

# Propagation and arrest of the May 2021 lateral dike intrusion at Nyiragongo (D.R. Congo)

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## Abstract

On the 22<sup>nd</sup> of May 2021, although no alarming precursory unrest had been reported, Nyiragongo volcano erupted and lava flows threatened about 1 million of inhabitants living in the cities of Goma (Democratic Republic of Congo) and Gisenyi (Rwanda). After January 1977 and January 2002, it was the beginning of the third historically known flank eruption of Nyiragongo volcano and the first ever to be recorded by dense measurements both on the ground and from space. In the following days, seismic and geodetic data as well as fracture mapping revealed the gradual southward propagation of a shallow dike from the Nyiragongo edifice underlying below Goma airport on May 23-24, then Goma and Gisenyi city centers on May 25-26 and finally below the northern part of Lake Kivu on May 27. Southward migration of the associated seismic swarm slowed down between May 27 and June 02. Micro seismicity became more diffuse, progressively activating transverse tectonic structures previously identified in the whole Lake Kivu basin. Here we exploit ground based and remote sensing data as well as inversion and physics-based

models to fully characterize the dike sized, the dynamics of dike propagation and its arrest against a structural lineament known as the Nyabihu Fault. This work highlights the shallow origin of the dike, the segmented dike propagation controlled by the interaction with pre-existing fracture networks and the incremental crater collapse associated with drainage which led to the disappearance of the world's largest long-living lava lake on top of Nyiragongo.

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# Outline



From Lake Kivu to Nyiragongo

- Ground Networks and Remote Sensing
- The eruption and its impact
- Absence of precursors
- A textbook-like dike
- Progressive Crater collapse
- Propagation Arrest
- What's next ?



Nyamulagira and Nyiragongo lights seen from Goma

# Ground Networks: Seismic, Infrasound, GNSS

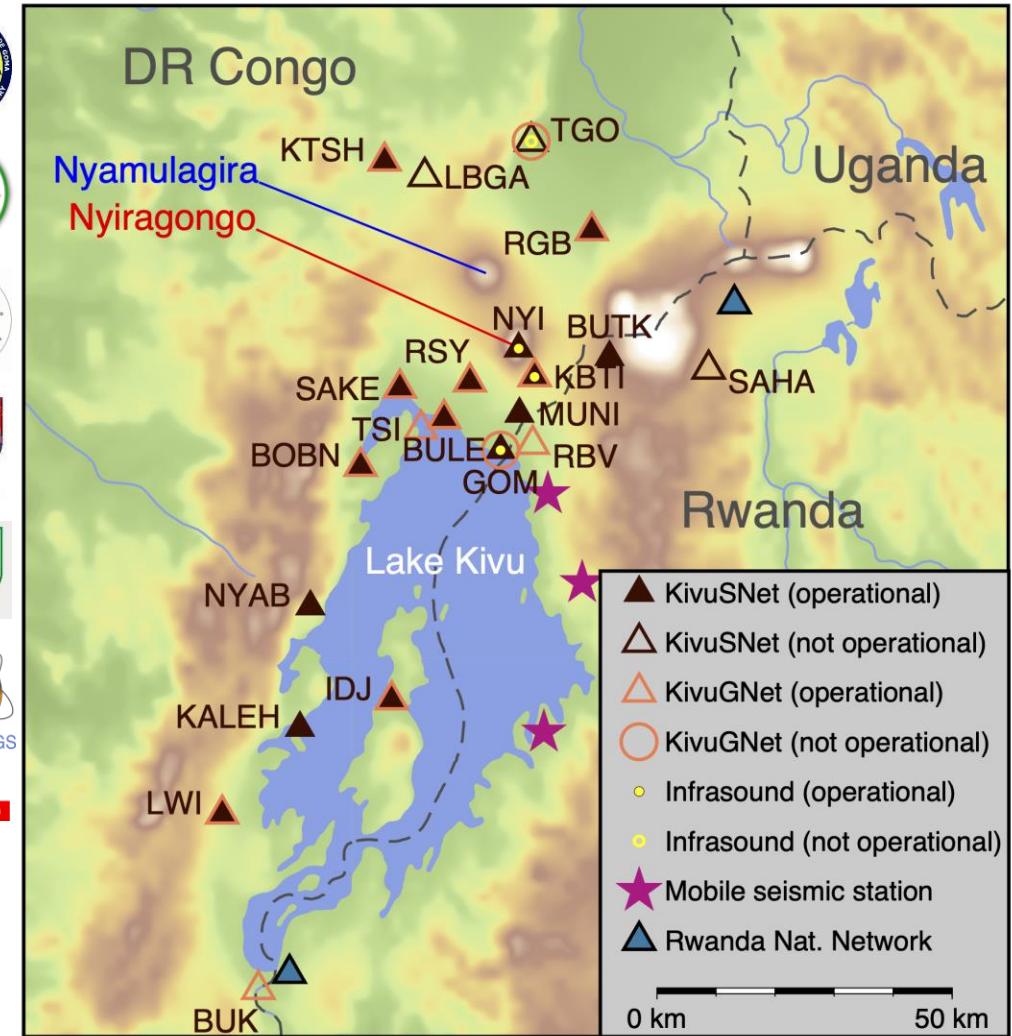
KivuSNet (broadband seismic and infrasound telemetered network)

- Up to 14 real time seismic stations available
- Up to 7 infrasound sensors available

KivuGNet (GNSS telemetered network)

- Up to 13 GNSS stations available

Simultaneous seismic & infrasound data acquisition through *Seedlink* servers at GVO (DRC), RMB (Rwanda) and ECGS (Lux.).



(\*) The Rwanda National Seismic Network was designed and installed by ECGS. Stations in Huye and Kigali not visible on this map.

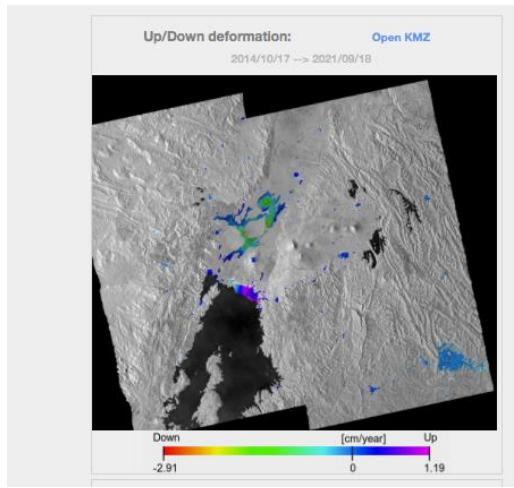
# Automated Tools: MasTer

## Examples of MasTer products

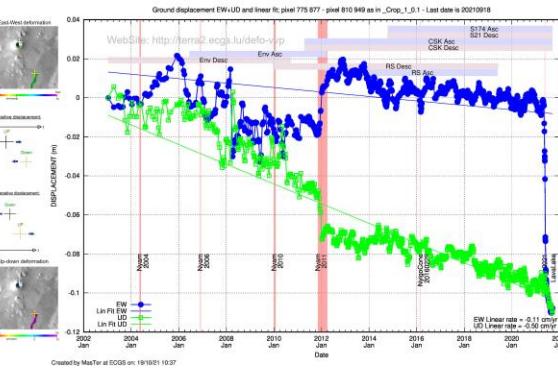
### InSAR mass processing + MSBAS time series processor

- Incremental and fully automatic
- Combines all available satellites and acquisition geometries
- Produce 2D time series (vertical and EW) and 1D (LOS)
- Provides all types of geocoded products

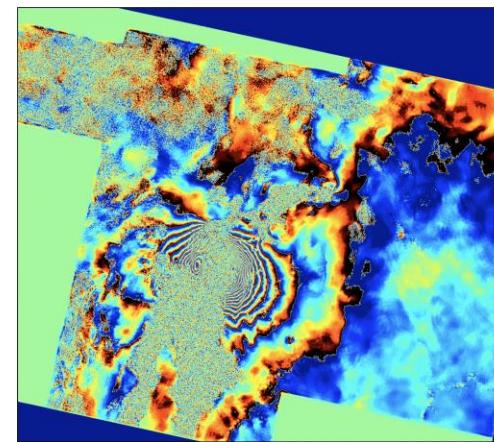
See poster by d'Oreye et al.  
On Thursday 16<sup>th</sup>, 16-18 CST



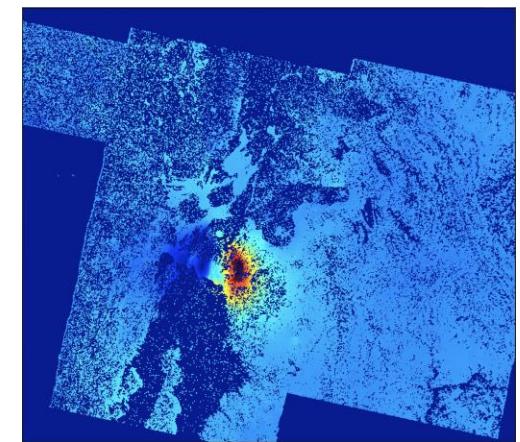
Vertical velocity wrapped on  
amplitude map



Vertical (Green) and EW (blue)  
ground deformation time series



S1 Desc filtered interferogram  
20210521-20210608



S1 Desc Detrended deformation map  
20210521-20210608

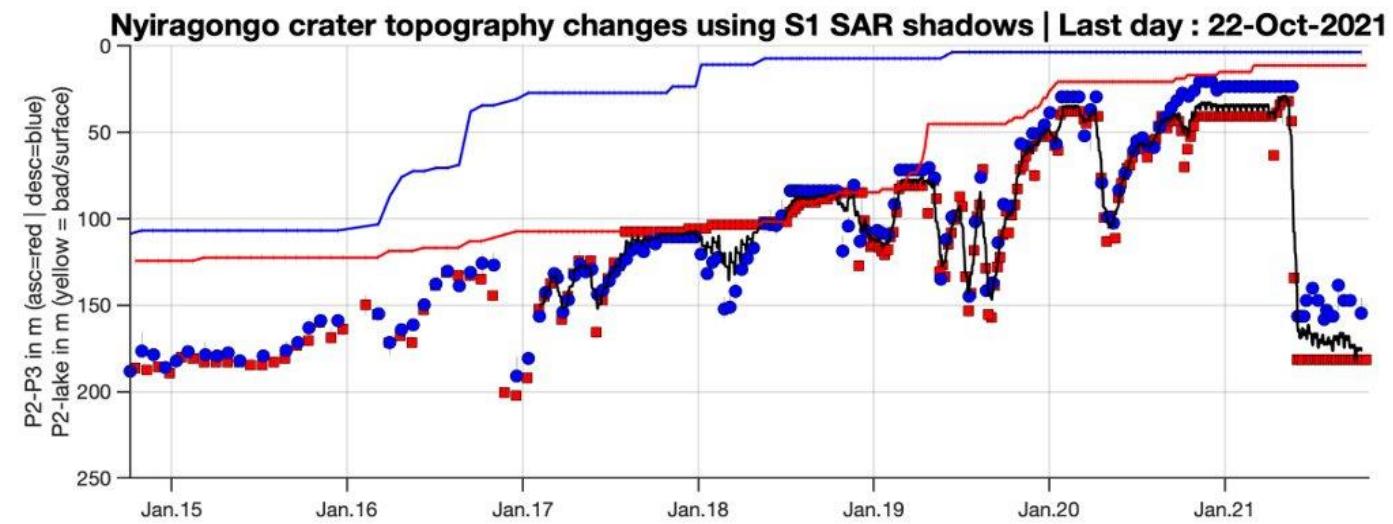
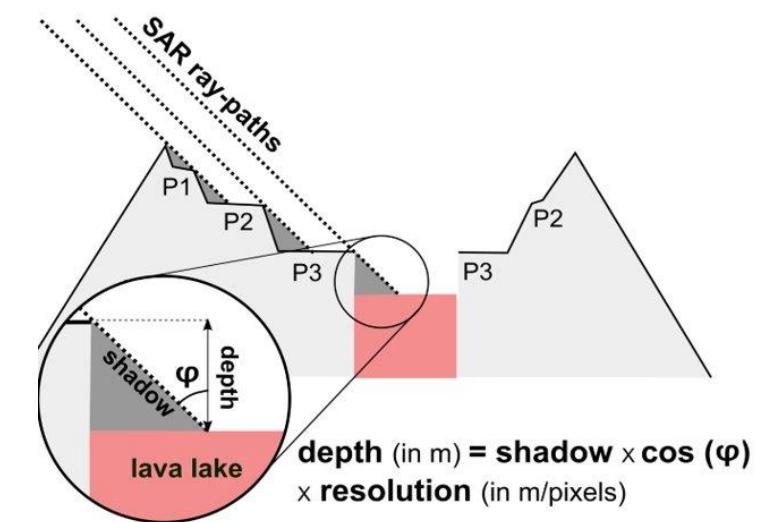
(Derauw et al., JSAES, 2020)  
(d'Oreye et al., IGARSS, 2021)

# Automated Tools: SAsha

Automatic processing of SAR amplitude images for measuring Nyiragongo's lava lake level

- Basic trigonometry in radar geometry to infer **lava lake level** changes from SAR shadow
- Results are available to GVO on a password-protected web page

See poster by Barrière et al.  
On Monday 13<sup>th</sup>, 16-18 CST



# The 22 May 2021 Nyiragongo eruption

**Around 16h30 UT (18h30 LT):**

first visual accounts of lava outbursts



*Lava flows from Nyiragongo on 21 May 2021*

*View of the lava lake from Nyiragongo summit on 21 May 2021*



**No warning signs for imminent eruption**

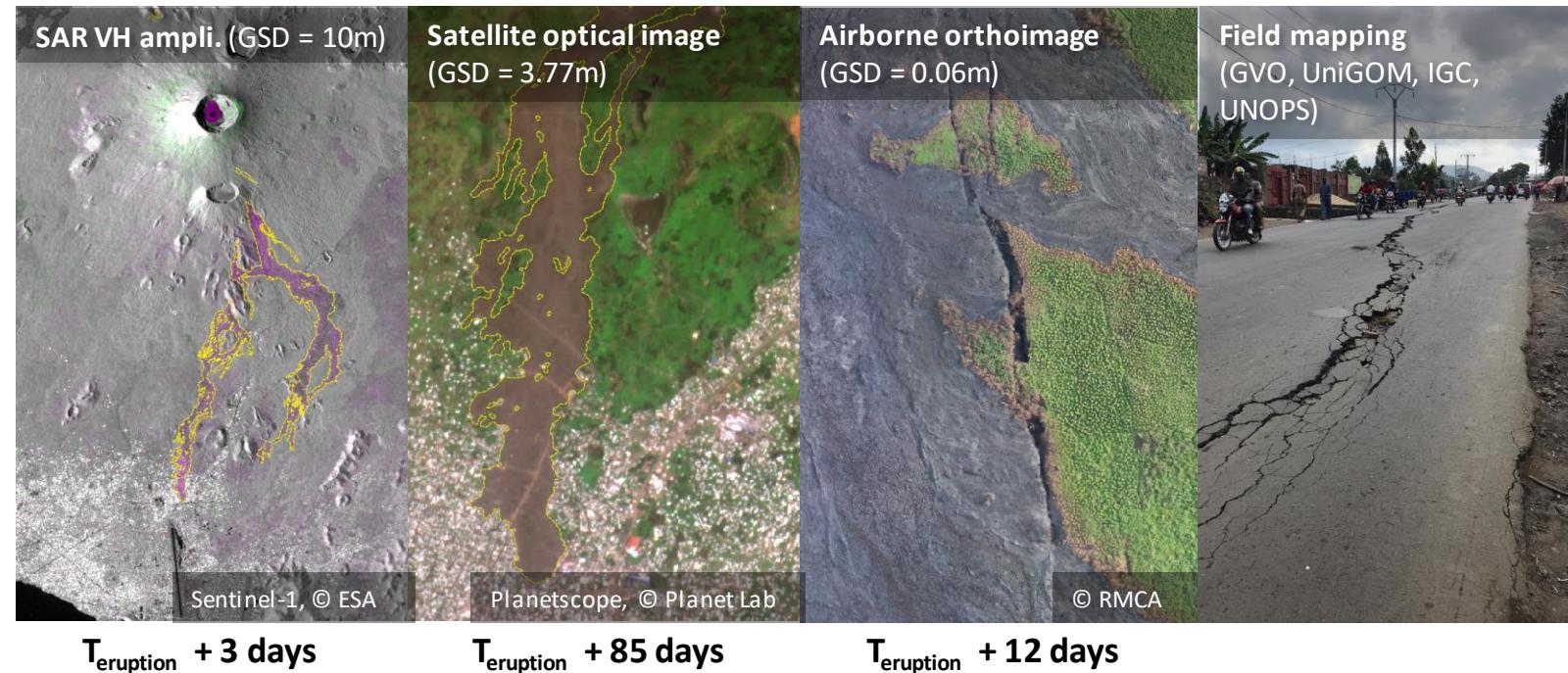
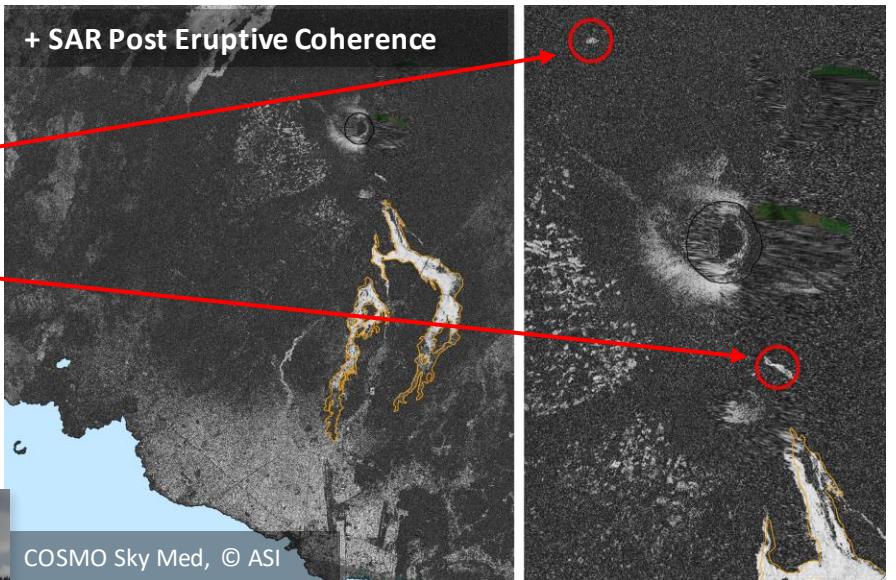
# The 22 May 2021 Nyiragongo eruption

The eruption lasted about 6 hours

Lava flows spewed from 4 main fissures (+ 2 small fissures)

Surface covered estimate: 10 km<sup>2</sup>

Emitted volume estimate: 10-15 Mm<sup>3</sup>



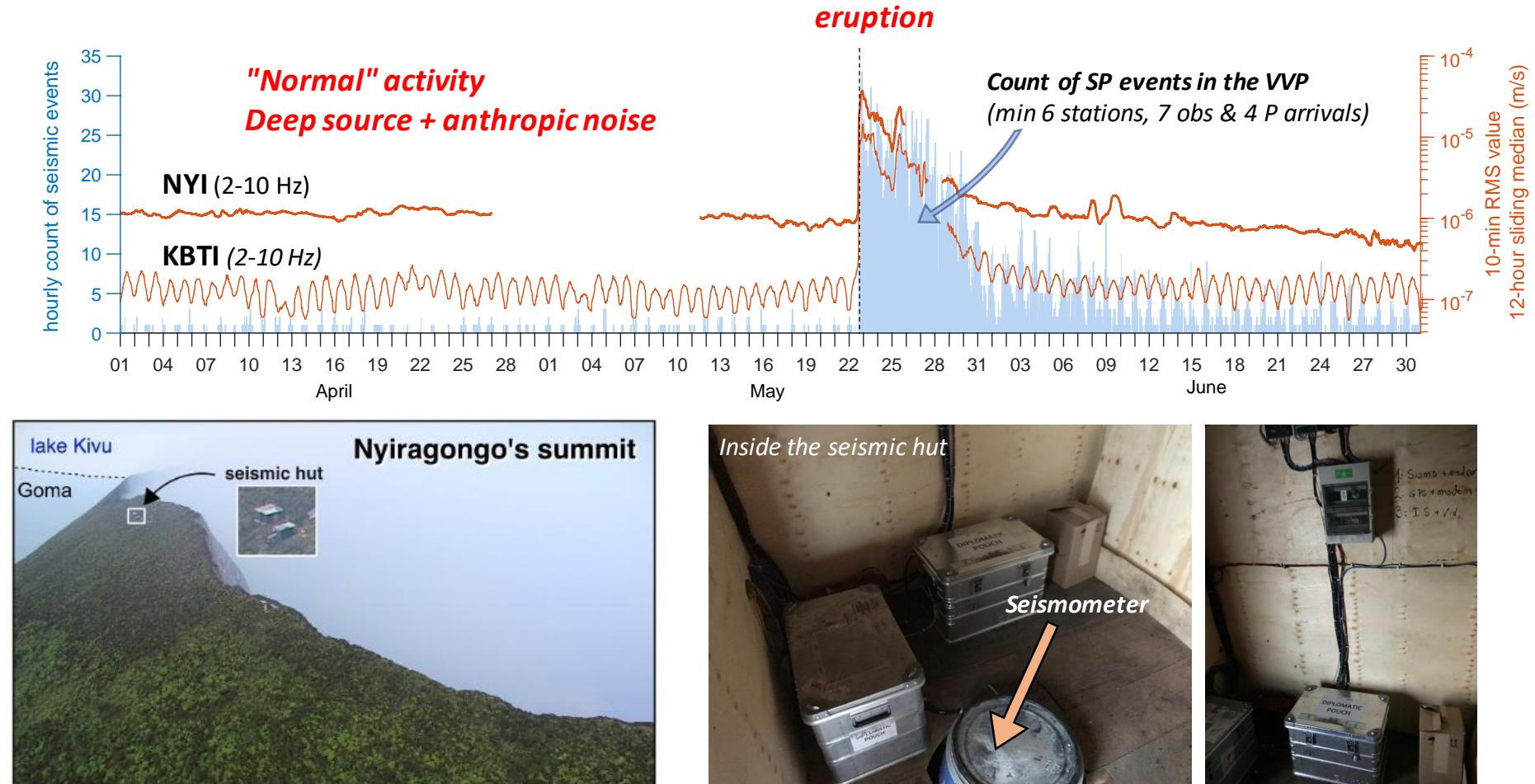
Lava Petrology and Geochemistry  
=> Drainage of the Lava lake system  
- few millimetre-scale bubbles  
- nepheline crystals

See also talk by Smets et al.  
On Wednesday 15<sup>th</sup>, 07:50-07:55 CST

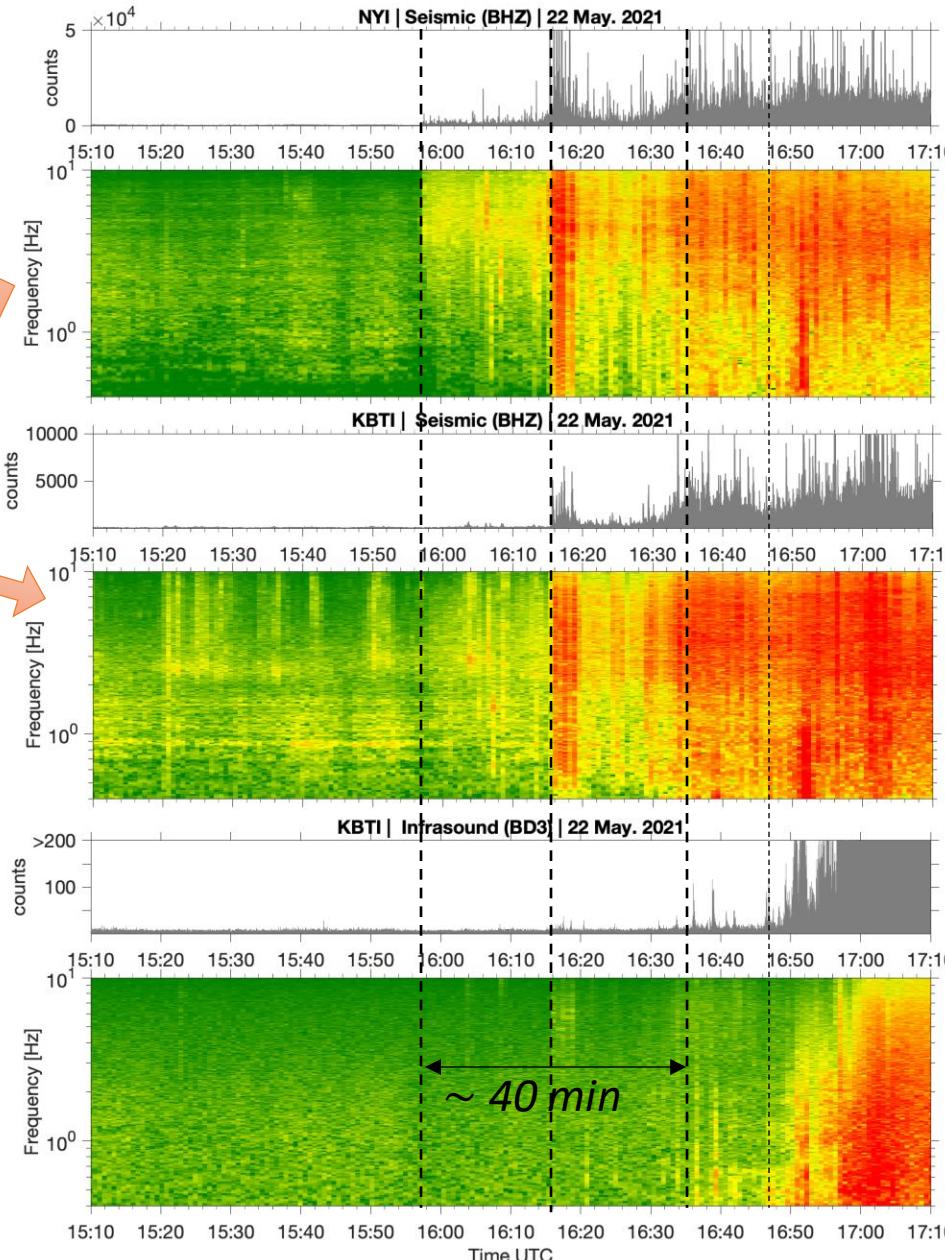
# No evident precursors

## KivuSNet (seismic & infrasound):

With the available network, no precursory seismicity patterns could have been associated with an impending eruption in a prospective forecasting framework



# No evident precursors



## Zoom in 22 May - 15:10 to 17:10 UTC

First seismic signals at station NYI at  $\sim$ 15:57 UTC (17:57 LT)

Clear seismic events at KBTI (& other stations) at  $\sim$ 16:15 UTC (18:15 LT)

Clear acoustic (infrasound) signals at KBTI starts with delay of  $\sim$ 20 min at  $\sim$ 16:35 UTC (18:35 LT), roughly coinciding with first visual accounts of lava outbursts

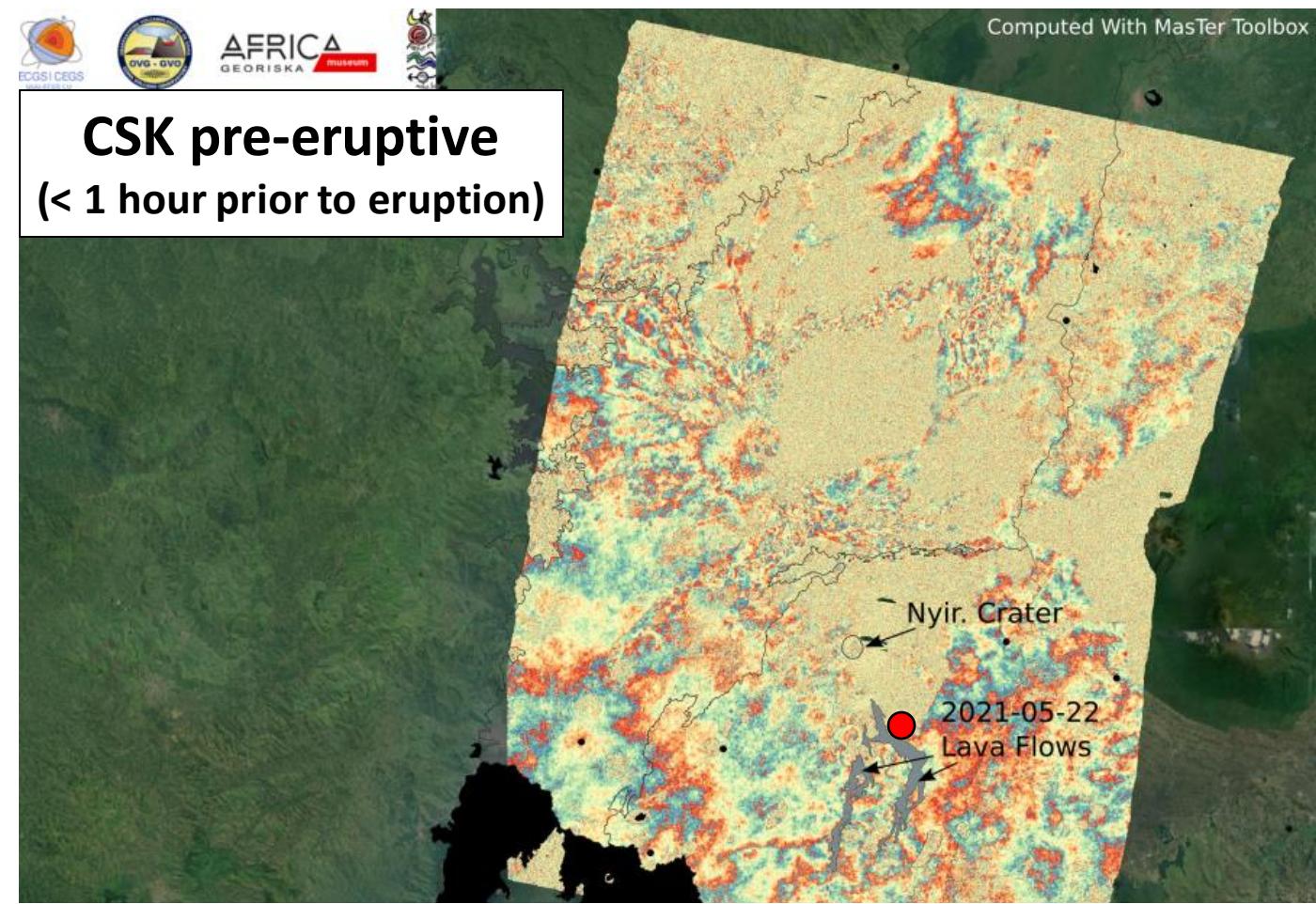
⇒ **(Very) short distance between magma source and surface**

⇒ **(Very) dense instrumentation of edifice might at best have provided some (very) short-term warning signs**

[https://georiska.africamuseum.be/en/news/nyiragongo\\_erection](https://georiska.africamuseum.be/en/news/nyiragongo_erection)

# No Precursory Deformation

MasTer (InSAR): in pre-eruptive interferogram

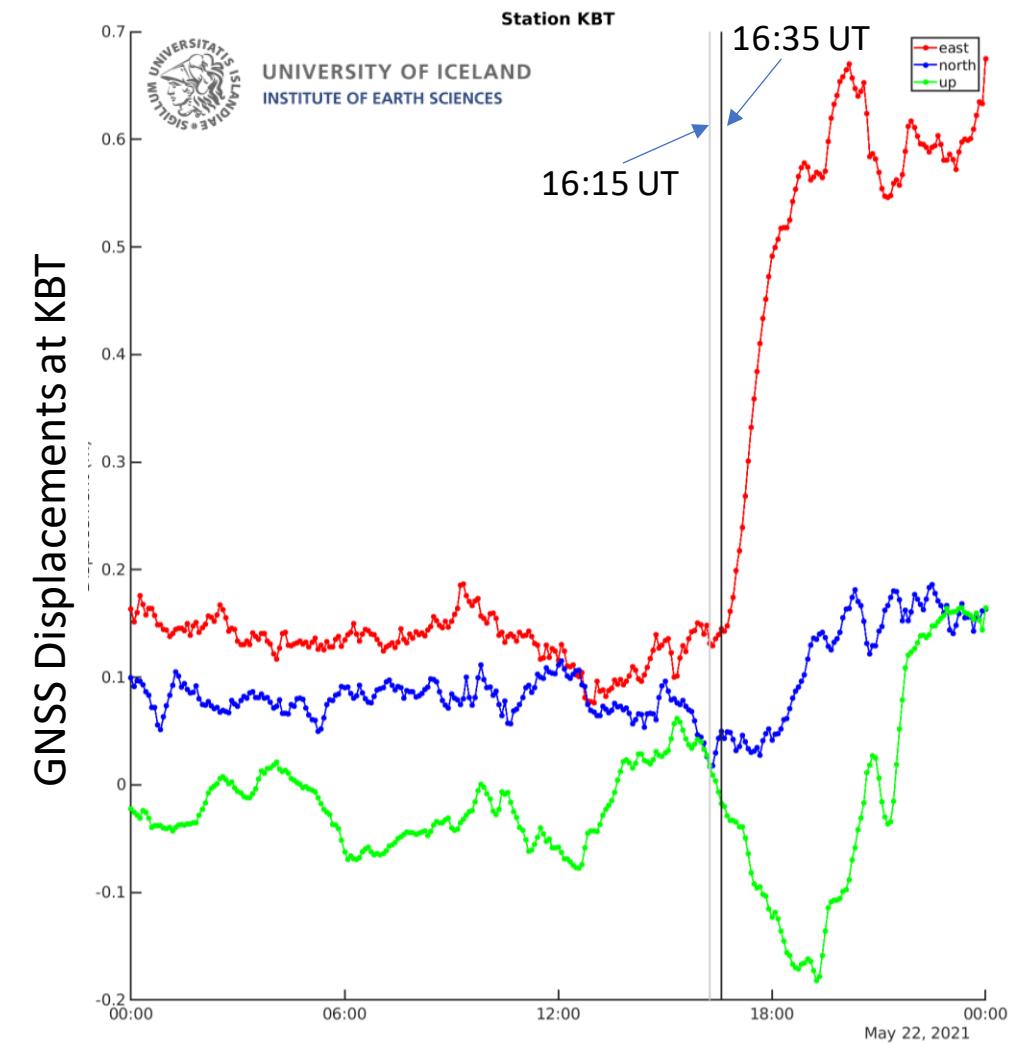


COSMO Sky Med Desc. ©ASI

2021-05-21 15:37 2021-05-22 15:37

1 fringe = 1.5cm deformation in LOS

KivuGNet (GNSS): at station closest to Nyiragongo



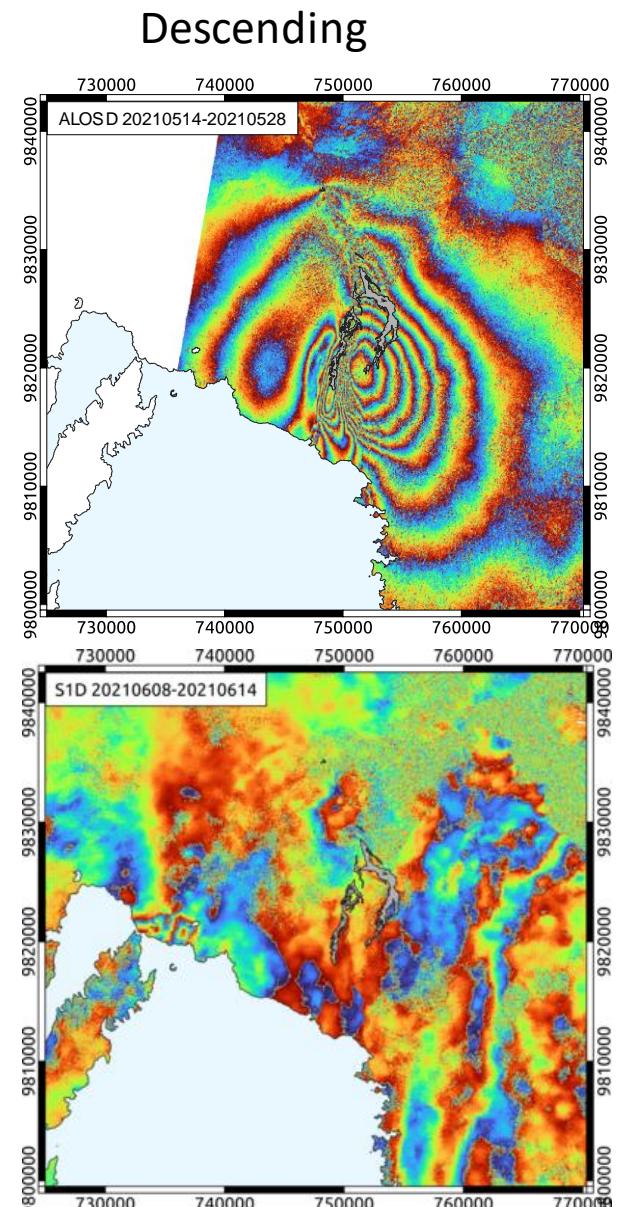
[https://georiska.africamuseum.be/en/news/nyiragongo\\_eruption](https://georiska.africamuseum.be/en/news/nyiragongo_eruption)

# Tracking and interpretation

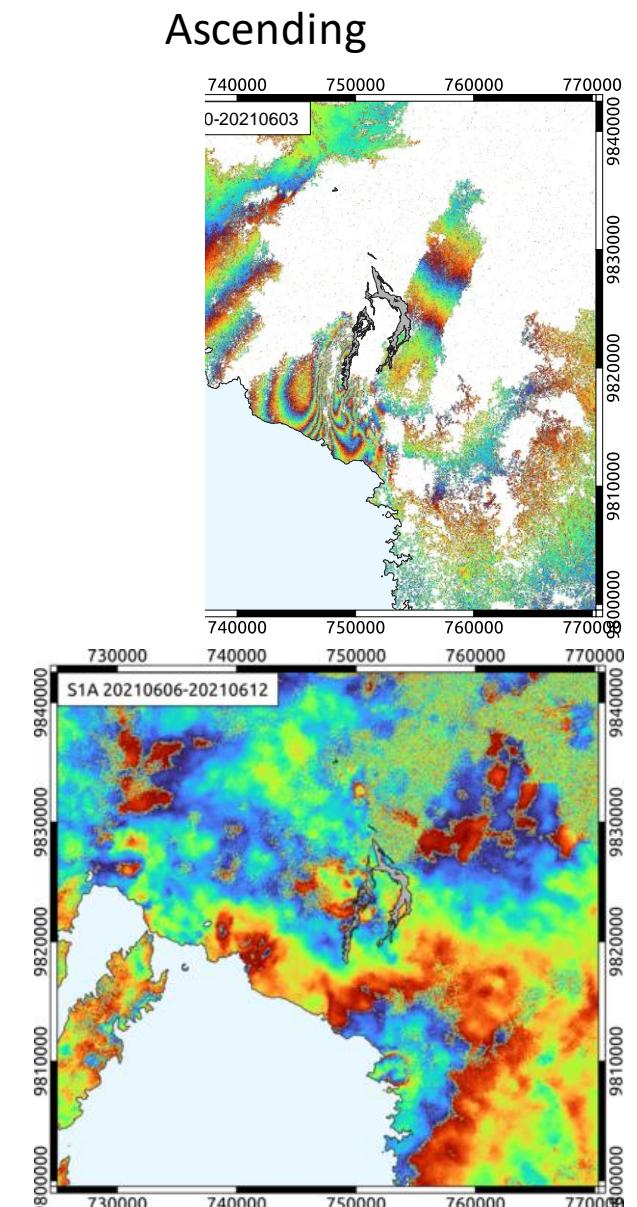
## Co-eruptive deformation (interferograms)

- 3 lobes-pattern : EW opening + graben subsidence
- Opening of around 1.5 m in Goma
- Dyke progression ("textbook-like")
- Graben faulting still on-going after June 2<sup>nd</sup>

ALOS



Sentinel-1



[https://georiska.africamuseum.be/en/news/nyiragongo\\_erection](https://georiska.africamuseum.be/en/news/nyiragongo_erection)

# Tracking and interpretation

## Pre-eruptive seismicity

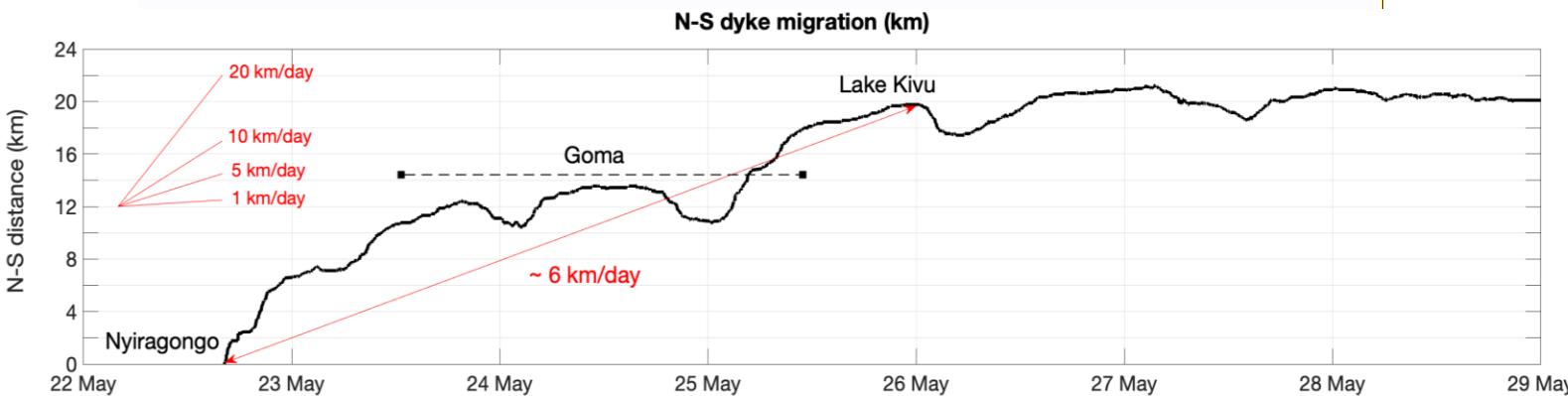
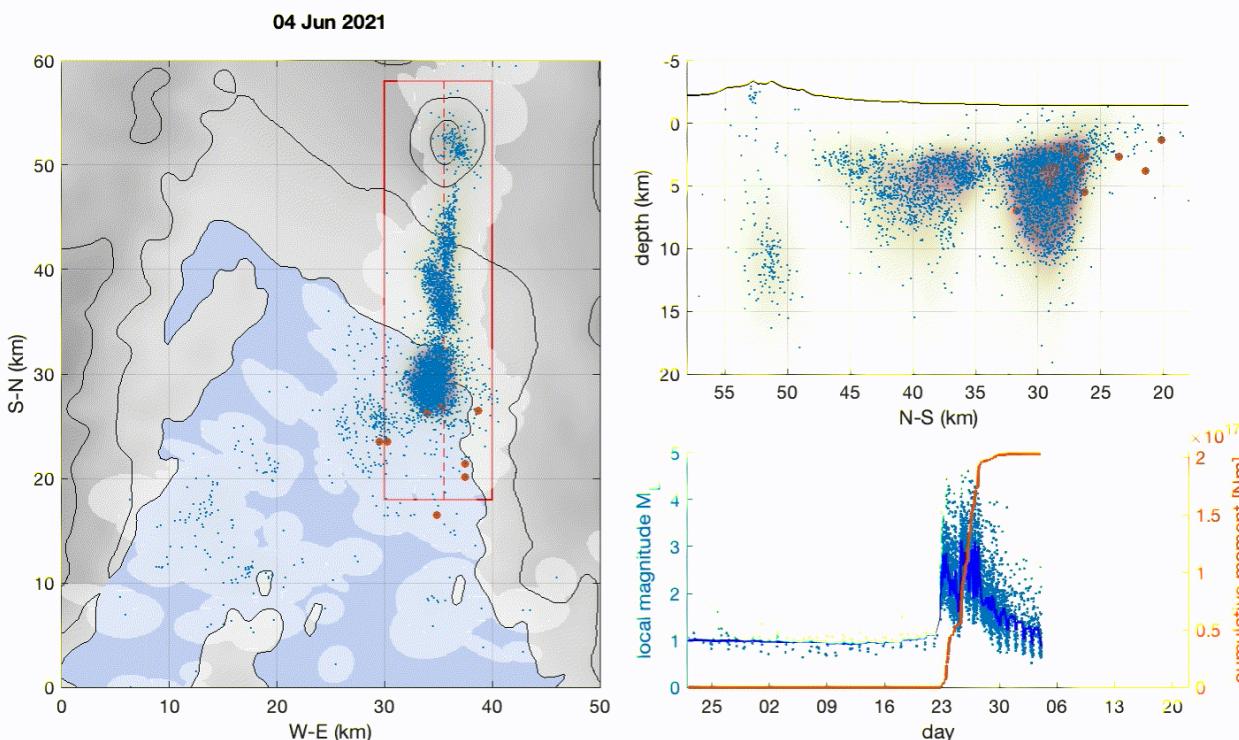
- Deep repetitive seismic source at 10 – 15 km (feeding system)
- Tectonic background seismicity in and around Lake Kivu (→ rift)
- Diurnal variations due to anthropogenic noise

## Volcanic crisis

Seismic swarm **migrating north to south**, evidencing dyke progression

Very shallow seismicity, strongly felt in cities of Goma and Gisenyi

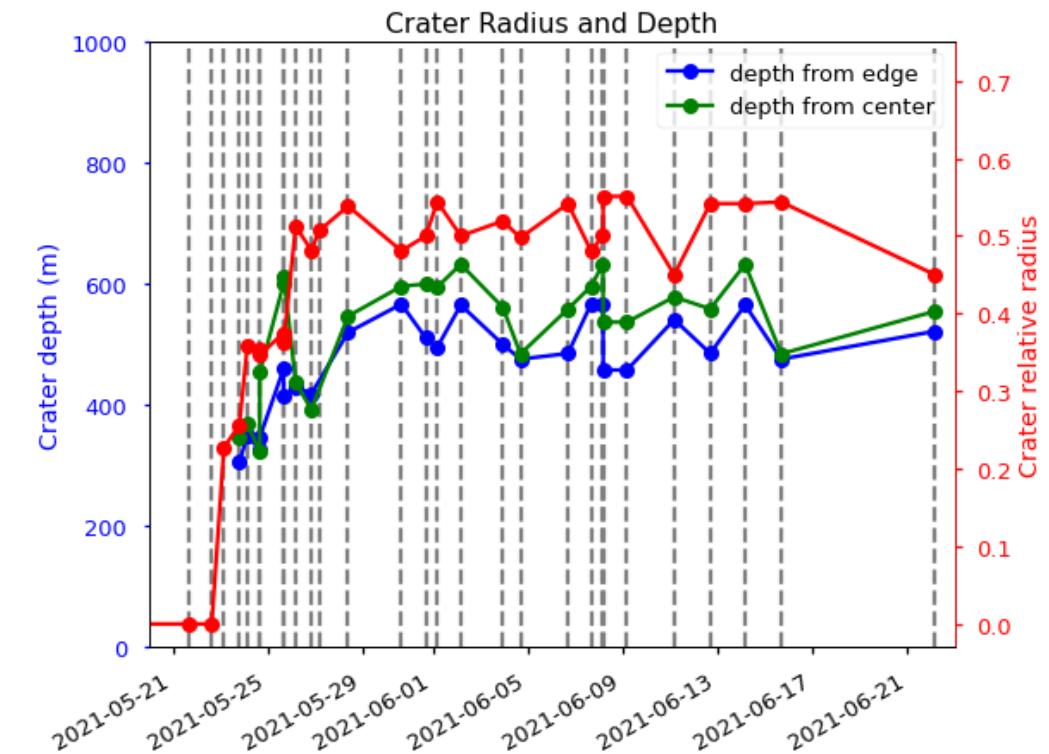
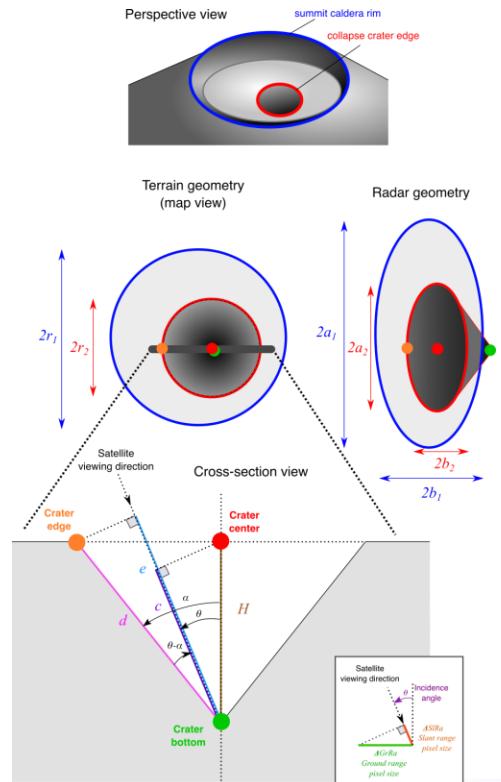
Dyke **progression in bursts**, velocities up to ~20 km/day



[https://georiska.africamuseum.be/en/news/nyiragongo\\_eruption](https://georiska.africamuseum.be/en/news/nyiragongo_eruption)

# Progressive Crater Collapse

Sentinel-2 Multi-spectral



[https://georiska.africamuseum.be/en/news/nyiragongo\\_erection](https://georiska.africamuseum.be/en/news/nyiragongo_erection)

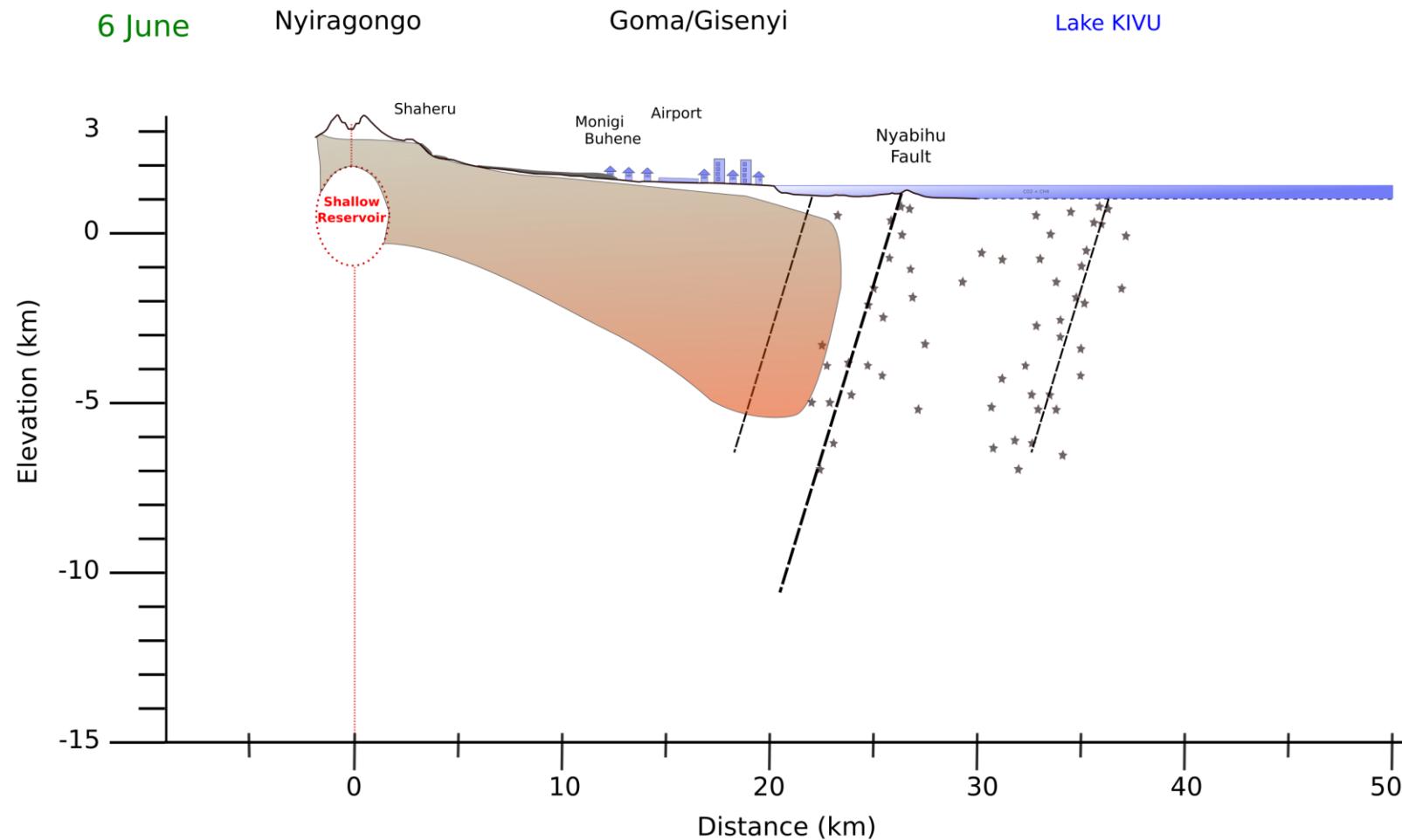
# Interpretation and Conclusions

First modelling results show a  $240\text{Mm}^3$  dyke progressing at **shallow depth** roughly in north-south direction

**Progression unpredictable** (up or down, lateral changes in direction, obstacles, Nyabihu fault)

**Very significant associated risks** (lava outbursts directly within Goma or Gisenyi, phreato-magmatic eruption, limnic eruption of Lake Kivu)

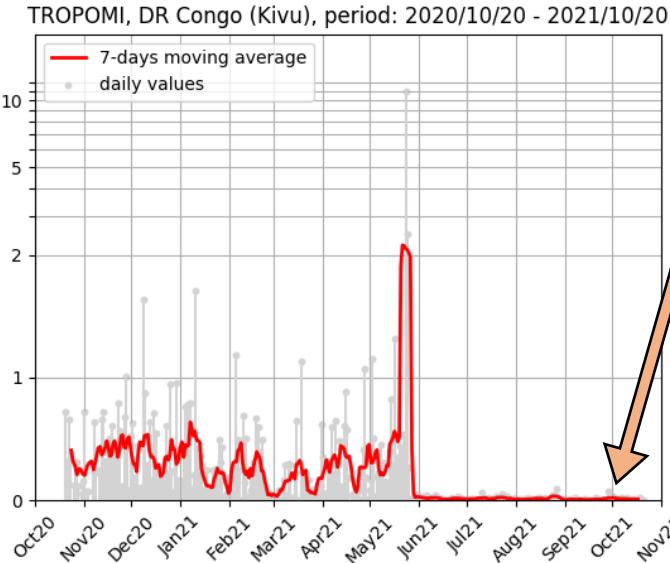
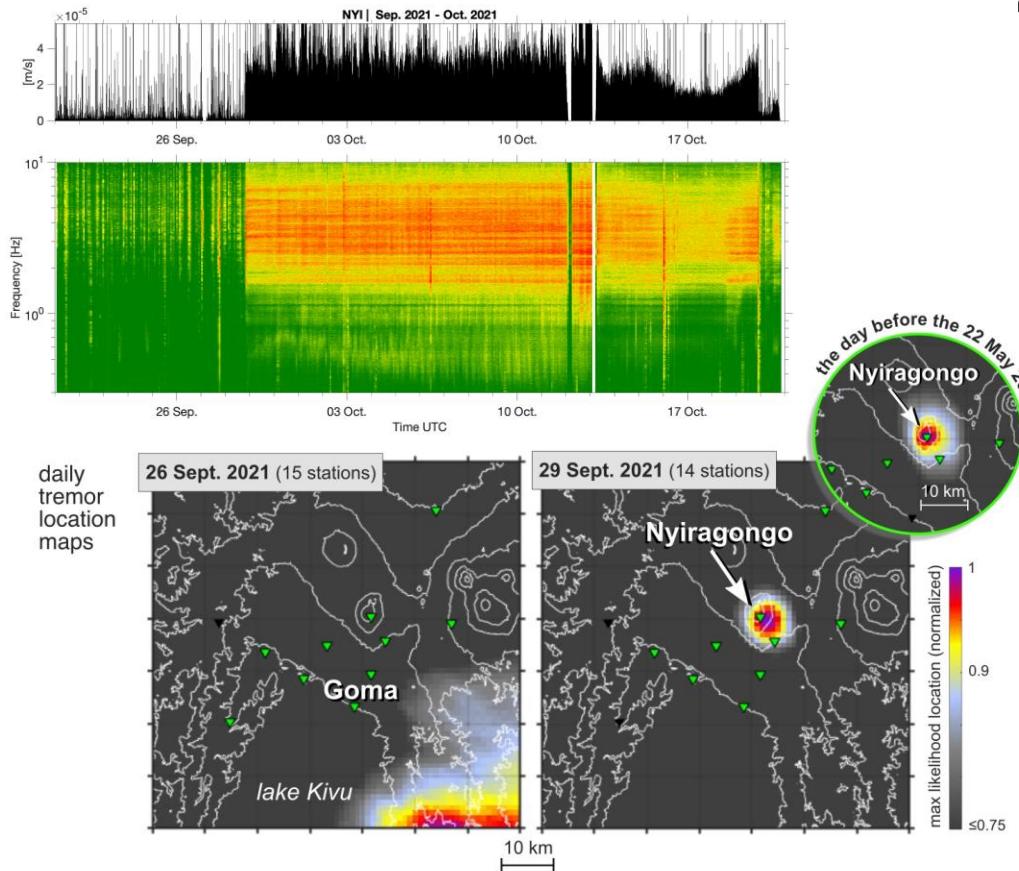
**(Re-)Activation of tectonic structures** in/around Lake Kivu



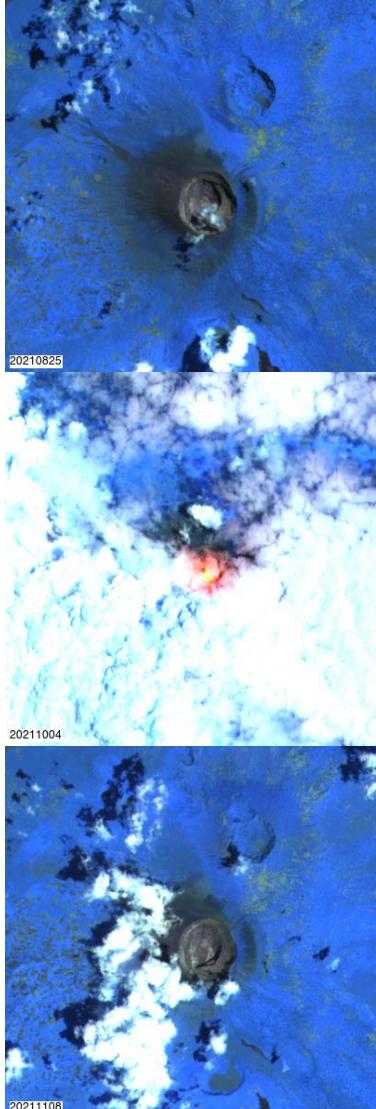
Schematic interpretation of the 2021 Nyiragongo volcanic crisis

# What's next?

**Summit activity is coming back;**  
similar seismic tremor signature  
still intermittent at the current stage



Still very low  
SO<sub>2</sub> emission



[https://georiska.africamuseum.be/en/news/nyiragongo\\_eruption](https://georiska.africamuseum.be/en/news/nyiragongo_eruption)

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