

Výzkum dvou silných zemětřesení na Kefalonii v r. 2014

J. Zahradník a kolektiv

Katedra geofyziky

Matematicko-fyzikální fakulta

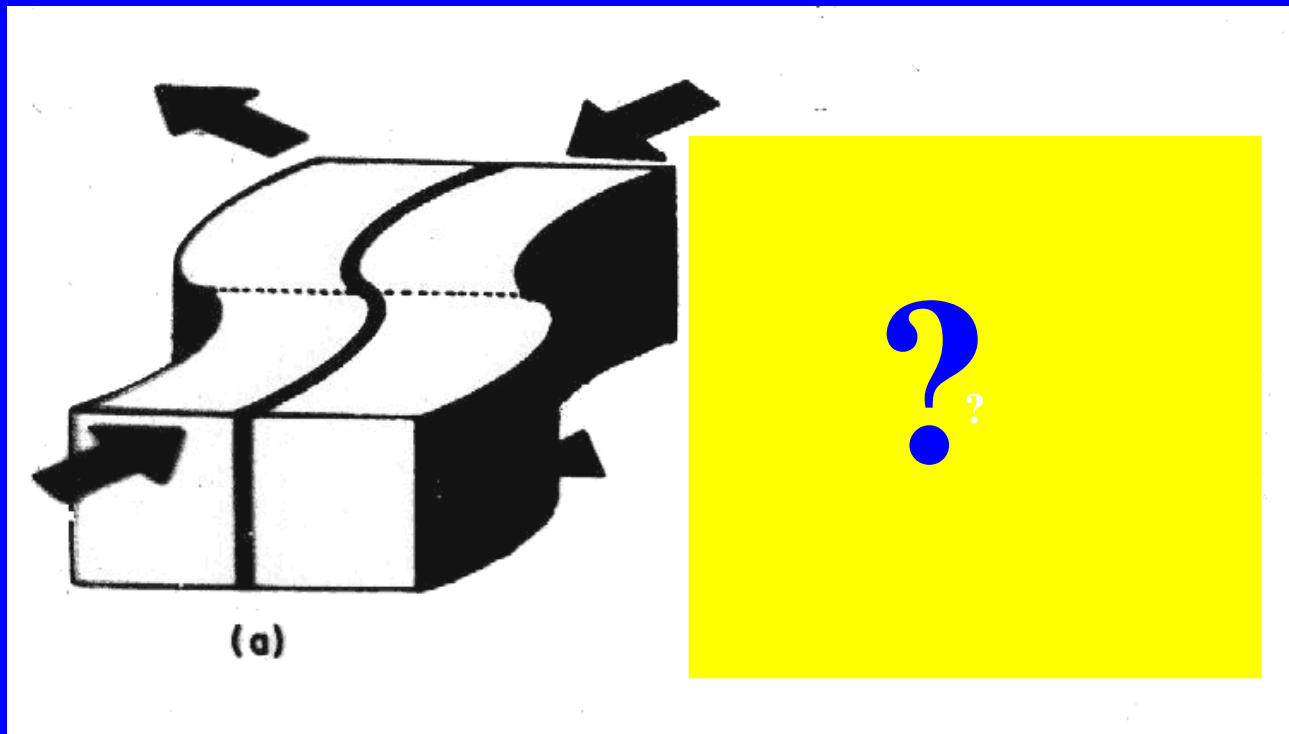
Univerzita Karlova

Nové Strašecí, 28. 4. 2015

Základní pojmy

Zemětřesení vzniká v místech
“zaklesnutí“ desek.

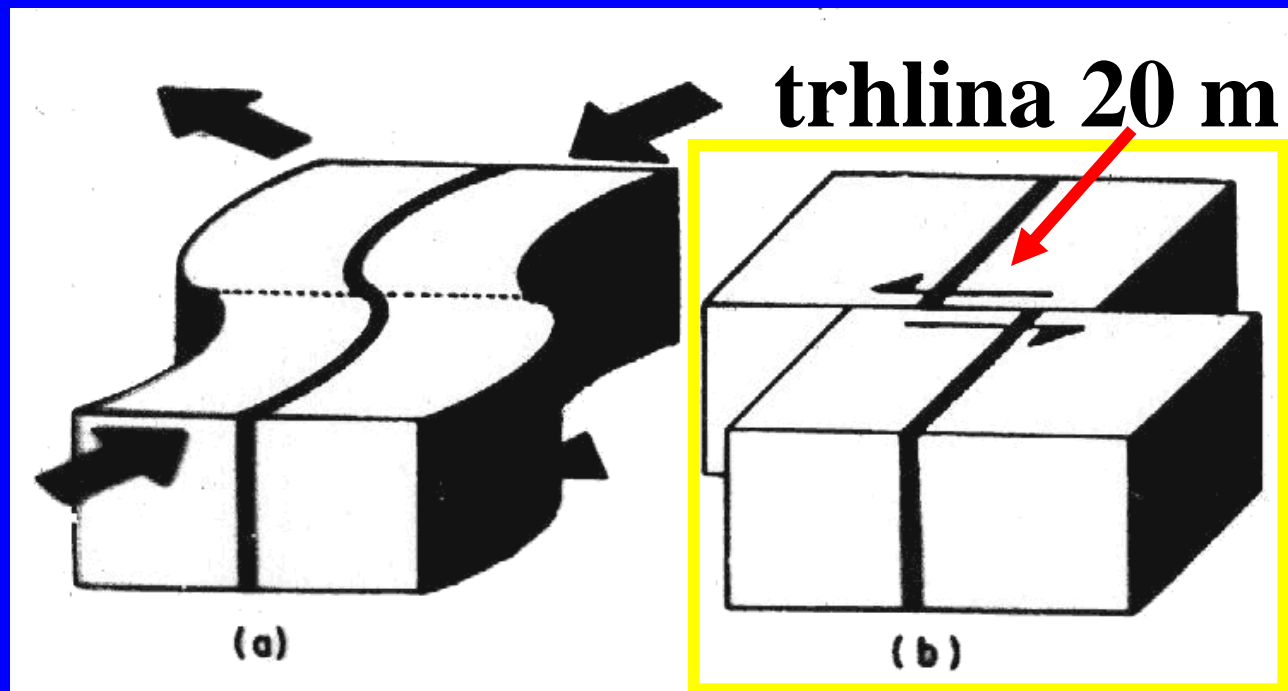
Kontakt se deformuje mnoho let a ...



Kontakt se deformuje mnoho let a ...

když praskne, nahromaděná energie se uvolní
během sekund.

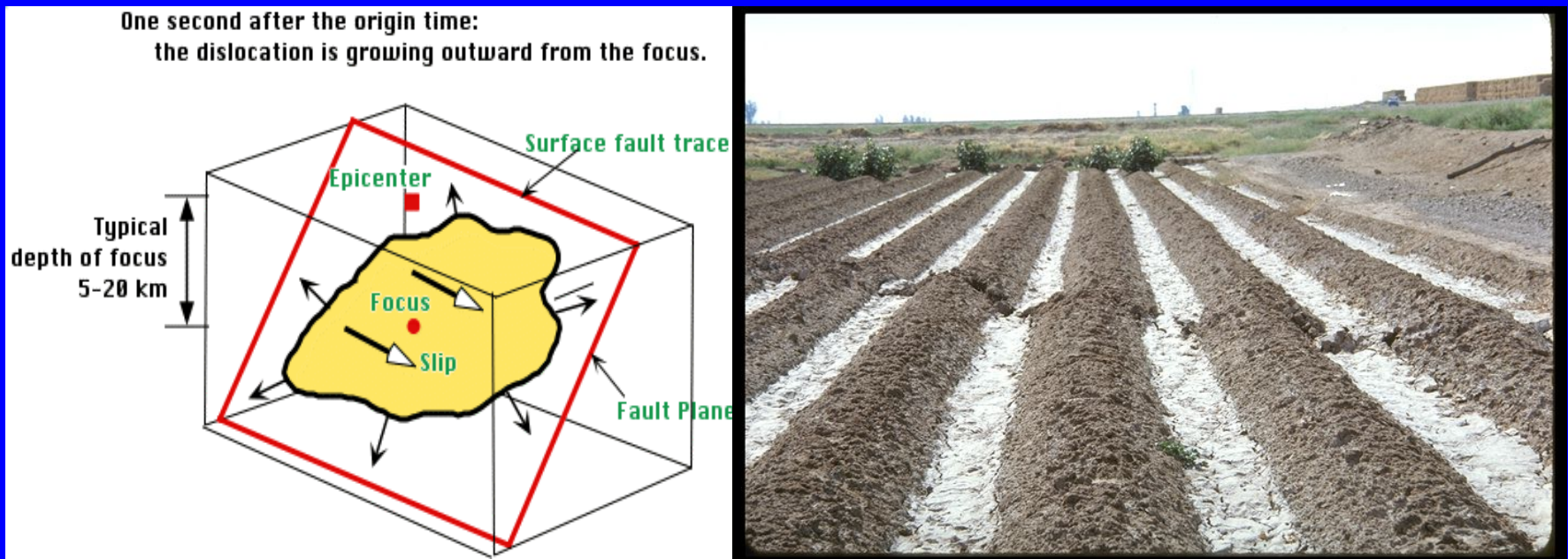
Japonsko 2011: $E_S \sim 10^{19}$ J, jako Temelín za 200 let !



kostka1

Styk desek je zlomová plocha
a na ní vznikají posunutí (trhliny).

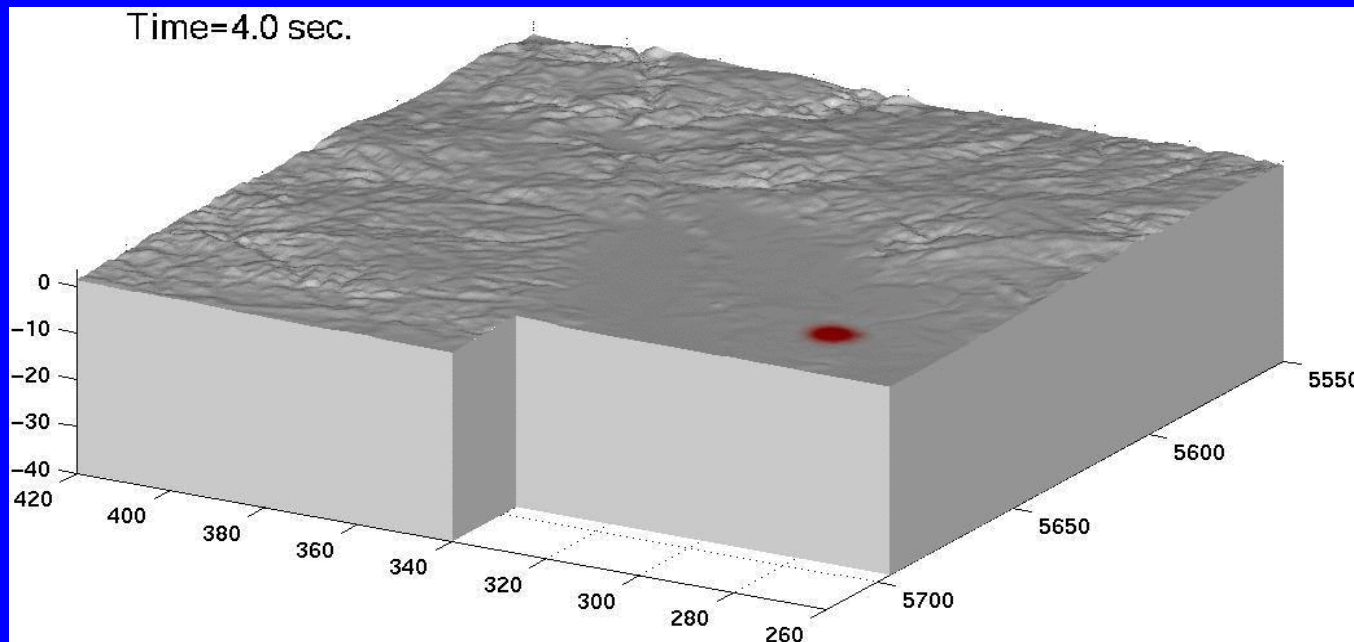
Zlom dosahuje k povrchu země jen výjimečně.



Jak studovat zlom v hloubce desítek km?

Seismické vlny nesou informaci o fyzikálních parametrech zemského nitra a také o zemětřesném procesu

Vznik a šíření vln lze matematicky modelovat





**Seismické vlny odhalí dvě plochy.
Jedna z nich je rovinou zlomu.**

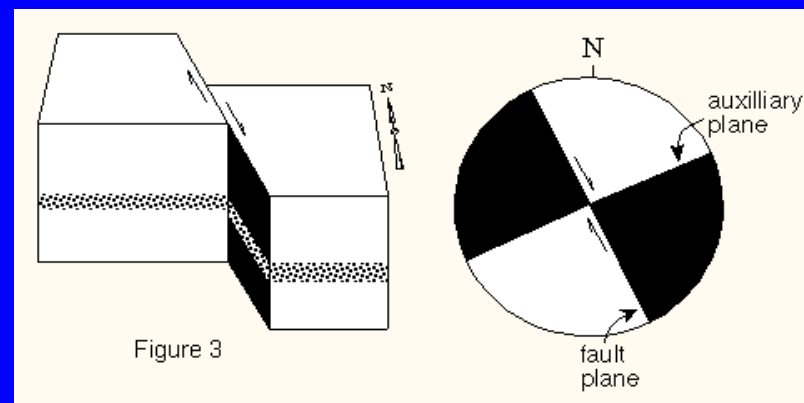
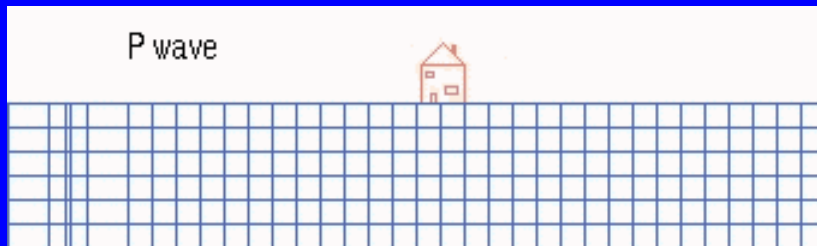
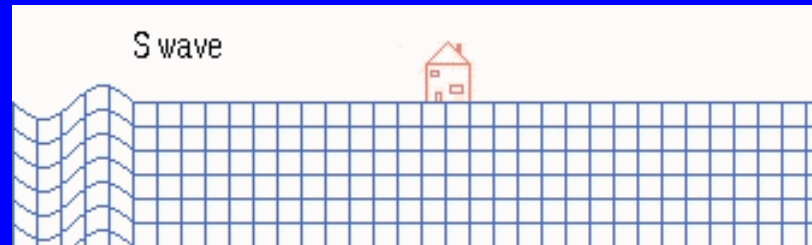


Figure 3

Podélné a příčné elastické vlny se šíří různou rychlostí.



$$V_p = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

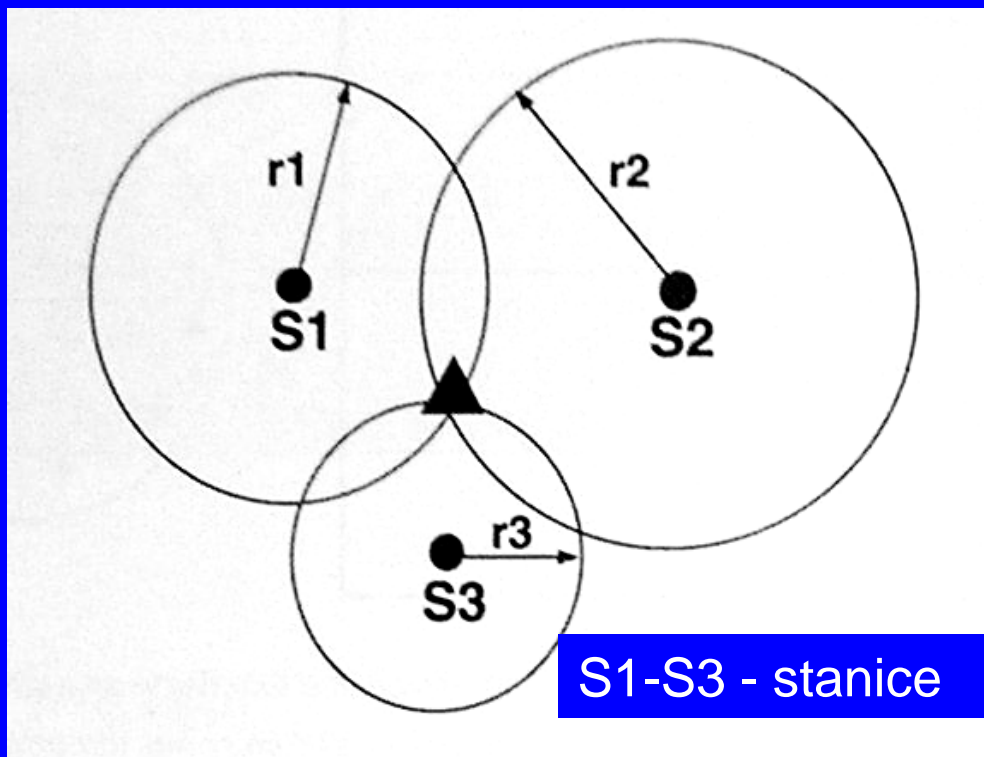


$$V_s = \sqrt{\frac{\mu}{\rho}}$$

$V_p > V_s$ (v zemské kůře ~ 10 000 km/hod)
podélná = primární (P), příčná = sekundární (S)

Rozdíl doby běhu P a S vln se
zvětšuje se vzdáleností
pozorovatele od zdroje vlnění.

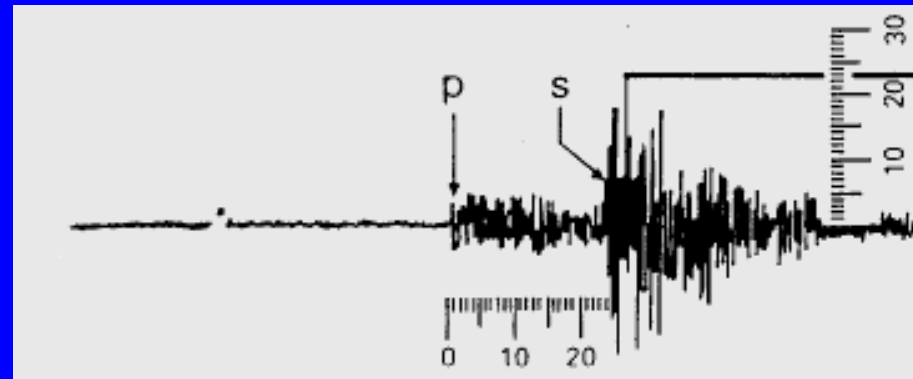
→ princip určování polohy zemětřesení



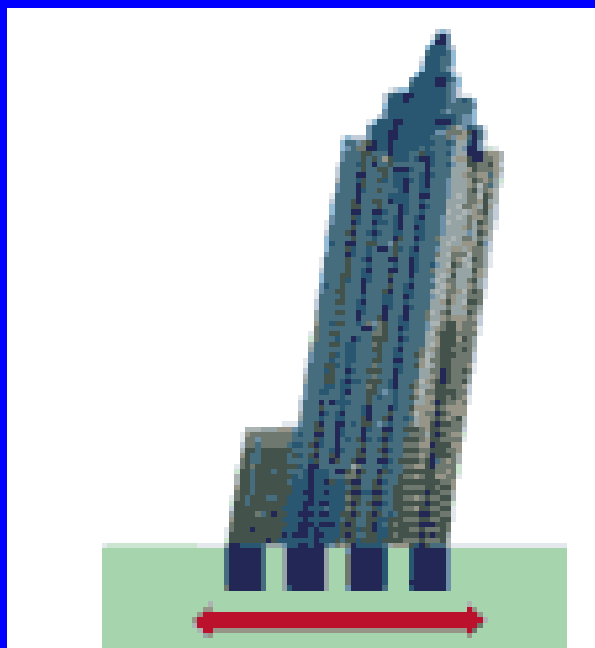
Amplitudy vln ubývají se vzdáleností.

Ch. Richter 1930

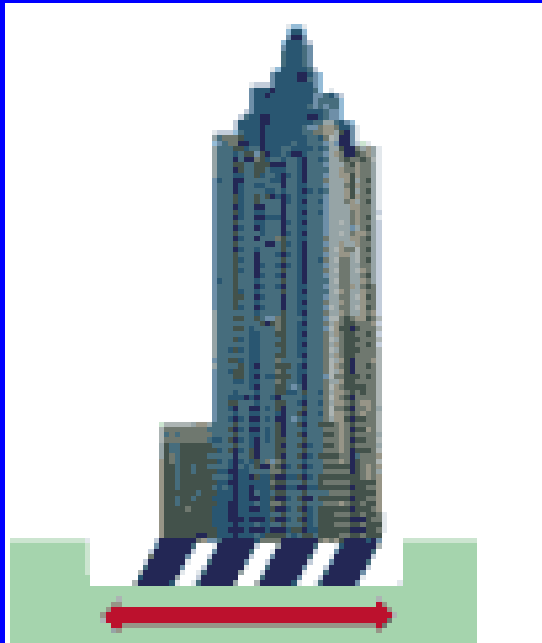
→ princip určování velikosti zemětřesení (magnitudo)



Modelování umožňuje také pochopit
ničivé účinky zemětřesení ...



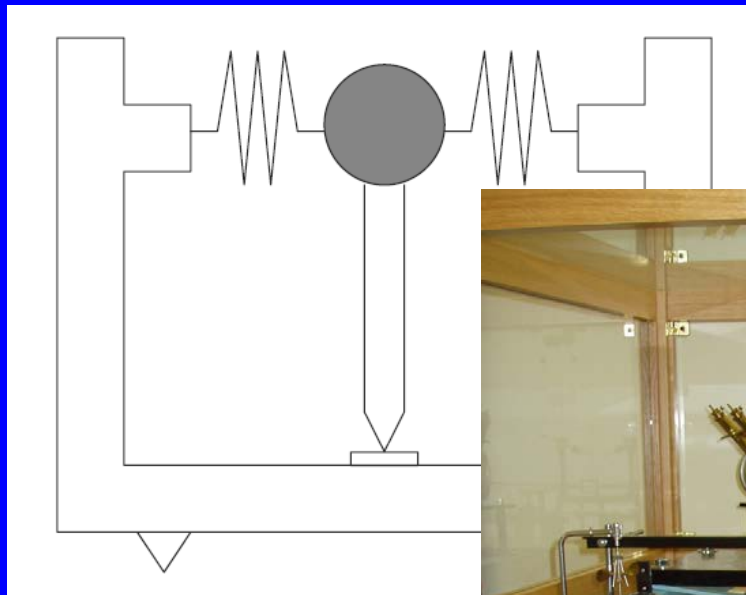
... a projektovat seismicky odolné stavby



Jak vlny zaznamenat, měřit?



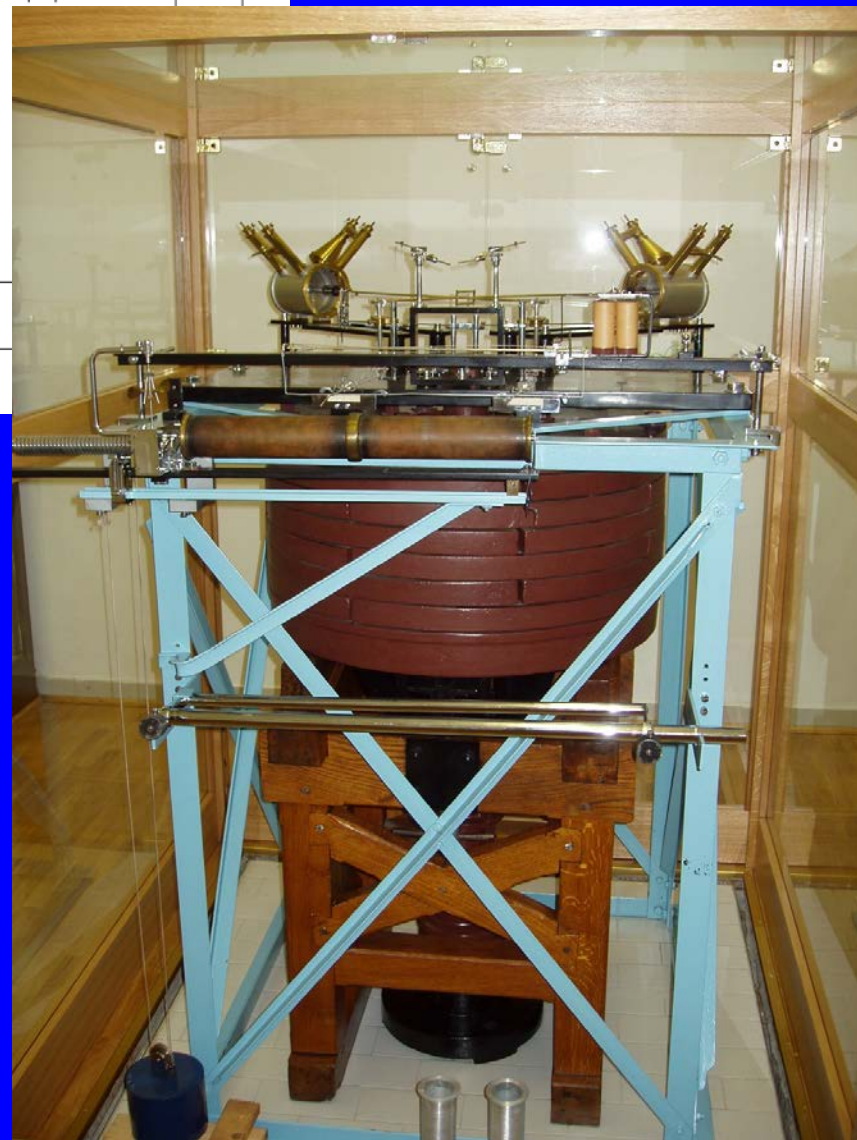
horizontální
kyvadlo



E. Wiechert 1909

kyvadlo o hmotnosti 1000 kg
vlastní perioda 10 sekund

Na naší fakultě instalován r. 1924



horiz_seismo.mov

A dnes ...
zpětnovazební (kompenzační) systémy
s širokým oborem period

kyvadlo o hmotnosti pouhých 100 gramů
vlastní perioda celého systému až 5 minut



Seismické sítě a satelitní přenos dat

Příklad:
stanice MFF v Řecku



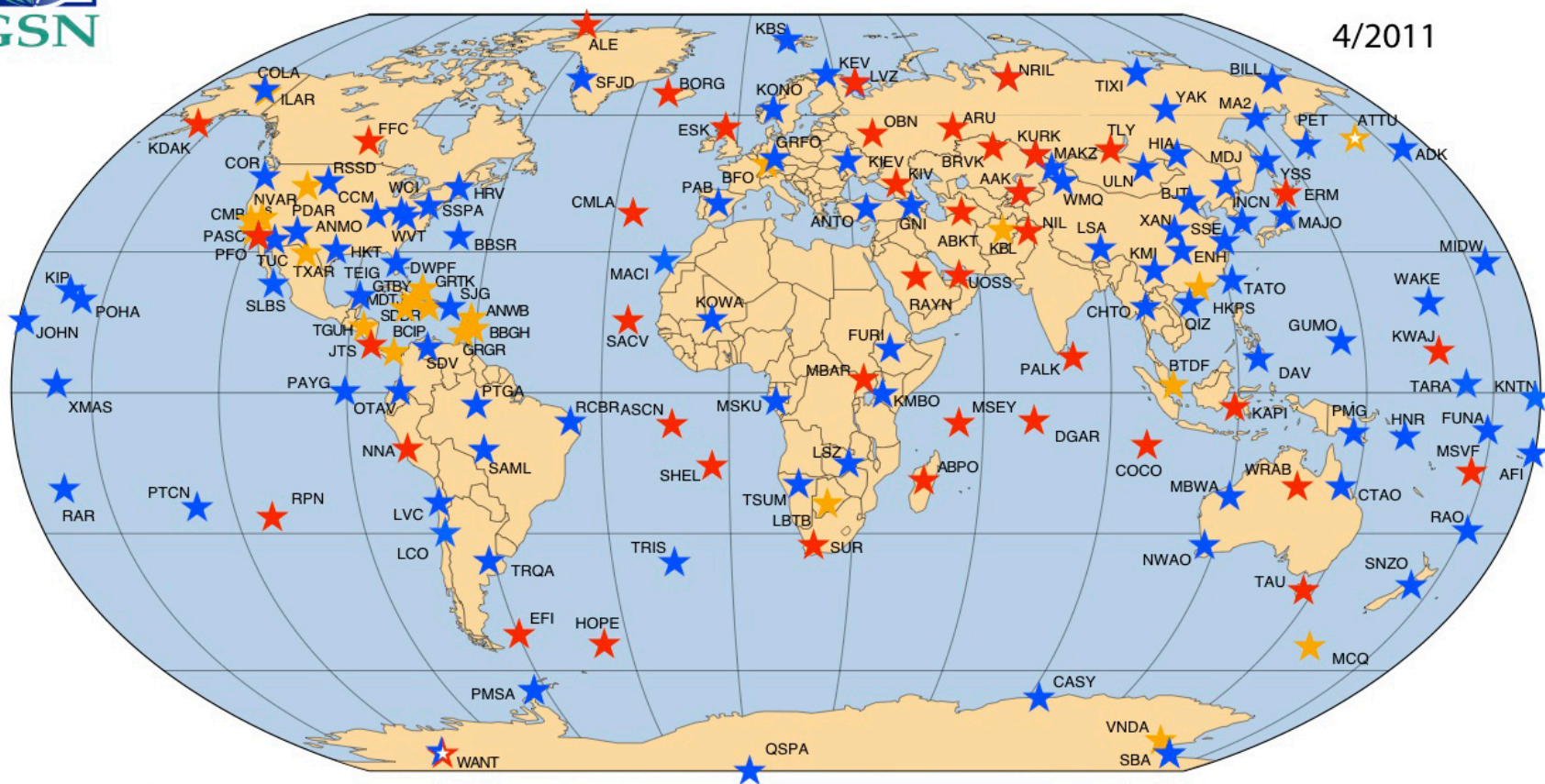
Globální seismická síť

Několik minut po velkém zemětřesení kdekoli na světě známe jeho polohu a velikost a můžeme vypočítat pravděpodobné účinky.



GLOBAL SEISMOGRAPHIC NETWORK

4/2011



Kefalonie 2014

Kefalonie nebo Ithaka?

Homér: Odysea

Z ženichů přední číhají na tebe v úžině,
jež dělí Ithaku od srázných břehů Samy.
Chtějí tě zabít, než stihneš Ithaky rodné!
Neboj se však! Spíš pohřbí země některého z nich,
kteří ti mrhají dědictví otců!



Kefalonia nebo Ithaka?

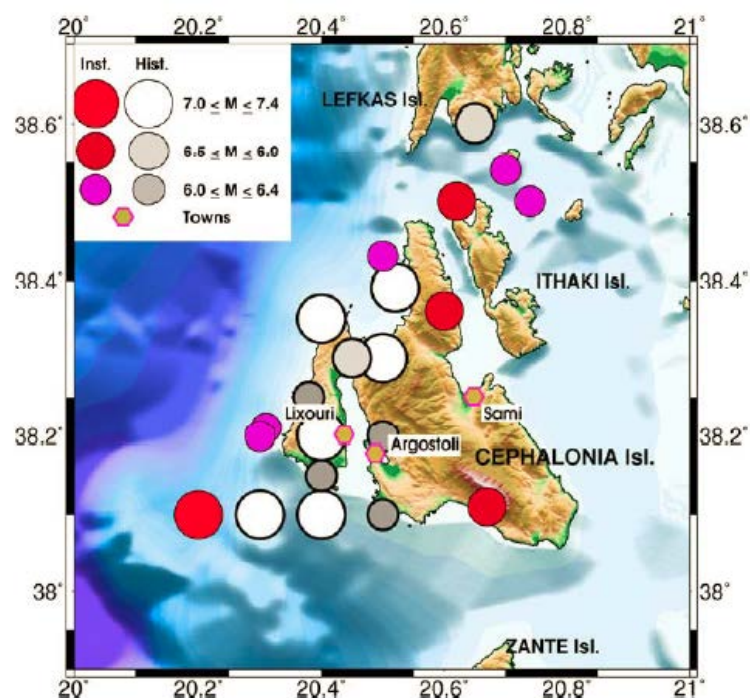


According to this hypothesis, the thin strip of sea separating the two islands is the channel that geographer Strabo (64/63 BC – c. AD 2) described when he visited the area (Fig. 2.1.3), that has been filled since with sediments, catastrophic rockfalls, co-seismic uplift events and relative sea-level change (Underhill, J. 2009).

Table 5.1.1. Information on source parameters of strong ($M \geq 6.0$) earthquakes in the area of Cephalonia from 1469 to 1983 (Papazachos and Papazachou, 2003).

Year	Date Time	Latitude	Longitude	Magnitude	Locality	max Intensity I_0
1469	Spring	38.30	20.50	7.2	Cephalonia	IX
1636	30-Sep midnight	38.10	20.30	7.2	Cephalonia	IX (Makropoulo)
1638	16-Jul	38.20	20.40	6.4	Cephalonia	VIII
1658	August 24	38.20	20.40	7.0	Cephalonia	IX (Lixouri)
1714	August 28	38.10	20.50	6.4	Cephalonia	VIII
1741	June 23	38.15	20.40	6.4	Lixouri	VIII
1759	June 13	38.20	20.50	6.3	Argostoli	VIII
1766	July 24	38.10	20.40	7.0	Cephalonia	IX
1767	July 22	38.30	20.40	7.2	Cephalonia	X (Lixouri)
1862	March 14	38.30	20.40	6.5	Argostoli	IX
1867	February 4 4:19	38.39	20.52	7.4	Cephalonia	X (Lixouri)
1912	January 24 16:22:51	38.11	20.67	6.8	Cephalonia	X Asprogeraki
1915	January 27 1:09:56	38.36	20.60	6.6	Ithaca	IX (Exozi)
1915	August 7 15:04:03	38.50	20.62	6.7	Ithaca	IX
1953	August 12 9:23:52	38.30	20.80	7.2	Cephalonia	X+ (Argostoli)
1972	September 17 14:07:15	38.21	20.31	6.3	Cephalonia	VII (Chavriata)
1983	January 17 12:41:31	38.10	20.20	7.0	Cephalonia	VI (Argostoli)

Historická zemětřesení



Známé seismogenní zlomy

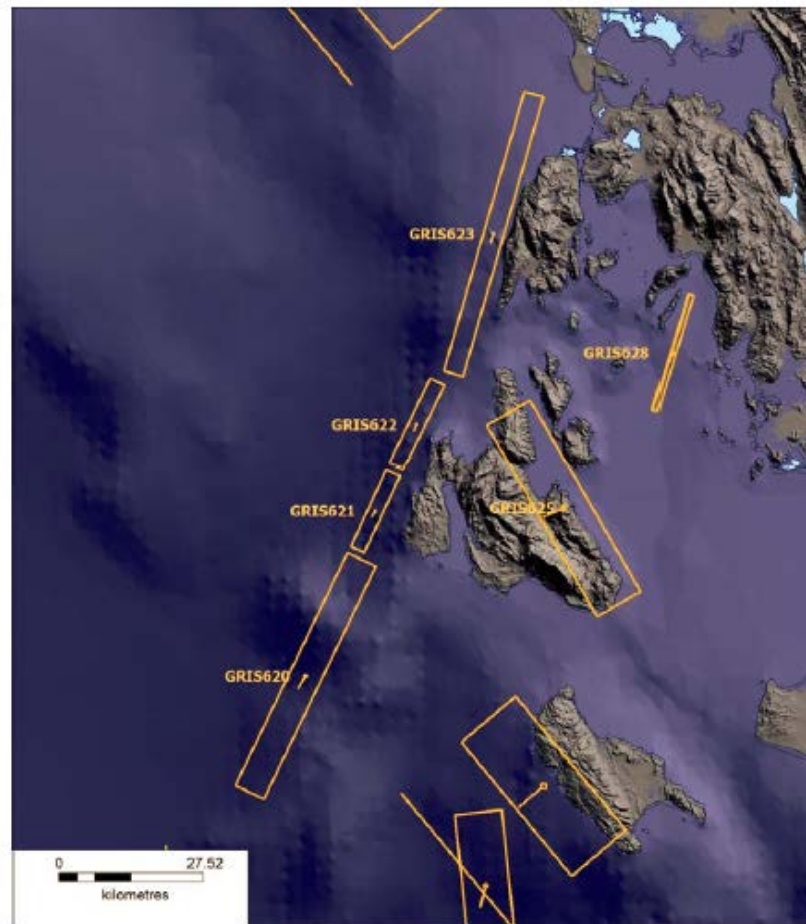


Figure 6.1.8. Seismogenic sources (i.e., active fault zones) in Cephalonia and surrounding areas, as mapped by the Gre.Da.S.S. team (Greek Database of Seismogenic Sources, redass.unife.it). Yellow rectangular shapes represent surface projection of fault zones, and the arrows indicate the fault rake.

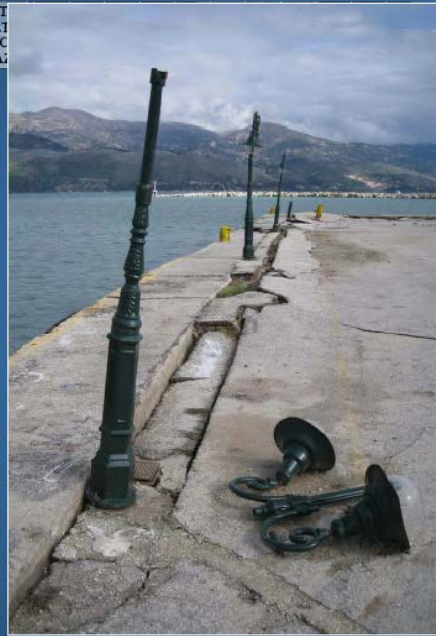
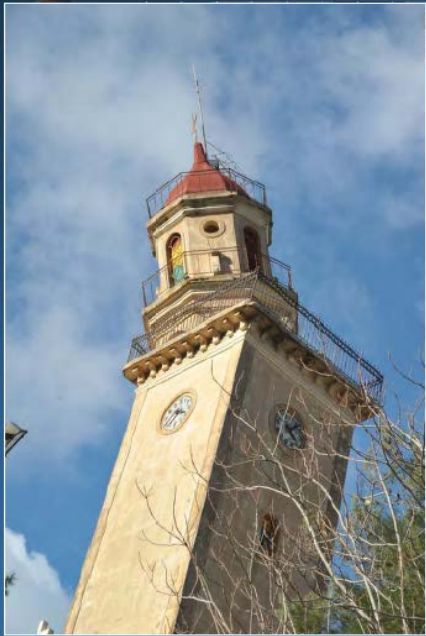
Zemětřesné „dvojče“ r. 2014

26. 1. (první) a 3.2. (druhý jev)

13:55

03:08









Mw 6.0 JAN 26 2014



Mw 6.0 FEB 4 2014



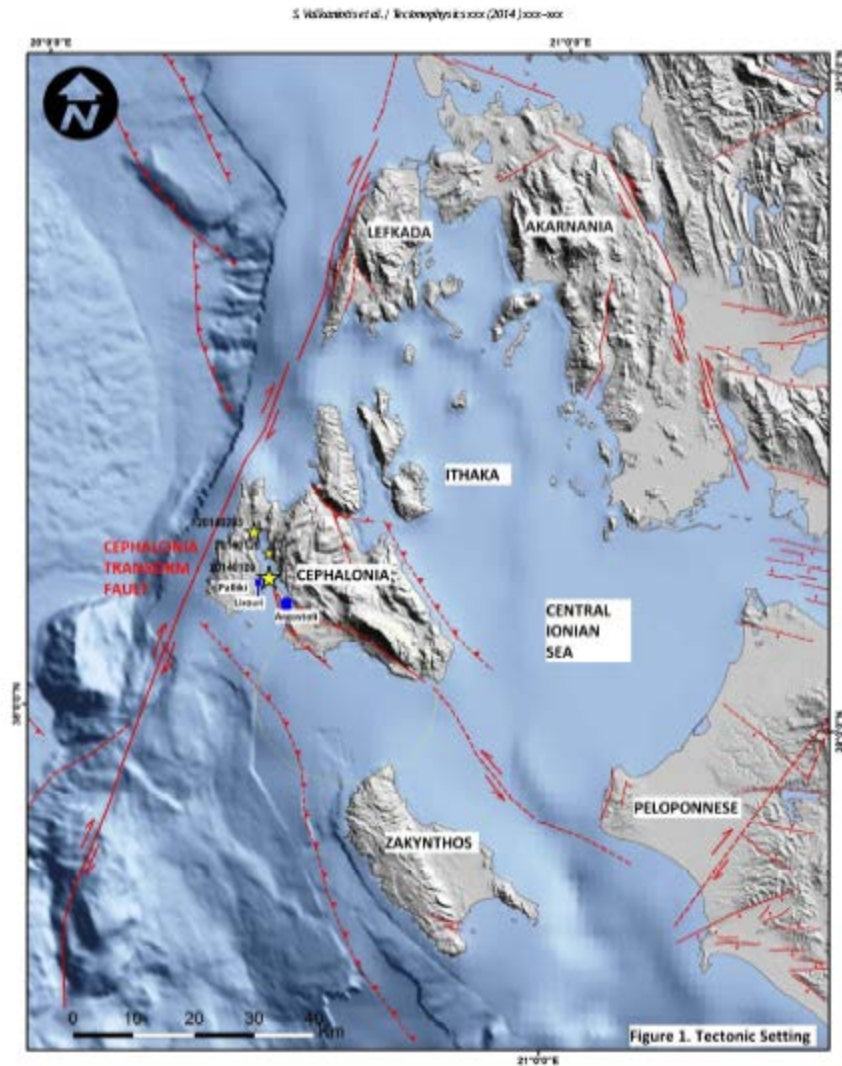
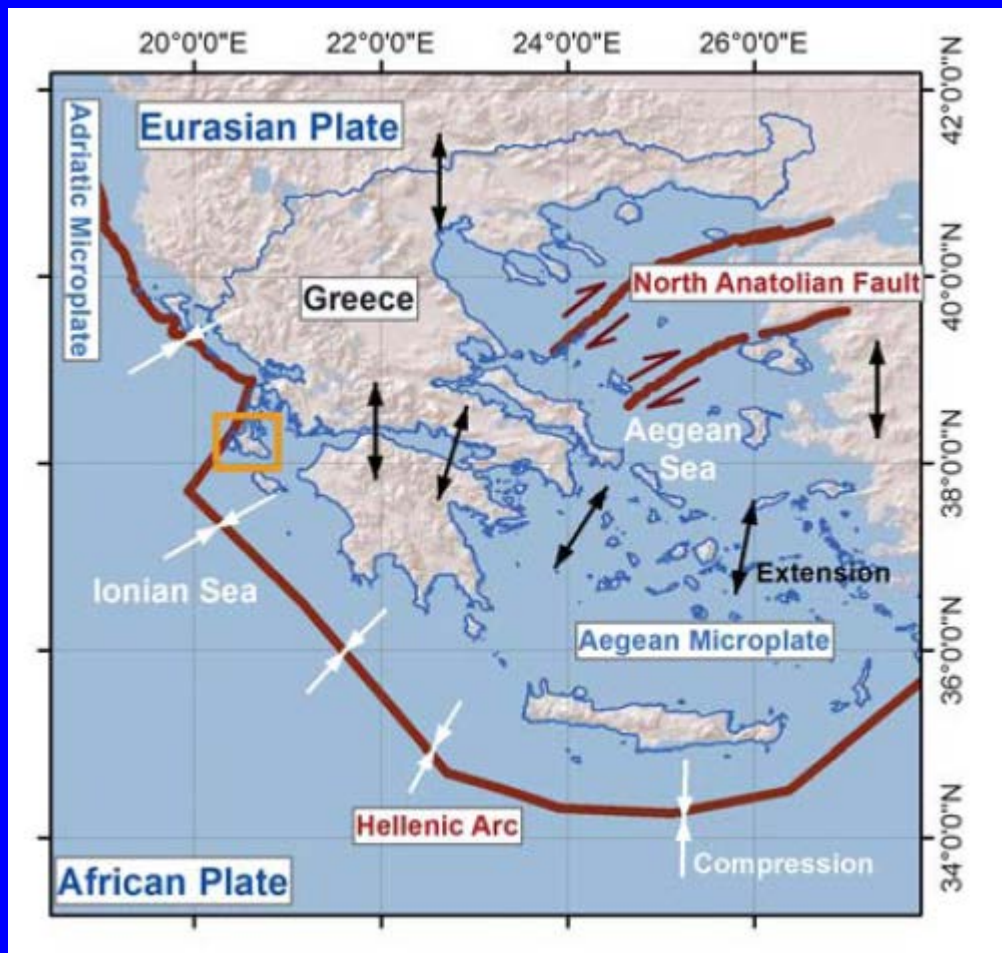
Mw 6.0 FEB 4 2014



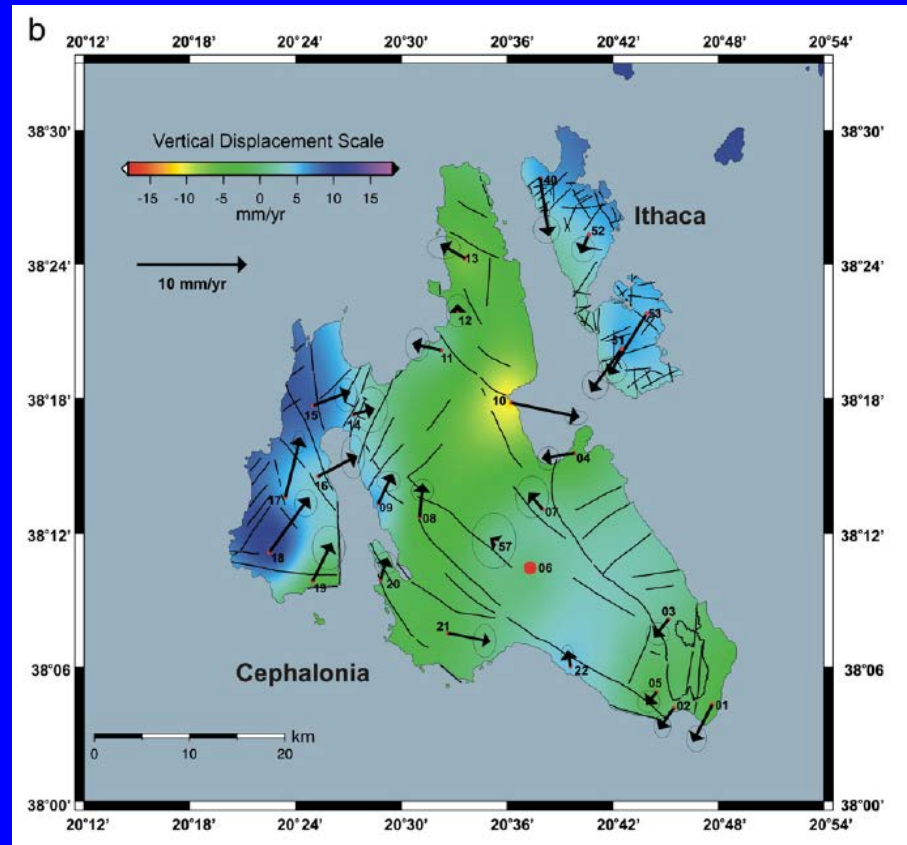
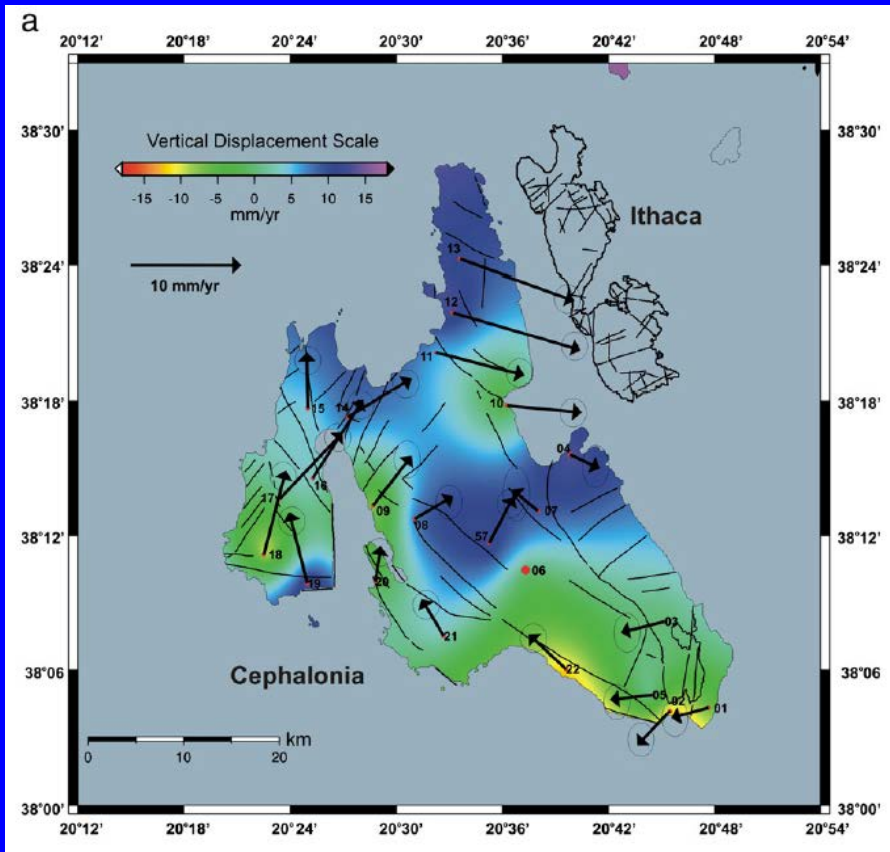
Mw 6.0 FEB 4 2014

Regionální tektonika a “příprava zemětřesení”

Kefalonský transformní zlom (CTF)



Příprava zemětřesení?



2001-2003

2003-2010

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

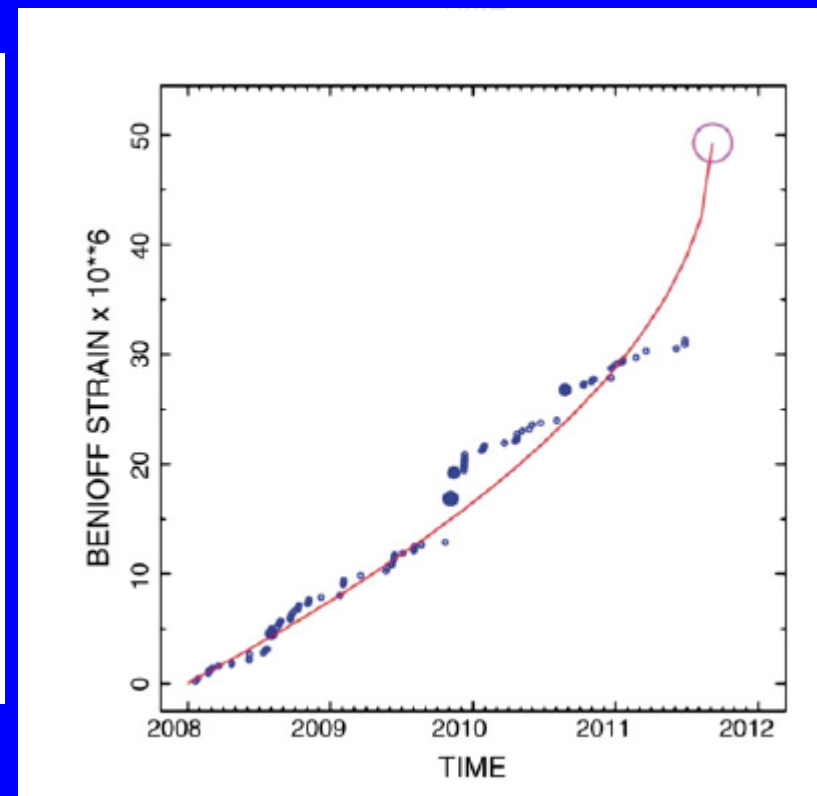
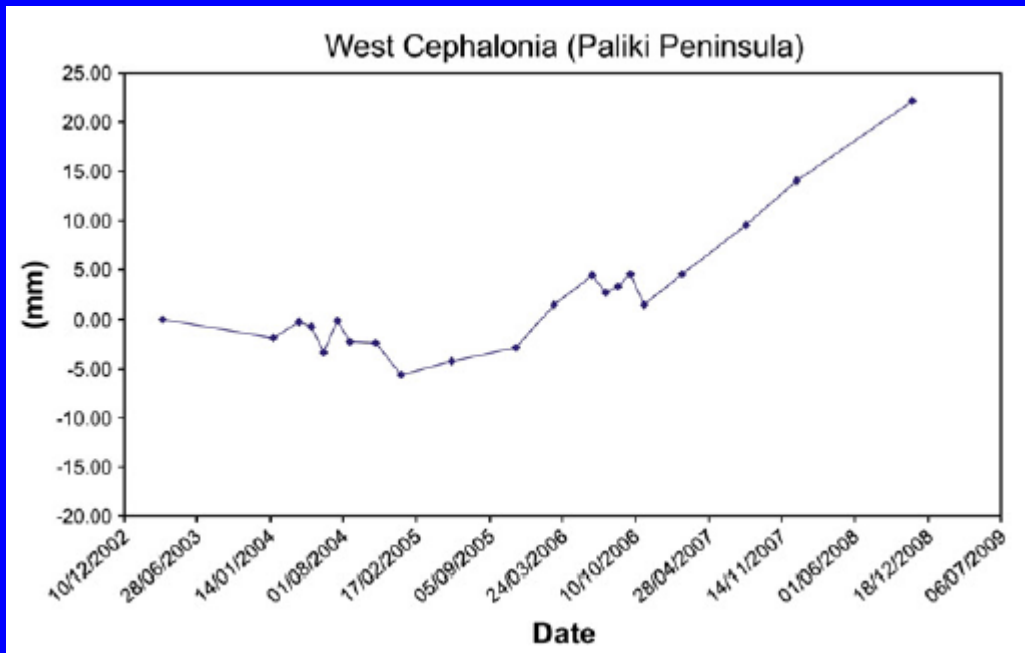
ELSEVIER

TECTONOPHYSICS
Earth and Planetary Science Letters

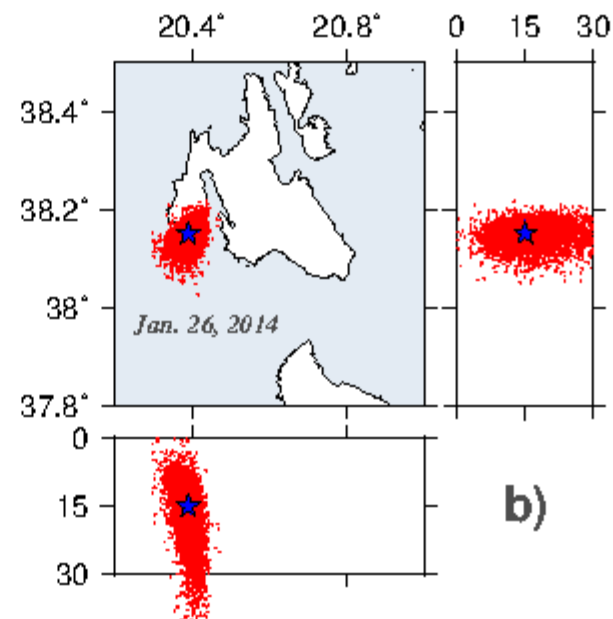
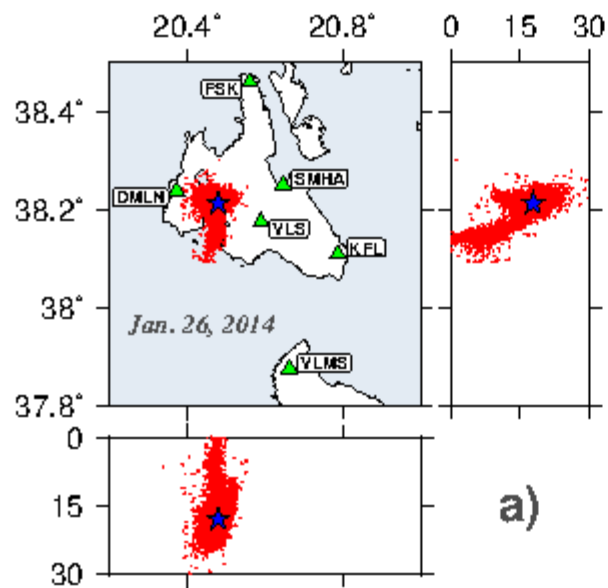
Combined Seismicity Pattern Analysis, DGPS and PSInSAR studies in the broader area of Cephalonia (Greece)

E. Lagios ^{a,*}, P. Papadimitriou ^a, F. Novali ^b, V. Sakkas ^a, A. Fumagalli ^b, K. Vlachou ^a, S. Del Conte ^b

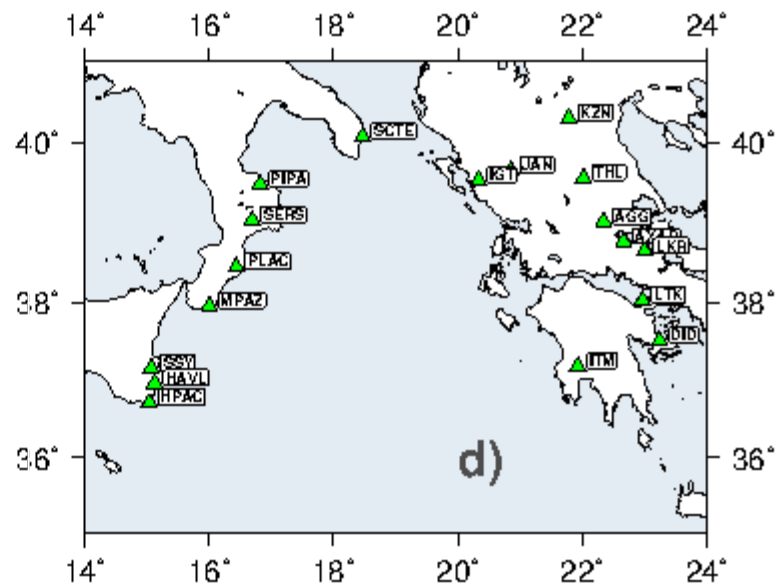
Výzdvih a 'zrychlená seismicita'

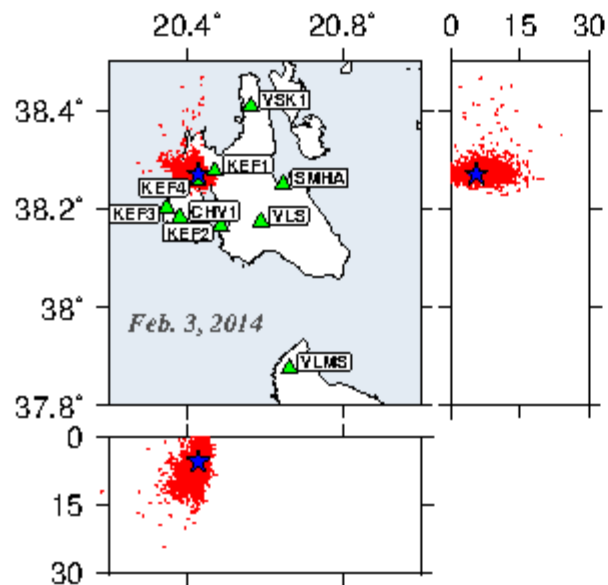
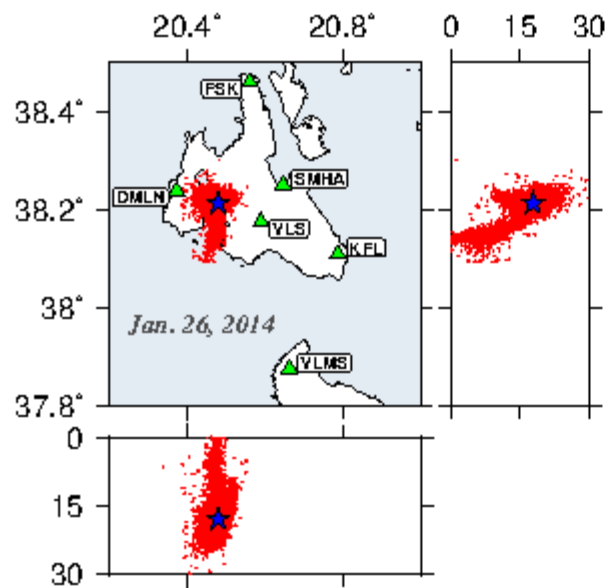


Naše výzkumy



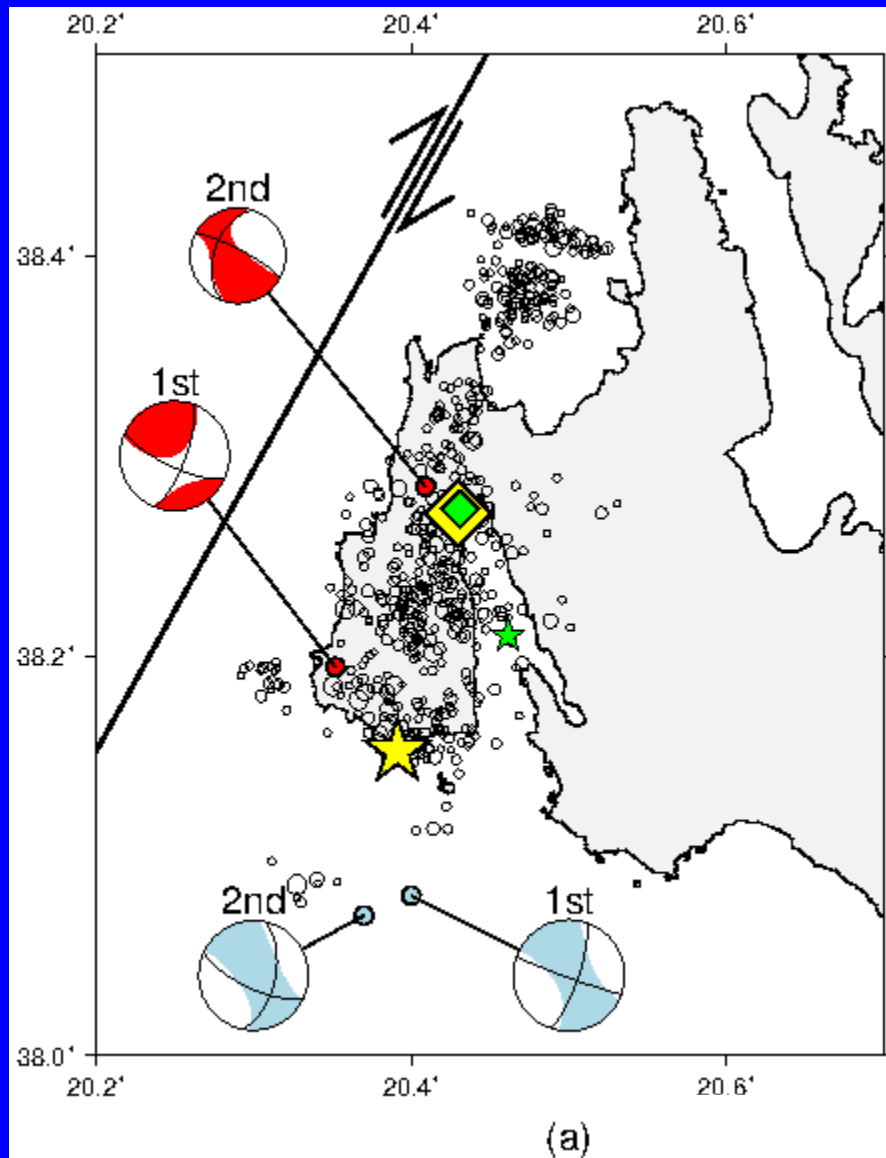
**Dvě
alternativní
lokalizace
prvního jevu**





**Druhý jev posunut
~10 km NNE
a do menší hloubky**

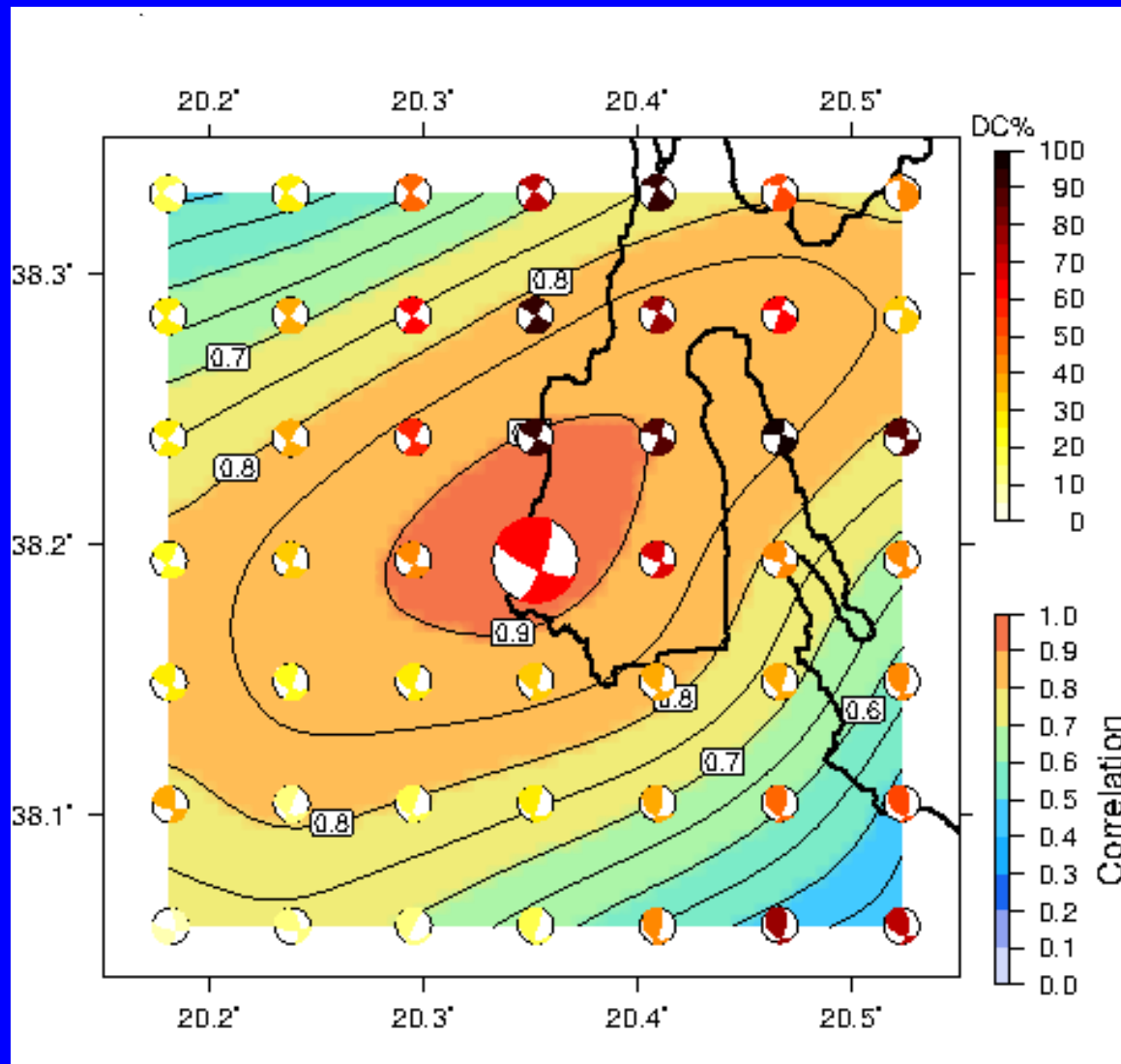
Dva Mw 6 otřesy a dotřesy $M_L > 3$



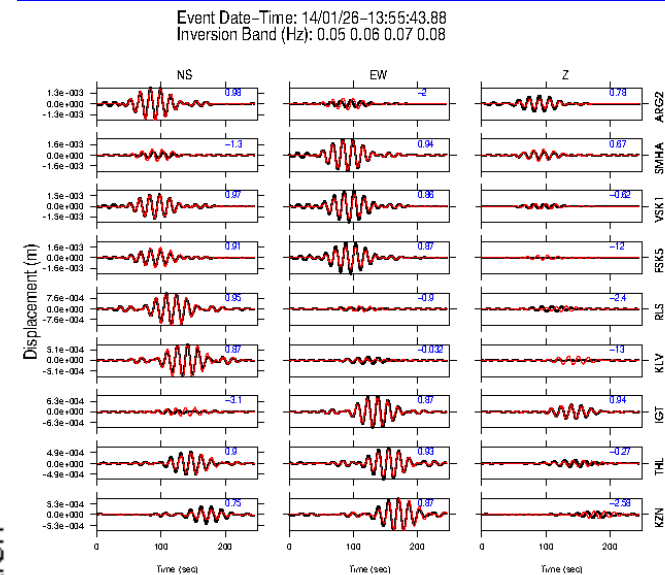
Epicentra:
Žlutá – naše
Zelená = Karasthatis

Centroid
a momentový tenzor:
Červená – naše
Modrá – Harvard GCMT

Centroid moment tensor (CMT) – 1. jev



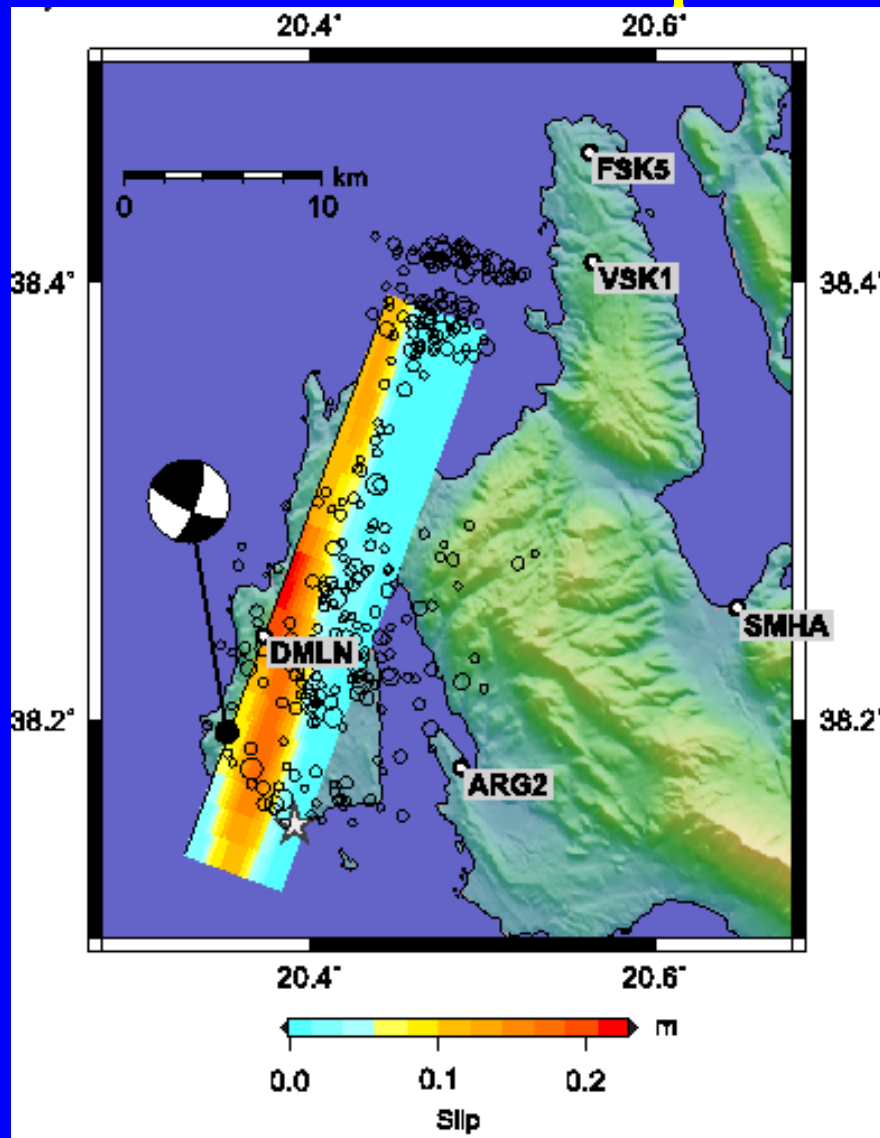
stanice do ~200 km
nízké frekvence
0.05-0.08 Hz



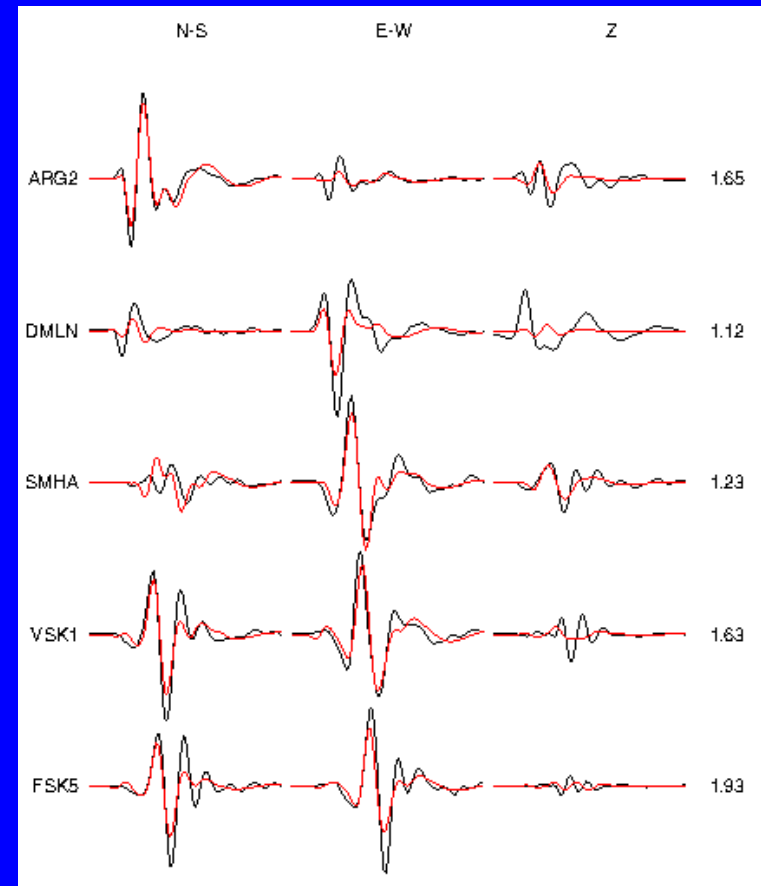
Zlomová plocha a její trhání

trhlina=skluz,
šíření trhliny

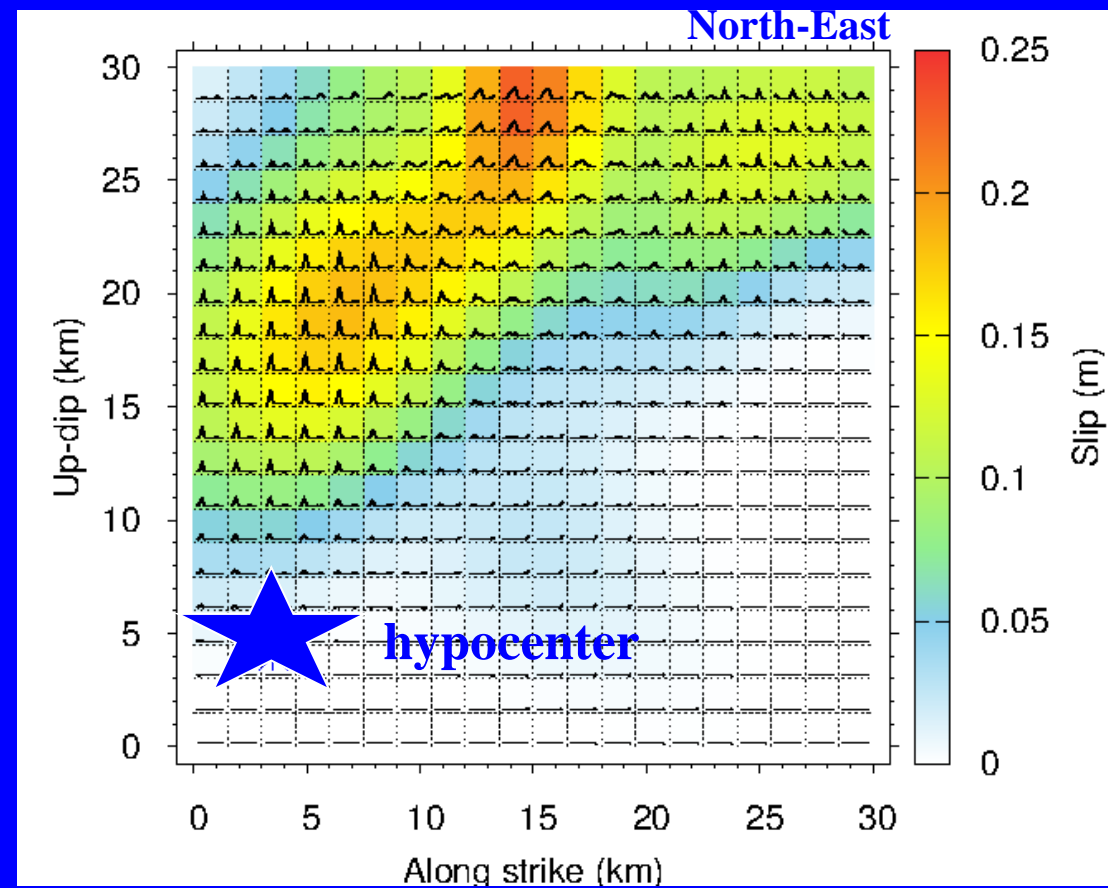
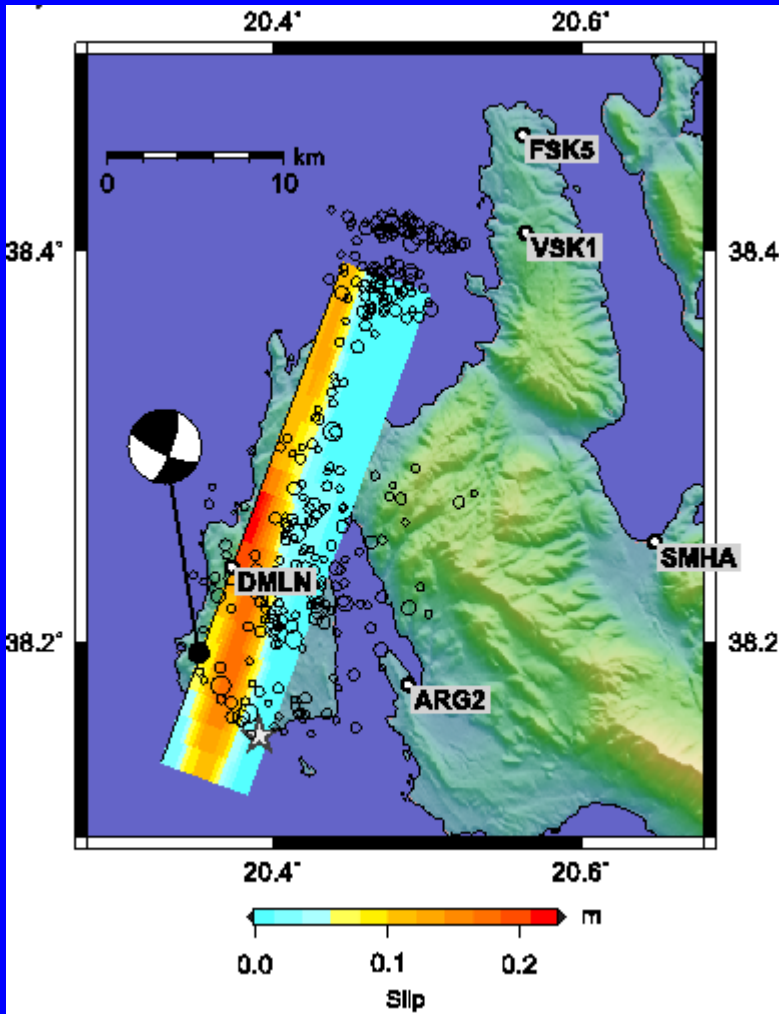
Skruzová inverze (F. Gallovič) – první jev



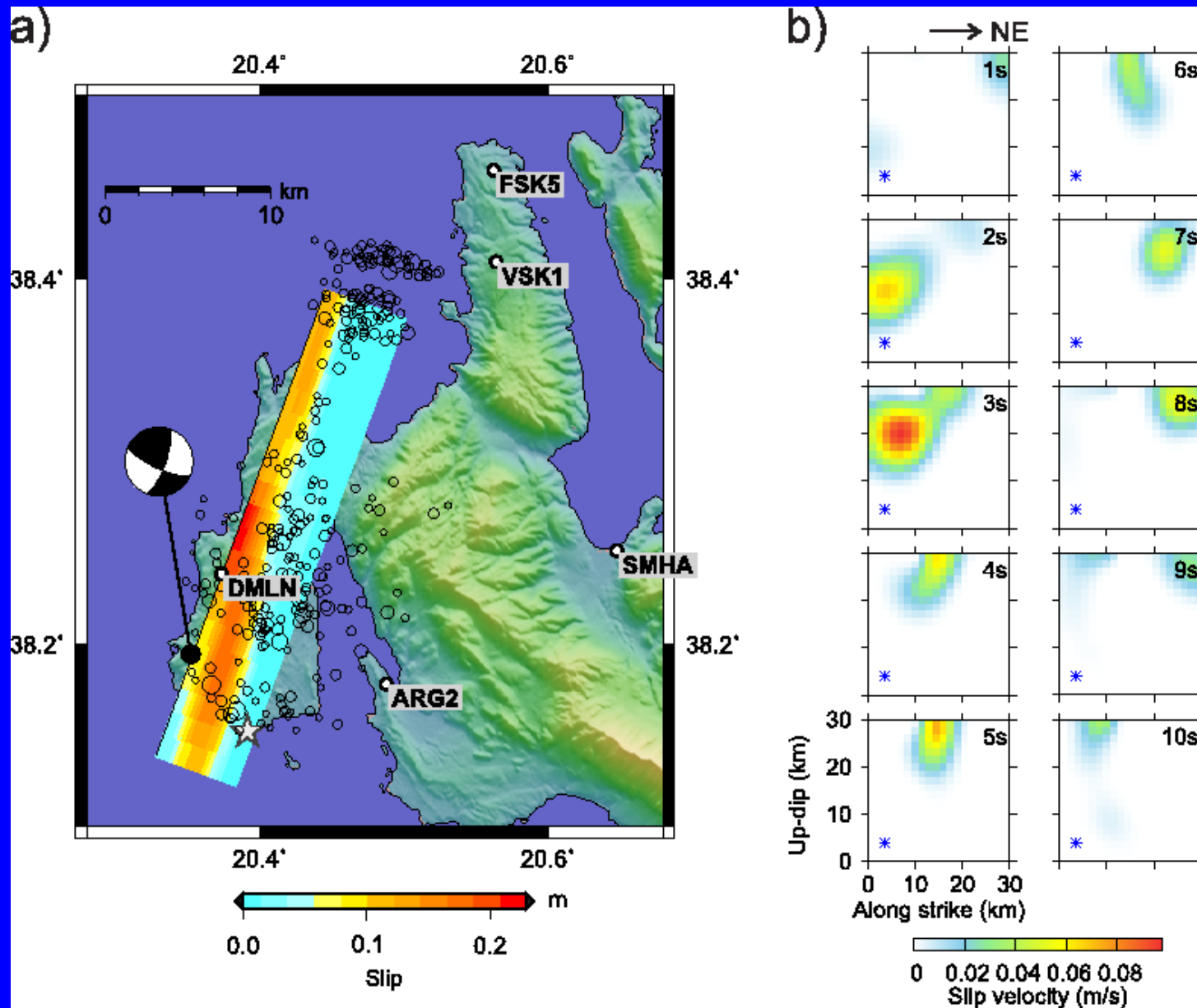
lokální stanice a
vyšší frekvence
0.05-0.20 Hz



Prostorové rozložení skluzu

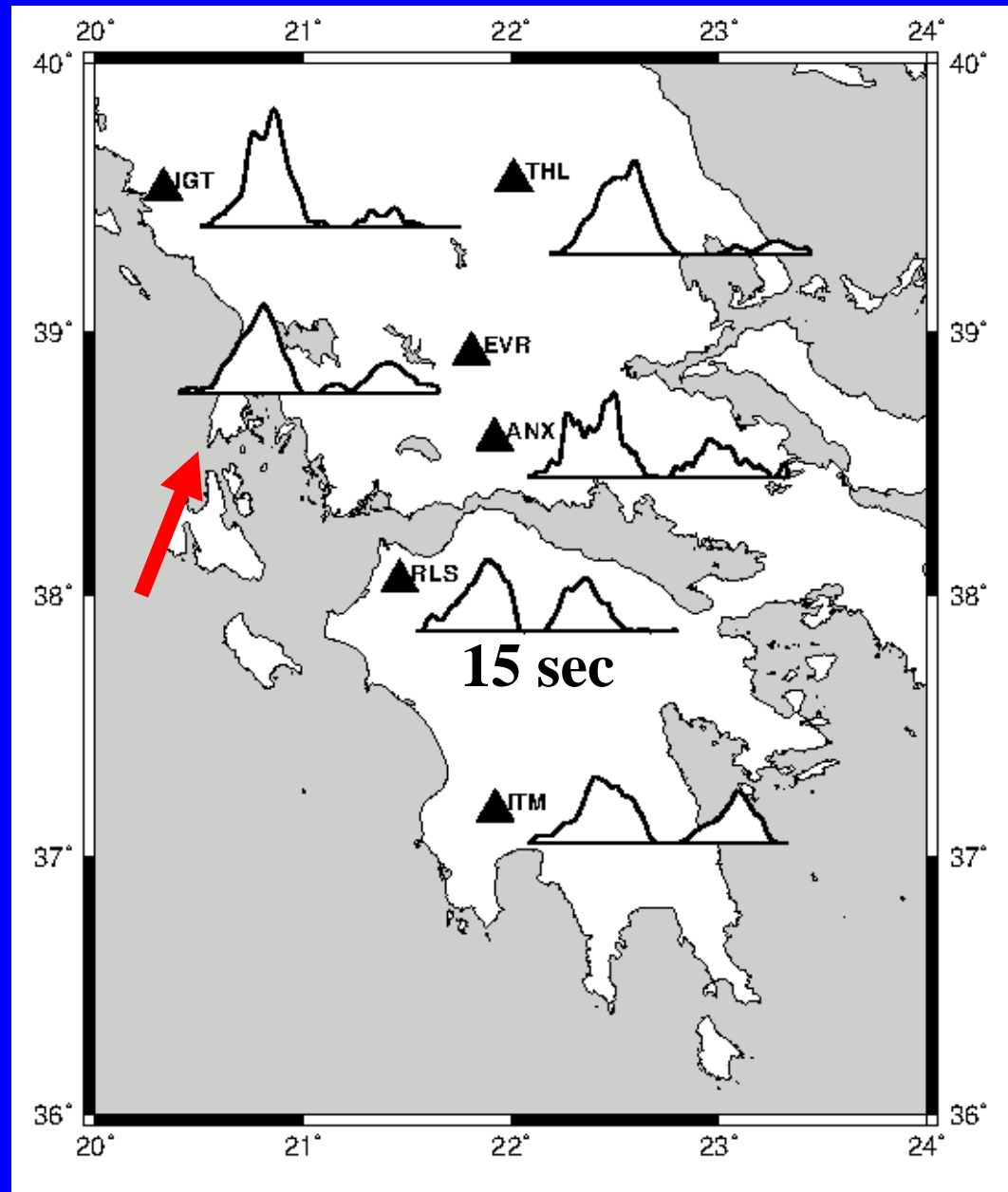


Prostorově-časové rozložení skluzu



Zdánlivé časové funkce metodou EGF

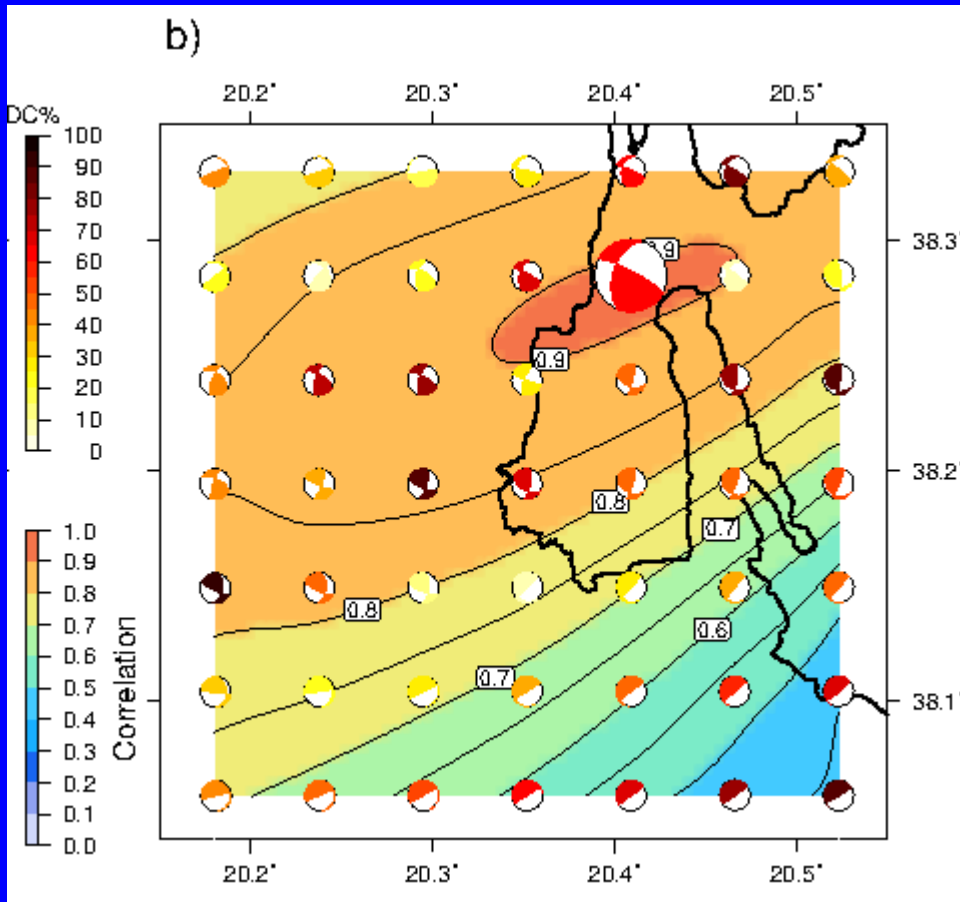
obdoba Dopplerova jevu



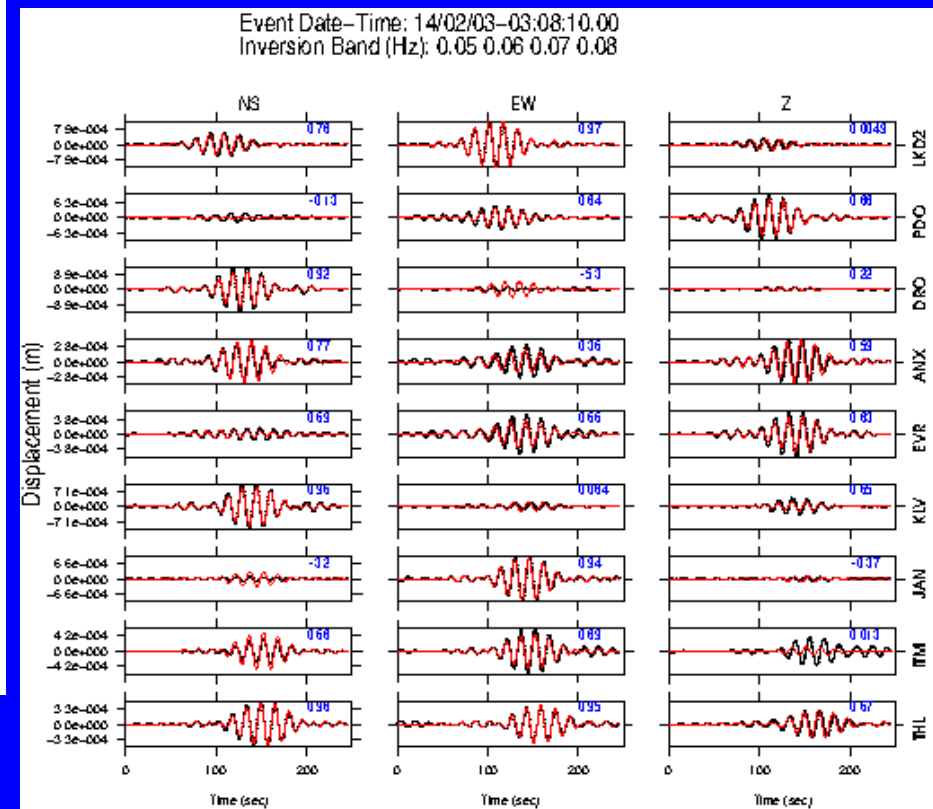
Druhý jev Mw 6

8 dní později

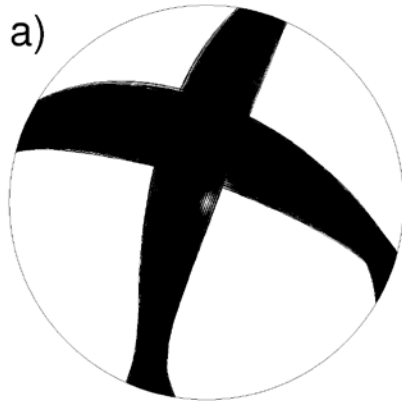
Centroid moment tensor - druhý jev má nestabilní řešení



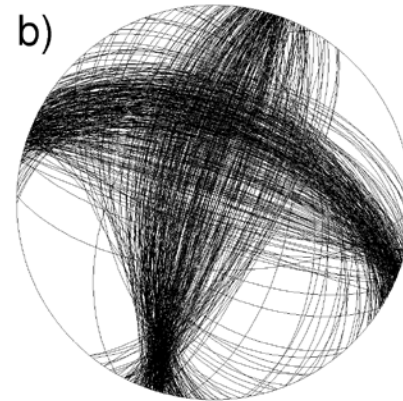
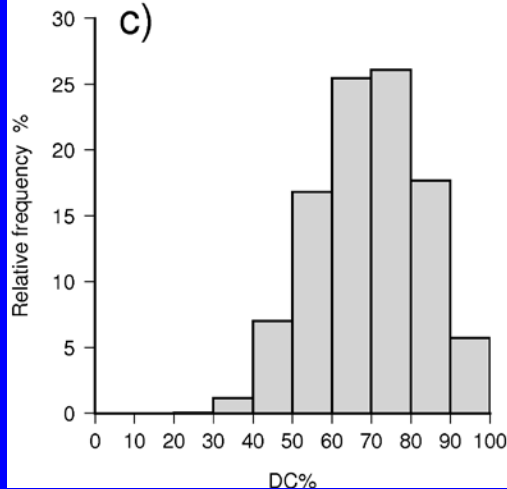
regionální stanice a
nízké frekvence
0.05-0.08 Hz



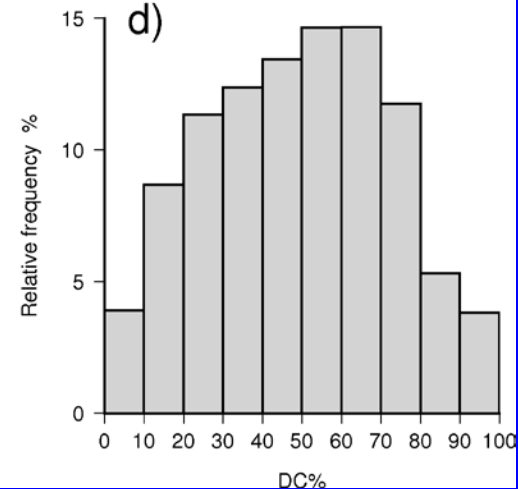
Možný výklad nestability nízkofrekvenčního CMT řešení: malá hloubka



hloubka 8.5 km



hloubka 2.5 km

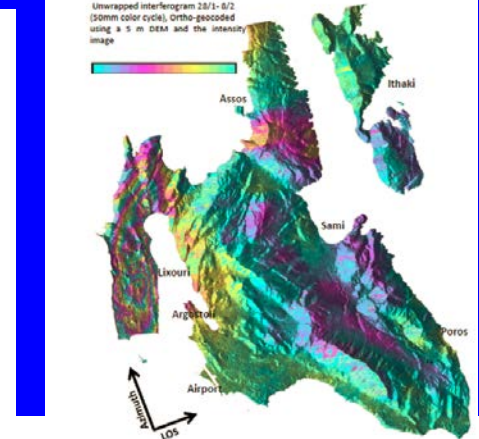


Jiné vysvětlení problémů
jednoduchého modelu?

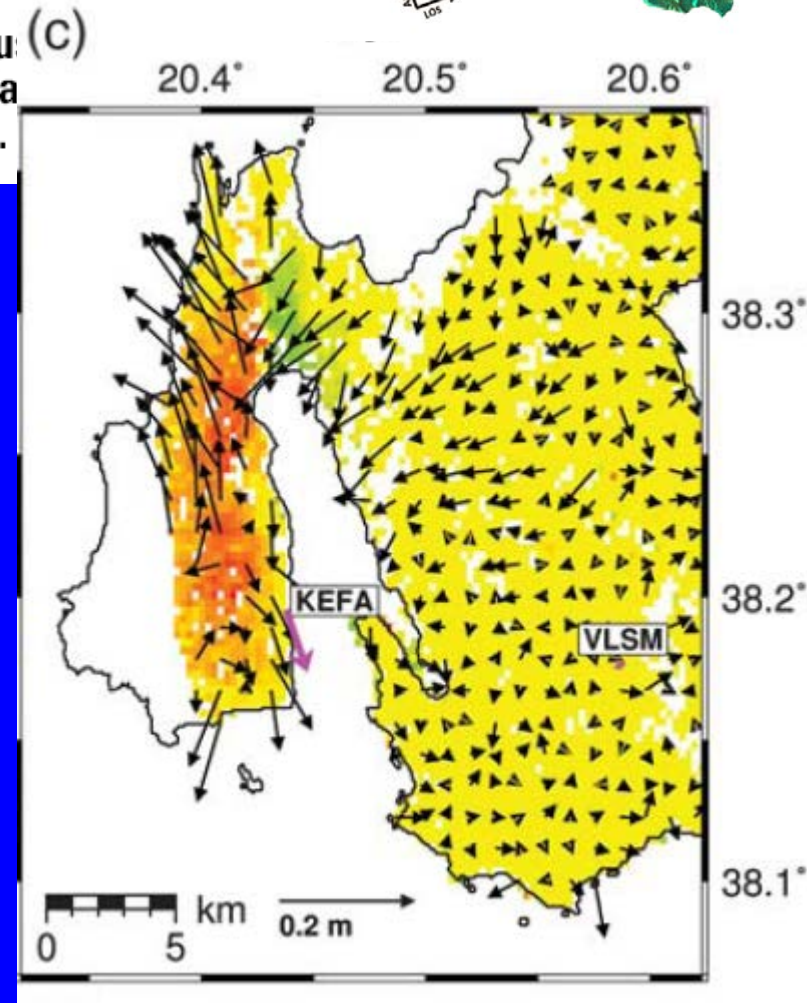
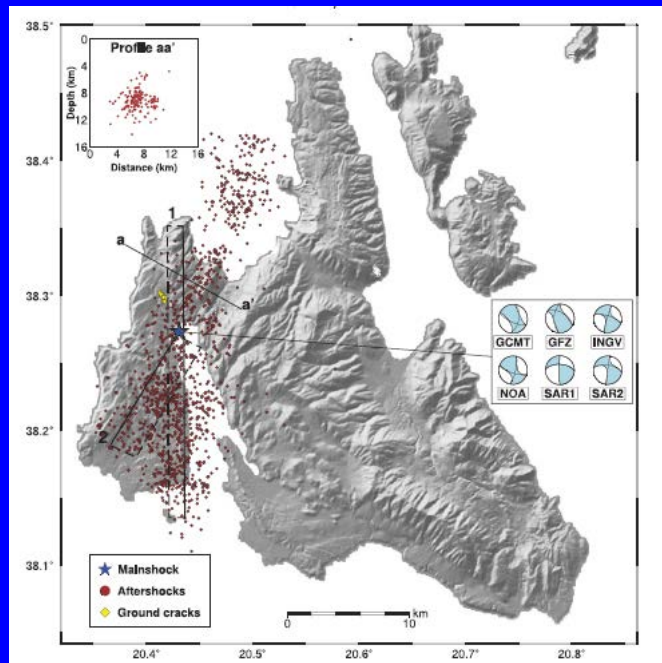
Dvě zlomové plochy aktivované při
jednom zemětřesení!

The February 2014 Cephalonia Earthquake (Greece): 3D Deformation Field and Source Modeling from Multiple SAR Techniques

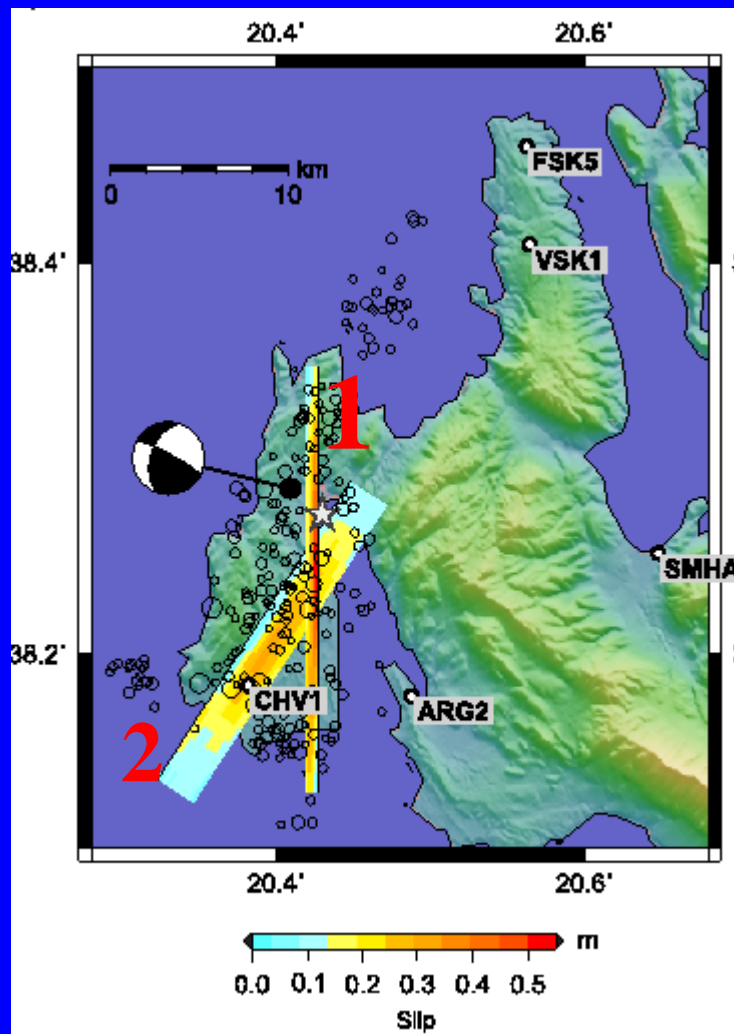
by John Peter Merryman Boncori, Ioannis Papoutsis, Giu (C)
Cristiano Tolomei, Simone Atzori, Athanassios Ganas, Va
Karastathis, Stefano Salvi, Charalampos Kontoes, and A.



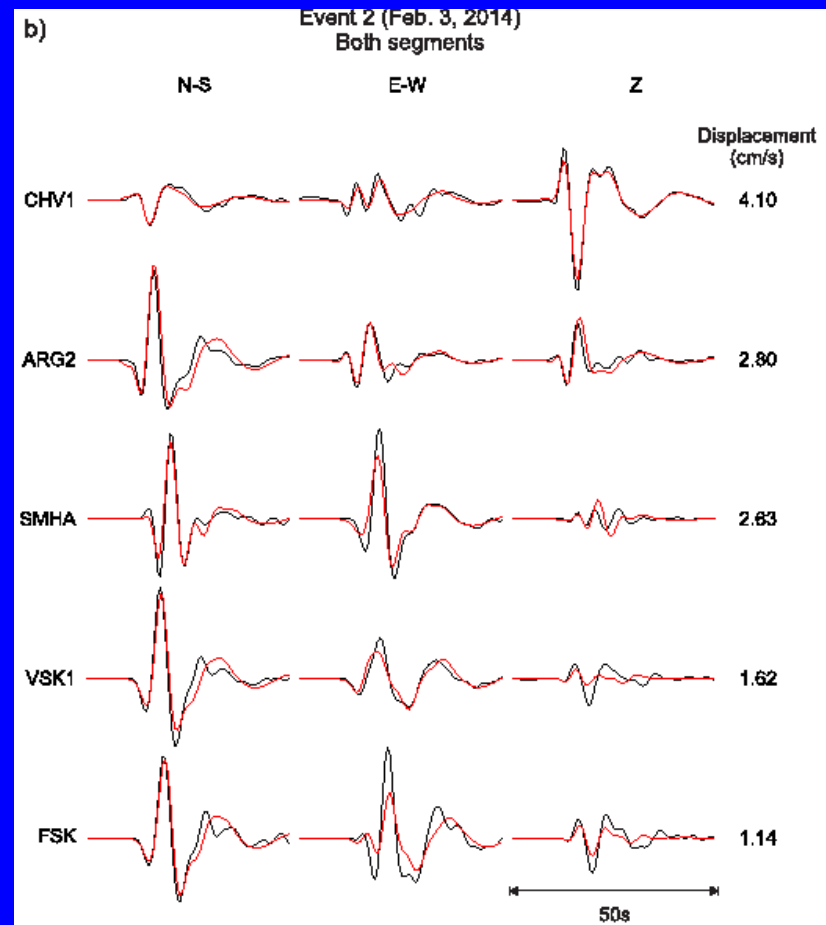
Zlom složený ze dvou segmentů
na základě družicové interferometrie



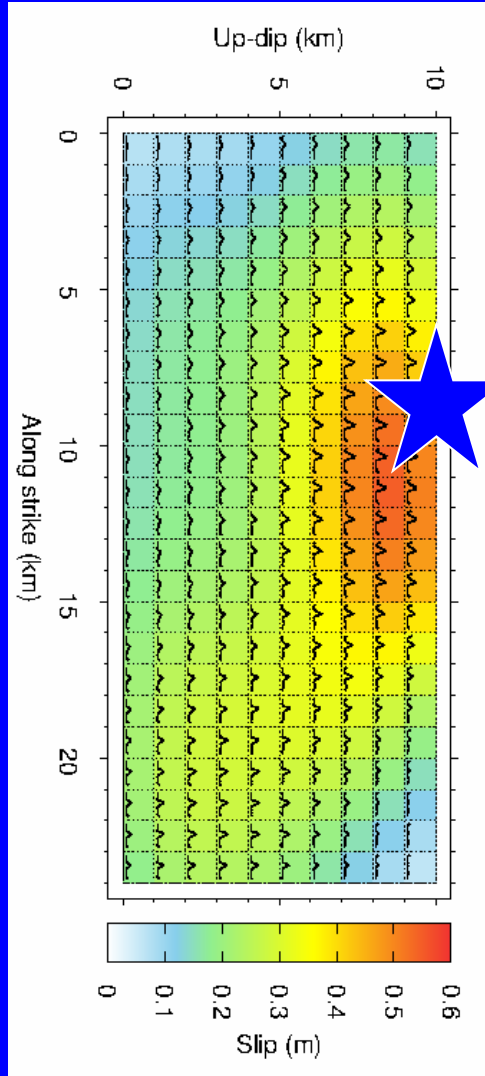
Skluzová inverze – druhý jev



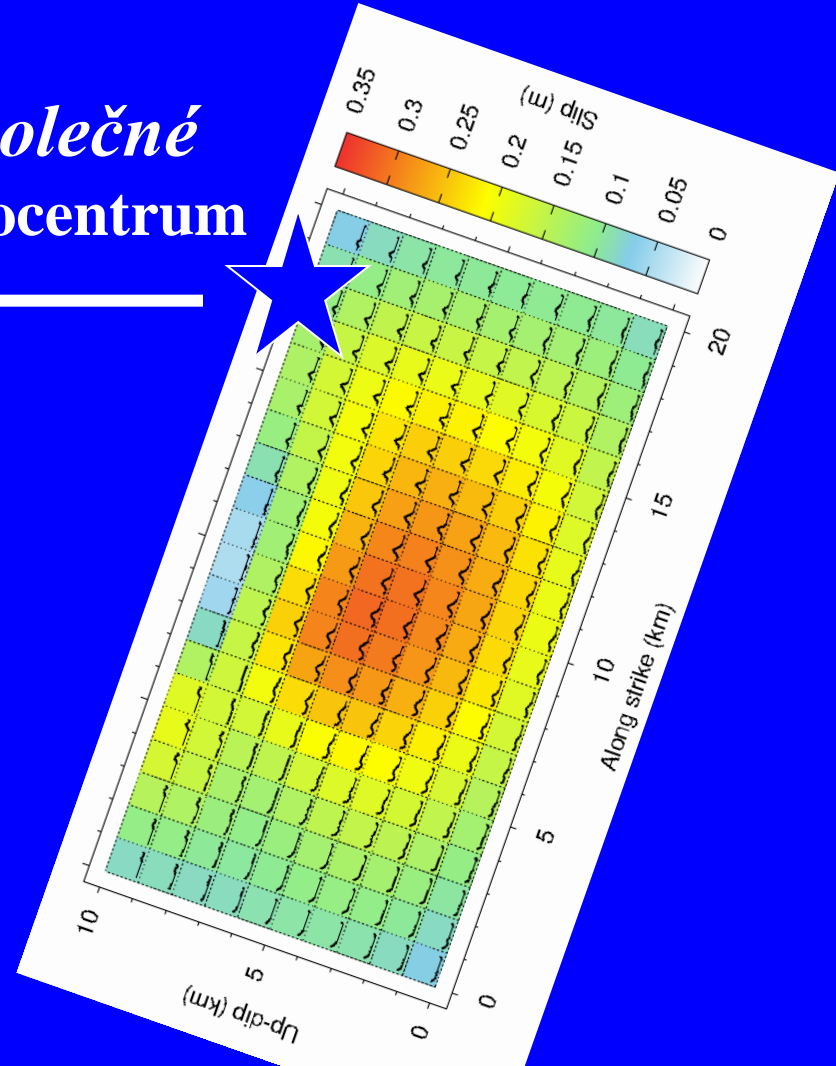
lokální stanice a
vyšší frekvence
0.05-0.20 Hz



Hypocentrum se nachází na křížení segmentů

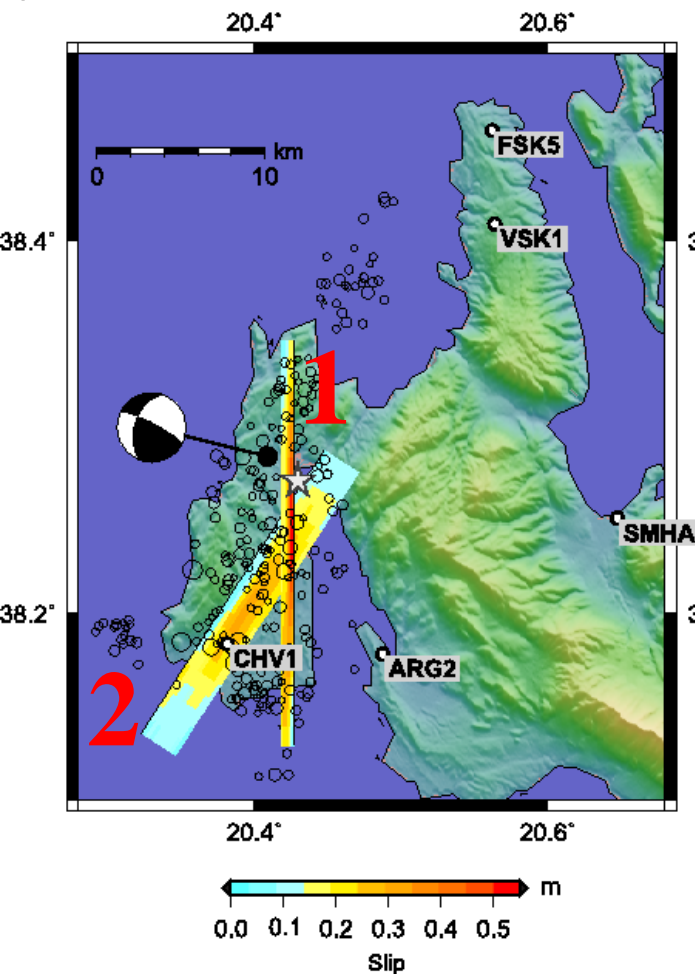


společné
hypocentrum

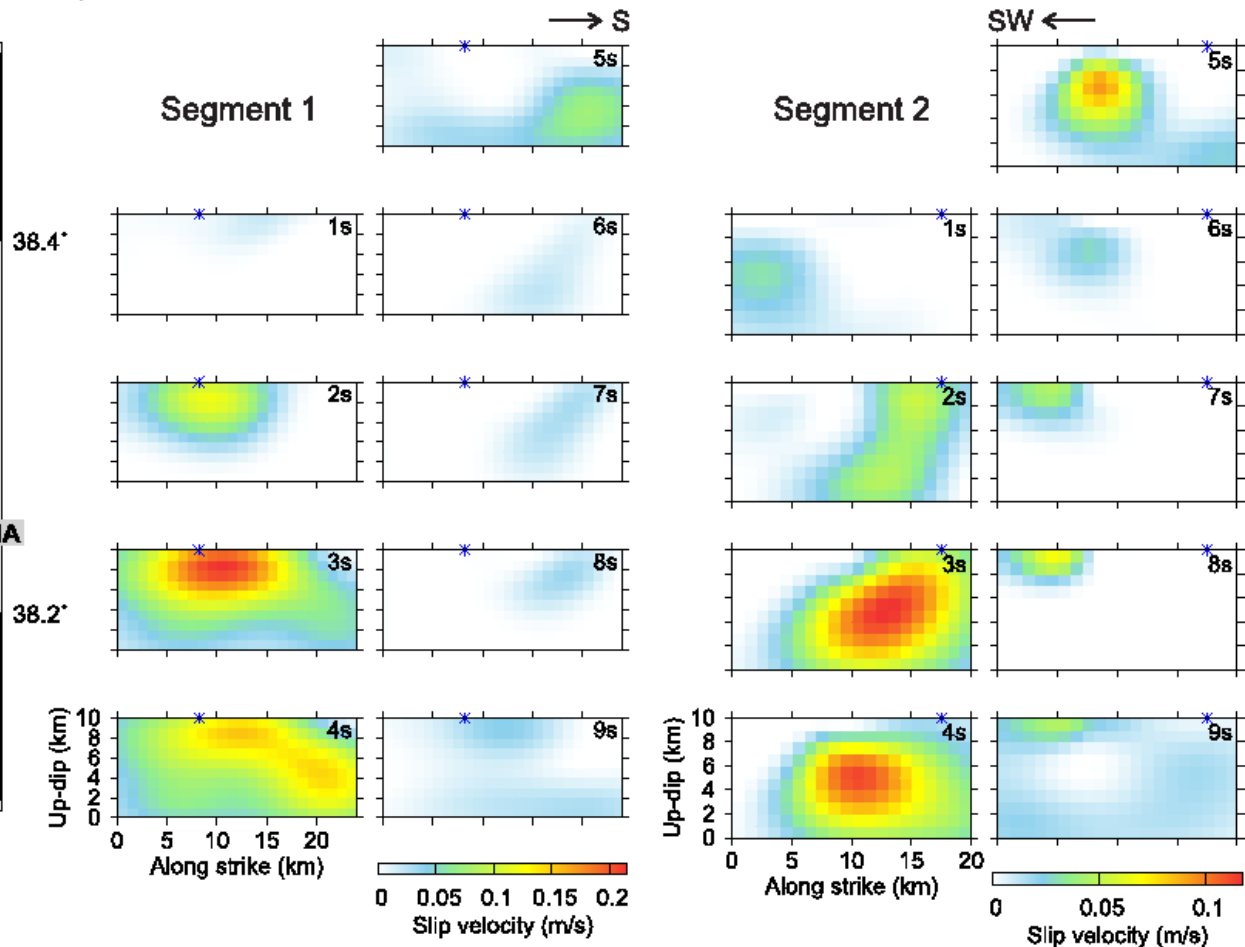


Prostorově-časové rozložení skluzu

a)

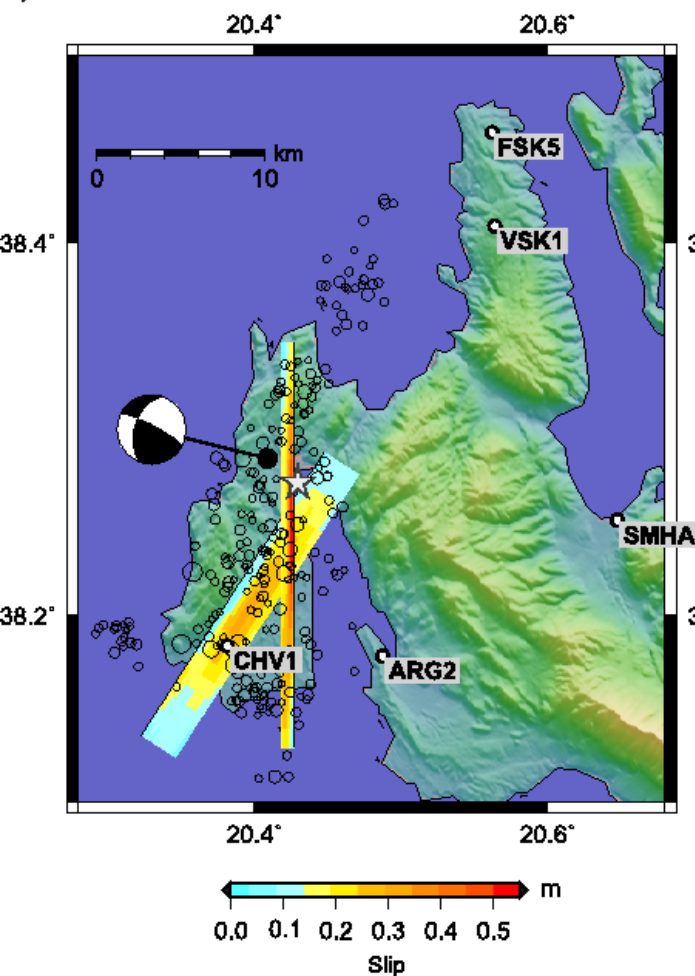


b)

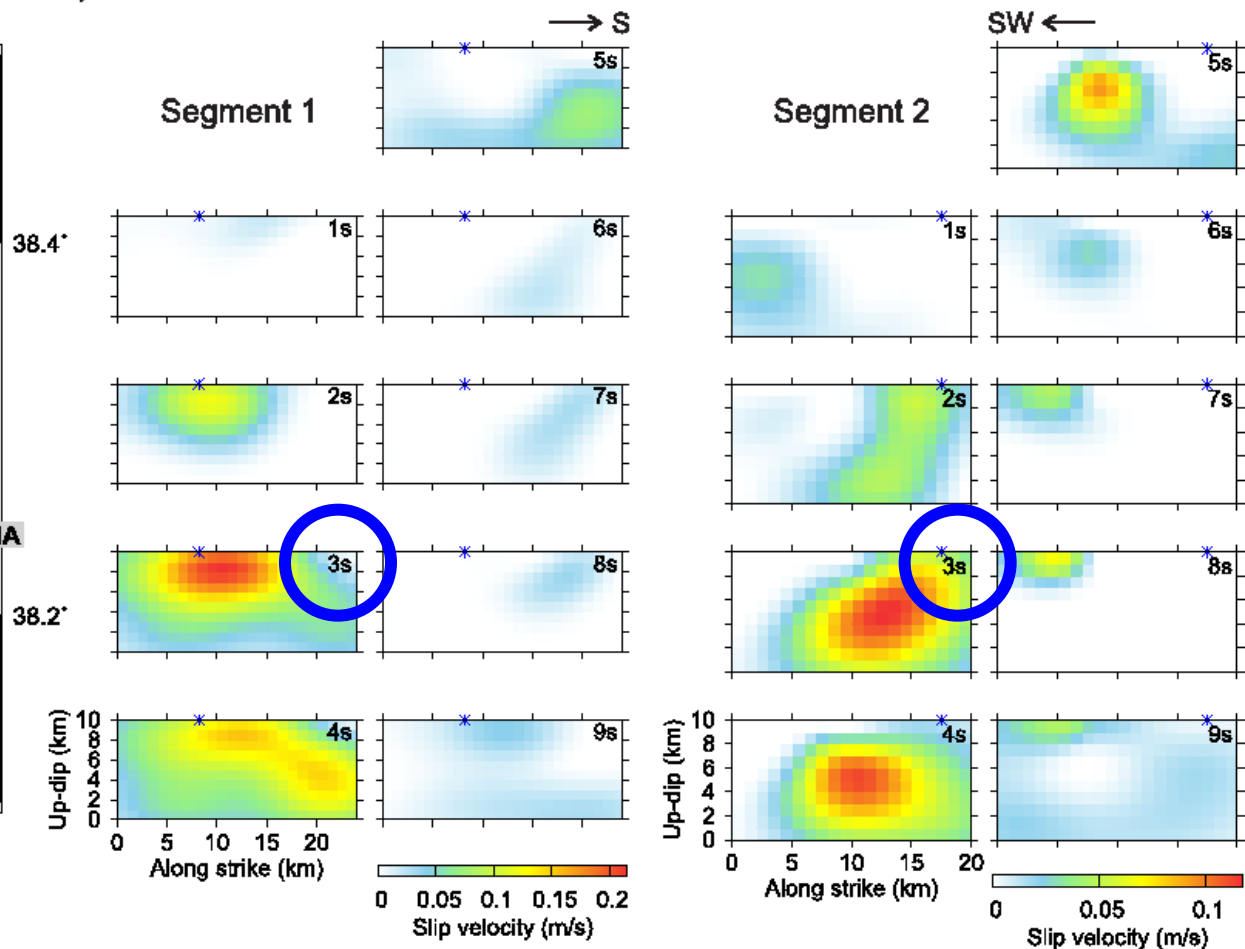


Prostorově-časové rozložení skluzu : oba segmenty praskaly *současně*

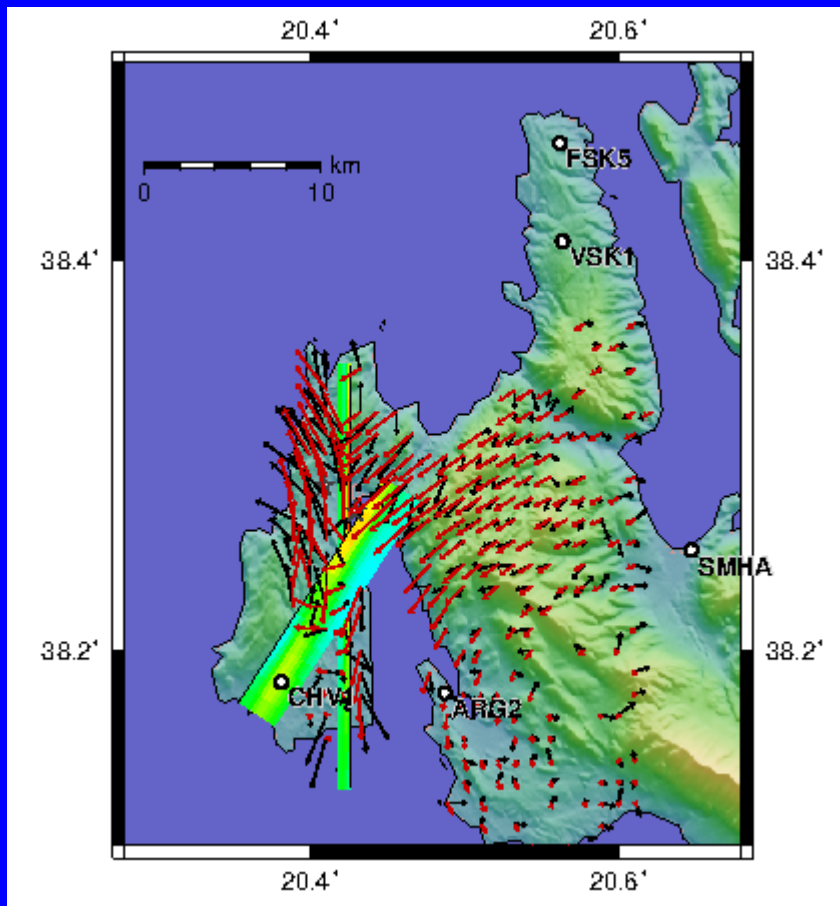
a)



b)



Srovnání vypočtených a naměřených nevratných posunutí – horizontální složka



černě – pozorování
červeně - simulace

Diskuse

Pohyby před zemětřesením a při něm

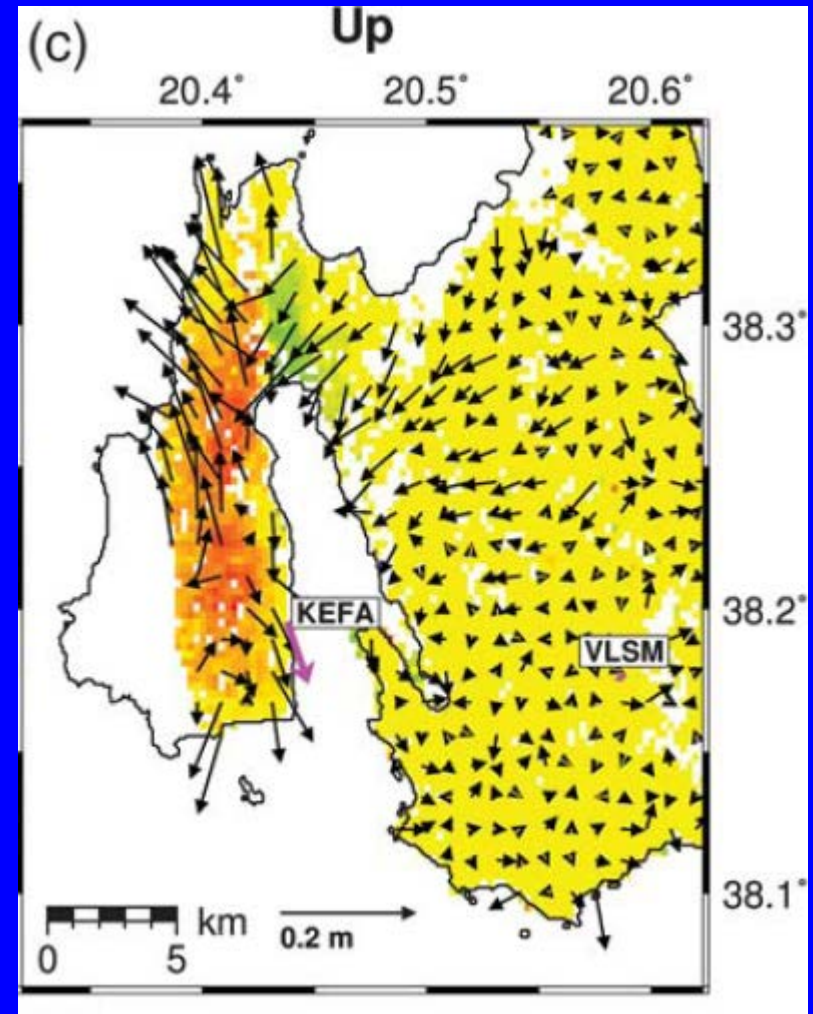
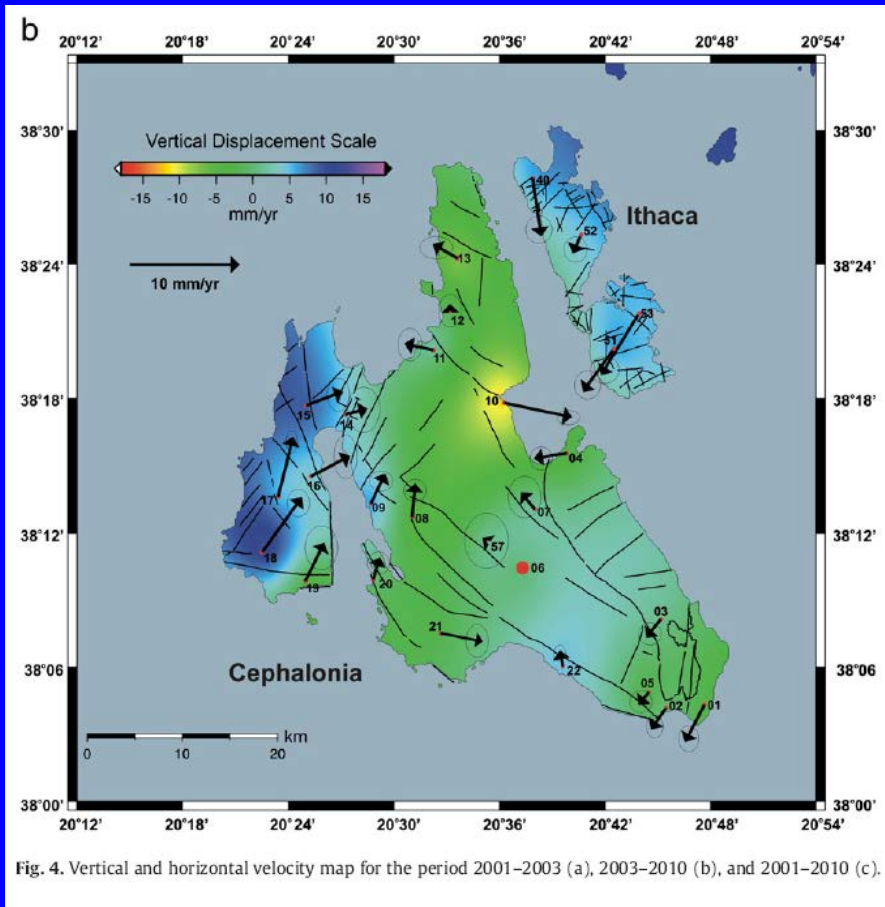
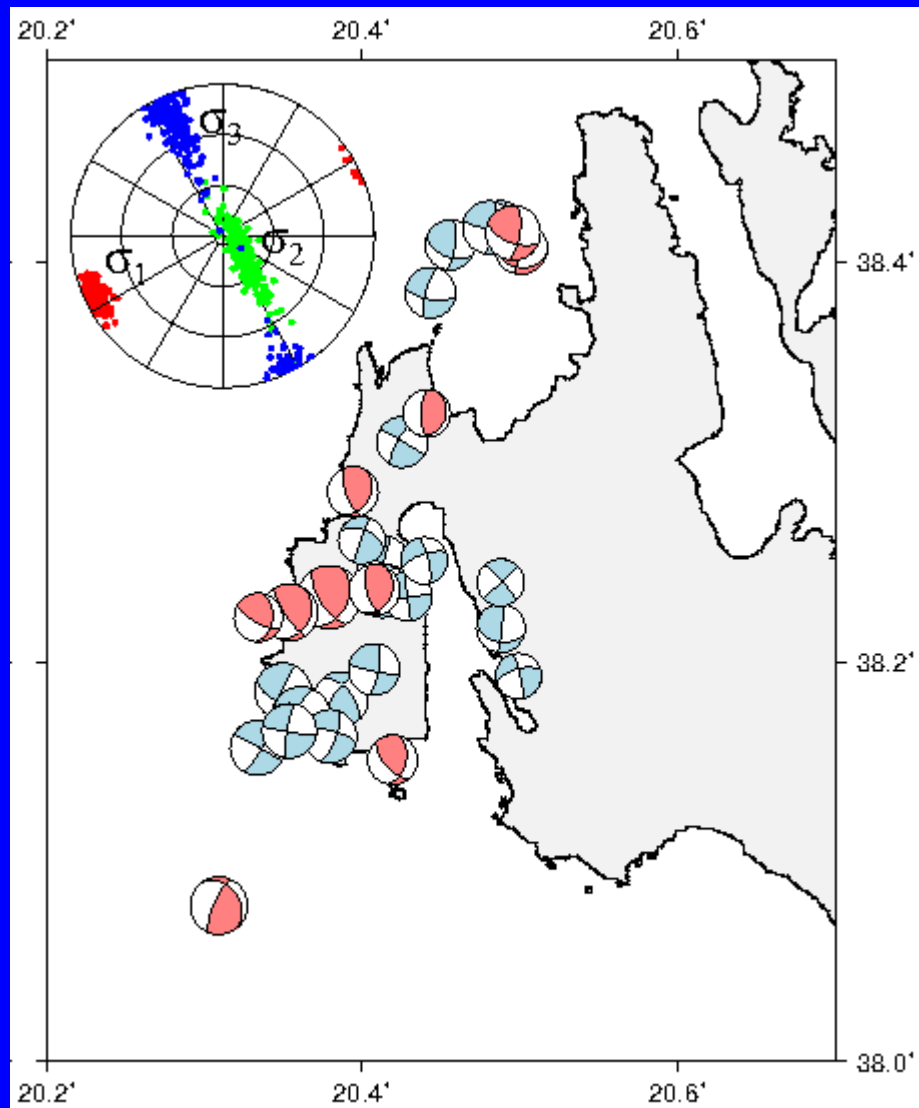


Fig. 4. Vertical and horizontal velocity map for the period 2001–2003 (a), 2003–2010 (b), and 2001–2010 (c).

Dotřesy a napět'ové pole





HISTORIC EARTHQUAKE SEQUENCES WITH TWO STRONG EVENTS

✿ 1513 – 18, 19 September

Sanudo, M. (1886), Μανούσασακας, Μ.Ι. (1967)

✿ 1767 – 11, 22 July

Ζώης, Λ.Χ. (1893), Κατράμης, Ν. (1880), Κονόμος, Ντ. (1970), Τσιτσέλης, Η. (1960), Kouskouna, V. et al (1993), Makropoulos, K. & Kouskouna, V. (1994)

✿ 1791 – 22, 23 October, 2 November

Ζώης, Λ.Χ. (1893), Κατράμης, Ν. (1880), Κολυβά, Μ. (1997), Χιώτης, Π. (1886), Barbiani (1863), Saint Sauverur (1800)

✿ 1820 – 17, 29 December

Ζώης, Λ.Χ. (1893), Ζώρας, Γ. (1973), Κονόμος, Ντ. (1970), Παπανικολάου-Κρίνστενσεν, Α. (1993), Τσιτσέλης, Η. (1960), Χιώτης, Π. (1886), Barbiani (1863),

✿ 1840 – 18, 30 October

Ζώης, Λ.Χ. (1893), Κολυβά, Μ. (1997), Κονόμος, Ν. (1970), Ρώμας, Δ. (1973), Χιώτης, Π., (1886), Barbiani (1863), Montessus de Ballore, F. (1900)

✿ 1872 – 10, 25 October

Χιώτης, Π. (1886)

✿ 1886 – 15, 27 August

Ζώης, Λ.Χ. (1893), Χιώτης, Π. (1886), Montessus de Ballore, F. (1900)

✿ 1893 – 19, 31 January

Ζώης, Λ.Χ. (1893), Issel, A. & Agamennone, G. (1894), Issel, A. (1893), Montessus de Ballore, F. (1900)

❖ 1953 – 9, 11, 12 August

9 August, M 6.4 11 August, M 6.8 12 August, M 7.2

600 victims

Lekkas et al. (1997)

1953



Figure 2.1.6. Argostoli before the 1953 earthquakes (from virtua

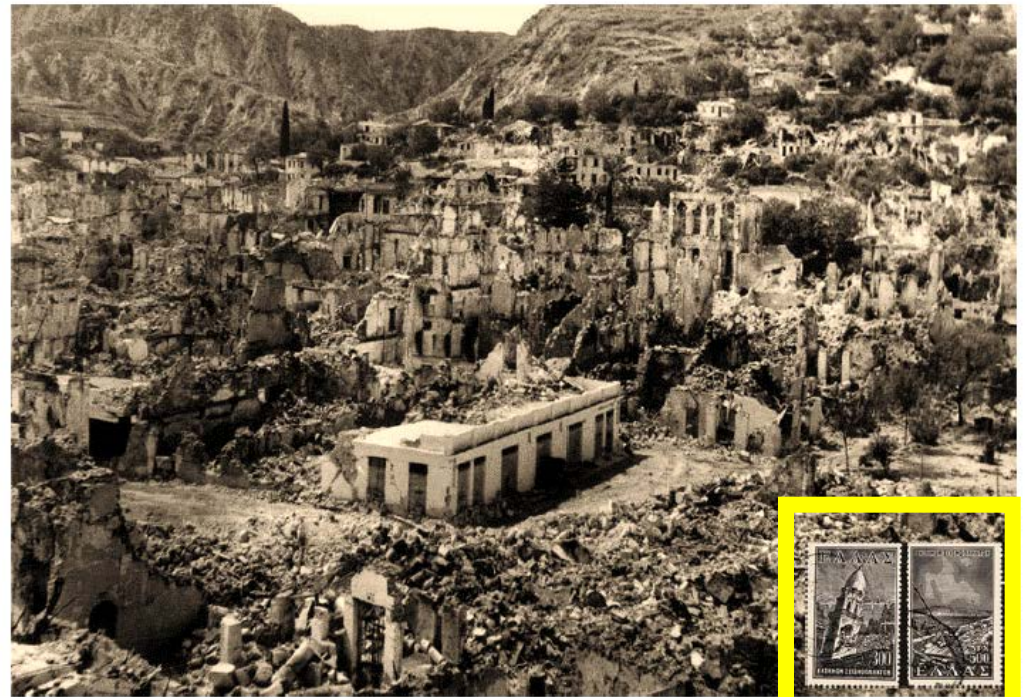


Figure 2.1.7 Argostoli after the 1953 earthquakes (53vorini.gr). Social welfare stamps issued by Greece after the 1953 earthquakes are shown on the bottom right insert (catawiki.com).

Aktualita – Nepál

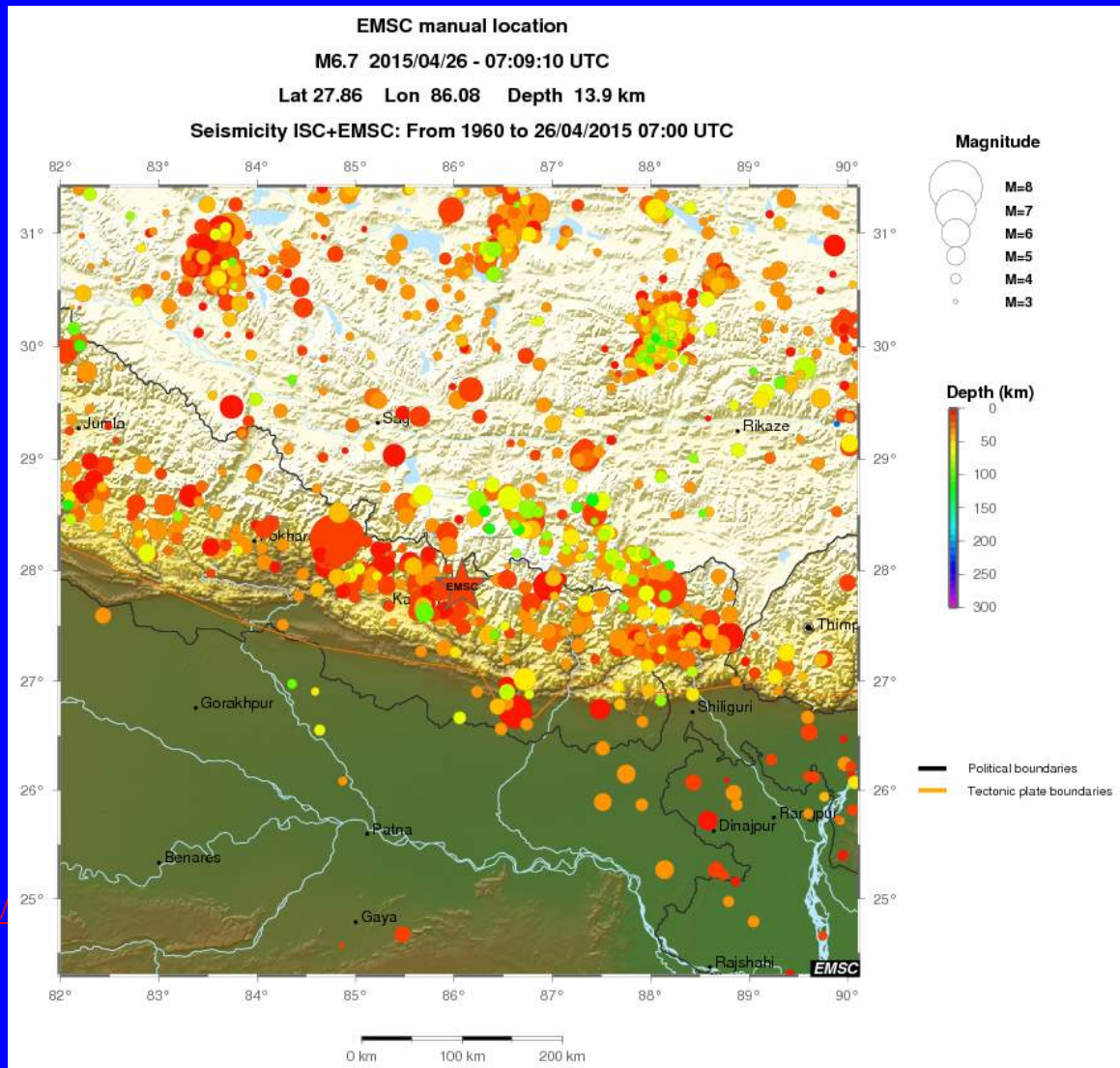


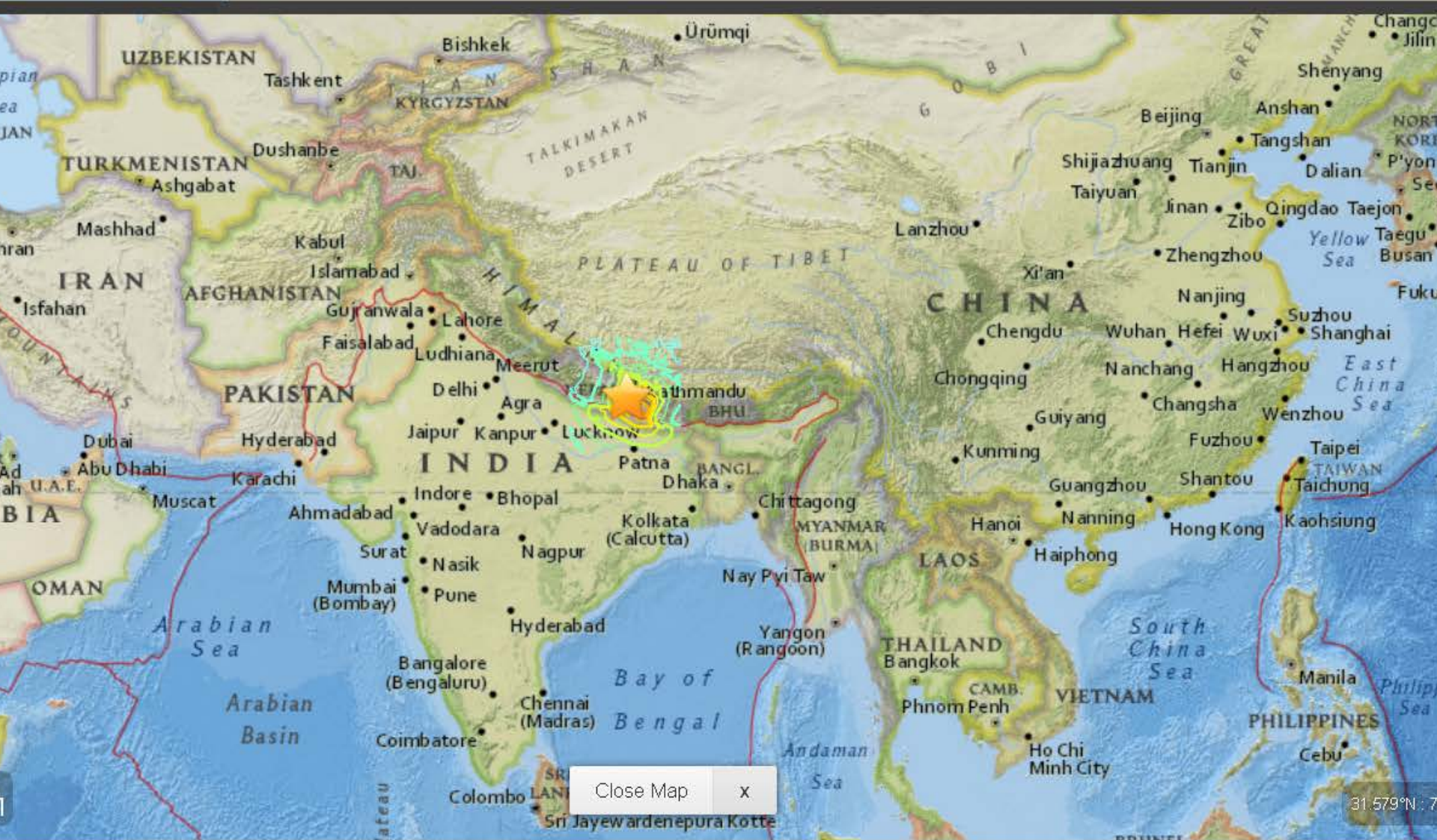
Nepál, M7.8, 25.4. 2015

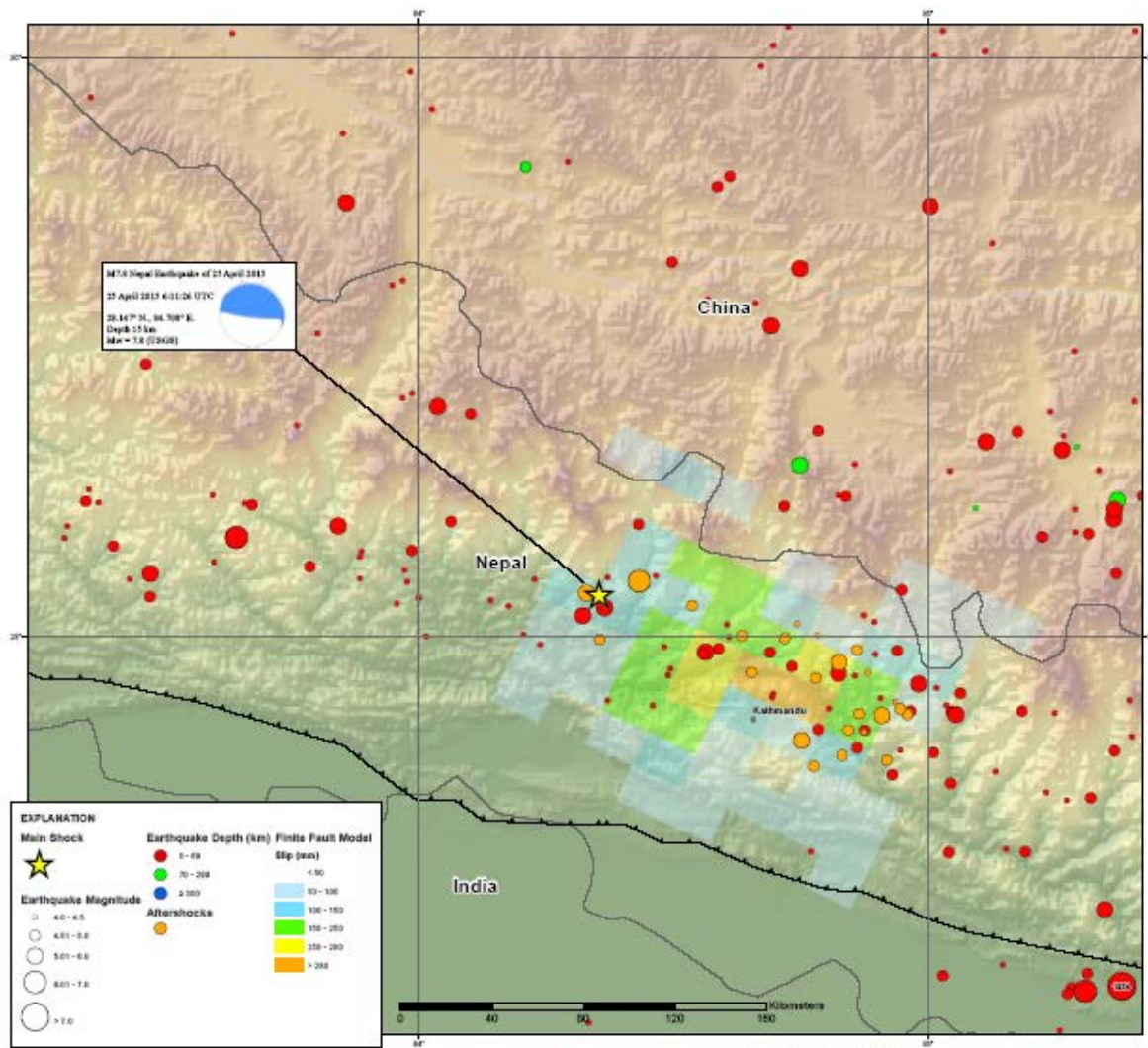
1905 M7.5 Kangr
1934 M8.0 Bihar
2005 M7.6 Kashmir

15th August 1950 M8.6
Assam
eastern India

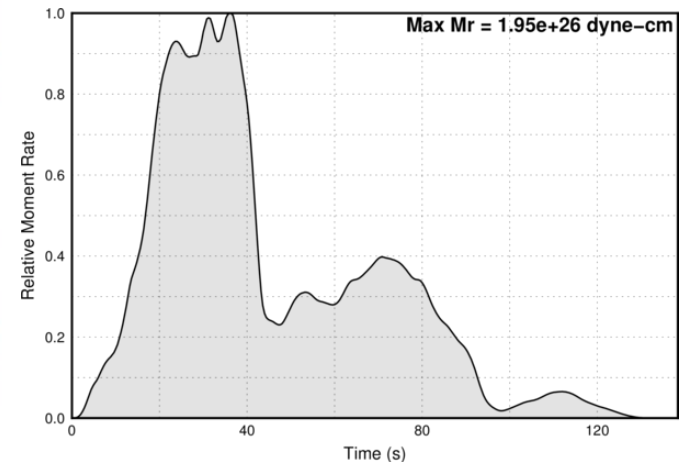
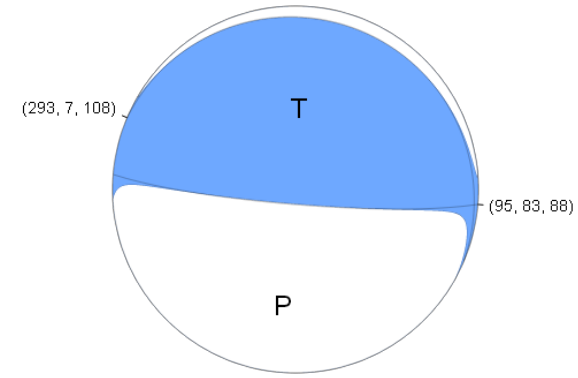
<http://earthquake.usgs.gov/>

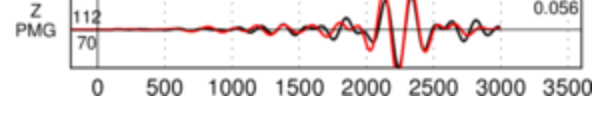
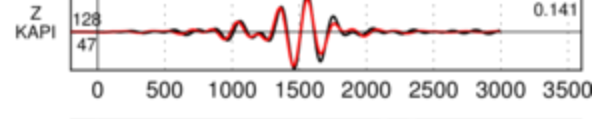
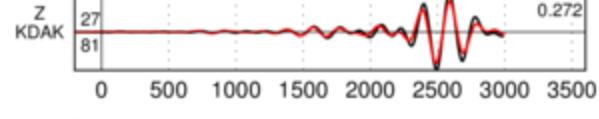
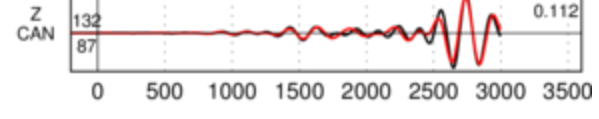
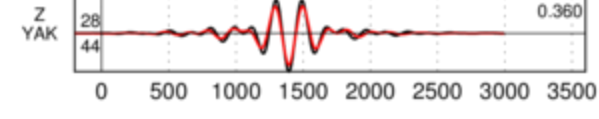
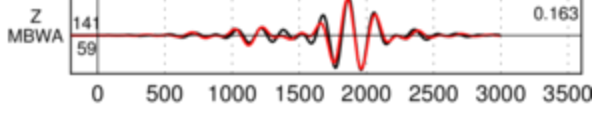
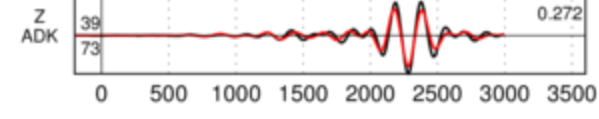
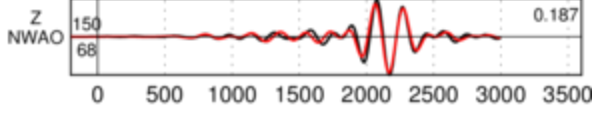
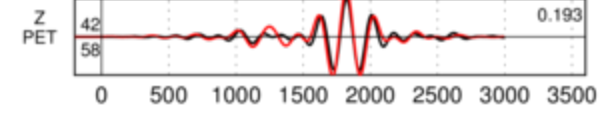
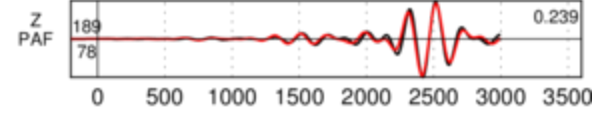
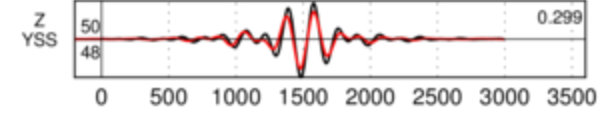
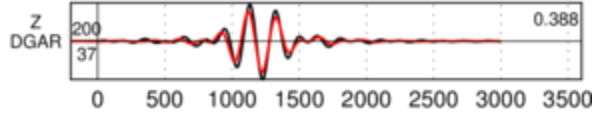
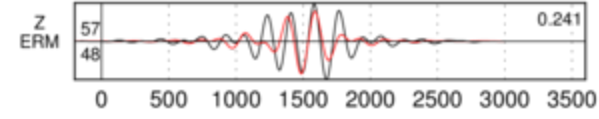
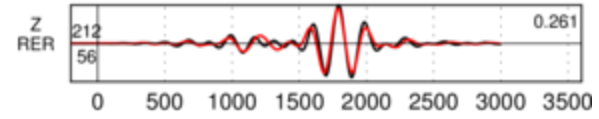
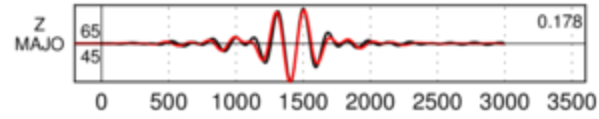
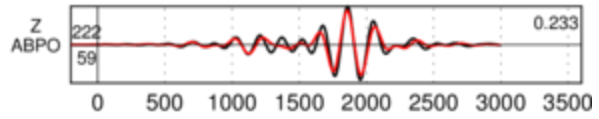
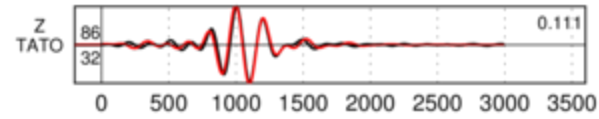
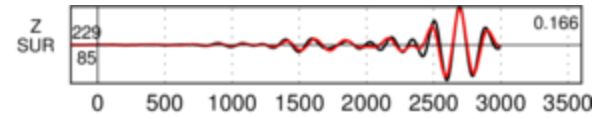
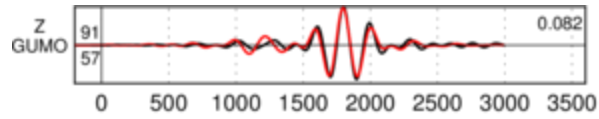






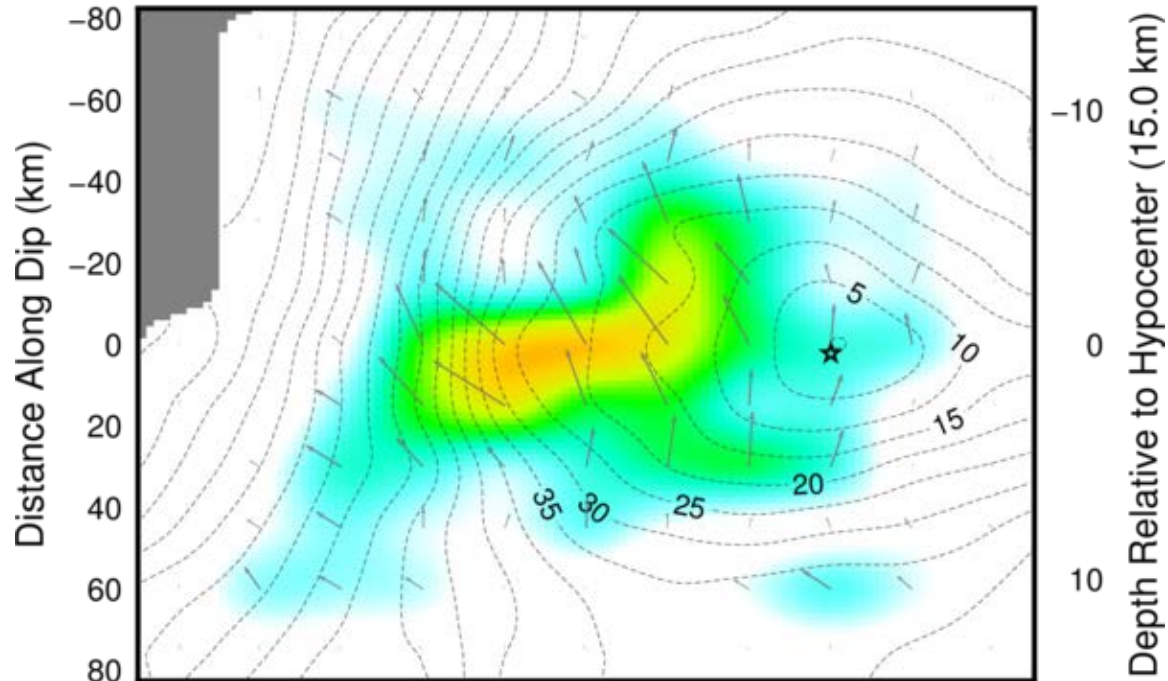
Finite Fault Model





Strike = 295 Distance Along Strike (km)

-160 -140 -120 -100 -80 -60 -40 -20 0 20 40

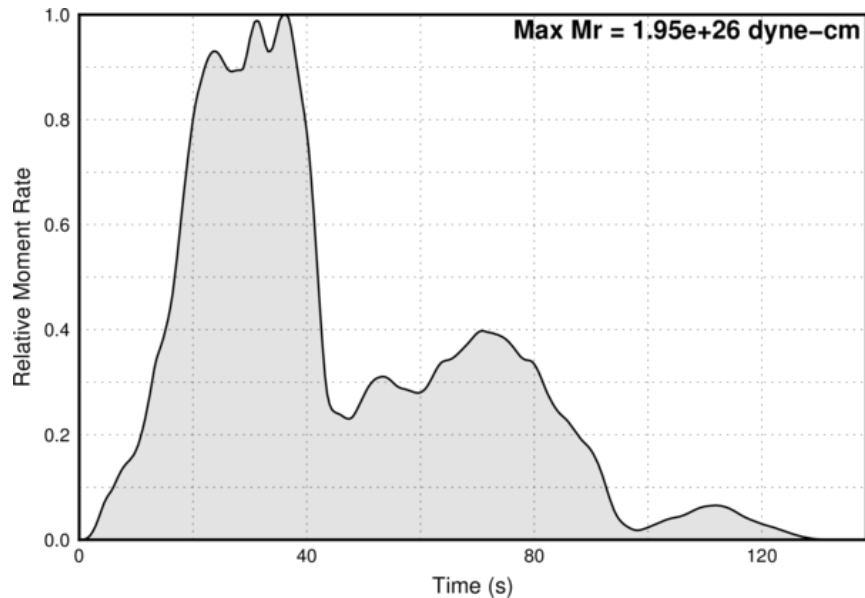


Rupture Front Contours Plotted Every 5 s



0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

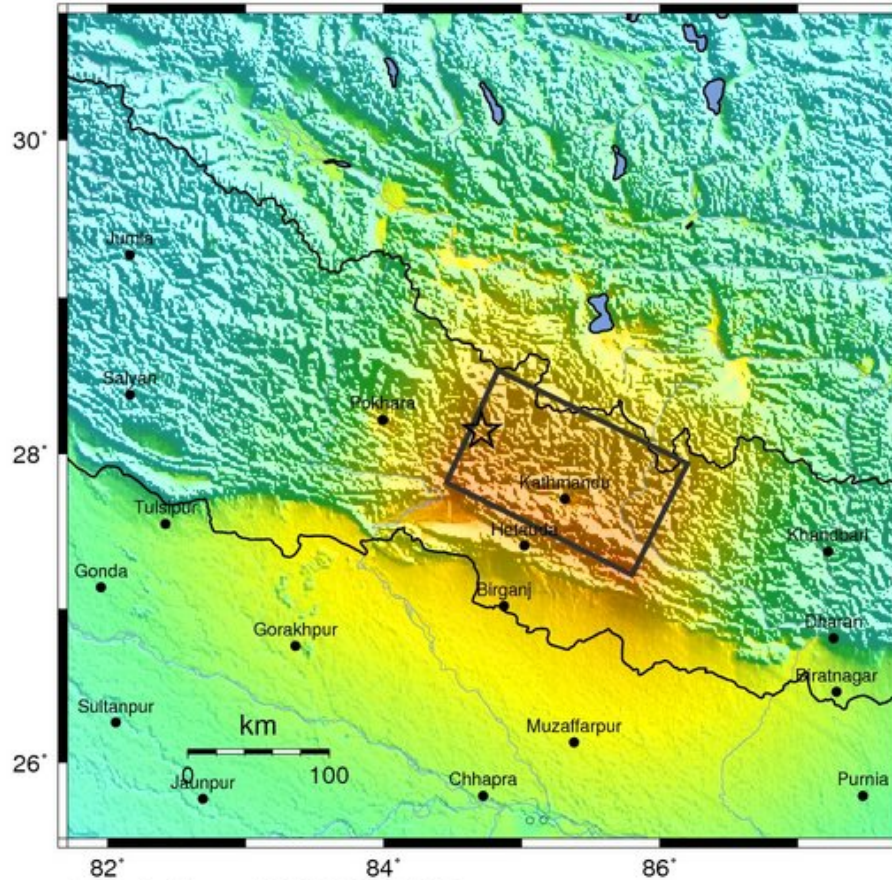
Slip (m)



Time (s)

USGS ShakeMap : NEPAL

Apr 25, 2015 06:11:26 UTC M 7.8 N28.15 E84.71 Depth: 15.0km ID:us20002926



Map Version 6 Processed 2015-04-25 21:32:54 UTC

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

Shake Map (USGS)



Earthquake Shaking  **Red Alert**



M 7.8, NEPAL

Origin Time: Sat 2015-04-25 06:11:26 UTC (11:56:26 local)

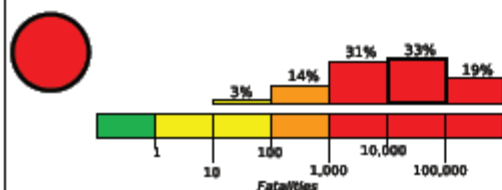
Location: 28.15°N 84.71°E Depth: 15 km

FOR TSUNAMI INFORMATION, SEE: tsunami.gov

Created: 15 hours, 36 minutes after earthquake

**PAGER
Version 6**

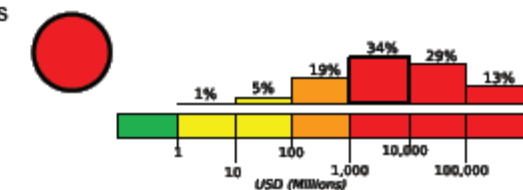
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses may exceed the GDP of Nepal.

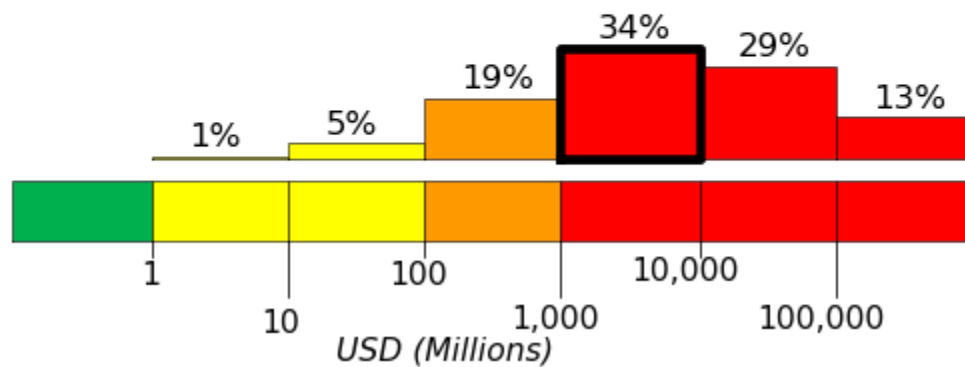
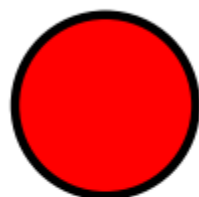
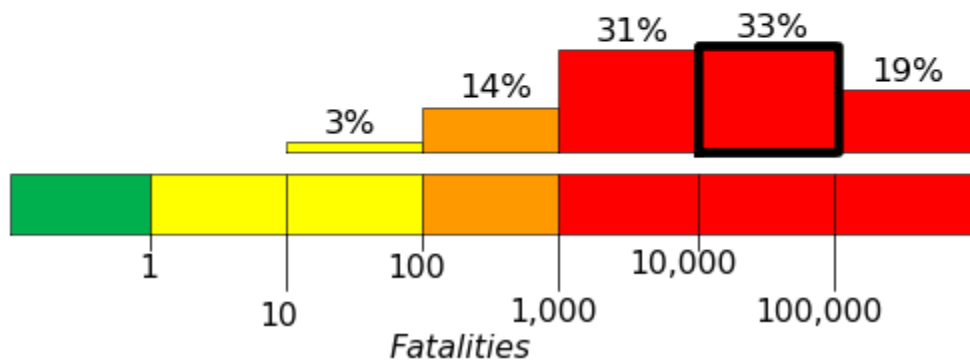
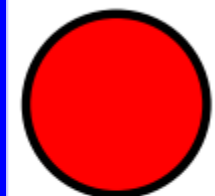
Estimated Economic Losses



Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)	--*	--*	5,616k*	69,912k*	61,669k	9,288k	5,299k	4k	0	
ESTIMATED MODIFIED MERCALLI INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+	
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme	
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

PAGER (USGS)



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emsc seismology - ... x Earthquake - Magni... x +

www.emsc-csem.org/Earthquake/earthquake.php?id=438791#

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emsc seismology Search Ask KMPlayer Hot KMP news Facebook Listen to music Amazon YouTube Options

Maps view: Seismicity from the previous 7 days in the area Previous 24h Previous 48h Previous 7 days

Switch to Google Maps

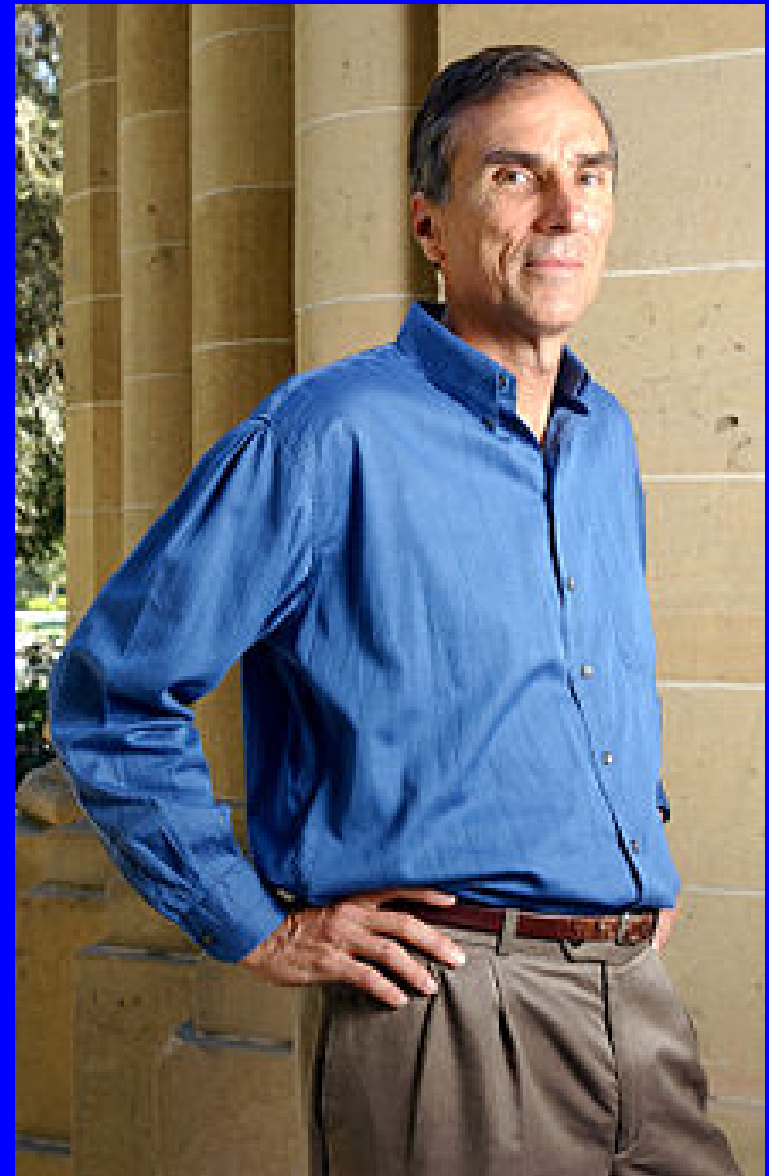
2D 3D Road Aerial Bird's eye Labels

50 miles

start karel.troja.mff... jz - karel - Wi... nove_strasecl... 3 Firefox Microsoft Pow... EN 18:10

<http://www.emsc-csem.org/Earthquake/earthquake.php?id=438791#map>

Dr. Brian Tucker Geohazards International



http://en.wikipedia.org/wiki/Brian_Tucker

Děkuji Vám za pozvání a za
pozornost!

<http://geo.mff.cuni.cz>

Dodatky

Ve stádiu prvních pokusů je využití GPS měření také pro zjištění míst „přípravy“ budoucích silných zemětřesení.

Zaklesnutí deskového kontaktu (uzamčení části zlomu) se totiž může projevit měřitelnou deformací zemského povrchu.

[gps_subdukce.mov](#)

Interplate seismogenic zones along the Kuril–Japan trench inferred from GPS data inversion

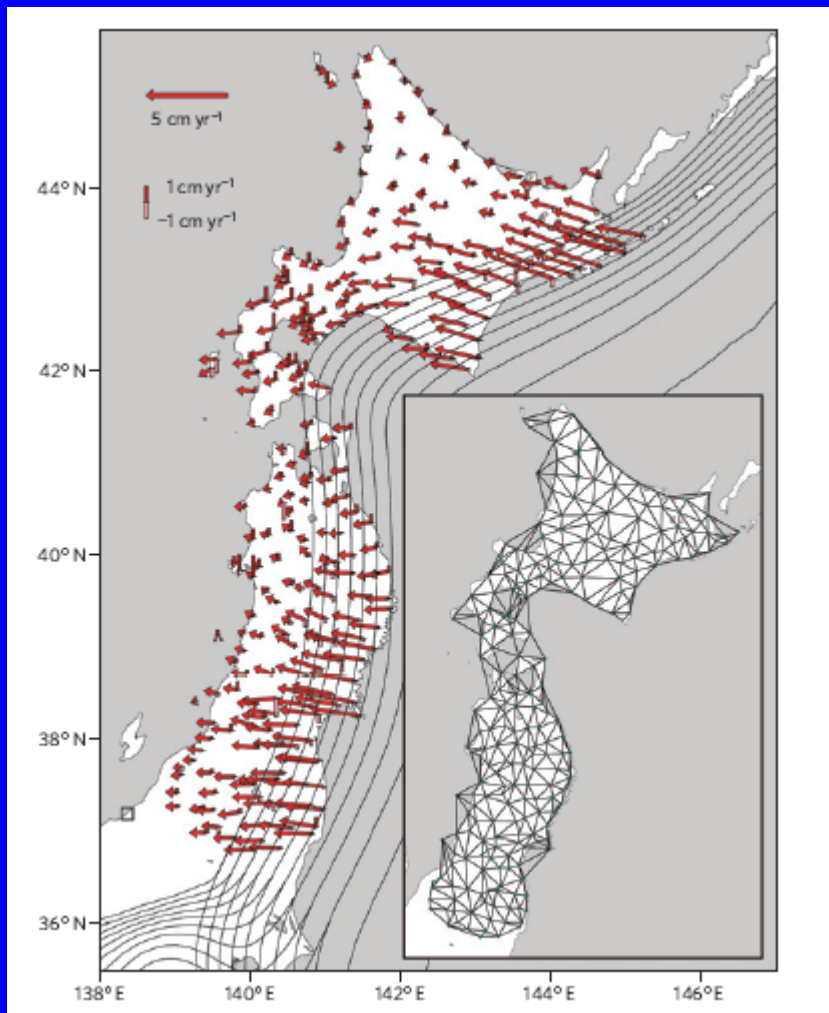
Chihiro Hashimoto^{1*}, Akemi Noda¹, Takeshi Sagiya² and Mitsuhiro Matsu'ura¹

In the subduction zones around Japan, where four plates interact with one another, large earthquakes have occurred repeatedly¹. These interplate earthquakes are part of the process of tectonic stress accumulation and release that is driven by relative plate motion^{2–4}. Stress accumulation between earthquakes results from slip deficit (slip that is insufficient to fully accommodate plate movement). For the prediction of large earthquakes, it is therefore important to monitor the distribution of slip deficit on plate interfaces. Here we apply an inversion method based on Bayesian modelling (using direct and indirect prior information on the magnitude and distribution of fault slip⁵) to horizontal and vertical velocities from global positioning system data. For the seismically calm period between 1996 and 2000, we obtain a precise distribution of slip-deficit rates on the interface between the North American and Pacific plates around Japan, which reveals a trench-parallel belt of slip deficit with six peaks in the depth range of 10–40 km. These peaks agree with the source regions of past large interplate earthquakes along the Kuril–Japan trench. We conclude that the slip-deficit zones identified with our method are potential source regions of large earthquakes.

Geographical Survey Institute of Japan since 1996. The GPS observations revealed the continuous crustal deformation of the Japanese islands during interseismic periods⁷, mainly caused by interplate coupling (slip deficit at plate interfaces). Hence, applying inversion methods to GPS velocity data, many researchers tried to estimate the precise interseismic slip-deficit rate distribution on the North American/Pacific plate interface around Japan^{8–11}. What makes this effort such a difficult problem is that the targeted slip-deficit regions are outside the GPS array on land.

In Bayesian statistical inference based on the entropy maximization principle^{12,13}, incorporation of prior information into observed data permits well-conditioned flexible formulation of ill-conditioned inverse problems. For geodetic data inversion, two types of Bayesian formulae have been widely used: the Jackson–Matsu'ura formula¹⁴ incorporating direct prior information about the magnitude of fault slip and the Yabuki–Matsu'ura formula¹⁵ incorporating an indirect prior constraint on the roughness of fault-slip distribution. The rational unification of these two formulae⁵ enabled us to incorporate the postulate of plate

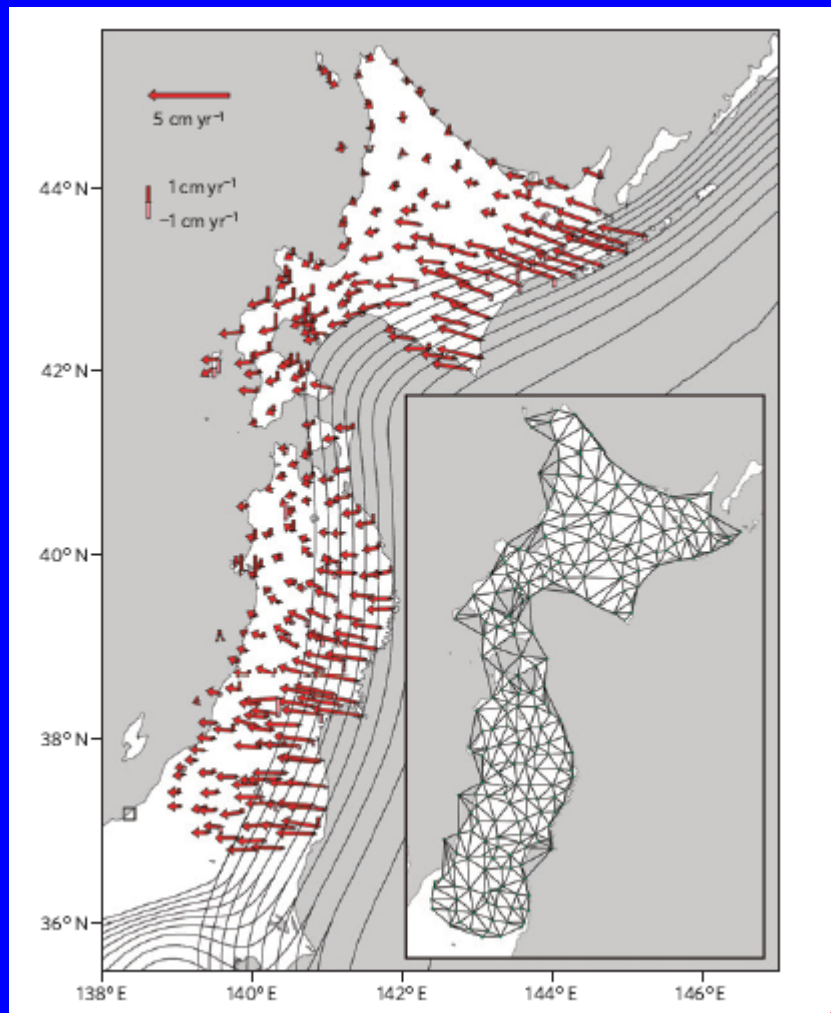
7.50° N
N



Relativní pohyby

(vůči bodu,
vyznačenému čtverečkem
v levé dolní části obrázku).

Jinými slovy, jedná se o uvolnění
nahromaděné vnitřní deformace
uvnitř Japonska.



Částečně uzamčené rozrání,
které pak prasklo a vyvolalo M9.

Dlouhodobá předpověď místa zemětřesení.

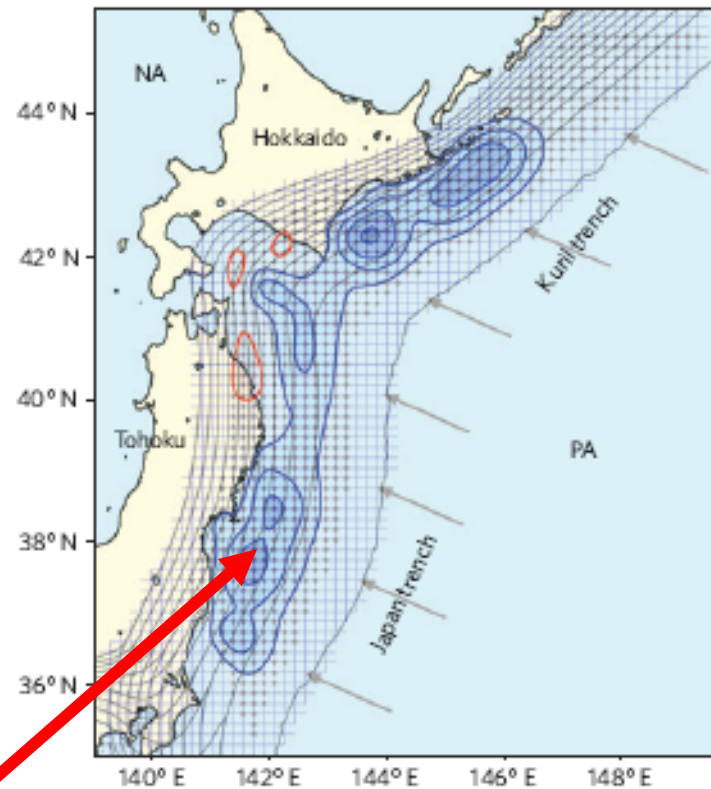
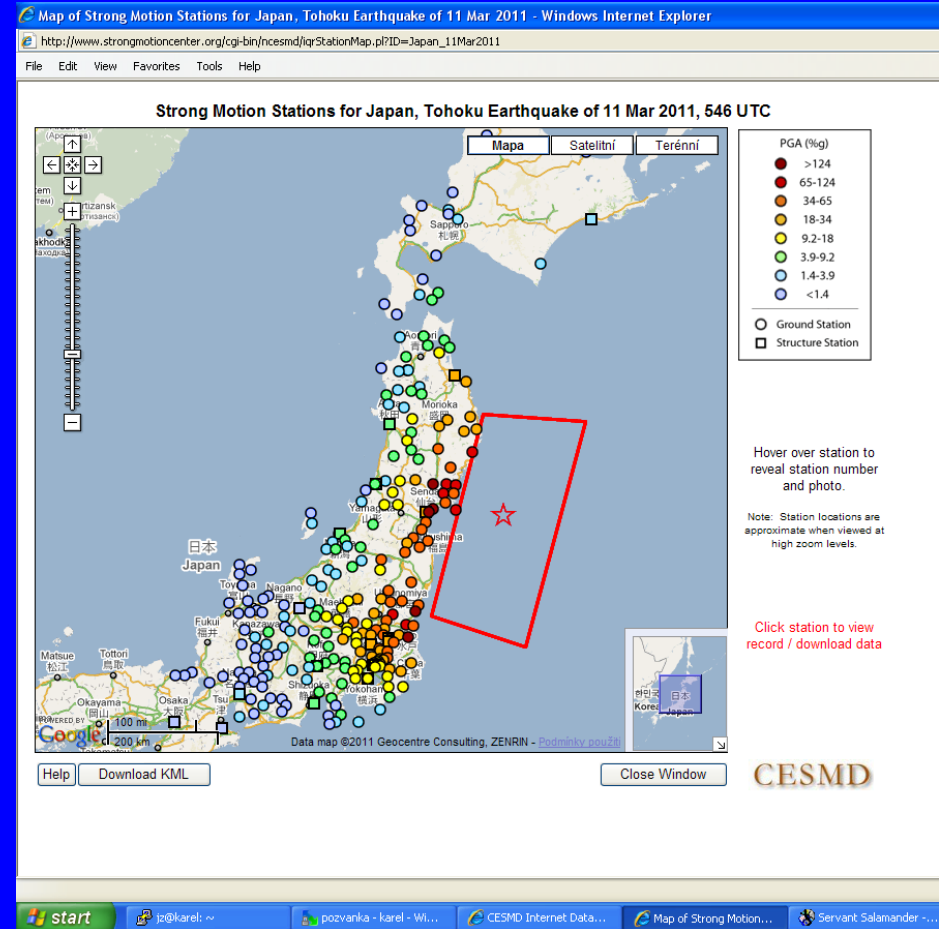


Figure 3 | Inverted slip-deficit rate distribution. The blue and red contours show, respectively, the inverted slip-deficit and slip-excess rates at intervals of 3 cm yr^{-1} . The grey dots indicate the central points of bi-cubic B-splines distributed on the North America/Pacific plate interface. The arrows indicate the relative plate motion calculated from NUVEL-1A (ref. 18).

Monitorování
silných pohybů
je možno provést
„v reálném čase“.

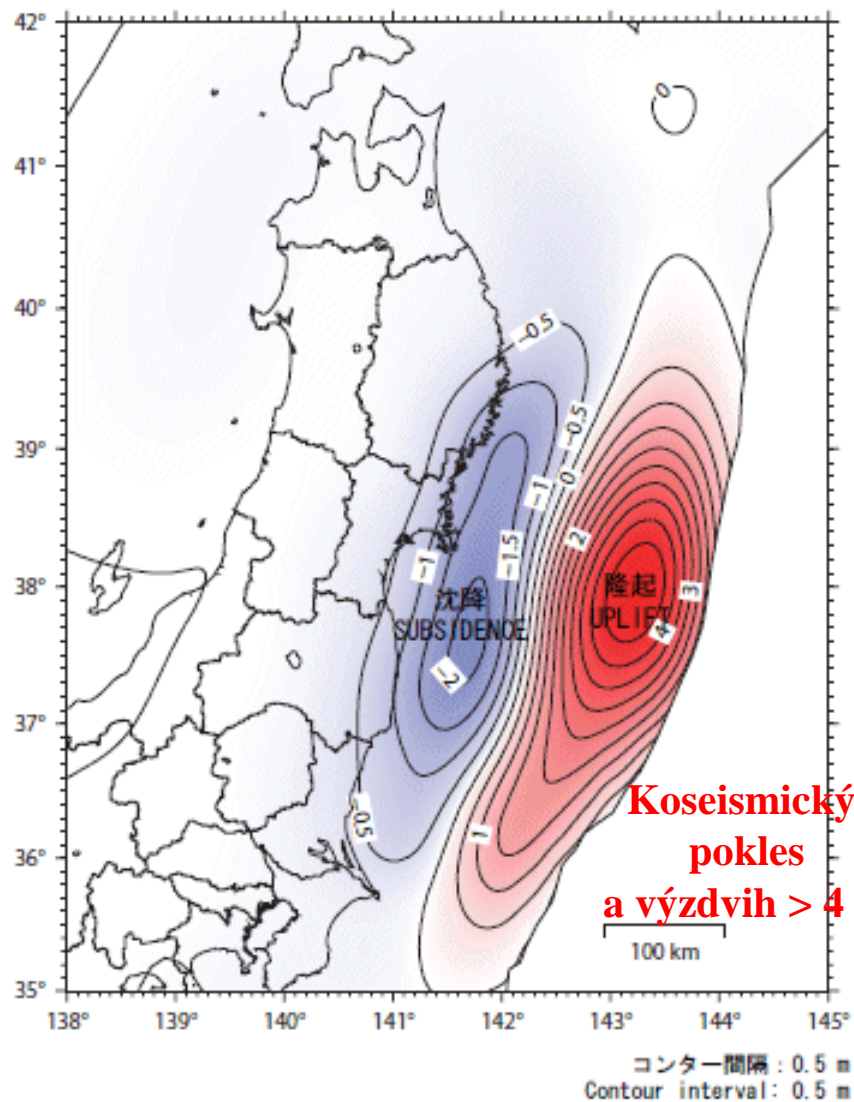
→ systémy
včasného varování



Japonsko 11.3. 2011
seismické stanice
cca 20 km od sebe

[silne_pohyby.mpeg](#)

Vertical deformation calculated from slip distribution model
(preliminary result)



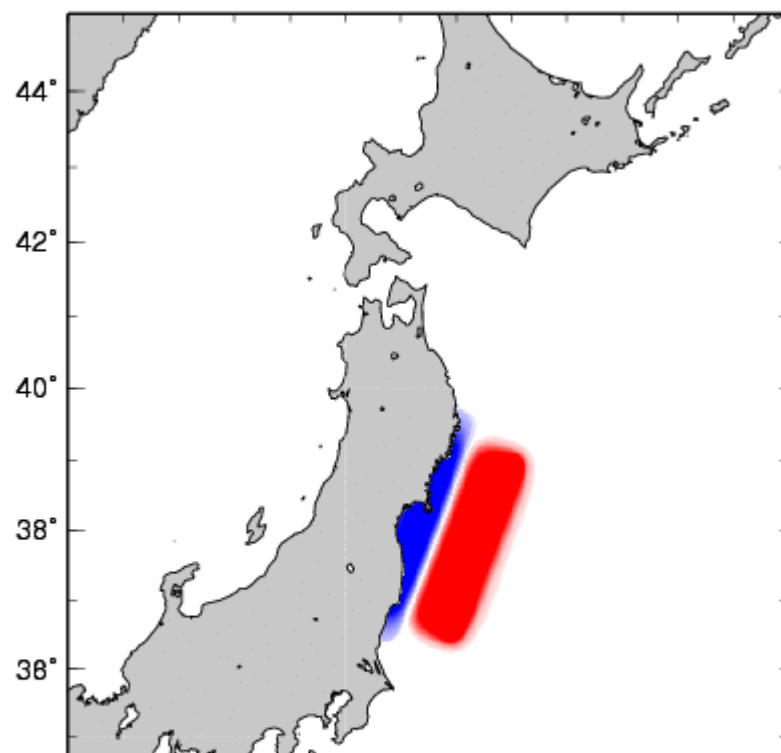
**Косеисмický
pokles
a výzdvih > 4 m**

※この上下変動図は、電子基準点 (GPS連続観測点) データからプレート境界面上での滑り分布モデルを推定し、そのモデルから想定される上下変動の推定値を図示したものです。従って実際の変動量とは必ずしも一致するものではありません。

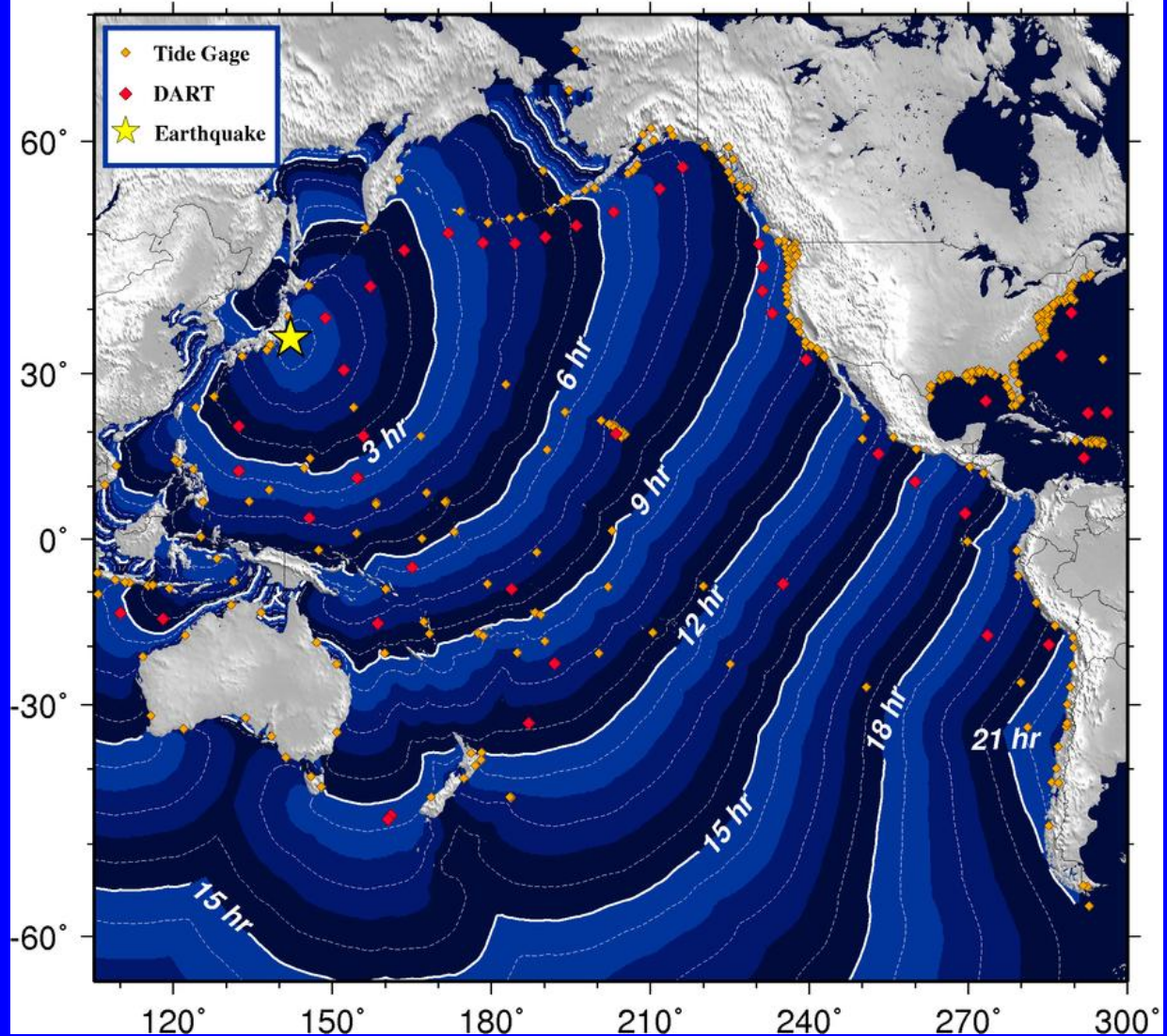
**Trhliny na zlomu --> trhliny nebo
nevratné posunutí
na zemském povrchu a na mořském dně.**

**Pohyb mořského dna
způsobuje vznik tsunami.**

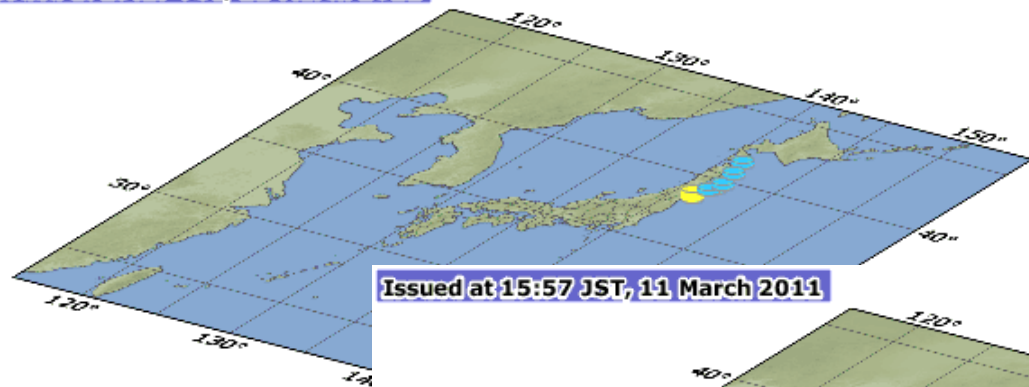
0 hour 2 min



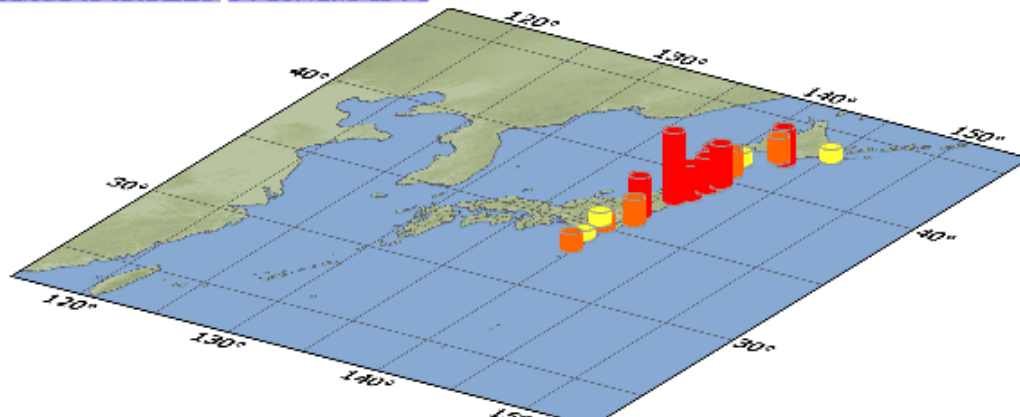
Tsunami Travel Times



Issued at 15:17 JST, 11 March 2011



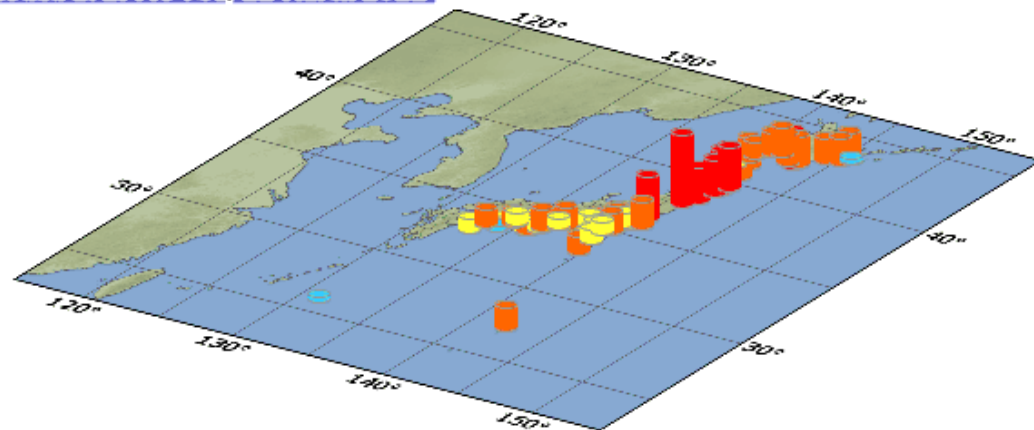
Issued at 15:57 JST, 11 March 2011



Notes

 less than 0.5meter

Issued at 17:48 JST, 11 March 2011



Notes

 less than 0.5meter

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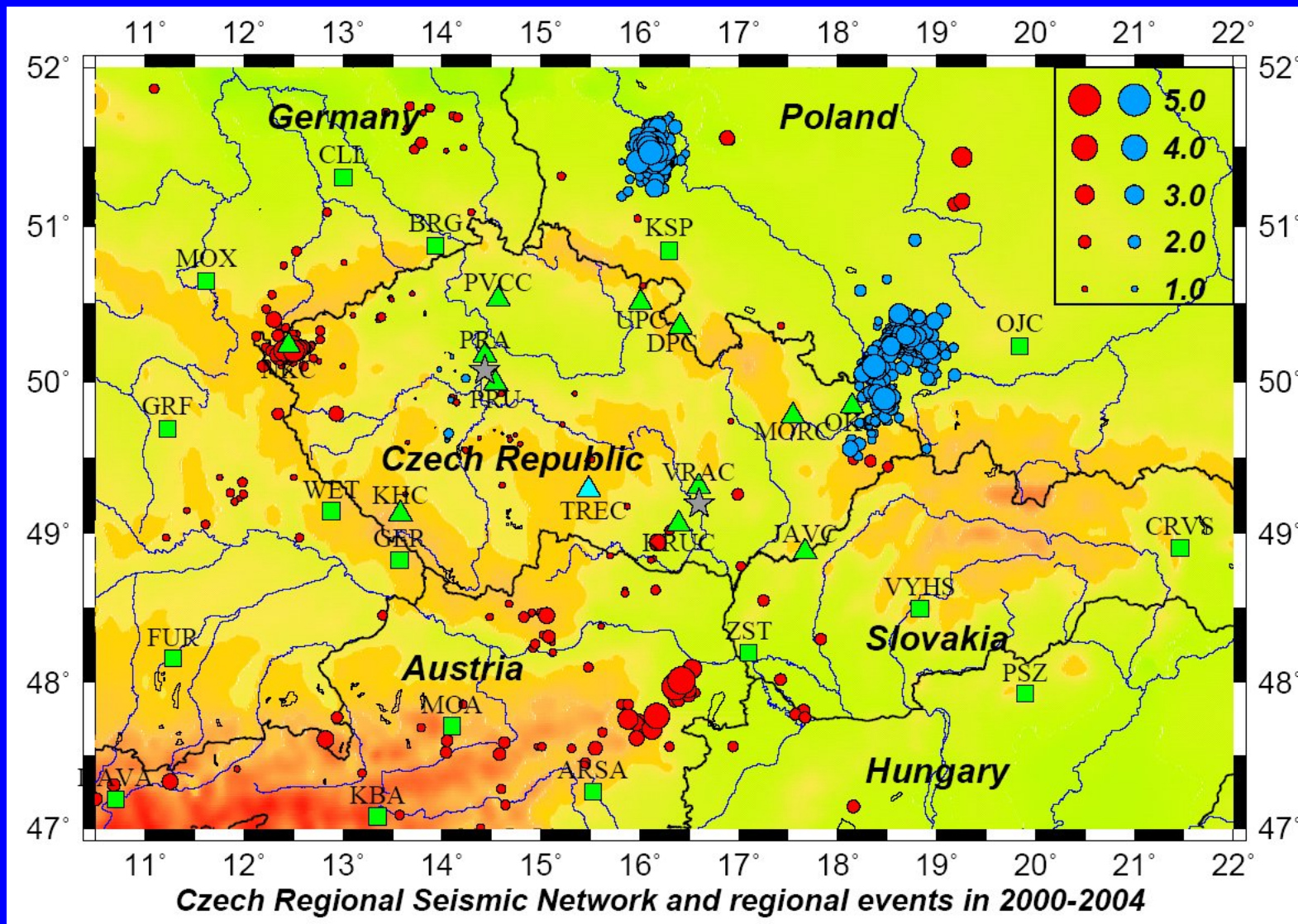
Notes

 less than 0.5meter

 less than 1meter

 less than 3meters

 3meters or more



Silné seismické
pohyby a
ničivé účinky

ovlivněny také
lokálním zesílením



