

GSNL Proposal for Permanent Supersite

A.1. Proposal Title: “Virunga Volcanoes Supersite”

Abstract:

The Virunga region is situated between Lake Kivu and Lake Edward in Eastern Africa, on the border of Democratic Republic of the Congo (RDC), Uganda and Rwanda. The Virunga is characterized with very fertile mountainous lands under a tropical climate where live millions of people grouped in cities and villages, and is additionally home for several unique wild animals such as the famous mountain gorillas. On the other hand, the Virunga is located in the western branch of the East African Rift System, and is thus prey to tectonic forces that are presently splitting apart the African plate. The rifting movements yielded the formation of Africa’s great lakes, among which the methane (CH₄) and carbon dioxide (CO₂)-rich Lake Kivu, and resulted in the highly active volcanoes whose most eruptions are initiated by the rift opening. The inhabitants of Virunga villages and cities (e.g. Goma in RDC and Gisenyi in Rwanda; ~ 1.5 million inhabitants) neighboring Nyiragongo and Nyamulagira active volcanoes and Lake Kivu live in a highly hazardous area. These populations are in fact permanently threatened by lava flows from the two volcanoes, and by a possible explosion of Lake Kivu that could release ~300 km³ CO₂ and 60 km³ of CH₄ dissolved in its deep waters. Such an explosion of Lake Kivu could be a regional catastrophe as it would affect the ~3 million people living in the catchment of the lake. Goma city and the surroundings have been many times affected by volcanic products. For example, Nyiragongo’s 1977 eruption caused the death of 70 to 100 people, whereas in 2002 Nyiragongo’s lava flows destroyed the houses of ~120,000 people (10 to 15% of Goma city), forced a mass self-evacuation of ~300,000 people of Goma (corresponding to ~75 % of inhabitants) and killed ~140 people. In parallel, Nyamulagira has erupted about 44 times since ~1880; with several eruptions whose lava flows destroyed many villages, and even reached Lake Kivu. The two volcanoes also release huge volcanic gases and ash into the atmosphere: Nyiragongo holds an active and persistent lava lake since May 2002 and Nyamulagira since April 2013. The gases and ash produce acid rain which damages vegetation and lead to lower harvest of crops, reduces milk production in cattle and damage the sheet metal roofing. These

effects are intensified during eruptions or intense activity of the lava lakes. The released gases (containing acidic gases such as CO₂, sulfur dioxide, carbon monoxide, hydrogen chloride, hydrogen fluoride...), the poor quality of rain and surface waters additionally cause health problems to human, e.g. the respiratory illnesses and endemic dental fluorosis disease found in the region. In the region are also encountered other natural hazards: earthquake hazard (e.g. the Mw 6.1 of 24 October 2002, the Mw 6.2 of 3 February 2008, the Mw 4.8 of 25 September 2016, in the Kivu basin), landslides (e.g. on October 25, 2014 in Kalehe), the Mazuku or high CO₂ soil-dry gas vents (up to 80% of CO₂ content), mudflows, flooding,... In Goma city and neighboring small towns and villages, the risk related to natural hazards is increased by the high vulnerability of the inhabitants. The latter is heightened by both the precarious living conditions of the populations, and the uncertainty and insecurity that have made natural hazards less threatening than the problems related to daily survival.

In such a context, the Virunga deserves a permanent and operating program to assess, monitor and prevent Natural Hazards in the region. Such a program can be successful when centered on a team of well-equipped and qualified local scientists and agencies collaborating with both international scientists and agencies involved in Disaster Risk Reduction and Management programs elsewhere. This justifies the need for establishing a “Virunga Volcanoes Supersites” which will help put together local and international scientists and agencies, support access to Earth Observatory data and potentially to equipment for ground-based data collection; support the building of a pool of collaborators which will encourage the collaborators to do capacity building in DRC and thus potentially attract funding. All the above mentioned supports and collaborations aiming at improving the early warning capacity of the local scientists and agencies involved in Natural Hazards assessment and monitoring, and risk reduction and management in the Virunga.

A.2. Supersite Coordinator

Email (Organization only)	balagizi.charles@gmail.com
Name:	Charles
Surname:	Balagizi
Position:	Senior Researcher
Personal web page:	<i>https://www.researchgate.net/profile/Charles_Balagizi</i>
Institution:	Goma Volcano Observatory
Institution type (Government, Education, other):	Government, Research institute
Institution web address:	www.ovggoma.org
Street address:	142, Avenue du Rond-Point, Quartier des Volcans, commune de Goma
City:	Goma
Postal Code/Zip Code:	
Country:	Democratic Republic of the Congo
Province, Territory, State, or County:	North Kivu Province
Phone Number:	+243975803568 / +243844020852

To sign legal agreements, for data accessibility and others questions that require official permission, the contact person is:

Prof. Katcho Karume

Goma Volcano Observatory Director
142, Avenue du Rond-Point
Quartier les volcans, Commune de Goma
Ville de Goma,
République Démocratique du Congo
Email: kkatcho@yahoo.com

A.3. Core Supersite Team

This section should provide the contact information of each participant to the initial Supersite team (the Core team). Further participants may be added at any time. Note that most space agencies require that each person using the data should sign a license agreement with specific rules on data use.

Email (Organization only)	balagizi.charles@gmail.com
Name:	Charles
Surname:	Balagizi
Position:	Researcher, Geochemist-Geohazards
Personal web page:	<i>https://www.researchgate.net/profile/Charles_Balagizi</i>
Institution:	Goma Volcano Observatory
Institution type (Government, Education, other):	Government, Research Institute
Institution web address:	www.ovggoma.org
Street address:	142, Avenue du Rond-Point, Quartier des Volcans, commune de Goma
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Country:	Democratic Republic of the Congo
Province, Territory, State, or County:	North Kivu Province
Phone Number:	+243975803568 / +243844020852

Email (Organization only)	mavotulu@gmail.com
Name:	Georges Mavonga
Surname:	Tuluka
Position:	Senior Researcher (Volcano Seismology), and Head of Department of Seismology
Personal web page:	<i><In case a personal web page does not exist, please provide a CV below</i>

	<i>this table></i>
Institution:	Goma Volcano Observatory
Institution type (Government, Education, other):	Government, Research Institute
Institution web address:	www.ovggoma.org
Street address:	142, Avenue du Rond-Point, Quartier des Volcans, commune de Goma
City:	Goma
Postal Code/Zip Code:	
Country:	Democratic Republic of the Congo
Province, Territory, State, or County:	North Kivu Province
Phone Number:	+243998584734

Email (Organization only)	kkatcho@yahoo.com
Name:	Katcho
Surname:	Karume
Position:	Senior Researcher and Director General of the Observatory
Personal web page:	<i>Please see CV provided below</i>
Institution:	Goma Volcano Observatory
Institution type (Government, Education, other):	Government, Research Institute
Institution web address:	www.ovggoma.org
Street address:	142, Avenue du Rond-Point, Quartier des Volcans, commune de Goma
City:	Goma
Postal Code/Zip Code:	
Country:	Democratic Republic of Congo

Province, Territory, State, or County:	North Kivu Province
Phone Number:	+243 (0) 994 304 633

Email (Organization only)	mahindageophys@gmail.com
Name:	Celestin
Surname:	Kasereka Mahinda
Position:	Researcher and Scientific Director of the Observatory
Personal web page:	<i><In case a personal web page does not exist, please provide a CV below this table></i>
Institution:	Goma Volcano Observatory
Institution type (Government, Education, other):	Government, Research Institute
Institution web address:	www.ovggoma.org
Street address:	142, Avenue du Rond-Point, Quartier des Volcans, commune de Goma
City:	Goma
Postal Code/Zip Code:	
Country:	Democratic Republic of the Congo
Province, Territory, State, or County:	North Kivu Province
Phone Number:	+243 994 458 794

Email (Organization only)	honoreciraba@yahoo.fr
Name:	Honoré Ciraba
Surname:	Mateso
Position:	Researcher and Head of Department of Geodesy
Personal web page:	<i><In case a personal web page does not exist, please provide a CV below this table></i>

	<i>this table></i>
Institution:	Goma Volcano Observatory
Institution type (Government, Education, other):	Government, Research Institute
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Postal Code/Zip Code:	
Country:	Democratic Republic of the Congo
Province, Territory, State, or County:	North Kivu Province
Phone Number:	+243 994 458 794

Email (Organization only)	yaliremat@yahoo.fr
Name:	Mathieu Yalire
Surname:	Mapendano
Position:	Researcher and Head of Department of Geochemistry and Environment
Personal web page:	<i><In case a personal web page does not exist, please provide a CV below this table></i>
Institution:	Goma Volcano Observatory
Institution type (Government, Education, other):	Government, Research Institute
Institution web address:	www.ovggoma.org
Street address:	142, Avenue du Rond-Point, Quartier des Volcans, commune de Goma
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Postal Code/Zip Code:	
Country:	Democratic Republic of the Congo
Province, Territory, State, or County:	North Kivu Province
Phone Number:	+243 994 458 794

Email (Organization only)	bo.galle@chalmers.se
Name:	Bo
Surname:	Galle
Position:	Professor, Optical Remote Sensing Researcher
Personal web page:	<i>https://www.chalmers.se/en/Staff/Pages/bo-galle.aspx</i>
Institution:	Chalmers University of Technology
Institution type (Government, Education, other):	Government, Education
Institution web address:	http://www.chalmers.se/en/Pages/default.aspx
Street address:	Hörsalsvägen 11, Floor 4
City:	Göteborg
Postal Code/Zip Code:	SE-412 96
Country:	Sweden
Province, Territory, State, or County:	Göteborg
Phone Number:	+46 31 772 5654

Email (Organization only)	mpoland@usgs.gov
Name:	Michael
Surname:	Poland
Position:	Research Geophysicist
Personal web page:	<i>https://www.usgs.gov/staff-profiles/michael-poland</i>

Institution:	U.S. Geological Survey, Cascades Volcano Observatory
Institution type (Government, Education, other):	Government, United States Department of the Interior
Institution web address:	https://volcanoes.usgs.gov/observatories/cvo/
Street address:	1300 SE Cardinal Court, Suite 100
City:	Vancouver
Postal Code/Zip Code:	WA 98683
Country:	United States of America
Province, Territory, State, or County:	Washington
Phone Number:	360-993-8906

Email (Organization only)	marcello.liotta@ingv.it
Name:	Marcello
Surname:	Liotta
Position:	Research Geochemist
Personal web page:	http://istituto.ingv.it/l-ingv/personale/mxmcontactsperson.2016-04-04.2263448035/view?set_language=en https://orcid.org/0000-0002-7203-1565
Institution:	Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Palermo
Institution type (Government, Education, other):	Government
Institution web address:	http://www.ingv.it/en/
Street address:	Via Ugo La Malfa, 153
City:	Palermo
Postal Code/Zip Code:	90146
Country:	Italy
Province, Territory, State, or	Sicily

County:	
Phone Number:	+39-0916809403

Email (Organization only)	yaoki@eri.u-tokyo.ac.jp
Name:	Yosuke
Surname:	Aoki
Position:	Assistant Professor
Personal web page:	<i>http://www.eri.u-tokyo.ac.jp/yaoki</i>
Institution:	Earthquake Research Institute, University of Tokyo
Institution type (Government, Education, other):	Education
Institution web address:	http://www.eri.u-tokyo.ac.jp
Street address:	1-1 Yayoi 1, Bunkyo-ku
City:	Tokyo
Postal Code/Zip Code:	113-0032
Country:	Japan
Province, Territory, State, or County:	Tokyo
Phone Number:	+81-3-5841-8283

A.4. Region of Interest

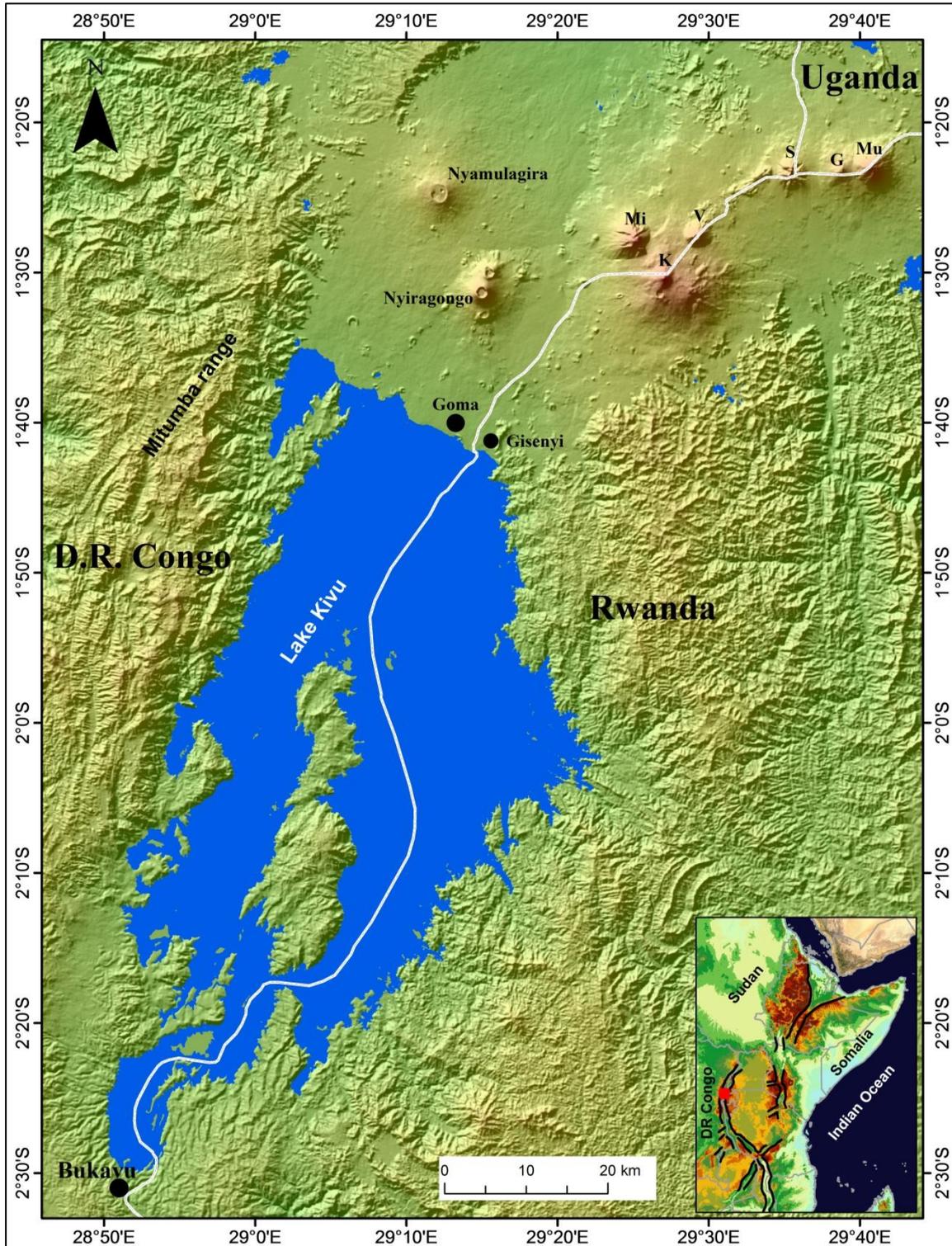


Figure 1. Map showing the region of interest with the Virunga eight major volcanoes to the north [i.e. Nyiragongo, Nyamulagira, Mikeno (Mi), Karisimbi (K), Visoke (V), Sabinyo (S), Gahinga (G) and Muhabura], and the seismically active basin of Lake Kivu to the south. The insert map shows the location of the Virunga Volcanoes within the western branch of the East African rift.

Table 1. Limits of the region of interest of the Virunga Volcanoes supersite.

Edge of boundary	Latitude	Longitude
North East	30.244°	-0.460°
South East	30.244°	-2.819°
North West	28.378°	-0.460°
South West	28.378°	-2.819°

A.5. Supersite motivation

A. 5. 1. Introduction to the Virunga Volcanoes and Lake Kivu

The East African Rift System (EARS) is a continuous geographic trench of ~6500 km long, averaging 30 to 65 km wide that runs from the Gulf of Aden/Red Sea to central Mozambique (Fig. 2). It is believed that the EARS' activity started to the north in the early Tertiary and then propagated toward the south, and is presently a region where tectonic forces are trying to create new plates by splitting apart the current ones. The extension of the EARS that consists of an Eastern and Western branches is supposed to having spreading rates ranging between 1.5 and 6.5 mm yr⁻¹ depending on location, and yields both intense volcanic and seismic activities. This extension yielded the formation of Africa's highest mountains chains such as the Virunga, the Mitumba, and the Ruwenzori Range in the Western branch; or Mt Kilimanjaro and Mt Kenya in the Eastern Branch. On the other hand, the extension process created shallow and deep depressions which were then fed and resulted in the African Great Lakes, among which the CH₄ and CO₂-rich Lake Kivu. The Virunga Mountains are thus located in the Western branch of the EARS, and are formed of a chain of volcanoes along the borders of the Democratic Republic of the Congo (DRC), Rwanda and Uganda (Fig. 1). Volcanic activity started in the Virunga during the mid-Miocene and presently consists of eight major volcanoes [i.e., Nyiragongo (3,470 m. a.s.l.), Nyamulagira (3,058 m), Visoke (3,711 m), Mikeno (4,437 m), Karisimbi(4,507 m) Sabinyo (3,645m), Gahinga (3,474 m) and Muhabura (4,127 m)], aligned nearly in an east-west direction which is accordingly perpendicular to the rift direction (Fig. 1).

Apart from the currently active Nyiragongo and Nyamulagira, Visoke last erupted

August 1-3, 1957. Nyamulagira is known as Africa's most active volcano with an average of one eruption every 1-4 years: it has erupted at least 44 times since 1882, and is characterized with long eruptions that can last up to ~2 years (Fig. 3). Nyamulagira has a low shield profile, so the majority of its eruptions develop on its flanks, along fractures and adventive cones. Less common summit caldera eruptions also occur, and are associated with intermittent lava lake activities. Nyiragongo, instead, is an alkaline stratovolcano that is well-known for its long-lived lava lake activity that has been repeatedly reported in its main crater: between 1928 and 1977, then from 1982 to 1994 or 17 January 2002, and from May 2002 to present. Nyiragongo's January 10, 1977 and January 17, 2002 eruptions (the only 2 known "external" eruptions since ~1882) occurred when the NS oriented system of fractures suddenly opened and emptied the lava lakes. In 2002 Nyiragongo lava flows devastated Goma city destroying 10 to 15% (Fig. 3) of the main town, and forced a mass evacuation of the population. The Virunga region and the Lake Kivu basin abound of shallow and deep dikes, several surface fissures and faults associated with the rift activity and which favor flank eruptions at Nyiragongo and Nyamulagira volcanoes.

Present-day activity at Nyiragongo and Nyamulagira is characterized by large gas plume emissions from their central calderas as they both hold an active lava lake (Fig. 4). The two volcanoes daily release tens of thousands of tons of volcanic gases into the atmosphere, and rank amongst the most powerful volcanic gas emitters on Earth. As an example, during the Nyiragongo 2002 eruption, the average SO₂ flux in the initial 2-3 hours were estimated at ~73 to 147 kilotons/day (kt/d), and the CO₂ flux to 9.3 kt/d. Also, the cumulative SO₂ emissions during 15 eruptions of Nyamulagira between 1980 and 2006 were estimated to be ~27 Mt (megatons). The emitted gases and ash locally and regionally lead to air pollution, but also interact with rainwater to produce acid rain which damages the environment, and yield low crops harvest. Moreover, the SO₂ and ash plume represent a threat to the air traffic crossing the region and the Goma airport operations. Nyiragongo and Nyamulagira fields are additionally characterized by continuous low temperature magmatic CO₂ emissions from the soil, fractures and lava flow front lines. These CO₂-rich and O₂-poor places are locally called "Mazuku", meaning "evil places or wind" because people often die there from asphyxia, but this is locally attributed to evil spirits. The CO₂ concentrations at some Mazuku show values up to 80 %_(v) and have shown any dropping during the last decade.

Lake Kivu (1460 m a.s.l.) is a meromictic lake located on the border of the Democratic Republic of the Congo and Rwanda (Fig. 1). The lake lies in the floor of the Western Branch of the EARS and is bordered to the north by Nyiragongo and Nyamulagira volcanoes, by the

Rwandan dorsal to the east, the Mitumba Mountains to the west and exits to the south to Lake

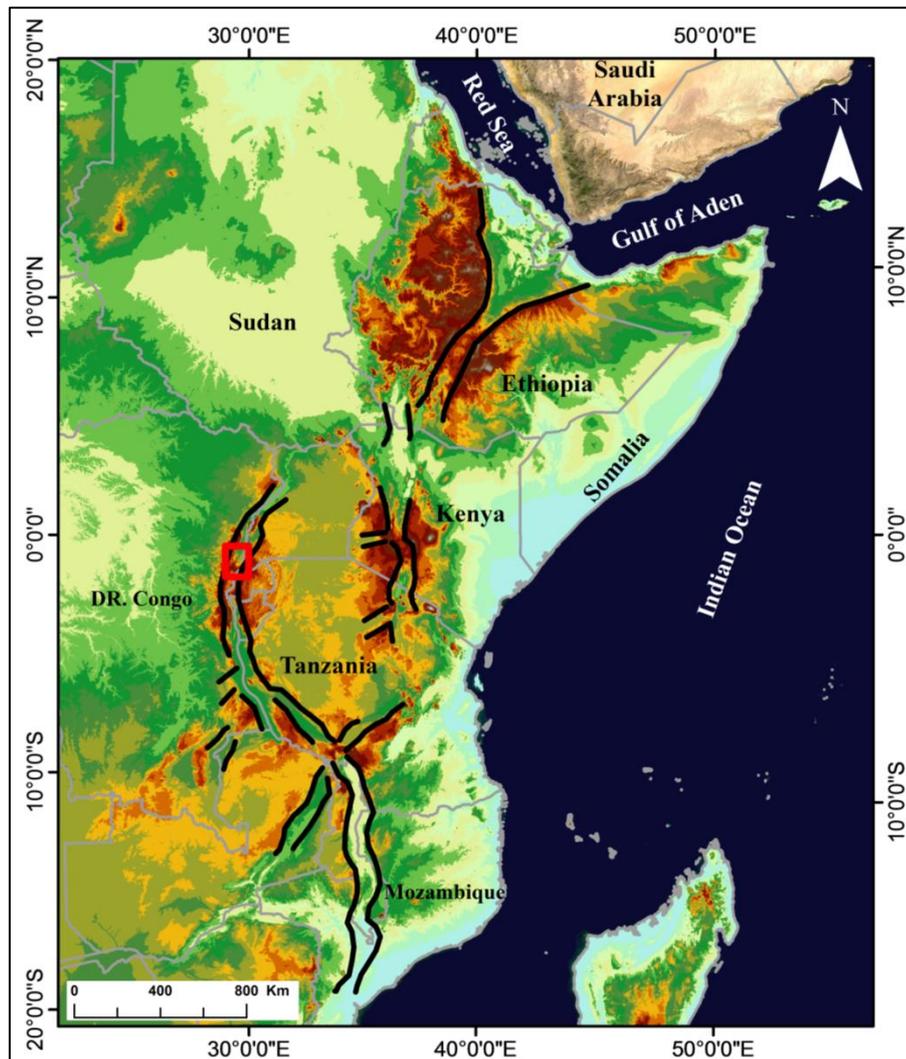


Figure 2. Map showing the East African Rift System and its two branches: the Western and Eastern. The Virunga Volcanoes supersite region of interest is located in the Western branch and is here shown by the red rectangle at the border of the Democratic Republic of the Congo, Uganda and Rwanda.

Tanganyika through the Ruzizi River. Lake Kivu has a maximum depth of 485 m, contains about 560 Km³ of water and spreads over 2370 Km² with a total catchment of 5097 km² excluding the lake area. With an estimated residence time of ~1000 years, the anoxic deep water of the lake contains enormous volumes of CO₂ and CH₄ estimated to 300 and 60 km³, respectively [at 0°C and 1 atm.]. Minerals and CO₂-rich groundwater and hydrothermal systems also discharge into the lake from the bottom and govern internal nutrient recycling and upward of dissolved gases. Methane in Lake Kivu is mainly formed by biogenic process; some authors have however hypothesized the possibility of CH₄ originating from the reduction of geogenic CO₂ with mostly

geogenic H₂, or direct geogenic CH₄ import to the water column.

The eruption of Nyiragongo in 1977 that caused the death of 70 to 100 people, while the 2002 eruption destroyed the houses of ~120,000 people, forced a mass self-evacuation of ~300,000 people from Goma (of estimated ~400,000 inhabitants), and killed ~140 people. After this eruption the government of the DRC created the Goma Volcano Observatory (GVO). Before this eruption the GVO was a small station of another Congolese research center located further to the south, the “Centre de Recherche en Sciences Naturelles” of Lwiro. Actually, as an independent research center, the GVO main missions are:

- (1) **Monitoring:** to conduct a real time monitoring of Virunga volcanoes, particularly the currently active and threatening Nyiragongo and Nyamulagira;
- (2) **Risk prevention and management:** realize the inventory and study of Geohazards in the Virunga region and Lake Kivu basin; and prevention and management of risk in these regions,
- (3) **Research:** use the major fields of Earth, planets and Environmental Sciences (Chemistry, Physics, Geology and Mathematics) to understand the functioning and evolution of the EARS, particularly its Western branch, and the eruptive mechanisms of Virunga volcanoes. The study of Lake Kivu was recently added, as well as the study of impacts related to the eruptive activity of Nyiragongo and Nyamulagira on the Environment and the population.

Natural hazards in Virunga and Lake Kivu basin include: (i) volcanic hazards [i.e. lava flows (e.g. Nyiragongo 1977 and 2002 eruptions; Nyamulagira 138-40, 1948, or 2010 eruptions), volcanic gases and ash, acid rain (Nyiragongo has an active and persistent lava lake since May 2002, and Nyamulagira since April 2013)]; (ii) earthquake hazard (e.g. the Mw 6.1 of 24 October 2002, the Mw 6.2 of 3 February 2008, the Mw 4.8 of 25 September 2016 which were responsible for human deaths, several serious injuries, and several damages to buildings in Bukavu (DR Congo) and Cyagugu (Rwanda)); (iii) landslides (e.g. on October 25, 2014 in Kalehe, in the Lake Kivu basin), (iv) rain and surface water quality (e.g. high fluoride content), and (v) Mazuku or soil-dry gas vents (in and around Goma city). Recently, hazards related to the CO₂ and CH₄ dissolved in the deep water of Lake Kivu have also been considered to be closely monitored since the lake may potentially erupt and thus release huge amounts of the dissolved gases into the atmosphere, such as happened at the Cameroonian Monoun and Nyos lakes in 1984 and 1986, respectively.

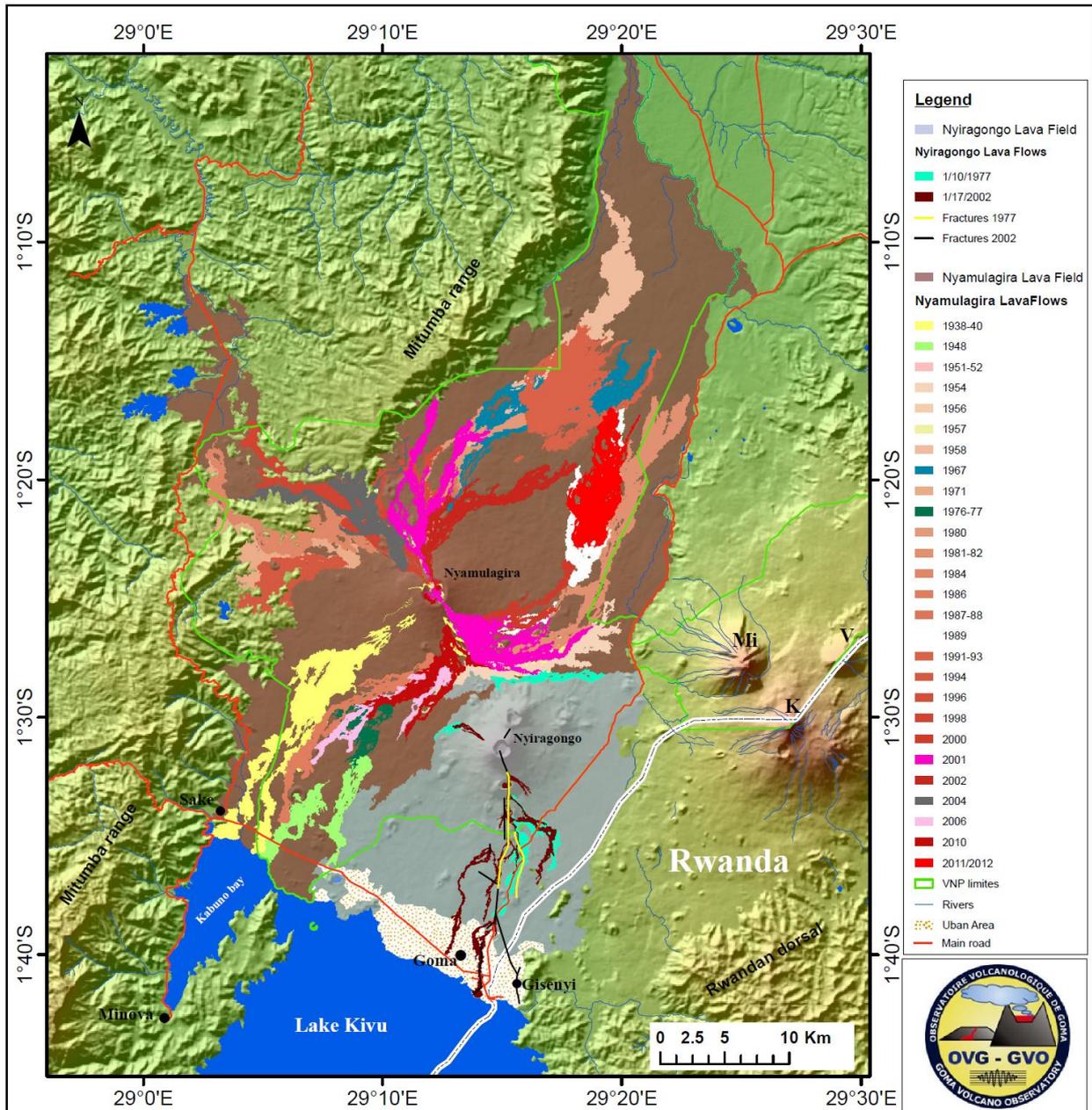


Figure 3. Volcanological map of the recent lava flows of Nyiragongo (1977 and 2002 eruptions) and Nyamulagira (from 1938 to 2012) of the VV P, the north basin of Lake Kivu and Goma (RDC) and Gisenyi (Rwanda) cities.

The information collected by the GVO about the current volcanic activity and that related to other Geohazards in the region has societal benefits as it is directly, on a weekly basis, communicated to the governmental (e.g. civilian protection) and non-governmental agencies involved in Emergency and Disaster Management. The information is additionally communicated to the neighboring Rwanda Republic and to all regional agencies involved in Environmental issues such as the Virunga National Park, and to the local Medias. As a matter of fact, all the studies which will contribute to improved assessment and the understanding of

Geohazards in the Virunga and Lake Kivu basin are critical for Disaster Risk Reduction in this highly populated region of very vulnerable population. Nyiragongo volcano alone threatens ~1.5 million inhabitants of Goma (DR Congo) and Gisenyi (Rwanda) cities in addition to people living in the surrounding villages. Furthermore, a massive release of the CO₂ and CH₄ dissolved in Lake Kivu could affect more than 3 million people living around the lake. Landslides and earthquakes repeatedly occur in this region and the associated risks related to the two are enhanced by factors such as the mountainous profile topography of the region, the anarchic constructions of buildings in most cities, soil types and their relatively constant high water-content. Therefore, the Virunga region displays various criteria to become recognized as a GeoHazard SuperSite, for both the study of various natural hazards and the mitigation of associated risks.

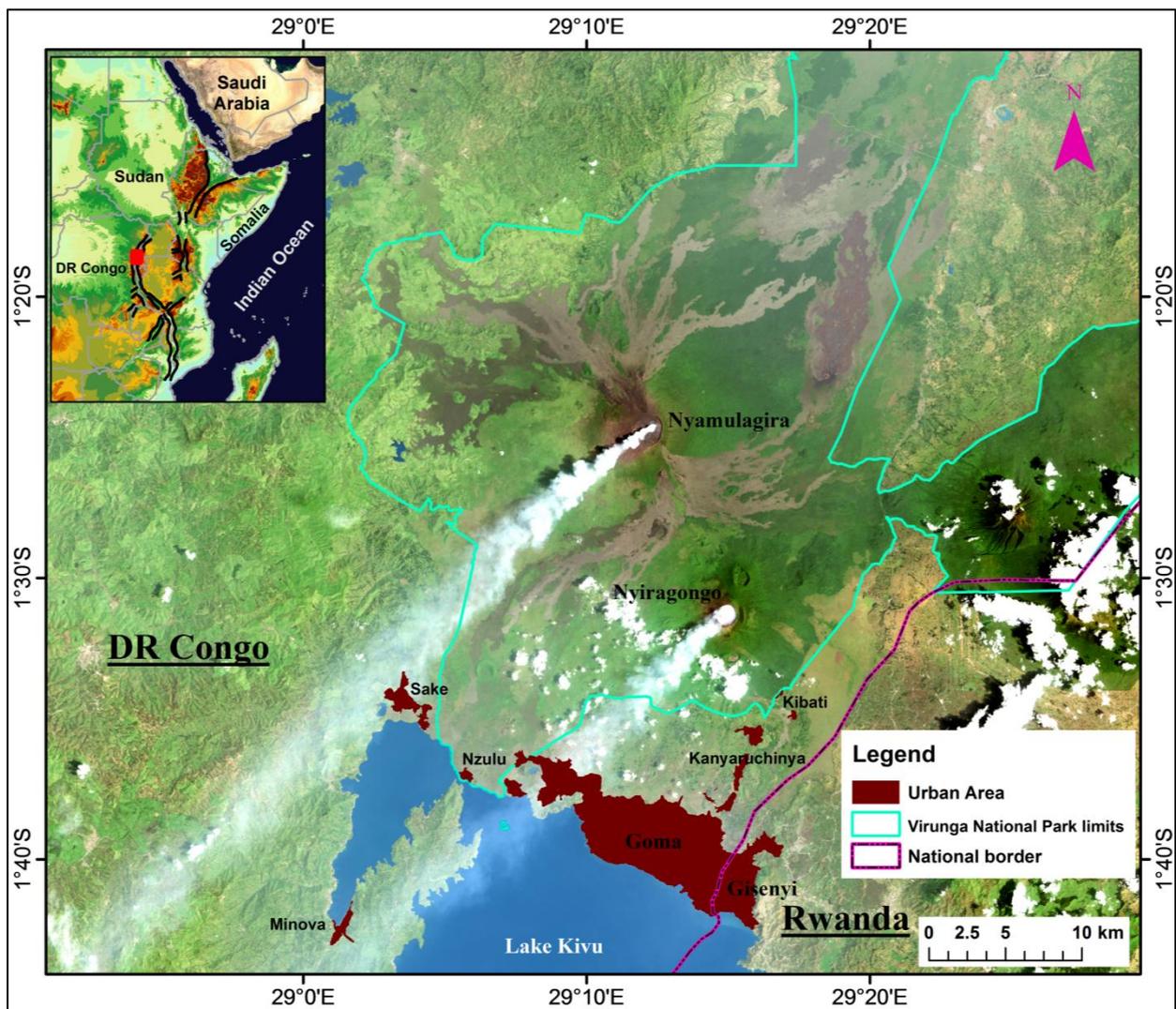


Figure 4. Nyiragongo and Nyamulagira permanent plumes pushed west-southwestward by the regional dominant wind as shown in the inset wind rose chart. The basement image was acquired on February 9, 2015 by the NASA's Earth Observatory Landsat 8.

A. 5. 2. Current scientific situation, available data and further data needed

Fifteen years after the Nyiragongo 2002 destructive eruption, the Goma Volcano Observatory remains under-equipped and with few qualified scientists. Presently (March 2017), only the seismic network really contributes to the monitoring of Nyiragongo and Nyamulagira volcanoes. Many valuable techniques commonly used for active volcano monitoring have never been applied or are currently unavailable in the Virunga (Table 1). Given the exceptional sismo-volcanic activity in this region - which makes it a remarkable natural geo-laboratory but also a site of high-level hazards and risks -, there is an urgent need for the GVO to be reinforced as regards both qualified local scientists and monitoring instrumental tools. This is a requisite condition to permit the GVO to provide accurate data, correct interpretations and timely warning of the natural hazards and disasters threatening the Virunga region. More ground-based and Earth Observation (EO) data are required for a better understanding of the Virunga volcanoes plumbing systems, their eruptive mechanisms, and the parameters that control and influence landslides, mudflows, flooding, in the region. Once the systems functionality understood, it should then be possible to accurately predict and manage disasters in the Virunga and Lake Kivu basin regions. Reliable disasters prediction in the Virunga and Lake Kivu region is very important to save lives, as the populations at risk and their vulnerability are continuously increasing, especially as a consequence of the repetitive wars that impacted the region.

A Disaster Risk Reduction and Management program is based on the collection of accurate scientific data (field and EO) and the availability of qualified human resources for their processing and interpretation. These two key points are still to be improved in the Virunga region and Lake Kivu basin, and we feel that the collaboration we want to establish between the Virunga local scientists and the international scientists through the Geohazards Supersites network is the most efficient way to overcome these difficulties; and improve Geohazards assessment and monitoring in the Virunga. Such partnership is in line with the objectives of the supersites initiative that promotes broad international scientific collaboration and open access to a variety of space- and ground-based data, and hence improves geophysical scientific research and Geohazards assessment in support of Disaster Risk Reduction.

As important keywords for priority resource support, the Goma Volcano Observatory expects, in term of optimistic outcomes, that the establishment of Virunga Volcanoessupersite will result in the following:

- Local scientists capacity building,

- Support to establish collaboration with international scientists, on an equal basis, and agencies in the monitoring of Virunga active volcanoes and Lake Kivu with the aim of preventing the related risks. A collaboration with international agencies will allow the observatory to contribute in globally established environment assessment monitoring programs, and in the Volcanic Ash Advisory Centre (VAAC) to perform Volcano Observatory Notice for Aviation (VONA) messages, furnishing strategic information on volcanic plume features,
- Get support from Geohazards Supersites to access space (E.O) data, which are useful for building natural hazards maps, and more particularly for lava flows path simulations.
- Get support from Geohazards Supersites and scientific community to attract funds from local and international agencies to achieve the above objectives.

Table 2. In situ collected by the Goma Volcano Observatory. Please note that none of the listed partners provide financial support to Goma Volcano Observatory.

		Number of stations	Type of monitoring	Partners
Seismology		14	Continuous	<ul style="list-style-type: none"> — Africa Array — European Center for Geodynamics and Seismology/Luxembourg — Royal Museum for Central Africa /Belgium — UN Mission for the stabilisation of the DR Congo
Ground Deformation	Continuous GPS (fix)	7	Continuous	<ul style="list-style-type: none"> — European Center for Geodynamics and Seismology/Luxembourg — INGV/Catania
	Campaign GPS (kinematic)	0	—	—
	Strain and tiltmeter	0	—	—
	High-precision digital elevation models	0	—	—
	Gravity	0	—	—
	Magnetotellurics	1	campaign	—
	Geospatial information	—	—	—
Geochemistry	Volcanic SO₂ emissions	4	Continuous and campaign	<ul style="list-style-type: none"> — Network for Observation of Volcanic and Atmospheric Change (NOVAC) — Chalmers University of Technology, Gothenburg / Sweden — University of Mainz / Germany — INGV-Palermo/ Italy
	Fumarole temperatures/Direct volcanic plume sampling using alkaline traps	0	—	—
	Soil CO₂ emission	3	Continuous and campaign	<ul style="list-style-type: none"> — University of Luxembourg — University of Florence/ Italy
	Soil Radon emission	2	Continuous and campaign	— University of Luxembourg
	Soil temperature	10	Continuous	<ul style="list-style-type: none"> — Institut de Physique du Globe de Paris / France — University of Luxembourg — INGV-Palermo / Italy
	Lake Kivu: dissolved gases and stratification stability		Campaign	<ul style="list-style-type: none"> — INGV-Palermo/ Italy — IAEA/Vienna-Isotope Hydrology Section — Lake Kivu Monitoring Program (LKMP)-Rwanda — University of Liège : Chemical Oceanography Unit — ISP/Bukavu — Second University of Naples
Geohazards and Risk Assessment	Vulnerability/Risk management			<ul style="list-style-type: none"> — Royal Museum for Central Africa / Belgium — University Of Bayreuth / Germany
	Hazard Assessment			<ul style="list-style-type: none"> — Royal Museum for Central Africa / Belgium — University Of Bayreuth / Germany

5.6. In situ data

Type of data	Data source / Type of sensor	Number of station	Type of monitoring
<i>Seismic waveforms</i>	<i>Broadband Sensor</i>	<i>14</i>	<i>Continuous</i>
<i>SO₂ data</i>	<i>FIX DOAS, Scanning remote sensing UV absorption spectroscopy (280 - 420 nm, Novac Network)</i>	<i>4</i>	<i>Continuous</i>
GPS	<i>Leica GNSS high performance system</i>	<i>7</i>	<i>Continuous</i>
<i>Soil temperature</i>	<i>Tinytag Plus data logger (HYDREKA SAS, -50 to +600 °C range)</i>	<i>10</i>	<i>Continuous</i>
<i>Soil Radon emission</i>	<i>Rad7</i>	<i>5</i>	<i>Continuous, Field campaign</i>
<i>Soil CO₂ emission</i>	<i>GA2000 portable landfill gas analyser (Geotechnical Instruments)</i>	<i>10</i>	<i>Continuous, Field campaign</i>
<i>Virunga rivers water geochemistry</i>	<i>Monthly field campaigns: - Physicochemical parameters - major and trace elements - stable and radiogenic isotopes (e.g. O, H, C, Sr) - Gases concentrations (e.g. CO₂, CH₄, N₂O)</i>	<i>14 rivers 7 cold springs 7 hot springs</i>	<i>Field campaign</i>
<i>Virunga rainwater geochemistry</i>	<i>Monthly field campaigns: - Physicochemical parameters - major and trace elements - stable and radiogenic isotopes (e.g. O, H, Sr)</i>	<i>14</i>	<i>Field campaign</i>
<i>Lake Kivu physicochemical parameters profile</i>	<i>Field campaigns, profiles of: - Physicochemical parameters - major and trace elements - stable and radiogenic isotopes (e.g. O, H, Sr) - secondary mineral saturation</i>	<i>Main basin Kabuno Bay</i>	<i>Field campaign</i>

The collected data will be shared with the scientific community, but the data will be accessed on request. In fact, we will define a data policy (on a long term) to rule the access on the data in order to give priority to the team that collected the data to publish. If not published

after a certain period of 2 years maximum, the data shall be opened to the scientific community. Also, we will put limitations to the sharing of data during crises or in special occasions. Partners that closed work with local scientific community for a regular basis in the collection and processing of the data will be associated in the management of the crises. We thus strongly recommend that the international scientific community involves the local scientists in the research and projects, at all levels, since this is the main way to build research capacities; this is also compliant and in line with the Open Science approach of GSNL.

A.7. Supersite activity work plan

Based on the present situation in Goma (the state of both human resources and infrastructures for in situ and space data collection, storage and for possible distribution), and given the need to quickly have local and international scientists start collaboration, the Supersite implementation plan for the two coming years is as following:

- 1°) Create interest for the scientific problems among the international community (present the Supersite at meetings, etc.)
- 2°) Work to attract funds from local and international sources, following an integrated approach
- 3°) With the help of the GSNL, GEO, and CEOS, establish the technological means for sharing the Supersite data

A.8. Available Resources

Presently the GVO has very little resources; we then expect that the international collaboration and the high visibility of the Supersite will allow attracting more resources within a time frame of 2-4 years. However, the GVO has its own official building with many offices, with permanent access to water and electricity and 3 permanent 4WD Vehicles for field activities. Available equipment resources can be found in table 2. As a government research institute, the Observatory benefits from a budget that pays the salaries of scientists, and sometimes for field works but is not enough to meet the needs listed in A.5. section (Supersite motivation).

A.9. EO data requirements

COSMO-Skymed:

	Information	Notes
Image mode	Stripmap/spotlight (tbd)	COSMO SkyMED is intended for near real time monitoring with InSAR Spotlight coverage might be requested for limited time and specific high resolution needs
Orbit pass	Descending and ascending passes	
Look direction		
Beam or incidence angle (range)	tbd	
Polarization		
Type of Product	SLC	
Number of archive images requested	The entire archive over the AOI, it is about 700 images	
Number of new images requested, per year	ca 100 SAR images (every 2 weeks during quiescence periods, plus maximum temporal coverage during unrest or eruption)	

TerraSAR X / TanDEM X:

	Information	Notes
Image mode	Stripmap	TerraSAR X (TanDEM X) is mostly for high resolution monitoring during quiescent periods and DEM production at selected sites.
Orbit pass	Ascending and descending	
Look direction		
Beam or incidence angle (range)		
Polarization		
Type of Product	SLC	
Number of archive images requested	The entire archive over the AOI about 70 datasets	
Number of new images requested, per year	ca. 100 images	

ALOS 2:

	Information	Notes
Image mode	Stripmap, Wide Swath	ALOS-2 is intended for near real time monitoring with InSAR; fundamental for highly vegetated areas.
Orbit pass	Ascending and descending	
Look direction		
Beam or incidence angle (range)		
Polarization		
Type of Product	slc	
Number of archive images requested	The entire archive over the AOI ca. 70 images	
Number of new images requested, per year	ca. 25 images	

RADARSAT 2:

	Information	Notes
Image mode	tbd	Rsat 2 is used for continuous monitoring in the quiescent periods. It will complement Sentinel 1 with images with different line of sights, useful to determine the 3D deformations
Orbit pass	Ascending and descending	
Look direction		
Beam or incidence angle (range)		
Polarization		
Type of Product	slc	
Number of archive images requested		
Number of new images requested, per year	ca. 50 images	

Sentinel 1:

	Information	Notes
Image mode	IW	Needed for monitoring of quiescent periods, but it can be used to complement other sensors during crises if a higher frequency is ensured
Orbit pass	Ascending and descending	
Look direction		
Beam or incidence angle (range)		
Polarization	vv	
Type of Product	SLC	
Number of archive images requested	open	
Number of new images requested, per year	Open, but we ask for 6 day revisit frequency	Need to improve revisit frequency

Pleiades:

	Information	Notes
Image mode	Nadiral, Tristereo	Optical images are intended for detection of morphological changes (e.g., variations of craters and lava lakes, glacier response to subglacial ice-melting; slow slope failure, etc.). Sub-meter DEMs from the tri-stereo are important for sin- and post-eruption changes in summit areas.
Orbit pass		
Look direction		
Beam or incidence angle (range)		
Polarization		
Type of Product		
Number of archive images requested		
Number of new images requested, per year	ca. 9 images	

A.10. Declaration of commitment

The Supersite is intended to provide open access to data to all scientists. We want to share the data, either collected by GVO, or by other institutions, or provided by the space agencies, according to a Data Policy to be defined. The data policy which will be agreed among all data contributors in the Supersite will be compliant to the Data Policy Principles of the GEO-GSNL Initiative.

The data will remain property of the owner, who will be given proper attribution using Persistent Identifiers, and will be shared according to rules set in data-specific licenses. We anticipate that during volcanic emergencies there could be temporary data access restrictions. Moreover, since one of the goals of the Supersite is to improve capacity building of the local monitoring/scientific community, the data policy will set rules to stimulate scientific collaboration with the local scientists.

A.11. Further comments

None.

List of international scientists member of the Core Supersite Team:

	Name, Surname	Institution	Email	Country
1	Dr. Michael Poland	U.S. Geological Survey, Cascades Volcano Observatory	m.poland@usgs.gov	Usa
2	Prof. Dr. Bo Galle	Chalmers University of Technology	bo.galle@chalmers.se	Sweden
3	Prof. Dr. Yosuke Aoki	Earthquake Research Institute, University of Tokyo	yaoki@eri.u-tokyo.ac.jp	Japan
4	Dr. Marcello Liotta	INGV, Palermo- Osservatorio Etneo	marcello.liotta@ingv.it	Italy

List of support letters from international scientists (the letters are listed after this table):

	Name, Surname	Institution	Email	Country
1	Prof. Giuseppe Puglisi	INGV Catania, Osservatorio Etneo	giuseppe.puglisi@ingv.it	Italy
2	Dr. Sven Borgstrom	INGV Naples, Vesuviano Observatoy	sven.borgstrom@ingv.it	Italy
3	Dr. Mauro Coltelli	INGV Catania, Osservatorio Etneo	mauro.coltelli@ingv.it	Italy
4	Prof. Dario Tedesco	University of Campania	Dario.TEDESCO@unicampania.it	Italy
5	Dr. Mario Mattia	INGV Catania	mario.mattia@ingv.it	Italy
6	Dr. John S. Pallister	VDAP, U.S. Geological Survey	jpallist@usgs.gov	USA
7	Prof. Estelle Chaussard	State University of New York	estellec@buffalo.edu	USA
8	Dr. Wendy McCausland	VDAP, U.S. Geological Survey	wmccausland@usgs.gov	USA
9	Dr. Fabien Albino	University of Miami	albino@rsmas.miami.edu	USA
10	Prof. Andy Hooper	University of Leeds	a.hooper@leeds.ac.uk	Unated Kigdom
11	Prof. Derek Keir	University of Southampton	d.keir@soton.ac.uk	Unated Kigdom
12	Dr. Juliet Biggs	School of Earth Sciences, University of Bristol	juliet.biggs@bristol.ac.uk	Unated Kigdom
13	Prof. Dr. Martin Doevenspeck	University of Bayreuth	doevenspeck@uni-bayreuth.de	Germany
14	Dr. Nicole Bobrowski	University Heidelberg	nbobrows@iup.uni-heidelberg.de	Germany
15	Dr. François Kervyn	Royal Museum for Central Africa	francois.kervyn@africamuseum.be	Belgium
16	Dr. Pierre-Yves Burgi	Société Volcanologique de Genève	Pierre-YvesBurgi@unige.ch	Switzerland
17	Dr. J. Maarten de Moor	Observatory of Volcanology and Seismology	maartenjdemoor@gmail.com	Costa Rica
18	Dr. Nicola dOreye	National Museum of Natural History	ndo@ecgs.lu	Luxembourg
19	Dr. Patrick Allard	Institut de Physique de Paris	pallard@ipgp.fr	France
20	Prof. Roberto Sulpizio	International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)	roberto.sulpizio@uniba.it	Italy
21	Philippe Husson	Volcanic Ash Advisory Center (VAAC) Toulouse	philippe.husson@meteo.fr	France

To Dr. Balagizi
Goma Volcano Observatory
142 Avenue du Rond-Point, Goma
DR Congo

Catania, 01 June 2017

subject: **“Virunga Volcanoes Supersite” supporting letter**

Dear Dr. Balagizi,

I am pleased to write in support of the proposal of the Goma Volcano Observatory for creating the “Virunga Volcanoes Supersite”. As Point of Contact of the Mt. Etna Supersite, I see the appointment of this new supersite as an important achievement in the implementation of the whole GEO GSNL initiative. Indeed, the area of Virunga has very significant characteristics for the initiative.

The area suffers of multiple natural threats (e.g., volcanic activity, degassing, seismicity, landslides, rainfalls, etc.), which considered altogether represent an unique test-bed for studying and implementing cutting-edge models and techniques aimed at better exploiting the monitoring data (both in-situ and EO) and improving hazard assessment and risk management.

In the challenging Virunga region, the GEO GSNL objectives of the scientific capacity building and societal resilience to natural hazards might gain a peculiar added value. The creation of the “Virunga Volcanoes Supersite” will foster the international scientific cooperation with the Goma Observatory giving support to study these volcanoes and to implement monitoring systems that are currently not available in the area. The impact on society (i.e., the management of the natural hazard on an inhabited region with more than 1.5 MI of people) will benefit from the international cooperation, through to the link of the Observatory with the agencies involved in Emergency and Disaster Management.

Personally, I feel strongly support the proposal of this new supersite, because after the 2002 Nyiragongo eruption, I was involved in the INGV team that cooperated with the UN in attempting to develop a network for the monitoring of ground deformation. Although the results were not exactly those expected, I believe that the current proposal is a legacy of that early initiative.

Please, do not hesitate to contact me for any further support that might be useful to this proposal.

Best regards



Giuseppe Puglisi
Point of Contact of Mt. Etna Supersite
INGV Sezione di Catania – Osservatorio Etno

Naples, May 30, 2017

To: Dr. Charles Balagizi
Goma Volcano Observatory
Democratic Republic of Congo

Dr. Sven Borgstrom, PhD
Istituto Nazionale di Geofisica e Vulcanologia
Sezione di Napoli "Osservatorio Vesuviano"
E-mail: sven.borgstrom@ingv.it

Support letter for the Virunga Volcanoes Supersite

Dear Dr. Balagizi,

I am pleased to express my solidarity for the Virunga Volcanoes Supersite proposal that you will submit on behalf of the Goma Volcano Observatory (OVG) to the Geohazard Supersites and National Laboratories (GSNL) Scientific Advisory Committee.

Although I never cooperated till now with OVG, I fully share with you your need for a continuous and in-depth monitoring of a Volcanic District which has two of the most active volcanoes in Africa, namely Nyiragongo and Nyamulagira, which threaten the city of Goma where about one million people live.

This is also my concern, as a researcher working in a Volcano Observatory and living in a city (Naples, Southern Italy) located between two active volcanoes (Mt. Vesuvius and Campi Flegreii), which threaten an overall population of more than two million people.

Two years of activity as a PoC (Point of Contact) of the Vesuvius/Campi Flegreii Supersite, allow me to say that the results achieved till now exploiting the data provided by GSNL for the Supersite I am coordinating, are actively contributing to improve the scientific knowledge of the area, results to be afterwards transferred to the competent Civil Protection bodies at local and national level for the updates of the National Emergency Plans.

And this is what I wish for you, after a successful approval of your proposal.

Good luck,

Dr. Sven Borgstrom



Catania, 16 June 2017

Concern: Support letter for Virunga Volcanoes Supersite

Dear Dr. Balagizi,

I support strongly the proposal for the Virunga Volcanoes Supersite that the Goma Volcano Observatory (GVO) is going to submit to GSNL. I think that Virunga volcanoes region is a magnificent site for people studying the volcanism and, in particular, the eruptive activity of basaltic volcanoes ranging from persistent lava lakes to periodic lava flow eruptions. The frequent large lava flows of Nyiragongo and Nyamulagira volcanoes that threaten the population of Goma city and the neighboring villages, represent an crucial objective for understanding the mechanisms, forecasting the paths and minimizing the dangerous effects that here, the only place in the world, killed several tens of people in the recent past.

I hope that this proposal will receive a positive evaluation because, in my opinion, the Geohazard Supersite initiative can represent a meaningful step toward the target of enhancing the volcano monitoring and research activity for scientists worldwide that can contribute to the grow of GVO and its scientific staff through a fruitful collaboration, and then contribute significantly to the safety of the people of Goma city and Virunga region.

Best regards,



Mauro Coltelli

Senior Researcher – volcanologist

INGV – Osservatorio Etno



June 6, 2017

Dear Dr. Balagizi,

It is with pleasure that I offer a support letter for the Virunga Volcanoes Supersite proposal which is being put forward by the Goma Volcano Observatory.

Working on volcanoes is always challenging, and oftentimes different groups work on the same volcanoes without having strong collaborations or even worse, without sharing data. This unfortunately happens often in volcanic regions where local scientists are not well equipped and prepared (in terms of techniques) or have funding problems, and for these reasons cannot study, work and correctly monitor their volcanoes.

The idea of establishing a supersite for the the Virunga active volcanoes -Nyiragongo and Nyamulagira – that will make the Virunga region member of the Geohazard Supersites and Natural Laboratories (GSNL) will enormously benefit for all the reasearchers, both local and international, working in the area and those who wish to come work there. Based on my experience after spent almost 22 years in the Virunga, I can state and certify that the the request made by the Goma Volcano Observatory to be enlisted in the GSNL, as a Virunga Volcano Supersites, is a faithful photo of the area and reflect correctly the state of the art and the hazards of the region. Hazards that have, very unfortunately, strongly increased in the last 15 years after the infamous eruptive event of January 17, 2002. In fact the local population steadily increased from 400,000 in 2002 to more than 1,000,000 in 2017.

Belonging to this platform I am sure that scientists from all over the world will start to get interest in such incredible and still very poorly known volcanoes (Nyiragongo and Nyamulagira) and to work at 360 degrees from basic monitoring, to understanding volcano activity, starting modelling the volcano, to work on eruptive scenarios and lava flows maps, to collaborate with Civil Defence to better understand which instruments will be necessary to educate and inform, timely and correctly the growing population in the city of Goma. Finally “end-users” redicing volcanic hazards, will become the center of the attention of a part of this platform.

It is also clear that local scientists are still under equipped and most of all, under educated (scientifically), and thus the “Virunga Volcanoes Supersite” will allow local and international scientists to collaborate, which will yield capacity building of local scientists, and help them to achieve Masters and Ph.D in field related to volcano monitoring and natural hazards and risks managment.



UNIVERSITÀ DEGLI STUDI DELLA CAMPANIA
LUIGI VANVITELLI

**DIPARTIMENTO DI SCIENZE E
TECNOLOGIE AMBIENTALI
BIOLOGICHE E FARMACEUTICHE**

I thus fully support the idea of Virunga Volcanoes Supersite. It is a great opportunity for local scientists as well for scientists from all over the world to share their science, experience and data obtained locally. Myself I will continue to work with the Goma Volcano Observatory and, as I always did, I will continue to share my data with all those who will be interested to work on. The Virunga Volcanoes Supersite proposal in my opinion should be accepted and a chance should be given to the Goma Volcano Observatory and its researchers.

Dario Tedesco

Dario TEDESCO
Full Professor,
Geochemistry and Volcanology

University of Campania – Luigi Vanvitelli
Dipartimento di Scienze e Tecnologie Ambientali, Biologiche e Farmaceutiche
Via Vivaldi n. 43
81100 Caserta
T.: +39 0823 274413 / 4587 / 4588
F.: +39 0823 274585
E.: distabif@unicampania.it
www.distabif.unina2.it

Catania, 12/06/2017

Support Letter

Dear Dr. Balagizi,

I strongly support your proposal for the Virunga Volcanoes Supersite that the Goma Volcano Observatory (GVO) is going to submit to GSNL. I think that Virunga volcanoes area a wonderful place for people interested in volcanology and, in particular, in the field of the studies related to the relationships between tectonics and volcanism. I hope that this proposal will receive a positive evaluation because, in my opinion, the Geohazard Supersite initiative can represent a meaningful step toward the target of a better monitoring and research activity for all the scientists worldwide, but principally for african scientists that will be able to find an easier way for their formation and for their collaboration with other scientists of other countries.

Best regards,

Mario Mattia

Senior Technologist – Geodesist

Istituto Nazionale di Geofisica e Vulcanologia – Osservatorio Etneo, Catania (Italy)



United States Department of the Interior
U.S. Geological Survey
Volcano Disaster Assistance Program
Cascades Volcano Observatory
1300 Cardinal Court
Vancouver, WA 98683

19 May 2017

Dear Dr. Balagizi:

I am pleased write in support of the Virunga volcanoes Supersite proposal that is being put forward by the Goma Volcano Observatory (GVO). Those of us in the Volcano Disaster Assistance Program (VDAP) are well aware of the volcanic hazards of Nyiragongo and Nyamulagira volcanoes, which result from the high density of population in the area, combined with the danger posed by breakout of lava from crater lakes and from flank eruptions, unusually rapid lava flowage and inundation, deadly CO₂ hazards at the Mazukus, and the potential for explosive phreatomagmatic eruptions.

I believe that enhanced radar-satellite monitoring and study of the Virunga volcanoes will be especially important, both for detecting changes that enable warnings of eruptions, as well as for advanced analysis of the internal structure, magmatic "plumbing" and eruption dynamics of the volcanoes. The Supersite designation, with the resulting access to repeat SAR data, would be a major step in advancing public safety and scientific understanding in the region.

Over the past decade the USGS-USAID has supported annual training for scientists from GVO through the Center for the Study of Active Volcanism, a partnership program of the University of Hawaii and VDAP. This training program has provided post-graduate experience in volcano monitoring for a number of GVO scientists. The CSAV program, along with long-established collaboration between scientists from GVO and many other international partners, puts the observatory in an excellent position to serve as an effective partner in the Supersite program, fostering expanded international collaboration and putting InSAR and SAR data to work to address the hazards and the science related to volcanic activity in the region.

Best regards,

Dr. John S. Pallister
Chief, Volcano Disaster Assistance Program
U.S. Geological Survey



The State University
of New York

Dr. Estelle Chaussard
Assistant Professor of Geophysics and Volcanology
State University of New York, Buffalo
Department of Geology
126 Cooke Hall
Buffalo, NY 14260-1350

May 2nd, 2017

Dear Dr. Balagizi,

I am writing this letter in support of the proposed Supersite initiative by the Goma Volcano Observatory. I have been performing geophysical and remote sensing research of lava flow emplacement using SAR imagery and I am eager to examine lava flows in Virunga. Nyamulagira volcano has erupted every few years, providing an ideal natural laboratory to develop models of lava flow emplacement and cooling to better constrain the parameters controlling the observed deformation signal. Such models are important for characterization of geologic hazards associated with volcanism in the region and would help better understand signals observed at volcanoes worldwide. Therefore, there is a need to gain access to data and to established strong collaborations with partners in the region to benefit from this natural laboratory and to improve hazards assessment and mitigation.

I am enthusiastic by the opportunities that this proposed Supersite initiative poses, and will be happy to participate with you and other colleagues in research and outreach projects, as I believe they would lead to a better understanding of the Virunga volcanoes and, by extension, of similar volcanoes worldwide. Please let me know how I can be of any further assistance.

Most Sincerely,

A handwritten signature in black ink that reads "E. Chaussard".

Estelle Chaussard



United States Department of the Interior
U.S. Geological Survey
Volcano Disaster Assistance Program
Cascades Volcano Observatory
1300 Cardinal Court
Vancouver, WA 98683

May 22, 2017

Dear Dr. Balagizi:

I am pleased to write in support of the Goma Volcano Observatory's (OVG) proposal to create a Supersite for the Virunga Volcanoes region. As the lead seismologist for the USAID-USGS Volcano Disaster Assistance Program, I understand the inherent hazards associated with the Virunga region that result from high density population living within an active volcanic and tectonic rift zone. Such hazards result from seismicity that precedes eruptions, from rapid moving lava flows that can initiate on the volcano's flanks and inundate populated areas, from gases that are continually released and form acid rain, or from CO₂ that exsolves from magma and collects in low lying areas (mazukus) and beneath Lake Kivu.

The Supersite designation will provide repeat SAR data and thus provide better time resolution of the evolving magmatic system of the region. Enhanced radar satellite monitoring and the study of the Virunga volcanoes will bring together local and international agencies and scientists to better understand and detect changes that precede eruptions and occur as a result of earthquakes and eruptions, thus better enabling the OVG to plan for and forecast potential hazards to at risk communities.

I have had the good fortune to work with you and other colleagues from the OVG over the last 6 years, both through the training I provide in the seismology section of the Center for the Study of Active Volcanism course and through ongoing collaborations regarding the interpretation of seismicity at Nyiragongo and Nyamulagira volcanoes. The OVG and its highly qualified scientists will serve as excellent partners in the Supersite program, and will foster further international collaboration in the Virunga region and take advantage of the InSAR and SAR data to address the many hazards and interesting science related to volcanic and seismic activity of the active continental rift region.

With my warmest regards,

Dr. Wendy McCausland
Volcano Disaster Assistance Program
U.S. Geological Survey



May 5, 2017

To:

Mr. Charles Balagizi

Goma Volcano Observatory, D.R of Congo

Letter of support for Virunga Supersite proposal

Dear Dr. Charles Balagizi,

I am writing this letter in support for the proposal of the Goma Volcano Observatory (GVO) to create a new Supersite on the Virunga volcanoes. Virunga Volcanic Province has two of the most active volcanoes in Africa, Nyiragongo and Nyamulagira, which threaten the city of Goma where about 1 million people live. There is therefore an important need to better understand the eruptive activity in this region. In the past years, I've been studying these volcanoes using ground deformation data (GPS and Radar interferometry). By using SAR imagery, my research has contributed to better quantify the volume of the lava flows emplaced during the 2011-2012 Nyamulagira eruption. Such information is important for volcano observatories because it helps to mitigate and forecast lava flows hazards. This example clearly illustrates how the GVO can benefit from international research projects to improve hazards assessment and risk mitigation. To pursue this effort, we need to establish strong collaborations between the GVO and international research teams, as well as to improve the accessibility of the geodetic data (GPS, InSAR, seismic) to facilitate research projects. Therefore, I believe that the creation of a Supersite on the Virunga volcanoes perfectly answers to these needs.

I am enthusiastic about research opportunities that this new Supersite will open, and I will be please to continue to participate in research projects in relation with Virunga volcanoes. Please let me know how I can be of any further assistance.

Sincerely,

Fabien Albino

A handwritten signature in black ink, appearing to read 'Fabien Albino'.

Fabien Albino
PhD in Geophysics

Phone: 1 305 421-7088 E-mail: fabino@rsmas.miami.edu

Prof. Andy Hooper
COMET
School of Earth and Environment
University of Leeds
Leeds LS2 9JT

T +44 (0) 113 343 7723
F +44 (0) 113 343 5259
a.hooper@leeds.ac.uk



UNIVERSITY OF LEEDS

To:
Dr. Charles Balagizi
Geochemistry and Environmental Department
Goma Volcano Observatory
142 Avenue du Rond-Point, Goma
DR Congo

Re. Letter of Support Virunga Volcanoes Supersite

Dear Dr. Balagizi,

I would like to express my strong support for the Virunga Volcanoes Supersite proposal that will be submitted by the Goma Volcano Observatory to the Geohazard Supersites and Natural Laboratories Scientific Advisory Committee (GSNL).

There have been several studies based on the relatively sparse satellite radar data set collected over the Virunga volcanoes until now, in which I have played a small part. But there remain many unresolved questions that could potentially be addressed with the additional data that would flow, should it be designated a Supersite. This highly active volcanic region offers an excellent natural laboratory to improve our understanding of magmatic plumbing systems and eruption dynamics in general, but importantly, it is also an area with a vulnerable population that would benefit directly from advances made.

Your proposal represents an excellent scientific opportunity that will also serve societal need, and I would be happy to contribute in any way that may be useful.

Yours Sincerely,

A handwritten signature in black ink, appearing to read 'Andy Hooper', with a long horizontal stroke underneath.

Professor Andy Hooper
COMET

Letter of support for Virunga Volcanoes Supersite

29 March 2017

To whom it may concern,

This is to offer my strong support for the proposal by the Goma Volcanological Observatory to make the Virunga volcanoes a Geohazards Supersite. The volcanoes and earthquakes of the East African rift present a major geohazard that is relatively poorly understood and quantified compared to most other regions of the planet. This is a major problem since Africa has one of the fastest growing populations with natural hazards posing one potential threat to economic and social development. These problems are particularly acute in the Virunga region. I therefore strongly support improvements to the capability of the Goma Observatory to monitor the continuous activity associated with rifting and volcanic activity, and to use higher volumes and quality of data to improve their, and the scientific communities, understanding of the process and their timescales that pose a potential threat to populations and infrastructure.

Sincerely,

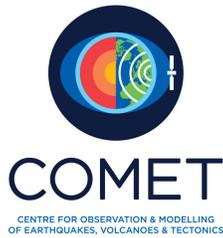


Derek Keir

PI of NERC large grant RiftVolc - Understanding volcanic and tectonic processes in the Ethiopian rift, past, present and future.

Associate Professor in Earth Science, School of Ocean and Earth Science
Direct tel: +44 (0)23 80593786; email: d.keir@soton.ac.uk
www.southampton.ac.uk/oes/about/staff/dk1d10.page





School of Earth Sciences
Wills Memorial Building
Bristol BS8 1RJ
juliet.biggs@bristol.ac.uk

Dear Dr. Balagizi:

I am writing in support of the Virunga Volcanoes Supersite proposal that is being put forward by the Goma Volcano Observatory. I am writing on behalf of Professor Tim Wright, who is currently the Director of the UK Centre for the Observations and Modelling of Volcanoes, Earthquakes and Tectonics (COMET) to express the support of the COMET network for the Virunga supersite. COMET researchers are actively involved with several other supersite and CEOS projects and would contribute to the Virunga supersite with similar enthusiasm.

I would also like to express my personal support for the project - I have been working on earthquakes and volcanoes in the East African Rift for the past decade, including research programmes in Ethiopia, Kenya, Tanzania and Malawi. I currently co-lead a £3.7M UK research project working to understand rift volcanism focused on the Main Ethiopian Rift and a £1.3M Global Challenges Project to build seismic resilience in Malawi. Understanding rift-related hazards is therefore a topic close to my heart, and it would be a great step forward to establish a supersite in this region where volcanism is understudied, with large population exposures, high uncertainties and little monitoring.

The recent UN Global Assessment of Risk ranked the Virunga volcanoes at hazard level 2 (on a scale of 1-3, with 3 the highest) and population exposure level 5 (on a scale of 1-6, with 5 the highest). Furthermore, continental rift volcanoes are scientifically interesting. Some open questions are: What are the pathways and timescales of magma transport in an extensional setting? What governs the bimodal and peralkaline composition of the magmas and what influence does that have on eruption styles and frequencies? Nyiragongo is a rare example of a lava lake volcano, and provides a valuable opportunity to study the processes and mechanics of shallow magma conduits. Unlike the majority of East Africa's volcanoes, the Virunga volcanoes have a dedicated volcano observatory and ground-based monitoring network. From scientific, societal and practical purposes therefore, Virungona is an ideal location for Africa's first supersite.

Finally, I wish you the best of luck with your proposal,

Yours sincerely,

Juliet Biggs
University of Bristol



**UNIVERSITÄT
BAYREUTH**

**Institute for Geography
Dept. of Political Geography
University of Bayreuth
Bayreuth, Germany**

Prof. Dr. Martin Doevenspeck

Geographisches Institut • 95440 Bayreuth

Dr. Charles Balagizi
Geochemistry and Environmental Department
Goma Volcano Observatory
142 Avenue du Rond-Point, Goma
DR Congo

Phone: (+49)921 / 55 - 2273

Telefax: (+49)921 / 55 - 4118

Email: doevenspeck@uni-bayreuth.de

23.05.2017

Virunga Volcanoes Supersite, support letter

Dear Dr. Balagizi,

I am pleased to offer my support for the Virunga Volcanoes Supersite proposal that will be submitted by the Goma Volcano Observatory to the Geohazard Supersites and Natural Laboratories Scientific Advisory Committee (GSNL). I have been coordinating a team working in the region of Goma, Gisenyi and Bukavu on topics related to migration, society-environment relations and risk and conflict. In the Virunga region in general, and particularly in the city of Goma and its surroundings the population lives with multiple and especially with extremely high volcanic risk. Facing armed conflict in the hinterland of Goma many people continue to move to the region in search of security and better living conditions. This mass movement contribute to the high population growth of Goma and continuously increase the population at risk.

As you know we have been collaborating with scientists and staff of the Goma Volcano Observation in order to evaluate the vulnerability of the population and the volcanic risk in the region of Goma. I am convinced that the opportunity offered by the Virunga Volcanoes supersite, with the support of the GSNL, will help to collect more information about natural hazards and the vulnerability of the population in the region, and thus yield improvement of volcanic risk reduction and management in Goma as our common goals.

I am looking forward to working with the Goma Volcano Observatory through the Virunga Volcano Supersite.

Kind regards,

Prof. Dr. Martin Doevenspeck



Ruprecht-Karls-Universität Heidelberg
Institut für Umweltphysik



Institut für Umweltphysik · Neuenheimer Feld 229 · D-69120 Heidelberg

Dr. Nicole Bobrowski

Im Neuenheimer Feld 229
69120 Heidelberg

Tel: +49 (0)6221) 54 6309

Fax: +49 (0)6221) 54 6405

nbobrows@iup.uni-heidelberg.de

<http://www.iup.uni-heidelberg.de>

27.05.2017

Dear Dr. Charles Balagizi,

It is a great pleasure to offer my support for the Virunga Volcanoes Supersite proposal which is being put forward by the Goma Volcano Observatory. As you know I have been working on Nyiragongo and Nyamulagira volcano since several years, and can thus attest Goma and the surroundings live under high volcanic risk.

Scientifically both volcanoes are very fascinating and since my first visit on Nyiragongo in 2007 we have gained interesting results on the very distinct plume composition of both volcanoes and also the occurring changes in gas emissions from 2007 until today, during various campaigns. The measurements carried out together with colleagues from OVG and colleagues from Italy were quite successful, e.g. the first gas composition measurements of Nyamulagira, the gas composition changes observed during lava lake level changes...etc. Often the campaigns were joined by other teams from US or also from Switzerland and Sweden, which was quite useful also for logistics and also to get a broader view of things. Like you know I'm really looking forward for a continuation in our collaboration, and it would be great to combine the measurements more interdisziplinär.

I certainly support the request of the OVG to establish a Virunga Supersite, which will facilitate and give good motivation for a wider international and local collaboration of scientist with a great potential to enlarge the understanding of the volcanic systems. The supersite initiative will also help to improve the monitoring of Virunga active volcanoes and therefore reduce the related hazards, which are many in the Virunga volcanic chain.

I would be happy to help also with further capacity building of OVG colleagues, done by seminars like during the last visits and short training units.

I'm really looking forward to a continuation of our fruitful collaboration.
with very best regards.

Nicole Bobrowski

François Kervyn
Royal Museum for Central Africa
Head of Natural Hazards Unit
Email : francois.kervyn@africamuseum.be
Phone : +32 2 769 54 33

To whom it may concern

Goma, 8th June 2017

Concerns: Proposal for the Virunga as a Super Site candidate

Since 2005, the Royal Museum for Central Africa (RMCA) together with the European Centre of Geodynamics and Seismology (ECGS) and the National Museum of Natural History (NMNH) are collaborating and supporting the Goma Volcano Observatory in DR Congo for the monitoring of the two active volcanoes of the Virunga, the Nyiragongo and the Nyamulagira.

As coordinator of the various projects developed since 2005, I was in charge of ensuring their accomplishment and fulfill of their respective objectives.

The RMCA research activities are focused on InSAR modeling of ground deformations, volcano-structural mapping from e.g. EO data, and the monitoring of the Nyiragongo lava lake dynamic and crater evolution.

Beside these natural science-oriented researches, the RMCA is also strongly involved in the assessment of the risk based on the combination of hazard data with vulnerability assessment of the population exposed to these hazards.

All these activities are following a multifold objective: 1/ a contribution to the better understanding of the geohazards and the associated risks, 2/ the reinforcement of the local expertise in geohazards studies, 3/ the development of decision supporting tools for the local partners and the authorities in-charge of risk management, and 4/ all of them are converging towards the development of the most appropriate DRR policies.

The Kivu Basin region is from different perspectives a particular context: a densely populated region affected by recurrent armed conflict and the related humanitarian consequences, a large variety of hazards that spreading over political borders, and a difficult institutional context with often governance difficulties affecting all the sectors.

Within that context, developing high quality research is a challenge that requires all these various aspects to be taken into account. It goes much farthest beyond deploying instruments and interpreting the signals: above all, it imposes to address in priority the long-term perspective where

training is required to ensure the maintenance of the equipment and incorporation of the shared capacities and tools. It also requires developing a network of contacts at decision levels in an often-changing political environment where geohazards have often a much lower priority status.

In that perspective, the proposal for promoting the Virunga as a Super Site is of course a very good initiative that I fully support. However, despite the fact that it would probably increase the scientific attention of the remote sensing community, that initiative must above all ensure the benefits of the local needs and in particular preserve the ground segment that has taken years to emerge. Therefore, after discussing that opportunity and, in agreement with the Goma Volcano Observatory management, I endorse the initiative but raise attention to the following challenging issues:

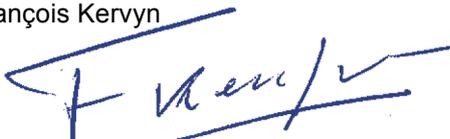
The Super Site initiative has

- to ensure the sustainability of the ground observation networks (maintenance, repair, replace, modernize) by providing the necessary support (i.e. funding but also on site expertise and support). This also includes the structural needs as transport, power, Internet, data transmission systems...);
- to ensure the GVO access to the EO data provided by the Super Site support;
- to ensure the development of the GVO staff skill in an efficient and sustainable way. This is for both consolidating the in-situ data acquisition and interpretation, and EO data processing and interpreting.

GVO, RMCA and ECGS/NMNH are at the origin of these data and consent the necessary time, energy and budget to make all this possible. But as research institutions, we would be very pleased to increase the science/logistic ratio and concentrate more on research. Should the Super Site initiative be in a position to find alternate solutions and support GVO, RMCA and ECGS/NMNH group or another to pursue these tasks it would be really appreciated.

Moreover, the Super Site initiative must consider that ground-based networks are resulting from a regional and international collaboration involving various institutions including GVO. Therefore, the share of ground-based data would necessarily involve a regional agreement with the Rwandese authorities, the University of Burundi, the Université Officielle de Bukavu, and the Centre de Recherche en Sciences Naturelles from Lwiro. All are contributors of the seismic, GNSS, and weather stations networks and are bonded in MoUs and Data Sharing Agreements designed to guarantee the contributing scientists from these institutions to take the full benefit of their work. They all spend a substantial part of their time in the field to solve logistical or political issues at the expense of the scientific exploitation of the data.

François Kervyn





Dr. Pierre-Yves Burgi
Vice-president of the Société Volcanologie Genève
1219 Geneva - Switzerland

Pierre-Yves.Burgi@unige.ch

To whom it may concern

Genève, May 26th, 2017

About: Support letter for the proposed « Virunga Volcanoes Supersite »

Dear Sir:

Through this letter I would like to testify my support to Dr. Charles Balagizi and his colleagues for their project of joining the Goma Volcanological Observatory to the Geohazard Supersites and Natural Laboratories (GSNL).

Several members of the Société Volcanologique Genève (SVG), which I represent herein, have been working on regular basis for many years (since 2005) and intend to carry on their effort in close collaboration with the scientists of the Goma Volcanological Observatory to study the Virunga volcanoes, particularly the Nyiragongo¹.

Having the Goma Volcanological Observatory become member of the GSNL would confer the scientists of the Goma region and those willing to work with them proven advantages in order to bring more knowledge about the Virunga volcanoes so that they can be better monitored with the possibility of reduced related risks. This would also enable the Goma Volcano Observatory to get more resources, which are very much needed in this African region prone to recurrent socio-economic crisis.

I thus can only encourage the future adhesion of the Goma Volcanological Observatory to the GSNL so as to create this much-needed "Virunga Volcanoes Supersite".

Sincerely yours,

Pierre-Yves Burgi

¹ For instance, Burgi et al., Dynamics of the Mount Nyiragongo lava lake, Journal of Geophysical Research. B: Solid Earth and Planets. 2014, 119 (5) 4106-4122.

SUPPORT FOR VIRUNGA VOLCANOES SUPERSITE PROPOSAL

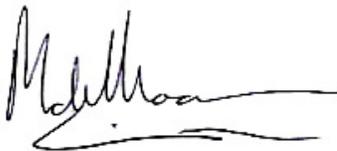
To Whom it May Concern,

This letter is intended to convey my most enthusiastic support for the proposal submitted by Dr. Charles Balagazi to recognize the Virunga Volcanoes as a GEO supersite. I am a specialist in volcanic gases, focusing on hazard assessment in Central America. From my professional perspective, Nyiragongo and Nyamulagira volcanoes present an extraordinary volcanic and gas hazard. Together, these two volcanoes emit more sulfur dioxide than all of the volcanoes in Central America combined, pointing to the vast and highly active magma systems feeding these volcanoes. The city of Goma, already wracked by decades of political instability, is directly threatened by fast-travelling (due to unusual magma composition and low viscosity) lava flows from Nyiragongo. Human health and development are undoubtedly adversely affected by acid rain and environmental degradation due to the ubiquitous presence of acidic volcanic gases.

Perhaps an even more worrying hazard than the volcanoes is the enormous mass of carbon dioxide and methane accumulated in Lake Kivu. The 1986 Lake Nyos disaster in Cameroon, which killed ~5000 people, highlights the hazard of gas accumulated in lakes. The mass of gas currently stored in Lake Kivu is orders of magnitude more than that release by Lake Nyos, and the number of people threatened by potential release of this gas is estimated at 1.5 million. Though the probability of massive gas release from Lake Kivu is probably significantly lower than lava flows in the near future, this hazard needs urgent attention from both research and mitigation perspectives.

There is enormous room for improvement in terms of monitoring the Virunga volcanoes and Lake Kivu. The recognition of this area as a GEO Volcano Supersite would bring unprecedented attention and resources to the impressive hazards present in the region. Whereas some important monitoring can be accomplished using satellites, there are many more sensitive ground-based methods that are urgently needed to fully assess the hazards and mitigate the risks. The team from Goma Volcano Observatory led by Dr. Charles Balagazi is the most qualified and enthusiastic group of volcanologists in Africa. They have my admiration for their persistence in facing the challenges presented to them on a daily basis. The Virunga Volcanoes should undoubtedly be recognized as a site of enormous concern from a hazards perspective as well as of unique scientific interest.

Sincerely,



Dr. J. Maarten de Moor
Volcanic Gas Specialist
OVSICORI (Observatory of Volcanology and Seismology – Costa Rica)
Universidad Nacional
Costa Rica

Kigali, June 8 2017

Being a long term partner of Goma Volcano Observatory (GVO), I am very happy to endorse this Super Site proposition.

The Virunga Volcanic Province is indeed a highly populated area threatened by two of the most active volcanoes in Africa. Despite the high volcanic risk that threatens the city of Goma and its surroundings (>1 million inhabitants), since the last eruption of the Nyiragongo in 2002, the international support so far provided to the Goma Volcano Observatory has failed to develop and maintain a sustainable monitoring capacity. This is partly due to the unique adverse context that characterizes the local situation: recurrent armed conflicts, commitment of the government limited by other priorities, limited skilled staff at GVO, inflation and irregular salary of the staff, insecurity, vandalism, destruction by lightning, unreliable infrastructure (transport, internet, power supply...) to mention a few issues. In that context, Earth Observation data provide an invaluable source of information. However, given the specific characteristics of the VVP volcanoes (open conduit system which usually does not favour long build up of pre-eruptive signals, extremely short eruption duration - one hour or less-, extreme fluidity of the lava etc...) and given the latency of the EO data delivery, the time required for downloading, processing and interpreting the EO data, these EO data alone are far from being sufficient to ensure the proper monitoring and protect the more than one million of inhabitants living in Goma and surrounding settlements.

As commonly implemented worldwide to monitor most of the regions threatened by volcanoes, remotely sensed databases must be complemented with real-time ground based data: seismic, ground deformation (GNSS, tiltmeters...), gas monitoring networks, etc. In addition, they must also be complemented with measurement campaigns such as microgravity, levelling etc.

However, the ground reality renders these activities very difficult to achieve and maintain in the Virunga region. Our experience is based on more **than 13 years of close cooperation with the Goma Volcano Observatory** through several successive research projects (co-)led by the Royal Museum for Central Africa (RMCA). Our development strategy prioritizes a long-term action and relies on the overlap of successive and complementary projects.

Over the last years, we have seen significant progress (improvement of the knowledge about the plumbing system and tectonic context, technological advances for data acquisition and transmission, cross-border initiatives, integrated multi geo-hazard studies...), but also some regress because of recurrent failures (e.g. by frequent lightning), robbery etc...

More specifically, in the frame of these successive projects, and often supported by limited resources from RMCA and NMNH/ECGS, we progressively conceived, developed and maintain a significant instrumental infrastructure: seismometers, GPS, infrasound and weather stations, gas sensors etc.

Today, the largest progress was achieved with the RESIST project (REmote Sensing and In Situ detection and Tracking of geohazards) that aims at studying the mechanisms leading to volcanic eruption in the Virunga and the triggering and controlling mechanisms of landslides in the Kivu. In the frame of that research project we developed and maintained **permanent seismic and geodetic networks. At the time of writing, these networks are composed respectively of 15 broad bands seismic stations, 3 infrasound arrays of 3 sensors each, and 15 GNSS stations located in DRC, Rwanda and Burundi.**

However, in the above-described context, it wouldn't be conceivable to acquire data for the sole benefit of scientific research without taking into account the urgent GVO needs for early warning tools. We wanted these efforts not only to be **valuable for research, but above all for monitoring needs.** We therefore spent a considerable amount of time to develop them as **real time monitoring systems, building full automated transmission and processing facilities at the local partners premises (at Goma Volcano Observatory and at the Rwanda Natural Resources Authority in Kigali).** We also spent considerable amount of time **ensuring appropriate training of the local partners** (e.g. 12 and 9 days long sessions organised in DR Congo and Rwanda in seismology and in GPS in 2015 and 2016, specific training during each of the several field missions conducted every year, specific training in Belgium, and support for master and PhD theses). This is complemented with a daily support by e-mail, Skype and Whatsapp to solve day-to-day minor and major issues.

All these time- and resource-consuming aspects go far beyond the commitments to the research project. The load of the task and the budget it requires (> than 2 full time jobs, requiring at least 4 visits on site per year —2 to 3 weeks each— and requiring many instrument repairs every year) is too heavy to be done without guaranty that we can at least produce some results along with GVO and/or the other local partners in the frame of that research RESIST project funded by the Belgian Science Policy (BELSPO) and the Luxembourg National Research Fund (FNR). Hence the access to these data is at present limited to the RESIST consortium and the local partners including GVO.

However, as announced in a recent paper published in Seismological Research Letters describing the seismic network, the seismic data acquired during the project will be open to the scientific community with a given latency period (see Oth et al, 2017, doi: 10.1785/0220160147), although data may be shared beyond this embargo policy for collaborative work. Given the very significant time required for field implementations and maintenance, a somehow longer though fair embargo for the data acquired in the RESIST framework is justified to ensure the consortium to reach the objective of the research that was funded by the project. This could be reconsidered in the case of an emergency or for collaboration with GVO that would not overlap with projects in the frame of which these instruments were deployed. For the data acquired after the project, a 3 years embargo was agreed with our local partners in the option that we would still be in charge of the maintenance of these networks.

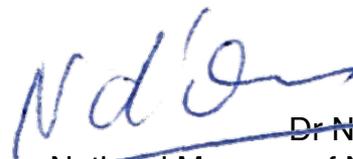
In addition, to facilitate the sharing at regional level and between other partners, MoU and data sharing agreements were signed to regulate the use of the produced data.

Today these data are telemetered and processed in real time at Goma Volcano Observatory (DRC), in Kigali (Rwanda) and in Luxembourg. A network of weather stations and rain gauges is completing the monitoring tools. Although additional seismic stations are expected to extend the existing network, **the monitoring capacity of the GVO still strongly relies on the strong partnership that has been developed since 2005.**

The Super Site initiative is definitely an exciting opportunity that could improve the local monitoring capacity. We therefore fully endorse it and are ready to reduce the data latency if GSNL or the community commit themselves in the long term support of GVO to sustainably produce these ground based data. In addition, if that task is ensured and/or funded on a long term basis by specific support that the Super Site Initiative can help to obtain, we would be ready to shorten this 3 years embargo. Such a decision and its conditions can, however, only be taken by the signatory parties of these MoU. See with that respect the following support letter from these signatory parties.

In conclusion, I recognize the urgent needs to help GVO in its tasks. I encourage the Super Site initiative to do so by motivating the international community to contribute to the research and monitoring for the primary benefit of that region. This will mean that considerable efforts will be required e.g. :

- **To allow GVO to access EO data (that is solving issues with internet quality, power supply, server infrastructure, archiving infrastructure, internet and computer security, lightning protection ...),**
- **To train GVO staff to the use of these EO data and offer Master and PhD opportunities, and**
- **To help GVO to ensure that it can fulfil its observatory tasks (budgetary and technical aspects, quick response in case of support needed etc...)**



Dr Nicolas d'Oreye
National Museum of Natural History
Dept. Geophysics/astrophysics
European Center for Geodynamics and Seismology
19 rue Josy Welter
L-7256 Walferdange
Grd Duchy of Luxembourg
ndo@ecgs.lu
www.virunga-volcanoes.org



Dr. Patrick ALLARD, Directeur de recherche CNRS emeritus
Institut de Physique du Globe de Paris
1 rue Jussieu, 75238 Paris Cedex 05
Tél: (+33)-1 83 95 76 30 - E-mail: pallard@ipgp.fr

Date: 04/06/2017

To Geohazards Supersite and Natural Laboratories SAC
www.earthobservations.org/gsnl.php

Object: Support Letter to the Proposal for a permanent Supersite '**Virunga Volcanoes**'

Dear colleagues,

I am honored to support a Proposal for establishing the very first permanent Geohazards Supersite in Africa, focused on Virunga Volcanoes and Lake Kivu, presented by Supersite Coordinator Dr. Charles Balagizi (Goma Volcano Observatory).

The Virunga-Kivu region, extending on the western branch of the East-African Rift (EAR), is an exceptional natural site for the great variety and high level of geohazards. It includes two permanently active volcanoes with lava lakes and frequent lava flow eruptions, tectonic earthquakes associated with rifting movements, landslides, CO₂-rich lethal gas emissions (mazuku), and potential threat from huge amounts (about 360 km³) of mixed CO₂-CH₄ dissolved in the deep water of Kivu lake. Moreover, these geohazards have long affected or/and threatened dense populations living in a status of high mean poverty at the borders of three countries (Democratic Republic of Congo, Rwanda and Uganda). Therefore, the Virunga-Kivu region, on the East-African Rift, definitely meets the requirements for becoming recognized as a GEO Supersite, involving international collaboration/support to improved scientific investigations, instrumental monitoring and operational risk mitigation.

In particular, the Virunga region hosts two of the most active volcanoes worldwide, Nyamulagira and Nyiragongo, which also rank amongst the most powerful emitters of SO₂ and other volcanic acid gases on Earth. Nyamulagira shield-volcano (3,058 m) erupts every 1-4 years, generating long-range (up to 30 km) destructive lava flows. Nyiragongo (3,470 m. a.s.l) hosts molten lava lakes of a highly fluid alkaline magma in its summit crater, whose potential drainage through volcano-tectonic fracturing directly threatens 1.5 million people living in the immediate surroundings and in the two cities of Goma (RDC) and Gisenyi (Rwanda). Such a

drainage previously occurred in January 1977 then in January 2002, delivering rapid lava flows onto the lower volcano slopes which made a high number of casualties. The 2002 eruption, especially, destroyed about 15% of Goma city and forced the temporary self-evacuation of ~300,000 persons. This event was actually the most destructive effusive eruption in modern history.

Therefore, it is quite logical that the Proposal headed by the Goma Volcano Observatory (GVO) be primarily focused on improved understanding and monitoring of the eruptive activities of both Nyamulagira and Nyiragongo. These two volcanoes are emblematic of continental rift alkaline magmatism on Earth, raising important questions upon their genesis and their long-term and short-term behavior. Since 2002 Charles Balagizi and the GVO team have been deeply involved into the various aspects dealing with Nyamulagira and Nyiragongo, including scientific research, instrumental monitoring and eruption forecasting (risk prevention and management). Over time the team has acquired a solid experience of the two volcanoes and of their surveillance. This makes Charles Balagizi and GVO the most obvious local coordinator of a Virunga Supersite. However, they badly need additional support from international agencies and networks in order to reinforce their capabilities in terms of number of qualified scientists and of diversity in modern (ground-based and space-borne) instrumental tools for both volcano monitoring and research. GNSL offers the dedicated international framework within which such a support could be provided if the Virunga Supersite Project becomes accepted and validated. A 'Virunga Volcanoes Supersite' should also stimulate international collaborations with GVO to study/monitor geohazards from Nyamulagira and Nyiragongo, as well as other geohazards related to tectonic activity in the East-African Rift (earthquakes, landslides, CO₂-rich gas emissions, and the potential of massive gas release in case of a destabilization of Kivu lake).

In summary, based on the above arguments I strongly recommend that GVO's proposal of creating a 'Virunga Volcanoes Supersite' – the very first Supersite in Africa – be positively considered by the SAC of GNSL.

I had the chance to early study Nyiragongo lava lake in July 1972 and to be among the four experts sent locally by France and UK during the 2002 eruption, so I am somewhat familiar with this incredible volcano. Since then, however, I had no personal interaction with GVO, so my support Letter is totally independent.



P. ALLARD

Vice-president of IAVCEI (2015-2019)

President of French volcanologists (CNFGG, since 2002)

Associate Researcher with INGV-Catania (Italy, since 2003)



**International Association of Volcanology and
Chemistry
of the Earth's Interior (IAVCEI)**

Bari, June 21, 2017

TO WHOM IT MAY CONCERN

This letter is to express the full support of International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) to the candidature of Virunga volcanoes for Geohazards Supersites and Natural Laboratories (GSNL).

Virunga volcanoes are located in a fertile and inhabited area, and deserve continuous observation and surveillance in order to mitigate volcanic hazards. These activities can be successful when based on a well-equipped, qualified and continuously entrained local scientist team. This justifies the need for establishing a "Virunga Volcanoes Supersites".

Sincerely,
Roberto Sulpizio
IAVCEI Secretary General

President
Donald B. Dingwell,
Department of Earth and Environmental
Sciences, Theresienstr. 41, 80333
Munich, Germany.
Tel: +49 (0) 89 2180 4136
Fax: +49 (0) 89 2180 4176
Email: dingwell@lmu.de

Secretary General
Roberto Sulpizio
Dipartimento di Scienze della Terra e
Geoambientali-UNIBA
Via Orabona 4, 70125 Bari, Italy
Tel: +39 0805442589
Fax: +39 0805442625
Email: roberto.sulpizio@uniba.it

Past-President
Ray Cas
School of Geosciences,
P.O. Box 28, Monash University,
Victoria 3800, Australia.
Tel: +61 3 9905 4897
Fax: +61 3 9905 4903
Email: ray.cas@monash.edu



**VAAC Toulouse,
42 Avenue G. Coriolis
3 1 0 5 7 T o u l o u s e
F r a n c e**

Toulouse, 27/06/2017

To :
Charles Balagizi, PhD
Geochemistry and Environmental
Department
Goma Volcano Observatory

142 Avenue du Rond-Point, Goma- DR

Letter of support

Dear Dr. Balagizi,

With this letter, the Volcanic Ash Advisory Center (VAAC) Toulouse commits its support to the Virunga Volcanoes Supersite proposal that is being submitted by the Goma Volcano Observatory (GVO) to the Geohazard Supersites and Natural Laboratories Scientific Advisory Committee.

The Virunga region, situated in the western branch of the East African Rift System is characterized with highly volcanic activity, where Nyiragongo and Nyamulagira eruptions, beyond the threat they pose to civil population in vicinity of the Virunga park, may release SO₂ and volcanic ash plumes.

The ash and gases emitted by Nyiragongo and Nyamulagira have the potential of crossing long distances, as was the case for the Nyamulagira 2006 eruption of which the plume crossed central Africa, the Middle East and even reached India.

They may thus represent a considerable danger for the local and international air navigation, and are accordingly of great interest for VAAC Toulouse, responsible for providing expertise on volcanic ash clouds (and very likely soon about SO₂ as well) to the International Civil Aviation Organization (ICAO) over Africa.



I strongly support the idea of establishing a supersite for the Virunga volcanoes, because of the following:

- the Virunga meets all the requirements for becoming recognized as a GEO Supersite,
- the idea of scientific investigations, through an EO data and in-situ instrumental monitoring based involving local and international scientists will yield the capacity building of local scientists. It will additionally improve the monitoring techniques and the early warning capacity of the local scientists and agencies, resulting in Risk Reduction in the Virunga.
- finally, the Virunga supersite will contribute, through the international scientific collaboration and collaboration with VAAC, to enhance the GVO's capability to issue on a regular basis VONA messages, as strongly recommended by the ICAO.

Looking forward to working with the Goma Volcano Observatory through the Virunga Volcano Supersite,

Best regards

Philippe HUSSON
MET Services for Aviation
Operations Head
VAAC Toulouse Manager

A handwritten signature in blue ink, consisting of stylized initials 'PH' followed by a long horizontal stroke.