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Atmospheric Chemistry and Physics 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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Point-to-point reply to the comment from the reviewer 1:

Review of 'Spatial features of rain frequency change induced by pollution and associated aerosols' by Lin et al. Suggestion: Major revisions Summary: My primary concern with the manuscript is that the conclusions reached by the authors, while plausible, are not supported quantitatively by the data. The analysis method employed by the authors is cursory and a more appropriate analysis is offered in the specific comments provided below. A secondary major concern is that the abstract implies causal relationships that are unsupported by the data. A final major concern is that some of the data are not properly referenced and described.

Major Comments: 1. Page 14499, Lines 22-26: What is the correlation? Is it statistically significant? Can you quantify the spatio-temporal discontinuity? Where is the rain gauge data coming from? All we know is that it is near Shanghai. This is not a reproducible or transparent result. Finally, A table of where the other sites are located and associated correlations and significance tests should be provided for the other sites from which similar conclusions can be drawn. At the very least some references and summary statistics need to be provided (i.e. how many sites were used and what percentage show significant trends that agree with the PR).

Answer: Thanks for the comments. The rain gauge data are from the Chinese National Meteorological Center, and the brief information for Shanghai station are as follows: station number (WMO station number) is 58362, located at 31°10âĂšN, 121°26âĂšE, altitude is 2.8m. The correlation coefficient between rain amount estimated from PR and that measured from surface rain gauge in Shanghai is 0.81 at a 95% confidence level, as shown in Figure S1.

Figure S1. Seasonal precipitation amount estimated from TRMM PR and measured from surface rain gauge from 1998 to 2009

The comparisons of seasonal precipitation amount estimated from TRMM PR and those measured by rain gauge at some typical sites during 1998-2009 are list in Table S1. Good correlations are observed between the two datasets, 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. Those comparisons illustrate that precipitation estimated from PR is representative at seasonal scale or longer time scales. Given the same instrument and retrieval algorithm for TRMM PR measurements, we expect that the trend of precipitation estimated from TRMM PR is reliable.

Table S1: The location and correlation of rain gauge and TRMM PR measured precipitation amount at various sites over China.

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The spatio-temporal discontinuity is always an issue for intercomparison between satellite and surface measurements, particularly at the pixel level. In this study, we calculated statistics of precipitation over a large spatial domain of $1^\circ \times 1^\circ$ at a long temporal scale (season). 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).

2. Page 14501, Line 23: 'In general, the significant decrease trends in precipitation frequency were detected at the industrial areas with rapid economic growth'. This statement is inconsistent with the large area in box #3 (India-Myanmar) highlighted in Figure 2 where there seems to be no change in pollution but a significant reduction in rainfall.

Answer: The sentence has been revised as "In Eastern China, the significantly decreasing trends of precipitation frequency were detected at the industrial areas with rapid economic growth, rather than the areas with high mean frequency." The possible reasons for the exception of box# 3 (i.e. the India-Myanmar Region) were illustrated in page 14502, line 8-16. The reduction of rain frequency may be attributed to the increasing trend of coarse mode particles which was indicated by Figure 2f.

3. Page 14502, Line 5: What is the spatial correlation? This is a major conclusion of the paper. Therefore, quantification of the results supporting the conclusion needs to be given.

Answer: Thanks for the suggestion. The detailed information of the spatial correlations of NO2 and aerosol with rain frequency is given in the reply to the Question 4.

4. Page 14502, Line 5: Following from the previous comment, a more appropriate analysis would correlate the time series of NO2 and aerosol with the time series of precipitation occurrence within each grid box. This analysis would make a much stronger case that the trends in aerosol and precipitation are related to each other. Answer: The spatial correlation between rain frequency trend and fine AOD was shown in Figure S2.

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Significant anti-correlation is obtained calculated based on the grids with significantly decreasing rain frequency trend over land. The correlation coefficient is 0.44 with a 95% confidence level. Similar method is applied to the analysis of spatial correlation between fine mode AOD trend and NO2 trend, as shown in Figure S3. A positive correlation was obtained with correlation coefficient is 0.46 at a 95% confidence level.

Figure S2. The anti-correlation between rain frequency trend and fine AOD

Figure S3. The correlation between trend of NO2 column concentration and fine AOD

5. The data and analysis method used are insufficient to reach a conclusion of causality. The authors need to be particularly mindful of this in the abstract (here causality is implied) and in the conclusions. Two specific concerns that need to be mentioned in the conclusions are given here. First, the seasonal mean data can be used to support the case for aerosol effects on cloud and precipitation. However, the processes in question occur on time scales of minutes and cannot be causally related through seasonal mean data. Do the relationships purported to be shown here by the authors exist on shorter time scales? Second, Aerosol indirect effects on precipitation follow a chain of events. An assertion of causality must address each of these events. It is insufficient to jump directly from aerosol to precipitation and assert causality. Take for example the 'second indirect effect' through which aerosol modify cloud microphysics which then affects coalescence processes which then effects the occurrence of precipitation. There is a potentially observable hypothesized effect on clouds that is unexamined by the authors. The 'semi-direct effect' hypothesizes cloud effects as well. In an area as contentious as aerosol-precipitation interactions it is best to exercise caution in asserting causality. Answer: Thanks for the comments. We already revised the abstract and the conclusions according to the reviewer's suggestion. We have done more analysis on the cloud properties and found that the positive correlation between warm cloud ratio and fine mode AOD over Yangtze River Delta and Yellow river during the study period, while there are not correlation between the two variables over background area with clean atmosphere, shown in Figure S4. The results demonstrate that the warm

cloud ratio increased with fine aerosol loading, which provides some support for the second indirect effects. Figure S4. Spatial correlation of fine mode AOD and warm cloud fraction.

Minor Comments: 1. Throughout the manuscript the words increase and decrease are used incorrectly. In many but not all places they should be changed to increasing and decreasing. Answer: Thanks for the comments. We have carefully checked the use of increase and decrease, and we think now the misuse of increase and decrease is properly changed to increasing and decreasing.

6. Page 14496, Line 12: ‘Besides the greenhouse gases-induced global warming, anthropogenic aerosols increase concentrations of cloud condensation nuclei (CCN) and ice-forming nuclei (IN), which alter the main path of precipitation-forming microphysical processes and the precipitation amount (e.g., Cotton and Pielke, 1995; Lohmann et al., 2005; Rosenfeld et al., 2008).’ This sentence is grammatically incorrect. Furthermore, it contains two unrelated thoughts. Answer: We have revised this paragraph in the introduction section.

7. Page 14496, Lines 15-20: I am troubled by the sentence ‘The response of the hydrological cycle to the aerosol indirect effect is different to the greenhouse effect, and the hydrological cycle is expected to be weakened due to aerosol effects (Ramanathan et al., 2001; IPCC, 2007)’. The authors might want to mention that the hydrologic cycle (global mean rain rate) is expected to increase due to greenhouse warming by 2-3%/K (Held and Soden: 2006, Stephens and Ellis, 2008). They mention the ‘aerosol indirect effect’, which I presume to mean a change in cloud albedo with variation in CCN concentration for a fixed liquid water path. They then proceed to mention aerosol effects on the hydrologic cycle in the same sentence and reference a paper (Ramanathan et al. 2001) that primarily addresses aborbing aerosols and regional precipitation changes. The authors need to be specific in what they are referring to (i.e. global or regional changes to precipitation and through which mechanisms) Answer: This sentence has been revised as mentioned in the reviewer’s Question 6.

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8. Page 14496, Lines 19: I believe that location should be changed to source. Answer: The original word "location" has been revised as "source".

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.

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 14495, 2010.

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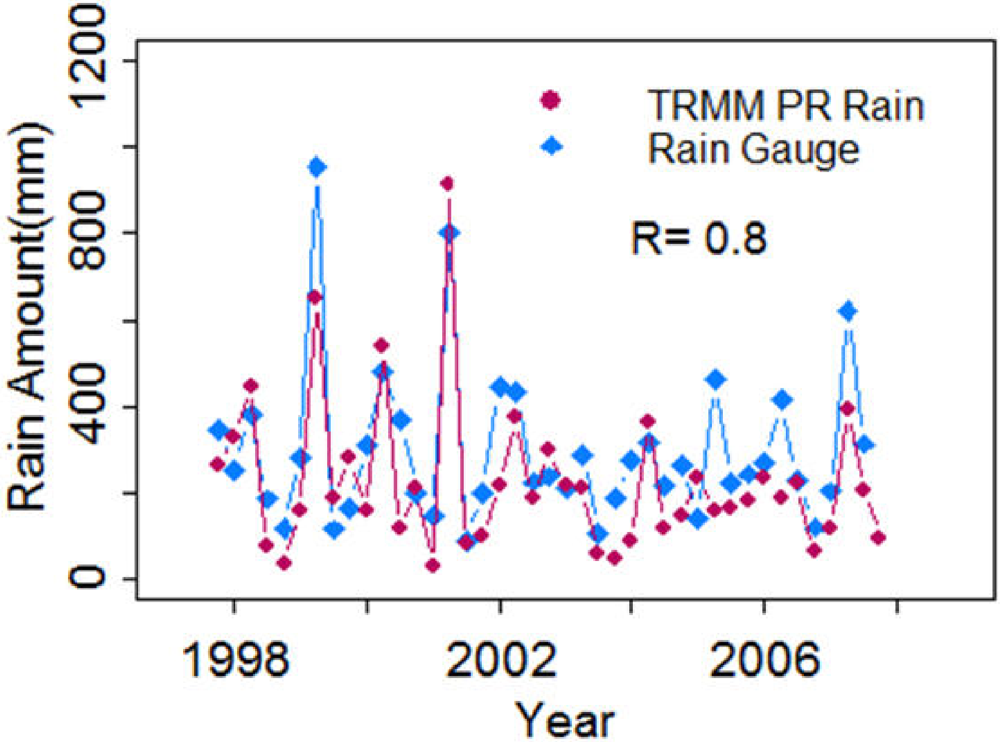

Fig. 1. Seasonal precipitation amount estimated from TRMM PR and measured from surface rain gauge from 1998 to 2009

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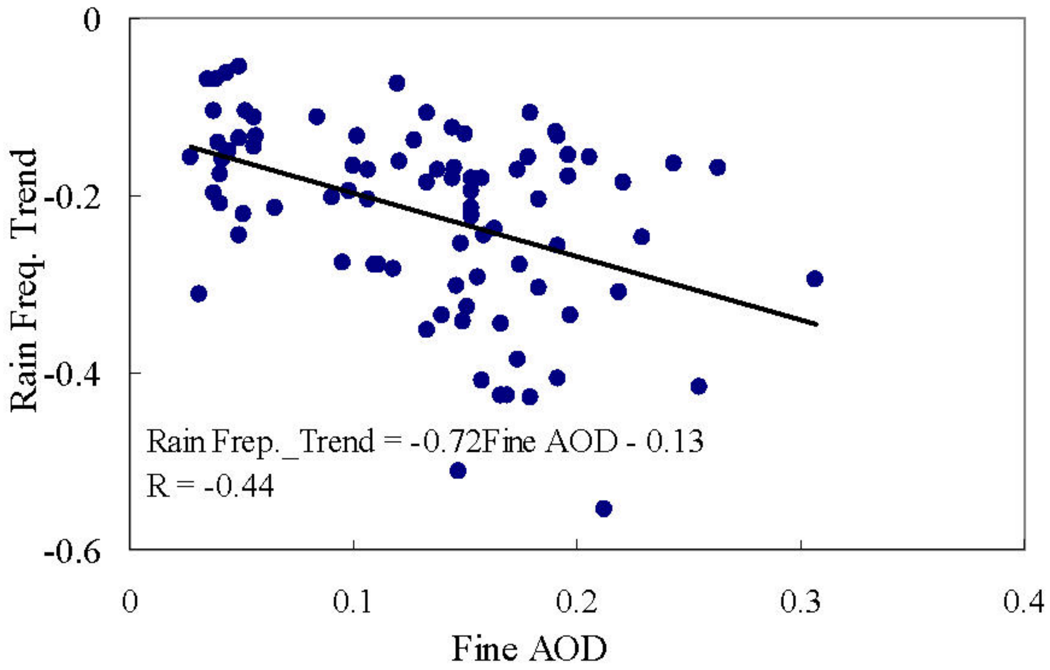

Fig. 2. The anti-correlation between rain frequency trend and fine AOD

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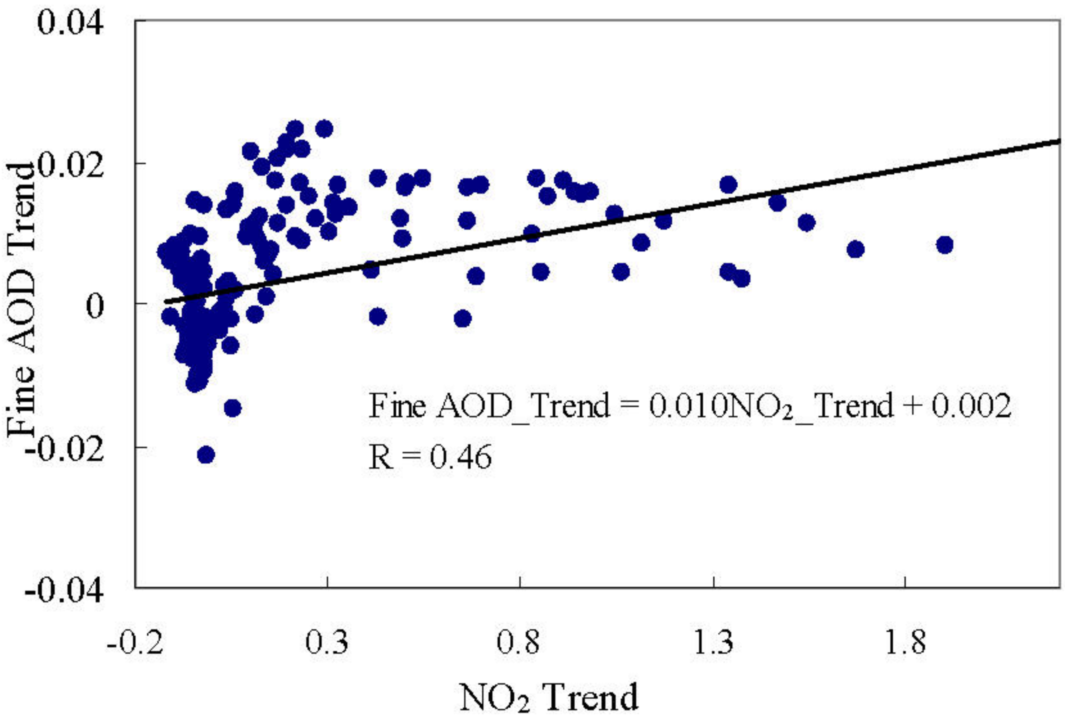

Fig. 3. The correlation between trend of NO2 column concentration and fine AOD

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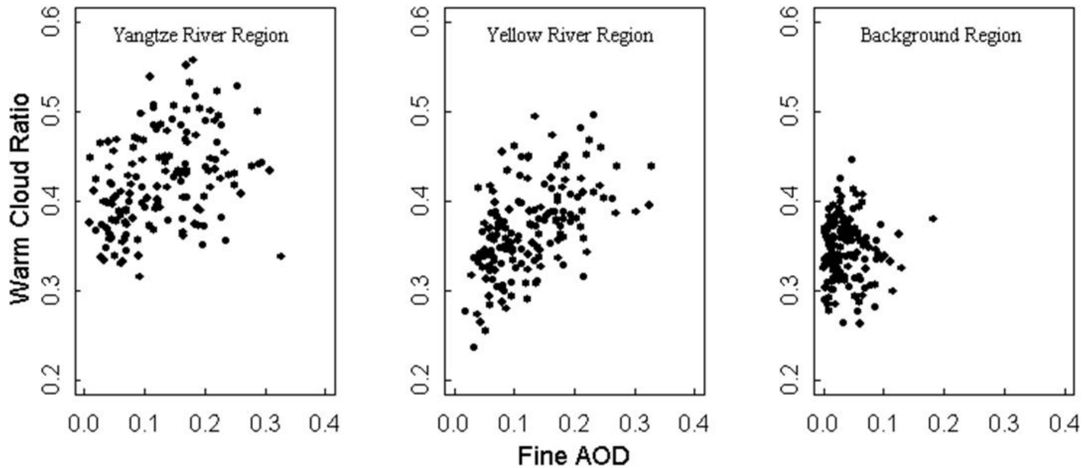

Fig. 4. Spatial correlation of fine mode AOD and warm cloud fraction.

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Table S1: 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. 5. Table S1: The location and correlation of rain gauge and TRMM PR measured precipitation amount at various sites over China.