

# Two Decades of InSAR Observations in the Kivu Basin, Western Branch of East African Rift

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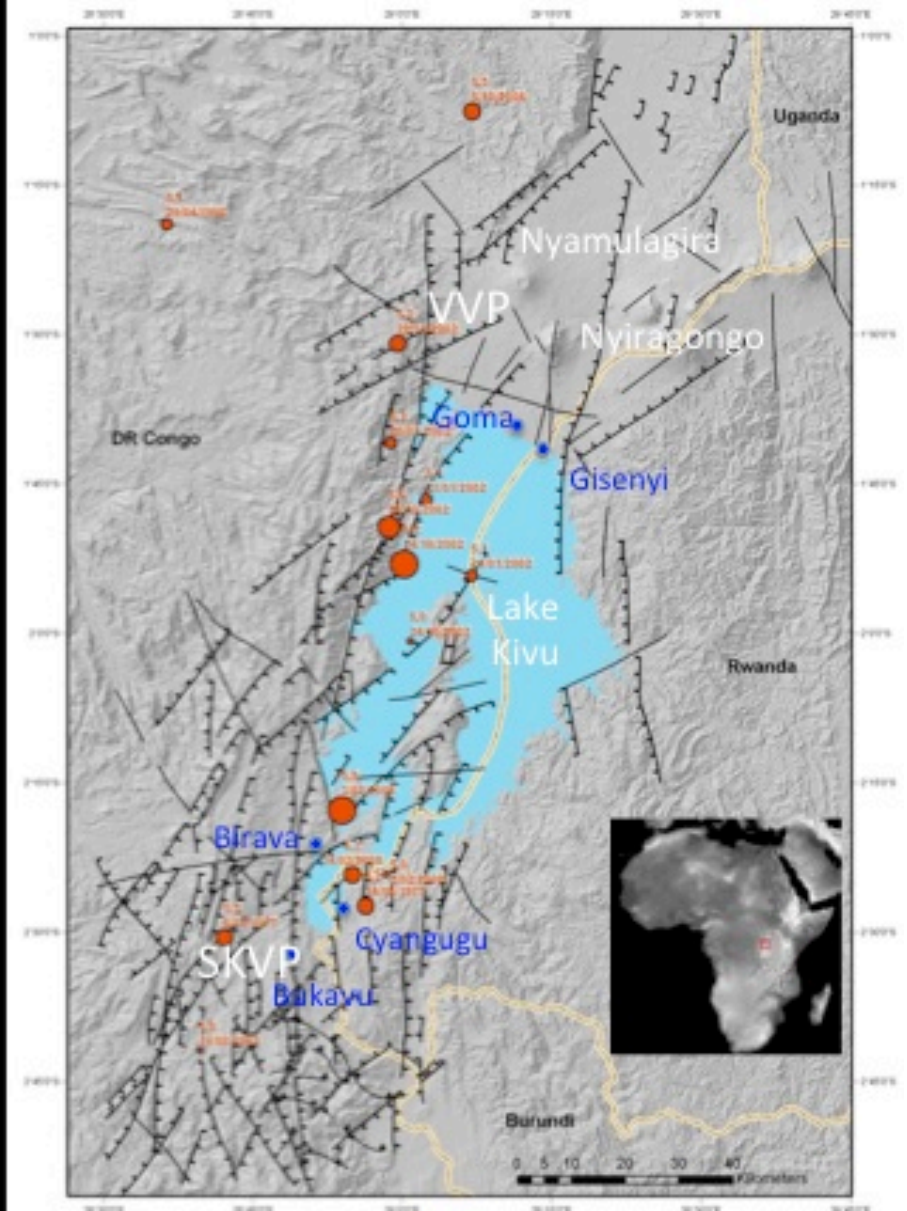
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# Two decades of SAR: overview

- What InSAR taught us about rift activity:  
Case studies :
  - 2002 Nyiragongo eruption
  - 2008 Bukavu-Cyangugu Earthquake
  - (2011/12 – 2010 – 2006 Nyamulagira eruptions)
  - (Former eruptions: 2004, 2002, 1998, 1996  
see e.g. C. Wauthier PhD, 2011)
- New opportunity offered by dense SAR database:
  - Multipath & multi sensors time series  
=> high resolution and low noise 2D (3D)

See related posters for more information:

- Wauthier et al.
- Cayol et al.
- Samsonov et al.
- Smets et al.

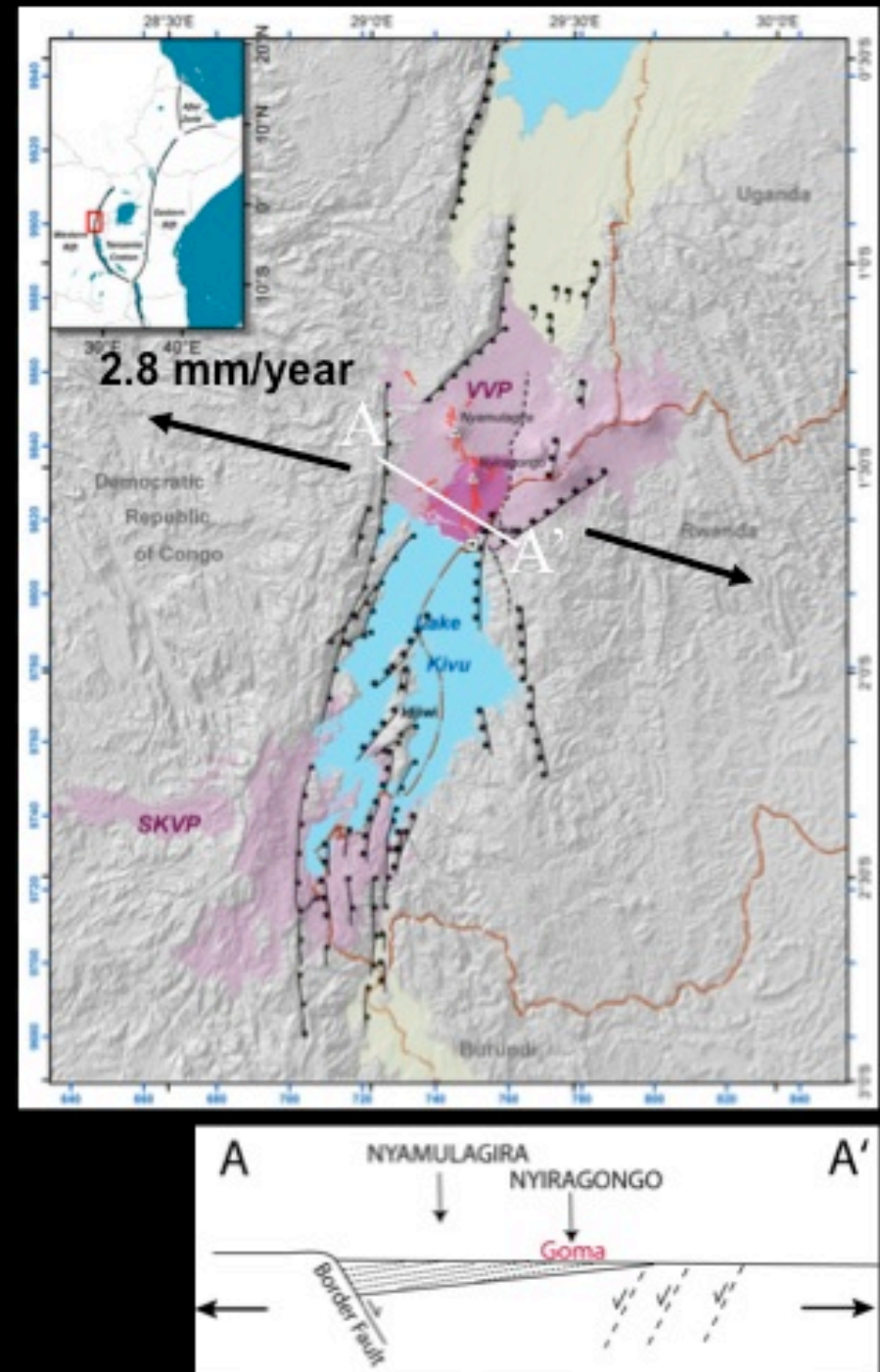


Mw >5 EQ (USGS ) and geological faults after [Villeneuve, 1980]



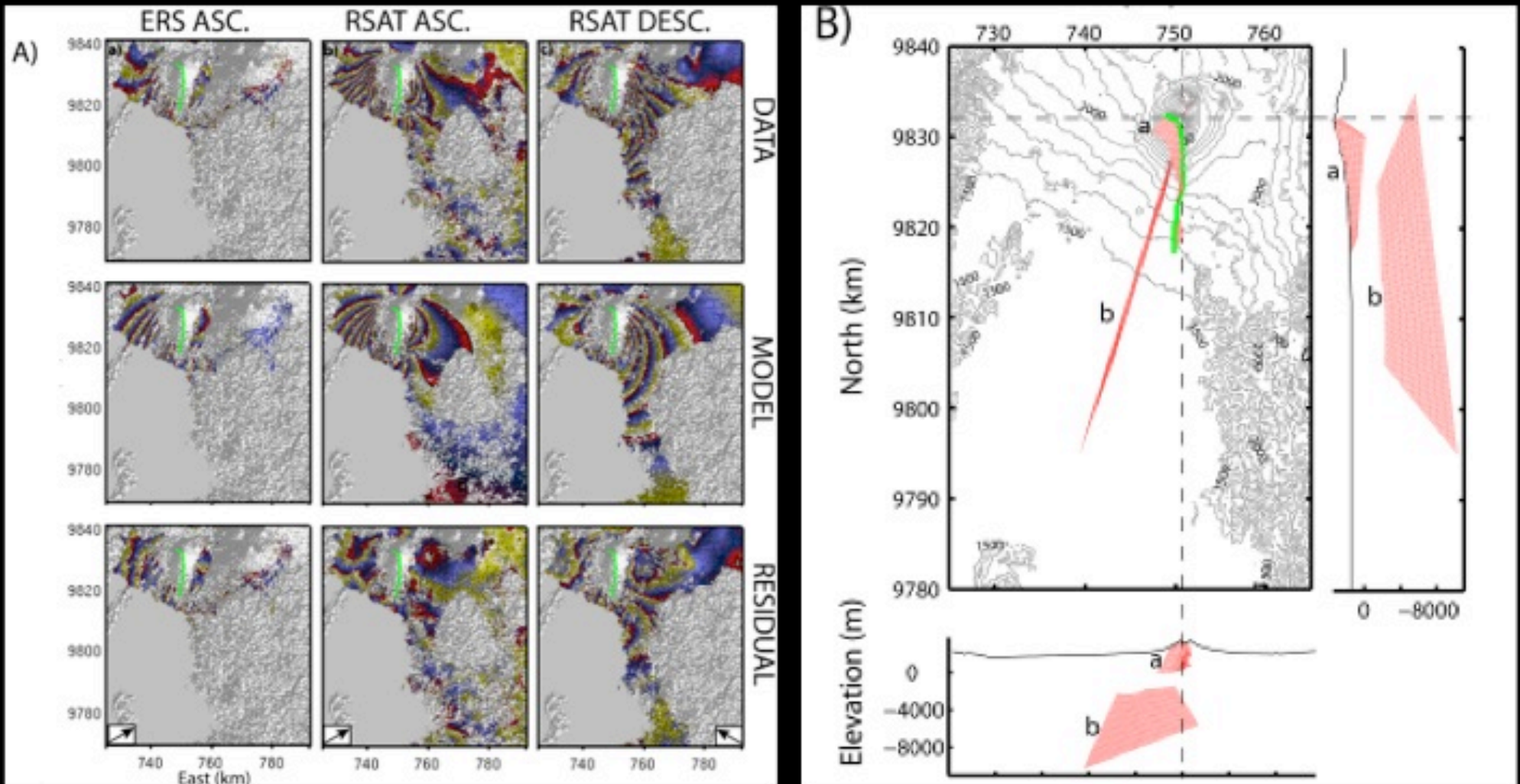
# Tectonic Context

- 100km long segments linked by accommodation zones (coincide with transfer faults and volcanic provinces)
- Unlike E branch, W rift experiences intense seismicity and less volcanism except in VP
- VVP: active since mid-Miocene (12 Ma)  
Today: Nyiragongo and Nyamulagira
- SKVP: 2-3 Ma younger though extinct (9 Ma)
- In amagmatic segments: opening accommodates through slip along border faults.
- In volcanically active areas: strain accommodation by magma intrusion decreases the amount of extension accommodated by fault-slip
- What about VVP and SKVP?
- Difficult area for on-site monitoring



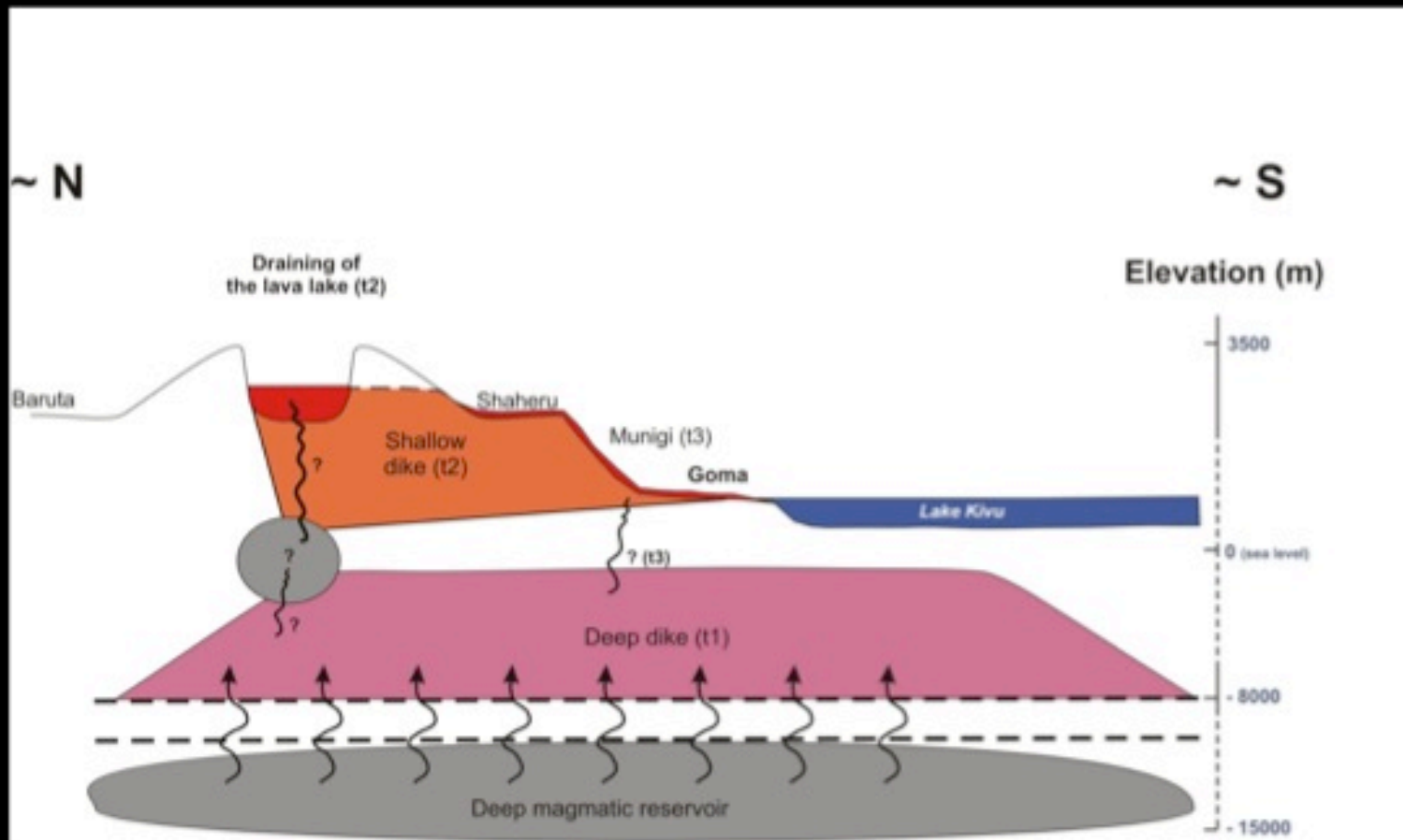
# Nyiragongo 2002 eruption

See poster by Wauthier et al.



(Wauthier et al. under review)

## Consistent with context, geochemistry etc...



(Wauthier et al. under review)

But not only ... : Small overpressure !



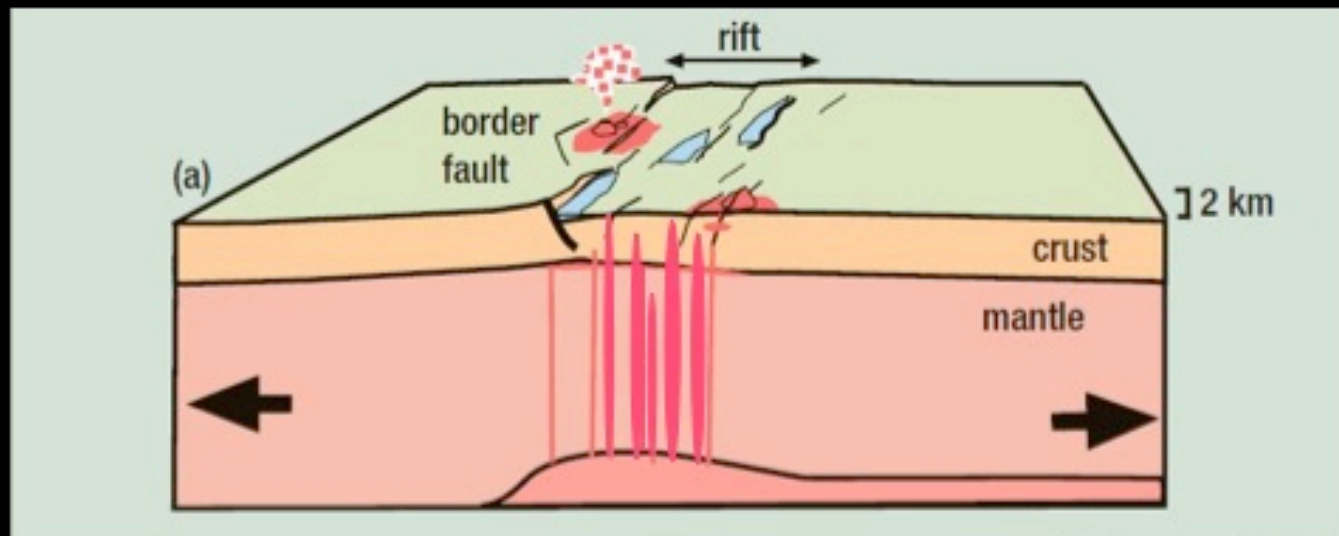
## Implication for opening mode assessment: (see poster by Cayol et al.)

- Direction of dikes is guided by rift extensional stress
- Low overpressure (1-5 Mpa) determined from modelling correspond to crustal stresses that are isotropic lithostatic
- But... if the rift is driven by fault motion:
  - horizontal stress must be small enough for faults to be on the verge of failure.
  - In this case horizontal stress would be  $\ll$  vertical stress and the overpressure (ie.  $P_m$  - horizontal stress) would be large, eg typically 45 MPa at few km depth (Rubin 1990)
- Now, the 0.7m opening => Compression would need 250 yr at the extensional rate of 2.8 mm/year to be relaxed.
- Since there was a similar eruption in 1977, eruptions have likely relaxed the rift extension

The rift would now be driven by magmatic rather than tectonic activity.

## Role of the mantle plume

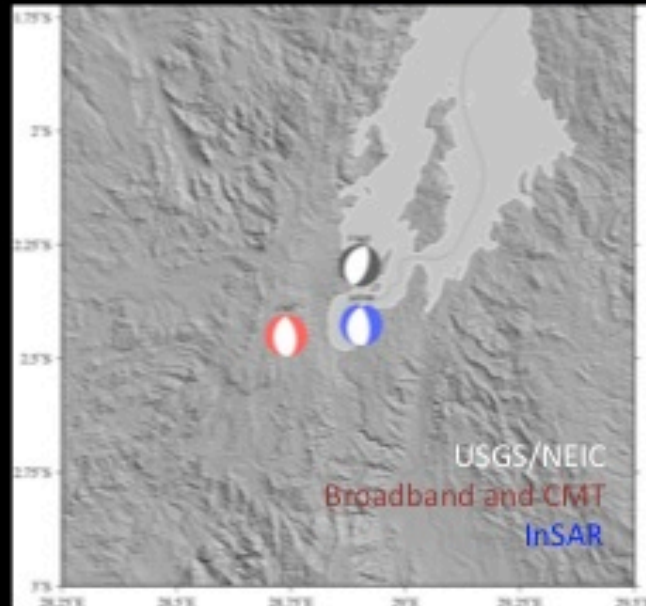
- Mature rifts are characterized by magma-driven extension and a thinned lithosphere
  - Here, the amount of tectonic extension is only 15 % : the rift is immature
  - It's too small to generate basalts by adiabatic decompression
- ➔ Magma could be supplied by the mantle plume beneath East Africa



(Ebinger 2005)

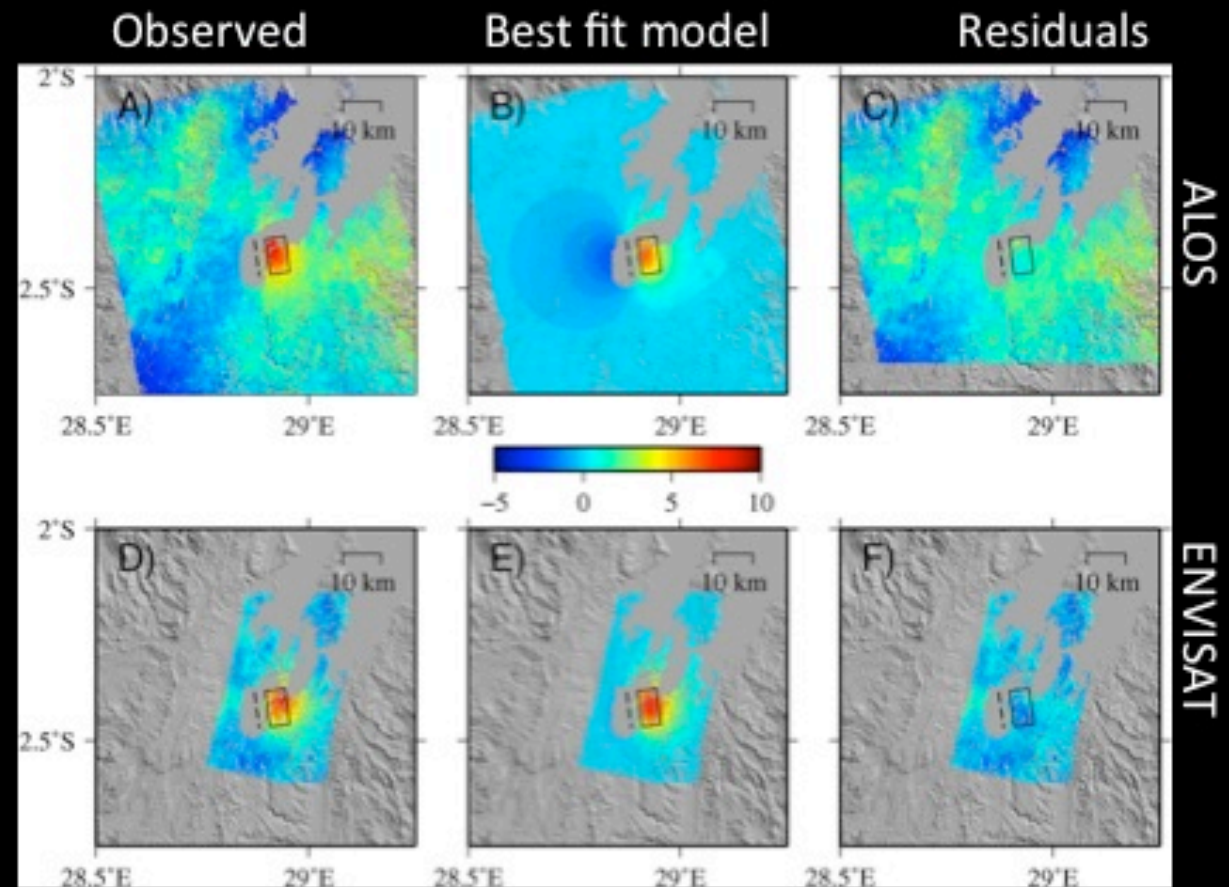
# What about SKVP?

## The Bukavu-Cyangugu 2008 Earthquake



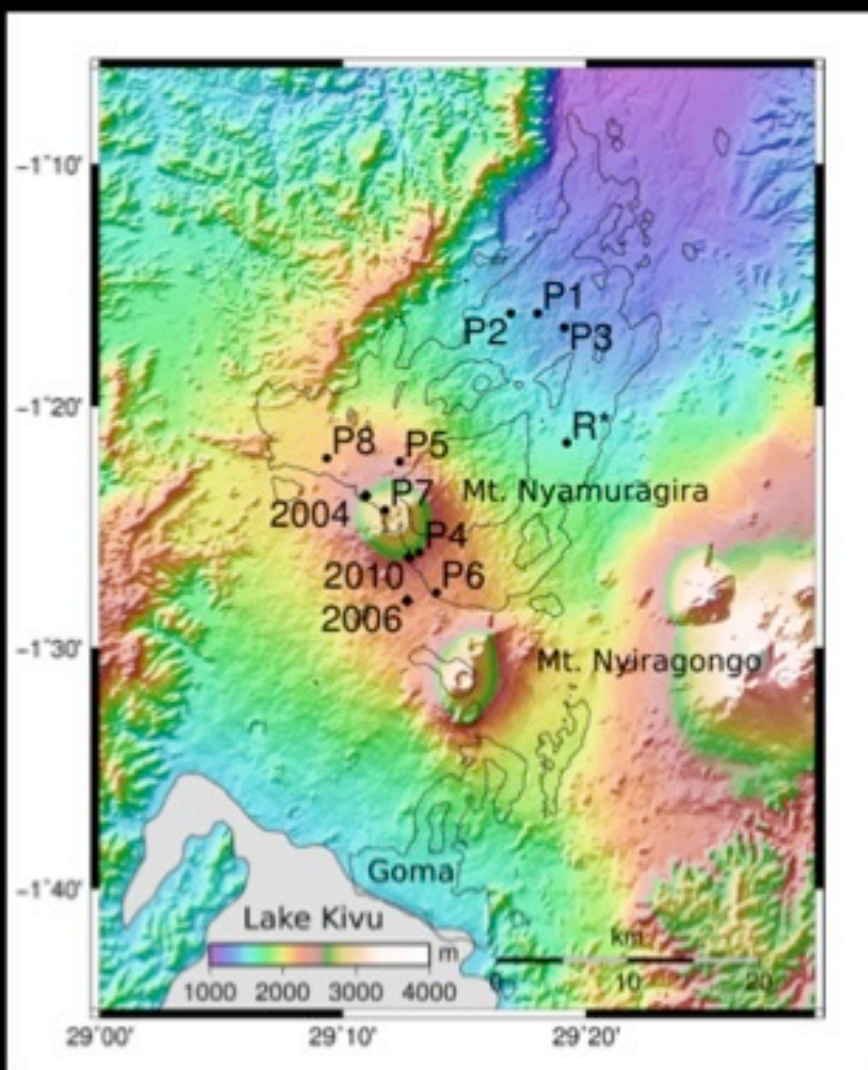
(d'Oreye et al., 2011)

- InSAR allowed accurate relocation
- Seismic  $\approx$  geodetic moment, i.e. brittle rupture : no magma involved at least at shallow depth => favours a mode of rift opening in which crustal extension is accommodated seismically





# New opportunities offered by dense SAR database



(Samsonov and d'Oreye, under review)

InSAR set	Time span	$\theta, ^\circ$	$\phi, ^\circ$	$N$	$M$
ENVISAT, Track 035IS2 (dsc)	20030116-20100916	-168	25	42	224
ENVISAT, Track 450IS7 (dsc)	20060519-20100910	-168	44	30	169
ENVISAT, Track 314IS7 (asc)	20060613-20100831	-12	44	41	308
ENVISAT, Track 228IS2 (asc)	20021225-20061025	-12	23	33	53
ENVISAT, Track 042IS5 (asc)	20080424-20100916	-12	38	20	96
ENVISAT, Track 493IS4 (dsc)	20080421-20100913	-168	34	18	86
ALOS, Track 580 (asc)	20071027-20100504	-12	39	9	36
RADARSAT-2, F21 (dsc)	20091215-20110527	-168	35	16	79
Total (only used images):	20030116-20100916			181	1051

We also have

- (limited) ERS-1/2 data starting from 1992,
- four more beams from ENVISAT (in various geometries) and
- recent Radarsat-2 Ultra-Fine and Fine beams data (different resolution and geometry).

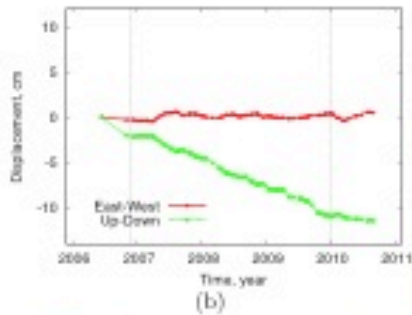
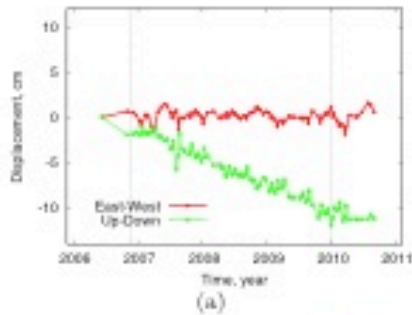
Can we produce continuous time series of ground deformation over the entire period?

# Multidimensional time series analysis of ground deformation from SAR data acquired in various orbital geometries

(See poster by Samsonov and d'Oreye)

- Method based on the Small Baseline Subset method (Berardino et al 2002).
- Combination of all possible air-borne and space-borne SAR data acquired with
  - different acquisition parameters,
  - temporal and spatial sampling and resolution,
  - wave-band and polarizationto reconstruct 2D (3D) displacement time series
- Singular Value Decomposition is used for finding a solution of underdetermined problem.
- Verified with theoretical deformation + noise using real time matrix

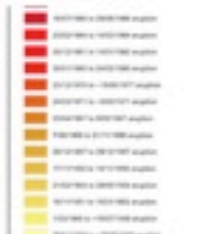
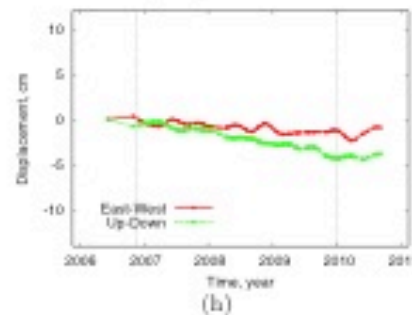
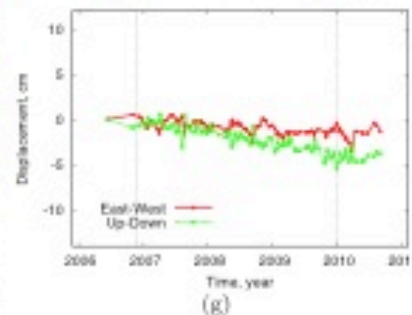
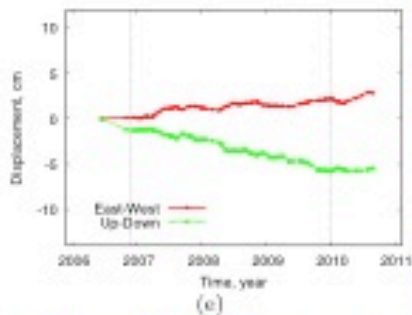
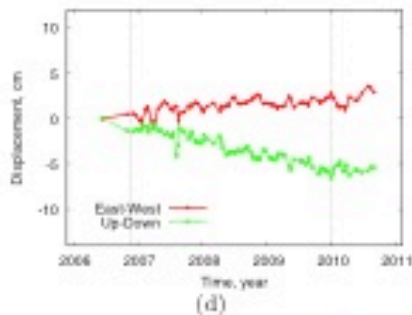
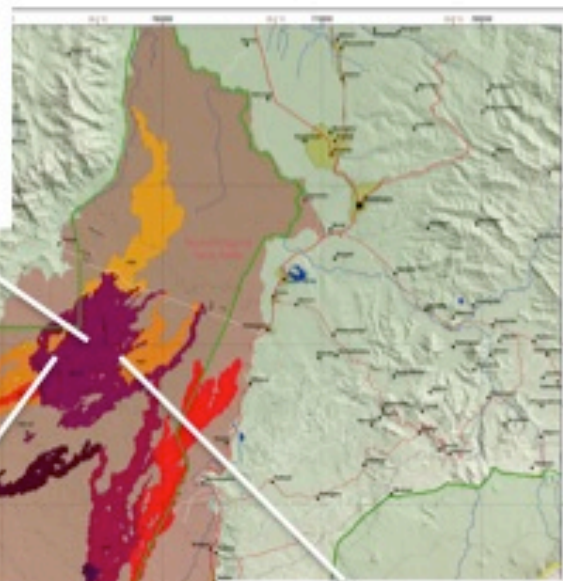




# Local map of Nyamulagira

Province - North Kivu, Democratic Republic of Congo

**GORISK**  
Scientific Network



Map realized in the framework of  
**SAMAAV project**  
**GORISK project**

Scale: 1:100,000





# Conclusions

- Despite the equatorial vegetation, InSAR offers unique opportunities
  - to monitor eruptions in the Virunga: source modeling, accurate location, lava flow mapping... (no presented here)
  - to study activity in the Virunga: provided hypothesis on the rifting mode in both the VVP and the SKVP
- Given the local context, it proved to be the most sustainable method for studying these volcanoes
- The dense database also offered the possibility to develop new methodology for time series analysis. Such tool allowed the first unambiguous detection of pre-eruptive deformations few weeks prior some eruptions in the VVP



Nyamulagira 2010 eruption



Thank you

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