Università di Padova
Dipartimento di Geoscienze

How can GNSS based Geodesy impact on Solid Earth Research? An example from the Kefalonia (Greece) seismic events of January/February 2014

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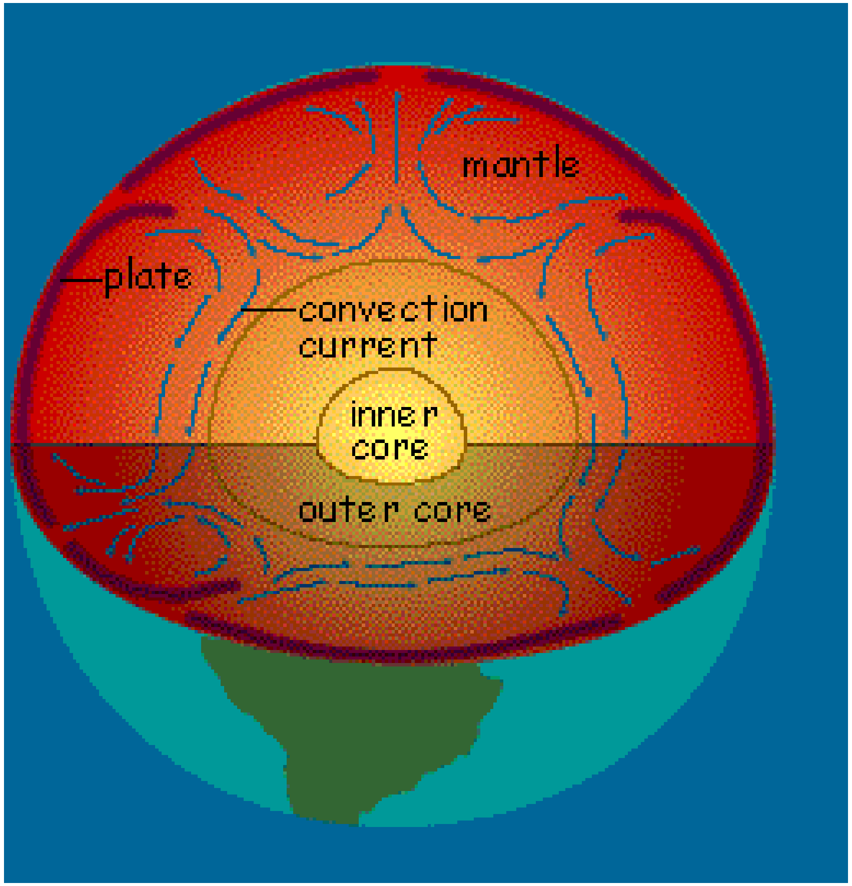
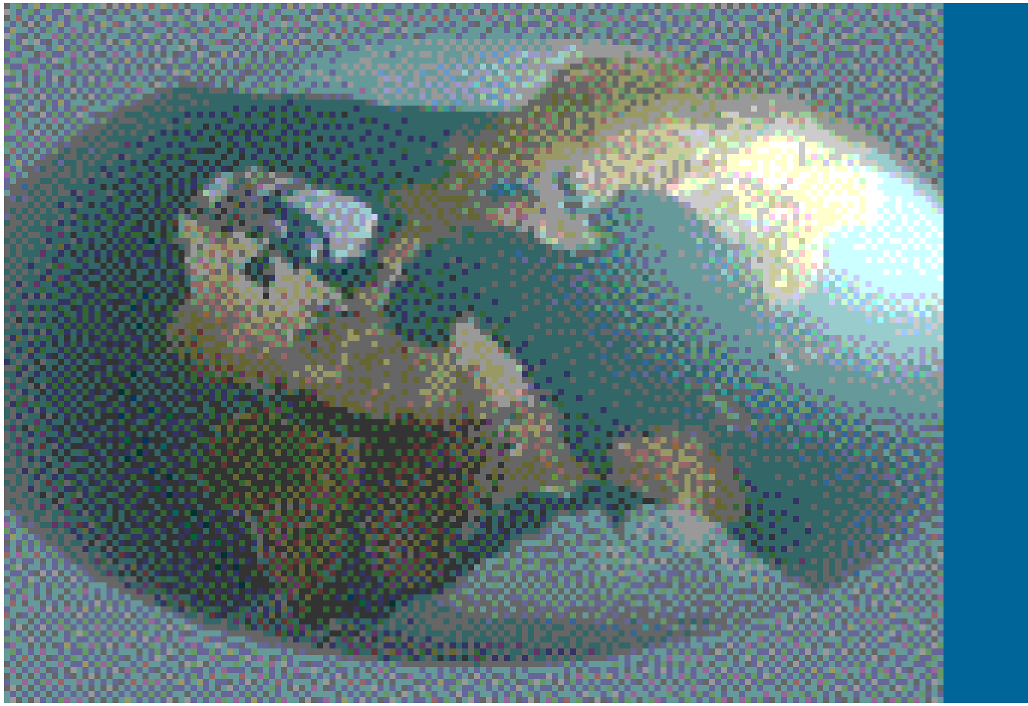
EUREF Symposium 2014, Vilnius -Lithuania

Summary

- Cause and consequences of Plate Tectonics
- The early days (80’s): NASA Crustal Dynamics Project and WEGENER
- How stress changes in the crust affect coordinates of sites/instruments on the surface
- Examples of integration of GNSS geodetic data, DInSAR, seismologic, geologic, historical earthquakes: how EPOS would work in practice!
- Conclusions

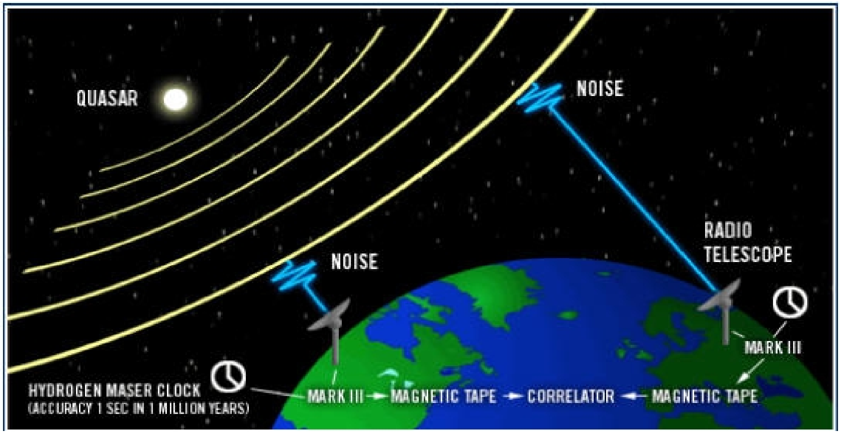
Causes and consequences of plate tectonics



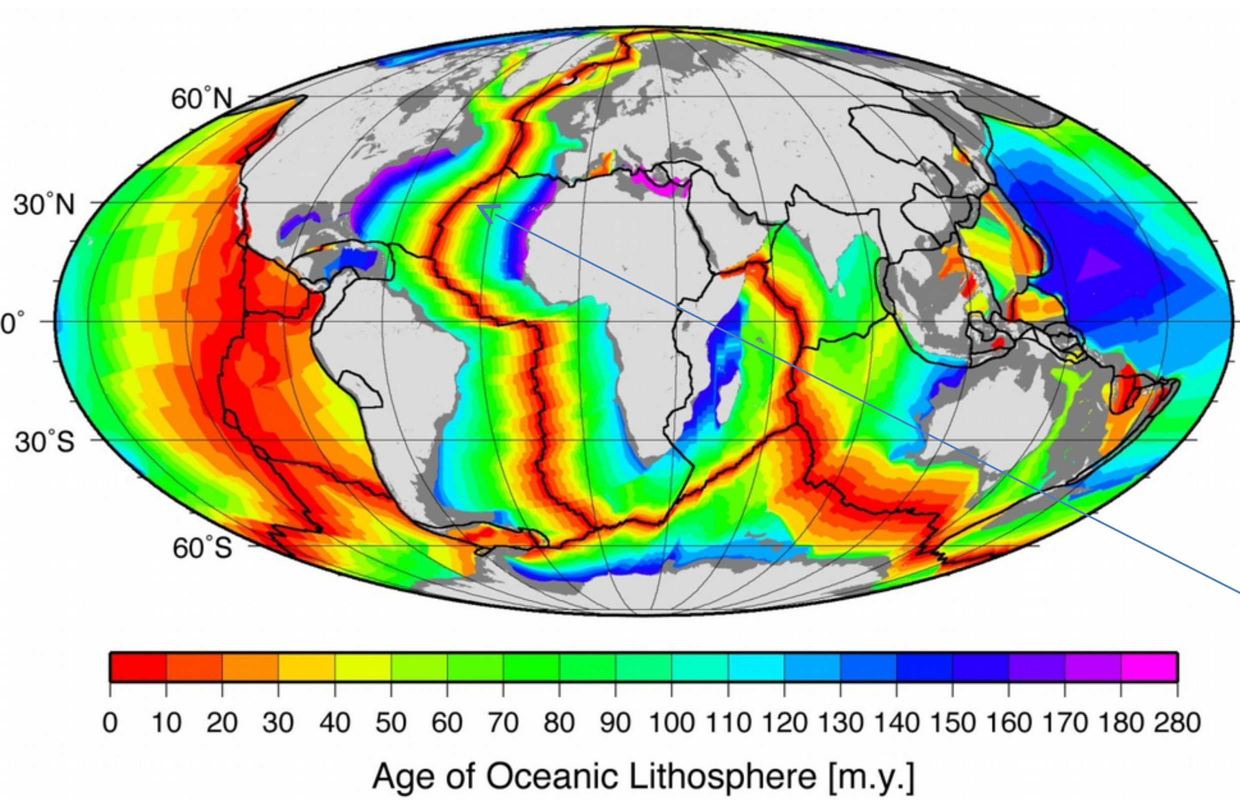


Convective motions of fluids in the mantle are a possible engine driving plate tectonics

Alfred Wegener
Berlin, 1.11.1889
Greenland 3.11.1930



Early evidence of Plate Tectonics comes from seafloor spreading



Early evidence of Plate Tectonics came from the symmetry of paleomagnetic lineations across oceanic ridges (average over Myrs)

Early measurements (1980's) of present days plate motion were done by VLBI, the ancestor of GNSS

Analysis of LAGEOS data in the 80's

Table 1. Main participants and their functions in the WEGENER-MEDLAS Project

Project Scientist:
- Prof. Dr. St. Müller, ETH Zürich

Associated Project Scientists:
- Prof. Dr. H.-G. Kahle, ETH Zürich
- Prof. Dr. G. Veis, NTU, Athens
- Prof. Dr. S. Zerbini, Univ. Bologna

Project Manager:
- Prof. Dr. E. Reinhart, IfAG, Frankfurt am Main

Operations Manager:
- Dr. P. Wilson, IfAG, Frankfurt am Main

Management Board:
- Dr. G. Bianco, ASI, Matera
- Mr. J. Bosworth, NASA-GSFC, Greenbelt, MD
- Dr. M. R. Pearlman, SAO, Cambridge, MA
- Prof. Dr. Ch. Reigber, DGFI, Munich
- Prof. Dr. E. Reinhart, IfAG, Frankfurt am Main
- Prof. Dr. H. Seeger, IfAG, Frankfurt am Main
- Dr. D. Smith, NASA-GSFC, Greenbelt, MD
- Dr. P. Wilson, IfAG, Frankfurt am Main
- Ir. E. Vermaat, DUT, Kootwijk

Computing and Analysis Centres:
- Quick-look and data integrity:
  - Dept. of Aerospace Engineering, DUT, Delft
  - Center for Space Research, Austin, Texas
  - Goddard Laser Tracking Network, Greenbelt, MD
- Full-rate:
  - Agenzia Spaziale Italiana - Telespazio, Rome
  - Dept. of Aerospace Engineering, DUT, Delft
  - DGFI, Dept. I, Munich
  - IfAG, Frankfurt am Main
  - University of Bologna, Bologna
  - University of Padua, Padua
  - University of Newcastle, Newcastle
  - Center for Space Research, U. of Texas, Austin
  - NASA - GSFC, Greenbelt, MD

European and Middle East permanent stations:
- Agenzia Spaziale Italiana, Matera
- DUT, Kootwijk
- Geophysical Observatory, Helwan
- GRGS, Grasse
- Institut für Angewandte Geodäsie, Wettzell
- INASAN, Simeiz
- Inst. for Petroleum Research and Geophysics, Bar Giyyora
- Institut für Weltraumforschung, Graz
- Royal Greenwich Observatory, Herstmonceux
- University of Bern, Zimmerwald
- University of Riga
- Zentralinstitut für Physik der Erde, Potsdam

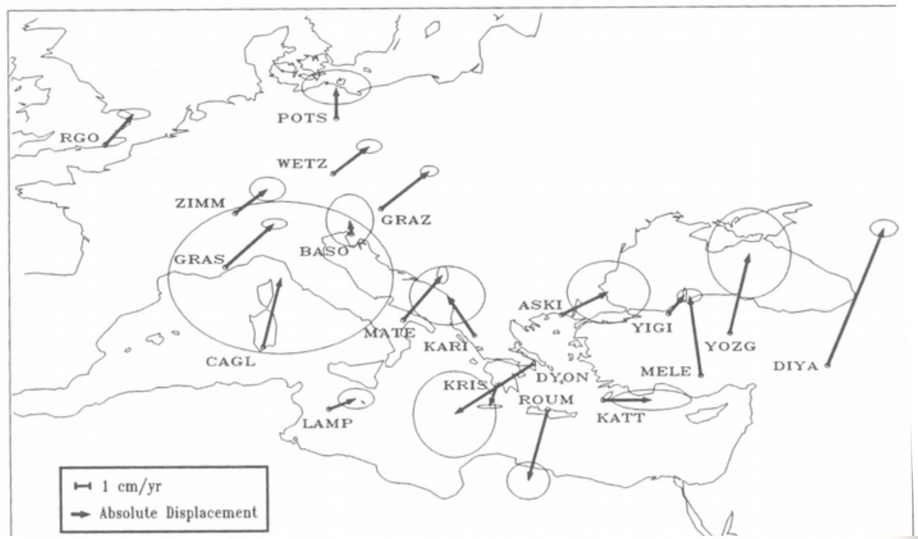


TABLE 1. Adopted Constants and Models for the TPZ-90 Solution.

LAGEOS CONSTANTS	
Satellite Mass	411.0 Kg
Satellite Area	0.28274 m^2
Satellite Center of Mass Offset	0.24 m
Nominal Reflectance Coefficient	1.17
Nominal Along Track Acceleration	-3.1704 10^{-12} m/s^2
KINEMATICAL MODEL	
Precession	IAU 1976
Nutation	IAU 1980
Reference System	1950.0
Earth Semi Major Axis	6378144.11 m
Flattening	1/298.255
DYNAMICAL MODEL	
Lunar and Planetary Ephemeris	JPL DE118
Gravity Field (•)	GEM-T1 (36,36)
Body Tides (♦)	Wahr Model
Ocean Tides (♠)	GEM-T1 terms with perturbation on LAGEOS angular parameters > 0."001
h_2, l_2, k_2	0.6040 , 0.0852, 0.299
GM	3.98600440 10^{14} m^3/s^2

PREPROCESSING OPTIONS
2 min. Normal Points following Herstmonceux recommendations. Laser wavelength dependent Marini and Murray

METHOD OF ANALYSIS	
Multi-Arc Length	6 months
Individual Arc Length	15 days
"Fixed" Stations	QUINCY constrained in latitude and longitude at the 1983 value of the NASA/GSFC SL7 solution and moved according to the M/J model. RGO constrained in latitude as above.

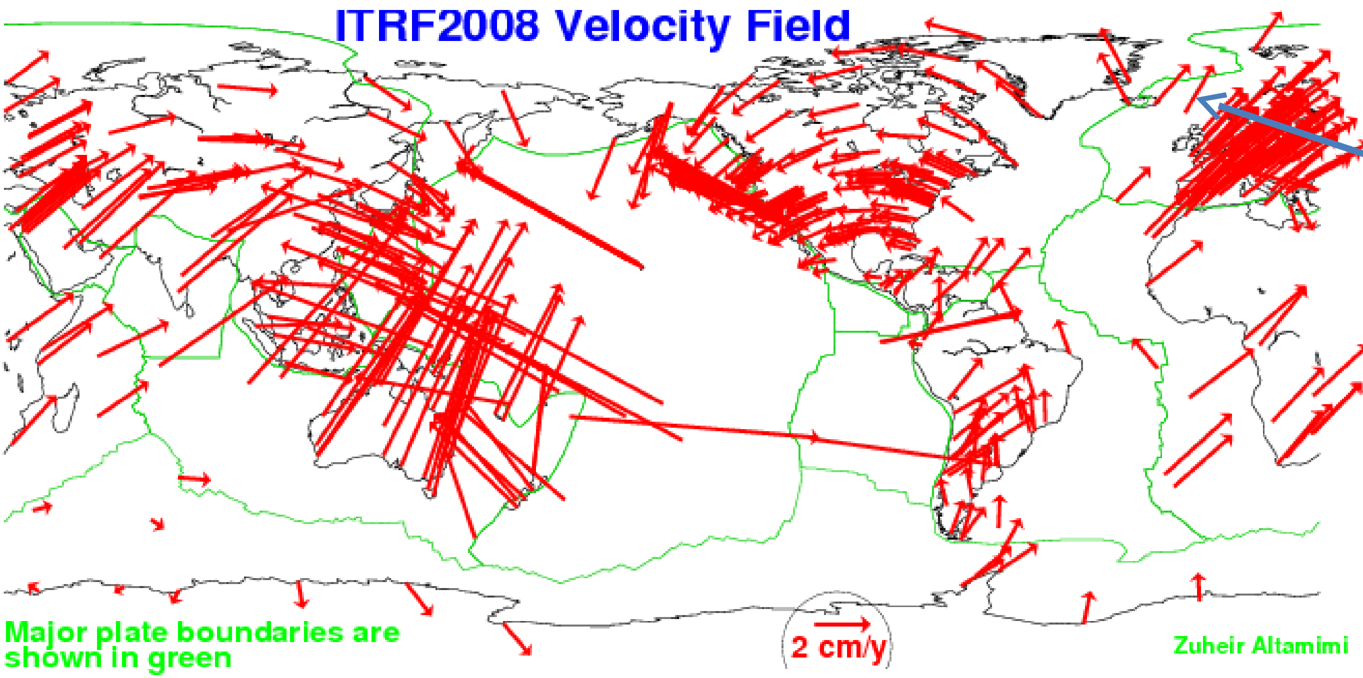
COMMON PARAMETERS ESTIMATED IN THE SOLUTION
- Station Coordinates.
- Earth rotation parameters at 2.5 day intervals; A1-UT1 constrained at the beginning of each single arc to BIH circ. D values.

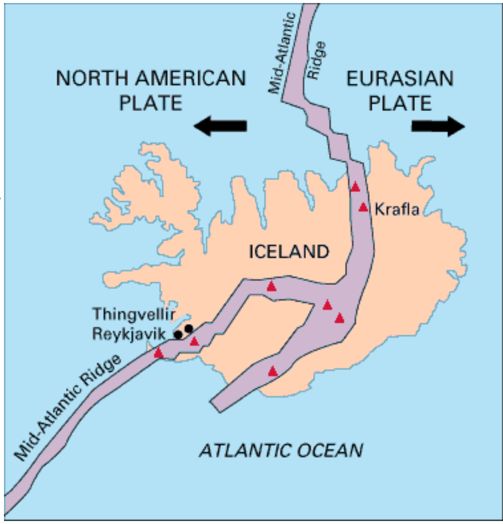
ARC PARAMETERS ESTIMATED IN THE SOLUTION
- Six Keplerian Elements.
- Constant Along Track Acceleration.
- Solar Radiation Coefficient.

OVERALL STATISTICS	
Total Time Span	76 months (Sept 83 to Dec 89)
Total Number of Data	374,524 Normal Points
Number of Weighted Data	347,499 Normal Points
Average Post-Fit RMS (all arcs)	7.1 ± 1.4 cm

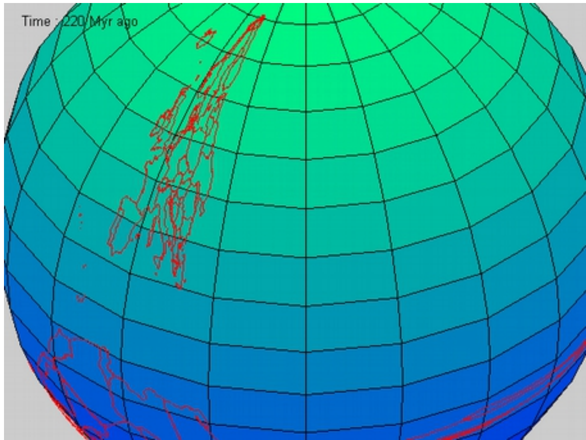
(•) [Marsh et al., 1988]; (♦) [Wahr, 1981]; (♠) [Christodoulidis et al., 1988].

Plate motion measured today with different techniques is linked to the concept of Reference Frame

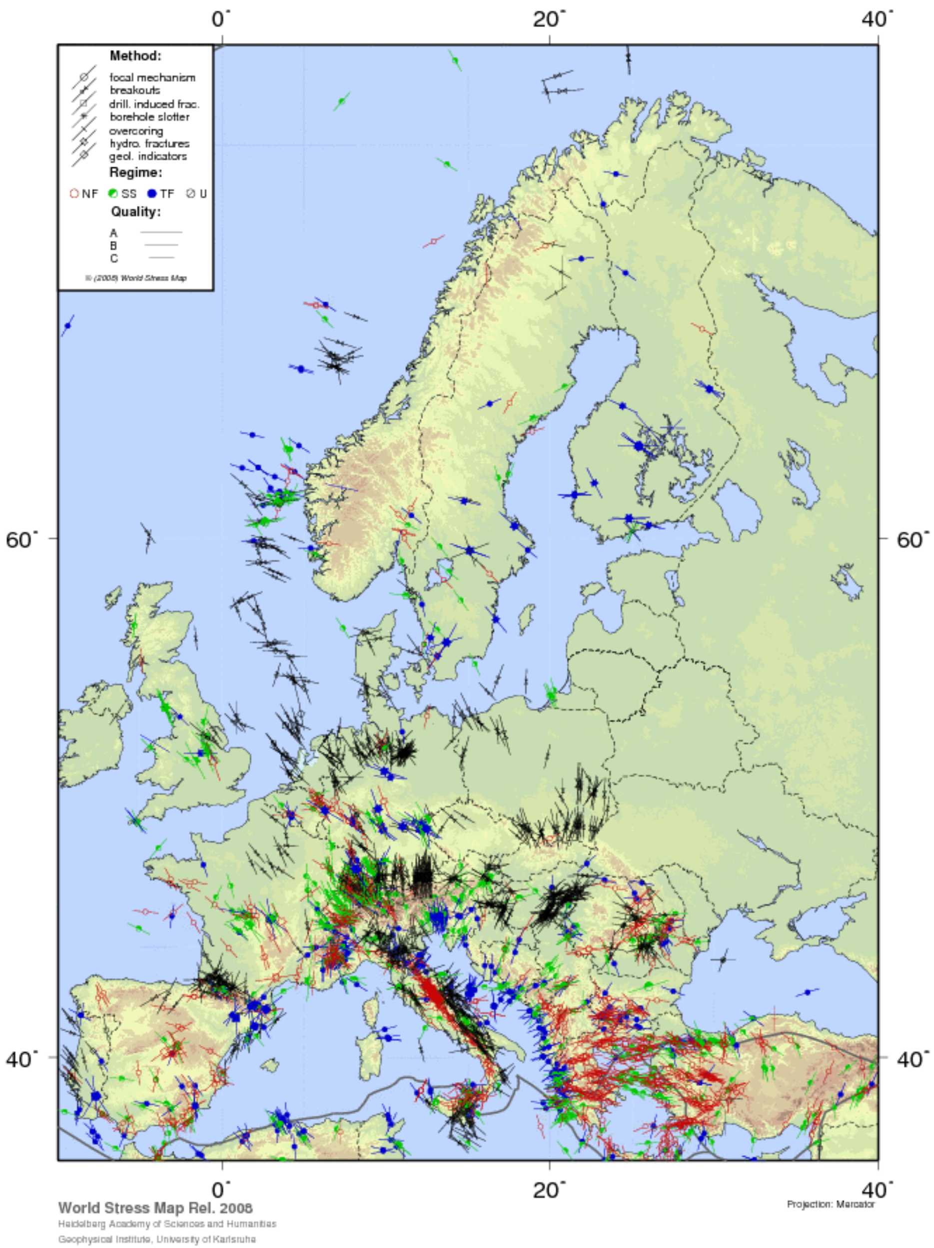




The major tectonic units move relative to each other
Geodetic networks **<u>across</u>** tectonic units are deformed/strained
Geodetic networks **<u>within</u>** a tectonic unit (eg Eurasia) may be considered as undeformed/rigid
However it turns out that small deformations (departures from rigidity) are measured within a tectonic unit
Epochwise realizations of a regional reference frame are not exactly connected by rigid body transformations



Stress in the crust can be measured:



- By Fault Plane Solutions of moderate to large earthquakes
- By geologic indicators on exposed faults
- By boreholes

Stress can be:

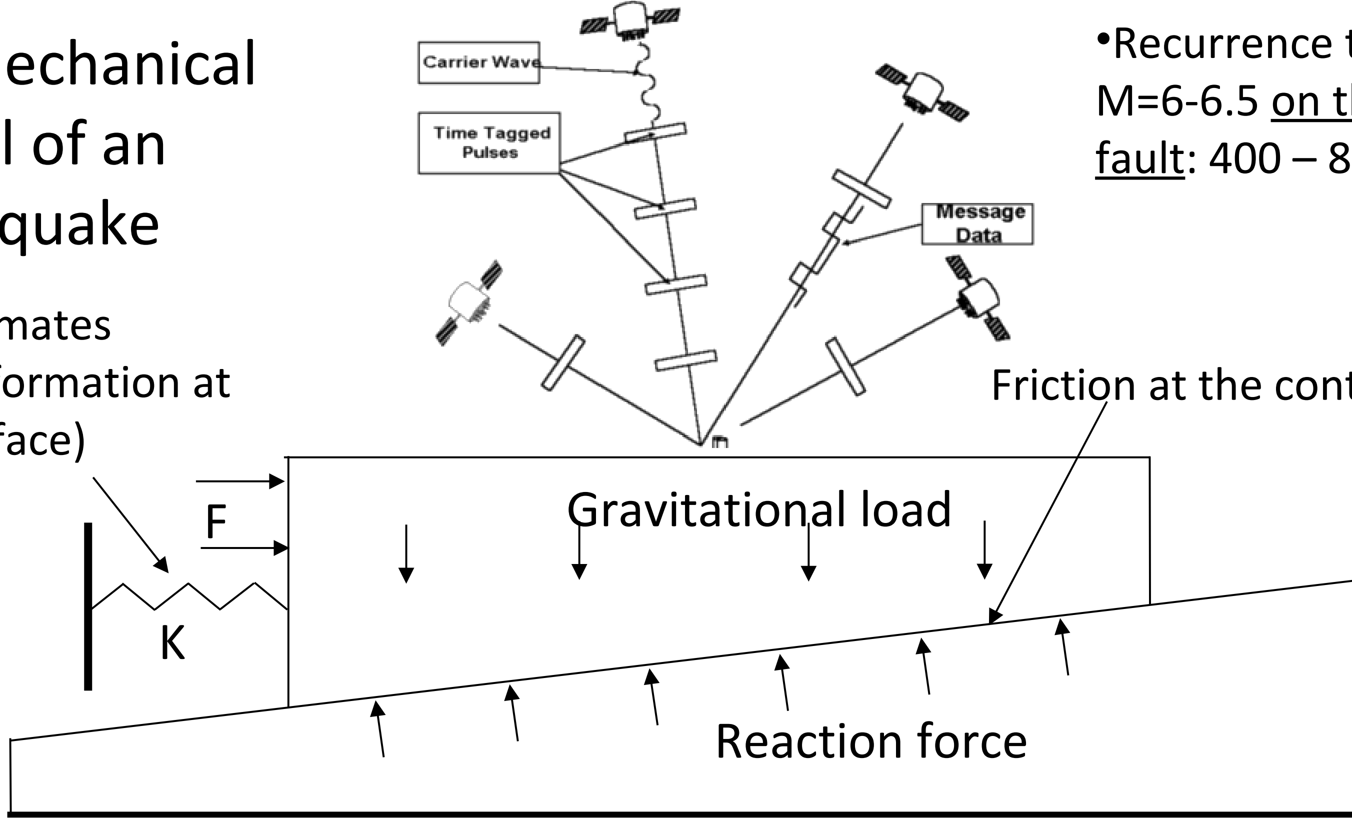
- permanently stored in the rocks
- released by creep, seismicity, heat
- transferred to nearby faults elastically or by diffusion of fluids

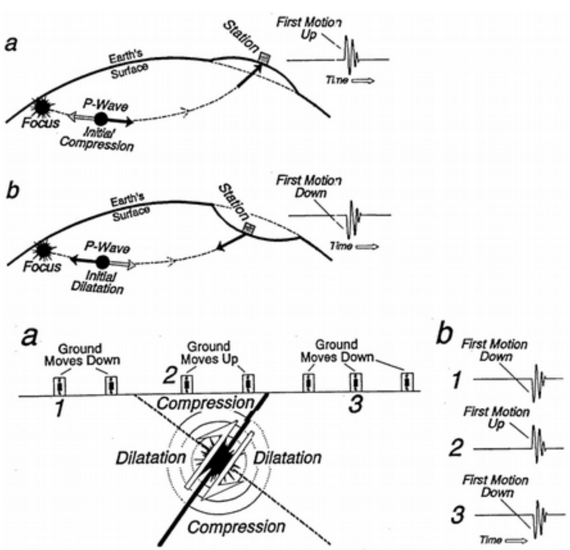
Simple mechanical model of an earthquake

•Recurrence time for M=6-6.5 <u>on the same fault</u>: 400 – 800 years

Spring (approximates elastic rock deformation at the contact surface)

Friction at the contact surface

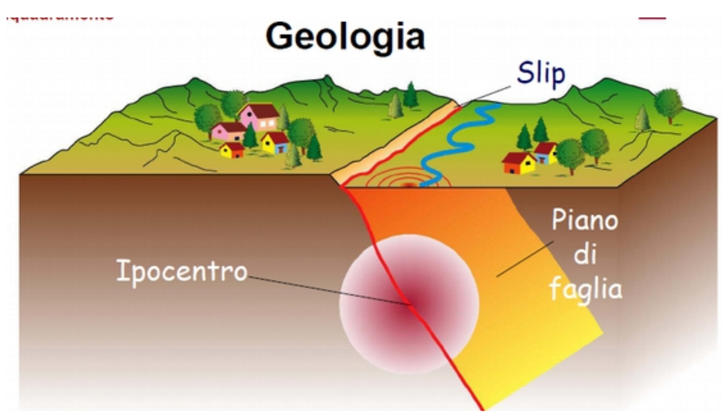




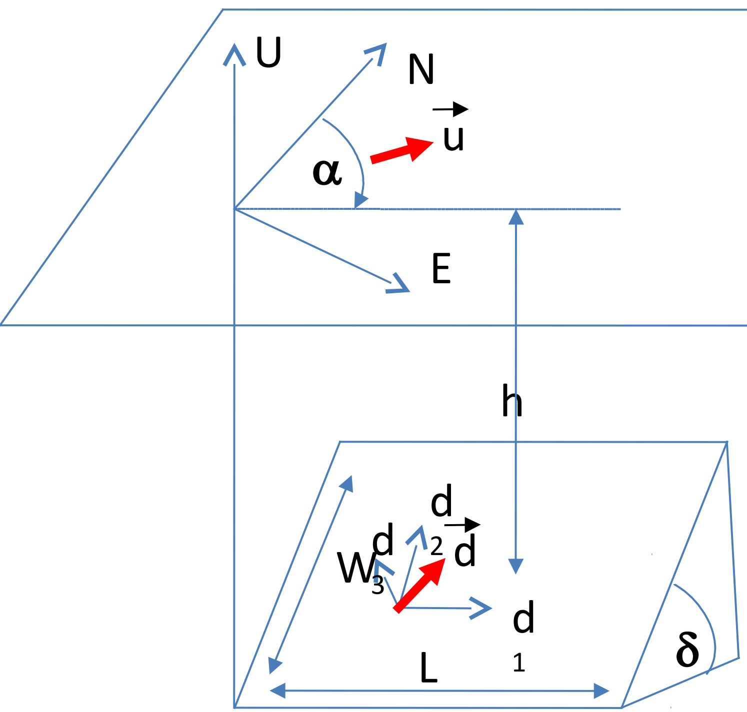
Phase of the first arrival helps constraining the polarity of the earthquake

Coseismic deformation up to tens of Hz

Amplitude of acceleration up to 1 g



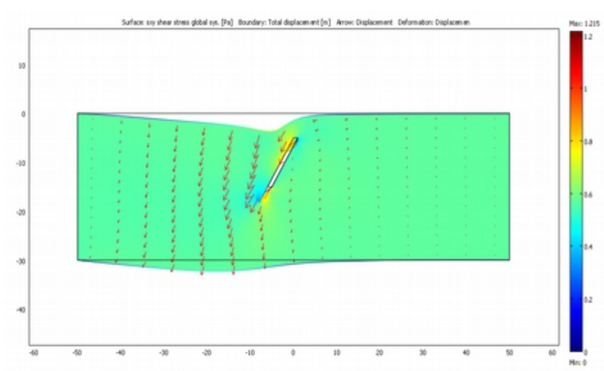
Understanding surface displacement of GNSS stations in terms of dislocation at depth

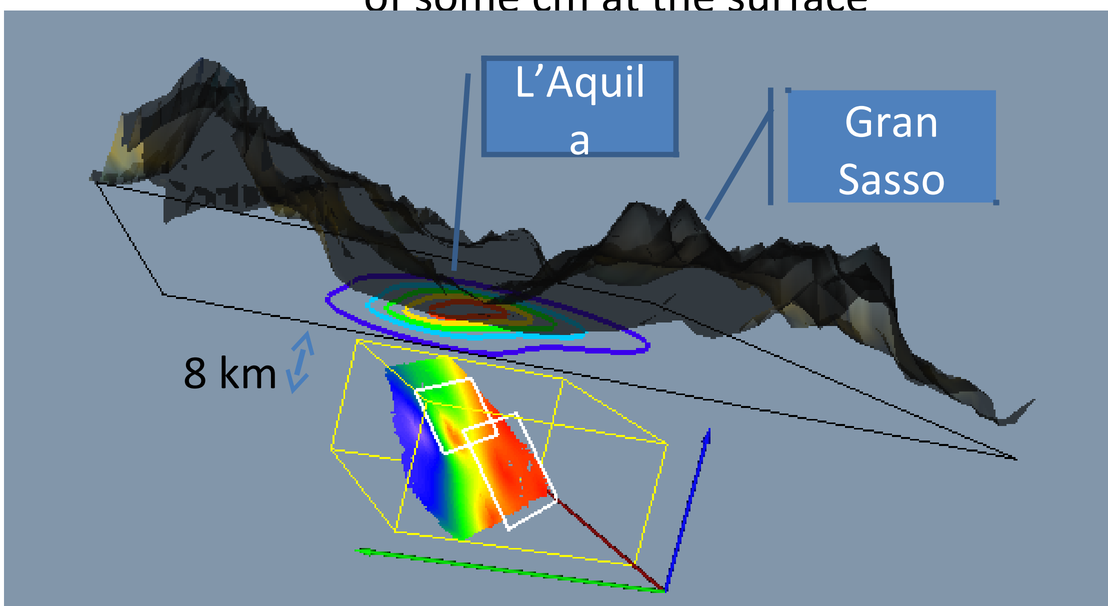


Elastic half space (Hooke law: stress is linearly related to strain)

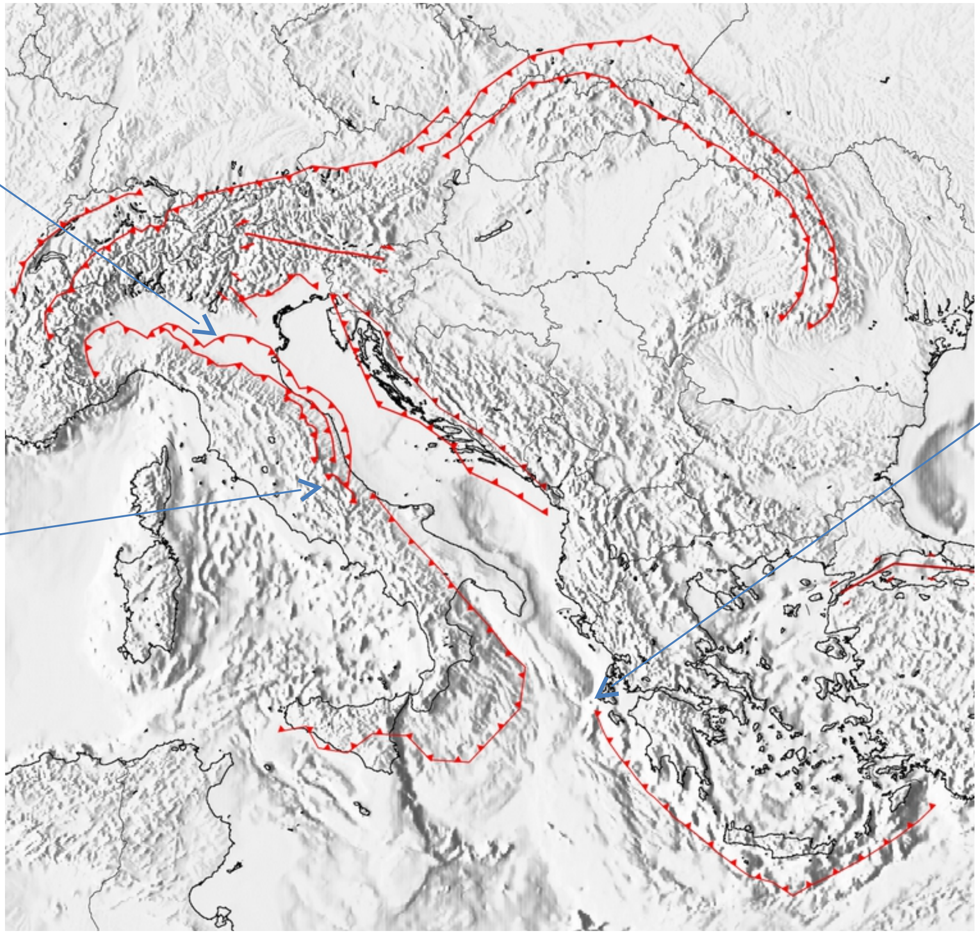
Rectangular fault12 x 8 km, at a mean depth of 8 km

A displacement of 70-80 cm at depth induces coordinate changes of some cm at the surface





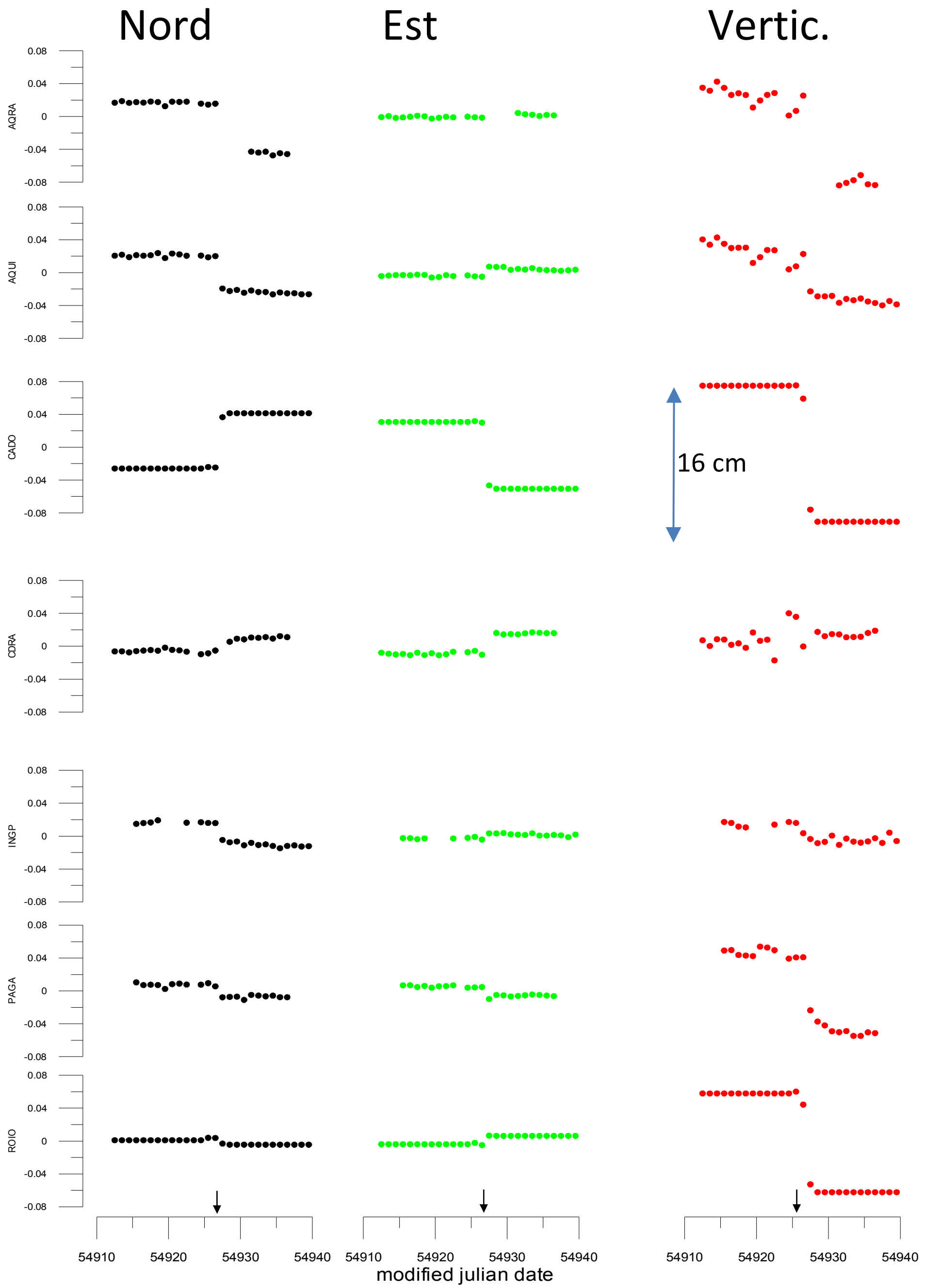
Three study cases (could be examples of EPOS related science)



Modena 2012
Reverse fault

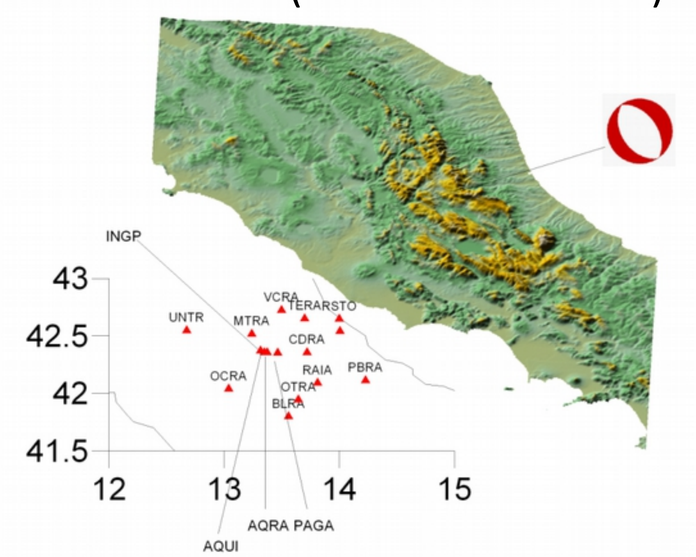
Aquila 2009
Normal fault

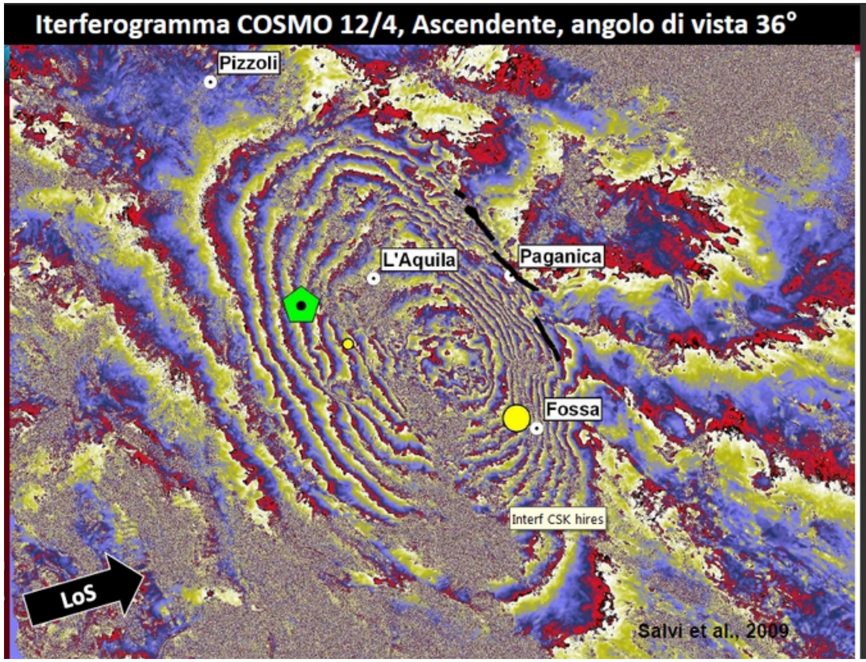
Kefalonia 2014
Transform fault



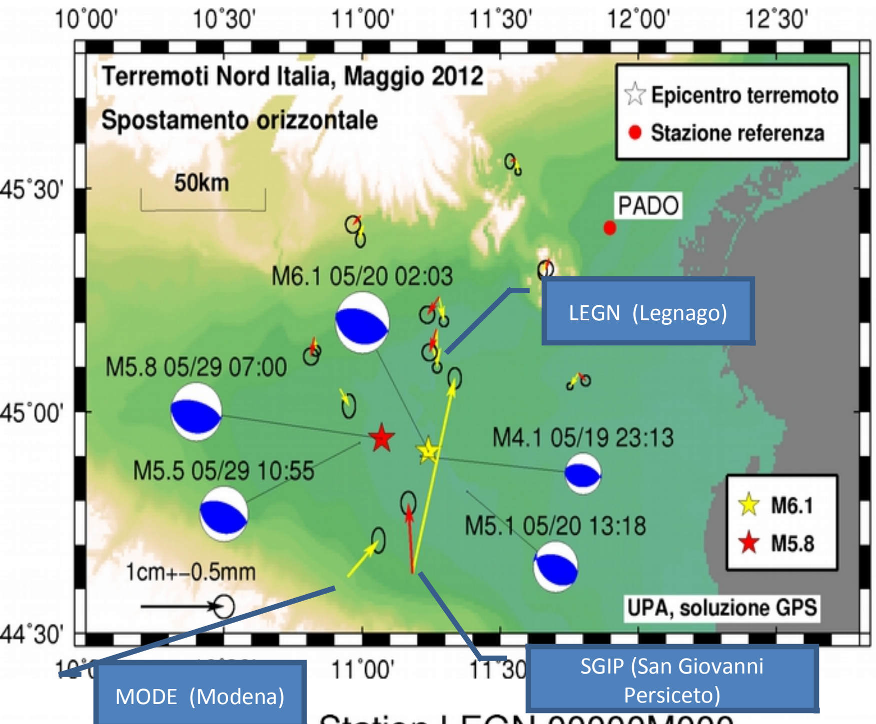
Caporali et al.,(2009)

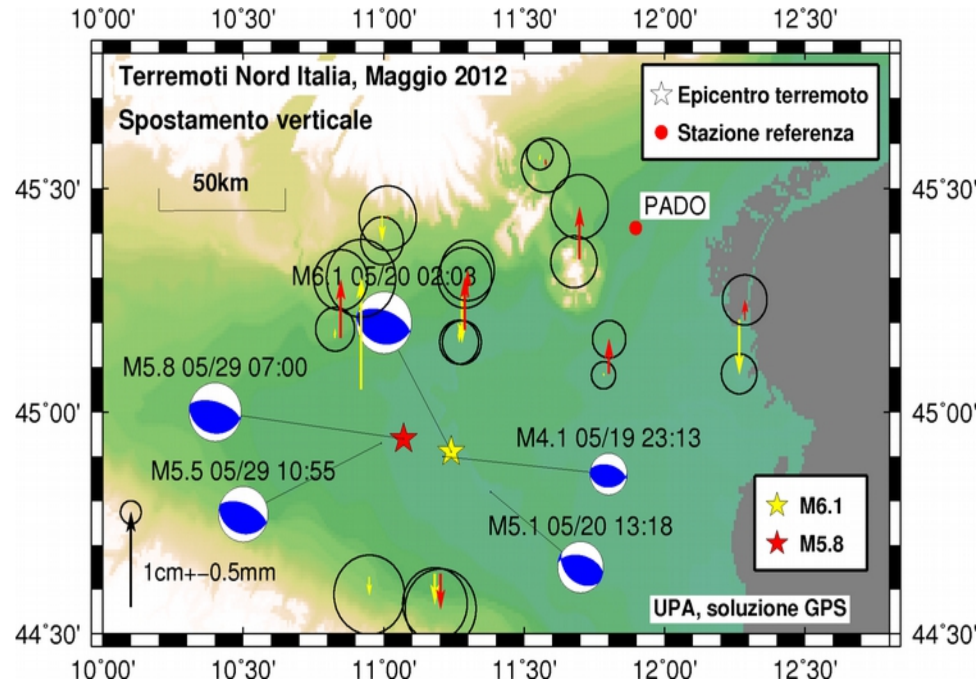
L'Aquila, 6 April 2009, Mw=6.25
Normal fault (extensional stress)

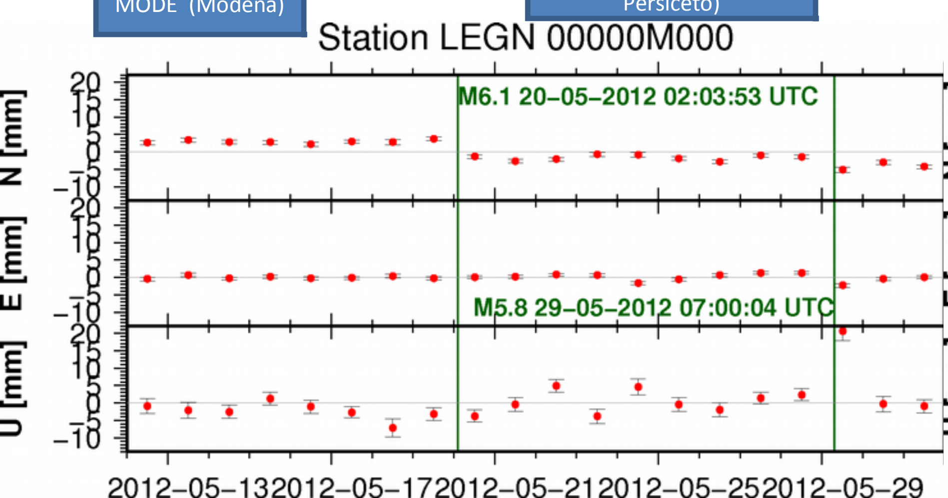


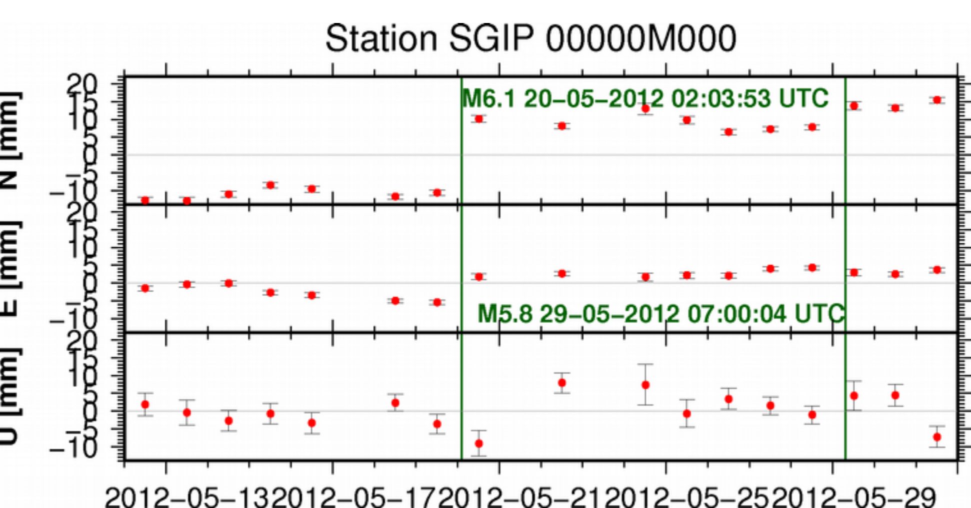


Modena 2012 6.1 – 5.8 events compressional stress









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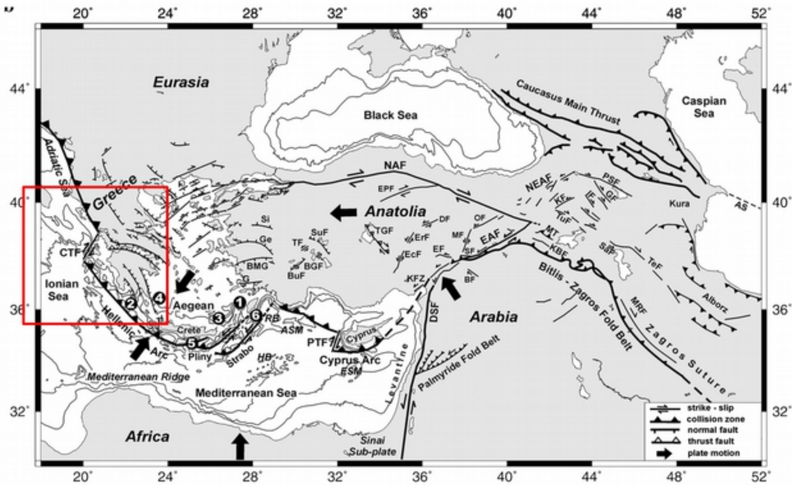
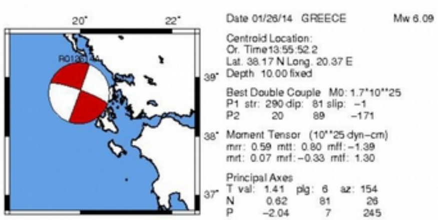
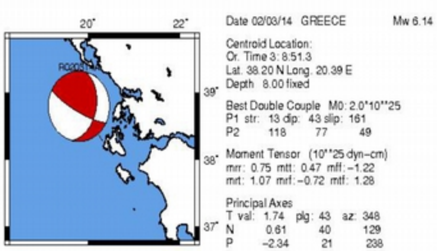
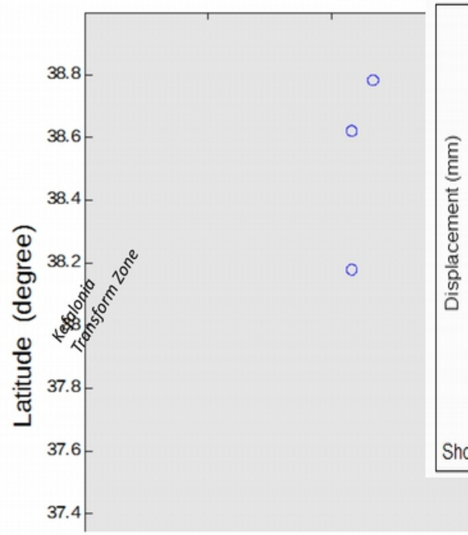


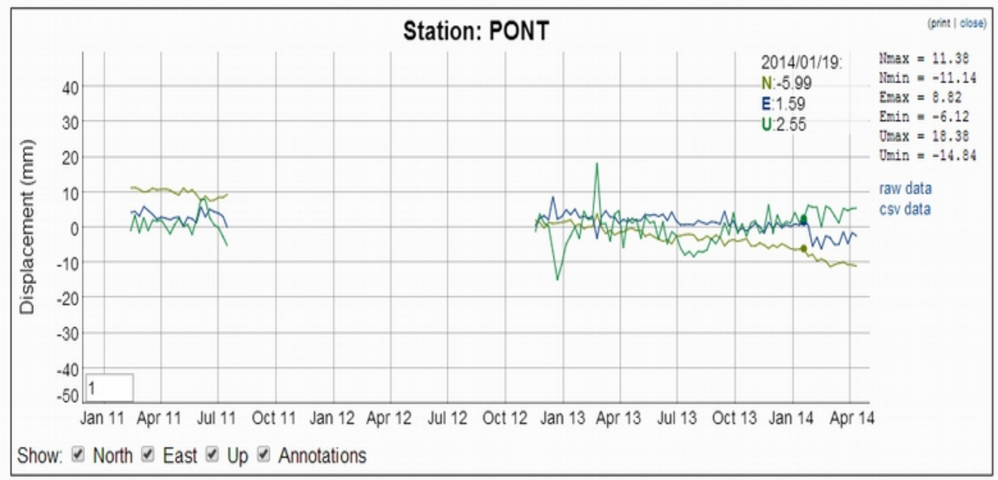
KTZ sei
Fault-plane soluti

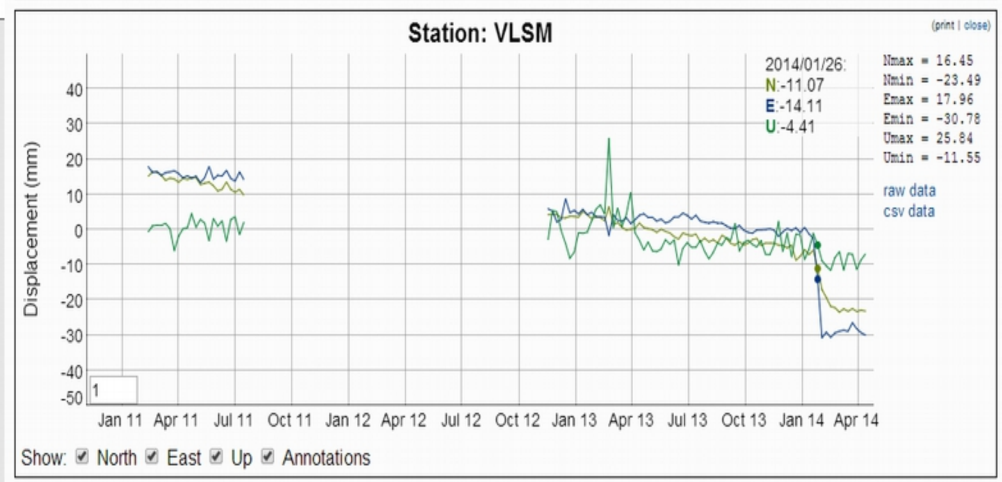






•Time series show two successive jumps, particularly in the N/E of VLSM
•Measured displacements can be compared with those predicted by a dextral shear displacement along a strike of 10-20 deg from seismologic data

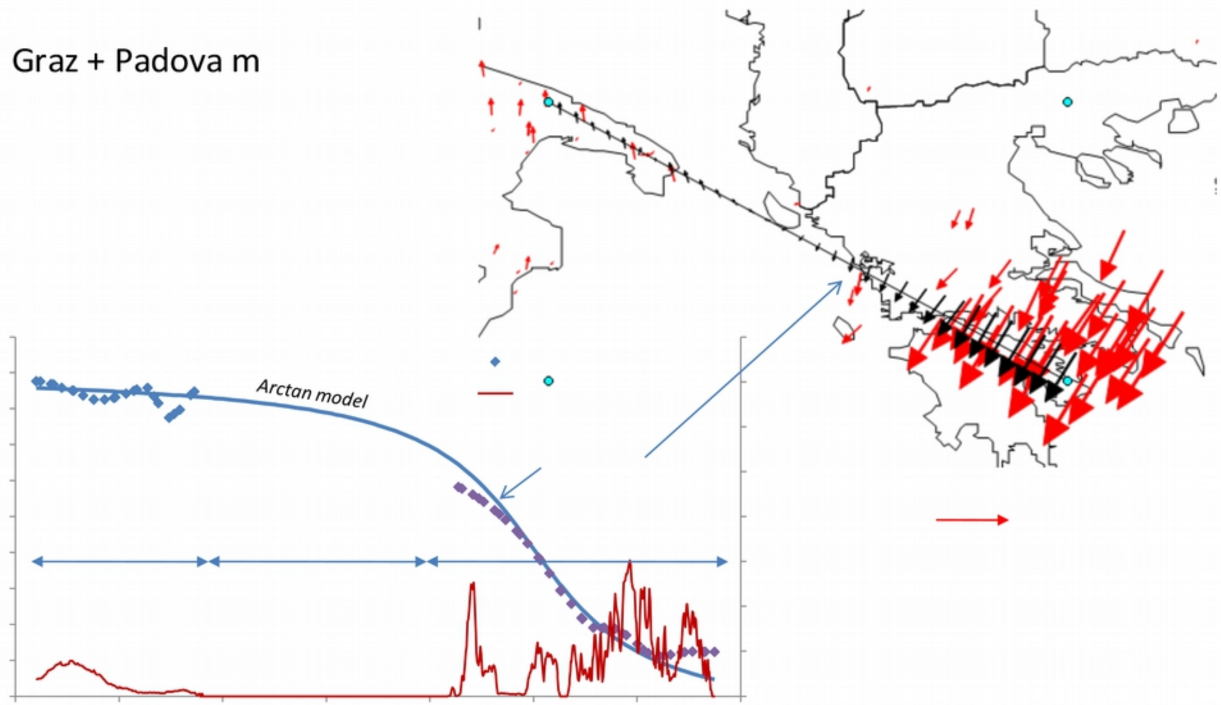




Investigating the steady state strain near the KTZ

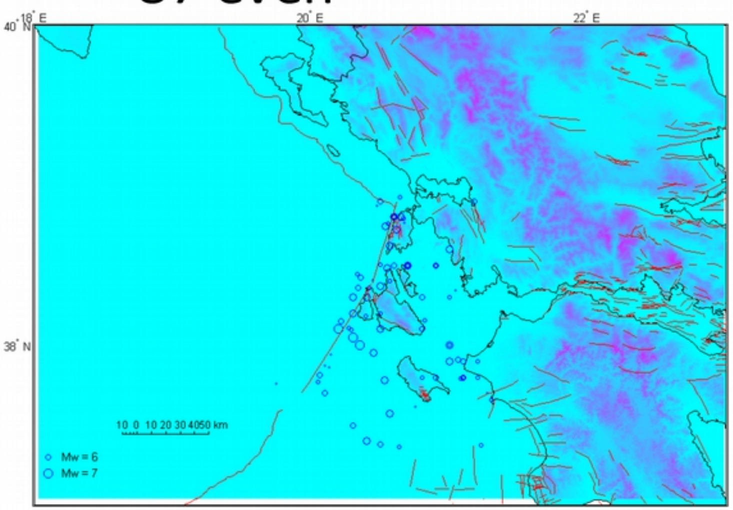
Regional

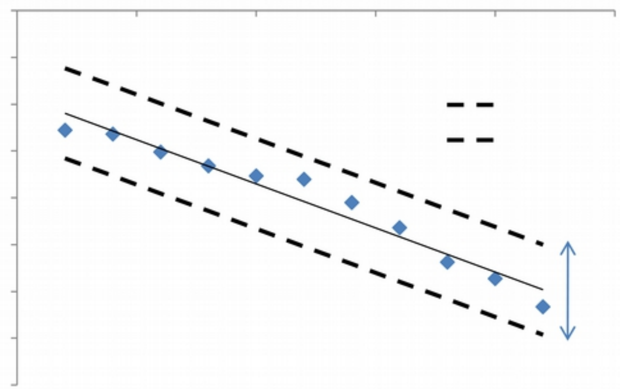
- Graz + Padova m

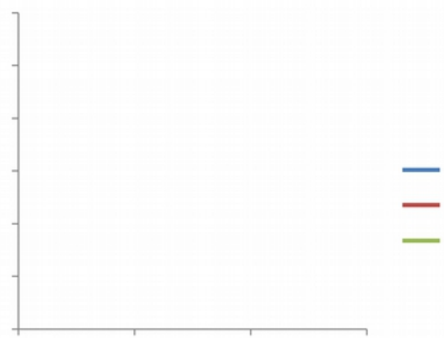


Maximum expected magnitudo from steady state shear strain, statistical seismicity and stress drop

87 even







Based on the available data, Mmax in the KTZ area can significantly exceed the historical maximum of 7.4 for a modest increase of the stress drop. Consequently it is not unlikely that events of Mw>7.4 can take place in the KTZ

Conclusions

- From the 80’s to date: Dramatic increase in time and spatial resolution of coordinates, velocities and reference frame. Standards. GNSS as a key technological step forward, relative to SLR/VLBI
- From WEGENER to EPOS = From SLR to integrated GNSS, DInSAR, geologic, gravity and seismological data.
- Standardization of geodetic products (velocities) require compliance with guidelines
- A service for the near future: prompt reaction to seismic events in terms of measurement of coordinate jumps, postseismic relaxation
- Focus on seismicity, but GIA important too.