# The Characteristics of Climate in Subtropical Islands around Japan

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## *ABSTRACT*

This paper analyzes the climatic characteristics of subtropical islands around Japan and their relationship with the climate on Japan's main islands, based on the Japan Meteorological Agency's meteorological data (averages for 1971–2000). The climatic features in the eastern area of the Asian continent were also analyzed by using Chinese meteorological data (averages for 1961–1990). The main results are summarized as follows.

(1) The horizontal distribution of monthly mean temperatures in both the subtropical islands and Japan's main islands (Hokkaido, Honshu, Shikoku, and Kyushu) can be expressed accurately as a function of latitude in both summer and winter. On the other hand, the monthly mean temperatures in the eastern area of the Asian continent are considerably lower than those in the temperate and subtropical areas around Japan in winter, although the monthly mean temperatures are almost the same as these areas during summer. The annual ranges of the monthly mean temperatures in Japan are smaller than those in the eastern Asian continent.

(2) The north-south difference in temperature is wide in winter but narrower in summer. The monthly mean temperatures on subtropical islands around Japan are almost the same as those in the southern area of Japan's main islands during summer.

(3) The mean diurnal ranges of temperature on the subtropical islands are around 5 °C, only about half of those inland on Japan's main islands. On the other hand, the mean diurnal ranges of temperature in the eastern Asian continent are roughly the same as those inland on Japan's main islands.

It is known that the ocean has the effect of reducing both temporal and spatial variation in temperature due to its large heat capacity. The strength of this thermal effect depends on the temporal and spatial scale of temperature variations. That is, the monthly mean temperatures in the whole of Japan (which include inland areas 100–200 km from the coastline) are under the influence of the thermal environments of the Pacific Ocean, but the thermal effect of the ocean on the diurnal variations in temperatures is restricted in the subtropical small islands and the coastal areas (within about 50 km of the coastline) on Japan's main islands.

On the other hand, the ocean also contributes to the supply of water vapor to the atmosphere, resulting in more precipitation over the temperate and subtropical areas around Japan. The characteristics of seasonal variations in precipitation and solar radiation on the subtropical islands around Japan were also analyzed to clarify the hydrological properties of these areas.


**Keywords:** East Asia, hydrometeorology, maritime climate, temperature, thermal effect of ocean

## Introduction

The Japanese archipelago stretches from temperate to subtropical areas of eastern Asia, and consists of the four main islands of Hokkaido, Honshu, Shikoku, and Kyushu, plus numerous small temperate or

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subtropical islands. The Japanese archipelago edges the Pacific Ocean, so it has a maritime climate (Yoshino, 2002). In particular, the small subtropical islands that form the Ryukyu and Ogasawara Islands are strongly influenced by the surrounding ocean.

Recently, Yoshino (2002, 2004) supervised two books that outline the characteristics of the Japanese climate. The objective of the present study is to elucidate in detail the characteristics of the climate, especially on the subtropical islands around Japan.

This study analyzes the characteristics of the climate on subtropical islands around Japan and their relationship with the climate on Japan's main islands by using routine meteorological data (averaged over 30 years). The climatic relationships between the Japanese archipelago and the eastern part of the Asian continent were also analyzed. The main themes of this study are to elucidate the climatic features in the temperate and subtropical areas (especially around the subtropical islands) around Japan and also to explain how the climate in these areas is affected by the ocean.

## Materials and methods

Figure 1 shows a map of the temperate and subtropical areas around Japan, together with the eastern part of the Asian continent. I used routine meteorological data (normal values for the period 1971–2000) obtained from the Japan Meteorological Agency (JMA). There are 154 meteorological stations whose altitudes do not exceed 1000 m MSL. According to the geographical features of each site, the meteorological stations are divided into 3 categories: coastal areas (= coast, 93 stations), inland areas (= inland, 38 stations), and islands (23 stations). All the stations which belong to the coastal and inland areas categories are located on Japan's main islands. Some of the meteorological stations in the island category are located on small subtropical islands. There are 7 meteorological stations on the Ryukyu Islands, and 2 meteorological stations on the Ogasawara Islands. The meteorological data are distributed as a CR-ROM package by the Japan Meteorological Business Support Center.

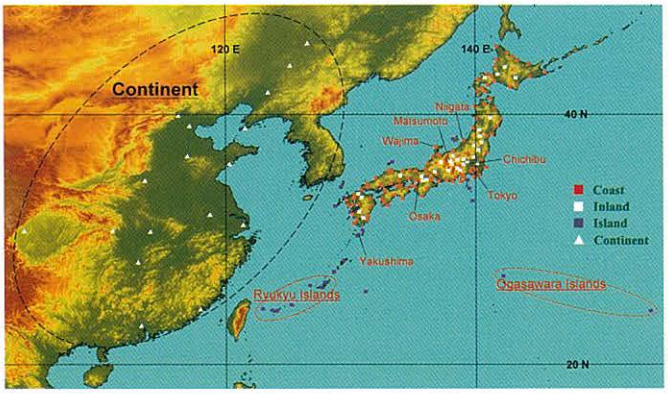


**Fig. 1A**

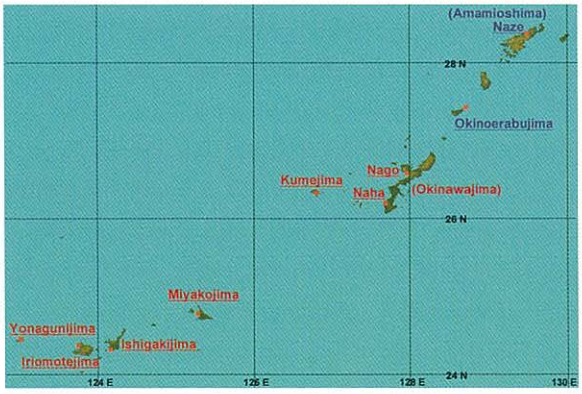


**Fig. 1B**

**A map 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.**

The meteorological data in China (normal values for the period 1961–1990) were also used to clarify the difference in climate between the maritime areas around Japan and the eastern Asian continent. I selected 17 meteorological stations in China with altitudes under 600 m MSL. These data were downloaded from the NOAA National Climate Data Center website (http://www.ncdc.noaa.gov/oa/ncdc.html).

Since the temperature values depend on the altitude of each meteorological station, the sea level temperatures were calculated from observed temperatures by using a lapse rate of 5 K $km^{-1}$. The sea level temperature for each meteorological station was used for the analysis in the present study. It should be noted that all data used in the present study are averaged over 30 years.

## Results and discussion

### *Latitudinal distribution of temperature*

Figures 2 and 3 show the latitudinal distribution of the monthly mean (sea level) temperature observed at the meteorological stations around Japan in winter (January) and summer (August). As can be seen in Fig. 2, the north-south difference in temperature is very wide in winter, reaching 30 °C from 24–45° N. In summer, this value narrowed to only 10 °C from 24–45° N (Fig. 3). That is, the monthly mean temperatures in subtropical islands around Japan are almost the same as those in the southern part of Japan's main islands in summer.

In both winter and summer, there is little difference in temperature among stations in the same latitude zone, except for the stations in China. This means that the horizontal distribution of monthly mean temperatures in both 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. On the other hand, the monthly mean temperatures in China (the eastern area of the Asian continent) were considerably lower than those in Japan during winter. In summer, however, the monthly mean temperatures in China were at the same level as those in Japan.

Figure 4 shows the latitudinal distribution of the annual mean temperature observed at meteorological stations around Japan. There is a somewhat different trend, even in the annual mean temperature, between Japan and China. The annual ranges of the monthly mean temperatures in Japan are smaller than those in China (not shown).

Typical examples of seasonal variations in (monthly mean) daily maximum and minimum temperatures in Japan's coastal areas and subtropical islands are shown in Figure 5. As shown in Figs. 2 and 3, there are large temperature differences between Japan's main islands and subtropical islands during winter. These differences narrow during the warm seasons, and no significant temperature differences between the two areas can be found in summer. It should be noted that the summertime daily minimum temperatures on Japan's main islands are somewhat lower than those on the subtropical islands, but that the summertime daily maximum temperature on Japan's main islands is almost the same as that on the subtropical islands. This is due to a smaller diurnal temperature range on the subtropical islands (see Fig. 5 in the next section).

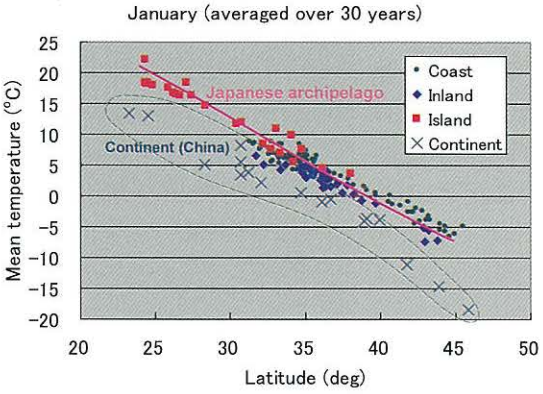


**Fig. 2. The latitudinal distribution of the monthly mean (sea level) temperature in winter (January) observed at meteorological stations around Japan (Coast: coastal area on Japan's main islands, Inland: inland area on Japan's main islands, Island: small islands around Japan, Continent: stations in China). The sea level temperature for each meteorological station was calculated from observed data using a lapse rate of 5 K km$^{-1}$. All data are averaged over 30 years.**

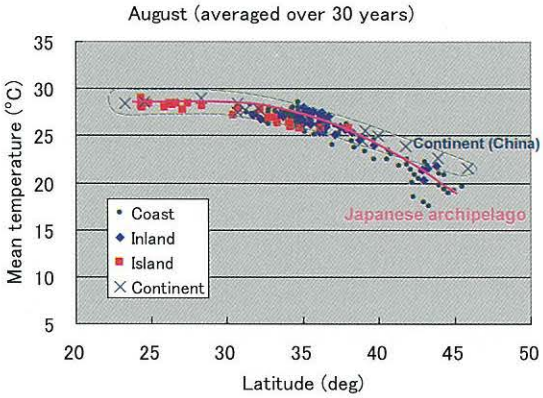


**Fig. 3. As in Fig. 2, except for summer (August).**

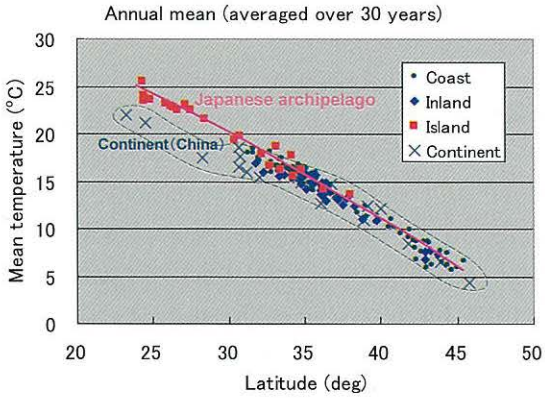


**Fig. 4. The latitudinal distribution of the annual mean (sea level) temperature observed at meteorological stations around Japan (averaged over 30 years).**

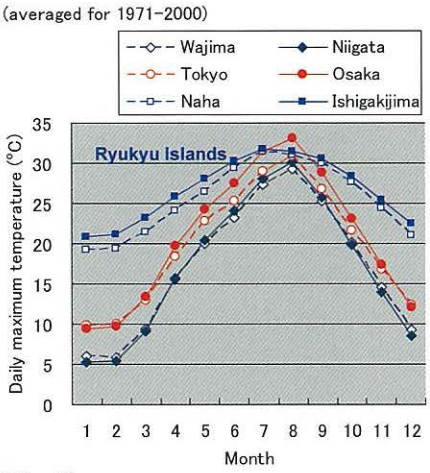


Fig. 5A

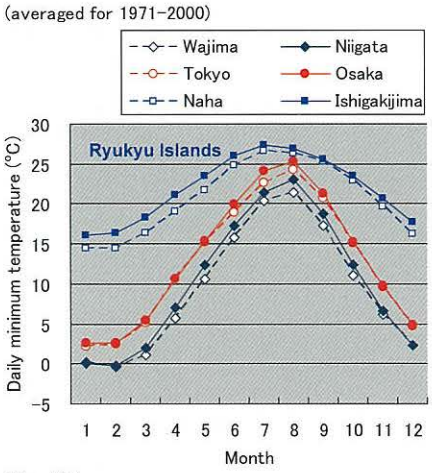


Fig. 5B

**Typical examples of the seasonal variation of daily maximum (A) and minimum (B) temperatures in the coastal areas of Japan and the subtropical islands (Wajima, Niigata, Tokyo, and Osaka: the coastal areas of Japan's main islands; Naha and Ishigakijima: subtropical islands). All data are averaged over 30 years. The location of each meteorological station is indicated in Figure 1.**

## *Diurnal ranges of temperature*

Figure 6 shows the annual mean diurnal ranges of temperature in Japan and China. The diurnal temperature range $\Delta T_D$ is defined as the difference between the daily maximum and minimum temperatures. The diurnal ranges of temperature are 8–12 ˚C inland on Japan's main islands, 5–10 ˚C in the coastal areas of Japan's main islands, and 4–8 ˚C in the temperate and subtropical small islands. On the other hand, the diurnal ranges $\Delta T_D$ in China (the eastern area of the Asian continent) are 7–12 ˚C, which are roughly the same as those in inland areas of Japan.

The diurnal ranges $\Delta T_D$ on the subtropical islands are only 4–6 ˚C, which are about half of those in the inland areas of Japan. On the other hand, larger values of $\Delta T_D$ of over 10 ˚C are found in the inland areas of Japan and in the eastern area of the Asian continent. These results suggest that the diurnal ranges of temperature in the subtropical small islands are restricted to a narrower range by the thermal effect of the surrounding ocean.

Typical examples of the seasonal variation of the monthly mean $\Delta T_D$ for each category are shown in Figure 7. The inland areas of Japan (Chichibu and Matsumoto) have very large seasonal variations, and the value of $\Delta T_D$ falls during the summer. Seasonal variations in $\Delta T_D$ are also found in the coastal areas of Japan (Tokyo and Osaka), which have two maximum peaks of $\Delta T_D$ in spring and autumn. However, there is no seasonal variation of $\Delta T_D$ in subtropical small islands (Naha and Ishigakijima).

## *Thermal effect of the Pacific Ocean on temperature*

It is known that, due to its large heat capacity, the ocean

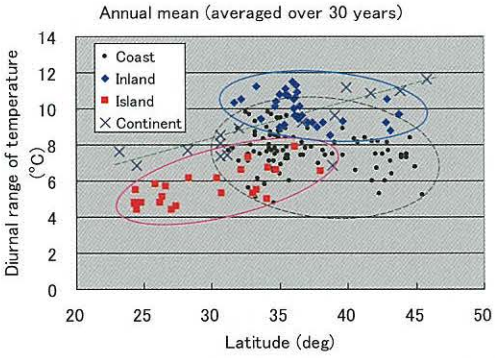


**Fig. 6. Annual mean diurnal ranges of temperature in Japan and China (Coast: coastal area on Japan's main islands, Inland: inland area on Japan's main islands, Island: small islands around Japan, Continent: stations in China). The diurnal temperature range is defined as the difference of the daily maximum and minimum temperatures. All data are averaged over 30 years.**

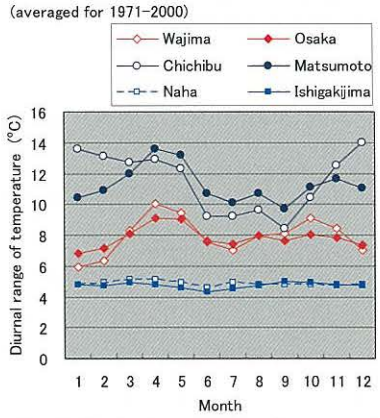


**Fig. 7. Typical examples of seasonal variation of the diurnal temperature ranges (Wajima and Osaka: coastal areas of Japan's main islands; Chichibu and Matsumoto: inland areas of Japan's main islands; Naha and Ishigakijima: subtropical islands). All data are averaged over 30 years. The location of each meteorological station is indicated in Figure 1.**

has the effect of reducing the temporal and spatial variation in temperature. The details of this mechanism are explained as follows.

The air temperature near the Earth's surface is determined by the exchange of energy between the air layer and the Earth's surface. If the Earth's surface temperature rises due to strong solar radiation, the air temperature similarly rises. On the other hand, the heat capacity of the ocean is considerably greater than that of the land, due primarily to the large heat capacity and high heat conductivity of water. Since the greater heat capacity of the sea surface suppresses changes in sea 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 horizontal atmospheric heat advection from the ocean. The strength of horizontal heat advection depends not only on the horizontal scale of the land area, but also the time scale of temperature variations. That is, as described in the previous section, the thermal effect of the ocean on diurnal (air) temperature variations is restricted in subtropical small islands and coastal areas (within about 50 km from the coastline), but the seasonal temperature variations over the whole of Japan, including the inland areas 100–200 km from the coastline, are influenced by the thermal environment of the Pacific Ocean. This is why the horizontal distribution of monthly mean temperatures in both Japan's subtropical islands and 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.

### *Precipitation*

Figure 8 shows the latitudinal distribution of the annual precipitation observed at meteorological stations around Japan (averaged over 30 years). The characteristics of this 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 wide variability in annual precipitation among the sites on Japan's main islands, but this variability is smaller on the subtropical islands.

The first characteristic is typical of a maritime climate. That is, the ocean contributes to the supply of 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 1000 to 3000 m MSL. The terrain-forced flow and thermally induced flow over complex terrains induces the development of clouds and increases precipitation (Kuwagata, 1997; Blumen, 1990). Since these geographical effects act on individual small areas over a complex terrain, the horizontal variability of precipitation is greater on Japan'

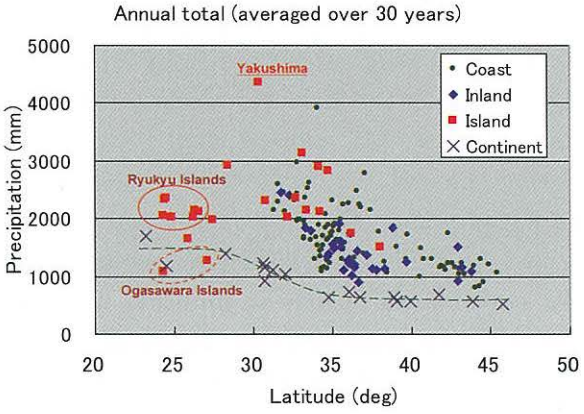


**Fig. 8. The latitudinal distribution of the annual precipitation observed at the meteorological stations around Japan (averaged over 30 years)**

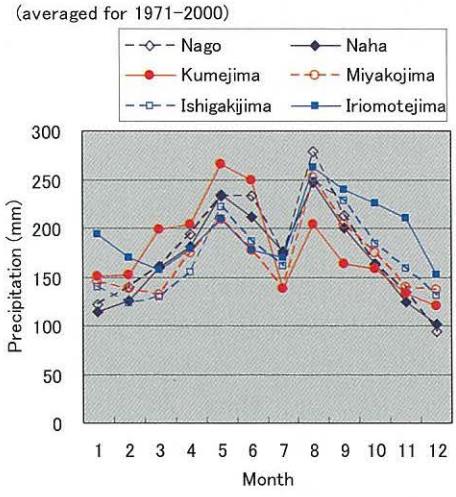


**Fig. 9. Seasonal variations in the monthly precipitation in the six subtropical islands (averaged over 30 years). The location of each meteorological station is indicated in Figure 1.**

s main islands. On the other hand, there are no steep mountains with altitudes of over 1000 m MSL on the subtropical islands around Japan. There is one exception, though: a large amount of precipitation is recorded on Yakushima (Fig. 8), which features several steep mountains with altitudes of around 2000 m MSL.

Figure 9 shows the seasonal variations in the monthly precipitation in the 6 subtropical islands (averaged over 30 years). These six islands are part of the Ryukyu Chain. 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.

### *Solar radiation*

The regional differences in sunshine duration and solar radiation are examined here. Figure 10 shows seasonal variations in the rate of sunshine duration $N/N_0$ in the coastal areas on Japan's main islands (Wajima, Niigata, Tokyo, and Osaka) and the subtropical islands in 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: at the same level as those in the Sea of Japan side on Japan's main islands (Wajima and Niigata). On the other hand, the values of $N/N_0$ in the Ryukyu Islands are very high during summer, reaching 0.6–0.7 in July. In the Ryukyu Islands, there are many cloudy days during the winter, but long sunny spells during the summer.

The seasonal variations in monthly mean solar radiation $S$ for the same sites are shown in Figure 11. 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 $S$ on Japan's main islands become smaller in winter, since the solar radiation in higher latitude zones is lower even in sunny weather conditions during winter. In the Ryukyu Islands, $S$ peaks in July, and its values are 1.2–1.3 times of those on Japan's main islands.

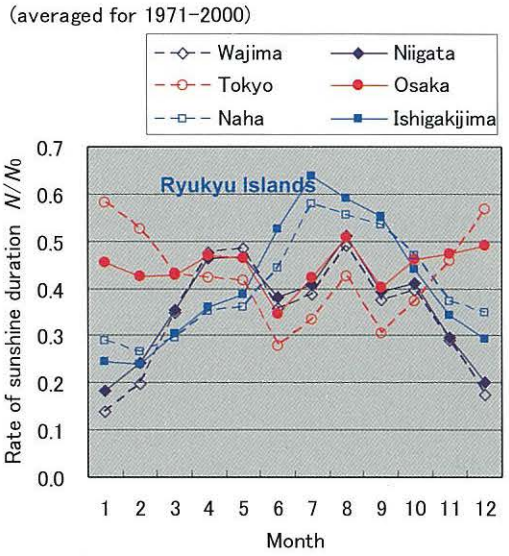


**Fig. 10. Seasonal variations in the rate of sunshine duration $N/N_0$ in the coastal areas on Japan's main islands (Wajima, Niigata, Tokyo, and Osaka) and in the Ryukyu Islands (Naha and Ishigakijima). $N$: monthly sunshine duration, and $N_0$: possible monthly sunshine duration. All data are averaged over 30 years. The location of each meteorological station is indicated in Figure 1.**

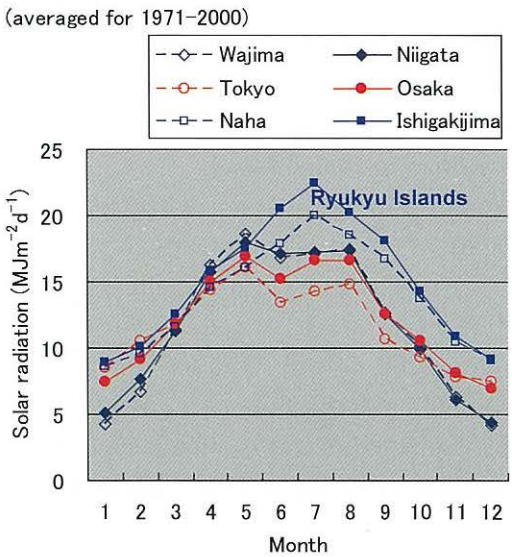


**Fig. 11. As in Fig. 10, except for the monthly mean solar radiation.**

### *Hydrological characteristics of the subtropical islands*

To examine the hydrological characteristics of subtropical islands (the Ryukyu Islands), I evaluated the potential evaporation $E_P$ and wetness index $WI$ suggested by Kondo and Xu (1997a,b). Here, $WI$ is defined as $Pr/E_P$ ($Pr$: precipitation). If the value of $WI > 1.0$ (when using the annual total $Pr$ and $E_P$), climatic conditions can be regarded as humid (Kondo and Xu, 1997b). The monthly mean data for wind speed, temperature, water

vapor pressure, solar radiation, and atmospheric pressure (averaged over 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 at a height of 1 m above the ground was used for calculating $E_P$, and was evaluated from the observed wind speed and aerodynamic roughness length for each site (Kondo and Yamazawa, 1986; Kuwagata and Kondo, 1991) by assuming a logarithmic wind profile. The downward long-wave radiation, which is also used for calculating $E_P$, was estimated using an empirical formula comprised of the monthly mean temperature, water vapor pressure, and solar radiation (Kuwagata *et al.*, 1990).

The annual mean value of *WI* was 1.31 ($Pr$ = 2038 mm, $E_P$ = 1551 mm) in Naha, and 1.25 ($Pr$ = 2061 mm, $E_P$ = 1664 mm) in Ishigakijima. That is, climatic conditions both in Naha and Ishigakijima can be regarded as humid. On the other hand, both in Naha and Ishigakijima, the monthly mean values of *WI* fall below 1.0 only in July because of the local minimum of precipitation (Fig. 9) and strong solar radiation (Fig. 11). The monthly mean values of *WI* in July were 0.92 ($Pr$ = 176 mm, $E_P$ = 192 mm) in Naha, and 0.75 ($Pr$ = 160 mm, $E_P$ = 215 mm) in Ishigakijima, respectively. There is a possibility that mild water stress in crops occurs in July in both the sites, since the monthly $Pr$ is less than the monthly $E_P$. The hydrological properties at the other sites in the Ryukyu Islands are expected to be similar to those in Naha and Ishigakijima.

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