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Precursory Activation of Seismicity in Advance of the Kobe, 1995, $M = 7.2$ Earthquake

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Abstract—A succession of precursory changes of seismicity characteristic to earthquakes of magnitude 7.0–7.5 occurred in advance of the Kobe 1995, $M = 7.2$, earthquake. Using the Japan Meteorological Agency (JMA) regional catalog of earthquakes, the *M8* prediction algorithm (KEILIS-BOROK and KOSSOBOKOV, 1987) recognizes the *time of increased probability*, TIP, for an earthquake with magnitude 7.0–7.5 from July 1991 through June 1996. The prediction is limited to a circle of 280-km radius centered at 33.5°N, 133.75°E. The broad area of intermediate-term precursory rise of activity encompasses a 175 by 175-km square, where the sequence of earthquakes exhibited a specific intermittent behavior. The square is outlined as the second-approximation reduced area of alarm by the "Mendocino Scenario" algorithm, *MSc* (KOSSOBOKOV *et al.*, 1990). Moreover, since the *M8* alarm starts, there were no swarms recorded except the one on 9–26 Nov. 1994, located at 34.9°N, 135.4°E. Time, location, and magnitude of the 1995 Kobe earthquake fulfill the *M8-MSc* predictions. Its aftershock zone ruptured the 54-km segment of the fault zone marked by the swarm, directly in the corner of the reduced alarm area. The Kobe 1995 epicenter is less than 50 km from the swarm and it coincides with the epicenter of the *M* 3.5 foreshock which took place 11 hours in advance.

Key words: Earthquake prediction, algorithms *M8* and *MSc*, seismicity, Japan.

Introduction

Each major earthquake raises the question as to whether or not it was preceded by some phenomena that could be considered as precursory. The "precursors" defined in advance (see e.g., WYSS, 1991) are of particular interest, since the earthquake verifies their significance and reliability. Here we examine this question as applied to the recent January 16, 1995, $M = 7.2$, Kobe (Hyogo-ken Nanbu) earthquake, Southern Japan (JAPAN METEOROLOGICAL AGENCY, 1997; HASHIMOTO *et al.*, 1996), and two completely reproducible intermediate-term earthquake prediction algorithms known as *M8* and *MSc* (KEILIS-BOROK and KOSSOBOKOV, 1990a; KOSSOBOKOV *et al.*, 1990). The destructive Kobe earthquake case-history poses an

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additional problem in monitoring seismic patterns, since major contributions to actual seismic hazard may result in our life-time, not from the largest but comparatively moderate-size earthquakes. Thus, a multitude of magnitude, as well as spatial and temporal, ranges should be considered simultaneously in a hierarchy of predictions that facilitate earthquake hazard mitigation.

Prediction Algorithms M8 and MSc

As has been shown in previous publications (KEILIS-BOROK, 1996; PEREZ and SCHOLZ, 1997) most large earthquakes are preceded by a set of rather simple universal symptoms of instability. These symptoms, known from studies on nonlinear dynamics, include the rise of intensity of background perturbations in a system and their concentration, as well as burst-like reaction to an excitation. The integral estimates of these characteristics form the basis of the *M8* algorithm designed for intermediate-term prediction of earthquakes (KEILIS-BOROK and KOSSOBOKOV, 1987, 1990a). The first testing of the algorithm dates to 1984 when it was applied retroactively to diagnose *times of increased probability*, TIPs for the world's largest (magnitude 8 or above) earthquakes, hence its name. Subsequently the algorithm is the subject of many studies on global and regional scales (KEILIS-BOROK, 1996).

In most applications, *M8* diagnoses TIPs in circles with a radius determined by the magnitude threshold M_0 which defines what large earthquake we intend to predict. The energy-space-time scaling is the essential part of the algorithm. Therefore, the magnitude scale should reflect the size of earthquake sources (e.g., for many catalogs this is equivalent to maximal magnitude reported). The algorithm analyses normalized integral characteristics of seismicity in each circle of investigation, CI. It issues a TIP if the values of these characteristics are abnormally high compared to the ranges observed in the circle over a longer background period. A TIP is declared and usually lasts for five years. In some cases, seismic changes may re-establish the limits of norm and anomaly, and therefore may cancel or extend the TIP. The ultimate definition of the algorithm is given by its source code and prefixed profiles (HEALY *et al.*, 1992, 1997).

Algorithm M8. For the reader's convenience, we describe the scheme of the *M8* algorithm in brief:

Prediction is aimed at the earthquakes of magnitude M_0 and above. We consider different values of M_0 with a step 0.5. The seismic territory is scanned by overlapping circles with the diameter $D(M_0)$. Within each circle the sequence of earthquakes is considered with aftershocks removed $\{t_i, m_i, h_i, b_i(e)\}$, $i = 1, 2 \ldots$. Here t_i is the origin time, $t_i \le t_{i+1}$; m_i is the magnitude, h_i—focal depth, and $b_i(e)$—the number of aftershocks during the first e days. The sequence is normalized by the lower magnitude cutoff $M_{\min}(\tilde{N})$, $\tilde{N}$ being the standard value of average annual number of earthquakes in the sequence. As mentioned above, the magnitude scale should reflect the size of earthquake sources. Accordingly, if reported the M_s-type magnitude is taken for larger events, while the commonly determined m_b magnitude is used for smaller ones.

Several running averages are computed for this sequence in the sliding time windows $(t-s, t)$ and magnitude range $M_0 > M_i \geq M_{\min}(\tilde{N})$. They measure intensity of earthquake flow, its deviation from the long-term trend, and clustering of earthquakes. The averages include: $N(t)$—the number of the main shocks. $L(t)$—the deviation of $N(t)$ from its long-term trend, $L(t) = N(t) - N_{\text{cum}}(t-s) \cdot (t-s)/(t-t_0-s)$, $N_{\text{cum}}(t)$ being the cumulative number of the main shocks with $M \geq M_{\min}(\tilde{N})$ from the beginning of the sequence t_0 to t. $Z(t)$—linear concentration of the main shocks estimated as ratio of the average diameter of the source l to the average distance between them r. $B(t) = \max_i\{b_i\}$—the maximal number of aftershocks (a measure of earthquake clustering); the earthquake sequence $\{i\}$ is considered in the time window $(t-s', t)$ and in the magnitude range $(M_0 - p, M_0 - q)$.

Each of the functions N, L, Z is calculated for $\tilde{N} = 20$ and $\tilde{N} = 10$. As a result, the earthquake sequence is given a robust description by seven functions: N, L, Z (twice each), and B.

"Very large" values are identified for each function, using the condition that they exceed Q percentiles (i.e., they are higher than Q% of the encountered values).

An alarm or TIP, "time of increased probability," is declared for five years, when at least 6 of 7 functions, including B, become "very large" within a narrow time window $(t-u, t)$. To stabilize predictions, this condition is required for two consecutive moments, t and $t+0.5$ years.

The following standard values of parameters indicated above are prefixed in the original version of the *M8* algorithm: $D(M_0) = 111.111 \cdot (\exp(M_0 - 5.6) + 1)$ km, where $\exp(x) \approx 10^{0.43x}$ is the natural exponent of x (this gives 384 km, 560 km, 854 km and 1333 km for $M_0 = 6.5$, 7.0, 7.5 and 8 respectively), $s = 6$ years, $s' = 1$ year, $g = 0.5$, $p = 2$, $q = 0.2$, $u = 3$ years, $Q = 75\%$ for B and 90% for the other six functions.

The territorial uncertainty of *M8* predictions can be reduced significantly, from 4 to 14 times, using the second-approximation prediction algorithm *MSc* (KOSSOBOKOV *et al.*, 1990), known also as "Mendocino Scenario." The second approximation is achieved after additional analysis of the low-level seismicity in the area of a TIP. *MSc* searches for an episode of "anomalous quiescence" when a part of the area of a TIP, which was steadily active in its formation, exposes a sudden and rather short (a few months) quiescence. That is, the *MSc* algorithm outlines such an area of the territory of alarm in which the activity is high and has been interrupted for a short time (the interruption must have a sufficient temporal and/or spatial span). In many cases such an intermittent episode in seismic regime occurs in a narrow vicinity of the expected large earthquake. It may start long after a TIP beginning, thus, reducing the temporal span of the alarm. An application of *MSc* requires a catalog which systematically reports the earthquakes of magnitude lower than the minimal threshold used by *M8*, i.e., $M_{\min}(20)$; therefore, in certain cases the second approximation could not be achieved with the existing data sources.

Algorithm MSc was designed by retroactive analysis of seismicity prior to the Eureka earthquake (1980, $M = 7.2$) near Cape Mendocino in California, hence its name. For reader's convenience, we describe here the scheme of the *MSc* algorithm in brief:

Given a TIP diagnosed for certain territory **U** at the moment **T**, the algorithm is aimed to find within **U** a *smaller* area **V** in which the predicted earthquake has to be expected. An application of the algorithm requires a reasonably complete catalog of earthquakes with magnitudes $M \geq (M_0 - 4)$ which is usually lower than a minimal threshold used by *M8*.

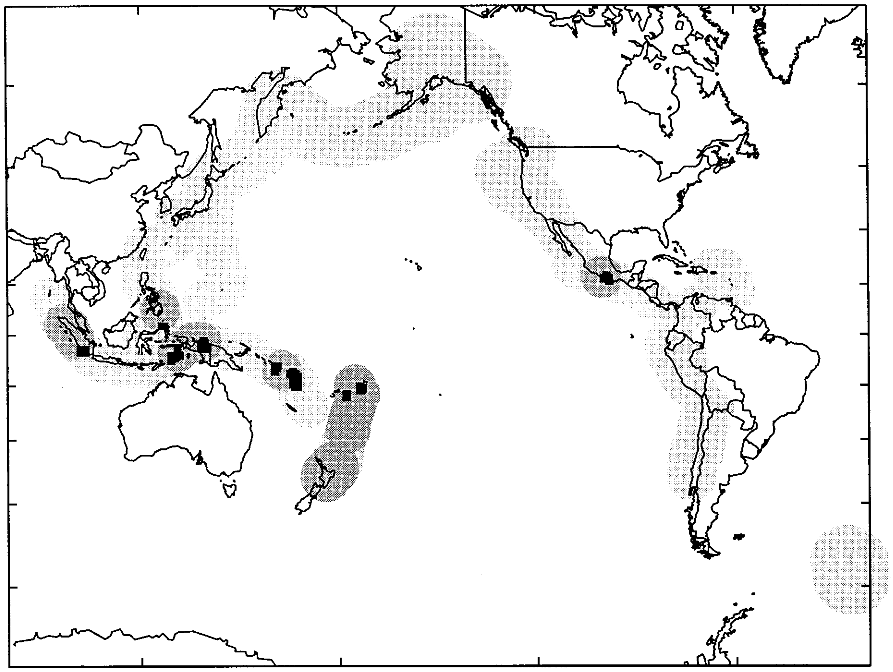
The essence of *MSc* can be summarized as follows. Territory **U** is coarse-grained into small squares of $s \times s$ size. Let (i, j) be the coordinates of the centers of the squares. Within each square (i, j) the number of earthquakes $n_{ij}(k)$, aftershocks included, is calculated for consecutive short time windows u months long, starting from the $(\mathbf{T} - 6$ years) onward, to allow for the earthquakes which contributed to the TIPs diagnosis; k is the sequence number of a time window. In this manner the time-space considered is divided into small boxes (i, j, k) of the size $(s \times s \times u)$. "Quiet" boxes are singled out for each small square (i, j); they are defined by the condition that $n_{ij}(k)$ is below the Q percentile n_{ij}. The clusters of q or more quiet boxes connected in space or in time are identified. Area **V** is the territorial projection of these clusters. The *standard values of parameters* adjusted for the case of the Eureka earthquake are the following: $u = 2$ months $Q = 10\%$, $q = 4$, and $s = 3D/16$, D being the diameter of the circle used in algorithm *M8*.

Application of the Algorithms Using the NEIC Data

Since 1990 the algorithms are applied systematically for a research real-time intermediate-term prediction in those regions worldwide where seismic catalogs are available and complete enough for the analyses. In particular, since 1992 in collaboration with the United States Geologic Survey, we carry out the experimental prediction of earthquakes with magnitude 7.5 and above in the Circum-Pacific as a rigid Test of *M8* (HEALY *et al.*, 1992). The later prediction is based on analysis of the NEIC GLOBAL HYPOCENTERS DATA BASE CD-ROM (1989) and its updates to the present. It also includes the territory of Japan.

The territory of Japan and adjacent regions were among the first regions in which the algorithms were tested although by retroactive application (KEILIS-BOROK and KOSSOBOKOV, 1990b). The prediction using NEIC GHDB aims at M 8.0+ and M 7.5+ events. In fact, the prediction results, both of retroactive as well as of forward testing (HEALY *et al.*, 1992; KOSSOBOKOV, 1994; KOSSOBOKOV *et al.*, 1996a), prove the efficiency of the algorithms here.

a



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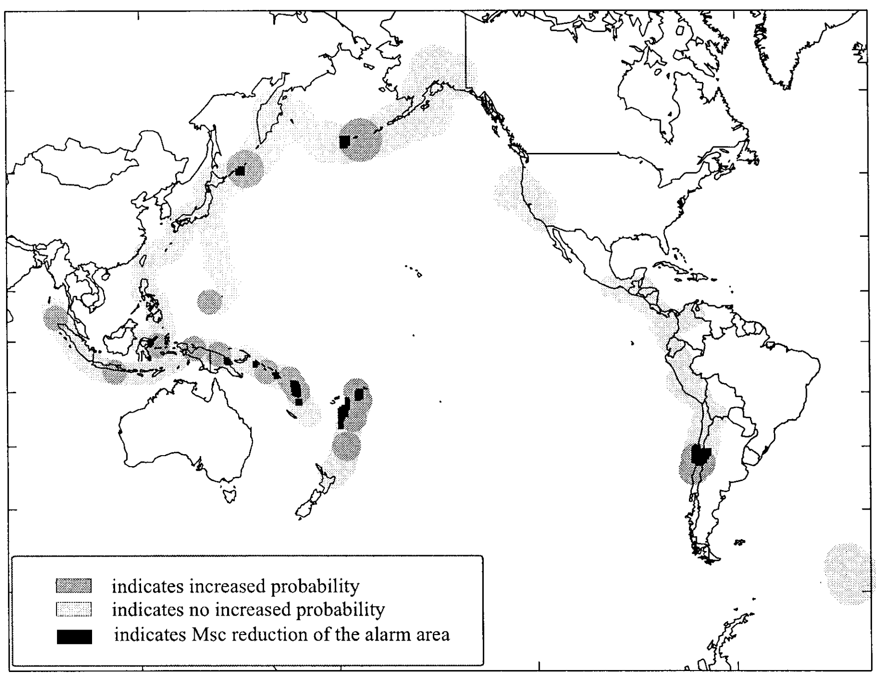


Figure 1
The regions of increased probability in the Circum-Pacific, July 1998 to December 1998 determined by the *M8* and *MSc* algorithms aimed to predict magnitude 8.0 + (a) and 7.5 + (b) events.

Figure 1 shows the *M8-MSc* predictions (KOSSOBOKOV *et al.*, 1999) as on July 1998. One may check that the only M 7.5+ earthquake in the Circum-Pacific during July–December 1998, i.e., the November 29, Ceram Sea earthquake, fulfills the *M8* prediction and misses the reduced area of alarm by one hundred km. According to the NEIC QED, the earthquake has $M_s = 7.7$ and epicenter located at 2.051°S 124.925°E (other magnitude determinations – $m_b = 6.5$, $M_W GS = 7.8$, $M_W HRV = 7.7$, and $MeGS = 8.1$). It adds a positive input to the overall statistics of the *M8* and *M8-MSc* predictions in the Circum-Pacific, 1985–1998, which have already demonstrated the high (above 99%) statistical significance level of the methods (KOSSOBOKOV *et al.*, 1999).

For the territory of Japan and adjacent regions the performance of both algorithms over a period of fourteen years is illustrated in Figure 2. For the entire territory of the Circum-Pacific where the prediction is made, the *M8* alarms aimed at prediction of M 8.0+ events cover on average one third of the seismic belt length at any given time, while *MSc* reduces this number to 10%. For prediction of M 7.5+ events these numbers are 40% and 6%. For the territory of Japan and adjacent regions the percentages of M 8.0+ alarms are 35% and 12%, correspondingly, while for M 7.5+ alarms they are 33% and less than 3%.

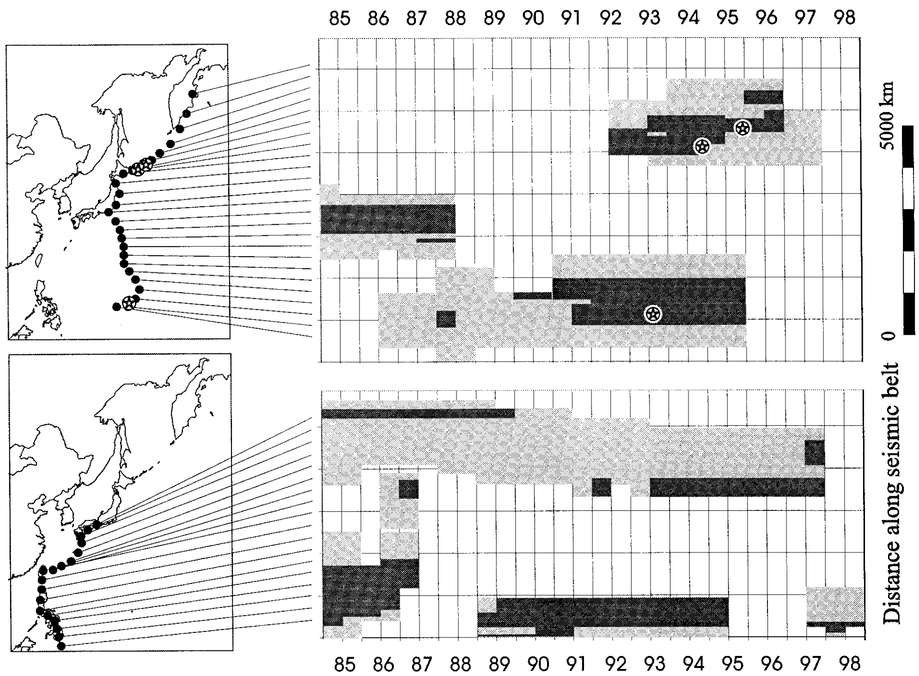
Although the performance of the algorithms is encouraging, the recent most destructive (Hyogo-ken Nanbu) earthquake in the region has $M = 7.2$ and, therefore, falls beyond the scope of analysis. The data available from NEIC GHDB for the region where this earthquake occurred is insufficient to determine even the first approximation prediction (i.e., to run the *M8* algorithm) aimed at prediction of magnitude 7.0+ events. To cover them by prediction, the *M8* and *MSc* algorithms require additional data that describe the dynamics of seismicity at lower magnitude ranges.

The JMA Data

We analyze systematically the seismicity of Japan as reported in the Japan Meteorological Agency (JMA) Catalog of Earthquakes through August 1996. In total, the catalog is apparently complete for M 6.0+ events since approximately the beginning of the century, for M 4.5+ events—since 1927, for M 4.0+ events—since about 1964, and, perhaps, for M 3.0+ events—since 1983 (Fig. 3).

Figure 2
The space-time distribution of the *M8* and *MSc* alarms aimed to predict M 8.0+ (a) and M 7.5+ (b) earthquakes in Japan and adjacent territories, 1985–1997. The territory considered is on the left. The space-time distribution of real time alarms and the great earthquakes (stars) are given on the right. Space coordinate is given as the distance along the belt.

a


85 86 87 88 89 90 91 92 93 94 95 96 97 98
5000 km
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Distance along seismic belt
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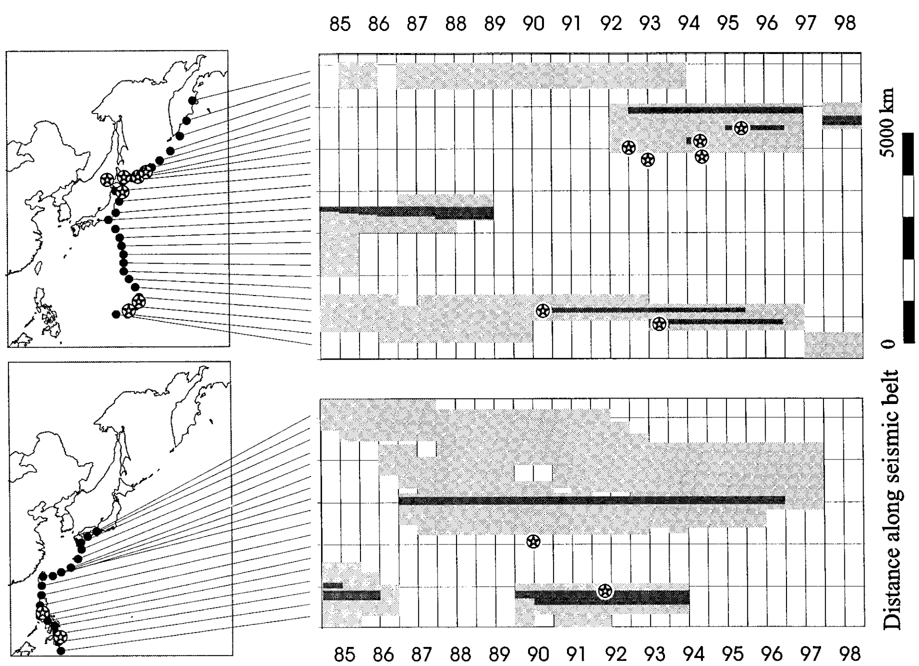
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Distance along seismic belt
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Thus, locally the JMA Catalog is indeed more complete than the NEIC GHDB providing the data required for prediction of magnitude below 7.5, e.g., the 7.0+ events. Local analysis in a dense set of CI's of 280-km radius, that corresponds to $M_0 = 7.0$, shows that the *M8* algorithm could be used here for earthquakes forecasts from 1985 to the present. Since information on the lower magnitude ranges is also available, one could apply the *MSc* algorithm from 1985 as well. However, the difficulty may arise from inhomogeneous data coverage of the territory under consideration.

To evaluate the territorial span of completeness of the JMA Catalog we have used the NEIC GHDB as an independent source of data. Specifically, we selected all magnitude 4.0 or greater earthquakes from the NEIC GHDB, 1963–1995, as a test set. Obviously such a test set is incomplete in some areas at magnitude 4 level, however we can use it to measure the territorial completeness of the local catalog. We presume that in the areas of its territorial completeness the JMA would record all or most events from the test set and the attributed magnitudes of those events would differ little. Thus we have determined those earthquakes from the test set

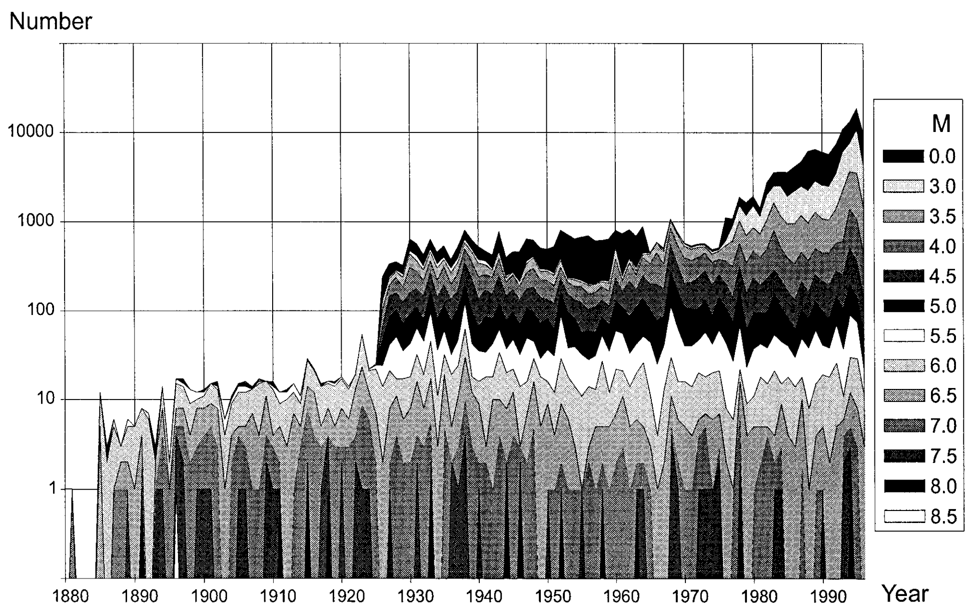

Figure 3

The annual number of earthquakes reported in the JMA Catalog of Earthquakes by time and magnitude in 1880 to August 1996. Each band corresponds to half-a-unit of magnitude *M*. These bands stacked from higher ranges provide the number of earthquakes above a certain threshold. Note: (1) an overall increase in the number of earthquakes which corresponds to the improvement of seismographs; (2) sharp changes at 1885, 1896, 1926, 1959–1964, and 1976–1983; (3) certain stability of the number of the magnitude 6.0 and larger events from 1896; (4) rather uniform width of the bands since 1964 in agreement with the Gutenberg-Richter relationship down to magnitude 4.0 and since 1983 down to magnitude 3.0.

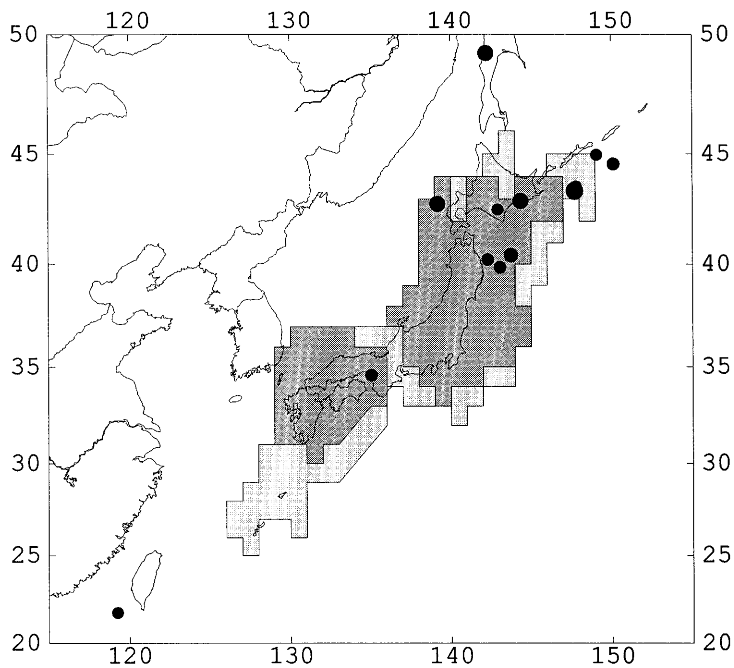

Figure 4
Spatial completeness of the JMA Catalog of Earthquakes and recent shallow earthquakes of magnitude 7.0 and larger (1985 to the present).

which have an equivalent among all magnitude 3.0 or greater earthquakes from the JMA Catalog. In our definition the equivalent events differ by less than one minute in time, 0.5° in latitude, 0.7° in longitude, and 33 km in depth. No additional limitation on magnitudes was set. We coarse-grain the territory into one by one degree cells between 20–50°N and 120–150°E. For each cell we count the total number of earthquakes from the test set in it (N) and those from the total that have an equivalent in the JMA Catalog (n). The ratio (n/N) characterizes the completeness of the JMA Catalog in a given cell. The spatial distribution of this ratio displays a high level of completeness (above 75%) for most of the Japan Islands. However, the completeness at Northern Hokkaido and along the Kuril, Ryukyu, and Izu trenches is considerably lower. Figure 4 shows the contours of 75 and 50% completeness along with the epicenters of all magnitude 7.0 and above earthquakes from the JMA Catalog, 1985–1996. The contours partially split the whole territory into two regions of a high level of completeness separated along 136°E, where the Japan subduction zone seismicity expires to the west. Note that the outlined areas differ slightly when other time interval or higher magnitude ranges (up to 5.0 and above) are considered.

The epicenters of magnitude 7.0 or greater events in 1985–1996 mark the northeastern edges of the two regions (Fig. 4). In the eastern region most of them occurred in 1993–1995, forming a unique cluster in the history of the instrumental seismology that includes five magnitude 7.5 or greater earthquakes and their aftershocks. Note that the first of them and the two largest events of magnitude 8.1 and 8.0 were predicted in real time (KOSSOBOKOV *et al.*, 1994, 1996b), in course the Test of *M8* (HEALY *et al.*, 1992). The western region contains the only *M* 7.0+ earthquake that occurred near Kobe on January 16, 1995 at 20:46 GMT.

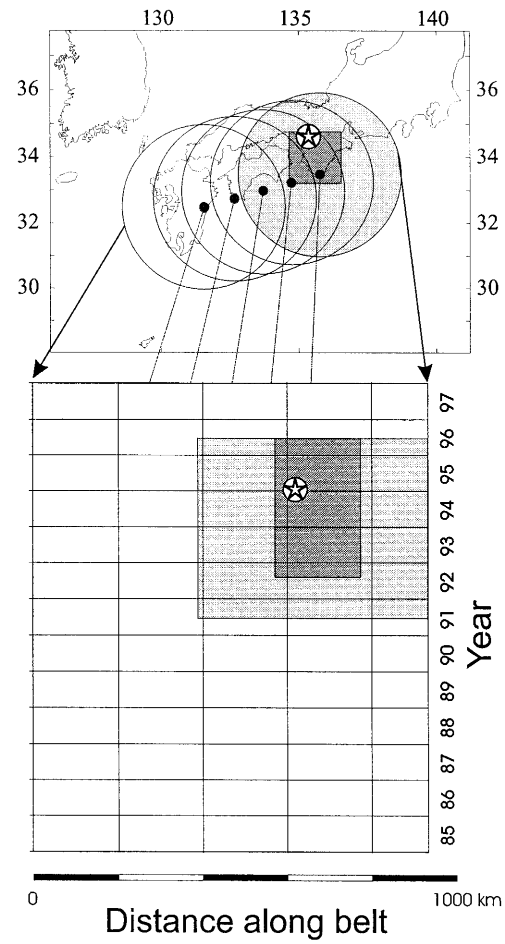

Figure 5
Space-time distribution of alarms: The territory of the five circles of investigation of 280-km radius (upper part) and temporal evolution of alarms (lower part). The *M8* times of increased probability (shaded light) are limited to one circle and 5-year interval; the *MSc* second approximation (shaded dark) narrows down the prediction to 175 × 175 km square and four years. The epicenter of the 1995 Kobe earthquake indicated with a star fulfills the *M8-MSc* predictions.

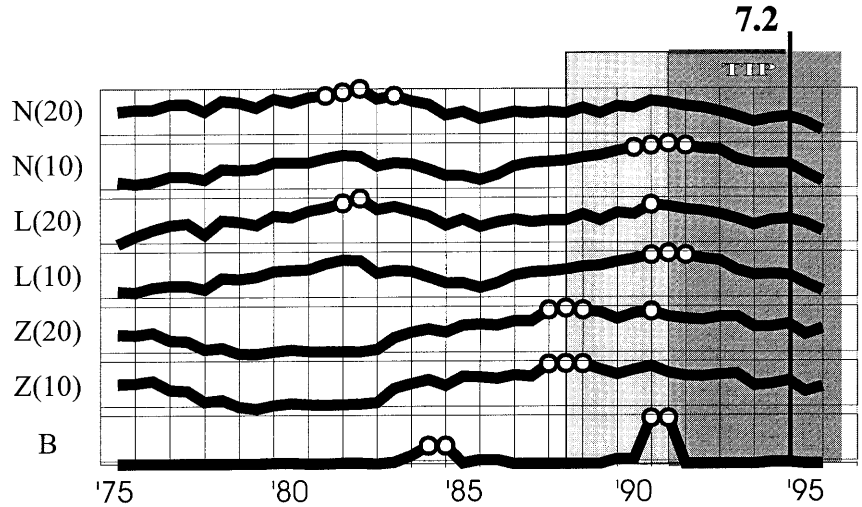

Figure 6
Functions of the *M8* algorithm in the circle centered at 33.5°N, 135.75°E with radius of 280 km for magnitude 7.0+ prediction. The abnormally high values of each function marked with circles concentrate in the 3-year interval (shaded light) ending on July 1, 1991. The observed coincidence of the abnormally high values, by the *M8* definition, starts the 5-year TIP (shaded dark). The time of the 1995 Kobe earthquake (vertical line) falls into this period.

Application of the Algorithms Using the JMA Catalog

To check whether the dynamics of seismicity prior to the 1995 Kobe earthquake followed the behavior suggested by the *M8* and *MSc* algorithms as precursory, we set $M_0 = 7.0$ and apply the algorithms to the territory of the western region. The upper part of Figure 5 shows the five CI's whose centers are evenly distributed along the line connecting 32.5°N, 131.6°E and 33.5°N, 135.75°E. They cover most of the western region including Western Honshu, Sikoku, and Ryukyu Islands. The retroactive monitoring of seismicity from 1975 by application of the *M8* algorithm aimed at *M* 7.0+ earthquakes supplies the only TIP in the most eastern CI spanning the period July 1991 through June 1996. The values of the *M8* algorithm functions counted in this CI are shown in Figure 6. We see that all but one measure of activity, namely $N(20)$, raised to their highest values, forming a TIP by the middle of 1991.

As on July 1991 the *MSc* algorithm gives no reduction of the *M8* prediction (the lower part of Fig. 5). The second approximation emerges one year later in July 1992 when *MSc* recognizes the precursory behavior for the 175 by 175-km square shown in Figures 5 and 7. The same area remains through each of the six half-year updates prior to January 16, 1995. In total, the space-time volume of alarm measured by distance along the belt times year occupies 2800 and 800 km × year in the first and the second approximation, correspondingly. In other words, the alarms of the first and the second approximation cover on average about 23.0 and 6.6% of the total belt length.

Thus, the combination of the *M8* and *MSc* algorithms using the JMA Catalog data through 1994 pinpoints the location of the Kobe 1995 epicenter and its aftershocks.

A Shorter-term Observation

Unusual swarms briefly preceded the two great earthquakes of magnitudes 8.1 and 8.0 to the northeast of Hokkaido that were predicted in real time (Kossobokov *et al.*, 1994, 1996a). A similar pattern is found for the Kobe 1995 main shock. Ten earthquakes of approximate magnitude 3.5 occurred at 34.9°N, 135.4°E on November 9–26, i.e., about 50 km distant from the forthcoming epicenter and verging on the edge of the aftershock zone (Fig. 7). The time span between this "swarm" and the main shock is about six weeks. Although the seismicity of Japan produces numerous swarm activities that are not followed by a large event, the swarm of November 9–26 is remarkable. Indeed, it is the only cluster of such kind in the 280-km radius circle of the *M8* TIP ever recorded by JMA; similar space-time density of earthquakes above magnitude 3.0 were previously observed in clear

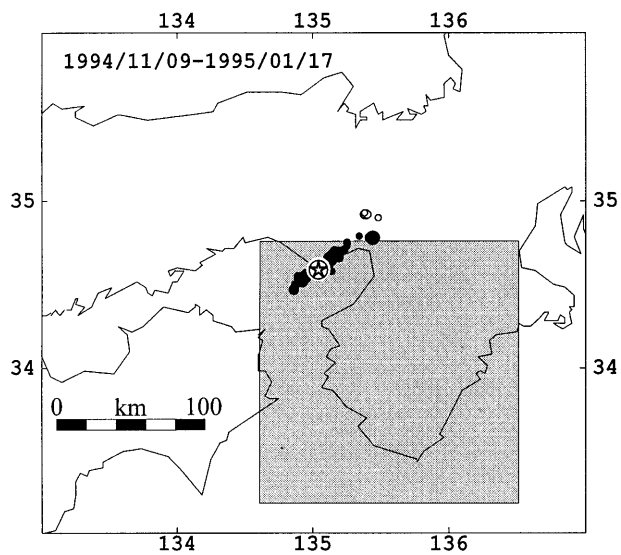

Figure 7
The localization of the *M8* alarm by the *MSc* algorithm (shaded square). Note a remarkable swarm (open circles) of November 9–26, the only one within the *M8* alarm limits, followed by the quake of January 9, 1995 on the fault then ruptured with the 1995 Kobe earthquake epicenter (star) and its aftershocks (solid circles). The epicenter of the 11-hour foreshock coincides with that of the main event.

aftershock sequences of only markedly larger events. It should be mentioned that this, apparently short-term, activation progresses: On January 9 a magnitude 3.1 event struck the fault of the future main rupture after which the epicentral area of the Kobe earthquake effected a magnitude 3.5 foreshock at 9:28 GMT on January 16.

Discussion and Conclusion

A novel understanding of the dynamics of seismicity has emerged over the last decade. The lithosphere, its earthquake-prone part in particular, is regarded as a hierarchical nonlinear system with dissipation of energy (e.g., NEWMAN *et al.*, 1994). Among sources of nonlinearity of the system is abrupt triggering of an earthquake when stress exceeds strength on a segment of a fault. Powerful sources of nonlinearity also may arise from the multitude of processes (such as filtration of fluids and stress corrosion, buckling and microfracturing, phase transition of the minerals, etc.) that control distribution of strength within the hierarchy of blocks and faults. Except for unique cases, none of the sources of nonlinearity predominates, as a result the others can be neglected. Therefore, from a position of intermediate-term earthquake prediction, the lithosphere appears to be a chaotic system. Predictability of chaos could be achieved, up to a certain limit, after averaging and/or after recognizing the beginning of a certain scenario that often surfaces in the process considered (MONIN, 1994).

The methods we used in this paper account for these conclusions on predictability of nonlinear systems by describing the preparation stage of the system in terms of robust averages. However, our analysis of the 1995 Kobe earthquake indicates rather than proves emerging possibilities of earthquake monitoring supported by intermediate-term prediction algorithms. The observed progression of seismic dynamics suggests that certain phenomena that are usually disregarded as short-term premonitory may become such on the background of an intermediate-term alarm. Our results for the 1995 Kobe earthquakes together with those achieved in a real-time testing Circum-Pacific (HEALY *et al.*, 1992; KOSSOBOKOV, 1994; KOSSOBOKOV *et al.*, 1994, 1996a,b, 1999) favor a hierarchical, step-by-step prediction technique which accounts for a multi-scale escalation of seismic activity to the main rupture. It starts with recognition of earthquake-prone zones for a number of magnitude ranges, then follows with determination of long- or intermediate-term areas and times of increased probability, and, finally, may come out with a short-term alert. The prediction of the Haicheng earthquake of February 4, 1975 remains the unique example of how this approach could lead to actual success in saving lives and reducing damage, although at that time some of the steps were lucky guesses, rather than statistically justified conclusions (ZHANG-LI *et al.*, 1984).

There is a prevailing opinion that earthquake hazard mitigation is more valuable than prediction. However, if one addresses the problem from a hierarchical viewpoint, it is clear that seismic hazard expectation is actually based on a zero-approximation prediction and its value strongly depends on how accurately the assumptions are used to derive seismic potential. Moreover, the practice of evaluating hazard potential by using exclusively historic data might be seriously biased due to a rather short period of observation. In most cases, the areas that have already exposed themselves as dangerous might be quasi relaxing while others are ready to go in the next strike. From an economical point of view, the issue of costs-and-benefits is still not clear for the expenditures on earthquake hazard mitigation in most seismic regions. Thus it is very possible that new strategies, based on reliable, statistically justified prediction methods, could outperform the existing ones (MOLCHAN, 1997). That is why testing of prediction algorithms is crucially important.

The ultimate test of any prediction method is the advance prediction. Inevitably each advance prediction experiment requires many years of a tedious, book-keeping investigation due to the infrequent occurrence of significant earthquakes. The procedures of such book-keeping should be rather transparent, so that other interested parties can repeat and/or revise *a posteriori* the results of the prediction experiment (HEALY *et al.*, 1992). All this may explain why we know of few studies on testing predictions. Nonetheless we repeat there is not other way achieve statistical justification of a prediction method except for actual prediction of earthquakes. The more predictions, fulfilled or not fulfilled, the stronger becomes our confidence for accepting or rejecting the underlying hypothesis we obtain. The results of this paper suggest extending to lower-magnitude ranges the testing of the *M8* and *MSc* algorithms in those segments of Circum-Pacific where regional data are complete enough for an adequate application.

The accumulated results of prediction by the *M8* and *MSc* algorithms (i.e., growing set of success and errors) provide a *pied à terre* for further development of prediction methods. The significance level achieved by these algorithms (KOSSOBOKOV *et al.*, 1997) might already be enough to address the question of development of civil-defense and/or economic instruments, among them activation of the existing low key safety measures that provide prevention of a significant part of the damage.

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