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The Characteristics of Agro-Climatic Environments in Subtropical Islands around Japan

Tsuneo KUWAGATA*

Agro-Meteorology Division, National Institute for Agro-Environmental Sciences
(Tsukuba, Ibaraki 305–8604, Japan)

Abstract

The agro-climatic environments in subtropical islands around Japan were analyzed by using meteorological data (average for 1971–2000). This study found that the horizontal distribution of monthly mean temperatures in both the subtropical islands and Japan's main islands can be expressed accurately as a function of latitude for all seasons. These relationships cannot be applied to the monthly mean temperatures in the eastern areas of the Asian continent except for summer. On the other hand, the annual mean diurnal ranges of temperature in the subtropical islands are around 5ºC, which are about only half of those in the inland areas of Japan's main islands. The ocean has the effect of reducing the temporal and spatial variations in temperature due to its large heat capacity. The strength of this effect depends on the temporal and spatial scale of temperature variations. That is, although the thermal effect of the ocean to the diurnal temperature variations is restricted to the subtropical islands and the coastal areas of Japan's main islands, the seasonal temperature variations in all areas of Japan are under the influence of the thermal environment of the Pacific Ocean. The ocean also contributes to supplying water vapor into the atmosphere, resulting in more precipitation over all areas of Japan. Water balances between precipitation and potential evaporation at several sites were estimated in order to elucidate the hydrological properties in the subtropical islands.

Discipline: Agro-meteorology
Additional key words: East Asia, hydrometeorology, maritime climate, temperature

Introduction

Climate is one of the most important environments for agriculture. Temperature, solar radiation and precipitation are important natural resources for crop production. The objective of the present study is to elucidate the characteristics of climatic resources for crop production in subtropical islands around Japan.

Japan (which is also called Japan Islands) is located in the temperate and subtropical areas of eastern Asia, and consists of Japan's main islands (four large islands; Hokkaido, Honshu, Shikoku, and Kyushu) and many small temperate or subtropical islands. There have been many studies about the climate of Japan. Recently, two books about the climate in Japan were published[11,12]. The outlines of the characteristics of climate in Japan were well summarized in them. Japan faces the Pacific Ocean, and the climate of Japan is under the influence of a maritime climate[9,11]. In particular, the small subtropical islands in the Ryukyu and Ogasawara Islands are strongly influenced by the surrounding ocean.

This study analyzed the agro-climatic characteristics of the subtropical islands around Japan and their relationships with the climate of Japan's main islands by using routine meteorological data (average over 30 years). The climatic relationships between Japan and the eastern part of the Asian continent are also analyzed in order to clarify the agro-climatic characteristics of Japan in the eastern part of Asia. Furthermore, the seasonal and spatial variations in water balance between precipitation and potential evaporation are evaluated in order to elucidate the hydrological properties in the subtropical islands around Japan, since hydrological condition is critical for crop production.

The present study will contribute to better understanding of agro-climatic environments not only in the subtropical islands around Japan but also in the eastern part of Asia, and the result of this study should be helpful for the planning of agricultural managements in subtropical islands.

*Corresponding author: fax +81–29–838–8211; e-mail kuwa@affrc.go.jp
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Materials and methods

Figure 1 shows the map of the temperate and subtropical areas around Japan, together with the eastern part of the Asian continent. The routine meteorological data (normal values for the period 1971 to 2000) of the Japan Meteorological Agency (JMA) were used. There are 154 meteorological stations whose altitudes do not exceed 1,000 m MSL (mean sea level). According to the geographical features of each site, the meteorological stations are divided into 3 categories; coastal area (= coast, 93 stations), inland area (= inland, 38 stations) and island (23 stations). All the stations which belong to the coastal and inland area categories are located in Japan's main islands. The meteorological stations located in the bottom of a basin were classified in the inland area cate-

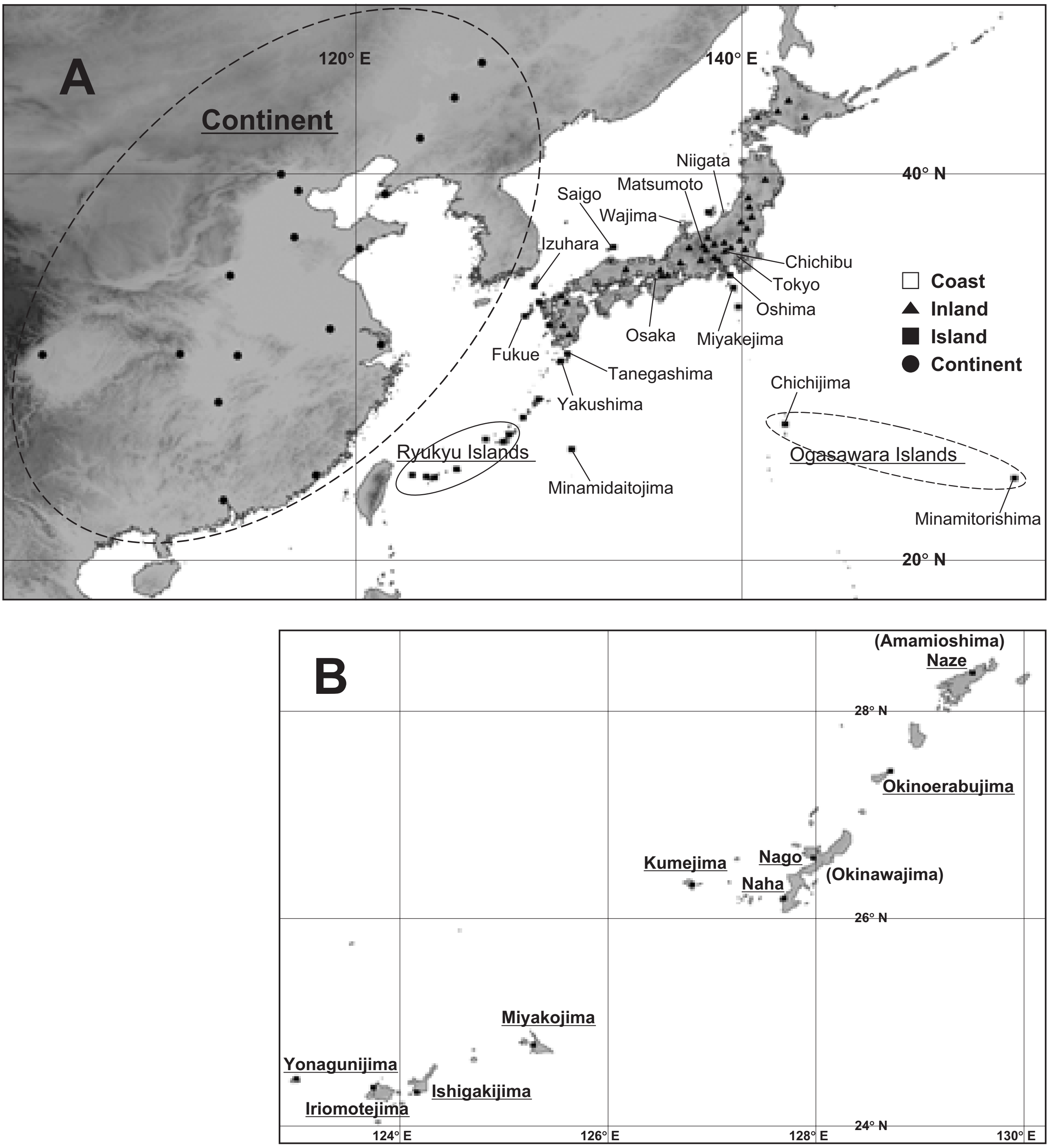

Fig. 1. The maps of the temperate and subtropical areas around Japan, together with the eastern part of the Asian continent
A: The whole area. B: The area of the Ryukyu Islands.

gory, and the stations located more than 15 km inland from the coastline were also classified in the same category. The stations in the coastal area category are located within 15 km from the coastline. On the other hand, all the stations in the island category are located in small temperate or subtropical islands. There are 7 meteorological stations in the Ryukyu Islands and 2 stations in the Ogasawara Islands.

The meteorological data in China (temperature and precipitation; normal values for the period 1961 to 1990, and relative humidity; normal values for the period 1961 to 1979) were also used in order to clarify the difference in climate between the maritime areas around Japan and the eastern Asian continent. Seventeen meteorological stations in China with altitudes under 600 m MSL were selected. These data were downloaded from the NOAA National Climate Data Center website (http://www.ncdc.noaa.gov/oa/ncdc.html). In the present study, the characteristics of temperature, precipitation and humidity in both Japan and China were analyzed.

Since the value of temperature depends on the altitude of each meteorological station, the sea level temperatures were calculated from observed temperatures by using the lapse rate of 5 K km^{-1}. The sea level temperature for each meteorological station was used in the analysis of spatial variation in temperature (Figs. 2 to 4). It should be noted that all data used in the present study are averaged for 30 years, except for the relative humidity data in China.

Results and discussion

1. Temperature

(1) Latitudinal distribution of temperature

Figure 2 shows the latitudinal distribution of the monthly mean (sea level) temperatures observed at the meteorological stations both in Japan and China for each season. As can be seen in Fig. 2, the north-south difference in temperature is very large in winter, reaching about 30ºC between 24 and 45ºN. In summer, this value

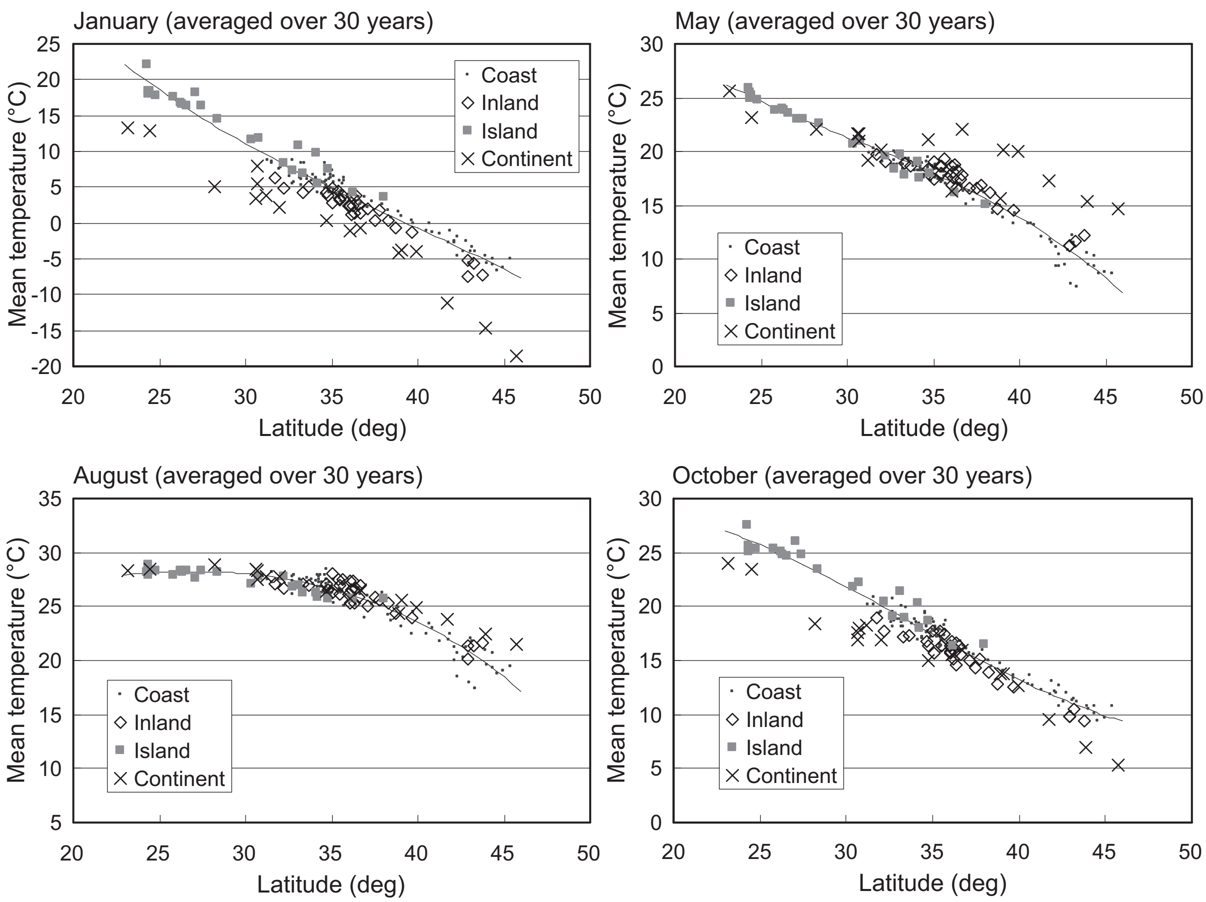

Fig. 2. The latitudinal distributions of the monthly mean (sea level) temperature
Coast: The coastal area of Japan's main islands, Inland: The inland area of Japan's main islands,
Island: Small islands around Japan, Continent: Areas in China.
Solid lines: The regression lines for the meteorological stations in Japan obtained by the least-square method.

became smaller, being only 10ºC between 24 and 45ºN. The monthly mean temperatures in the subtropical islands around Japan are almost the same as those in the southern part of Japan's main islands in summer.

For all seasons, there is little difference in temperature among the stations in the same latitude zone, except for the stations in China. That is, the horizontal distribution of monthly mean temperatures in both the subtropical islands and Japan's main islands can be expressed accurately as a function of latitude. This result suggests that the monthly mean temperatures in the whole of Japan are under the influence of the maritime climate of the Pacific Ocean.

There is a different trend in the monthly mean temperatures between Japan and China (the eastern area of the Asian continent). That is, the monthly mean temperatures in China are considerably lower than those in Japan during winter (January), and a similar trend can be found also in autumn (October). In summer (August), however, the monthly mean temperatures in China reach the same levels as those in Japan. On the other hand, in spring (May), the northern parts of China become warmer than those of Japan.

Figure 3A shows the latitudinal distribution of the annual mean temperature. The north-south temperature difference in Japan is about 20ºC between 24 and 45ºN. There is a somewhat different trend, even in the annual mean temperature, between Japan and China. The annual range of the monthly mean temperature is defined as the difference between maximum and minimum values of the monthly mean temperature. The annual ranges of the monthly mean temperatures in Japan are smaller than those in China (Fig. 3B). This is primarily due to lower temperatures in China during winter. Finally, the regression lines for the monthly (or annual) mean temperatures in Japan obtained by the least-square method are summarized in Table 1.

Typical examples of seasonal variations in (monthly mean) daily maximum and minimum temperatures in both the coastal areas of Japan's main islands and the subtropical islands are shown in Fig. 4. As shown in Fig. 2, there are large temperature differences between Japan's main islands and the subtropical islands during winter. These differences become smaller during the warm seasons, and no significant temperature differences between the two areas can be found in summer.

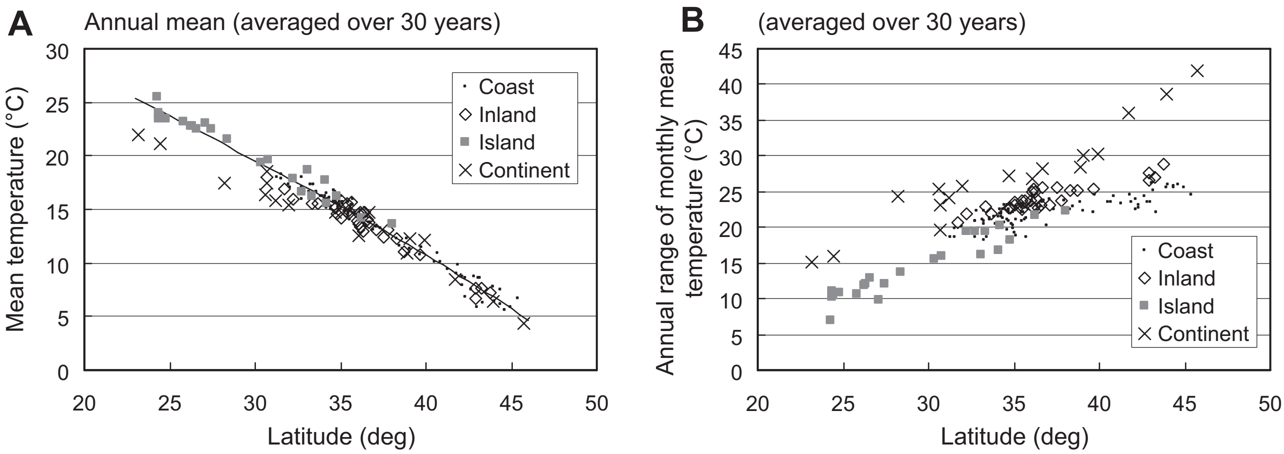

Fig. 3. The latitudinal distributions of the annual mean (sea level) temperature (A) and annual ranges of the monthly mean temperature (B)

Table 1. The regression lines for the mean temperatures in Japan obtained by the least-square method (average for 1971–2000)

	January	May	August	October	Annual mean
A_0	98.65	69.77	23.87	13.63	49.59
A_1	–5.288	–3.531	–0.066	2.218	–1.378
A_2	0.10564	0.09538	0.02277	–0.09219	0.01969
A_3	–0.0008891	–0.0010515	–0.0005326	0.0009123	–0.0002385

$T = A_0 + A_1Y + A_2Y^2 + A_3Y^3$, T: Temperature (ºC), Y: Latitude (deg).

Another important result is that the summertime daily minimum temperatures in Japan's main islands are somewhat lower than those in the subtropical islands but that the summertime daily maximum temperature in Japan's main islands is almost the same as that in the subtropical islands (daily maximum temperature at Osaka is higher than those at Naha and Ishigakijima during summer). This is due to a smaller diurnal temperature range in the subtropical islands, which will be discussed in the next section (see Fig. 5).

(2) Diurnal ranges of temperature

Figure 5 shows the latitudinal distribution of the annual mean diurnal ranges of temperature in Japan and China. The diurnal range of temperature ΔT_D is defined as the difference between the daily maximum and minimum temperatures. The annual mean diurnal ranges of temperature are 8–12ºC in the inland areas of Japan's main islands, 5–10ºC in the coastal areas of Japan's main islands, and 4–8ºC in the temperate and subtropical small islands. On the other hand, the annual mean values of ΔT_D in China (the eastern area of the Asian continent) are 7–12ºC, which are roughly the same as those in the inland areas of Japan.

The annual mean values of ΔT_D in the subtropical islands are only 4–6ºC, which are about half of those in the inland area of Japan. On the other hand, larger values of ΔT_D over 10ºC are found in the inland areas of Japan

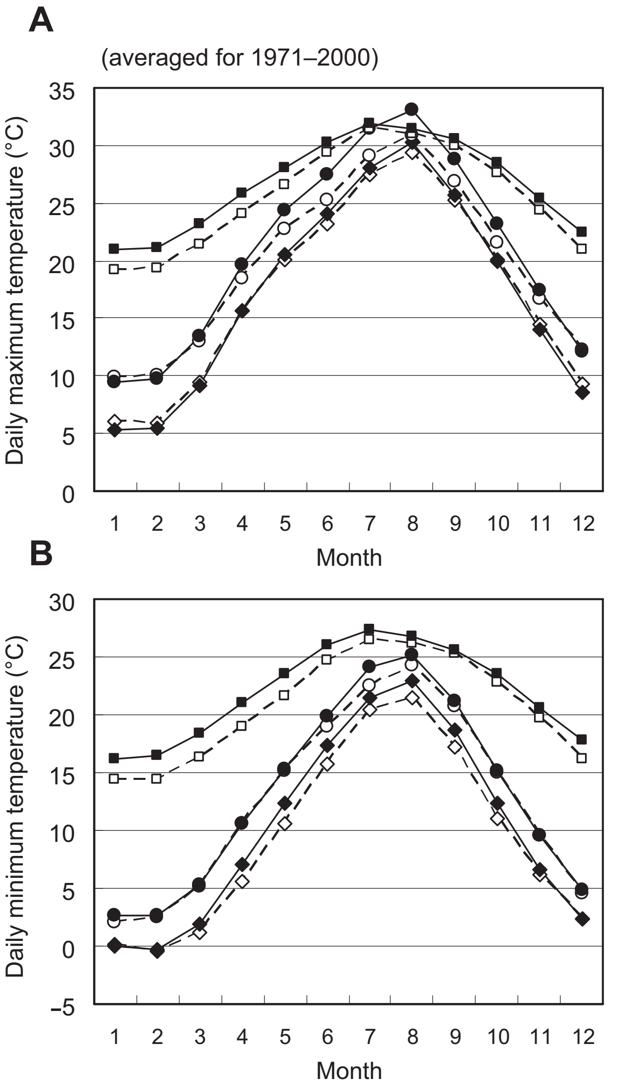

Fig. 4. The seasonal variations of (monthly mean) daily maximum (A) and minimum (B) temperatures

- -◇- - : Wajima, —◆— : Niigata, - -○- - : Tokyo,
—●— : Osaka; the coastal area of Japan's main islands,
- -□- - : Naha, —■— : Ishigakijima; the Ryukyu Islands.

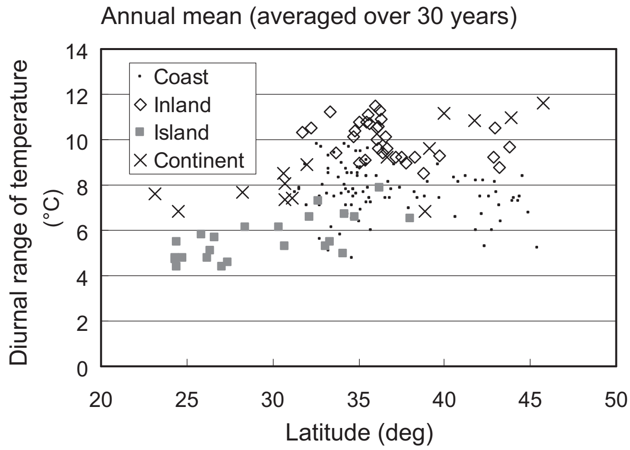

Fig. 5. The latitudinal distributions of the annual mean diurnal ranges of temperature

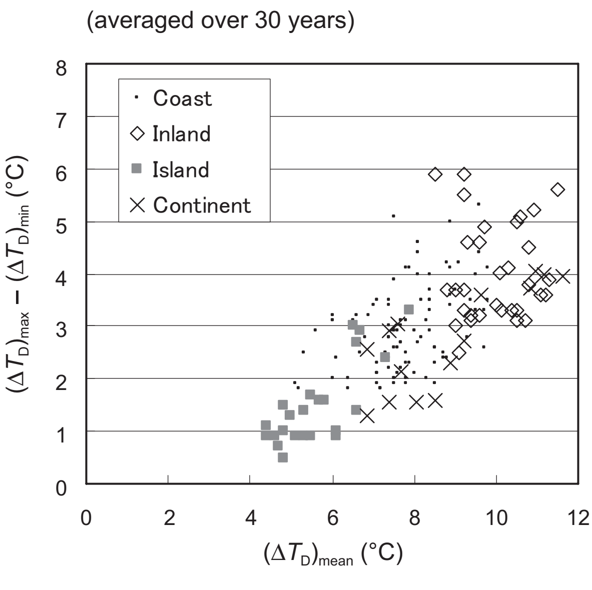

Fig. 6. The relationships in the annual mean diurnal ranges of temperature $(\Delta T_D)_{mean}$ and the annual range in (monthly mean) diurnal ranges of temperature $(\Delta T_D)_{max} - (\Delta T_D)_{min}$

and in the eastern area of the Asian continent. These results suggest that the diurnal ranges of temperature in the subtropical small islands are strongly suppressed by the thermal effect of the surrounding ocean.

The annual range in (monthly mean) diurnal range of temperature is defined as $(\Delta T_D)_{max} - (\Delta T_D)_{min}$, where $(\Delta T_D)_{max}$ is the maximum value of monthly mean diurnal range of temperature and $(\Delta T_D)_{min}$ is the minimum value of monthly mean diurnal range of temperature. Figure 6 shows the relationship between the annual mean diurnal ranges of temperature $(\Delta T_D)_{mean}$ and the annual range in diurnal range of temperature $(\Delta T_D)_{max} - (\Delta T_D)_{min}$. There is positive correlation between $(\Delta T_D)_{mean}$ and $(\Delta T_D)_{max} - (\Delta T_D)_{min}$.

Typical examples of the seasonal variation of the monthly mean ΔT_D for each category in Japan are shown in Fig. 7. The inland areas of Japan (Chichibu and Matsumoto) have considerably larger seasonal variation, and the value of ΔT_D becomes smaller during summer. The seasonal variation of ΔT_D is also found in the coastal areas of Japan (Tokyo and Osaka), which have two maximum peaks of ΔT_D in spring and autumn. However, there is no seasonal variation of ΔT_D in the subtropical small islands (Naha and Ishigakijima).

As can be seen in Figs. 5 and 6, the temperate small islands tend to have somewhat larger values of both $(\Delta T_D)_{mean}$ and $(\Delta T_D)_{max} - (\Delta T_D)_{min}$ than those in the subtropical islands. The seasonal variations of the monthly mean ΔT_D in the 6 temperate small islands are shown in Fig. 8. The seasonal variation of diurnal ranges of temperature is clear except in Tanegashima and Miyakejima. It should be noted that these temperate islands are located near Japan's main islands. There is a possibility that temperatures in these islands are affected by Japan's main islands.

(3) Thermal effect of the Pacific Ocean on temperature

The ocean has the effect of reducing the temporal and spatial variation of temperature, due to its large heat capacity. The details of this mechanism are explained as follows.

Air temperature near the earth's surface is determined by the energy exchange between air and the earth's surface. As the earth's surface temperature is heated by solar radiation, air temperature becomes higher. On the other hand, heat capacity of the ocean is considerably larger than that of the land, due primarily to the large heat capacity and high heat conductivity of water. Since the larger heat capacity of the ocean suppresses changes in the sea's surface temperature, the temporal and spatial variation of air temperature over the ocean becomes smaller than that over the land.

Air temperature over the land surface is also affected by that over the ocean, through the horizontal

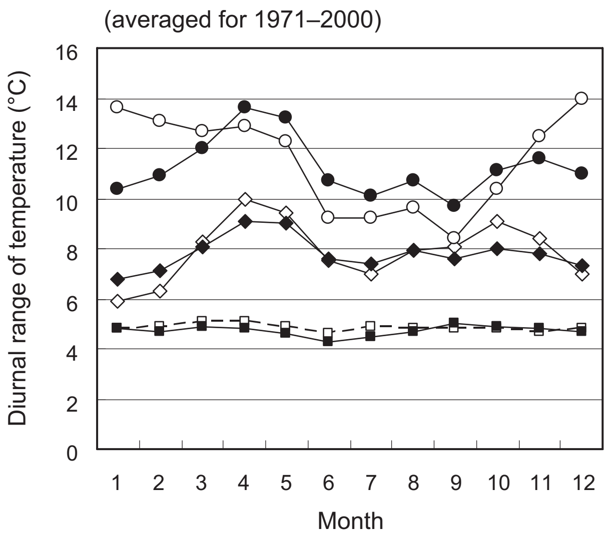

Fig. 7. The seasonal variations of the monthly mean diurnal range of temperature

—◇— : Wajima, —◆— : Osaka; the coastal area of Japan's main islands.
—○— : Chichibu, —●— : Matsumoto; the inland area of Japan's main islands.
- -□- - : Naha, —■— : Ishigakijima; the Ryukyu Islands.

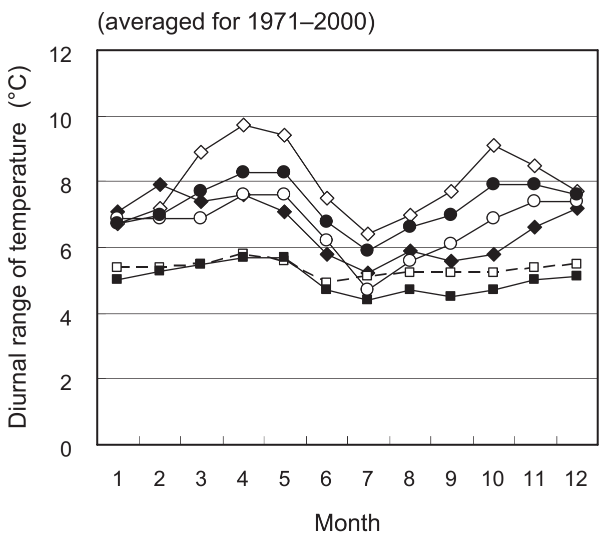

Fig. 8. The seasonal variations of the monthly mean diurnal range of temperature in the temperate islands

—◇— : Saigo, —◆— : Oshima, —○— : Izuhara,
—●— : Fukue, - -□- - : Tanegashima,
—■— : Miyakejima.

atmospheric heat advection from the ocean. The strength of the horizontal heat advection depends on not only the horizontal scale of land area, but also the time scale of temperature variations. That is, as shown in the previous section, the thermal effect of the ocean to the diurnal (air) temperature variations is restricted in the subtropical small islands and the coastal areas (within about 50 km from the coastline), but the seasonal temperature variations in the whole of Japan (which includes the inland areas 100–200 km from the coastline) are influenced by the thermal environment of the Pacific Ocean. This is the reason why the horizontal distribution of monthly mean temperatures in both the subtropical islands of Japan and Japan's main islands can be expressed accurately as a function of latitude, in spite of the difference in the diurnal ranges of temperature between the two areas.

2. Precipitation

Figure 9 shows the latitudinal distribution of the annual precipitation observed at the meteorological stations in both Japan and China (averaged over 30 years). The characteristics of the annual precipitation are summarized as follows:

① The annual precipitation in Japan is greater than that in China. There is greater precipitation over the temperate and subtropical areas around Japan than the eastern area of the Asian continent.

② There is large variability in annual precipitation among the sites in Japan's main islands, but their variability is smaller in the Ryukyu Islands (also in the Ogasawara Islands).

The first characteristic is typical of a maritime climate. That is, the ocean contributes to supplying water vapor into the atmosphere, resulting in more precipitation over the temperate and subtropical areas around Japan.

Concerning the second characteristic, the geographical effect of mountains is significant. Japan's main islands have complex terrain, including many steep mountains with altitudes of 1,000 to 3,000 m MSL. The terrain-forced flow and thermally induced flow over complex terrains induce the development of clouds and increase precipitation[1,7]. Since these geographical effects act on individual small areas over a complex terrain, the horizontal variability of precipitation becomes larger in Japan's main islands. On the other hand, there are no steep mountains with altitudes of over 1,000 m MSL in the subtropical islands around Japan. Exceptionally, a large amount of precipitation is observed in Yakushima which is a small island in Japan (see Fig. 9), because there are several steep mountains with altitudes of around 2,000 m MSL in Yakushima.

Figure 10 shows the seasonal variations of the monthly precipitation in the 6 subtropical islands (averaged over 30 years). These six islands are part of the Ryukyu Islands. There is no significant difference in the seasonal variations among all the islands, and the values of monthly precipitation are always over 100 mm, with two maximum peaks of precipitation in May and August. The first peak corresponds to the rainy season due to the *Bai-u* front and the second one is attributed to heavy rain carried by typhoons. There are two local minimum values in July and December.

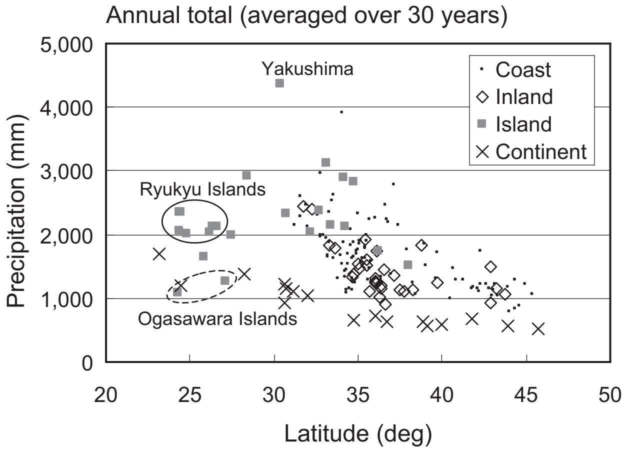

Fig. 9. The latitudinal distribution of the annual precipitation

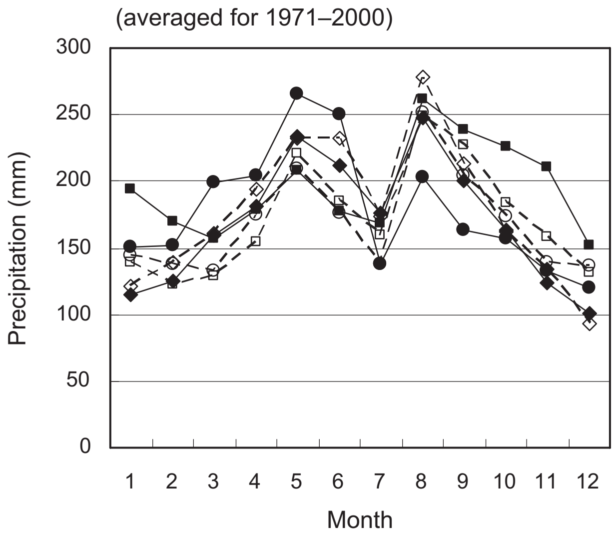

Fig. 10. The seasonal variations of the monthly precipitation in the subtropical islands

: Nago, : Naha, : Kumejima, : Miyakojima, : Ishigakijima, : Iriomotejima.

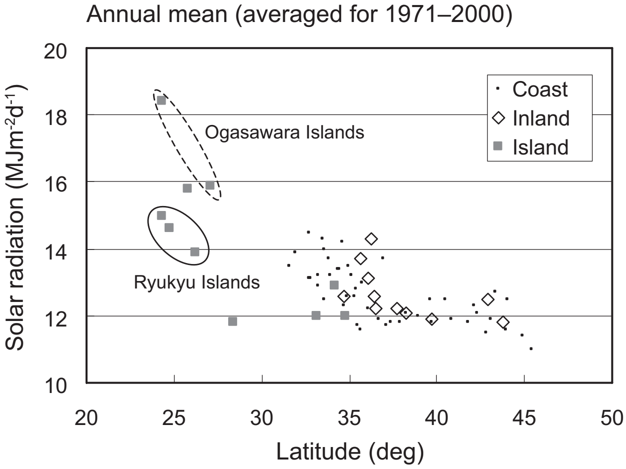

Fig. 11. The latitudinal distribution of the annual solar radiation

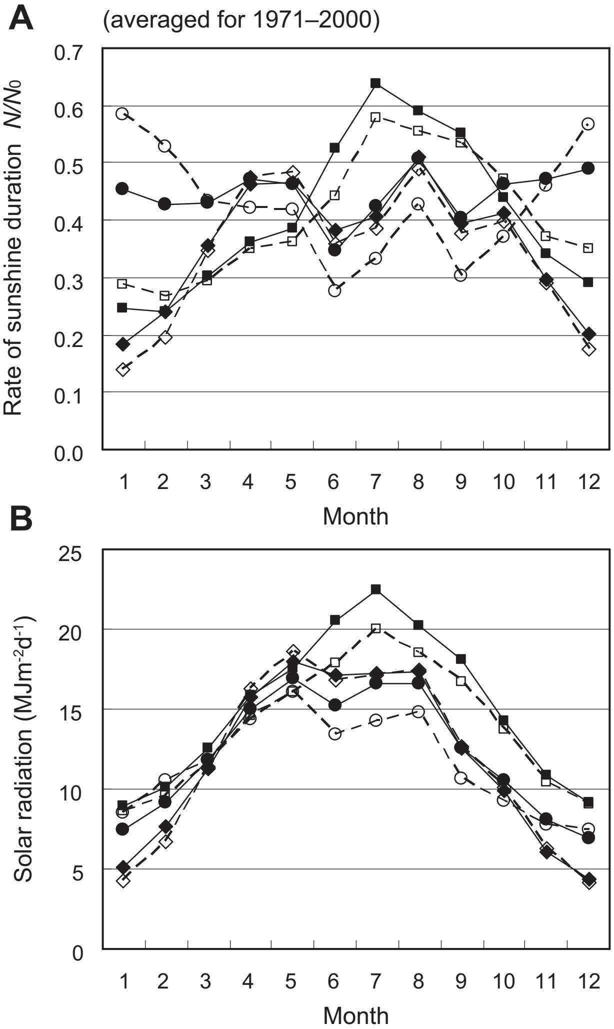

Fig. 12. The seasonal variations of the rate of sunshine duration N/N_0 (A) and the monthly mean solar radiation (B)

N : The monthly sunshine duration,

N_0: The possible monthly sunshine duration.

- -◇- - : Wajima, —◆— : Niigata, - -○- - : Tokyo, —●— : Osaka, - -□- - : Naha, —■— : Ishigakijima.

3. Solar radiation

Solar radiation is one of the most important factors for crop production, and it is also related to the hydrological properties. Figure 11 shows the latitudinal distribution of the annual solar radiation observed at the meteorological stations in Japan (averaged over 30 years). It should be noted that there are only 67 sites where solar radiation was observed. Annual solar radiation S increases with decreasing latitude, resulting in larger values of S in the subtropical islands. This is the general trend which can be easily understood.

Next, the seasonal variations in sunshine duration and solar radiation in both Japan's main islands and the subtropical islands are examined. Figure 12A shows typical examples of the seasonal variations in the rate of sunshine duration N/N_0 in the coastal areas of Japan's main islands (Wajima, Niigata, Tokyo, and Osaka) and the subtropical islands of the Ryukyu Islands (Naha and Ishigakijima). Here, N is the monthly sunshine duration, and N_0 is the possible monthly sunshine duration, respectively. The values of N/N_0 in the Ryukyu Islands are very small during winter, which are the same level as those in the Sea of Japan side of Japan's main islands (Wajima and Niigata). On the other hand, the values of N/N_0 in the Ryukyu Islands are very large during summer, attaining around 0.6 in July. In the Ryukyu Islands, cloudy days continue during winter due to the northeasterly moist seasonal wind, but there are many sunny days during summer.

The seasonal variations of monthly mean solar radiation S for the same sites are shown in Fig. 12B. The values of S in the Ryukyu Islands are not very small during winter, in spite of smaller N/N_0. On the other hand, the values of S in Japan's main islands become smaller in winter, since the solar radiation in higher latitude zones is lower even in the sunny weather conditions during winter. In the Ryukyu Islands, S becomes largest in July, and its values are 1.2 to 1.3 times those of Japan's main islands.

4. Relative humidity

Figure 13 shows the latitudinal distribution of the annual mean relative humidity RH in both Japan and China. The annual mean values of RH in the temperate areas of Japan are greater than 70%, except for several sites in the 32–38ºN zone of Japan's main islands. The lower RH values (below 70%) at these sites are attributed to the existence of a relatively dry season with little precipitation. On the other hand, the annual mean RH in the subtropical islands are greater than 74%; no dry season can be found in these areas. There is a somewhat different trend in the annual mean RH between Japan and

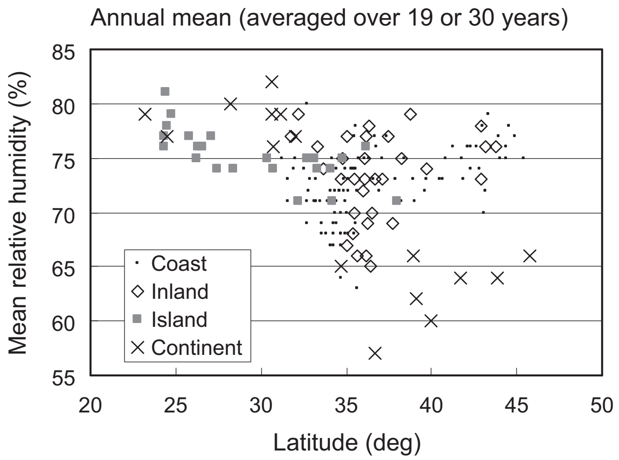

Fig. 13. The latitudinal distribution of the annual mean relative humidity
Continent: Averaged for 1961–1979.
Other categories: Averaged for 1971–2000.

China. That is, *RH* values in the northern part of China (> 33ºN) are lower than those in Japan, while *RH* values in the southern part of China are the same levels as those in Japan.

As shown in Fig. 13, the subtropical islands in Japan are characterized as having a humid climate with higher *RH*. Higher *RH* values in these areas must be caused by the water vapor supply from the surrounding ocean.

5. Hydrological characteristics of the subtropical islands

(1) Calculation procedure of potential evaporation

In this section, the water balances between precipitation and potential evaporation at several meteorological stations were estimated in order to elucidate the hydrological properties in the subtropical islands around Japan. For estimating the water balance, I evaluated the potential evaporation E_P and wetness index *WI* suggested by Kondo and Xu[4,5]. E_P is defined as the evaporation from a saturated surface, such as a newly planted paddy field with dripping wet leaves, and it can be regarded as the upper limit of evapotranspiration from a crop field[2,10] (procedure for calculating E_P is described in Xu et al.[10]).

On the other hand, *WI* is defined as the ratio $WI = Pr/E_P$ (*Pr*: precipitation). Climatic conditions can be classified into four categories by using monthly or annual values of *Pr* and E_P ($WI > 1.0$: humid climate, $1.0 \geq WI > 0.3$: semi-humid climate, $0.3 \geq WI > 0.1$: semi-arid climate, $WI \leq 0.1$: arid climate). If $WI > 1.0$, precipitation exceeds potential evaporation and runoff must occur. When $WI < 1.0$, soil water content is less than its saturated value and a crop is subjected to water stress[5,10].

The monthly mean data of wind speed, temperature, water vapor pressure, solar radiation, and atmospheric pressure (averaged for 30 years) were used to calculate the monthly values of E_P (in units of mm), and the annual value of E_P was calculated as a sum of the monthly E_P. The wind speed (u_{1m}) at a height of 1 m above the ground was used for calculating E_P, and it was evaluated from the observed wind speed by using the following procedure: First, the wind speed (u_{100m}) at a height of 100 m above the ground was calculated from the observed wind speed and aerodynamic roughness length (z_0) for each site[3,6] by assuming a logarithmic wind profile. Next, the value of u_{1m} was evaluated from u_{100m} by assuming $z_0 = 0.005$ m. The downward long-wave radiation, which is also used for calculating E_P, was estimated by using an empirical formula comprised of the monthly mean temperature, water vapor pressure, and solar radiation[8].

(2) Annual water balance between precipitation and potential evaporation

The water balances were analyzed at the 7 sites in the subtropical islands and 4 sites in the coastal area of Japan's main islands. Table 2 summarizes the annual water balances at the 11 sites. The annual values of *WI* are greater than 1.0, except for the 2 sites in the Ogasawara Islands. These results suggest that the climatic condition in the Ryukyu Islands can be regarded as a humid climate and that the Ogasawara Islands (Chichijima and Minamitorishima) are classified as a semi-humid climate. On the other hand, as shown in Table 2, it can be expected that most areas in Japan's main islands are classified as a humid climate. The annual values of *WI* in the Sea of Japan side (Wajima and Niigata) are larger than those in the Pacific Ocean side (Tokyo and Osaka).

(3) Seasonal variation of water balance between precipitation and potential evaporation

The seasonal variations of monthly water balances at the 4 sites are shown in Fig. 14. The characteristics of the water balance for each site are summarized as follows:

① The Sea of Japan side of Japan's main islands: In Wajima, *Pr* greatly exceeds E_P (monthly $WI > 1.0$) from September to February. This contributes to larger annual *WI*. *Pr* is roughly the same as E_P from April to August. A similar result was found in Niigata (not shown).

② The Pacific Ocean side of Japan's main islands: In Osaka, *Pr* is somewhat larger than E_P (monthly $WI > 1.0$) in June and September, and smaller than E_P (monthly $WI < 1.0$) in August. *Pr* is roughly the same

Table 2. The annual water balances at the 11 sites (average for 1971–2000)

Station	Category	Lat. (ºN)	Lon. (ºE)	Elev. (mMSL)	T (ºC)	u_{1m} (ms^{-1})	e (hPa)	S (Wm^{-2})	Pr (mm)	E_P (mm)	WI
Wajima	Coast	37.39	136.90	5.2	13.2	2.4	13.2	137	2,157	951	2.267
Niigata	Coast	37.91	139.05	1.9	13.5	3.0	12.9	137	1,776	1,099	1.617
Tokyo	Coast	35.69	139.76	6.1	15.9	1.9	13.3	134	1,467	1,101	1.332
Osaka	Coast	34.68	135.52	23.0	16.5	2.1	13.8	142	1,306	1,222	1.069
Naze	Island	28.38	129.50	2.8	21.5	1.9	20.1	137	2,914	1,193	2.443
Naha	Island	26.20	127.69	28.1	22.7	3.4	21.9	161	2,037	1,552	1.312
Miyakojima	Island	24.79	125.28	39.9	23.3	3.7	23.4	169	2,019	1,606	1.258
Ishigakijima	Island	24.33	124.16	5.7	24.0	3.2	23.8	174	2,061	1,645	1.253
Minamidaitojima	Island	25.83	131.23	15.3	23.1	2.9	22.8	183	1,650	1,586	1.040
Chichijima	Island	27.08	142.18	2.7	23.0	2.4	22.7	184	1,277	1,505	0.848
Minamitorishima	Island	24.30	153.97	8.3	25.4	3.9	25.1	214	1,078	2,057	0.524

Lat.: Latitude, Lon.: Longitude, Elev.: Elevation above the mean surface level, T: Temperature, u_{1m}: Wind speed at a height of 1 m above the ground, e: Water vapor pressure, S: Solar radiation, Pr: Annual precipitation, E_P: Annual potential evaporation, $WI = Pr/E_P$. Coast: The coastal area of Japan's main islands, Island: Small islands around Japan.

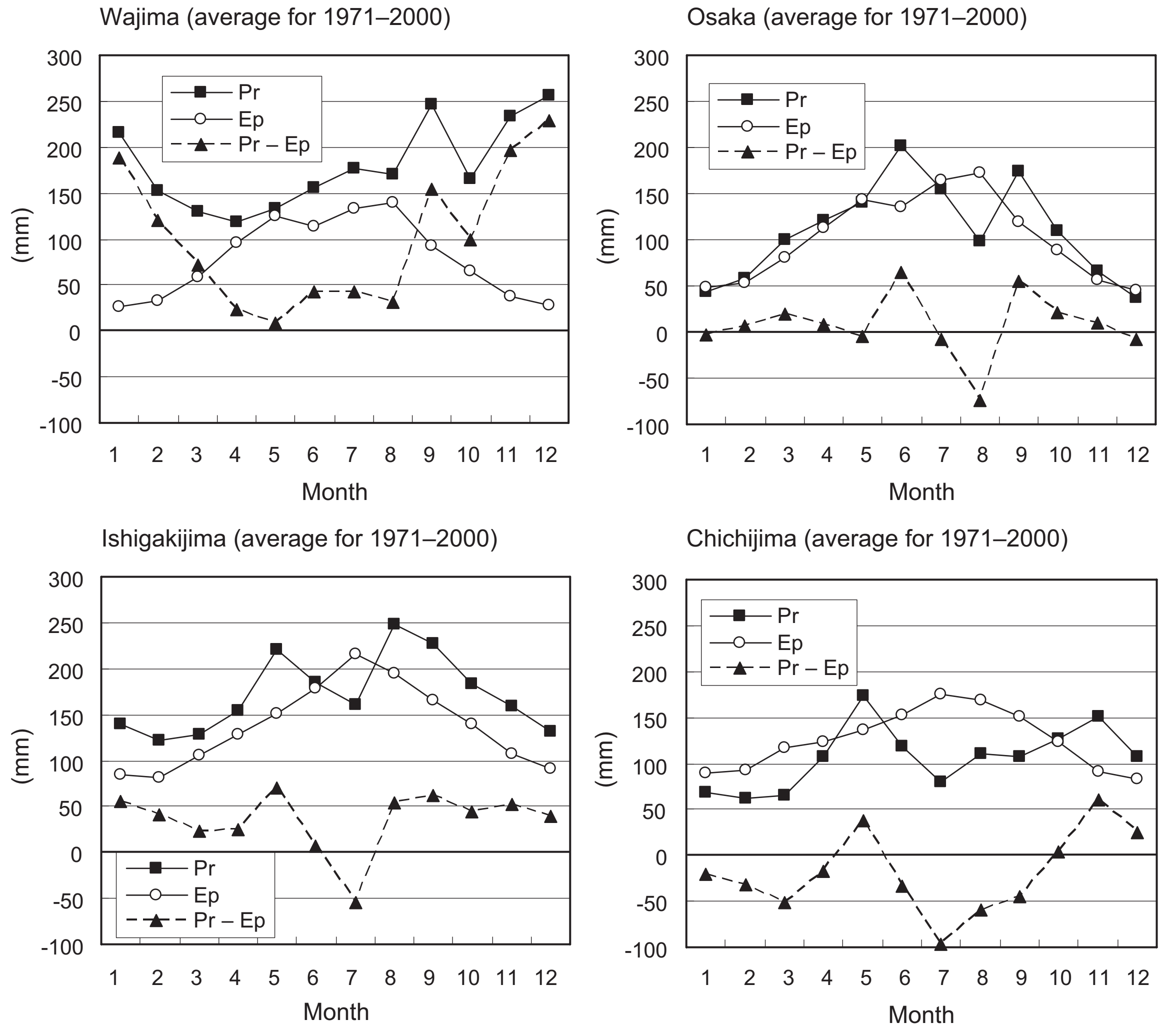

Fig. 14. The seasonal variations of the monthly water balances between precipitation *Pr* and potential evaporation E_P

as E_P in other periods. A similar result was found in Tokyo, except for August ($Pr \approx E_P$ in August, not shown).

③ The subtropical islands: In Ishigakijima, Pr is less than E_P (monthly $WI < 1.0$) only in July because of the local minimum in precipitation (Fig. 10) and strong solar radiation (Fig. 12). The seasonal water balance in both Naha and Miyakojima is almost the same as that in Ishigakijima (not shown). There is a possibility that mild water stress in crops sometimes occurs in July in the Ryukyu Islands. On the other hand, climates in both Minamidaitojima (not shown) and Chichijima are somewhat hydrologically dryer than those in the Ryukyu Islands because of smaller amounts of precipitation. Pr becomes less than E_P (monthly $WI < 1.0$) for longer periods in both the two islands.

Precipitation is the most important factor for determining the hydrological climatic environments. The humid climate in the temperate and subtropical areas around Japan is mainly caused by large amounts of precipitation. As described in the previous sections, the ocean plays an important role in forming the hydrological climatic environments in Japan. On the other hand, the hydrological climate in the eastern part of the Asian continent is dryer than that in Japan; annual wetness index WI is less than 1.0 in most parts of China[10].

In this study, the hydrological climatic environments were evaluated using the meteorological data averaged over 30 years. It should be noted that somewhat large variability in the annual precipitation was observed at all the meteorological stations in Japan. This causes a large annual variation in the hydrological environments for each site, and this variation is also important for crop production and agriculture.

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