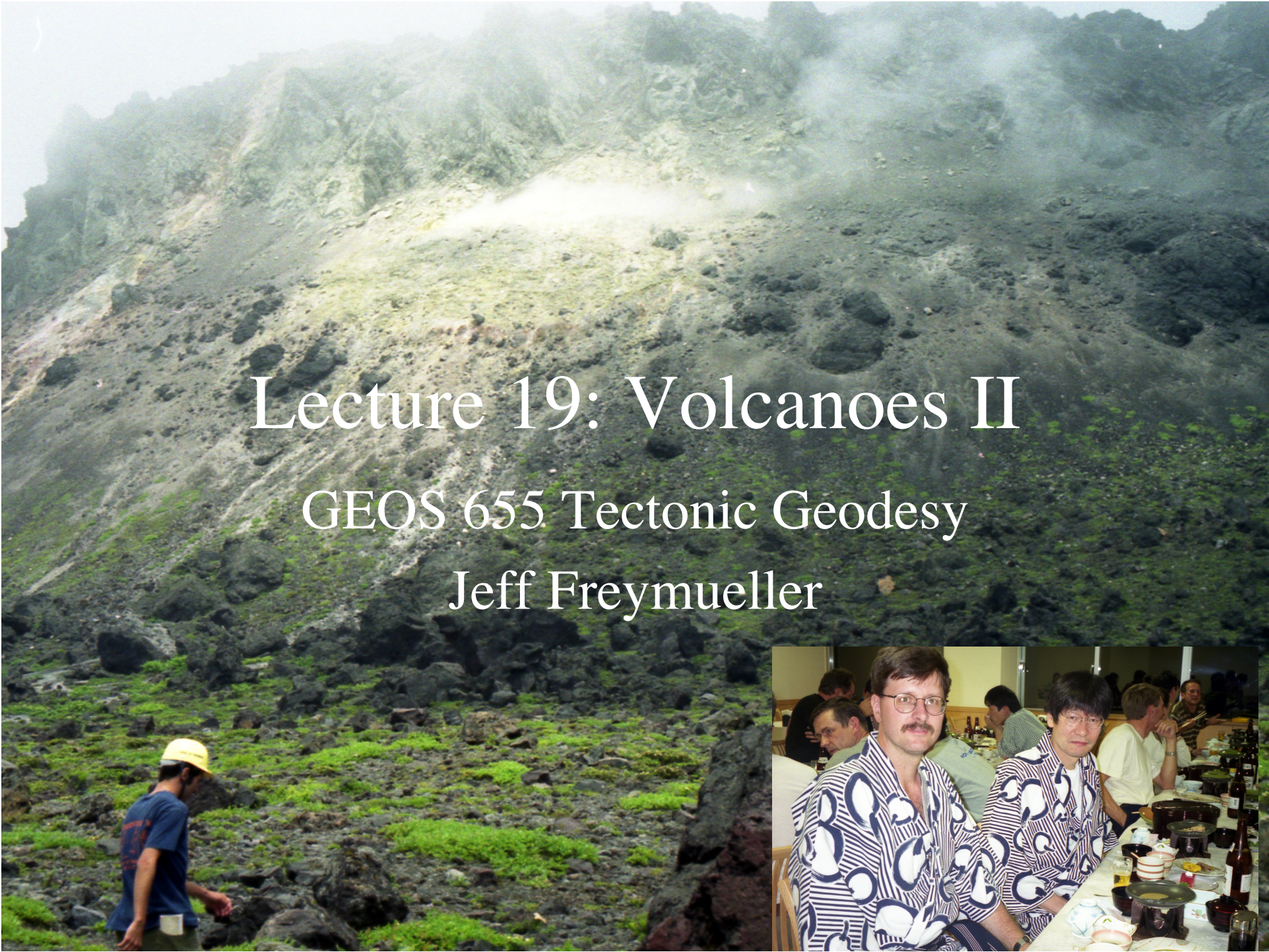




Lecture 19: Volcanoes II

GEOS 655 Tectonic Geodesy

Jeff Freymueller



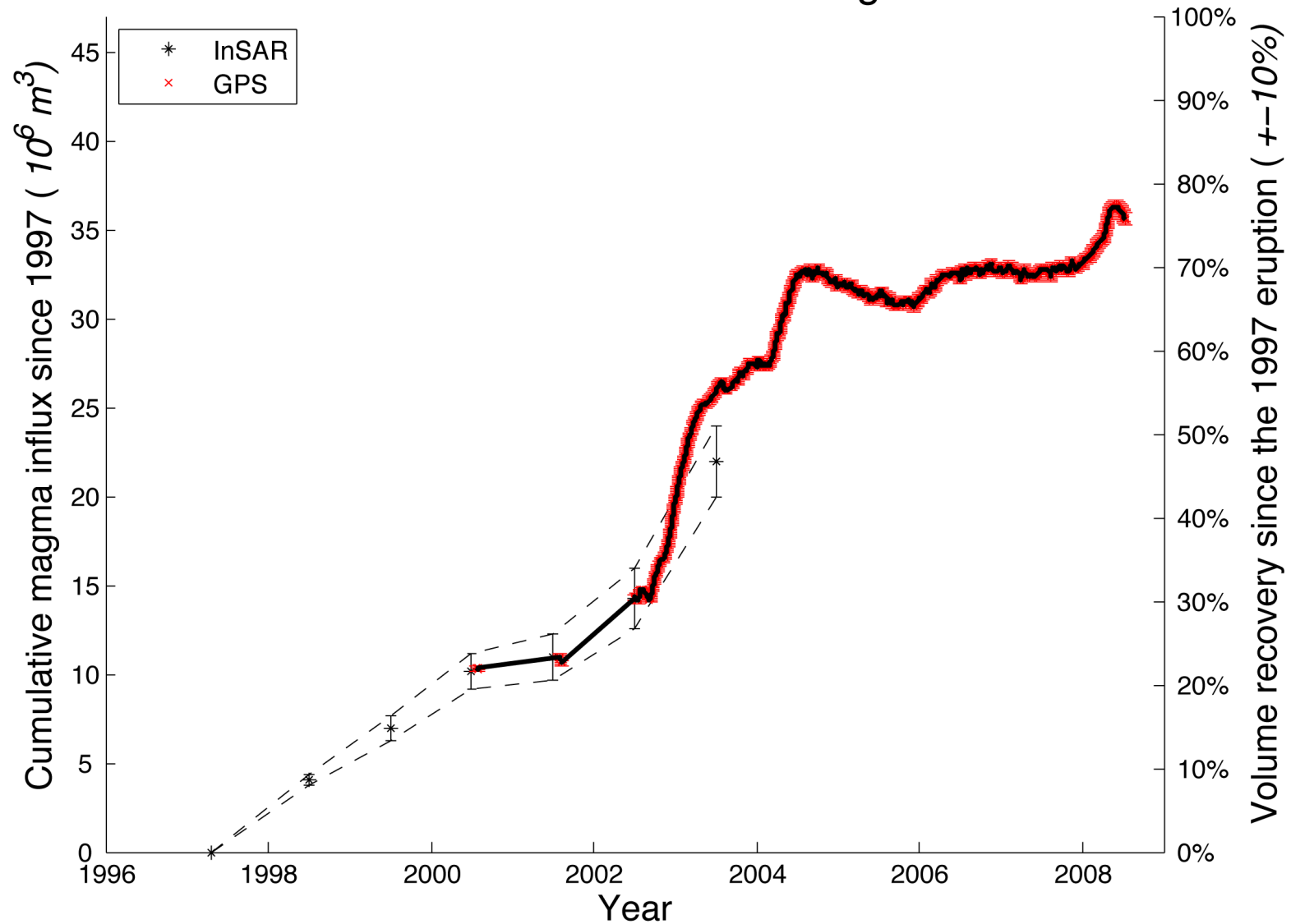
A photograph of a powerful volcanic eruption. A thick, dark grey plume of ash and smoke billows upwards from a crater, expanding as it rises. The plume has a textured, cauliflower-like appearance. Below the main plume, a layer of white steam or ash clouds spreads across the crater floor. In the foreground, the dark, sloping rim of the volcano is visible, partially shrouded in white mist or ash. The sky above is a clear, bright blue.

July-August 2008

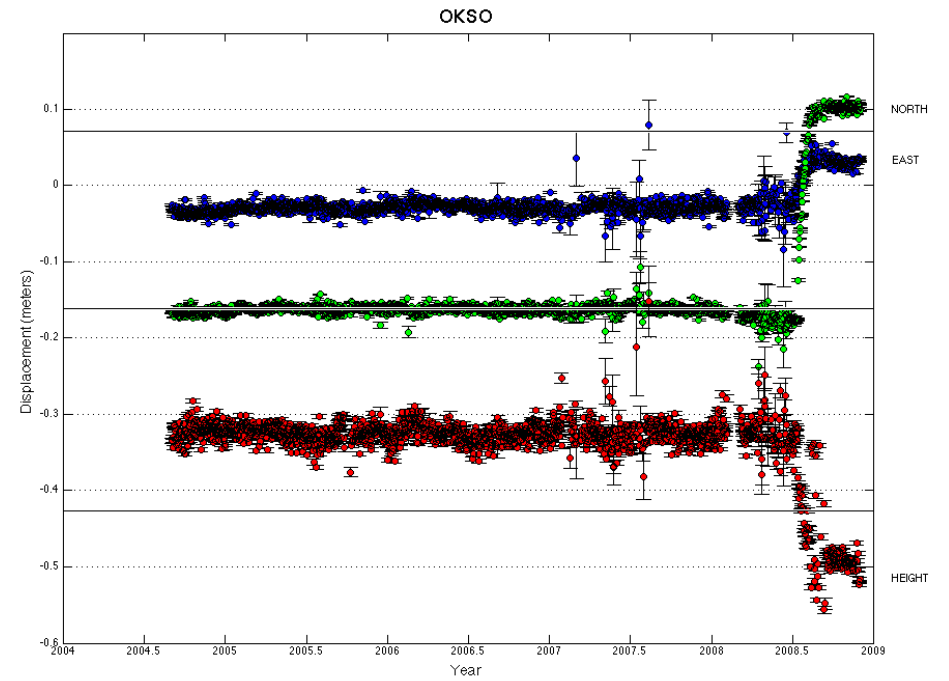
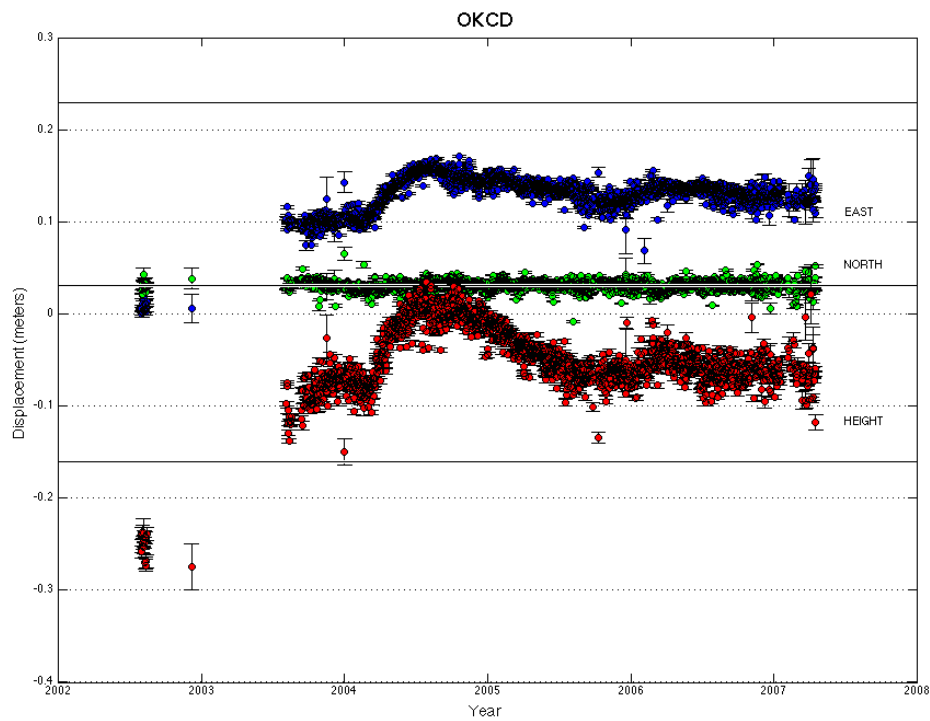
Photo J. Larsen, AVO

Volume Change Inferred from Model

Cumulative Volume Change



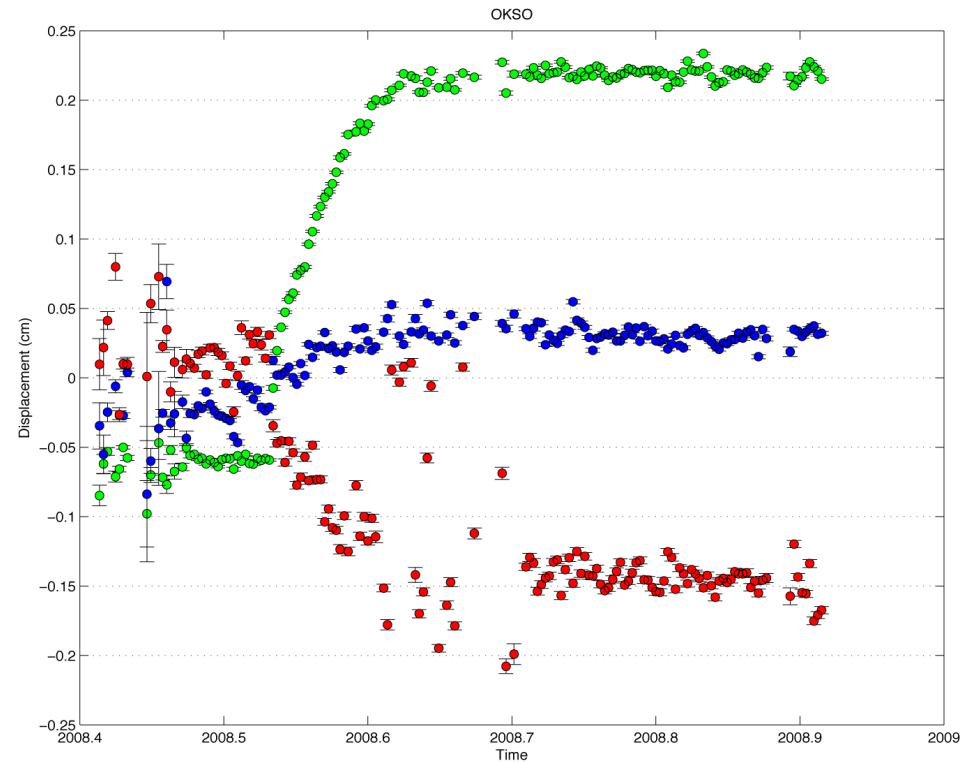
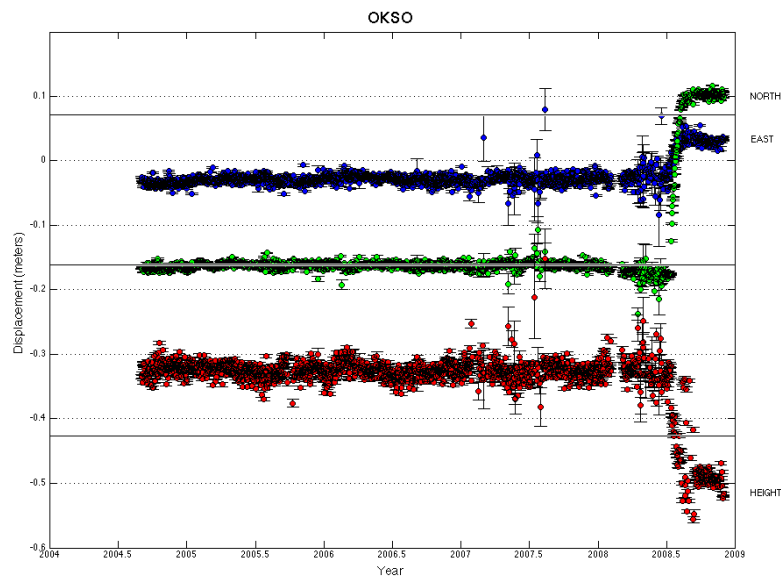
GPS Site Time Series



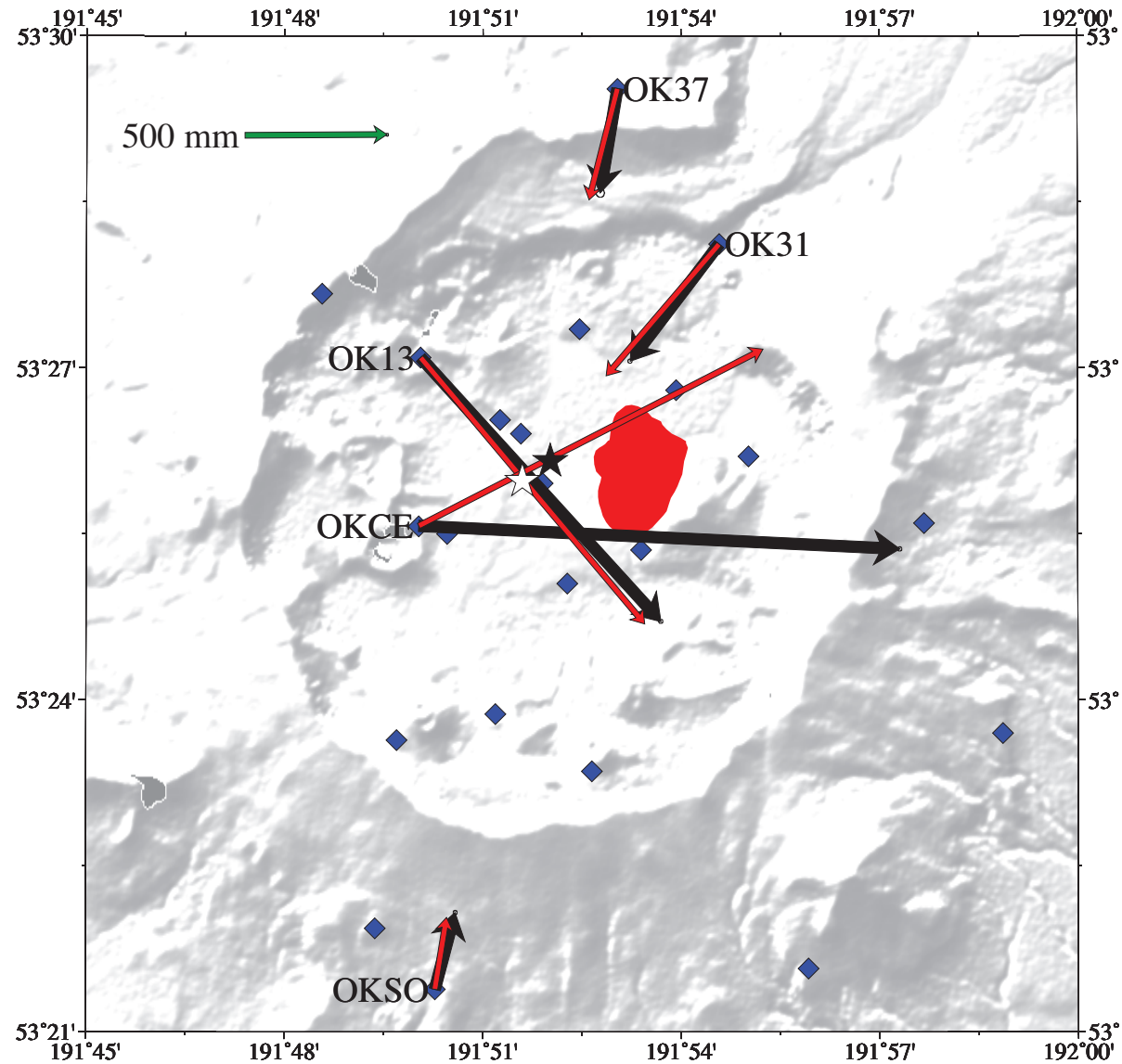
Average rate from 2005.0-2008.0 subtracted

Eruption Time Period in Detail

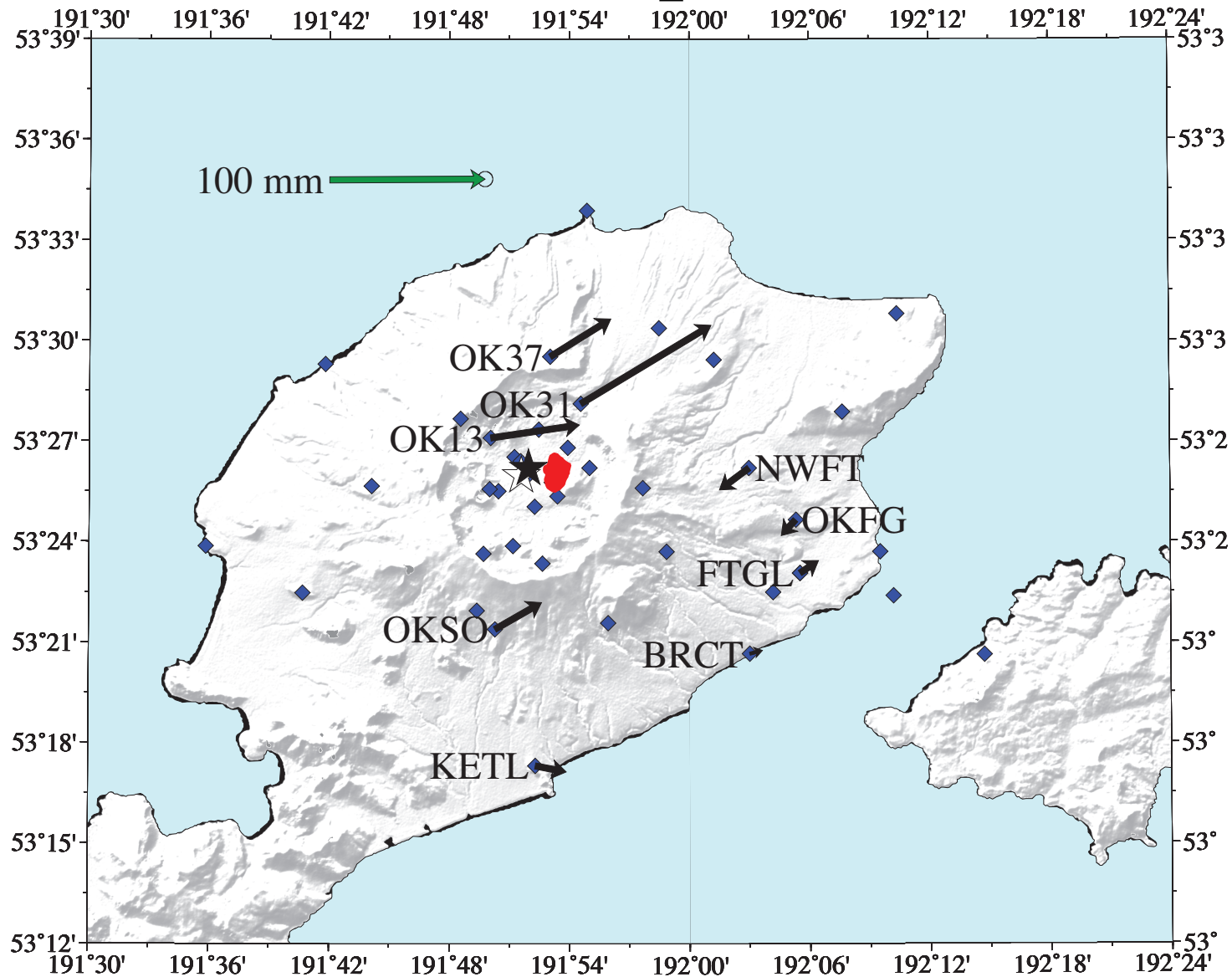
Large scatter in vertical from signals delayed by heavy ash plume.



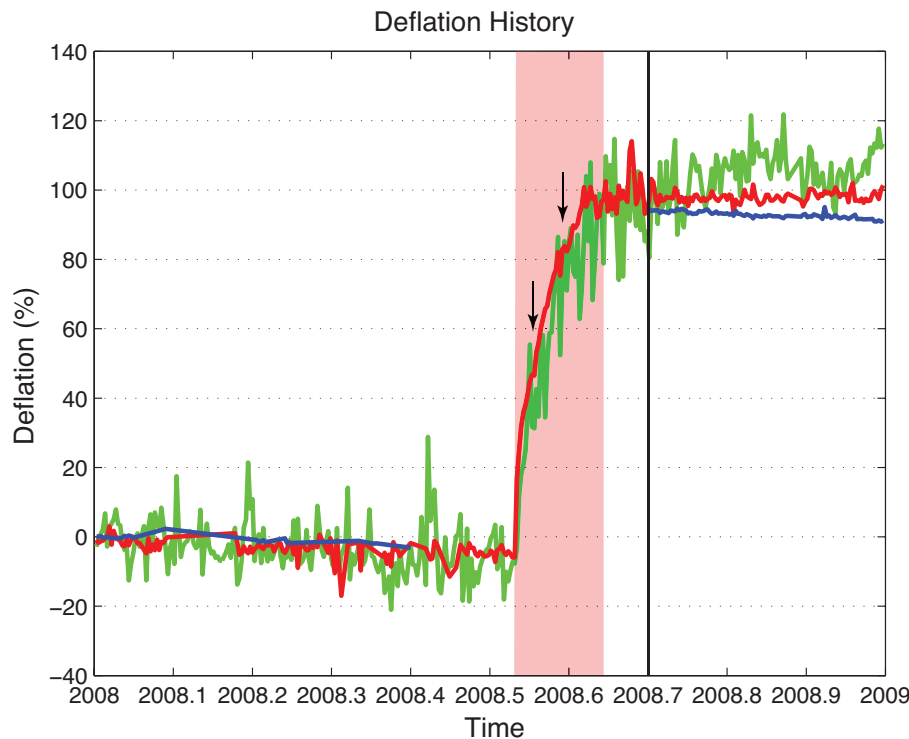
Eruptive Displacements + Model



Residuals (except for OKCE)

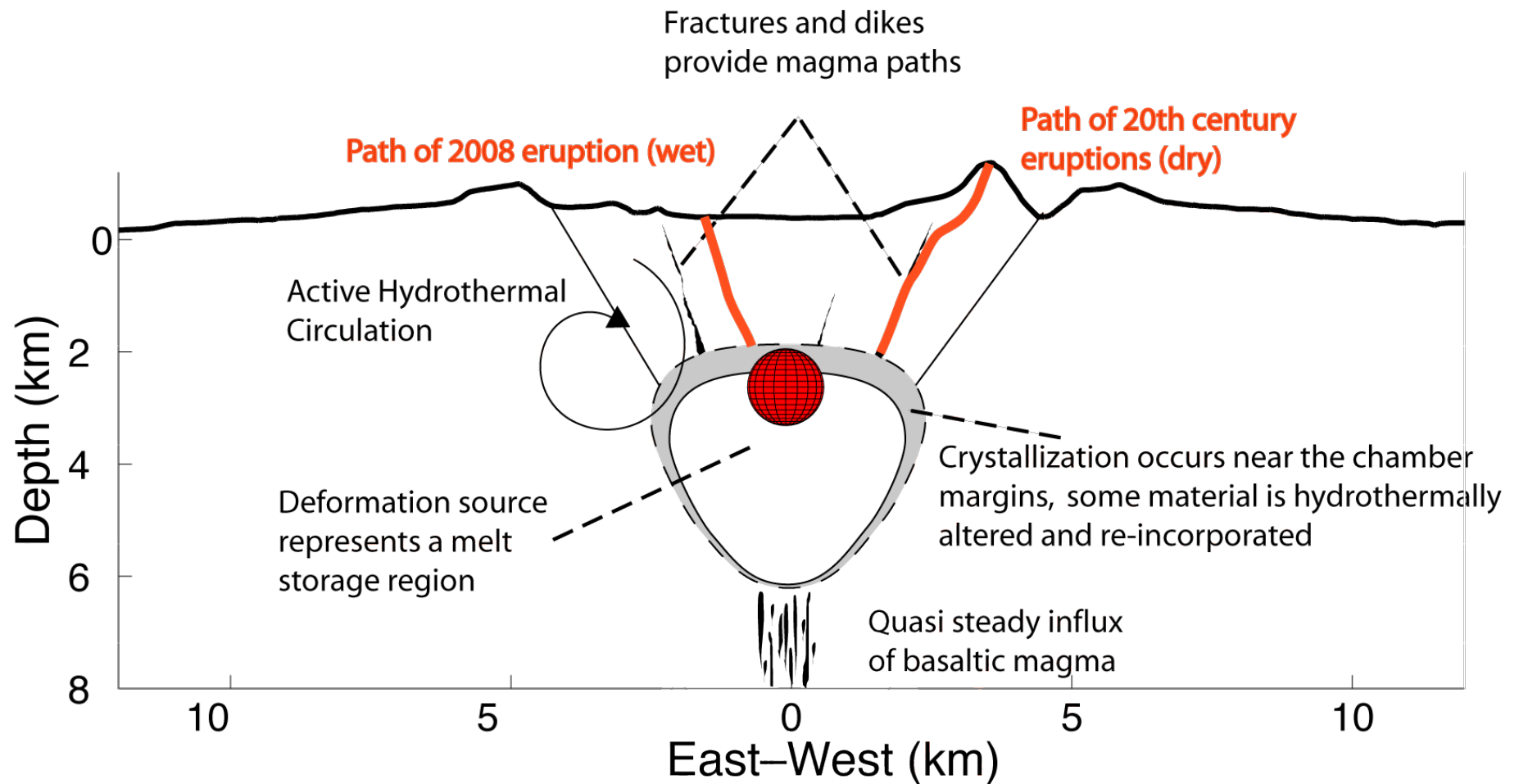


Time History of Eruption

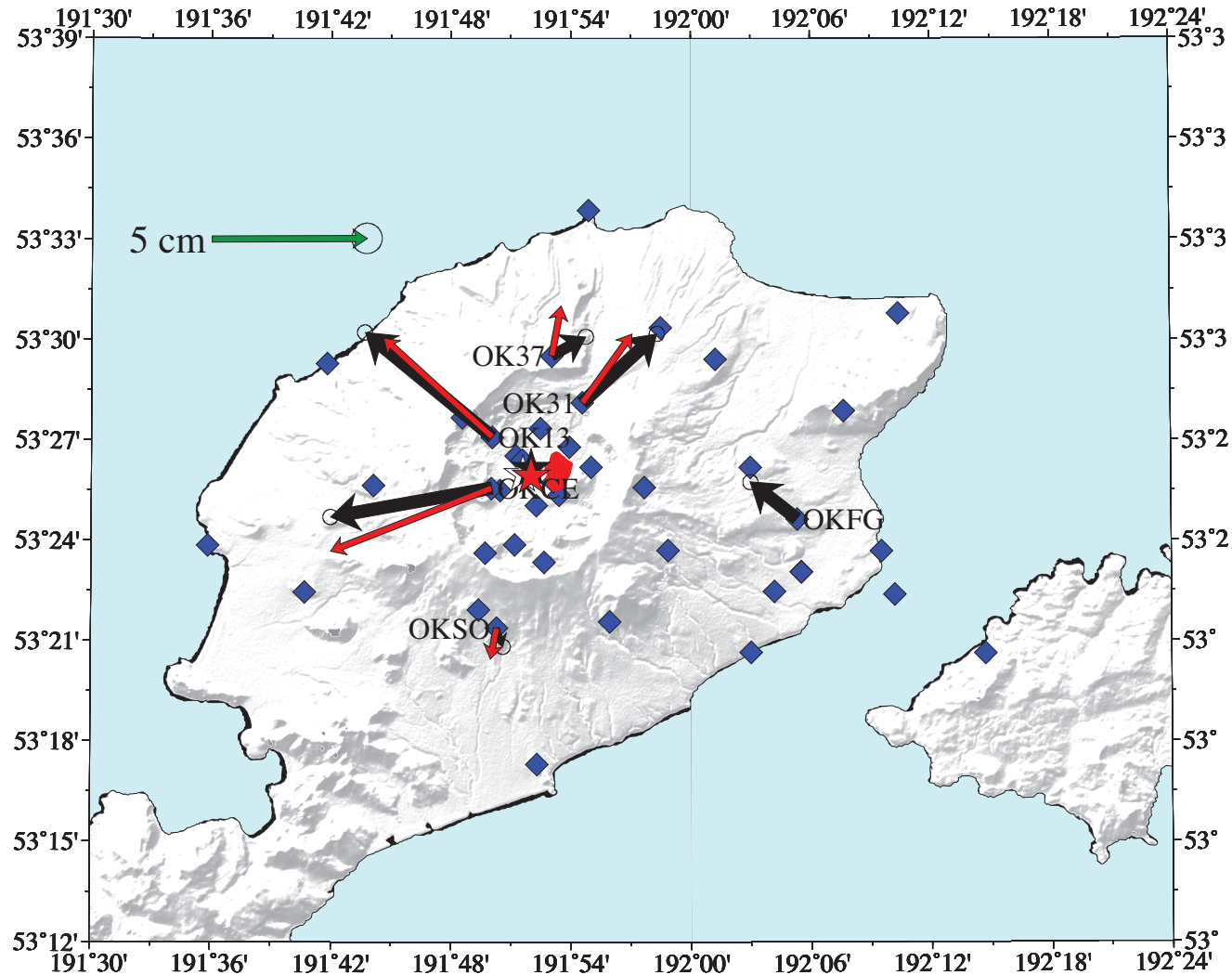


- The three continuous sites show similar time history
 - OKFG record (green) scaled up based on total displacement
 - Also higher scatter from plume
- OKCE (blue) and OKSO (red) show onset of re-inflation within days to weeks after eruption

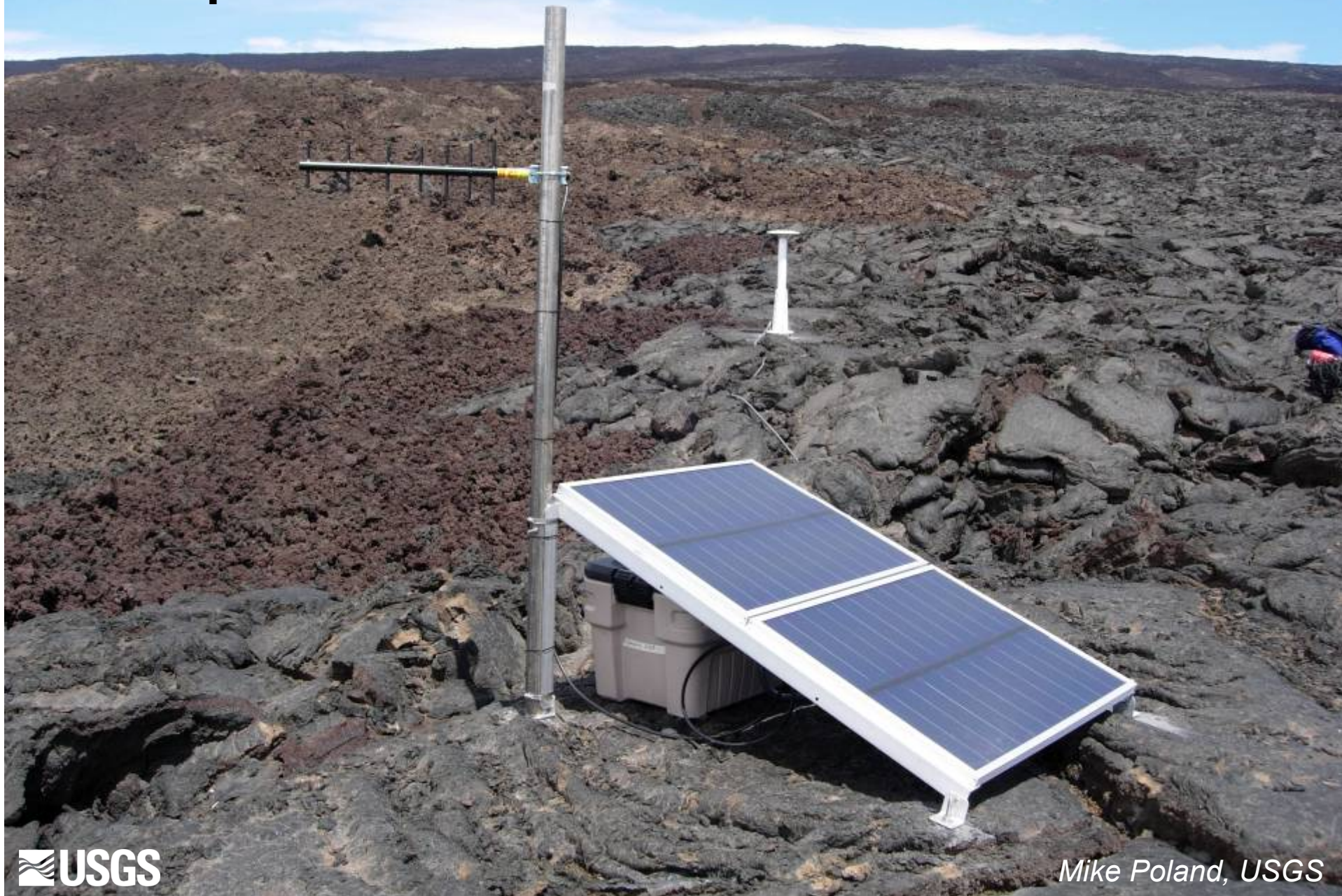
Interpretive Cross-Section

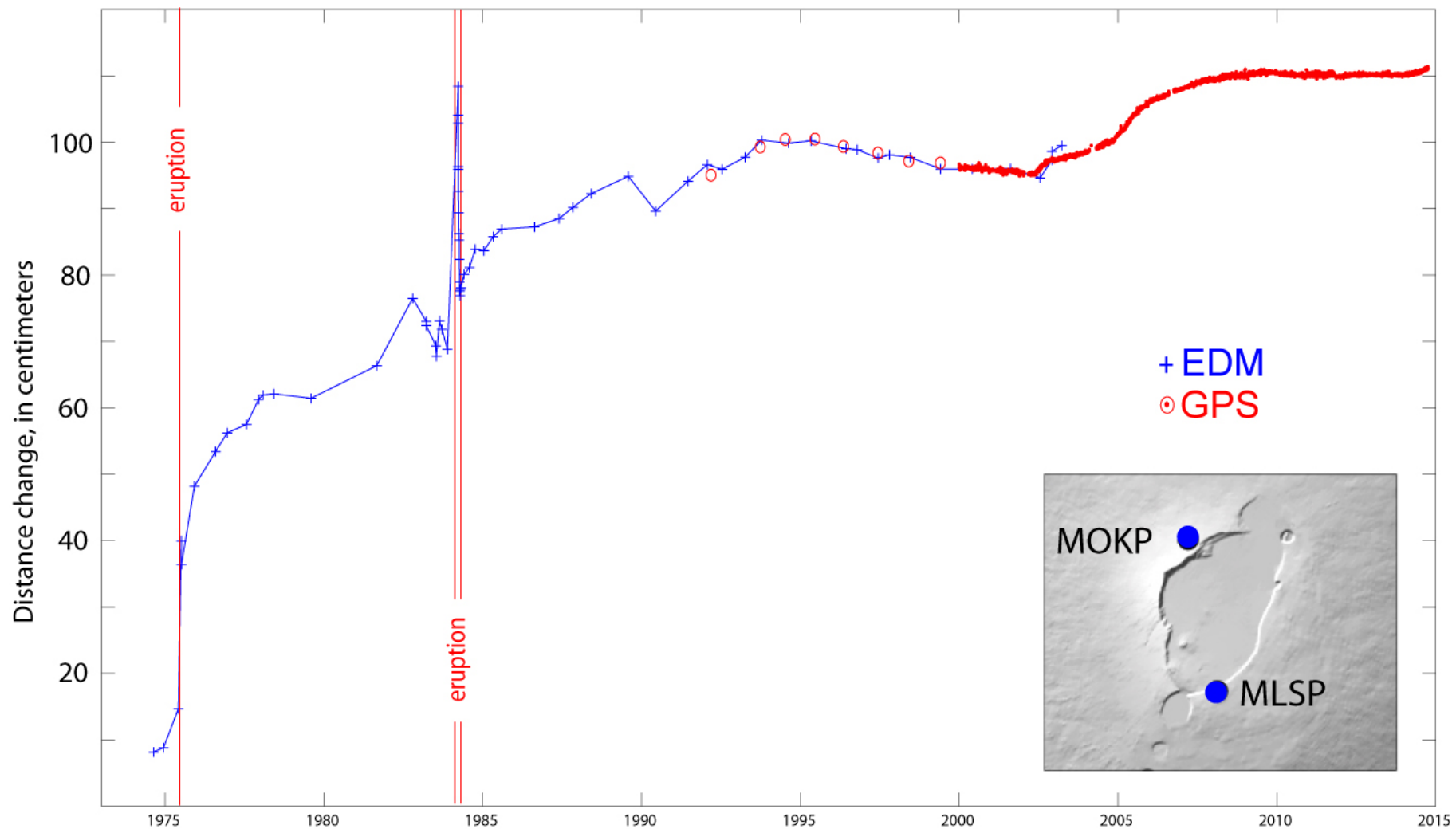


Re-inflation afterward (4 mo)



Examples from Hawaii



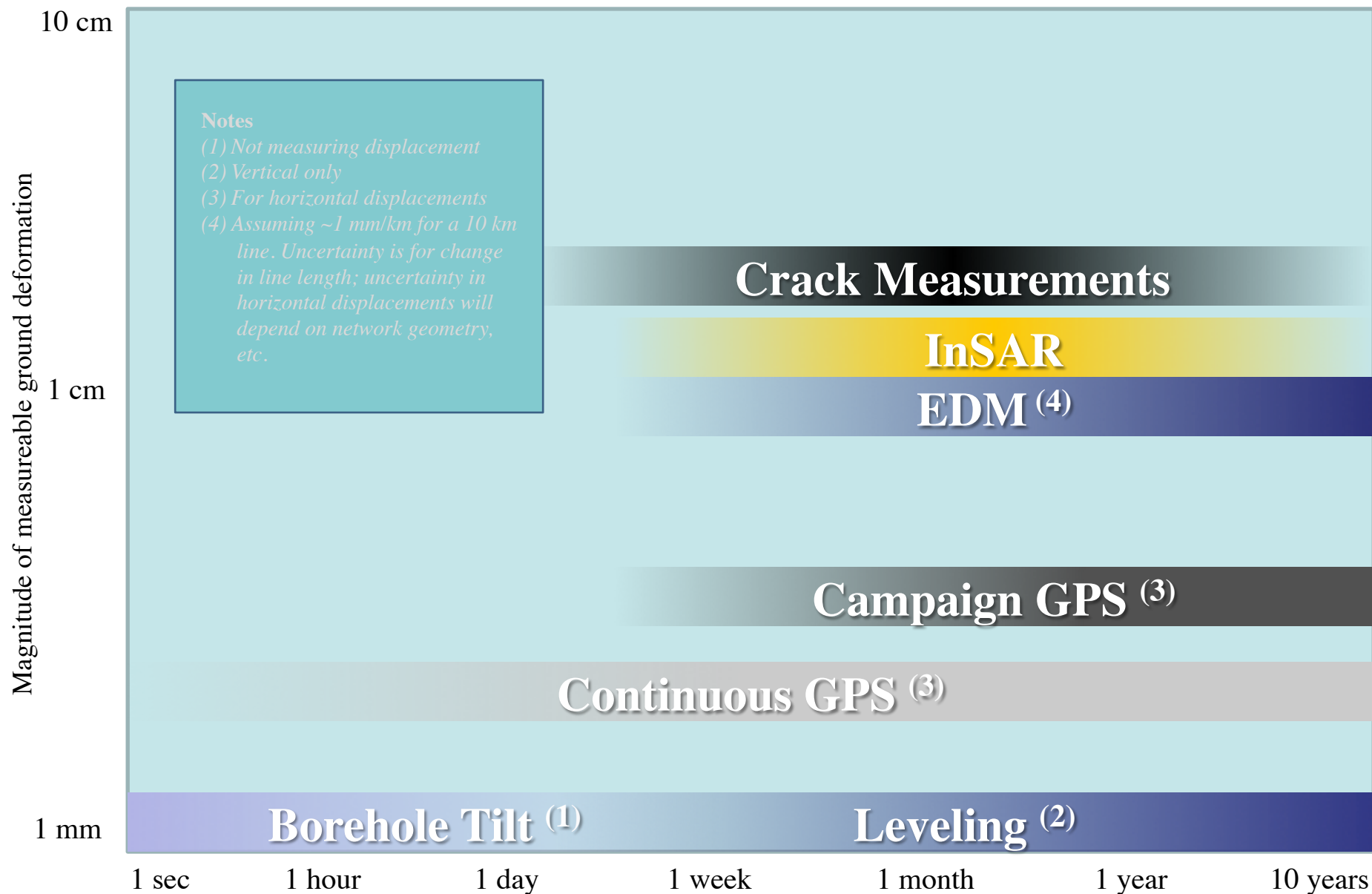


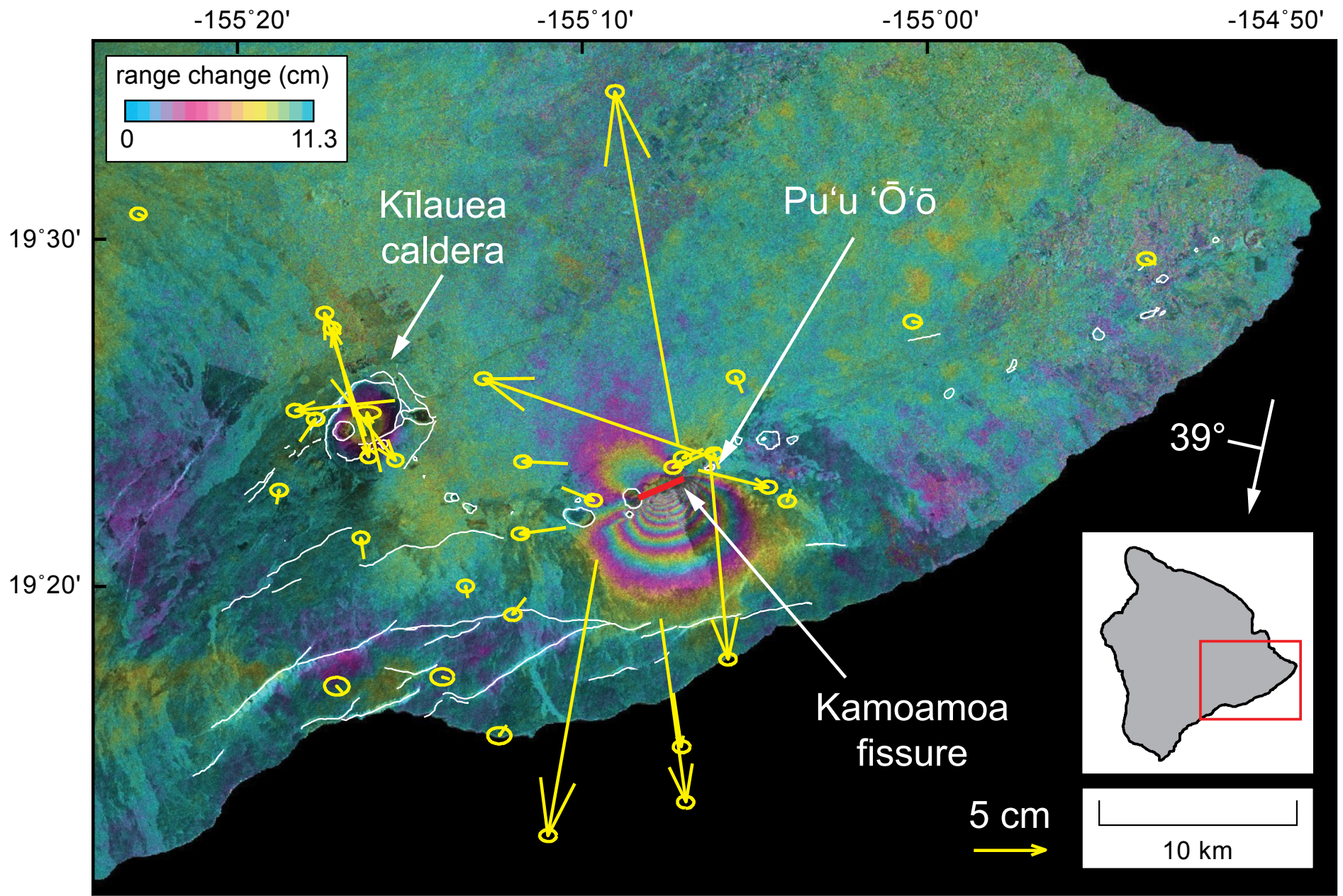
Pros**Cons**

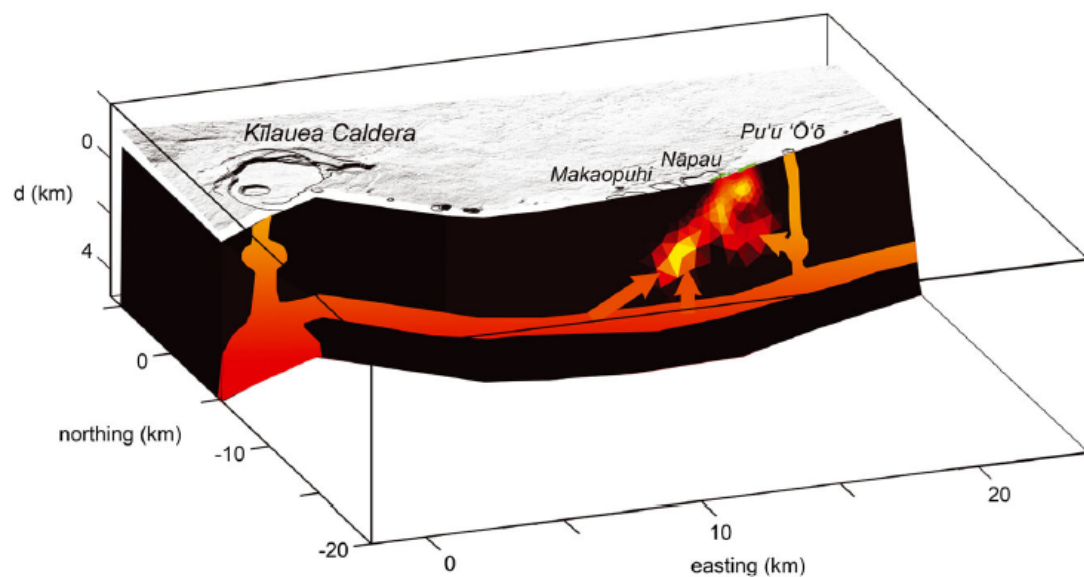
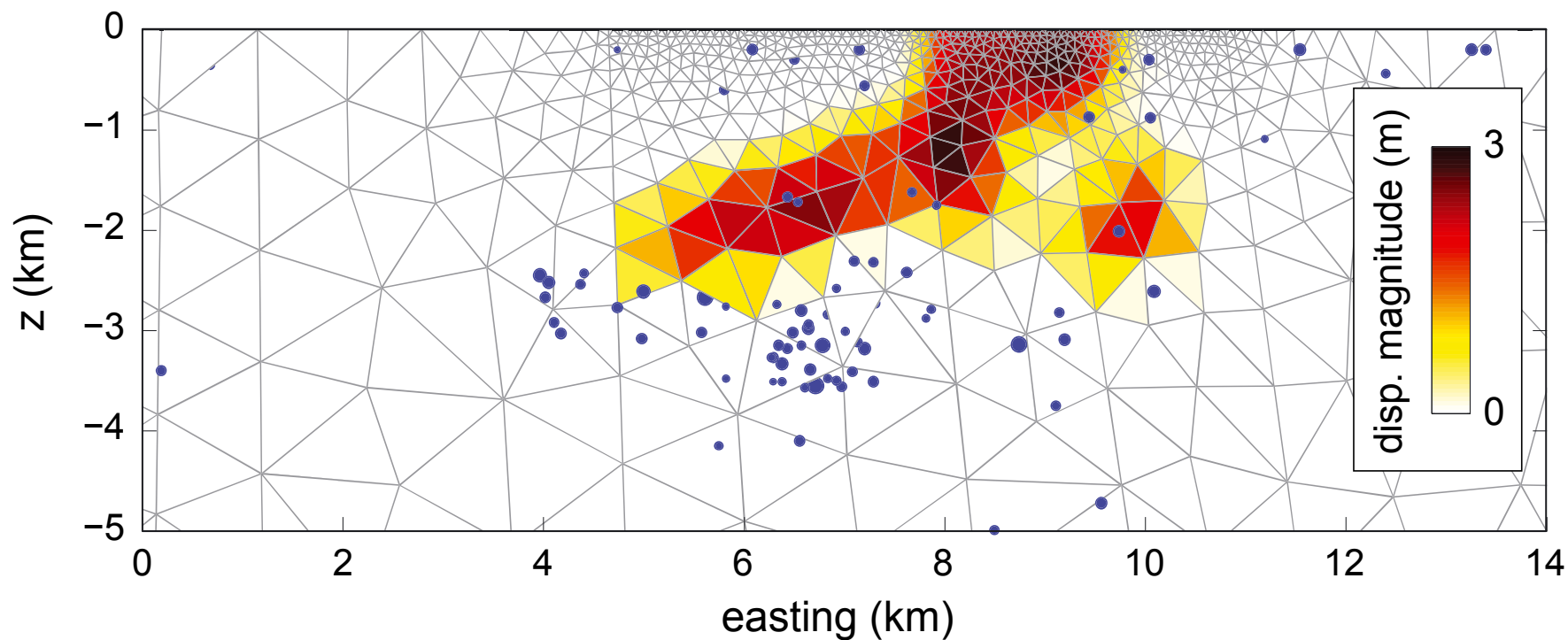
Continuous	> Excellent temporal resolution > After installation, no personnel required (except for maintenance)	> Expensive > Low spatial resolution
Campaign	> High spatial resolution > Inexpensive (equipment is not dedicated to a specific site)	> Low temporal resolution > Relatively time-intensive for few data points
Kinematic	> Can cover a lot of ground in a day > Inexpensive > Excellent spatial resolution in small networks	> Low temporal resolution > Requires continuous GPS site as a local reference > Centimeter accuracy (as opposed to millimeter)

Magnitude of Measureable Ground Deformation vs. Repeat Time

Typical values (may be higher or lower in practice)





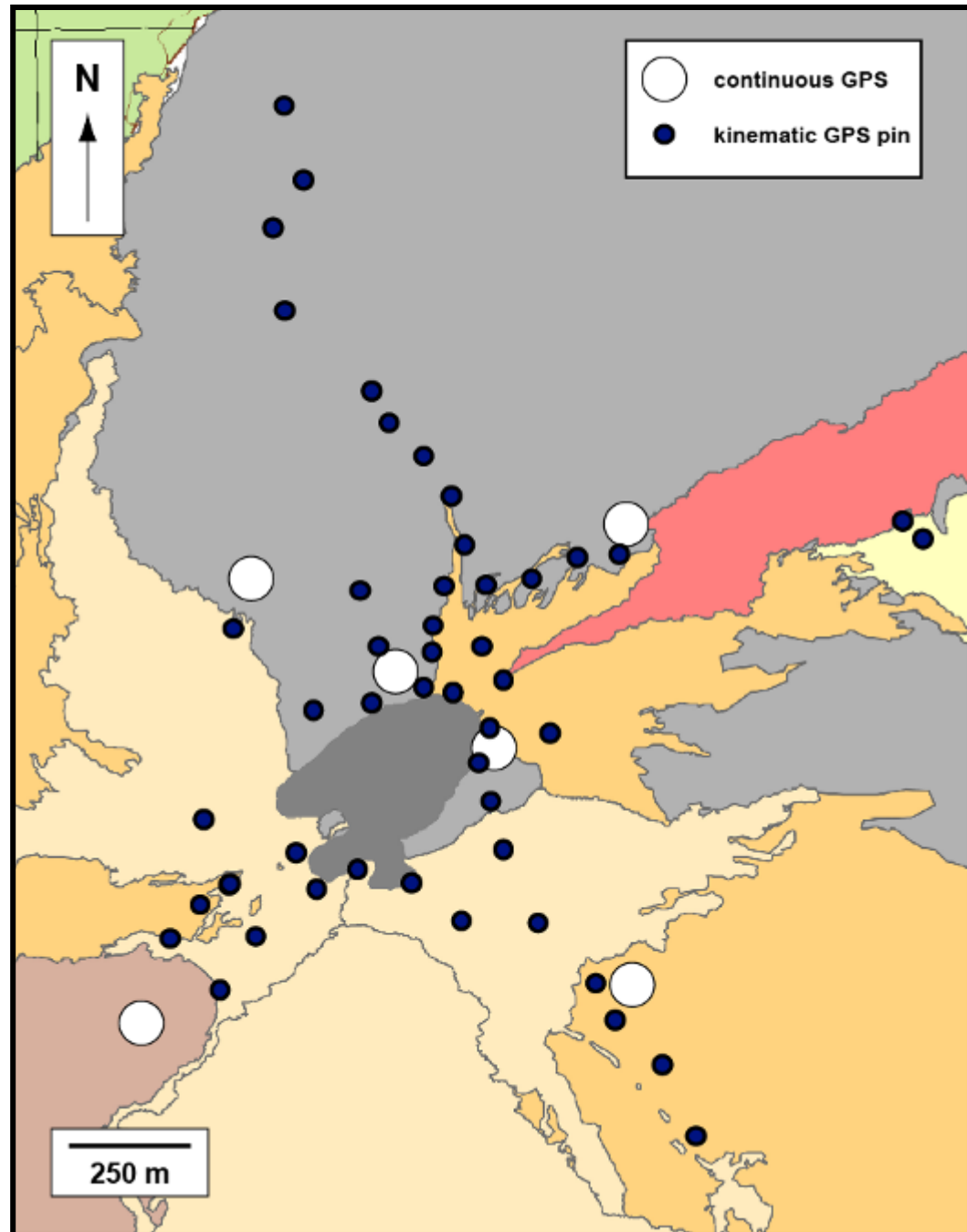


Combining different types of geodetic data allows you to image magma sources and transport

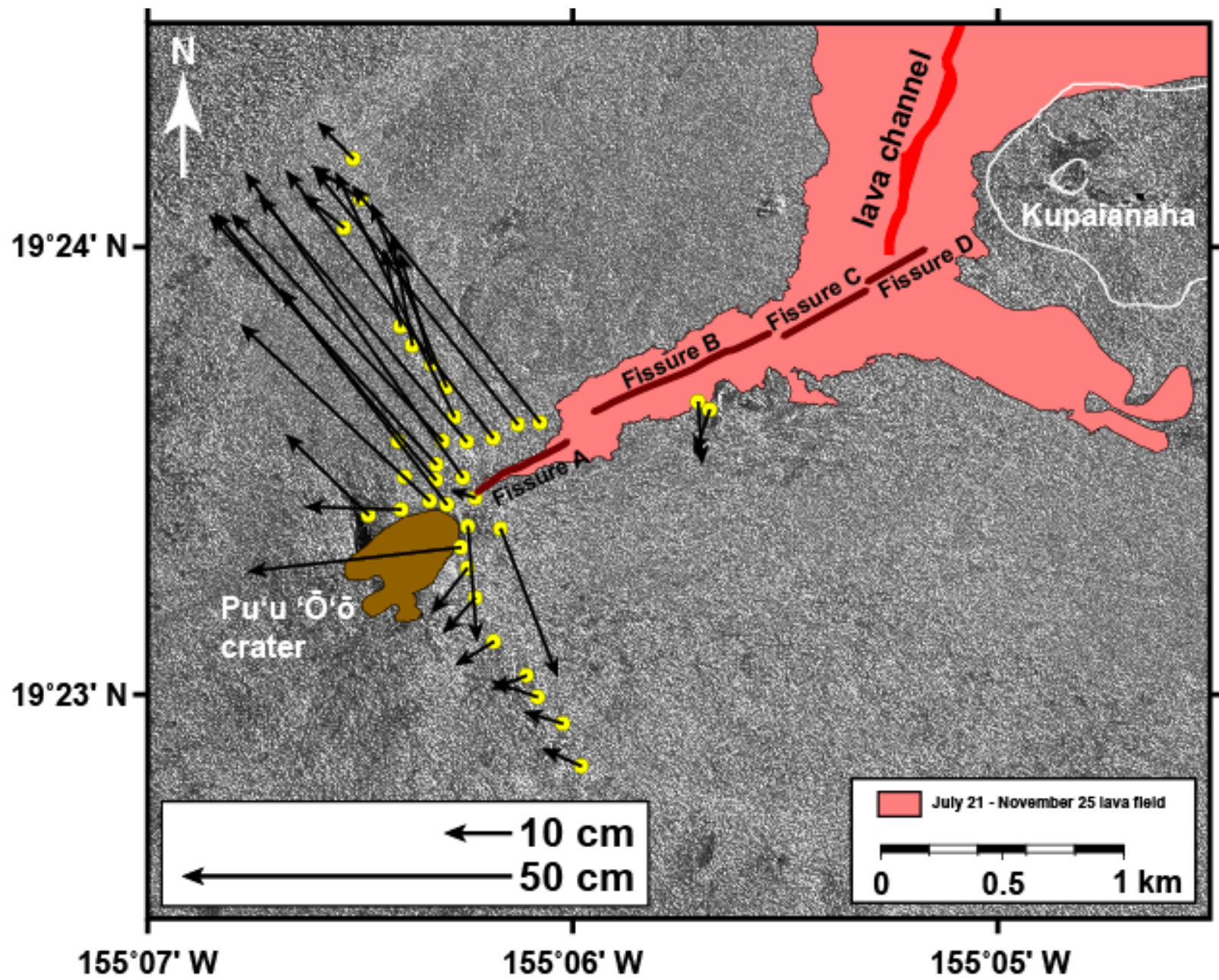
Kinematic GPS



The Pu'u 'Ō'ō kinematic GPS network



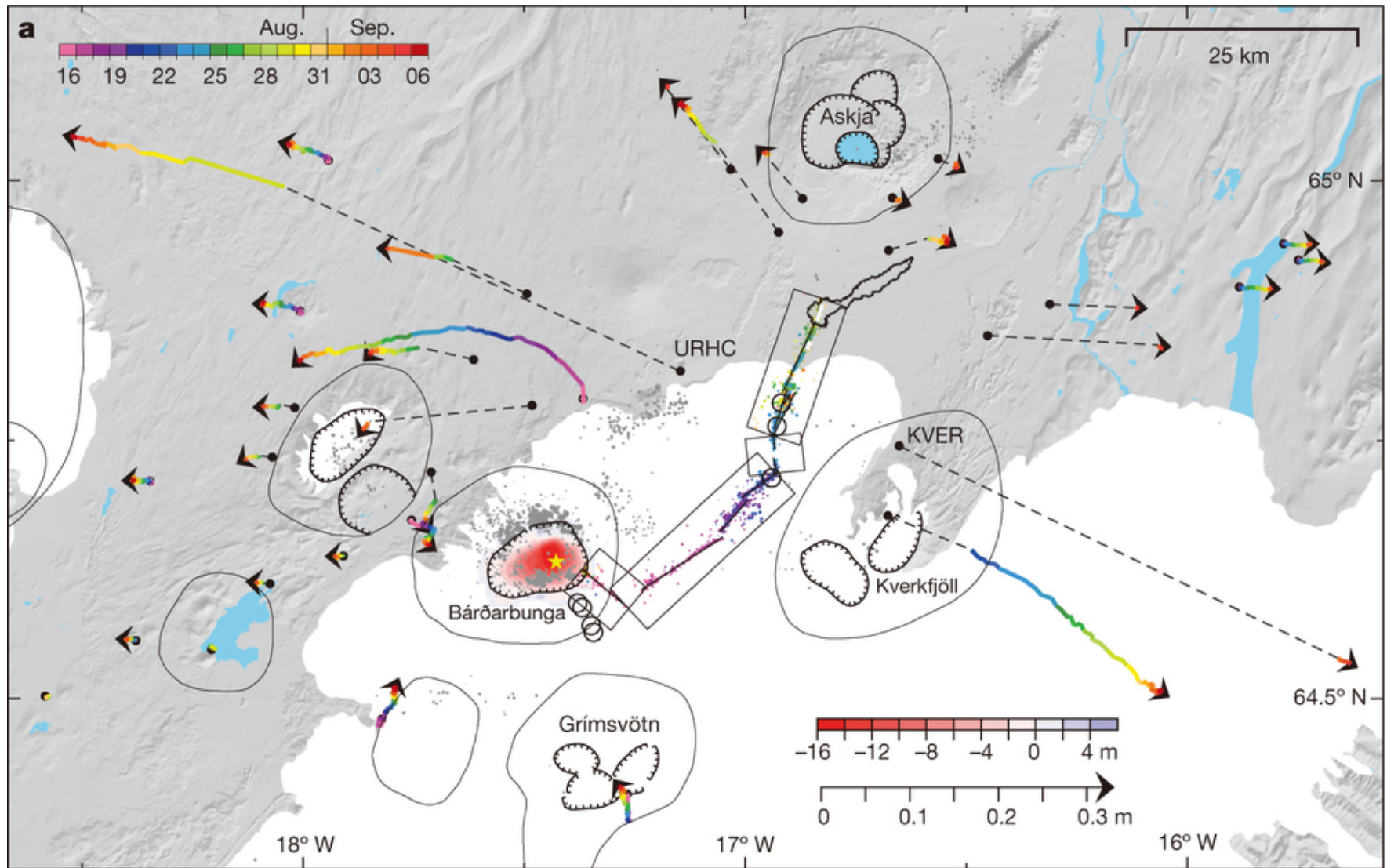
Mike Poland, USGS



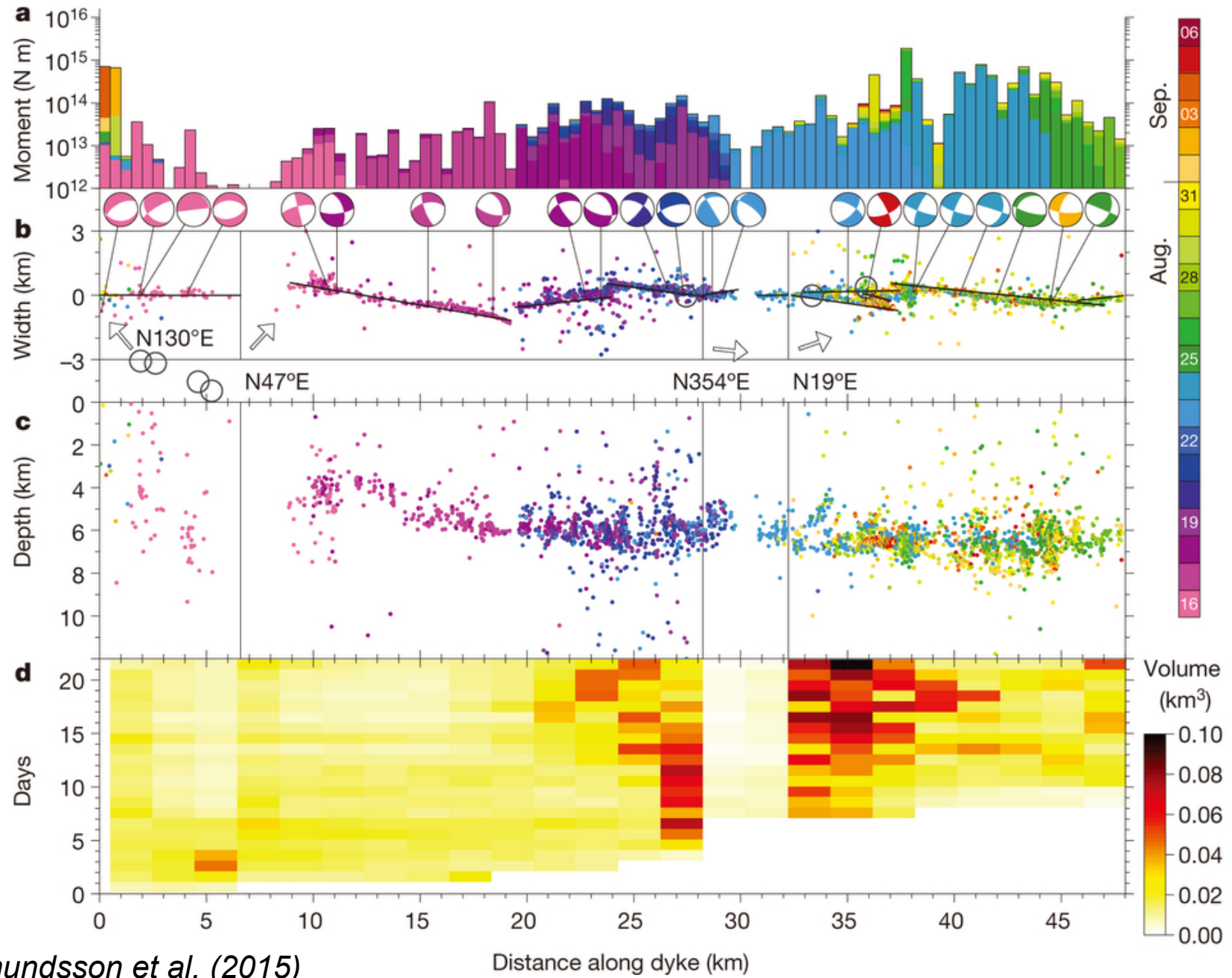


<http://icelandmag.visir.is>

Deformation Through Time

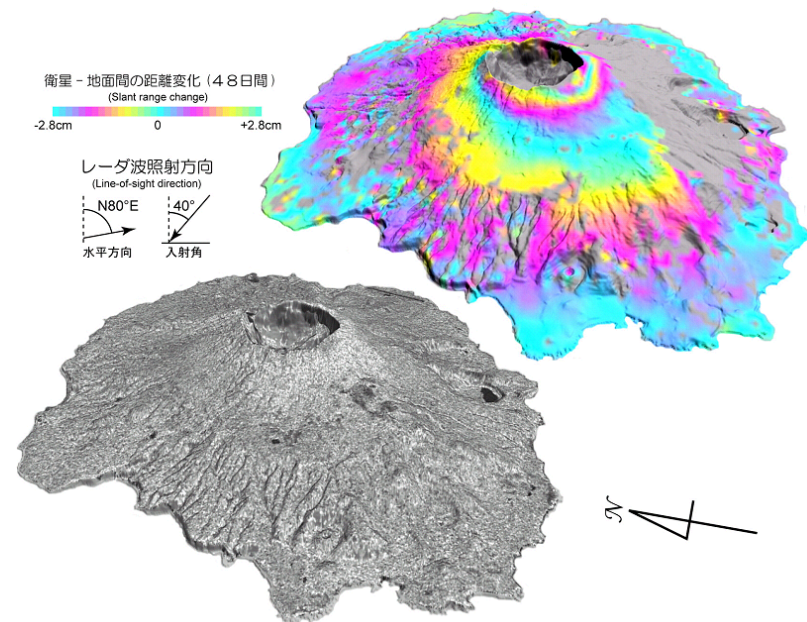


Sigmundsson et al. (2015)



Sigmundsson et al. (2015)

Miyakejima (Japan) 2000



letters to nature

Evidence from the AD 2000 Izu
islands earthquake swarm that
stressing rate governs seismicity

Shinji Toda*, Ross S. Stein † & Takeshi Sagiya‡

* Active Fault Research Center, Geological Survey of Japan, AIST, Tsukuba
305-8567, Japan

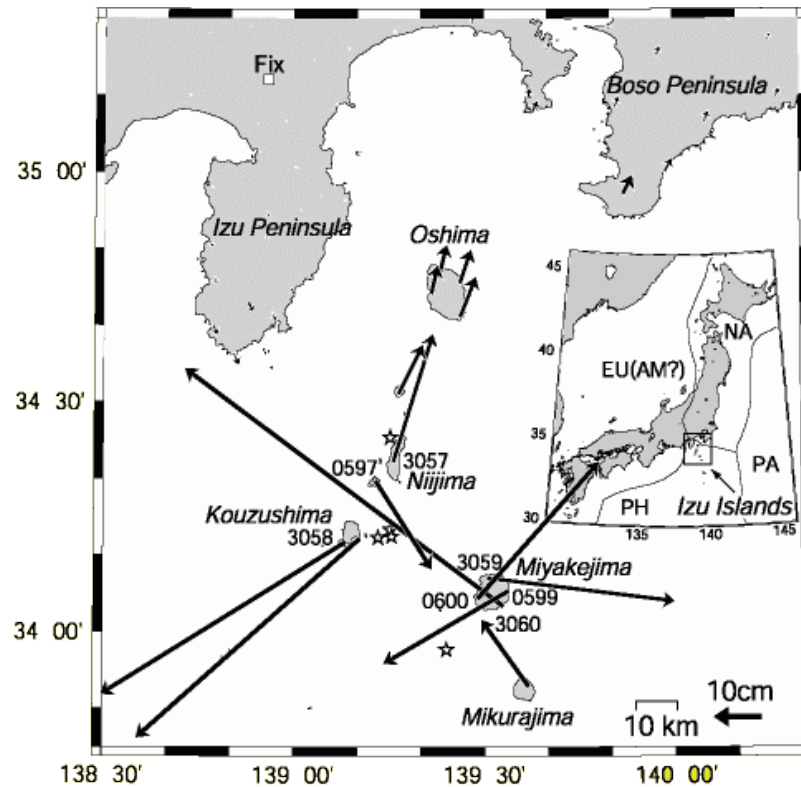
† US Geological Survey, MS 977, Menlo Park, California 94025, USA

‡ Geographical Survey Institute, Tsukuba 305-0811, Japan

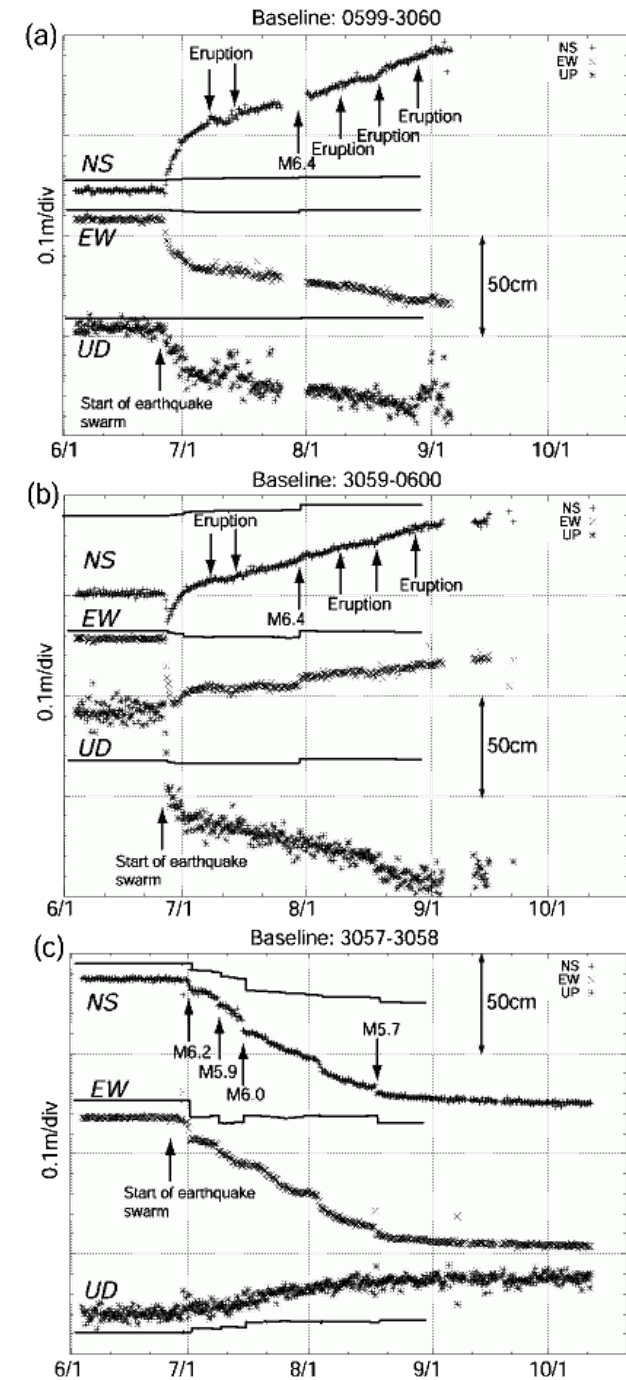
NATURE | VOL 419 | 5 SEPTEMBER 2002 | www.nature.com/nature

Results from GSI, Japan and several papers

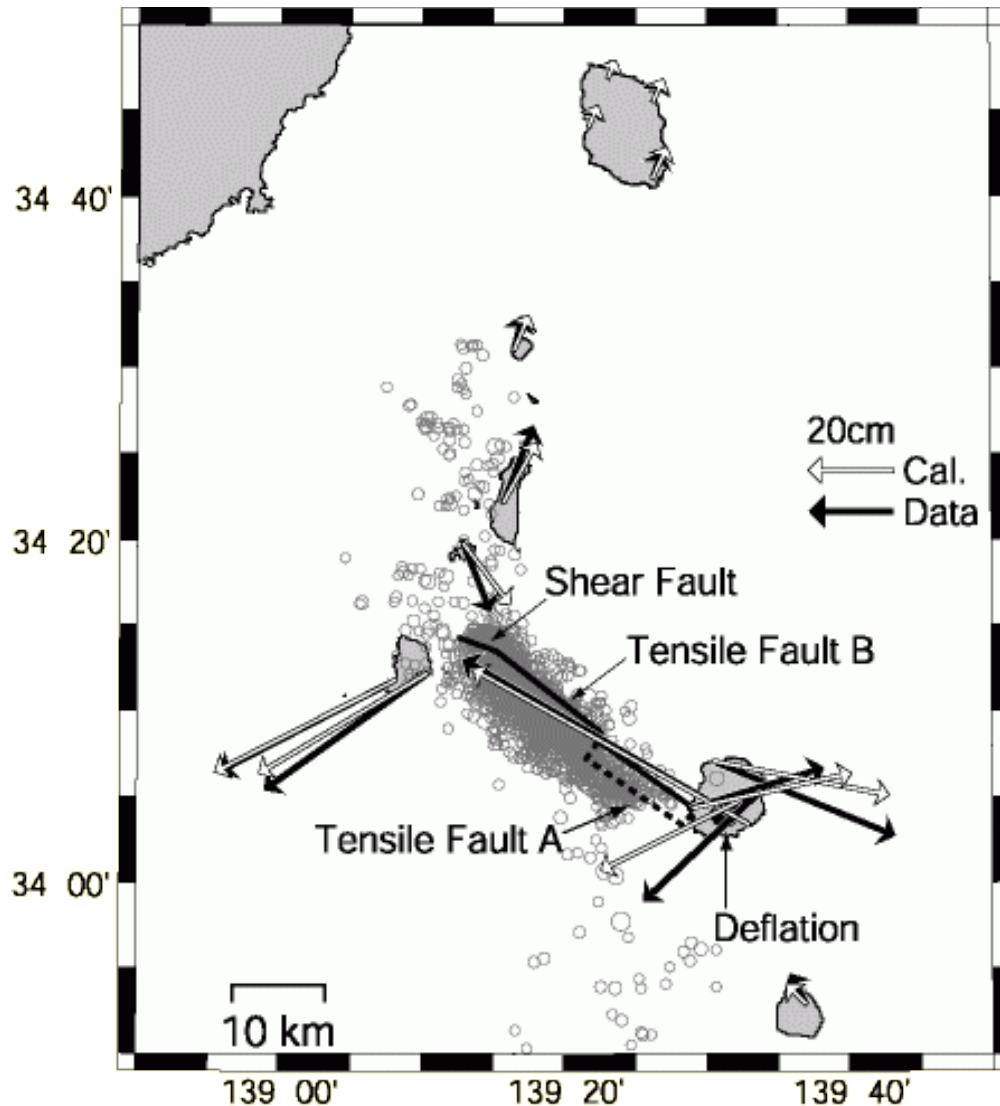
GPS Vectors and Time Series



Nishimura et al. (2001, GRL)

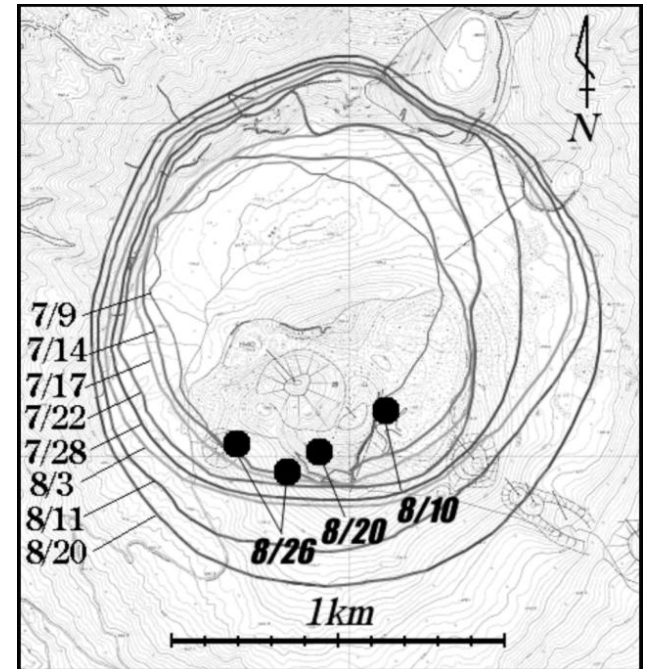
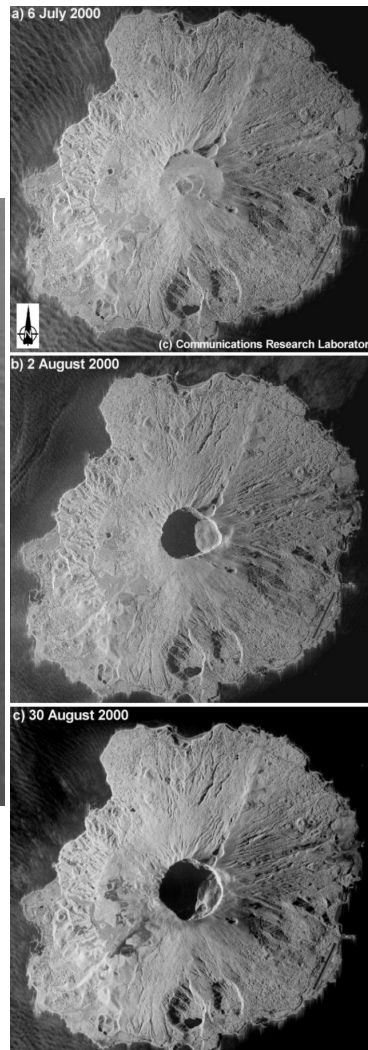


Deformation Model



- Eruption at Miyakejima was accompanied by
 - Submarine eruption
 - Intrusion of a large dike ~40 km long with meters of opening
 - Collapse of summit after magma drained out
- Intense seismicity swarm
- Magma in dike was >> magma removed from Miyakejima

Collapse of Summit Caldera



Time History of Seismicity

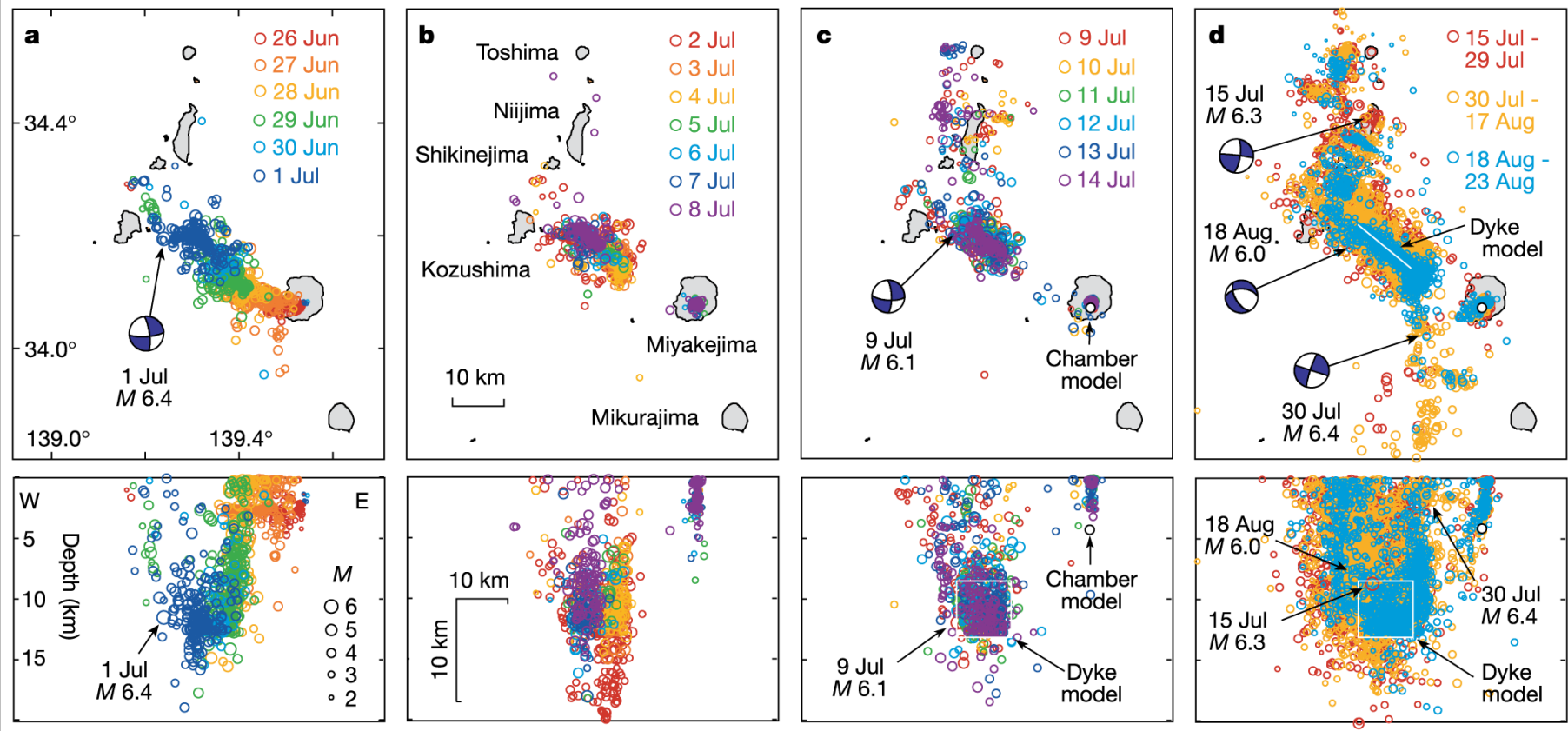


Figure 1 Swarm evolution in map view (top panels) and cross-section (bottom panels). (a) shows the initial seismicity within 3 days of the main shock, and expands substantially after two weeks. (d) shows the geometry of the seismicity at the end of the swarm. The off-dyke seismicity is shown in grey, the dyke and magma chamber is shown in blue and purple, respectively.

Geodetic Model for Dike

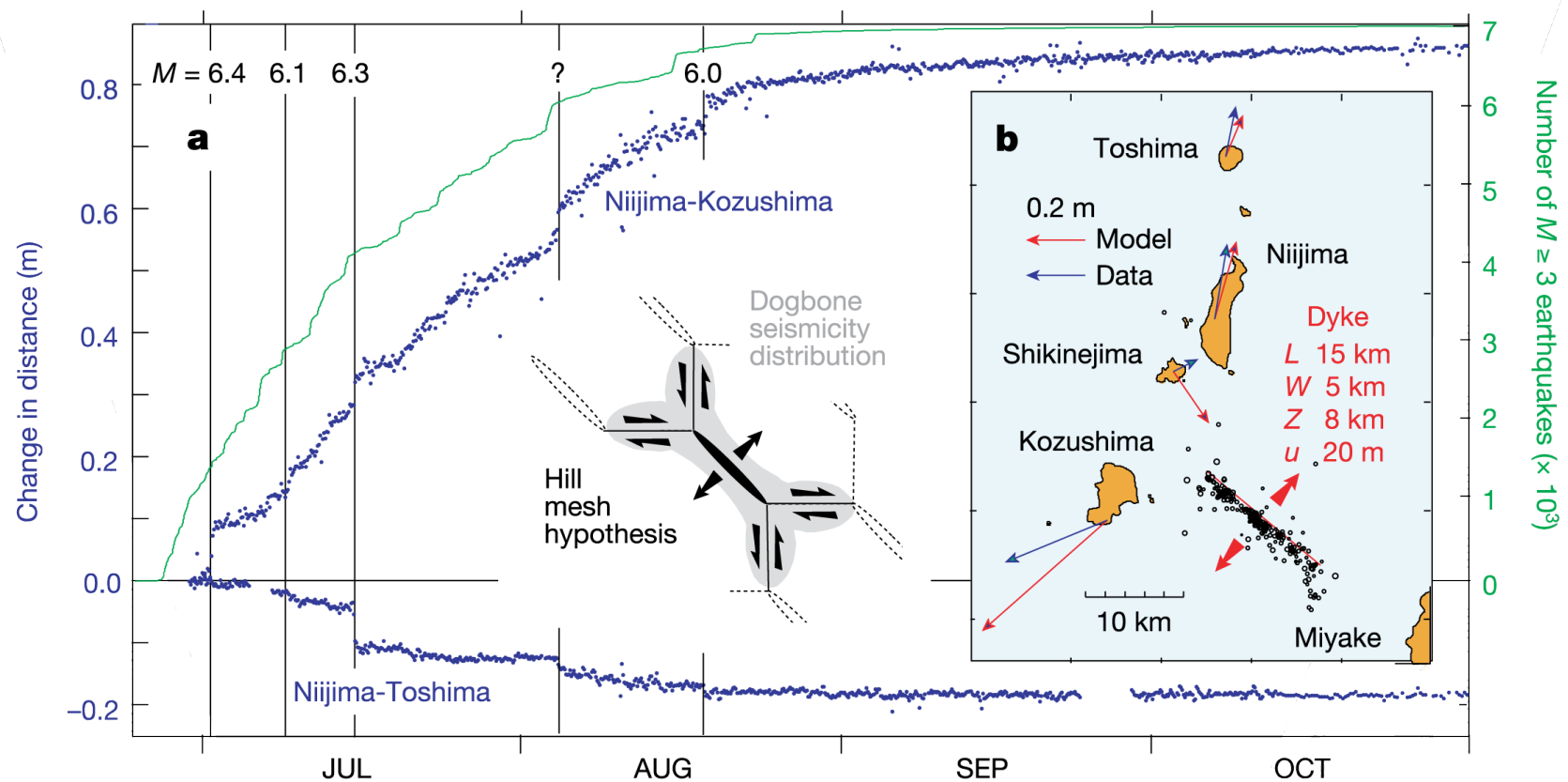


Figure 3. Intrusion geometry and deformation. GPS line-length changes and cumulative Japan Meteorological Agency (JMA) shocks, with the observed 'dogbone' pattern (grey) and Hill mesh explanation (black) inset. We use epicentres at 9–12 km depth located by ocean bottom seismometers to constrain the dike position. The inferred dike position, length, width, upper depth, opening. The volume lost to collapse of the summit caldera (0.60 km³) and magma chamber deflation (0.12 km³), and eruptions (0.02 km³) is about half that inferred for the dike intrusion (1.5 km³), suggesting that some magma migrated from greater depths. The inferred dike position, length, width, upper depth, opening. The inferred dike position, length, width, upper depth, opening. The inferred dike position, length, width, upper depth, opening.

Stress Change to EQ Rate

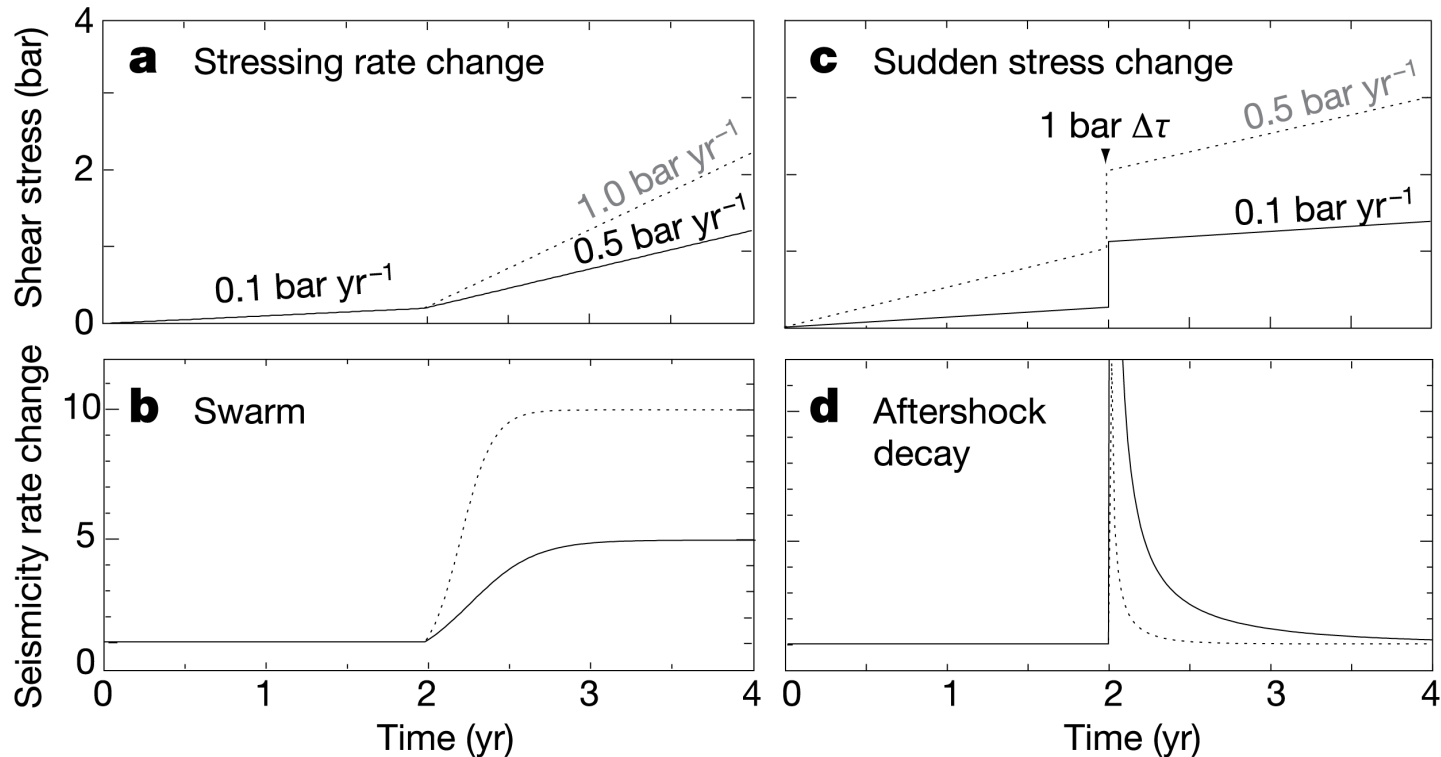


Figure 5 The rate/state effect of stress on seismicity. Details of the calculations are given in Methods. A change in the stressing rate (a) causes a swarm (b). A sudden stress change $\Delta\tau$ (c), causes an aftershock sequence that decays inversely with time (d). The Izu swarm has several aftershock sequences embedded in it. Comparison of dashed and solid curves shows that the higher the stressing rate, the more quickly the seismicity rate reaches equilibrium. As the stressing rate change is highest close to the source, swarm seismicity appears to migrate away from an intrusion or creep site.

Montserrat



Vulcanian Explosions, Oct. 1997



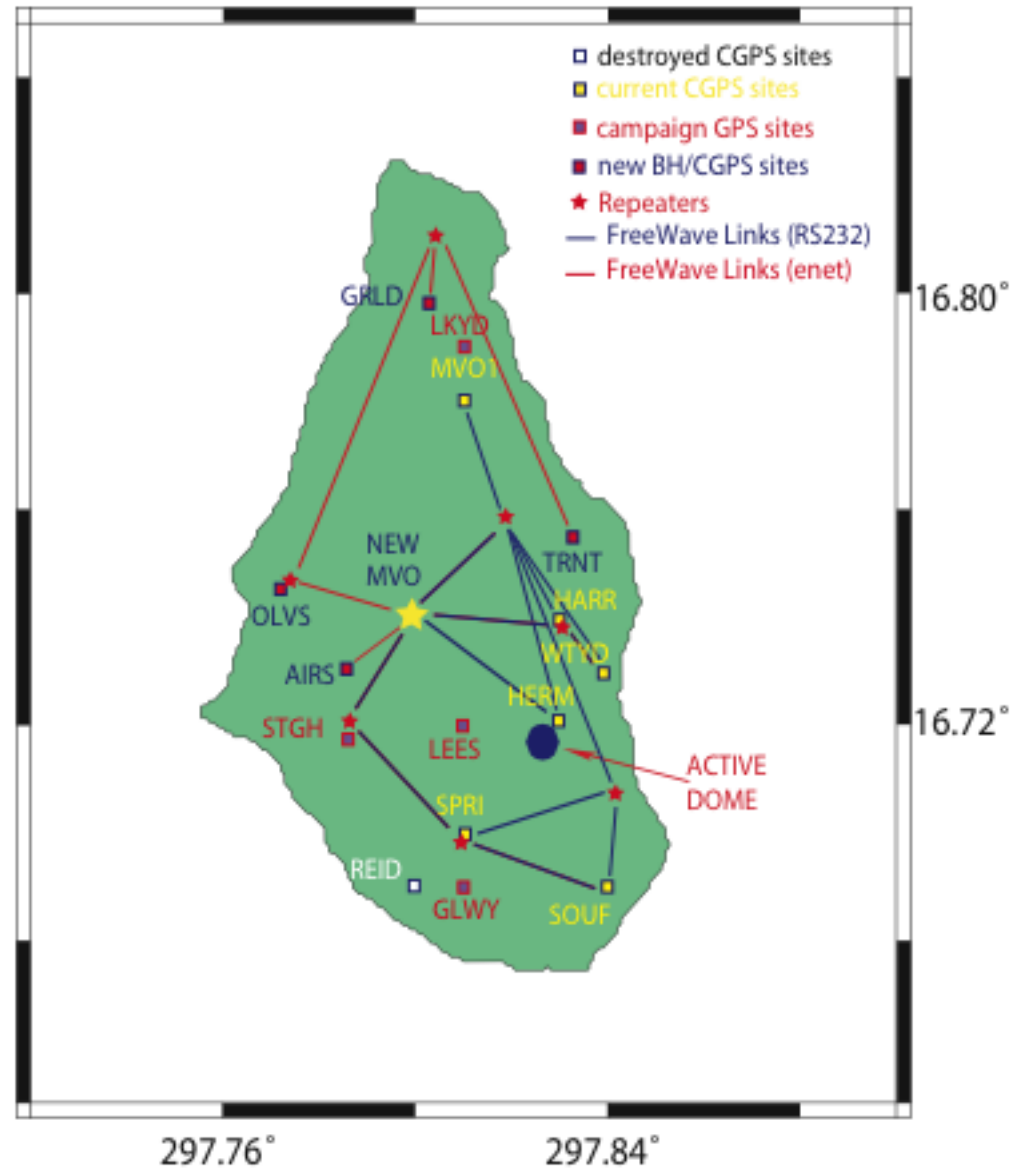
Photo credits: G. Mattioli

Data from: Mattioli et al., 2001; Sparks et al., 1998

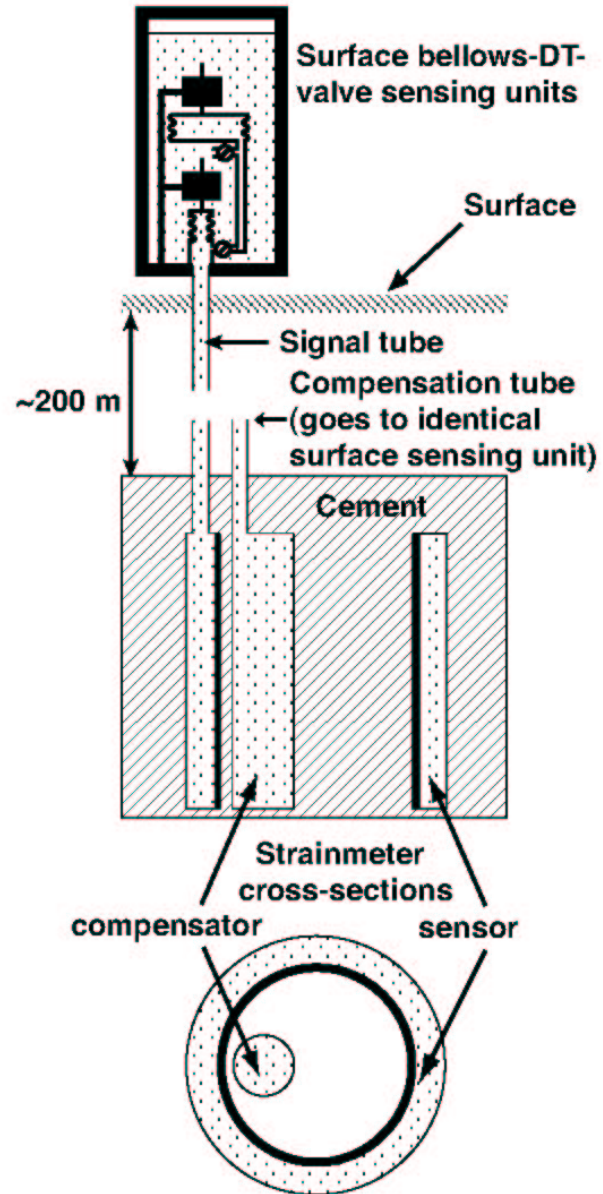
CALIPSO Borehole Observatory

- Sacks-Evertson single component dilatometer (10^{-9} strain)
- Nearly broadband 3 component seismometer (~ 2 Hz to 1 kHz)
- Pinnacle Systems short-baseline electronic tiltmeter
- Ashtech μ -Z code-phase CGPS w/ choke ring antenna

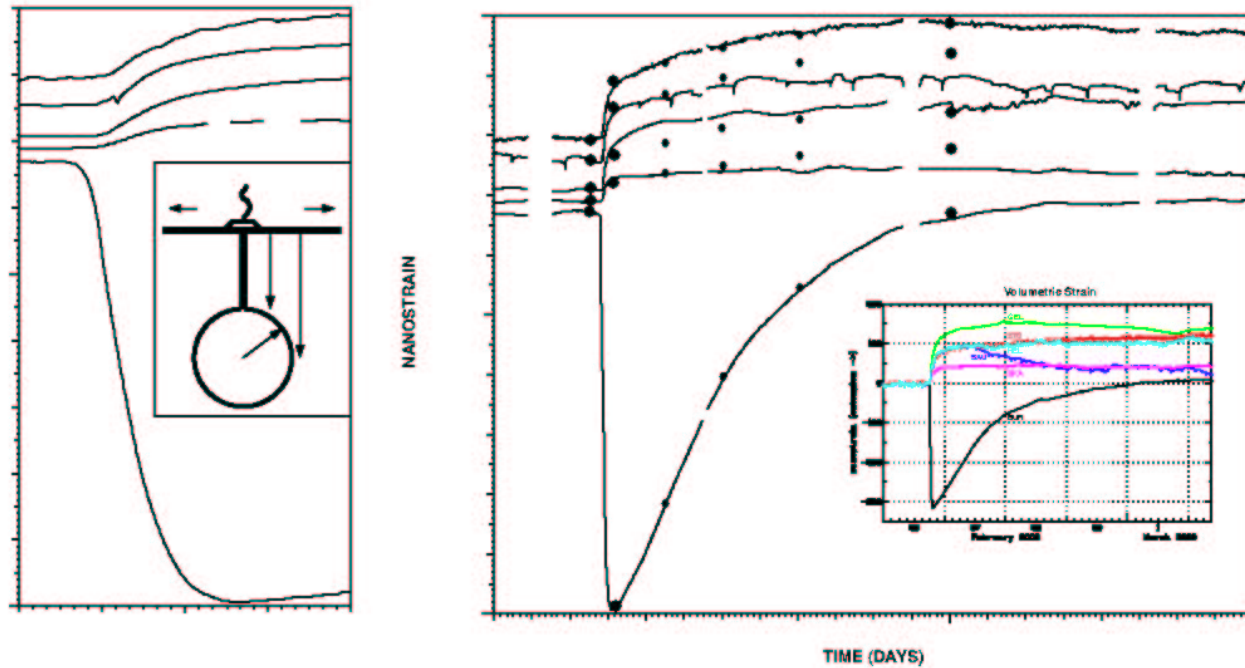
CALIPSO BH sites and existing CGPS/Telemetry infrastructure



Sacks-Evertson single-component dilatometer schematic



A. Linde's models of single-component dilatometer data from Iceland



NB that strain signal preceded Surface eruption by several hours!

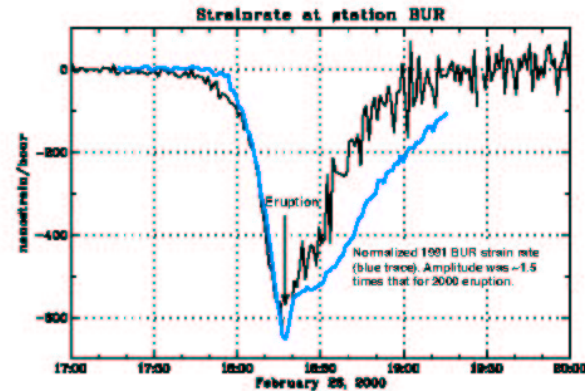
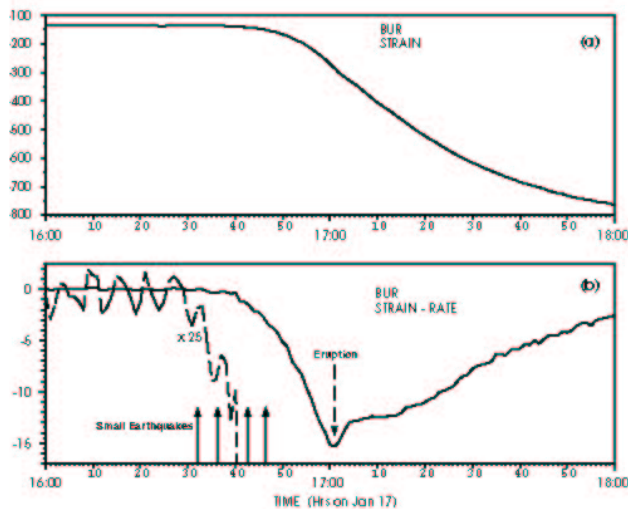


Photo of dome in Dec. 02 on a rare clear day. By July 2003 the dome had grown to $>230 \text{ M m}^3$ and had not collapsed significantly for 2 years!



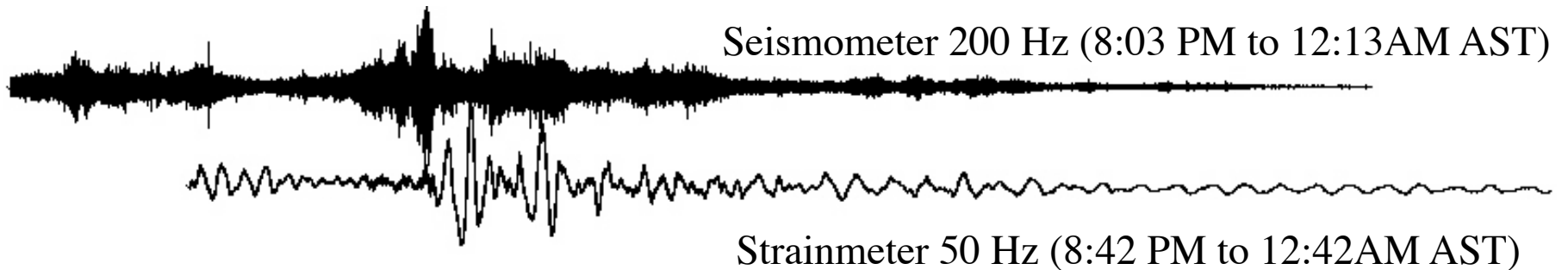
Photo credit: G. Mattioli

July 12th, 2003 - Dome collapse begins at 9 AM AST
By sunset, pyroclastic flows are getting more energetic
and now routinely reach the sea at the Tar River delta.
NB white is steam while gray is co-ignimbrite ash cloud.



Photo credit: G. Mattioli

Trants Borehole Seismic and Strain Records for July 12th Dome Collapse and Vulcanian event at ~11 PM AST



Although Trants site was impacted by ash during the culminating event of the July 12th dome collapse, the CALIPSO BH instruments functioned throughout the eruption.

Photo credit: G. Mattioli

First visit to Air Studios on July 14th - 12.5 cm of ash and 6 cm mud in crypt; NB infrasound microphone under ash, but CALIPSO was still up!



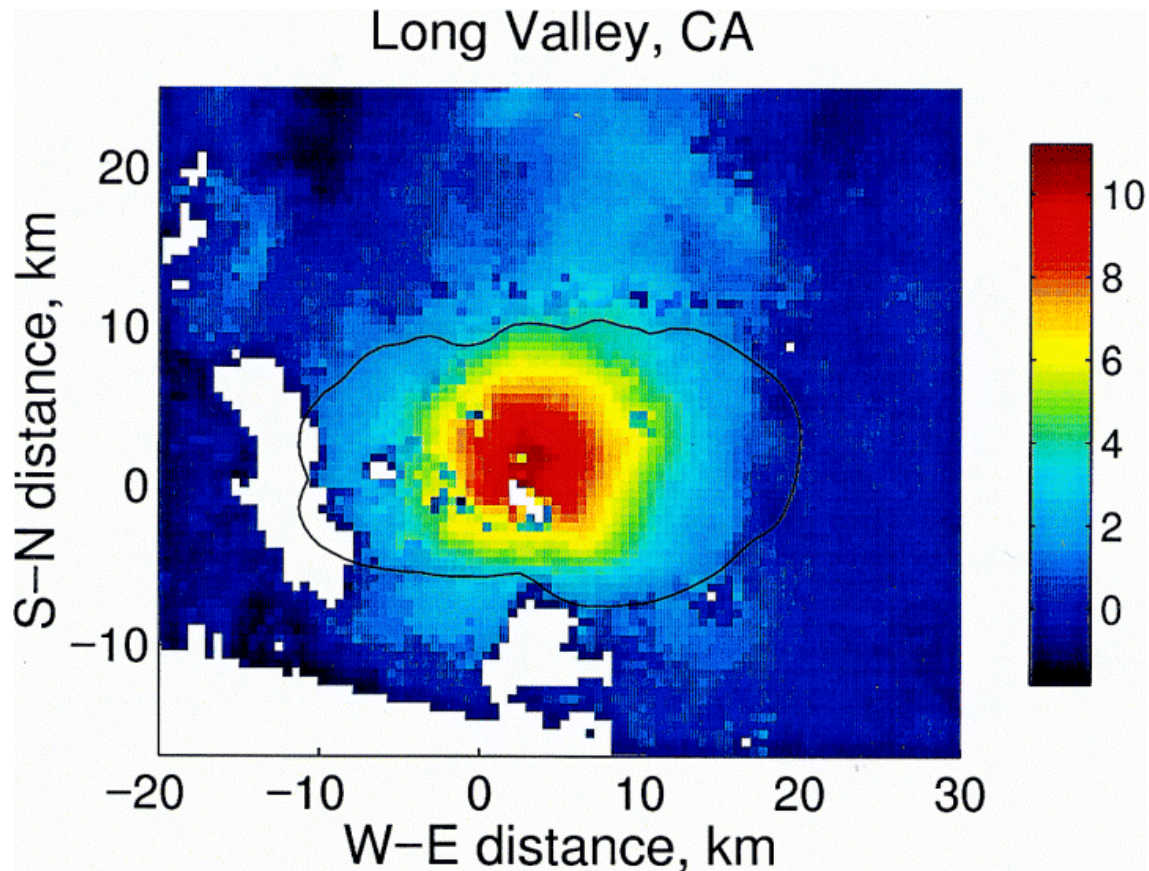
Photo credits: G. Mattioli

CALIPSO Air Studios site after cleanup on July 14th



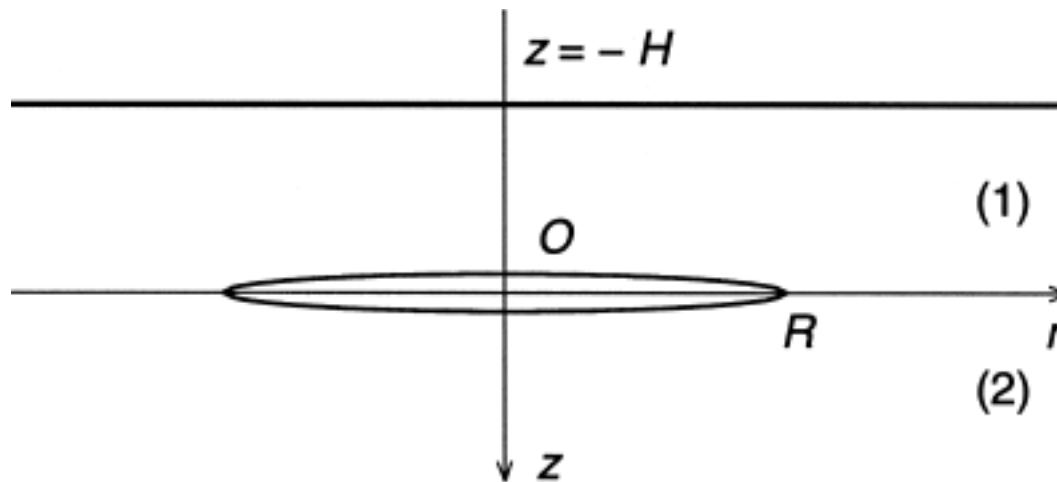
Photo credit: G. Mattioli

Long Valley



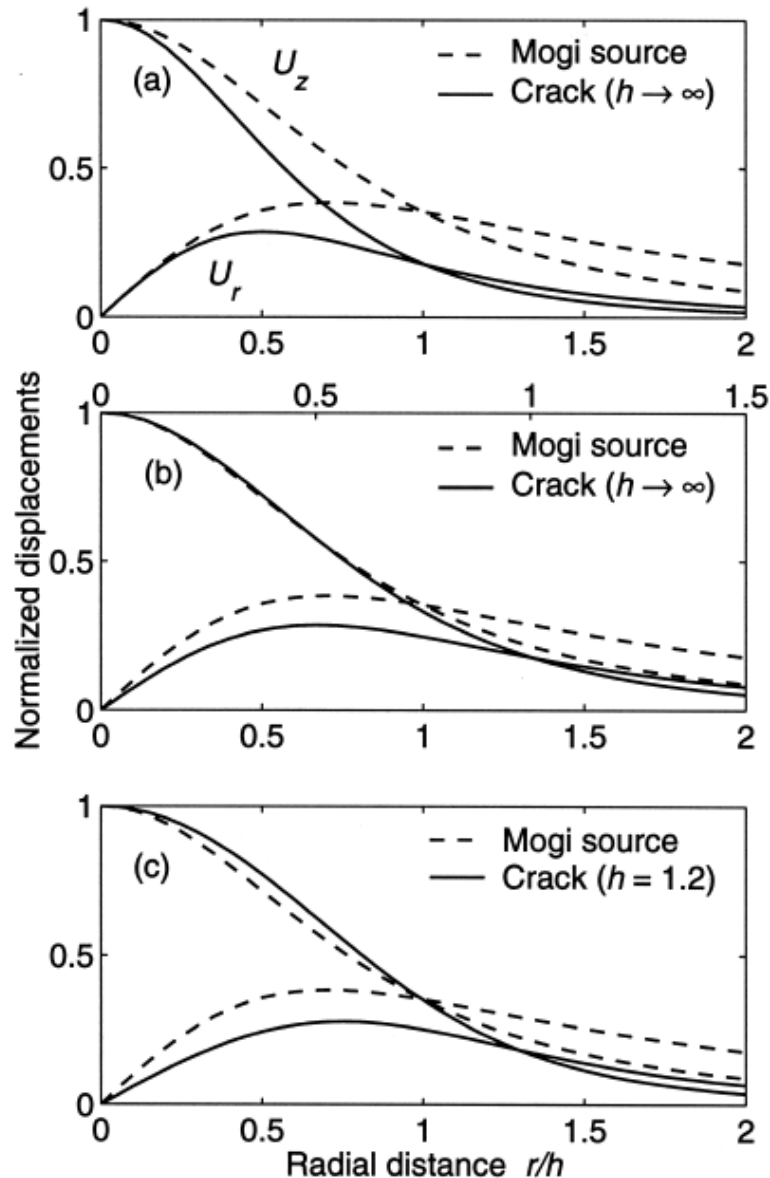
Interferogram 1996-1998, from Fialko et al. (2001b)

An Alternative Source Model Penny-Shaped Crack



Use condition of *uniform pressure*, not uniform displacement

Comparison of crack to Mogi

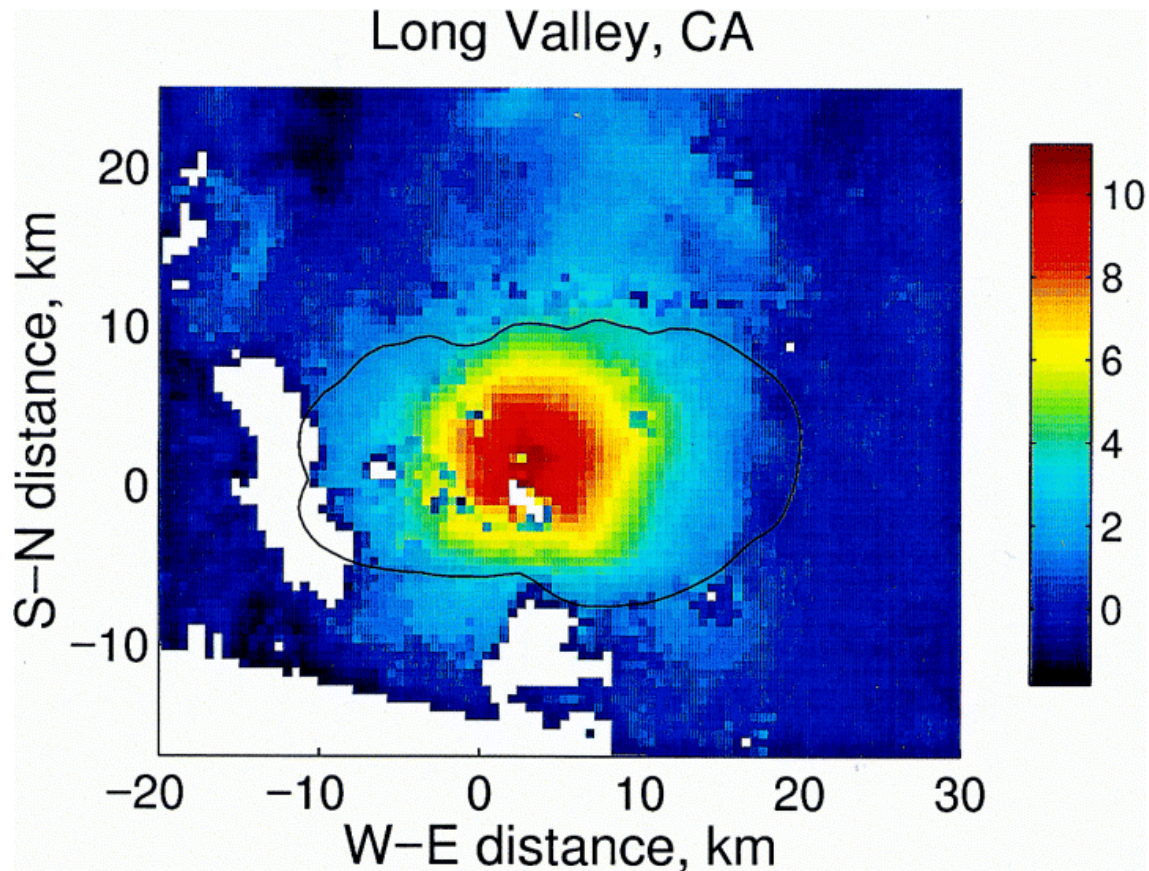


- Equations are rather complicated
 - If radius is small compared to depth, then

$$U_z^{\max} = \frac{4}{\pi} \frac{1 - \nu}{\mu} \Delta P \frac{R^3}{H^2},$$

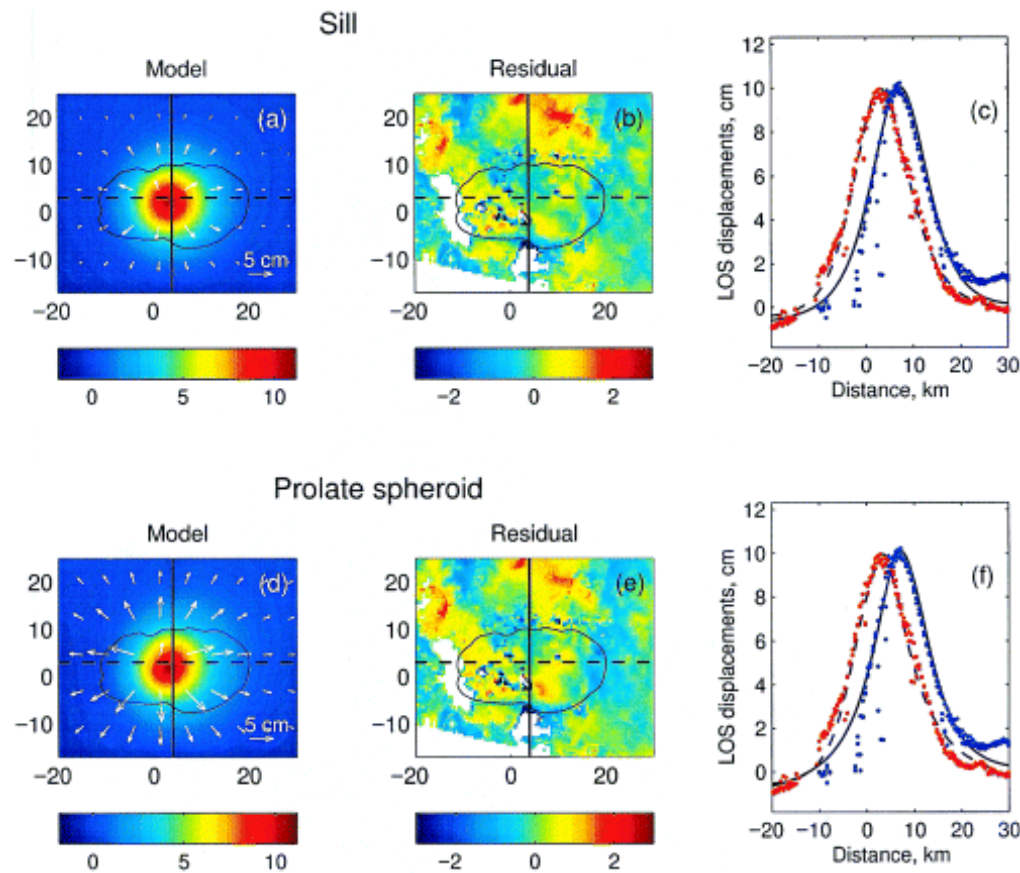
- Compared to Mogi source that produces same vertical, produces less horizontal (panel b).
- Cylindrical pipes produce more horizontal than vertical relative to Mogi source
- Fialko et al. (2001)

Long Valley



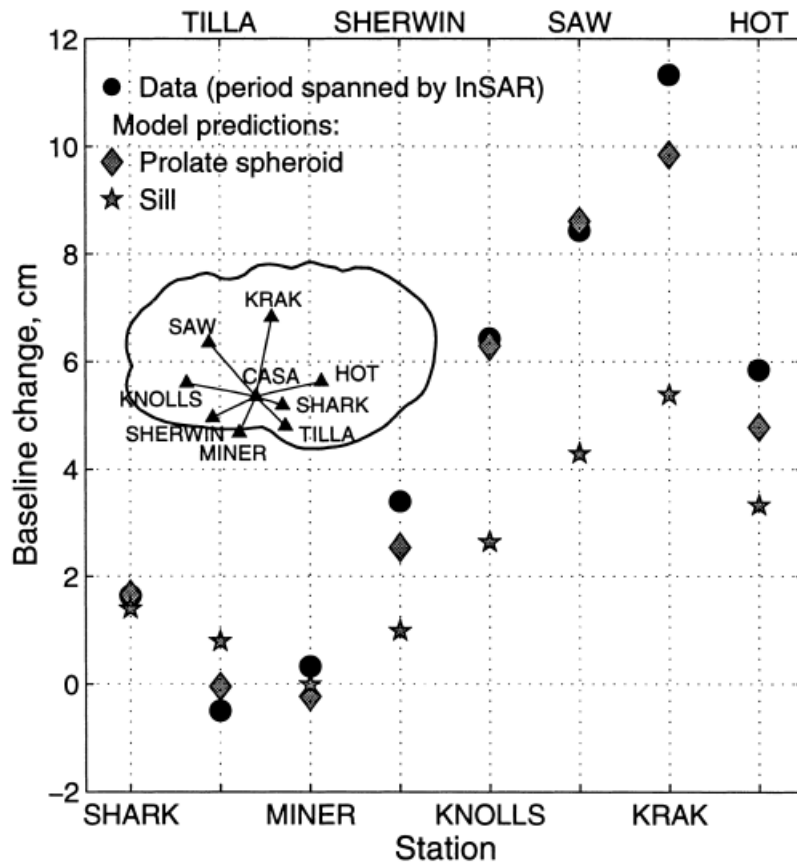
Interferogram 1996-1998, from Fialko et al. (2001b)

Sill vs. Prolate Spheroid



Both can fit InSAR data

Horizontal 2-color laser data

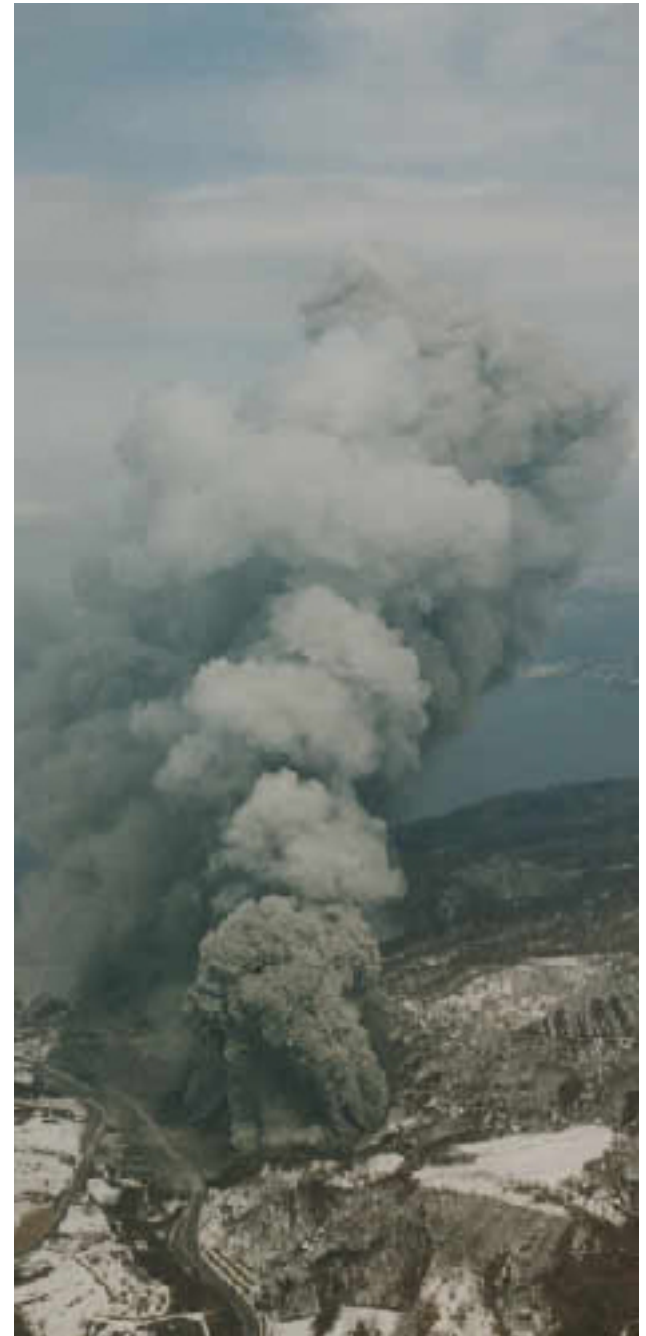


- InSAR data fit equally well by sill or prolate spheroid
 - Because you can get almost the same vertical profile from different source models
- Horizontal data fit by spheroid, not sill
 - 7 km depth
 - 2.3:1 vertical:horizontal
 - Nearly vertical long axis (97°)

Usu (Japan) 2000



No Stratocone



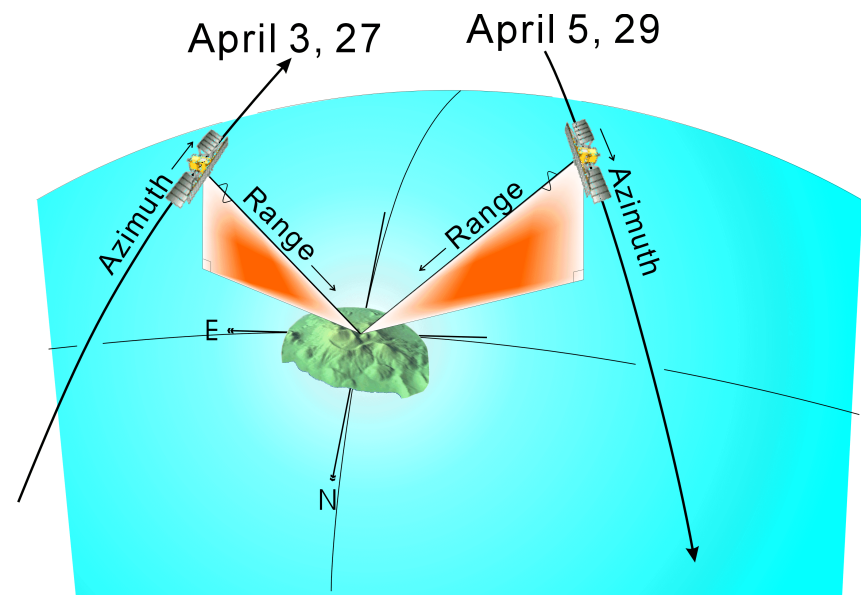
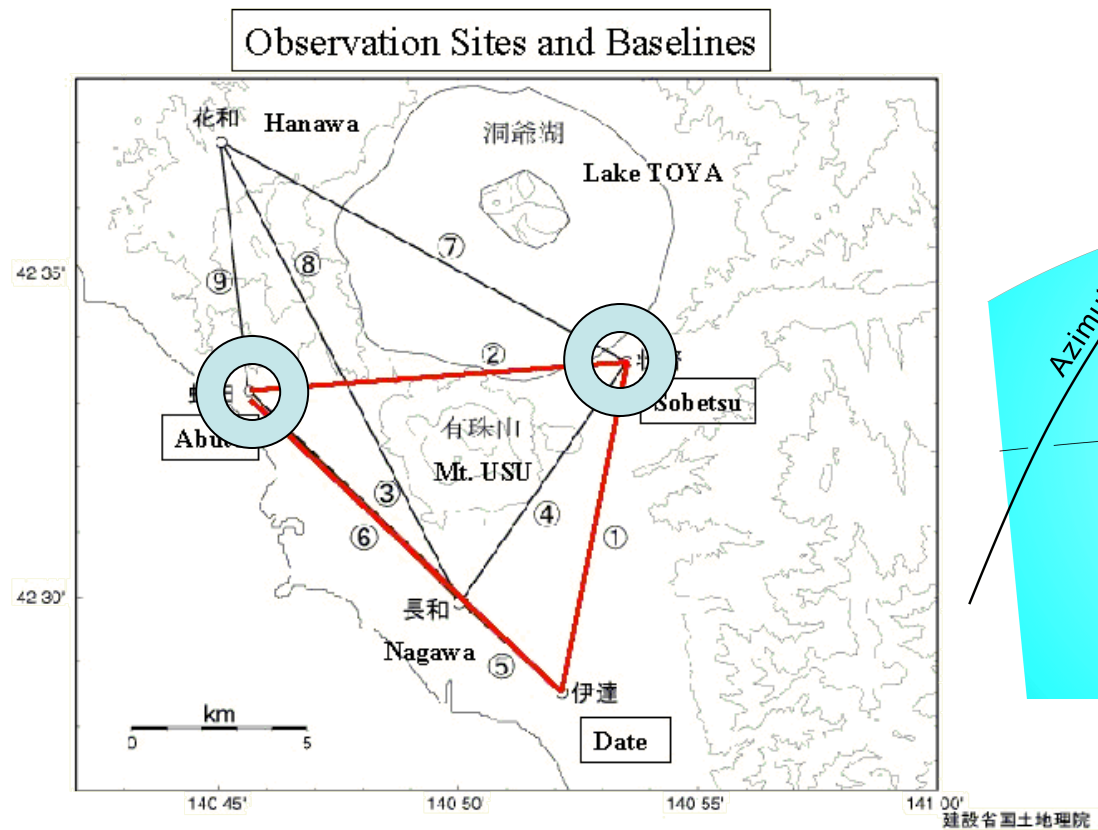
Key observations

- Adjacent to Lake Toba caldera
- Usu vent not associated with topography
 - “New” eruptive vent
- Enormous ground deformation (meters)
 - Data from GPS and from InSAR
 - Complex source to explain
 - Broad area deflation
 - Inflation near vent

Sources of Data

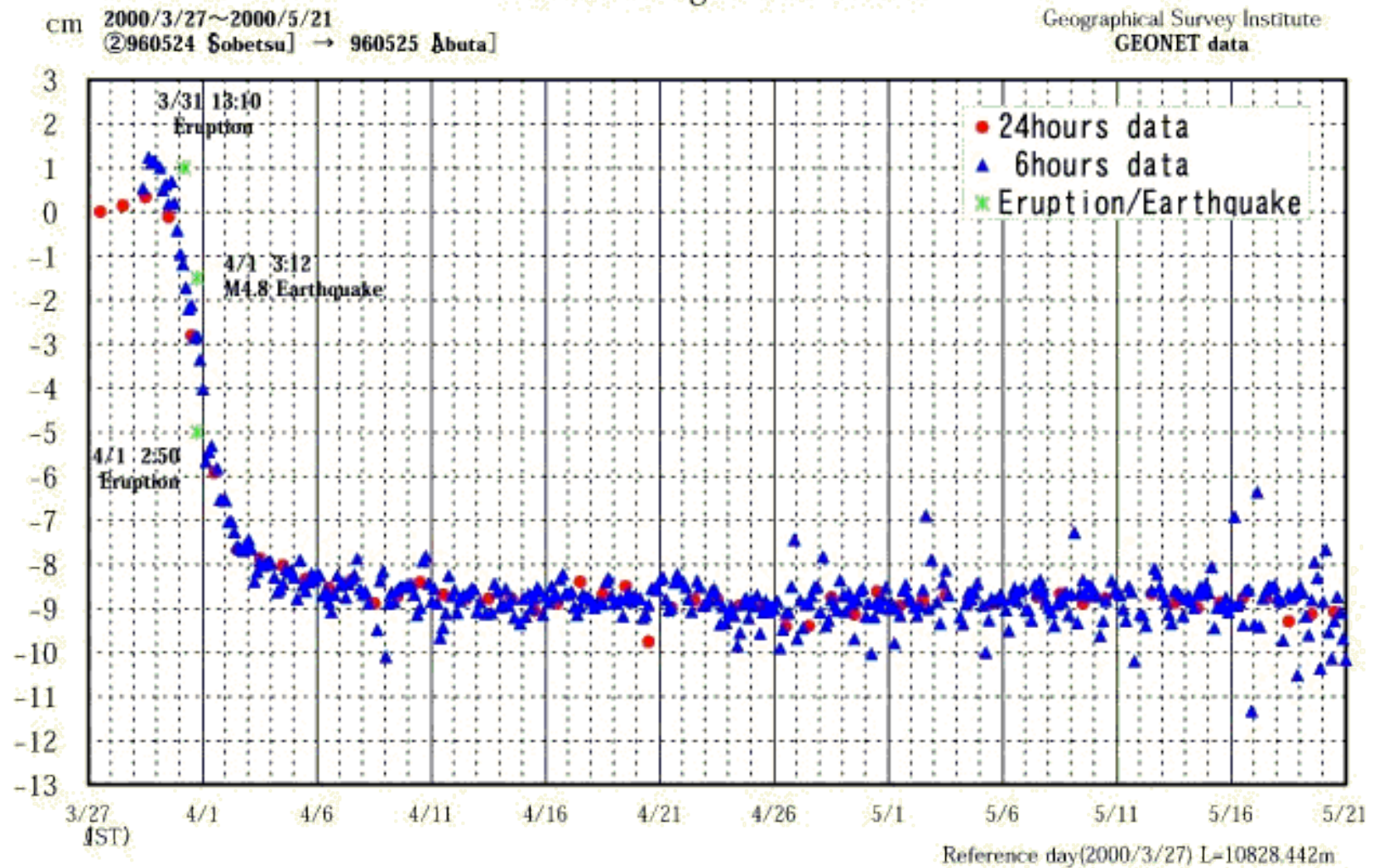
InSAR and SAR image correlation

GPS Baselines



GPS Time series

Baseline length time series



Standard InSAR Result

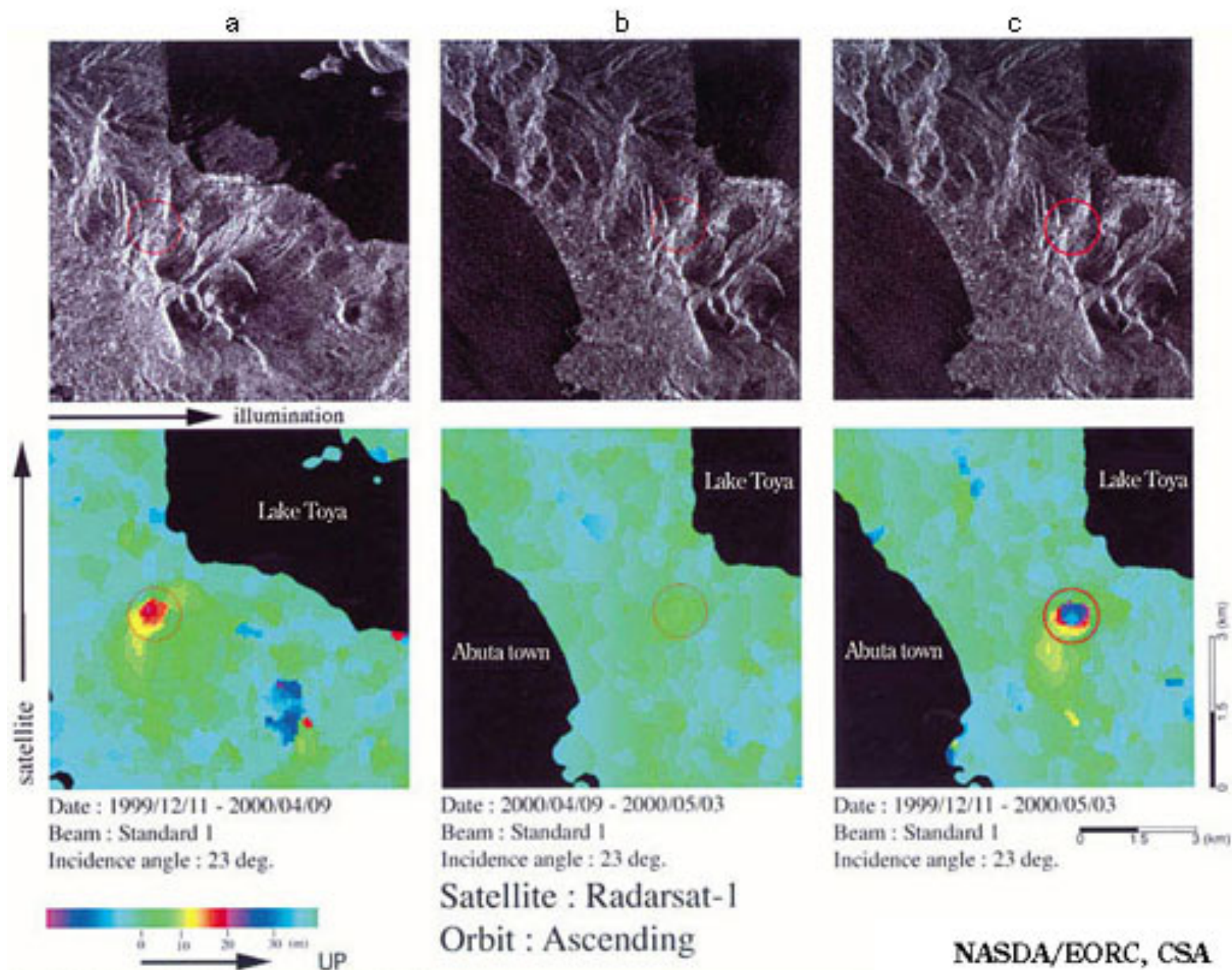
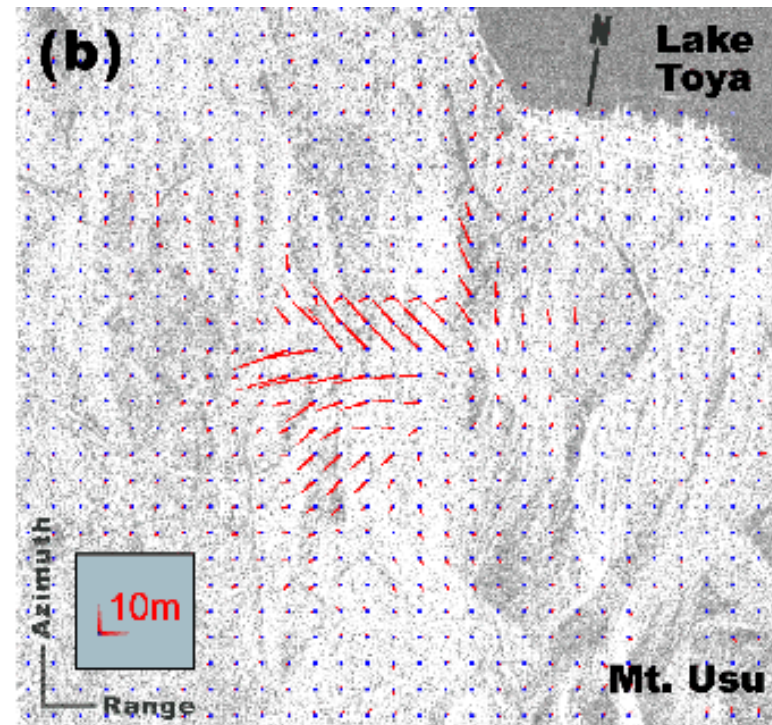
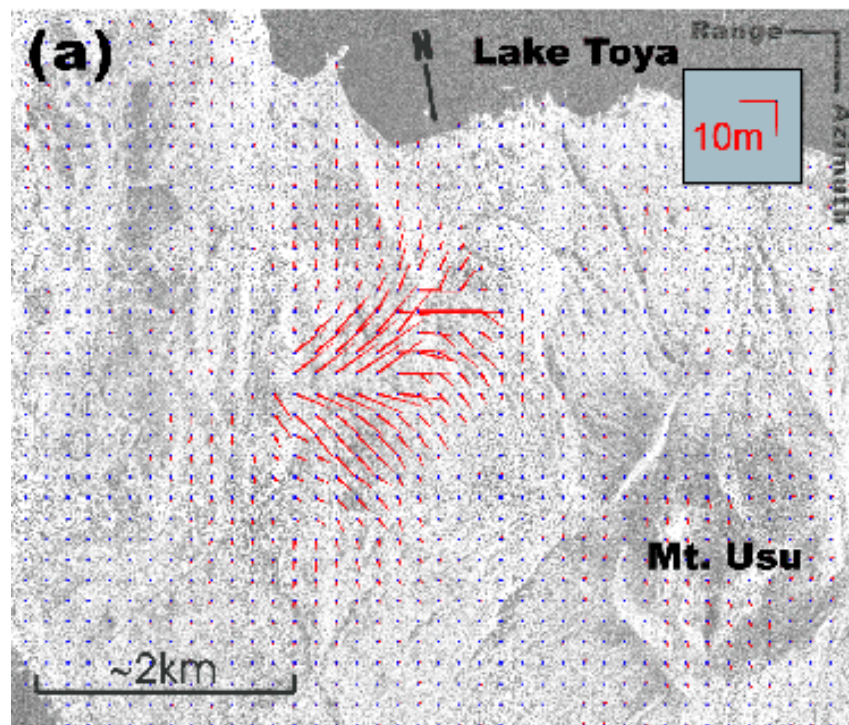
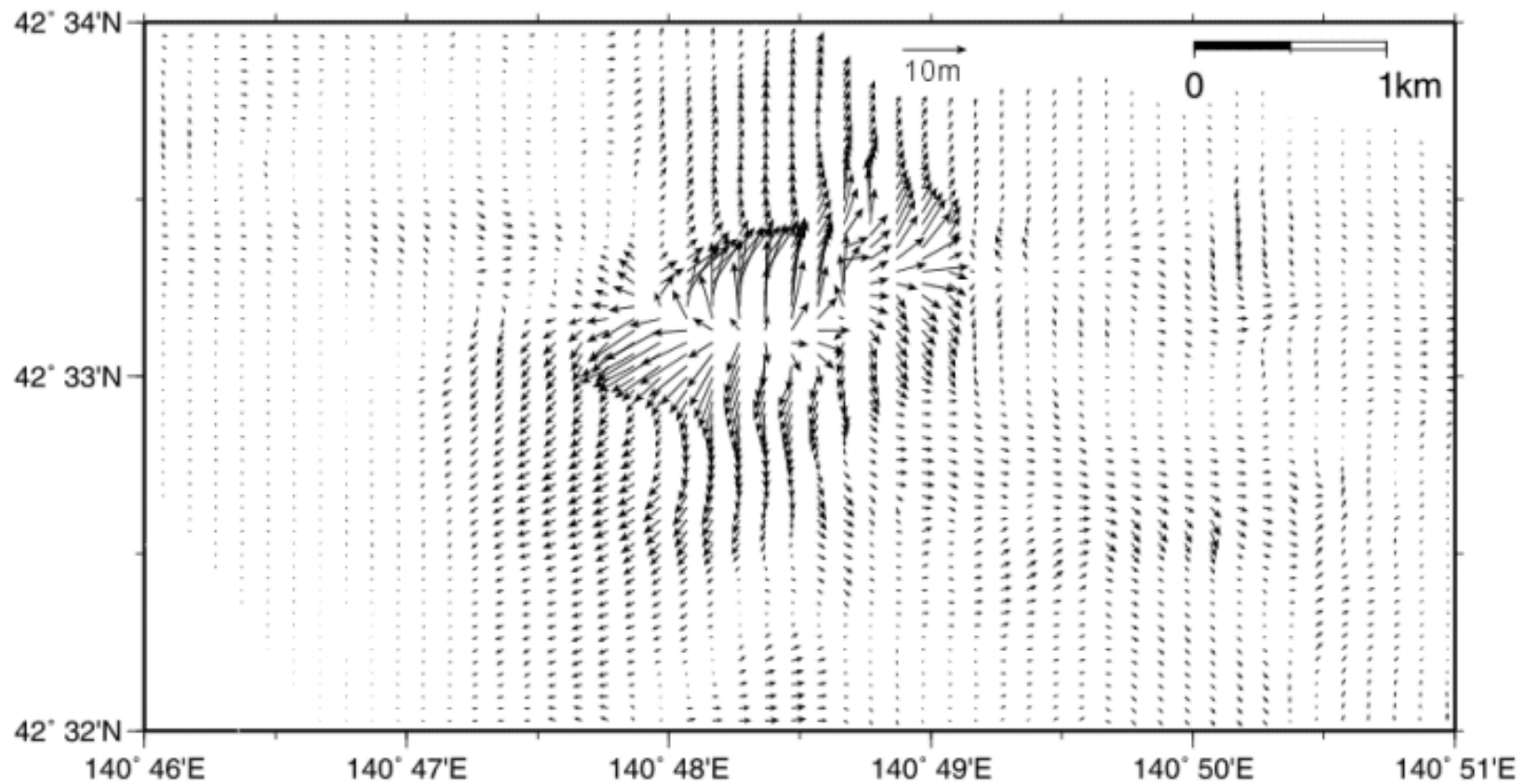


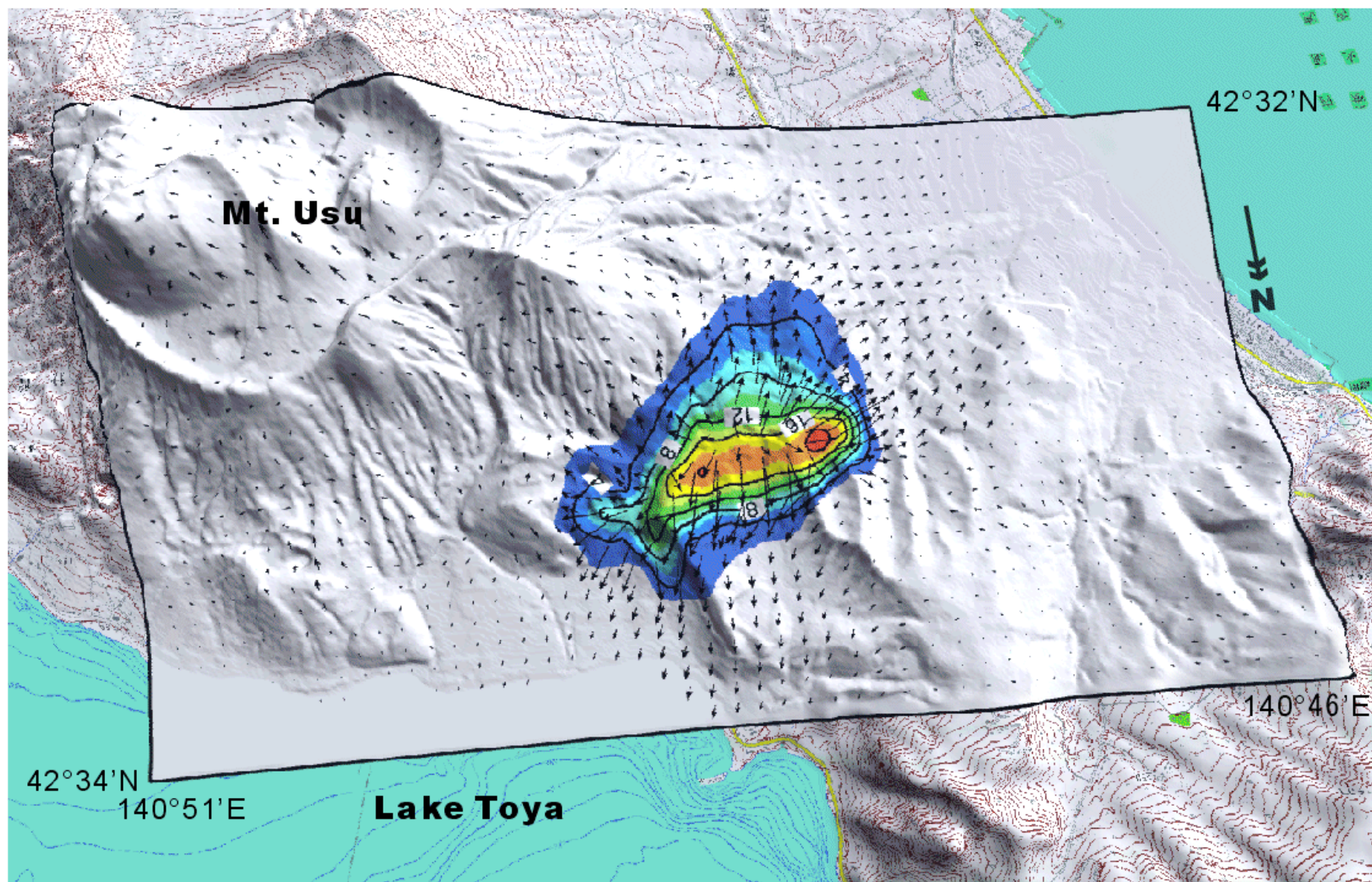
Fig. 2 Ground deformation of Mt. Usu

Image Correlation (two tracks)



Horizontal (2D motions)





Horizontal displacement vector



Vertical displacement

