Trends in Precipitation Extremes over Southeast Asia

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Abstract

The authors investigate trends in precipitation extremes using daily precipitation data from Southeast Asian countries during 1950s to 2000s. Number of wet days, defined by a day with at least 1 mm of precipitation, tends to decrease over these countries, while average precipitation intensity of wet days shows an increasing trend. Heavy precipitation indices, which are defined by precipitation amount and percentile, demonstrate that the number of stations with significant upward trend is larger than that with significant downward trend. Heavy precipitation increases in southern Vietnam, northern part of Myanmar, and the Visayas and Luzon Islands in the Philippines, while heavy precipitation decreases in northern Vietnam. Annual maximum number of consecutive dry days decreases in the region where winter monsoon precipitation dominates. Decrease of precipitation event in the dry season is suggested in Myanmar.

1. Introduction

Most precipitation in Southeast Asian countries is brought by summer and/or winter monsoons, where annual amount exceeds 1500 mm with a very clear seasonal variation of precipitation (e.g., Matsumoto 1997). There are some mountain ranges that are elongated from north to south in the Indochina Peninsula, and their orographical effects on precipitation during summer monsoon were discussed (e.g., Xie et al. 2006; Hoyos and Webster 2007). Hoyos and Webster (2007) found that interaction between monsoon intra-seasonal oscillation and orography is important for defining the spatial pattern of summer monsoon precipitation. During winter monsoon, cold surge originated from Siberia can reach Southeast Asia. A cold surge and tropical disturbance existed over the South China Sea, which induced heavy orographic precipitation in central Vietnam (Yokoi and Matsumoto 2008).

From the 1990s, a number of studies examined changes in heavy precipitation during the 20th century (e.g., Iwashima and Yamamoto 1993; Karl and Knight 1998). In recent years, long-term changes in heavy precipitation have been intensively examined for several countries and regions, including some Asian countries (e.g., Zhai et al. 2005; Endo et al. 2005, 2006; Zhang et al. 2005; Klein Tank et al. 2006). Manton et al. (2001) examined trends in extreme daily precipitation from 1961 to 1998 over Southeast Asia and the South Pacific. They found that the number of rainy days (a day with at least 2 mm of rain) has generally decreased significantly in Southeast Asia. In addition, the extreme precipitation frequency has declined without statistical significance in Southeast Asia except at some stations.

Heavy precipitation tends to occur on the windward side of mountains with large-scale dominant monsoonal flow. However, only 14 stations in the Indochina Peninsula were available for Manton et al. (2001). This means that heavy precipitation events, which are related to interaction between monsoonal flow and mountains, are limitedly captured. Therefore, examination of trends in precipitation extremes with much more stations is needed in Southeast Asia.

The purpose of this study is to describe spatial distribution of trends in precipitation extremes from the 1950s to the early 2000s over Southeast Asia by using high-density station data.

2. Data, quality control and precipitation extreme indices

Daily precipitation data were collected by the National Meteorological or Hydro-meteorological Services in Southeast Asian countries as part of activities of the Global Energy and Water cycle Experiment (GEWEX) Asian Monsoon Experiment (GAME) and the Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction (MAHASRI). We select stations when following conditions are met: 1) more than 30 years of daily precipitation data existed, 2) year with more than 15 missing data is not used for index calculation, and 3) five years, or less, of missing data allowed. Years of missing data are not concentrated in specific era except around the mid 1970s in southern part of Vietnam. Missing data are not compensated in this study. It is noted that precipitation data are recorded at 1 mm resolution in Myanmar and Brunei, and daily precipitation data with 0.1 mm resolution are available for Thailand, Laos, Vietnam, Malaysia, Singapore and the Philippines. A total of 203 stations are selected from Myanmar, Thailand, Laos, Vietnam, Malaysia, Singapore, Brunei, and the Philippines. Daily precipitation data are available at 95 stations in Malaysia, Thailand and the Philippines from the 1950s, and at 58 stations in Vietnam from the 1950s and the early 1960s. For the 39 stations in Myanmar, daily precipitation data in digital form after the 1960s are used in this study.

The homogeneity of the precipitation data is checked using four statistical tests as recommended by Wijngaard et al. (2003): the standard normal homogeneity test, the Buishand range test, the Pettit test, and the Von Neumann ratio test. The tests show that three stations have possible inhomogeneity in the precipitation data. Since we have no station metadata that may include information for station relocation, change of rain-gauge type, and change of observation practices, we cannot judge whether human-induced discontinuity is the cause at these three stations. In order to avoid a false conclusion, the three stations were discarded from the analysis. The stations used are listed in Supplement-1, and shown in Fig. 1.
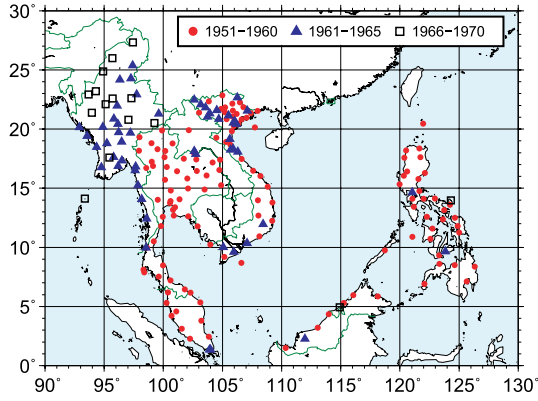
Twelve rainfall indices are calculated and listed in

Fig. 1. Location of the 200 weather stations. Symbols are used to indicate the start year of each precipitation record.
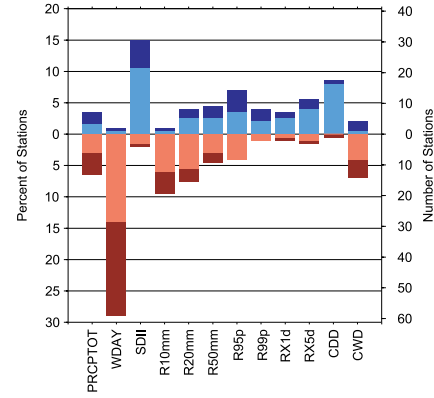

Fig. 2. Percentage of stations with statistically significant trends in precipitation indices over Southeast Asia. Dark blue (dark red) and cyan (magenda) indicate increasing (decreasing) trend with statistical significance at 1% and 5%, respectively.

Table 1. Precipitation indices and their definitions and units. RR is the daily rainfall rate. A wet day has RR ≥ 1 mm, while a dry day has RR < 1 mm. All indices are calculated annually from January to December.

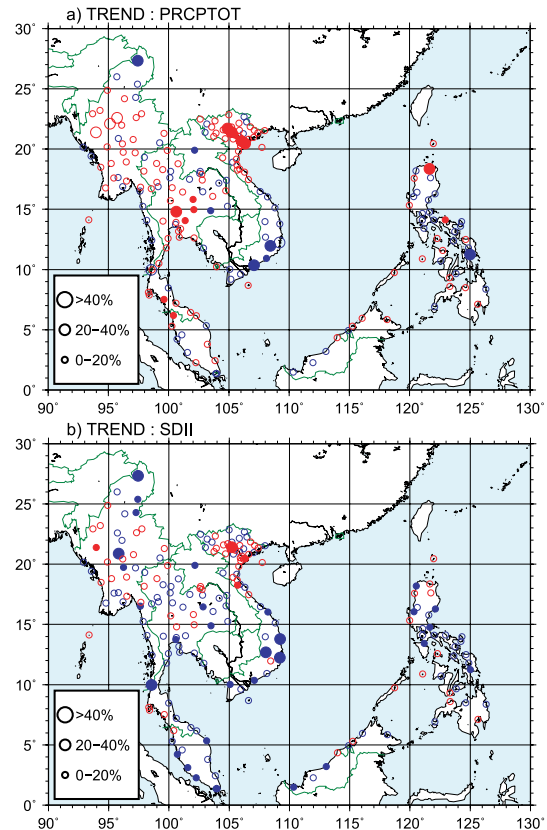| Index	Definitions	Units
PRCPTOT	Annual total precipitation from wet days	mm
WDAY	Number of days with daily precipitation ≥ 1 mm	days
SDII	Average precipitation from wet days	mm day^{-1}
R10mm, R20mm, R50mm	Number of days per year with precipitation amount ≥ 10 mm, ≥ 20 mm, and ≥ 50 mm, respectively.	days
R95p, R99p	Precipitation amount per year above a site-specific threshold value for very and extremely wet days, calculated as the 95th and 99th percentile of the distribution of daily precipitation amounts on days with 1 mm or more precipitation in the 1961–1990 baseline period. If the station record starts 1961, baseline period is first year–1990.	mm
RX1day	Annual maximum 1-day precipitation	mm
RX5day	Annual maximum consecutive 5-day precipitation	mm
CWD	Annual maximum number of consecutive wet days	days
CDD	Annual maximum number of consecutive dry days	days

Fig. 3. Trends in PRCPTOT and SDII. Trends are expressed as percentage variations with respect to the mean value over the data available period. Blue (red) symbol indicates increasing (decreasing) trend. Solid symbol denotes statistical significance at 5% level.

Table 1. Most of the indices are related to extreme precipitation, although three of the indices are more indicative of changes to the entire precipitation distribution: PRCPTOT, WDAY and SDII. A wet day refers to a day with at least 1 mm of precipitation.

Kendall (1975) introduced τ to measure the strength of the monotonic relationship between two variables. The nonparametric Mann-Kendall's test (MK test) has been used to evaluate the trend in the time series of climatological and hydrological data (e.g., Hirsch et al. 1982; Lettenmaier et al. 1994). The MK test is applied to the data for evaluating trends in the indices of precipitation extremes in this study. For presentation purpose, ordinary least squares fit is also applied to the data.

3. Results

Figure 2 summarizes the trends in the precipitation extreme indices over these countries. Number of stations with statistically significant trends is generally less than about 10% of the total stations, except when using WDAY and SDII. Significant decreasing trends in WDAY are observed at more than 58 stations, and are widely distributed over the countries (not shown). Although we use a different threshold of rainy days, the decrease of WDAY corresponds well with the result of Manton et al. (2001). Decreasing trend of WDAY is dominated over Myanmar in this study, while Manton
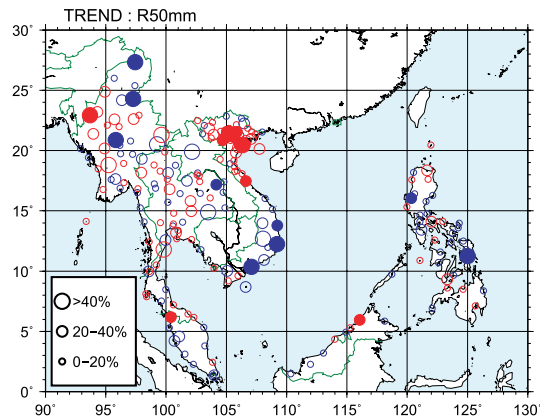
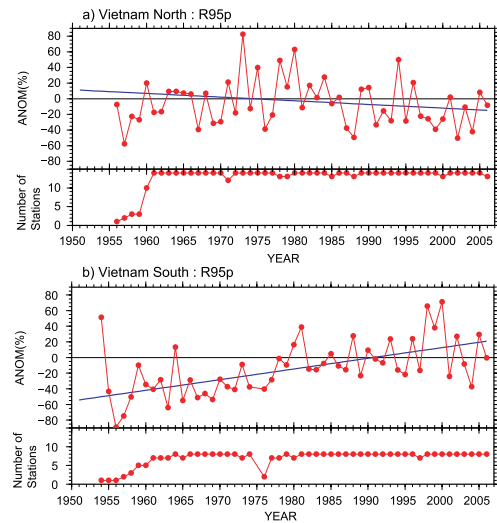Fig. 4. Same as Fig. 3, except for trends in R50mm.

Fig. 5. Regionally averaged percent anomaly time series of R95p for (a) northern and (b) southern Vietnam. Percent anomaly is calculated for each station, then the arithmetic average is obtained (Frich et al. 2002). Linear regression is applied to the data between 1961 and 2006, and regression line is also plotted.
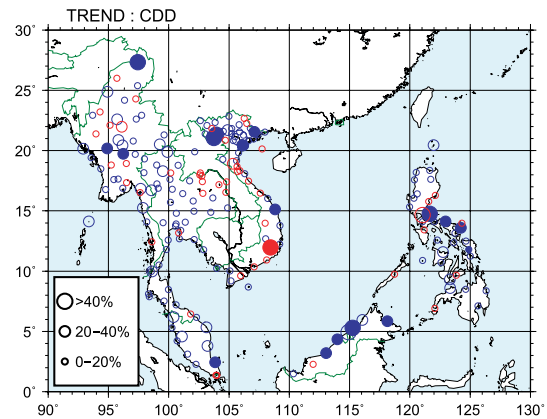

Fig. 6. Same as Fig. 3, except for trends in CDD.

et al. (2001) shows increasing trend of WDAY at two stations in Myanmar. The difference is mainly due to different data length and periods examined.

Number of stations with significant decreasing trends is larger than that with significant increasing trends (Fig. 2). Figure 3a shows spatial distribution of trends in PRCPTOT. PRCPTOT declines at most stations in Myanmar, Thailand, and northern Vietnam. However, statistically significant decreasing trends are only observed at six stations around Bangkok and at five stations along the Hong River in northern Vietnam. PRCPTOT tends to increase in southern Vietnam and the Luzon Island in the Philippines, and four stations show statistical significance.

SDII tends to increase with statistical significance at 30 stations (Fig. 2). Figure 3b shows spatial distribution of trends in SDII. Increasing trend of SDII is observed at many stations in Myanmar, Thailand, and the Philippines. In Peninsular Malaysia, significant increase of SDII is observed at five stations. In Vietnam, directions of trend are different between its northern and southern parts. In southern Vietnam, increasing trends with statistical significance appear at seven stations. Although there coexist increasing and decreasing trends in SDII over northern Vietnam, SDII declines at four stations with statistical significance.

The number of stations with positive or negative trend is comparable for R50mm (Fig. 2). Figure 4 shows spatial distribution of trends in R50mm, which is similar to that of PRCPTOT. R50mm tends to increase in southern Vietnam, but decreases in northern Vietnam. In Myanmar, R50mm tends to increase in northern mountainous regions, and decreases on eastern flank of the Arakan Mountains. Decreasing and increasing trends coexist in Thailand. R50mm has increased in Peninsular Malaysia without statistical significance. Increase of R50mm is observed in the Visayas Islands and some parts of the Luzon Island in the Philippines. Although threshold definitions in R95p are different among the stations, spatial distributions of trends of R95p are similar to those of R50mm (not shown). In addition, the number of stations with statistically significant trend for R95p is larger than that for R50mm (see Fig. 2). The number of stations with significant increasing trends is much larger than that with significant decreasing trends for R99p, RX1d, and RX5d. Furthermore, spatial distribution of these trends is also similar to that of R50mm. Thus, the spatial distribution of trends in heavy precipitation seems to be robust in these Southeast Asian countries. For R10mm and R20mm, the number of stations with significant de-

creasing trends is larger than that with significant increasing trends. However the spatial distributions of trends for R10mm and R20mm are similar to that of R50mm.

Temporal tendencies of extreme precipitation and that of PRCPTOT are evidently different between northern and southern Vietnam. Regionally averaged anomaly time series of R95p are shown in Fig. 5. Time series in northern Vietnam show that its linear trend is negative (Fig. 5a). However, the frequency of R95p is lower in the 1960s and the 1990s and is higher in the 1970s; that is, decadal variations are evident in R95p in northern Vietnam. R95p is climatologically observed in August and September in northern Vietnam. In these months, landfall of tropical cyclone frequently occurs in northern Vietnam, and much more frequently in these months of El Niño years (Fudeyasu et al. 2006). However, the number of El Niño year and that of La Niña year are comparable in the 1970s, while El Niño years dominate in the 1990s. Therefore, impact of tropical cyclone landfall on R95p seems to be limited in northern Vietnam.

Figure 5b shows regionally averaged anomaly time series of R95p in southern Vietnam, where an increasing trend is clearly observed. Despite of the existence of a clear increasing trend, monotonic increase is terminated around 1980, and the anomaly fluctuates around the mean with large signals appearing from 1998 to 2000.

Figure 2 shows that 17 out of the 200 stations have significant increasing trends of CDD, and CDD significantly decreases at one station. On the contrary, stations with significant decreasing trends dominate in CWD.

Increasing trend of CDD is observed widely in Myanmar and Thailand with some exceptions (Fig. 6). Since the rainy season and the dry season are obviously distinguished in Myanmar and Thailand, increase of CDD could be considered as decrease of precipitation events during the dry season in recent years.

CDD also increases in Peninsular Malaysia, Borneo, some parts of the Philippines and central Vietnam. These regions correspond to the region where winter monsoon precipitation dominates (e.g., Chang et al. 2005). The winter monsoon precipitation is typically brought by interaction between a cold surge from the cold Asian Continent and orography. Climatologically last days of CDD appeared in later half of winter monsoon (see Supplement-2). Recently, Wang et al. (2009) found that the East Asian winter monsoon became weaker since around the late 1980s. The weakening of the East Asian winter monsoon suggests a decrease of frequency and/or intensity of the cold surge from Siberia into the South China Sea and the Philippine Sea. Thus, the increase of CDD in the regions may be due to change of cold surge activity during the East Asian winter monsoon.

4. Conclusion

Long-term trends in precipitation extreme indices are examined for more than 200 stations in Southeast Asia from the 1950s to the 2000s. Decreasing trends in annual precipitation are widely distributed in Myanmar, Thailand, and northern Vietnam, whereas annual precipitation tends to increase in southern Vietnam, the Visayas Islands and Luzon Island. Decreasing trend of number of wet days is dominated, while average precipitation intensity increases over these countries. Extreme precipitation (R50mm and R95p) has similar spatial distribution of temporal trends in annual precipitation over Southeast Asia. Statistically significant increasing (decreasing) trend of extreme precipitation has some spatial extent in southern (northern) Vietnam. The annual maximum of consecutive dry days tends to increase in Myanmar and in regions where winter monsoon precipitation dominates.

Acknowledgments

Supplements

Supplement-1 is list of stations used in this study.

Supplement-2 shows histogram of normalized frequency of the last day of CDD in the east coast of Malay Peninsula and the northwestern coast of Borneo Island.

References

Chang, C.-P., Z. Wang, J. McBride, and C.-H. Liu, 2005: Annual cycle of southeast Asia - Maritime Continent rainfall and the asymmetric monsoon transition. *J. Climate*, **18**, 287–301.

Endo, N., B. Ailikun, and T. Yasunari, 2005: Trends in precipitation amounts and the number of rainy days and heavy rainfall events during summer in China from 1961 to 2000. *J. Meteor. Soc. Japan*, **83**, 621–631.

Endo, N., T. Kadota, J. Matsumoto, B. Ailikun, and T. Yasunari, 2006: Climatology and trends in summer precipitation characteristics in Mongolia for the period 1960–98. *J. Meteor. Soc. Japan*, **84**, 543–551.

Frich, P., L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. M. G. Klein Tank, and T. Peterson, 2002: Observed coherent changes in climatic extremes during the second half of the twentieth century. *Clim. Res.*, **19**, 193–212.

Fudeyasu, H., S. Iizuka, and T. Matsuura, 2006: Impact of ENSO on landfall characteristics of tropical cyclones over the western North Pacific during the summer monsoon season. *Geophys. Res. Lett.*, **33**, doi:10.1029/2006GL 027449.

Hirsch, R. M., J. R. Slack, and R. A. Smith, 1982: Techniques of trend analysis for monthly water quality data. *Water Resour. Res.*, **18**, 107–121.

Hoyos, C. D., and P. J. Webster, 2007: The role of intraseasonal variability in the nature of Asian monsoon precipitation. *J. Climate*, **20**, 4402–4424.

Iwashima, T., and R. Yamamoto, 1993: A statistical analysis of the extreme events: Long-term trend of heavy daily precipitation. *J. Meteor. Soc. Japan*, **71**, 637–640.

Karl, T. R., and R. W. Knight, 1998: Secular trends of precipitation amount, frequency, and intensity in the United States. *Bull. Amer. Meteor. Soc.*, **79**, 231–241.

Kendall, M. G., 1975: Rank correlation methods, 4ᵗʰ edn. Griffin, London.

Klein Tank, A. M. G., and co-authors, 2006: Changes in daily temperature and precipitation extremes in central and south Asia. *J. Geophys. Res.*, **111**, doi:10.1029/2005JD 006316.

Lettenmaier, D. P., E. F. Wood, and J. R. Wallis, 1994: Hydro-Climatological Trends in the Continental United States, 1948–88. *J. Climate*, **7**, 586–607.

Manton, M. J., and co-authors, 2001: Trends in extreme daily rainfall and temperature in Southeast Asia and the south Pacific: 1961–1998. *Int. J. Climatol.*, **21**, 269–284.

Matsumoto, J., 1997: Seasonal transition of summer rainy season over Indochina and adjacent monsoon region. *Adv. Atmos. Sci.*, **14**, 231–245.

Wang, L., R.-H. Huang, L. Gu, W. Chen, and L.-H. Kang, 2009: Interdecadal variations of the East Asian winter monsoon and their association with quasi-stationary planetray wave activity. *J. Climate*, doi:10.1175/2009JCLI2973.1, accepted.

Wijngaard, J. B., A. M. G. Klein Tank, and G. P. Können, 2003: Homogeneity of 20ᵗʰ century European daily temperature and precipitation series. *Int. J. Climatol.*, **23**, 679–692.

Xie, S.-P., H. M. Xu, N. H. Saji, and Y. Q. Wang, 2006: Role of narrow mountains in large-scale organization of Asian monsoon convection. *J. Climate*, **19**, 3420–3429.

Yokoi, S., and J. Matsumoto, 2008: Collaborative effects of cold surge and tropical depression-type disturbance on heavy rainfall in central Vietnam. *Mon. Wea. Rev.*, **136**, 3275–3287.

Zhai, P.-M., X. B. Zhang, and H. Wan, 2005: Trends in total precipitation and frequency of daily precipitation extremes over China. *J. Climate*, **18**, 1096–1108.

Zhang, X.-B., and co-authors, 2005: Trends in Middle East climate extreme indices from 1950 to 2003. *J. Geophys. Res.*, **110**, doi:10.1029/2005JD006181.