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35. *Case Study of Probability Prediction; The 1980 East off Izu Peninsula Earthquake.*

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Abstract

A method of probability prediction using magnitude differences M_1-F_1 and M_1-A_1 (YAMASHINA, 1980a, b), is applied to the 1980 East off Izu Peninsula earthquake and the other recent major earthquakes ($M \geqq 5.0$) in the Izu region. The results show that the method was quite useful for earthquake prediction at least as preliminaries to further detailed studies.

1. Introduction

The 1980 East off Izu Peninsula earthquake ($M=6.7$) successfully showed that the method of probability prediction proposed by YAMASHINA (1980a, b) is useful for earthquake prediction as will be shown later. Studying statistically the earthquake catalogs compiled by the Japan Meteorological Agency (JMA) and the International Seismological Centre (ISC), YAMASHINA (1980a, b) proposed the following empirical rules on earthquake prediction, using magnitude differences M_1-F_1, M_1-A_1 and others. Here, M_1 is the magnitude of the largest event in an earthquake sequence which has already occurred at time t when we would like to predict forthcoming activity. F_1 and A_1 are those of the largest foreshock and aftershock with respect to M_1, respectively. When magnitudes of the largest two events are equal to each other, both M_1-F_1 and M_1-A_1 are defined to be 0.0. The proposed rules are: [1] When seismic activity occurs with M_1-$F_1 \leqq 0.4$ within about a week, it may be a foreshock sequence followed by a larger event. The probability is about 20-30%. [2] A similar rule is also applicable for M_1-$A_1 \leqq 0.2$. The probability is about 20-25%. [3] If $0.5 \leqq M_1-F_1 \leqq 0.6$ or $0.3 \leqq M_1$-$A_1 \leqq 0.4$, the probability is about 10-15%. It is only about 5-10% or less for $0.7 \leqq M_1$-F_1 and $0.5 \leqq M_1$-A_1. In these cases, M_1 can be expected to be a main shock with high probability. The rest [4-9] are omitted here.

In recent years, the Izu region has been quite active in seismic activity. The major shocks with magnitude greater than 5.0 are as follows (see Fig. 1); the 1974 Izu-Hanto-oki (M=6.9), the 1976 Eastern Izu Pen. (Kawazu, M=5.4), the 1978 Near Izu-Oshima (Izu-Oshima-kinkai, M=7.0), the 1978 Central Izu Pen. (Amagi, M=5.1, 5.8 and 5.4), the 1978 Northeastern Izu Pen. (Kawanazaki-oki, M=5.4), and the most recent 1980 East off Izu Pen. (Kawanazaki-oki, M=6.7) earthquakes.

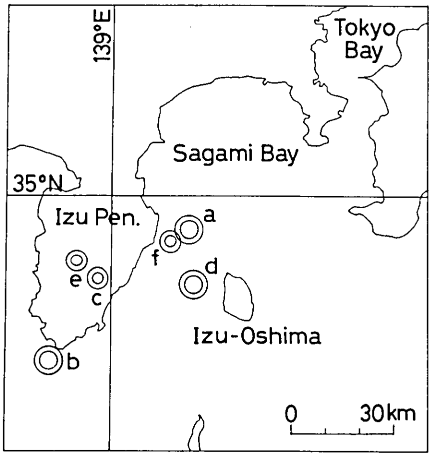

Fig. 1. Epicentral distribution of the six major shallow earthquakes occurred recently in the Izu region; (a) East off Izu Pen. (1980, M=6.7), (b) Izu-Hanto-oki (1974, M=6.9), (c) Eastern Izu Pen. (1976, M=5.4), (d) Near Izu-Oshima (1978, M=7.0), (e) Central Izu Pen. (1978, M=5.8), and (f) Northeastern Izu Pen. (1978, M=5.4).

In the present paper, the method of probability prediction just described above is applied to these major sequences in the Izu region, assuming that the activity was monitored continuously. Lists of recorded earthquakes and their magnitudes (Table 1 and Fig. 2) are shown after the Seismological Bulletin of JMA (monthly).

2. Case Study

(a) The 1980 East off Izu Pen. (M=6.7)

First, we will discuss the most recent M=6.7 earthquake, which was preceded by two M=4.9 foreshocks. Accordingly, criterion [1] (or [2]) could result in a successful prediction if we had monitored the seismic activity with special attention on using the method of probability predic-

Table 1. Lists of six major earthquake sequences in the Izu region taken from the Seismological Bulletin of the Japan Meteorological Agency (monthly). In this Table, only the events which contributed M_1-F_1 and/or M_1-A_1 are compiled. "Alarm" represents that a larger event is expected with a 20-30% probability. "Main shock ?" denotes that the largest event which has already occurred is expected to be a main shock with a high probability. A magnitude within parentheses represents an event which was preceded by a larger event. Stars represent the onset and duration of alarm for a larger event.

(a) The East off Izu Peninsula earthquake (M=6.7)

Origin Date			Time(JST) h	m	Long(E) °	′	Lat(N) °	′	Depth km	M	M_1-F_1	M_1-A_1	Comments
1980	6	25	18	39	139	18	34	56	10	2.0	—	—	
			18	45	139	12	34	56	10	3.4	1.4	—	Main shock? (False)
			18	48	139	09	34	56	10	(3.0)	1.4	0.4	
	6	27	05	43	139	12	34	56	10	3.5	0.1*	—	Alarm
			05	46	139	17	34	59	0	(2.4)	0.1*	1.1	
			05	48	139	17	34	59	10	(3.2)	0.1*	0.3	
			05	55	139	13	34	56	0	4.6	1.1	—	Main shock? (False)
			06	03	139	14	34	57	10	(2.8)	1.1	1.8	
			06	04	139	13	34	58	10	(3.2)	1.1	1.4	
			06	06	139	13	34	56	0	4.9	0.3*	—	Alarm
			06	12	139	12	34	55	10	(3.4)	0.3*	1.5	
			06	14	139	12	34	54	10	(3.8)	0.3*	1.1	
	6	28	11	50	139	12	34	57	0	(4.4)	0.3*	0.5	
			12	05	139	12	34	56	0	(4.9)	0.0*	0.0*	
	6	29	16	20	139	14	34	55	10	6.7	1.8	—	Main shock?
			16	26	139	16	34	54	0	(3.2)	1.8	3.5	
			16	29	139	13	34	52	10	(3.7)	1.8	3.0	
			16	36	139	11	34	56	0	(4.1)	1.8	2.6	
	6	30	02	23	139	14	34	51	10	(4.9)	1.8	1.8	

(b) The Izu-Hanto-oki earthquake (M=6.9)

Origin Date			Time(JST) h	m	Long(E) °	′	Lat(N) °	′	Depth km	M	M_1-F_1	M_1-A_1	Comments
1974	5	9	08	33	138	48	34	34	10	6.9	—	—	Main shock?
			08	48	138	44	34	43	0	(3.6)	—	3.3	
			08	54	138	49	34	34	10	(4.2)	—	2.7	
			09	24	138	47	34	43	10	(4.3)	—	2.6	
			09	30	138	44	34	42	10	(4.5)	—	2.4	

(c) The Eastern Izu Peninsula earthquake (M=5.4)

Origin Date			Time(JST) h	m	Long(E) °	′	Lat(N) °	′	Depth km	M	M_1-F_1	M_1-A_1	Comments
1976	8	18	02	18	138	57	34	47	0	5.4	—	—	Main shock?
	8	26	13	55	138	57	34	49	0	(4.5)	—	0.9	

(d) The Near Izu-Oshima earthquake (M=7.0)

Origin Date			Time (JST) h	m	Long (E) °	′	Lat (N) °	′	Depth km	M	M_1-F_1	M_1-A_1	Comments
1978	1	13	20	38	139	17	34	44	10	3.7	—	—	
	1	14	08	12	139	15	34	43	0	3.8	0.1*	—	Alarm
			08	31	139	15	34	42	0	(3.6)	0.1*	0.2*	
			09	36	139	17	34	43	0	4.6	0.8	—	Main shock? (False)
			09	38	139	15	34	42	0	(4.0)	0.8	0.6	
			09	45	139	16	34	44	0	4.9	0.3*	—	Alarm
			09	47	139	13	34	40	0	(4.9)	0.0*	0.0*	
			12	24	139	15	34	46	0	7.0	2.1	—	Main shock?
			12	31	139	04	34	47	0	(3.7)	2.1	3.3	
			13	30	139	13	34	45	0	(4.1)	2.1	2.9	
	1	19	17	14	139	17	34	44	0	(4.2)	2.1	2.8	
	1	30	09	00	139	22	34	47	0	(4.3)	2.1	2.7	

(e) The Central Izu Peninsula earthquake (M=5.1, 5.8 and 5.4)

Origin Date			Time (JST) h	m	Long (E) °	′	Lat (N) °	′	Depth km	M	M_1-F_1	M_1-A_1	Comments
1978	1	14	12	33	138	56	34	49	0	3.7	—	—	
			13	41	138	53	34	49	0	5.1	1.4	—	Main shock?
			13	46	138	52	34	53	0	(2.8)	1.4	2.3	
			17	39	138	54	34	51	10	(2.9)	1.4	2.2	
	1	15	03	46	138	51	34	49	0	(4.9)	1.4	0.2*	Alarm
			07	31	138	53	34	50	20	5.8	0.7	—	Main shock?
			07	34	138	53	34	49	0	(4.1)	0.7	1.7	
			07	36	138	50	34	48	10	(5.4)	0.7	0.4	

(f) The Northeastern Izu Peninsula earthquake (M=5.4)

Origin Date			Time (JST) h	m	Long (E) °	′	Lat (N) °	′	Depth km	M	M_1-F_1	M_1-A_1	Comments
1978	11	26	01	53	139	11	34	56	10	2.1	—	—	
			02	15	139	10	34	56	10	2.3	0.2*	—	Alarm
			03	07	139	07	34	55	10	2.5	0.2*	—	Alarm
			09	35	139	02	34	56	10	(2.1)	0.2*	0.4	
			09	45	139	07	34	55	10	(2.3)	0.2*	0.2*	
			15	27	139	06	34	56	10	2.6	0.1*	—	Alarm
	11	27	02	16	139	14	34	57	10	(2.3)	0.1*	0.3	
			08	34	139	12	34	58	10	(2.4)	0.1*	0.2*	
			09	41	139	07	34	54	10	2.9	0.3*	—	Alarm
	11	28	08	25	139	07	34	57	10	(1.9)	0.3*	1.0	

		08	25	139 07	34 54	10	3.4	0.5	—	Main shock? (False)
		08	43	139 09	34 55	10	(2.2)	0.5	1.2	
		08	50	139 06	34 56	10	(2.3)	0.5	1.1	
		09	14	139 08	34 54	10	(2.6)	0.5	0.8	
		09	15	139 07	34 54	10	(2.7)	0.5	0.7	
		12	08	139 10	34 58	10	3.8	0.4*	—	Alarm
		12	10	139 08	34 56	10	(3.0)	0.4*	0.8	
12	1	20	40	139 07	34 54	10	(3.2)	0.4*	0.6	
12	2	01	07	139 07	34 54	10	(3.5)	0.4*	0.3	
12	3	22	15	139 08	34 53	0	4.1	0.3*	—	Alarm
		22	15	139 11	34 53	20	5.4	1.3	—	Main shock?
		22	24	139 08	34 58	0	(2.0)	1.3	3.4	
		22	30	139 08	34 52	0	(2.5)	1.3	2.9	
		22	39	139 10	34 55	10	(3.1)	1.3	2.3	
12	4	13	33	139 08	34 50	10	(3.3)	1.3	2.1	
12	7	16	27	139 07	34 54	10	(3.5)	1.3	1.9	

tion described earlier.

Foreshock activity started around June 23 (e. g. KARAKAMA et al., 1980). The first shock (M=2.0) of which magnitude was determined by JMA occurred at 18:39 on June 25 (Japanese Standard Time=Universal Time+9 hours). The M=3.4 and 3.0 events followed 6 and 9 minutes later, respectively. At this point of time, criterion [3] suggested that, with a high probability of about 85-95%, the M=3.4 event would be a main shock and no larger events would occur thereafter. Against this, however, the M=3.5 event occurred at 05:43 on June 27. Since M_1-F_1 now satisfied criterion [1] (M_1-F_1=0.1), an impending larger event was expected with a probability of 20-30%. Twelve minutes later, the larger event (M=4.6) actually occurred, just as expected. Although M_1-F_1 was redetermined as 1.1 and an alarm was canceled by criterion [3], the M=4.9 event occurred 11 minutes later at 06:06. By this event, an alarm for a larger event was again provided with a 20-30% probability, since M_1-F_1 was determined as 0.3 (criterion [1]). This alarm continued until the M=6.7 main shock occurred at 16:20 on June 29. After the main shock, M_1-F_1 was 1.8 and M_1-A_1 was no less than 1.8. Therefore, the M=6.7 event was correctly expected to be a main shock by criterion [3] with a 85-95% probability.

In summary, both alarms provided by criterion [1] correctly predicted larger events; M=4.6 and 6.7. Predictions that no larger events would occur were given three times by criterion [3]. Two of these, however, resulted in false predictions and the M=3.5 and 4.9 events could

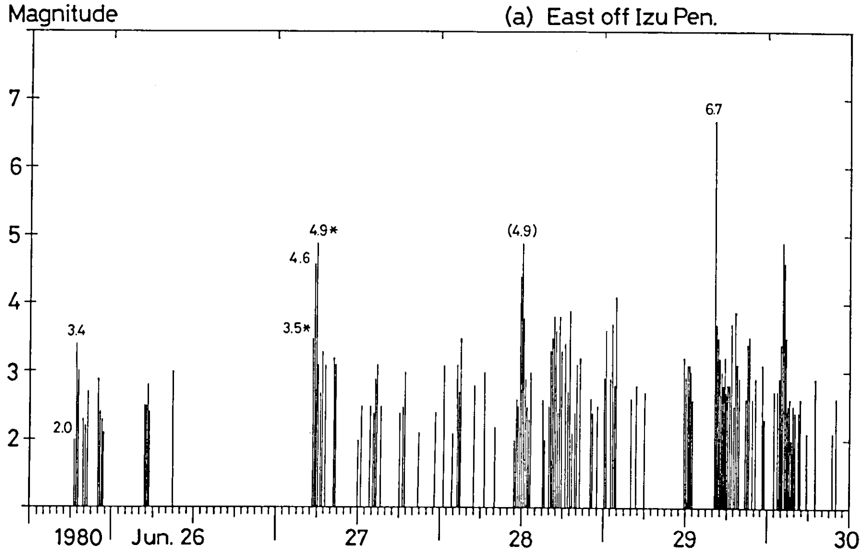
Magnitude
(a) East off Izu Pen.
7
6
5
4
3
2
3.4
2.0
4.9*
4.6
3.5*
(4.9)
6.7
1980 Jun. 26
27
28
29
30

Fig. 2(1).

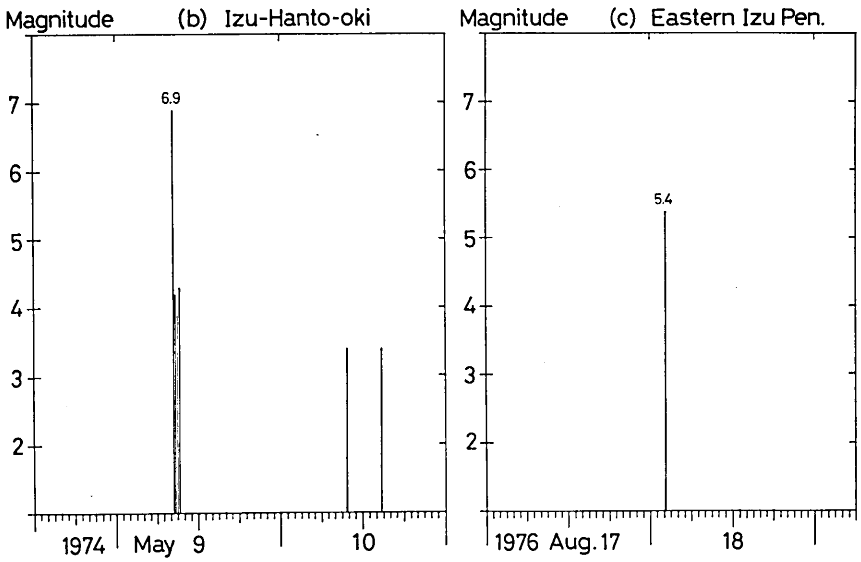
Magnitude
(b) Izu-Hanto-oki
7
6
5
4
3
2
6.9
1974 May 9
10
Magnitude
(c) Eastern Izu Pen.
5.4
1976 Aug. 17
18

Fig. 2(2).

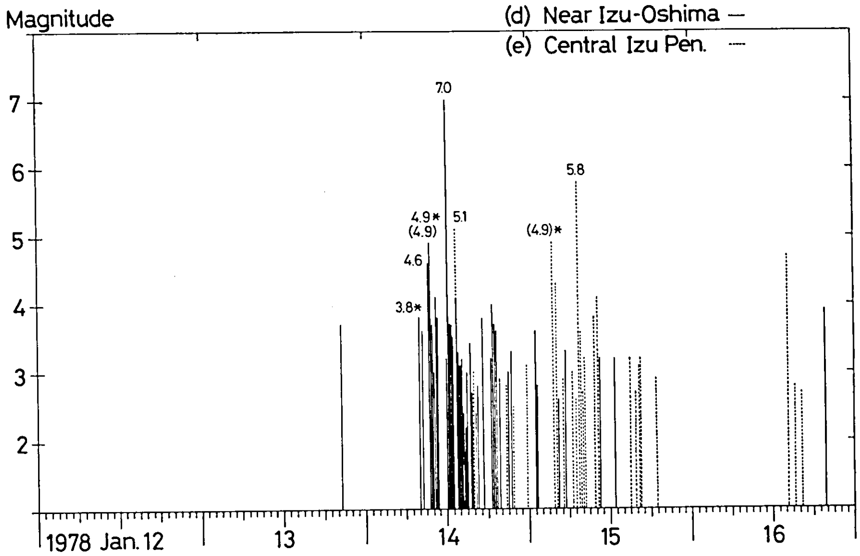

Fig. 2(3).

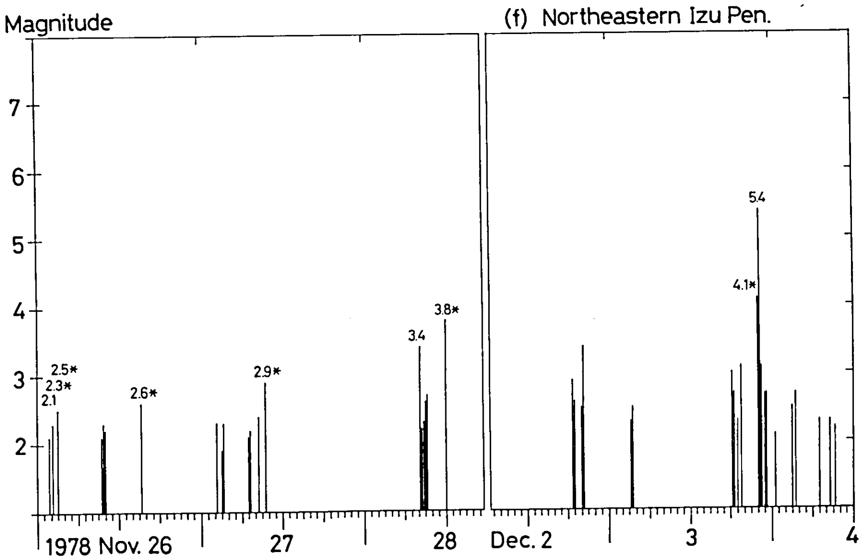

Fig. 2(4).

Fig. 2. Six major earthquake sequences in the Izu region (see Table 1.). Stars represent the onset of alarm for a larger event.

not be predicted by the present method.

(b) The 1974 Izu-Hanto-oki (M=6.9)

Since no foreshocks were observed, the M=6.9 main shock was, of course, impossible to predict by the present method. The largest aftershock (M=4.5) occurred 57 minutes after the main shock. Accordingly, M_1-A_1 was no less than 2.4, and M_1-F_1 was, even if F_1 existed, larger than at least 3-4. Although the occurrence of the M=6.9 event was not predicted, it was correctly predicted by criterion [3] that the M=6.9 event would be a main shock and no larger events would occur.

(c) The 1976 Eastern Izu Pen. (M=5.4)

This M=5.4 earthquake was also not preceded by apparent foreshock activity. The largest aftershock (M=4.5) occurred 8 days after the main shock. Since M_1-A_1 was no less than 0.9 and M_1-F_1 was, if F_1 existed, larger than at least 2-3, the M=5.4 event was correctly expected to be a main shock by criterion [3].

(d) The 1978 Near Izu-Oshima (M=7.0)

Foreshocks remarkably swarmed from the evening one day before the M=7.0 main shock. The first and the second shocks with magnitudes of M=3.7 and M=3.8 were determined by JMA to have occurred at 20:38 on January 13 and at 08:12 on January 14, respectively. A small M_1-F_1 value (i. e. 0.1) suggested a possible larger event. Such an event actually occurred at 09:36 (M=4.6). After this, since M_1-F_1=0.8 and M_1-$A_1 \geqq 0.6$, the alarm for a larger event was canceled (criterion [3]). By the M=4.9 event at 09:45, an alarm was again provided because of a small M_1-F_1 value (i. e. 0.3; criterion [1]). The M_1-F_1 value became 0.0 two minutes later when the second M=4.9 event occurred. This alarm resulted in a successful prediction of the M=7.0 main shock at 12:24. After the main shock, M_1-F_1=2.1 and M_1-$A_1 \geqq 2.7$ (or 1.2 if we take into consideration the activity in the central part of the Izu Peninsula). The M=7.0 event was also correctly expected to be a main shock by criterion [3].

(e) The 1978 Central Izu Pen. (M=5.1, 5.8 and 5.4)

Just after the 1978 Near Izu-Oshima earthquake (M=7.0), remarkable activity also began to occur in the central part of the Izu Peninsula. Since the focal region extended somewhat continuously to that of the M=7.0 event (e. g. TSUMURA et al., 1978), these earthquakes had best be regarded as aftershocks of the M=7.0 event. There is, however, no doubt that they constituted a subcluster. Therefore, we will try to apply the present method to this subcluster as follows.

In the central part of the Peninsula, the M=3.7 event occurred at 12:33 (9 minutes after the M=7.0 event) on January 14. Some minor shocks succeeded in the Peninsula. It was, however, difficult to recognize that these events suggested the onset of a subcluster of activity there until the M=5.1 event occurred at 13:41. An alarm was given by the M=4.9 event at 03:46 on January 15 (M_1-A_1=0.2; criterion [2]). Once the M=5.8 largest event occurred at 07:31, the alarm was correctly withdrawn (M_1-F_1=0.7 and M_1-$A_1 \geqq 0.4$; criterion [3]).

(f) The 1978 Northeastern Izu Pen. (M=5.4)

Activity during November—December in 1978 was also remarkable. An alarm for a larger event was at first given by the M=2.1 and 2.3 events at 01:53 and 02:15 on November 26, respectively (criterion [1]). The M=2.5, 2.6, 2.9 and 3.4 events at 03:07, 15:27 on November 26, at 09:41 on November 27, and at 08:25 on November 28, respectively, were all predicted by criterion [1]. However, the next M=3.8 event at 12:08 on November 28 was not predicted, because M_1-F_1=0.5 and M_1-A_1 $\geqq 0.7$ after the previous M=3.4 event (criterion [3]). This M=3.8 event gave a new alarm which predicted the M=4.1 event at 22:15 on December 3 (M_1-F_1=0.4; criterion [1]). The M=4.1 event again gave an alarm for the impending M=5.4 main shock (M_1-F_1=0.3; criterion [1]). Once the main shock occurred, M_1-F_1=1.3 and M_1-A_1 was no less than 1.9. Therefore, the M=5.4 event was also correctly expected to be a main shock (criterion [3]).

3. Discussion and Conclusions

Among the six major earthquake sequences which occurred recently in the Izu region, four were preceded by foreshocks, which satisfied criterion [1] or/and [2]. If we had monitored the activity using the present method, all of the four main shocks could have been correctly predicted. Including the remaining two, in which there were no apparent foreshocks, all the main shocks were also correctly expected to be main shocks by criterion [3] before the activities ended.

In some cases, however, an alarm for a larger event was canceled in the course of foreshock sequences. Therefore, some major foreshocks were not predicted by the present method. This suggests that, even if the alarm was once withdrawn, we must continuously monitor the subsequent activity whether M_1-F_1 and M_1-A_1 may again satisfy criterion

[1] or/and [2].

Up to the present, we have discussed only the six major sequences. Studying statistically the earthquake catalog compiled by JMA during January 1974—June 1980, there were 20 cases in which M_1-F_1 was no more than 0.4. Among these, 11 cases were followed by a larger event. As for M_1-A_1, 5 out of 10 cases with M_1-$A_1 \leqq 0.2$ were followed by a larger event. Consequently, if we predicted the possibility of a forthcoming larger event based on criterion [1] or [2], it would result in a successful prediction with about a 50-55% probability. This percentage is about twice the average in general cases (YAMASHINA, 1980a, b), suggesting that in the Izu region foreshocks and earthquake swarms are more likely to occur than in the other regions as previously shown by MOGI (1963). This also reflects in the percentage of successful predictions provided by criterion [3]. In the same period, 17 out of 23 cases, when criterion [3] was satisfied, were successful in identifying the main shock before the end of the activity. The percentage was about 74%, which was less than the average value of 85-95%.

The present method of earthquake prediction is quite a simple one. Although it is not deterministic, and we can only speak in terms of probability, it is useful to know when and where we must pay special attention. More detailed analyses of data with this special attention and/or temporary observations in the expected epicentral region may improve the probability (UTSU, 1977) or, in some cases, may even result in a deterministic prediction.

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35. 1980年伊豆半島東方沖地震の確率予測

地震研究所　山科健一郎

マグニチュードの差 M_1-F_1 や M_1-A_1 を用いた確率予測の方法（山科，1980a, b）を，1980年伊豆半島東方沖地震や最近の伊豆地域の大きな地震（M≧5.0）に適用する．その結果，この方法が，少なくとも，もっと詳しい検討を始める手がかりとして，地震活動の予測のために役に立つことが示される．