Volcano monitoring in the Virunga Volcanic Province, DR Congo

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Introduction:

The poster presents the efforts initiated in 2005 to contribute to the study and the monitoring of Nyiragongo and Nyamulagira volcanoes, two of the most active volcanoes in Africa located in the Virunga Volcanic Province (VVP) in Democratic Republic of Congo. Satellite radar interferometry (InSAR) proved to be the most reliable technique as, unlike the ground based monitoring systems, it does not suffers from interruptions resulting from the local insecurity, lack of infrastructure, geopolitical instability, or more natural causes like lightning or rodent. However, it is not continuous in time and ground based monitoring systems remain fundamental tools for the Goma Volcano Observatory. In 2008, we started deploying a network of 8 permanent real-time geodetic GPS receivers that helped to monitor the 2010 and 2011/12 Nyamulagira eruptions. Maintaining ground based networks is however a challenge in the specific socio-economic and political context of North Kivu.
InSAR and ground based measurements in VVP and South Kivu Volcanic Province provide tools for studying the continental break up along that portion of the East African rift and the related hazards.

The Nyamulagira 2010 eruption :

On January 2, 2010, Nyamulagira started to erupt after less than two hours of seismic precursors. Thanks to the numerous remote sensed data and the ground based networks, this is the most quantitatively documented eruptions of Nyamulagira (Smets et al., in prep.). Deformations were captured by InSAR from 8 look angles by 3 satellites. Deformations are best fitted with two dykes with two independent overpressures and a deflating sill-like reservoir below Nyamulagira caldera (Wauthier et al., in press). Seismic and tilt data confirmed the visual observations of 4 different phases of the eruption. Innovative multidimensional small baseline subset InSAR times series method allowed identifying unambiguous pre-eruptive deformations that started more than 2 weeks prior the lava outburst (Samsonov and d'Oreye, in press). Deformations measured by the permanent GPS network show a deformation pattern that contrasts with the deformations observed during the following 2011/12 eruption. Nyamulagira 2010 eruption ended on January 27.

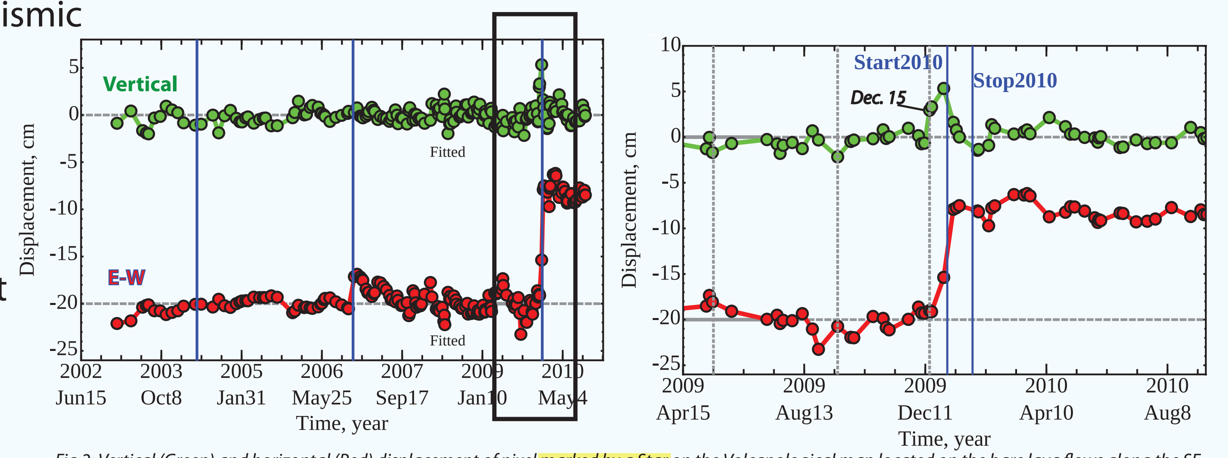

Fig 2: Vertical (Green) and horizontal (Red) displacement of pixel marked by a Star on the Volcanological map located on the bare lava flows along the SE flank of Nyamulagira. Displacements are computed using a novel InSAR Time Series method (adapted from SBAS method) that allow combining all SAR data acquired with different acquisition parameters, temporal and spatial sampling and resolution, wave-band and polarization (Samsonov and d'Oreye, in press).
Left: Displacement from January 2003 to September 2010. The 3 vertical blue bars mark the 2006, 2010 and 2011 eruptions. A linear trend computed between 2006 and 2010 eruptions was removed. Signals associated to the two last eruptions are visible. Black box around the 2010 eruption marks the portion of the Time Series that is enlarged in the Right panel.
Right: Unambiguous pre-eruptive deformations are visible up to 2 weeks prior the eruption. See the 3 vertical uplift reaching 2.9, 3.3 and 5.3 cm resp. on December 15, 17 and 29, which is about 4 to 6 times larger than the rms calculated for this particular portion of time-series.

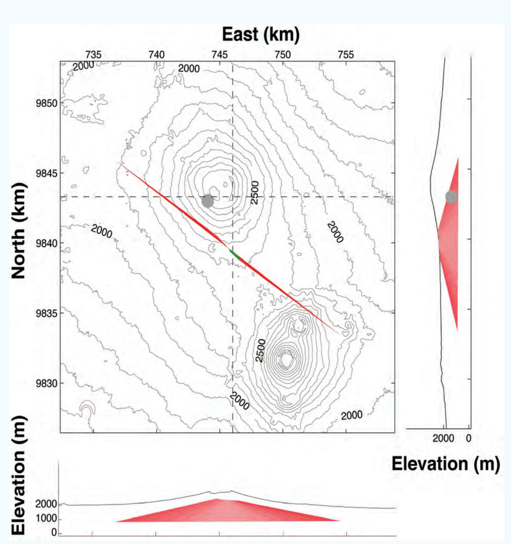

Fig 3: Geometry of the preliminary best fit model of a dyke intrusion (red) and an inflating reservoir (grey) associated with the 2006 eruptive fissures (in green). Dashed lines indicate the locations of the vertical cross-sections shown to the right of, and below (Cayol et al., 2010; Wauthier et al, in press).

The Nyamulagira 2006 eruption:

The first eruption since the systematic monitoring of the VVP by InSAR started on November 27th 2006 after 1.5 day of intense seismic activity. The deformations capture by satellite from 3 different look angles. At least two sources are needed to account for the observed deformation: one dyke extending below Nyamulagira and Nyiragongo (connected to eruptive fissure) and an inflating sill-like source or a spherical reservoir (Wauthier et al, in press). Preliminary models however only partially fit the observed deformation. Unfortunately no ground based deformation data were available. The eruptions lasted probably until December 5th 2006.

The Bukavu/Cyangugu seismic crisis :

On 2008 February 3, a Mw 5.9 earthquake occurred near the cities of Bukavu (DRC) and Cyangugu (Rwanda), on the southern tip of lake Kivu. It was followed by many felt aftershocks. A temporary local seismic network installed 5 days later recorded more than 700 aftershocks over the following 3 weeks. The seismic sequence killed about 40 people, caused > 1000 injured and > 5000 houses were destroyed. It is the second largest earthquake recorded in the Kivu basin. However, at the time of the main shock, no local seismic network was operating. InSAR allowed to accurately determine its source parameters and showed that opening in the South Kivu Volcanic Province is probably accommodated by slip along faults without assistance of magma, at least at shallow depth (d'Oreye et al., 2011).

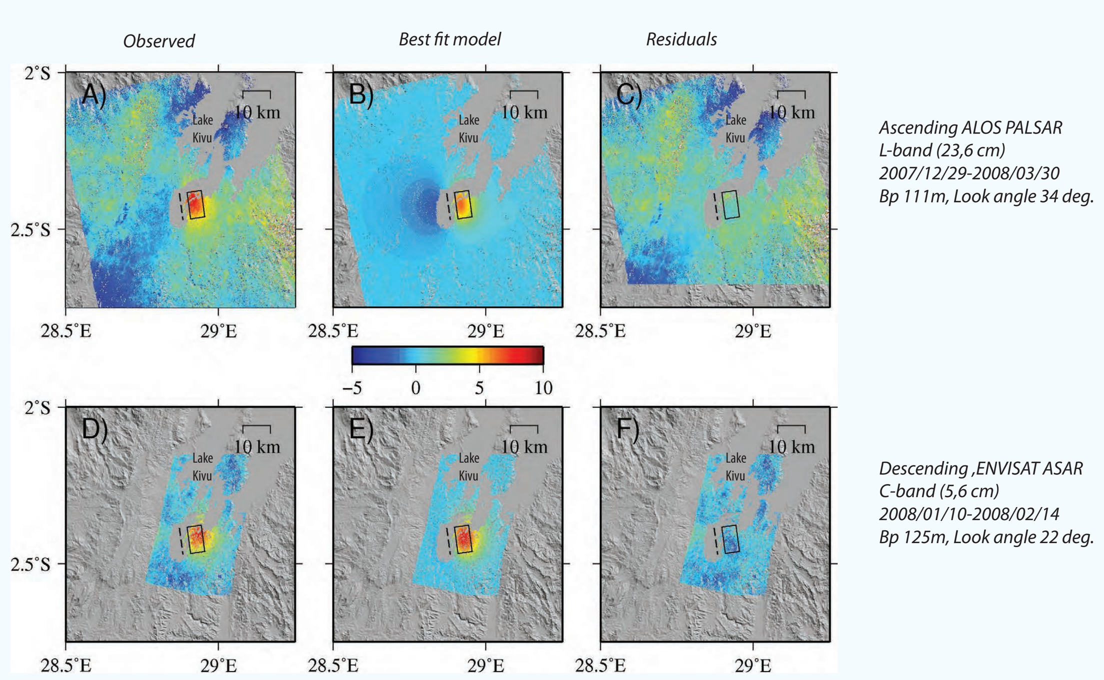

Fig 4: Coseismic ground deformation (range displacement – positive away from the satellite, in cm) associated to the 2008 Bukavu-Cyangugu earthquake measured by ALOS and ENVISAT InSAR data (A and D resp.). Corresponding best-fit models of a uniform slip elastic dislocation (B and E). The black solid rectangle indicates the projection of the fault rupture onto the surface and the dashed line shows where the fault, if lengthened, would cut the surface. Residuals are shown in (C and F).

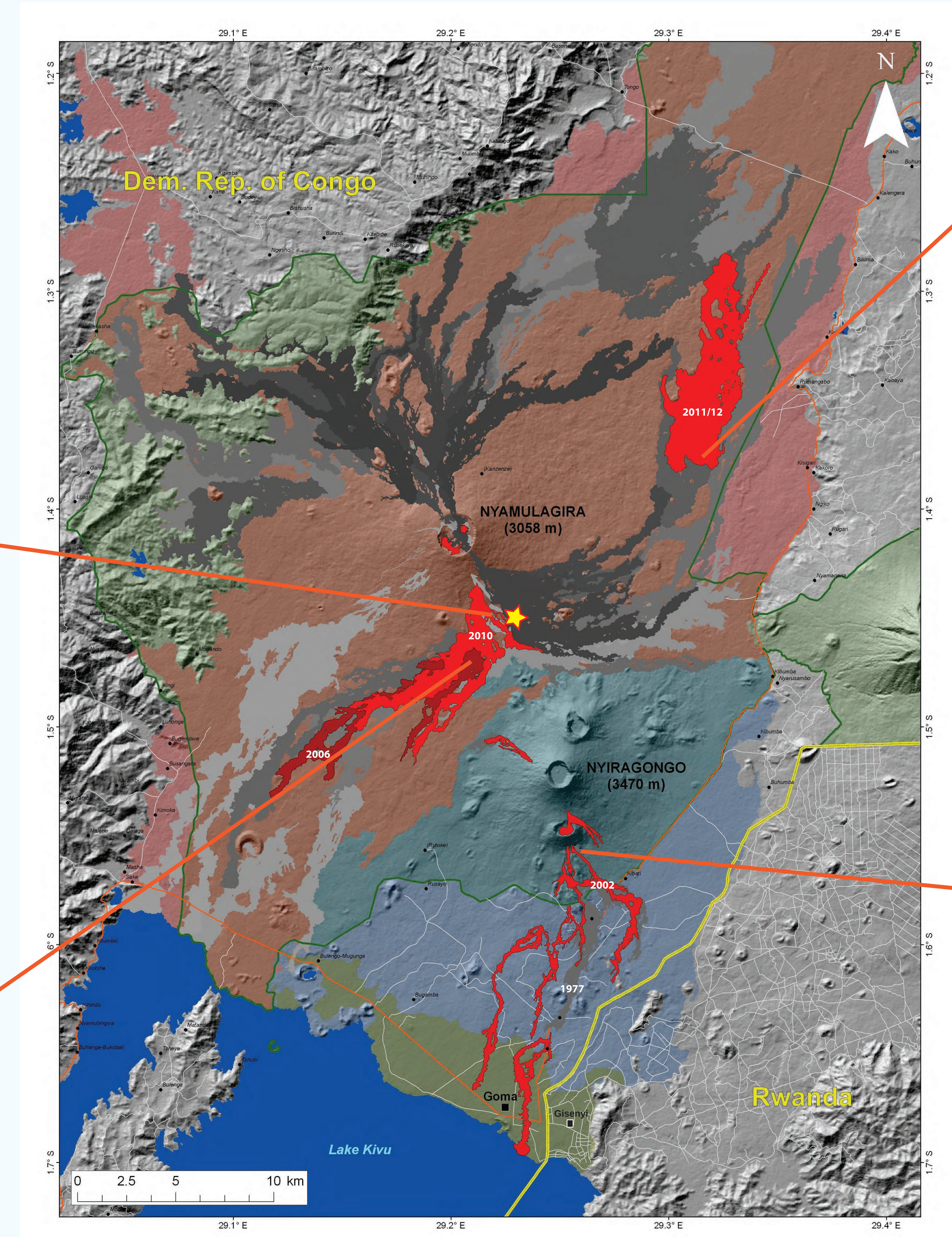

Fig 1: Volcanological map of Nyamulagira-Nyiragongo volcanoes (after Smets et al. 2010). The 24 eruptions of Nyamulagira from 1938 to 2004 are mapped in light to dark gray. The 3 last eruptions in 2006, 2010 and 2011/12 are mapped in red. The yellow star marks the zone close to the 2006 and 2010 Nyamulagira eruptive fractures for which the displacement time series are shown in Fig 2.
The only two known historical eruptions of Nyiragongo in 1977 and 2002 are mapped in light gray and red respectively.

The Nyamulagira 2011/12 eruption :

Nyamulagira volcano started to erupt on November 6th, 2011 after two days of intense seismic activity and ended 4-5 months later. Location, duration and erupted volume contrast with the previous recent eruptions. Deformations are captured by InSAR from 6 different look angles. InSAR data revealed more than 15cm and more than 50cm ground deformations respectively in the Nyamulagira main crater and at the two eruptive fractures located 12km to the N-E of Nyamulagira. Preliminary modeling of the InSAR deformations suggests that eruption started with the opening of a E-NE dike at the eruptive fractures and an almost NS diking intrusion below the summit crater. Preliminary weekly solutions from the GPS permanent network revealed a sustained subsidence at the Nyamulagira during the whole duration eruption.

Fig 5: Displacements (in cm) measured at the Goma Volcano Observatory permanent GPS station. Preliminary weekly solutions of displacements from May 1, 2011 to September 9, 2012 computed using Bernese 5.0 software. Vertical black line points the onset of Nyamulagira 2011/12 eruption that took place 35km to the North. Progressive Northward and downward movement is observed during the whole duration of the eruption.

The Nyiragongo 2002 eruption :

On 17 January 2002, Nyiragongo volcano erupted along a 20 km-long fracture network extending from the volcano to the city of Goma. The event was captured by InSAR data. The best model to account for the observed deformations involved a shallow dike and a deeper dike (see poster by Wauthier et al. this issue).
The low overpressures inferred (1–10 MPa) for these dikes are consistent with lithostatic crustal stresses close to the dikes and low magma pressure. As a consequence, the dike direction is probably not controlled by stresses but rather by a reduced tensile strength, inherited from previous rift intrusions. The lithostatic stresses indicate that magmatic activity is intense enough to relax tensional stresses associated with the rift extension (Wauthier et al. 2012).

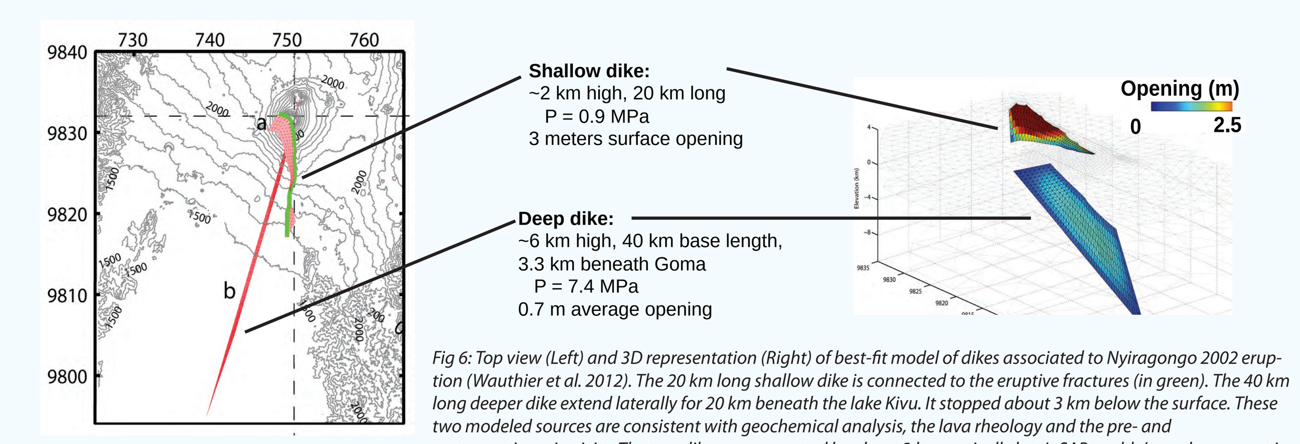

Fig 6: Top view (Left) and 3D representation (Right) of best-fit model of dikes associated to Nyiragongo 2002 eruption (Wauthier et al. 2012). The 20 km long shallow dike is connected to the eruptive fractures (in green). The 40 km long deeper dike extend laterally for 20 km beneath the lake Kivu. It stopped about 3 km below the surface. These two modeled sources are consistent with geochemical analysis, the lava rheology and the pre- and post-eruptive seismicity. The two dikes are separated by about 2 km vertically but InSAR couldn't resolve connection between both dikes.

Conclusions :

That portion of the East African Rift, and the Virunga Volcanic Province in particular, is a complex and highly active system as illustrated by the numerous recent and historical events. InSAR, and more recently GPS offer new opportunities to study that peculiar portion of rift zone. Combined to future structural and geomorphological studies (see poster by Kervyn and d'Oreye; this issue), ongoing research are contributing to address more fundamental questions like: what is the plumbing system below these volcanoes and what drives the magma storage within the active rift system; where and how does the strain accommodates during extension; what are the interactions between tectonics and magmatism; what controls the rift opening... Moreover, these fundamental questions are not limited to the specific context of VVP but are also of major interest for the study of the EAR and the rifting mechanisms in general.

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