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Key Points:
- Thunderstorm and lighting have increased significantly in SE China
- The increase is accompanied by worsening air pollution
- No such trends over the mountains in the same region

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Increases in thunderstorm activity and relationships with air pollution in southeast China

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Abstract This study analyzes 15 years of Tropical Rainfall Measuring Mission (TRMM) satellite data, together with surface observations of thunderstorms and visibility, to study trends and relationships between aerosols and thunderstorms in southeast China. TRMM data used are from the lightning imaging sensor (LIS) and the precipitation radar (PR). Surface data are human-observed thunderstorm occurrence and visibility for the period of 1990–2012 at 70 plain stations and 4 mountain stations. Thunderstorm and lightning activities, as well as PR echo top heights, have all increased significantly over the region during the period under study, while regional mean visibility has decreased greatly at the plain stations. The daily rainfall amount during thunderstorm days has increased significantly, but rainfall without thunderstorms has no trend during this period. In comparison, the four mountain weather stations at elevations greater than 1100 m showed little trend in the number of thunderstorm days during the period of 1990–2012. The ratio of the number of thunderstorm days between plain and mountain stations has increased significantly. The distinct trends seen between plain and mountain stations may originate from large differences in aerosol concentration between the plain and mountain regions. The accumulation of pollution aerosols in the plain region likely invigorates thunderstorms, whereas a lesser, or no, impact on intense convection is found over high-altitude regions.

1. Introduction

Pollution aerosols are thought to have an invigorative effect on convective clouds by suppressing warm precipitation in moist and convectively unstable environments [*Rosenfeld et al.*, 2008], while the theory on the mechanisms of this invigoration has been revised recently [*Fan et al.*, 2013]. This effect has been observed from aircraft [*Andreae et al.*, 2004], from the ground over the southeast United States [*Bell et al.*, 2008; *Li et al.*, 2011], around the world from space [*Koren et al.*, 2005, 2012; *Lin et al.*, 2006; *Niu and Li*, 2012], and over the Philippines during and after an abrupt volcanic eruption [*Yuan et al.*, 2011]. As clouds develop to above the freezing level, mixed phase clouds containing ice and supercooled water can grow further more readily and induce cloud electrification and thunderstorms during summertime [*Zipser*, 1994; *Orville et al.*, 2001]. *Bell et al.* [2009] reported a significant weekly cycle in lightning activity over the southeastern United States, associated with midweek peaks in anthropogenic pollution.

In South Korea, increases in lightning frequency were found to have a strong relationship with PM10 and SO_2 concentrations [*Kar et al.*, 2009]. In central India, lightning frequency decreased during the monsoon period relative to the premonsoon period, and the reduction was attributed to low aerosol concentrations during the monsoon period [*Lal and Pawar*, 2009]. In southeastern China, the summer monsoon brings in abundant water vapor from the Pacific Ocean which helps intensify convective activities like thunderstorms and lightning [*Wang et al.*, 2009]. Aerosol loading in this region is very high as a result of the rapid development of the region's economy and population [*Li et al.*, 2007; *Deng et al.*, 2008].

Few studies have investigated the link between aerosol loading and long-term changes in intense convective activities over southeast China. *Rosenfeld et al.* [2007] and *Yang et al.* [2013a, 2013b] investigated the microphysical and radiative effects of aerosols on precipitation and thunderstorm activity in central west China surrounding Xi'an, a semiarid area located in Shaanxi Province.

The goal of this study is to investigate long-term trends in thunderstorm and lightning activities in a moist environment containing high aerosol concentrations. The impacts of aerosols on clouds and precipitation are difficult to extract from those caused by synoptic/climate factors [*Tao et al.*, 2012]. We strive to limit, if not remove, synoptic influences by conducting various analyses using a variety of data sets.

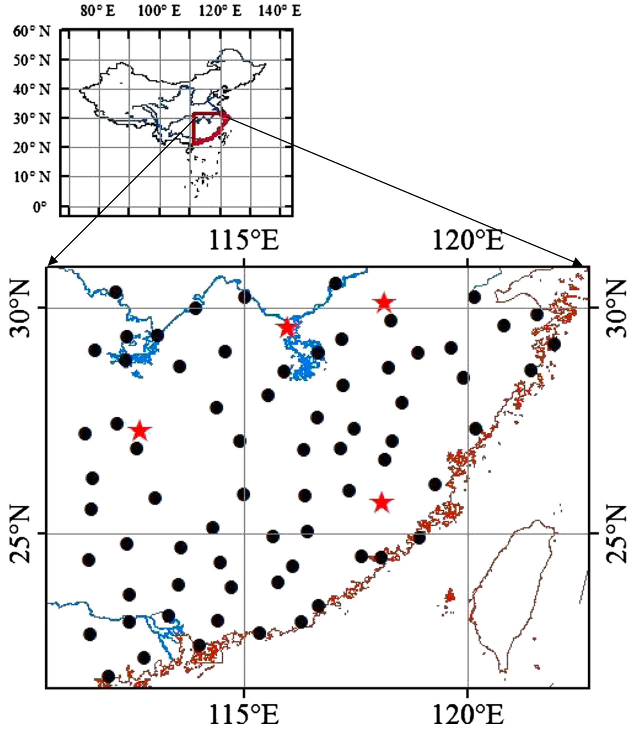

Figure 1. Geographic distribution of meteorological stations in southeastern China. Mountain stations are denoted by red stars, and plain stations are denoted by black dots.

Section 2 describes the data sets and methodology used in the study. Section 3 presents the trends in lightning and thunderstorm frequencies, storm height, and the differences between mountain and plain stations. Conclusions are given in section 4.

2. Data Sets and Methodology

The following products derived from Tropical Rainfall Measuring Mission (TRMM) satellite data are employed: lightning data measured by the Lightning Imaging Sensor (LIS) and the precipitation radar (PR) echo product 2A23. The TRMM satellite has been in operation since late 1997. The LIS detects lightning at a resolution of 3–6 km (3 km at nadir, 6 km at limb) with a swath width of 550 km at the Earth's surface. The LIS data set includes flash rates, frequency, and optical radiance. The LIS records the time and location of total lightning, including cloud-to-ground and intracloud discharges. However, LIS does not discriminate between these two. The lightning detection efficiency of LIS decreases during daytime. A real-time event processor is used to determine when a lightning flash occurs, even in bright sunlit clouds (http://ghrc.nsstc.nasa.gov/uso/ds_docs/lis/lis_dataset.html). Previous studies suggest that about 70% of total lightning can be detected near local noon and higher proportions (90%) can be detected at other times [*Christian et al.*, 1999; *Boccippio et al.*, 2000; *Xu et al.*, 2013]. LIS data are available from the website of the Global Hydrology Resource Center (http://ghrc.msfc.nasa.gov).

The TRMM radar product has a spatial resolution of 4–5 km and a swath width of 215 km [*Tropical Rainfall Measuring Mission Precipitation Radar* (*TRMM PR*) *Team*, 2011]. Note the different sizes of the areas covered by the LIS and the PR. This may not cause a serious problem for this study because our analyses rely on highly averaged quantities during all summer months from 1998 to 2012. Data are averaged over the entire study region (see below). The PR is one of the primary instruments onboard TRMM and is tasked with providing three-dimensional rainfall structures and obtaining quantitative measurements of rain rates over both land and ocean [*TRMM PR Team*, 2011]. TRMM PR data used in this study are the estimates of the "effective storm height," which is the maximum height at which a radar echo is detected. It differs from cloud top heights that are generally higher. These storm heights have been used for detecting the weekly cycle of rainstorms associated with pollution aerosols [*Bell et al.*, 2008] and for determining the characteristics of diurnal rainfall [*Ichikawa and Yasunari*, 2006].

The region of study and locations of the meteorological stations are shown in Figure 1. Seventy stations are located in the plain area, and four stations are located in the mountainous area. The mean altitude of the plain stations is 98.9 m, and the mean elevation of the mountain stations is 1481.1 m. Aerosol concentration generally decreases rapidly with height [*Liu et al.*, 2012], so the air above the mountain stations is more pristine than over the plain stations. Because most intense convective activities occur in summertime, this study is limited to the period of May to September from 1990 to 2012. Surface observations used in this study are weather reports, cloud type, visibility, humidity, and precipitation. The "present weather" reports provide information about thunderstorm occurrence and cloud type using synoptic codes defined by the World Meteorological Organization [*WMO*, 2011]. Other weather events recorded include rain, snow, fog, thunderstorm, lightning, and other types of weather phenomena at the time of observation. Similar to "present weather" reports, "past (recent) weather" reports also describe weather events but just those that occurred

Table 1. Synoptic Codes for Weather Phenomena of Interest to This Study[a]

Data Set	Code	Meaning
Present weather	13	Lightning visible, no thunder heard
	17	Thunderstorm but no precipitation at the time of observation
	91–94	Thunderstorm during the preceding hour but not at time of observation
	95–99	Thunderstorm at time of observation
Past weather	09	Thunderstorm(s) with or without precipitation
Low-level cloud type	02	Cumulus of moderate or strong vertical extent, generally with protuberances in the form of domes or towers, either accompanied or not by other cumulus or by stratocumulus, all having their bases at the same level
	03	Cumulonimbus the summits of which, at least partially, lack sharp outlines but are neither clearly fibrous (cirriform) nor in the form of an anvil; cumulus, stratocumulus, or stratus may also be present
	04	Stratocumulus from the spreading out of cumulus; cumulus may also be present
	09	Cumulonimbus, the upper part of which is clearly fibrous (cirriform), often in the form of an anvil, either accompanied or not by cumulonimbus without anvil or fibrous upper part, by cumulus, stratocumulus, stratus, or pannus

[a]Extracted from *World Meteorological Organization* [2011].

during the period between the most recent past two transmission times. Synoptic codes for weather phenomena of interest to this study are listed in Table 1. There are uncertainties inherent to human eye observations. Nevertheless, these records are valuable because of their long-term time coverage at a large number of weather stations in China, which makes them unique for this study. Visibility has been widely used as a proxy for aerosol concentration because direct measurements of the latter are scarce and costly. Visibility measurements have been used for investigating the role of aerosols in fog events in China [*Niu et al.*, 2010], trends in air pollution, and impacts on meteorological variables [*Che et al.*, 2007; *Rosenfeld et al.*, 2007; *Wang et al.*, 2009; *Yang et al.*, 2013a].

In this study, a "thunderstorm day" refers to a day during which at least one thunderstorm was reported. The number of thunderstorm days during the period of May to September was summed for each year, yielding the total number of summer thunderstorm days selected from convective clouds with synoptic codes of 02, 03, 04, or 09, as recorded in the cloud type report (cf. Table 1). Meteorological station data were obtained from the China National Routine Meteorological Information Center's website (http://cdc.cma.gov.cn).

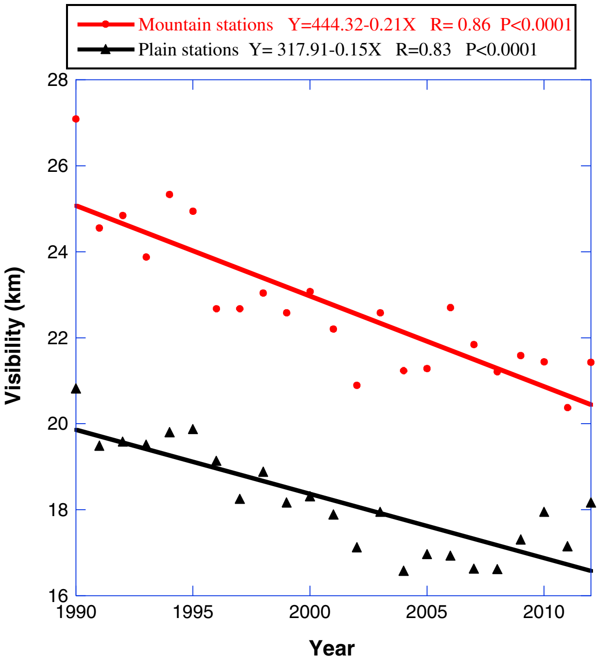

Figure 2. Time series of the mean visibility at plain (black triangles and line) and mountain (red dots and line) stations for summer months during the period of 1990–2012. The *P* value denotes the correlation probability where lower *P* values indicate a higher correlation between the two groups.

To use visibility as a proxy of aerosol concentration, the influence of humidity is corrected following *Rosenfeld et al.* [2007]. Moreover, visibility records were excluded if fog and precipitation occurred. Given the potentially large human errors in these records, all visibility records from May to September are averaged for plain stations and mountain stations, respectively. As shown in Figure 2, mean visibility at all stations has decreased steadily over the period of 1990–2012, suggesting a significant increase in aerosol loading in the study region during this period.

Southeast China has high aerosol concentrations [*Li et al.*, 2007; *Deng et al.*, 2008], and the bulk of it resides within the planetary boundary layer. At a high altitude, the atmosphere is much more pristine than at nearby plains. The visibility at mountain tops is higher than in the plains, as shown in Figure 2. If aerosols affect clouds and strong convection, there should be a great difference between thunderstorm activities over mountain and plain regions, given their distinct aerosol loadings. Four mountain-top stations in southeast China (altitudes greater than 1100 m) were thus chosen to represent relatively cleaner background conditions. Locations and altitudes of these four mountain stations are listed in Table 2.

Table 2. Mountain Station Locations and Altitudes

Station	Latitude	Longitude	Altitude (m)
Jiuxianshan	25°43′N	118°06′E	1653.5
Nanyue	27°18′N	112°42′E	1265.9
Lushan	29°35′N	115°59′E	1164.5
Huangshan	30°08′N	118°09′E	1840.4

3. Analysis Results

3.1. TRMM Flashes

Lightning has been employed as a proxy for convective activity [*Xu et al.*, 2013; *Bell et al.*, 2008]. In the present study, we focus on the long-term trend in intense convective activity during summer. Figure 3a presents the time series of the total number of flashes and the total number of rainy pixels over the study region, divided by the number of days in the selected period in each year from 1998 to 2012. Lightning occurrence increases significantly over this period of time. The autocorrelation coefficient of the time series of the lightning occurrence is 0.61, and the *P* value of the increasing trend is 0.01. The seasonally averaged daily mean number of raining pixels over the whole region has a decreasing trend. These opposite trends in the numbers of rainy pixels and flash times cannot be explained by a common cause of changes in synoptic dynamics because they both respond positively to increasing convective activities. Using the onset of rainfall as a proxy for synoptic episodes and the occurrence of lightning as a measure of the strength of convection during the summer season, their ratio (the number of flashes per raining pixel) may help reduce the influence of weather. The potential impact of aerosols on convection can then be better inferred.

The different areal coverage of the LIS and the TRMM PR (the scan swath of the PR is about 215 km, and the field of view of the LIS is ~550 km × 550 km) has not been taken into account. This might not be a serious problem because the data are averaged over large time and space scales. As illustrated in Figure 3b, both the daily number of flashes and the ratio are inversely correlated with visibility, with similarly high correlation coefficients ($R = 0.69$ and $R = 0.66$, respectively) and high levels of correlation confidence ($p = 0.004$ and $p = 0.007$, respectively). This finding is consistent with that from a similar study made by *Bell et al.* [2008] using data from the United States. To reinforce the causal relationship, other potential influences that may bring about apparent causal relationships must be excluded.

3.2. TRMM Storm Height

Convective clouds in summertime often develop to high altitudes in a polluted environment [*Li et al.*, 2011]. Distinct from cloud top heights, storm heights provided by the TRMM 2A23 product are the maximum

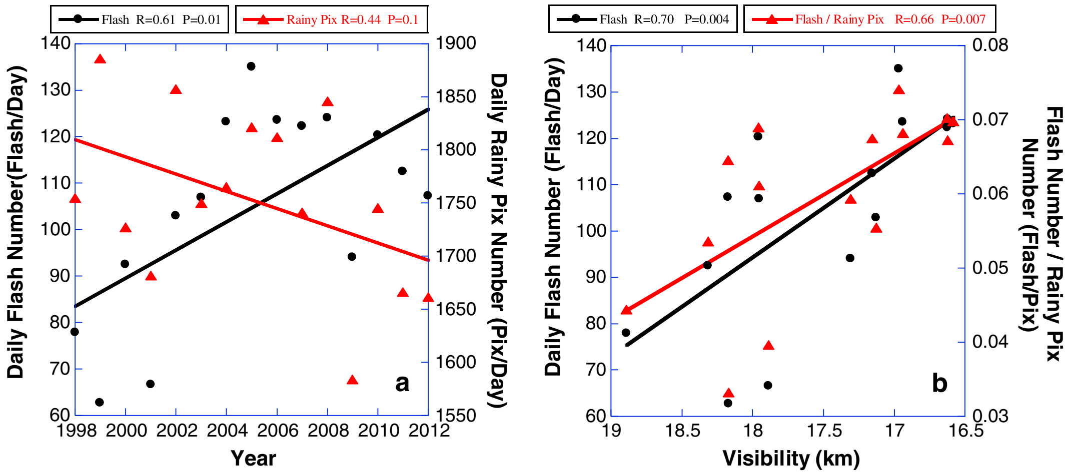

Figure 3. (a) Time series of the numbers of daily flashes from the TRMM LIS (left *y* axis, black dots and line) and rainy pixels from the TRMM 2A23 product (right *y* axis, red triangles and line), averaged over 21°–33°N, 111°–130°E and (b) the number of flashes per day (left *y* axis, black dots and line) and the ratio of the number of flashes per day to the number of rainy pixels per day (right *y* axis, red triangles and line) as a function of regionally averaged visibility for summer months during the period of 1998–2012. Note that the visibility axis in Figure 3b is plotted in reverse.

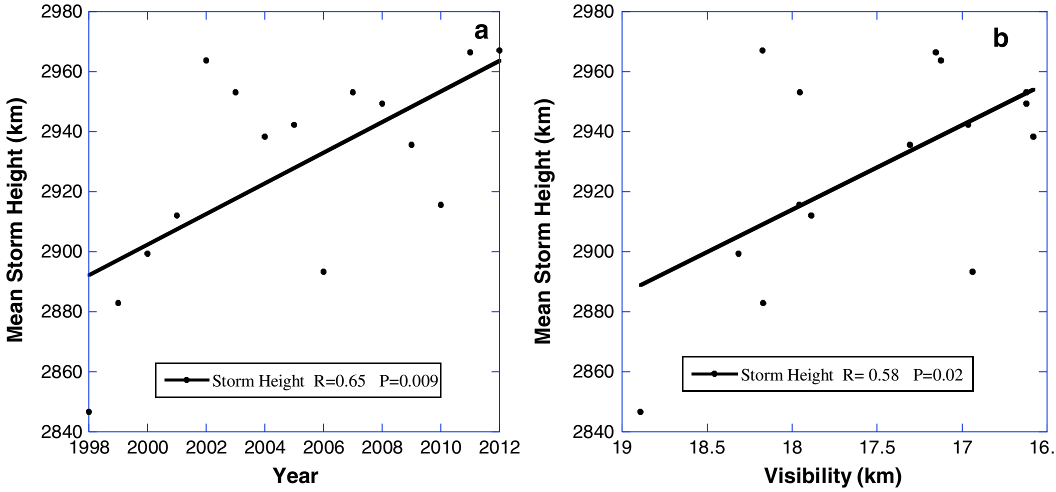

Figure 4. (a) Time series of PR echo heights of storm systems with tops lower than 4 km and (b) mean storm height as a function of regionally averaged visibility for summer months during the period of 1998–2012. Storm height data are from the TRMM 2A23 product averaged over 21°–33°N, 111°–130°E. Note that the visibility axis in Figure 4b is plotted in reverse.

detectable echo tops, indicating the highest altitude large droplets or particles can reach. Therefore, the storm height is a useful parameter to measure the vertical development of clouds. Storm heights provided by the TRMM 2A23 product have been used in many studies [*Bell et al.*, 2008; *Ichikawa and Yasunari*, 2006; *Liu and Zipser*, 2009]. In this study, we analyze trends in storm heights below 4 km, which is about the height of the freezing level in subtropical regions [*Liu and Zipser*, 2009]. Because cloud top heights might be much higher than PR echo heights, clouds with PR echoes higher than 4 km should exceed the freezing level and have regions of mixed phase cloud particles where charge separation and thunderstorm activity occurs.

Figure 4 shows the time series of regionally averaged storm heights for storms with PR echo tops below 4 km and mean storm height as a function of visibility. The increasing trend in storm heights shown in Figure 4a ($p = 0.009$) suggests that the vertical development of low clouds is strengthened at the expense of the suppression of the warm rain process as seen from the change in raining pixels. Therefore, more water vapor was transferred to higher levels and further enhanced the intensity of storms. Storm heights are also inversely correlated with visibility (Figure 4b, $R = 0.58$), consistent with the correlations for lightning flashes and raining pixels and their ratio.

3.3. Trend in Thunderstorm Days

The time series of thunderstorm days is shown in Figure 5a. The number of thunderstorm days in summertime has increased significantly. The increases in thunderstorm days and storm height suggest that the intensification of convection is enhanced not only in frequency but also in intensity.

Similar to the analysis in section 3.1, the time series of the ratio of thunderstorm days to rainy days is also investigated in order to remove the influence of rainfall changes on thunderstorm frequency. As shown in Figure 5a, there were significant increases in the numbers of both rainy and thunderstorm days for the 70 plain stations during the summer seasons from 1990 to 2012. The increase is more dramatic for thunderstorm days, as shown in the plot of the ratio of thunderstorm days to rainy days (Figure 5b). The ratio was calculated for each station and then averaged over all stations to obtain regional values. The normalized number of thunderstorm days is less sensitive to synoptic conditions. This indicates that the enhancement in thunderstorm frequency over southeast China is substantial and cannot be explained by changes in rainfall alone. A significant negative correlation between thunderstorm activity and visibility is seen in Figure 5c ($R = 0.72$). Trends in the daily rainfall amount with and without thunderstorms are shown in Figure 5d. A strong upward trend is seen for rainfall from deep convective clouds with thunderstorms, but little, or no, trend is seen for rainfall without thunderstorms.

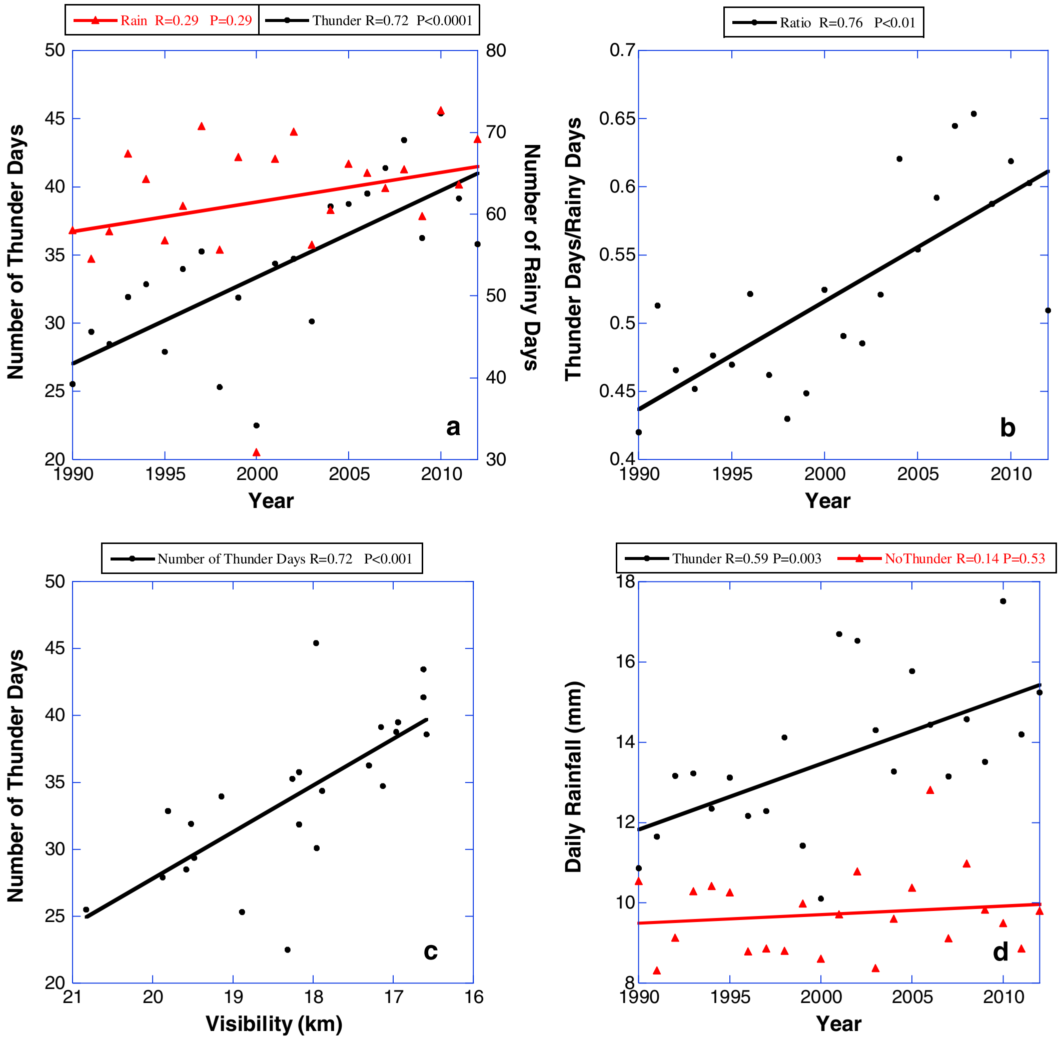

Figure 5. (a) Time series of mean numbers of thunderstorm days (left *y* axis, black dots and line) and rainy days (right *y* axis, red triangles and line), (b) time series of the ratio of the mean number of thunderstorm days to the mean number of rainy days, (c) the mean number of thunderstorm days as a function of the mean visibility, and (d) time series of daily rainfall with (black dots and line) and without (red triangles and line) thunderstorms. All data represent the plain region. Note that the visibility axis in Figure 5c is plotted in reverse.

3.4. Plain-Mountain Region Comparisons

One approach to isolate the influence of aerosols from dynamics is to study the contrast between mountains and nearby plains because they are governed by the same large-scale synoptic systems but have distinct aerosol loadings [*Givati and Rosenfeld*, 2005; *Rosenfeld et al*., 2007; *Yang et al*., 2013a]. Figure 6a shows the time series of the plain-to-mountain-site ratios of thunderstorm days and cloudy days. The ratio is between the numbers of thunderstorm days averaged for all the plain stations and for all the mountain stations during the summer months of a particular year. Because the four mountain stations are far away from each other (Lushan and Huangshan are the closest two stations, separated by about 550 km), thunderstorm records would not correlate among these stations. Their mean may thus represent the large-scale background conditions of a relatively clean environment, whereas the mean from the widely distributed plain stations represents a heavily polluted environment. Cloudy days are calculated in the same way as thunderstorm days. The plain-to-mountain ratio of thunderstorm days increased substantially during the period of 1990–2012. At the same time, the number of thunderstorm days for the mountain stations has a much weaker trend (Figure 6b), suggesting that the increase in thunderstorm activities is much more significant at plain stations than at mountain stations. The ratio of cloudy days had no trend over the years. This suggests that the general synoptic conditions favorable for the development of thunderstorms remained almost the same over

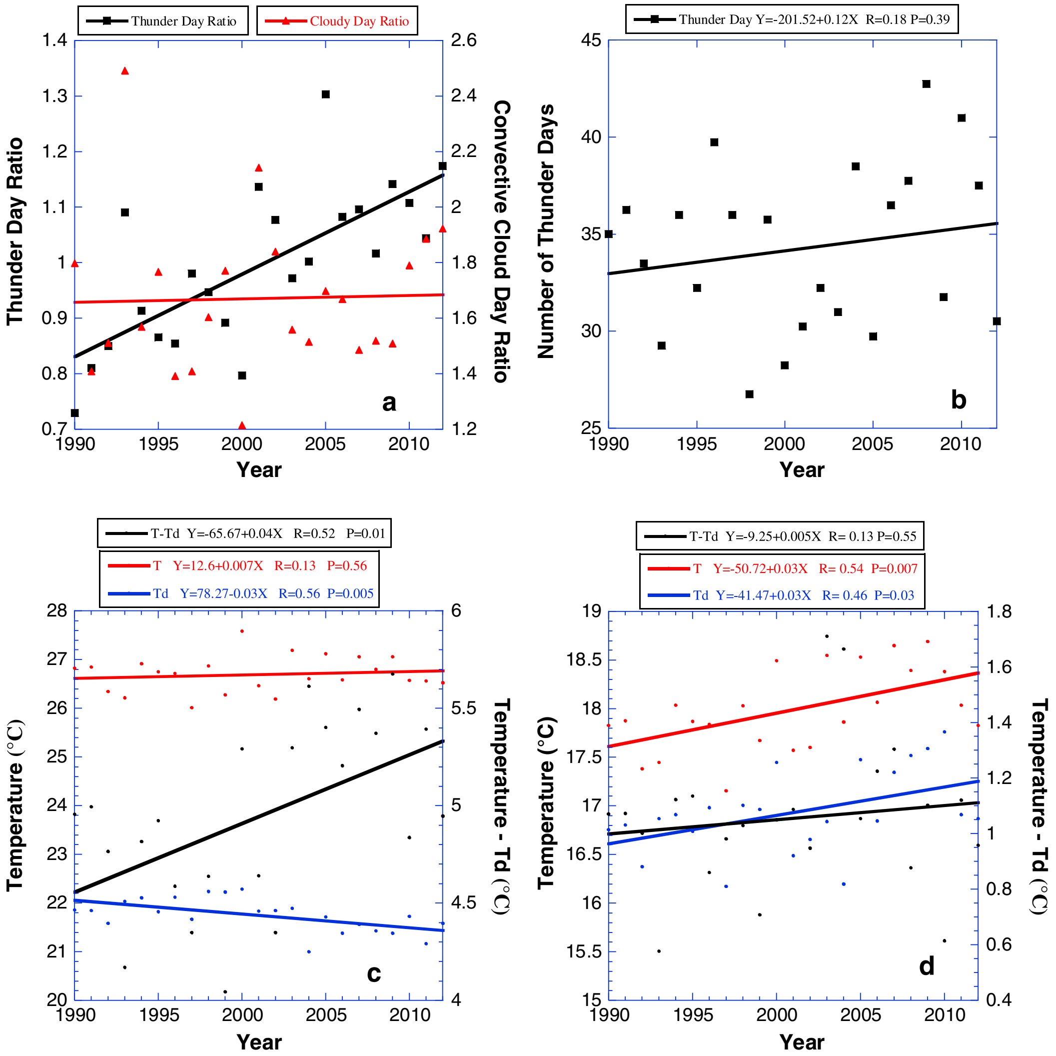

Figure 6. (a) Time series of the ratio of plain to mountain groups for the mean number of thunderstorm days (left *y* axis, black squares and line) and the mean number of convective cloudy days (right *y* axis, red triangles and line); (b) time series of the mean number of thunderstorm days for the mountain stations; (c) time series of mean air temperature (*T*, red points and line), dew-point temperature (Td, blue points and line), and their difference (*T* − Td, black points and line) at the plain stations; and (d) the same as Figure 6c but for the mountain stations.

the years. The sharper increase in thunderstorm occurrence over the plain region, compared to the mountain region, may thus not be explained by synoptic reasons but are more likely due to the action of aerosols. Figures 6c and 6d provide other evidence which supports the notion that changes in the atmospheric environment cannot explain the increasing trend in thunderstorm activities in the plain region. Atmospheric moisture has decreased more over plain stations than over mountain stations. Figure 6c shows that while the ambient air temperature has remained constant, the mean dew-point temperature at plain stations has decreased significantly from 1990 to 2012. The increasing trend in the difference between ambient air temperature and dew-point temperature may indicate that the atmospheric environment has become much drier over the plain region. However, no mean drying trend in the atmospheric environment over mountain stations is seen (Figure 6d). The temperature/moisture analysis also disapproves the climate/synoptic explanation regarding the enhancement of thunderstorm activities in the plain region.

4. Discussion

The correlation between storm heights and visibility may indicate that the enhancement of the vertical development of low clouds is closely related to aerosol loading in southeastern China. Tropical cyclones over the North Pacific may play a role in the intensification of thunderstorms, but studies have reported that the number of tropical cyclones, as well as their duration, has been decreasing over recent years in the North Pacific and other basins around the world [*Webster et al*., 2005; *Ren et al*., 2011]. The aerosol microphysical effect is the most likely mechanism behind the strengthening of cloud updrafts and the elevation of PR echo heights, providing a favorable environment for charge separation and lightning activity. This agrees with the new theory proposed by *Fan et al*. [2008], who stress the importance of the aerosol microphysical effect on deep convection and thus on thunderstorm activity. From Figure 5d, the amount of precipitation during thunderstorm days has increased over time, but rainfall amounts for days without thunderstorms have almost no trend. The distinct difference in rain rate between thunderstorm days and nonthunderstorm days seems to argue against a dominating role for the synoptic influence on changes in rainfall amount. The substantial increase in rainfall amount for thunderstorm days is likely a response to increases in aerosol concentration.

The enhancement of thunderstorms associated with increasing aerosol loading in southeastern China agrees with some previous studies [*Rosenfeld et al*., 2008; *Bell et al*., 2009] but not with all studies, including our own study in a different region of China. *Yang et al*. [2013b] reported the suppression of thunderstorms during the summertime over the Xi'an valley in central China. Differences in aerosol concentration and type, as well as water vapor supply regimes between northwestern [*Yang et al*., 2013b] and southeastern (this study) China, may explain this contradiction. As proposed in previous studies [*Koren et al*., 2008; *Rosenfeld et al*., 2008], aerosol microphysical and radiative effects can offset each other depending on the aerosol concentration and optical properties as well as the moisture supply. A higher aerosol loading more readily invigorates storms in a moist and convectively unstable environment but inhibits convection and clouds in a dry environment with strong absorbing aerosols. Therefore, the enhancement of thunderstorms reported in this study and the suppression of thunderstorms reported by *Yang et al*. [2013b] are not truly contradictory. Note that southeastern China is more humid than northwestern and central China. But the single-scattering albedo of aerosols in southeastern China is larger than in northwestern and central China [*Lee et al*., 2010]. The difference suggests that the influence of aerosols on convection and clouds depends on meteorological conditions. In the United States, aerosol loading is much lower with a much lower concentration of soot, both in absolute magnitude and relative proportion, leading to more of an invigoration effect than a suppressing effect, as found by *Li et al*. [2011] over the Southern Great Plains in the South Central United States.

The urban heat island (UHI) effect could enhance lightning activity through different mechanisms. But over a large area like southeastern China, the UHI effect cannot be the main influence, based upon storm heights and flash numbers derived from TRMM satellite data. Pollution aerosols could affect deep convection [*Li et al*., 2011] through both radiative [*Yang et al*., 2013b] and microphysical effects [*Bell et al*., 2008]. Asian anthropogenic aerosols could intensify thunderstorm tracks over the Pacific Ocean [*Zhang et al*., 2007], whereas the UHI effect is limited to local scales and plays a minor role in areas where aerosol concentrations show an increasing trend [*Lal and Pawar*, 2011]. *Yang et al*. [2013b] attempted to separate these effects by studying summer thunderstorm activity over three representative sites: a big city, a rural site, and a nearby mountaintop site. The intensification of thunderstorm activity by pollution aerosols over southeastern China is in agreement with studies using surface observations from the National Lightning Detection Network in the Southern United States [*Orville et al*., 2001] and LIS satellite data over the Philippines [*Yuan et al*., 2011]. Also consistent with the finding of *Bell et al*. [2008], no significant trend in total rainfall amount with increasing pollution was detected, especially if the data were not stratified by time of day.

5. Conclusions

By analyzing lightning data derived from the TRMM satellite (1998–2012) and from surface observations (1990–2012), we find that thunderstorm activity has significantly increased in southeastern China during recent decades. Over the same period, however, the rainfall frequency derived from both TRMM and surface observations showed little trend, which suggests that the synoptic, or climate, background did not play a key role in the enhanced thunderstorm and lightning activities. Relative to the number of rainy pixels or rainy days, the lightning occurrence has increased significantly over plain stations in southeastern China where air pollution has increased over the years. Based upon TRMM retrievals and surface records, the ratio of thunderstorm days to rainy days has increased, suggesting a general trend in the intensification of thunderstorms in southeastern China even though weather regimes seem to not have changed over the period of study.

This inference is consistent with the findings of increases in storm heights and ratios of rainfall days with and without thunderstorms. Increases in both the frequency and intensity of lightning activity are negatively correlated with increasing visibility due to the persistent increase in aerosol loading over southeastern China.

Increases in the number of thunderstorms are much more significant in the plain region than in the nearby mountain region under study. Both regions experience the same weather systems but have different aerosol loadings. The heavy aerosol loading in the plain region will more likely invigorate storms than the lower aerosol loading in the mountain region because the bulk of the aerosol particles are located near the surface. Temperature/moisture differences between the plain and mountain regions cannot explain the enhancement of thunderstorm activities in the plain region. The atmospheric environment over the plain region has become drier compared to that over the mountain region.

Our analyses using several independent data sets covering relatively long periods of time (15 years for TRMM and 23 years for surface observations) in mountain and nearby plain regions that experience similar meteorological, but distinct, environmental conditions seem to suggest a large impact of aerosols on thunderstorm activities.

Findings from an individual study like this may not pinpoint a definitive causal relationship. Consistent findings from more analyses using independent data sets, however, may constitute collective evidence compelling enough to not be overlooked or discarded. As more evidence emerges, the chance that findings, such as presented here, are a fortuitous coincidence decreases. Because the increase in thunderstorm activity cannot be solely attributed to the increase in aerosol emissions, more studies similar to this one must be conducted in other regions of the world experiencing rapid changes in their atmospheric environments.

Acknowledgments
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