

Extreme Precipitation and Its Long-Term Changes over China and USA

Fang Wang^{1,2}, Song Yang², and R. Wayne Higgins²

¹National Climate Center, China Meteorological Administration, Beijing, China

²Climate Prediction Center, NOAA/NWS/NCEP, Camp Springs, MD, USA

1. Introduction

Accompanied by global warming, both precipitation and precipitation extremes in the world has changed greatly in historical records. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Meanwhile, the frequency of heavy precipitation events has increased over most land areas, even in those where there has been a reduction in total precipitation amount, consistent with warming and observed increases of atmospheric water vapor (IPCC, 2007).

China and USA are located across the Pacific Ocean, and are characterized by different climate features due to their differences in land-sea thermal contrast and ocean-atmosphere interaction between the western and eastern Pacific. Many previous studies have demonstrated the link of climate signals across the North Pacific, especially between Asia and North America (Lau *et al.* 2002; Wang *et al.* 2001; Zhang *et al.* 2005; Ding *et al.* 2005; Li *et al.* 2005; Zhao *et al.* 2011). This study will focus on the long-term changing features of extreme precipitation and their links to SST/Ts and atmospheric patterns from annual and seasonal timescale, mainly in the country-wide regard for both China and USA.

2. Data and methodology

2.1 Data

The following data sets are used in this study: (1) Station-based daily precipitation over China from 1961 to 2009, (2) USA daily precipitation from US Daily Precipitation Gridded Analysis from 1948 to 2009, (3) NOAA extended reconstructed SSTs V3b datasets from 1854 to the present (Smith *et al.*, 2008), (4) Surface air temperature from the station observation-based global land monthly mean surface air temperature dataset from 1948 to the present (Fan *et al.*, 2008), (5) Monthly wind and vertical velocity data from NCEP/NCAR Reanalysis1 (Kalnay *et al.*, 1996).

2.2 Methodology

Three precipitation indices are used to portrait the characteristics of the total and extreme precipitation. They are defined as follows:

P_{95} - Extreme precipitation based on 95% percentile. Let R_{wj} be the daily precipitation amount on a wet day ($R \geq 1.0\text{mm}$) in period j (j can be year or season, the same below) and let R_{wn95} be the 95th percentile of precipitation on wet days in the 1971-2000 period. If W represents the number of wet days in the period, then:

$$P_{95j} = \sum_{w=1}^W R_{wj}, \text{ where } R_{wj} > R_{wn95}$$

P_{TOT} - Annual or seasonal total precipitation in wet days. Let R_{ij} be the daily precipitation amount on day i in period j . If I represents the number of days in j , then

$$P_{TOTj} = \sum_{i=1}^I R_{ij}$$

R_{95p} - Ratio of extreme precipitation to total precipitation. It measures the relative importance of extreme precipitation.

$$R_{95p} = P_{95} / P_{TOT} * 100$$

In this study, we will focus on R_{95p} and P_{TOT} , mainly due to the high correlation between P_{TOT} and P_{95} .

The angular distance weighting (ADW) algorithm is used to interpolate station indices to regular grids over China (New *et al.* 2000). The long-term trends of the indices are estimated by the non-parametric Mann-Kendall test and Sen's method (Kendall 1955; Sen 1968).

3. Results

3.1 Annual features

The annual variations and long-term trends of total precipitation and the ratio are given in Fig. 1. Obvious differences can be seen between China and USA from the country-wide perspective. Over China, total precipitation nearly has no trend, and the ratio shows a slight positive trend of about 0.22% per decade, but not statistically significant. In contrast, over USA, total precipitation increases significantly, with a trend about 13.2mm per decade. Meanwhile, the ratio shows a moderate decrease by -0.15% per decade.

Fig. 2 gives the correlation patterns between precipitation and SST/Ts and 850hPa wind. We compare these patterns between original data and detrended data to distinguish the long-term features from the features on interannual timescales. For China, only few significant features can be seen for total precipitation. However, the ratio has strong relations to the SSTs in the Indian Ocean to western Pacific, the South and East China Sea, ocean east of Australia and the tropical Atlantic Ocean. Corresponding to SST pattern, a strong easterly from central Pacific passes through Philippine Sea and South China Sea, then turns to the northeast, forming a significant anti-cyclonic pattern in the western Pacific. When we removed the trend of the ratio, these SST relationships become much weaker especially in Indian Ocean, indicating an apparent link of SST and the ratio for their long-term changes. That is, the positive trend of China ratio is related to the long-term warming in these oceans.

As for USA, total precipitation has more significant features related to SST/Ts and circulation than the ratio (Fig. 3). It can be seen that total precipitation has significant relationships with the SSTs in the Indian Ocean and the eastern Pacific. The total precipitation also has a negative correlation with the North Pacific

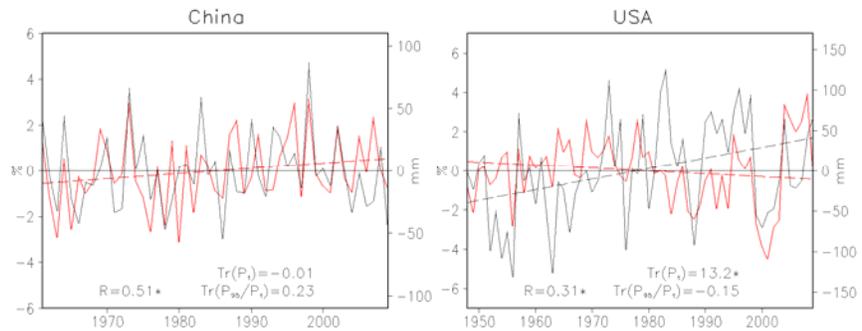


Fig. 1 Annual variations of total precipitation (black line) and the ratio (red line) for China (left) and USA (right). Dashed lines represent the linear trend.

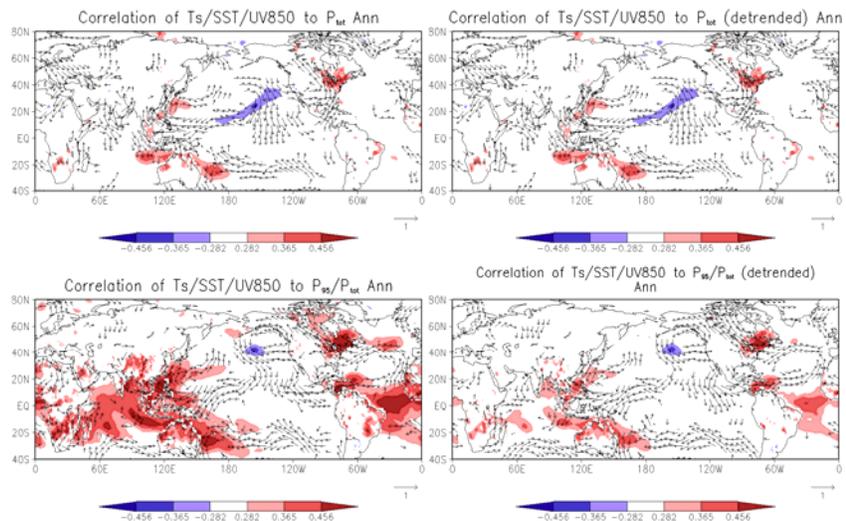


Fig. 2 Correlation patterns of total precipitation (upper) and the ratio (bottom) over China to SST/Ts and V850 wind. Left plots: original data; right plots: detrended data.

SST. Especially, the correlation pattern in Pacific may be related to the long-term change of Pacific decadal Oscillation (PDO), which has experienced an obvious shift from cool phase to warm phase about in 1976. In warm phase, strong warm SST anomalies occurred in central and eastern Pacific and distinct cooling is located in North Pacific around 40°N, corresponding to a relatively-abundant rainy era of USA although strong inter-annual variation exists. Meanwhile, the trade wind in central and eastern Pacific weakens strongly, leading to higher SST in tropical eastern Pacific and near seas to the west of North America, and subsequently abundant water vapor transferring from Pacific to east of USA, passing through Central America and Gulf of Mexico, favoring USA precipitation. It also can be seen that USA total precipitation has a high correlation to SST in Indian Ocean. After the trend is removed, these SST relationships become apparently weaker in Pacific, and entirely disappear in Indian Ocean, again suggesting that the relationships are for the long-term changes of SST and precipitation. Namely, the increasing trend of PDO index in recent decades may play important role in the positive trend in total precipitation over USA. Meanwhile, Indian Ocean warming may also play an important role in its long-term trend.

3.2 Seasonal features

Precipitations show distinct features in different seasons especially over China. In this section, the seasonal features of precipitation indices are addressed as well as their links to oceanic and atmospheric conditions. The methods used here are the same as the annual mean.

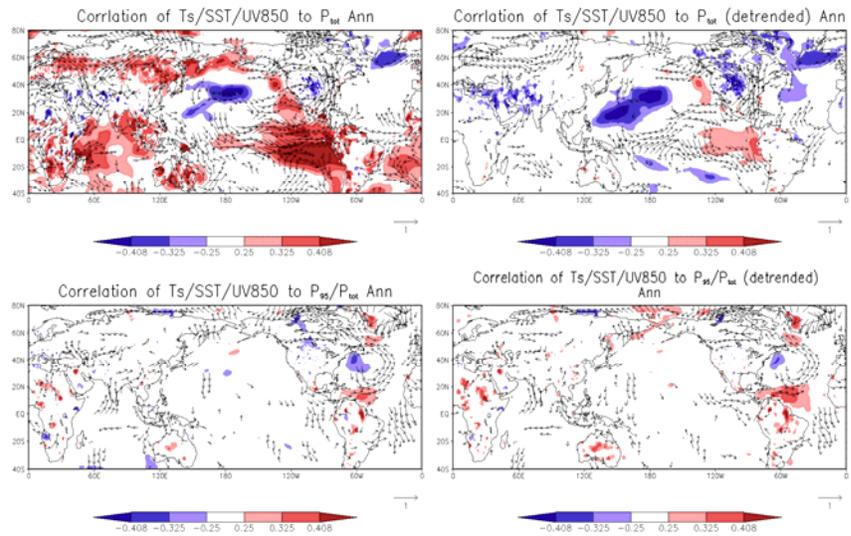


Fig. 3 Same as Fig. 2, but for USA.

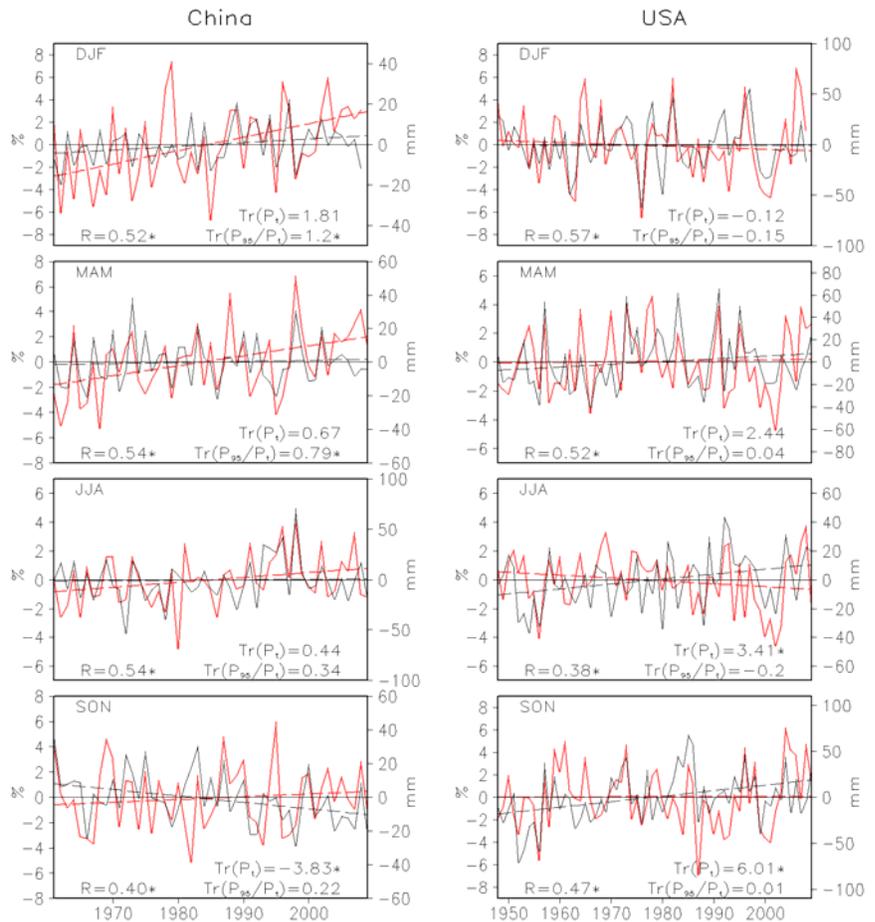


Fig. 4 Same as Fig. 1, but for different seasons.

Fig. 4 provides the variations of seasonal-mean ratio and total precipitation, averaged for China and USA. Over China, total precipitation changes insignificantly in winter, spring and summer, only slight positive trends being detected. While in fall, it shows significant negative trend. However, the ratio shows consistent positive trend in all seasons, especially significant in winter and spring. In contrast, over USA, total precipitation shows positive trend in seasons other than winter, especially significant in summer and fall. However, the ratio has little long-term change except the moderate negative trend in winter and summer.

Over China, only few SST and atmospheric circulation features are linked to total precipitation (Figure not shown), so we focus on the ratio. The ratio over China has consistent long-term positive trend in all seasons, particularly significant in winter and spring. Here we extract the

SST and circulation features associated with the long-term changes of the ratio by comparing the original and detrended correlations (Fig. 5). In winter, the ratio is significantly related to SSTs in Indian Ocean to Maritime Continent, South China Sea and seas to the east of China, concurrent with an intensification of northeast wind and an anomalous cyclonic pattern in north Pacific. In summer, the relationships enhance greatly as compared to spring. Furthermore, the ratio also has a significant relation to SSTs in the eastern tropical Pacific and tropical Atlantic Ocean. In fall, the high correlation is mainly located in South China Sea and Philippine Sea, which are key areas to East Asia Summer Monsoon (EASM). After the ratio is detrended, its relationships to SST become much weaker in most areas, indicating the apparent link of the long-term changes between the ratio and SST in these areas. In particular, tropical Oceans warming especially in Indian Ocean, eastern Pacific and Atlantic Ocean, and their corresponding atmospheric circulations, may play an important role in the long-term change in the ratio over China, particularly for spring.

Over USA, total precipitation increases obviously except in winter, especially significant in summer and fall, However the ratio has little trend. Therefore, we mainly focus on the SST and circulation features related to total precipitation (Fig. 6). It can be seen that total precipitation over USA is greatly affected by the SST and atmospheric circulation anomalies across North Pacific to North Atlantic Ocean and these features are mainly on interannual timescale. For all seasons a cyclonic pattern can be seen located in USA continent, although the center varies with the season, which is beneficial to precipitation over USA. By comparing the original and detrended features, we find SSTs in tropical eastern Pacific has significant positive correlation with total precipitation over USA, accompanied by strong weakening of trade wind in central and eastern Pacific, which is apparently due to their long-term changes. In addition, SST warming trend in Indian Ocean and tropical Atlantic Ocean also has significant teleconnection with USA summer precipitation. As for the

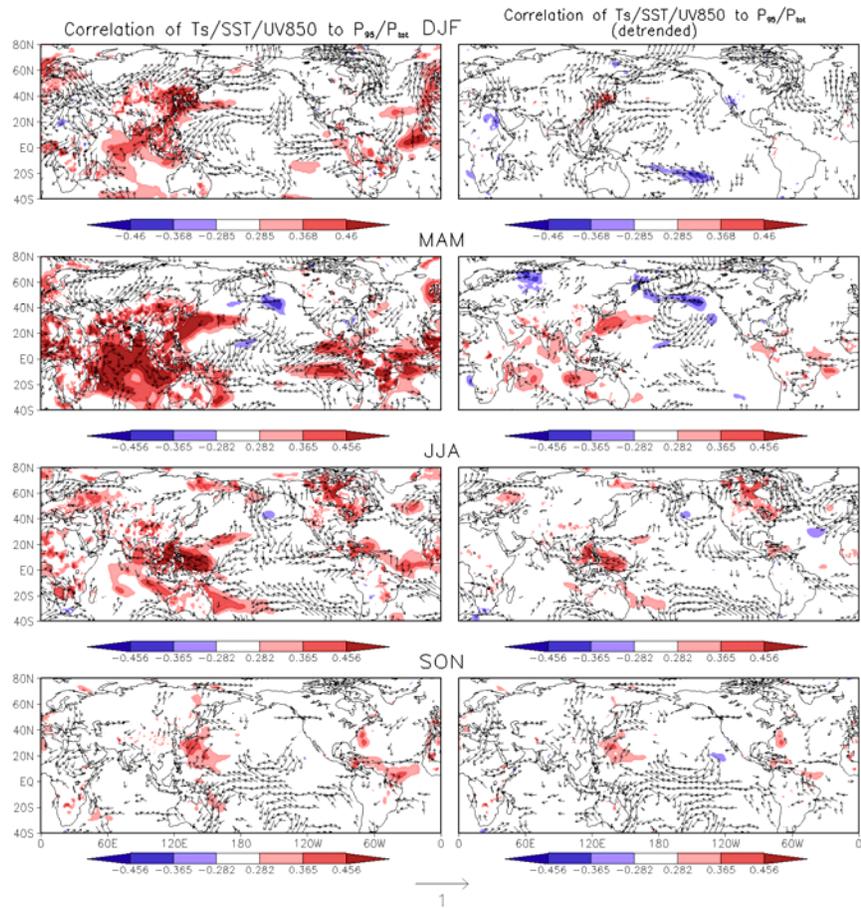


Fig. 5 Correlation patterns of the ratio over China to SST/Ts and V850 winds. Left plots: original data; right plots: detrended data.

ratio, few features can be seen linked to SST and circulation both on interannual and long-term timescales (figure not shown). Similar with annual mean, it can be inferred that the seasonal long-term change of PDO exerts an important effect on the precipitation trends, especially in summer and fall. Meanwhile, the long-term warming trend in Indian Ocean SST may also play an important role in change in USA precipitation in fall.

4. Summary

Using station-based daily precipitation over China and high-resolution daily precipitation analysis over USA, we analyzed the temporal and spatial patterns of total precipitation and extreme precipitation with the focus on long-term changes.

Features of both total precipitation amount and the extreme precipitation ratio are apparently different between China and the USA, and differences occur not only in the annual means but also in seasonally-averaged values. Annually, the total precipitation over China changes insignificantly and the ratio shows only a slight positive trend. However, the annual total precipitation over USA increases significantly although the ratio decreases moderately. In China, the ratio exhibits positive trends in all seasons, especially in winter and spring, and the total precipitation shows small positive trends except a significant negative trend in fall. In the USA, the total precipitation increases remarkably in all seasons, except a slight decrease in winter, and the ratio decreases in winter and summer but increases in spring and fall.

The change in extreme precipitation ratio over China has a strong link to the SSTs in the Indian Ocean to western Pacific, the South and East China Sea, ocean east of Australia and the tropical Atlantic Ocean. The change in total precipitation over USA is associated with the change in SSTs over both the Indian Ocean and the eastern Pacific Ocean. These relationships become much weaker when the trend of total precipitation or ratio is removed, indicating an apparent impact of SST on the long-term change in precipitation. The trends of precipitation are also linked to the long-term changes in atmospheric circulation including the trade wind, the North Pacific anticyclone, the Asian cyclone, and others.

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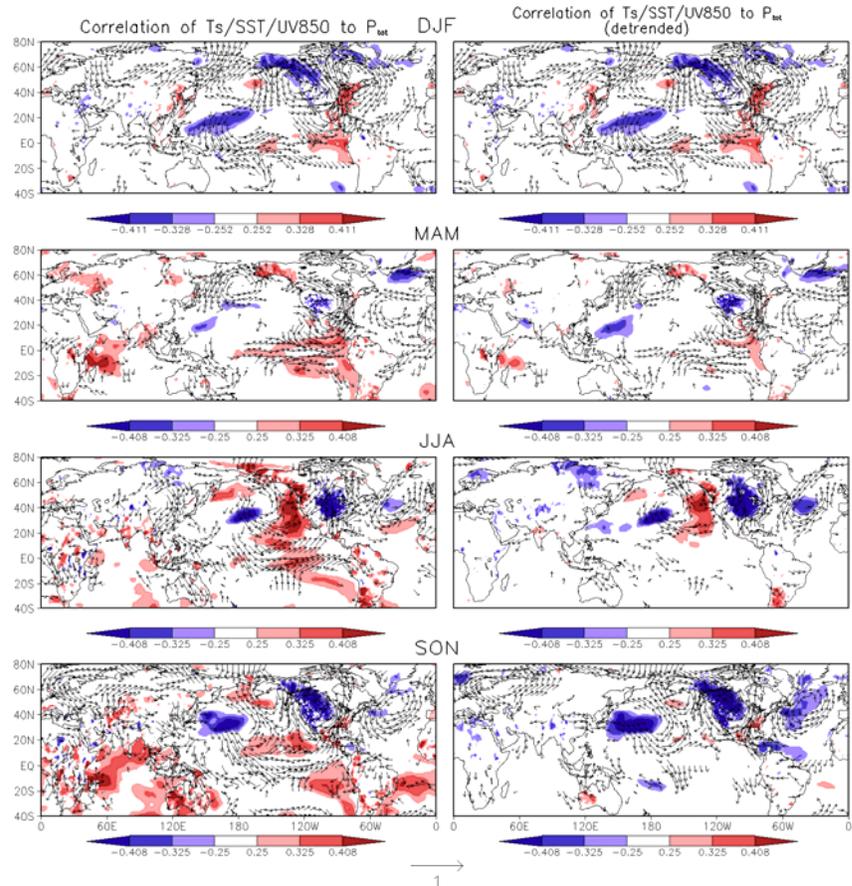


Fig. 6 Same as Fig. 5, but for total precipitation over USA.

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