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Atmospheric
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Discussions

Interactive comment on "Spatial features of rain frequency change induced by pollution and associated aerosols" *by* Yanfen Lin et al.

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The paper describes analysis of rain frequency changes due to air pollution. The work relies on satellite observed distribution of rain frequency, NO2 and aerosol concentrations. The results and conclusions are based on data from 1998 to 2009 over Shanghai.

General Comments: The authors claim that the pollution enhancement occurring over the research period is responsible for the changes in frequency of precipitation events. They stress that this work only relates to the frequency of storms rather than to rainfall amounts. Although the authors mention that both direct and indirect effects could be responsible for the observed changes, they devote most of the paper to the potential impact of the indirect effect, namely the role of CCN increases in modifying the precipitation frequency. It is not clear to me what the relative effect of each of the above

processes is. One could easily argue that the effects of the pollution on changing the atmospheric stability are more important than their microphysical impact on the clouds. Furthermore, in the whole paper there is no mention of other very important factors such as the urban effects (e.g. urban heat island, changes in wind speed due to the urbanization, changes in soil moisture and more). These factors could be much more important in changing the rainfall frequency than any of the other factors mentioned in the paper.

ANSWER: Thanks for the comments. We modified paper to make it clear that our conclusions are based on a spatial-temporal analysis over eastern Asia from 1998 to 2009 using multi-satellite measurements. Analysis over Shanghai is to illustrate reliability of satellite measurements and possible mechanisms, as there were more surface observations available in Shanghai. In our study, we speculate two effects (direct and indirect) of pollution and associated aerosols on precipitation, as possible mechanisms. It is difficult to quantify the relative devotion of direct and indirect effects by using the satellite retrieved data in climatologically perspective. The other factors, such as urban effects, are important and can not be excluded from the reduction of rain frequency over urban area (at small local scale). The observed spatial features of reduction of rain frequency here are at a larger spatial domain at regional scale. In our revision, we stress that "The inverse relationship is observed at large temporal and spatial scales, illustrating potential climatological consequence of increased pollution and aerosols on precipitation. However, aerosol effects on precipitation follow a chain of microphysical and thermodynamical processes that occur at shorter time scales. Also other effects, such as urban effects, may contribute to the reduction of rain frequency at small local scale. Hence, more robust statistical study at various temporal and spatial scales and detailed modeling investigation are warranted to further understand the observed relationship between the rain frequency and the pollution and associated aerosols." One important problem that I find with the paper is the fact that they draw conclusions based on only twelve years of data. This is especially true since the data is so noisy and varies a great deal from year to year (see fig. 1). Extending the period of observation by only a few years may reveal a completely different picture.

ANSWER: The TRMM PR is only satellite sensor that directly measures precipitation. As TRMM PR was launch on November 1997 and provides data from December 1997 to present, a time series of twelve years (from 1998-2009) is the most long term we may use to study precipitation properties from TRMM PR. Many studies based on a longer term surface rain gauge measurements show similar precipitation trends (see references in the paper). Although the interannual variability is large, we believe that extending the period of observation for a few years may not change our conclusions. Furthermore, those long-term surface rain gauge measurements are sparse. As aerosols and precipitation have large spatial and temporal variability, remote sensing from satellites delivers the most reliable information about their regional and global distribution. Hence, we investigate the spatial features of rain frequency change induced by pollution and associated aerosols from the spatial-temporal perspective by utilizing multi-satellite observations over East Asia.

The paper does not cover the literature in detail. For example, in the introduction, papers such as Alpert et al, J. App. Meteor., 2008; van den Heever and Cotton, J. App. Meteor., 2007; Changnon et al, Bull. Amer. Soc., 1981 and others have not been mentioned, although they deal with a similar topic.

ANSWER: We have added several related references in the introduction section.

Specific Comments: On page 14497- line 8 the references to Levin et al, JGR, 1996, Wurzler, et al JAS, 1997 JAS; Wurzler, et al, JGR, 2000 are just examples of what should be mentioned.

ANSWER: Several relate references have been added to the introduction section.

On page 14498 line 9 – only the role of aerosol pollution as CCN is mentioned. Here is another place where the direct effect of pollution on the stability of the atmosphere and the resulting effects on precipitation development should be discussed.

ANSWER: Thanks for the suggestion. We have added explanation about the direct effect of pollution in the paragraph as “Precipitation can be influenced by anthropogenic aerosols associated with pollution through their roles in cloud condensation nuclei and ice nuclei, and through the direct effect of pollution on the stability of the atmosphere.”

Page 14499 lines 5-14- here the authors argue that the increase in NO2 concentration is correlated with increases in AOD, primarily in the fine fraction aerosols. They also mention the frequent dust storms that occur during the spring period. It is not clear how they separate the effects on precipitation of the GCCN from dust from those of the fine fraction aerosols. In fact, in Fig 1a the variations in AOD ratio are so large, that one can assume that extending the period of observation by only a few years would reveal a completely different trend. Similarly, the figure shows no correlation between AOD and NO2 concentrations over the years.

ANSWER: As shown in Fig 1, despite the large interannual variation which makes poor correlation between AOD and NO2 concentration, the fine AOD show an increasing trend just as the NO2 concentration. We made no attempt to separate the effects of GCCN and CCN on precipitation. As stated in the paper, aerosols (both coarse and fine) may have impacts on precipitation. Furthermore, we did not use the trend from one site to correlate the two variables, but used the trends as relative independent variables (less bias) to study spatial feature of NO2 concentration and AOD changes.

Page 14499 from line 21 – the authors use TRMM data with 100 km box and correlate it with a single rain gauge in the middle of the urban area. This seems to be a very poor comparison. Changes in spatial and temporal distributions of rainfall could be expected to occur due to the urban development as has been shown by many papers (e.g. van den Heever and Cotton, J. Appl. Meteor. Climat., 2007; Alpert et al, 2008: J. Appl. Meteor., 47, 933–943, 2008; Halfon et al, Environ. Res. Lett. 4, 2009). Therefore, correlation with a single station is not sufficient.

ANSWER: The spatio-temporal discontinuity is always an issue for intercomparison between satellite and surface measurements, particularly at the pixel level. As many studies indicate that such a spatio-temporal scale the measurements of TRMM PR and surface rain gauge are comparable(Bowman, 2005; Bowman et al., 2003; Li and Fu, 2005; Shimizu et al., 2001) [in particular, a detailed comparison study in China by Liu, P. 2009: "Comparison of Precipitation between Rain Gauge Observation and TRMM PR Measurements", Master thesis, University of Science and Technology of China. Available at http://cdmd.cnki.com.cn/Article/CDMD-10358-2010019059.htm]. In this study, we calculate statistics of precipitation over a large spatial domain of 1°×1° at a long temporal scale (season). Although the precipitation amount derived from TRMM PR are more or less lower than the surface rain gauge measurement, which could be probably due to the sensitivity of PR that limits its detection of precipitation over 0.4mm/hour, there is good correlation between the two datasets. We have analyzed several surface stations. The comparison of TRMM PR estimated and rain gauge measured seasonal precipitation amount from other typical sites are listed in Table R1. It illustrates that precipitation estimated from PR is representative at seasonal scale or longer time scales. Given the same instrument and retrieval algorithm of TRMM PR measurements, we expect that the trend of precipitation estimated from TRMM PR is reliable.

Table R1: The location and correlation of rain gauge and TRMM PR measured precipitation amount at various sites over China.

Page 14500 near the top – the author state: "Clearly, the decrease trend of 4.04% per year in rain frequency (0.21% per year in absolute rain frequency) is slightly greater than the decrease trend of 2.49% per year in rain amount (5.75mm per year in absolute rain amount). It suggests that reduction in precipitation is mainly due to the suppression of rain occurrence with a slight enhancement of rain intensity". This needs to be better explained especially since the variations in rainfall frequency (Fig 1b) vary so much and cover only 12 years of data.

ANSWER: Thanks for the suggestion. The rain frequency in this paper was defined as the ratio of rain pixels to total sample pixels in the domain, and the rain amount is the sum of rain rate (rain intensity) over all rain pixels in the domain. If the precipitation amount keeps unchanged, a decrease of rain frequency means the greater rain rate (rain intensity) in the domain, so we may speculate a suppression of rain occurrence and an enhancement of rain intensity in Shanghai. Results similar with Shanghai were also observed from most of the typical sites (Table R2) despite the large interannual variability of rain frequency and rain amount at single site.

Table R2 The mean and annual change of rain frequency and rain amount in spring

Page 14502 paragraph starting in line 15 – the references used here deal with orographic rainfall. The authors should refer to papers that deal with rainfall in urban areas (e.g. see references mentioned above).

ANSWER: Thanks for the suggestion and we have added several related references in the paragraph.

Reference: Bowman, K. P.: Comparison of TRMM Precipitation Retrievals with Rain Gauge Data from Ocean Buoys, J. Climate., 18, 1, 178-190, 2005. Bowman, K. P., Phillips, A. B., and North, G. R.: Comparison of TRMM rainfall retrievals with rain gauge data from the TAO/TRITON buoy array, Geophys. Res. Lett., 30, 14, -, 2003. Li, R., and Fu, Y.: Tropical precipitation estimated by GPCP and TRMM PR observations, Adv. Atmos. Sci., 22, 6, 852-864, 2005. Shimizu, S., Oki, R., and Igarashi, T.: Ground validation of radar reflectivity and rain rate retrieved by the TRMM precipitation radar, Adv. Space Res., 28, 1, 143-148, 2001.

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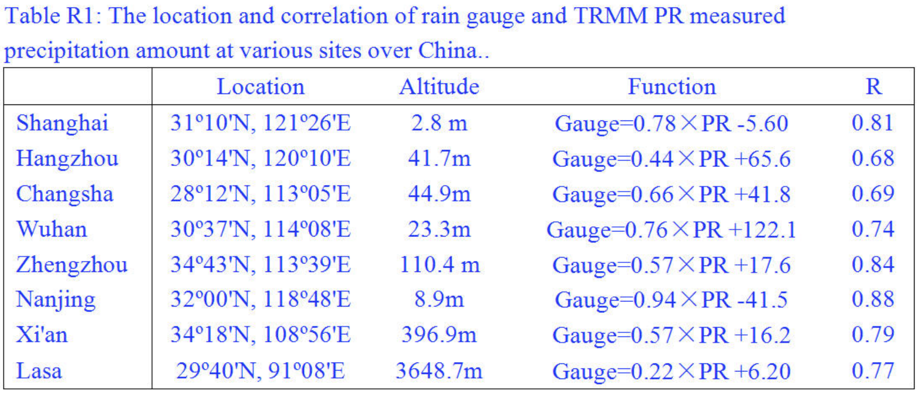

Table R1: The location and correlation of rain gauge and TRMM PR measured precipitation amount at various sites over China..

	Location	Altitude	Function	R
Shanghai	31°10'N, 121°26'E	2.8 m	Gauge=0.78×PR -5.60	0.81
Hangzhou	30°14'N, 120°10'E	41.7m	Gauge=0.44×PR +65.6	0.68
Changsha	28°12'N, 113°05'E	44.9m	Gauge=0.66×PR +41.8	0.69
Wuhan	30°37'N, 114°08'E	23.3m	Gauge=0.76×PR +122.1	0.74
Zhengzhou	34°43'N, 113°39'E	110.4 m	Gauge=0.57×PR +17.6	0.84
Nanjing	32°00'N, 118°48'E	8.9m	Gauge=0.94×PR -41.5	0.88
Xi'an	34°18'N, 108°56'E	396.9m	Gauge=0.57×PR +16.2	0.79
Lasa	29°40'N, 91°08'E	3648.7m	Gauge=0.22×PR +6.20	0.77

Fig. 1. Table R1: The location and correlation of rain gauge and TRMM PR measured precipitation amount at various sites over China.

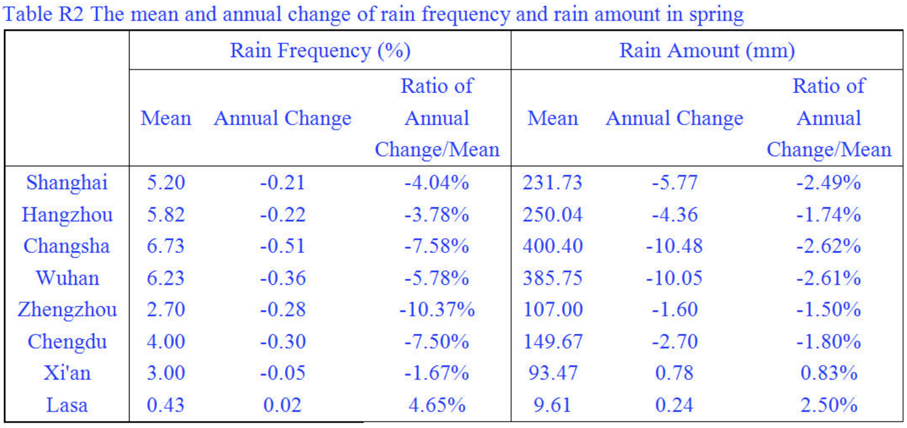

Table R2 The mean and annual change of rain frequency and rain amount in spring

	Rain Frequency (%)			Rain Amount (mm)		
	Mean	Annual Change	Ratio of Annual Change/Mean	Mean	Annual Change	Ratio of Annual Change/Mean
Shanghai	5.20	-0.21	-4.04%	231.73	-5.77	-2.49%
Hangzhou	5.82	-0.22	-3.78%	250.04	-4.36	-1.74%
Changsha	6.73	-0.51	-7.58%	400.40	-10.48	-2.62%
Wuhan	6.23	-0.36	-5.78%	385.75	-10.05	-2.61%
Zhengzhou	2.70	-0.28	-10.37%	107.00	-1.60	-1.50%
Chengdu	4.00	-0.30	-7.50%	149.67	-2.70	-1.80%
Xi'an	3.00	-0.05	-1.67%	93.47	0.78	0.83%
Lasa	0.43	0.02	4.65%	9.61	0.24	2.50%

Fig. 2. Table R2 The mean and annual change of rain frequency and rain amount in spring