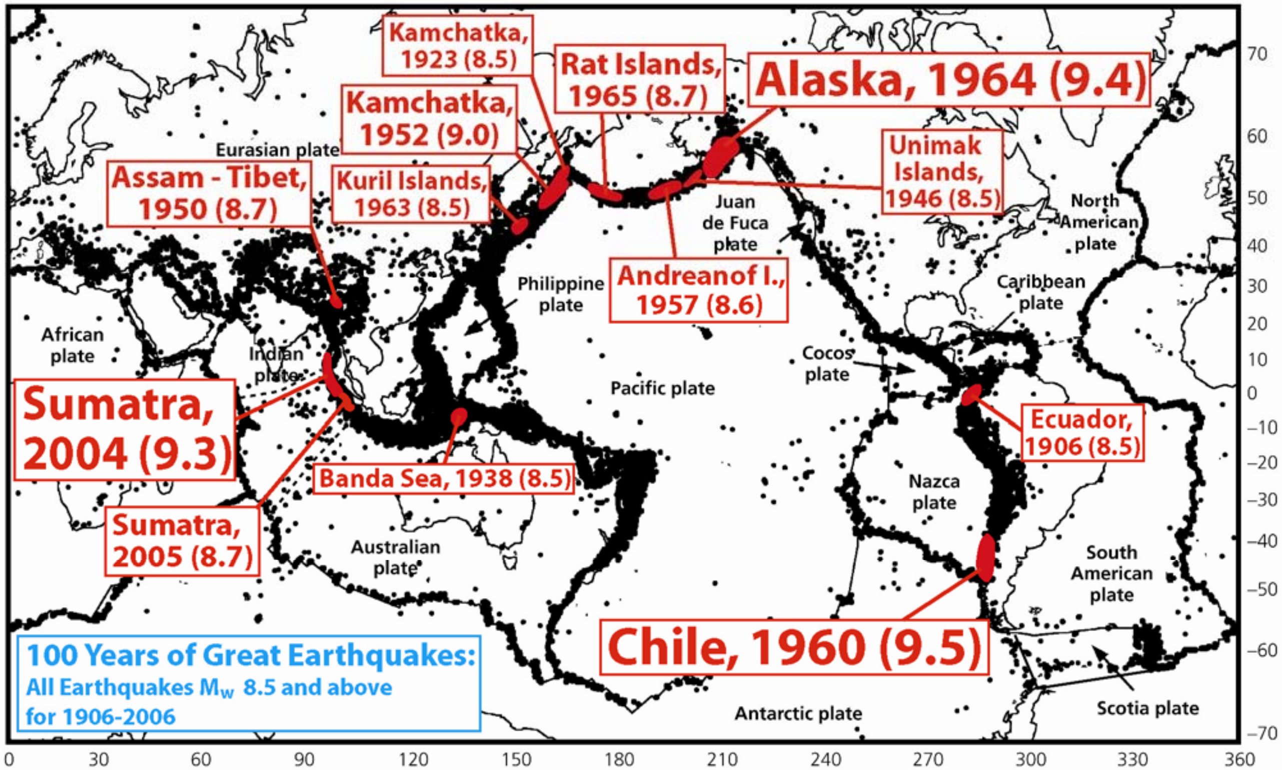
Realizing the Potential of GGOS for Geohazard Prediction and Early Warning



Courtesy of Seth Stein

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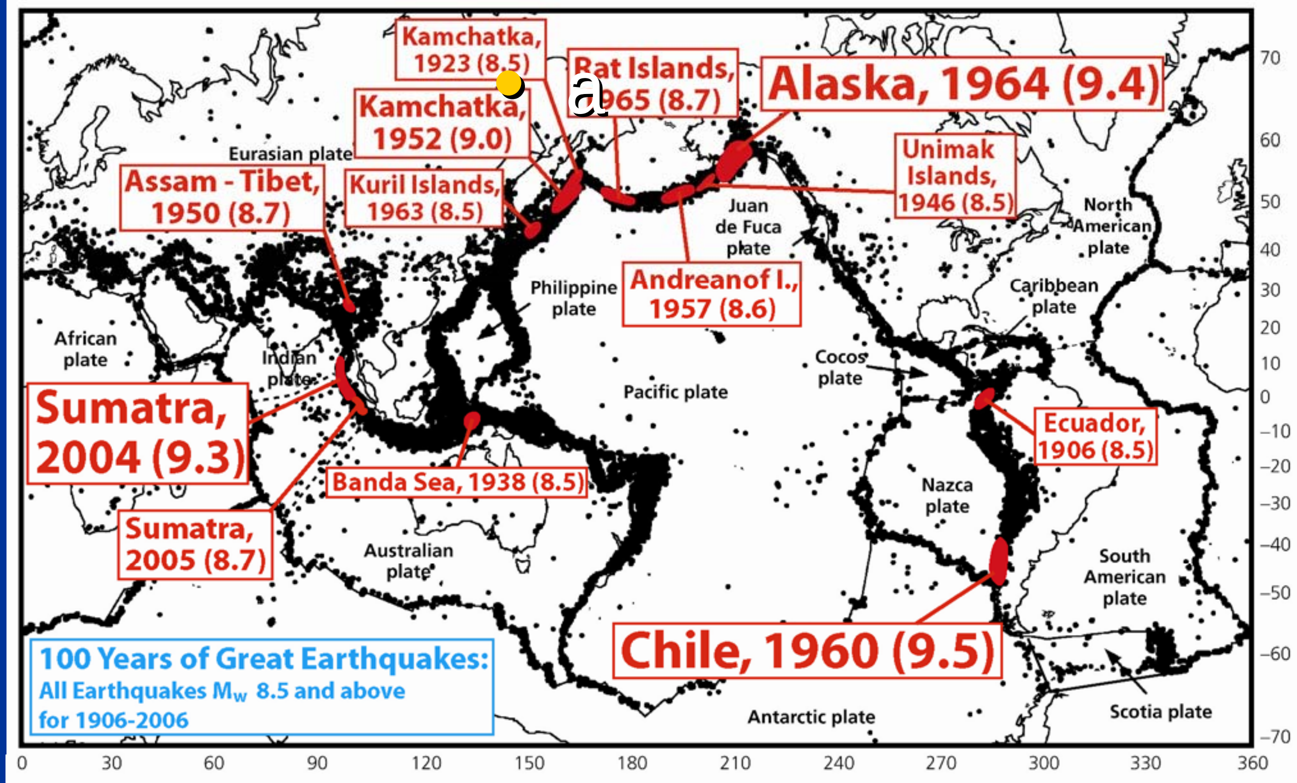
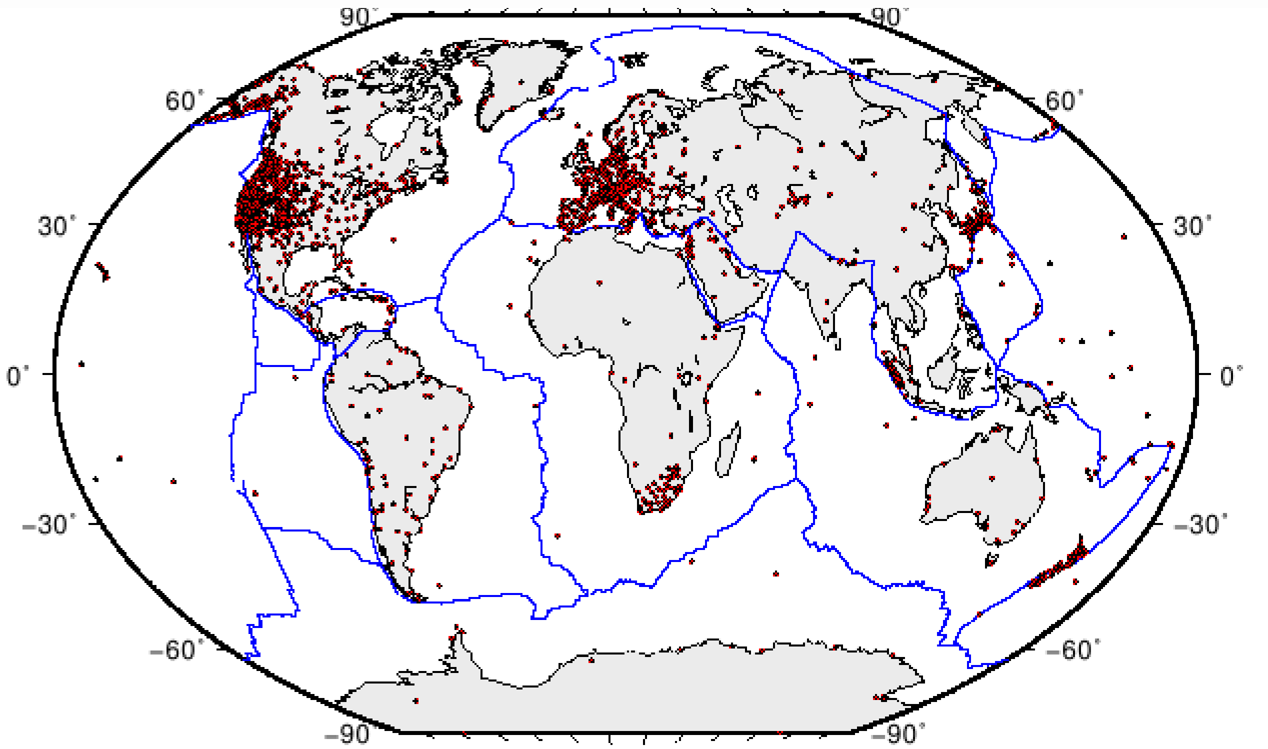
Regions at Risk

- 100 years of great earthquakes
- Mw > 8.5 can create oceanwide tsunami



- GPS network today:
  - 2000 stations
  - **plus** Japan!
- Many ideally located
  - Plate Boundary Observatory (PBO)
- Many holes to fill



Nature of (Many) Geohazards

Long-term Cumulative Process → **Precipitously Damaging Event**

Nature of (Many) Geohazard Investigations

Study of Long-term Cumulative Process ← **Precipitously Damaging Event**

There's got to be a better way...

Prediction/Monitoring System ↔ **Early Warning System**

GGOS spans bandwidth!

Prediction versus Early Warning

- Prediction Systems
  - Inform *strategic* deployment of *mitigation* systems
- Characterized by…
  - Long-term stability as basis for prediction
  - Frame of reference
  - Detailed modeling aimed at understanding
  - Highest accuracy

- Early Warning Systems
  - Inform *tactical* deployment of *rapid response* systems
- Characterized by…
  - Real-time sensitivity and response
  - Automatic trigger and alarm (knowledge-based)
  - Robustness to false alarms

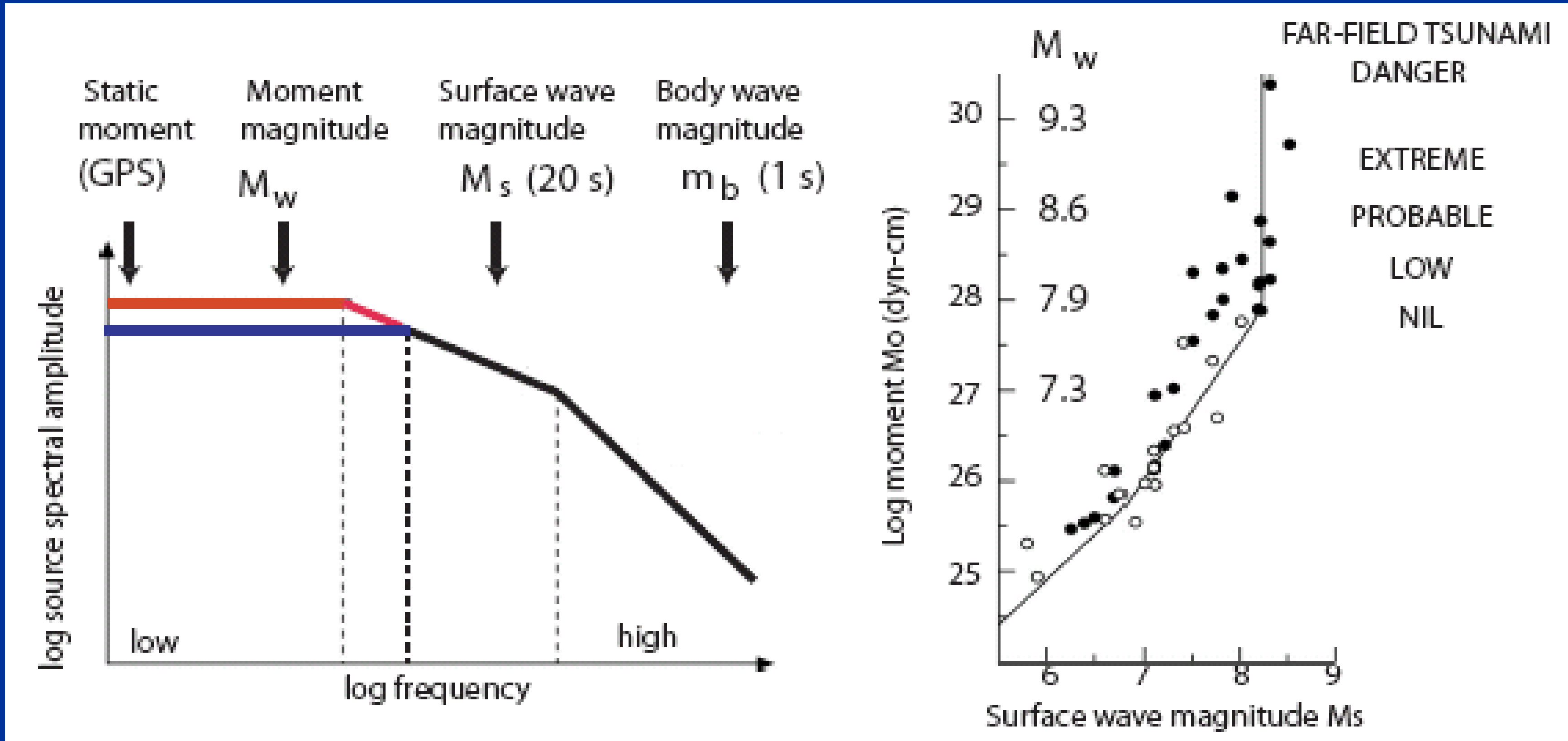
Prediction and Early Warning Systems

- Early warning and prediction systems work best if they are mutually informed and mutually consistent.
- GGOS spans the bandwidth and so can play both roles, solving the problem of mutual consistency and mixed requirements.
- Example: Incorporate real-time (R/T) stations into GGOS/ITRF with same standards of monumentation, instrumentation,….
- Example: Upgrade established continuous stations to R/T, while retaining original “prediction” roles.
- Example: Stream R/T data AND archive low-rate data.
- Example: Produce R/T GPS orbits consistent with final orbits, in the same reference frame and using high-accuracy models.

Recommendations, Part 1:

- GGOS should facilitate both prediction systems and early warning systems
- R/T GPS needs to be part of GGOS
- So that early warning can be better informed by prediction, R/T GPS infrastructure development and deployment should be designed to play a dual role both for
  - early warning (real-time, higher rate data) and
  - prediction (lower rate data, integrated with GGOS, tied to ITRF)

Seismic Magnitude Saturation: A Major Obstacle to Early Warnings

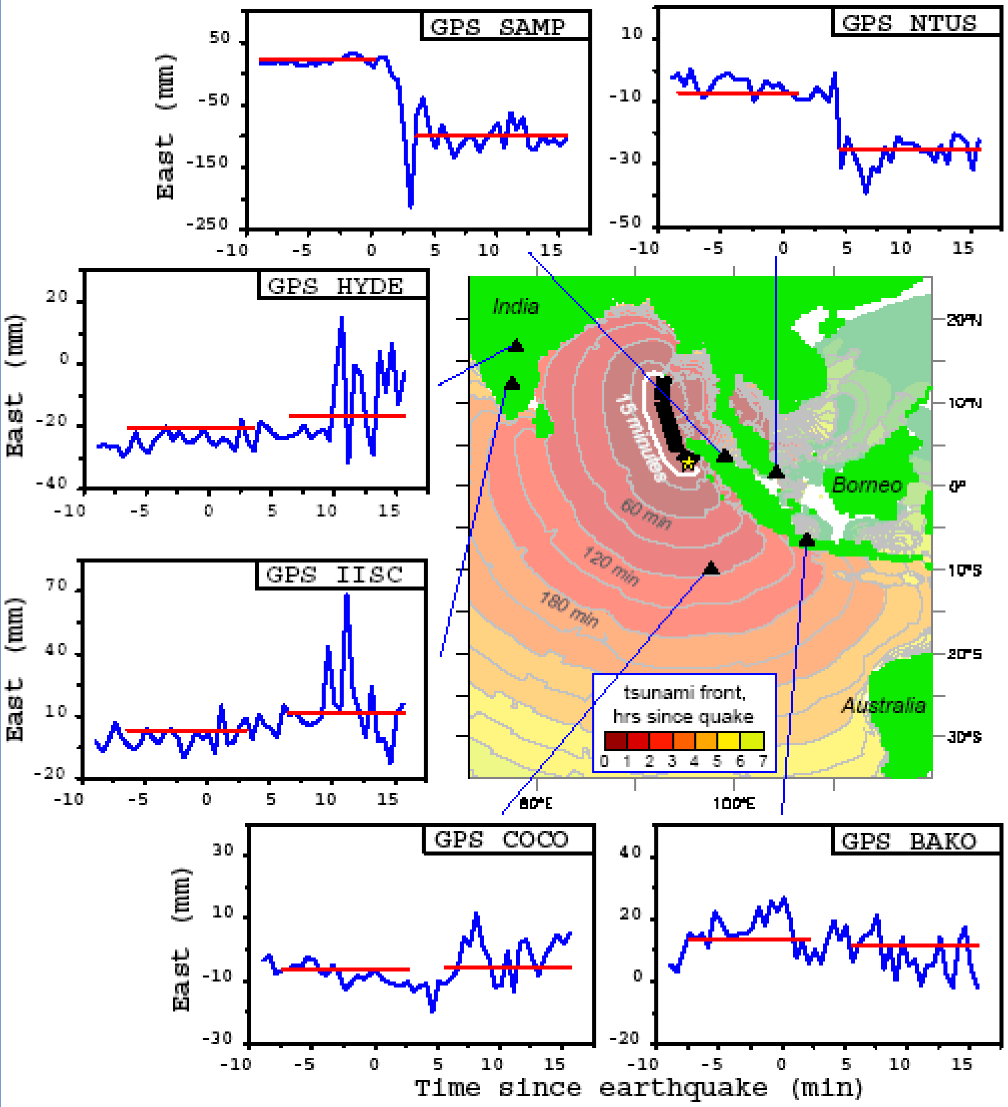


- Early seismic magnitudes saturate at 8–8.3 (Geller, 1976)
  - but oceanwide tsunamis typically require $M_w > 8.5$
- But $M_w > 8.0$ can be given accurately & early using GPS

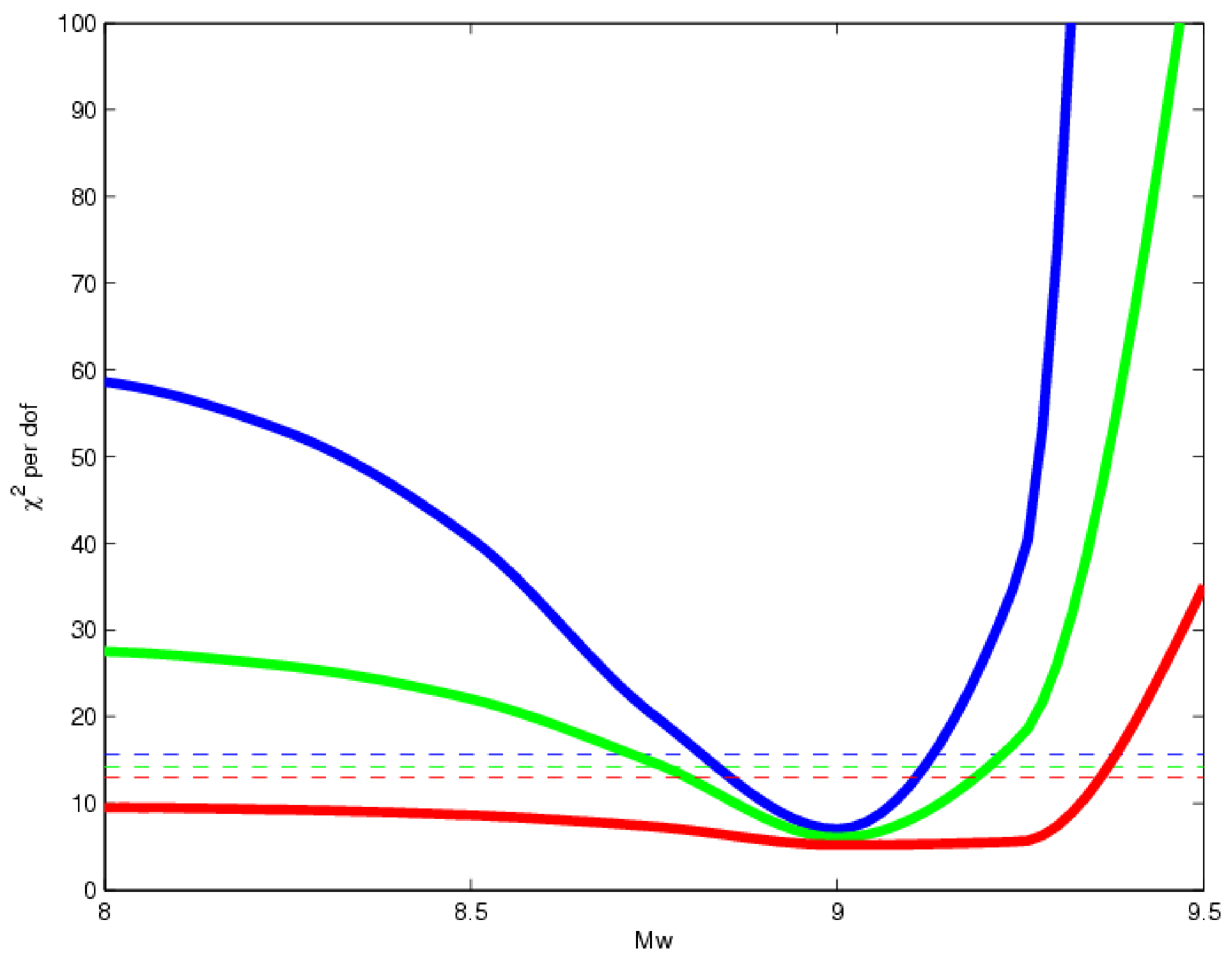
GPS Results: Sumatra 2004

- Rapid displacement
  - Data confirm that it arrives mostly with body waves
  - Can be resolved <15 minutes after the quake origin time
  - Accuracy ~ 7 mm
- Can be used to estimate earthquake slip model
  - Model displacements ~ 3 mm
- And keep in mind...
  - Network was far from optimal

GPS 30-sec Series



Rapid Moment Magnitude Estimation by GPS



- Best fit models:
  M_w = 8.9 – 9.1
  rupture = 1000 km
- Blue
  - using all sites
- Green
  - no SAMP (300 km)
- Red
  - no SAMP (300 km)
  - no NTUS (900 km)

Recommendations, Part 2:

- GPS/GNSS early warning system requirements should be based on the value added to current components of post-earthquake response and tsunami warning systems (seismic systems, ShakeMap, etc.) .
- Effective implementation requires coordination between
  - The international level (GEO/GEOSS, GGOS) and
  - The national level (US example: NASA, NOAA, USGS,...)

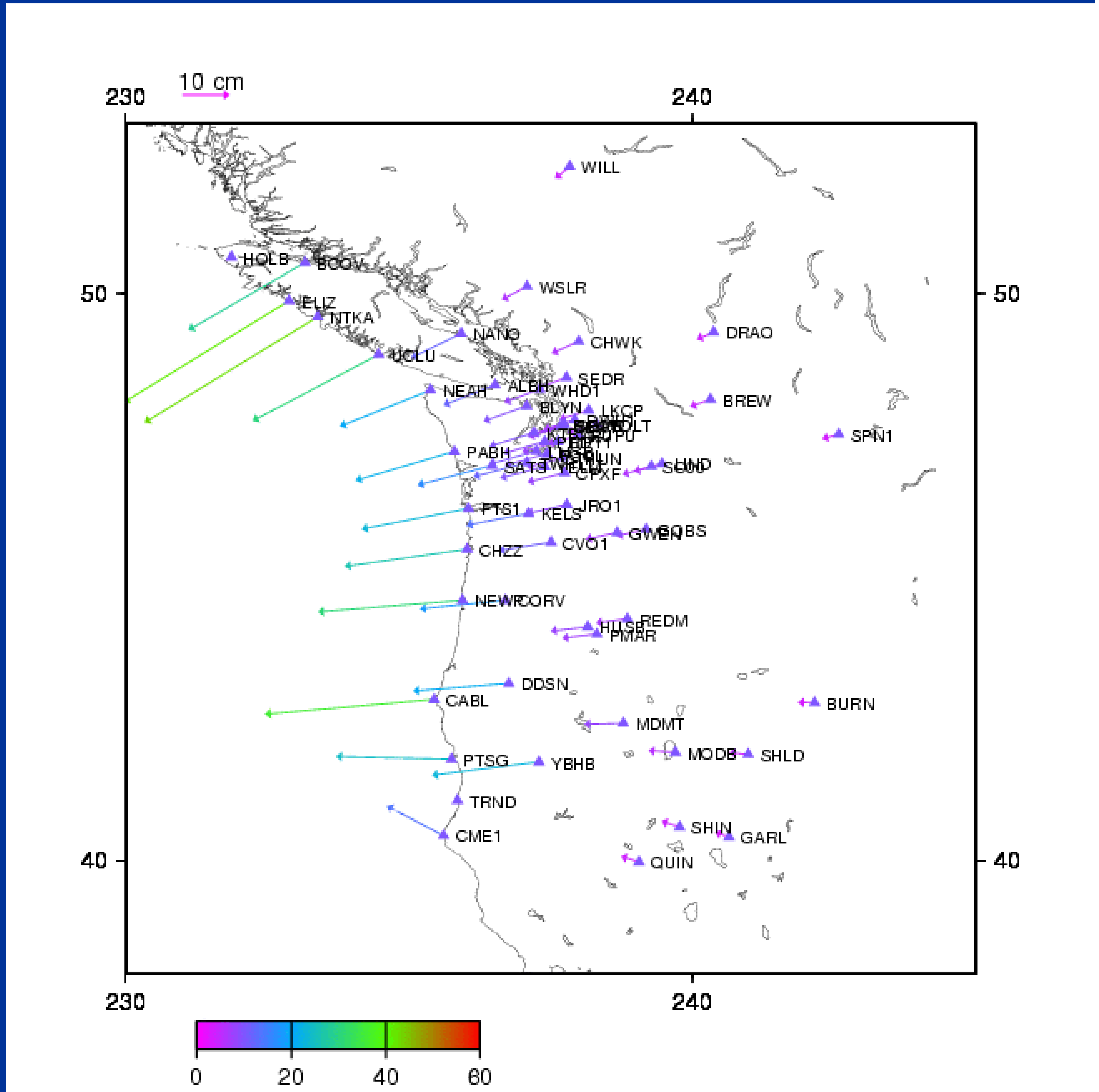
Global Geodetic Observing System (GGOS): Requirements for Early Warning...

1. Reference Frame to tie all observations in context
2. GPS/GNSS network delivering real-time data
3. Real-time high-accuracy positioning software
4. Real-time high-accuracy GPS orbits and clocks

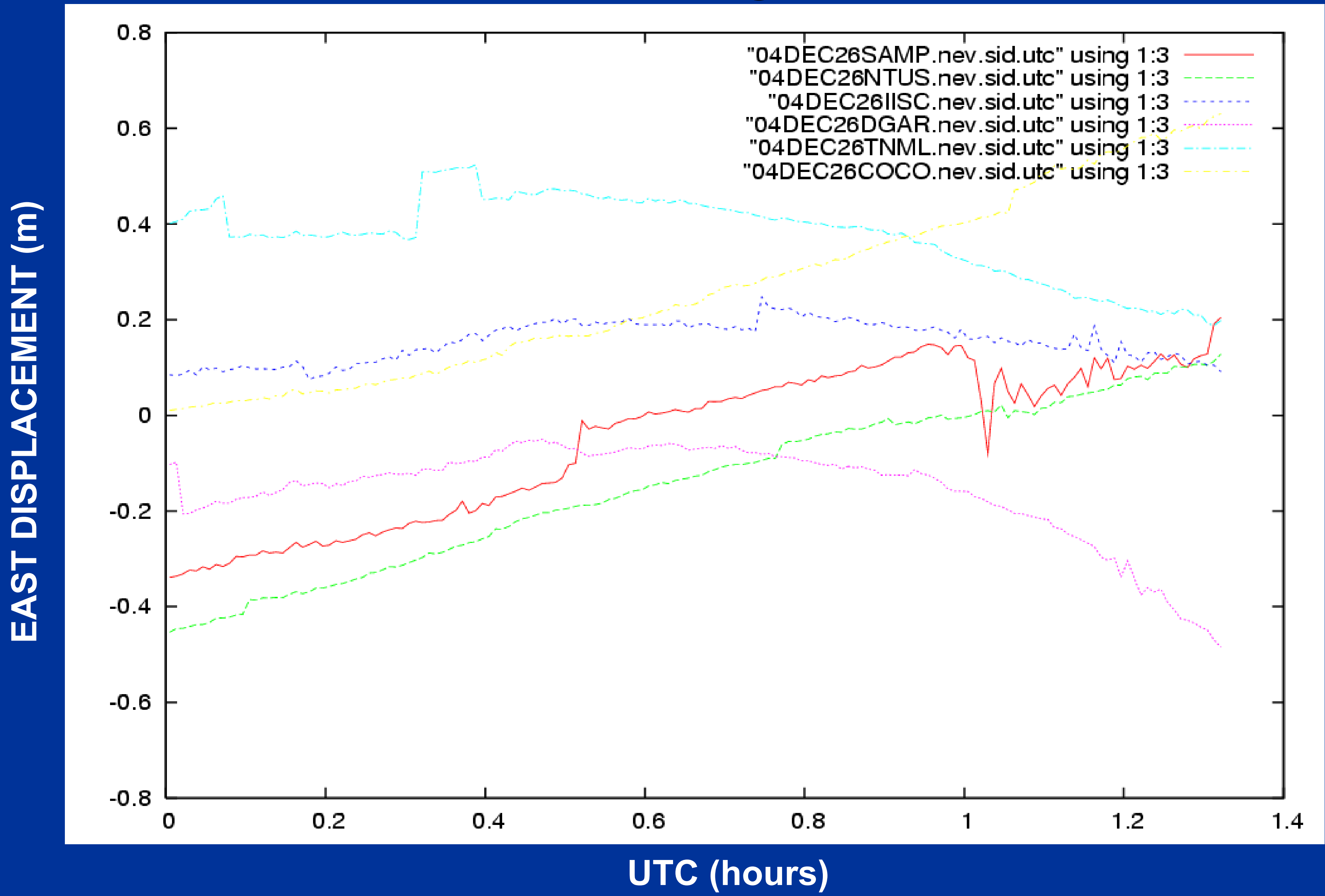
- Example: NASA's Global Differential GPS/GNSS System
- Example: IGS Real Time Pilot Project

Prediction Networks ↔ Early Warning Networks

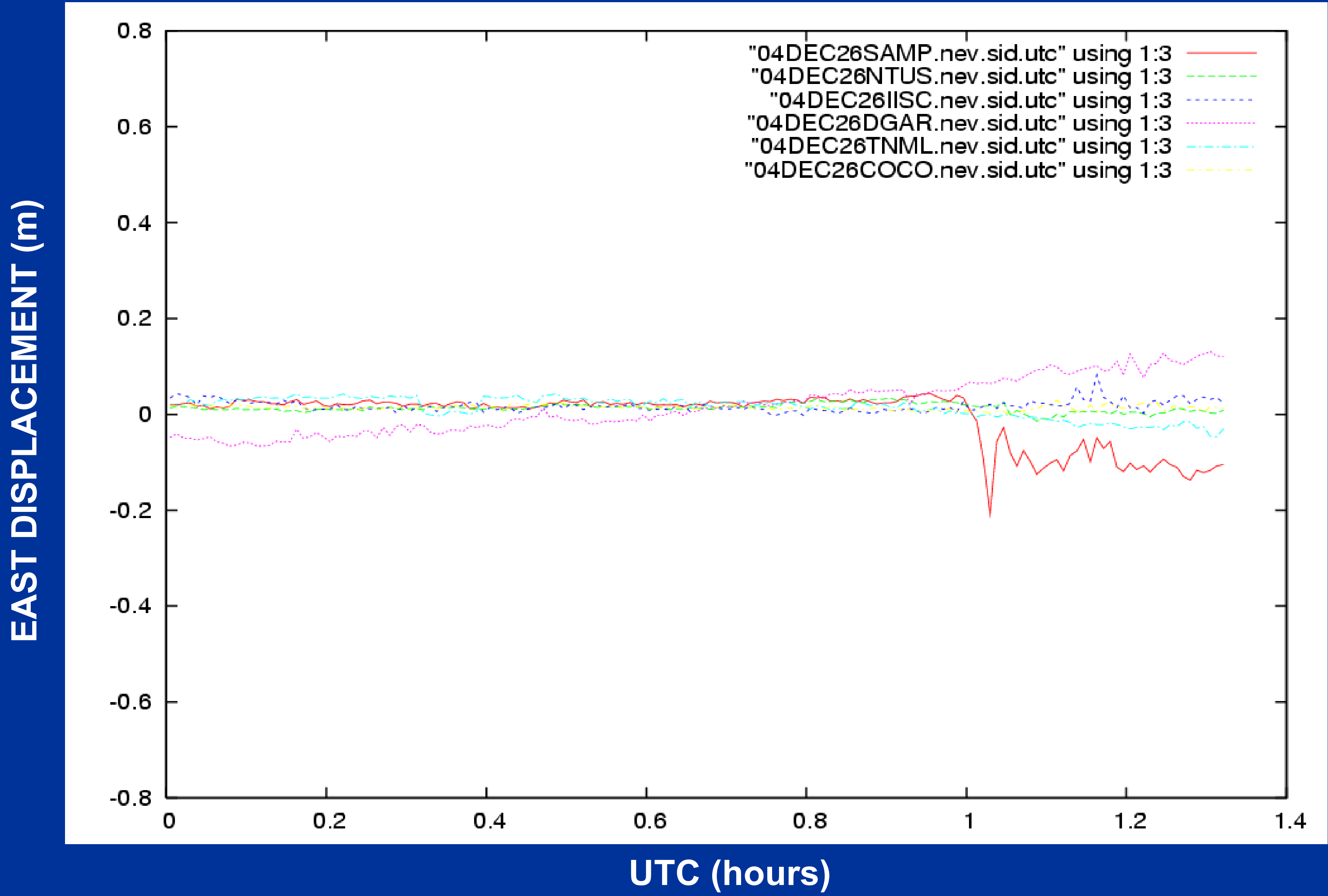
- Example:
  - Cascadia Subduction Zone
  - PANGA / PBO
  - Simulation of Mw 9.0 quake
  - ~10 cm static displacements



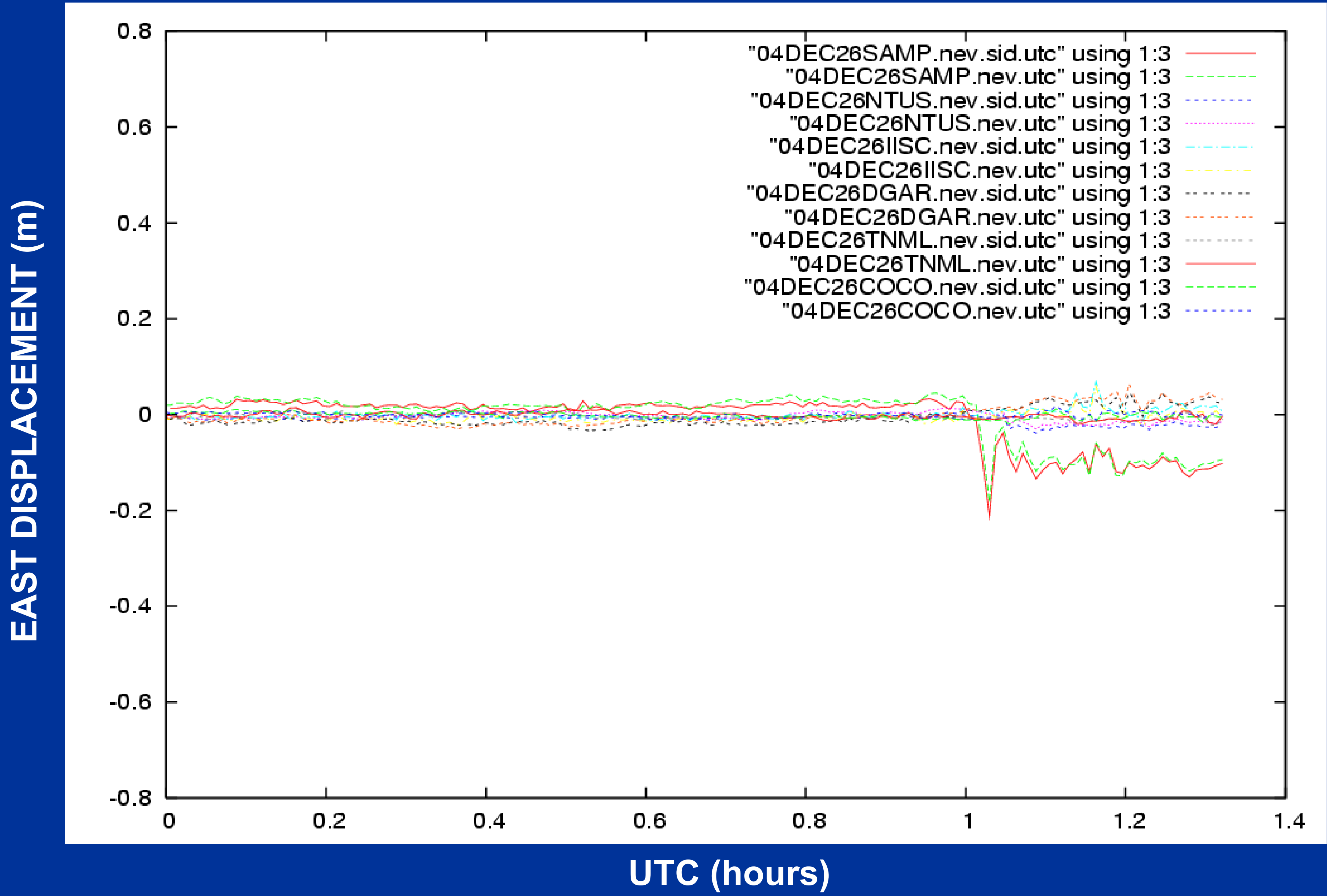
The Need for Accurate Frame and Orbits: 30-sec Time Series using Broadcast Orbits



The Need for Accurate Frame and Orbits: 30-sec Time Series using IGS Ultra-Rapids



The Need for Accurate Frame and Orbits: 30-sec Time Series using Estimated Orbits



Recommendation, Part 3:

- IGS R/T Pilot Project should form the basis of a future operational service to facilitate early warning of geohazards
- To realize full potential, such an R/T service should eventually enable centimeter-level real-time positioning.

Conclusions

- GGOS can provide mutual consistency between prediction systems and early warning systems for geohazards
- GGOS should provide the observational basis for ITRF to tie all observations in context
- Geodetic components can add value to current geohazard early warning systems that are based on other technologies
- GGOS could operate a real time service to facilitate real time positioning for geohazard early warning systems
  - Future spin-off from the IGS Real Time Pilot Project