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InSAR Captures Rifting and Volcanism in East Africa

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In the past decade, synthetic aperture radar interferometric (InSAR) has enjoyed increasing use as a tool for detecting and characterizing surface deformation associated with volcanoes, earthquakes, glaciers, and other geological processes. Though InSAR can only image deformation that occurs along the radar line-of-sight and is subject to atmospheric, orbital, and other errors that can be difficult to quantify, the method has the advantage of high spatial resolution (especially in arid, unvegetated environments) without requiring equipment on the ground. As a result, InSAR is extremely useful for mapping deformation in poorly accessible or unmonitored parts of the world.

One such area is the Kivu Basin of East Africa. Located along the border of the Democratic Republic of the Congo and Uganda/Rwanda, the Kivu Basin is part of the East African Rift System, an area of abundant volcanic and seismic activity that has formed as a result of tectonic extension between East Africa and the rest of the continent. The basin is the site of Lake Kivu and the city of Goma (population > 400,000), which lies on the northern shore of the lake. This population is at risk from two volcanoes; Nyiragongo and Nyamulagira. Nyiragongo's summit is only 18 km north of Goma and has been the source of eruptions of unusually fluid lava that caused hundreds of fatalities. Northwest of Nyiragongo, 15 km distant, is Nyamulagira volcano, a massive shield that erupts lava flows every 3 years on average, though seldom into populated areas.

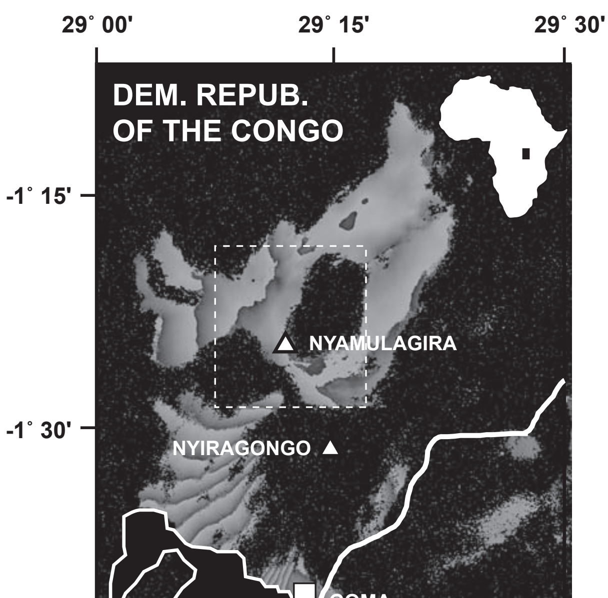

Figure 1 – RADARSAT-1 ascending mode 6 interferogram spanning December 31, 2001 to February 17, 2002. Inset of Africa in the upper right shows the location of the study area. The international border is shown as a white line, with the volcanoes as white triangles and the city of Goma as a white square. The dashed box shows the area covered by Figure 2.

On January 17, 2002, Nyiragongo erupted with little precursory warning. Cracks opened between the summit of the volcano and Goma, and within a few hours, lava had inundated a heavily populated portion of the city, entered the lake, and formed a small delta. The eruption was over by the next day, but about 15% of Goma had been destroyed, 70-100 people were killed (mostly by indirect causes associated with the eruption), and 120,000 left homeless.

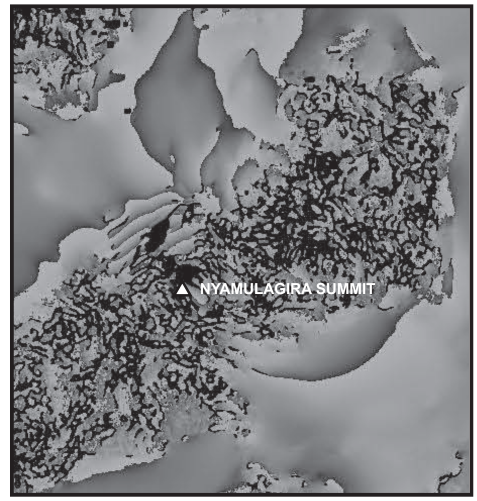

Figure 2 – RADARSAT-1 ascending mode 6 interferogram spanning February 17, 2002 to October 15, 2002. Localized interferometric fringes near the summit of Nyamulagira volcano indicate deformation associated with an eruption in August 2002.

Because there was little seismic monitoring and no terrestrial geodetic data (for example, from GPS), the cause of the eruption was difficult to assess. SAR scenes from RADARSAT-1 however, captured the region before and after the eruption. A comparison of numerous pre-and post-eruption scenes shows widespread deformation in the entire Kivu Basin, not just displacements focused in the vicinity of Nyiragongo (Figure 1). The InSAR-derived deformation is consistent with a pattern of tectonic rifting of the entire region and a model of the eruption (based on fracture patterns, eruptive chronology, geochemistry, etc.) that proposes rifting as a trigger for the activity. Magma contained in a summit lava lake, which had been crusted over since the late 1990s, apparently drained into a set of fractures that had last been active in 1977, mixed with fresh subsurface magma, propagated the fractures down the south flank of the volcano, and erupted at several points between the volcano's summit and Goma.

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Asymmetric Opening and Episodic Faulting in the Asal Rift, Djibouti

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Located at the western end of the Aden Ridge, the Asal Rift is the first subaerial opening segment of the ridge propagating into Afar (Fig. 1a). In November 1978, the rift was the locus of a major seismo-volcanic crisis producing a fissural eruption, 2 m of horizontal extension between the rift shoulders, 0.7 m of subsidence of the inner floor and a number of signs of ground deformation, including up to one meter of slip on large bounding faults and numerous open fissures (1-3). After the 1978 crisis, the rate of opening across the rift remained high (6±1 cm/yr) until 1987 and then returned to a value of ~1.5 cm/yr, comparable to the long-term plate motion. Small earthquakes (M<3) occur during crises lasting a few months but are generally not associated with visible movements on faults.

We used the interferometry method (InSAR) with RADARSAT-1 scenes acquired between 1997 and 2005 to survey the surface deformation field in the Asal Rift (Fig. 1b). The turbulent atmosphere in this subtropical region produces phase delay errors in the data exceeding the tectonic signal we seek. Data averaging and time series analysis allowed us to mitigate this signal.

A 2-component surface displacement field was constructed using interferograms from 15 ascending and 15 descending image pairs. We assume that the horizontal movement of the crust in and around the rift is approximately perpendicular to the main faults and solve for the ~N35°E horizontal and vertical components from radar observations along ascending and descending lines of sight. The average displacement field shows the following features (Fig. 2). A ~30 km-wide zone centered 4 km north of the rift axis is inflating at a rate of up to 8 mm/yr. The ~8 km-wide central rift subsides asymmetrically (down-tilted to the north) with respect to the rift shoulders as a result of slip on Fault γ to the north and Fault E to the south, both of which were active during the 1978 crisis. The horizontal velocity shows extension across the central rift at a rate of ~13 mm/yr, gradually decreasing in the far field. A local maximum of 16 mm/yr in the horizontal velocity occurs on the northern shoulder of the rift and coincides with the area of maximum uplift. This divergent velocity between both shoulders of the rift exceeds the 11 mm/yr, far field motion between the Arabia and Nubia plates (4), suggesting that magmatic activity is currently driving the opening of the Asal rift. Elastic models show that a 4 km-deep, dyke system, expanding both laterally and upward, combined with down-dip slip and horizontal opening of Fault γ and Fault F, accounts for most of the observed velocity across the rift.

The horizontal extension measured across the opening faults suggests that the sub-vertical faults at the surface have shallower dipping planes at depth. For example, the mean vertical throw rate on Fault E is ~1.8 cm/yr and its opening rate is ~3.8 cm/yr, indicating that the fault has a dip of ~26° at depth. Vertical throw and horizontal extension rates are approximately equal on Fault γ indicating a dip of ~45° for the deeper part of the fault.

We constructed an 8 year timeline of the surface deformation in the Asal Rift from the data acquired from RADARSAT-1 descending passes using the small-baseline subset approach (5). The time-series shows that slip rates on Faults γ and E vary in time with slow and steady creeping periods, interrupted by accelerated slip events of a few millimeters. These events are coeval with bursts of micro-earthquakes in the area of

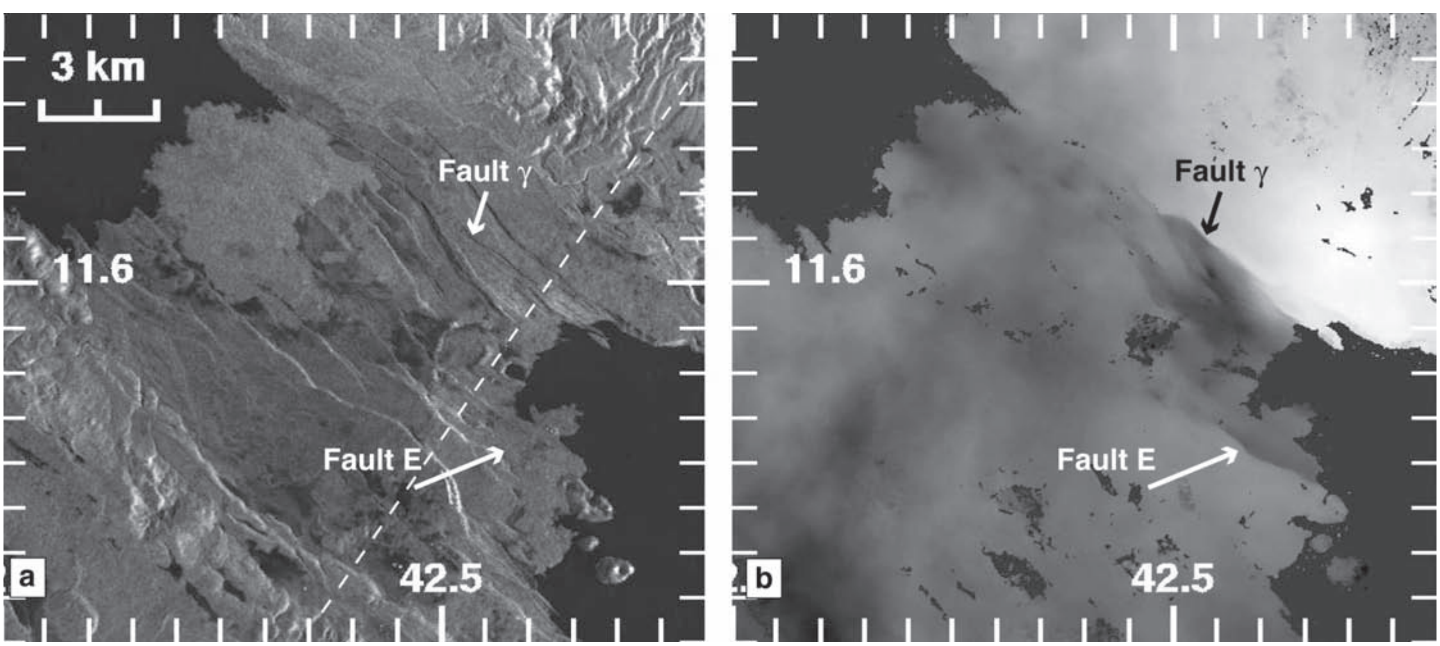

Figure 1: (a) Radar amplitude image of the Asal Rift, between the Goubbet Gulf (SE) and the Asal Lake (NW). Illumination is from the ESE on descending passes of RADARSAT-1. Prominent NW-SE fault scarps are visible on both sides of the rift axis. Dashed line indicates axis of profile shown in Figure 2. (b) Mean radar line of sight velocity of the ground obtained by averaging data from descending passes of the satellite. Grey shades range ~1 cm/yr from the darkest to the brightest tones.

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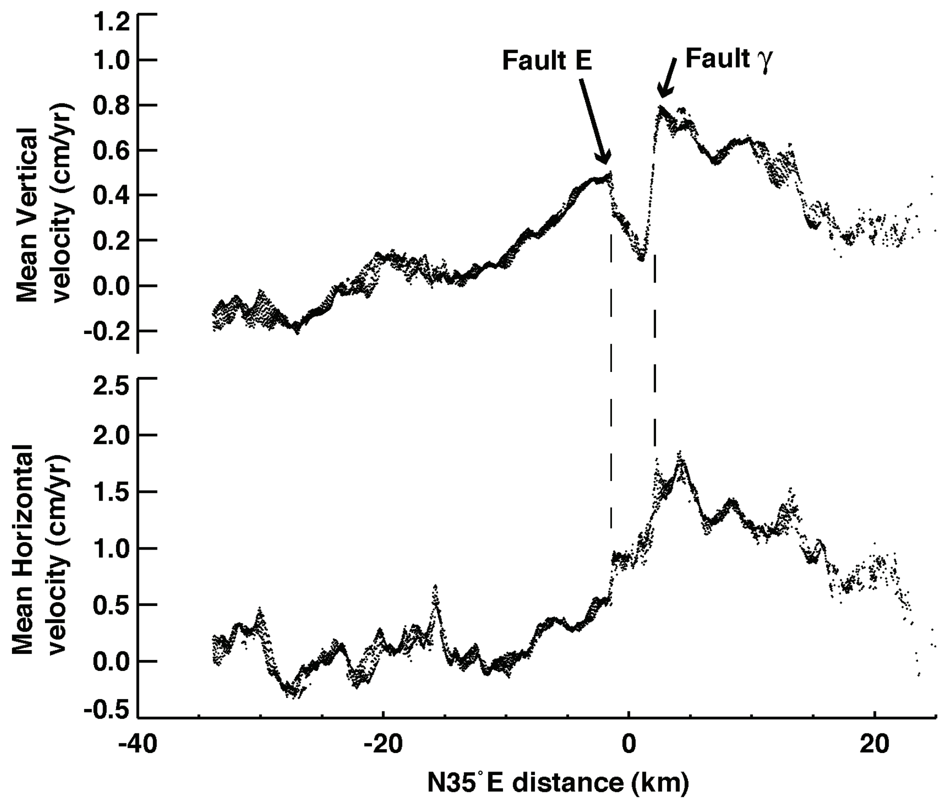

Figure 2: Horizontal (N35˚E) and vertical components of mean velocity field along profile line shown in Fig. 1. Note that profile extends beyond edges of Figure 1. Dashed lines are aligned with fault locations highlighting association between vertical throw on faults and horizontal opening of the structure.

the creeping faults, although the seismic moment released during these bursts is three orders of magnitude lower than a rough estimate of the geodetic moment associated with the slip events. This shows the aseismic nature of the slip events on Faults γ and E.

The coeval occurrence of fault-slip events and bursts of micro-earthquakes distributed around the slipping faults suggests that both phenomena respond to a sudden change in the stress condition in the upper crust. Fluid pressure changes in the magmatic/hydrothermal system can explain these observations. If the fluid pressure increases in the fissures connecting to faults at depth, it results in the decrease of the normal stress on the fault, hence bringing it closer to failure. In the extensional stress regime, prevailing in and around the rift, such pressure changes are likely to trigger small earthquakes and control aseismic slip events on normal faults.

These preliminary results demonstrate the interest of data averaging and time-series construction to track micro-deformation and fault-slip events associated with transient processes. Future work will include completion of a two-dimensional time series, including data from both ascending and descending passes and the development of mechanical models.

References:

(1) Abdallah, A., et al., Afar seismicity and volcanism: relevance to the mechanics of accreting plate boundaries. Nature 282, 17-23 (1979).

(2) Le Dain, A.-Y., Robineau, B. & Tapponnier, P. Les effets tectoniques de l'événement sismique et magmatique de Novembre 1978 dans le rift d'Asal-Ghoubbet. Bull. Soc. Géol. France 7, 817-822 (1979).

(3) Ruegg, J.-C., Lépine, J.-C. & Tarantola, A., Geodetic measurements of rifting associated with a seismo-volcanic crisis in Afar. Geophys. Res. Lett. 6, 817-820 (1979).

(4) Vigny, C., et al., 25 years of geodetic measurements along the Tadjoura-Asal Rift system, Djibouti, East Africa. In review for J. Geophys. Res. (2006).

(5) Berardino, P., Fornano, G., Lanari, R. & Sansosti, E., A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Trans. Geosc. Remote Sens. 40, 2375-2383 (2002). ◆

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Given the importance of the InSAR results for characterizing volcano-tectonic activity in the region (especially in the absence of other geodetic data), a program of regular InSAR monitoring of both Nyiragongo and Nyamulagira was initiated using RADARSAT-1 and ENVISAT SAR acquisitions. In the years since the January 2002 eruption of Nyiragongo, no further rifting events have taken place, and no deformation has been observed at Nyiragongo, despite renewed lava lake activity and episodes of intense seismic activity.

Nyamulagira volcano has erupted twice (in August 2002 and May 2004) since that time. In both instances, no pre-eruptive deformation has been observed in InSAR data, though co-eruptive deformation localized to the vicinity of the eruptive vent is apparent in image pairs that span the eruptions (Figure 2). Such deformation is probably associated with the shallow magma feeder system. The lack of precursory deformation suggests that magma rises quickly beneath Nyamulagira and that there is little, if any, months-long accumulation of magma in a subsurface reservoir.

Despite the fact that no deformation prior to eruptions has yet been detected in the Kivu Basin, it is important to continue the program of InSAR monitoring. The method is by far the most effective for measuring surface displacements in the region and offers the best chance of detecting any precursory deformation to future volcanism or tectonism, in addition to characterizing displacements associated with past activity. InSAR results from the Kivu Basin exemplify the utility of such data in understanding volcano-tectonic processes and argue for continued application in the Kivu Basin and elsewhere, especially where other deformation measurements are lacking. ◆

URSA Goes Live!

ASF's User Remote Sensing Access (URSA) became operational on April 28, after months of effort by a dedicated team of developers and testers.

The web site replaces the Level 0 order form for ordering Synthetic Aperture Radar (SAR) imagery from the European Space Agency's ERS-1 and ERS-2 satellites, the Japan Aerospace Exploration Agency's JERS-1 satellite, and the Canadian Space Agency's RADARSAT-1 satellite. Currently, only Level 0 data is available through URSA. However, Level 1 and unrestricted data products will become available in the future. The new interface streamlines the order process and allows real-time feedback to users about order status.

Come check out the new interface at https://ursa.asf.alaska.edu or click on "Get Data" off the ASF home page.

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