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Atmospheric Chemistry and Physics Discussions

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

Anonymous Referee #2

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In this manuscript, the authors examined changes in rain frequency and pollution and associated aerosols by using multi-satellite observations over East Asia during 1998-2009 (AOD from MODIS is from 2000-2009), with a focus on the spring season. They found that the change in rain frequency is associated with changes in pollution-produced aerosols and long-range transport mineral dust. Cloud fraction from satellite observations and NCEP reanalysis data are also used to establish the causality between the change in rain frequency and changes in aerosols. The topics and results are interesting, and substantial efforts are made to analyze data and in revising the manuscript (I noted that this is a resubmission of Lin et al., 2010, ACPD). However, uncertainties in satellite data are not acknowledged, and the causality between the change in rain frequency and changes in aerosols implied by the authors are still not adequately supported by their data. The short time period and large variations from

year to year are also troubling. I would recommend the publication of the paper after my following concerns are addressed:

Major comments:

1. Uncertainties in satellite retrievals.

The authors did not adequately acknowledge the uncertainties in satellite data. One example is about the fine mode AOD. The total AOD from MODIS does not show significant trend during 2000-2009 over Shanghai (Fig. 2), but the fine mode AOD does. In fact, the decreasing trend in the fine mode AOD over polluted regions is the key finding in this paper. However, the retrieval of the fine mode AOD is much less reliable than the total AOD, especially over the land areas, as this is the case in the current study. Uncertainties in the retrieval of the fine mode AOD are not discussed at all in the current manuscript. It is equally important for the authors to discuss whether these satellite data is suitable for trend analysis. For example, though the same instrument and the same algorithm are applied for measuring MODIS AOD and fine mode AOD, how about changes in surface properties or any drift in instrument accuracy that may affect the retrievals during 2000-2009? The same argument can be also applied to TRIMM PR measurements. These issues should be discussed in detail, and the authors should also more prominently acknowledge these issues in abstract and conclusion.

2. The short time period

Here I want to underline the point made by the previous reviewer #2 about the short time period used in this study. The large variations in rain frequency from year to year make the short time period especially troubling. As shown in Figure 2, if we only use the rain frequency data from 2000 to 2009, the same period as the MODIS AOD observations, we will not see any significant trend in rain frequency during this period over Shanghai (Fig. 2). The decreasing trend in rain frequency over Shanghai in this paper is mainly caused by the large rain frequency in the first two years examined (1998 and 1999). I would expect the trend in rain frequency in Figure 3 will also change if

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the authors exclude 1998 and 1999 in their analysis. Statistically significant changes in rain frequency are another key finding of the current manuscript.

3. The causality between changes in aerosols and changes in rain frequency.

The causality issue was raised by previous reviewers for Lin et al., 2010, ACPD. The authors took a substantial effort to address this issue in the revision, but to my opinion, it is not quite successful yet. For example, one key argument the authors used is the spatial distribution of correlation coefficient between rain frequency and AOD (Figure 7). But the area of stronger negative correlation does not really overlap with the regions with strong reduction in rain frequency (Figure 3) (See below for my comments on this). Another example is cloud fraction (Figure 4). As pointed out by previous studies, the positive correlation between cloud fraction and AOD in satellite observations can be caused by many non-indirect-effect factors (See below for my comments on this). It will be more appropriate to examine the trend of cloud droplet effective radius and cloud liquid water path from MODIS during 2000-2009. Change in droplet effective radius will be the first response of clouds due to aerosol indirect effects, and changes in liquid water path will then be expected from the 2nd aerosol indirect effects.

Given the short time period (10 years), the larger noise and small signal in the observationtal data, I doubt the authors can ever firmly establish the causality between changes in aerosols and changes in rain frequency. Given these challenges, it is important for the authors to more prominently acknowledge the correlation study nature of this paper, and to caution the readers for the causality in both the abstract and the conclusion.

Specific comments:

P. 8748, abstract: the abstract should acknowledge the uncertainty in satellite data, and cautions the readers about the causality, since the causality is not adequately supported by their data yet.

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P. 8750, l. 20: please specify the months included in the spring season.

P. 8751, l. 3: Is the rain rate date used in Figure 1 and Figure 2 the same? If it is the same, why the rain rate is larger in 1999 than in 1998 in Figure 1, but it is larger in 1998 than in 1999 in Figure 2?

P. 8751, l. 7: What is the unit of PR and Gauge in Table 1?

P. 8752, l. 24: The authors stated that "the dramatic increase in NO2 concentration implies a substantial enhancement of atmospheric aerosol loading.' High NO2 concentrations does not necessarily lead to high aerosol loading. As shown in Zhang et al. (2009) (Table 2), though NOx emission increased substantially from 2001 to 2006, the emission of PM2.5 particles increased quite moderately from 2001 to 2006.

P. 8753, l. 1: It is difficult to claim that AOD increases in recent year from Figure 2. If we exclude the first 2 year data and start from 2002, there is not evident increase in AOD.

P. 8753, l. 12-13: The first sentence in this paragraph is redundant, as this has been stated in Section 2. I suggest the authors to remove it.

P. 8754, l. 12: why is 'particually the rain frequency', but not rain amount? references or explanations.

P. 8754, l. 29: figure 3d-f: what is the unit for the AOD trend?

P. 8755, l. 4: 'MAM' is not defined.

P. 8755, l. 11-12: It is fair to state that 'the spatial distributions of rain frequency trends were different from the mean rain frequency distribution' based on Figure 3h and i. It is more fair to say that 'the spatial distributions of rain frequency trends were close to the mean rain frequency distribution'. This will also affect the subsequent statement about large scale dynamical changes.

P. 8756, l. 4: Please clarify about Figure 4. What does each data point in Figure 4

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mean? Is the fine mode AOD averaged over individual regions for the spring season? The correlation between fine mode AOD and warm cloud fraction is really small over Yangtze River region, similar to that over Background region. Also, cloud fraction has been shown to have a positive correlation with AOD in satellite data by many previous studies, and potential reasons can be due to cloud contamination in AOD retrievals, the swelling effects of aerosol by clouds, and so on (Quaas et al., 2010), and the positive relationship between AOD and cloud fraction does not necessarily mean the 2nd aerosol indirect effects.

P. 8756, l. 18-20: Can the authors elaborate why the coarse mode AOD increases over the India-Myanmar region?

P. 8757, l. 16: R is 0.48 in Figure 6a.

P. 8757, l. 24-25: The statement "the wet scavenging has no dormant effect in the observed trend of AOD at long-term scales" is not supported by their data. Even if the wet scavenging has dormant effect in the observed trend of AOD, I do not see why the correlation between AOD trend and NO2 trend should not be positive. Please remove this statement here and in Section 4 (p. 8759, line 15-17).

P. 8577, l. 25: Figure 6b). Should be X axis 'Fine mode AOD' or 'Fine mode AOD trend'?

P. 8757, l. 27: R is 0.82 in Figure 6b.

P. 8758, l. 2: Figure 7. Figure 7b is not correct, as the spatial pattern of Figure 7b is not the same as Figure 7a. Also, I noted that Figure 7b and Figure 7 f are identical.

P. 8758, l. 8-9: The area of stronger negative correlation does not really overlap with the regions with strong reduction in rain frequency. Comparing Figure 3b with Figure 7d, it is clear that many areas with stronger reduction in rain frequency shows smaller or even positive correlation between rain frequency and fine mode AOD (e.g., Yangze River regions, and Pearl river regions). Please clarify this statement.

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P. 8758, l. 15-26: This paragraph does not provide enough evidence for its claim that 'the observed changes in precipitation were not related to the dynamical changes in the atmosphere'. The authors only examined two parameters, PW and DWVT, which do not cover the full sets of dynamical parameters.

P. 8759-8760, conclusion and discussion: Need more discussion about the uncertainty associated satellite data, and the authors also need to more prominently acknowledge the correlation study nature of this paper, and to caution the readers for the causality in both the abstract and the conclusion.

Technical corrections:

P. 8749, l. 16: 'of and' → 'of'.

P. 8753, l. 25: 'that' → 'than'.

References: Quaas, J., Stevens, B., Stier, P., and Lohmann, U.: Interpreting the cloud cover – aerosol optical depth relationship found in satellite data using a general circulation model, Atmos. Chem. Phys., 10, 6129-6135, doi:10.5194/acp-10-6129-2010, 2010.

Zhang, Q., Streets, D. G., Carmichael, G. R., He, K. B., Huo, H., Kannari, A., Klimont, Z., Park, I. S., Reddy, S., Fu, J. S., Chen, D., Duan, L., Lei, Y., Wang, L. T., and Yao, Z. L.: Asian emissions in 2006 for the NASA INTEX-B mission, Atmos. Chem. Phys., 9, 5131-5153, doi:10.5194/acp-9-5131-2009, 2009.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 8747, 2011.