Spatial distribution of δD - $\delta^{18}O$ values of surface and shallow groundwaters from Japan, south Korea and east China

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Spatial distribution of δD and $\delta^{18}O$ values of surface water and shallow groundwaters from Japan, south Korea and east China was mapped with contours of 10 and 1‰ intervals for δD and $\delta^{18}O$, respectively, on the basis of the data base including more than 600 analyses made in the present and previous studies. The δD and $\delta^{18}O$ values generally decrease with increasing the latitude. There is a systematic decrease in δD and $\delta^{18}O$ values with contours of close intervals from the coast toward inland of southwestern Japan along the stream of the Kuroshio, a warm current in the Pacific Ocean. The δD and $\delta^{18}O$ lows are observed in mountainous inland of central and northern Japan and east China. The trends are comparable with those observed previously for the North American continent. The map will provide fundamental information for the studies of geochemical processes such as hydrology, water-rock interaction, and precipitation of authigenic minerals in which meteoric water is involved.

INTRODUCTION

The isotopic ratios of hydrogen (D/H) and oxygen ($^{18}O/^{16}O$) of meteoric waters at a given locality are related to geographical parameters, i.e., air temperature, latitude, altitude, distance from the coast, and intensity of precipitation (Dansgaard, 1964). Local climatic and topographic features can modify the above general variations. Large isotopic variations can occur within continents when major mountain ranges are involved as illustrated for North America (Taylor, 1974). The Japanese island arc, Korean peninsula and east China are situated on the eastern margin of the Eurasian continent. Among the regions, the Japanese islands extend in the north to southwest direction with complicated topography. Therefore, a large variation in the hydrogen and oxygen isotopic compositions of meteoric waters is expected in Japan. Besides that, marked seasonal changes in the source of wet air masses (Fukui, 1977), from which precipitations derive, could enhance the variation.

Oxygen and hydrogen isotopic data for local

meteoric waters are indispensable for discussing regional hydrology and water-rock interaction and mineral precipitation in the systems that are dominated by meteoric water. The purpose of this study is to supply a detailed picture of the spatial distribution of oxygen and hydrogen isotope compositions of meteoric waters in Japan, south Korea and east China.

A number of δD - $\delta^{18}O$ values have been reported for meteoric waters from the areas. However, they are for waters from the regions with a limited watershed. They include central-southern Hokkaido (Matsubaya *et al.*, 1978), Akita (Matsubaya and Etchu, 1987), Nagano (Matsubaya *et al.*, 1980), Gunma (Matsubaya *et al.*, 1985a), Toyama (Mizutani and Oda, 1983; Mizutani, 1986), except the work by Waseda and Nakai (1983) who measured the δD - $\delta^{18}O$ values of meteoric waters across central and northeast Japan. Besides these published data, we have analyzed the water samples collected systematically from whole Japan, south Korea and east China to map the geographical distribution of the δD and $\delta^{18}O$ values of meteoric water of the areas.

STRATEGY OF SAMPLE COLLECTION

The δD and $\delta^{18}O$ contours with 10 and 1‰ separation would be sufficient to use the map for practical applications. The separation is precise enough to illustrate the regional isotopic variations, and is an order of magnitude greater than the analytical errors in hydrogen and oxygen isotopic analyses of water samples. Firstly, all the literature δD - $\delta^{18}O$ data for the relevant areas were examined geographically. Data for thermal and mineral spring waters were excluded, because their isotopic compositions might have been modified by water-rock interaction and possible contamination with waters of other sources such as fossil seawater, connate water and magmatic water (Sakai and Matsubaya, 1974). Based on the examination, the areas with sparse δD - $\delta^{18}O$ data were chosen for additional sample collection.

Surface waters and specifically shallow groundwaters were collected in the present study, because they represent an average of annual precipitation for a given area. Precipitation waters (rain and snow) generally show a marked variation in δD - $\delta^{18}O$ values, whereas surface waters (river, stream and spring water) show a very limited variation due to leveling through infiltration, migration and issuing processes (Kusakabe *et al.*, 1970; Vogel and Vanurk, 1975; Matsuo *et al.*, 1985; Sanjo, 1991), giving an average value of precipitation. Shallow groundwaters whose depths are higher than that of the current river beds were also included. Localities of water samples including the sites for the literature values are shown in Fig. 1. The samples analyzed in the present study were collected mainly in late spring to autumn before snowing.

ANALYTICAL METHODS

Water samples were collected in a 50 ml polyethylene bottle with double seals. The D/H analysis of water samples was carried out by preparation of hydrogen from the water by a conventional zinc reduction technique (Coleman *et al.*, 1982), followed by the hydrogen isotope mass

spectrometry. The $^{18}O/^{16}O$ ratio of water samples was determined using the automated CO_2 - H_2O equilibration technique (Epstein and Mayeda, 1953; Chiba *et al.*, 1985), followed by the mass spectrometric measurements. The analytical errors of the isotopic measurements are ± 1.5 and ± 0.1 ‰ for δD and $\delta^{18}O$, respectively. All the hydrogen and oxygen isotopic ratios are presented by a common δ notation, permil deviation from those of the Vienna Standard Mean Ocean Water (V-SMOW, Coplen *et al.*, 1983).

Appendix includes all data necessary for the isotopic mapping including the literature values. Hydrogen isotope analysis was done for some selected samples which showed the lowest and highest $\delta^{18}O$ values in a region.

RESULTS AND DISCUSSION

Spatial distribution of δD and $\delta^{18}O$ values

There has been known a marked seasonal difference in the source of precipitation water in Japan (Suzuki, 1962; Fukui, 1977). It is considered that such a difference may cause systematic variations in the δD and $\delta^{18}O$ values of Japanese meteoric waters. All the water samples from Japan were classified into three groups as shown in Fig. 1, according to the climatic classification of Suzuki (1962). Zone I is characterized by high winter precipitation dominantly supplied by wet air mass from the Sea of Japan, whereas zone III represents summer rainfall dominantly derived from the Pacific Ocean. Zone II represents an intermediate area with less rainfall, sandwiched by zones I and III.

Figures 2 and 3 show the spatial distribution of the δD and $\delta^{18}O$ values with contours of 10 and 1‰ intervals for surface and shallow groundwaters from Japan, south Korea and east China. Relevant features can be summarized as follows.

1. There is a distinct tendency that the δD and $\delta^{18}O$ contours are nearly parallel to the latitude. Waters from lower latitudes are generally more enriched in D and ^{18}O than those from higher latitudes. The differences in δD and $\delta^{18}O$ values between the lowermost and highermost latitudes

Fig. 1. Map showing sample localities (dots) of surface and shallow groundwaters from Japan, south Korea and east China. Hatched areas show localities with dense sampling. Climatic zones were taken from Suzuki (1962). Zone I is characterized by winter precipitation, zone III by summer precipitation, and zone II is intermediate. Prefectural abbreviations are AOM; Aomori, AKT; Akita, IWT; Iwate, YGT; Yamagata, MYG; Miyagi, NGT; Niigata, FKS; Fukushima, NGN; Nagano, GUM; Gunma, TOC; Tochigi, IBR; Ibaraki, ISK; Ishikawa, TYM; Toyama, FKI; Fukui, GIF; Gifu, STM; Saitama, TYO; Tokyo, KNG; Kanagawa, CHB; Chiba, SIG; Shiga, AIC; Aichi, SZO; Shizuoka, HYG; Hyogo, KYO; Kyoto, OSK; Osaka, NAR; Nara, MIE; Mie, WKY; Wakayama, SMN; Shimane, TTR; Tottori, YAM; Yamaguchi, HRS; Hiroshima, OKY; Okayama, EHM; Ehime, KGW; Kagawa, KOC; Kochi, TKS; Tokushima, FKO; Fukuoka, NGS; Nagasaki, SAG; Saga, OIT; Oita, KMT; Kumamoto, MZK; Miyazaki, KGS; Kagoshima and ONW; Okinawa.

Fig. 2. Map showing δD contours of surface and shallow groundwaters from Japan and south Korea with the approximate average δD values (see text). Some δD values are shown for east China.

in the area are up to about 40 and 8‰, respectively. Waters from south Korea have rather a small variation up to 20‰ in δD and 5‰ in $\delta^{18}O$, respectively. This probably reflects less complicated topography than in Japan. The δD and $\delta^{18}O$ contours in east China are not shown in Figs. 2 and 3 because of a small number of sampling localities in the area. The δD and $\delta^{18}O$ values in east China increase systematically with increasing distance from the coast.

2. There is a systematic decrease in δD and $\delta^{18}O$ values with dense contours as we go from the coast toward inland of southwestern Japan along the stream of the Kuroshio, a warm current in the Pacific Ocean (Fig. 1). The Kuroshio warm current (average temperature of 15°C) is a major source of water vapor in the area. Such an isotopic trend observed in the region may be explained by Rayleigh fractional condensation processes of water vapor derived from the Kuroshio warm cur-

Fig. 3. Map showing $\delta^{18}O$ contours of surface and shallow groundwaters from Japan and south Korea with the approximate average $\delta^{18}O$ values (see text). Some $\delta^{18}O$ values are shown for east China.

rent. A similar feature has been reported for the Great Plain of the United States, although it covers much larger geographic areas (Taylor, 1974). The tendency is opposite to that observed in dry inland of Canada where enrichment of D and ^{18}O occurs in surface waters which have evaporated from soil surface under the continental climate. This phenomenon is called continentality by Hitchon and Krouse (1972).

3. In northeastern Japan, only a small δD and

$\delta^{18}O$ difference can be seen between the Sea of Japan and the Pacific Ocean coasts. This possibly indicates that wet air masses with similar δD and $\delta^{18}O$ values may be responsible for the precipitation for both regions, although the definite mechanism is not understood yet. Data of Waseda and Nakai (1983, their Figs. 8 and 9) also imply a comparable trend.

4. The δD and $\delta^{18}O$ lows are observed in mountainous districts. They are found in central

Japan with an average altitude as high as 3,000 m above sea level, backbone mountains of NE Japan, and around Mt. Yotei (42°49' N, 140°48' E) and Mt. Niseko (42°53' N, 140°28' E) volcanoes in Hokkaido. The isotopic lows are also found around Changbaishan volcano (42°01' N, 128°03' E) in east China (Figs. 1, 2 and 3). The tendency reflects the altitude effect (Dansgaard, 1964).

Relationships between δD and $\delta^{18}O$ values

The Japanese meteoric waters in Appendix are grouped for zone I, zone II and zone III, following the climatological zonation (Suzuki, 1962). The following regression equations are obtained for the δD and $\delta^{18}O$ values of waters from these three groups, i.e.,

$$\delta D = 7.17\delta^{18}O + 12.0$$

($n = 74$, $r^2 = 0.933$) for zone I,

$$\delta D = 7.07\delta^{18}O + 8.0$$

($n = 83$, $r^2 = 0.929$) for zone II, and

$$\delta D = 7.73\delta^{18}O + 12.7$$

($n = 145$, $r^2 = 0.957$) for zone III.

There can be seen a small difference in slopes of the equations. A greater slope is observed for zone III waters which are characterized by dominant summer precipitation. A shallower slope for zone II waters may result from possible contribution of evaporation during infiltration and issuing processes under the conditions of smaller rainfall.

It is not surprising that the slopes observed here are slightly different from that of a well known equation for the meteoric water line proposed by Craig (1961),

$$\delta D = 8\delta^{18}O + 10,$$

because this famous equation was derived from the isotopic analyses of worldwide freshwater including rivers, lakes, rain and snow, covering wide ranges from -320 to +40‰ for δD and -40 to +6‰ for $\delta^{18}O$. Our data points constitute only a part of his wide range. In addition, about 130 data

points presented in Craig's figure actually lie between two equations with the slopes between 7.4 and 8.3. A very good linear relationship exists between the amount weighted mean values of δD and $\delta^{18}O$ of the precipitation samples from the worldwide IAEA network (Yurtsever and Gat, 1981). This is expressed as

$$\delta D = (8.17 \pm 0.08)\delta^{18}O + (10.55 \pm 0.64)$$

($n = 74$, $r^2 = 0.997$, $\sigma = \pm 3.3\%$),

confirming Craig's equation. However, there are many examples where the δD - $\delta^{18}O$ relationship of precipitation in a given region differs from the global equation. A slope of 5-6 is known for arid and tropical regions. The slope of 8 of the meteoric water line, therefore, does not represent a continuous fractionation process, but rather reflects the integrated effects of climatic parameters and the isotopic difference in the source vapor (Gat, 1980).

Nevertheless, the "*d*-parameter" ($d = \delta D - 8\delta^{18}O$) defined by Dansgaard (1964) may be considered to bring about information regarding the source vapor and evaporative enrichment in D. Table 1 gives the *d*-parameters calculated for the meteoric water samples from the three climatic zones as previously described in this paper. Although the difference is not very significant, the average value of the *d*-parameters tends to be higher in zone I where winter precipitation is characterized by snow mainly supplied from the Sea of Japan. On the contrary, a lower value is seen for zone III, where major precipitation occurs as summer rainfall derived mainly from the Pacific Ocean. This is consistent with the observation made by Waseda and Nakai (1983) who noticed a

Table 1. The d-parameter (‰) of surface and groundwaters from zones I, II and III

Climatic zone	<i>d</i> -parameter	
	Range	Average
I	12 to 28	20
II	11 to 25	17
III	-4 to 24	15

clear tendency that d -parameter decreases from the Sea of Japan side (zone I) to the Pacific Ocean side (zone III) at both central and northeast Japan.

CONCLUSIONS

Spatial distribution of hydrogen and oxygen isotopic ratios of surface and shallow groundwaters from Japan, south Korea and east China was shown on a map with contours of 10 and 1‰ intervals for δD and $\delta^{18}O$, respectively. The map indicates the important effects of latitude, altitude and distance from coast on the δD and $\delta^{18}O$ distribution of meteoric waters in the areas studied.

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Appendix. Hydrogen and oxygen isotopic ratios of surface and ground waters from Japan, south Korea and east China

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
8 July 92	Soya, HKD	45°29'	141°54'	R	II		-10.5	This study
20 May 91	Wakkanai, HKD	45°25'	141°42'	R	II		-10.5	This study
8 June 92	Onishibetsu, HKD	45°19'	142°01'	G	II		-9.4	This study
8 June 92	Nitoromanai, HKD	45°17'	141°55'	R	II		-10.6	This study
8 June 92	Yuuchi, HKD	45°16'	141°37'	R	I		-10.8	This study
2 Jan. 91	Hamatonbetsu, HKD	45°07'	142°23'	R	II		-10.6	This study
30 Apr. 91	Nayoro, HKD	44°21'	142°28'	R	II	-67.1	-10.8	This study
29 May 91	Kamiyubetsu, HKD	44°09'	143°35'	R	I	-74.2	-12.2	This study
2 May 91	Abashiri, HKD	44°01'	144°17'	R	II		-10.5	This study
26 June 91	Rumoi, HKD	43°57'	141°40'	R	II	-74.1	-11.0	This study
20 July 91	Hamamasu, HKD	43°29'	141°25'	R	I		-10.7	This study
22 May 91	Furano, HKD	43°22'	142°24'	G	I	-61.0	-9.7	This study
20 July 91	Bibai, HKD	43°21'	141°52'	R	II	-76.9	-12.4	This study
20 July 91	Shippu, HKD	43°21'	141°27'	G	II	-74.0	-12.3	This study
27 Apr. 91	Asahikawa, HKD	43°17'	142°24'	G	II	-68.6	-10.4	This study
19 June 92	Ashoro, HKD	43°17'	143°36'	R	I	-81.0	-12.9	This study
31 July 91	Ashoro, HKD	43°15'	143°35'	G	III		-10.4	This study
29 May 91	Otaru, HKD	43°11'	141°01'	R	II	-62.2	-9.8	This study
20 May 91	Hamanaka, HKD	43°09'	145°07'	G	I		-11.3	This study
16 May 91	Ebetsu, HKD	43°07'	141°33'	G	III	-74.1	-11.0	This study
19 June 92	Yuutari, HKD	43°06'	143°32'	R	II	-81.0	-12.9	This study
29 May 91	Otofuke, HKD	43°04'	143°09'	G	III	-62.3	-10.0	This study
29 May 91	Otofuke, HKD	43°04'	143°09'	R	III	-76.9	-12.4	This study
28 Jan. 92	Kushiro, HKD	43°02'	144°23'	R	III		-10.7	This study
30 May 91	Shimizu, HKD	43°01'	142°51'	G	III		-9.8	This study
19 June 92	Shimizu, HKD	42°58'	142°54'	R	III		-11.3	This study
29 May 91	Ikeda, HKD	42°57'	143°28'	G	III		-9.8	This study
19 June 92	Oiwake, HKD	42°56'	141°53'	R	III	-52.8	-9.1	This study
20 July 91	Oiwake, HKD	42°53'	140°49'	G	II	-61.5	-10.4	This study
20 July 91	Eniwa, HKD	42°53'	140°32'	G	II	-68.6	-10.4	This study
19 June 92	Hidaka, HKD	42°53'	142°27'	G	II	-70.6	-12.0	This study
20 July 91	Kyogoku, HKD	42°52'	140°52'	G	II	-73.7	-11.2	This study
19 June 92	Hobetsu, HKD	42°46'	142°09'	G	II	-55.2	-8.9	This study
20 July 91	Rusuru, HKD	42°44'	140°54'	G	II	-62.9	-10.0	This study
18 May 91	Tomakomai, HKD	42°39'	141°33'	G	II	-59.9	-9.6	This study
20 July 91	Tomakomai, HKD	42°39'	141°31'	G	III	-74.2	-12.2	This study

20 July 91	Shiraori, HKD	42°34'	141°21'	G	III	-74.7	-11.2	This study
20 July 91	Usu, HKD	42°31'	140°47'	G	II	-69.5	-10.9	This study
20 July 91	Noboribetsu, HKD	42°28'	141°11'	G	II	-53.7	-8.3	This study
20 May 91	Urakawa, HKD	42°10'	142°47'	G	II	-54.3	-11.3	This study
16 May 91	Hakodate, HKD	41°48'	140°44'	G	II	-90.4	-9.3	This study
24 May 91	Shiruiuchi, HKD	41°37'	140°18'	G	II	-62.5	-13.7	This study
15 July 75	Oofunagawa, HKD			R	II	-62.5	-10.1	Matsubaya <i>et al.</i> (1978)
15 July 75	Nigorikawa, HKD			G	II	-62.7	-10.4	Matsubaya <i>et al.</i> (1978)
15 July 75	Yurappu, HKD			R	II	-59.3	-9.9	Matsubaya <i>et al.</i> (1978)
15 July 75	Raiden-Asahi, HKD			R	II	-66.2	-11.3	Matsubaya <i>et al.</i> (1978)
15 July 75	Nimi, HKD			G	I	-72.0	-12.0	Matsubaya <i>et al.</i> (1978)
15 July 75	Rangoshi, HKD			R	II	-70.1	-11.6	Matsubaya <i>et al.</i> (1978)
15 July 75	Konbu, HKD			G	II	-71.2	-11.9	Matsubaya <i>et al.</i> (1978)
15 July 75	Niseko-Ohyu, HKD			R	II	-69.7	-11.8	Matsubaya <i>et al.</i> (1978)
15 July 75	Yunosawagawa, HKD			R	I	-78.5	-12.5	Matsubaya <i>et al.</i> (1978)
15 July 75	Shiraigawa, HKD			R	I	-78.6	-12.7	Matsubaya <i>et al.</i> (1978)
15 July 75	Noboribetsu, HKD			R	II	-61.9	-9.8	Matsubaya <i>et al.</i> (1978)
15 July 75	Idashubetsu, HKD			R	II	-80.1	-12.3	Matsubaya <i>et al.</i> (1978)
15 July 75	Iwaobetsu, HKD			R	II	-85.0	-12.0	Matsubaya <i>et al.</i> (1978)
15 July 75	Horohestu, HKD			R	II	-78.5	-11.5	Matsubaya <i>et al.</i> (1978)
15 July 75	Shibetsugawa, HKD			R	II	-78.2	-11.6	Matsubaya <i>et al.</i> (1978)
15 July 75	Amemasugawa, HKD			R	II	-75.5	-11.2	Matsubaya <i>et al.</i> (1978)
9 Aug. 86	Okirika, HKD			R	I	-76.5	-12.2	Matsubaya <i>et al.</i> (1978)
	Ishikarigawa, HKD			R	II	-67.7	-11.9	Inoue <i>et al.</i> (1985)
6 Aug. 85	Noishi, HKD			R	II	-61.9	-10.3	NEDO (1990a)
2 July 92	Nigorikawa, HKD			R	II	-89.0	-9.6	Yoshida (1990)
2 July 92	Kamikawa, HKD			R	II	-72.0	-13.4	NEDO (1991b)
	Akan, HKD			R	II	-76.0	-10.6	NEDO (1992)
	Ashoro, HKD			R	III		-11.1	NEDO (1992)
15 Sept. 91	Aomori, AOM	40°49'	140°46'	G	I	-55.9	-9.7	This study
7 May 91	Kuroishi, AOM	40°39'	140°38'	R	I	-66.7	-11.3	This study
21 Oct. 91	Shimofuro, AOM	41°29'	141°06'	R	II		-9.0	This study
22 Apr. 91	Ken-yoshi, AOM	40°28'	141°22'	R	II		-10.2	This study
4 June 73	Owani, AOM			G	I	-57.1	-9.2	Matsubaya <i>et al.</i> (1975a)
4 June 91	Hiraga, AOM			R	I	-65.1	-10.8	Matsubaya <i>et al.</i> (1975a)
4 June 91	Ikarigaseki, AOM			R	I	-57.2	-9.5	Matsubaya <i>et al.</i> (1975a)
27 May 81	Hachinohe, AOM			R	II	-59.9	-9.2	Marumo <i>et al.</i> (1982)
13 Sept. 85	Hakkoda, AOM			G	II	-66.4	-11.3	NEDO (1986a)
23 Sept. 84	Hakkoda, AOM			R	II	-69.5	-11.5	NEDO (1986a)
	Fukaura, AOM			R	I	-49.2	-8.2	Matsubaya and Fukudome (1989)

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
	Osorezan, AOM			R	I	-56.0	-9.5	Aoki (1992)
June 91	Oga, AKT	39°55'	139°55'	R	I	-52.1	-9.3	This study
25 June 91	Akita, AKT	39°45'	140°09'	R	I	-45.3	-8.2	This study
2 July 91	Akita, AKT	39°44'	140°09'	R	I	-50.6	-8.9	This study
23 June 91	Akita, AKT	39°43'	140°08'	G	I		-8.5	This study
30 May 92	Yuwa, AKT	39°37'	140°13'	R	I		-8.9	This study
21 Sept. 90	Nangaimura, AKT	39°27'	140°20'	R	I		-8.2	This study
	Oodate, AKT			G	I	-54.0	-8.9	Matsubaya <i>et al.</i> (1973)
4 June 73	Oodate, AKT			R	I	-56.3	-9.2	Matsubaya <i>et al.</i> (1973)
4 June 73	Tamagawa, AKT			R	I	-65.0	-11.0	Matsubaya <i>et al.</i> (1973)
4 June 91	Gojome, AKT			R	I	-55.7	-9.1	Matsubaya <i>et al.</i> (1975)
4 June 91	Noshiro, AKT			R	I	-54.5	-9.2	Matsubaya <i>et al.</i> (1975)
4 June 91	Gojome, AKT			R	I	-46.5	-7.7	Matsubaya <i>et al.</i> (1975)
	Goshogake, AKT			R	I	-67.4	-11.5	Matsubaya <i>et al.</i> (1975)
26 May 81	Tazawa, AKT			R	I	-58.0	-9.7	Matsubaya <i>et al.</i> (1975)
27 May 81	Yatate, AKT			R	I	-55.6	-9.1	Matsubaya <i>et al.</i> (1983)
19 Oct. 82	Kazuno, AKT			R	II	-60.6	-10.2	Matsubaya <i>et al.</i> (1983)
26 May 82	Hinai, AKT			R	I	-56.5	-9.6	Matsubaya <i>et al.</i> (1983)
19 Oct. 82	Soma, AKT			R	I	-56.6	-10.0	Matsubaya <i>et al.</i> (1983)
19 Oct. 82	Moriyoshi, AKT			R	I	-62.3	-10.5	Matsubaya <i>et al.</i> (1983)
26 May 81	Fujisato, AKT			R	I	-52.1	-8.9	Matsubaya <i>et al.</i> (1983)
26 May 81	Futatsui, AKT			G	I	-50.9	-8.7	Matsubaya <i>et al.</i> (1983)
25 Oct. 82	Moritake, AKT			R	I	-52.1	-8.0	Matsubaya <i>et al.</i> (1983)
28 May 81	Ogura, AKT			R	I	-51.2	-8.3	Matsubaya <i>et al.</i> (1983)
28 May 81	Kainosawa, AKT			R	I	-50.5	-8.9	Matsubaya <i>et al.</i> (1983)
	Shibari, AKT			R	I	-72.4	-11.6	Matsubaya <i>et al.</i> (1983)
	Akagawa, AKT			R	I	-72.2	-11.9	Matsubaya <i>et al.</i> (1983)
20 Oct. 82	Toroko, AKT			R	I	-68.3	-11.4	Matsubaya <i>et al.</i> (1983)
26 Sept. 80	Goshogake, AKT			R	I	-71.2	-11.7	Matsubaya <i>et al.</i> (1983)
25 Sept. 80	Ohbuka, AKT			R	I	-69.3	-11.8	Matsubaya <i>et al.</i> (1983)
	Fukenyoyu, AKT			R	I	-69.8	-11.4	Matsubaya <i>et al.</i> (1983)
20 Oct. 82	Sakebisawa, AKT			R	I	-66.2	-10.6	Matsubaya <i>et al.</i> (1983)
2 Oct. 81	Tamagawa, AKT			R	I	-67.4	-11.1	Matsubaya <i>et al.</i> (1983)
2 Oct. 81	Shinhatonoyu, AKT			R	I	-55.8	-9.7	Matsubaya <i>et al.</i> (1983)
22 Nov. 82	Ganiba, AKT			R	I	-66.5	-10.6	Matsubaya <i>et al.</i> (1983)
24 June 81	Oogama, AKT			R	I	-66.8	-10.8	Matsubaya <i>et al.</i> (1983)
	Iwakura, AKT			R	I	-51.7	-9.3	Matsubaya <i>et al.</i> (1983)
	Konoura, AKT			R	I	-63.6	-10.3	Matsubaya <i>et al.</i> (1983)

Date	Location	Sample	Type	R	I	Value	Reference
15 Sept. 84	Omonogawa, AKT			R	I	-9.3	Inoue <i>et al.</i> (1985)
21 July 88	Nyuto, AKT			R	II	-10.3	Matsubaya <i>et al.</i> (1985b)
	Yokote, AKT			R	I	-9.6	Matsubaya and Etschu (1987)
3 June 91	Karumai, IWT	40°20'		R	II	-9.7	This study
31 July 91	Joboji, IWT	40°11'		R	II	-10.5	This study
15 Sept. 91	Miyata, IWT	40°11'		R	II	-10.3	This study
June, 93	Nodatoge, IWT	40°09'		R	III	-9.0	This study
2 July 91	Joboji, IWT	40°09'		G	II	-11.4	This study
2 July 91	Arayashinmachi, IWT	40°06'		R	II	-10.4	This study
2 July 91	Tashirota, IWT	40°05'		G	II	-11.2	This study
2 July 91	Terada, IWT	39°59'		R	II	-10.8	This study
15 Sept. 91	Maemori, IWT	39°59'		R	II	-11.4	This study
3 June 91	Hachimantai, IWT	39°58'		R	II	-9.8	This study
30 May 92	Goshikinuma, IWT	39°58'		G	II	-12.1	This study
16 June 92	Matsuo, IWT	39°55'		G	II	-11.9	This study
2 July 91	Oobuke, IWT	39°55'		G	II	-11.5	This study
12 Mar. 93	Nameiri, IWT	39°54'		G	I	-10.2	This study
30 May 92	Oide, IWT	39°52'		G	II	-10.7	This study
16 June 92	Oide, IWT	39°52'		G	II	-11.1	This study
13 May 91	Himekami, IWT	39°51'		R	II	-10.1	This study
20 May 91	Himekami, IWT	39°51'		R	II	-10.4	This study
11 May 91	Shizukuishi, IWT	39°44'		R	II	-10.9	This study
7 June 91	Morioka, IWT	39°42'		G	II	-9.4	This study
7 May 91	Miyako, IWT	39°39'		R	III	-9.8	This study
7 May 91	Heii, IWT	39°38'		R	II	-9.5	This study
12 Mar. 93	Sawauchi, IWT	39°26'		G	II	-9.6	This study
11 May 91	Kitakami, IWT	39°18'		R	II	-10.2	This study
5 June 91	Kamaishi, IWT	39°18'		R	III	-9.6	This study
17 Oct. 92	Yukawanuma, IWT	39°17'		R	II	-9.9	This study
30 May 92	Waga, IWT	39°15'		R	II	-10.3	This study
26 Oct. 91	Taneyama, IWT	39°10'		R	II	-9.9	This study
21 Oct. 91	Sumita, IWT	39°09'		R	II	-9.4	This study
21 Oct. 91	Sumita, IWT	39°09'		R	II	-8.3	This study
10 Nov. 91	Mizusawa, IWT	39°09'		R	II	-8.5	This study
21 Oct. 91	Oofunato, IWT	39°06'		R	III	-8.1	This study
16 Nov. 91	Oofunato, IWT	39°02'		R	III	-7.9	This study
7 Dec. 91	Maesawa, IWT	39°02'		R	II	-8.8	This study
23 May 91	Ichinoseki, IWT	38°57'		R	II	-10.0	This study
	Kiakamigawa, IWT			R	II	-9.1	Inoue <i>et al.</i> (1985)
8 July 82	Matsukawa, IWT			R	II	-11.1	Matsubaya <i>et al.</i> (1985b)
				R	II	-72.5	

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
6 June 82	Kakkonda, IWT			R	II	-68.5	-10.8	Matsubaya <i>et al.</i> (1985b)
25 Aug. 85	Amihari, IWT			R	II	-68.8	-11.1	Matsubaya <i>et al.</i> (1985b)
21 Oct. 91	Mamuro, YGT	38°56'	140°13'	R	I		-9.8	This study
26 Sept. 91	Shinjo, YGT	38°47'	140°19'	R	I		-10.2	This study
27 Apr. 91	Shinjo, YGT	38°47'	140°19'	R	I	-62.7	-10.9	This study
15 Sept. 91	Tsuruoka, YGT	38°45'	139°52'	R	I	-49.2	-9.2	This study
3 May 91	Yamagata, YGT	38°17'	140°22'	R	I		-10.6	This study
30 Sept. 81	Mogamigawa, YGT			R	I		-9.6	Inoue <i>et al.</i> (1985)
1 Oct. 81	Mogamigawa, YGT			R	I		-10.0	Inoue <i>et al.</i> (1985)
	Obanzawa, YGT			R	I	-56.0	-9.8	NEDO (1991c)
7 Dec. 91	Chusonji, MYG	38°59'	141°06'	R	II		-9.6	This study
9 June 91	Ishinomaki, MYG	38°58'	141°19'	R	III	-48.3	-7.8	This study
2 July 91	Honshioyama, MYG	38°49'	141°02'	R	I	-58.6	-10.1	This study
7 Dec. 91	Kannari, MYG	38°48'	141°06'	R	II		-9.1	This study
7 Dec. 91	Shiwahime, MYG	38°46'	141°04'	R	II		-9.6	This study
7 Dec. 91	Narugo, MYG	38°45'	140°42'	R	II		-9.9	This study
27 Nov. 90	Utsu, MYG	38°43'	141°31'	G	III		-7.4	This study
25 June 91	Chojabaru, MYG	38°38'	140°57'	R	II	-55.6	-9.0	This study
9 June 91	Kogota, MYG	38°34'	141°03'	R	II	-48.1	-7.9	This study
7 Dec. 91	Sanbongi, MYG	38°31'	140°55'	R	II	-59.6	-10.0	This study
7 Dec. 91	Tsurusu, MYG	38°25'	140°53'	R	II		-9.9	This study
4 May 92	Izumi, MYG	38°21'	140°53'	R	II		-8.8	This study
7 June 91	Sendai, MYG	38°17'	140°54'	R	III	-48.6	-8.2	This study
3 May 92	Sendai, MYG	38°15'	140°52'	R	III	-50.4	-8.4	This study
7 Dec. 91	Sendai, MYG	38°13'	140°49'	R	II		-8.6	This study
17 Oct. 92	Shiroishi, MYG	38°03'	140°39'	R	II		-10.8	This study
20 June 92	Kamasaki, MYG	38°02'	140°35'	R	II		-9.1	This study
13 Mar. 93	Zao Spa, MYG	38°00'	140°25'	R	II		-11.3	This study
1 Apr. 92	Niizu, NGT	37°48'	139°08'	R	I	-61.9	-10.6	This study
1 Apr. 92	Shirane, NGT	37°45'	139°01'	R	I		-10.7	This study
17 June 91	Sado, NGT	37°41'	138°16'	G	I	-46.0	-8.2	This study
1 Apr. 92	Nagaoka, NGT	37°26'	138°53'	R	I		-10.8	This study
31 Mar. 92	Kashiwazaki, NGT	37°22'	138°36'	R	I	-47.2	-9.4	This study
Jan. 73	Senami, NGT			G	I	-46.4	-8.2	Matsubaya <i>et al.</i> (1973)
Jan. 73	Senami, NGT			R	I	-48.4	-9.0	Matsubaya <i>et al.</i> (1973)
Jan. 73	Muikamachi, NGT			R	I	-56.9	-10.2	Matsubaya <i>et al.</i> (1973)

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
26 Apr. 91	Ichihara, CHB	35°29'	140°08'	R	III	-33.2	-6.2	This study
14 July 91	Narita, CHB	35°46'	140°23'	G	III	-61.2	-8.9	This study
9 Sept. 83	Tonegawa, CHB			R	III		-10.4	Inoue <i>et al.</i> (1985)
	Kamogawa, CHB			G	III		-5.3	Yoshida and Miyazaki (1991)
17 Oct. 76	Kusatsu, GUM			G	III	-77.4	-11.9	Matsubaya <i>et al.</i> (1973)
17 Oct. 76	Manza, GUM			R	I	-84.5	-13.0	Matsubaya <i>et al.</i> (1973)
17 Oct. 76	Iriyama, GUM			R	III	-79.3	-12.0	Matsubaya <i>et al.</i> (1980)
	Shitsubo, GUM			R	III	-79.7	-11.6	Matsubaya <i>et al.</i> (1980)
	Kakuma, GUM			R	III	-86.7	-13.1	Matsubaya <i>et al.</i> (1980)
27 Oct. 82	Katashina, GUM			R	II	-80.7	-12.3	Matsubaya <i>et al.</i> (1985a)
16 Aug. 80	Tanigawa, GUM			R	II	-67.8	-10.6	Matsubaya <i>et al.</i> (1985a)
16 Aug. 80	Numata, GUM			G	III	-64.9	-9.7	Matsubaya <i>et al.</i> (1985a)
16 Sept. 83	Shima, GUM			R	III	-71.4	-10.9	Matsubaya <i>et al.</i> (1985a)
13 Nov. 83	Shima, GUM			R	III	-68.4	-10.4	Matsubaya <i>et al.</i> (1985a)
16 Sept. 83	Kazawa, GUM			R	III	-85.8	-12.5	Matsubaya <i>et al.</i> (1985a)
8 Oct. 82	Yagenzawa, GUM			R	III	-83.6	-12.3	Matsubaya <i>et al.</i> (1985a)
21 Aug. 83	Koikegawa, GUM			R	III	-80.9	-11.9	Matsubaya <i>et al.</i> (1985a)
6 Oct. 82	Nurugawa, GUM			R	III	-65.1	-10.0	Matsubaya <i>et al.</i> (1985a)
22 Apr. 82	Kawanaka, GUM			R	III	-67.9	-9.6	Matsubaya <i>et al.</i> (1985a)
13 Oct. 81	Nyogi, GUM			G	III	-59.9	-8.9	Matsubaya <i>et al.</i> (1985a)
	Nogurisawa, GUM			R	III	-75.0	-11.1	Matsubaya <i>et al.</i> (1985a)
	Hoshio, GUM			R	III	-71.4	-10.1	Matsubaya <i>et al.</i> (1985a)
3 June 91	Kisofukushima, NGN	35°51'	137°42'	R	II		-10.9	This study
21 Oct. 91	Sugadaira, NGN	36°32'	138°20'	R	II	-88.0	-13.0	This study
17 Oct. 76	Kashio, NGN			G	III	-74.9	-11.3	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Kashio, NGN			R	III	-71.0	-11.1	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Kamisawa, NGN			G	III	-79.1	-11.6	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Kamisawa, NGN			G	III	-82.4	-12.3	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Tobira, NGN			R	III	-76.7	-11.6	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Shibu, NGN			R	II	-81.0	-11.5	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Nozawa, NGN			R	I	-73.2	-12.2	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Hoshina, NGN			R	II	-80.2	-11.8	Matsubaya <i>et al.</i> (1980)
17 Oct. 76	Matsushiro, NGN			R	II	-80.2	-11.8	Matsubaya <i>et al.</i> (1980)
	Kashio, NGN			R	III	-73.7	-11.6	Masuda <i>et al.</i> (1988)
	Ina, NGN			R	II	-71.8	-10.6	Marumo <i>et al.</i> (1982)
31 Mar. 92	Takko, TYM	36°49'	136°59'	R	I		-8.6	This study

	Toyama, TYM	Kurobegawa, TYM	G	III	-9.7 -13.0	Mizutani and Oda (1983) Satake <i>et al.</i> (1984)
31 Mar. 92	Kamikobaru, ISK	36°53'	R	I	-8.8	This study
31 Mar. 92	Kamikobaru, ISK	36°57'	R	I	-8.5	This study
31 Mar. 92	Yokota, ISK	37°10'	R	I	-51.0	This study
31 Mar. 92	Omata, ISK	37°16'	R	I	-8.6	This study
31 Mar. 92	Yunokawa, ISK	37°05'	R	I	-8.2	This study
Mar. 72	Suzu, ISK		G	I	-43.5	Matsubaya <i>et al.</i> (1973)
Sept. 73	Kanazawa, ISK		G	I	-47.6	Matsubaya <i>et al.</i> (1973)
27 May 91	Fukui, FKI	36°03'	R	I	-8.8	This study
3 Apr. 91	Mizunami, AIC	35°22'	R	III	-47.0	This study
5 Aug. 91	Toyohashi, AIC	34°46'	R	III	-7.2	This study
5 Aug. 91	Okazaki, AIC	34°57'	R	III	-45.9	This study
5 Aug. 91	Nagoya, AIC	35°09'	R	III	-9.9	This study
	Kisogawa, AIC		R	III	-9.6	Inoue <i>et al.</i> (1985)
	Naegi, AIC		R	III	-64.8	Marumo <i>et al.</i> (1982)
8 Aug. 91	Shizuoka, SZO	35°09'	R	III	-8.4	This study
5 Aug. 91	Hamamatsu, SZO	34°43'	R	III	-9.9	This study
7 Feb. 92	Nihondaira, SZO	34°58'	R	III	-44.3	This study
	Shimogamo, SZO		R	III	-41.1	Mizutani and Hamasuna (1972)
July 73	Atami, SZO		G	III	-48.6	Matsubaya <i>et al.</i> (1973)
July 73	Atami, SZO		G	III	-49.0	Matsubaya <i>et al.</i> (1973)
July 73	Itoh, SZO		R	III	-43.3	Matsubaya <i>et al.</i> (1973)
July 73	Atagawa, SZO		R	III	-40.3	Matsubaya <i>et al.</i> (1973)
July 73	Atagawa, SZO		G	III	-41.1	Matsubaya <i>et al.</i> (1973)
July 73	Fujigawa, SZO		R	III	-8.6	Inoue <i>et al.</i> (1985)
	Tenrugawa, SZO		R	III	-9.9	Inoue <i>et al.</i> (1985)
1 Apr. 91	Shinohara, SIG	35°06'	R	II	-44.9	This study
1 Apr. 91	Maibara, SIG	35°19'	G	II	-7.3	This study
3 Apr. 91	Ise, MIE	34°29'	R	III	-36.1	This study
	Wakayama, WKY	34°22'	R	III	-7.6	This study
	Hashimoto, WKY	34°19'	R	III	-8.5	This study
	Shingu, WKY		R	III	-32.9	Matsubaya <i>et al.</i> (1973)
June 73	Shirahama, WKY		R	III	-36.2	Matsubaya <i>et al.</i> (1973)

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
Sept. 73	Nachi, WKY Shingu, WKY Shingu, WKY			R R R	III III III	-34.4 -43.9 -35.3	-6.1 -7.2 -6.5	Matsubaya <i>et al.</i> (1973) Masuda (1986) Masuda (1986)
July 73	Ryujin, NAR Yoshino, NAR Yoshino, NAR Yoshino, NAR Yoshino, NAR Totsukawa, NAR	33°57'	135°33'	R R R R R R	II III III III III II	-50.5 -54.9 -45.6 -57.4 -46.0	-9.1 -8.7 -8.9 -7.7 -8.4 -7.5	This study Masuda (1986) Masuda (1986) Masuda (1986) Masuda (1986) Matsubaya <i>et al.</i> (1973)
21 June 91	Ashu, KYO Maizuru, KYO	35°18'	135°42'	R R	II II	-51.7	-9.1 -8.2	This study Inoue <i>et al.</i> (1985)
Jan. 73 Feb. 73	Kawachinagano, OSK Kawachinagano, OSK Yodogawa, OSK			G R R	III III III	-48.2 -52.0	-7.4 -7.9 -7.8	Matsubaya <i>et al.</i> (1973) Matsubaya <i>et al.</i> (1973) Inoue <i>et al.</i> (1985)
28 Jan. 92 15 Jan. 92 Jan. 73 Feb. 73	Nishinomiya, HYG Takazazuka, HYG Arima, HYG Mikaeribashi, HYG Mino, HYG Yunesaki, HYG Ginzan, HYG Shikano, HYG Sanaka, HYG	34°44' 34°49'	135°16' 135°21'	G G R R R R R R R	III III III III III III III III III	-39.9 -41.9 -49.1 -46.8 -44.6 -44.7 -50.5 -56.5 -52.0	-6.7 -7.1 -8.0 -7.3 -7.6 -7.1 -7.6 -7.9 -8.4	This study This study Matsubaya <i>et al.</i> (1973) Masuda <i>et al.</i> (1985) Masuda <i>et al.</i> (1985) Masuda <i>et al.</i> (1985) Masuda <i>et al.</i> (1985) Masuda <i>et al.</i> (1985) Masuda <i>et al.</i> (1985)
24 Aug. 91 24 Aug. 91 24 Aug. 91	Kurayoshi, TTR Yonago, TTR Urayasu, TTR Kurayoshi, TTR	35°28' 35°25' 35°19'	133°51' 133°20' 133°41'	R R R R	II III I III	-48.5 -54.0	-8.8 -8.5 -8.2 -9.1	This study This study This study Matsubaya <i>et al.</i> (1973)
20 July 91 23 Oct. 91 31 Oct. 91 18 Oct. 91	Oki, SMN Yatsuka, SMN Nishikawazu, SMN Masuda, SMN Masue, SMN Ooda, SMN	36°01' 35°24' 35°19' 34°41'	133°02' 133°09' 133°05' 131°50'	G G G R R R	II II II III III II	-7.6 -8.1 -7.8 -7.8 -8.3 -8.0	-7.6 -8.1 -7.8 -7.8 -8.3 -8.0	This study This study This study This study Inoue <i>et al.</i> (1985) Inoue <i>et al.</i> (1985)

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
29 Sept. 91	Hojo, EHM	33°56'	132°41'	R	III		-7.1	This study
29 Sept. 91	Tanbara, EHM	33°56'	133°03'	R	III		-8.5	This study
29 Sept. 91	Matsuyama, EHM	33°53'	132°53'	R	III		-8.2	This study
29 Sept. 91	Matsuyama, EHM	33°52'	132°52'	G	III		-8.3	This study
29 Sept. 91	Matsuyama, EHM	33°52'	132°52'	R	III	-51.6	-8.3	This study
29 Sept. 91	Tanbara, EHM	33°51'	132°02'	R	III	-53.4	-8.5	This study
29 Sept. 91	Tanbara, EHM	33°49'	132°59'	R	III		-7.8	This study
2 Oct. 91	Kuma, EHM	33°42'	132°53'	R	II	-54.7	-8.9	This study
2 Oct. 91	Yoshikawa, EHM	33°35'	132°59'	R	II		-8.6	This study
2 Oct. 91	Kuma, EHM	33°37'	132°55'	R	II		-8.2	This study
1 Oct. 91	Uchiko, EHM	33°33'	132°39'	R	II		-7.4	This study
26 Apr. 91	Oozu, EHM	33°31'	132°33'	R	II	-41.9	-7.2	This study
1 Oct. 91	Yahatahama, EHM	33°27'	132°26'	R	II	-47.3	-7.8	This study
1 Oct. 91	Yahatahama, EHM	33°27'	132°26'	R	II		-8.1	This study
1 Oct. 91	Uwajima, EHM	33°14'	132°35'	R	II		-6.8	This study
1 Oct. 91	Uwajima, EHM	33°14'	132°35'	G	III	-41.8	-6.6	This study
	Nihama, EHM			R	II	-50.5	-8.2	Masuda (1986)
	Iyomishima, EHM			R	III	-59.7	-8.4	Masuda (1986)
2 Oct. 91	Nagaoka, KOC	33°50'	133°47'	R	III		-7.8	This study
2 Oct. 91	Ootoyo, KOC	33°47'	133°42'	R	III		-7.2	This study
2 Oct. 91	Nangoku, KOC	33°39'	133°38'	R	III	-34.0	-6.5	This study
2 Oct. 91	Agawa, KOC	33°34'	133°08'	R	III	-43.8	-7.9	This study
17 Nov. 91	Monomobegawa, KOC	33°33'	133°28'	R	III		-6.4	This study
2 Oct. 91	Takaoka, KOC	33°33'	133°13'	R	III		-6.9	This study
2 Oct. 91	Ino, KOC	33°33'	133°26'	R	III		-7.0	This study
30 Dec. 91	Ikumi, KOC	33°31'	134°17'	R	III		-6.0	This study
2 Oct. 91	Sagawa, KOC	33°31'	133°17'	R	III		-6.9	This study
30 Dec. 91	Teyui, KOC	33°31'	133°46'	R	II	-28.2	-5.9	This study
30 Dec. 91	Anaichigawa, KOC	33°31'	133°52'	R	III		-6.1	This study
30 Dec. 91	Namuragawa, KOC	33°27'	133°57'	R	III		-6.5	This study
30 Dec. 91	Misaki, KOC	33°27'	134°14'	R	III	-32.4	-6.2	This study
30 Dec. 91	Biwanotaki, KOC	33°26'	134°00'	R	III		-6.3	This study
30 Dec. 91	Hakegatani, KOC	33°24'	134°03'	R	III		-6.0	This study
30 Dec.	Ozakigawa, KOC	33°22'	134°12'	R	III		-6.3	This study
26 Dec. 91	Kokura, FKO	33°52'	130°50'	R	III	-40.4	-7.3	This study
7 May 91	Mizumaki, FKO	33°51'	130°41'	R	III	-36.8	-6.4	This study
30 Apr. 91	Ikuhashi, FKO	33°44'	130°58'	G	III	-40.5	-7.0	This study

25 Dec. 91	Fukuoka, FKO	33°34'	130°23'	G	III		-7.2	This study
6 Jan. 93	Sagittagawa, FKO	33°29'	130°29'	R	III		-7.0	This study
6 Jan. 93	Futsukaichi, FKO	33°29'	130°32'	G	III		-6.9	This study
18 Aug. 91	Futsukaichi, FKO	33°29'	130°32'	G	III	-43.4	-7.4	This study
16 Aug. 91	Tanushimaru, FKO	33°21'	130°41'	G	III		-7.5	This study
25 July 92	Ukiha, FKO	33°20'	130°46'	G	III	-42.3	-7.6	This study
13 Nov. 91	Kurume, FKO	33°17'	130°31'	G	III	-42.9	-7.0	This study
25 July 92	Hainuzuka, FKO	33°13'	130°30'	G	III		-6.7	This study
15 Aug. 91	Yame, FKO	33°12'	130°32'	G	III		-6.7	This study
25 July 92	Funagoya, FKO	33°11'	130°31'	R	III		-7.4	This study
16 Aug. 91	Yamawaka, FKO	33°07'	130°31'	G	III		-7.1	This study
6 Jan. 93	Omuta, FKO	33°02'	130°27'	R	III		-7.0	This study
	Fukuoka, FKO			R	III	-47.0	-6.8	Kokubu <i>et al.</i> (1961)
	Fukuoka, FKO			R	III	-44.0	-6.6	Kokubu <i>et al.</i> (1961)
	Yame, FKO			G	III	-40.2	-6.8	Marumo <i>et al.</i> (1982)
	Kurume, FKO			R	III		-8.0	Inoue <i>et al.</i> (1985)
	Katakasu, FKO			G	III	-47.3	-7.1	Sakai and Matsubaya (1989)
31 July 91	Oochi, SAG	33°21'	129°59'	R	III	-25.6	-5.4	This study
4 Apr. 93	Kamimine, SAG	33°21'	130°26'	R	III		-6.7	This study
10 Aug. 91	Takagi, SAG	33°17'	130°18'	R	III		-7.5	This study
10 Aug. 91	Imari, SAG	33°16'	129°53'	R	III		-7.0	This study
9 Apr. 93	Momonokawa, SAG	33°16'	129°58'	R	III		-6.8	This study
10 Aug. 91	Nakazato, SAG	33°16'	130°01'	R	III	-41.5	-7.1	This study
10 Aug. 91	Kohhoku, SAG	33°13'	130°10'	R	III		-7.7	This study
10 Aug. 91	Hirado, NGS	33°22'	129°34'	R	III		-6.7	This study
27 Dec. 91	Kaze, NGS	33°16'	129°35'	R	III		-6.8	This study
10 Aug. 91	Takenokoba, NGS	33°15'	129°37'	R	III	-37.8	-6.8	This study
27 Dec. 91	Sasebo, NGS	33°09'	129°41'	R	III		-7.1	This study
10 Aug. 91	Isahaya, NGS	32°51'	130°02'	G	III	-39.3	-6.6	This study
21 Aug. 87	Fukue, NGS			R	III	-30.6	-6.5	NEDO (1990b)
18 Aug. 91	Himeshima, OIT	33°43'	131°40'	G	III		-4.9	This study
18 Aug. 91	Imi, OIT	33°41'	131°36'	R	III		-6.0	This study
12 Aug. 90	Usa, OIT	33°33'	131°21'	R	III	-48.7	-7.6	This study
23 Aug. 93	Beppu, OIT	33°19'	131°29'	G	III	-52.1	-8.7	This study
18 Aug. 91	Yunoku, OIT	33°17'	130°54'	R	III		-8.3	This study
14 Aug. 91	Nakamura, OIT	33°13'	131°12'	R	III		-8.6	This study
26 Jan. 92	Kuju, OIT	33°02'	131°18'	G	III		-8.6	This study
13 Nov. 91	Takeda, OIT	32°58'	131°23'	G	III	-49.6	-8.6	This study

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
7 Jan. 92	Saiki, OIT	32°58'	131°54'	R	III		-6.7	This study
June 73	Beppu, OIT			R	III	-52.8	-8.5	Matsubaya <i>et al.</i> (1975b)
Mar. 90	Beppu, OIT			G	III	-54.9	-8.5	Kitaoka <i>et al.</i> (1993)
June 73	Kuju, OIT			G	III	-33.0	-7.0	Matsubaya <i>et al.</i> (1973)
Aug./Nov. 84	Kuju, OIT			R	III	-57.3	-9.8	Mizutani <i>et al.</i> (1986)
4 Aug. 74	Handa, OIT			G	III	-61.9	-9.8	Matsubaya <i>et al.</i> (1975b)
	Oita, OIT			R	III		-8.4	Inoue <i>et al.</i> (1985)
16 Aug. 91	Tamana, KMT	32°58'	130°36'	R	III		-6.8	This study
16 Aug. 91	Kumatoto, KMT	32°59'	130°46'	R	III	-43.4	-7.6	This study
7 Jan. 92	Ichinomiya, KMT	32°58'	131°08'	R	III		-8.3	This study
16 Aug. 91	Takuma, KMT	32°48'	130°48'	R	III		-7.2	This study
16 Aug. 91	Midorikawa, KMT	32°43'	130°46'	R	III		-6.9	This study
16 Aug. 91	Miyahara, KMT	32°33'	130°41'	R	III		-7.8	This study
26 Dec. 91	Tanoura, KMT	32°31'	130°31'	R	III	-36.5	-6.4	This study
16 Aug. 91	Sakamoto, KMT	32°27'	130°40'	R	III	-43.4	-7.3	This study
16 Aug. 91	Yamae, KMT	32°20'	130°44'	R	III		-7.6	This study
16 Aug. 91	Sajiki, KMT	32°18'	130°30'	R	III		-6.7	This study
16 Aug. 91	Ashikita, KMT	32°17'	130°33'	G	III		-7.0	This study
16 Aug. 91	Kyusendo, KMT	32°16'	130°37'	R	III		-7.5	This study
16 Aug. 91	Hitooyoshi, KMT	32°14'	130°46'	R	III		-7.6	This study
16 Aug. 91	Watari, KMT	32°14'	130°42'	R	III	-41.6	-7.3	This study
	Yatsushiro, KMT			R	III		-7.6	Inoue <i>et al.</i> (1985)
27 May 91	Shiiba, MZK	32°25'	131°06'	R	III		-7.9	This study
	Nobeoka, MZK			R	III		-7.8	Inoue <i>et al.</i> (1985)
	Miyazaki, MZK			R	III		-6.9	Inoue <i>et al.</i> (1985)
16 Aug. 91	Hirakawa, KGS	31°27'	130°31'	R	III	-32.1	-6.5	This study
7 May 91	Kanoya, KGS	31°23'	130°51'	R	III	-36.7	-6.3	This study
	Chiran, KGS	31°22'	130°26'	R	III	-34.1	-6.1	This study
6 Dec. 91	Tanegashima, KGS	30°42'	131°04'	R	III	-32.1	-5.8	This study
11 Jan. 91	Tanegashima, KGS	30°33'	131°02'	R	III		-6.0	This study
11 Jan. 91	Yakushima, KGS	30°19'	130°39'	G	III		-6.7	This study
9 Apr. 91	Yakushima, KGS	30°18'	130°32'	R	III		-6.9	This study
9 Apr. 91	Tokunoshima, KGS	27°40'	128°57'	R	III	-30.3	-5.7	This study
June 73	Ibusuki, KGS			G	III	-42.6	-7.0	Matsubaya <i>et al.</i> (1973)
	Satsuma-Iwojima, KGS			G	III	-33.0	-6.0	Matsubaya <i>et al.</i> (1975b)
2 Aug. 74	Kirishima, KGS			R	III	-46.1	-7.4	Matsubaya <i>et al.</i> (1975b)

2 Aug. 74	Ibusuki, KGS				G	III	-40.8	-6.9	Matsubaya <i>et al.</i> (1975b)
7 Aug. 74	Kirishima, KGS				G	III	-46.5	-7.5	Matsubaya <i>et al.</i> (1975b)
	Sendai, KGS				R	III	-36.8	-6.2	Marumo <i>et al.</i> (1982)
	Sendai, KGS				R	III		-7.1	Inoue <i>et al.</i> (1985)
	Kushikino, KGS				G	III		-6.3	Matsuhisa <i>et al.</i> (1985)
28 Sept. 84	Kokubu, KGS				G	III	-39.5	-7.9	NEDO (1986c)
7 Sept. 85	Kokubu, KGS				G	III	-43.0	-7.3	NEDO (1986c)
23 Sept. 87	Hishikari, KGS				G	III	-37.2	-6.3	NEDO (1991a)
	Hishikari, KGS				R	III	-39.7	-6.6	NEDO (1991a)
25 Mar. 93	Nago, ONW	26°35'	127°58'		G	III		-4.9	This study
	Naha, ONW				G	III	-28.0	-4.6	Waseda and Nakai (1983)
26 June 91	Chungchong, RK	37°53'	127°45'		R		-67.6	-10.3	This study
26 June 91	Yoji, RK	37°17'	127°40'		R		-61.7	-9.2	This study
26 June 91	Suweon, RK	37°16'	127°02'		R		-50.8	-8.1	This study
26 June 91	Taeon, RK	36°43'	126°19'		R		-41.4	-7.1	This study
26 June 91	Shinju, RK	36°36'	127°32'		R		-48.7	-7.6	This study
26 June 91	Daejong, RK	36°19'	127°28'		R		-49.2	-7.7	This study
26 June 91	Iri, RK	35°56'	126°59'		R		-39.7	-6.4	This study
26 June 91	Daegu, RK	35°35'	128°38'		R		-47.6	-7.3	This study
26 June 91	Guangju, RK	35°09'	126°57'		R		-40.4	-7.2	This study
26 June 91	Kuangyan, RK	34°58'	127°39'		R		-38.2	-6.5	This study
Nov. 80	Seoul, RK				R		-61.5	-8.7	Waseda and Nakai (1983)
31 Oct. 79	Chucksan, RK				R		-62.3	-9.0	Kim and Nakai (1981)
1 Nov. 79	Oseg, RK				R		-70.7	-10.1	Kim and Nakai (1981)
27 Oct. 79	Echon, RK				R		-51.0	-7.0	Kim and Nakai (1981)
26 Oct. 79	Suanbo, RK				R		-59.8	-7.7	Kim and Nakai (1981)
24 Oct. 79	Ducksan, RK				R		-42.7	-6.1	Kim and Nakai (1981)
24 Oct. 79	Dogo, RK				R		-43.2	-6.1	Kim and Nakai (1981)
24 Oct. 79	Onyang, RK				R		-40.3	-5.5	Kim and Nakai (1981)
26 Oct. 79	Yusung, RK				R		-47.3	-6.9	Kim and Nakai (1981)
30 Oct. 79	Backsam, RK				R		-61.7	-8.4	Kim and Nakai (1981)
30 Oct. 79	Pohang, RK				R		-50.5	-7.7	Kim and Nakai (1981)
29 Oct. 79	Bugog, RK				R		-43.5	-5.6	Kim and Nakai (1981)
29 Oct. 79	Magamsan, RK				R		-43.5	-6.1	Kim and Nakai (1981)
30 Oct. 79	Haiundae, RK				R		-39.5	-5.5	Kim and Nakai (1981)
30 Oct. 79	Dongrae, RK				R		-41.7	-5.2	Kim and Nakai (1981)
19 July 80	Duggu, RK				R		-64.1	-8.7	Kim and Nakai (1981)
5 Nov. 79	Cheju, RK				G		-43.7	-6.8	Kim and Nakai (1981)
1 Nov. 79	Kangneung, RK				G		-54.3	-7.6	Kim and Nakai (1981)

Sampling date	Locality	Latitude (N)	Longitude (E)	Source	Climatic zone	del D	del O-18	Reference
1 Nov. 79	Dumae, RK			G		-61.3	-7.7	Kim and Nakai (1981)
29 Oct. 79	Yeonhwa, RK			G		-65.6	-9.2	Kim and Nakai (1981)
23 Oct. 79	Seoul, RK			G		-51.6	-7.5	Kim and Nakai (1981)
22 Oct. 79	Bupyeong, RK			G		-56.9	-7.5	Kim and Nakai (1981)
6 Nov. 79	Jechon, RK			G		-53.2	-6.3	Kim and Nakai (1981)
6 Nov. 79	Yeoju, RK			G		-50.5	-6.5	Kim and Nakai (1981)
5 Nov. 79	Shinyemi, RK			G		-65.0	-9.4	Kim and Nakai (1981)
5 Nov. 79	Cheju, RK			G		-43.7	-6.8	Kim and Nakai (1981)
14 July 80	Youngju, RK			G		-57.3	-7.5	Kim and Nakai (1981)
21 July 80	Inchon, RK			G		-58.9	-7.9	Kim and Nakai (1981)
	Sangdong, RK			G		-65.0	-9.5	Kim <i>et al.</i> (1988)
25 July 91	Harbin, PRC	45°48'	126°37'	G		-86.5	-11.5	This study
30 Oct. 91	Daan, PRC	45°31'	124°16'	G			-10.4	This study
18 July 91	Jilin, PRC	43°53'	126°32'	R		-87.0	-11.9	This study
25 Oct. 91	Shuangliao, PRC	43°33'	123°29'	G			-9.3	This study
22 July 91	Huadian, PRC	42°59'	126°42'	R			-10.5	This study
19 July 91	Yanji, PRC	42°55'	129°31'	G		-75.0	-10.1	This study
19 July 91	Helong, PRC	42°46'	129°26'	R			-12.5	This study
19 July 91	Sihe, PRC	42°29'	128°02'	R			-13.0	This study
20 July 91	Changbaishan, PRC	42°00'	128°01'	R		-103.6	-14.7	This study
16 July 91	Shengyang, PRC	41°49'	123°25'	G			-8.5	This study

For prefectural abbreviations, see Fig. 1 except for PRC; People's Republic of China, and RK: Republic of Korea.
 G and R stand for groundwater and river water, respectively.
 Climatic zones I, II and III are shown in Fig. 1.