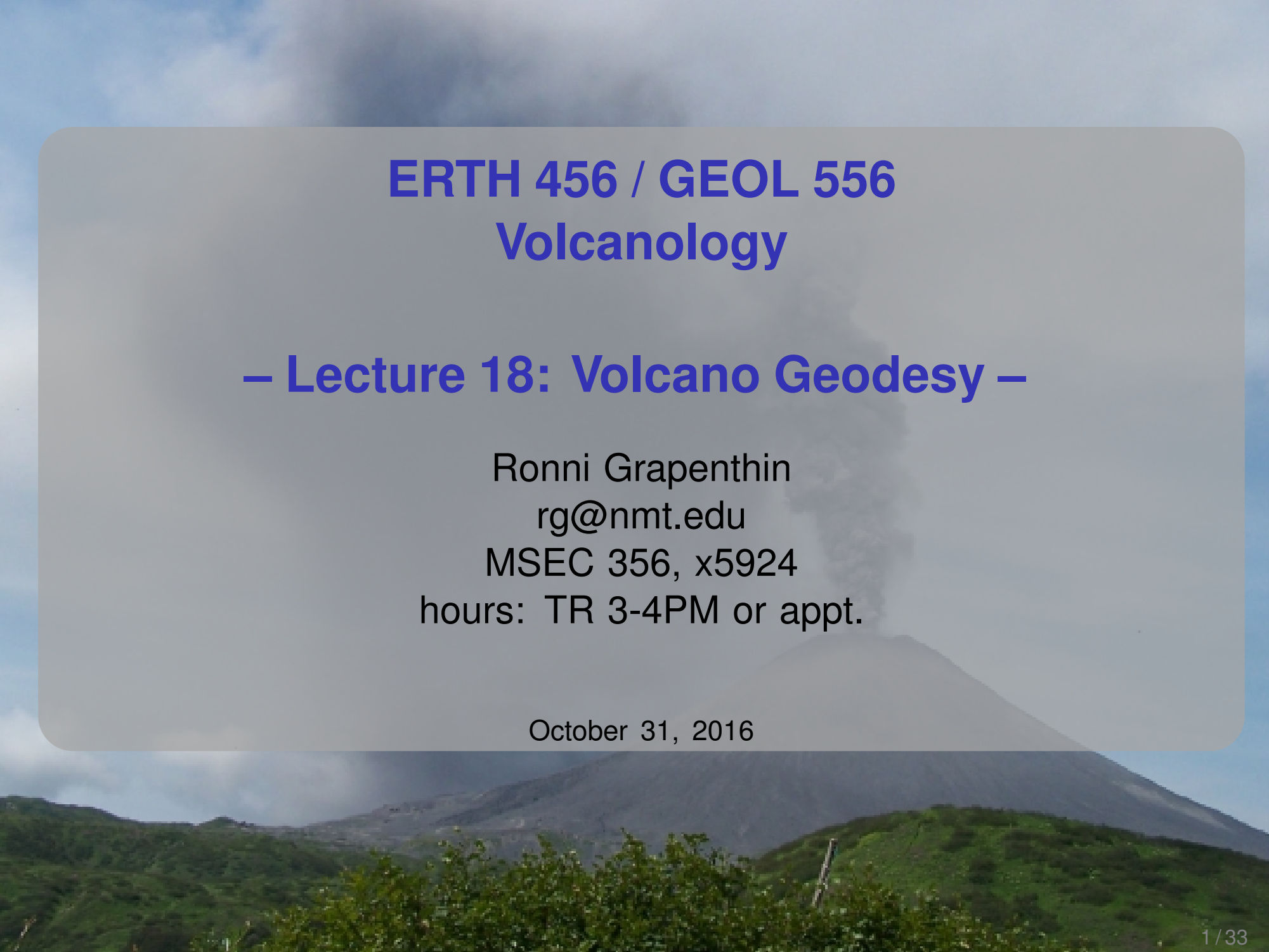

ERTH 456 / GEOL 556
Volcanology

– Lecture 18: Volcano Geodesy –

Ronni Grapenthin
rg@nmt.edu
MSEC 356, x5924
hours: TR 3-4PM or appt.

October 31, 2016

1. Plumbing: How does a Volcano Deform?

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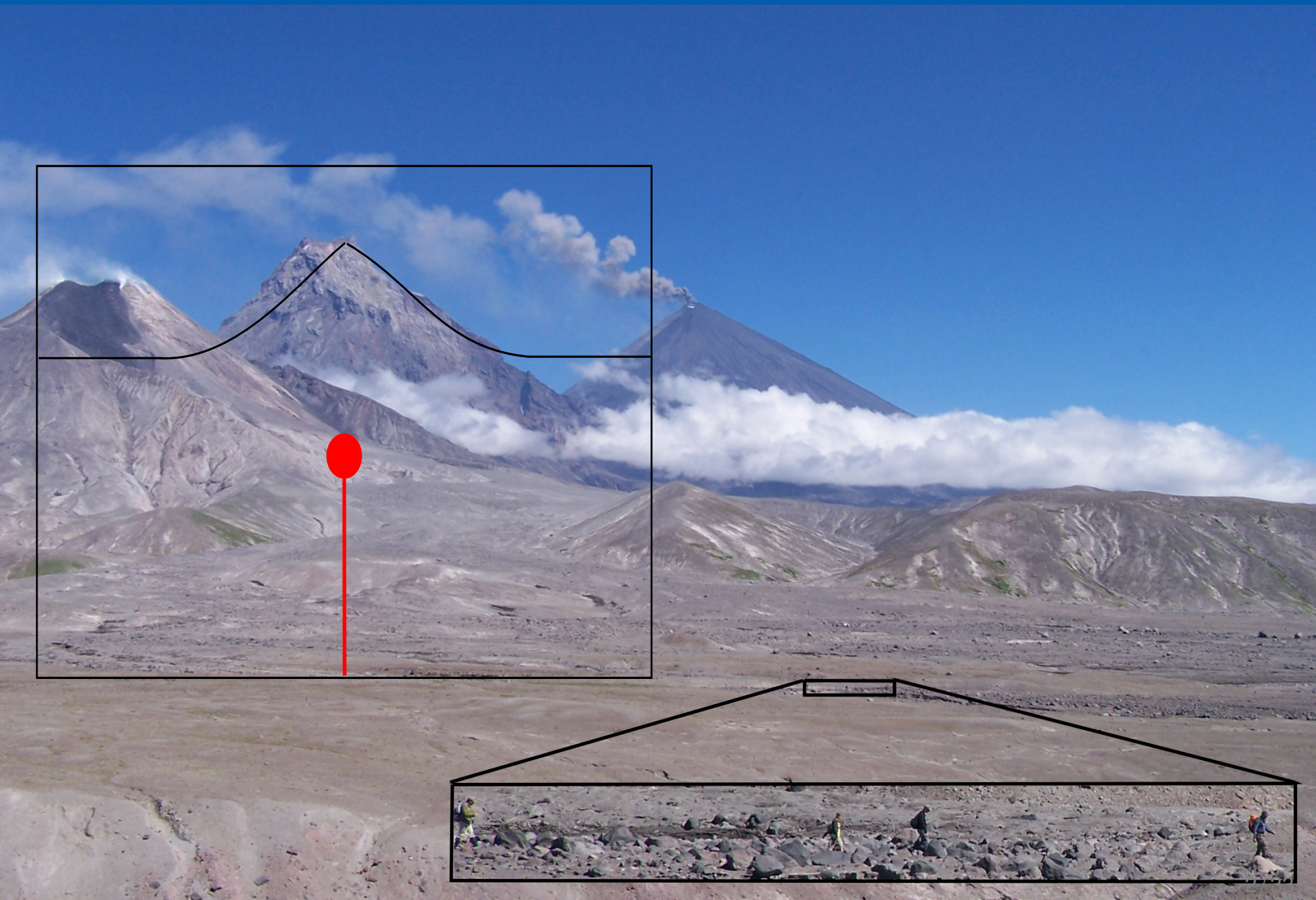
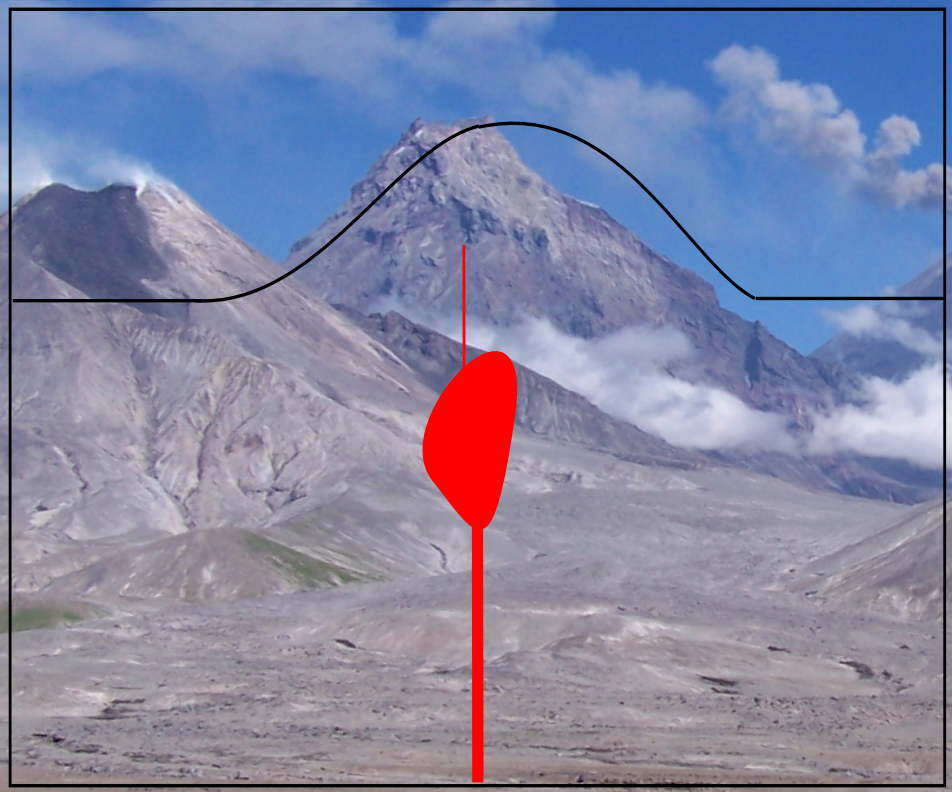


1. Plumbing: How does a Volcano Deform?



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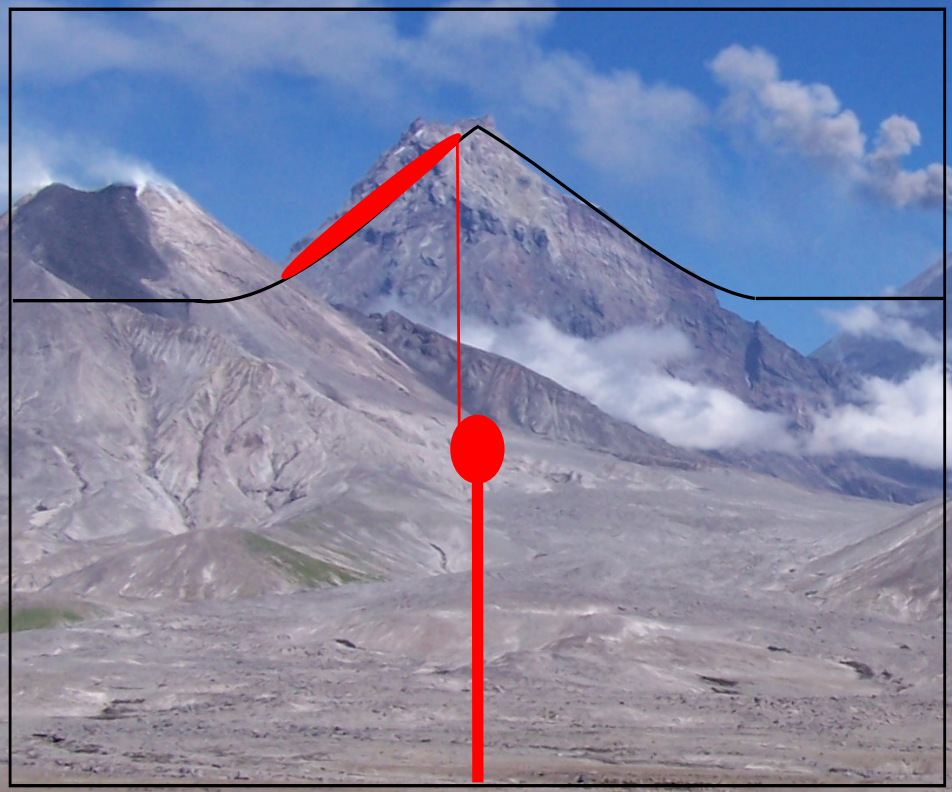
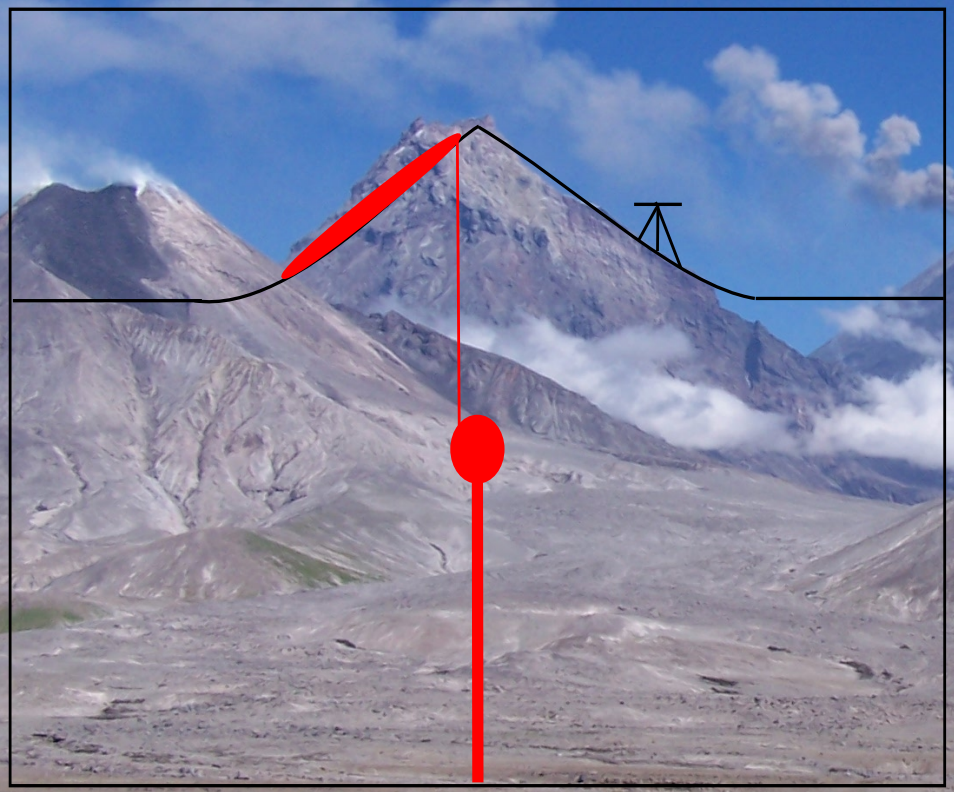
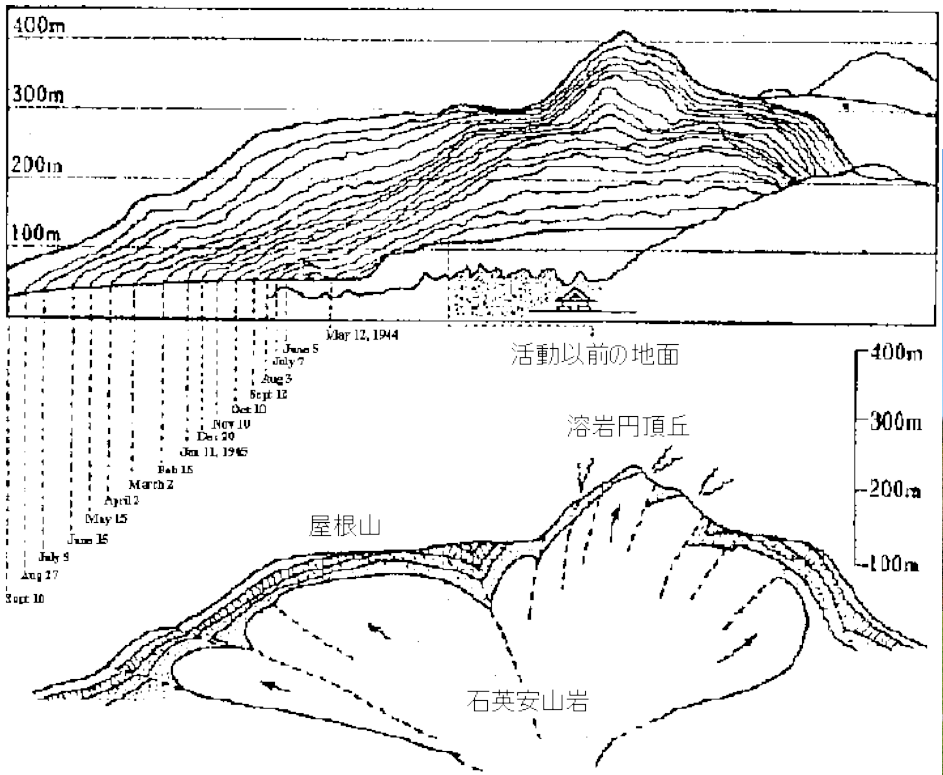


1. Plumbing: How does a Volcano Deform?



- Geodetic tools measure deformation: GPS, InSAR, ...
- Analytical models link deformation to volcano source characteristics

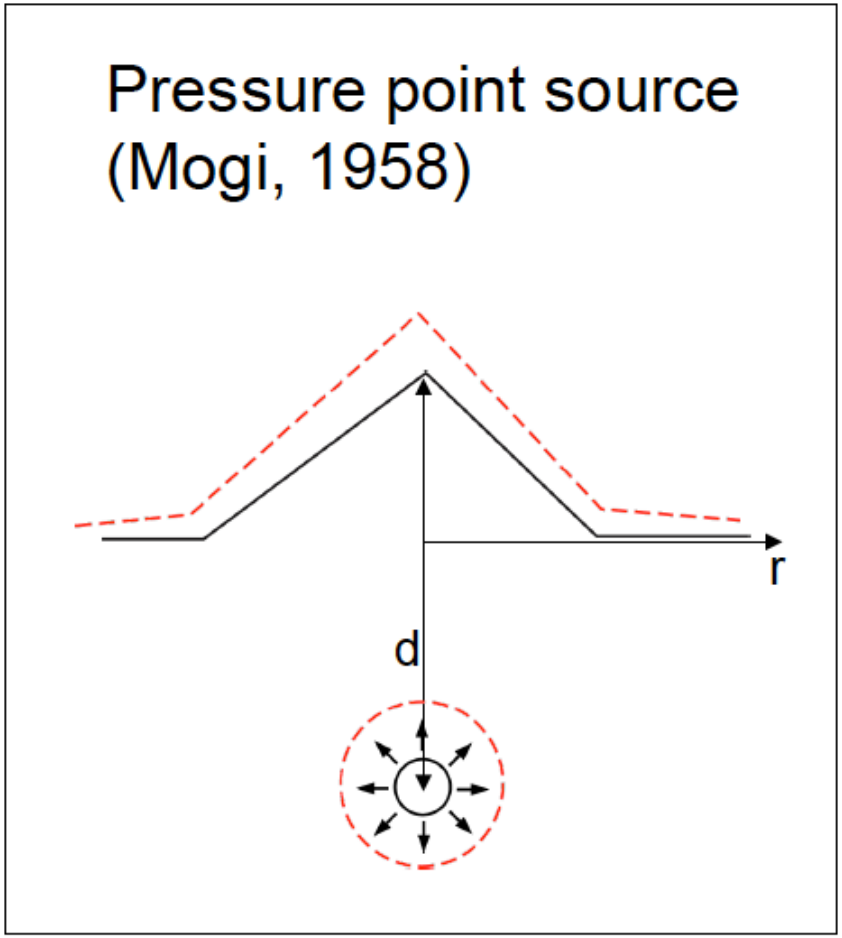
Mimatsu Diagram

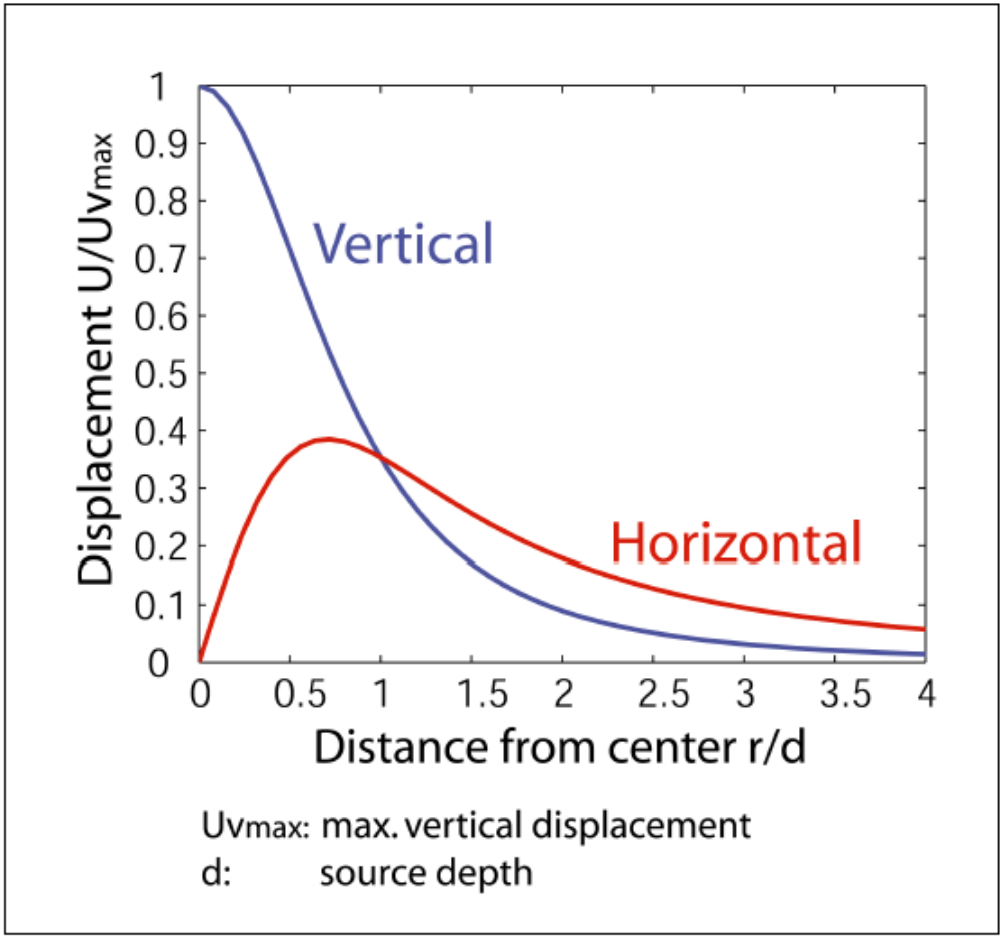


source: Internet

Masao Mimatsu, Japanese postmaster, documented growth of Showa Shinzan (398 m tall) from wheat field in 1944-45.

Source Models: Mogi (1958)

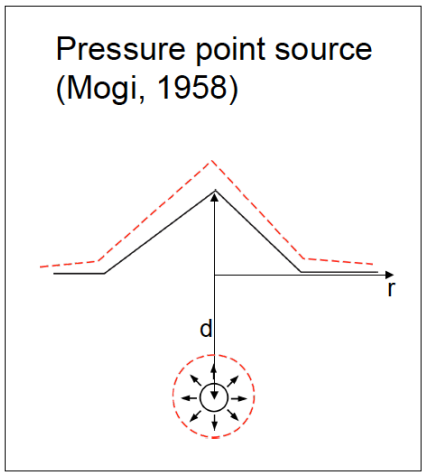


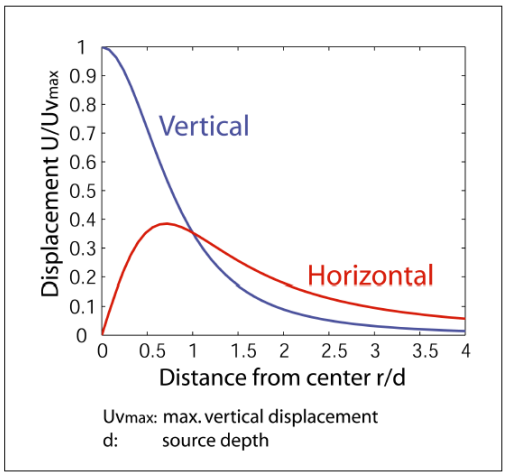


Jeff Freymueller

Model parameters: lat, lon, depth, source strength

Source Models: Mogi (1958)





$$u_z = \frac{(1-\nu)\Delta V}{\pi} \frac{d}{(r^2+d^2)^{3/2}}$$

$$u_r = \frac{(1-\nu)\Delta V}{\pi} \frac{r}{(r^2+d^2)^{3/2}}$$

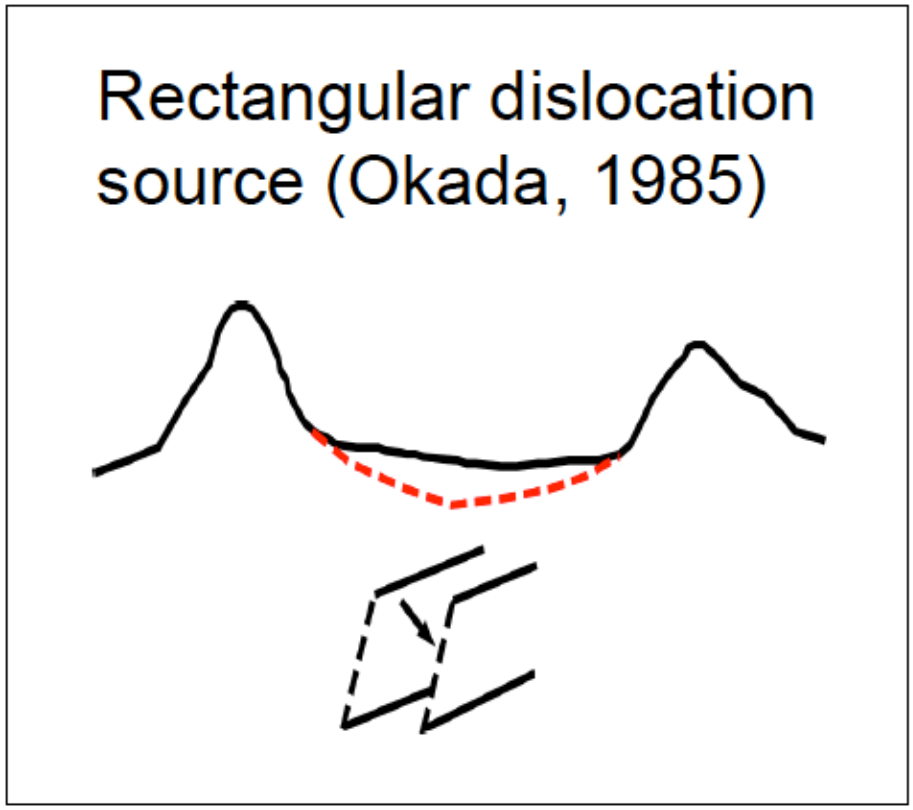
Jeff Freymueller

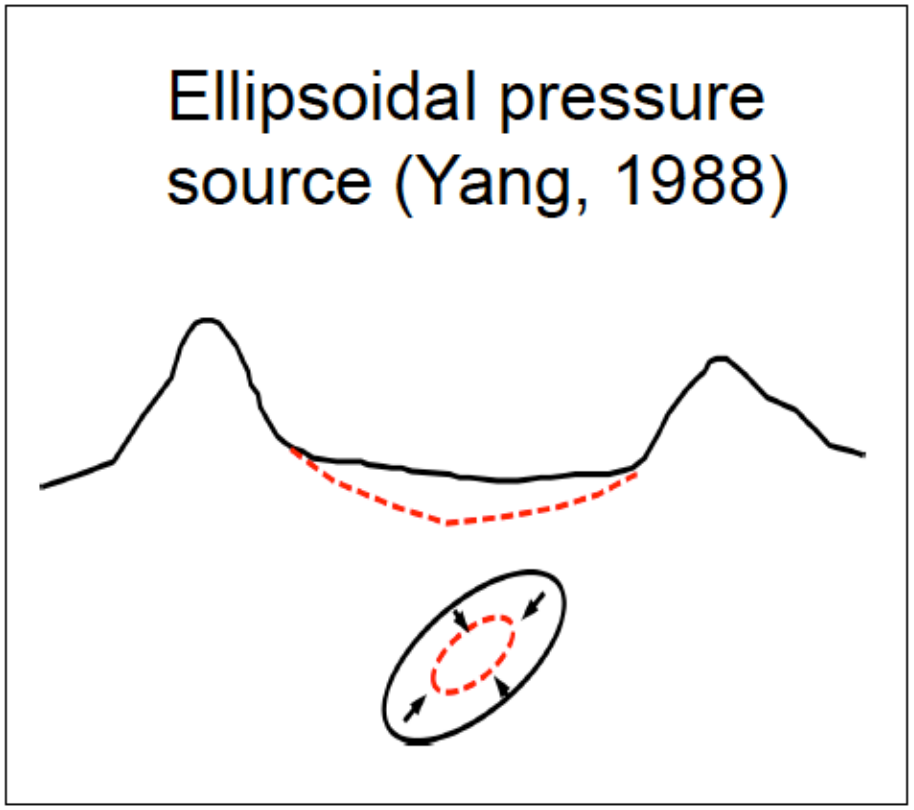
- r - radial distance from source
- d - source depth
- ν - Poisson's ratio (0.25)
- $C = \frac{(1-\nu)\Delta V}{\pi}$ - source strength
- $\Delta V = \frac{\pi p a^3}{\mu}$ - source volume change (see later!)
- p - pressurization
- a - source radius
- μ - shear modulus

Source Models: Mogi (1958)

- ΔV is volume change of the chamber $\neq$ magma volume change
- equivalent to scaled pressure change in cavity
- doesn't consider magma compressibility (more compressible the more gases are exsolved)
- volume is function of pressure and mass
- point source approximation means $a << d$, in practice good approx. for $a < 0.5d$

Source Models: Okada (1985), Yang (1988)





Jeff Freymueller

Model parameters: lat, lon, depth, length, width, dip, strike, source strength

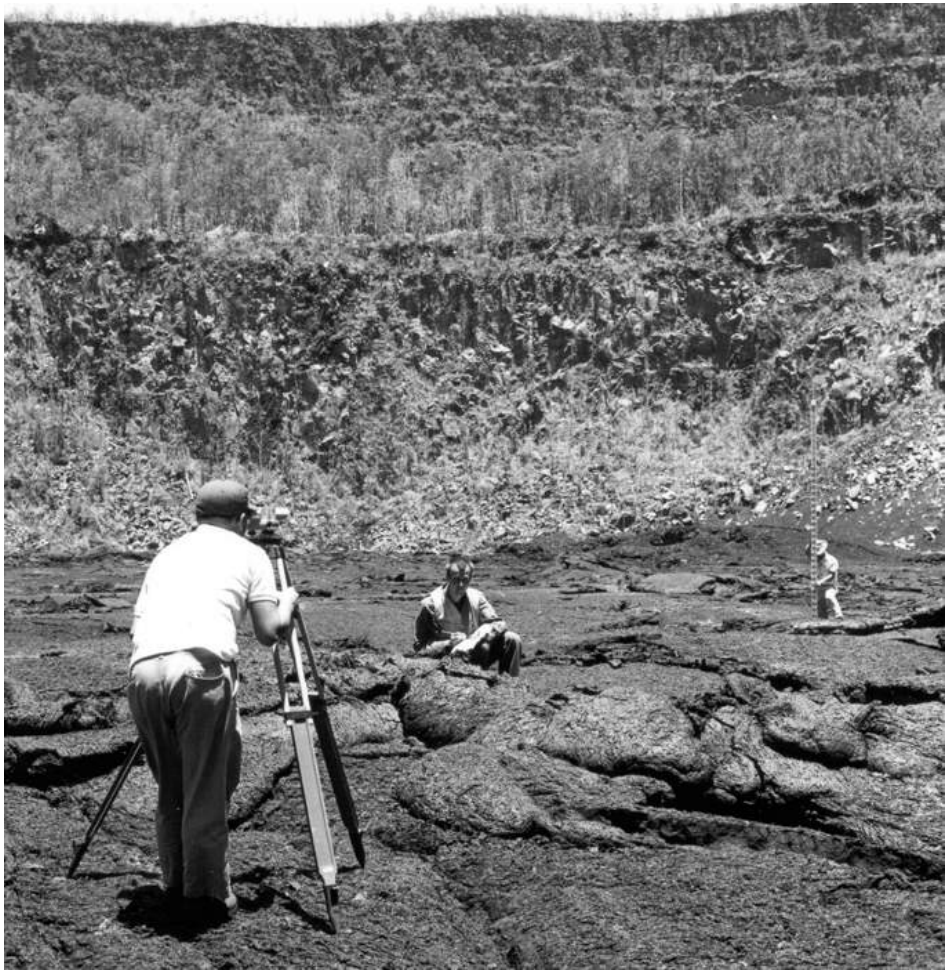
Deformation Measurement Techniques

- Electronic Distance Measurement (EDM)
- Leveling
- Tilt
- GPS / GNSS
- InSAR

Electronic Distance Measurement (EDM)

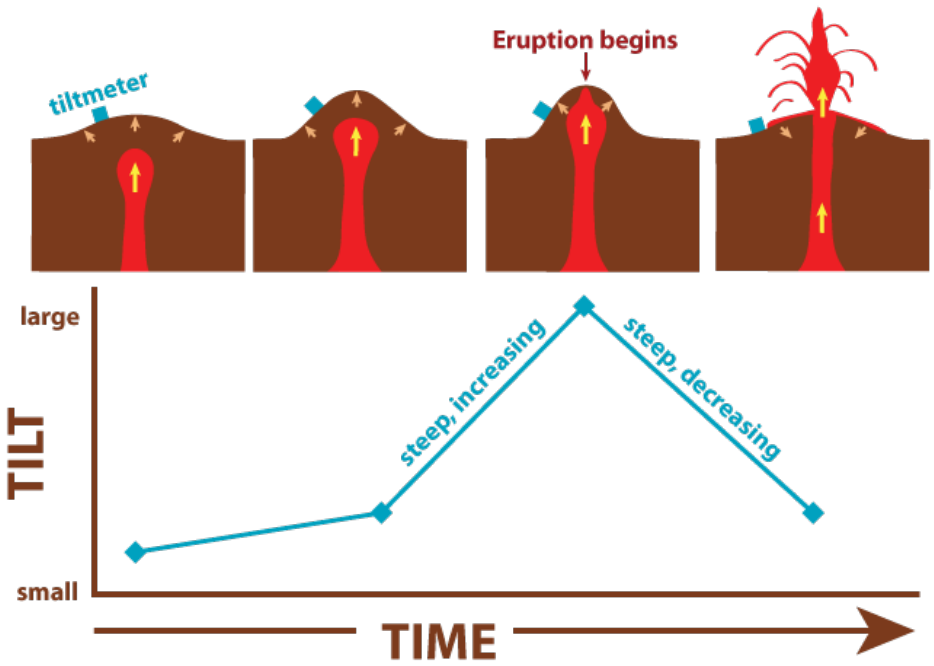
http://volcano.si.edu/Photos/full/035031.jpg

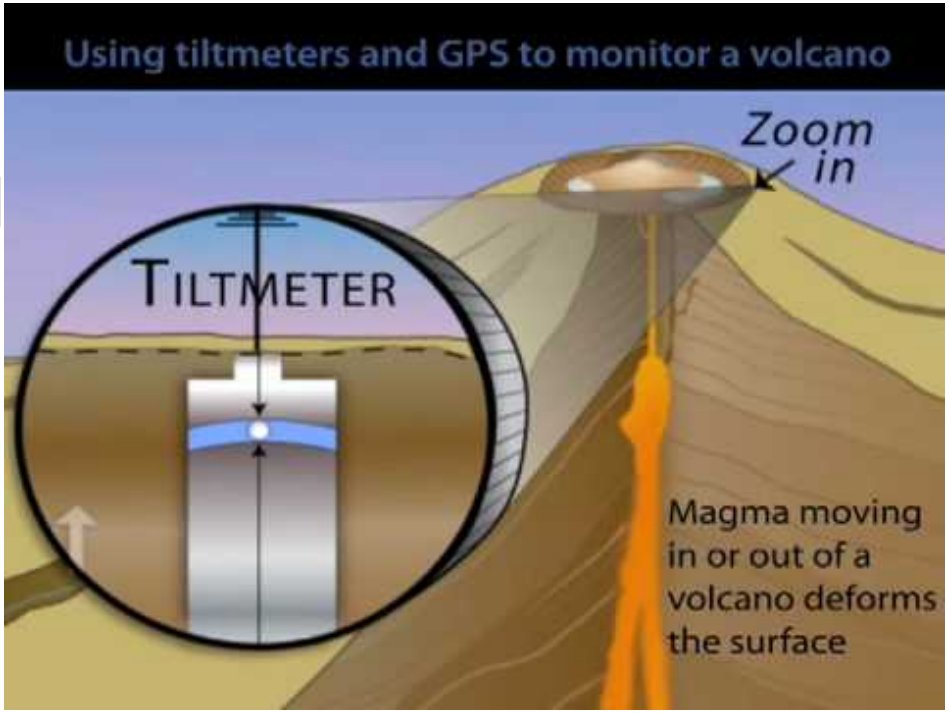
Leveling



http://luirig.altervista.org/cpm/albums/geolus-60/30569-Hawaii-Volcanoes-National-Park–Leveling-on-the-surface-of-Alae.jpg

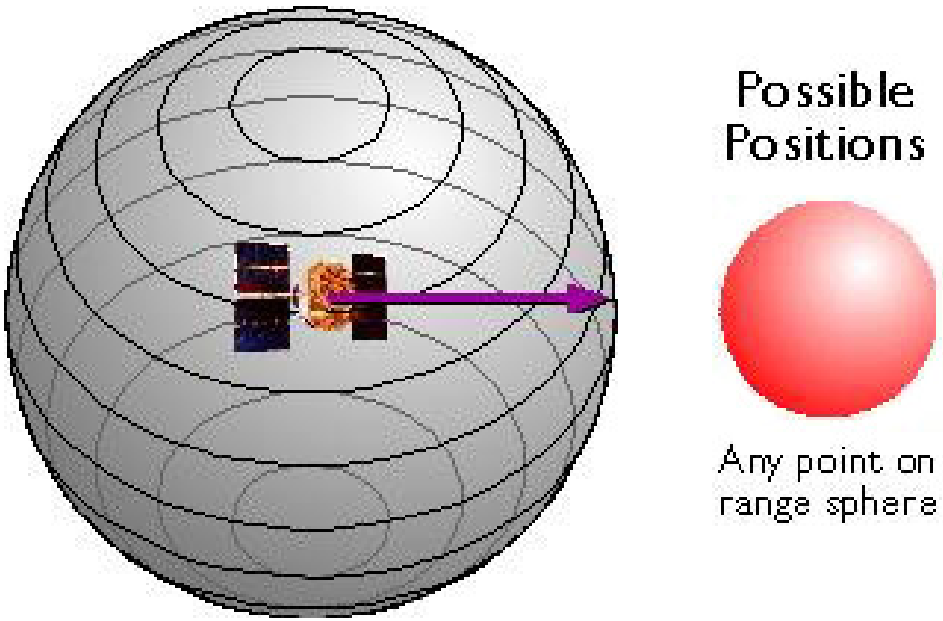
Tilt





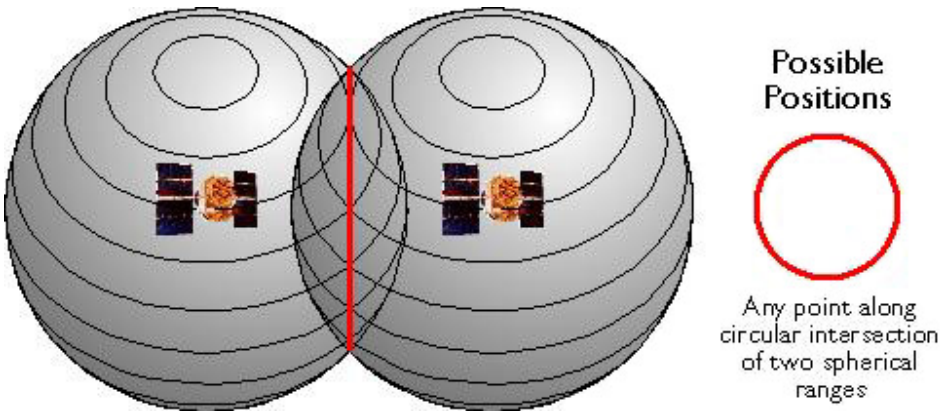
Mount St. Helens Science & Learning Center; Iris

GPS Positioning (in a Nutshell) – Ranging



https://www.e-education.psu.edu/geog482spring2/c5_p18.html

GPS Positioning (in a Nutshell) – Ranging



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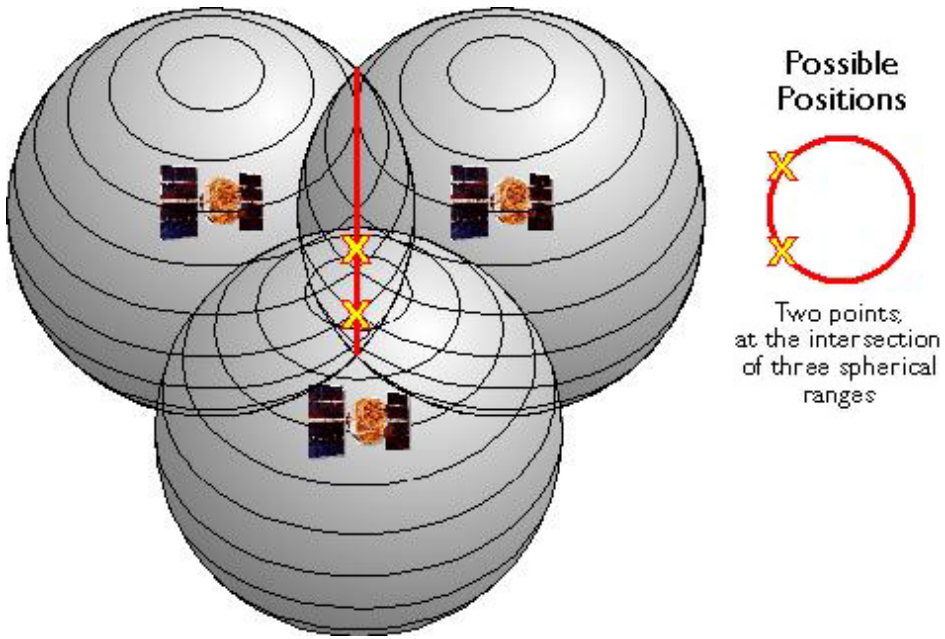
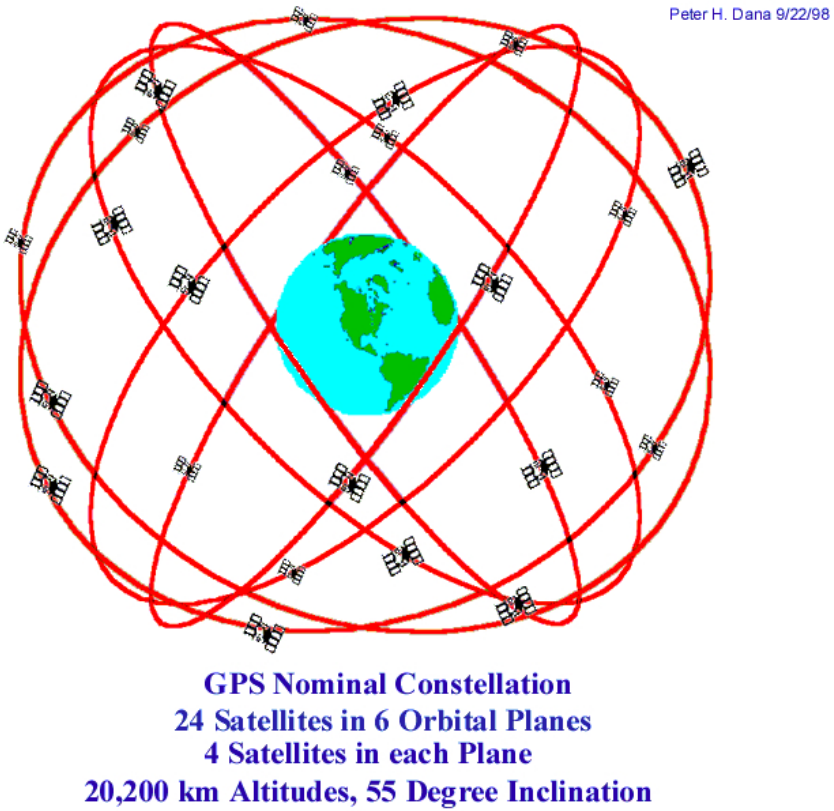


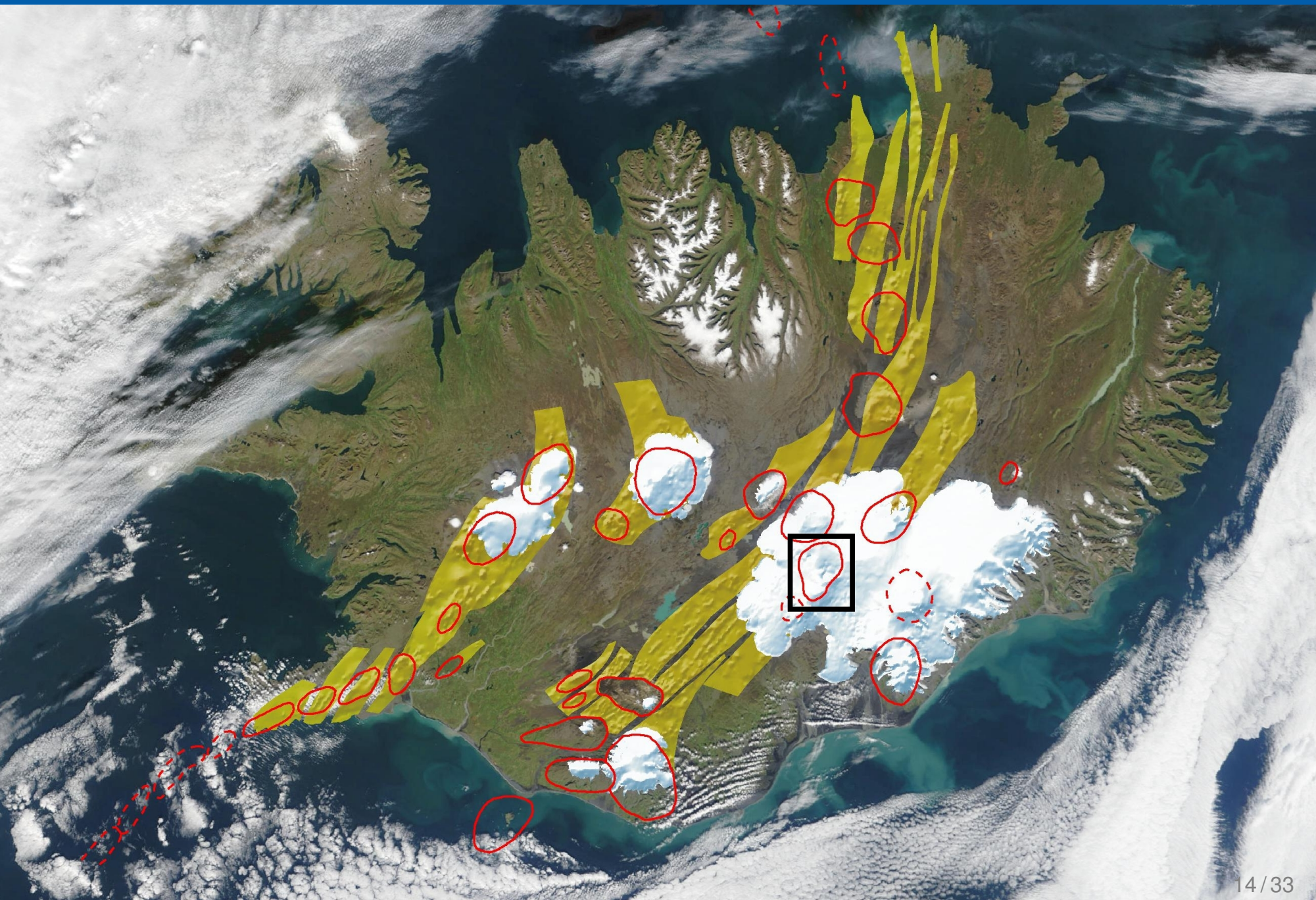
https://www.e-education.psu.edu/geog482spring2/c5_p18.html

System Architecture (Space Segment)

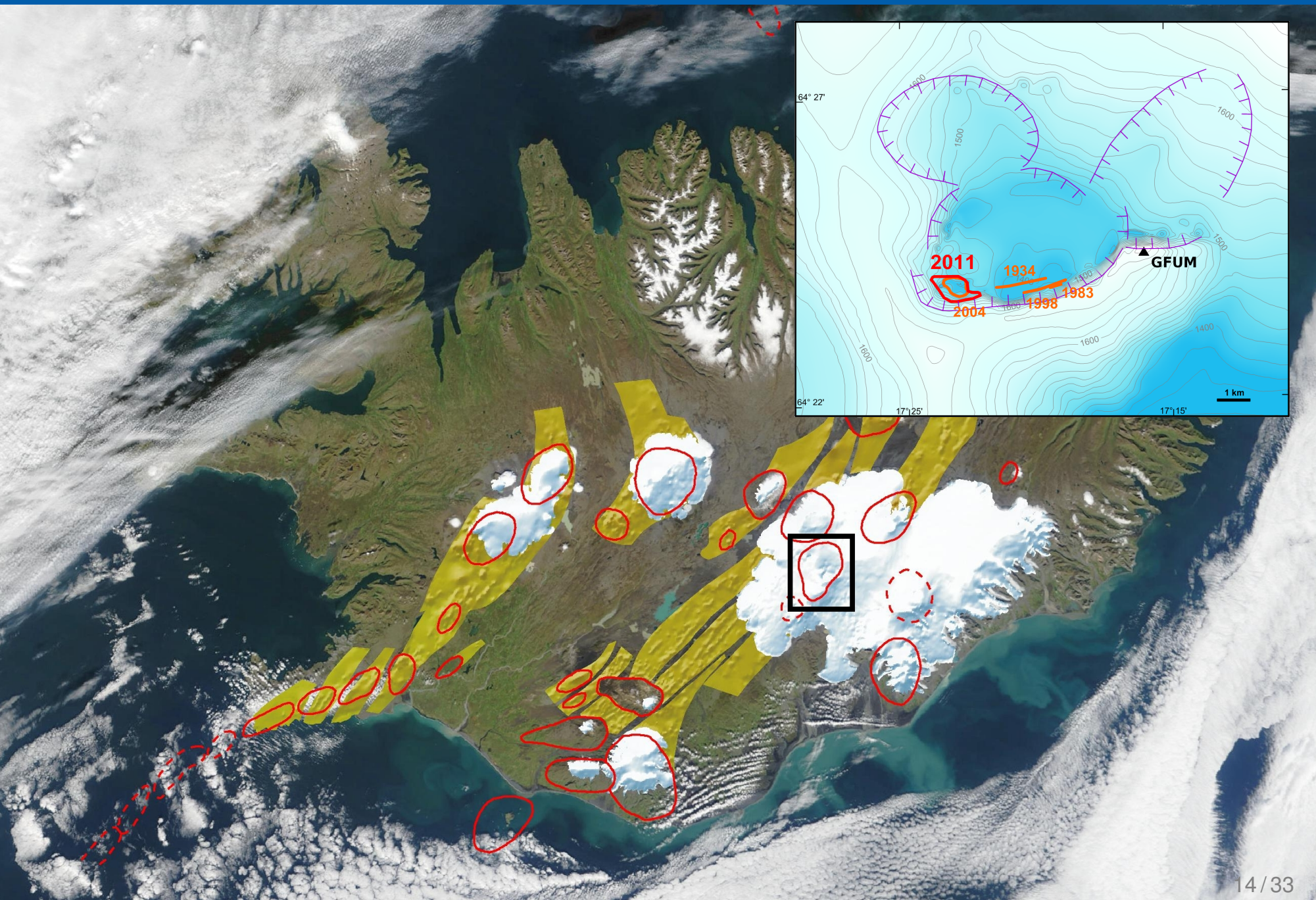
- Baseline constellation 24 satellites, 6 orbital planes, 55° inclined
- Period $\approx$ 12 hours, stationary ground tracks
- Currently 32 satellites operational
- Constellation Status / Outages: `http://www.navcen.uscg.gov/`
- E.g. `http://navcen.uscg.gov/?Do=constellationStatus`



2011 Grímsvötn



2011 Grímsvötn



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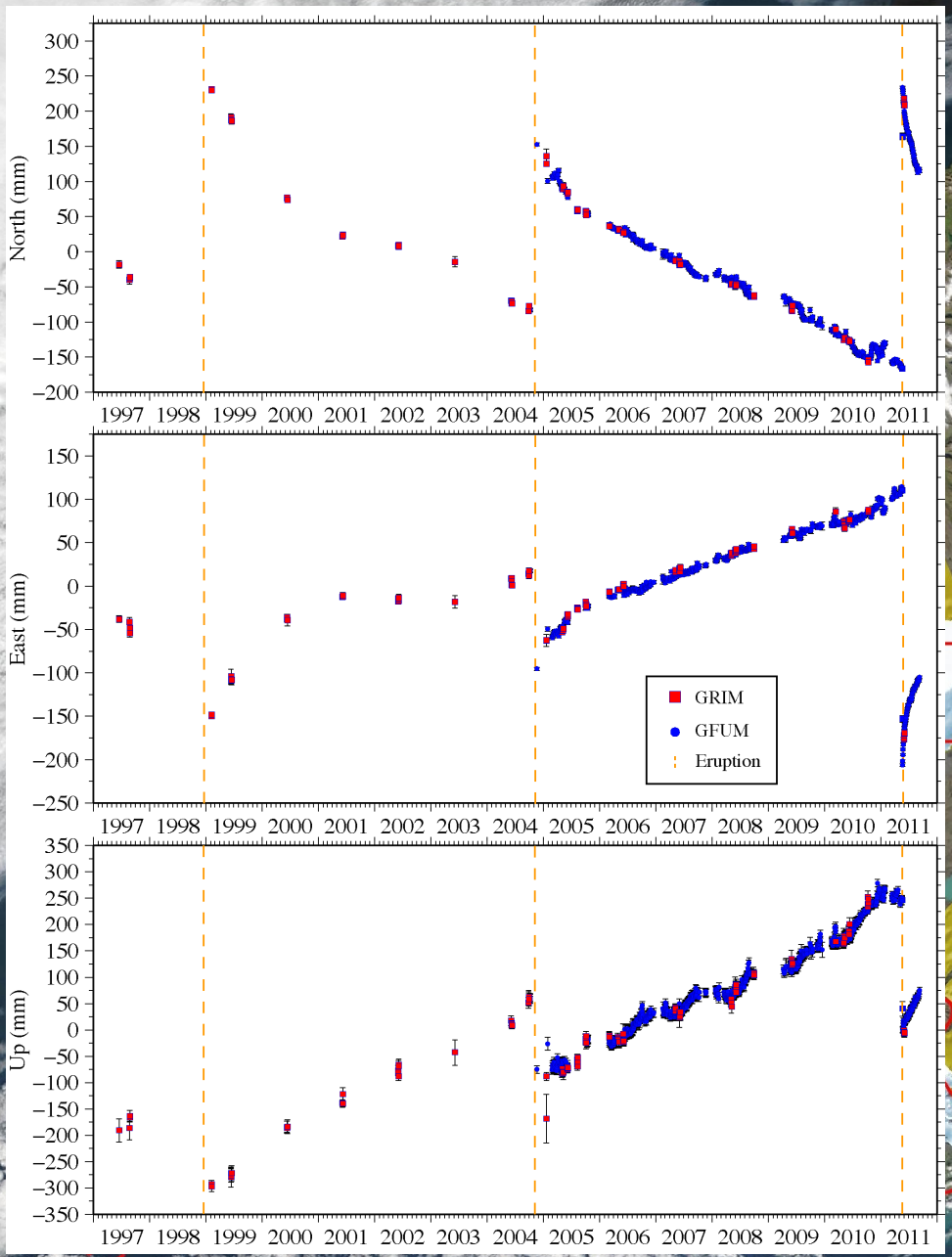

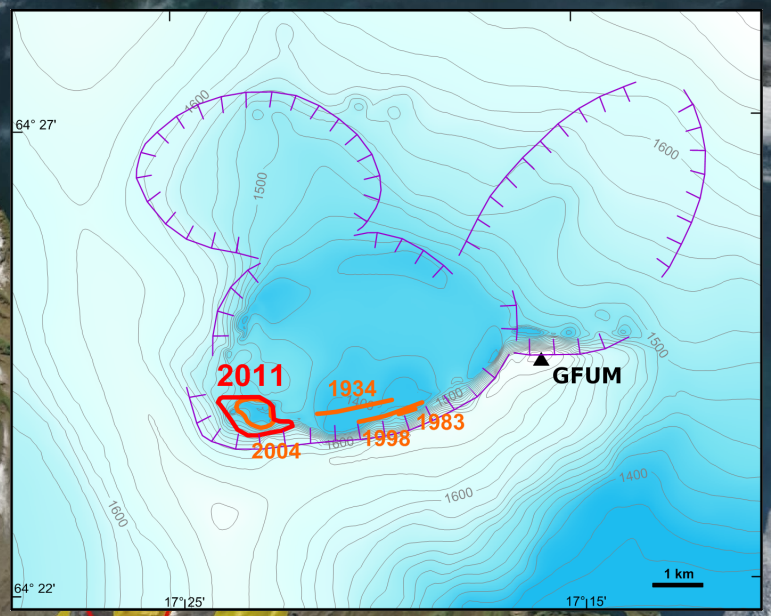

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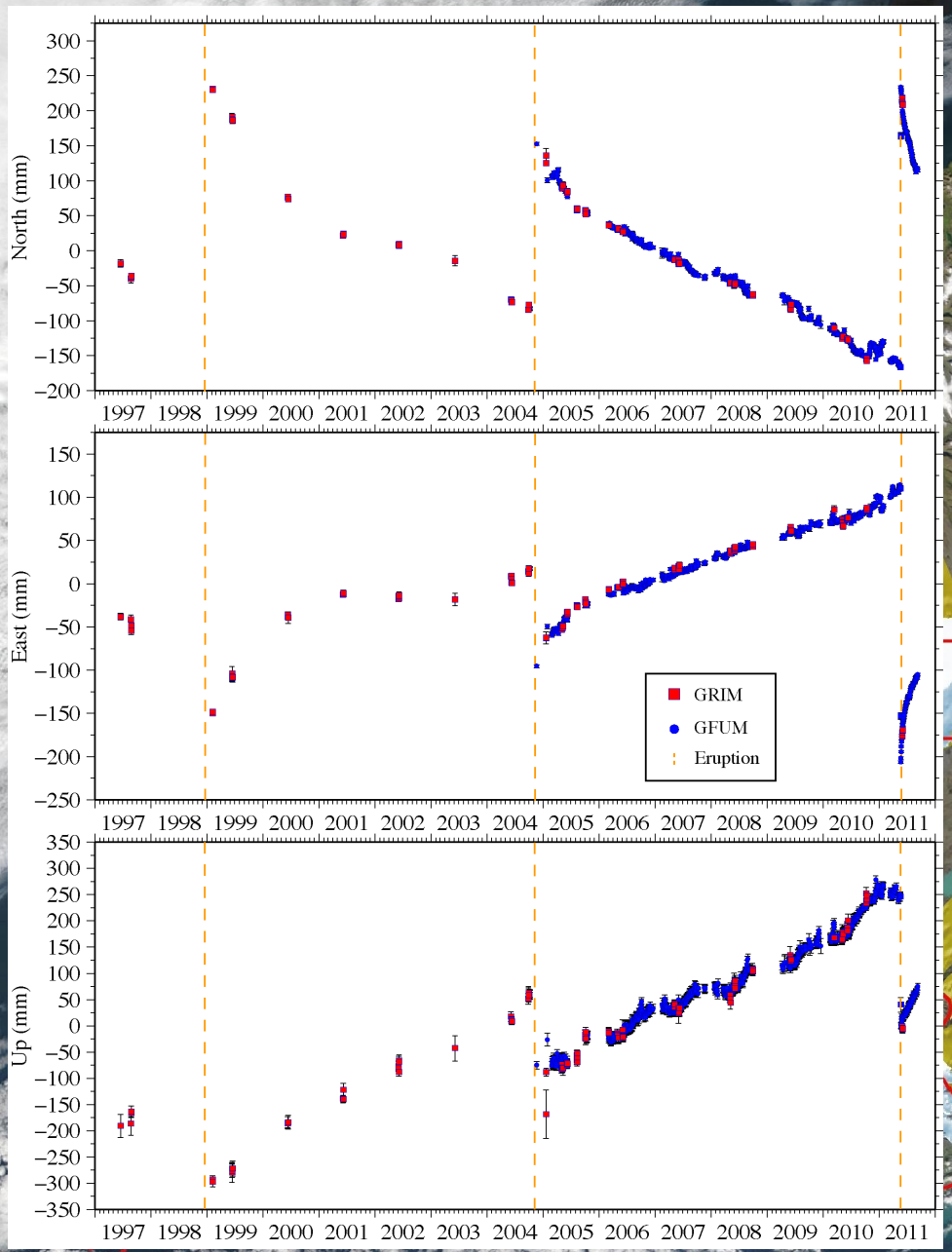
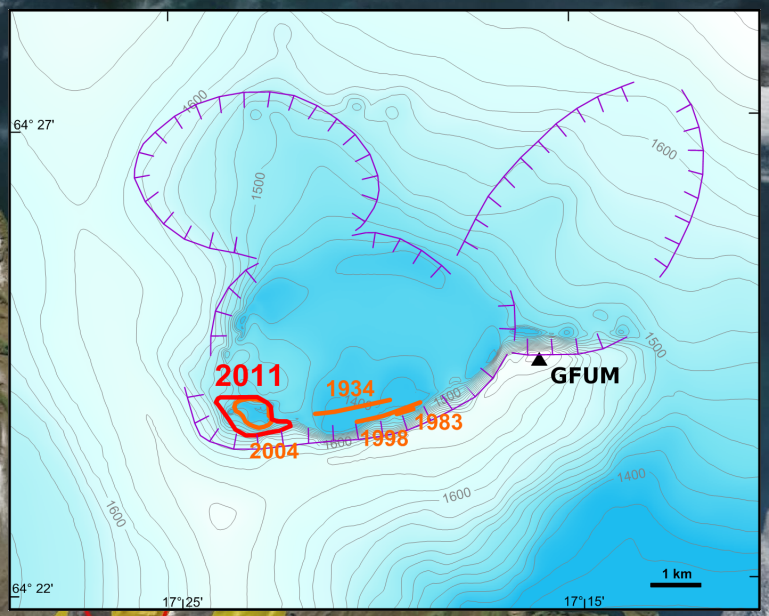
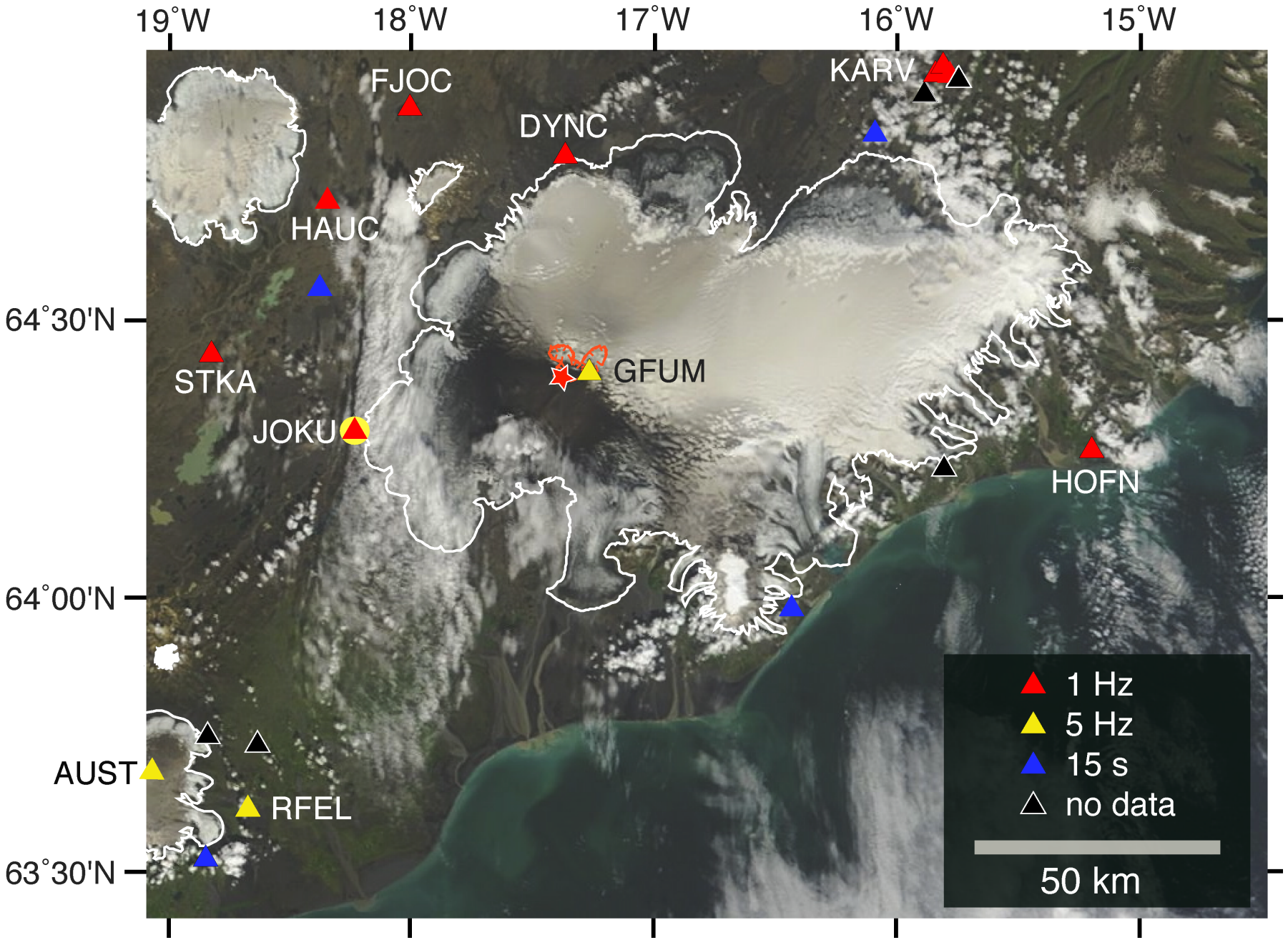




- explosive eruption 21-28 May 2011
- plumes $> 20\,km$
- continuous inflation, gradual increase in seismicity

2011 Grímsvötn: Geodetic Network



2011 Grímsvötn: Results

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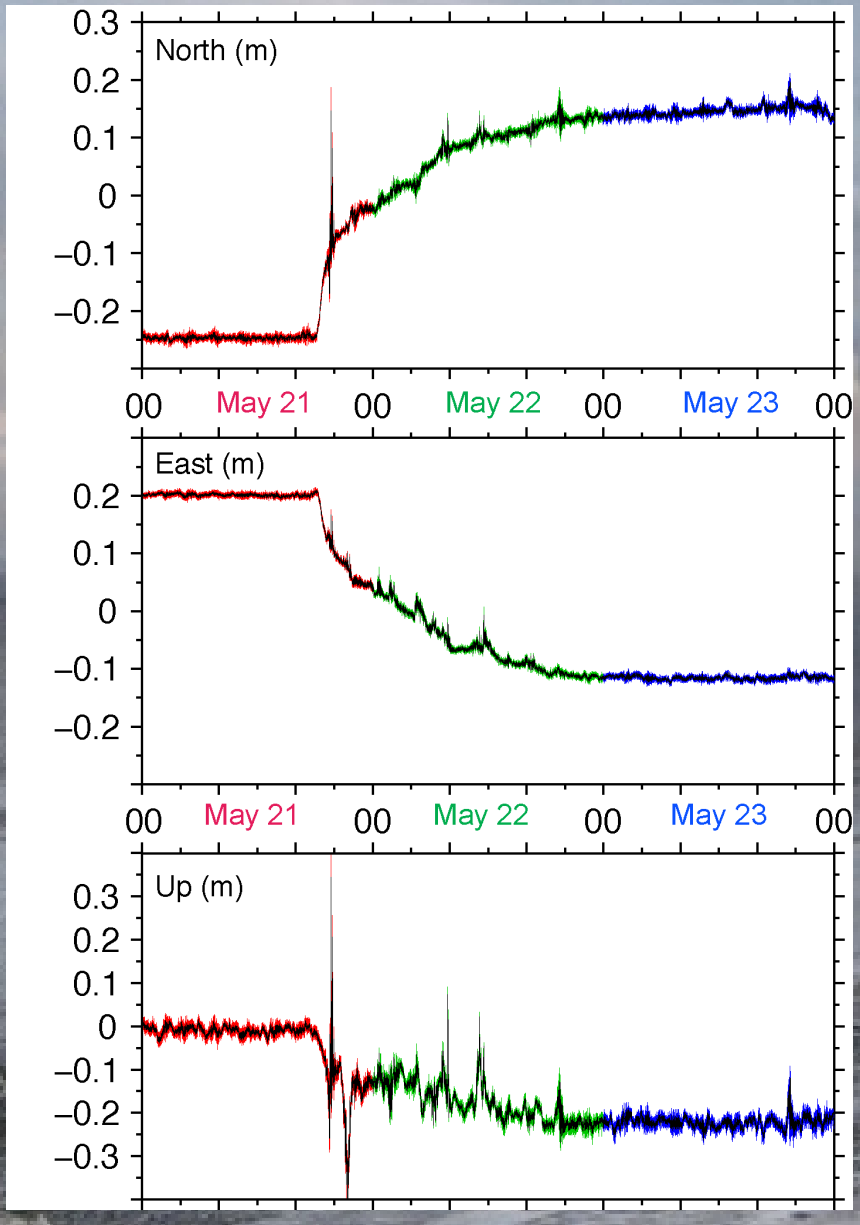
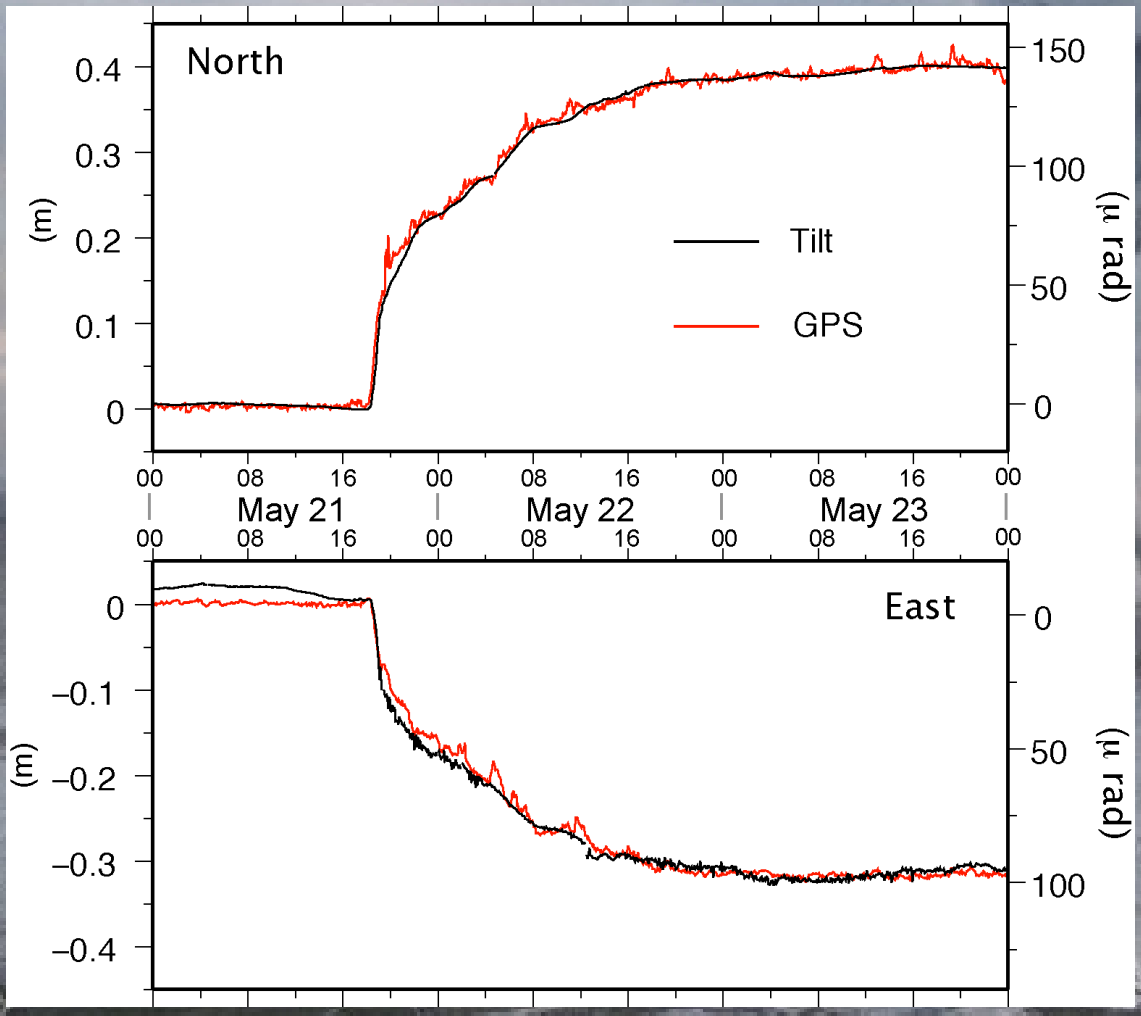
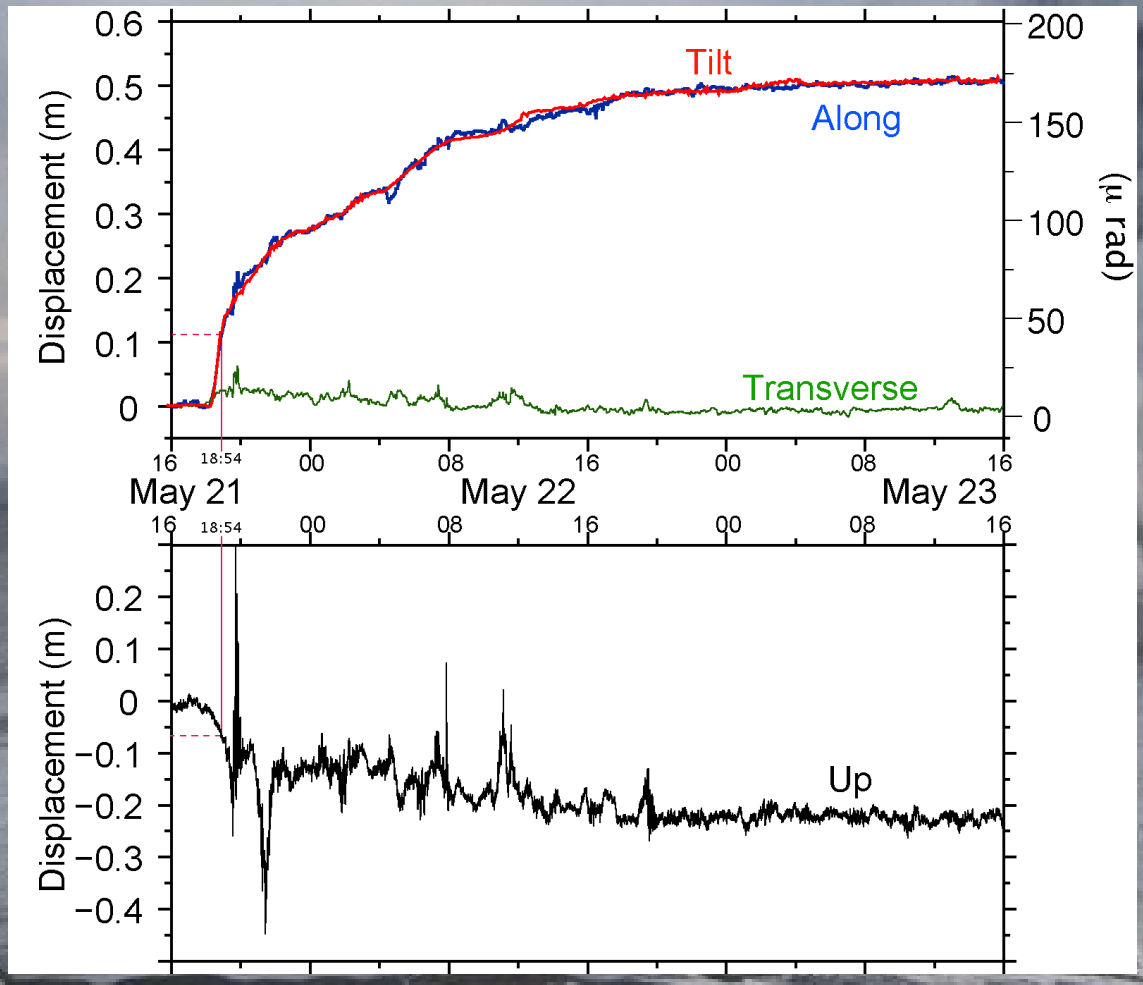


2011 Grímsvötn: Results



2011 Grímsvötn: Results



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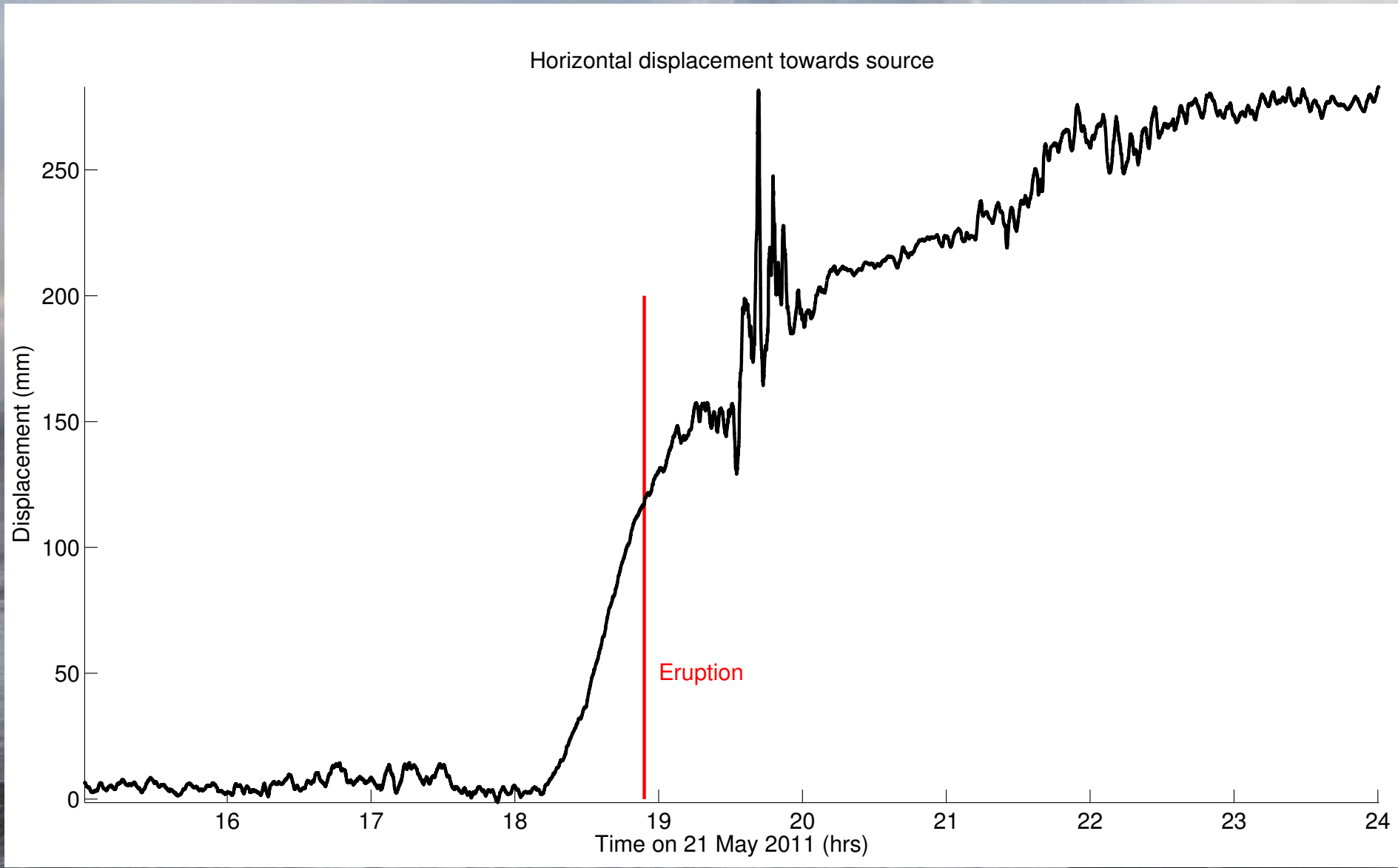
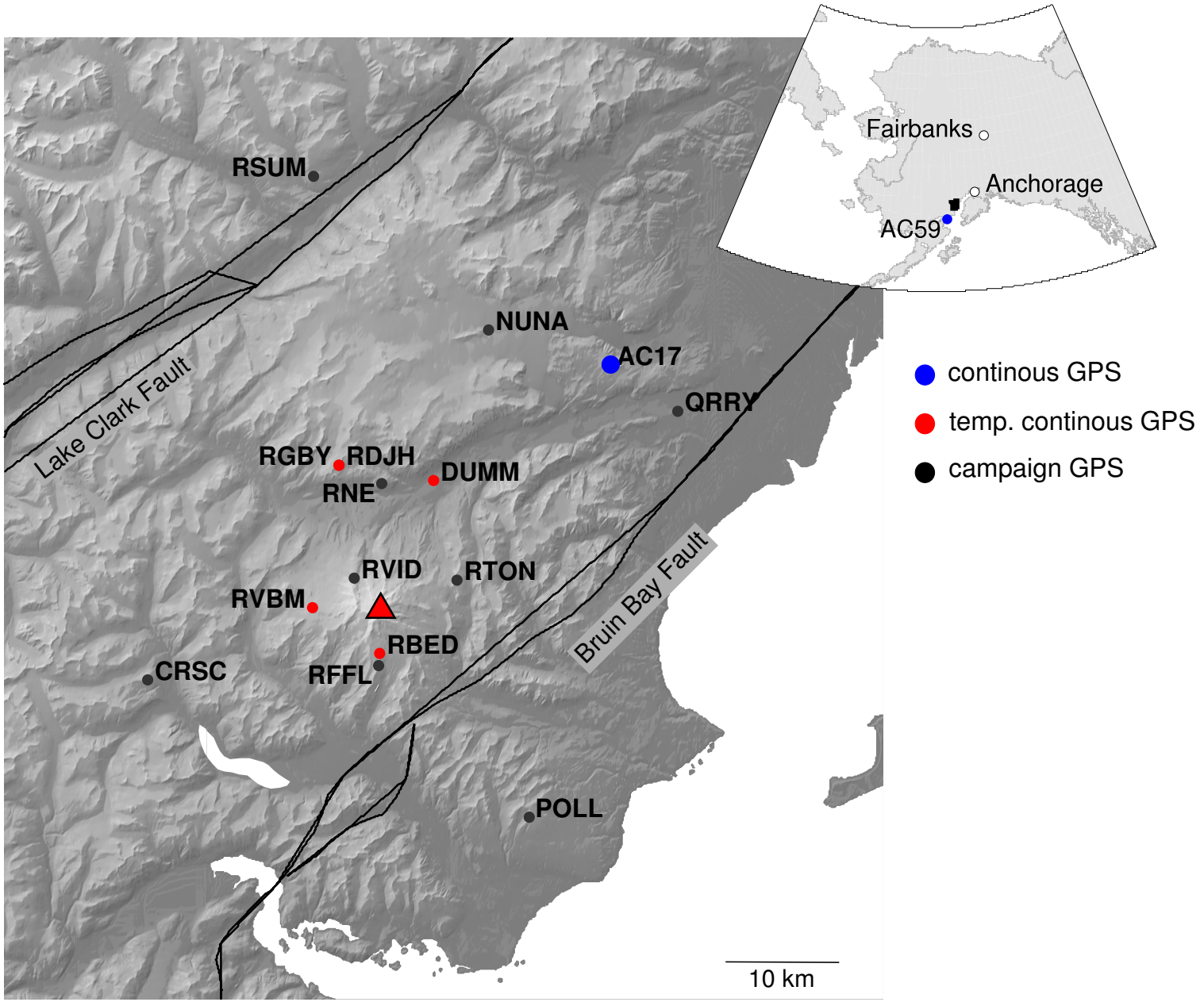
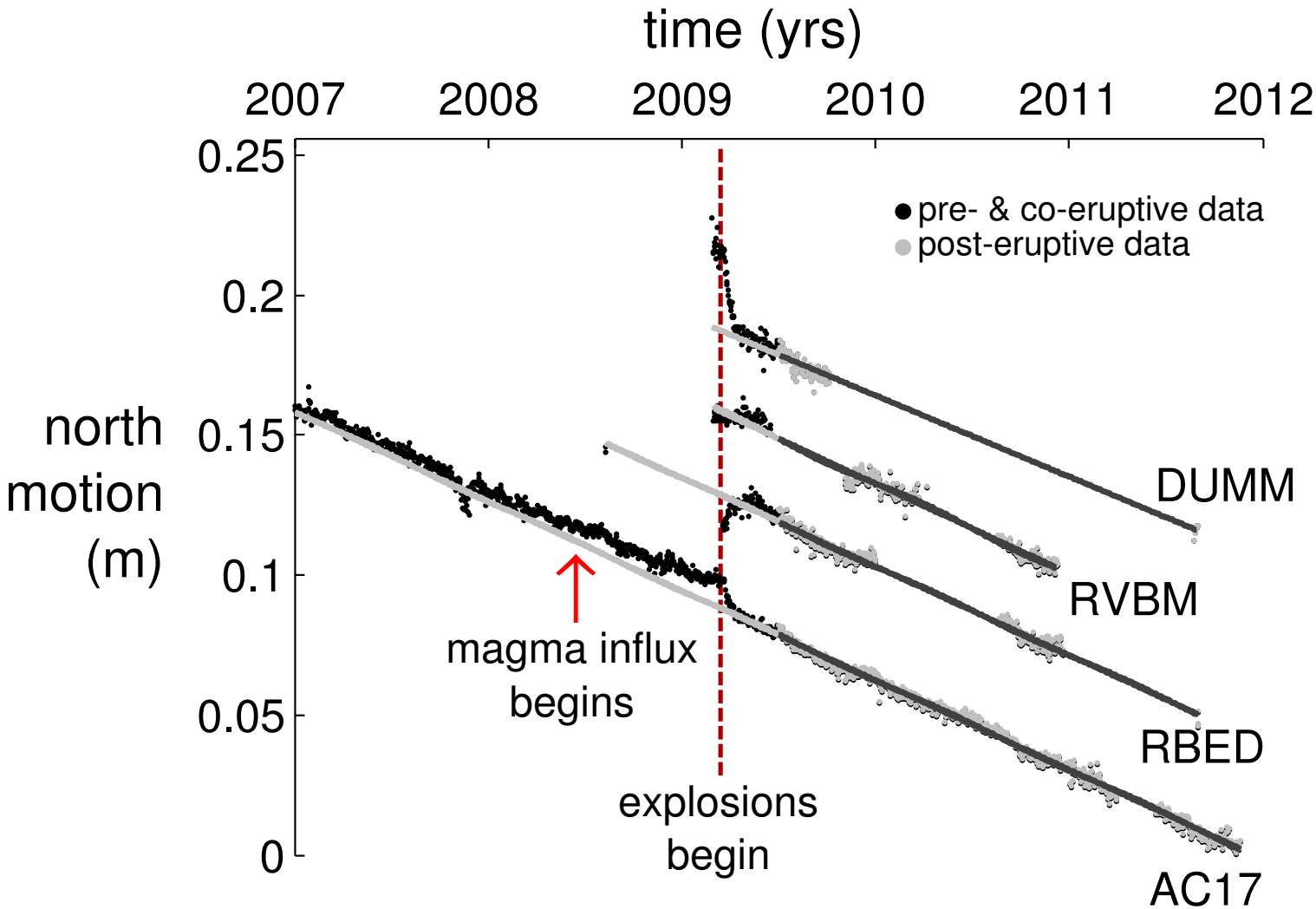


Mt Redoubt, Alaska, 2009

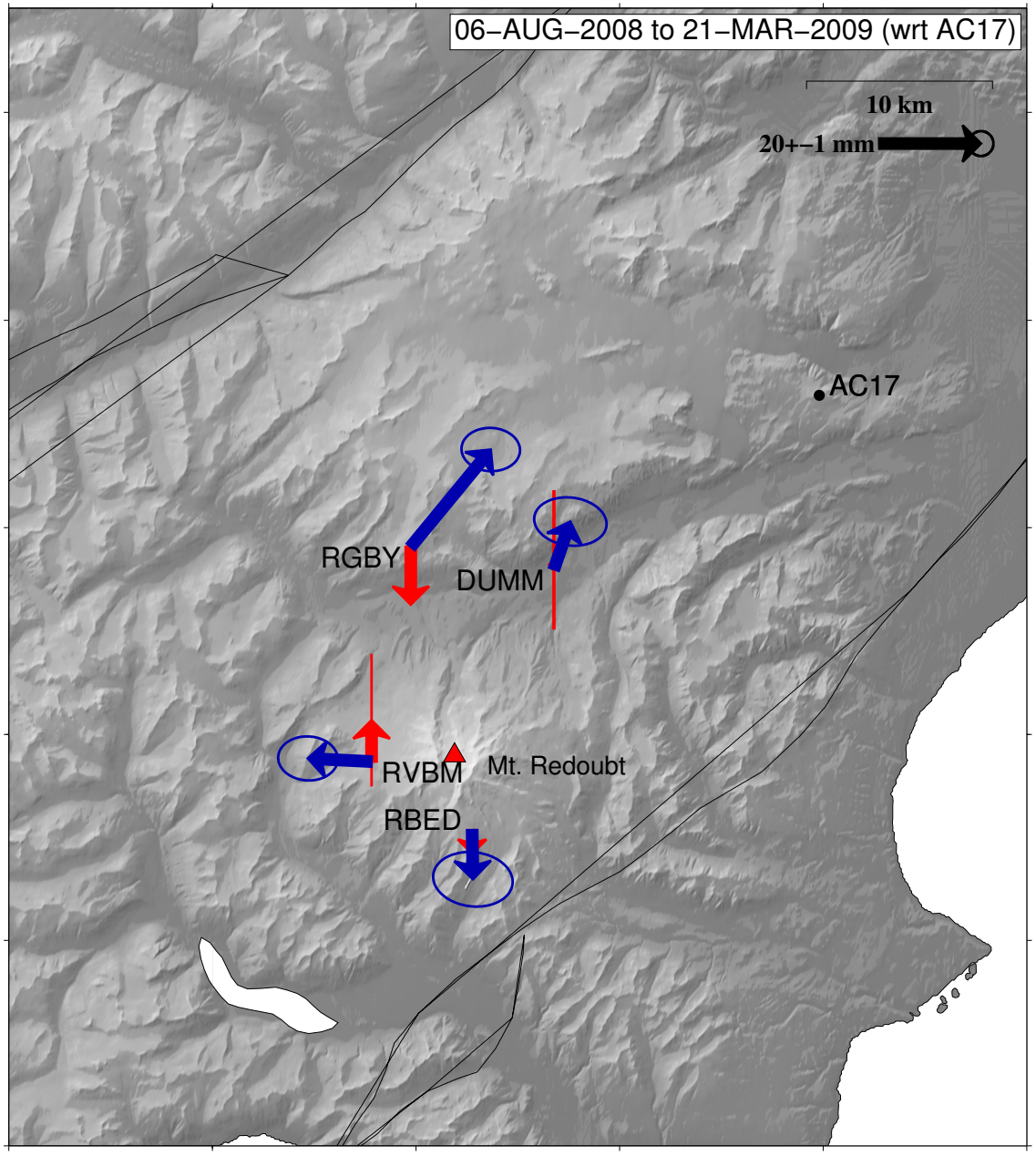
1. Weeks to Months: Mt. Redoubt Source Models



GPS Time Series relative to North America



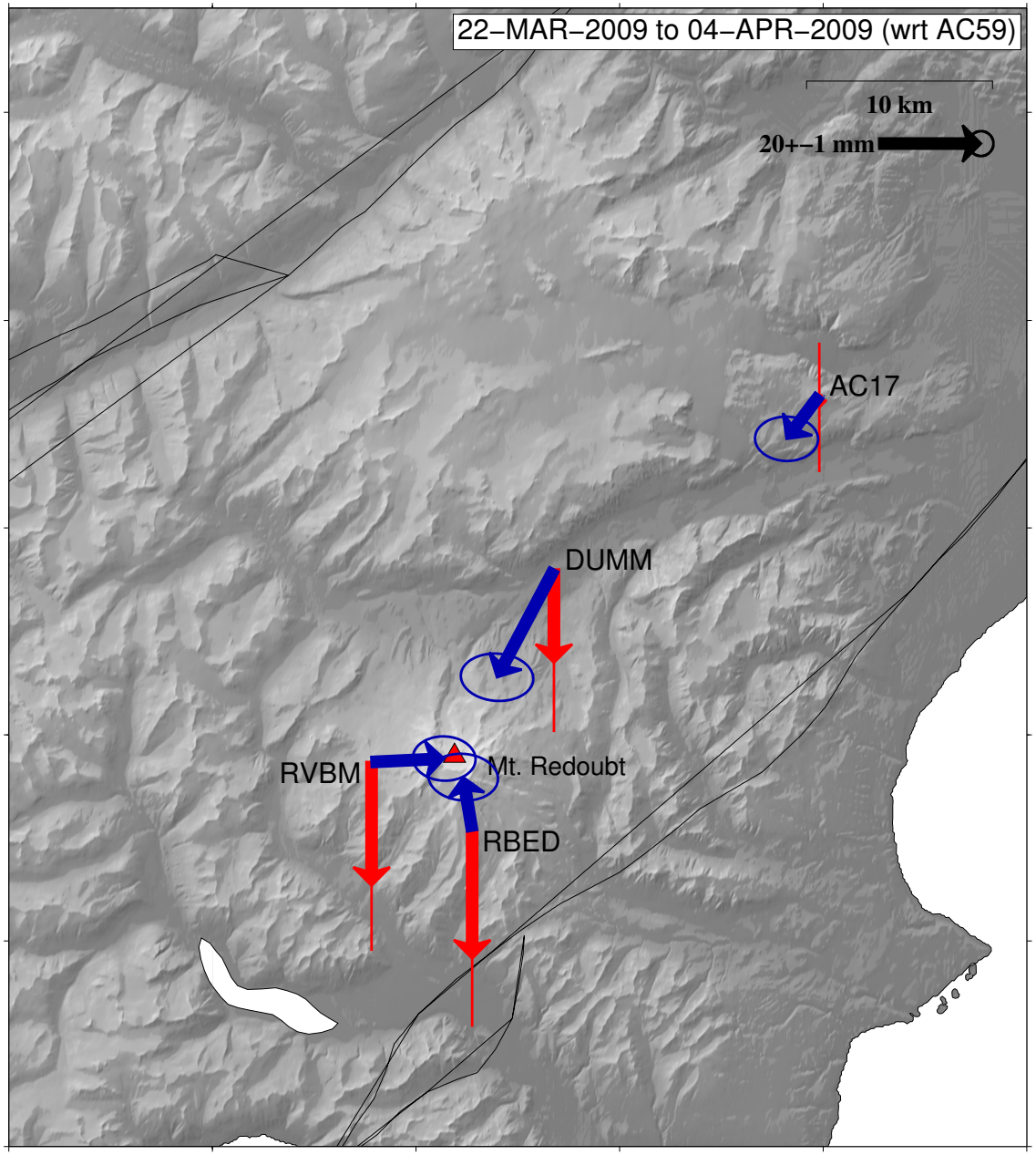
Pre-eruptive Phase – Inflation



Data
horizontal
vertical

Model
horizontal
vertical

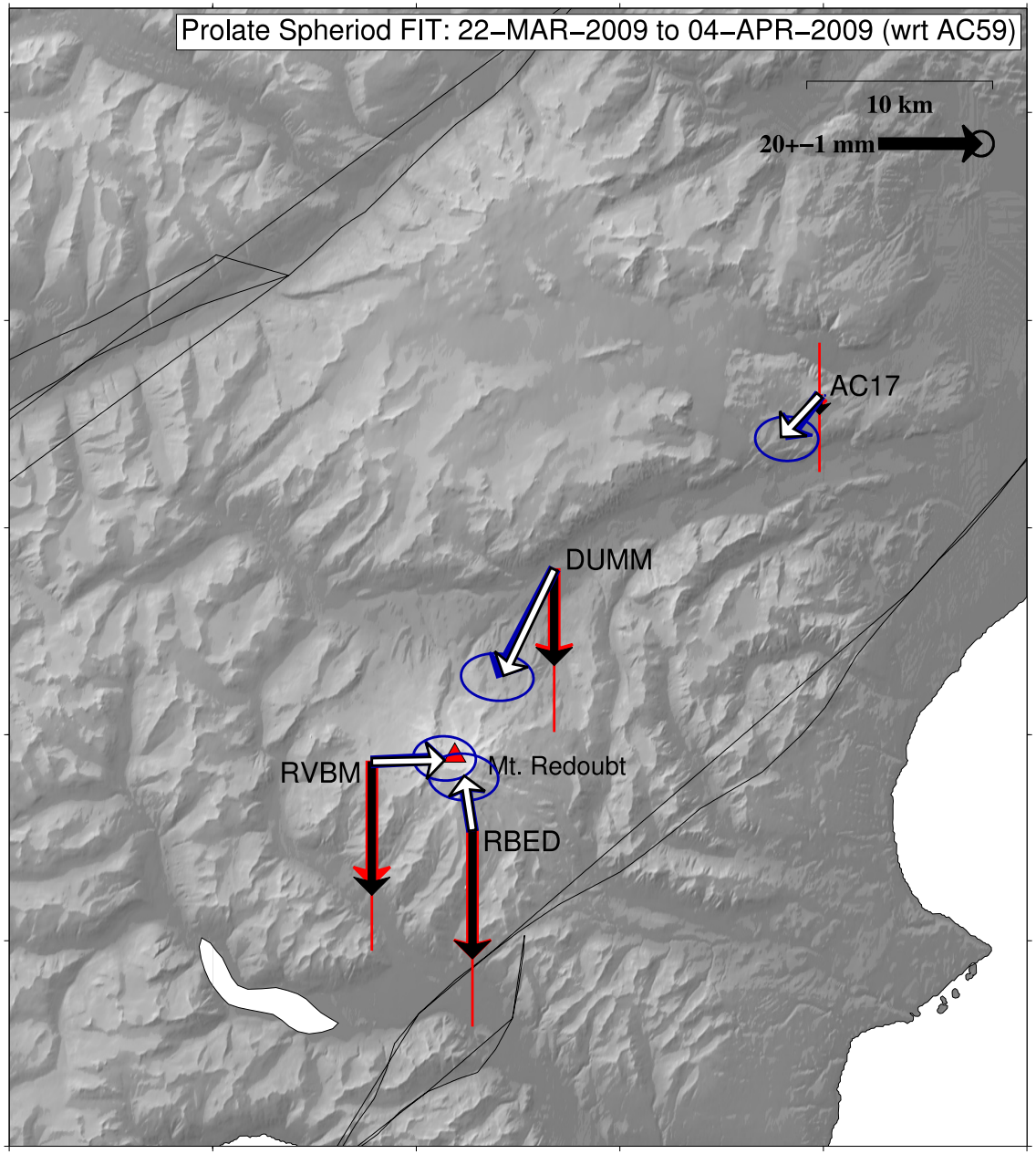
Explosive Phase – Deflation



Data
horizontal
vertical

Model
horizontal
vertical

Explosive Phase – Deflation



General Spheroid:

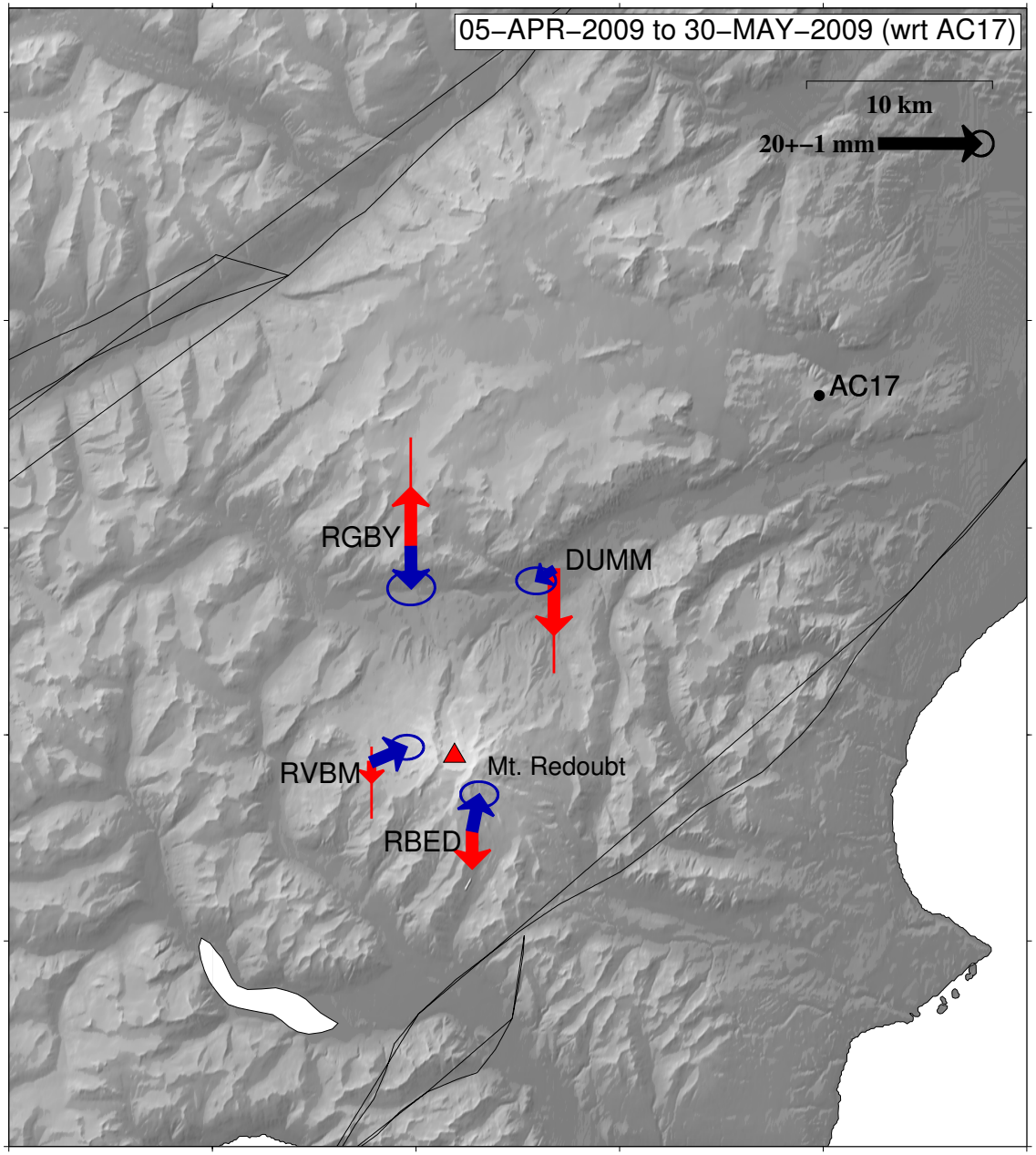
$$
\begin{aligned}
r &= 0.5\,km\,\text{E of dome} \\
d &= \mathbf{9.17}\ {}^{6.92}_{15.17}\ km \\
a &= \mathbf{4.50}\ {}^{1.25}_{>10.00}\ km \\
b &= \mathbf{0.475}\ {}^{0.3}_{>4.00}\ km \\
\Delta V &= -(\mathbf{0.05}\ {}^{0.028}_{>0.1})\ km^3
\end{aligned}
$$

F-Test: Spheroid preferred.

Data
horizontal →
vertical →

Model
horizontal ⇒
vertical →

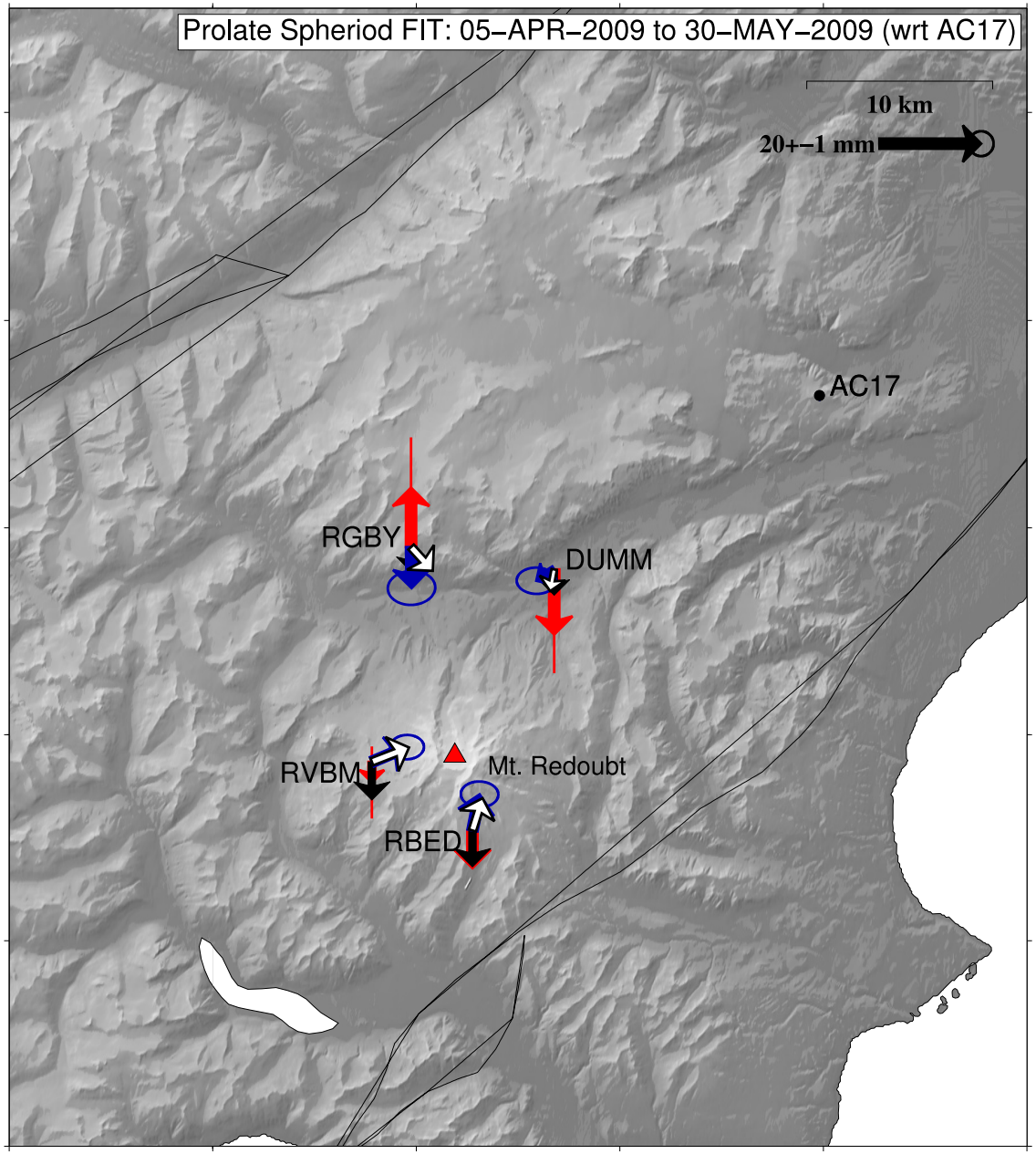
Effusive Phase – Deflation



Data
horizontal
vertical

Model
horizontal
vertical

Effusive Phase – Deflation



General Spheroid:

$$\Delta V = -(\mathbf{0.017}\ ^{0.011}_{0.023})\ km^3$$

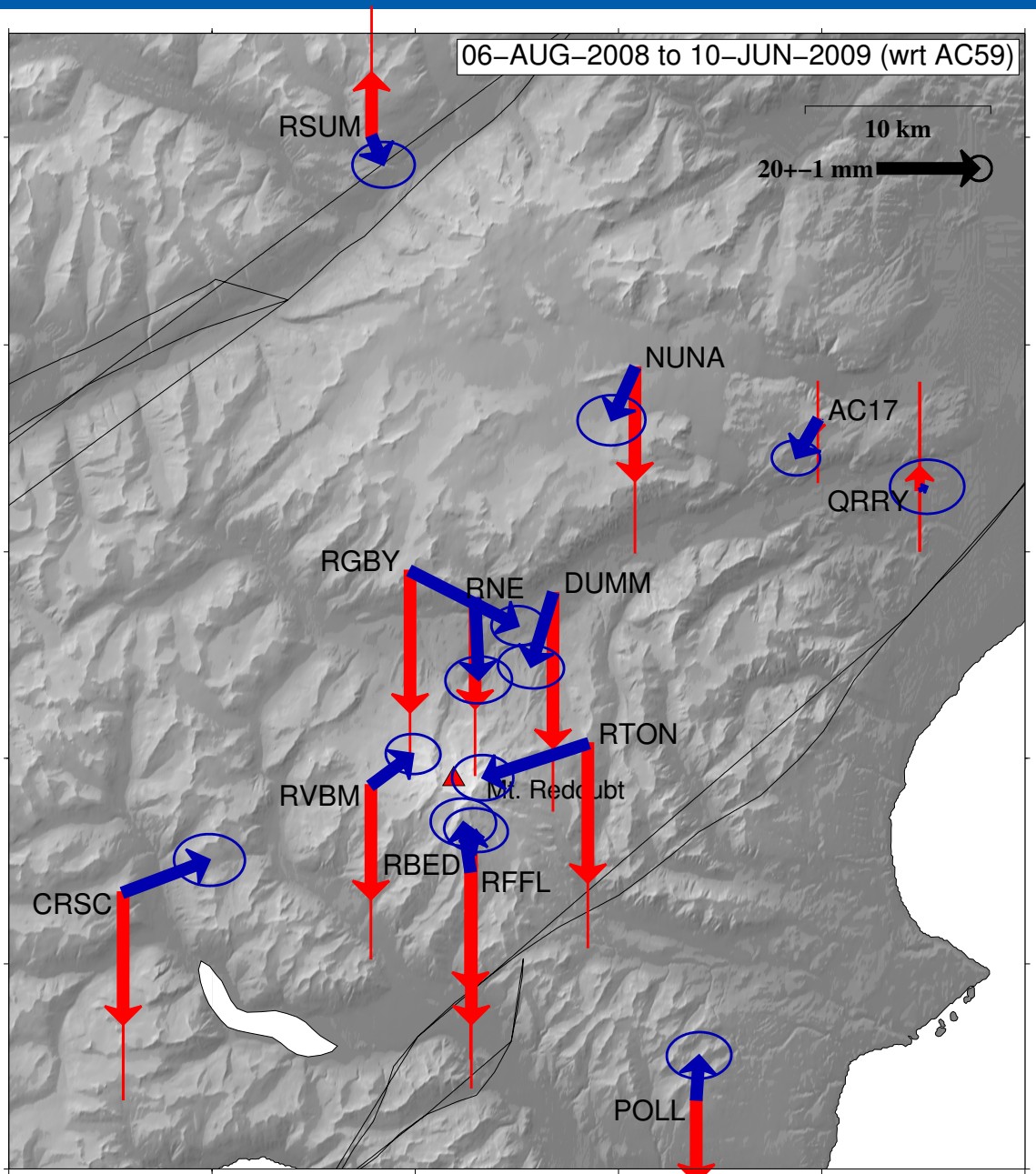
Mogi fits better

F-Test rejects Mogi

Data
horizontal
vertical

Model
horizontal
vertical

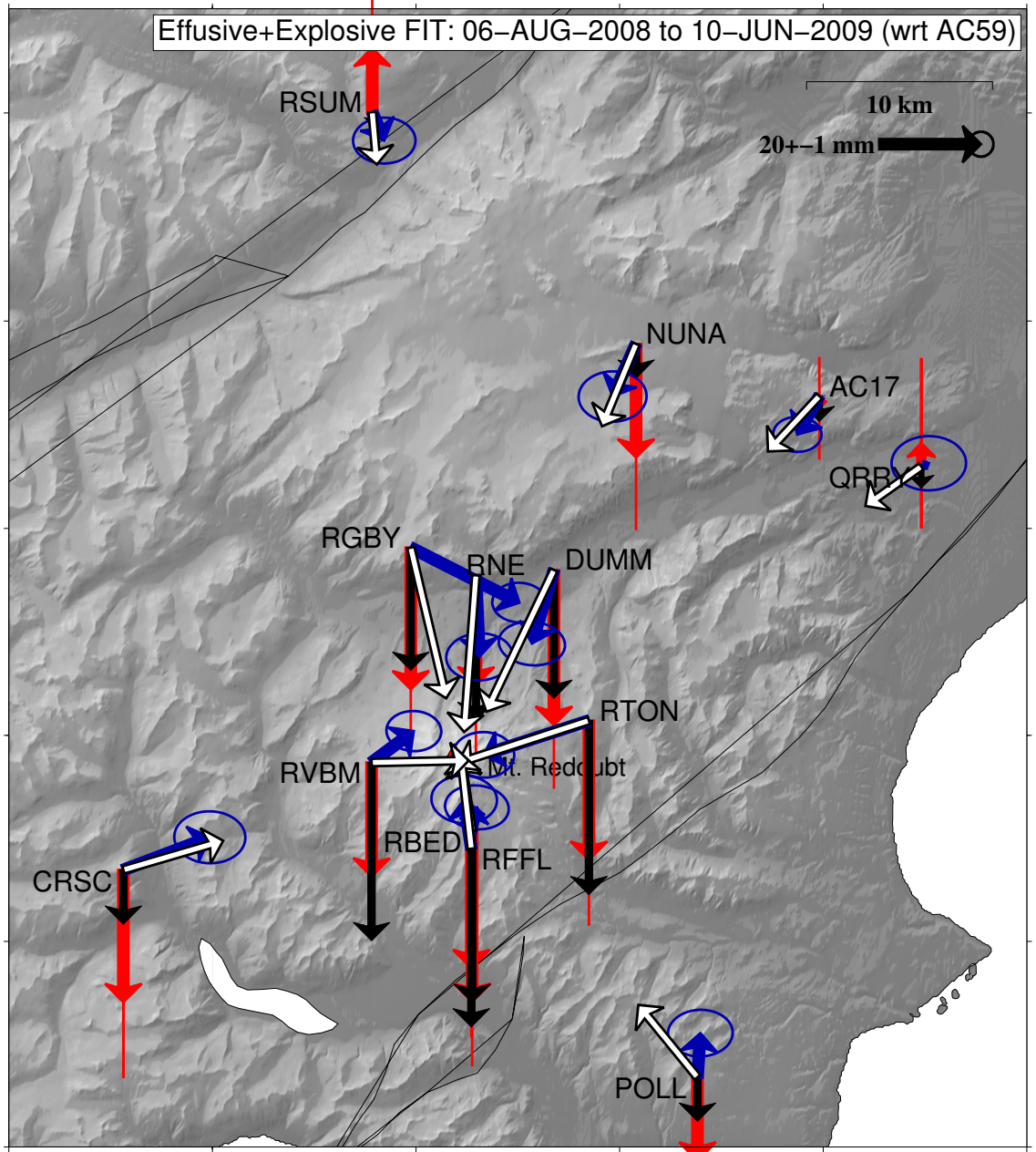
Full Eruption – Net Deflation



Data
horizontal
vertical

Model
horizontal
vertical

Full Eruption – Net Deflation



Explosive: Prolate Spheroid

$$
\begin{aligned}
r &= \mathbf{0.5}\ km\ \text{E of dome} \\
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a &= \mathbf{4.50}\ {}^{1.25}_{>10.00}\ km \\
b &= \mathbf{0.475}\ {}^{0.3}_{>4.00}\ km \\
\Delta V &= -(\mathbf{0.05}\ {}^{0.028}_{>0.1})\ km^3
\end{aligned}
$$

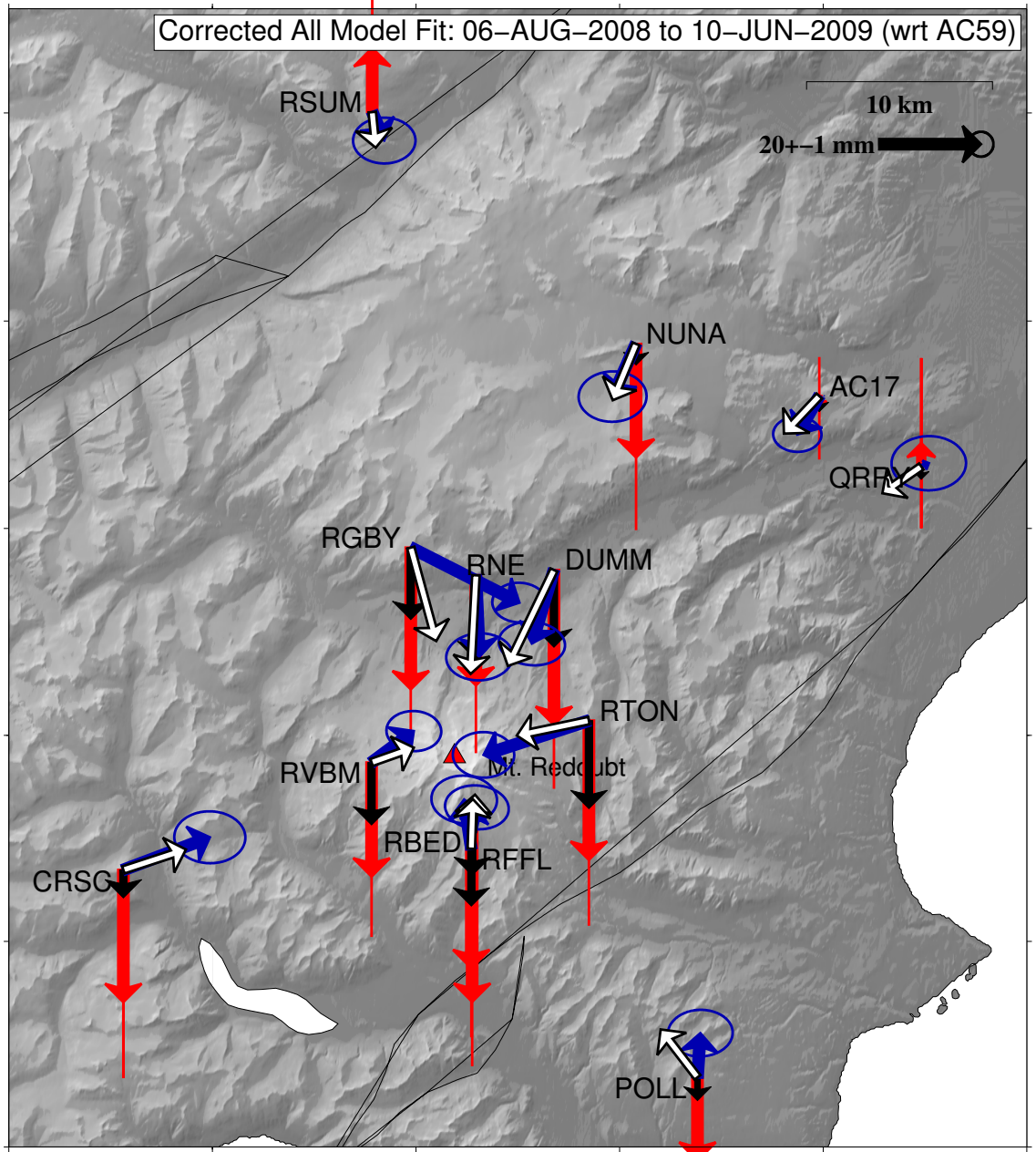
Effusive: same.

$$\Delta V = -(\mathbf{0.017}\ {}^{0.011}_{0.023})\ km^3$$

Data
horizontal →
vertical →

Model
horizontal ⇒
vertical →

Final Model



Explosive: Prolate Spheroid

$$r = 0.5\,km\,\text{E of dome}$$
$$d = 9.17\ {}^{6.92}_{15.17}\,km$$
$$a = 4.50\ {}^{1.25}_{>10.00}\,km$$
$$b = 0.475\ {}^{0.3}_{>4.00}\,km$$
$$\Delta V = -(0.05\ {}^{0.028}_{>0.1})\,km^3$$

Effusive: same.

$$\Delta V = -(0.017\ {}^{0.011}_{0.023})\,km^3$$

Pre-eruptive: Mogi

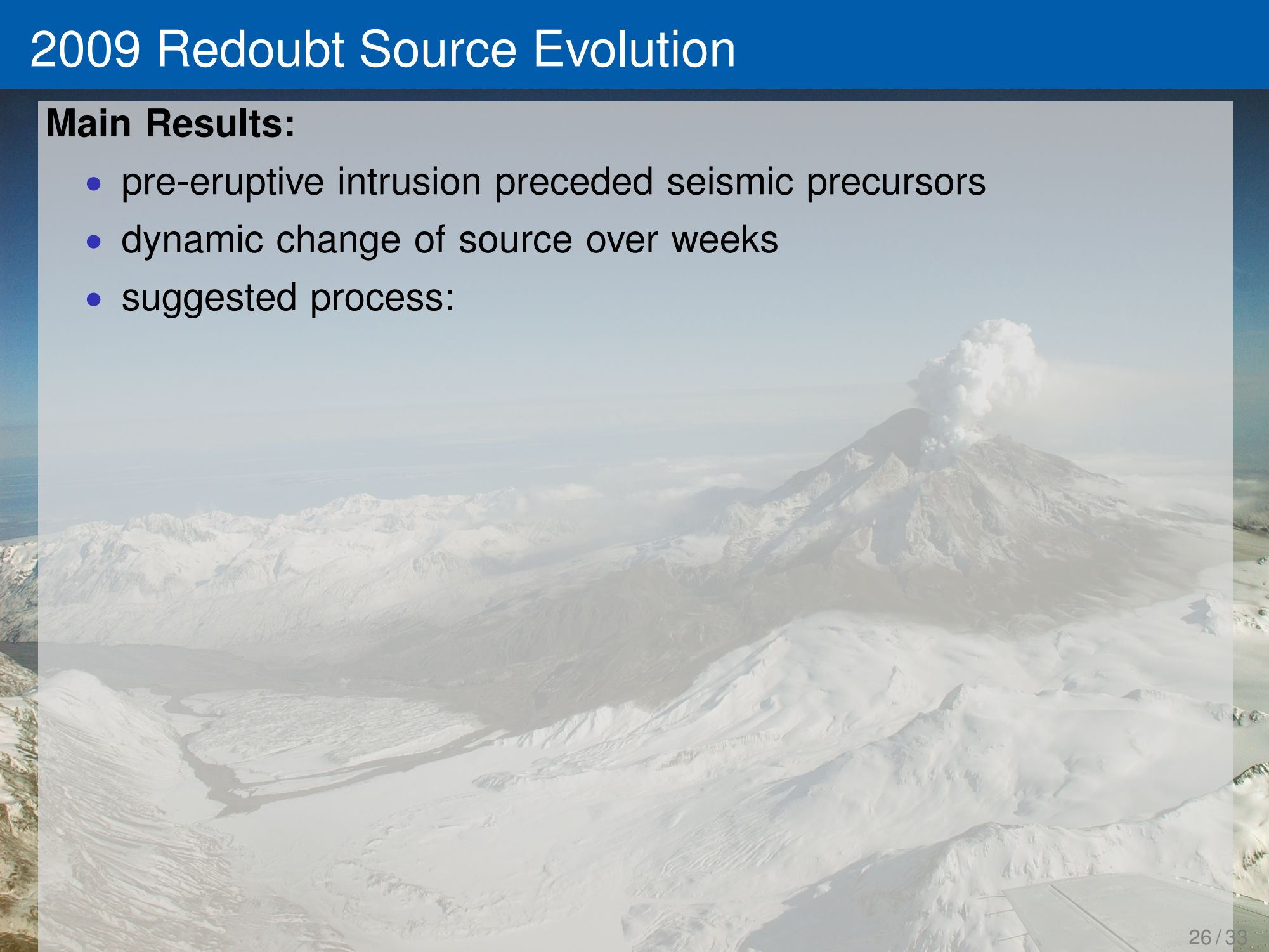
$$r = 1.25\,km\,\text{S of dome}$$
$$d = 13.50\ {}^{10.17}_{17.33}\,km$$
$$\Delta V = 0.0194\ {}^{0.0092}_{0.0340}\,km^3$$

2009 Redoubt Source Evolution

2009 Redoubt Source Evolution

Main Results:

- pre-eruptive intrusion preceded seismic precursors
- dynamic change of source over weeks
- suggested process:



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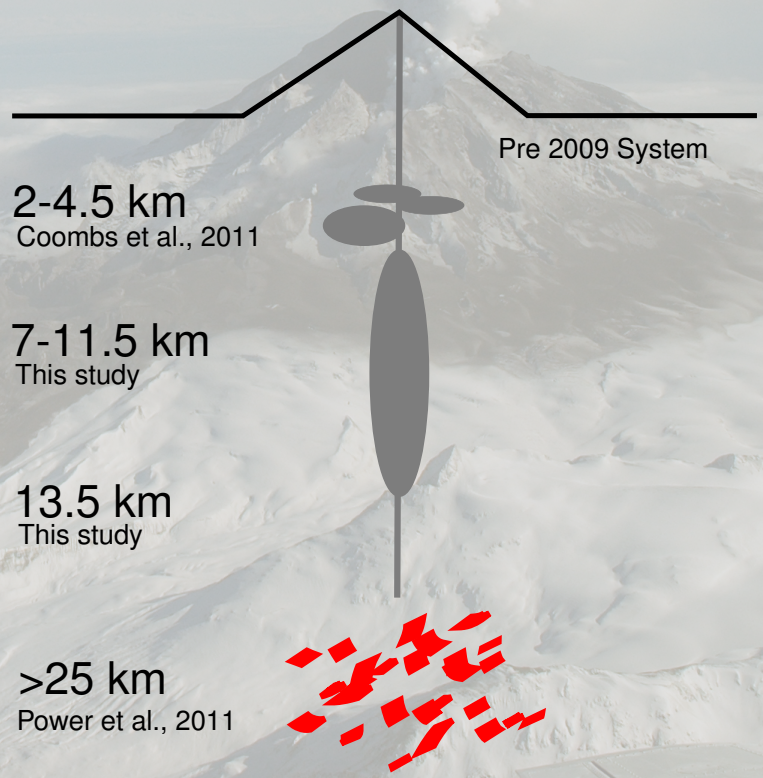

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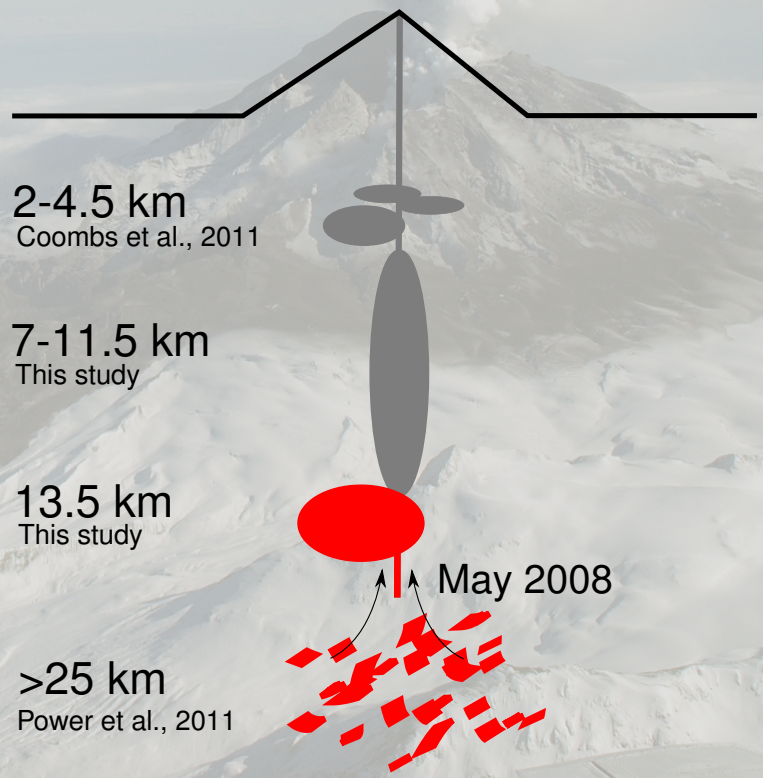

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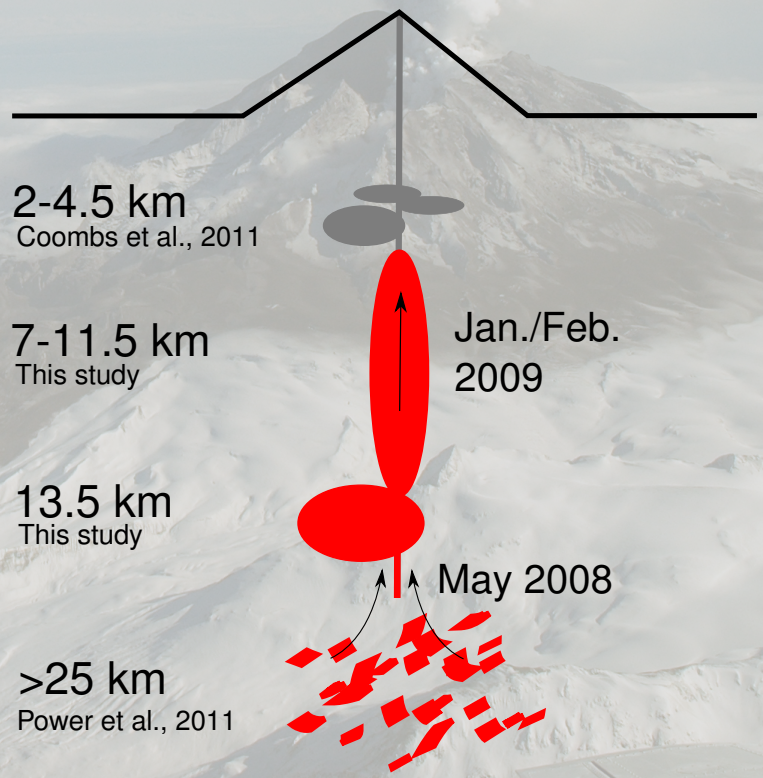

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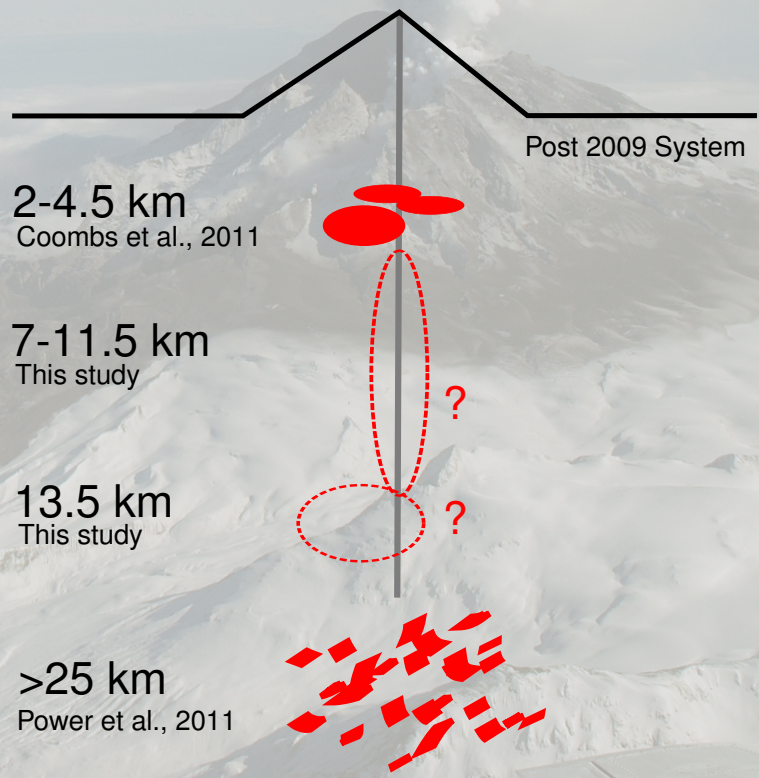
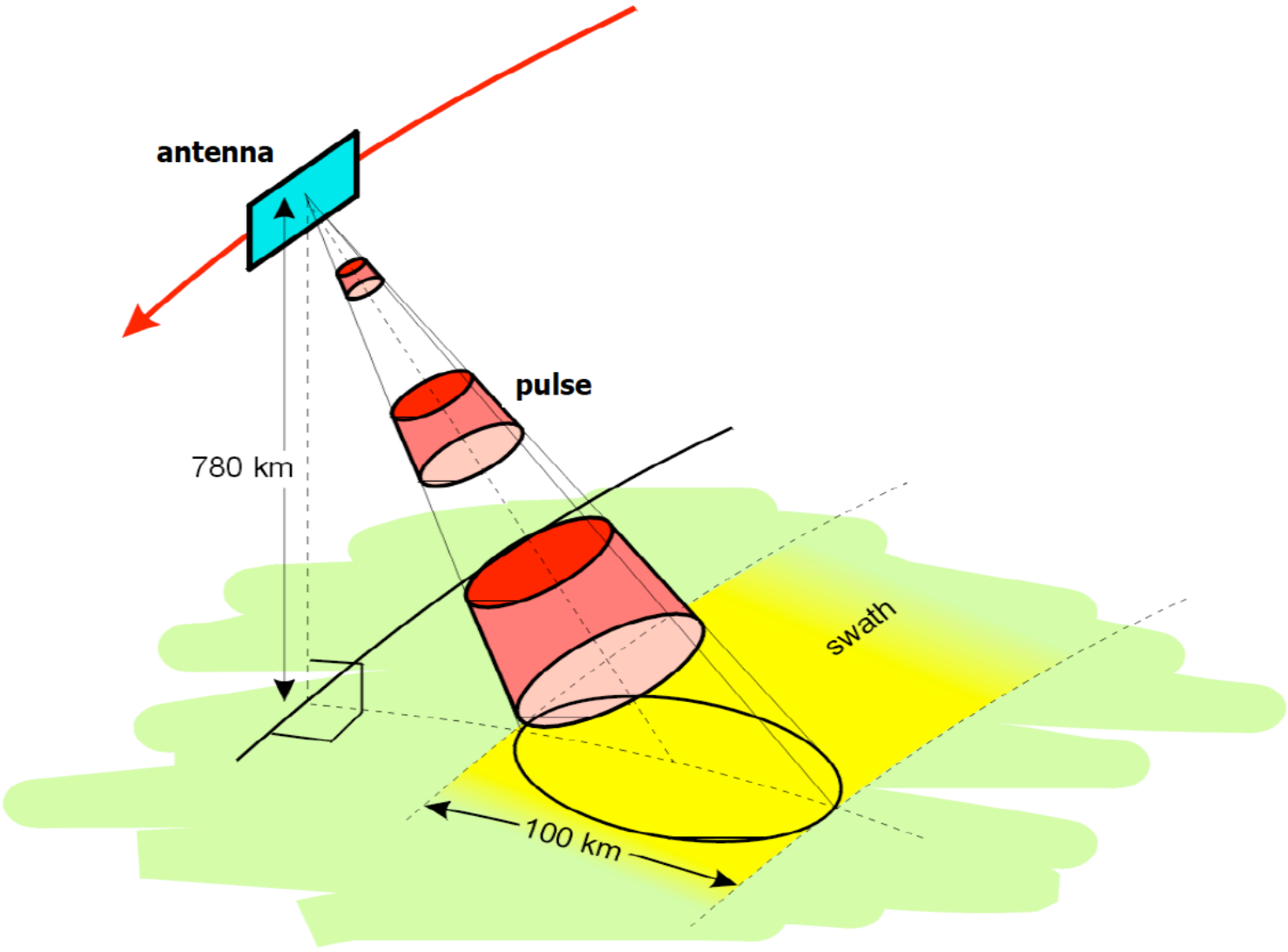
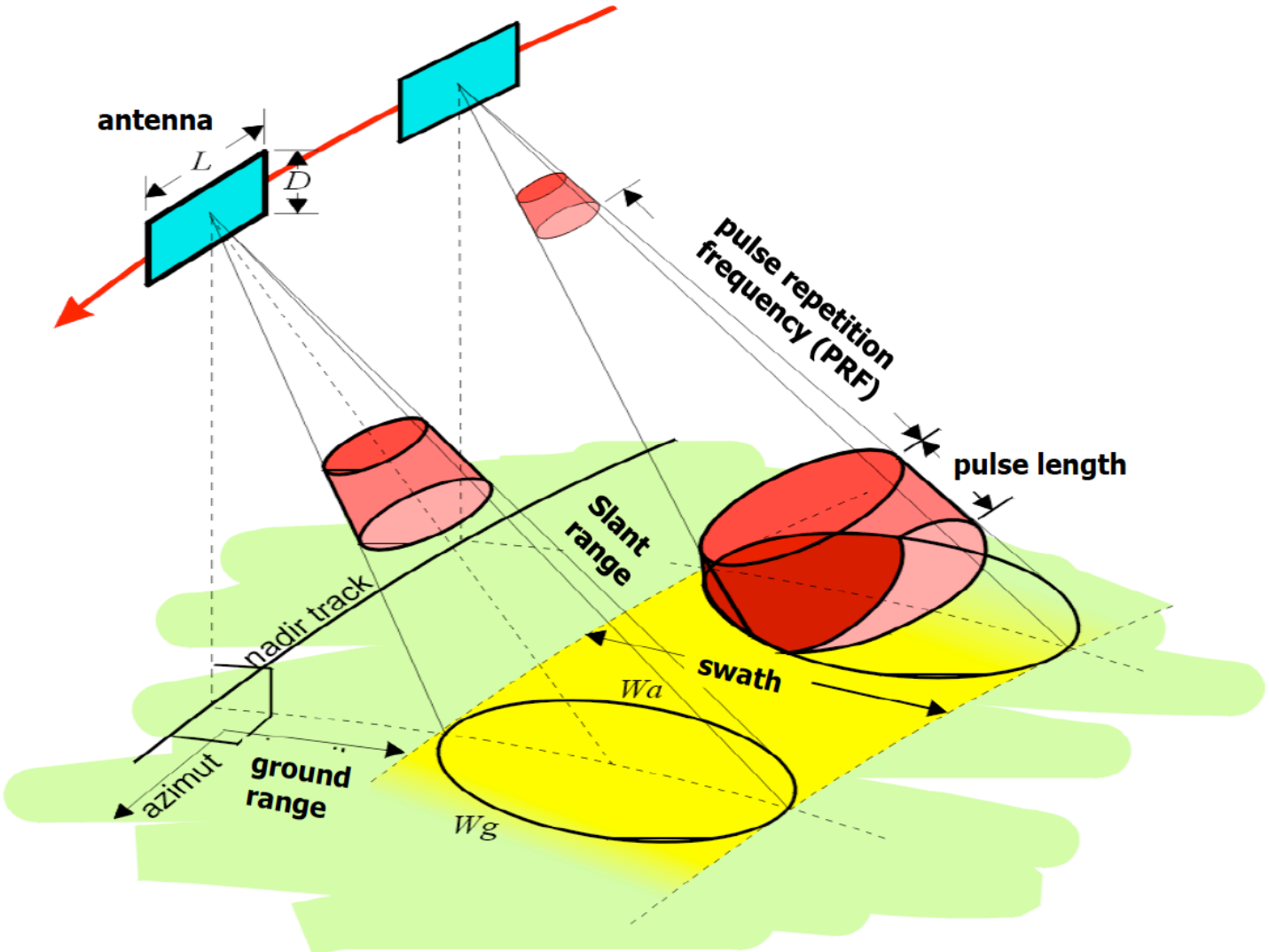


InSAR - General Concept



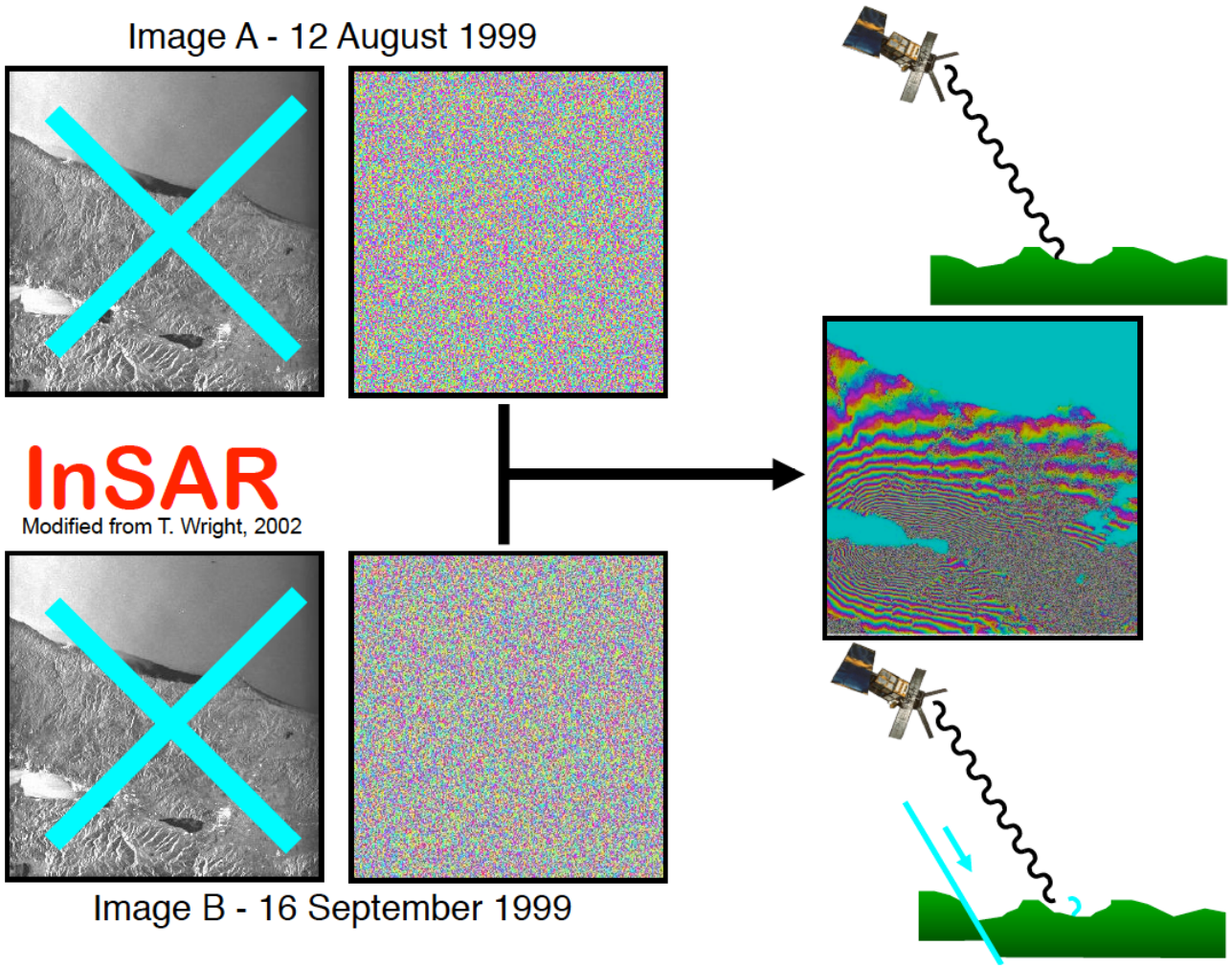
loaned from *J. Freymueller*

InSAR - General Concept



loaned from *J. Freymueller*

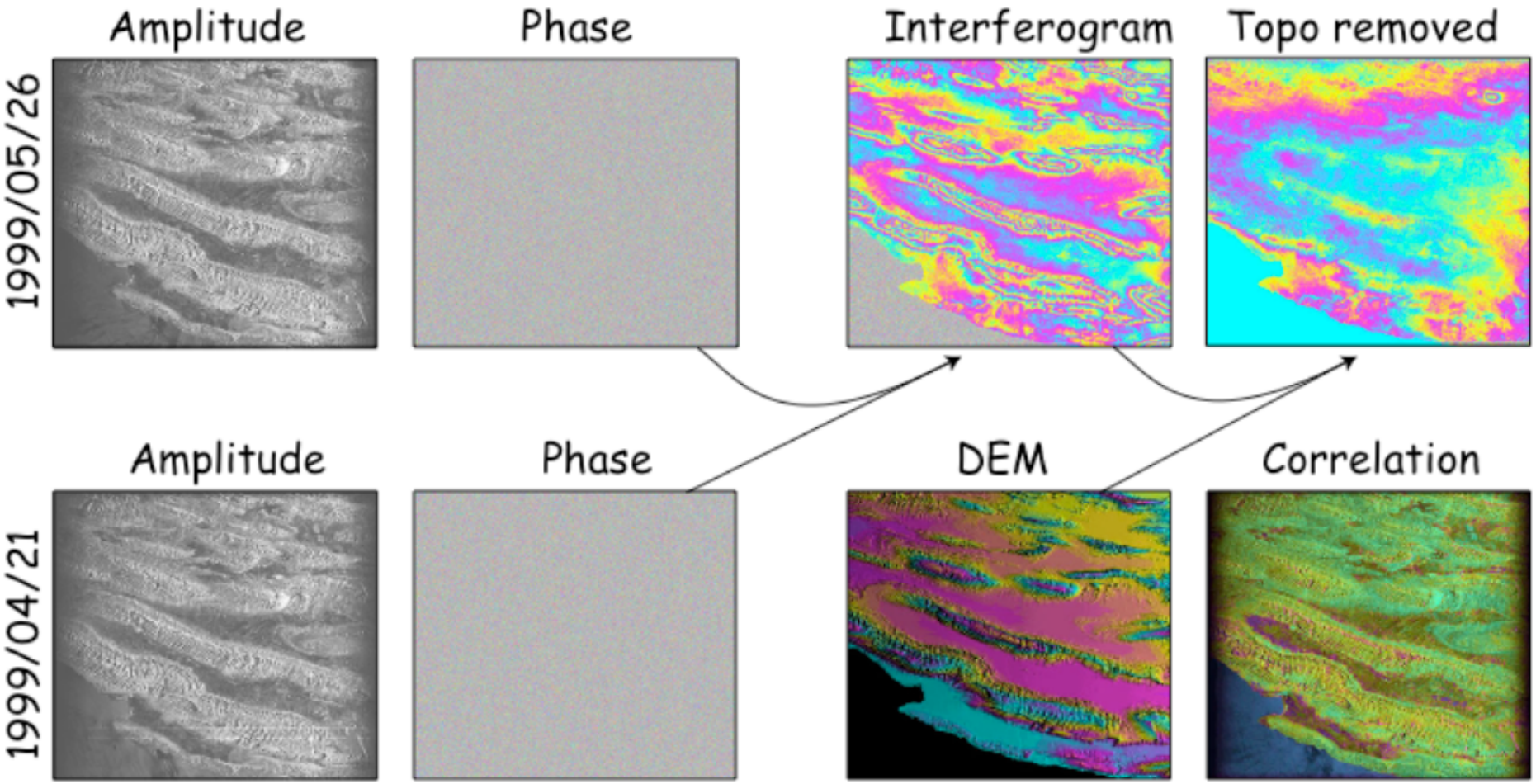
InSAR - General Concept



loaned from *R. Bürgmann*

complex values radar signal contains information on amplitude $a = \sqrt{Im^2 + Re^2}$, and phase $\phi = arctan\frac{Im}{Re}$

InSAR - General Concept



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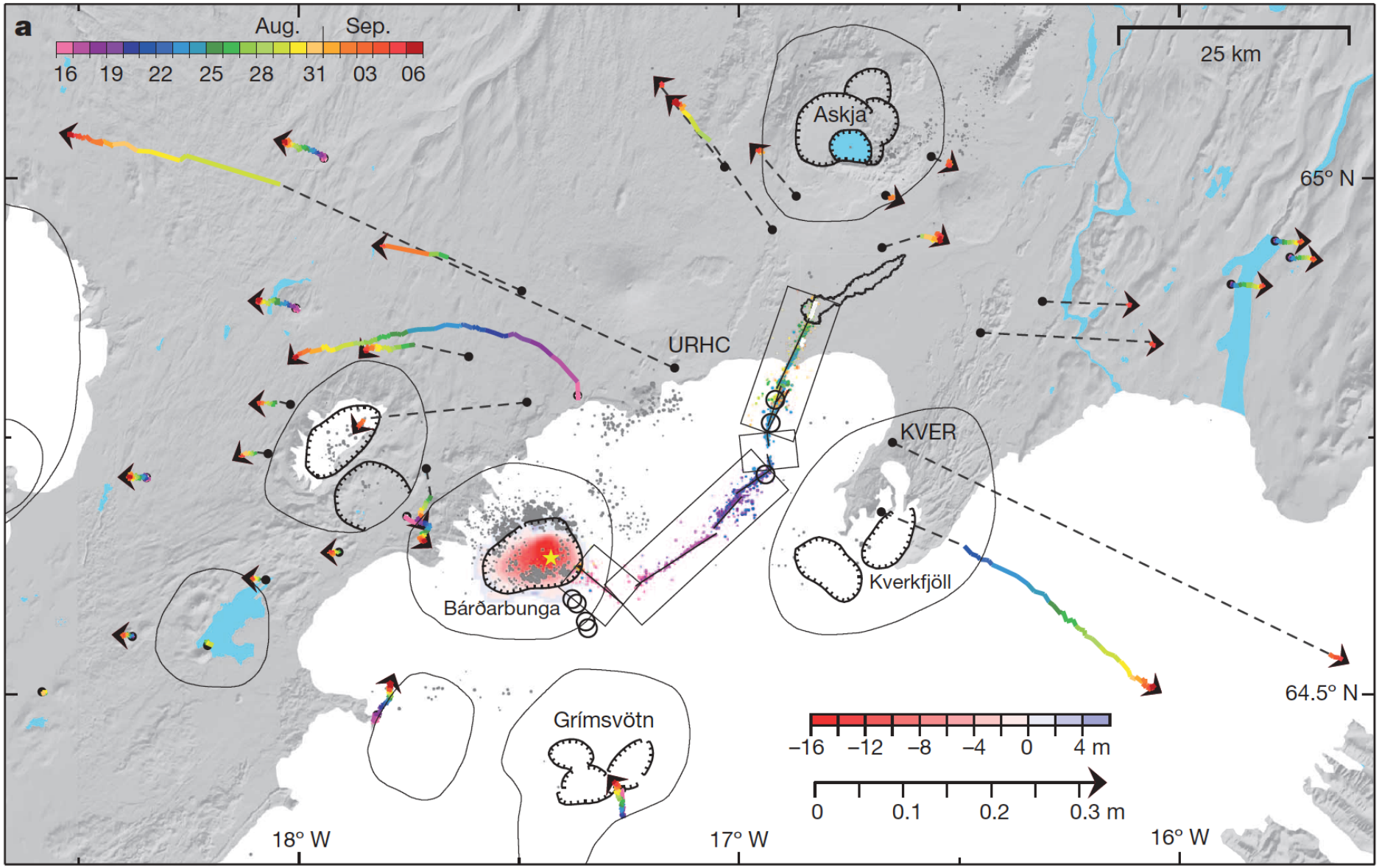
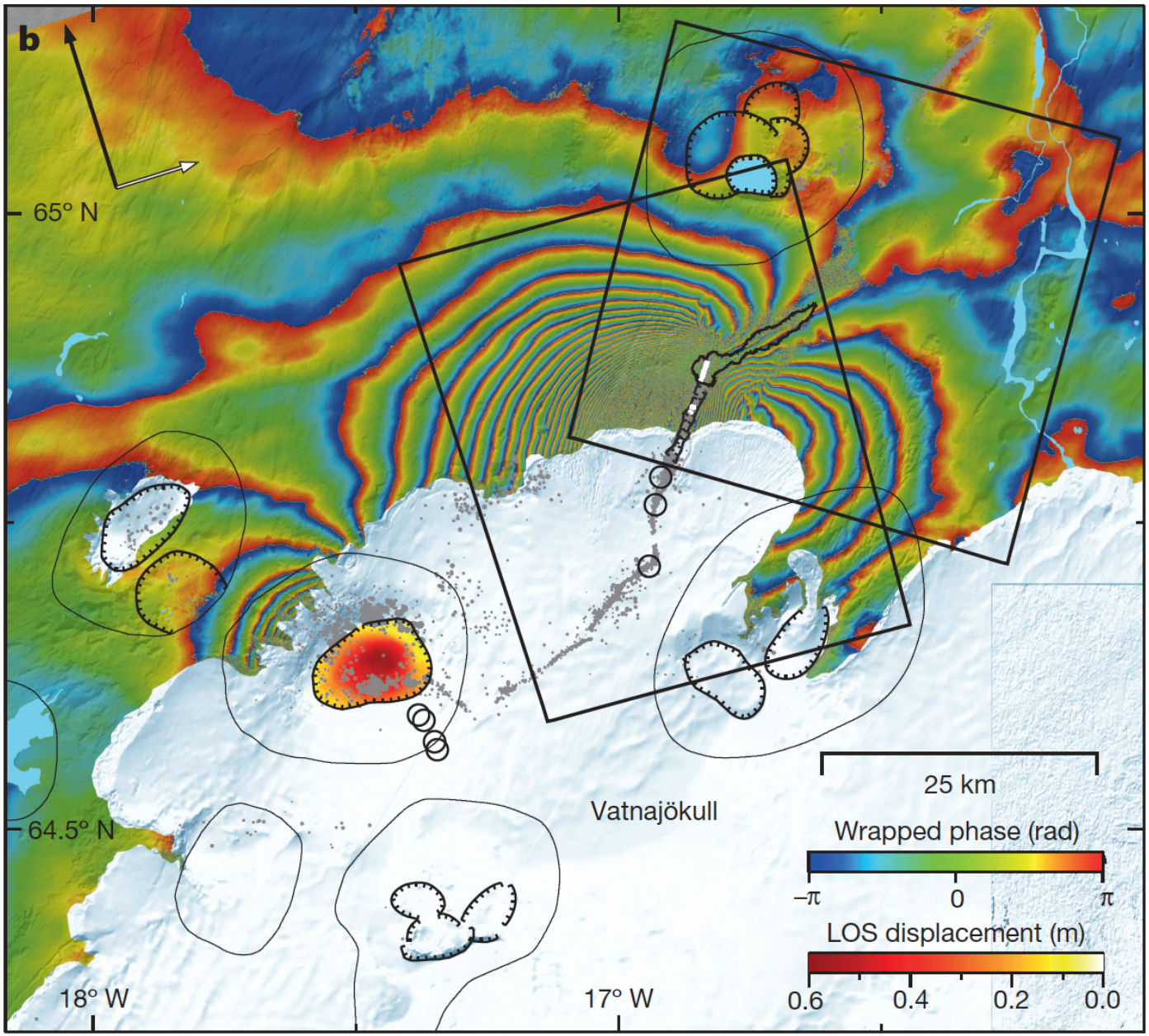
Holuhraun 2014/2015



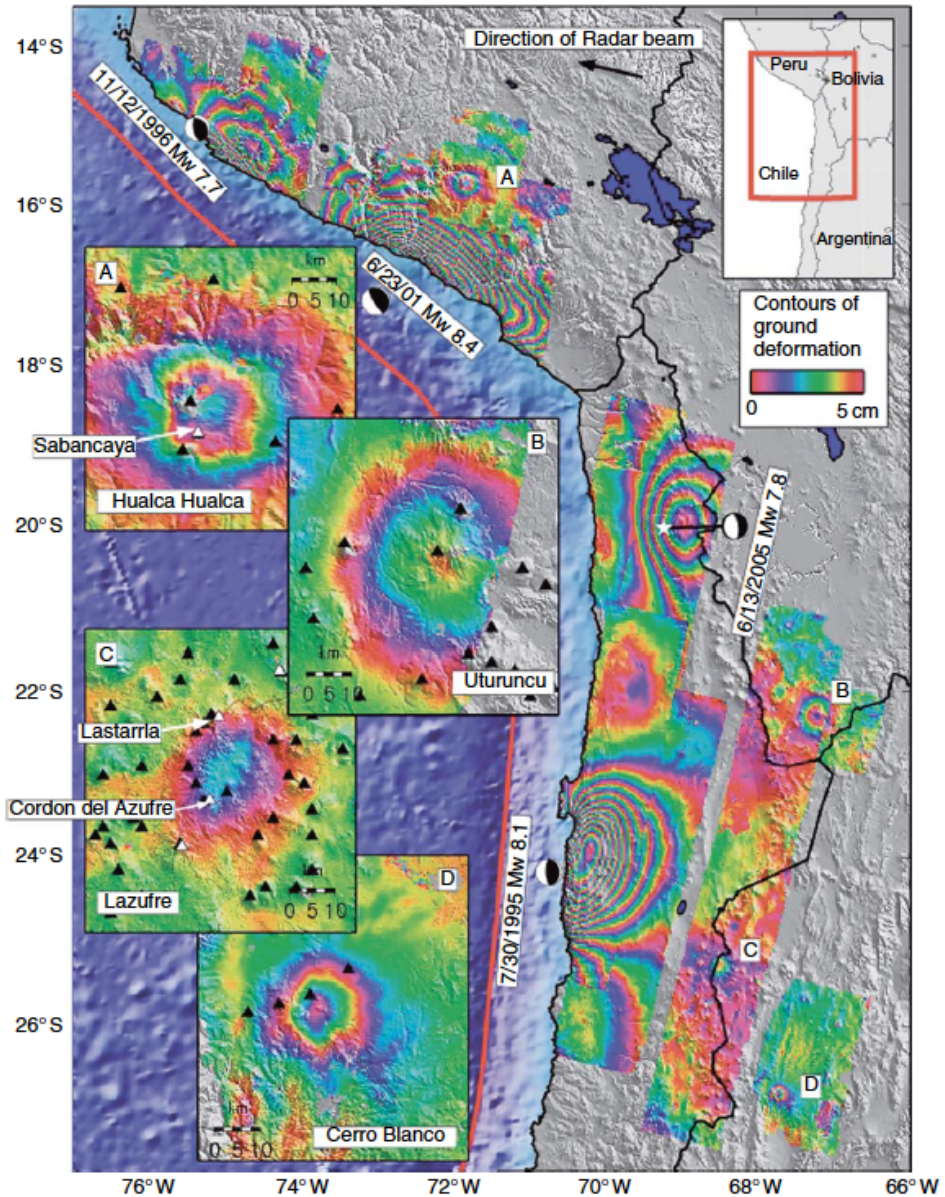
Sigmundsson et al., 2015

Holuhraun 2014/2015



Sigmundsson et al., 2015

South America



Simons and Rosen, 2007