Monitoring of volcanic activity in the Goma region (N-Kivu, Democratic Republic of Congo) and mitigation of related risks by both spaceborne and ground-based techniques: experience of the GORISK project.

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1. Introduction

The Nyiragongo and Nyamulagira volcanoes, which are amongst the most active in Africa, are sources of several hazards that threaten the region of Goma (N-Kivu, D.R. of Congo). The Nyiragongo eruption that occurred in January 2002 produced spectacular lava flows that destroyed about 15% of the city of Goma. Although the amount of casualties was limited, hundred thousands of inhabitants were forced to evacuate in difficult conditions, which added more pressure in a highly politically sensitive area.

This paper presents an overview of the ongoing “GORISK” project. Launched in 2007, GORISK is a multidisciplinary project involving scientific teams from Belgium, Luxembourg and Italy and 3 local DRC end users (the Goma Volcanological Observatory - GVO, the Belgian NGO CEMUBAC active in public health and the United Nation Risk Management Unit in Goma - UGR) and is oriented towards the implementation and improvement of ground-based and spaceborne tools for volcanic risk and health impact assessment. The main activities are the monitoring of ground deformations, the sampling, the analysis and the monitoring of geochemical parameters in water and gas vents, the study of the volcanic plume dispersion and its possible impact on human health, the updating of the map of Goma and the implementation of a GIS platform integrating all the results.

2. Ground Deformation Monitoring

The ground deformation monitoring is addressed by both spaceborne (InSAR) (Figure 1) and ground based techniques. A network of 5 telemetered tiltmeters has been installed in the frame of the project (Figure 2). A geodetic GPS network of 7 permanent stations (loaned by the National Museum for Natural History) is under development. This complements the existing seismic network installed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV, Italy) after the 2002 eruption and maintained by the Goma Volcanological Observatory, providing a (near)-real time monitoring with continuous and high resolution measurements.
Figure 1: ground deformations associated with the January 2002 eruption of the Nyiragongo. Deformation interferogram (time span: 6th September 2000 to 3rd July 2002) wrapped on the colour-coded SRTM digital elevation model. The 2002 eruption produced a 15km long network of fractures (yellow lines) and two of the lava flows (in plain red) intruded into the city of Goma. Each fringe (one full colour cycle) represents a 2.83 cm ground displacement (or range change) in the satellite line of sight (LOS). Note that the dense vegetated areas that are decorrelated (absence of interferometric significant signal) had been masked. Narrow fringes in the Goma area, indicating a range increase, correspond mainly to subsidence with a maximum ground displacement of about 15 cm in LOS. Symbols mark the location of the permanent stations networks.
Figure 2: Example of tilt records at Rusayo station from July 2007 to October 2007. Curves from top to bottom: Supply voltage (volts); acquisition system (green, °C) and tilmeter temperature (red, °C); North-South tilt (µRad); West-East tilt (µRad). One can clearly identify the daily ~1 Volt charge/discharge cycle of the solar power supply, the daily temperature variations of ~5 degrees inside the station damped to ~2 degrees within the sensor, and the diurnal tilt cycles. Large amplitude steps on the tilt records are related to drift corrections applied by the operator while spikes are earthquakes signatures. Data are transmitted automatically to the GVO by mobile phone.

The capacity to detect efficiently ground deformations by InSAR in densely vegetated volcanic environment has been evidenced by previous works [1]. The systematic InSAR monitoring of the Goma region is performed using ENVISAT ASAR data acquired in a routine mode (~ one acquisition per week). The hundreds of satellite radar images (including ERS archives) have been processed and more than 1400 interferograms have been computed out of that ~15-years long database with the open source DORIS software [2]. As a result, ground deformations associated to the Bukavu 2008 Mw 5.9 earthquake [1, 3] and to the most recent eruptions of the Nyiragongo (2002) and Nyamulagira (2002 and 2006) were successfully detected (figure 1) and studied into details [4, 5]. For example, concerning the 2002 Nyiragongo eruption, preliminary modeling studies show that a dyke and a normal fault can explain most of InSAR data close to Nyiragongo and city of Goma [1, 4].
3. Geochemistry and Health

Monitoring water quality and gas emanations from the sub-surface involves a network of 3 continuous Radon and CO$_2$ measuring stations and the sampling and analyses of both water and gas.

Special attention has also been paid to the study of *mazuku*, these dry and cold-ambient CO$_2$-rich gas vents that correspond to depressions where carbon dioxide, being heavier than air, accumulates by gravity at high – often lethal – concentrations (figure 3). Abundant in Goma and its vicinity, and more generally in the area South of Nyiragongo and Nyamulagira volcanoes, *mazuku* are known since a long time [6, 7 & 8]. Yet the process of formation had never been studied in detail and scientists still debate about their origin. However, fieldworks allowed us to distinguish some preferential areas where gas escapes from the ground and accumulates. Geochemical studies on gas isotopes (C and He ratios) are also performed to understand the origin(s) of gas and highlight or not a relationship with the volcanic activity. *Mazuku* are also a serious hazard. People are killed by gas every year and given the important demographic and urban growths of the region of Goma coupled with the current insecurity situation that cause sudden migration of population, the risks associated to *mazuku* are increasing accordingly. A location map with all known *mazuku* areas was produced as a tool both for scientific studies and risk management.

![Figure 3: CO$_2$ concentration (%) in mazuku in the Goma area - the graphic shows that more than 98% of surveyed mazuku exceed the deadly concentration level at ground surface for a short term exposure [7].](image)

Epidemiological data are studied to assess the possible impact on health of the volcanic activity and especially the influence of the permanent SO$_2$ plume emanating from the Nyiragongo and the episodic plume of Nyamulagira. To achieve this objective, GORISK takes benefit from the ongoing EU-FP6 project NOVAC [9] and US-NSF project ViSOR [10] that are focused respectively on ground-based and
spaceborne monitoring of the volcanic gas plume. VISOR provides SO\textsubscript{2} dispersion maps created from OMI satellite sensor, whereas NOVAC uses DOAS systems for SO\textsubscript{2} concentration measurements from the ground. Health data are provided by the Belgian NGO CEMUBAC and are gathered in health centers scattered all over the province in both plume-prone and plume-free areas. These quarterly data include four pathologies (breath disease, skin and eye infections and diarrhea) for 2 age categories (<5 years and ≥ 5 years). The SO\textsubscript{2} dispersion maps are put together with these epidemiological indicators of water or air related diseases in order to attest for a possible relationship between volcanic activity and human health. Such a correlation is nevertheless not always clear and the preliminary results are evidencing that other parameters such as sanitary conditions, urban pollution, meteorological data and access to health centers need to be taken into consideration.

4. Map updating

Until recently, the map for the urban area of Goma did virtually not exist. There is an archive map created in colonial time when Goma was still a very small locality but it strongly contrasts with the size of the actual ~5 to 700.000 inhabitants city. A new map was created locally by an NGO project [11] based on Quickbird image dated from February 2005. But since then important demographic movements related to unstable political situation and to the war were responsible for rapidly increasing urban growth. Acquisition of STEREO PRECISION IKONOS images was planned at the beginning of the project but remained unsuccessful because of the poor visibility due to atmospheric conditions. As an alternative, we acquired recently archive non-stereo IKONOS images dated from June and July 2008. Differential GPS field measurements for ground control point acquisition were performed in order to orthorectify the images and the digitalization of the urban area has started.

5. GIS platform

The implementation of a tool with analysis capability to support the data interpretation is realized through the integration of all the collected data into a GIS platform. Data are stored into a common database that can be exploited by the local end users. It contains base maps created through other initiatives, the GORISK layers associated to instruments records (tilt, GPS, geochemistry,…), the InSAR deformation and coherence maps, the updated map of the urban and infrastructure networks and the epidemiological data.

6. Training

To ensure the sustainability of the methods and to improve the capacity building of the end-users, seminars have been organized in Goma during field campaigns by the different European partners to train local staff to the maintenance and use of the tilt- and GPS-networks, to some GIS and InSAR basics as well as to the collection of water and gas (mazuku) and to the recovering of the Rn/CO\textsubscript{2} data.

One member of GVO and one member of UGR spent four months (Sept. – Dec. 2007) at the Royal Museum for Central Africa (RMCA) to be trained in GIS and remote sensing.
7. Conclusion
During the past two years, we improved the ground-based deformation monitoring tools by installing real time permanent GPS and tiltmeters networks. However these networks, as well as the seismic and geochemical networks and the fieldwork campaigns, suffered from serious problems related to the local, economical, security and political context. Looting episodes, inaccessibility to stations and to the field because of the war, records interruptions due to unexpected station dismantling, power supply and data transmissions interruptions are indeed so many factors preventing the continuous data collection.
On the other hand spaceborne techniques proved to be the most reliable tool for long term and systematic studies in that specific and unfavorable context. However spaceborne methods cannot replace ground based monitoring for early warning purposes to mention the least.

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9. References


