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Diagnostics of Times of Increased Probabilities of Strong Earthquakes in the Himalayan Seismic Belt Using Pattern Recognition Algorithm CN*

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INTRODUCTION

This paper discusses the results of on going research(1,2,3,4) on earthquake prediction in the Himalayan region.

Paper(1) studied the prediction of strong earthquakes using precursors Sw and SIGMA. First precursor reflects the anomalous clustering of earthquakes and second one - the increase of the total focal area in the middle magnitude range just below M. These precursors were investigated for the prediction of strong earthquakes of magnitude $M \geq 8$ within the time period 1900-1977. Three strong earthquakes occurred within this period two of them were preceded by at least one of the two precursor's. This paper makes the conclusion that in North-East Himalaya an earthquake with $M \geq 8.5$ should be expected before 1993.

The Alpine seismic belt is considered in the paper.(2) Using pattern recognition method the author found the features of location where a strong earthquakes may occur.

Paper(3) studied the prediction of earthquakes with $M = 8 \pm 0.5$ on the basis of earthquake swarms and quiescence period in the area bounded by 21°N and 25.2° N latitude and 93°E and 96° E longitude. This paper states that an earthquake with M

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= 8+0.5 might occur before 1990. Now the authors suppose that they predicted the earthquake of August 1988.

Two more or less similar pattern recognition algorithms (M8 and CN) for discerning the Time of Increased Probabilities (TIPs) of strong earthquakes are described in detail in.(5,6) They are based on a wide range of phenomena which reflect the characteristics of earthquakes flow. This approach has been worked out and applied successfully to various regions of the world with a wide range of seismotectonic settings [7,8]. The results of application of the algorithm M8 for prediction of the strong earthquakes with $M \geq 7$ in the Himalayan belt and surrounding area is adduced in paper.(4)

In this paper we have considered the results of application of the algorithm CN for prediction of the strong earthquakes with $M \geq 6.4$ in the Himalayan belt.

ALGORITHM CN

We have applied a version of CN algorithm described in.(5) This algorithm is based on searching of the anomalous variations of earthquakes flow.

Parameters of seismicity are presented as functions of time defined on a sequence of main shocks in the region within a sliding time window.

Level of seismic activity

N - number of main shocks with the magnitude above some threshold

Sigma - the total energy of main shocks

G - the ratio of numbers of main shocks in two magnitude ranges

Seismic quiescence

q - 'deficiency' of the seismic activity

Temporal variation of seismicity

K - Difference between numbers of main shocks in two successive time-intervals

Spatial concentration

S_{max} - the average area of fractures at foci

Z_{max} - the ratio of the average radius of fractures at foci to the average distance between them

Clustering in time and space

B_{max} - maximal number of aftershocks

Some combinations of these functions for the time periods before strong earthquakes (periods D) and the periods of time far from strong earthquakes (periods N) had been found for California and Nevada catalogs.(2) These combinations are called attributes D and N respectively (Table 1.1 and 1.2).

Time of Increased Probability (TIP) of appearance of a strong earthquake is announced in the region at the moment λ t λ if

1. $\Delta(t) = n1\,(t) - n_2\,(t) \geq \bar{\Delta}$
2. $\sigma(t) = 10^{-\beta(Mo-\alpha)} \quad \Sigma \quad 10^{-\beta(Mi-\alpha)} \quad < \bar{\Sigma}$

here n_1 n_2 - number of attributes D and N respectively, (t) - estimates the total fracture area for three preceding years, M - magnitude of strong earthquakes, M magnitude of the 1-th earthquake (α= 0.5 and β= 1).

The TIP lasts a year consecutive TIPs may overlap and prolong each other. If no strong earthquake occurred during the TIP it is called a false alarm. Strong earthquake which was not preceded by a TIP is a failure to predict. The total duration of TIPs is called alarm time.

For California-Nevada region standard values of $\bar{\Delta}$ and $\bar{\Sigma}$ are 5 and 4.9 respectively.

DATA ANALYSIS

We used catalog [9] from 1900 to 1989 as a data base, because the local observation networks are functioning there since 1980 only. This catalog contains only magnitudes, M_p of strong recorded by station at Pasadena for period before 1963. After 1963 the magnitudes of earthquakes M_b defined by body waves are recorded and from 1971 one can find magnitude M_s defined by surface waves in this catalog. Values of magnitude M_s are quite compatible with values of M_p, for events for which these two magnitudes are given. That is why we have chosen the magnitude M_s as the magnitude of an event. For the event without magnitude M_s, we used M_p where as for events having only M_b values we recalculated it into M_s according to the relation $M_s = M_b - 5.34$.(10) We have considered the catalog from 1966. The catalog was not uniform in time due to detection increase of small events during the second part of the period under review. To smooth the earthquakes flow we used all events which had occured before 1975 and only events with $M \geq 3.4$ after this time. We applied the standard procedure of selection of aftershocks to obtain the catalog of main shocks.(11)

The area considered, embraces the central and eastern parts of the Himalaya including some territories of India and Burma and all territories of Nepal, Bhutan and Bangladesh. This region is characterized by contrasting neotectonic movements and hence by rather high seismicity level. Since the beginning of the century this area has experienced three devastating earthquakes of M ≥ 8.0. One of them occurred in the western segment while the other two occurred in the eastern segment.

We divided the Himalayan belt into three seismic regions. We selected boundaries of regions taking into account of the spatial distributions of earthquakes. The boundaries should not cross clouds of epicenters and must be located far enough from epicenters of strong earthquakes. Each of these regions include the epicentral zones of devastating earthquakes. Boundaries of these regions lie along the active fault and all area is located in the inferred zone of recent compression. Obviously this division is nonunique.

Boundaries of these regions and the historical seismicity are shown in Fig. 1. Epicenters of main shocks which occurred during the period 1970-1989 are shown in Fig. 2. Magnitude and time of occurrence of strong earthquakes are given in Table 2.

Here, as in California we have selected the earthquakes with M ≥ 6.4 as strong earthquakes.

To calculate most of the functions characterizing the earthquakes flow the time interval should be at least four year thus we can diagnose the TIPs only after 1970. We have considered only sallow earthquakes with depth H ≤ 100 km.

Let us describe the seismicity of these regions in more detail.

Region-1

This region contains the epicentral zone of Kangra earthquake of magnitude 8.7 of 1905. This region has experienced 5 events of magnitude greater than 6.4 during the past 90 years. Among them two were with M = 6.8. We didn't considered the event of 1975 (M = 6.6) as it is an aftershock not included in the catalog of main shocks.

Region-2

In the past there were two catastrophic events in this region, one in 1897 with M = 8.7 and another in 1934 with M = 8.4. Since the begining of this century 25 earthquakes with M ≥ 6.4 are recorded, three of them after 1970. It is interesting to note that these strong events are clustered in time, only 4 earthquakes among them are single all the rest form 7 groups. There are from 2 to 5 events in a group with average time interval of about 10 months and the maximum time interval of 18 months. Earthquakes belonging to one group often occurred at different faults and rather far from each other. That is why it seems natural to consider this area as the single seismic region.

Region-3

Here the largest event with $M=8.7$ occurred in 1950. Among the 20 earthquakes recorded with $M \geq 6.4$, 12 out of them are with magnitude $M \geq 7$. Based on the data from catalog [9] relative quiescence is observed since 1964. After 1964 only two earthquakes have occurred -one in 1970 and another in 1988.

4. Results

We have used algorithm CN without change of it's numerical parameters. The thresholds for the discretization of functions for regions 2 and 3 are chosen accordingly a priory given values of the quanties.(5) The period D and N should be taken into account to choose the thresholds of discretization. When number of strong events is small or there are not such events at all, it is not clear that in a territory in such a stage a strong-earthquake may occur. The same problem arose when algorithm was worked out [5]. That is why for region 1 where only one strong earthquake has occured, we have used the thresholds of region 2.

The results of TIPs diagnostics in the regions 1,2 and 3 are given in Fig. 3. We obtained these results using standard thresholds of algorithm CN for $\overline{\Delta}$ and $\overline{\Sigma}$. The time of alarm occupies 15%, 31% 19% for regions 1,2 and 3 respectively. The TIPs preceded all strong earthquakes in regions 1, 2 and one earthquakes in region 3. The failure to predict the July 1970 earthquake, in region 3, may be due to the incomplete nature of catalog the false alarm began just after this events.

We checked the stability of the results of TIP's diagnostics regarding following free parameters- the choice of the boundaries of the regions and thresholds of discretization. These results are given in Table 3. One can see from this that the number of failures to predict didn't increased with the change of these parameters. The total time of alarm changed considerably in the regions 2 and 3 when they were extended, apparently, due to capturing of zones of preparation of strong earthquakes from neighboring regions. Moreover, the increase of the time of alarm in region 3 in the first experiment can be explained by the choice of thresholds of discretization as it has been done for small number of strong events. We suppose that all these experiments demonstrate the stability of results of the TIP's diagnostic for regions 1 and 2.

We analyzed which features D appear more often before strong earthquakes in these regions and which are responsible for false alarms.

In region 1 all features 6,9,10,11 and 12 of period D (Table 1.1), in which the function of K has small or moderate values and the function Z max has large values arouse the false alarms. Only features 1,7,8,13,14 and 16 which have large and moderate value of the function K preceded strong earthquake. Among them only the features 1 didn't produced a false alarm. All the rest five features didn't appeared in this region.

In region 2 all features appeared at least before one of the three earthquakes except the feature 13 for which the value of Z max is not large. The features 1 and 9 indicate that the number of events in a region under consideration doesn't decreases but their spatial concentrations and the number of aftershocks grow. They occur before each strong earthquake, moreover the feature 1 is not met during the period N. Features 6,10,11 and 12 with small and moderate values of the function K and larges values of Z max appear before earthquakes of July 1980 and August 1988. Features 14,15 and 16 with the function of K having large values occurred only before the earthquake of January 1982. There are false alarms before and after the earthquake of January 1975 (M = 6.8) which occurred in the region 1.

In the region 3 all features except the first appeared before the earthquakes of August 1988. Some of the false alarms occurred after the earthquake of August 1976 with M = 6.1 (M_b = 6.4).

Features of period N practically didn't appeared before strong earthquakes.

CONCLUSIONS

The retrospective analysis of the data has shown that the algorithm CN can be applied with standard thresholds for all regions of this area. At present the TIP is recognized for the region 2. The alarm lasts until January 1990, and probably it will continue after receiving of the new catalog. The implicit confirmation of the possibility for a new strong earthquake to occur is the clustering of the strong events in time in this region. Let us note that there were not recurring events after the earthquake of August 1988.

Naturally, the reliability of TIPs diagnostics needs further monitoring of earthquakes flow i.e. by forward prediction. The analysis carried out in this paper should be considered only as the basis for such testing. It is worthwhile to follow the behaviour of the functions K and B max the features 1 of period D, because this feature preceded all strong events and didn't arouse the false alarms.

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Table 1.1: Features of the period D

number of features	N2	K	G	Σ	S max	Z max	N3	q	B max
1.		m, 1							1
2.								1	
3.							m,1	m,1	m,1
4.						1		m,1	
5.		m,1					s		m,1
6.		s,m				1			m,1
7.		m,1				s,m			m,1
8.		m,1	m,1						m,1
9.					1	1			
10.		s,m		1		1			
11.		s				1			
12.	1	s,m				m,1			
13.		1			s,m				
14.		1			m,1				
15.		1		m,1					
16.		1	s,m						

Note: s,m and 1 mean the small, moderate and large values of functions.

Table 1.2: Features of the period N

number of features	N2	K	G	Σ	S max	Z max	N3	q	B max
1.					s,m				s
2.						s,m		s,m	s,m
3.				s,m,				s,m,	s,m
4.		s,m						s,m,	s,m,
5.							m,1		s,m
6.					s				s,m
7.		s,m				s,m			s,m
8.	s,m					s,m			s,m
9.				s,m			m,1	s,m	
10.					s			s,m	

11.						s,m	1		
12.					s		m,1		
13.		s,m			s				
14.		s,m		s					
15.		s				s,m			
16.		s,m	s,m		s,m				
17.		s			s, m				
18.		s		s,m					

The same notations as at the Table 1.1

Table 2:
Strong earthquakes of three regions of the Himalayan seismic belt during the time interval 1970-1989.

number of regions	Strong earthquakes			
	Date	ϕ	λ	M
1	19. 1.1975	32.46	78.43	6.8
	29. 7.1980	29.60	81.09	6.5
2	23. 1.1982	31.70	82.25	6.5
	20. 8.1988	26.77	86.60	6.6
	29. 7.1970	26.02	95.40	6.4
3	6. 8.1988	25.20	95.00	7.2

Table 3: Variants of TIPs identification

Number of region	Number of earthquakes		Total alarm time (%)			
			Initial	Variant of experiments		
	in all	in TIPs	results	1	2	3
1	1	1	15	20	15	15
2	3	3	31	36	42	36
3	2	1	19	34	35	23

Note: 1 - redefinition of threshold of descretisation, 2 - boundaries of the regions extended by 0.5 degrees of longitude and latitude; 3 - decreased the size of the regions by same amount as in 2 (Fig. 2).

Tips of Diagnostics