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Light rain events change over North America, Europe, and Asia for 1973–2009

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Abstract

Analysis of daily precipitation data reveals diverse long-term trends of light rain events in North America (NA), Europe (EU), and Asia (AS), but overall a decreasing trend is found from 1973–2009, especially over East Asia, where a remarkable shift from light to heavy rain events has been observed. Although it has been argued that global warming may lead to a shift from light to heavy rain, regionally little correspondence is found between light rain trends and temperature/precipitable water (PW) trends. This argues for the need to include other factors such as atmospheric circulation and aerosol changes that affect regional rain rates and cloud processes. Copyright © 2010 Royal Meteorological Society

Keywords: **light rain; North America; Europe; Asia**

1. Introduction

Precipitation, a key physical process linking many aspects of climate, weather, and the hydrological cycle, is an ultimate source of fresh water sustaining ecosystems and human life. Research on precipitation variability and prediction has been of great interest in the meteorology and climate community (IPCC, 2007). While extremely heavy precipitation, which can potentially lead to floods, is a big concern worldwide (Allan and Soden, 2008), chronic reduction of precipitation frequency, which is very important for soil moisture, can potentially cause drought (Qian *et al*., 2007). Many regions of the world, such as Africa and Northern China, have experienced severe drought in the past several decades, leading to huge economic losses.

It is widely accepted that the global mean temperature has been rising since 1850 and will continue to rise in the coming decades (IPCC, 2007). In response to long-term climate forcing, the global water cycle is likely to change not only in rainfall amount but also in precipitation frequency and extreme events (Lau and Wu, 2007). Recent studies have shown a significant increase in precipitation over land at high latitudes since the 1950s, a possible increase over tropical oceans, and a reduction over tropical land areas (New *et al*., 2001; Kumar *et al*., 2003; Bosilovich *et al*., 2005). Some studies have revealed widespread increasing trends for heavy precipitation and attributed these changes to global warming because, theoretically, tropospheric warming can lead to an increase in the atmospheric water-holding capacity (Allen and Ingram, 2002; Trenberth *et al*., 2003, 2005).

However, precipitation is affected not only by atmospheric structure and water vapor content but also by cloud microphysical processes (e.g. cloud condensation nuclei, CCN). Both observational evidence and modeling results show that more aerosol particles in the atmosphere may increase cloud droplet numbers and decrease cloud droplet size, which may change the lifetime of cloud and suppress precipitation (Stevens and Feingold, 2009).

North America (NA), Europe (EU), and Asia (AS) are the most populated and industrialized regions of the world, with the highest man-made pollutant emissions and aerosol loading to the atmosphere. While pollutant emissions have been relatively stable over NA and EU, emissions in AS have been continuously increasing in the past several decades. Meanwhile, near-surface and tropospheric air temperatures have predominantly increased over most regions of the northern hemisphere (Fu *et al*., 2006). Although changes and variability in total and heavy precipitation have been more extensively studied, the variability of light rain, which makes a major contribution to precipitation frequency, has not been investigated at a global scale. This paper compares the changes of light rain events over NA, EU, and AS, with a goal of better understanding the role of global warming and anthropogenic aerosols in the changes of precipitation characteristics at the regional scale.

2. Data and method

The daily precipitation data used in this study are from NOAA's National Climate Data Center (NCDC) Global Surface Summary of the Day dataset (ftp://ftp.ncdc.noaa.gov/pub/data/gsod/). We screened all daily precipitation records for 24 549 stations and found that records after 1972 are more complete; therefore, we analyzed only the data over 37 years from 1973 to 2009. The year (season) is classified as unusable if the percentage of missing days exceeds 10% during that year (season). A station with more than two unusable years (seasons) during 1973–2009 is regarded as an unusable station and is excluded in the analysis. Also, we remove all the stations with unreasonable precipitation values or with record lengths <35 years. As a result, only about 5% of the original 24 549 stations are used in our analysis.In this study, light rain days are identified as those with daily precipitation <10 mm. Unfortunately, trace precipitation and missing data cannot be separated for many stations in the NCDC dataset because some countries use the same code for trace precipitation and missing data. Therefore, we focus on analysis of precipitation events between 1 and 10 mm/day (abbreviated as $1 < p < 10$) in this study.

3. Results

Figure 1 shows the spatial distribution of trends in the number of light rain days ($1 < p < 10$) for the summer (JJA) and annual total (January–December, abbreviated as ANN), respectively. It can be seen that the light rain trend varies considerably in different regions. Over NA, about half of the stations show an increasing trend and about half shows a decreasing trend during JJA. However, the trend magnitude is larger for the stations showing a decreasing trend. For the number of annual light rain events, the majority of stations show a decreasing trend over NA, at some stations up to 10 days/decade. Over EU, around 40–45% of stations show an increasing trend and 55–60% of stations show a decreasing trend for both JJA and ANN. However, the stations

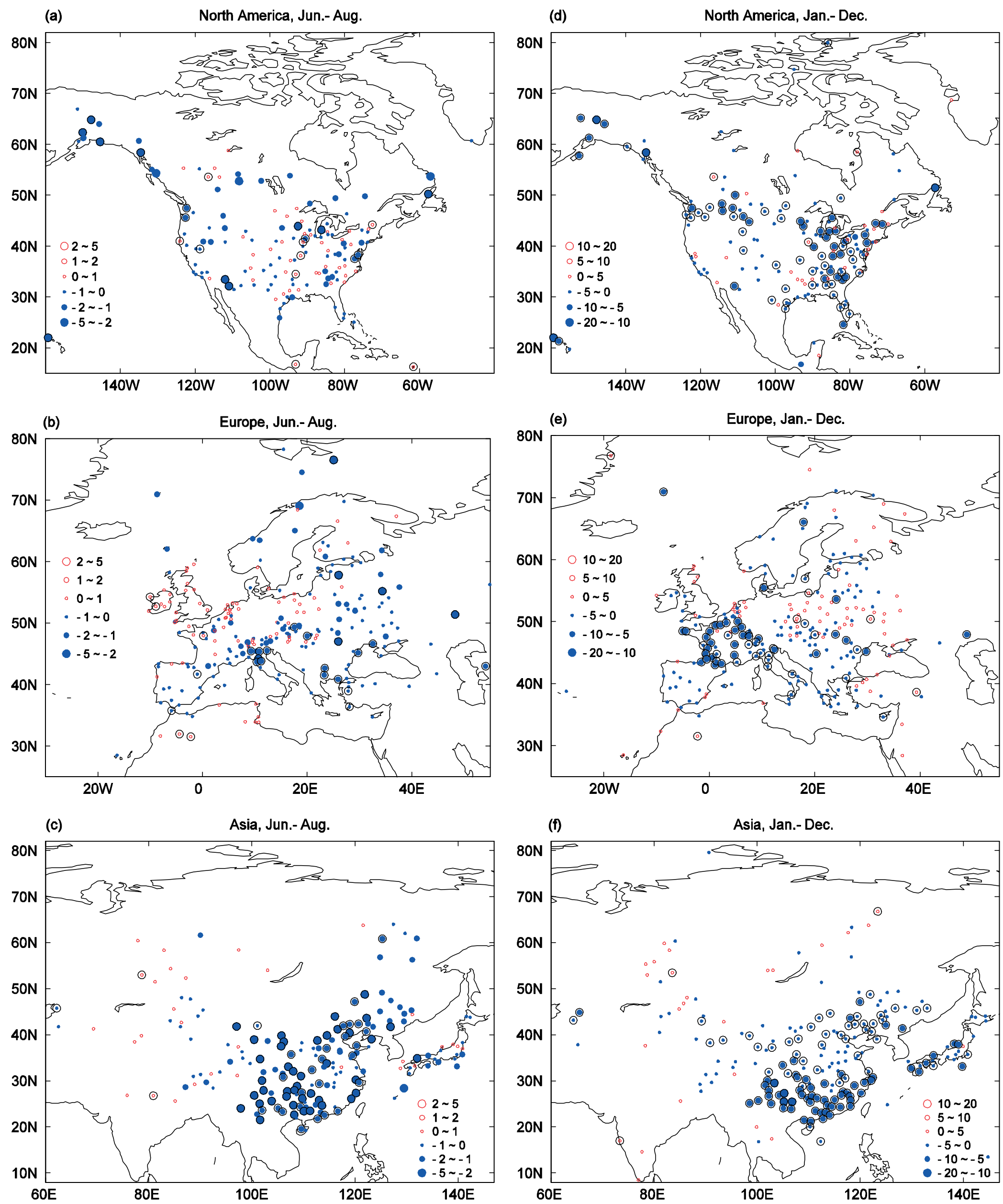

Figure 1. Trends of number of summer (JJA; left, a, b, and c) and annual (January–December; right, d, e, and f) total light rain days ($1 < p < 10$) over NA (a and d), EU (b and e), and AS (c and f), respectively, estimated using the least-squares technique.

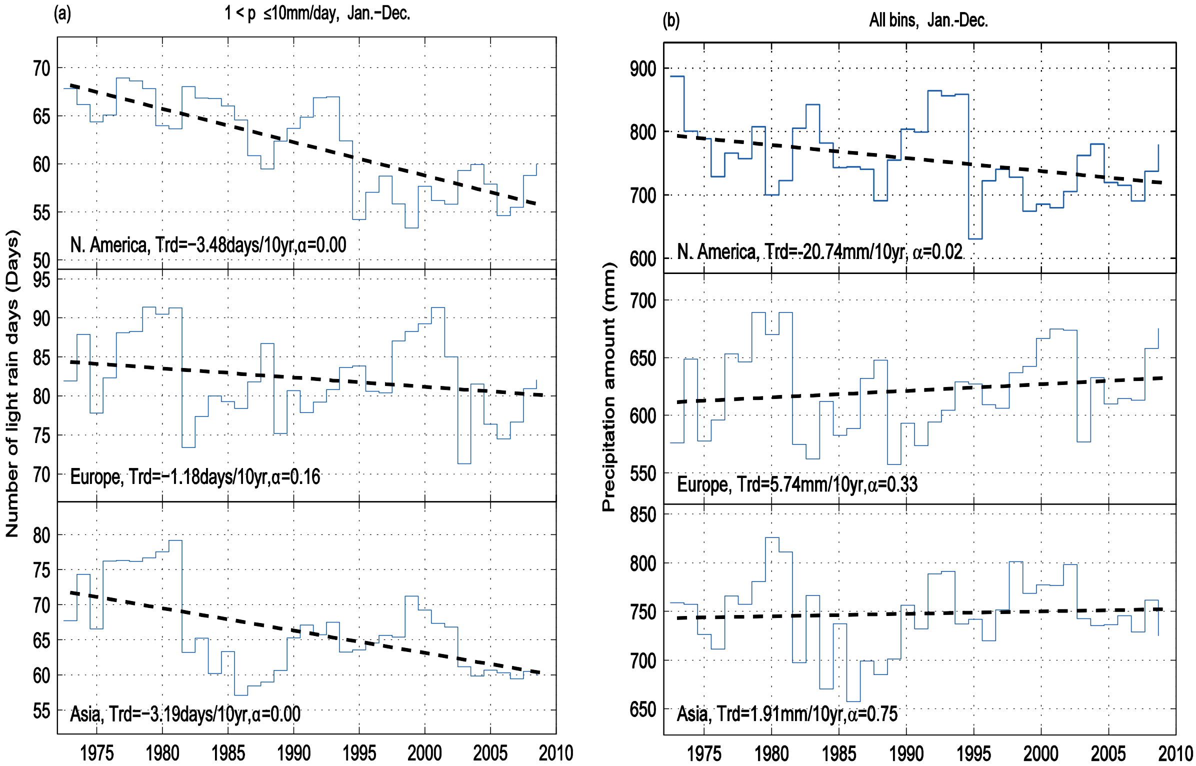

Figure 2. Time series of (a, left) the number of annual days with light rain ($1 < p < 10$) and (b, right) total precipitation amount averaged over NA, EU, and AS, respectively, for 1973–2009.

showing a decreasing trend are mainly located inland during JJA, but annually they are located differently (e.g. France). This follows the seasonal migration of precipitation from coastal to more inland and widespread between the cold and warm seasons. Similar to NA, the magnitude of trend is larger for the stations showing a decreasing trend than those showing an increasing trend. Over East Asia, the light rain days show a decreasing trend (statistically significant at the 95% significance level) for the majority of the stations. The number of light rain days has declined by 0.5–5 days/decade for JJA and 2–20 days/decade for ANN. This is consistent with the decreasing trend in light rain days found by Qian *et al*. (2009) using data from a similar set of stations for a longer time period.

Figure 2(a) shows the time series of the annual number of light rain days averaged for all valid stations over NA, EU, and AS, respectively, for 1973–2009. The light rain events have decreased by 3.48 days/decade over NA and 3.19 days/decade over AS: their trends are significant at the 95% confidence level. The annual light rain events have slightly decreased over EU but the trend is not significant. For contrast, the time series for total annual precipitation amount is shown in Figure 2(b), in which a significant decreasing trend can be found only over NA. A slight, but not significant, increasing trend can be found over both EU and AS. It is noticed that an abrupt drop of light rain days and total precipitation amounts occurred in the early 1980s in EU and AS. This may be partly related to the 1982/1983 El Nino, which generally reduces precipitation over land, and the 1982 El Chichón that led to global cooling and drying (Gu *et al*., 2007; Trenberth and Dai, 2007).

To shed additional light on changes in precipitation frequency, we examined the trends of rainy days (Figure 3) and rainfall amount (not shown) as a function of daily precipitation amount. Figure 3 (a–f) displays the trends from 1973 to 2009 for the rainy day frequency at 10 precipitation bins averaged over NA, EU, and AS during JJA and ANN, respectively. Over NA, an overall decreasing trend can be found across the majority of precipitation amount bins for both JJA and ANN, except for extremely light rain with a precipitation rate of 1–2 mm/day and moderate rain with a precipitation rate of 15–20 mm/day, where an increasing trend is found for both rainy days and rainfall amount. It is interesting that the most significant changes are found for lighter rain with a daily precipitation rate of 6–8 mm/day and for heavy rain with precipitation rates larger than 50 mm/day: both decreased by 10–15% on an annual basis. Therefore, heavy precipitation has become less severe or frequent in NA. Consequently, the total rainy days show decreasing trends, especially during ANN in NA, as shown by the 'Tot' bar in Figures 3(a) and (b). It is not surprising that the trend for both total rainy days (not shown) and rainfall amount (Figure 2(b)) is consistent with that for light rain events observed in NA because the moderate and heavy rain events also show a decreasing trend similar to the light rain. The decreasing trend of precipitation over NA observed in this study are different from the century-scale trends, but is similar to

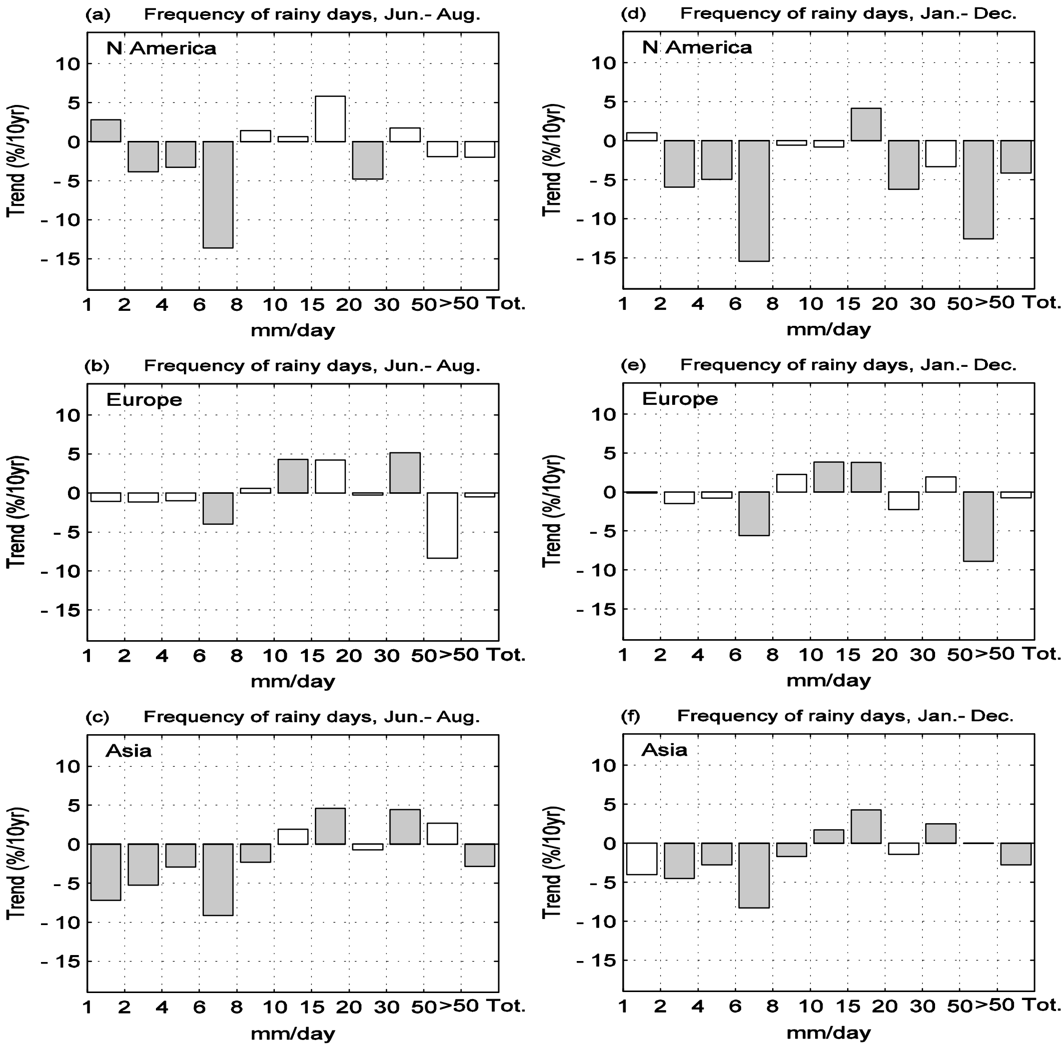

Figure 3. Trends for rainy day frequency at various precipitation bins over NA (a and d), EU (b and e), and AS (c and f) during JJA (left) and ANN (right), respectively. The dark shaded bar indicates trend significant at 95% significance level.

the general trends over the last 27 years (1979–2005) of the record as shown in Figure 3.13 in IPCC (2007).

Over EU, the trends differ for various precipitation rates. Generally, both light rain (<8 mm/day) and heavy rain (>50 mm/day) show a decreasing trend but the moderate rain (8–50 mm/day) show an increasing trend for both rainy days and precipitation amount during JJA and ANN. It should be noted that the extreme heavy rain events with precipitation rates >50 mm/day has decreased by 8–15%, but the trends for light rain, especially those <6 mm/day are small and not significant at the 95% significance level. The total rainfall amount does not show a significant trend as averaged over all the stations in EU, as shown in Figure 2(b).

Over AS, light rain ($1 < p < 10$) shows a decreasing trend and moderate and heavy rain show an increase trend for both rainy days and precipitation amount in JJA and ANN, which is consistent with the results revealed by Qian *et al*. (2009) for 1956–2005. The rainy days decreased by around 5%/decade for light rain <10 mm/day. For rain events with precipitation rates larger than 10 mm/day, positive trends can be found in most precipitation bins, suggesting a shift of precipitation rate from light to heavy in AS. Consequently, the total rainy days for all precipitation rates show a significant decrease trend ('Tot' bar in figure 3(c)) because light rain days account for a higher percentage in the total number of rainy days, but the trend of total rainfall amount is negligible for both JJA and ANN over AS (Figure 2(b)) because heavy rain accounts for a higher percentage in the total precipitation amount.

4. Summary and discussion

In this study, we compared changes in precipitation characteristics, especially the light rain events, over NA, EU, and AS based on the NOAA's NCDC Global Surface Summary of the Day dataset for 1973–2009. Results reveal diverse long-term trends of light rain events over these regions, but overall a decreasing trend is found from 1973 to 2009.

Over NA, both the number of stations showing a decreasing trend and the magnitude of the decreasing trend for light rain are larger than that of increasing trends, so annual light rain days have decreased by 3.48 days/decade when averaged over all the NA stations used. However, an overall decreasing trend can also be found for other precipitation rates, including the heavy rain events exceeding 50 mm/day, implying that both heavy and total precipitation have decreased over NA. Over EU, around half of the stations show an increasing trend and half show a decreasing trend in the number of light rain events. Therefore the trend of light rain events, especially for those <6 mm/day, is not significant when averaged for all the EU stations used. Over AS, especially East Asia, the light rain days show an overwhelming decreasing trend with high spatial coherency. Annual light rain days have decreased by 2–20 days/decade for most stations and decreased by 3.19 days/decade when averaged for all AS stations used for 1973–2009. Meanwhile, the number of moderate and heavy rain events (>10 mm/day) has increased, suggesting a remarkable shift of precipitation rate from light to heavy rain in AS.

While the trends of light rain events over NA, EU, and AS are presented in this study, a more interesting question is what factors caused the diverse features of light rain changes in different regions. It has been argued that global warming may lead to a shift from light to heavy rain (Liu *et al.*, 2009). Figure 4(a) shows the MSU tropospheric temperature trend for 1979–2009. Consistent with Fu *et al.* (2006), the majority of areas show a warming trend in the northern hemisphere, with maximum warming over high-latitude areas. Comparing the trends over continents in the northern hemisphere, the tropospheric warming is highest in EU and more moderate in AS. The warming is not significant over the northern parts of NA. As the atmospheric water-holding capacity increases according to the Clausius–Clapeyron equation, Trenberth *et al.* (2003) hypothesized that the amount of moisture in the atmosphere is expected to rise. This hypothesis may be valid on a global-average scale, but little correspondence is found regionally between the trends of warming and the amount of moisture in the atmosphere as we compare Figure 4(a) with 4(b) and (c).

Figure 4(b) and (c) shows the global distribution of trends in precipitable water (PW) over 1973–2001 based on the NCEP-NCAR and ECMWF reanalysis, respectively. Although, the reliability of current reanalysis datasets for PW is argued (Trenberth *et al.*, 2005), the common features appearing in both datasets include (1) PW increased over the western North Atlantic Ocean and USA, especially eastern USA, (2) no significant increase in PW is found over EU, although a large warming trend is observed there, (3) PW increased over the South China Sea but no significant change is seen over mainland China. The low spatial correlation between warming and PW trends suggests that PW is influenced more by atmospheric moisture transport than by local evaporation, and changes in regional PW reflect mainly changes in

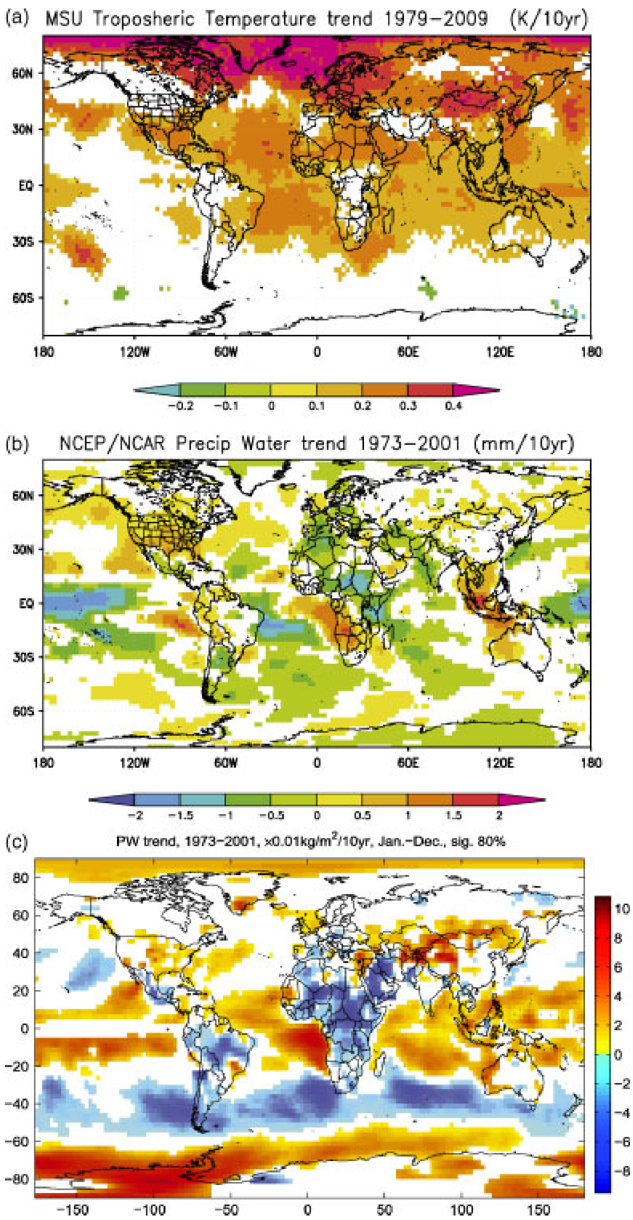

Figure 4. Trends for (a) MSU tropospheric temperature (shaded at 95% significance level) for 1979–2009, the PW based on (b) NCEP-NCAR, and (c) ECMWF reanalysis for 1973–2001 (shaded at 80% significance level). Unit for PW trend is mm (or kg m^{-2}) per decade.

large-scale circulation and/or changes in atmospheric moisture at the source regions.

Trenberth *et al.* (2003) suggest that the amount of moisture in the atmosphere may rise much faster with increasing temperature than the total precipitation amount because the latter is constrained by the surface heat budget through evaporation. They further argued that heavy precipitation should increase at about the same rate as atmospheric moisture because it depends on low-level moisture convergence. As total precipitation increases at a much lower rate than atmospheric moisture, increasing heavy precipitation must be compensated by decreasing light to moderate precipitation or decreasing precipitation frequency. If this hypothesis is true, it may partly explain the light rain reduction and heavy rain increase over AS. The PW change is minor over EU, which might partly explain why the changes for both total precipitation amount and light rain events are small over EU. The question remains, however, why both the light and heavy rain frequency as well as precipitation amount have decreased over NA, while PW has increased over the western North Atlantic Ocean and the USA. This apparent anti-correlated trend in precipitation and PW/RH deserves further study (Dai *et al*., 2006).

The above discussion illustrates the difficulty in relating light and total precipitation changes to atmospheric moisture availability on a regional basis. Clearly, precipitation is affected not only by atmospheric structure and water vapor amount but also by other factors. While the intensity of precipitation, especially for heavy events, depends on moisture availability and atmospheric stratification for deep convection, light rain, with high frequency of occurrence, is more directly affected by cloud microphysical processes. Man-made aerosol particles in the atmosphere have been dramatically and continuously increasing in the past several decades in China, which may have increased cloud droplet number concentration and decreased cloud droplet size in the atmosphere, thus changing cloud lifetime and suppressing precipitation, especially light rain events (Qian *et al*., 2009). This mechanism may partly explain why significant and spatially coherent light rain reductions are found over East AS. While both warming at the global scale and increased atmospheric aerosols may have affected light rain events, it remains challenging to quantitatively detect and separate the causes of light rain changes in different regions. More modeling studies combined with ground-based and satellite observational data analysis are needed to detect and attribute light rain changes in different regions around the world.

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