Using multi-sensor data to characterise the dynamic of magmatic systems along the East African Rift

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RIFT VOLC

University of BRISTOL

COMET
CENTRE FOR OBSERVATION & MODELLING OF EARTHQUAKES, VOLCANOES & TECTONICS

LiCS
LOOKING INSIDE THE CONTINENTS FROM SPACE

NERC
SCIENCE OF THE ENVIRONMENT

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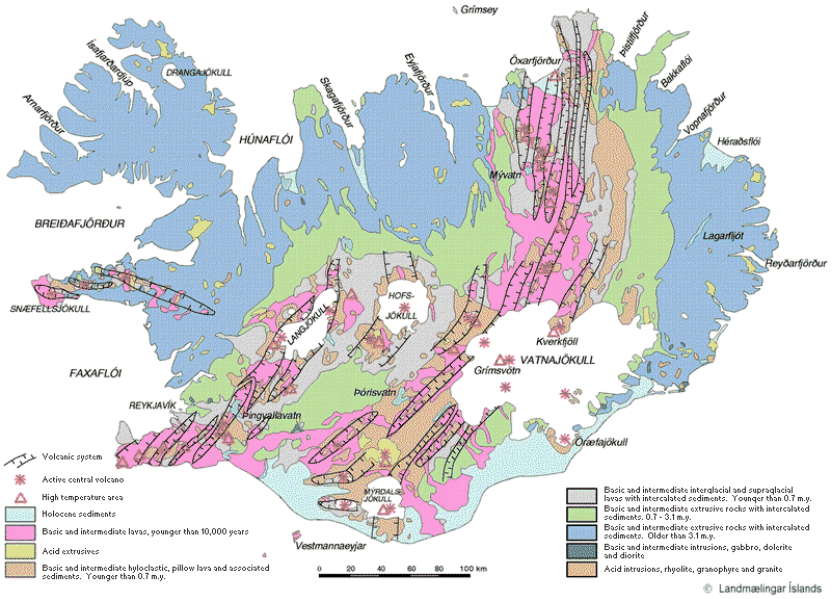
[3] Istituto Nazionale di Geofisica e Vulcanologia, Pisa, Italy

Volcanism in a rift setting

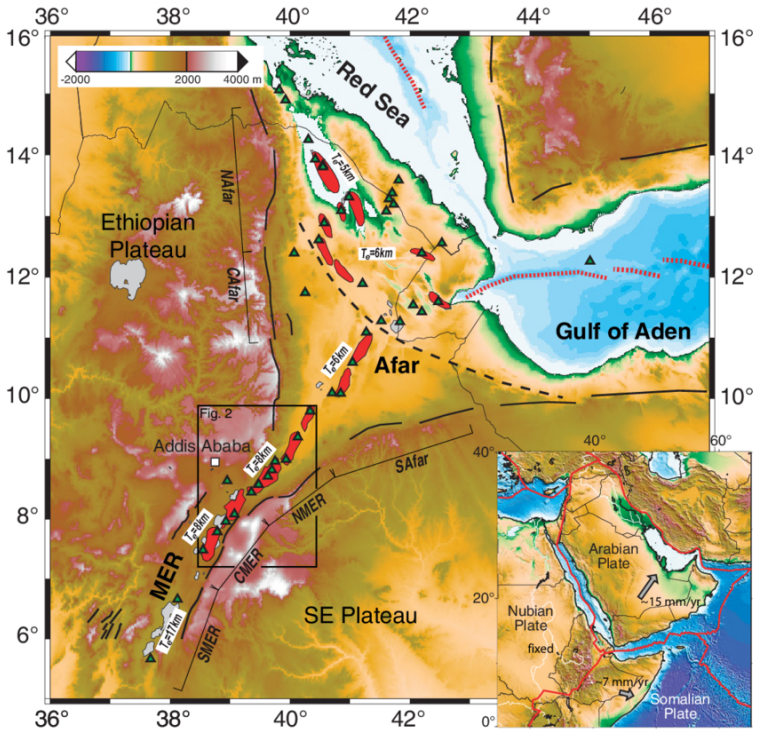
Why the study of rift volcanism is important?

- **Activity**: Many events as extension regime facilitates magma transport
- **Diversity**: Eruptive style ranges from mafic fissures to silicic caldera
- **Complexity**: Interaction between rifting and magmatism

…but land observations are limited: **Iceland** and **East African Rift**

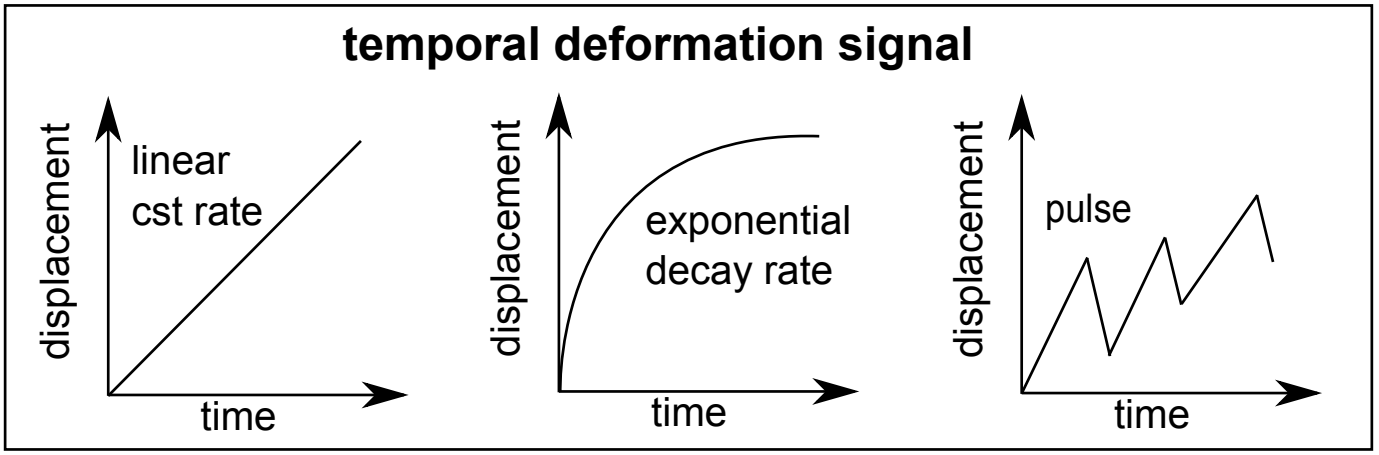


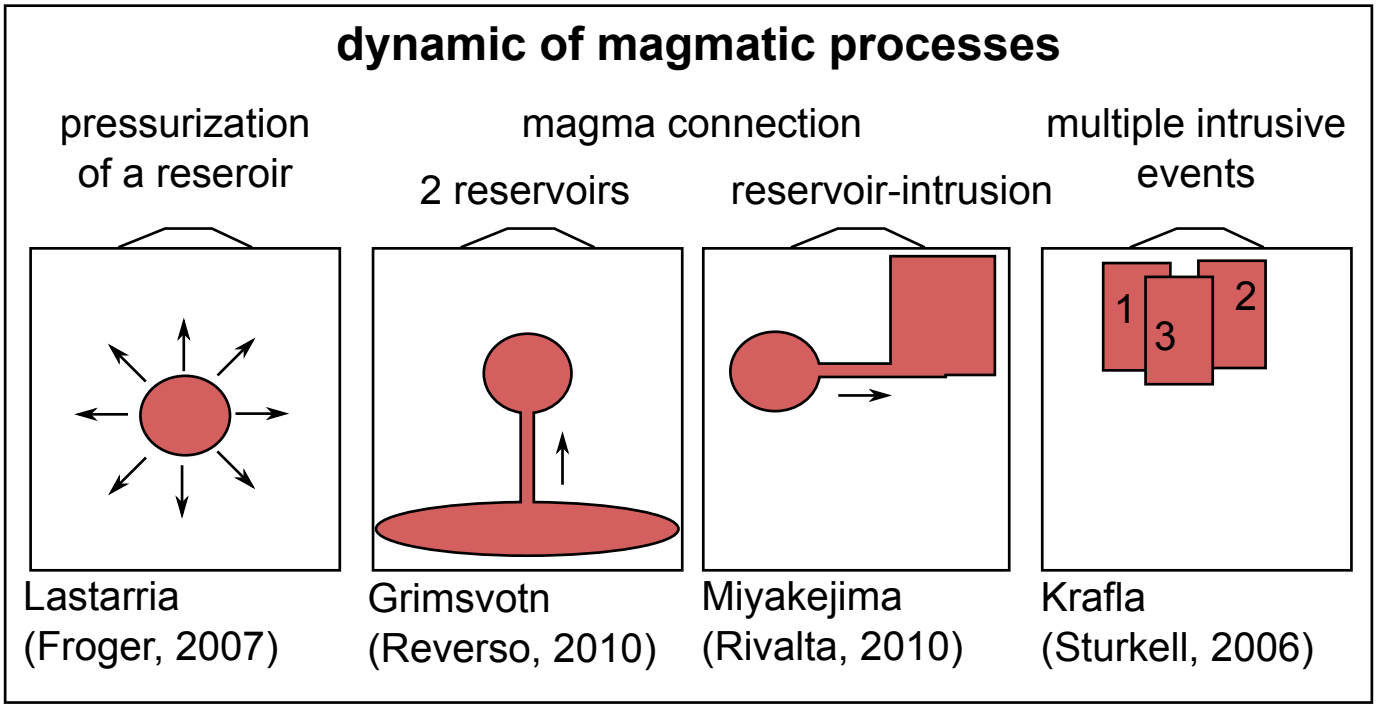
Source: Landmælingar Íslands



(modified from Keir et al., 2013)

Information from ground deformation





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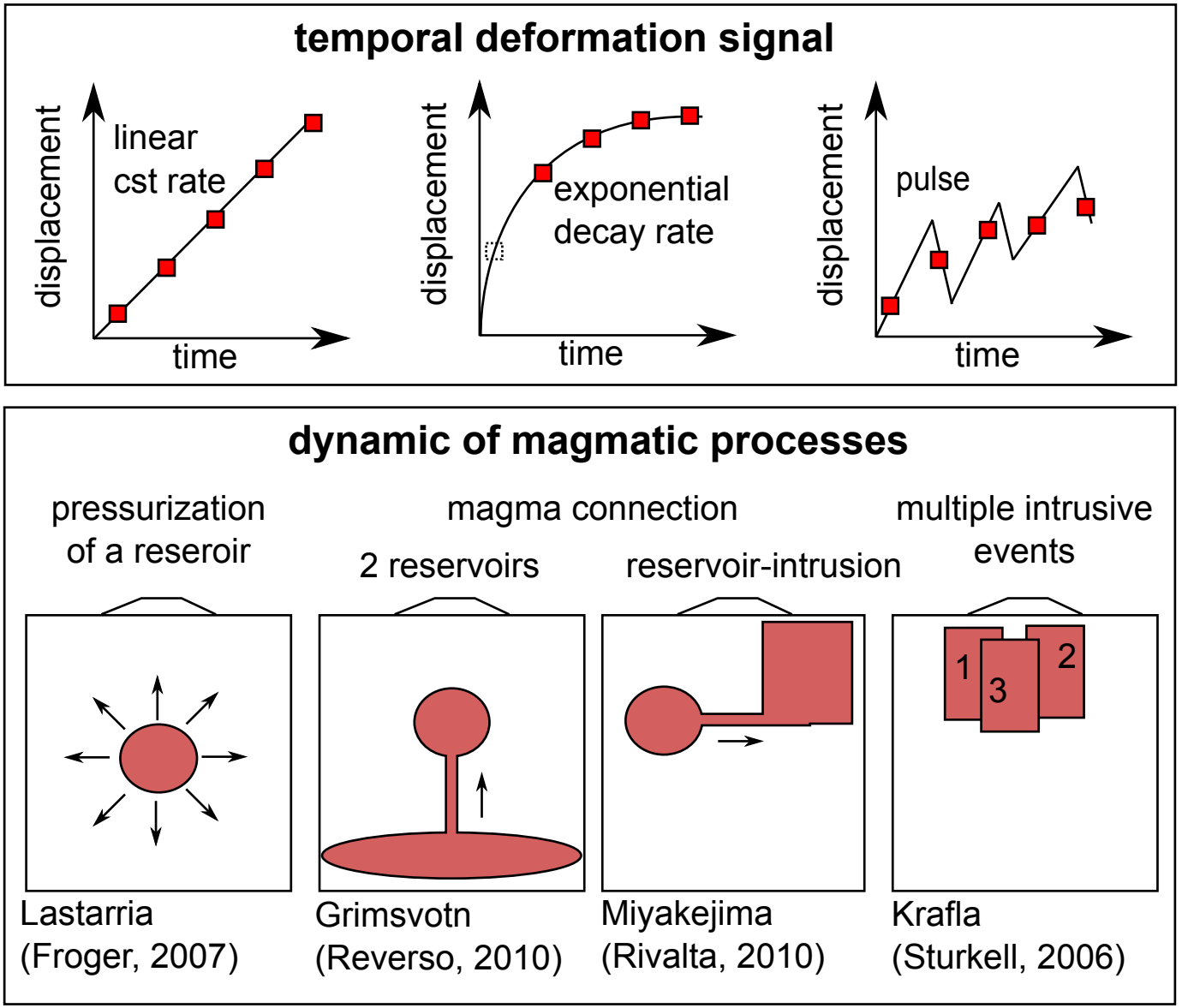
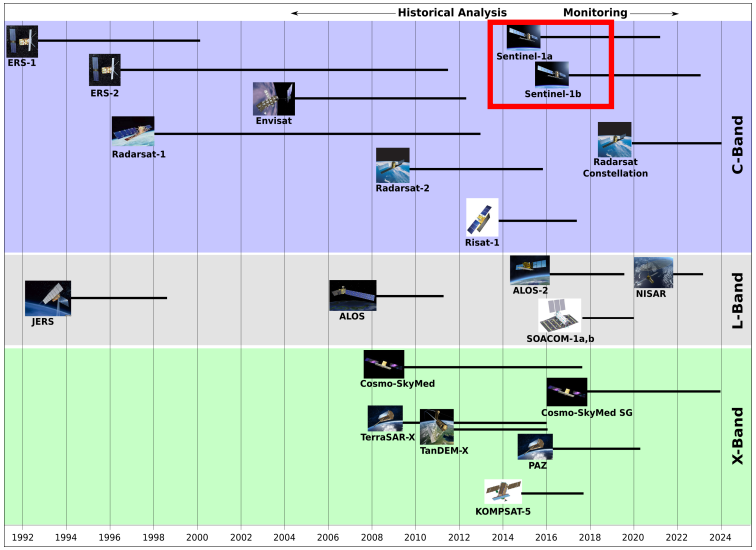
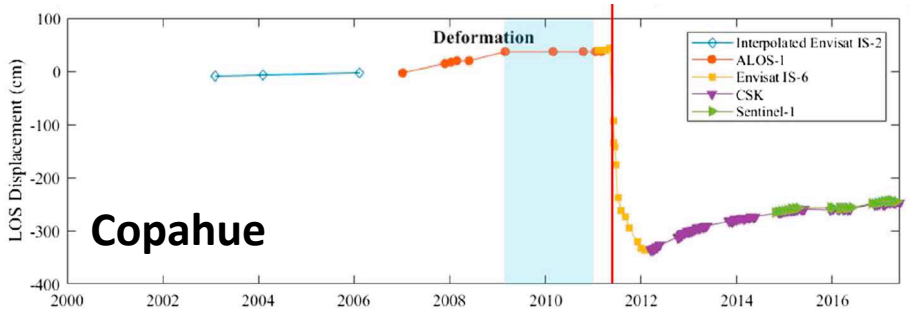
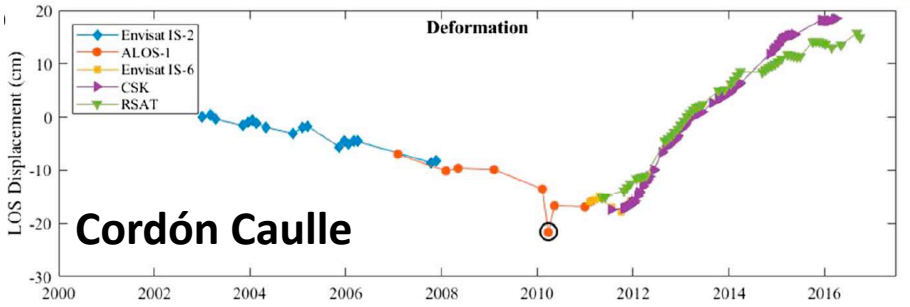


Complementarity of SAR data



- Open-data
- High temporal resolution: 6-12 days
- Lifetime: 7 years per satellites
- Available in near real-time





- Combination of InSAR results
- Long-term survey (10-20 years)
- Subduction arc (Andes)

Reath et al., 2018

Tasks of the project

1- Sentinel-1 InSAR survey (2014-2019)

2- Comparison with previous InSAR survey (ENVISAT, ERS)

3- Combination with additional dataset:
Thermal time series (ASTER), Cornell University

4- Modelling the sources of deformation

Tasks of the project

1- Sentinel-1 InSAR survey (2014-2019)

2- Comparison with previous InSAR survey (ENVISAT, ERS)

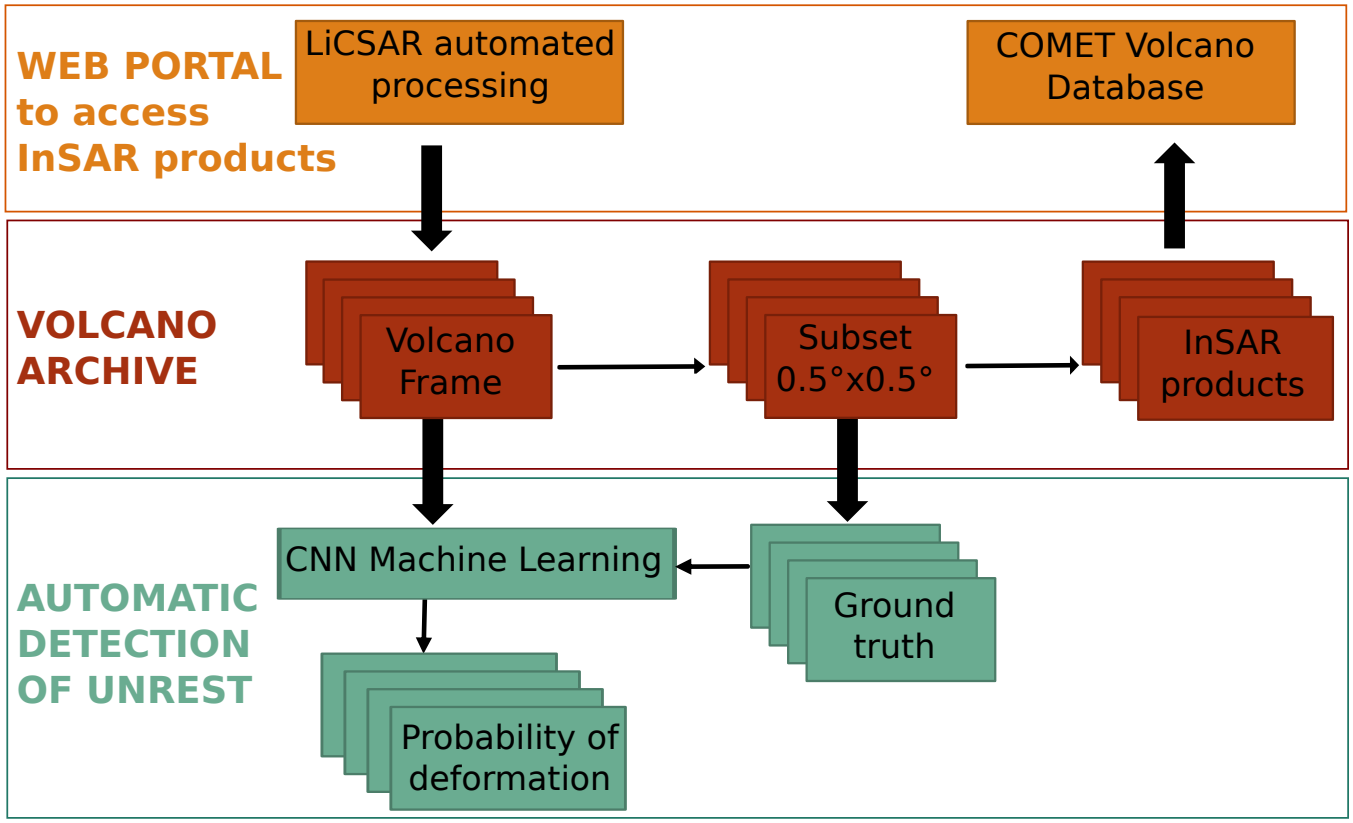
3- Combination with additional dataset:

a) thermal time series (ASTER)
b) gravimetry survey (field work in January 2020)

4- Modelling the sources of deformation

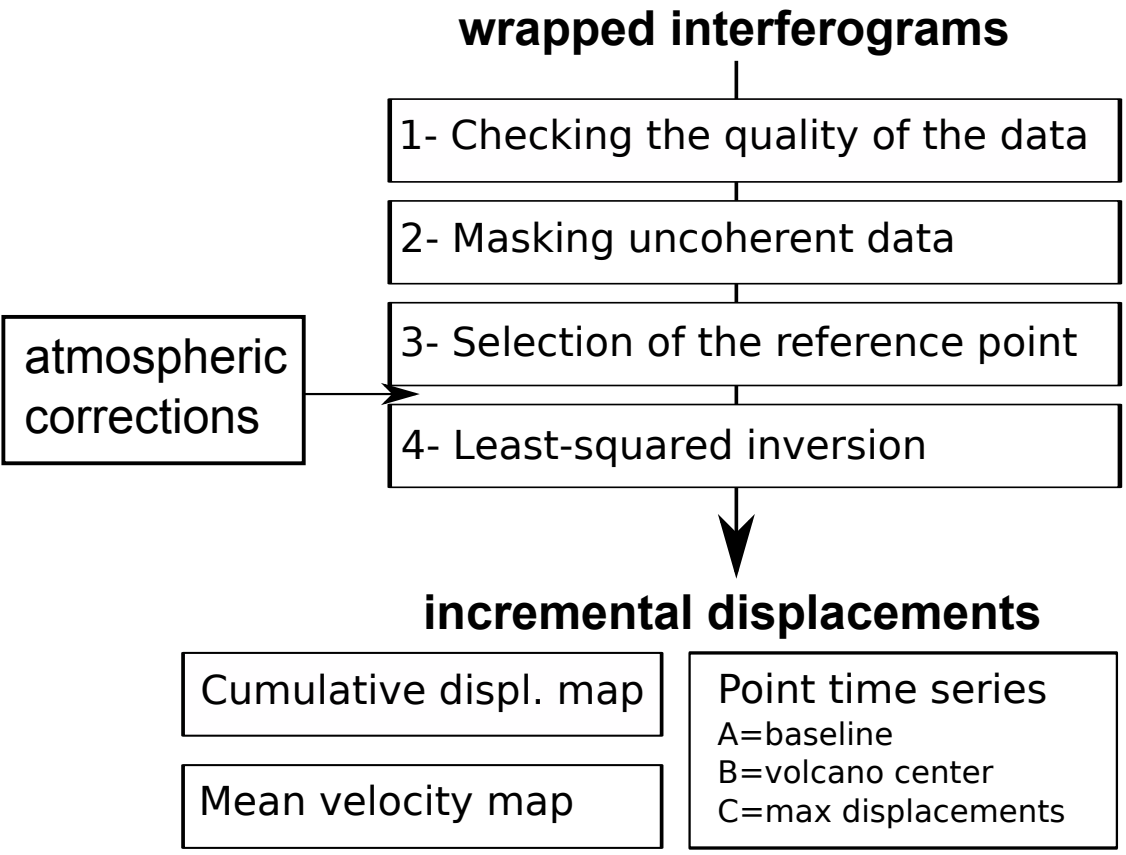
METHOD

LiCSAR: automated Sentinel-1 InSAR processing



- Processing the three short-duration interferograms
- Operational on about 900 active volcanoes
- Current database: **32.000** subset interferograms on Africa volcanoes

LiCSAR: production in routine of time series



LiCSAR: production in routine of time series

wrapped interferograms

1- Checking the quality of the data

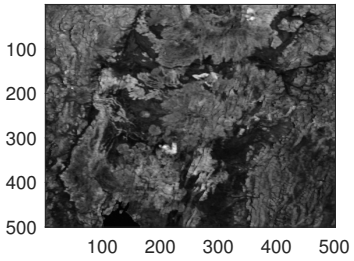
2- Masking uncoherent data

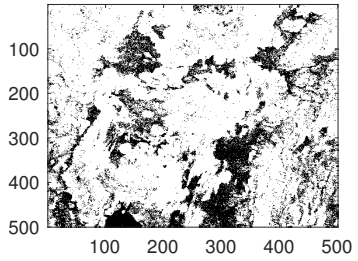
atmospheric corrections → 3- Selection of the reference point

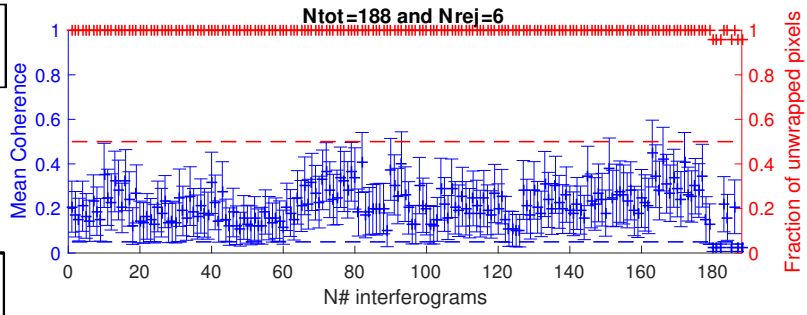
4- Least-squared inversion

incremental displacements

- Cumulative displ. map
- Mean velocity map
- Point time series
  - A=baseline
  - B=volcano center
  - C=max displacements







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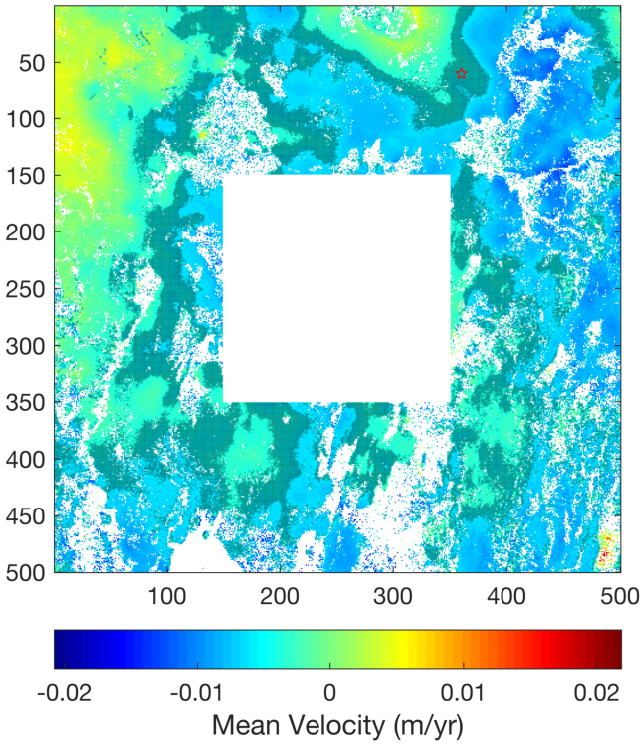

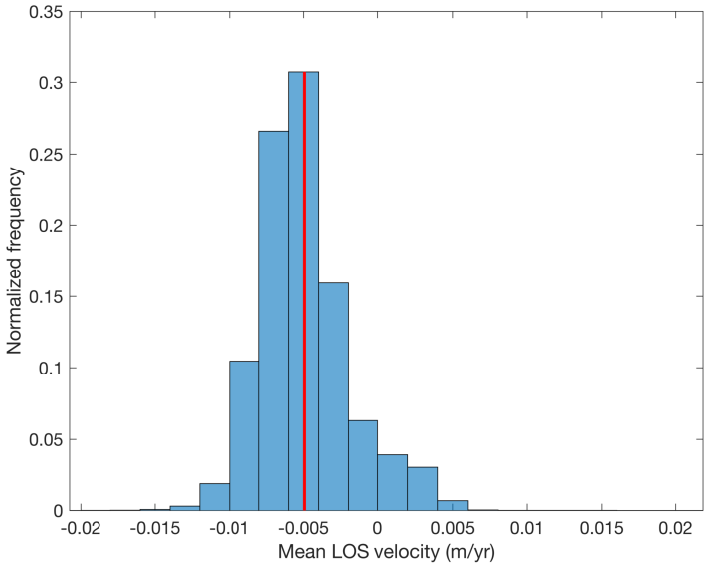

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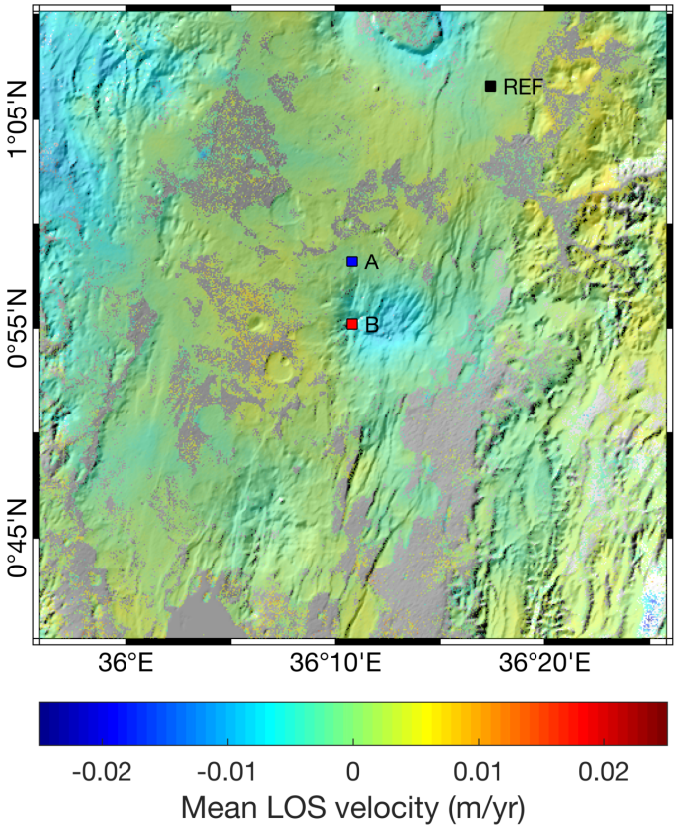

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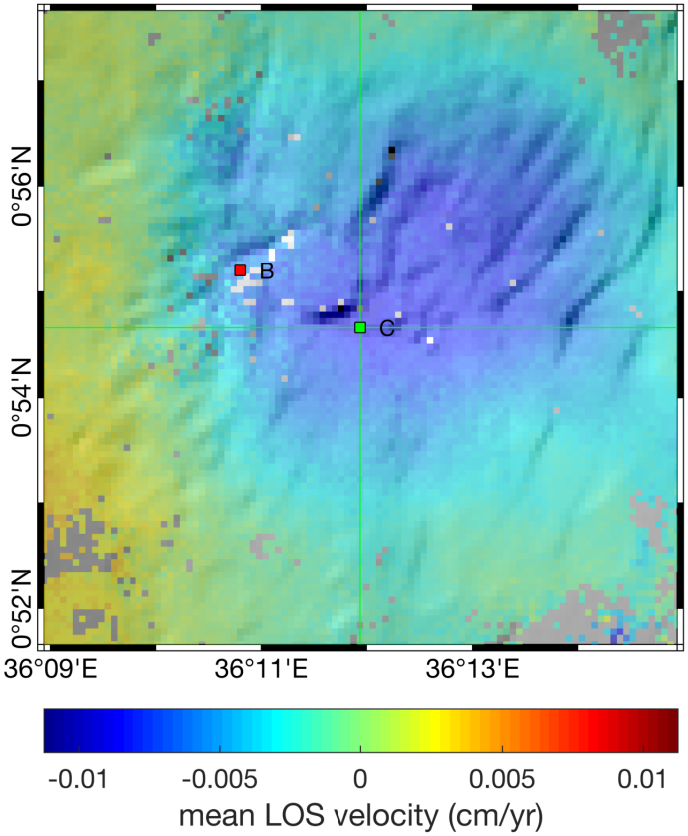
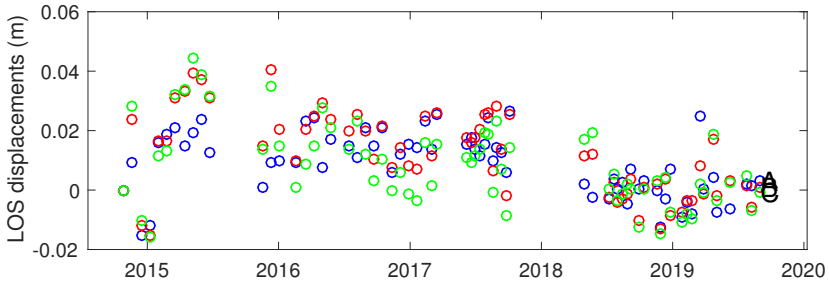
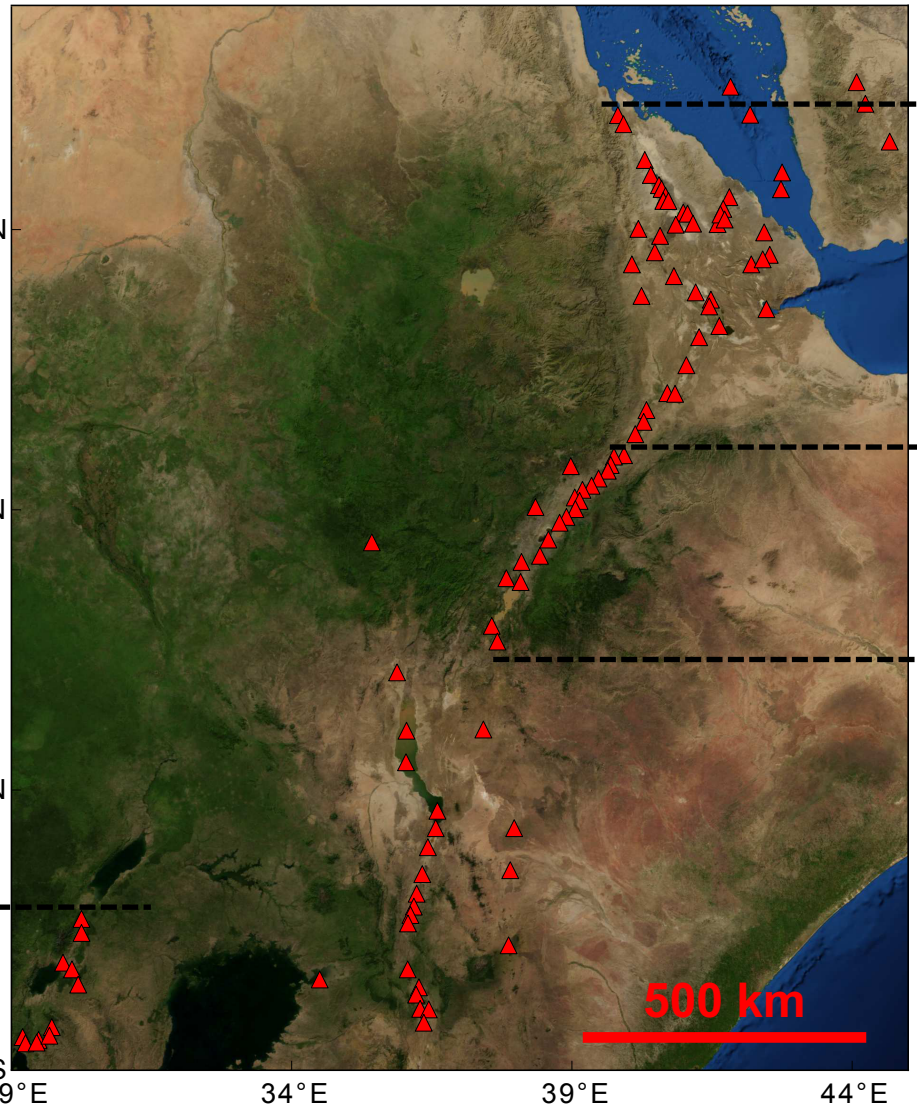




RESULTS

Studied area: ~80 active volcanoes



AFAR
~30 volcanoes

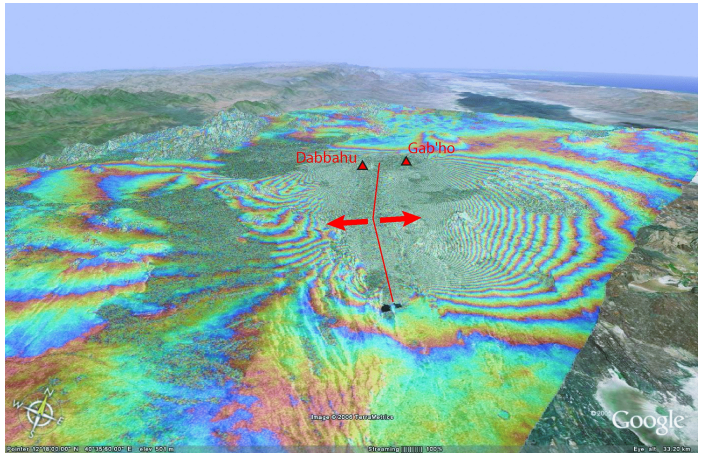
Main Ethiopian Rift
~20 volcanoes

Kenyan-Tanzanian rift
~20 volcanoes

Congo rift
~10 volcanoes

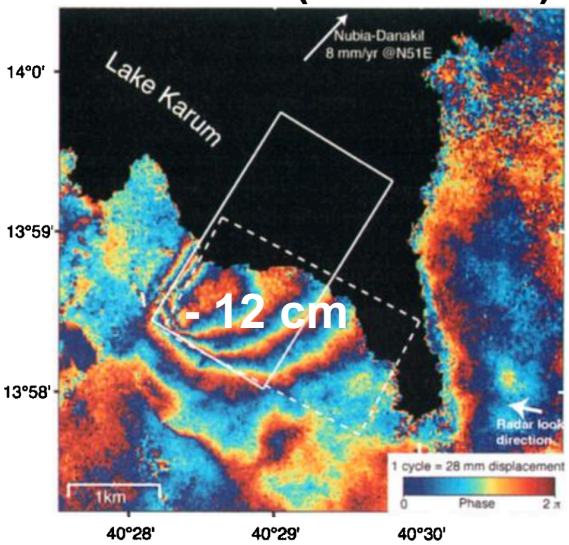
AFAR:
ERS and ENVISAT survey

Dabbahu 2005 rifting event



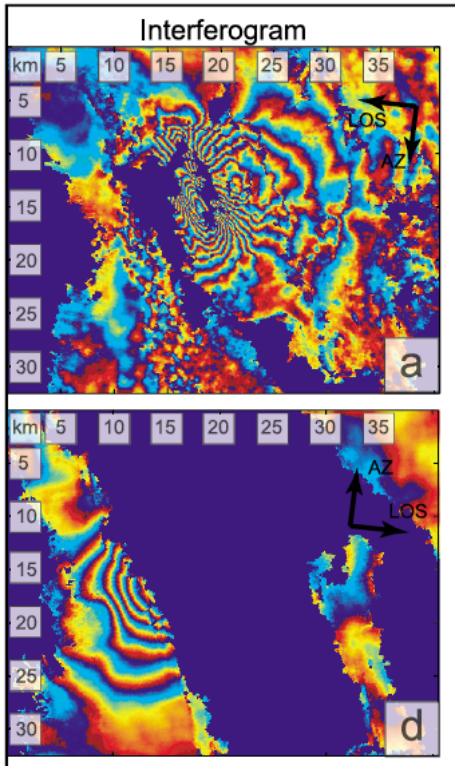
Wright et al., 2006

Gada Ale (1993-1996)



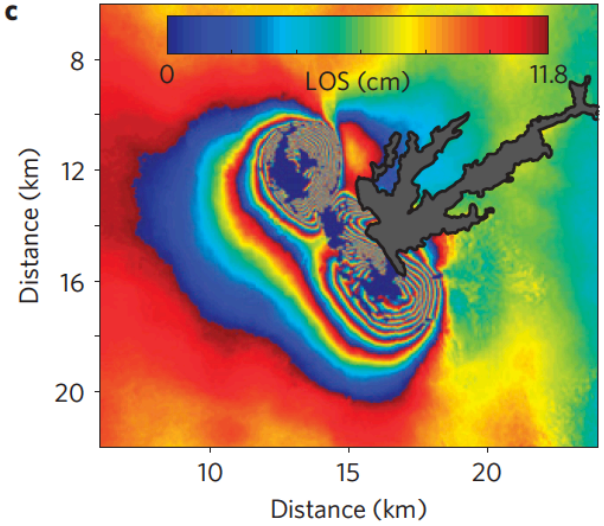
Amelung et al., 2000

Dallol 2004 intrusion



Nobile et al., 2012

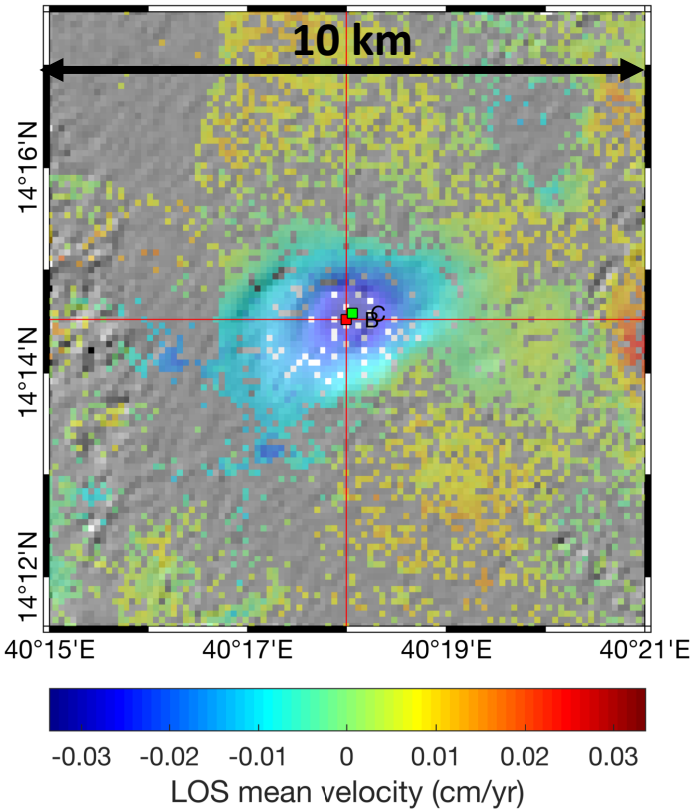
Alu-Dalafilla 2008 eruption

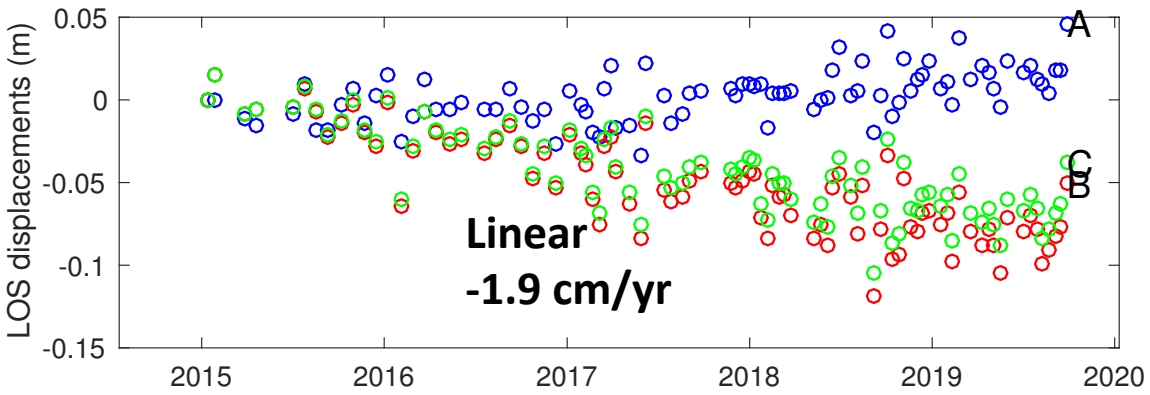


Pagli et al., 2012

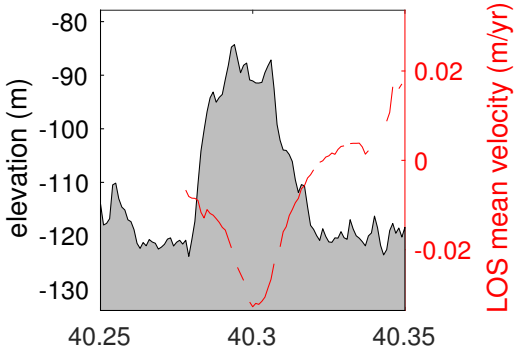
And many more…

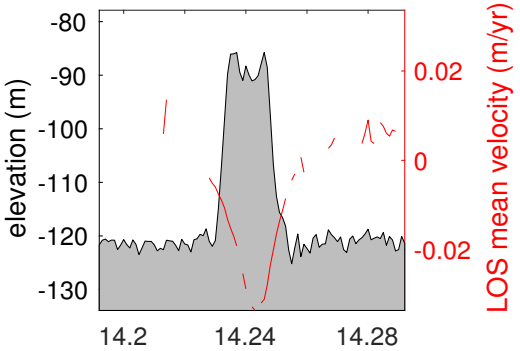
AFAR: Dallol
Sentinel-1 survey (2015-2019)



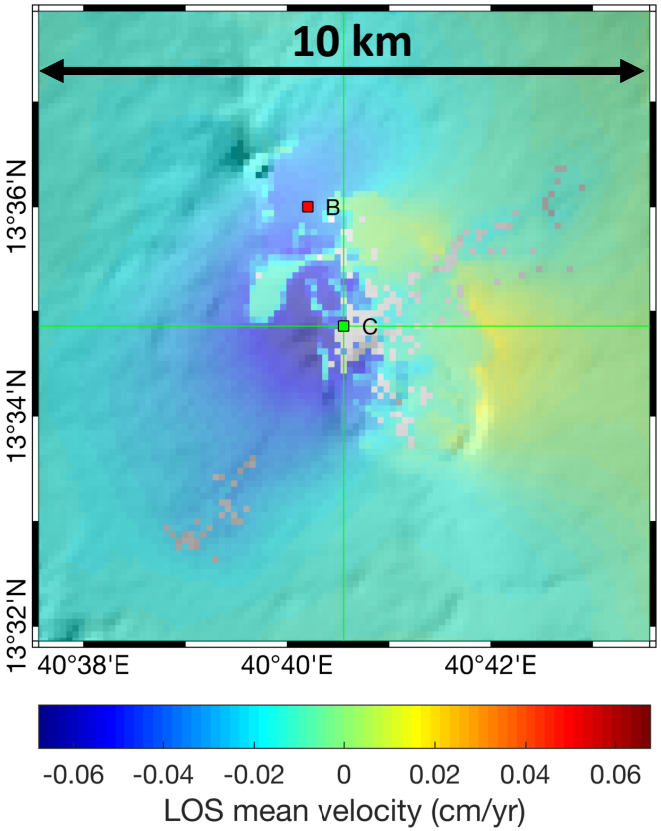


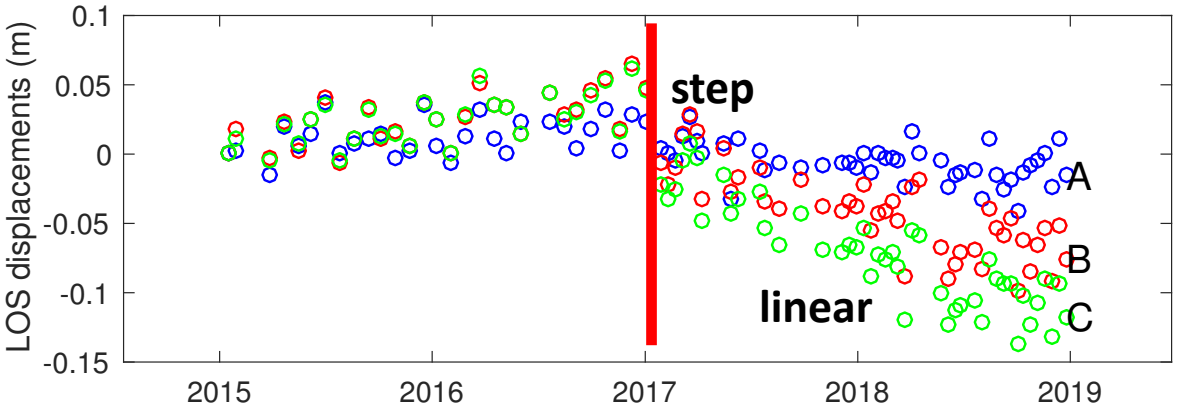
- Small signal located in the edifice
- Linear subsidence at a rate of 1.9 cm/yr
- Contraction of magma body following the 2011 eruption?



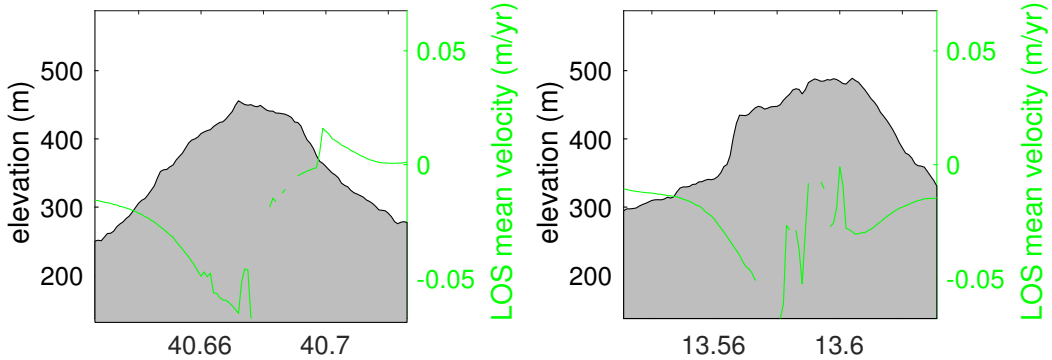


AFAR: Erta Ale
Sentinel-1 survey (2015-2019)

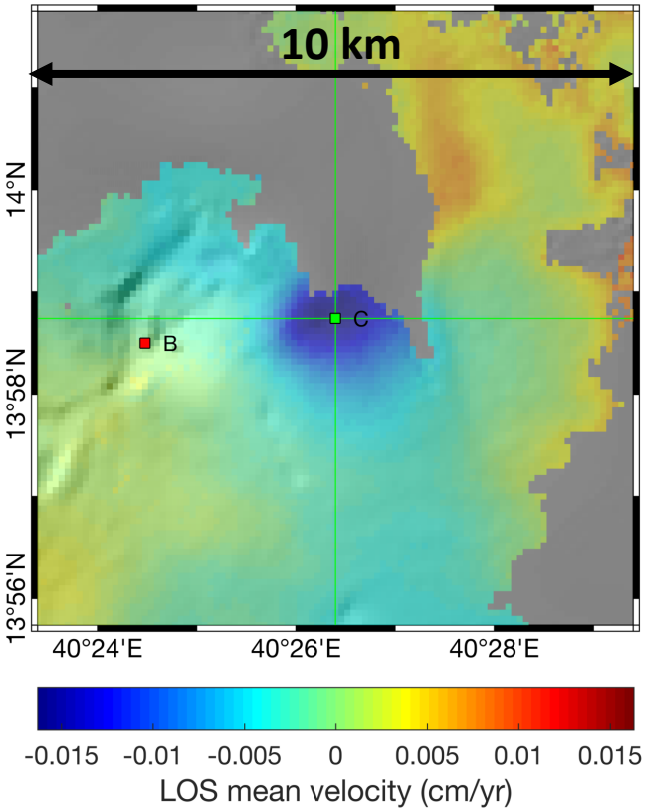


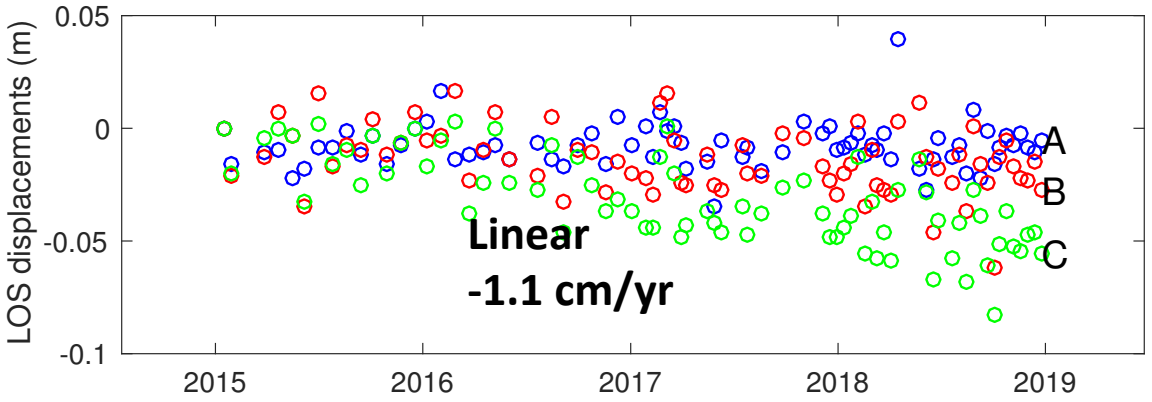


- Slow pre-eruptive inflation associated to pressure build up
- Rapid co-eruptive displacements due to two magma intrusions (**Moore et al., in review**)
- Linear post-eruptive subsidence at a rate of ~5 cm/yr

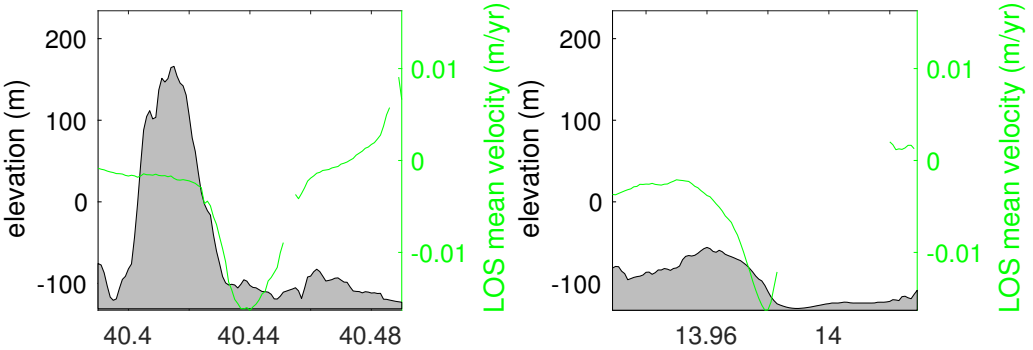


AFAR: Gada Ale
Sentinel-1 survey (2015-2019)





- Small signal at the edge of lava flows
- Linear subsidence at a rate of 1.2 cm/yr for the entire period



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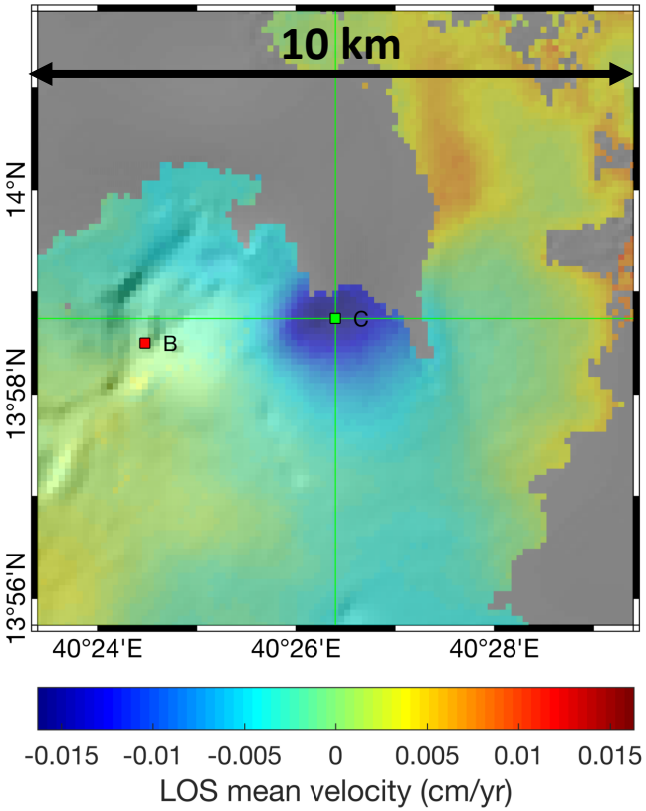
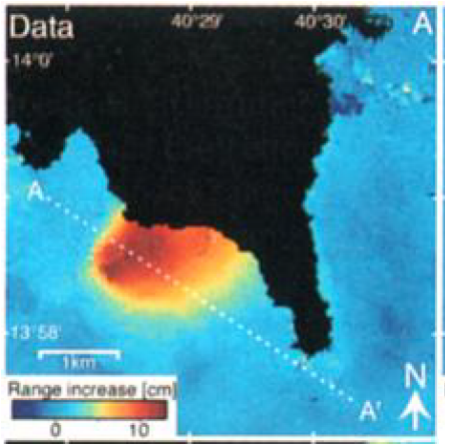
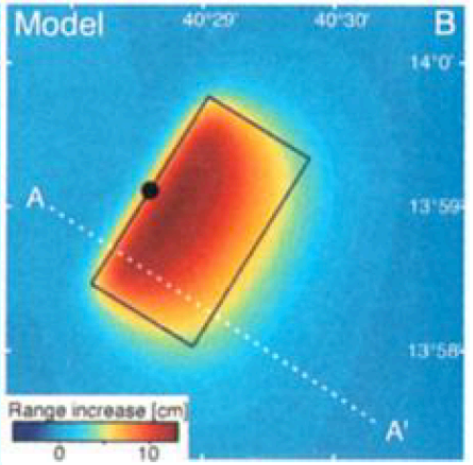
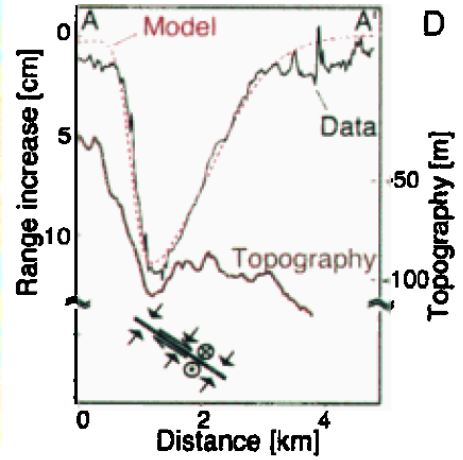


ERS 1993-1996



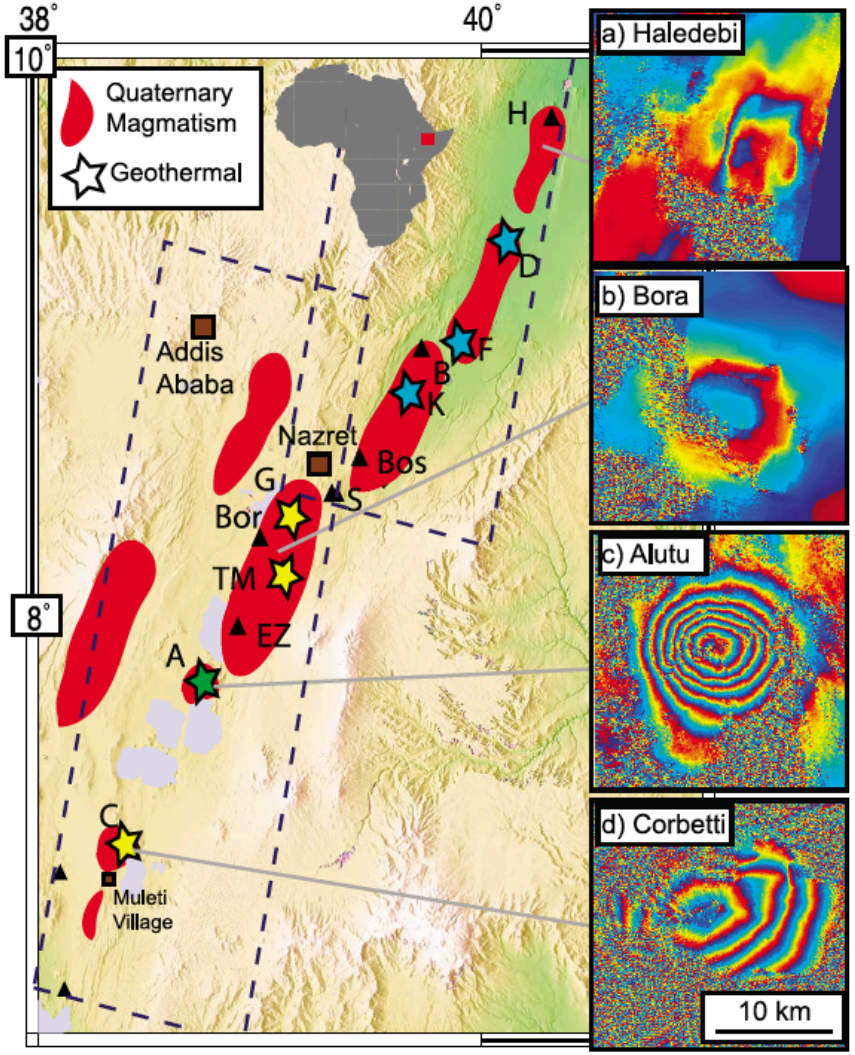


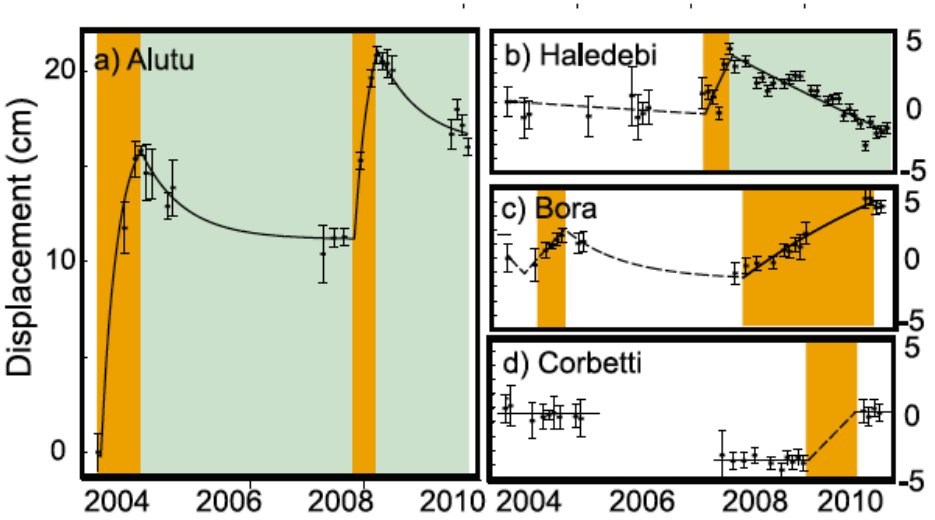
(Amelung, 2000)



- Same location
- Slower rate: 1.1 cm/yr (3.7 cm/yr in 1993-1996)
- Dislocation Model: a combination of contraction of source + normal faulting (sill intrusion?)
- Is the source persistent from 1993 to 2019?

4- Main Ethiopian rift: ENVISAT survey (2004-2010)



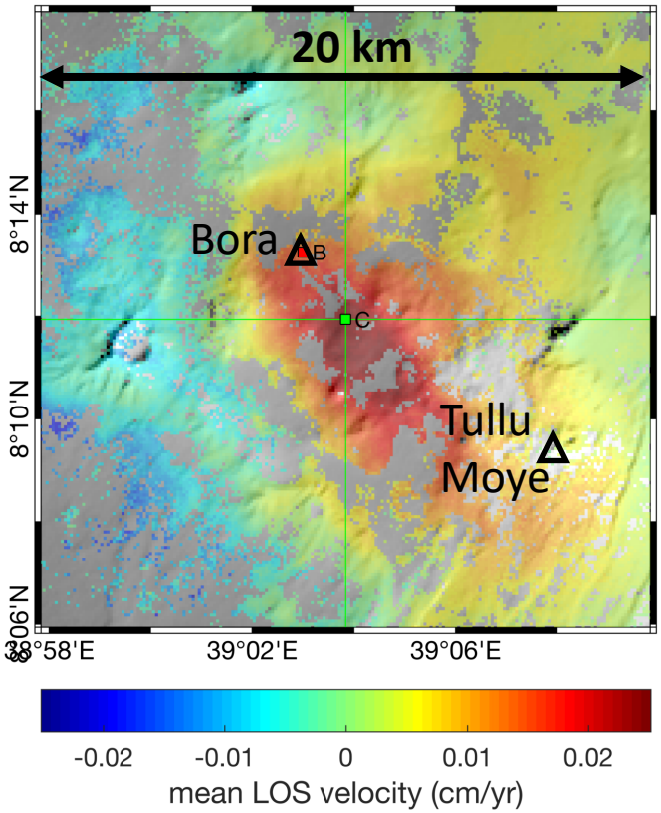


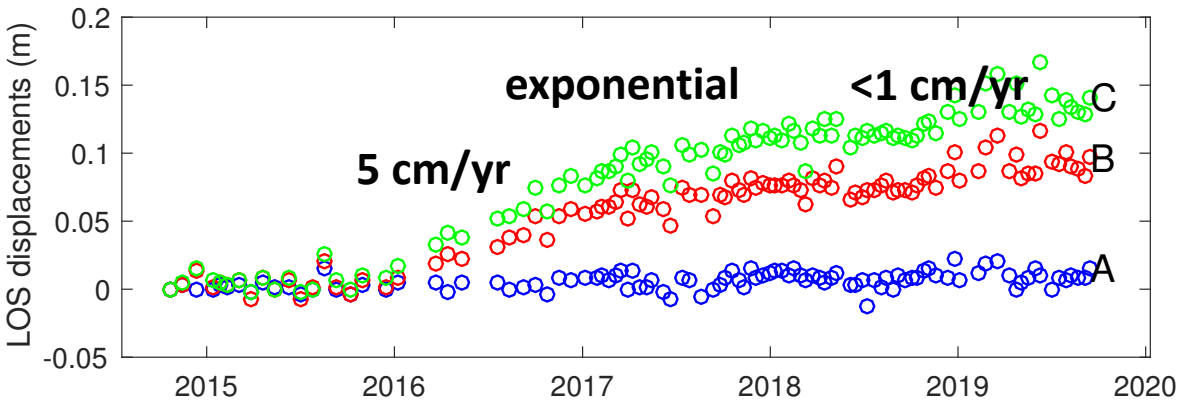
Unrest at 4 volcanic centers

- Haledebi: inflation ~3 cm
- Bora: inflation 2-5 cm, 2 pulses
- Alutu: rapid inflation 10-15 cm, 2 pulses
- Corbetti: inflation 5 cm

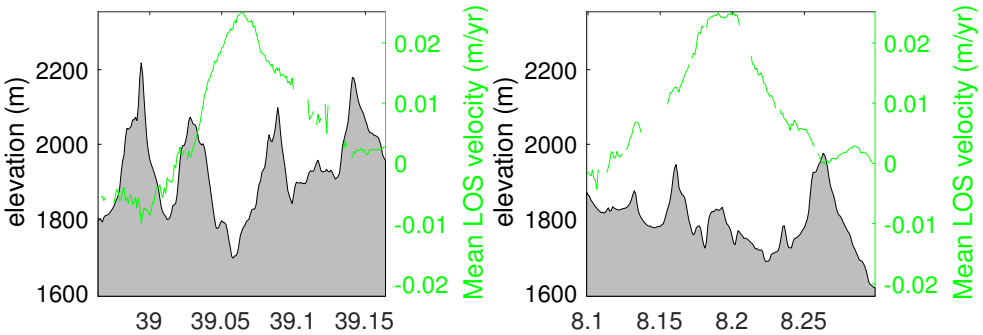
Biggs et al., 2011

MER: Bora - Tullu Moye Sentinel-1 survey (2015-2019)

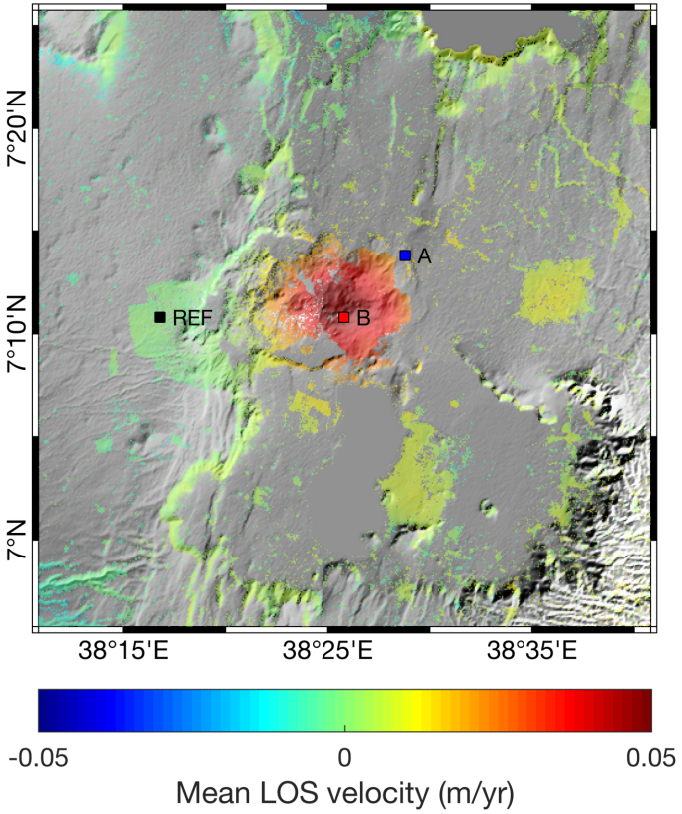


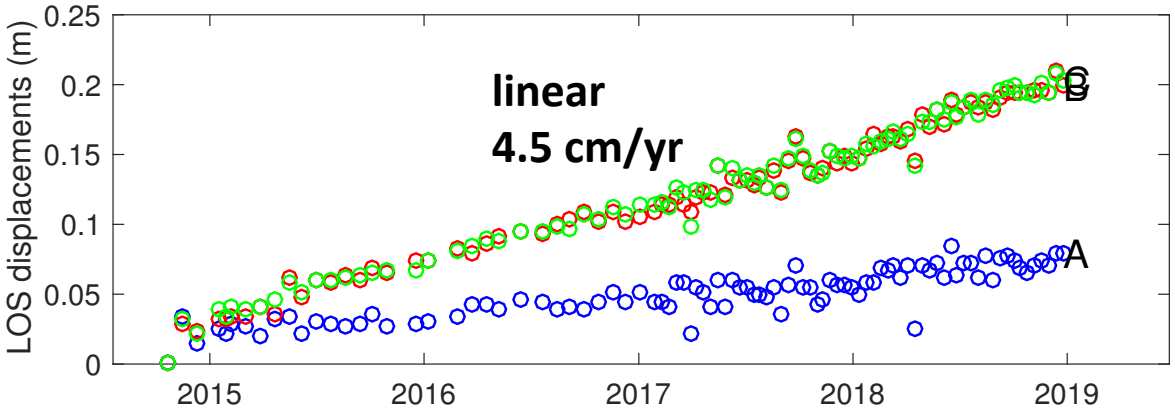


- Large elongated uplift signal between Bora and Tullu Moye volcanic centres
- Exponential trend started in 2016 at a rate of 5 cm/yr
- Possible indication of magma transport (**Temtime et al., in preparation**)

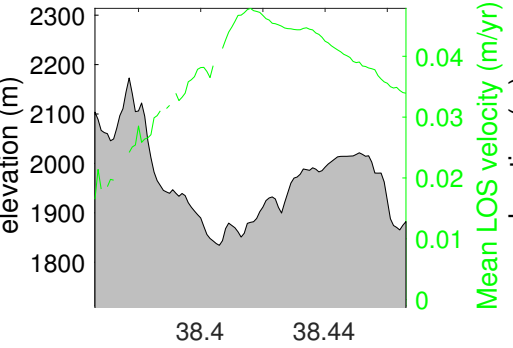


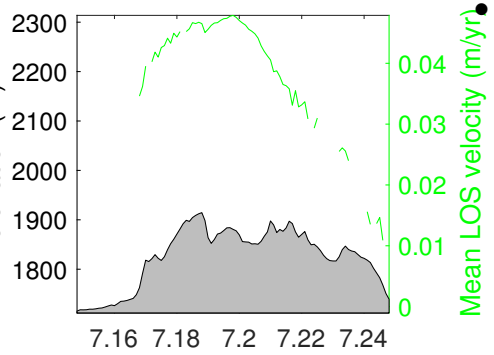
MER: Corbetti caldera
Sentinel-1 survey (2015-2019)





- Large uplift signal located inside the caldera structure
- Linear trend between 2015 and 2019 at a rate of 4.5 cm/yr
- Indication of continuous pressurization of the same reservoir





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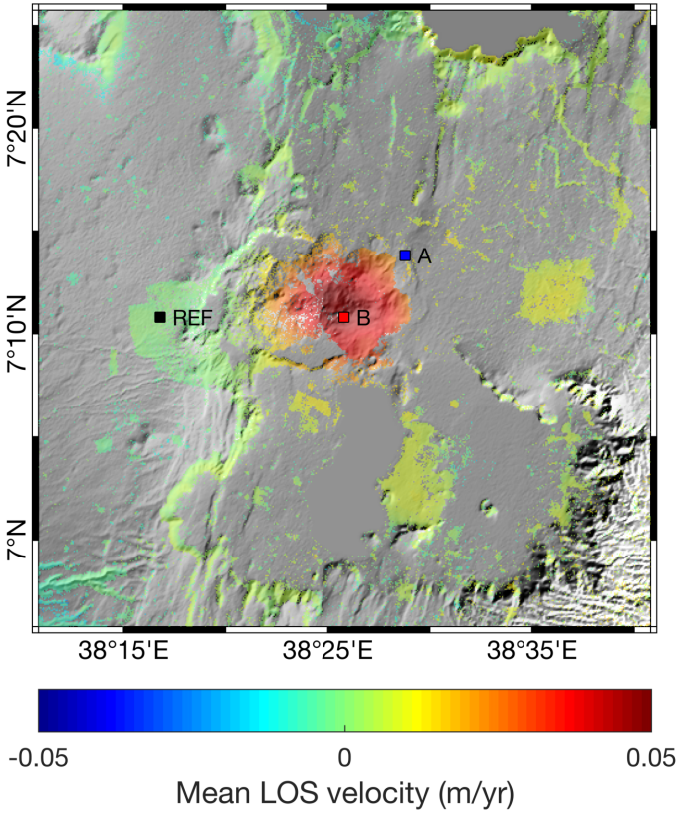
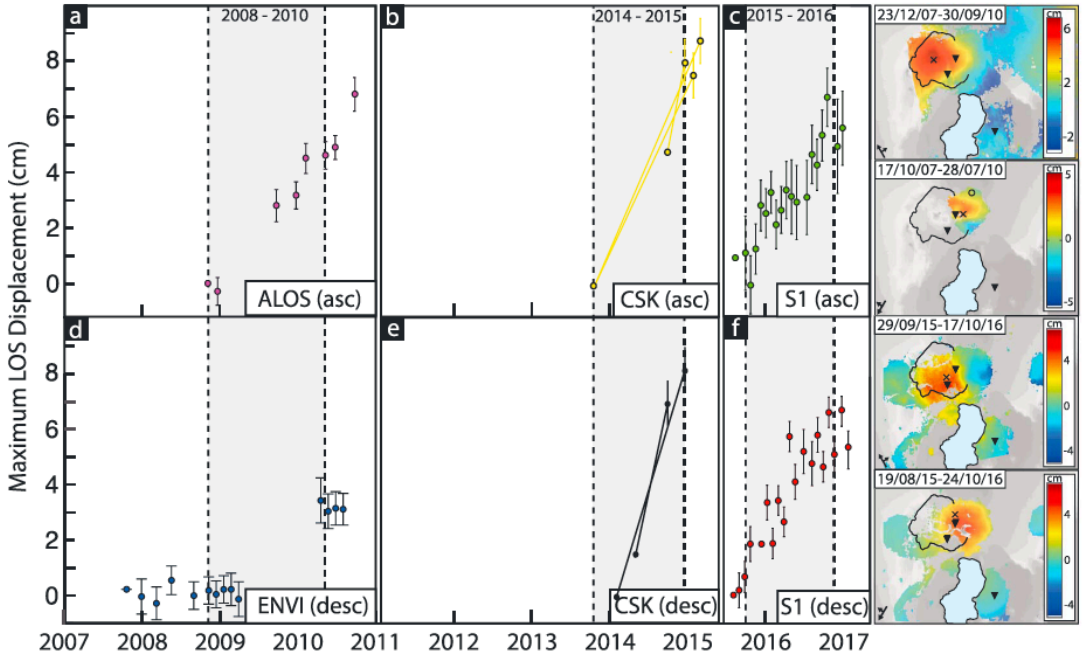


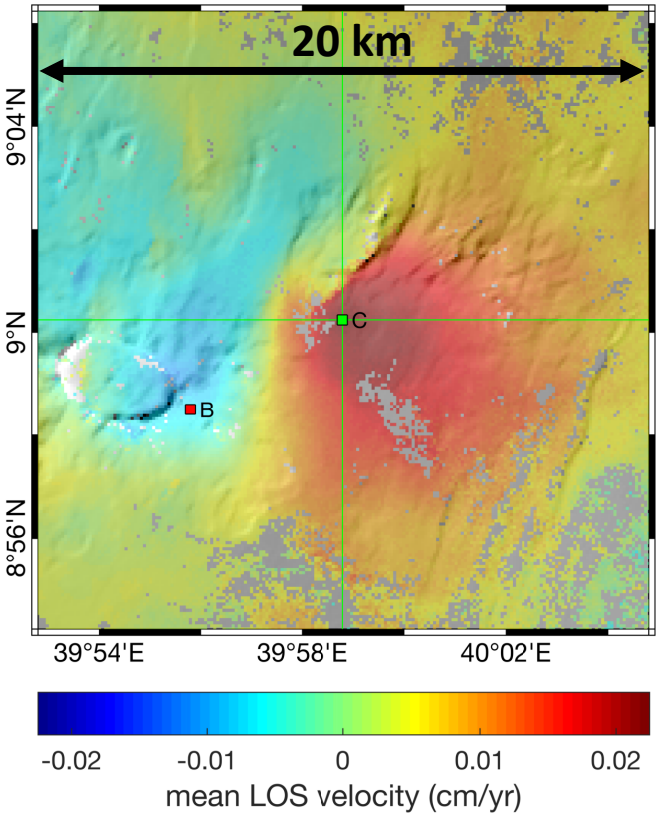


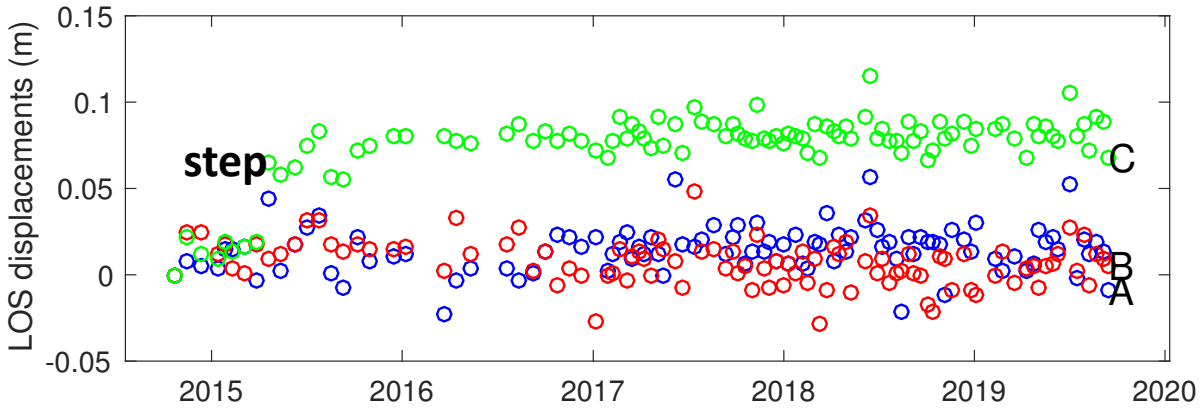
Lloyd et al., 2018

- Consistent with recent studies, which reported ~5 cm/yr
- From previous sensors, we know the inflation started in mid-2019
- Magmatic origin validated by gravimetry measurements

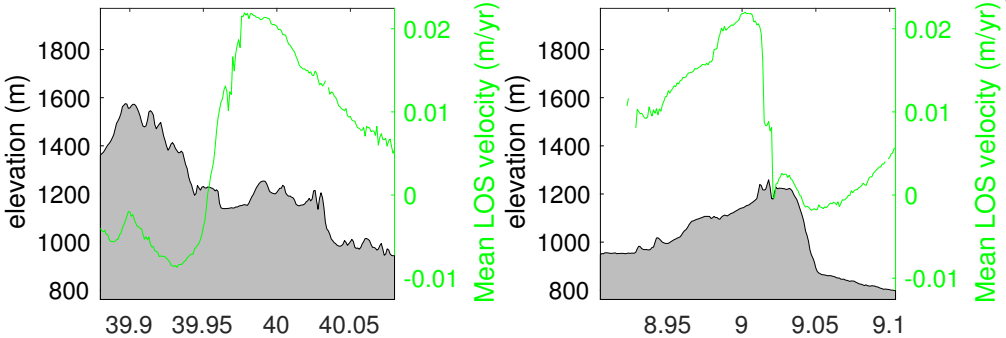
(Gottsman, Nature communication, in review)

MER: Fentale
Sentinel-1 survey (2015-2019)

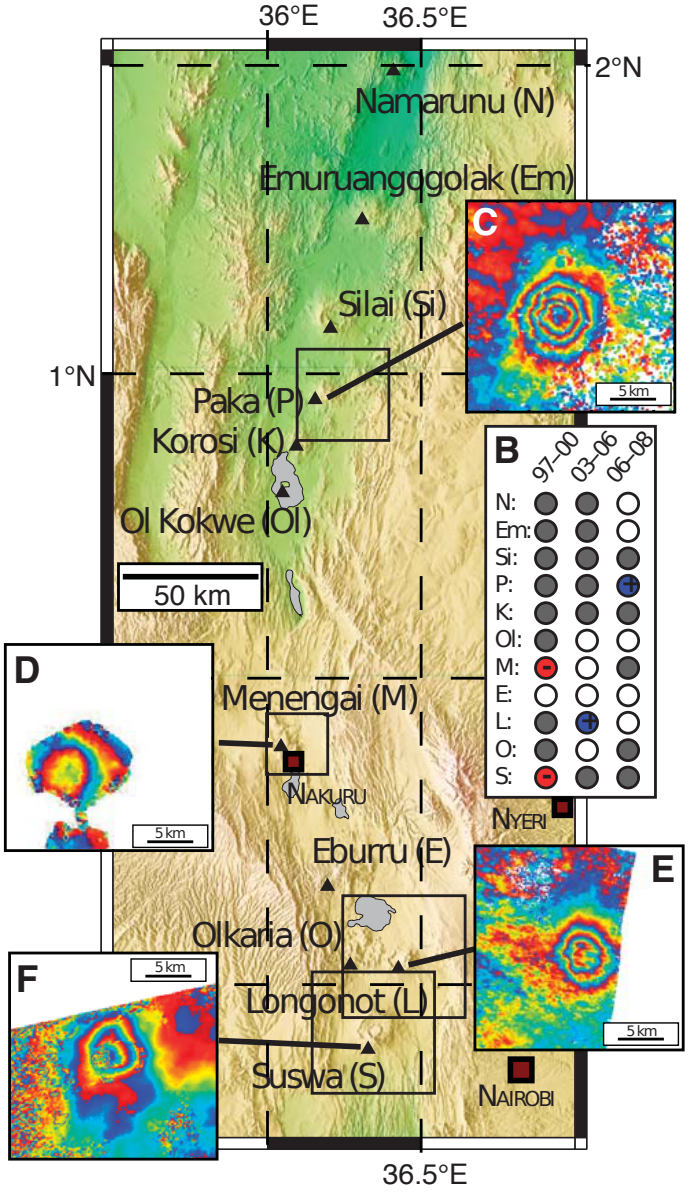




- Rapid uplift located 5 km NE from Fentale volcano
- Uplift of ~ 5 cm, lasting for 4 months
- Pattern modelled by a dyke intrusion (*Temtime et al., submitted*)



4- Kenyan rift:
ERS and ENVISAT survey (1997-2008)

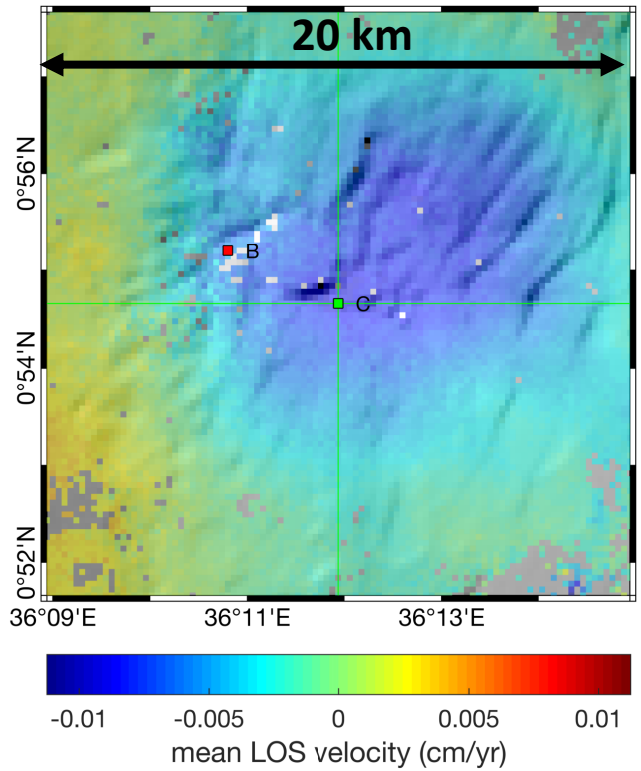


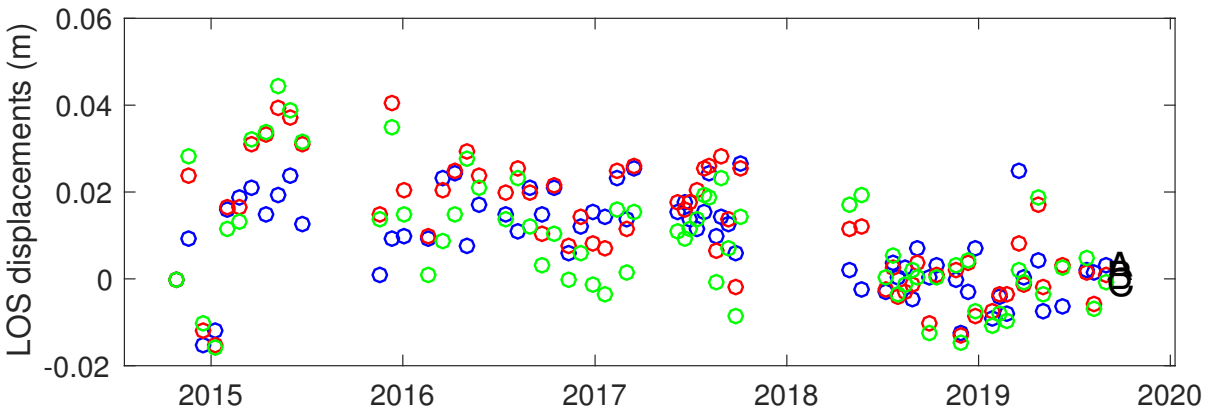
Biggs et al., 2009

Unrest at 4 volcanic centers

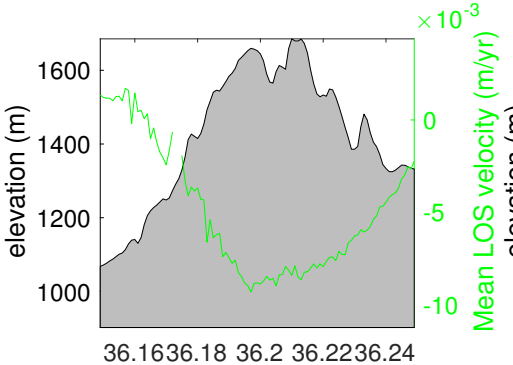
- Paka: 21.3 cm of inflation (2006-2007)
- Menengai: -3 cm of subsidence (1997-2000)
- Longonot: 9.2 cm of inflation (2004-2006)
- Suswa: -4.6 cm of subsidence (1997-2000)

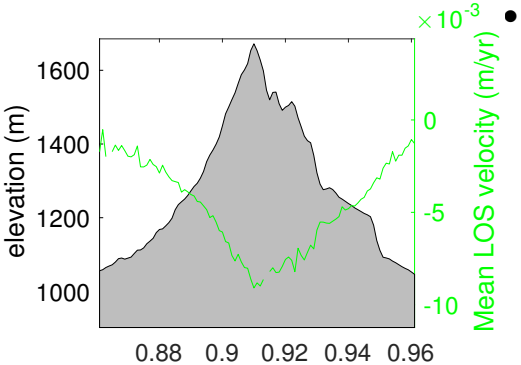
Kenyan rift: Paka
Sentinel-1 survey (2015-2019)



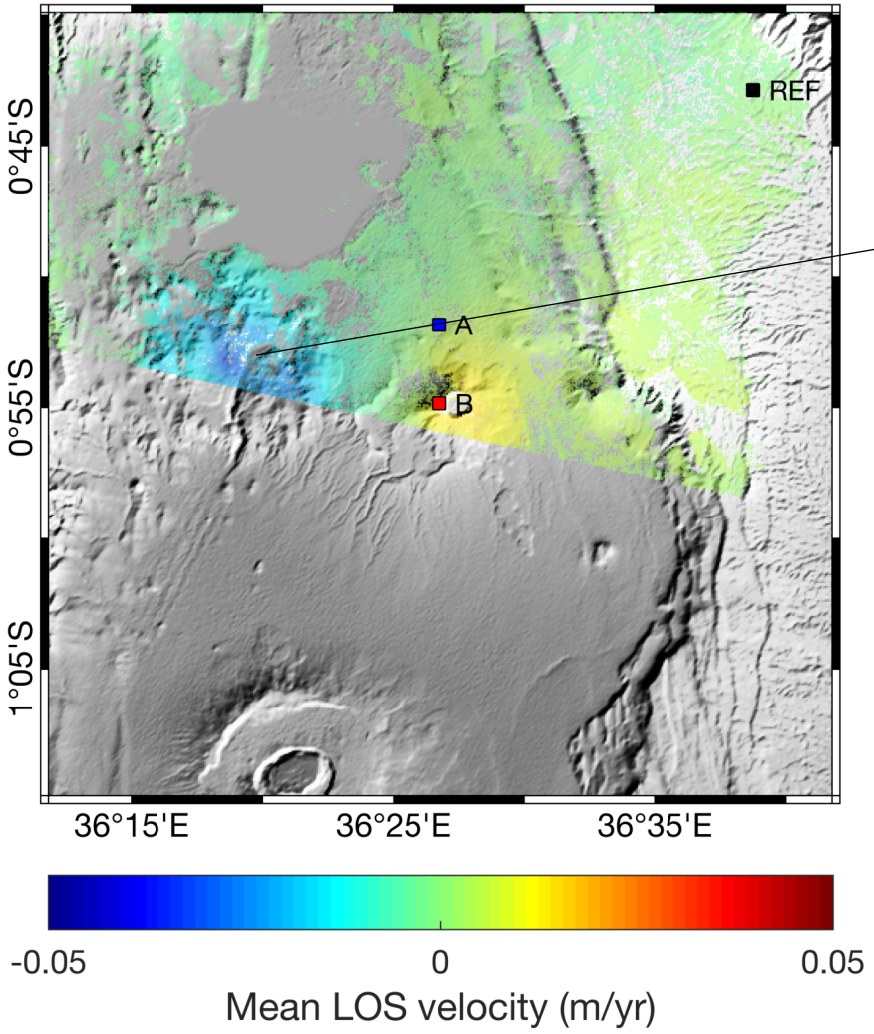


- No clear signal as all points have the same behaviour
- Profiles indicate a strong correlation with topography
- Need atmospheric correction



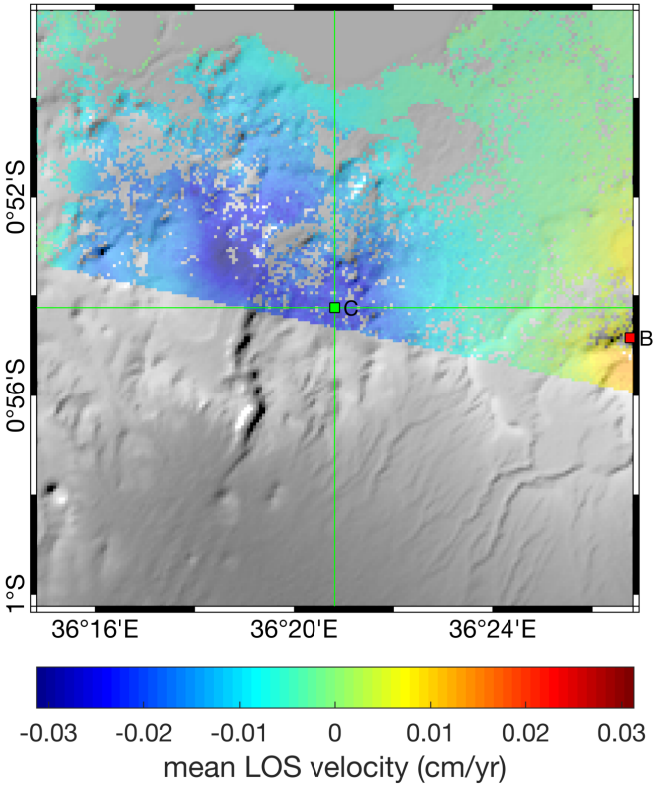


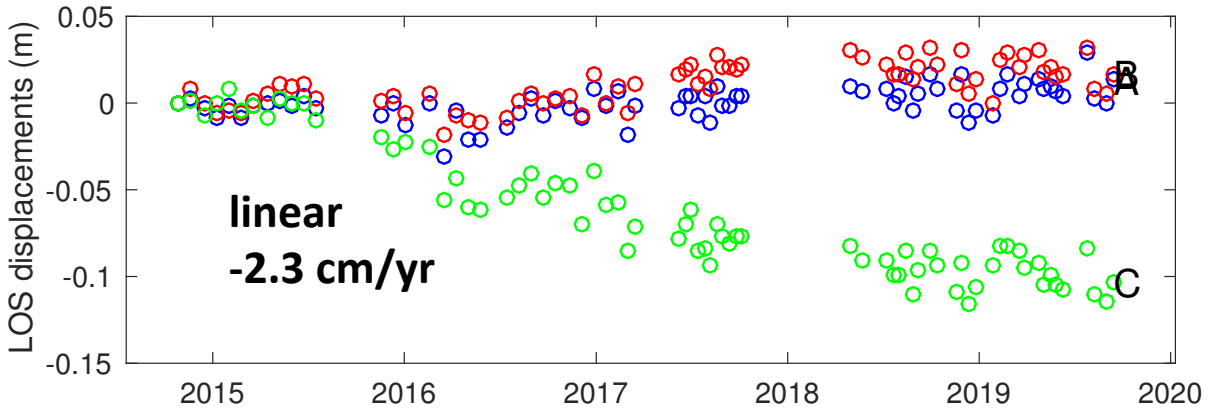
Kenyan rift: Olkaria
Sentinel-1 survey (2015-2019)



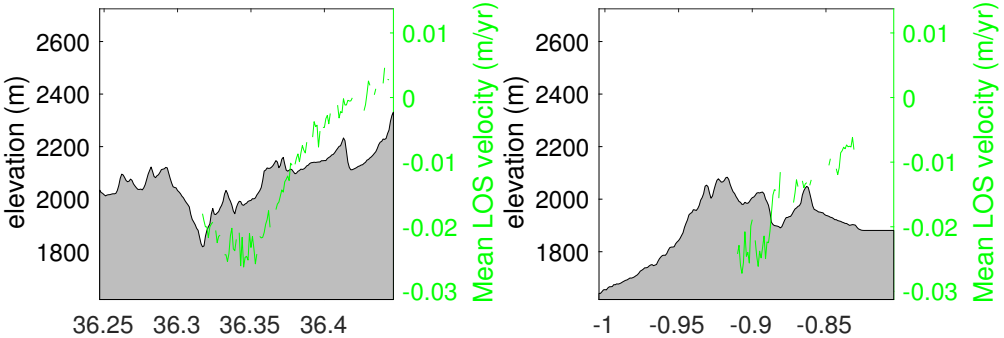
- Olkaria volcanic complex
- 6 geothermal power stations
- Olkaria I (185 MW, first operation in 1981)
- March 2016: 5-years plan to increase the capacity at this power station from 185 to 190.7 MW

Kenyan rift: Olkaria
Sentinel-1 survey (2015-2019)

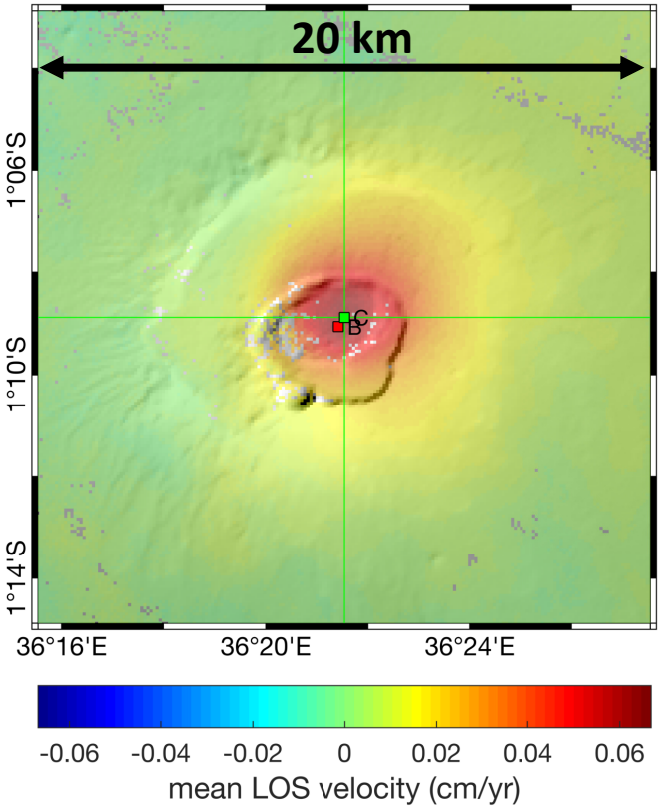


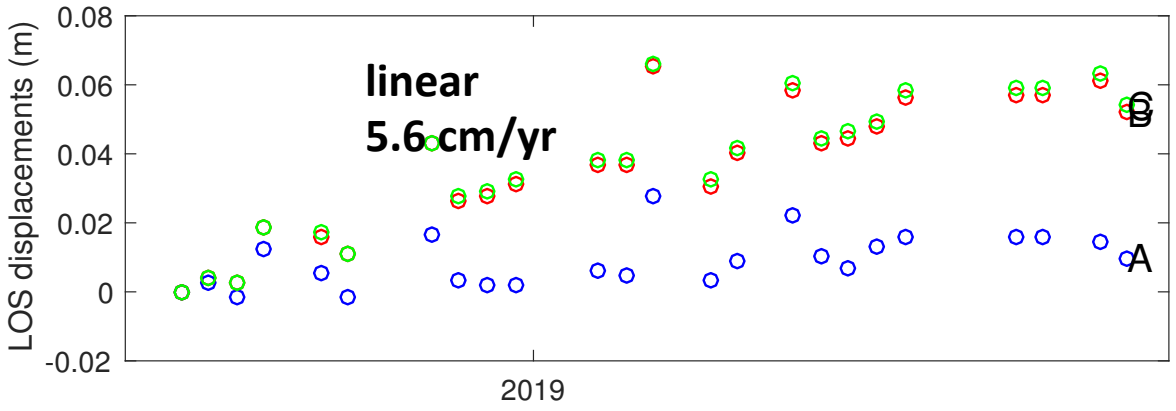


- Rapid subsidence at **Olkaria volcanic complex**
- Linear subsidence at a rate of 2.3 cm/yr starting in 2016
- Can be related to geothermal exploitation
  Robertson et al., 2016
  Koros et al., 2016

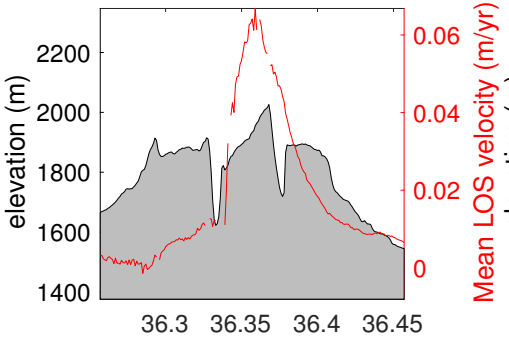


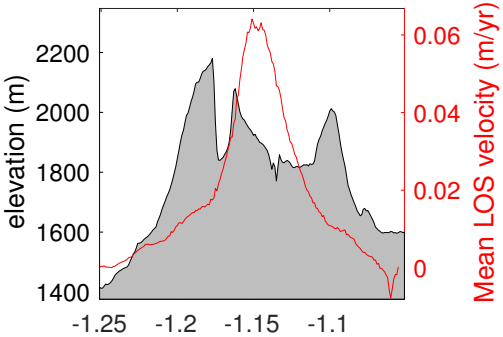
Kenyan rift: Suswa
Sentinel-1 survey (2018-2019)



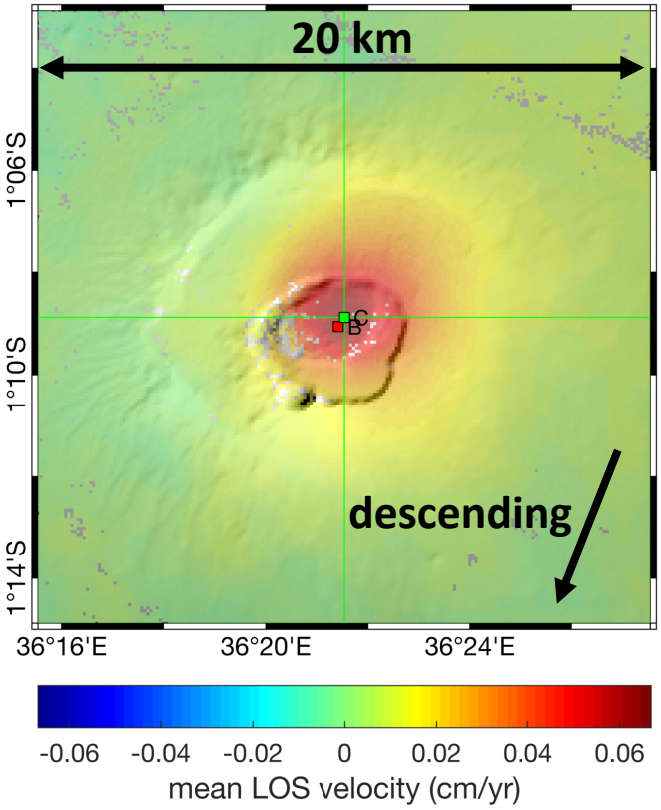


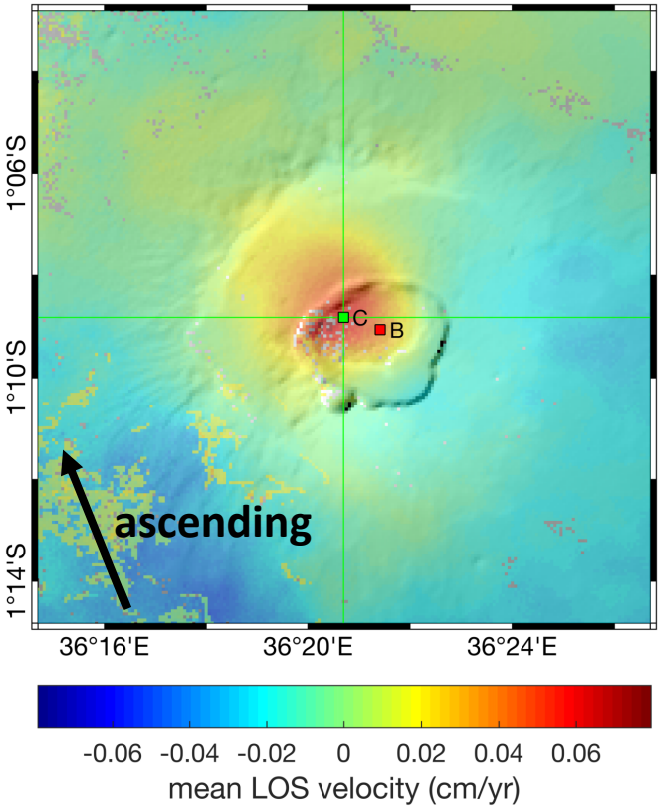
- Spherical signal (R=3.74 km) confined in the crater
- Linear uplift at a rate of ~ 5-6 cm, starting in mid 2018
- Pattern typical of point source
- Strong rate of displacements in the second crater: (“piston effect”)

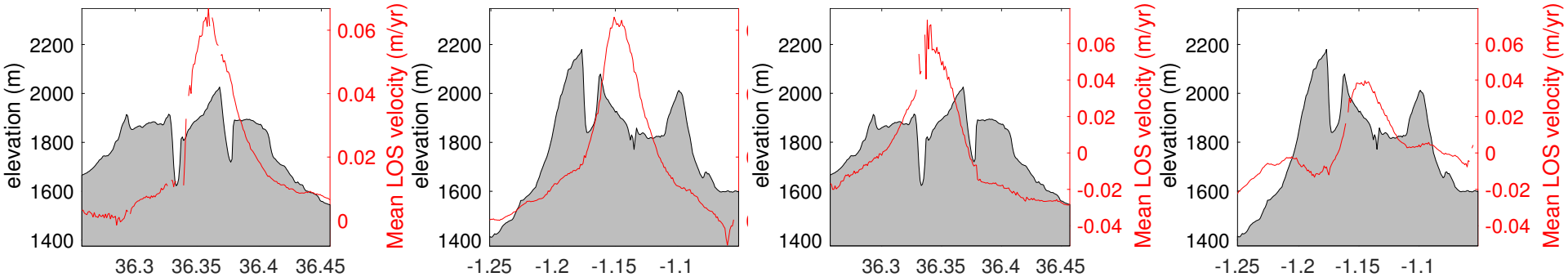




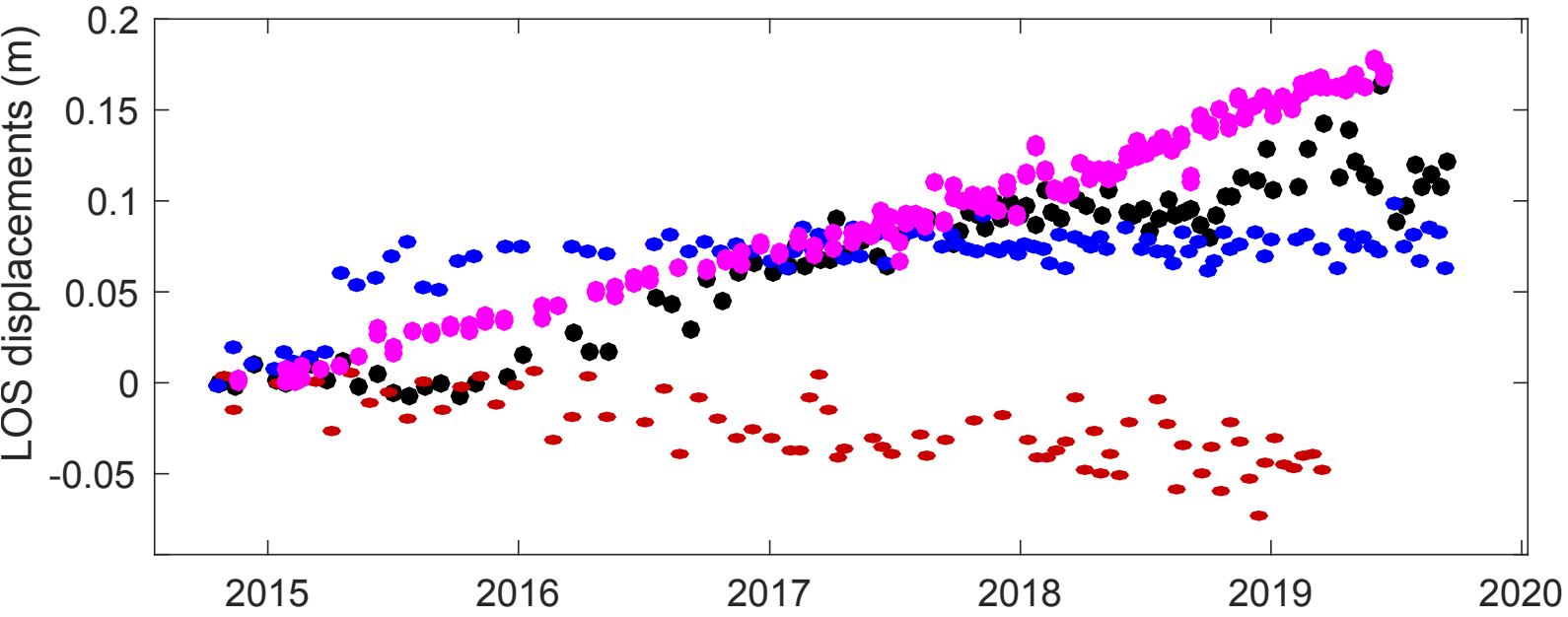
Kenyan rift: Suswa
Sentinel-1 survey (2018-2019)

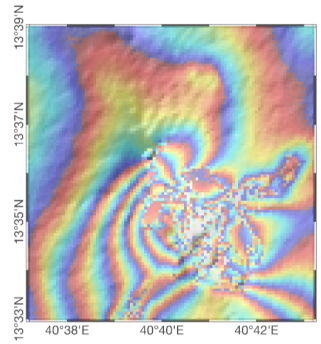


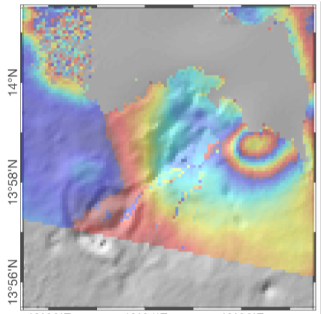


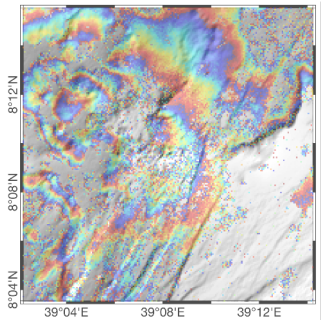


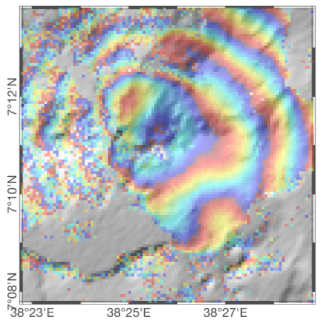
Summary of the Sentinel-1 survey

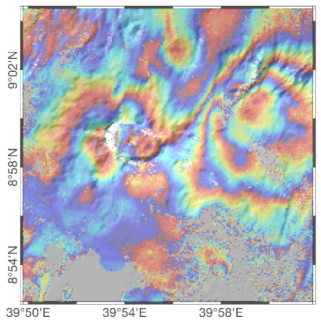


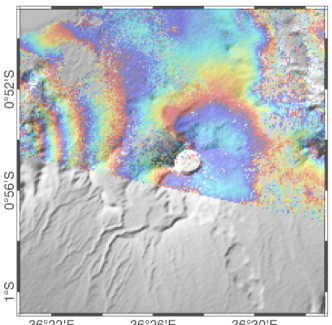


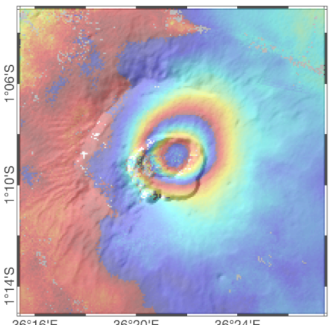


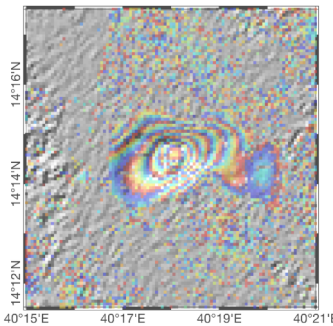












Summary of the Sentinel-1 survey

<u>8 ground deformation signals detected:</u>

- 2 **linear subsidence signals** due to contraction of magma bodies
Gada Ale (-1.1 cm/yr, 2015-2019), Dallol (-1.9 cm.yr, 2015-2019)

- 1 subsidence signal related to geothermal exploitation
Olkaria (-2.3 cm/yr, 2016-2019)

- 2 **short-term inflation** related to magma intrusions
Erta Ale (days), Fentale (months)

- 1 long-term **exponential uplift** related to magma transport
Tullu Moye (12 cm, 2016-2018)

- 10 years **continuous uplift** related to magma pressurization
Corbetti (4-5 cm/yr, 2009-2019)

- **New unrest** related to the replenishment of a shallow reservoir
Suswa volcano (5.6 cm, 2018-2019)