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HYDROCLIMATIC CONDITIONS DURING THE FIRST HALF OF THE 20TH CENTURY IN THE BONIN (OGASAWARA) ISLANDS

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Abstract According to past studies based on long-term variations in precipitation and air temperature, climate in Chichi-jima of the Bonin (Ogasawara) Islands was rather wetter during the first half of the 20th century than during the latter half through present. The present study revealed actual hydroclimatic conditions using detailed meteorological components on monthly basis in the Annual Report of the Central Meteorological Observatory in terms of estimating potential evaporation and wetness index. As results of reevaluation of potential evaporation, Thornthwaite method underestimates potential evaporation especially during the cold season (from December to April) due to lower air temperature relatively to solar radiation. Thus, frequency of semi-dry month increased to 40-50% in this season. Annual wetness index is 1.24 in average (1907-1939) and only 5 years with less than 1.0 (semi-dry year). Small pan evaporation observed from 1931 to 1939 in Japan exhibits that Chichi-jima was one of the largest evaporation sites, namely the driest site in Japan although hydroclimatic conditions was wetter during the period.

Keywords: hydroclimate, potential evaporation, wetness index, small pan evaporation, the Bonin (Ogasawara) Islands

1. Introduction

The Bonin (Ogasawara) Islands is one of the typical isolated oceanic islands in the Pacific Ocean. There are lots of endemic plant and animal species. Hydroclimatic conditions, such as frequency and intensity of rainfall and dry period, are substantial environmental regulations for their survival and evolution as well as their own interspecific competition. Furthermore, the hydroclimatic knowledge increases their importance in order to clarify the influence of the recent climatic changes on the actual response within the multi-decadal and centurial time scales.

Centurial scale of hydroclimatic conditions in the Bonin Islands have been studied using meteorological data after starting of official observation in 1906 at Chichi-jima Island. Most of studies have been made of analysis using air temperature and precipitation data in order to detect

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long-term trend (Shimizu 1928; Maejima and Oka 1981; Oka *et al.* 2000; Iijima *et al.* 2005,Yoshida *et al.* 2006). These studies have also clarified seasonal and interannual variations in water surplus and deficit based on computation of potential evaporation by Thornthwaite method (Thornthwaite 1948) which is an empiric formula using only air temperature. However, Iijima *et al.* (2004) have found discrepancy between potential evaporation by Thornthwaite method and by physical based calculation (Kondo and Xu 1997) using detailed meteorological data during 1970-2001. Therefore, it is also needed to clarify the hydroclimatic conditions during the first half of 20th century based on detail analyses of meteorological components and physical based reevaluation of potential evaporation. In the present study, therefore, the further clarification of hydroclimatic history in Chichi-jima Island is carried out using detailed meteorological components observed during the first half of the 20th century which are newly digitized. Our focus is placed on the long-term variation in seasonal wetness (dryness) conditions in terms of potential evaporation and wetness index throughout the century. In addition, we explored actual hydroclimatic conditions based on comparison with observation of small pan evaporation.

2. Data

The present study used monthly meteorological data at Chichi-jima observatory (27°5' N, 142°11' E) from 1906 to 1940 compiled in the Annual Report of the Central Meteorological Observatory (the forerunner of the Japan Meteorological Agency). We digitized monthly values of air pressure, air temperature, water vapor pressure, precipitation, cloudiness, solar duration, small pan evaporation, wind speed and day numbers of each weather type. In order to clarify hydroclimatic conditions, the potential evaporation (E_{pot}) defined by Kondo and Xu (1997) was estimated using these monthly data. The computation of E_{pot} is the same method used by Yoshida *et al.* (2002) except for estimations of global solar radiation and downward longwave radiation. Estimation of global solar radiation was made using cloudiness and sunshine duration data (Kondo 1994). Downward longwave radiation was also computed using parameterization by Kondo (1994) which is reliably applied in Japan using air temperature, relative humidity, air pressure, and cloudiness. In addition, we used potential evaporation by Thornthwaite method (E_{thorn}) computed in Yoshida *et al.* (2006) for the comparison with E_{pot}.

Evaporation from a small pan with 0.2 m in diameter was recorded in the report from 1931 to 1939 at Chichi-jima. In addition, we extracted the small pan evaporation data at 11 sites in Japan based on perfect continuity of data. These 11 sites have also been chosen by Asanuma *et al.* (2003). They analyzed long-term trends of large pan (1.2 m in diameter) evaporation data during 1967-2000 that replaced small pan during the 1960s.

3. Meteorological Components at Chichi-jima during 1907-1940

Figure 1 exhibits the time series of monthly meteorological components at Chichi-jima. The averaged annual variations during both two periods from 1907 to 1939 and from 1971 to 2000 are added in this figure. Atmospheric station pressure is originally recorded as the unit of mm Hg and converted into hPa (Fig. 1a). Annual minimum generally appeared in August (1010.3 hPa in average during 1907-39) and maximum in January (1018.6 hPa). Comparing with the latter 30 years (1971-2000), atmospheric pressure has positive bias with +1.4 hPa in mean annual value. According to the site information in the report, Chichi-jima station has never been relocated throughout the period up to present so that the difference might indicate long-term difference.

Mean annual air temperature during 1907-1940 is 22.6 °C, whereas 23.0 °C during 1971-2000 (Fig. 1b). Temperature increase is prominent during the cold season. The largest difference of air temperature is 0.8 °C in January. As shown in Yoshida *et al.* (2006), long-term amplitude of variation and the trend of mean annual air temperature are consistent with those averaged over representative 17 sites in Japan. That is, higher temperature appeared in the 1910s and 1930s and lower temperature in the 1920s.

Water vapor pressure calculated using monthly air temperature and relative humidity shows comparable interannual variation to air temperature (Fig. 1c). The water vapor pressure during 1907-39 is slightly higher during the cold season (14.1 hPa; +0.3 hPa in February), whereas lower during the warm season (29.4 hPa; -1.0 hPa in August), which is somehow contradictory to larger amount of precipitation during this period.

Precipitation shows the largest difference between two periods as the most of studies (e.g., Maejima and Oka 1981; Yoshida *et al.* 2006) have pointed out (Fig. 1d). Annual precipitation during 1907-1940 is 1,611 mm and 1,277 mm during 1971-2000. There is no year with less than 1,000 mm of annual precipitation, which occurred 5 years during 1969-2007. The difference in monthly precipitation between both periods exceeds +20 mm except for November and largest difference appears in August (+45 mm). As for seasonal variation during both periods, however, month with minimum precipitation occurs in February and another minimum is in July just after the rainy season. The remarkable difference between the periods is occurrence of the dry month. Number of months with less than 50 mm of precipitation had nearly doubled (47 months during 1911-1940; 101 months during 1971-2000) and the difference is prominent from February to April and June. Inversely, number of month with extreme rainfall of more than 300 mm is not changed (15 months during 1911-1940; 14 months during 1971-2000).

Sunshine duration was observed with Jordan sunshine recorder during 1908-1939. To make homogeneous data after replacement by rotating sunshine recorder after 1987, correction based on Japan Meteorological Agency (1991) was made throughout the period (Fig. 1e). Seasonal variations during both periods are almost similar with less than 160 hours from October to April and abrupt increase in June and July. The monthly difference is the largest in May and June with -10 hours smaller than that during 1971-2000, which implies difference of cloudiness during the rainy season. In fact, coefficients of variation of precipitation and sunshine duration are the largest in June due to the large interannual variability of the rainy season, still appearing in recent decades.

The most problematic variation is found in wind speed (Fig. 1f). There are several discontinuous changes during the period; that is 1906-1909, 1910-1920, 1921-1924, and 1925-1939. The period during 1920-23 especially exhibits abnormally high wind speed with quite different seasonal variation. These changes are likely caused by observational discontinuity, such as changes in instrument and observation height, difference in sampling and averaging criteria. For example, the height of the anemometer several times changed 14-15 m according to the description of observatory in the report. Although there is the inhomogeneity of data, averaged annual variation indicates comparable to that during 1971-2000. Wind speed is the weakest in July with 2.2 m/s in average and highest during the cold season with 3.5 m/s in February.

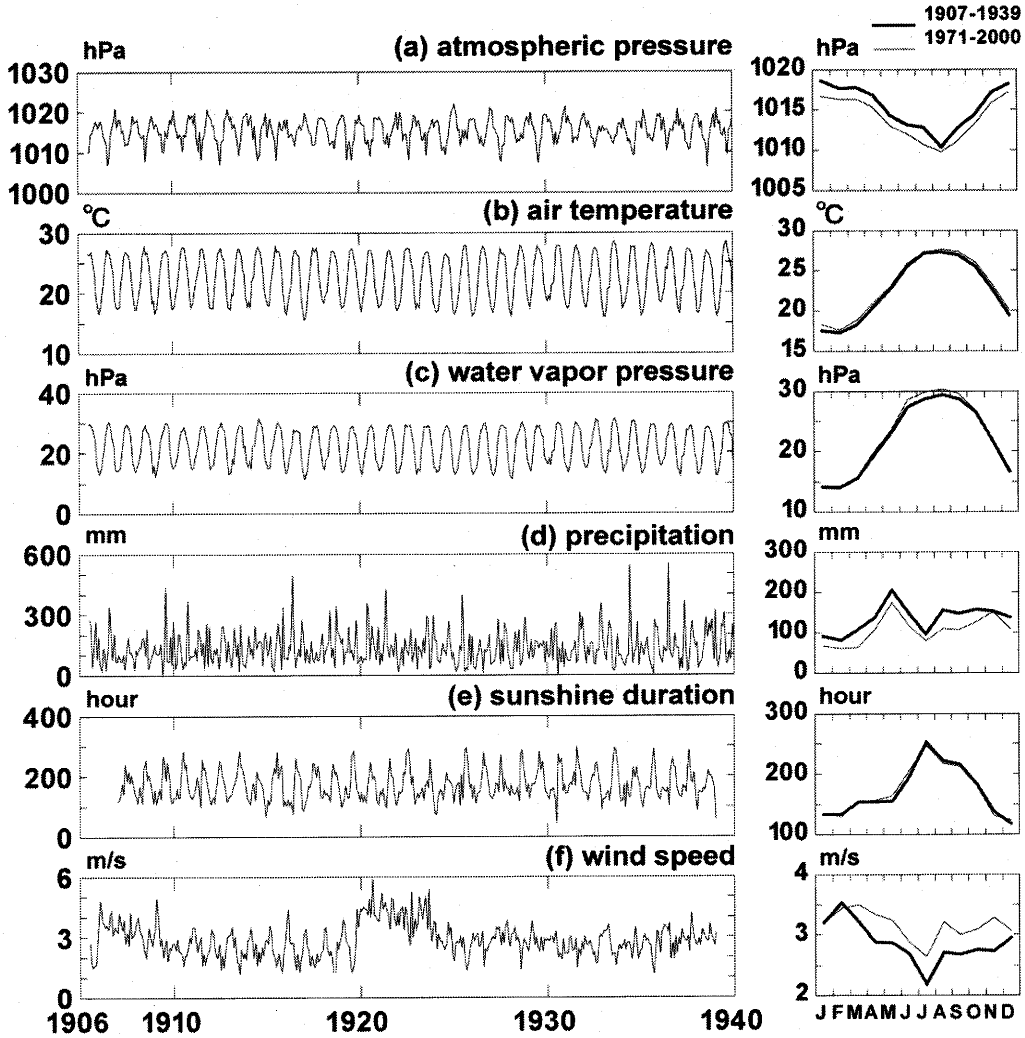

Fig. 1 Time series of monthly meteorological components at Chichi-jima observatory from 1906 to 1940. (a) atmospheric pressure, (b) air temperature, (c) water vapor pressure, (d) precipitation, (e) sunshine duration, and (f) wind speed. Right figure denotes annual variations of each component during 1907-1939 (bold line) and 1971-2000 (thin line).

4. Long-Term Variations in Potential Evaporation and Wetness Index

Figure 2 shows the long-term variations in monthly wetness index (Prec/E_{pot}) and annual amounts of potential evaporation and precipitation. It should be noted that E_{pot} was likely overestimated during 1920-1923 because of the higher bias of wind speed. Except for 1920-1923, annual amount of E_{pot} ranges from 1,169 mm in 1915 to 1,415 mm in 1930 and is 1,300 mm in average. E_{pot} has increased to 1,385 mm in average during 1971-2000 (1,239 mm in minimum in

1976, 1,497 mm in maximum in 1991). Monthly E_{pot} has increased between the periods throughout a year with marked increase during the rainy season from March to June. Inversely, annual precipitation was significantly larger during 1907-1940 than during 1971-2000. Consequently, as generally consistent with previous studies (Maejima and Oka 1981; Yoshida *et al.* 2006), the first period (1907-1940) indicates wetter hydroclimatic conditions than the latter period (1970-2000). Namely, annual wetness index is 1.24 in average during 1907-1940 and 0.92 during 1970-2000. It is notable that number of semi-dry year with 0.3-1.0 of wetness index was only 5 years (1908, 1914, 1918, 1923, and 1927) during 1907-1940, whereas 22 years during 1970-2007.

Figure 2b shows that annual amount of E_{pot} was ca. 10 % larger than E_{thron}. The discrepancy was mainly caused due to difference in estimation from January to May (Fig. 3) as Iijima *et al.* (2004) have detected the difference during 1970-2000. During the cold season through the rainy season in May, air temperature is rather lower comparing with the solar radiation by influence of the winter monsoon and mid-latitude air mass over north western Pacific. Therefore the empirical formula of E_{thron} made in northern American plain was somehow inadequate for the estimation. As the result, water deficit based on E_{thorn} tends to be very small during the cold season (Oka *et al.* 2000; Yoshida *et al.* 2006). On the other hand, since E_{pot} takes surface radiation and energy balance into account, we could properly correct potential evaporation during the cold season. In fact, wetness index using E_{pot} could exhibit that frequency of semi-dry month during the cold season from January to April was corrected to 39-52 % (Fig. 2a), whereas the frequency was only 9-24 % by E_{thorn}. In addition, E_{pot} could properly detect significant decrease of potential evaporation in June associated with the prolonged rainy season. Fore example, less than -σ from average (110 mm) of E_{pot} in June occurred in 5 years (1912, 1926, 1929, 1931, and 1937), corresponding with the abnormal reduction of sunshine duration (less than 140 hours). Interestingly, the abnormally low E_{pot} in June rarely occurred during 1970-2006 (only 1987).

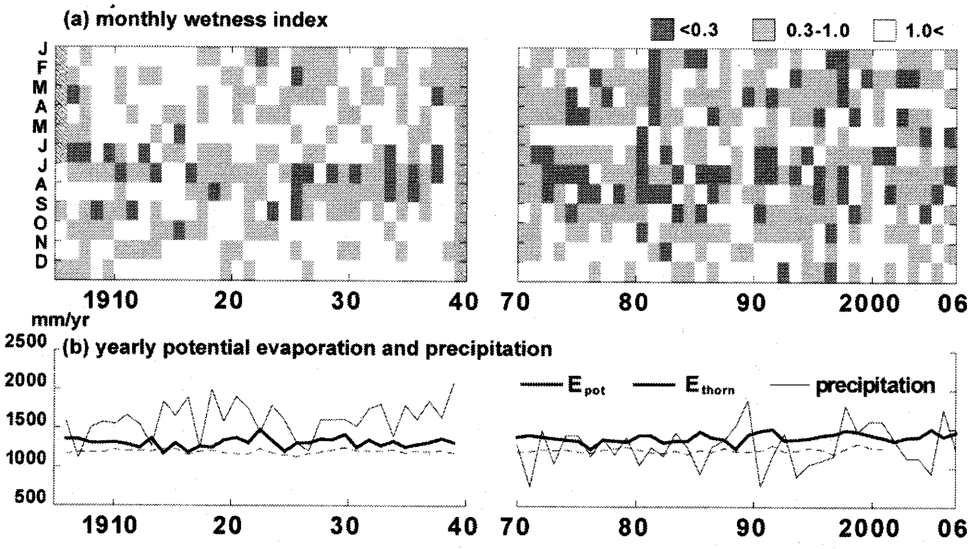

Fig. 2 Temporal variations in (a) monthly wetness index and (b) annual amounts of potential evaporations (E_{pot}: Kondo and Xu method; E_{thorn}: Thornthwaite method) and precipitation. E_{thorn} was provided by Yoshida *et al.* (2006).

In Chichi-jima, severe droughts occurred during the warm season in 1980, 1990, and 2004 at a rate of almost once a decade. These years had continuously low wetness index with less than 1.0 from May to October. It is notable that such a persistent drought starting from the rainy season had never occurred during 1907-1940. According to Yoshida *et al.* (2002), dry season with less than 0.3 of wetness index is well associated with severe depletion of soil moisture reaching almost wilting point. Only in 1926 and 1934, the dry period continued for 3 months during the warm season.

5. Small Pan Evaporation

Figure 3 demonstrates annual variation in E_{pot} and E_{thorn} and small pan evaporation (E_{pan}) during 1931 to 1939 at Chichi-jima. Small pan evaporation in Japan was observed at 0.2 m height from surface of observation field (Kondo personal communication). Theoretically, small pan has the larger effective transfer velocity so that evaporation from the small pan tends to be larger than potential evaporation. The ratio of E_{pan} to E_{pot} climatologically ranges from 0.9 to 1.3 (Kondo and Xu personal communication). In fact, the ratio during 1931-1939 in each month varied within the range of 1.12-1.32. The consistent seasonal variations in E_{pot} and E_{pan} imply that the estimation of E_{pot} is reliable to indicate actual hydroclimatic conditions. In this period, summer dry period as pointed out by Iijima *et al.* (2004) clearly occurred in July and August.

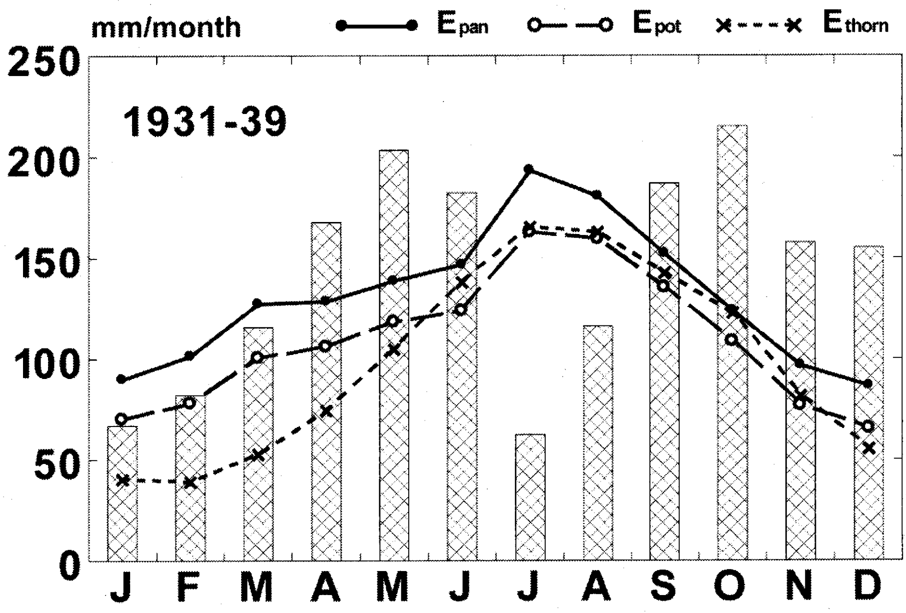

Fig. 3 Annual variations in potential evaporations (E_{pot}: Kondo and Xu method; E_{thorn}: Thornthwait method), small pan evaporation (E_{pan}) and precipitation (bar) during 1931-39.

Figure 4 shows that the distribution of annual amounts of small pan evaporation and ratio of annual precipitation to E_{pan} at 11 sites in Japan. E_{pot} at Chichi-jima is 140 mm larger than at Naha (1,245 mm) during 1971-2000. However, small pan evaporation shows larger evaporation at Naha (1,787 mm) and Kagoshima (1,619 mm) than at Chichi-jima (1,563 mm). This change might imply the possibility of hydroclimatic change occurring not only at Ogasawara Islands but extending over subtropical area of Japan. The ratio of precipitation to E_{pan} shows that Chichi-jima is one of the lowest sites (1.1) in Japan although wetter climatic condition than the recent decades.

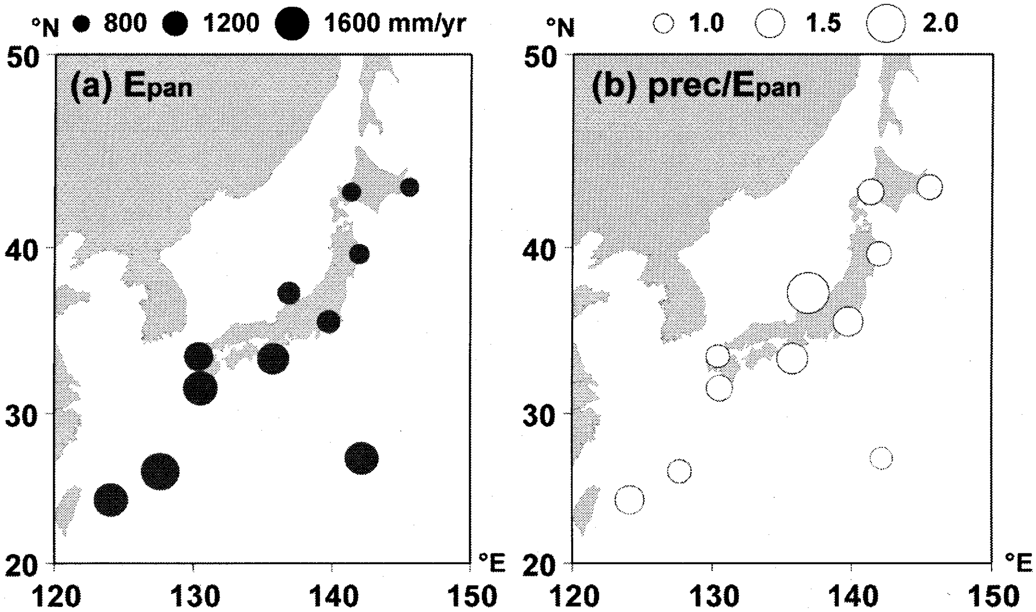

Fig. 4 The maps of (a) annual amounts of small pan evaporation (E_{pan}) and (b) Ratio of annual precipitation (Prec) to E_{pan} at 11 sites in Japan.

6. Conclusions

In the present study, we examined the long-term change in the hydroclimatic conditions with reevaluation of potential evaporation and wetness index during the first half of the 20th century using actual meteorological components which were newly digitized. More reliable feature of seasonal variation could be captured, such as weak but frequent occurrence of dry month during the cold season and several remarkable reduction of potential evaporation during the rainy season. Consequently, we could reconfirm further wetter conditions during the period and it could be concluded with more confidence that the remarkable change to be a drier climate was going on in the Ogasawara Islands during the 20th century. According to the differences in atmospheric pressure, humidity, and sunshine duration in addition to air temperature and precipitation during the first and latter half of the 20th century, there is the possibility of changing climatic system over the north western Pacific region. Westward expansion of North Pacific subtropical high strongly related with variation in convective activity over warm pool region in the equatorial Pacific (Lu 2001) affects substantial influence on frequency of dry period during the warm season. Decaying trend of winter monsoon (Xu *et al.* 2006) could be another important cause to reduce frequency of cyclone passage over the Ogasawara Islands during the cold season. It is further necessary to detect actual climatic signal by careful evaluation of past observational data for clarifying realistic feature of hydroclimatic change in this islands.

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