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Determination of Three-dimensional Attenuation Structure and Source Acceleration by Inversion of Seismic Intensity Data: Japanese Islands

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Abstract

The three-dimensional seismic attenuation structure beneath the Japanese Islands is determined from seismic intensity data. The source accelerations which indicate "size" of earthquakes at hypothetical point sources, are also simultaneously determined by inversion of seismic intensity data.

1. Introduction

The main purpose of this paper is to describe the detailed results of inversion, in which the three-dimensional attenuation structure and "size" of earthquakes in and around the Japanese Islands are estimated from seismic intensity data.

HASHIDA and SHIMAZAKI (1984) formulated the method to estimate attenuation structure and "size" of earthquakes from intensity data. Since then the method has been applied to several regions of the Japanese Islands (HASHIDA and SHIMAZAKI, 1985; 1987 a), New Zealand (SATAKE and HASHIDA, 1987), and the Aegean region (HASHIDA *et al.*, 1987). In this paper, the method is applied to the whole region of the Japanese Islands and only the result is presented. Discussions on this result are given in another paper (HASHIDA, 1987).

Once we estimate a reliable attenuation structure from intensity data, we can calculate intensity for a specific pair of station and earthquake. HASHIDA and SHIMAZAKI (1986, 1987 b) show that the calculated intensities based on the attenuation structure are in good agreement with observed ones even in a region such as the Tohoku district where the intensity distribution often shows an anomalous pattern. Therefore tables of the three-dimensional attenuation structure presented in this paper are available for predicting the intensity.

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First, a brief summary of the method will be given. After descriptions of data and actual inversion procedures, the obtained attenuation structures and "size" of earthquakes will be shown.

2. Method

Detailed descriptions of the method and several assumptions used in the method are given in HASHIDA and SHIMAZAKI (1984). Here we will briefly review them.

The seismic intensity data which measure the degree of ground shaking contain information on the "size" of earthquake source and attenuation along the path from event to stations. We assume that the JMA intensity is related to the maximum ground accleration of S-wave. The relation between the medium value of maximum acceleration, a^{obs} (gal) and the corresponding intensity, I is given by KAWASUMI (1943) as follows,

$$a^{\mathrm{obs}}=10^{I/2-0.35} \quad (0<I\leq 5)\ . \tag{1}$$

By taking spatially heterogeneous attenuation of intensity into account, the acceleration a at a station can be formulated as follows:

$$a=S\cdot G\cdot g\cdot \exp\left(-\sum_k D_k\cdot T_k\right)\ , \tag{2}$$

where

S; acceleration at the seismic source,
G; geometrical spreading factor,
g; amplifying effect at the earth's surface,
D_k; attenuation coefficient (sec^{-1}) in the k-th block region,
T_k; travel time (sec) in the k-th block region.

The S is assumed to be radiated at the seismic source isotropically. Summation $\sum_k$ is made over block regions where the seismic ray penetrates.

The attenuation coefficient D is related to the quality factor Q as follows:

$$D=\pi f/Q\ , \tag{3}$$

where f is a representative frequency related to seismic intensity. Generally the representative frequency is considered to be around 1 Hz, varying from event to event and/or station to station. Because of limited information on the frequency from intensity data, we do use attenuation coefficient D instead of Q value in this study. Weak attenuation corresponds to high Q, and *vice versa*.

First we assume a horizontally layered attenuation structure as the initial model, in which the attenuation coefficient of D_{0k} is given. We can then calculate the initial acceleration S_0 at the source from the observed acceleration a^{obs} as follows:

$$S_0=\frac{1}{N_s}\sum_i a_i^{\mathrm{obs}}/(G_i\cdot g_i\cdot \exp(-\sum_k D_{0k}\cdot T_{k,i}))\ , \tag{4}$$

where N_s means number of stations and summation $\sum_i$ is made over stations reporting intensities. Actually the effect of ground amplification g_i is fixed to be 2.0 for all stations by only taking the free-surface effect into account. Now we can get a calculated acceleration at the i-th station, a_i^{cal} from eq. (2) based on the initial structure D_{0k} and the initial acceleration at source S_0.

By taking the difference between the natural logarithms of the observed and calculated accelerations, which is denoted by $O-C$ hereafter, we get the following observational equation,

$$\ln a^{\mathrm{obs}}-\ln a^{\mathrm{cal}}=\delta S-\sum_k \delta D_k\cdot T_k+e\ , \tag{5}$$

where $\delta D_k=D_k-D_{0k}$ and $\delta S=\ln(S/S_0)$. As we assume the same geometrical spreading factor G for the observed and calculated accelerations, which imply that the variation in S-wave velocity is much smaller than the variation in attenuation, the error e includes not only observational error mainly due to conversion of intensity to acceleration by using eq. (1) but also parametric error due to simplified formulation of the problem.

Perturbations δS for each event and δD_k for the k-th block are determined by solving a set of observational equations given by eq. (5) for many pairs of event and station. We can estimate those perturbations by the damped least-squares inversion which simultaneously minimizes the squared sum of e and that of perturbations. The perturbation will be tabulated in section 5 with its resolution and standard error. More detailed description on the inversion is given in HASHIDA and SHIMAZAKI (1984) and AKI and LEE (1976).

3. Data

The data consist of seismic intensities reported by JMA (1951–1983) in the JMA eight-degree scale (0–7). The intensity 0 which has been listed in the Seismological Bulletins of JMA since 1961 means that the shaking is not felt by people but recorded by seismometers. There is no lower limit of shaking for the intensity 0 as far as a seismometer records the shaking. Then the intensity 0 data are not necessarily

Fig. 1. The distribution of stations used in this study.

consistent with KAWASUMI (1943)'s relation given in eq. (1). In order to overcome this problem, we only employ intensity 0 data at stations in a shorter epicentral distance than maximum felt distance and extend the relation of eq. (1) to intensity 0. There are only a few data for intensity 6 and no data for intensity 7 since 1951. We convert the intensity 6 to acceleration 316 gal which is a medium value in a sense of the logarithm between 250 and 400 gal.

The seismic intensities have been observed at JMA stations. Listed in the bulletins of JMA before 1961 are the intensities at the weather stations and climate stations ("kunai-kansokusho" in Japanese), but since 1961 only the intensities at the weather stations. We used the intensities not only at the weather stations but also at many climate stations in order to increase the quantity of intensity data for each event. Accuracy of attenuation coefficients increases as the number of data increases (HASHIDA and SHIMAZAKI, 1984). The distribution of those stations used in this study is shown in Fig. 1.

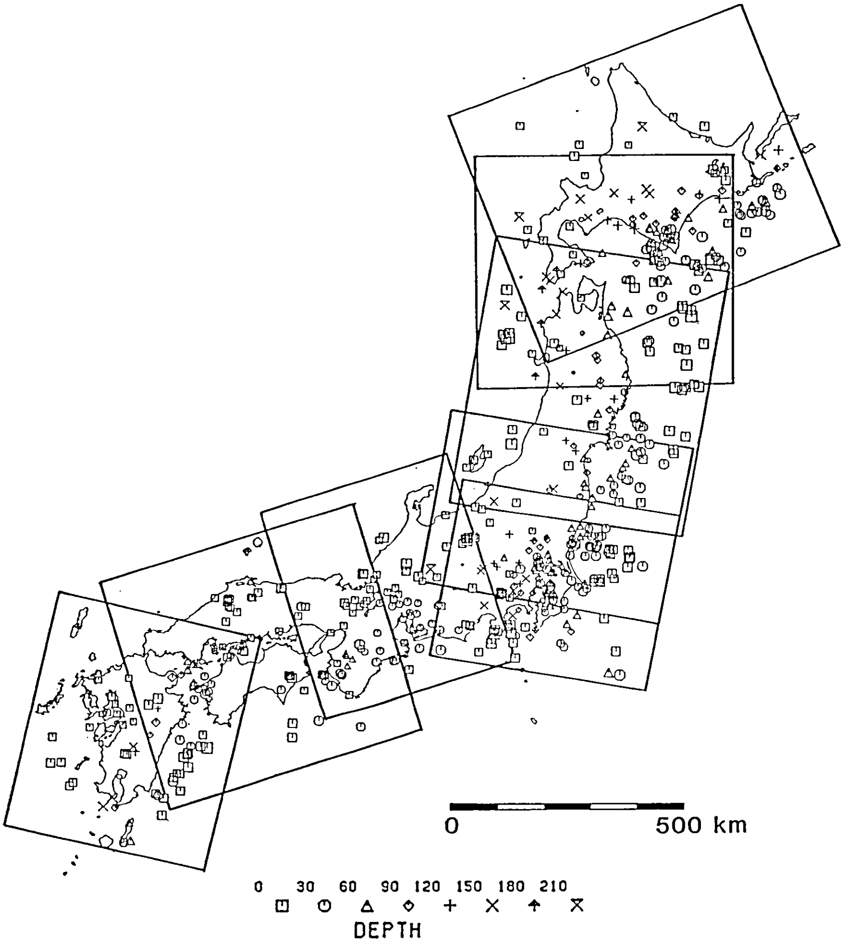


Fig. 2. The distribution of epicenters used in this study and the locations of the eight districts. The Japanese Islands are divided into the eight districts which are mutually overlapping.

The distribution of earthquakes used in this study is shown in Fig. 2. That represents the general feature of seismicity in the period. In and around the Japanese Islands felt earthquakes, including destructive large ones, have been occurring often along the Pacific coast and sometimes inland along the Japan Seacoast, along the Philippine Seacoast and at intermediate depths (*e.g.*, USAMI, 1975; UTSU, 1982). The earthquakes in Fig. 2 include all events greater or equal to M_J 6.0 and many events smaller than M_J 6.0.

We do not use the earthquakes that occurred near the Japan Trench whose reported depths are deeper than 30 km, because it is difficult to accurately judge the depths. We employ the hypocenters determined by JMA except for the following case. If the reported focal depth of shallow earthquakes along the Japan Seacoast is deeper than 30 km, the depth is changed to 20 km because the precise determination of hypocenters based on the microearthquake network (*e.g.*, SATO *et al.*, 1986) suggests that shallow earthquakes along the Japan Seacoast occur at a depth less than 30 km.

4. Inversion

We divide the Japanese Islands into eight districts to obtain the three-dimensional attenuation structure. The reason is that the number of unknown parameters in inversion, *i.e.* the sum of the number of blocks penetrated by rays and the number of earthquakes, has its limit due to the limited storage area of available computers. The eight districts are mutually overlapped as shown in Fig. 2, to construct the three-dimensional structure over all the islands by combining their results.

The eight districts from the northeast to the southwest will be called Hokkaido, S. Hokkaido-N. Tohoku, Tohoku, S. Tohoku-N. Kanto, Kanto, Chubu-Kinki, Chugoku-Shikoku, and Kyushu. The locations of these districts and block configurations for inversion are tabulated in Table 1. The horizontal block size (in the X- and Y-directions) varies from 50 to 90 km depending on the number of data and ray geometry of each district, but the vertical size (in the Z-direction) is fixed at 30 km for all districts so that the obtained structures could be combined for each layer.

Table 1. Locations and block configurations of the eight districts.

District	Locations			Block configurations $(X\times Y\times Z)$[♯]	
	Origin	Rotation* of Y-axis	Distance to S-W end (km)	Size (km^3)	Number
Hokkaido	(142°E, 43°N)	20°	(−240, −233)	80×90×30	8×6×8
S. Hokkaido-N. Tohoku	(142°E, 41.5°N)	0°	(−280, −210)	65×60×30	8×8×9
Tohoku	(141.5°E, 39.5°N)	−10°	(−260, −280)	60×70×30	8×8×9
S. Tohoku-N. Kanto	(140°E, 36°N)	−10°	(−250, − 50)	50×60×30	9×6×8
Kanto	(140°E, 36°N)	−10°	(−200, −200)	50×60×30	9×6×6
Chubu-Kinki	(136.5°E, 35°N)	20°	(−175, −150)	50×50×30	8×9×3
Chugoku-Shikoku	(133.5°E, 34.5°N)	20°	(−270, −275)	60×55×30	9×9×4
Kyushu	(131°E, 32.5°N)	−10°	(−210, −238)	60×70×30	7×7×6

[♯] X and Y are in the horizontal directions and Z is in the vertical direction.

* Rotation of the Y-axis is measured counter-clockwise from the north.

The block configuration used in this study is not a spherical-layer type, but a flat-layer type. Any corrections for the spherical layer are not taken, because the horizontal extent of each district is much smaller than the radius of the earth and the error induced by no correction is much smaller than observational error mainly due to conversion of intensity to acceleration.

The initial attenuation coefficients are $7.85\times10^{-3}\,\text{sec}^{-1}$ for the uppermost layer and $3.14\times10^{-2}\,\text{sec}^{-1}$ for the deeper layers. This initial attenuation model will be used as a reference model. In the results of inversion, we will show the deviations from these reference attenuation coefficients as solutions. The reference coefficients can be converted to Q values, 400 for the uppermost layer and 100 for the deeper layers, if we assume that the representative frequency related to the intensity is 1 Hz. These Q values are in good agreement with those estimated by UMINO and HASEGAWA (1977) in northeastern Honshu and also with those of the standard earth model estimated from longer period waves by ANDERSON and HART (1978). The S-wave velocities which are used to calculate the ray path, geometrical spreading factor and travel time in each block, are assumed to be 3.8 km/sec in the uppermost layer and 4.3 km/sec in the deeper layers for all districts.

After a calculation of initial source accelerations by eq. (4), the intensity data are inverted to estimate the three-dimensional attenuation structure of each district. The same damping factors given by the ratio of the variance in the data $(O-C)$ to expected variance in the unknown parameter are used for all districts, which are the same as values used in the preceding papers (HASHIDA and SHIMAZAKI, 1984; 1985; 1987 a). Those are $(0.34/0.17)^2$ and $(0.34/0.01\,\text{sec}^{-1})^2$ for perturbations of δS in each event and δD in each block, respectively.

The number of unknown parameters as well as the numbers of

Table 2. Numbers of earthquakes, stations and intensity data used in this study. Number of unknown parameters of inversion and variance improvements after inversion are also listed.

District	Earthquakes	Stations	Intensity data	Unknown parameters	Variance improvement
Hokkaido	114	67	1726	268	37.9%
S. Hokkaido-N. Tohoku	122	65	1994	355	46.6%
Tohoku	101	66	1630	317	33.5%
S. Tohoku-N. Kanto	98	66	1943	273	38.2%
Kanto	171	74	4358	346	23.8%
Chubu-Kinki	69	74	1336	155	22.9%
Chugoku-Shikoku	68	77	1352	202	25.7%
Kyushu	65	60	831	185	37.9%
(Total)	808	549	15170	2101	—

Table 3. Results of inversion for three-dimensional attenuation structure. Solution (deviation from the reference attenuation coefficient) and the standard error are given in units of 1.0×10^{-2} sec^{-1}. Resolution means the diagonal element of the resolution matrix.

(a) Hokkaido

Solution

Layer 1

-	-0.8	-0.8	5.4	0.5	-	-	-
-	1.8	-0.5	-0.8	0.4	-0.8	-	-
-	2.1	0.2	4.9	1.1	4.4	-	-
-0.8	2.1	1.1	1.2	0.8	1.3	-0.8	-
-0.8	1.3	1.7	1.0	-0.2	-0.0	5.0	-
-	-0.7	-0.8	-0.8	2.7	1.3	-	-

Layer 2

-	-	-	1.3	0.6	-	-	-
-	-	-	-2.1	-1.2	-	-	-
-	-	8.8	5.9	5.3	-0.1	-	-
1.0	6.4	0.4	0.1	1.9	1.6	3.8	-
2.0	1.9	-1.2	-2.8	-3.1	-3.1	-3.1	-
-	-	-0.2	0.4	0.8	-1.3	1.1	-

Layer 3

-	-	-	1.5	-	-	-	-
-	-	0.3	-2.6	1.3	1.1	-	-
-	-	3.9	9.1	-1.2	3.9	-	-
3.6	5.7	1.8	-0.2	-3.1	-3.1	4.0	1.7
6.0	11.9	-3.1	-2.4	-1.7	-0.5	-1.5	-
-	-	-3.1	-1.4	-1.3	1.1	-	-

Layer 4

-	-	-	-	-	-	-	-
-	-	0.2	1.2	-	-	-	-
-	1.3	-1.4	0.3	2.0	4.1	-	-
3.1	-1.4	-1.4	-3.1	1.9	-1.5	-0.7	4.3
8.7	-2.8	-3.1	-2.7	-3.1	-3.1	2.9	-
-	-	-	-	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	-	-	2.1	-	-	-	-
-	1.1	-2.4	0.6	0.9	2.3	0.6	-
3.9	8.0	-3.1	-3.1	-3.1	-3.1	-3.1	2.0
0.6	-3.1	0.6	0.4	-3.1	3.6	-	-
-	-	-	-	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	-	-	2.1	-	-	-	-
-	-0.7	-2.3	-1.4	-1.3	-	-	-
5.3	-3.1	-3.1	-2.6	-	-	-1.8	-
-3.1	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-
-	-	-	-	2.0	-	-	-
0.7	-2.4	-	-2.0	-0.8	-	-	-
0.8	-2.5	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
-	-	-	-	1.9	-	-	-
-1.9	-	-	-2.1	-0.5	-	-	-
-2.4	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Resolution

Layer 1

-	0.133	0.202	0.500	0.074	-	-	-
-	0.547	0.525	0.575	0.671	0.007	-	-
-	0.677	0.841	0.889	0.834	0.730	-	-
0.465	0.909	0.951	0.945	0.940	0.945	0.757	-
0.356	0.898	0.923	0.966	0.962	0.948	0.902	-
-	0.025	0.501	0.825	0.731	0.321	-	-

Layer 2

-	-	-	0.049	0.006	-	-	-
-	-	-	0.359	0.369	-	-	-
-	-	0.306	0.516	0.325	0.133	-	-
0.015	0.589	0.892	0.928	0.913	0.786	0.402	-
0.006	0.643	0.947	0.967	0.966	0.948	0.765	-
-	-	0.503	0.758	0.748	0.428	0.017	-

Layer 3

-	-	-	0.018	-	-	-	-
-	-	0.036	0.163	0.030	0.020	-	-
-	-	0.154	0.340	0.078	0.055	-	-
0.102	0.316	0.617	0.762	0.708	0.638	0.265	0.007
0.047	0.223	0.755	0.861	0.811	0.789	0.379	-
-	-	0.325	0.363	0.262	0.018	-	-

Layer 4

-	-	-	-	-	-	-	-
-	-	0.008	0.043	-	-	-	-
-	0.045	0.233	0.230	0.019	0.187	-	-
0.067	0.297	0.594	0.716	0.626	0.367	0.402	0.044
0.096	0.226	0.428	0.649	0.625	0.414	0.379	-
-	-	-	-	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	-	-	0.038	-	-	-	-
-	0.086	0.232	0.109	0.090	0.030	0.006	-
0.088	0.232	0.519	0.403	0.234	0.261	0.377	0.078
0.162	0.299	0.045	0.060	0.148	0.101	-	-
-	-	-	-	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	-	-	0.038	-	-	-	-
-	0.089	0.027	0.128	0.141	-	-	-
0.100	0.184	0.169	0.181	-	-	0.057	-
0.054	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Table 3. (Continued)

Layer 7

-	-	-	-	-	-	-	-
-	-	-	-	0.033	-	-	-
0.066	0.079	-	0.148	0.148	-	-	-
0.130	0.179	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 8

-	-	-	-	0.030	-	-	-
0.143	-	-	0.061	0.154	-	-	-
0.202	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Standard Error

Layer 1

-	0.7	0.9	1.1	0.6	-	-	-
-	0.9	1.3	1.4	1.3	0.2	-	-
-	1.2	0.8	0.8	1.0	1.1	-	-
1.0	0.7	0.6	0.6	0.7	0.6	1.2	-
1.2	0.8	0.7	0.5	0.5	0.6	0.8	-
-	0.4	1.0	1.0	0.9	1.2	-	-

Layer 2

-	-	-	0.5	0.2	-	-	-
-	-	-	1.0	1.1	-	-	-
-	-	1.2	1.4	1.2	0.8	-	-
0.3	1.3	0.8	0.7	0.8	1.1	1.3	-
0.2	1.3	0.6	0.5	0.5	0.6	1.0	-
-	-	1.3	1.0	1.0	1.0	0.3	-

Layer 3

-	-	-	0.3	-	-	-	-
-	-	0.5	0.8	0.4	0.3	-	-
-	-	0.8	1.1	0.6	0.6	-	-
0.8	1.1	1.2	1.0	1.2	1.2	1.1	0.2
0.6	1.1	1.1	0.8	1.0	1.0	1.1	-
-	-	1.1	1.0	0.9	0.4	-	-

Layer 4

-	-	-	-	-	-	-	-
-	-	0.2	0.5	-	-	-	-
-	0.5	1.0	1.0	0.4	1.0	-	-
0.6	1.1	1.1	1.0	1.1	1.2	1.1	0.6
0.7	1.1	1.2	1.2	1.2	1.3	1.0	-
-	-	-	-	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	-	-	0.5	-	-	-	-
-	0.6	1.1	0.8	0.7	0.4	0.2	-
0.7	1.0	1.1	1.1	1.0	1.1	1.1	0.5
0.7	1.1	0.4	0.6	0.9	0.4	-	-
-	-	-	-	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	-	-	0.5	-	-	-	-
-	0.6	0.4	0.7	0.7	-	-	-
0.7	0.9	0.8	0.6	-	-	0.4	-
0.3	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-
-	-	-	-	0.4	-	-	-
0.5	0.6	-	0.8	0.7	-	-	-
0.7	0.9	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
-	-	-	-	0.4	-	-	-
0.7	-	-	0.6	0.7	-	-	-
0.7	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

(b) S.Hokkaido-N.Tohoku
Solution

Layer 1

-	-	-0.1	-0.6	-	-	0.7	-0.8
-	2.0	3.5	1.9	2.0	-0.8	0.8	-0.8
-	6.3	1.1	3.0	2.3	1.5	-0.8	0.2
-	1.3	2.8	3.6	0.4	1.6	-0.7	-0.8
1.4	2.7	2.6	1.6	-0.2	0.4	3.3	-0.4
2.2	-0.8	0.7	-0.8	1.0	0.3	-0.8	-
-0.7	1.3	2.4	-0.8	0.7	0.8	1.2	-
-0.8	-0.8	4.8	-0.8	1.3	1.1	-0.8	-

Layer 2

-	-	-	-	-	-	-	-
-	-	3.3	0.3	1.6	-1.0	-3.1	-3.0
-	1.4	11.9	1.2	-2.7	-3.1	-3.1	-1.2
-	-0.2	5.5	-1.9	-3.1	-3.0	-1.8	-2.6
-	-	5.6	-1.6	-3.0	-2.0	-1.8	1.4
-	-	2.4	-3.1	-3.1	-1.6	-3.0	-
-	1.2	0.4	-2.0	-3.1	-2.4	-	-
-	4.7	3.1	-3.1	-3.1	-	-	-

Layer 3

-	-	-	-	-	-	-	-
-	-	5.4	6.1	-2.6	-1.4	-2.2	-3.1
-	1.3	3.0	0.2	0.6	0.1	-1.2	-0.6
-	-0.6	2.8	4.8	-3.1	0.3	0.3	-2.3
-	-	3.6	-2.9	-3.1	-1.6	-1.7	-
-	0.9	2.8	-3.0	-3.1	-3.1	2.8	-
-	1.4	-0.0	-3.0	-2.1	-	-	-
-	2.4	-0.3	-3.1	-	-	-	-

Table 3. (Continued)

Layer 4

-	-	-	-	-	-	-	-
-	-	5.3	6.5	-3.1	4.3	0.3	0.7
-	1.1	3.6	4.8	-3.1	-1.3	-2.8	5.0
-	2.4	-1.8	-3.1	-2.5	-3.1	-2.7	-
-	-1.6	0.4	0.2	-3.1	-0.2	-0.5	-
-	3.9	-2.8	-3.1	-2.9	-	-	-
-	1.4	3.0	-3.1	-	-	-	-
-	0.5	-2.1	-0.0	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	-	4.7	-0.4	1.3	0.4	-1.0	0.8
-	3.4	-2.2	-3.0	-1.6	0.6	-3.1	0.8
-	2.5	-1.8	-3.1	0.2	-	-	-
-	4.8	-3.1	-3.1	-	-	-	-
-	1.6	-3.0	-1.2	-	-	-	-
-	5.3	-3.1	-2.7	-	-	-	-
-	-	0.2	-	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	-	-0.5	-1.9	2.0	-2.5	-	-
-	7.1	-3.1	-3.1	-1.5	0.0	-	-
-	-1.7	3.3	-	-	-	-	-
0.6	-3.1	-3.1	-	-	-	-	-
-	1.2	-2.7	-	-	-	-	-
-1.1	2.2	-2.6	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	1.9	-0.7	-	-	-	-	-
0.5	-2.4	-	-	-	-	-	-
1.7	-0.1	-0.5	-	-	-	-	-
0.1	-0.0	-0.4	-	-	-	-	-
-0.9	-1.8	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
1.4	-2.5	-	-	-	-	-	-
-	-1.4	-	-	-	-	-	-
-0.0	0.4	-	-	-	-	-	-
0.4	-1.6	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 9

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-0.6	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Resolution

Layer 1

-	-	0.001	0.077	-	-	0.254	0.269
-	0.054	0.602	0.892	0.876	0.779	0.869	0.722
-	0.542	0.915	0.897	0.913	0.922	0.839	0.694
-	0.647	0.889	0.932	0.893	0.949	0.888	0.454
0.294	0.745	0.804	0.896	0.855	0.877	0.854	0.185
0.462	0.747	0.890	0.915	0.875	0.889	0.607	-
0.454	0.732	0.853	0.896	0.883	0.858	0.501	-
0.086	0.724	0.839	0.924	0.905	0.563	0.024	-

Layer 2

-	-	-	-	-	-	-	-
-	-	0.055	0.401	0.610	0.483	0.593	0.194
-	0.139	0.398	0.836	0.914	0.908	0.871	0.263
-	0.128	0.520	0.869	0.935	0.931	0.781	0.348
-	-	0.395	0.879	0.944	0.877	0.556	0.094
-	-	0.504	0.871	0.907	0.770	0.202	-
-	0.271	0.753	0.868	0.862	0.590	-	-
-	0.220	0.442	0.481	0.280	-	-	-

Layer 3

-	-	-	-	-	-	-	-
-	-	0.117	0.132	0.375	0.518	0.347	0.110
-	0.048	0.250	0.455	0.757	0.807	0.616	0.177
-	0.149	0.389	0.597	0.789	0.822	0.486	0.088
-	-	0.424	0.672	0.787	0.664	0.474	-
-	0.004	0.510	0.734	0.730	0.332	0.116	-
-	0.197	0.353	0.526	0.061	-	-	-
-	0.072	0.137	0.242	-	-	-	-

Layer 4

-	-	-	-	-	-	-	-
-	-	0.081	0.149	0.288	0.445	0.539	0.269
-	0.035	0.082	0.375	0.639	0.721	0.630	0.078
-	0.179	0.407	0.690	0.704	0.597	0.357	-
-	0.118	0.495	0.627	0.509	0.047	0.016	-
-	0.172	0.480	0.285	0.025	-	-	-
-	0.126	0.270	0.182	-	-	-	-
-	0.002	0.089	0.038	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	-	0.076	0.257	0.349	0.219	0.131	0.095
-	0.068	0.260	0.347	0.448	0.104	0.203	0.098
-	0.155	0.237	0.309	0.187	-	-	-
-	0.259	0.518	0.308	-	-	-	-
-	0.224	0.440	0.018	-	-	-	-
-	0.099	0.442	0.034	-	-	-	-
-	-	0.094	-	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	-	0.027	0.086	0.194	0.083	-	-
-	0.114	0.141	0.069	0.058	0.004	-	-
-	0.126	0.091	-	-	-	-	-
0.009	0.333	0.423	-	-	-	-	-
-	0.310	0.352	-	-	-	-	-
0.037	0.115	0.026	-	-	-	-	-
-	-	-	-	-	-	-	-

Table 3. (Continued)

Layer 7

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	0.136	0.049	-	-	-	-	-
0.003	0.191	-	-	-	-	-	-
0.057	0.183	0.034	-	-	-	-	-
0.025	0.126	0.006	-	-	-	-	-
0.026	0.086	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.080	0.119	-	-	-	-	-	-
-	0.005	-	-	-	-	-	-
0.034	0.034	-	-	-	-	-	-
0.108	0.080	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 9

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.092	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Standard Error

Layer 1

-	-	0.1	0.7	-	-	1.2	1.1
-	0.6	1.3	0.9	0.9	1.2	0.9	1.1
-	1.2	0.7	0.9	0.8	0.8	1.0	1.2
-	1.3	0.9	0.7	0.9	0.6	0.8	1.3
0.9	1.1	1.1	0.9	1.0	0.9	0.9	1.1
1.3	1.1	0.9	0.8	0.9	0.8	1.1	-
0.9	1.1	1.0	0.8	0.9	0.9	1.1	-
0.8	1.1	1.0	0.7	0.8	1.3	0.4	-

Layer 2

-	-	-	-	-	-	-	-
-	-	0.6	1.3	1.3	1.4	1.3	-
-	0.8	1.3	1.0	0.8	0.8	0.9	1.2
-	0.9	1.4	0.9	0.7	0.7	1.1	1.2
0.2	0.8	1.3	0.9	0.6	0.9	1.3	0.6
0.8	1.0	1.4	0.9	0.8	1.1	1.1	-
0.6	1.1	1.2	0.9	0.9	1.3	-	-
-	1.0	1.4	1.3	1.3	-	-	-

Layer 3

-	-	-	-	-	-	-	-
-	-	0.9	0.9	1.2	1.2	1.2	0.9
-	0.6	1.1	1.3	1.1	1.0	1.3	0.8
-	0.9	1.2	1.3	1.1	1.0	1.3	0.7
-	-	1.2	1.3	1.1	1.2	1.2	-
-	0.2	1.3	1.1	1.2	1.3	0.9	-
-	0.9	1.2	1.2	0.7	-	-	-
-	0.6	0.9	1.0	-	-	-	-

Layer 4

-	-	-	-	-	-	-	-
-	-	0.7	0.9	1.2	1.3	1.2	1.0
-	0.5	0.7	1.2	1.1	1.1	1.2	0.7
-	0.9	1.2	1.2	1.2	1.3	1.2	-
-	0.9	1.2	1.3	1.3	0.6	0.3	-
-	0.9	1.2	1.2	0.4	-	-	-
-	0.8	1.1	1.0	-	-	-	-
-	0.1	0.7	0.4	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	-	0.7	1.1	1.1	1.0	0.8	0.5
-	0.6	1.1	1.1	1.2	0.7	1.0	0.7
-	0.9	1.1	1.2	1.0	-	-	-
-	1.1	1.2	1.2	-	-	-	-
-	1.0	1.2	0.4	-	-	-	-
-	0.7	1.1	0.5	-	-	-	-
-	-	0.7	-	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	-	0.2	0.5	0.8	0.6	-	-
-	0.8	0.8	0.7	0.6	0.2	-	-
-	0.8	0.8	-	-	-	-	-
0.2	1.0	1.2	-	-	-	-	-
-	1.2	1.1	-	-	-	-	-
0.5	0.8	0.4	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	0.7	0.6	-	-	-	-	-
0.2	0.9	-	-	-	-	-	-
0.6	0.9	0.4	-	-	-	-	-
0.4	0.8	0.2	-	-	-	-	-
0.4	0.6	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.5	0.7	-	-	-	-	-	-
-	0.2	-	-	-	-	-	-
0.5	0.5	-	-	-	-	-	-
0.6	0.7	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 9

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.4	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Table 3. (Continued)

(c) Tohoku
Solution

Layer 1

-	-0.2	5.7	-0.8	0.7	-	-	-
-0.8	-0.8	1.0	0.6	-0.8	-0.8	-0.7	-
5.9	-0.8	2.8	1.0	-0.7	1.2	-0.8	-0.3
2.0	-0.8	4.7	-0.3	-0.7	2.1	-0.7	-0.8
-0.7	0.5	2.8	1.1	-0.8	1.9	0.9	0.2
0.3	0.1	1.9	3.0	1.7	0.5	-0.8	-0.2
1.2	0.8	1.6	1.0	-0.8	0.3	-0.6	-
-0.8	2.6	-0.7	-0.8	0.2	-	-	-

Layer 2

-	-	5.0	-3.0	-0.6	0.7	1.0	-
-	-	1.6	-3.1	-2.9	1.2	-0.3	-
-	-	3.8	-0.0	-3.1	-3.1	3.4	-
-	-0.2	3.8	-1.9	-2.8	-3.1	1.7	-
-	3.0	-1.8	-3.1	-3.1	-3.1	-0.9	-
-2.4	-2.2	3.9	0.8	-3.1	-3.1	0.1	-
-0.3	-1.0	3.8	-0.3	-3.1	-3.1	1.3	-
2.4	2.1	1.2	-3.0	-2.2	-0.4	-	-

Layer 3

-	-	5.8	-	-	-	-	-
-	-0.9	2.2	-1.2	-1.2	-	-	-
-	0.2	7.4	-1.9	-3.1	-	-	-
-	-2.1	4.4	0.3	0.0	-	-	-
-1.6	0.5	-3.1	-0.2	-3.1	-	-	-
-0.7	1.3	1.1	1.7	-3.1	-1.6	-	-
-0.0	3.9	2.9	3.0	0.6	-0.6	-	-
2.4	2.2	1.5	3.0	-0.7	-	-	-

Layer 4

-	-	1.9	-	-	-	-	-
-	0.2	2.7	-	-	-	-	-
-	-0.4	0.3	-1.2	-	-	-	-
-1.4	-0.0	-1.4	-3.1	-3.0	-	-	-
-1.4	1.8	4.0	-1.2	-2.3	-	-	-
1.3	-0.8	-1.9	-3.1	-0.4	-	-	-
-	-	-2.4	-1.0	-3.1	-	-	-
2.4	4.4	0.9	3.8	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	1.0	-3.1	-	-	-	-	-
-	-1.0	-2.1	-	-	-	-	-
-	-0.6	-3.0	-3.1	-	-	-	-
0.9	-0.4	3.8	-1.7	1.8			
-	-0.1	0.5	-3.1	-	-	-	-
-	-	-0.4	-3.1	-	-	-	-
2.8	-0.2	0.4	0.5	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	-2.5	1.8	-	-	-	-	-
-0.1	0.8	-3.1	-	-	-	-	-
1.6	-3.0	-0.8	-	-	-	-	-
0.5	0.3	-2.5	-1.3	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
5.0	-3.1	-	-2.9	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-
-1.5	-0.6	-	-	-	-	-	-
2.1	-1.8	-	-	-	-	-	-
1.6	-2.4	-	-	-	-	-	-
-	0.4	-0.9	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
1.7	-2.5	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
-0.7	-	-	-	-	-	-	-
1.0	-0.6	-	-	-	-	-	-
-1.5	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 9

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-1.2	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Resolution

Layer 1

-	0.020	0.686	0.405	0.121	-	-	-
0.188	0.553	0.727	0.838	0.718	0.507	0.412	-
0.543	0.752	0.862	0.936	0.934	0.803	0.680	0.145
0.546	0.816	0.891	0.929	0.956	0.910	0.800	0.198
0.465	0.800	0.910	0.946	0.963	0.908	0.748	0.002
0.373	0.708	0.921	0.945	0.955	0.826	0.658	0.056
0.822	0.848	0.830	0.930	0.803	0.492	0.012	-
0.240	0.345	0.210	0.314	0.001	-	-	-

Layer 2

-	-	0.148	0.178	0.263	0.170	0.096	-
-	-	0.335	0.672	0.709	0.629	0.308	-
-	-	0.406	0.809	0.841	0.682	0.080	-
-	0.319	0.537	0.872	0.905	0.681	0.284	-
-	0.301	0.705	0.863	0.917	0.799	0.159	-
0.244	0.521	0.721	0.869	0.888	0.834	0.225	-
0.416	0.598	0.591	0.704	0.803	0.689	0.149	-
0.033	0.222	0.257	0.259	0.119	0.003	-	-

Layer 3

-	-	0.077	-	-	-	-	-
-	0.014	0.219	0.282	0.213	-	-	-
-	0.009	0.278	0.734	0.613	-	-	-
-	0.152	0.271	0.733	0.542	-	-	-
0.165	0.206	0.498	0.721	0.582	-	-	-
0.205	0.298	0.523	0.702	0.635	0.290	-	-
0.018	0.102	0.155	0.497	0.550	0.150	-	-
0.033	0.034	0.139	0.223	0.010	-	-	-

Table 3. (Continued)

Layer 4

-	-	0.010	-	-	-	-	-
-	0.053	0.234	-	-	-	-	-
-	0.196	0.451	0.206	-	-	-	-
0.018	0.288	0.477	0.469	0.203	-	-	-
0.102	0.239	0.411	0.409	0.325	-	-	-
0.078	0.148	0.226	0.481	0.091	-	-	-
-	-	0.216	0.303	0.253	-	-	-
0.328	0.055	0.123	0.040	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	0.199	0.295	-	-	-	-	-
-	0.265	0.483	-	-	-	-	-
-	0.252	0.460	0.046	-	-	-	-
0.114	0.192	0.260	0.198	0.054	-	-	-
-	0.063	0.059	0.104	-	-	-	-
-	-	0.069	0.317	-	-	-	-
0.033	0.101	0.078	0.104	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	0.182	0.061	-	-	-	-	-
0.003	0.314	0.248	-	-	-	-	-
0.030	0.331	0.124	-	-	-	-	-
0.037	0.146	0.273	0.004	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.056	0.146	-	0.039	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-
0.036	0.039	-	-	-	-	-	-
0.060	0.227	-	-	-	-	-	-
0.121	0.149	-	-	-	-	-	-
-	0.053	0.003	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.031	0.022	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
0.009	-	-	-	-	-	-	-
0.131	0.026	-	-	-	-	-	-
0.020	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 9

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.090	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Standard Error

Layer 1

-	0.4	1.1	1.1	0.8	-	-	-
0.7	1.2	1.2	1.0	1.0	1.1	0.8	-
1.2	1.0	0.9	0.6	0.6	0.9	1.0	0.6
1.0	0.9	0.8	0.7	0.5	0.7	0.8	0.5
1.0	1.0	0.8	0.6	0.5	0.7	1.0	0.1
1.0	1.1	0.7	0.6	0.5	0.9	0.8	0.3
0.9	0.9	1.0	0.6	1.0	1.2	0.3	-
1.0	1.2	1.0	1.2	0.1	-	-	-

Layer 2

-	-	0.8	0.9	1.0	0.8	0.6	-
-	-	1.1	1.2	1.1	1.0	1.0	-
-	-	1.3	1.0	0.9	1.1	0.7	-
-	1.0	1.3	0.9	0.8	1.2	0.8	-
-	1.2	1.2	0.9	0.7	1.0	0.9	-
0.9	1.3	1.1	0.9	0.8	0.9	1.0	-
1.1	1.2	1.2	1.1	1.0	0.9	0.7	-
0.4	1.0	1.0	1.1	0.8	0.1	-	-

Layer 3

-	-	0.6	-	-	-	-	-
-	0.3	0.9	1.0	0.9	-	-	-
-	0.2	1.1	1.1	1.2	-	-	-
-	0.9	1.1	1.1	1.2	-	-	-
0.9	0.9	1.2	1.1	1.3	-	-	-
0.9	1.1	1.2	1.1	1.2	1.0	-	-
0.3	0.8	0.9	1.2	1.2	0.5	-	-
0.4	0.4	0.8	1.0	0.2	-	-	-

Layer 4

-	-	0.2	-	-	-	-	-
-	0.5	0.9	-	-	-	-	-
-	1.0	1.1	1.0	-	-	-	-
0.3	1.0	1.1	1.2	1.0	-	-	-
0.7	1.0	1.2	1.2	0.9	-	-	-
0.6	0.9	1.0	1.1	0.7	-	-	-
-	-	1.0	1.1	0.9	-	-	-
0.4	0.5	0.8	0.5	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-
-	0.9	1.0	-	-	-	-	-
-	1.0	1.1	-	-	-	-	-
-	1.0	1.0	0.5	-	-	-	-
0.7	0.9	1.0	0.9	0.4	-	-	-
-	0.5	0.6	0.7	-	-	-	-
-	-	0.6	1.1	-	-	-	-
0.4	0.6	0.7	0.7	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-
-	0.7	0.5	-	-	-	-	-
0.1	1.1	0.9	-	-	-	-	-
0.4	1.1	0.8	-	-	-	-	-
0.4	0.8	0.8	0.1	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.5	0.7	-	0.3	-	-	-	-

Table 3. (Continued)

Layer 7

-	-	-	-	-	-	-	-
0.5	0.3	-	-	-	-	-	-
0.6	0.9	-	-	-	-	-	-
0.7	0.8	-	-	-	-	-	-
-	0.3	0.1					
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.3	0.3	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-
0.2	-	-	-	-	-	-	-
0.5	0.4	-	-	-	-	-	-
0.3	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 9

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.4	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

(d) S.Tohoku-N.Kanto
Solution

Layer 1

-	-	-	-	-	-	-	-	-
-	0.5	7.7	2.8	-0.8	-0.8	-0.8	-0.8	-
0.6	2.3	-0.8	6.4	0.7	-0.8	-0.8	0.3	-0.5
0.8	6.3	2.1	1.3	1.9	0.0	2.7	-0.8	-0.0
-	3.9	6.8	1.8	1.0	-0.8	3.5	-0.7	-0.8
-	3.4	-0.1	2.5	1.5	-0.2	3.8	-0.8	-

Layer 2

-	-	-	-	-	-	0.8	2.1	-
-	-0.7	-3.1	4.5	2.6	-2.0	-3.1	-0.2	-
2.6	-0.1	2.9	4.6	1.8	-3.1	-3.1	0.7	-
-	-2.5	-0.0	2.0	-1.9	-3.0	-3.1	-3.1	0.3
-	3.4	3.2	3.3	-3.1	-3.1	-2.2	-2.0	1.1
-	-0.9	4.1	-1.2	-3.1	2.9	0.3	-1.0	-

Layer 3

-	-	-	-	-	-	-	-	-
-	-	-	-	-0.7	-1.2	-3.1	1.8	-
1.4	2.6	4.9	1.0	-3.1	-1.7	0.4	-	-
4.1	4.2	6.5	-0.4	-3.1	0.1	2.2	-	-
-	2.5	2.9	-2.8	-2.7	-2.3	2.5	-	-
-0.5	2.0	3.2	1.3	-3.1	0.6	-	-	-

Layer 4

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	2.6	3.3	-0.3	0.0	-2.3	0.5	-	-
5.5	4.3	1.5	-3.1	-2.0	-3.1	-	-	-
0.0	3.0	-2.5	-2.1	-2.7	-0.5	-	-	-
0.0	-0.9	0.0	-1.0	-3.0	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	1.5	5.6	-3.1	-0.1	-1.2	-	-	-
-	1.5	1.6	-3.1	1.3	-0.4	-	-	-
1.3	0.6	-2.7	-0.1	0.9	-	-	-	-
3.7	-2.2	-0.5	-3.0	-0.4	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	2.1	-1.5	-0.9	-0.3	-	-	-	-
-	0.2	-3.1	0.2	-	-	-	-	-
5.8	-3.1	-1.4	-	-	-	-	-	-
1.6	-1.5	-1.8	-	-	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	1.5	-2.5	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
0.7	-0.5	-	-	-	-	-	-	-
3.6	-2.5	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-0.5	-0.8	-	-	-	-	-	-	-

Resolution

Layer 1

-	-	-	-	-	-	-	-	-
-	0.458	0.488	0.419	0.527	0.696	0.242	0.176	-
0.014	0.780	0.814	0.738	0.873	0.901	0.753	0.520	0.140
0.005	0.804	0.817	0.806	0.915	0.934	0.914	0.680	0.019
-	0.839	0.924	0.942	0.955	0.951	0.839	0.675	0.175
-	0.651	0.704	0.883	0.903	0.844	0.774	0.155	-

Layer 2

-	-	-	-	-	-	0.012	0.112	-
-	0.070	0.349	0.378	0.271	0.318	0.416	0.387	-
0.014	0.435	0.615	0.665	0.695	0.746	0.749	0.337	-
-	0.362	0.627	0.773	0.871	0.928	0.870	0.378	0.011
-	0.273	0.649	0.858	0.932	0.937	0.833	0.284	0.238
-	0.114	0.331	0.640	0.729	0.600	0.140	0.017	-

Layer 3

-	-	-	-	-	-	-	-	-
-	-	-	-	0.111	0.367	0.194	0.011	-
0.004	0.044	0.073	0.121	0.370	0.626	0.460	-	-
0.035	0.142	0.238	0.369	0.645	0.728	0.435	-	-
-	0.159	0.358	0.652	0.736	0.660	0.173	-	-
0.006	0.084	0.232	0.394	0.243	0.024	-	-	-

Layer 4

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.044	0.068	0.193	0.097	0.267	0.004	-	-
0.062	0.143	0.243	0.442	0.300	0.157	-	-	-
0.016	0.040	0.309	0.468	0.457	0.057	-	-	-
0.039	0.120	0.307	0.354	0.105	-	-	-	-

Table 3. (Continued)

Layer 5

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.012	0.100	0.147	0.170	0.018	-	-	-
-	0.092	0.261	0.285	0.024	0.010	-	-	-
0.064	0.045	0.229	0.086	0.026	-	-	-	-
0.098	0.175	0.308	0.163	0.002	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.040	0.164	0.004	0.027	-	-	-	-
-	0.053	0.231	0.010	-	-	-	-	-
0.066	0.128	0.042	-	-	-	-	-	-
0.122	0.255	0.131	-	-	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.046	0.109	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
0.002	0.003	-	-	-	-	-	-	-
0.157	0.253	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
0.189	0.004	-	-	-	-	-	-	-

Standard Error

Layer 1

-	-	-	-	-	-	-	-	-
-	1.2	1.2	1.1	1.2	1.1	1.0	0.5	-
0.3	1.0	1.0	1.1	0.8	0.7	1.0	1.0	0.5
0.2	1.0	1.0	1.0	0.7	0.6	0.7	1.1	0.3
-	0.9	0.7	0.6	0.5	0.5	0.9	0.9	0.5
-	1.2	1.1	0.8	0.7	0.9	1.0	0.9	-

Layer 2

-	-	-	-	-	-	0.3	0.6	-
-	0.5	1.0	1.1	1.0	1.1	1.1	0.9	-
0.3	1.1	1.2	1.2	1.1	1.1	1.0	1.1	-
-	1.2	1.2	1.0	0.8	0.7	0.8	1.2	0.3
-	1.0	1.1	0.9	0.6	0.6	0.8	0.9	0.6
-	0.8	1.1	1.2	1.0	1.2	0.9	0.3	-

Layer 3

-	-	-	-	-	-	-	-	-
-	-	-	-	0.8	0.7	0.7	0.2	-
0.2	0.5	0.6	0.8	1.2	1.2	1.0	-	-
0.4	0.8	1.0	1.1	1.1	1.1	1.1	-	-
-	0.8	1.1	1.1	1.0	1.1	1.0	-	-
0.2	0.6	0.9	1.1	0.9	0.4	-	-	-

Layer 4

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.5	0.6	0.9	0.7	0.8	0.2	-	-
0.6	0.7	1.0	1.1	1.1	0.9	-	-	-
0.3	0.5	1.1	1.1	1.0	0.6	-	-	-
0.5	0.7	1.0	1.0	0.7	-	-	-	-

Layer 5

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.3	0.7	0.8	0.6	0.3	-	-	-
-	0.6	0.9	1.0	0.4	0.2	-	-	-
0.6	0.5	0.9	0.6	0.2	-	-	-	-
0.6	0.8	1.0	0.7	0.1	-	-	-	-

Layer 6

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.4	0.7	0.1	0.2	-	-	-	-
-	0.5	0.7	0.2	-	-	-	-	-
0.6	0.8	0.4	-	-	-	-	-	-
0.7	0.9	0.7	-	-	-	-	-	-

Layer 7

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	0.4	0.5	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
0.1	0.1	-	-	-	-	-	-	-
0.6	0.7	-	-	-	-	-	-	-

Layer 8

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
0.4	0.1	-	-	-	-	-	-	-

(e) Kanto
Solution

Layer 1

-0.3	2.7	-0.8	3.1	-0.8	2.3	-	-
4.5	4.6	1.5	-0.7	-0.7	1.3	-0.8	-0.8
4.6	5.1	1.5	1.2	0.1	3.5	-0.8	-0.7
2.9	-0.8	1.4	0.4	-0.2	4.5	-0.8	-
3.8	3.3	3.1	-0.8	4.3	4.4	-0.8	-0.7
5.6	6.1	8.0	1.4	-0.6	2.4	1.4	-0.2

Layer 2

1.1	-	-	1.9	-3.1	1.9	-0.2	-
2.3	1.5	2.5	-1.9	-3.1	-3.0	-0.2	1.5
4.7	2.9	1.2	-3.1	-1.0	-0.6	-1.1	2.0
0.5	-0.0	-2.3	-2.2	-1.3	0.1	-3.1	-
-1.1	-0.5	0.3	-2.3	-1.1	0.5	1.4	-0.3
-3.1	-3.0	0.5	0.2	4.9	-3.0	2.9	0.2

Layer 3

3.4	-	0.9	-3.1	-0.4	1.6	-	-
3.6	9.0	0.4	-2.3	-2.1	-1.2	-	-
2.3	-0.0	-0.4	-1.3	1.3	3.1	-	-
2.8	4.5	1.4	-1.7	-2.3	-0.4	-	-
0.7	3.3	4.7	0.4	0.3	3.3	-2.2	-
0.3	1.0	2.6	0.3	-0.8	-	-2.2	-3.1

Layer 4

1.8	1.7	-0.6	-2.5	-	-	-	-
2.4	6.3	0.1	1.7	-0.9	-	-	-
1.3	0.5	-3.1	-3.0	-3.1	-	-	-
0.7	-2.8	-1.8	-3.1	-1.0	-	-	-
-	3.5	1.4	0.6	-1.2	-2.9	-	-
-	-	-	-0.5	-	-	-	-

Table 3. (Continued)

Layer 5

-	2.9	-3.1	-	-	-	-	-
-	-0.2	0.0	0.4	-	-	-	-
-	-1.0	-1.4	-0.8	-	-	-	-
-	1.8	-3.1	-3.1	-	-	-	-
-	5.7	4.1	-3.1	-0.1	-	-	-
-	-	-	-	-	-	-	-

Layer 6

-	-1.5	-	-	-	-	-	-
-	-2.2	-	-	-	-	-	-
-	-0.0	-	-	-	-	-	-
-	-0.9	-1.3	0.5	-	-	-	-
-	3.1	-3.1	-0.5	-	-	-	-
-	-	-	-	-	-	-	-

Resolution

Layer 1

0.048	0.378	0.308	0.804	0.853	0.809	-	-
0.843	0.819	0.858	0.955	0.944	0.899	0.710	0.167
0.899	0.954	0.969	0.972	0.971	0.939	0.801	0.101
0.802	0.954	0.971	0.973	0.944	0.899	0.580	-
0.809	0.934	0.970	0.961	0.572	0.572	0.477	0.247
0.758	0.889	0.882	0.704	0.181	0.141	0.155	0.088

Layer 2

0.004	-	-	0.123	0.353	0.355	0.018	-
0.164	0.557	0.731	0.882	0.942	0.878	0.337	0.179
0.280	0.757	0.911	0.958	0.970	0.931	0.321	0.290
0.432	0.748	0.916	0.967	0.956	0.873	0.291	-
0.466	0.747	0.875	0.896	0.846	0.731	0.586	0.027
0.276	0.522	0.407	0.435	0.504	0.480	0.480	0.325

Layer 3

0.038	-	0.023	0.062	0.003	0.012	-	-
0.095	0.231	0.410	0.671	0.756	0.358	-	-
0.118	0.536	0.734	0.840	0.793	0.289	-	-
0.108	0.553	0.731	0.837	0.812	0.584	-	-
0.027	0.341	0.542	0.675	0.648	0.364	0.017	-
0.017	0.048	0.096	0.124	0.008	-	0.267	0.154

Layer 4

0.010	0.009	0.059	0.022	-	-	-	-
0.051	0.180	0.376	0.400	0.130	-	-	-
0.058	0.438	0.677	0.659	0.070	-	-	-
0.026	0.399	0.651	0.662	0.122	-	-	-
-	0.140	0.360	0.498	0.389	0.108	-	-
-	-	-	0.087	-	-	-	-

Layer 5

-	0.063	0.084	-	-	-	-	-
-	0.261	0.224	0.031	-	-	-	-
-	0.263	0.287	0.134	-	-	-	-
-	0.321	0.477	0.433	-	-	-	-
-	0.144	0.337	0.212	0.028	-	-	-
-	-	-	-	-	-	-	-

Layer 6

-	0.155	-	-	-	-	-	-
-	0.138	-	-	-	-	-	-
-	0.044	-	-	-	-	-	-
-	0.141	0.031	0.046	-	-	-	-
-	0.138	0.089	0.029	-	-	-	-
-	-	-	-	-	-	-	-

Standard Error

Layer 1

0.5	1.2	0.9	1.0	0.9	0.9	-	-
0.9	0.9	0.8	0.5	0.6	0.7	0.8	0.5
0.7	0.5	0.4	0.4	0.4	0.5	0.8	0.5
1.0	0.5	0.4	0.4	0.6	0.7	1.0	-
1.0	0.6	0.4	0.5	0.6	1.0	0.8	0.9
1.1	0.8	0.8	1.0	0.8	0.7	0.7	0.5

Layer 2

0.1	-	-	0.8	1.1	1.1	0.2	-
0.9	1.1	1.0	0.8	0.6	0.7	0.9	0.7
1.0	1.0	0.7	0.5	0.4	0.6	0.9	0.7
1.1	1.1	0.7	0.4	0.5	0.8	1.1	-
1.1	1.0	0.8	0.7	0.9	1.0	0.9	0.7
0.8	1.1	1.1	1.1	1.0	1.0	1.0	0.5

Layer 3

0.4	-	0.3	0.5	0.1	0.3	-	-
0.7	1.0	1.1	1.1	0.9	0.9	-	-
0.8	1.1	1.0	0.8	0.9	1.0	-	-
0.7	1.1	1.0	0.9	0.8	1.1	-	-
0.4	1.1	1.1	1.0	1.1	1.0	0.3	-
0.3	0.5	0.7	0.8	0.2	-	0.9	0.5

Layer 4

0.2	0.2	0.5	0.3	-	-	-	-
0.5	0.8	1.1	1.0	0.7	-	-	-
0.5	1.0	1.0	1.0	0.6	-	-	-
0.4	1.0	0.9	0.9	0.8	-	-	-
-	0.7	1.0	1.0	1.1	0.5	-	-
-	-	-	0.6	-	-	-	-

Layer 5

-	0.5	0.6	-	-	-	-	-
-	0.9	0.9	0.2	-	-	-	-
-	0.9	1.0	0.8	-	-	-	-
-	0.9	1.0	1.0	-	-	-	-
-	0.7	1.0	0.9	0.3	-	-	-
-	-	-	-	-	-	-	-

Layer 6

-	0.5	-	-	-	-	-	-
-	0.7	-	-	-	-	-	-
-	0.5	-	-	-	-	-	-
-	0.5	0.3	0.3	-	-	-	-
-	0.5	0.6	0.3	-	-	-	-
-	-	-	-	-	-	-	-

Table 3. (Continued)

(f) Chubu-Kinki

Solution

Layer 1

-	-	-	-	-	-0.8	-0.8	-
-	-	-	2.6	0.4	0.1	-0.8	-
-	-0.8	-0.8	0.1	3.3	0.5	2.8	-
-0.8	-0.7	0.2	-0.2	-0.2	2.3	1.8	-0.7
7.4	2.2	-0.8	0.2	-0.8	-0.8	-0.8	-
0.5	3.5	-0.2	-0.5	-0.8	-0.8	-0.0	-
-0.8	0.5	1.8	2.1	5.2	9.7	1.0	-
5.6	1.0	-0.1	-0.7	4.7	2.4	-	-

Layer 2

-	-	-	-	-	-	-	-
-	-	-	-	-1.9	-2.1	-	-
-	-	-	-0.2	-3.1	-3.1	-	-
-1.9	-2.1	-0.3	-3.1	-0.6	3.7	-	-
-3.1	-2.3	-3.1	-3.1	-3.1	-3.1	-1.3	-
1.9	-1.4	-0.9	-3.1	-3.1	-3.1	-0.4	-
-3.1	1.3	-3.1	-3.1	-3.1	-0.5	-	-
2.7	2.6	9.3	-	-	-	-	-

Layer 3

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-1.1	1.1	-0.3	-	-	-	-	-
1.3	-2.2	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Resolution

Layer 1

-	-	-	-	-	0.439	0.094	-
-	-	-	0.131	0.417	0.476	0.242	-
-	0.518	0.496	0.846	0.822	0.759	0.262	-
0.252	0.811	0.907	0.917	0.865	0.846	0.724	0.002
0.755	0.902	0.928	0.931	0.893	0.833	0.390	-
0.837	0.886	0.906	0.915	0.790	0.733	0.452	-
0.628	0.767	0.860	0.696	0.412	0.658	0.468	-
0.374	0.735	0.124	0.096	0.137	0.032	-	-

Layer 2

-	-	-	-	-	-	-	-
-	-	-	-	0.026	0.057	-	-
-	-	-	0.003	0.118	0.143	-	-
0.003	0.061	0.336	0.424	0.506	0.369	-	-
0.256	0.547	0.752	0.780	0.758	0.554	0.047	-
0.577	0.818	0.865	0.832	0.793	0.572	0.008	-
0.653	0.777	0.697	0.677	0.459	0.158	-	-
0.097	0.037	0.125	-	-	-	-	-

Layer 3

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.025	0.383	0.028	-	-	-	-	-
0.008	0.207	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Standard Error

Layer 1

-	-	-	-	-	1.1	0.7	-
-	-	-	0.7	1.1	1.2	0.8	-
-	1.2	1.1	0.9	0.9	1.0	1.0	-
1.0	0.9	0.7	0.7	0.8	0.9	1.1	0.1
1.0	0.7	0.6	0.6	0.7	0.9	1.2	-
0.9	0.8	0.7	0.7	1.0	1.1	1.2	-
1.1	1.0	0.8	1.1	1.2	1.1	1.1	-
1.1	1.1	0.8	0.4	0.8	0.4	-	-

Layer 2

-	-	-	-	-	-	-	-
-	-	-	-	0.4	0.5	-	-
-	-	-	0.1	0.7	0.8	-	-
0.1	0.6	1.2	1.2	1.2	1.1	-	-
1.0	1.2	1.0	1.0	1.0	1.2	0.5	-
1.1	0.9	0.8	0.9	0.9	1.1	0.2	-
0.9	1.0	1.1	1.1	1.1	0.8	-	-
0.2	0.1	0.8	-	-	-	-	-

Layer 3

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.1	0.9	0.4	-	-	-	-	-
0.7	0.8	-	-	-	-	-	-
-	-	-	-	-	-	-	-

(g) Chugoku-Shikoku

Solution

Layer 1

-	-	-	-	-	1.2	-	-
-	-	-	-	2.7	-0.7	-	-
-	-0.7	1.6	-0.8	-0.8	-0.8	-0.8	-0.8
-0.8	-0.4	-0.8	-0.8	-0.1	-0.0	-0.8	1.3
11.3	0.4	-0.8	-0.4	-0.7	0.5	3.7	0.8
-0.8	-0.7	0.1	0.3	0.0	-0.8	0.2	3.2
1.3	-0.8	1.9	-0.7	4.0	-0.8	0.1	4.5
-0.8	2.3	7.7	2.4	-0.2	4.9	0.7	3.7
-	-	-	-	-0.7	-	-	-

Table 3. (Continued)

Layer 2

-	-	-	-	-	-	-	-
-	-	-	-	0.2	-1.3	-	-
-	-	-0.2	0.0	-3.1	-3.1	-1.7	-
2.1	5.1	-2.7	-3.1	-3.1	-1.4	1.9	-1.9
2.7	-3.1	-1.7	-3.1	-0.2	-3.1	-3.0	-3.1
-0.4	0.7	-2.7	-1.0	-0.3	-0.6	-1.2	-1.8
-1.7	1.7	1.1	0.6	-1.4	-1.7	0.7	-2.1
0.2	0.0	-	2.5	-2.9	-3.1	4.8	1.9
-	-	-	-	-	0.8	-3.1	2.5

Layer 3

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-1.9	-	-	-	-
-	3.9	-0.6	-3.1	-0.4	-	-	-
2.8	1.9	-1.9	-0.7	1.3	-	-	-0.0
-1.6	2.0	-2.0	3.7	1.1	-	0.3	0.6
1.3	-1.2	3.2	0.2	0.3	-	-	-1.9
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 4

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-0.4	-1.0	-	-	-	-	-
-	-0.8	2.0	-	-	-	-	-
3.9	-3.1	-1.9	-	-	-	-	-
-0.8	1.7	0.2	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Resolution

Layer 1

-	-	-	-	-	0.186	-	-
-	-	-	-	0.622	0.536	-	-
-	0.029	0.688	0.792	0.922	0.856	0.746	0.069
0.534	0.622	0.814	0.907	0.935	0.905	0.841	0.764
0.403	0.496	0.810	0.914	0.932	0.923	0.903	0.709
0.332	0.764	0.870	0.886	0.924	0.915	0.894	0.524
0.542	0.626	0.824	0.765	0.861	0.784	0.714	0.339
0.249	0.640	0.578	0.562	0.525	0.476	0.539	0.289
-	-	-	-	0.030	-	-	-

Layer 2

-	-	-	-	-	-	-	-
-	-	-	-	0.236	0.038	-	-
-	-	0.009	0.373	0.231	0.215	0.134	-
0.032	0.246	0.584	0.739	0.684	0.718	0.511	0.025
0.040	0.559	0.784	0.786	0.724	0.777	0.780	0.530
0.170	0.565	0.811	0.767	0.785	0.817	0.824	0.543
0.168	0.368	0.415	0.587	0.657	0.749	0.668	0.305
0.007	0.110	-	0.066	0.356	0.446	0.418	0.189
-	-	-	-	-	0.015	0.187	0.036

Layer 3

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	0.057	-	-	-	-
-	0.065	0.397	0.232	0.071	-	-	-
0.052	0.442	0.712	0.431	0.131	-	-	0.010
0.086	0.367	0.513	0.393	0.050	-	0.138	0.133
0.049	0.163	0.122	0.112	0.031	-	-	0.013
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 4

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	0.003	0.014	-	-	-	-	-
-	0.338	0.226	-	-	-	-	-
0.237	0.387	0.112	-	-	-	-	-
0.225	0.244	0.007	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Standard Error

Layer 1

-	-	-	-	-	0.6	-	-
-	-	-	-	1.1	1.1	-	-
-	0.4	1.1	0.9	0.6	0.8	1.0	0.6
1.1	1.1	0.9	0.7	0.6	0.7	0.9	1.0
1.1	1.2	0.9	0.7	0.6	0.6	0.7	1.1
1.0	1.0	0.8	0.8	0.6	0.6	0.7	1.2
1.1	1.1	0.9	1.0	0.8	1.0	1.1	1.1
0.8	0.9	1.0	1.1	1.0	1.2	1.1	1.0
-	-	-	-	0.3	-	-	-

Layer 2

-	-	-	-	-	-	-	-
-	-	-	-	0.9	0.5	-	-
-	-	0.2	1.0	1.0	1.0	0.8	-
0.4	1.0	1.2	1.0	1.1	1.0	1.1	0.4
0.4	1.1	0.9	0.9	1.0	1.0	1.0	1.1
0.9	1.1	0.8	0.9	0.9	0.9	0.9	0.9
0.8	1.0	1.1	1.2	1.1	1.0	1.0	1.0
0.1	0.7	-	0.5	1.1	0.9	1.0	0.4
-	-	-	-	-	0.3	0.6	0.4

Layer 3

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	0.5	-	-	-	-
-	0.6	1.0	1.0	0.6	-	-	-
0.5	1.0	0.9	1.0	0.7	-	-	0.3
0.6	1.1	1.1	1.1	0.5	-	0.8	0.5
0.5	0.8	0.7	0.7	0.4	-	-	0.3
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Table 3. (Continued)

Layer 4

-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	0.1	0.3	-	-	-	-	-
-	0.7	0.9	-	-	-	-	-
0.9	1.0	0.7	-	-	-	-	-
0.6	0.9	0.4	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Layer 6

-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-0.1	-	-	-
-	-	-	-0.5	-	-	-
-	-	-0.6	-0.9	-	-	-
-	-	1.6	-1.7	-	-	-

(h) Kyushu

Solution

Layer 1

-	-	-	-0.8	0.2	-0.8	-
-0.2	5.1	4.6	4.9	-0.8	1.4	2.8
-0.8	-0.7	-0.8	4.9	-0.8	1.9	1.0
5.5	5.5	3.8	1.7	1.6	2.3	2.3
4.1	2.0	4.7	3.2	-0.8	2.4	-
0.1	-0.8	-0.8	1.9	2.1	-0.7	-
-	-	-	4.8	7.7	-	-

Layer 2

-	-	-	-	-3.1	-0.6	-
-	4.2	3.3	-3.1	-1.1	-3.1	-
-	-0.1	3.9	1.8	-3.0	-3.1	-
1.0	3.5	4.3	2.3	-3.1	0.0	-
1.6	-0.2	3.8	2.0	-3.0	-0.7	-
-	0.0	0.8	-3.1	0.8	-	-
-	-	-	-3.1	-3.1	-	-

Layer 3

-	-	-	-	-	-	-
-	-	3.8	4.2	-1.6	0.2	-
-	-	1.4	0.1	-2.5	-	-
-	-	6.0	-3.1	-0.9	-2.2	-
-	3.0	3.4	0.4	-1.7	-0.9	-
-	-	0.2	0.6	3.0	-	-
-	-	-	-0.2	4.9	-	-

Layer 4

-	-	-	-	-	-	-
-	-	-	5.5	-3.1	-	-
-	-	-	2.7	-1.3	-	-
-	-	-0.3	3.1	-2.0	-	-
-	-1.0	-2.1	-1.2	1.6	-	-
-	2.8	3.8	-3.1	-2.4	-	-
-	-	-	-0.5	-	-	-

Layer 5

-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	0.0	-0.7	-	-
-	-	-	-2.6	-0.7	-	-
-	-	-0.5	2.2	-	-	-
-	-	-0.3	-2.8	-	-	-
-	-	-	-0.2	-	-	-

Resolution

Layer 1

-	-	-	0.101	0.265	0.407	-
0.429	0.300	0.604	0.719	0.559	0.812	0.076
0.187	0.523	0.927	0.870	0.887	0.843	0.468
0.705	0.771	0.925	0.934	0.912	0.770	0.104
0.420	0.686	0.717	0.867	0.907	0.605	-
0.045	0.495	0.671	0.821	0.795	0.109	-
-	-	-	0.748	0.348	-	-

Layer 2

-	-	-	-	0.071	0.008	-
-	0.196	0.214	0.550	0.621	0.559	-
-	0.006	0.413	0.771	0.804	0.624	-
0.026	0.226	0.570	0.696	0.844	0.576	-
0.109	0.256	0.503	0.711	0.779	0.225	-
-	0.009	0.180	0.522	0.610	-	-
-	-	-	0.491	0.349	-	-

Layer 3

-	-	-	-	-	-	-
-	-	0.110	0.193	0.501	0.012	-
-	-	0.169	0.409	0.493	-	-
-	-	0.290	0.395	0.457	0.063	-
-	0.169	0.323	0.460	0.410	0.023	-
-	-	0.109	0.430	0.121	-	-
-	-	-	0.304	0.260	-	-

Layer 4

-	-	-	-	-	-	-
-	-	-	0.145	0.115	-	-
-	-	-	0.218	0.234	-	-
-	-	0.063	0.403	0.237	-	-
-	0.013	0.287	0.386	0.214	-	-
-	0.037	0.127	0.408	0.049	-	-
-	-	-	0.127	-	-	-

Layer 5

-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	0.020	0.001	-	-
-	-	-	0.166	0.016	-	-
-	-	0.006	0.172	-	-	-
-	-	0.314	0.419	-	-	-
-	-	-	0.046	-	-	-

Table 3. (Continued)

Layer 6

-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	0.001	-	-	-
-	-	-	0.021	-	-	-
-	-	0.009	0.042	-	-	-
-	-	0.013	0.017	-	-	-

Layer 6

-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	0.1	-	-	-
-	-	-	0.2	-	-	-
-	-	0.2	0.4	-	-	-
-	-	0.3	0.3	-	-	-

Standard Error

Layer 1

-	-	-	0.9	1.3	1.4	-
1.3	1.3	1.5	1.3	1.5	1.1	0.8
1.1	1.4	0.8	1.0	1.0	1.1	1.5
1.3	1.2	0.8	0.8	0.8	1.1	0.9
1.3	1.3	1.4	1.0	0.8	1.3	-
0.4	1.2	1.3	1.2	1.1	0.9	-
-	-	-	1.3	1.5	-	-

Layer 2

-	-	-	-	0.8	0.3	-
-	1.1	1.2	1.4	1.4	1.4	-
-	0.2	1.5	1.3	1.1	1.4	-
0.4	1.2	1.4	1.4	1.1	1.3	-
0.8	1.2	1.5	1.3	1.2	1.1	-
-	0.3	1.1	1.4	1.3	-	-
-	-	-	1.4	1.2	-	-

Layer 3

-	-	-	-	-	-	-
-	-	0.9	1.1	1.1	0.3	-
-	-	1.1	1.4	1.4	-	-
-	-	1.2	1.3	1.4	0.2	-
-	1.0	1.2	1.4	1.4	0.1	-
-	-	0.9	1.3	0.9	-	-
-	-	-	1.3	0.9	-	-

Layer 4

-	-	-	-	-	-	-
-	-	-	0.9	0.8	-	-
-	-	-	1.1	1.2	-	-
-	-	0.7	1.3	1.2	-	-
-	0.3	1.3	1.3	1.2	-	-
-	0.5	0.8	1.1	0.6	-	-
-	-	-	0.9	-	-	-

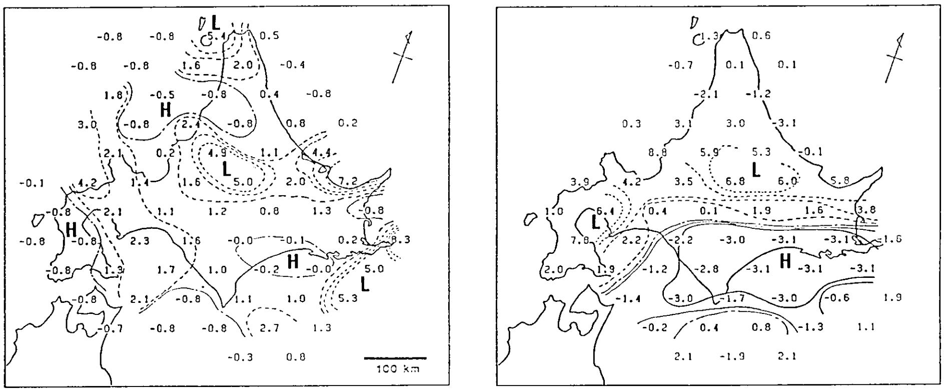
Layer 5

-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	0.3	0.1	-	-
-	-	-	1.0	0.4	-	-
-	-	0.2	0.3	-	-	-
-	-	1.1	1.0	-	-	-
-	-	-	0.6	-	-	-

events, stations, and intensity data are listed for each district in Table 2. The total number of intensity data and unknown parameters amount to 15,000 and 2,100, respectively. Also tabulated is the variance improvement. The value is defined by a ratio of reduction of square sum of $O-C$ by inversion to the square sum of $O-C$ before inversion.

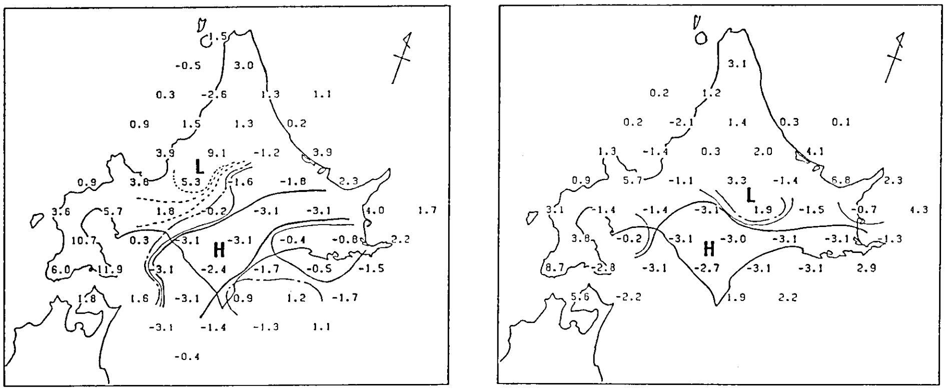
5. Result

Results of inversion are shown in Table 3 and Fig. 3 for the attenuation structure. Tables 3 (a) to (h) correspond to the eight districts from the northeast to the southwest. The tables list for each district obtained deviations from the reference attenuation coefficients, diagonal elements of resolution matrix, and standard error. The deviations and standard errors are given in units of $10^{-2}\,\mathrm{sec}^{-1}$. The negative (positive) in the deviations indicates that the attenuation is weaker (stronger)



LAYER 1 (0-30 km)

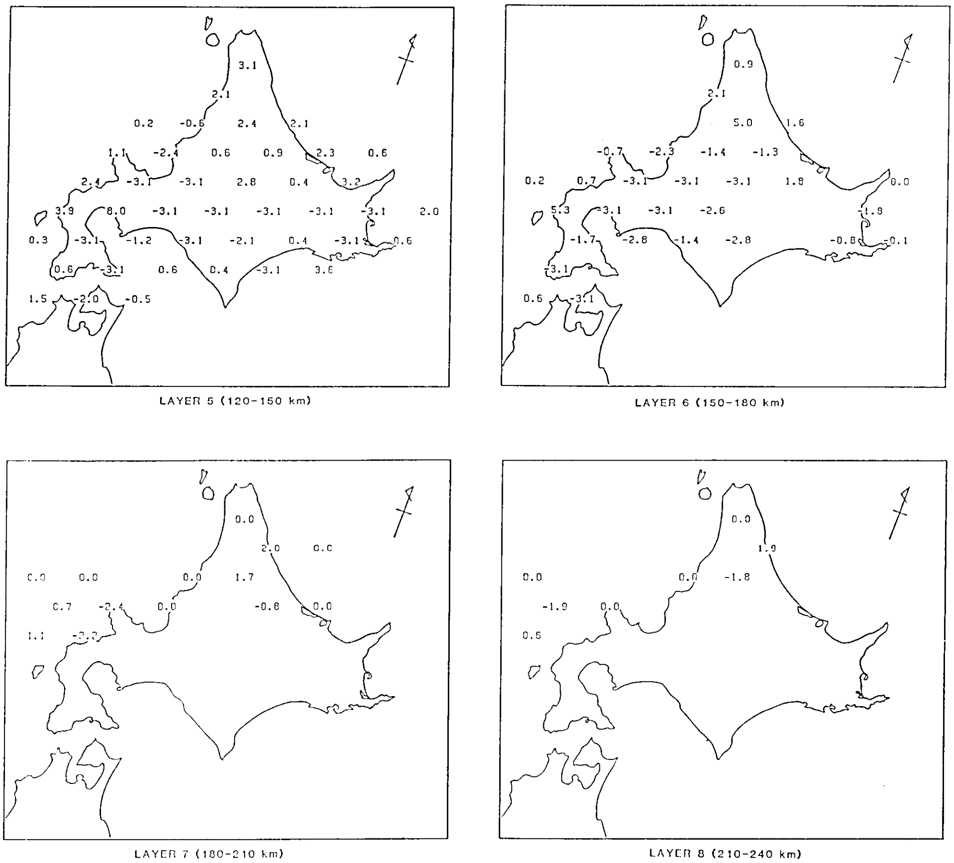
LAYER 2 (30-60 km)



LAYER 3 (60-90 km)

LAYER 4 (90-120 km)

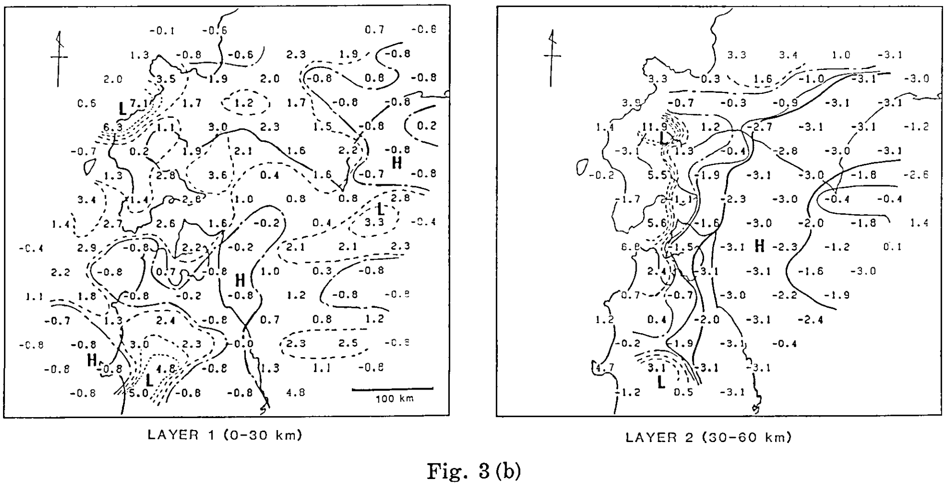
Fig. 3 (a)



LAYER 5 (120-150 km) LAYER 6 (150-180 km)

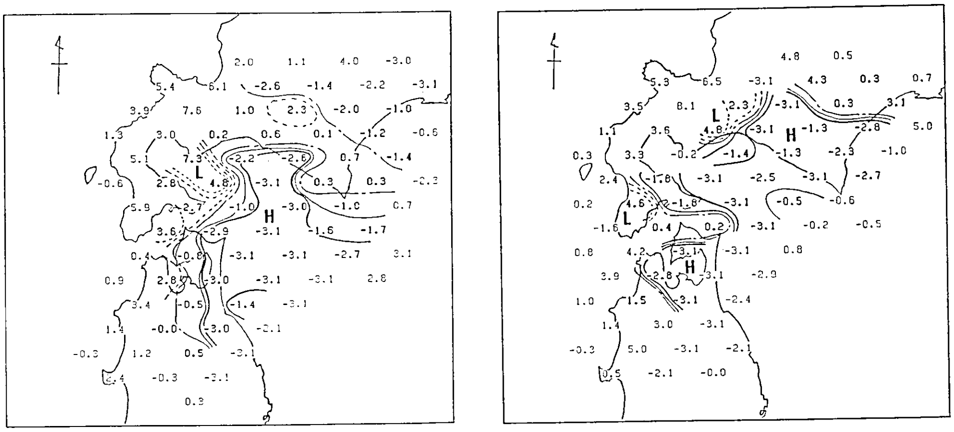
LAYER 7 (180-210 km) LAYER 8 (210-240 km)

Fig. 3(a). (Continued)



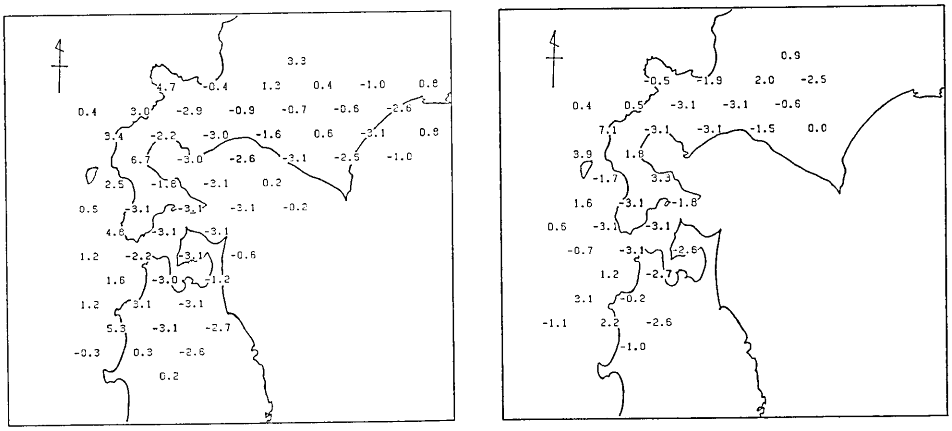
LAYER 1 (0-30 km) LAYER 2 (30-60 km)

Fig. 3(b)



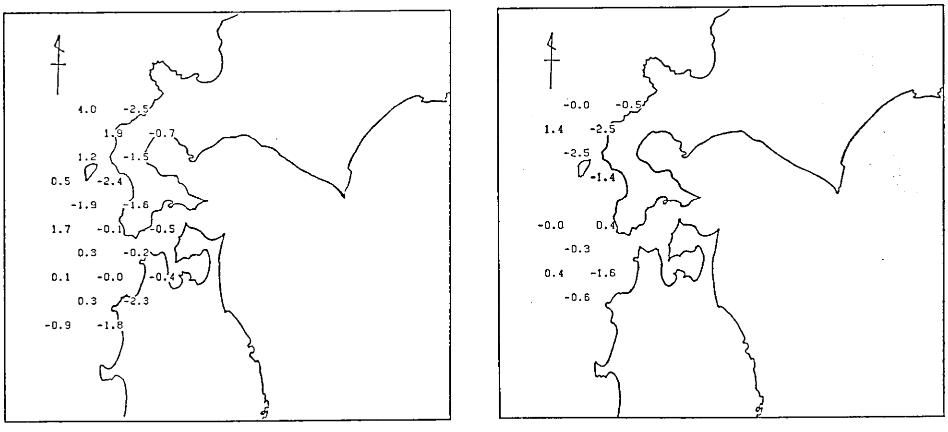
LAYER 3 (60-90 km)

LAYER 4 (90-120 km)



LAYER 5 (120-150 km)

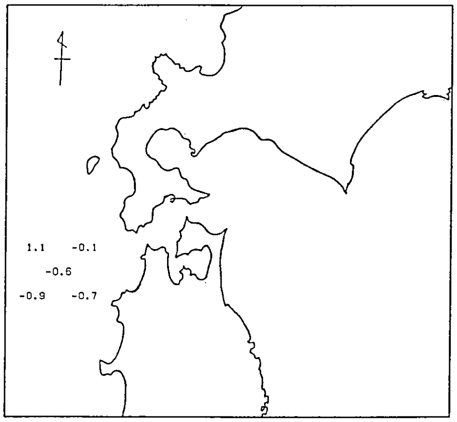
LAYER 6 (150-180 km)



LAYER 7 (180-210 km)

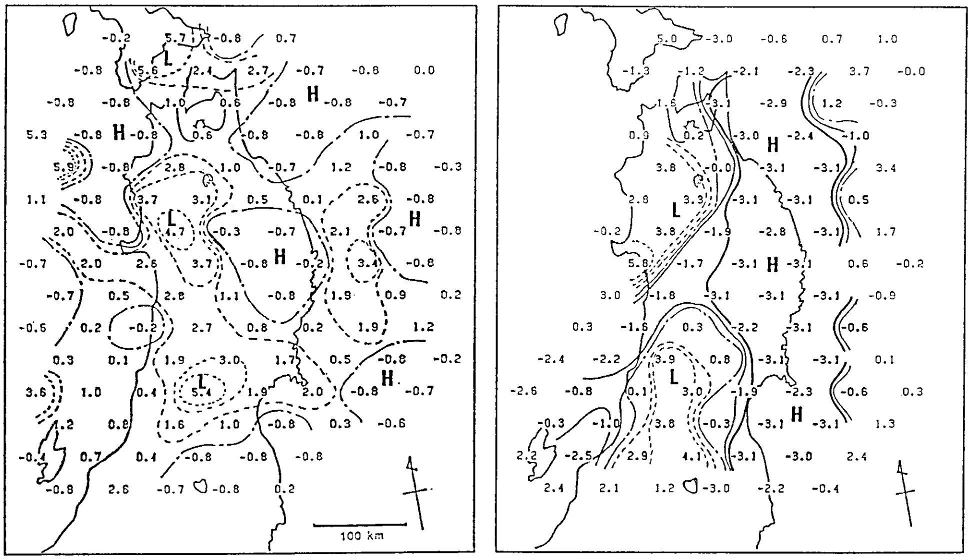
LAYER 8 (210-240 km)

Fig. 3 (b). (Continued)



LAYER 9 (240-270 km)

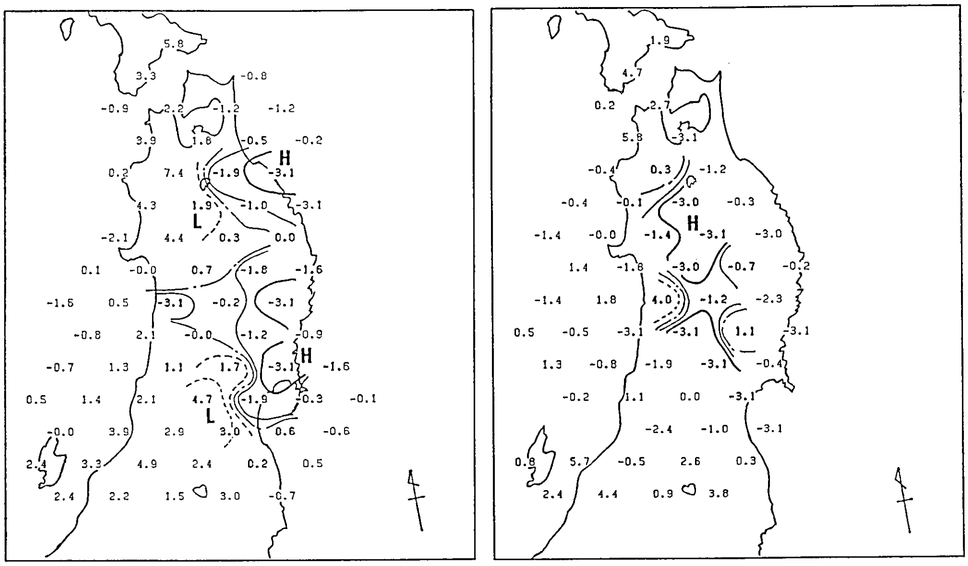
Fig. 3 (b). (Continued)



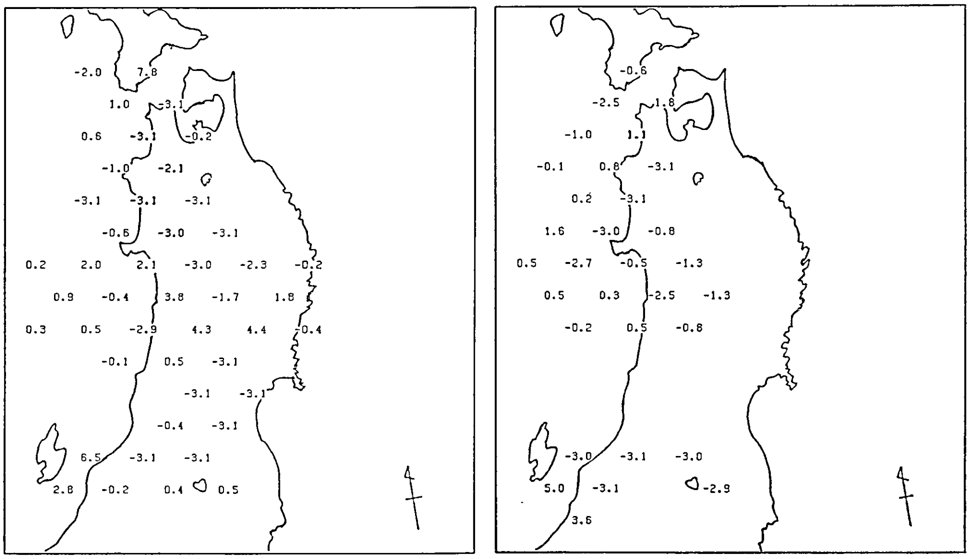
LAYER 1 (0-30 km)

LAYER 2 (30-60 km)

Fig. 3 (c)

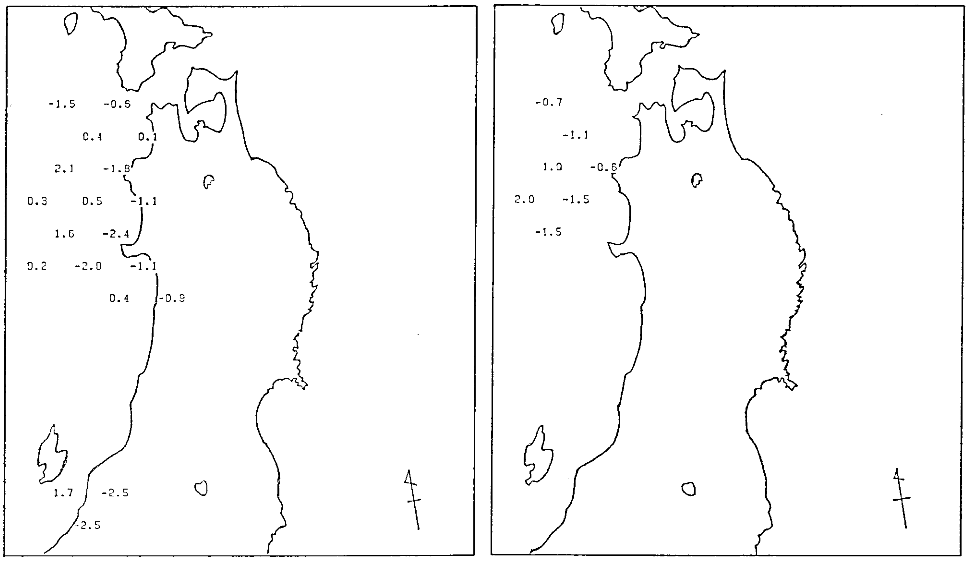


LAYER 3 (60-90 km) LAYER 4 (90-120 km)



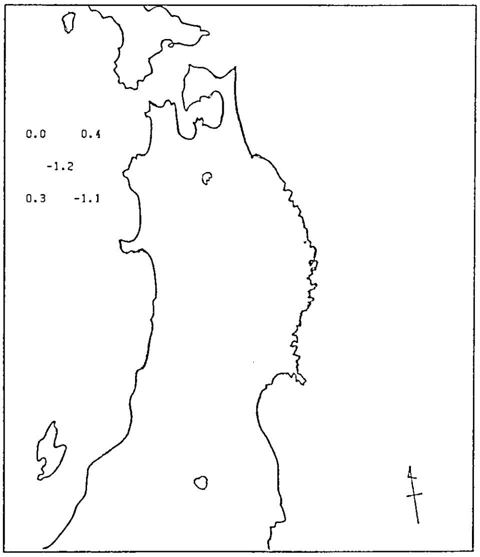
LAYER 5 (120-150 km) LAYER 6 (150-180 km)

Fig. 3 (c). (Continued)



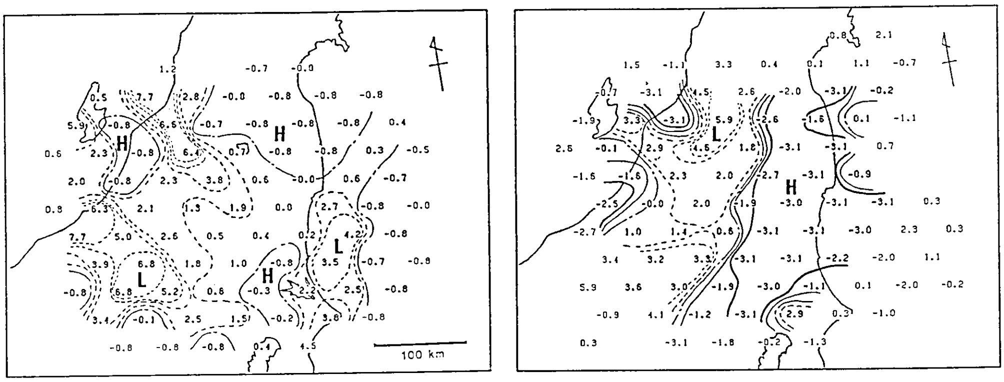
LAYER 7 (180-210 km)

LAYER 8 (210-240 km)



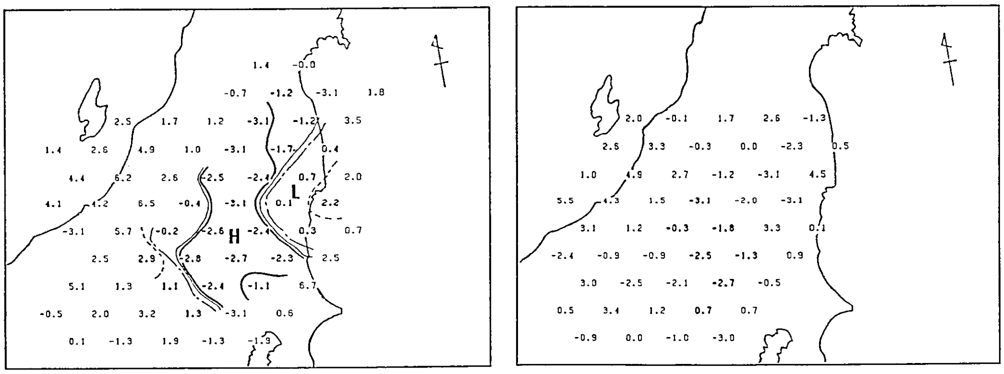
LAYER 9 (240-270 km)

Fig. 3 (c). (Continued)



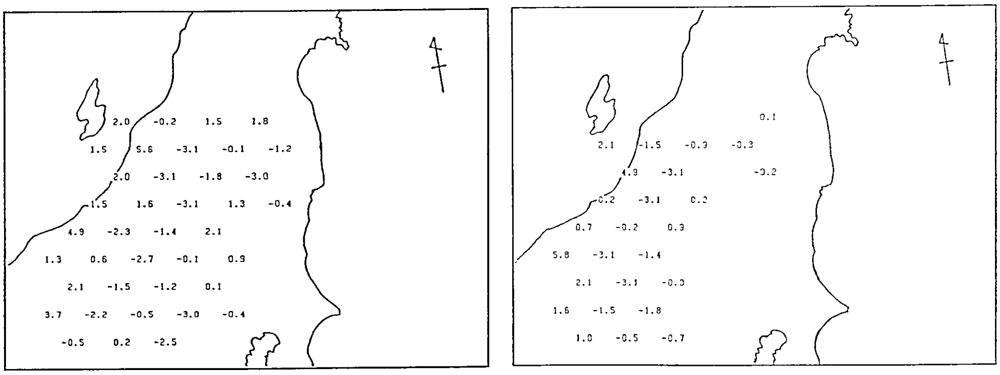
LAYER 1 (0-30 km)

LAYER 2 (30-60 km)



LAYER 3 (60-90 km)

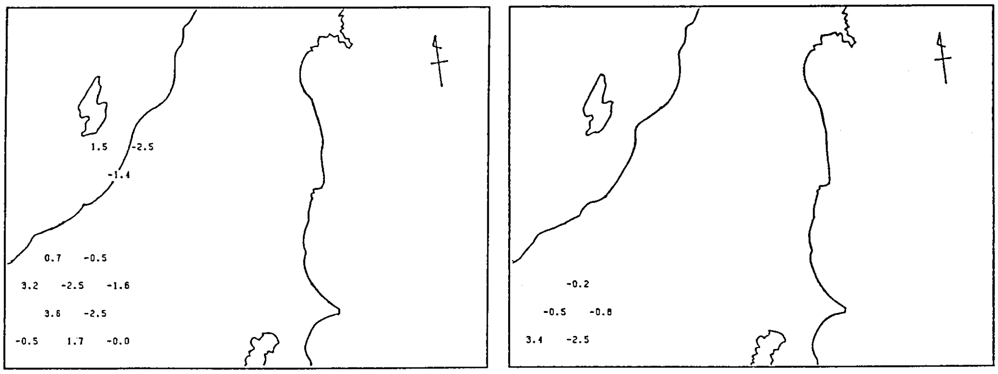
LAYER 4 (90-120 km)



LAYER 5 (120-150 km)

LAYER 6 (150-180 km)

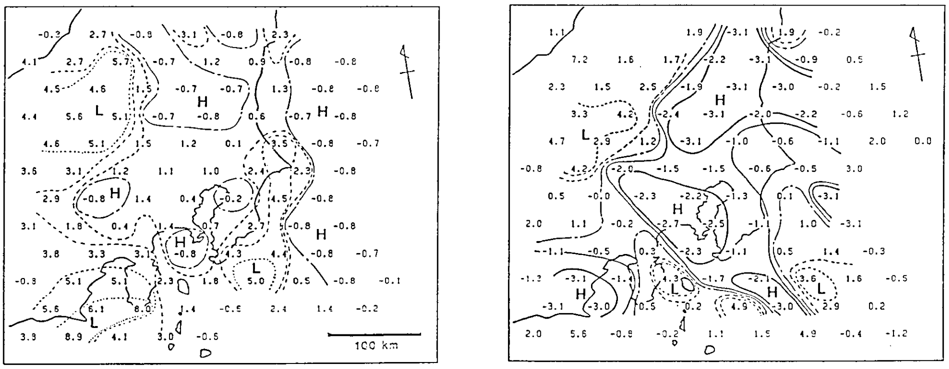
Fig. 3 (d)



LAYER 7 (180-210 km)

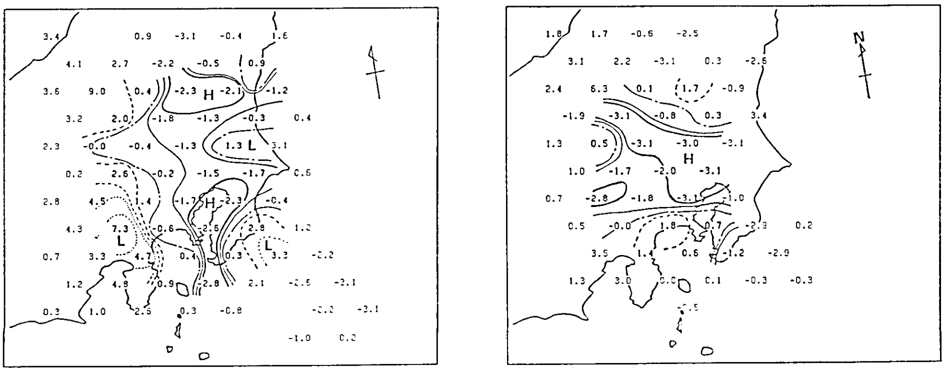
LAYER 8 (210-240 km)

Fig. 3 (d). (Continued)



LAYER 1 (0-30 km)

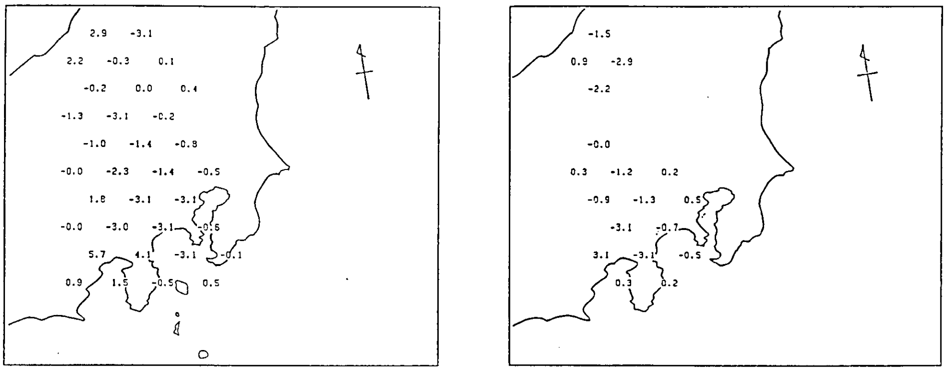
LAYER 2 (30-60 km)



LAYER 3 (60-90 km)

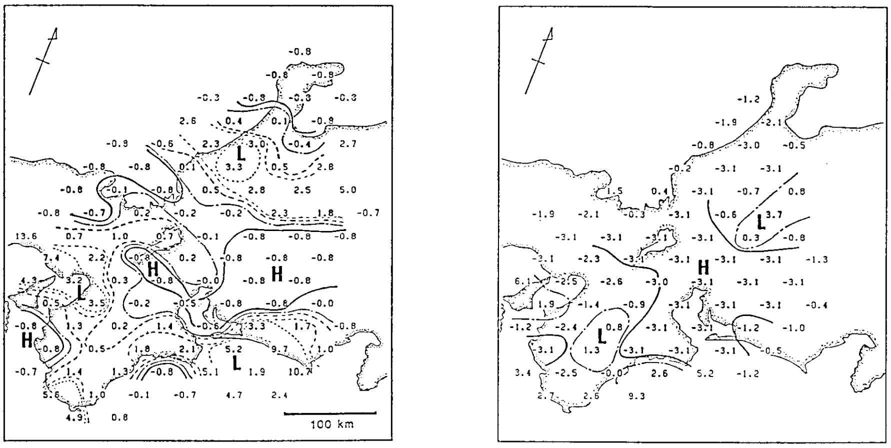
LAYER 4 (90-120 km)

Fig. 3 (e)

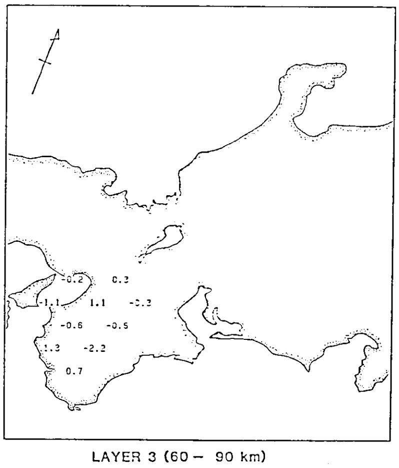


LAYER 5 (120-150 km) LAYER 6 (150-180 km)

Fig. 3(e). (Continued)

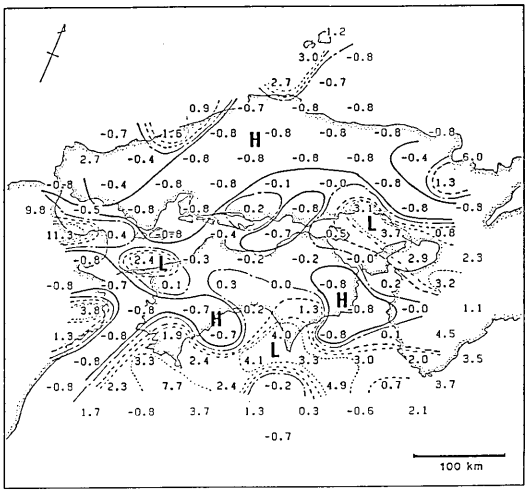


LAYER 1 (0 - 30 km) LAYER 2 (30 - 60 km)

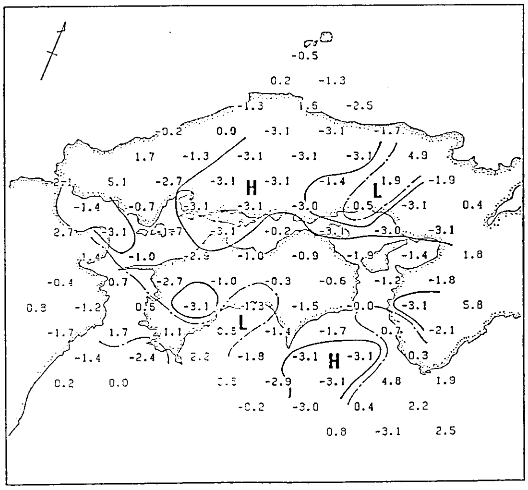


LAYER 3 (60 - 90 km)

Fig. 3(f)

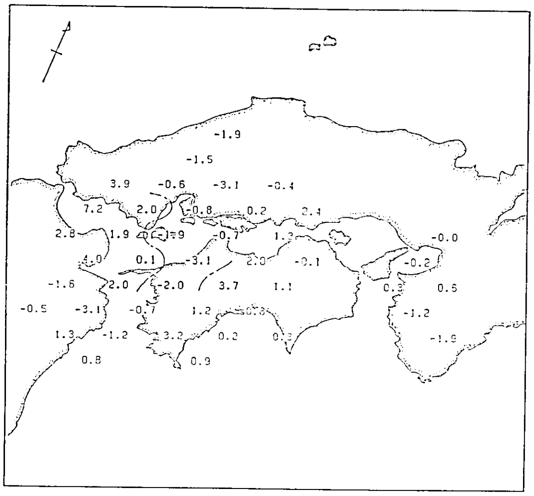


LAYER 1 (0 - 30 km)

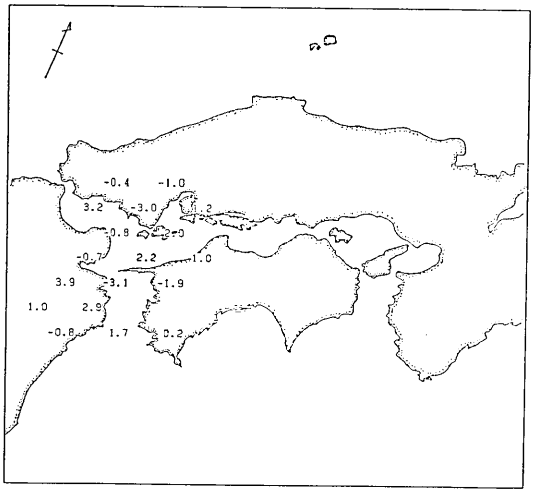


LAYER 2 (30 - 60 km)

Fig. 3 (g)

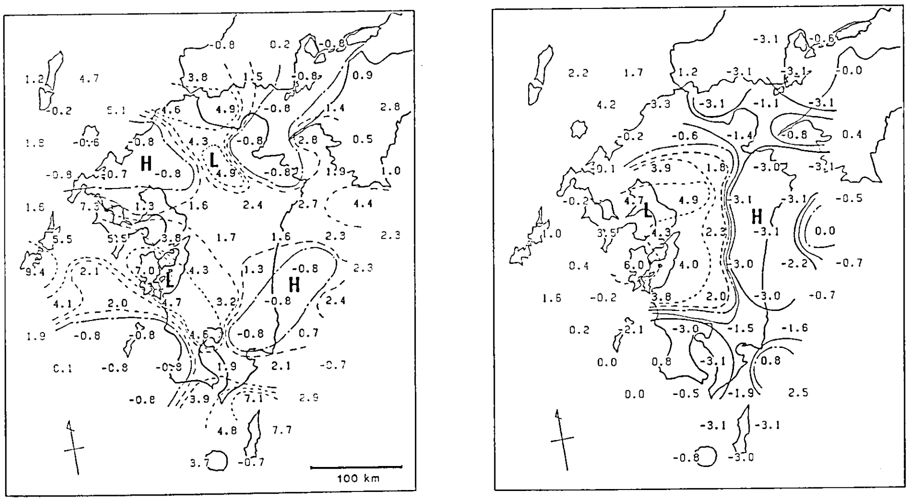


LAYER 3 (60 – 90 km)



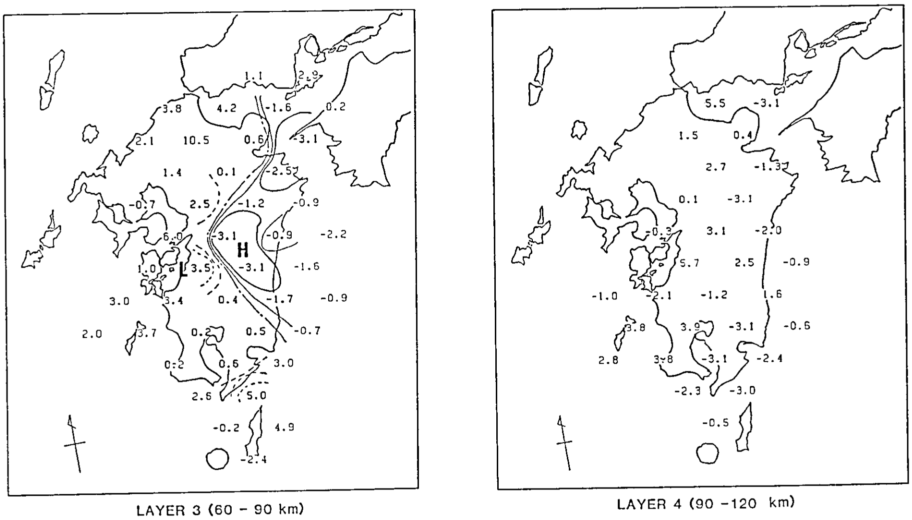
LAYER 4 (90 – 120 km)

Fig. 3 (g). (Continued)



LAYER 1 (0 - 30 km)

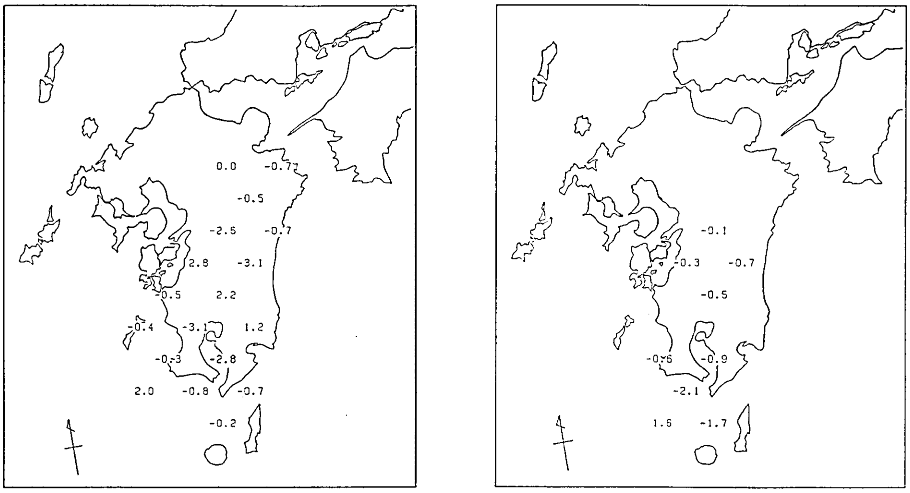
LAYER 2 (30 - 60 km)



LAYER 3 (60 - 90 km)

LAYER 4 (90 -120 km)

Fig. 3 (h)



LAYER 5 (120 - 150 km)

LAYER 6 (150 - 180 km)

Fig. 3 (h). (Continued)

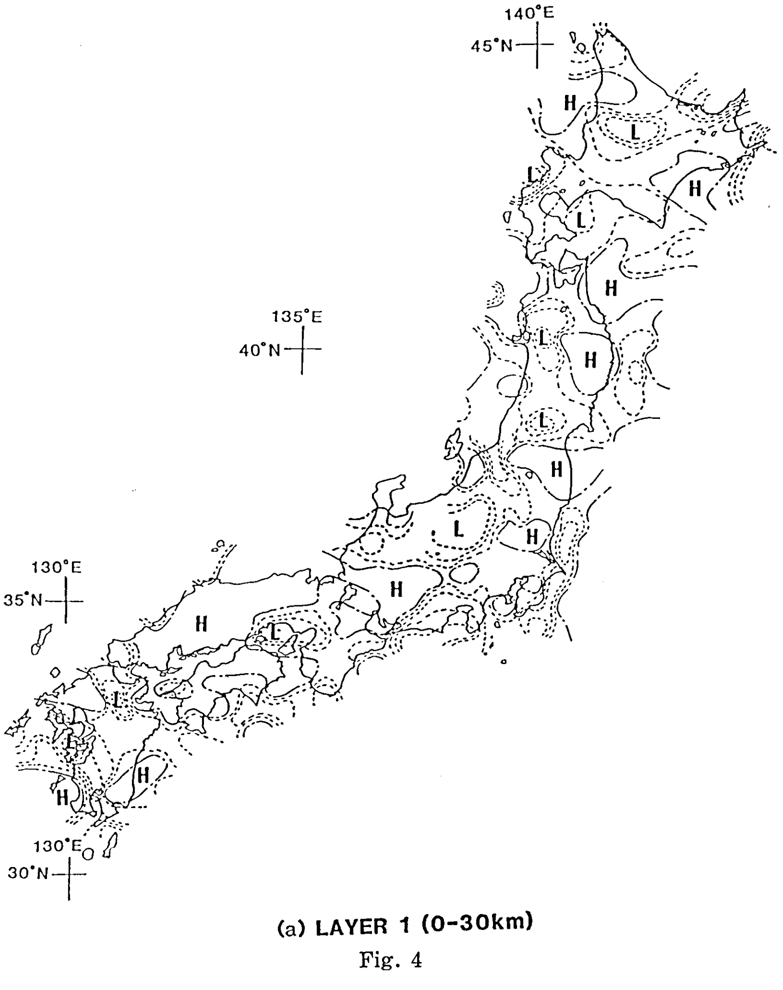
Fig. 3. The obtained three-dimensional attenuation structures for each layer in the eight districts. Figs. (a) to (h), respectively, show Hokkaido, S. Hokkido-N. Tohoku, Tohoku, S. Tohoku-N. Kanto, Kanto, Chubu-Kinki, Chugoku-Shikoku, and Kyushu districts. Numerals in the parentheses indicate depth range in km. In areas where broken contour lines are drawn, attenuation coefficients are larger than the reference values. In areas where thick contour lines are drawn, attenuation coefficients are smaller than the reference values. Detailed explanation of the figures can be referred to in the text.

than the reference value. That corresponds to higher (lower) Q. Areas without numerals in the tables correspond to blocks where no seismic ray penetrates.

Figs. 3 (a) to (h) show the obtained attenuation structures of the eight district in the same order. The figures include coast lines and contours of deviation values for each layer. To draw the contours smoothly, we shift the block configuration by half a block size in the southwest direction and obtain another attenuation structure for each district, which is also shown in Fig. 3. The contours are drawn in areas where the corresponding diagonal elements of resolution matrix are higher than 0.35. The threshold value 0.35 is chosen on the basis of numerical experiments in HASHIDA and SHIMAZAKI (1984). Weaker attenuation areas are shown by the thick contour lines (interval: $1.0\times10^{-2}\,\mathrm{sec}^{-1}$), and stronger attenuation areas by the broken contour lines (interval: $1.5\times10^{-2}\,\mathrm{sec}^{-1}$). The contour intervals for the Chubu-Kinki and the Chugoku-Shikoku districts are somewhat modified to see the details, particularly for the vast weak-attenuation areas. The letters **H** and **L** mean high and low Q, respectively.

We combine the three-dimensional structures of the eight districts shown in Fig. 3 for each layer to construct the structure over the Japanese Islands. We sometimes have inconsistent structures in the overlapping areas, because the areas are situated in peripheral regions of each district where the solutions are poorly resolved. In such cases, we choose the solution with higher resolution. The structure for the uppermost three layers is constructed, because in the lower layers the reliable solutions with high resolution are not mutually overlapped or no reliable solution exists. The constructed attenuation structure down to a depth of 90 km is shown in Fig. 4. We do not discuss the tectonic implications of the attenuation structure here. The discussions appear in HASHIDA (1987) and HASHIDA and SHIMAZAKI (1985, 1987 a).

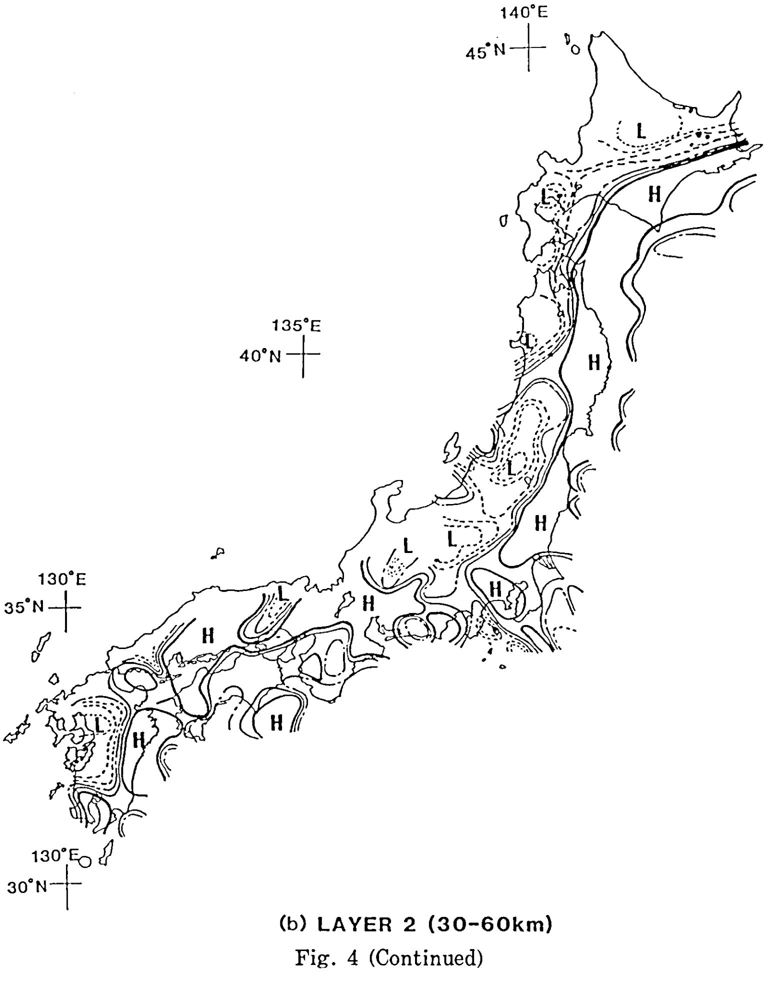
The size of the earthquake source, which is called "source accelera-



(a) LAYER 1 (0-30km)

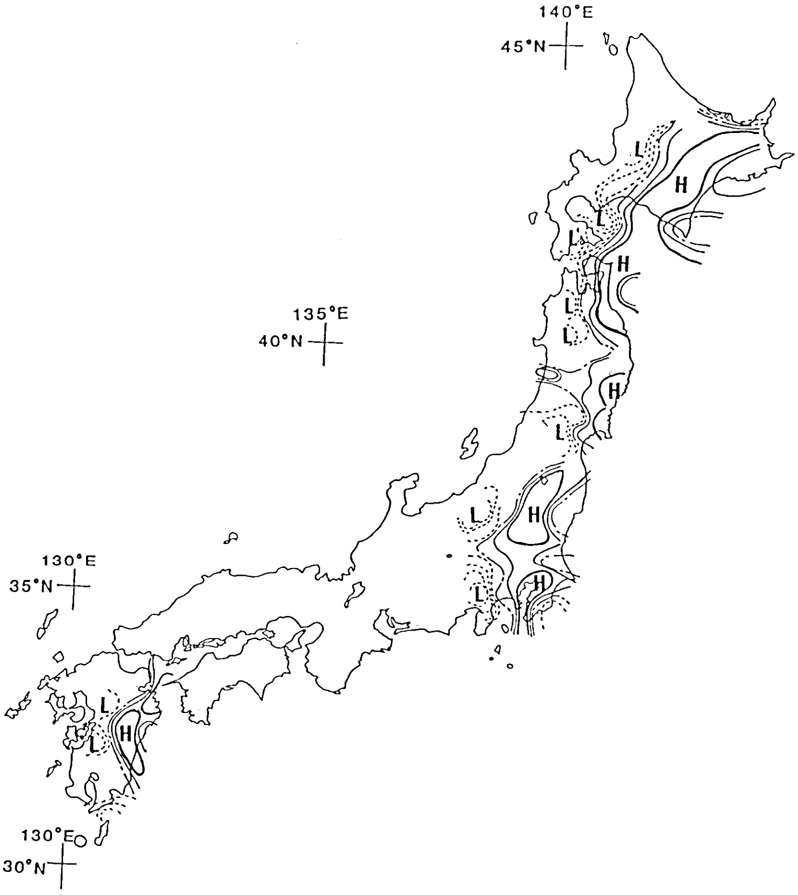
Fig. 4

tion" here, is also estimated by inversion. The source accelerations are plotted against the JMA magnitude M_J in Fig. 5. We do not present the results of inversion for each earthquake, because of a large number of the earthquakes, 808. For almost all the earthquakes, however, the diagonal element of resolution matrix is higher than 0.8 and the standard error of source accelerations is smaller than 0.1 in terms of the logarithm. Thus we can conclude that reliable source accelerations are estimated by inversion. Actually, accelerations for the same earthquakes independently estimated in two neighbouring districts show nearly equal values (Fig. 5). The distinct examples which show reliable estimation of the source acceleration are the three largest earthquakes, the 1952 Tokachi-Oki (M_J 8.2), the 1968 Tokachi-Oki (M_J 7.9), and the 1983 Nihonkai-Chubu (M_J 7.7).



(b) LAYER 2 (30-60km)

Fig. 4 (Continued)



(c) LAYER 3 (60-90km)

Fig. 4. The combined three-dimensional attenuation structure of the Japanese Islands for each layer. Numerals in the parentheses indicate depth range for the layer. The contour intervals are 1.0×10^{-2} (thick lines) and 1.5×10^{-2} (broken lines) sec^{-1}, respectively, for areas where attenuation coefficients are smaller and larger than the reference values. The reference values are $7.85 \times 10^{-3}\, sec^{-1}$ for Layer 1 and $3.14 \times 10^{-2}\, sec^{-1}$ for the lower layers.

There are many unrealistic accelerations exceeding 1000 gal in Fig. 5. Those large accelerations do not represent actual accelerations at the source. They are calculated at a hypothetical focal sphere with a radius of one km for all earthquakes. Obviously the source radius is larger than one km for the events with hypothetical source acceleration exceeding 1000 gal.

Linear relationships between the source accelerations and the JMA magnitudes are obtained for all the earthquakes and also for events in three ranges of focal depth as shown in Fig. 6, by using only earth-

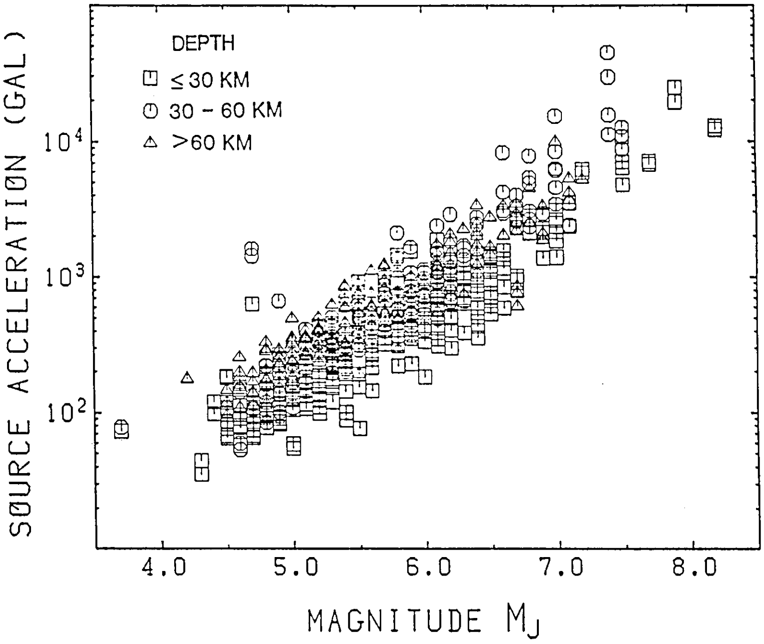


Fig. 5. Obtained source accelerations of all earthquakes used in this study plotted against JMA magnitudes M_J. The number of events amounts to 808. Squares, circles and triangles denote the events whose depths are shallower than 30 km, 30 to 60 km, and deeper than 60 km, respectively.

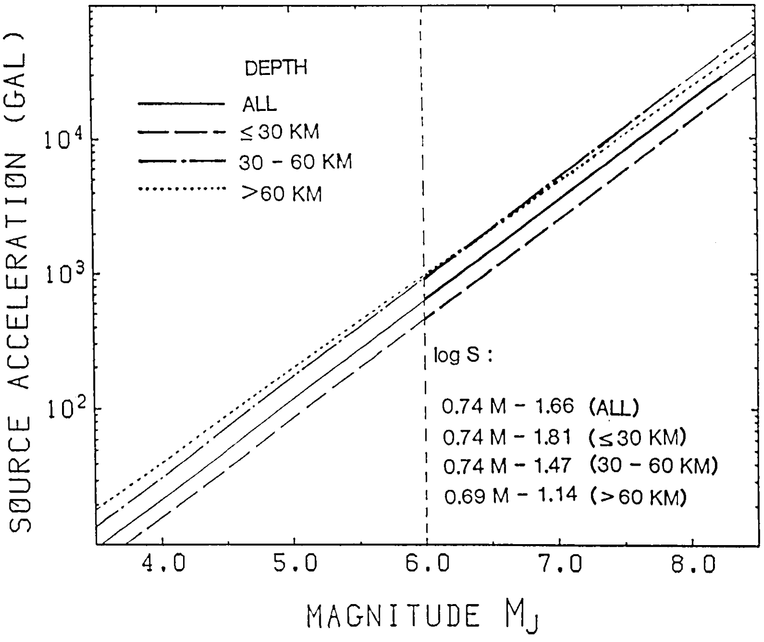


Fig. 6. The relations between the source accelerations and JMA magnitudes M_J. Four relations are given for all earthquakes, those shallower than 30 km, those at a depth of 30 to 60 km, and those deeper than 60 km.

quakes greater than M_J 5.9. This linearity as well as the three-dimensional structure mentioned above are available in predicting intensity for a specific pair of earthquake and station (*e.g.*, HASHIDA and SHIMAZAKI, 1986, 1987 b). They are also helpful in estimating magnitudes of historical earthquakes.

6. Summary

We have presented the detailed results of inversion, in which the three-dimensional attenuation structure and earthquake source accelerations in and around the Japanese Islands are estimated from seismic intensity data.

The method developed by HASHIDA and SHIMAZAKI (1984) is used for inversion, where the intensity is assumed to be the measure of the maximum ground acceleration of S-wave at the observational point. The data consist of about 15,000 intensity readings for about 800 earthquakes reported by JMA during a period from 1951 to 1983. Three-dimensional attenuation structures are estimated for the eight districts which are mutually overlapping and covering the Japanese Islands. Those structures are given in Fig. 3 and are tabulated in Table 3 with resolutions and standard errors of the solutions. The combined three-dimensional structure over the islands for each layer is given in Fig. 4. The obtained source accelerations of earthquakes used in this study are shown in Fig. 5 and the relations with the JMA magnitude are given in Fig. 6. The three-dimensional structures and the source accelerations can be employed to calculate the intensity for a specific pair of station and earthquake and/or to estimate the magnitude of historical earthquakes.

Acknowledgements

I wish to thank Prof. K. SHIMAZAKI for his advice and encouragement throughout this study. Profs. T. UTSU, T. USAMI, S. UYEDA, and K. YAMASHINA, Dr. T. MIYATAKE, and Mr. K. SATAKE gave me helpful comments. This paper constitutes a part of a Ph. D. dissertation accepted to the University of Tokyo.

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Appendix

Station amplifying factors are presented here. The factor is estimated from an averaged value of residuals ($O-C$ of eq. (5)) for each station. As the $O-C$ is given by the natural logarithm of acceleration, the amplifying factor can be converted to intensity deviation ΔI using eq. (1) or to site amplifying effect g (a half value of g in eq. (2), because the effect of free surface is taken into account in eq. (2)). Figure A-1 shows the site amplifying effect g for stations used in the inversion of which the reported number of intensity was more than 10. The distribution of amplifying factor $O-C$, intensity deviation ΔI, and site amplifying effect g is shown in Fig. A-2. These values are available in predicting JMA intensities (*e.g.*, HASHIDA and SHIMAZAKI, 1986; 1987 b).

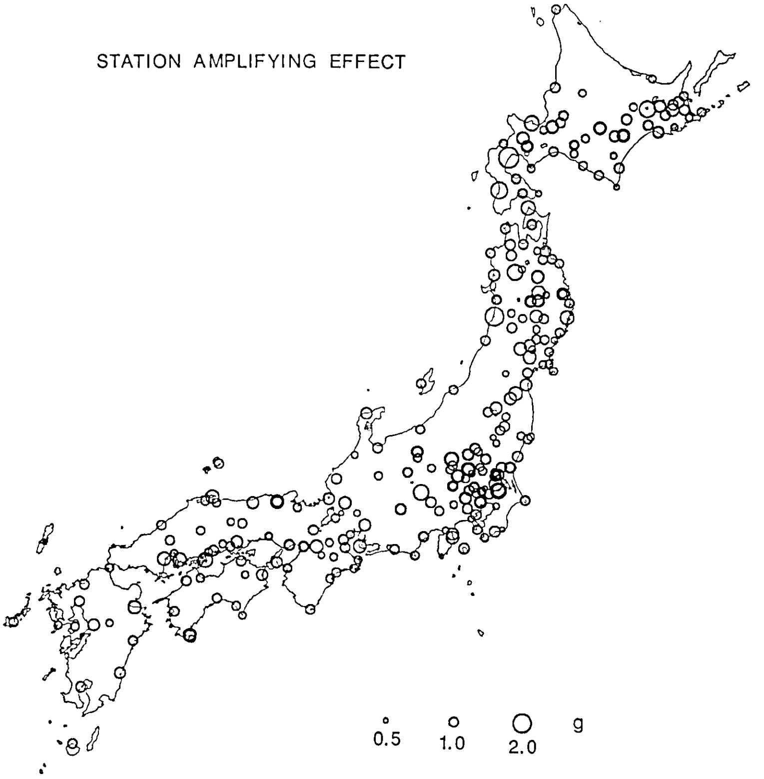

Fig. A-1. The site amplifying effects for the stations used in this study. The amplifying effect g converted from the amplifying factor is plotted for stations of which the reported number of intensity was more than 10.

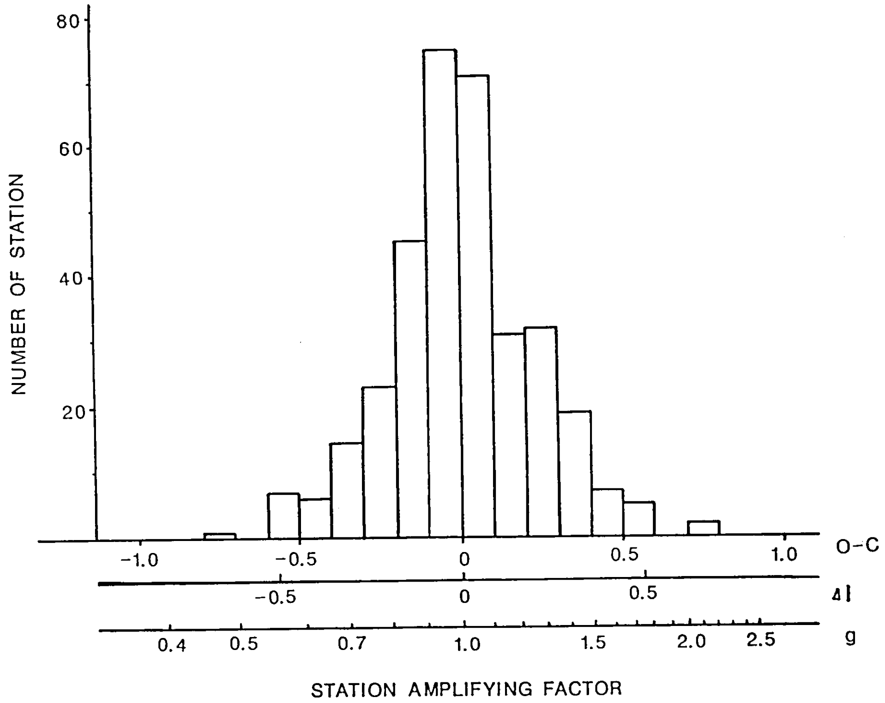

Fig. A-2. The distribution of the amplifying factor ($O-C$), intensity deviation ΔI, and site amplifying effect g. Stations of which the reported number of intensity was more than 10 are plotted in this figure.

震度データのインバージョンによる3次元減衰構造と地震規模の決定：日本列島

東京大学地震研究所　橋田俊彦

日本列島下の3次元減衰構造と地震の規模（点震源を仮定したときの震源における加速度）が，震度データから求められている．

インバージョンに際して，HASHIDA and SHIMAZAKI (1984) が開発した方法を使った．この方法では，震度は観測点における S 波の最大加速度に対応することが仮定されている．1951年から1983年までに日本列島およびその周辺で発生した約800個の地震に対して気象庁によって報告された約15,000個の震度をデータとして用いた．

日本列島を8地域に分け，各地域について3次元減衰構造と震源での加速度が求められた．その3次元構造は表3と図3に示されている．さらに，8地域の減衰構造を各層ごとに結びあわせることによって，日本列島全域の減衰構造を第3層（深さ90 km）まで求めた（図4）．また，求められた震源での加速度と気象庁マグニチュードとは，1次式で表される（図5・6）．

ここに求められた3次元減衰構造と震源における加速度は，特定の地震と観測点に対する震度予測や，歴史地震のマグニチュード推定に利用することができる．