

Who should be Responsible for Precipitation Change, Natural Variation or Human Activities?

—Characteristics of Precipitation in South China and its Surrounding Area as viewed by TRMM PR and MODIS

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Theoretically, precipitation is regarded as the result of synthetic interaction between atmospheric thermodynamic processes and geographic environment factors, and is considered as one of the proxies for climate change. The spatiotemporal distribution of precipitation in turn will impact on atmospheric thermodynamic processes and lead to changes of other atmospheric parameters, i.e. the feedback process on climate. Therefore, investigating global or regional precipitation variations is important for understanding climate change.

Studies suggest that complicate changes have occurred in global climate in the latest 40 years (Trenberth and Hurrell, 1994; HU, 1997; Wang and Ding, 2006; Zhou et al., 2008; Zhou et al., 2009). It was proposed that the global temperature in troposphere has increased 0.13°C decade⁻¹ (IPCC, 2007). Accompany with this global warming, global atmospheric circulation showed that some climate systems have weakened e.g., the weakening Asian summer Monsoon over the last decades (Liu et al., 2012; Wu et al., 2012; Zhu et al., 2012). The responses and possible feedbacks of precipitation to this thermodynamic and dynamic changes are unclear. On the other hand, the carbon dioxide and air pollutants including aerosols emitted from human activities can change the radiative budget in atmosphere and earth surface. As a consequence, it may make significant impacts on spatiotemporal distribution of cloud and precipitation in hydrological cycle at regional and global scales. In this aspect, the effect of aerosol on cloud and precipitation (i.e. aerosol indirect effect) reflects the influences of human activities on weather or climate (Koren et al., 2012; Rosenfeld et al., 2012). However, recently cold evidences including the heavy snow storm events in America in the beginning of 2014 raised suspicions to the hypothesis of global warming. Also the aerosol-radiative effect remains one of the biggest uncertainties in climate modeling and prediction. It is still unclear as to how much human activities effect on climate change right now.

In order to understand if precipitation change was induced by natural process or by human activities, in this study, summer precipitation in South China together with nine typical regions in Asia (Fig. 1a) was investigated by using TRMM (Tropical Rainfall Measuring Mission) PR (Precipitation Radar) data and MODIS (Moderate-Resolution Imaging Spectro-radiometer) data. During summer, rainfall in these regions is mainly controlled by monsoon, in the meantime it may also be affected by human activities due to fast economic development in some of these regions. Therefore, it provides ideal test-bed to study the impacts from those two convolved factors on regional precipitation.

One of the standard datasets of TRMM PR, 3A25, supplies monthly mean near-surface rain rates (overall and conditional convective and stratiform rain) at 0.5 degree horizontal resolution from 1998 to 2011 for this study. Researchers have demonstrated good data quality and reliability of this data (Liu et al. 2010). To reveal air pollution resulted from human activities, monthly mean aerosol optical depth (AOD, 1.0 degree spatial resolution) at 550 nm from measurements of MODIS aboard Terra from 2000 to 2011 was used. Wind at 850hPa and geopotential height at 500hPa at 0.5° degree horizontal resolution issued by National Centers for Environmental Prediction (NCEP)–Climate Forecast System Reanalysis (CFSR) were also used to explore atmospheric circulation during the Asian summer monsoon. The changes in the strength of summer monsoon were represented by three selected monsoon indices (i.e. the EASMI, SCSSMI and SASMI, Li and Zeng, 2005).

Based on PR data, Figure 1 shows the spatial distributions of mean near surface rain rate during rainy season (May-August) in south of 38°N of Asia from 1998 to 2011. Nine typical regions are marked by boxes in Figure 1a, i.e., East China continent (EC), South China (SC), Southwest China (SW), the Tibetan plateau (TP), East adjacent Sea (EAS), East China Sea (ECS), South China Sea (SCS), middle to north of Indian subcontinent (IS), and the Bay of Bengal (BB). These regions all receive significant impacts from monsoon and are at different economic development levels which are correlated to local aerosol loadings. For example, EC, its downwind EAS, and SC have higher AOD as a result of the greater economic development while in SW AOD is smaller as the speed of economic development is slower. The selected TP and SCS can be considered as clean regions where atmosphere is less affected by human activities. For the same reason, IS (heavy polluted) and BB (relatively clean) can also serve as contrast regions for studying man's impact on nature.

Basically, the overall mean rain rate in the selected area is 2-3 mm/h, while conditional convective and stratiform rain rate is 3-10 mm/h and less than 2 mm/h, respectively. Rainfall in Figure 1 shows the maxima (greater than 4.5 mm/h) rain rate in the southern slope of TP, BB, SC, and east of SCS. Most strong rain rate appears in regions where the warm and moist monsoonal flowing is forced to lift by the large or middle scale topographic (Fu et al., 2008). It is clear that the main Asian rainfall band is associated with southwest or south wind at 850 hPa (Figure 1b). The geopotential height at 500 hPa illustrates that rainfall in EC and ocean is modulated by the ridge of the Western Pacific Subtropical High, while in SI and BB rainfall is situated in the monsoon trough. A study of comparison between PR data and rain gauge data in Southern China proves the reliability of PR precipitation products in monthly scale (Liu et al., 2010), which encourages studies on precipitation trend over global and regional scales.

Before revealing the precipitation trend over the last decades, it is necessary to examine the Asian monsoon variability. As illustrated by Figure 2a, temporal patterns of monsoon index in the three domains that cover the nine regions all show weakening trends , which is consistent with Liu et al. (2012), i.e., the Asian summer monsoon has been weakening since the end of the 1970s. How does the Asian precipitation change under such a weakening monsoon circulation? To answer the question, time series and linear trend of convective and stratiform rain rate and AOD in the nine regions are plotted in Figures 2 and 3. Figure 2 shows significant inter-annual variability for both convective rain rate and AOD. Basically, AOD is almost stable or slight decreasing in TP and SCS, decreasing in SC and SW, increasing in EC, EAS and BB, and stable in ECS. The increasing trend of AOD in EAS and BB is considered a result of human activities in their upwind area.

Corresponding to the AOD trends, Figure 2 only shows increase of the convective precipitation in EAS but decrease or no significant trends in other regions (Figure 2). For stratiform precipitation, the increase trends are observed in most selected regions in Asia, except for IS and BB (Figure 3). For quantitatively discussing the potential connections among precipitation, aerosol and monsoon, Table 1 gives the linear trend coefficients of rain rate and AOD in the nine regions. It is reasonable to draw the conclusion that the weakened Asian monsoon results in increased rain

rate of stratiform precipitation in both polluted and clean regions. Logically, the stratiform precipitation is mainly affected by the monsoon activities i.e. it is mainly controlled by atmospheric thermodynamic processes (nature factor). The mechanism underneath may be that the weakening monsoon circulation enhances the atmospheric stability, and in turn increases steady stratiform precipitation and its intensity. For convective, the intensity is modulated by both monsoonal circulation and human activities. In EC, for example, the aerosol concentration is higher while the water vapor is limited so that more aerosols-induced CCN compete with each other to obtain condensed liquid water (the second indirect effect of aerosol). It is hard for cloud particles to grow up in such circumstances, which leads to reduction in convective rain intensity. In contrast to EC, although there is high concentration of aerosols in EAS, ocean can supply enough water vapor for cloud particles growing up. This process causes stronger intensity of convective precipitation in EAS comparing to EC. Thus, the influence of human activities on precipitation depends on rain type and more importantly the capacity of available water vapor in the atmosphere.

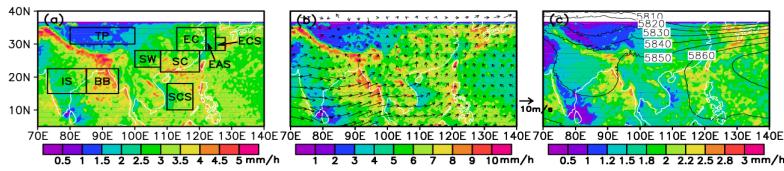


Figure 1. (a) Overall rain rate near surface, conditional rain rate near surface of (b) convective and (c) stratiform from TRMM PR averaged from May to August during 1998-2011(shaded). Nine typical regions indicated by 9 boxes ,i.e., East China (EC), South China (SC), Southwest China (SW),The Tibetan plateau (TP), East adjacent Sea (EAS), East China Sea (ECS), South China Sea (SCS), middle to north of Indian subcontinent (IS), and Bay of Bengal (BB). The vector arrow in (b) and contour lines in (c) are the associate 850hPa wind vector and 500hPa geopotential height, respectively, during the same period.

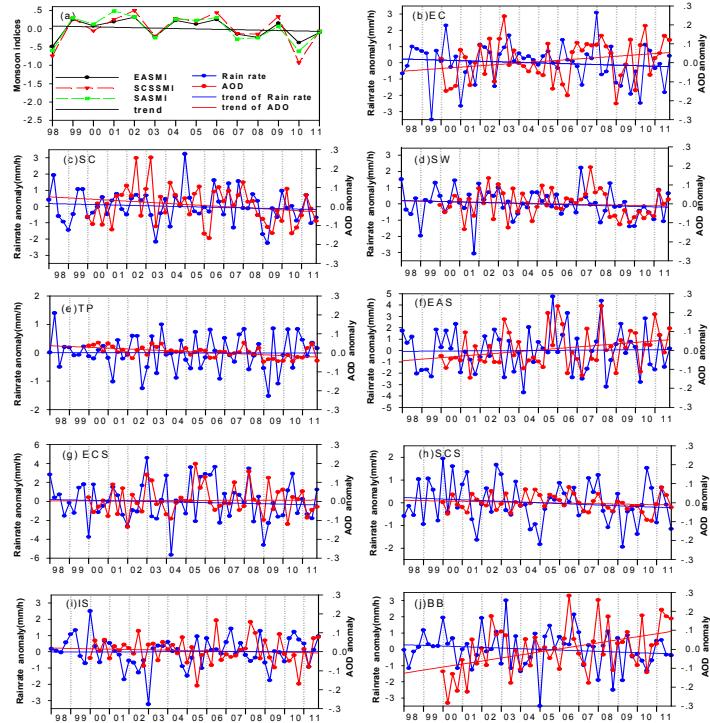


Figure 2. Monthly mean anomalies of (a) three monsoon indices , ((b)-(j)) convective rain rate (blue) and AOD (red) in selected nine typical regions from May to August during 1998-2011. The solid lines are fitted linear trends with a least square. EASMI, SCSSMI, and SASMI represent East Asian summer monsoon index, South China Sea summer monsoon index, and Southeast Asian Summer Monsoon index, respectively.

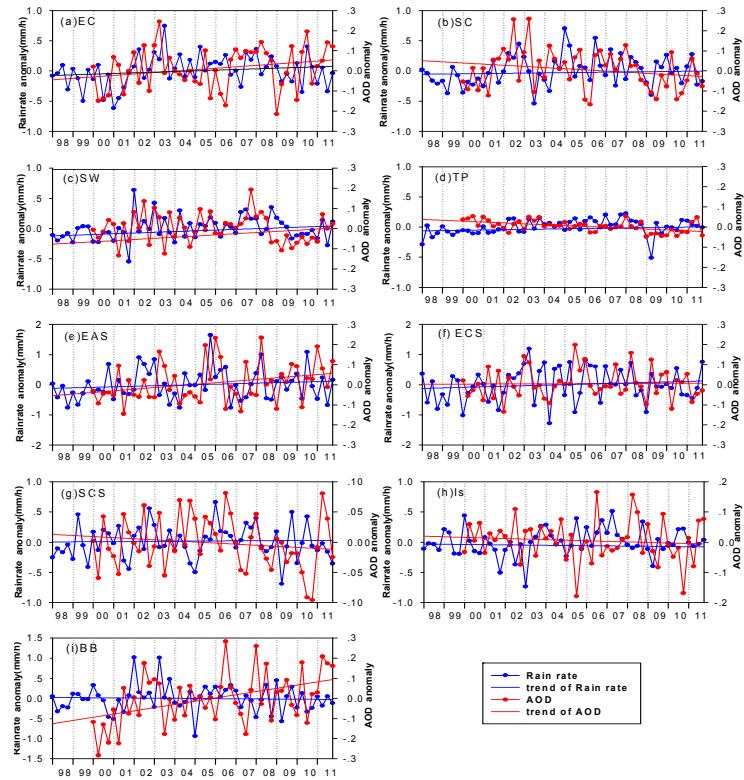


Figure3. The same as Figure 2, but for stratiform precipitation.

Table 1. The linear trend coefficients of monthly mean anomalies of convective and stratiform rain rate, and AOD in the selected nine typical regions as shown in Figures 2 and 3.

Regions	Trend of anomaly of		
	Convective rain	Stratiform rain	AOD
EC	-0.009	0.004	0.003
SC	-0.008	0.003	-0.002
SW	-0.008	0.003	-0.001
TP	0.000	0.002	-0.002
EAS	0.003	0.004	0.003
ECS	-0.008	0.003	0.000
SCS	-0.008	0.001	-0.001
IS	0.000	0.000	-0.001
BB	-0.010	0.000	0.004