Typical Scenario of Preparation, Implementation, and Aftershock Sequence of a Large Earthquake

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Abstract

The global CMT catalog was used to construct the generalized space-time vicinity of a large earthquake (LEGV large earthquake general vicinity) and to investigate the seismicity behavior in LEGV. LEGV was formed of earthquakes falling into the zone of influence of a large number (100, 300, or 1,000) of largest earthquakes. The LEGV construction aims at enlarging the available statistics, diminishing a strong random component, and revealing typical features of pre- and post-shock seismic activity in more detail.

As a result of the LEGV construction the character of fore- and aftershock cascades was examined in more detail than was possible without of the use of the LEGV approach. A few anomalies in the behavior of different earthquake parameters were found also. The amplitudes of all these anomalies increase with the approaching time of the generalized large earthquake (GLE) as a logarithm of time interval remaining from the GLE occurrence.

The mentioned anomalies agree well with common features expected in the evolution of instability and with results obtained in laboratory acoustic emission (AE) studies.

In addition to these common-type precursors, one earthquake-specific precursor was found. The decrease in mean earthquake depth presumably found in a closer LEGV probably provides an evidence of a deep fluid (of low density) involvement in the process.

Note, that the majority of the anomalies in earthquake parameters appear to have a secondary character, largely connected with an increase in mean magnitude and decreasing share of moderate size events (mw5.0 - 6.0) in the nearest GLE vicinity. This deficit of moderate size events can hardly be caused entirely by their incomplete reporting and can presumably reflect some features in the evolution of seismic instability.

1. Method of LEGV Construction

In LEGV construction the radius of the zone of influence of a given large earthquake magnitude M is measured in kilometers or in units of a typical size of earthquake of a given magnitude M. The relationship between magnitude and mean earthquake source size S in km from (Kasahara, 1981) has the form

S, km = 10^(0.5M–1.9). (1)

More accurate relations characterizing the interconnection between moment magnitude and earthquake rupture length and rupture area were suggested in (Wells & Coppersmith, 1994), where it was taken into account that the rupture zone of a large earthquake is typically much longer than the width. This consideration suggests two relations between magnitude mw and rupture length RL, and mw and mean rupture area diameter RAD:

RL, km = 10^(0.59mw–2.44), (2)

or

RAD, km = 10^(0.45 mw–1.7). (3)

The difference in (1) - (3) relations has a secondary importance in the LEGV approach.

In the time domain the simple method of epoch superposition is used. The parameters of the seismic regime (rate, mean depth, others) are calculated for groups of subsequent earthquakes; groups are composed in majority of cases of 30 events.

2. RESULTS

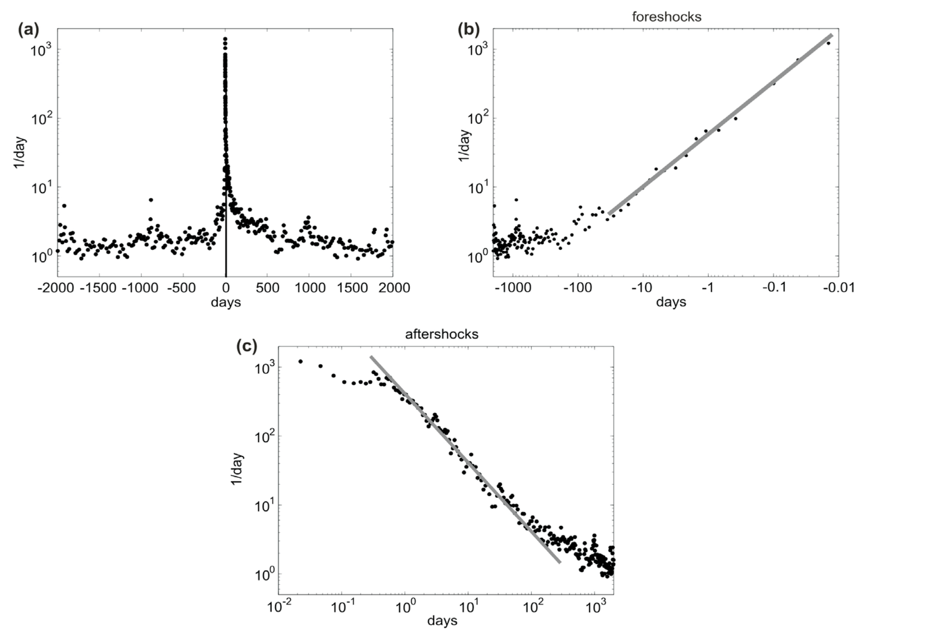

Fig.1. Change in the rate of earthquakes (a), foreshock (b) and aftershock (c) sequences in the generalized vicinity of a large earthquake (LEGV). Zero time corresponds to the moment of occurrence of the generalized main shock, the typical p=1 Omori law and the p'=0.8 typical of the LEGV foreshock sequence relations are shown by lines.

Parameters of the LEGV: one thousand largest events, spatial (R <1 RL) and magnitude (mw > 5.4) limitations are applied.

The parameters of the seismic regime (rate, mean depth, others) are calculated for groups of subsequent earthquakes; groups are composed in majority of cases of 30 events.

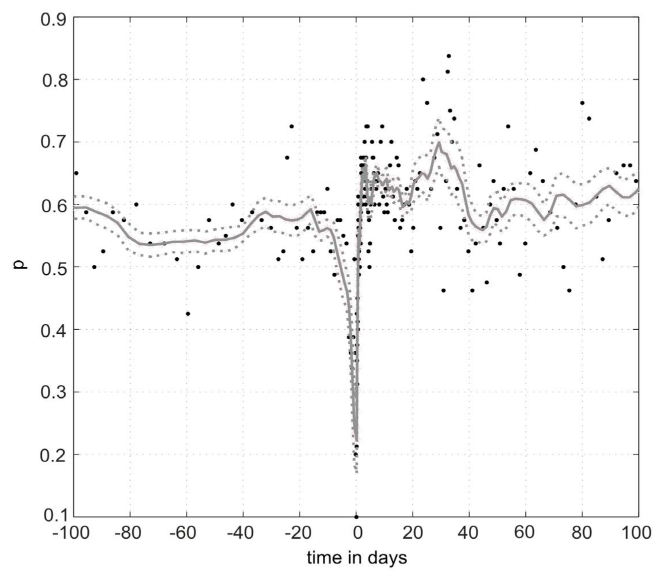

Fig.5. Change of share (p) of moderate size earthquakes in the closer GLE vicinity. Solid and dotted lines show a tendency of change in share of 5.0-5.5 mw earthquakes in subsequent groups of mw > 5.0 events (points); scatter of mean values is obtained by numerical boot-strap method.

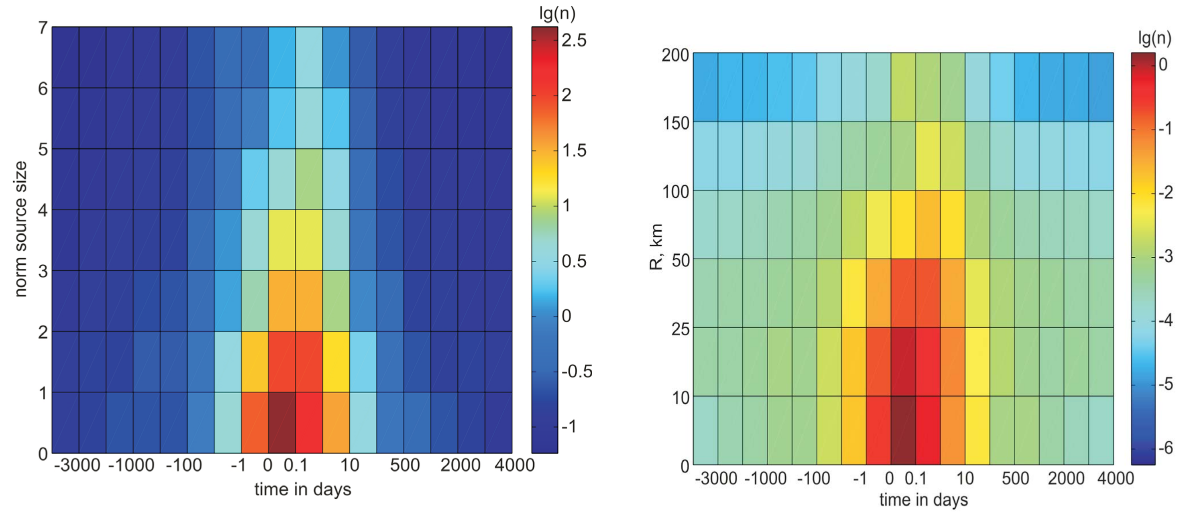

Fig. 2. The distance-time diagram of earthquake rate in a vicinity of GLE (general large earthquake). The distances from the GLE are given in main shock size S units, relation (1) (Fig.2a) and in km (b), x-axis shows the numbers of days before and after the GLE occurrence.

Parameters of the LEGV: one thousand largest events, spatial R ≤ 7 S (a) and R ≤ 200 km (b), magnitude (mw ≥ 5.0) limitations are applied.

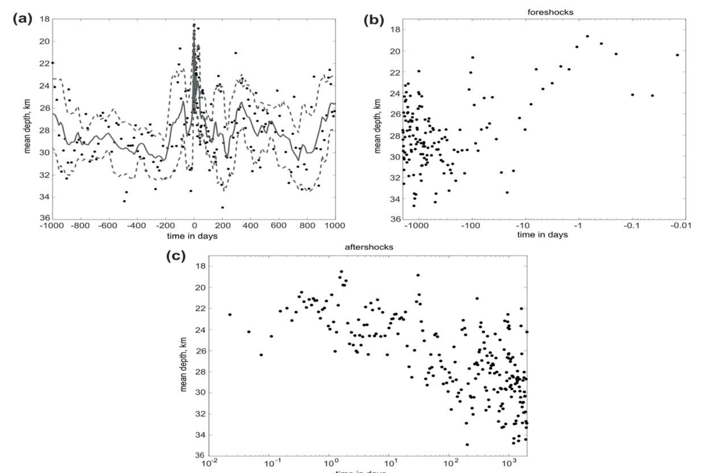

Fig.4. Change in mean earthquake depth (a); foreshock (b) and aftershock (c) sequences are given in logarithmic time scale. Parameters of the LEGV: one thousand largest events, spatial (R< 1 RL) and magnitude (mw > 5.4) limitations are applied. The tendency of a change in mean depth and of depth scatter obtained by numerical boot-strap method is shown (a).

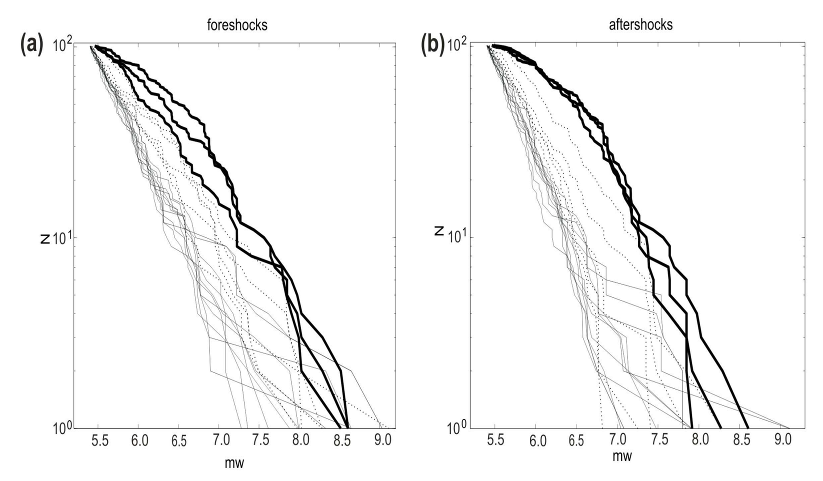

Fig.6. Change in character of Gutenberg-Richter plots for 100 events clusters with step 50 events in foreshock (a) and in aftershock (b) domain.

Three nearest to GLE occurrence plots are given by thick lines, the following 3-8 plots are given as dotted lines, the more time distant from the GLE occurrence 9-20 clusters are given as thin lines.

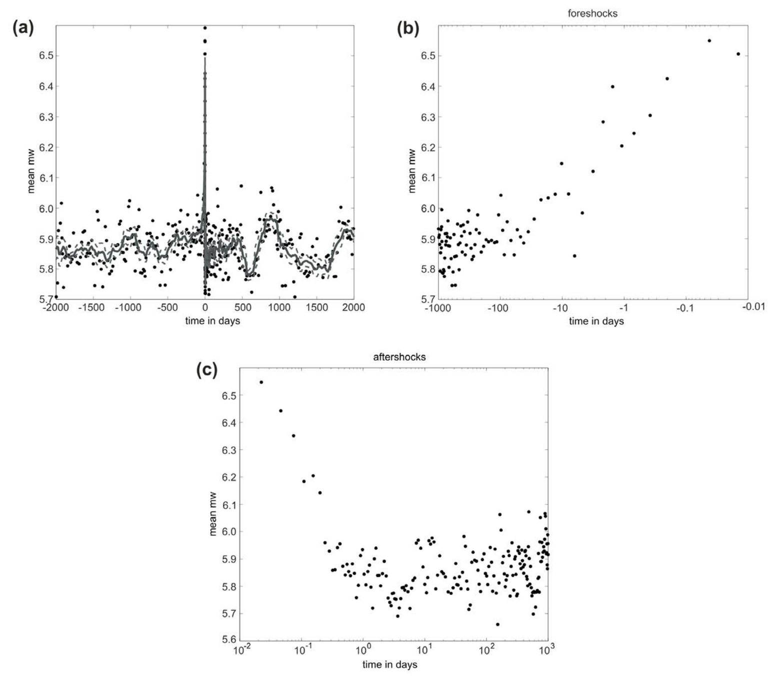

Fig.3. Change in mean mw values (a), foreshock (b) and aftershock (c) power-law sequences are given in logarithmic time scale. Solid and dotted lines (a) show the tendency of varying mean mw values and the scatter of mean mw values obtained by the numerical boot-strap method.

Parameters of the LEGV: one thousand largest events, spatial (R ≤ 1 RL) and magnitude (mw ≥ 5.4) limitations are applied.

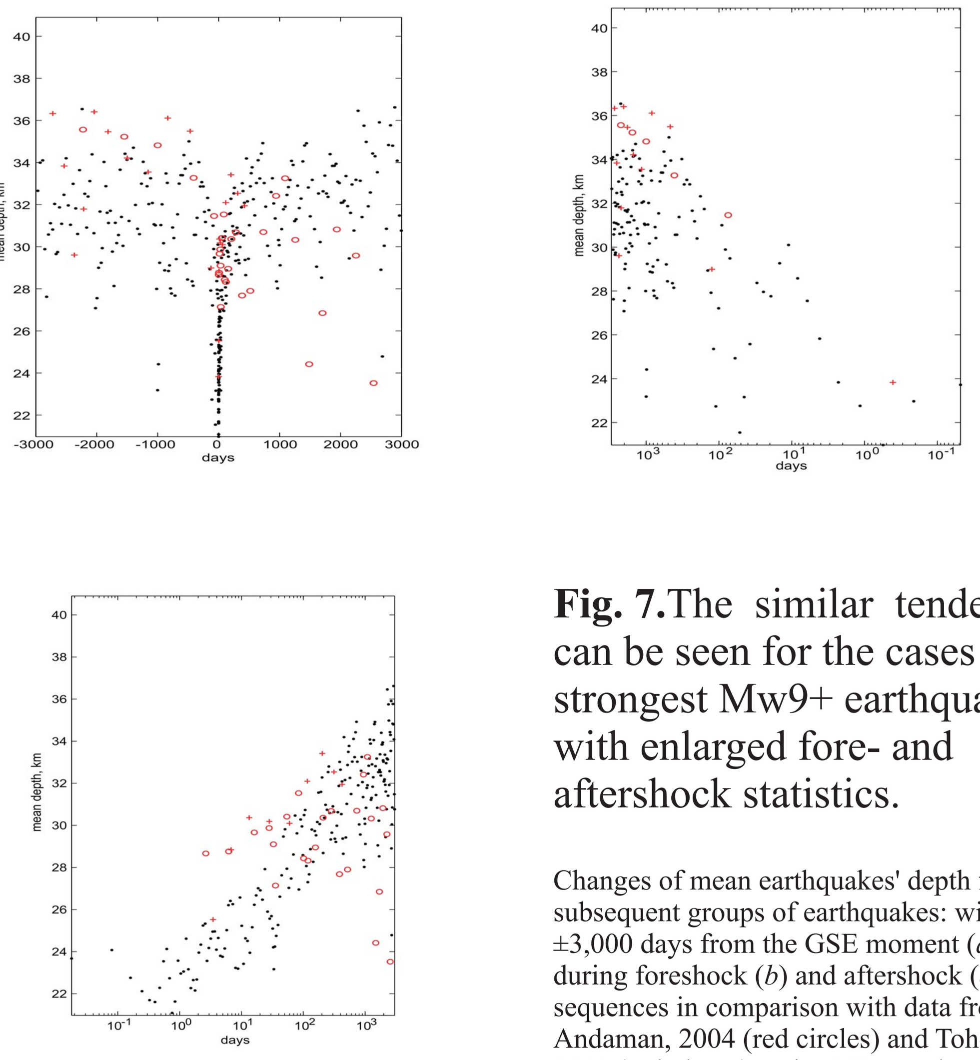

Fig. 7. The similar tendencies can be seen for the cases of strongest Mw9+ earthquakes with enlarged fore- and aftershock statistics.

Changes of mean earthquakes' depth for subsequent groups of earthquakes: within ±3,000 days from the GSE moment (a), and during foreshock (b) and aftershock (c) sequences in comparison with data from Andaman, 2004 (red circles) and Tohoku, 2011 (red pluses) major M9+ earthquakes.

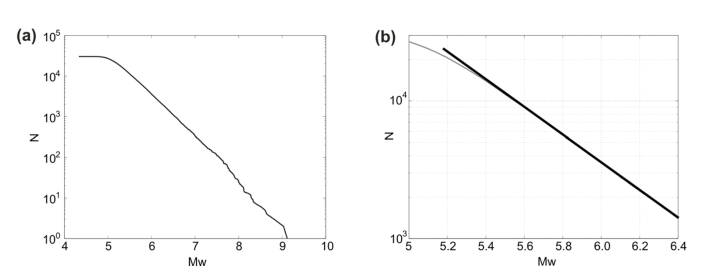

Fig.8. Validity of the used magnitude restriction.

Cumulative plot of used shallow (H≤ 70) GCMT events (a) and an enlarged portion of this graph (b); the straight line corresponding Gutenberg-Richter relation is shown (b).

3. Conclusion

The Harvard GCMT catalog for 1977-2015 was used to construct the generalized vicinity of a large earthquake (LEGV) based on the combined data for the vicinities of the 100, 300, or 1,000 individual largest earthquakes from the GCMT catalog.

The behavior of seismicity in LEGV was studied and two modes of increase in seismic activity in pre- and aftershock periods were found (Figs. 1, 2). The first mode is connected with a weak background increase in earthquake rate that, on average, lasts a few years before and after the main shock. The second mode of growth in seismic activity occurs in a smaller vicinity of a large earthquake. Power-law foreshock and aftershock cascades are the main features of this second mode.

The detection of the first mode of growth in seismic activity can be put together with a long-term earthquake forecasting, while the detection of the second mode corresponds to a short-term forecasting.

Besides these cascades in earthquake rate, a few earthquake parameters were found to have anomalies that linearly increase in amplitude with decreasing logarithm of time interval remaining from the generalized large earthquake occurrence (Figs. 3, 4)..

The majority of anomalies identified in LEGV are those expected in a common scenario for the evolution of instability. Besides these unspecific precursors, one earthquake-specific precursor was presumably found. This precursor is a tendency of decreasing mean earthquake depth in LEGV (Fig.4); this finding provides probably a new evidence for the deep fluid involvement in the precursory process of large earthquakes.

A substantial part of the anomalies as here identified could come from an unexpected finding of a prominent decrease in the share of moderate size earthquakes in the latest foreshock and the earliest aftershock LEGV sequences (Figs. 5, 6). It seems hardly possible to explain this deficit by incomplete reporting of moderate size events only.

The set of precursors found in the LEGV can be used to develop earthquake prediction algorithms. The evident possibility of "prediction" of a generalized large earthquake in the LEGV provides a reason to hope that the short-term (days to hours) prediction of large earthquakes is also possible in principle. It could be supposed that such prediction will have become possible when the volume of seismic information available for predictive purposes will increase by a factor of one hundred, approaching the volume of data available in the LEGV examination. In support of this idea we present the results of examination of vicinities of strongest Mw9+ earthquakes. In this specific case of highly enlarged statistics the behavior of individual fore- and aftershock sequences approaches the behavior of LEGV (Fig.7)..

Rodkin M.V., Seismicity in the Generalized Vicinity of Large Earthquakes. Journal of Volcanology and Seismology, 2008, Vol. 2, No. 6, pp. 435–445.

Rodkin, M.V. (2012), Patterns of seismicity found in the generalized vicinity of a strong earthquake: Agreement with common scenarios of instability development, in Extreme Events and Natural Hazards: The Complexity Perspective, Geophys. Monogr. Ser., vol. 196, edited by A. S. Sharma et al. 27–39, AGU, Washington, D. C., doi:10.1029/2011GM001060.