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SMR/107 - 9

WORKSHOP ON PATTERN RECOGNITION AND ANALYSIS OF SEISMICITY

(5 - 16 December 1983)

E X E R C I S E S

to the diagnosis of pattern B (Burst of aftershocks)
using the programs SUBCAT, DISTR, AFT

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Note: this is one of several premonitory seismicity patterns; none, including this, is confirmed beyond any reasonable doubt; therefore it has to be used on the trial basis.

After you leave this workshop, questions may be adressed to Drs Gabrielov A.M. or Keilis-Borok V.I., or Kuznetsov I.V., or Rotwain I.M. (Institute of Physics of the Earth, B.Gruzinskaya 10, Moscow 123242 USSR).

Final Goal

of this set of exercises:

having the catalog of earthquakes in a region

to compare the occurence of patterns B and strong earthquakes

This may be used in the further research in long-term prediction of strong earthquakes in the region, including forward monitoring of pattern B.

But this gives no ready recipe for routine prediction.

I. The test of the boundaries of the region (are they consistent with the map of epicentres ?)

Pattern B is monitored for a certain region. The boundaries of this region are determined by the seismotectonics non-uniquely.
Among other seismotectonic considerations, the boundary should satisfy two following conditions:

(i) it should not cross the dense clouds of epicentres - otherwise some patterns may be lost;

(ii) it should not go near the epicentres of strong earthquakes - otherwise their precursors may occur outside the boundaries.

Exercise.

The map of epicentres (artificial example) is shown on the Fig. I. Circles are "strong" earthquakes and dots are the medium earthquakes.

Question: which of the three versions of Eastern boundary, I , II or III, satisfies the above conditions ?

Notes: If the conditions (i), (ii) can not be satisfied, the overlapping regions may be chosen.
In the absence of convenient map of epicentres, its substitute can be generated by the program DIST.X . It can generate the distribution of the epicentres as on the Table I, which corresponds to Fig. I .

II. The choice of M_o

(we are looking for precursors to earthquakes with $M \geq M_o$; such earthquakes are called "strong").

The choice of M_o should satisfy two following conditions:

(i) The average interval between "strong" earthquakes should be much larger than the duration of the TIP; otherwise our prediction will lead to almost continuous alarm.

Specifically: our catalog has N earthquakes with $M \geq M_o$ for the time interval T.
Duration of the TIP is τ . We do not want to have the TIP's larger than I/3 of all time. Then M_o should satisfy the condition

$$N \leq \frac{T}{3\tau}$$

(ii) The earthquakes with magnitudes close to M_o should be not too numerous: otherwise the results of predictions are not stable to the errors in magnitude.

Specifically: M_o should be situated near the local minimum on the histogram of magnitudes. Sometimes this condition can not be satisfied.

Exercise: Given is the catalog of earthquakes with $M \geq 7$ (Table 2). It is obtained by the program SUBCAT. Draw the histogram of M. Choose possible values M_o for τ = 4 years.

III. The choice of the time interval for retrospective prediction.

During this interval the catalog should be reasonably complete for magnitudes $\geq (M_o - a_3)$, $a_3 \approx 3.5$; this is the lower threshold for the aftershocks counted in the pattern B.

The catalog is considered complete on the linear segment of the magnitude - frequency of occurence law.

Exercise: Given is the histogram showing the distribution of earthquakes in time and magnitude (Table 3, artificial example).

Let $M_o = 8$. Choose the time interval for retrospective prediction. For which magnitudes the catalog seems to be complete during this interval ?

IV. Separation of the catalog into main shocks and aftershocks.

Definition of aftershocks. Consider two earthquakes: one - with the origin time t_1 and magnitude M_1; another - with the origin time t_2 and magnitude M_2. Second earthquake is an aftershock of the first one if the following conditions are satisfied:

$$0 \leq t_2 - t_1 \leq T(M_1)$$

$$M_2 \leq M_1$$

$r \leq R(M_1)$, where r is the distance between their epicentres;

$d_h \leq H(M_1)$, where d_h is the difference between the depths of the sources.

Here $R(M_1)$, $T(M_1)$, $H(M_1)$ are empirical functions of the magnitude of the first earthquake, which is not an aftershock of some other preceeding earthquake.

The algorithm of separation of main shocks and aftershocks.

The first earthquake in the catalog has to be counted as a main shock. Its aftershocks are identified and excluded from the catalog. The first remaining earthquake is the second main shock, etc.

Exercise: Separate the catalog in Table 4 into the main shocks and aftershocks. Use the following empirical functions:

$R(M_1) = 100$ km, $H(M_1) = 100$ km, $T(M_1) = 2$ years.

Note: Different main shocks may have a common aftershock; it should be assigned to the strongest main shock. If these main shocks have equal magnitudes, it should be assigned to the latest main shock.

V. The count of the aftershocks.

Consider the main shocks with $M_o - a_2 \leq M \leq M_o - a_1$. For each main shock $b(e)$ is the number of its aftershocks with $M \geqslant M_o - a_3$ during first e days.

A strong earthquake (with $M \geqslant M_o$) may occur in the region during one of the e–days intervals. In other words, it may happen that

$$t_m \leq t_o \leq t_m + e$$

where t_o is the moment of a strong earthquake, t_m is the moment of a main shock. In this case the count is terminated just before t_o.

Exercise: Count b(e) for each main shock in the Table 4.

Main shocks and aftershocks are identified by previous exercise.

Parameters: e=2 days; $M_o = 7$; $a_1 = 0.1$; $a_2 = 1$; $a_3 = 3.5$.

VI. The choice of $\bar{B}$.

We diagnose the occurence of pattern B, when for some main shock

$$b(e) \geqslant \bar{B}.$$

To choose the threshold $\bar{B}$ we may use the histogram of values of b. $\bar{B}$ should be choosen near a minimum of the histogram; otherwise the diagnosis of pattern B will not be stable to possible uncertainty in the choice of $\bar{B}$. Another condition for $\bar{B}$: The number of patterns B should not be too small (preferably not less than the number of strong earthquakes) nor too large (to have the TIP's not more than I/3 of all time).

Exercise: Given is the catalog of main shocks with values of b(e); this catalog is generated by the program AFT (Table 5). Make the histogram of the values of b(e), e = 2 days and choose the value of $\bar{B}$.

VII. Retrospective prediction.

τ years after the occurence of each pattern B are considerd as the Time of Increased Probability of strong earthquake ("TIP"). The TIP is terminated after the strong earthquake. If a strong earthquake did not occur within τ years, the TIP is considered as a false alarm and is terminated too.

Failure to predict is a strong earthquake which occured outside of any of the TIP.

Exercise: Using table 5 count the characteristics of retrospective prediction:

- total duration of the TIPs (of "alarms");
- the number of "successful predictions" (strong earthquakes occured during the TIPs);
- the number of failures to predict;
- the number of false alarms.

Parameters: τ = 4 years; $\overline{B}$ = I4; M_o = 7.8, $a_1 = 0.1$, $a_2 = 1$

VIII. Do patterns B really indicate the approach of a strong earthquake ?

An unpleasant alternative is that the patterns B and strong earthquakes are independent. We expect the occurence of a strong earthquake within the interval τ years after each pattern B.

T – time interval, for which patterns B are diagnosed (exercise III);

T_a – total duration of the TIP's (full τ years each; overlapping parts are counted once);

n_a – the number of strong earthquakes within the TIP's;

n – the total number of strong earthquakes.

The probability, that n_a out of n strong earthquakes follow the pattern B (within τ years) just by chance is

$$P = \sum_{j=n_a}^{n} C_n^j \left(\frac{T_a}{T}\right)^j \left(1 - \frac{T_a}{T}\right)^{n-j}$$

Small value of P, a few percent or less, suggests that pattern B has predictive power in this region. However, P is not a confidence level in a strict sense in typical cases, when some parameters – most often B and/or M_o – are data-fitted.

Exercise: Estimate P for retrospective prediction, obtained in exercise VII.

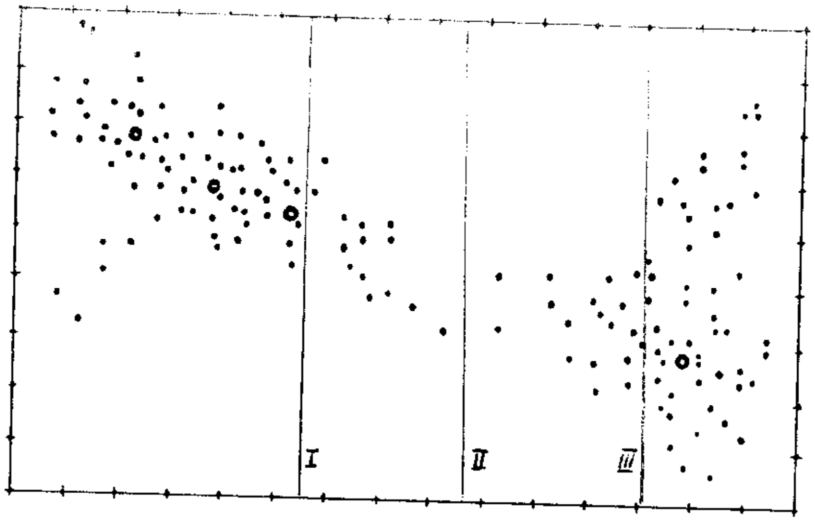

Figure I. Map of epicentres.

0	2	I	0	0	0	0	0	0	0	0	0	0	0	0
2	4	4	I	0	0	0	0	0	0	0	0	0	I	2
I	5	7	5	6	2	0	0	0	0	0	0	I	4	0
0	0	3	7	7	5	2	I	0	0	0	0	3	3	I
0	2	I	2	I	2	4	I	0	I	I	I	4	3	0
I	I	0	0	0	0	I	2	I	I	2	5	5	3	I
0	0	0	0	0	0	0	0	0	0	I	4	6	6	2
0	0	0	0	0	0	0	0	0	0	0	0	3	4	0
0	0	0	0	0	0	0	0	0	0	0	0	I	I	0

Table I. Histogram $N(\lambda,\varphi)$.

YEAR	MO	DA	HO	MI	LAT	LON	DEP	MB	MS	ML	MP
1900	10	7	21	4	-4.00	140.00	25	0.00	0.00	0.00	7.80
1914	5	26	14	22	-2.00	137.00	0	0.00	0.00	0.00	7.90
1916	1	13	8	20	-3.00	135.50	25	0.00	0.00	0.00	8.10
1918	7	3	6	52	-3.50	142.50	0	0.00	0.00	0.00	7.50
1925	6	9	13	40	-3.00	140.00	0	0.00	0.00	0.00	7.00
1926	10	26	3	44	-3.25	138.50	25	0.00	0.00	0.00	7.90
1931	8	7	2	11	-4.00	142.00	0	0.00	0.00	0.00	7.10
1935	9	20	1	46	-3.50	141.75	0	0.00	0.00	0.00	7.90
1935	9	20	5	23	-3.25	142.50	0	0.00	0.00	0.00	7.00
1942	1	27	13	29	-4.50	135.00	0	0.00	0.00	0.00	7.10
1945	9	22	9	10	-4.00	147.00	50	0.00	0.00	0.00	7.00
1946	9	23	23	30	-6.00	145.00	100	0.00	0.00	0.00	7.20
1947	3	2	19	9	-5.00	144.50	50	0.00	0.00	0.00	7.00
1947	4	2	5	39	-1.50	138.00	0	0.00	0.00	0.00	7.40
1947	5	27	5	58	-1.50	135.25	0	0.00	0.00	0.00	7.25
1948	11	26	5	36	-5.00	145.00	70	0.00	0.00	0.00	7.00
1952	11	6	19	47	-4.60	144.90	0	0.00	0.00	0.00	7.38
1954	3	3	6	2	-5.50	142.50	0	0.00	0.00	0.00	7.00
1957	6	22	23	50	-1.50	137.00	0	0.00	0.00	0.00	7.50
1970	10	31	17	53	-4.93	145.47	42	6.00	7.00	0.00	7.00
1971	1	10	7	17	-3.13	139.70	33	7.30	8.10	0.00	7.90
1976	6	25	19	18	-4.60	140.09	33	6.10	7.10	0.00	7.10
1976	10	29	2	51	-4.52	139.92	33	6.10	7.10	0.00	7.20
1979	9	12	5	17	-1.68	136.04	5	6.30	7.90	0.00	7.90

Table 2.

Year	M=0	3-3.4	3.5-3.9	4-4.4	4.5-4.9	5-5.4	5.5-5.9	6
I956-57	I.5	0	0	0.2	0.5	0.9	0.7	0.2
I958-59	0.9	0.2	0.2	0.5	0.67	0.5	0.3	0.2
I960-6I	I.7	0.2	0.3	0.3	0.5	I	0.9	0.5
I962-63	I.7	0.5	0.7	0.7	0.9	0.9	0.5	0
I964-65	I.5	0.9	I.5	I.3	I.2	0.9	0.7	0.33
I966-67	I.7	I	I.7	I.2	0.9	0.7	0.2	0.2
I968-69	I.4	I.2	I.5	I.5	I	0.5	0.5	0
I970-7I	I.3	I.2	I.3	I.2	0 9	0.7	0.7	0.3
I972-73	I	0.9	I.9	I.5	I.3	I.2	0.9	0.5
I974-75	I	I	I.5	I	I.2	0.9	0.7	0.2
I976-77	I.3	I	I.5	I.2	0.7	0.7	0.3	0.2

Table 3. lg N(M) .

Table 4.

№		φ°	λ°	M
I	I970. I. I	60.0	I24.3	6.I
2	I970. I. 3	60.0	I24.0	5.9
3	I970. I. 4	60.0	I24.3	3.2
4	I970. I. 4	60.0	I25.3	6.2
5	I970. I. 5	60.0	II7.4	3.6
6	I970. I. 6	60.0	I24.9	6.0
7	I970. I. 7	60.0	I23.9	4.0
8	I970. I. 7	60.0	I25.0	4.8
9	I970. I. 8	60.0	I25.2	5.7
I0	I970. I.9	60.0	I25.8	6.6
II	I970. I. 9	60.0	II6.8	7.4
I2	I970. I.I0	60.0	I24.3	4.5
I3	I97I. 4.I8	60.0	I23.9	6.I
I4	I97I. 6.20	60.0	I24.2	4.2
I5	I972. 6.25	60.0	II7.0	7.3
I6	I972. 7.28	60.0	II6.9	6.5
I7	I973. 2.I2	60.0	II7.2	6.I
I8	I973. 2.I3	60.0	II9.9	6.3
I9	I973. 2.I3	60.0	II6.5	7.0
20	I973. 2.I4	60.0	II9.4	6.0
2I	I973. 2.I5	60.0	II6.9	6.3
22	I974. 8.II	60.0	I24.3	3.I

All the earthquakes are normal (H = 33 km).

year	mon	day	lat	lon	dep	mag	b
I962	7	30	-3.40	I43.70	33	6.88	2
I963	8	I4	-3.40	I35.40	33	6.99	0
I964	I	I	-3.20	I39.70	33	6.88	0
I968	IO	23	-3.33	I43.25	I2	6.80	3
I970	IO	3I	-4.93	I45.47	42	7.00	I6
I970	II	8	-3.44	I35.63	33	6.80	5
I97I	I	IO	-3.I3	I39.70	33	8.IO	94
I976	6	25	-4.60	I40.09	33	7.IO	I9
I976	IO	29	-4.52	I39.92	33	7.20	4
I979	9	I2	-I.68	I36.04	5	7.90	I4
I980	7	I6	-4.46	I43.52	34	7.IO	0

Table 5.

Answers to the exercises:

I. Line II.

II. M_o=7.7 or 7.6 or 7.8 . Here $N = 7$.

III. Catalog seems to be complete enough for $M \geq 5.0$ since I956 and for $M \geq 4.5$ since I964. By the adding of the earthquakes with unknown magnitude we may fit the linear law for $M \geq 4$ since I956.

We may try retrospective prediction for $M_o \geq 8$ for the period after I964; it is worth to try it then for the period after I956, counting all the aftershocks ($M_{aft} = 0$).

IV–V.

Main shocks	Aftershocks	b(e)
I	2,3	I
4	6,7,8,9,I3	I
5		weak
IO	I2,I4	0
II		strong
I5	I6,I7,I9,2I	strong
I8	20	I
22		weak

VI. Any number between 6 and I5.

VII. Total duration of the TIPs is about 3.4 years.

Successful predictions – 2.
Failures to predict – 0.
False alarms – 0.

VIII. $T = 20$; $T_a = 3.4$; $n_a = 2$; $n = 2$; $p = 0.03$.

If we do not terminate the TIP at the moment of a strong earthquake then $T_a = 8$ and $p = 0.I6$.