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Air Pollution or Global Warming: Attribution of Extreme Precipitation Changes in Eastern China—Comments on "Trends of Extreme Precipitation in Eastern China and Their Possible Causes"

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ABSTRACT

The recent study "Trends of Extreme Precipitation in Eastern China and Their Possible Causes" attributed the observed decrease/increase of light/heavy precipitation in eastern China to global warming rather than the regional aerosol effects. However, there exist compelling evidence from previous long-term observations and numerical modeling studies, suggesting that anthropogenic pollution is closely linked to the recent changes in precipitation intensity because of considerably modulated cloud physical properties by aerosols in eastern China. Clearly, a quantitative assessment of the aerosol and greenhouse effects on the regional scale is required to identify the primary cause for the extreme precipitation changes.

Key words: aerosol effects, global warming, extreme precipitation

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1. Introduction

The widely observed phenomena of suppressed light precipitation and enhanced heavy precipitation represent a critical issue for understanding of changes in climate and the global hydrological cycle (IPCC, 2013). As the two major forcing agents in the climate system, greenhouse gases and anthropogenic aerosols have been inevitably linked to the modification of precipitation intensity in many previous studies (Li et al., 2008, 2009; Rosenfeld et al., 2009). However, the attribution of the observed changes in extreme precipitation to the forcing components remains an open question and under considerable debate, especially on the regional scale. Recently, Liu et al. (2015) analyzed long-term gauge precipitation measurements from 101 meteorological stations in eastern China and found statistically significant trends of declining precipitation in the bottom 10% precipitation intensities but increasing precipitation in the top 10% during 1955–2011. By differentiating the precipitation data between urban and rural locations, they found the similar trends in extreme precipitation over urban and rural areas. To explore the possible influence from global warming, Liu et al. (2015) further examined precipitation from Global Precipitation Climatology Project (GPCP) data and derived the interannual trends over the equatorial tropics (10°S–10°N), sub-tropics (10°–20°N), and mid-latitude (20°–45°N), showing the similar shifts in precipitation intensity towards heavy precipitation over the three latitude zones. On the basis of their regional and global analyses of the precipitation records, the authors concluded that air pollution did not account for the enhanced heavy precipitation and reduced light precipitation in eastern China.

2. Discussion

As recognized by IPCC AR5, detection and attribution of climate changes are still largely uncertain, and, in particular, the aerosol direct radiative effect by scattering and absorbing solar radiation and indirect effect by modifying cloud formation represent the largest uncertainty in the projection of future climate by anthropogenic activities. Because of their longevity and well-mixed state in the atmosphere, accumulating greenhouse gases likely induce warming on the global surface temperature, even though the warming is spatially inhomogeneous. From the thermodynamical perspective, the warming of the atmosphere results in increased water vapor amount but reduced relative humidity, which contributes to a shift in precipitation intensity from light to heavy precipitation (Trenberth et al., 2003; Held and Soden, 2006). Moreover, climate modeling studies suggested that the modulated meridional circulations in this warming climate accel-

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erated the precipitation changes in a "wet-get-wetter" and "dry-get-drier" manner (Lau et al., 2013; Su et al., 2014). Liu et al. (2015) provided observational evidence by showing similar responses in extreme precipitation to temperature changes over different latitude zones from GPCP and reanalysis data. However, there is a caveat in the underlying assumption of Liu et al. (2015) that Asian pollution would have resulted in a larger change in precipitation intensity in the mid-latitudes than in the equatorial tropics during 1979–2007 because of the aerosol effects. In fact, anthropogenic emissions of aerosols and their precursor gases have been significantly reduced over the developed countries of the mid-latitudes such as USA, because of regulatory controlled emissions of air pollution levels since 1970s. A recent study has suggested negligible net radiative forcing in the global mean from the spatially shifted emission centers in the Northern Hemisphere since the 1980s (Murphy, 2013). Therefore, the inhomogeneous distributions of anthropogenic aerosols make it difficult to attribute the precipitation intensity changes by simply comparing precipitation trends between broad latitude locations.

It is widely accepted that anthropogenic aerosols operate through various pathways to alter precipitation efficiency and intensity. By scattering or absorbing solar radiation, aerosols modulate the regional radiation budget, perturb the thermodynamical profile, and affect convection initialization. Surface "dimming" effects of anthropogenic aerosol have been extensively reported over the polluted regions (Ramanathan et al., 2005, 2007). Also, Wang et al. (2013) pointed out that absorbing aerosol layers, which frequently occur over South and East Asia, produce a temperature inversion in the lower troposphere, a larger negative energy associated with convective inhibition, and a higher convection condensation level (CCL). Meanwhile, pollution plumes induce larger convective available potential energy (CAPE) above the CCL, facilitating more intensive vertical development above cloud bottoms. Such a radiative effect of the absorbing aerosols operates in the same direction as the more prominent aerosol microphysical effects on precipitation intensity. By serving as cloud condensation nuclei (CCN), the elevated aerosols to reduce cloud droplet size, suppress light and warm rain processes but enhance ice-phase processes which produce heavier precipitation with larger latent heat release (Li et al., 2008; Rosenfeld et al., 2008; Li et al., 2011).

In eastern China, one of the key regions on the global air pollution map, aerosol effects on clouds, convection and precipitation have been extensively studied using long-term in-situ measurements. Qian et al. (2009) systematically analyzed the observed trends of light precipitation, large-scale moisture and particulate matters in eastern China for the period 1956–2005. They found that aerosols, other than large-scale moisture availability, account for the declining trend in light precipitation, which contradicts the hypothesized primary role of global warming in eastern China by Liu et al. (2015). More recently, Guo et al. (2014) reported the significant effect of aerosols on the suppression of light precipitation on the basis of surface precipitation and visibility measurements during 1955–2005. Different light rain formation mechanisms were examined in their study, and environmental factors such as atmospheric moisture content, CAPE and wind shear were all excluded from explaining the observed changes in precipitation intensity.

To tease out aerosol effects from large-scale impacts like global warming in observational data analysis, a widely adopted approach is to contrast the precipitation and aerosol conditions between "mountain-plain" pairs of stations (Rosenfeld et al., 2007; Yang et al., 2013; Guo et al., 2014). Using such an approach, Rosenfeld et al. (2007) suggested hilly light precipitation could be decreased by 30%–50% during hazy conditions over Mountain Hua and the Xi'an area of China. However, the urban–rural contrast in Liu et al. (2015) to identify the aerosol effects is questionable, since a haze layer typically covers a large portion of eastern China due to the efficient transport processes, especially over the North China Plain. The snap shot of the satellite image and the climatological distributions of the aerosol optical depth in eastern China clearly prove this point. The comparison in Liu et al. (2015) of eastern China to Taiwan is also controversial, since the background aerosol concentrations, aerosol types and characteristics of the prevailing cloud systems are expected to be distinct between these two regions.

To validate the aerosol effects on precipitation in eastern China, a wide range of aerosol-cloud-precipitation simulations using cloud-resolving models have been carried out. Fan et al. (2012) and Guo et al. (2014) employed the Weather Research and Forecasting (WRF) model with a sophisticated spectral-bin cloud microphysics scheme and revealed the critical role of anthropogenic aerosols in regulating precipitation efficiency under the typical cloud regimes of the warm and cold seasons in Southeast China. Wang et al. (2011) adopted cloud-resolving WRF simulations with a two-moment bulk microphysical scheme to elucidate that elevated aerosol loading suppresses light and moderate precipitation but enhances heavy precipitation in southern China.

The radiative and microphysical effects of aerosols in eastern China are not limited to precipitation; they can induce changes in other extreme events in the atmosphere. Wang et al. (2011) revealed that both heavy precipitation and lightning frequency are highly correlated with air pollution levels in the Pearl-River-Delta (PRD) area of southern China based on in-situ measurements during 2000–07. Such relationships were further corroborated by simulated aerosol invigoration effects on the convection, ice-phase microphysics and lightning potential using WRF model. Similarly, Yang and Li (2014) analyzed 15 years of satellite data and surface measurements in Southeast China, and found that the number of thunderstorm days measured at surface stations and lightning activities measured by Lightning Imaging Sensor (LIS) have all increased significantly along with decreased regional mean visibility. Clearly, those locally enhanced lighting frequency and intensity in Southeast China cannot be explained by global warming.

3. Summary

Although global warming caused by increasing greenhouse gases likely induces a global adjustment in moisture availability and precipitation intensity, the dramatic variations of anthropogenic aerosols and the wide range of aerosol forcings complicate the role of the global warming in regional and global changes of the hydrological cycle and climate. Previous theoretical, observational, and modeling studies have unambiguously demonstrated the profound impacts of anthropogenic aerosols on extreme precipitation and other extreme weather events in eastern China. A quantitative assessment of the impacts of aerosols and greenhouse gases on the precipitation trend in East Asia has yet to be made on the decadal time scale. Currently, conventional climate models fail to account for the aerosol microphysical effects on convective clouds and precipitation. Therefore, there is a fundamental need for comprehensive climate modeling studies that undertake the challenge of attributing extreme precipitation changes on the regional and global scales.

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