Alaska Satellite Facility
ASF News & Notes
Fall 2005, volume 2:3

Comparison of GPS and InSAR deformation measurements at Okmok volcano, Alaska

Dr. Zhong Lu, Science Applications International Corporation (SAIC), U.S. Geological Survey Center for Earth Resources Observation and Science, Sioux Falls, SD 57198; email: lu@usgs.gov; http://edc.usgs.gov/Geo_Apps/ Yousuke Miyagi, Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University; email: yousuke@eos.hokudai.ac.jp

Since the 1980s, two modern geodetic techniques, namely the Global Positioning System (GPS) and Interferometric Synthetic Aperture Radar (InSAR), have revolutionized the study and monitoring of active volcanoes. These techniques have documented patterns of deformation before, during, and after eruptions of volcanoes, and enabled exploration of quantitative physical models to understand the magmatic processes.

The two techniques work in a remarkably similar fashion, both utilizing phases of electromagnetic waves to resolve the precise distance between the satellites and ground targets. The capabilities of the two techniques compliment each other where GPS can provide a 3-D deformation vector at each GPS station with an accuracy of a few millimeters, while InSAR can image the line-of-sight component of ground deformation over a large area at spatial resolution of tens of meters with an accuracy of centimeters to sub-centimeters.

In GPS observations, dual-frequency waves and temporal averaging enable the removal of ionospheric anomalies and the reduction of tropospheric artifacts, both of which plague InSAR deformation measurements. Furthermore, InSAR measurements suffer from the loss of interferometric coherence due to modification of the imaged surface characteristics caused by vegetation, snow, ice, and other environmental factors. Regardless, the combination of both GPS measurements and InSAR deformation images can enhance mapping, modeling and interpretation of ground deformation at active volcanoes.

Okmok volcano is among a limited number of volcanoes in the world being monitored by both GPS and InSAR techniques. Okmok is a dominantly basaltic central volcanic complex that occupies most of the northeastern end of Umnak Island, Alaska (Figure 1). Catastrophic pyroclastic eruptions circa 12.0 and 2.05 ka resulted in the formation of two overlapping summit calderas. Subsequent eruptions produced a field of small cones and lava flows, including several historically active vents within the younger caldera [Grey, 2003; Miller et al., 1998]. Most of the volcano's historical eruptions are poorly documented owing to its remote location. Minor explosive eruptions occurred in 1931, 1936, 1938, 1943, 1960-1961, 1981, 1983, and 1986-1988; blocky basaltic flows were extruded during relatively large effusive eruptions in 1945, 1958, and 1997. These eruptions originated from Cone A, located on the southern edge of the caldera floor (Figure 1), which formed almost entirely during the 20th century.

Continued on page 2

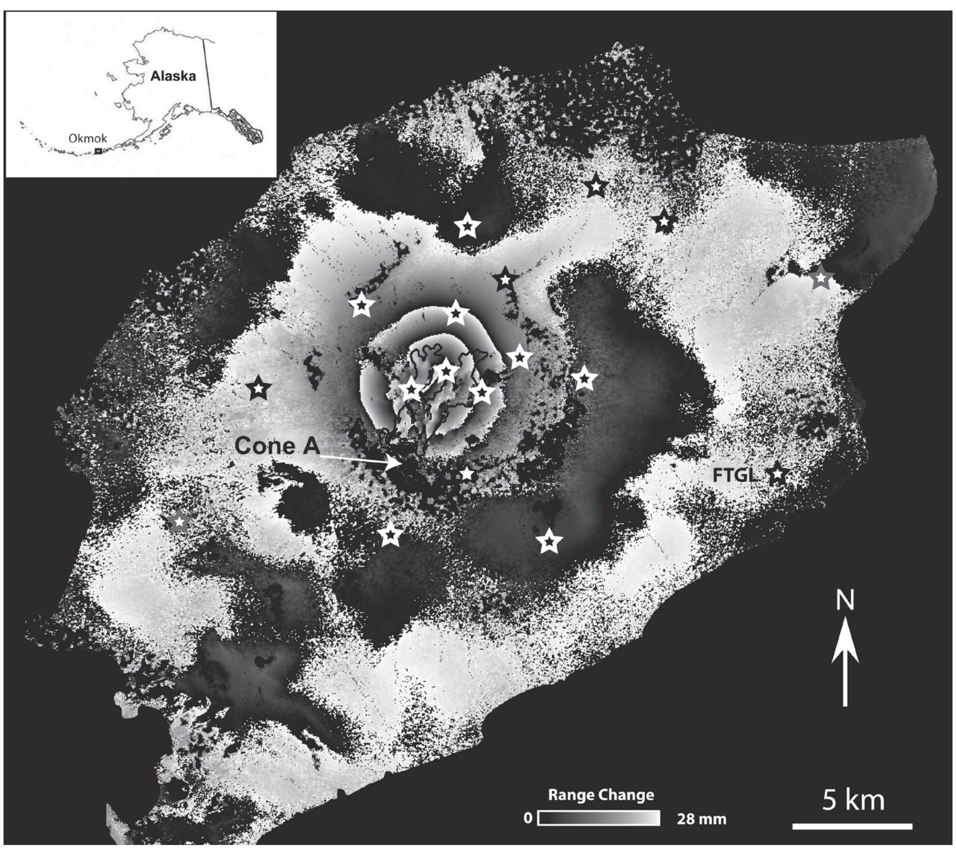

Figure 1: An InSAR image showing deformation of Okmok volcano during 2000-2002. GPS stations that were surveyed in 2000 and 2002 are shown in stars.

A Note from Dr. Gens

Summer SAR class Photo by Cheryl Katje

What an experience! From the feedback, we have concluded that there is a need for this kind of course and we hope to provide it again next summer.

In late June, we had a two-week summer course, SAR and InSAR: Principles and Applications. The rapid paced, two-week summer course was very intense. Nevertheless, it allowed people to learn about SAR and InSAR without taking a semester long course that may not be available at other universities.

The days of the course were divided in two parts: 1) lectures were held in the mornings and, 2) hands-on lab exercises filled the afternoons. During the first week, we covered SAR fundamentals, processing, geocoding, terrain correction and SAR applications. In the second week we tackled in-depth interferometry techniques including interferometric processing, interferogram generation, phase unwrapping, DEM generation and differential interferometry.

ASF welcomed guest lecturer, Richard Carande, of Neva Ridge Technologies, who provided an overview of SAR data and a glimpse of its current applications in research. ASF Engineering Manager, Jeremy Nicoll, introduced the class to our SAR training processor and its various functions. Additionally, presentations from the ASF and UAF research community, including Matt Nolan, Claude Duguay and myself, provided results of extensive research work that utilized a number of different SAR methods and applications.

We learned a lot from the students about their particular application backgrounds, spanning volcanology and glaciology to various forms of deformation measurement. The sessions were extremely interactive with a lot of questions, answers and interest in the processing aspects of SAR and SAR interferometry.

As the main instructor of the summer SAR class, and on behalf of ASF, I would like to thank the course participants (especially the 10 students that visited us from outside Alaska), collaborative guests and researchers whose contributions made the sessions a complete success.

Comparison of GPS and InSAR deformation measurements at Okmok volcano, Alaska *continued*

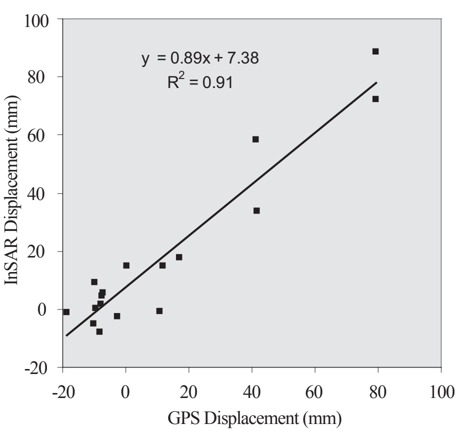

Figure 2: Comparison of displacement measurements between GPS and InSAR.

InSAR images were used to study transient deformation of the volcano before, during, and after the 1997 eruption at Okmok volcano. Spherical point-source models suggest that a magma reservoir, residing at a depth of 3-4 km below sea level and located beneath the center of the caldera and about 5 km northeast of the 1997 vent, is responsible for observed volcano-wide deformation: 1) surface inflation of more than 18 cm during 1992-1995 and subsidence of 1-2 cm during 1995-1996, prior to the 1997 eruption; 2) more than 140 cm of surface deflation during the 1997 eruption; and 3) 5-15 cm/year inflation during 1997-2004, after the 1997 eruption.

Figure 1, an interferogram spanning 2000-2002, is one of the interferograms with the greatest coherence. From this InSAR image one can infer several distinct deformation processes: 1) volcano-wide inflation due to replenishment of the shallow magma reservoir (i.e., the broad fringes across the whole caldera), and 2) deformation of the 1997 lava flows (i.e., the localized fringes over and around the 1997 lava flows).

Campaign GPS surveys were also carried out during 2000-2002 (Figure 1): the uplift of the caldera center relative to the caldera rim was about 9 cm during 2000-2002. These GPS surveys allow us to compare the GPS displacement vectors with InSAR deformation measurements.

To compare GPS displacements with InSAR measurements, we first referenced both GPS displacement vectors and InSAR observations to a GPS station FTGL (Figure 1). We projected the 3-D GPS displacement vectors into the deformations along InSAR line-of-sight direction. We then unwrapped the interferometric phase values and converted them into line-of-sight displacements. Figure 2 compares the line-of-sight displacements between GPS and InSAR measurements. In general, the two sets of observations agree with each other, with a correlation value of $r^2 = 0.91$. As only a single InSAR image is used in the comparison, atmospheric delay anomalies in the InSAR image may be one cause for the dispersion between GPS and InSAR observations.

Continued on page 4

Intern spends summer with ASF

by Steven Balistreri

After a winter of data calibration research and planning, the ASF Data Quality group geared up for a summer of new beginnings. The short season in Alaska provides suitable weather for numerous hardware maintenance, retrieval and deployment tasks. This year produced several elaborate creations that will move ASF data calibration into the years ahead.

Advances this year were made with the support of Ernst Weissbrodt, a student of electro-engineering from the University of Karlsruhe, Germany. Each spring, ASF welcomes an intern to assist with the added workload that includes building, improving and recovering remotely located data calibration equipment.

Weissbrodt arrived at ASF in late April, when Alaska's interior was still swept with snow. The schedule of summer projects included a slew of trips through Alaska, from Prudhoe Bay to Delta Junction. Along the way, Weissbrodt experienced his fair share of wildlife encounters including caribou, moose, buffalo, musk ox and brown bears.

Under the leadership of Wade Albright, the ASF Data Quality group focused work on advancing its hardware fleet. The portable reflector design ASF developed last summer has been revisited with a new, collapsible generation of 2.45-meter-trihedral corner reflectors. "Design research is an ongoing process" says Albright, "With the intention of utilizing corner reflector calibration methods for a variety of data types and applications."

Five 1.8-meter, portable reflectors were constructed to provide permanent scatter and tie points in remote locations that will likely include Chena Hot Springs and various Aleutian islands.

Deployment sites in Fairbanks and Cantwell, Alaska were developed to provide increased coverage supporting ScanSAR geometric calibration. In addition, a number of 3-meter reflector skirts, or extensions, were constructed and deployed to increase reflective surface area.

Although not all design projects make it into the field, the Data Quality group is always testing its boundaries. Weissbrodt was challenged to explore modifications that could improve the reflected signal of the trihedral design. This task included drafting and testing both alternative corner reflector configurations and an experimental conical reflector. "Initially I had my doubts," said Weissbrodt, "but after we had the prototype, I really wanted to see the results."

The work of ASF interns is often integrated into the everyday development

Ernst Weissbrodt Photo by Charles Slater

of calibration work. When it comes to projects like these, Albright says, "We often work with the extended university community and it always pays off." The mix of professional and educational resources at ASF is a bonus for interns and ASF alike. According to Weissbrodt, one of the benefits of working in a research institution is that the work is not entirely abstract, "It's a reward to see that at the end of all this theory there is a nice, working image for researchers to use."

Weissbrodt brought more than just enthusiasm to the table. Since 2004, Weissbrodt has been studying space electronics, telemetry and microwaves in relation to the German Aerospace Centre (DLR) TerraSAR X satellite calibration. "His experience significantly reduced the learning curve," according to Albright.

Weissbrodt toured other parts of the United States on his way back to Germany while ASF reviewed the conical reflector test results. Weissbrodt's methods and results will benefit ASF as the SAR community shifts toward polarmetric instruments in the years to come. Likewise, Weissbrodt will take more than lasting work experience back home, "I liked the contrast of being in the office, working on technical things like satellites and remote sensing, then being in the middle of nowhere, among bears and caribou on the weekend."

Next spring, the Data Quality group will be deploying five corner reflectors in the Amazon Rainforest in preparation for new calibration efforts. Read more about upcoming data calibration projects, corner reflectors and ASF internships at ASF on-line: www.asf.alaska.edu. u

Visiting Researcher Enjoys Alaska Fishing

Dr. Ken Jezek of Byrd Polar Research Center-Ohio State University, was a visiting speaker for the University of Alaska Fairbanks' Remote Sensing and Geographic Information Systems Seminar Course. His talk titled "Physical Properties of the Antarctic Ice Sheet Observed with RADARSAT-1" highlighted research results from RAMP (1997), MAMM (2000), and ongoing efforts. His presentation provided UAF students, faculty, and staff with recent results of Antarctic mapping.

Following 2 days of productive discussions, Jezek accompanied Don Atwood and Rick Guritz, both of

Ken Jezek Photo by Rick Guritz

ASF for an Alaskan fishing excursion on the Delta Clearwater River. Within minutes of casting, Jezek hooked the day's first of many silver salmon.

On the long drive back to Fairbanks, Jezek discussed his long-standing pursuit of the elusive maple leaf sAMMon for which he claims SARdines are the bait of choice. u

Comparison of GPS and InSAR deformation measurements at Okmok volcano, Alaska *continued*

Of course, the integration of GPS and InSAR goes beyond comparing the deformation values from each dataset. First, precise GPS positions can be used to improve InSAR baseline estimates (i.e., estimates of the spatial separation between satellite vantage points when the two images comprising an interferogram were acquired) and therefore, enhance deformation accuracy of InSAR images. Second, the perceptible water-vapor content retrieved from Continuous GPS (CGPS) networks presents an appealing opportunity for estimating atmospheric water-vapor content as a means to correct atmospheric delay anomalies in InSAR deformation measurements. By modeling and interpolating water-vapor values from CGPS measurements, the measurement accuracy of InSAR images will be improved. Innovative methods of comparing and integrating GPS and InSAR measurements will facilitate enhanced volcanic deformation mapping and provide a better understanding of volcanic processes.

More information about this work can be found at: Lu, Z., T. Masterlark, and D. Dzurisin, Interferometric Synthetic Aperture Radar (InSAR) Study of Okmok volcano, Alaska, 1992-2003: Magma Supply Dynamics and Post-emplacement Lava Flow Deformation, Journal of Geophysical Research, 110, B2, B02403, DOI:10.1029/2004JB003148, 2005; Yousuke M., J. Freymueller, F. Kimata, T. Sato, and D. Mann, Surface deformation caused by shallow magmatic activity at Okmok volcano, Alaska, detected by GPS campaigns 2000–2002, Earth Planets Space, 56, e290e32, 2004.

Submissions and Subscriptions

This newsletter, published by the Alaska Satellite Facility, was created to provide detailed information about special projects and noteworthy developments, as well as science articles highlighting the use of ASF data.

To receive the newsletter by postal mail, please fill out the subscription form linked to the ASF homepage at www.asf.alaska.edu. Current and back issues of the newsletter can also be obtained in PDF format through the ASF Web site.

Submissions to the *News & Notes* and suggestions about content are always welcome. If you are interested in contributing materials, please call or send an email to the editor:

ASF User Services
907-474-6166
uso@asf.alaska.edu.

Alaska Satellite Facility Office of the Director

Nettie La Belle-Hamer .... Director
Scott Arko .... Deputy Director

ASF Center Managers

Jeremy Nicoll .... Engineering
Don Atwood.................. Remote Sensing Support
Scott Arko .... Operations

Alaska Satellite Facility
UAF Geophysical Institute
903 Koyukuk Drive
PO Box 757320
Fairbanks, AK 99775-7320

www.asf.alaska.edu