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# 3. *Accuracy of Origin Time, Epicentre and Focal Depth of Local Earthquake Determined Routinely by the Japan Meteorological Agency.*

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## Introduction

The Japan Meteorological Agency (*JMA*) operates 107 seismological stations throughout the country and publishes the origin time, epicentre, focal depth and magnitude of local earthquakes together with the data supplied from each station in the monthly Seismological Bulletin of *JMA*. This bulletin is the most important source of information for the investigation of seismicity of Japan.

Recently the seismological data processing at *JMA* has been much improved by the use of a digital computer.[1] The computer program designed at *JMA* for locating earthquakes is nearly the same as the one described by Bolt[2], except that *JMA* uses the Wadati-Sagisaka-Masuda's travel time table while Bolt uses the Jeffreys-Bullen table. There are, incidentally, some unique features in the *JMA* program; it can use $S$ times as well as $P$ times for earthquake location, thereby avoiding the indeterminate solution in the absence of direct waves.[3] Another unique feature is that the focal depth is determined in such a way that several trial depths (at 20 km steps) are given and the one with the least sum of squared residuals is chosen, avoiding the negative focal depth.

The travel time-tables used in the earthquake location by *JMA* is now obsolete, as can be seen from the comparison with observations[4] of waves from artificial explosions. The discrepancy is as much as 3 seconds as shown in Fig. 1. The purpose of the present paper is to estimate how

1) *Technical Report of the Japan Meteorological Agency*, No. 22, (1963).

2) B. A. BOLT, GEOPHYS. J., **3** (1960), 433-440.

3) J. M. NORDQUIST, *Bull. Seism. Soc. Amer.*, **52** (1962), 431-437.

4) Research Group for Explosion Seismology, *Bull. Earthq. Res. Inst.*, **31** (1953), 281-290; **32** (1954), 79-86; **33** (1955), 699-708; **36** (1958), 329-348; **37** (1959), 495-508; **39** (1961), 285-326.

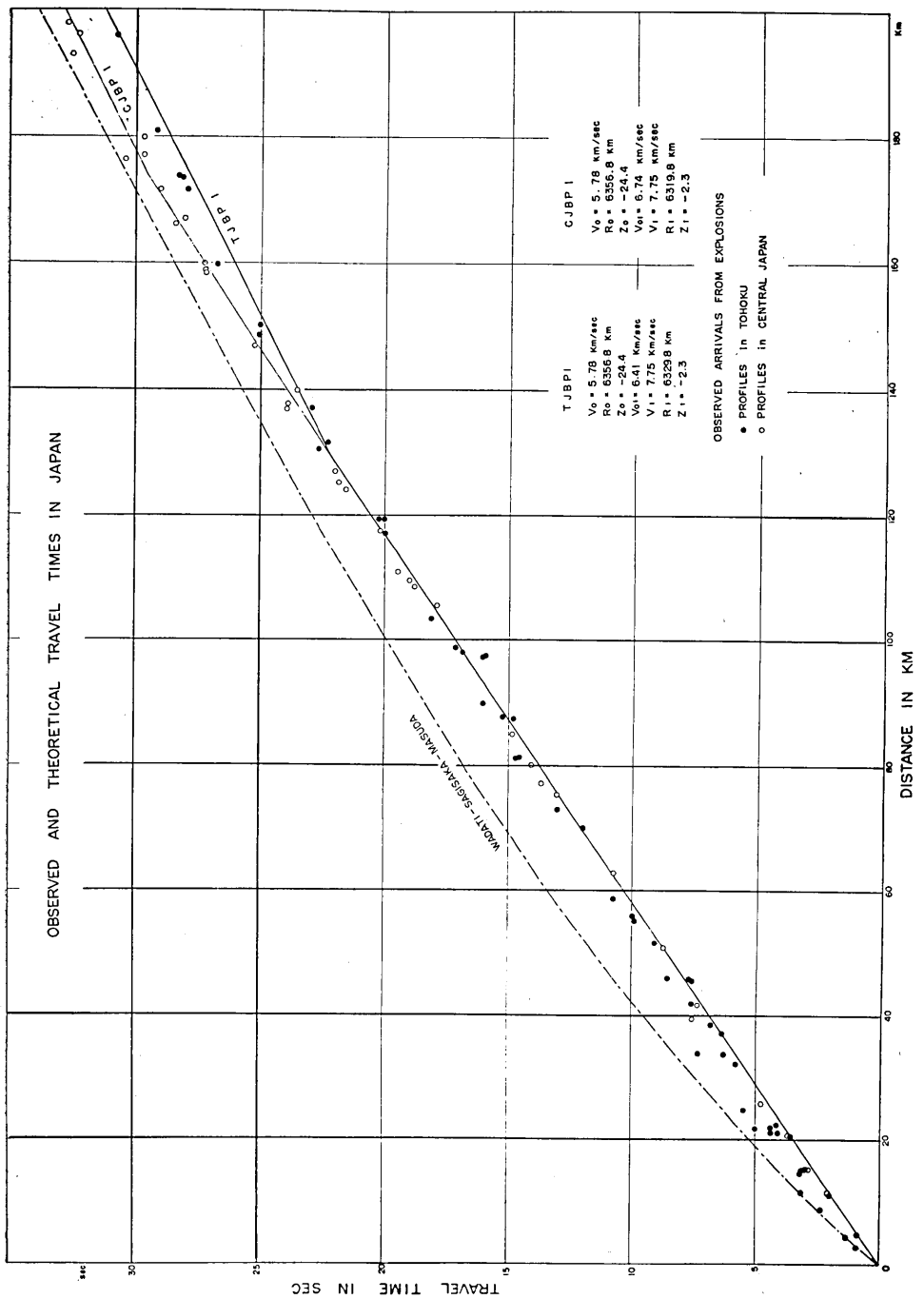


Fig. 1. Comparison of observed and theoretical travel times in Japan

much correction will be required to the origin time, epicentre and focal depth given by *JMA* if the travel time data are revised. We used the computer program described by the present writer in a separate paper[5]. This program uses only $P$ waves, and locates earthquakes in a wave medium which may be, to some extent, arbitrarily specified.

We shall also estimate the error of focal depth determination, which is not given in the Bulletin of *JMA*. Since *JMA* gives trial focal depths at 20 km steps and solves the least-squares equation for origin time, latitude and longitude, the probable errors of these three solutions are given in the Bulletin.

## Crustal Structure

The crustal structure in Japan has been studied by various methods. The refraction method has been applied since 1950 by a group of Japanese seismologists of the Research Group for Explosion Seismology. The phase velocity of Rayleigh and Love waves were determined for various regions of Japan by Aki[6),7)] and Kaminuma[8),9)]. Discussion of these data combined with gravity data was made by Aki[10)] and in more detail by Kanamori[11),12),13)].

The crustal structure is best known for the eastern half of Honshu (the main island of Japan). We divide this into two regions; Tohoku (excluding its western part and including northern Kanto) and Chubu (including western Kanto). In Fig. 1 travel times of $P$ waves along several refraction profiles (some are reversed and others are not) in Chubu (open circle) and in Tohoku (closed circle) are shown in a single diagram[14)]. The wave medium in our computer program consists of a crust with velocity distribution $v=v_0(r/r_0)^{z_0}$ and an upper mantle with velocity distribution $v=v_1(r/r_1)^{z_1}$, where $r$ is the distance from the earth's centre. A reasonable agreement between the observed and the calculated times was obtained by the choice of following parameters for Tohoku,

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5) K. AKI, *Bull. Earthq. Res. Inst.*, **43** (1965), 15-22.
6) K. AKI, *Bull. Earthq. Res. Inst.*, **39** (1961), 255-283.
7) K. AKI and K. KAMINUMA, *Bull. Earthq. Res. Inst.*, **41** (1963), 243-259.
8) K. KAMINUMA and K. AKI, *Bull. Earthq. Res. Inst.*, **41** (1963), 217-241.
9) K. KAMINUMA, *Bull. Earthq. Res. Inst.*, **42** (1964), 19-38.
10) K. AKI, *Bull. Earthq. Res. Inst.*, **40** (1962), 425-430.
11) H. KANAMORI, *Bull. Earthq. Res. Inst.*, **41** (1963), 743-760.
12) H. KANAMORI, *Bull. Earthq. Res. Inst.*, **41** (1963), 761-780.
13) H. KANAMORI, *Bull. Earthq. Res. Inst.*, **41** (1963), 801-818.
14) Research Group for Explosion Seismology, *loc. cit.*, 4).

$v_0=5.78$ km/sec
$r_0=6356.8$ km
$z_0=-24.4$
$v_1=7.75$ km/sec
$r_1=6329.8$ km
$z_1=-2.3$

and for Chubu,

$v_0=5.78$ km/sec
$r_0=6356.8$ km
$z_0=-24.4$
$v_1=7.75$ km/sec
$r_1=6319.8$ km
$z_1=-2.3$ .

We call the model structure for Tohoku *TJBP*1, and that for Chubu *CJBP*1. The upper mantle in both models is identical with the *B*-layer of Bullen.[15] The low mantle velocity in Japan at the *M* discontinuity ($v_1=7.75$ km/sec) is supported from various evidences.[16] Crustal thickness ($r_0-r_1$) adopted in each region approximately agrees with the average value in the respective region obtained from the phase velocity of Rayleigh waves. Anyway, it is clear from Fig. 1 that our structure models better explain the observation than the Wadati-Sagisaka-Masuda's travel time curve.

## Data

Fig. 2 shows 15 stations in Tohoku used for locating earthquakes in and near the region. Fig. 3 shows 33 stations used for earthquakes in Chubu. The *P* times at these stations as well as the trial values of coordinates and time of origin are obtained from the Seismological Bulletin of the Japan Meteorological Agency for the years 1961 to 1962. The stations reporting *eP* are neglected in the computation.

Earthquakes are grouped into *A*, *B* and *C* (Fig. 2) in Tohoku according to the position of epicentre. Earthquakes in *A* region occurred within

15) K. E. BULLEN, *Introduction to the Theory of Seismology* (Cambridge, 1959), p. 211.
16) K. AKI, *Trans. Amer. Geophys. Union*, **44** (1963), 807-811.

the station network, those in $B$ within 100 km from the network, and those in $C$ apart between 100 and 200 km from the network. All the earthquakes in Chubu studied in this paper occurred within the

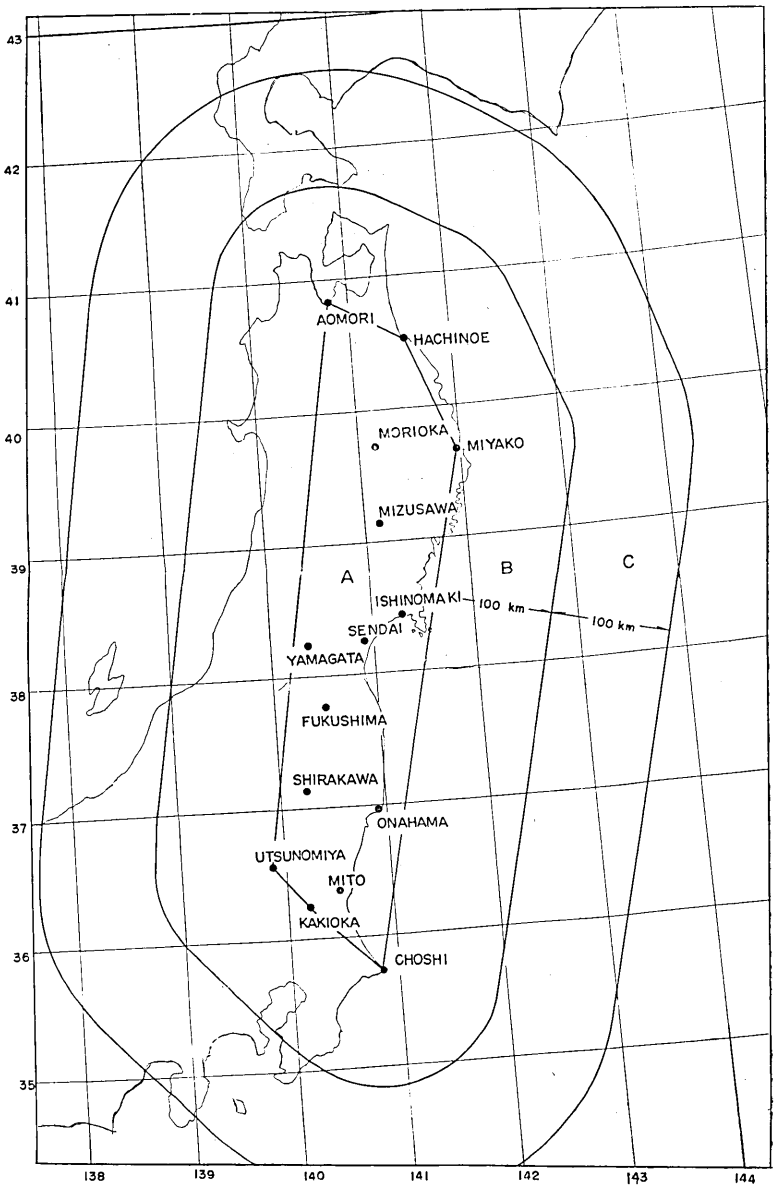


Fig. 2. Map of stations in Tohoku

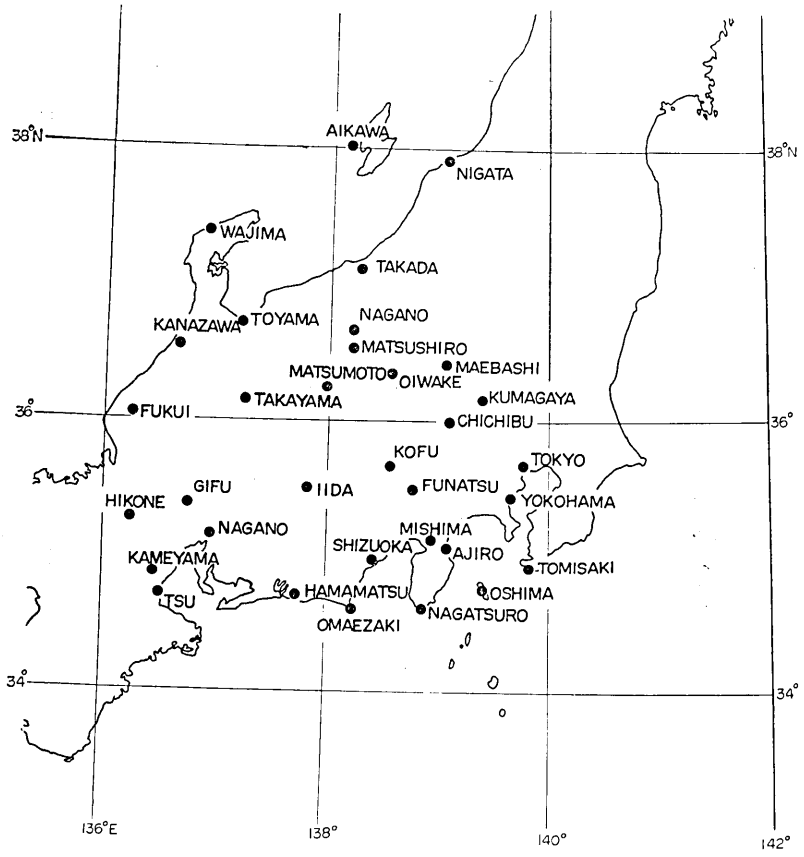


Fig. 3. Map of stations in Chubu

station network. Table 1 lists the coordinates and times of origins of these earthquakes together with their probable errors as published in the Seismological Bulletin of *JMA*.

## Result

The coordinates and times of origins of earthquakes listed in Table 1 are revised by the use of our computer program[17] on the basis of the crust-mantle models described before. We used model *TJBP*1 for Tohoku region and *CJBP*1 for Chubu. The result of computation is shown in Table 2, where the corrections to the origin time and coordinates are given with the probable errors for each earthquake. We notice that the cor-

17) K. AKI, *loc. cit.*, 5).

Table 1. List of Earthquakes
(from Seismological Bulletins of *JMA*)

| No. Date | Origin Time (h : m : sec) | Latitude (deg, min) | Longitude (deg, min) | Depth (km) |
|---|---|---|---|---|
| Tohoku, Region A | | | | |
| 1. 1961 March 9 | 18 : 12 : 40.2±0.4 | 38 : 19±1N | 141 : 11±4E | 60 |
| 2. 1961 April 9 | 04 : 18 : 52.8±0.2 | 37 : 55±1 | 140 : 44±2 | 120 |
| 3. 1961 July 4 | 08 : 14 : 24.2±0.2 | 36 : 42±1 | 141 : 01±2 | 80 |
| 4. 1961 Sept. 2 | 18 : 03 : 52.4±0.2 | 36 : 49±1 | 140 : 59±2 | 60 |
| 5. 1962 April 15 | 16 : 32 : 07.8±0.3 | 36 : 16±1 | 140 : 57±2 | 20 |
| 6. 1962 April 30 | 11 : 26 : 21.0±0.2 | 38 : 44±1 | 141 : 08±2 | 00 |
| 7. 1962 April 30 | 16 : 55 : 24.9±0.3 | 38 : 41±1 | 141 : 09±2 | 00 |
| 8. 1962 May 14 | 03 : 48 : 52.3±0.3 | 38 : 38±1 | 141 : 10±2 | 20 |
| 9. 1962 June 1 | 06 : 43 : 42.9±0.2 | 37 : 05±1 | 141 : 08±2 | 60 |
| 10. 1962 June 23 | 13 : 23 : 40.9±0.4 | 37 : 02±1 | 141 : 17±3 | 40 |
| 11. 1962 July 15 | 15 : 47 : 21.6±0.1 | 39 : 29±1 | 141 : 18±1 | 100 |
| 12. 1962 July 20 | 07 : 05 : 45.0±0.1 | 39 : 30±1 | 141 : 09±2 | 100 |
| Region B | | | | |
| 13. 1961 Jan. 16 | 16 : 20 : 04.7±1.3 | 36 : 02±3 | 142 : 16±6 | 40 |
| 14. 1961 Jan. 16 | 23 : 03 : 49.9±1.4 | 36 : 03±4 | 142 : 31±6 | 40 |
| 15. 1961 Jan. 16 | 23 : 44 : 06.2±1.0 | 36 : 21±3 | 141 : 42±6 | 00 |
| 16. 1961 Jan. 17 | 00 : 41 : 07.0±1.1 | 36 : 09±3 | 142 : 08±5 | 40 |
| 17. 1961 Jan. 21 | 07 : 34 : 46.1±0.4 | 37 : 06±1 | 141 : 37±2 | 40 |
| 18. 1961 Feb. 3 | 22 : 31 : 39.8±0.4 | 36 : 26±1 | 141 : 15±2 | 20 |
| 19. 1961 Feb. 26 | 00 : 23 : 07.9±0.2 | 36 : 08±1 | 139 : 54±1 | 60 |
| 20. 1961 March 5 | 07 : 26 : 00.6±0.6 | 37 : 50±1 | 142 : 22±3 | 40 |
| 21. 1961 March 19 | 18 : 18 : 44.5±0.6 | 36 : 38±2 | 141 : 28±3 | 60 |
| 22. 1961 March 25 | 07 : 57 : 05.5±0.8 | 35 : 44±2 | 141 : 17±4 | 00 |
| 23. 1961 March 30 | 03 : 10 : 13.7±0.6 | 36 : 48±1 | 141 : 47±3 | 20 |
| 24. 1961 May 27 | 19 : 23 : 06.8±0.2 | 38 : 40±1 | 141 : 54±2 | 60 |
| 25. 1961 June 23 | 20 : 04 : 57.0±0.3 | 35 : 43±1 | 140 : 09±2 | 80 |
| 26. 1961 Aug. 22 | 02 : 00 : 36.9±0.5 | 40 : 54±1 | 139 : 19±3 | 40 |
| 27. 1961 Sept. 14 | 08 : 17 : 23.6±0.2 | 36 : 08±1 | 140 : 07±1 | 60 |
| 28. 1961 Sept. 15 | 06 : 50 : 42.3±0.7 | 37 : 33±2 | 141 : 30±4 | 40 |
| 29. 1961 Nov. 14 | 19 : 02 : 27.2±0.1 | 35 : 28±1 | 139 : 22±1 | 160 |
| 30. 1961 Nov. 20 | 13 : 32 : 32.0±0.3 | 37 : 03±1 | 141 : 38±2 | 60 |
| 31. 1961 Nov. 26 | 05 : 19 : 46.2±0.6 | 36 : 12±1 | 141 : 43±3 | 20 |
| 32. 1961 Nov. 29 | 01 : 37 : 50.6±0.5 | 35 : 39±2 | 140 : 51±3 | 60 |
| 33. 1961 Dec. 19 | 23 : 31 : 11.5±0.5 | 37 : 06±1 | 141 : 50±3 | 40 |
| 34. 1961 Dec. 29 | 14 : 40 : 46.5±0.4 | 37 : 30±1 | 141 : 51±3 | 60 |

(to be continued)

Table 1. List of Earthquakes (continued)

| No. Date | Origin Time (h : m : sec) | Latitude (deg, min) | Longitude (deg, min) | Depth (km) |
|---|---|---|---|---|
| 35. 1962 April 23 | 12 : 54 : 37.9±0.1 | 36 : 13±1 N | 139 : 48±1 E | 60 |
| 36. 1962 May 15 | 00 : 19 : 07.3±0.2 | 36 : 07±1 | 140 : 05±1 | 60 |
| 37. 1962 June 9 | 01 : 04 : 21.0±0.3 | 37 : 28±1 | 141 : 40±2 | 40 |
| 38. 1962 July 27 | 03 : 45 : 23.8±0.3 | 35 : 43±1 | 140 : 39±2 | 40 |
| 39. 1962 July 29 | 04 : 42 : 57.5±0.6 | 36 : 40±1 | 142 : 03±4 | 40 |
| 40. 1962 July 30 | 19 : 51 : 02.7±0.4 | 39 : 17±1 | 142 : 08±3 | 40 |
| Region C | | | | |
| 41. 1961 Jan. 15 | 20 : 53 : 08.0±0.5 | 39 : 36±1 | 143 : 16±3 | 80 |
| 42. 1961 June 19 | 16 : 38 : 20.0±0.6 | 39 : 09±2 | 143 : 39±3 | 40 |
| 43. 1961 Dec. 6 | 11 : 15 : 55.6±0.8 | 37 : 45±1 | 142 : 56±4 | 60 |
| 44. 1961 Dec. 24 | 04 : 11 : 54.6±0.1 | 34 : 41±2 | 138 : 23±2 | 240 |
| 45. 1962 April 12 | 09 : 52 : 39.4±0.5 | 37 : 58±1 | 142 : 49±3 | 40 |
| 46. 1962 April 12 | 14 : 16 : 00.9±0.5 | 37 : 45±1 | 142 : 54±3 | 40 |
| 47. 1962 April 18 | 05 : 54 : 04.3±0.6 | 38 : 02±1 | 142 : 48±4 | 40 |
| 48. 1962 April 26 | 00 : 47 : 22.9±0.7 | 38 : 14±1 | 143 : 05±4 | 60 |
| 49. 1962 July 16 | 00 : 12 : 36.6±0.4 | 40 : 01±1 | 142 : 52±3 | 00 |
| Chubu | | | | |
| 50. 1961 Jan. 2 | 12 : 39 : 13.6±0.3 | 35 : 33±1 | 138 : 51±2 | 00 |
| 51. 1961 Feb. 2 | 03 : 39 : 03.8±0.3 | 37 : 27±1 | 138 : 50±2 | 20 |
| 52. 1961 Feb. 17 | 22 : 31 : 35.2±0.2 | 35 : 31±1 | 139 : 01±1 | 20 |
| 53. 1961 July 6 | 20 : 23 : 39.2±0.3 | 35 : 32±1 | 138 : 16±2 | 20 |
| 54. 1961 July 14 | 08 : 41 : 32.1±0.2 | 36 : 02±1 | 139 : 57±1 | 60 |
| 55. 1961 Aug. 10 | 21 : 03 : 19.6±0.3 | 37 : 17±1 | 137 : 03±2 | 40 |
| 56. 1961 Aug. 19 | 14 : 33 : 29.9±0.2 | 36 : 01±1 | 136 : 46±1 | 00 |
| 57. 1961 Aug. 19 | 15 : 25 : 42.5±0.3 | 36 : 05±1 | 136 : 43±1 | 00 |
| 58. 1961 Aug. 19 | 17 : 07 : 15.6±0.4 | 36 : 00±2 | 136 : 35±1 | 00 |
| 59. 1961 Aug. 19 | 22 : 24 : 11.8±0.2 | 36 : 30±1 | 137 : 39±1 | 00 |
| 60. 1961 Sept. 2 | 03 : 59 : 32.2±0.1 | 35 : 26±1 | 139 : 12±1 | 20 |
| 61. 1961 Oct. 25 | 18 : 49 : 27.3±0.2 | 34 : 52±1 | 138 : 24±1 | 40 |
| 62. 1961 Nov. 14 | 19 : 02 : 27.2±0.1 | 35 : 28±1 | 139 : 22±1 | 160 |
| 63. 1961 Dec. 15 | 02 : 24 : 20.4±0.1 | 35 : 18±1 | 139 : 18±1 | 20 |
| 64. 1961 Dec. 15 | 02 : 53 : 10.2±0.2 | 35 : 16±2 | 139 : 17±2 | 40 |
| 65. 1961 Dec. 24 | 04 : 11 : 54.6±0.1 | 34 : 41±2 | 138 : 23±2 | 240 |
| 66. 1962 Jan. 4 | 13 : 16 : 01.7±0.2 | 35 : 06±1 | 139 : 17±1 | 160 |
| 67. 1962 Feb. 6 | 07 : 55 : 52.5±0.1 | 35 : 52±1 | 139 : 17±1 | 120 |
| 68. 1962 March 5 | 16 : 32 : 31.2±0.1 | 35 : 40±1 | 136 : 33±1 | 20 |
| 69. 1962 April 1 | 13 : 45 : 46.3±0.2 | 35 : 37±1 | 137 : 05±1 | 20 |

(to be continued)

Table 1. List of Earthquakes (continued)

| No. Date | Origin Time (h : m : sec) | Latitude (deg, min) | Longitude (deg, min) | Depth (km) |
|---|---|---|---|---|
| 70. 1962 May 6 | 01 : 42 : 59.8±0.1 | 35 : 47±2 N | 137 : 11±2 E | 280 |
| 71. 1962 May 11 | 00 : 09 : 45.1±0.4 | 36 : 41±2 | 136 : 25±2 | 00 |
| 72. 1962 May 27 | 14 : 37 : 27.6±0.1 | 36 : 10±1 | 137 : 32±1 | 20 |
| 73. 1962 June 30 | 03 : 54 : 10.9±0.1 | 35 : 34±1 | 137 : 47±1 | 20 |
| 74. 1962 Nov. 13 | 01 : 16 : 58.9±0.1 | 35 : 12±1 | 136 : 29±1 | 40 |
| 75. 1962 Dec. 9 | 08 : 15 : 21.4±0.2 | 37 : 30±2 | 138 : 39±2 | 200 |
| 76. 1962 Dec. 31 | 02 : 56 : 26.1±0.1 | 35 : 28±0 | 139 : 08±1 | 00 |

Table 2. Corrections to the times and coordinates of origins of earthquakes given by *JMA* and probable errors of corrections

| No. Date | Origin Time (sec) | Latitude (deg) | Longitude (deg) | Depth (km) |
|---|---|---|---|---|
| Tohoku, region A | | | | |
| 1. 1961 March 9 | +0.2±0.35 | +.025±0.25 | −.076±.069 | +25.6± 4.5 |
| 2. 1961 April 9 | +0.4±0.44 | +.005±.022 | −.001±.102 | +18.6± 5.3 |
| 3. 1961 July 4 | −0.3±0.48 | −.026±.022 | +.088±.052 | +14.3± 6.5 |
| 4. 1961 Sept. 2 | +1.1±0.09 | +.009±.004 | −.028±.010 | + 3.9± 1.1 |
| 5. 1962 April 15 | +2.2±0.32 | −.047±.020 | +.010±.035 | + 6.8± 3.3 |
| 6. 1962 April 30 | +2.6±0.32 | +.001±.013 | −.020±.038 | − 4.3± 3.7 |
| 7. 1962 April 30 | +2.0±0.39 | +.019±.019 | +.052±.055 | −11.7± 5.8 |
| 8. 1962 May 14 | 0.0±0.46 | +.031±.019 | −.082±.049 | −34.2± 5.7 |
| 9. 1962 June 1 | +2.0±0.22 | −.005±.011 | −.050±.032 | −10.6± 4.0 |
| 10. 1962 June 23 | +2.4±0.37 | +.006±.018 | −.096±.052 | + 9.0± 6.8 |
| 11. 1962 July 15 | +0.9±0.46 | +.031±.020 | −.006±.068 | + 4.0± 5.4 |
| 12. 1962 July 20 | +4.1±0.20 | −.046±.010 | −.036±.027 | −34.4± 2.9 |
| Region B | | | | |
| 13. 1961 Jan. 16 | +5.2±1.36 | −.017±.073 | −.328±.111 | 0.0±49.6 |
| 14. 1961 Jan. 16 | +8.3±0.94 | +.187±.045 | +.669±.086 | +18.5±15.7 |
| 15. 1961 Jan. 16 | +3.0±1.80 | +.005±.078 | −.028±.128 | + 7.0±15.0 |
| 16. 1961 Jan. 17 | +5.5±0.75 | +.069±.043 | −.372±.079 | + 0.2±27.0 |
| 17. 1961 Jan. 21 | +0.8±0.78 | −.034±.035 | +.047±.100 | + 8.6±17.4 |
| 18. 1961 Feb. 3 | +2.6±0.82 | −.056±.031 | −.104±.067 | + 1.7± 5.3 |
| 19. 1961 Feb. 26 | +0.2±0.59 | −.179±.031 | −.170±.053 | −20.9± 4.7 |
| 20. 1961 March 5 | +1.3 | +.017±.024 | −.019±.093 | −20.6 |

(to be continued)

Table 2. Corrections to the times and coordinates of origins of earthquakes given by *JMA* and probable errors of corrections (continued)

| No. Date | Origin Time (sec) | Latitude (deg) | Longitude (deg) | Depth (km) |
|---|---|---|---|---|
| 21. 1961 March 19 | +2.6±0.12 | −.007±.006 | −.208±.018 | −11.3± 2.6 |
| 22. 1961 March 25 | +6.0+0.85 | +.110±.057 | −.074±.075 | +20.0± 7.1 |
| 23. 1961 March 30 | +6.0±0.60 | +.052±.016 | −.262±.042 | + 8.4± 3.8 |
| 24. 1961 May 27 | +1.1±0.38 | +.058±.019 | −.111±.062 | +20.3± 6.0 |
| 25. 1961 June 23 | +4.9±0.45 | +.144±.029 | +.032±.037 | −39.8± 3.4 |
| 26. 1961 Aug. 22 | +9.8±2.15 | −.321±.258 | +.819±.303 | −23.3±29.2 |
| 27. 1961 Sept. 14 | +0.8±1.36 | −.022±.063 | −.070±.107 | + 5.0± 9.8 |
| 28. 1961 Sept. 15 | +2.1±0.87 | −.009±.034 | −.123±.120 | +25.0±17.1 |
| 29. 1961 Nov. 14 | +5.9±2.23 | +.217±.113 | +.104±.166 | −29.5±10.0 |
| 30. 1961 Nov. 20 | +2.2±0.31 | −.002±.014 | −.114±.045 | −10.8± 8.2 |
| 31. 1961 Nov. 26 | +4.4±1.15 | +.083±.030 | −.255±.073 | −12.5±10.5 |
| 32. 1961 Nov. 29 | +2.1±0.89 | −.027±.061 | −.244±.021 | −13.6± 5.7 |
| 33. 1961 Dec. 19 | +3.1±1.05 | +.055±.029 | −.213±.084 | −25.4± 7.3 |
| 34. 1961 Dec. 29 | +0.1±1.02 | −.032±.024 | −.135±.057 | −64.7± 5.8 |
| 35. 1962 April 23 | +2.6±0.96 | −.036±.049 | +.140±.089 | −10.3± 6.2 |
| 36. 1962 May 15 | −0.6±1.46 | −.036±.062 | −.124±.114 | +11.0± 9.5 |
| 37. 1962 June 9 | +2.2±0.22 | +.015±.009 | −.027±.034 | −22.2±12.5 |
| 38. 1962 July 27 | +3.0±0.79 | +.187±.070 | −.044±.080 | −39.0±12.9 |
| 39. 1962 July 29 | +1.2±2.78 | −.005±.047 | −.061±.133 | −26.1±15.5 |
| 40. 1962 July 30 | +2.9±0.53 | +.062±.019 | −.092±.072 | + 3.5± 7.6 |
| Region C | | | | |
| 41. 1961 Jan. 15 | −2.2±1.88 | −.091±.067 | +.781±.236 | −85.5±25.4 |
| 42. 1961 June 19 | −0.4±1.48 | −.001±.033 | +.203±.155 | −34.9±49.5 |
| 43. 1961 Dec. 6 | +2.7±0.78 | −.001±.023 | −.071±.106 | −22.9±30.0 |
| 44. 1961 Dec. 24 | +8.5±4.23 | +.357±.235 | +.869±.253 | − 8.5±20.7 |
| 45. 1962 April 12 | +2.8±0.68 | +.047±.020 | −.063±.082 | −36.3±37.8 |
| 46. 1962 April 12 | +1.3±0.67 | −.021±.022 | +.104±.075 | −41.4±39.4 |
| 47. 1962 April 18 | +2.9±1.36 | +.001±.043 | −.055±.162 | - 58.7±74.7 |
| 48. 1962 April 26 | +2.5±1.54 | −.025±.049 | +.010±.198 | −58.0±42.1 |
| 49. 1962 July 16 | −4.1±3.89 | +.067±.050 | +.456±.220 | −23.7±16.4 |
| Chubu | | | | |
| 50. 1961 Jan. 2 | +2.3±0.21 | +.034±.014 | −.101±.029 | +17.1± 3.1 |
| 51. 1961 Feb. 2 | −0.2±3.04 | −.082±.125 | +.074±.269 | −36.3±41.1 |
| 52. 1961 Feb. 17 | +0.8±0.27 | −.009±.021 | −.007±.028 | − 8.0± 5.4 |
| 53. 1961 July 6 | +1.0±0.63 | +.010±.013 | +.053±.023 | −20.2±16.6 |

(to be continued)

Table 2. Corrections to the times and coordinates of origins of earthquakes given by *JMA* and probable errors of corrections (continued)

| No. | Date | Origin Time (sec) | Latitude (deg) | Longitude (deg) | Depth (km) |
|---|---|---|---|---|---|
| 54. | 1961 July 14 | +1.6±0.60 | −.001±.026 | −.046±.062 | − 5.3± 7.2 |
| 55. | 1961 Aug. 10 | +0.8±1.4 | +.008±.076 | +.091±.079 | −42.5±15.0 |
| 56. | 1961 Aug. 19 | +2.8±1.09 | +.065±.049 | −.022±.084 | − 3.8±14.9 |
| 57. | 1961 Aug. 19 | +3.9±0.50 | −.089±.024 | +.102±.050 | − 5.6± 6.4 |
| 58. | 1961 Aug. 19 | +0.7±0.80 | +.014±.038 | −.035±.058 | −15.9±10.6 |
| 59. | 1961 Aug. 19 | +1.2±1.58 | +.010±.077 | +.006±.084 | −15.8±30.1 |
| 60. | 1961 Sept. 2 | +1.2±0.22 | +.024±.014 | −.049±.021 | −14.9± 3.8 |
| 61. | 1961 Oct. 25 | +1.5±0.30 | +.135±.038 | −.048±.035 | −25.5± 4.2 |
| 62. | 1961 Nov. 14 | +1.3±0.50 | −.026±.015 | −.019±.028 | − 2.5± 4.4 |
| 63. | 1961 Dec. 15 | +0.7±0.37 | +.036±.019 | −.030±.028 | −30.7± 7.4 |
| 64. | 1961 Dec. 15 | +1.8±0.26 | +.072±.013 | −.028±.019 | −45.3± 4.9 |
| 65. | 1961 Dec. 24 | +6.0±21.8 | +.152±.713 | −.172±.459 | −38.7±284.1 |
| 66. | 1962 Jan. 4 | +3.5±2.90 | −.029±.108 | −.011±.159 | −24.7±26.4 |
| 67. | 1962 Feb. 6 | +1.5±0.60 | +.017±.018 | +.013±.040 | − 3.5± 5.8 |
| 68. | 1962 March 5 | +1.3±0.30 | +.032±.015 | +.055±.028 | −17.2± 5.1 |
| 69. | 1962 April 1 | +0.8±0.20 | −.017±.012 | +.060±.017 | −14.2± 4.5 |
| 70. | 1962 May 6 | −1.1±1.80 | +.028±.030 | +.093±.035 | +25.4±16.7 |
| 71. | 1962 May 11 | +3.2±3.50 | +.035±.171 | +.080±.192 | +14.9±14.4 |
| 72. | 1962 May 27 | +0.7±0.24 | −.014±.011 | +.013±.013 | −26.5± 3.7 |
| 73. | 1962 June 30 | +0.7±0.12 | +.020±.009 | −.011±.009 | −10.5± 2.0 |
| 74. | 1962 Nov. 13 | +1.6±0.82 | +.055±.047 | +.024±.079 | − 5.1±13.5 |
| 75. | 1962 Dec. 9 | +5.7±6.10 | −.327±.33 | −.065±.150 | −12.6±51.0 |
| 76. | 1962 Dec. 31 | +1.2±0.12 | +.001±.008 | −.013±.011 | + 8.7± 2.8 |

rection to orign time exceeds the corresponding probable error for 80% of the earthquakes, and that to focal depth for two-thirds of them. On the other hand, the corrections to latitude and longitude (except for region *B* of Tohoku) exceeds the probable error for nearly half of the earthquake. This is expected by the definition of probable error, if these corrections are random and insignificant. Therefore, we may say that significant corrections are necessary to origin time and focal depth, but not for latitude and longitude (except for region B).

In order to estimate the proper values of corrections for each region, we averaged the corrections with the weight inversely proportional to the squared probable error. The averaged corrections are shown in Table 3, where the italic is used when the average value exceeds three times its

probable error. The averages for Chubu are given separately for shocks in the crust and those in the mantle.

We see in the table that a significant correction to origin time as much as +1 to +2 seconds is required for all the regions. The correction to latitude is insignificant for all the regions. A significant correction to longitude is required for *B* region of Tohoku. The epicentres in this region are all in the ocean and the stations are on the west side of the epicentre, therefore the revision of reference travel time caused a significant correction of longitude.

Table 3. Averaged Corrections

| | Origin time (sec) | Latitude (deg) | Longitude (deg) | Depth (km) |
|---|---|---|---|---|
| Tohoku (A) | *+1.58* | +0.002 | *−0.026* | −0.02 |
| Tohoku (B) | *+2.64* | +0.010 | *−0.151* | *−12.7* |
| Tohoku (C) | *+1.96* | +0.008 | +0.081 | *−33.5* |
| Chubu (crust) | *+1.16* | +0.013 | −0.003 | *−9.54* |
| Chubu (mantle) | *+1.40* | −0.004 | +0.015 | −2.68 |

The correction to focal depth is negative for all regions. However, the values for *B* and especially *C* regions of Tohoku may not be trustworthy because our result is based on an over-simplified assumption that the crust under region *A* extends to these oceanic regions uniformly. For an accurate location of earthquake in these regions, we need a network of ocean-bottom seismograph stations.

The revised epicentres are shown in Fig. 4 and Fig. 6. The revised focal depths are shown in Fig. 5 and Fig. 7 in profiles taken perpendicular to the trend of Honshu Island (for Chubu along $A-A'$ in Fig. 6). These figures confirm the well-known fact that the shocks in the mantle occur in a zone which deepens towards the continent, the width of the zone being about 100 km, and that, in the land area, the seismic activity in the crust is separated from that in the mantle by an aseismic block of the upper mantle.

As mentioned before, *JMA* gives focal depths at 20 km steps and does not publish the error of depth determination. We gave the probable error for each earthquake in Table 3, from which we counted the number of earthquakes which show the error in specified ranges. The result is shown in Table 4. We see that the majority of earthquakes show the error less than 10 km, and most of them less than 20 km. Therefore, the step of 20 km taken by *JMA* seems to be appropriate.

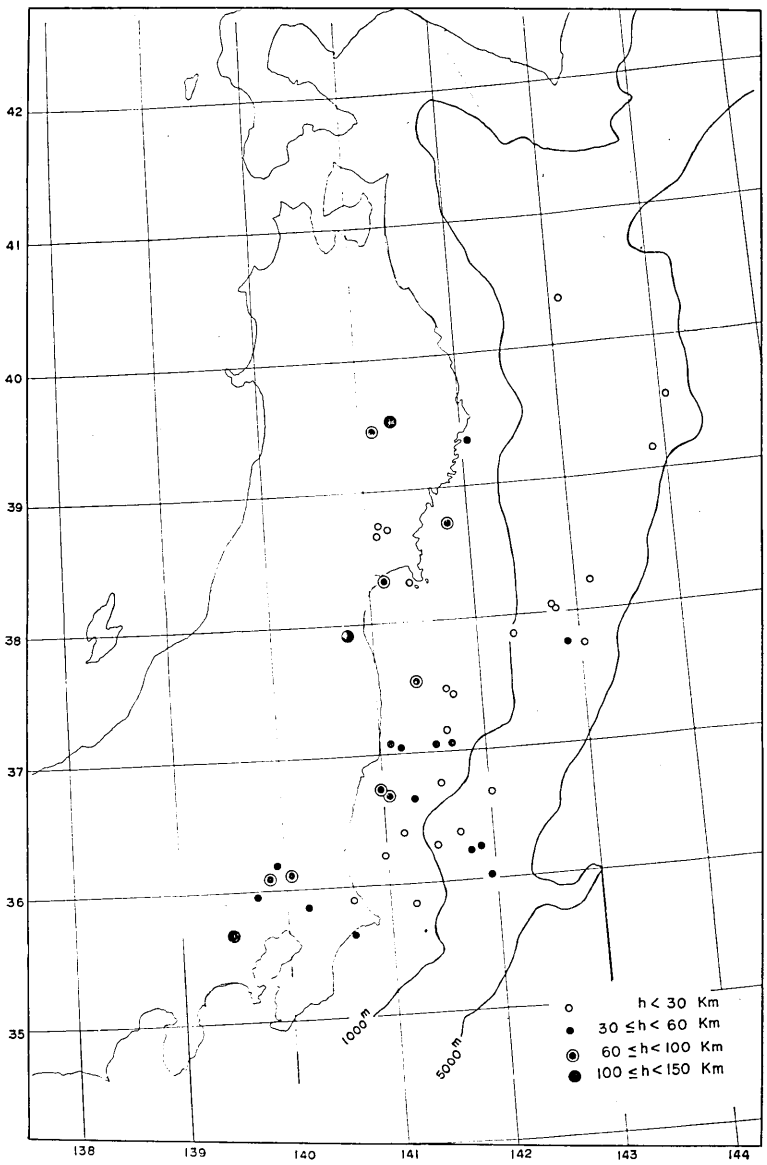


Fig. 4. Revised epicentres for Tohoku region

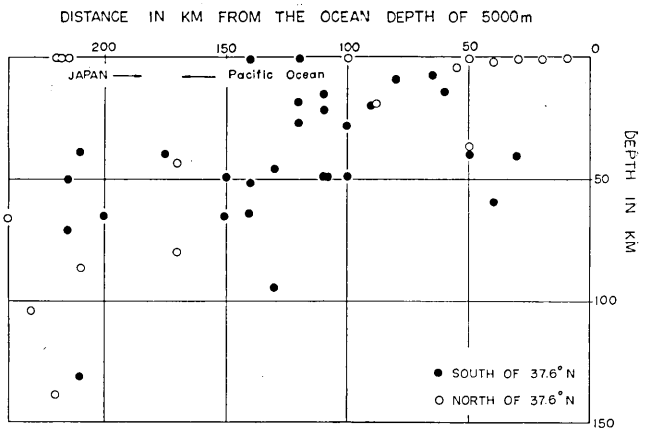


Fig. 5. Revised focal depths for Tohoku region

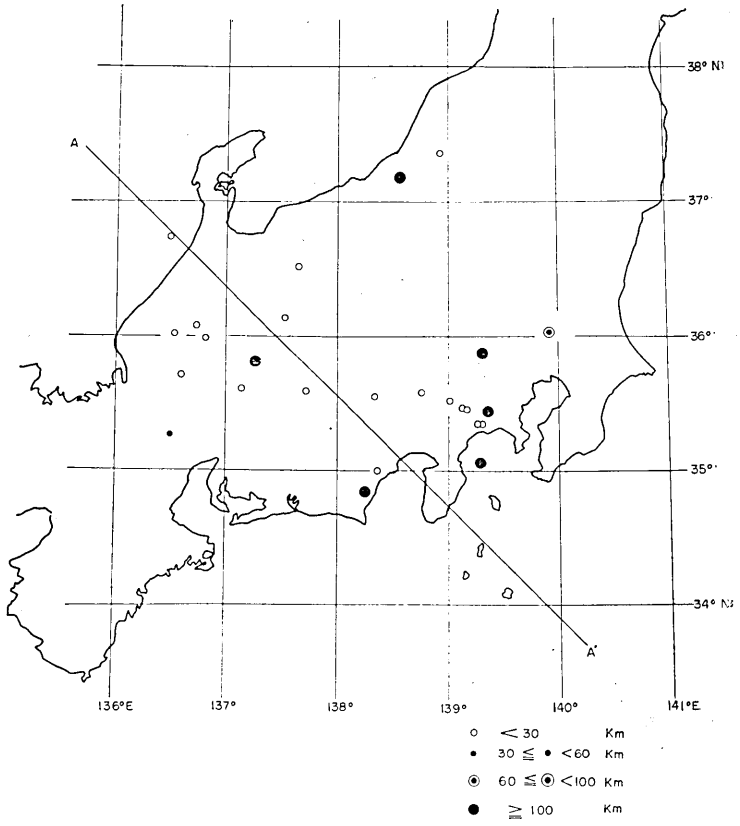


Fig. 6. Revised epicentres for Chubu region

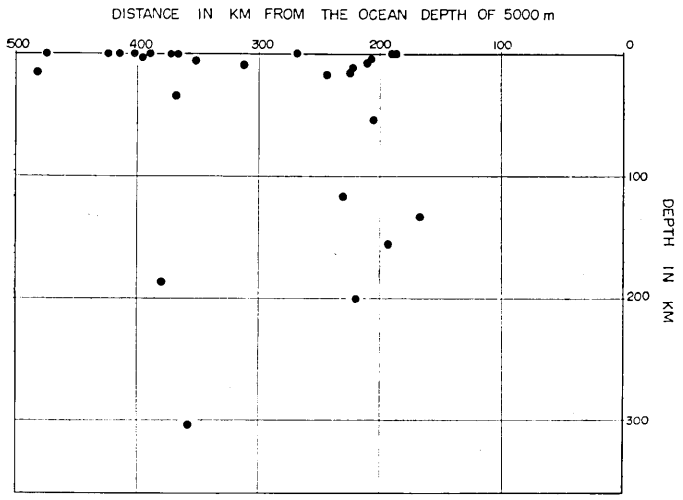


Fig. 7. Revised focal depths for Chubu region

Table 4. Number of shocks in given range of probable error of depth determination

| Probable error of depth | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 km | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Chubu | 9 | 6 | 4 | 3 | 0 | 1 | 1 | 0 | 2 | 26 |
| Tokoku (A) | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| Tohoku (B) | 4 | 10 | 4 | 5 | 0 | 1 | 0 | 0 | 1 | 25 |

# 3. 気象庁震源決定の精度

地震研究所 安芸敬一

気象庁が業務として行なつている地震観測資料の処理は，最近電子計算器の利用によつて著しく進歩した．しかし，よく知られているように，気象庁で震源決定に用いる和達・怒坂・益田の走時表は，爆破地震動研究グループによつて日本各地で観測された値とかなりくい違つている．そこで爆破グループの走時結果をよく説明するような地殻構造を基にして，気象庁地震月報の資料を用い，震源を決め直してみた．1961年および62年に，東北関東中部地方に生じた地震76個について調べた結果，次のような結論が得られた．

1. 震央の緯度に関しては，地殻構造を変えても有意義な差異を生じない．
2. 東北地方の沖の海の地震を除けば，経度についても同様のことがいえる．
3. 発震時については，気象庁の決めた値に，1乃至2秒加える必要がある．
4. 震源の深さについては東北地方の陸地では，有意義な差を認めなかつたが，中部地方では，気象庁発表のものは，約10キロ深すぎるようである．
5. 震源の深さの誤差は，probable error にして，過半数の地震について10キロ以下，大部分の地震で20キロ以下である．
6. 海におこる地震の正確な震源決定のためには，どうしても常設的海底地震観測網が必要である．