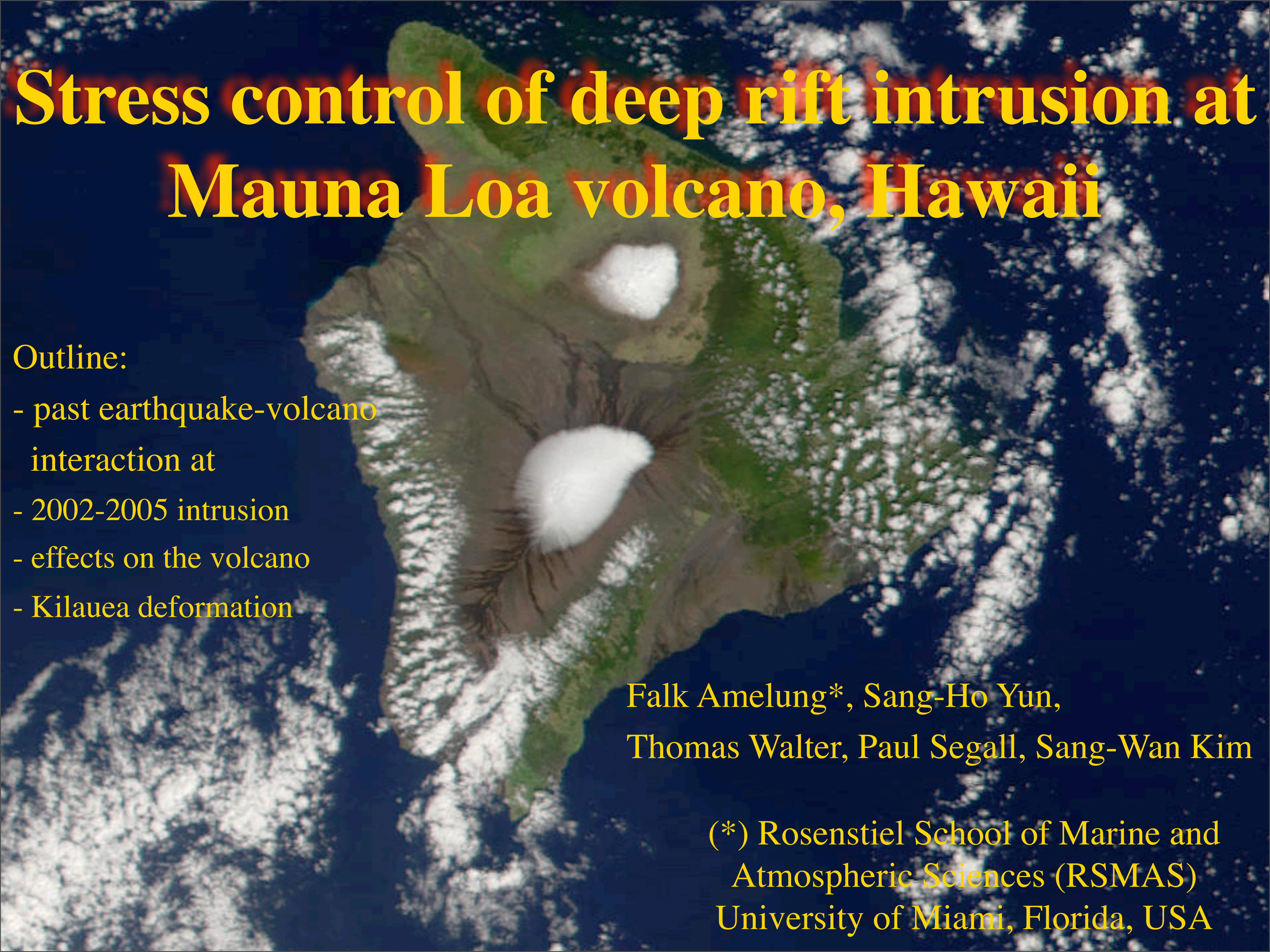


Stress control of deep rift intrusion at Mauna Loa volcano, Hawaii

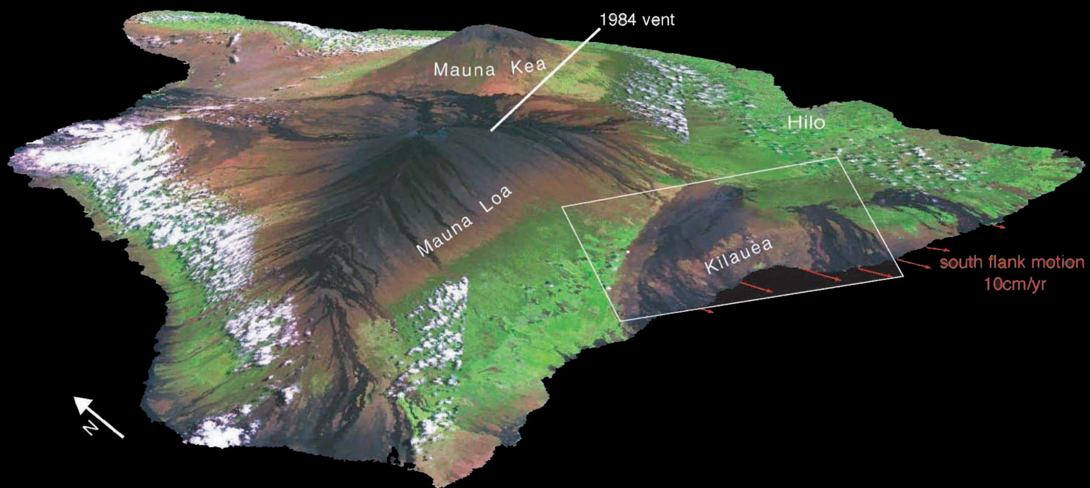
Outline:

- past earthquake-volcano interaction at
- 2002-2005 intrusion
- effects on the volcano
- Kilauea deformation

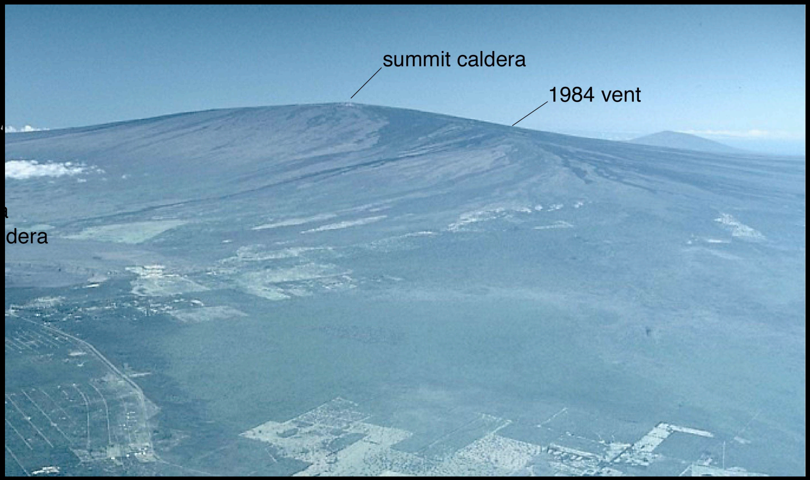
Falk Amelung*, Sang-Ho Yun,
Thomas Walter, Paul Segall, Sang-Wan Kim

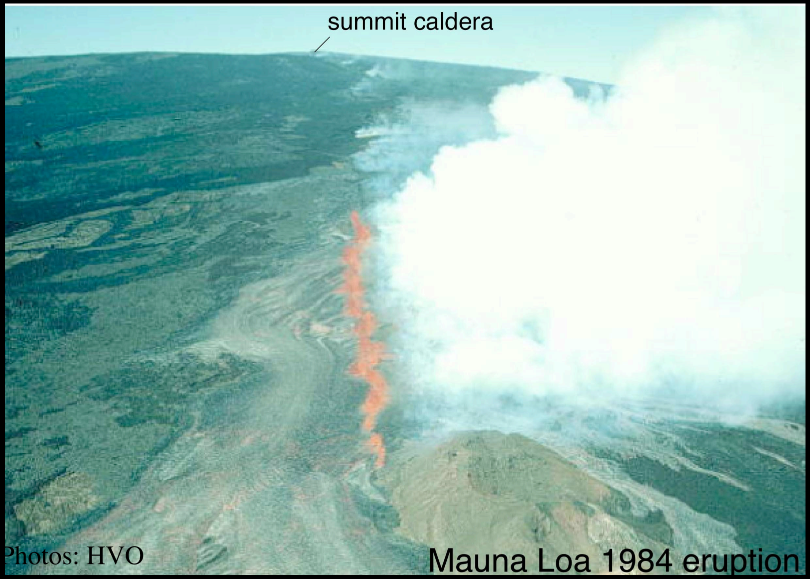
(*) Rosenstiel School of Marine and Atmospheric Sciences (RSMAS)
University of Miami, Florida, USA

The Hawaiian volcanoes



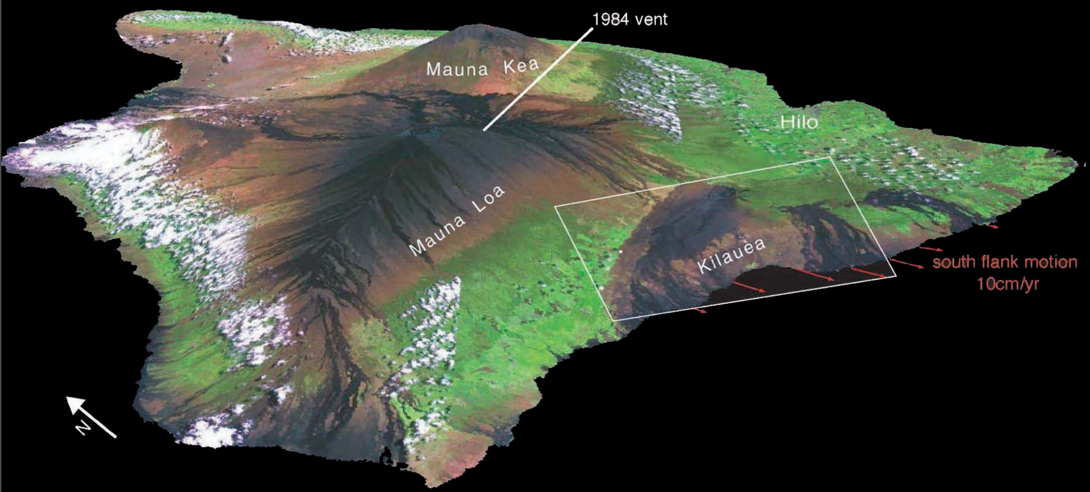
Mauna Loa:
eruptions in 1950, 1975, 1984

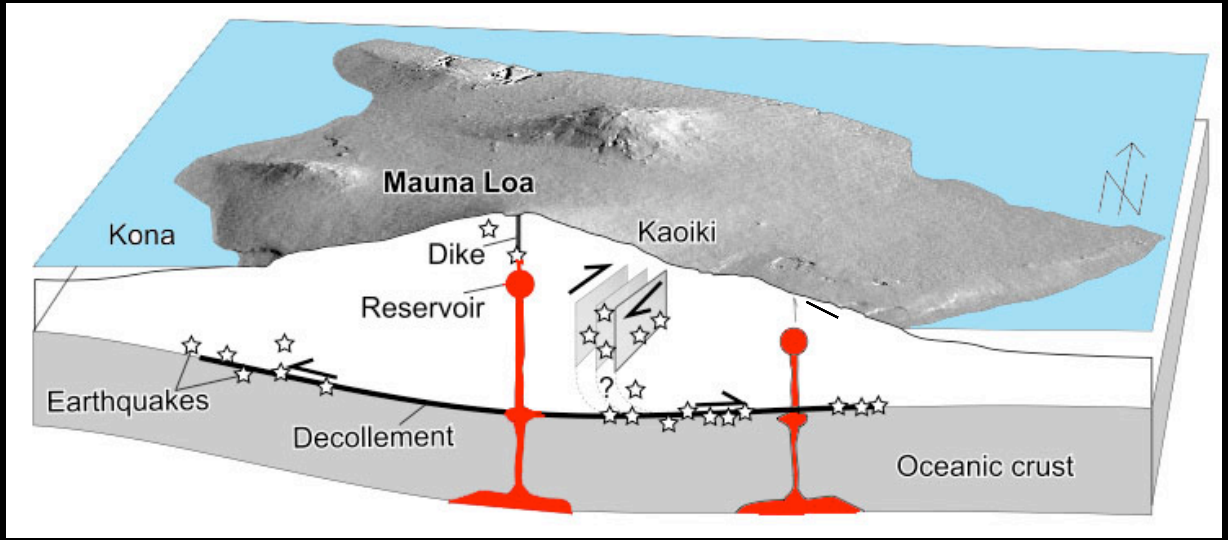




Kilauea: continuous eruption since 1983

The Hawaiian volcanoes

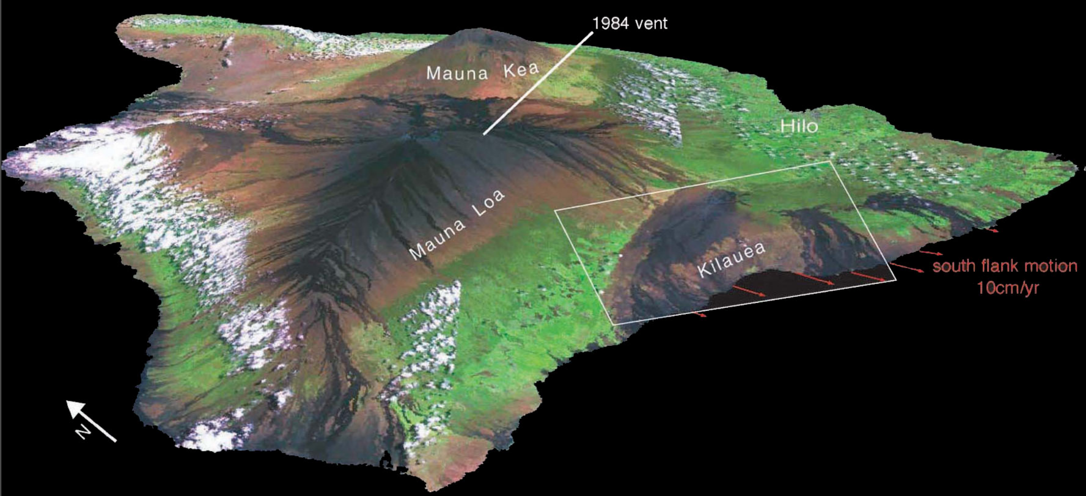




The modes of deformation:

- ❑ rift intrusion
- ❑ seismic/aseismic decollement slip
- ❑ flank motion
- ❑ magma chamber inflation/deflation

The Hawaiian volcanoes



1975 M7.2 Kalapana earthquake

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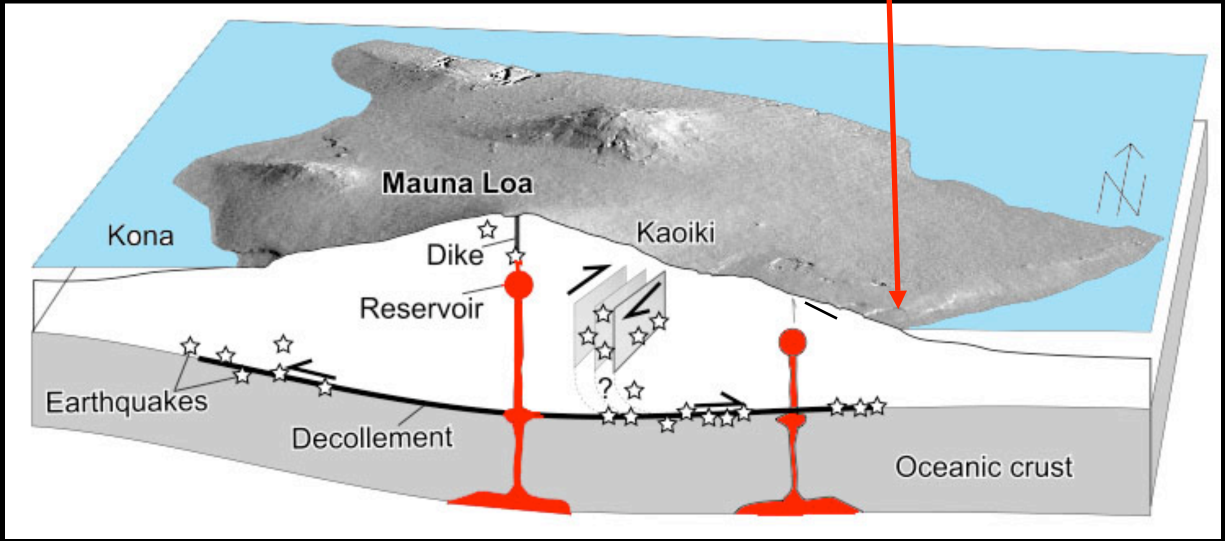
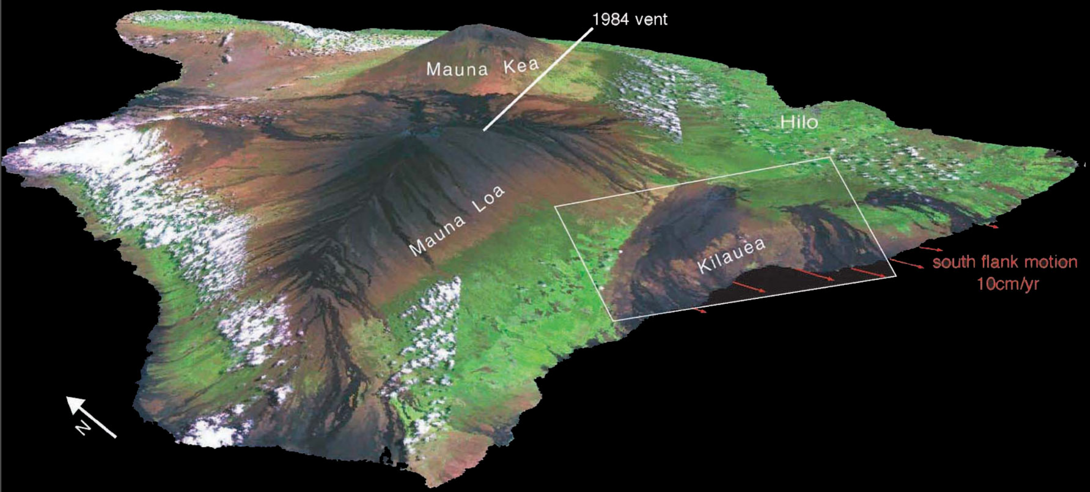


The Hawaiian volcanoes



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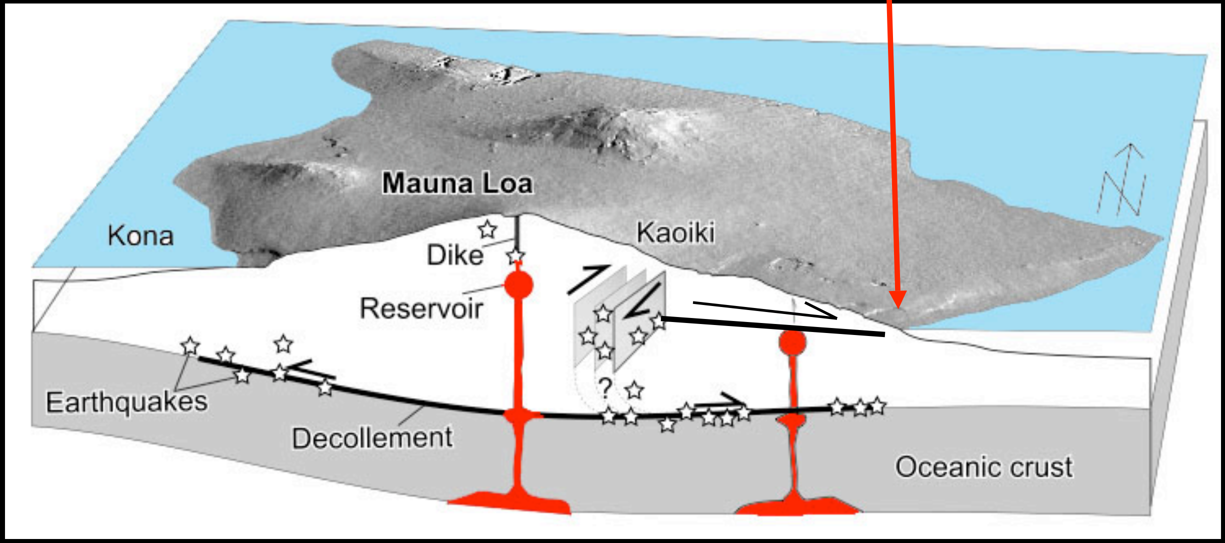

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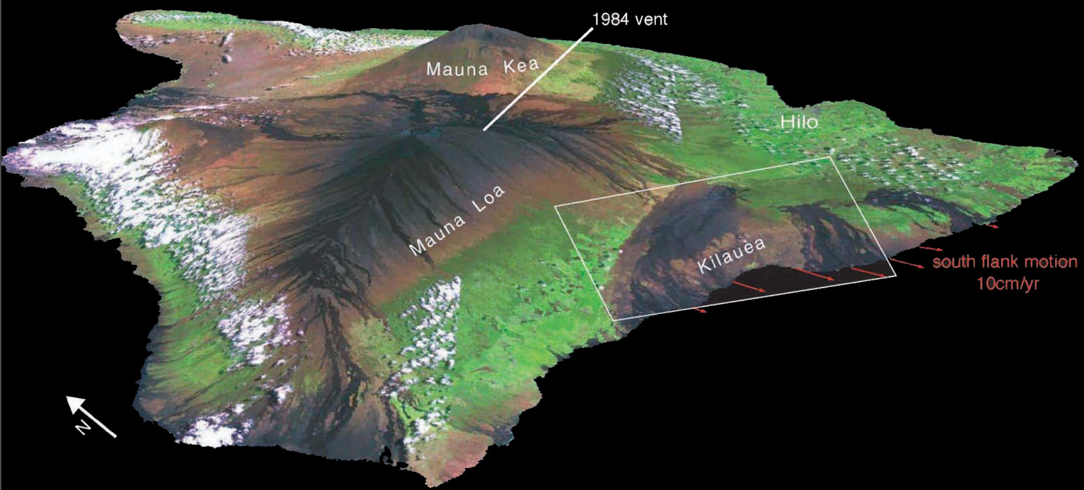
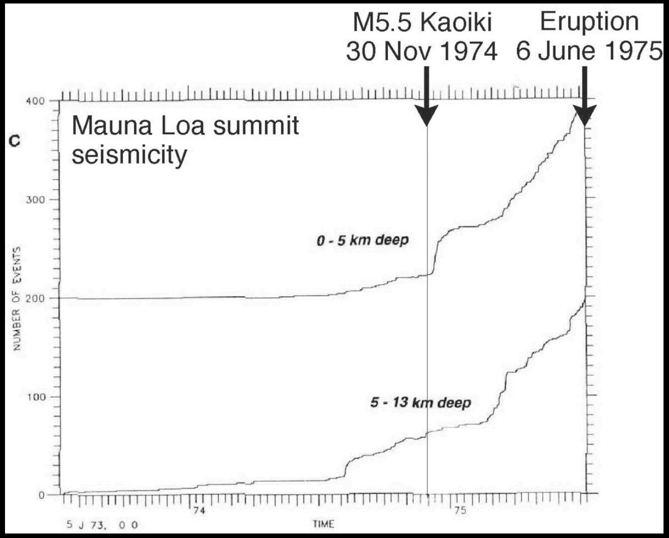
The Hawaiian volcanoes

Did the 1974 earthquake trigger the 1975 eruption ?





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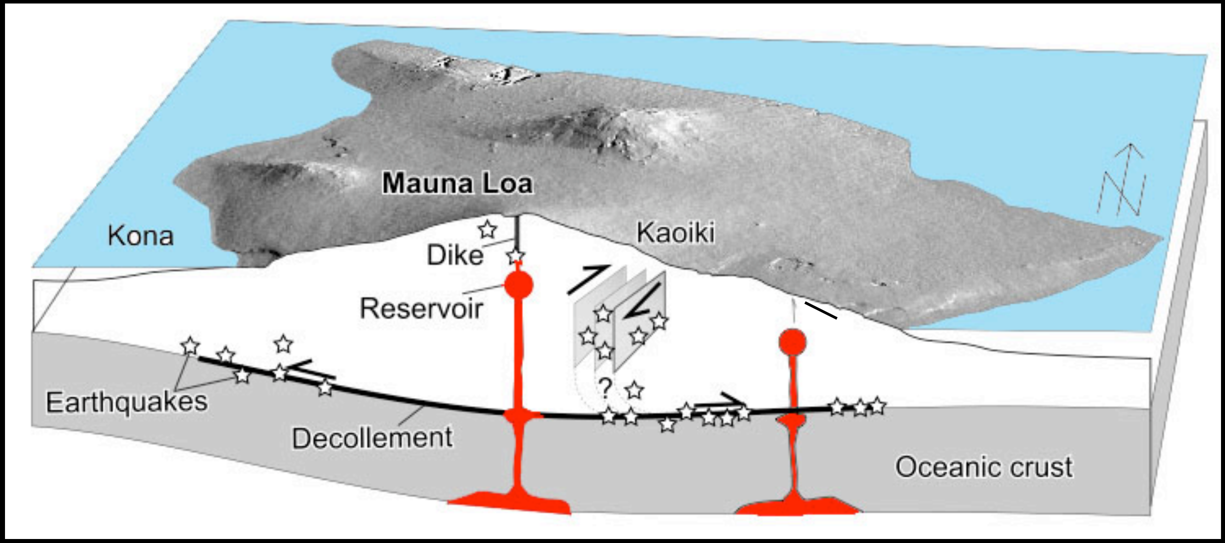

The Hawaiian volcanoes

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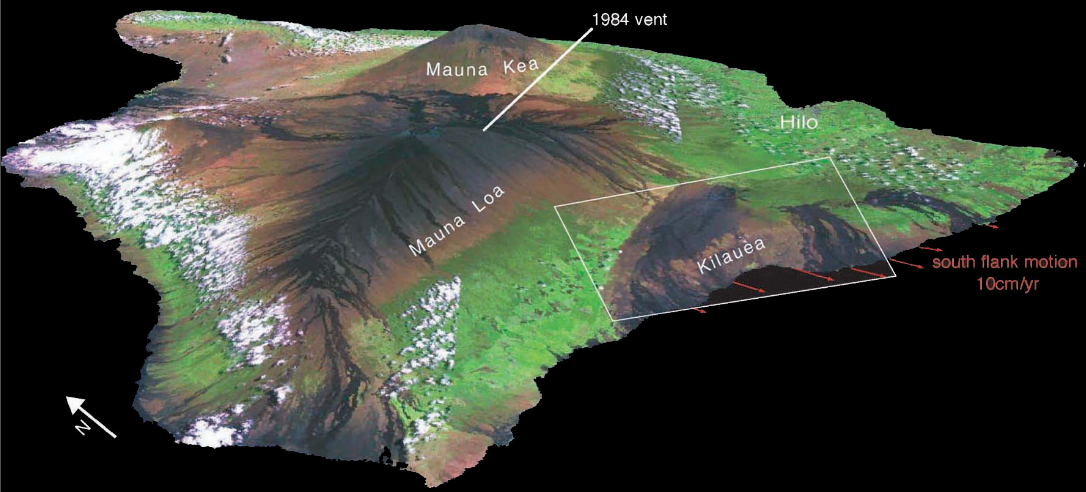

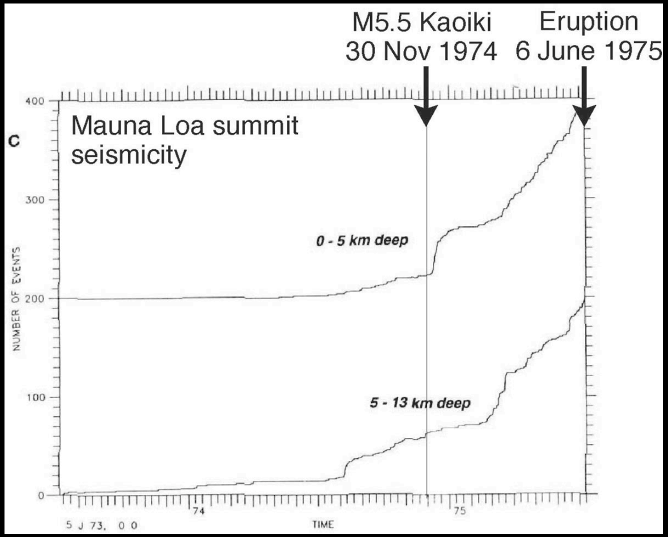

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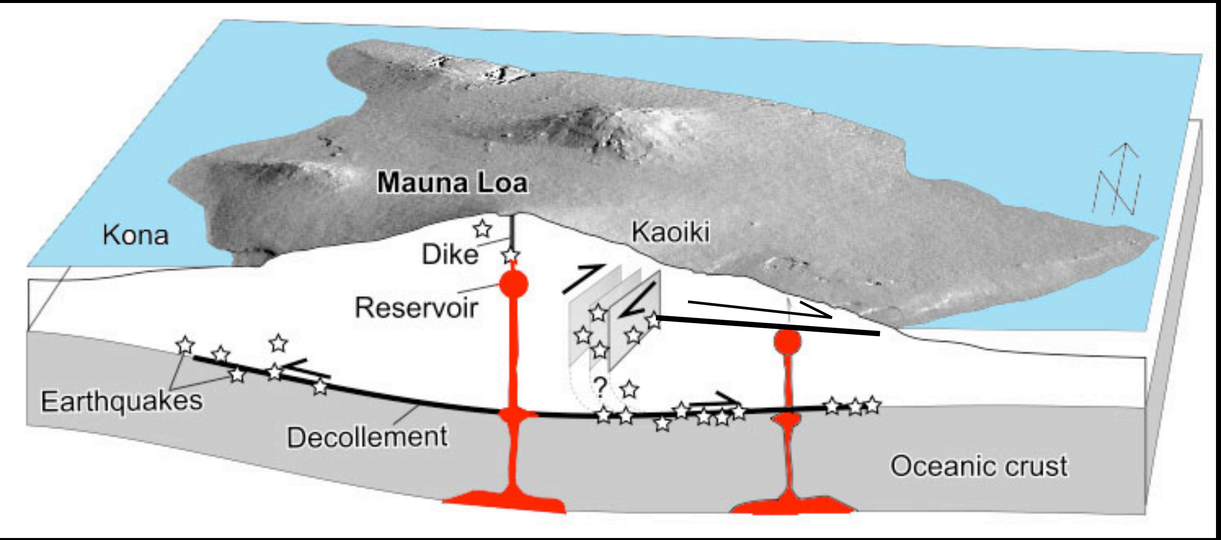
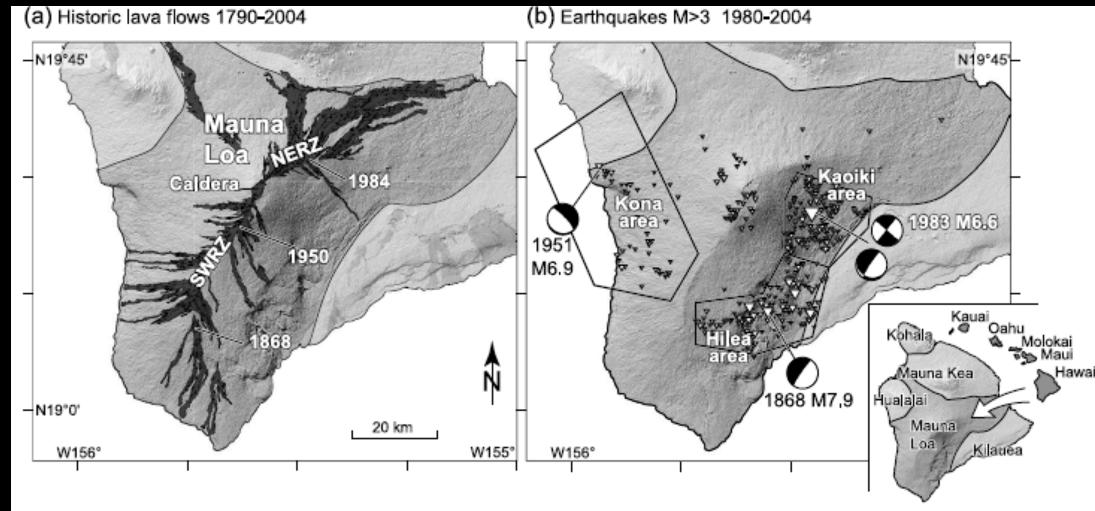
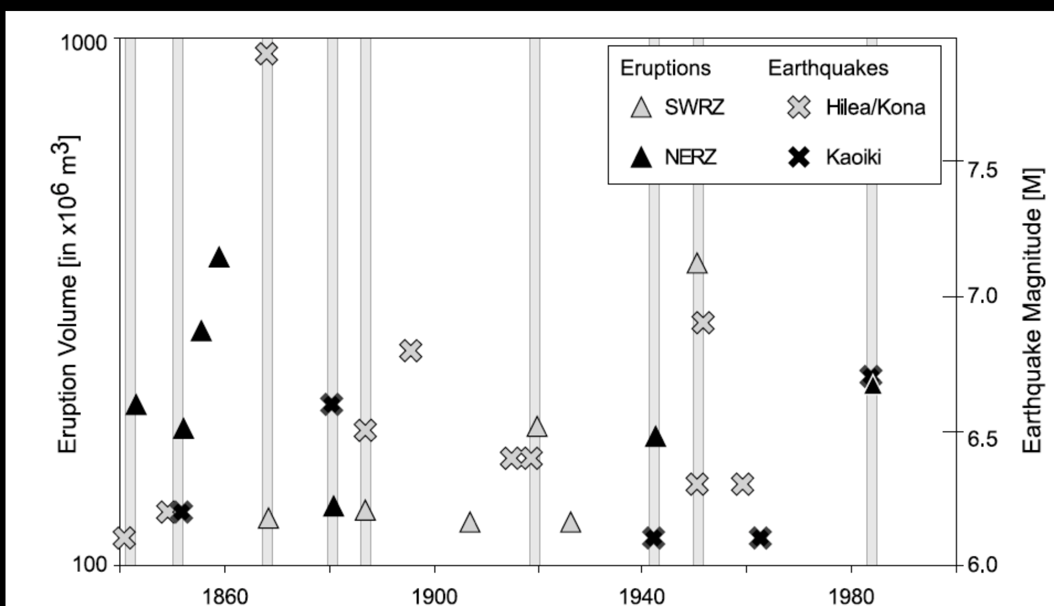


Earthquakes and eruptions at Mauna Loa





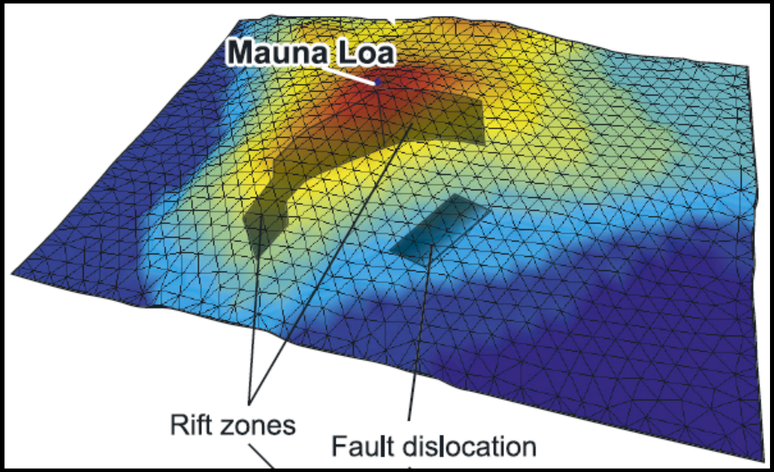
Walter and Amelung, JGR, 2006

- 17 eruptions since 1850
- 15 earthquakes sin 1850 (M>6)
- 75% of eruptions and earthquakes are part of 2-yr sequences (random probability is 20%)

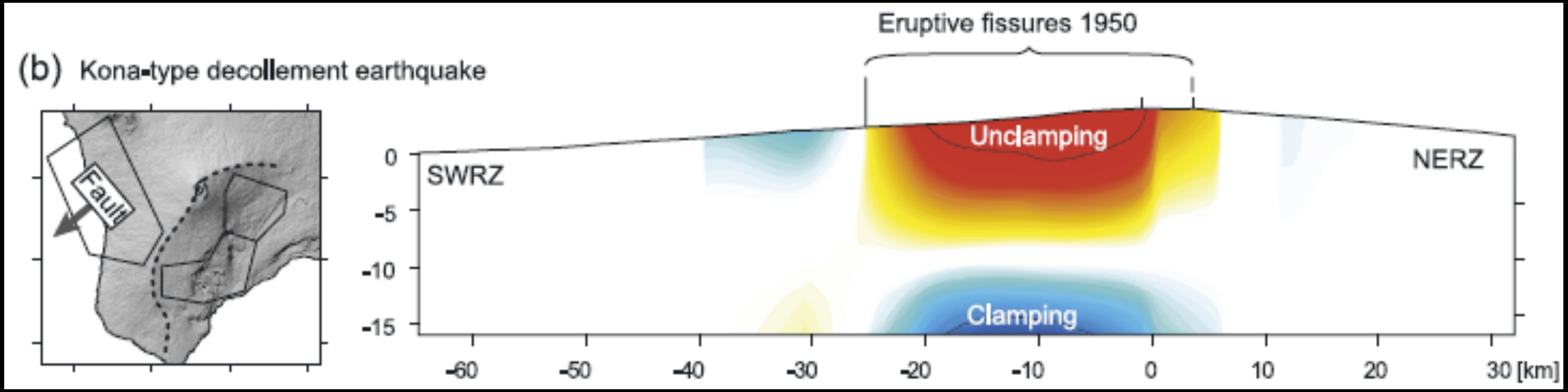
earthquake-volcano interaction !

- pairs of NERZ eruptions and Kaoiki earthquakes.
- pairs of SWRZ eruptions and Kona or Hilea earthquakes

Stress changes due to earthquakes



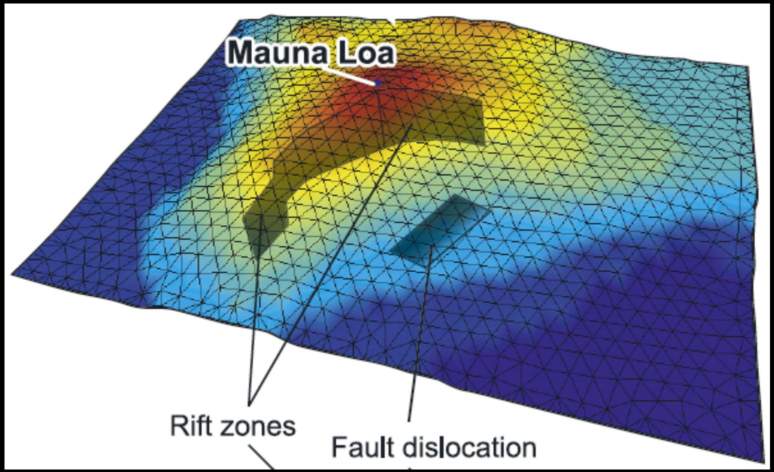
Normal stress along the rift zone
due to 1950 Kona earthquake



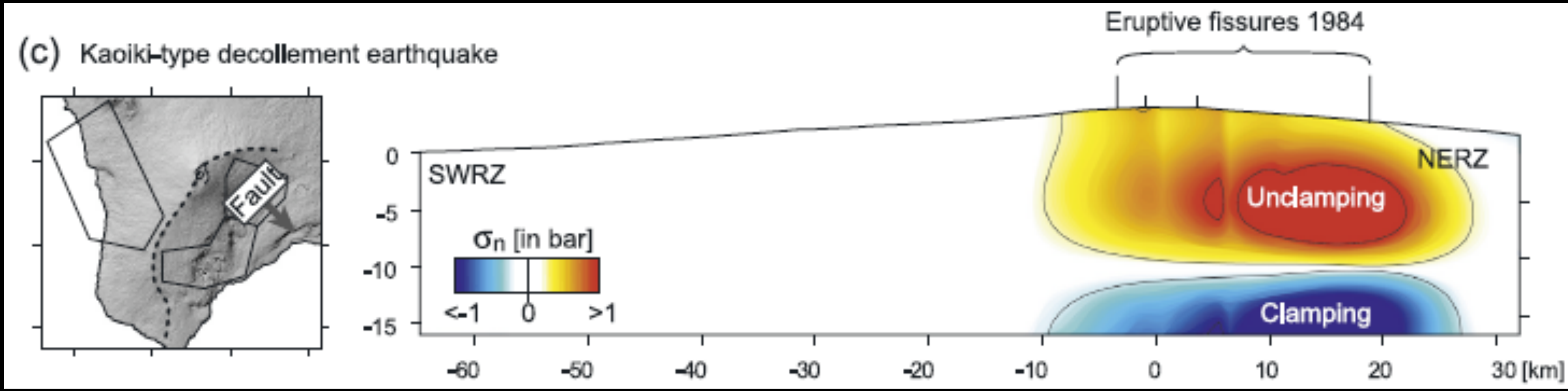
Walter and Amelung, JGR, 2006

The 1950 dike intruded in a section
of the rift zone unclamped by the earthquake !

Stress changes due to earthquakes



Normal stress along the rift zone
due to 1983 Kaoiki earthquake

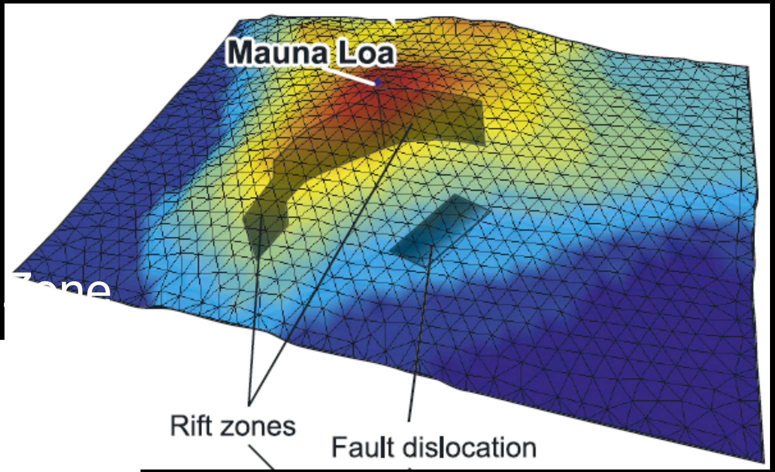


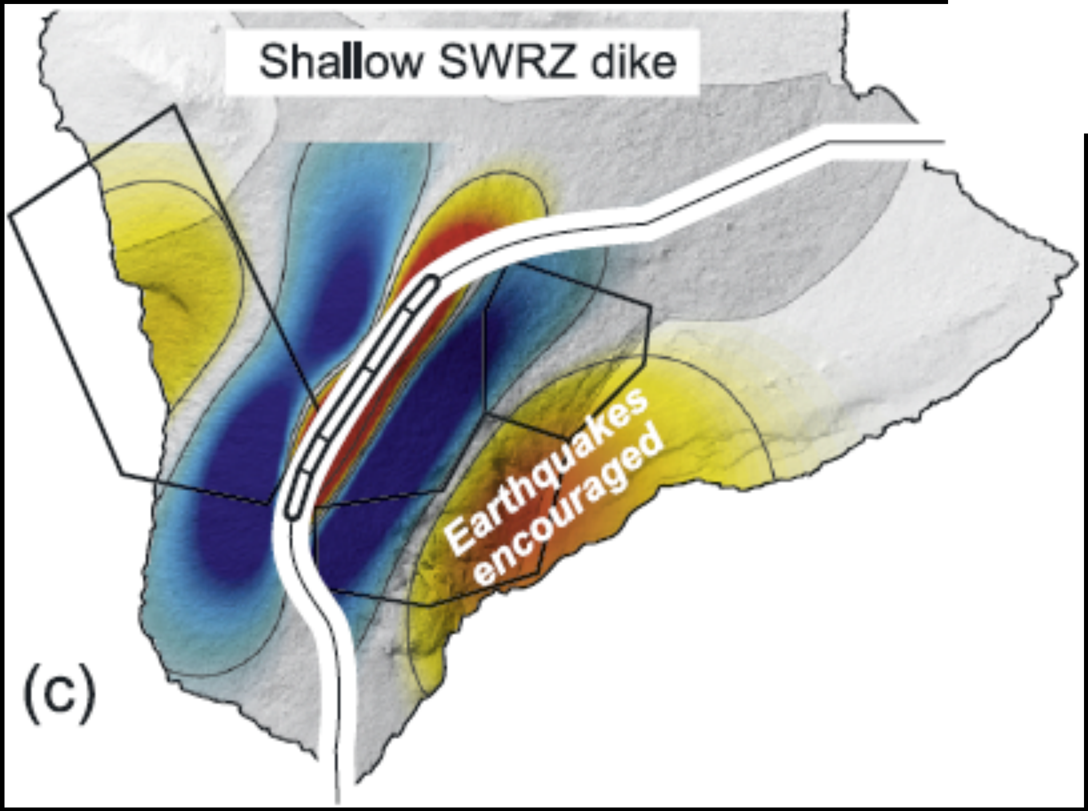
Walter and Amelung, JGR, 2006

The 1984 dike intruded in a section
of the rift zone unclamped by the earthquake !

Stress changes due to dike intrusions

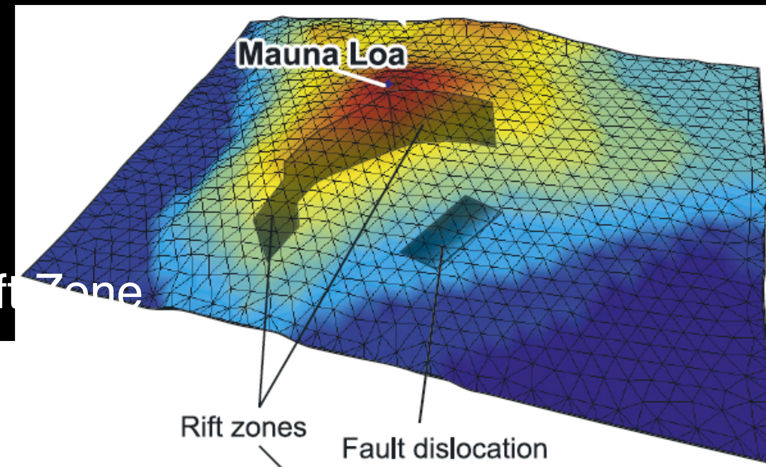
Coulomb failure stress along decollement
due to dike intrusion into the North East Rift Zone



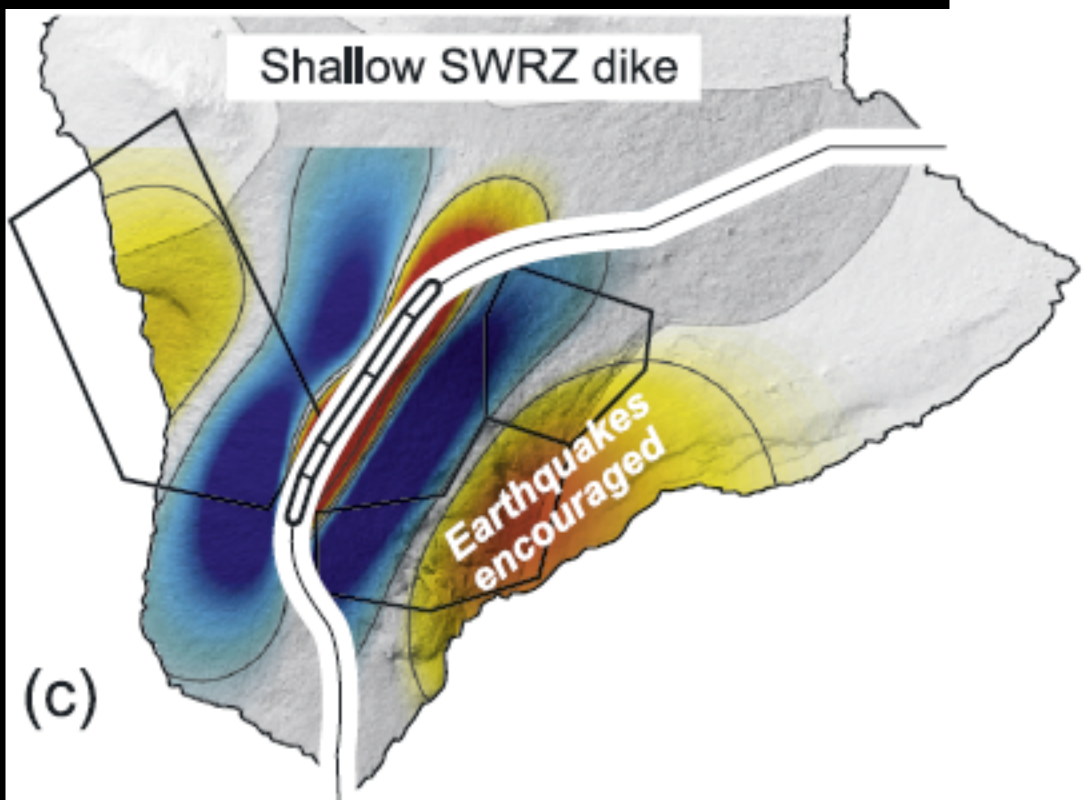


NERZ intrusions encourage
Kaoiki earthquakes !

Stress changes due to dike intrusions

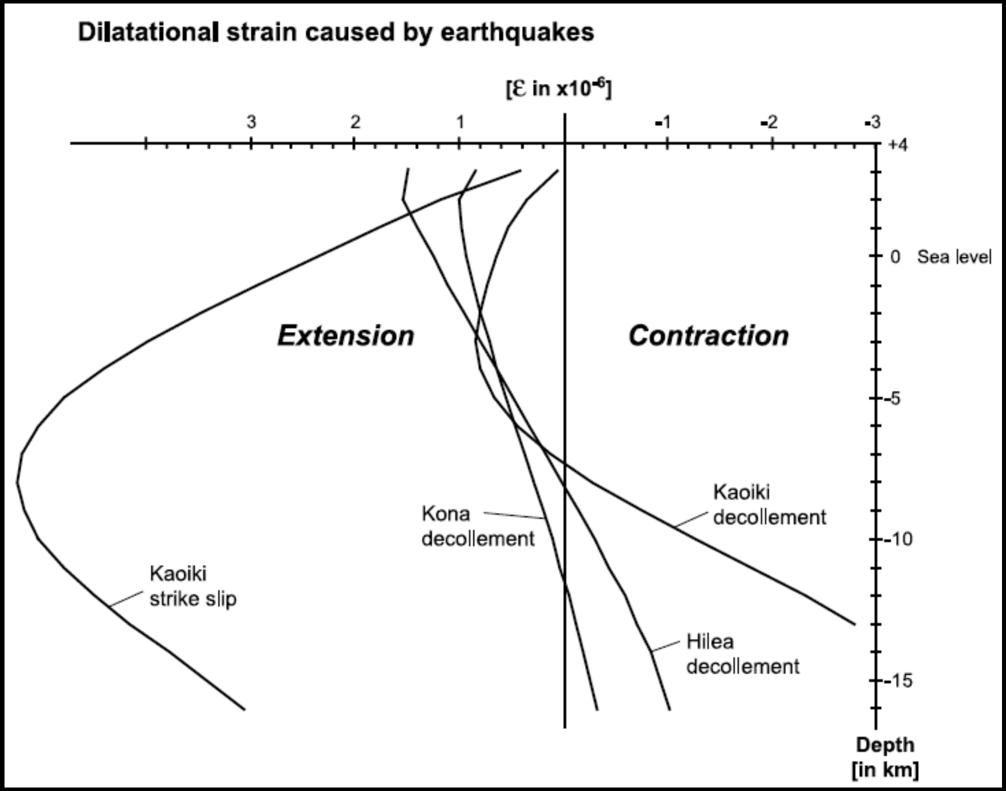


Coulomb failure stress along decollement
due to dike intrusion into the South West Rift Zone



SWRZ intrusions encourage
Hilea and Kona earthquakes !

Stress changes at magma body due to earthquakes



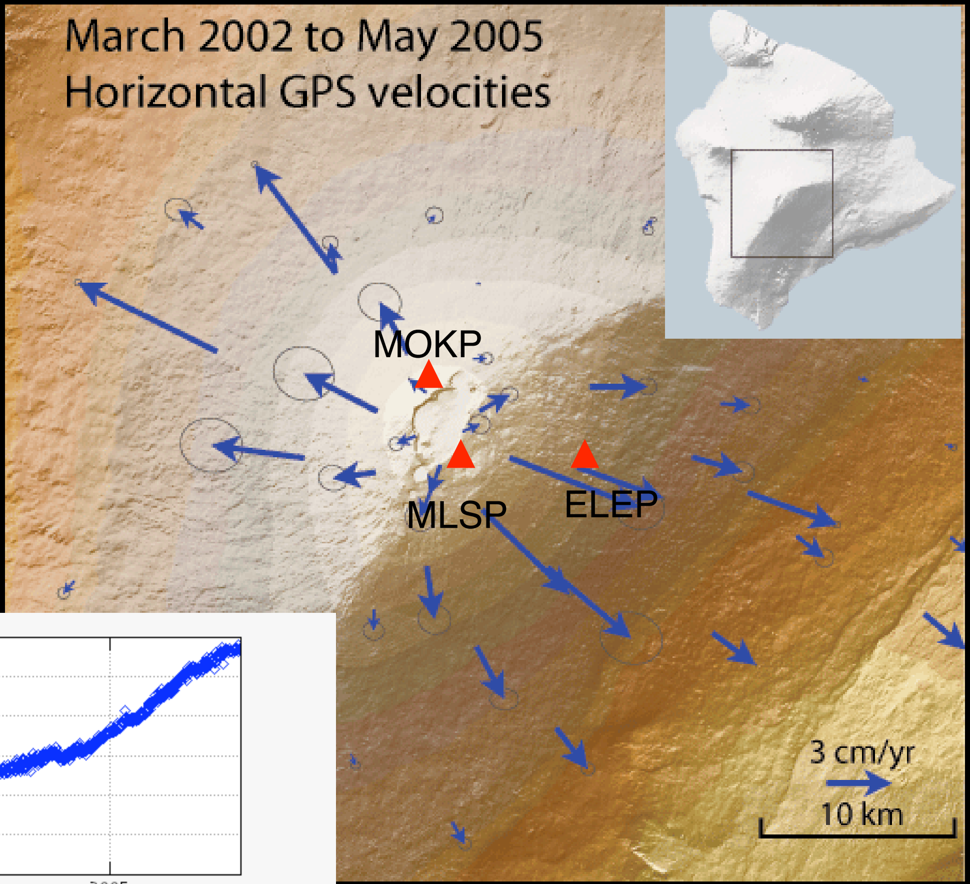
Conclusion:

magma chamber decompression encourages eruptions

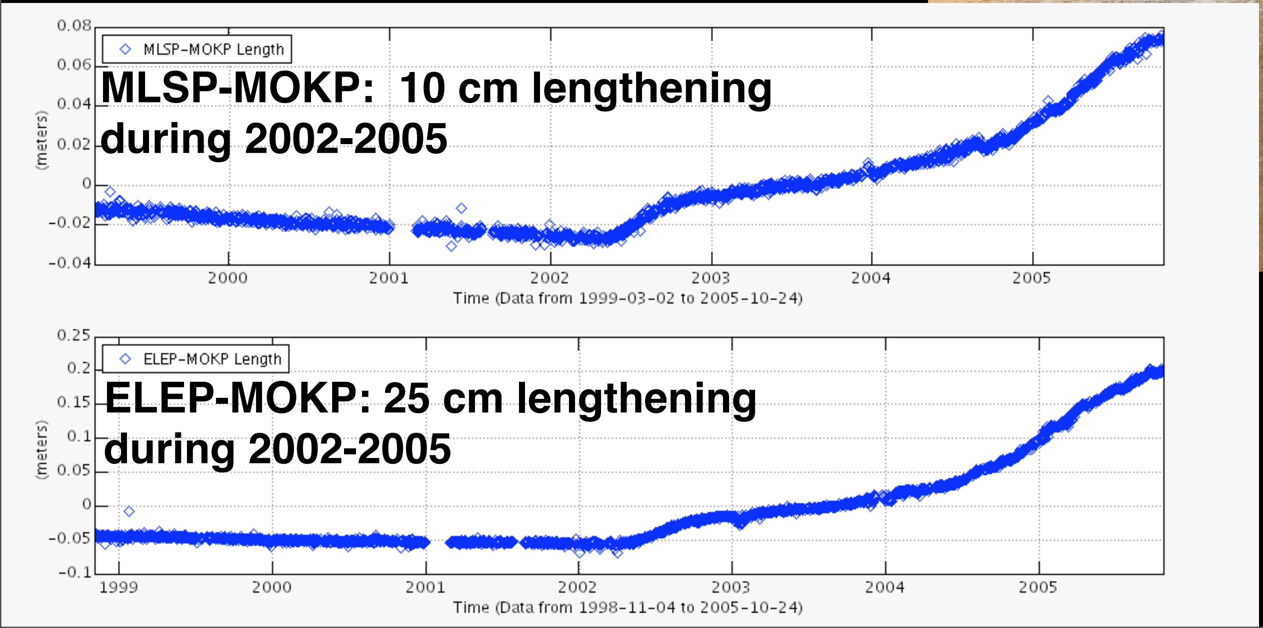
All earthquake types cause extension.

Walter and Amelung, JGR, 2006
Walter and Amelung, Geology, 2007

Mauna Loa inflation 2002-2005

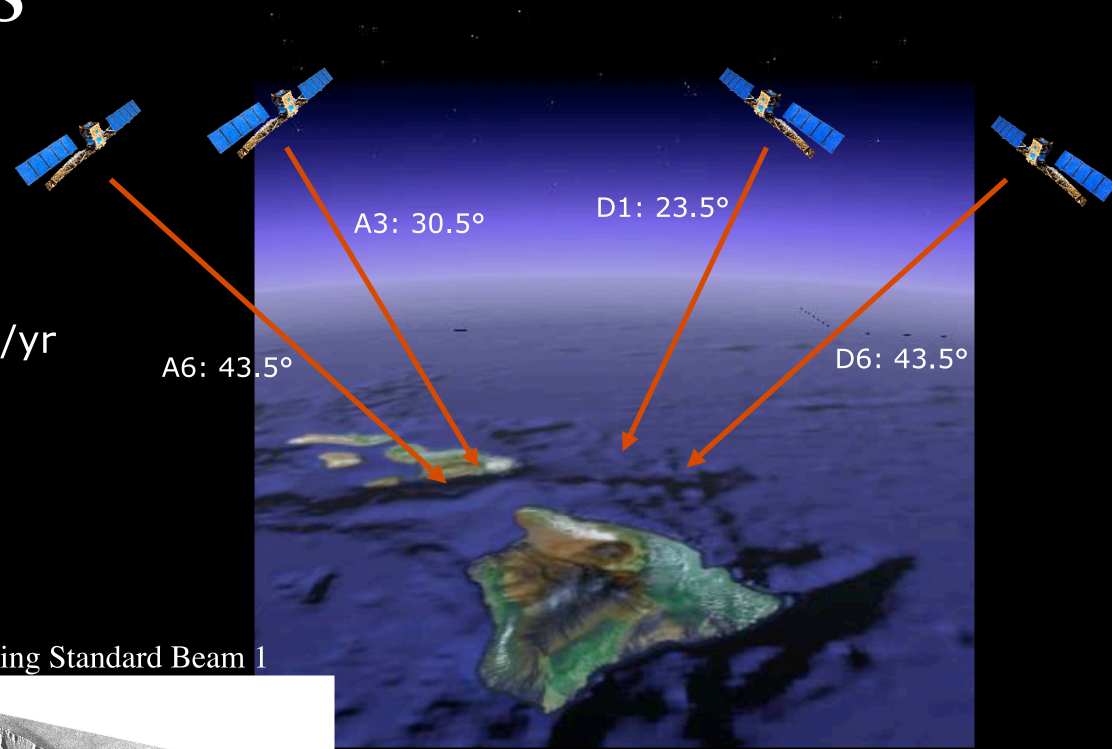


GPS-measured baseline length



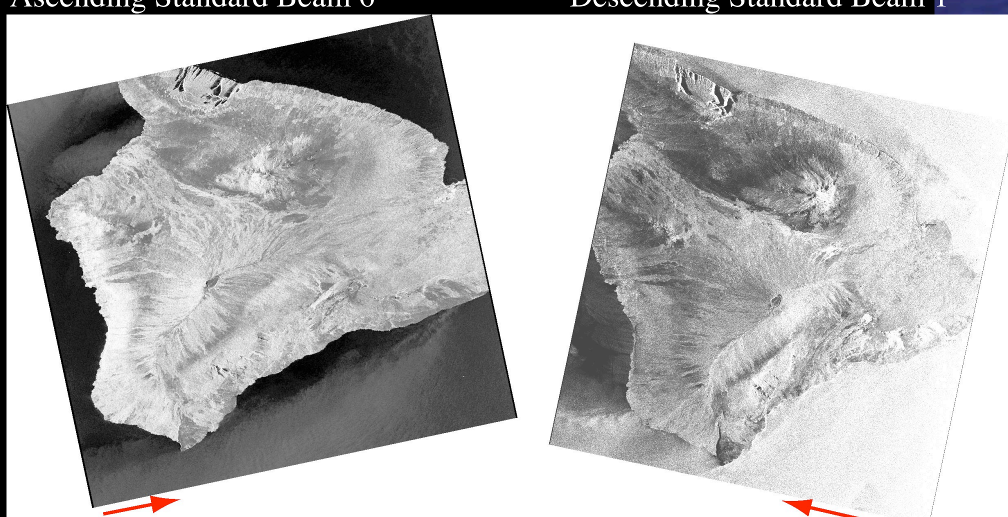
Interferograms

Radarsat
- Jan 2002 – Dec 2005
- 4 beams (23.5° - 43.5°)
- 5-8 interferograms stacked per beam
- repeat cycle of 24 days -> 60 images/yr



Ascending Standard Beam 6

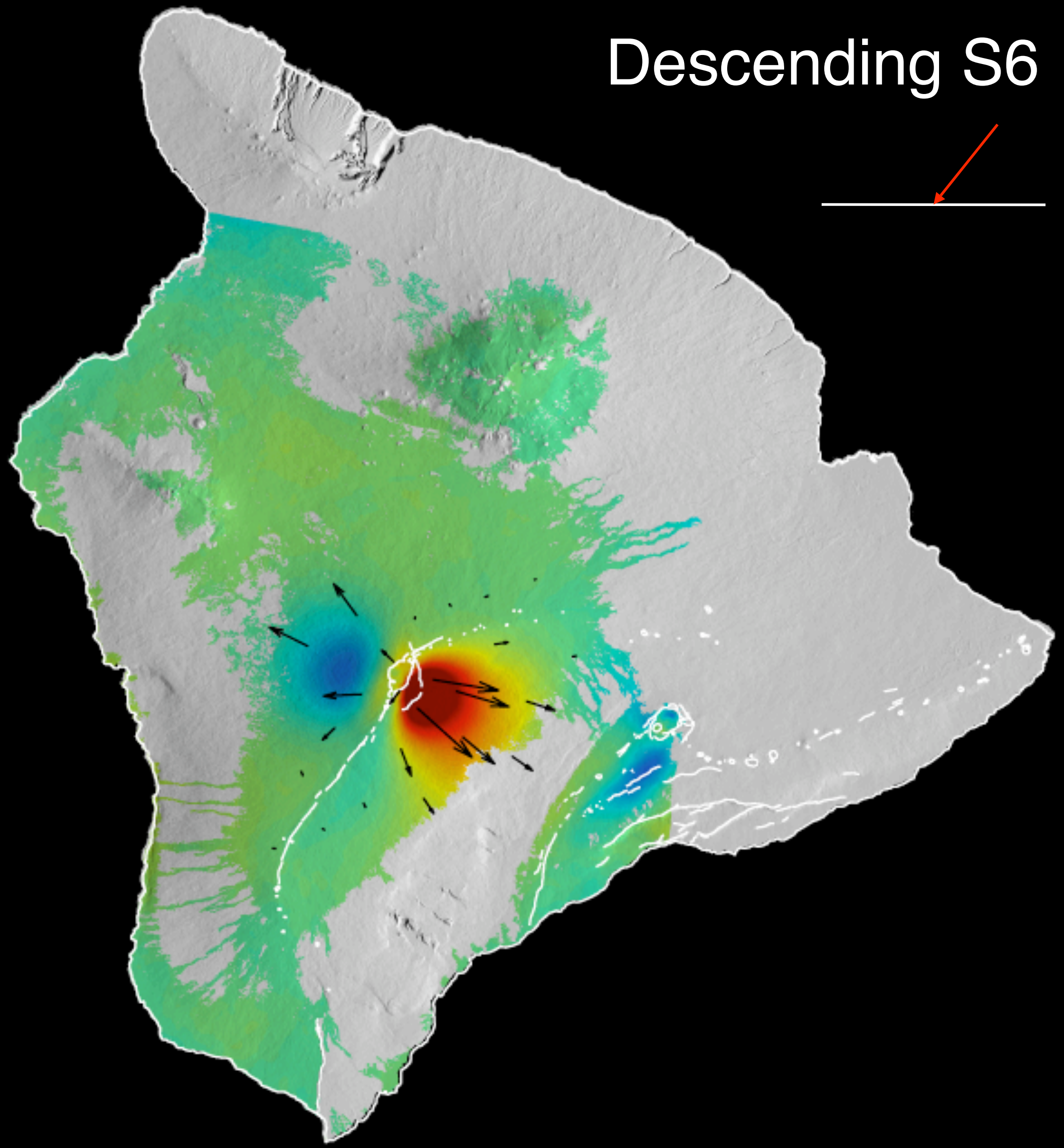
Descending Standard Beam 1



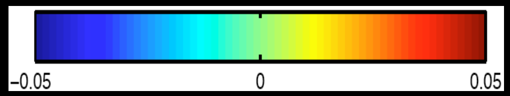
incidence angle 43.5°

incidence angle 23.5°

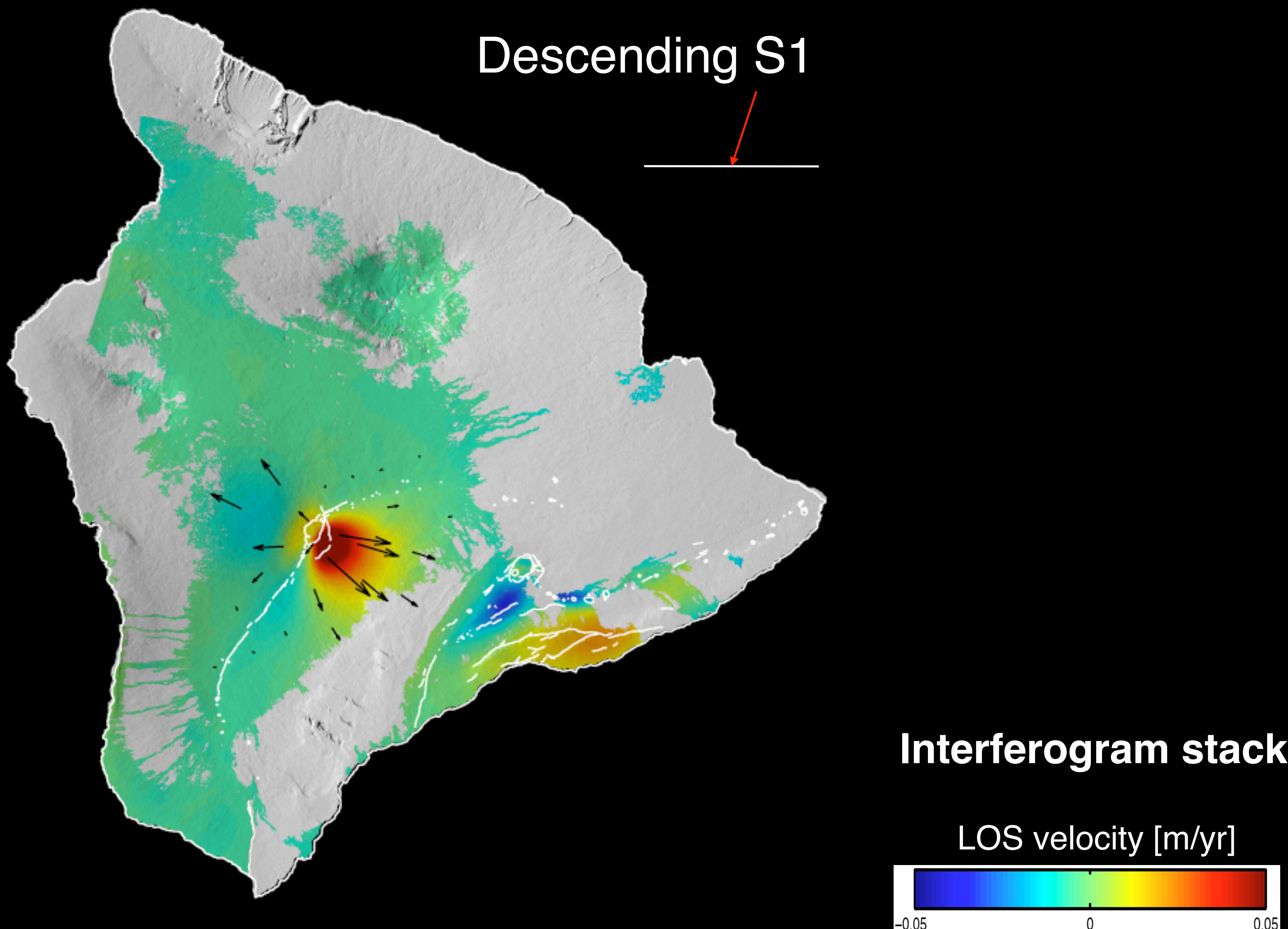
Mauna Loa volcano, Hawaii



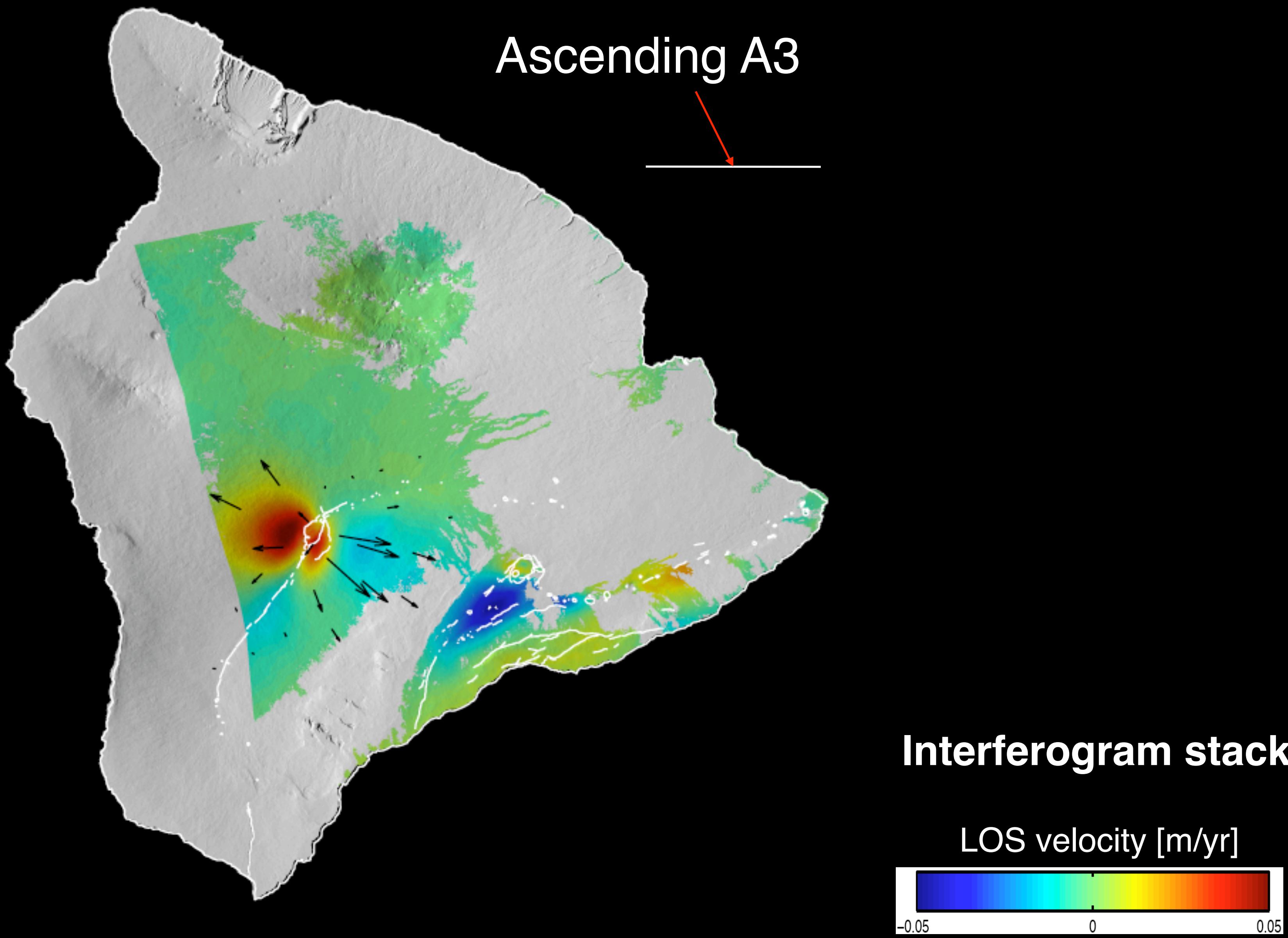
Interferogram stack



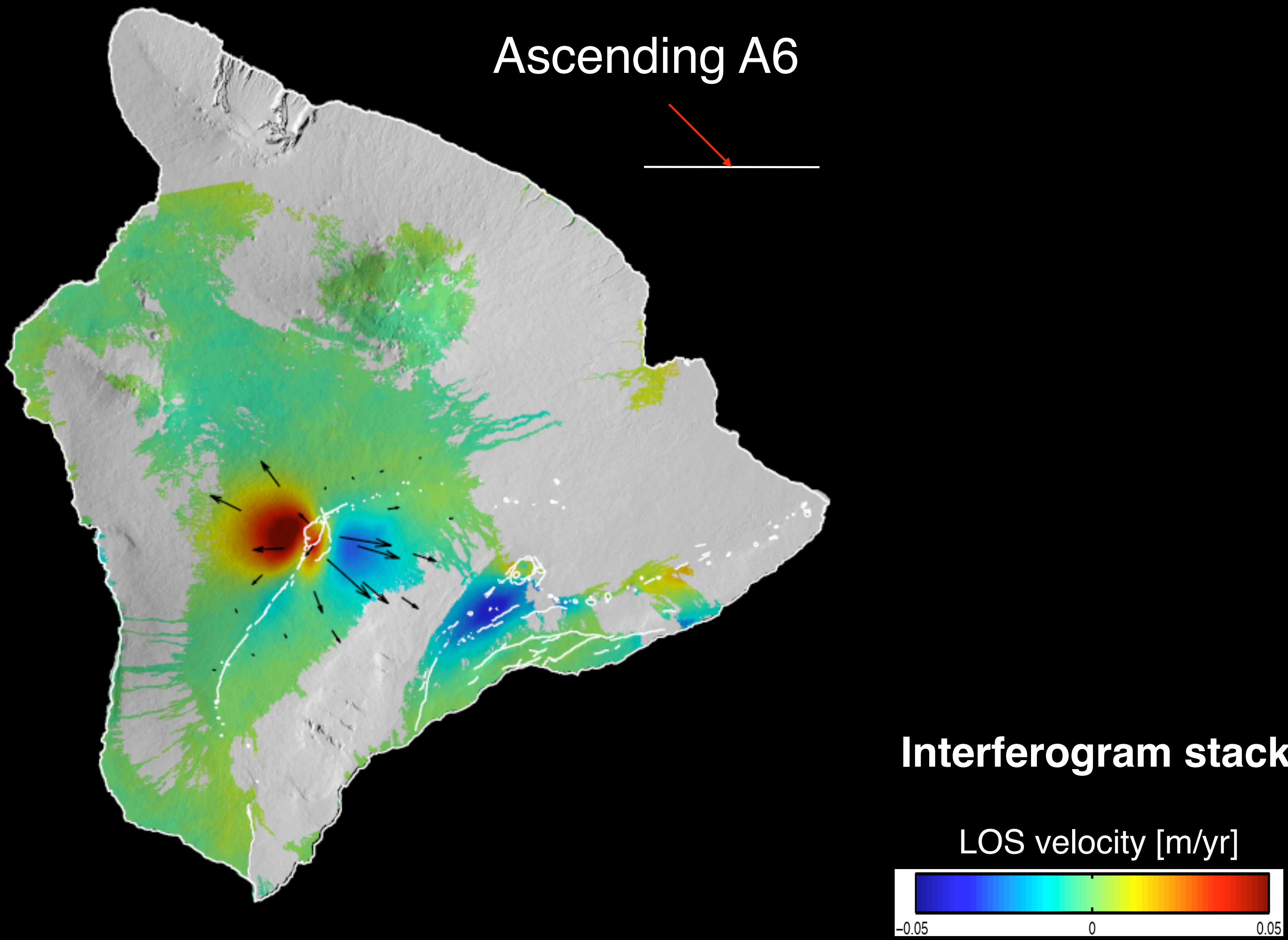
Mauna Loa volcano, Hawaii



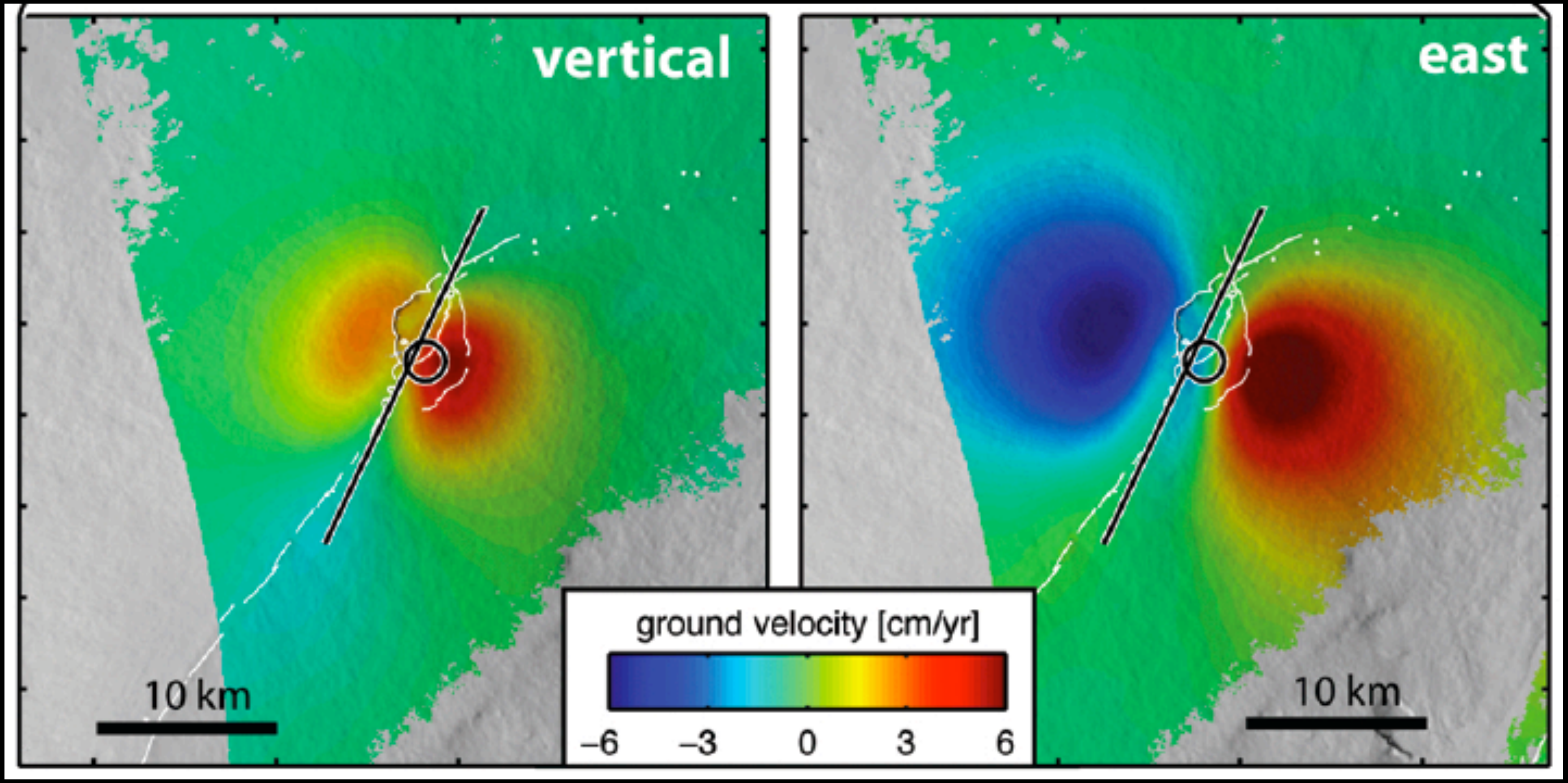
Mauna Loa volcano, Hawaii



Mauna Loa volcano, Hawaii



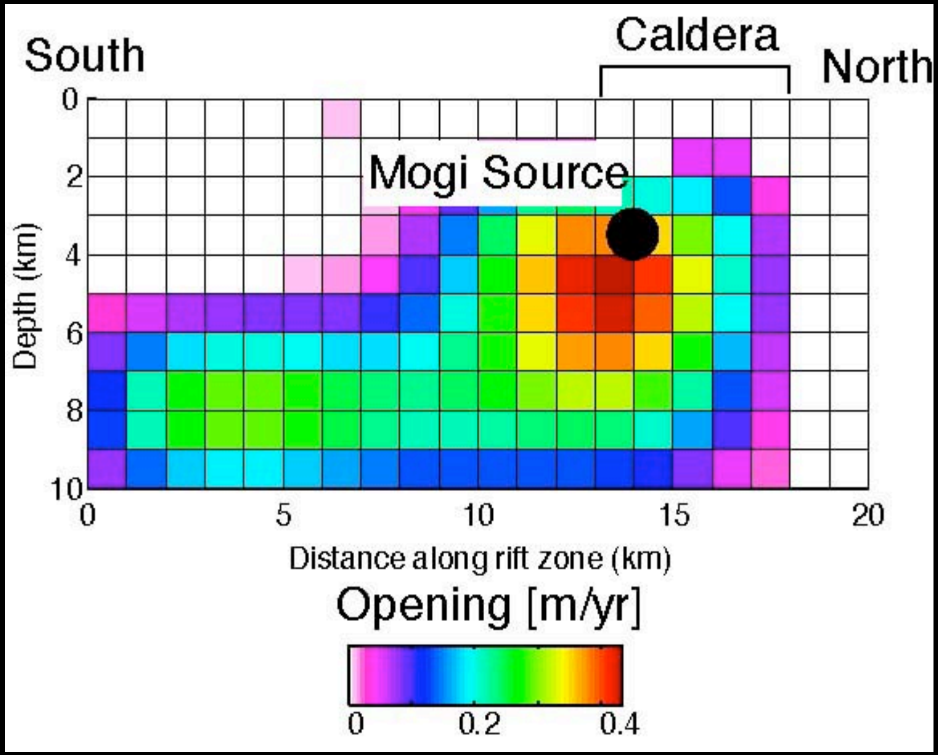
Mauna Loa volcano, 2002-2005 2-D velocity field

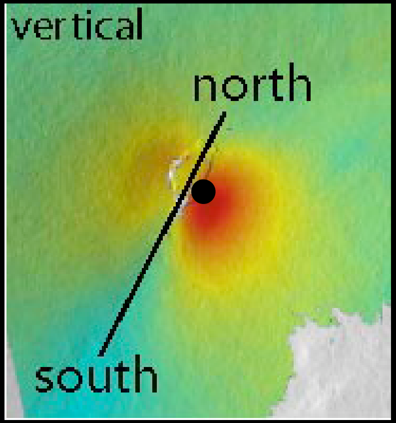


based on ~60 SAR images

Amelung et al., Science, 2007

Magma source model: Distributed dike opening + Mogi





this model: independent dislocation and point sources.
next model: account for interaction between dike and magma chamber
using a constant magma excess pressure model
--> inferred parameter: excess pressure, chamber radius

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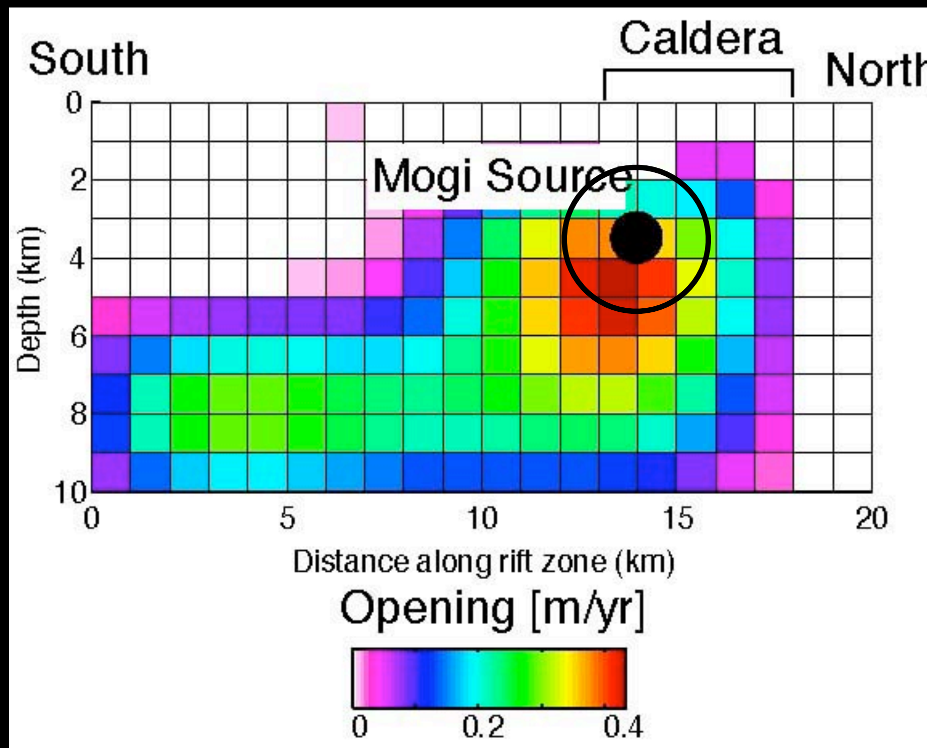

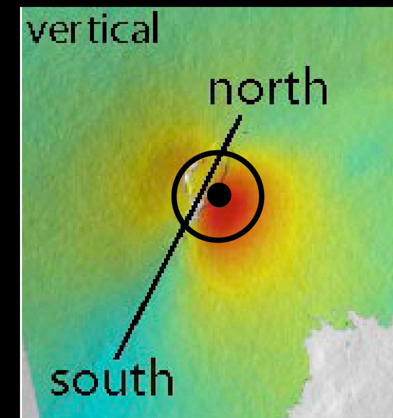

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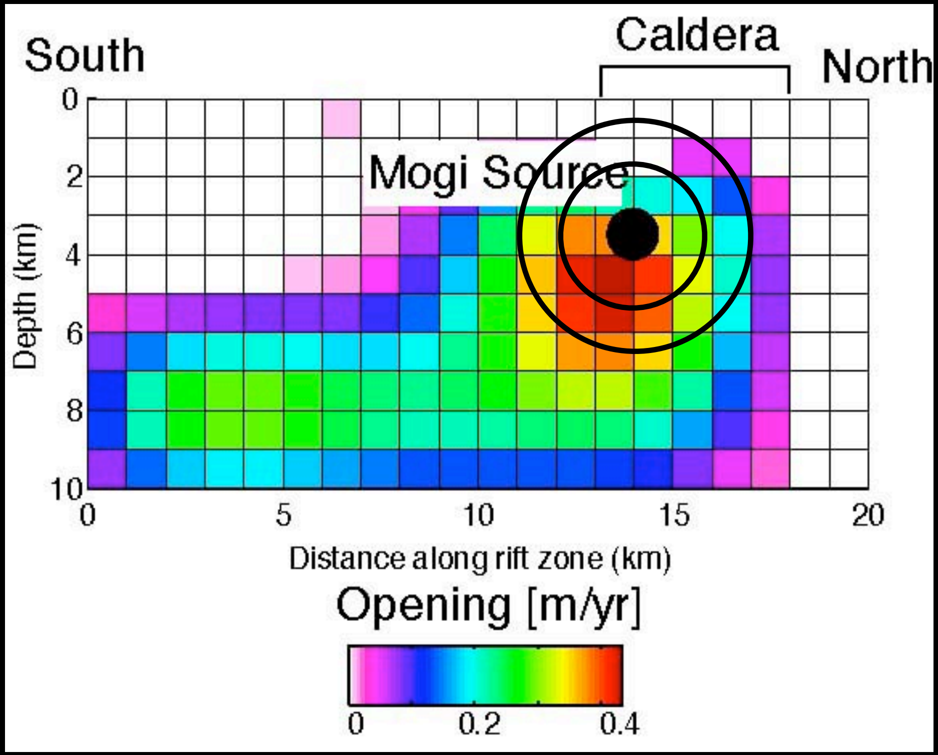

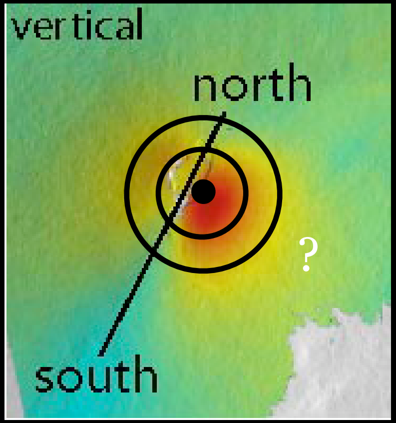

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next model: account for interaction between dike and magma chamber
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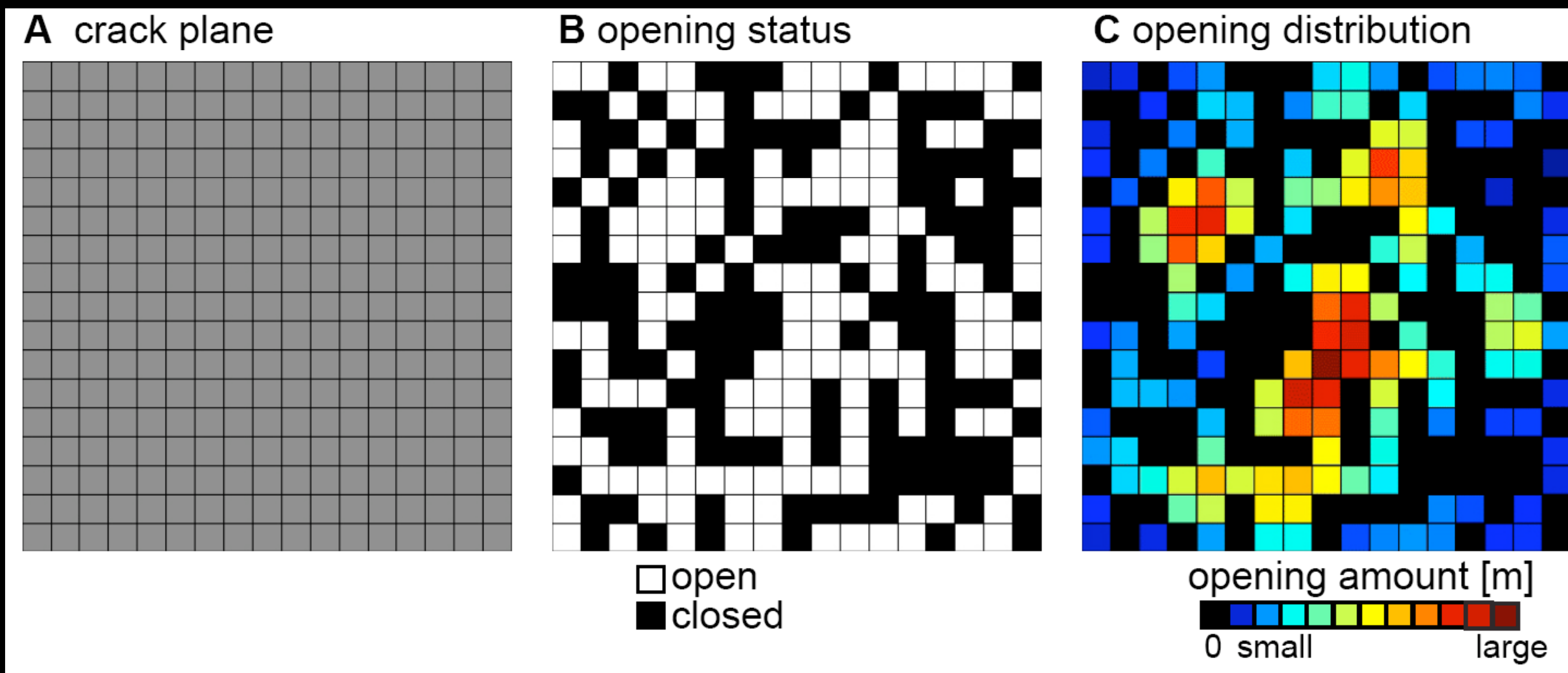
--> inferred parameter: excess pressure, chamber radius

Magmatic system modelling approach

0	0	0	0	0
0	0	1	1	0
0	0	0	1	0
0	1	0	0	0
0	0	0	0	0

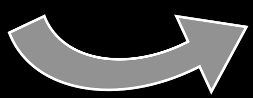
Coupled constant excess pressure dike-chamber model (binary dike)



Dike opening depends on how open elements are connected (Yun et al., 2005)

Geophysical Inversion: Boundary Element Approach

- Dike divided into elements, either open or closed, subject to constant pressure
- Simulated Annealing Procedure used to find optimal parameters.
- Invert for : excess pressure
dike geometry
sphere geometry



Simulation: Sang-Ho Yun

Geophysical Inversion: Boundary Element Approach

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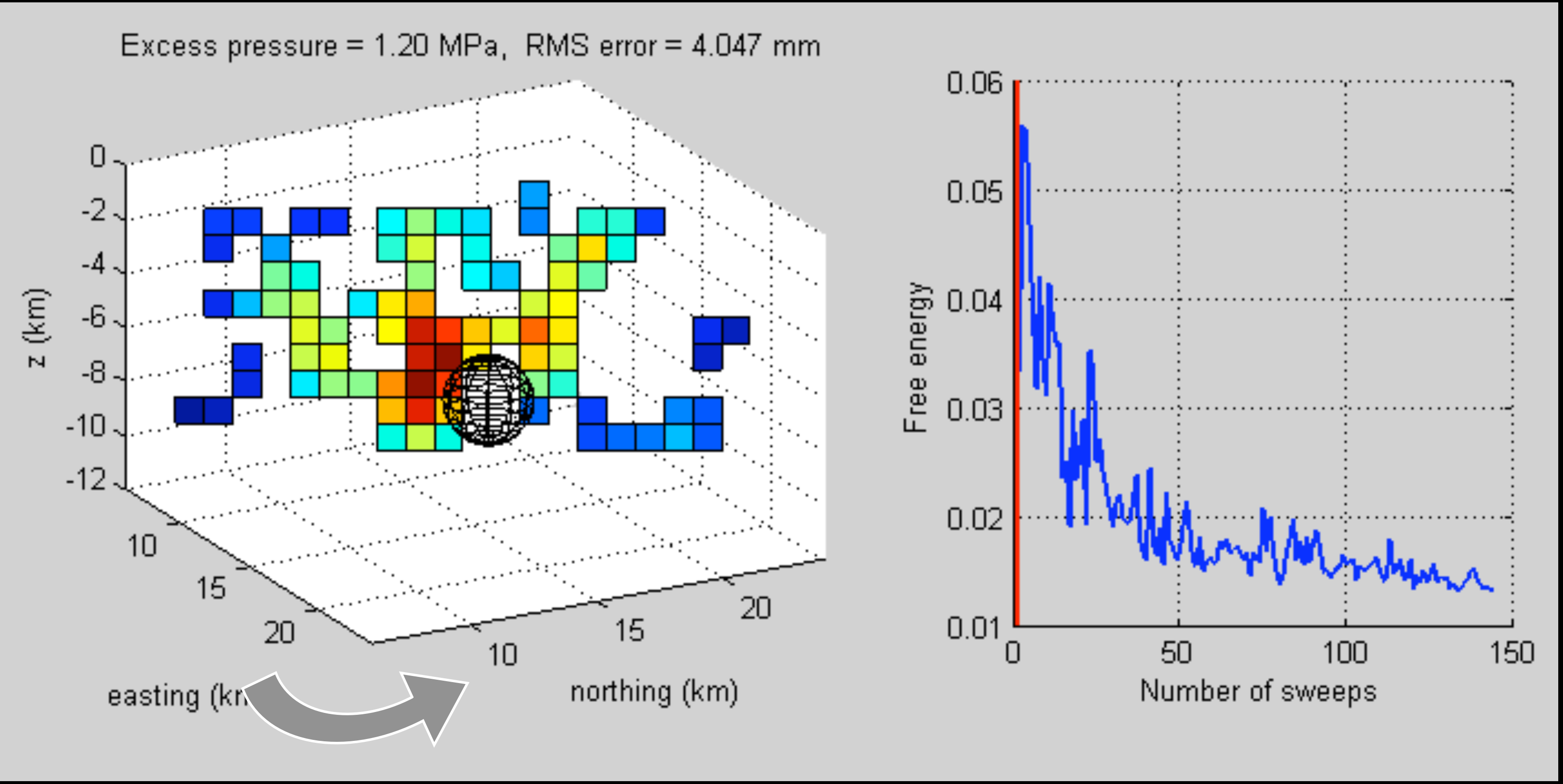
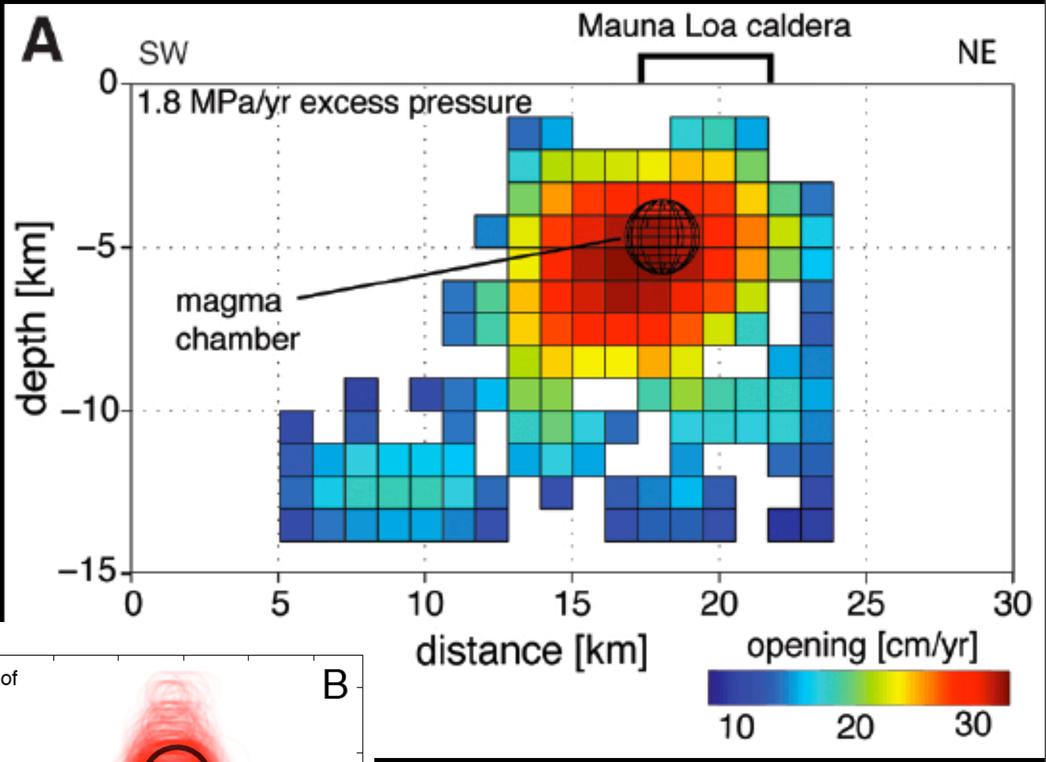


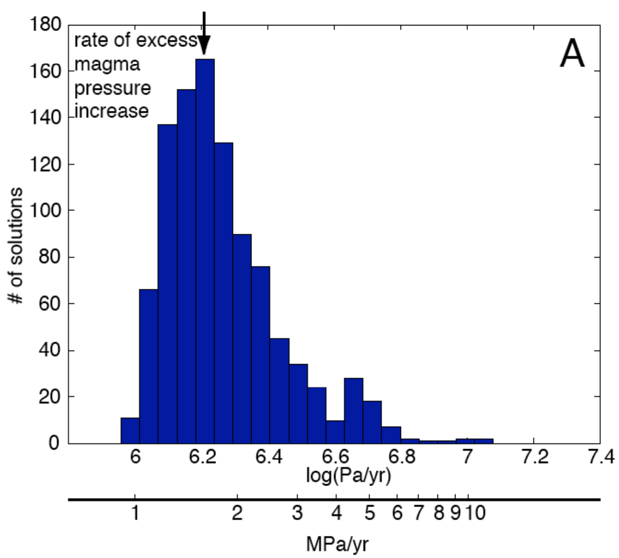
Simulation: Sang-Ho Yun

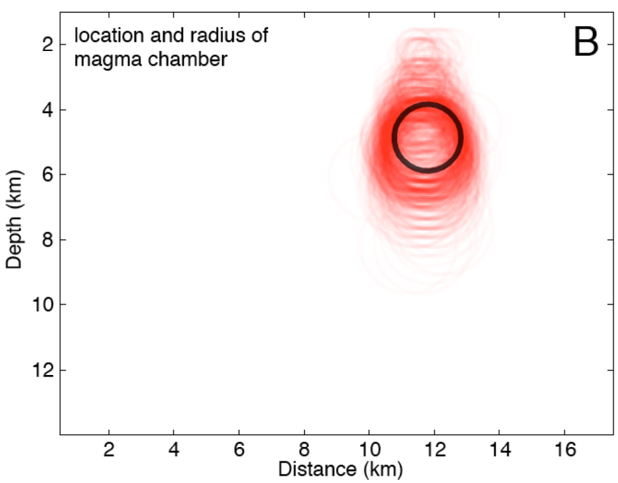
Preferred model

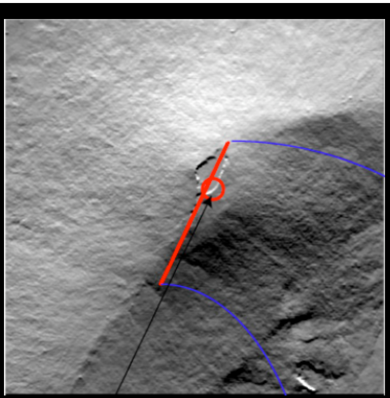


<u>Model features:</u>

Dike opening under summit and uppermost SWRZ
Intrusion along 20 km of SWRZ/summit riftzone
Max. opening 30 cm/yr (--> 1.3 m 2002-2007)
Magma chamber at 4.8 km depth
Chamber diameter 1.3 km
1.8 MPa/yr excess pressure (--> 8 MPa 2002-2007)

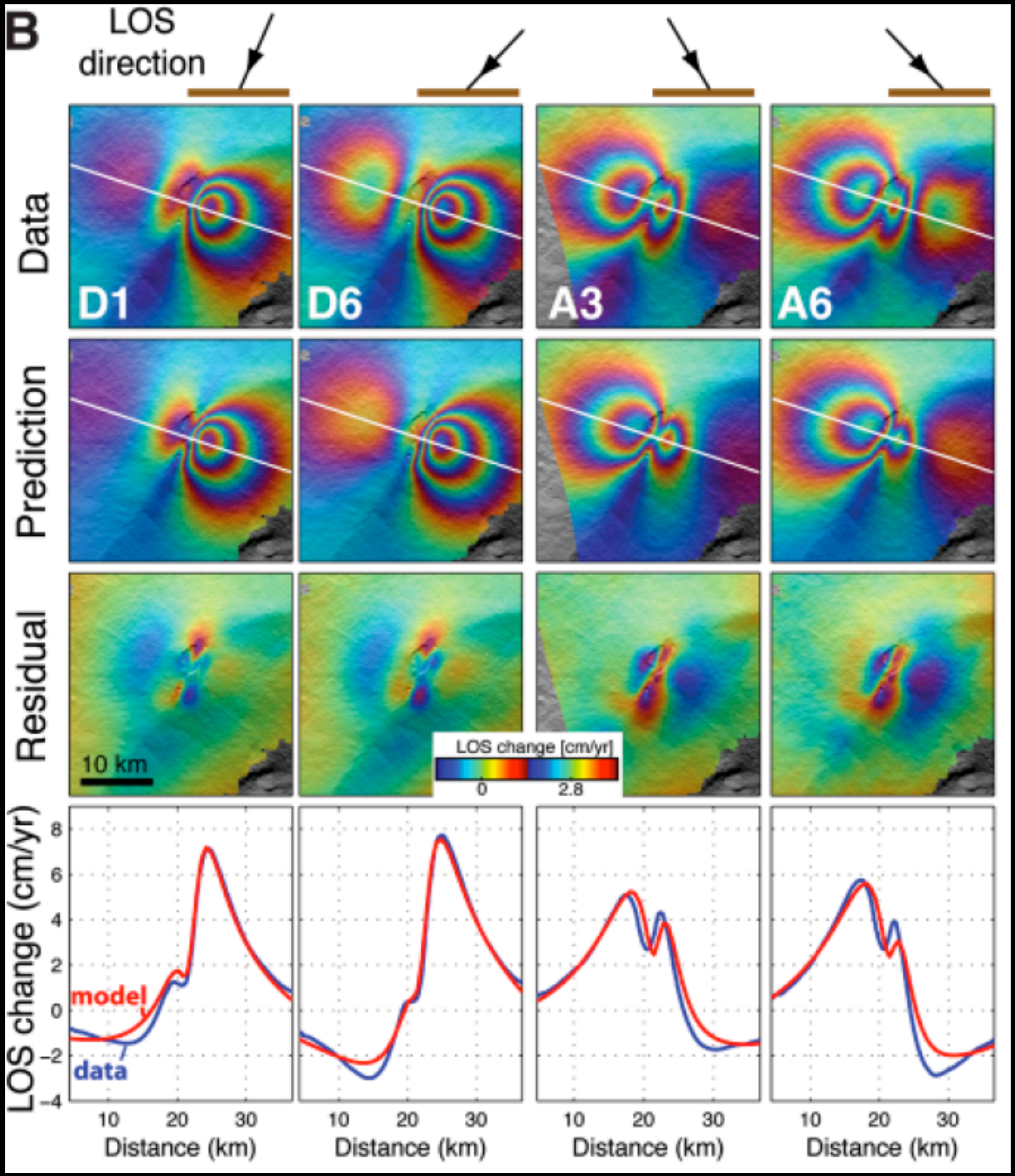




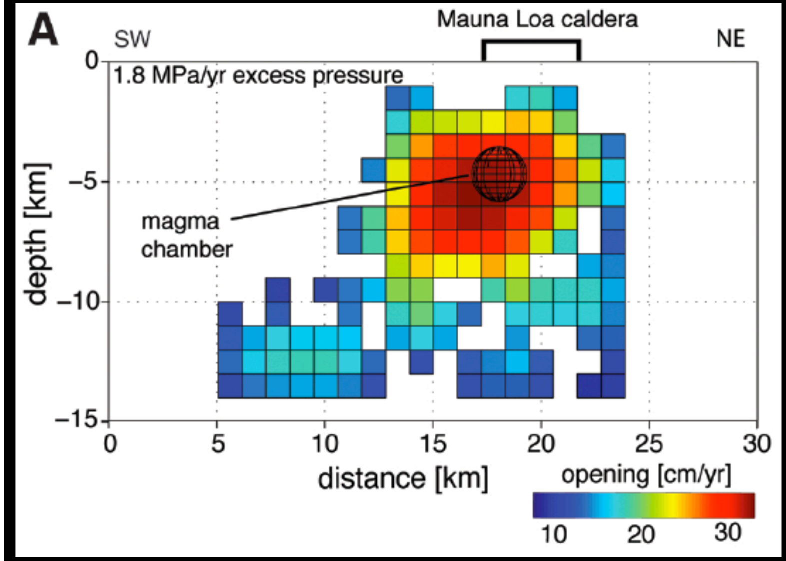


Amelung et al., Science, 2007

Mauna Loa: Model Fit



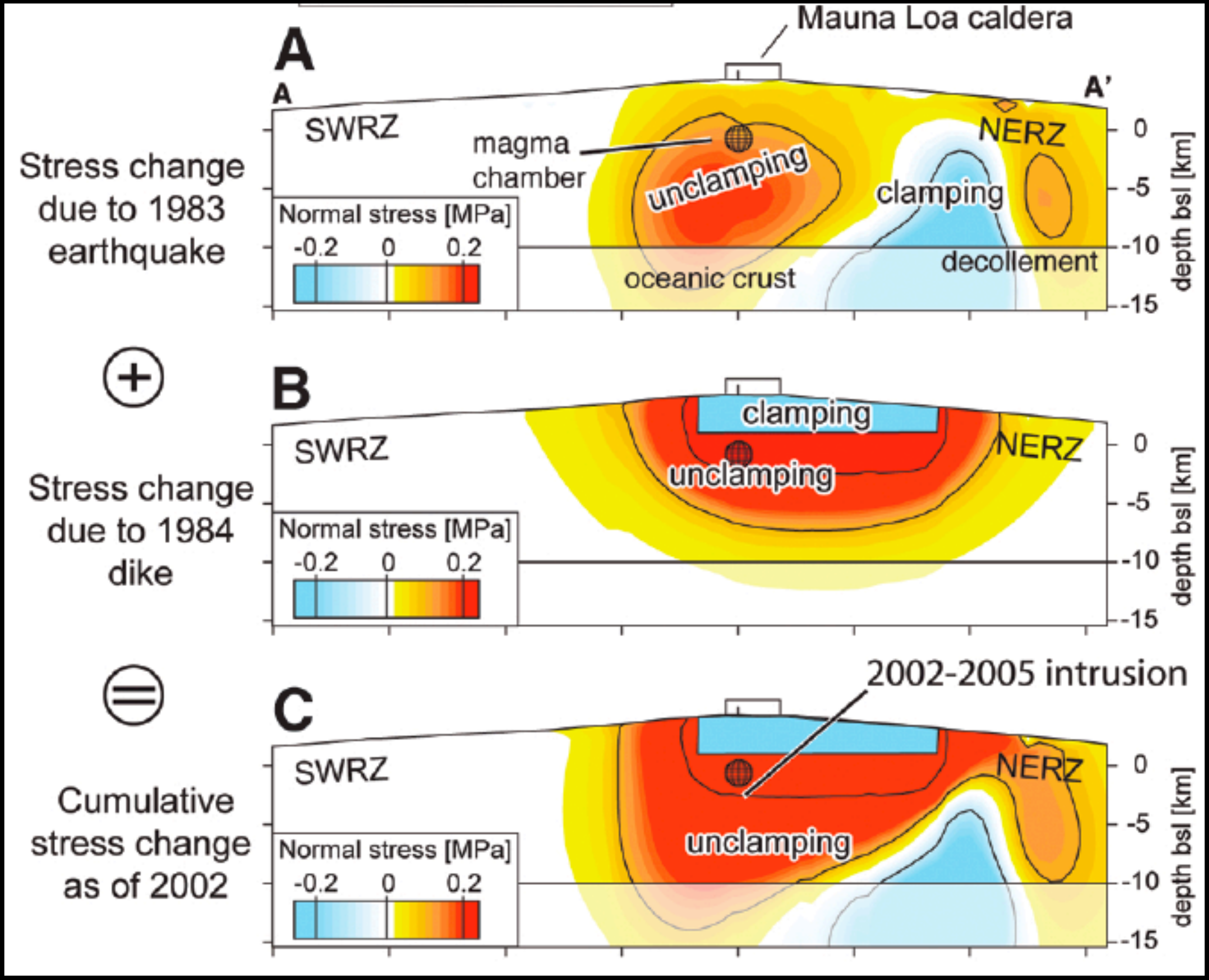
Preferred model

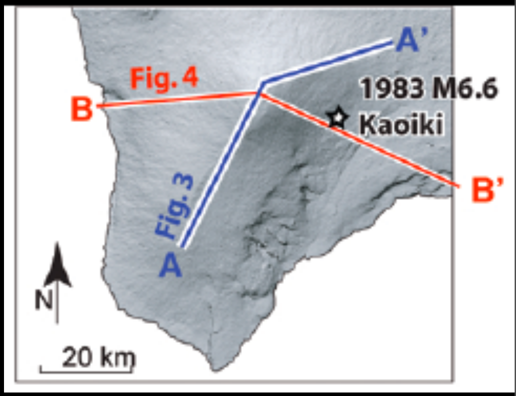


Differences are due to
- simplified chamber model
- unmodelled decollement slip.

Why did the intrusion occur in the SWRZ ?

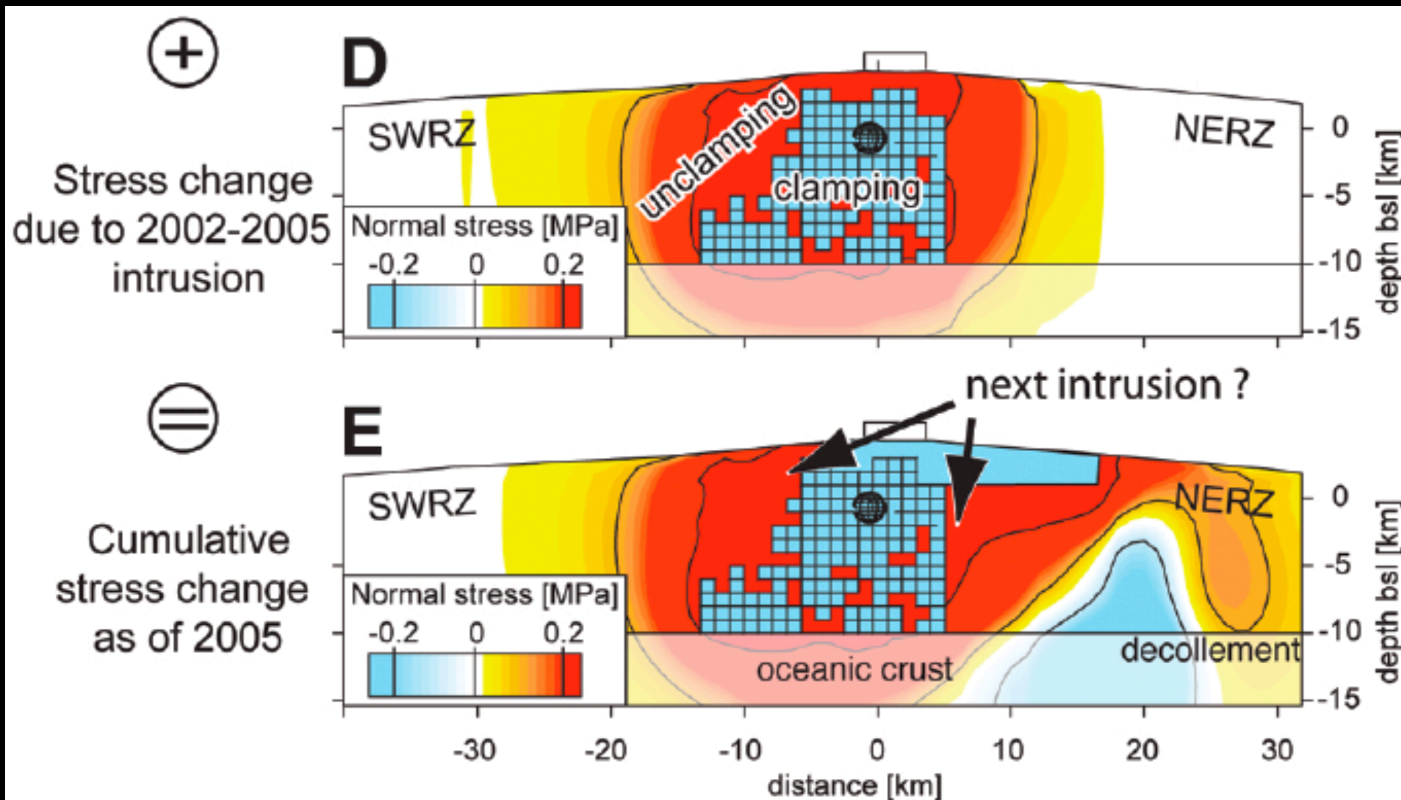
Proposed answer: Stress transfer





2002-2005 intrusion occurred into section of rift zone unclamped by 1983 earthquake and 1984 eruption.

Where would we expect the next intrusion?

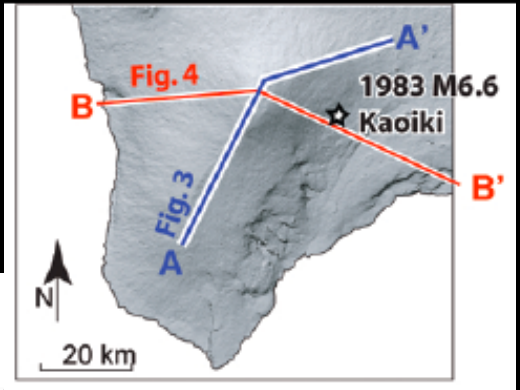


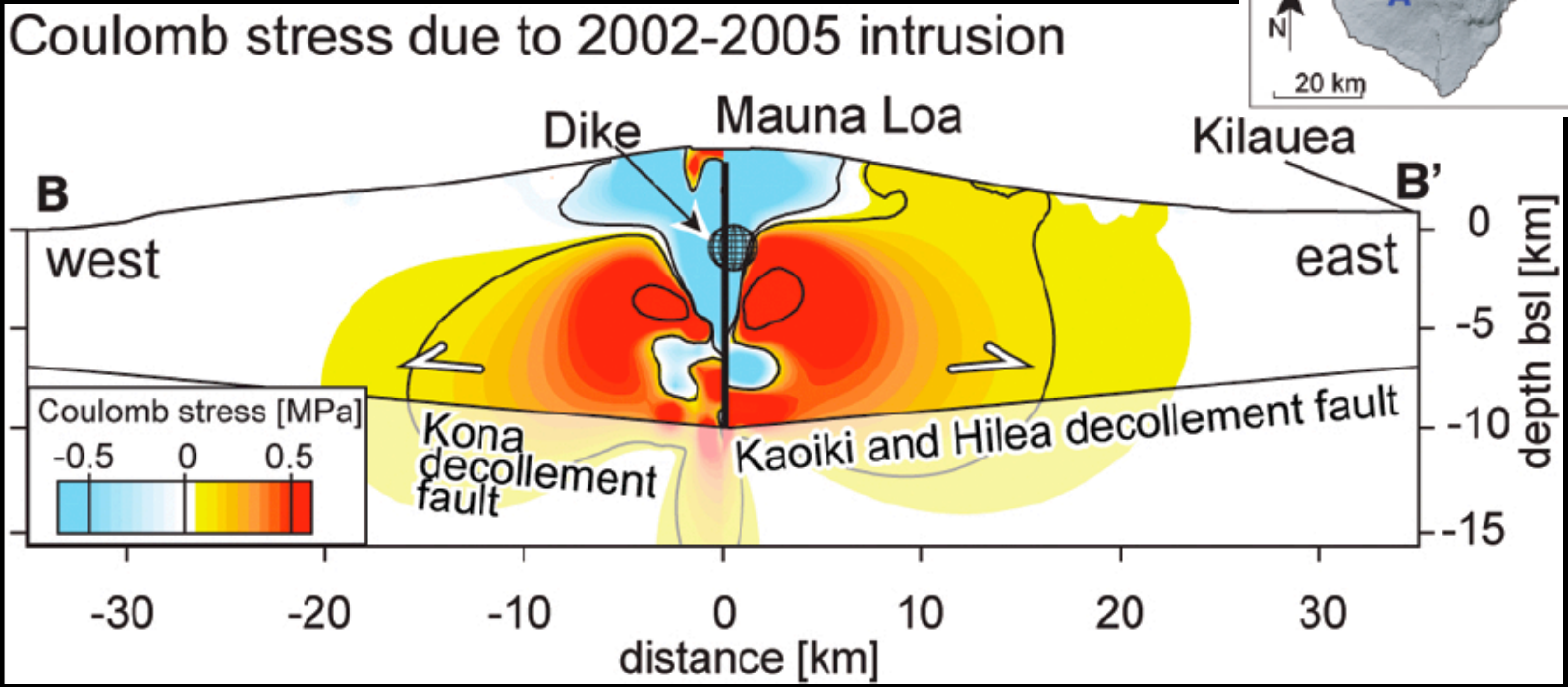
2002-2005 caused strongest unclamping next to it.

Forecast: one of three scenarios will occur (stress model based):

- current intrusion continues and next eruption occurs from SWRZ
- current intrusion stops, next intrusion occurs into rift sections of strongest unclamping
- intrusion triggers earthquake (or aseismic slip)

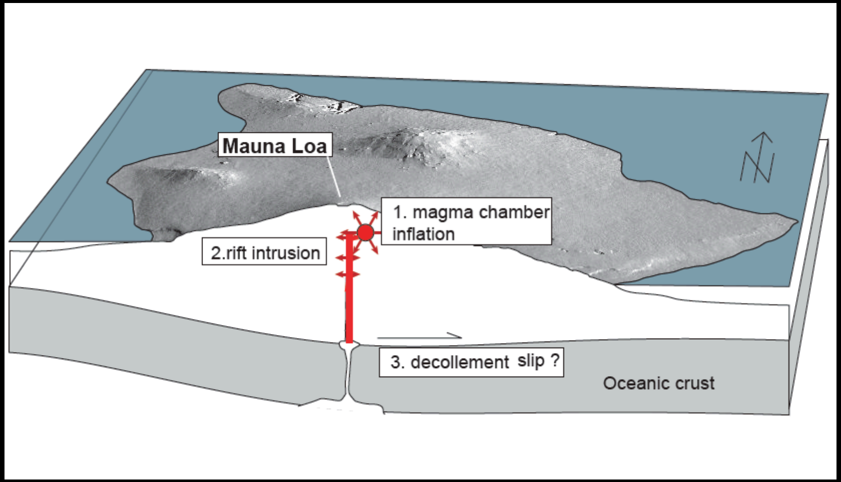
Coulomb stress

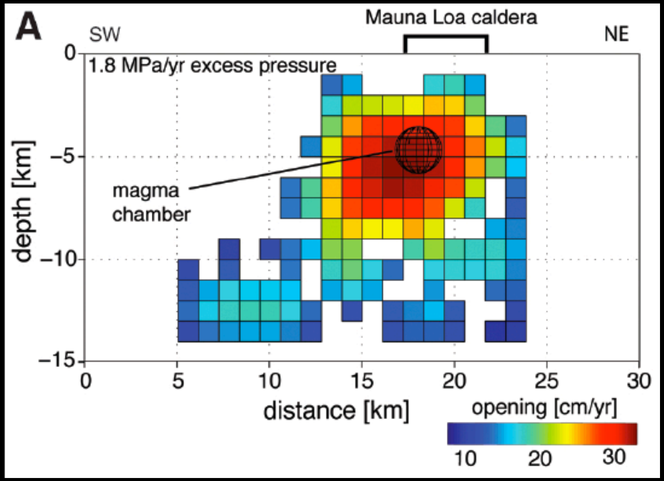




- Coulomb stress for seaward motion along horizontal fault planes increased by > 0.5 MPa.
- Intrusion encouraged seismic or aseismic decollement motion
- Aseismic slip may already be occurring

Conclusions:

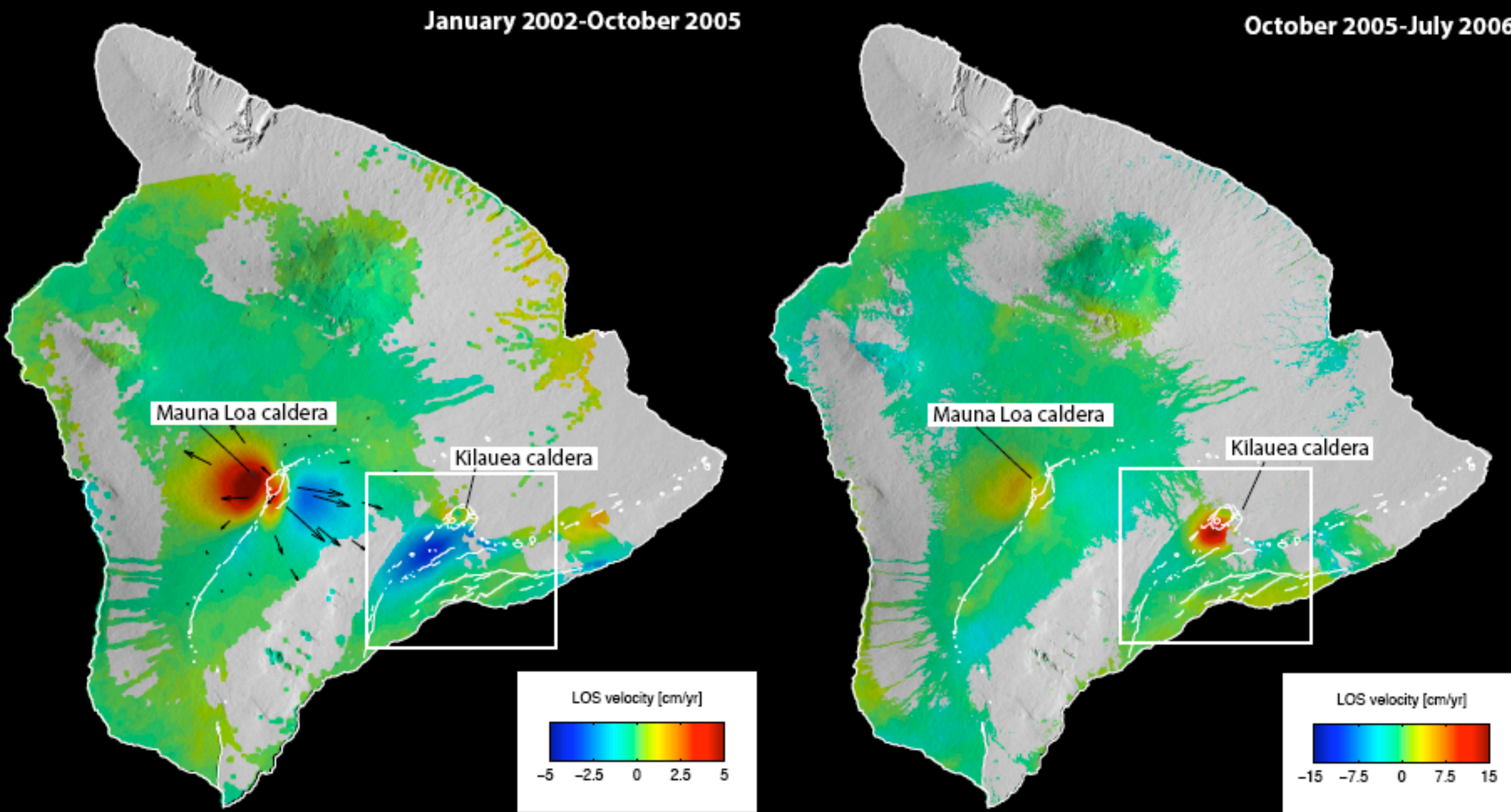




1. Magmatic system (2002-2005):
   - rift intrusion at depth under summit and SWRZ
   - magma chamber at 4.5 km below summit
   - magma chamber 1.3 km radius
   - magma excess pressure ~2 MPa/yr

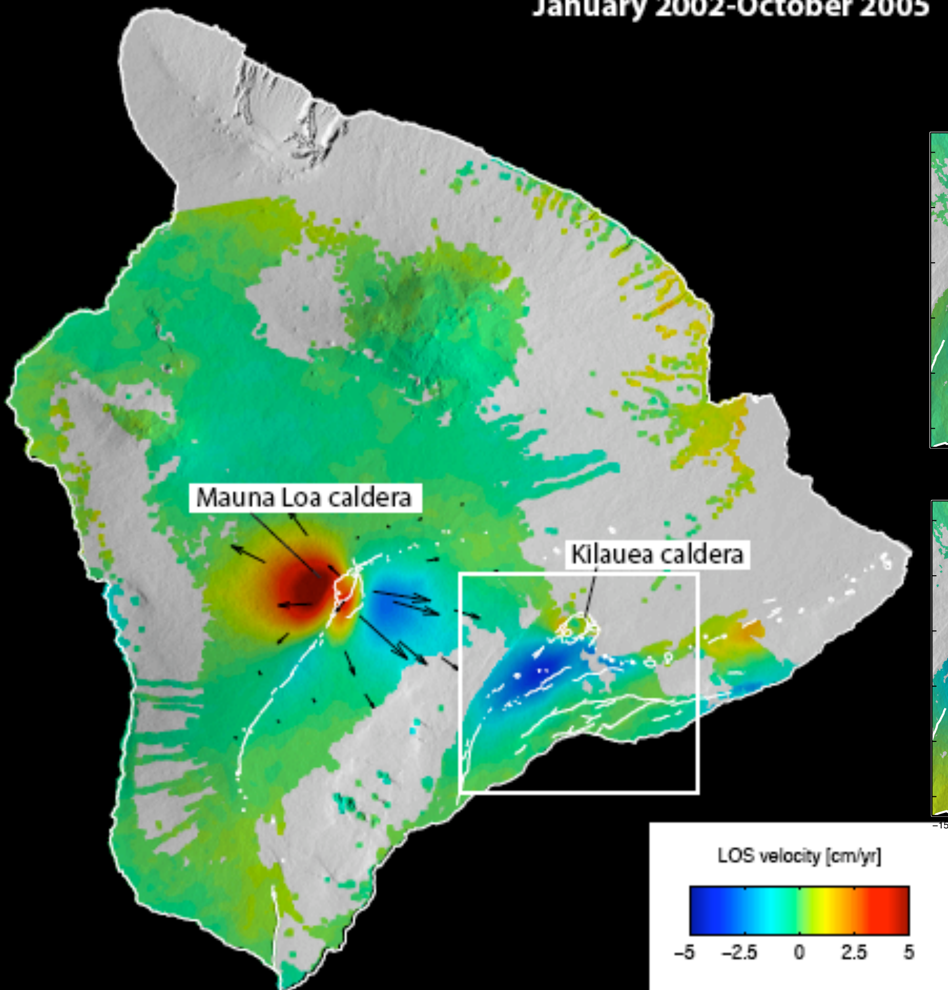
2. Stress transfer:
   - intrusion occurred in rift section unclamped by 1983/84 earthquake and intrusion.
   - intrusion encouraged new intrusions into parts of SWRZ
   - intrusion encouraged decollement faulting (seismic or aseismic)

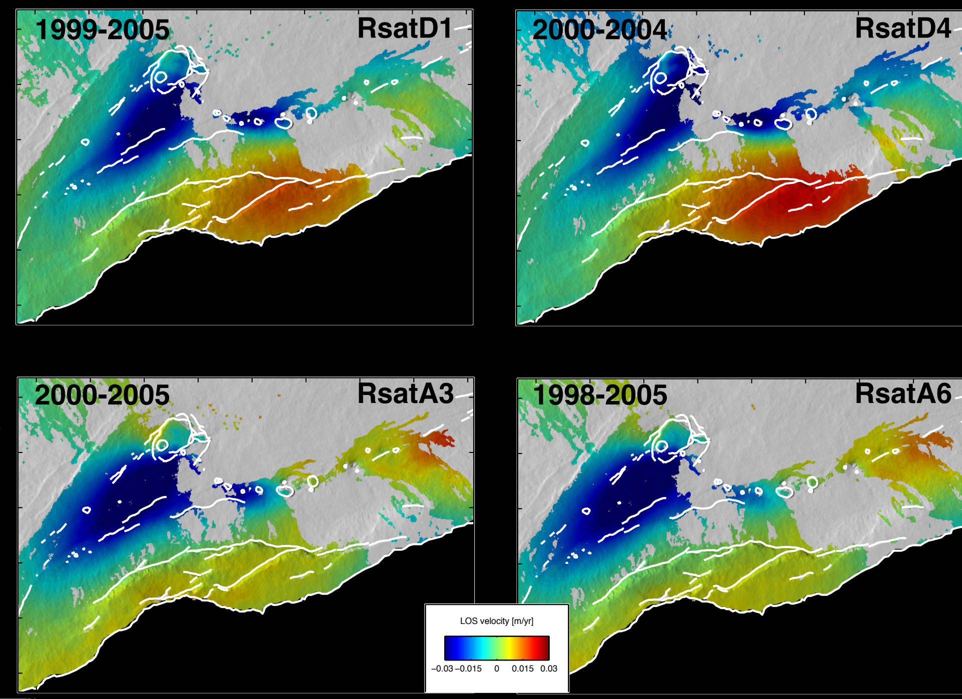
The dynamic Hawaiian volcanoes



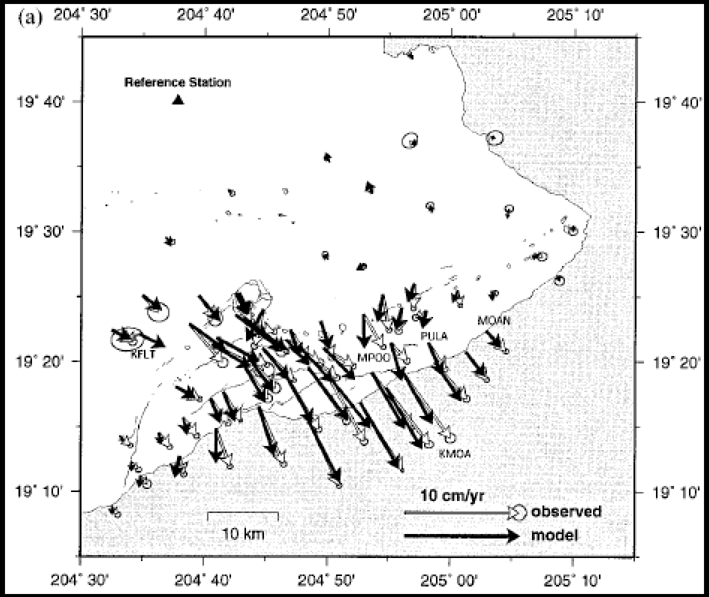
Kilauea volcano

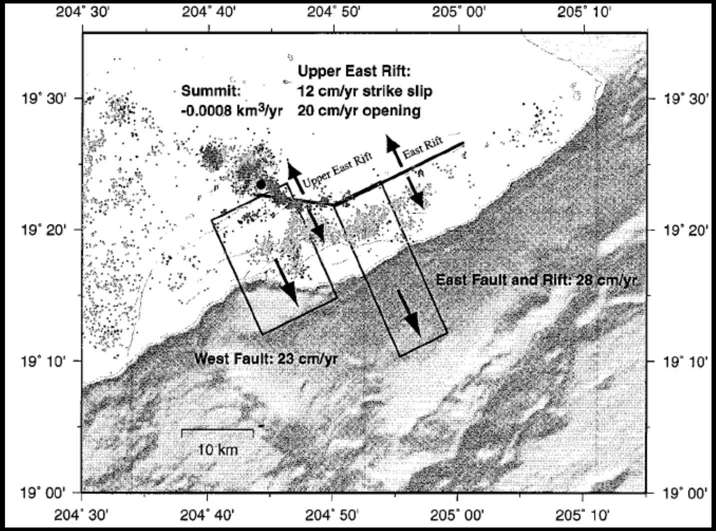
January 2002-October 2005

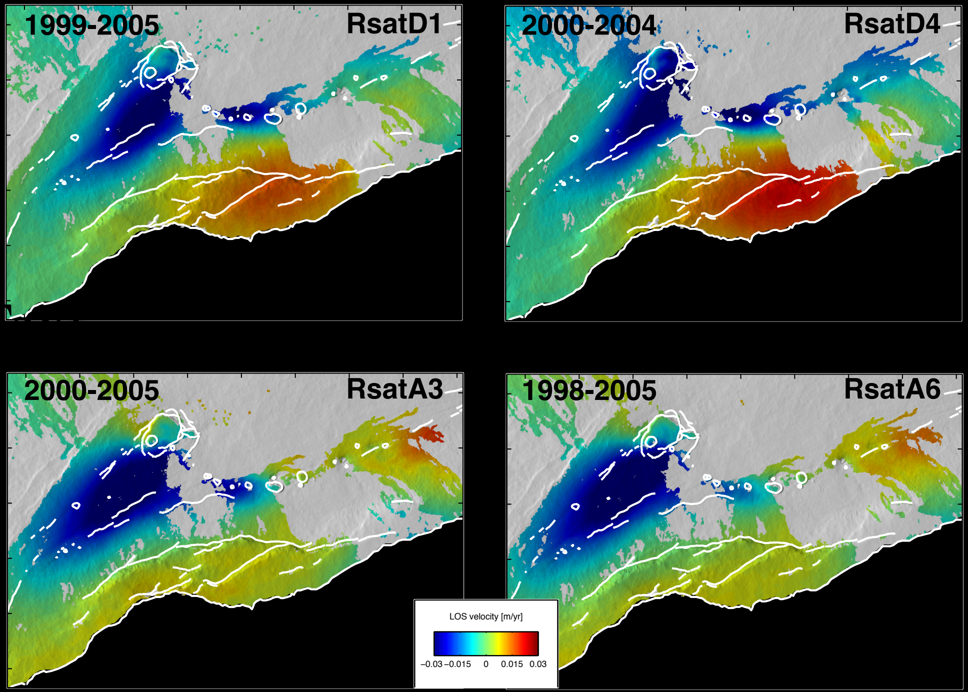




Kilauea volcano



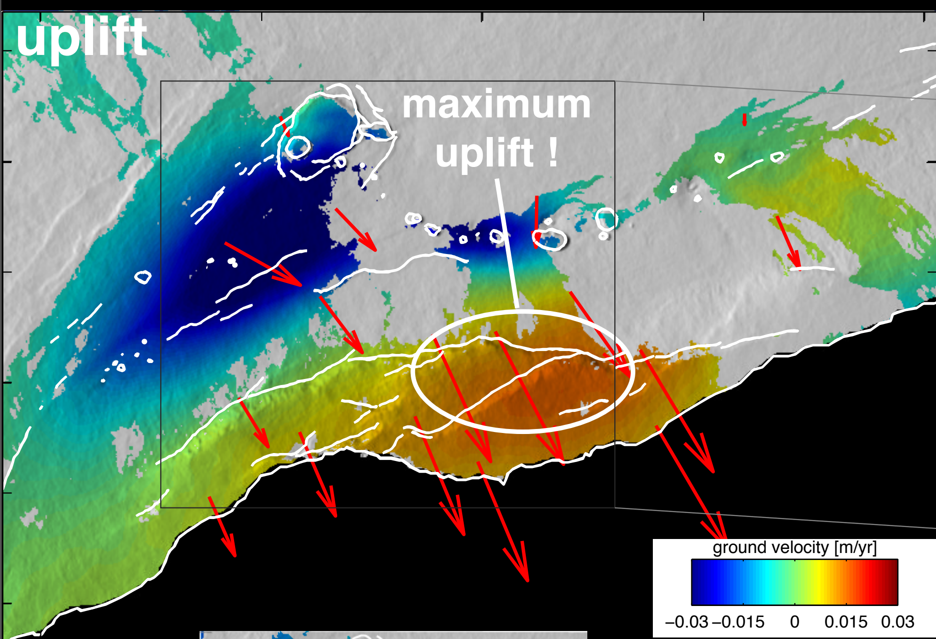




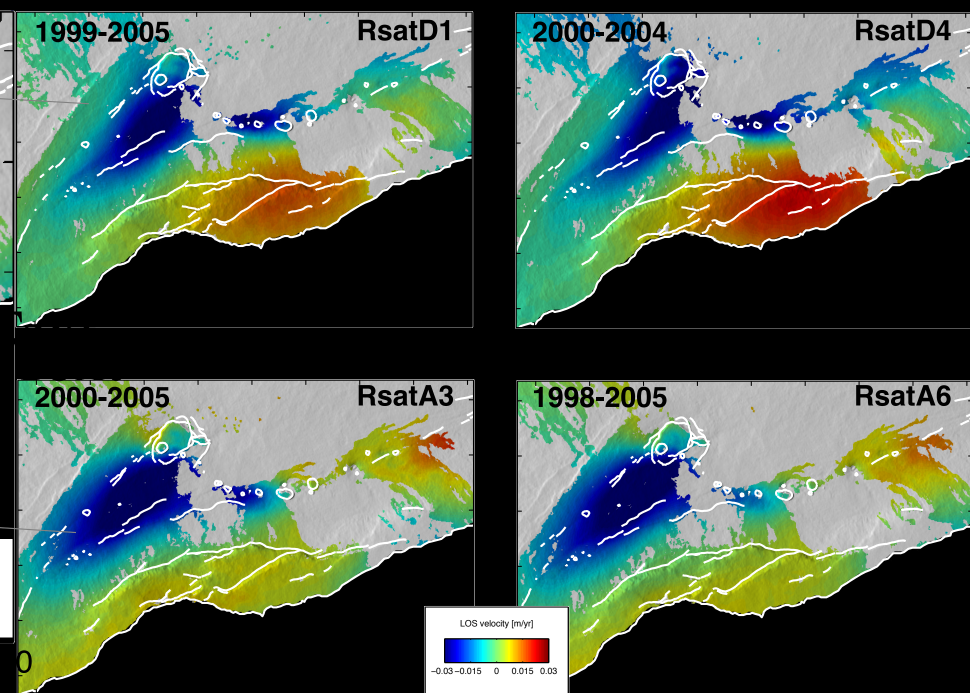
Southflank seaward motion explained by decollement slip and rift intrusion (Owen et al.,2000)

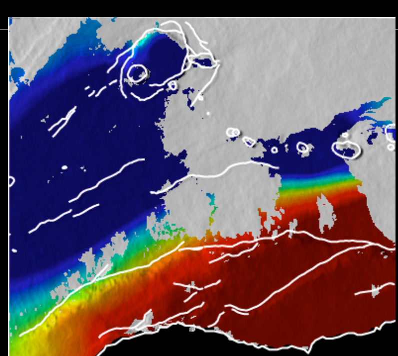
Kilauea volcano

uplift



LOS-velocity

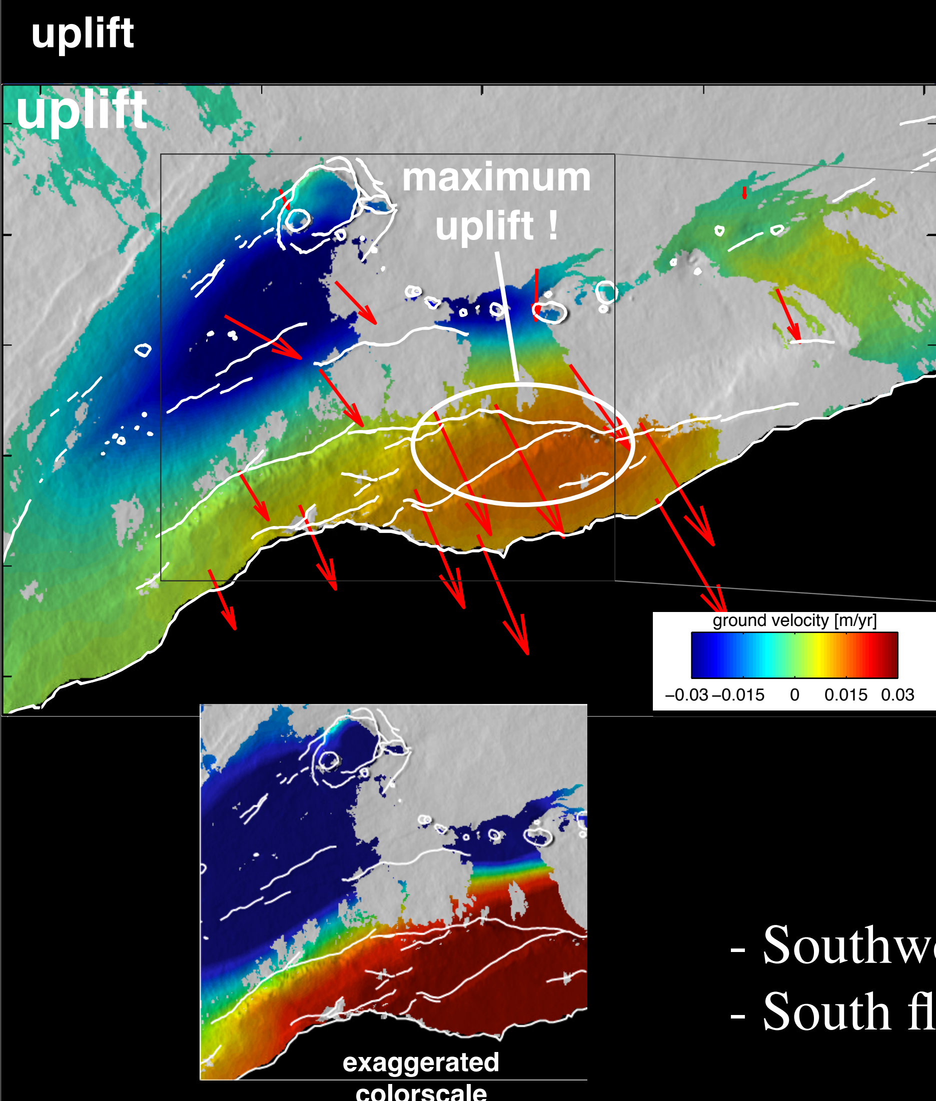




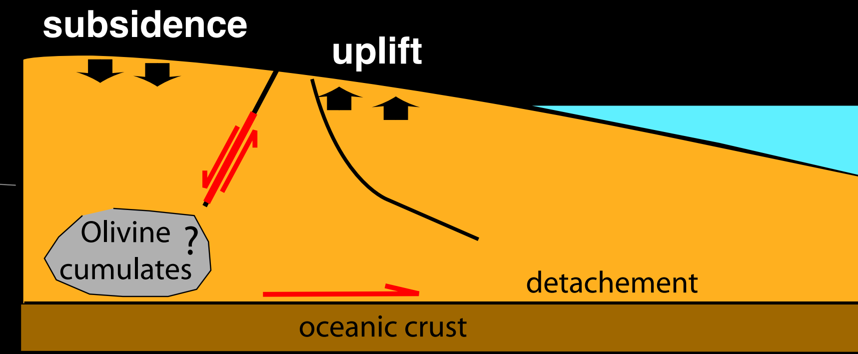
exaggerated
colorscale

- Southwest rift zone subsiding at 6-7 cm/yr
- South flank uplifting at 1.5 cm/yr

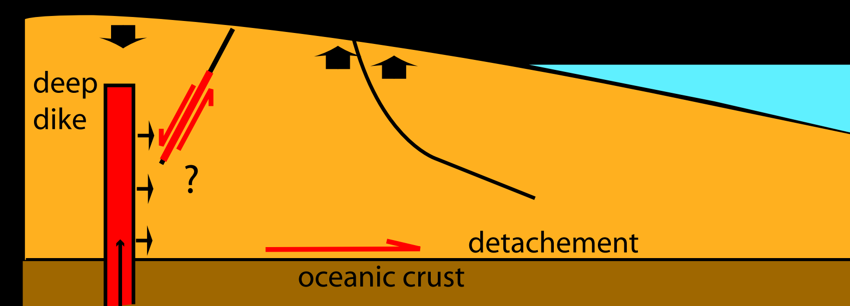
Kilauea volcano



Southwest rift zone



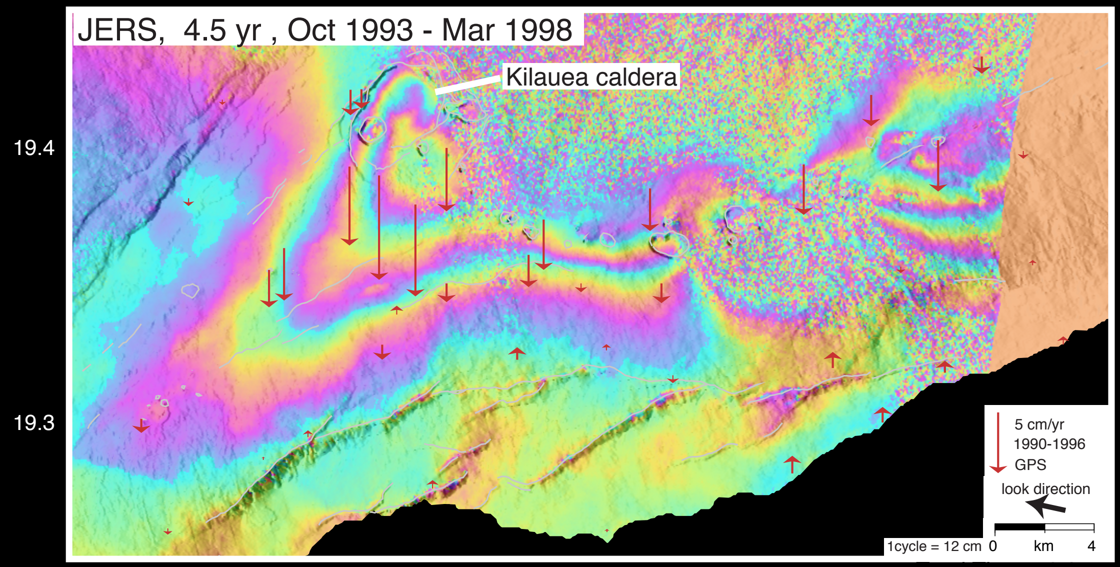
East rift zone



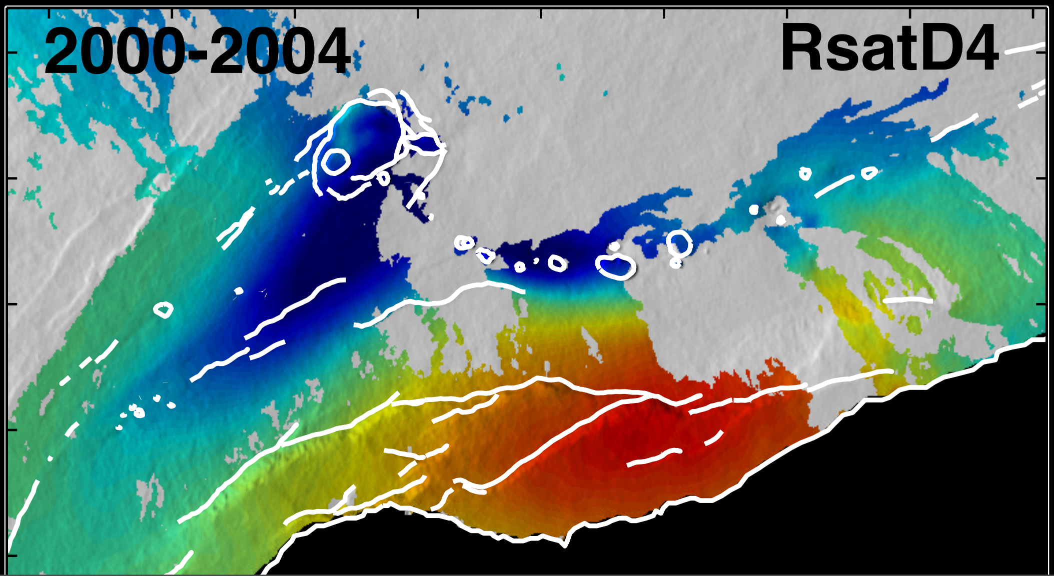
- Southwest rift zone subsiding at 6-7 cm/yr
- South flank uplifting at 1.5 cm/yr

Continuity with time

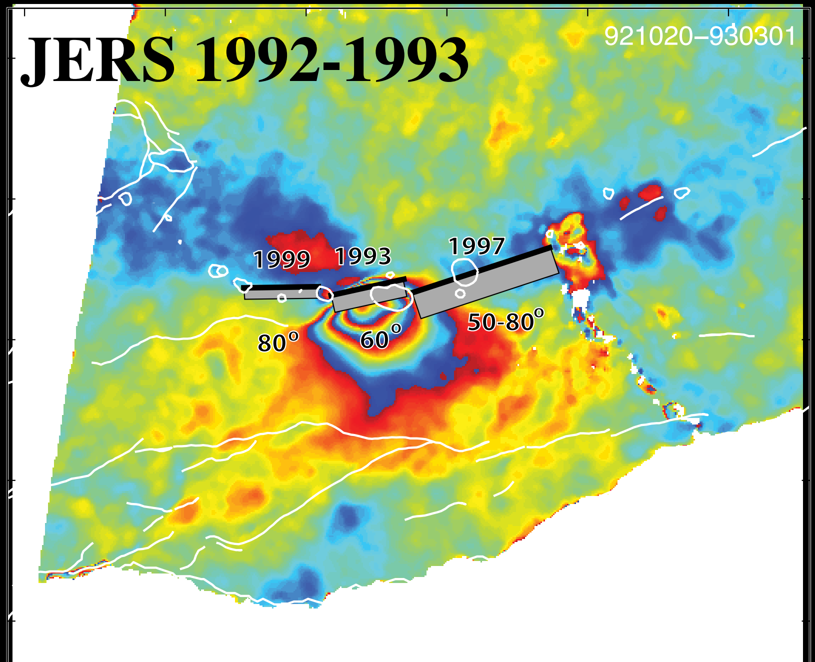
JERS
1993-1998

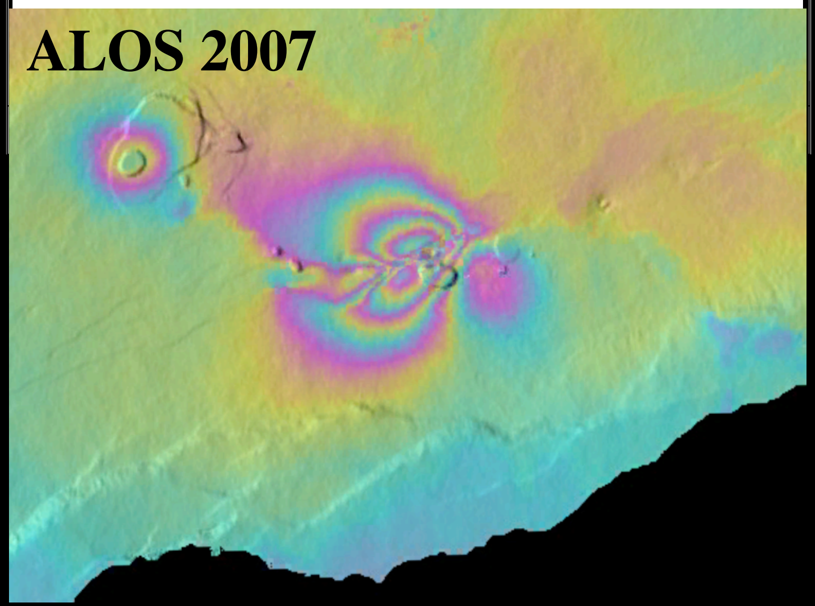


Radarsat
2000-2004



Intrusions


JERS 1992-1993
921020–930301
1999
1993
1997
80°
60°
50-80°


ALOS 2007

Conclusions

Mauna Loa:

- magma intrusion into rift zone and shallow magma reservoir
- intrusion occurrs into a section of the rift zone that was unclamped by the 1983 earthquake
- stress change modelling is a tool for intrusion forecasting

Kilauea

- very dynamic with secular subsidence and uplift in the summit area, repectively
- intrusions into east rift zone and summit area
- time-series analysis needed