The rapid deployment of portable seismographic networks for real-time earthquake hazard assessment.

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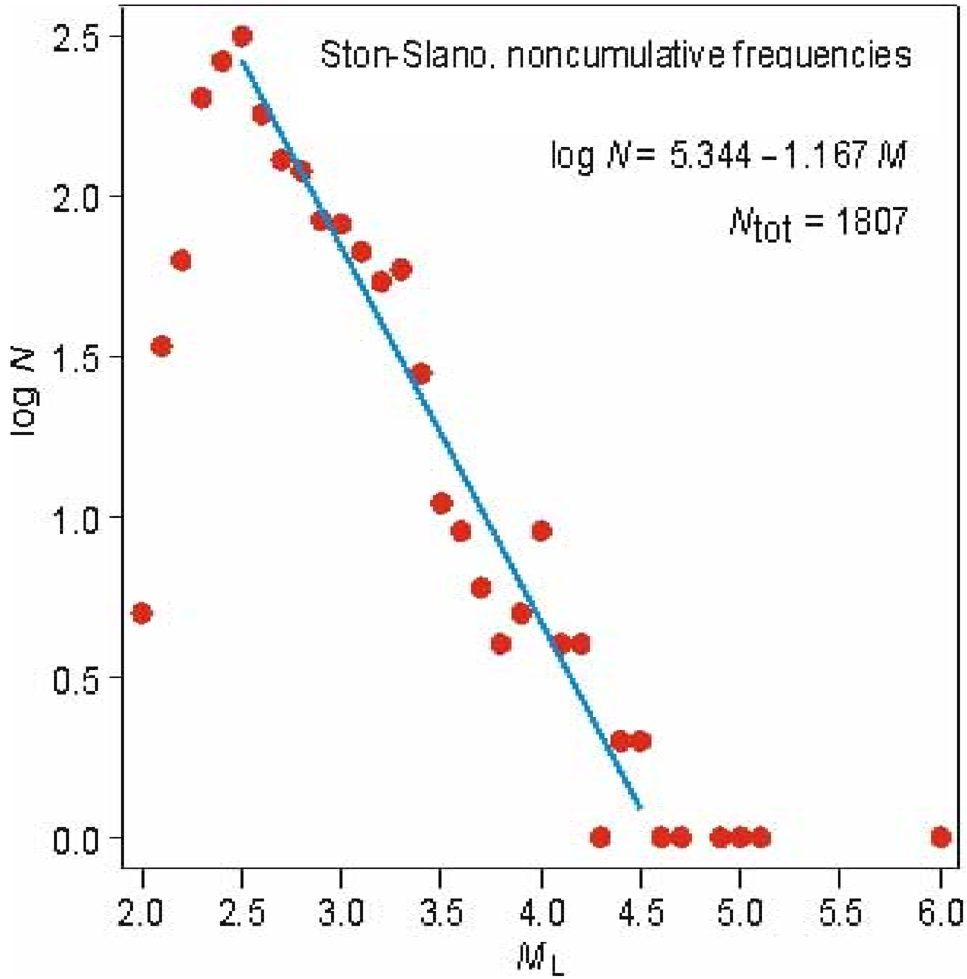
Engineering Seismology

In order to estimate important parameters, seismologists need:

- Complete earthquake catalogues that extend well into the past,
- Records of strong earthquakes and small events from near-by epicentral regions,
- Information on the soil structure and properties at the construction site, as well as on the path between epicentre and the site

Observational Seismology
Statistics-Frequency of Occurrence



- **Gutenberg-Richter frequency-magnitude relation:**

  log $N = a - bM$

  ***On a large scale b* is approximately constant, *b* = 1 world-wide → there are ~10 times more M=5 than M=6 earthquakes**

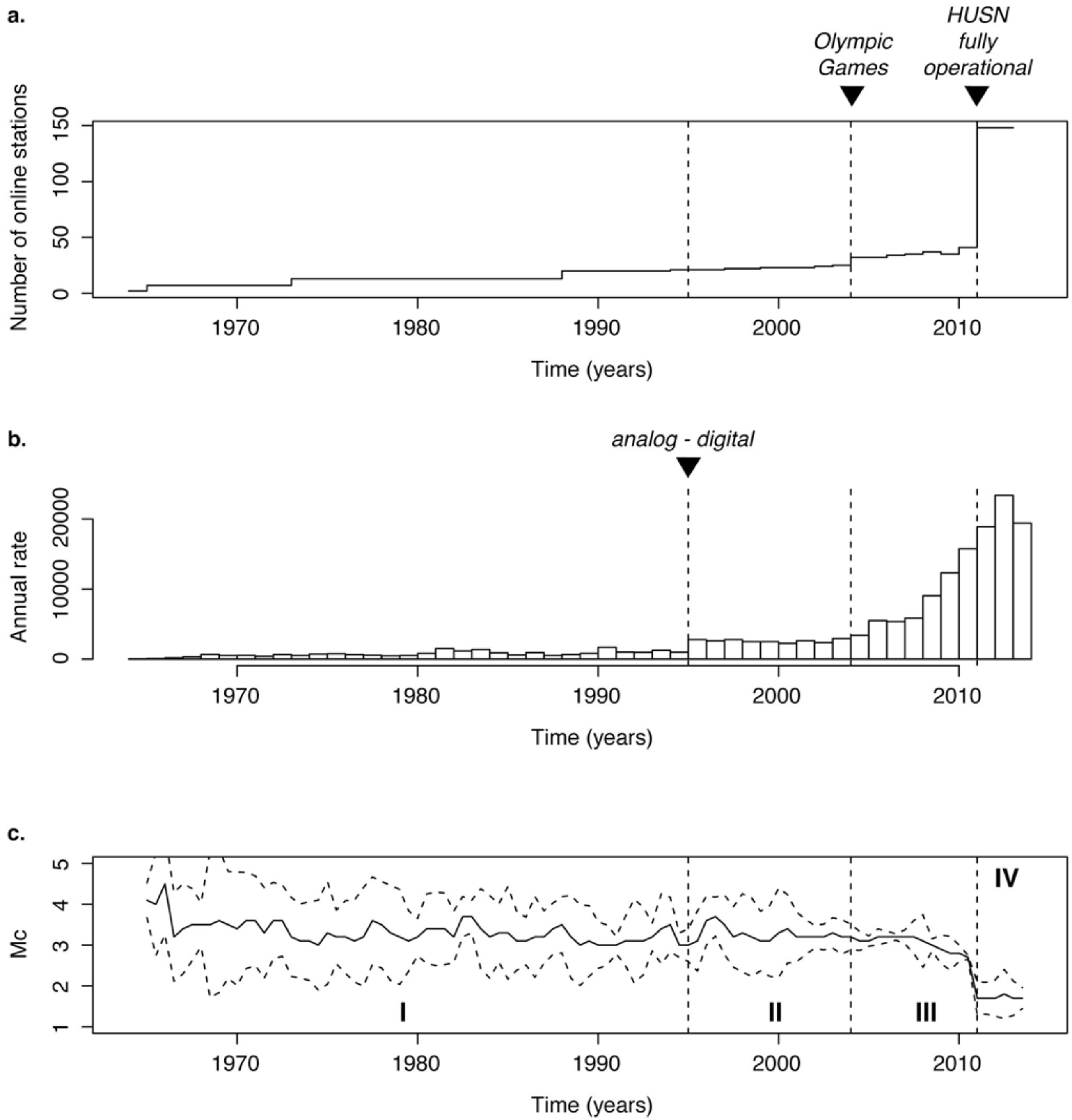
The FMD describes the relationship between the frequency of occurrence and the magnitude of earthquakes (Ishimoto and Iida, 1939; Gutenberg and Richter, 1944):

$$\mathrm{Log}N = a - bM$$

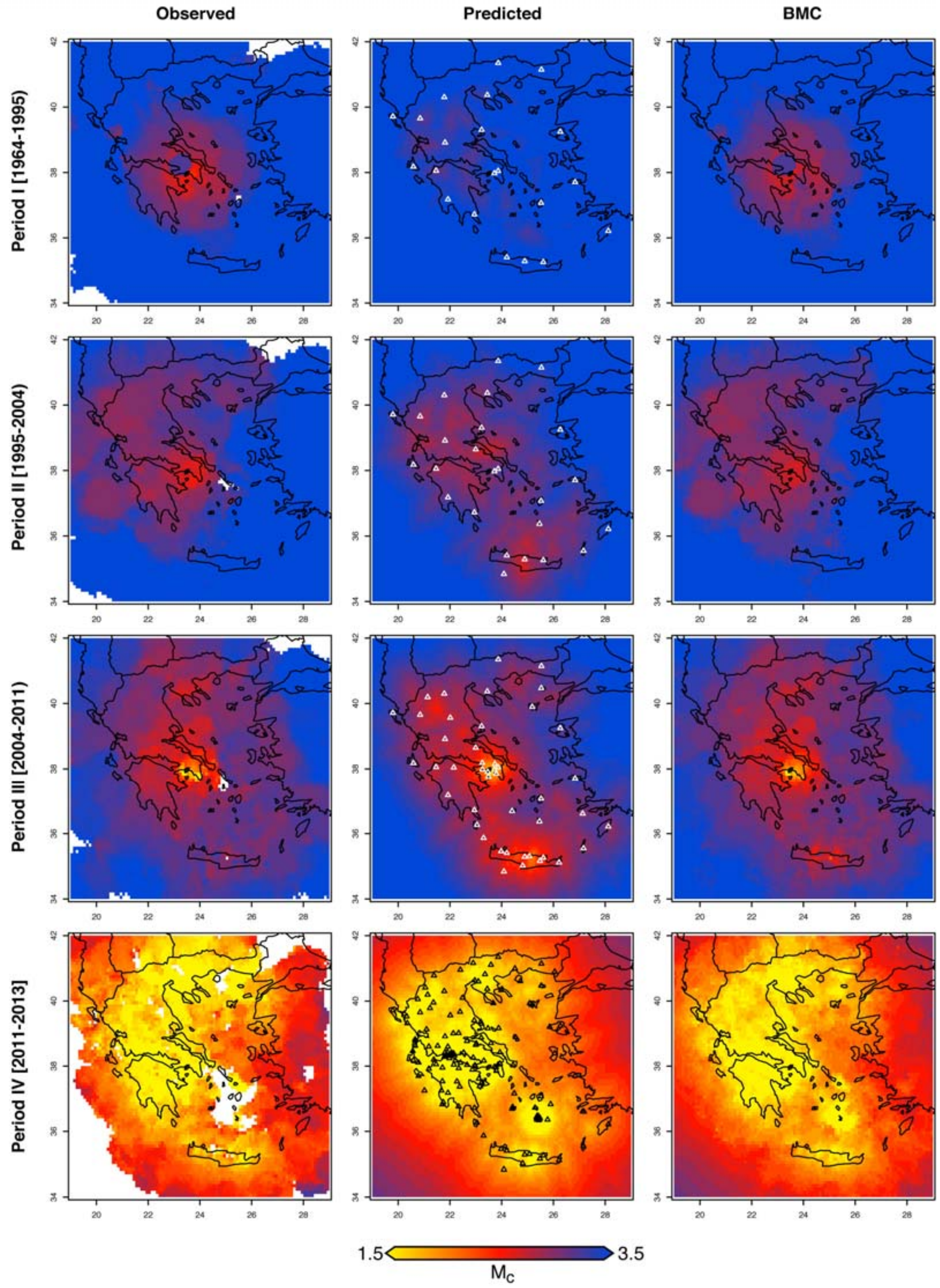
Where N is the cumulative number of earthquakes having magnitudes larger than M, a and b are constants. The b-value describes the relative size of the events. Variations of the b-value of the Gutenberg Richter frequency magnitude distribution have been associated with *crustal stress level fluctuations and large earthquakes* (Sumatra, 2004, Tohoku, 2011, Nanjo et al., (2012)).

It is postulated 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).



a.
Olympic Games
HUSN fully operational
Number of online stations
0
50
100
150
1970
1980
1990
2000
2010
Time (years)
b.
analog - digital
Annual rate
0
10000
20000
1970
1980
1990
2000
2010
Time (years)
c.
Mc
1
2
3
4
5
I
II
III
IV
1970
1980
1990
2000
2010
Time (years)



Observed
Predicted
BMC
Period I [1964-1995]
Period II [1995-2004]
Period III [2004-2011]
Period IV [2011-2013]
1.5
3.5
M_c

Portable Network

SEISMOMETER: LENNARTZ 3D/20sec

Sensitivity: 1000 V*s/m

2 zeros + 2 poles

-0.223 0.223
-0.223 -0.223

Ao= 1

DIGITIZER: SMART24 GEOTECH

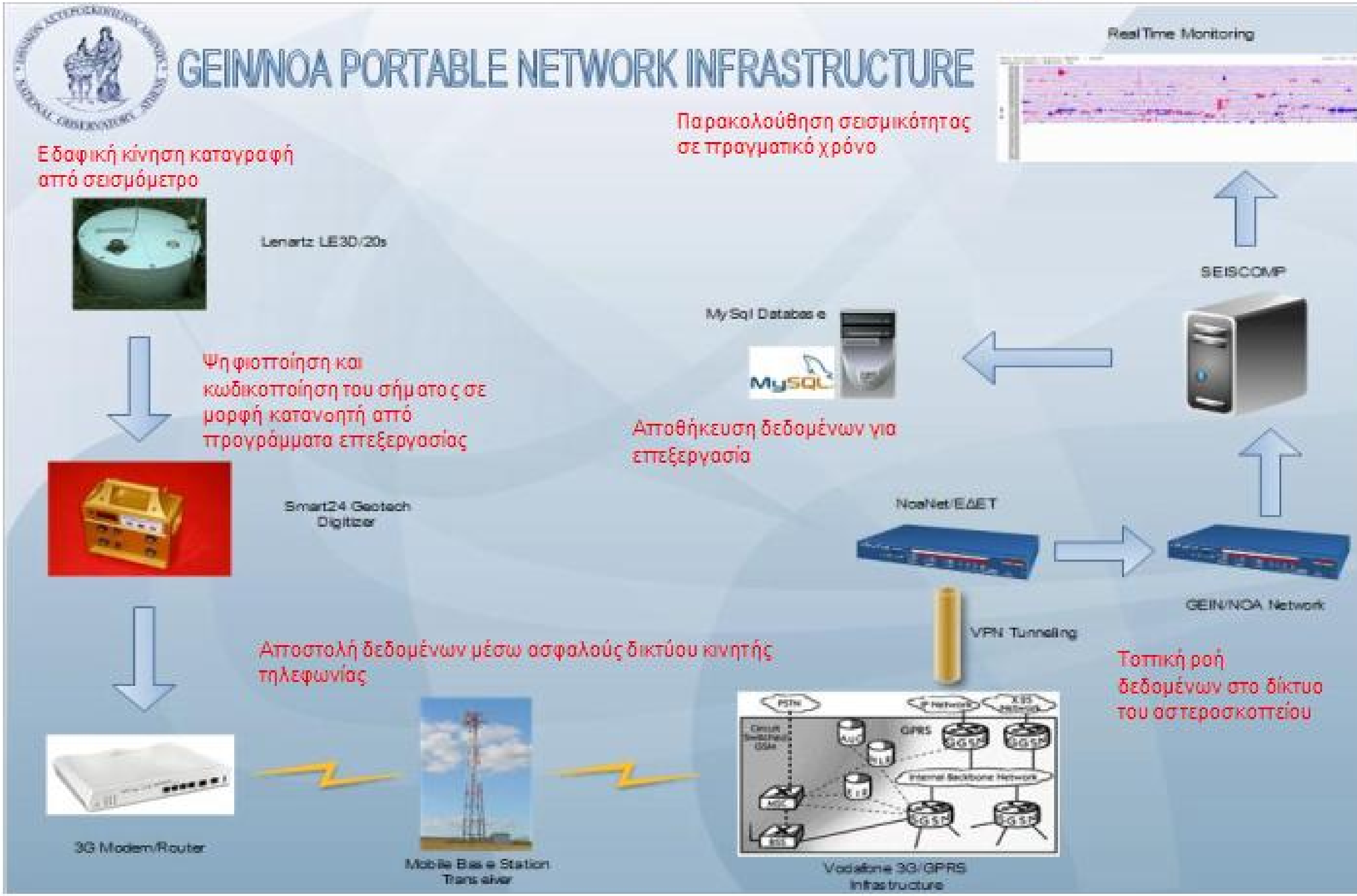
Number of inputs: - 3 or 6 channels
Input type: - Balanced differential with transient protection suitable for both passive and active sensors

Input range: - 40, 20 and 5 volts p-p bipolar differential maximum
Gain: - Software selectable gains of 1, 2, 4, 8, 16, 32 and 64
Common mode rejection:- Greater than 90 dB
A/D Converter:- Over sampled 24-bit Delta Sigma ADC with DSP, 1 per channel
Anti-alias filter: - Brickwall digital FIR filter, cutoff at 80% of and 130 dB down at output Nyquist
Dynamic range: - up to 138 dB
Intermodulation distortion:- Less than -100 dB
Signal to distortion: - Less than -100 dB
Sample rates: - 1, 5, 10, 20, 40, 50, 100, 125, 200, 250, 500, 1000 and 2000 sps primary sample rates (plus secondary)
Noise: - < 1 count rms at 100 sps

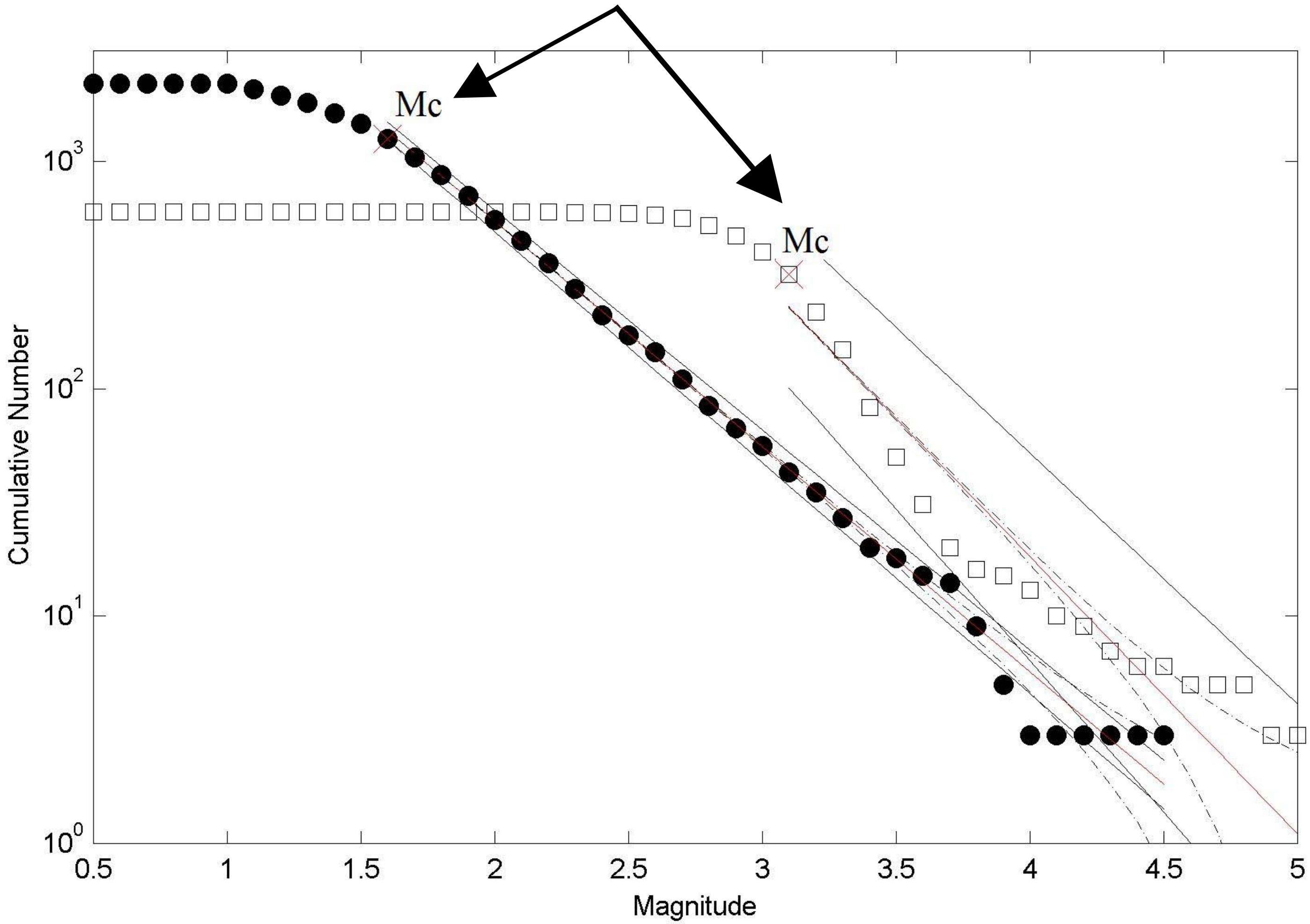
COMMUNICATION: DRAYTEK VIGOR MODEM/ROUTER

Physical Interfaces:
- LAN Ports (Switch)
  - 1 X Gigabit Ethernet (1000Mb/s) Ports
  - 3 X Megabit (100Mb/s) Ports
- WAN Ports:
  - ADSL Port Compliant with:
    - Annex M
  - Secondary WAN Port : 10/100
  - USB Port for 3G Cellular Modem or Printer

Communication Diagram



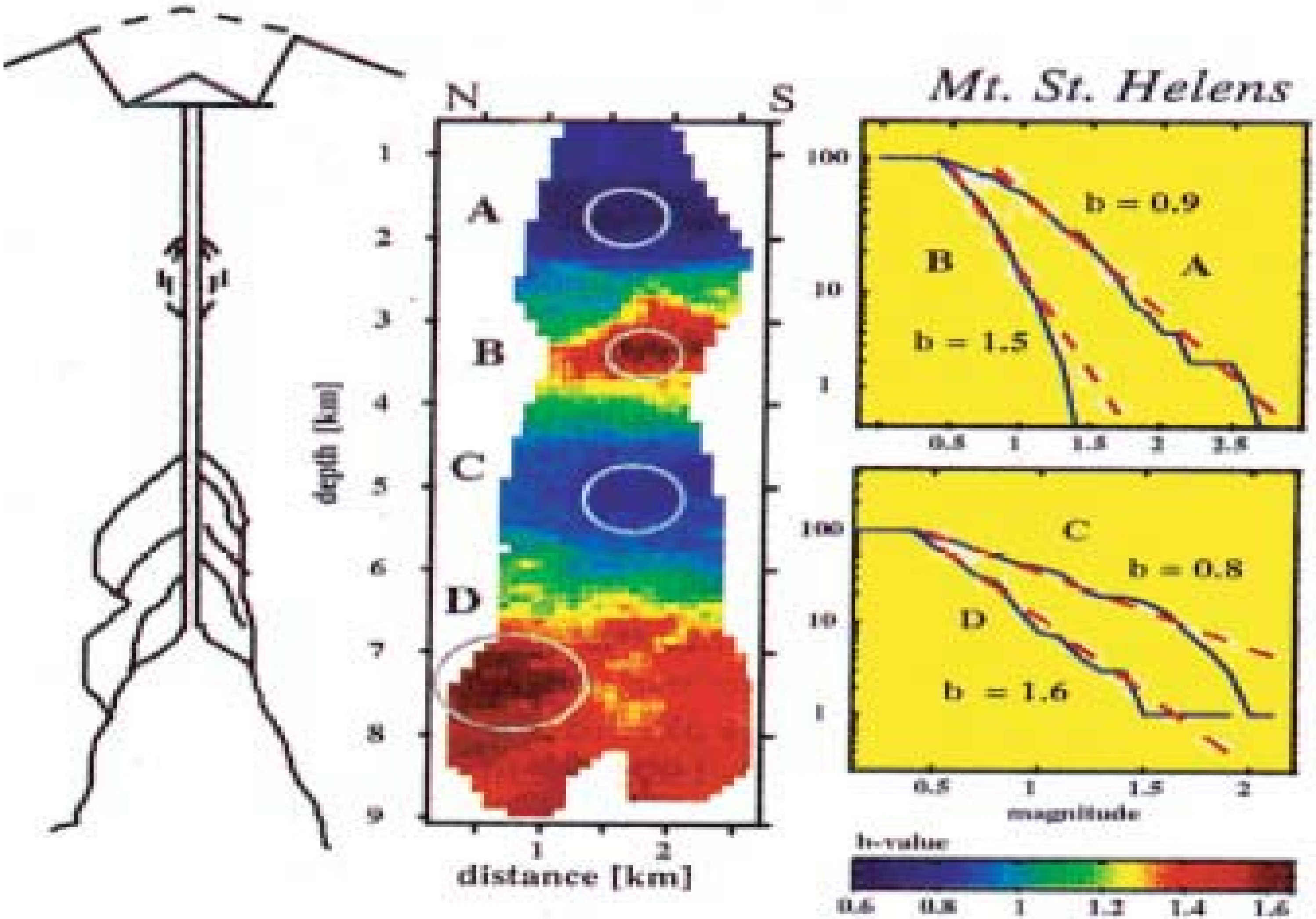
Detection Improvement



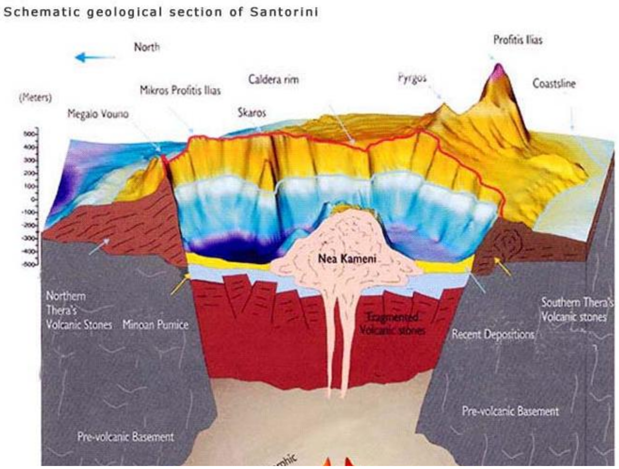
b1: -1.22, b2: -0.991

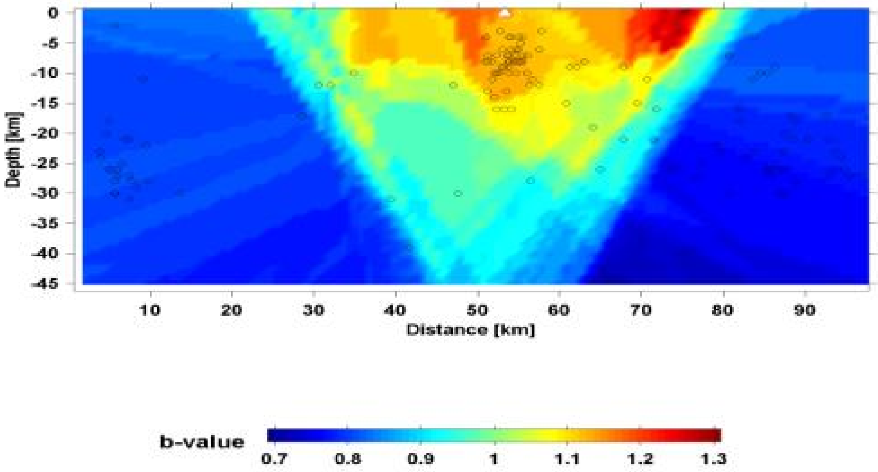
b-value (W LS, Mc >= 1.6): -0.991 +/- 0.01, a-value = 4.7205

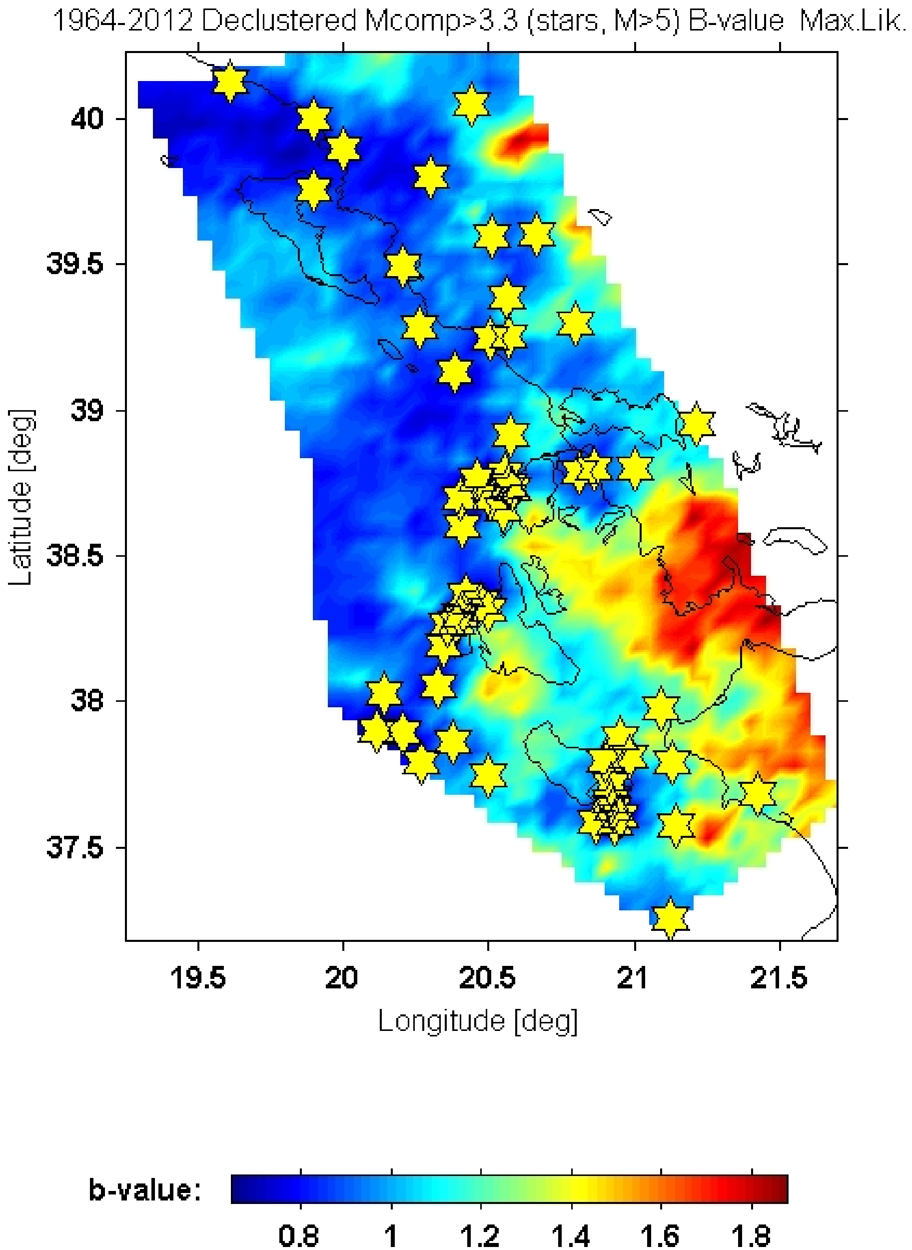
b-value (W LS, Mc >= 3.1): -1.22 +/- 0.15, a-value = 6.1372



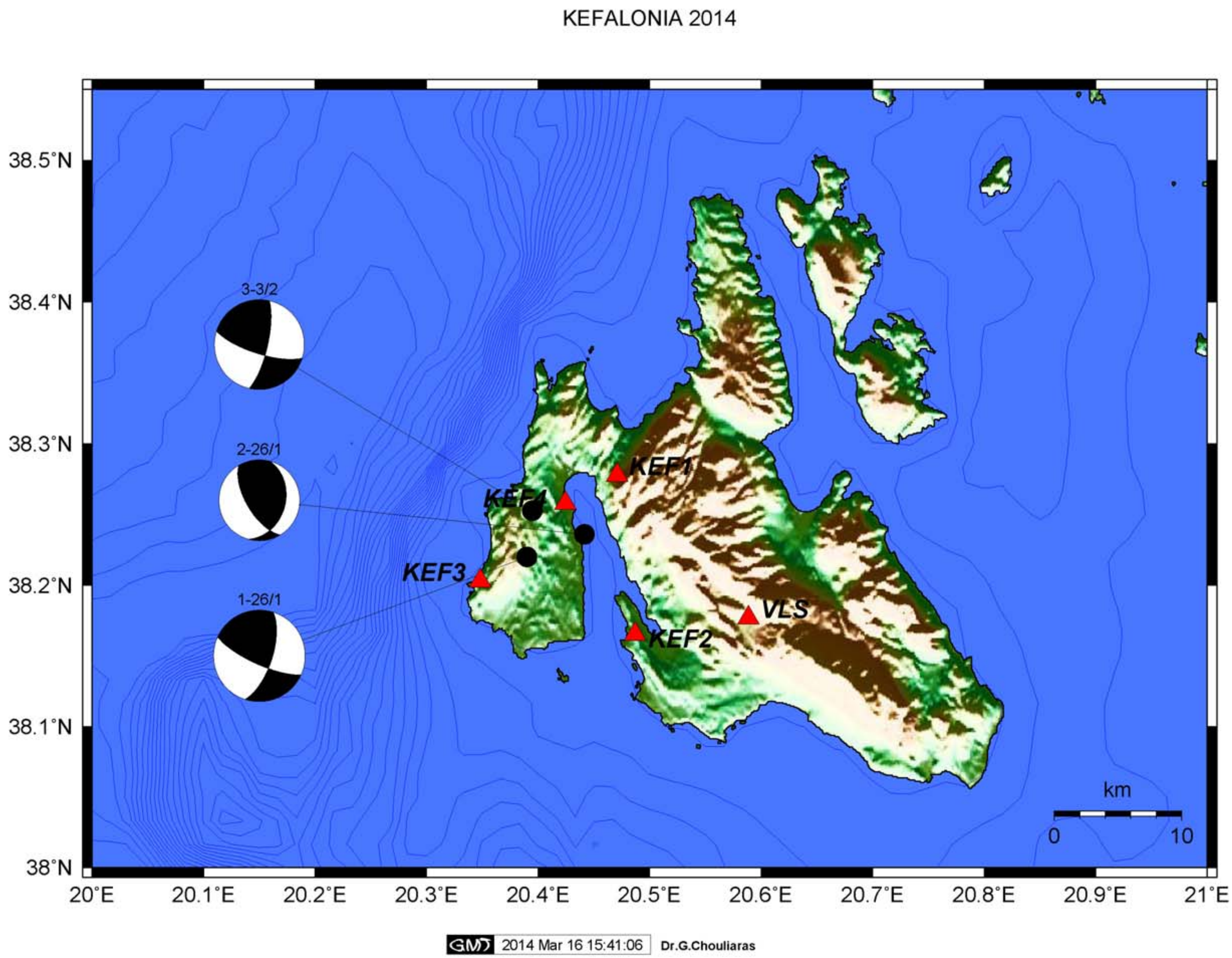
From Wiemer and Mc-Nutt (1997)


Schematic geological section of Santorini
North
Profitis Ilias
Coastsline
Pyrgos
Caldera rim
Mikros Profitis Ilias
Skaros
Megalo Vouno
(Meters)
Nea Kameni
Northern Thera's Volcanic Stones
Minoan Pumice
Fragmented Volcanic stones
Recent Depositions
Southern Thera's Volcanic stones
Pre-volcanic Basement
Pre-volcanic Basement

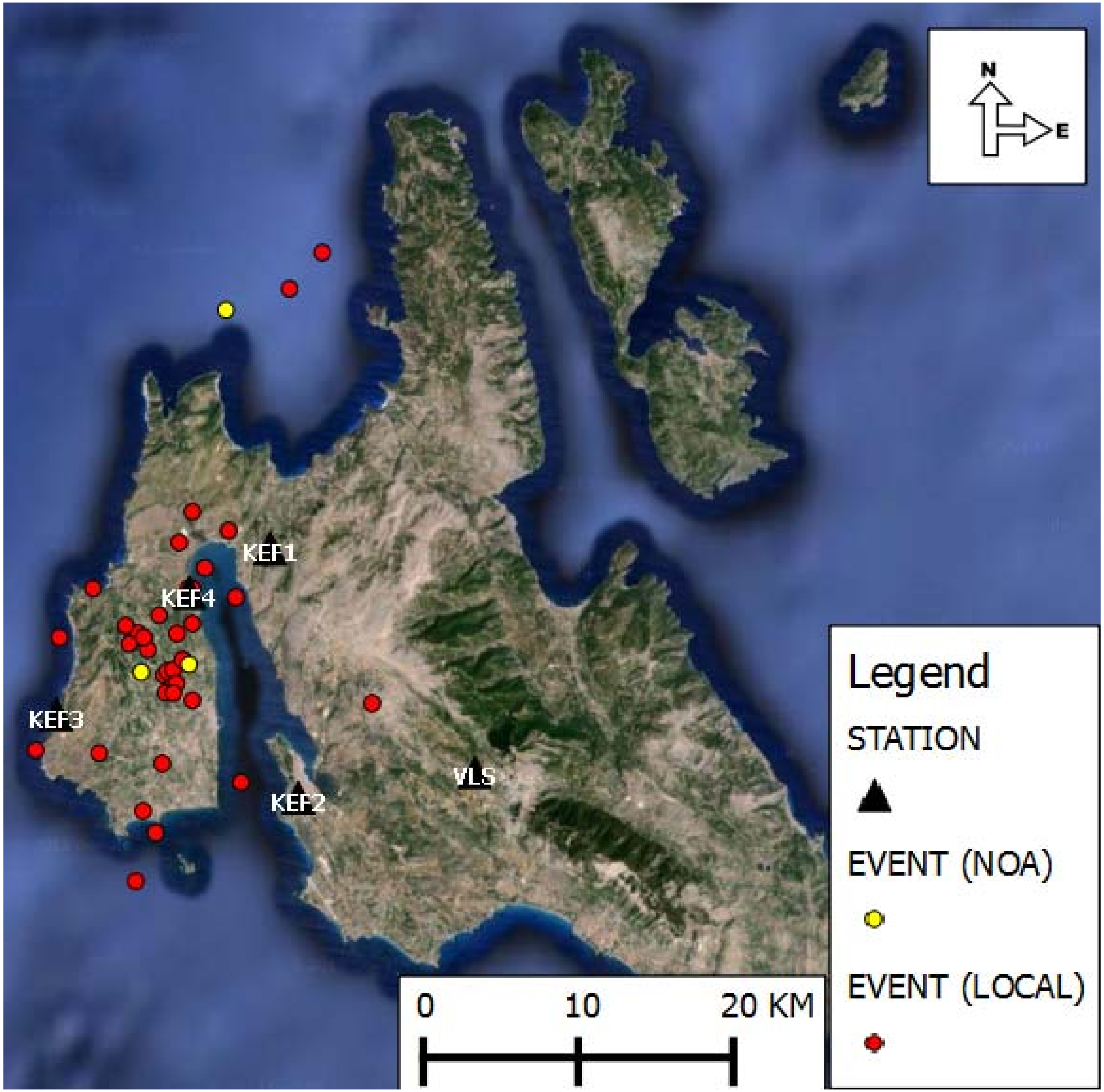

Depth [km]
Distance [km]
b-value
0.7
0.8
0.9
1
1.1
1.2
1.3



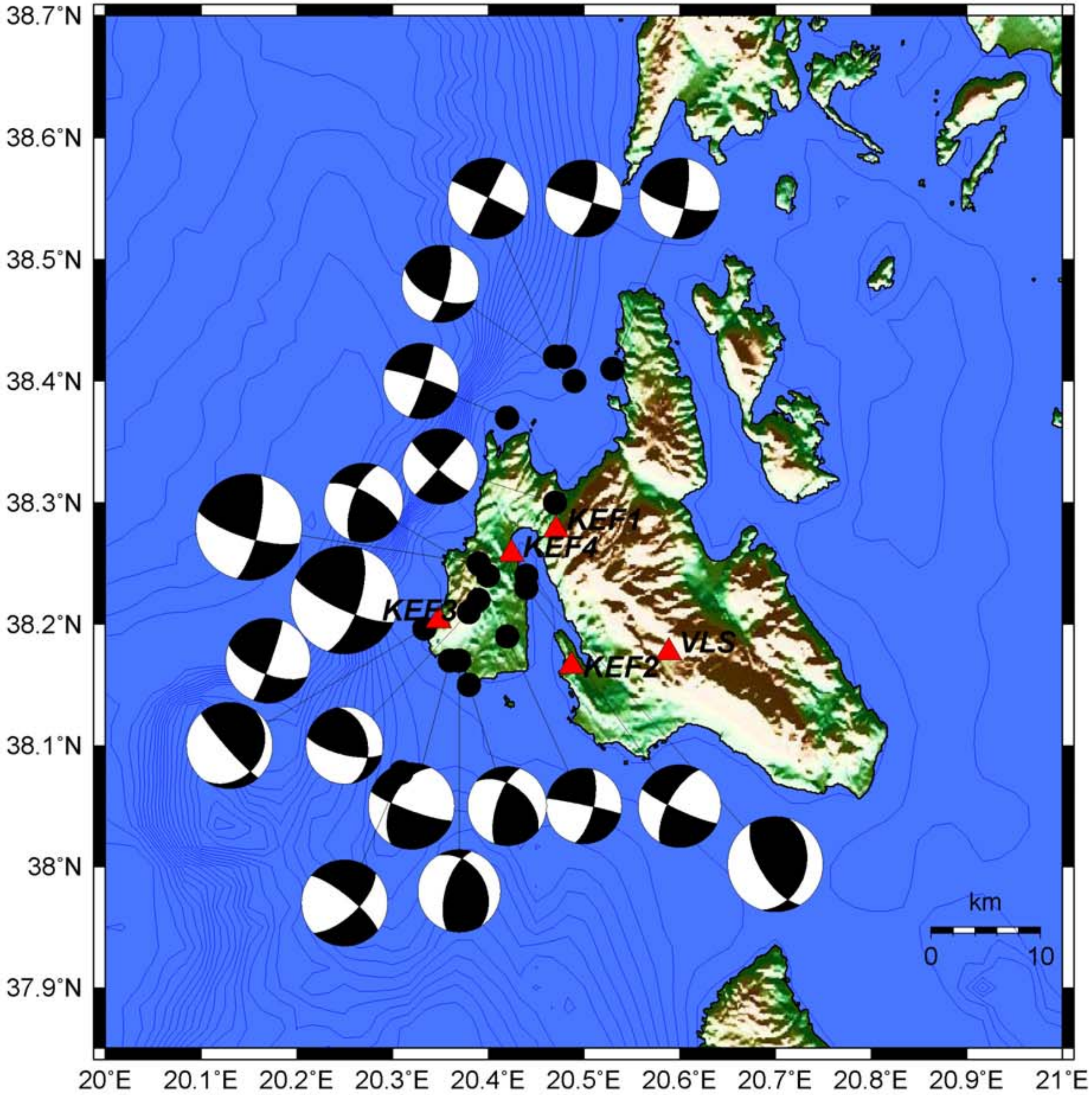
1964-2012 Declustered Mcomp>3.3 (stars, M>5) B-value Max.Lik.
40
39.5
39
38.5
38
37.5
Latitude [deg]
19.5
20
20.5
21
21.5
Longitude [deg]
b-value:
0.8
1
1.2
1.4
1.6
1.8



KEFALONIA 2014
38.5°N
38.4°N
38.3°N
38.2°N
38.1°N
38°N
20°E
20.1°E
20.2°E
20.3°E
20.4°E
20.5°E
20.6°E
20.7°E
20.8°E
20.9°E
21°E
3-3/2
2-26/1
1-26/1
KEF1
KEF2
KEF3
KEF4
VLS
km
0
10
GMT 2014 Mar 16 15:41:06
Dr.G.Chouliaras

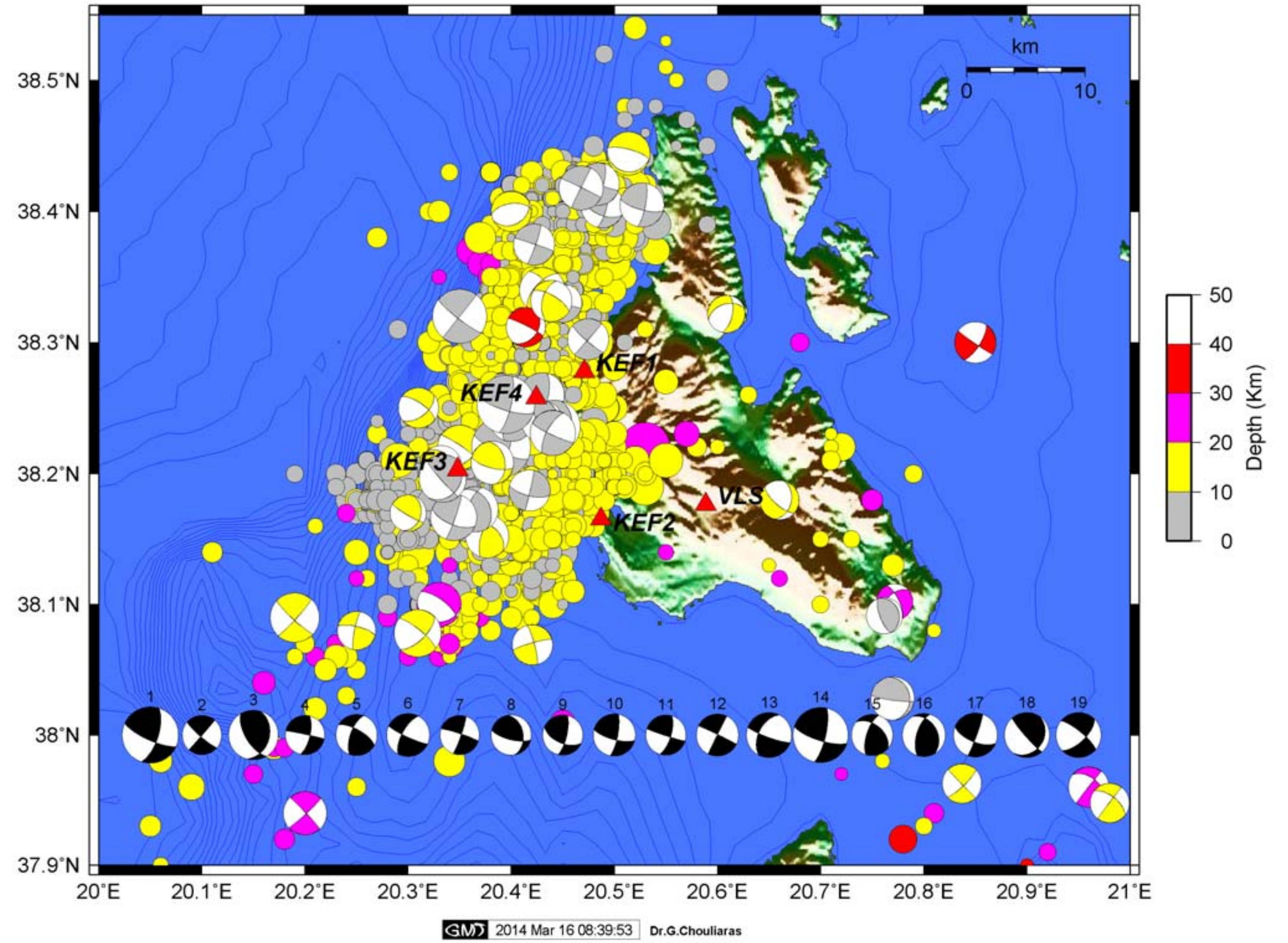

N
E
KEF1
KEF4
KEF3
KEF2
VLS
Legend
STATION
EVENT (NOA)
EVENT (LOCAL)
0
10
20 KM

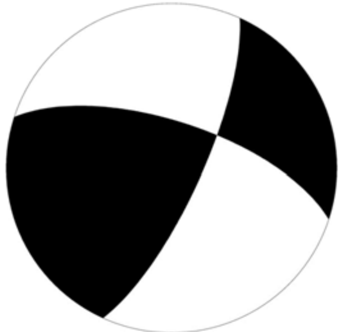
KEFALONIA Portable Seismographic Network 2014

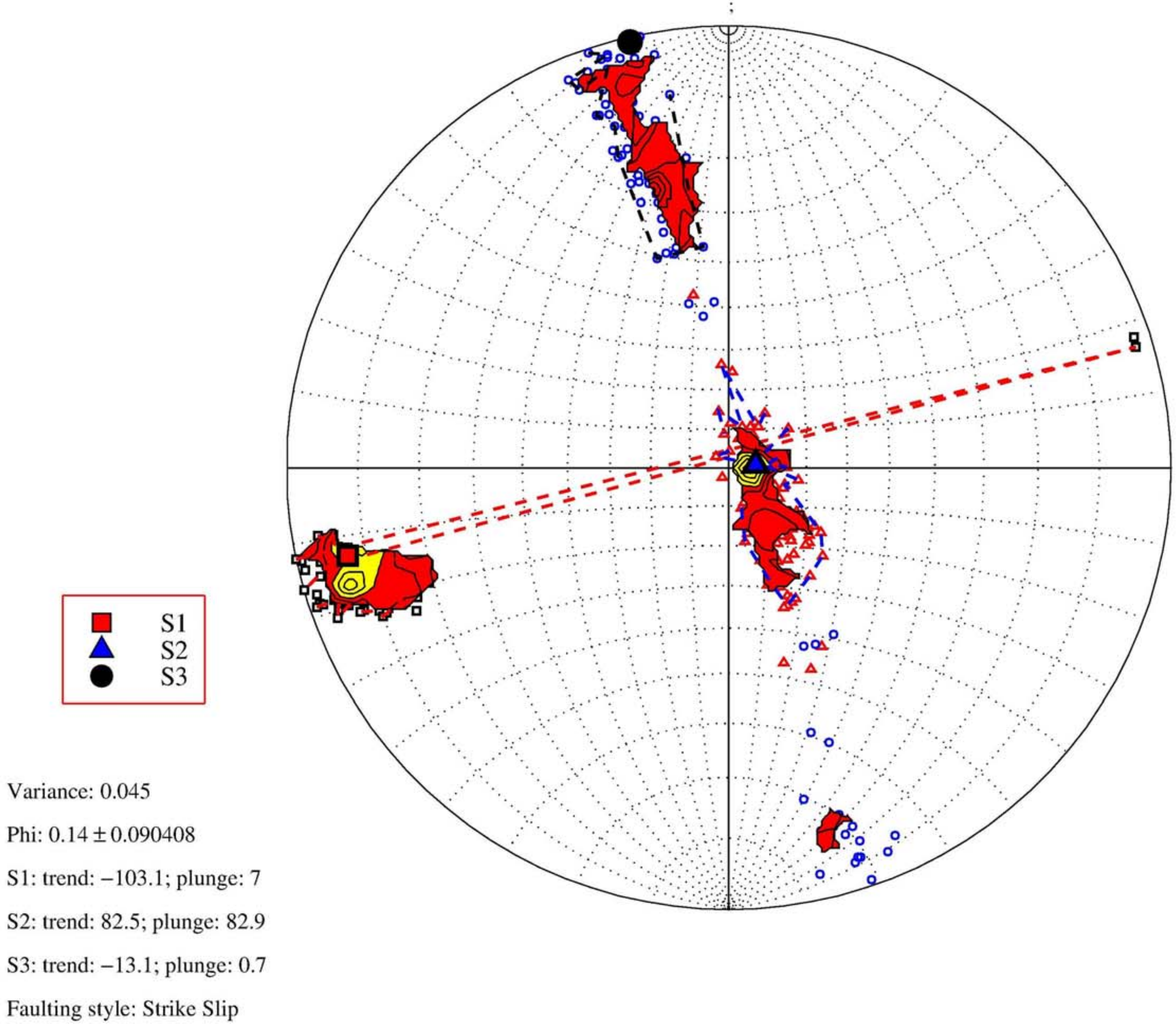


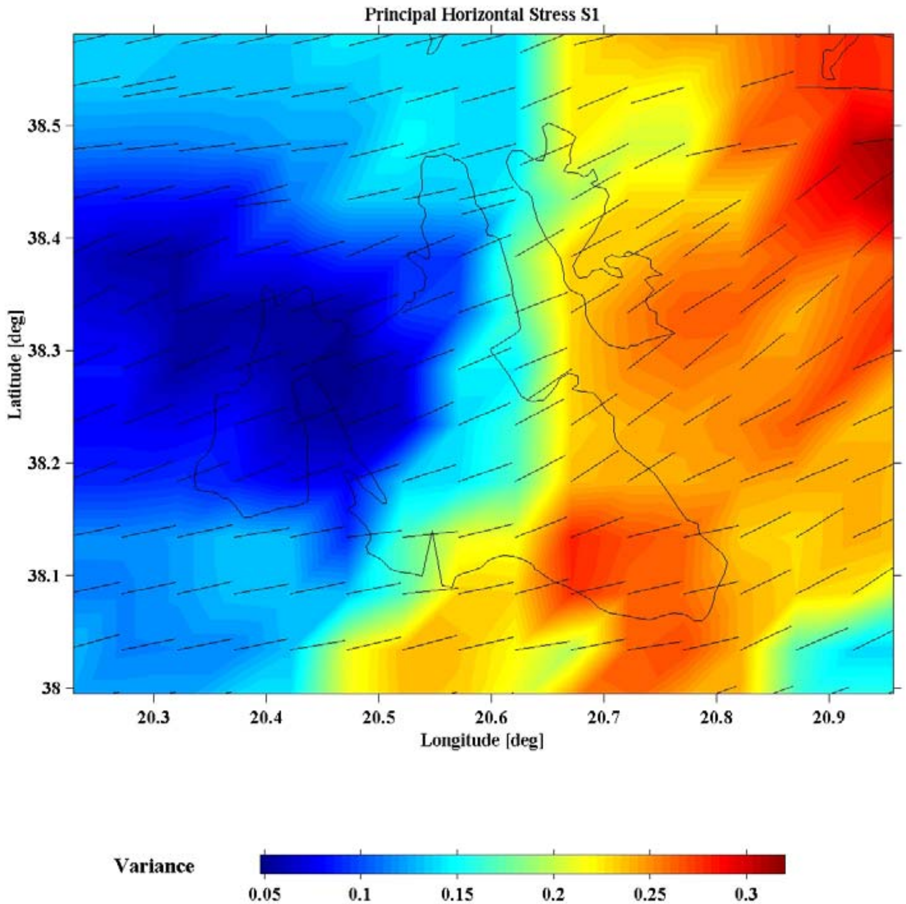
GMT 2014 Mar 15 17:47:55 Dr.G.Chouliaras

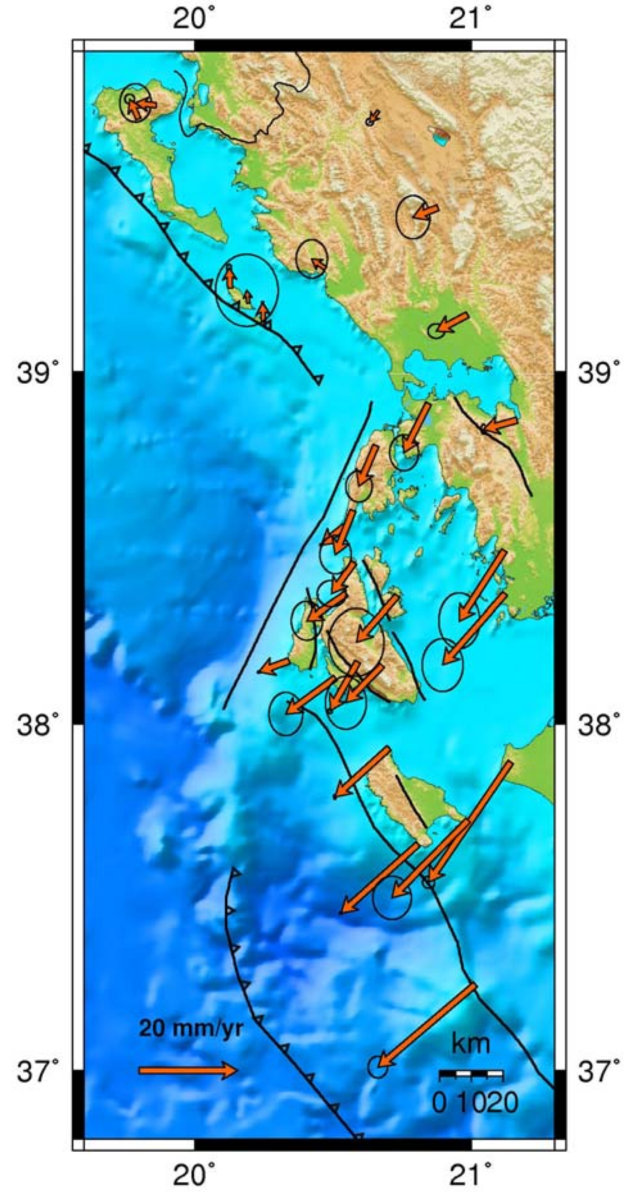
Kefalonia 2014, Mechanism Time Series, NOA Data

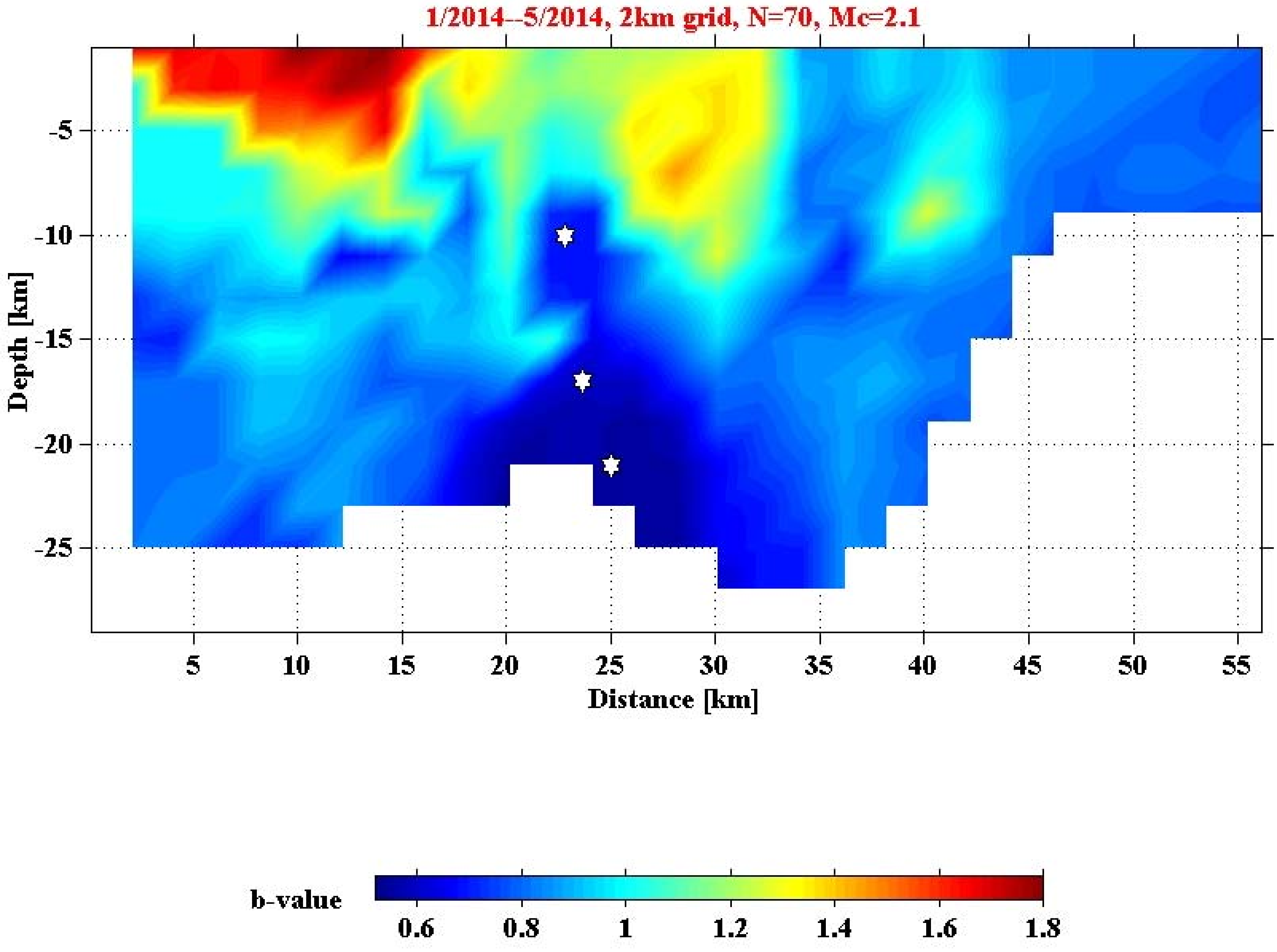


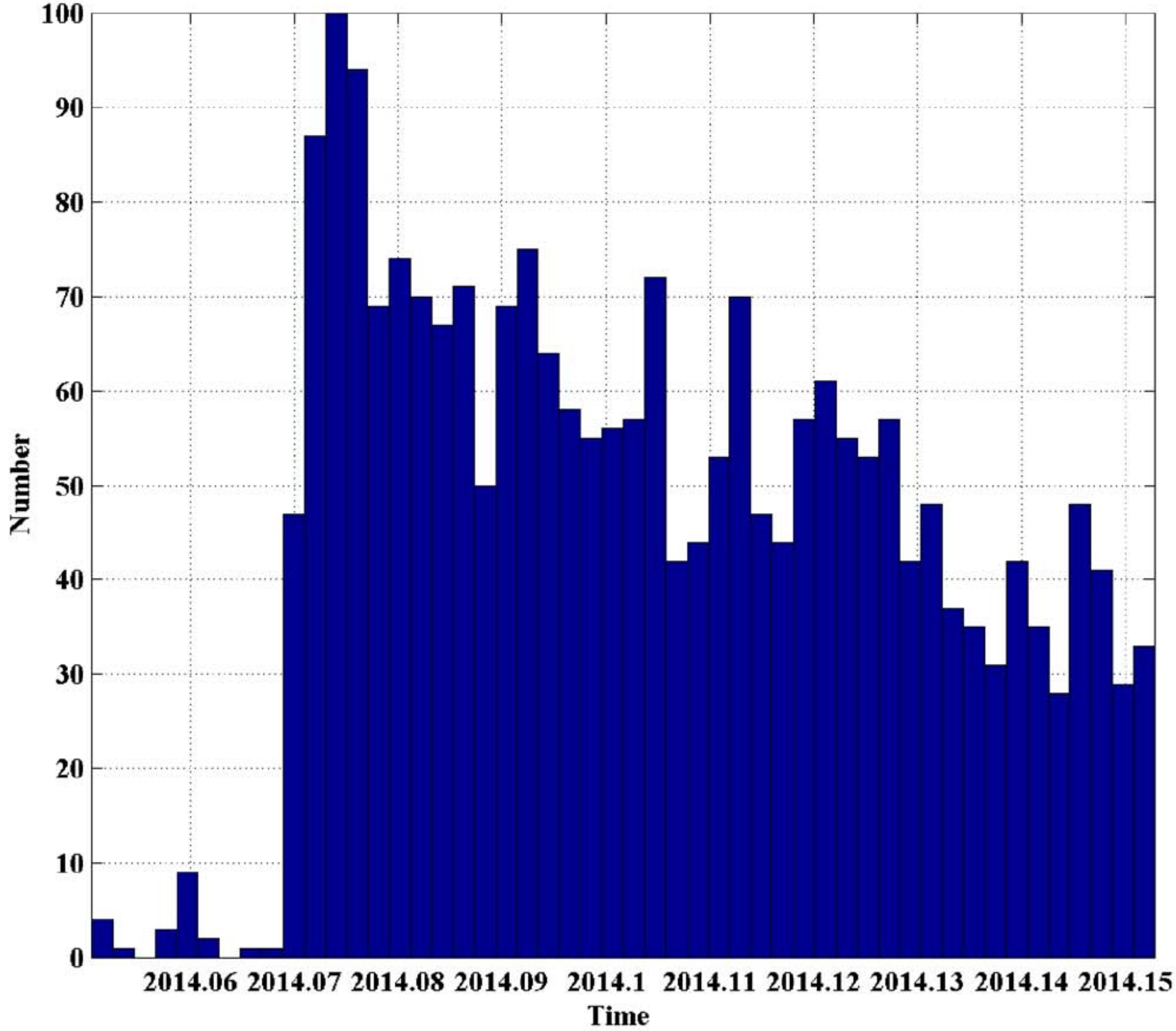



S1
S2
S3
Variance: 0.045
Phi: 0.14 ± 0.090408
S1: trend: −103.1; plunge: 7
S2: trend: 82.5; plunge: 82.9
S3: trend: −13.1; plunge: 0.7
Faulting style: Strike Slip

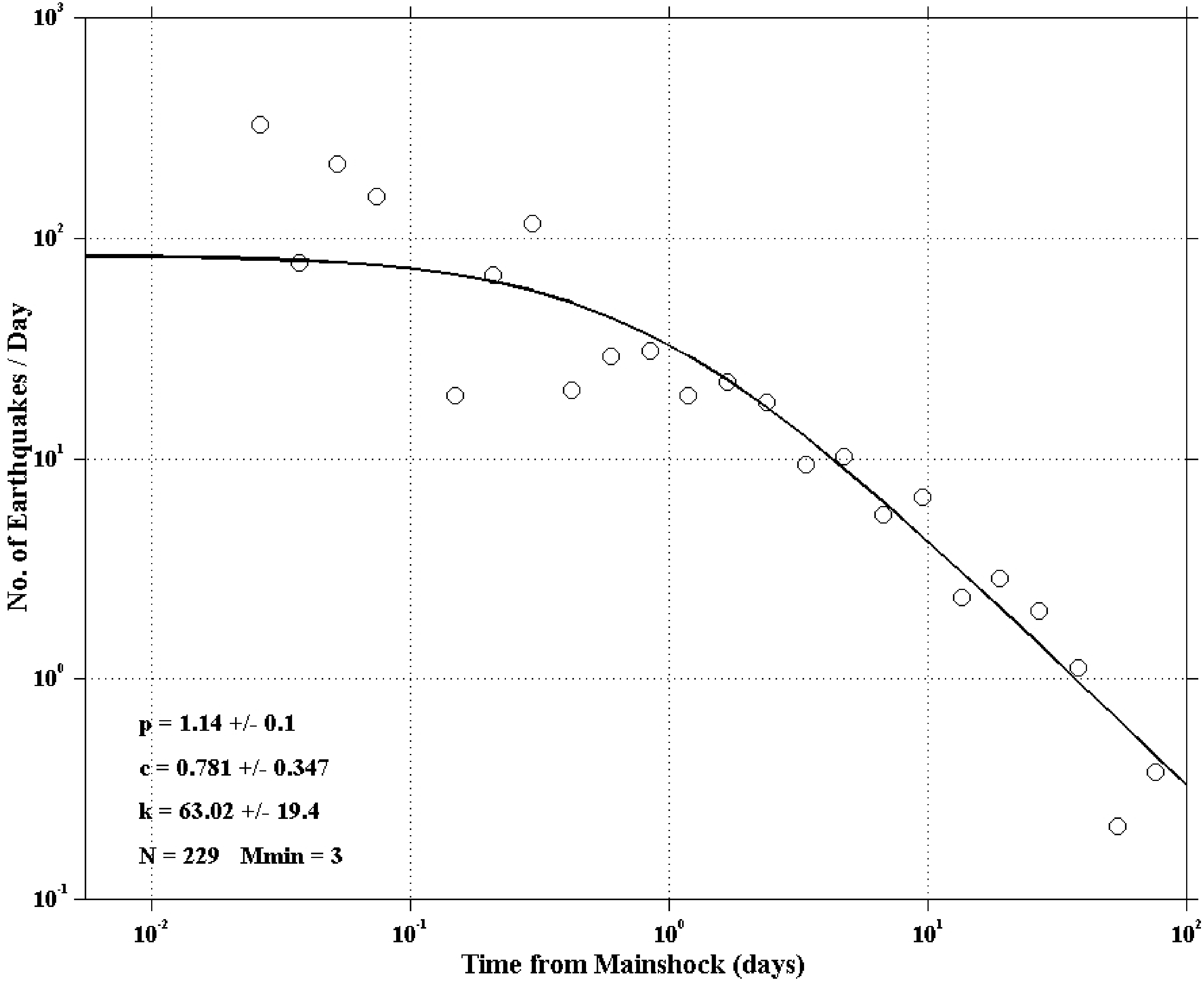

Principal Horizontal Stress S1
Latitude [deg]
38.5
38.4
38.3
38.2
38.1
38
20.3
20.4
20.5
20.6
20.7
20.8
20.9
Longitude [deg]
Variance
0.05
0.1
0.15
0.2
0.25
0.3


20°
21°
39°
38°
37°
20 mm/yr
km
0 1020


1/2014--5/2014, 2km grid, N=70, Mc=2.1
Depth [km]
-5
-10
-15
-20
-25
5
10
15
20
25
30
35
40
45
50
55
Distance [km]
b-value
0.6
0.8
1
1.2
1.4
1.6
1.8

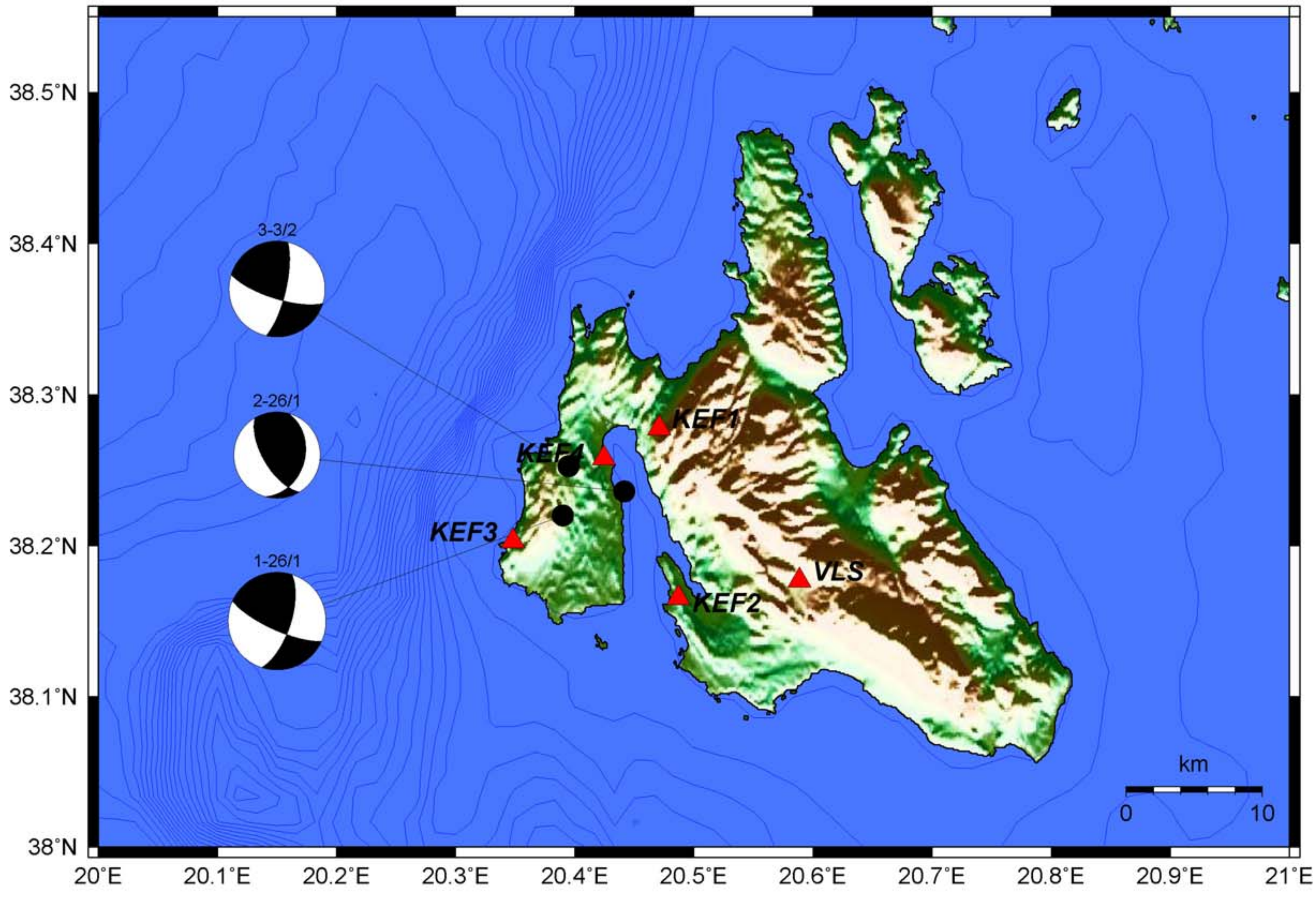


100
90
80
70
60
50
40
30
20
10
0
Number
2014.06
2014.07
2014.08
2014.09
2014.1
2014.11
2014.12
2014.13
2014.14
2014.15
Time

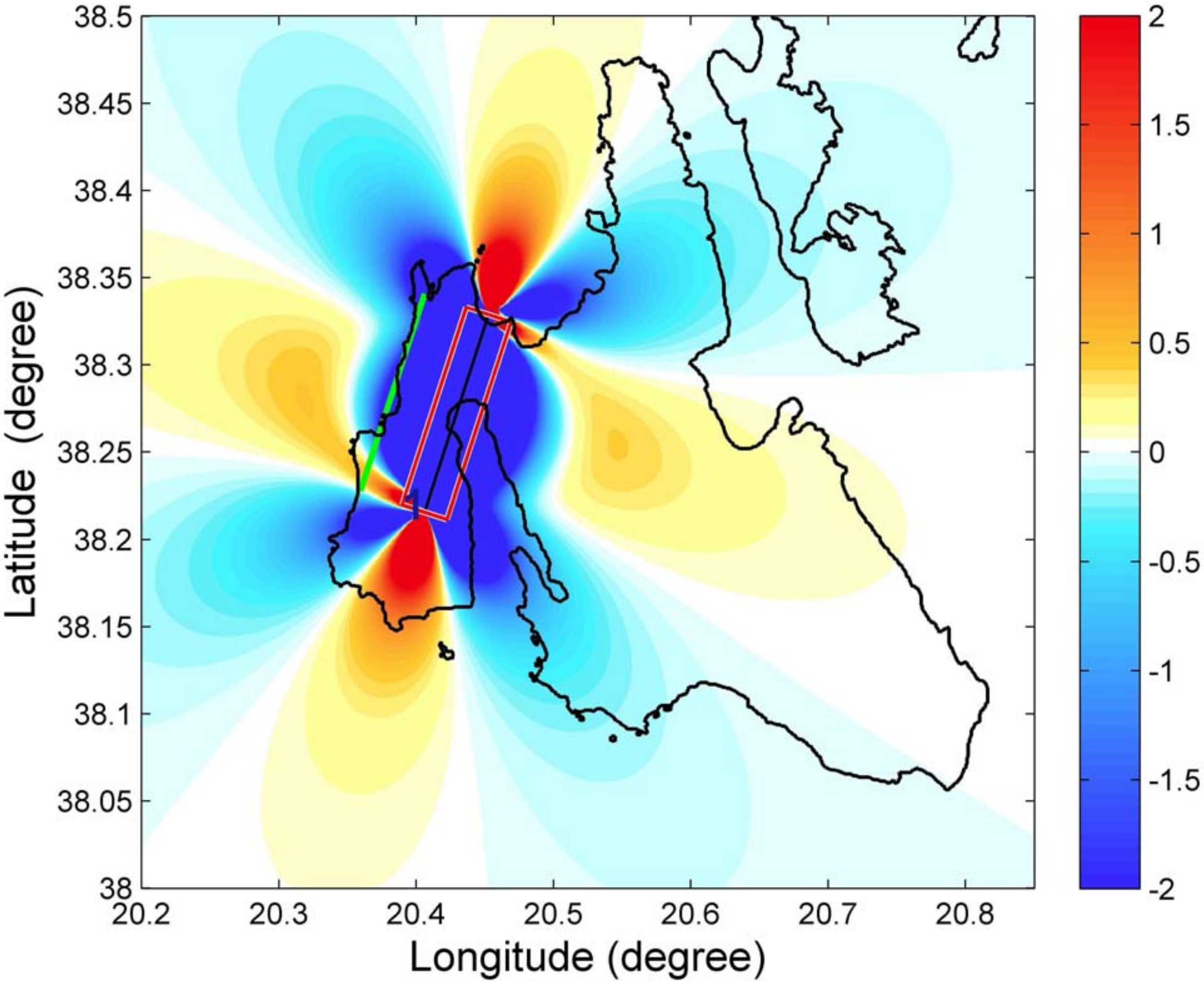


10^3
10^2
10^1
10^0
10^{-1}
No. of Earthquakes / Day
10^{-2}
10^{-1}
10^0
10^1
10^2
Time from Mainshock (days)
p = 1.14 +/- 0.1
c = 0.781 +/- 0.347
k = 63.02 +/- 19.4
N = 229 Mmin = 3

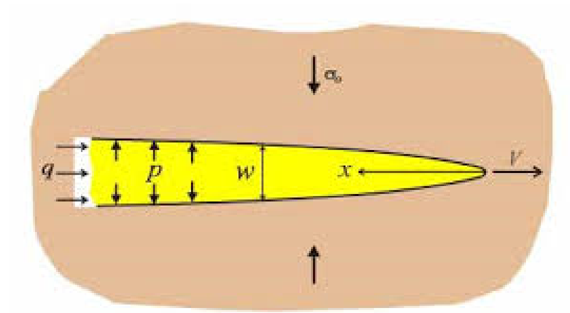
KEFALONIA 2014



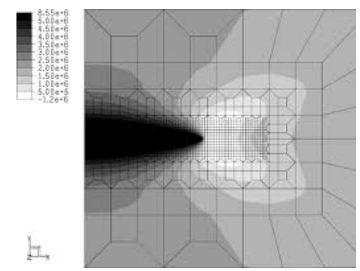
GMT 2014 Mar 16 15:41:06 Dr.G.Chouliaras



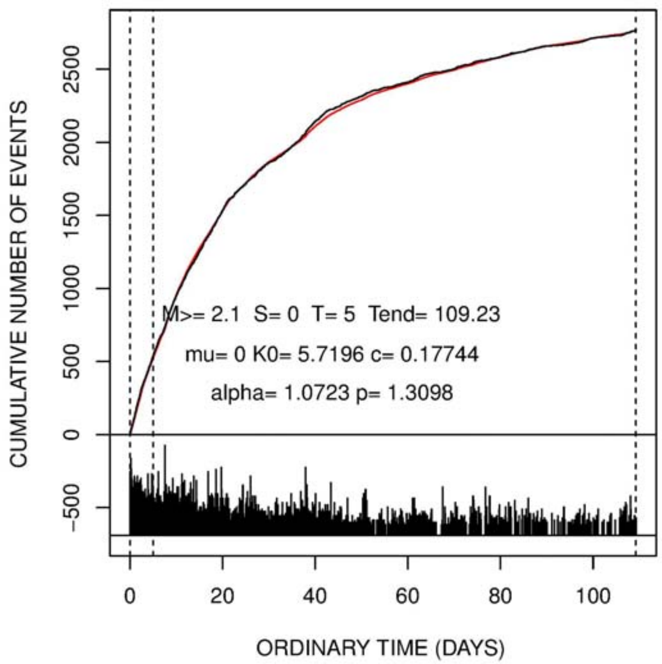
Latitude (degree)
Longitude (degree)
38.5
38.45
38.4
38.35
38.3
38.25
38.2
38.15
38.1
38.05
38
20.2
20.3
20.4
20.5
20.6
20.7
20.8
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

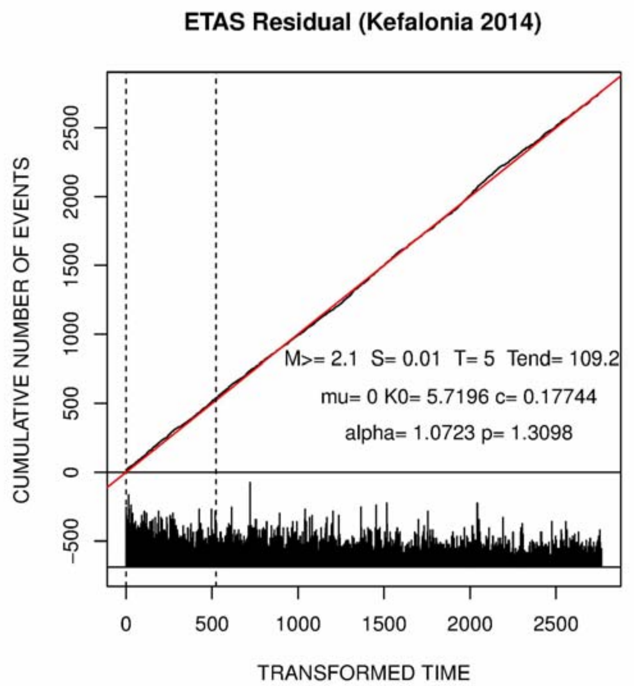


σ_0
q
p
w
x
V



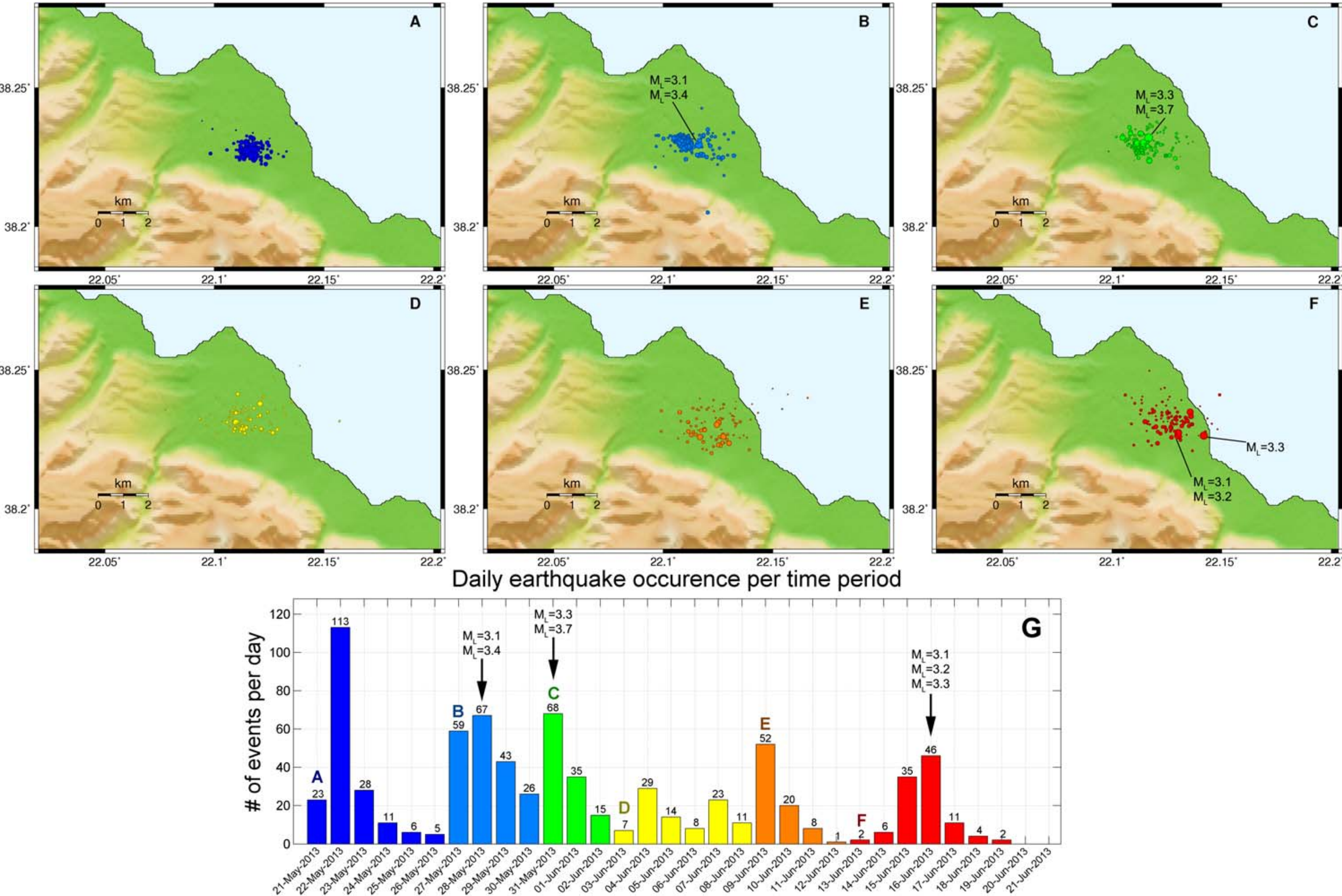
ETAS Fit and Prediction (Kefalonia 2014)





ETAS Residual (Kefalonia 2014)
CUMULATIVE NUMBER OF EVENTS
TRANSFORMED TIME
M>= 2.1 S= 0.01 T= 5 Tend= 109.2
mu= 0 K0= 5.7196 c= 0.17744
alpha= 1.0723 p= 1.3098
0
500
1000
1500
2000
2500
−500

Seismicity bursts – migration of seismic activity



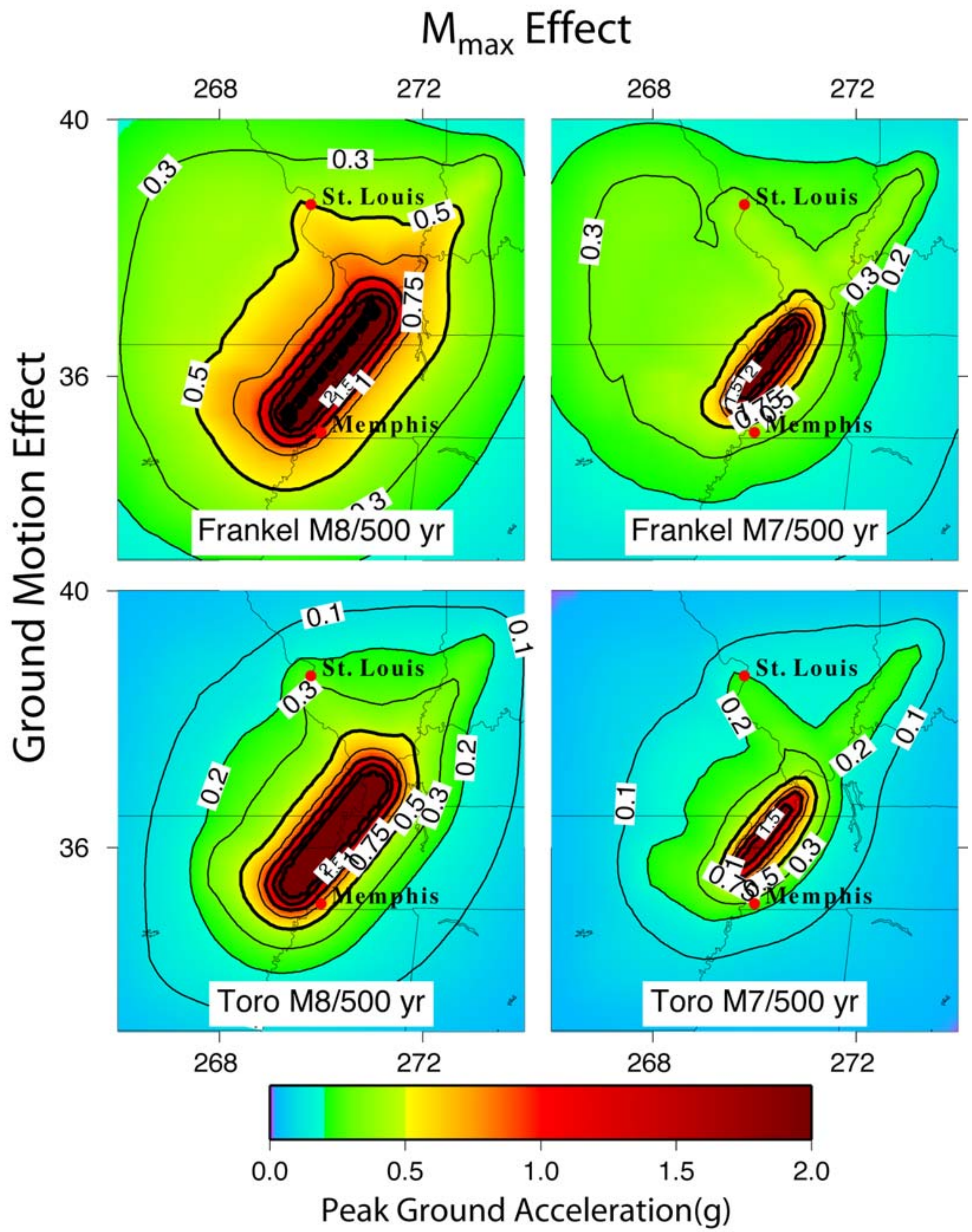
It is the operational responsibility for NOA to evaluate the seismic hazard of an ongoing earthquake sequence and provide this information rapidly to the Greek civil protection authorities.

Therefore, it is of great importance to rapidly resolve the nature of the seismic/volcanic sequence in progress i.e., whether a foreshock activity which may lead to a large earthquake or volcanic explosion, or a minor microseismic activity with a weak main shock, or even a most frequently observed, swarm activity with no prevailing main shock.

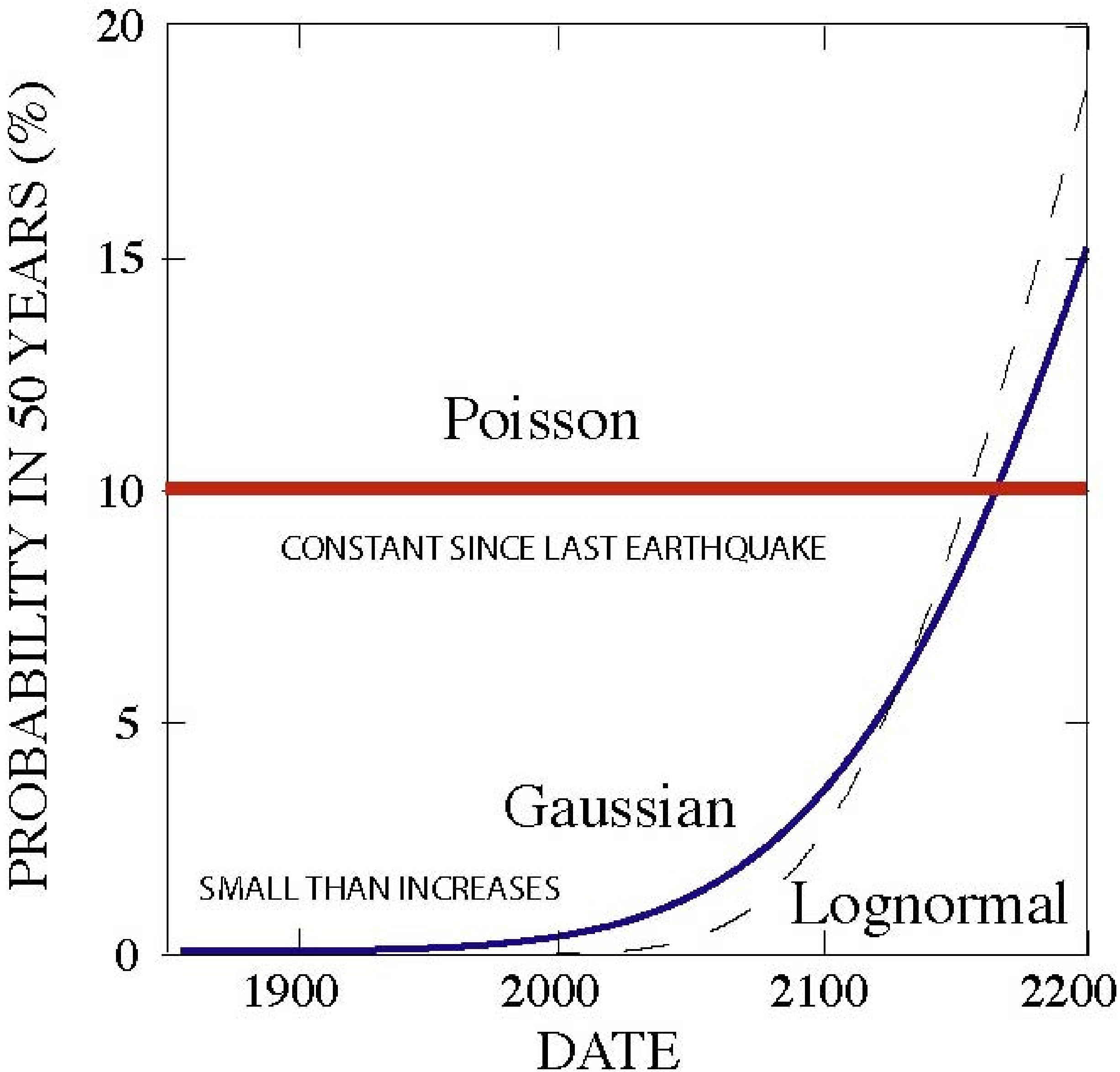
Each of these types of seismic activity has been associated with characteristic spatial and temporal seismicity patterns and seismicity rates and the monitoring of these physical processes may provide valuable information for the mitigation of seismic hazard in populated areas.

EXPLAIN UNCERTAINTIES

Individuals and society are used to making decisions in the presence of uncertainty: we buy life insurance and decide how much to spend on safety features in cars.



Can get huge range of probabilities, depending on assumptions of magnitude and recurrence



HAZARD ASSESSMENTS AND MITIGATION POLICIES SHOULD UNDERGO PEER REVIEW

Hazard estimates prepared by one organization should be reviewed by a different one.

This would ensure that crucial economic and societal issues are fully explored before a decision is made.

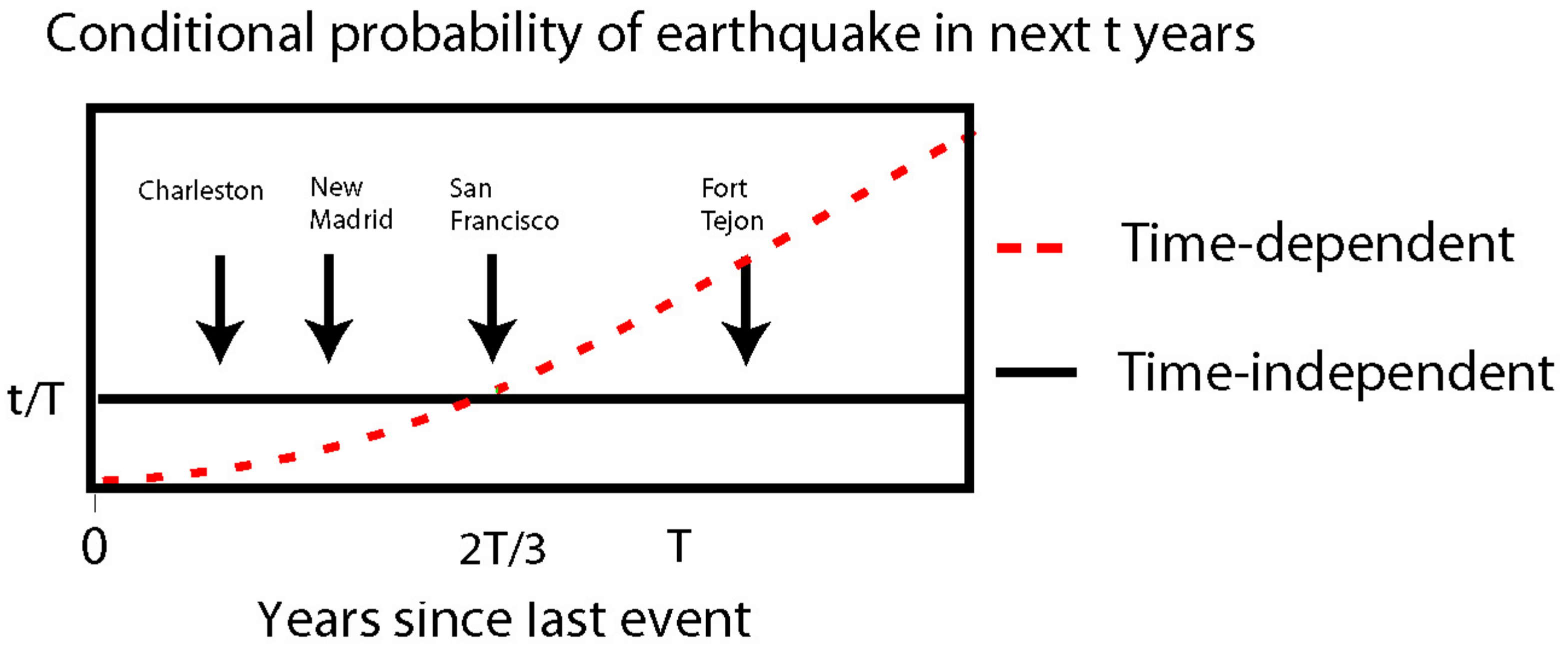
AVOID OVERESTIMATING HAZARD

Estimates biased toward high values distort policy decisions by favoring seismic safety over resource uses.

i.e. Don’t want to turn away patients from earthquake-safe hospitals

Need careful balance

If our understanding of earthquake probabilities becomes sufficient to confidently identify how large earthquake probabilities vary with time, the construction standards could be adjusted accordingly.



Thank You