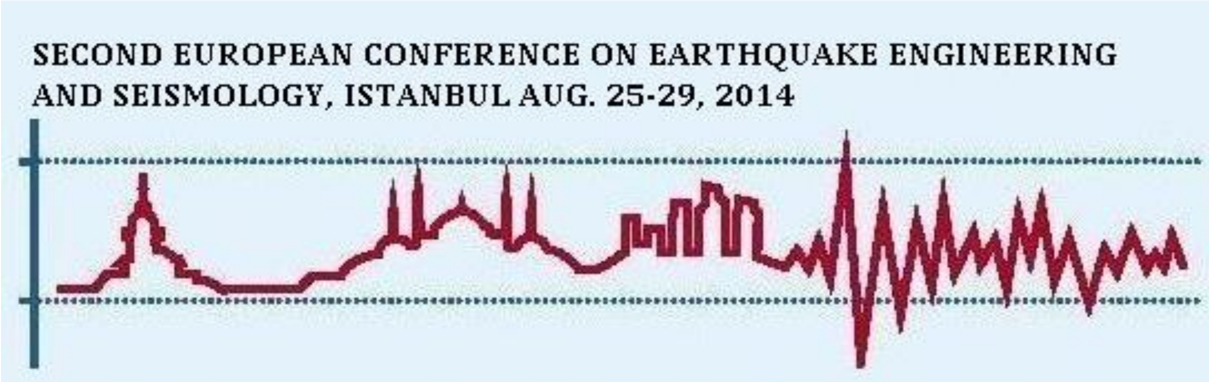

AFTERSHOCK PROCESS FORECAST

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Forecasting aftershock activity is important because buildings, get initially damaged by the mainshock, then can be destroyed by a series of less stronger. In contrast to mainshock, genesis of the aftershock activity is more deterministic process, being similar to microfracturing in brittle rock (Scholz, 1968).

After a strong earthquake occurs, seismic monitoring organizations estimate an expected seismic activity. For example, USGS supports the Collaboratory for the Study of Earthquake Predictability (CSEP). The web site of CSEP (http://relm.cseptesting.org/home) provides some methodologies for forecasting seismicity as well as the results of their implementation. One of the methodologies STEP, (Gerstenberger et al., 2005) was used in USGS as official one for estimating the next-day probability of earthquake occurrence, but the official use of that methodology has been stopped due to large forecast errors.

In this paper we suggest a simple approach for forecasting aftershock activity in different magnitude ranges. This method is based on the joint use of temporal models of aftershock decay rate and the Gutenberg-Richter (G-R) law. The key question is the way of estimating the *b*-value. The b-value may be not always estimated because a strong earthquake can occur in the area with previously low seismicity, e.g. well-known Racha-Dzhava (Fuenzalida et al.,1997) and Olutorskoe (Olutorskoe, 2007) earthquakes. Moreover, *b*-value changes with time during an aftershock process (Chen et al., 2014; Smirnov et al., 2010). Here, we suggest to estimate the *b*-value by using the analyzed aftershock sequence in a sliding window.

The suggested methodology comprises the following steps (fig. 1). (1) Fitting the aftershock process model and G-R law in a basic time interval (0, t) with maximum likelihood method; 0 is the mainshock time. (2) Using the estimated parameters calc aftershock number with different magnitudes in forecast interval (t, $h\cdot t$), $h > 1$ by means of the idea of Reasenberg and Jones (1989) which connects time model of aftershock decay rate and the G-R law:

$$N(t, M) = \int_{M}^{\infty}\int_{t}^{ht} 10^{b(M_0 - m)} n(\tau) dm d\tau , \quad (1)$$

where t is time after the mainshock; M_0 - the magnitude of completeness; $n(t)$ - aftershock process model, e.g., Omori law with parameters estimated in the previous step; b - parameter in G-R law which is also estimated in basic interval with maximum likelihood method (Aki, 1965).

(3) According to Reasenberg and Jones (1989), the estimated probability that in the time interval of (t, $2t$) at least one earthquake will occur

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defined by at least one event with the magnitude greater than M:

$$P(t,M) = 1 - \exp[-N(t,M)], \quad (2)$$

where $M = M_0$, Mm-2, and Mm-1 (Mm is the mainshock magnitude).

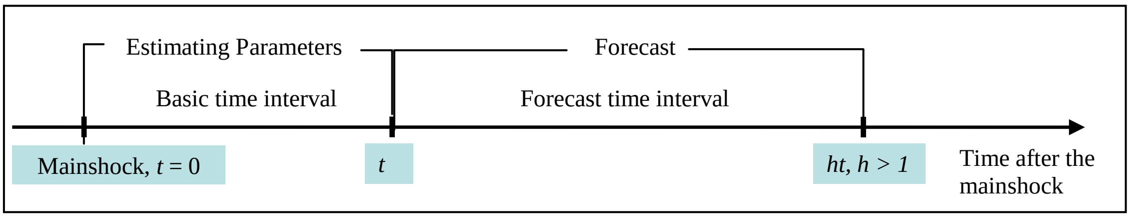

Figure 1. Approach to forecast an aftershock process

We tested four models of aftershock processes (the modified Omori law, ETAS, LPL, MSTREXP) and found out that the modified Omori law gives better results for most of the cases. Also, we tried to use Akaike information criterion for choosing the best model in the basic time interval to make a forecast. However, the best, according to this criterion, does not provide the best forecast. model We refused this technique because in many cases the best model from statistical point of view.

We tested the methodology making retrospective forecast for 8 aftershock sequences from the areas which have different types of earthquake occurrence (table 1). We estimated the model parameters in the basic time interval from 0 till $t = 0.5j$ days ($j = 1, 2, ...$) and made forecast for the interval of (t, $2t$). Thus, we use data for t days to forecast the aftershock number that will occur by $2t$ days after the mainshock.

Table 1. Aftershock sequences used for testing the methodology for forecasting aftershock processes. Mm is the mainshock magnitude, M_0 - the magnitude of completeness.

N	Place, Name	Date	Mm	M_0	Aftershock Nu	Duration (days)
1	Kamchatka, Kronotskii area	12.05.1997	7	4	1035	550
2	Kamchatka, Olutorskoe	20.04.2006	7.1	3.5	514	729
3	Tuva, Bussingolskoe	27.12.1991	6.7	2	1638	154
4	Tuva, 1st Tuvinskoe	27.12.2011	6.3	2	509	60
5	Georgia, 1st Racha-Dzhava	29.04.1991	6.9	2.5	708	47
6	Georgia, 2nd Racha-Dzhava	15.06.1991	6.2	2.5	263	189
7	Chechen Republic, Curchaloiskoe	10.11.2008	58	2	514	39
8	Spitsbergen, Storefjord Starit	21.02.2008	6	2	514	399

This methodology allows forecasting well the quantity of aftershocks with $M \geq M_0$ (fig. 1) and $M \geq$ Mm-2. Probabilities that that in the time interval of (t, $2t$) at least one earthquake will occur (2) also correspond to the real data. After increasing the magnitude threshold till Mm-1 for forecasting strong aftershocks the methodology gives time lags booth in estimated aftershock number and the probabilities calculated by (2). The reason of worsening the forecast for strong aftershocks is due to changing b-value with time and deviation of strong aftershocks from Gutenberg-Richter line. We suppose that for improving the forecasting for strong aftershocks it is necessary to use some additional criteria.

The suggested methodology can be used in the centers of seismic monitoring for estimating aftershock activity after a strong earthquake.

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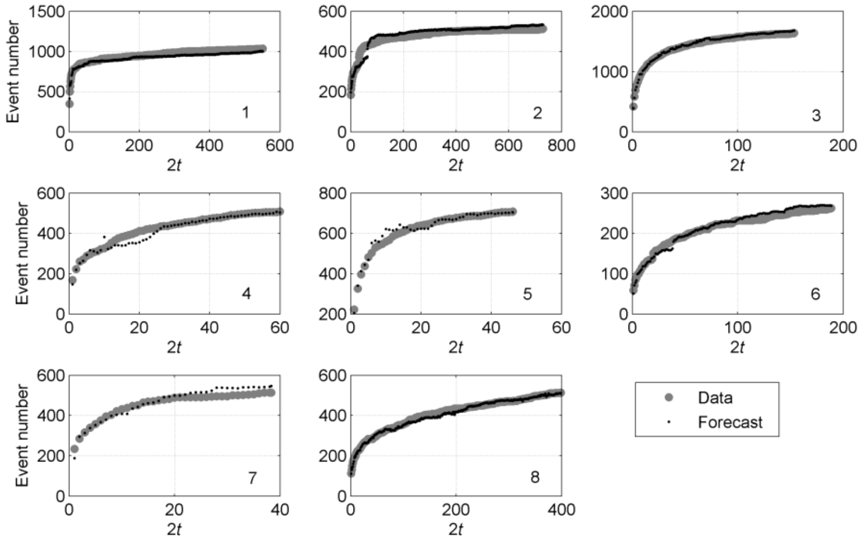

Figure. 1. Observed (black points) and forecasted (gray points) by the methodology aftershock number. The time is measured from the moment of mainshock. The number in the lower left corner of each plot corresponds to the number of aftershock sequence in table 1.

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