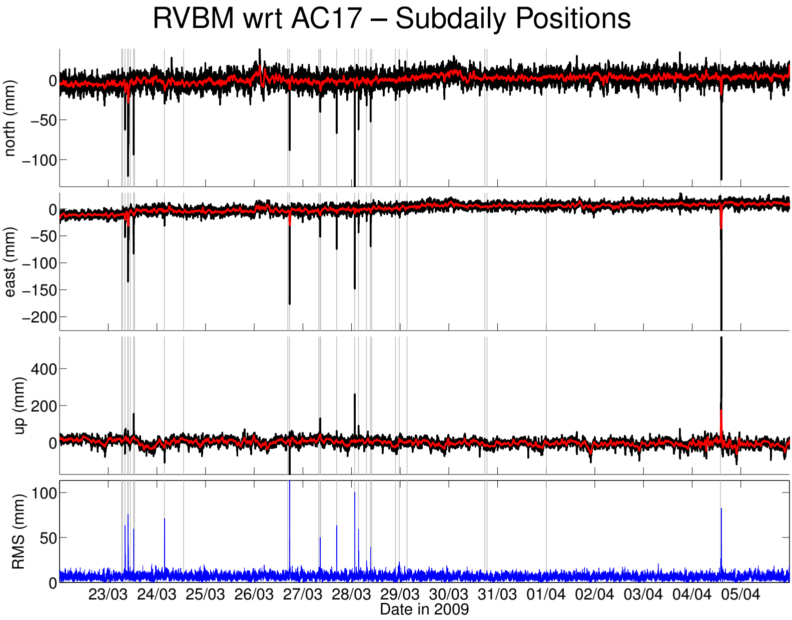

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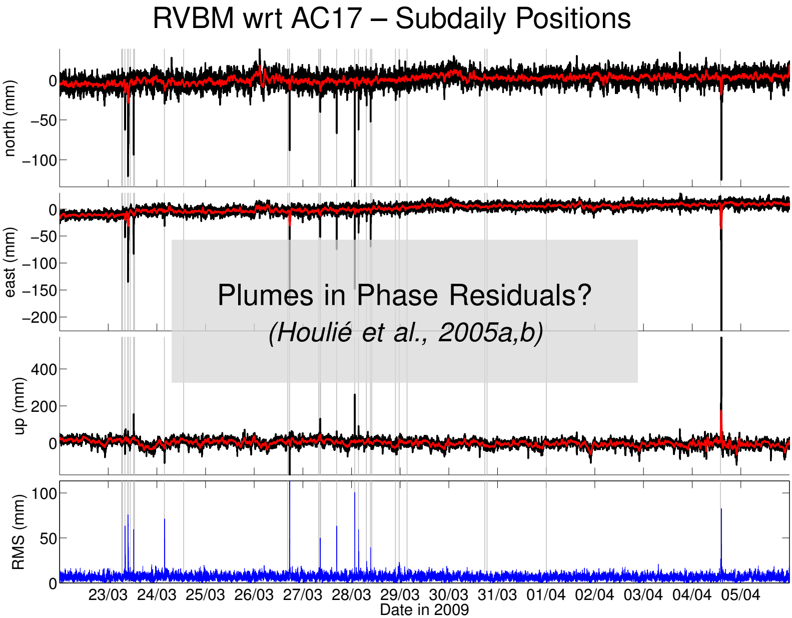
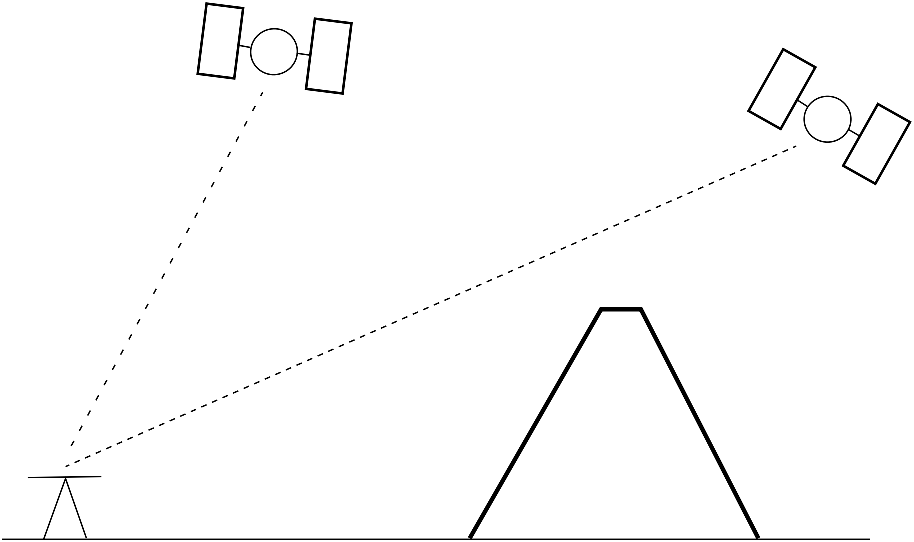


Plumes: How does GPS “see” them?



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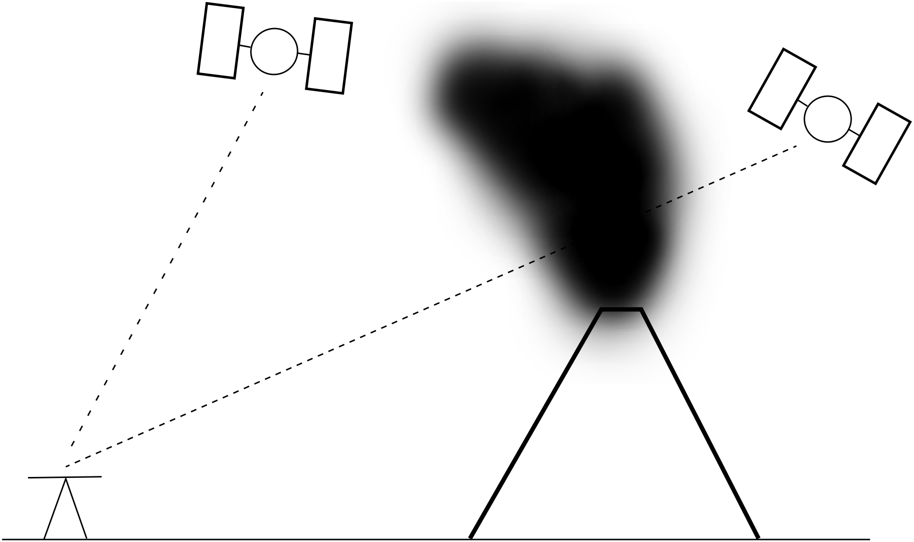

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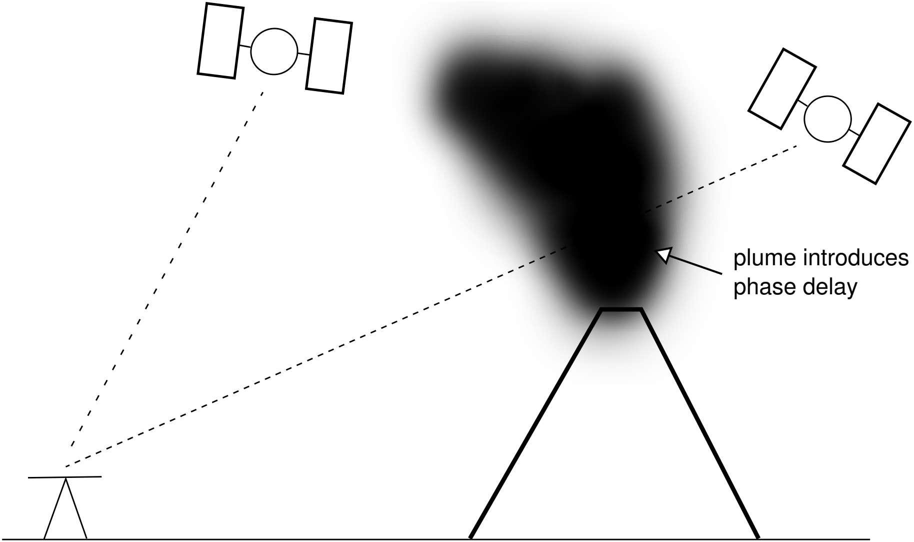

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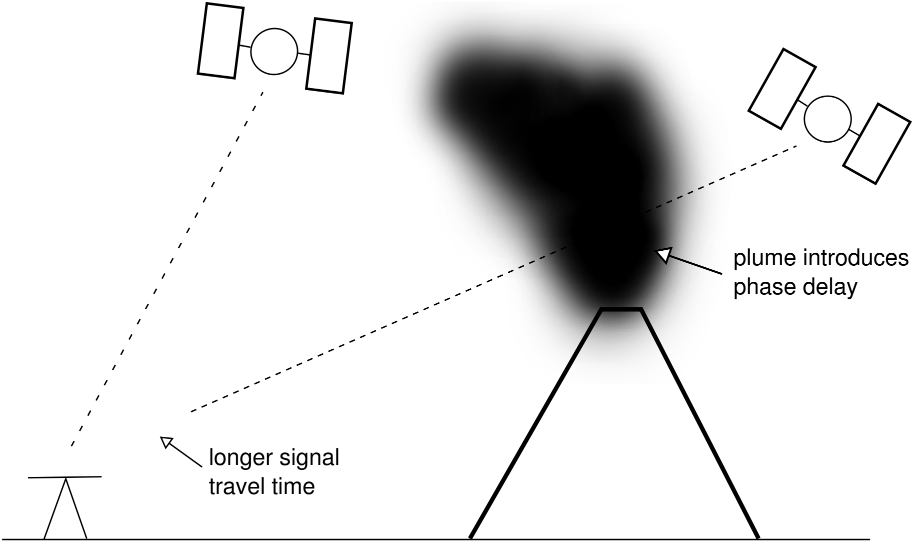

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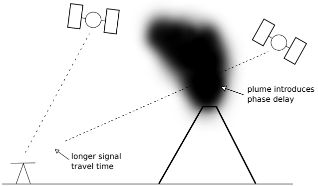
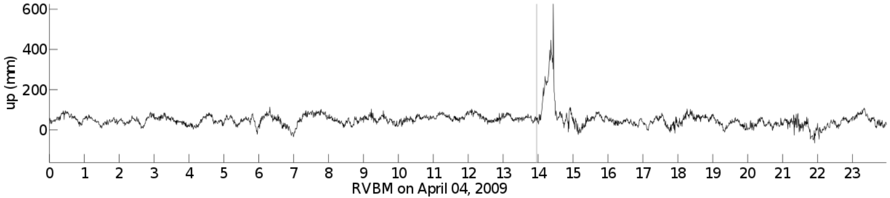
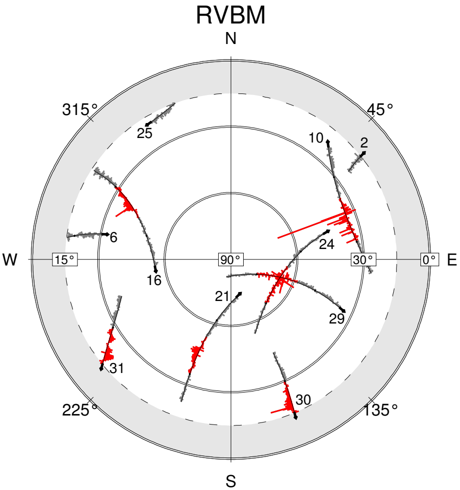


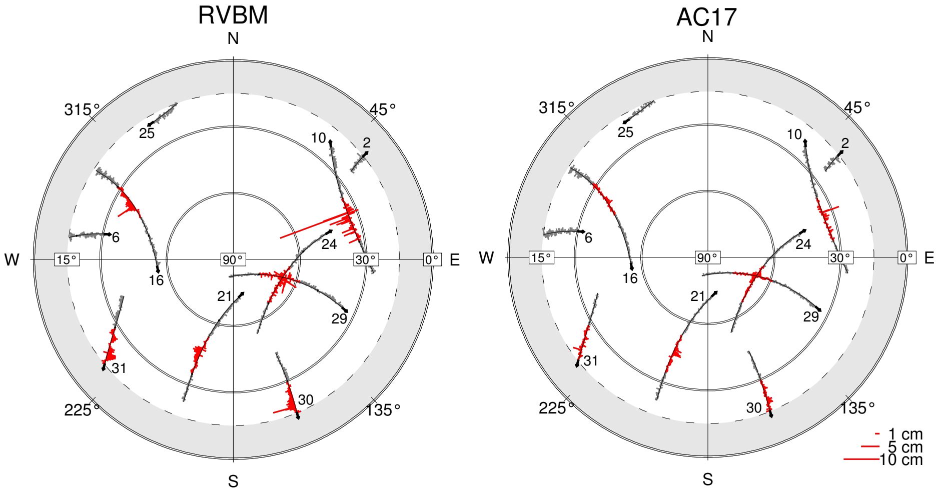


Phase Residuals Skyplots



Explosion: 04 April 2009, 14:00 to 14:40 UTC

Grapenthin et al., JVGR (2013b)



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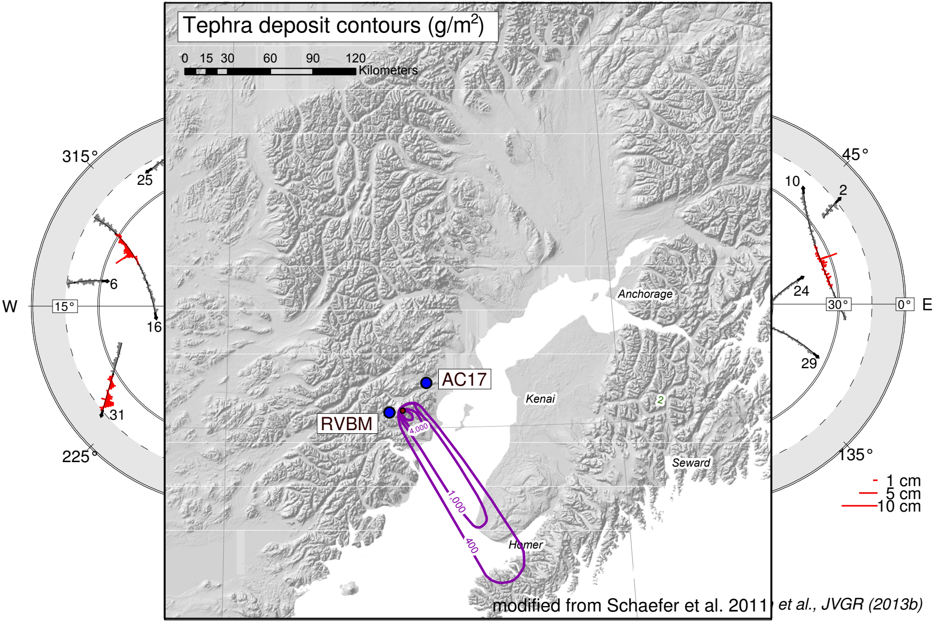

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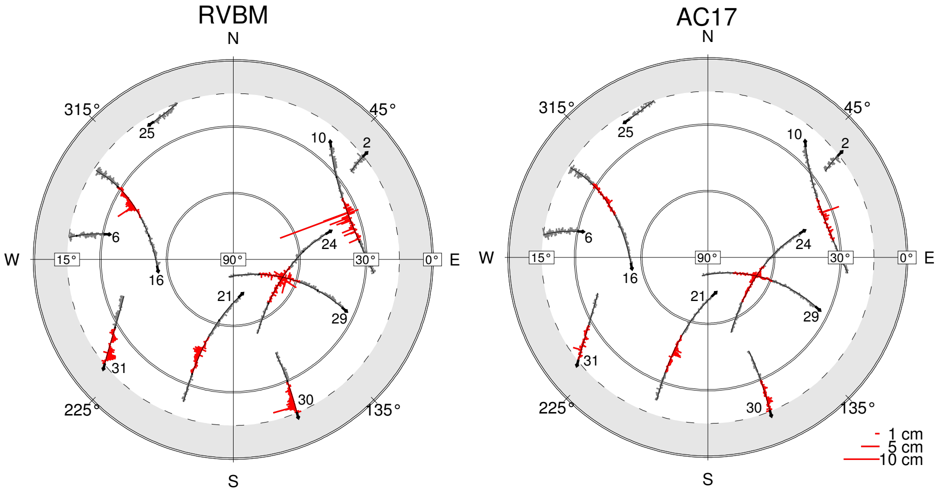

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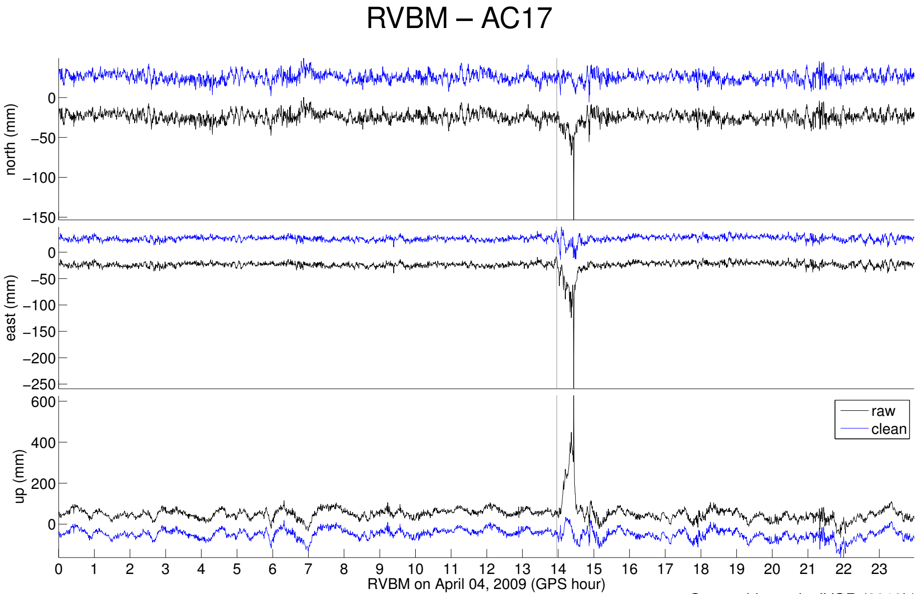
Phase Residuals: Clean up . . .



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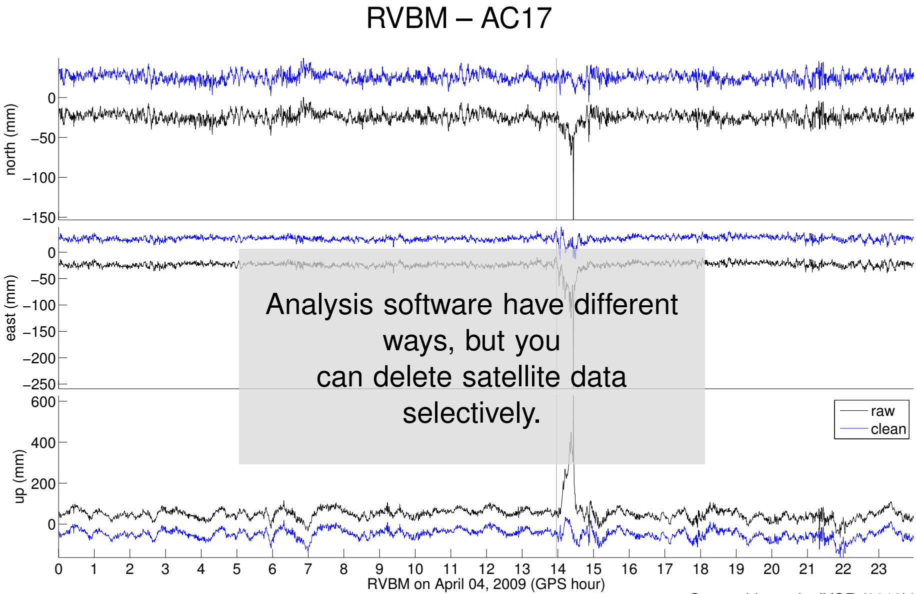
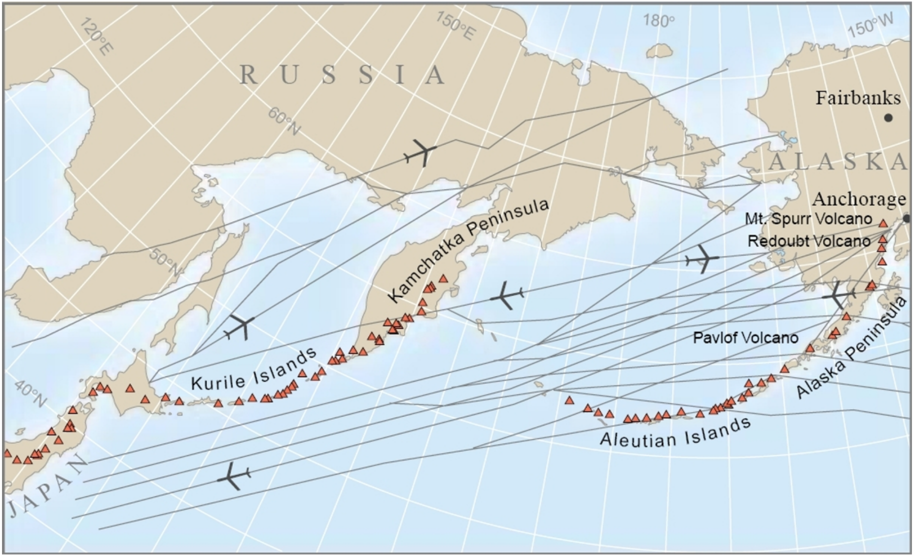
Phase Residuals: Clean up . . .



Analysis software have different ways, but you can delete satellite data selectively.

Grapenthin et al., JVGR (2013b)

Plumes w/ GPS Why do we care?



courtesy of USGS

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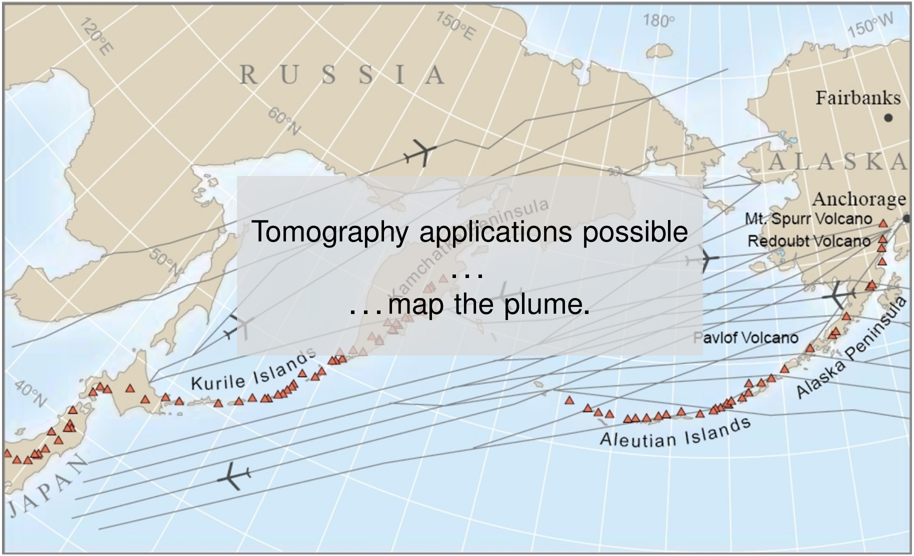


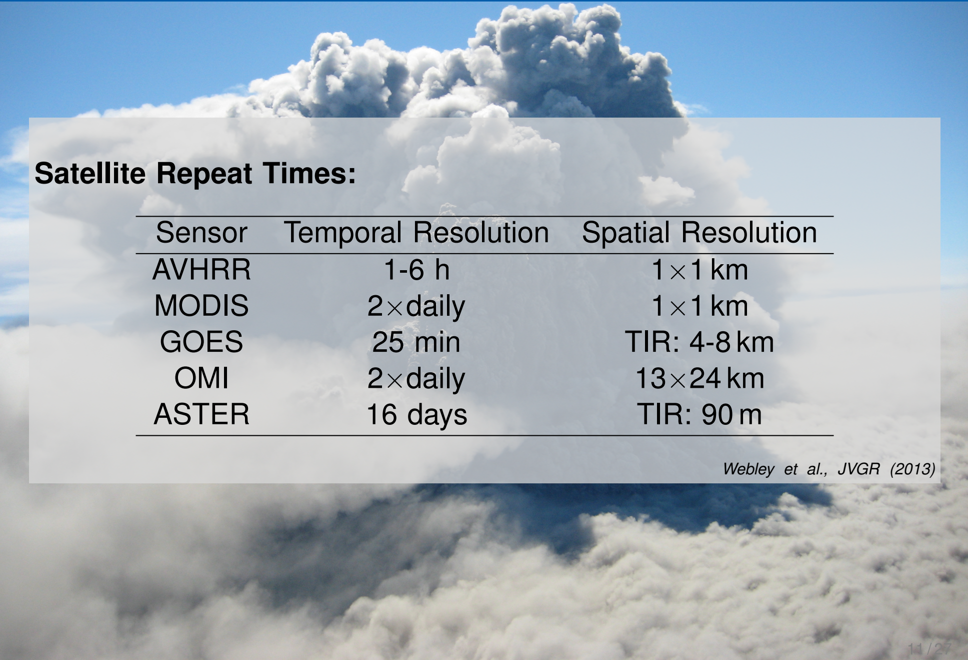
Tomography applications possible

…

…map the plume.

courtesy of USGS

Plumes: What's with Remote Sensing?



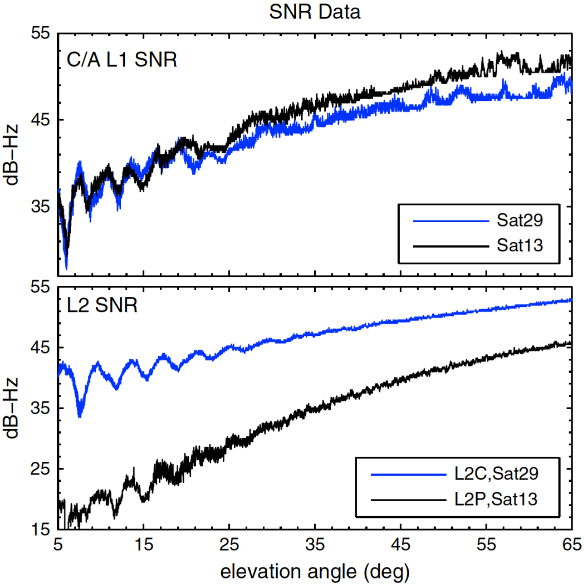
Satellite Repeat Times:

Sensor	Temporal Resolution	Spatial Resolution
AVHRR	1-6 h	1×1 km
MODIS	2×daily	1×1 km
GOES	25 min	TIR: 4-8 km
OMI	2×daily	13×24 km
ASTER	16 days	TIR: 90 m

Webley et al., JVGR (2013)

SNR: Signal to Ratio as a Signal

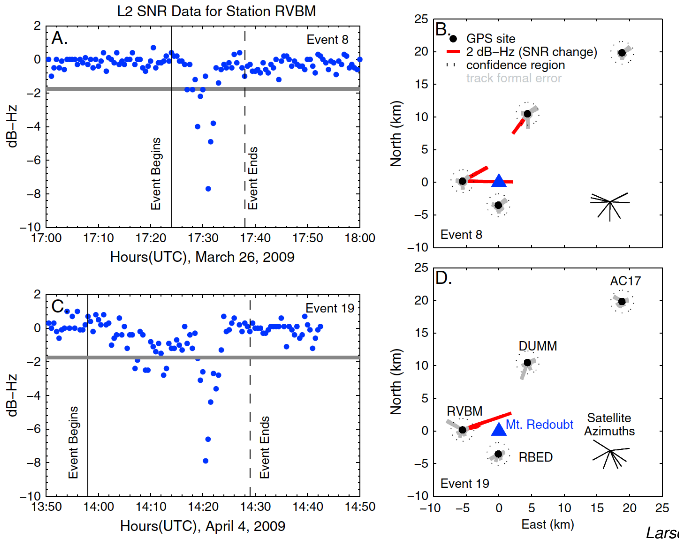
SNR from L1 Code vs L2 Code & Phase:



Larson, GRL (2013)

SNR: Signal to Ratio as a Signal

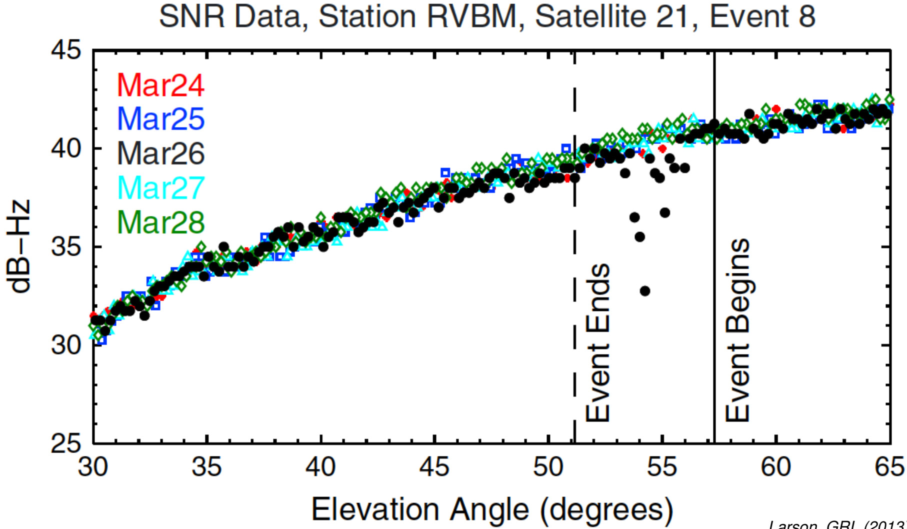
Plume in signal travel path: Signal strength drops:



Larson, GRL (2013)

SNR: Signal to Ratio as a Signal

Where is the plume?



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Plumes: SNR vs. Phase Residuals

- phase residuals: mostly affected by water vapor
- SNR: mostly affected by solids
- some plumes will show up in one method, but not the other.

Reflectometry with Multipath

- direct (A_d) and reflected (A_m) signals interfere – multi-path
- interference effect provides:
  - how wet reflecting surface is
  - distance between reflecting surface and antenna
- High-precision GNSS antennas are designed to suppress multipath
- don't entirely remove it, but $A_m << A_d$ (A is SNR Amplitude, see below)

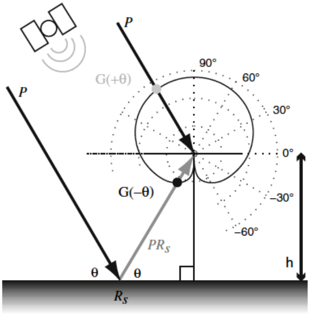


Fig. 2 Geometry of a single ground-bounce multipath signal and effects on signal power, for antenna height h and satellite elevation angle θ. Concentric *dashed circles* indicate power levels of receiving antenna gain pattern G (*solid line*), while *arrows* indicate GPS signal paths. For an incoming GPS signal of power P, the direct signal will pierce the gain pattern at an angle equivalent to the satellite elevation angle, so that $A_d = PG(+\theta)$. A parallel incoming signal will be reflected from the ground and attenuated by a reflectivity factor R_s. Assuming perfect specular reflection, the attenuated, multipathed signal will enter the gain pattern at the negative (below-horizon) satellite elevation angle, so that $A_m = (PR_s)\ G(-\theta)$. In general, $G(+\theta) >> G(-\theta)$. Gain pattern pierce points are indicated by *large filled circles*, with elevation angles marked on the outside ring

Larson et al., 2008, GPS Solutions

Reflectometry with Multipath

- new L2 C/A (L2C) (Block IIR-M satellites and above) 20 db-Hz improvement in recorded SNR over old L2 signals
- direct component of SNR must be removed
- MP contribution to SNR is small, but oscillatory
- direct contribution to SNR large in magnitude, but only 1 complete cycle per satellite pass
- depending on application discard data above/below certain elevation angles

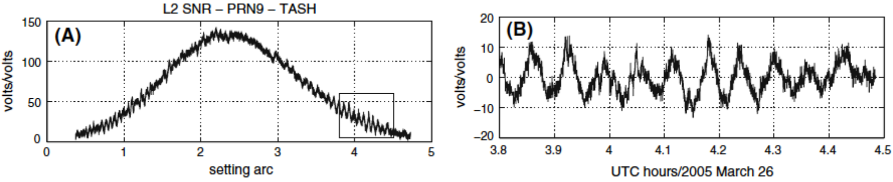
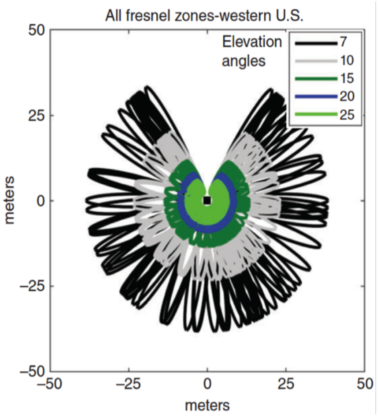


Fig. 3 **a** L2 SNR data for satellite (PRN) 9 at TASH on 2005 March 26; **b** SNR data for setting satellite with direct signal contribution removed with a low-order polynomial

Larson et al., 2008, GPS Solutions

Reflectometry by satellite: Fresnel Zones

- Fresnel zone characterizes GPS-IR footprint
- results in large footprint of 20-30 m radius for most GPS antennas
- compare to 0.01-5 m^2 of in situ sensors
- hole to the north: due to satellite orbit geometry



Larson et al., 2016, Wiley Interdiscip. Rev.: Water

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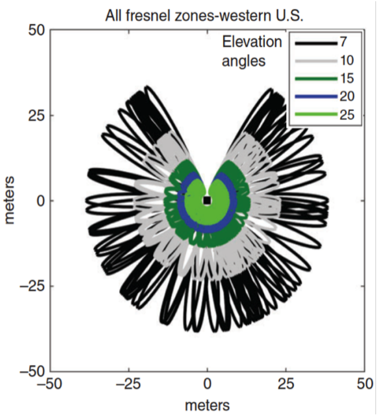

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- depends on antenna height, *h* and satellite elevation angle, θ (e.g., Hannah, 2001):
  - semi-minor axis $r_{minor} = \sqrt{\lambda h / sin(\theta)}$
  - semi-major axis $r_{major} = r_{minor} / sin(\theta)$

Reflectometry with Multipath

- multipath from horizontal, planar reflectors (ground) simple to model
- multipath affects all observations (pseudorange, carrier phase, SNR), focus on SNR!
- SNR independent of orbits, atmospheric delays, clocks!
- MP contribution to GPS SNR (signal to noise ratio):

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$$SNR = A\cos\left(\frac{4\pi h}{\lambda}\sin(E) + \phi\right)$$

$$f = \frac{4\pi h}{\lambda}$$

- *SNR*: signal to noise ratio
- *f*: multipath frequency
- *h*: antenna height
- λ: GPS signal wavelength
- *E*: satellite elevation angle
- *A*: SNR amplitude
- ϕ: SNR phase offset

Reflectometry with Multipath

- SNR interference pattern related to:
  - snow depth: linearly related to SNR frequency
  - soil moisture: near surface changes produce small changes in SNR phase offset
  - vegetation water content: decreases in SNR amplitudes
- Daily products at `http://xenon.colorado.edu/portal`.

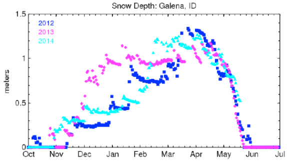

Figure 7. Snow depth measured at GPS site near Galena, Idaho for three water years. For clarity, error bars are not shown, but on average are 4 cm.

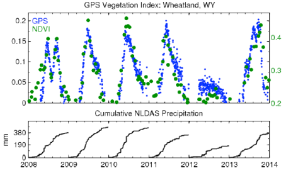

Figure 5. GPS vegetation index (left axis and blue circles) compared with NDVI (right axis and green circles). Cumulative precipitation derived from NLDAS is shown in black.

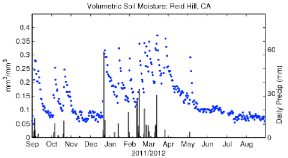

Figure 8. Volumetric soil moisture estimated at a PBO site in Northern California. Daily precipitation data come from NLDAS.

Larson and Small, 2014, Proc. IGARSS

Reflectometry: Soil Moisture Algorithm (Chew et al, 2016)

- phase most affected by changes in soil moisture
- BUT: surface slope and vegetation permittivity and height also affect phase
- solution: estimate vegetation impact from amplitude, predict its impact on phase and remove it (*Chew et al., 2015; 2016*)
- once vegetation removed from measurement get soil moisture:

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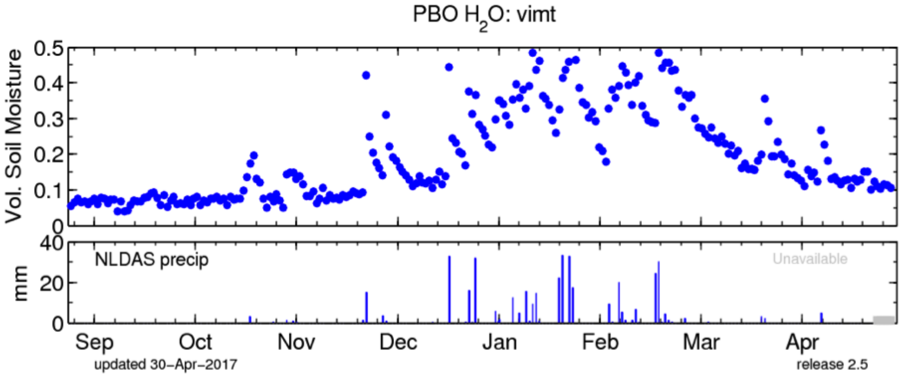
- once vegetation removed from measurement get soil moisture:
  - removing the mean of the 15% lowest phase measurements
  - determine residual soil moisture content SMC_{resid} (USGS STATSGO, gravimetry)
  - convert phase changes to SMC: $SMC_t = S\Delta\phi_t + SMC_{resid}$
  - S is scaling factor $\approx$ 1.48 $cm^3/cm^3/deg$ (*Chew et al., 2014*)
  - average SMC along all satellite tracks for each day to get site average

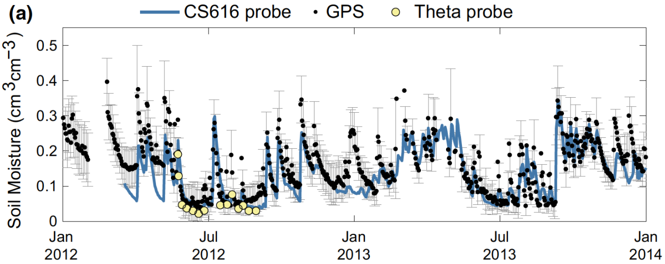
Reflectometry: Soil Moisture Algorithm (Chew et al, 2016)

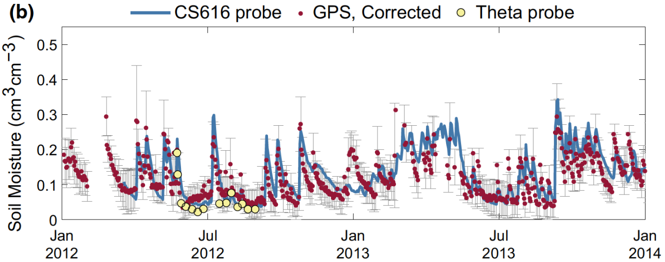
Volumetric soil moisture observations at PBO site VIMT compared to NLDAS precipitation records, California, Estrella:



`http://xenon.colorado.edu/portal`

Reflectometry: Vegetation Correction





Chew et al., 2016, GPS Solut.

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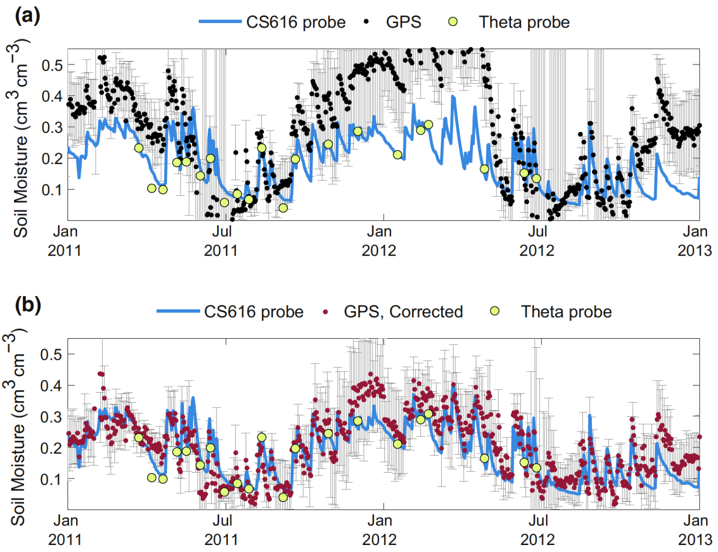

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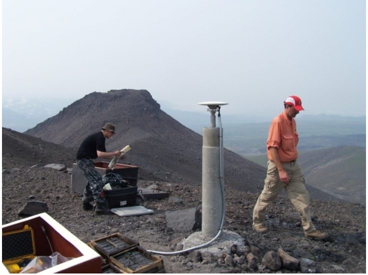
Getting Data. From where?

1) Your own campaigns: periodically go out and occupy benchmarks

Getting Data. From where?

2) build continuous sites ($10+ k)



Getting Data. From where?

3) data archives

- UNAVCO DAI `http://www.unavco.org/data/gps-gnss/data-access-methods/dai2/app/dai2.html`
- UNAVCO FTP `ftp://data-out.unavco.org/pub/`
- SOPAC `ftp://garner.ucsd.edu/pub/`, `http://sopac.ucsd.edu/dataBrowser.shtml`
- UNR (products) `http://geodesy.unr.edu/billhammond/gpsnetmap/GPSNetMap.html` (have ftp, too)
- regional networks, e.g. BARD: `http://seismo.berkeley.edu/bard/`

Getting Data. From where?

3) data archives (continued)

- Japan GEONET: open, but need to register `http://datahouse1.gsi.go.jp/terras/terras_english.html`
- New Zealand GEONET: `ftp://ftp.geonet.org.nz/gps/`, 1Hz: `ftp://ftp.geonet.org.nz/rtgps/rinex1Hz/PositioNZ/`
- NSF funded research required to make data available publicly, not all research in US NSF funded, though
- Other countries may not have open data sharing policy - contact potential collaborators!