Part IV:
InSAR Applications

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http://volcanoes.usgs.gov/activity/methods/insar/zhong.php

Acknowledgement

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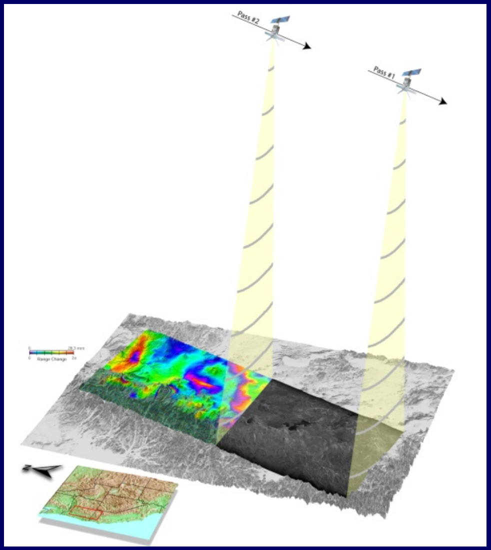
- Original SAR data are copyrighted ESA, CSA, JAXA , or DLR

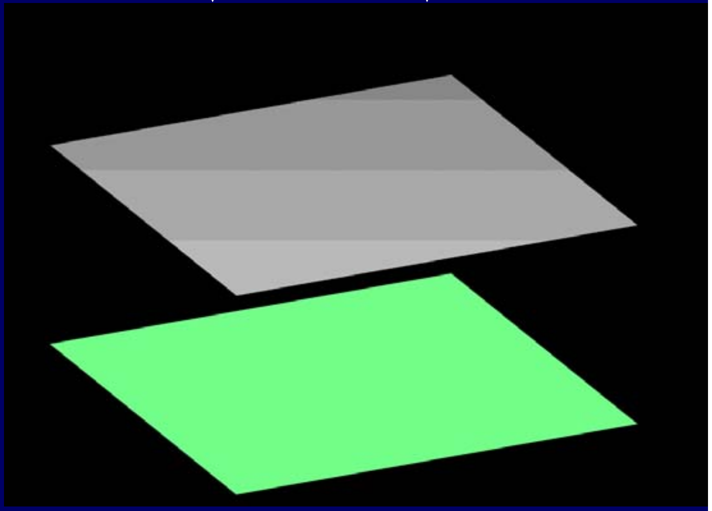
About SAR/InSAR

• SAR – all-weather day and night operational imaging capability, sensitive to terrain slope, surface roughness and dielectric constant.

• Interferometric synthetic aperture radar (InSAR) combines phase information from two or more radar images of the same area acquired from similar vantage points at different times to produce an interferogram.

• The interferogram, depicting range changes between the radar and the ground, can be further processed with a digital elevation model (DEM) to image ground deformation at a horizontal resolution of tens of meters over areas of ~100 km x 100 km with centimeter to sub-centimeter precision under favorable conditions.





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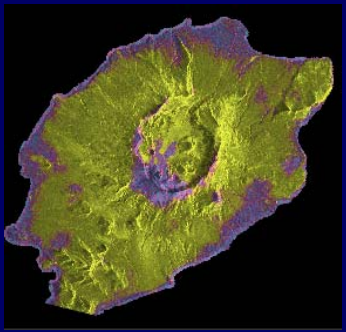
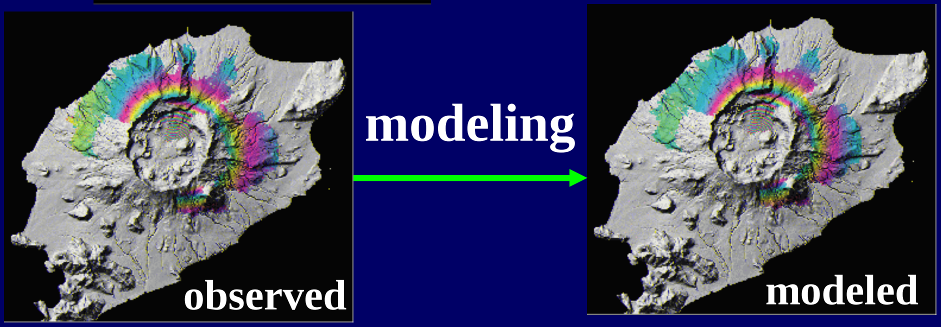
InSAR Products

- SAR intensity images -
  - terrain slope
  - roughness
  - dielectric constant

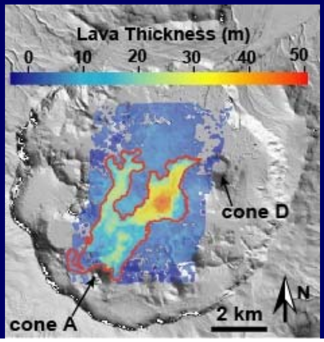
- InSAR coherence image -
  - change detection



- InSAR deformation image -
  - deformation & modeling

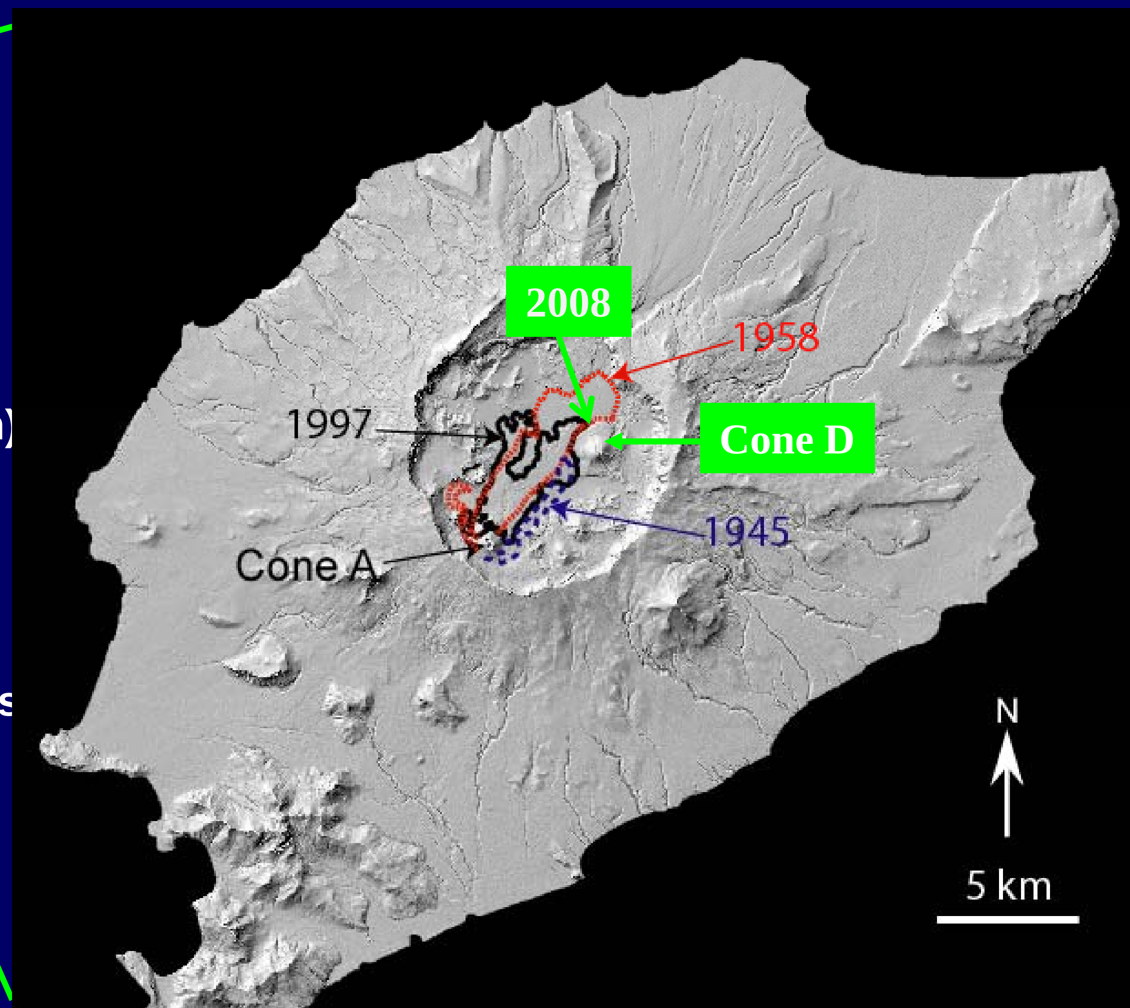


- InSAR DEM



Okmok Volcano

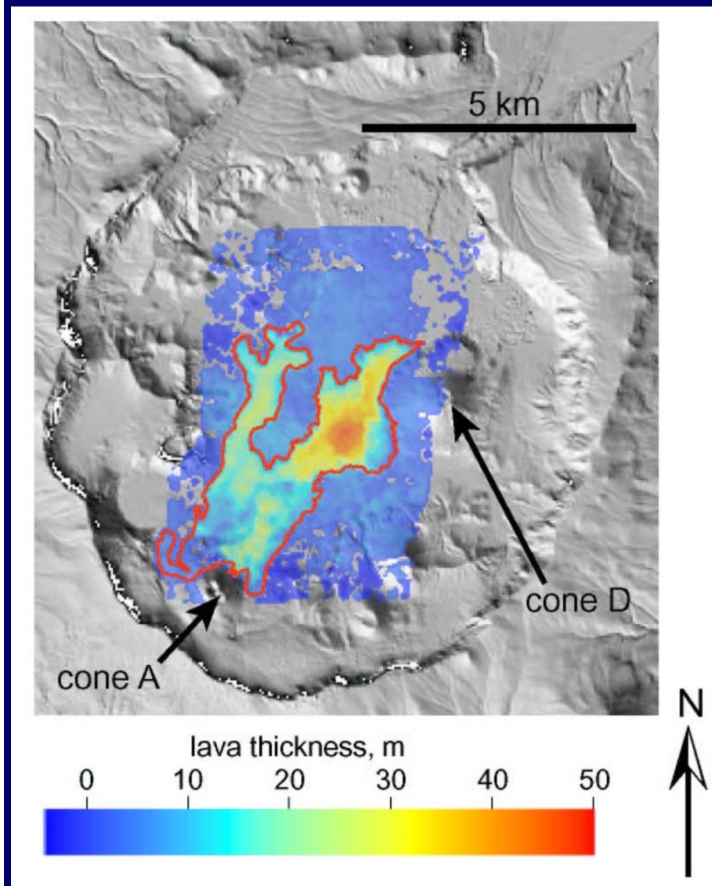
- Shield volcano
- Caldera formed 2050 years ago
- ~10 minor explosive eruptions (ash) in 20th century
- 3 large effusive eruptions (basaltic flows) in 1945, 1958 and 1997 from Cone A
- Hydrovolcanic eruption, July-Augus 2008, from near Cone D

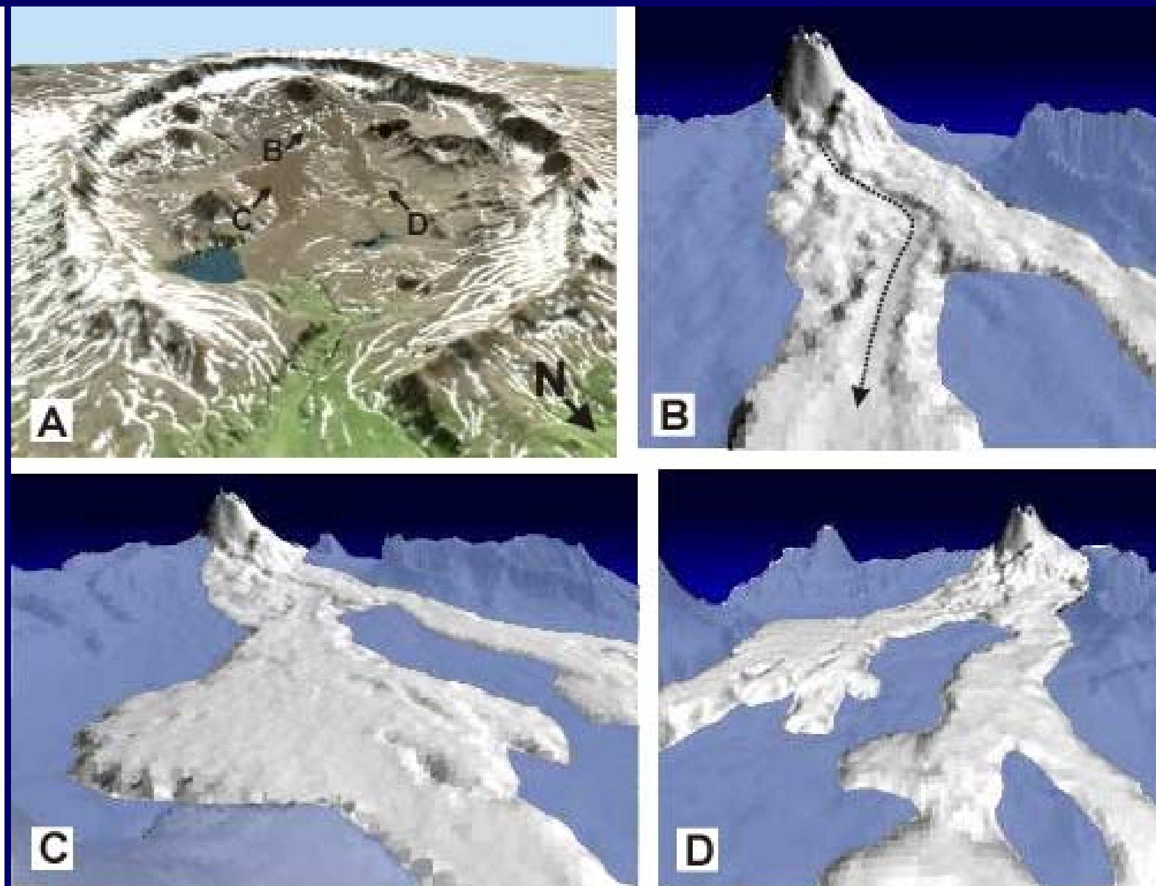


Lu et al., EOS, 1998
Lu et al., JGR, 2000
Mann et al., JGR, 2002
Lu et al., IEEE TGRS, 2003
Lu et al., JGR, 2005
Lu et al., JGR, 2010
Lu & Dzurisin, JGR, 2010

Imaging 1997 Eruption Volume

3-D Lava Thickness Map
Okmok Volcano, AK

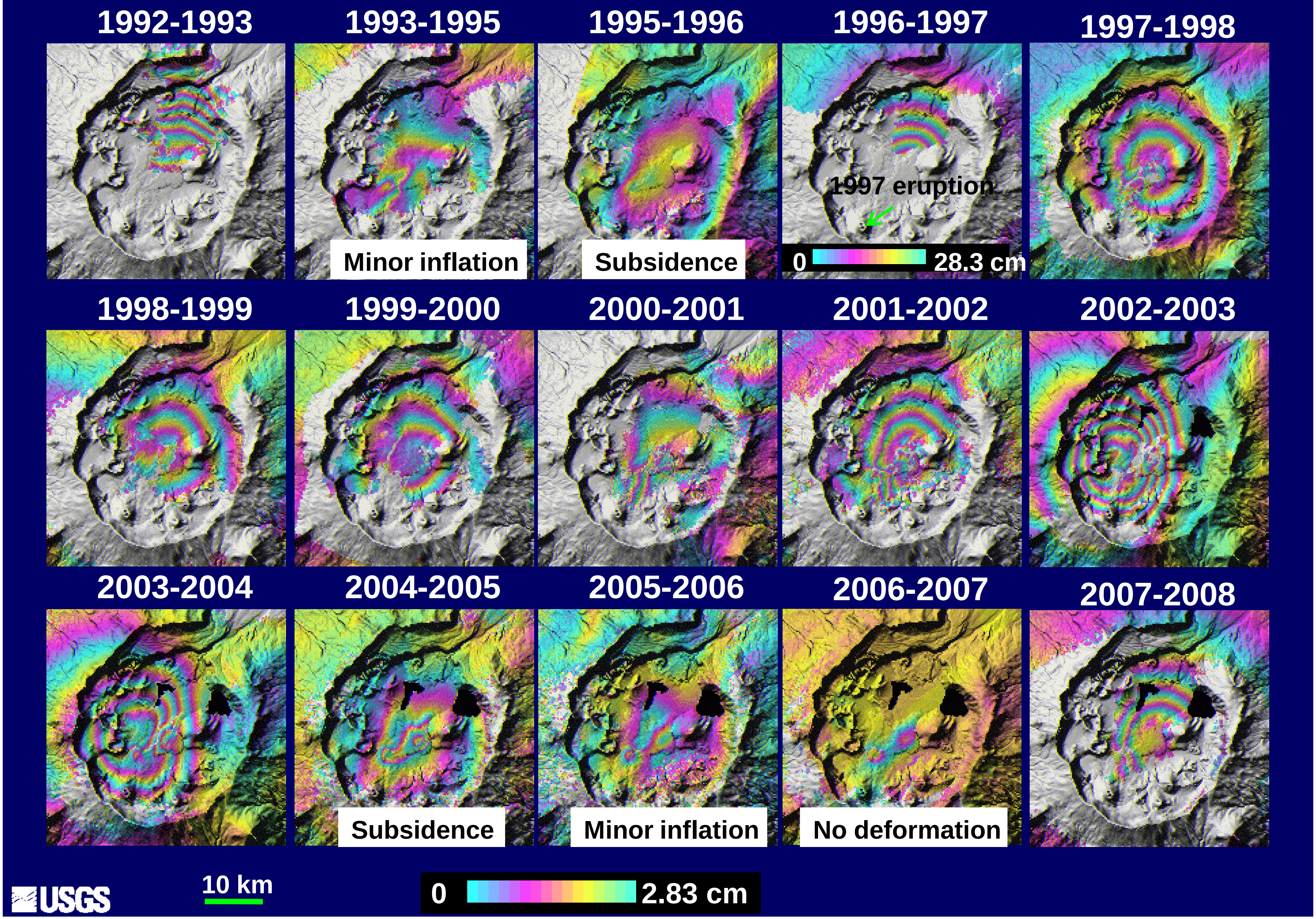




1997 eruption of Okmok Volcano

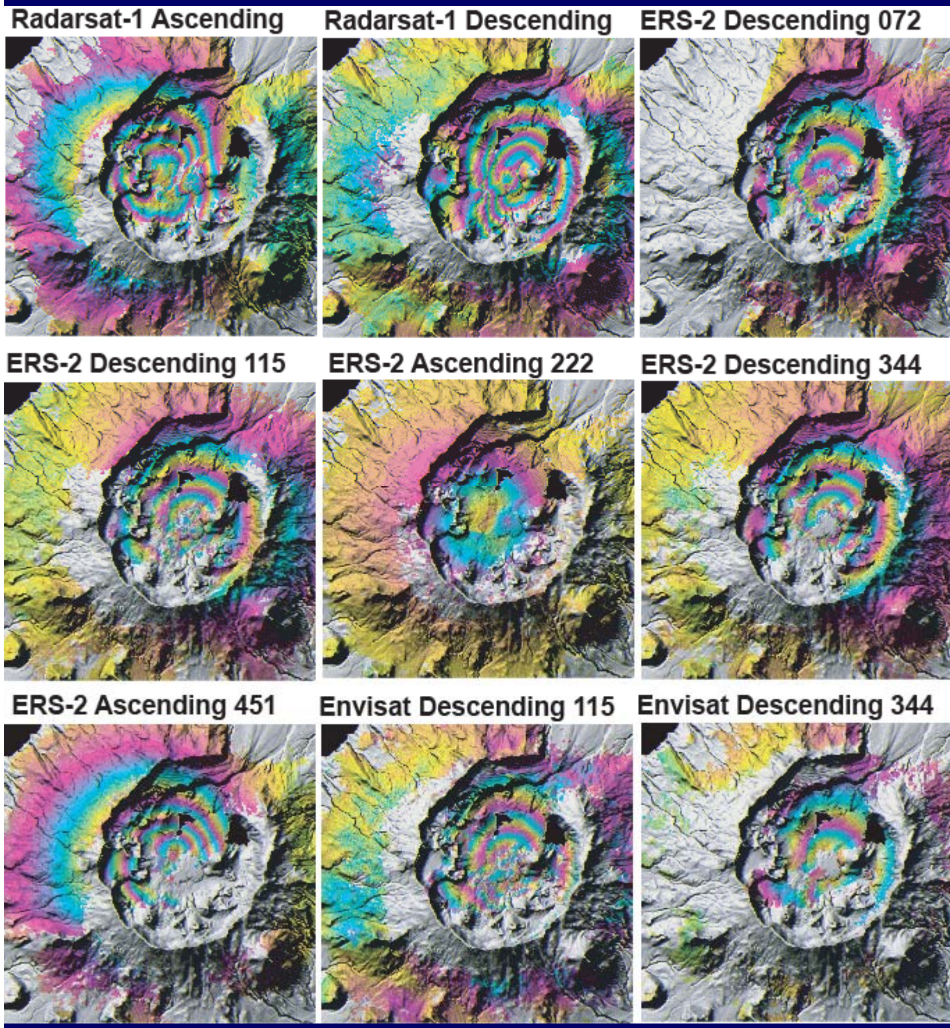
Lu et al., 2003; Patrick et al., 2003

Deformation of Okmok volcano 1992-2008

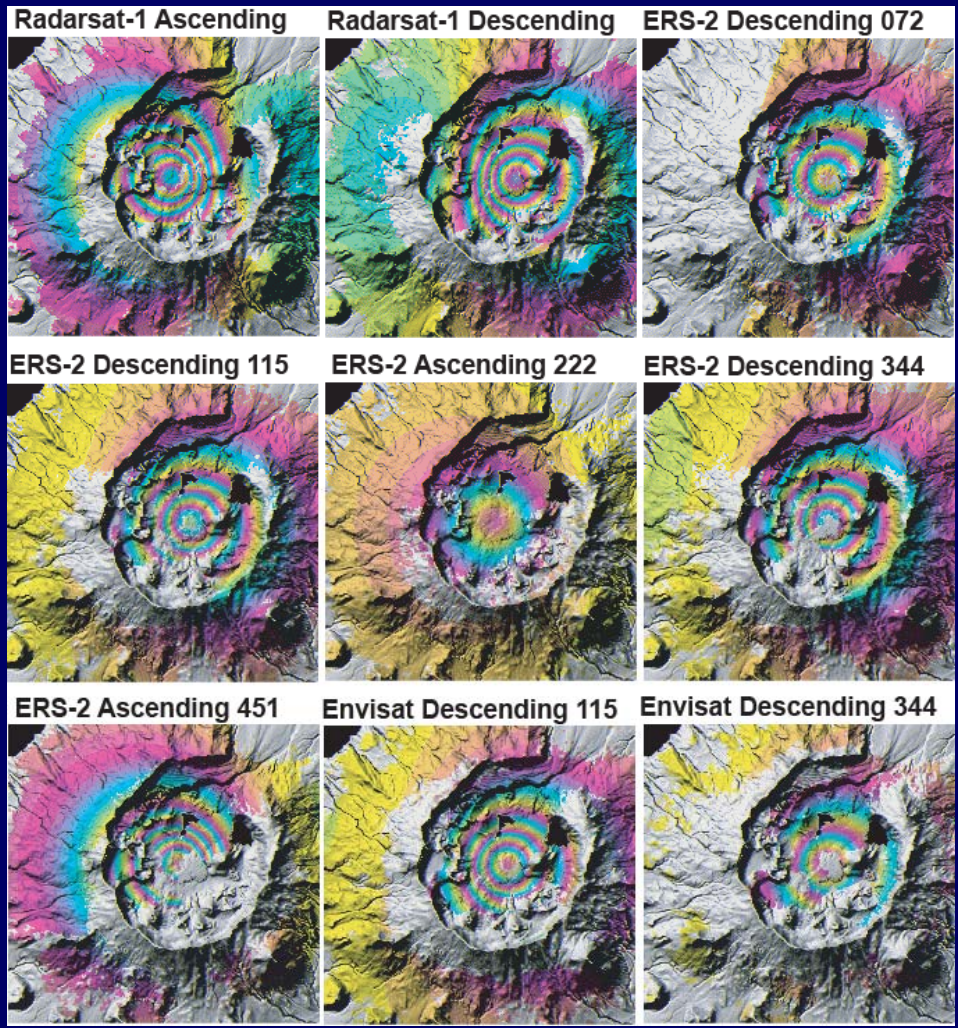


Modeling – Mogi source

Observed (different tracks)

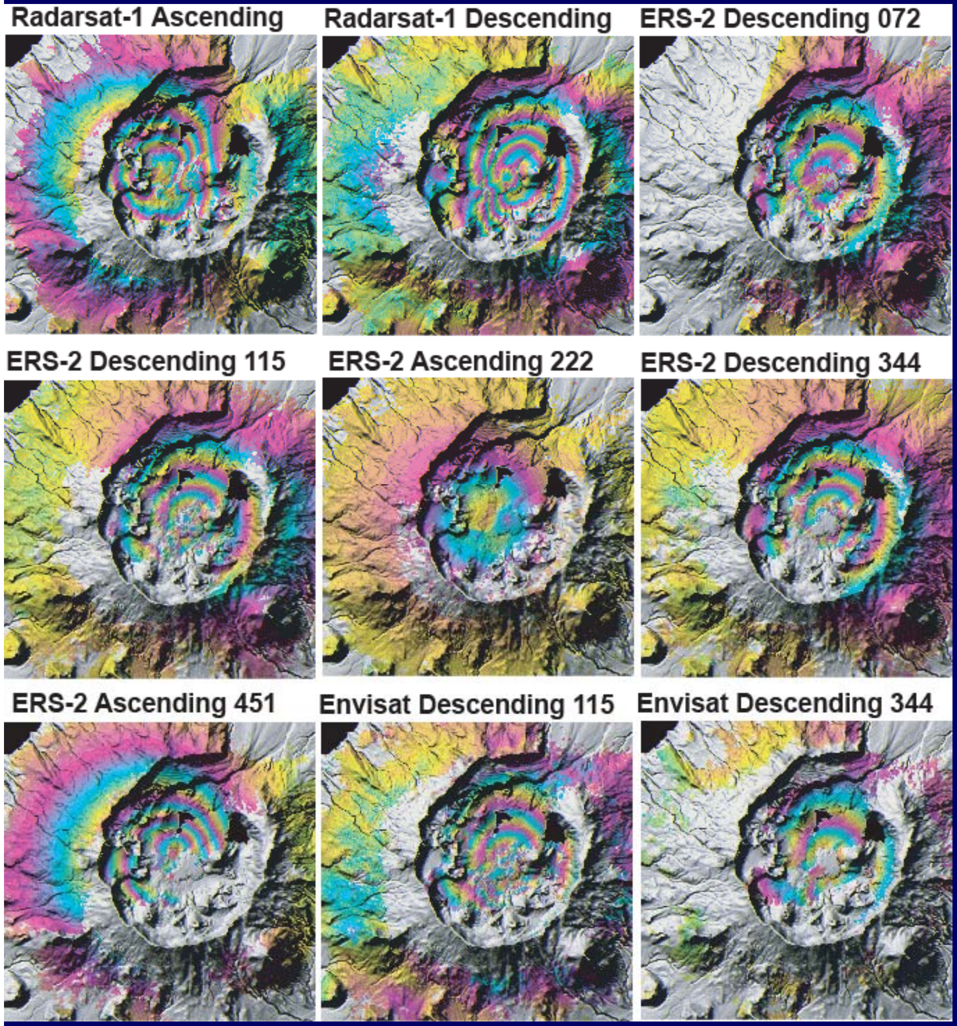


Modeled (Mogi)

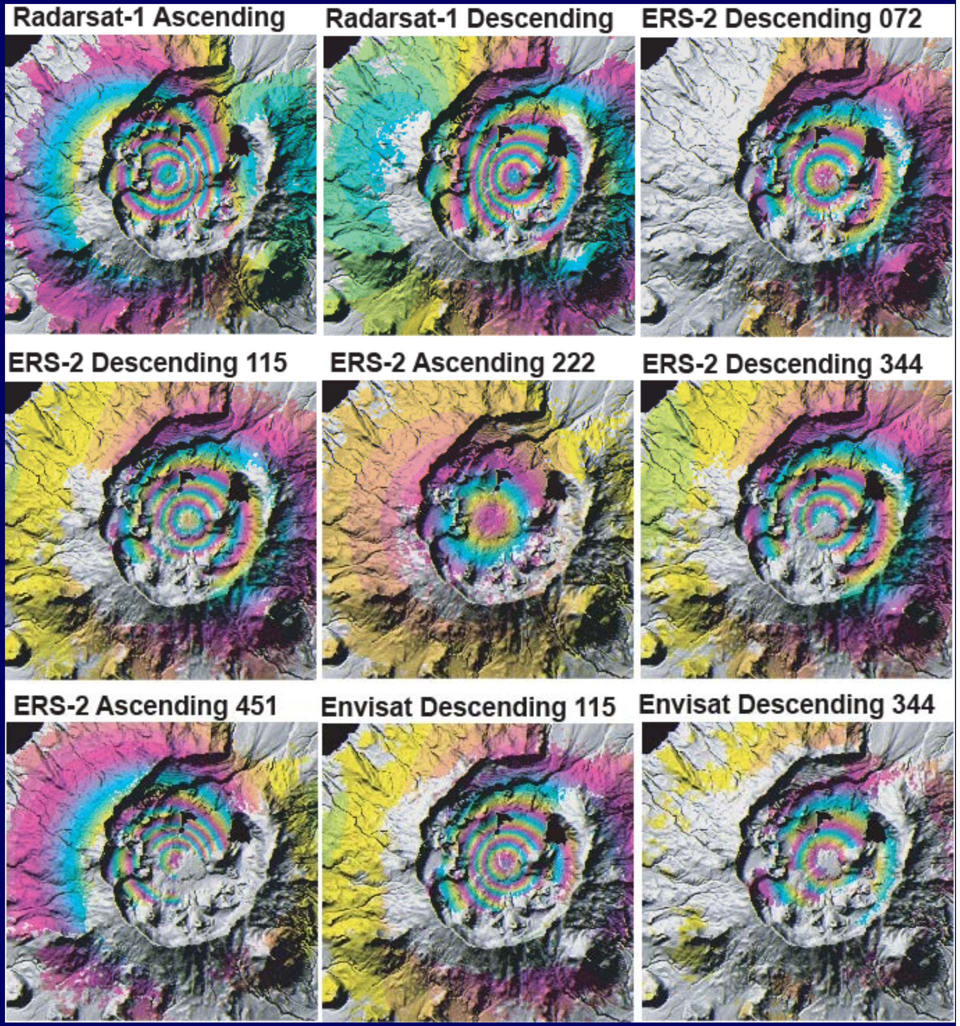


Modeling – Prolate spheroid source

Observed (different tracks)



Modeled (Prolate spheroid)

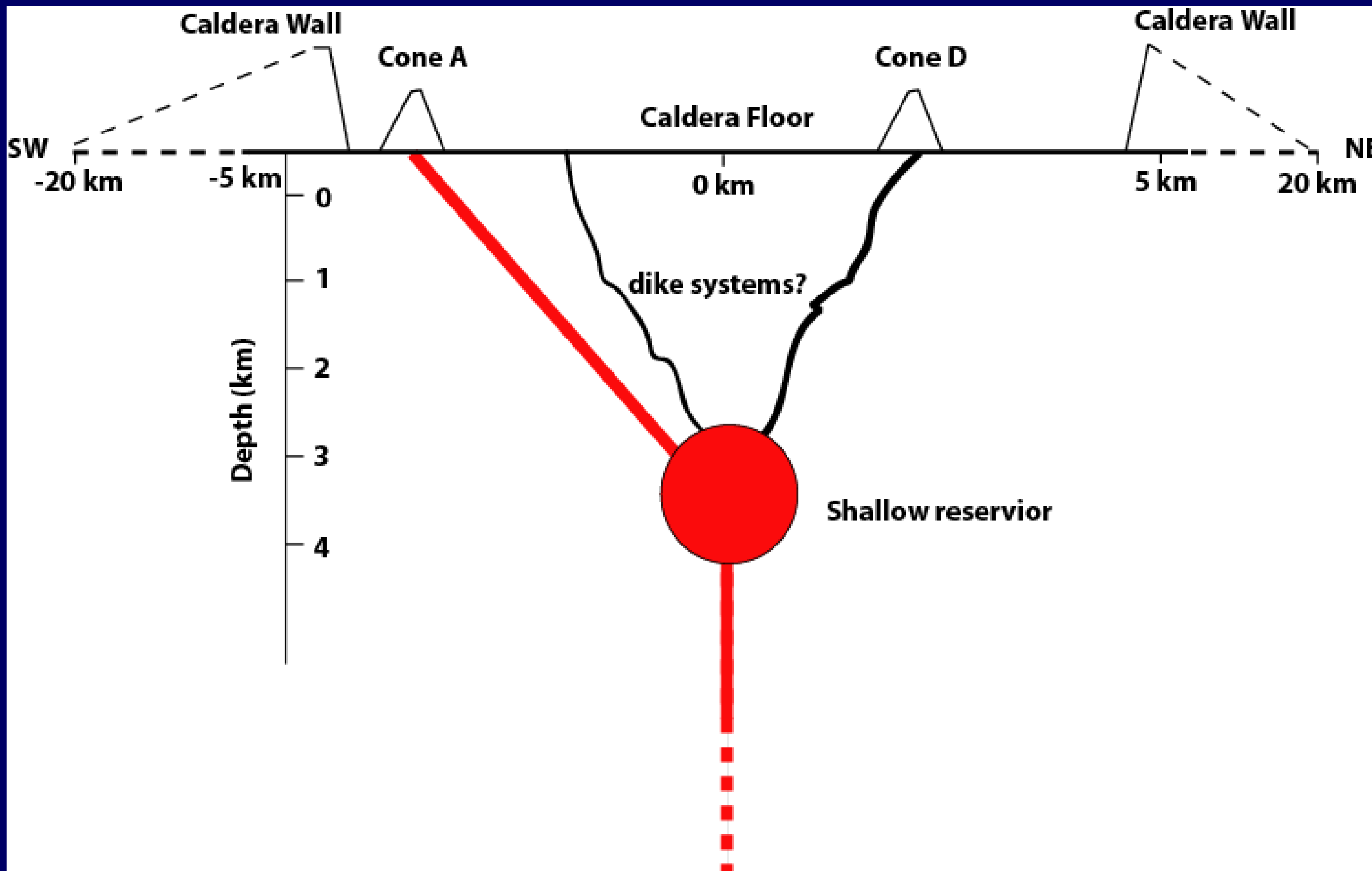


Mogi vs Prolate Spheroid

		X (km)	Y (km)	Z (km)	Major-axis (km)	Minor-axis (km)	Best RMSE (mm)
InSAR images are individually modeled	**Mogi**	20.51±0.13	21.80±0.07	2.78±0.28	NA	NA	NA
	Spheroid	20.48±0.26	21.85±0.18	3.09±0.46	2.08±1.08	1.99±1.02	NA
InSAR images are jointly modeled	**Mogi**	20.50±0.02	21.80±0.02	3.08±0.05	NA	NA	3.5
	Spheroid	20.48±0.04	21.80±0.05	3.05±0.11	2.01±0.34	1.94±0.35	3.5

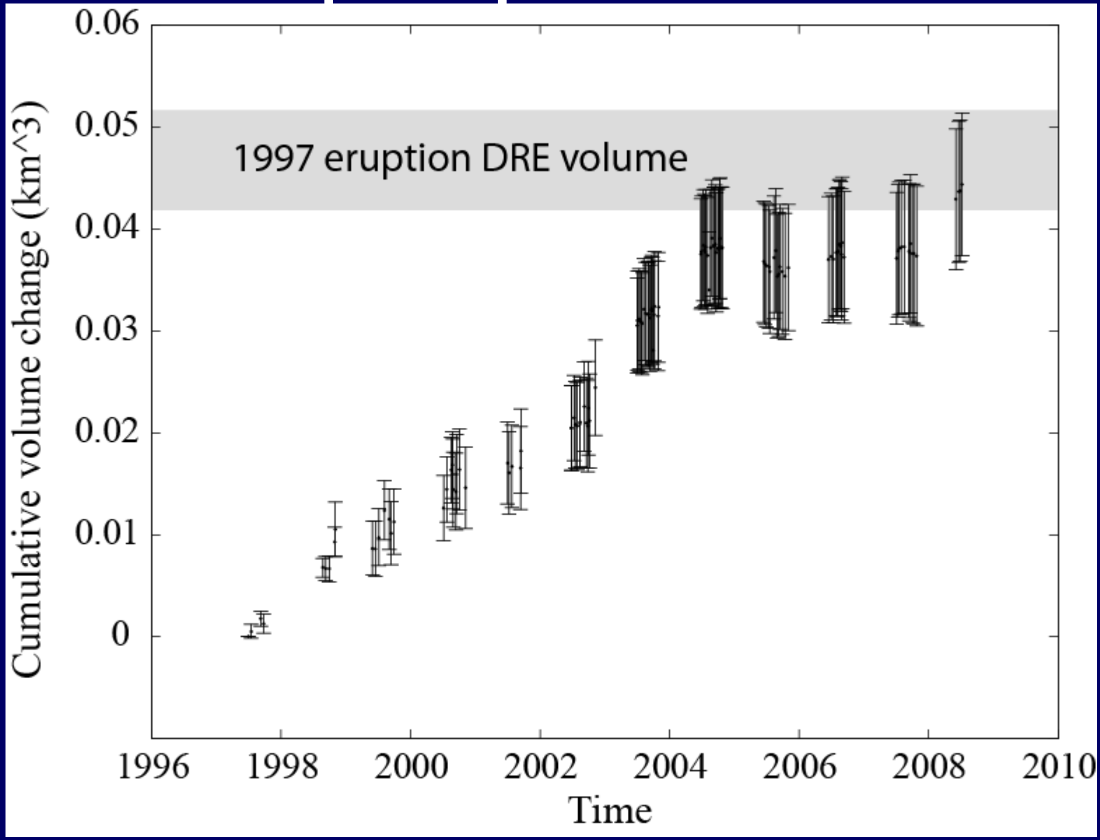
- **A Mogi point pressure source or a finite sphere with a radius of 1 km provides a good fit to the time-series deformation images.**

Magma Plumbing System



- A shallow magma storage zone centered about ~3.5 km beneath the center of the 10-km-diameter caldera floor has been responsible for the observed deformation.
- The reservoir offsets from the active vent (Cone A) by ~5 km.

Magma accumulation from InSAR modeling
Inter-eruption period: 1997 - 7/10/2008



- **The inter-eruption deformation during 1997–2008 is characterized by an initially rapid inflation followed by oscillatory but generally slowing inflation, suggesting that the magma supply rate decreased with time in response to the diminishing pressure difference between the shallow magma storage zone and a deep magma source.**

Lu et al., JGR, 2010
Lu & Dzurisin, JGR, 2010

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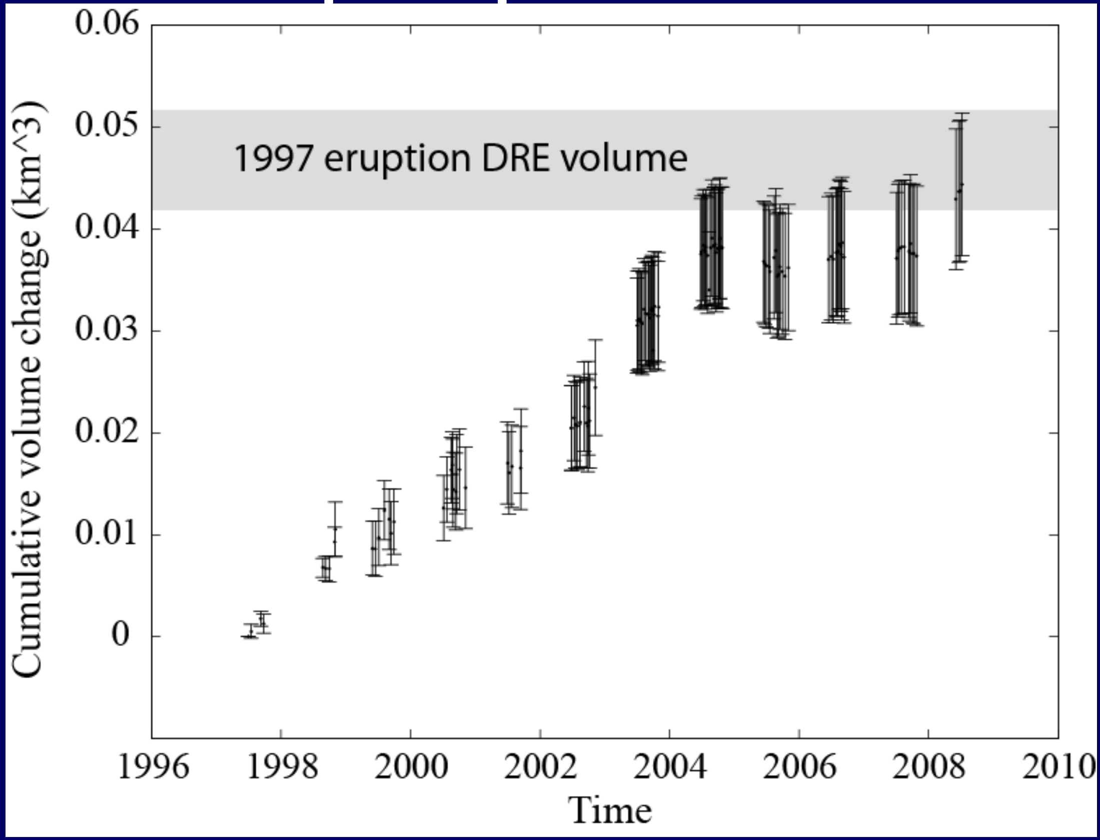
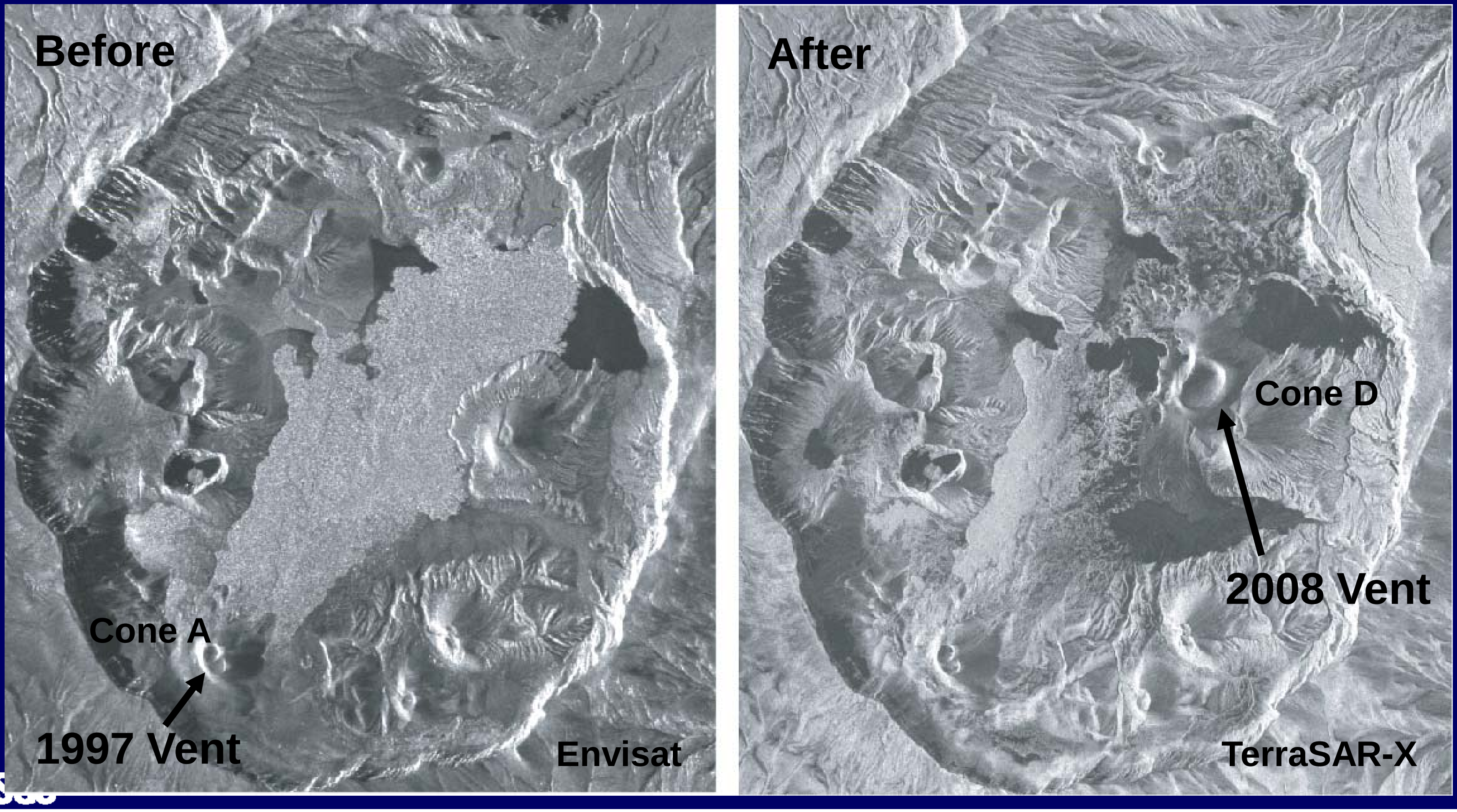
Magma accumulation from InSAR modeling
Inter-eruption period: 1997 - 7/10/2008

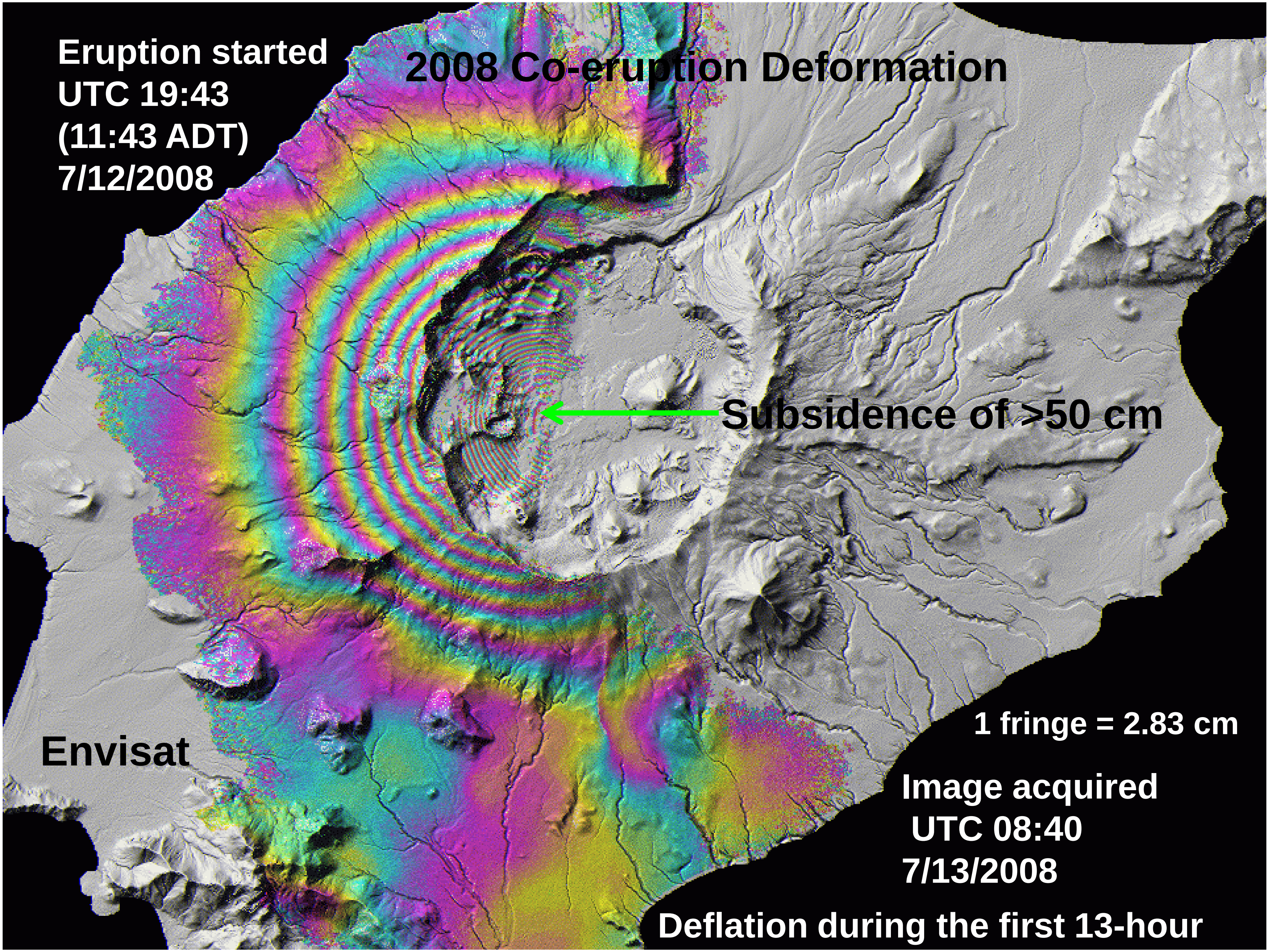


- **The total amount of magma added to the shallow storage zone from the end of the 1997 eruption to a few days before the 2008 eruption was 85–100% of the 1997 eruption volume.**
- **Eventually, exsolution of magmatic volatiles and the resulting vesiculation of accumulated magma in the shallow storage zone caused a critical pressure threshold to be exceeded, triggering the 2008 eruption.**

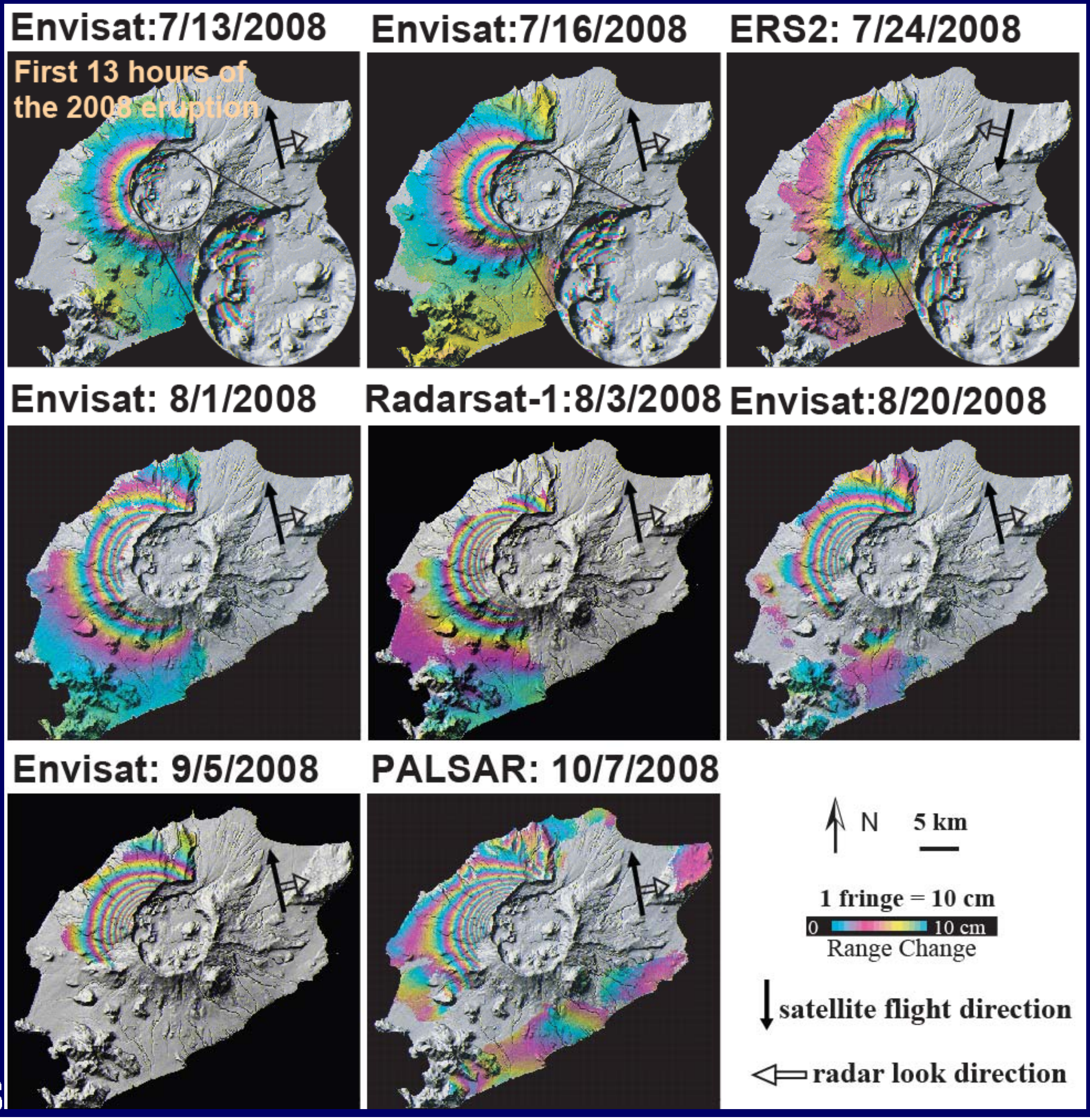
July-August 2008 Eruption

- The 2008 eruption started from near Cone D whereas past eruptions were from Cone A.
- The 2008 eruption was explosive and hydrovolcanic in nature, indicating strong magma interactions with groundwater and surface water.
- Past eruptions produced basaltic lava flows; the 2008 eruption was non-effusive and blanketed much of the caldera and adjacent landscape with fine-grained tephra.



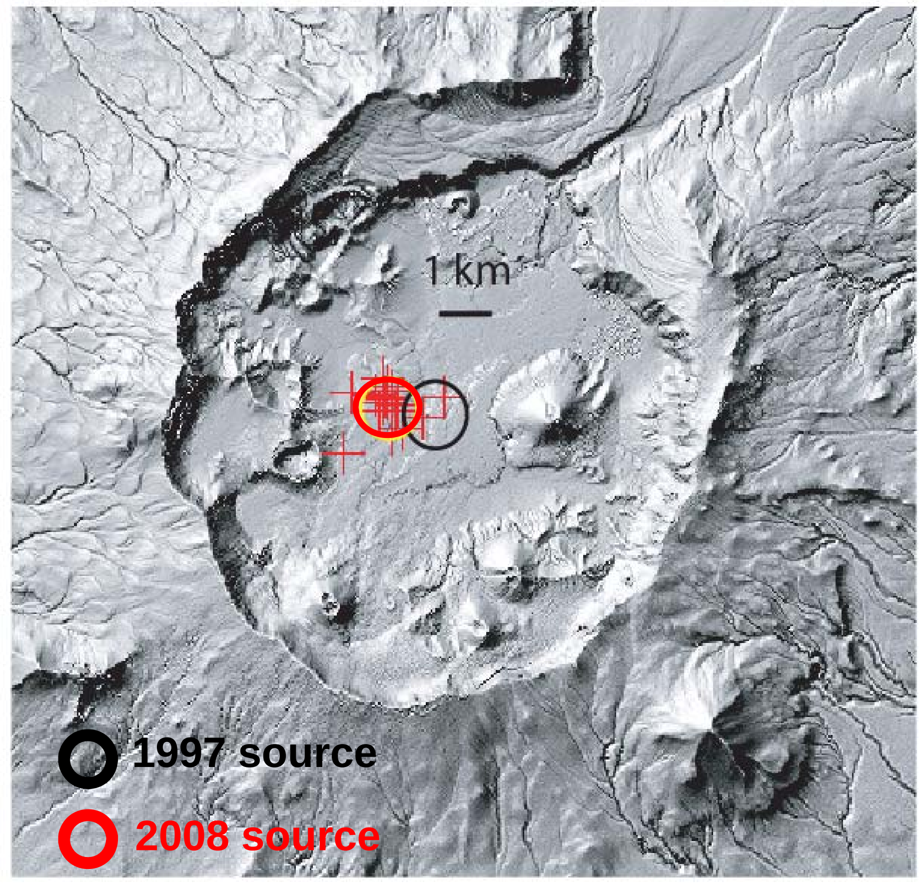

Eruption started
UTC 19:43
(11:43 ADT)
7/12/2008
2008 Co-eruption Deformation
Subsidence of >50 cm
1 fringe = 2.83 cm
Envisat
Image acquired
UTC 08:40
7/13/2008
Deflation during the first 13-hour

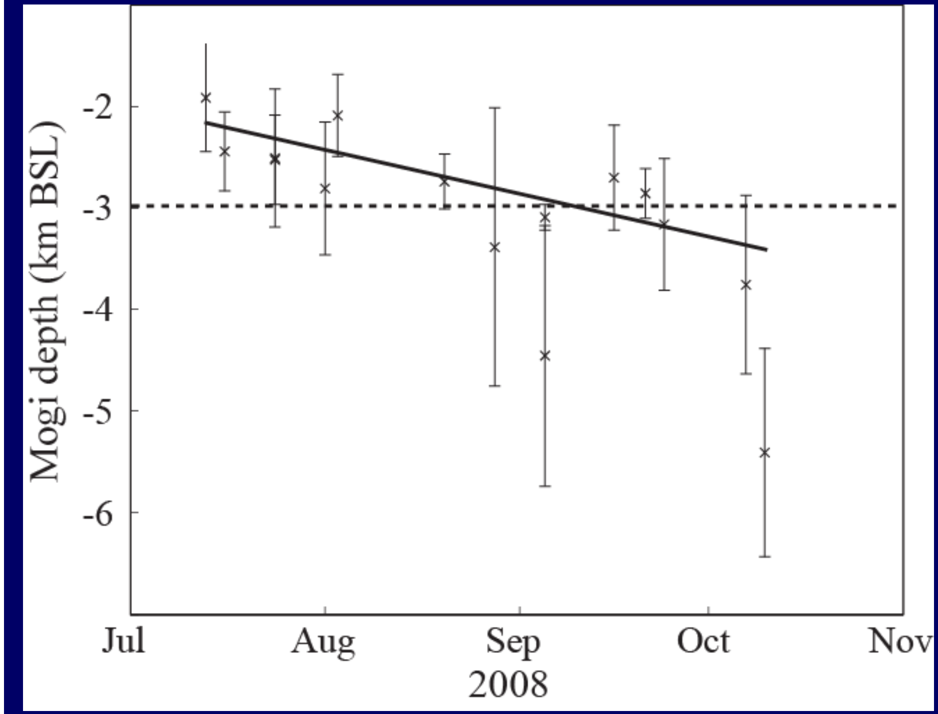
Multi-satellite InSAR Monitoring of 2008 Eruption



Lu & Dzurisin, JGR, 2010

2008 source depth and location





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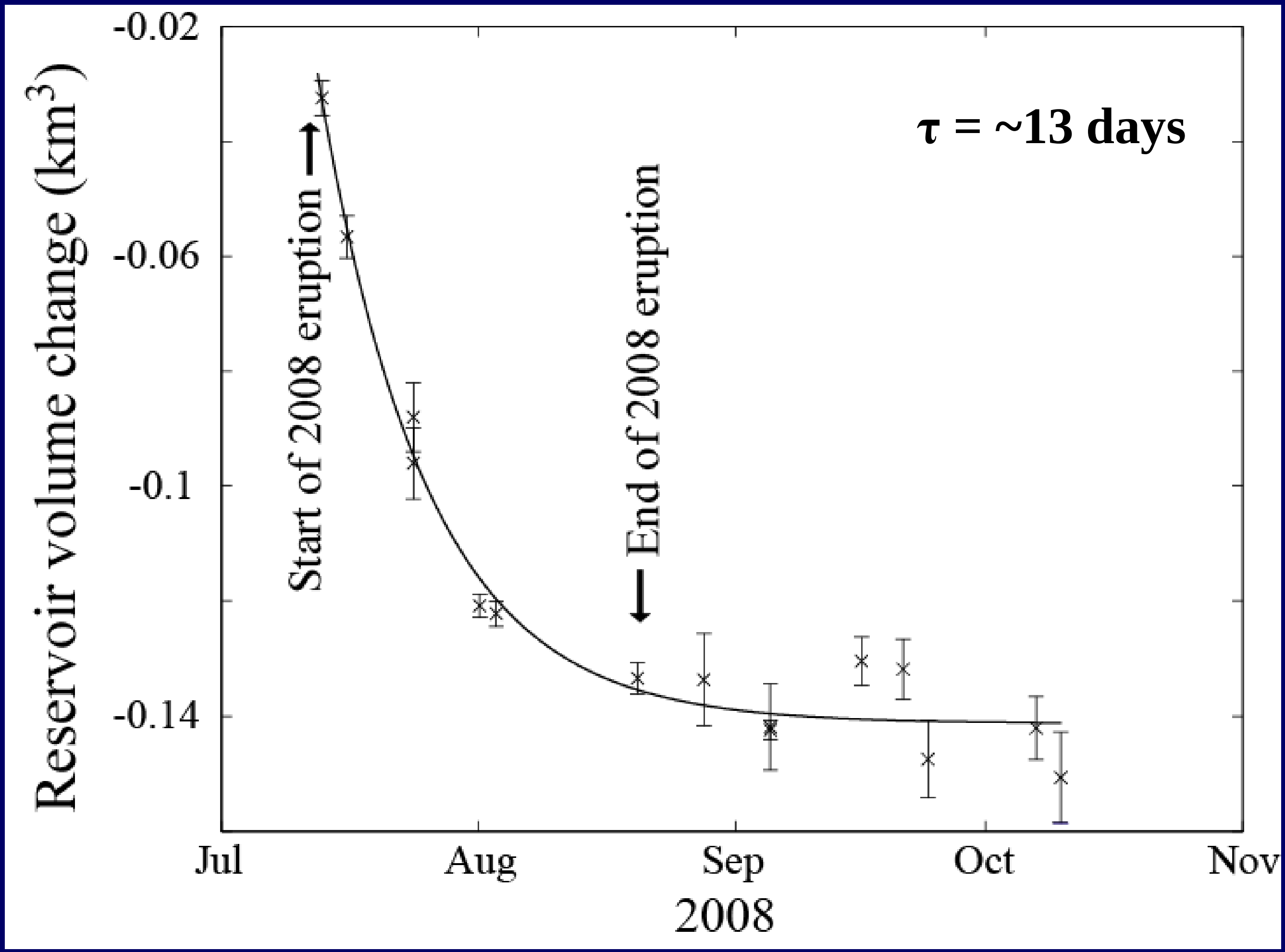
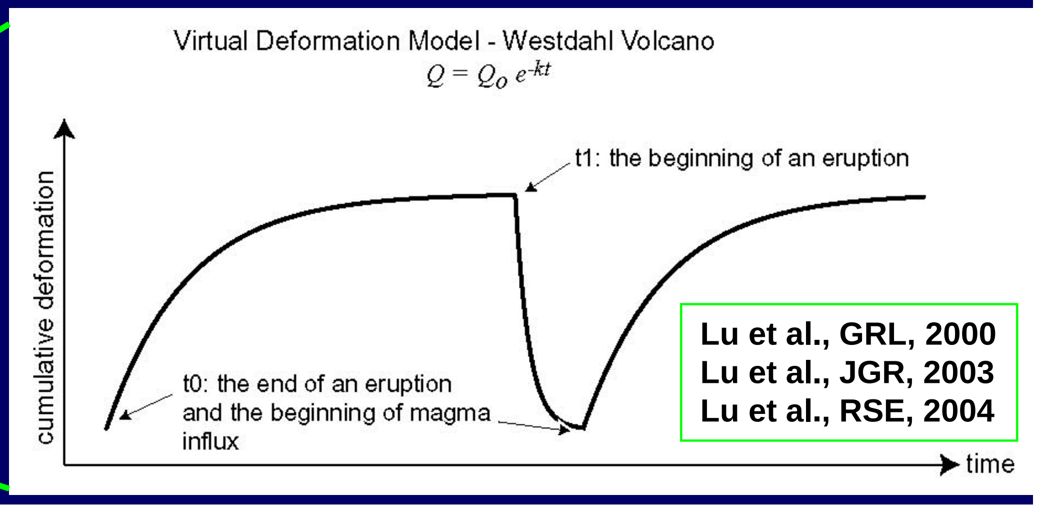
Magma loss during 2008 eruption



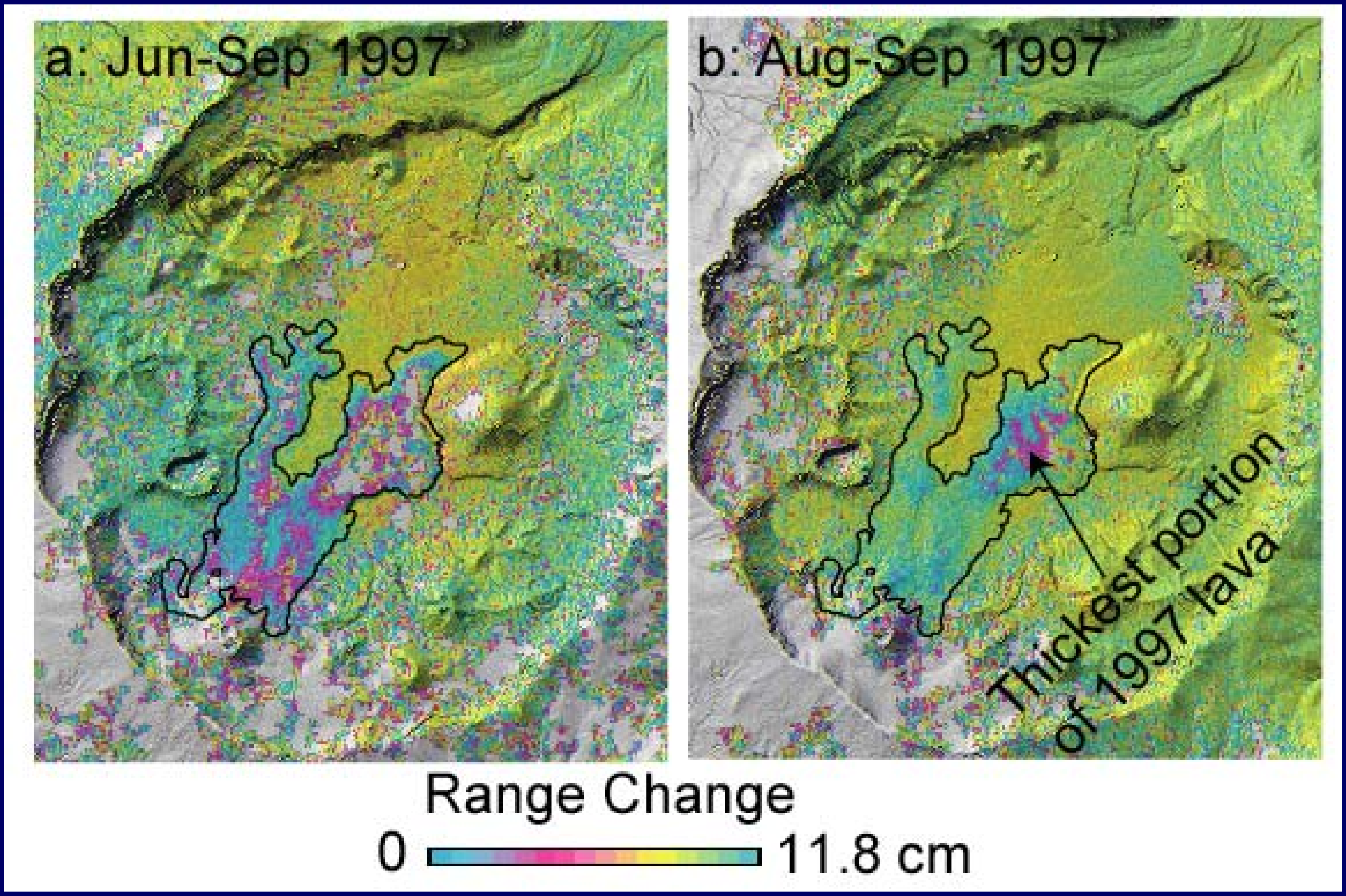
Okmok volcano – remarks

- Most of the surface deformation that occurred during the eruption is explained by deflation of a Mogi-type source located beneath the center of the caldera and ~3 km BSL, *i.e*., essentially the same source that inflated prior to the eruption.
- During the eruption the reservoir deflated at a rate that decreased exponentially with time with a 1/*e* time constant of ~13 days.
- The rate at which the reservoir deflates during an eruption may be controlled by the diminishing pressure difference between the reservoir and surface.
- A similar mechanism might explain the tendency for reservoir inflation to slow as an eruption approaches.
- A similar deformation pattern has been observed at Westdahl volcano, Alaska.



Deformation of 1997 lava flows from JERS-1 Imagery

L-band Images

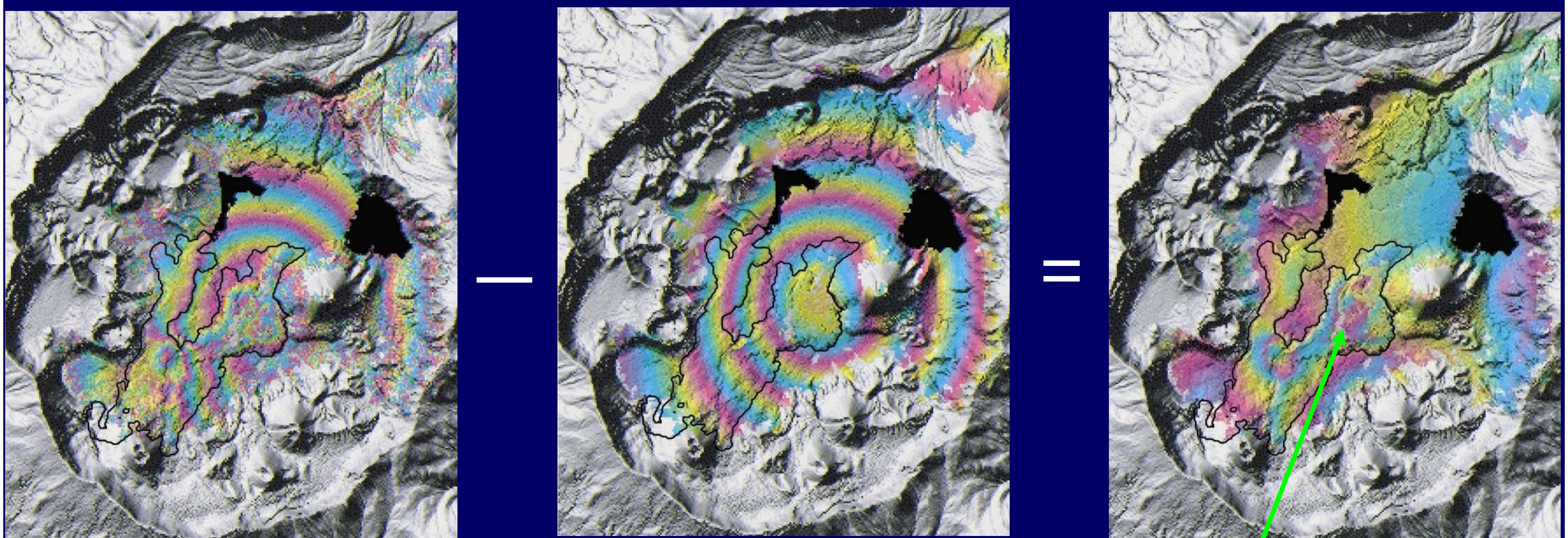


Surface displacement due to lava contraction and consolidation could reach ~2 mm/day 4 months after the emplacement

USGS

Deformation of lava flows after 1997 eruption

Observed | **Modeled (magma accumulation)** | **Residual**



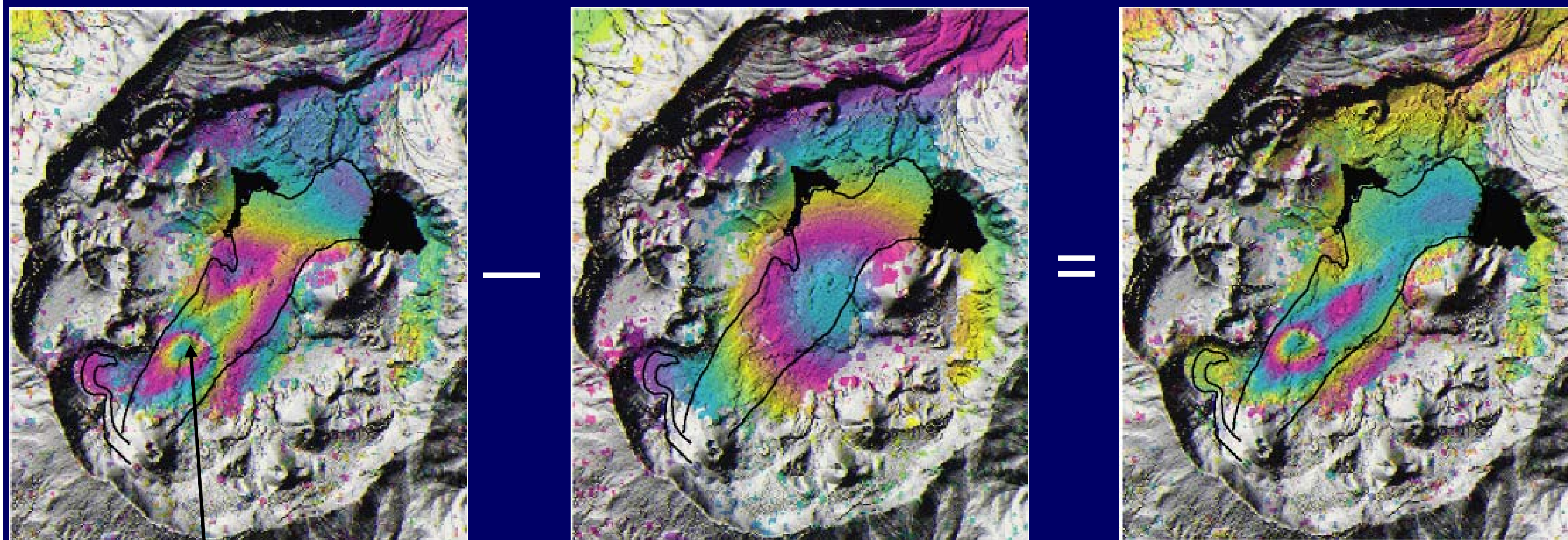
2001-2002 InSAR Image

0 2.83 cm

1997 lava flows subside at 5-10 cm/year after the 1997 eruption

Deformation of lava flows erupted before 1997

Observed — **Modeled** = **Residual**



1958 lava flow

1993-1995 Interferogram

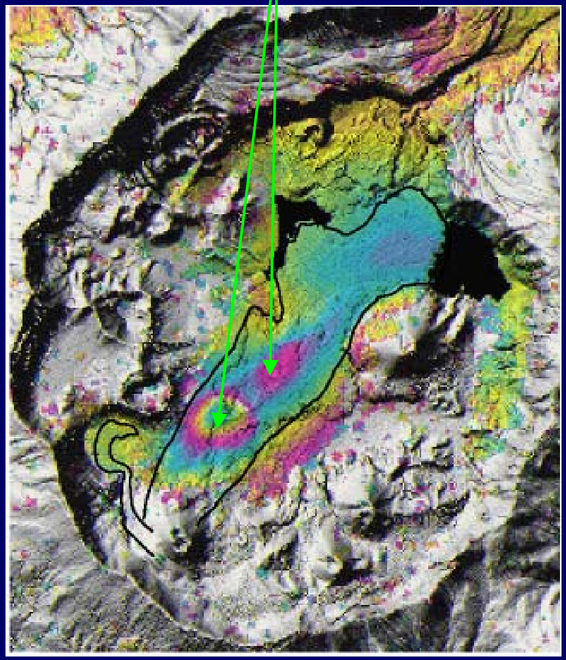
Contraction of ~1.5 cm/year

0 2.83 cm

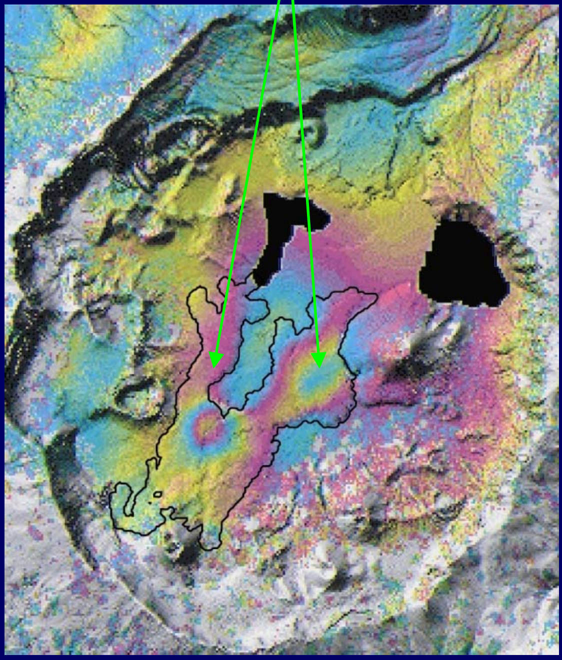
USGS

Deformation of lava flows before & after 1997 eruption

1958 lava flow



1997 lava flow



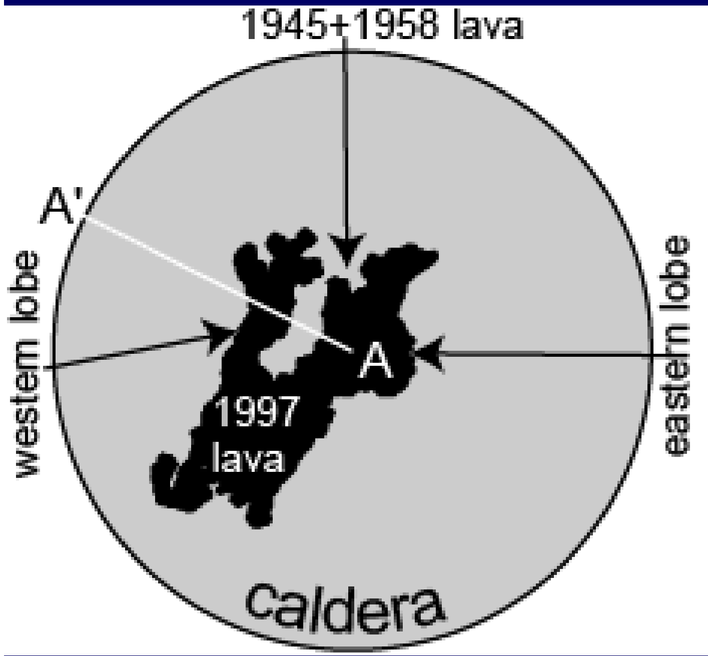
InSAR image of 1993-1995:
35 yrs after the 1958 eruption
-> -1.5 cm/year

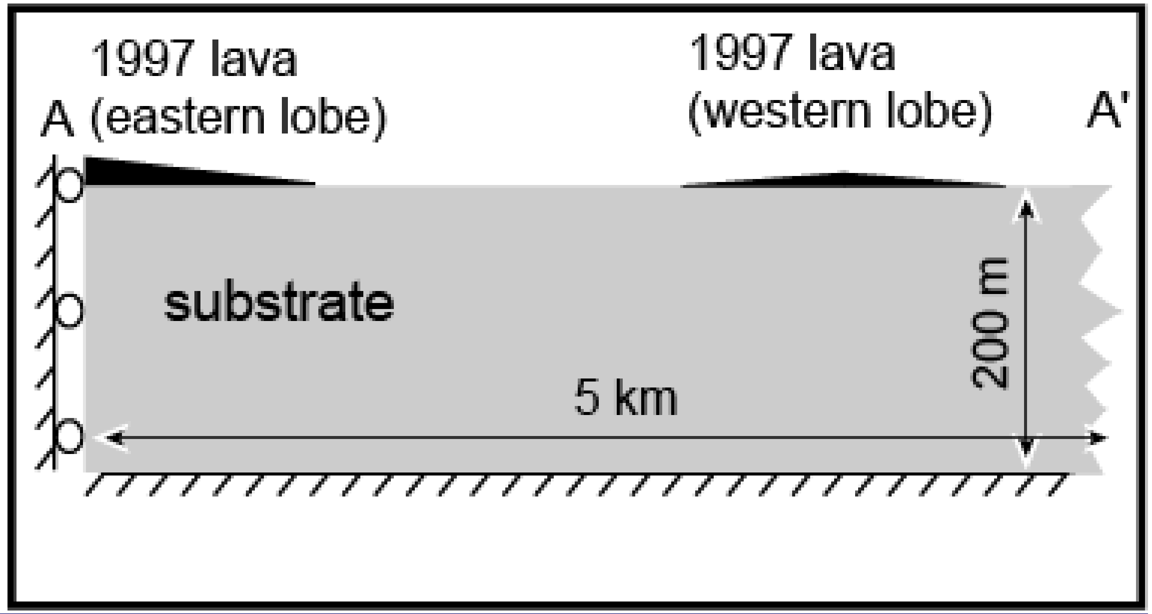
InSAR image of 2005-2006:
7 yrs after the 1997 eruption
-> -3.0 cm/year

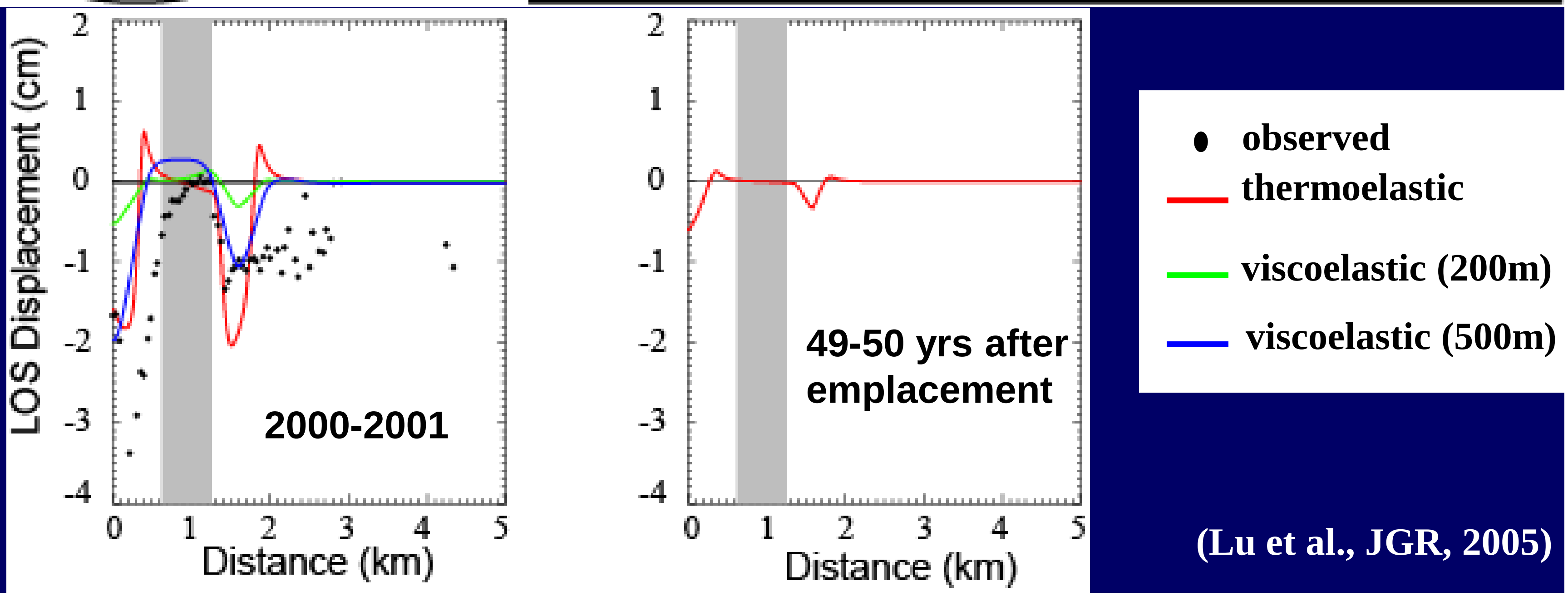
0 2.83 cm

USGS

Understanding lava flow deformation





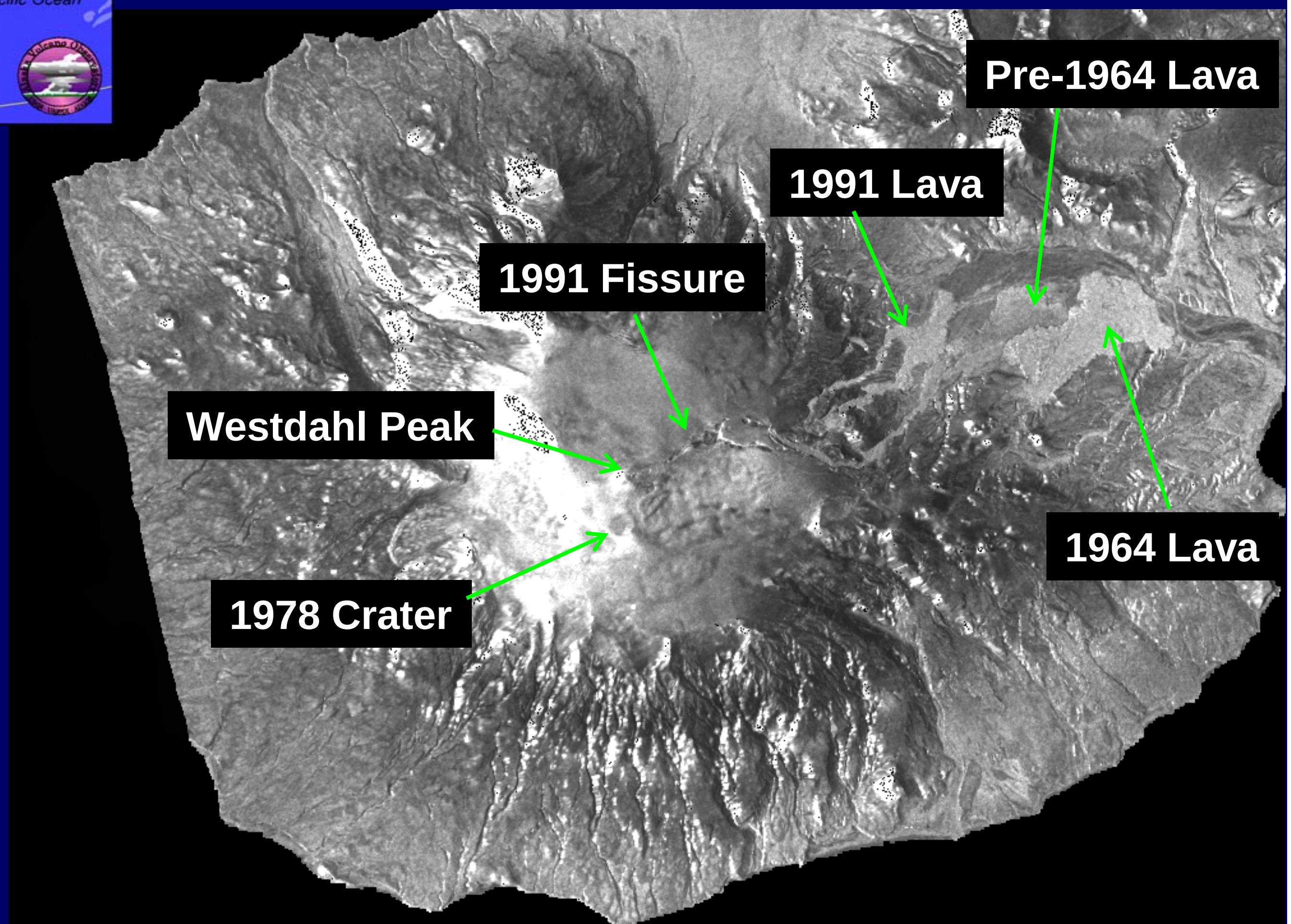


(Lu et al., JGR, 2005)

Tracking Magma Accumulation at Westdahl

Westdahl

- Glacier-capped shield volcano
- Eruptions: 1964, 1978-79, and 1991-92

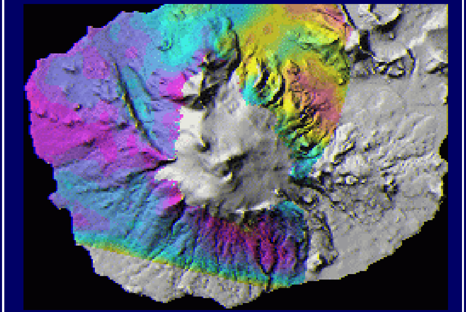


Lu, Z., et al., GRL, 2000
Lu, Z., et al., JGR, 2003
Lu, Z., et al., RSE, 2004

USGS

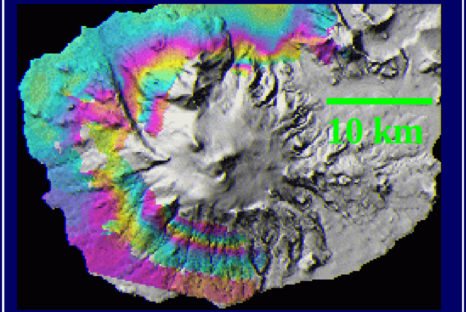
InSAR images can characterize transient deformation of Westdahl volcano before, during and after the 1991 eruption

pre-eruption



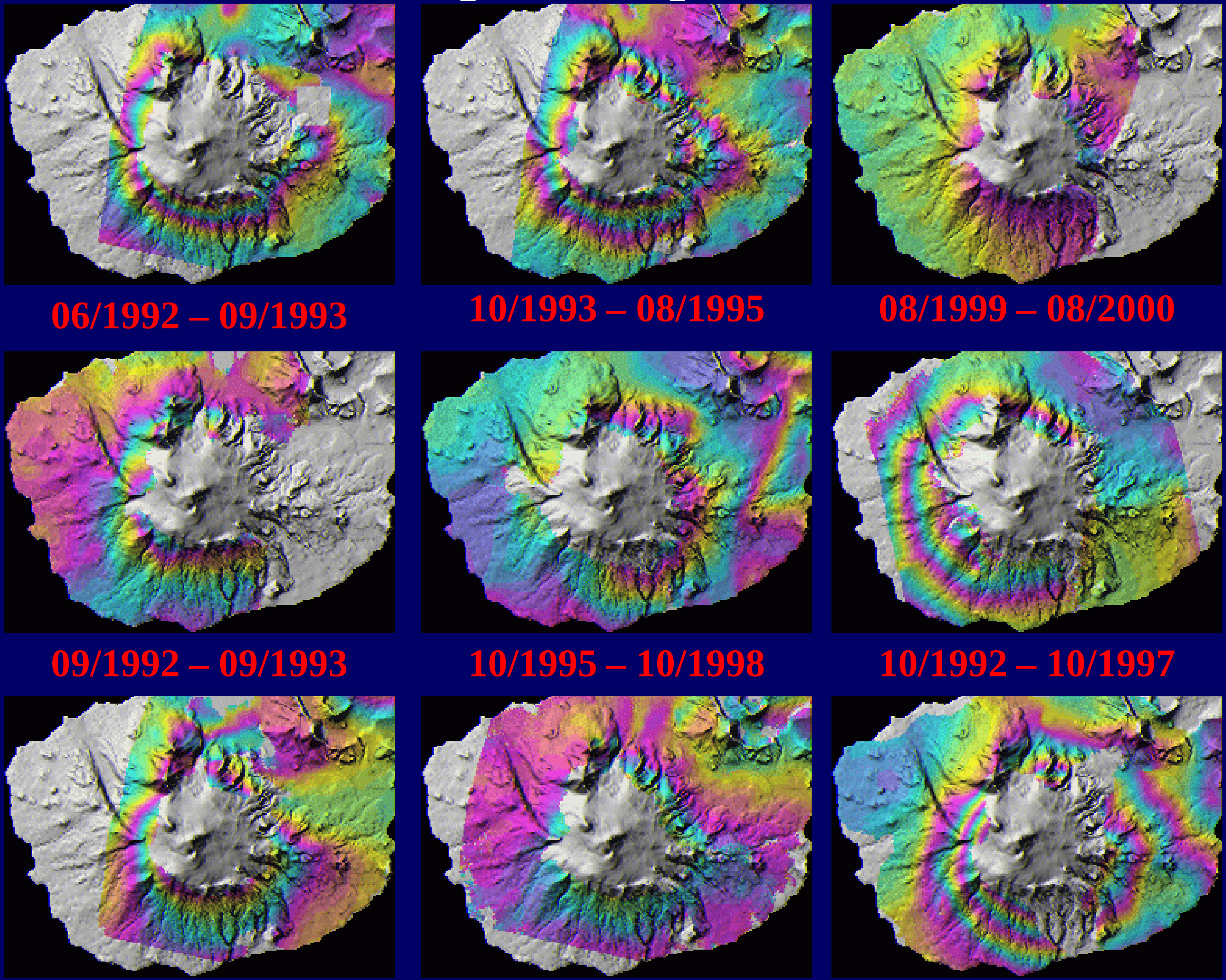
09/07/1991 – 10/28/1991

co-eruption



11/21/1991 – 11/30/1991

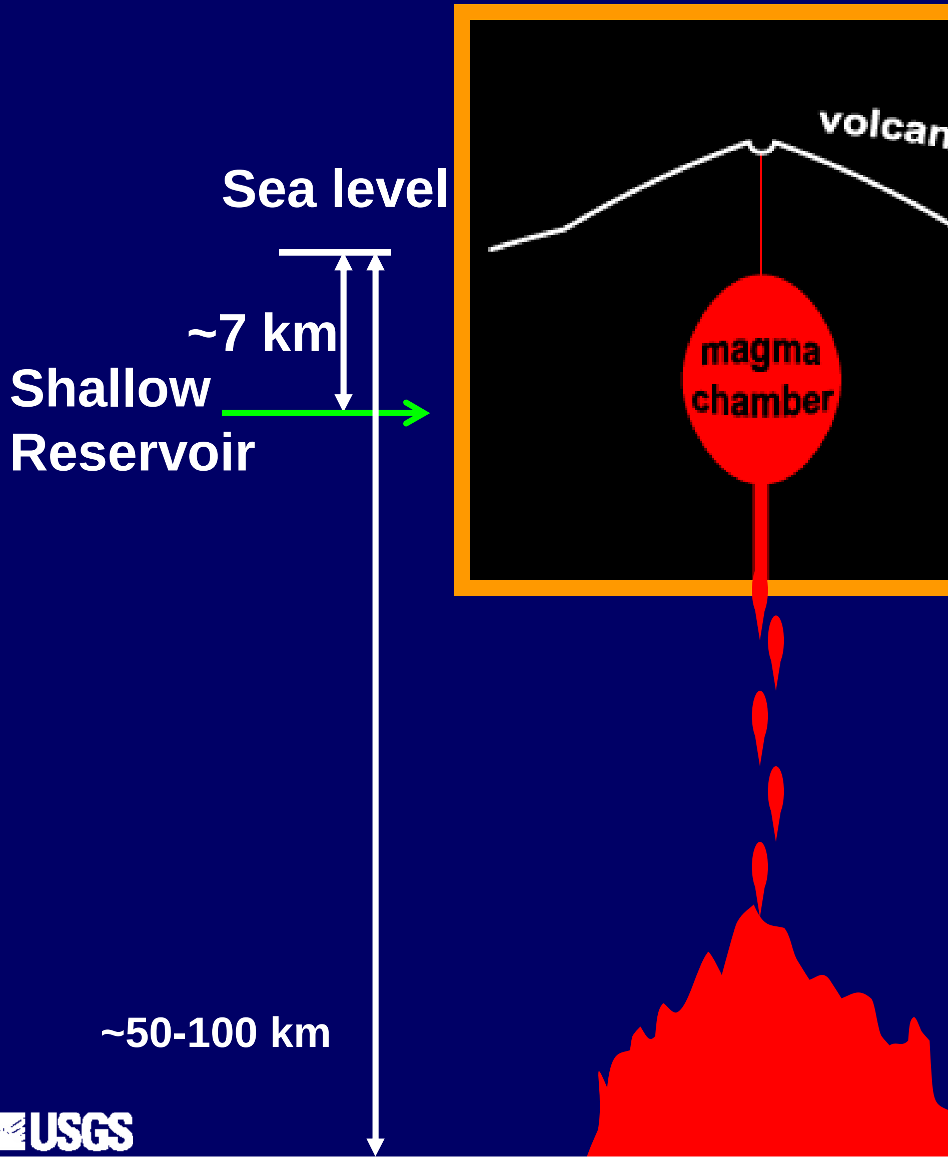
post-eruption



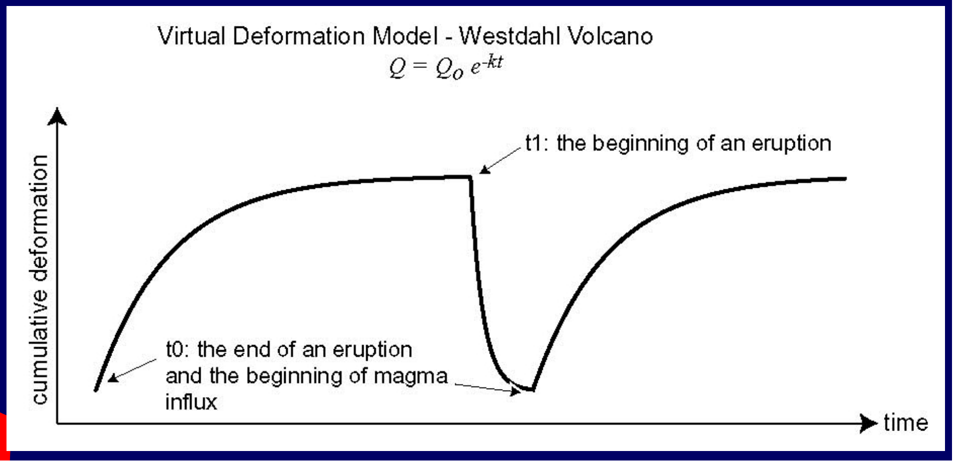
0 2.83 cm

Lu et al., GRL, 2000
Lu et al., JGR, 2003
Lu et al., RSE, 2004

Magma plumbing system for Westdahl volcano, inferred from InSAR and modeling



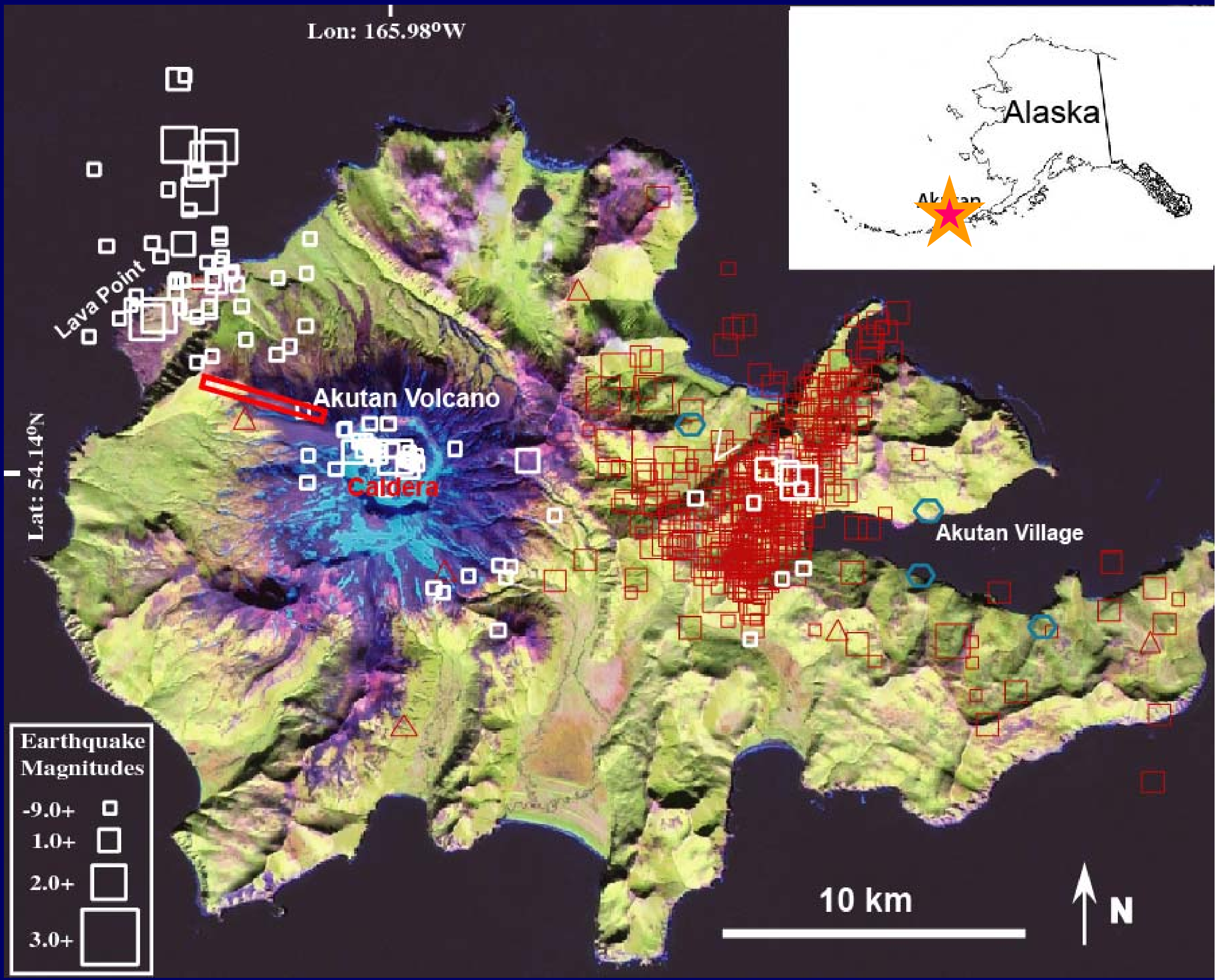
Lu et al., GRL, 2000
Lu et al., JGR, 2003
Lu et al., RSE, 2004



Deformation Associated Magma Intrusion at Aktuan

Akutan

- The 2nd most active in the Aleutian arc
- 27 separate eruptive episodes since 1790
- Latest seismic crisis: March 1996



Lu et al., JGR, 2000
Lu et al., CJRS, 2005

USGS

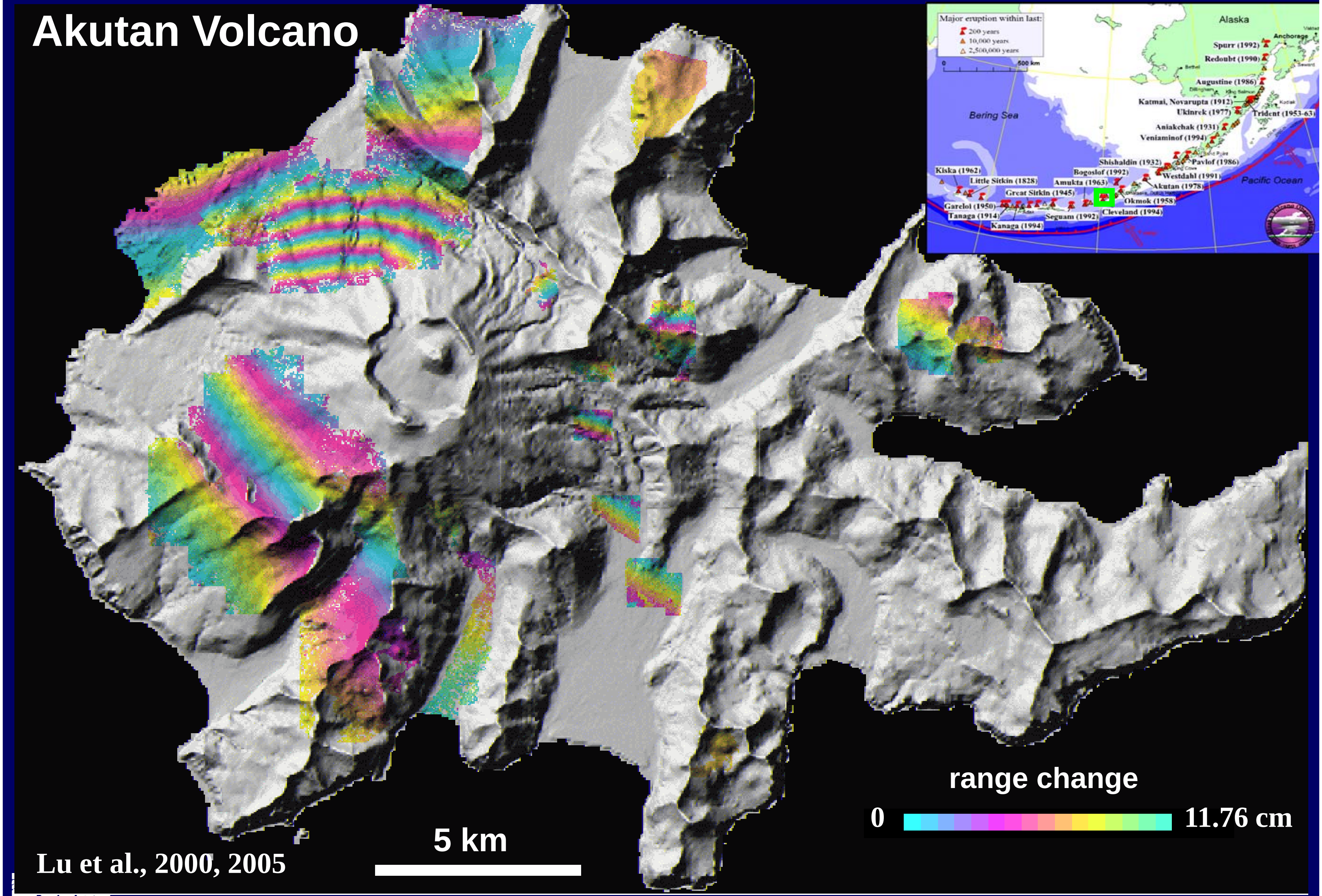
Ground Cracks

Courtesy of AVO

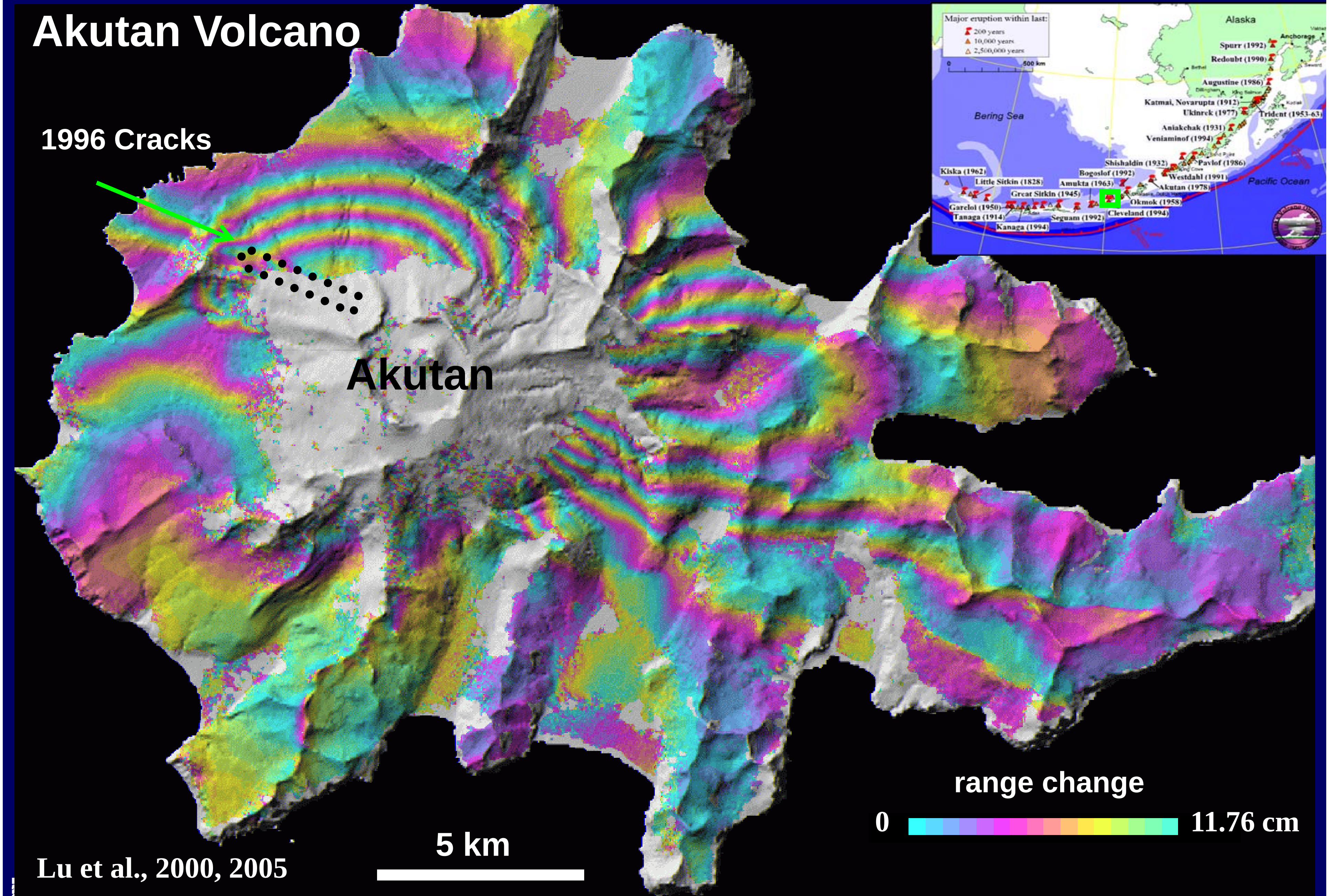
Ground Cracks

Courtesy of AVO

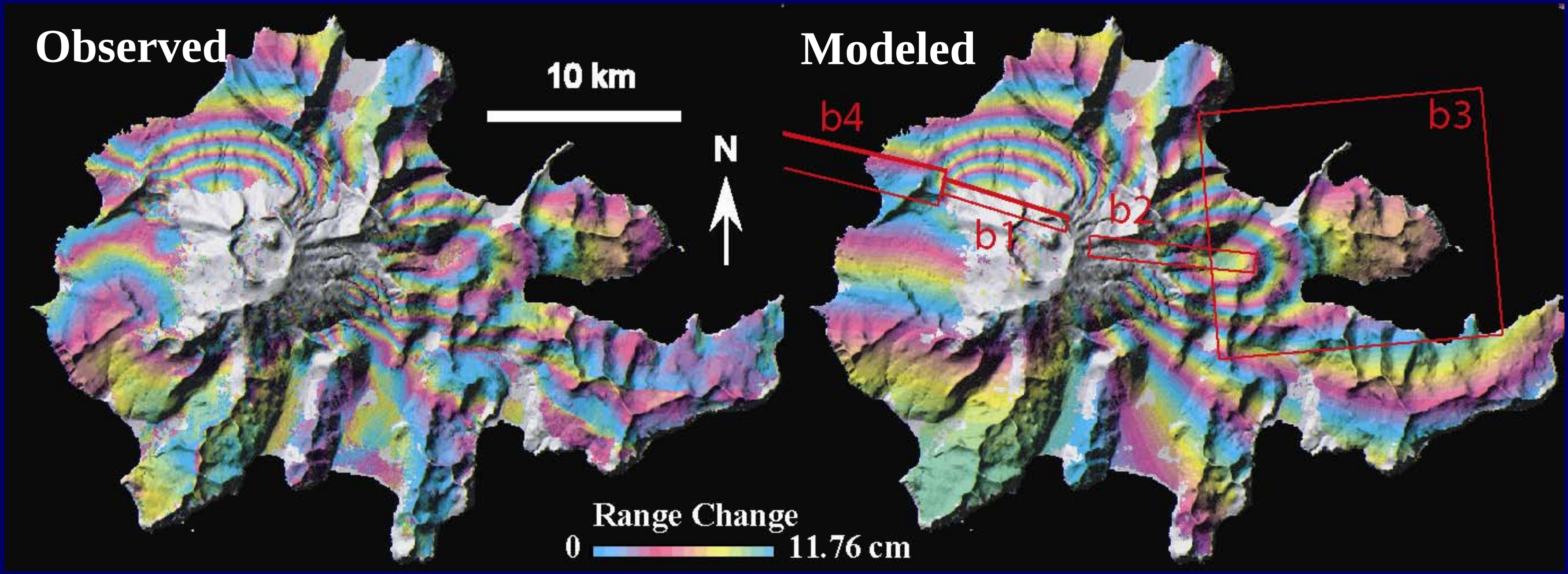
Deformation mapped by ERS (C-band, λ = 5.66 cm) InSAR



Deformation mapped by JERS (L-band, λ = 23.53 cm) InSAR



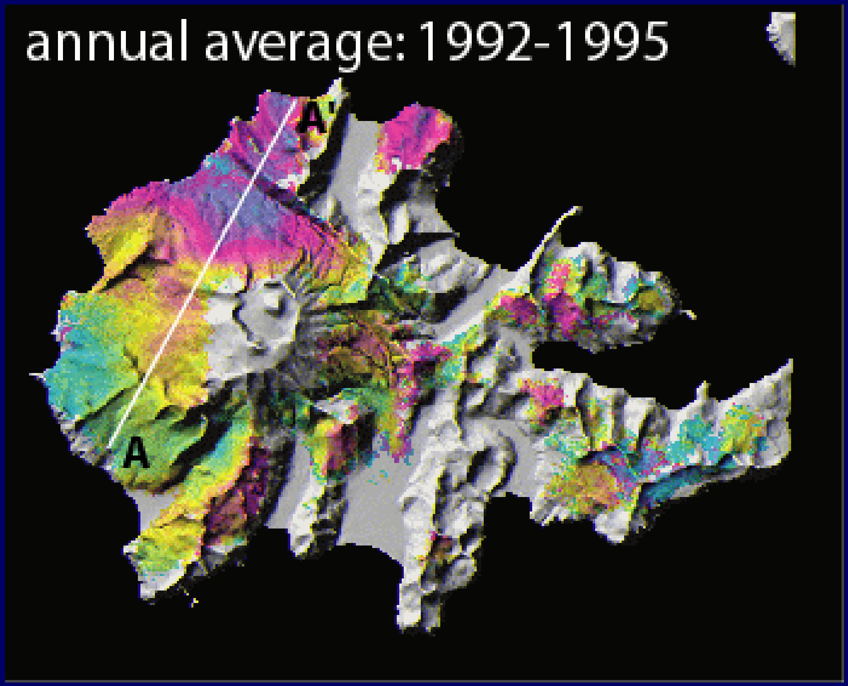
Observed and modeled deformation images

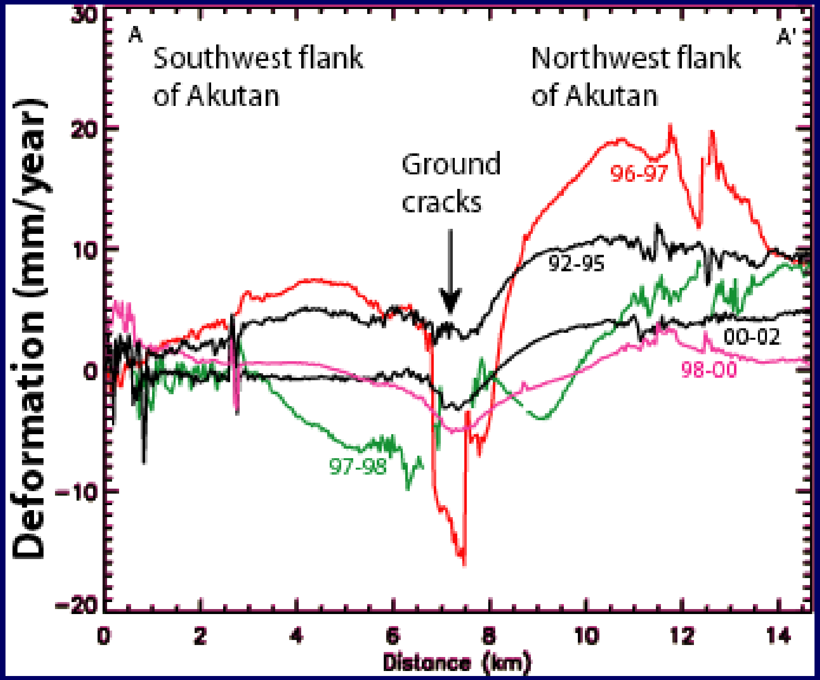


Deformation sources:

• **b1: a shallow expanding source representing intrusion of magma.**
• **b2, b3, & b4: contracting sources that together account for observed subsidence of the eastern part of the island.**

Long-term deformation





- Both before and after the swarm, the northwest flank was uplifted 5-20 mm/year relative to the southwest flank, probably by magma intrusion.

- The zone of fresh cracks subsided about 20 mm during 1996-1997 and at lesser rates thereafter, possibly because of cooling and degassing of the intrusion.

A Preliminary Model of Magma Plumbing System for Akutan Volcano

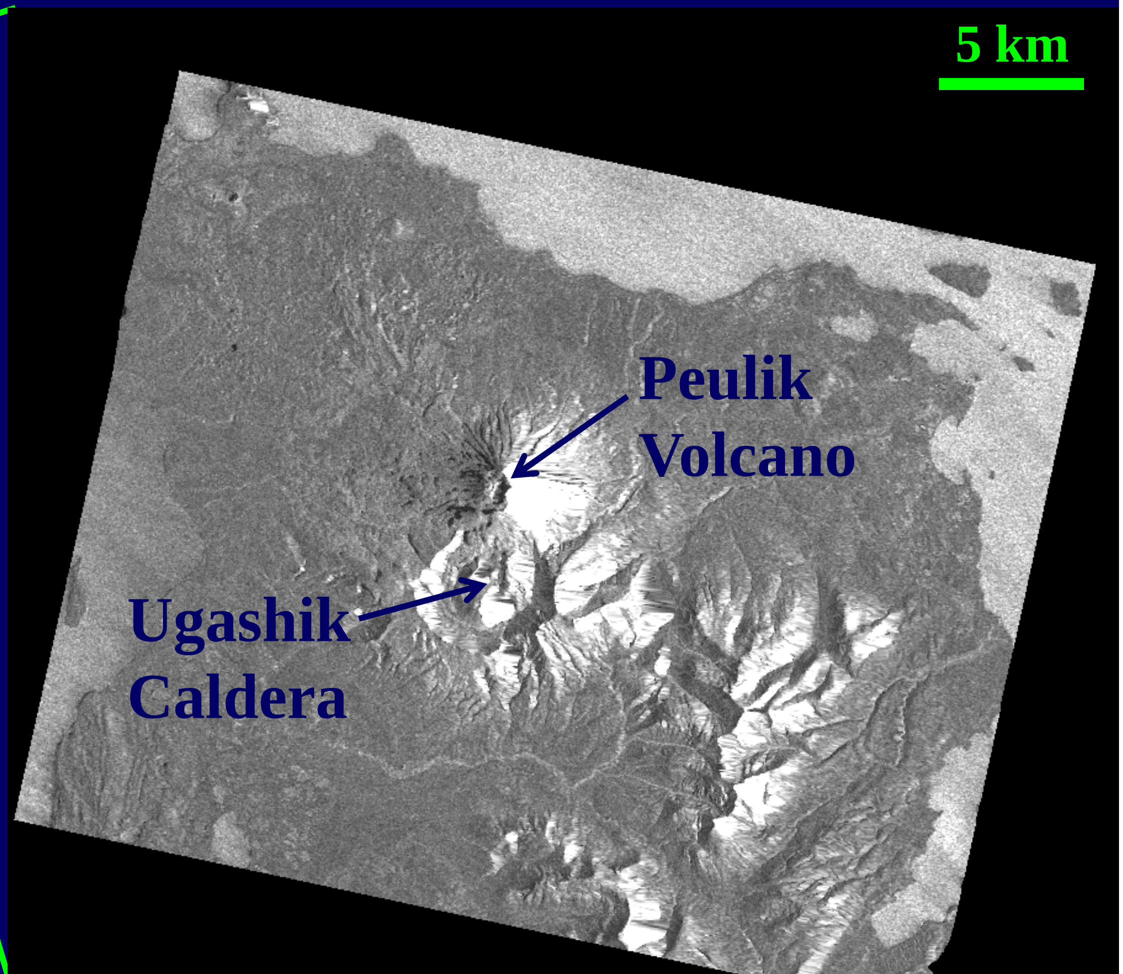
1. **Magma constantly accumulates at a deep dike (~ 5-10 km beneath Akutan), producing 5-20 mm/year uplift.**

2. **Magma episodically intrudes into a shallow dike (near the surface) from the deep dike, producing ground surface deformation (and seismic swarms).**

3. **The magma degassing process is efficient such that the viscosity and density of the shallow magma increase dramatically and vertical magma transportation stalls at the shallow dike without extrusion.**

4. **The above process will eventually produce a major eruption.**

Peulik Volcano

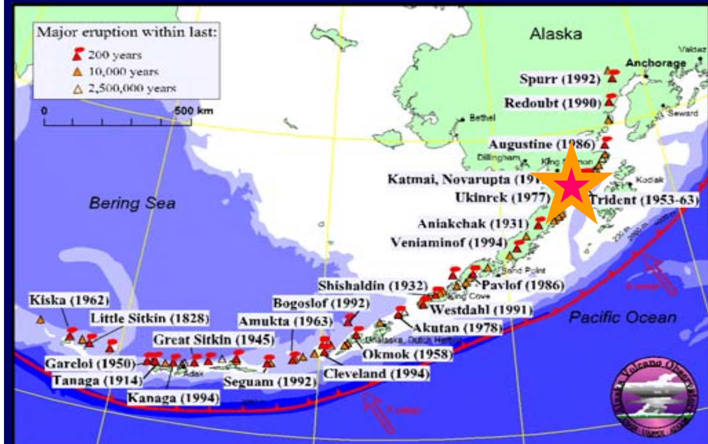


- Statovolcanoes
- Last eruption >150 years ago

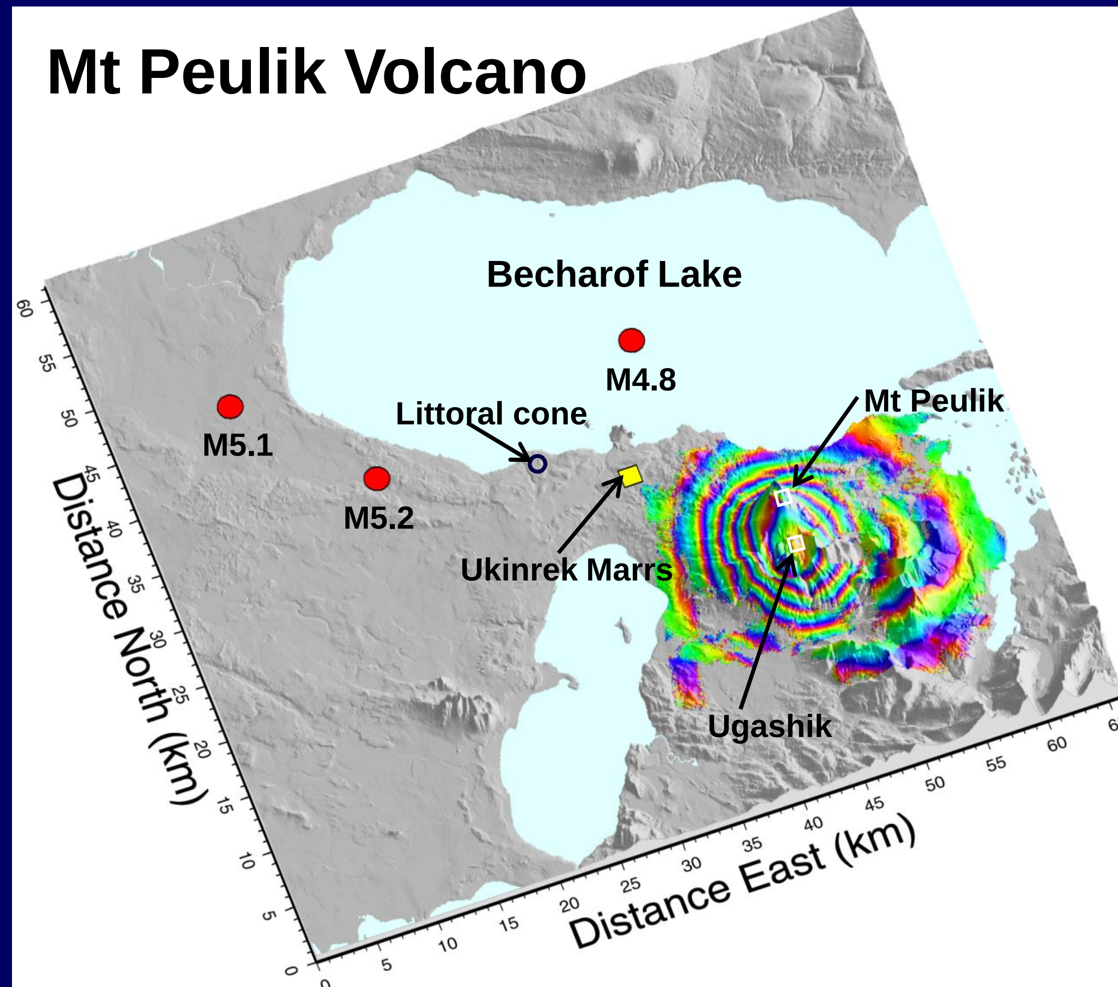
Lu et al., JGR, 2002

USGS

Deformation Associated With Seismic Swarm



Peulik
- **Statovolcanoes**
- **Last eruption >150 years ago**

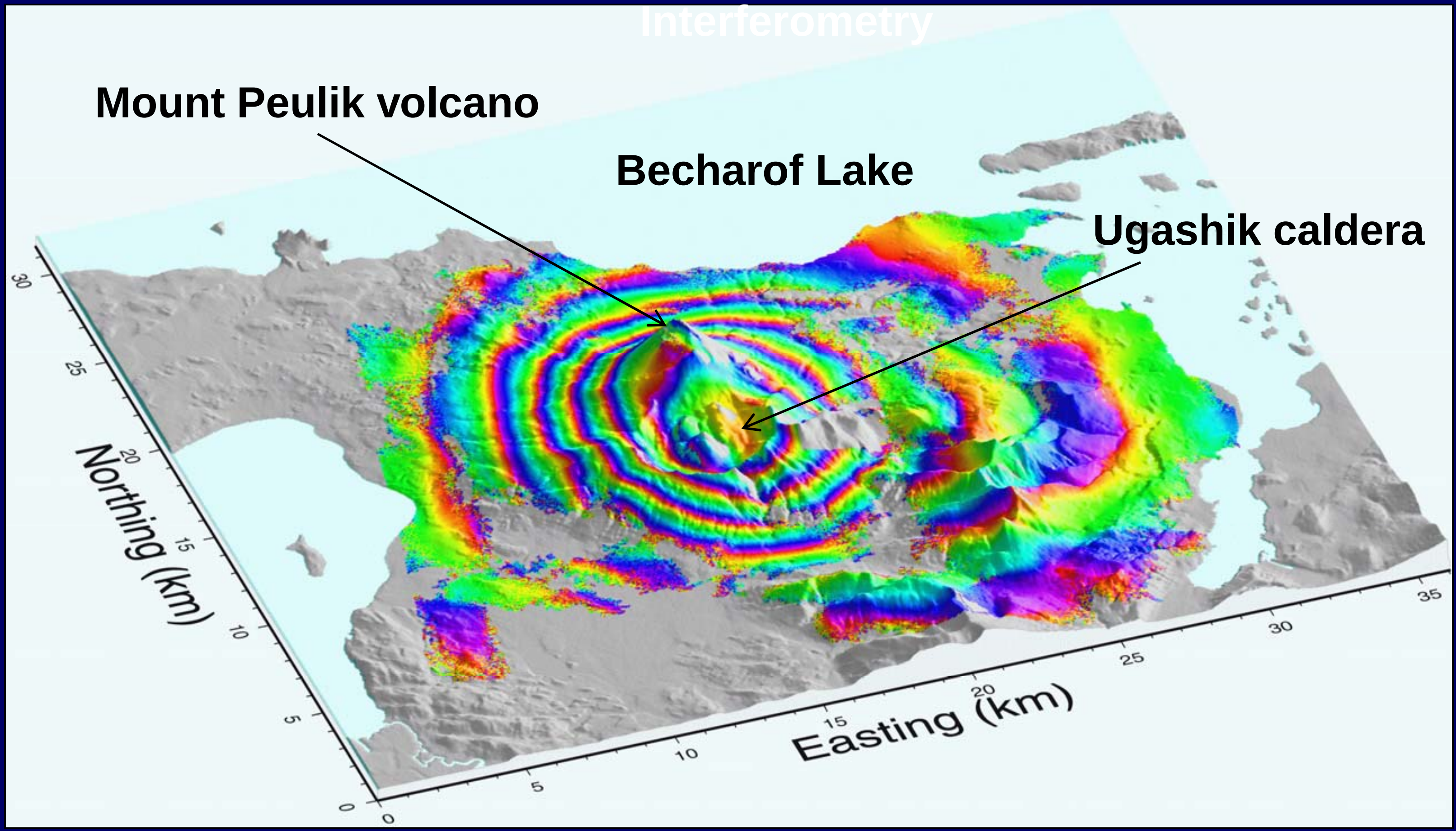


- **Progressive inflation of 24 cm during 1996-19**
- **Seismic swarms in May 1998**

Lu et al., JGR, 2002

USGS

Magmatic Inflation at a Dormant Stratovolcano: 1996-98 Activity at Mount Peulik Volcano, Alaska, Revealed by Satellite Radar Interferometry

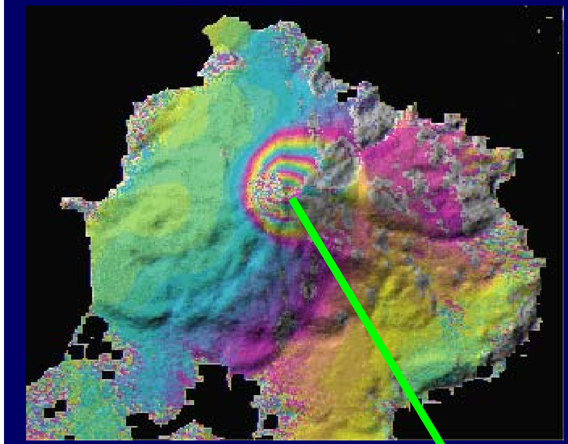


InSAR study of the 1996-98 inflation episode at Mount Peulik i) confirms that InSAR can detect magma accumulation beneath dormant volcanoes at least several months before other signs of unrest are apparent, and perhaps years before an eventual eruption; ii) includes a possible case of earthquake stress triggering by a magmatic intrusion that might otherwise have gone unnoticed; iii) represents a first step toward understanding the eruption cycle at Peulik and other stratovolcanoes with characteristically long repose periods, and could lead to improved eruption forecasting and hazards mitigation. (Lu et al., JGR, 2002)

Volcano Subsidence

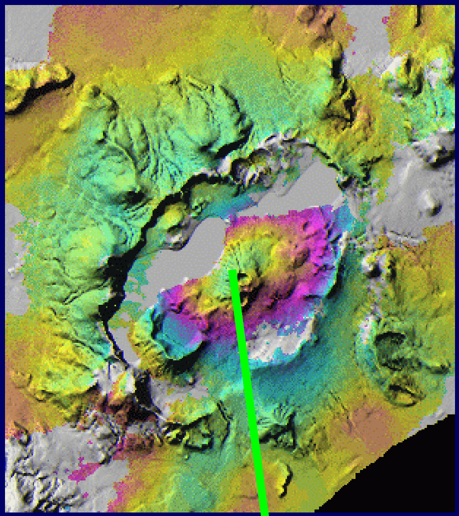
Kiska

Summit subsidence (several cm/year) associated with hydrothermal activity (source depth: ~1 km)



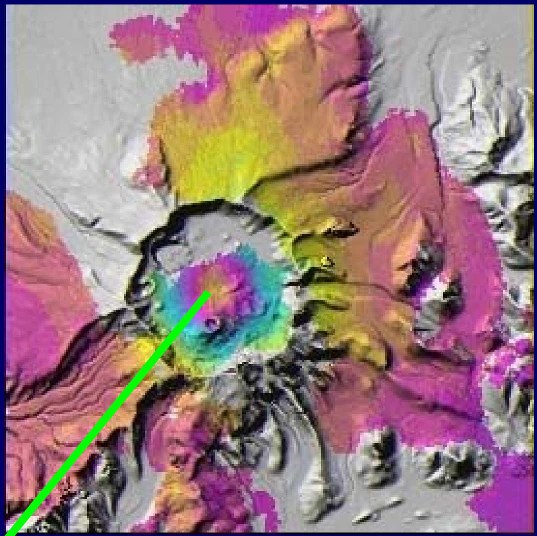
Fisher

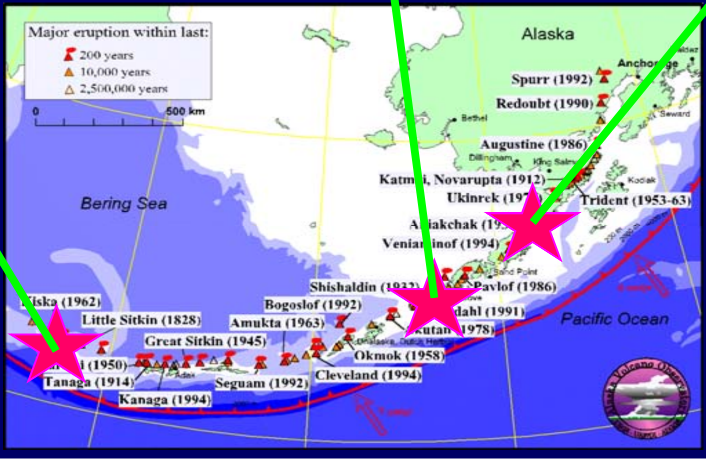
1-2 cm/year subsidence (source depth: 3-5 km)



Aniakchak

1.5 cm/year subsidence (source depth: 3-5 km)



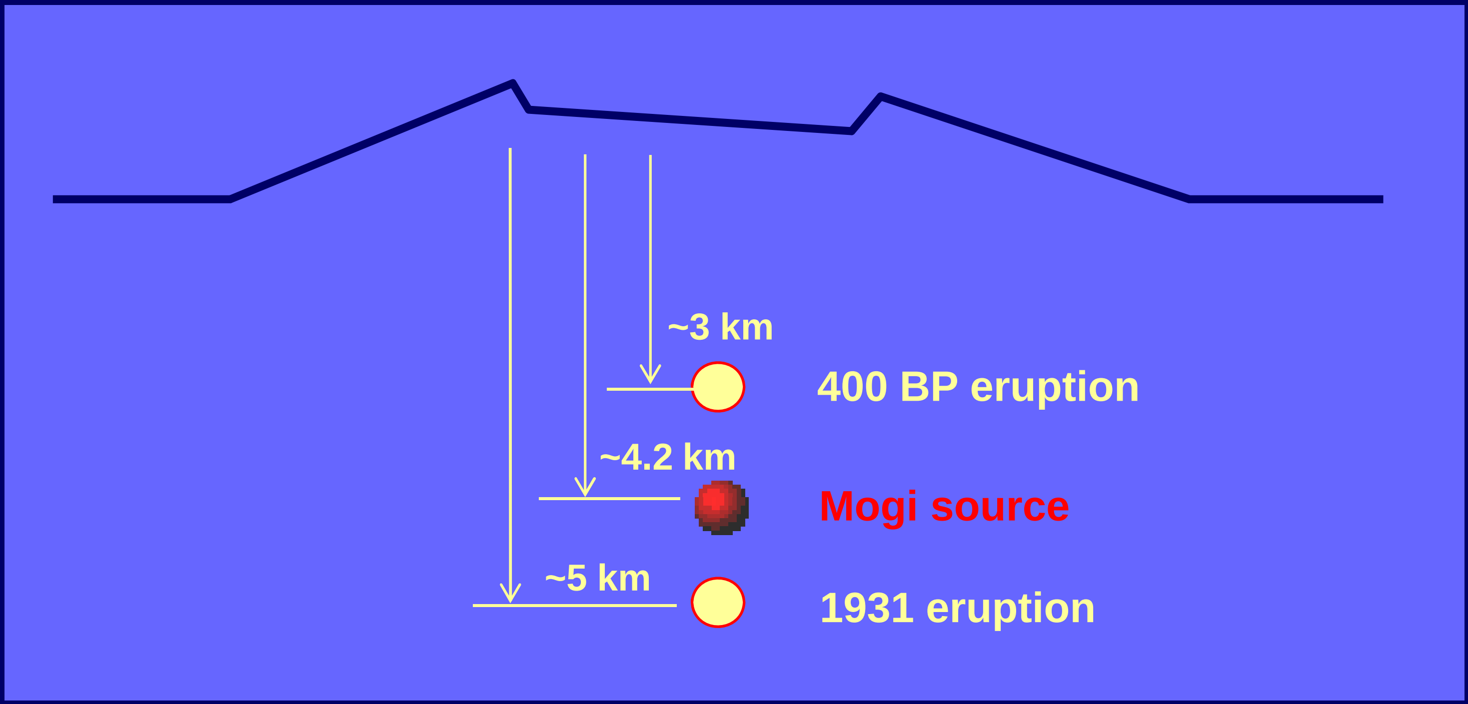


Lu et al. 2002b
Lu et al., 2007
Kwoun et al., 2006

USGS

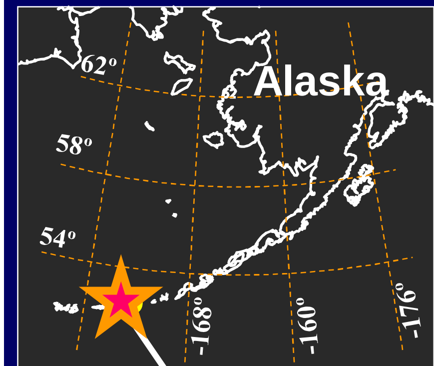
Deformation Source for Aniakchak Volcano

Based on water contents and Fe-Ti oxide data, Bacon [2000] estimated that the pre-eruption magma storage depths for the last two significant eruptions at Aniakchak were 5 km for the 1931 event and 3 km for the 400 BP eruptions.

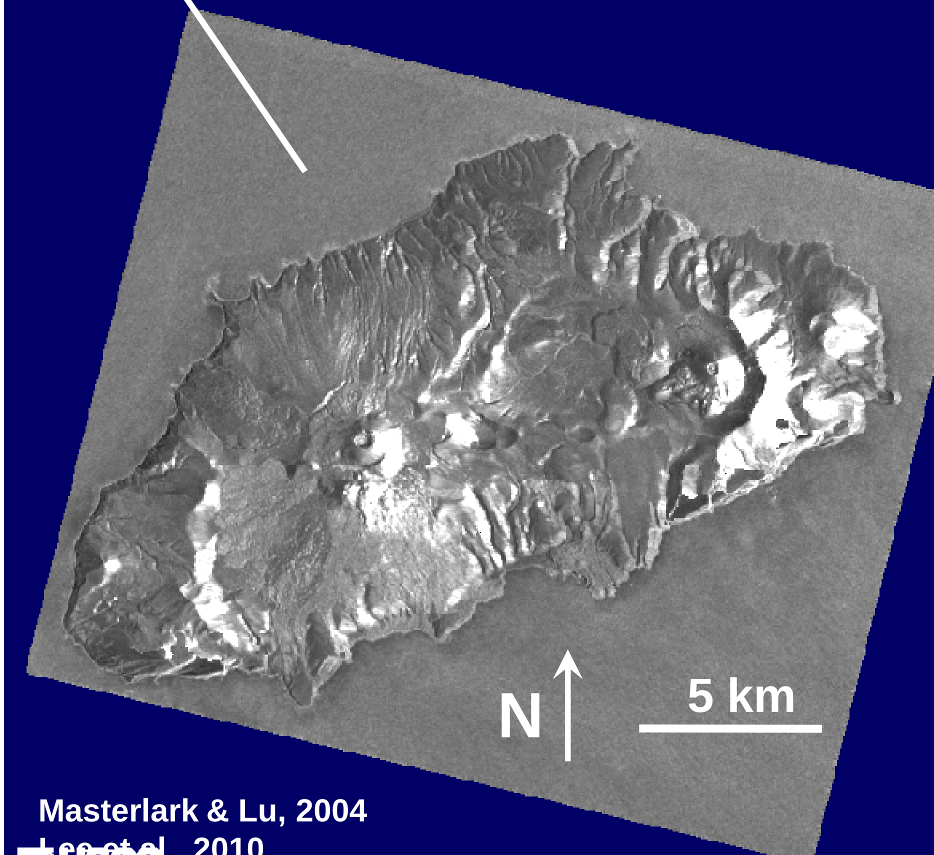


Our result from Mogi modeling suggests that the surface subsidence is related to the cooling/contraction of magma body.

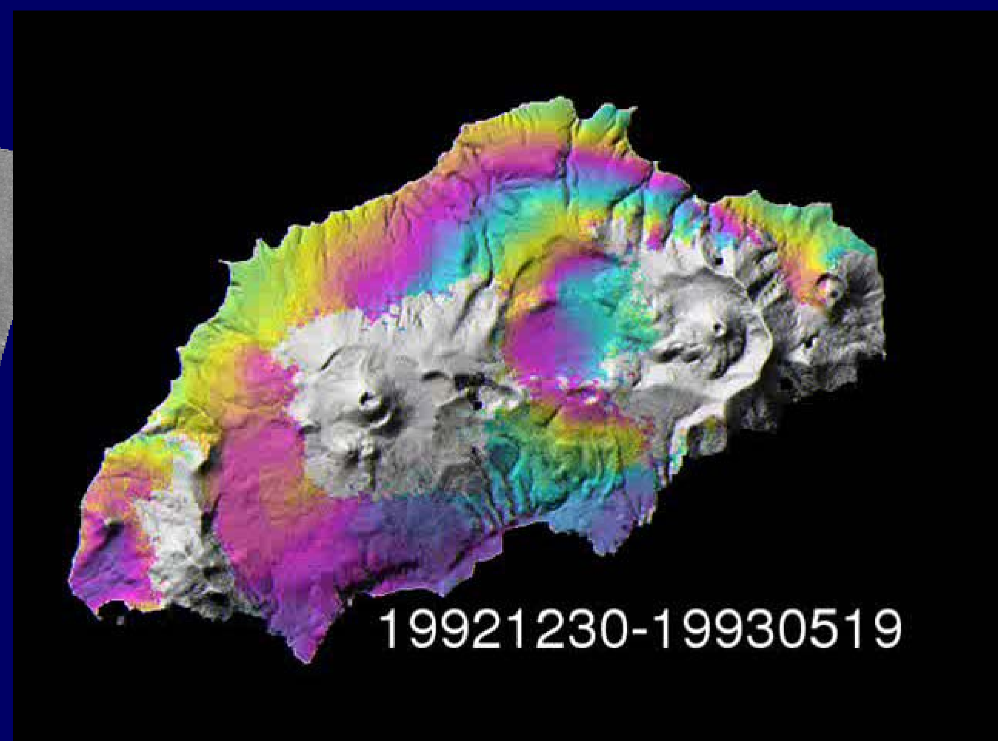
Dynamic deformation of Seguam volcano



Seguam Volcano: Documented eruptions occurred in 1786-1790, 1827, 1891, 1892, 1901, 1927, 1977, and 1992-1993.



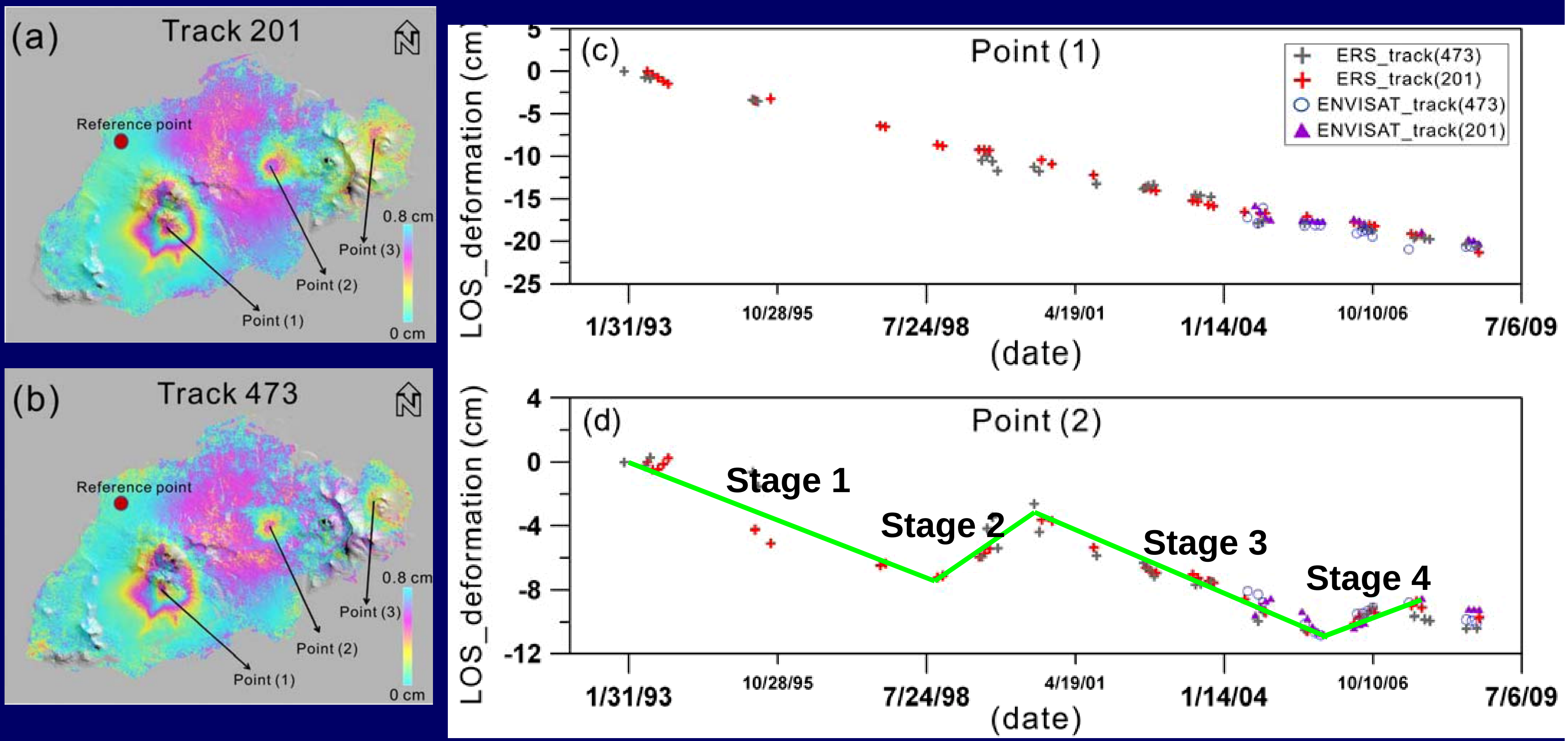
Multi-temporal InSAR Images



Masterlark & Lu, 2004
Lee et al., 2010

USGS

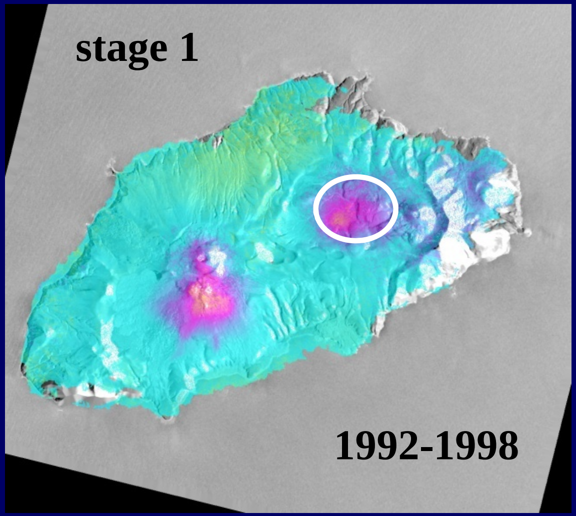
Time-series deformation

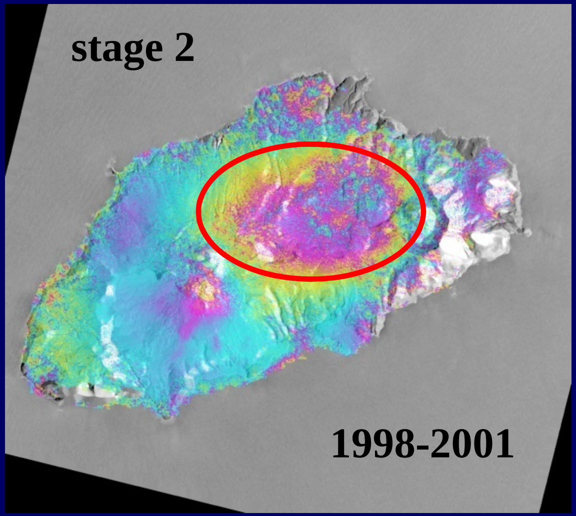


Lee et al., 2010

Dynamic deformation patterns

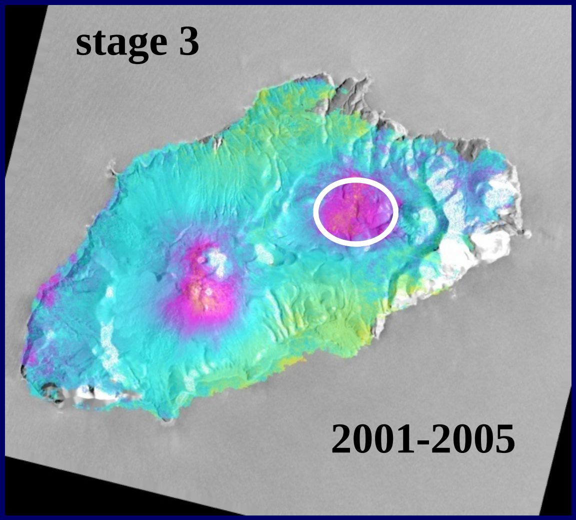
Subsidence:
Depth = 1-2 k m

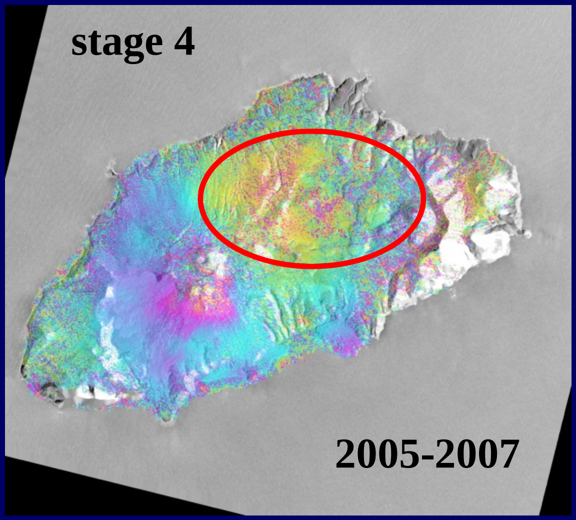




Inflation:
Depth = 4-5 k m

Subsidence:
Depth = 1-2 k m

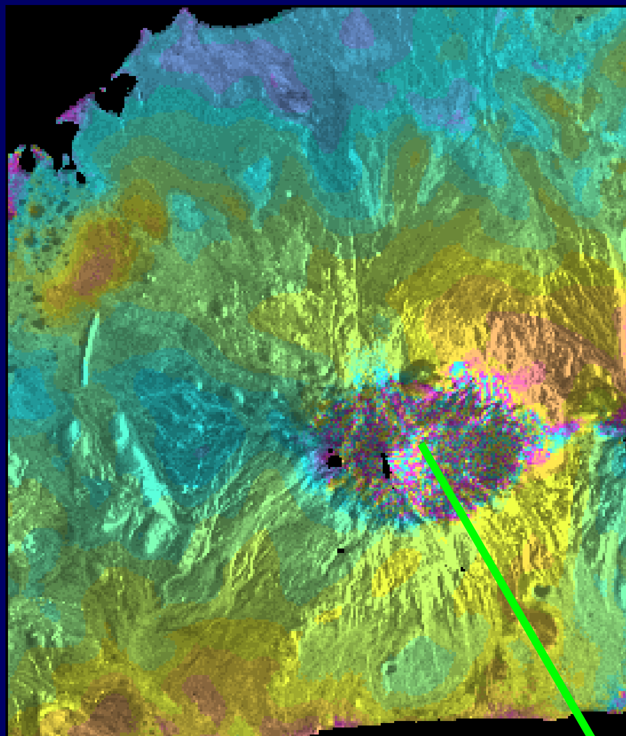




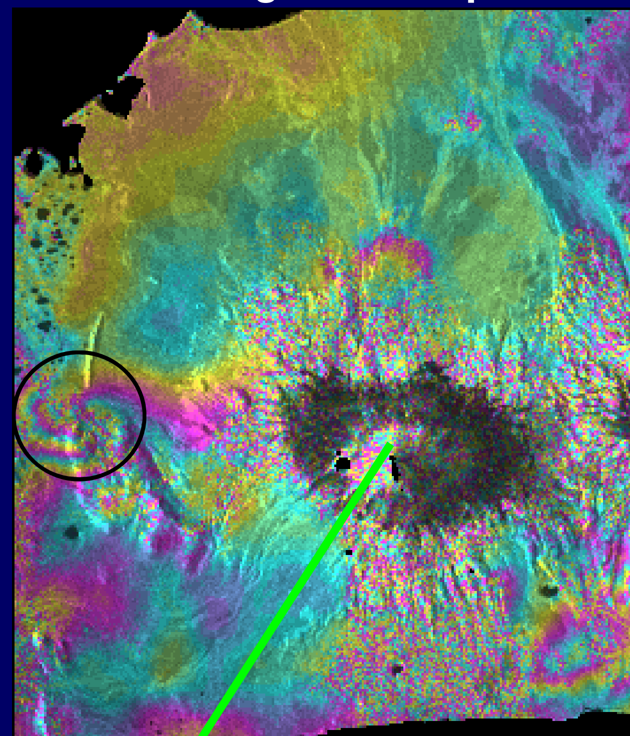
Inflation:
Depth = 4-5 k m

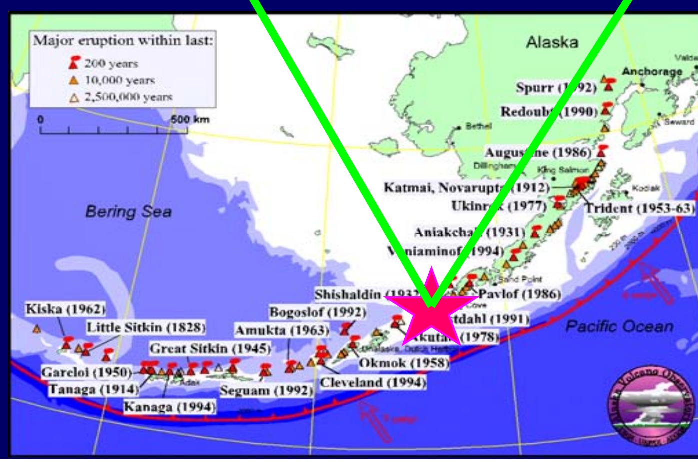
Insignificant Co-eruptive Deformation?

1993-1996 Image covering 1995 eruption



1998-1999 Image covering 1998 eruption





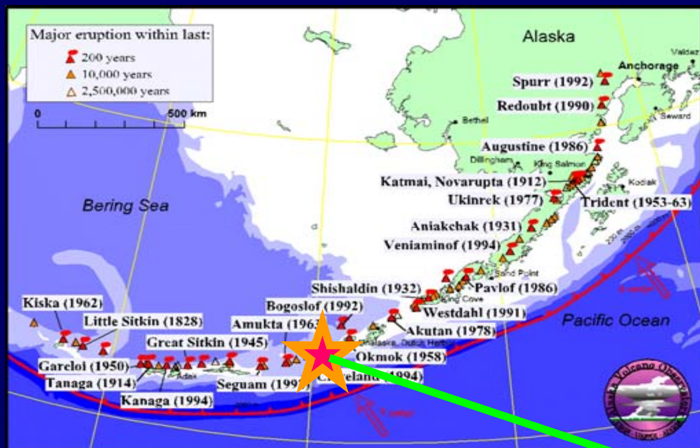
Shishaldin

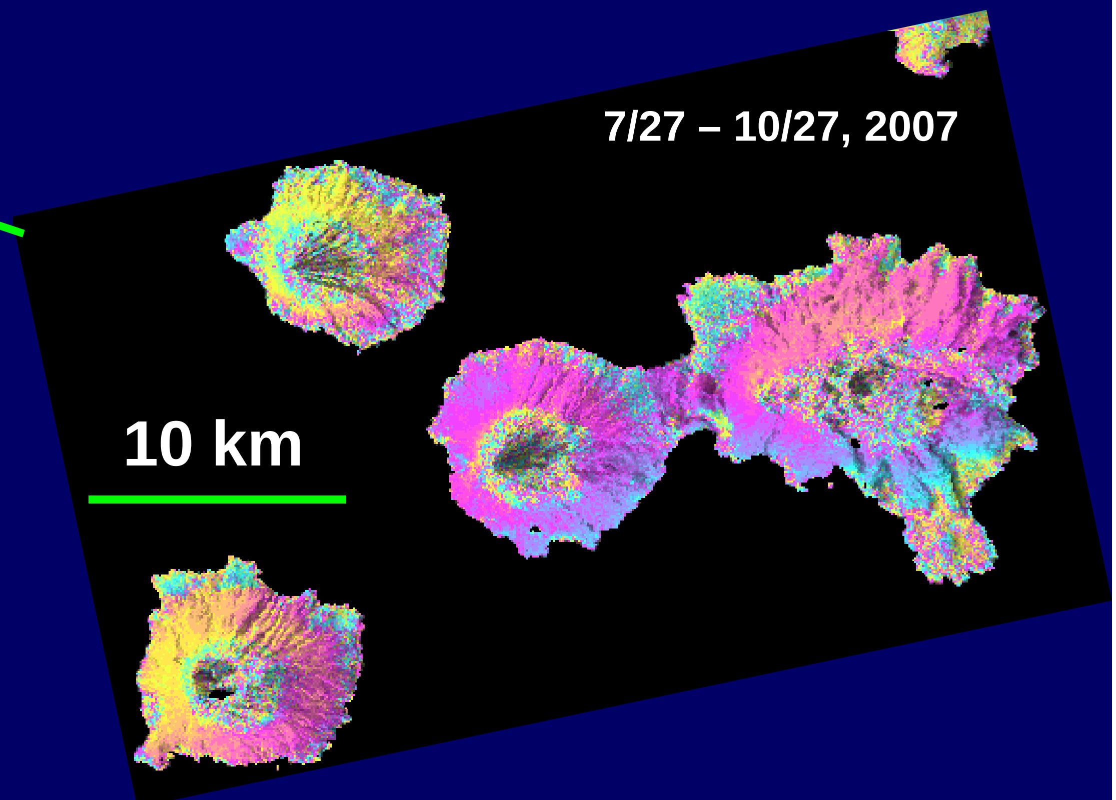
3rd most active volcano In Aleutians.

Moran et al., 2006

USGS

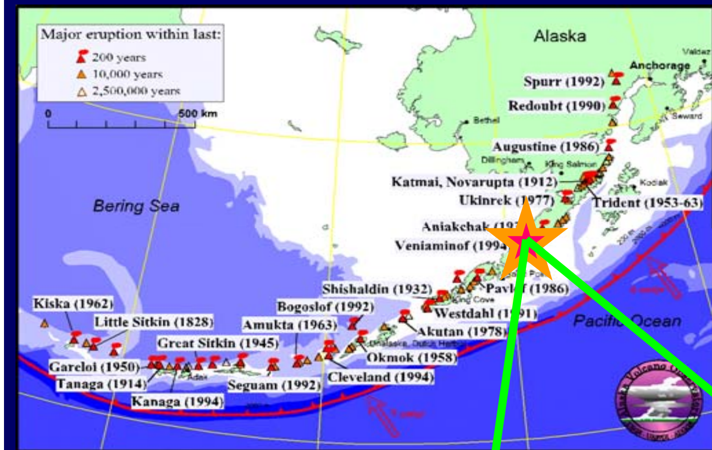
Frequent eruptions at Cleveland

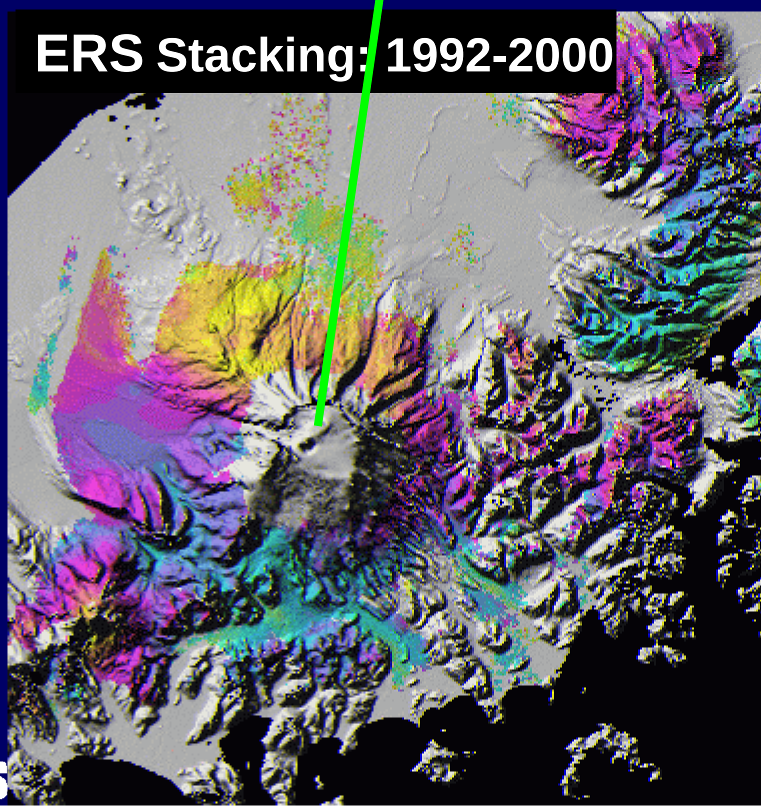


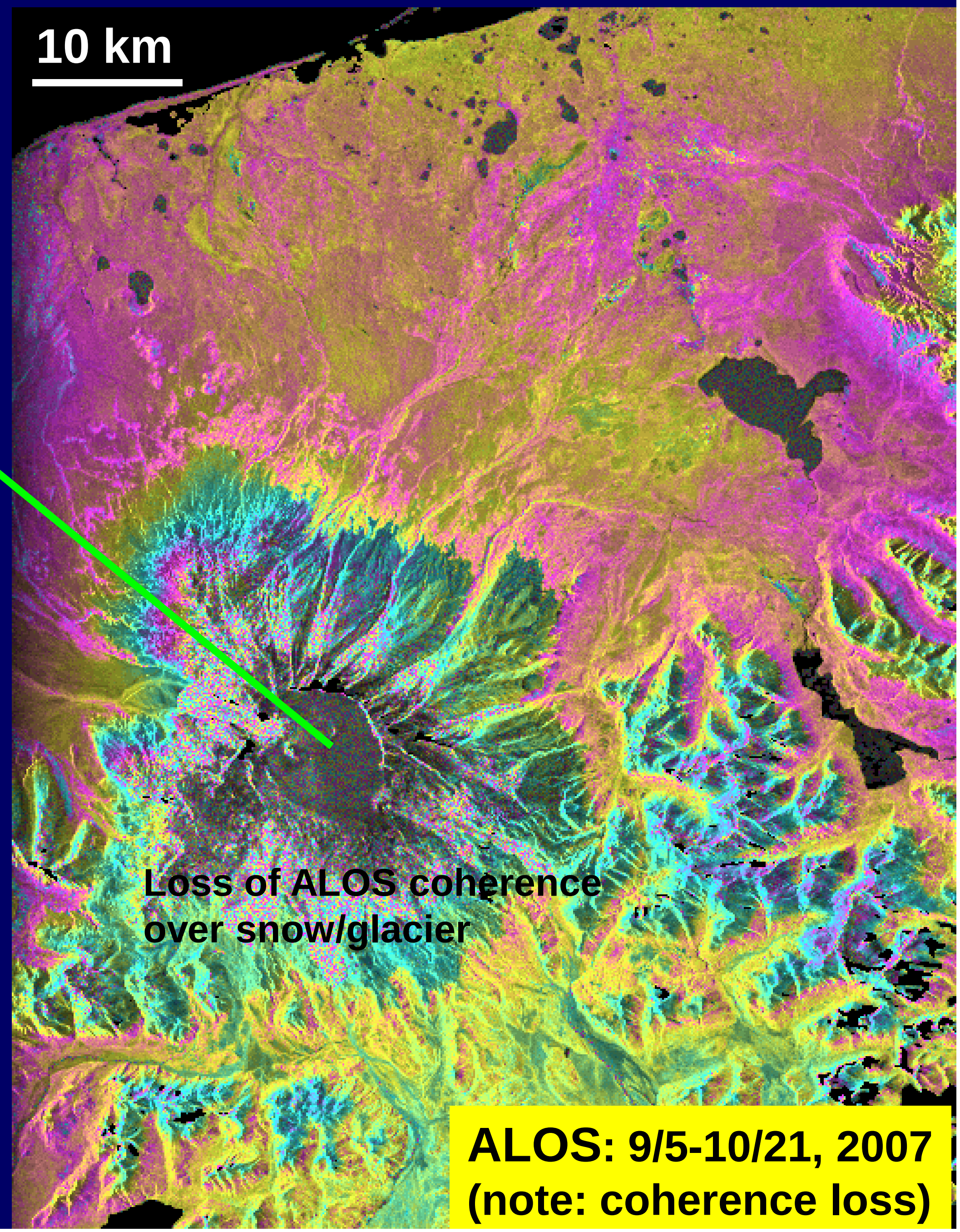


92-day ALOS interferogram spanning an eruption in 2007 (note: lost coherence)

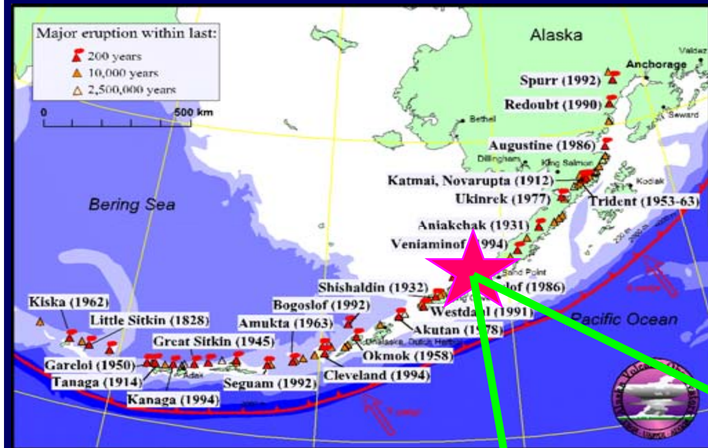
Frequent eruptions at Veniaminof

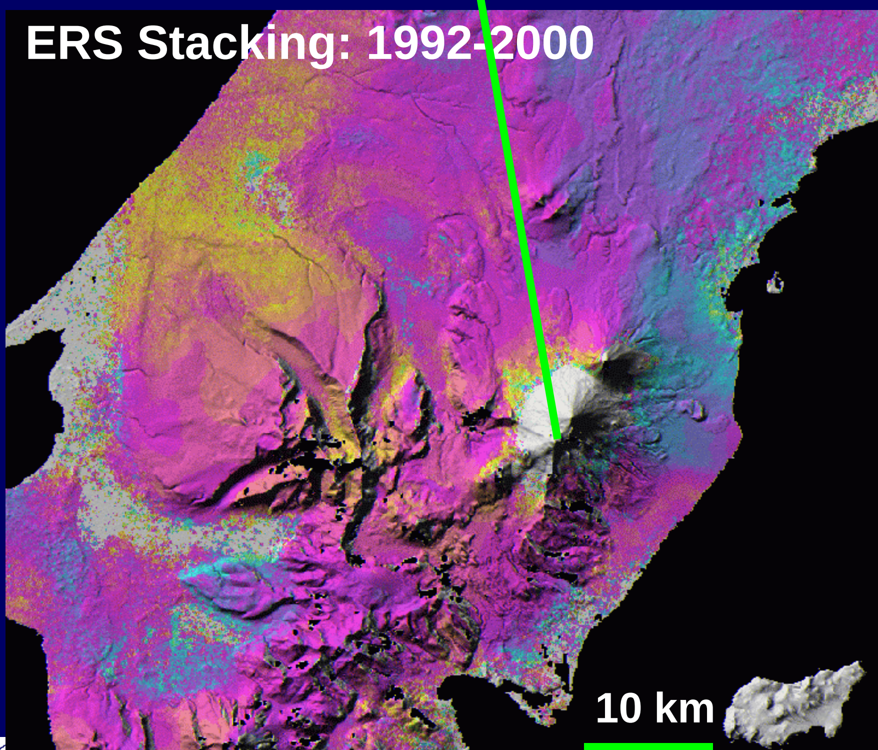


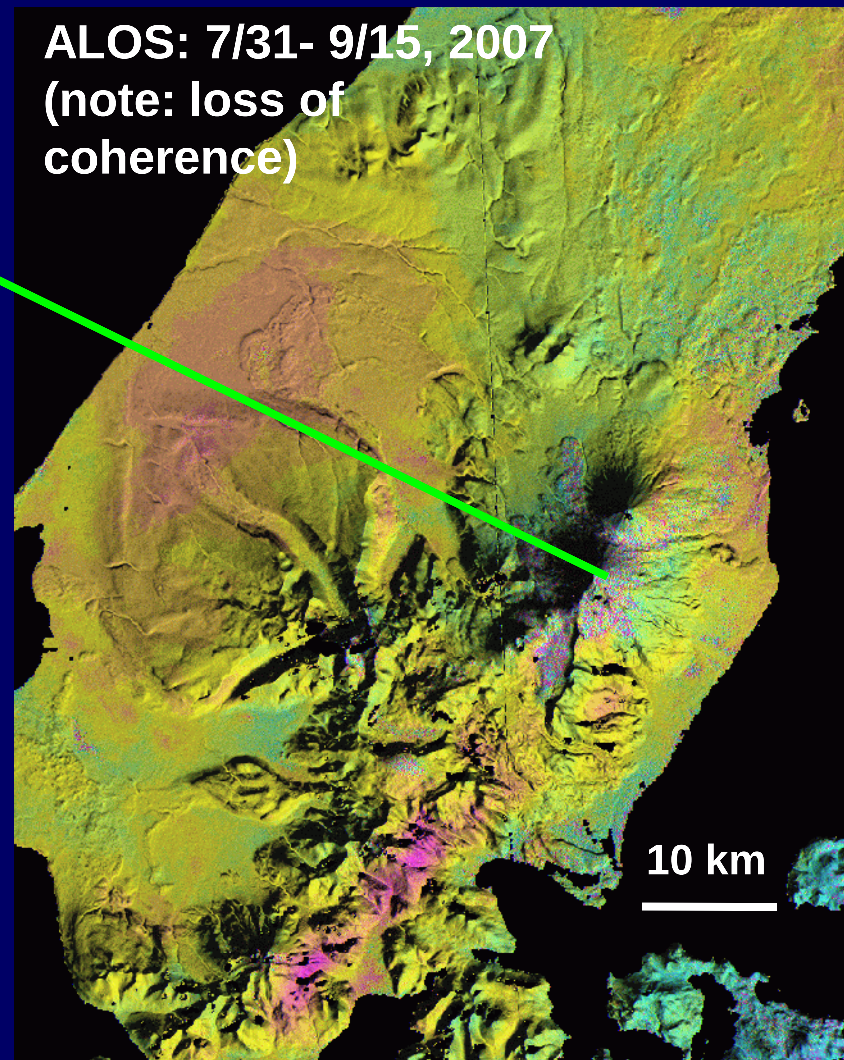




Frequent eruptions at Pavlof







Lack of expected deformation

- All of these volcanoes are stratovolcanoes, have symmetric cones, and are frequently active.

- Co-eruption interferograms with 1- or 2-year separation do not show significant InSAR measurements of deformation associated with recent eruptions. Three possible scenarios:

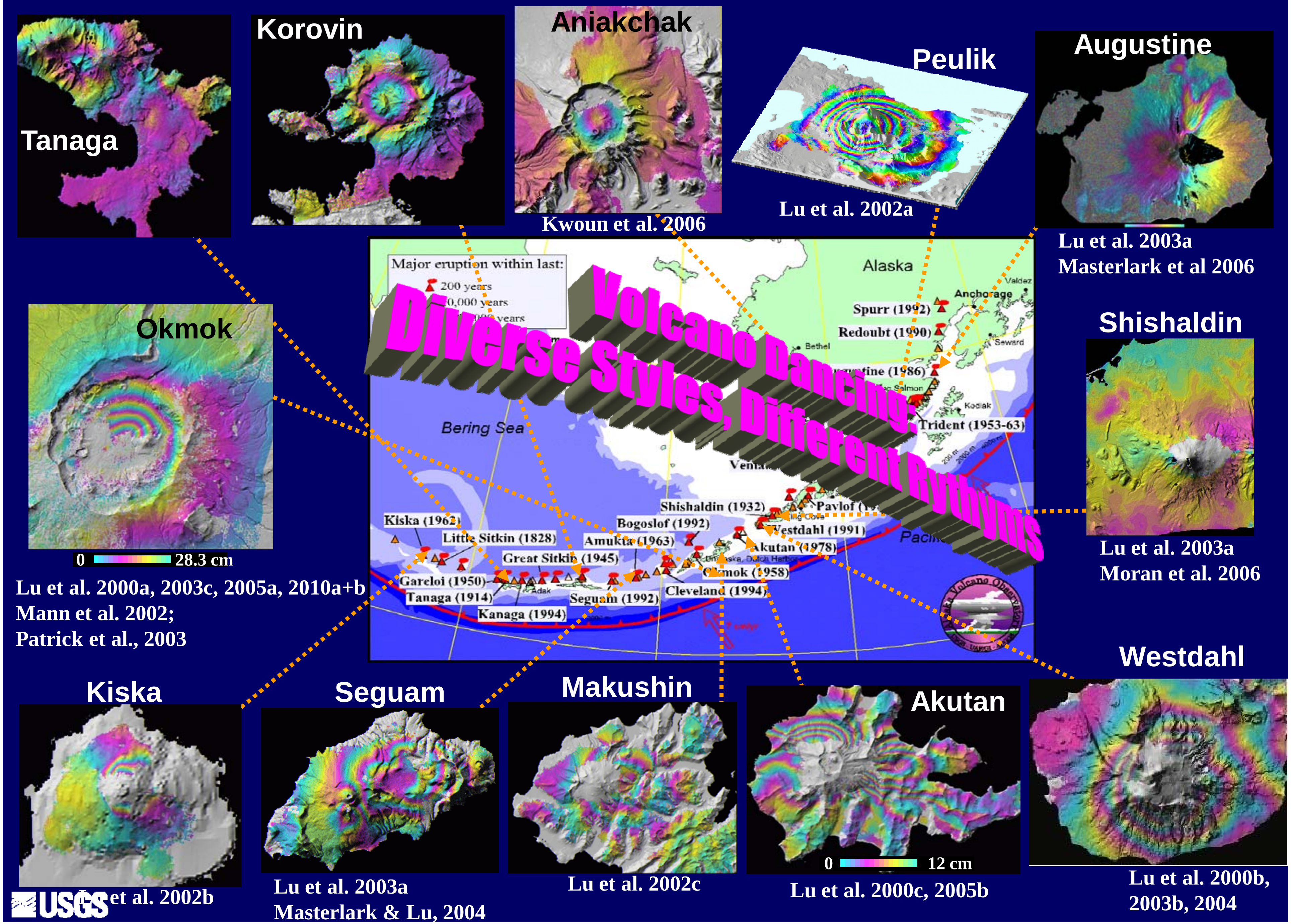
    - 1) no significant pre-eruptive and co-eruptive deformation was associated with these eruptions;

    - 2) short-lived pre-eruptive inflation was balanced by co-eruptive deflation and no net displacement could be observed => Magma accumulation/transfer occur relatively quickly

    - 3) the magma source is very shallow and magma strength is small so that deformation could only occur over the region of lost coherence.

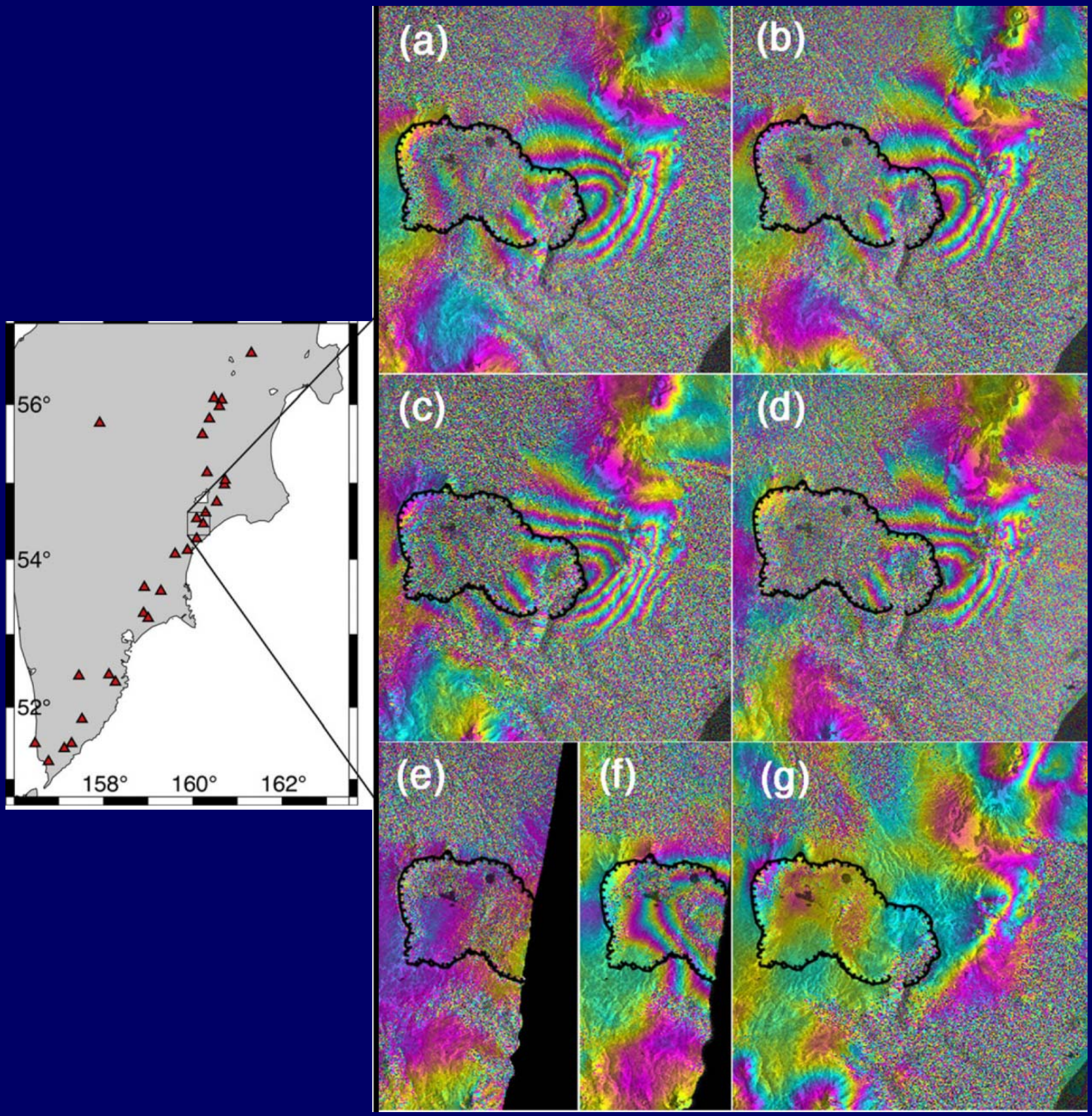
- Call for InSAR images with shorter time separations (a few days) and continuous GPS measurements to capture localized deformation if it exists.

Deformation of Aleutian volcanoes from InSAR



InSAR survey of volcanoes in Kamchatka (2000-2004)

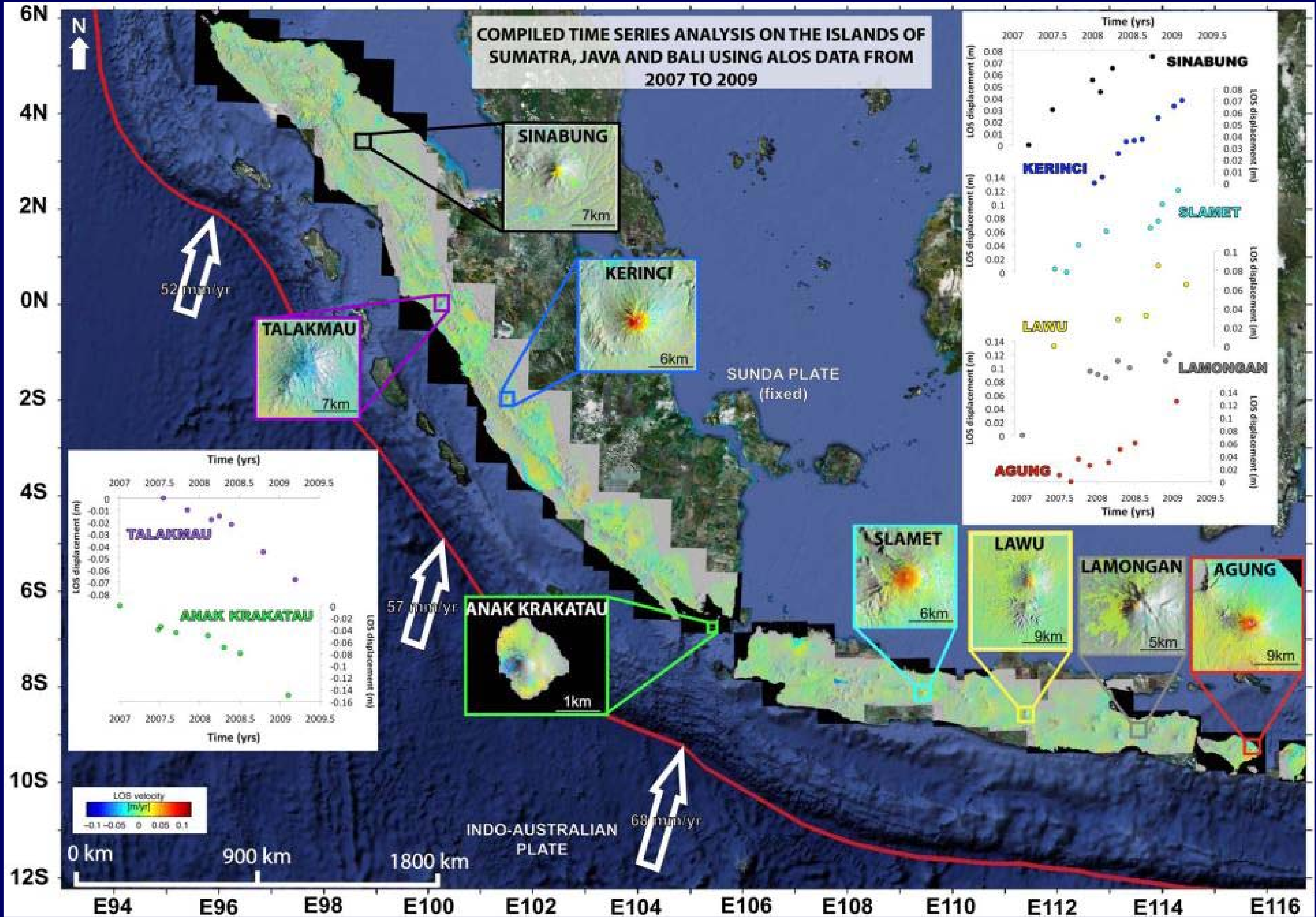
- **No significant deformation at erupting volcanoes**
- **Episodic inflation at Uzon volcano during 2000-2003**



Uzon volcano

USGS **Lundgren & Lu, 2006**

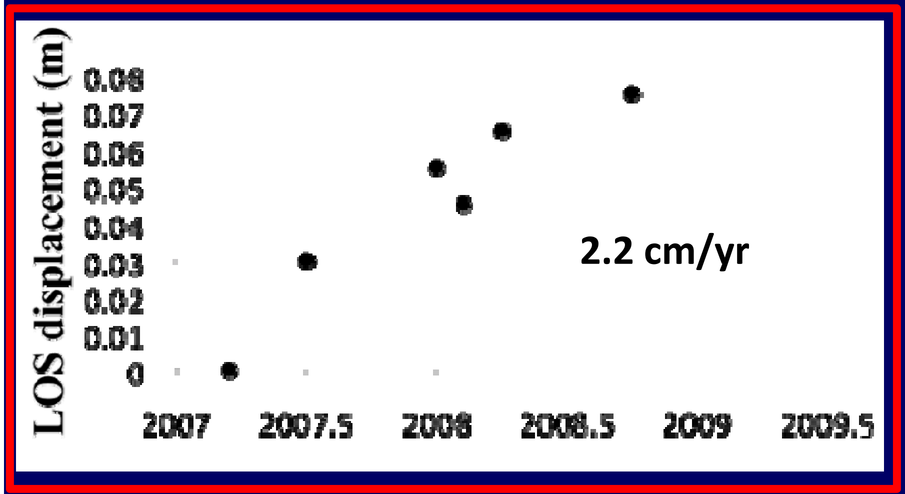
InSAR survey of volcanoes of Sumatra, Java and Bali (2007-9)



Courtesy of E. Chaussard & F. Amelung

USGS

Sinabung, Sumatra

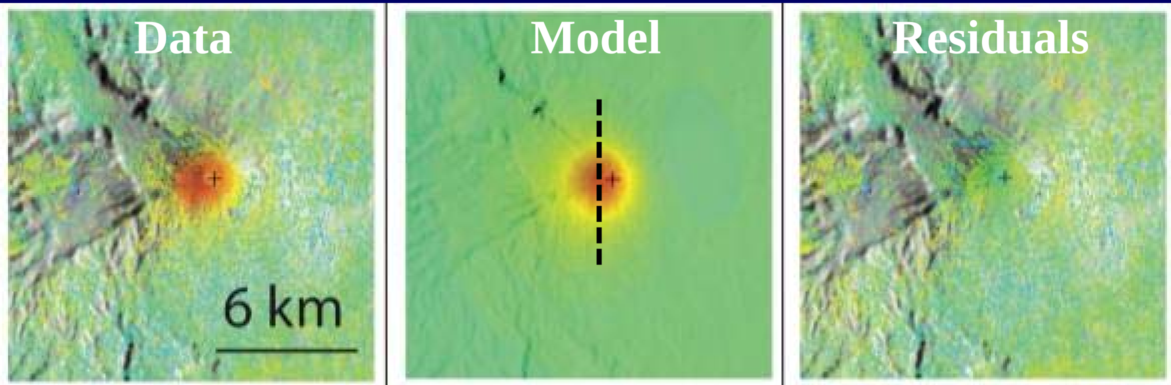


- Last eruption ~300 years ago
- InSAR detects ~8 cm during 2007-2009 before the 2010 eruption
- Source depth: ~0.7 km

USGS

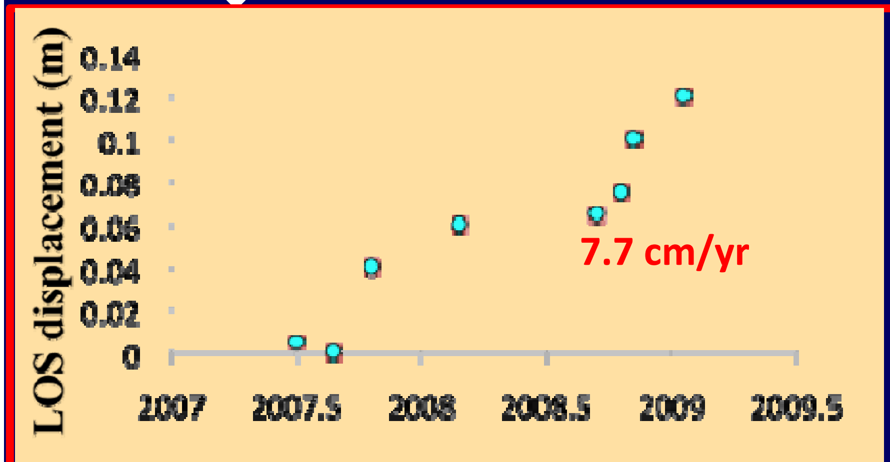
Courtesy of E. Chaussard & F. Amelung

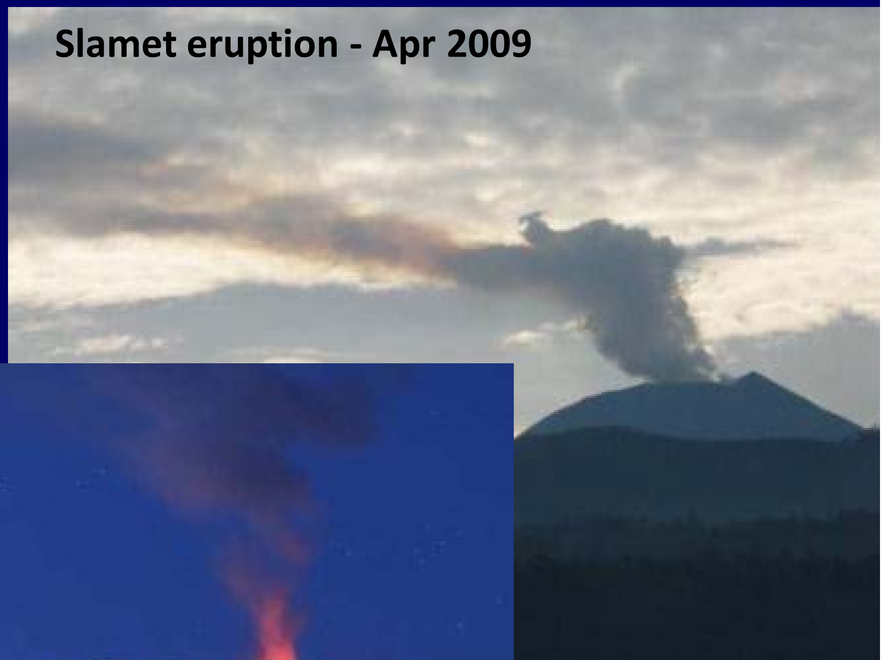
SLAMET (Java)



Depth

1,73 km





- Last eruption: ~2000
- Source depth: ~1.7 km

Courtesy of E. Chaussard & F. Amelung

InSAR survey of volcanoes of Sumatra, Java and Bali (2007-9)

- **Deformation at 8 volcanic centers:**
  - **SUMATRA :**
    - **Sinabung : 4 cm of uplift between 2007.2 and 2009**
    - **Talakmau : 6.8 cm of subsidence between 2007.55 and 2009.2**
    - **Kerinci : 7 cm of uplift between 2008 and 2009.1**
    - **Anak Krakatau : 15 cm of subsidence between 2007 and 2009.1**
  - **JAVA :**
    - **Slamet : 12 cm of uplift between 2007.5 and 2009.05**
    - **Lawu : 6.5 cm of uplift between 2007.1 and 2009.15**
    - **Lamongan : 12 cm of uplift between 2007.1 and 2009**
  - **BALI :**
    - **Agung : 13 cm of uplift between 2007.5 and 2009.1**

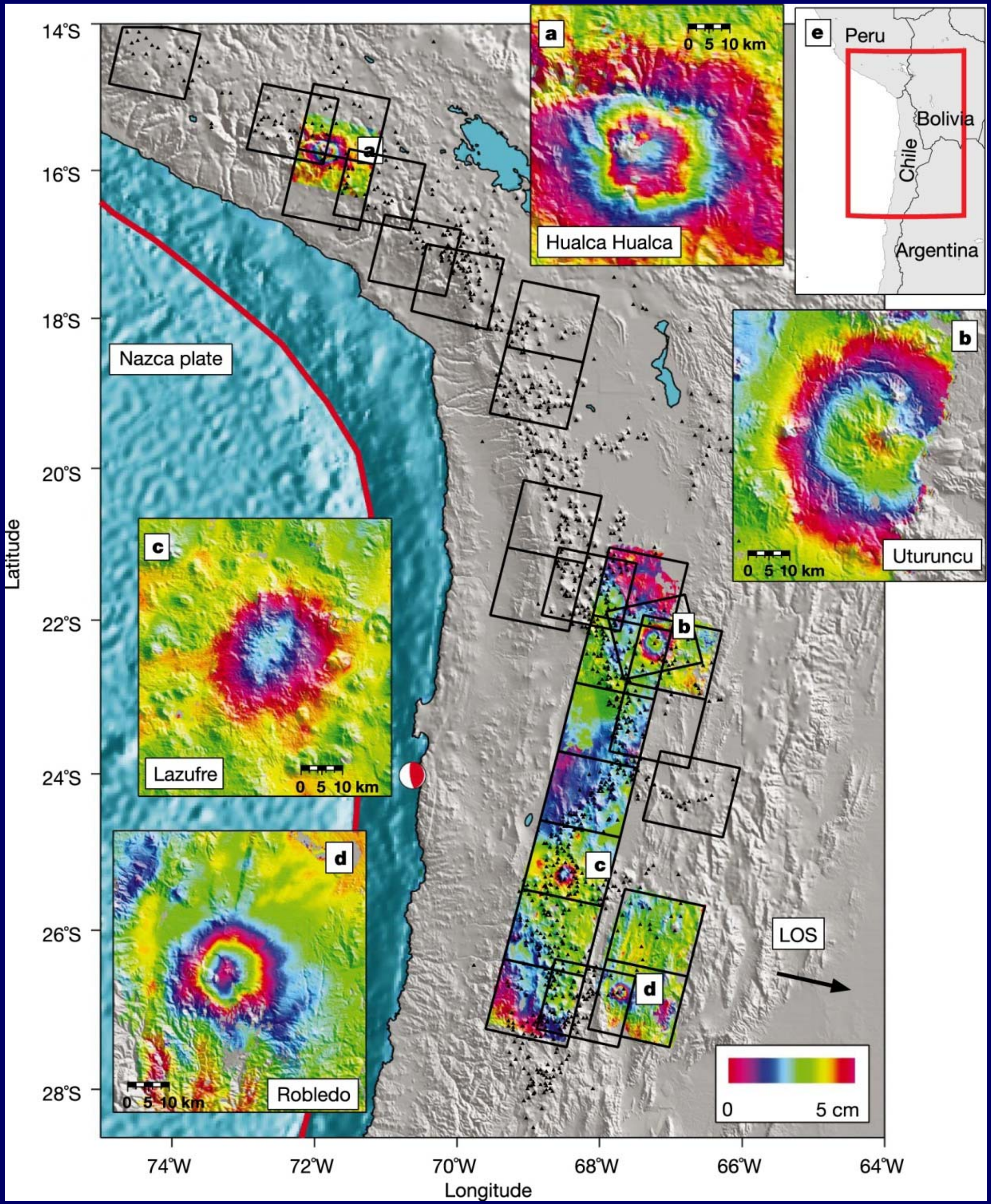
USGS

Courtesy of E. Chaussard & F. Amelung

InSAR survey of volcanoes in Andes

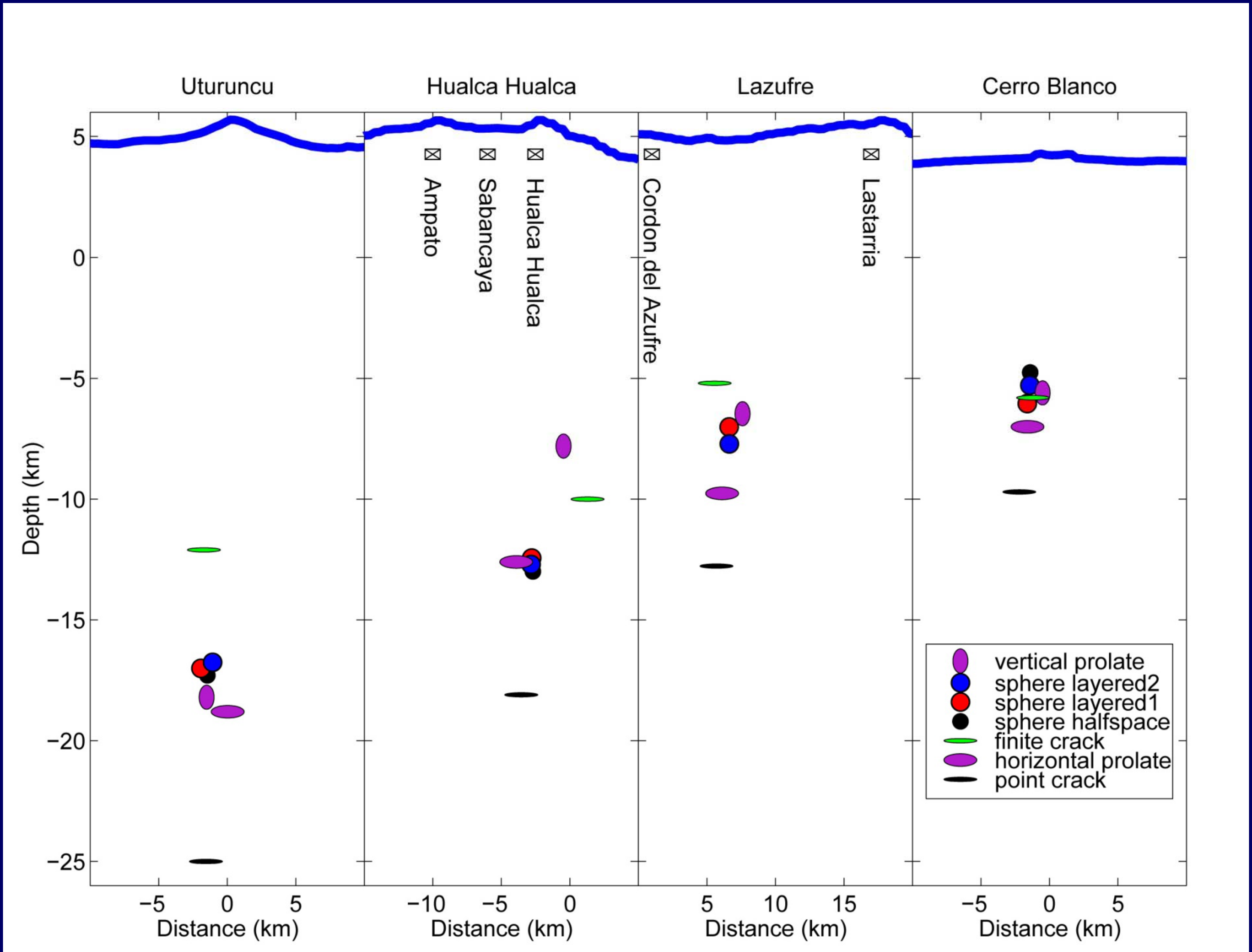
- None of these deformation centers are at volcanoes currently classified as potentially active

- Co-eruption interferograms show no significant deformation



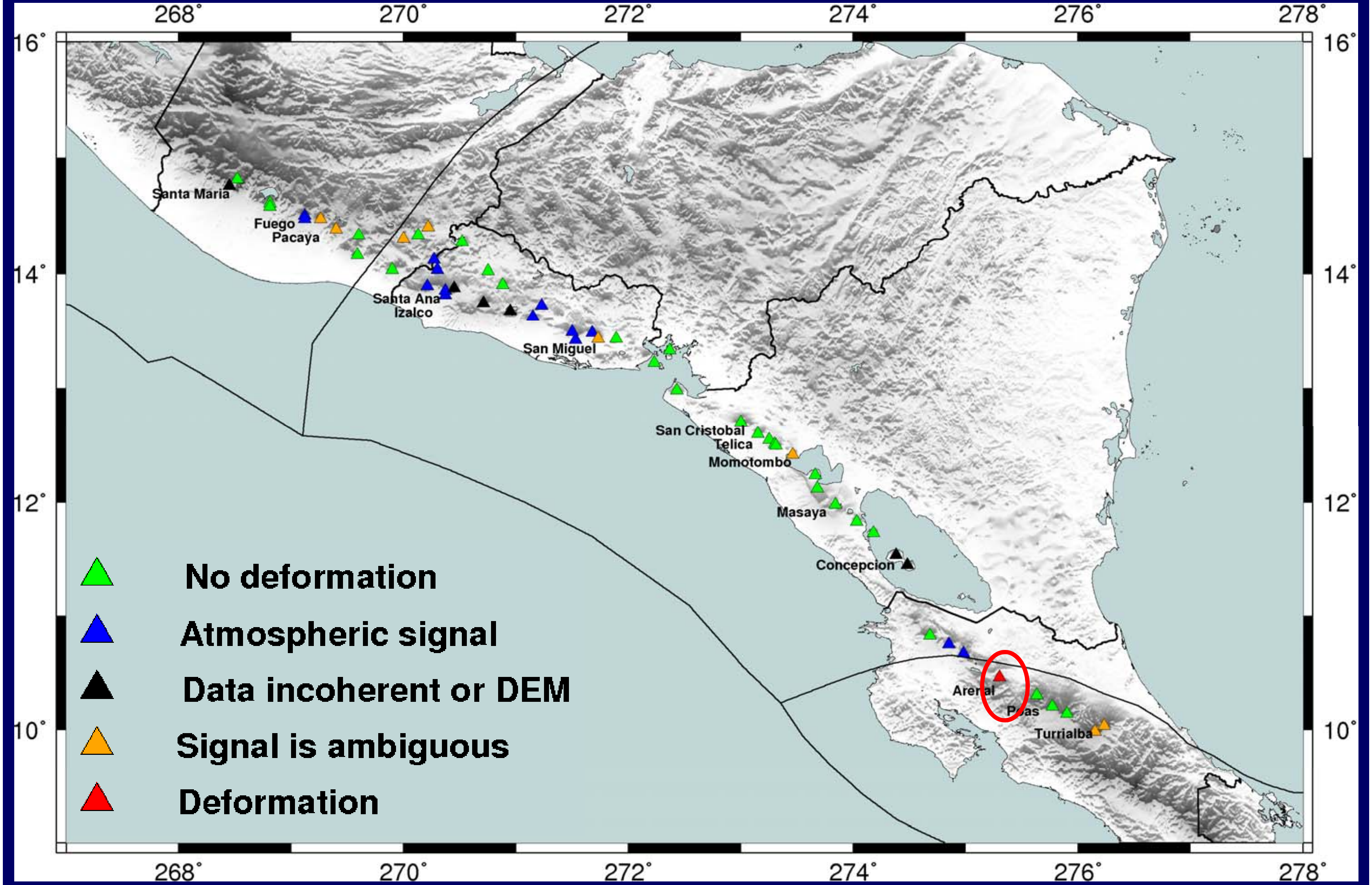
USGS Pritchard & Simons, 2002

Source depth of deforming volcanoes



Pritchard & Simons, 2004

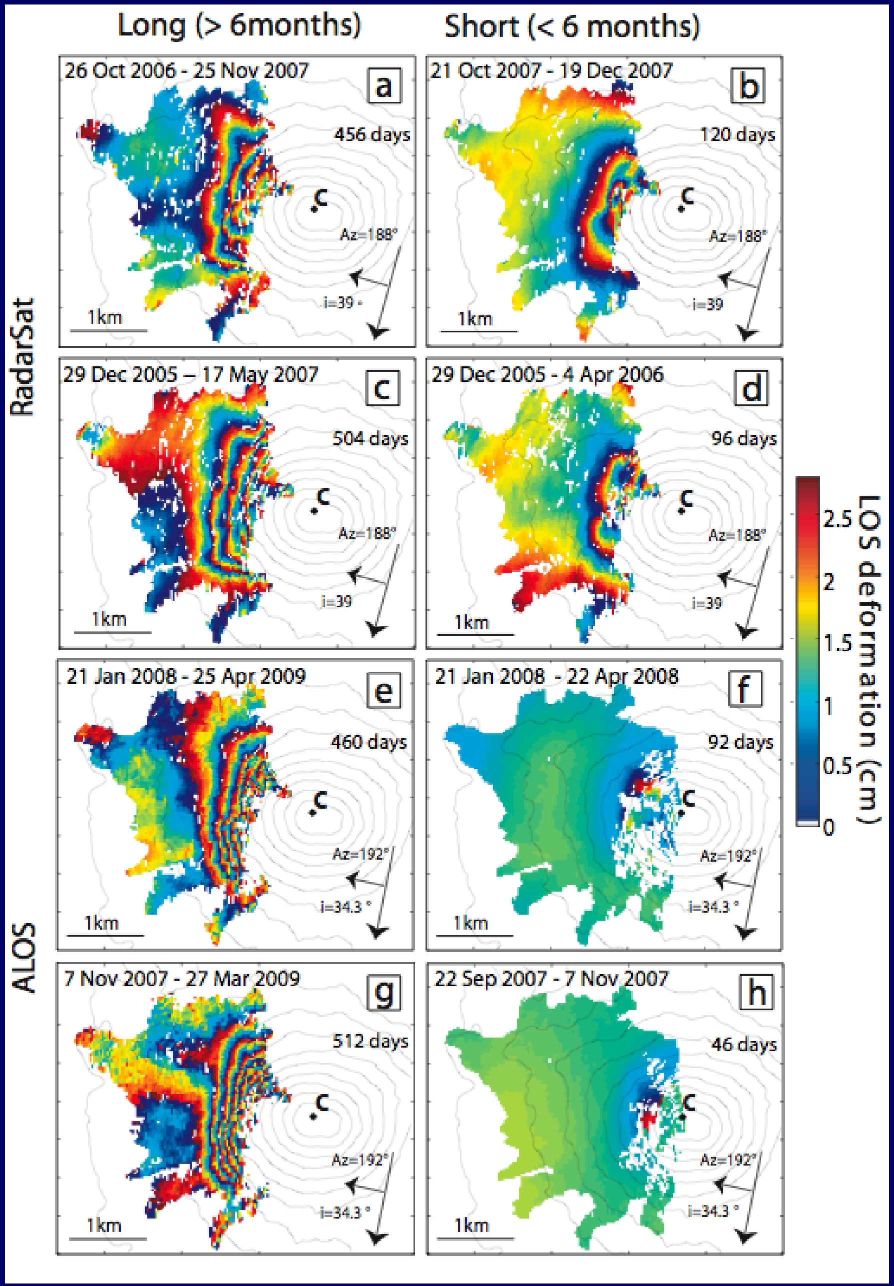
InSAR Imaging of Volcanoes in Central America (2007-9)



USGS

Courtesy of S. Ebmeier, Oxford Univ

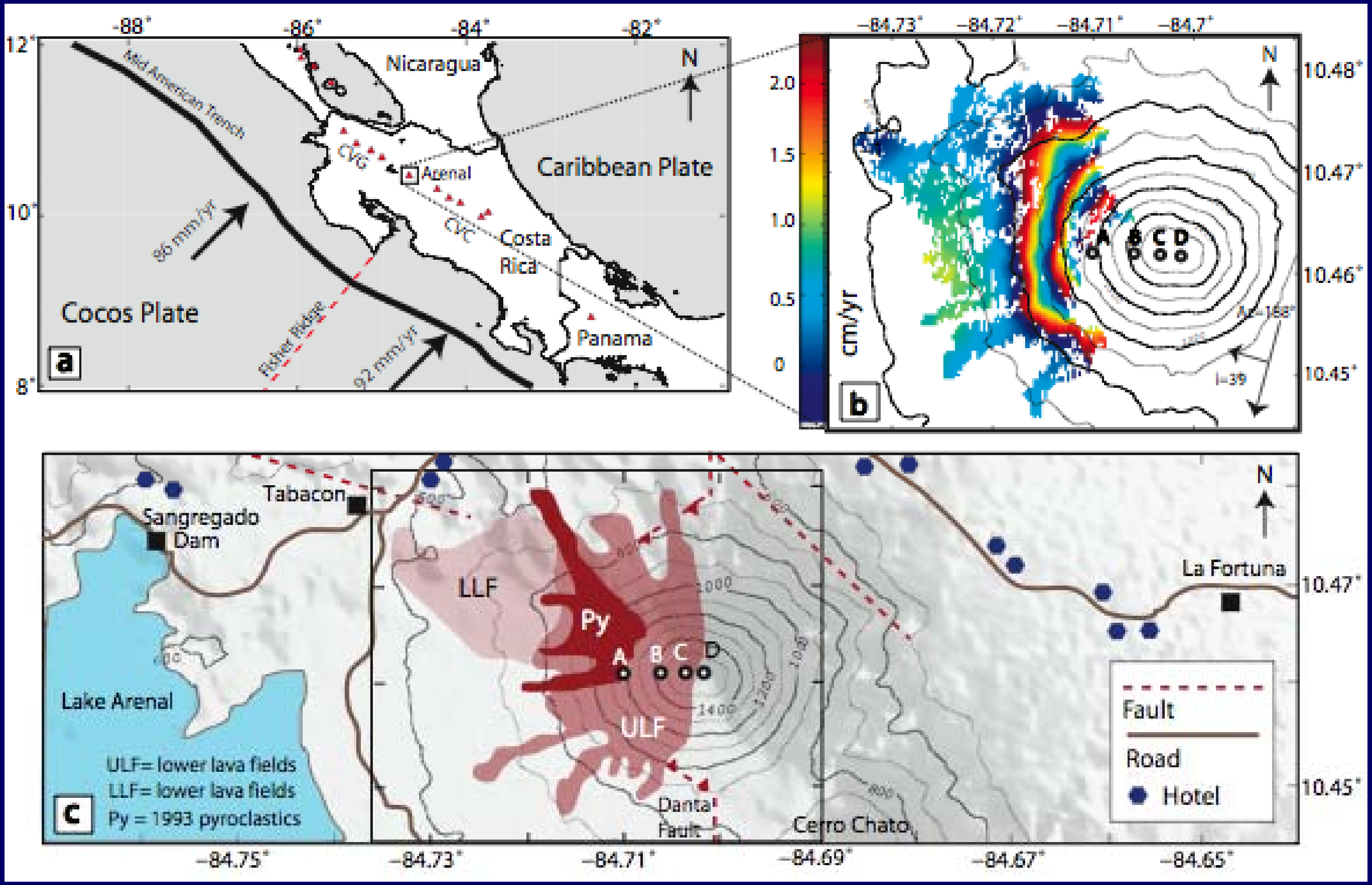
Arenal Volcano



Examples of L-band & C-band interferograms showing deformation between 2005 and 2009

Ebmeier et al., G[3], 2010

Arenal Volcano

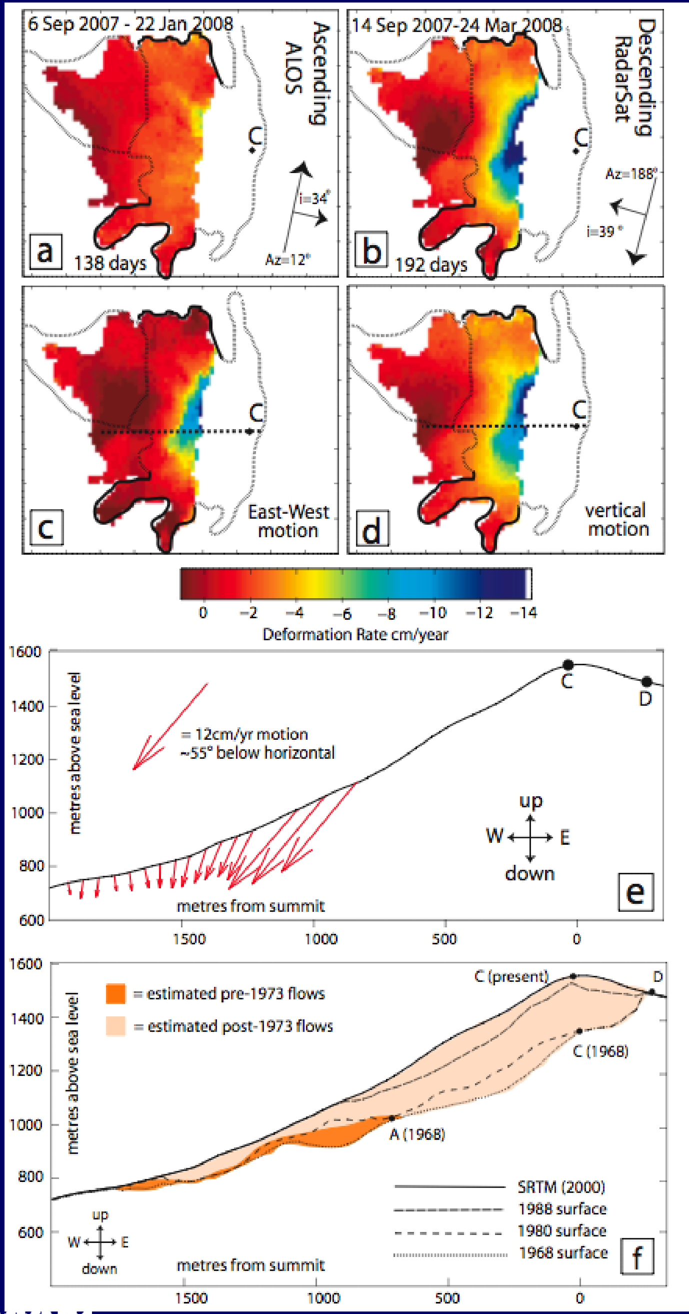


Average Radarsat signal (2005-2009) for interferograms over Arenal. Coherence is limited to younger post-1968 eruption deposits

USGS

Ebmeier et al., G^3, 2010

Arenal Volcano



Ascending and descending interferograms (a+b) used to resolve vertical (d) and horizontal (c) components of motion.

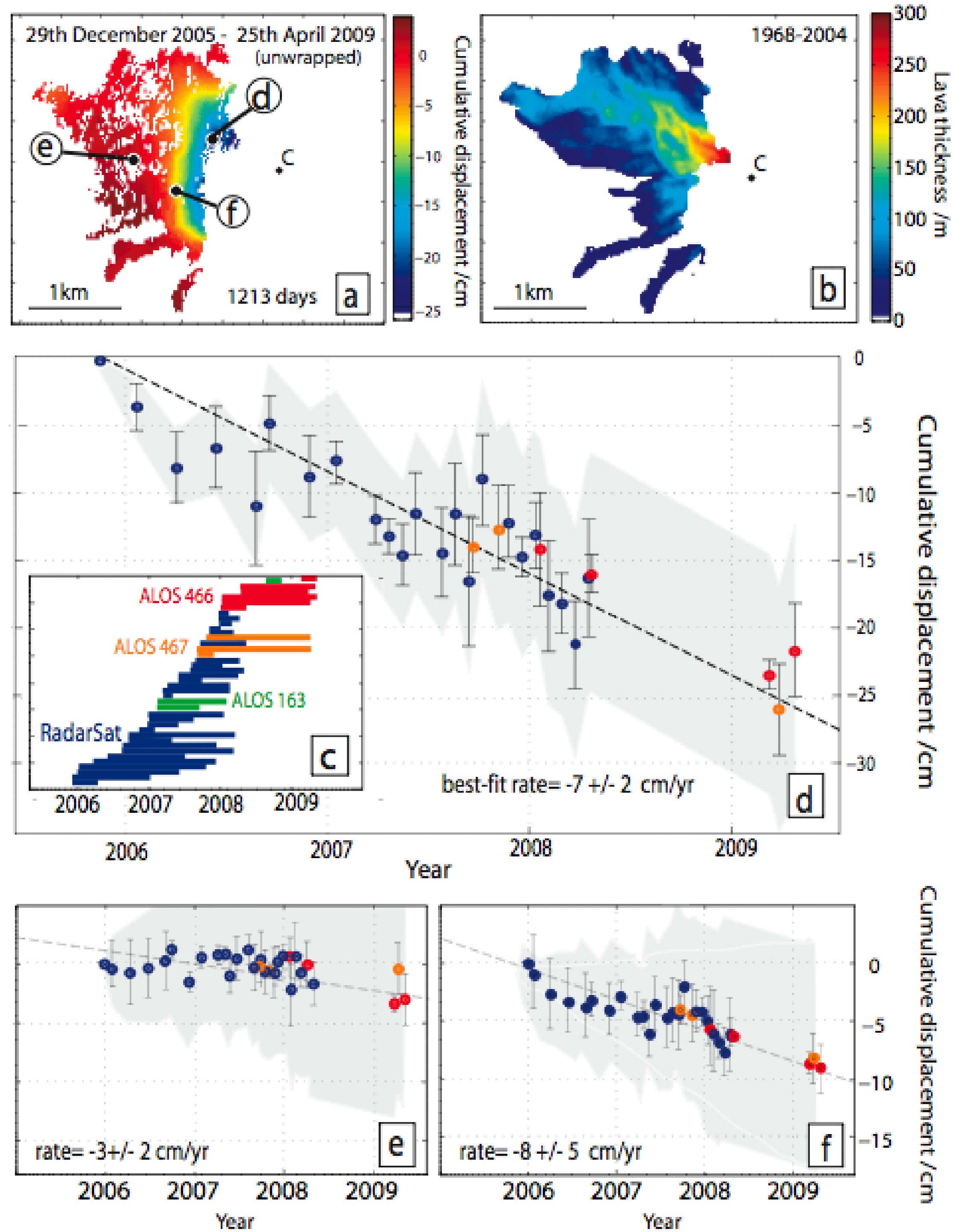
e) shows resolved vectors of deformation on an E-W profile through Arenal volcano

We interpret this motion as gravity-driven slip (~7cm/yr downslope), possibly on the plane between post-1968 lavas and older paleosols.

Ebmeier et al., G^3, 2010

Arenal Volcano

Timeseries showing deformation over time at various points on Arenal's western flank.



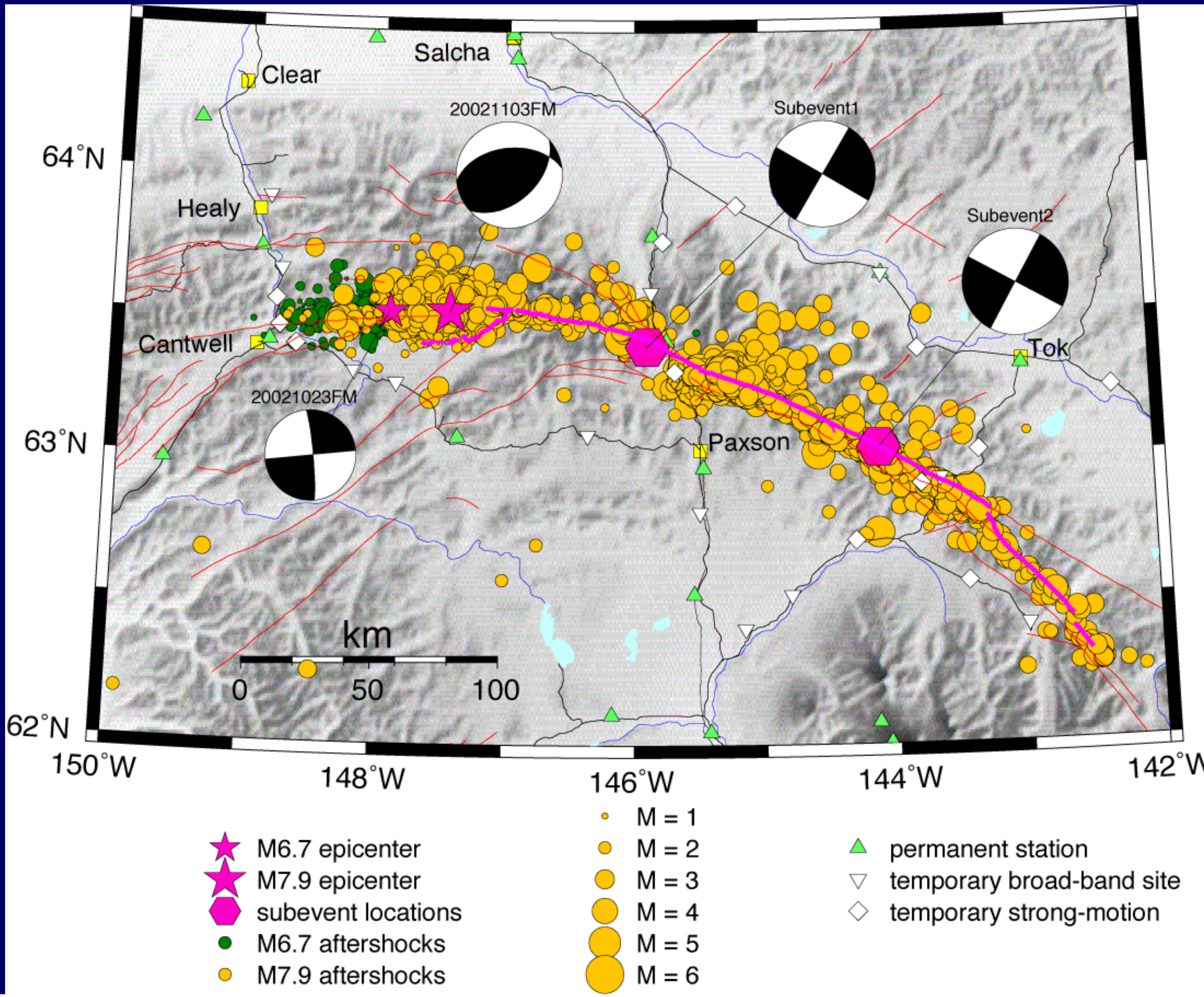
USGS

Ebmeier et al., G[3], 2010

Earthquakes

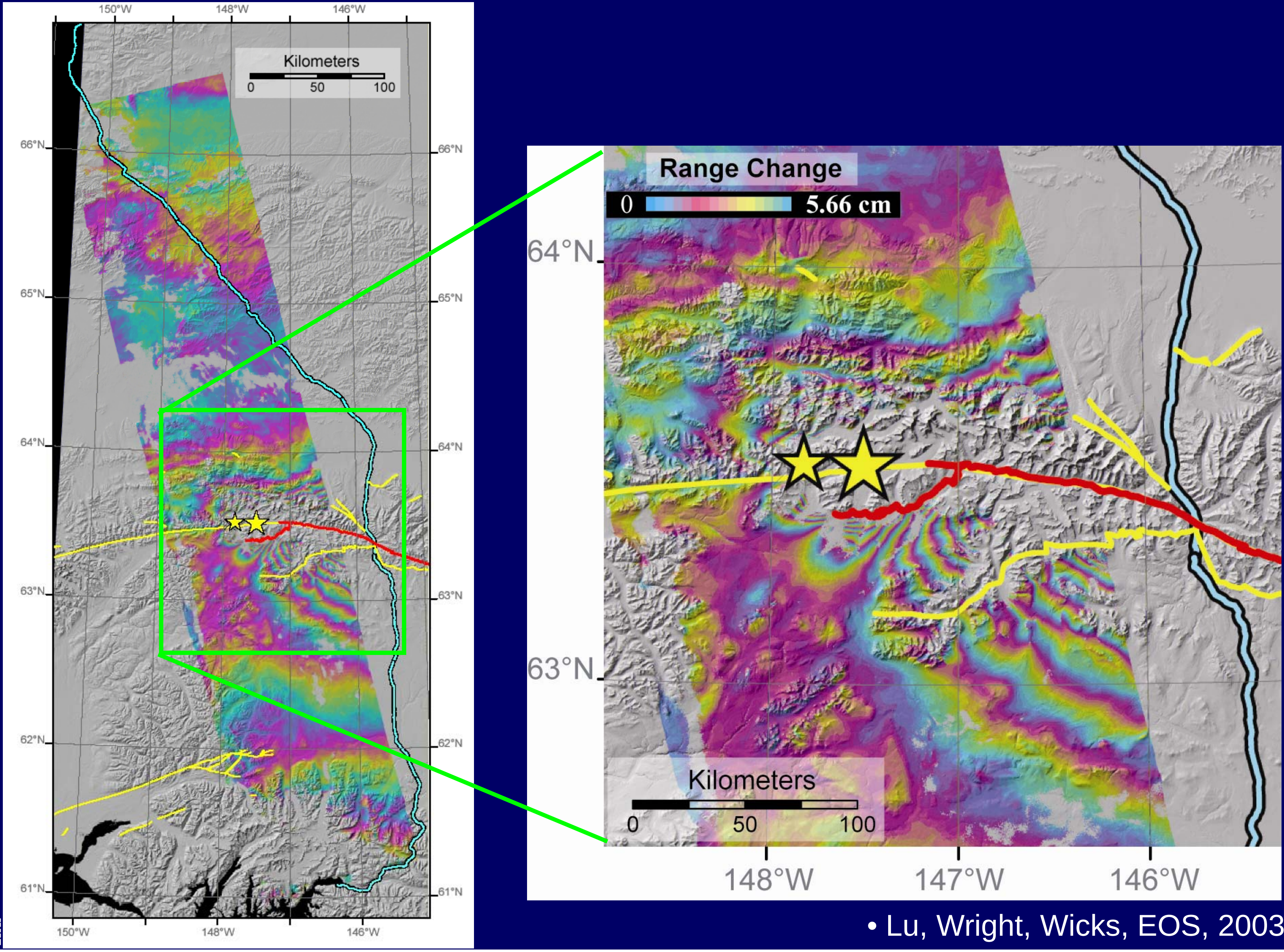
Measuring spatial and temporal patterns of surface deformation in seismically active regions are extraordinarily useful for estimating seismic risks and improving earthquake predictions

Nov 3, 2002 Denali Earthquake



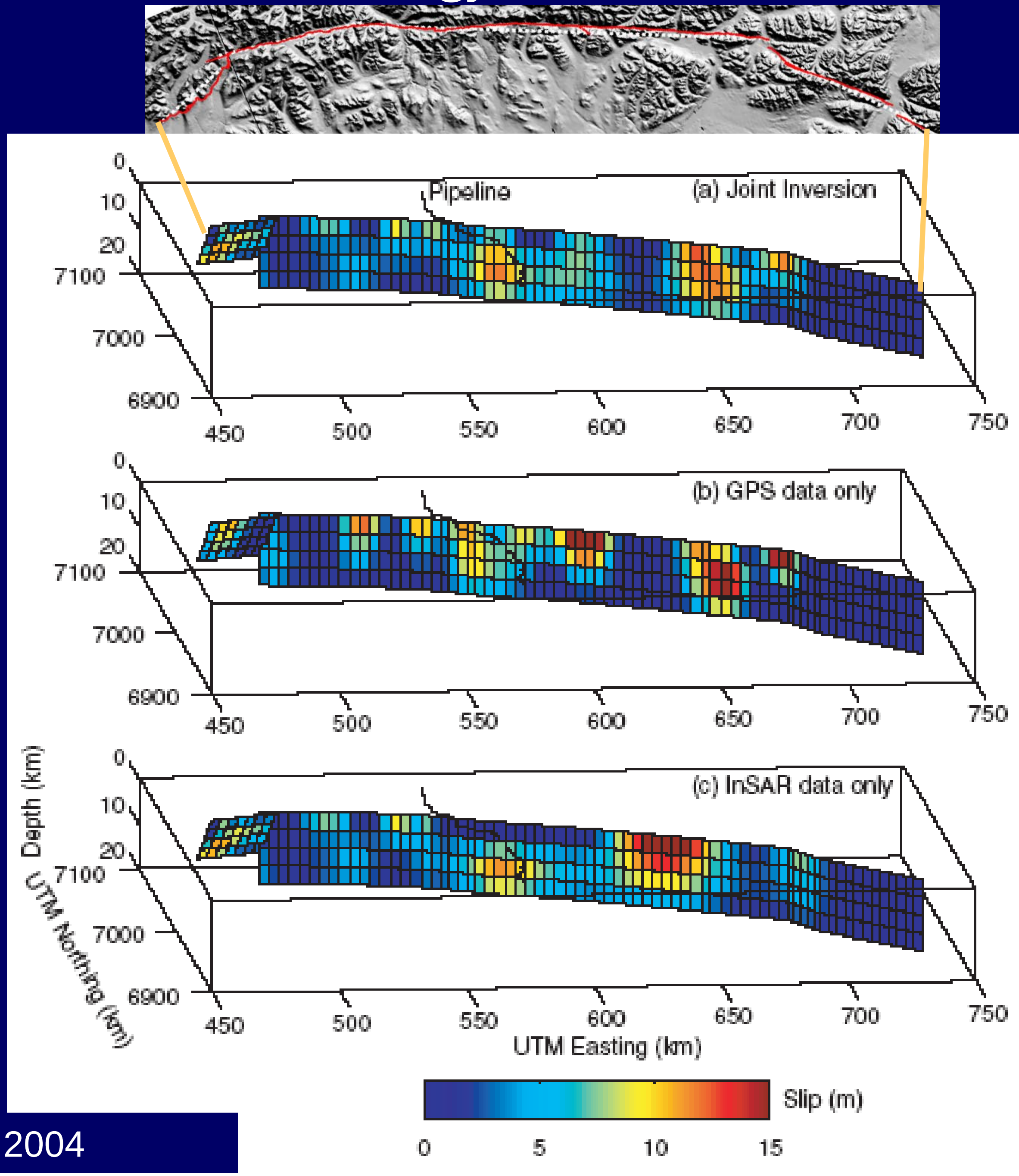
USGS

Co-seismic deformation: Nov 3, 2002 Earthquake



• Lu, Wright, Wicks, EOS, 2003

Seismic energy distribution



Joint Inversion

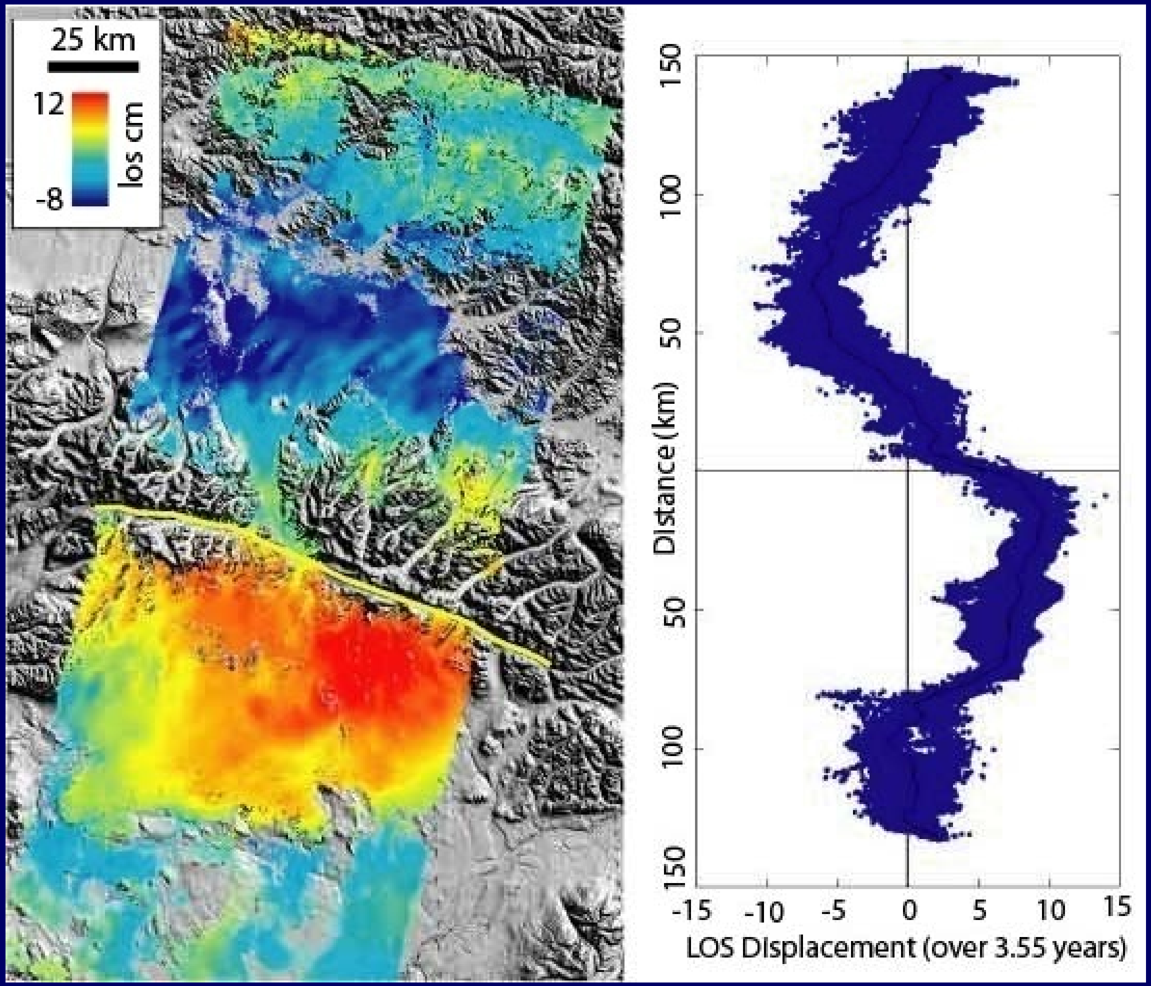
Inversion from GPS data

Inversion from InSAR data

• Wright, Lu, Wicks, 2004

Post-seismic deformation: Nov 3, 2002 Earthquake

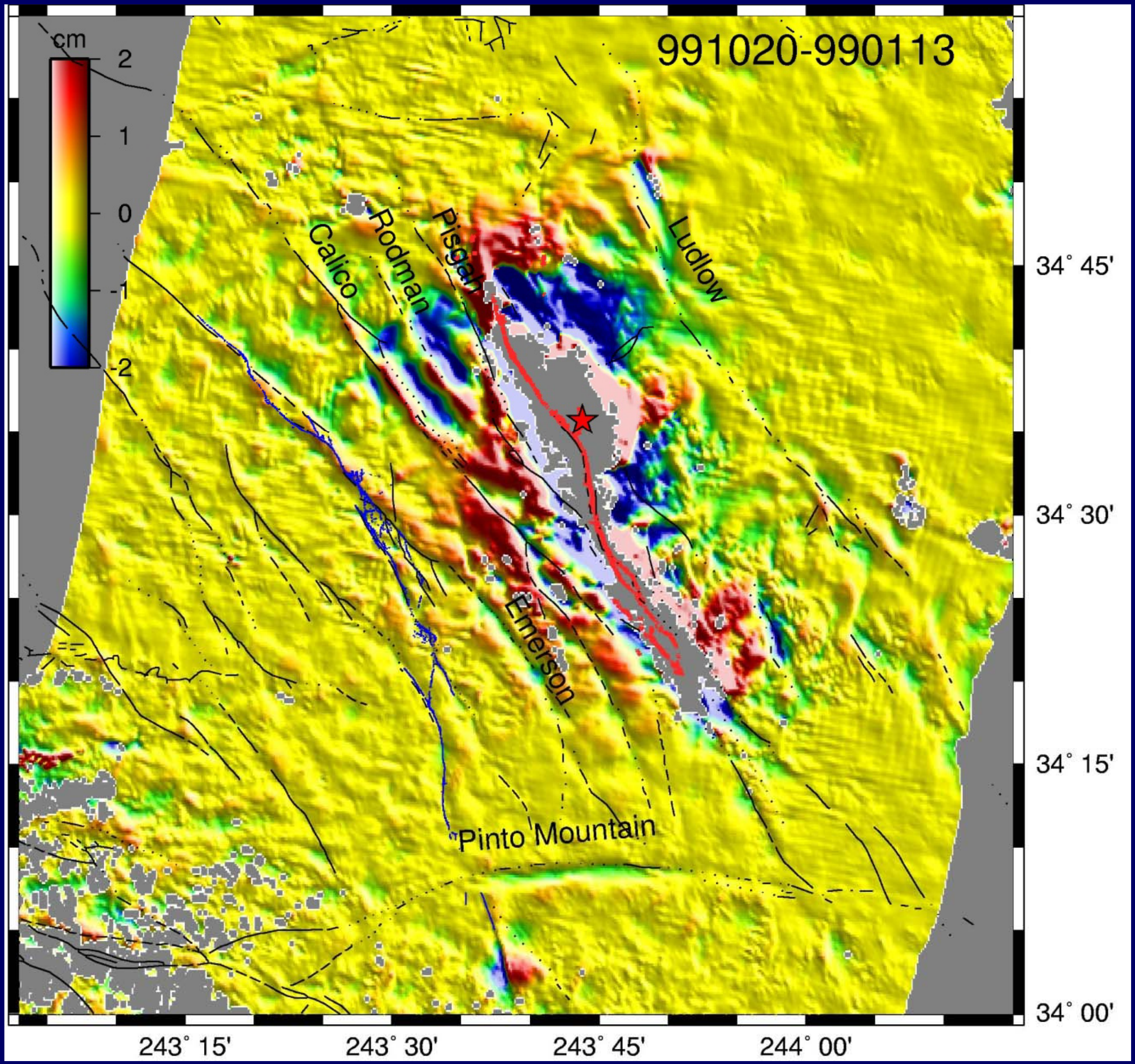
Measuring the response of the Earth to an earthquake can provide vital clues to the properties of the Earth's crust and upper mantle



Ground response to the 2002 Denali Fault earthquake during 2003–2004 (Biggs et al., 2009). Peak deformation is at a distance of ~60 km, suggesting that the viscoelastic USGS tion occurs below 60-km depth.

Post-seismic deformation

Deformation on nearby faults induced by the stress changes generated by the earthquake



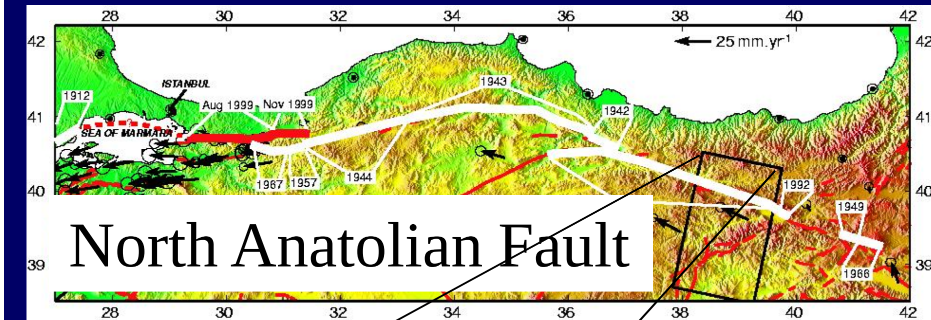
1999 Hector Mine Earthquake, CA

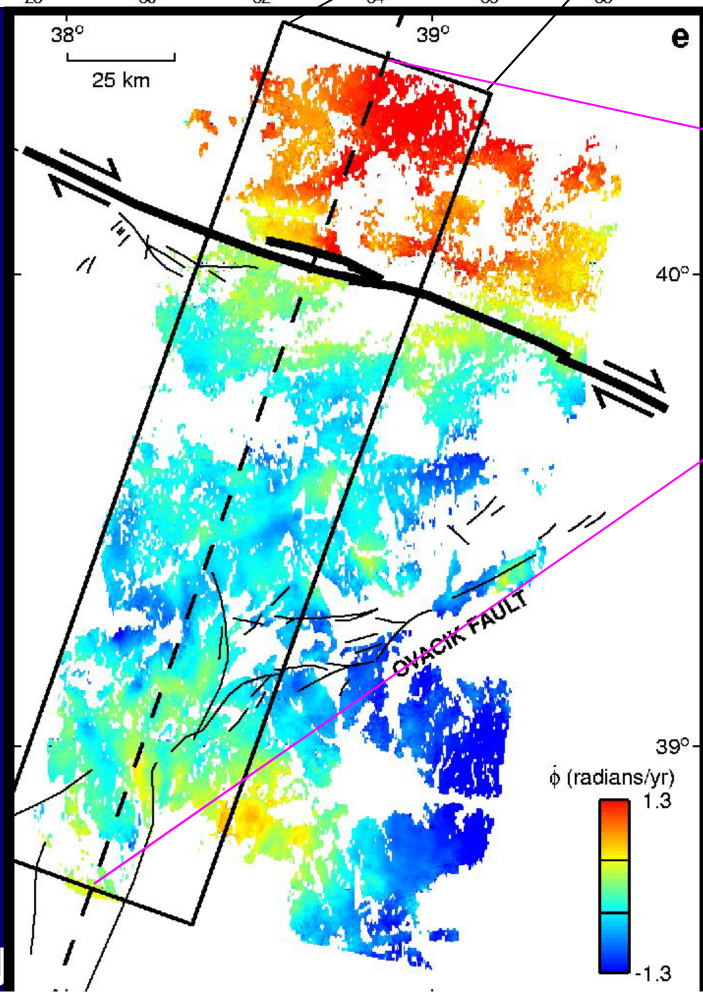
Fialko et al., 2002

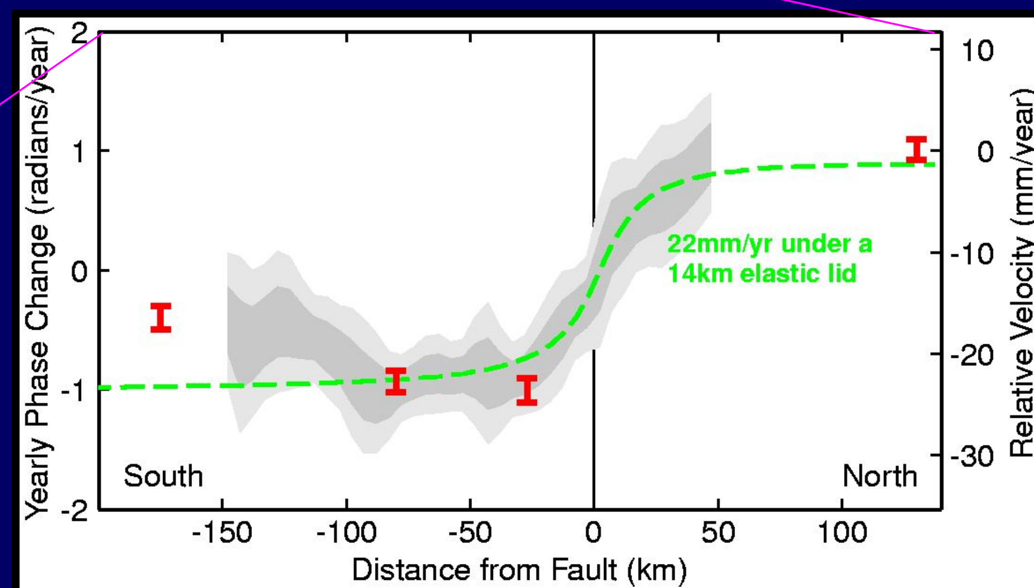
USGS

Inter-seismic deformation

Strain build-up between large earthquakes





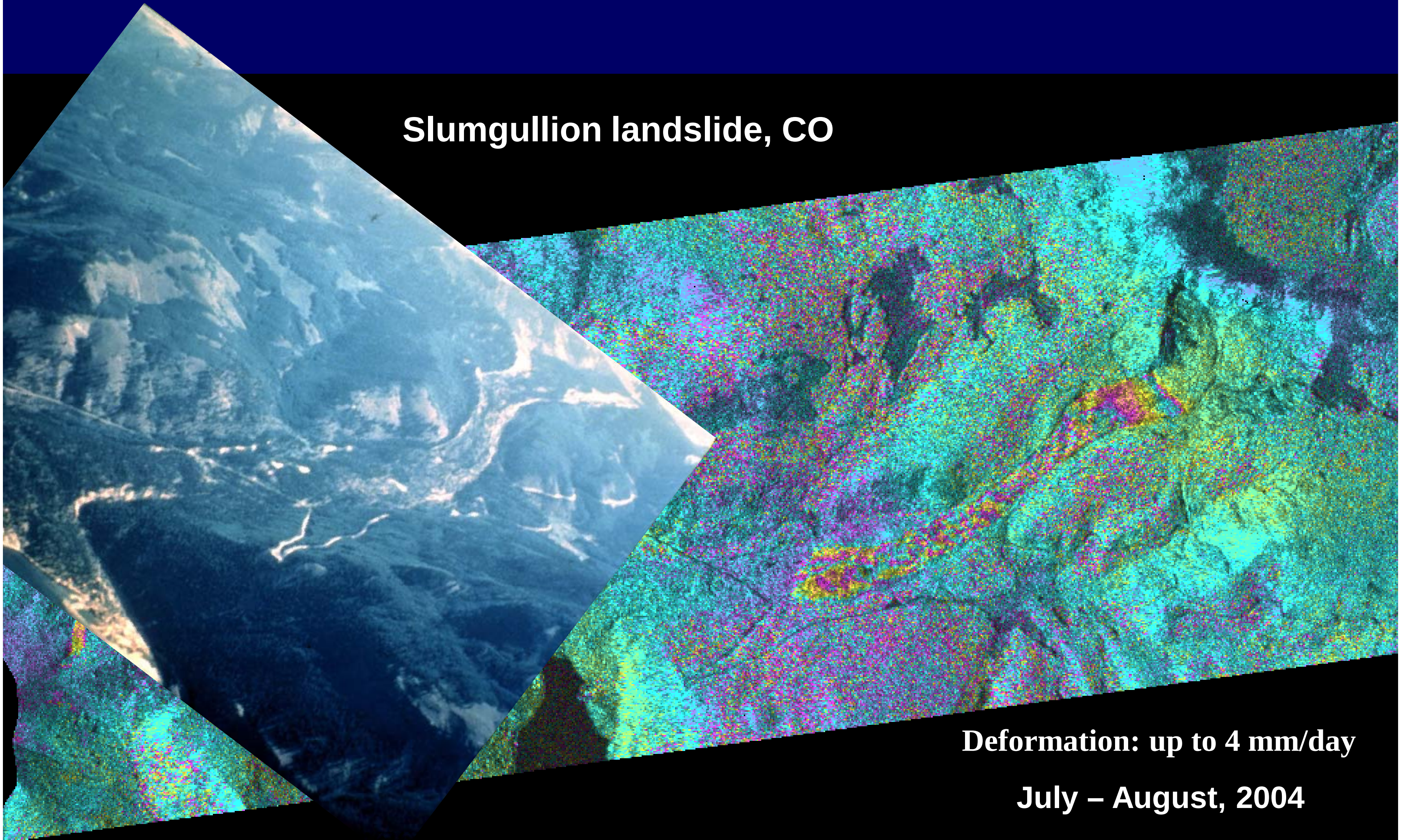


Wright et al., 2001

Landslides

Measuring and documenting how landslides develop and are activated are prerequisites to minimize the hazards they pose in areas of rapid urban growth

Landslide monitoring from InSAR



Slumgullion landslide, CO

Deformation: up to 4 mm/day

July – August, 2004

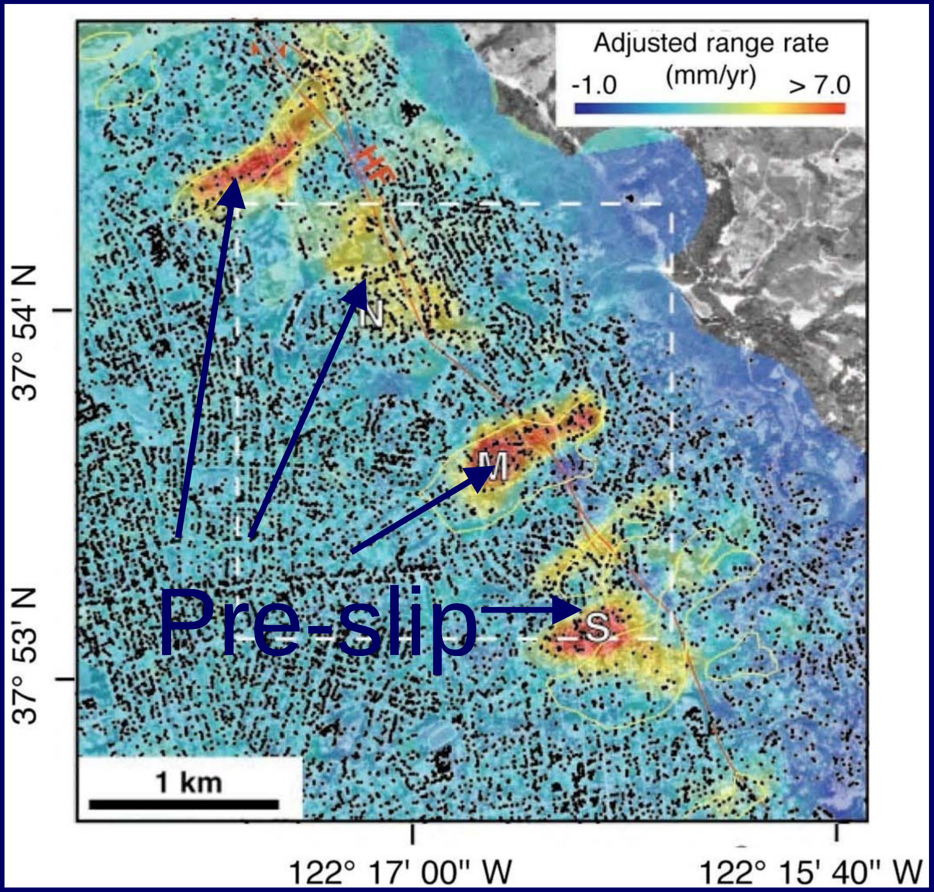
Range Change

0 — 2.8 cm

• Lu et al., 2010

USGS

Monitoring Landslides Over Berkeley Hills, California



- Pre-slip before landslides is observable
- Mitigate losses from landslides

USGS

Courtesy of G. Hilley

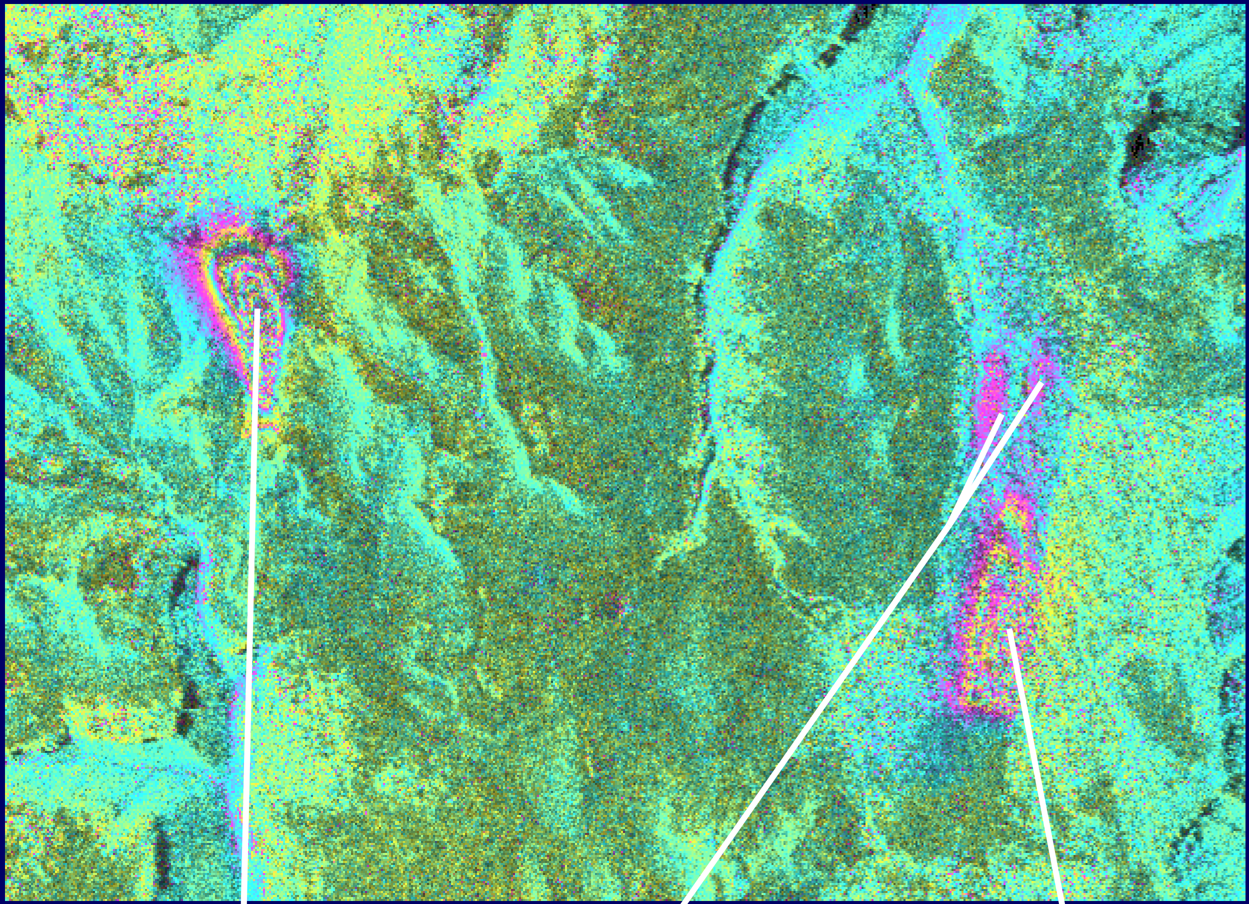
Mapping of Mining-Related Subsidence

ALOS PALSAR InSAR image of Dec 6, 2006 – June 8, 2007

Subsidence

0 **15.4 cm**

5 km



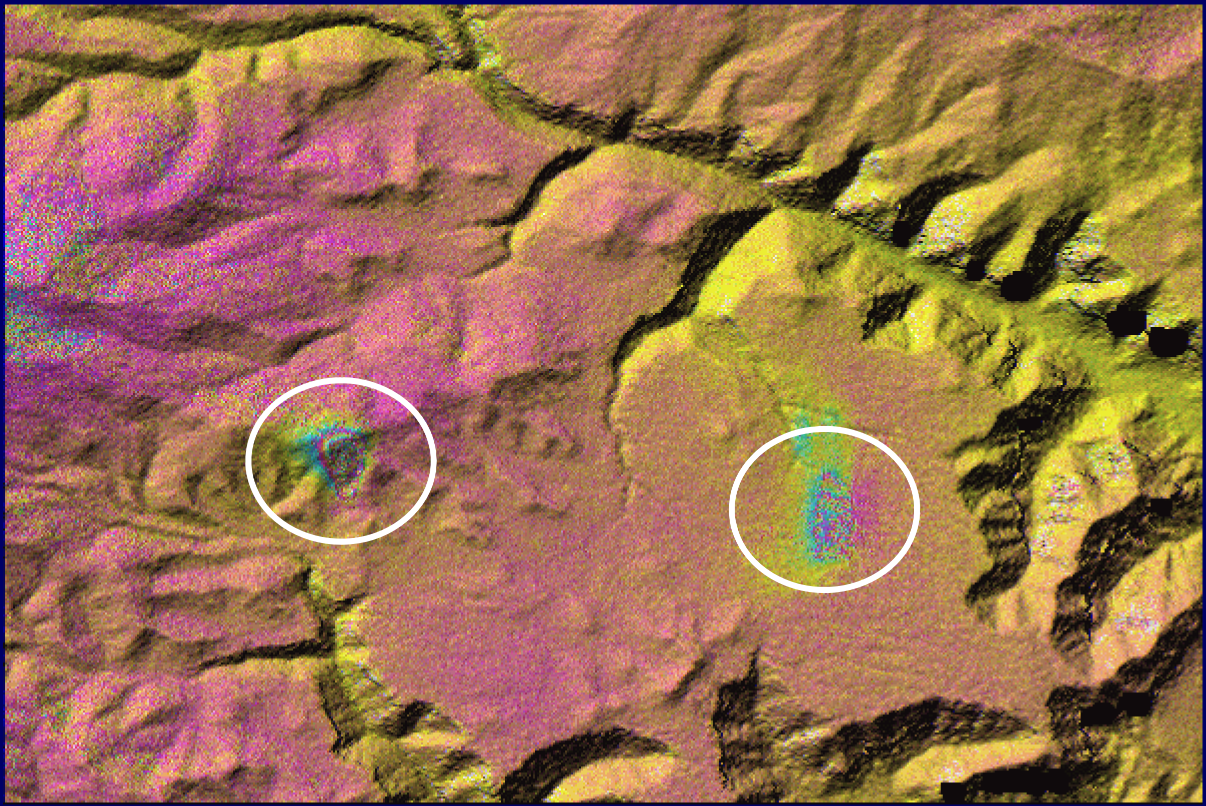
subsidence of > 60 cm

subsidence of ~5 cm

subsidence of > 30 cm

Mining-induced Subsidence, Utah

12/06/2006 – 06/08/2007

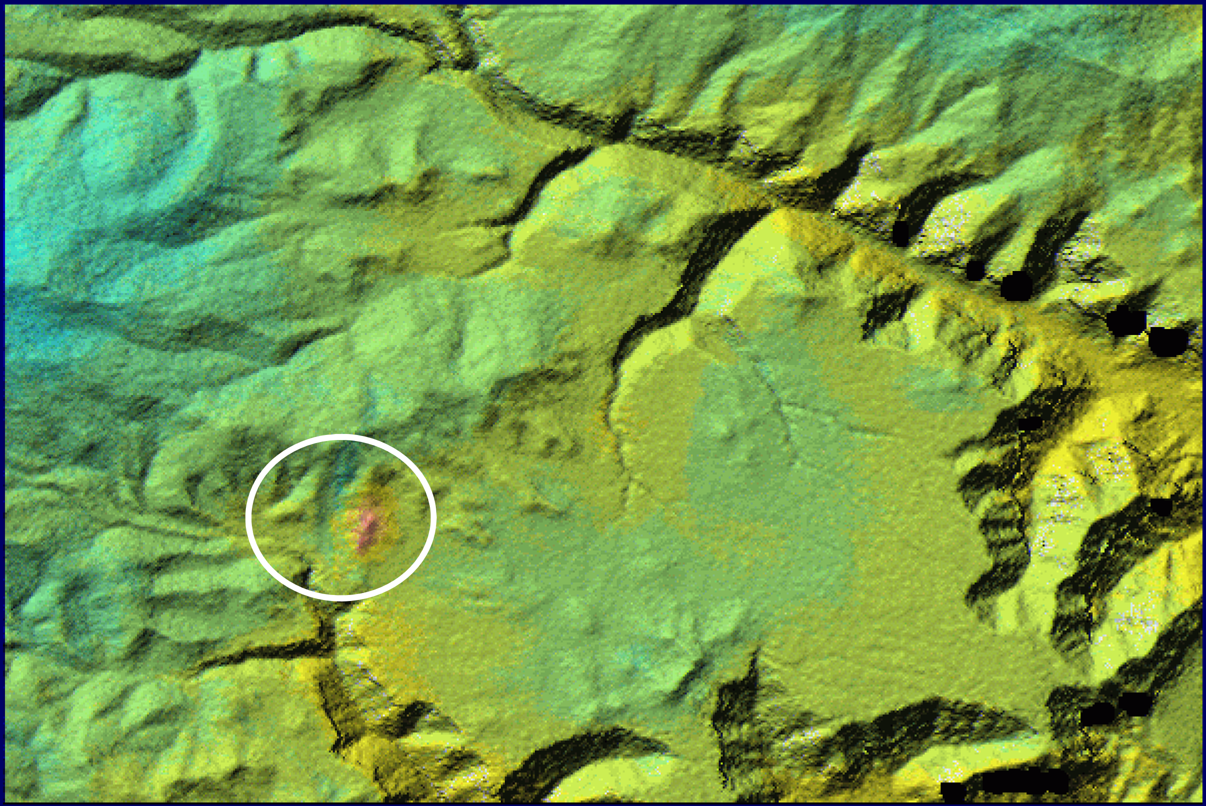


Subsidence

0 **15.4 cm**

Mining-induced Subsidence, Utah

06/08/2007 – 09/08/2007



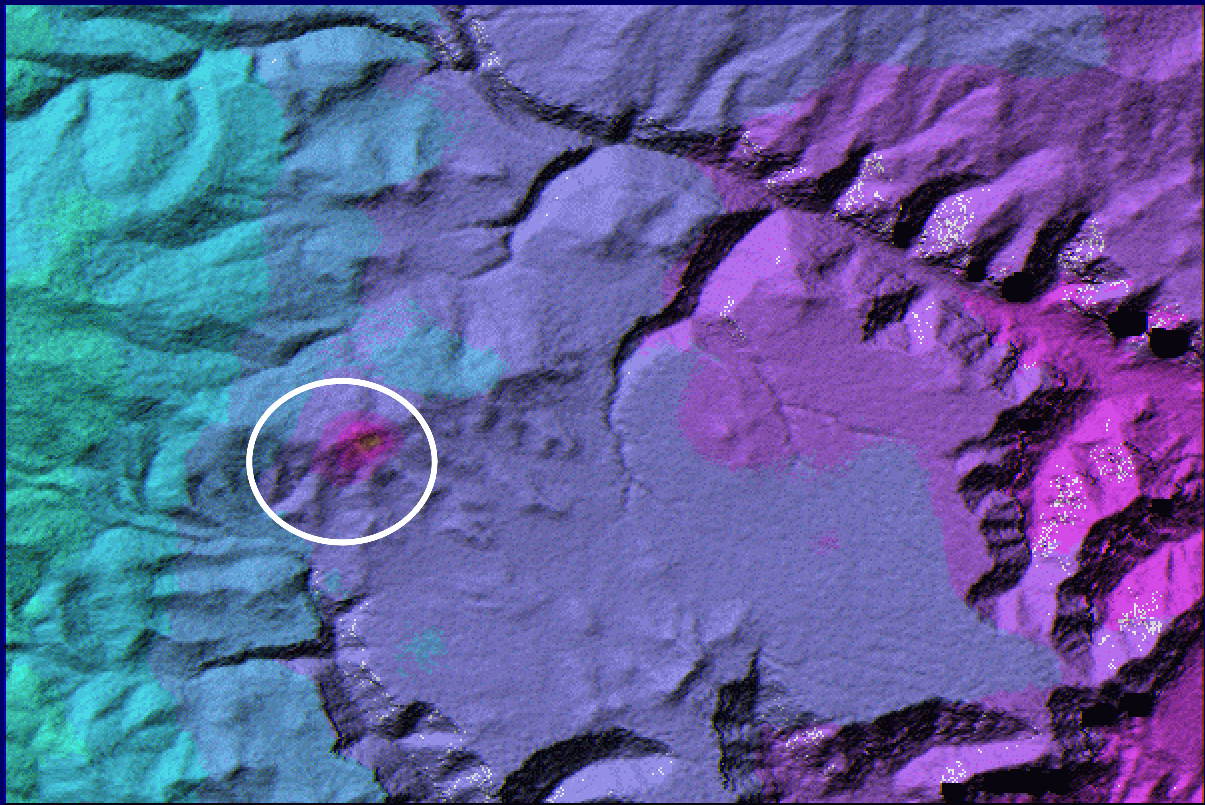
Subsidence

0 **15.4 cm**

USGS

Mining-induced Subsidence, Utah

09/08/2007 – 10/24/2007



Subsidence

0 **15.4 cm**

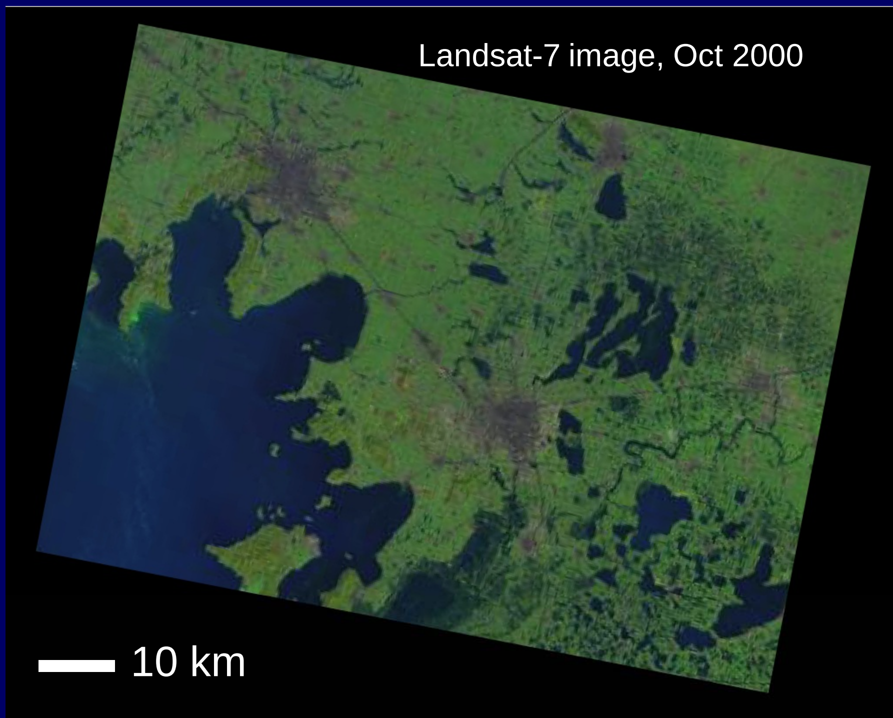
USGS

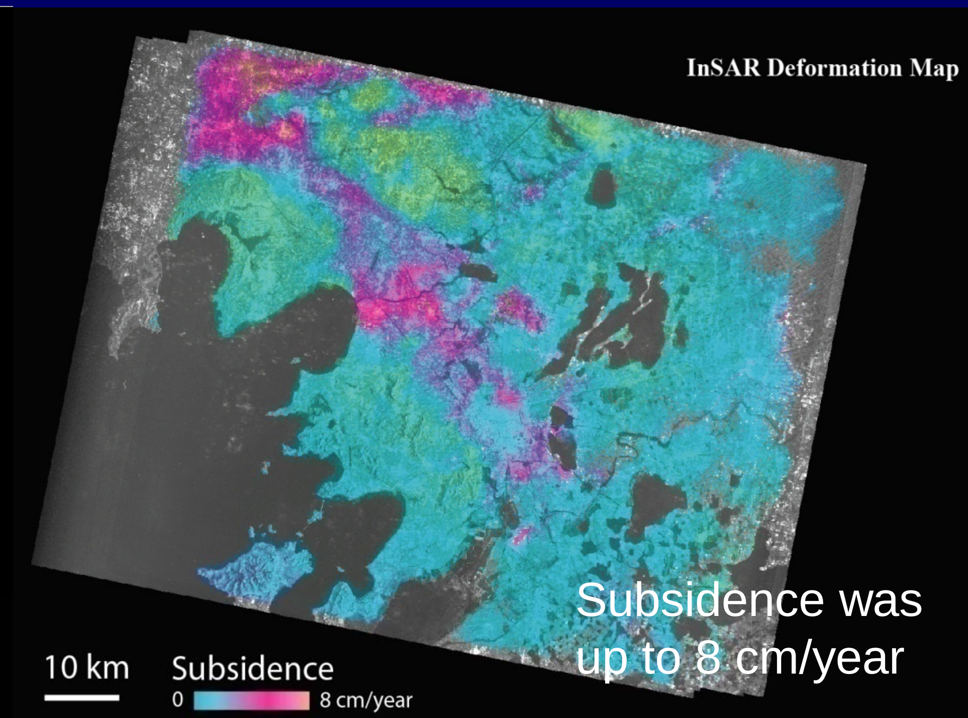
Land Subsidence

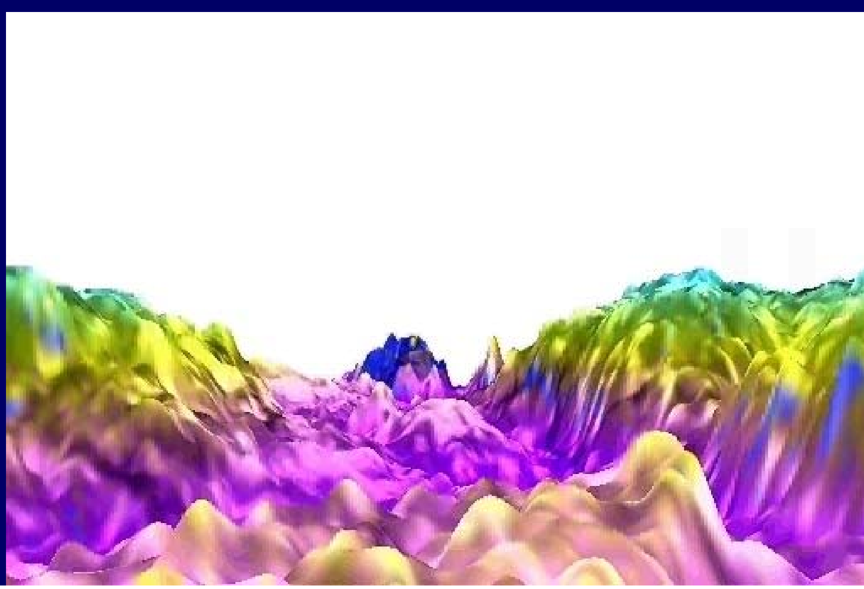
due to both man-made and natural hazards

Mapping surface subsidence and uplift related to extraction and injection of fluids in groundwater aquifers and petroleum reservoirs provides fundamental data on reservoir/aquifer properties and processes and improves our ability to assess and mitigate undesired consequences

Subsidence mapping, Su-Zhou, China







Geological survey

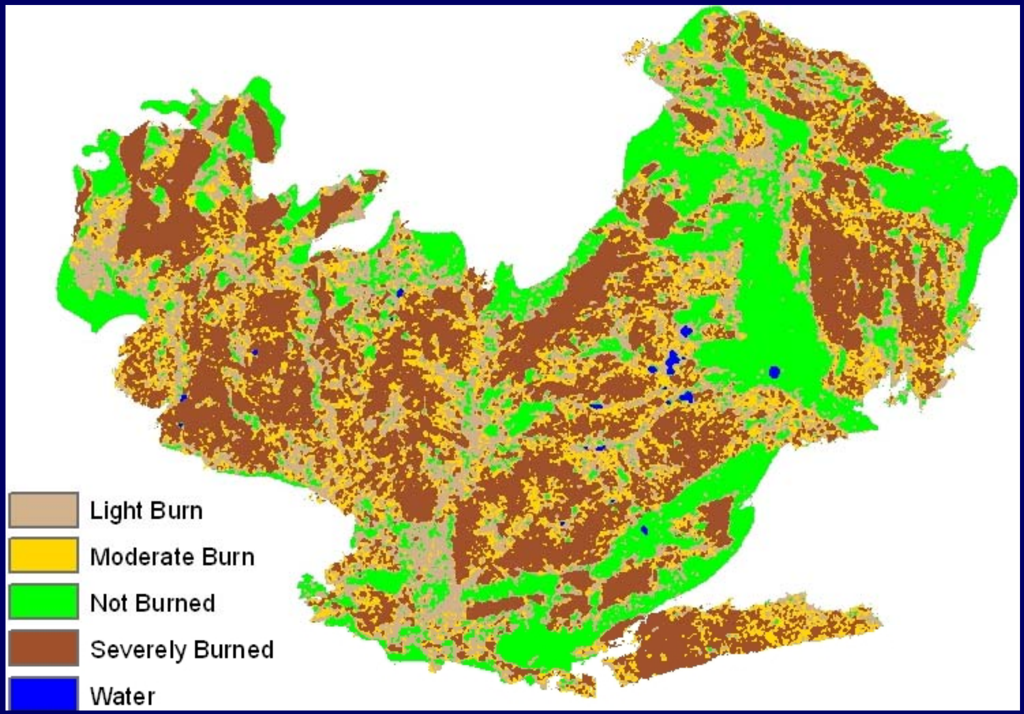
Lu, in prep

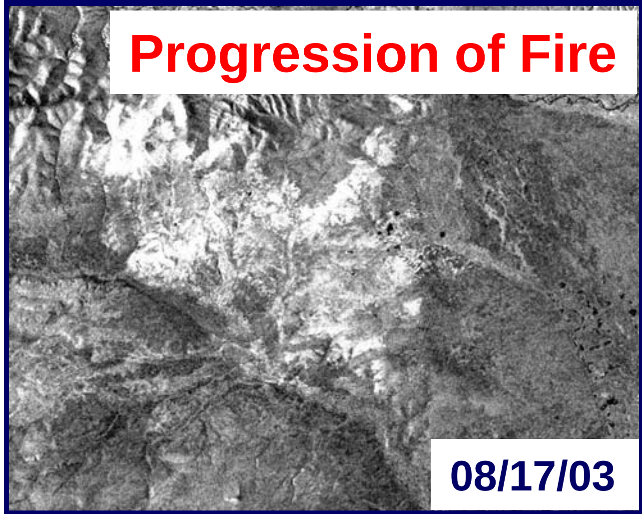
Wild Fires

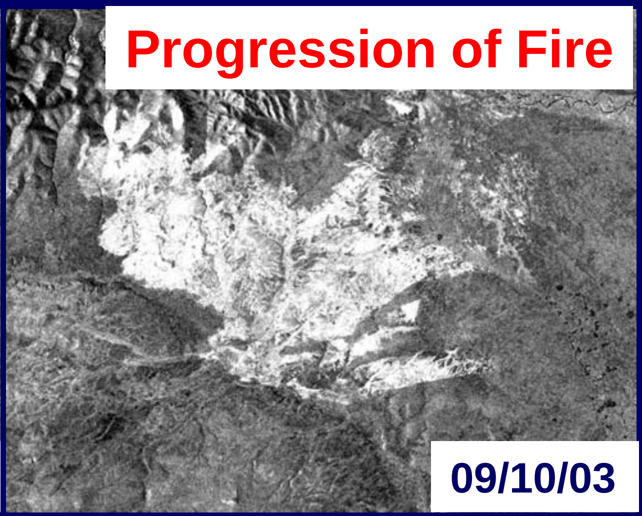
All-weather SAR imaging offers great promise for mapping fire scars and measuring fuel load in the management of fire hazards

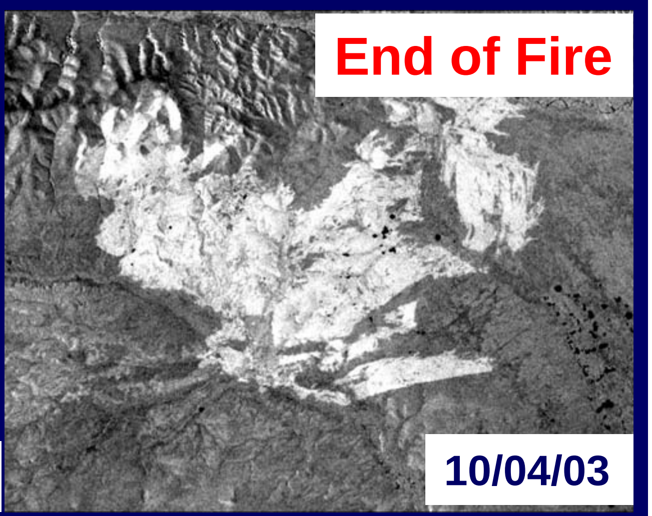
Mapping Fire Scar & Severity Using Multi-temporal SAR Images

Yukon River Basin, Alaska





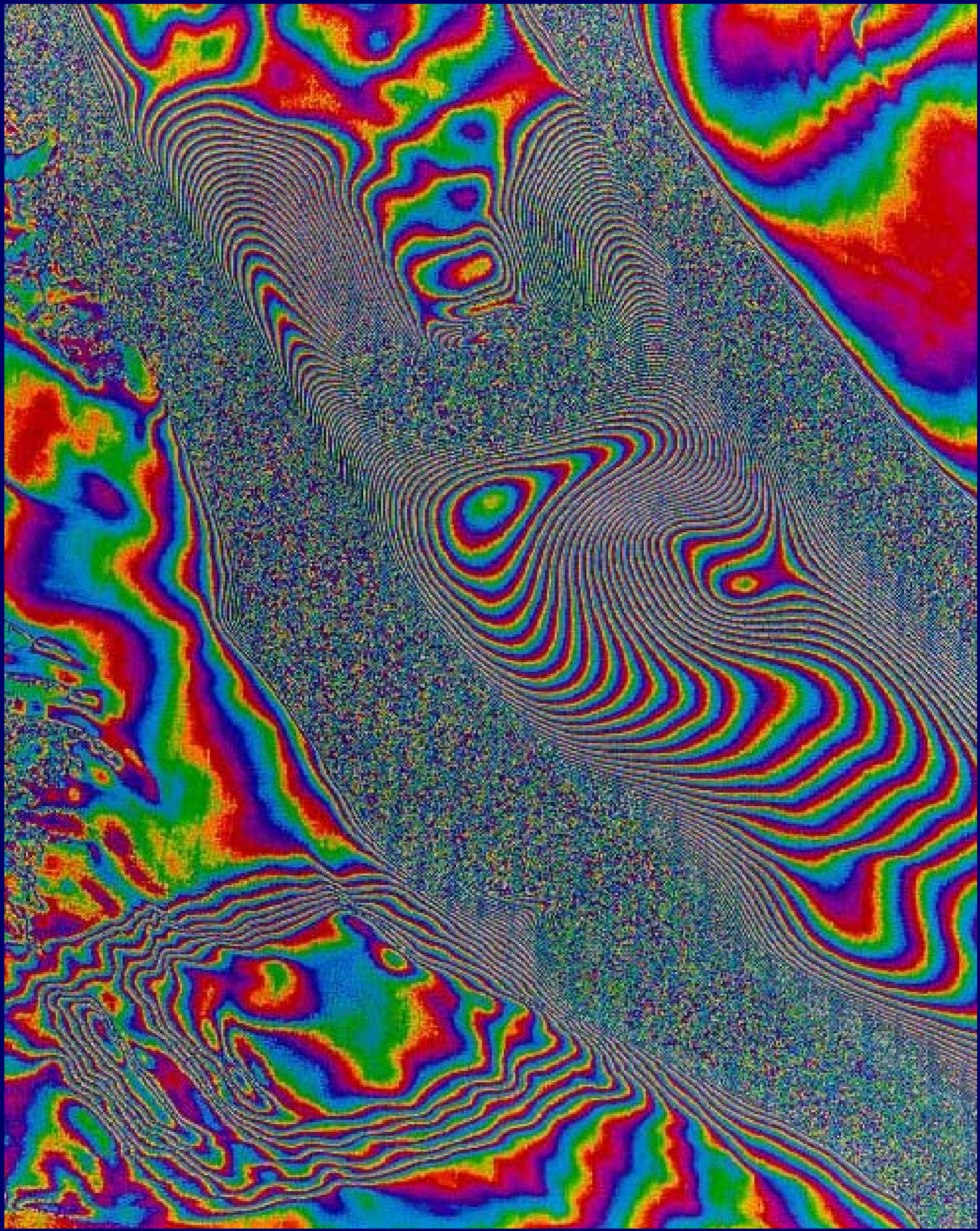




Rykhus & Lu, 2010

Glacier and Ice

Rutford ice stream, Antarctica



Goldstein et al., 1993

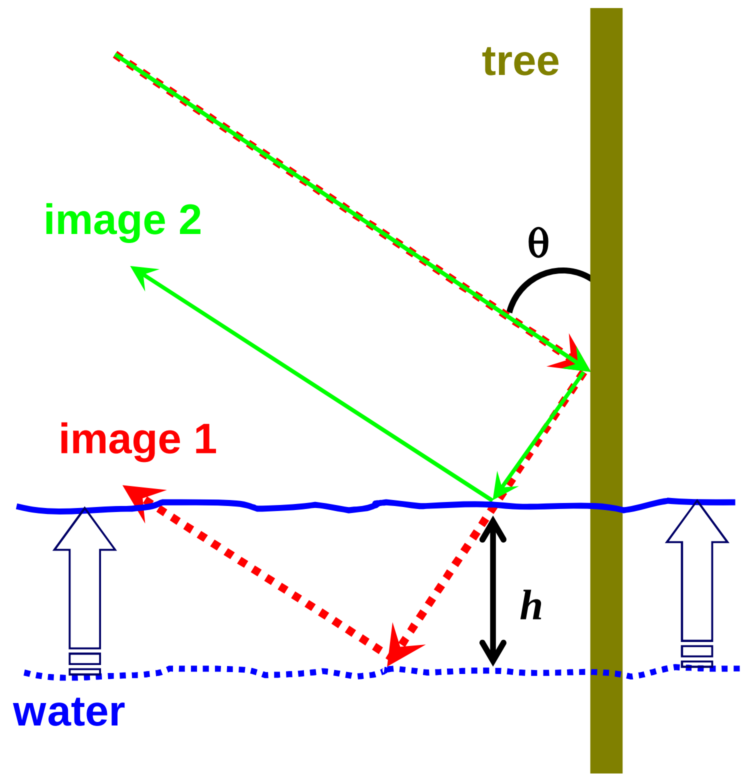
Flooding and Severe Storms

- SAR images can map flooding extents to serve in rapid damage assessments caused by flooding;
- InSAR is an effective tool in the accurate measurement of water-level changes in river valleys and wetlands, which can improve hydrological modeling predictions and enhance the assessment of future flood events over wetlands

Double-bounced radar signal and water-level change detection

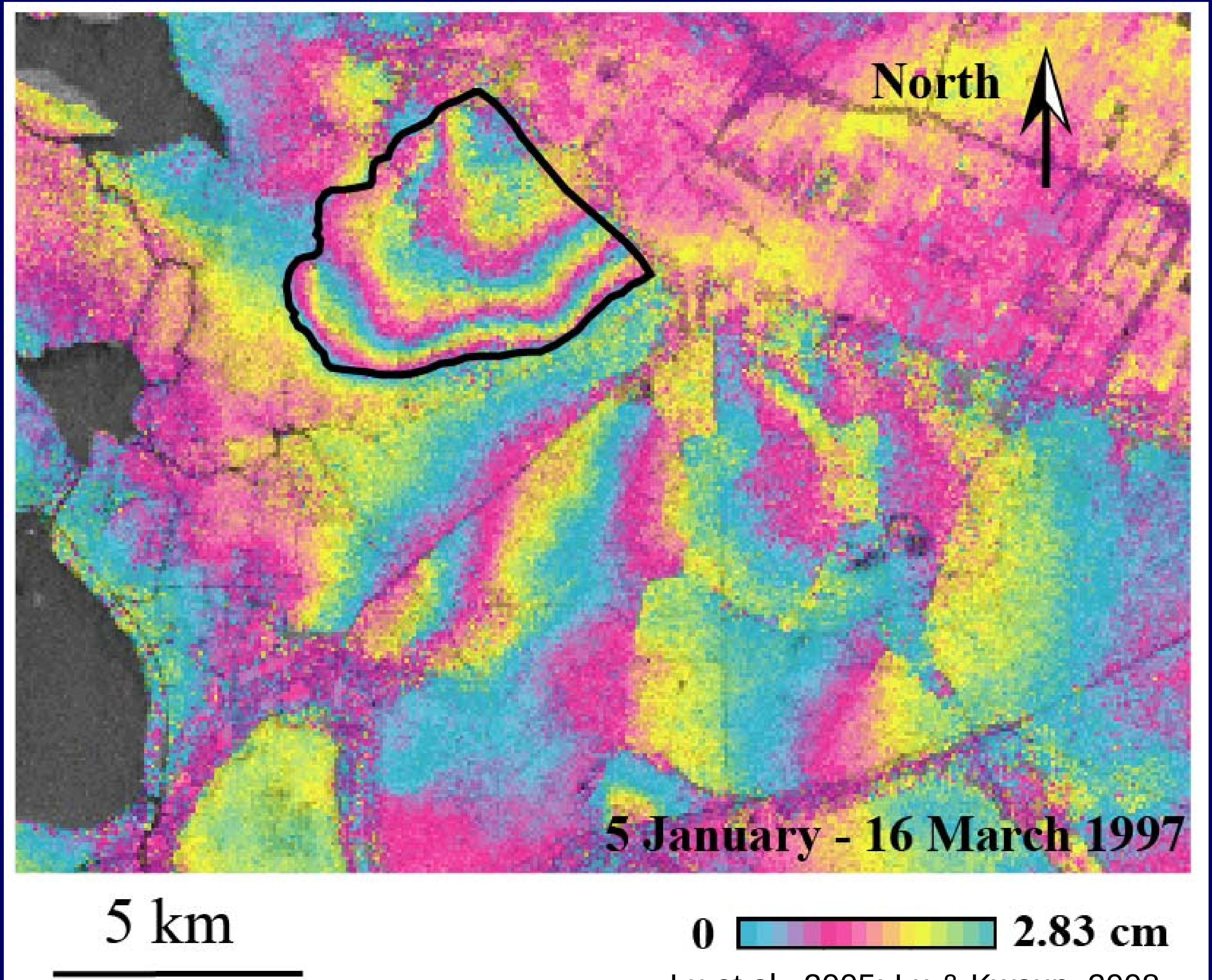
$$h = \frac{\Delta\phi}{4\pi\cos\theta}\cdot\lambda$$

h **: water level change**
Δφ : interferometric phase change
λ : radar wave length
θ : incidence angle



USGS

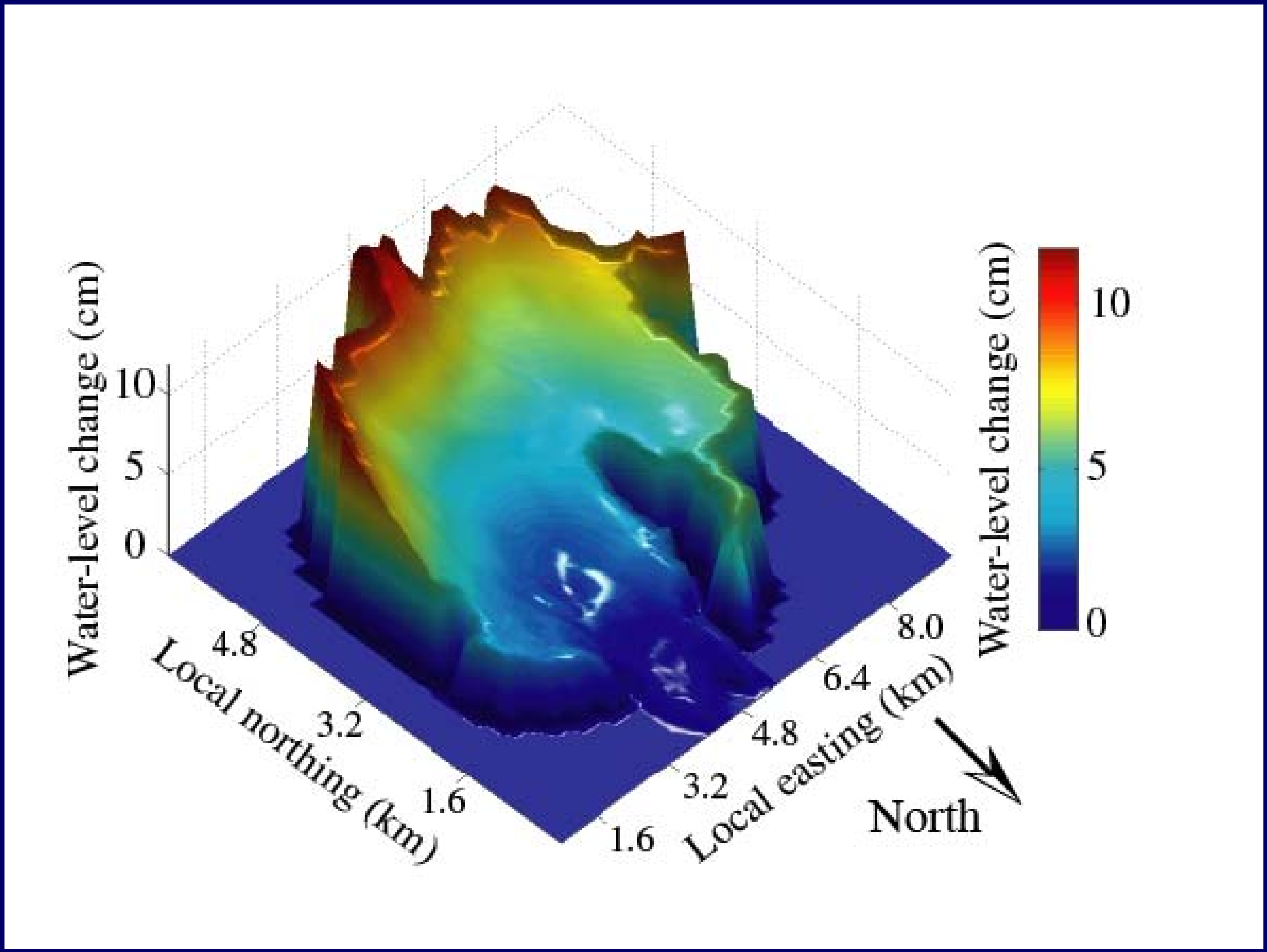
Water-level changes imaged by C-band InSAR



• Lu et al., 2005; Lu & Kwoun, 2008

USGS

Water-level changes imaged by C-band InSAR



• Lu et al., 2005; Lu & Kwoun, 2008

SAR/InSAR Processing

Incomplete list of free software packages

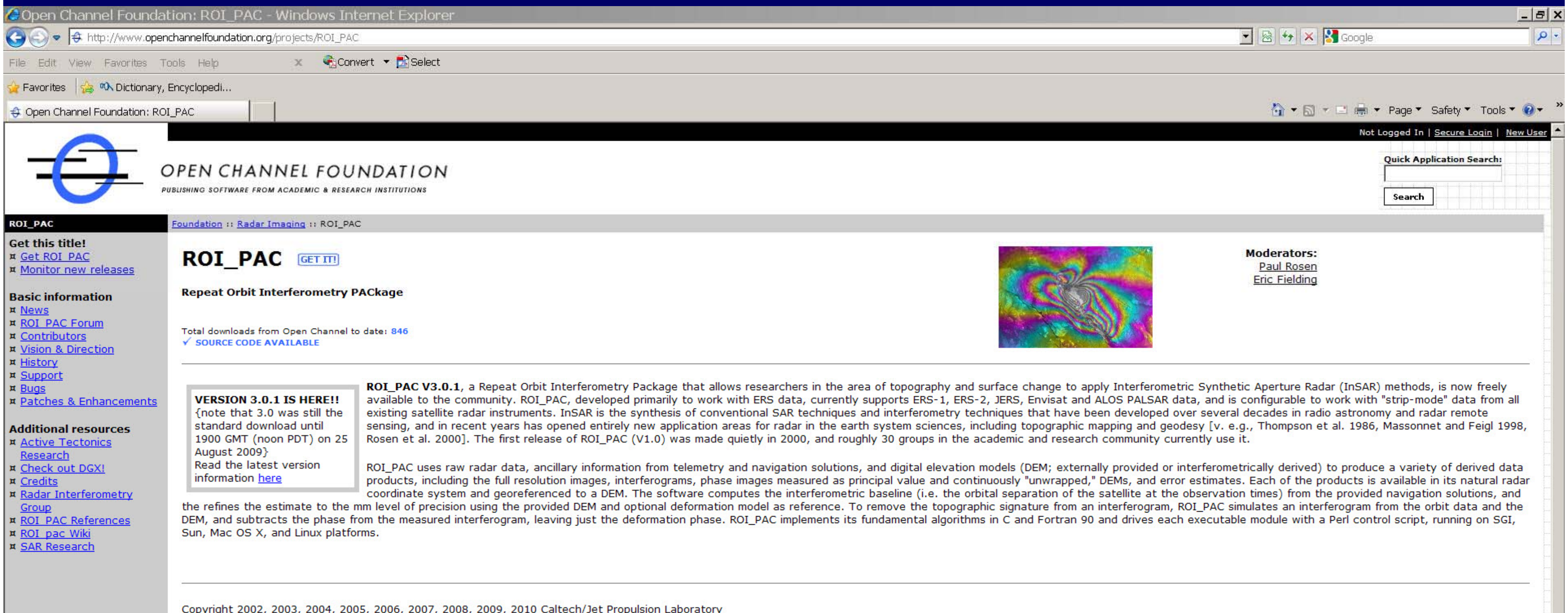
ROI_PAC: http://www.roipac.org/ROI_PAC
ASF tools: http://www.asf.alaska.edu/softwaretools/
DORIS: http://enterprise.lr.tudelft.nl/doris/
StaMPS: http://www.hi.is/~ahooper/stamps/index.html
IDIOT: http://www.cv.tu-berlin.de/idiot/
…

Incomplete list of commercial packages

(in alphabetical order)
Altamira Information, Spain
Atlantis Scientific Inc (Vexcel)
Envi: SARScape
Gamma RS
PCI: Earthview
TeleRilevamento Europa (TRE), Italy
…

USGS

"Free" InSAR Processing Package (with source codes): ROI_PAC


Open Channel Foundation: ROI_PAC - Windows Internet Explorer

http://www.openchannelfoundation.org/projects/ROI_PAC

Not Logged In | Secure Login | New User

OPEN CHANNEL FOUNDATION

PUBLISHING SOFTWARE FROM ACADEMIC & RESEARCH INSTITUTIONS

Quick Application Search:

Search

ROI_PAC

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Basic information
- News
- ROI_PAC Forum
- Contributors
- Vision & Direction
- History
- Support
- Bugs
- Patches & Enhancements

Additional resources
- Active Tectonics Research
- Check out DGX!
- Credits
- Radar Interferometry Group
- ROI_PAC References
- ROI_pac Wiki
- SAR Research

ROI_PAC

GET IT!

Repeat Orbit Interferometry PACkage

Total downloads from Open Channel to date: 846

✓ SOURCE CODE AVAILABLE

Moderators:
Paul Rosen
Eric Fielding

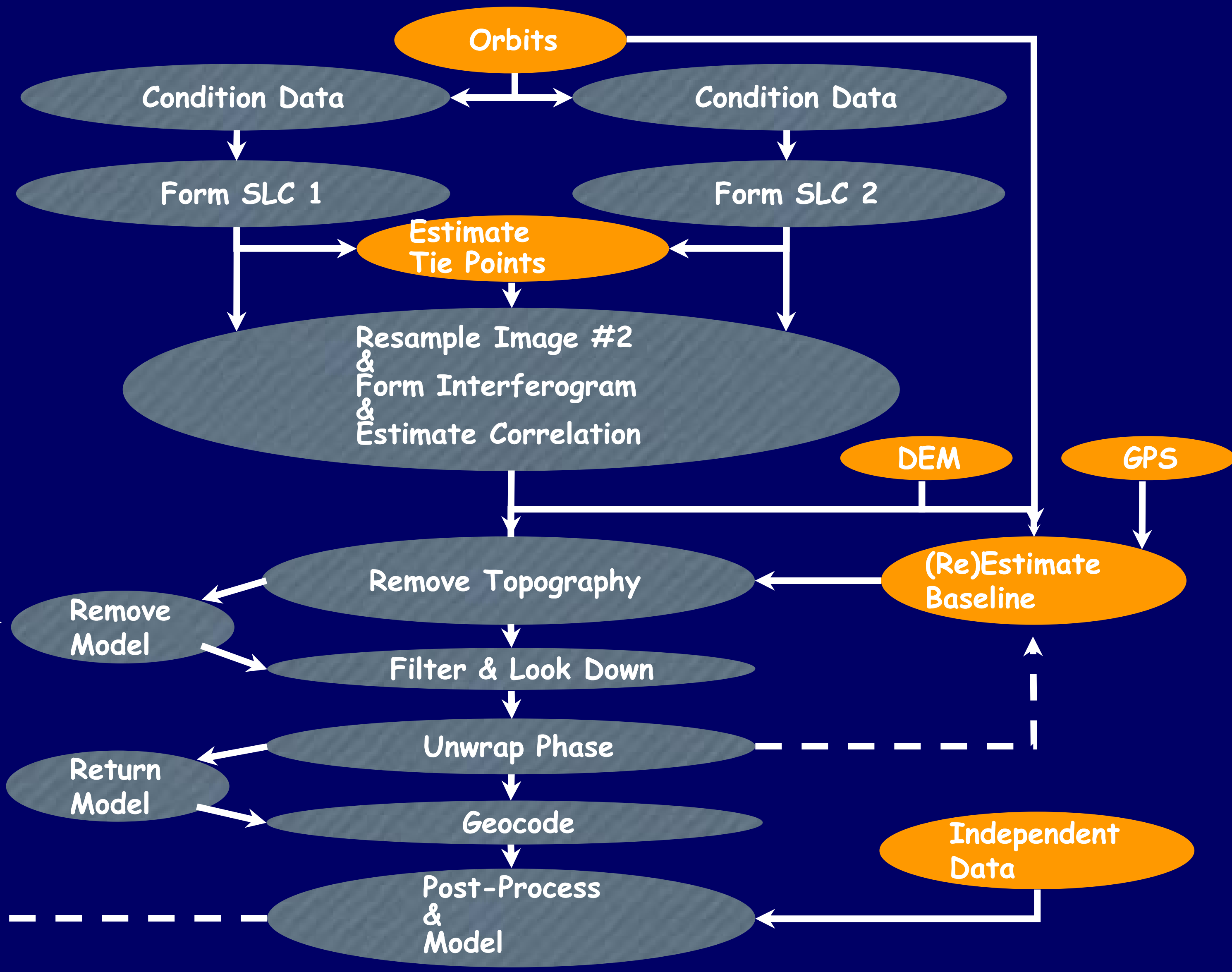
VERSION 3.0.1 IS HERE!!
{note that 3.0 was still the standard download until 1900 GMT (noon PDT) on 25 August 2009}
Read the latest version information here

ROI_PAC V3.0.1, a Repeat Orbit Interferometry Package that allows researchers in the area of topography and surface change to apply Interferometric Synthetic Aperture Radar (InSAR) methods, is now freely available to the community. ROI_PAC, developed primarily to work with ERS data, currently supports ERS-1, ERS-2, JERS, Envisat and ALOS PALSAR data, and is configurable to work with "strip-mode" data from all existing satellite radar instruments. InSAR is the synthesis of conventional SAR techniques and interferometry techniques that have been developed over several decades in radio astronomy and radar remote sensing, and in recent years has opened entirely new application areas for radar in the earth system sciences, including topographic mapping and geodesy [v. e.g., Thompson et al. 1986, Massonnet and Feigl 1998, Rosen et al. 2000]. The first release of ROI_PAC (V1.0) was made quietly in 2000, and roughly 30 groups in the academic and research community currently use it.

ROI_PAC uses raw radar data, ancillary information from telemetry and navigation solutions, and digital elevation models (DEM; externally provided or interferometrically derived) to produce a variety of derived data products, including the full resolution images, interferograms, phase images measured as principal value and continuously "unwrapped," DEMs, and error estimates. Each of the products is available in its natural radar coordinate system and georeferenced to a DEM. The software computes the interferometric baseline (i.e. the orbital separation of the satellite at the observation times) from the provided navigation solutions, and the refines the estimate to the mm level of precision using the provided DEM and optional deformation model as reference. To remove the topographic signature from an interferogram, ROI_PAC simulates an interferogram from the orbit data and the DEM, and subtracts the phase from the measured interferogram, leaving just the deformation phase. ROI_PAC implements its fundamental algorithms in C and Fortran 90 and drives each executable module with a Perl control script, running on SGI, Sun, Mac OS X, and Linux platforms.

Copyright 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010 Caltech/Jet Propulsion Laboratory

ROI_pac 2-pass Processing Flow



Courtesy of M. Simons

USGS

ROI_PAC tutorials

ROI_PAC Wiki:

http://www.roipac.org/

ROI_PAC at Open Channel Foundation:

http://www.openchannelsoftware.com/forum/forum.php?forum_id=99

ROI_PAC at Cornell:

http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/matt/flowchart.html

ROI_PAC at George Tech:

http://geophysics.eas.gatech.edu/classes/MGM/InSAR/index.html

ROI_PAC at Univ of Oregon:

http://pages.uoregon.edu/das/WikiRoiPac/doku.php?id=roipac:scripts:scripts

ROI_PAC at Berkeley:

http://seismo.berkeley.edu/~burgmann/WINSAR/index.html

ROI_PAC at UCSD:

http://sioviz.ucsd.edu/~fialko/insar/InSAR_Manual_2007.doc

ROI_PAC at ASF:

http://www.asf.alaska.edu/program/sdc/insar_help

……..

Deformation Modeling

Incomplete list of free codes

http://www.rsmas.miami.edu/divs/mgg/insar/mimicwiki/

http://sioviz.ucsd.edu/~fialko/software.html

…

How to obtain SAR data?

Alaska Satellite Facility - https://ursa.asfdaac.alaska.edu

- **Radarsat-1, ERS-1, ERS-2 and JERS-1 imagery for Alaska and Antarctic (and North America and other parts of the Earth)**
  - **- free after projects are approved (1-page proposal)**
- **ALOS for Americas (and other parts of the Earth)**
  - **- free through ALOS Data Consortium sponsored by NASA/USGS/NSF**

WInSAR Consortium - http://winsar.unavco.org/main.php

- **ERS-1, ERS-2, and Envisat for Western US – free**

Geoearthscope - http://geoes-insar.unavco.org/main.php

- **ERS-1, ERS-2, Envisat, Radarsat-1 for Western US and some areas over east coasts – free**

European Space Agency - http://www.esa.int/esaCP/index.html

- **ERS-1, ERS-2, Envisat (http://eoli.esa.int/geteolisa/WebInstallers/install.htm)**
- **free after projects are approved (simple project proposals) http://www.esa.int/esaCP/index.html**

Japan Aerospace Exploration Agency (JAXA)

- **JERS-1 ($30/scene), ALOS (~$250/scene)**

How to obtain SAR data?

MDA

- **Radarsat-1 and Radarsat-2 (variable price)**

German Space Agency (DLR)

- **TerraSAR-X ($250/scene after projects are approved)**

COSMO-SkyMed images

- **e-GEOS SpA**

Questions?
Future correspondence?

=> lu@usgs.gov