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ASSESSING GLOBAL CLIMATE VARIABILITY UNDER COLDEST AND WARMEST PERIODS AT DIFFERENT LATITUDINAL REGIONS

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ABSTRACT

Effect of climate change on water balance will play a key role in the biosphere system. To study the global climate change impact on water balance during 95-year period (1901-1995), long-term grid climatic data including global mean monthly temperature and precipitation at 0.5 x 0.5 degree resolution were analysed. The trend and variation of climate change, the time series of monthly air temperature and precipitation data were aggregated into annual arithmetic means for two extreme periods (1901-1920 and 1990-1995). The potential evapotranspiration (*Eo*) was calculated using Thornthwaite method. The changes in mean annual value were obtained by subtracting the maximum period data from 1990 to 1995 (Max) with the minimum period data from 1901 to 1920 (Min). The results revealed that over 95-year period, mean global air temperature increased by 0.57°C. The temperature increase varied greatly in Asia, with more than 3.0°C, especially at 45-70°N, as well over the northern part of America (60-65°N) and Europe (55-75°N). In low latitude across Asia, Africa, and South America, the variation was less than 1.5°C. In 80-85°N region, the variation was relatively small and at higher latitudes it increased significantly. Precipitation varied temporally and spatially. In the 40-45°N and 40-45°S regions, increasing precipitation of more than 100 mm occurred during the June-August and September-November, especially in the northern hemisphere. The *Eo* increase of 2000 mm during 95 years occurred in the tropical northern America, middle Africa, and South-East Asia. A grid in Central Java of Indonesia showed that the *Eo* increase of 2500 mm during 95 years resulted in the decrease of growing period by 100 days. In coping with climate change, adjustment of cropping calendar is imperative.

[***Keywords***: Climate change, air temperature, potential evapotranspiration, precipitation]

INTRODUCTION

It is widely recognized that the record of the states and flows of the biosphere's climate has changed dramatically. For example increasing greenhouse gas emission also increased surface air temperature (Jones *et al.* 1999; Runtunuwu *et al.* 2001) and global rates of precipitation and evaporation (Houghton *et al*. 1992; Kattenberg *et al*. 1996), rised sea level (Warrick and Oerlemans 1990; Douglas 1992; Gornitz 1995), and changed vegetation distribution (Sewall *et al.* 2000). Phenomenon of the climate change also occurred in Indonesia. Based on ground rainfall data in Tasikmalaya, West Java, the growing period decreased for one cropping period during 1889-2006 (Runtunuwu and Syahbuddin 2007).

Salinger (2005) reviewed the past, present, and future global climate change. However, the impact of the global climate change on evapotranspiration has not yet been studied. The goal of this research was to analyze the effect of latitudinal global historical changes in air temperature and precipitation during 95-year period (1901-1995) on the global and regional potential evapotranspiration.

MATERIALS AND METHODS

The global climate data used in this research were monthly air temperature and precipitation from 1901 to 1995 derived from the Climatic Research Unit, University of East Anglia (New *et al*. 1999; 2000). The data are originated from the grid of 0.5 x 0.5 degree latitudinal and longitudinal resolutions.

Climate Change Analysis

Several analyses were performed based on their spatial scale and time series to determine trends over the past 95-year period. In this study, the available climate data were divided into two main periods, which include the two extreme coldest (Min) and the warmest (Max) periods (Fig. 1).

To examine the record for systematic temporal variation, the monthly air temperature and precipitation were aggregated into seasonal and annual arithmetic means. The 0.5 degree resolution data were calculated to produce 5° latitudinal belts for all terrestrial areas and each continent, with the starting and ending points of the global and continental (North America, South America, Africa, Europe, Asia, and Australia) as shown in Figure 2.

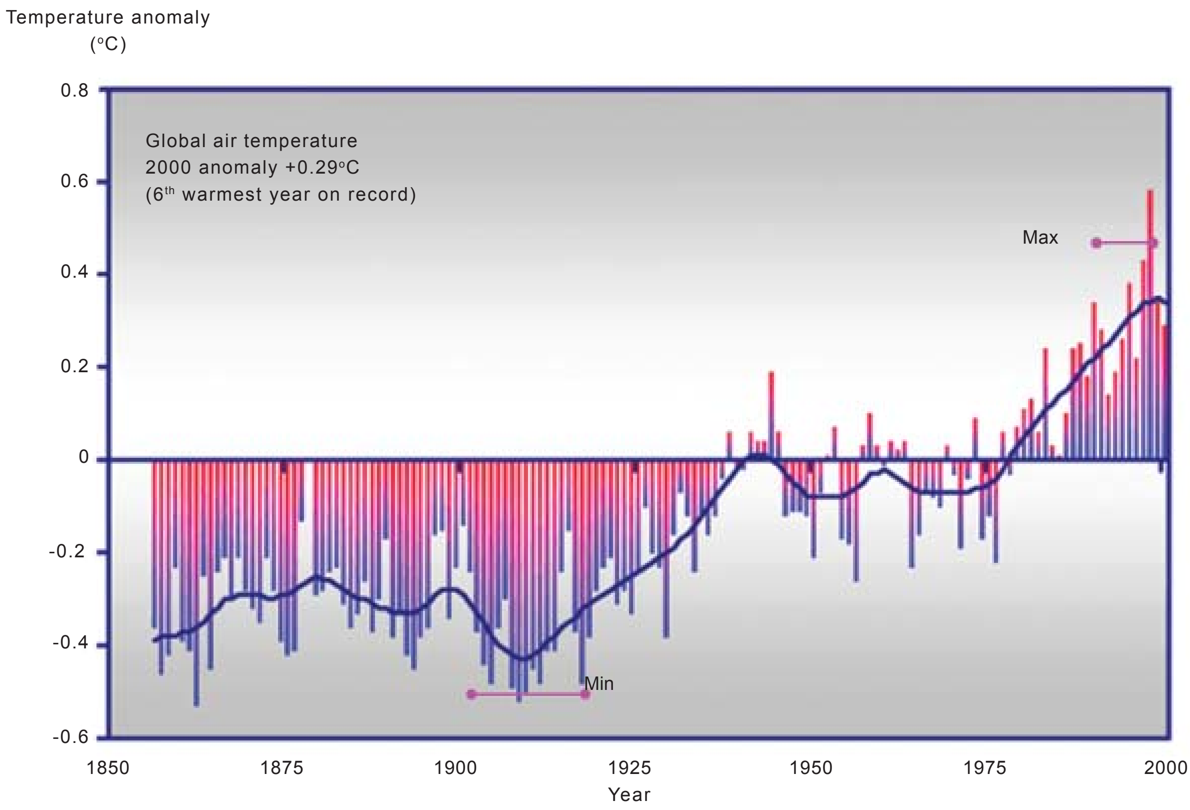

Fig. 1. Global air temperature anomaly record from 1856 to 2000 (Jones *et al*. 1999).

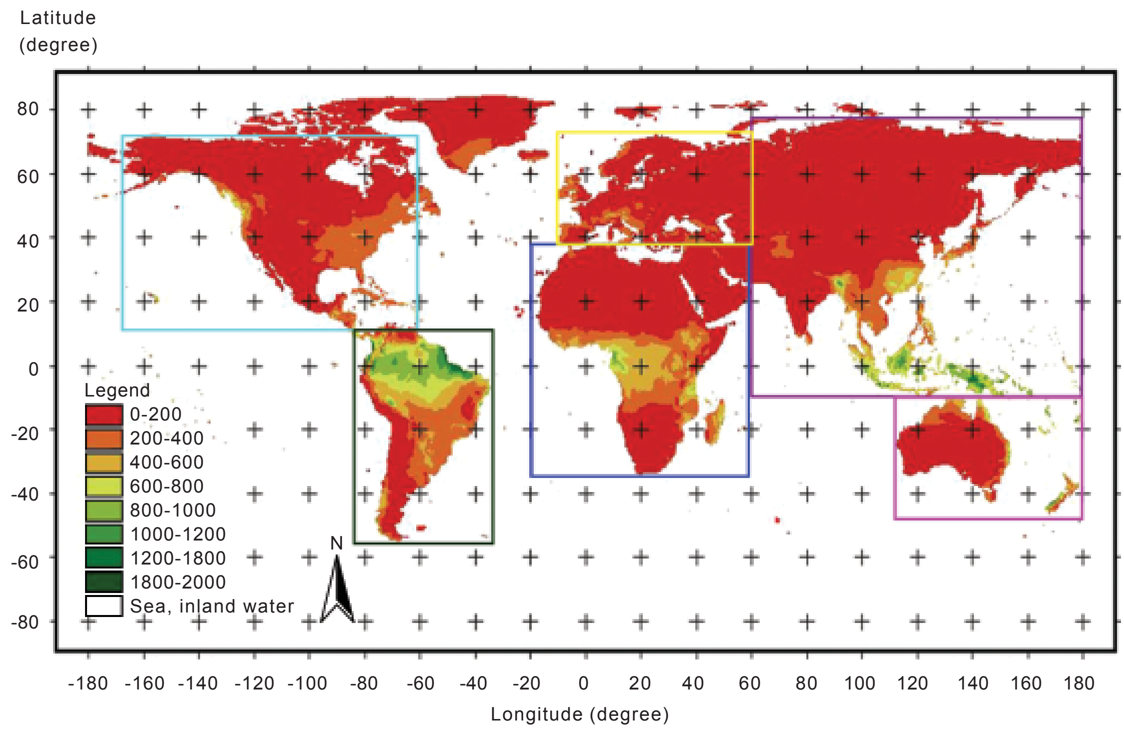

Fig. 2. Starting and ending points of each continent used in this study.

Statistical Analysis

The significance of the change of temperature and precipitation patterns among regions were analysed statistically using the t-test (Steel and Torrie 1993).

Potential Evapotranspiration (*Eo*)

There are numerous methods for computing *Eo* input. Kondoh (1994) examined four methods, i.e. Thornthwaite, Penman, modified Brutsaert-Stricker, and Morton, using FAOCLIM Agroclimatic Database, to calculate *Eo* for more than 800 points in Monsoon Asia. However, Jensen *et al*. (1990) having compared 20 different methods suggested the Penman-Monteith equation being the most accurate to estimate monthly from well-watered grass under varied climatic conditions.

Due to limited available spatial image datasets, the *Eo* in this study was calculated using the Thornthwaite method (Thornthwaite 1948). The Thornthwaite method has been selected in global climate change analysis as this method only requires the air temperature as input data, which are available for the two extreme periods (1901-1920 and 1990-1995). In calculating and comparing *Eo* results of both periods, the magnitude of *Eo* change due to climate change could be estimated. Thornthwaite method assumes that the upper limit of evapotranspiration under given atmospheric conditions is not limited by water stress. Thornthwaite formulated *Eo* (mm month^{-1}) as:

$$Eo = 1.6 \cdot \left(\frac{l_1}{12}\right) \cdot \left(\frac{N}{30}\right) \cdot \left(\frac{10T_a}{I}\right)^{ai} \quad [1]$$

$$a_1 = 6.75 \text{ x } 10^{-7} I^3 - 7.71 \text{ x } 10^{-5} I^2 + 1.79 \text{ x } 10^{-2} I + 0.49 \quad [2]$$

$$I = \sum_{i=1}^{12} \left(\frac{T_a}{5}\right)^{1.514} \quad [3]$$

Where l_1 is actual day length (h), N is the number of days in a month, T_a is the mean monthly air temperature (°C), I is heat index derived from the sum of 12 monthly index values i.

The values of monthly rainfall and *Eo* were furthermore used to find out the length of growing period (LGP). Trojer (1976) determined the starting of growing season when the rainfall was more than 0.5 *Eo* and stopping when rainfall was less than the 0.5 *Eo*. For reducing the differences between estimated and observed, we applied the correction factor for Thornthwaite method as used by Xu and Chen (2005) as:

$$Eo^* = 1.4X + 0.92 \quad [4]$$

Where Eo^* is corrected evapotranspiration, X is estimated *Eo* by Thornthwaite method, and 0.92 is the intercept value.

The result of monthly *Eo* analysis, monthly precipitation and soil water holding capacity data were used in the next step to calculate the three other water balance components, including soil moisture, actual evapotranspiration, and water surplus and deficit (Thornthwaite and Mather 1957; Kondoh *et al*. 2004).

RESULTS AND DISCUSSION

Air Temperature

The air temperature was recorded from 1901 to 1995 for selected latitudinal ranges of 80-85ºN, 40-45ºN, 0-5ºN, 40-45ºS, and 55-60ºS. The difference between air temperature (T) and mean temperature (Tmean) of a given year for 1901-1995 periods was shown in Figure 3. The figure suggests an increasing trend in the annual and seasonal air temperature means. The air temperature change in the high latitude (in the northern hemisphere), dominated by tundra and glacier ice, was small compared to the other latitudes. The greatest change was found in the northern (40-45ºN) and southern (40-45ºS) hemispheres.

The change in mean annual air temperature (Fig. 4 and 5) was calculated by subtracting the maximum period data from 1990 to 1995 (Max) with the minimum period data from 1901 to 1920 (Min). The change is sinusoidal and the maximum change was found over the high latitudes (northern and southern), while the minimum change was found over the lower latitudes. Warming of more than 2.0ºC occurred over the high northern latitudes, especially at 60-70ºN, over the 95-year period. This result was consistent with those of Jones *et al*. (1999) and Rind (1998). Jones *et al*. (1999) noted that warming was generally greatest over the high latitudes in the northern continents. Rind (1998) concluded that, in general, condition in Alaska was warmer than that in Greenland, and there were warming in Asia, moisture changes in the United States, and drying in the Sahel and the subtropics.

Warming also occurred over the southern latitude, particularly at 20-25ºS, of around 0.5ºC over 95 years, as well as at the northern part of North America and parts of northern Europe (Fig. 6). The air temperature change in each continent (Fig. 6) varied greatly in Asia, at more than 3.0ºC over 95 years, especially at 45-70ºN. Similar change was also observed over the

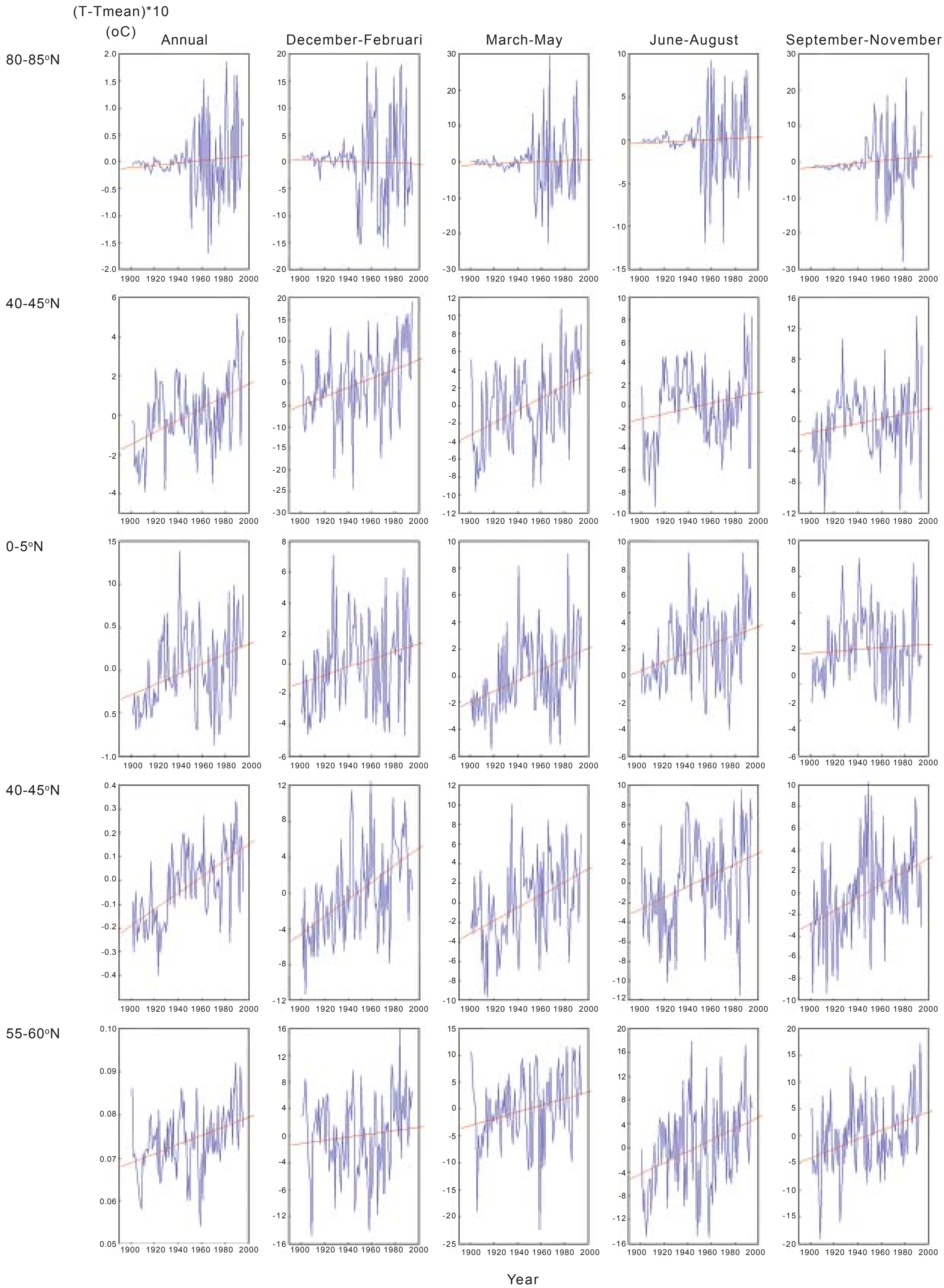

Fig. 3. Variation of annual air temperature from 1901 to 1995 averaged for selected 5° latitudinal bands, for annual, December-February, March-May, June-August, and September-November (blue line) and the trend (red line).

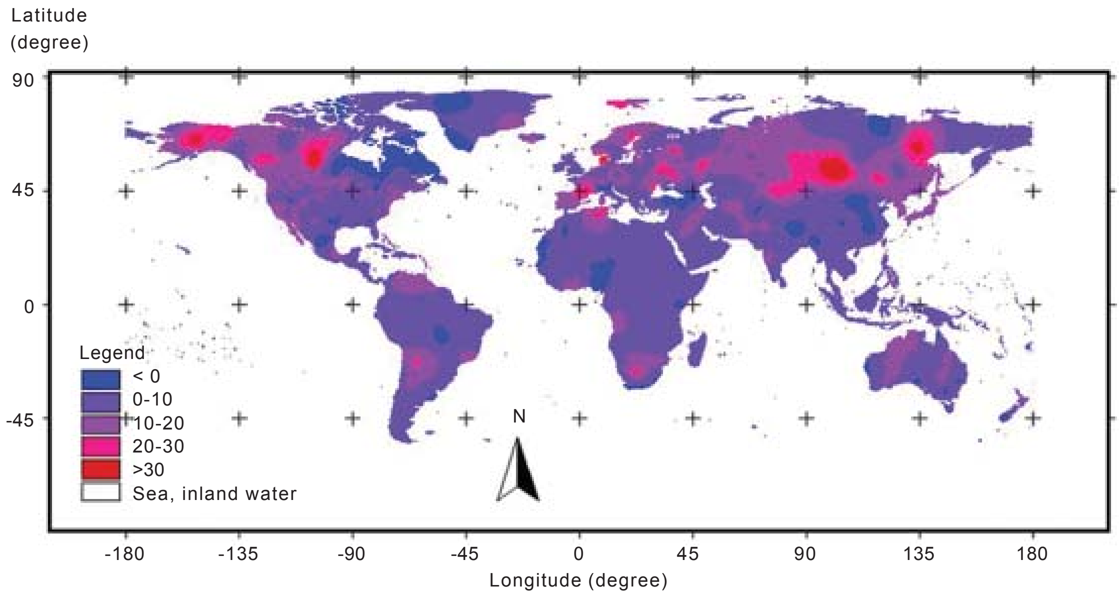

Fig. 4. Mean annual air temperature change (°C*10) for global terrestrial area for 1901-1920 compared to 1990-1995 period.

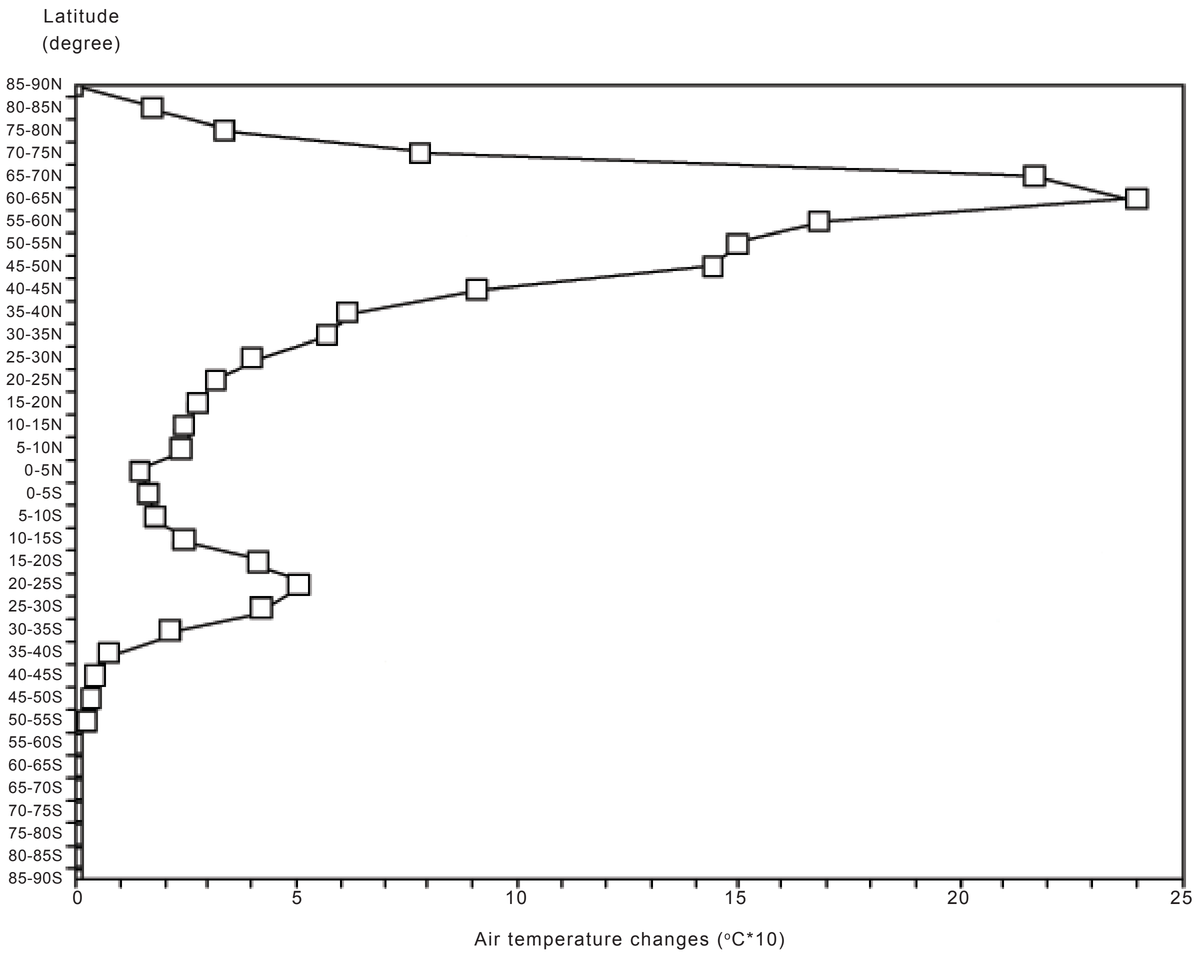

Fig. 5. Difference of mean annual air temperature for global terrestrial area for 1901-1920 compared to 1990-1995 period as a function of longitudinal positions.

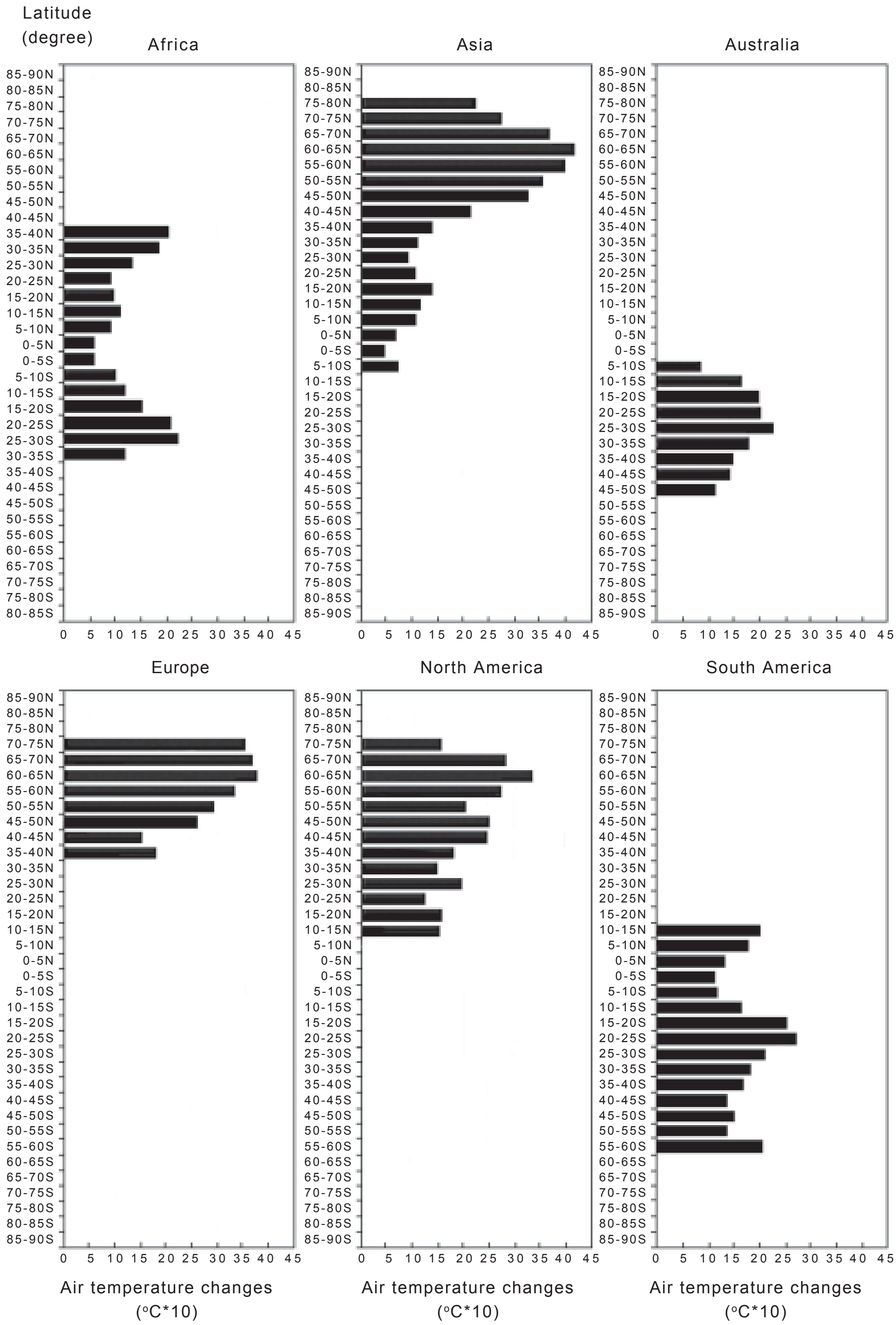

Fig. 6. The change in mean annual air temperature for each continent for the period of 1901-1920 compared to that of 1990-1995.

northern part of North America (60-65ºN) and northern Europe (55-75ºN). For low latitudes across Asia, Africa, and South America, the variation was lower than 1.5ºC in 95 years. The mean global air temperature increased by 0.57ºC during the 1901-1995 period.

Precipitation

The precipitation data were also recorded from 1901 to 1995 (Fig. 7) for selected latitudinal ranges: 80-85ºN, 40-45ºN, 0-5ºN, 40-45ºS, and 55-60ºS. The figure suggests an increasing trend in annual and seasonal precipitation.

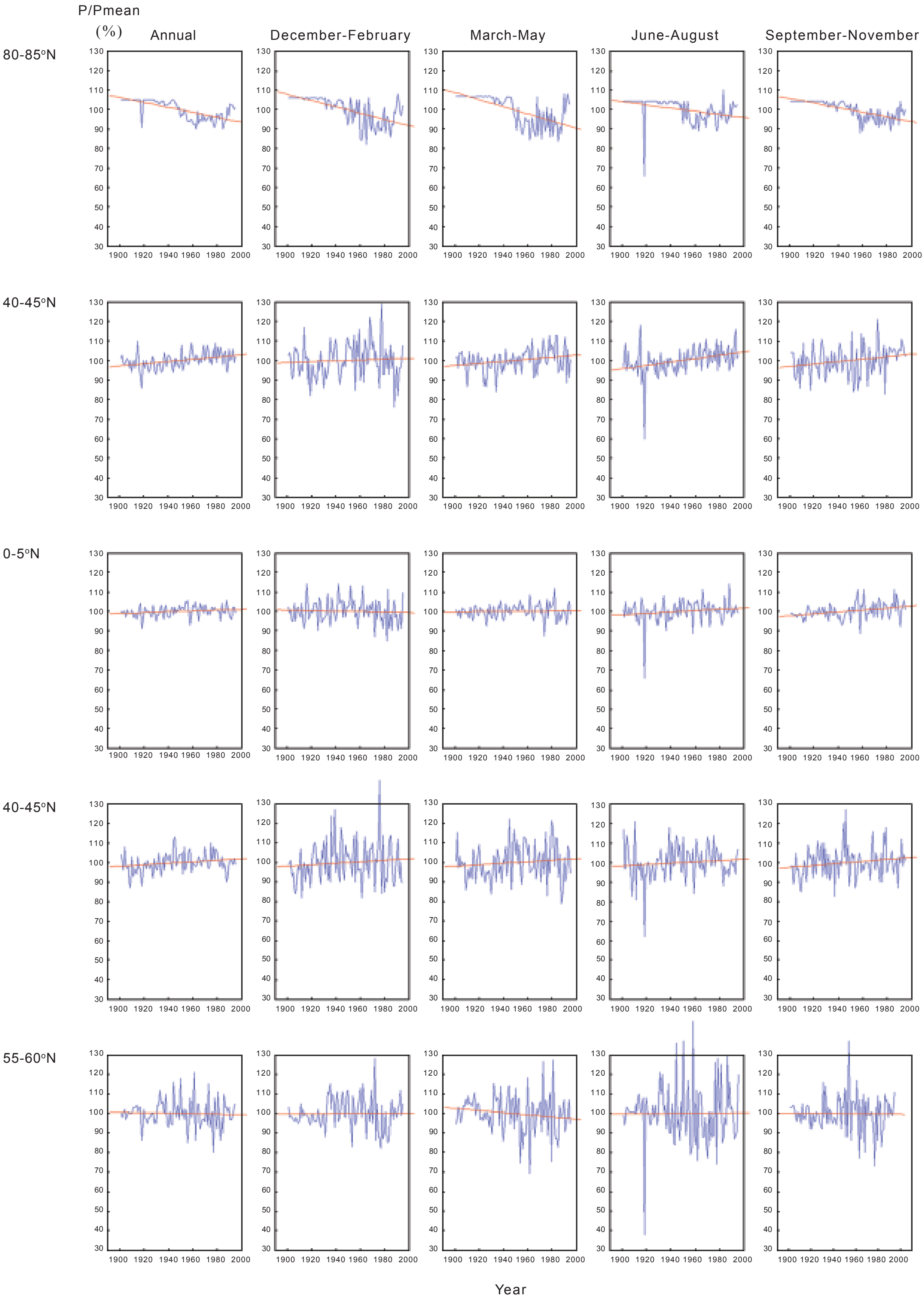

Fig. 7. Variation of precipitation from 1901 to 1995 within 5° latitudinal bands for annual, December-February, March-May, June-August, and September-November (blue line) and the trend (red line).

For 80-85ºN regions, the variation of precipitation was relatively small over 1901-1995, and after that it increased significantly. For the 40-45ºN and the 40-45ºS regions, the annual as well as the June-August and September-November precipitation tended to increase. In the period of 1901-1995, the greatest precipitation occurred during the June-August and September-November seasons, especially in the northern hemisphere.

Further, if the data is considered on an annual basis, there were also some indications that over the period of 1901-1995 the precipitation have changed, as shown in Figure 8. The increase of more than 100 mm occurred in the eastern part of North America, South America, and northern part of Europe and Russia. It also occurred in the tropics, i.e. eastern part of Indonesia, India, and northern Australia. However, in most parts of Australia, the precipitation decreased (Fig. 9a) or increased (Fig. 9b) negligibly.

The t-test (Table 1) was done to examine the significance of change between the warmest and coldest periods for both temperature and precipitation. All value shows the significant differences, except for the global precipitation changes.

Potential Evapotranspiration

The distribution of *Eo* using Thornthwaite method (Fig. 10) which ranged from 0 to over 1000 mm year^{-1} was divided into eight classes. The lowest value of 0-100 mm year^{-1} was distributed in Greenland, North America. For 100-300 mm year^{-1} was found in the high latitude of northern hemisphere (more than 45º) and also in the desert areas of Kazakhstan and Mongolia. The medium *Eo* value of 300-750 mm year^{-1} was distributed mainly in temperate and subtropical region, i.e. in China, Northern Australia, North America, and high latitude of southern hemisphere. The higher *Eo* value of over 1000 mm year^{-1} was distributed in the tropics, i.e. in Central America, Southern America, South-East Asia, Central Africa, and Eastern Australia.

This study indicates that *Eo* change as the consequence of increasing contribution from air temperature could be expected to increase over all continents. However, in certain location the *Eo* change had a different pattern from air temperature, such as the greatest air temperature change (3.5-4.1ºC) over 95 years occurred in the high latitude of northern Asia (45º-70ºN), while the highest increased (≈200mm year^{-1}) occurred in the low latitude (10ºS-10ºN) particularly in the tropical part of northern America, middle Africa, and South-East Asia, including some places in Indonesia.

The increase of *Eo* can reduce water availability for crops; and thus the length of growing period (LGP). For example, one grid data (110.74ºN and 6.71ºS) in Central Java, Indonesia (Fig. 11) shows that the LGP decreased around 100 days. Decreasing LGP undoubtedly has a significant effect on crop production. Naylor *et al*. (2007) noted that natural climate vari-

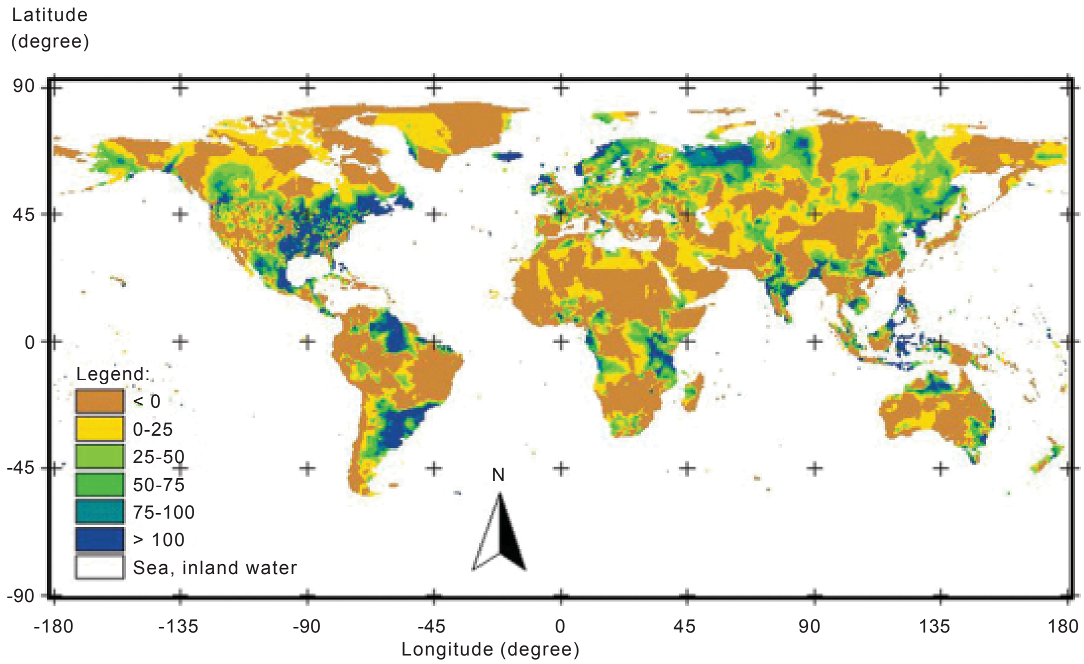

Fig. 8. Mean annual precipitation (mm) change for global terrestrial area for 1901-1920 subtracted by 1990-1995 period.

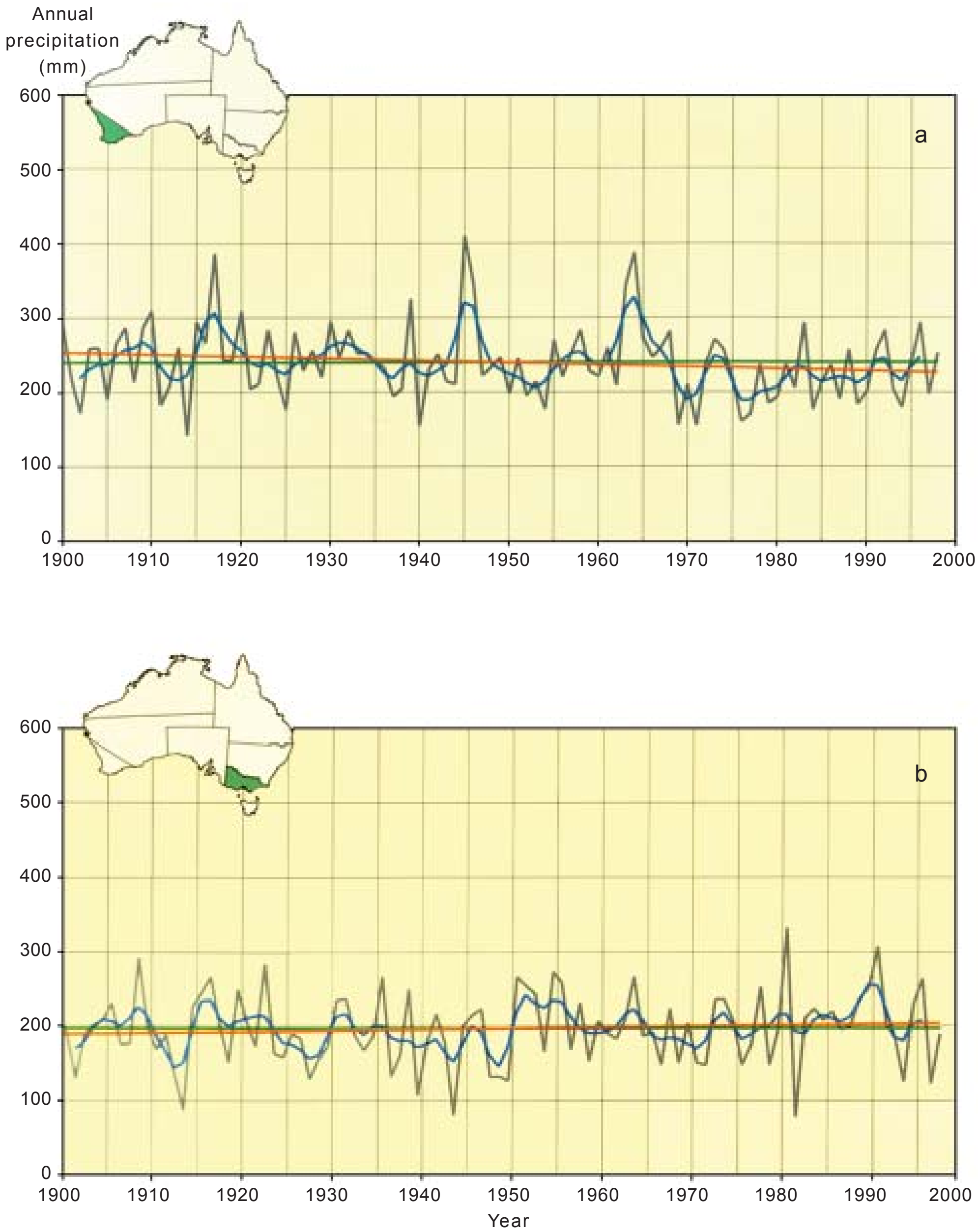

Fig. 9. Annual precipitation from 1900 to 1997 for (a) Southwestern Australia and (b) Victoria (Auslig 2000). Green line is mean value, while the yellow line is the trend.

Table 1. T-test result for temperature and precipitation differences between the warmest and coldest periods of 95 years with a two-tailed distribution.

Regions	Degrees of freedom	T_{table} (a/2 = 0.005)	| t-test |	
			Temperature	Precipitation
North America	13	3.012	12.447*	6.315*
South America	14	2.977	14.301*	8.830*
Africa	14	2.977	9.385*	7.381*
Europe	11	3.106	7.363*	7.412*
Asia	14	2.977	7.030*	8.238*
Australia	11	3.106	8.180*	8.421*
Global	28	2.763	4.807*	1.998

*Significant at a = 0.01.

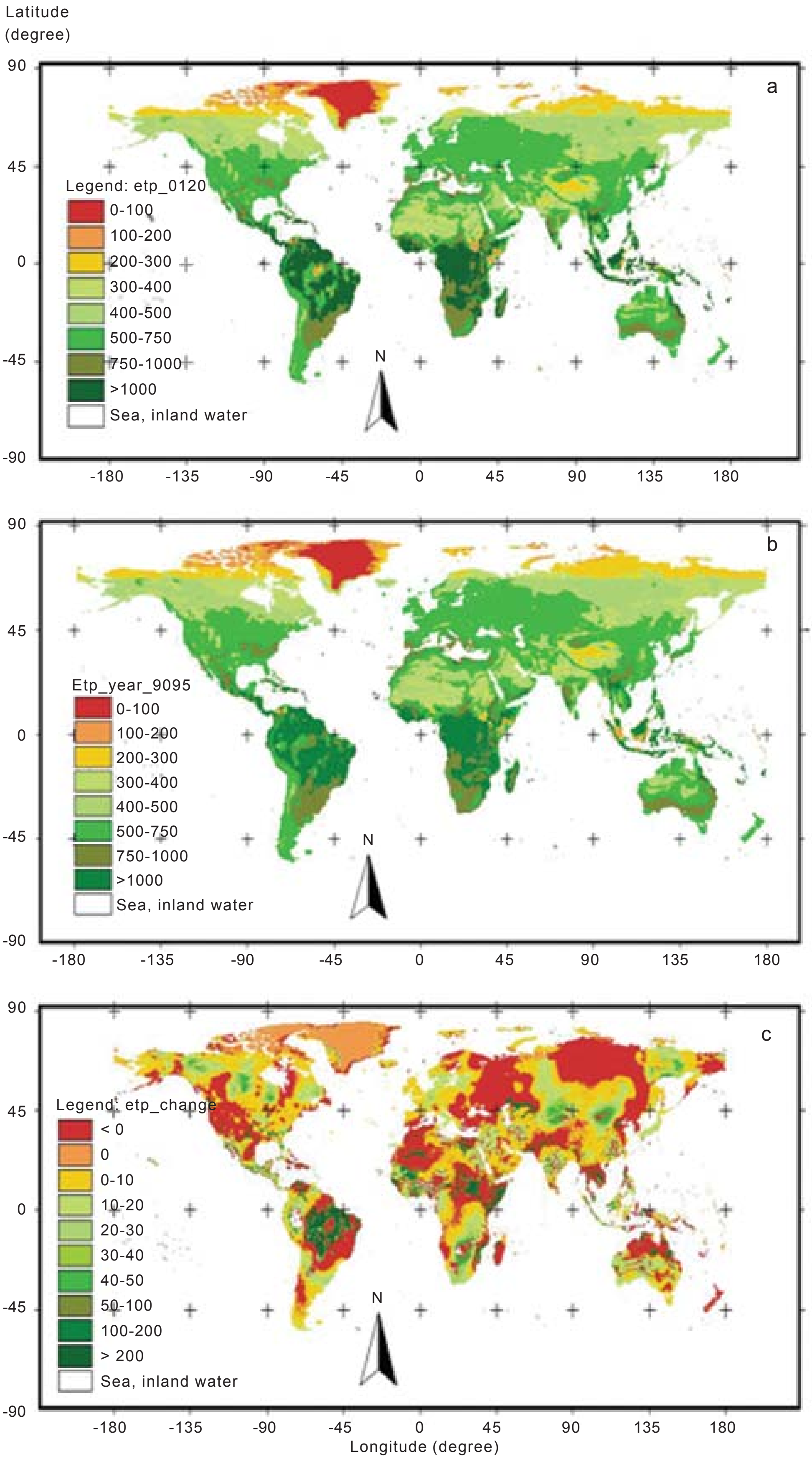

Fig. 10. Distribution of potential evapotranspiration change for (a) 1901-1920, (b) 1990-1995, and (c) 1990-1995 periods subtracted by 1901-1920.

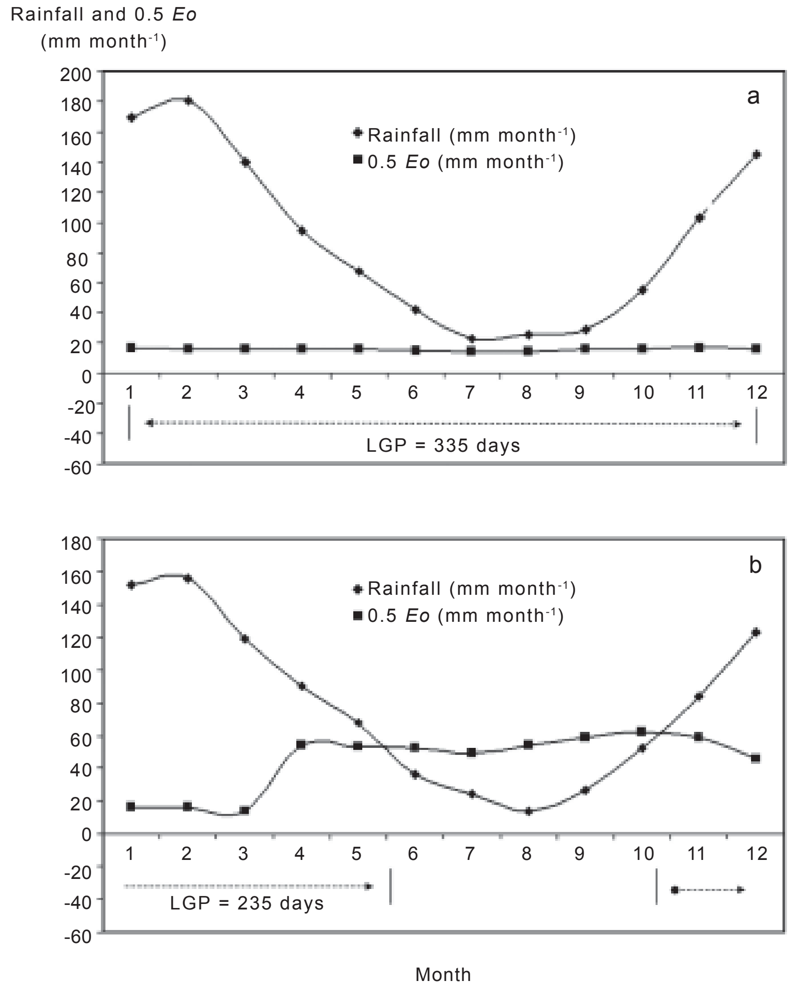

Fig. 11. The length of growing period (LGP) change due to the climate change for (a) 1901-1920 and (b) 1990-1995 periods.

ability will exert a greater impact on Indonesian rice agriculture and food security in 2050 with changes in the mean climate. Therefore, the climate change is a serious problem in agriculture.

CONCLUSION

We have analyzed the global surface air temperature and precipitation dataset based on 1901-1995 period. The global surface air temperature and precipitation have significantly changed. The change of both parameters was slightly greater in northern hemisphere than that in the southern hemisphere. In general, the warming is strongest over northern Asia, especially in Siberian area and it also occurred over northern North America and parts of northern Europe. In some places, such as Greenland of Northern America, the air temperature has decreased. In addition, the precipitation has increased in eastern parts of North America and South America, as well as in northern parts of Europe and Asia (Russia), and decreased in tropics, such as eastern part of Indonesia, India, and northern part of Africa. Because of this climate change phenomenon, the evapotranspiration has also changed and it reduced the water availability for crop as well as the length of growing period.

To cope with the climate change phenomenon for sustainable agricultural development in Indonesia, some adaptation actions are recommended as follows: (1) change planting dates and other crop management systems, (2) shift to species that have more stable production under high temperature and drought, (3) develop irrigation systems and new crop varieties adaptive to climate change, and (4) improve long-term and short-term climate prediction for changing crop calendar.

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