GPS and Volcanic Ash Plumes: The eruptions of Okmok 2008 and Redoubt 2009, Alaska

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The eruptions of Okmok Volcano in 2008 and Mt. Redoubt in 2009 produced significant ash plumes reaching over 15 km of altitude. It is known that the injection of volcanic ash in the atmosphere induces phase delays not modeled by GPS analysis tools, which results in apparent displacements in GPS time series (Houlíe et al. 2005a,b). However, little work has been done on turning this problem into an effective volcano monitoring tool. Satellite based remote sensing techniques provide good spatial coverage for the detection of volcanic plumes, but slow satellite repeat times (>30 minutes) and cloud cover can prevent the detection entirely. GPS, in turn, provides excellent temporal coverage, but requires favorable satellite–station–geometry such that the signal propagates through the plume if to be used for plume detection.

The recent eruptions of Okmok and Redoubt volcanoes in Alaska were recorded by sparse continuous GPS networks (Figures 1,4) recording at 15-30 second intervals. We analyze these records to investigate the use of GPS phase residuals for plume monitoring, sensing and tracking. A straightforward result is the derivation of plume azimuths from phase residuals plotted along the sky tracks of individual satellites. However, the phase residuals are not necessarily linearly related to the phase delay as some of it is mapped into station coordinates and likely other parameters. The derivation of plume densities hence not only depends on how a plume effectively slows a signal at speed of light, but also how this error is mapped into the various parameters to be estimated when solving for a station position.

Methods

- Satellite phase residual values (RMS) reported by GIPSY software in kinematic network processing mode
- Plot phase RMS with `cf2sky` by Hilla (2004), which visualizes `teqc` (Estey and Meertens, 1999) plot files along a satellite's trajectory in a skyplot.
- We modified `cf2sky` to run on a Linux platform and translated GIPSY postfit data into UNAVCO COMPACT format readable by `cf2sky`.

Conclusions, Next Steps

The technique of detecting ash plumes with GPS has been described before by (Houlíe et al. 2005a,b), but is not well explored. Phase residuals along sky tracks of satellites provide easy access to plume azimuths. Gaps in vent crossing station-satellite pairs may prohibit detection of plumes or ash concentrations may not be large enough to affect the signal significantly. Therefore, this technique should be seen as complementary to seismic and remote sensing monitoring.

Future experiments necessary to explore how a plume affects the GPS signal:

- Study stations experiencing little to no volcanic displacements during plume ejection and fix all solution parameters to reasonable a-priori parameters.
- Then we can track plumes and infer path delay
- To derive plume densities the effects of plumes on radio signals needs to be investigated.

References

1. Estey, L.H., C.M. Meertens, TEQC : The Multi-Purpose Toolkit for GPS / GLONASS Data, GPS Solutions, 3, 42–49 (1999).
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3. Hilla, S., Plotting Pseudorange Multipath with Respect to Satellite Azimuth and Elevation, GPS Solutions, 8, 44–48 (2004).
4. Houlie, N., P. Briole, A. Nercessian, M. Murakami, Sounding the plume of the 18 August 2000 eruption of Miyakejima volcano (Japan) using GPS, Geophys. Res. Lett., 32, L05302 (2005).
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Case 1 – Redoubt: April 04, 2009

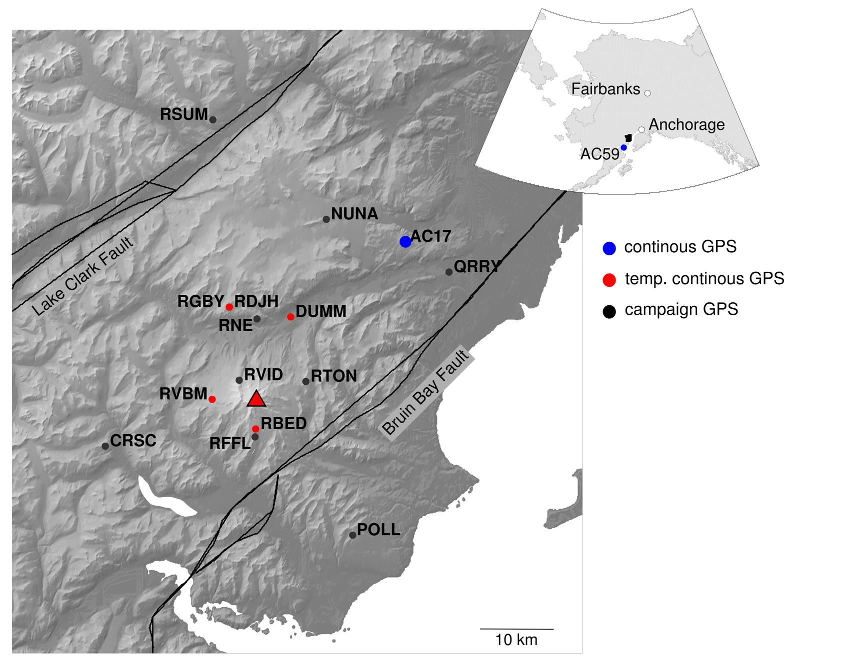

Figure 1: Map of Redoubt area with GPS stations. Red triangle marks Mt. Redoubt. The black lines from SW to NE show major faults in the region. The black square in the inset indicates the location of this detail map.

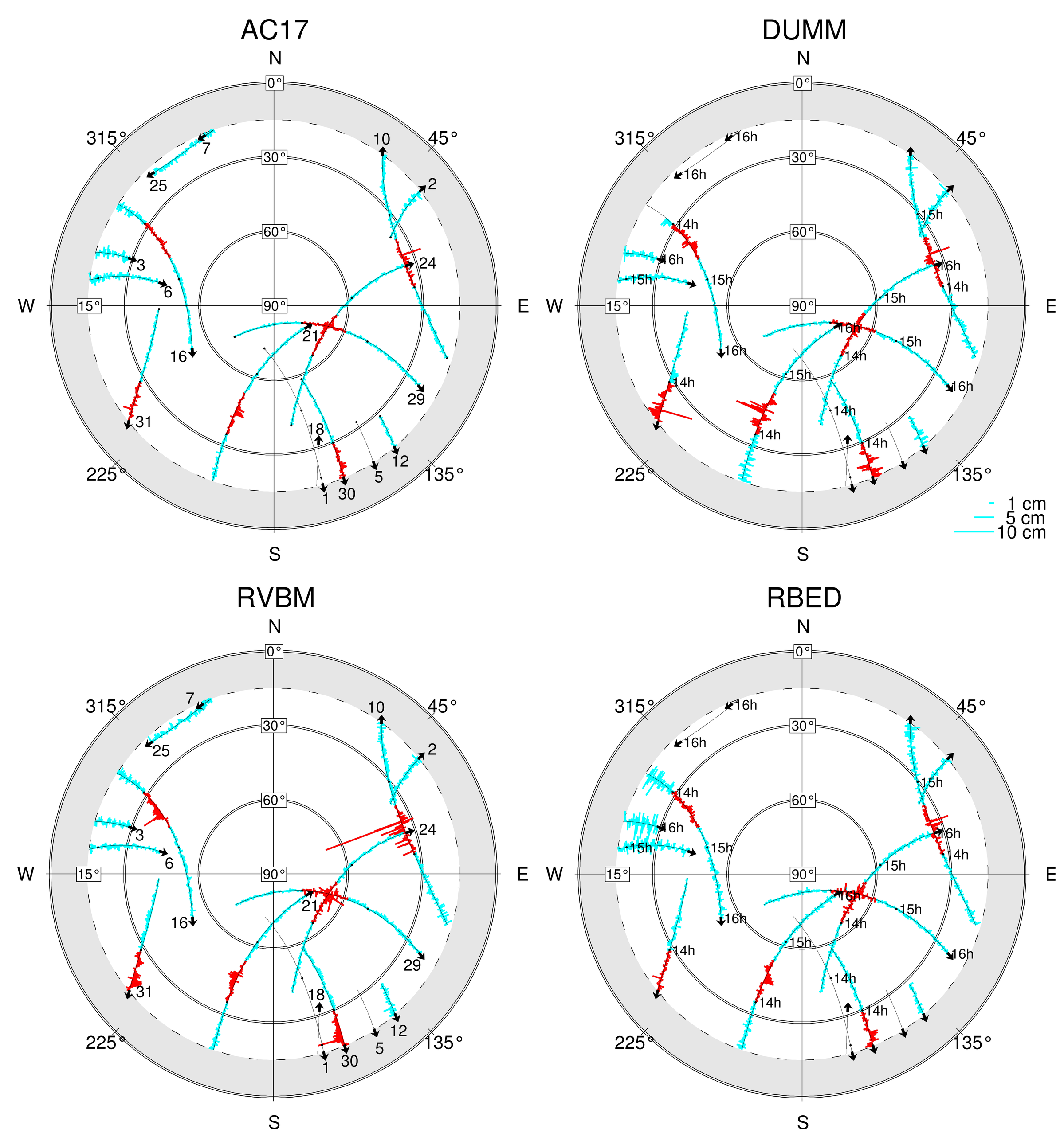

Figure 2: Skyplot of phase residuals (turquoise) along satellite sky tracks. Satellite PRN in the left column. Full UTC hours next to black dots in the right column. Red sections indicate time of eruption from about 14:00–14:40 UTC (plume went to the SE, and left a very narrow footprint (Schaefer, 2011). Note spikes at DUMM to SW and RVBM to E during eruption showing plume azimuth.

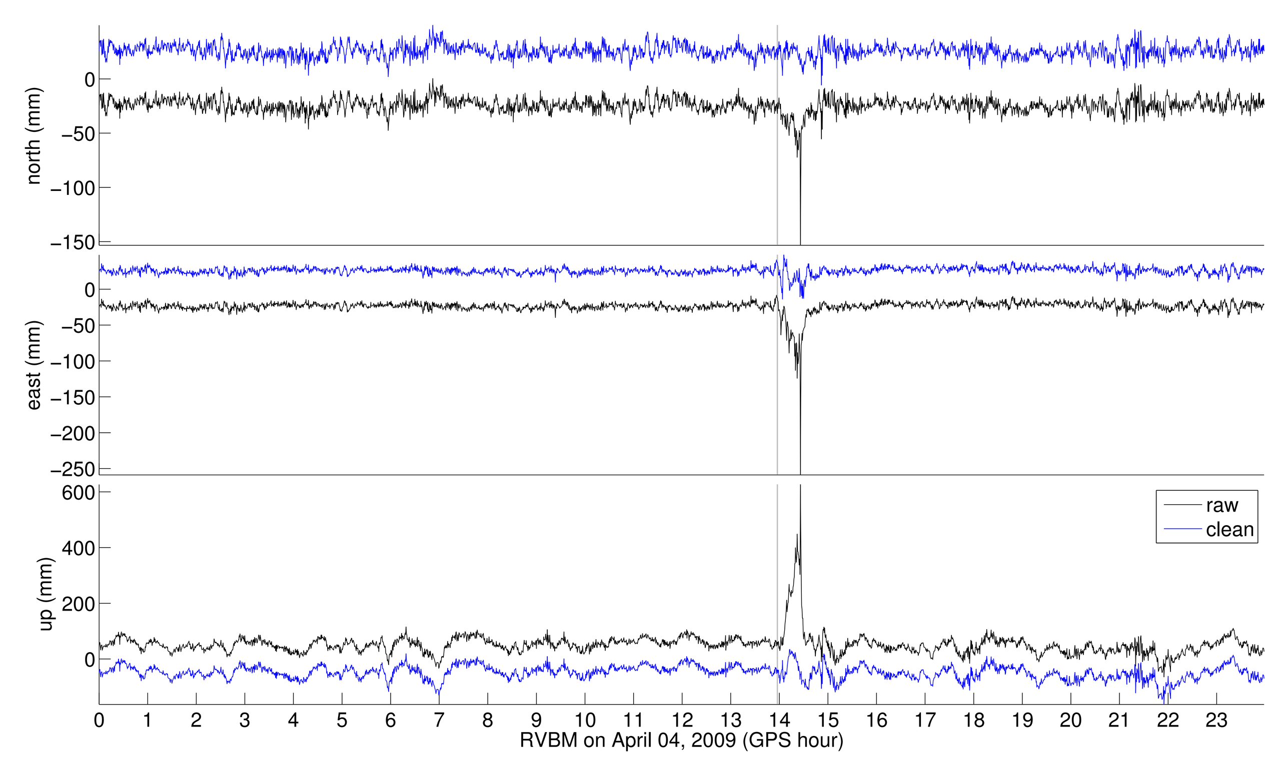

Figure 3: Kinematic solution for RVBM. Black line is original solution, blue line has PRN 10 deleted from 14:00-14:45 GPS time. Spike in the position time series is reduced. Some scatter remains, likely due to the other satellites affected by ash or actual ground motion due to the eruption.

Case 2 – Okmok: July 12, 2008

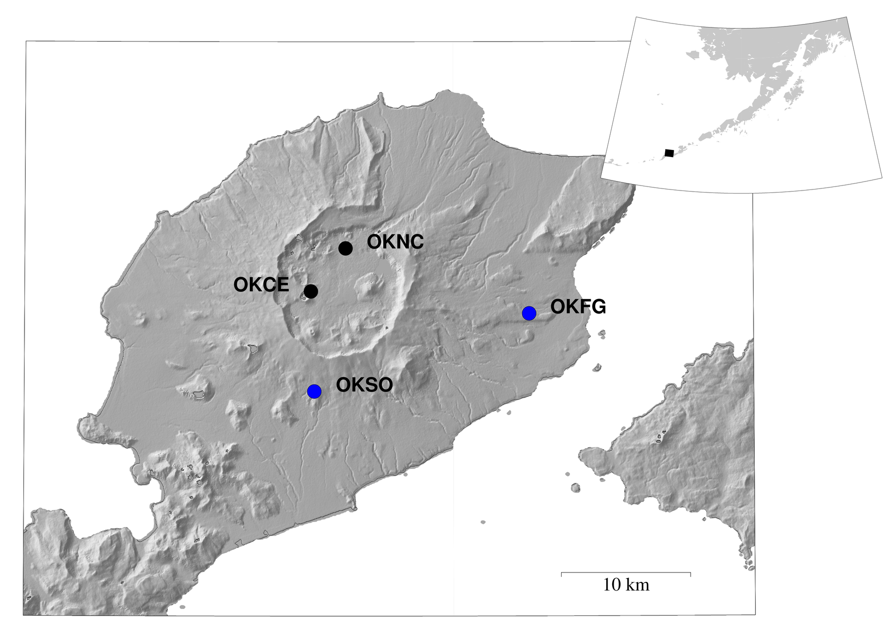

Figure 4: Map of Okmok area with continuous GPS stations. Blue dots: operational stations during the 2008 event. Black dots: OKNC installed in 2010, OKCE not operational. Black square in inset indicates location of detail map.

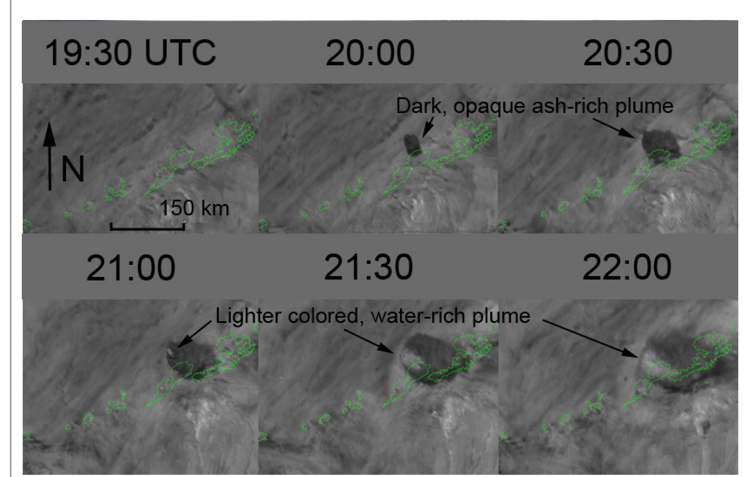

Figure 5: From Larsen et al. (2009), Time series of Geostationary Operational Environmental Satellite (GOES) visible satellite imagery from 12 July showing emergence of the first, dark, ash-rich plume drifting to NW and the second, white, water-rich plume with radius >100 km. Images in 30-minute intervals.

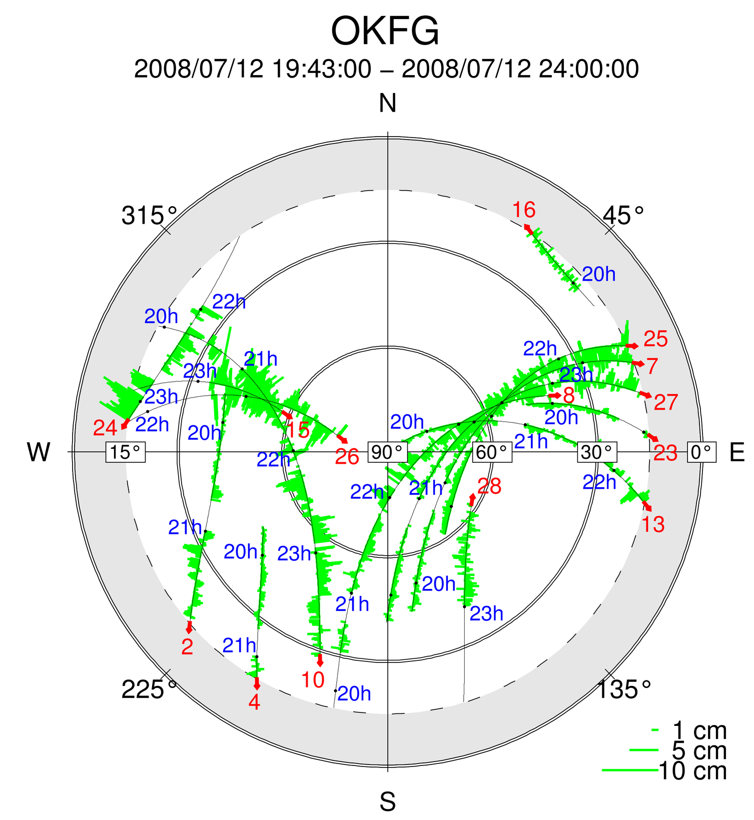

Figure 6: Phase residuals for OKFG (E of vent, similar setup to Figure 2). Time from onset of first explosion to midnight July 12. Many data gaps due to loss of signal, distinct peaks of phase residuals to WNW not until after 22:00. Compare to Figure 5: Initial plume drifts to North, northern sky free of satellite tracks.

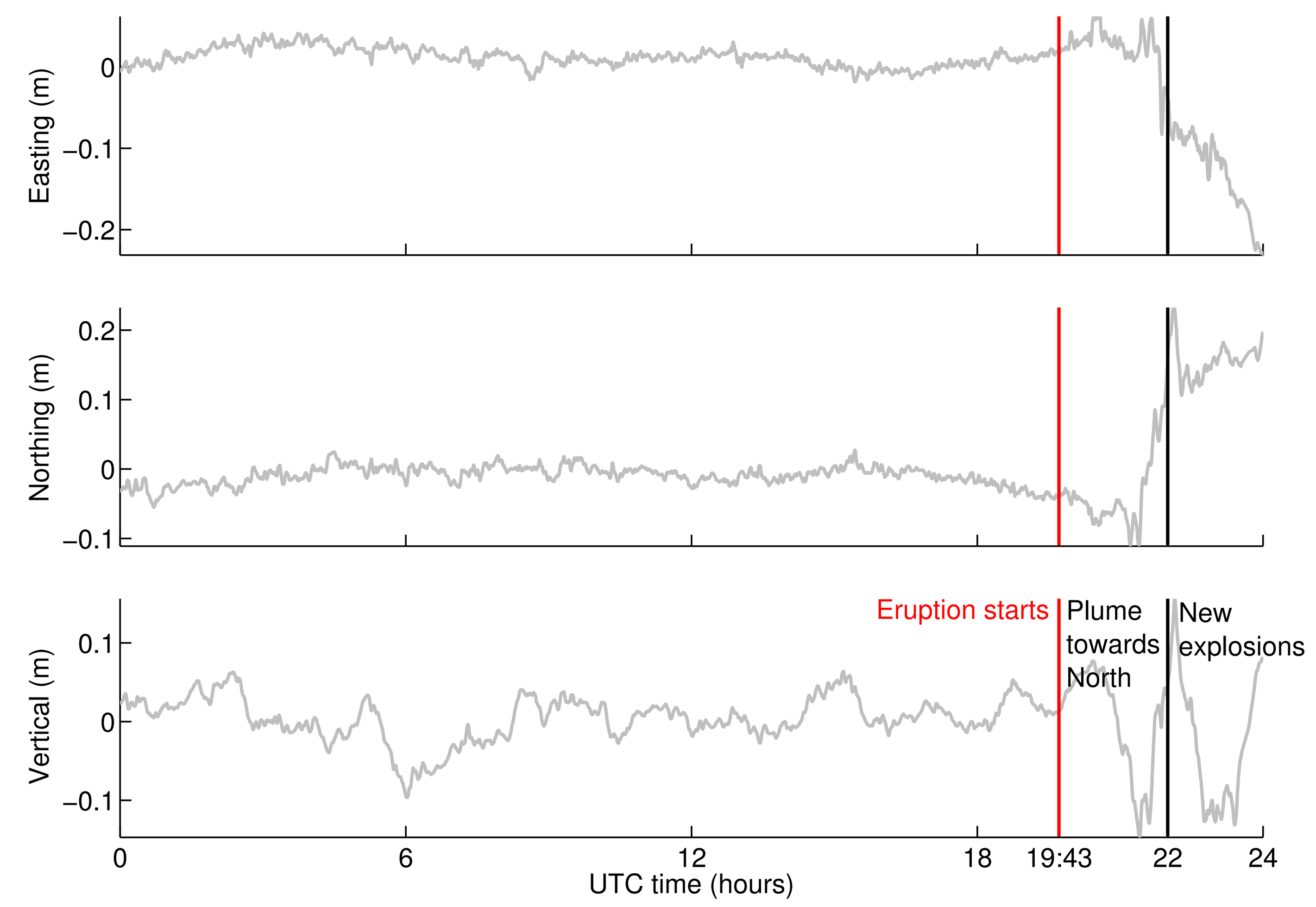

Figure 7: Kinematic solution for OKFG (gray). Permanent displacements during entire eruption (Freymueller and Kaufman, 2010, in mm): -96 ± 3 East, 5 ± 3 North, -31 ± 4 Up are smaller than offsets shown in this time series. Red line marks time of first explosion with ash-rich plume (see Figure 5) drifting to North. Black line at 22:00 UTC shows time when water rich plume shows in GOES data. Significant position offsets show plume effects sooner than that, but not at onset of eruption as satellite signal does not penetrate plume due to unfavorable satellite–station–geometry. A station to North of vent would improve detection.

T. Fournier provided the Okmok regional map. We used A. Aschwanden's LaTeX template as a basis for this poster.