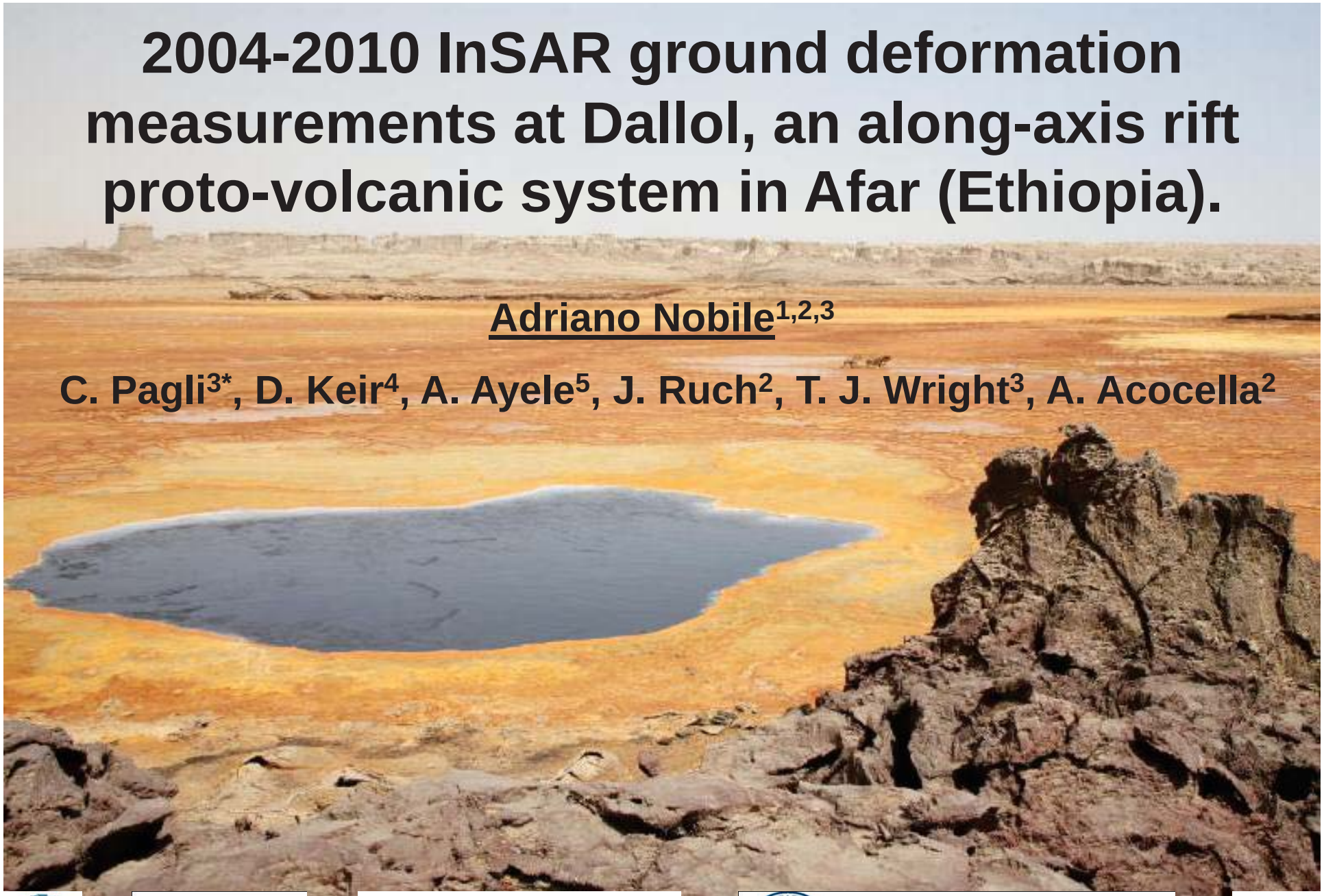
2004-2010 InSAR ground deformation measurements at Dallol, an along-axis rift proto-volcanic system in Afar (Ethiopia).



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INGV

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UNIVERSITY OF LEEDS

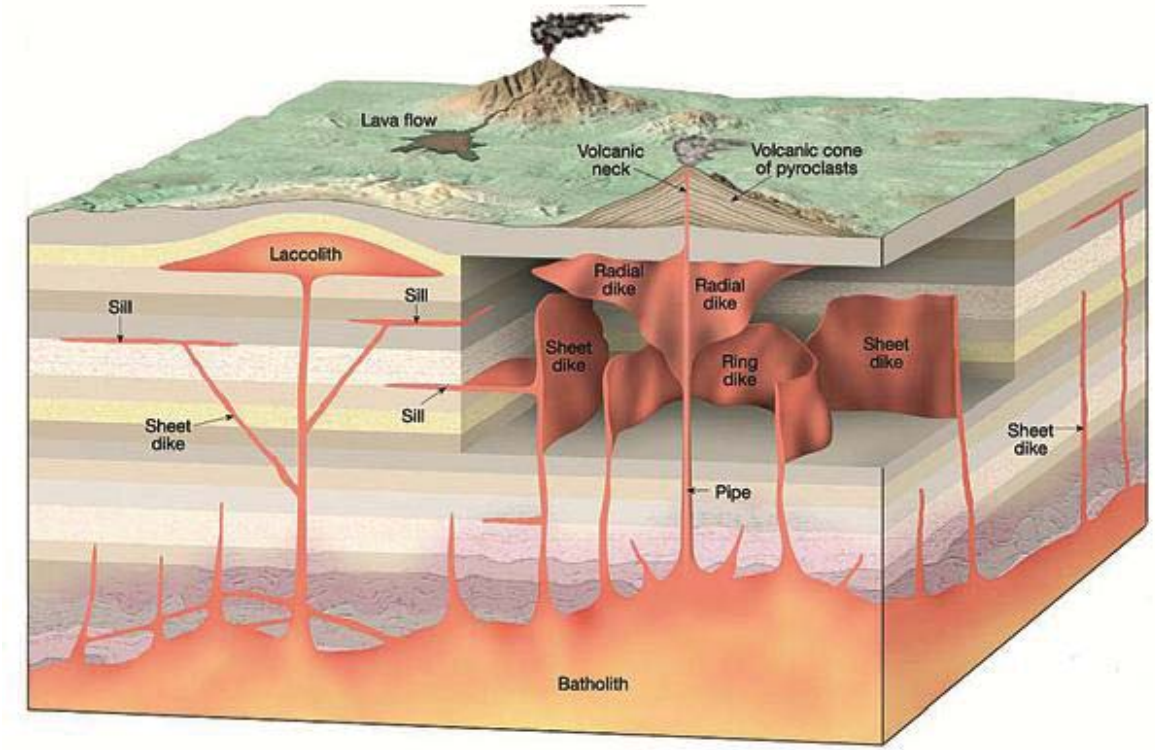
National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

ADDIS ABABA UNIVERSITY

Outline

- Introduction
- Afar
- Dallol
  - 2004 dyke intrusion
  - 2005-2010 deformation time series
- Conclusions

Volcanic system



- Magma emplacement (reservoir) and propagation (conduit, dike and sill)
- Pressurization of hydrothermal system
- Detected by: seismicity, gas emission, surface deformation

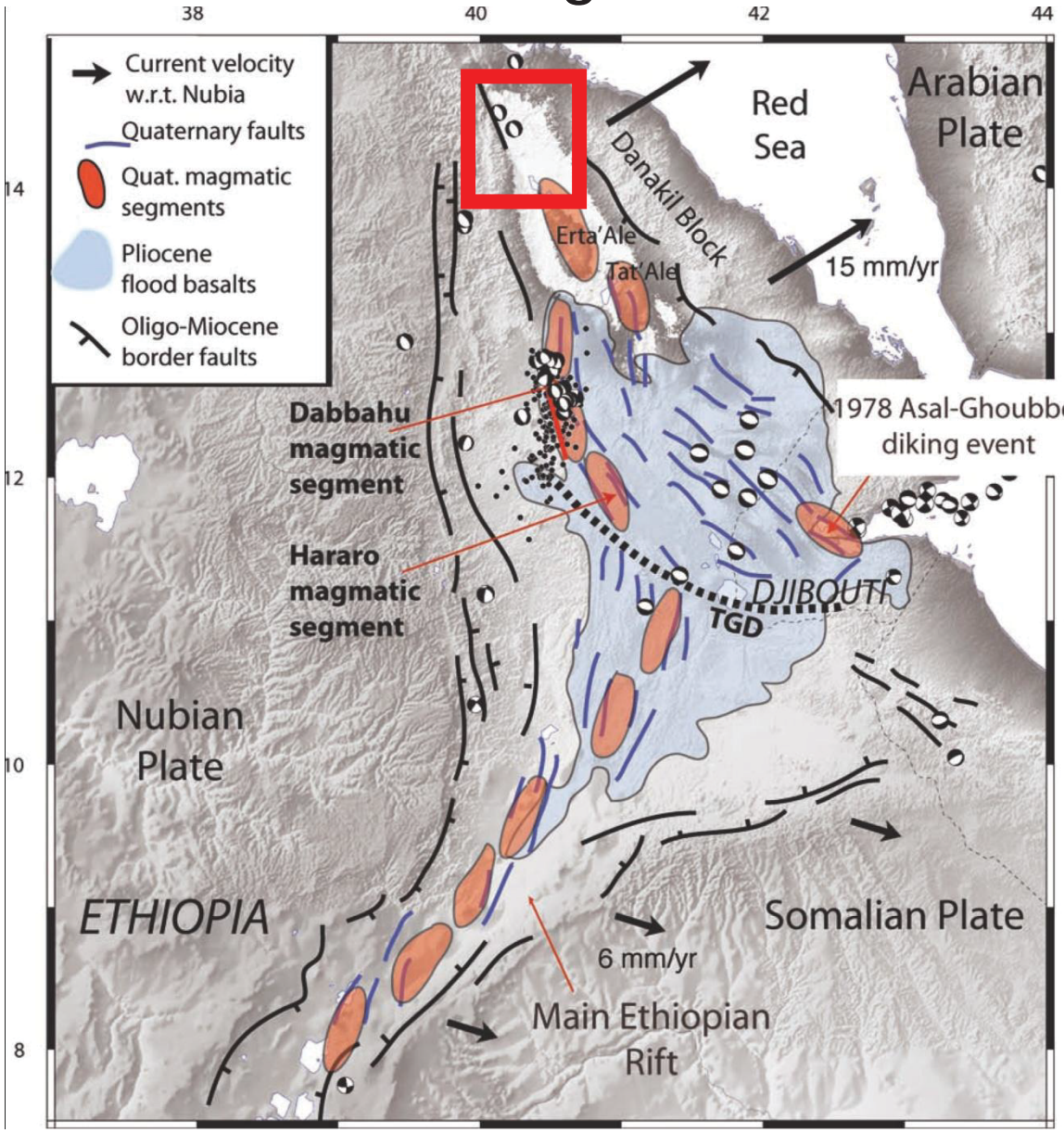
Magma can reach the surface producing an eruption or the volcanic system can return to quiescence

Why InSAR?

- measure elastic and anelastic surface deformation
- mm scale displacements
- over wide areas (spatial info, deformation maps)
- remote approach (complimentary to field analysis)

InSAR analysis of ground deformation to study the nature and behavior of magmatic systems

Divergent Plate Boundary – Afar

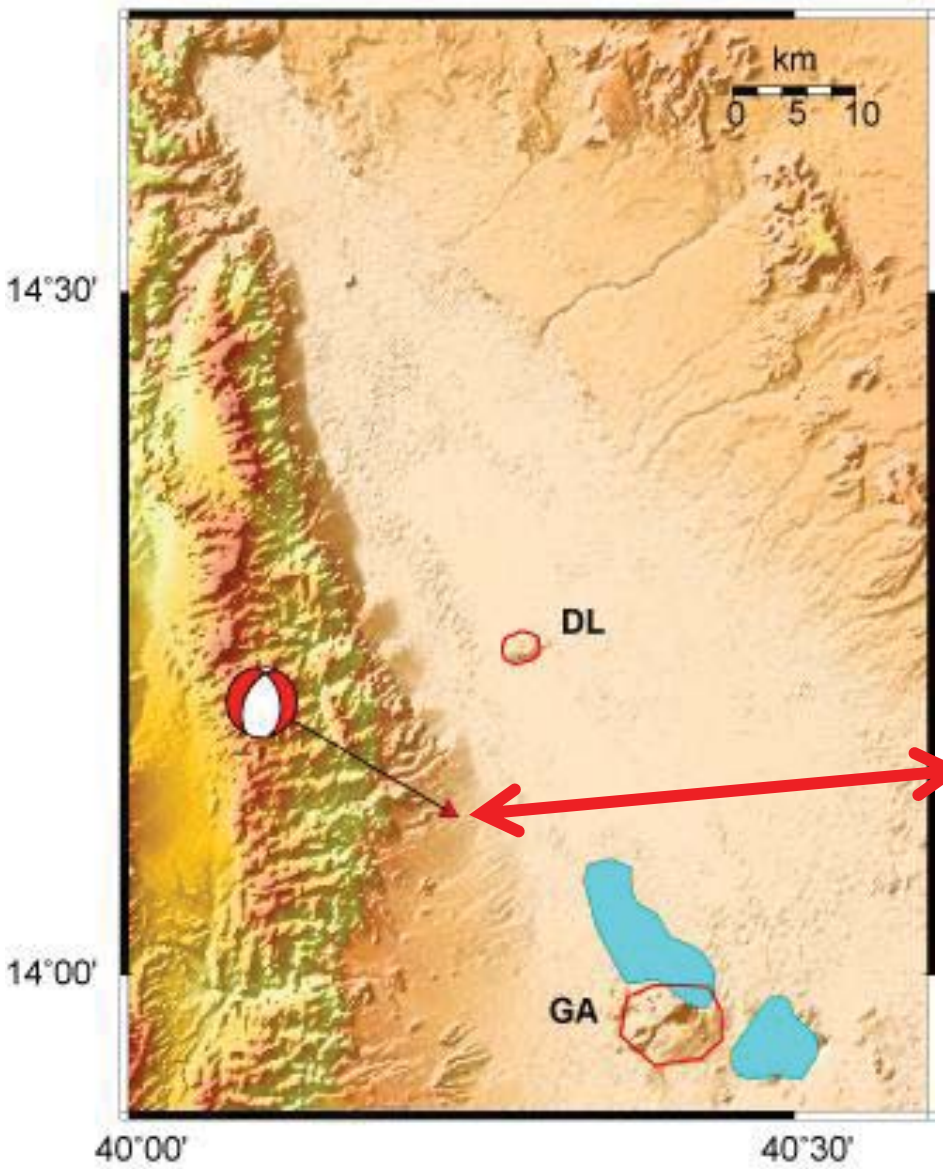


Ebinger et al., 2008

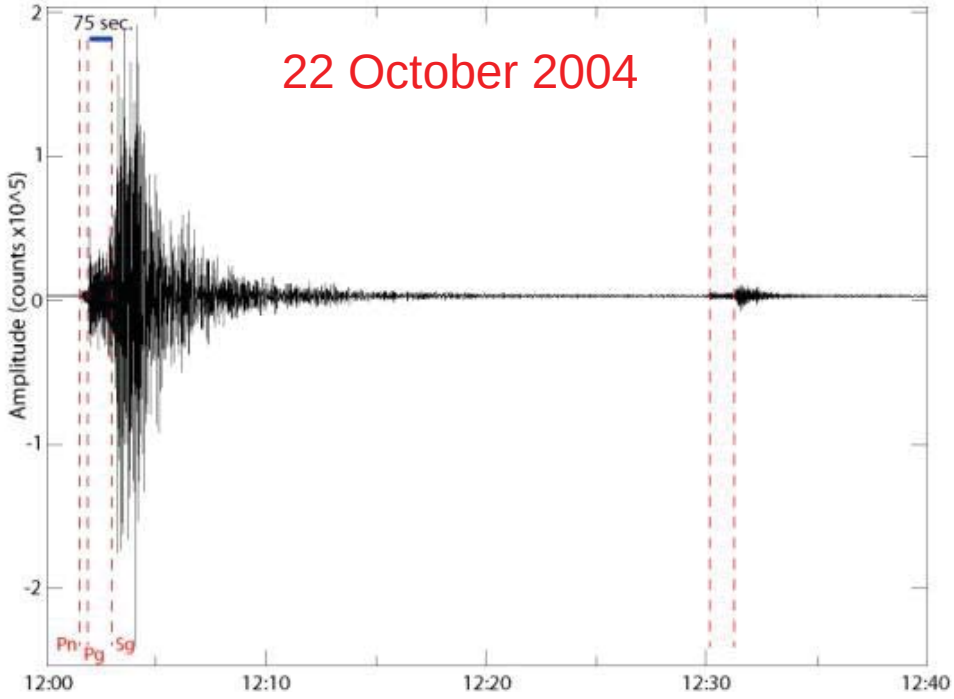
- 3 plates diverge with non uniform velocities
- Extension and volcanism located along different magmatic segments
- Thin crust (14 km in N Afar)
- Several dyke intrusions (Asal 1978, Dabbahu 2005-2010)

Another active magmatic system along rift axis

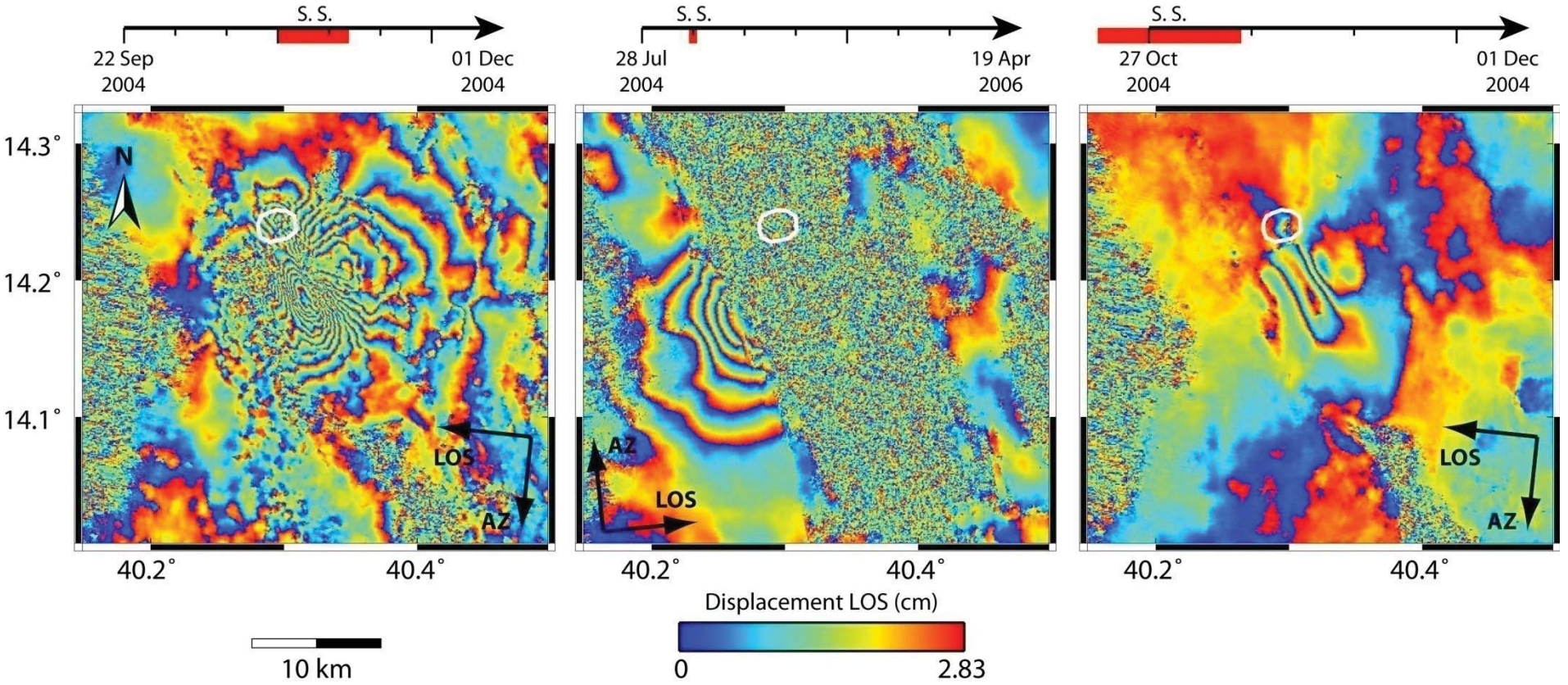
Dallol segment



- Dallol mound (DL) 80 m bsl
- High hydrothermal activity
- No volcanic products
- 2 recent seismic swarms

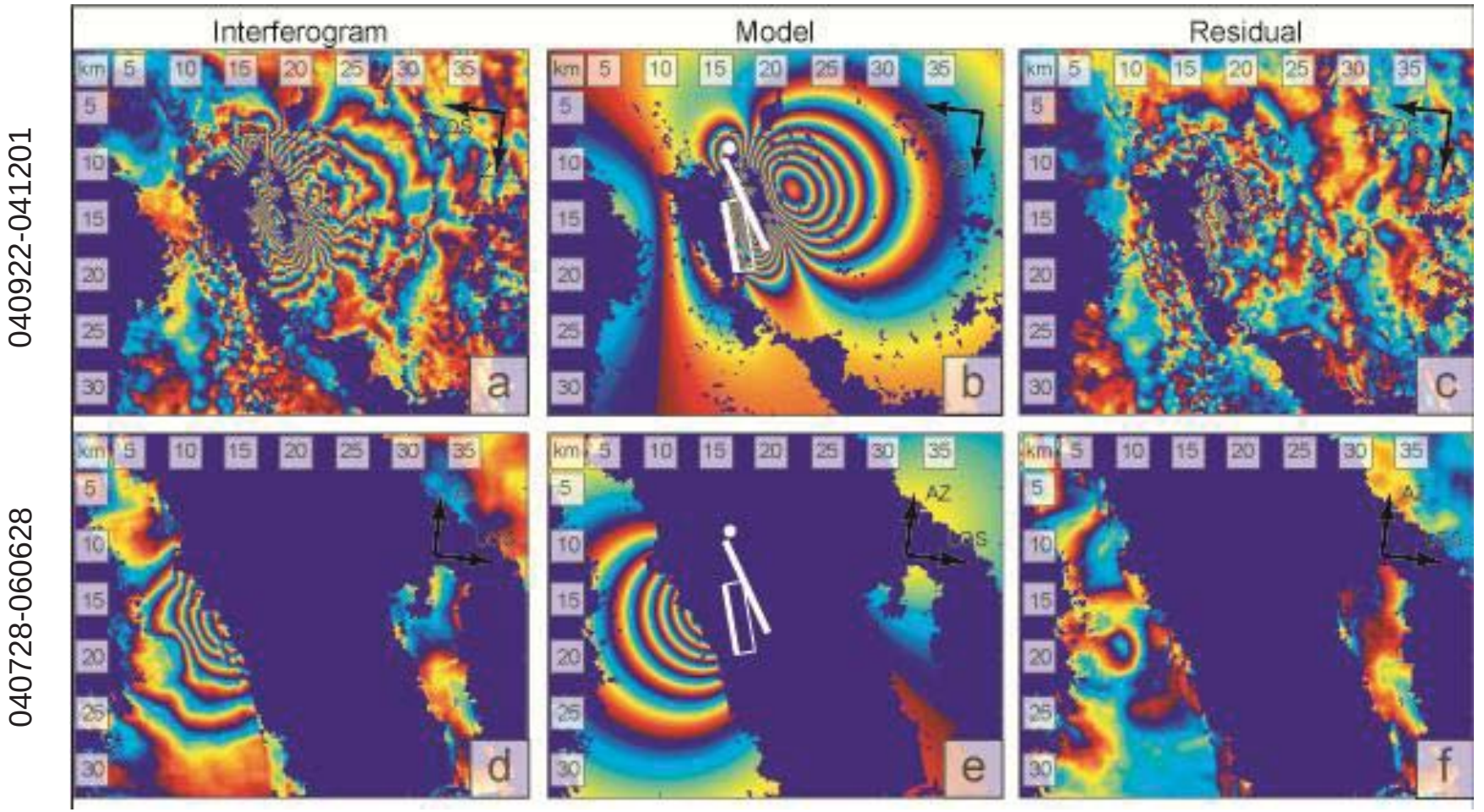


October 2004 seismic swarm



- Envisat SAR images
- Ascending & descending tracks

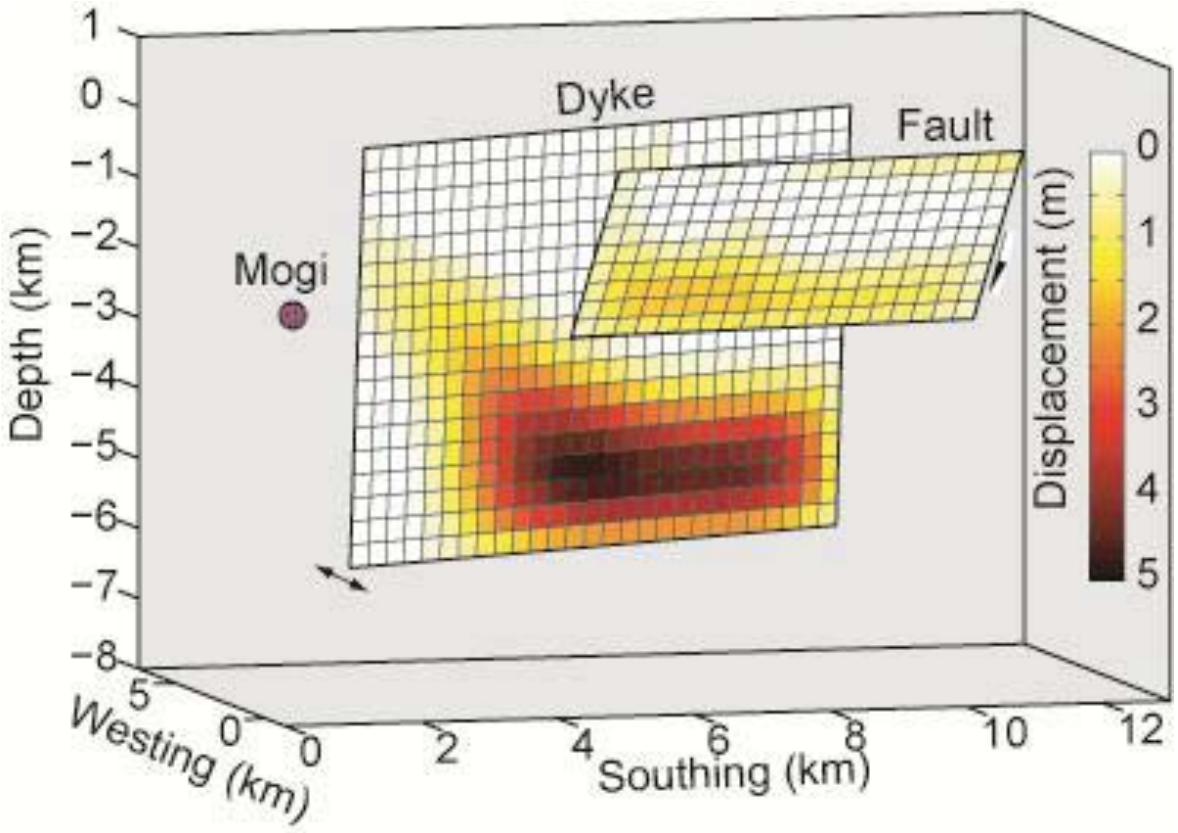
Dallol – October 2004 Dyke intrusion model



- Joint inversion of two interferograms
- 3 deformation sources (dyke, fault, Mogi)
- Elastic half space

- Two steps inversion
1) Non-linear inversion to fix geometries
2) Linear least-square method for variable opening and slip

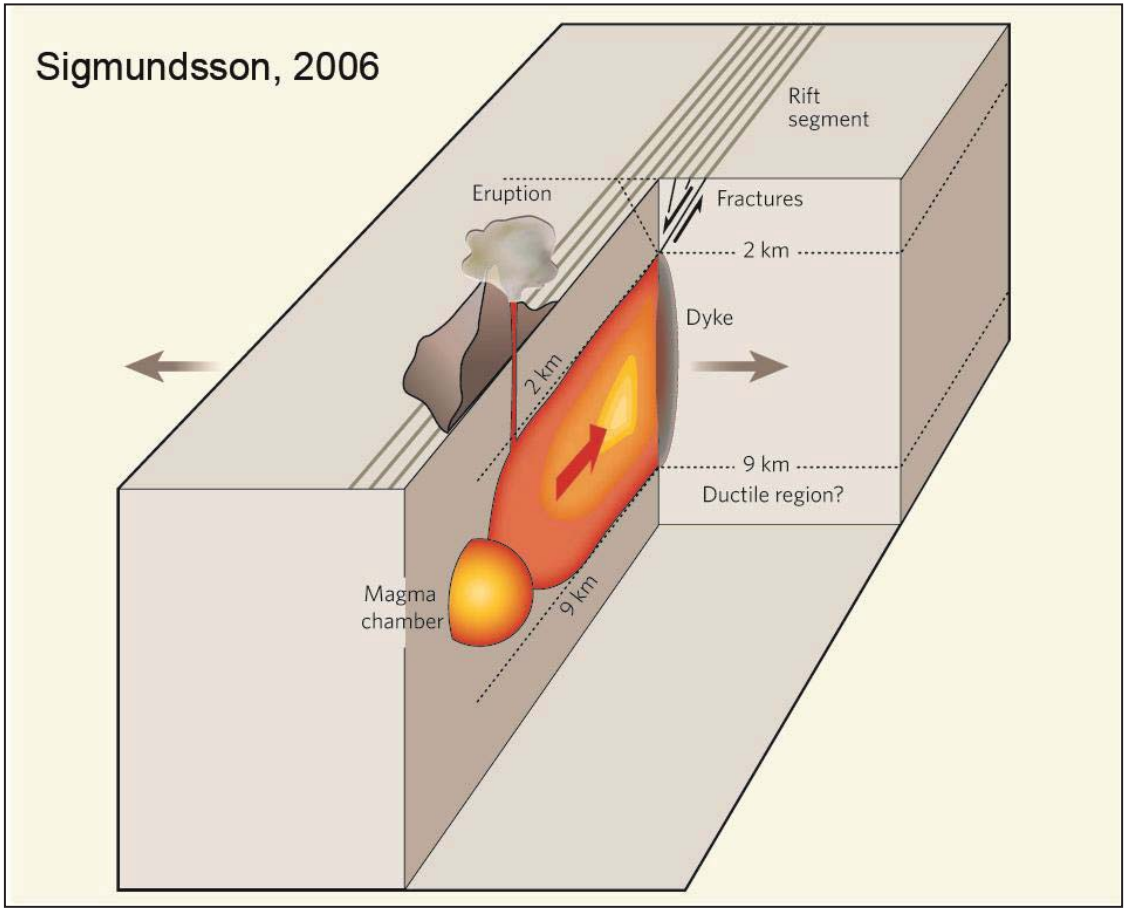
Dallol – October 2004 Dyke intrusion model



- Dyke volume ~0.06 km^3
- Max opening ~4.5 m
- Mogi depth 2.4 km
- M_w 5.6 modeled Eq.
- RMS = 2.3 cm
- Data variance 95%

- Proto-volcanic system (no volcanism at the surface)
- Magma induced opening of rift axis segments

Magma does the split



2005 Dabbahu rifting episode:

- Dyke length ~60 km
- Up to 8 m opening

Magma overcomes tectonics in opening rifts

Dallol and other dyke intrusions along rifts

Several dyke intrusion along rifts in the last 10 years

- 2004 Dallol
- 2005-2010 Dabbahu (14)
- 2007 Lake Natron
- 2009 Harrat Lunayyir

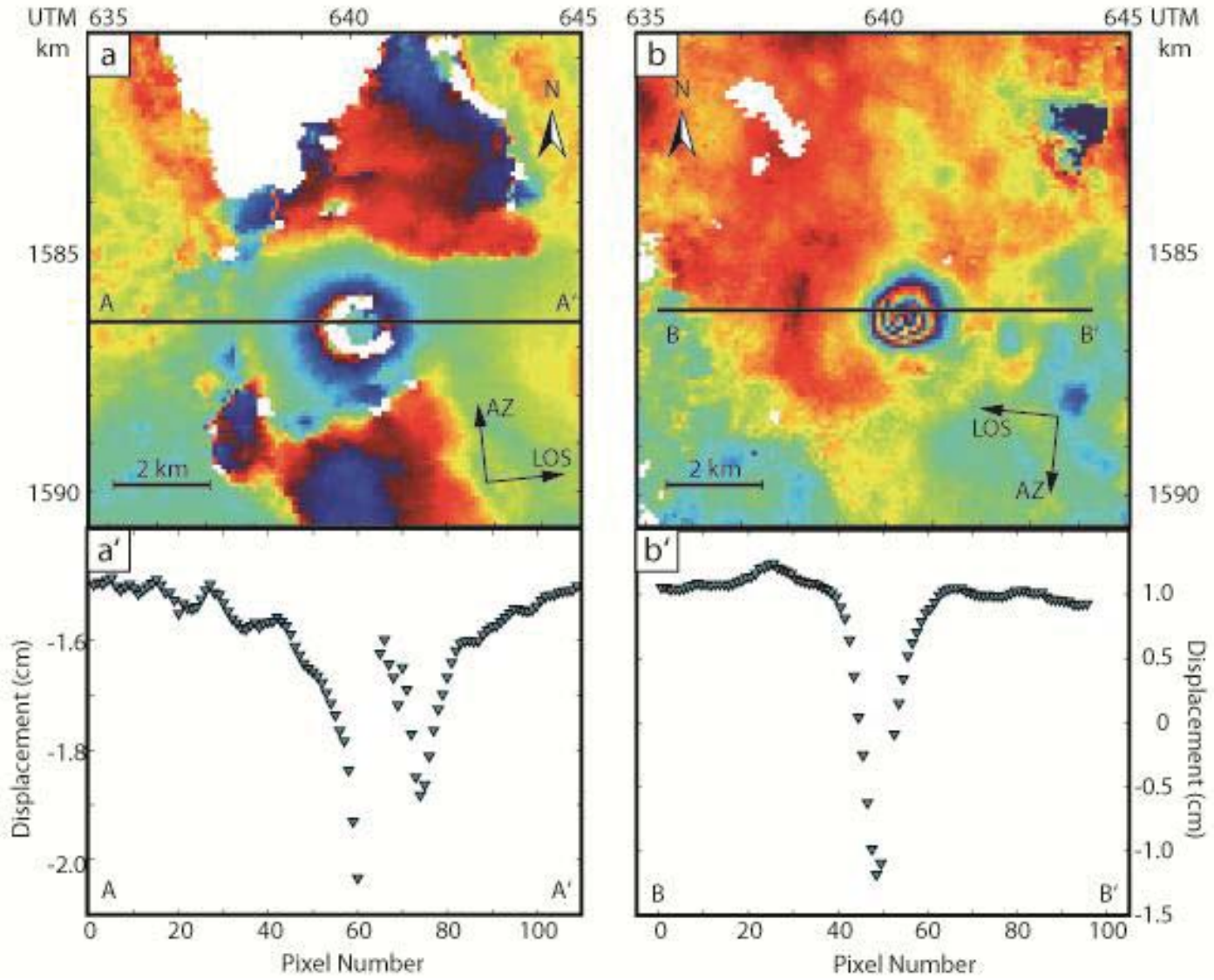
Dallol and other dyke intrusions along rifts

Area	Data	Ml	Seism. Mom. (10^{17}Nm)	Geod. Mom. (10^{17}Nm)	SM/GM %	Volume (km^3)	Ref.
Dallol	Oct-Nov 2004	2.6-5.5	2.28	22.0	10.4	0.058	
Dabbahu	Sep 2005	1.8-5.5	25[a]-34[b]	800[c]-896[b]	3.1-3.8	1.8[b]-2.5[c]	a,b,c
	Jun 2006	2.5-4.7	1.80	54.4	3.3	0.120	d
	Jul 2006	2-3	0.02	32.4	0.1	0.042	d
	Sep 2006	2.6-3.4		32.0	0.1[a]	0.088	a
	Aug 2007	<3	0.01	24.1	0.0	0.048	d
	Nov 2007	2.9-4.5	1.03	60.1	1.7	0.15	d
	Mar-Apr 2008	<3	0.16	37.2	0.4	0.088	d
	Jul 2008	<3	0.08	32.1	0.2	0.066	d
	Oct 2008	1.8-4.6	1.78	78.8	2.3	0.17	d
	Feb 2009	2-3.5	0.27	30.2	0.9	0.077	d
	Jun 2009	<4	0.01	18.1	0.1	0.046	d
Lake Natron	Jul-Aug 2007	3-5.9	14.00	40.0	35.0	0.09	e
Harrat Lunayyir	Apr-Jun 2009	3-5.4	2.79	44.1	6.3	0.13	f

- Dallol: 10% GM due to seismicity
- SM in Dallol > Dabbahu, < Natron and ~ Lunayyir

High seismic moment suggests that normal border faults accomodate extension

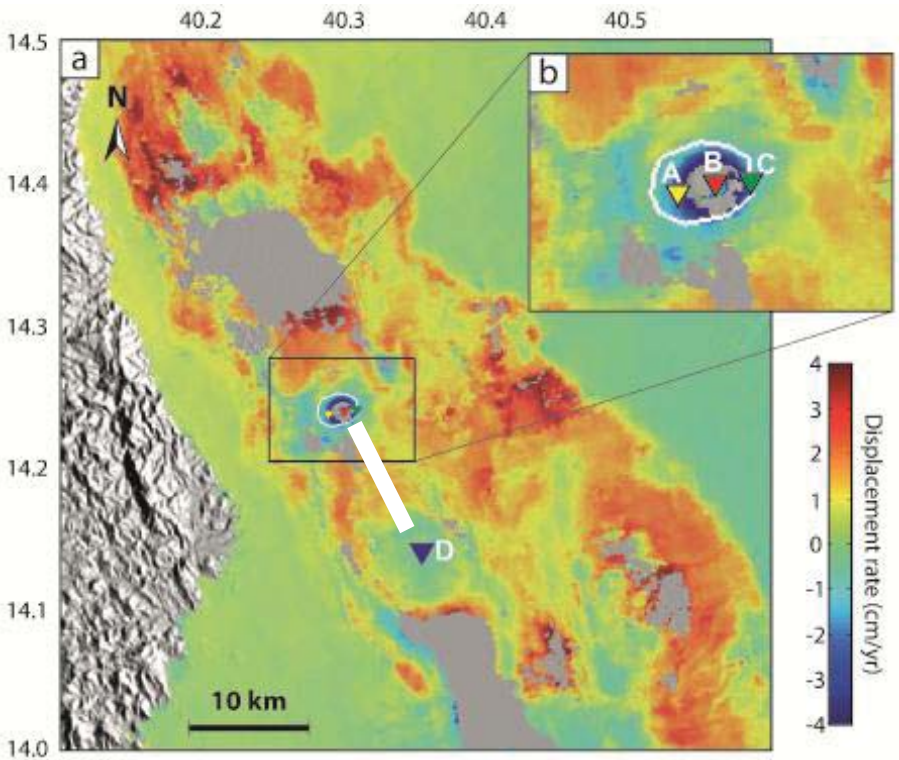
Dallol - Post dyke ground deformations

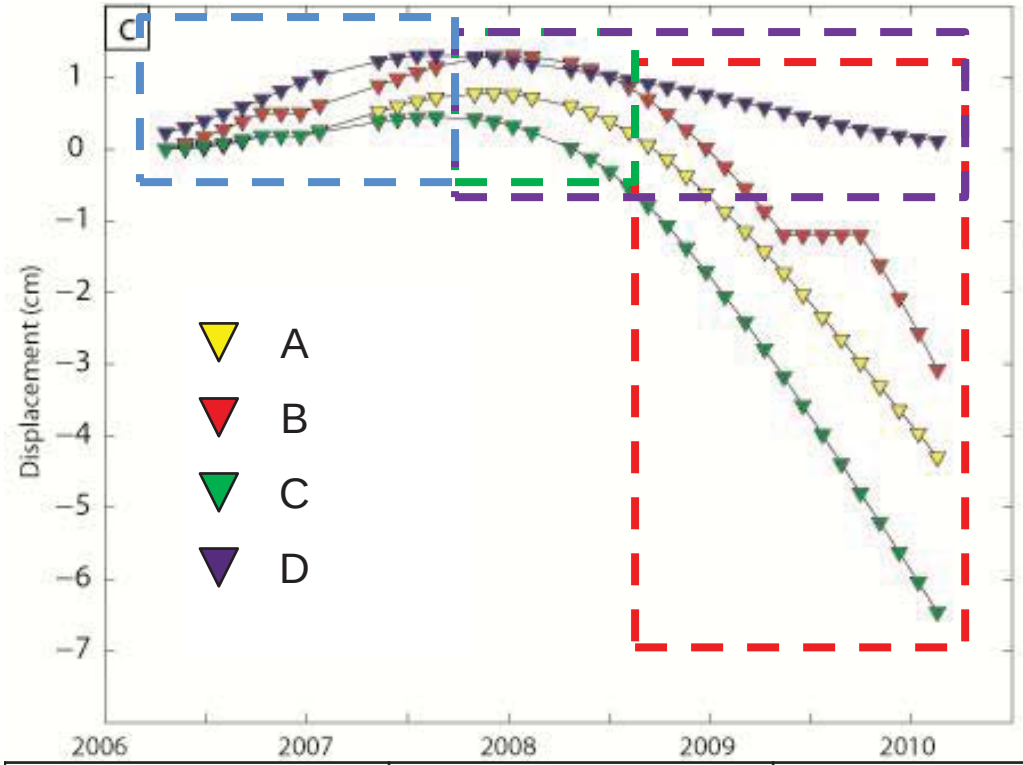


a) 081119-090128 – Track 28 (A) b) 090325-090429 – Track 321 (D)

Dallol – Mean-term deformation (2005-2010)

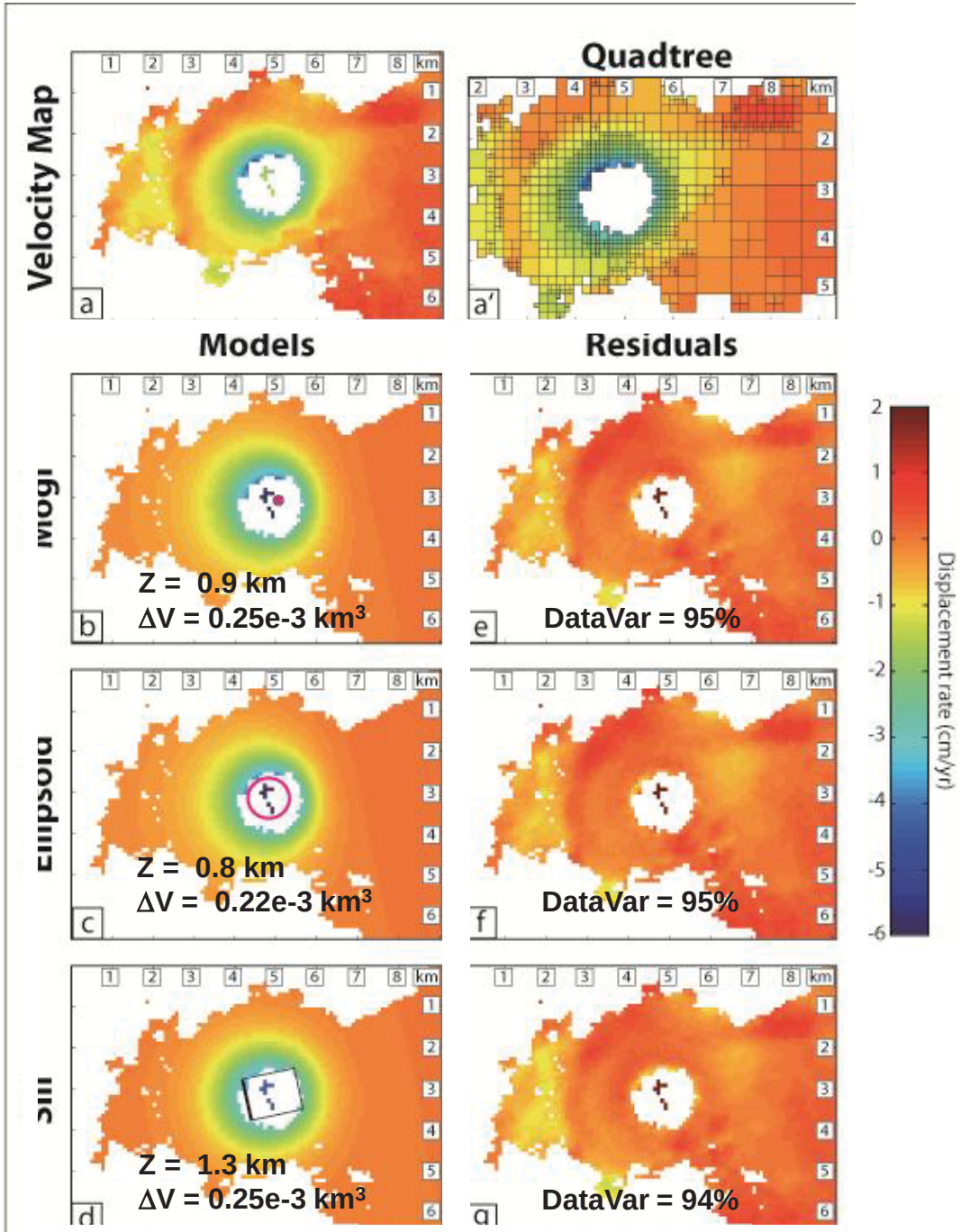
- **Nov. 2005 – Aug. 2007**: A,B,C and D uplift of 0.5 - 1 cm
- **Sep. 2007 - Feb. 2010**: D subsides ~1 cm
- **Sep. 2007 – Aug. 2008**: A,B,C uplift/subsid
- **Sep. 2008 – Feb. 2010**: A,B and C subside with a constant rate of ~4 cm/yr





We modeled the deformation source for the subsidence between Sep. 2008 – Feb. 2010

Dallol - Modeling
Sep. 2008 – Feb. 2010

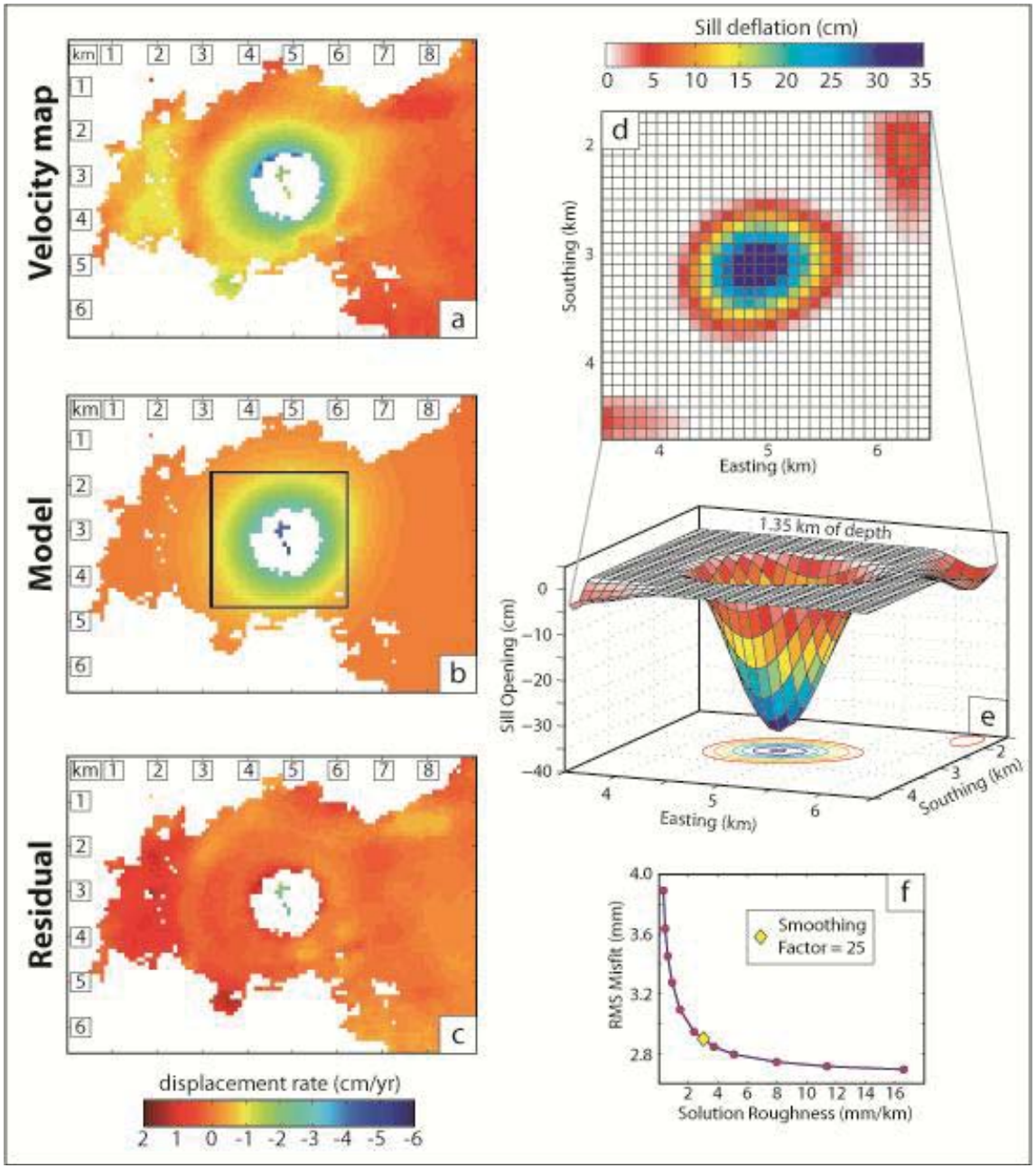


- Deformation rate map between Sep. 2008 – Feb. 2010
- Data resampling using Quadtree algorithm
- 3 different sources (Mogi, ellipsoid and sill)
- Elastic half space with Poisson's ratio 0.25

Shallow deformation source

Dallol -Modeling
Sep. 2008 – Feb. 2010

Distributed model for the sill

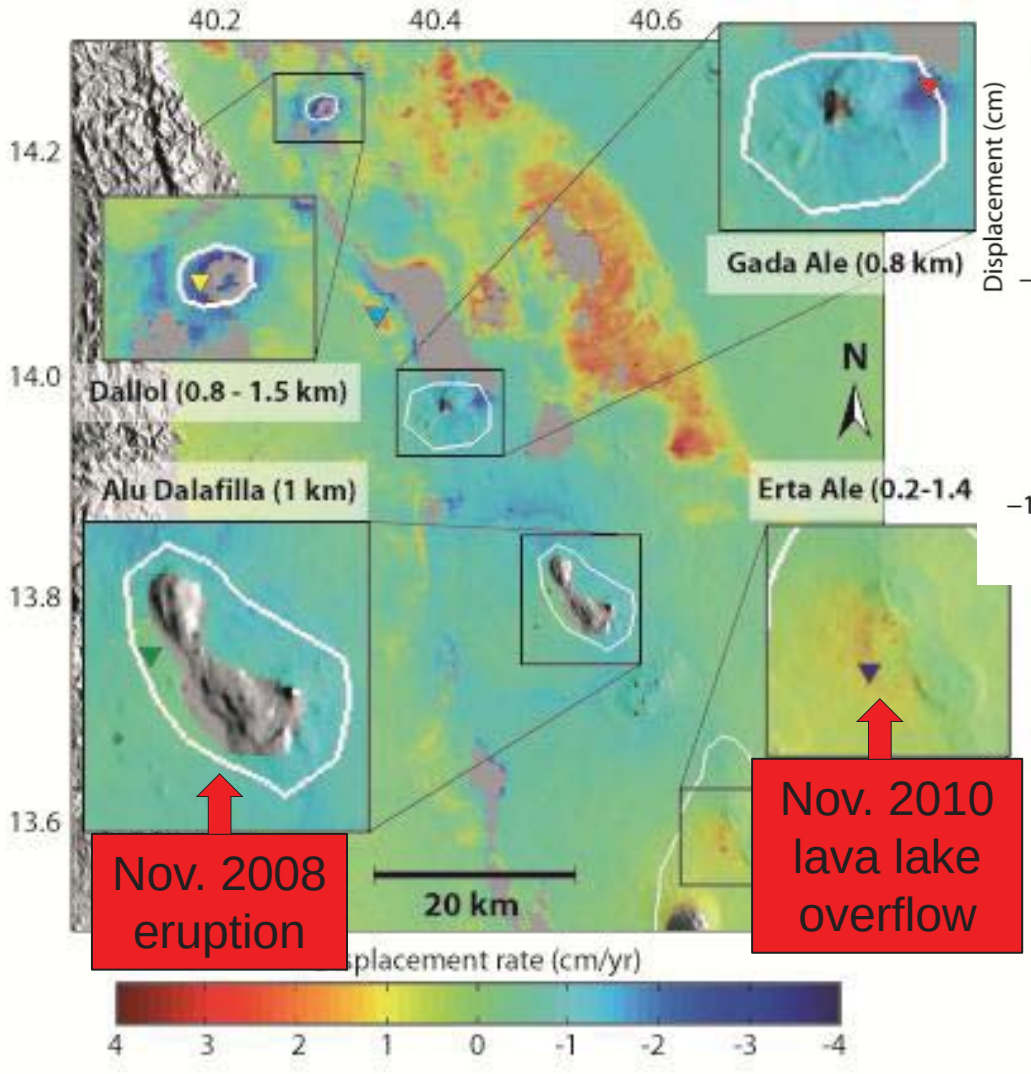


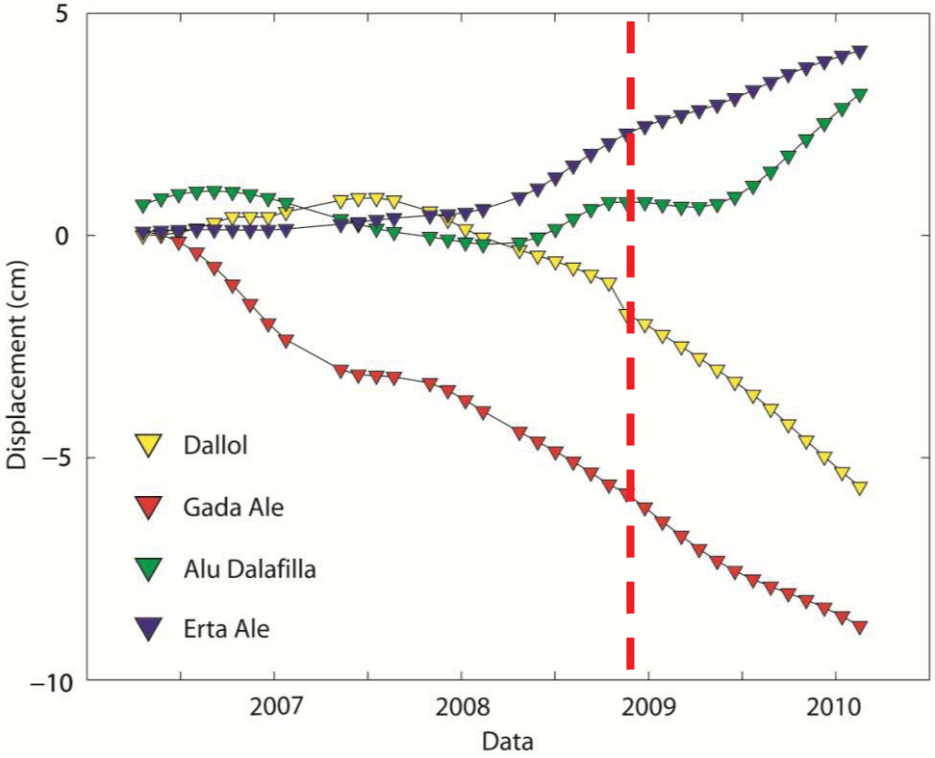
- Source depth 1.35 km
- Volume change 0.25e-3 km^3
- Deformed area ~2 km^2
- Max opening ~35 cm
- 96% of data variance

Not possible to distinguish between magmatic or hydrothermal source

Dallol and the Erta Ale Range

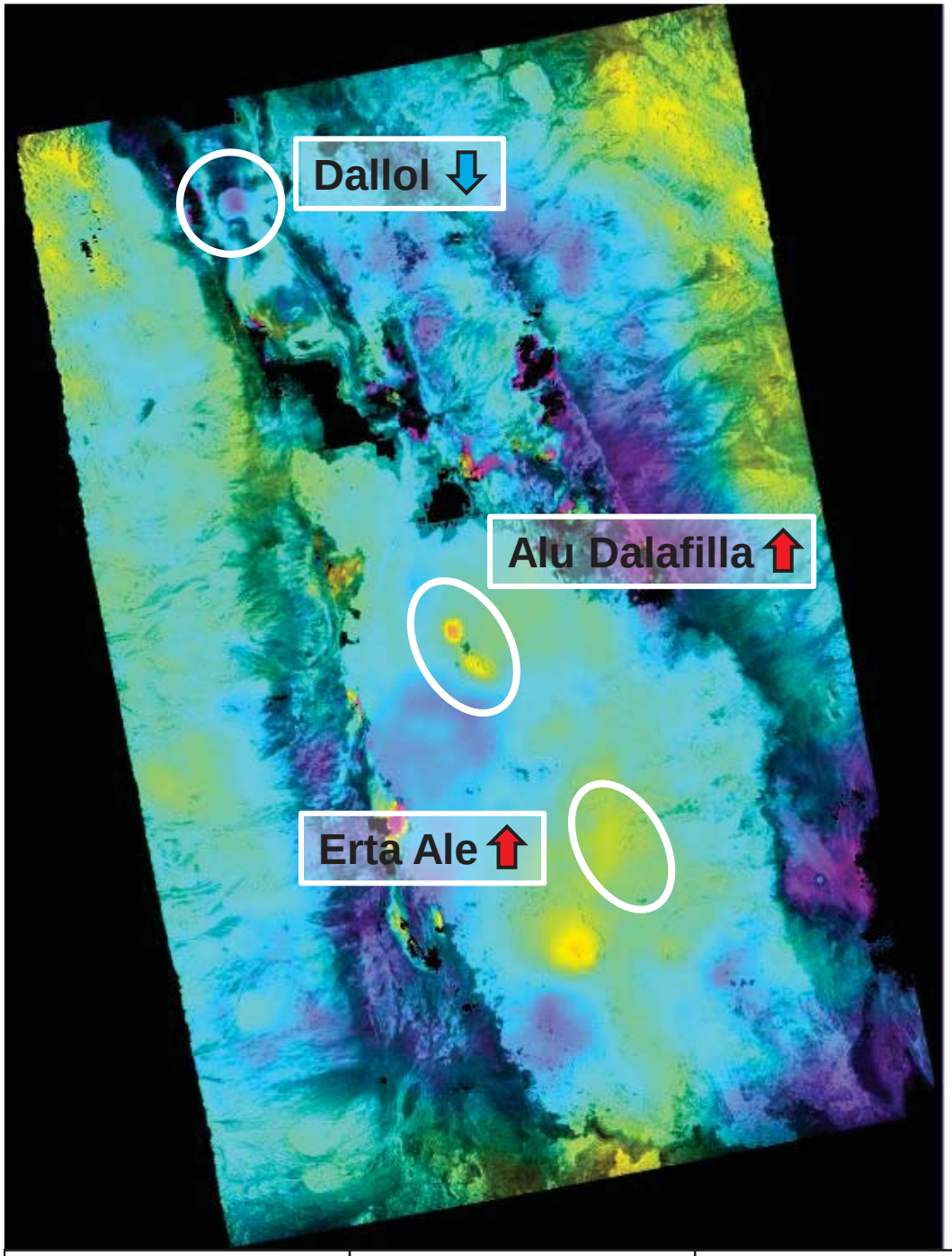
Deformation rate map
Nov .2005 – Feb. 2010





- Subsidence in Dallol and Gada- Ale
- Uplift in Alu-Dalafilla and Erta Ale

Correlation between deformation in Dallol and Erta Ale Range?



Dallol and the Erta Ale Range
June – August 2010

- Few months before Erta Ale lava lake overflow
- ALOS sensor

Correlation between gound deformation at Dallol and Erta Ale Range continued until August 2010

Dallol and the Erta Ale Range

- Assuming a shallow magmatic deformation source at Dallol
- Shallow magma reservoir suggested for different volcanoes along Erta Ale Range
- Considering the correlation between the deformation at Dallol and along the Erta Ale Range

Possible connection at deeper level between these two magmatic segments?

Conclusions

- InSAR monitoring of a remote and poorly studied area
- Unnoticed dyking event (one year before the 2005 mega dyke intrusion at Dabbahu)
- Shallow (<3 km) magmatic source in area without volcanism: capturing a proto-volcanic system in a hydrothermal area
- Extension along the rift segment partially seismically accommodated
- Possible correlation between deformations at Dallol and along the Erta Ale Range


Thank you!!!

Affiliations

1. INGV – CNT – Roma

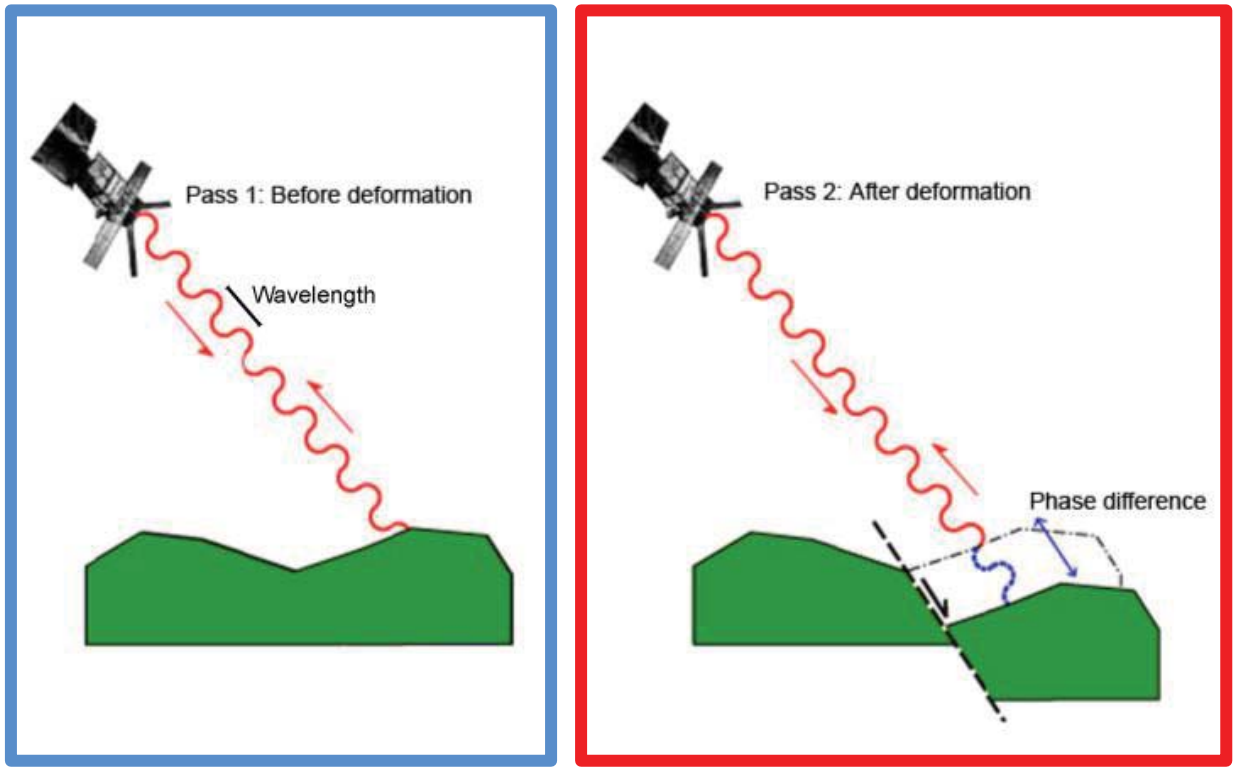
2. Dipartimento di Scienze – Università Roma Tre

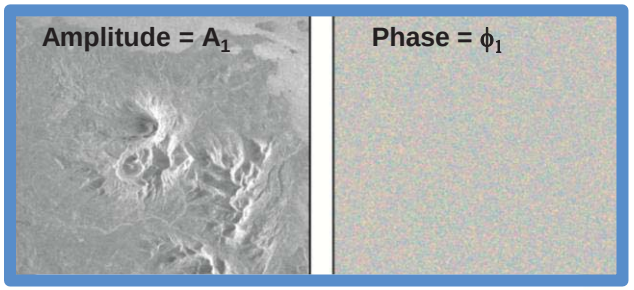
3. SEE - Leeds University

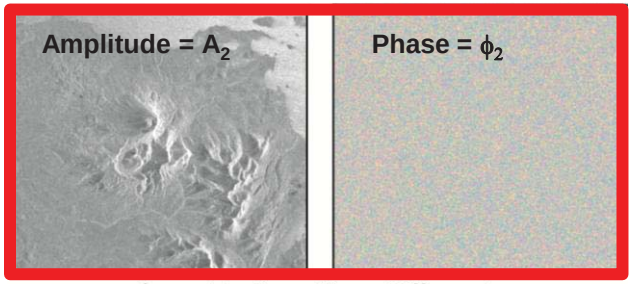
4. NOC – University of Southampton.

5. Addis Abeba University

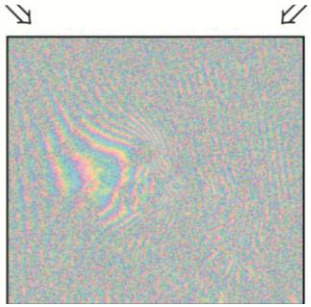
InSAR technique







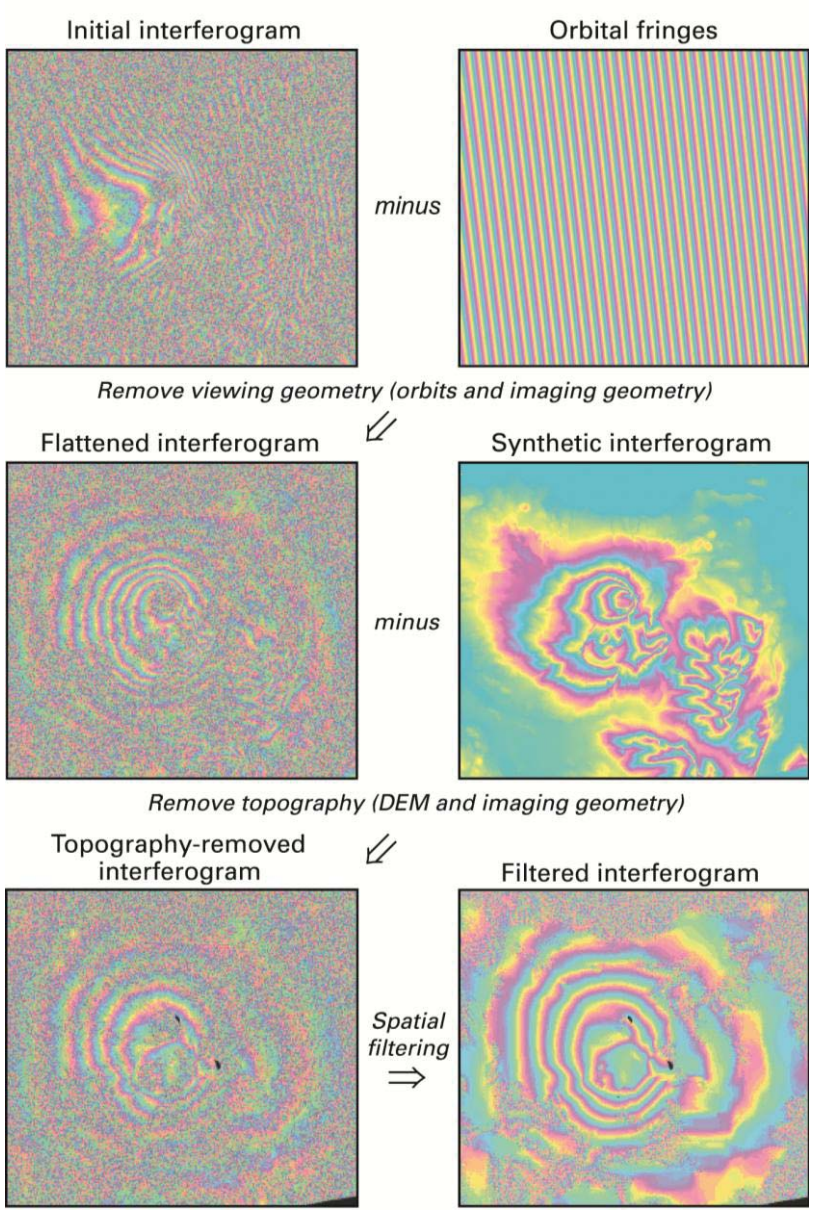
Co-registration + Phase Differencing



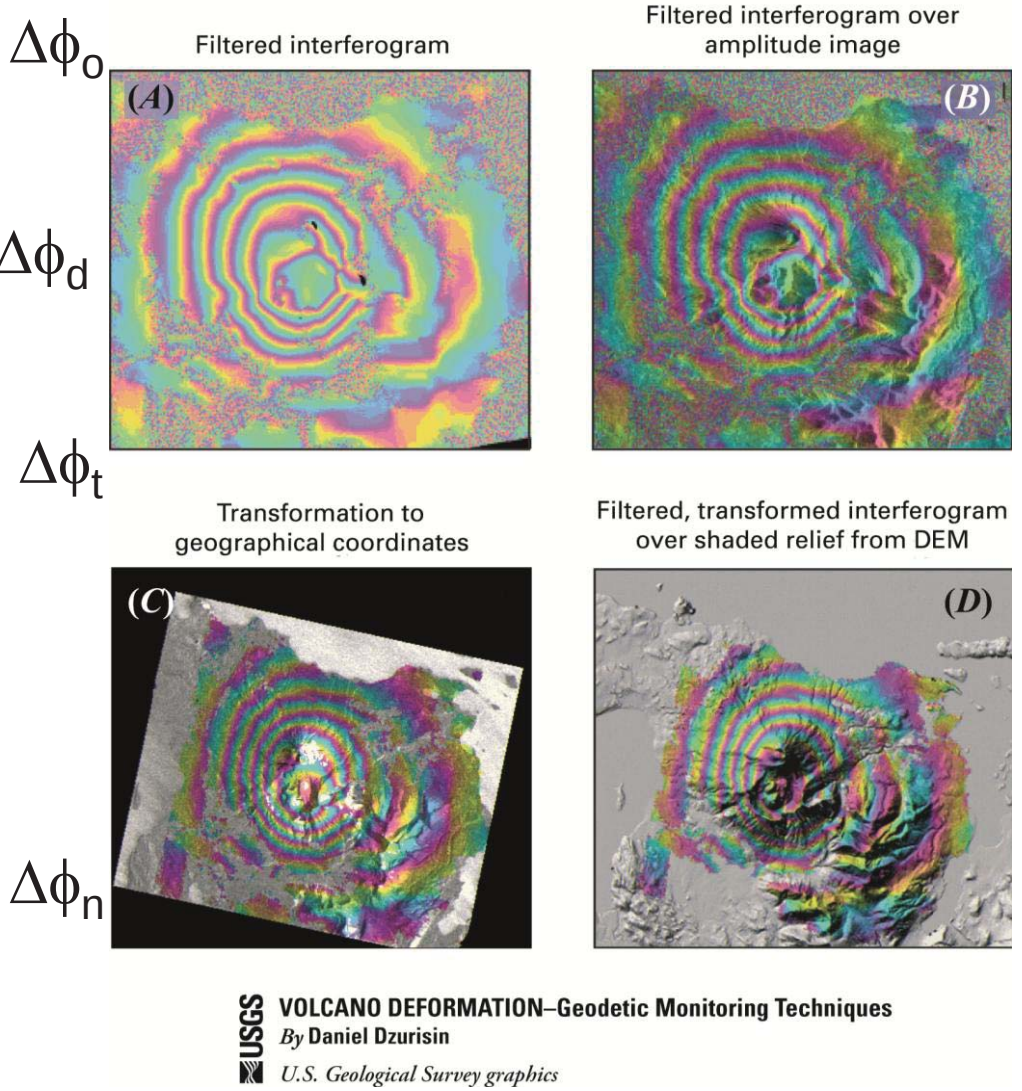
- 2 SAR images acquired in different time.
- images co-registration.

$$\Delta\phi_i = \phi_1 - \phi_2$$

InSAR technique



$$\Delta\phi_i = \Delta\phi_o + \Delta\phi_t + \Delta\phi_n + \Delta\phi_d$$



USGS **VOLCANO DEFORMATION–Geodetic Monitoring Techniques**
By **Daniel Dzurisin**
U.S. Geological Survey graphics