Satellite Geodesy for Science and Hazard Applications
Some Examples from Africa

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A natural laboratory for continental breakup
At the Surface…

Earthquakes

Volcanoes
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
Phase measurement

Sat-rec. distance = \[ \Phi_i^k(t) = \rho_i^k(t) \times \frac{f}{c} + (h_i^k(t) - h_i(t)) \times f + ion_i^k(t) + trop_i^k(t) - N_i^k + \varepsilon \]

Precision of phase data \( \sim 0.1\% \) wavelength \( \Rightarrow \) precision of position \( \sim \) few millimeters
GPS station in Dar Es Salaam, Tanzania
Current Plate Motions

Earthquakes M>6 (NEIC) - GPS velocities ITRF2005

Somalia/Nubia Euler poles:
- Geologic
- Geodetic

2 cm/yr
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

“Boinas” = only source of water...
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

6 May – 28 Oct 2005
• 2.5 km³ magma intruded along dyke (Mt St Helens 1980 1.2 km³; Krafla ~ 1 km³ total).
• 0.5 km³ 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

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?
  - Atmospheric 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.