Aggregated Seismicity Time Series: Is There Clear Evidence Of Precursory Patterns?

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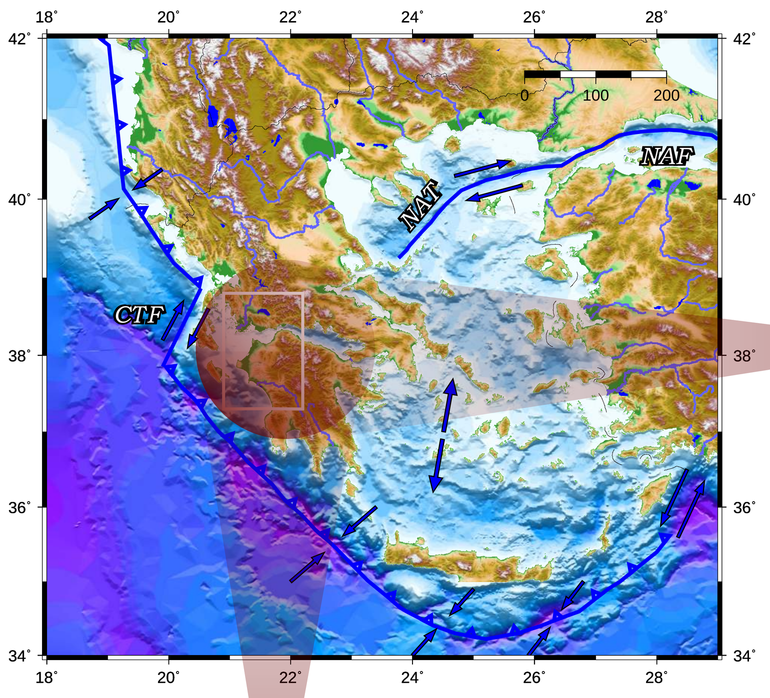
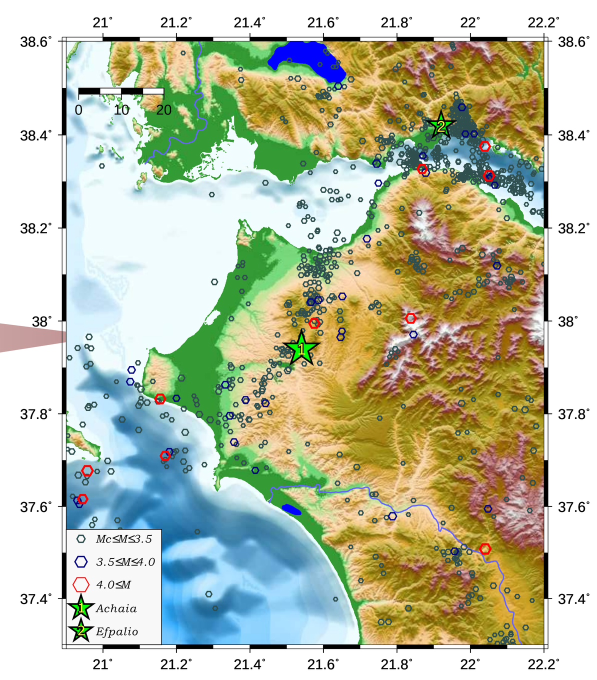
Introduction

Developing methods for reliable short-term forecasting of strong earthquakes has been a major target in seismology over the years. Many phenomena prior to large events have been investigated in order to assess their possible predictive value, but generally with limited success. A group of such phenomena are those related to temporal changes in seismicity patterns preceding large events.

We investigate inter-event times between earthquakes that occurred in a defined area as a time-specific proxy for seismicity rate. Using data from Greece we found some evidence of seismicity changes but the patterns are insufficiently clear and consistent in order to judge if these are precursory activity or some more unrelated phenomenon. However, when we aggregated the proxy seismicity-rate data before several events, a more clear pattern emerged showing an acceleration in seismic activity for about 1 month prior to the events.

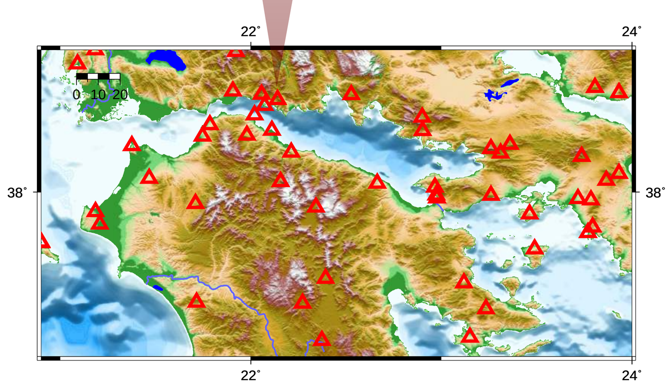
Data





Study Area:
W Corinth Gulf
NW Peloponnese

Seismicity:
2008-09-01 until
2010-01-17
Mc=2.1



Data set:
Catalog of M>2.0
Source:
Aristotle University of Thessaloniki

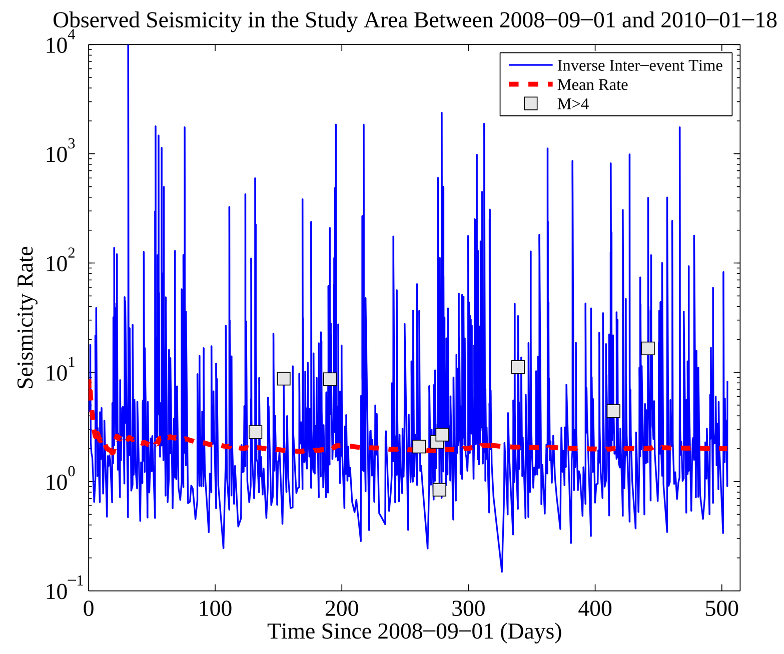
Network Density:
Hellenic Unified Seismological Network surrounding the Corinth Gulf

Major Events:
2008, June:
Achaia area
Strong event (M>6.0),

2010, January
Efpalio area
Doublet of M>5.0

Methods

In order to study the mechanism of foreshock activity and assess the prognostic value of this phenomenon, scientists can apply several statistical tests. A common methodology includes a comparison of observation (related to potential precursors) to what is predicted by cluster-type models, eg ETAS (Bouchon et. al., 2013, Marsan et. al., 2014, Mignan, 2014 (for a review), Ogata and Katsura, 2014). We here present a concept based on real data.



The mean rate looks rather stable but there are fluctuations
No clear precursory activity
Is it reasonable to look for precursors?

Step 1: Following specific criteria, some of the largest events are defined as "mainshocks"

Step 2: Superimpose data from large events , ie aggregate the preshock sequences. The resulting aggregated time series might give evidence of potential rate changes prior to these "mainshocks"

Step 3: The same number of sequences but with randomly chosen (from the data set) "mainshocks" are also stacked and averaged. This step is repeated 100 times to estimate the empirical confidence intervals (95%)

If the apparent acceleration is simply a consequence of that the data is temporally clustered, then the seismicity patterns prior to all events, large or small, should be the same
If they are not, the above concept can be rejected with some confidence.

Mainshock Selection Criteria:

Magnitude above a threshold (4.0)

Sufficient distance between them or time difference between the times of occurrence

Not preceded by any event of bigger magnitude within 10km and during 50 days prior to the mainshock occurrence (in order to avoid possible aftershocks)

Preshock Sequences Criteria:

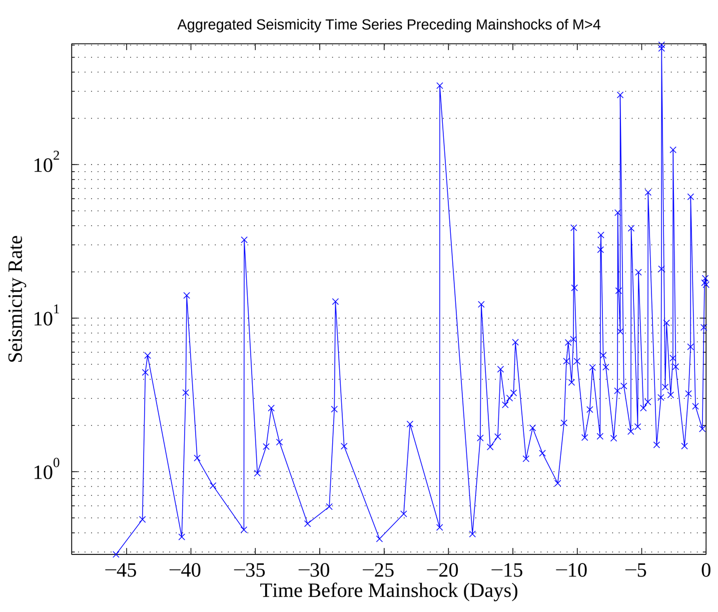
Events that occurred:
- within the same radius from the corresponding mainshocks
- 50 days (or less) before the mainshock

Same contamination of independent background events

Small radius and short time periods: less probable to get differences in seismicity rates because of changes in Mc

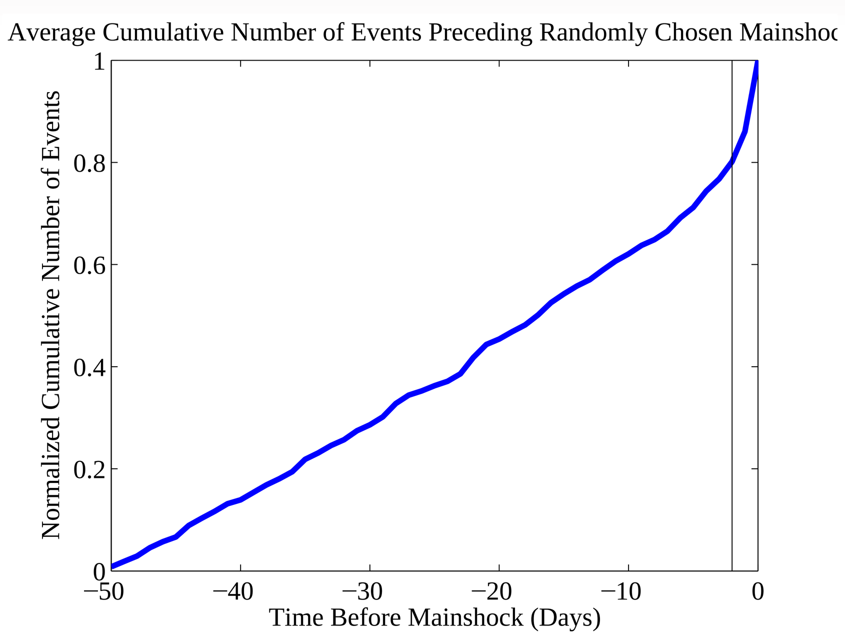
Results

The preshock sequences are aggregated
All events considered as mainshocks occurred during 2009
The magnitude difference between the strongest event of each preshock sequence and the corresponding mainshock is bigger than 0.6 in all cases



Seismicity seems to accelerate about 1 month prior to t_0, ie the occurrence of the main-shocks
Is this acceleration related to a geophysical process or is it a result of the seismicity tendency to cluster?

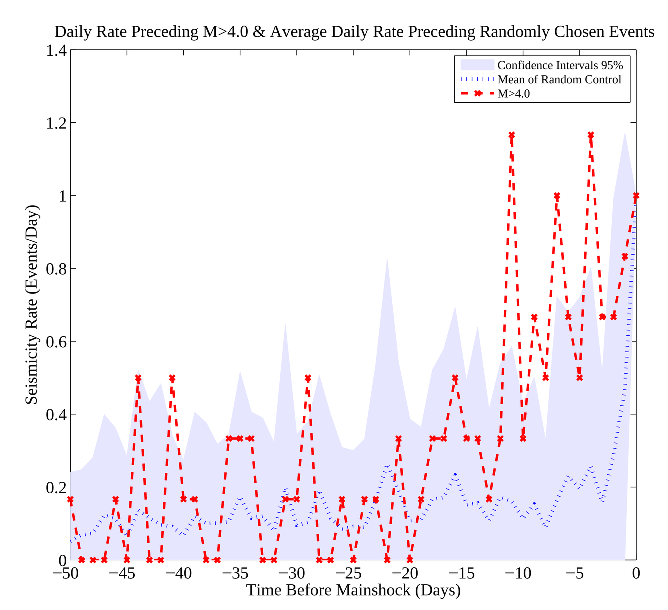
Following the same criteria as before but without a magnitude threshold, the same number of events are randomly chosen (100 times) and their preceding events are aggregated and averaged

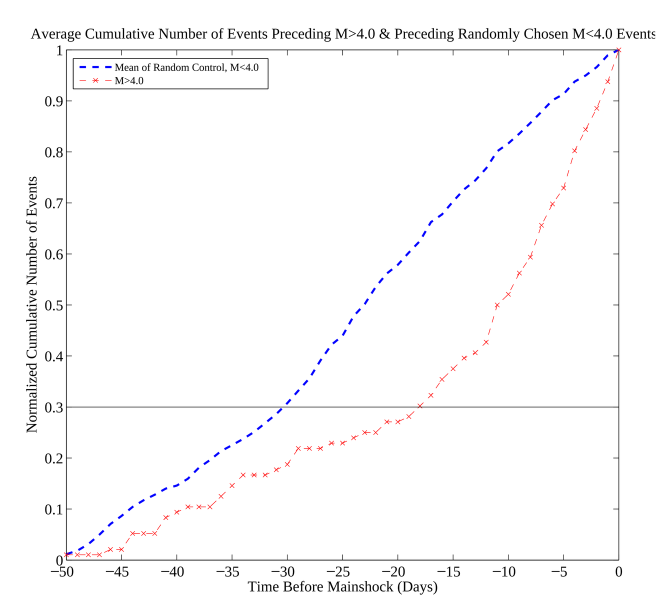


There is an apparent acceleration in seismicity (statistical inverse Omori law) but only 2 days before the mainshocks

(Left) The preshock sequences of the selected main-shocks (M>4.0) are stacked and averaged
The same number of sequences but with randomly chosen mainshocks are also stacked and averaged
The process is repeated 100 times and the confidence intervals (95%) are estimated

(Right) The averaged cumulative number of events of the aggregated preshock sequences for M>4.0 mainshocks is compared to the averaged stacked cumulative number of events prior M<4.0 mainshocks, again randomly chosen (100 times)





Although there is an apparent acceleration in seismicity in both cases, the increasing rate of the aggregated time series preceding M>4.0 mainshocks seems to be more significant during the last 20 days

For the relatively larger mainshocks, 70% of their preceding events (in the selected sequences) occurs during the last 20 days

Discussion - Conclusions

There are several possibilities regarding seismicity rate preceding larger events
(i) no change at all in seismicity rate
(ii) a period of decreased rate ("quiescence")
(iii) an "acceleration" (increase in seismicity rate) with deterministic components (accumulation of near-critical stress on the fault)
(iv) a "stochastic" acceleration, i.e. all events can be regarded as aftershocks to earlier events, with a probability of occurrence steered (presumably) by the modified Omori law and magnitude randomly selected from a Gutenberg-Richter type distribution (ETAS)

For our data we can reject both possibilities (i) and (ii)

Our data is insufficient to reliably investigate individual events
| Can changes in activity be observed before mainshocks?
| Can "foreshock" activity be distinguished from "clustering"?
We seek generic behavior. Assuming that there is an underlying common behavior for all events, we stack or aggregate data to seek patterns

In an ETAS model, an "acceleration" exists prior to larger events, and may be observable (depending on our data). In one sense, there are then foreshocks. However, in the ETAS model of the type we consider, these contain no predictive power for the coming larger event. Testing data for consistency with an ETAS model can be complex, partly because of issues related to e.g. data completeness. We can however rather easily test the internal consistency of the data relative to an ETAS model

| We can test empirically if the seismicity patterns prior to all events, large or small, are the same
| With some assumptions which are minor relative to most similar analyses, this provides a necessary but not sufficient test, at the given confidence level, for if the data is consistent with an ETAS model of the defined type
| In our case, the ETAS-type model can be rejected with over 95% confidence
| This approach is insensitive to many problems, such as data incompleteness

If there are deterministic changes in seismicity rate prior to larger events then, in contrast to the ETAS concept, this implies that there may be some possibility of using seismicity data for short-term prediction.
However, in order to achieve this we must better understand the possible patterns which are there, and to do this we probably need significantly more data i.e. significantly more sensitive seismic networks.

References
Bouchon et. al., 2013, The long precursory phase of most large interplate earthquakes, Nature Geoscience, 6, 299-302
Marsan et al., 2014, Foreshock activity related to enhanced aftershock production, Geophys. Res. Lett. 41, 6652-6658
Mignan, 2014, The debate on the prognostic value of earthquake foreshocks: A meta-analysis, Sci. Rep., 4, 4099
Ogata and Katsura, 2014, Comparing foreshock characteristics and foreshock forecasting in observed and simulated earthquake catalogs, J. Geophys. Res. Solid Earth, 119, 8457-8477