

Contribution of Africa Geodesy to Geodynamics



2026 GGOS – Africa Workshop - Nairobi

Building the Foundation for Geodetic Excellence in Africa

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Geodynamics: How is the Earth changing in space and time?

What can we measure using Geodetic Tool :

- Position — Where a point is located
- Velocity — How rapidly it moves
- Acceleration/nonlinear motion — How movement changes with time
- Vertical motion — Uplift and subsidence
- Strain — How the crust deforms
- Gravity changes — Redistribution of mass
- Earth rotation — Changes in the orientation and rotation of the Earth
- Atmospheric and hydrological signals

**Geodetic observations → Deformation measurements →
Geodynamic interpretation**

Geodetic Data – GNSS – Gravity – Satellite Images (InSAR)



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Africa crustal Dynamics



Africa's tectonics are Dominated by

- The Relative Motion of the two large Tectonic Plates (**Nubia and Somalia**), which are slowly rifting. (Somalia Rifting East – South Direction + Three Smaller Subplates VP, RP and LP quantified more than a decade ago
- The Motion collide with the Arabia and Eurasian Plates to the north, forming mountain ranges e.g the Atlas.

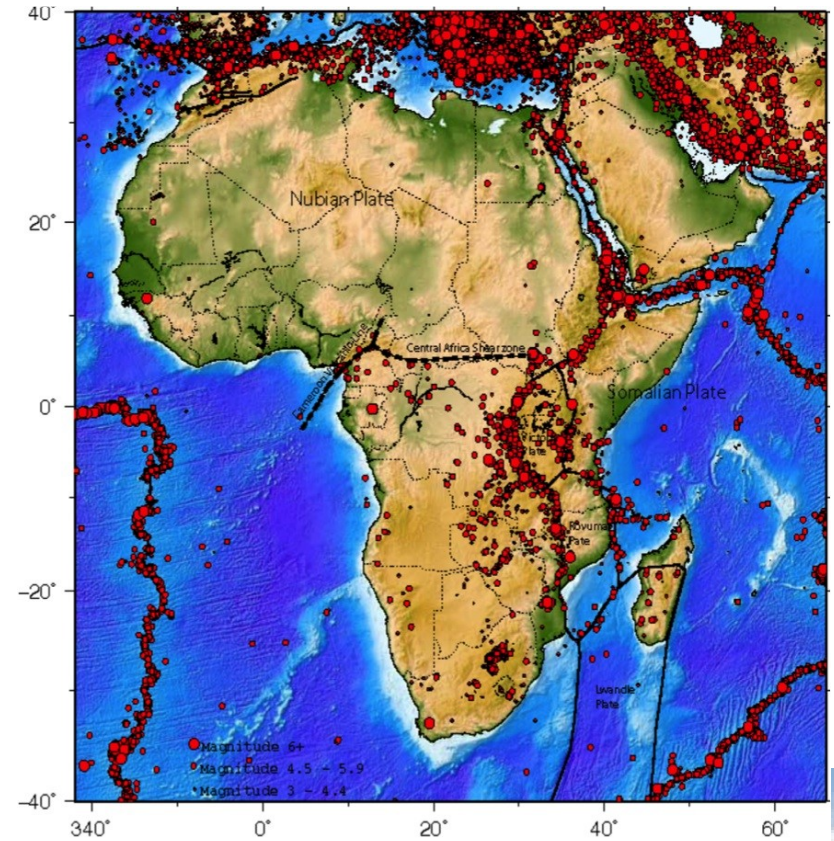


Key features include

- The spreading divergent boundaries along the Mid-Atlantic Ridge to the west and South West Indian Ridges (SWIR)
- And the East African Rift (EAR)

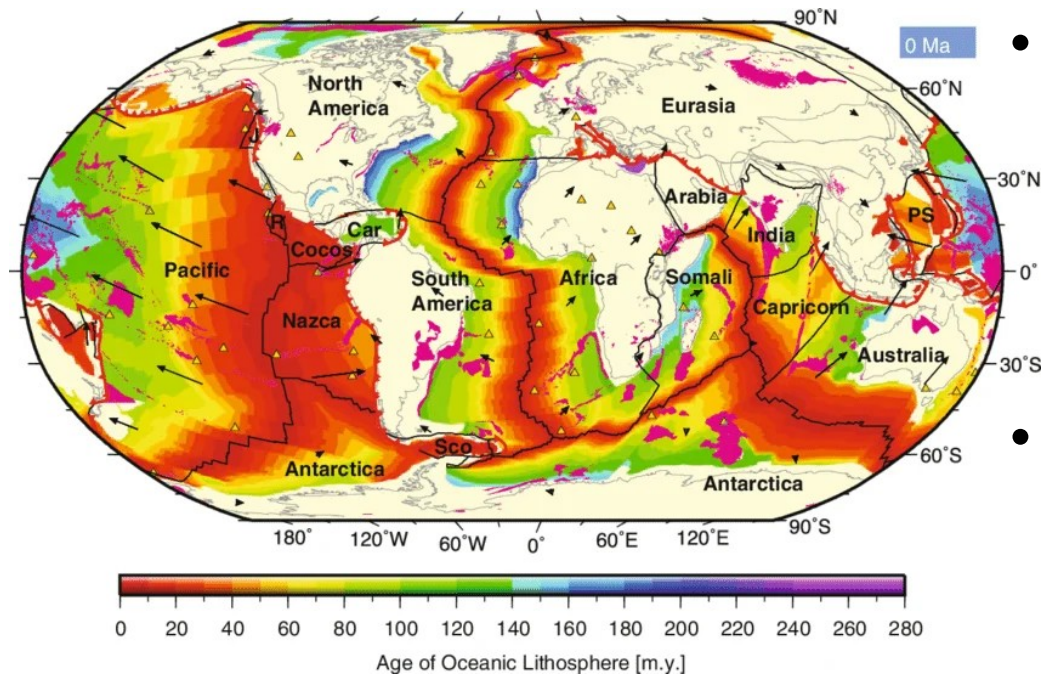
Results are

The continent tearing apart shaping modern Africa and its future landscape, creating volcanoes and earthquakes



Africa Geodynamics before 2000

- Geodynamics had developed from a predominantly geological discipline
- Data – Spreading Rates + Transform Fault Azimuth



- Global plate motion model **1960s–1970s** used Sparse Marine anomaly data. e.g. Chase (1978), Le Pichon (1968), Minster & Jordan (1978), and Morgan (1968)
- Global plate motion model **NUVEL-1 and NUVEL-1A (1990–1994)** – Used more Marine anomaly data e.g. from mid-ocean ridges
- In 2000 First model **REVEL (2000)** started using Geodetic Data Augmenting in the Geological Data



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Sella 2002 and Prawirodirdjo - 2004

■ Sella 2002:

1st Geodesy based study:

Global Plate motion model

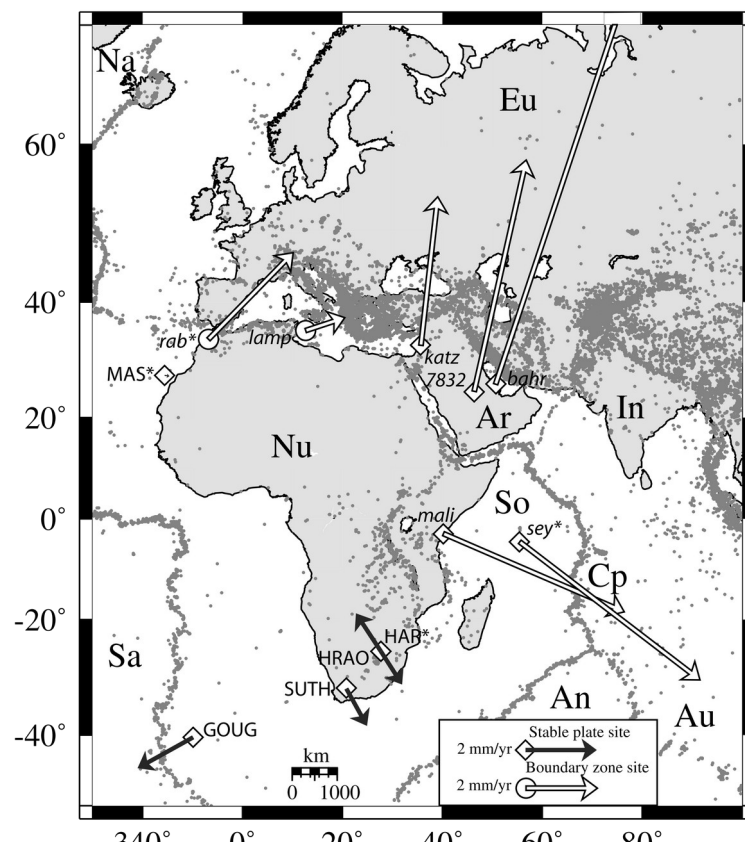
Evaluated Motion Somalia wrt Nubia - Using 3 sites on Somalia and 5 sites on Nubia
3 from SA



■ Prawirodirdjo and Bock 2004:

2nd Geodesy based study: **Global plate motion**

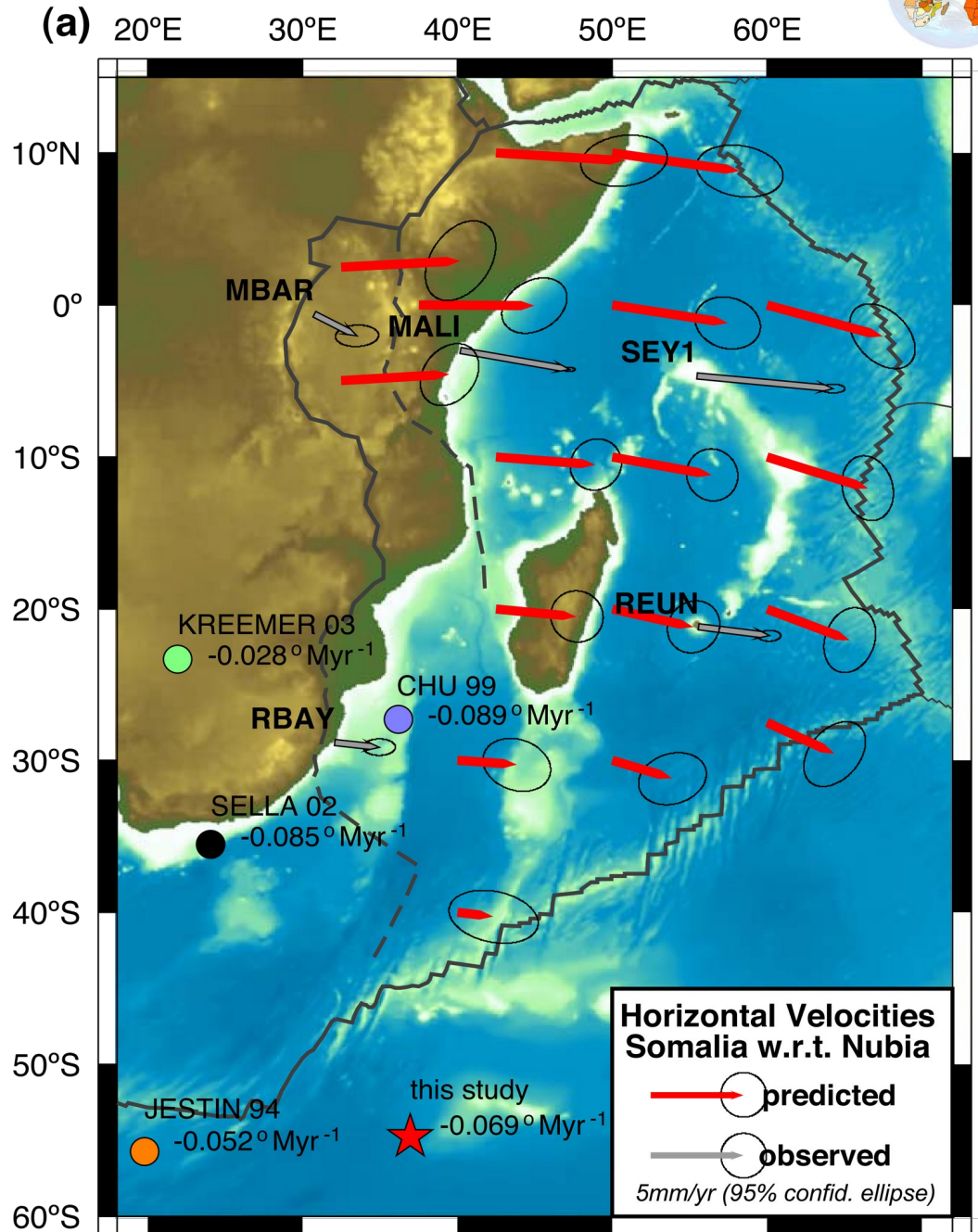
Evaluated Motion Somalia wrt Nubia
- Using 3 sites on Somalia and 7 sites on Nubia



Geodetic solution
from increase
sites in Africa

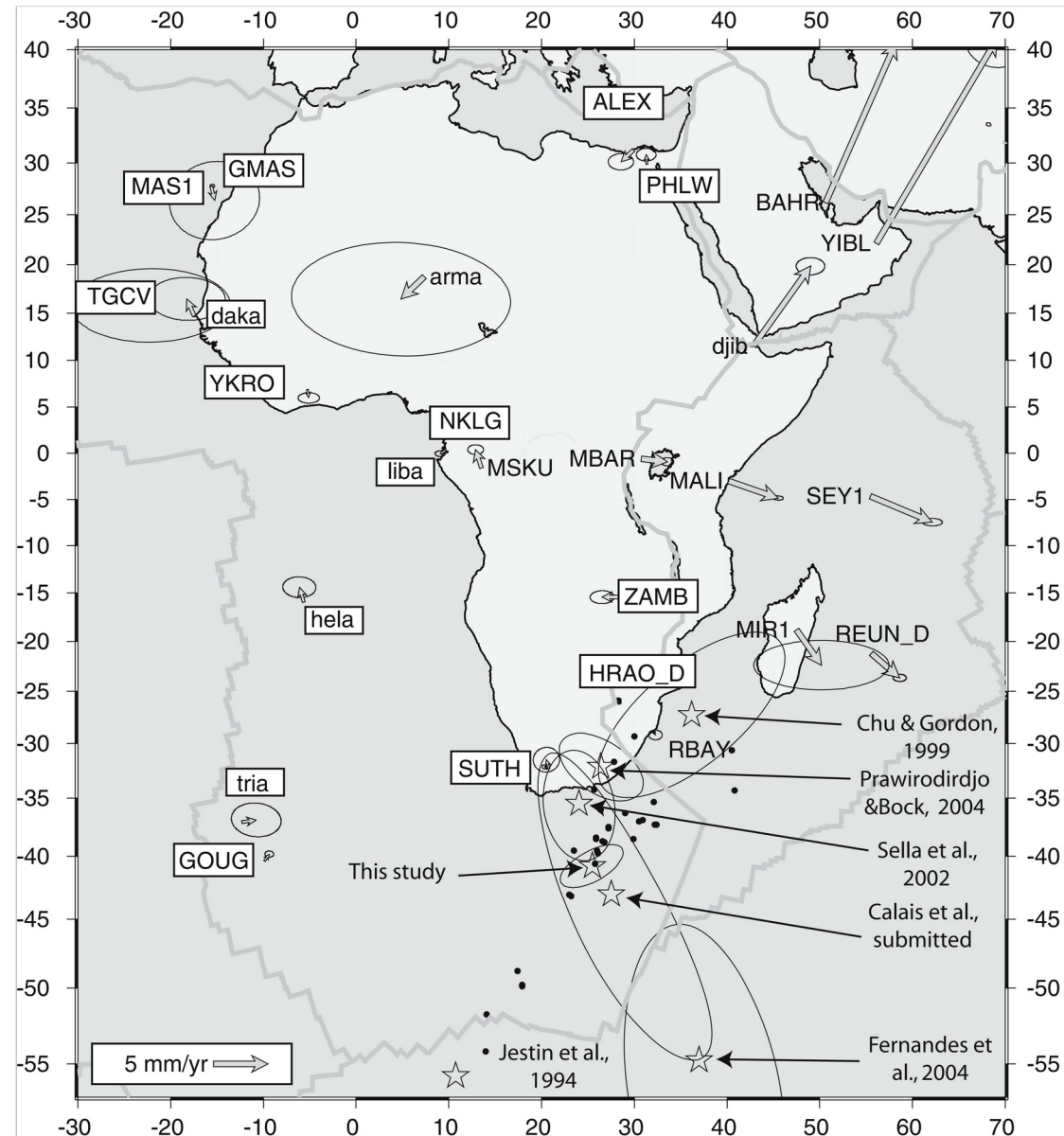
Evaluated Motion
Somalia wrt Nubia

- Using 4 sites on
Somalia and 10
sites on Nubia



Evaluated Motion
Somalia wrt Nubia
using combined
DORIS and GPS
solution

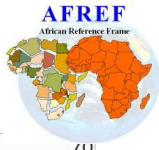
16 Sites on Nubia (5
DORIS and 11 GPS)
5 sites on Somalia





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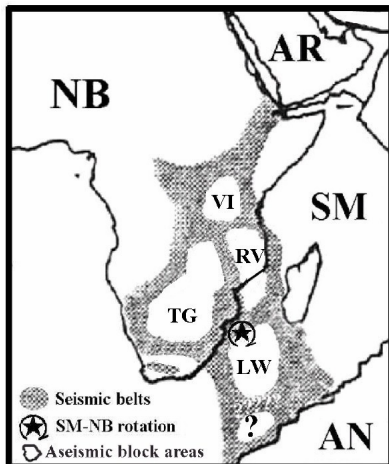
Calais et al., 2006



Evaluated Motion
Somalia wrt Nubia
using GPS solution +
ESV for Victoria

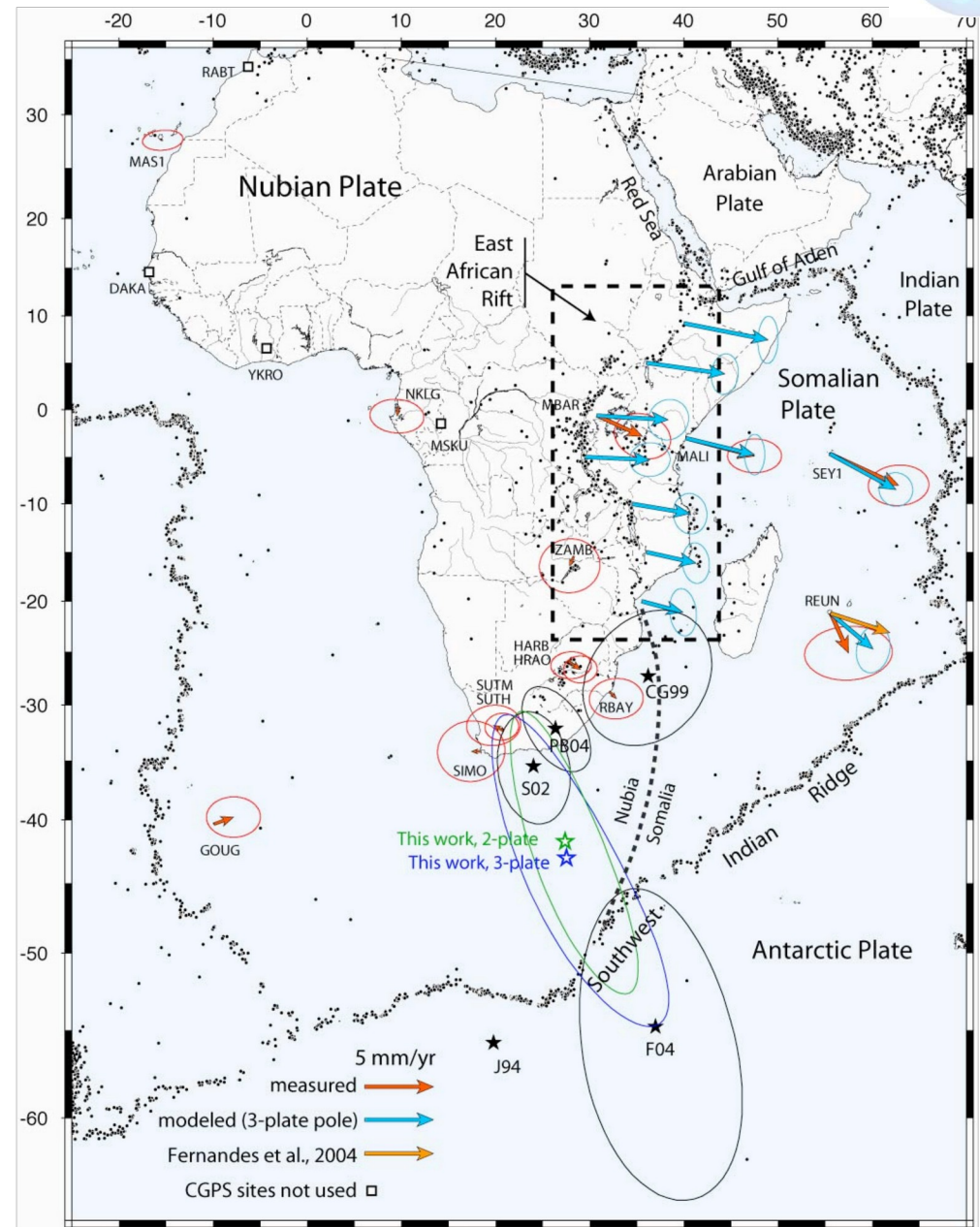
5 GPS Sites on Nubia
3 or 4 sites on Somalia

*MBAR proposed to belong to
Victorian Plate*



After
Hartnrad
2002

Geology
suggested
blocks





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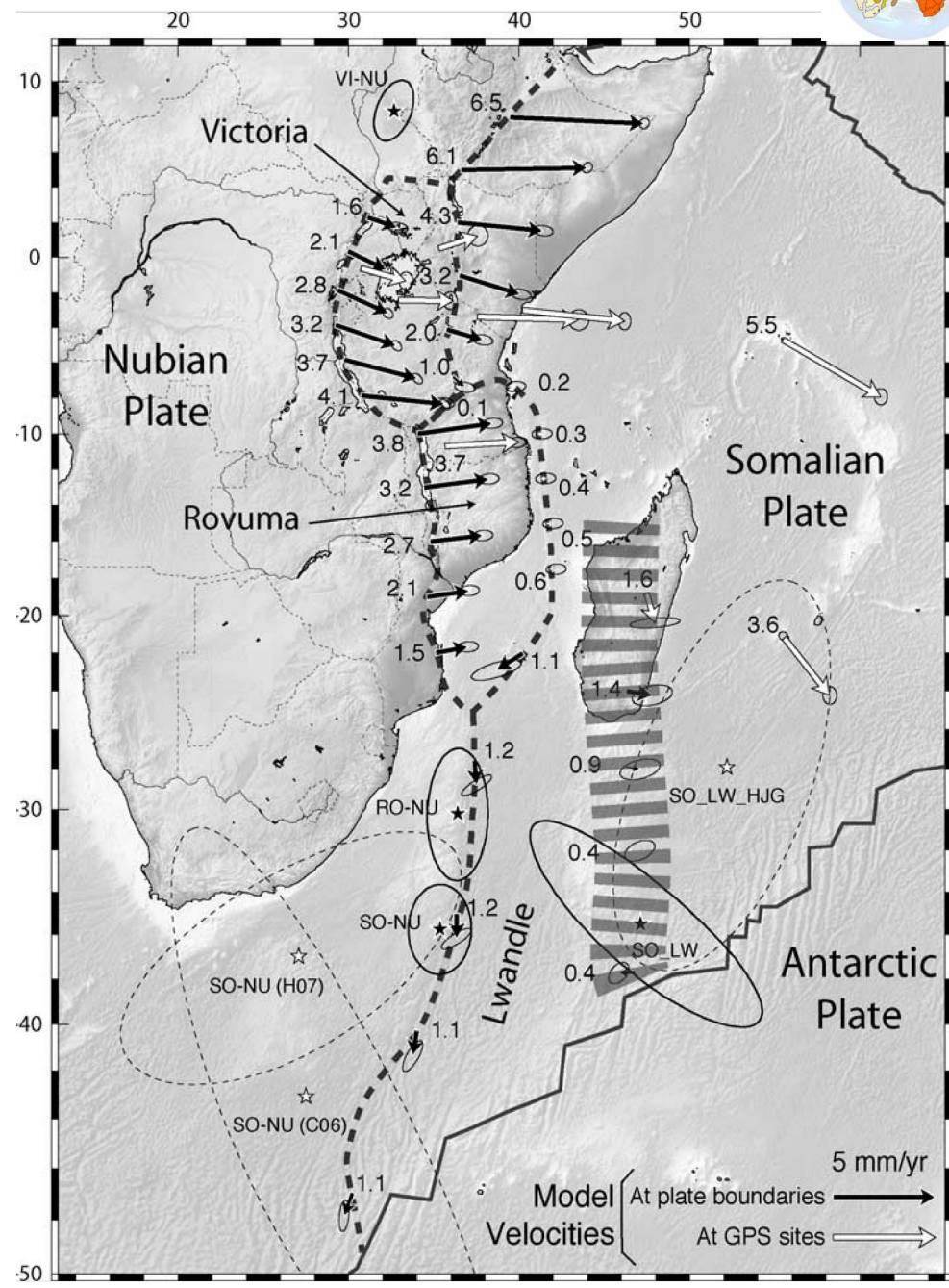
Stamps et al., 2008

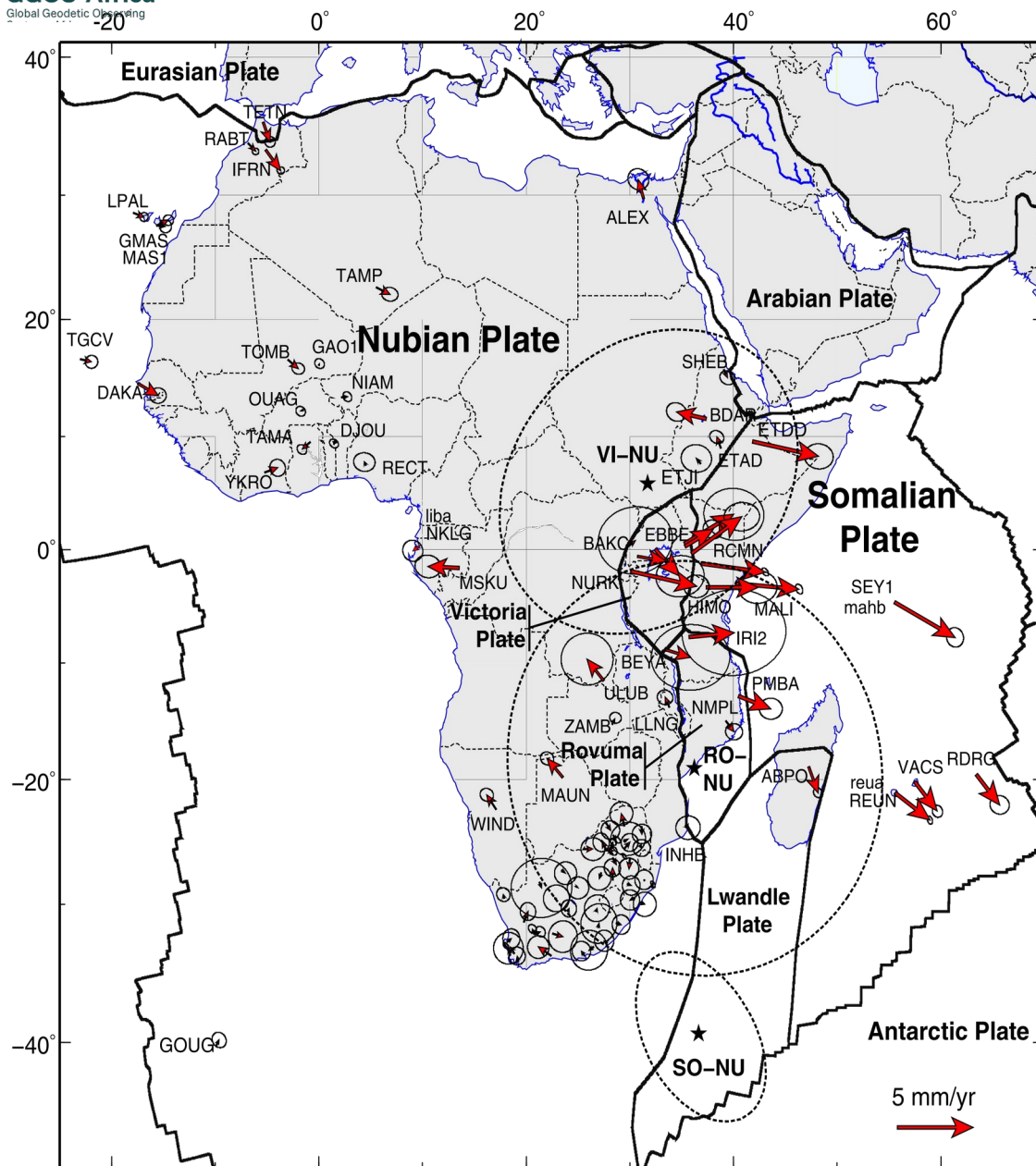


Evaluated Motion Somalia
wrt Nubia using combined
DORIS and GPS solution +
Geophysical and
Geological Data

15 Sites on Nubia (5
DORIS and 10 GPS)
5 sites on Somalia + ESV
+ increase Geologic Data

2 Site on Victoria + ESV
1 Site on Rovuma + ESV
ESV + Geology - Lwandle





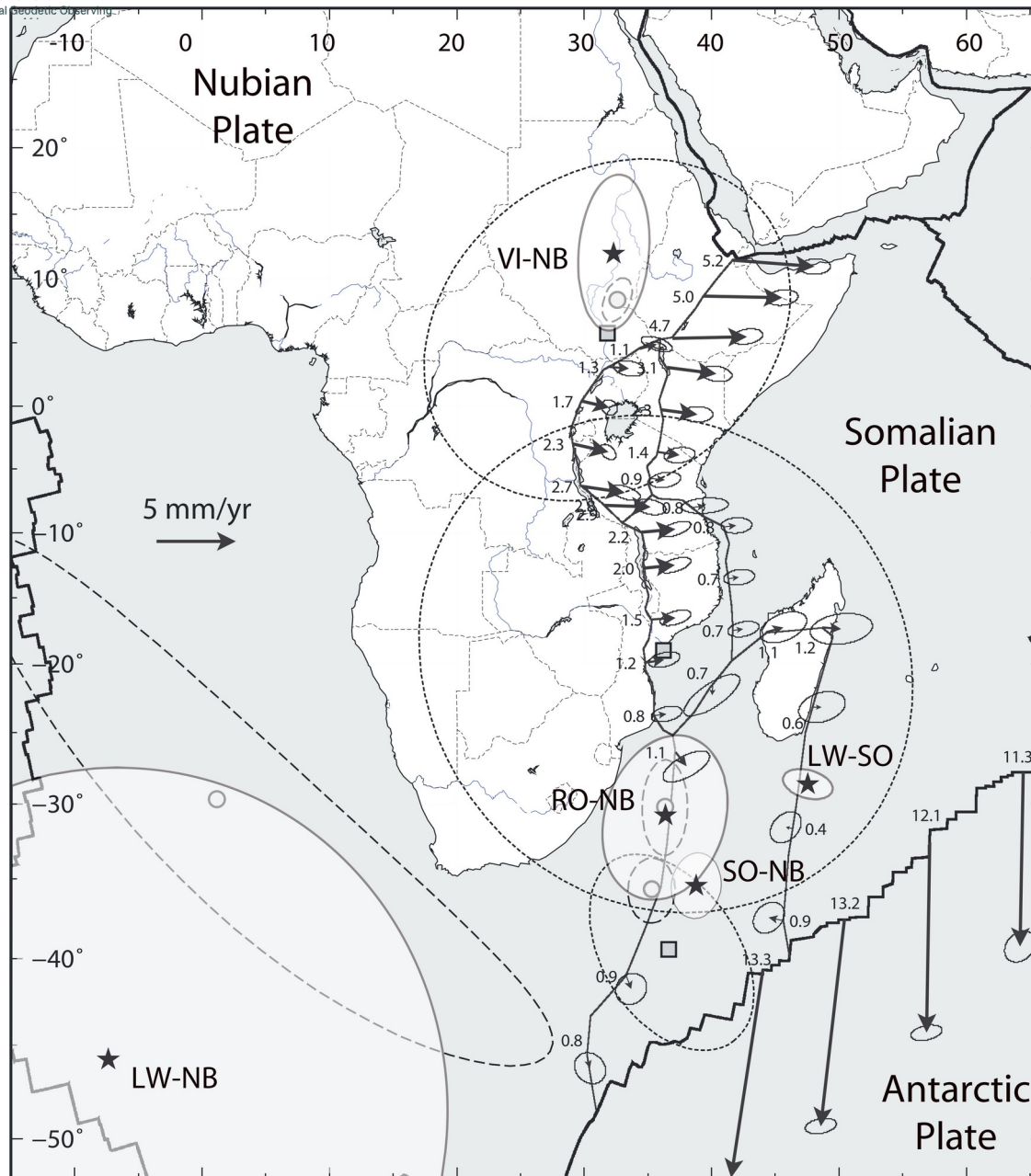
GPS + DORIS Data

- Nubia define ~40 sites with WRMS ~0.6mm/yr
- Somalia and Nubia are well determined
- Rovuma and Victoria are poorly determined => Not very good sites in the region
- Lwandle was yet to be determined – Only one site exist



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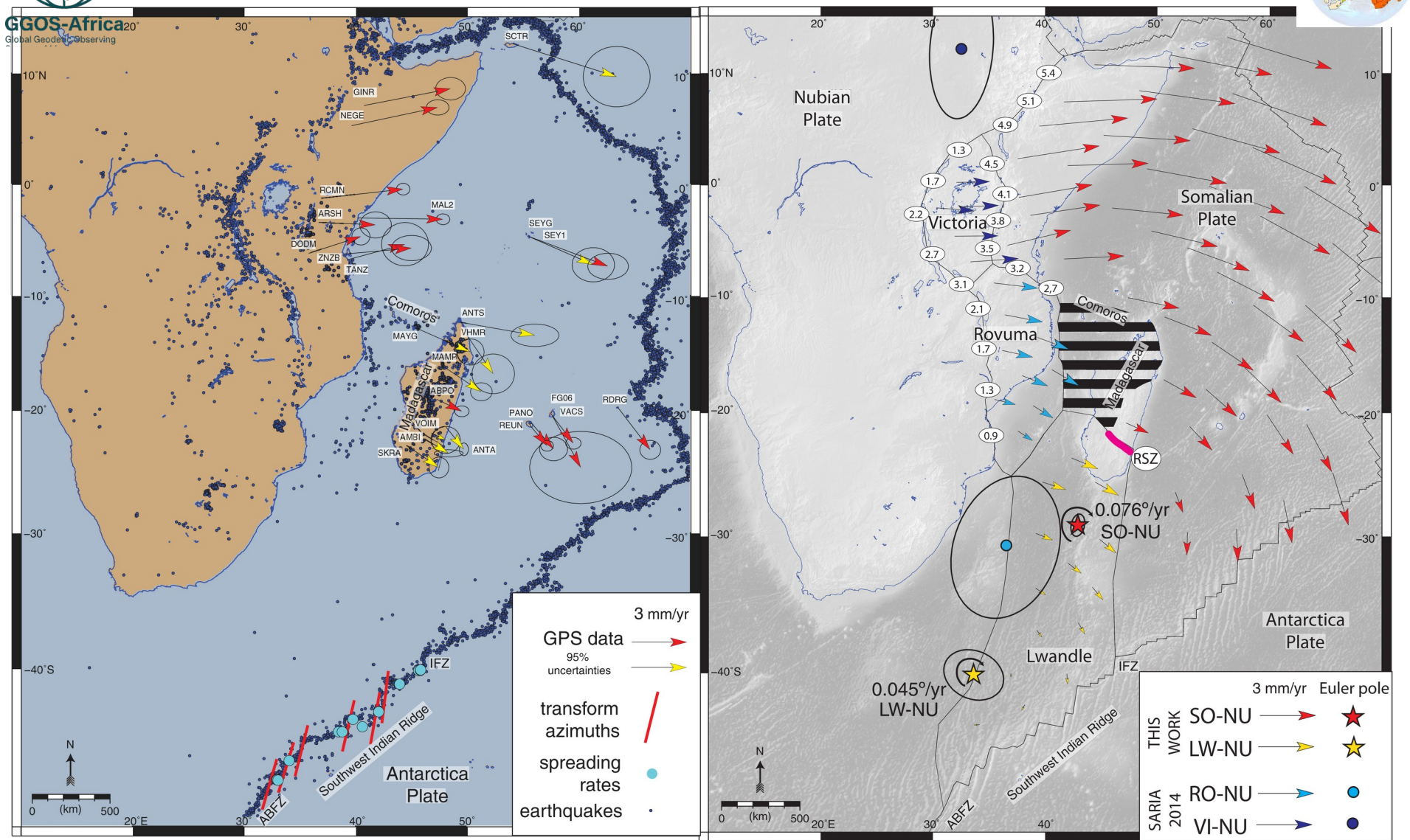
Saria et al., 2014



- GPS solution - 149 sites, including campaign measurements
- ESV + TFZ + SR along the SWIR
- Victoria and Rovuma only use GPS and ESV
- Nubia, Somalia, Lwandle use GPS, ESV, TFZ and SR
- **More data than previous studies:**
 - GPS > 200% increase
 - ESV > 50%
 - TFZ+SR = 0%, however improved uncertainties



Stamps et al., 2021 – Redefining EAR Kinematics

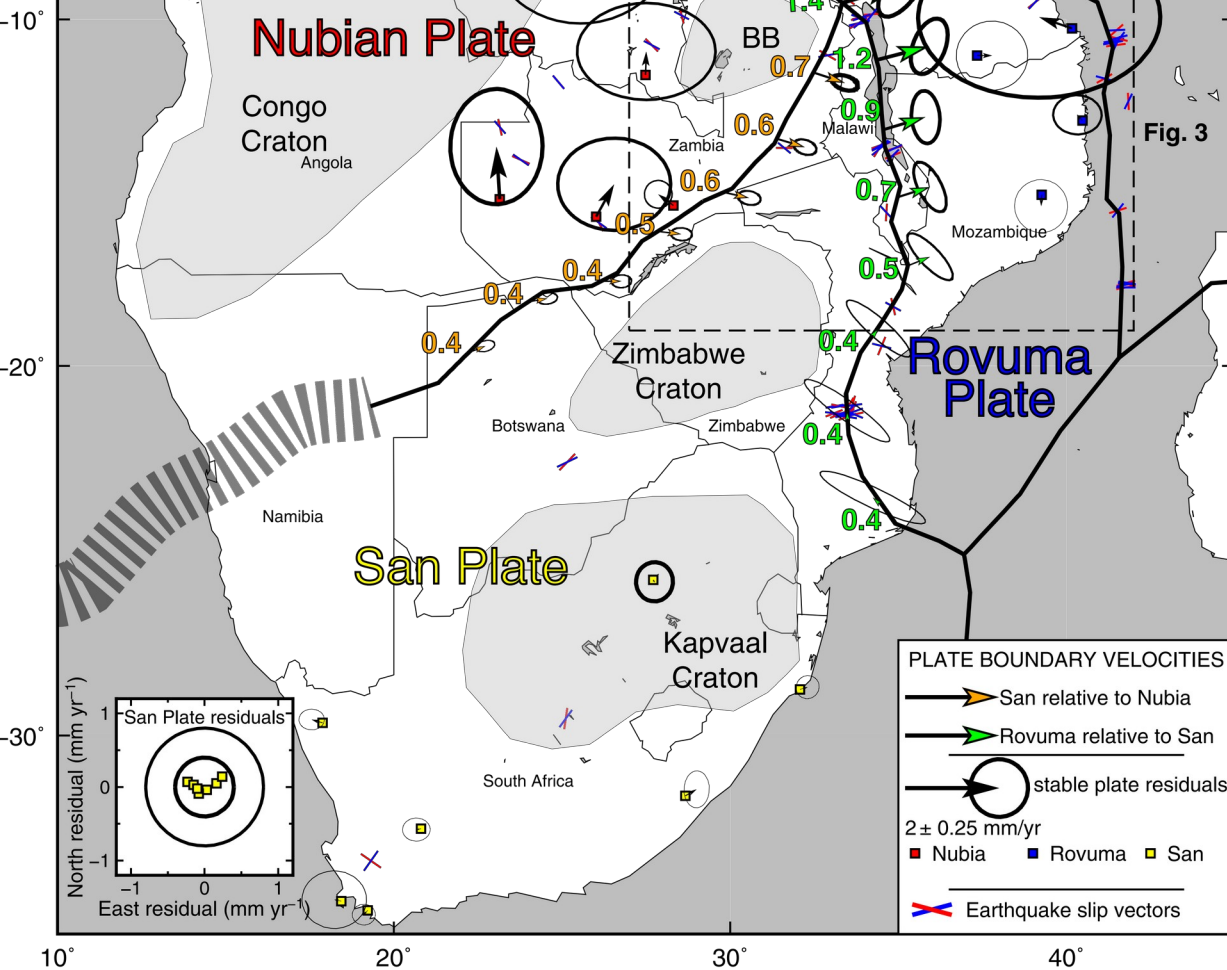


Used Saria et al., 2014 data Plus Additional GNSS data on Samalia and Lwandle (Madagascar)



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Wedmore et al., 2021



RF - realized on rigid part of the continent (e.g. *EUREF*, *NAREF*)

○ To be consistent through time with little or no distortion

AFREF- to be realized on Nubia

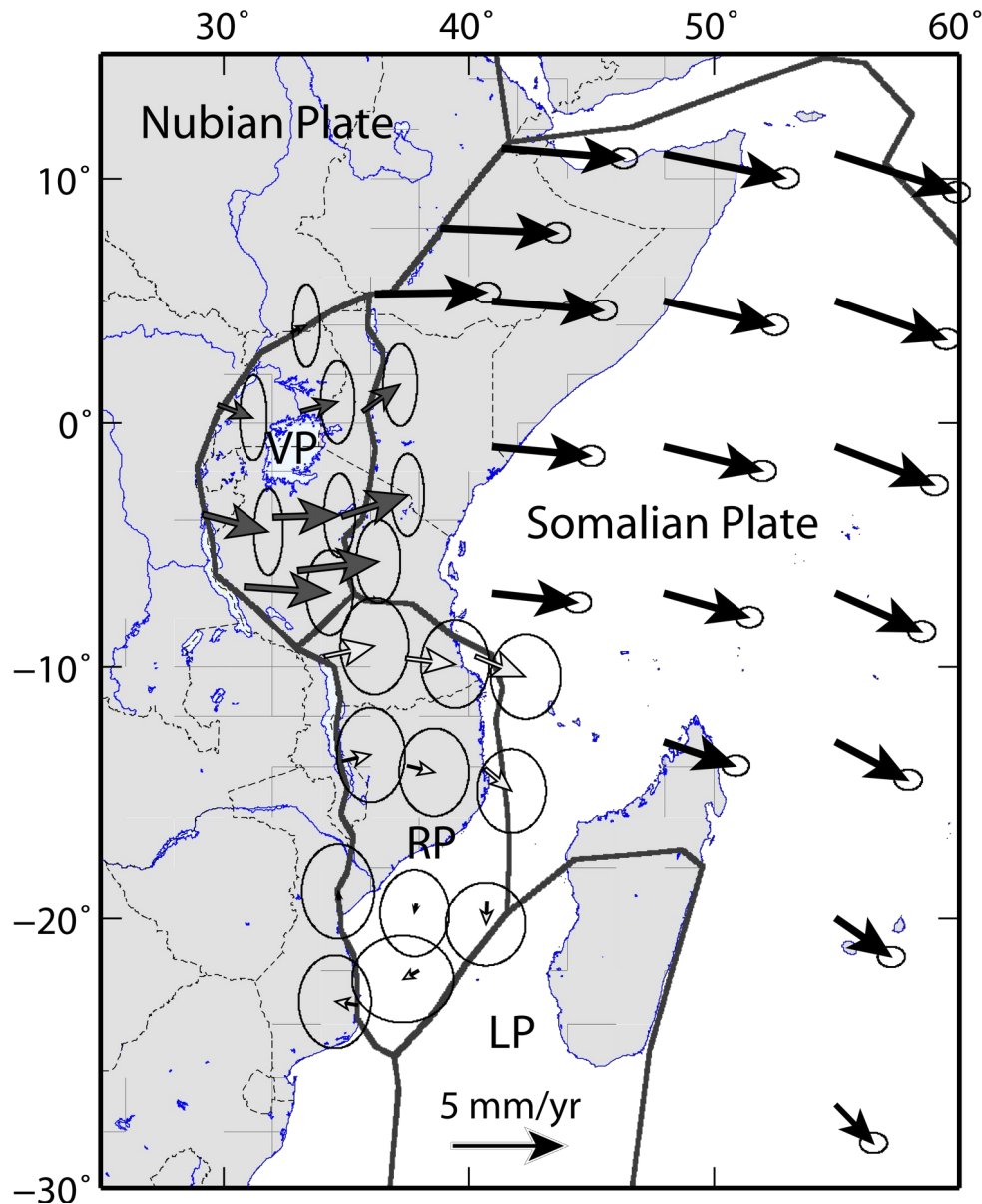
- “San” microplate - Distinct from Nubia, with deformation of 0.4–0.7 mm/yr

AFREF definition requires to understand

○ Present-day kinematics of Nubia (& level - internal deformation)

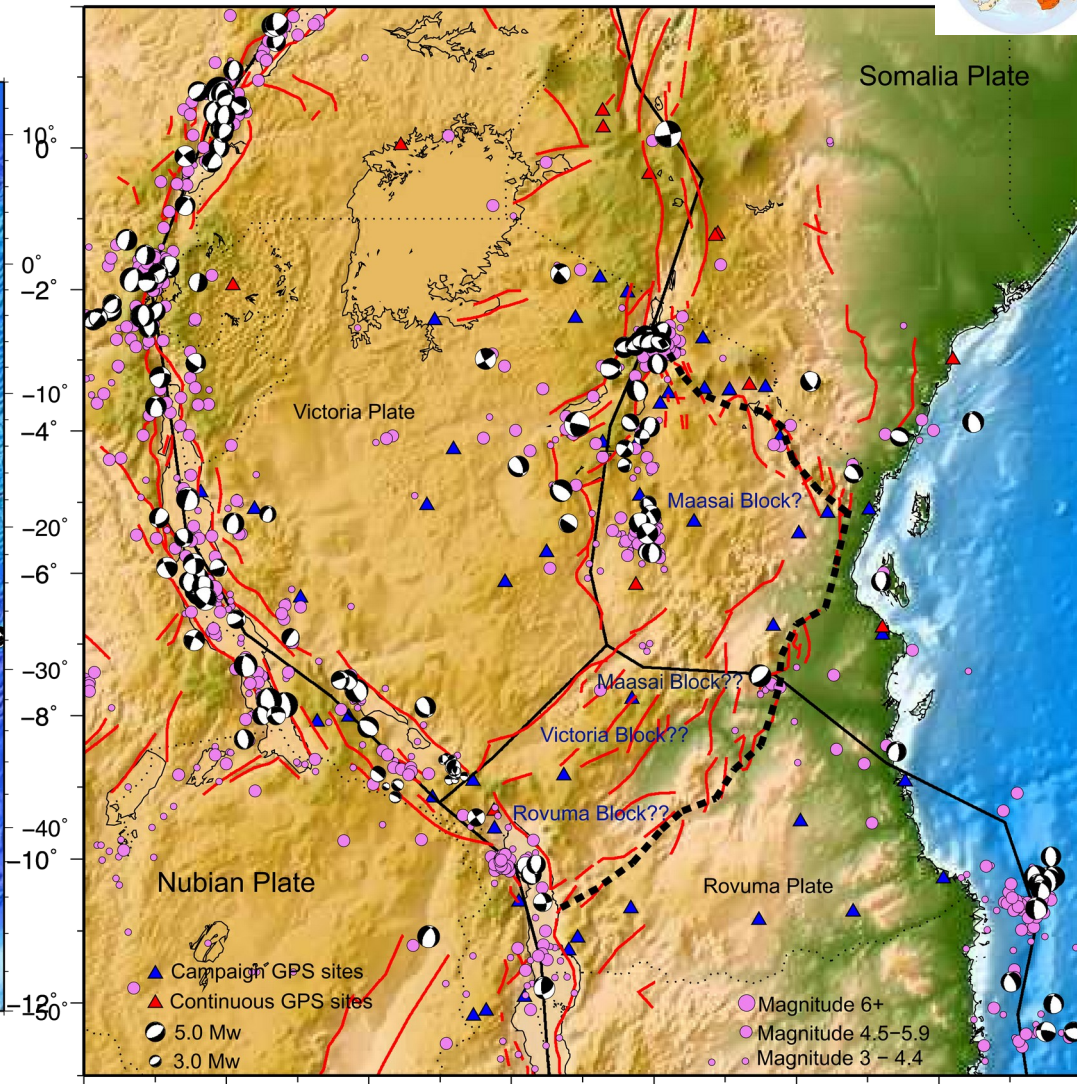
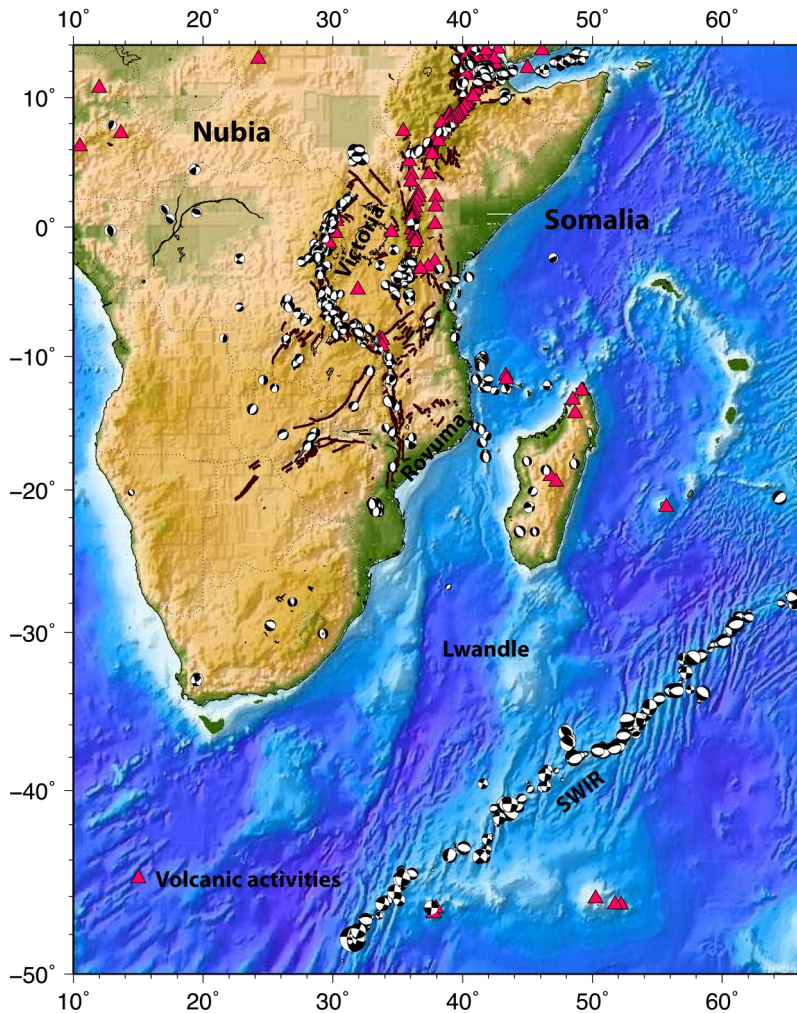
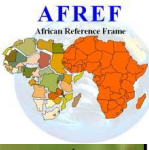
○ Kinematic of the EAR

Implication for Practical Reference Frame Usage



- Nubia = WRMS 0.6mm/yr
 - Practical to Surveyor?
 - For 2cm = ~30 yrs
- East African Rift: from Tanzania-Ethiopia ~4-5 mm/yr
- Implication for surveyors?
 - For 2cm = ~5yrs (significant)
 - Solution: realize a dynamic or semi Dynamic frame

Tectonic Structure of the East African Rift

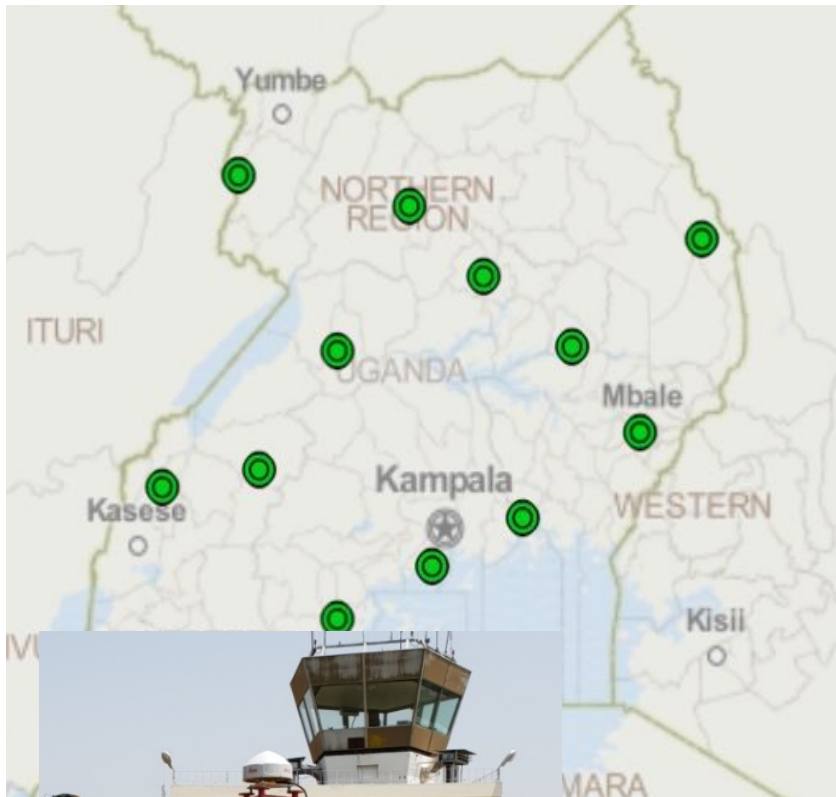


- Mapped faults (mostly normal fault)
- Seismicity (focal mechanisms)
- Volcanoes

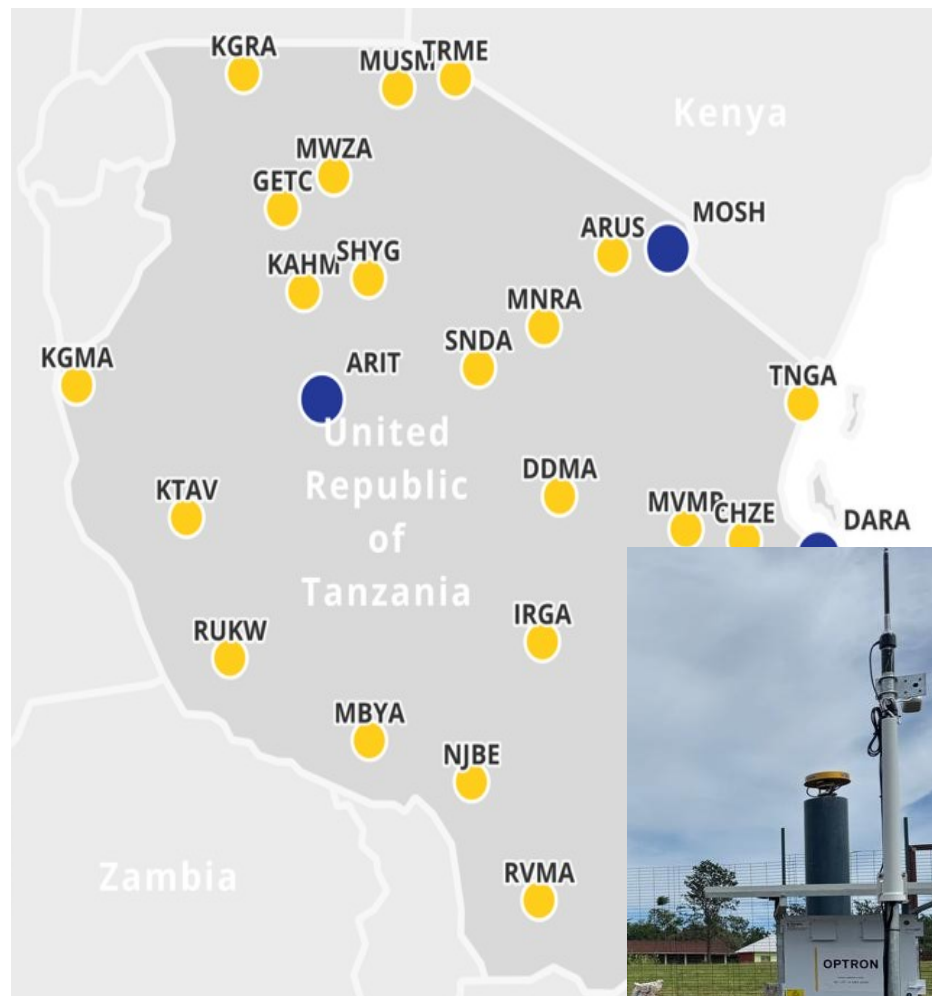
Tanzania
The Most Tectonically
affected Country

Increased Geodetic Infrastructure

GNSS CORS in Uganda



GNSS CORS in Tanzania





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Next AFREF Project

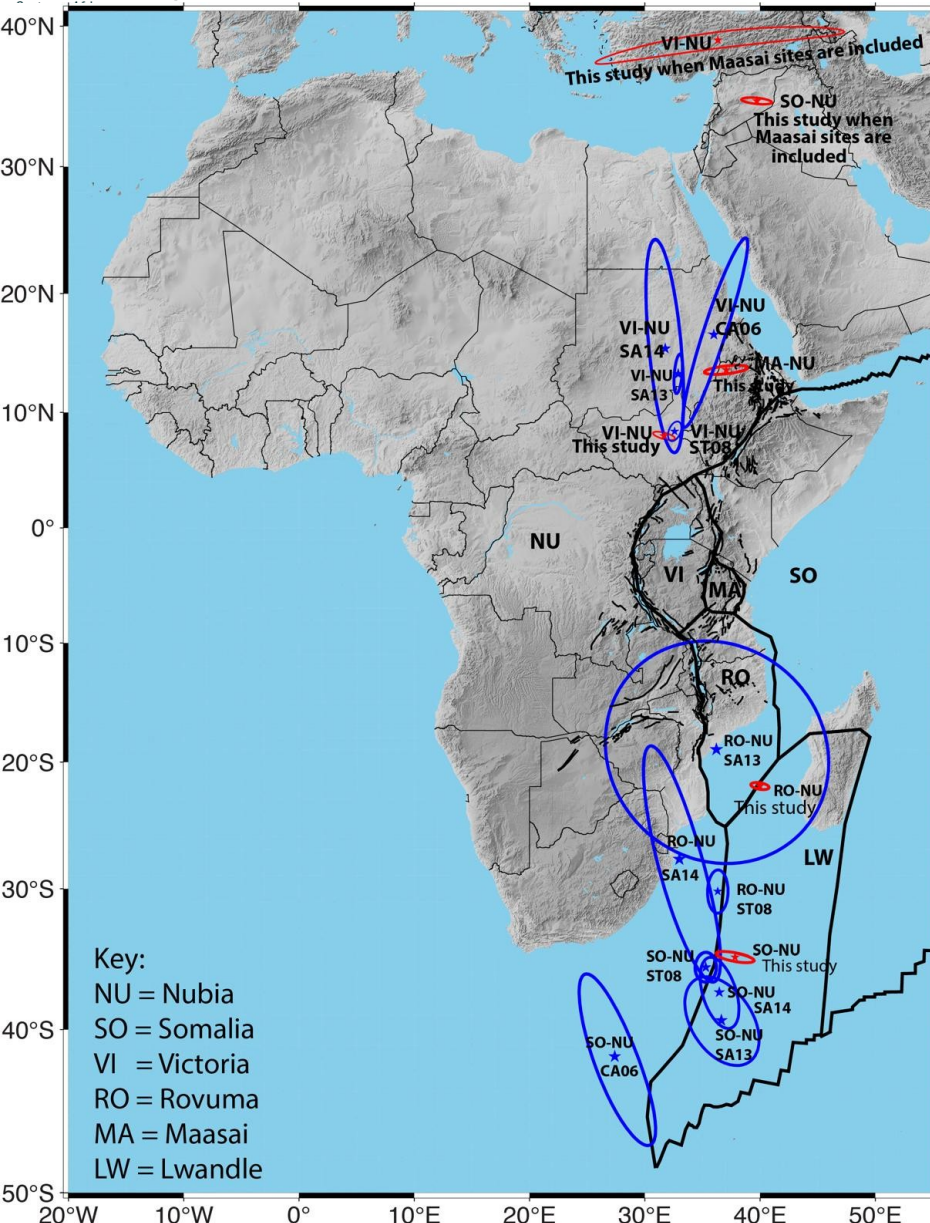
A Complete AFREF Model requires

Nubia, Somalia, Maasai, San, Victoria, Rovuma and Lwandle

Quantified

More rigorous Geodetic computation on available GNSS (IGS + CORS) network from A-ACs is planned to be 2027 – 2028 = AFREF Solution

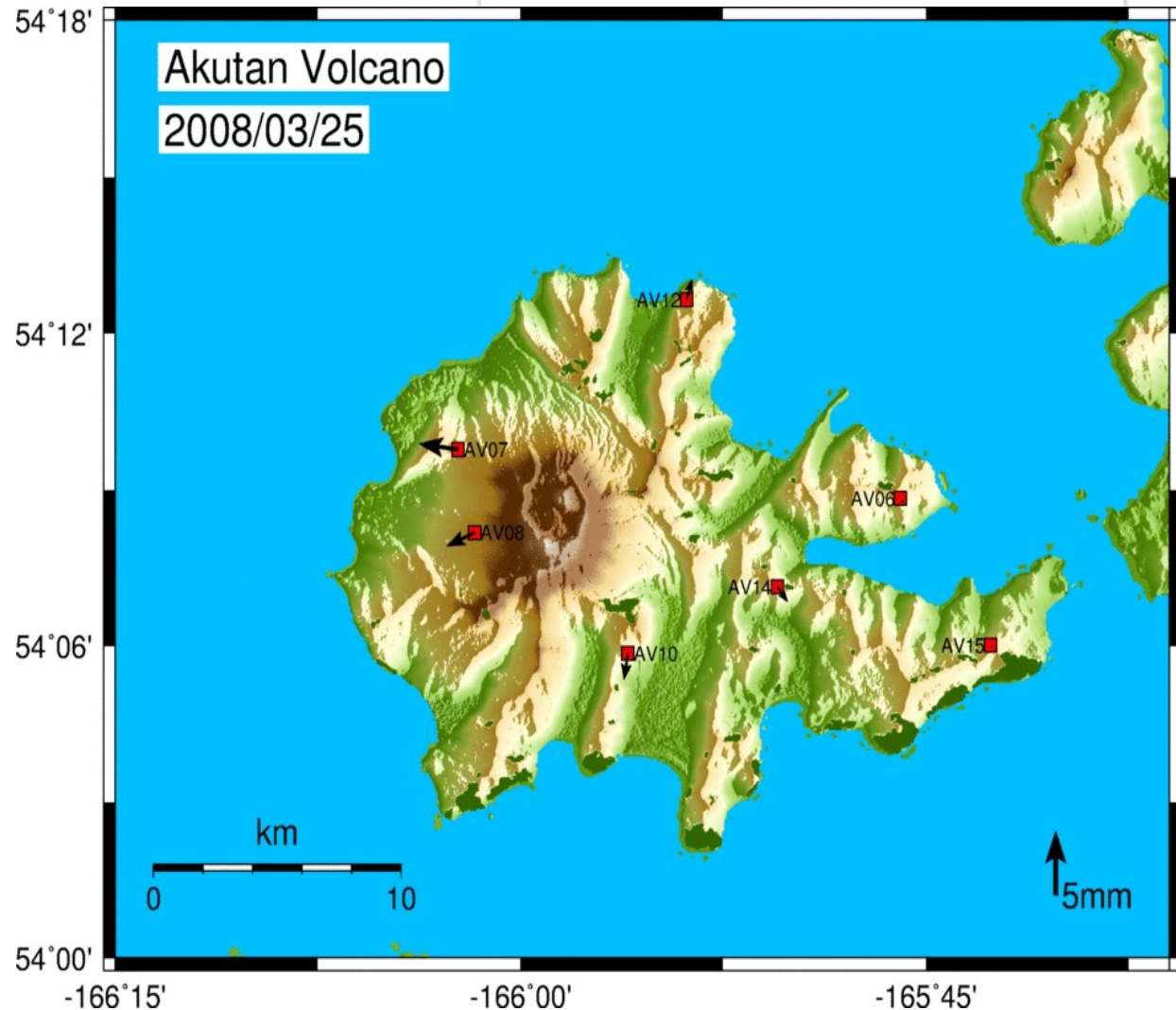
Then a test will be conducted to see if the data fit better with 7 Blocks (NU, SA, SO, VI, RV, MS, LW) or Fewer Blocks –= AFREF tectonic Model



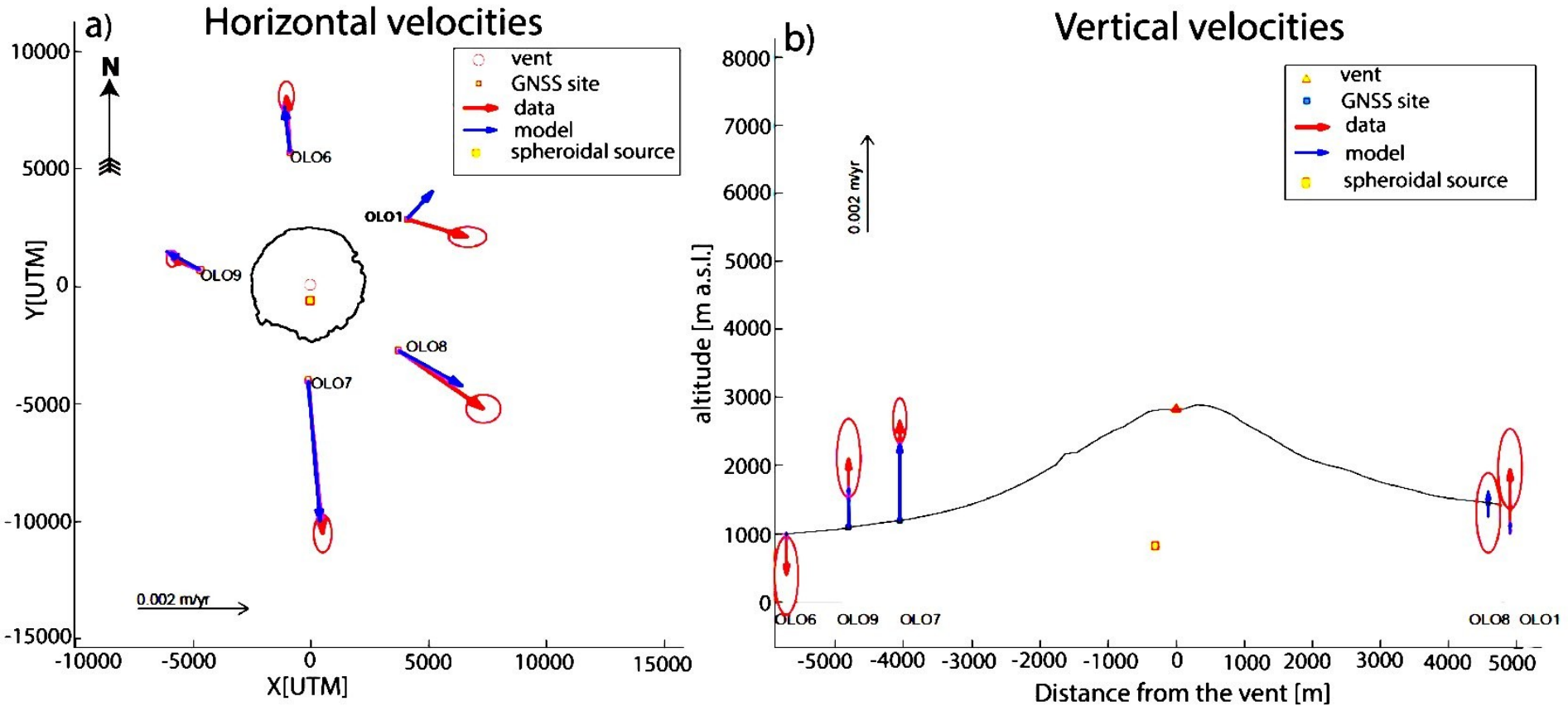
Geodetic Obsns Can Detect Localized Deformation

Example GNSS/GPS network in Alaska
2008 - 2015

- GPS can detect stress build-up from **volcanic deformation**
 - *Magma chambers beneath volcanoes inflate and deflate from movement of magma and causes surface deformation of mm/yr to cm/yr*

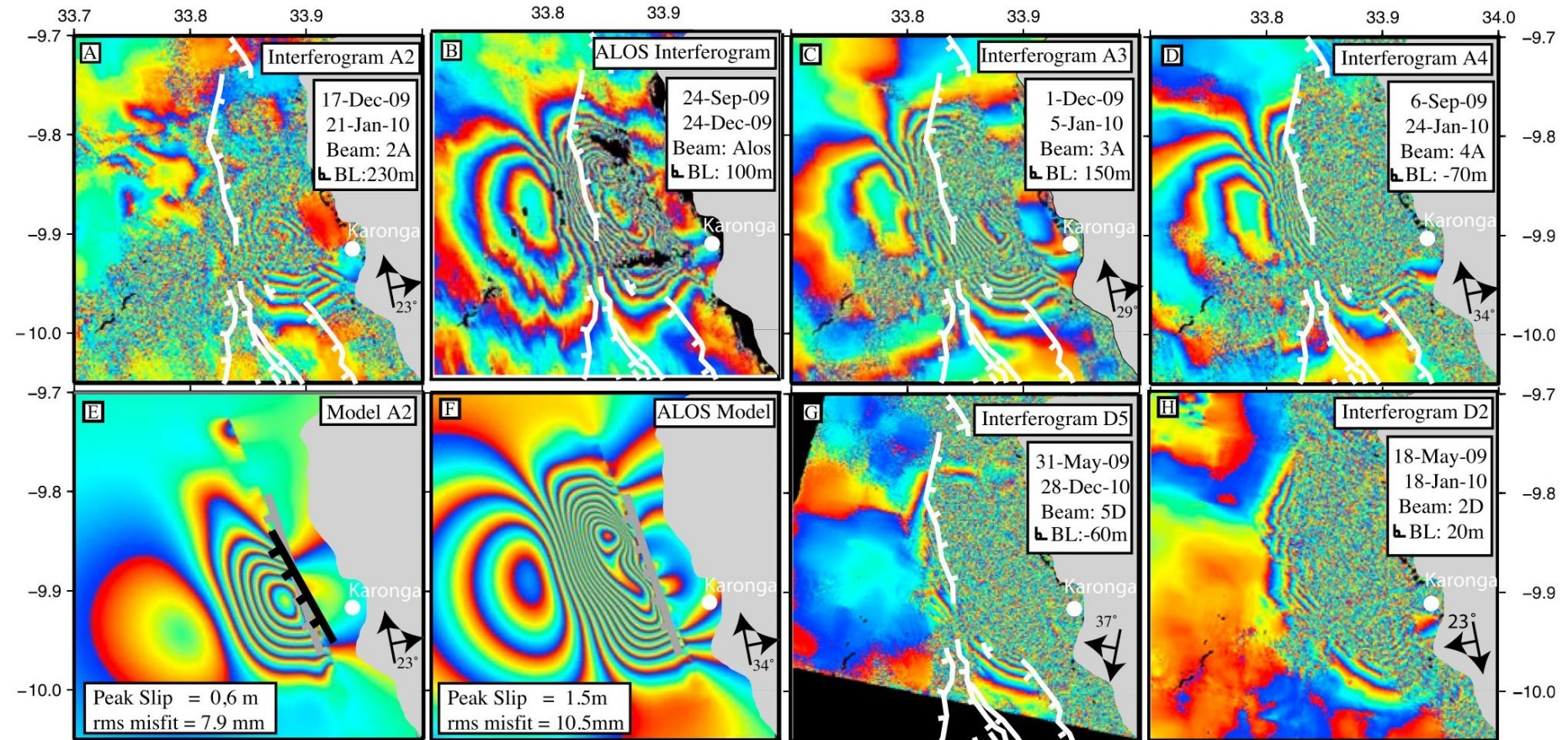


Geodetic Obsns Can Detect Localized Deformation



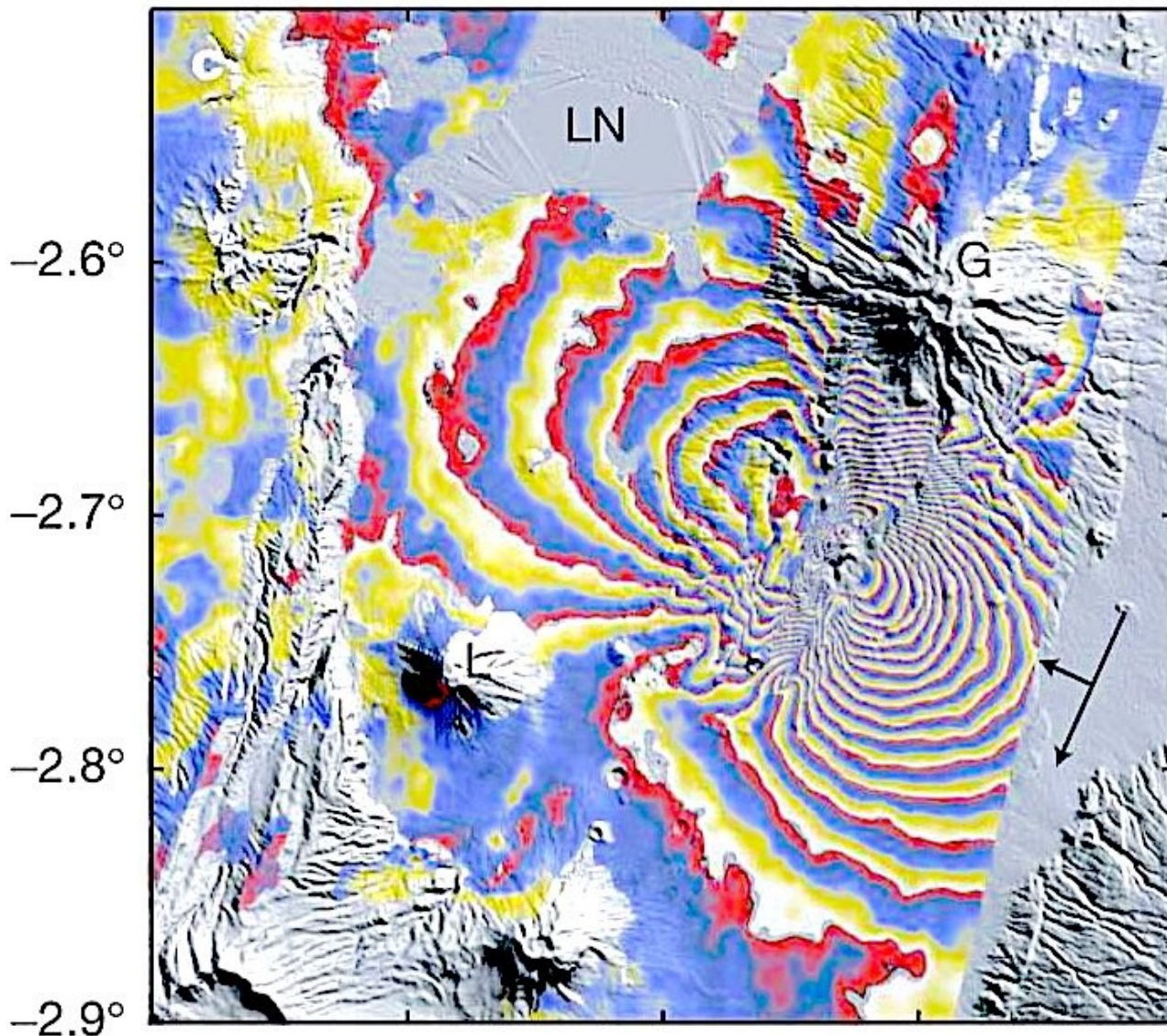
TZVOLCANO Project - Monitoring Inflation – Deflation of Oldoinyo Lengai Volcano in Arusha Tanzania

Geodetic Obsns Can Detect Localized Deformation



Envisat Interferograms for the 2009 Karonga earthquakes

Geodetic Obsns Can Detect Localized Deformation



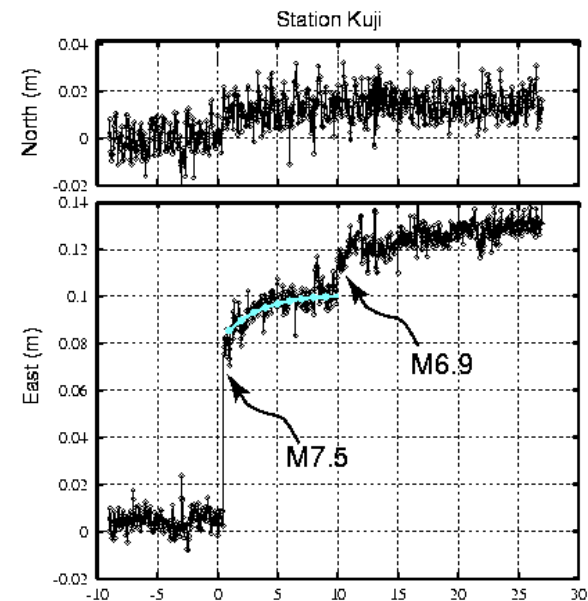
Phase Change for the 2008 Oldoinyo Lengai Arusha earthquakes



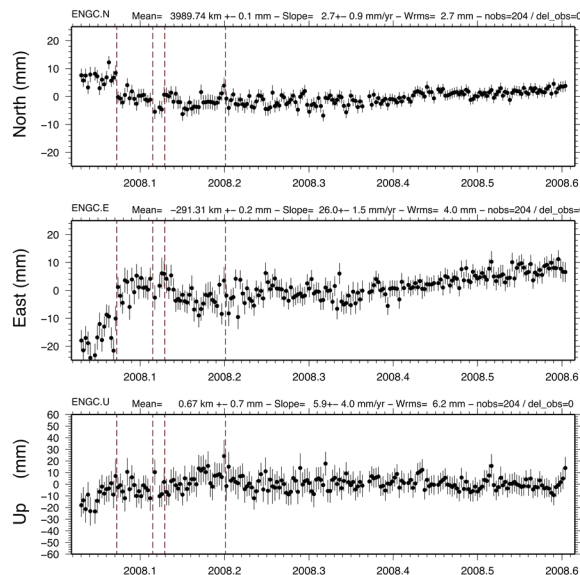
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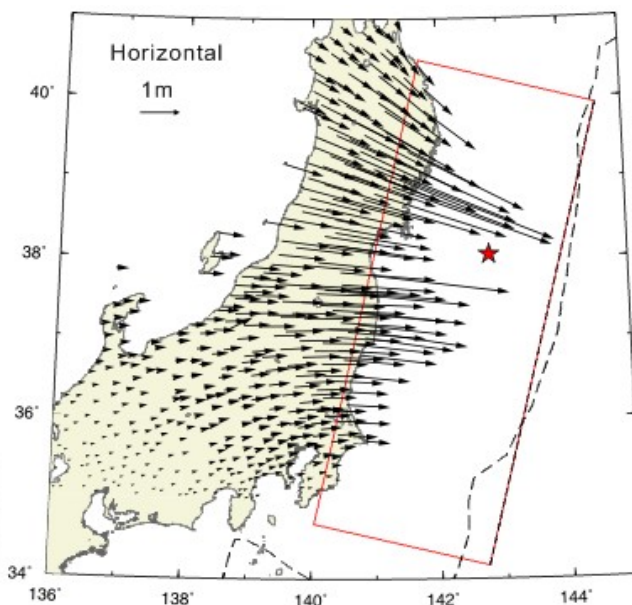
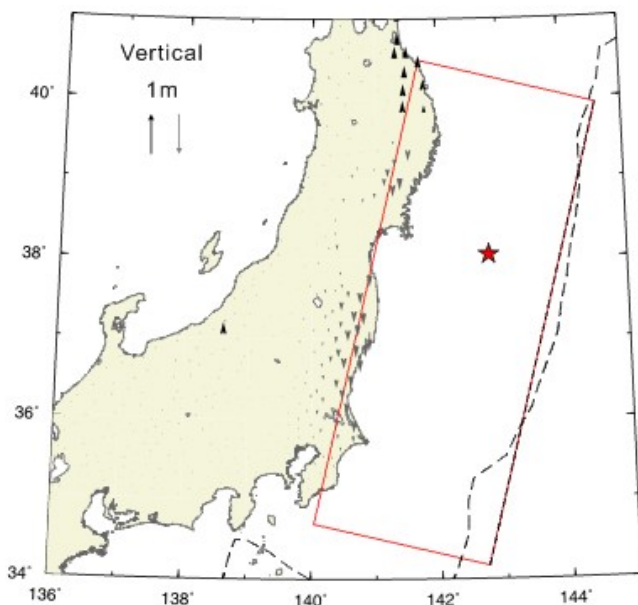
Applications Seismic Deformation



**Inter – Co
– and
Post-
Seismic
EQ event
In Japan**



**Post and
Inter-
Seismic EQ
event In
Tanzania
2008**



**Co-Seismic EQ
event In Japan**

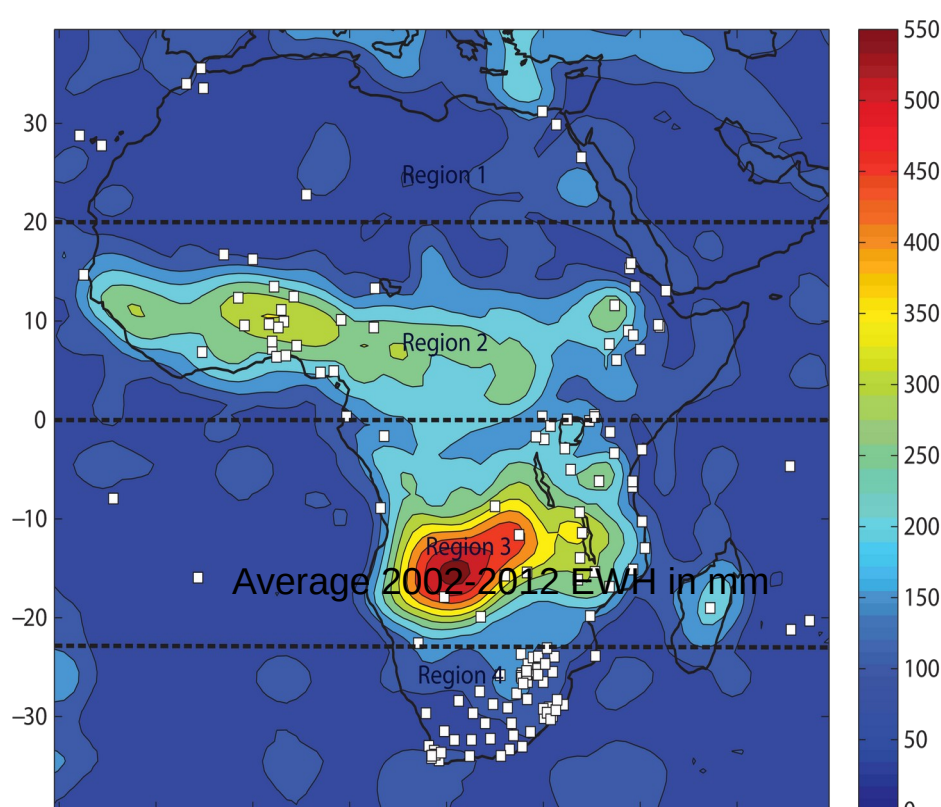
2011

TSUNAMI Event



EWH and Ground Displacements - GRACE

- Gravity field can then be converted into equivalent water height (EWH)
- EWH is a load acting on the (elastic) Earth, which causes deformation
- EWH varies seasonally, so does deformation => time-varying deformation



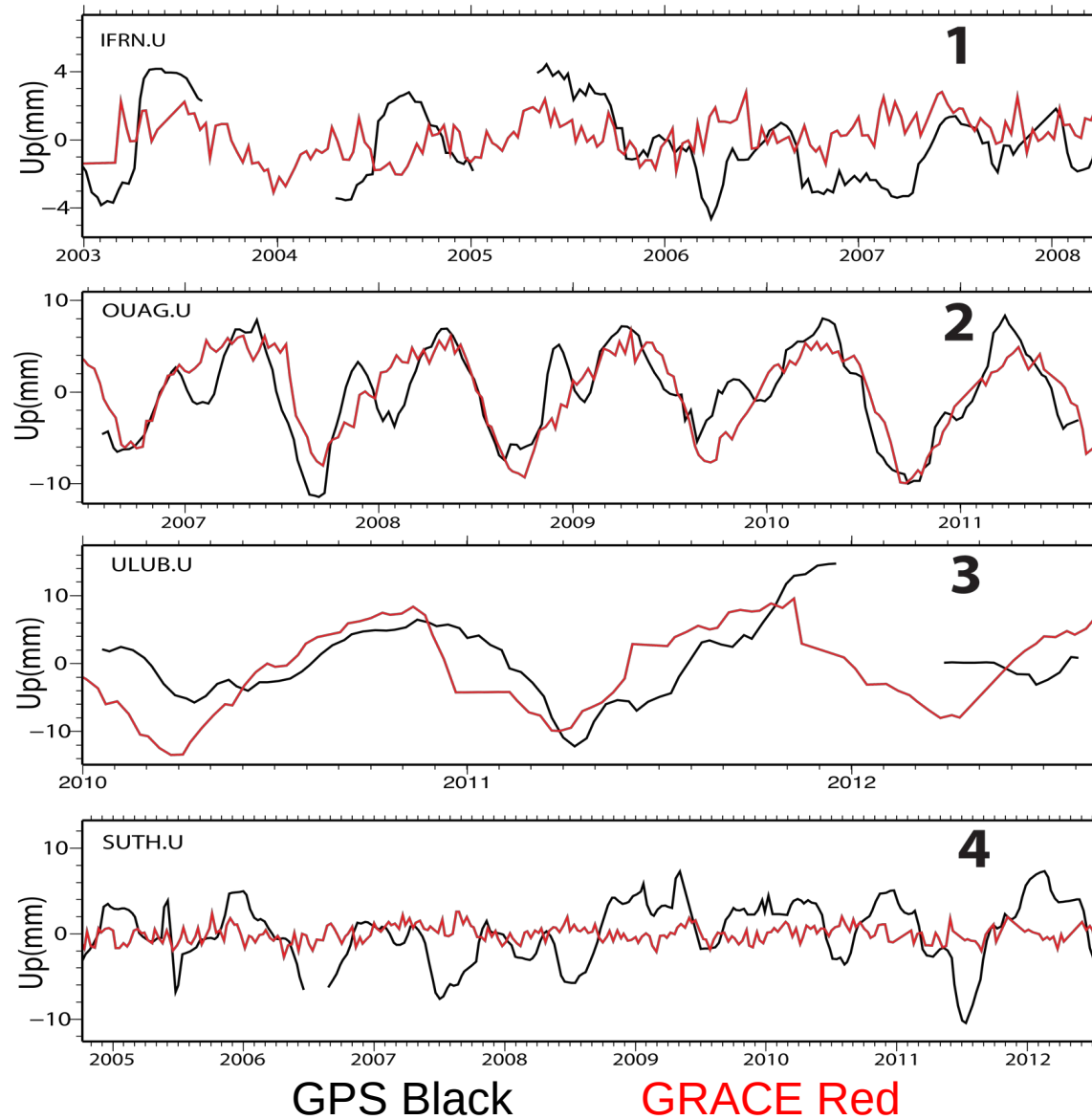
EWH = residual after removal of:

- Static Earth (EGM2008)
- Atmospheric and Ocean
- Other systematic errors e.g. Ocean and Earth tides

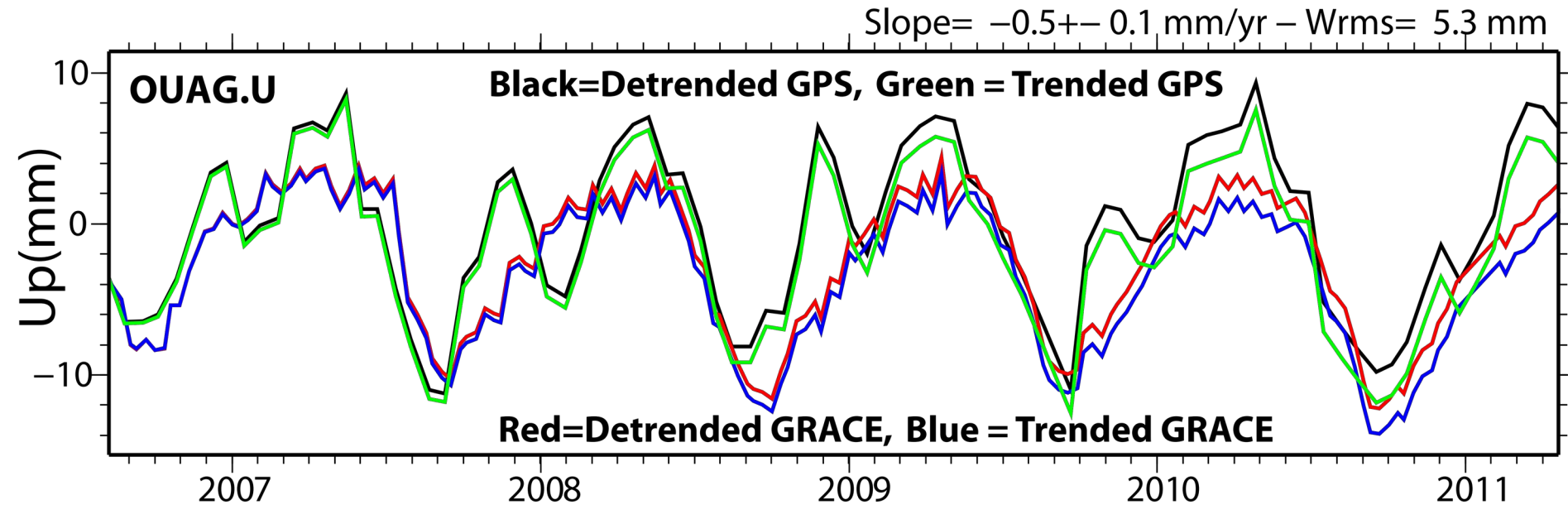
Deformation is computed according to the load of EWH Assumption = Earth is purely elastic.

Displacement (time-varying):

Compare vertical time-series GPS-GRACE



- Four “regions”
- GRACE-derived displacements show the same periodicity as GPS.
- Agreement with hydrological signal (compare with EWH)
- Sometimes GPS amplitudes larger – why?
- Region 3: very few GPS close to the basin



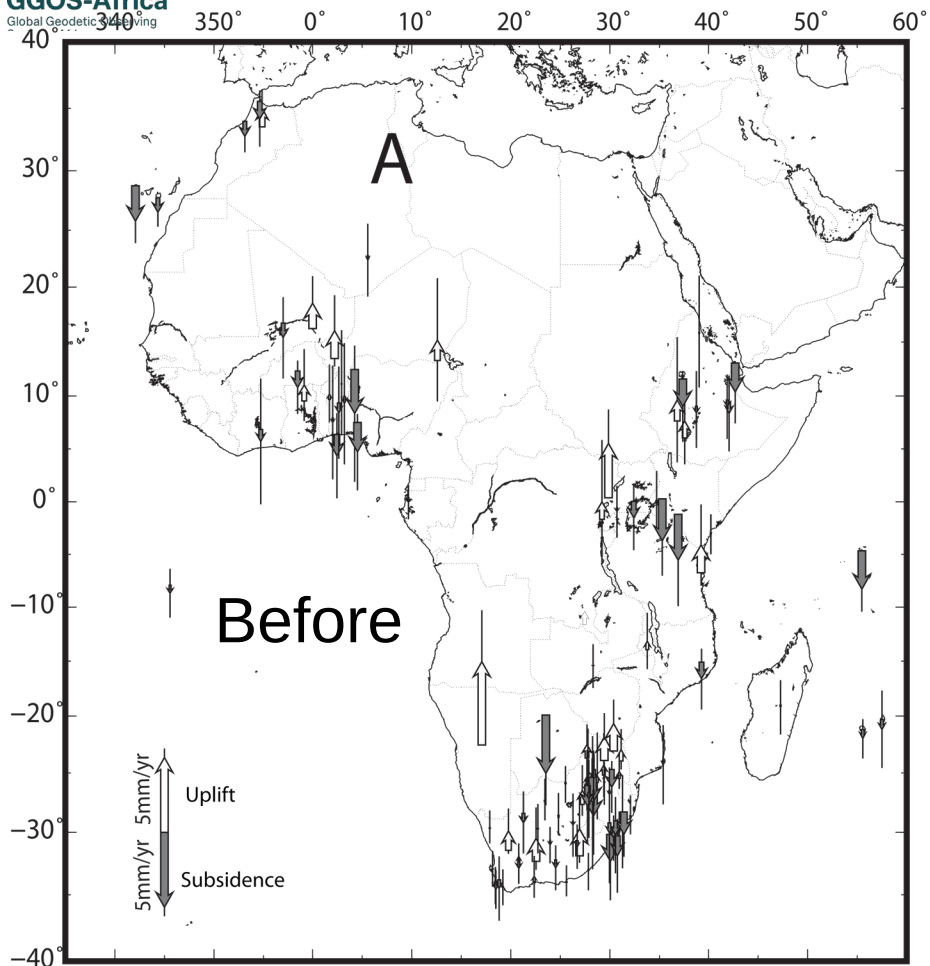
GPS and GRACE both have same trend).

Means that, We can use results from GRACE = GRAVITY to remove seasonal signal that affect GNSS Measurements

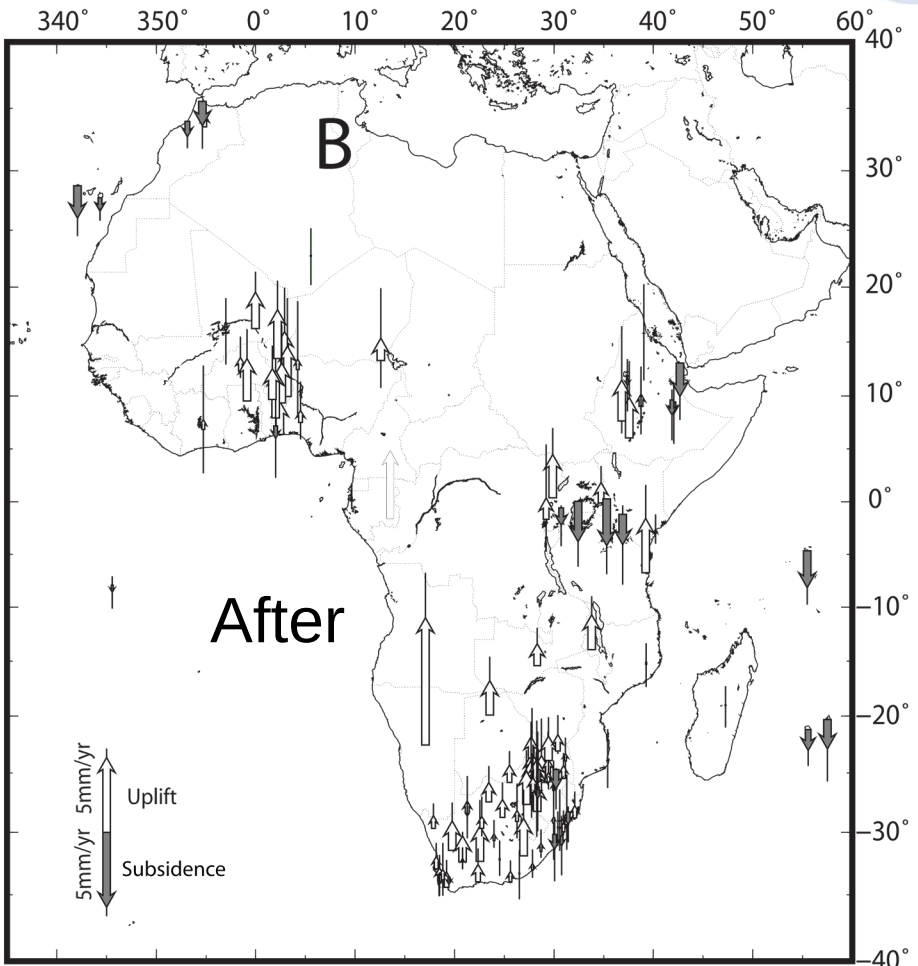
GRACE derived long-term signal removed from GPS



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- No pattern observed
- W. Africa - ~ mixed
- Eastern - Subsidence



- Pattern observed
- W. Africa - ~ 2mm/yr
- Eastern - Subsidence

Summary - Principal Contr. Is Capacity Building in

- ❖ Measure present-day plate motion and Quantify crustal deformation
- ❖ Resolve microplate kinematics and Monitor active rifting
- ❖ Detect earthquake deformation and Monitor volcanic processes
- ❖ Measure vertical land motion and Observe mass redistribution through gravity
- ❖ Integrate Africa into the global ITRF
- ❖ Provide the foundation for dynamic national and continental reference frames

- ❑ Geodynamic study in Africa has improved as Geodetic Data and Time span are increasing.
- ❑ Using Increased data IGS and CORS from individual Countries in Africa, new and Improved AFREF Solution may be expected 2027 – 2028. Efforts from African Acs GGOS and UN-GGIM
- ❑ GNSS and InSAR can also be used on Localized deformation study eg Dams, Volcano, Bridges
- ❑ Studies have shown that the seasonal displacements observed in vertical GPS time series can be, in part, explained by variation in the large scale hydrology as provided by GRACE. However, many issues remain before GRACE data can be directly used to correct vertical motions (either seasonal or long-term) observed in GPS time series.
- ❑ Inter-Seismic, Co-Seismic and Post-Seismic events can be detected in GNSS time series

Conclusions

THANKS