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Determination of hypocenter using seismic intensity distributions and 3-D attenuation structure

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ABSTRACT

Seismic intensity distribution is affected by 3-D attenuation structure. Therefore, hypocenter and magnitude of historical earthquake have been empirically estimated by seismic intensity distribution as compared with the seismic intensity distribution of recent earthquake. This paper examined the determination of hypocenter using the seismic intensity data and 3-D attenuation structure beneath Japanese islands that had been obtained by tomographic inversion method. We first compared the attenuation relation of peak ground accelerations for the 1994 Sanriku-Haruka-Oki earthquake with empirical relation, and identified the location of source strongly affects the amplitudes of seismic ground motion, and it should be possible to locate earthquakes of subduction zone. We second examined the hypocenters for recent earthquakes using the seismic intensity data and 3-D attenuation structure under the condition of magnitudes are known parameter. We obtained the epicenters in this study were determined near source area, although in case of no seismic intensity data in the Hokkaido district. This method should be useful to locate earthquake in case of using only amplitude data like as historical earthquakes.

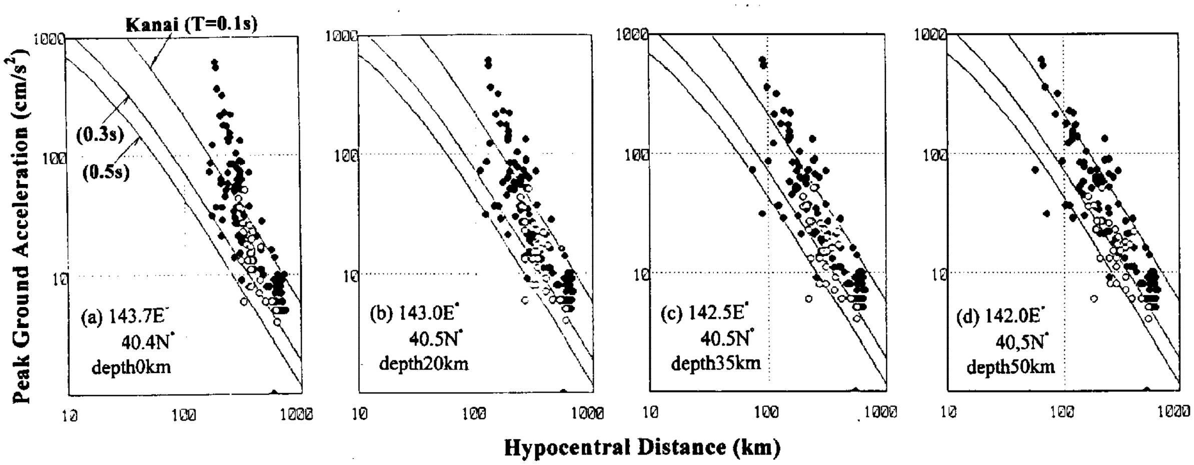
KEYWORDS

3-D attenuation structure; seismic intensity; hypocenter; epicenter; locating earthquake; historical earthquake, the 1994 Sanriku-Haruka-Oki earthquake.

Effect of the epicenter position on the attenuation relations

In large size of earthquake, estimation of seismic ground motion using attenuation relation is affected by source position. Kanamori (1993) suggests that it should be possible to locate earthquakes using amplitude data. Fig.1 shows the attenuation of PGA for the 1994 Sanriku-Haruka-Oki earthquake (The National Research Institute for Earth Science and Disaster Prevention,1995). The PGA shown here is a larger one of the two horizontal components. The solid circle shows a station located in the east of the steeply decay line of seismic intensity (SDLSI; Usami *et al.*, 1992), and the open circle shows a station in the western of this line. The SDLSI is almost parallel to the volcanic front (fig.2), and the seismic intensity decays steeply across this line. The reason of decrease of seismic intensities on SDLSI should be 3-D attenuation structure beneath the Japanese Islands.

Fig.3 shows the aftershocks of the 1994 Sanriku-Haruka-Oki earthquake. The mainshock epicenter was determined by JMA (Japan Meteorological Agency) at the east end of the aftershock region, since the fault rupture started at this epicenter and propagated to the west.



(●:the east side, ○:the west of the SDLSI shown in Fig.2.)

Fig. 1 Attenuation of peak ground acceleration for the 1994 Sanriku-Haruka-Oki earthquake at the distance from deferent locations (a),(b),(c) and (d) in the source region shown in Fig.3.

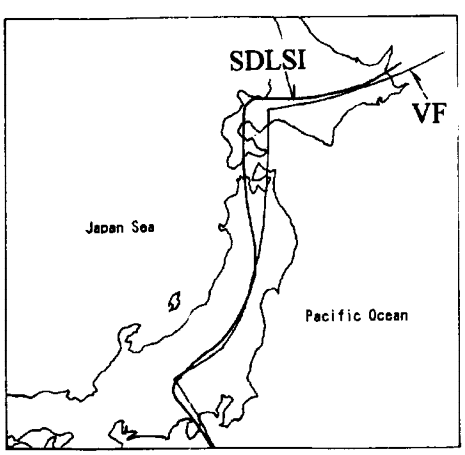


Fig.2 Location of the steeply decay line of seismic intensity (SDLSI) and the volcanic front (VF).

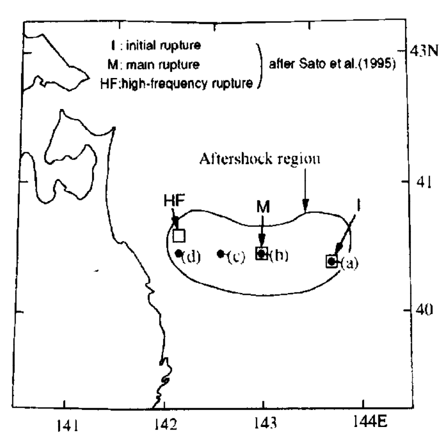


Fig.3 Aftershock region of the 1994 Sanriku-Haruka-Oki earthquake. (a),(b),(c)and (b) denote the locations shown in Fig.1.

Fig.1(a) shows the attenuation relation in case of the epicentral distance is from the JMA epicenter. Figs.1(b), (c) and (d) show the cases of the distance from longitude 143.0° E, 142.5° E and 142.0° E, respectively. The latitudes are fixed at 40.5° N. The solid lines in each figure show the relationship of Kanai' s empirical relation (Kanai and Suzuki,1968) with dominant periods of 0.1,0.3 and 0.5s.
The gradient of the attenuation relation using distance from the JMA epicenter is steeper than that of the Kanai's relation. In case of the epicentral distance from the west end of aftershock region, where high frequency motion released (Sato *et al.*, 1995), the attenuation relation agrees well with the Kanai's relation. We can conclude that the location of source strongly affects the amplitudes of seismic ground motion, and it should be possible to locate earthquakes of subduction zone.

Method

Hashida and Shimazaki (1984a) presented the method of determination of hypocenter and magnitude using the seismic intensity data and 3-D attenuation structure in the Tohoku distorict, Japan. On the other hand, Nakamura *et al.* (1994,1995) obtained the 3-D attenuation structure in the whole of the Japanese Islands by tomographic inversion of a large quantity of previous seismic intensity data. The formulation of observational equation is based on Hashida and Shimazaki(1984b). The results of inversion showed that the Pacific and the Philippine Sea plates tend to show high Q (Fig.4). This result is consistent with the reported result of P wave velocity tomograpy (e.g. Kamiya et al.,1989).

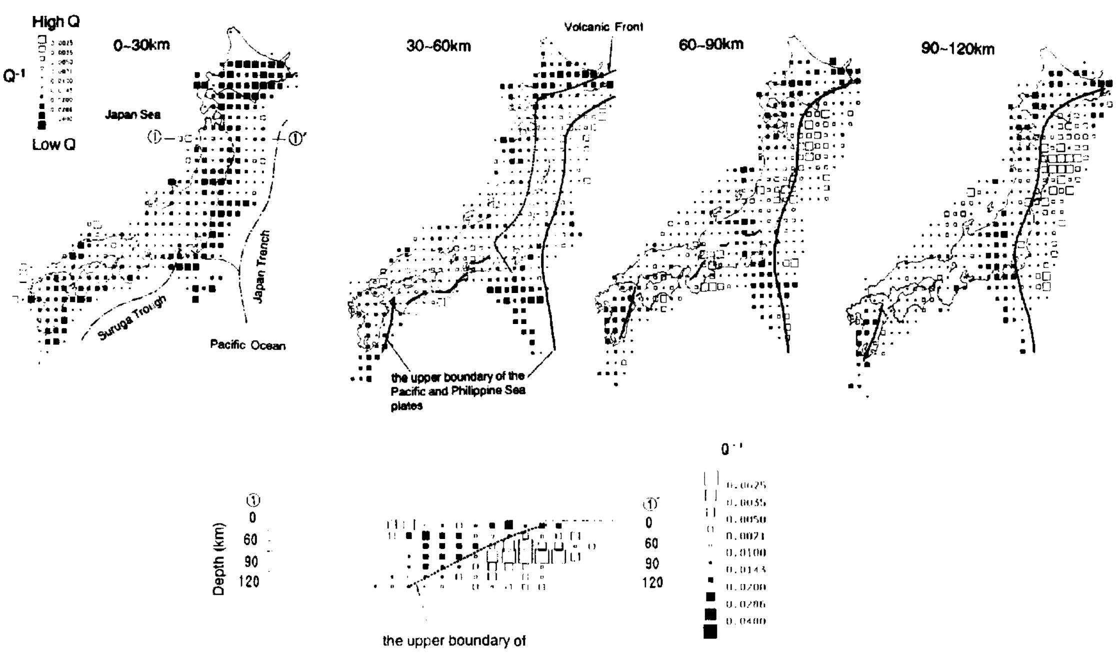


Fig.4 Distribution of 1/Q values after Nakamura *et al.*(1994,1995).

In this study, according to Hashida and Shimazaki (1984a), we take residual between observed acceleration and calculated acceleration as index parameter. The observed acceleration α_{obs} (gal) translated from the seismic intensity in JMA scale by Kawasumi (1943)'s relation (Fig.5). The calculated acceleration α_{cal} (gal) at a station can be expressed as follows,

$$\alpha_{cal} = S \cdot G \cdot g \cdot \exp\left\{-\pi \cdot f \cdot \sum \left(T_K / Q_K\right)\right\}, \tag{1}$$

where,

S: point source acceleration (gal),
G: geometrical spreading factor,
g: amplifying effect at the earth's free surface,
f: frequency ,
T_K : travel time (sec) in the k-th block,
Q_K: quality factor in the k-th block.

The residual ε at a station I, can be expressed as follows,

$$\varepsilon_I = \ln\left(\alpha_{obs}\right) - \ln\left(\alpha_{cal}\right). \tag{2}$$

The standard deviation of the residuals in N-station is,

$$\sigma = \sqrt{\sum_N \varepsilon_I^2 \Big/ N} . \tag{3}$$

We assume that the point source acceleration is $10^{0.6M}$gal considering the relation between magnitude and the point source acceleration after Nakamura *et al.* (1994) . We assume that magnitude is known. The geometrical spreading factor is equal to the inverse of the distance along the ray path. The amplifying effect at the earth's surface g is fixed as 2.0, because the local site effect is found to be smaller than the effect of the 3-D structure.

The attenuation $1/Q$ in the lithosphere strongly depends on the frequency and is proportional to $f^{-1} \sim f^{0.5}$ (Sato,1991). Thus the term f/Q in the formula becomes less dependent on the frequency. We simply assume the representative frequency of JMA intensity as 1Hz.

The ray path from the source to the station is calculated with the spherically layered earth model. We adopt the S-wave velocity model proposed by Ichikawa and Mochizuki (1971). The summation Σ is made over the blocks where the seismic ray penetrates.

The quality factor in the k-th block are after Nakamura *et al.*(1994).

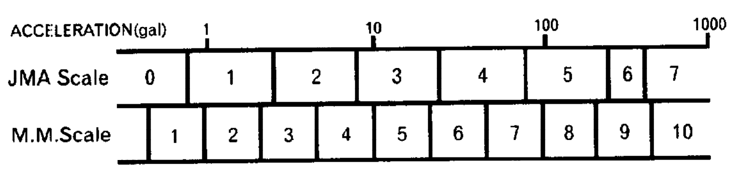


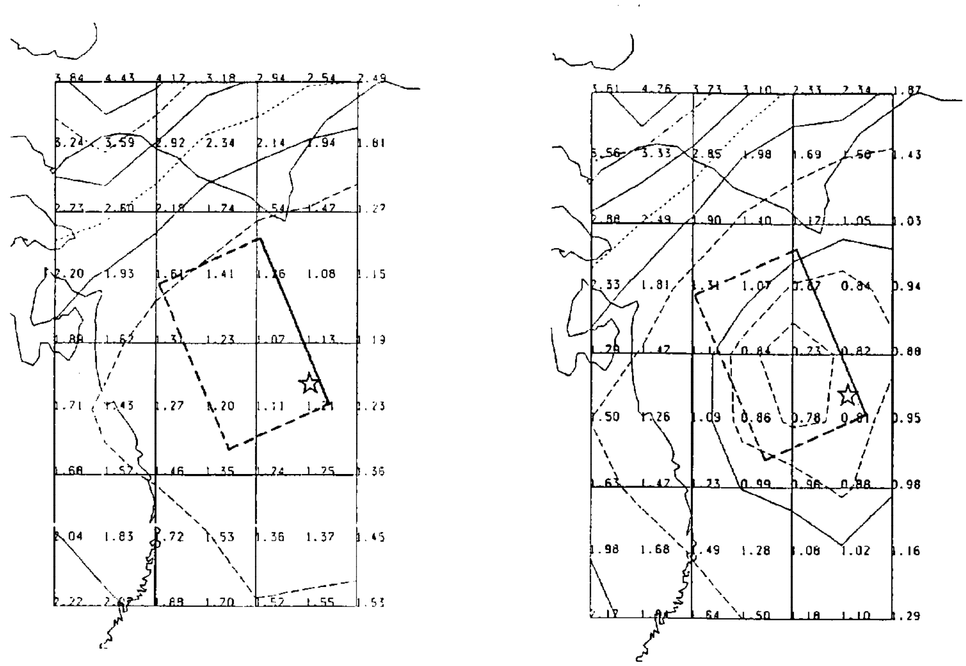
Fig.5 The Japanese Meteorological Agency seismic intensity scale (JMA) and the Modified Mercalli seismic intensity scale (MMI).

Results

We study the case of recent earthquakes using the 1968 Tokachi-Oki earthquake ($M_{JMA}7.9$), the 1994 Sanriku-Haruka-Oki earthquake ($M_{JMA}7.5$,$M_W7.6$), the 1938 Hukushimaken-Toho-Oki earthquake ($M_{JMA}7.5$), and the 1995 Hyogoken-Nanbu earthquake ($M_{JMA}7.2$, $M_W6.9$).

Fig.6 shows a result of calculation in case of the 1968 Tokachi-Oki earthquake as contour map of the standard deviation σ of the residuals ε . Minimum value locate near epicenter by JMA at depth of 80km. Hypocenter tend to be obtained deeper than JMA(0km). Figs.7 and 8 show the minimum location of the standard deviasion σ of the recent earthquakes in this study.

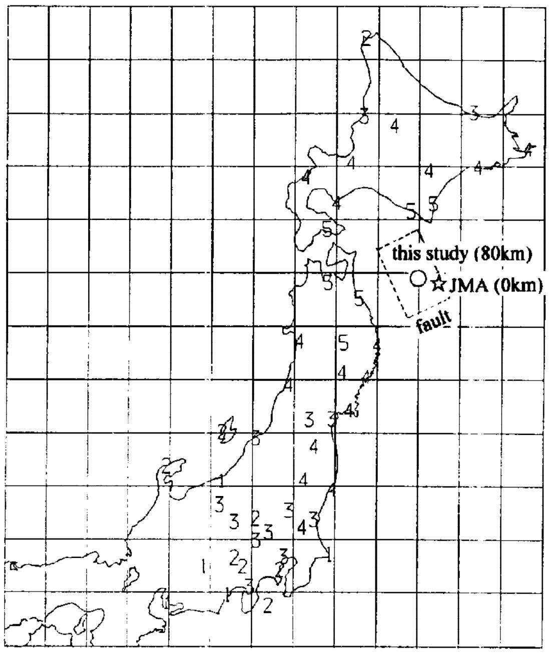
The locations are in good agreement with the hypocenters determined by the instrumental observations of JMA. The 1994 Sanriku-Haruka-Oki earthquake epicenter of this study was at the center of the aftershock region, where was located at about 1° east from the high-frequency rupture after Sato *et al.* (1995). In the case of the 1995 Hyogoken-Nanbu earthquake, we obtain the epicenter near the Nojima fault which dislocated at this earthquake. The seismic intensity data are rare in Hokkaido district on historical age. We calculated using no seismic intensity data in Hokkaido district of the1968 Tokachi-Oki earthquake data. The result of this case shown in Fig.11, and also show good agreement with the epicenter determined by JMA.



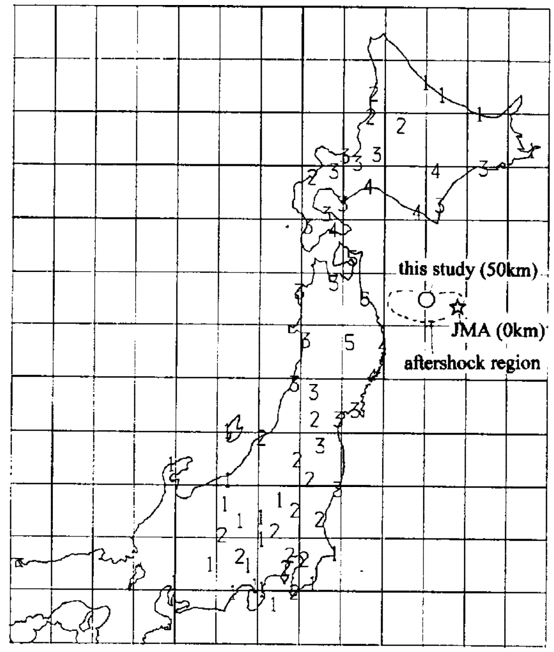
(a) depth=40km

(b) depth=80km

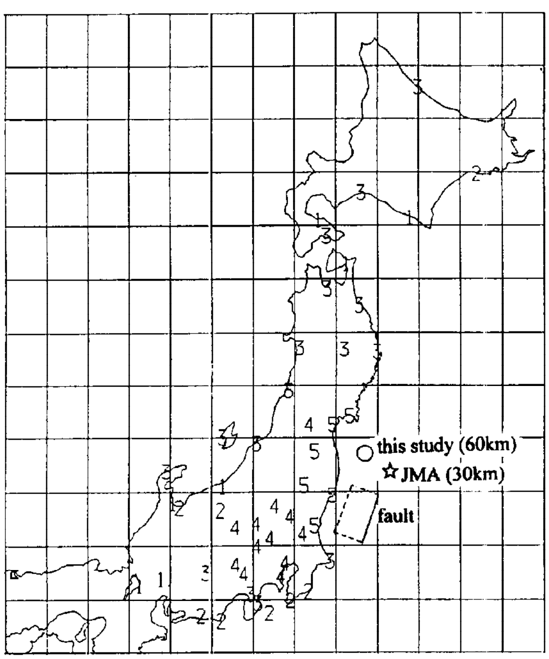
Fig.6 Contour map in case of the 1968 Tokachi-Oki earthquake. The numerical , rectangle and open star indicates σ , the fault plane and epicenter determined by JMA(depth=0km).



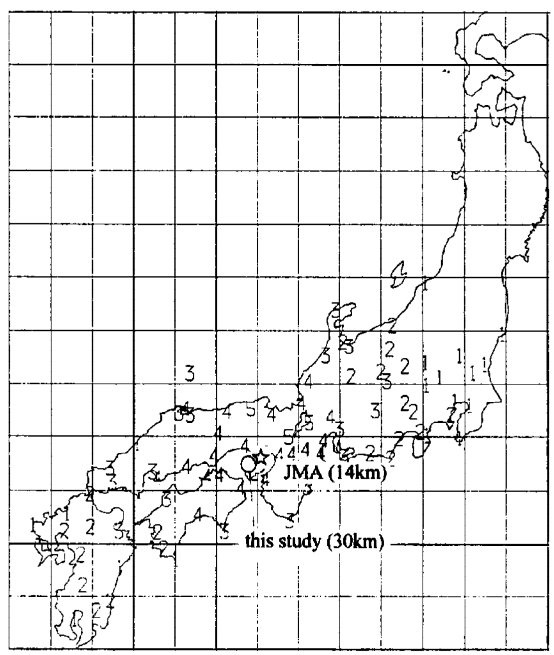
(a) The 1968 Tokachi-Oki earthquake



(b) The 1994 Sanriku-Haruka-Oki earthquake



(c) The 1938 Hukushimaken-Toho-Oki earthquake



(d) The 1994 Hyogoken-Nanbu earthquake

Fig.7 Results of location of hypocenter.
The open circle and the star indicate the hypocenter determined using seismic intensity data and the hypocenter determined by JMA. Numeral in parentheses shows depth of hypocenter. Numeral of integer indecate the JMA seismic intensity used in this study.

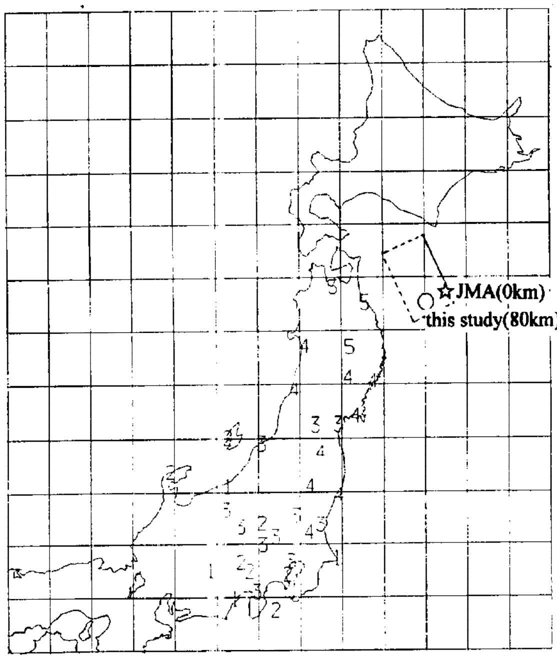


Fig.8 Result of no seismic intensity data in Hokkaido district.

Conclusions

Epicenter and magnitude of historical earthquake are empirically estimated by seismic intensity comparing with recent earthquakes. The location of source strongly affect to amplitudes of seismic ground motion, and it should be possible to locate earthquake using the amplitudes. The seismic intensities are the information of the amplitude of the seismic ground motion. So, we could be determined earthquake location using the seismic intensity data.

On the other hand, the seismic intensity distribution affected by 3-D attenuation structure. Nakamura *et al.* (1994,1995) obtained 3-D attenuation structure beneath Japanese islands by tomographic inversion of seismic intensity data and explained the seismic intensity distribution of the 1993 Kushiro-Oki earthquake simulated using this 3-D attenuation structure.

In this study, we try to obtained hypocenter using the 3-D attenuation structure and the seismic intensity distribution of some recent earthquakes under the condition of magnitudes are known parameter. The epicenters are determined near the epicenter or the faults which dislocated. In spite of no seismic intensity data in the Hokkaido, the epicenter of this study obtained near source area. This method should be usefull to locate earthquake in case of using only amplitude data like as histrical earthquakes.

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