Rapid Determination of Earthquake Magnitude using GPS for Tsunami Warning Systems

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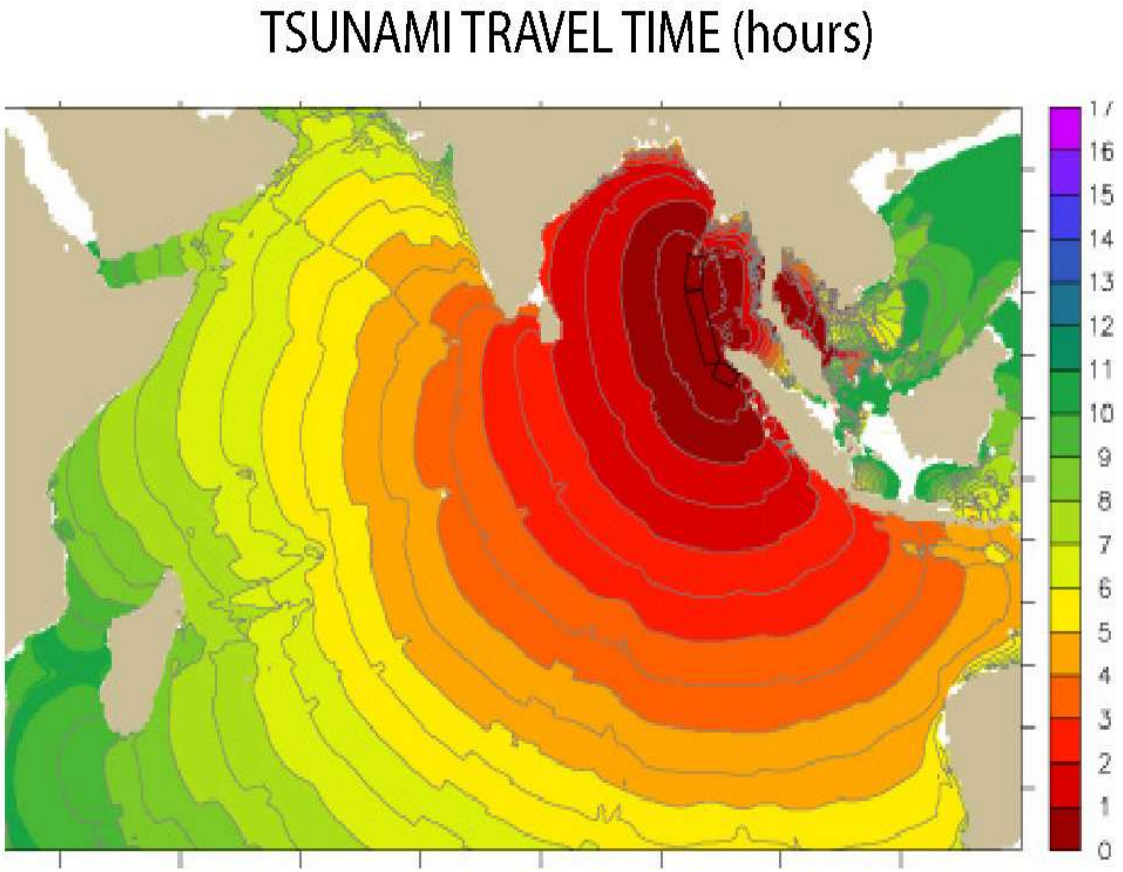
Rapid Determination of Earthquake Magnitude using GPS for Tsunami Warning Systems

- Magnitude Saturation: A Major Obstacle for Early Warnings
- Displacements Field of the Sumatra December 2004 Earthquake
- Near-Real Time GPS-Based Magnitude Estimates
- Towards Real Time GPS-Based Magnitude Determination

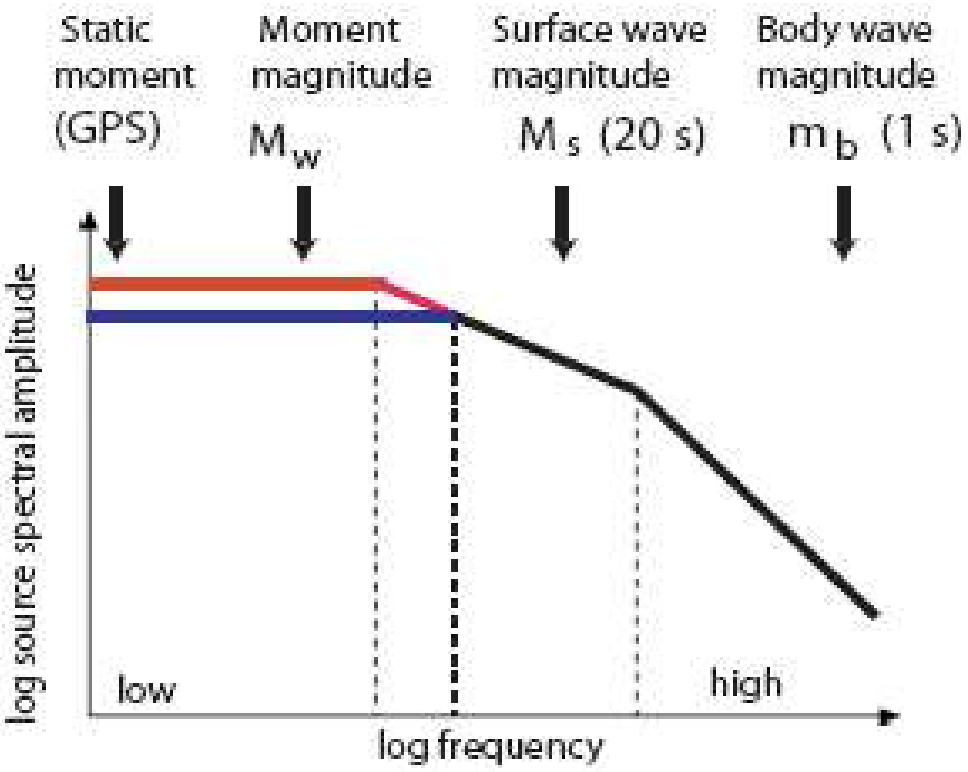
Magnitude Saturation: A Major Obstacle for Early Warnings

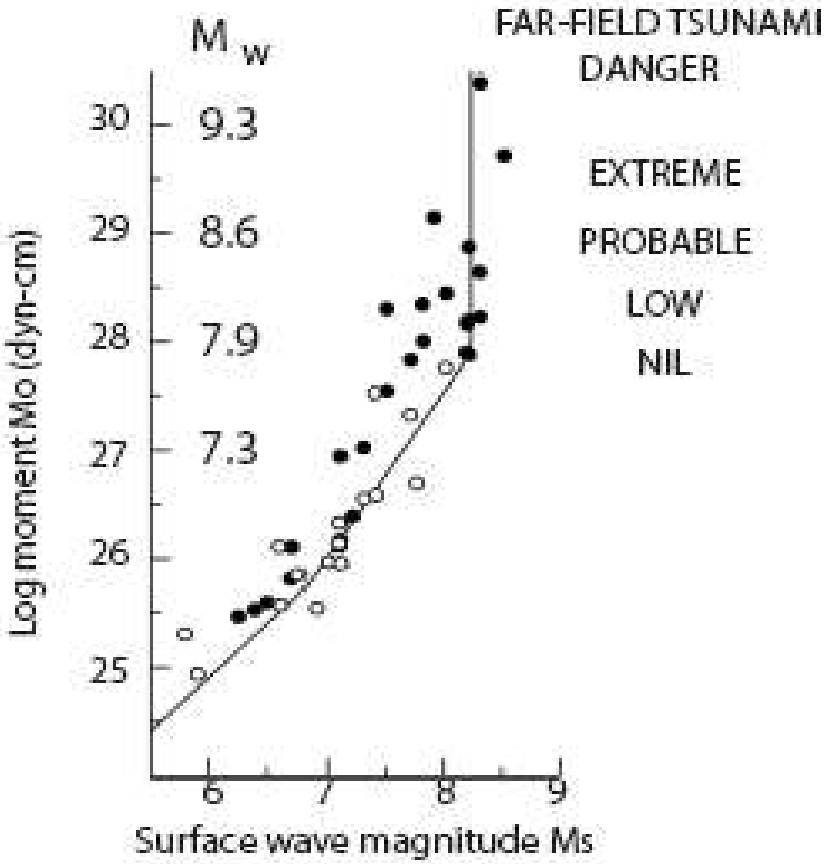


- The first one to two hours are important for early warning for oceanwide tsunamis.

- Underestimation of the tsunamigenic potential of large and great earthquakes in the first one to two hours compromises early warning (*Kerr, 2005; Menke and Levin, 2005*)

Magnitude Saturation: A Major Obstacle for Early Warnings





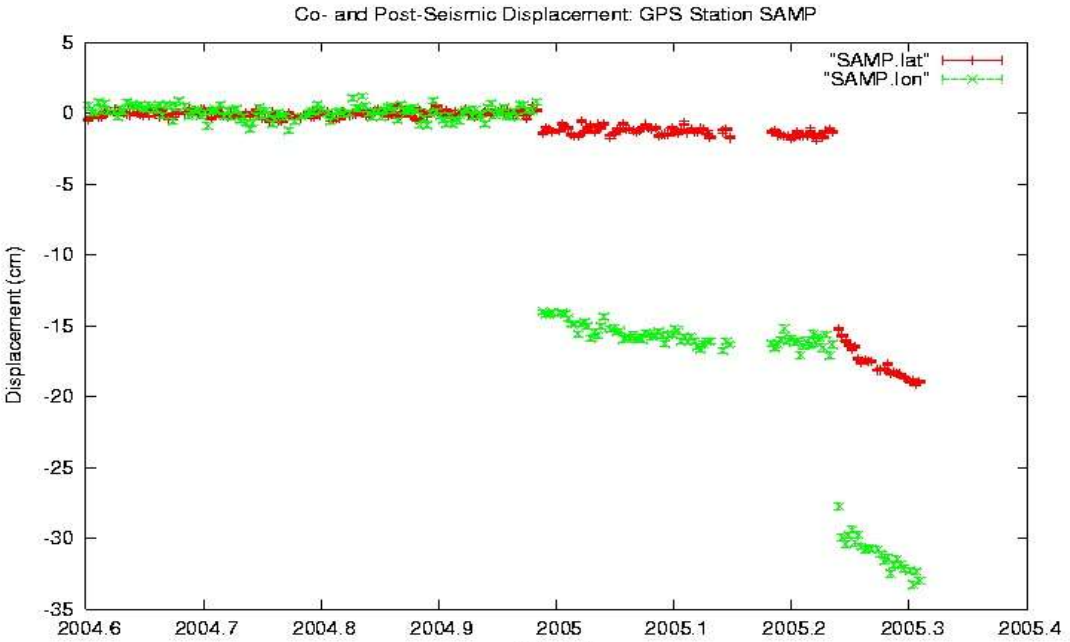
Early magnitudes based on seismic surface waves are saturated at magnitude ~8 to 8.3 (*Geller, 1976*)

Magnitude Saturation: A Major Obstacle for Early Warnings

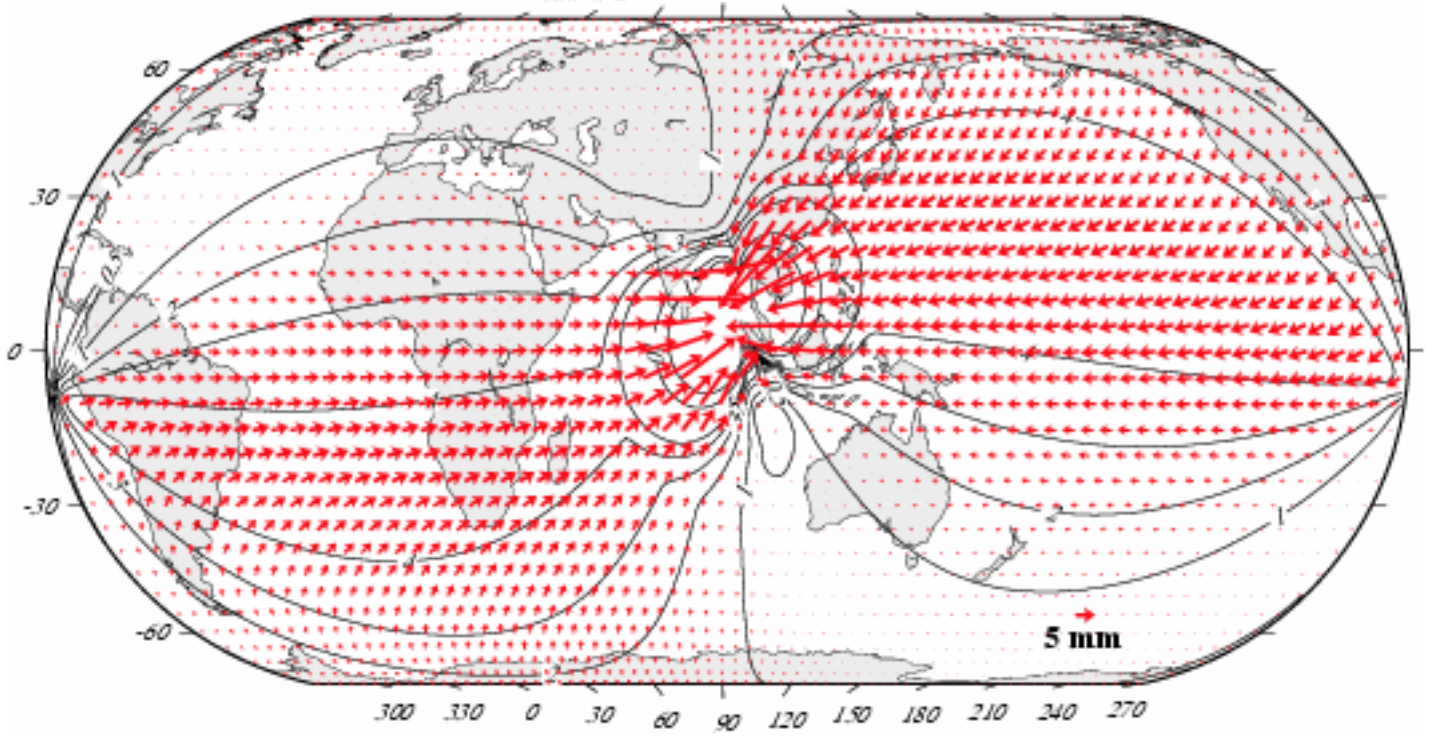
Can a rapid determination of the coseismic displacement field help to improve initial magnitude estimates in near-real time?

Can the displacement field be determined in near-real time from GPS observations as part of an early warning system?

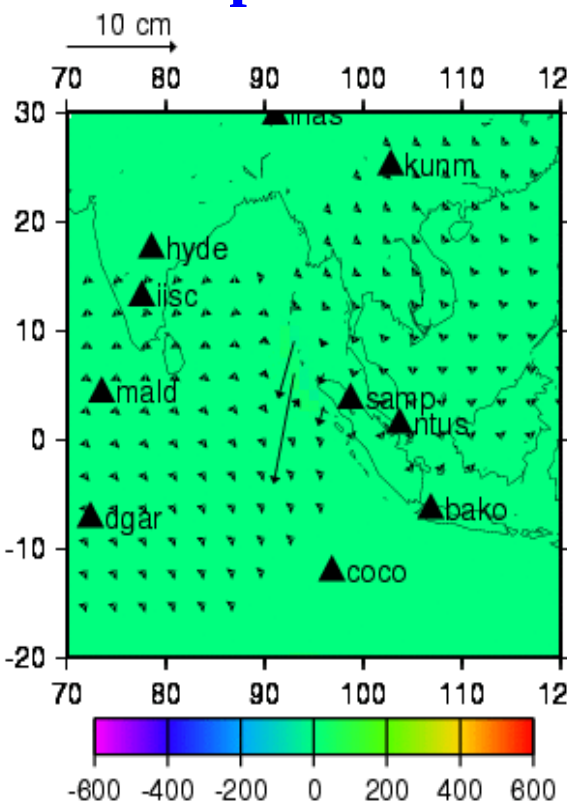
Displacements Field of the Sumatra December 2004 Earthquake



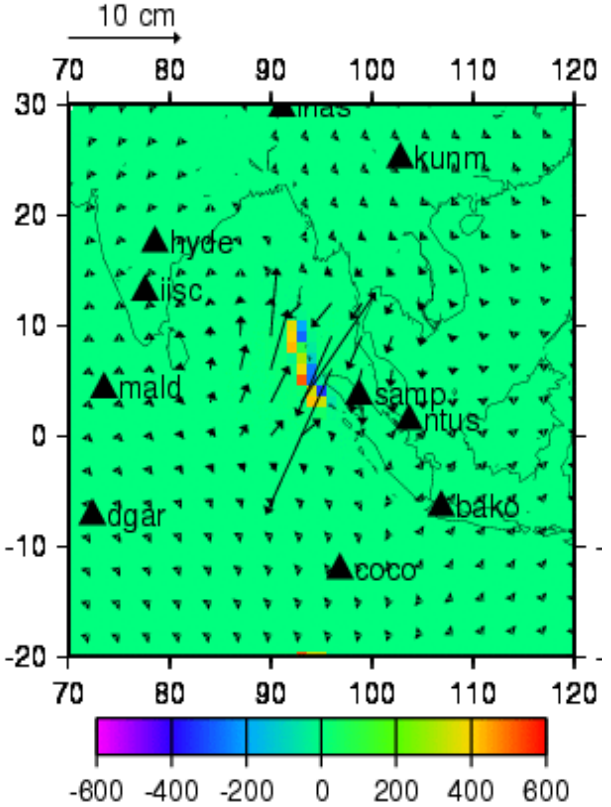
- Post-event determination of displacement field based on GPS
- Displacement field provides constraints on rupture processes and magnitude



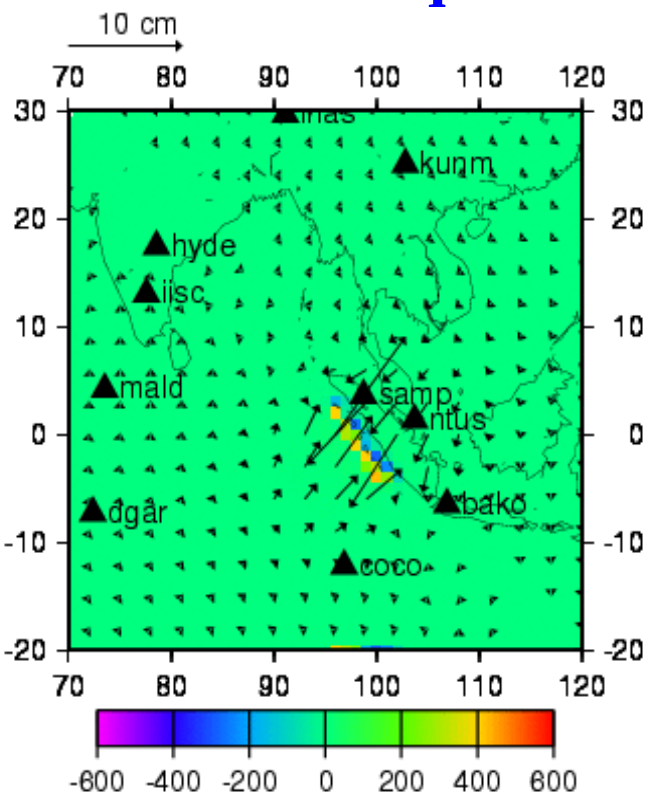
Displacements Field of the Sumatra December 2004 Earthquake



Rupture length: 1000 km
Magnitude: 8.50



Rupture length: 1000 km
Magnitude: 9.25



Rupture length: 1000 km
Magnitude: 9.25
(southward rupture)

Predictions for different rupture length, rupture directions, dips, slip rates show characteristic fingerprints in displacement.

Co-seismic offset: When does it arrive at the station?

Near-Real Time GPS-Based Magnitude Estimates

Model predictions:

- Starting point: Initial estimate of epicenter location and time of onset from seismology
- Computation of a large number (order 100) of predicted displacement fields for different rupture length and direction, slips, and dips

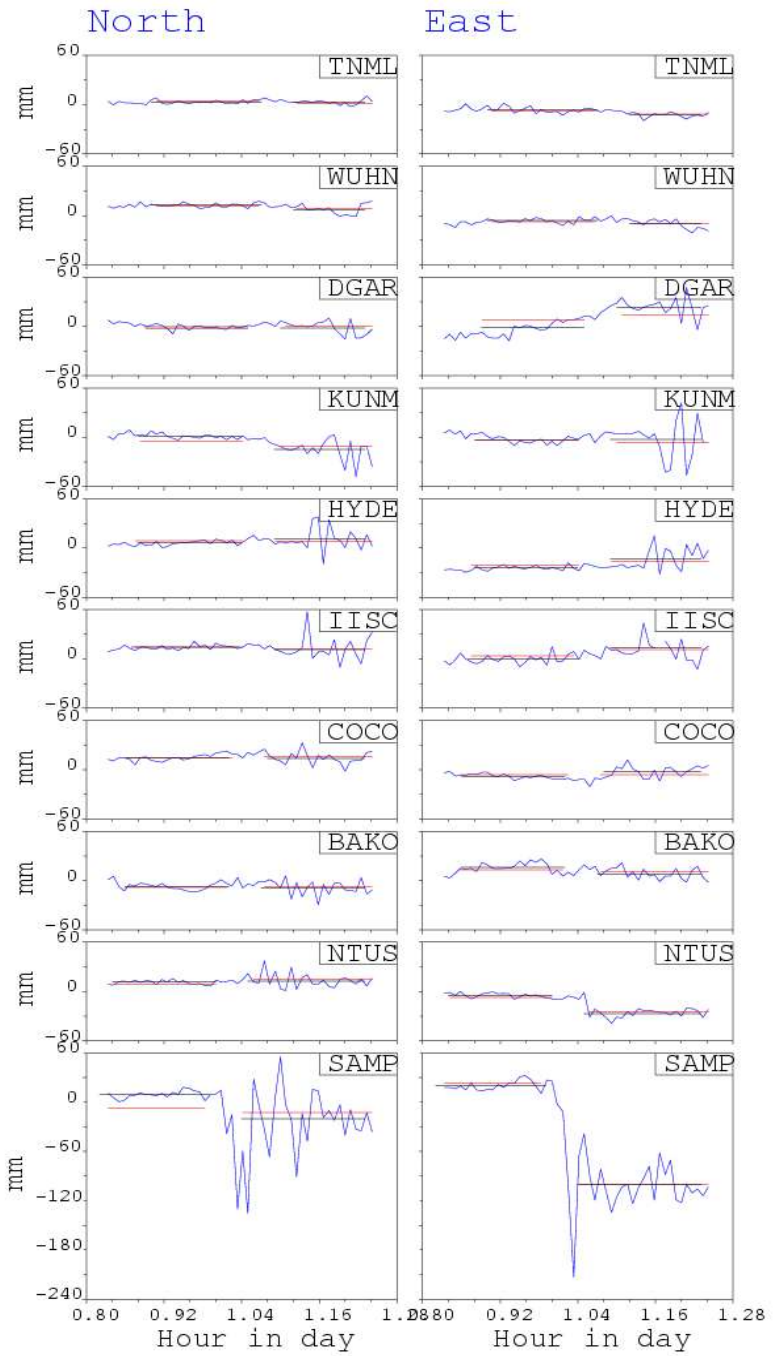
GPS analysis:

- Simulation under real time conditions
- Improvement of orbits and clocks in real time
- Time series with 30 second temporal resolution

Two different approaches for determination of best fitting displacement field:

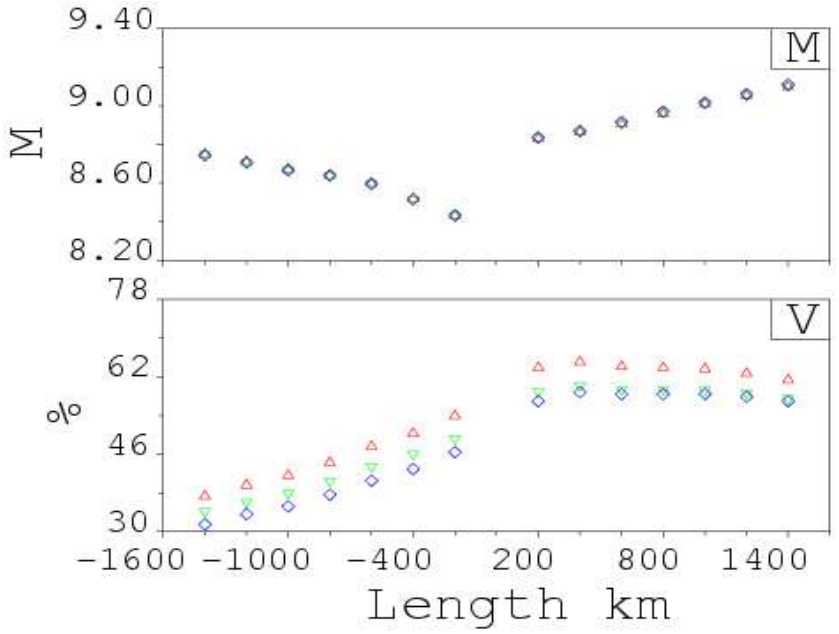
- Analysis of individual time series to determine offsets at each station, subsequent search for best fitting predictions
- Regression analysis for networks giving for each geometry the best fitting magnitude

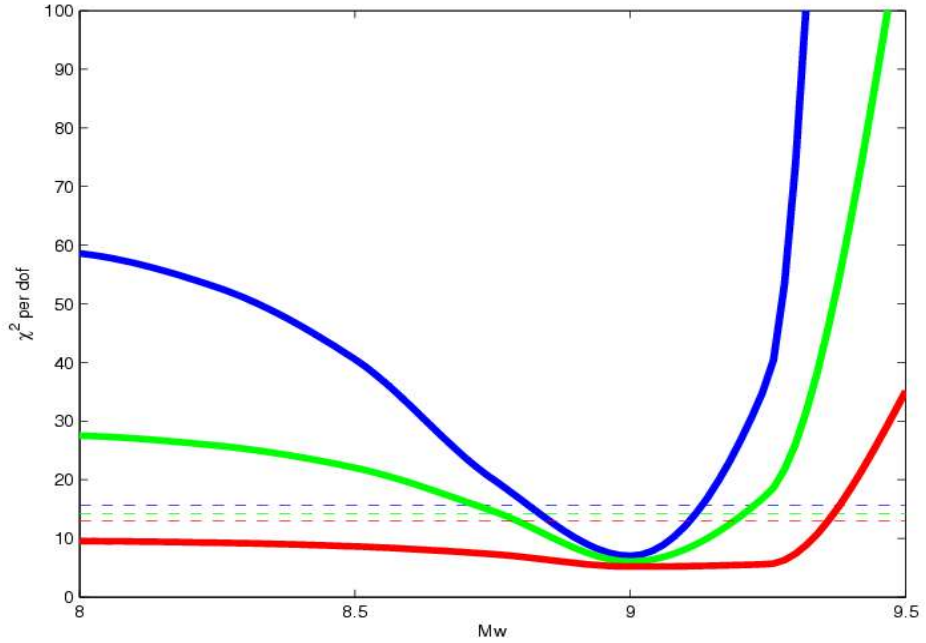
Near-Real Time GPS-Based Magnitude Estimates



- The permanent offsets appears to travel with the p-wave velocity
- Stations up to 3000 km experience significant offsets
- Offsets can be determined within 15 minutes after the earthquake initiation

Near-Real Time GPS-Based Magnitude Estimates





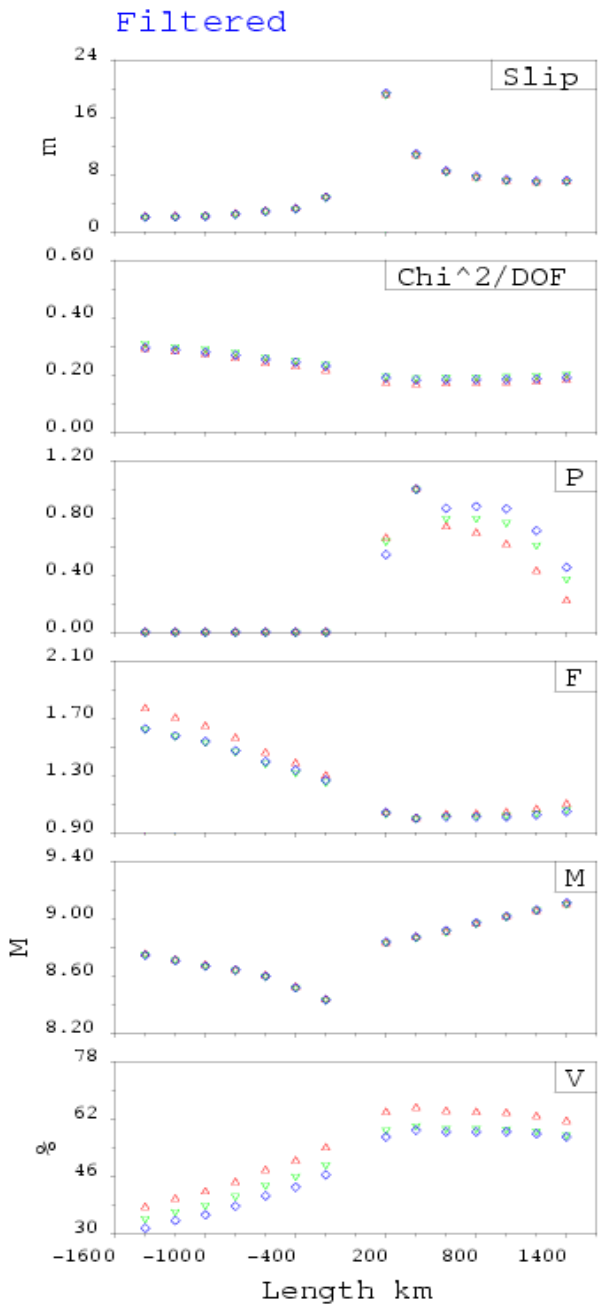
Two different approaches:

- Regression analysis to determine magnitude for each geometry
- Inversion of the offsets determined from the GPS time series

Results within 15 minutes after earthquake initiation are:

- Rapture progresses to the north
- Magnitude estimate is 9.0+-0.2
- Displacement field for tsunami modeling

Near-Real Time GPS-Based Magnitude Estimates



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Towards Real Time GPS-Based Magnitude Determination

Conclusion:

- Near-real time GPS-based magnitude determination can contribute to a solution of the problems due to saturation.

Requirements:

- GPS/GNSS tracking networks around major fault systems.
- Spatial resolution 500 to 1000 km.
- Data available in real time.

GPS in Early Warning:

- The International Association of Geodesy (IAG), the Global Geodetic Observing System (GGOS) and the International GNSS Service (IGS) are working towards real time availability of GNSS data.
- GNSS tracking networks are multi-purpose networks (geodesy, ionosphere, troposphere, navigation).