Projects and current initiatives for scientific research and hazard assessment in the Albertine Rift

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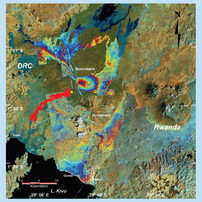
Available Remote sensing tools and products and ground based monitoring networks: a heritage from recent projects.

During recent research projects in the Albertine Rift, the essential support of Earth Observation data has been evidenced using optical and radar images, both at medium- and high-resolution. These images were used for various purposes ranging from mapping to monitoring applications. Radar interferometry (InSAR) more specifically is used for the monitoring and analysis of ground deformations associated to volcano-tectonic activity among others in the Albertine rift since 2005. Systematic SAR acquisition programs are implemented in the frame of various projects with European, Japanese, German and Canadian Space Agencies.
The gained experience evidences the need for such a systematic high frequency SAR acquisition program to support the ground-based observations and to improve preparedness. Such a systematic acquisition procedure provides enough SAR images to increase the chances to produce interferograms with temporal and geometrical baselines small enough to overcome the rapid decorrelation induced by the vegetation that affect equatorial regions such as the Kivu basin.
But remote sensing must be supported by ground based monitoring networks. Various instruments (GPS, CO2 and Radon, tiltmeters…) were deployed in the Goma-Nyiragongo area in the Virunga Volcanic Province since 2007 in the frame of the "Gorisk" project. We present hereafter these ground based and remotely sensed tools inherited from previous projects and that constitute the springboard for ongoing and future research activities.

Satellite Radar Interferometry

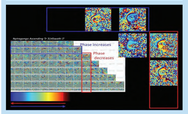
As illustrated with various recent events (see poster by d'Oreye et al.; this issue), **InSAR proved to be an efficient tool** for studying volcanic and tectonic events related to the rifting activity. See for instance how it helped to better understand the mechanisms that led to the Nyiragongo 2002 destructive eruption (see poster by Wauthier et al.; this issue; Wauthier et al., JGR 2012), or helped to the monitoring of recent Nyamulagira eruptions (Wauthier et al., GSL, in press; Cayol et al. 2010…), or to accurately determine the source parameters of the 2008 Bukavu/Cyangugu Mw 5.9 earthquake (d'Oreye et al., GJI 2011) and provide hypothesis on the opening mode of that portion of the rift.
These results could be achieved despite the equatorial vegetation thanks to the systematic SAR imagery acquisition procedure.



Interferogram showing deformations associated to 2006 Nyamulagira volcano captured by Envisat. Star marks the location of eruptive center and lava flow is mapped in red. Only one pair of image in one acquisition geometry has a geometrical and temporal baseline small enough to partly overcome the decorrelation induced by the vegetation to the South West of eruptive center.

The large amount of data acquired in the frame of these **systematic acquisition** procedures also required/offered the possibility to develop tool both for methodological development and for additional studies of past events. See for instance here after the frame about the "**InSAR data mining web tool**" that is more than a visualization tool (d'Oreye and Celli, 2010).
An **innovative time series technique** based on SBAS method was also developed (Samsonov and d'Oreye, GJI, in press). It integrates multiple InSAR data sets for computation of 2D or 3D time series of deformation. It allows combination of all possible SAR data acquired with different acquisition parameters, temporal and spatial sampling and resolution. Produced time series have combined coverage, improved temporal resolution and lower noise level. The technique was applied to SAR data acquired by ENVISAT, Radarsat-2 and ALOS starting from 2003 to 2010 over the Virunga Volcanic Province. Produced horizontal and vertical time series of ground deformation clearly identify lava compaction areas, long term deformations of Nyamulagira and 2004, 2006 and 2010 pre- and co-eruptive deformation (see poster by d'Oreye et al.; this issue).

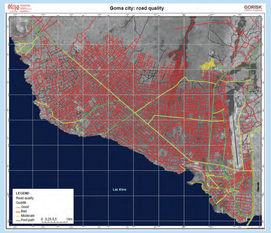
InSAR data mining web tool



For the need of volcano monitoring in Africa, all possible ENVISAT ASAR data for a given set of Modes, Tracks and Swaths were acquired. These data were processed using a (semi-) automated procedure based on the DORIS InSAR open source software (TU Delft), Mathematica© routines and shell scripts running on Mac OS X environment. This mass processing produces thousands of phase interferograms, coherence maps, amplitude images and deformation maps (in cm). The results are available as Sun-Rasters in radar geometry or as geocoded images in conventional GIS format (ENVI© or GMT grid). A web-based tool was developed for visualizing the rapidly increasing number of classical differential SAR Interferograms (InSAR) and related products (d'Oreye and Celli, 2010). More than a simple visualization tool, it also helps to easily discriminate artifacts from deformations, deformations, to detect seasonal variations or continuous slow phenomena (Heleno et al., 2010), or to detect timing errors or frame shifts. Eventually potentially interesting interferograms, identified thanks to this bulk procedure are re-processed using manually fine-tuned parameters. The tool will be adapted for further background campaigns (using any available SAR sensor) and is also useful for crisis management.

High resolution optical imagery

High resolution optical imagery is of limited use as a systematic monitoring tool because of the frequent cloud screen and the volcanic plume. It is used however for mapping purpose.
The city of Goma is expanding very rapidly often disregarding urban rules. This of course is a major concern for risk management. A new map was produced with Ikonos imagery and field control. Road quality was classed for emergency plan purpose. That map is continuously updated.

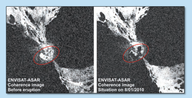


GIS and mapping tools

The same large SAR database available today constitute also an invaluable tool for mapping, regional studies, and crisis management support.

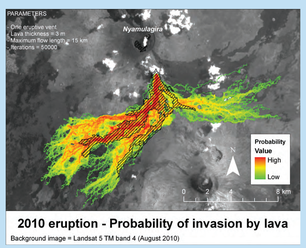
Combined to optical (ASTER and Landsat) images, the SAR archives allowed to map the recent Nyamulagira eruptions from 1938 to 2012 (Smets et al., JAES, 2010). The results are integrated into a Geographical Information System (GIS) and coupled with additional data sources. GIS use makes the new database a flexible – and easy-to-update – tool for scientific purposes as well as for risk, environmental and humanitarian management.

SAR images also offered useful tools to study the various phases of eruptions and mapping eruptive centers and lava flows. In support for crisis management this is particularly useful in the VVP environment where security issues and cloud covers often prevent visual observations and efficient situation assessment.



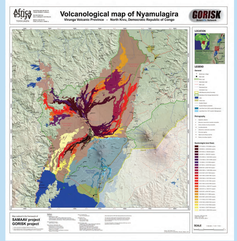
This figure illustrates the detection (thanks to correlation change) of unsuspected lava flows in the caldera during the 2010 flank eruption. Such information is essential for the monitoring but also for analysis of the source mechanism.

Accurate eruptive center location is a prerequisite for lava flow modeling and probability of invasion mapping. When that information is available, such mapping are performed and are used among other to inform local partners and contribute to regular progress reports posted on our web-page (http://www.ecgs.lu/gorisk/)

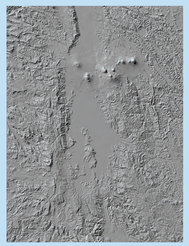


2010 eruption - Probability of invasion by lava
Background image = Landsat 5 TM band 4 (August 2010)

Lava flow probability modeling for Nyamulagira 2010 eruption in green to red colors (resp. low to high probability). Contour of the flow that emplaced during the 3 weeks long eruptions is hatched in black.



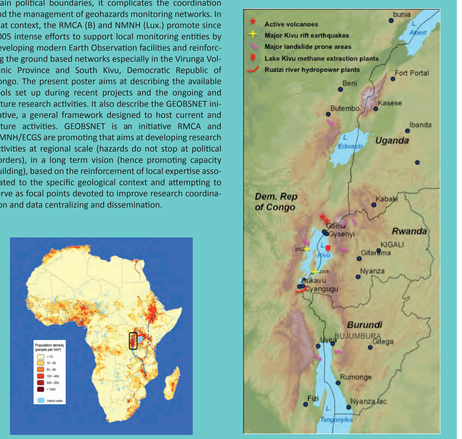
Volcanological map of Nyamulagira and Nyiragongo volcanoes (Smets et al. 2010). The only two known Nyiragongo eruptions in 1977 and 2002 are mapped in dark and light blue respectively. The 25 eruptions that occurred at Nyamulagira from 1938 to 2006 are mapped in yellow to brown colors. The two more recent eruptions (2010 and 2011/2) were mapped, integrated in the GIS, and used for crisis management (see contour of the flows in poster by d'Oreye et al. this issue).



Derived products like new generations of high resolution DEM (see "Vi-X project" frame) are used for various applications: lava flow modeling, geomorphological and structural studies etc..

ABSTRACT

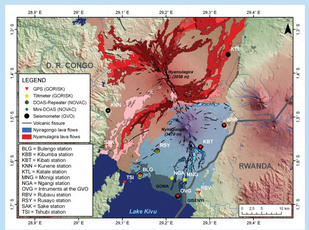
In some places, geo-hazards are a major concern both for life and local to regional economy. This is especially the case in the East African Rift (EAR), where high volcanic and tectonic activity is sometimes combined with socio-political issues and dense population. The Kivu is a perfect example of that. This area is one of the most densely populated regions of Central Africa and is affected by decades of political instability and subsequent humanitarian crisis. Geohazards in Kivu are poorly assessed despite the numerous recent and historical events. As the relief of the rift in this area defines the main political boundaries, it complicates the coordination and the management of geohazards monitoring networks. In that context, the RMCA (B) and NMNH (Lux.) promote since 2005 intense efforts to support local monitoring entities by developing modern Earth Observation facilities and reinforcing the ground based networks especially in the Virunga Volcanic Province and South Kivu, Democratic Republic of Congo. The present poster aims at describing the available tools set up during recent projects and the ongoing and future research activities. It also describe the GEOBSNET initiative, a general framework designed to host current and future activities. GEOBSNET is an initiative RMCA and NMNH/ECGS are promoting that aims at developing research activities at regional scale (hazards do not stop at political borders), in a long term vision (hence promoting capacity building), based on the reinforcement of local expertise associated to the specific geological context and attempting to serve as focal points devoted to improve research coordination and data centralizing and dissemination.



The Kivu rift is a one of the most densely populated region of Africa. Major geohazards like volcanoes, earthquakes, and mass movements are affecting that area and are often combined. They are strongly impacting populations and infrastructures on the long term.

Ground based operating networks

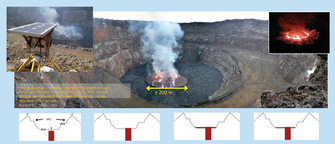
In the framework of the GORISK project (van Overbeke et al., 2010), ground based networks have been implemented in complementarity with the space borne ground deformation measurements. Based on the experience, results and outputs of the GORISK project, the scientific consortium carried out various self supported researches under the name of "The GORISK network".
Subsequent ongoing projects are now designed to match a more global (thematically and geographically wider) approach encompassing multi-hazard monitoring at a regional scale (see GEOBSNET frame, this poster).



Ground based monitoring networks installed in the frame of the GORISK project.

Monitoring the lava lake level fluctuations: Space borne and ground based methods

The monitoring of the lava lake fluctuations is therefore a very important parameter to monitor. In the frame of the Nyalha project, a permanent Stereographic Time-Lapse Camera (STLC) system has been installed into the crater in order to correlate field observations of the lava lake activity with physical and chemical parameters.
A space borne technique is also developed in the framework of the Vi-X project (see Vi-X frame, this poster).



The lava lake is contained in a central pit. Its level can increase or decrease of several tens of meters within few 10's minutes. The successive lava overflows progressively raise the platform level. It is suggested that a certain threshold exists above which the pressure is too high and the lava lake drains out through fissures in the flank of the volcano.

Ongoing research projects and the GEOBSNET initiative framework.

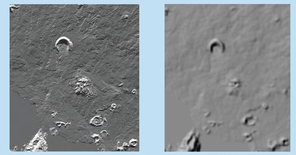
GEOBSNET initiative concept aims at developing a regional network of focal points/geo-observatories dedicated to study and monitor key parameters and disseminate information linked to geo-risks. As such it represents a way for federating more efficiently sustainable research activities in the related domains.
The ongoing projects such as **Vi-X**, **GeoRisCA, Nyalha** as well as future efforts for **capacity building** (in prep.) are all designed to match GEOBSNET objectives. **Other ongoing projects** currently addressing closely related geo-risks or addressing similar geo-risks in neighboring countries may benefit from that collaborative approach as it is already the case with some of them.

The Vi-X project: Study and monitoring of Virunga volcanoes using Tandem-X

The Vi-X project aims at assessing the use of TANDEM-X data for the study of Virunga Volcanic Province (VVP) and the monitoring of the active volcanoes.

High Resolution TANDEM-X DEM

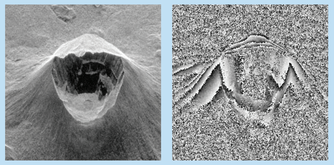
High resolution digital elevation models allow new geomorphological interpretations and the production of volcano-structural maps.



The figure displays the comparison between the TANDEM-X DEM (left) and the SRTM DEM (right) of the Rumoka volcanic cone area. High resolution DEM provides additional information such like lava flows contours. Recent unknown cones -post SRTM- have also been detected.

Split-Band SAR Interferometry

The SBInSAR technique is developed as a new tool to monitor the lava lake level rise in the Nyiragongo crater.
Range resolution of SAR images is a function of the emitted radar signal bandwidth. Most recent SAR sensors use wide band signals in order to achieve metric range resolution. By comparison, ENVISAT or ERS sensors used 15MHz bandwidth chirps while TerraSAR-X or Cosmo-SkyMed use nominal signals having 150MHz bandwidth leading to a potentially ten times higher range resolution.
SBInSAR is a technique taking advantage of the wide bandwidth offered by most recent SAR sensors. The wide band can be subdivided into sub-bands: Each sub-band is centered on its own central carrier frequency. When performing an inverse Fourier transform of sub-bands, each one leads to a SAR image of lower resolution when back into the image space.
Through linear behaviour of the interferometric phase with respect to carrier frequency, one may extract absolute interferometric phase on a point-by-point basis. In the case of InSAR, this allows getting coherent elevation measurements between unconnected zones. In case of DInSAR measurements, it allows getting absolute displacement measurement of single scatterer.



Other International/national projects

-EAGLES - East African Great Lake Ecosystem Sensitivity to changes: Coord.: University of Namur (Belgium)
- Double diffusion: (Coord.: EAWAG - Swiss)
- Lake sediments and sub-aquatic sources (Coord: EAWAG - Swiss)
- MacArthur foundation grant for the collect of scientific measurements for benchmarking hazards threatening biodiversity in the Lake Kivu Region (Rwanda)

A regional approach to address the geohazards globally

GEOBSNET: A regional network dedicated to geohazards

Based on the experience acquired in Africa in the field of geohazard assessment, a new initiative has been designed and is currently discussed with the national authorities and stakeholders of the countries involved (Rwanda, DRC, Burundi; Uganda and Tanzania for a later stage) to improve the regional coordination and to setup a network of geobservatories: GEOBSNET.

The major motivating factors are:

- the high density of population
- the convergence of numerous major geohazards
- the severe gap in long baseline of monitoring systems with continuous measurements
- that the geohazards are crossing political boundaries
- that scientific activities are often isolated

The main objective of GEOBSNET are therefore:

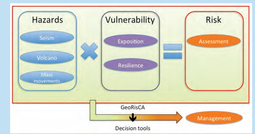
=> Facilitate through a global approach the study of the past events
=> Monitor and record the present-day evolution through key-parameters over long and continuous periods
=> Serve as focal points devoted to improve research coordination and data centralizing and dissemination
=> Serve as regional training and information centers for geo-hazards related matters
=> Foster research in this complex matter, preferring an integrated approach to a succession of isolated initiatives
=> Foster international cooperation and the development of local scientific knowledge and excellence.

That global approach is currently under discussion at technical level between existing entities and at political level in the three countries. The concept is intended to be used as a framework and tool for designing new proposals for research projects, and therefore create a coherent ensemble of coordinated activities

The GeoRisCA project (Georisks in Central Africa; 2012-2016) illustrates this: it has been designed to globally assess the risk (volcanic, seismic, mass movements…) taking into account both the hazards and the vulnerability of populations. Such a global initiative is complemented with more specific research projects like Vi-X (Study and monitoring of Virunga volcanoes using Tandem-X; 2012-2014).

GeoRisCA — GeoRisCA: Assessing the global georisks in the Kivu rift area

GeoRisCA is a 4 years project (2012 - 2016) funded by the Belgium Ministry of Research. It aims at assessing the risk related to the major geohazards (volcanoes, earthquakes, mass movements) in the North Tanganyika - Virunga rift region. The global risk results from the combination of the hazards assessment with the assessment of the vulnerability of populations and assets; this therefore provides the project with an important societal dimension.



The assessment of the global risk is performed through the assessment of the major hazards combined with the assessment of the population vulnerability that is characterized by the exposure and the adaptation capacity (or resilience). The project does not perform risk management but instead provide tools to improve decision making processes (risk maps, hazard maps, vulnerability maps, recommendations, models, methodologies…).

The assessment of the global risk is performed at two different scales: regional using existing data and local at pilot sites using existing data and by deploying field surveys. At both scales, the interaction with local stakeholders is strongly required.

Three pilot sites have been selected:

Bujumbura (Burundi) and Bukavu (DRC): major mass movement (landslides, erosion) are directly or indirectly threatening the development of those rapidly growing cities.

Goma (DRC): The city leaves under the direct threat of the Nyiragongo active volcano lava flows.

GeoRisCA consortium:

Royal Museum for Central Africa, Dept. of Geology & Dept. of History (Belgium)
Free University of Brussels (ULB), Dept. of Geography (Belgium)
Free University of Brussels (VUB), Dept. of Geography (Belgium)
University of Liège (ULg), Dept. of Geology (Belgium)
European Center of Geodynamics and Seismology (Luxemburg)

Major local stakeholders:

DRC: Goma Volcano Observatory, Université Officielle de Bukavu, Instit. Sup. Pédagogique de Bukavu, local authorities (urban planning, environment, cadaster…)
Burundi: Université du Burundi, Civil Protection, local authorities
Rwanda: Energy, Water and Sanitation (EWSA) , Geological Dept., Ministry of Disasters and Refugee Affairs (MIDIMAR)
Regional: Communauté Economique des Pays des Grands Lacs (CEPGL), Development Cooperation agencies, private sector (energy)

CONCLUSIONS

The rift region of the Kivu basin is densely populated and affected by various geohazards. The ground based monitoring is complicated by political instability, making the Earth Observation data essential for mapping and monitoring applications.
Built on >8 years of experience in research activity in a very difficult context it appeared that a global approach is essential. Long term perspectives requires the local capacity building and technique appropriation to ensure the sustainability of the deployed efforts. For that reason ongoing and future projects are all designed to match the GEOBSNET initiative concept.

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