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Interactive comment

Interactive comment on "Understanding meteorological influences on $PM_{2.5}$ concentrations across China: a temporal and spatial perspective" *by* Ziyue Chen et al.

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Interactive comment on "Understanding meteorological influences on PM2.5 concentrations across China: a temporal and spatial perspective" by Ziyue Chen et al. Anonymous Referee #1 Received and published: 21 August 2017 Chen et al. present an interesting analysis of the spatial and temporal variation of the relationships of meteorology and PM2.5 over most of China. The cross convergent mapping analysis provides a unique method of understanding the causality of the relationships, which might otherwise be missed with typical correlation analysis. They highlight that the meteorological influence on PM2.5 varies widely by location and season, and that attempts to

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engineer favorable air quality meteorology should take these differences into account. The paper is well-written and relatively thorough, however it requires some additional explanations and detail. Thus I recommend publication following minor revision.

Dear referee: Thanks so much for your encouragement and valuable comments. We have fully revised this manuscript according to your general and detailed comments, as well as comments from other reviewers. We would like to make further revision in due stages if you have further requirements.

Page 2, lines 56-57: "Although quantitative contributions of different sources (e.g. coal burning and automobile exhaust) to airborne pollutants remain controversy" – It's not clear what you mean here with the "controversial" – politically or scientifically? If scientifically – the direct emissions and/or subsequent chemistry?

R: Yes, the controversy mainly comes from the mixed understanding of relative contribution. For instance, some scholars claimed that automobile exhaust took up only 4% of relative contributions to PM2.5 concentrations. However, many following papers argued that the actual contribution from automobile exhaust took up more than 20%. The difference was that the former mainly considered the direct emissions whilst the latter ones comprehensively considered the direct emission and following secondary pollutants. So yes, your point was exactly the situation.

Page 4, section 2.1.1: How do you quality control the data and/or deal with missing data?

R: For this research, all released data were previously maintained by specific institutions and there are several stations for each city to report hourly PM2.5 concentrations conditions. For some stations, missing data lead to 0 value. If there are stations with Non-0 value, then the mean PM2.5 concentration for a specific city was calculated using these stations. So for most days in each city, a valid mean PM2.5 concentration value could be calculated. For days when the measured PM2.5 concentration from all stations was 0, then mean PM2.5 concentration was 0. The record for this day

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was deleted. Only a very small proportion of cities experienced days with no daily average data. And since few missing records would not influence the order of time series of PM2.5 and meteorological data, the CCM result would not be influenced by the missing data. Meanwhile, for cities (e.g. Liaocheng and Zhuji) with a large amount of missing meteorological data, we deleted this city for this research.

CCM method: How does the time lag parameter affect the results? The resolution of the map is mentioned but how does it affect the physical interpretation of the results? – Especially for those variables that may act on a shorter time scale.

R: We compared the CCM analysis result calculated using different parameters: 2 ,5, 10, 20 and the result was generally the same. Just the resolution of the map was higher with a small time lag. And you made a good point here that the physical interpretation of the results may lead to biased p value. Actually, the presented CCM map was simply for a basic demonstration about how CCM works. For exact p value, the provided CCM algorithm actually calculated an accurate p value with the increase of time series, and the CCM map was produced based on a series of accurate p values. So for this research, it is not feasible and reliable to physically interpret the p value for 190*18*4 CCM maps and the p value used for producing the wind-rose and other maps were extracted directly from the program.

Page 13, lines 295-296: This causality seems to be backwards: i.e., why would differences in PM levels cause differences in meteorological influences? What mechanism would cause this?

R: This is a very good question. Actually, this phenomenon was revealed and proposed in Chen et al. (2017). Chen et al. (2017) found that in the Beijing-Tianjin-Hebei region, the causality influence of individual meteorological factors on PM2.5 concentrations was the strongest in winter, when the PM2.5 concentrations were the highest, for all cities, Meanwhile, the causality influence of individual meteorological factors on PM2.5 concentrations was the weakest in winter, when the PM2.5 concentrations were the lowest. The potential mechanism could be that similar meteorological conditions may lead to large variations of PM2.5 concentrations when PM2.5 concentrations were high. For instance, in winter, when the PM2.5 concentrations were high and may lead to haze episodes, a strong northwester wind may immediately reduce the PM2.5 concentrations to a very low level. Meanwhile, high wind-speed in summer may lead to small variations of PM2.5Âň concentrations, as the original PM2.5 concentrations are low. Similarly, other meteorological factors are more likely to change PM2.5 concentrations significantly when the PM2.5 concentrations are high. In the revised manuscript, we have rephrased this part to avoid unnecessary confusions.

Page 14, lines 330-333: This sentence is very vague – can you be more specific?

R: Thanks so much for pointing this out. Yes, this part should be explained with more details. Actually, what we mean here is that some meteorological factors can be dominant factors across China. For instance, according to Fig 3, you can see such factors as temperature and wind were dominant meteorological factors in many regions, including Northeast, Northwest, coastal areas and inland areas; Meanwhile, some meteorological factors such as wind direction, were the dominant meteorological factors for limited regions (Mainly middle inland cities). This part has been added to the revised manuscript.

Figure 2 and 3: I would suggest the background of concentrations be in a gray scale so the colored icons/wind roses stand out more. Also, how different would the maps be if the correlation coefficient were used instead? A statement or two would reinforce the argument for the use of CCM rather than correlation coefficient.

R: Thanks so much for the cartography suggestions. We have updated the Fig 2 and 3 according to your suggestions and made some further revisions to improve the quality of maps. Another referee also mentioned that the difference between the p value and the correlation coefficient. And we are sorry that we did not make this clear in previous manuscript. Here we simply explained the advantages of CCM method and some findings concerning the comparison between correlation analysis and the CCM method from our previous studies.

The CCM method was proposed by Sugihara et al. (2012). 1 Sugihara, G., May, R., Ye, H., Hsieh, C., Deyle, E., Fogarty, M., Munch, S. 2012. Detecting Causality in Complex Ecosystems. Science, 338, 496-500. Sugibara et al. (2012) pointed out that correlation analysis could extract mirage correlations, especially in complicated ecosystems. For instance, two variables A and B that have no causality may demonstrate significant correlations due to the existence of an agent variable C, which interacts with both A and B. Through a series of experiments, Sugihara et al. (2012) proved that this type of mirage correlations could be detected using the CCM method by calculating a p value of 0. The CCM method not only performed better than the correlation analysis in causality analysis by excluding the influence of other variables, but also demonstrated the advantage of detecting weak causality compared with other causality analysis method (e.g. Granger Causality), which may fail to detect weak to moderate coupling between variables. In our previous studies, we employed both the correlation and the CCM method to examine the influence of individual meteorological factors on PM2.5 concentrations in the Beijing-Tianjin-Hebei region and compared the performance of correlation and CCM method. 2 Chen, Z., Cai, J., Gao, B.B., Xu, B., Dai, S., He, B., Xie, X.M. Detecting the causality influence of individual meteorological factors on local PM2.5 concentration in the Jing-Jin-Ji region. Scientific Reports 2017. 7:407352 The comparison suggests that the causality influence of individual meteorological factors on PM2.5 concentration is better revealed using the CCM method than the correlation analysis. By comparing the correlation coefficient and value in Table 2, one can see that some correlations between meteorological factors and PM2.5 concentration may result from mirage correlations (e.g. the correlation between meanRHU and PM2.5 concentration in Hengshui in summer). Secondly, CCM analysis reveals weak or moderate coupling (e.g. the interactions between SSD and PM2.5 concentration in Cangzhou in summer) whilst correlation analysis cannot. Additionally, due to interactions between different meteorological factors, the value of correlation coefficients cannot interpret the quantitative influence of individual meteorological factors on PM2.5 concentration. Instead, the value from CCM method is designed to understand the coupling between two variables by excluding influences from other factors. Through comparison, the value of the correlation coefficient for some meteorological factors is notably different from the value for these meteorological factors. A large correlation coefficient for one meteorological factor may correspond to a much smaller value from the CCM analysis. The previous research (Chen et al., 2017) proved that the CCM method outperform the correlation analysis in many aspects.

Page 20, lines 414-420: While higher relative humidity does lead to hygroscopic growth of aerosols, this is probably not evident in the observed concentrations since most measurements are taken at a constant relative humidity (e.g, 35% in US and Europe). Measurements in China may not do this, and if so, should be explicitly stated since this can have a major effect to aerosol mass depending on the composition of the aerosol.

R: Thanks so much for this explanation. This information is very useful for future comparison of meteorological influences, especially the humidity factor, on PM2.5 concentrations in China and other regions. The reason we added the general introduction of mechanisms how meteorological factors may interact with PM2.5 concentration is that one referee during the first stage of ACPD review process suggested we do so. However, during this round of ACPD review, you and other referee all suggested that the part of introduction is well known to scholars with meteorological background and we have deleted this part in the revised manuscript.

Page 23, lines 515-535: This paragraph seems out of place with the rest of the section. Page 23, line 525: I am not able to read Cheng et al. (2015), but I'm wondering what the model is using for predictors? If they are "static" models, isn't that just the mean state? I'm having a hard time understanding. If the argument is to use CCM instead of correlations, an example (see above) would help to reinforce this.

R: Static statistical models did not consider the influence of meteorology on PM2.5

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concentrations whilst dynamic models select some reliable and key meteorological influencing factors for better predicting PM2.5 concentrations. The advantage of p value compared with the correlation analysis has been explained above and added to the revised manuscript. As suggested by another referee, the improvement of models based on the CCM method could be important practical applications of the meteorological influences on PM2.5. So more in-depth discussion concerning this part has been added to the revised manuscript.

Page 24, lines 562-566: How does the frequency of precipitation affect this statement? For example, if precipitation is rare in Beijing during winter, especially compared to the Yangtze River Basin.

R: This is a very good point and has also been pointed out by another referee. Yes, it is highly possible that precipitation is more effective at removing PM along the coasts because it rains at a higher frequency and intensity. As we know that the PM2.5 concentrations drop significantly after a heavy rain whilst light rain may not reduce PM2.5 concentrations significantly. Meanwhile, PM2.5 concentrations may also affect the influence of precipitation. Light rains may have limited washing-off effects on high-concentration PM2.5 concentrations and may increase the relative humidity in the environment, which is favorable for the rising of PM2.5 concentrations. In the drier interior, the PM2.5 concentrations are usually much higher and the intensity and frequency of precipitation are much lower than those along coasts. These two factors may both be the reason that precipitation is more effective at removing PM along the coasts. Due to these influencing factors, precipitation may still be a less important meteorological driving force for PM2.5 concentrations in the drier interior, even if there were a way to normalize by the amount of total rainfall. We have added more discuss on this in the revised manuscript.

Results/Discussion: Much of this review of meteorology-PM2.5 relationships in the discussion would probably be better suited in the introduction and in the results as it pertains to different locations within China. Many of the statements in the results are rather vague (e.g., page 14, line 330-333) and could be elaborated to include specific meteorological factors and specific locations.

R: Thanks so much for your comments. As explained above. the review of meteorology-PM2.5 relationships has been removed in the revised manuscript. And some vague statements in the previous manuscript have been re-phrased with more details.

Minor comments

Page 2, line 61: were correlated

RïijŽ Corrected

Page 3, line 68: “fractions of three different sizes” of particulate matter

RïijŽ Corrected

Page 4, lines 119-120: What does this sentence mean?

RïijŽ Sorry that we did not make this clear. The API (Application Programming Interface) tool we programmed can automatically downloaded hourly air pollution data since the execution of this tool.

Page 12, line 288: Awkward wording

R: Rephrased

Page 20, line 426: Wikipedia is not an appropriate citation.

R: Other definition has been added in the revised manuscript in other parts.

Page 20, line 427 and elsewhere: Check your usage of “by analogy” – you may be looking for a different phrase.

R: Thanks so much for this suggestion. We have changed this to “similarly”.

Page 20, line 433 and elsewhere: Check subject verb agreement, specifically for

“PM2.5” and “concentration(s)”

R: Thanks so much for this. We have corrected all these incorrectly used format.

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