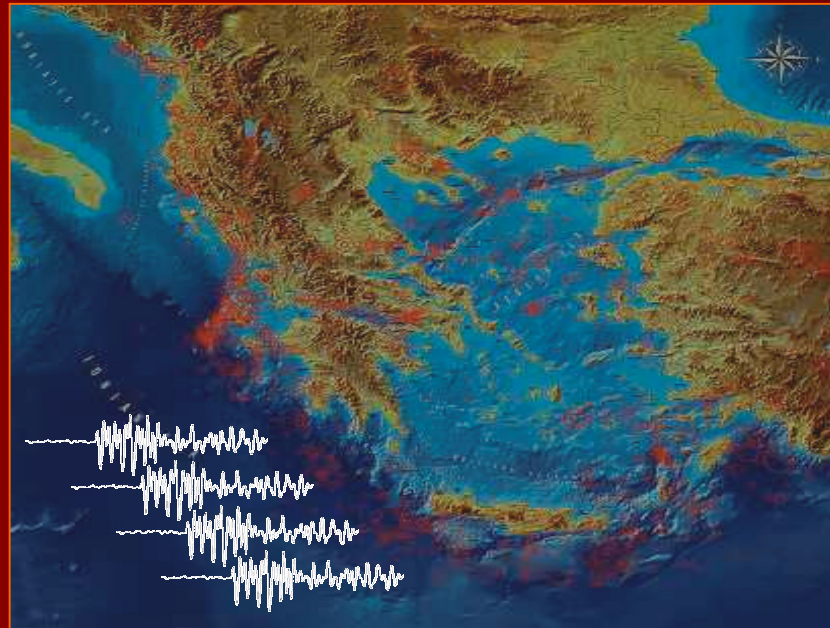


Modeling Earthquakes in Greece

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Nikolaos THEODULIDIS, ITSAK

Douglas DREGER, Berkeley Seismological Laboratory

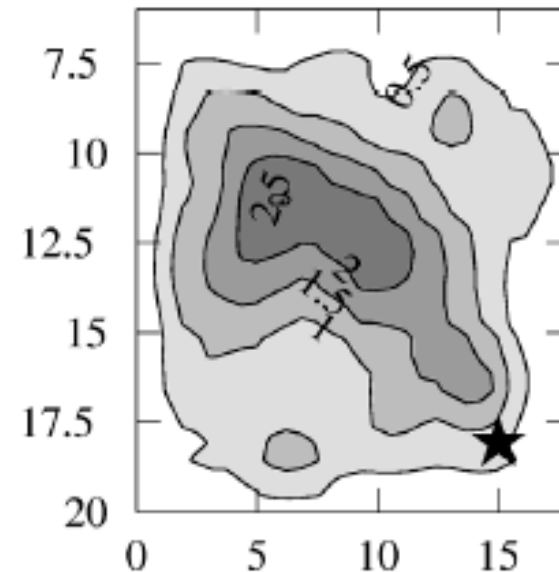
Presentation Frame

- **Short description of the STFs inversion method**
- **Slip distribution study of the 2001, $M_w=6.4$ Skyros earthquake**
- **Slip distribution study of the 1999, $M_w=5.9$ Athens earthquake**
- **Stochastic simulation of strong ground motion from the 1999 Athens earthquake**

The Source Time Functions Inversion Method

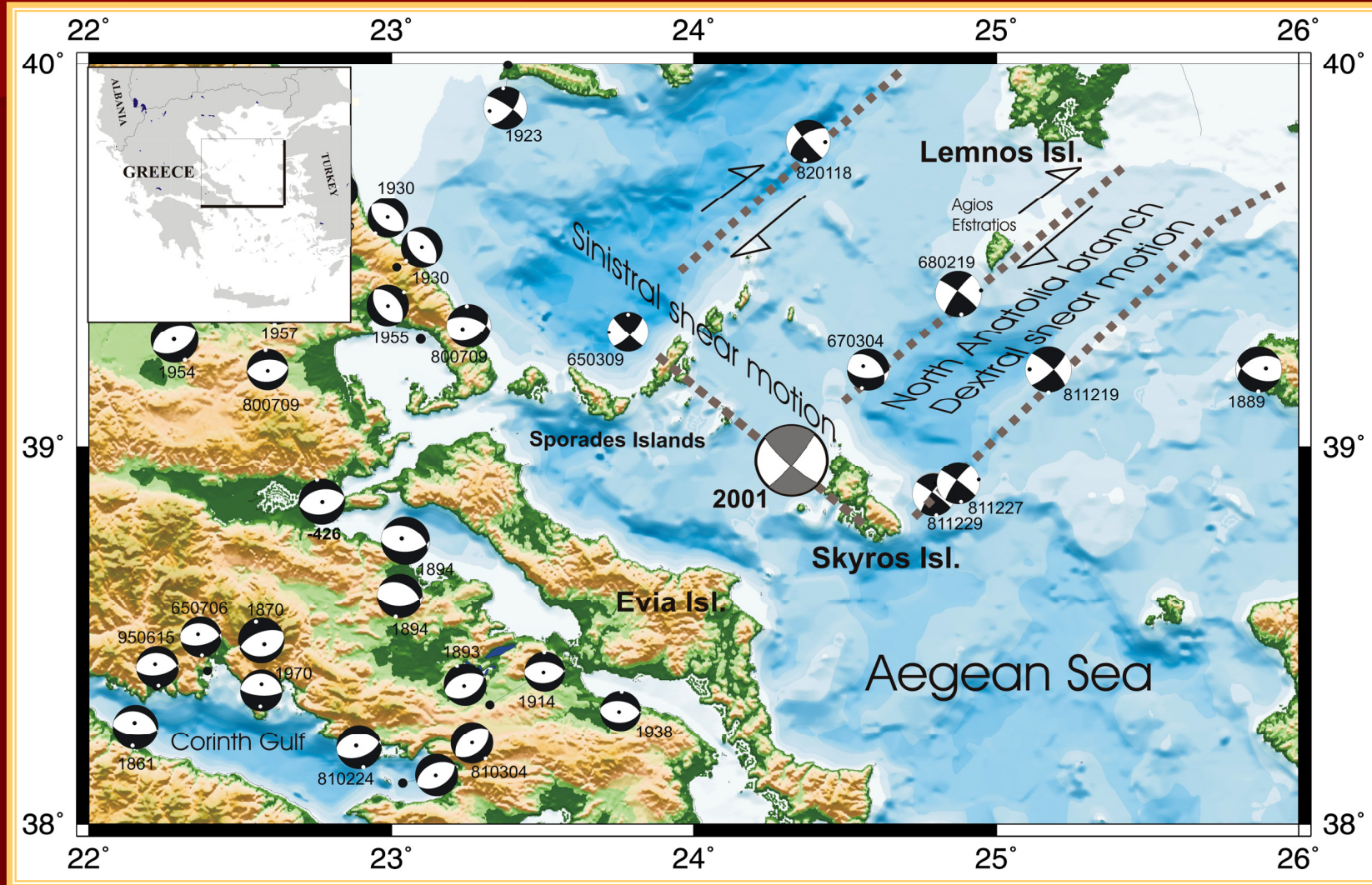
Source Time Functions Inversion

- Select a small earthquake to be used as empirical Green's Function
- Convert original data to displacement
- Apply low-pass filter
- Deconvolve the waveforms of the small and larger events → **Source Time Functions of the large event**
- Stack results from individual components
- Invert the source time functions → *Slip distribution*

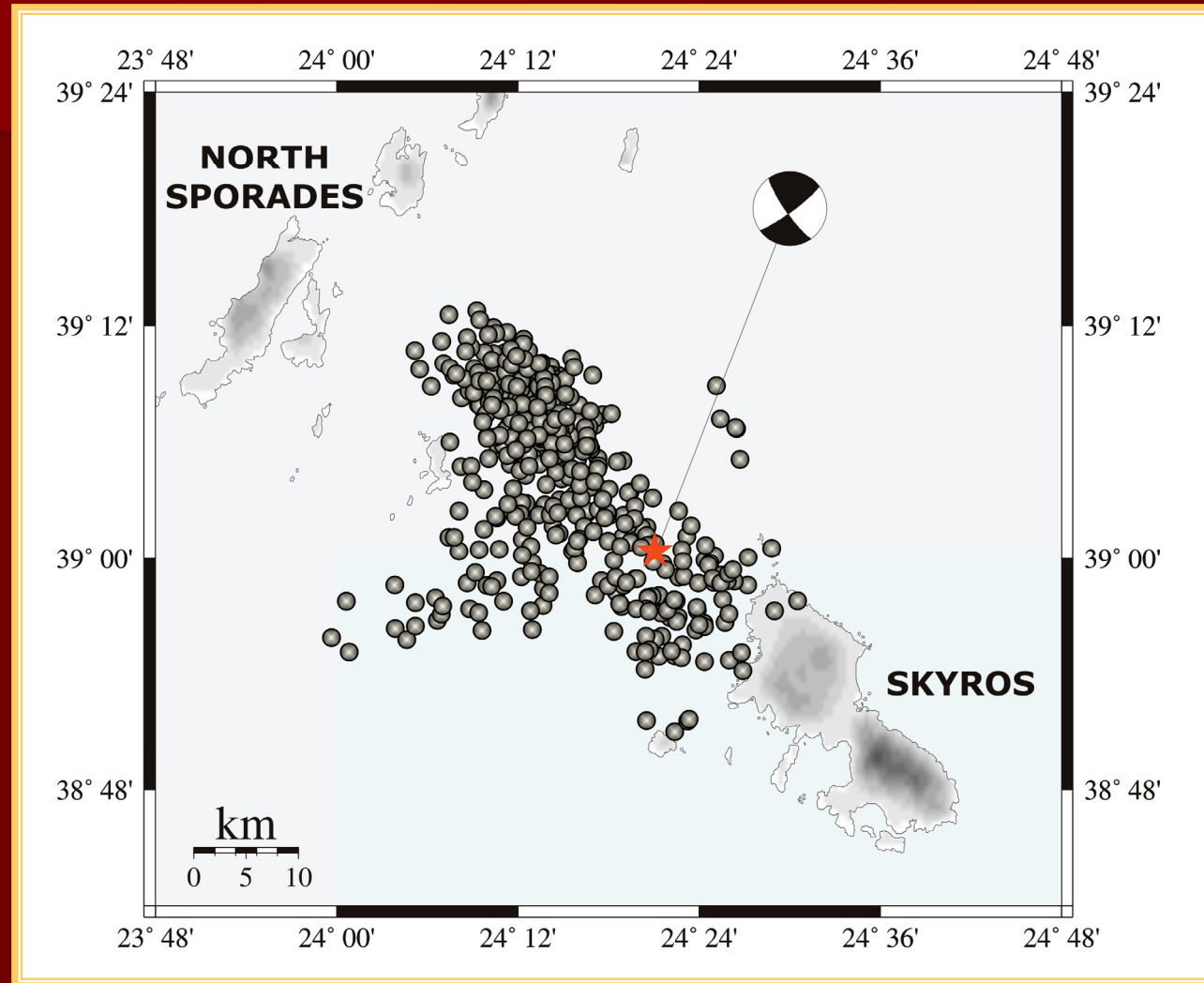


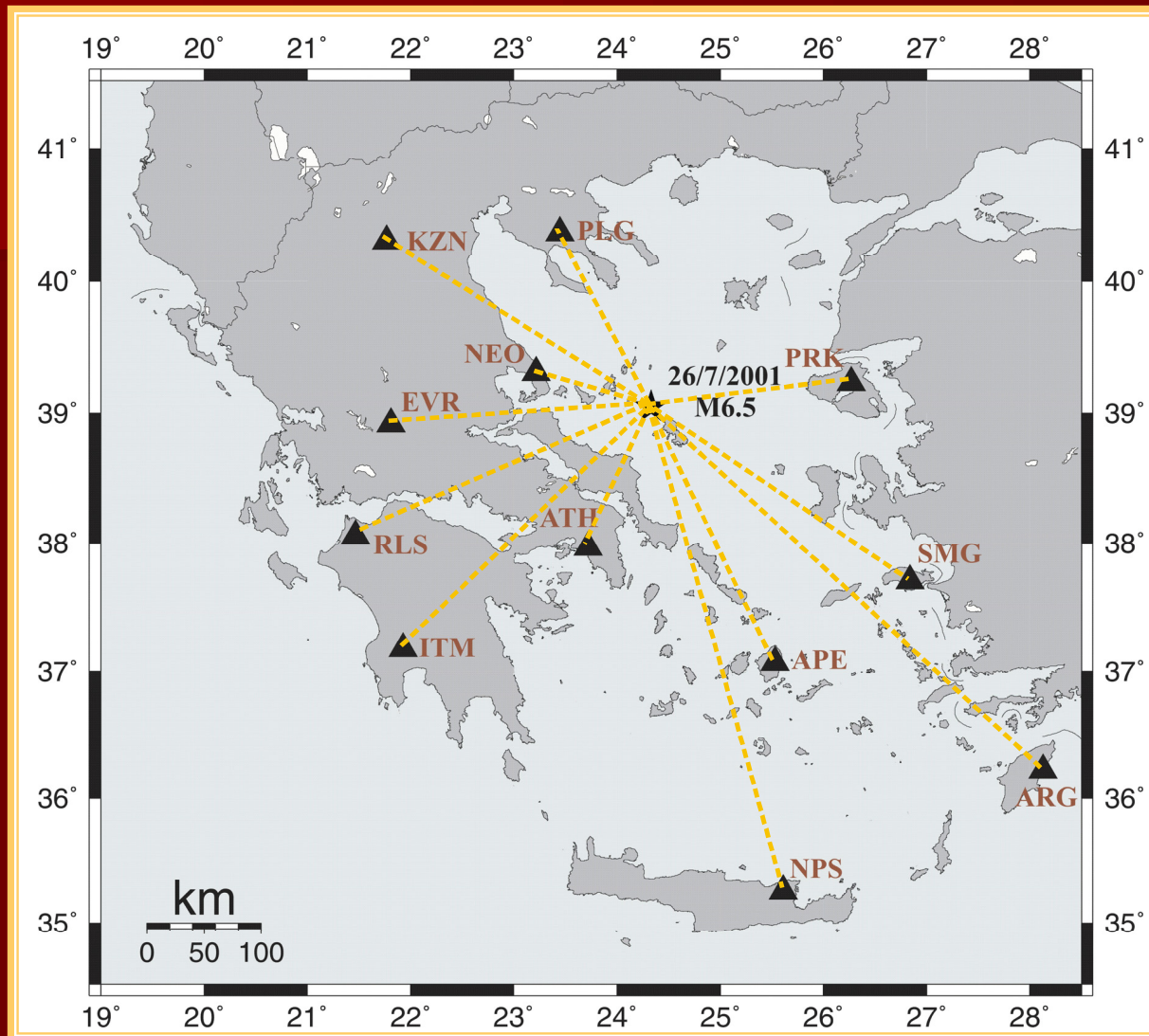
Slip Distribution Study of the 26 July 2001, $M_w=6.5$ Skyros Earthquake

Skyros Earthquake – Region of occurrence



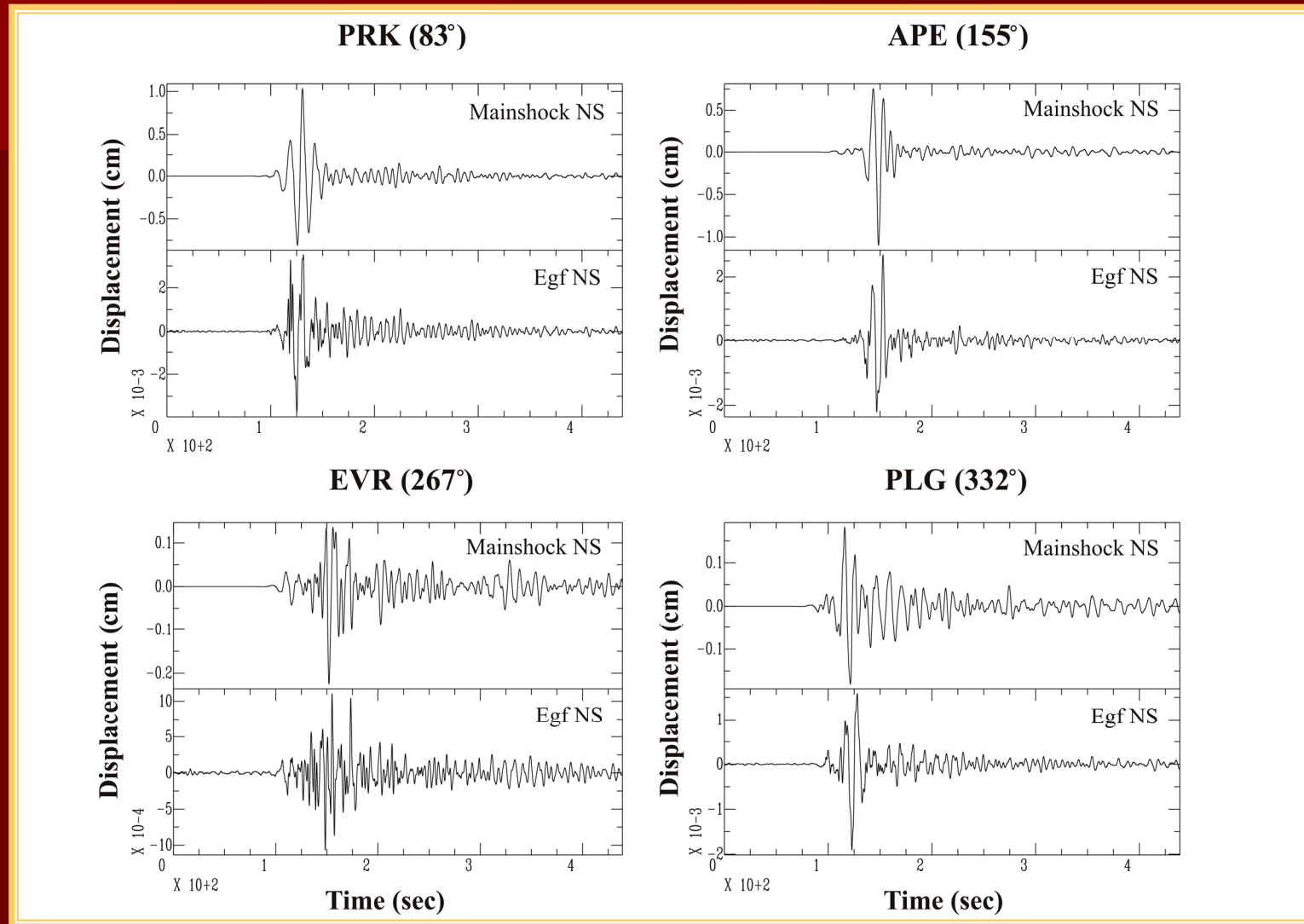
Skyros Earthquake Sequence – Distribution of epicenters



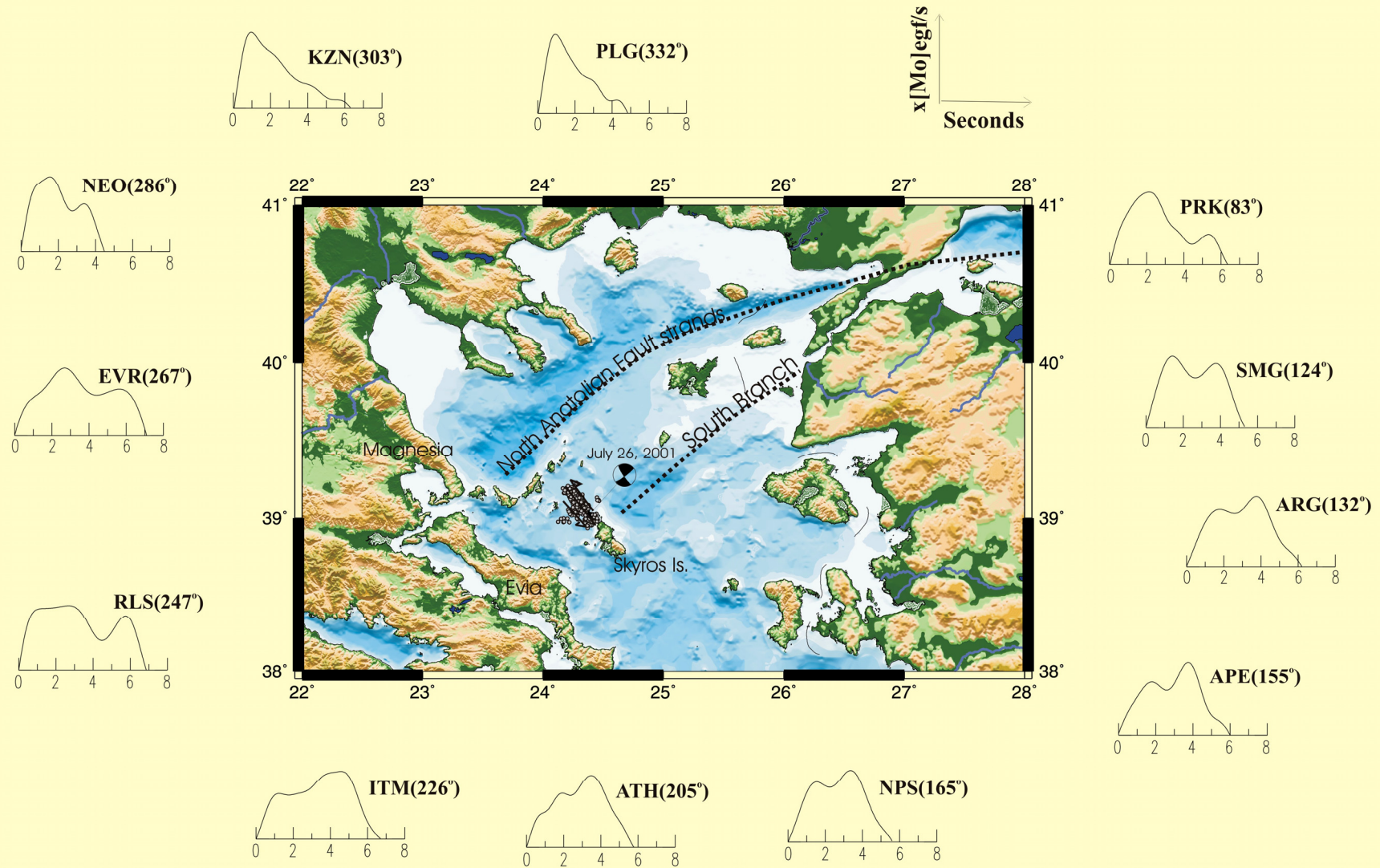


**Azimuthal
distribution of
stations used in
the STF
inversion**

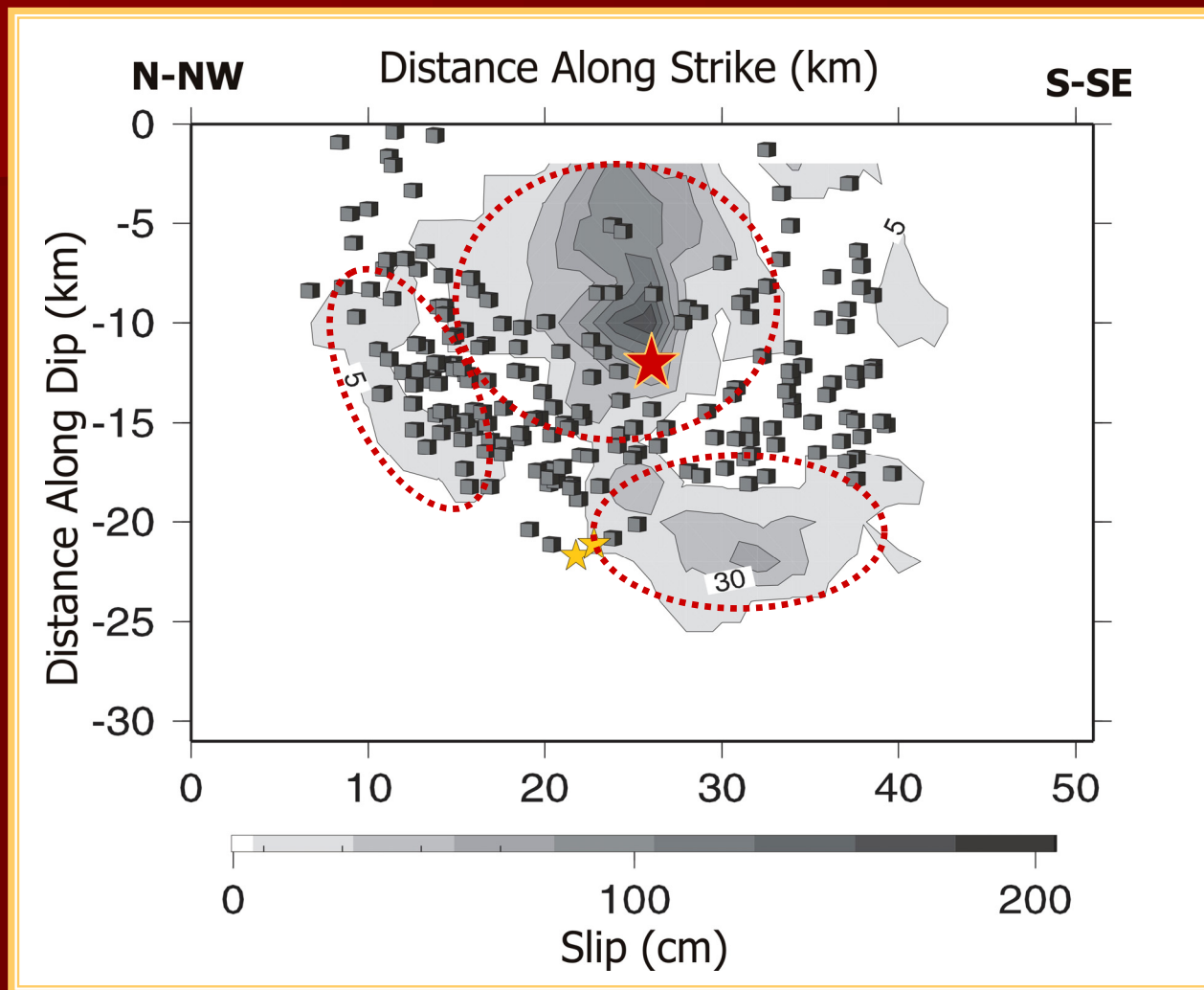
Comparison between mainshock and egf waveforms

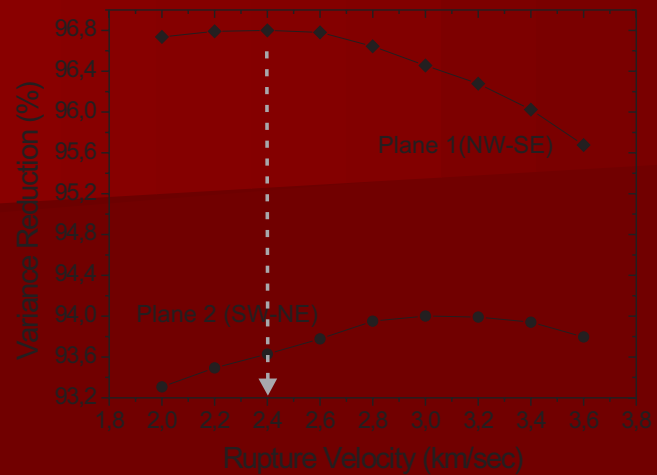
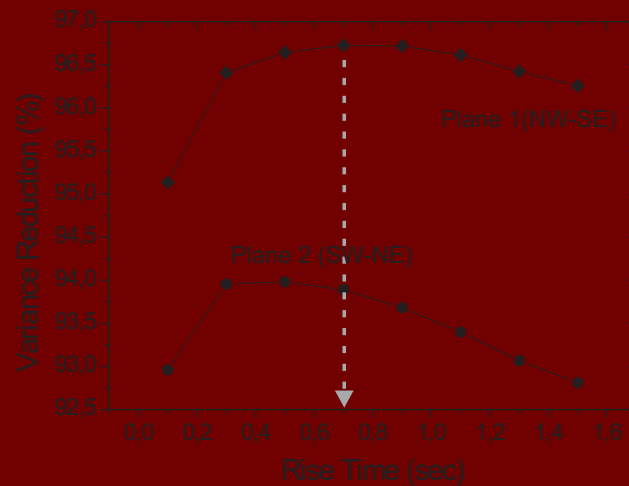


Source Time Functions of the Skyros Mainshock



Slip distribution model for the Skyros earthquake





Grid search for the optimum values of rise time and rupture velocity

Conclusions

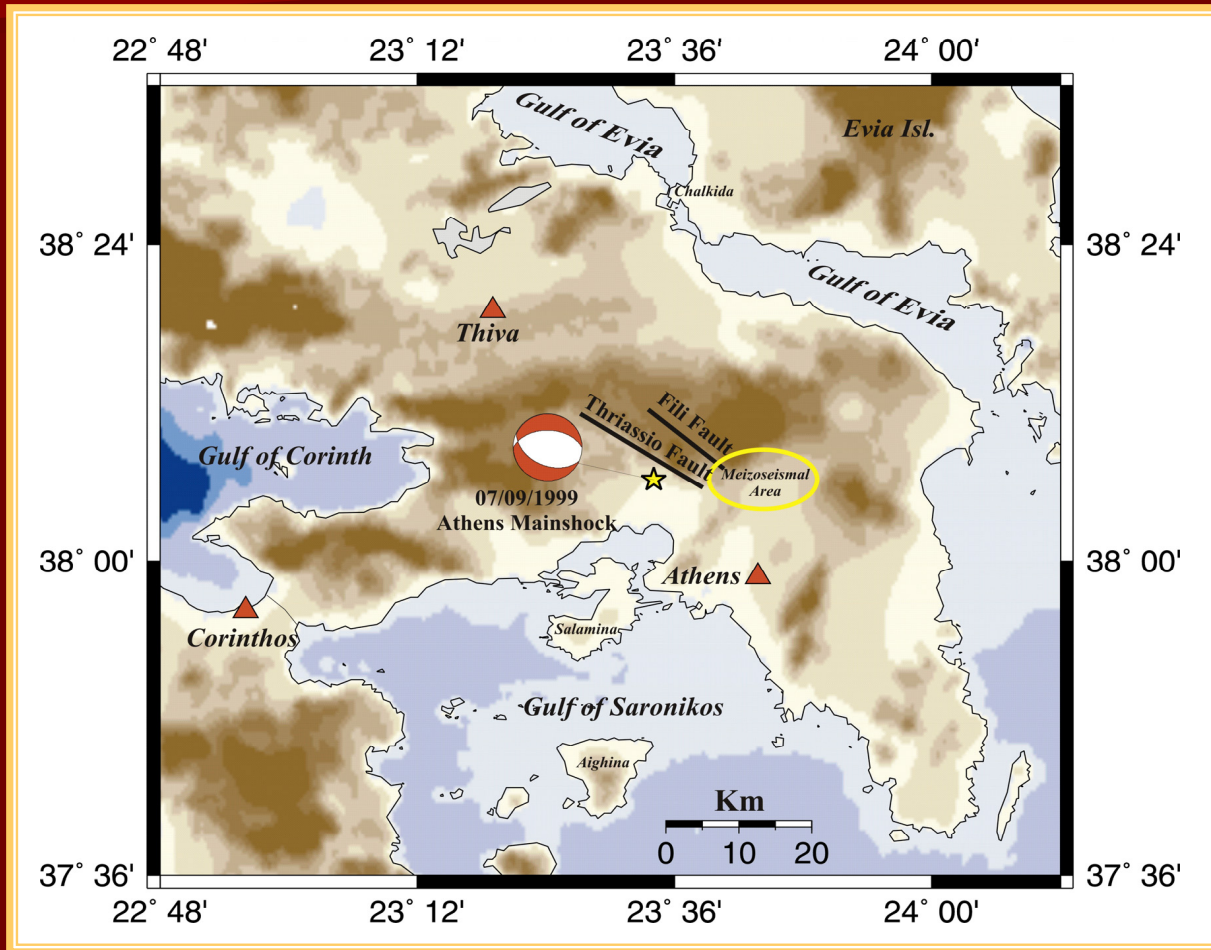
Source process during the 2001 Skyros earthquake

- Dimensions of ruptured area: 30x25 km
- Slip concentration in 3 slip patches
- Mostly upward rupture propagation
- Average and maximum slip: 0.23 και 1.8 m, respectively
- Bilateral rupture propagation
- Rise time: $\tau=0.7$ sec
- Rupture velocity: $V_r=2.4$ km/sec
- Statistical significant distinction between the two nodal planes

Slip Distribution Study of the 1999, Mw=5.9, Athens Earthquake

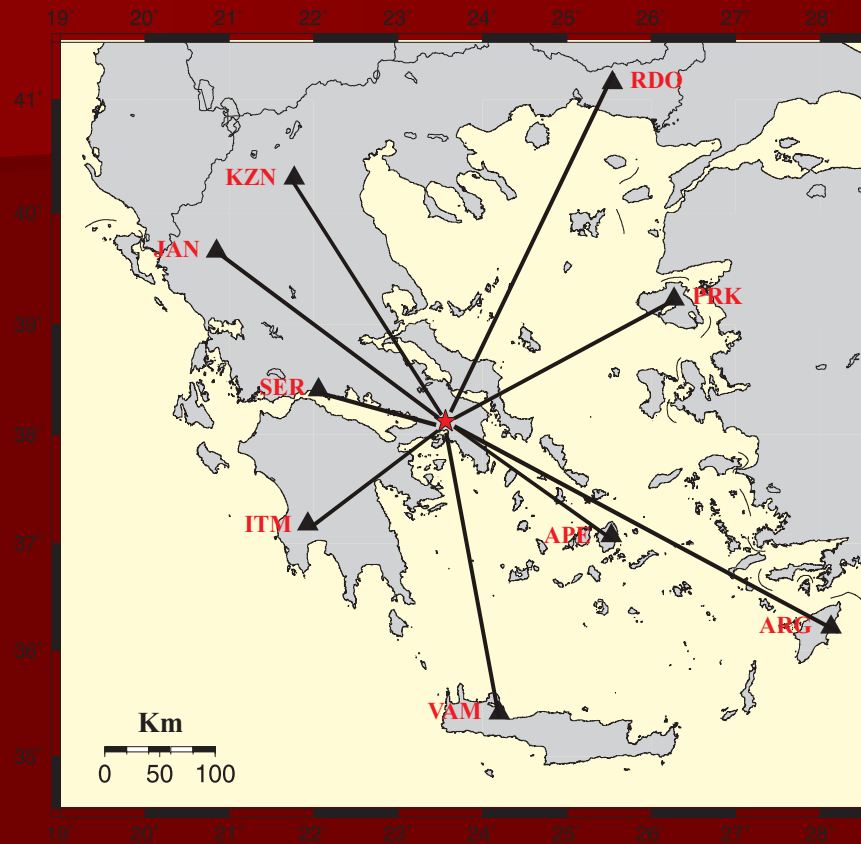
Athens Earthquake - Region of occurrence

Questions associated with this earthquake:

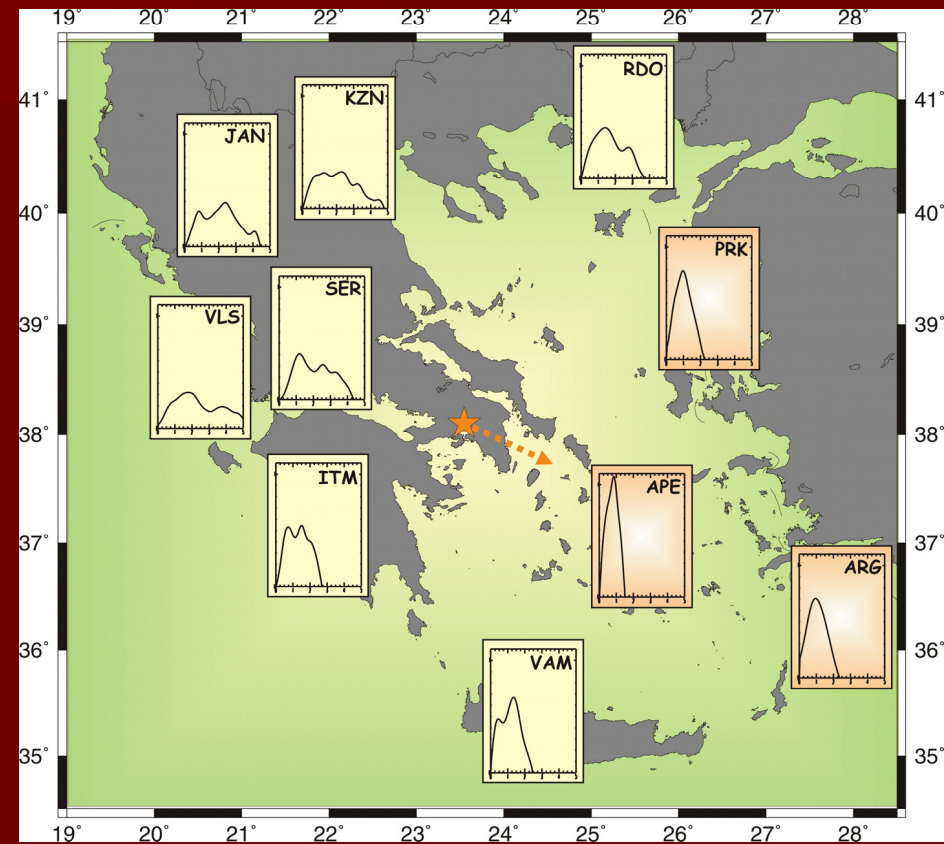


- **Seismogenic Fault:** known mapped structure or blind fault?
- **Explanation of the “unusual” damage distribution pattern**
- **Which one of the proposed hypocenter solutions is the correct one?**
- **Did the rupture reach the earth surface?**

Source Time Functions Inversion:

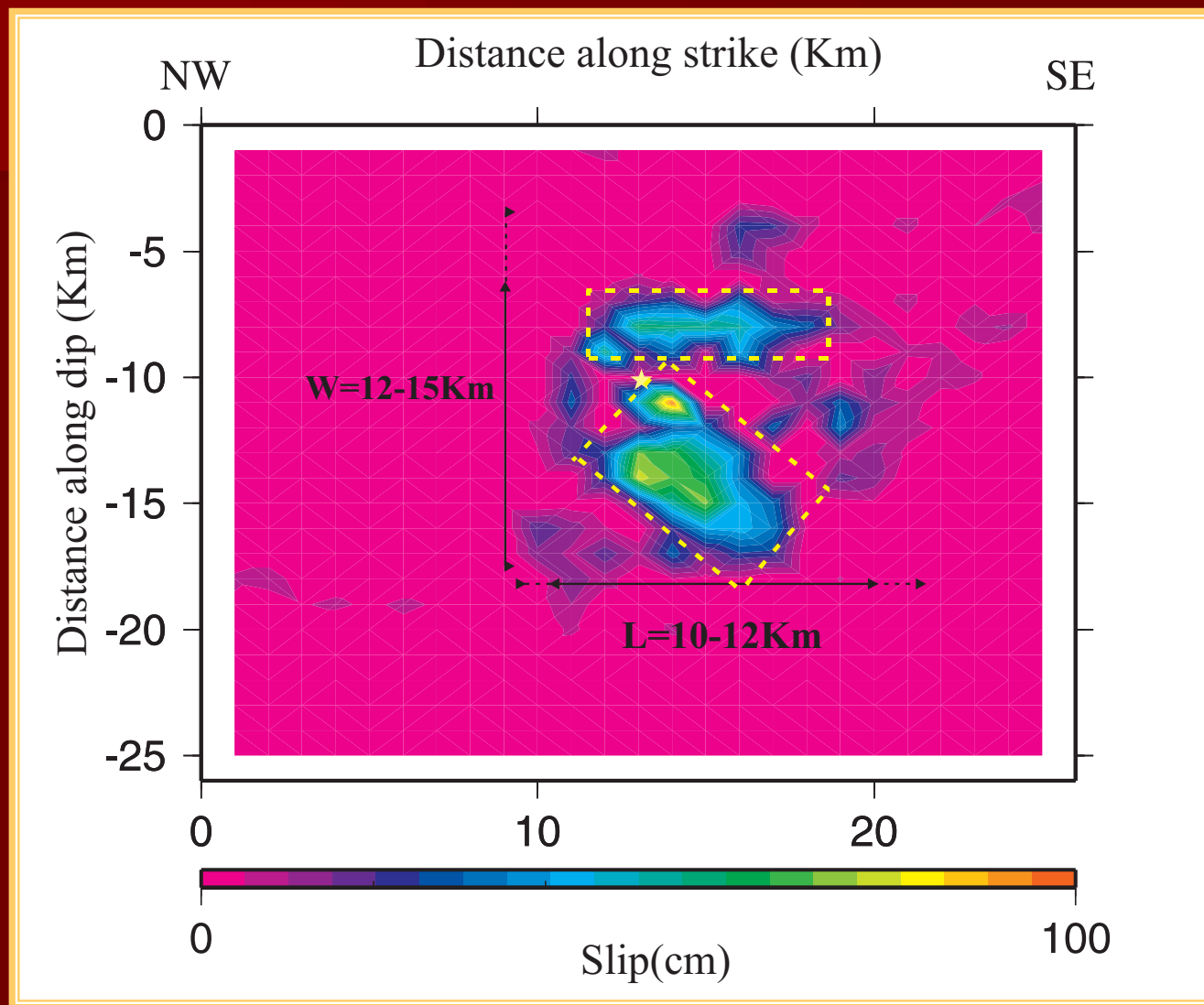


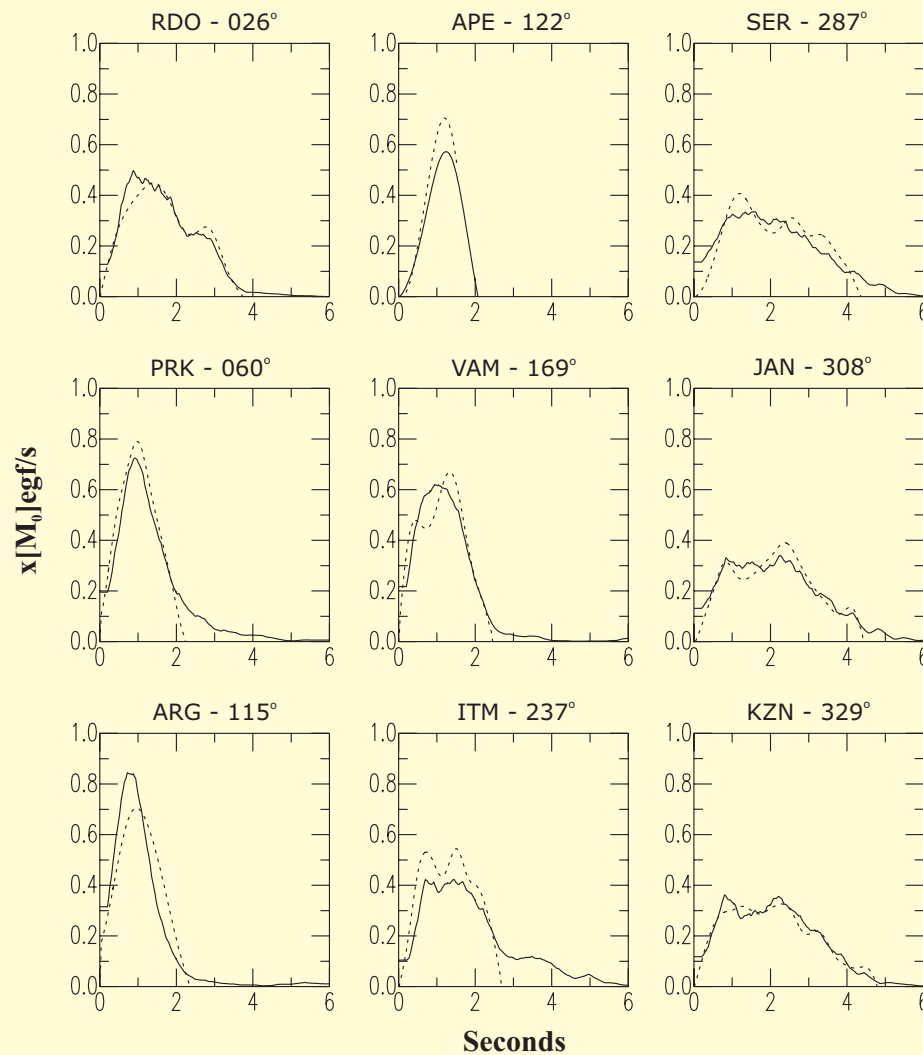
Available broadband stations



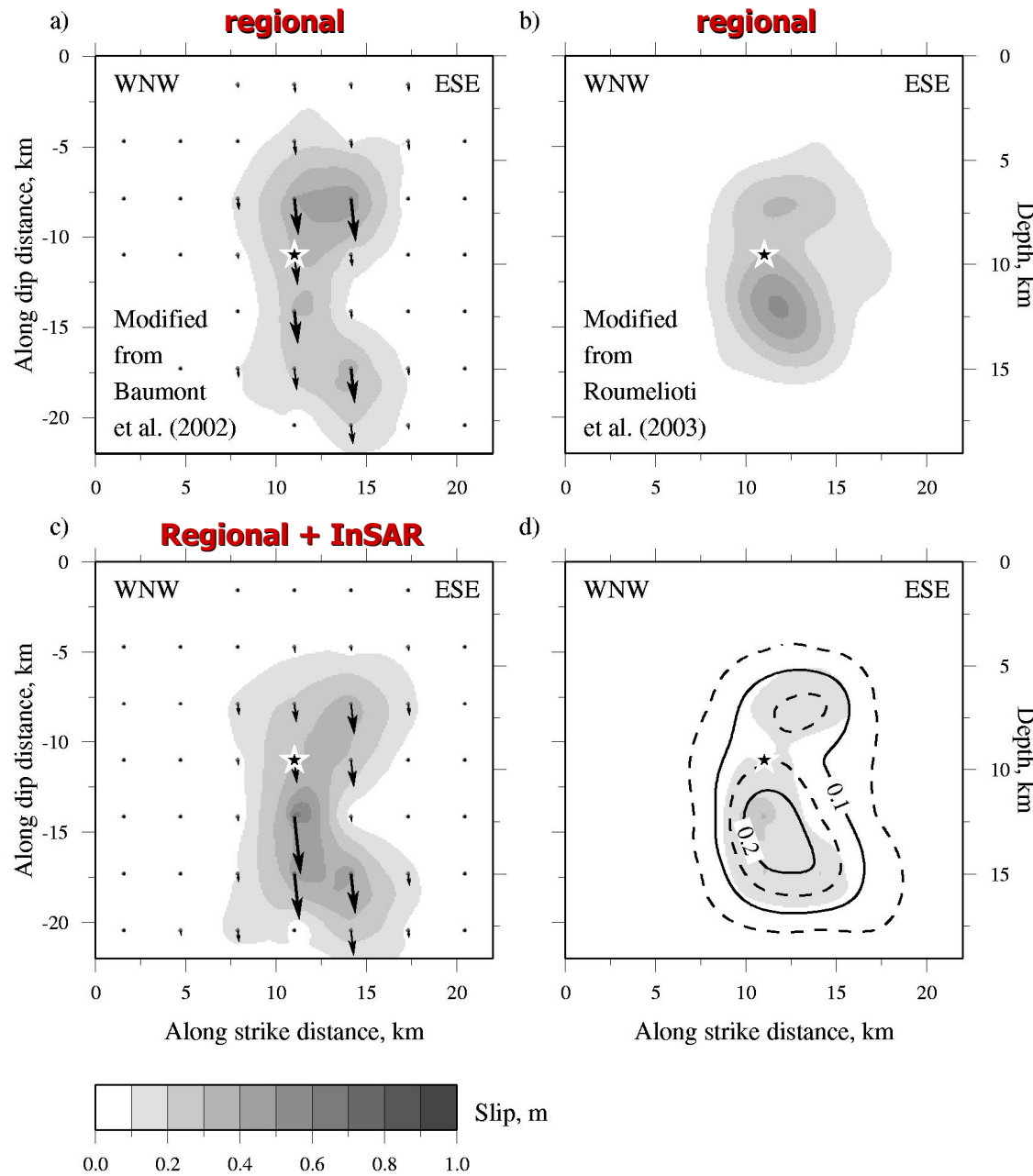
Computed Source Time Functions

Athens Earthquake: Proposed slip distribution model

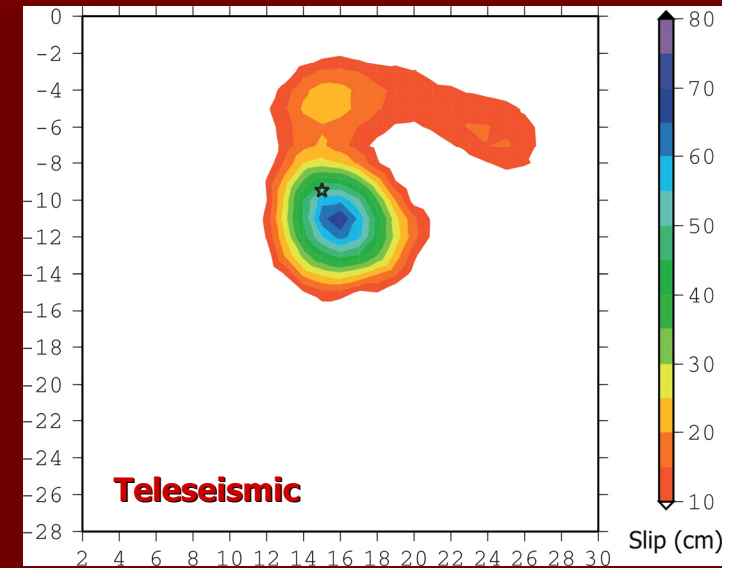




**Comparison between
observed and
theoretical source
time functions**



Comparison of heterogeneous slip distribution models proposed for the 1999 Athens earthquake



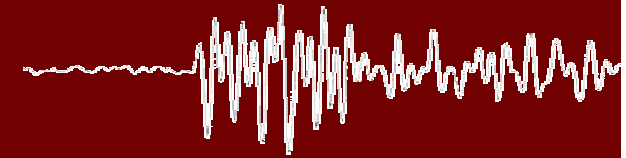
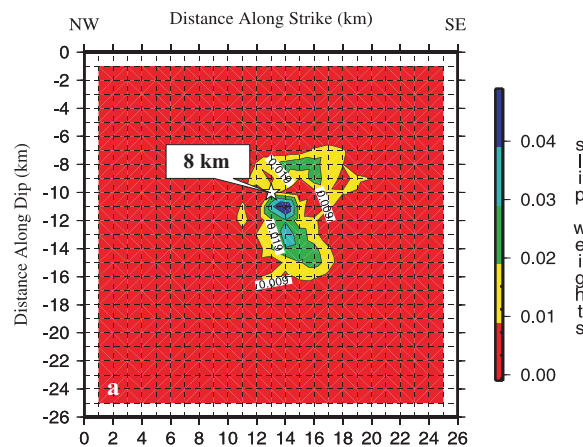
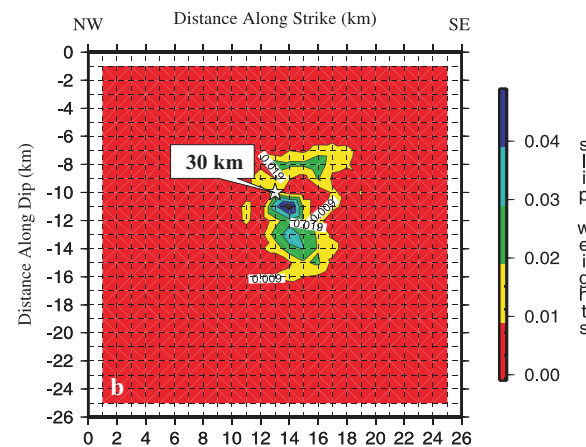
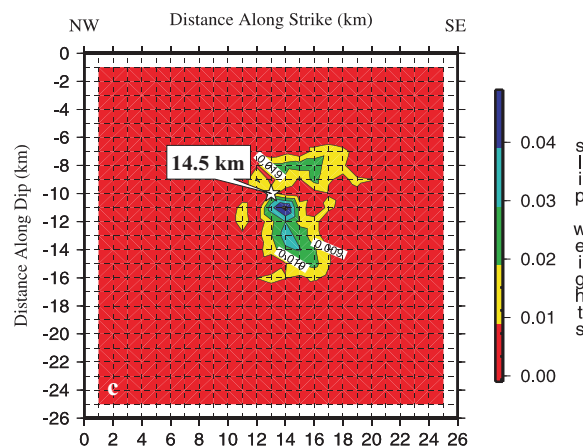
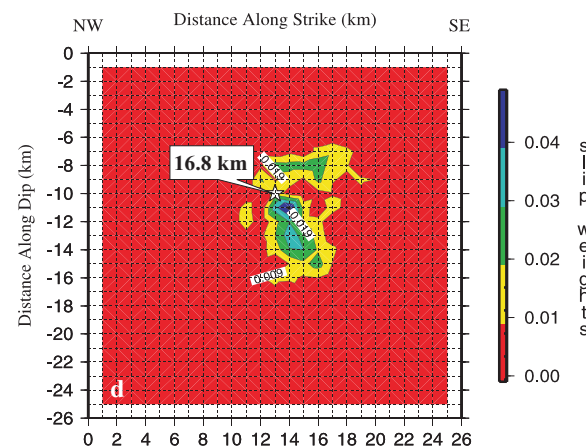
Benetatos, unpublished results

Baumont et al., 2004

Simulation of the Static Displacement Field Caused by the Athens Earthquake

Effect of the use of different hypocenters to the slip distribution model

Differences between published hypocentral locations: 3 – 16 km horizontally
6.5 – 22 km vertically



Slip distribution patterns from different epicenters proposed for this earthquake

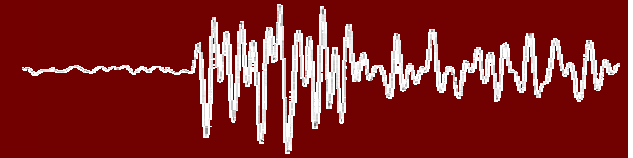


Distribution relative to the hypocenter remains unchanged

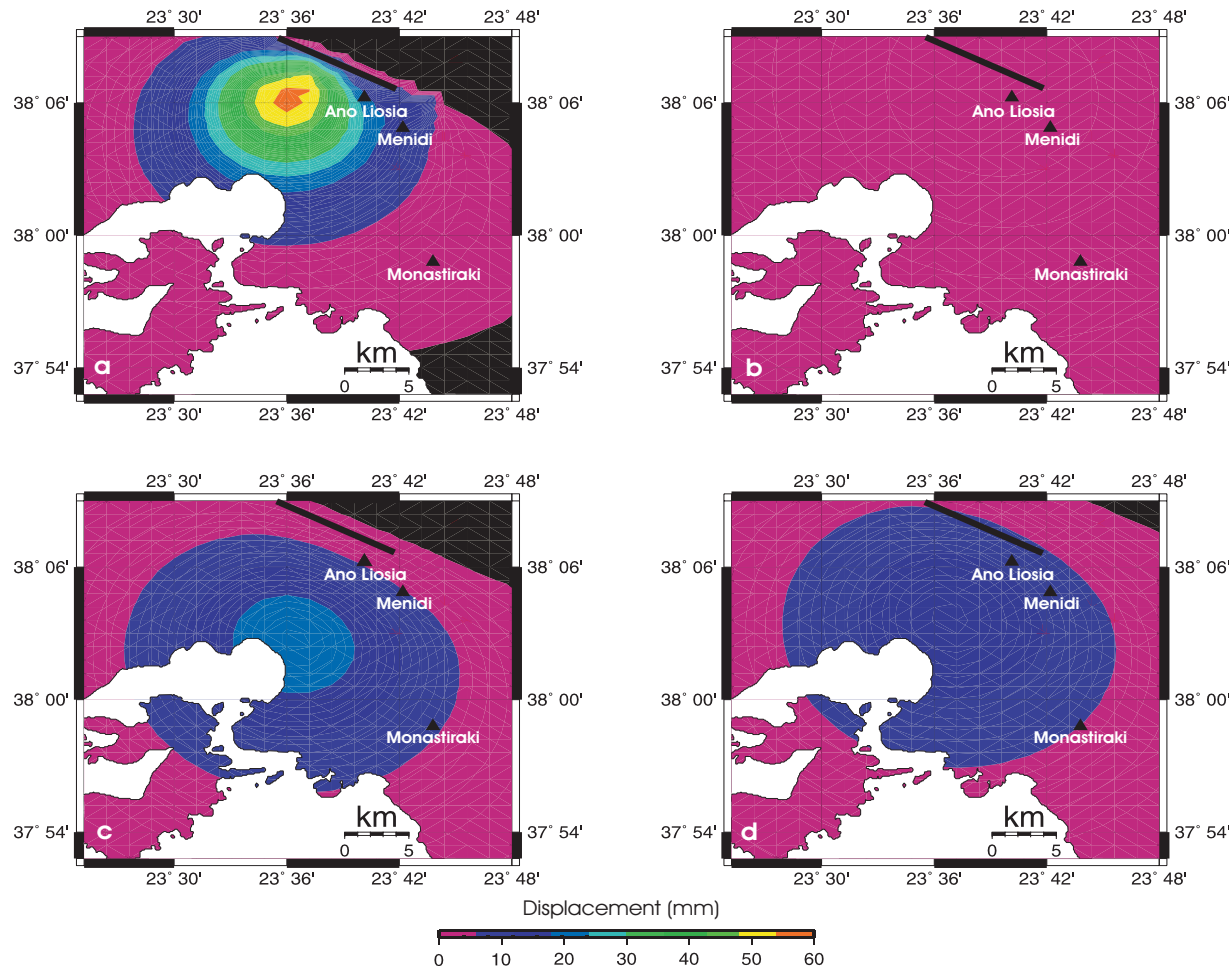


Cannot determine the optimum hypocenter from seismological data only

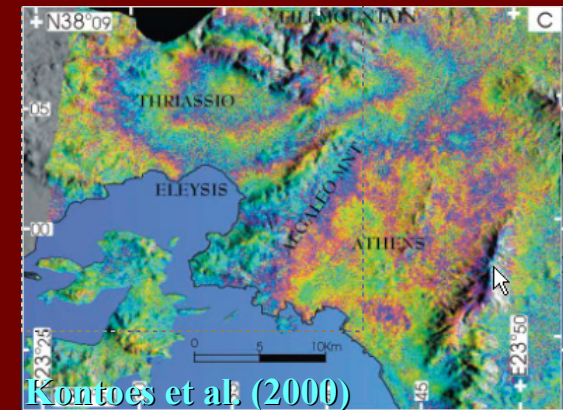
Effect of the use of different hypocenters to the synthetic static displacement field



Synthetic Surface Displacements



InSAR Data

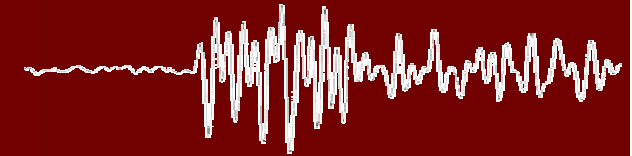
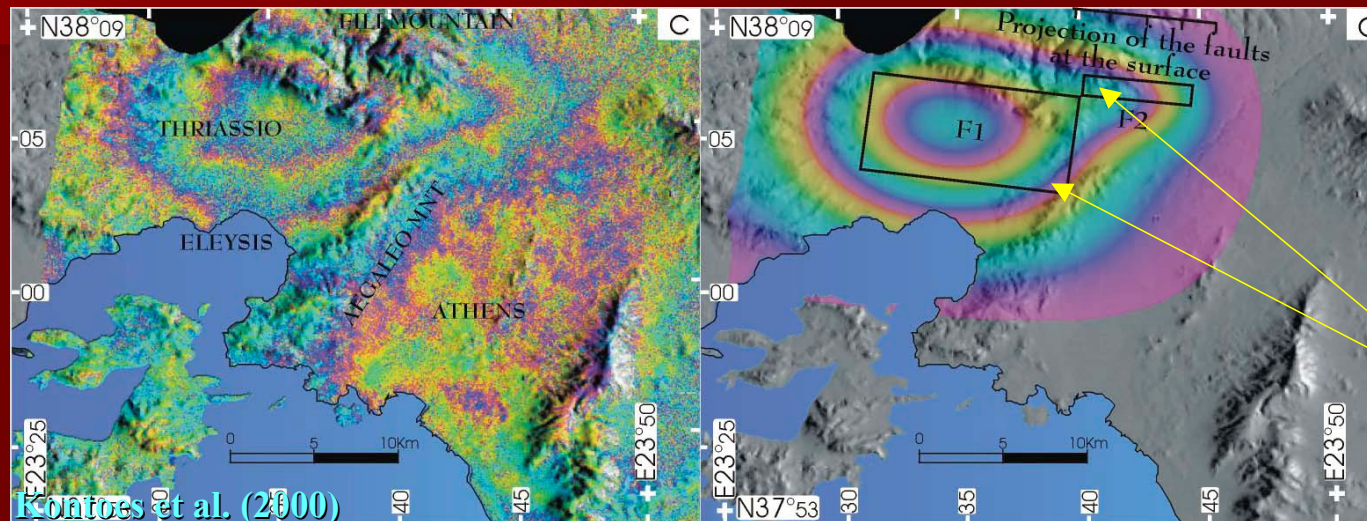


**Forward modeling of
the surface
displacement field**

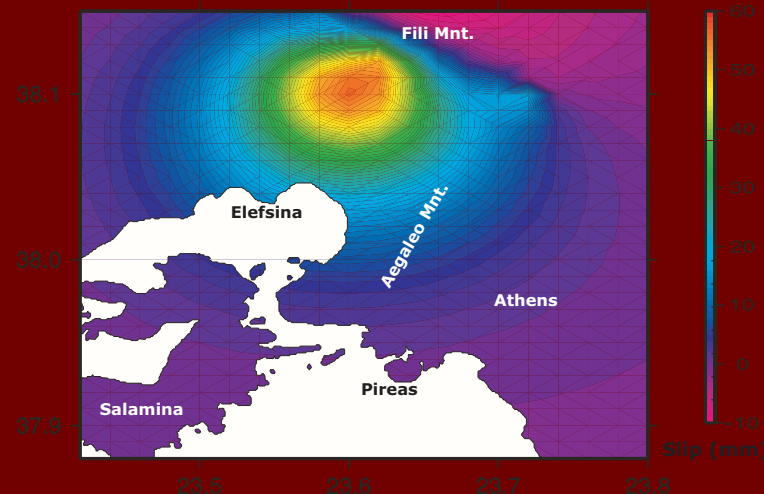


**The optimum
hypocenter can be
determined based on a
comparison with the
InSAR data**

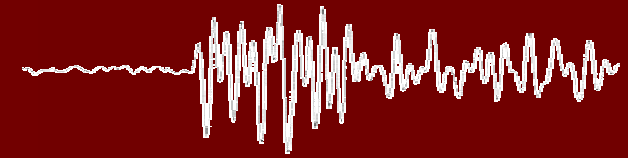
Comparison between observed and synthetic static displacement field



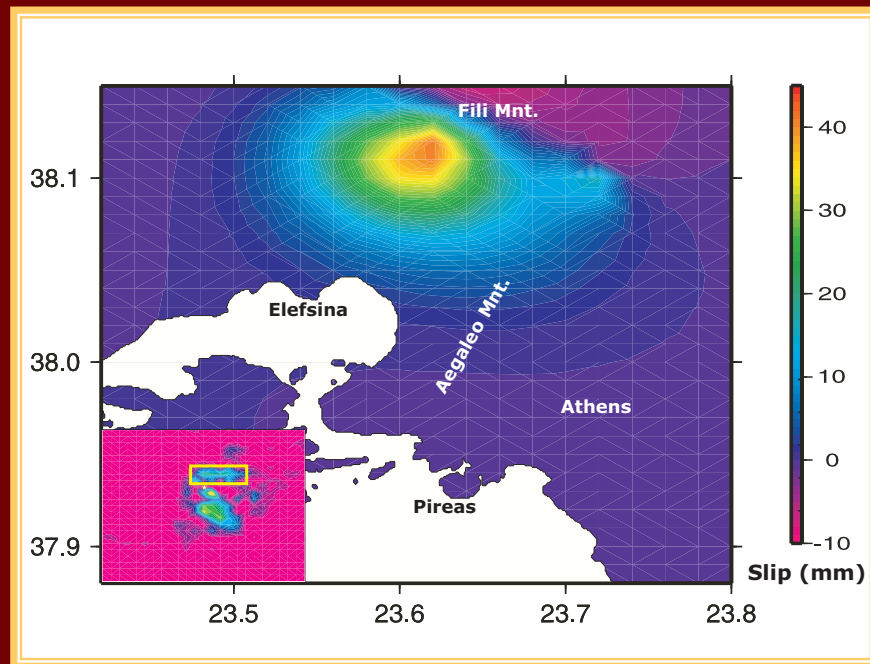
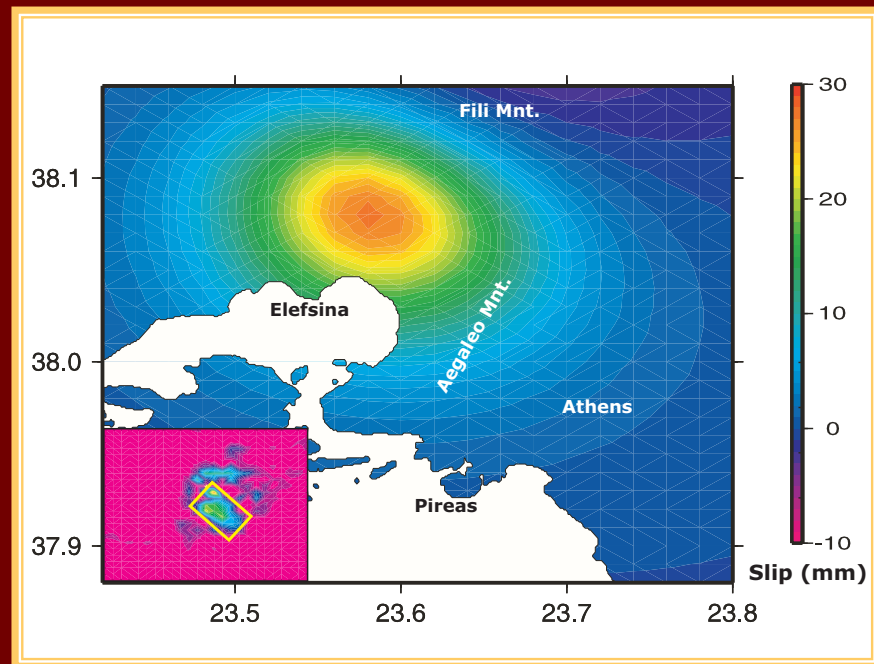
InSAR
data only
↓
2 faults



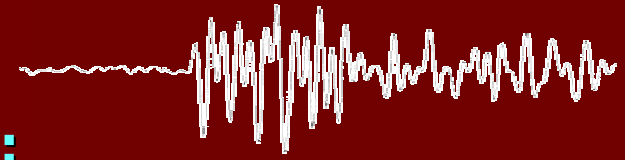
Seismological+ InSAR data
↓
1 fault with inhomogeneous slip
distribution



Individual contributions of the two distinct slip patches to the overall surface displacement field



Answers for the 1999 Athens Earthquake through combination of different sets of data:



- 1. The observed static displacements can be explained by a single fault if non-uniform slip distribution is taken into account**
- 2. The rupture did not reach the surface**
- 3. Definition of the optimum hypocenter solution**

Stochastic Simulation of Strong Ground Motion from the 1999 Athens Earthquake

Short Description of the Stochastic Method

Site Effect

Amplification
function

High frequency
diminution factor, κ

Seismic Source

Source Dimensions

Rupture Initiation

Slip Distribution

Seismic Moment

Sfact, high frequency
radiation

Propagation Path

Empirical attenuation
relations

Geometrical attenuation

Rupture
Initiation

Slip Patches

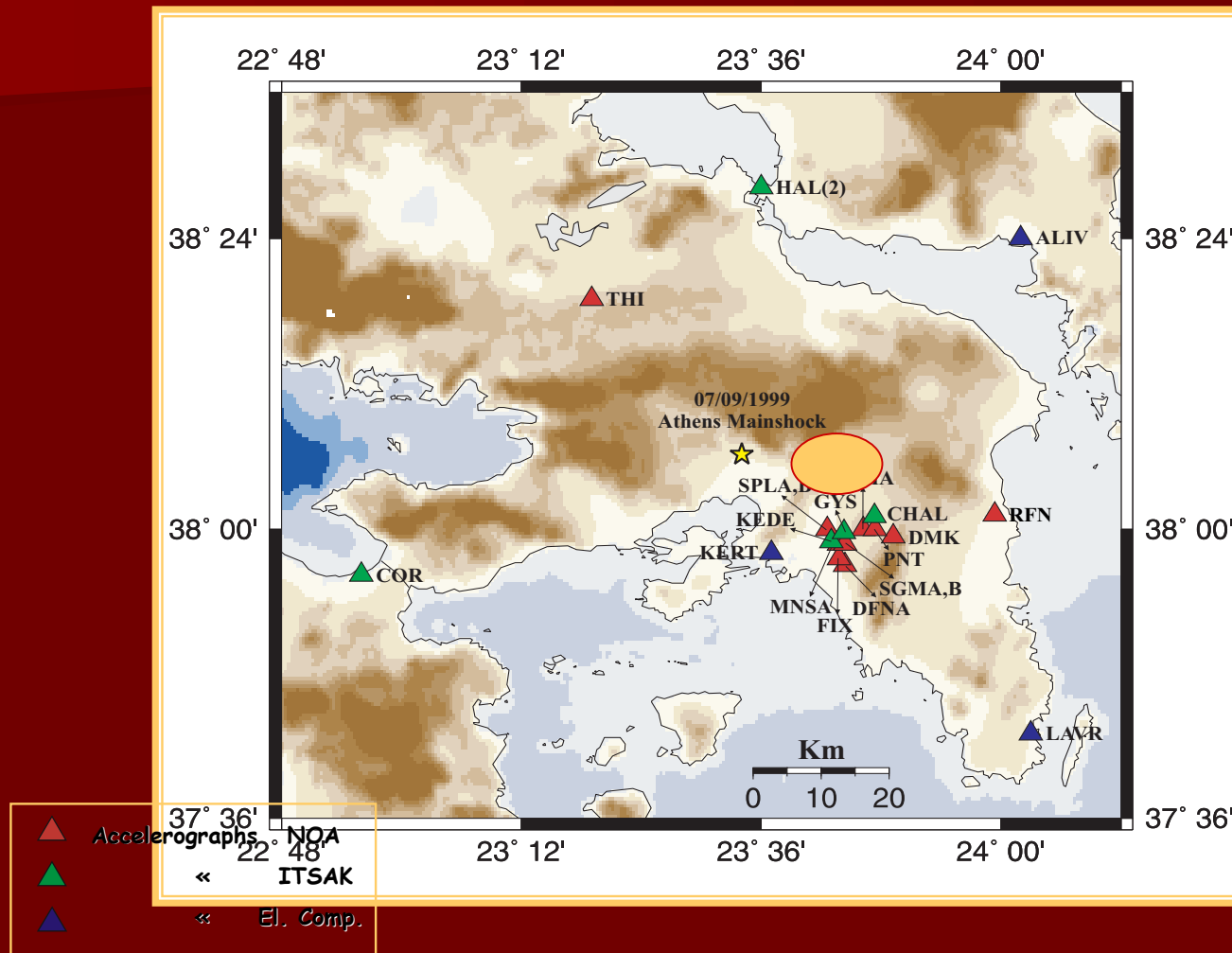
Fault Plane

Surface Geology

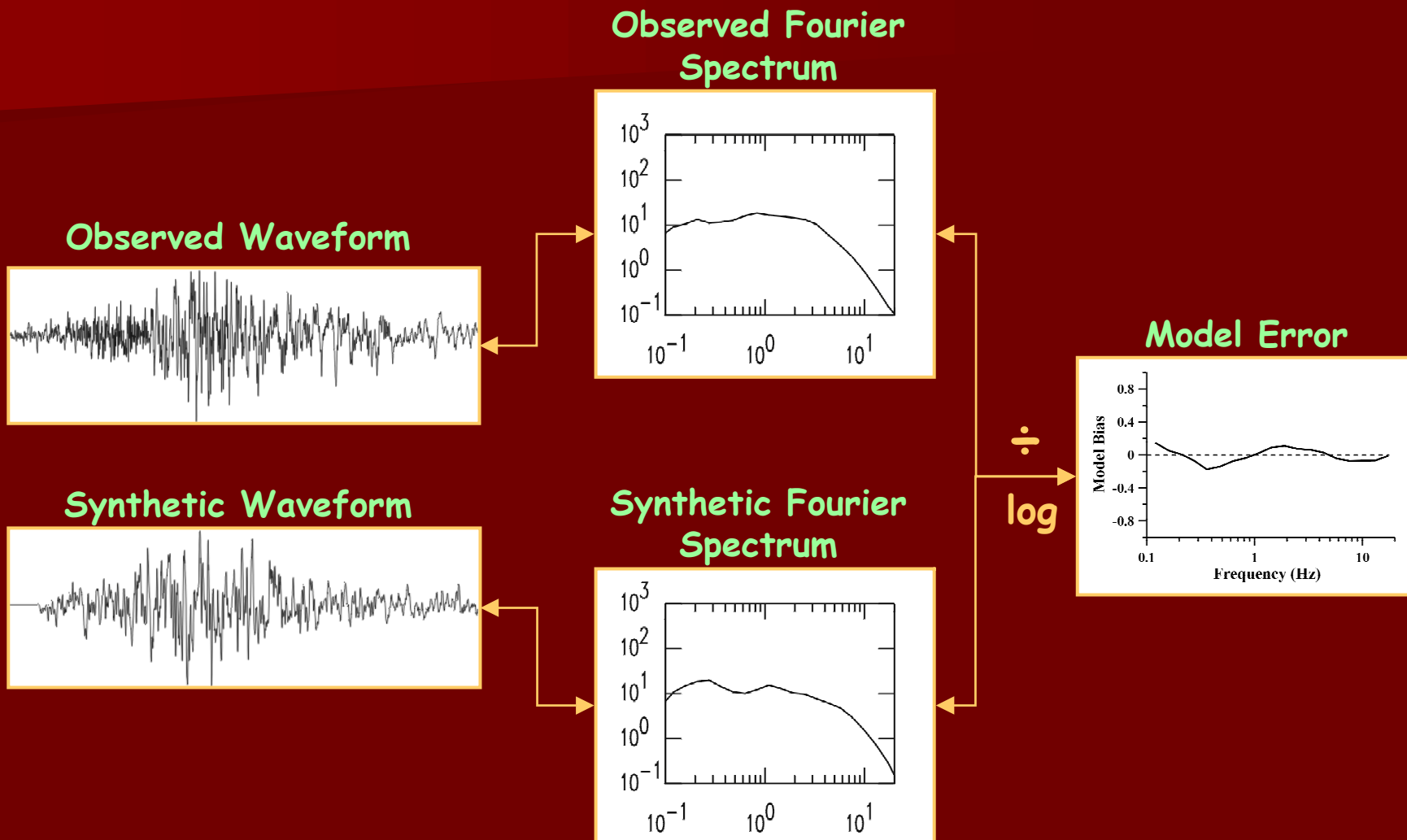
Basic Steps in the Application of the Stochastic Method

- **Validation of the model at free-field strong motion station sites**
- **Check the reliability of the validated model through simulation of available strong motion data**
- **Application of the validated model at sites for which we have no records**

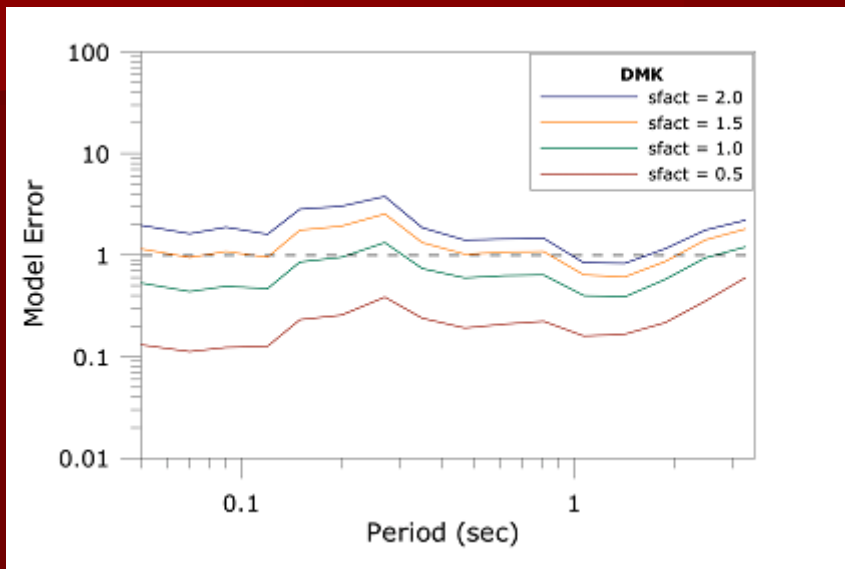
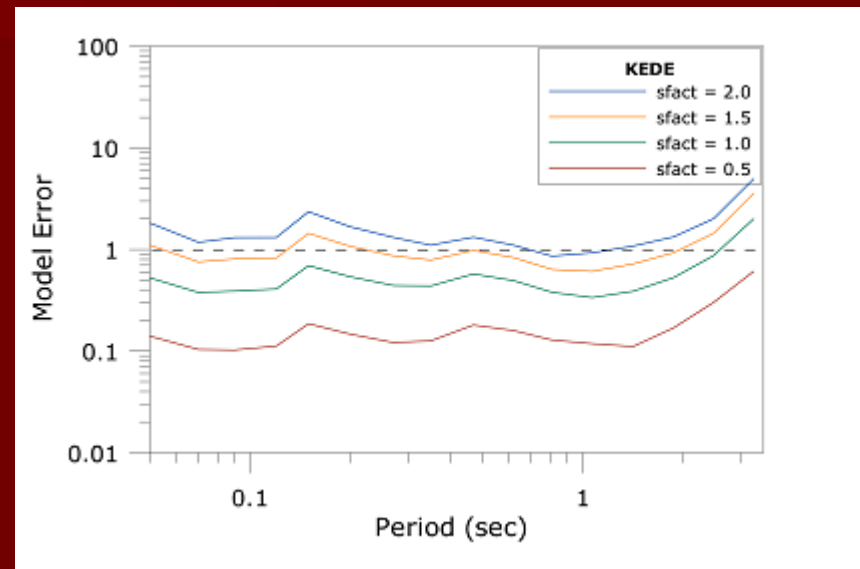
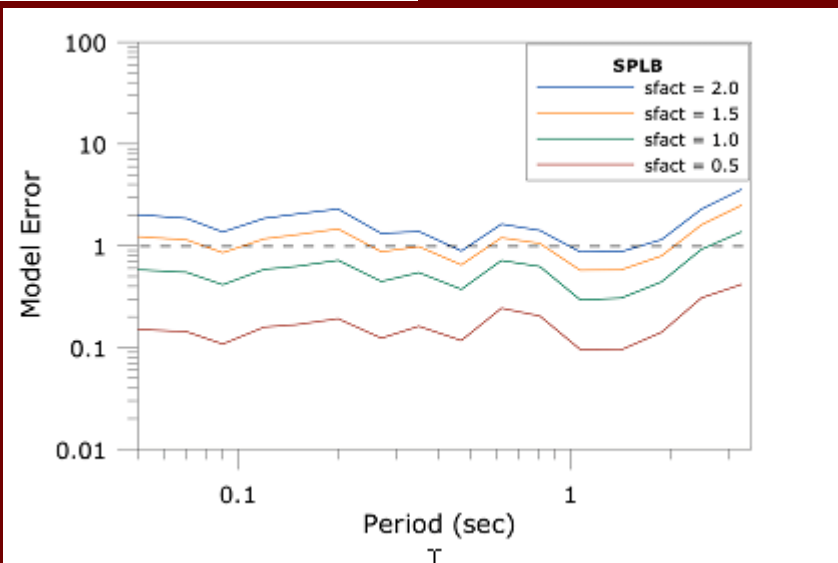
Distribution of Accelerographs that Recorded the 1999 Athens Earthquake



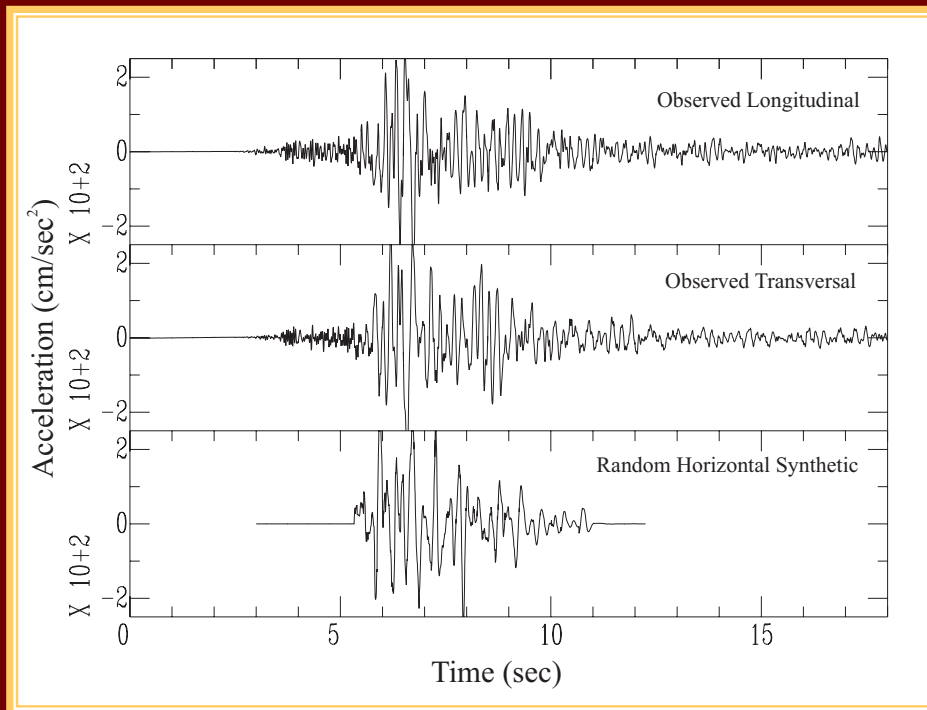
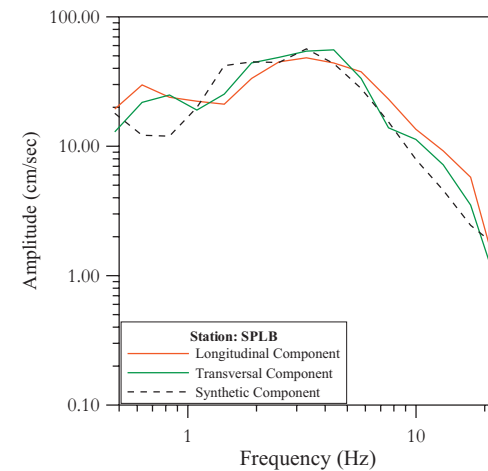
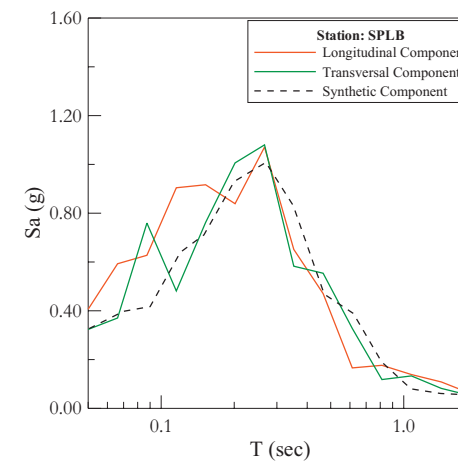
Definition of "Model Error"

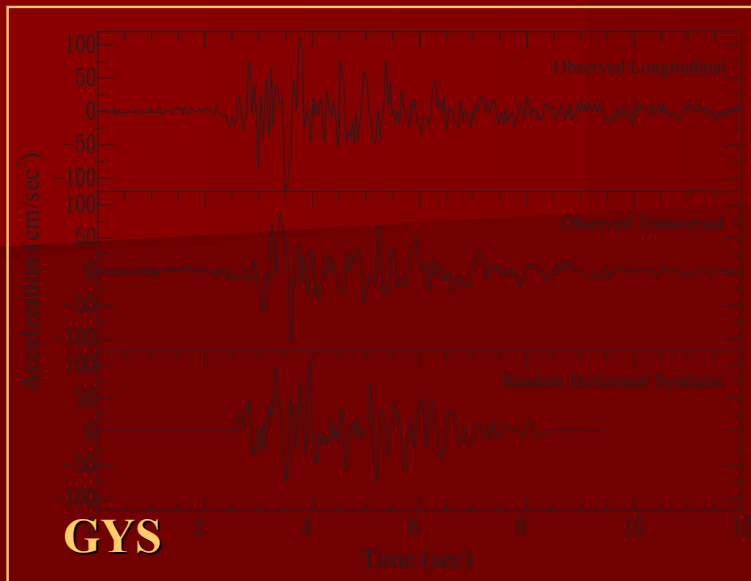
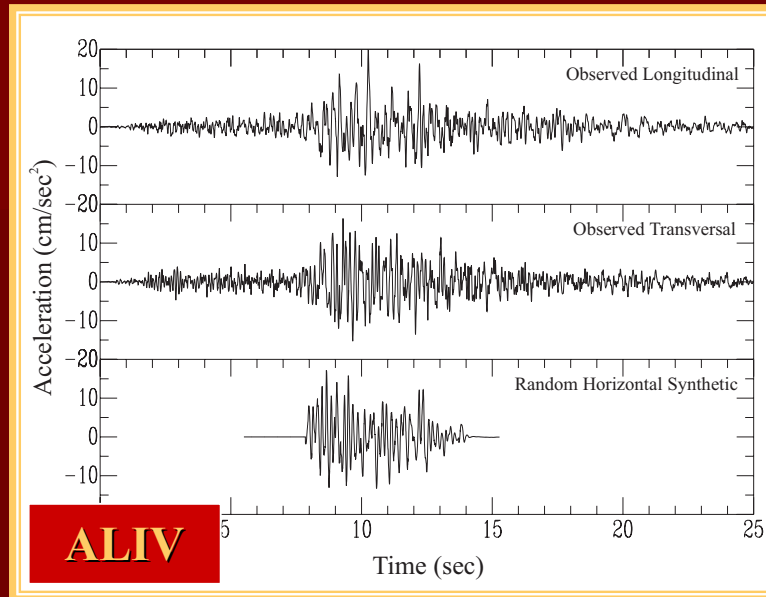
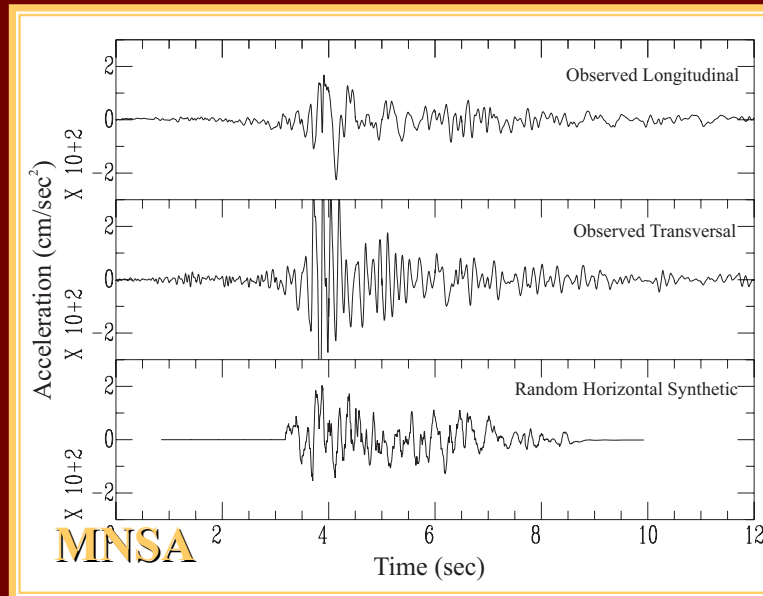
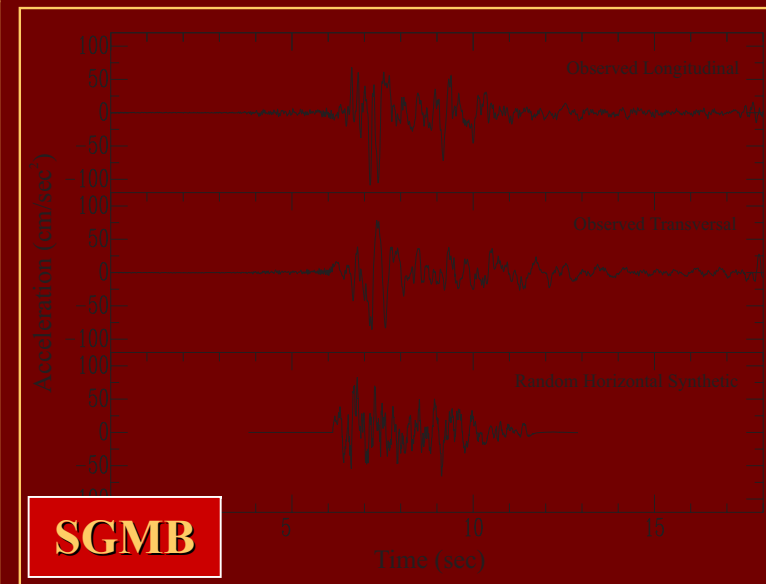


Model Error at the three validation sites for different values of sfact

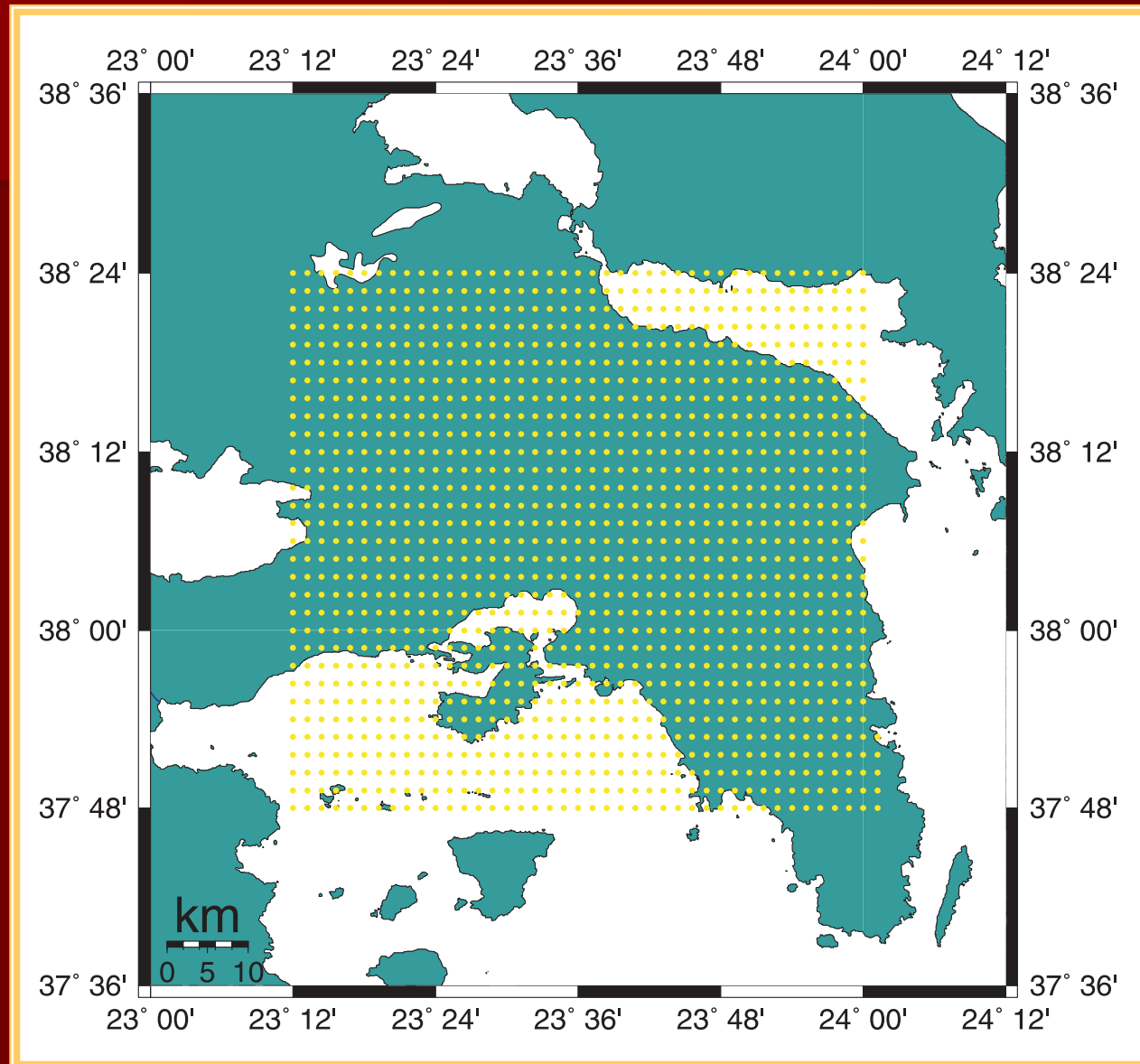


Stochastic Simulation at Station SPLB

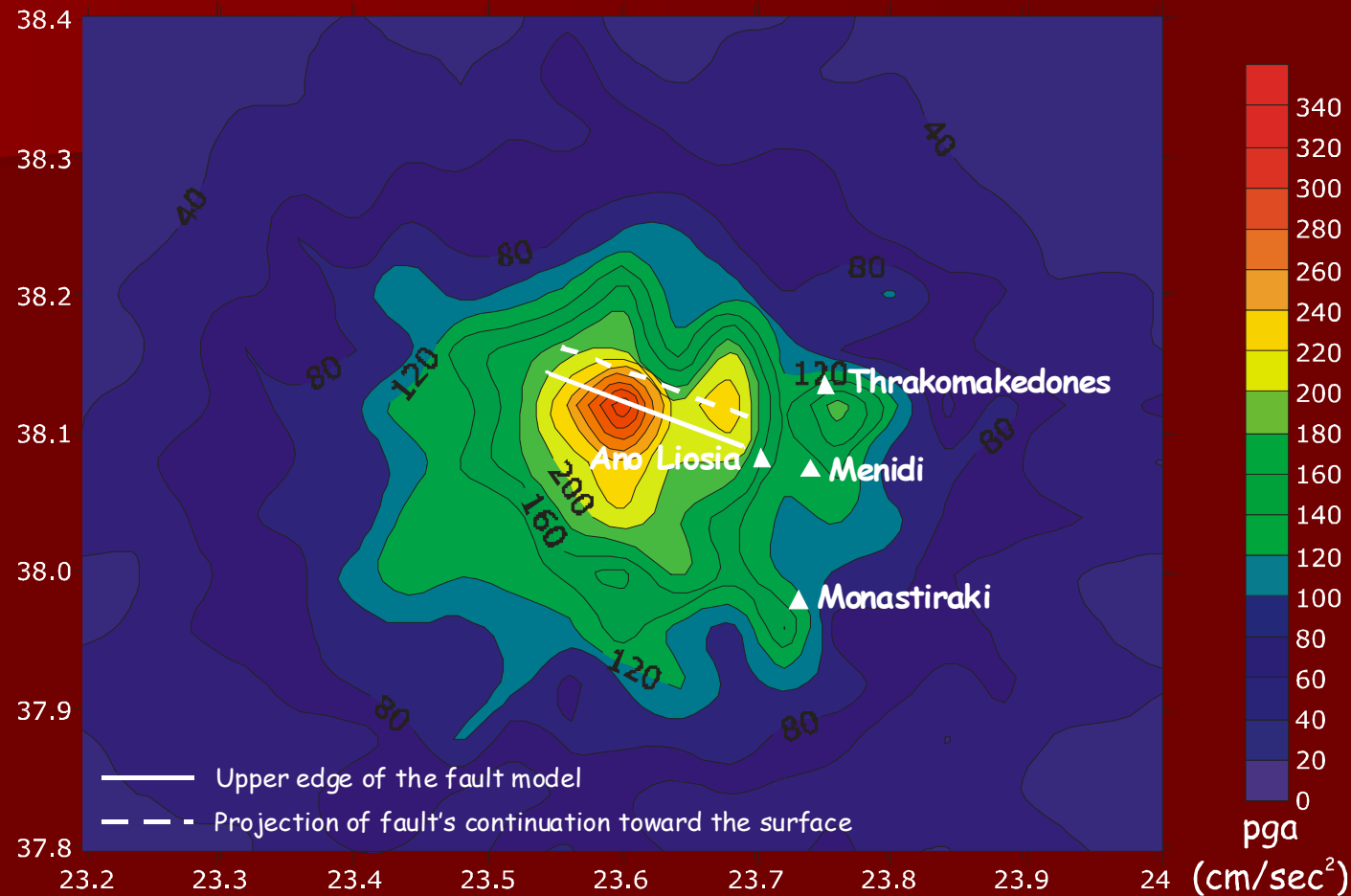




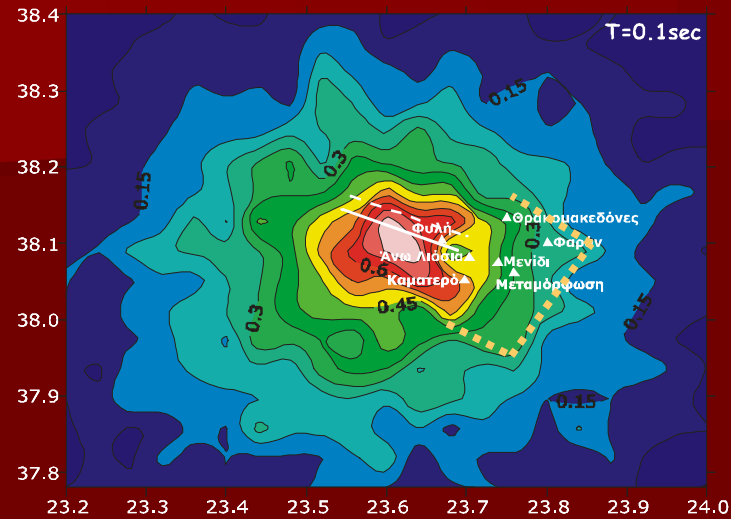
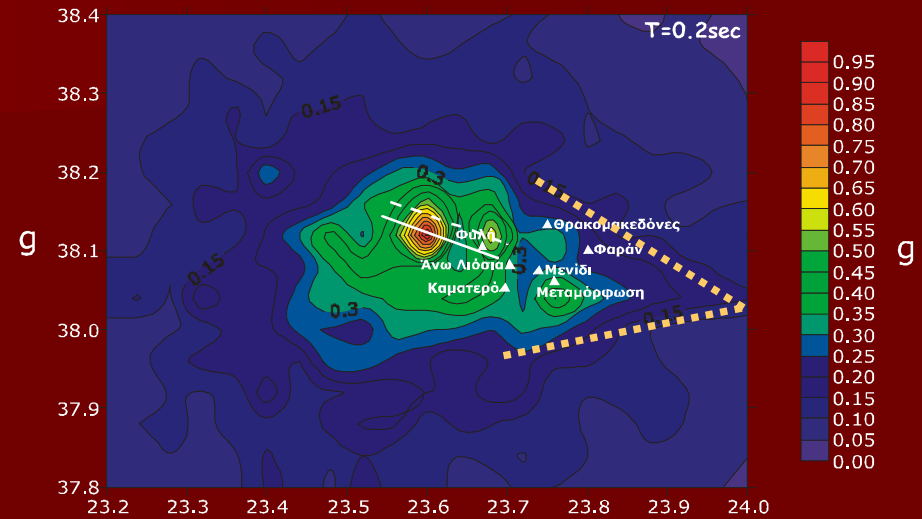
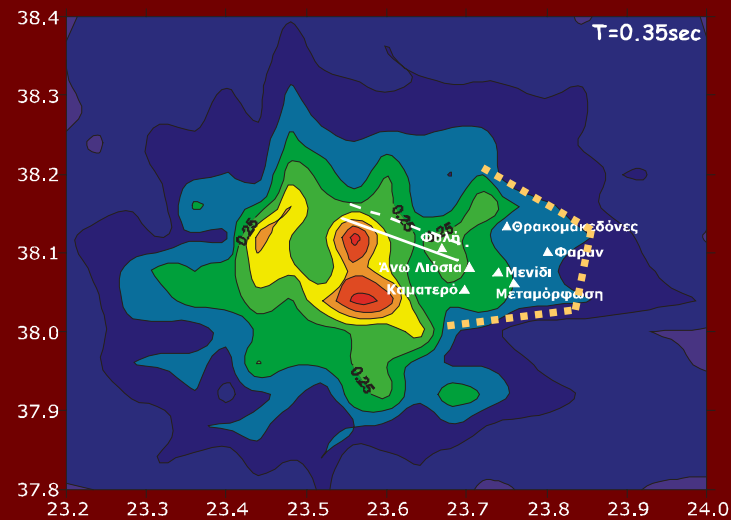
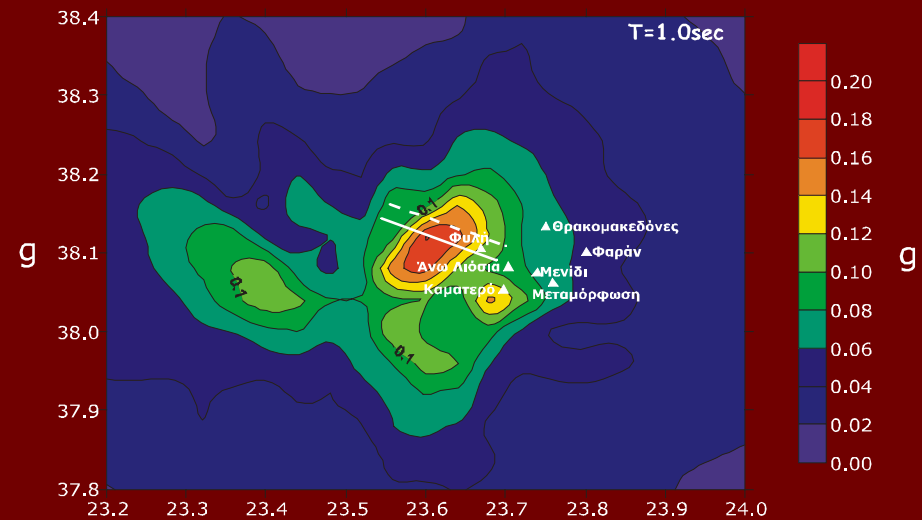
Grid of points for stochastic simulations

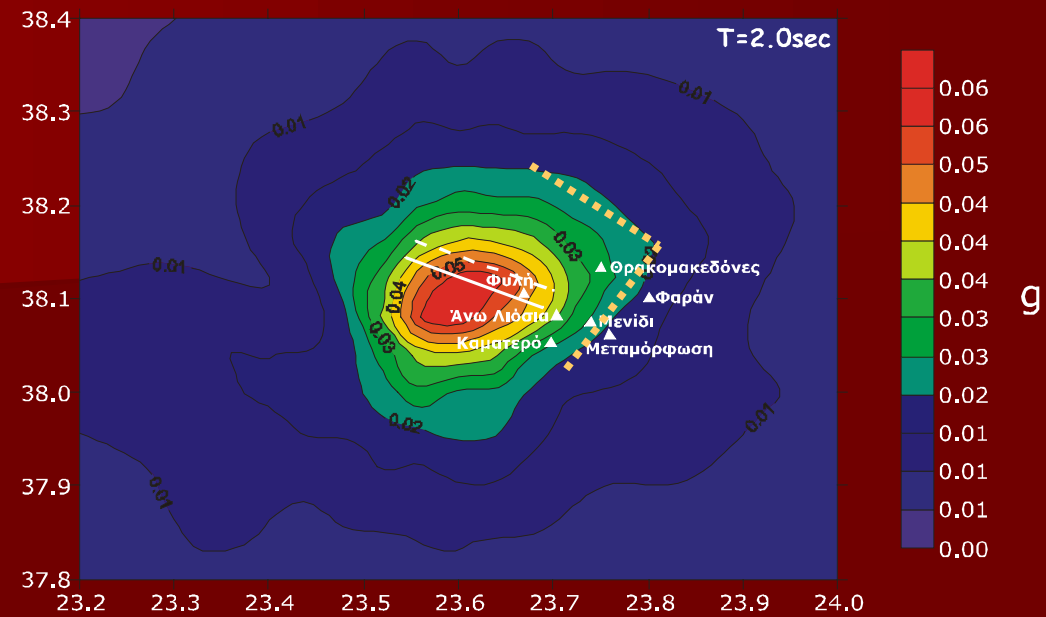
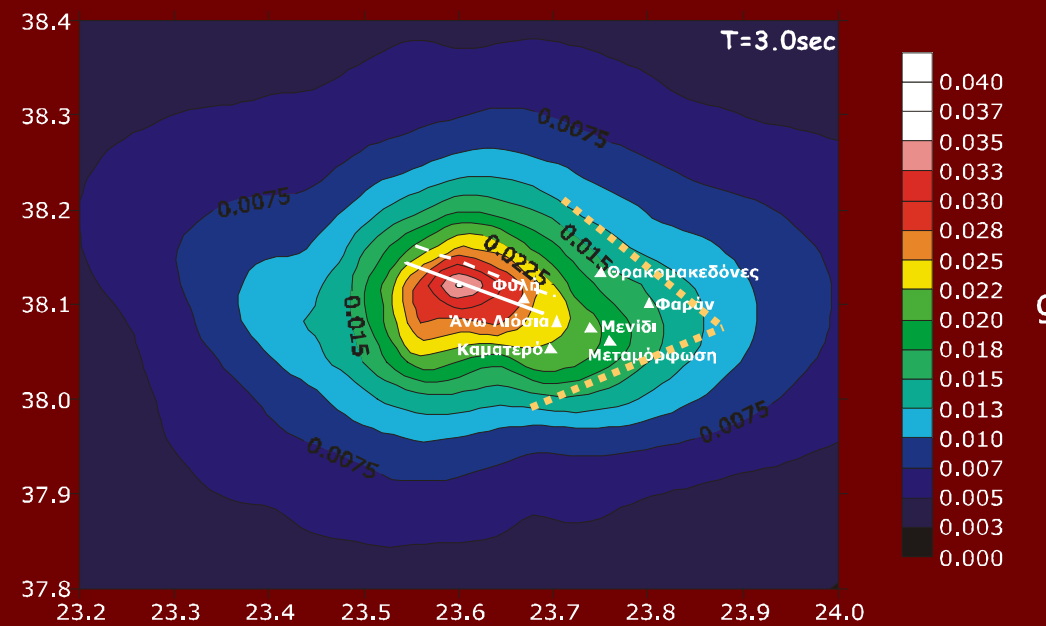


PGA Map for the 1999 Athens Earthquake



PSA Maps at selected periods





Conclusions

Stochastic strong ground motion simulation from the 1999 Athens earthquake

- The heterogeneous slip model in combination with H/V ratios for the description of site effect provide satisfactory fit between synthetics and observed records
- Largest values of PGA at bedrock were $< 350 \text{ cm/sec}^2$
- Rupture directivity contributed to:
 - the increase of PGA values within the meizoseismal area (locally up to 50%)
 - amplification of the spectral amplitudes at periods 0.2-0.3 sec and > 2 sec