Satellite Geodesy for Science and Hazard Applications Some Examples from Africa

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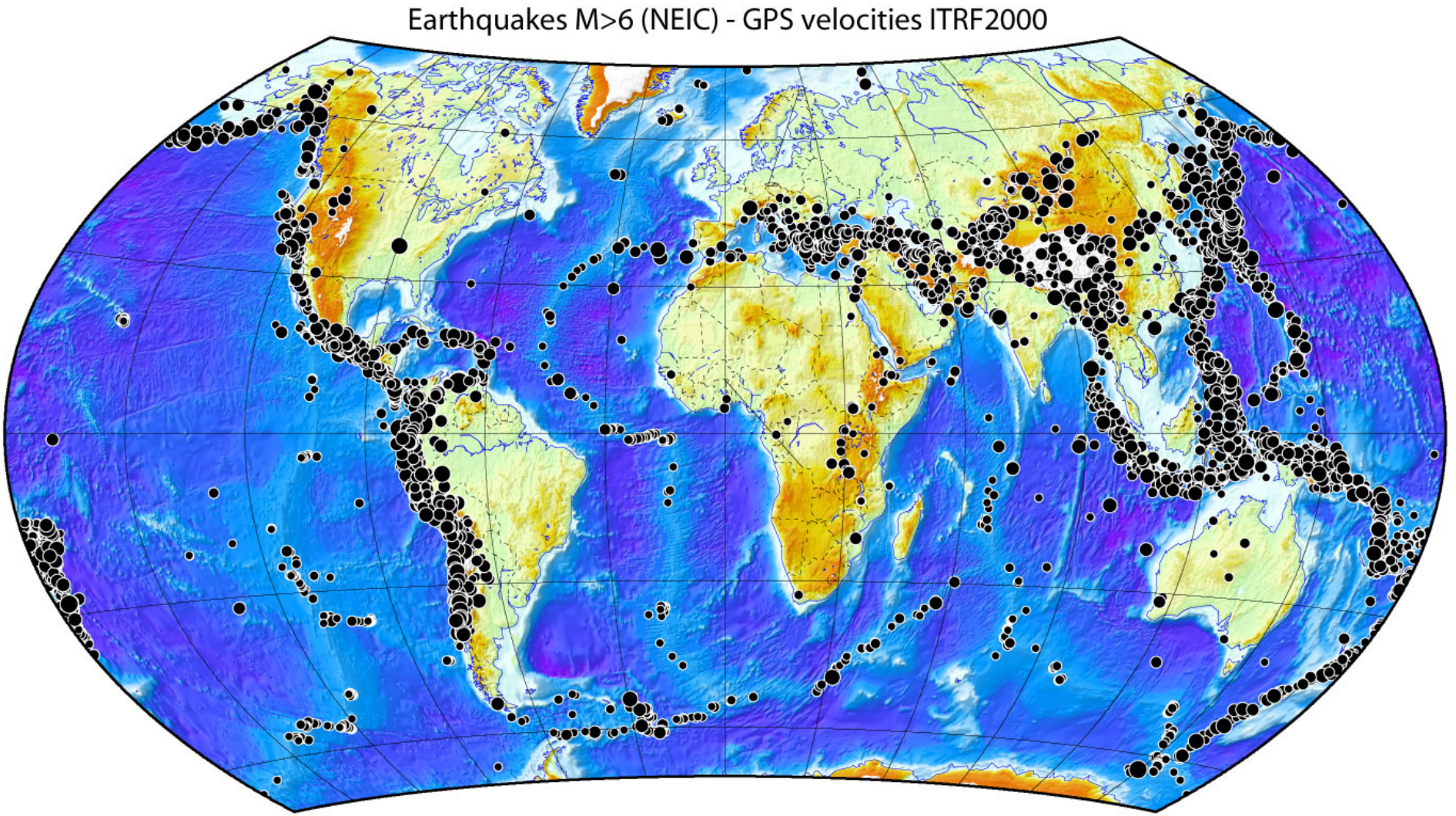
UNAVCO

NSF

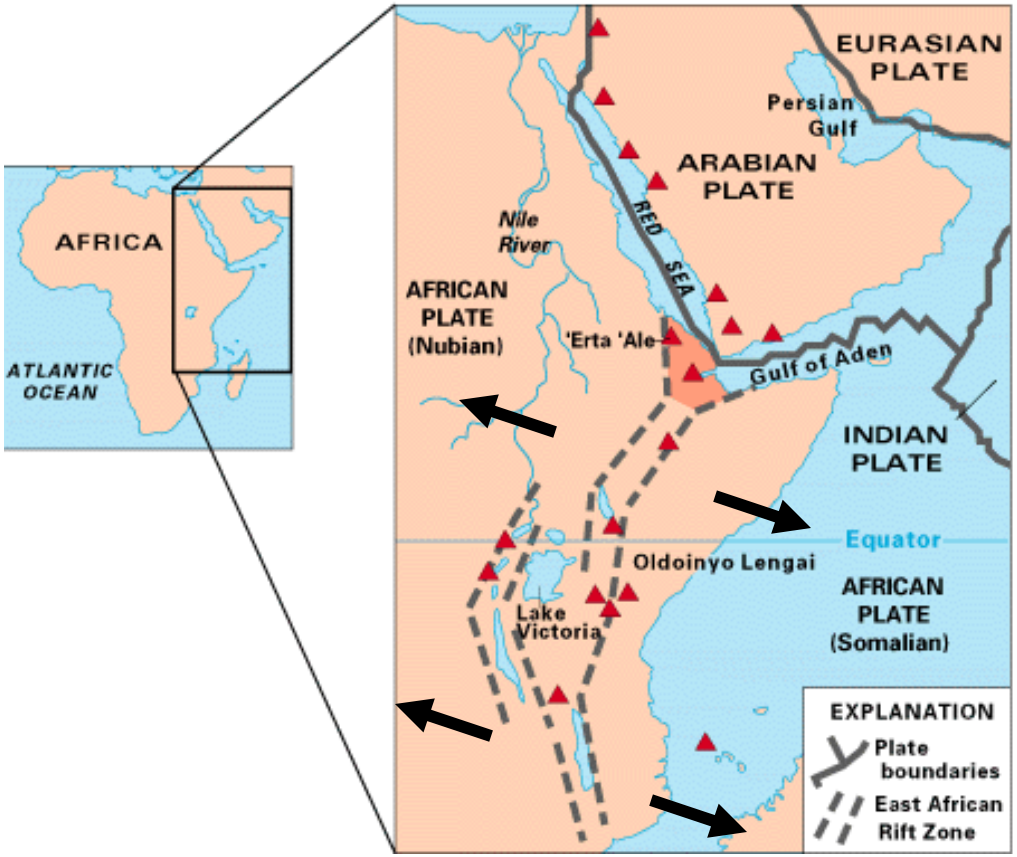
Ethiopian Mapping Agency

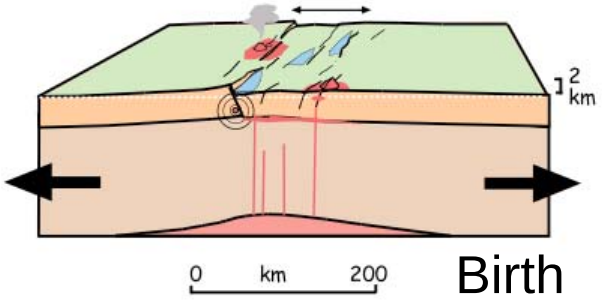
Survey and Mapping Dpt. Tanzania

An Active Planet

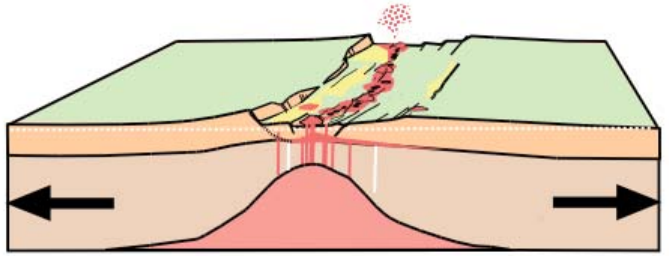


A natural laboratory for continental breakup

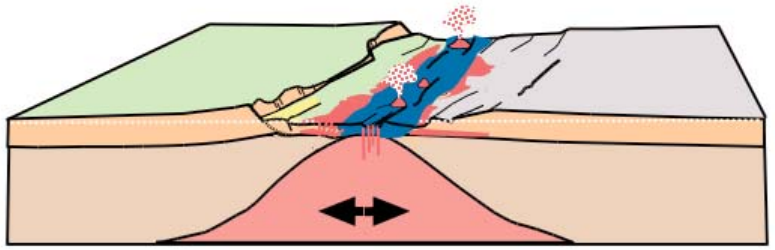




Birth

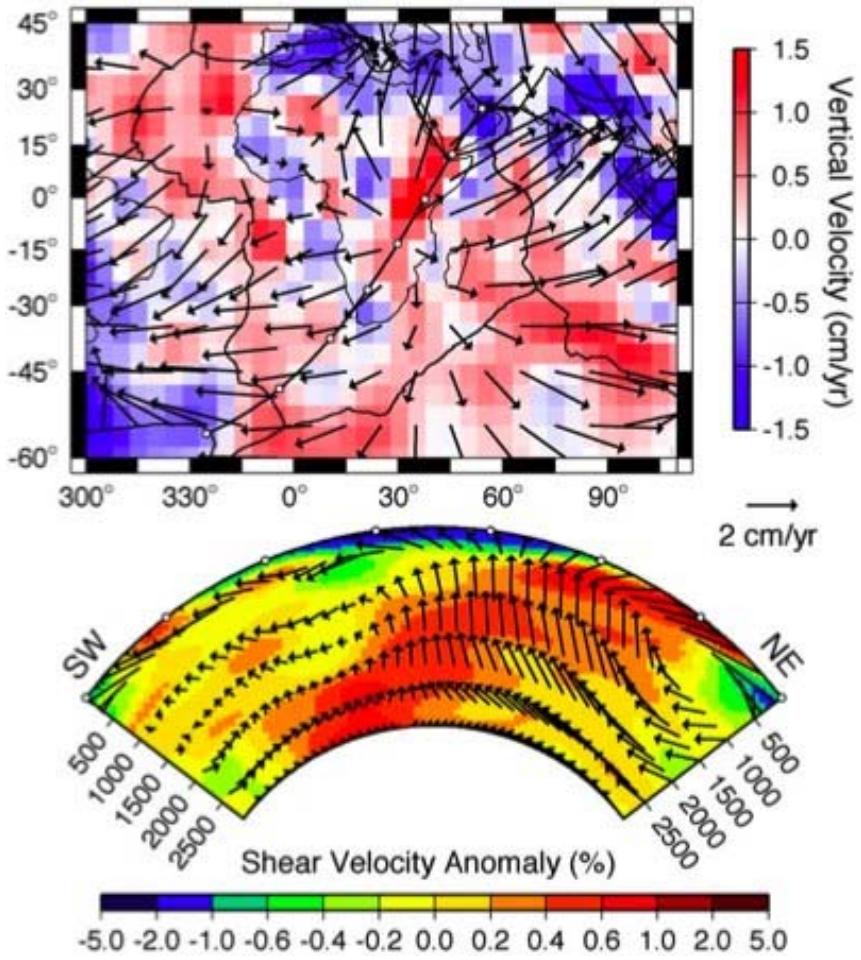


Transition

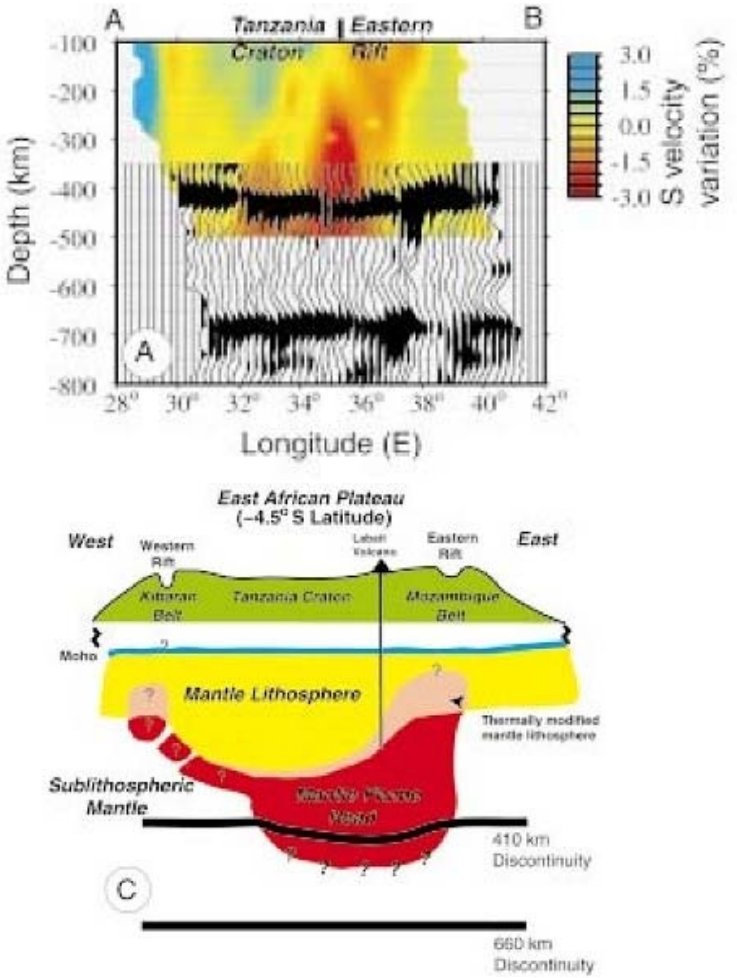


Breakup

At Depth…



The “Arican Superplume” and associated mantle flow (Behn et al., 2000)



Thermal anomalies in the upper mantle below the East African Rift (Nyblade et al., 2000).

At the Surface…

Earthquakes

Volcanoes

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

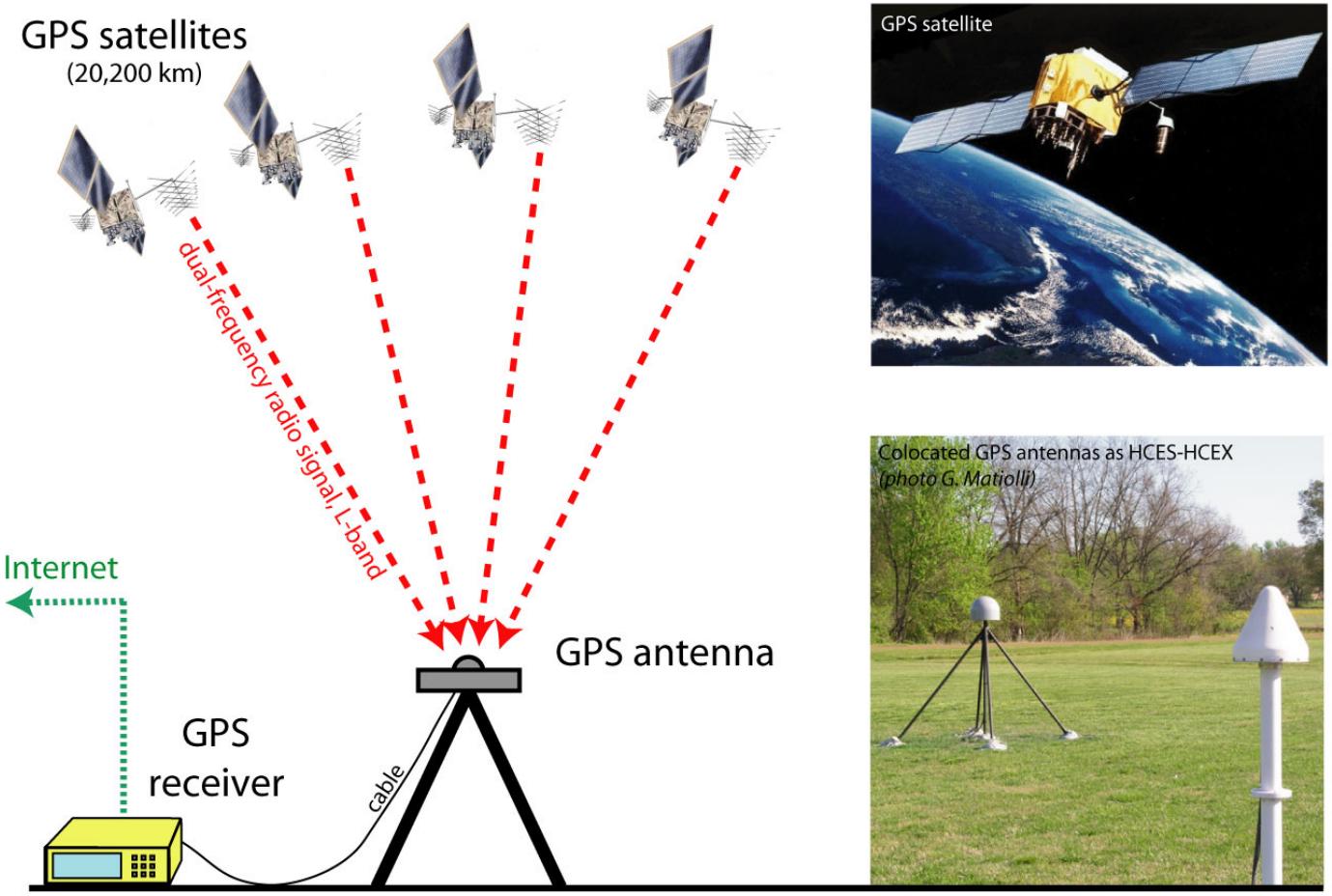
Questions posed

- How do continents break apart to form oceans: physics of continental breakup? Forces at play / strength of the lithosphere? Role of deep-earth processes (mantle)?
- Can we quantify the hazards posed by actively deforming areas?

→ Need to measure deformation of Earth surface from large scale (plate motion) to local scale (individual earthquakes and volcanoes)

→ Satellite geodesy:

  - GNSS = provide autonomous geo-spatial positioning with discrete, global, coverage
  - Radar interferometry = provide ground deformation measurements with continuous, local, coverage



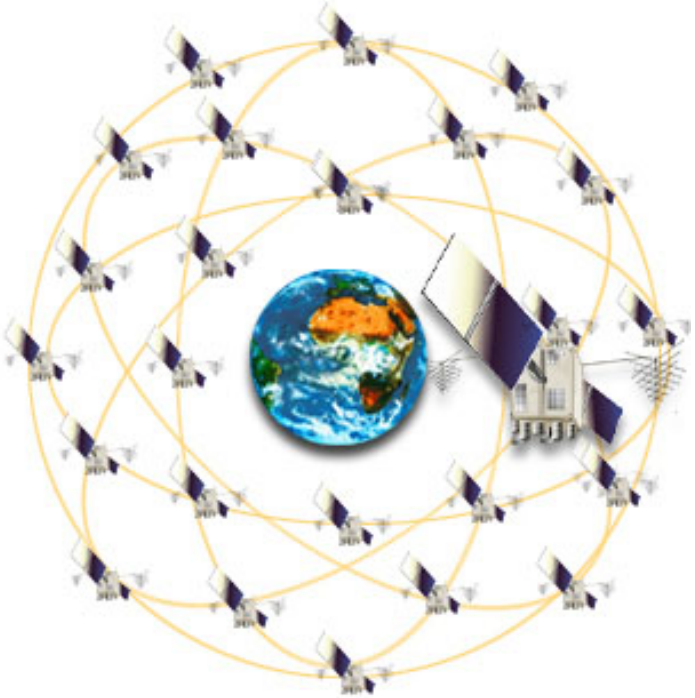
4 satellites => solve for latitude, longitude, elevation, time

$$\Phi_i^k(t) = \rho_i^k(t) \times \frac{f}{c} + \left(h^k(t) - h_i(t)\right) \times f + ion_i^k(t) + trop_i^k(t) - N_i^k + \varepsilon$$

Phase measurement	=	Sat-rec. distance	+	Clock errors	+	Ionospheric delay	+	Tropospheric delay	+	Phase ambiguity	+	Other noise sources

Precision of phase data ~ 0.1% wavelength => precision of position ~ few millimeters

1



2

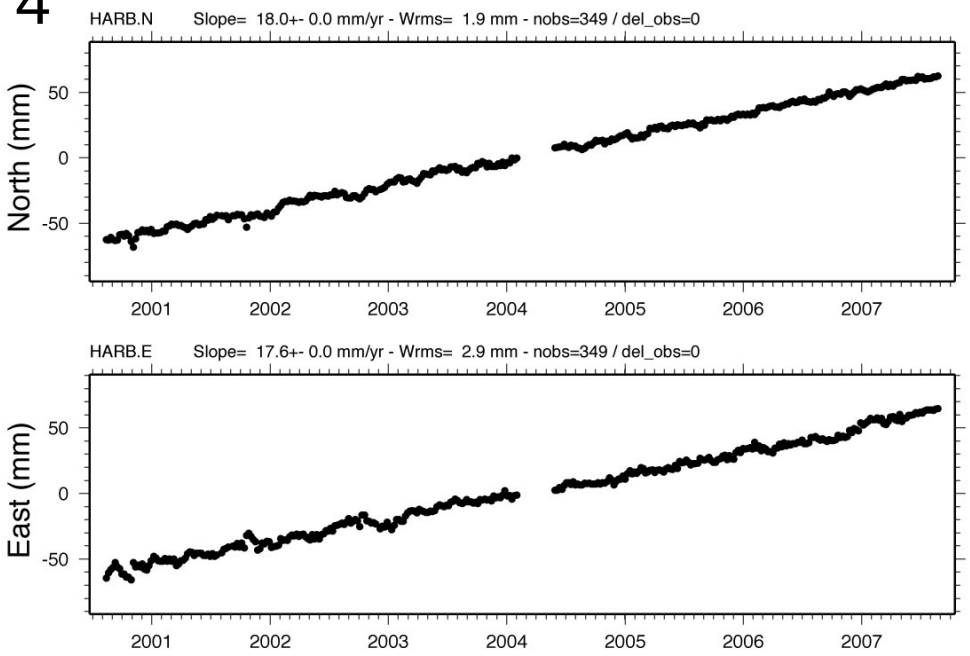

GPS station in Dar Es Salaam, Tanzania

3

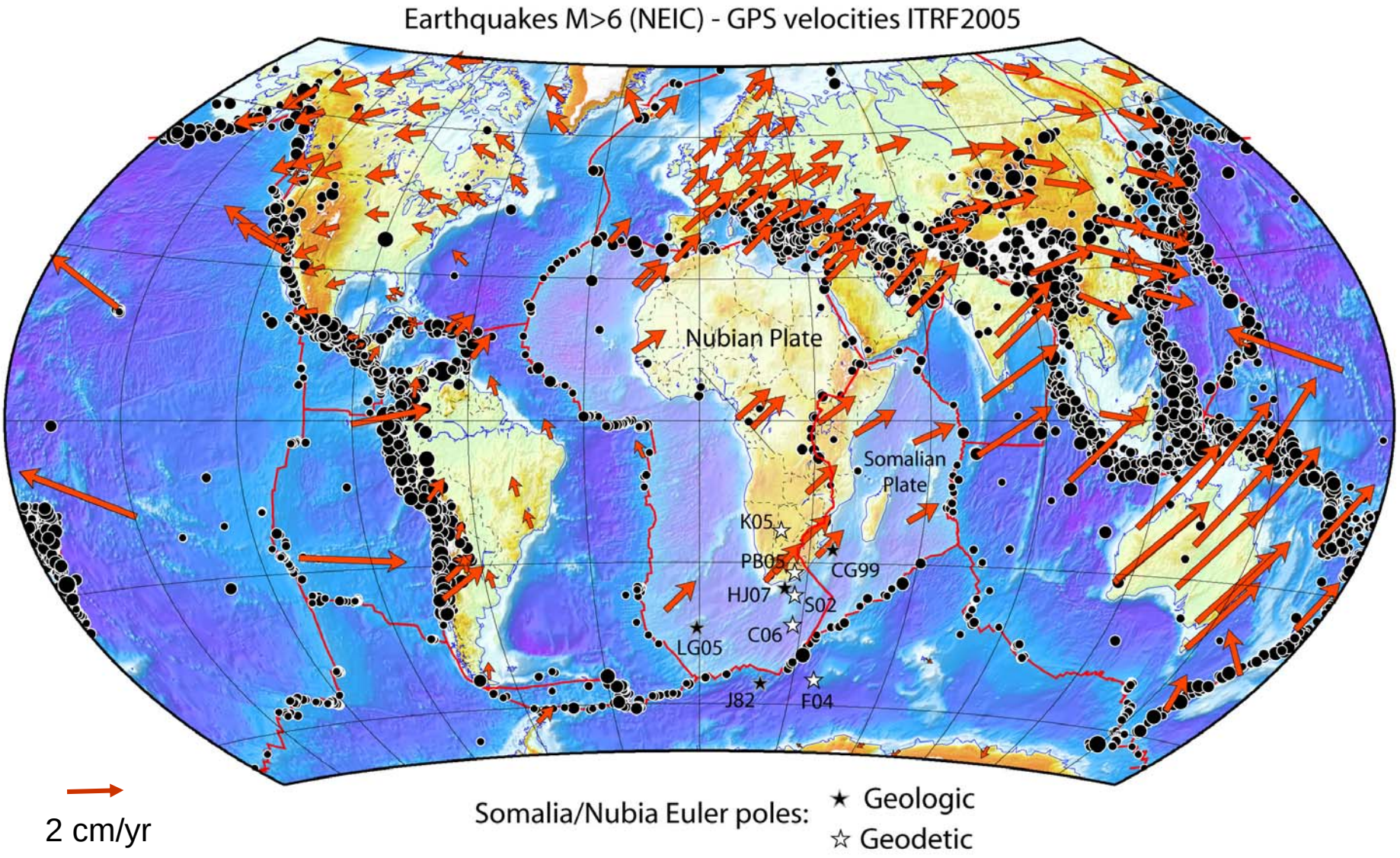

Elifuraha Saria

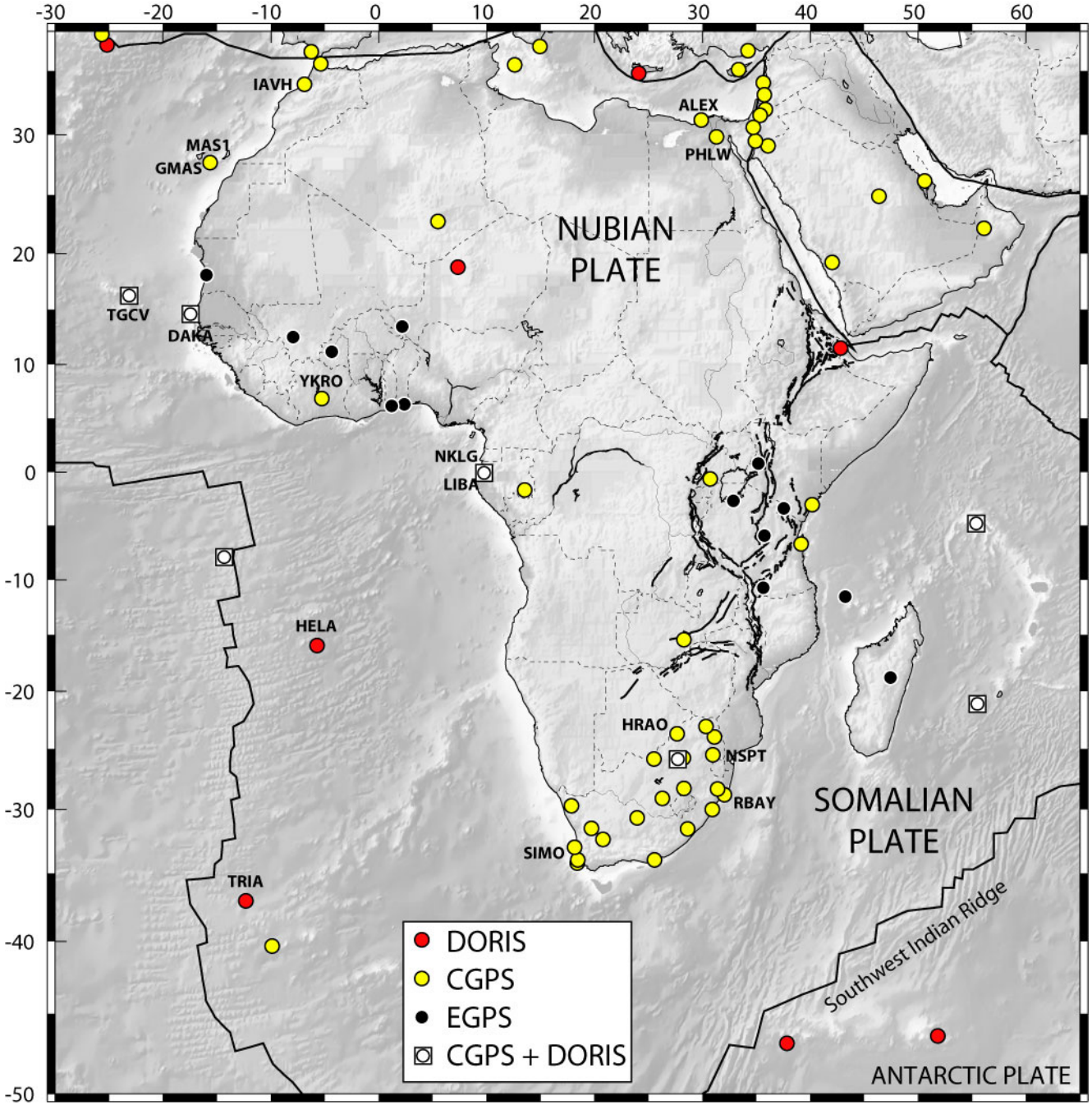

Sarah Stamps

4


HARB.N Slope= 18.0+- 0.0 mm/yr - Wrms= 1.9 mm - nobs=349 / del_obs=0
North (mm)
50
0
-50
2001
2002
2003
2004
2005
2006
2007
HARB.E Slope= 17.6+- 0.0 mm/yr - Wrms= 2.9 mm - nobs=349 / del_obs=0
East (mm)
50
0
-50
2001
2002
2003
2004
2005
2006
2007

Current Plate Motions




-30
-20
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20
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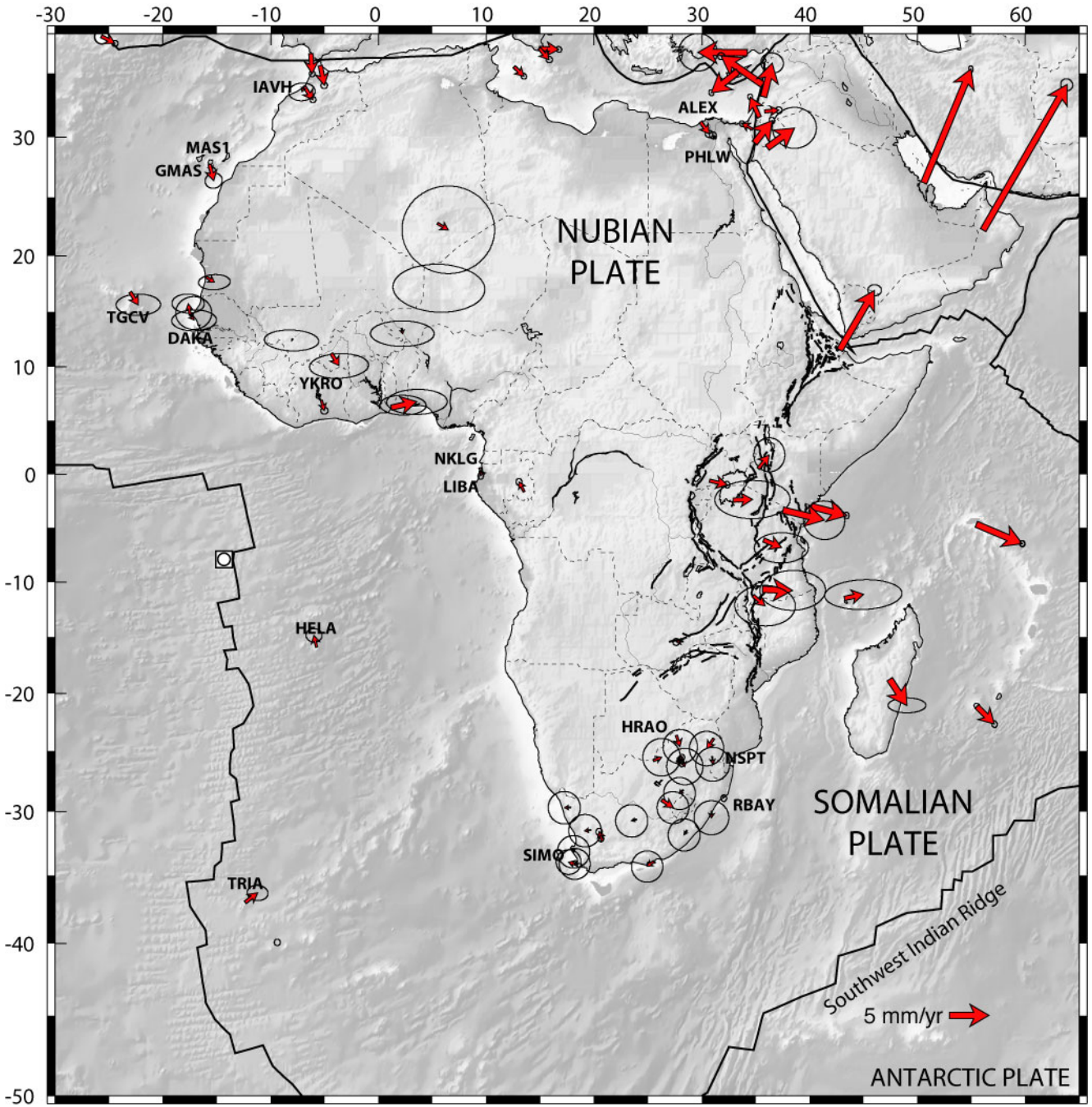
-40
-50
IAVH
ALEX
MAS1
GMAS
PHLW
NUBIAN
PLATE
TGCV
DAKA
YKRO
NKLG
LIBA
HELA
HRAO
NSPT
RBAY
SOMALIAN
PLATE
SIMO
TRIA
Southwest Indian Ridge
ANTARCTIC PLATE
DORIS
CGPS
EGPS
CGPS + DORIS


-30
-20
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20
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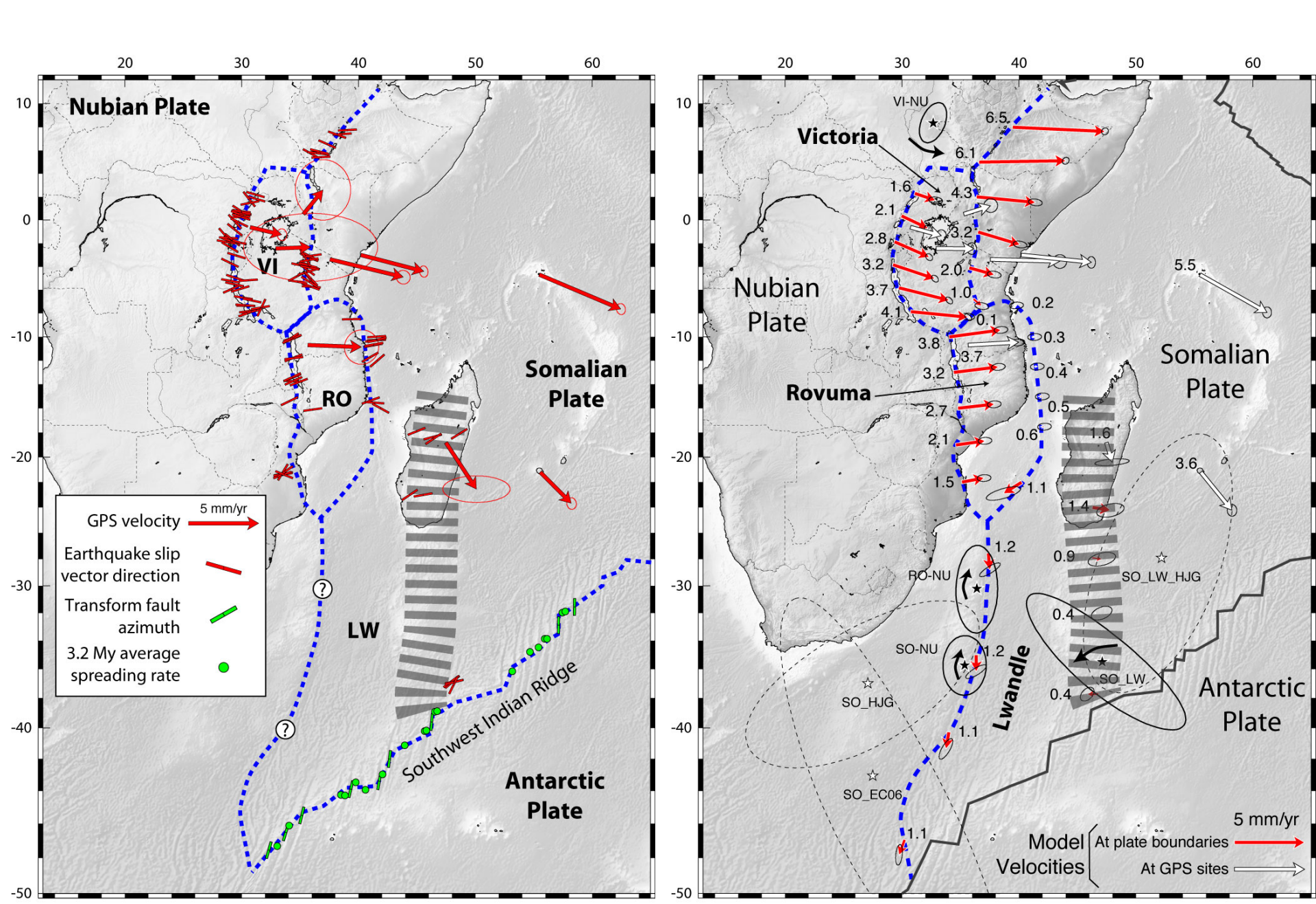
0
-10
-20
-30
-40
-50
IAVH
ALEX
PHLW
MAS1
GMAS
NUBIAN
PLATE
TGCV
DAKA
YKRO
NKLG
LIBA
HELA
HRAO
NSPT
RBAY
SIMO
TRIA
SOMALIAN
PLATE
Southwest Indian Ridge
5 mm/yr
ANTARCTIC PLATE

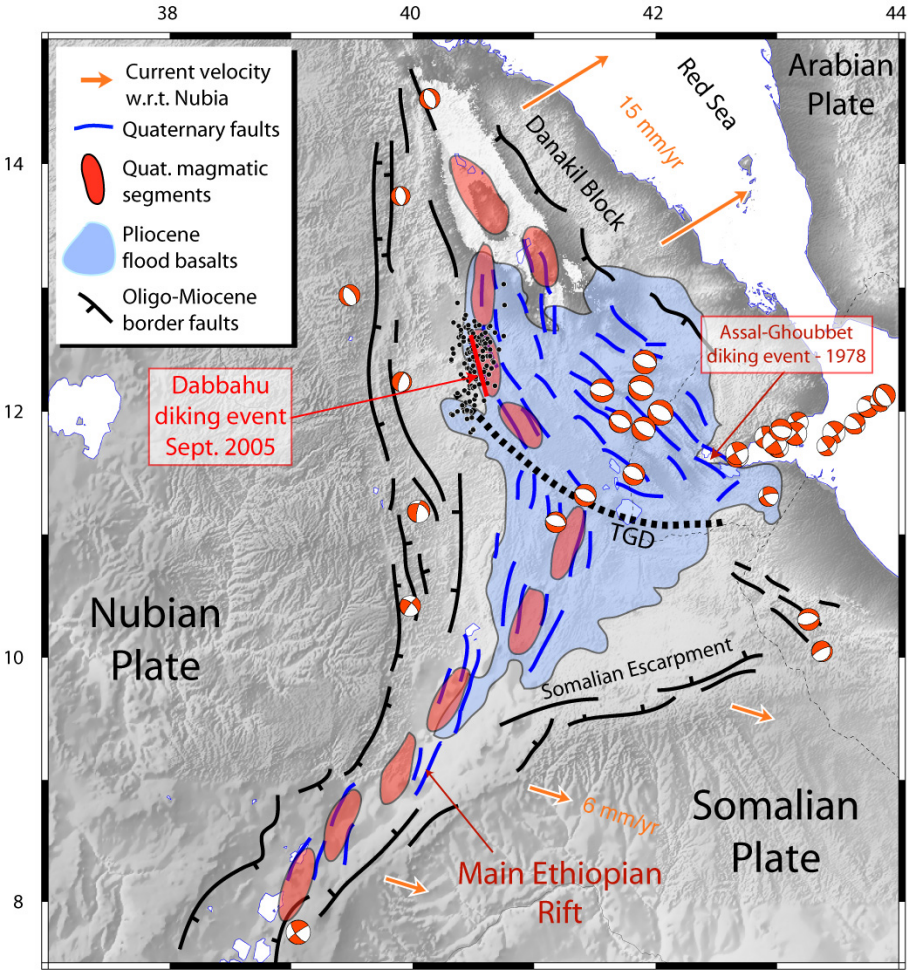

Nubian Plate
Somalian Plate
Antarctic Plate
VI
RO
LW
Southwest Indian Ridge
GPS velocity
5 mm/yr
Earthquake slip vector direction
Transform fault azimuth
3.2 My average spreading rate
Victoria
VI-NU
Rovuma
RO-NU
SO-NU
Lwandle
SO_HJG
SO_EC06
SO_LW_HJG
SO_LW
Model Velocities
At plate boundaries
At GPS sites

Training

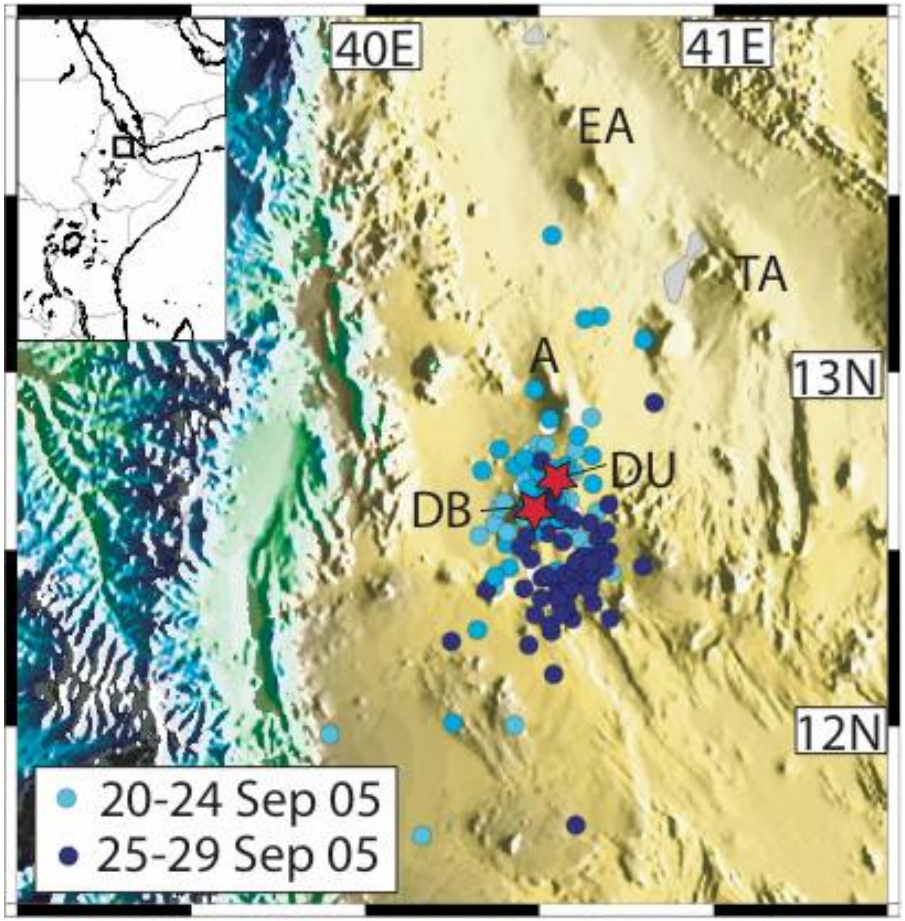
With the Survey and Mapping Department, Tanzania

With students in the field

On-going Deformation in Afar, Ethiopia



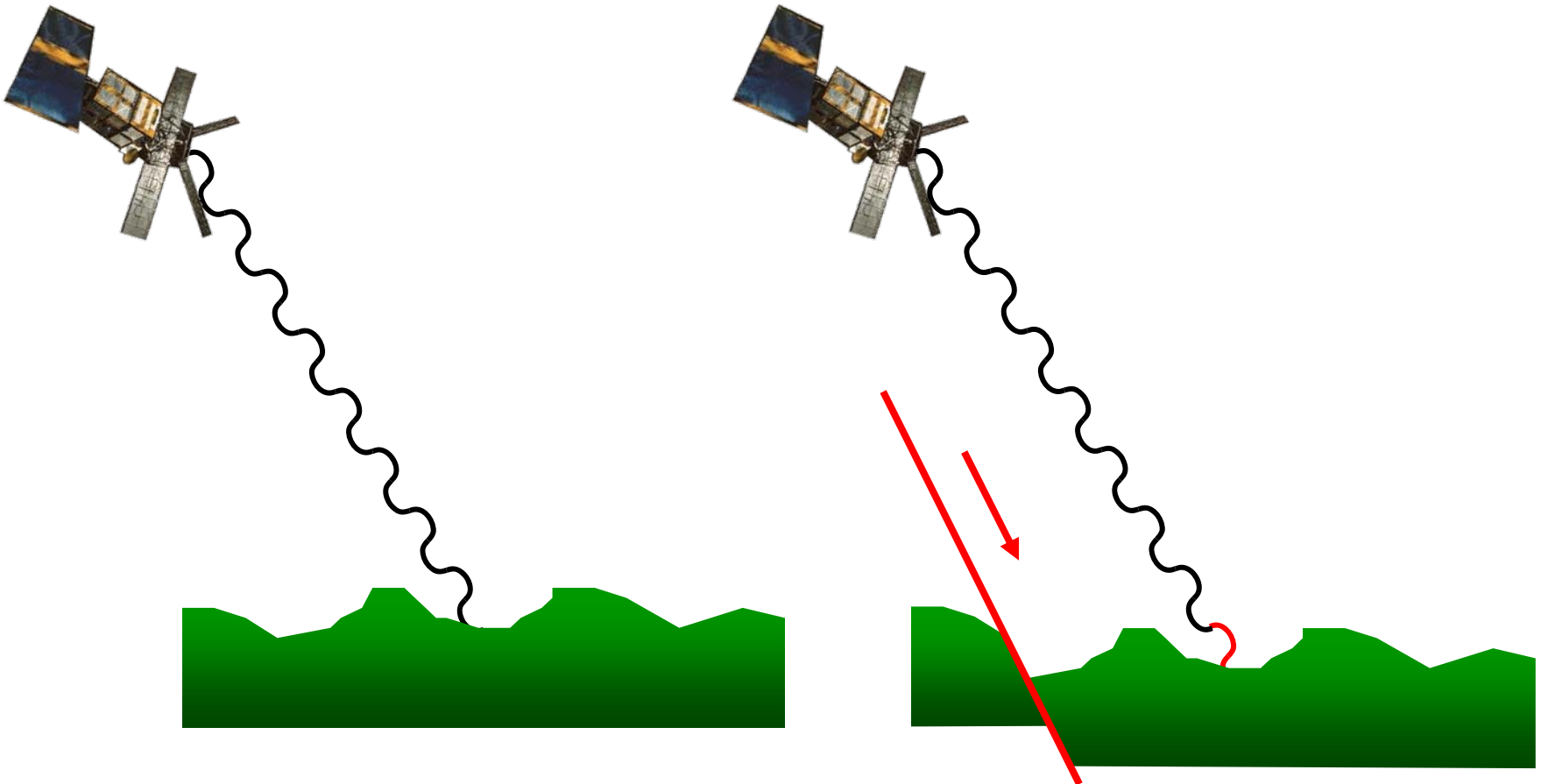
Afar: a young volcanic province at the triple junction between Arabia, Nubia, and Somalia plates.



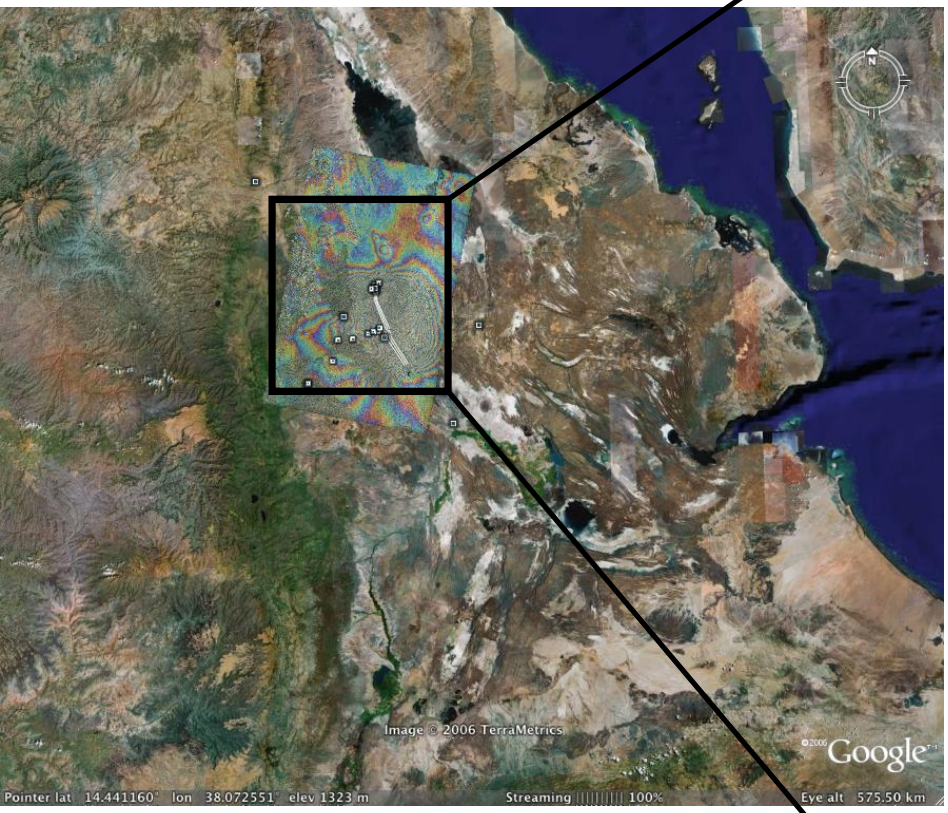
September 2005: earthquake swarm, open fissures, small volcanic eruption

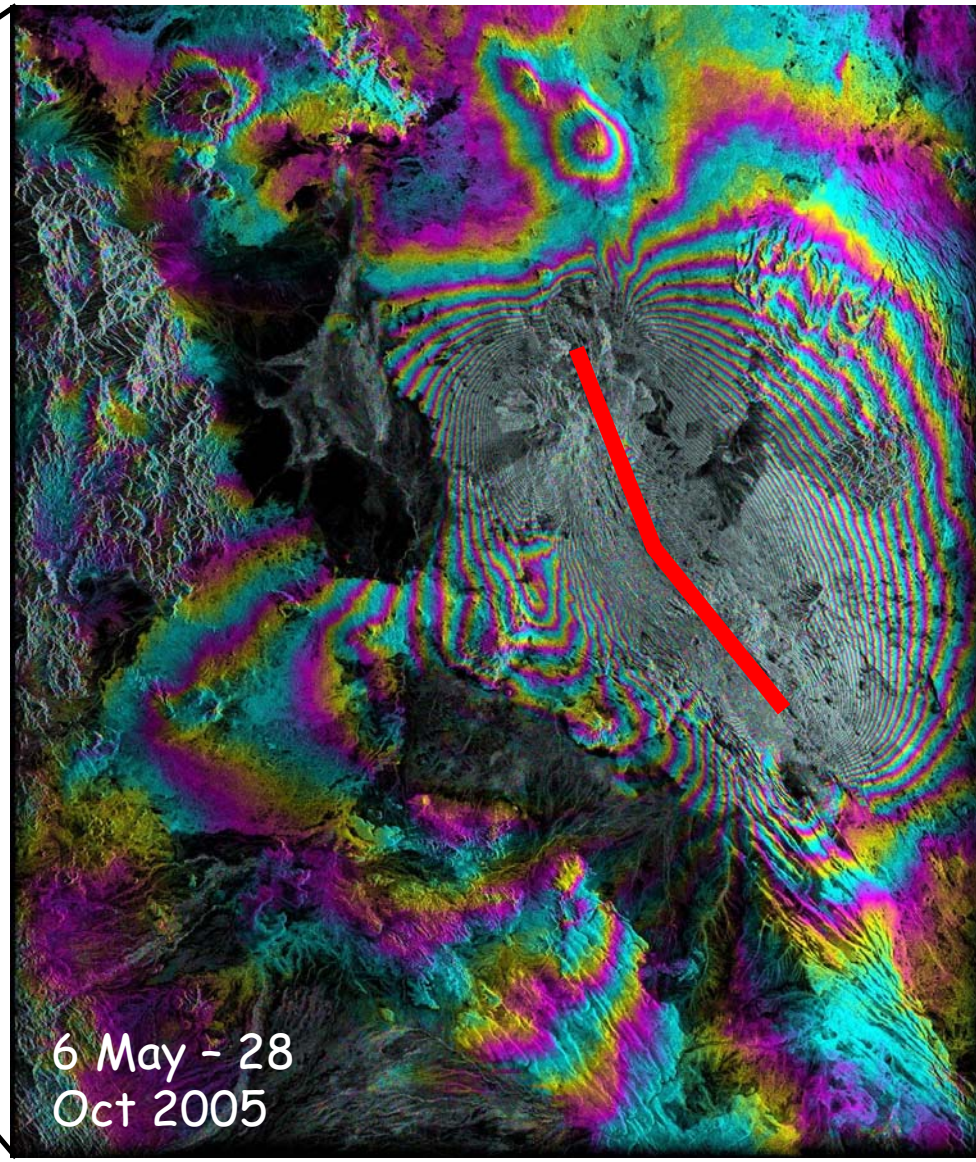
Satellite Radar Interferometry

- Two successive satellite passes over region of interest, compute range difference
- Remove the interferometric phase due to geometry and topography.
- If the ground does not move, then residual phase will be zero apart from effects of environmental and instrumental noise.
- If the ground moves between SAR observations, then the residual phase will not be zero.



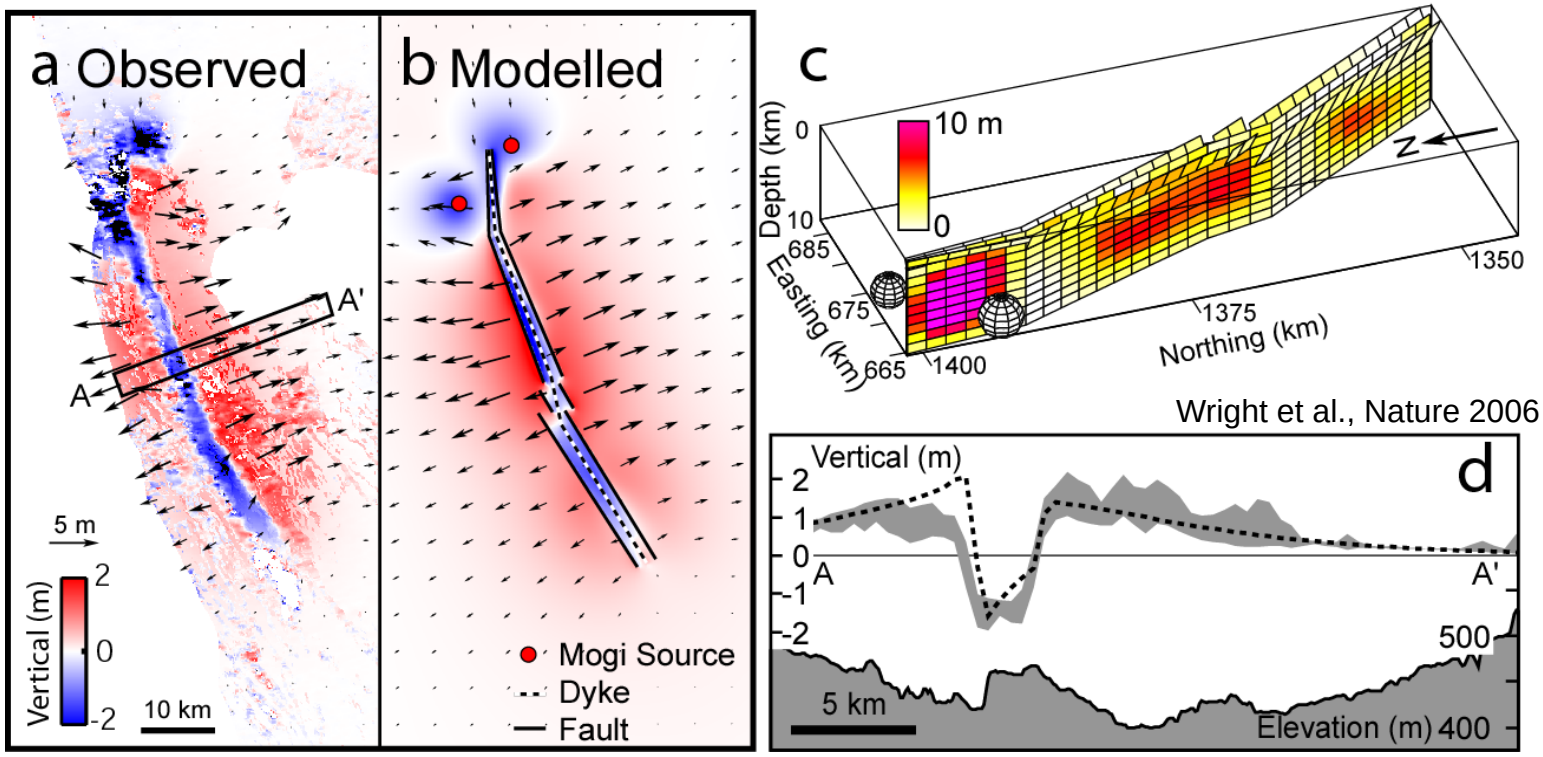
Ground displacement: up to 5 m in ~2 weeks





1 fringe = 2.8 cm displacement in ground-satellite direction

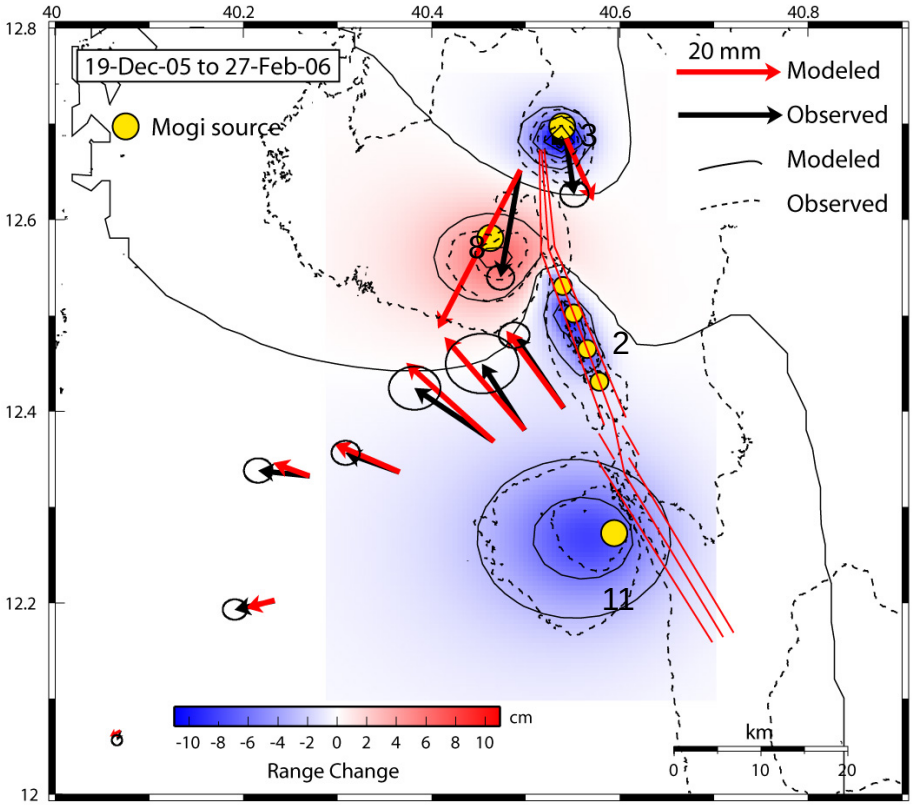
Largest dyke in space geodesy era



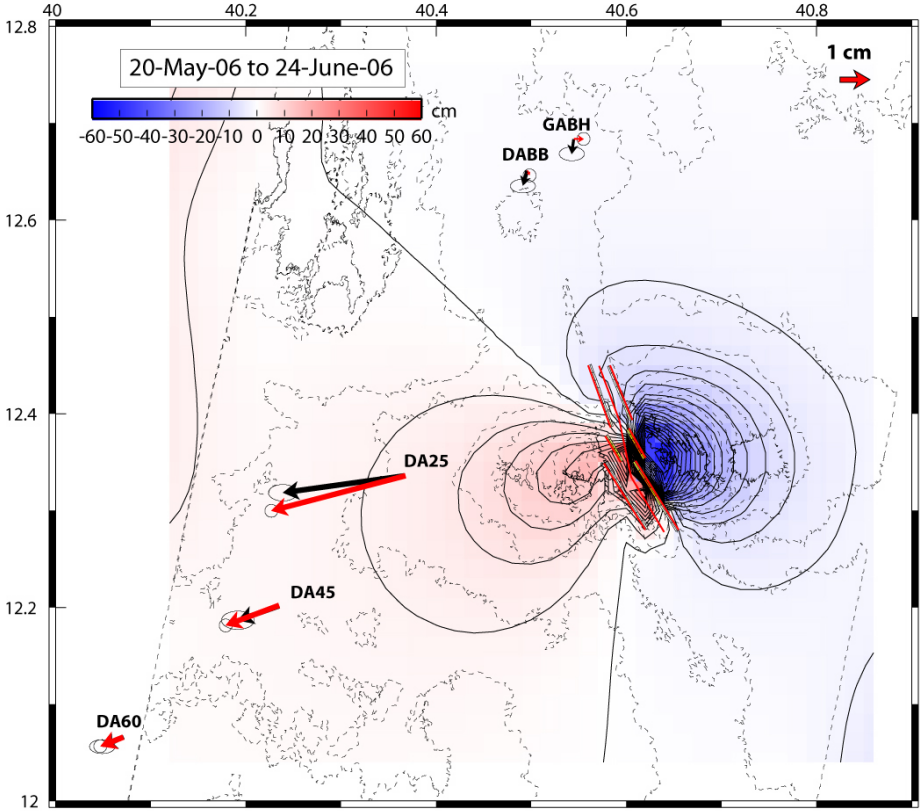
Wright et al., Nature 2006

- 2.5 km^3 magma intruded along dyke (Mt St Helens 1980 1.2 km^3; Krafla ~ 1 km^3 total).
- 0.5 km^3 sourced from Dabbahu and Gabho volcanoes at North.
- Where does the rest of the magma come from? How are magma chambers replenished? Where does magma evolve?
- Is it over…?

The “plumbing system” at work

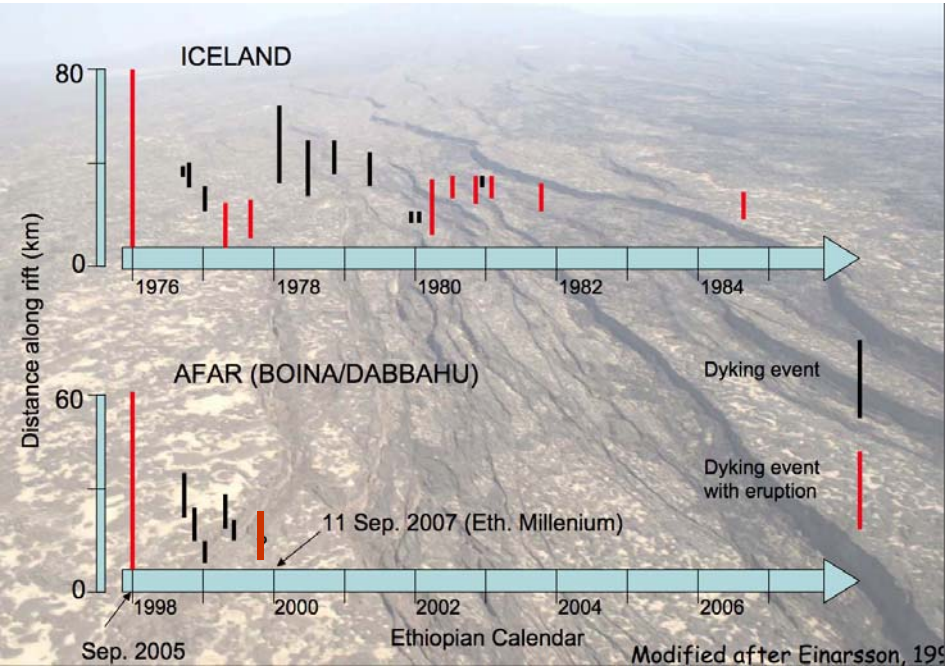


Next 8 months: the magmatic plumbing system at work (blue areas = inflation, red = deflation)



Then a new, smaller, dyke intrusion

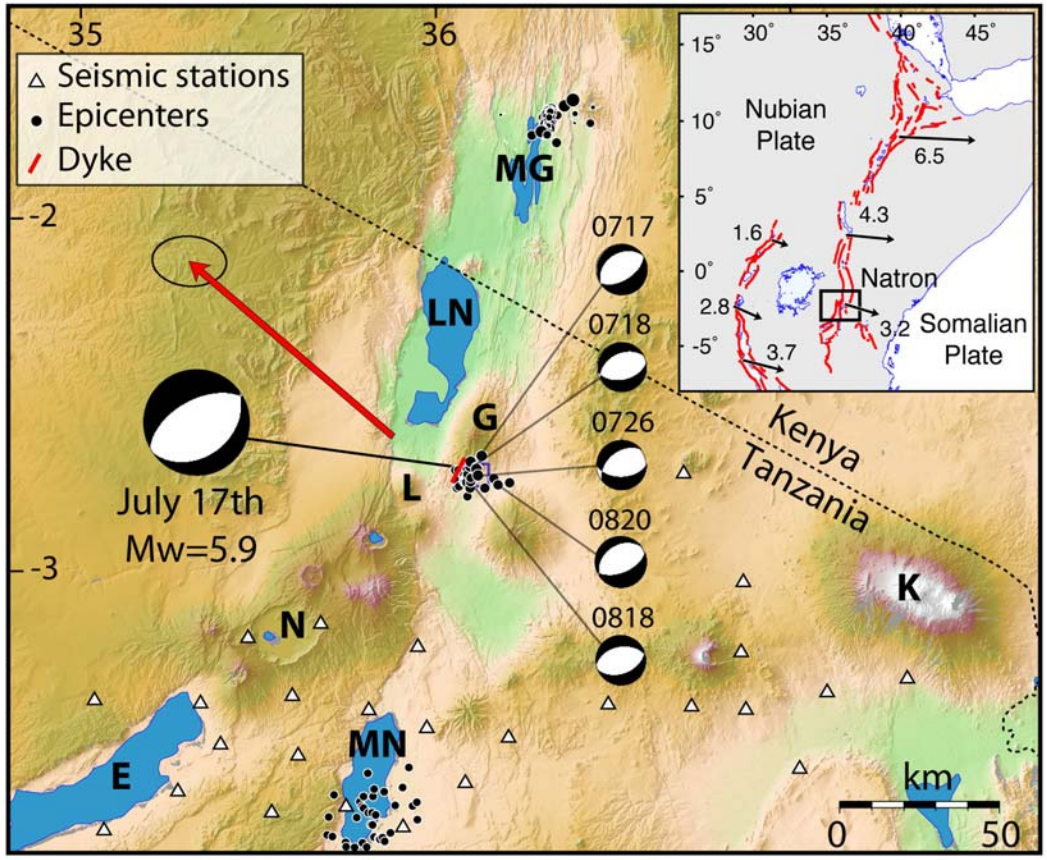
A long-lasting volcano-tectonic crisis



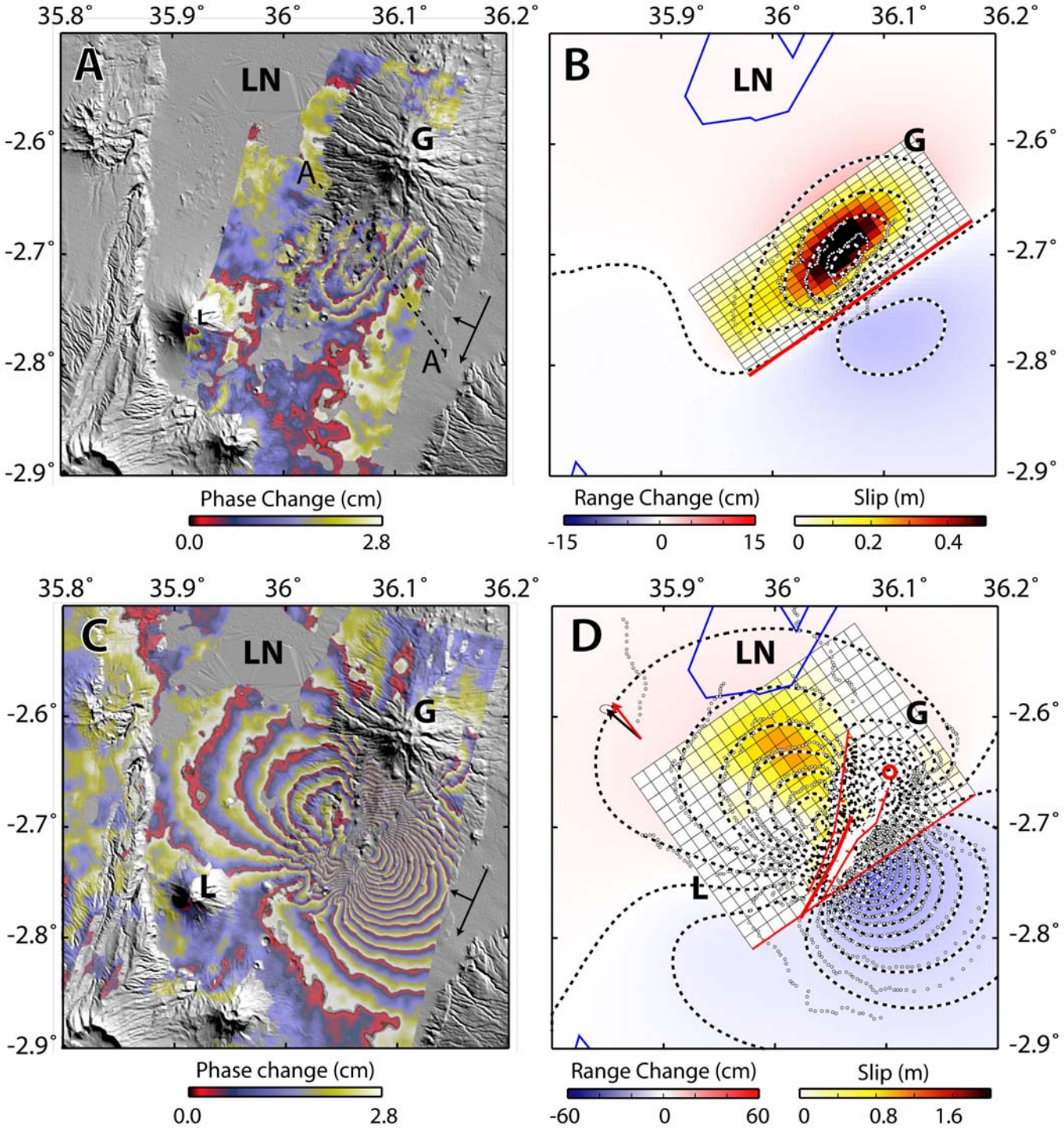
Comparison with a similar size rifting event in Iceland

Briefing Afar authorities (Ethiopia) about volcanic hazard

On-going activity in Natron rift



July-August 2007: series of earthquakes followed by eruption of Ol Doniyo Lengai.



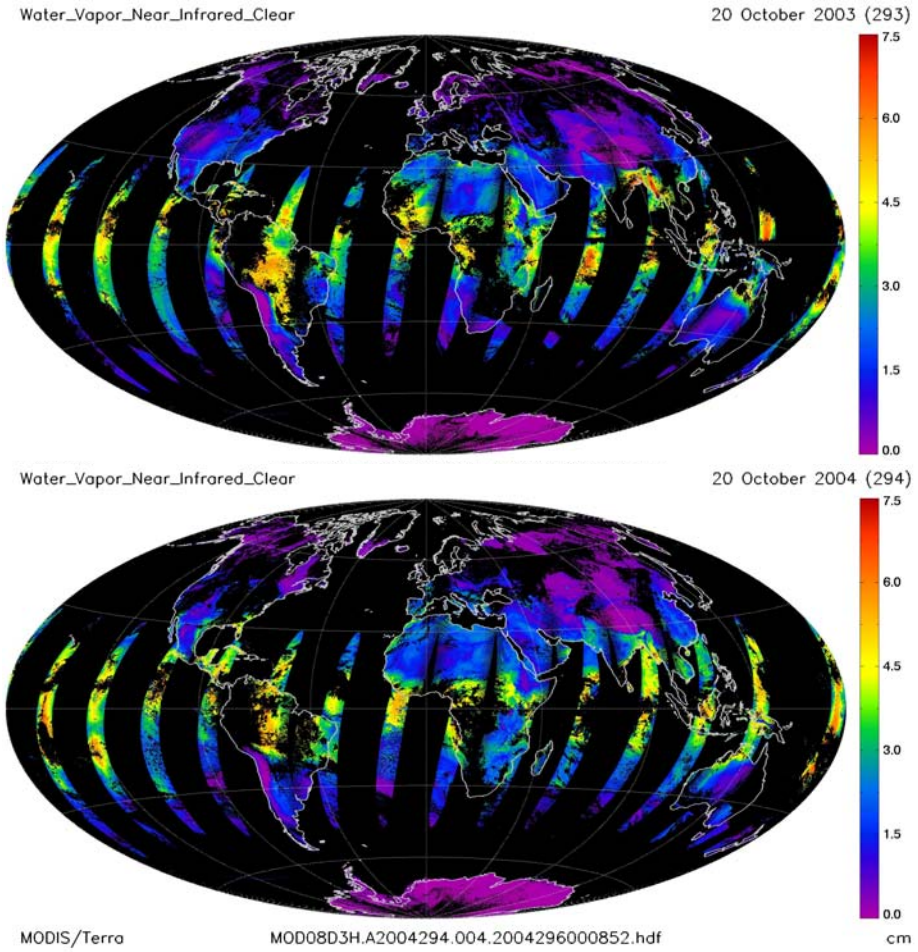
Step 1 (before July 17): aseismic slip on a NW-dipping normal fault

Step 2 (July 17 - August 21): dyke intrusion

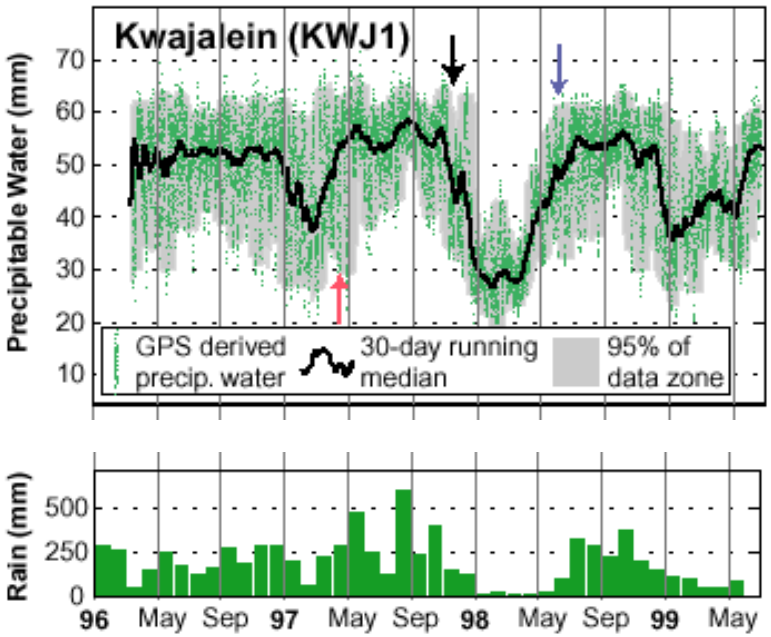
Climate Change

- 50-year-long drying trend tightly linked to substantial warming of the Indian Ocean => by mid-century there could be a 10 to 20% drying in the Feb-Apr wet season compared with the average for the last half of the 20th century (J. Hurrel, NCAR).
- Is Sahel getting rainier? Debated…
- Uncertainties in projections likely to remain high as long as gaps persist in collecting meteorological data over Africa.
- Major difficulty: measuring water vapor and its interannual to daily variability --> can be done using GNSS signals

ENSO and African Climate



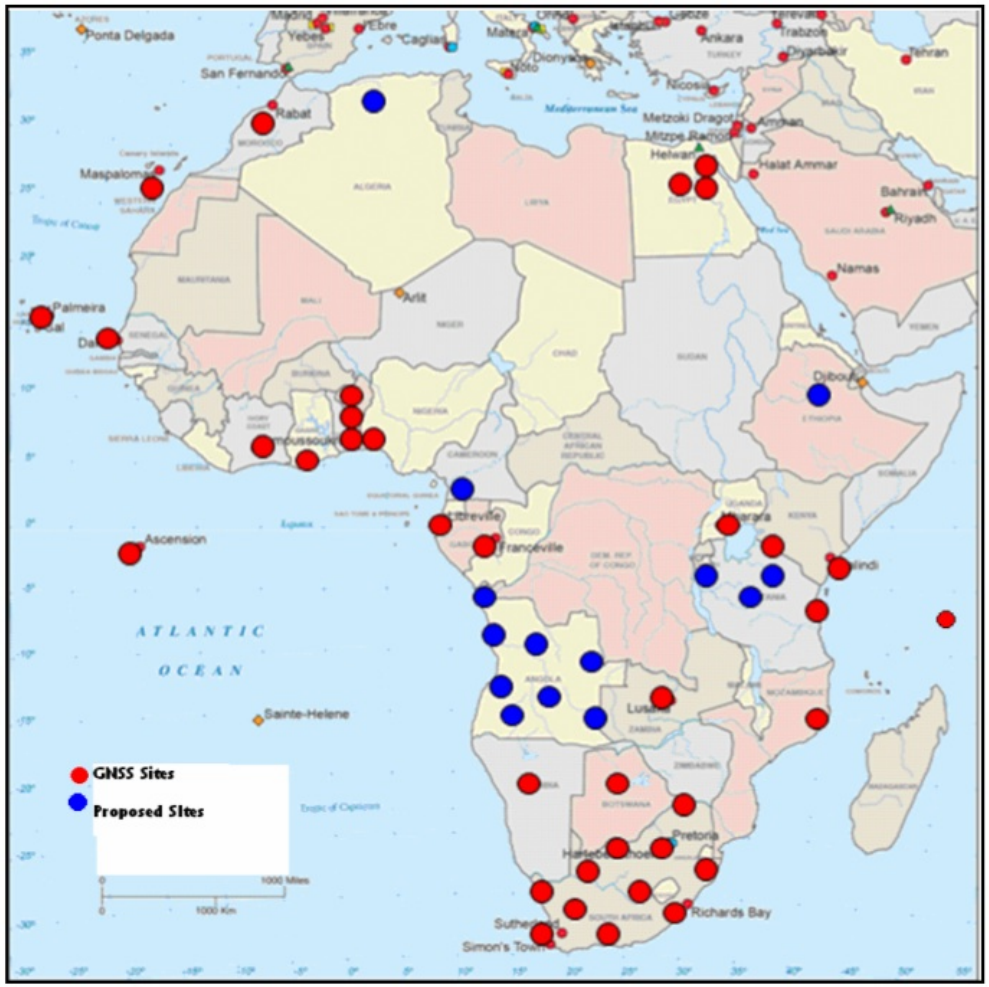
MODIS images of integrated column water vapor illustrate the interannual variability of the Inter-tropical convergence zone, linked to El Nino.



- GPS measurements of tropospheric water vapor in the SW Pacific showing the 1998 El Nino event.
- High accuracy and stability.
- Continuous time sampling => information at all temporal scales from diurnal to interannual variability.

A unified geodetic reference frame for Africa: AFREF

- Requirements similar to geophysics
- Other continents:
  - Japan > 2,000 GPS
  - North America ~2,000 GPS
  - Western Europe ~1,000 GPS
- Crucial importance of open data policy



Summary

- East African Rift remains the least understood of all major tectonic plate boundaries with first-order science questions at stake.
- Africa particularly vulnerable to climate change - regional models have large uncertainties.
- Critical lack of basic quantitative data:
  - How fast do plates move, is there magma movement at depth?
  - Amospheric water vapor: interannual variability and diurnal cycle data crucial to model long term climate in Africa.
- GNSS in Africa is key component for environmental monitoring: solid earth deformation and climate trends.
- Added benefits, e.g. unified reference frame for mapping applications.