太平洋沖の地震の余震活動予測の試み

Experiment for forecasting aftershocks of the 2011 off the Pacific coast earthquake in Japan

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はじめに

余震活動の有効な予測手法を探るため，今回の地震に際しても大きな余震の事前予測を試みた．本震の発生は3月11日14時46分であったが，気象庁の地震速報によってその後の余震活動の経過をたどると，後述のような簡便な方法（Yamashina，2008年地震学会）が，今回の活動にもかなりよく当てはまるように見受けられた．そこで，11日22時に最初の予測を作成した．これは，「11日24時までにM7.0±0.5」の発生を予測したものであったが，その期間に該当する大きな余震は起こらなかった．しかし，想定の13分後に速報M6.6の余震が起きており，予測は，それほど見当外れではなかったと思われる．その後，18日までの時点で合計6回の予測を作成し，適中3回，誤報3回という結果を得た．しかし誤報の3回には，上記のように13分後に発生した事例や，Mが0.1だけ小さかった事例が含まれるから，かなり実態に近い予測だったのではないかと思われる．

Prospective forecasts of large aftershocks were tested based on a simple method proposed by Yamashina(2008). Considering the aftershock activity preliminarily announced by JMA, the first alarm made at 22:00 on March 11 (occurrence of the main shock was at 14:46 on the same day) was that "M=7.0±0.5 by 24:00". Although it was false, an event with M=6.6? occurred only 13 minutes after the alarm period. Among 6 alarms obtained up to March 18, 3 cases were successful. In the remaining cases, time delay of only 13 minutes and a lack of magnitude value of only 0.1 were included. Therefore, the present forecast method was proved to be useful in the current activity at least to some extent.

Current forecasts by JMA:

気象庁では，余震活動の確率予測を実施中：例えば，

■3月13日10時から3日間以内に
マグニチュード7.0以上の余震発生確率は70%.

■3月14日14時から3日間以内に
最大震度5強以上の余震発生確率は40%.

■3月18日00時から21日24時までの4日間に
M5.0以上の余震回数は数回～50回程度.

Example:

- Magnitude 7 or greater within 3 days from 10:00 on March 13 : 70%.
- Seismic Intensity 5+ or greater in JMA scale within 3 days from 14:00 on March 14 : 40%.
- Magnitude 5 or greater from 00:00 on March 18 to 24:00 on March 21 : several to 50 times.

どのような予測情報が役に立つだろうか？

ということを念頭におきながら，

少し形を変えた予測を模索

What sort of information is useful?
Different approach is under testing.

Although JMA are making an effort to inform a perspective of the aftershock activity, additional or somewhat different information, if possible, may also be useful.

今回事前予測を試みた最初の例

2011年3月11日22時00分の予測

■太平洋沖の余震(3月11日14時46分頃にM8.8;36-39N, 141-144E付近):
3月11日24時頃までにM7.0±0.5の可能性.

本予想は3月11日の気象庁ほかによる暫定的な活動資料に基づいて試験的に試みているもので,「可能性」は20～30%くらいの確率を想定.

First announcement of the prospective forecast
at 22:00 on March 11 (in Japanese Standard Time)
■Magnitude 7.0±0.5 by 24:00 on March 11 (20-30%)

予測の結果は？

2011年3月11日22時00分の予測

■太平洋沖の余震（3月11日14時46分頃にM8.8；36-39N，141-144E付近）：
3月11日24時頃までにM7.0±0.5の可能性.

本予想は3月11日の気象庁ほかによる暫定的な活動資料に基づいて試験的に試みているもので，「可能性」は20～30%くらいの確率を想定.

First announcement of the prospective forecast
at 22:00 on March 11 (20-30%)
■Magnitude 7.0±0.5 by 24:00 on March 11 (20-30%)

→ Δ：M6.6? at 00:13 on March 12.

False but nearly successful

その後の予測の結果は？(Mの値は暫定値)

Forecast at 22:00 on March 11 (20-30%)

■Magnitude 7.0±0.5 by 24:00 on March 11

→ Δ：M6.6? at 00:13 on March 12.

Forecast at 00:20 on March 12 (20-30%)

■Magnitude 7.0±0.5 by 07:00 on March 12

→ Δ：M6.4? at 05:11 on March 12.

Forecast at 00:40 on March 12 (20-30%)

■Magnitude 7.2±0.5 by 08:00 on March 12

→ X：M6.4? or less.

Forecast at 10:30 on March 12 (20-30%)

■Magnitude 6.8±0.5 by 02:00 on March 13

→ O：M6.8? at 10:47 on March 12.

Forecast at 10:00 on March 13 (50%)

■Magnitude 6.7±0.5 by 20:00 on March 14

→ O：M6.6? and M6.5? on Mar.13-14.

18日現在の予測は？

2011年3月17日12時00分の予測

■太平洋沖の余震（3月11日14時46分頃にM9.0；36-39N，141-144E付近）：
3月20日15時頃までにM6.6±0.5の可能性が増大．

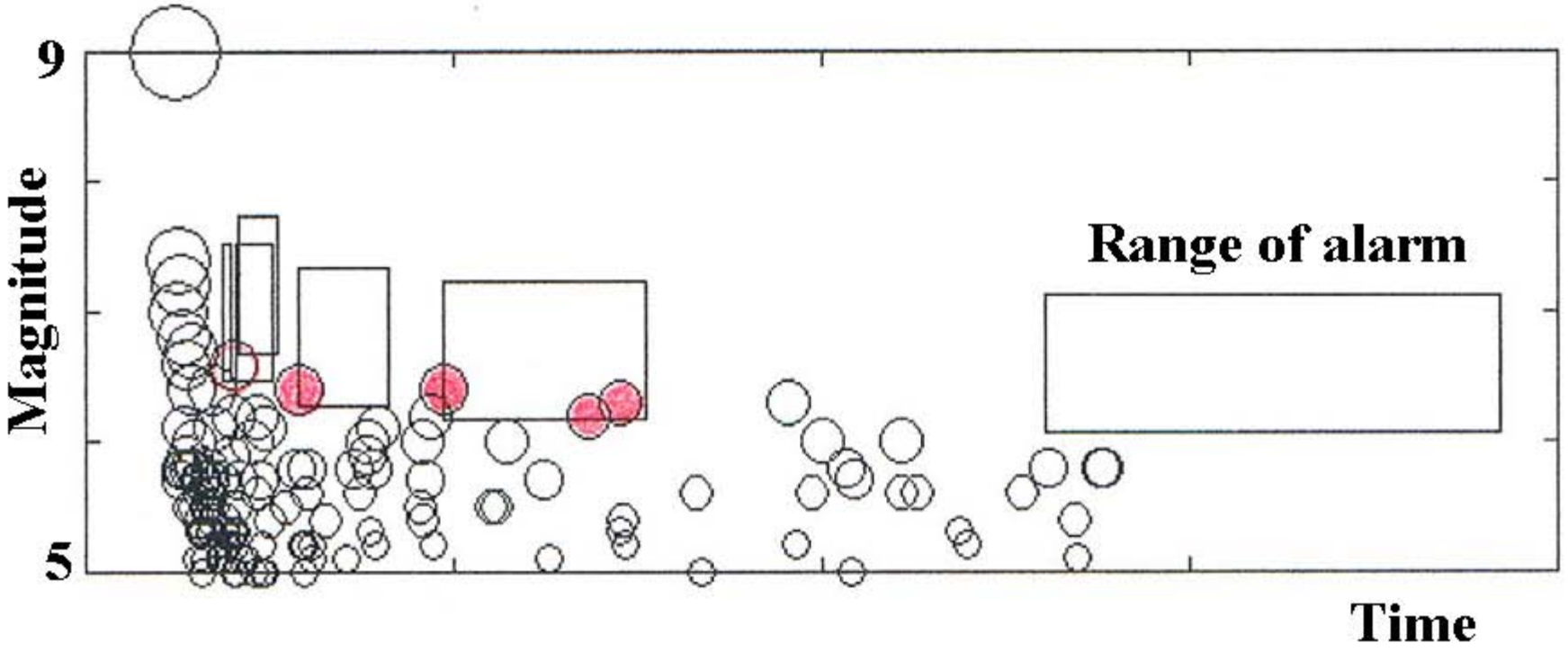
本予想は気象庁ほかによる暫定的な活動資料に基づいて試験的に試みているもので，「可能性が増大」は50%くらいの確率を想定．

Latest example： Forecast at 12:00 on March 17 (50%)

■Magnitude 6.6±0.5 by 15:00 on March 20

→ ?

Hereafter, M6.1? occurred on March 19

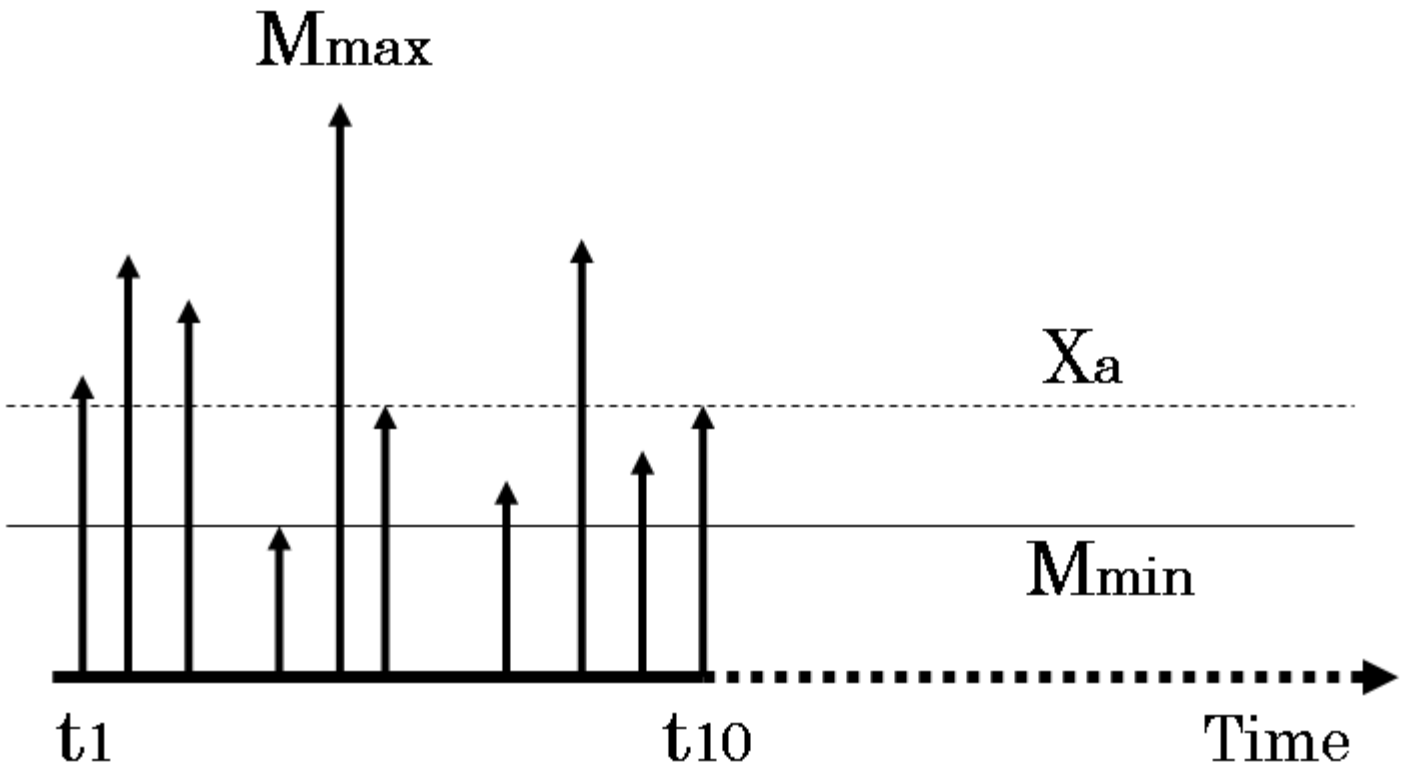


Alarm periods and magnitude ranges of the present forecasts (rectangles) and the magnitudes of aftershocks (circles) announced by JMA immediately after the occurrence. Red circles represent the events forecasted by the present alarms.

予測手法の説明：

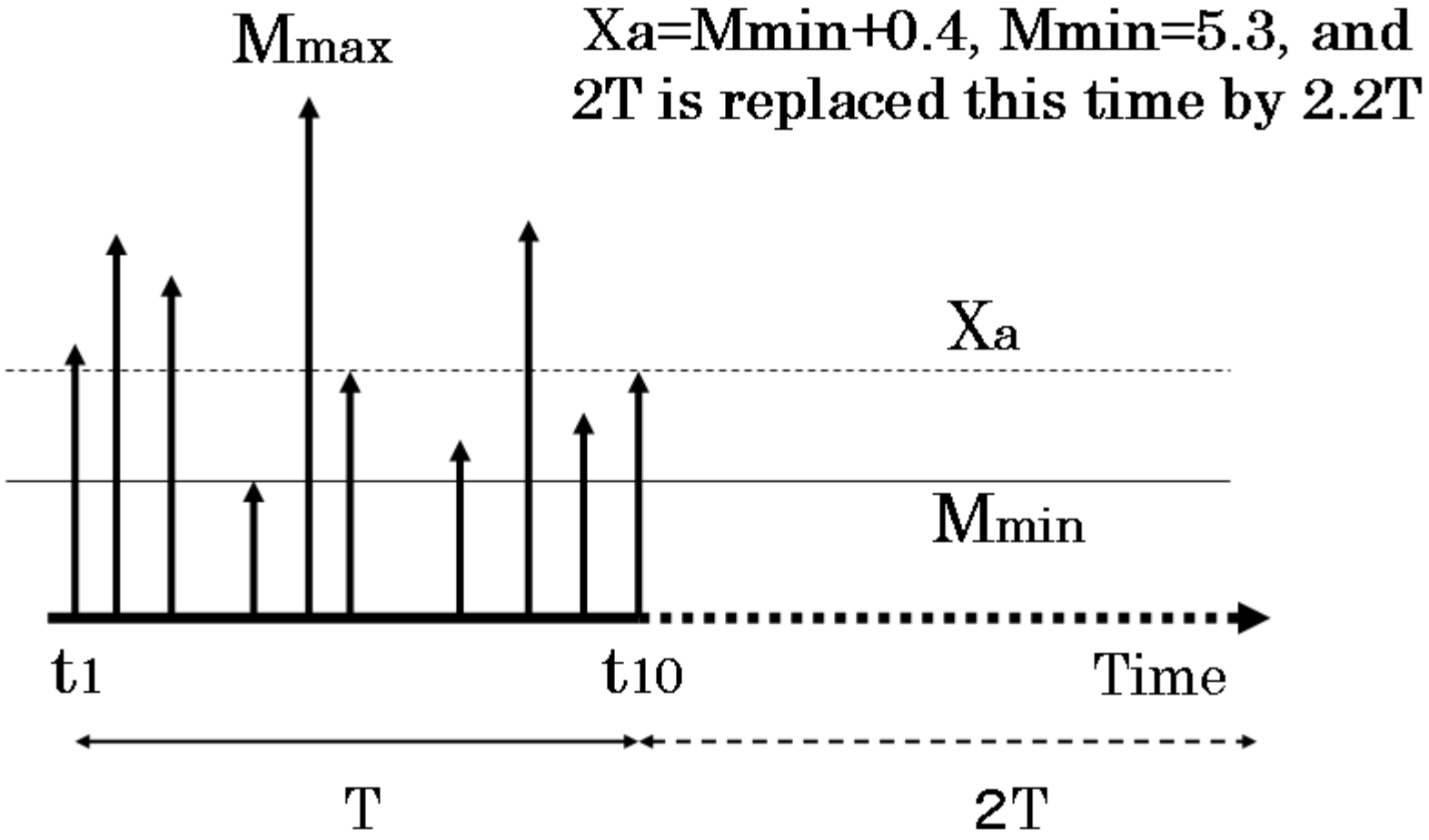
Method of the present forecast

Notice to the latest 10 events
Mean magnitude of 10 events：X



予測手法の説明：

Alarm：If X ≦Xa,
then Mmax+0.6(±0.5) is expected during 2T



Previous results tentatively obtained in 2008

Results of virtual prediction (during two months from the main shock)

Date	Location	M	Successful alarm	Incorrect rejection
2003 9 26	Off Tokachi	8.0	100% (14/14)	31% (21/68)
2004 10 23	Chuetsu	6.8	88% (59/67)	44% (104/235)
2005 3 20	Fukuoka	7.0	80% (45/56)	13% (4/32)
2007 3 25	Off Noto	6.9	62% (56/90)	12% (7/60)
2007 7 16	Off Chuetsu	6.8	29% (10/34)	0% (0/23)
2008 6 14	Iwate-Miyagi	7.2	87% (27/31)	24% (16/67)
2008 5 12	Sichuan(CEA)	8.0	65% (39/60)	35% (12/34)

High rate of successful alarms was obtained in many cases.

今回の余震について，予測を逐次出すことが可能だったときの成功率は

If real-time forecasts were possible
in the present aftershock activity:

(From 19:11 on March 11 to 03:41 on March 15)

Rate of successful alarm:
16/24=67%

Rate of incorrect rejection of alarm:
6/34=18%

今回の成果

1) 大きな余震を予測する簡便な方法を適用して，活動の事前予測を試みた．

2) 3月18日までに作成された6回の予測のうち，3回は想定される大きな余震が発生した．残りのうちの2回も，想定の13分後，あるいは想定に近い大きさの余震が発生した．

3) 適用された予測手法は，改良大森公式やグーテンベルクリヒターの式の性質を反映しているが，しばしばそれらから期待される以上の適中率が得られるようにみえる．手法の改良やその物理的背景についての考察を進めたい

Tentative summary

1) A convenient method of forecasting large aftershocks are tested prospectively.

2) Successful or nearly successful forecasts were obtained in many cases.

3) Improvement of the present empirical rule and efforts to make clear the physical basis are expected.

Appendix: Abstract of the 2008 meeting of the Seismological Society of Japan

A rule for predicting large aftershocks

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1. Hint to a new prediction rule

It is known that a large aftershock may be preceded by abnormal decrease in aftershock activity. It is, however, quite limited in occasion to be able to detect the significant decrease in activity prior to the occurrence of a large aftershock.

In some cases, the decrease in aftershock activity will appear in larger events slightly more than smaller ones. Consequently, a certain parameter which will represent the difference of the activity between larger and smaller aftershocks may help us to think about forthcoming large aftershocks.

2. Proposal of a prediction rule

Considering that a rule should be simple and easy to be applicable to the limited available data, notice here only to the latest 10 aftershocks with magnitudes larger than a certain threshold. In the present primitive discussion, parameters are defined as follows.

Mo: Magnitude of the main shock
Mmin: Lower threshold of the magnitudes of aftershocks
Mmax: The largest magnitude among the latest 10 aftershocks (which are larger than Mmin)
Ma: Expected magnitude of a forthcoming large aftershock
dM: Additional magnitude defined by Ma−Mmax
X: Mean magnitude of the latest 10 aftershocks
Xa: Level of the alarm
Ta: Time period of the alarm
T1 and T10: Time of the occurrence of the first and the last events of the latest 10 aftershocks, respectively

When the value X will become less than Xa, a large aftershock with magnitude Ma will be expected between T10 and T10+Ta. Although suitable values of the parameters would be examined for respective aftershock sequence, standard values are tentatively proposed as follows, based on the 2008 Sichuan, the 2004 Sumatera and recent several Japanese earthquakes: Xa=Mmin+0.2～0.4. dM=0.6±0.5 (i.e. Ma=Mmax+0.6±0.5). Ta=2×(T10−T1). In addition, Mmin will be Mo−3～4, and almost all earthquakes larger than Mmin are required to be observed.

In the present case, T_a was slightly changed as $2.2\times(T_{10}-T_1)$.