



# Virunga volcanoes monitoring infrastructure

## Ground-based network and satellite remote sensing



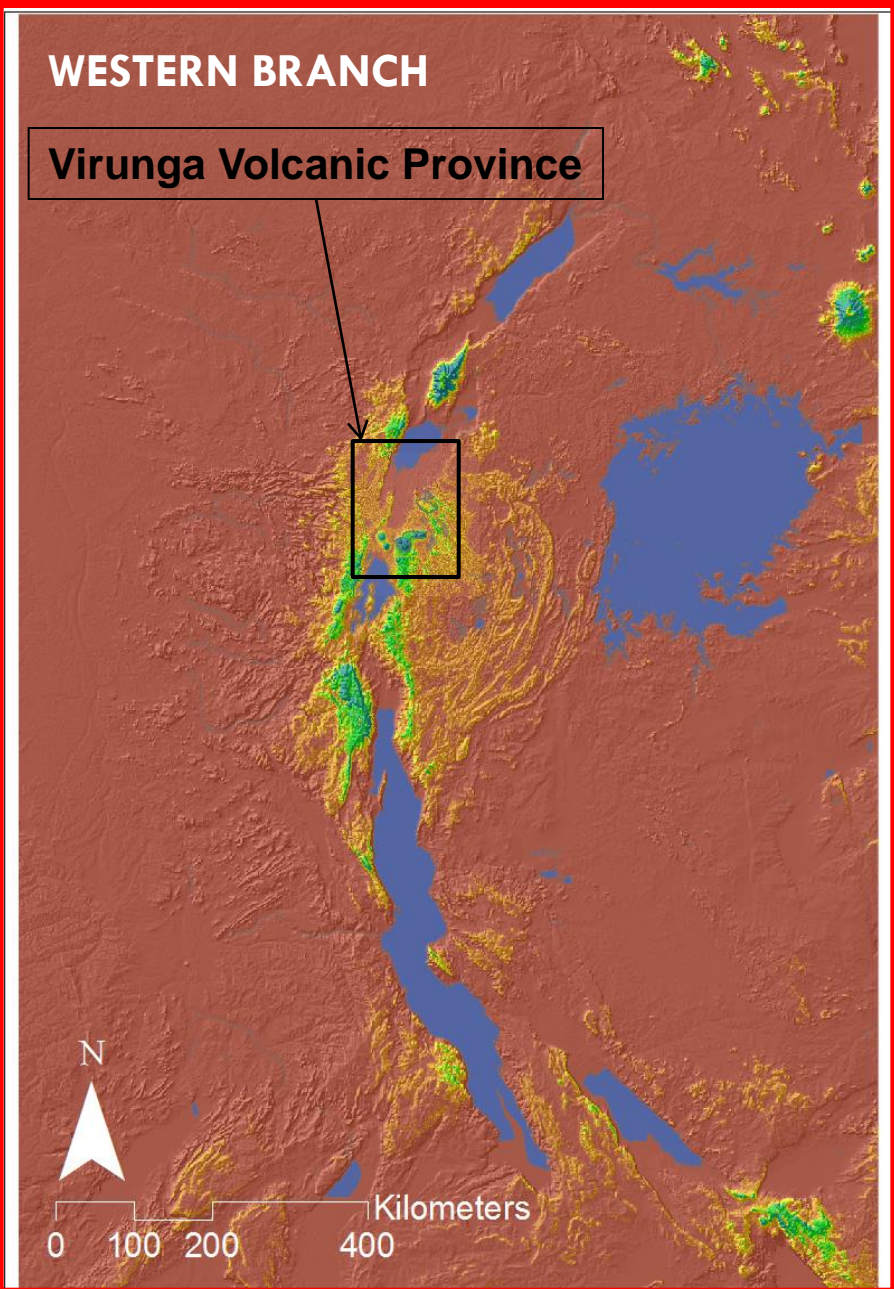
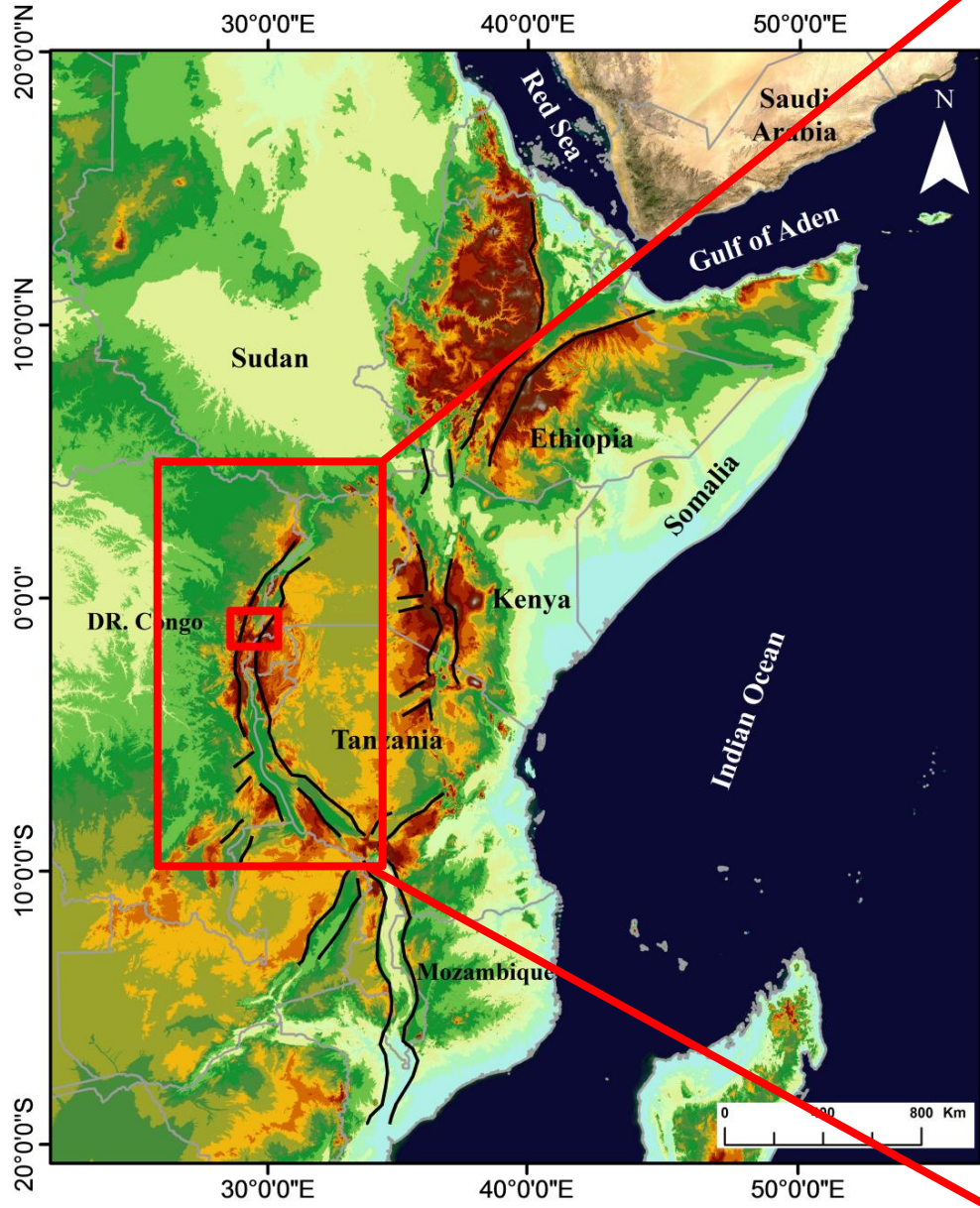
Charles Balagizi  
Virunga Volcanoes Supersite  
Goma Volcano Observatory

Workshop on volcano monitoring  
infrastructure on the ground and in space

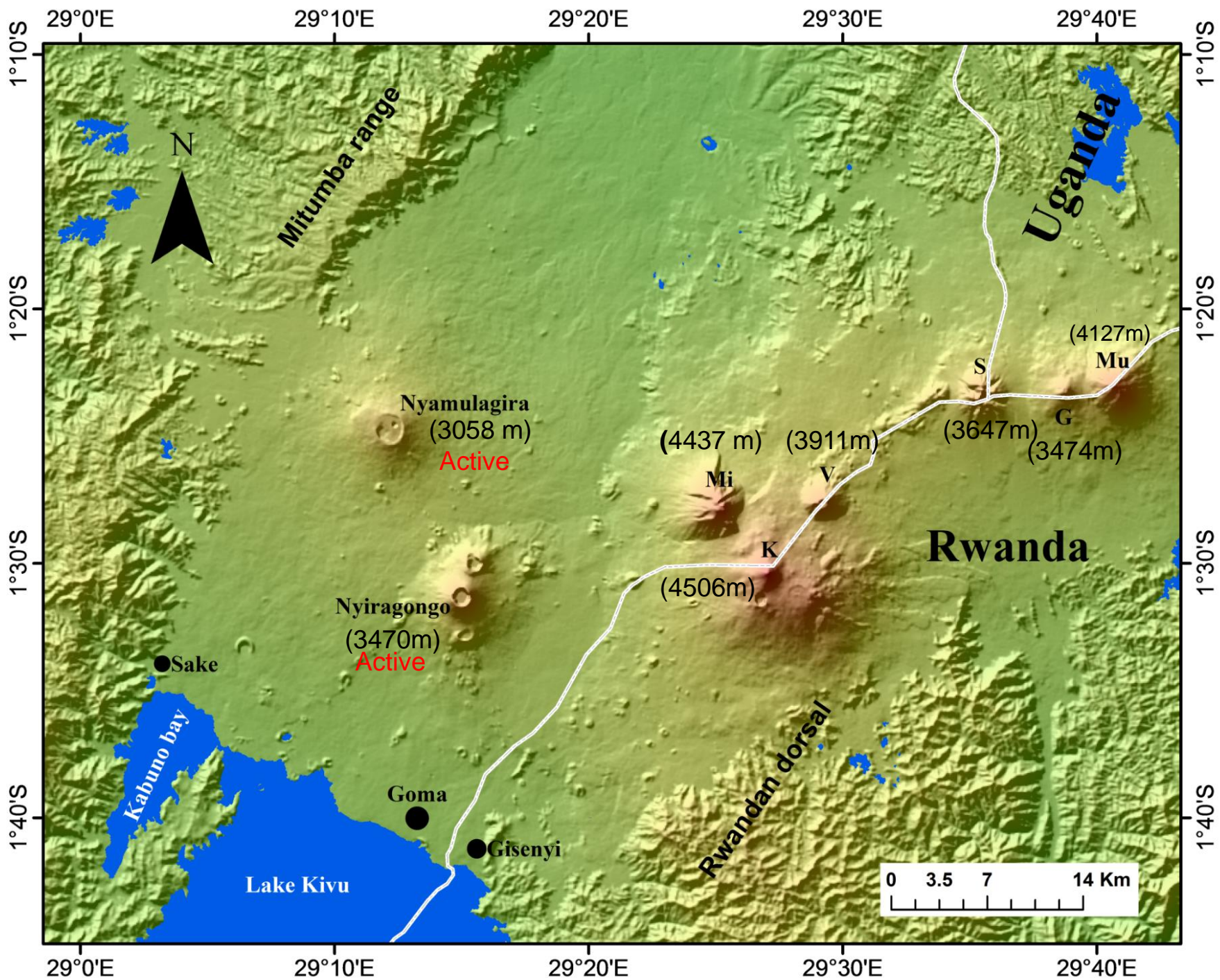
Feb 18- 23, 2021



# The East African Rift and the Virunga Volcanic Province





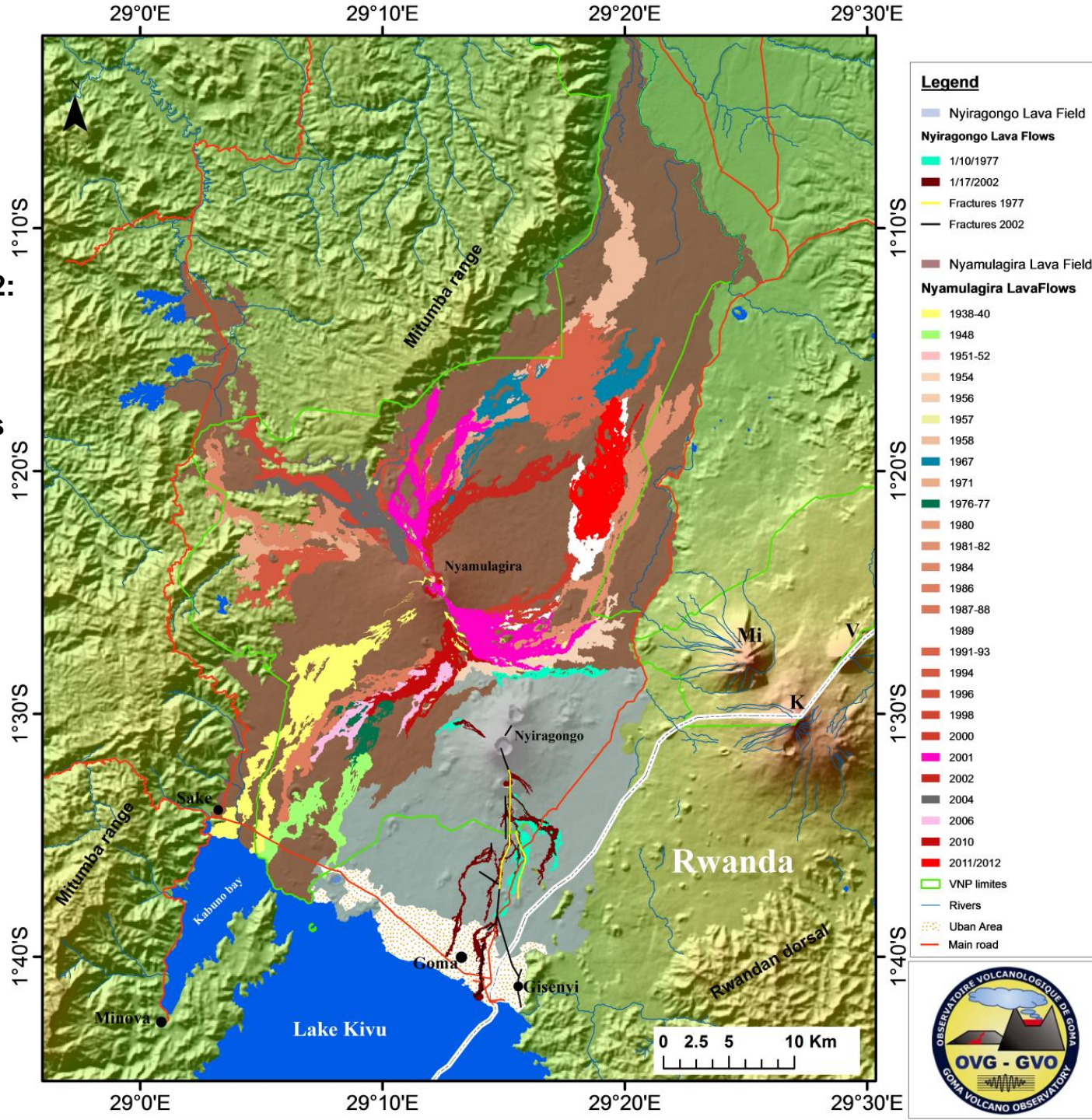




# Volcanological map

Known eruptions since 1882:

- Nyiragongo : 2 eruptions
- Nyamulagira: 44 eruptions





Nyirangongo

Nyamulagira



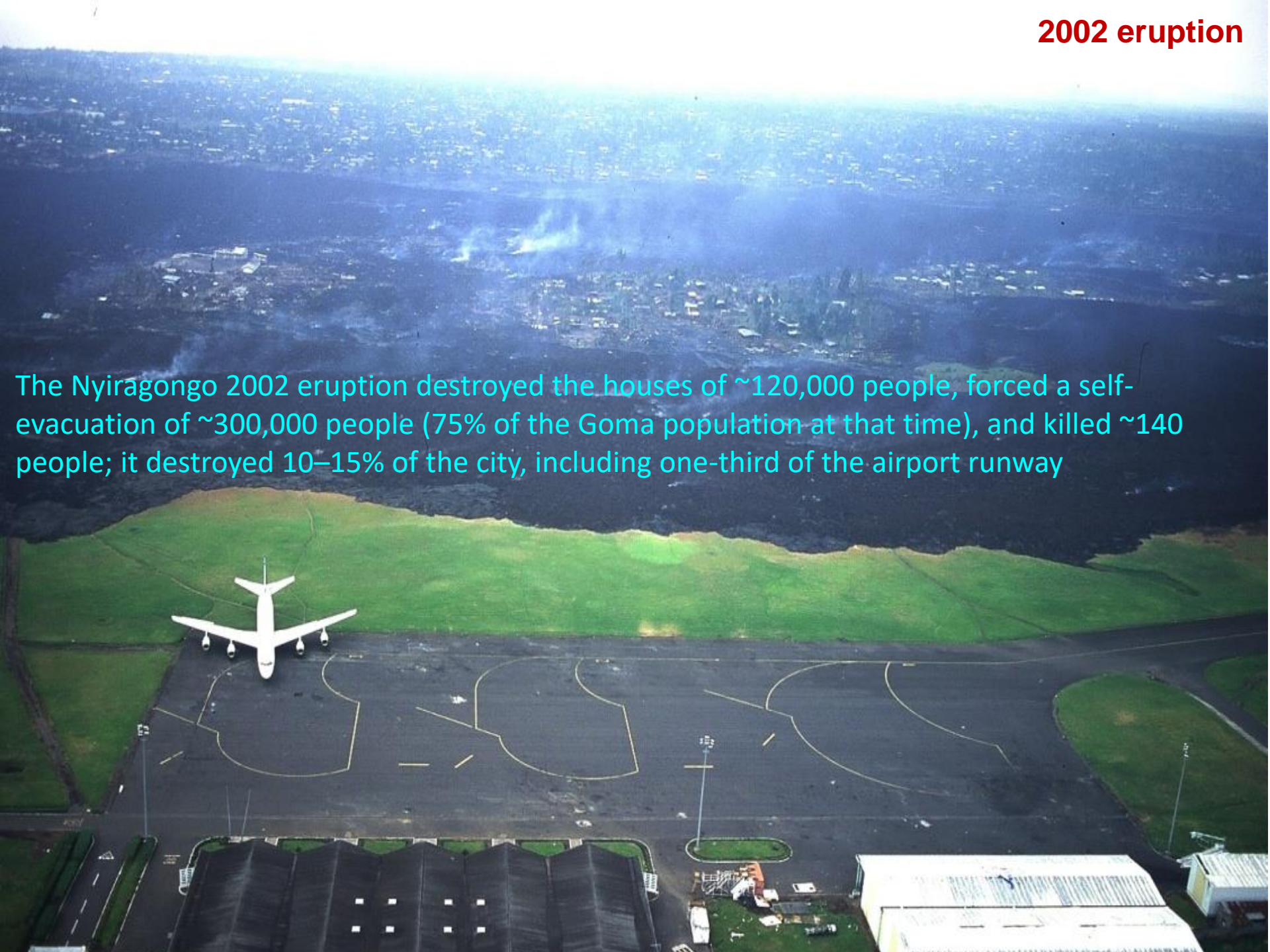


**~ 1,1 million people live in Goma city, 2013**





The Nyiragongo 2002 eruption destroyed the houses of ~120,000 people, forced a self-evacuation of ~300,000 people (75% of the Goma population at that time), and killed ~140 people; it destroyed 10–15% of the city, including one-third of the airport runway





## Goma, 2002 eruption

The Nyiragongo 2002 eruption destroyed the houses of ~120,000 people, and killed ~140 people; it destroyed 10–15% of the city,





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Nyiragongo 2002 eruption : forced a self-evacuation of ~300,000 people (75% of the Goma population at that time)



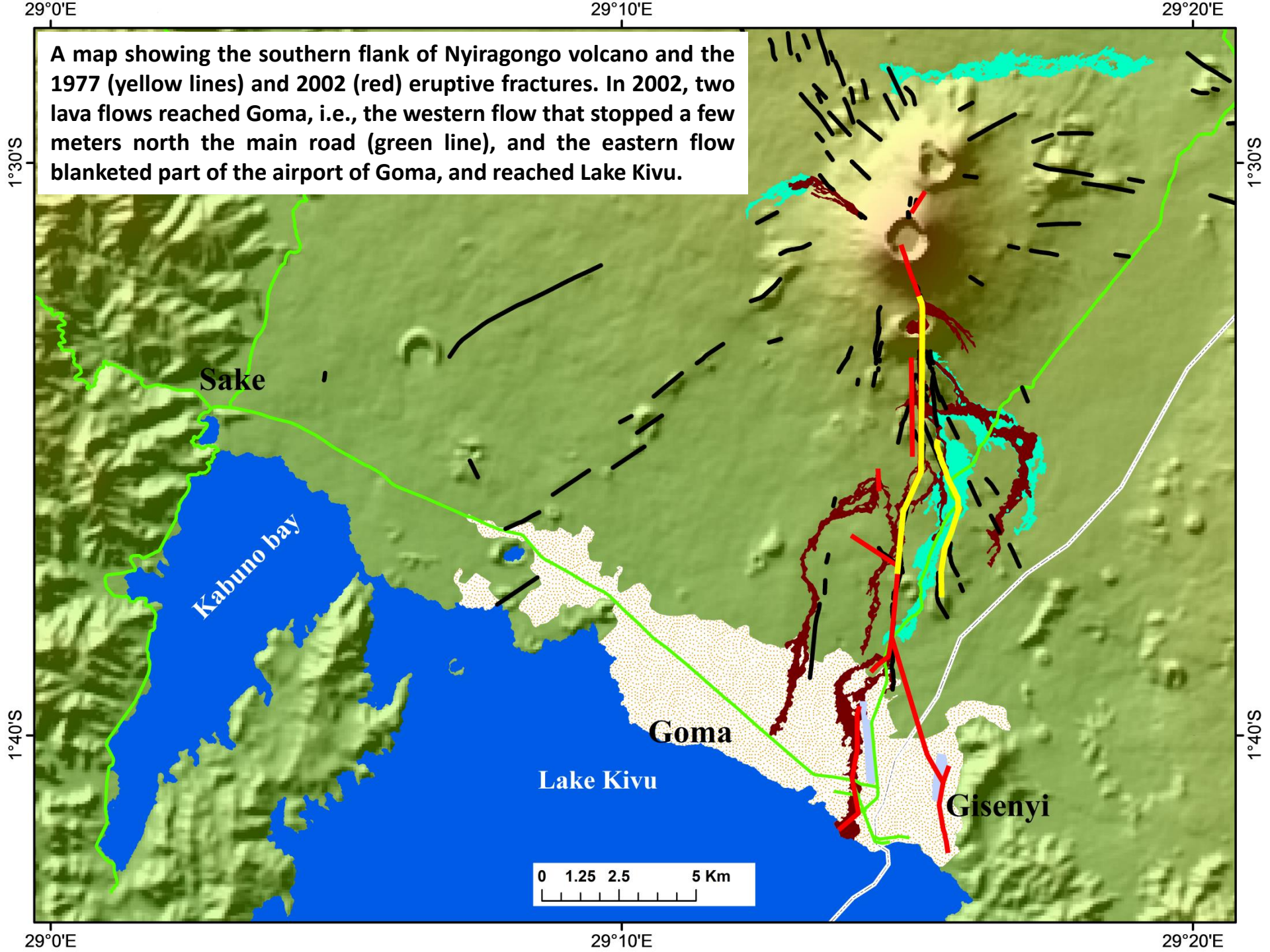


Nyiragongo 2002 eruption : forced a self-evacuation of ~300,000 people (75% of the Goma population at that time)

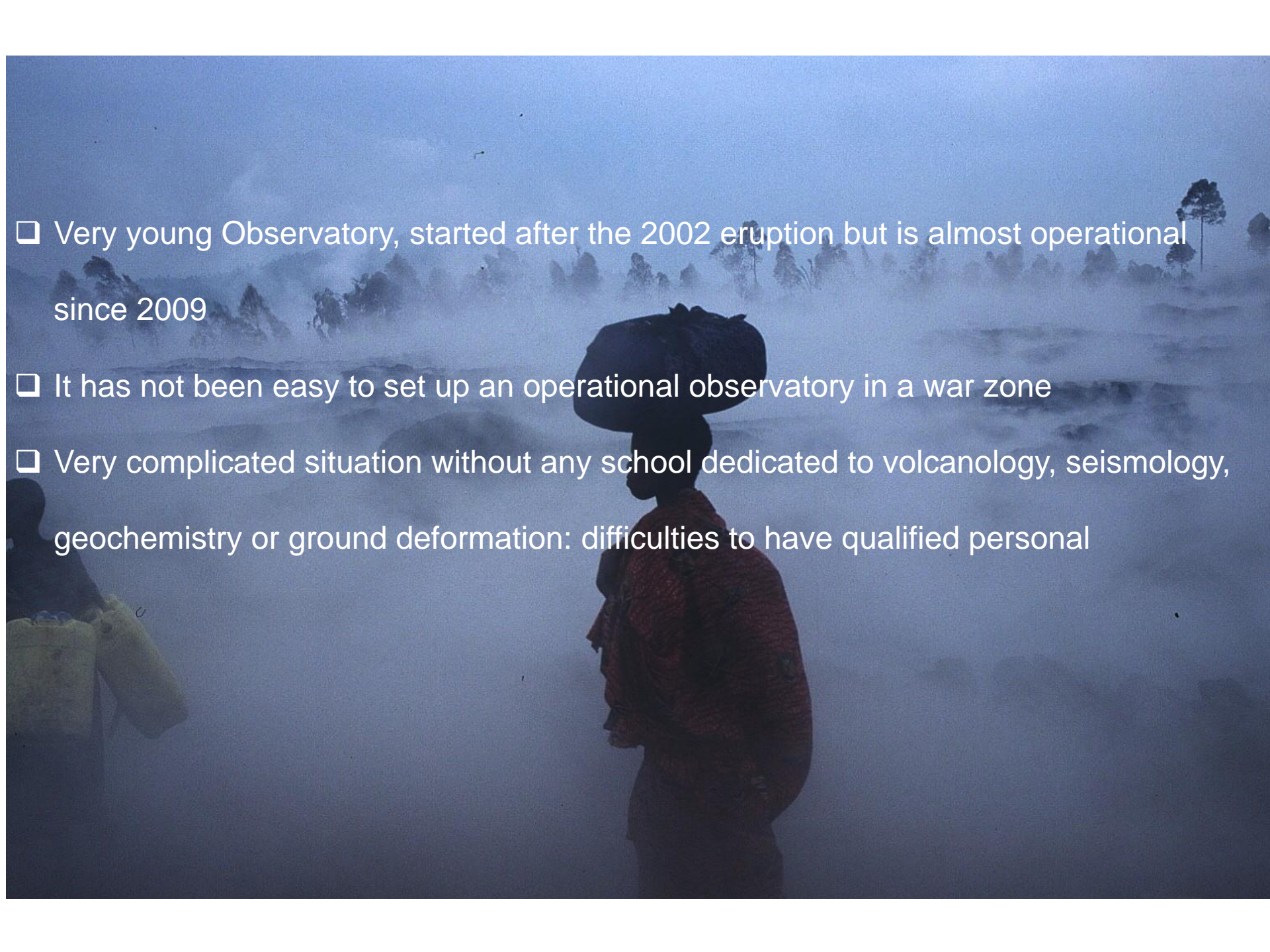




A map showing the southern flank of Nyiragongo volcano and the 1977 (yellow lines) and 2002 (red) eruptive fractures. In 2002, two lava flows reached Goma, i.e., the western flow that stopped a few meters north the main road (green line), and the eastern flow blanketed part of the airport of Goma, and reached Lake Kivu.





- 
- A person is seen from the side, carrying a large, dark, rounded basket or pot balanced on their head. They are wearing a red, textured garment. The background is a hazy, blue-tinted landscape, likely a volcanic area, with some trees visible in the distance. The overall atmosphere is misty and somber.
- ❑ Very young Observatory, started after the 2002 eruption but is almost operational since 2009
  - ❑ It has not been easy to set up an operational observatory in a war zone
  - ❑ Very complicated situation without any school dedicated to volcanology, seismology, geochemistry or ground deformation: difficulties to have qualified personal



# I.1. Presently available ground-based infrastructure

## SEISMOLOGY & GROUND DEFORMATION

### 15 seismic & 10 GNSS stations

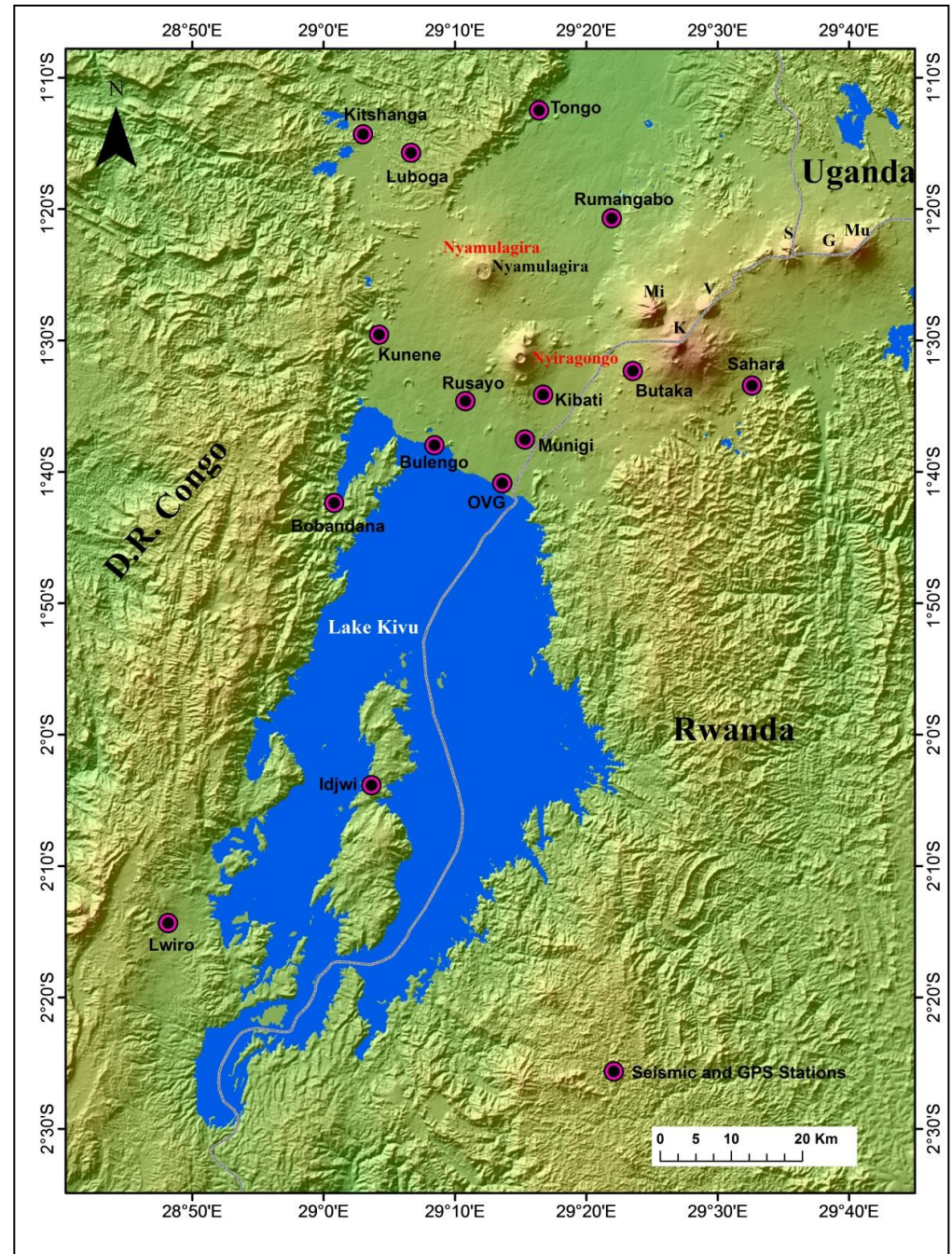
Data is sent to Europe in real time, we have to pay for the internet to get the data back in Goma.

No internet since at least 6 months, no real time.

Data is backed in the stations on key drives, but it is not possible to collect the data every day by going in the field. This is expensive that pay for the Internet.

### Data processing and interpretation

- Great and well team for seismic data processing and interpretation
- No capacity for GNSS data processing/interpretation (need to develop this)





# EDM at the summit of Nyiragongo



**EDM downtown**



**Extensometer measurements**



# GEOCHEMISTRY

Scan DOAS stations



Permanent station to be deployed at the summit of Nyiragongo

Mobile MultiGas



CO<sub>2</sub>, Rn, T° inside Nyamulagira crater



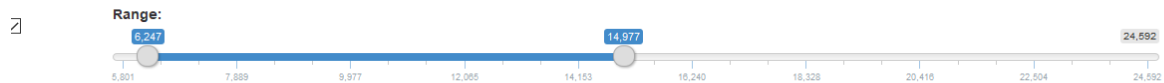
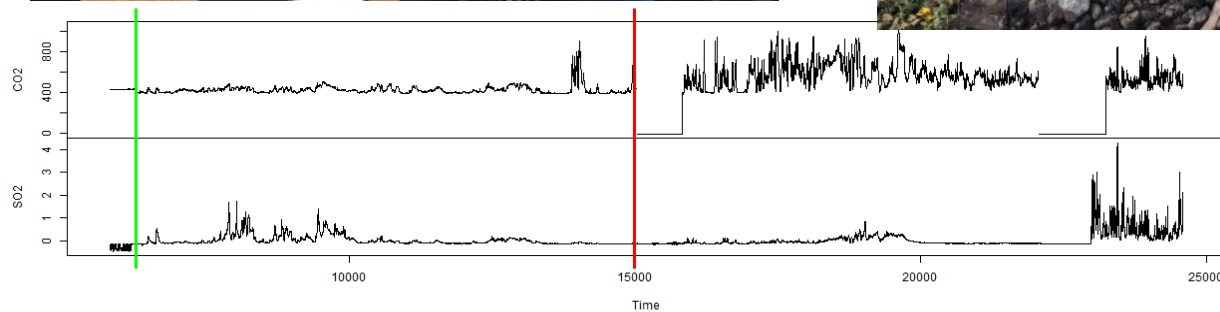


# MultiGas measurements

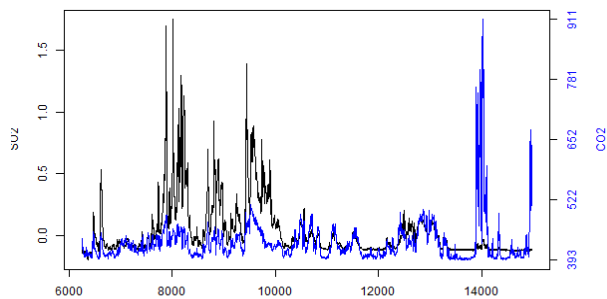
Training in Vancouver



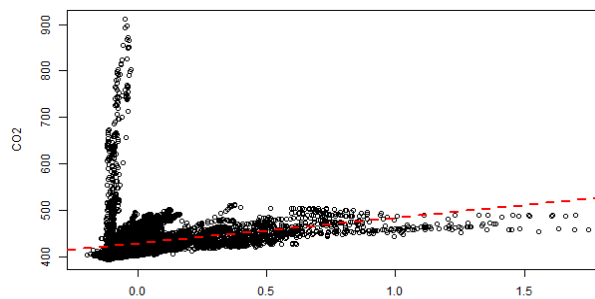
Field at Nyiragongo



# sample = 8731 max CO2 = 911



ratio = 13188  $y = 55.47x + 428.7$   $R = 0.2807$



Field data at Nyiragongo, monitoring



# GEOCHEMISTRY

29°0'E

29°10'E

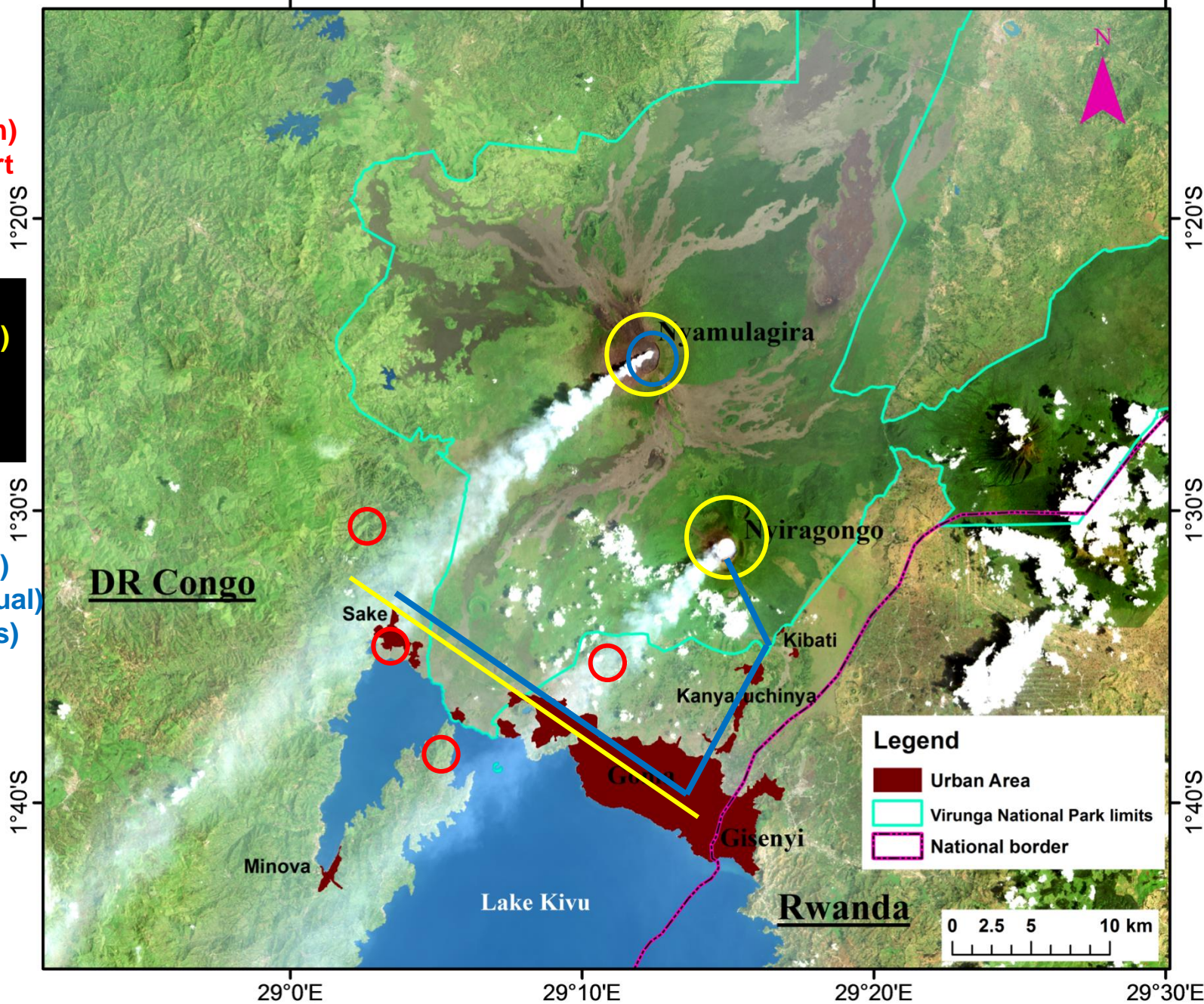
29°20'E

29°30'E

4 DOAS stations  
(1 is operational,  
2 others will soon)  
VDAP will support

MultiGas  
(1 station at Nyira)  
(other is mobile)  
VDAP donated

Soil CO<sub>2</sub> (punctual)  
Soil Radon (punctual)  
Soil T° (continuous)



29°0'E

29°10'E

29°20'E

29°30'E

1°20'S

1°30'S

1°40'S

1°20'S

1°30'S

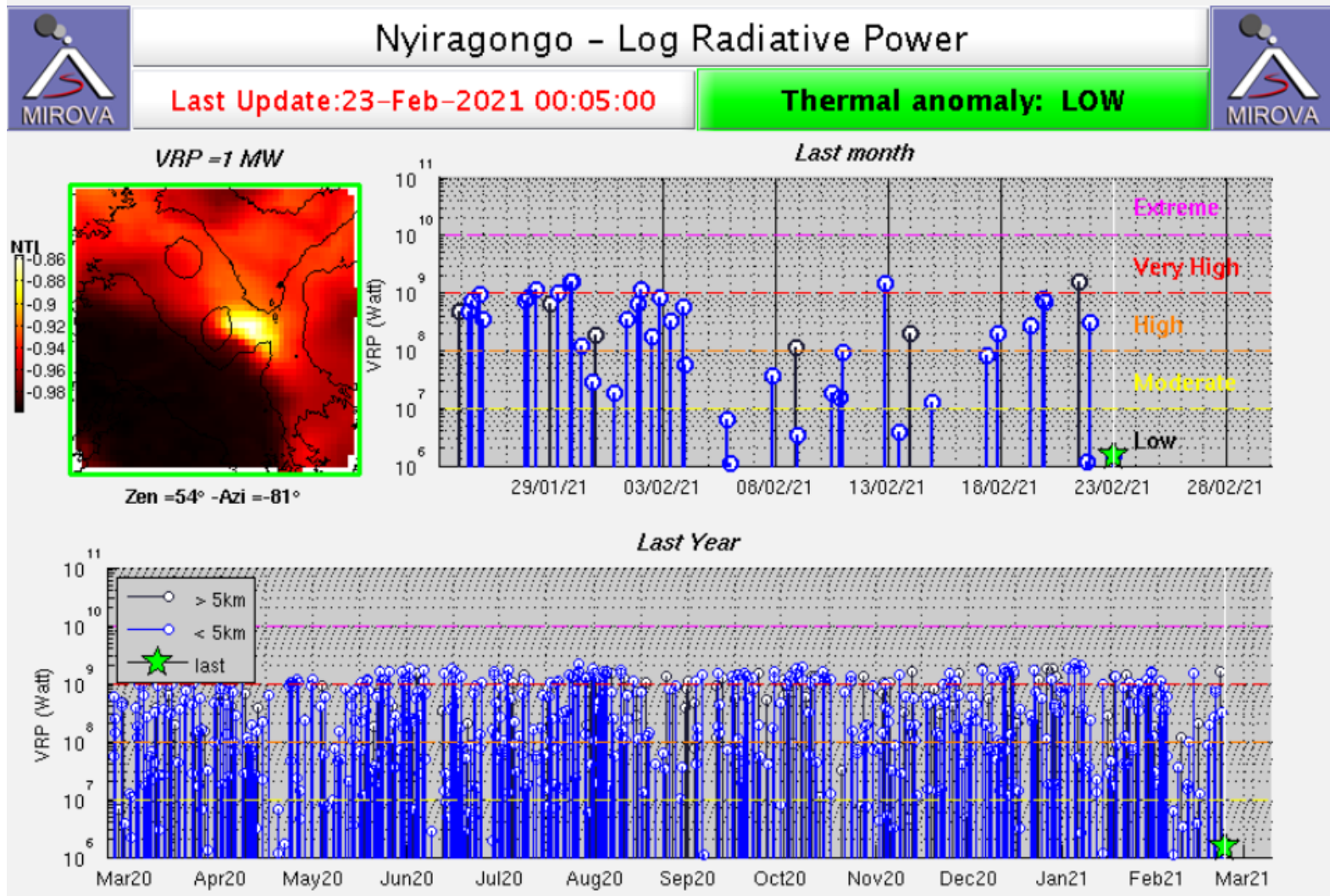
1°40'S



# I.2. Satellite remote sensing data

## Currently available satellite remote sensing processed data

### 1. Near real time thermal activity at Nyiragongo and Nyamulagira volcanoes MIROVA system



Data time series xls. file are received via email on request. Thanks Dr Diego Coppola ([diego.coppola@unito.it](mailto:diego.coppola@unito.it))

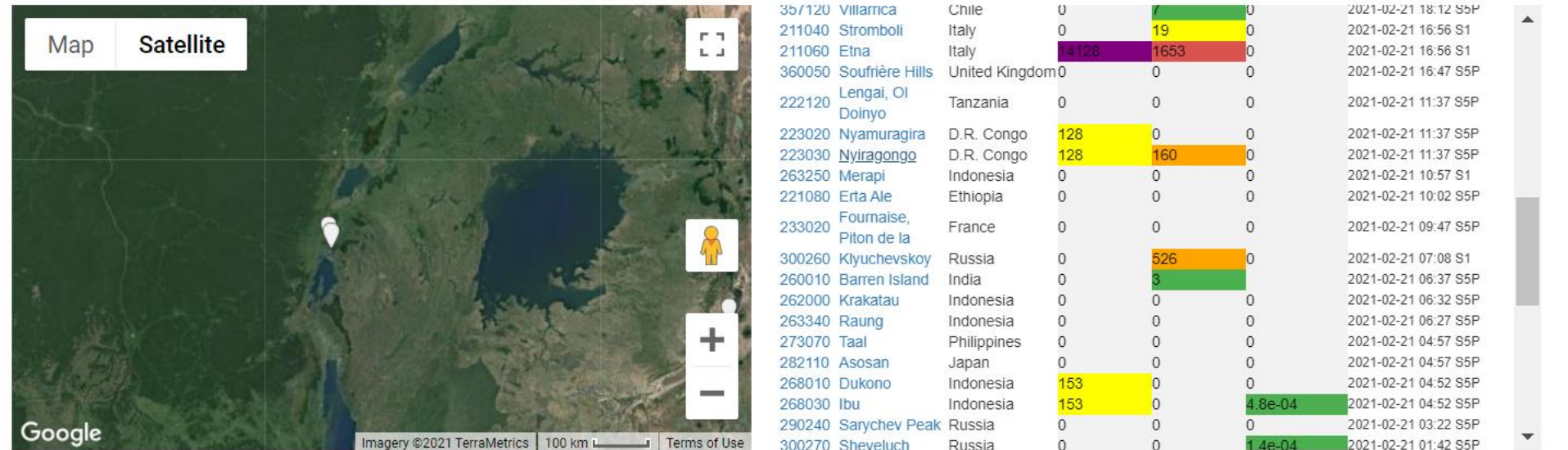


## 2. Near real time SO<sub>2</sub> emissions and ground deformation by MOUNTS (Sentinel-1, Sentinel-2, Sentinel-5P).



### Volcano Monitoring System powered by Sentinel satellites (1, 2, 5P) and AI

60 monitored volcanoes (and growing)



\* Hover on value to see image acquisition time, click on value to open image.

SO <sub>2</sub> scale [tons]	NONE	≥1	≥10 <sup>2</sup>	≥10 <sup>3</sup>	≥5 · 10 <sup>3</sup>	≥10 <sup>4</sup>
Thermal Anomaly scale [n. pixels]	NONE	≥1	≥10	≥10 <sup>2</sup>	≥10 <sup>3</sup>	≥10 <sup>4</sup>
Deformation scale [m]	NONE	>0	≥1 · 10 <sup>-3</sup>	≥5 · 10 <sup>-3</sup>	≥1 · 10 <sup>-2</sup>	≥3 · 10 <sup>-2</sup>

Contact [valade@igeofisica.unam.mx](mailto:valade@igeofisica.unam.mx) to register for automatic email alerts.



Not possible to distinguish Nyiragongo emissions from those from Nyamulagira, the two volcanoes are too close



Nyiragongo

D.R. Congo

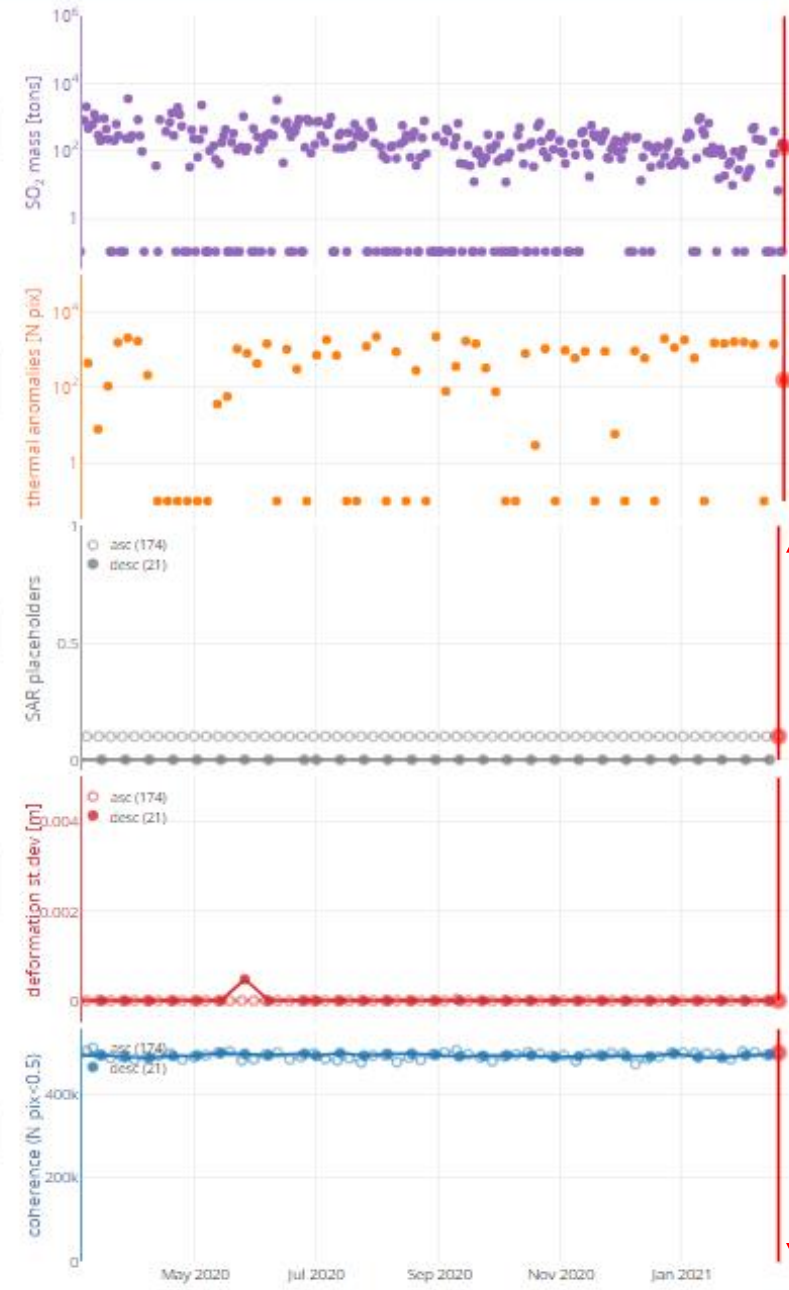
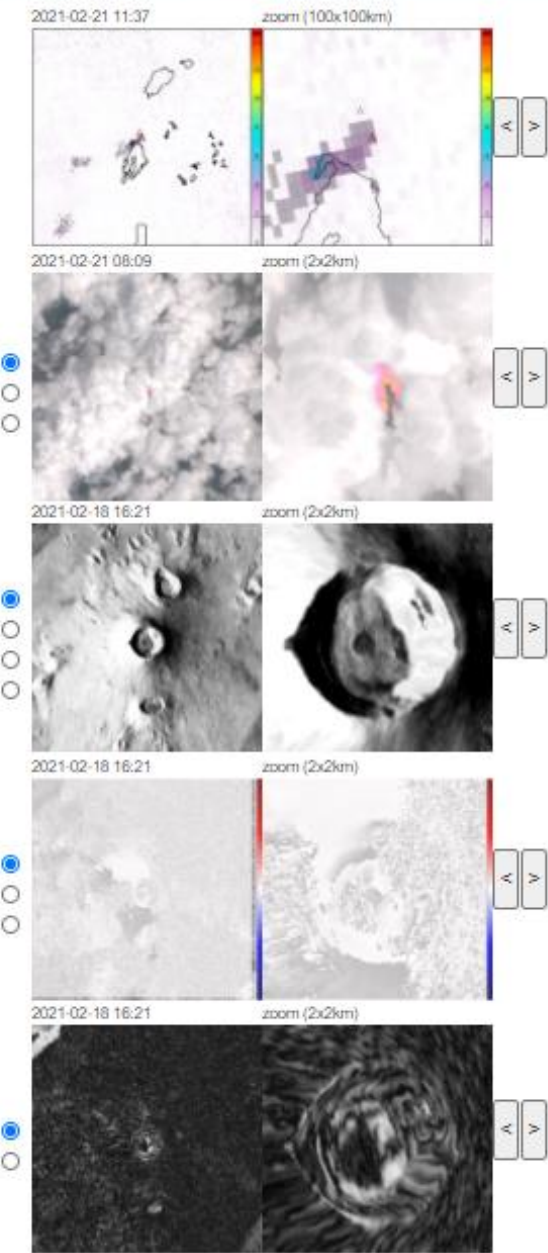
Latitude	Longitude	Altitude	ID
-1.52	29.25	3470 m	223030

Monitoring priority: high

**Time series**

- Image grid
- Image player
- Image slider
- Google Earth
- Earthquakes
- MIROVA

Off select page options



↑ in use

↓ Not used yet

Data time series xls. file are received via email on request. Thanks Dr Sebastien Valade ([valade.sebastien@gmail.com](mailto:valade.sebastien@gmail.com))



# EO data accessed in the framework of the Virunga Volcanoes Supersite, free of charge



HOME

ABOUT

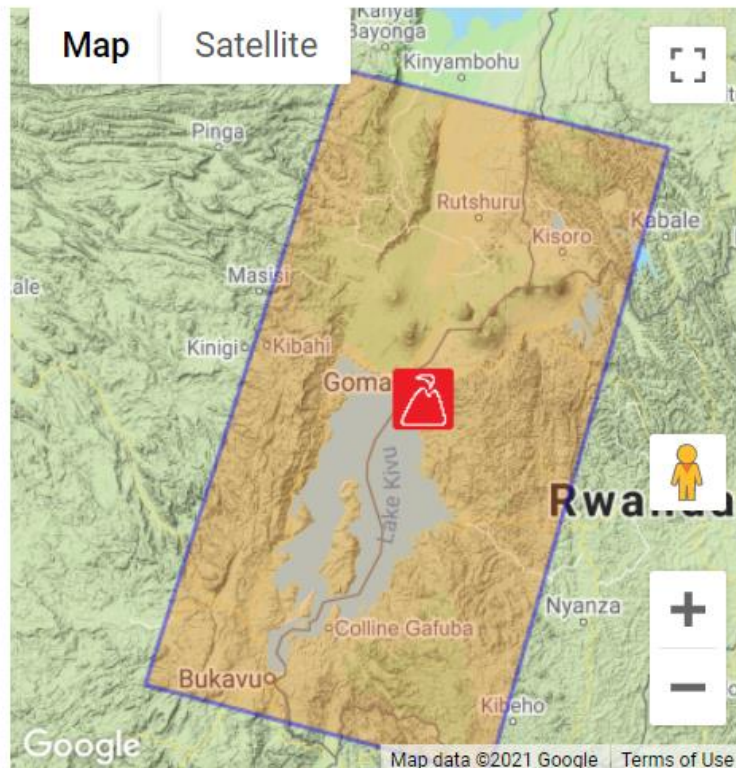
SUPERSITES

OPEN DATA

OUTREACH

GSNL > SUPERSITES > PERMANENT SUPERSITES > VIRUNGA SUPERSITE

## Virunga Supersite



### Supersite history

- Biennial report 2017-2019, DOI: <https://doi.org/10.5281/zenodo.3910912>
- Virunga Supersite Final revised proposal
- Acceptance: CEOS Acceptance Letter, SAC acceptance letter

### Open Data

Please read the Virunga Supersite Data Policy

COSMO-SkyMed SAR data can be accessed from the ESA Geohazard Exploitation Platform. See instructions for use [here](#).

For all other **in situ and satellite** data contact Supersite Coordinator: [balagizi.charles@gmail.com](mailto:balagizi.charles@gmail.com)



# The CEOS supports the Virunga Supersite with COSMO-Skymed and Pleiades

Agenzia Spaziale Italiana (ASI)	COSMO-Skymed: entire archived imagery over the AOI + 100 new products/year for a period of 2 years
Centre National d'Etudes Spatiales (CNES)	Pleiades: quota of 9 images tristereo (on the basis of one Pléiades monoscopic scene 400km <sup>2</sup> ) / year which is roughly equivalent to 3.600km <sup>2</sup> of tristereo acquisitions / year, for a period of 2 years. Total ~22.000 km <sup>2</sup> . <b>2018-2019 quota</b>

Dear Mr. Balagizi,

On behalf of the Committee on Earth Observing Satellites (CEOS) it is my privilege to inform you that, following the the positive review of your Virunga Volcanoes Supersite 2017-2019 report by the CEOS WG Disasters and the by the GSNL SAC, your renewal demand as been accepted on the following basis.

CEOS agencies intend to support the Virunga Volcanoes Geohazard Supersite with the following data resources (**per year for a period of 2 years**): **2020-2021 quota**

Agenzia Spaziale Italiana (ASI)	<b>COSMO-Skymed:</b> 200 scenes
Centre National d'Etudes Spatiales (CNES)	<b>Pleiades:</b> 11000 km <sup>2</sup> (to be divided by 2 for stereo or 3 for tri-stereo)







# Land Use and Land Cover Map

## Dissemination/Publication

The products (maps) are available through the EMS Copernicus Portal at the following URL: <http://emergency.eu/mapping/list-of-components/047>.  
 Delivery formats are GeoPDF, GeoJPEG and vectors (ESRI GDB format).  
 No restrictions on the publication of the mapping apply.

## Contact

The map was produced (under the Service Contract nr 259811 of the European Commission) on 30/03/2018 by GEOAPIKONISIS (EL) – NOA (EL) – CIMA (IT) – TRE ALTAMIRA (ES).  
 Name of the release inspector (quality control): JRC.  
 E-mail: [ems-risk-recovery-mapping@jrc.ec.europa.eu](mailto:ems-risk-recovery-mapping@jrc.ec.europa.eu)  
<http://emergency.copernicus.eu/mapping>



Glide Number: N/A Activation ID: EMSN-047 Product N.: 01NYIRAGONGO\_v1\_English

## Nyiragongo - Democratic Republic of the Congo Volcanic Risk Assessment Land Use and Land Cover Map - Overview

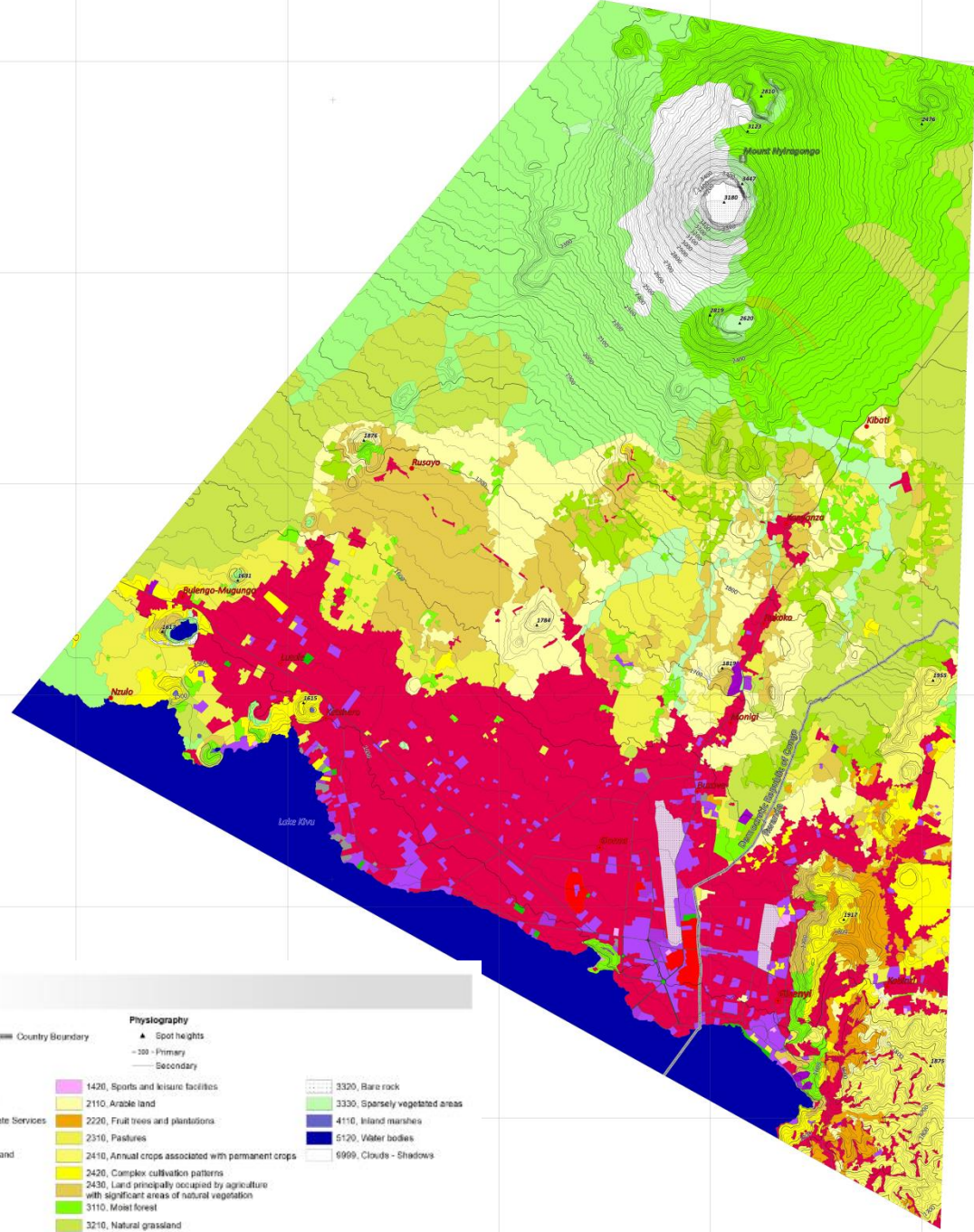
Production date: 30/03/2018

## Cartographic Information

1:50.000 Full color A1, high resolution (300dpi)



Grid: WGS 84 / UTM zone 35S map coordinate system  
 Tick marks: WGS 84 geographical coordinate system



## Legend

- |   |   |   |
|---|---|---|
| <p><b>Populated places</b></p> <ul style="list-style-type: none"> <li>● Town</li> <li>● Village</li> </ul> <p><b>Land Use - Land Cover</b></p> <ul style="list-style-type: none"> <li>1110, Continuous Urban Fabric</li> <li>1120, Discontinuous urban fabric</li> <li>1211, Commercial Public and Private Services</li> <li>1212, Industry and Utilities</li> <li>1221, Main roads and associated land</li> <li>1230, Port areas</li> <li>1240, Airports</li> <li>1310, Mineral extraction sites</li> <li>1330, Construction sites</li> <li>1340, Abandoned land</li> <li>1410, Green urban areas</li> </ul> | <p><b>Physiography</b></p> <ul style="list-style-type: none"> <li>▲ Spot heights</li> <li>- 100 - Primary</li> <li>- Secondary</li> </ul> <ul style="list-style-type: none"> <li>1420, Sports and leisure facilities</li> <li>2110, Arable land</li> <li>2220, Fruit trees and plantations</li> <li>2310, Pastures</li> <li>2410, Annual crops associated with permanent crops</li> <li>2420, Complex cultivation patterns</li> <li>2430, Land principally occupied by agriculture with significant areas of natural vegetation</li> <li>3110, Moist forest</li> <li>3210, Natural grassland</li> <li>3220, Bushes and Shrubs</li> <li>3240, Transitional woodland/shrub</li> </ul> | <ul style="list-style-type: none"> <li>3320, Bare rock</li> <li>3330, Sparsely vegetated areas</li> <li>4110, Inland marshes</li> <li>5120, Water bodies</li> <li>9999, Clouds - Shadows</li> </ul> |
|---|---|---|

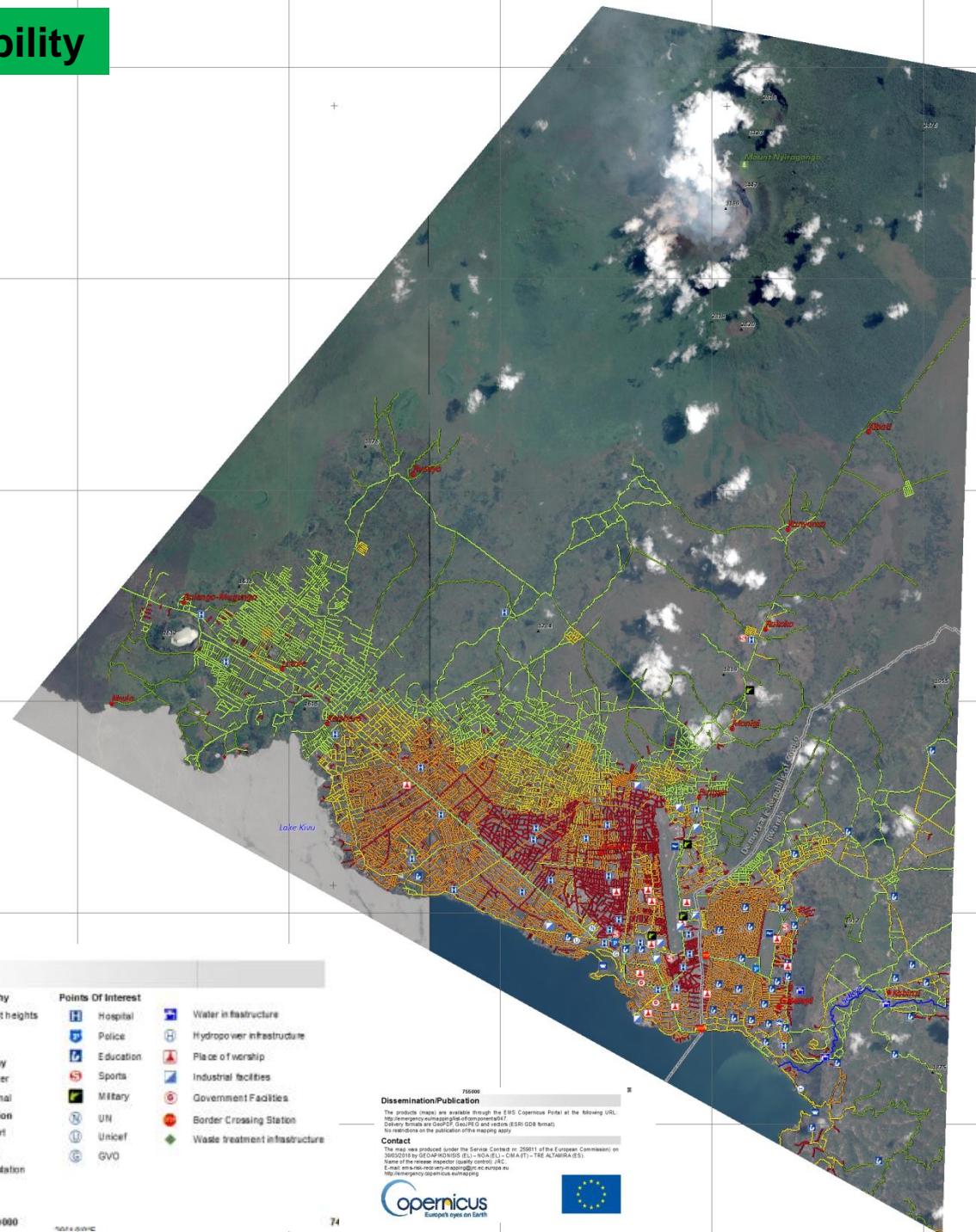






# Transportation Network Vulnerability

Consequences within the AOI	Vulnerability Level				
Transportation Network (km)	Very Low	Low	Medium	High	Very High
Primary	7,670	34,546	1,230	0,936	0,091
Secondary	-	10,835	9,085	0,364	0,196
Tertiary	0,979	7,498	29,985	6,507	0,365
Local and service	15,869	369,387	219,737	407,923	214,617
Other	89,755	42,715	1,578	0,829	0,421
Bridges (Nr)	1	3	4	1	-



Grids Number: N/A  
 Activation ID: EM5N-041  
 Product N: 01NYRAGONGO\_v1\_English

## Nyiragongo - Democratic Republic of the Congo Volcanic Risk Assessment

Transportation Network Vulnerability to disruption Map - Overview  
 Production date: 30/03/2018

**Cartographic Information**  
 1:50.000 Full color A1, low resolution (100dpi)



Grid: WGS 84 / UTM zone 35S map coordinate system  
 Tick marks: WGS 84 geographical coordinate system

### Legend

- Vulnerability Level**
  - Very low (Green)
  - Low (Light Green)
  - Medium (Yellow)
  - High (Orange)
  - Very High (Red)
- Populated places**
  - City (Red circle)
  - Village (Red dot)
  - Country Boundary (Black line)
- Physiography**
  - Spot heights (Black triangle)
- Hydrography**
  - River (Blue line)
  - Canal (Dashed blue line)
- Transportation**
  - Airport (Blue plane icon)
  - Port (Blue ship icon)
  - Bus station (Blue bus icon)
- Points Of Interest**
  - Hospital (Blue H icon)
  - Police (Blue P icon)
  - Education (Blue book icon)
  - Sports (Blue ball icon)
  - Military (Green flag icon)
  - UN (Blue UN icon)
  - Unicef (Blue UNICEF icon)
  - GVO (Blue GVO icon)
  - Water in infrastructure (Blue water tap icon)
  - Hydro power infrastructure (Blue dam icon)
  - Place of worship (Blue church icon)
  - Industrial facilities (Blue factory icon)
  - Government Facilities (Blue government icon)
  - Border Crossing Station (Red border icon)
  - Waste treatment infrastructure (Green waste icon)

**Dissemination/Publication**  
 The products (maps) are available through the EMS Copernicus Portal at the following URL:  
<http://emergency.europa.eu/geoinformation/>  
 Contents: National and Copernicus Data/Info and services (ESRI GDB format)  
 For more details on the publication of the mapping apply.

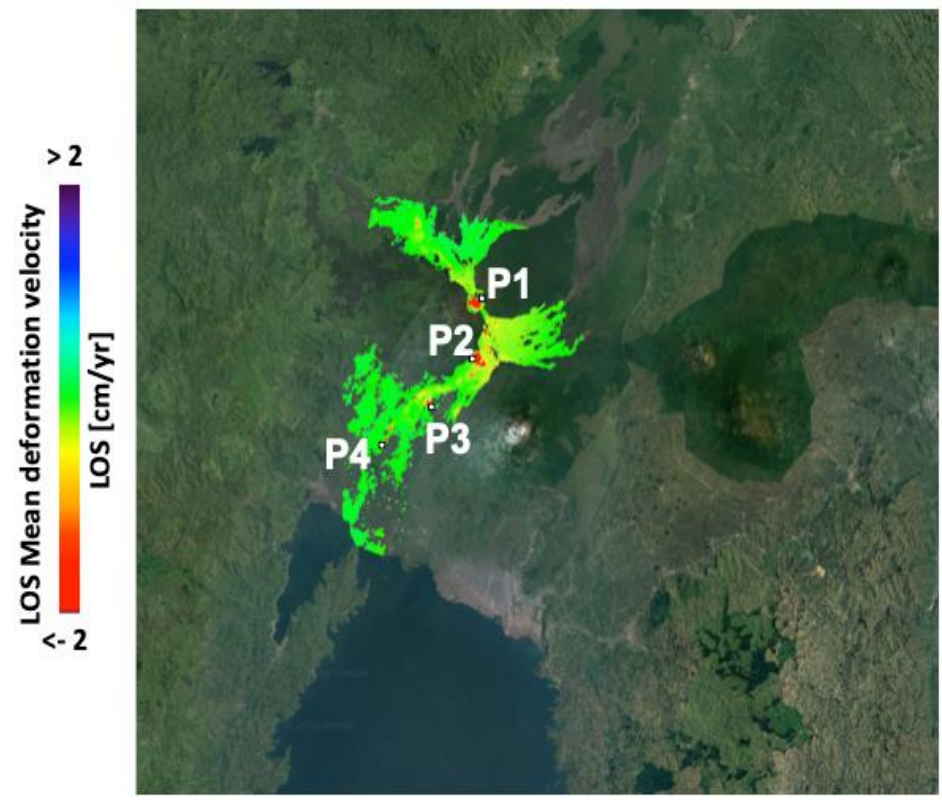
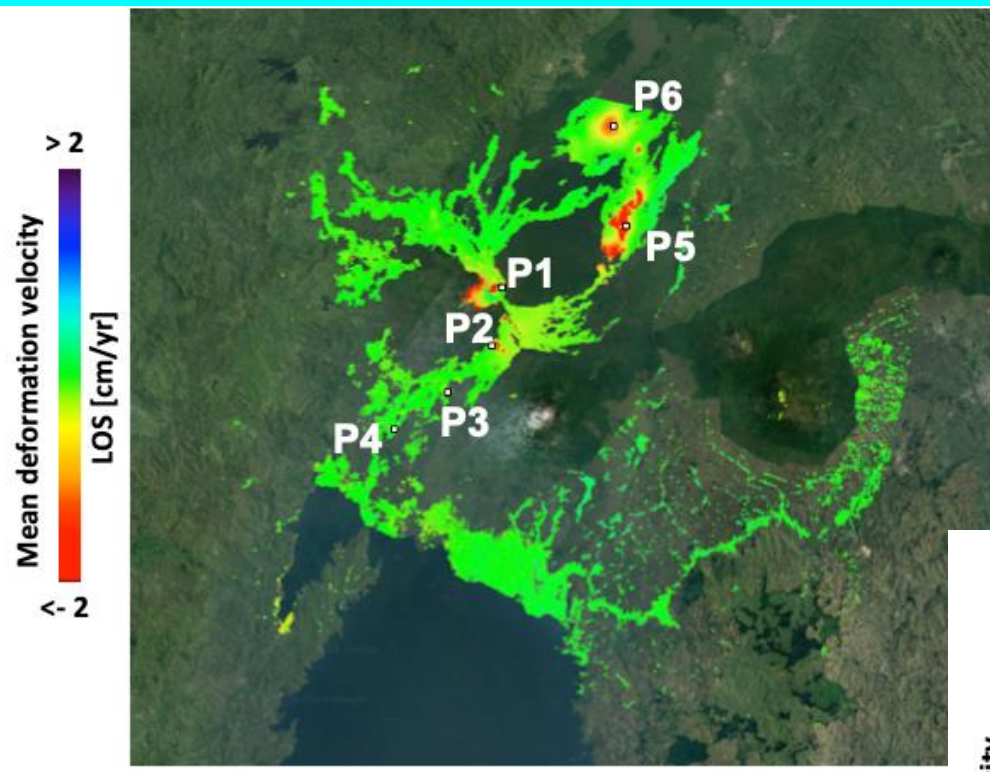
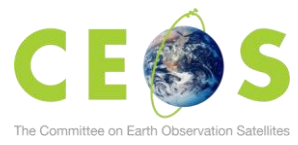
**Contact**  
 The map was produced under the Service Contract n° 20811 of the European Commission on 30/03/2018 by G24/AR/2018/05 (L1 - NGA-PL - CMA-PT) - THE AT/ANNA (ES)  
 Name of the release inspector (quality control): JAC  
 E-mail: [info-nis-ops@copernicus.eu](mailto:info-nis-ops@copernicus.eu)  
<http://emergency.europa.eu/emergency>





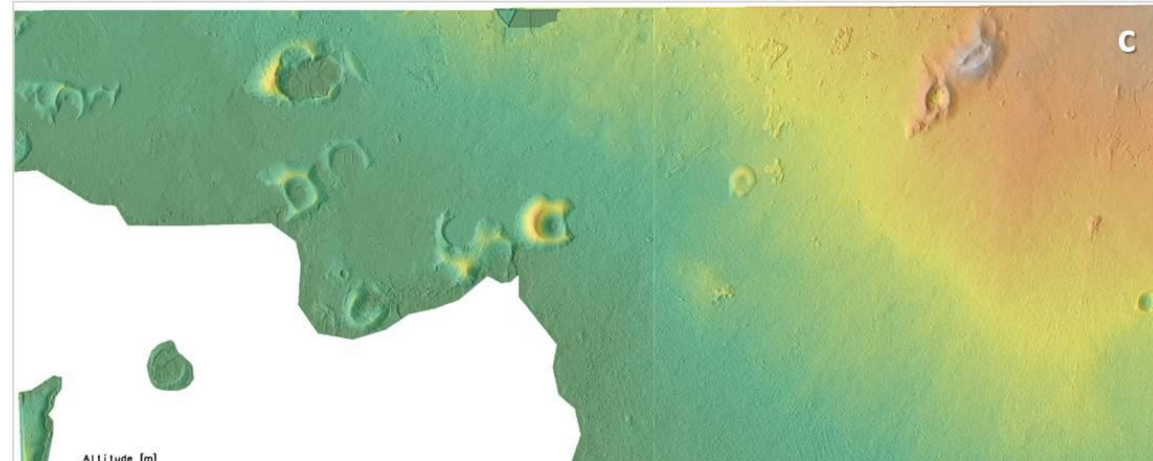
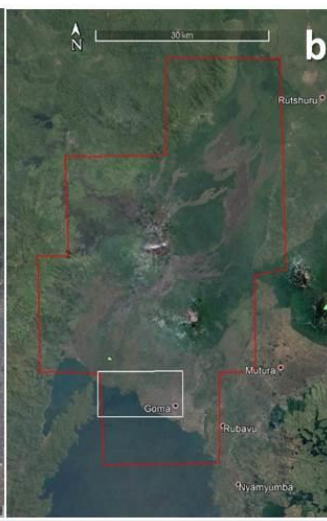
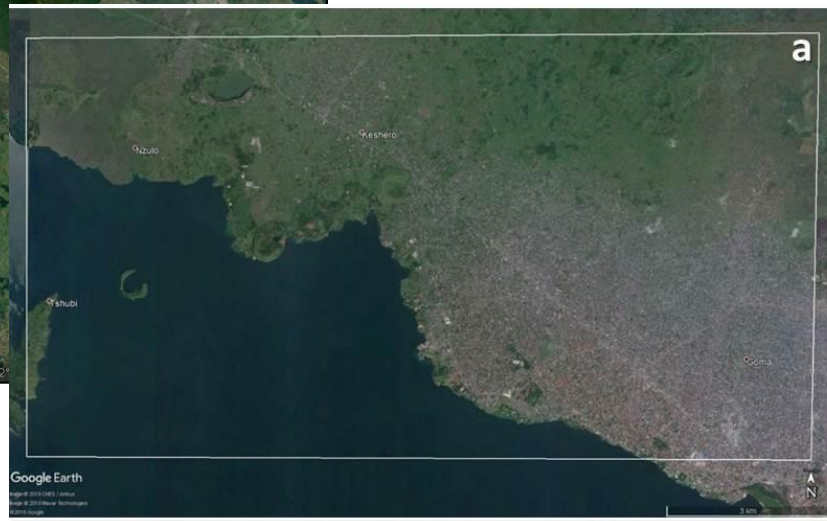
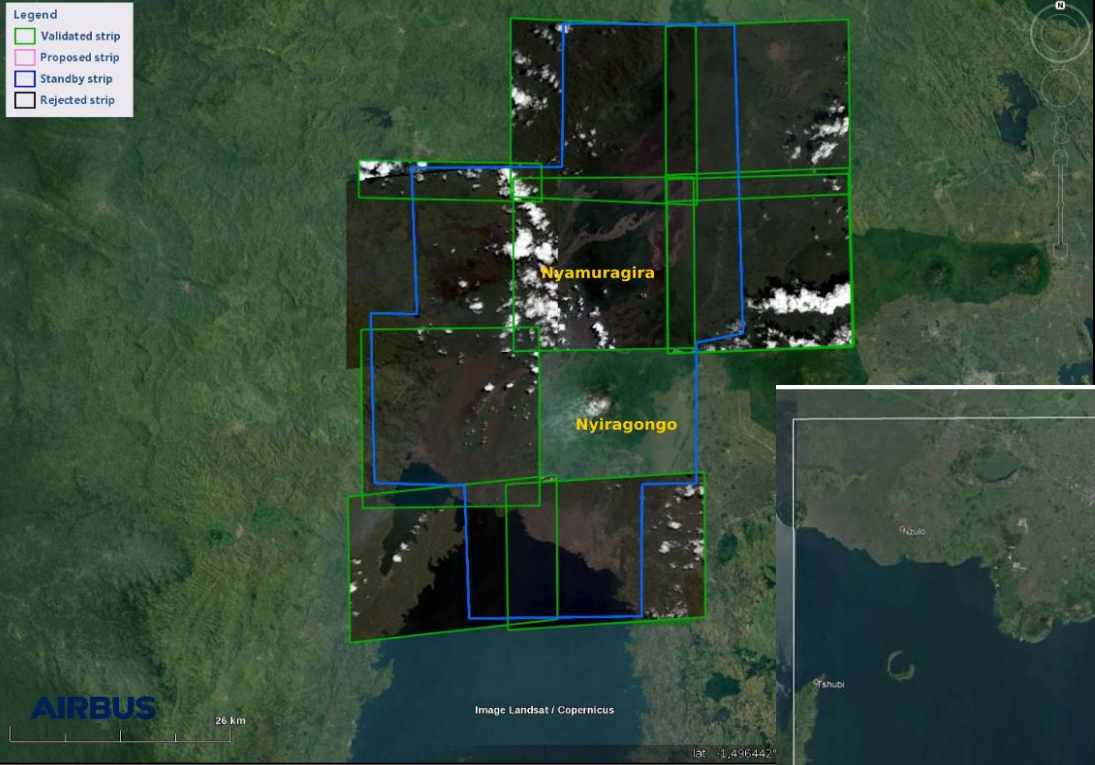
# COSMO-Skymed data used to study and monitor Nyiragongo and Nyamulagira

The Agenzia Spaziale Italiana (ASI) provides COSMO-Skymed 200 scenes per year





# Pleiades data used to study and monitor Nyiragongo and Nyamuragira





# What kind of data needed/lacking; priority/necessary during unrest/crisis response

- Video camera on the top of Nyiragongo for lava lake monitoring
- Continuous measurements of CO<sub>2</sub> in fractures
- Continuous extensometer measurements
- Receive data in real time: now, during unrest and for crisis response

## Future plan on completing & addressing their needs

The urgent needs are not related to data but to infrastructures and capacity development:

- Infrastructures at the observatory and telemetry network (internet??) to directly send the data in real time at the observatory.
- Infrastructures such as computer machines, internet connection (data telemetry, EO data download, etc), servers,... (stock, process and share the data)
- Capacity development: data exist (e.g. GNSS, CSK and other EO data) but there is no qualified human resources to process and interpret

The need for improving the scientific and technical capacities of the GVO personnel



# I.3. Interest in the Global Volcano Monitoring Infrastructure (GVMID)

- Your thought about GVMID initiative

**This is a great idea/plan which we fully support**

- Commitment to actively participate (data contribution, periodic update)

- **We will actively participate through data contribution and periodic update**

- **The EO data obtained through the Supersite are open**

- **Ground-based data is subject to data policy which may depends agreements we have with partners or the fact data this is data for monitoring.**

- Data policy & data sharing

**Some non-sensitive data may be open, the other has an embargo period and can be fully accessible after the embargo.**

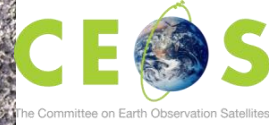
**The data policy is accessible here:**

[http://geo-gsnl.org/wp-content/Documents/Supersites/Virunga/History/Virunga%20Supersite\\_Data%20Policy.pdf](http://geo-gsnl.org/wp-content/Documents/Supersites/Virunga/History/Virunga%20Supersite_Data%20Policy.pdf)





# Thanks for your attention



Thanks to our partners



# References

- [1] [Charles M. Balagizi, 2020](#). How global collaboration and open science can support hazard and risk assessment in low income countries: the case of the Goma Volcano Observatory experience, DR Congo. 2020 UNDERSTANDING RISK FORUM, December 1-3, 2020; doi: 10.13140/RG.2.2.10854.24642/1
- [2] [Charles M. Balagizi](#); Georges Mavonga; Marcellin Kasereka; Marcello Liotta; Mariarosaria Manzo; Riccardo Lanari; Manuela Bonano; Claudio De Luca; Giovanni Onorato; Jeanpy Lukindula; Gaetana Ganci; Ciro Del Negro; Annalisa Cappello; Mauro Coltelli; Mario Mattia; Diego Coppola; Raymond J Durrheim; Pierre Mukambilwa; Albert Kyambikwa; Niche Mashagiro; Honoré Ciraba; Jacob B. Lowenstern; Peter J Kelly; Wendy McCausland; Antoine Kies; 2020. Virunga Volcanoes Supersite Biennial Report: 2017-2019; DOI: 10.5281/zenodo.3910912; <https://zenodo.org/record/3911065#.XxHxQ54zY2w>
- [3] [Charles M. Balagizi](#), Antoine Kies, Marcellin M. Kasereka, Dario Tedesco, Mathieu M. Yalire, Wendy A. McCausland (2018) Natural hazards in Goma and the surrounding villages, East African Rift System. Springer's Journal of Natural Hazards, <https://doi.org/10.1007/s11069-018-3288-x>
- [4] [Charles M. Balagizi](#), Marcellin M. Kasereka, Emilio Cuoco, Marcello Liotta, 2017. Rain-plume interactions at Nyiragongo and Nyamulagira volcanoes and associated rainwater hazards, East Africa, Applied Geochemistry 81 (2017) 76-89 ; <http://dx.doi.org/10.1016/j.apgeochem.2017.03.018>
- [5] [Charles M. Balagizi](#), Mathieu M. Yalire, Honoré M. Ciraba, Vicky B. Kajeje, Abel S. Minani, Annie B. Kinja Marcellin M. Kasereka, 2016. Soil temperature and CO<sub>2</sub> degassing, SO<sub>2</sub> fluxes and field observations before and after the February 29, 2016 new vent inside Nyiragongo crater. Bulletin of Volcanology, 78 (9):1-11, <https://link.springer.com/article/10.1007/s00445-016-1055-y>
- [6] Coppola, D., Campion, R., Laiolo, M., Cuoco, E., Balagizi, C., Ripepe, M., Cigolini, C., Tedesco, D. (2016). Birth of a lava lake: Nyamulagira volcano 2011-2015. Bulletin of Volcanology, vol. 78(3), p. 1-13. <https://link.springer.com/article/10.1007%2Fs00445-016-1014-7>
- [7] Coppola D., Cigolini C. (2013). Thermal regimes and effusive trends at Nyamuragira volcano (DRC) from MODIS infrared data. Bulletin of Volcanology , vol. 75(8), p. 1-15, <https://doi.org/10.1007/s00445-013-0744-z>
- [8] Valade, Sébastien; Ley, Andreas; Massimetti, Francesco; D'Hondt, Olivier; Laiolo, Marco; Coppola, Diego; Loibl, David; Hellwich, Olaf; Walter, Thomas R. 2019. "Towards Global Volcano Monitoring Using Multisensor Sentinel Missions and Artificial Intelligence: The MOUNTS Monitoring System" Remote Sens. 11, no. 13: 1528. <https://doi.org/10.3390/rs11131528>