GPS-aided Real-Time Earthquake and Tsunami (GREAT) Alert System

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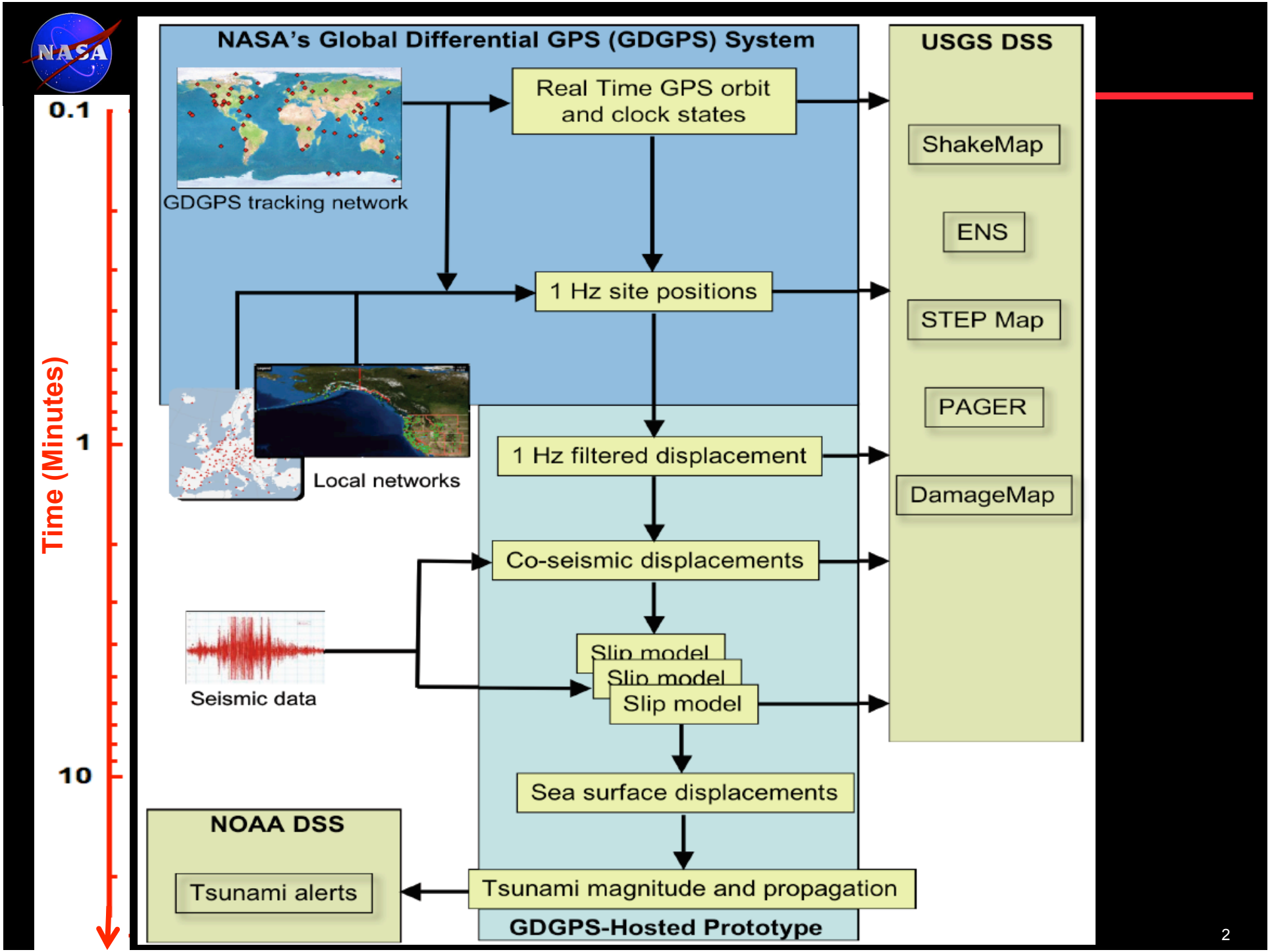
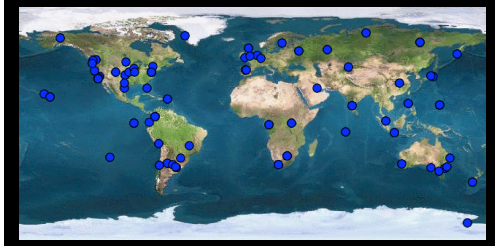

NASA's Global Differential GPS (GDGPS) System
GDGPS tracking network
Real Time GPS orbit and clock states
1 Hz site positions
Local networks
1 Hz filtered displacement
Co-seismic displacements
Seismic data
Slip model
Slip model
Slip model
Sea surface displacements
Tsunami magnitude and propagation
GDGPS-Hosted Prototype
USGS DSS
ShakeMap
ENS
STEP Map
PAGER
DamageMap
NOAA DSS
Tsunami alerts
Time (Minutes)
0.1
1
10

The Global Differential GPS (GDGPS) System

http://www.gdgps.net

99.999% Reliability since inception in 2000

Tracking Network (100+ sites)



Measurements

Internet, Frame

Triple Redundant Operation Centers

Commercial Services

Internet, Frame

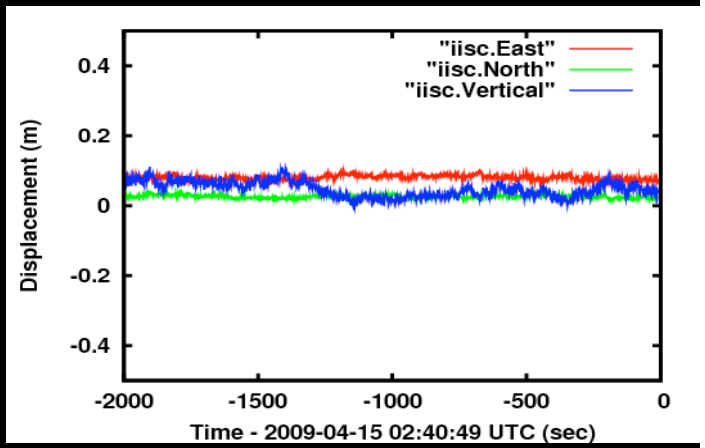
Public Services:

APPS – Automatic Precise Positioning Service

RT-PPP – Real Time Precise Point Positioning

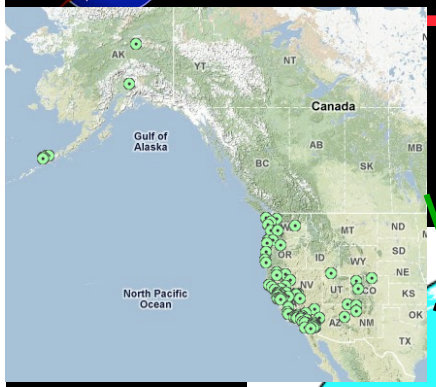
Real-time PPP http://ppp.gdgps.net

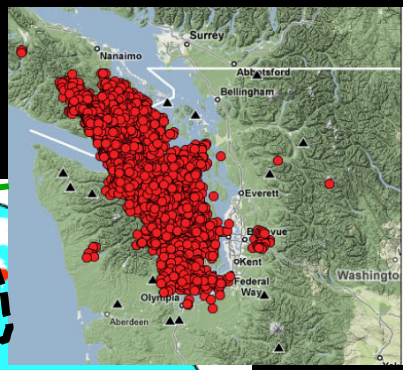
- Position streams at 1 Hz from 100+ sites globally are currently available. Target 1000s of sites
- Strictly for natural hazard monitoring
- Share your 1 Hz real-time measurement stream, get real-time position time series

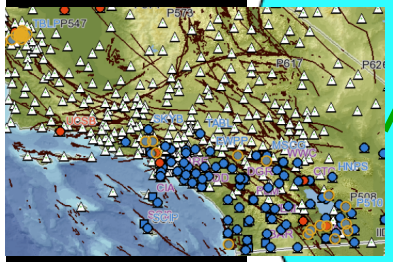


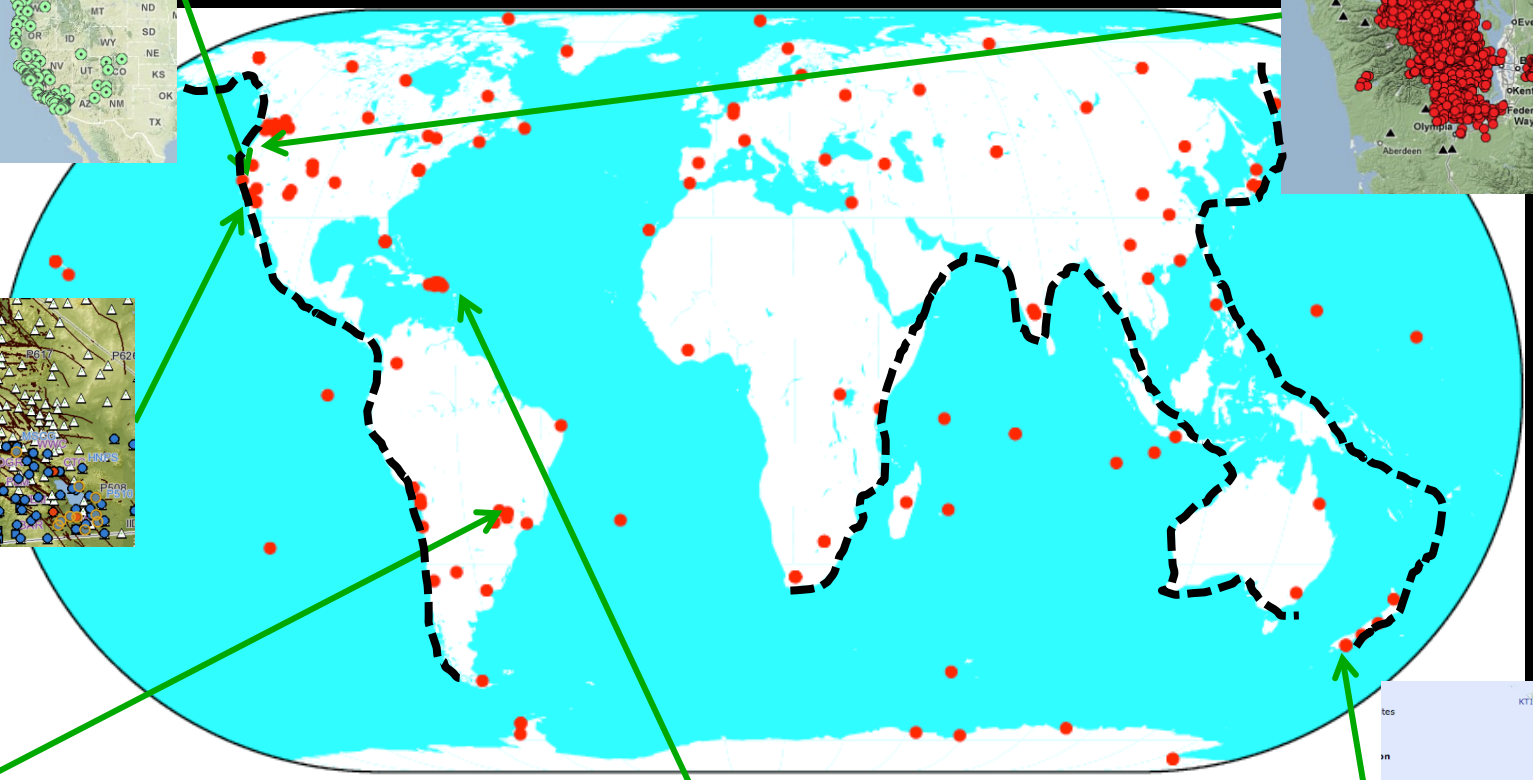
Local Networks Augmentation

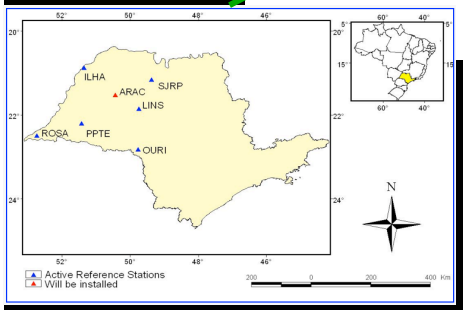
GDGPS-based PPP enables local networks to be anchored to the ITRF

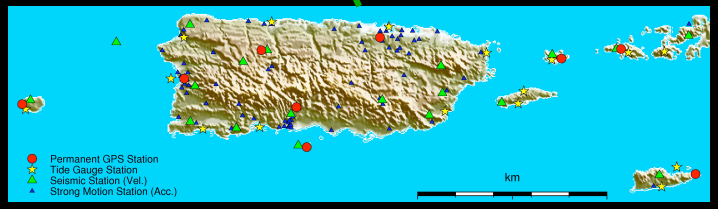


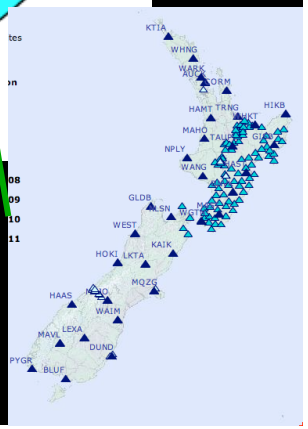




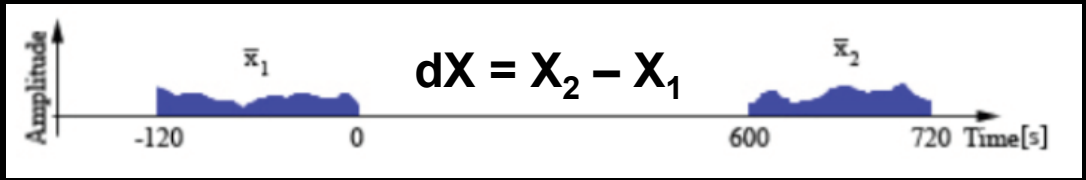


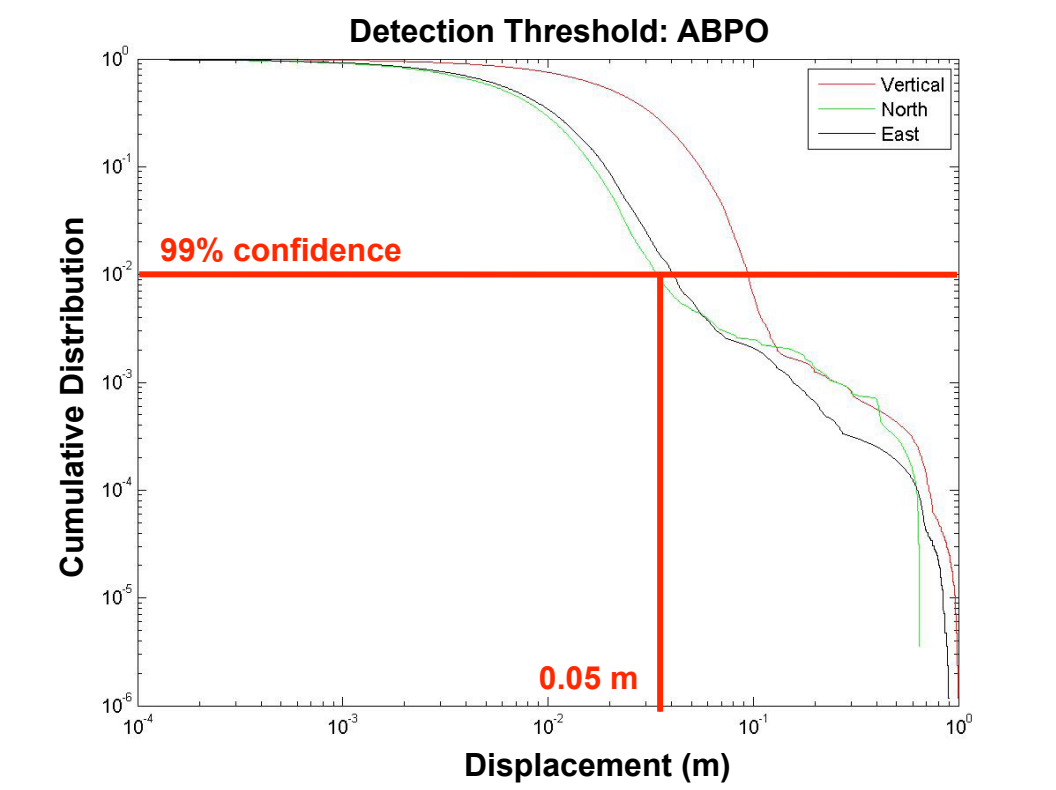






Displacement Detection in GPS PPP Time Series





Blewitt et al., 2006 demonstrated accurate retrieval of the magnitude of the 2004 Sumatra earthquake from GPS displacements (Rapid determination of earthquake magnitude using GPS for tsunami warning systems, *Geophys. Res. Letters)*

Earthquake Source Determination with the Fingerprint Method

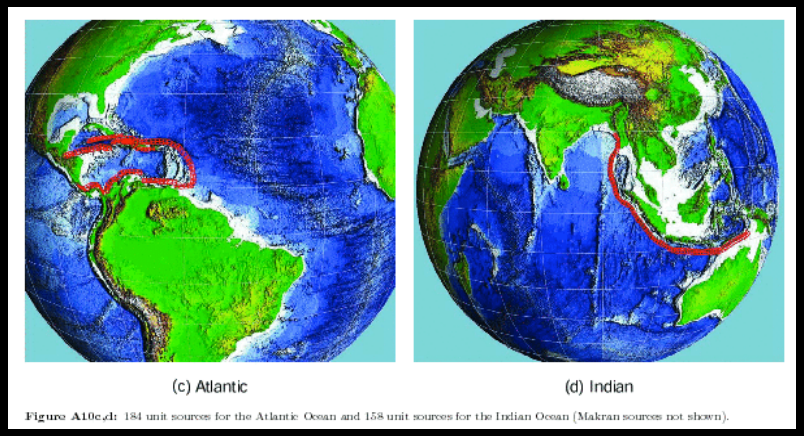
Fingerprint: static displacement field due to a unit slip on a fault element

$$\vec{X}(\vec{r},t) = \Sigma_{j=1}^{N} \left\{ \alpha_j \vec{A}_j(\vec{r}) + \beta_j \vec{B}_j(\vec{r}) \right\} H(t - t_{0j}(\vec{r})) + \vec{M}(\vec{r},t)$$

Slip size — Dip-Slip Fingerprint — Slip size — Strike-Slip Fingerprint

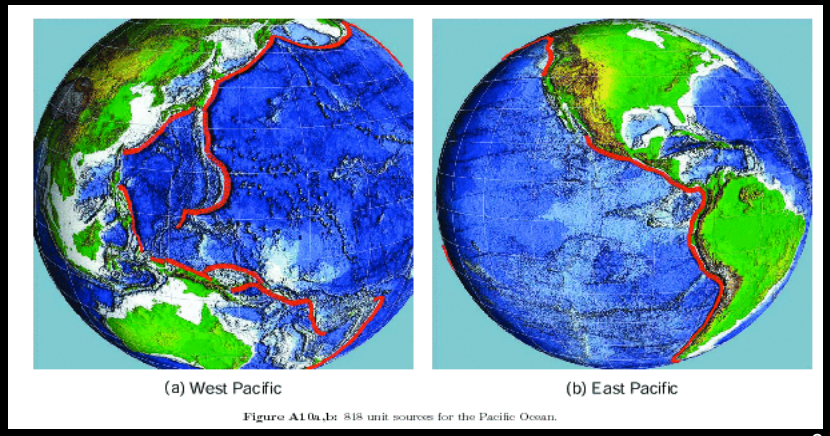
Pre-Analysis Steps:

1. Built a fault data base: reasonably sized (~100 km) elements for all tsunamigenic faults. (Gica et al., 2008, *Development of the Forecast Propagation Database for NOAA's Short Term Inundation Forecast for Tsunamis (SIFT)*, NOAA Technical Report)
   - Fault planes for 573 fault elements
   - For each element, upper and lower starting point plane; 1146 planes
2. Compute "fingerprints" for all fault elements



(c) Atlantic (d) Indian

Figure A10c,d: 184 unit sources for the Atlantic Ocean and 158 unit sources for the Indian Ocean (Makran sources not shown).



(a) West Pacific (b) East Pacific

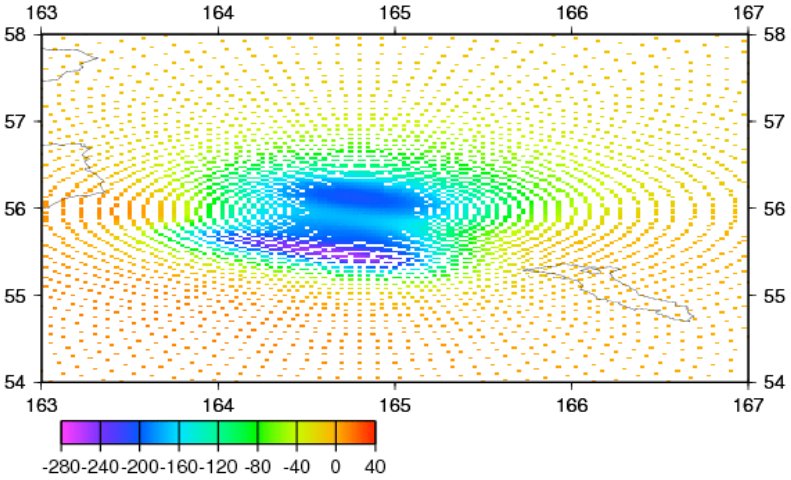
Figure A10a,b: 848 unit sources for the Pacific Ocean.

Fingerprint Method: Operations

1. Get alert with first estimates of earthquake epicenter
2. Identify GPS/GNSS sites that are in a certain radius and acquire position time series
3. Identify likely fault elements and prepare search
4. Determine displacement at GPS sites
5. Determine displacement field and magnitude through search in model space
6. Inform tsunami assessment component

Current Setup (configurable):

- 100 km fault element (can be grouped)
- Displacement are determined on a concentric grid
  - Radial sampling (in degrees): $R_j = (0.3 + j\ 0.03)^3$, $j = 1,112$ (≈ 3 - 5400 km)
  - Angular sampling: every 2°
- Interpolate grid displacements to GPS sites

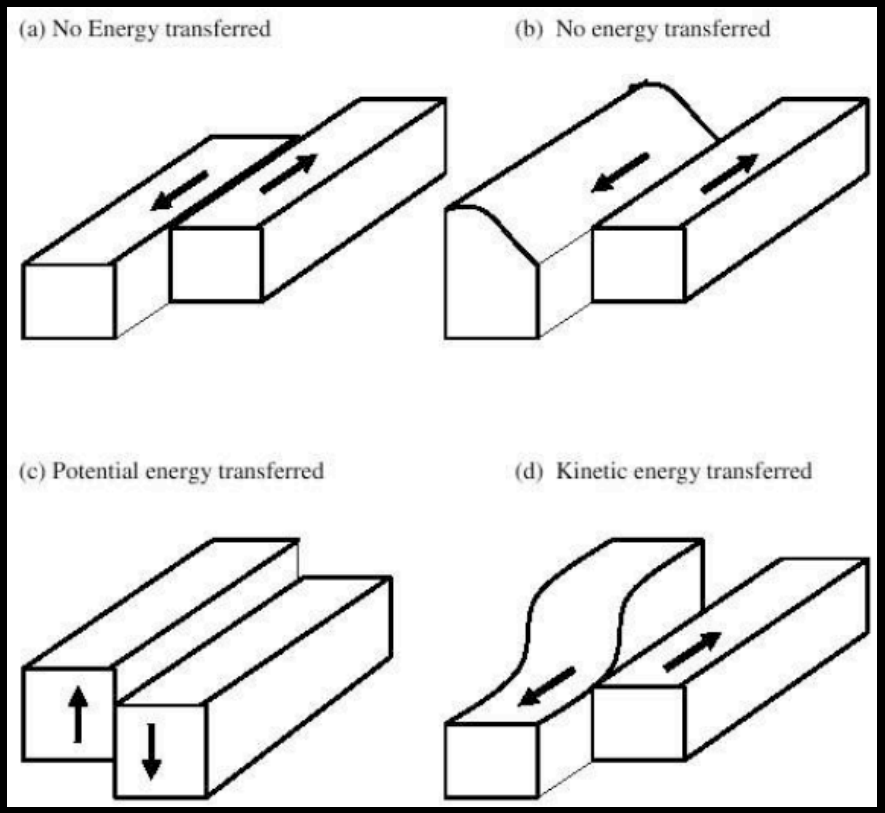


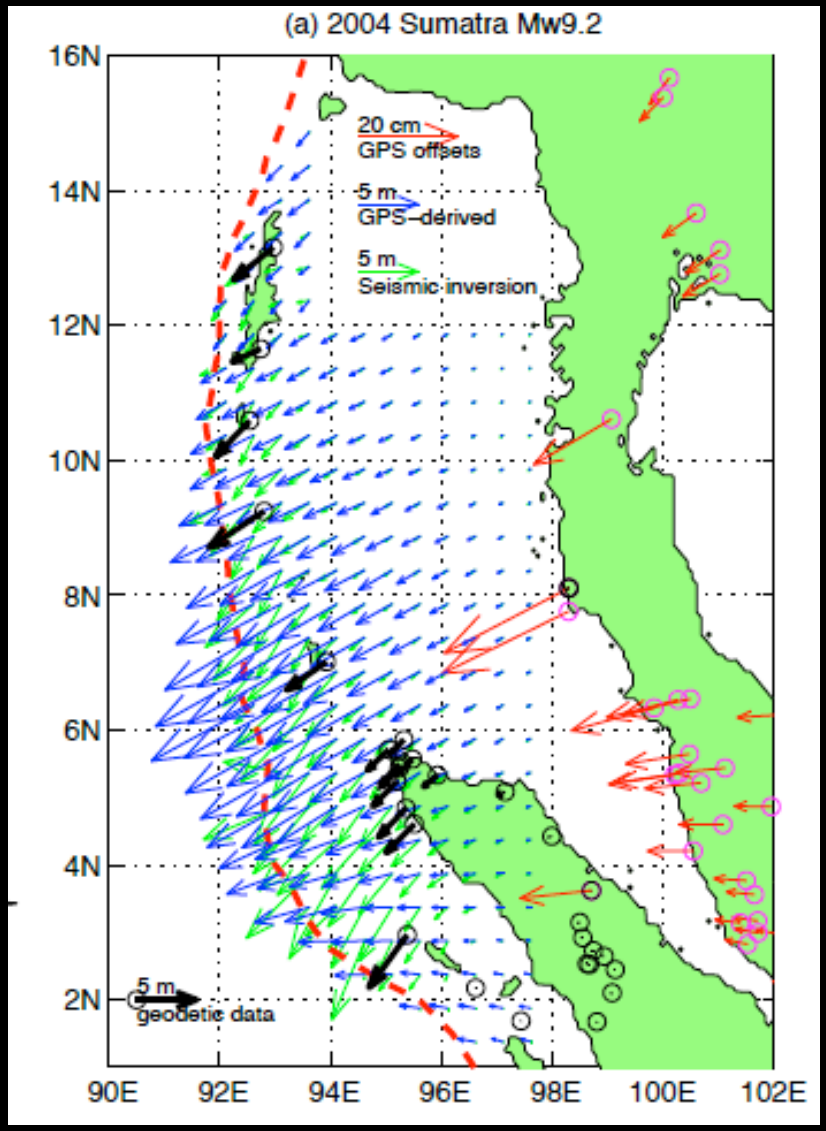
Sea Floor Displacement and Energy Transfer

See floor displacement can be inferred from the Fingerprint model or from alternative models, e.g., Song's empirical model

Determine the potential and kinetic energy transferred to the ocean

- The 2004 Sumatra tsunami was primarily driven by kinetic energy (K_e/K_p = 5:1)





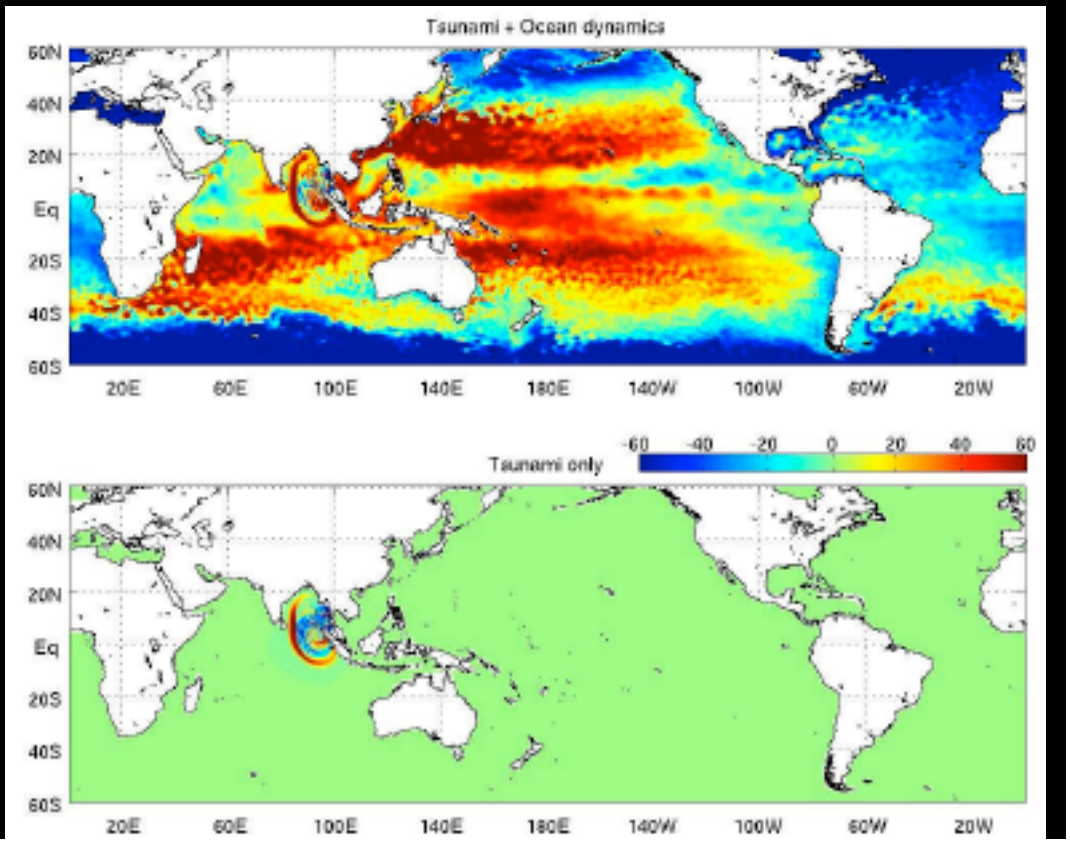
Determining Tsunami Scale and Propagation

Tsunami Scale Formulation: $S_T = log_{10}E_T - 10$

Earthquake Magnitude	Tsunami Energy (from GPS)	Tsunami Scale (from GPS)	Basin-Wide Warning? $S_T = 5$ Threshold
2004 Sumatra (M_w 9.2)	$6.0*10^{15}$ J	5.8	**Yes**
1964 Alaska (M_w 9.1)	$8.2*10^{15}$ J *(Geodesy)*	5.9 *(Geodesy)*	**Yes**
2005 Nias (M_w 8.7)	$2.8*10^{14}$ J	4.4	**No**

Current PTWC alerts are based solely on earthquake magnitude

Mw less than 6.5 (Mw: Moment Magnitude)	Earthquake Message Only
Mw 6.5 to 7.5	Tsunami Information Bulletin
Mw 7.6 to 7.8	Regional Tsunami Warning
Mw > 7.8	Expanding Warning / Watch
Confirmed Teletsunami	Pacific-Wide Warning



Results from the M8.8 Chile Earthquake