INTERNATIONAL SCHOOL AND WORKSHOP

NONLINEAR MATHEMATICAL PHYSICS AND NATURAL HAZARDS

November 28 – December 02, 2013,
Bulgarian Academy of Sciences, Sofia

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Conference venue: *Kedar Hotel, Dom na Uchenia,*
1113 Sofia, Geo Milev, 50 Shipchenski Prohod Blvd.,
+359 2 8702140, +359 2 8710009
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IInd ANNOUNCEMENT

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Statistical Seismology and Earthquake Prediction Research in Greece

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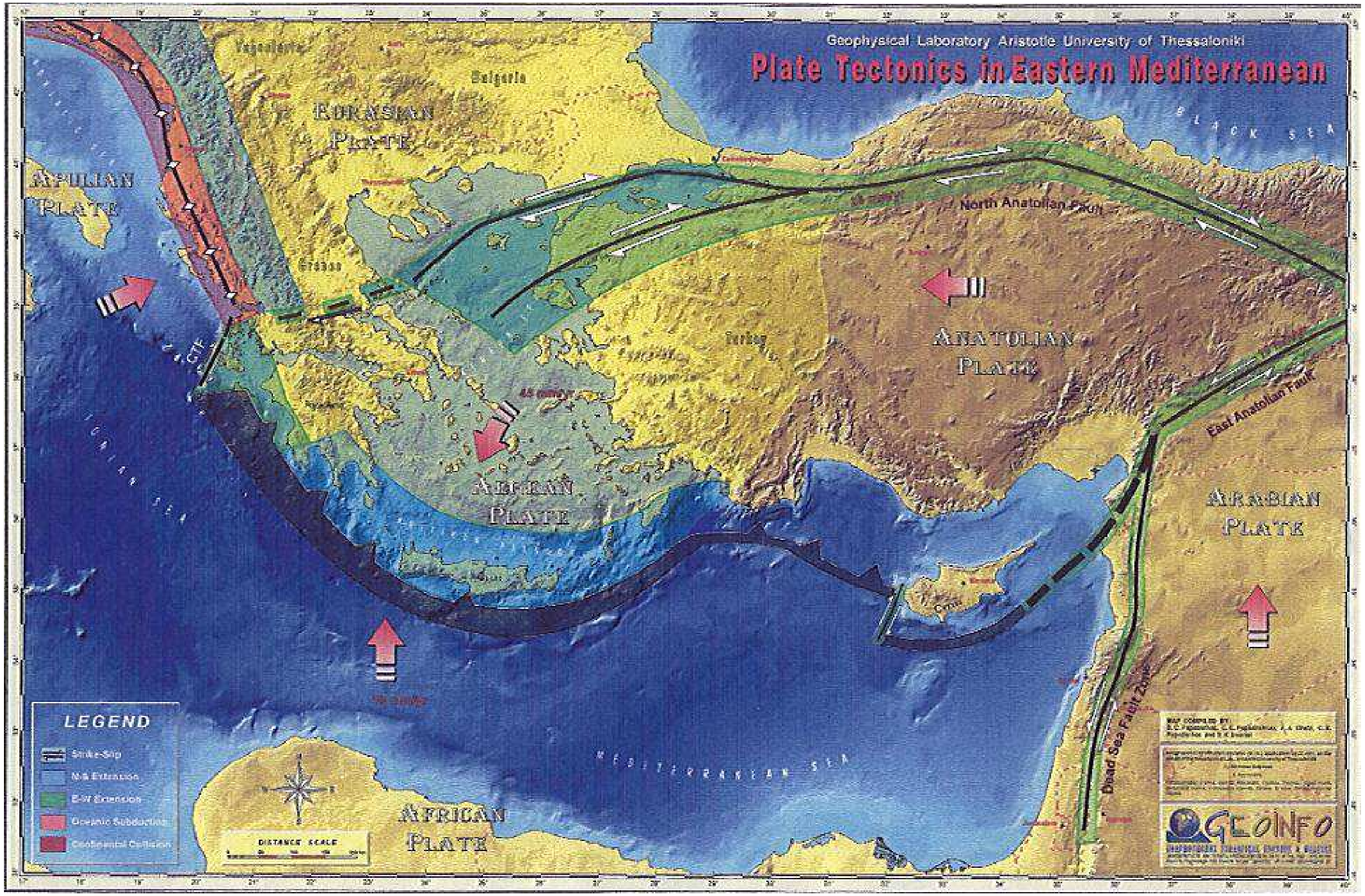
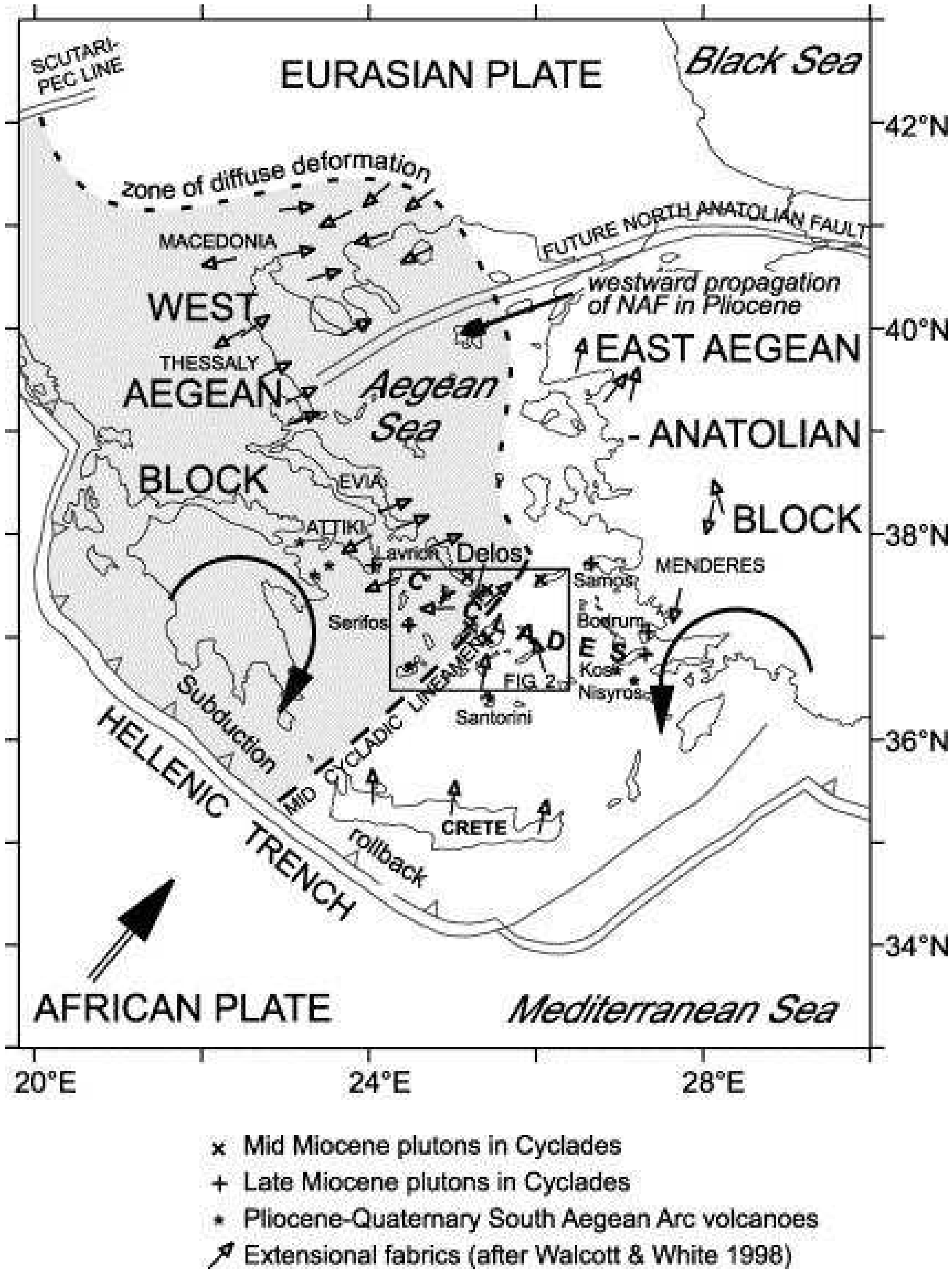
The instrumental earthquake catalog of the National Observatory of Athens (NOA) starts in 1964 and it reports seismic events uninterrupted for the last 50 years. This is the most detailed seismicity catalog for Greece containing more than 160000 events and it is compiled daily by standard seismological observatory practice which has been established at the Geodynamic Institute since 1893. Greece has the highest seismicity production in Europe and it is monitored by the Hellenic Unified Seismological Network (HUSN) coordinated by NOA. At present, the network is composed by more than 145 broadband seismic stations and 80 accelerographic stations transmitting real-time data and automatic parametric solutions are accessible via the internet (**www.gein.noa.gr**).

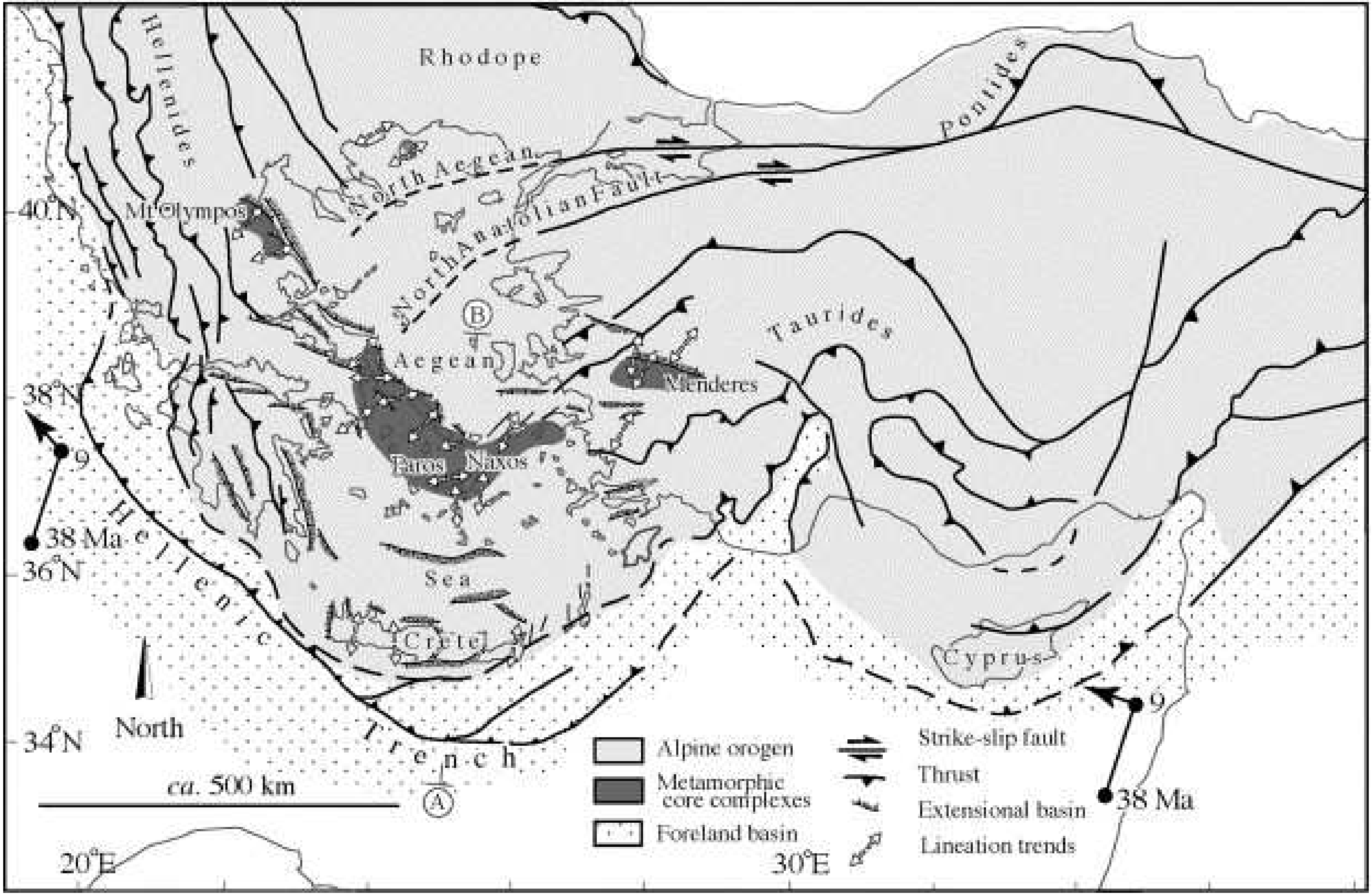
Earthquake catalogs are the basic product of seismology and a plethora of statistical investigations and earthquake prediction research have employed the NOA catalog as the backbone of earthquake hazard and risk studies. In this presentation a detailed statistical analysis of the NOA catalog is demonstrated in terms of the homogeneity and magnitude of completeness. Anomalous seismicity patterns prior to large earthquakes in Greece are investigated by the mapping of seismicity rates that are associated with the precursory phenomena of accelerated seismic release and seismic quiescence. In addition, recent seismicity swarms associated with volcanic and tectonic activity are analyzed in order to reveal local and regional tectonic stress variations which are associated with the stress field.

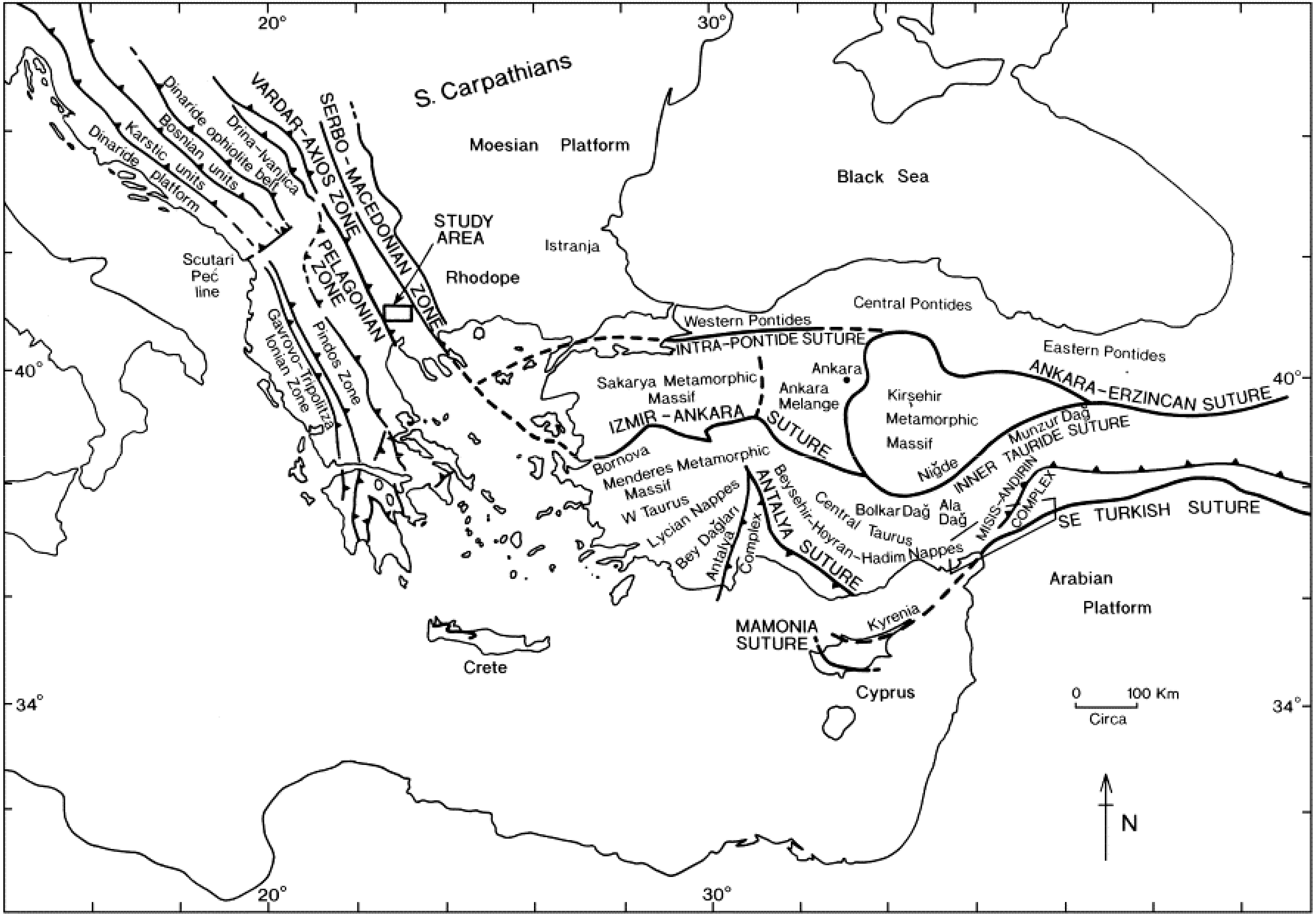
INSTITUTE OF GEODYNAMICS

NATIONAL OBSERVATORY OF ATHENS


Geophysical Laboratory Aristotle University of Thessaloniki
Plate Tectonics in Eastern Mediterranean
EURASIAN PLATE
APULIAN PLATE
ANATOLIAN PLATE
AEGEAN PLATE
ARABIAN PLATE
AFRICAN PLATE
Bulgaria
Greece
Turkey
BLACK SEA
MEDITERRANEAN SEA
North Anatolian Fault
East Anatolian Fault
Dead Sea Fault Zone
LEGEND
Strike-Slip
N-S Extension
E-W Extension
Oceanic Subduction
Continental Collision
DISTANCE SCALE
GEOINFO

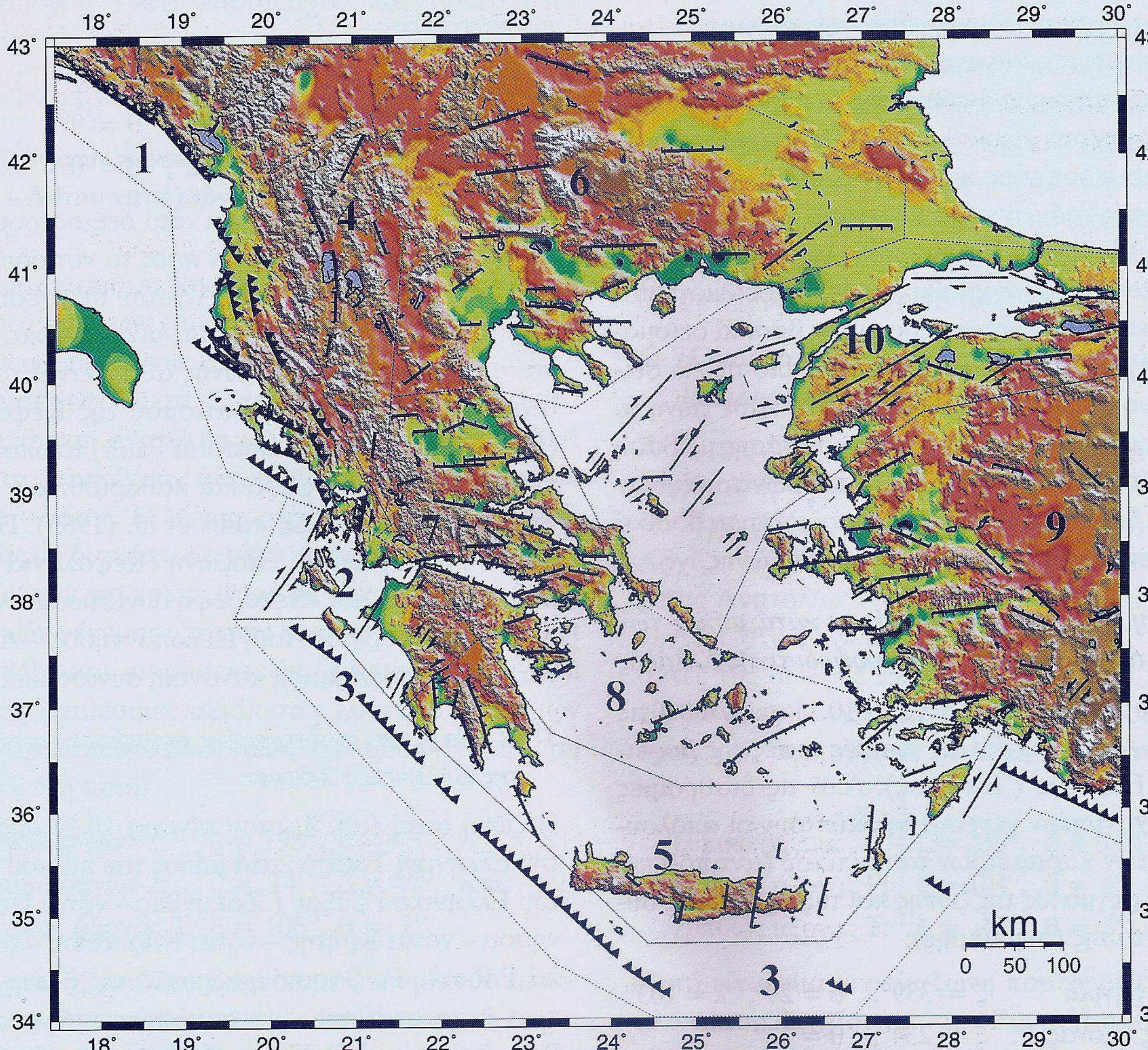

EURASIAN PLATE
Black Sea
SCUTARI-PEC LINE
42°N
zone of diffuse deformation
MACEDONIA
FUTURE NORTH ANATOLIAN FAULT
westward propagation of NAF in Pliocene
WEST AEGEAN BLOCK
THESSALY
40°N
EAST AEGEAN - ANATOLIAN BLOCK
Aegean Sea
EVIA
ATTIKI
38°N
Lavrion
Delos
CYCLADES
Samos
MENDERES
Serifos
Bodrum
Kos
Nisyros
FIG. 2
Santorini
Subduction
MID CYCLADIC LINEAMENT
36°N
HELLENIC TRENCH
CRETE
rollback
34°N
AFRICAN PLATE
Mediterranean Sea
20°E
24°E
28°E
Mid Miocene plutons in Cyclades
Late Miocene plutons in Cyclades
Pliocene-Quaternary South Aegean Arc volcanoes
Extensional fabrics (after Walcott & White 1998)


Rhodope
Hellenides
Pontides
North Aegean
North Anatolian Fault
Mt Olympos
40°N
B
Aegean
Taurides
Menderes
38°N
9
Paros
Naxos
38 Ma
Hellenic
36°N
Sea
Crete
Cyprus
9
North
34°N
Trench
A
ca. 500 km
Alpine orogen
Metamorphic core complexes
Foreland basin
Strike-slip fault
Thrust
Extensional basin
Lineation trends
38 Ma
20°E
30°E

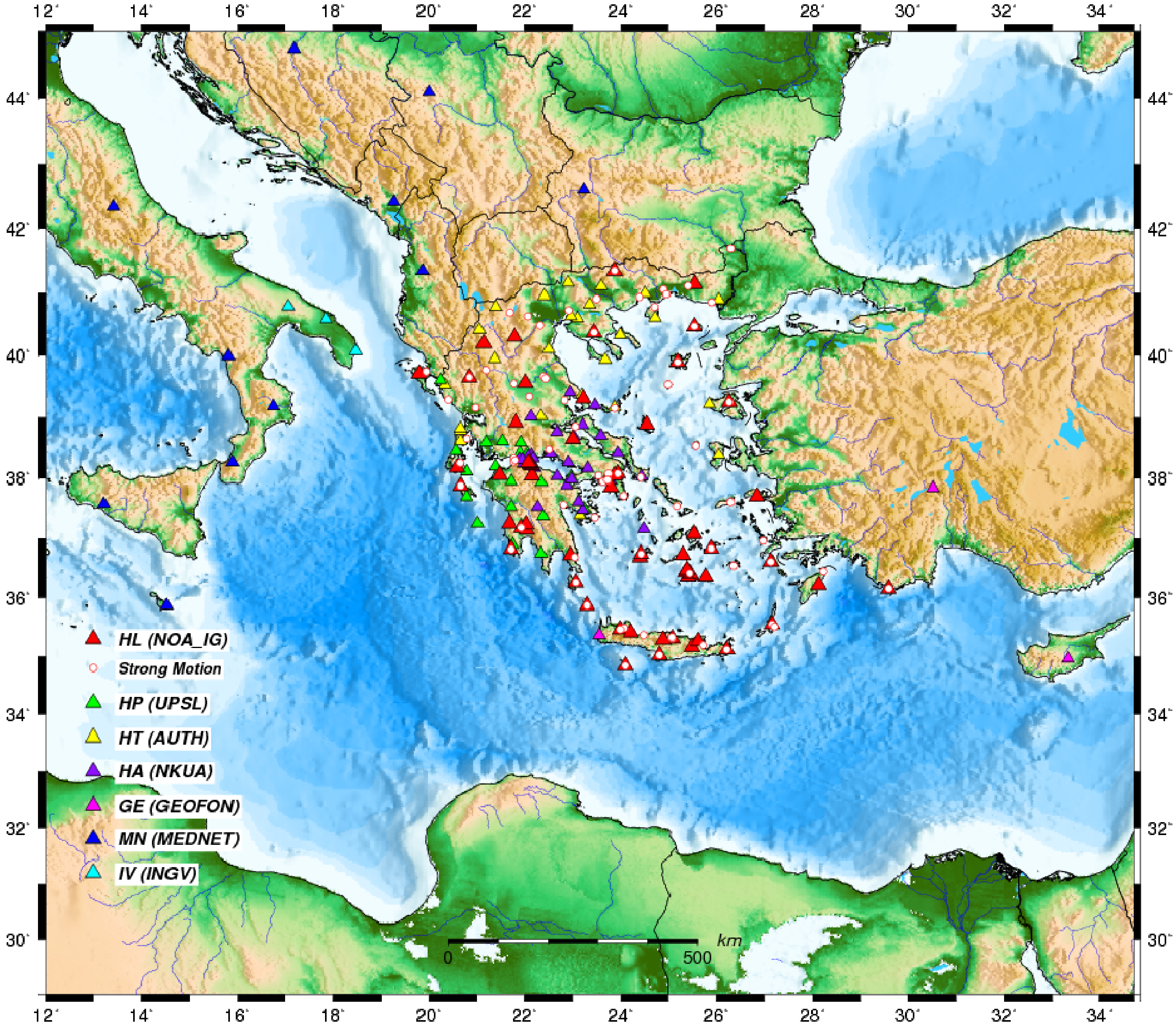

20°
30°
S. Carpathians
Moesian Platform
Black Sea
Dinaride ophiolite belt
Drina-Ivanjica
Bosnian units
Karstic units
Dinaride platform
VARDAR-AXIOS ZONE
SERBO-MACEDONIAN ZONE
STUDY AREA
Istranja
Rhodope
Scutari Peć line
PELAGONIAN ZONE
Gavrovo-Tripolitza Ionian Zone
Pindos Zone
Western Pontides
Central Pontides
INTRA-PONTIDE SUTURE
Eastern Pontides
Ankara
Ankara Melange
Sakarya Metamorphic Massif
IZMIR-ANKARA SUTURE
Kirşehir Metamorphic Massif
ANKARA-ERZINCAN SUTURE
Munzur Dağ
INNER TAURIDE SUTURE
Niğde
40°
Bornova
Menderes Metamorphic Massif
W Taurus
Lycian Nappes
Bey Dağları
Antalya
Complex
ANTALYA SUTURE
Beyşehir-Hoyran-Hadim Nappes
Central Taurus
Bolkar Dağ
Ala Dağ
MISIS-ANDIRIN COMPLEX
SE TURKISH SUTURE
Arabian Platform
Kyrenia
MAMONIA SUTURE
Cyprus
Crete
34°
0 100 Km
Circa
N

F.Y.R.O.M.
Bulgaria
Albania
Din
Hellenides
MS
NAFZ
NAT
Greece
Ep
C
Turkey
SpB
Sp
SB
S
Le
Anatolia
GA
L
KF
A
KFZ
K
GP
GC
Ev
Aegean Sea
At
Pel
Z
Cyclades
Ionian Sea
volcanic arc
Kos
N
Hellenic trench
WHA
R
Kp
Crete
Mediterranean ridge
Ptolemy trench
Pliny trench
Strabo trench
41°
40°
39°
38°
37°
36°
35°
34°
19°
20°
21°
22°
23°
24°
25°
26°
27°
28°
29°

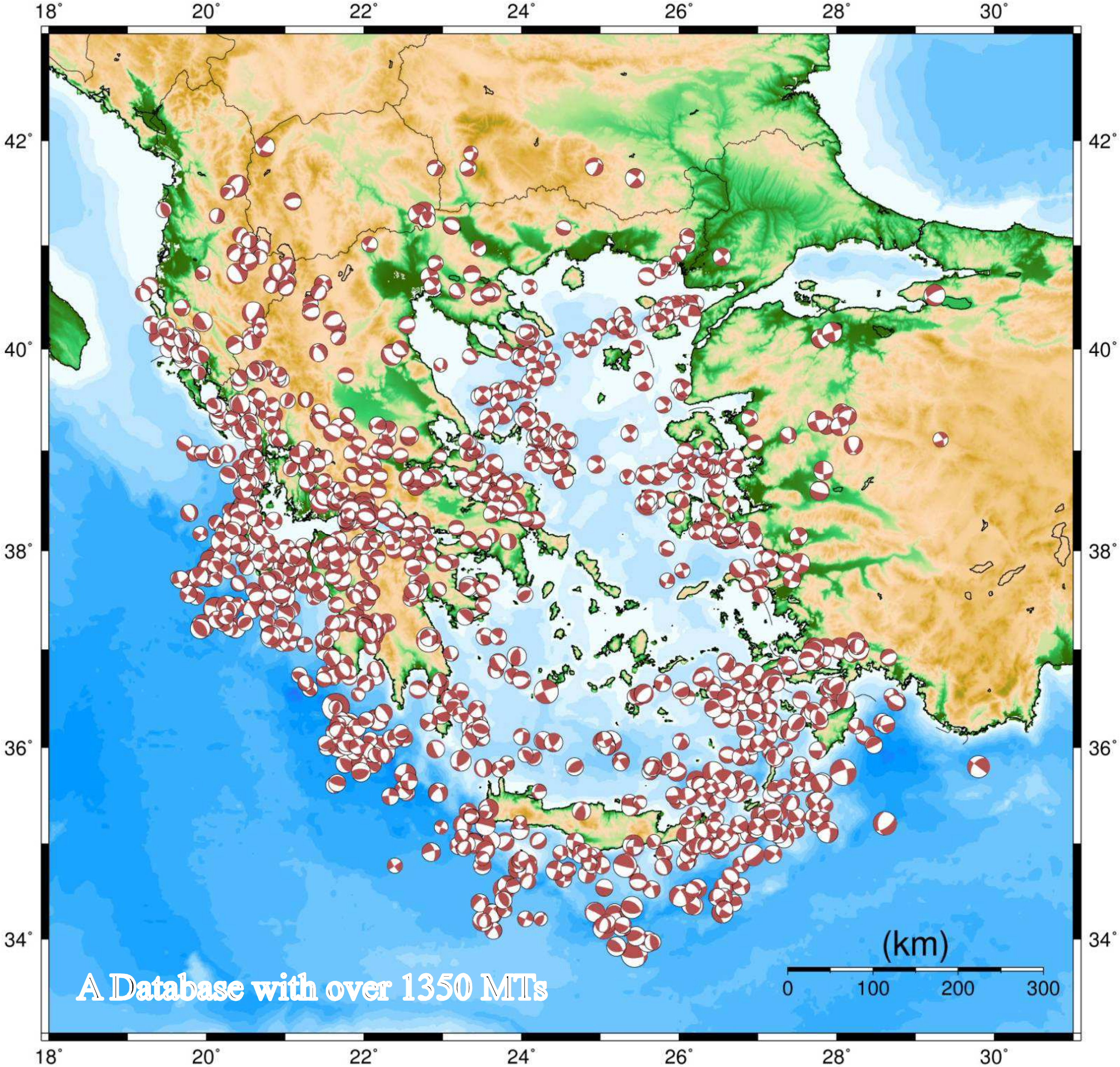
(a)



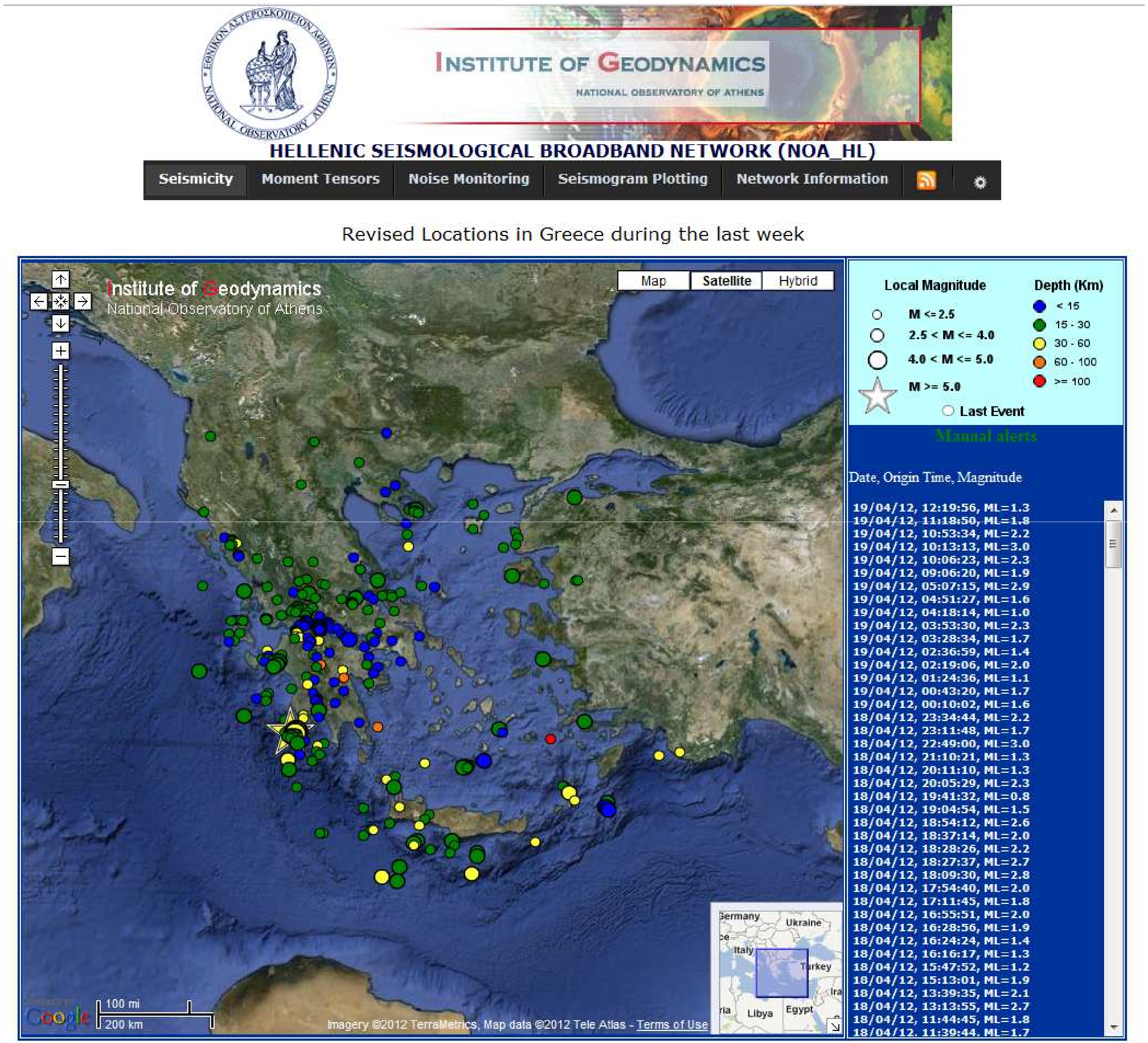
18°
19°
20°
21°
22°
23°
24°
25°
26°
27°
28°
29°
30°
43°
42°
41°
40°
39°
38°
37°
36°
35°
34°
1
2
3
4
5
6
7
8
9
10
3
km
0
50
100

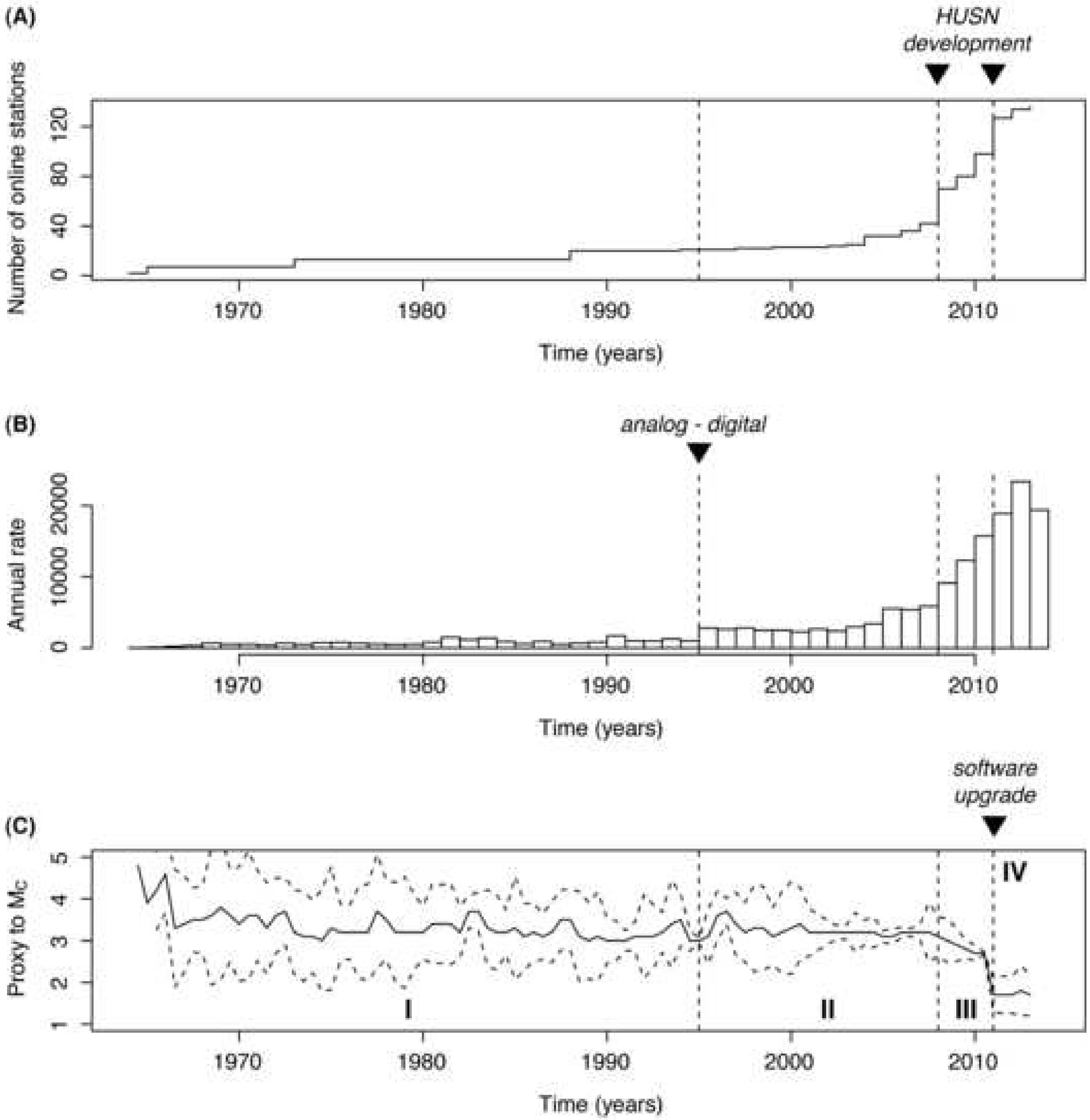


HL (NOA_IG)
Strong Motion
HP (UPSL)
HT (AUTH)
HA (NKUA)
GE (GEOFON)
MN (MEDNET)
IV (INGV)
0
500
km
12°
14°
16°
18°
20°
22°
24°
26°
28°
30°
32°
34°
30°
32°
34°
36°
38°
40°
42°
44°

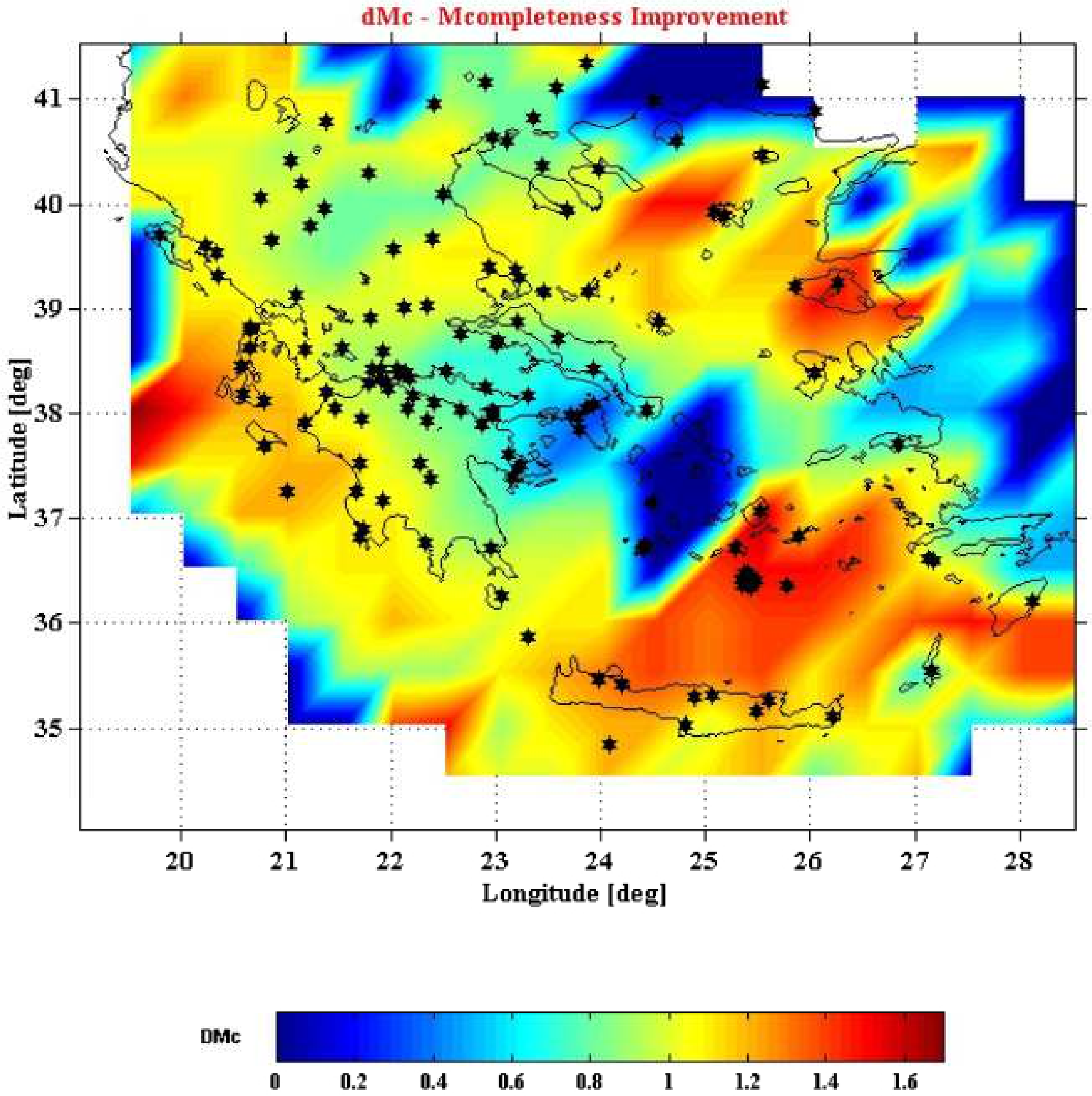


18° 20° 22° 24° 26° 28° 30°
42° 40° 38° 36° 34°
(km)
0 100 200 300
A Database with over 1350 MTs

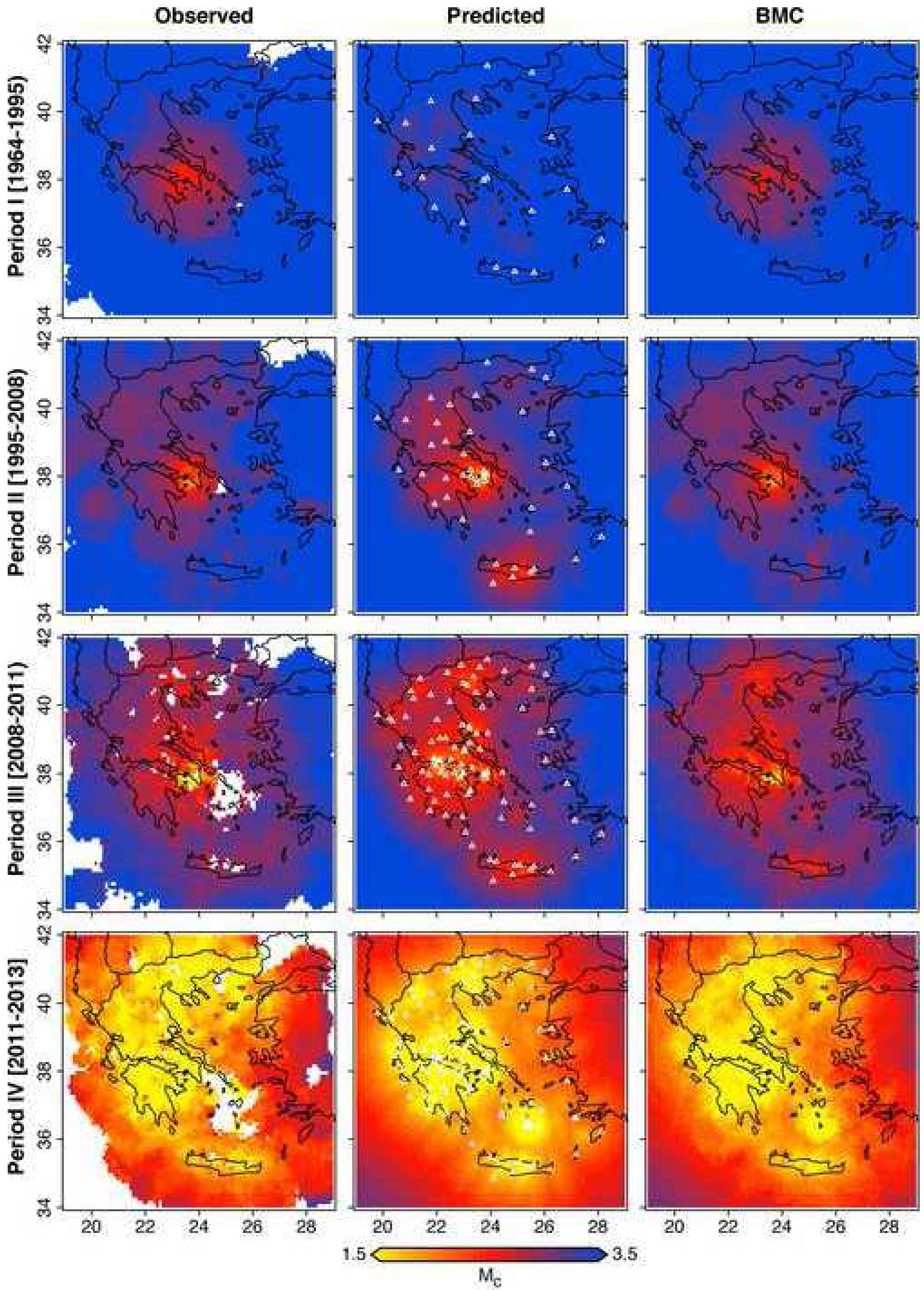

INSTITUTE OF GEODYNAMICS
NATIONAL OBSERVATORY OF ATHENS
HELLENIC SEISMOLOGICAL BROADBAND NETWORK (NOA_HL)
Seismicity
Moment Tensors
Noise Monitoring
Seismogram Plotting
Network Information
Revised Locations in Greece during the last week
Institute of Geodynamics
National Observatory of Athens
Map
Satellite
Hybrid
Local Magnitude
M <= 2.5
2.5 < M <= 4.0
4.0 < M <= 5.0
M >= 5.0
Depth (Km)
< 15
15 - 30
30 - 60
60 - 100
>= 100
Last Event
Manual alerts
Date, Origin Time, Magnitude
19/04/12, 12:19:56, ML=1.3
19/04/12, 11:18:50, ML=1.8
19/04/12, 10:53:34, ML=2.2
19/04/12, 10:13:13, ML=3.0
19/04/12, 10:06:23, ML=2.3
19/04/12, 09:06:20, ML=1.9
19/04/12, 05:07:15, ML=2.9
19/04/12, 04:51:27, ML=1.6
19/04/12, 04:18:14, ML=1.0
19/04/12, 03:53:30, ML=2.3
19/04/12, 03:28:34, ML=1.7
19/04/12, 02:36:59, ML=1.4
19/04/12, 02:19:06, ML=2.0
19/04/12, 01:24:36, ML=1.1
19/04/12, 00:43:20, ML=1.7
19/04/12, 00:10:02, ML=1.6
18/04/12, 23:34:44, ML=2.2
18/04/12, 23:11:48, ML=1.7
18/04/12, 22:49:00, ML=3.0
18/04/12, 21:10:21, ML=1.3
18/04/12, 20:11:10, ML=1.3
18/04/12, 20:05:29, ML=2.3
18/04/12, 19:41:32, ML=0.8
18/04/12, 19:04:54, ML=1.5
18/04/12, 18:54:12, ML=2.6
18/04/12, 18:37:14, ML=2.0
18/04/12, 18:28:26, ML=2.2
18/04/12, 18:27:37, ML=2.7
18/04/12, 18:09:30, ML=2.8
18/04/12, 17:54:40, ML=2.0
18/04/12, 17:11:45, ML=1.8
18/04/12, 16:55:51, ML=2.0
18/04/12, 16:28:56, ML=1.9
18/04/12, 16:24:24, ML=1.4
18/04/12, 16:16:17, ML=1.3
18/04/12, 15:47:52, ML=1.2
18/04/12, 15:13:01, ML=1.9
18/04/12, 13:39:35, ML=2.1
18/04/12, 13:13:55, ML=2.7
18/04/12, 11:44:45, ML=1.8
18/04/12, 11:39:44, ML=1.7
Ukraine
Italy
Turkey
Libya
Egypt
100 mi
200 km
Imagery ©2012 TerraMetrics, Map data ©2012 Tele Atlas - Terms of Use



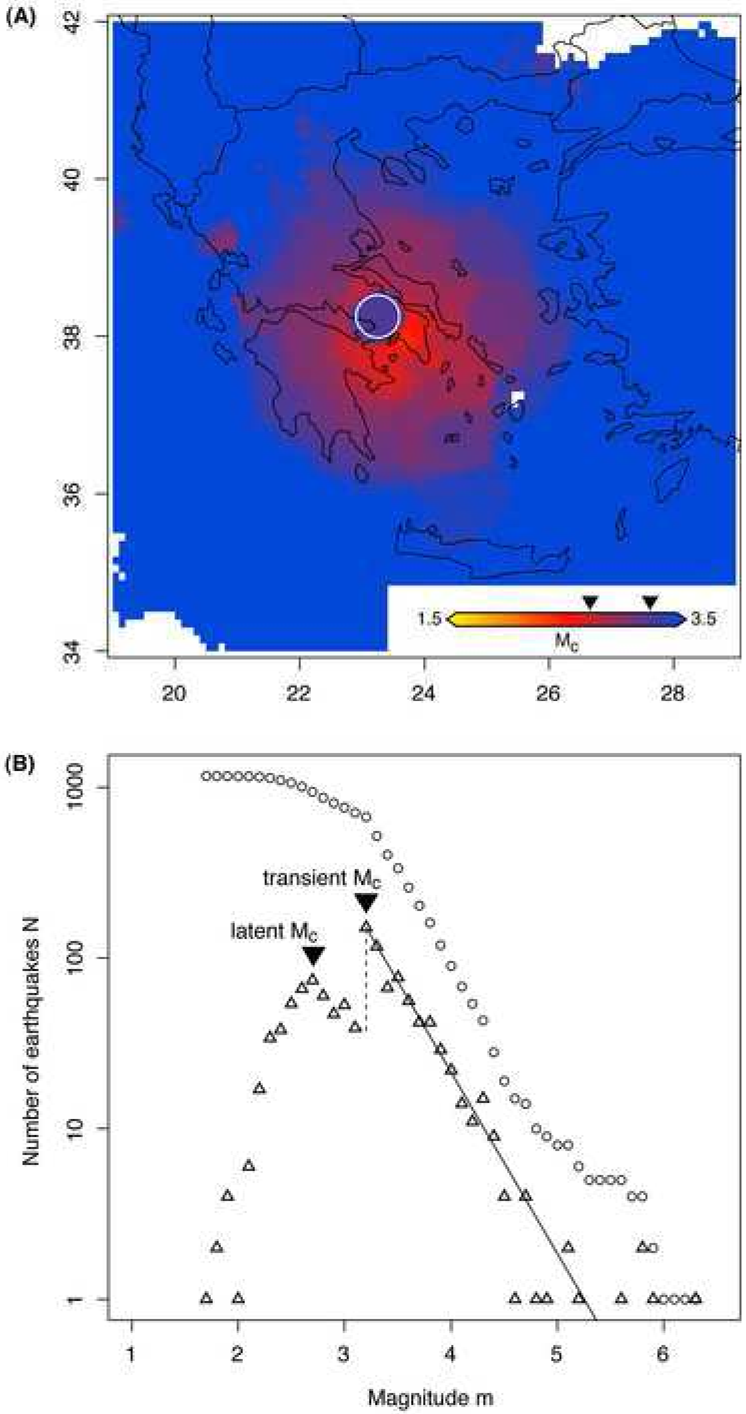
(A)
HUSN development
Number of online stations
0
40
80
120
1970
1980
1990
2000
2010
Time (years)
(B)
analog - digital
Annual rate
0
10000
20000
1970
1980
1990
2000
2010
Time (years)
(C)
software upgrade
Proxy to Mc
1
2
3
4
5
I
II
III
IV
1970
1980
1990
2000
2010
Time (years)

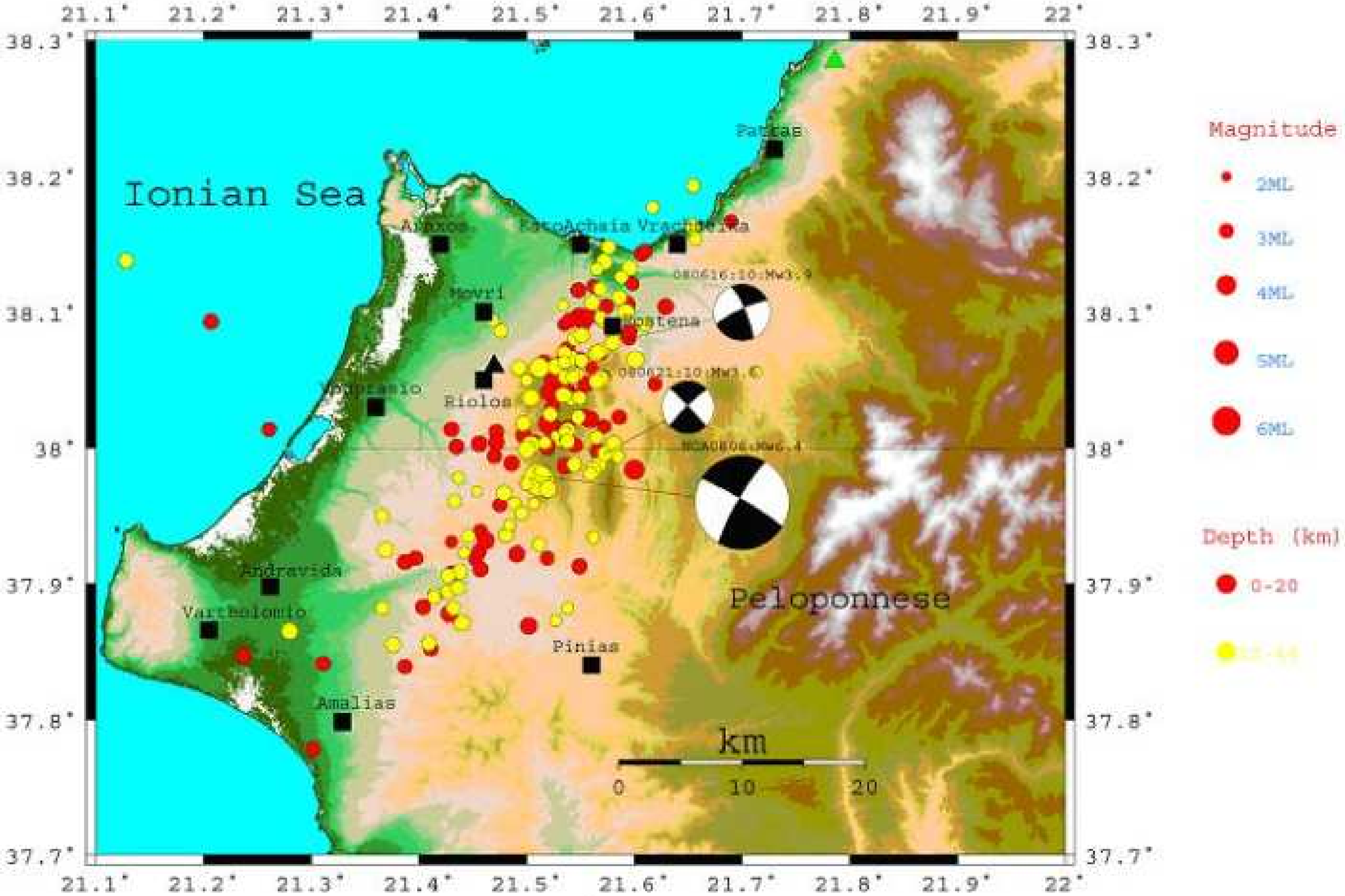


dMc - Mcompleteness Improvement
Latitude [deg]
Longitude [deg]
41
40
39
38
37
36
35
20
21
22
23
24
25
26
27
28
DMc
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

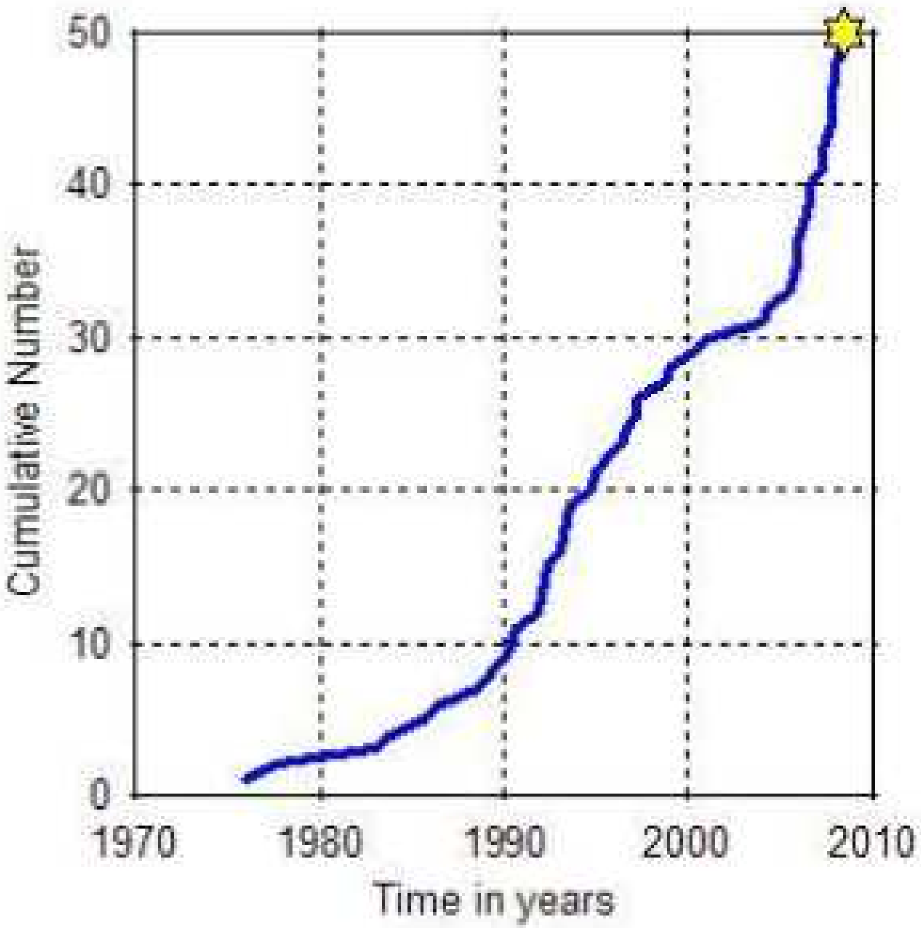


Observed
Predicted
BMC
Period I [1964-1995)
Period II [1995-2008)
Period III [2008-2011)
Period IV [2011-2013]
42
40
38
36
34
20
22
24
26
28
1.5
3.5
M_c


(A)
42
40
38
36
34
20
22
24
26
28
1.5
3.5
M_c
(B)
1000
100
10
1
Number of earthquakes N
transient M_c
latent M_c
1
2
3
4
5
6
Magnitude m



21.1° 21.2° 21.3° 21.4° 21.5° 21.6° 21.7° 21.8° 21.9° 22°
38.3° 38.2° 38.1° 38° 37.9° 37.8° 37.7°
Ionian Sea
Patras
Araxos
Movri
Rioloa
Andravida
Vartholomio
Amalias
Pinias
Peloponnese
080616:10:Mw3.9
km
0 10 20
Magnitude
2ML
3ML
4ML
5ML
6ML
Depth (km)
0-20

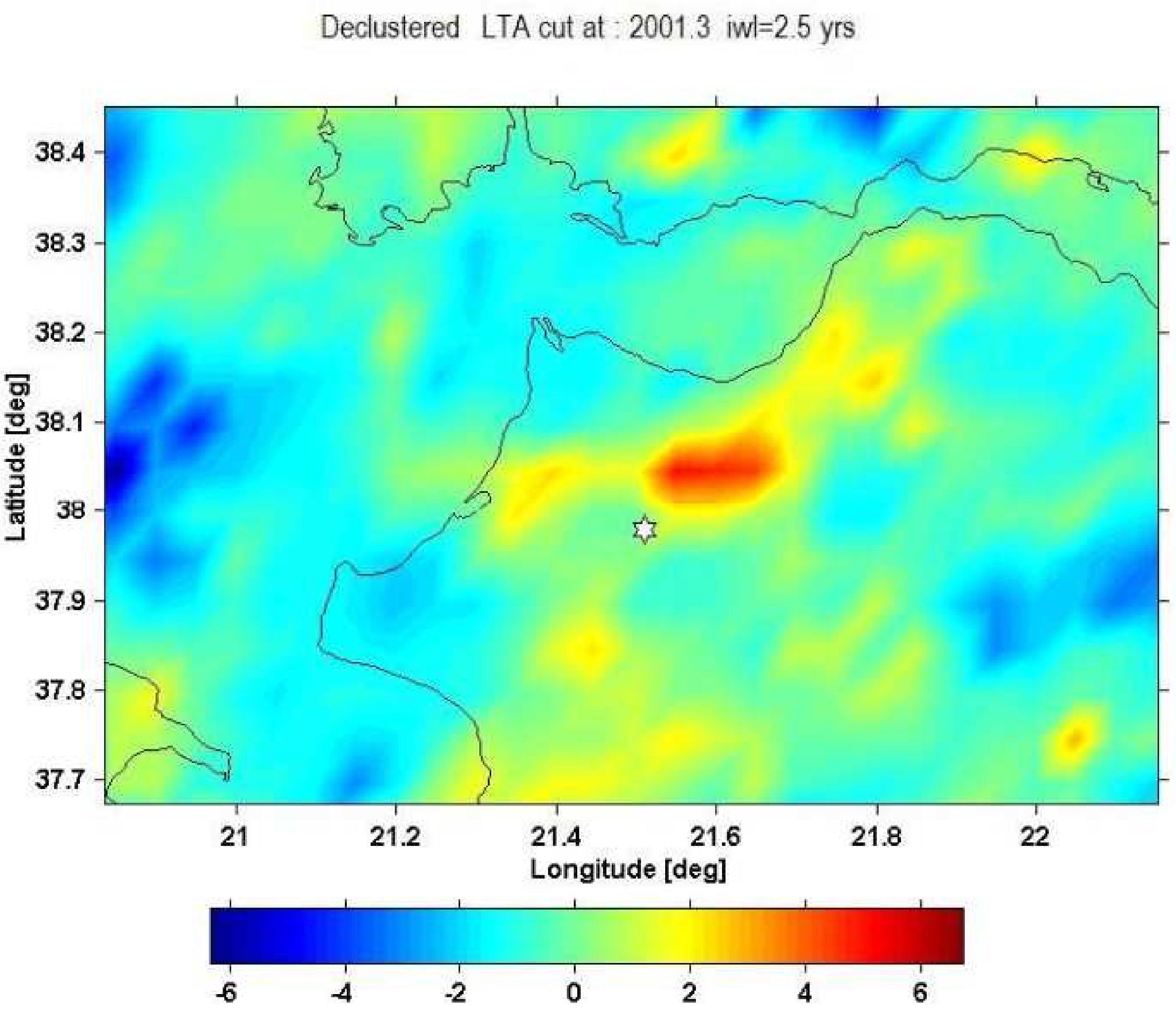


50
40
30
20
10
0
1970
1980
1990
2000
2010
Time in years
Cumulative Number

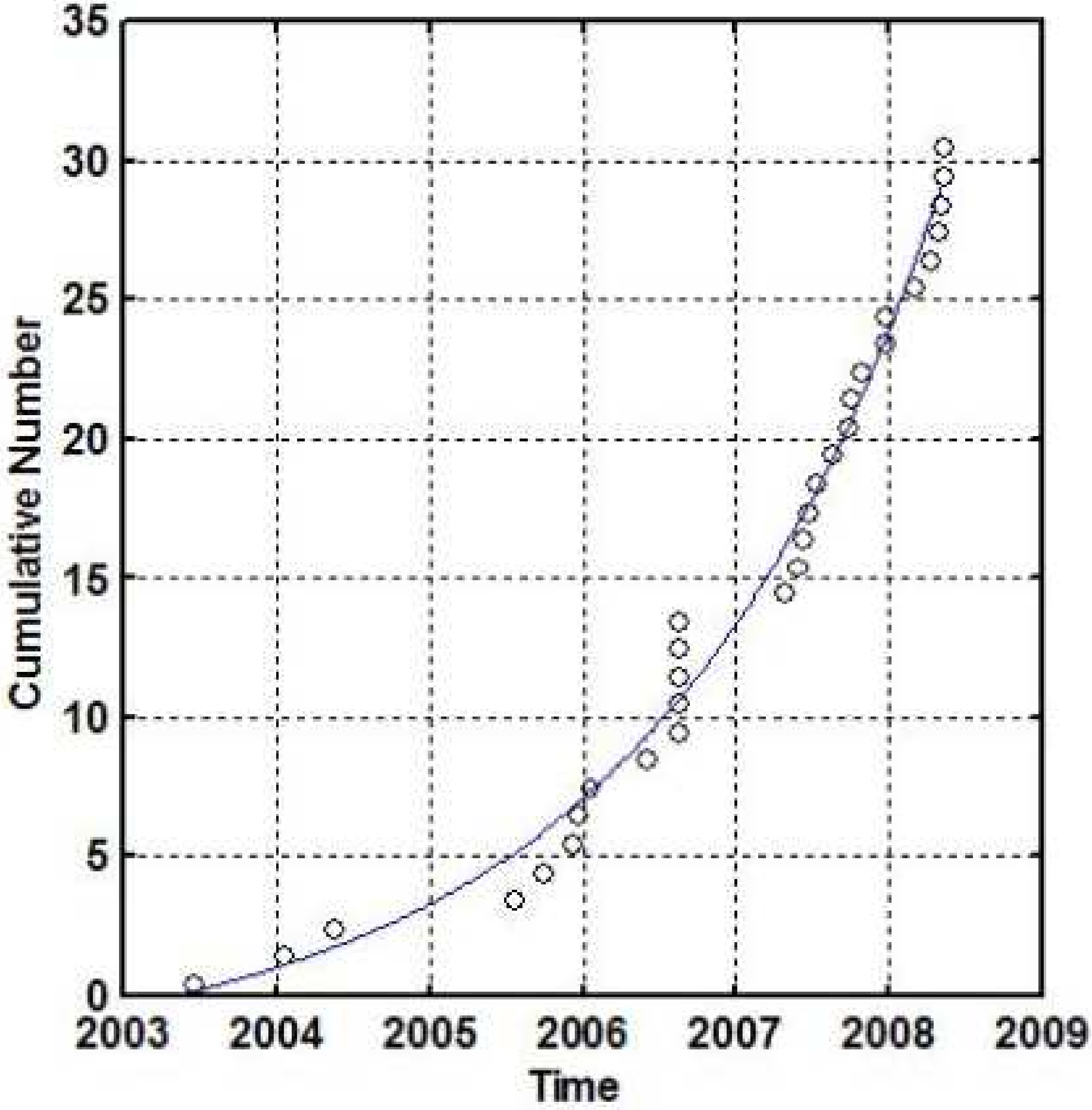
In order to rank the significance of quiescence,we used the standard deviate Z, generating the LTA(t) function (Wyss and Burford, 1985, 1987;Wiemer and Wyss, 1994).

$$\mathbf{Z=(R1-R2)/(S1^2/n1+S2^2/n2)^{1/2}}$$

which measures the significance of the difference between the mean seismicity rate within window R1, and the backround rate R2, defined as the mean rate outside the window but within the same volume. S1 and S2 are the variances of the means and n1 and n2 are the corresponding number of bins with a measured seismicity rate. Thus at each node a z value is computed and these z-values are then ordered according to size. The computed z-values are then contoured and mapped, revealing the z-value distribution at the beginning of the window for which they are evaluated, since we want to define the onset of a significant rate change in the seismicity.



Declustered LTA cut at : 2001.3 iwl=2.5 yrs
38.4
38.3
38.2
38.1
38
37.9
37.8
37.7
Latitude [deg]
21
21.2
21.4
21.6
21.8
22
Longitude [deg]
-6
-4
-2
0
2
4
6



35
30
25
20
15
10
5
0
2003
2004
2005
2006
2007
2008
2009
Time
Cumulative Number

The accelerated seismicity may be analyzed with the accelerated moment release (AMR) hypothesis according to which the rate of seismic moment release is proportional to an inverse power of the remaining time-to-failure (Varnes, 1989, Bufe and Varnes, 1993, Bufe et. al., 1994). The so called time-to-failure analysis is an empirical technique based on the equation (Varnes (1989):

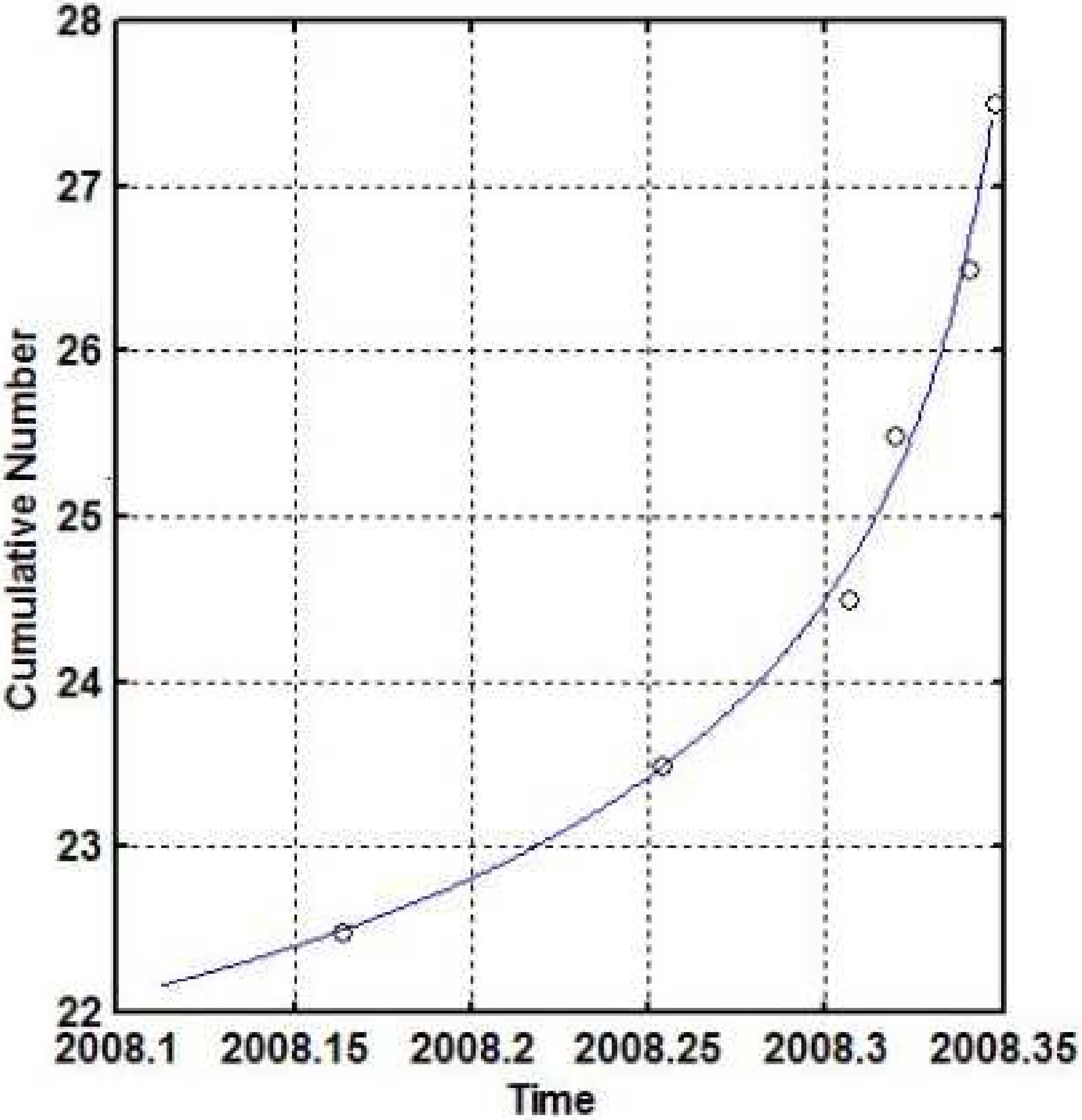
$$\sum \Omega (t) = K+(k/(n-1)) \bullet (t_f - t)^m$$

where Ω is a measure of seismic energy release, K, k and n are constants, m=1-n (n≠1) and t_f is the time-to-failure (main shock). The ‘seismic release’ as defined by Bufe and Varnes, (1993) is determined from the earthquake magnitude using the expression:

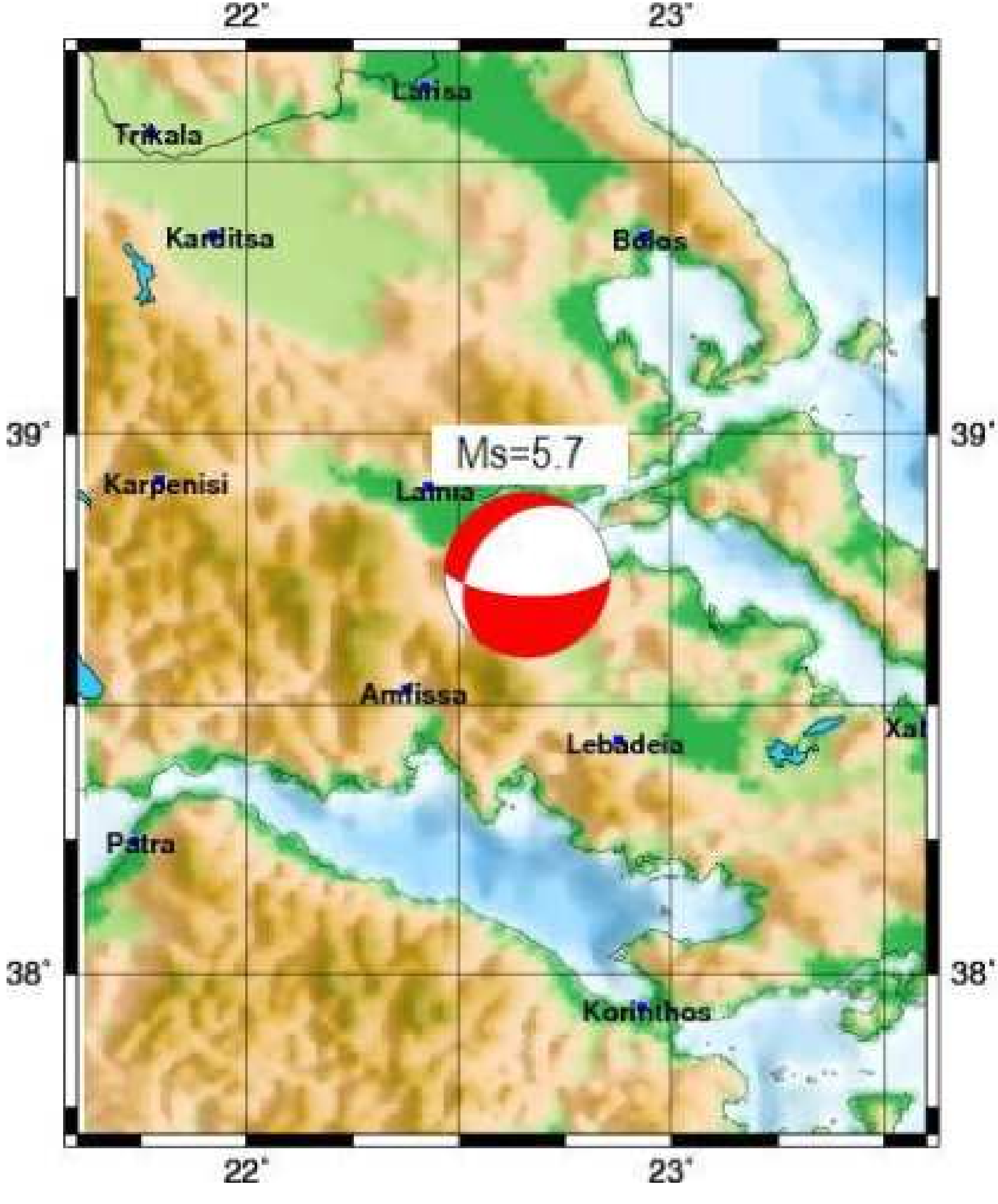
$$\log10\ \Omega = c \bullet M + d$$

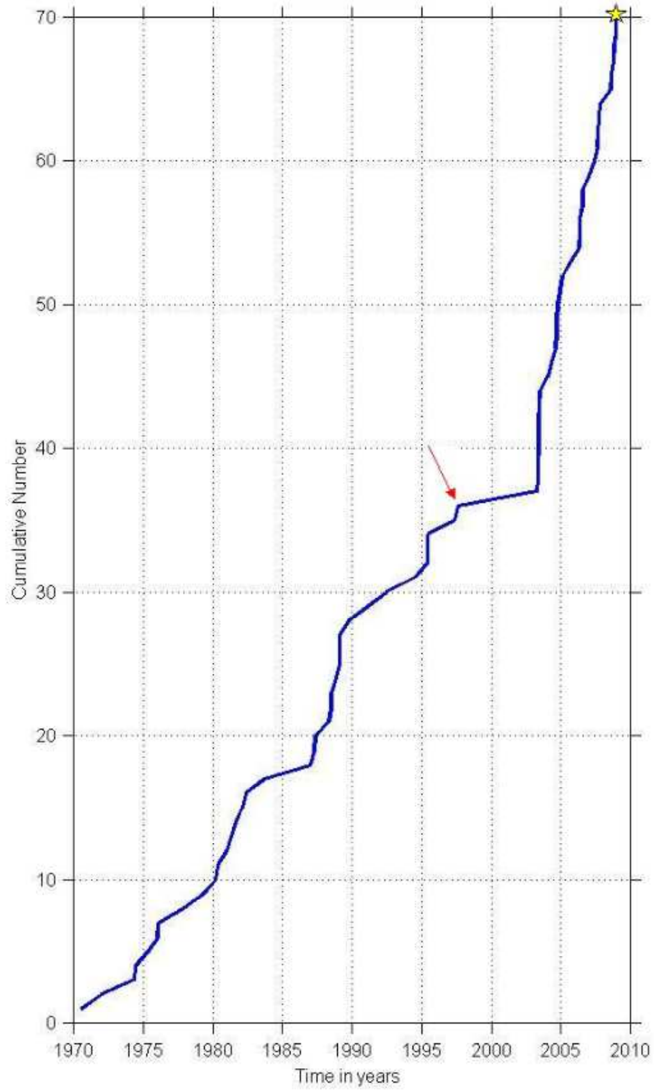
where M is the earthquake magnitude and c and d are constants. The coefficient c is 1.5 for moment or energy, 0.75 for Benioff strain release and zero for event counts (Kanamori, 1977).

We use event counts instead of the seismic energy (which is frequently used) and an unconstrained best fit of the foreshock data (free tf and m) simply to show a power law distribution in time for the analyzed foreshocks. That study showed that both long (5 year) and short (5 months) term earthquake activities in the foreshock sequence well fit to the time-to-failure equation, in general agreement with the discussion of Bufe and Varnes (1993) concerning the pattern of long and short cyclic earthquake activity based on the pioneering work on ‘seismic cycles’ by Fedotov (1976).

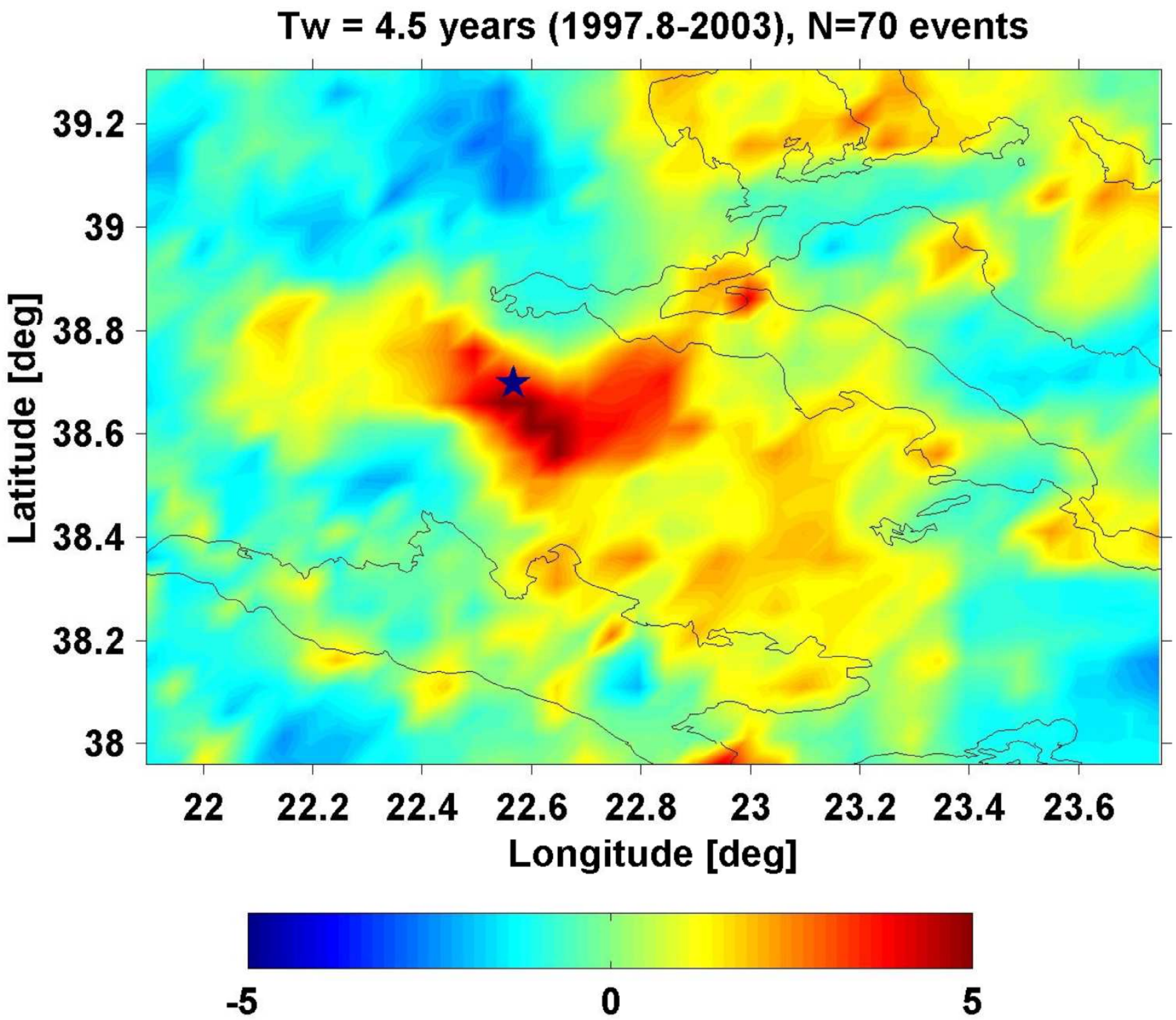


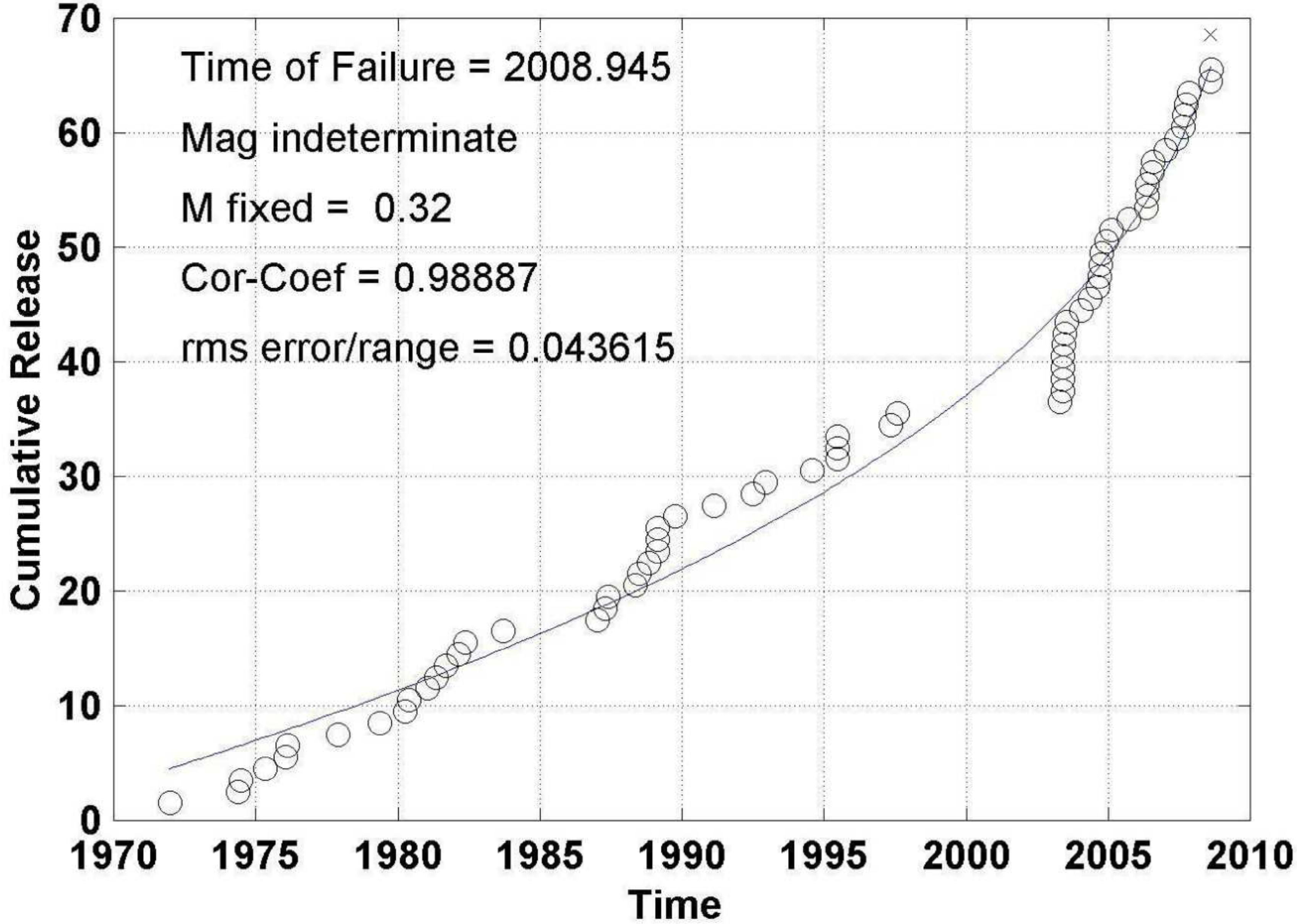
28
27
26
25
24
23
22
Cumulative Number
2008.1
2008.15
2008.2
2008.25
2008.3
2008.35
Time

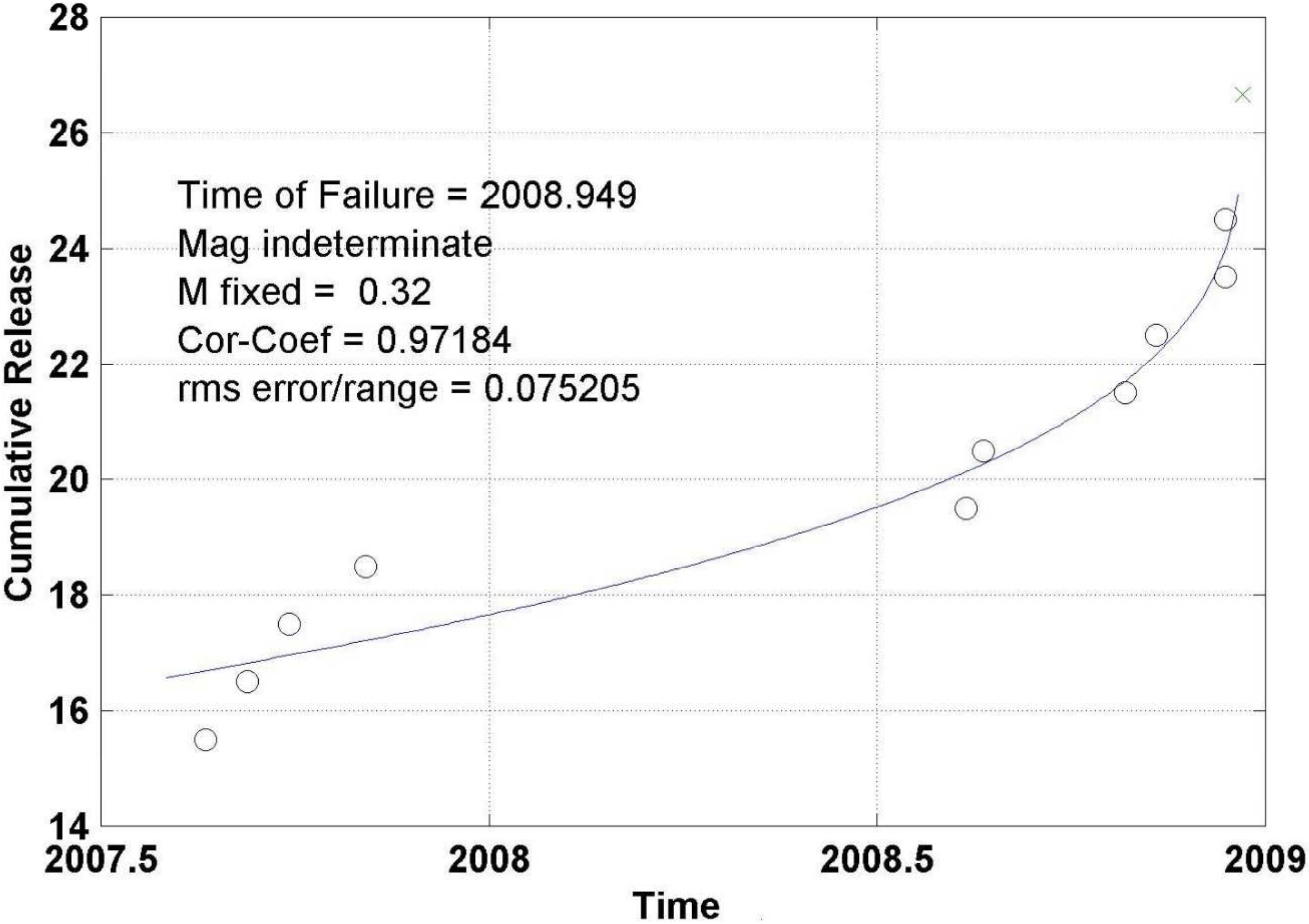

22˚
23˚
39˚
38˚
Larisa
Trikala
Karditsa
Bolos
Karpenisi
Ms=5.7
Lamia
Amfissa
Lebadeia
Xal
Patra
Korinthos



70
60
50
40
30
20
10
0
Cumulative Number
1970
1975
1980
1985
1990
1995
2000
2005
2010
Time in years

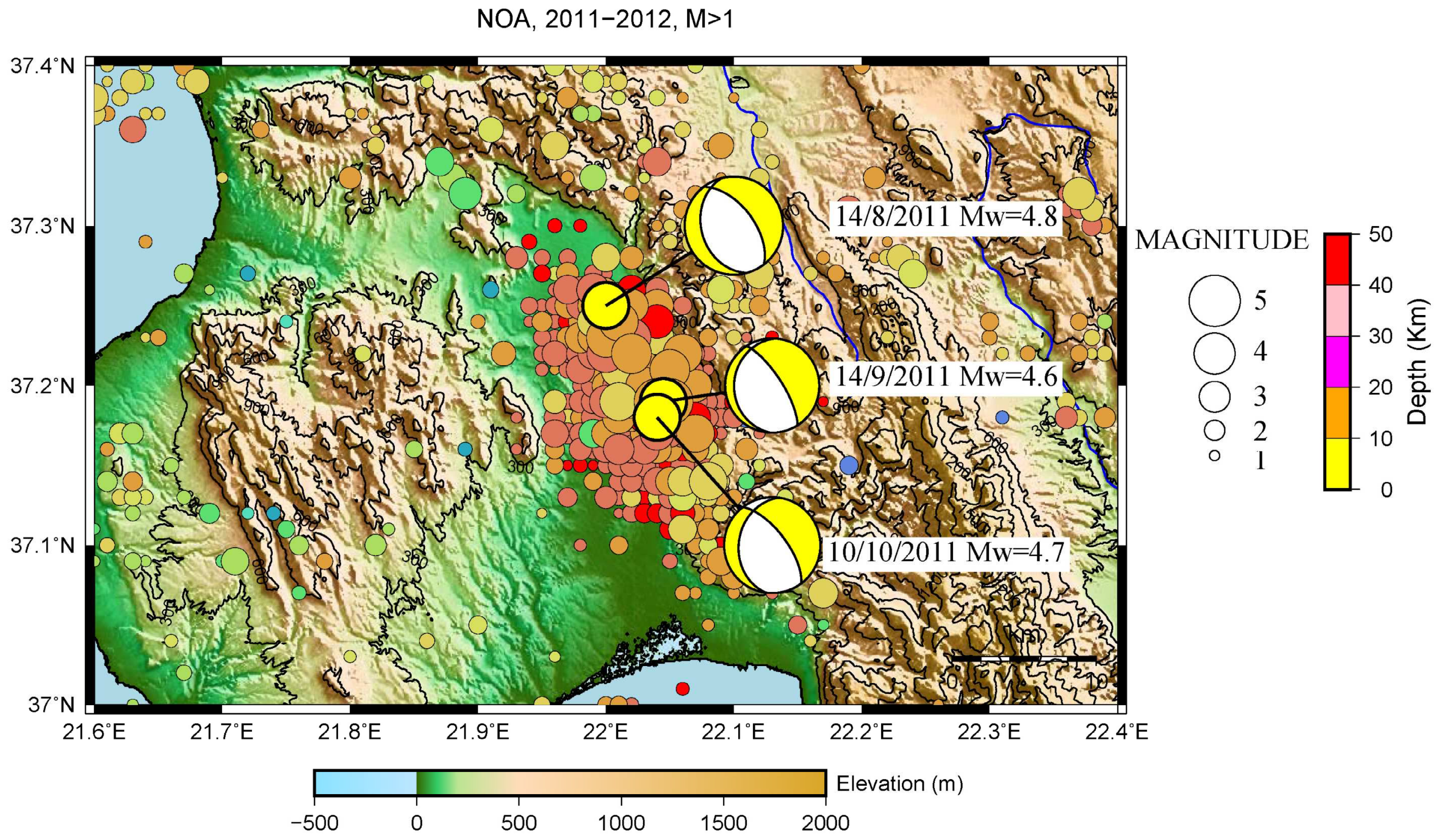

Tw = 4.5 years (1997.8-2003), N=70 events
Latitude [deg]
39.2
39
38.8
38.6
38.4
38.2
38
22
22.2
22.4
22.6
22.8
23
23.2
23.4
23.6
Longitude [deg]
-5
0
5

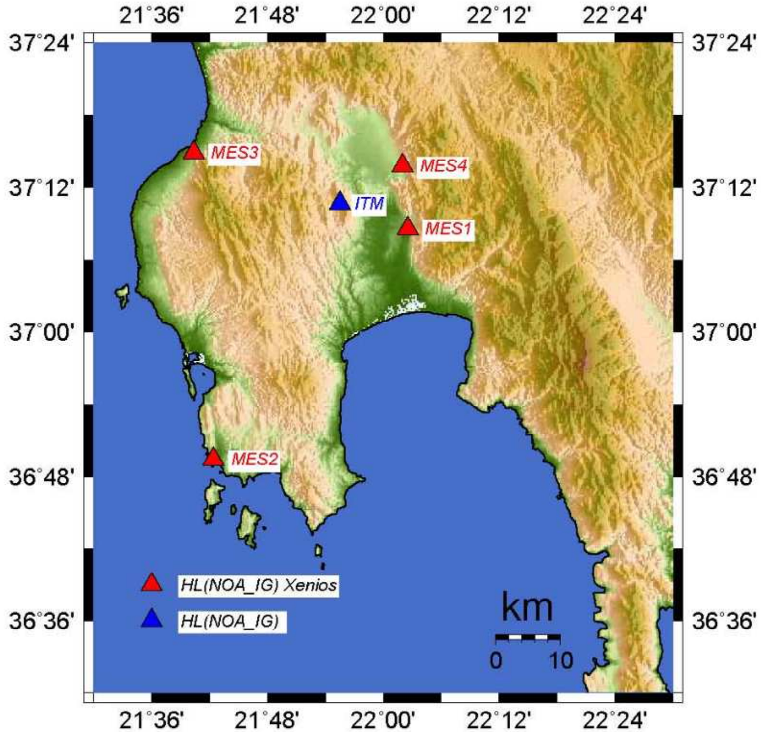

Time of Failure = 2008.945
Mag indeterminate
M fixed = 0.32
Cor-Coef = 0.98887
rms error/range = 0.043615
Cumulative Release
Time
0
10
20
30
40
50
60
70
1970
1975
1980
1985
1990
1995
2000
2005
2010

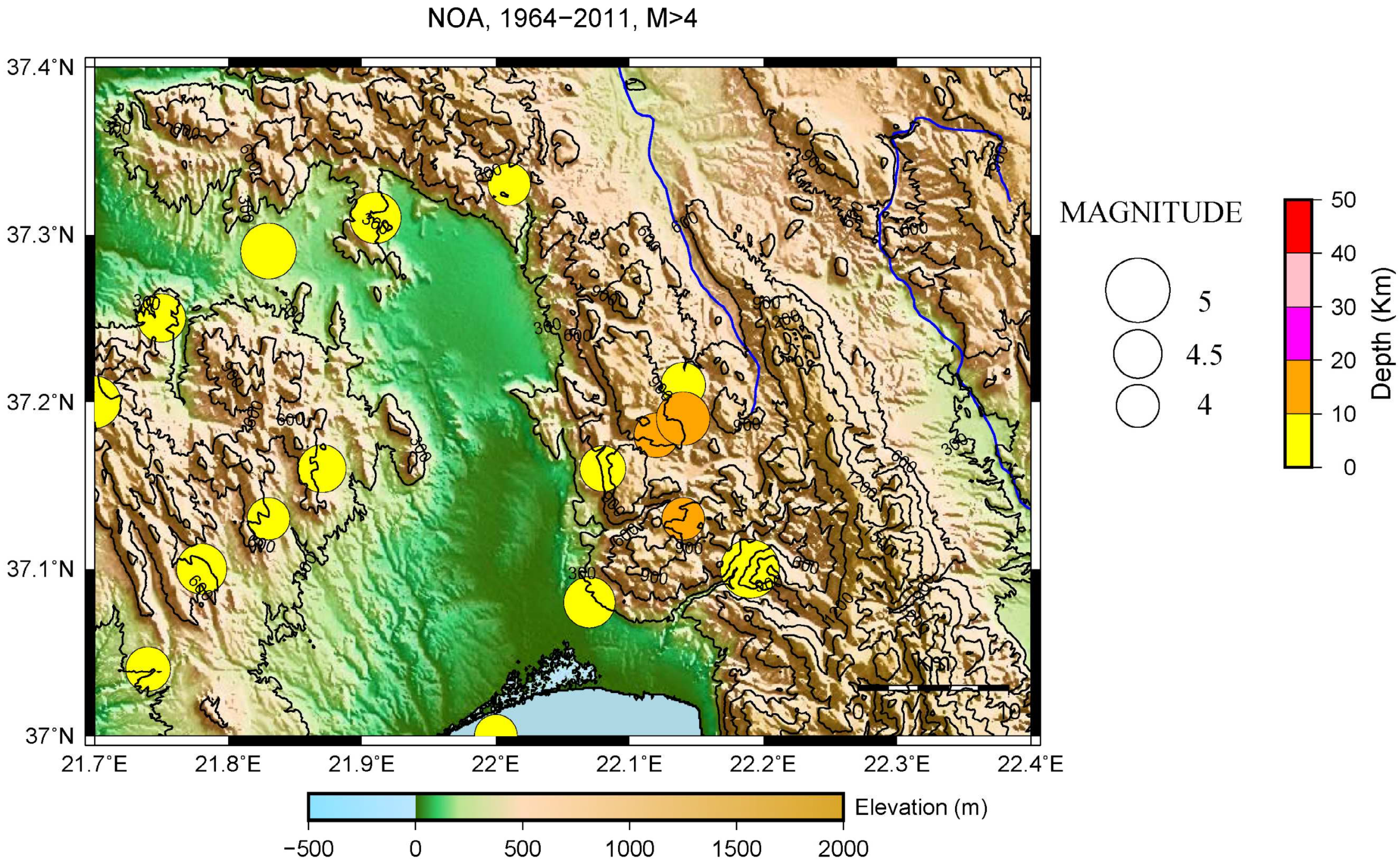


Time of Failure = 2008.949
Mag indeterminate
M fixed = 0.32
Cor-Coef = 0.97184
rms error/range = 0.075205
Cumulative Release
Time
28
26
24
22
20
18
16
14
2007.5
2008
2008.5
2009

It is the operational responsibility for NOA to evaluate the seismic hazard of an ongoing earthquake sequence and provide this information rapidly to the Greek civil protection authorities. Therefore, it is of great importance to rapidly resolve the nature of the seismic sequence in progress i.e., whether a foreshock activity which may lead to a large earthquake, or a minor microseismic activity with a weak main shock, or even a most frequently observed, swarm activity with no prevailing main shock. Each of these types of seismic activity has been associated with characteristic spatial and temporal seismicity patterns and seismicity rates and the monitoring of these physical processes may provide valuable information for the mitigation of seismic hazard in populated areas.


NOA, 2011−2012, M>1
37.4°N
37.3°N
37.2°N
37.1°N
37°N
21.6°E
21.7°E
21.8°E
21.9°E
22°E
22.1°E
22.2°E
22.3°E
22.4°E
14/8/2011 Mw=4.8
14/9/2011 Mw=4.6
10/10/2011 Mw=4.7
MAGNITUDE
5
4
3
2
1
Depth (Km)
50
40
30
20
10
0
Elevation (m)
−500
0
500
1000
1500
2000

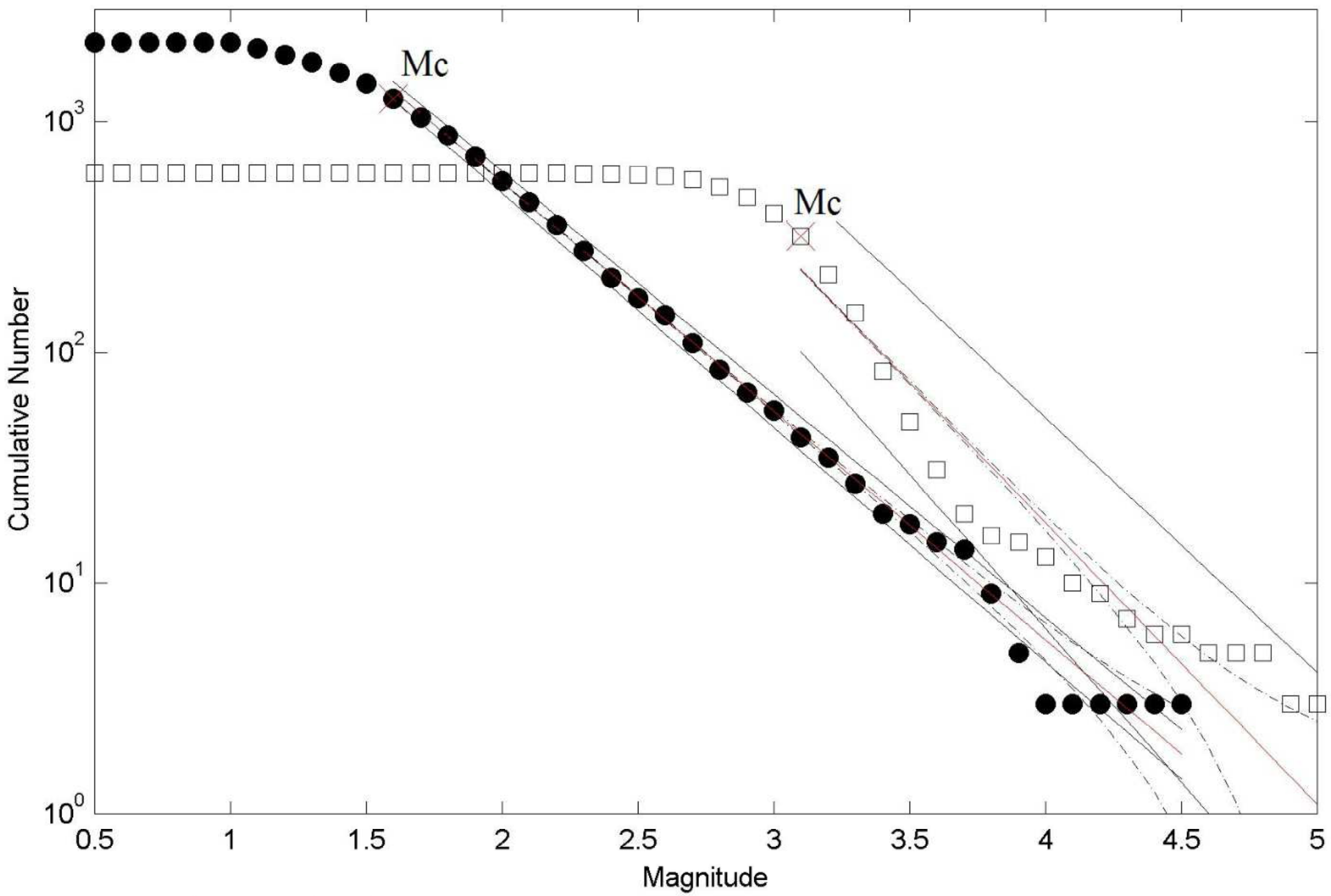

21°36'
21°48'
22°00'
22°12'
22°24'
37°24'
37°12'
37°00'
36°48'
36°36'
MES3
MES4
ITM
MES1
MES2
HL(NOA_IG) Xenios
HL(NOA_IG)
km
0
10


NOA, 1964−2011, M>4
37.4°N
37.3°N
37.2°N
37.1°N
37°N
21.7°E
21.8°E
21.9°E
22°E
22.1°E
22.2°E
22.3°E
22.4°E
MAGNITUDE
5
4.5
4
Depth (Km)
0
10
20
30
40
50
Elevation (m)
−500
0
500
1000
1500
2000
Km
0
10

The FMD describes the relationship between the frequency of occurrence and the magnitude of earthquakes (Ishimoto and Iida, 1939; Gutenberg and Richter, 1944):

$$\mathbf{Log10N(M) = a - bM}$$

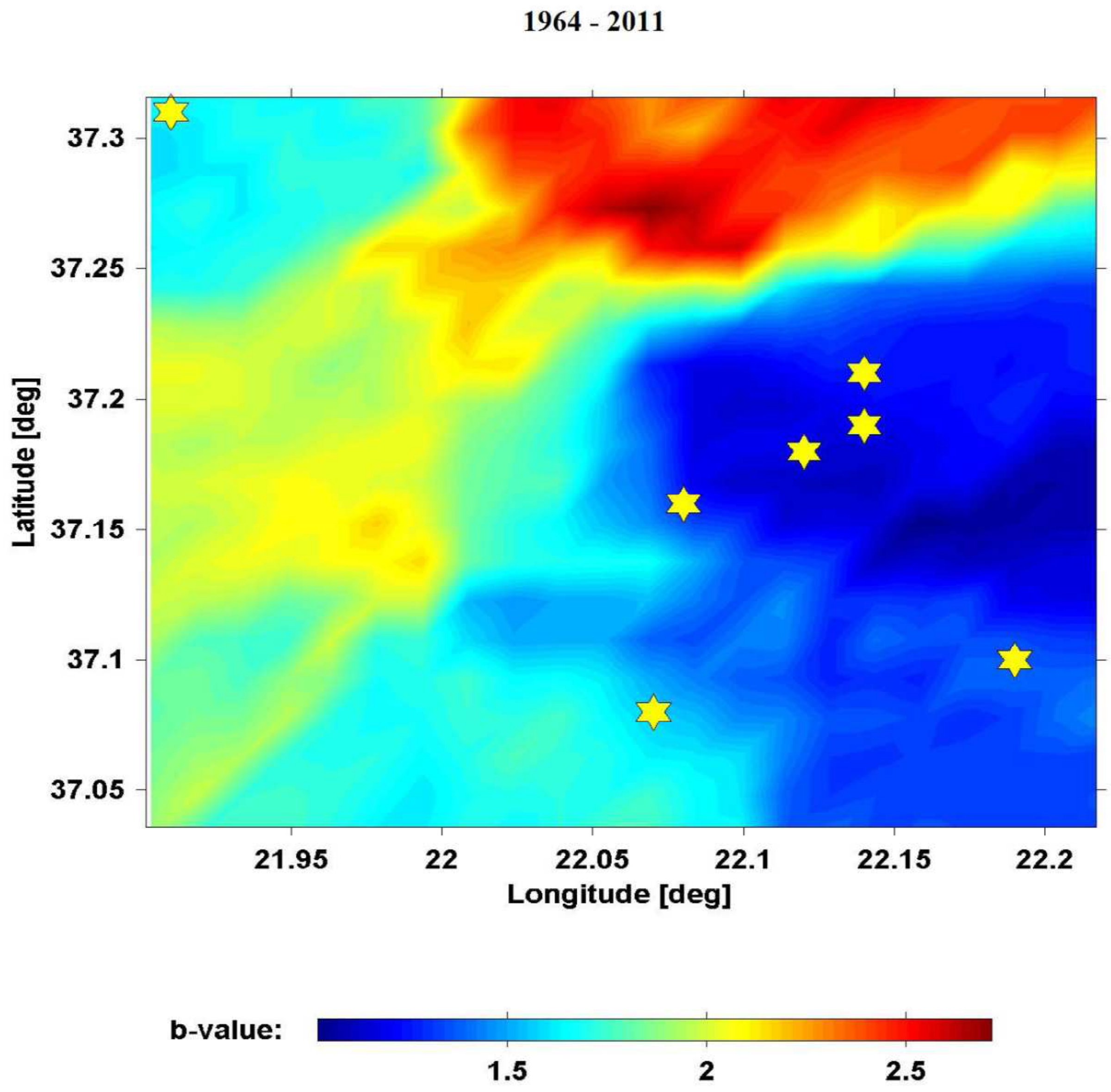
Where N is the cumulative number of earthquakes having magnitudes larger than M, a and b are constants. The b-value describes the relative size of the events. Variations of the b-value of the Gutenberg Richter frequency magnitude distribution have been associated with crustal stress level fluctuations and great M9-class earthquakes (Sumatra, 2004, Tohoku, 2011, Nanjo et al., (2012)). It is proposed that the b-value is inversely proportional to the applied stress, so the increase in confining pressure prior to large earthquakes will cause the b value to decrease accordingly (Scholz, 1968). Similarly, patterns of acoustic emissions have been reported to follow stress build up and release in laboratory fracture experiments (Goebbel et al., 2013). On the basis that b-values are found to vary systematically for different faulting types and Schloemmer et al. (2005) suggested that b-values may act as a ‘stress-meter’ of the applied differential stress. On a larger scale, the general observation that b values approach the value of 1 encouraged Kagan (1999) to indicate the universality of b=1 as a seismological constant. Departing from this constant are volcanic swarms and aftershock sequences with higher b-values, due to the high heterogeneity of smaller fractures and continental seismic swarms with lower b-values, due to the increase in the pore pressure from crustal fluid intrusion (Fisher et al., 2010, Ibs-von Seht, 2008).



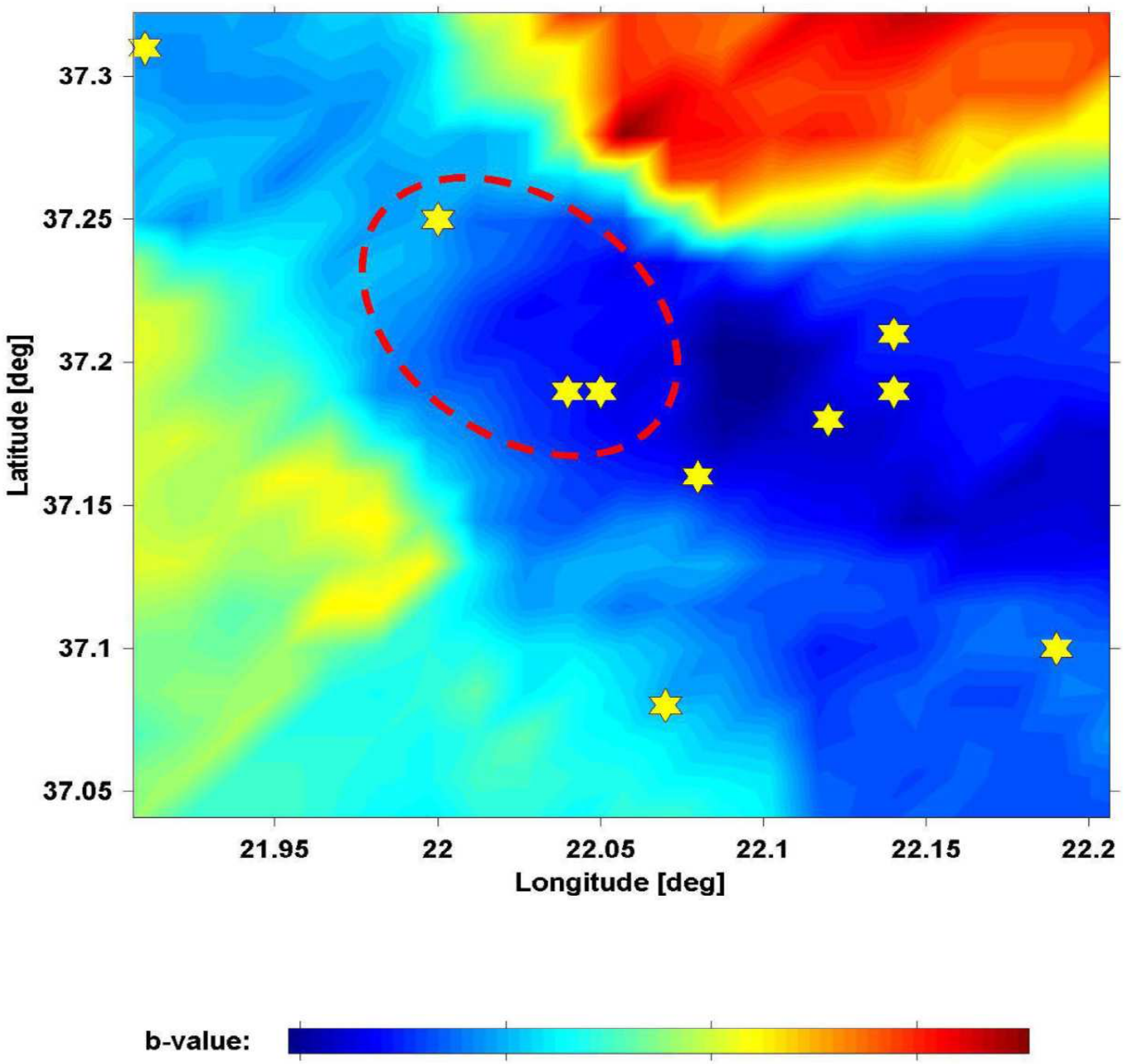
b1: -1.22, b2: -0.991

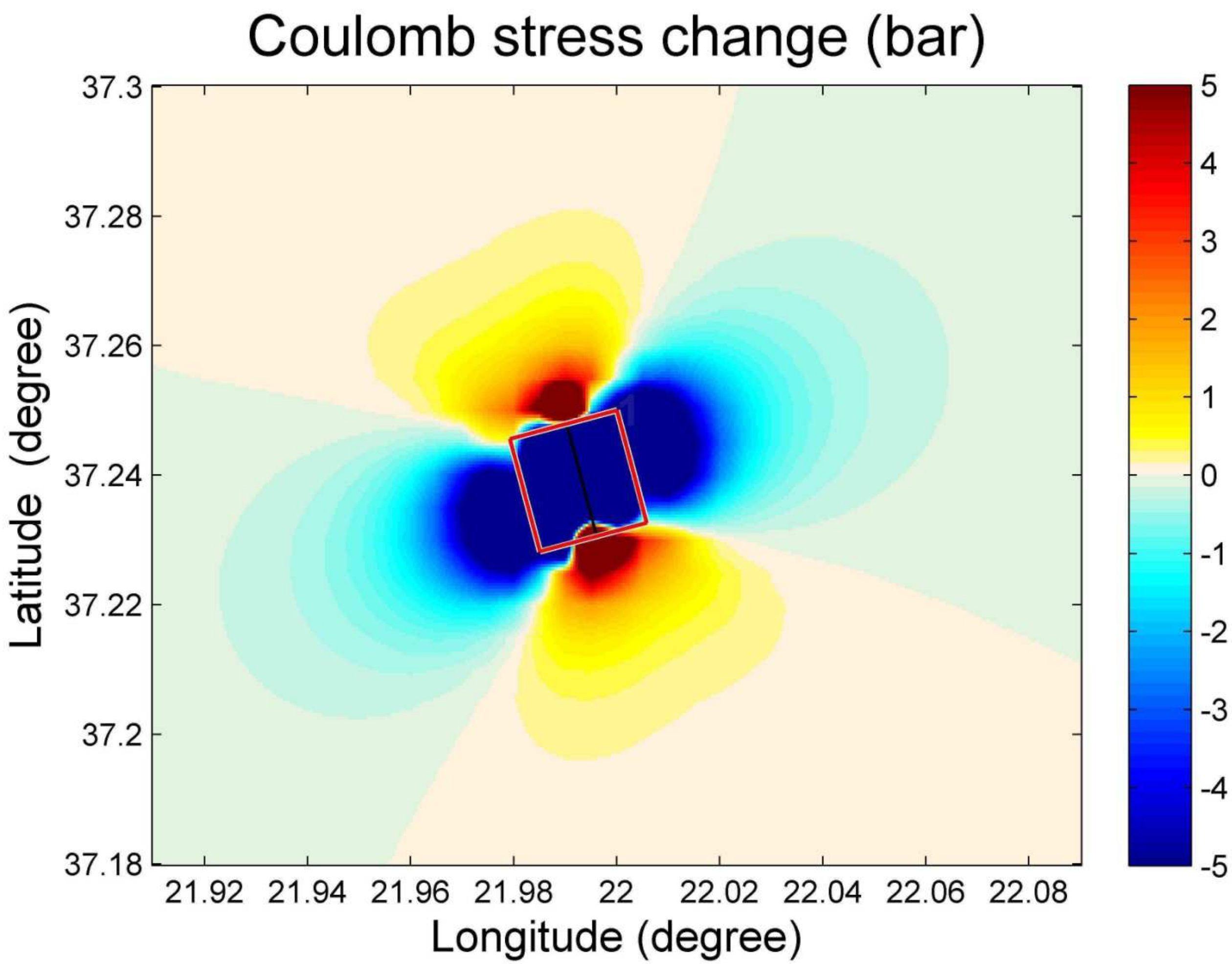
b-value (W LS, Mc >= 1.6): -0.991 +/- 0.01, a-value = 4.7205

b-value (W LS, Mc >= 3.1): -1.22 +/- 0.15, a-value = 6.1372

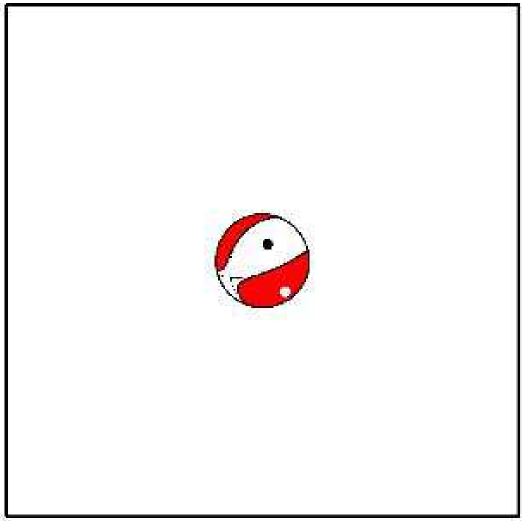

1964 - 2011
37.3
37.25
37.2
37.15
37.1
37.05
Latitude [deg]
21.95
22
22.05
22.1
22.15
22.2
Longitude [deg]
b-value:
1.5
2
2.5

1964 - 2012


37.3
37.25
37.2
37.15
37.1
37.05
Latitude [deg]
21.95
22
22.05
22.1
22.15
22.2
Longitude [deg]
b-value:
1
1.5
2
2.5



Strike/Dip/Rake: 165/34/-71
Depth: 6.6 km,
Friction: 0.4



MOMENT TENSOR SOLUTION

HYPOCENTER LOCATION (NOA-IG)

Origin time 20130531 08:57:25.26
Lat 38.2372 Lon 22.1207 Depth 10

CENTROID

Trial source number : 5 (Fixed Epicenter inversion)
Centroid Lat (N)38.2372 Lon (E)22.1207
Centroid Depth (km) : 10
Centroid time : +1.2 (sec) relative to origin time

Moment (Nm) : 3.654e+14
Mw : 3.6
VOL% :0
DC% :81.2
CLVD% :18.8
Quality :B1
Var.red.(for stations used in inversion):0.51 Condition Number : 2.46
Var.red.(for all stations) :0.012

Strike	Dip	Rake
201	33	-136
72	68	-65

P-axis	Azimuth	Plunge
	18	59

T-axis	Azimuth	Plunge
	144	19

Mrr	Mtt	Mpp
-2.188	1.337	0.851

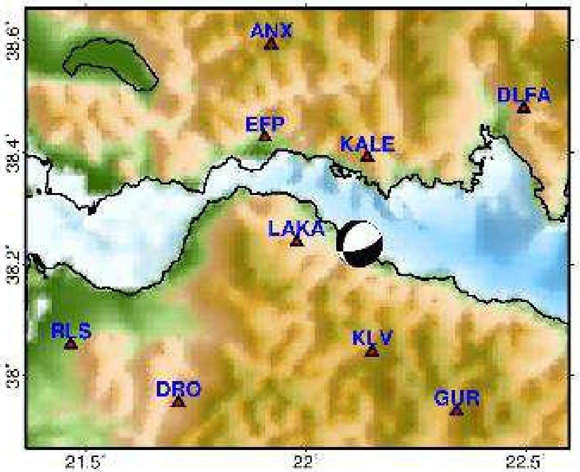
Mrt	Mrp	Mtp
-2.353	-0.344	2.011

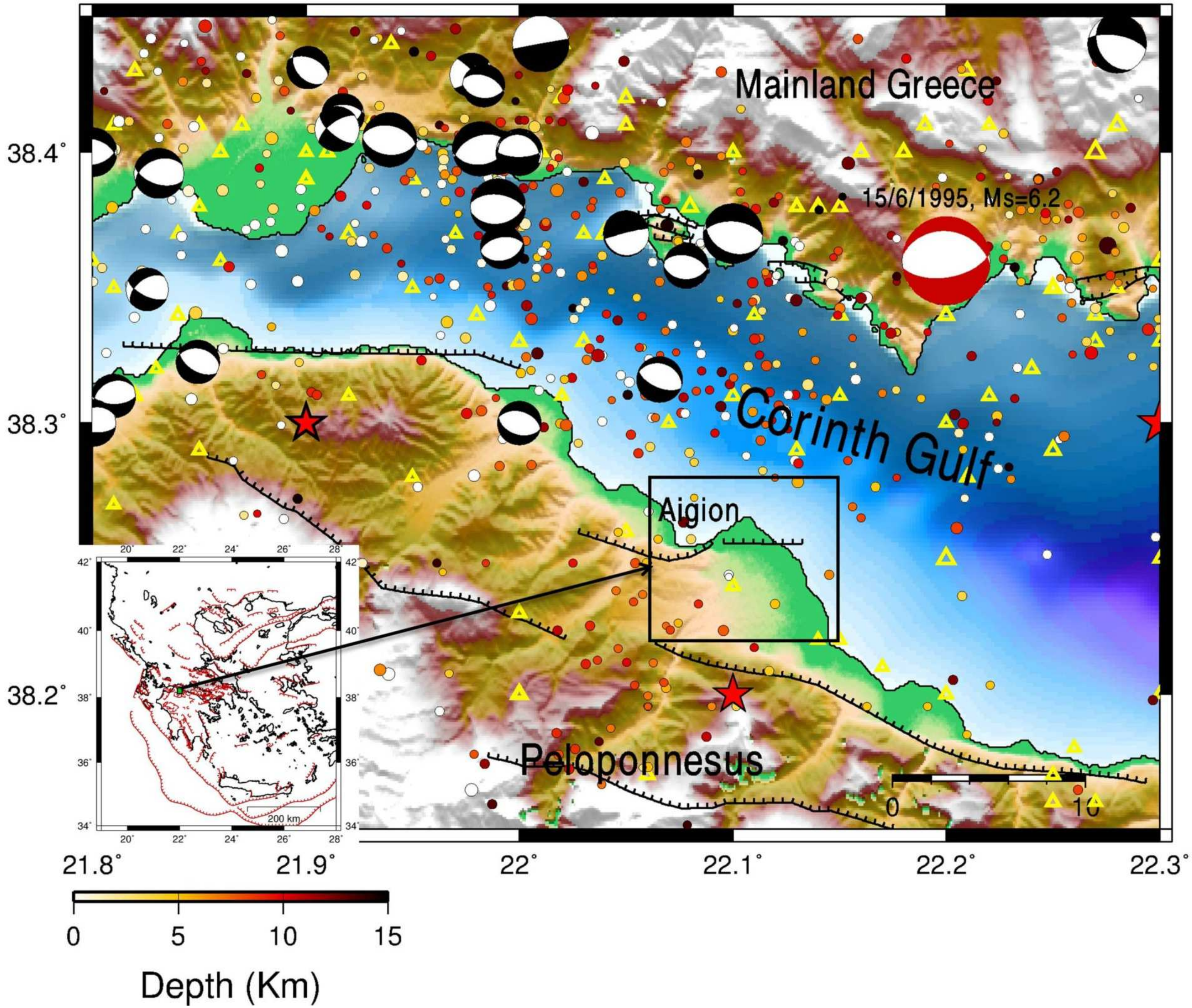
Exponent (Nm): 14

Frequency band used in inversion (Hz)
0.04 - 0.05 -- 0.08 - 0.09

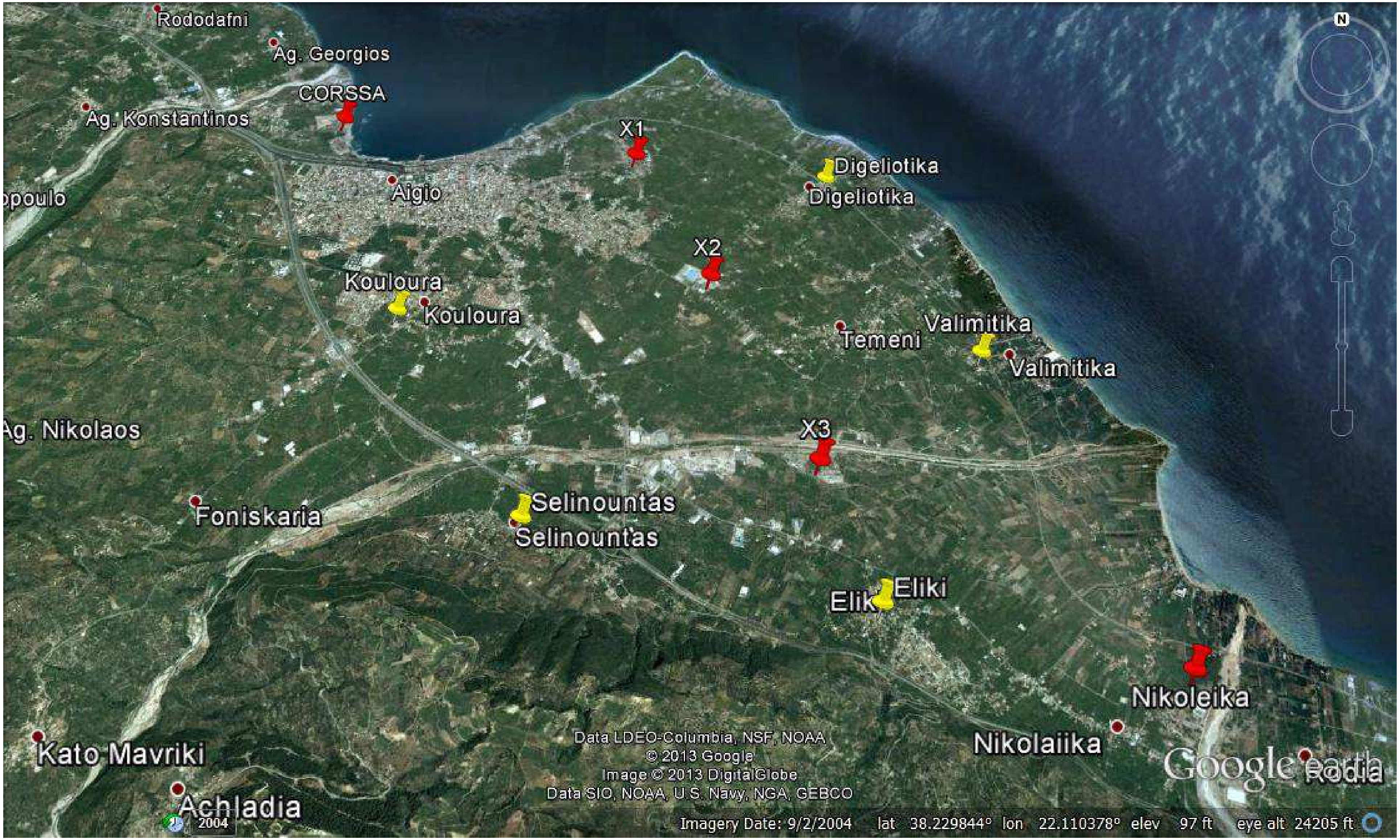
Stations-Components Used-Distance

	NS	EW	Z	D(km)
LAKA	+	-	+	12
KALE	+	+	+	17
KLV	+	+	+	22
EFP	-	-	-	28
GUR	+	-	+	39
DLFA	-	-	-	42
ANX	+	+	+	43
DRO	+	-	+	48
RLS	-	-	-	61

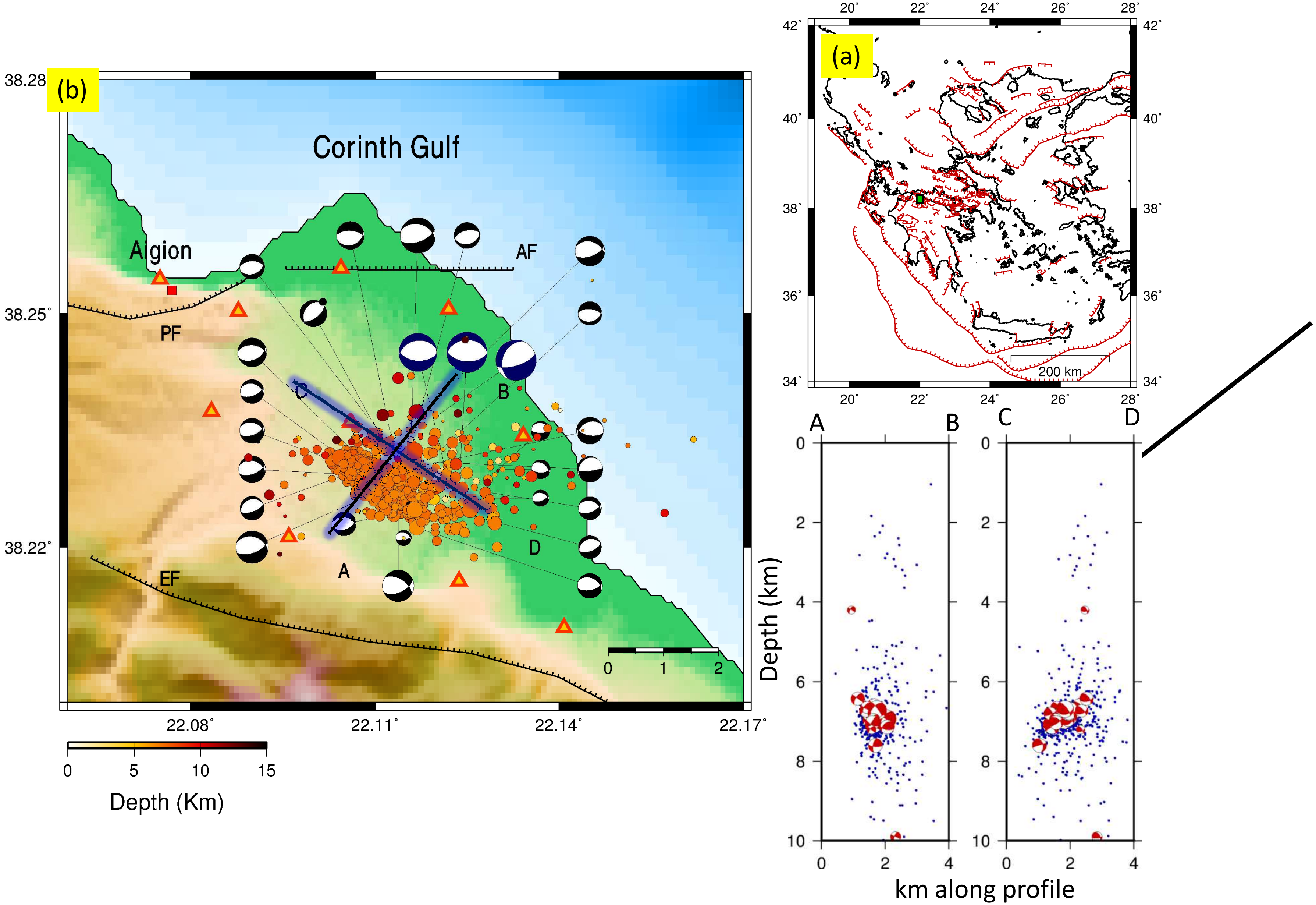


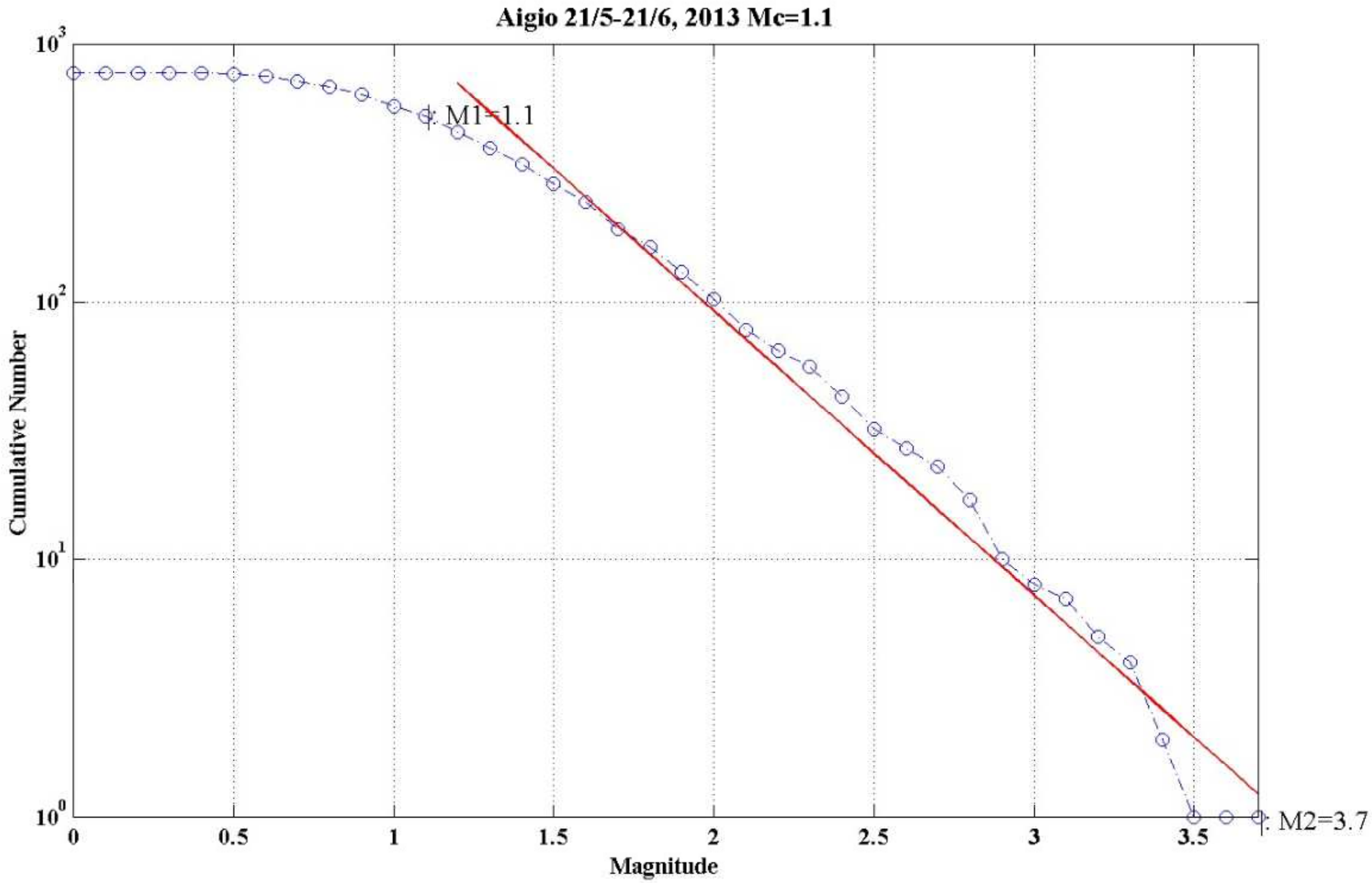


Mainland Greece
15/6/1995, Ms=6.2
Corinth Gulf
Aigion
Peloponnesus
38.4°
38.3°
38.2°
21.8°
21.9°
22°
22.1°
22.2°
22.3°
0
10
200 km
0
5
10
15
Depth (Km)



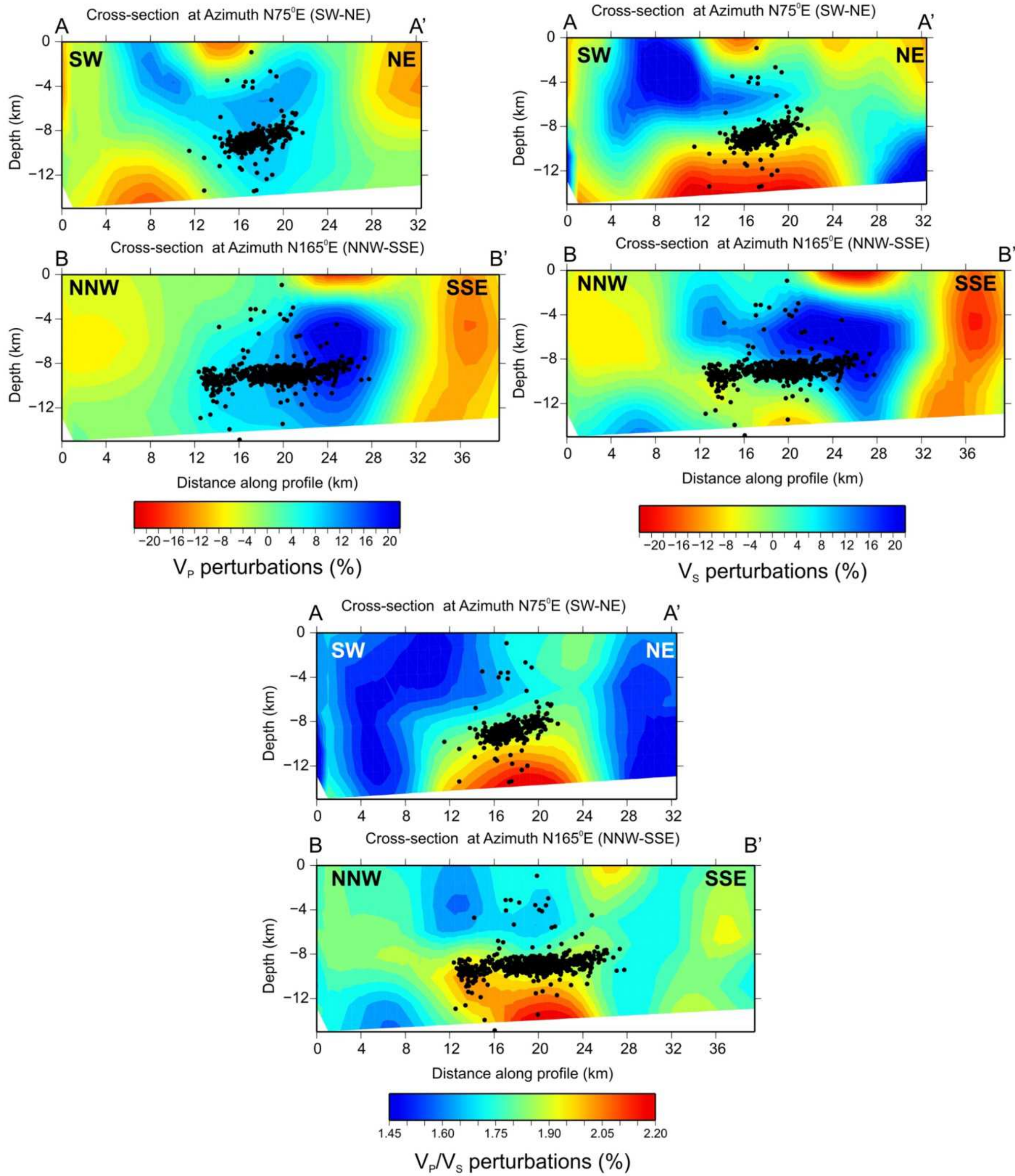
Rododafni
Ag. Georgios
CORSSA
Ag. Konstantinos
X1
Digeliotika
Digeliotika
Aigio
opoulo
X2
Kouloura
Kouloura
Temeni
Valimitika
Valimitika
Ag. Nikolaos
X3
Selinountas
Selinountas
Foniskaria
Eliki
Elik
Nikoleika
Nikolaiika
Kato Mavriki
Achladia
Rodia
Data LDEO-Columbia, NSF, NOAA
© 2013 Google
Image © 2013 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
2004
Imagery Date: 9/2/2004 lat 38.229844° lon 22.110378° elev 97 ft eye alt 24205 ft


(b)
Corinth Gulf
Aigion
AF
PF
EF
A
B
C
D
0
1
2
38.28
38.25°
38.22°
22.08°
22.11°
22.14°
22.17°
0
5
10
15
Depth (Km)
(a)
20°
22°
24°
26°
28°
42°
40°
38°
36°
34°
200 km
A
B
C
D
Depth (km)
km along profile



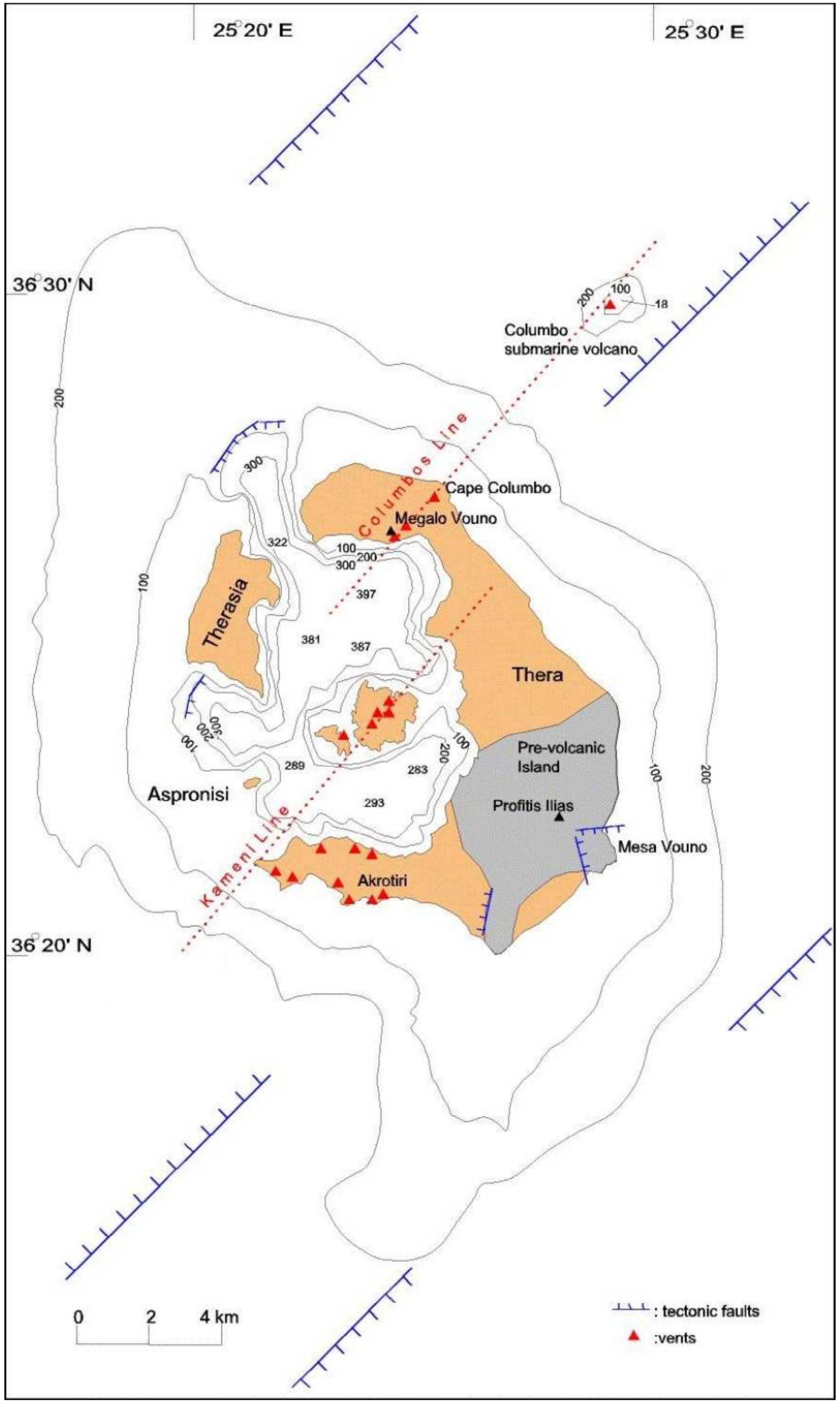
B-Value: 1.1

Standard Deviation: 0.11

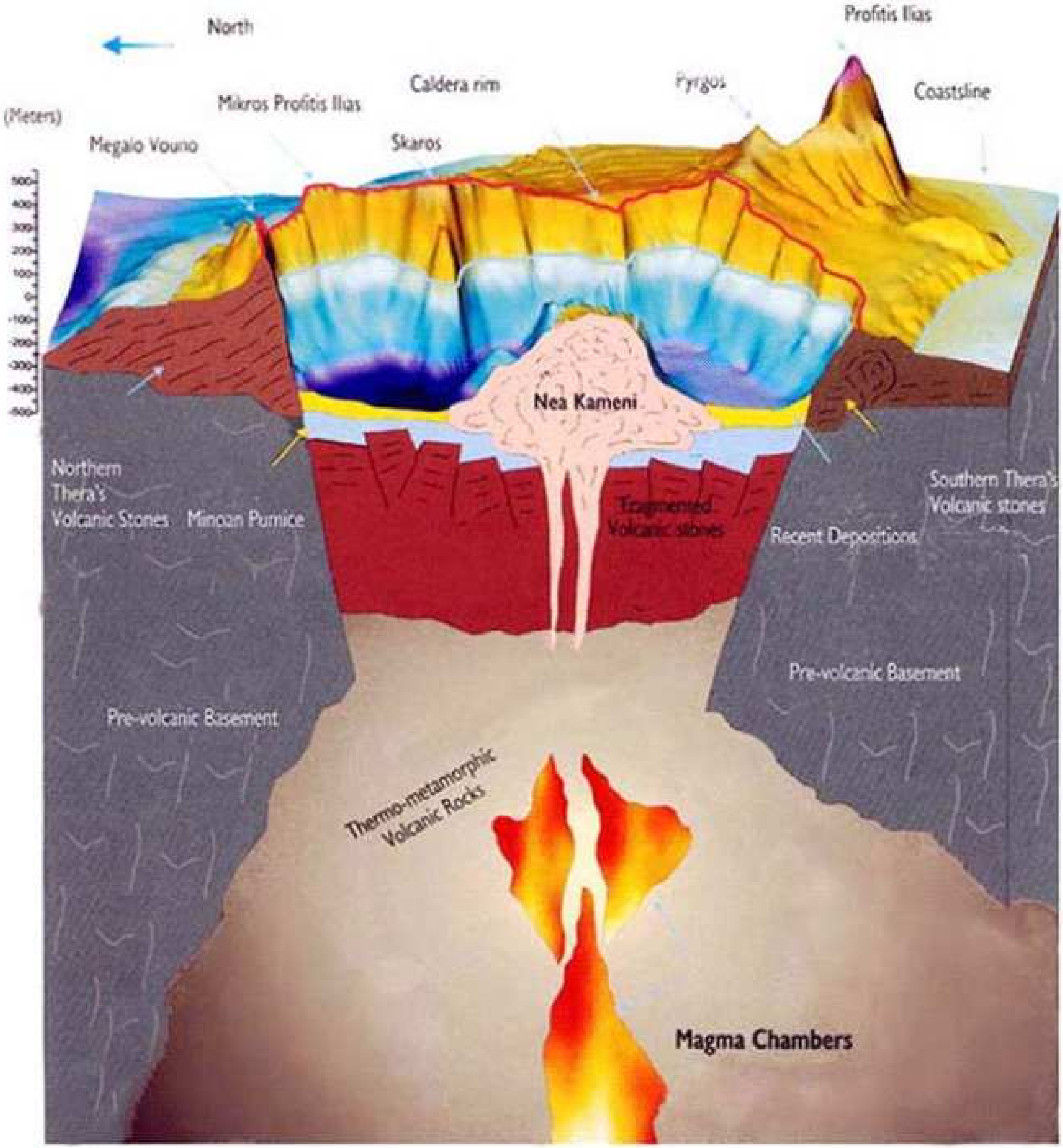


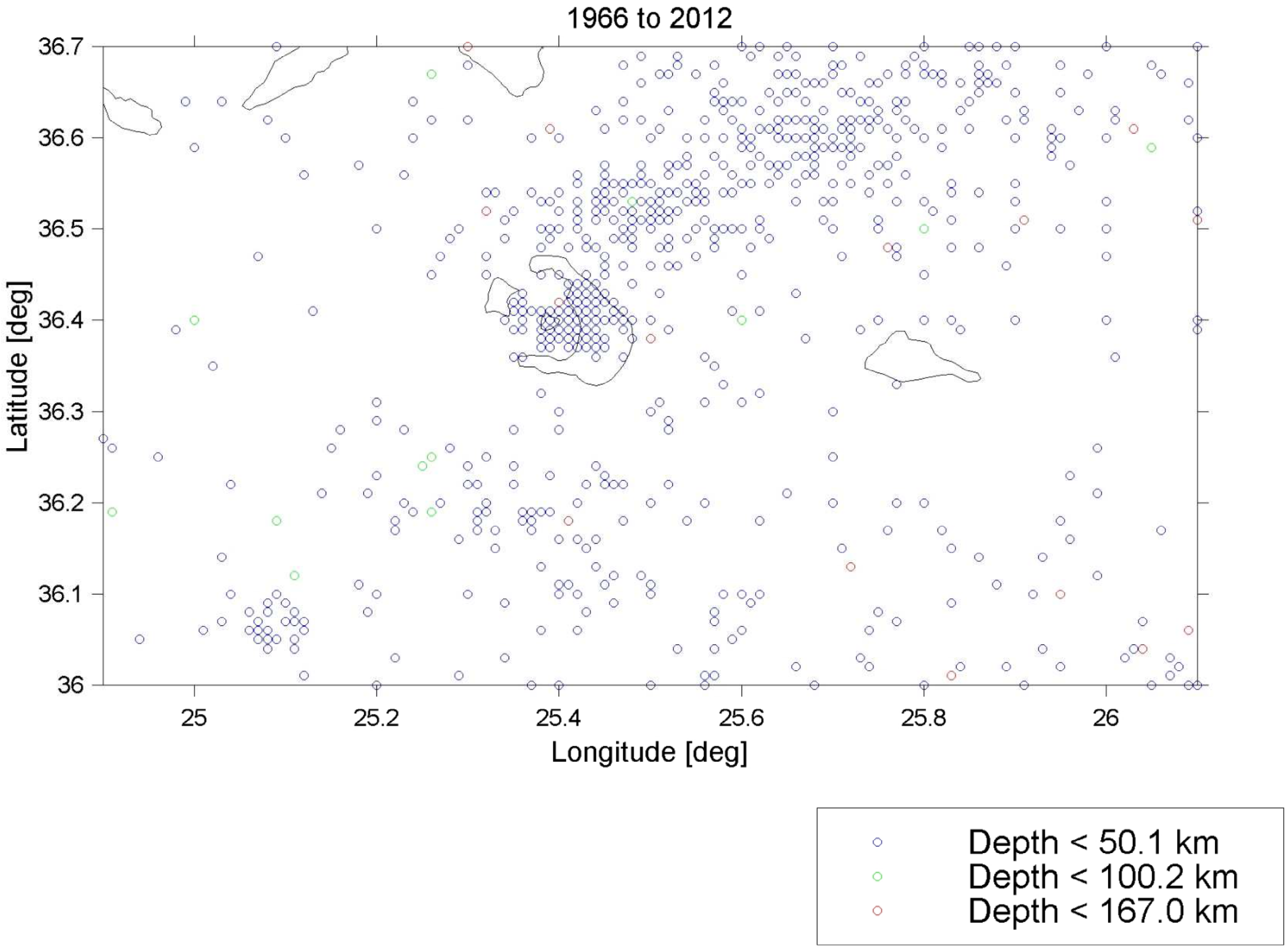
Cross-section at Azimuth N75°E (SW-NE)
A
A'
SW
NE
Depth (km)
0
-4
-8
-12
0 4 8 12 16 20 24 28 32
Cross-section at Azimuth N165°E (NNW-SSE)
B
B'
NNW
SSE
0 4 8 12 16 20 24 28 32 36
Distance along profile (km)
−20 −16 −12 −8 −4 0 4 8 12 16 20
V_P perturbations (%)
V_S perturbations (%)
1.45 1.60 1.75 1.90 2.05 2.20
V_P/V_S perturbations (%)

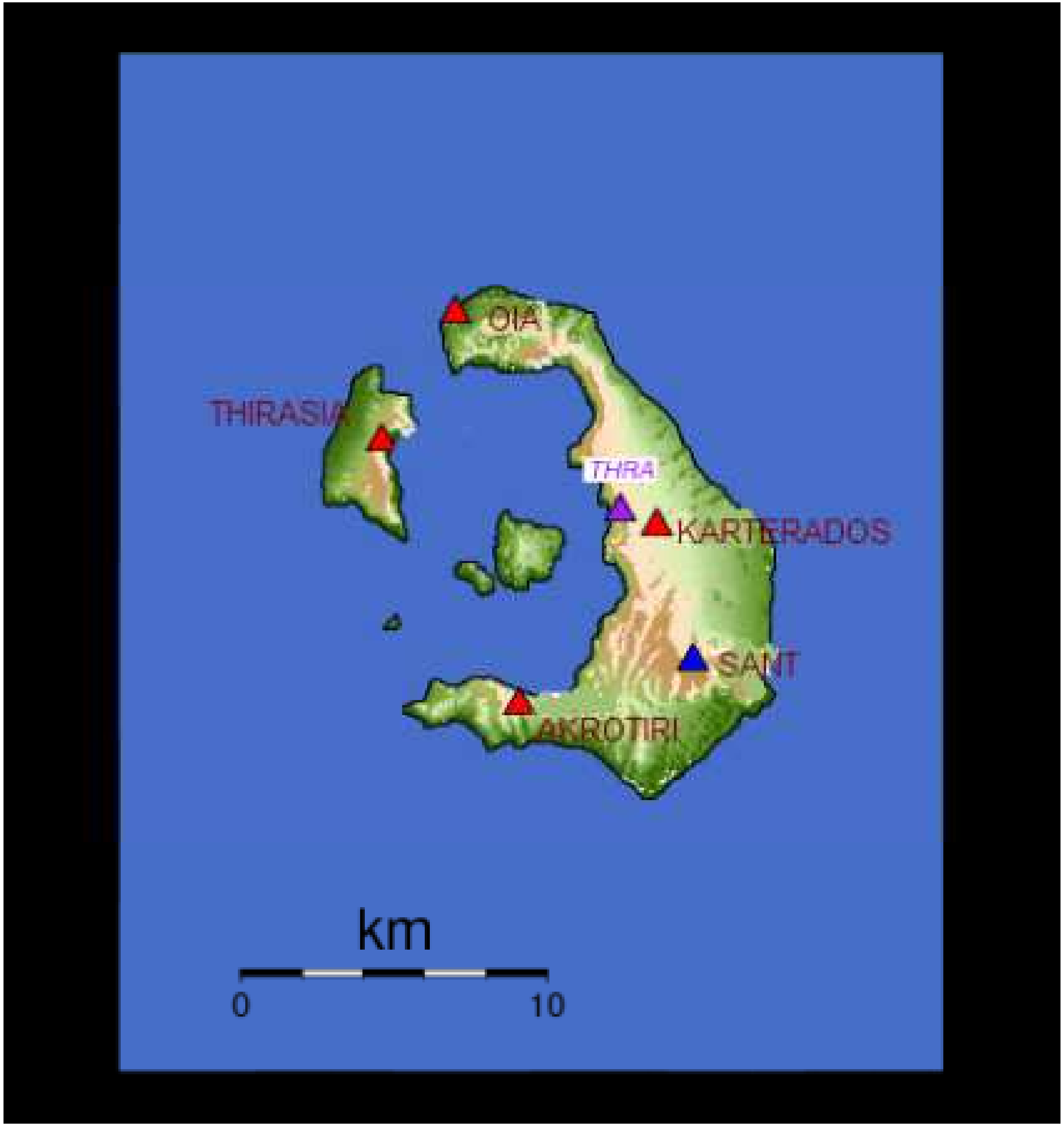

ARCHIPELAGO
SANTORIN
ISLAND
ANCIENT THERA
SURVEYED BY CAPTAIN THOMAS GRAVES F.R.G.S
H.M.S. VOLAGE
1848.
SOUNDINGS IN FATHOMS
THERASIA
NEO KAIMENI
MIKRO KAIMENI
PALÆO KAIMENI
ASPRO NISI
Vineyards
Nautic Miles

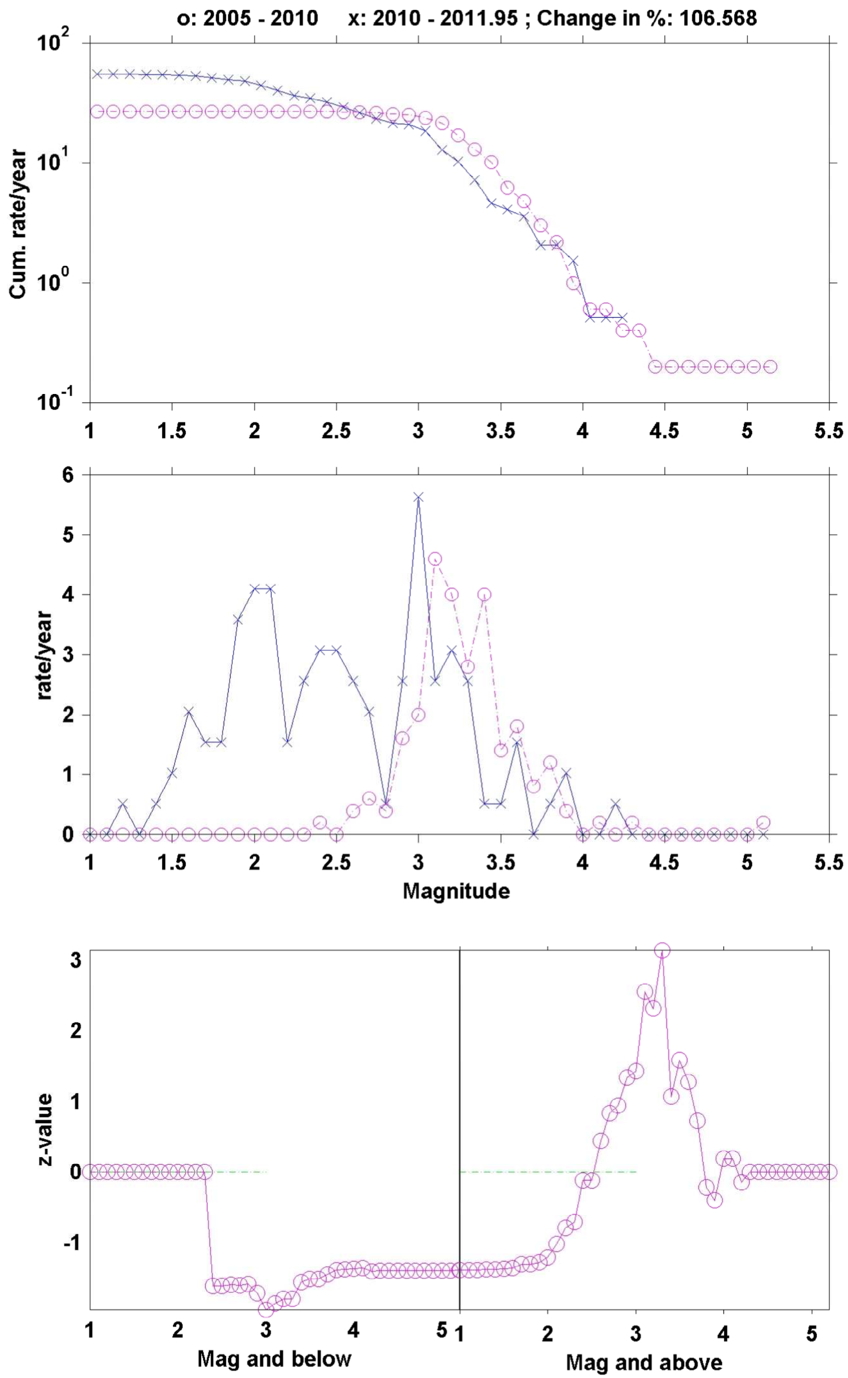

25°20' E
25°30' E
36°30' N
36°20' N
Columbo submarine volcano
Columbos Line
Cape Columbo
Megalo Vouno
Therasia
Thera
Pre-volcanic Island
Profitis Ilias
Mesa Vouno
Aspronisi
Akrotiri
Kameni Line
0 2 4 km
: tectonic faults
:vents

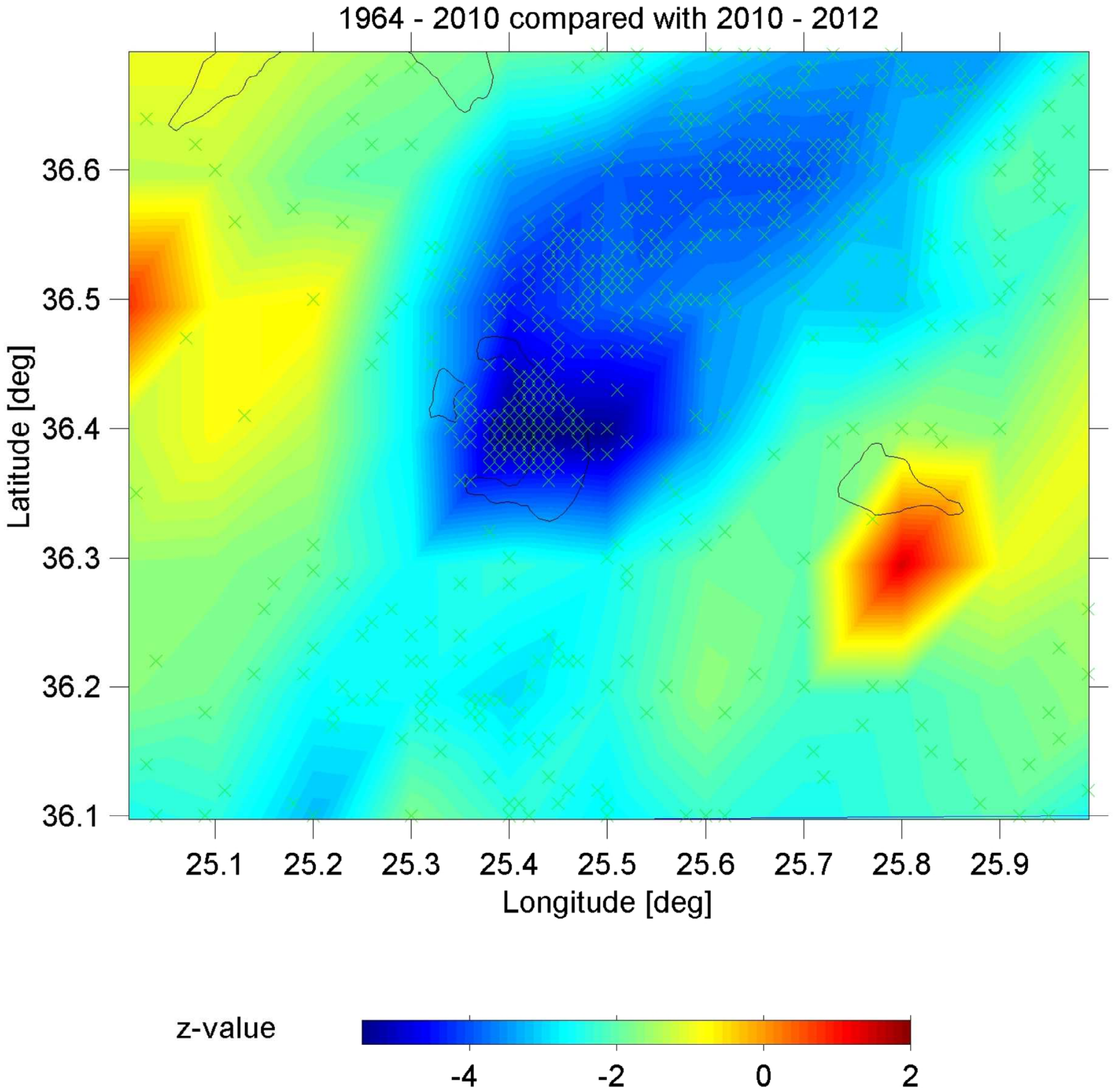
Schematic geological section of Santorini



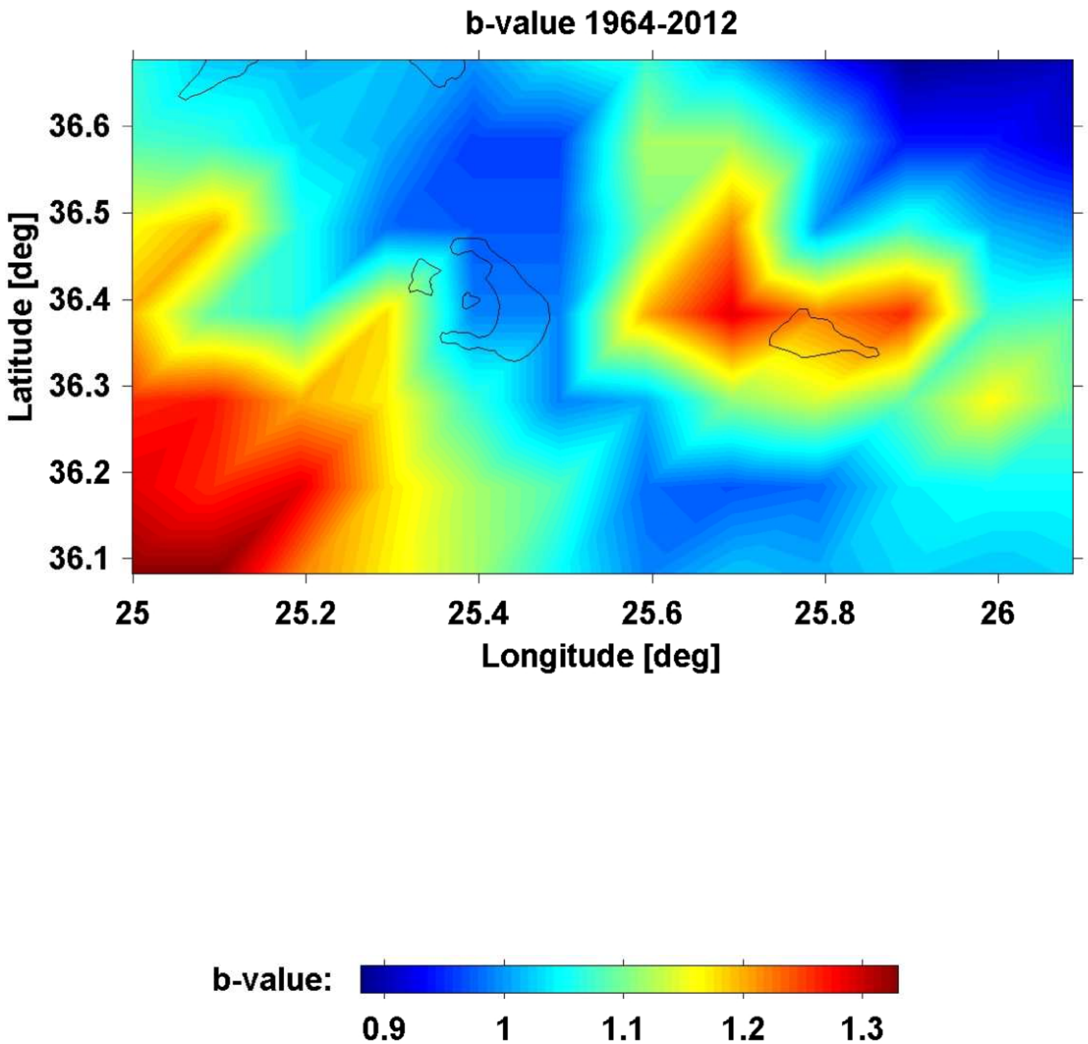

1966 to 2012
36.7
36.6
36.5
36.4
36.3
36.2
36.1
36
Latitude [deg]
25
25.2
25.4
25.6
25.8
26
Longitude [deg]
Depth < 50.1 km
Depth < 100.2 km
Depth < 167.0 km


OIA
THIRASIA
THRA
KARTERADOS
SANT
AKROTIRI
km
0
10

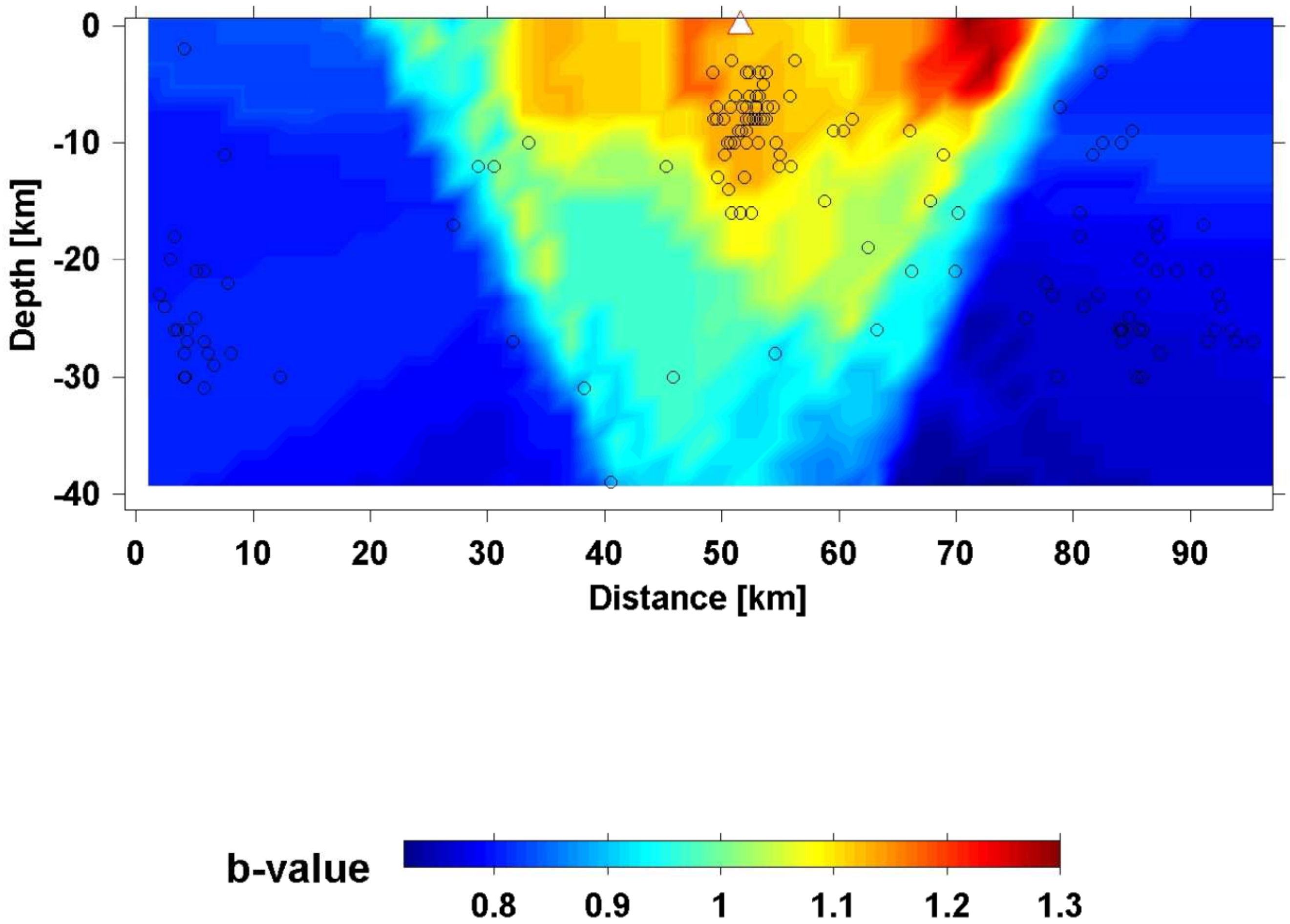

o: 2005 - 2010 x: 2010 - 2011.95 ; Change in %: 106.568
Cum. rate/year
rate/year
Magnitude
z-value
Mag and below
Mag and above



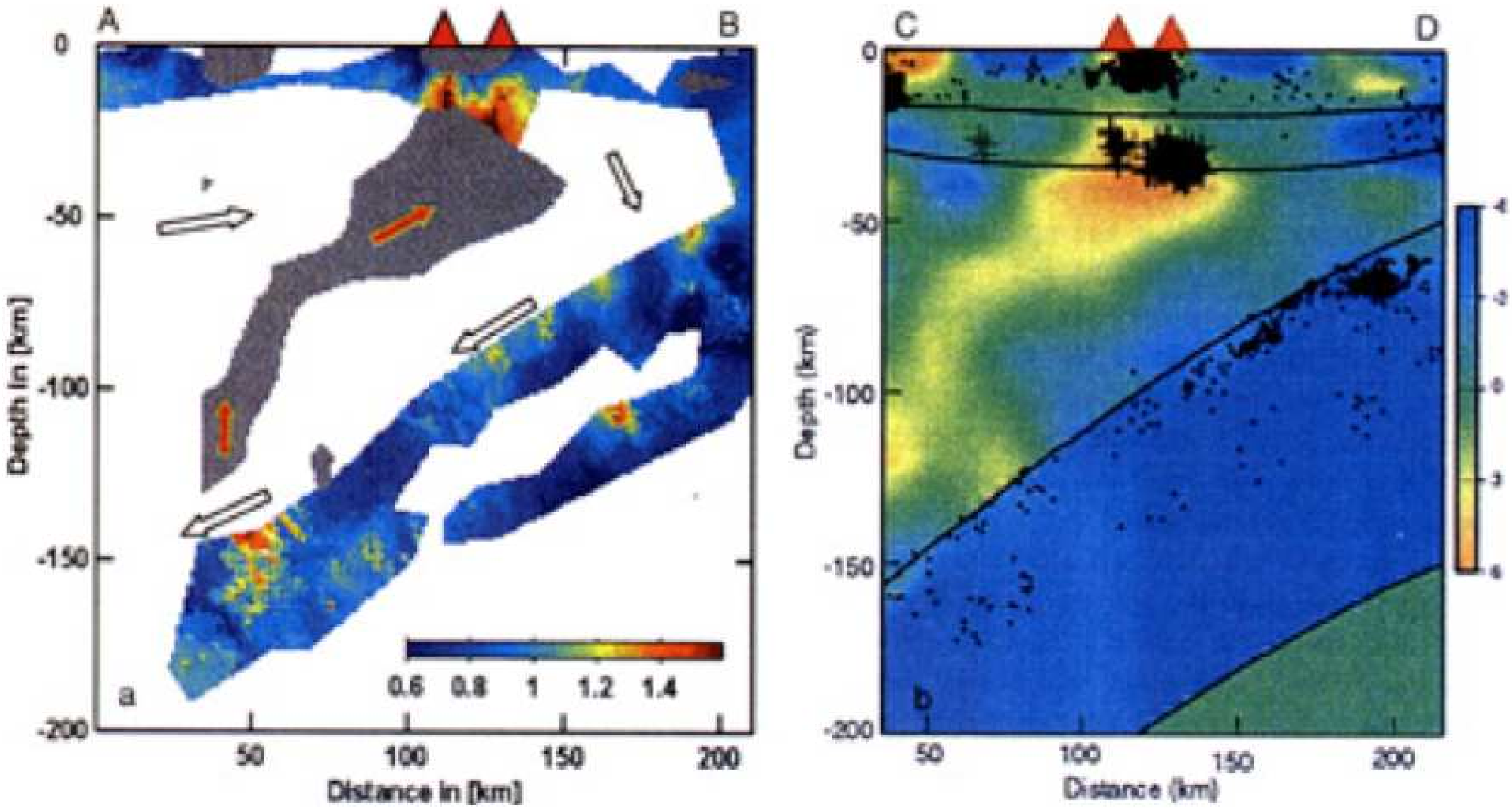
1964 - 2010 compared with 2010 - 2012
Latitude [deg]
36.6
36.5
36.4
36.3
36.2
36.1
25.1
25.2
25.3
25.4
25.5
25.6
25.7
25.8
25.9
Longitude [deg]
z-value
-4
-2
0
2



b-value 1964-2012
36.6
36.5
36.4
36.3
36.2
36.1
Latitude [deg]
25
25.2
25.4
25.6
25.8
26
Longitude [deg]
b-value:
0.9
1
1.1
1.2
1.3

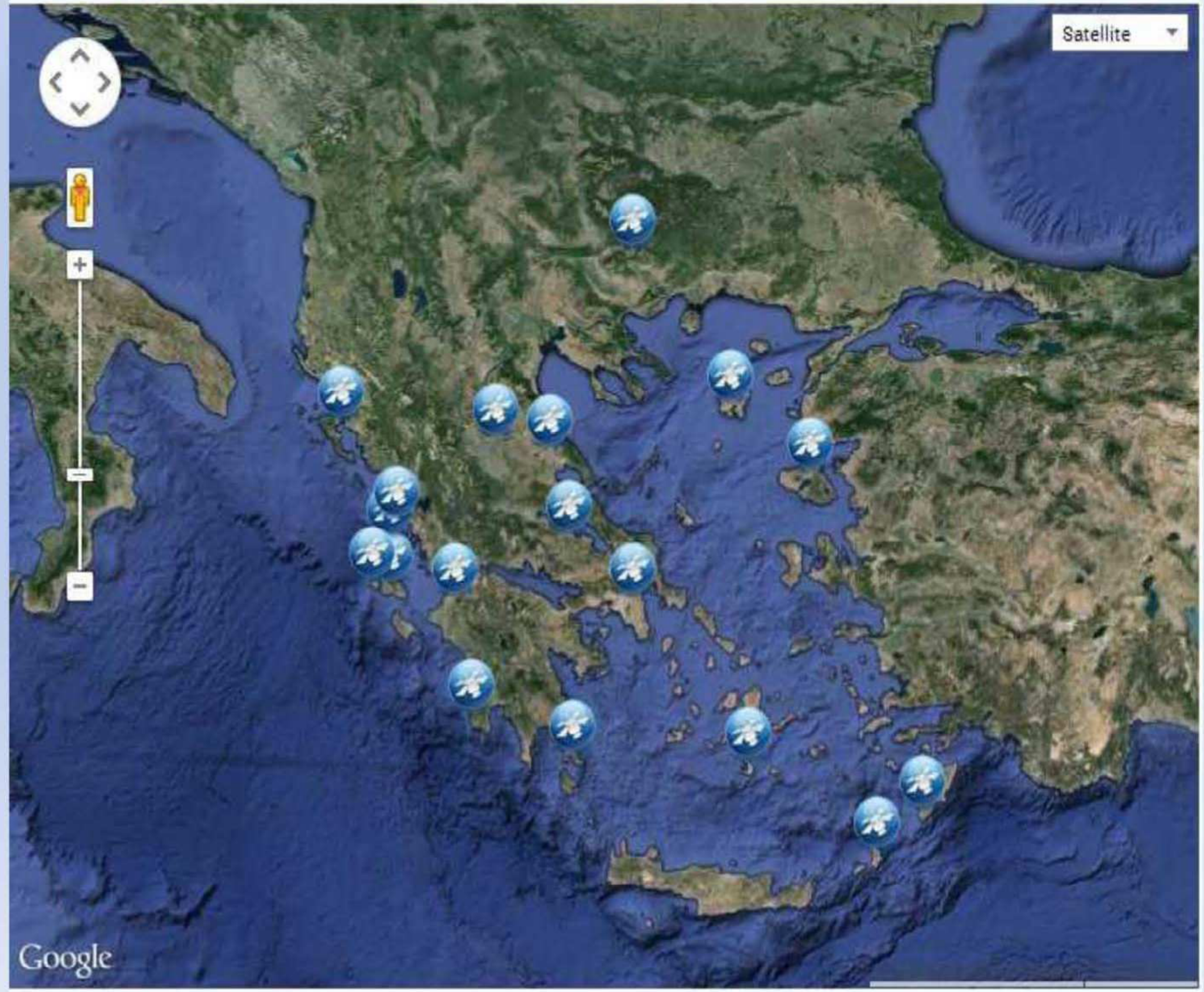


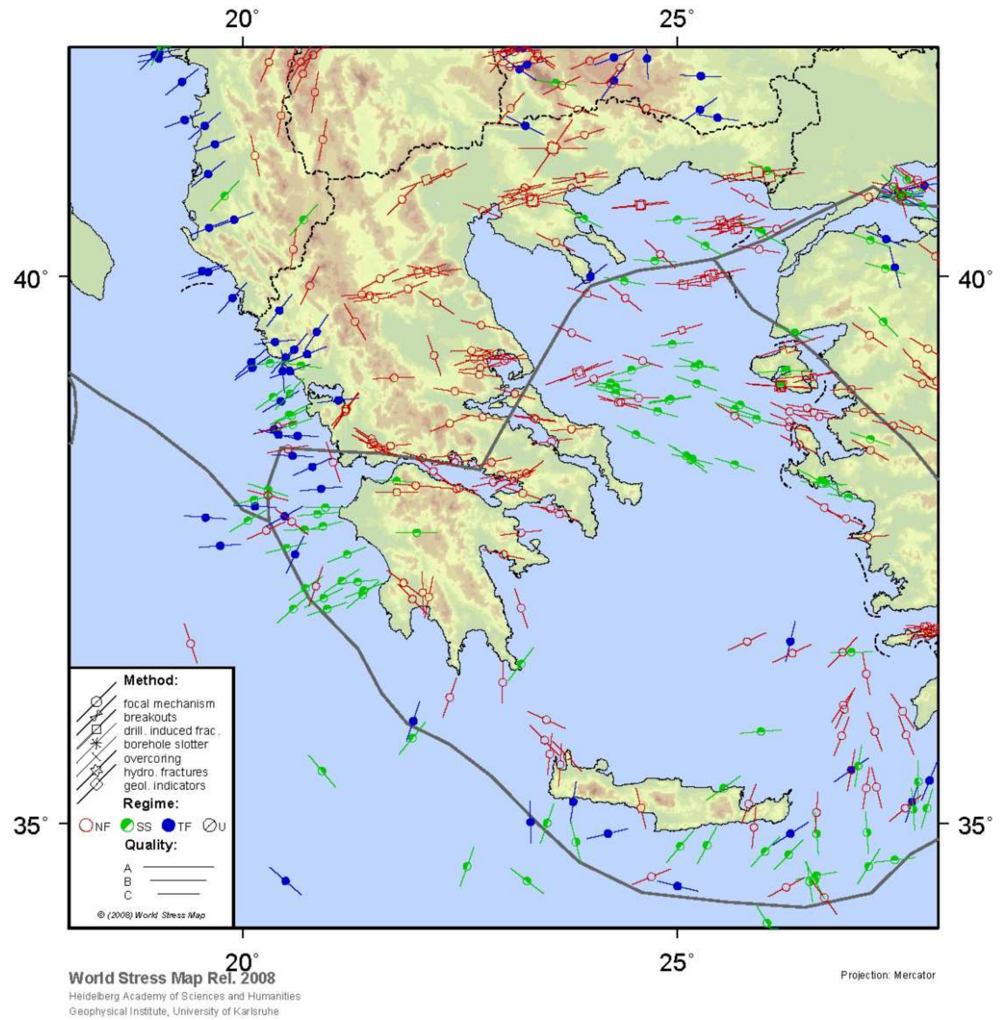
0
-10
-20
-30
-40
Depth [km]
0
10
20
30
40
50
60
70
80
90
Distance [km]
b-value
0.8
0.9
1
1.1
1.2
1.3

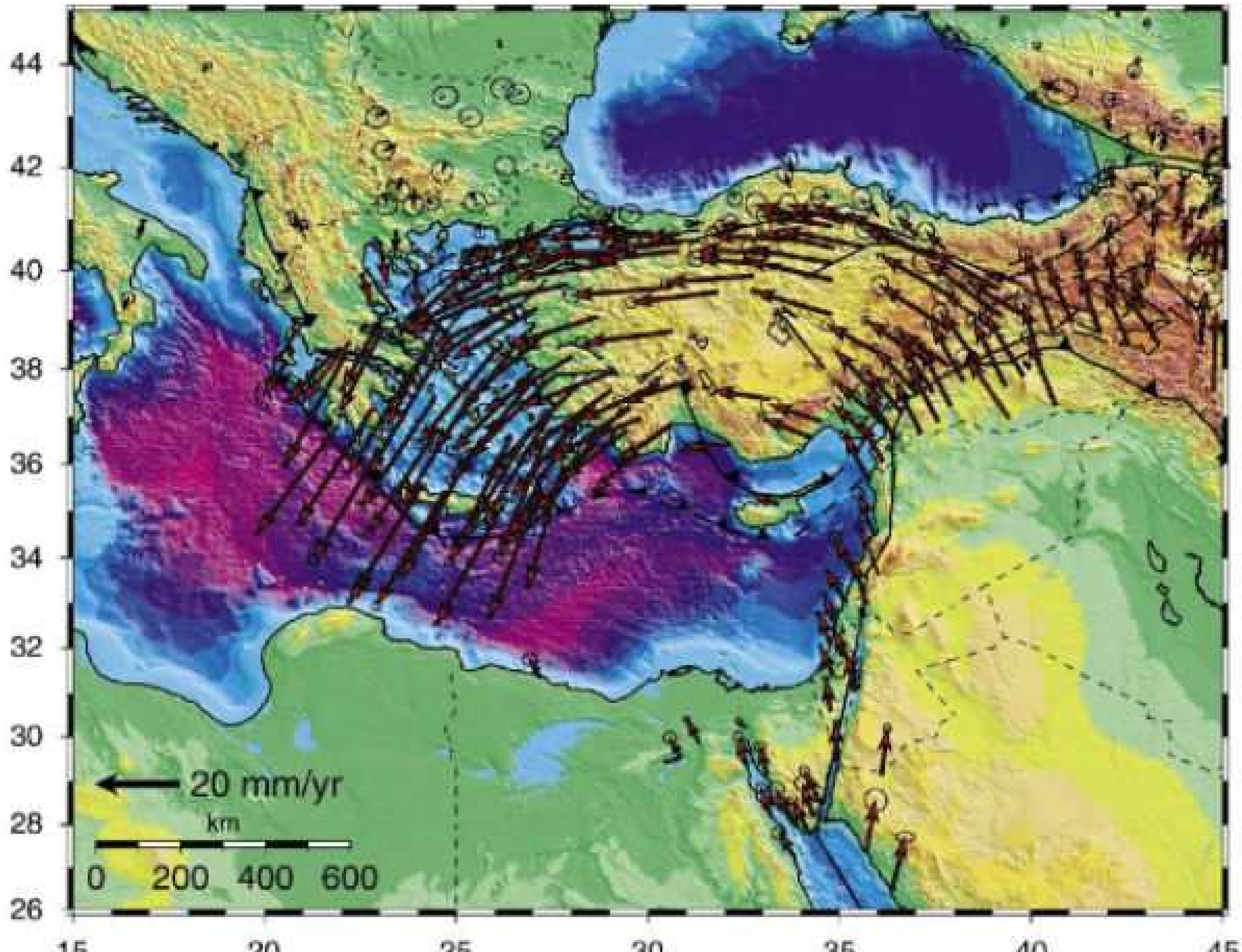

A
B
0
-50
-100
-150
-200
Depth in [km]
50
100
150
200
Distance in [km]
0.6
0.8
1
1.2
1.4
a
C
D
Depth (km)
Distance (km)
b

Networks operated by NOA

A **GPS network** of continuous **20** stations with data to rapidly detect uplift and subsidence is expansion combining existing CGPS stations operating off line for research purposes real time operation and link to the HL-NTWC.



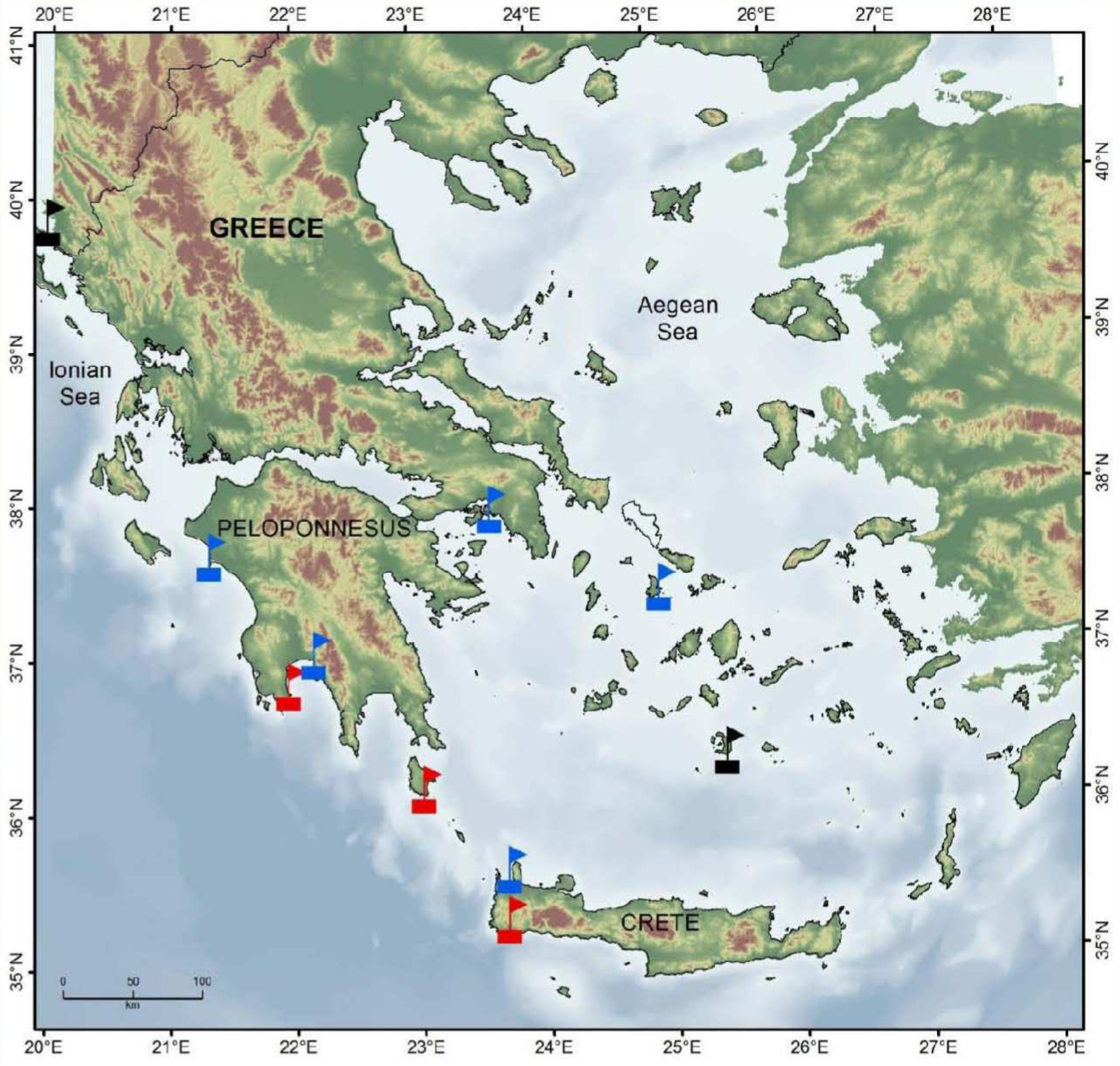

20°
25°
40°
35°
Method:
focal mechanism
breakouts
drill. induced frac.
borehole slotter
overcoring
hydro. fractures
geol. indicators
Regime:
NF SS TF U
Quality:
A
B
C
© (2008) World Stress Map
World Stress Map Rel. 2008
Heidelberg Academy of Sciences and Humanities
Geophysical Institute, University of Karlsruhe
Projection: Mercator


44
42
40
38
36
34
32
30
28
26
15
20
25
30
35
40
45
20 mm/yr
km
0
200
400
600

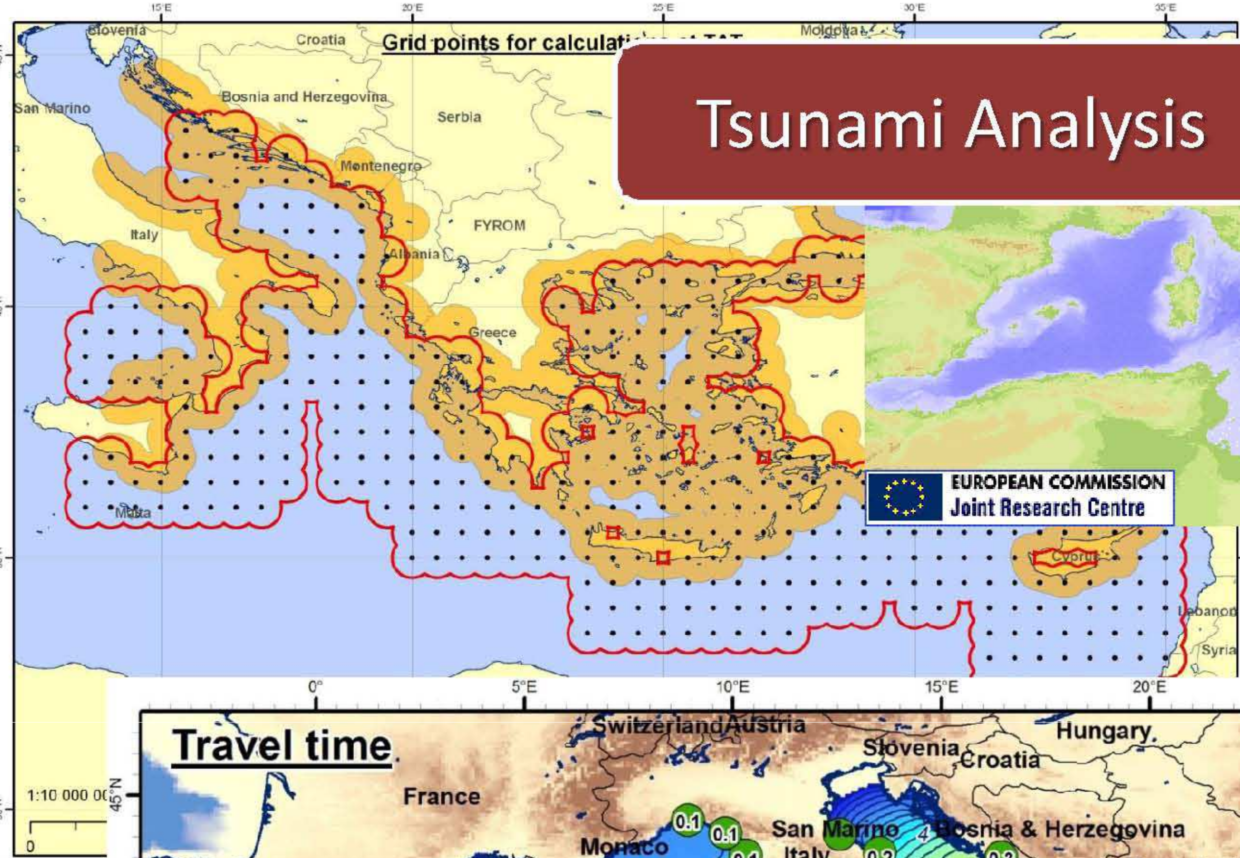
Networks operated by NOA

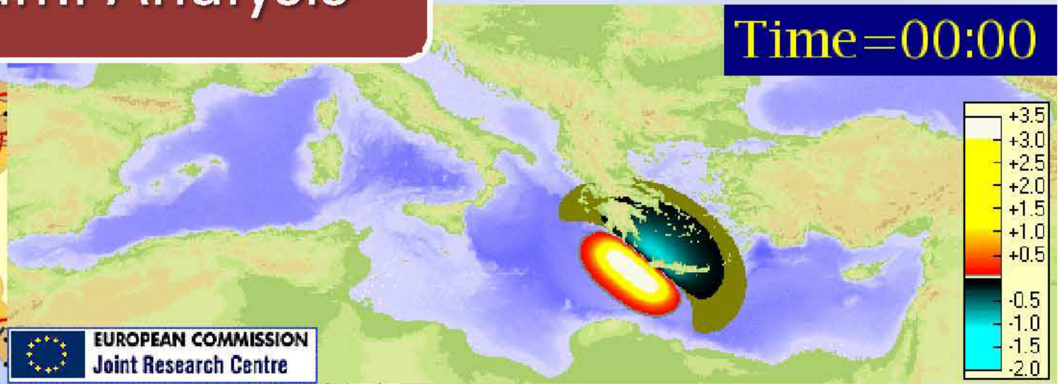
A **tide-gauge network** of **11** stations is already available in real time to NOA-HLNTWC.

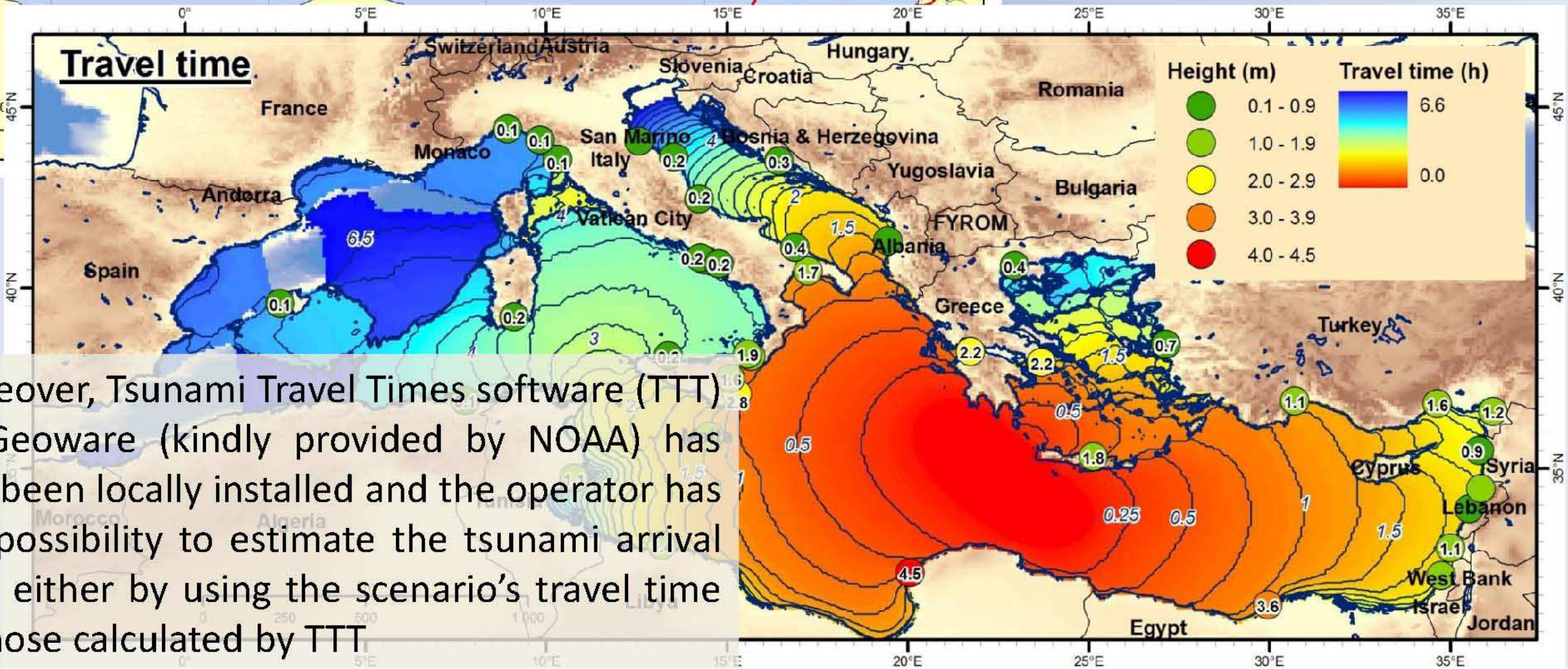
A new network is being prepared which will involve 20 new tide gauge stations including CGPS at each site.



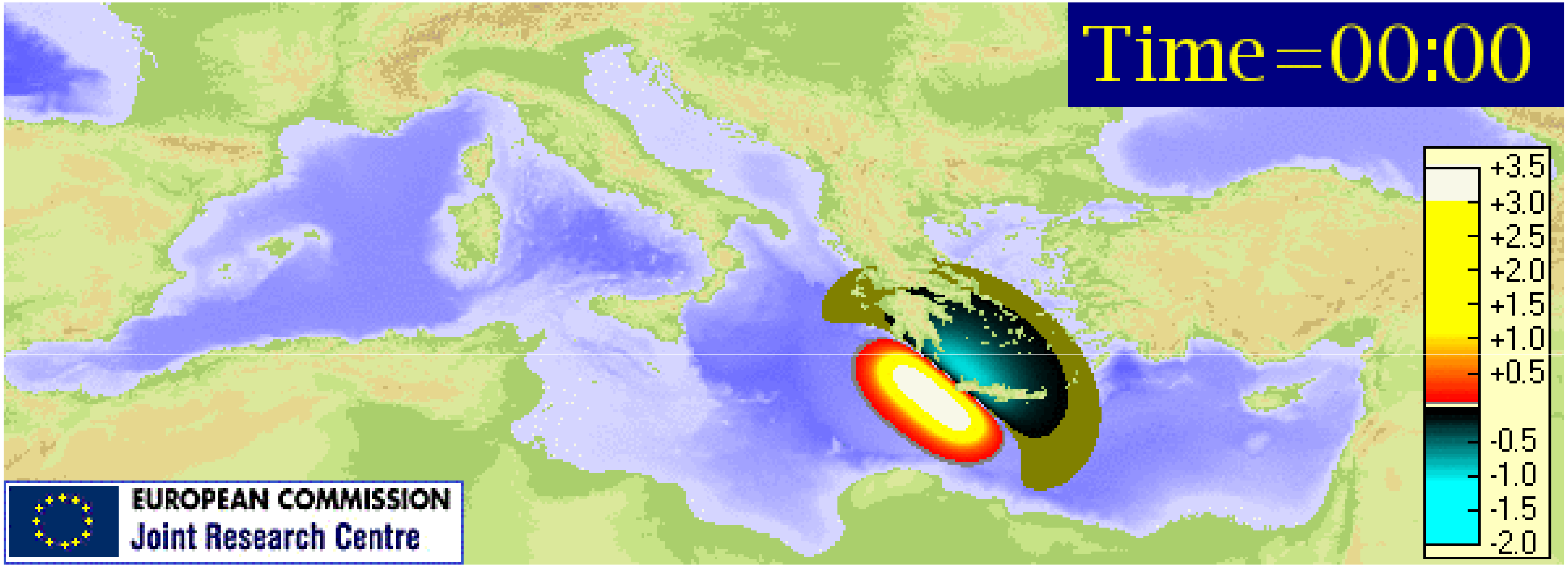
Tsunami Analysis

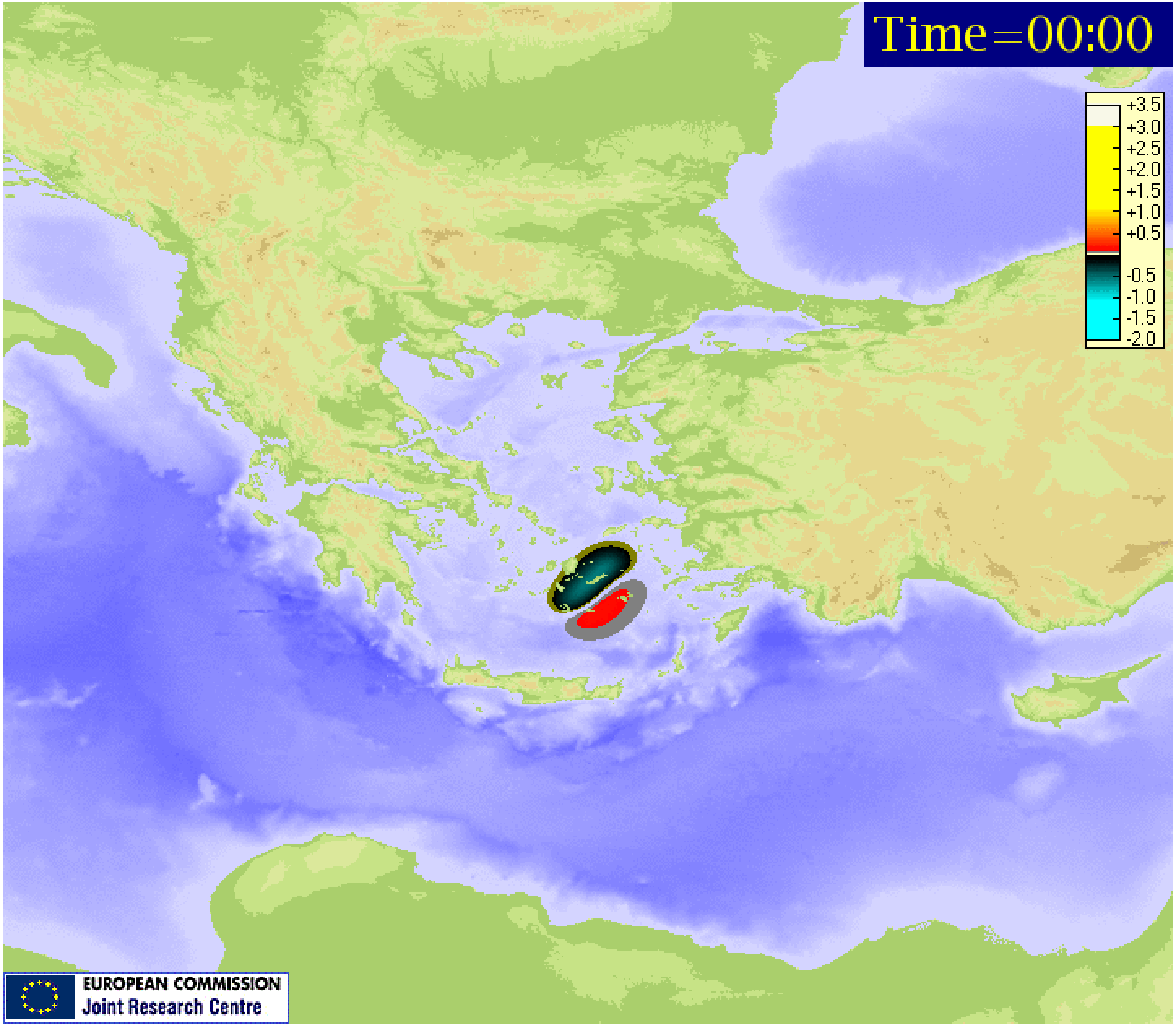






Moreover, Tsunami Travel Times software (TTT) by Geoware (kindly provided by NOAA) has also been locally installed and the operator has the possibility to estimate the tsunami arrival time either by using the scenario's travel time or those calculated by TTT


Time=00:00
+3.5
+3.0
+2.5
+2.0
+1.5
+1.0
+0.5
-0.5
-1.0
-1.5
-2.0
EUROPEAN COMMISSION
Joint Research Centre


Time=00:00
+3.5
+3.0
+2.5
+2.0
+1.5
+1.0
+0.5
-0.5
-1.0
-1.5
-2.0
EUROPEAN COMMISSION
Joint Research Centre