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Increasing Summer Night Temperatures during a 24- Year Periods in Japan: Implications for Rice Production

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Abstract

Summer night temperatures are increasing across most of the globe. In this study, we attempted to detect variability in recent increasing trends in summer night temperatures in Japan. Hourly night temperatures higher than 25°C and 30°C measured by the Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency were accumulated for each night during each of six approximately 10-day periods during July and August from 1979 to 2002. These two parameters, called ANT_{25} and ANT_{30}, were used for our analyses. Although increasing trends in night temperature were conspicuous in large cities such as Tokyo, Osaka, and Nagoya, they were also observed widely throughout Japan, including small cities and rural areas. The highest rates of increase in ANT_{25} were found in early August from Kanto and Hokuriku districts and to the west along the coast. The effects of night warming on rice production in Japan are discussed.

Keywords: *Global warming, Night temperature, Rice production, Urbanisation*

Introduction

The global average surface temperature has increased over the 20th century by about 0.6°C (IPCC, 2001a). Several studies have demonstrated that the rate of increase in daily minimum temperature was greater than that of the daily maximum temperature over the last few decades (Karl et al., 1993; Easterling et al., 1997; Gaffen and Ross, 1998; Peng et al., 2004). This indicates that night temperatures have been increasing more than day-time temperatures on the terrestrial surface of the globe. A similar tendency has been also observed in Japan; the number of days in which the daily minimum temperature in summer exceeds 25°C or 28°C has been increasing continuously since the 1970's (JMA, 2002; Fujibe, 2004), while the number of days in which the daily maximum temperature in summer exceeds 30°C has not showed clear increasing trends since the 1960's (JMA, 2002).

Night temperatures are increasing not only in most urban areas but also in most rural areas in Japan (Fujibe, 2004). Kato (1996) reported that air temperatures in Japan have been increasing at a rate of 0.8°C per century if urbanised effects on rising temperature are statistically removed. Because of this, we should pay attention to various environmental changes in factors affecting our lives: human health, energy consumption, and natural and agricultural ecosystems (IPCC, 2001b). For instance, the yield of rice, one of the major crops in Japan, is

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closely related to summer night temperatures (Peng et al., 2004). High night temperatures in summer during the ripening period of rice may have been lined to decrease in rice quality (Terashima et al., 2001; MAFF, 2006a). This will result in considerable damages to society and the economy in Japan. Therefore, we need an evaluation of recent changes in summer night temperatures in terms of stable crop production nationwide.

In this study, we focused on recent trends in summer night warming observed in Japan, and attempted to detect temperature changes occurring in shortly divided periods within summer. Then, we discussed the relationships between night temperatures and biological phenomena occurring in a short period within summer. Rice ripening is one of the phenomena of interest.

Methods

We divided the mid-summer season (July and August) into six periods consisting of 10 or 11 days, and then evaluated the interannual variations in night temperature over the course of 24 years from 1979 to 2002 for each period. Because biological responses to high temperatures were assumed to be sensitive to both temperature itself and its continuous time, hourly accumulated temperatures were used for analyses in this study. Data on air temperature, recorded at 1-hour intervals from 1979–2002 by Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency, was used in this study. This data was obtained from CD-ROMs, offered by the Japan Meteorological Business Support Center. All the observatory points where data acquisition continued at the same point during the 24 years were assessed. For each of the 10 days in the early and middle parts of the month and for each of the 11 days in the late part of the month (both are called "10-day periods" hereafter) during July and August in each year of the period, we calculated the daily mean values of accumulated night-time temperatures that exceeded 25°C (ANT_{25}, °C·h·d^{-1}) as,

$$ANT_{25} = ((\sum_d \sum_h (T_{dh} - 25)) / 10 \text{ (or } 11), \quad \text{for} \quad T_{dh} > 25,$$

where T_{dh} is the night-time temperature observed on a hour (h) in a day (d). Hours before sunrise (0:00–6:00) and after sunset (18:00–24:00) were used for the accumulation. ANT_{30} (°C·h·d^{-1}) was calculated in the same way, but with the critical temperature set to 30°C. These temperatures, 25°C and 30°C, were familiar with critical temperatures for extremely hot nights (so called "Nettai-ya") and hot days ("Manatsu-bi") in Japan.

Then, yearly averaged values of ANT_{25} and ANT_{30} during the first set (1979–1983) and last set of five years (1998–2002) on the whole were calculated for each 10-day period in July and August. In total, calculations were made for 689 and 733 AMeDAS points during 1979–1983 and 1998–2002, respectively.

Trends in yearly transition of ANT_{25} and ANT_{30} during 24 years (1979–2002) were also analysed for every 10-day period in the 689 AMeDAS points by using linear regression. Ahead of the regression analysis, moving averages of five-year values were taken throughout all of the years on both parameters for each 10-day period. The values of the interannual changing rate (slope of the regression line, °C·h·d^{-1}·yr^{-1}) were plotted in colour only when the slopes of the regression lines were statistically significant (Probability value (P) < 0.01) and the coefficient of determination (R^2) exceeded 0.36 in each regression.

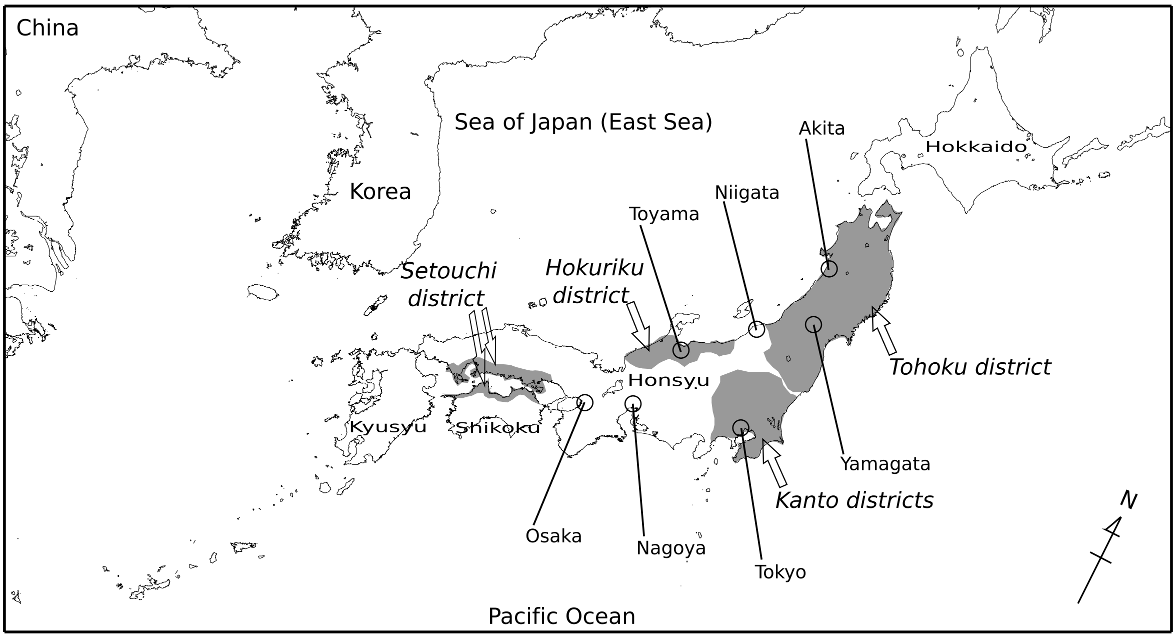

Figure 1. Map of Japan.

Results

Figure 1 shows locations of the cities and districts focused on this study. Higher values of ANT_{25} were observed in western to eastern Japan, and lower values were found in northern Japan (Fig. 2). The points of the AMeDAS stations that had above 2.4°C·h·d^{-1} for ANT_{25} (coloured area except blue) were widely distributed in the final five years (1998–2002) than in the first five years (1979–1983) in every 10-day period (Fig. 2). In the final five years, especially in late July to mid August, extremely warm areas that had above 12°C·h·d^{-1} for ANT_{25} (red coloured area) spread from Kanto and Hokuriku districts and to the west. In the first five years, night temperatures were already higher in the urban areas of the three largest cities, Tokyo, Osaka, and Nagoya, than in their surrounding areas. However, in the final five years, night temperature warming increased further and was more widely spread over the outside area of these cities.

Although summer night temperatures rarely exceeded 30°C in the first five years, higher values of ANT_{30} were observed in many regions in the final five years (Fig. 3). From late July to early August in the final five years, an extremely warm area recorded above 1.0°C·h·d^{-1} for ANT_{30} (red coloured area) was widely distributed over western Japan. The red coloured area was spread across the Sea of Japan toward the Tohoku district in early August. High values of ANT_{30} were also observed in the three largest cities and their surrounding areas throughout summer in the final five years.

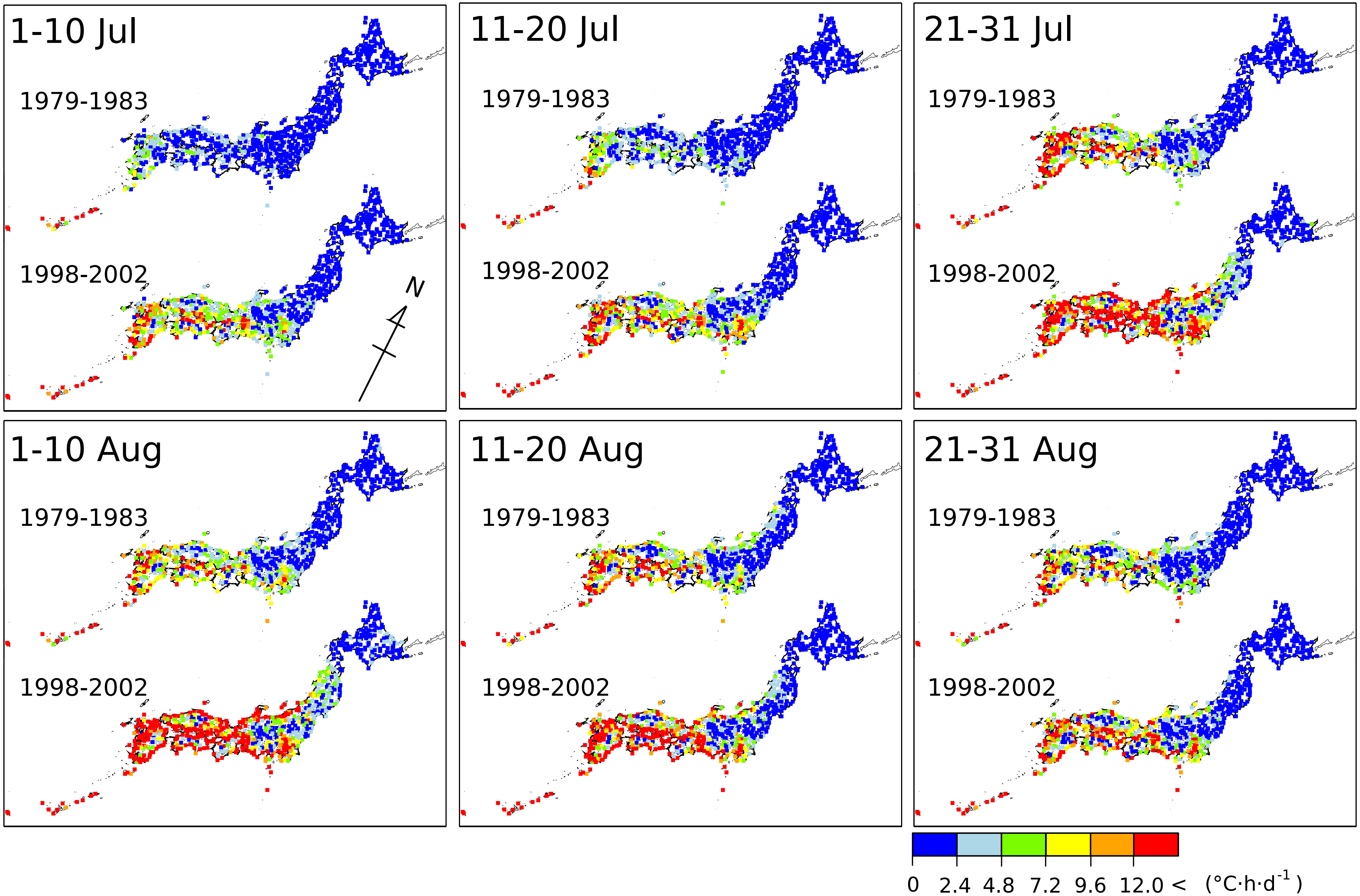

Figure 2. Distribution of averaged value of ANT_{25} during five years from 1979 to 1983 and from 1998 to 2002.

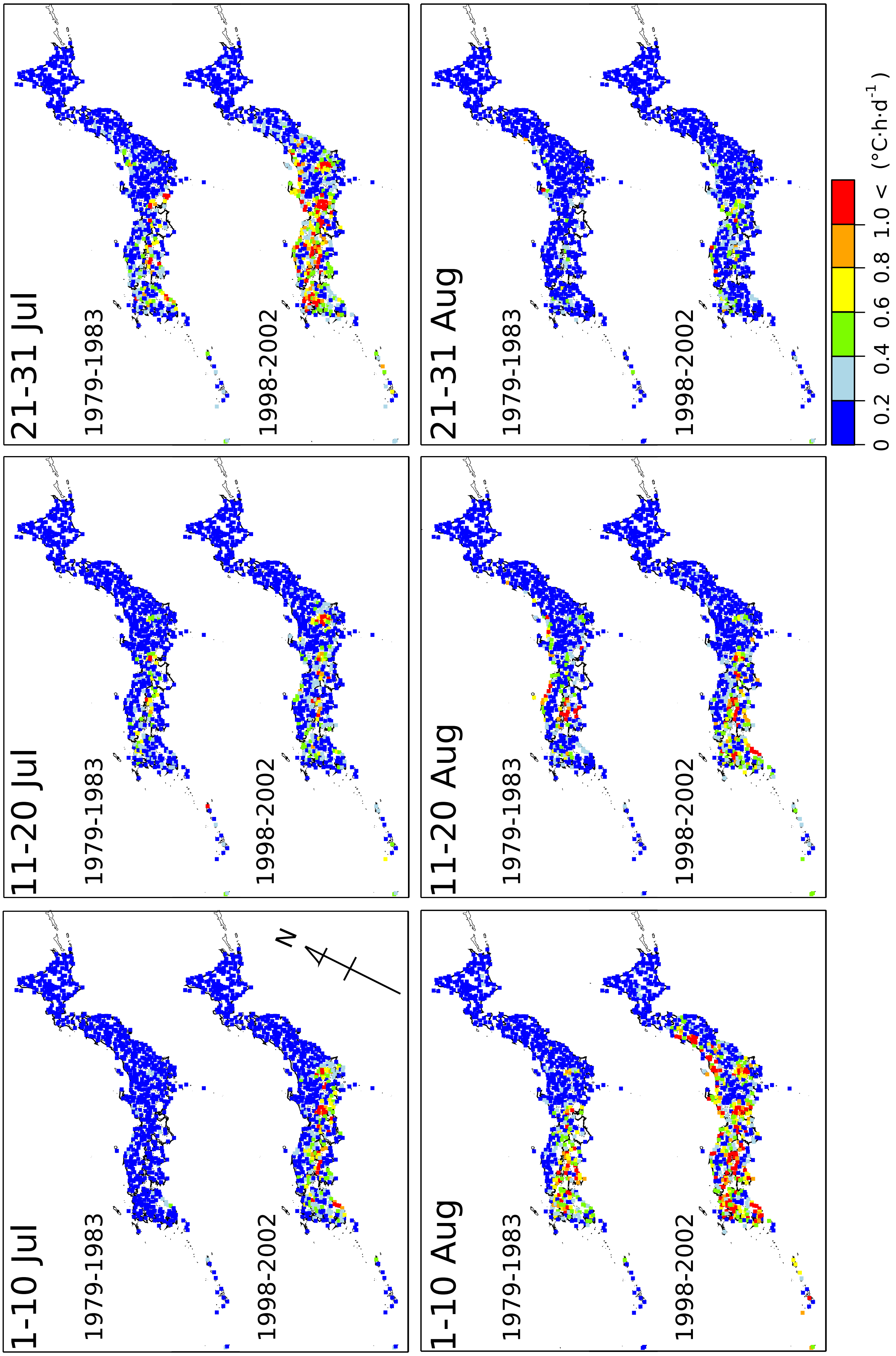

Figure 3. Distribution of averaged value of ANT_{30} during five years from 1979 to 1983 and from 1998 to 2002.

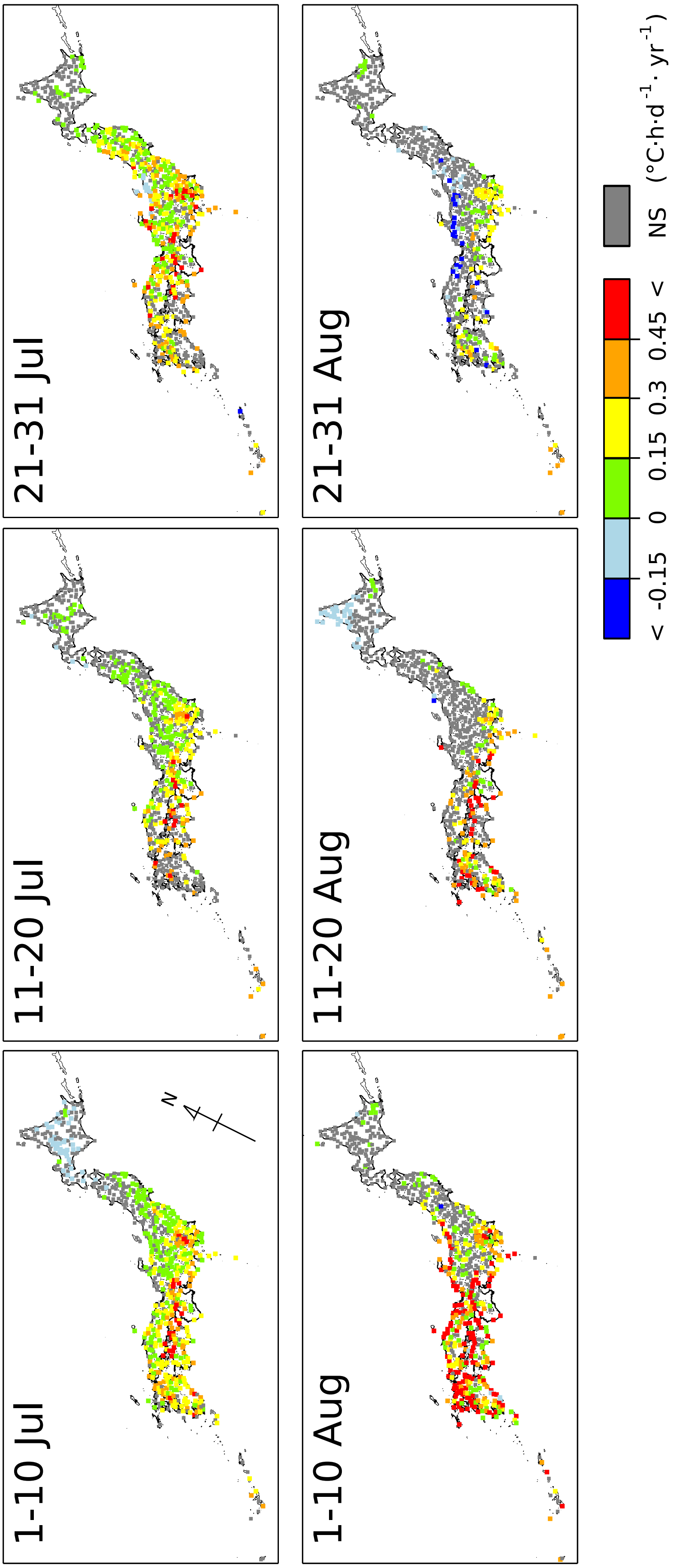

Figure 4. Distribution of changing rate for ANT_{25} from 1979 to 2002.

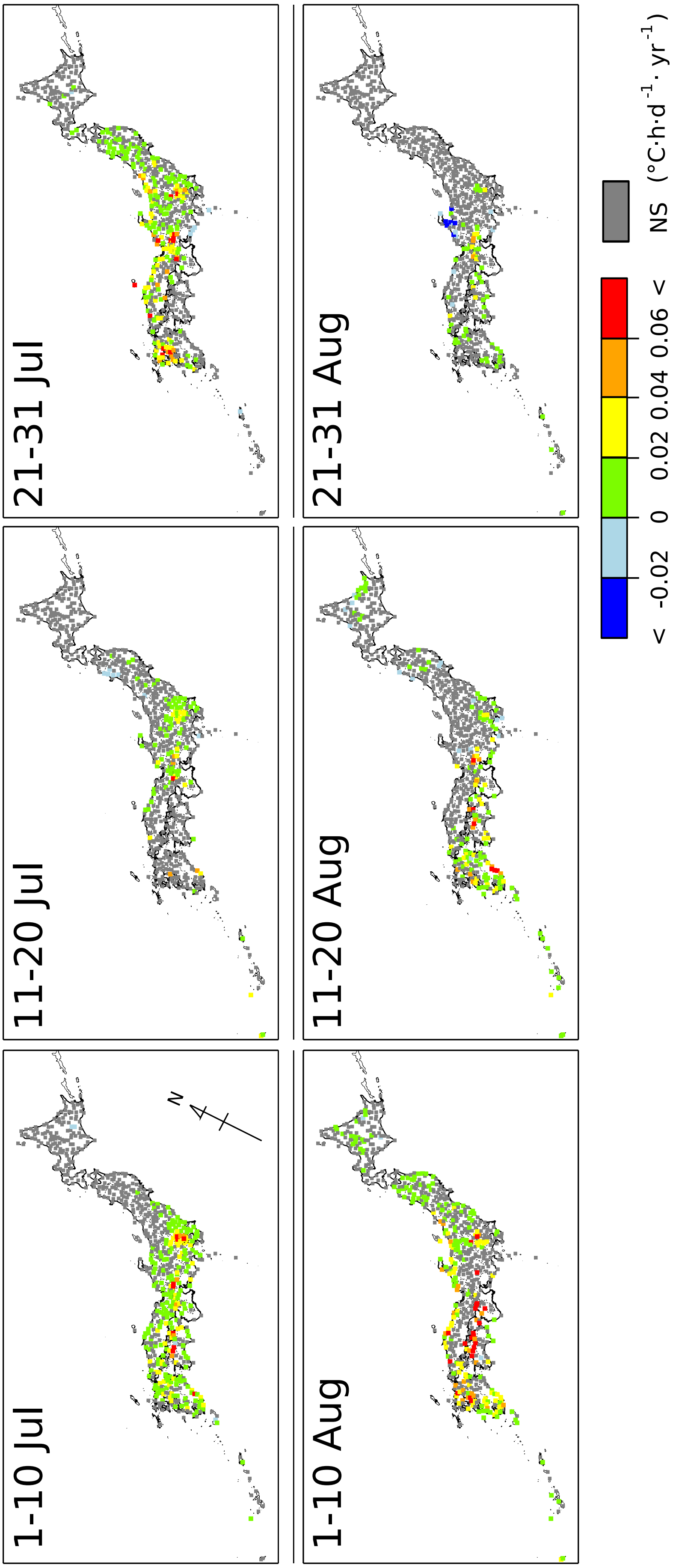

Figure 5. Distribution of changing rate for ANT_{30} from 1979 to 2002.

Significant increasing trends for ANT_{25} during the period from 1979 to 2002 were detected in large parts of Japan from early July to early August (Fig. 4). Although the warming area covered the mid-land region in July, it was found along the coastal area in August. The highest increase rate of ANT_{25}, marked in red (over 0.45°C·h·d^{-1}·yr^{-1}), was especially conspicuous in early August, and its area was distributed from Kanto and Hokuriku districts and to the west. The urban area of the three largest cities, Tokyo, Osaka, and Nagoya, showed the highest increase rate of ANT_{25} from early July to early August. However, the coastal area along the Sea of Japan, Kyushu, and Setouchi district also showed the highest increase rate in early August.

As shown in figure 5, significant increasing trends for ANT_{30} from 1979 to 2002 were not obvious compared with those for ANT_{25}. The warming area, shown in colour points in the figure, shifted from western to northeastern Japan during July. The highest increase rate of ANT_{30} over 0.06°C·h·d^{-1}·yr^{-1} (coloured in red) was observed mainly in the three largest cities, Tokyo, Osaka, and Nagoya, and in the Setouchi district.

Discussion

Summer night temperatures have been rising during the last 24 years in large parts of Japan. Significant increasing trends in night temperature were detected in the largest cities (i.e., Tokyo, Osaka, and Nagoya) and their surrounding areas (Fig. 2-5). This may be partly due to increased urbanisation (Gaffen and Ross, 1998; Fujibe, 1997, 2004). However, because warming areas have spread widely throughout Japan (Fig. 2-5), night temperatures may also be increasing in smaller cities and rural areas, as suggested by Fujibe (2004). In addition to urbanised effects, increases in night temperatures may be partially due to an anthropogenic increase in greenhouse gases and aerosols (Karl et al., 1993) or natural variability in climate occurring on a decadal scale (Karl et al., 1993; Gu et al., 1997; Nakamura et al., 1997; Linsley et al., 2000; Fujibe, 2004).

Fujibe (2004) reported that the increasing trend in night temperatures was recently conspicuous in the coastal area of the western Japan and Kanto district. We also found this in early August in our study (Fig. 4). The magnitude of warming varied in space and time within a summer (Fig. 2–5). This may cause serious damages to rice production. A reduction in rice quality, as measured by such factors as formation of milky-white rice kernels, has frequently occurred in recent years throughout Japan (Iida et al., 2002; Nishimura et al., 2000; Terashima et al., 2001; Kobata et al., 2004; MAFF, 2006a). For example, the proportion of first-grade rice to the total yield continuously decreased from 95% in 1995 to 55% in 2002 in Toyama prefecture (Toyama Agricultural Development Center, 2004). The recent decrease trends in rice quality would not related closely with the long-term increase trends in summer night temperature which showed high interannual fluctuations. However, extremely high night temperatures are still suspected to be one of the reasons for the decrease in rice quality (Nagato and Ebata, 1960; Terashima et al., 2001; MAFF, 2006a; but Morita and Matsuba, 1993), because high night temperature increase respiration in rice (NARCT, 2006) and there is a critical temperature for forming milky-white rice kernels at 23–24°C based on daily minimum temperature during 20 days after the first day that heads start to emerge, or heading day (Terashima et al., 2001; NARCT, 2006; MAFF, 2006a). The most popular rice “Koshihikari” has emerging heads in early August in many parts of Japan in recent years (MAFF, 2006b) as a result of delayed transplanting against heat damages. In this study, we found the highest increasing rate of

ANT_{25} in early August (Fig. 4), exactly matching that of the heading day and subsequent ripening periods of the "Koshihikari". High values of ANT_{25} and ANT_{30} were recently observed in the coastal area along the Sea of Japan (Fig. 2 and 3): Akita, Yamagata, Niigata, and Toyama, which are part of a major rice-producing centre in Japan. If the trends of an increasing number of nights with temperatures over 25°C in early August continues, the decrease in rice quality may become serious in the region. At present, the decrease in rice yield is not as much of a threat as the decrease in rice quality in Japan. However, unless transplanting date is properly controlled, potential yield of "Koshihikari" is simulated to decrease in many regions of western Japan after 50 or 100 years under global warming conditions (Toritani et al., 1999; NIES, 2003). Further, a recent report demonstrated that the rice yield was affected by high night temperatures, more so than high day-time temperatures (Peng et al. 2004). The changes in rice yield as well as rice quality may need to be monitored based on the increasing night temperatures.

Summer night warming will also bring other problems. Humid warm nights cause a public health problem particularly for elderly people (Gaffen and Ross 1998, IPCC 2001b). The spread of tropical plagues like malaria and dengue fever (IPCC 2001b, Kobayashi et al. 2002) in temperate regions is also a threat for us. Unexpected serious problems will occur if summer night temperatures continue to increases.

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