

18 years of InSAR observations at Fernandina volcano, Galápagos: *dynamics of magma storage and eruption*

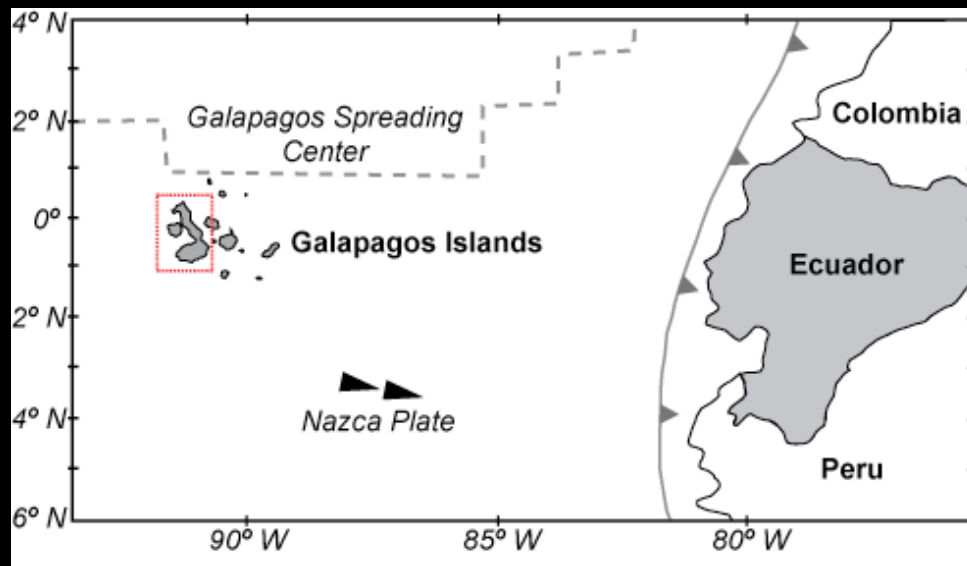
MARCO BAGNARDI
F. Amelung – S. Baker

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE



April 2009 eruption. Photo by Paulo Martel

THE GALÀPAGOS ISLANDS



21 volcanic islands

Eruptions since 1940:

Fernandina: 10

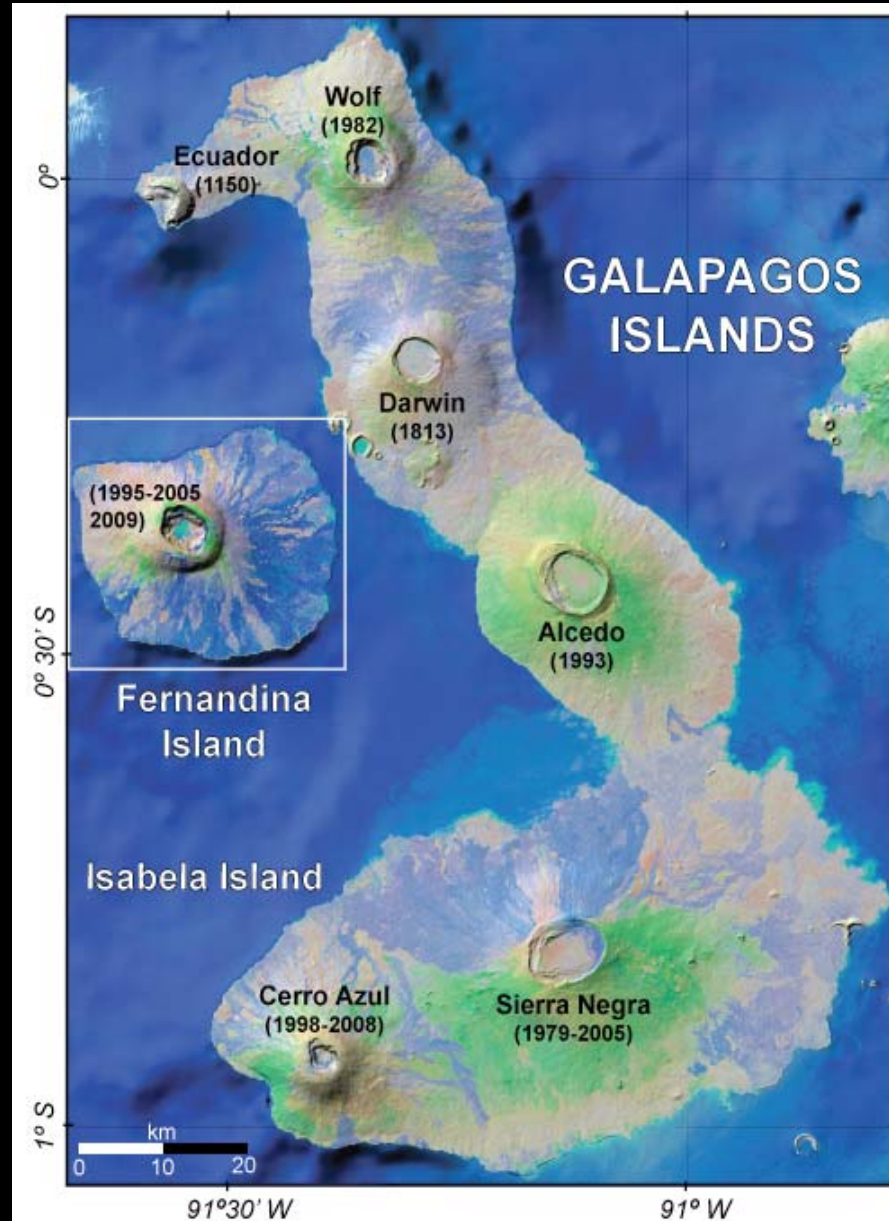
Sierra Negra: 6

Cerro Azul: 5

Wolf: 2

Alcedo: 2

Marcena: 1

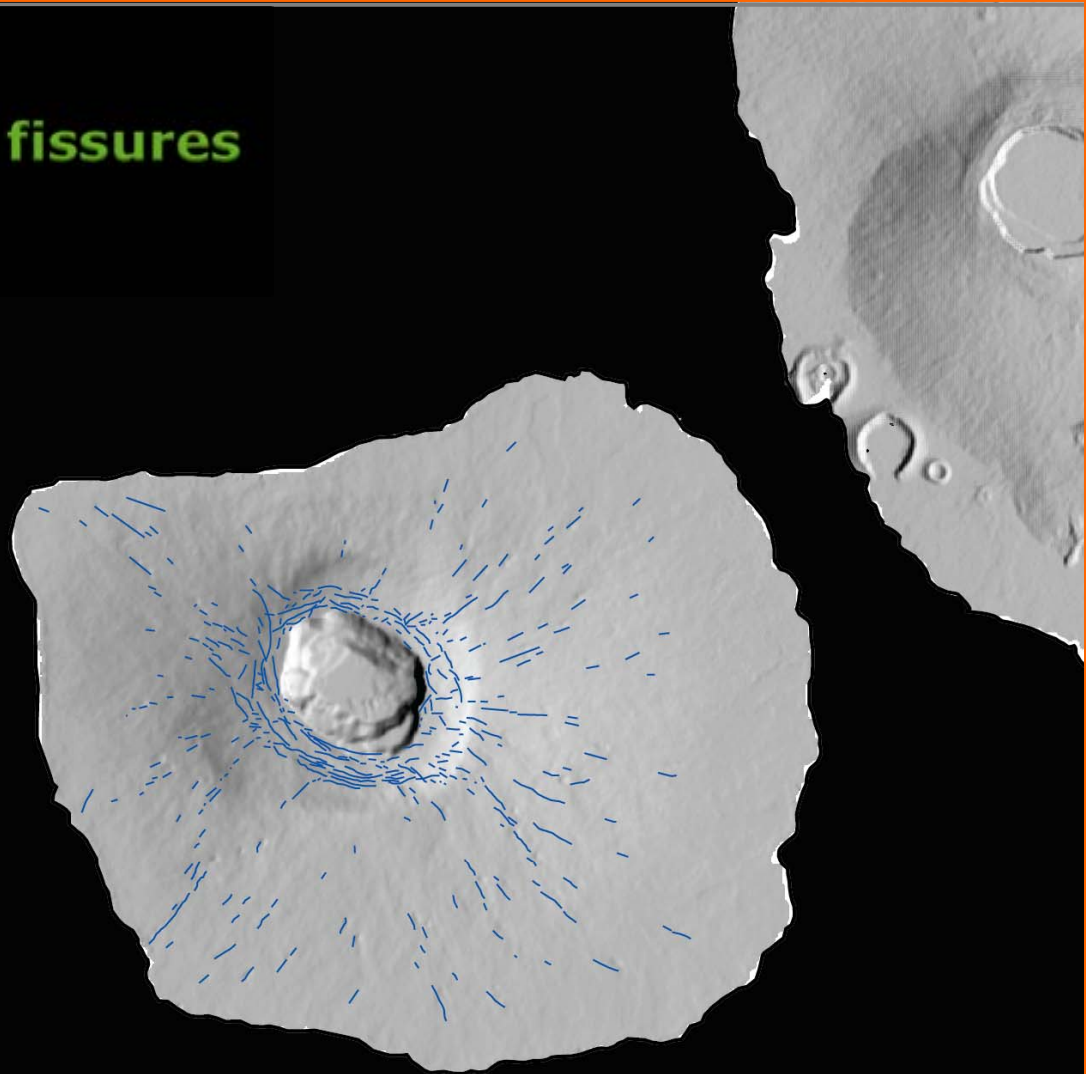
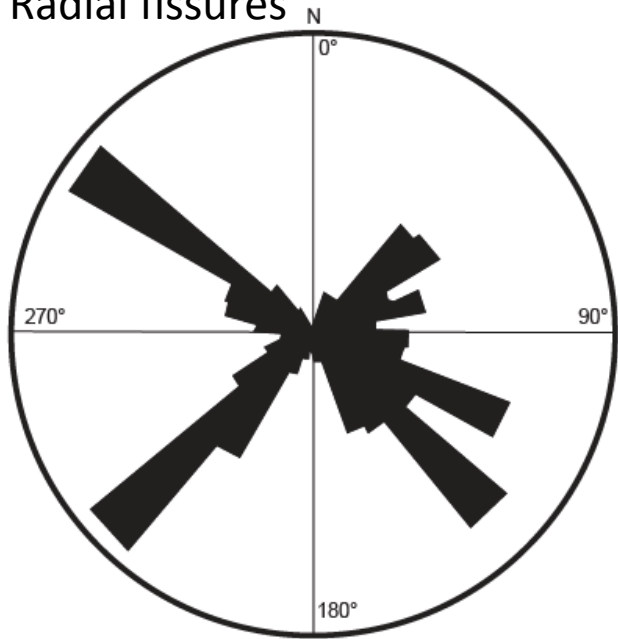


FERNANDINA

Radial and circumferential fissures

[Chadwick and Howard, 1991]

Radial fissures



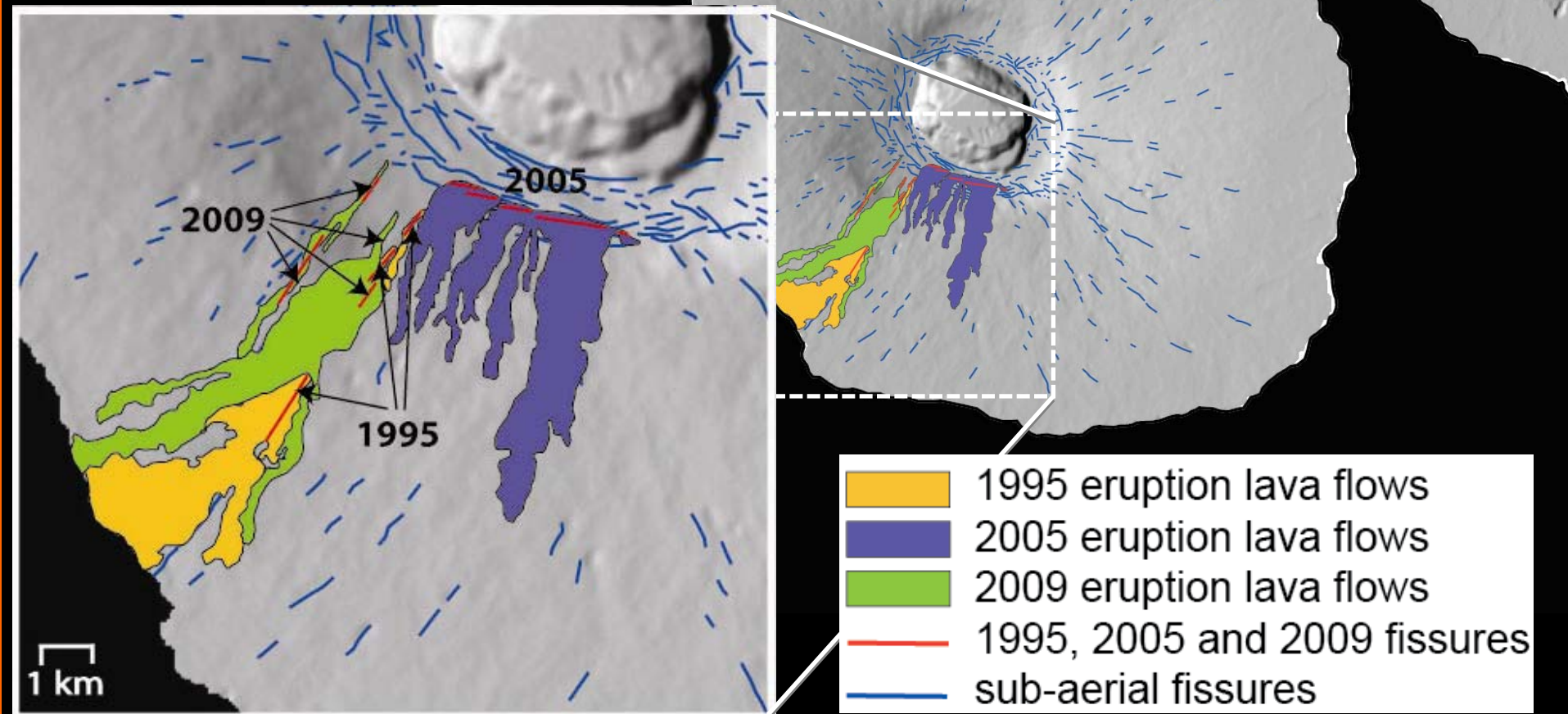
FERNANDINA

Latest eruptions:

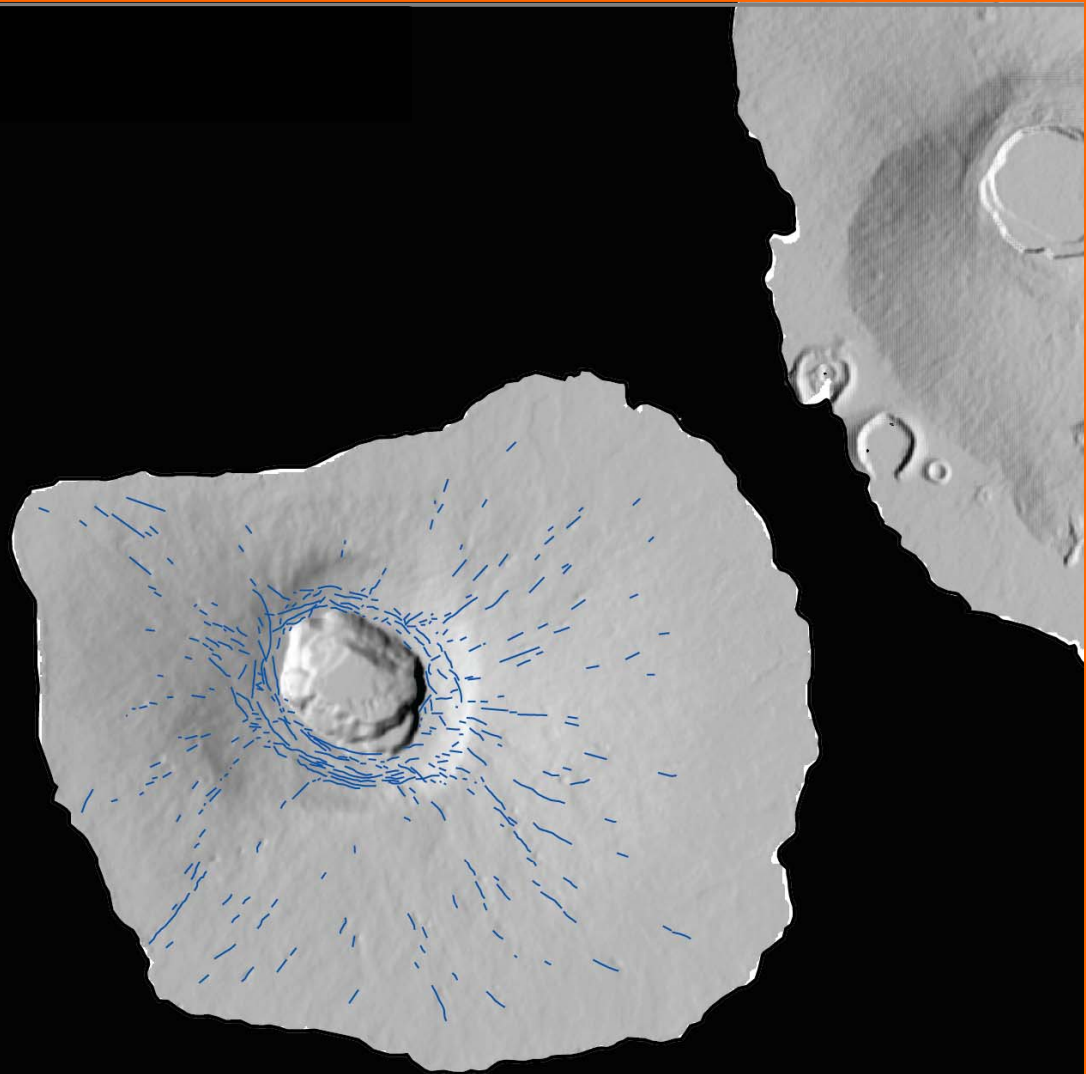
1995 [Jónsson et al., 1999]

2005 [Chadwick et al., 2010]

2009 [Bagnardi et al., in prep. 2011]



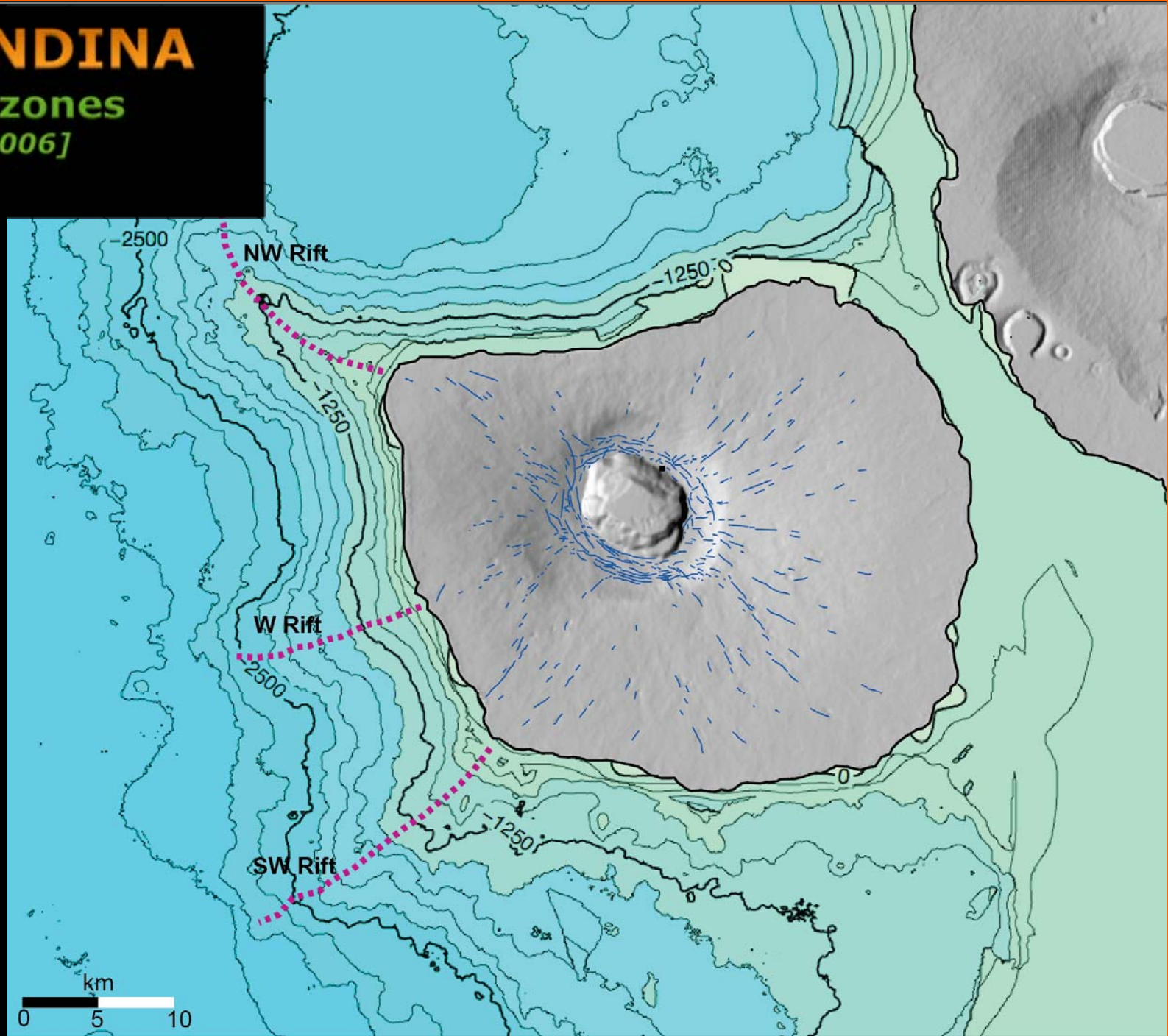
FERNANDINA



FERNANDINA

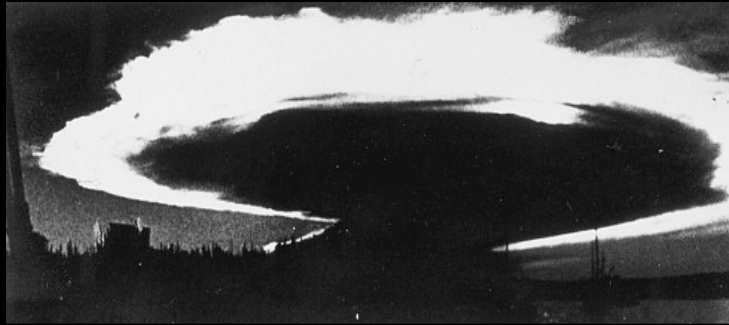
Three rift zones

[Geist et al., 2006]



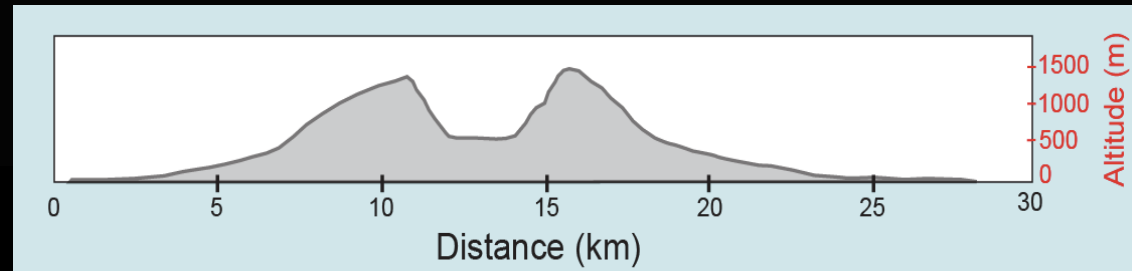
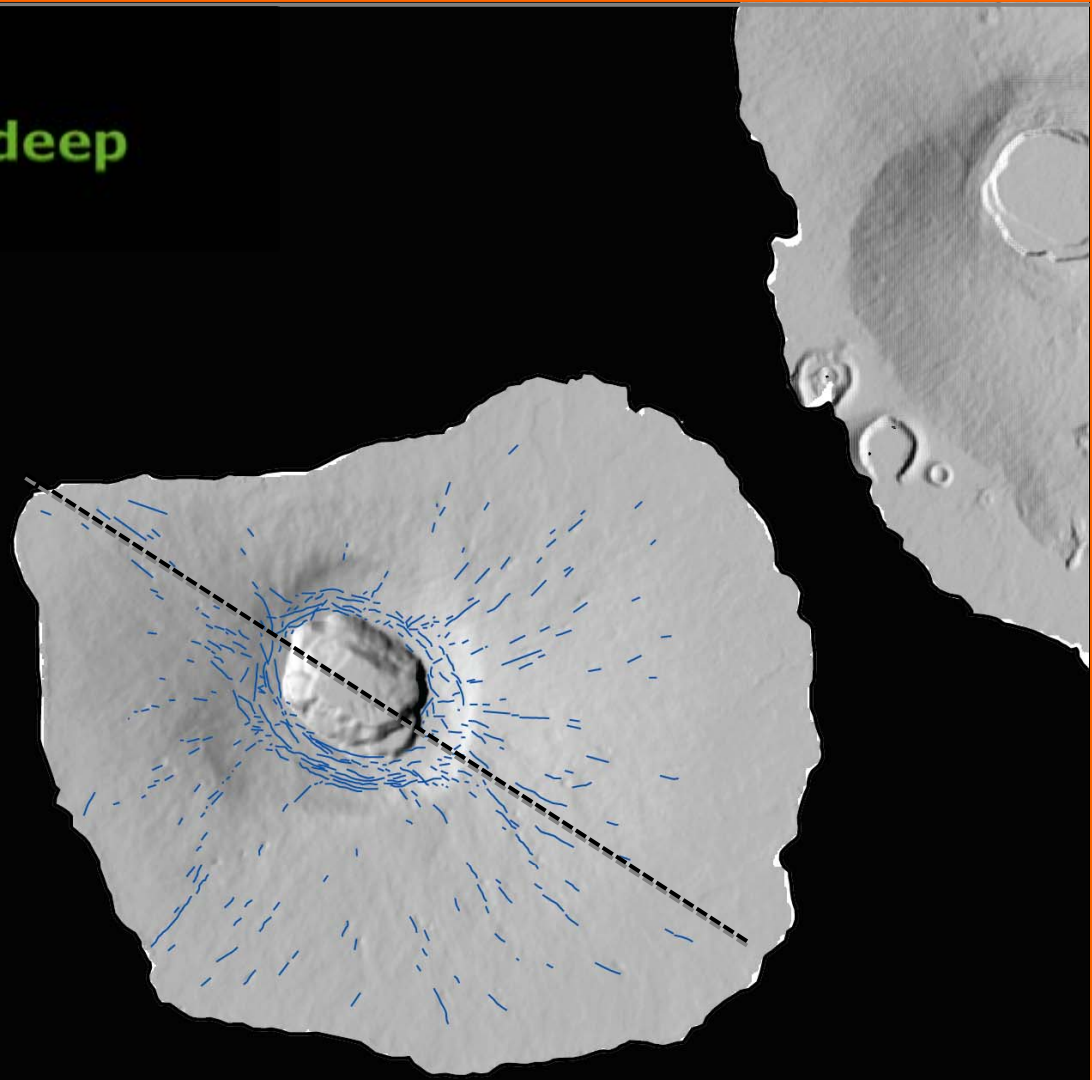
FERNANDINA

Summit caldera: ~ 900 m deep
1968 collapse: 350 m



Volume erupted:
100 times smaller than
estimated volume of
collapse!

[Simkin and Howard, 1970]



The starting point...

**Few SAR acquisitions
2 satellites (ERS-1/2)**

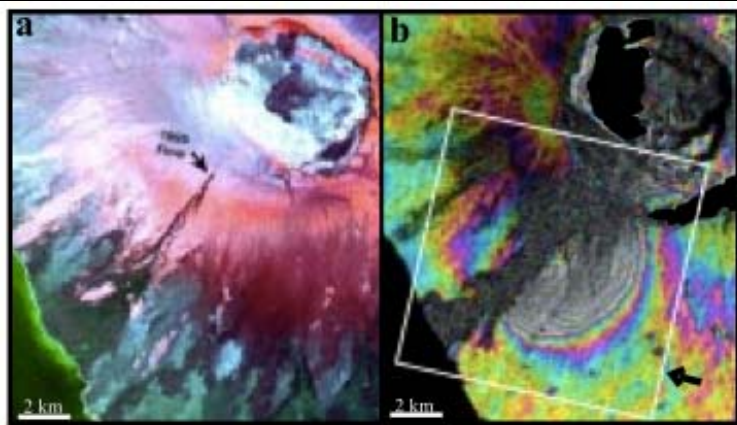
1992 – 1997/98

GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO. 8, PAGES 1077-1080, APRIL 15, 1999

**A Shallow-Dipping Dike fed the 1995 Flank Eruption at
Fernandina Volcano, Galápagos, Observed by Satellite
Radar Interferometry**

Sigurjón Jónsson, Howard Zebker, Peter Cervelli, Paul Segall
Geophysics Department, Stanford University, California

Harold Garbeil, Peter Mouginiis-Mark, Scott Rowland
Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu



Jónsson et al., 1999

26 October 2000

International weekly journal of science

nature

\$19.00

www.nature.com

Galàpagos volcanoes relax

Brain damage

Repairing the
central nervous
system

Kuiper belt objects

A dynamical link
with colour

Glutamate receptors

Structural basis of
ligand binding



nature jobs

focus on neuroscience

Amelung et al., 2000

Where we are ...

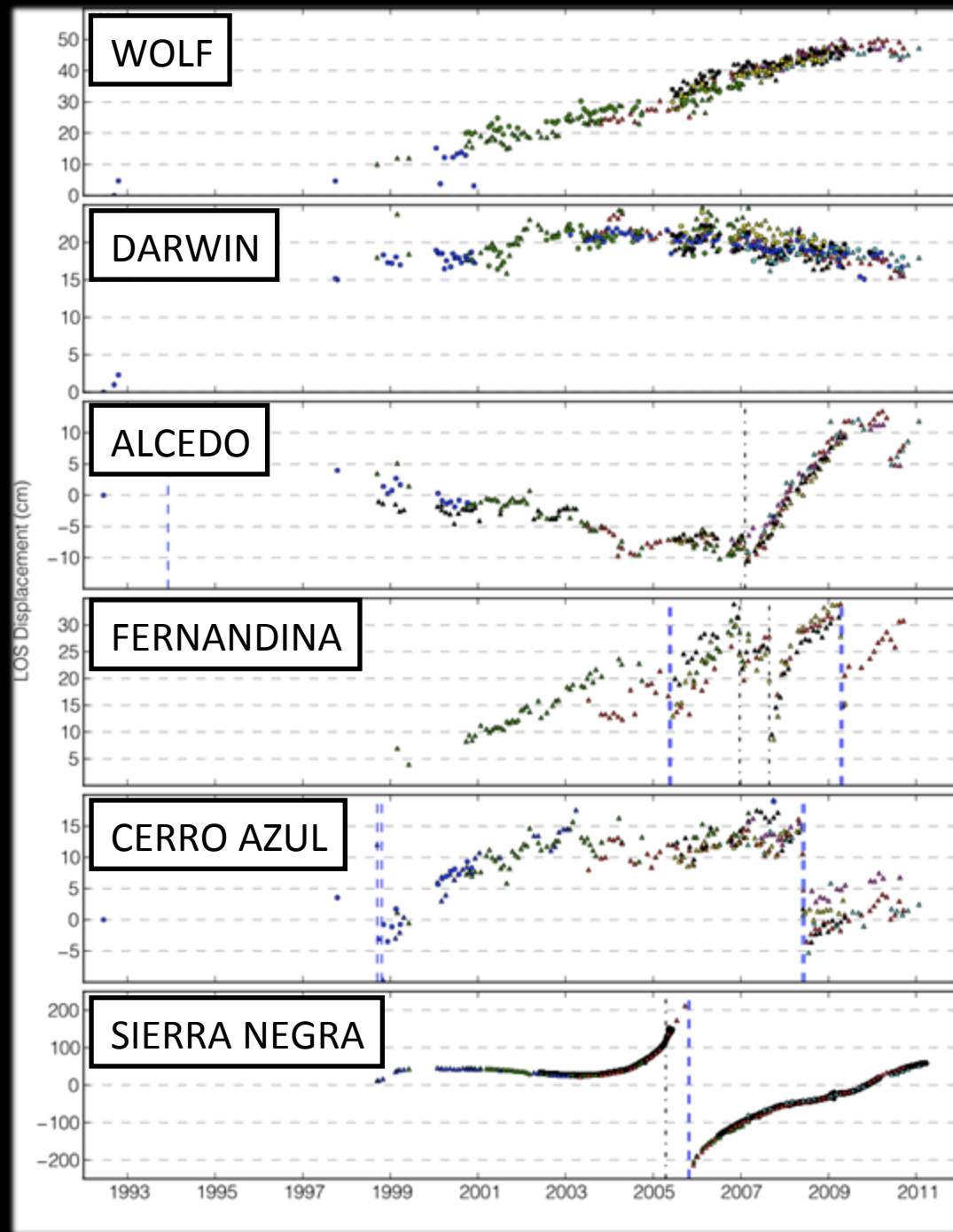
> 500 SAR acquisitions
6 satellites

ERS-1 and ERS-2
JERS-1
RADARSAT-1
ENVISAT
ALOS

SBAS – TIME SERIES

Poster today!

Baker et al., in prep. (2011)



Where we are ...

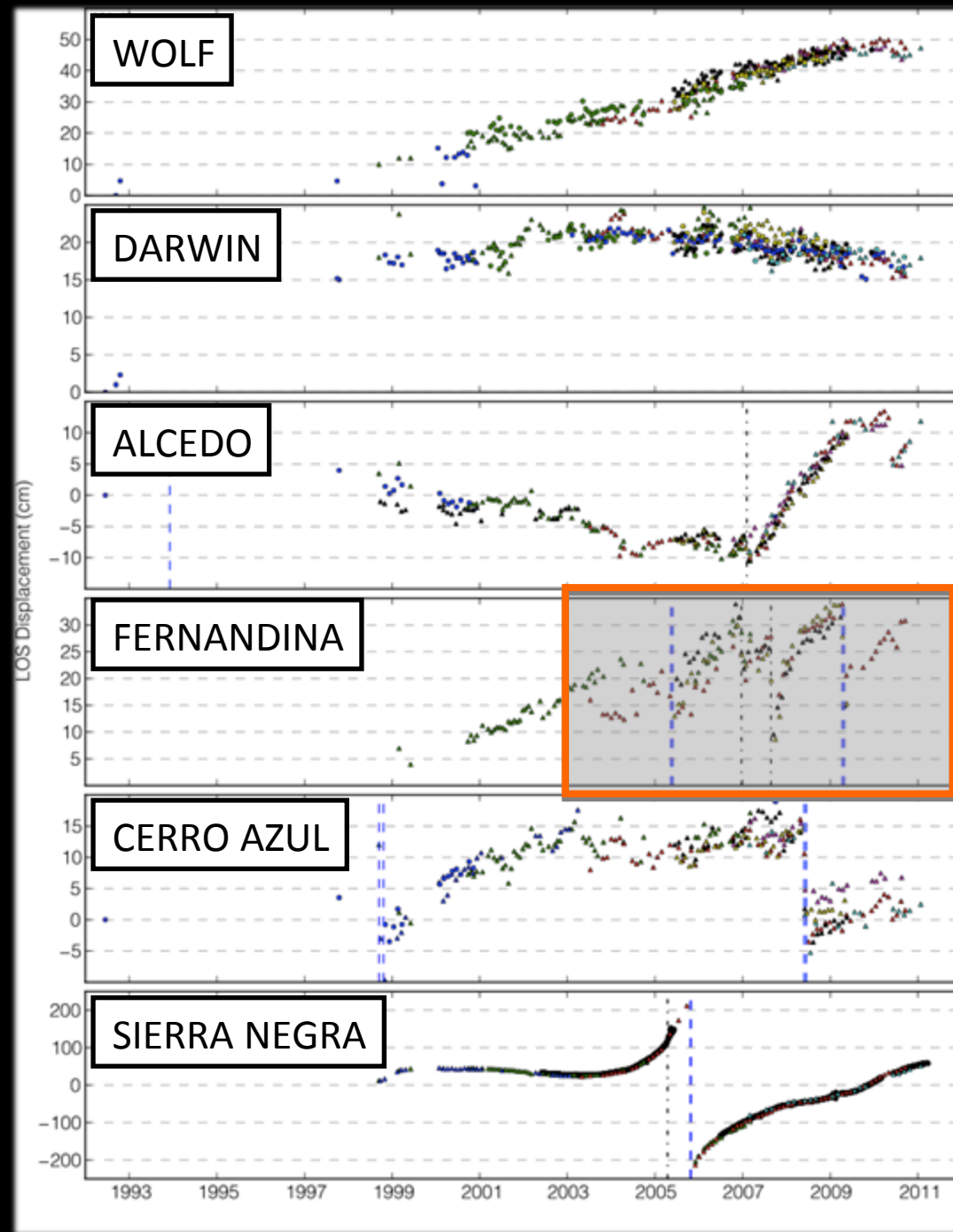
> 500 SAR acquisitions
6 satellites

ERS-1 and ERS-2
JERS-1
RADARSAT-1
ENVISAT
ALOS

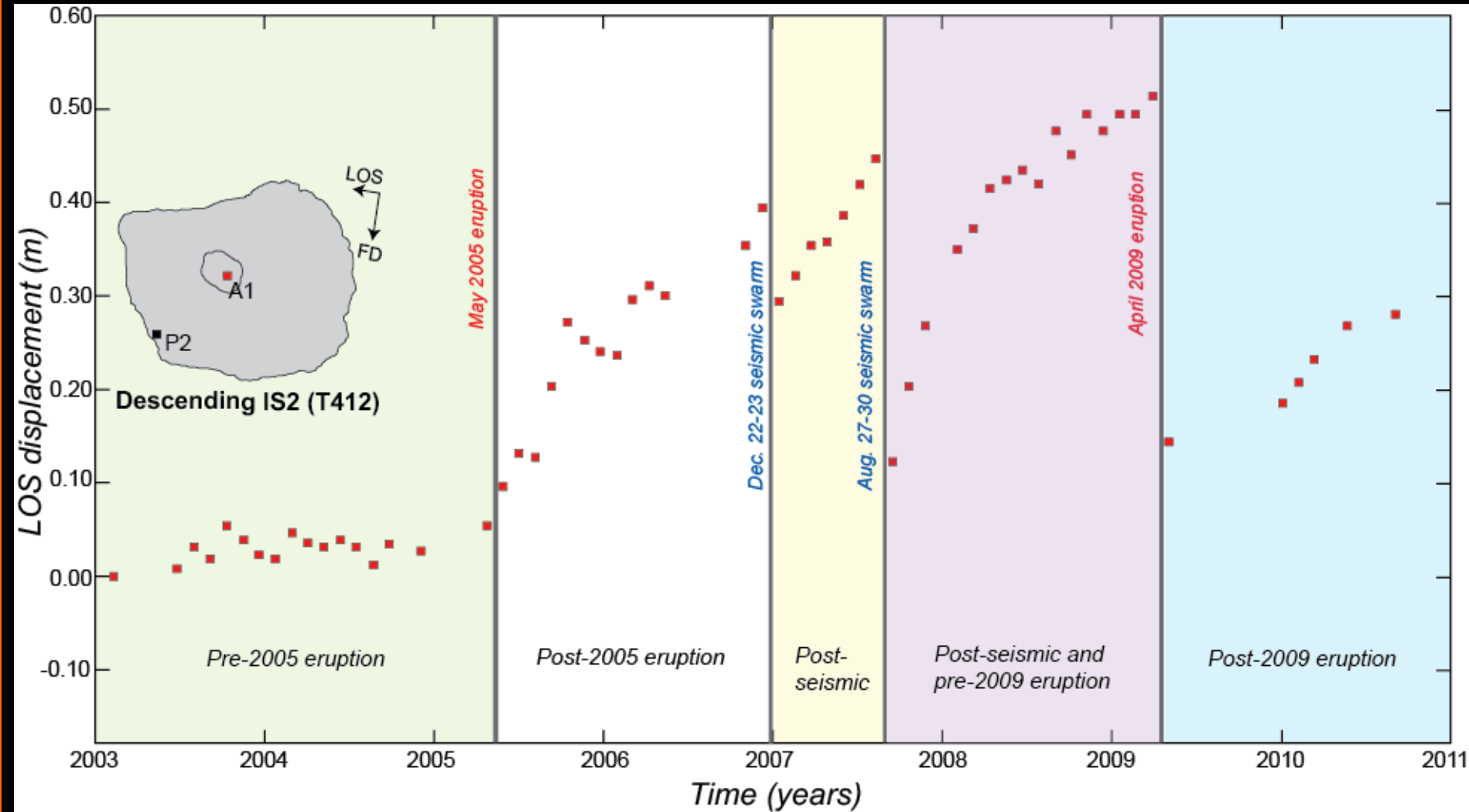
SBAS – TIME SERIES

Poster today!

Baker et al., in prep. (2011)



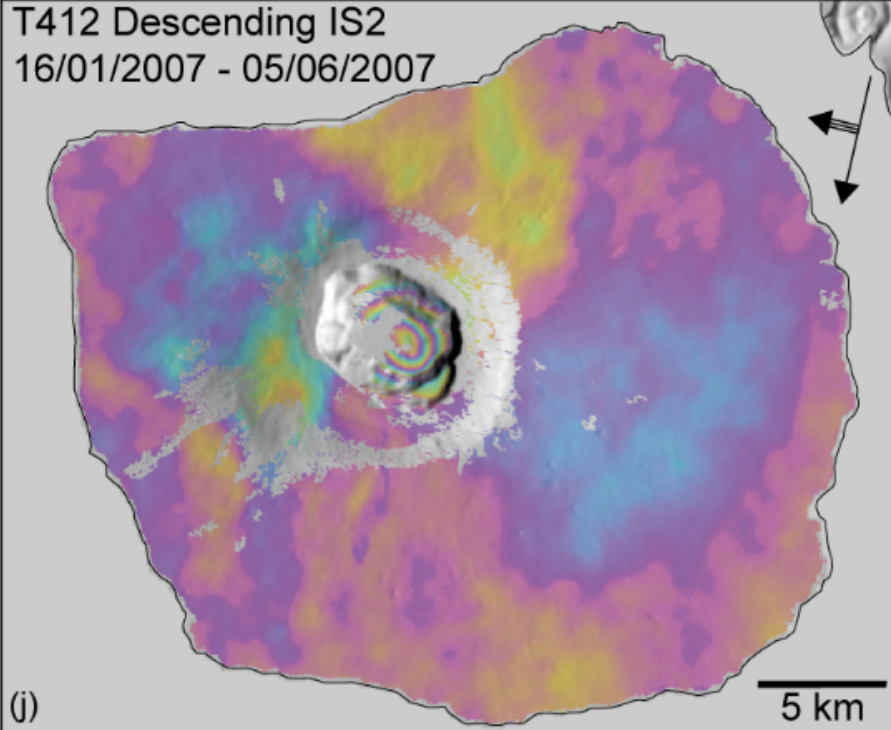
SBAS TIME SERIES: Envisat 02/2003 – 09/2010



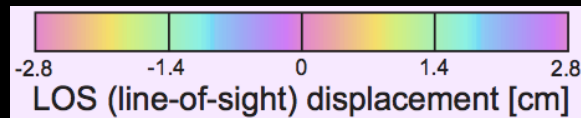
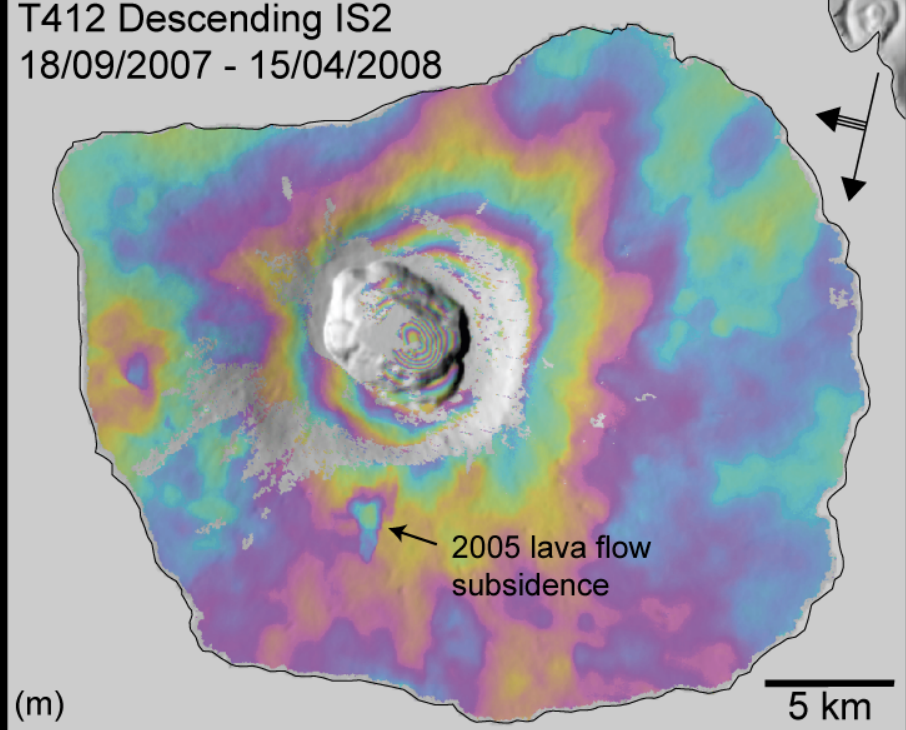
2 eruptions (2005 – 2009) 2 seismic swarms (Dec. 2006 – Aug. 2007)

INFLATION: 2 types

T412 Descending IS2
16/01/2007 - 05/06/2007



T412 Descending IS2
18/09/2007 - 15/04/2008



Intra-caldera:

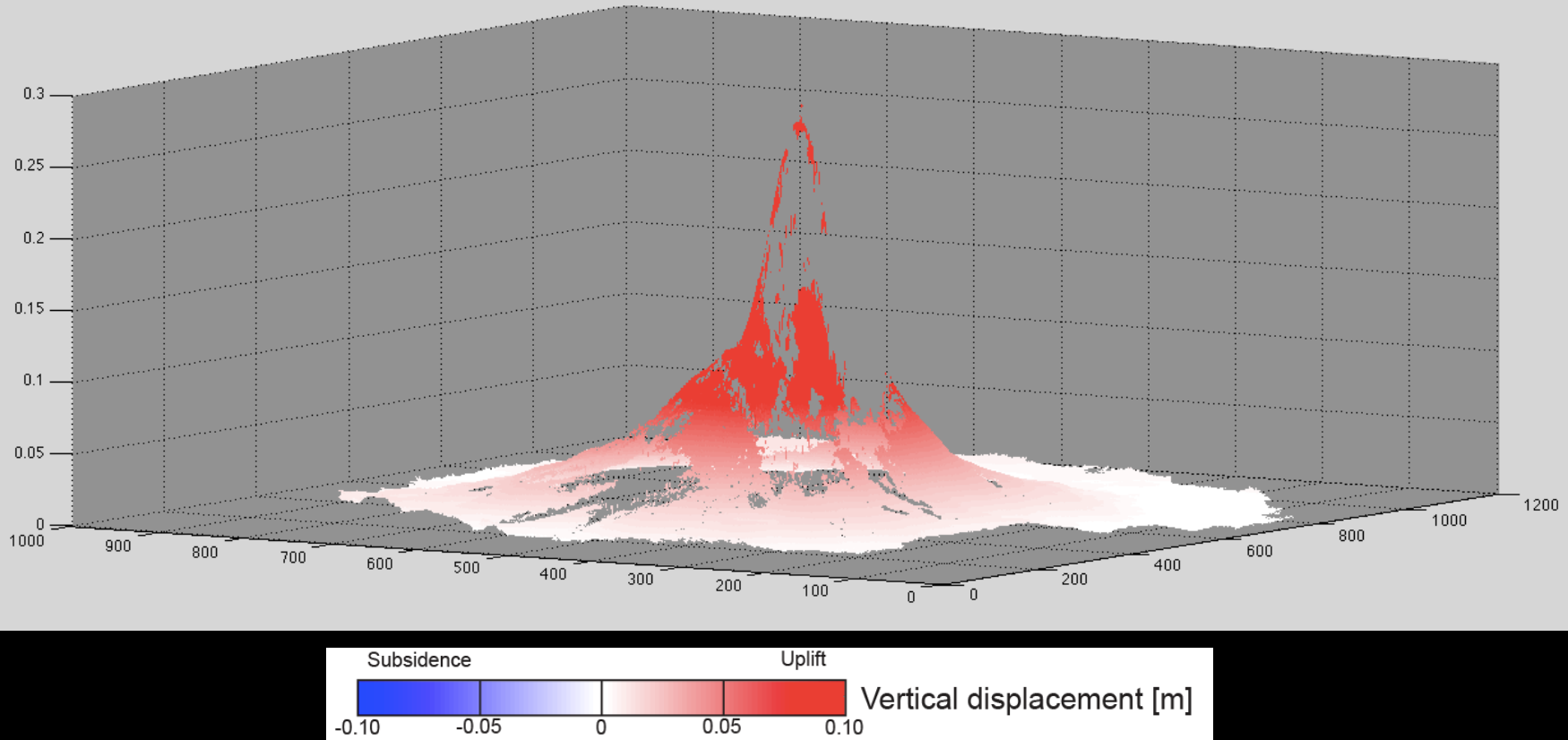
- long-term
- almost continuous
- high gradient

Extended:

- short-term
- discontinuous
- Low gradient

INFLATION: 2 types

28/09/2007 – 26/04/2008



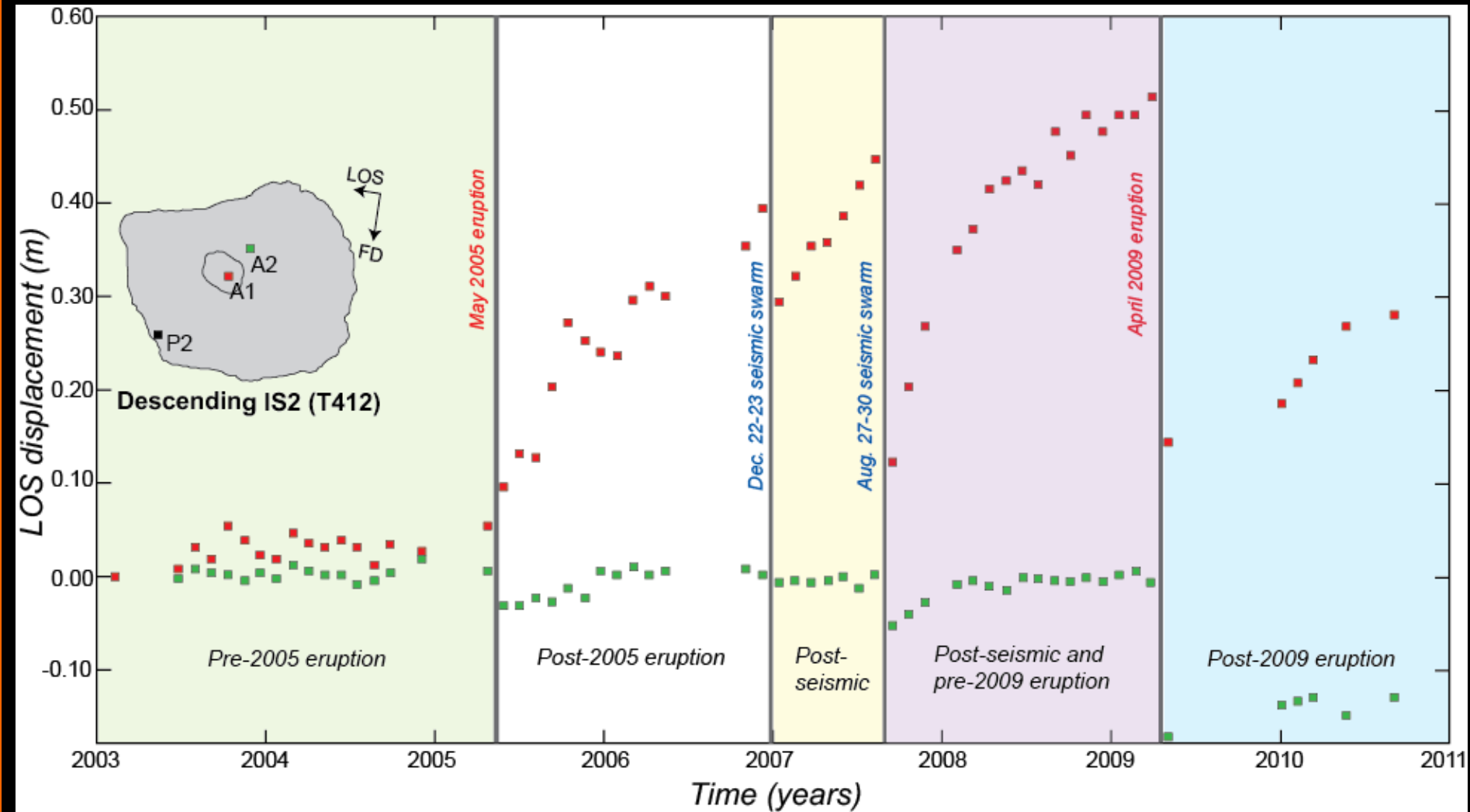
Intra-caldera:

- long-term
- almost continuous
- high gradient

Extended:

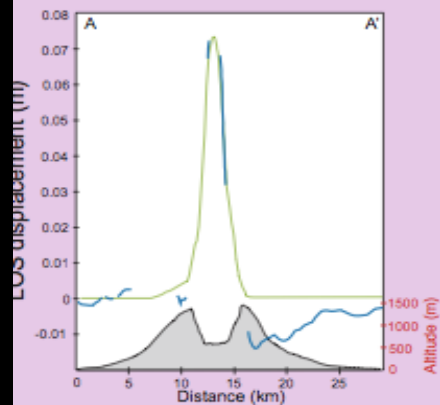
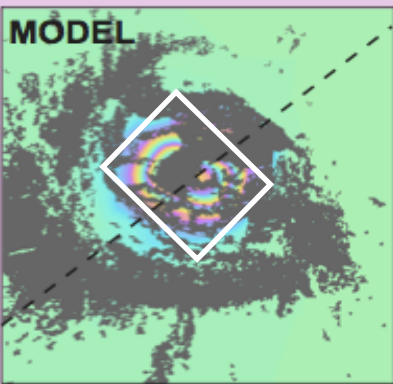
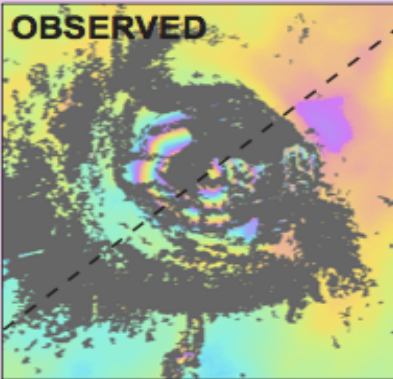
- short-term
- discontinuous
- Low gradient

SBAS TIME SERIES: Envisat 02/2003 – 09/2010

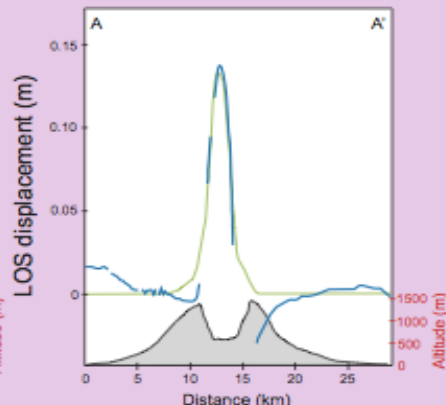
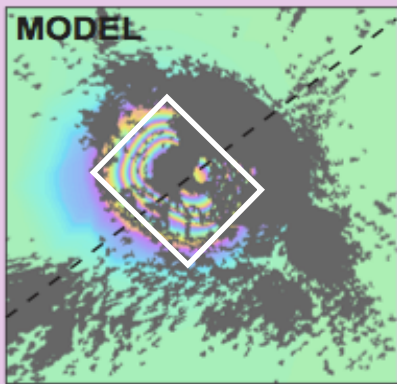
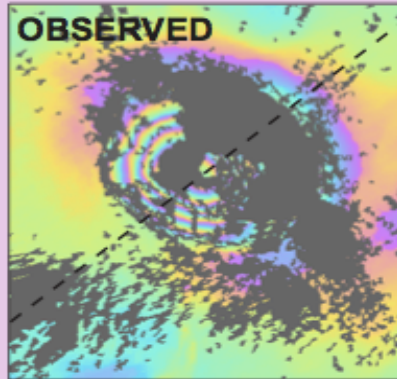


INTRA- CALDERA INFLATION

Caldera source:
15/07/2005 - 29/10/2005



Caldera source:
26/01/2007 - 20/07/2007



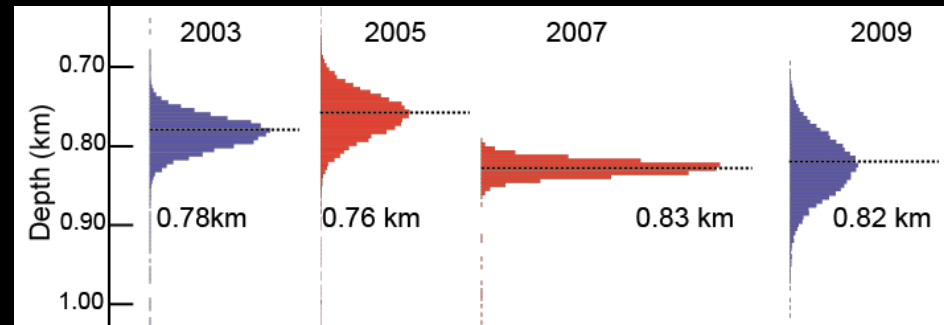
Uniform opening horizontal sill
(planar dislocation [*Okada, 1992*])

Length: 3.00 km

Width: 2.00 km

Strike: 119°

Depth: 0.80 km b.s.l.

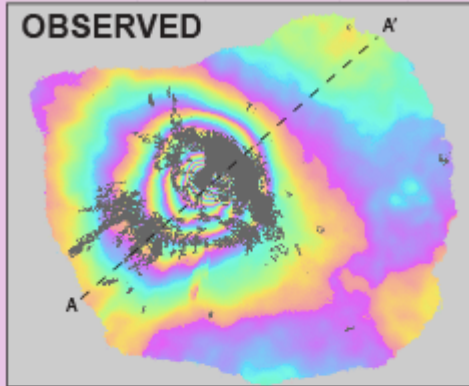


Gibbs sampling(100,000 iterations)

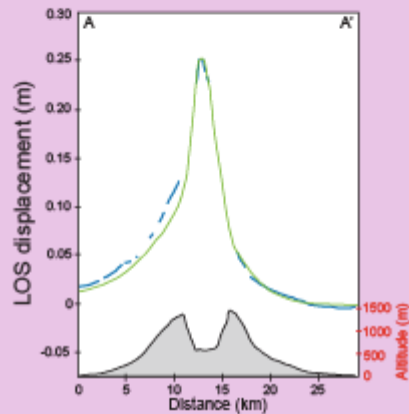
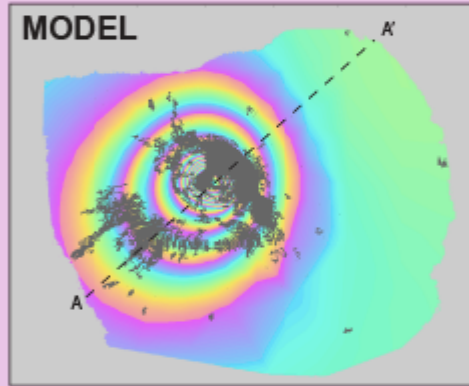
BROAD INFLATION

Two sources:
28/09/2007 - 26/04/2008

OBSERVED



MODEL



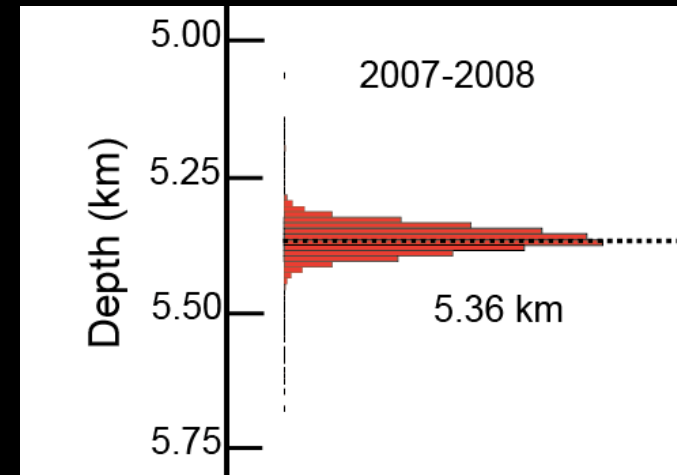
Uniform opening horizontal sill
(planar dislocation [Okada, 1992])

Length*: 3.0 km
Width*: 2.00 km
Strike*: 119°
Depth*: 0.80 km b.s.l.

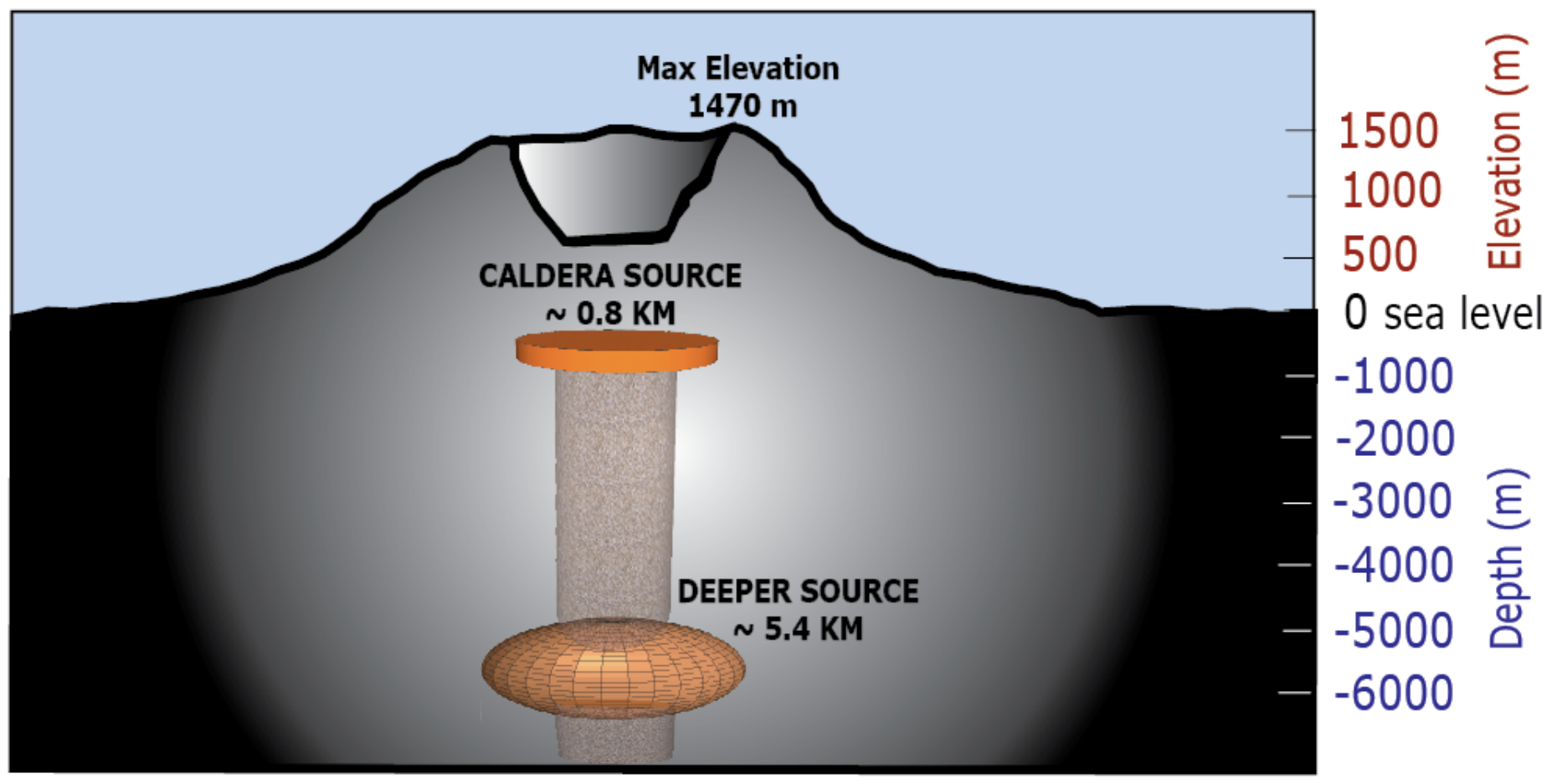
* fixed

Ellipsoidal cavity
(prolate spheroid [Yang, 1988])

Aspect ratio: 0.2
Dip: 0° (horizontal)
Strike: 48°
Depth: 5.36 km b.s.l.



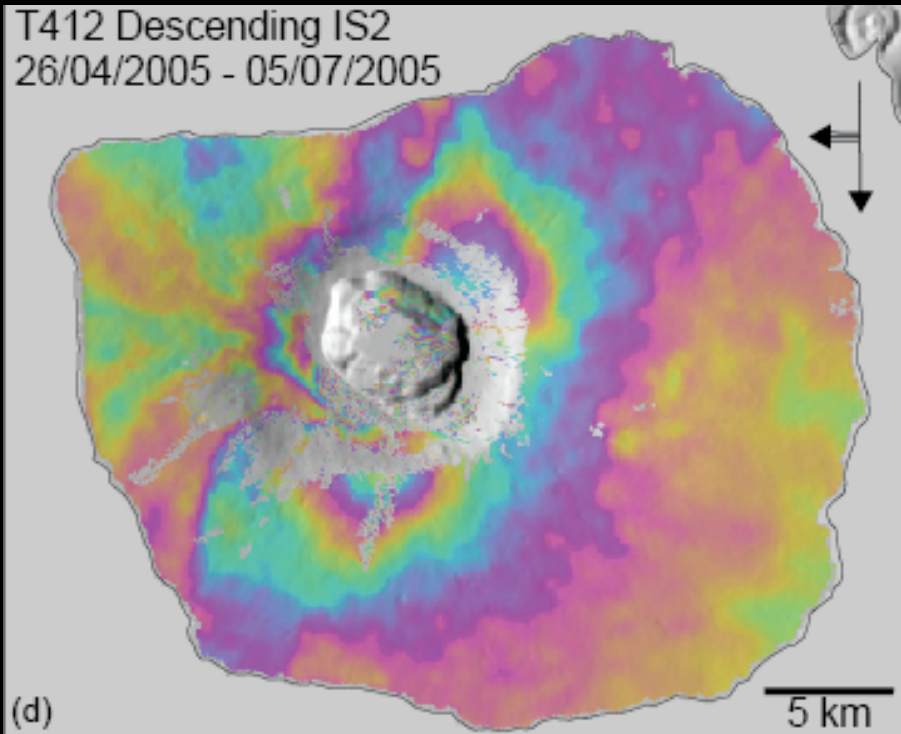
MAGMA STORAGE SYSTEM



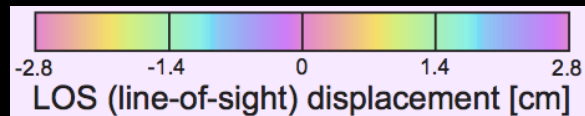
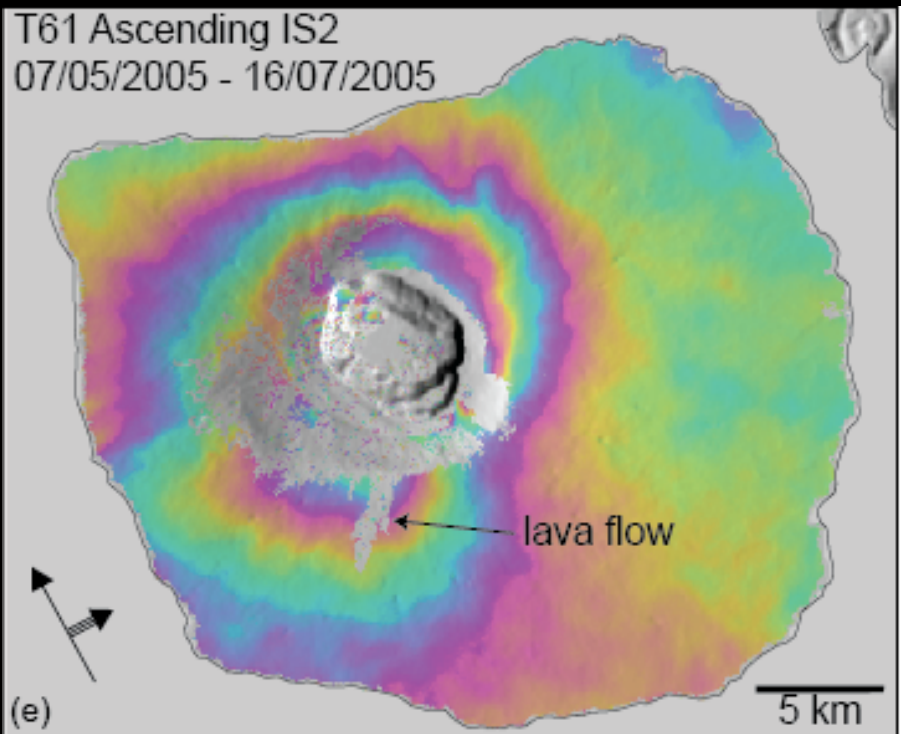
Two permanent magma reservoirs

May 2005 ERUPTION

T412 Descending IS2
26/04/2005 - 05/07/2005



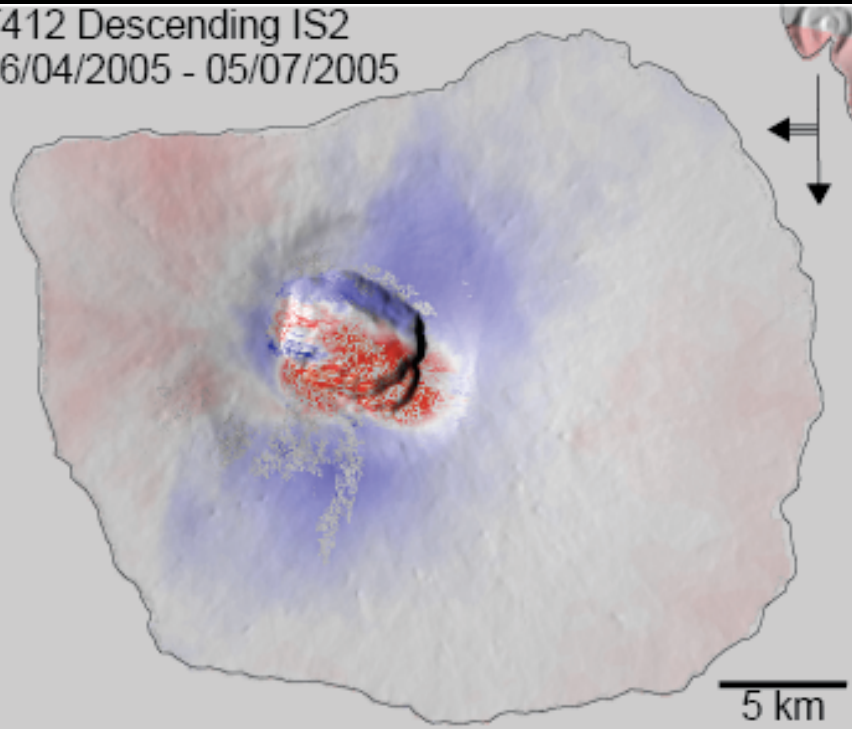
T61 Ascending IS2
07/05/2005 - 16/07/2005



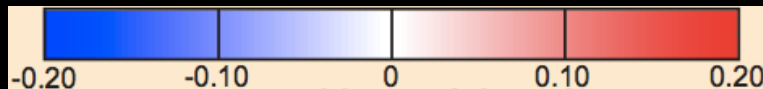
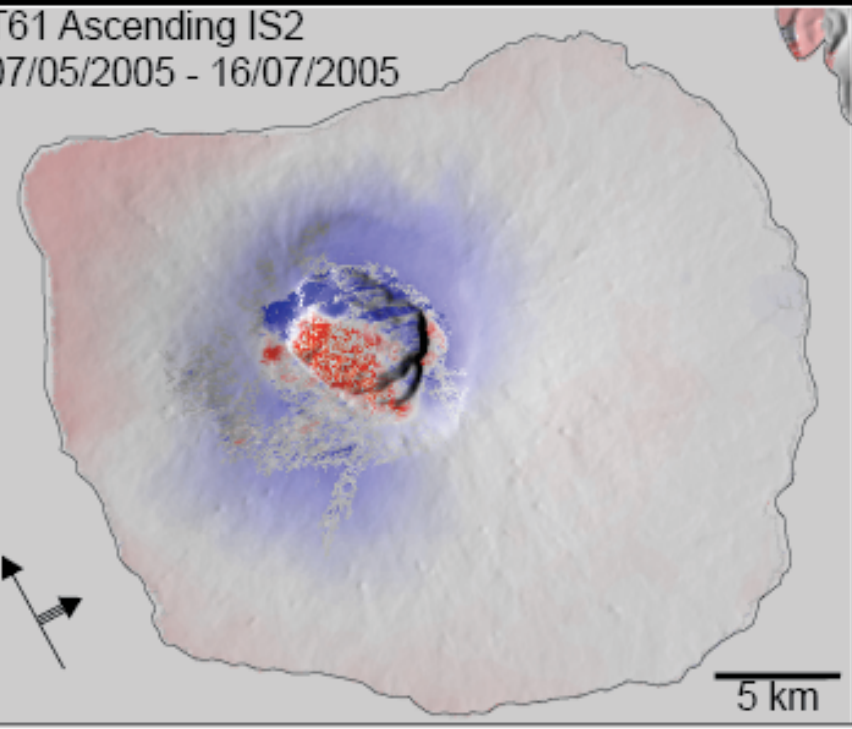
Circumferential fissures on the southern caldera rim

May 2005 ERUPTION

T412 Descending IS2
26/04/2005 - 05/07/2005



T61 Ascending IS2
07/05/2005 - 16/07/2005



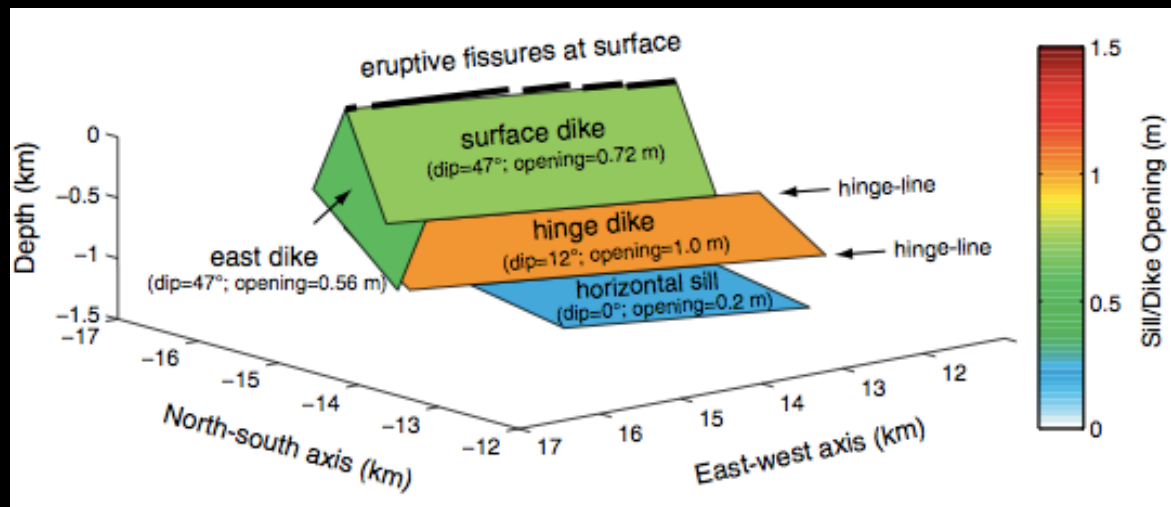
LOS displacement (cm)

Circumferential fissures on the southern caldera rim

May 2005 ERUPTION

The May 2005 eruption of Fernandina volcano, Galápagos: The first circumferential dike intrusion observed by GPS and InSAR

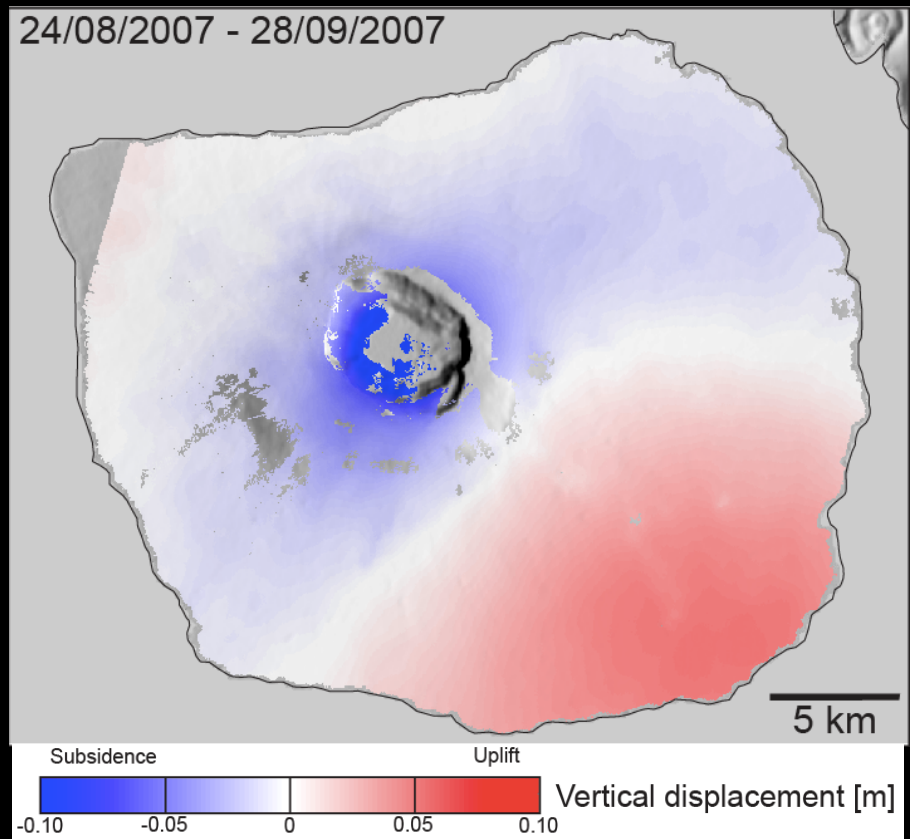
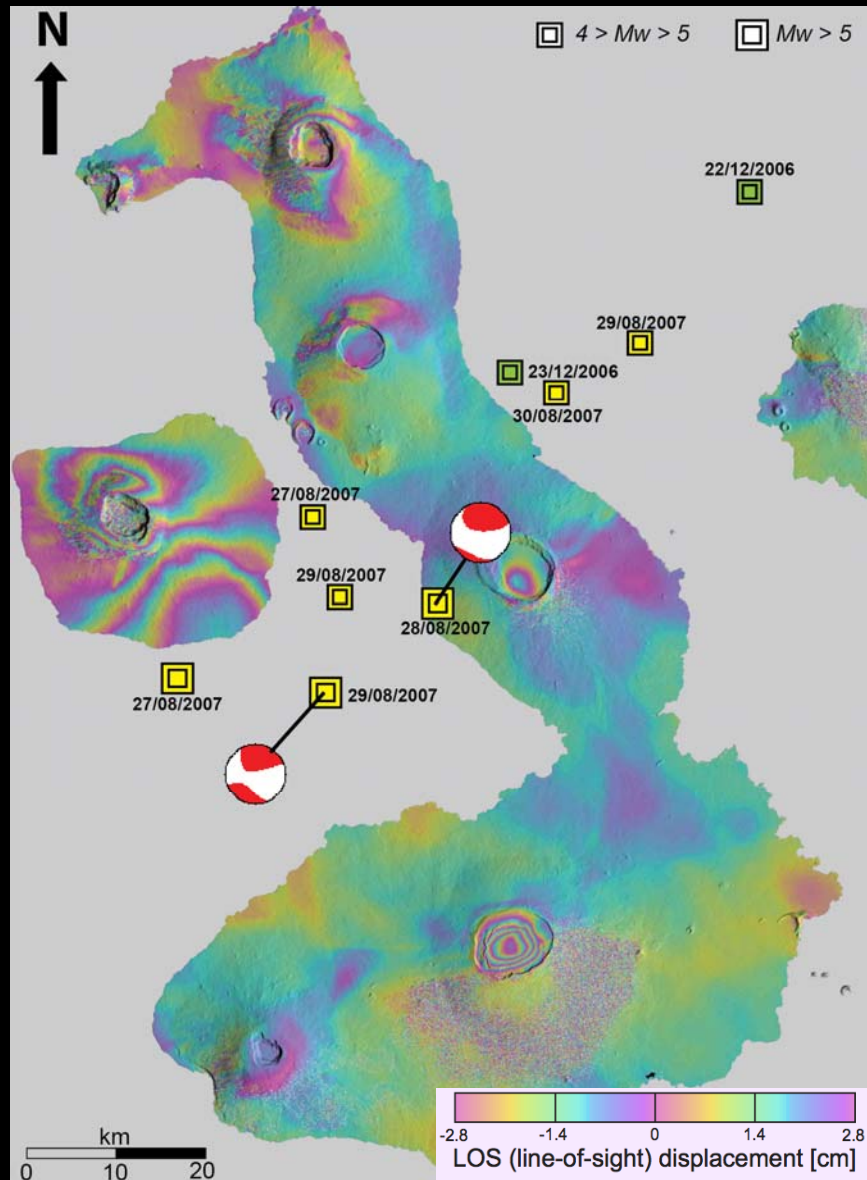
William W. Chadwick Jr • Sigurjon Jónsson •
Dennis J. Geist • Michael Poland • Daniel J. Johnson •
Spencer Batt • Karen S. Harpp • Andres Ruiz



Chadwick et al., 2010

27-30 August 2007 seismic swarm

7 major earthquakes (M_w 3.8 – 5.4)

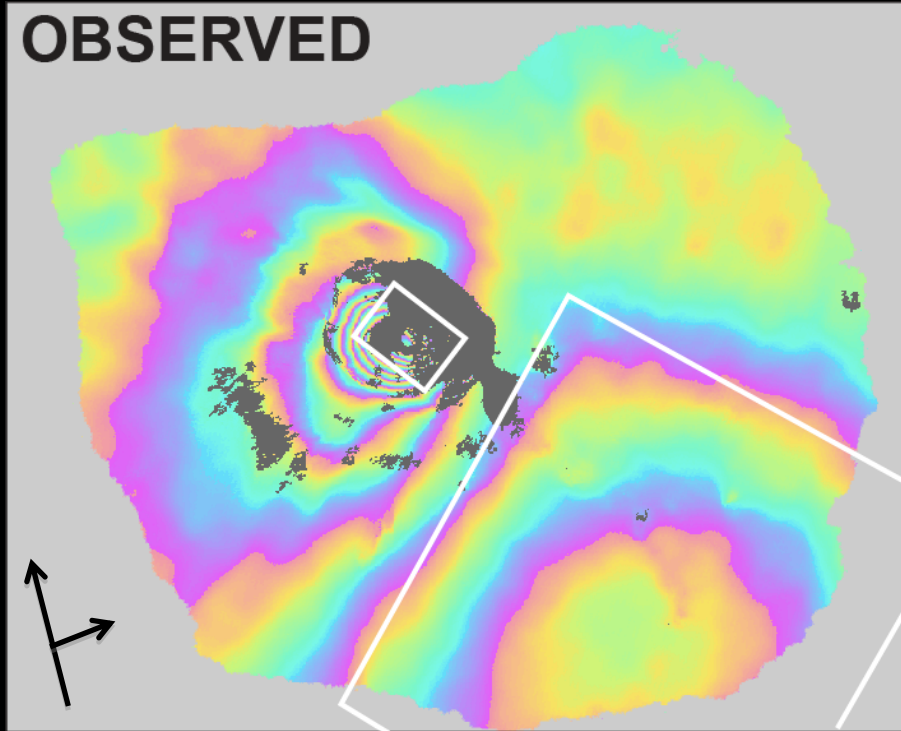


**Sill-intrusion and
summit deflation**

27-30 August 2007 seismic swarm

Sill-intrusion and summit deflation

OBSERVED



Asc. 12 (25/08/2007 – 29/09/2007)

Uniform opening sill

Planar dislocation [Okada, 1992]

Length: 18.00 km

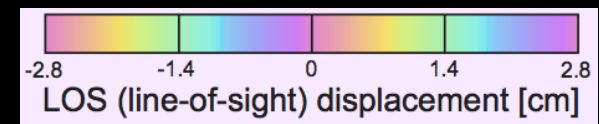
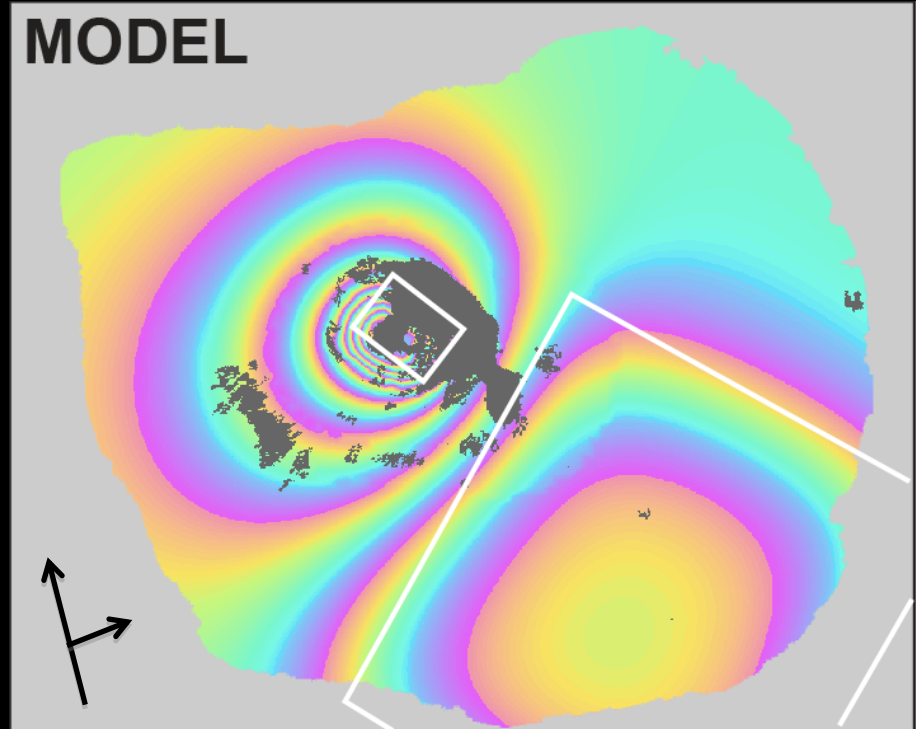
Width: 17.50 km

Depth: 5.86 km b.s.l.

Dip: $\sim 0^\circ$

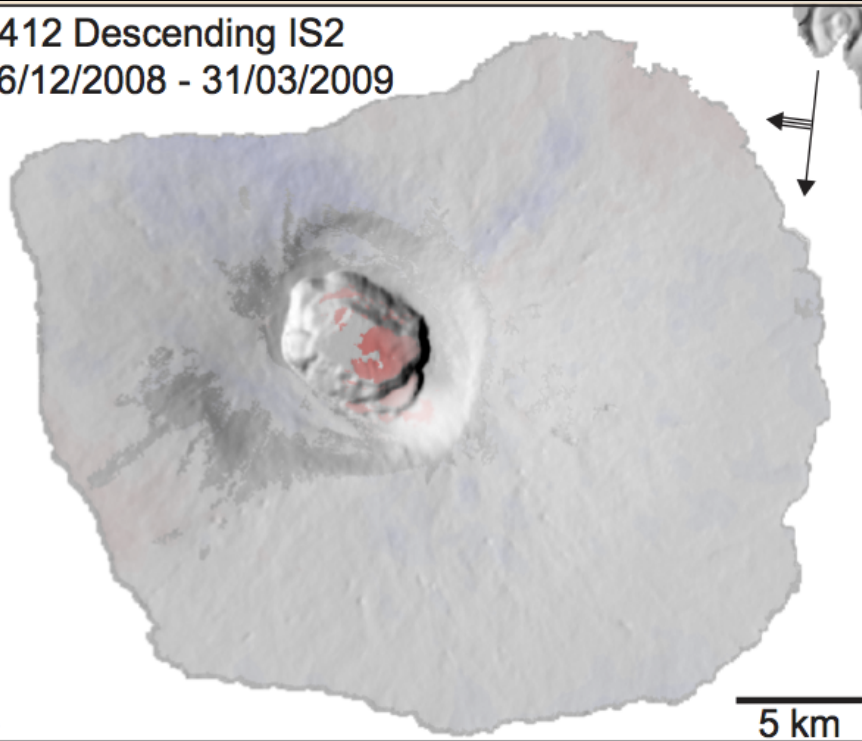
Strike: 115°

MODEL

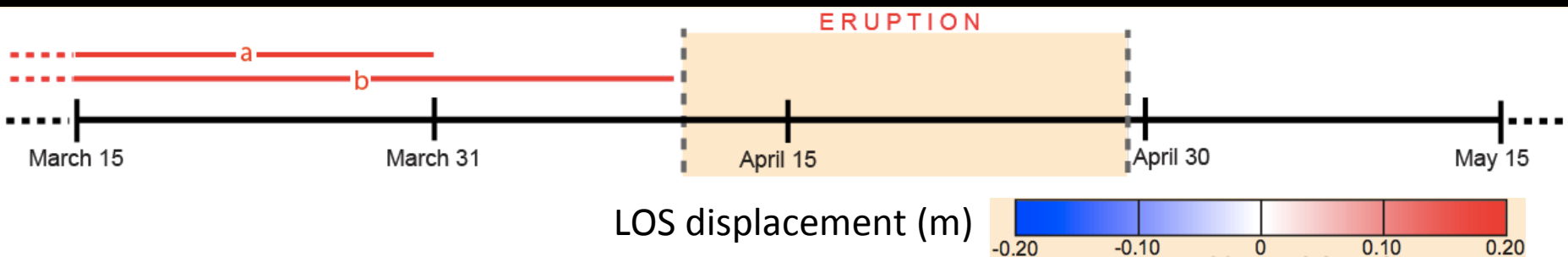
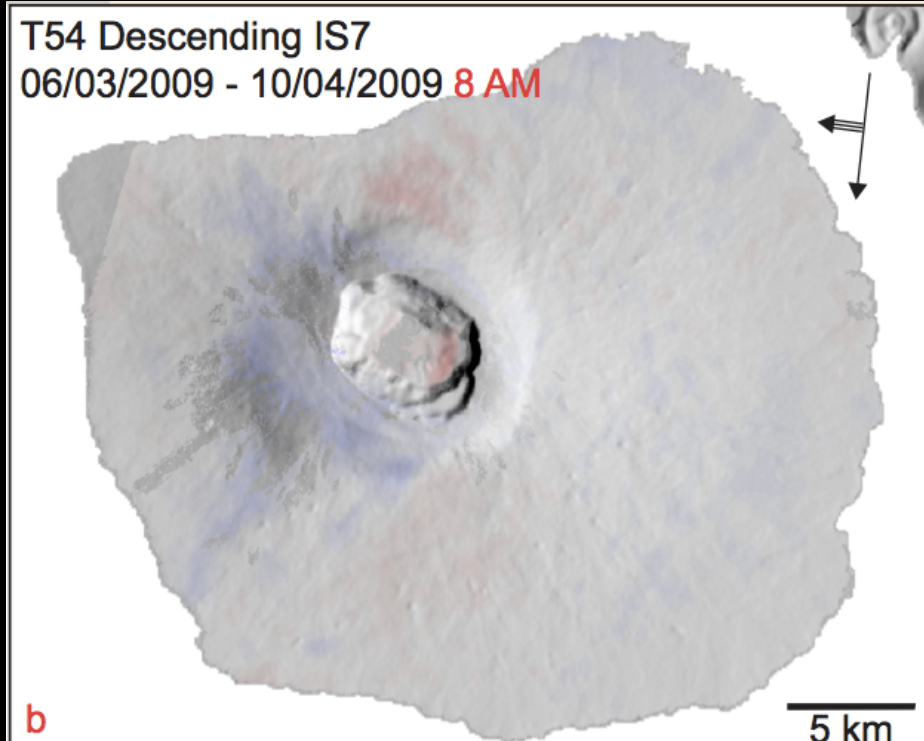


April 10th 2009 eruption (11 PM LT): *pre-eruptive deformation*

T412 Descending IS2
16/12/2008 - 31/03/2009



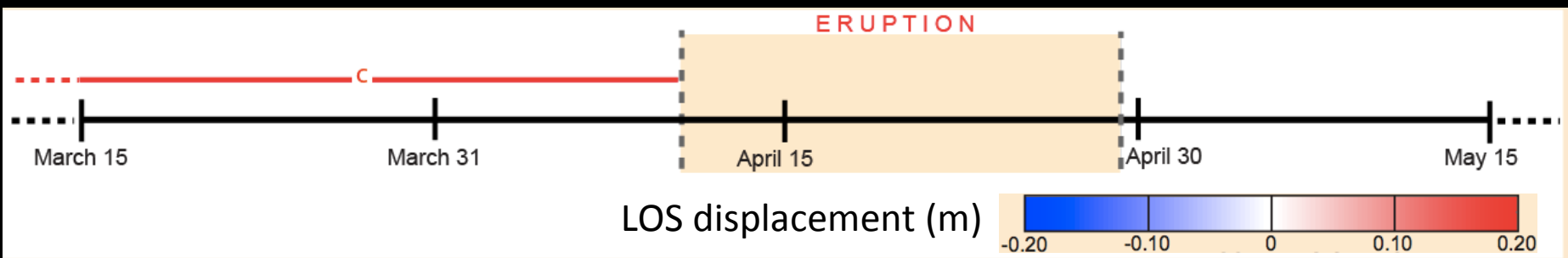
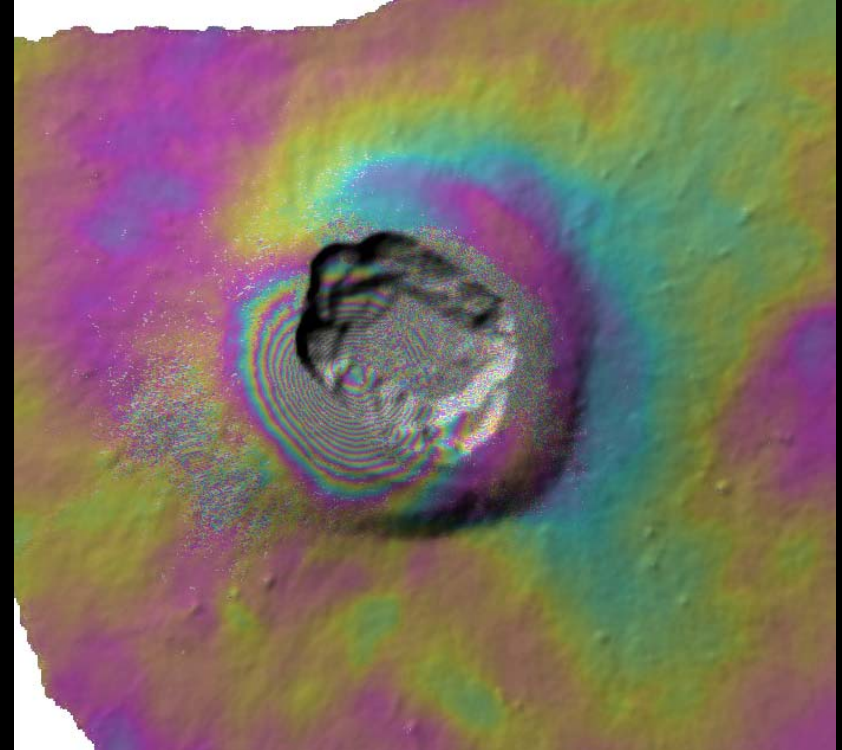
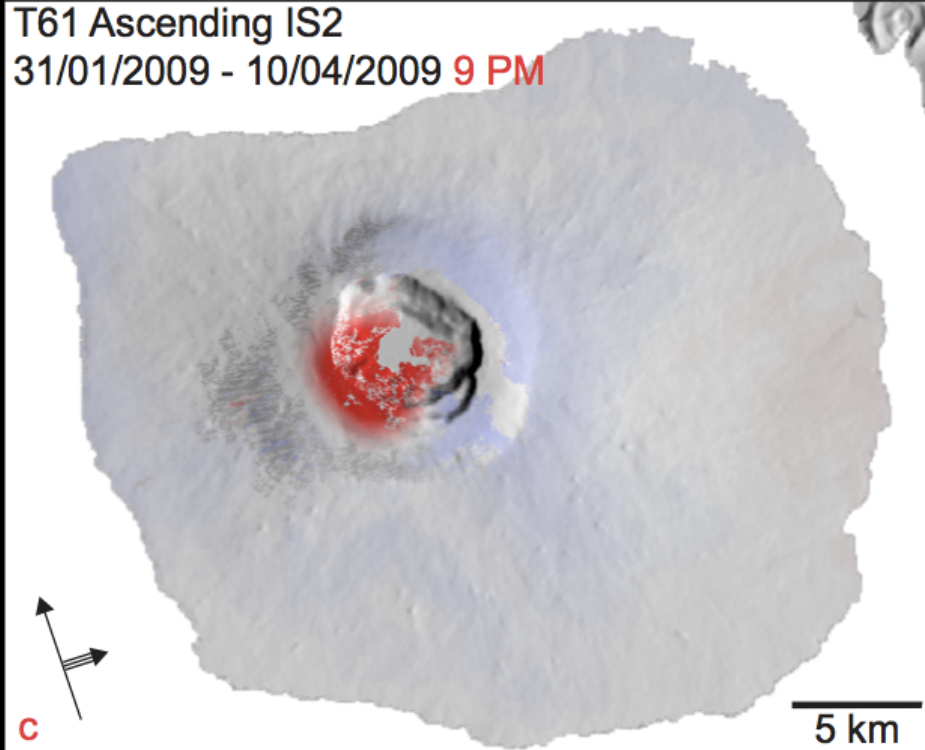
T54 Descending IS7
06/03/2009 - 10/04/2009 **8 AM**



April 10th 2009 eruption (11 PM LT): *Sheet intrusion (phase 1) April 10th 9 PM*

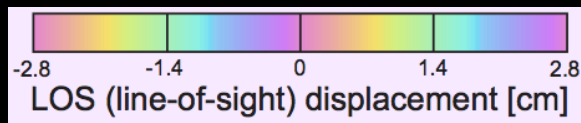
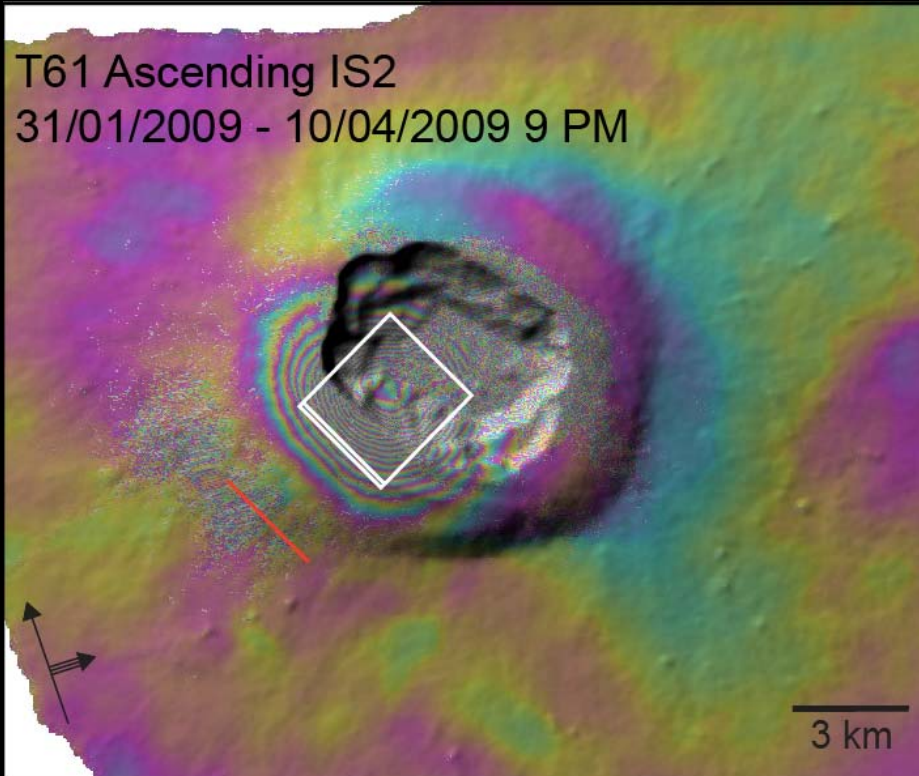
T61 Ascending IS2

31/01/2009 - 10/04/2009 9 PM



April 2009 eruption:

Sheet intrusion (phase 1) April 10th 9 PM



Planar dislocation [Okada, 1992]

Length: 2.56 km

Width: 2.76 km

Min depth: 0.83 km

Max depth: 1.73 km

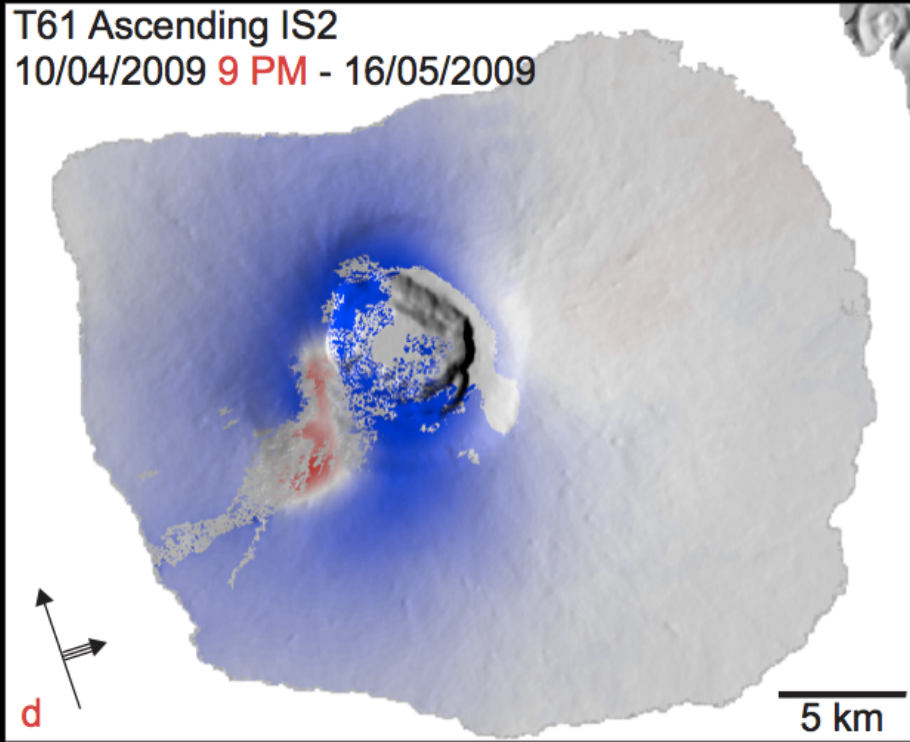
Dip: 19°

Strike: 130°

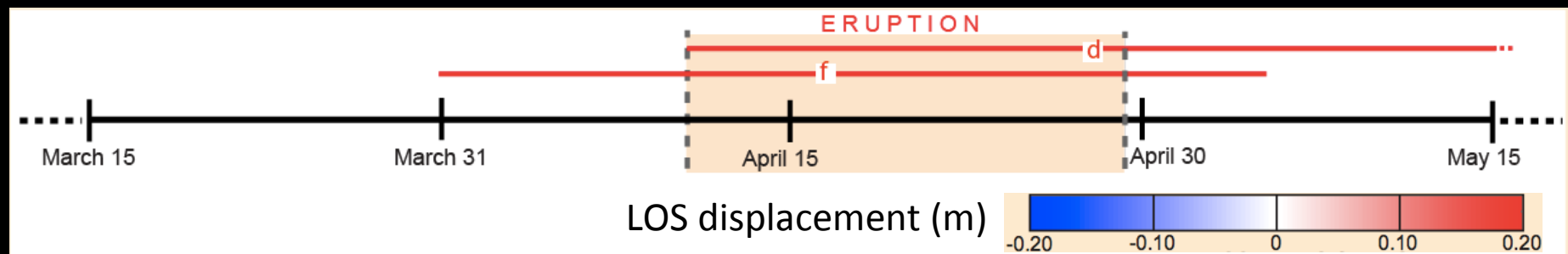
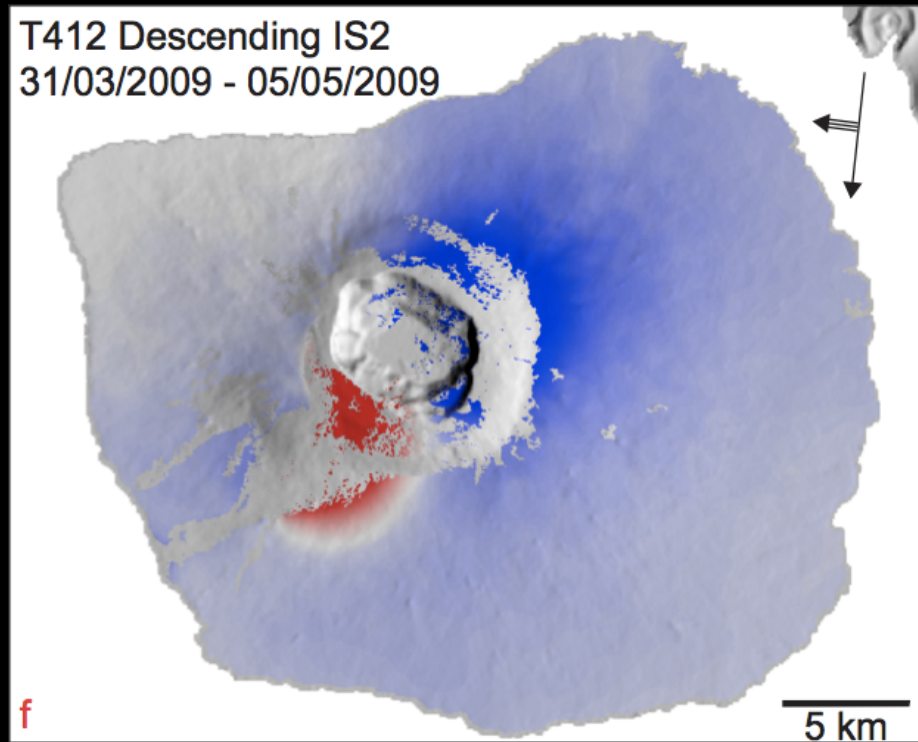
Opening: 0.62 m

April 2009 eruption: *Dike intrusion (phase 2)*

T61 Ascending IS2
10/04/2009 9 PM - 16/05/2009

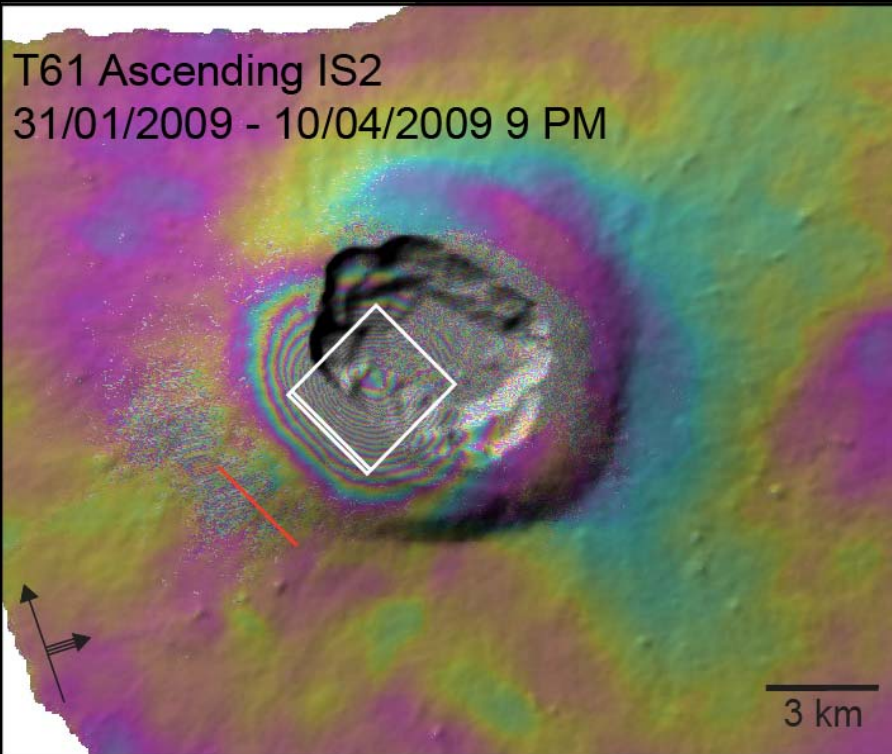


T412 Descending IS2
31/03/2009 - 05/05/2009

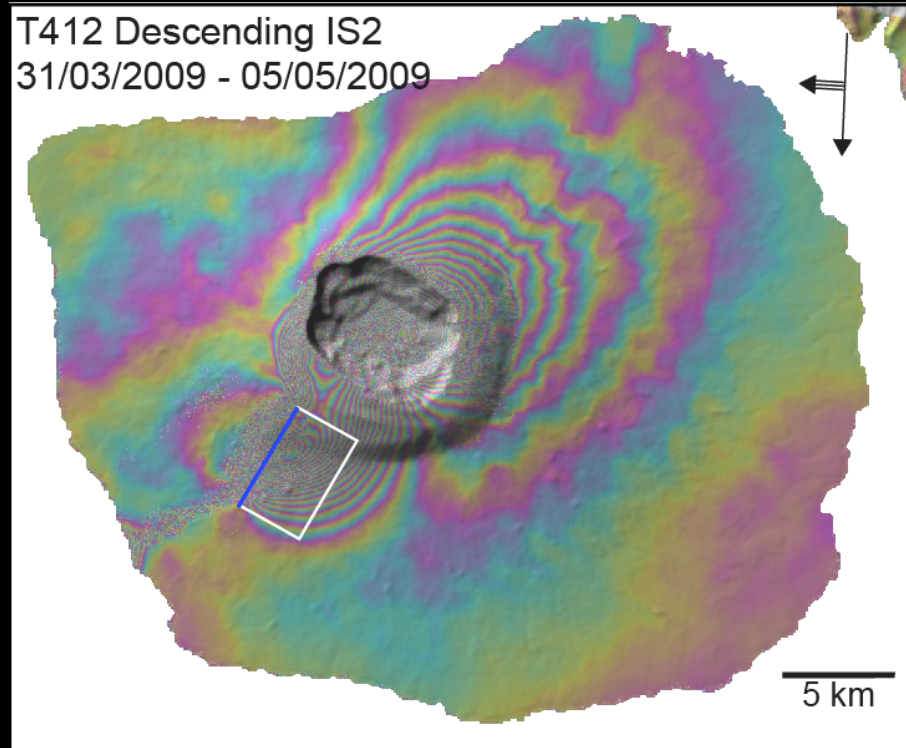


April 2009 eruption: *Dike intrusion (phase 2)*

T61 Ascending IS2
31/01/2009 - 10/04/2009 9 PM



T412 Descending IS2
31/03/2009 - 05/05/2009



Planar dislocation [*Okada, 1992*]

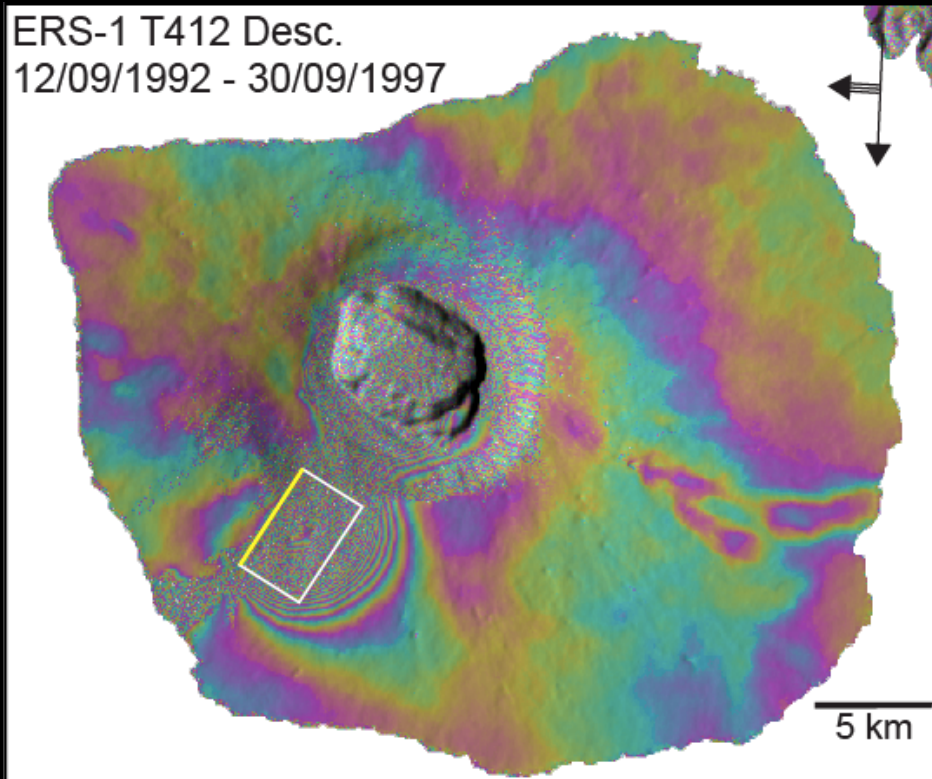
Length: 6.00 km
Min depth: 0.00 km
Dip: 31°
Opening: 0.49 m

Width: 3.00 km
Max depth: 1.50 km
Strike: 215°

January 1995 eruption:

Radial fissures

ERS-1 T412 Desc.
12/09/1992 - 30/09/1997



Jónnson et al., 1999

Shallow-dipping radial dike

Planar dislocation [*Okada, 1992*]

Length: 3.8 km

Width: 2.3 km

Min depth: 0.00 km

Max depth: 1.50 km

Dip: 34°

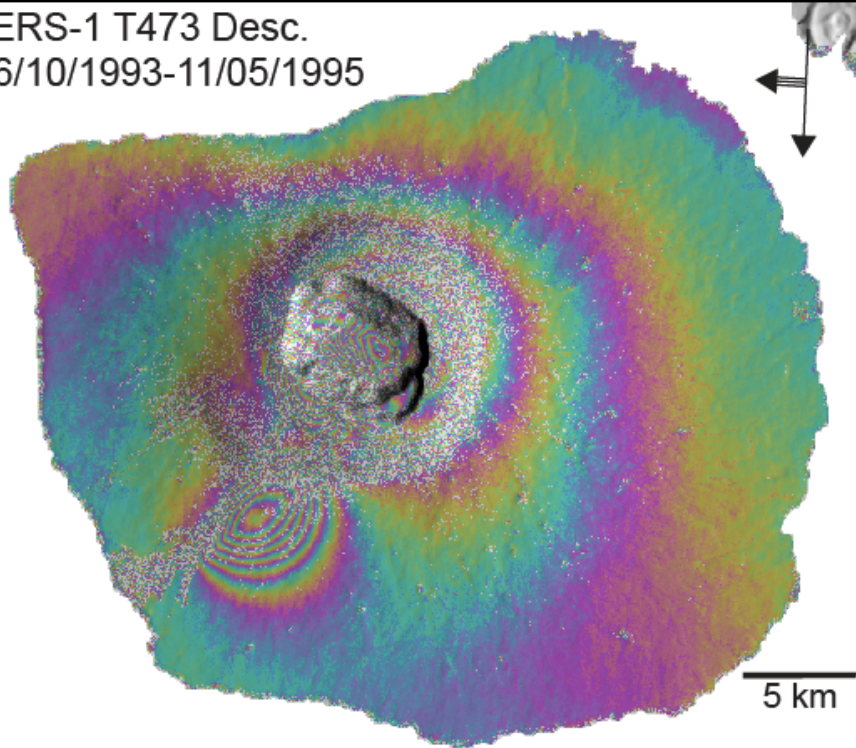
Strike: 227°

Opening: 0.86 m

1995 and 2009 "twin" eruptions

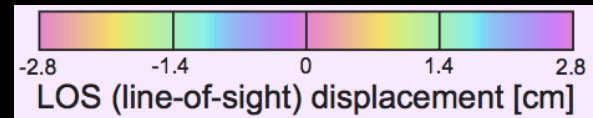
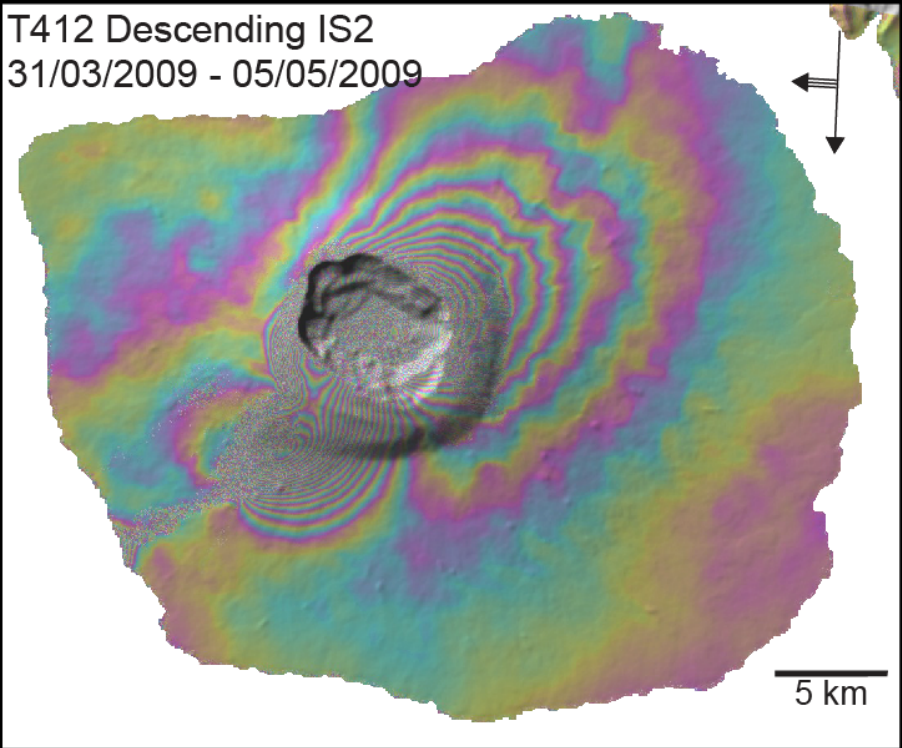
1995

JERS-1 T473 Desc.
16/10/1993-11/05/1995



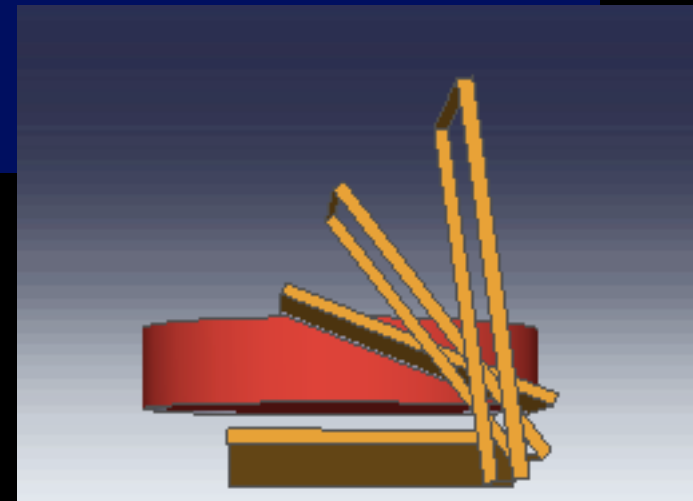
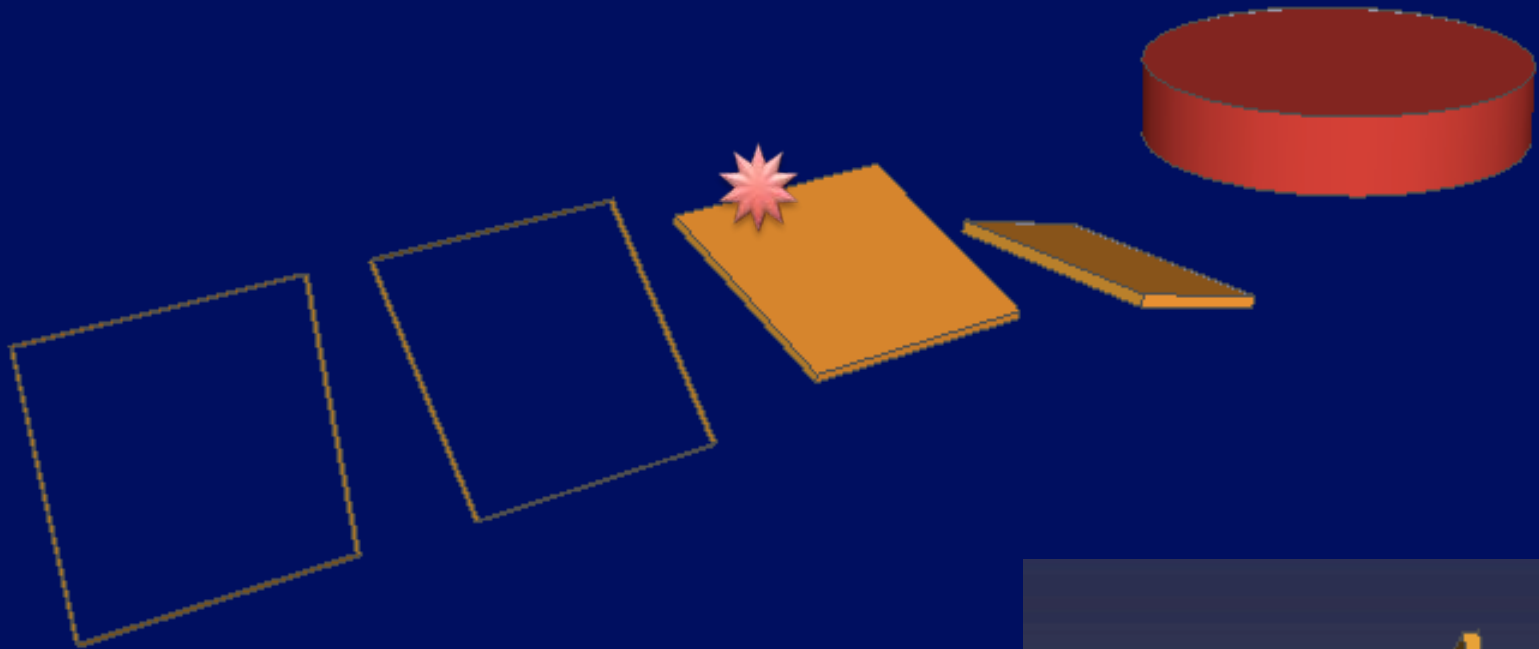
2009

T412 Descending IS2
31/03/2009 - 05/05/2009

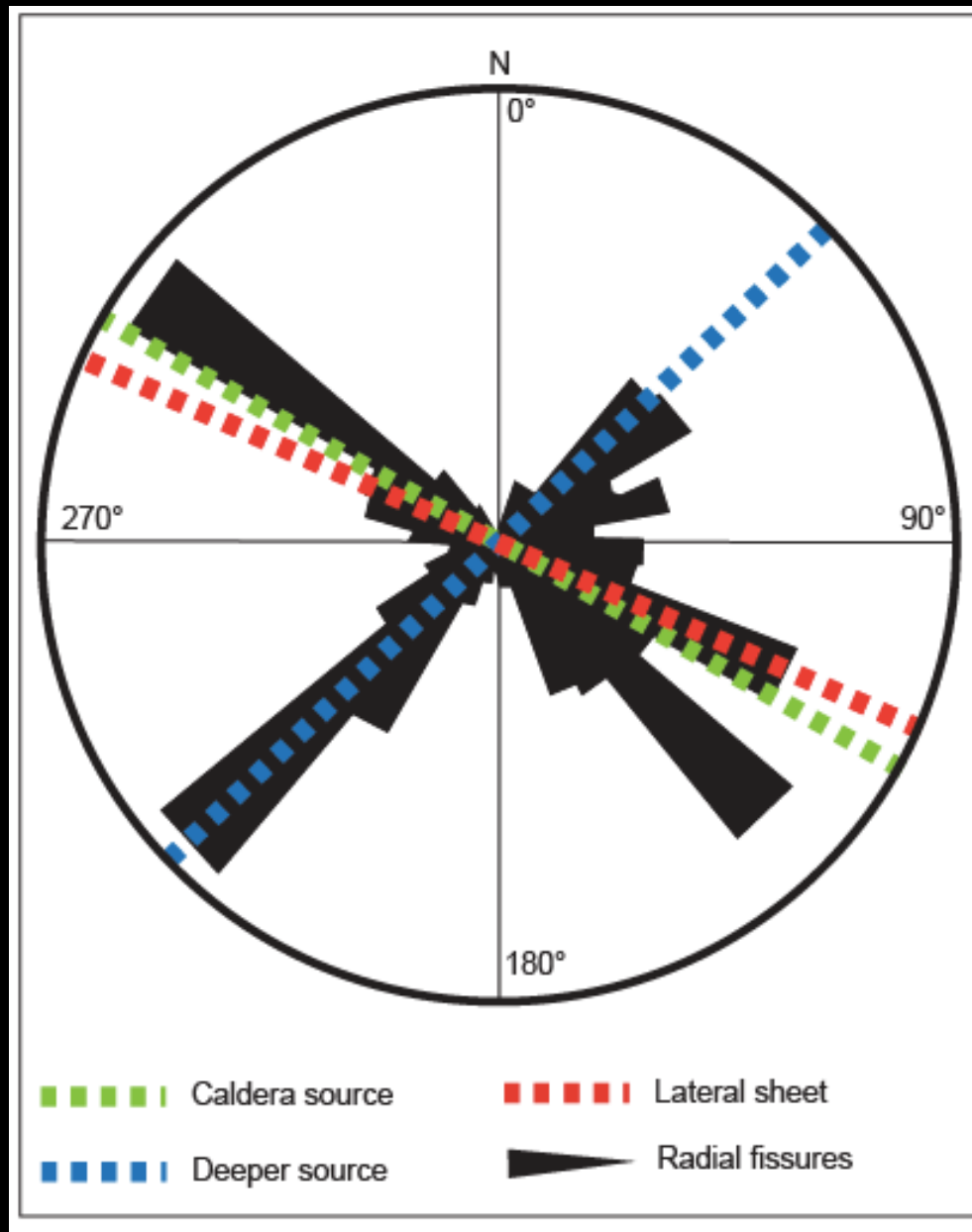


Radial dike rotation

Shallow magma reservoir



Structure orientation



SUMMARY

MAGMA STORAGE SYSTEM:

- “STACK” OF TWO MAGMA RESERVOIRS (0.8 KM – 5.4 KM)
- VERTICAL CONNECTIONS

ERUPTIONS:

- ALTERNATION BETWEEN RADIAL AND CIRCUMFERENTIAL DIKES
- SIGNIFICANT VARIATIONS IN THE STATE OF STRESS AND FEED-BACK
- SPATIAL ROTATION OF RADIAL DIKES → LOW DIP ANGLE WHEN THEY INTERCEPT THE SURFACE

SEISMICITY:

- CAN TRIGGER LATERAL INTRUSIONS → RAPID DRAINAGE AND CALDERA COLLAPSE (e.g. 1968)

Since February 2011

Since February 2011



→ **FRINGE 2011 WORKSHOP**

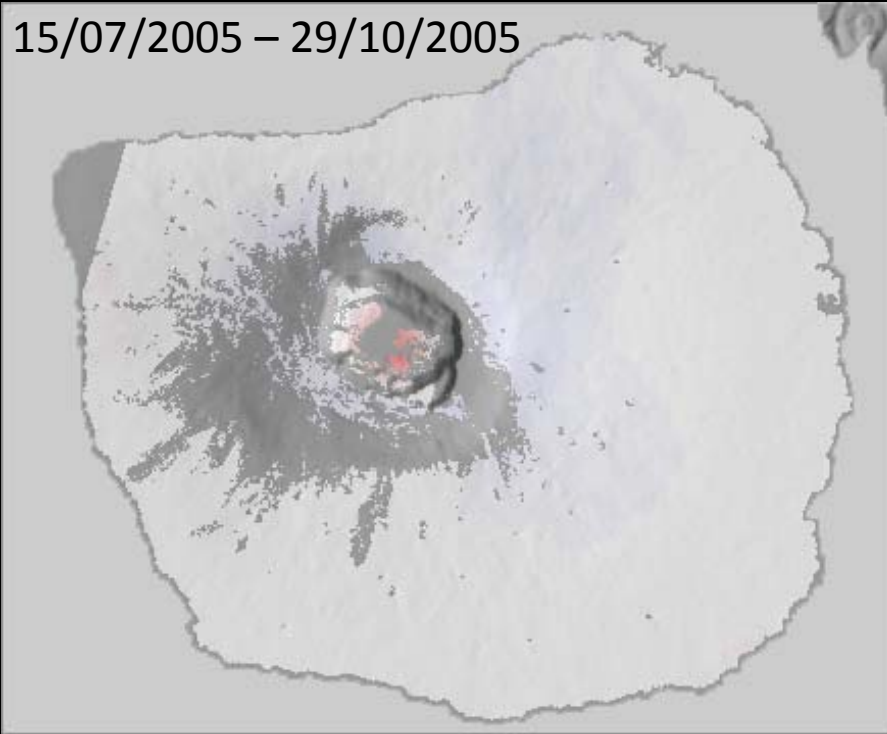
GRAZIE!
(thank you!)

→ FRINGE 2011 WORKSHOP

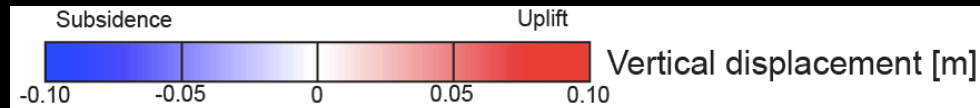
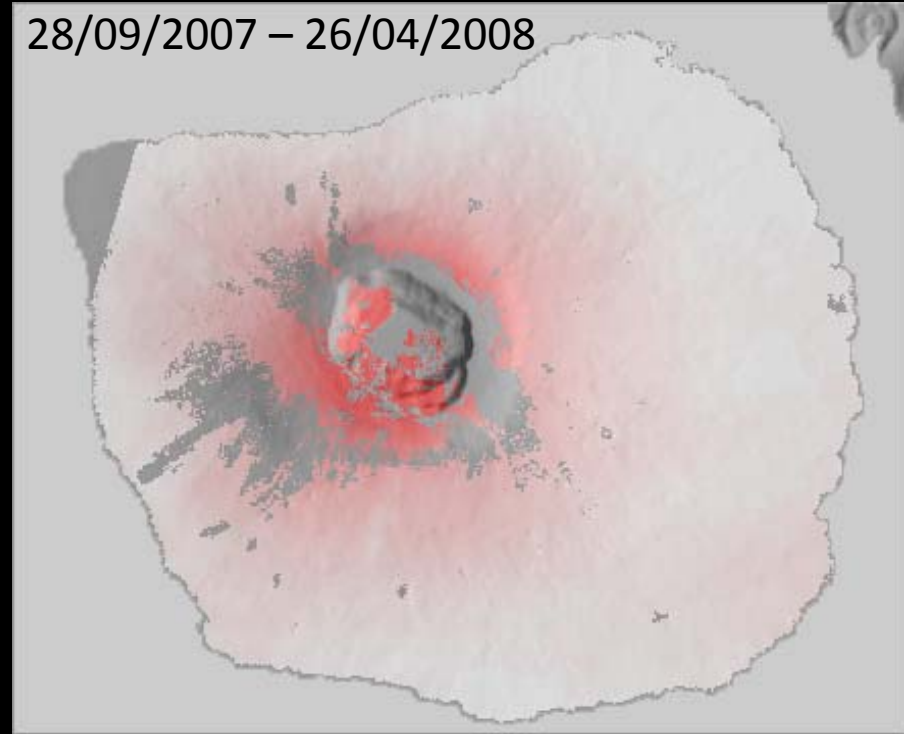
extras

INFLATION: 2 types

15/07/2005 – 29/10/2005



28/09/2007 – 26/04/2008



Intra-caldera:

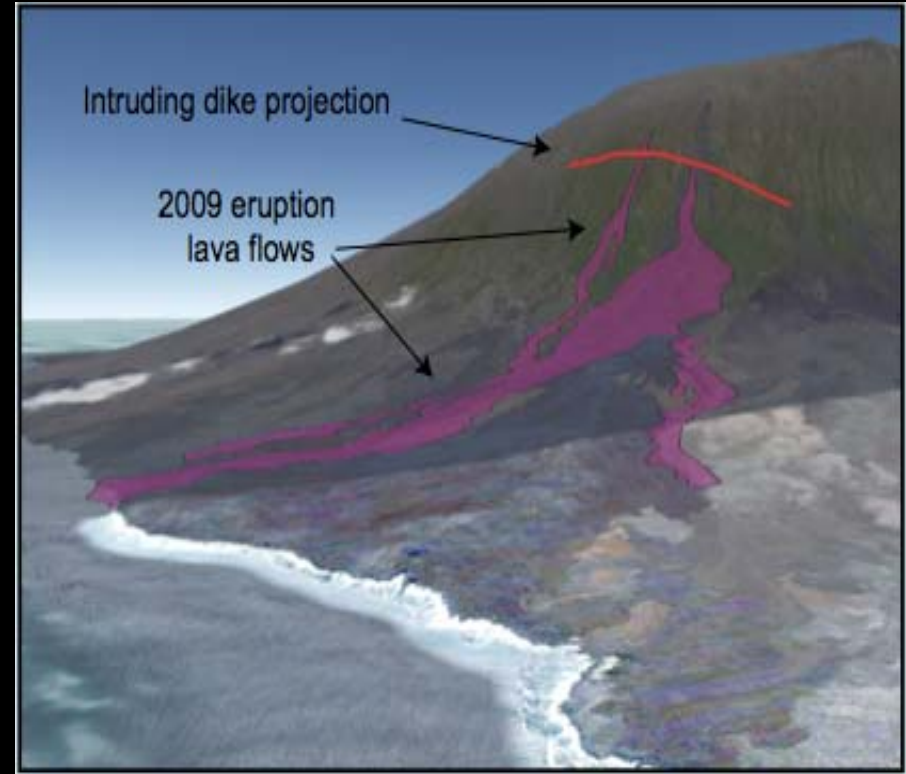
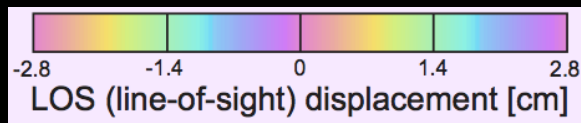
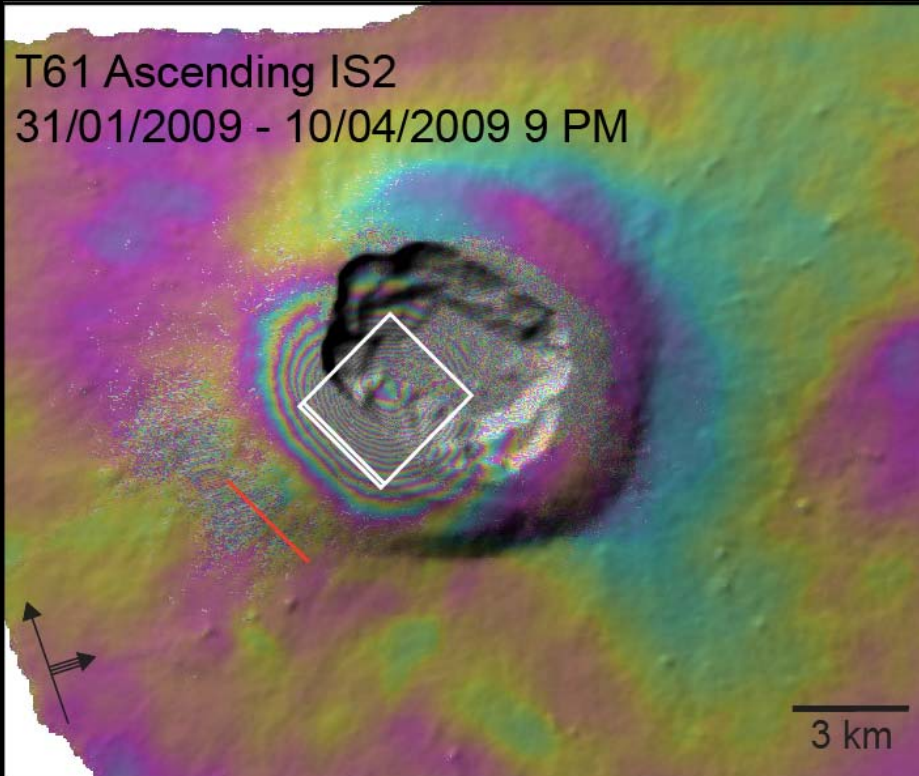
- long-term
- almost continuous
- high gradient

Extended:

- short-term
- discontinuous
- Low gradient

April 2009 eruption:

Sheet intrusion (phase 1) April 10th 9 PM



Planar dislocation [*Okada, 1992*]

Length: 2.56 km

Min depth: 0.83 km

Dip: 19°

Opening: 0.62 m

Width: 2.76 km

Max depth: 1.73 km

Strike: 130°

SBAS TIME SERIES: Envisat 02/2003 – 09/2010

