Using GPS Signal Strength Data to Detect Volcanic Plumes
Kristine M. Larson, Siddesh Naik, Scott Palo, David Schneider, Yusaku Ohta, Mario Mattia, Massimo Rossi, Valentina Bruno, Mauro Coltell
Department of Aerospace Engineering Sciences, University of Colorado, Boulder
USGS Alaska Volcano Observatory, Anchorage
Tohoku University, Japan
Istituto Nazionale Geofisica e Vulcanologia, Catania, Italy

Contact information: kristinem.larson@gmail.com
http://spot.colorado.edu/~kristine

Introduction
GPS is a L-band navigation system. GPS satellites are operated by the U.S. Department of Defense, and jointly managed with the U.S. Department of Transportation. They transmit coded signals at two prime frequencies: 1.575 MHz (L1) and 1.2276 GHz (L2). As part of a modernization program, a third frequency (L5) was recently added, but with GPS signal can be tracked with newer instrumentation. GPS has been used by geoscientists for decades to measure crustal deformation. It is also used to monitor water vapor in the atmosphere and timing. GPS has been used to monitor volcanoes for over twenty years. Generally, geodetically-qualified GPS units are deployed on the volcano, recording dual-frequency ranging observations at sampling rates of 30 seconds. From this data, GPS instruments measure the one-way travel time between satellites and a single GPS antenna. Modeling of satellite orbits, satellite and receiver clock, relativistic effects and atmospheric delays satellite frequencies to estimate position (altitude, longitudinal, and height) with high-precision techniques. With appropriate software, mm-cm level measurements of ground displacements can be easily made.

About 10 years ago, volcanic geodeticists began to evaluate the effects on volcanic plumes on GPS signals (Houlle et al., 2009; Probert-Jones, 2015). As with most geodetic studies, these focused on using the measured range changes between the satellites and the GPS antenna because ranging measurements are longer if there is water vapor in it. More recently, dynamic plumes in Alaska, New Zealand and Japan, and Italy have been studied with GPS ranging measurements (Gaertenfels et al., 2013; Ohta et al., 2015; Avanzini et al., 2013; Fournier and Jolly, 2014). Typically the volcanic plume is detected by evaluating least squares residuals used when estimating these positions. This has the unfortunate effect of combining the volcanic plume effect (which generally only affects a single satellite) with all the satellites that were in view at the same time. Larson (2013) showed that GPS signal strength (SNR) data can also be used to identify and locate volcanic plumes. Currently many groups of volcanic geodeticists are looking closely at detecting plumes with GPS, which could demonstrate this concept.

GPS Signal Strength Data

Although ranging measurements are the primary observables produced by a GPS instrument, all receivers will calculate an engineering measurement (CMs) which is a proxy for signal strength. These data are frequently called the GPS SNR signal to noise ratio. A typical example is shown in Fig. 2. The direct signal – the one that travels along the straight line between the satellite and the antenna – has a very simple CM profile which can be approximated by a mathematical function. The lower SNR values as the satellite moves and sets primarily due to the gain pattern of the antenna. The oscillations seen at low elevation angles in this figure (circled in green) are due to signal strength reflected from the ground. The amplitude and phase of these oscillations can be used to measure water vegetation content, snow depth, and soil moisture (Small et al., 2010; Larson et al., 2009; Larson et al., 2008).

GPS Plume Detections in Italy and Japan

Below we show GPS SNR data from two different small plumes on Mount Etna and Redoubt. In the left panel shows the SNR data from the northwestern source at northern sources as a function of elevation. The data peaks in intensity in the region where the plume is indicated by the shaded portion of the graph. The right panel shows the SNR data as a function of time. The peak SNR values are indicated by the boxes. As the plume moves and sets, the SNR values decrease. The data can be used to identify the presence of volcanic plumes.

Ongoing Work

We are developing a forward model for SNR changes due to volcanic plumes. We are tracking these changes with older and new instrumentation. As we are developing a method to detect and identify volcanic plumes, we are also working to develop forward models for different plume conditions so that we can convert SNR detections into parameters that would be of more value to the community.

References

Conclusions

We have shown that there are strong correlations (up to 0.98) between SNR data and volcanic plumes. SNR data are insensitive to water vapor, and thus have potential to contribute to detect volcanic activity at volcanic observatories. SNR data are computed at a geodetic station, the health of our instruments are thus easy to monitor. We are evaluating both the precision and accuracy of SNR data so that we can place uncertainty bounds on our plume detections. We are also working to develop forward models for different plume conditions so that we can convert SNR detections into parameters that would be of more value to the community.

We encourage any country that operates a GPS network with open data policies to contact us if they are interested in testing their data, as we would be happy to share software with you.

Acknowledgements
This research is supported by NSF EAR 136810 and NASA NASA-NA11AG14G grant to the University of Colorado. GPS data from the Mt. Redoubt and Okmok eruptions were collected by Jeff Freymueller and Ronni Grapenthin (University of Alaska, Fairbanks), and are freely available from UNAVCO. GPS data from Mt. Etna were collected by Mario Mattia and Massimo Rossi (Dipartimento Nazionale di Geofisica e Vulcanologia) and data from Mount Shindake were provided by Yusaku Ohta of Tohoku University and Geographic Survey Institute of Japan.