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Interactive comment on "Characteristics of dust storm events over the western United States" *by* H. Lei and J. X. L. Wang

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Responses to comments of Reviewer 2

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We wish to express our great appreciation to Reviewer 2 for the careful review, instructive comments, and detailed editing. Your very careful comments have effectively improved the quality of our draft. In the revised manuscript, we have incorporated all your comments. In the response below, we carefully address each of these comments. The Reviewer's comments are italicized and our responses immediately follow.

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General comments The authors used the reports of dust storm events by media or NASA earth observatory and the in-situ measurements of surface particulate matter concentrations to understand the characteristics of dust storm processes over the western US. This study aims to develop a comprehensive and objective methodology by integrating measurements from various observing networks in order to support further reconstruction of dust climatology and model verification. All dust storms recorded are classified into four types related to typical meteorological conditions, and their characteristics are analyzed accordingly. The study finally suggests that the combination of in-situ and satellite observations can provide a good chance to better record the dust storms. Dust is an important aerosol species in the atmosphere and has significant impact on the air quality and climate at regional and global scales. The dust over the western US may affect the air quality and hydrological cycles over the around regions. I find this topic about the characteristics of dust storms over the western US is interesting and important. However, I don't quite understand how authors divide the dust storms into 4 types based on meteorological conditions and how they can link the storm types with the specific observations, which are critical. I have some specific comments listed below.

Re: In this revision, we include more meteorological characteristics of dust storm events to improve the interpretation of four types of dust storms. We also following both reviewer's comments and suggestions on this issue.

Specific Comments 1. In terms of observations, this study uses IMPROVE PM2.5 and PM10. Since IMPROVE has PM2.5-dust measurements, why not use them as the direct measurements of soil dust? In addition, MODIS deep-blue has been found with large biases compared to in-situ measurements (e.g., AERONET) over the bright surface. It is questionable to use it as a reference for dust storms.

Re: Three reasons that IMPROVE PM2.5 cannot be used as indicators of dust storms: (1) Other than mineral dust emission, road dust caused by anthropogenic processes contribute seriously on IMPROVE PM 2.5 soil observations [Bell et al., 2007; Tong et

al, 2012]. (2) Local base-level PM2.5 soil concentration recorded by IMPROVE dataset varies largely for non-dust event days. For instance, on Arizona it is around 40-70 μg/m3; on Northern Texas, it is around 20-50 μg/m3; on the eastern part of Washington state, it is around 5-15 μg/m3, and can be as low as 30 μg/m3 during dust storm day. As a result, a non-dust day in Arizona may be counted as a dust storm day if using the PM2.5 as an unified indicator. (3) Significant characteristic of dust storm is not the increase of PM2.5 [This study and Tong et al, 2012]. The mass of soil particles in dust storm mainly distribute in size larger than 2.5 μm.

Although AOD in MODIS deep-blue 5.0 was found with large biases in comparison with AEROMET, the newly developed products in 5.1 and 6.0 have been calibrated with AERONET [Kim et al., 2011]. We used here is mainly the properties of extreme (/high) AOD values in contrast to normal values, which the existed biases may not seriously affects. Using MODIS AOD in dust storm identification can compensate the defects in spatial coverage of stationary datasets. We try to link them in order to develop a coordinated method.

2. Kim et al., 2012 at the line 5 of page 14198 is not in the reference list.

Re: It was finally published in 2013. The reference has been added.

3. At the line 10 of page 14199, please provide reference for the media reports and NASA earth observatory record.

Re: Possible reference added.

4. The methods to classify the weather systems into fronts, downbursts, tropical disturbance, and cyclogenesis should be provided (e.g., based on winds, temperature, pressure?). I don't understand why and how weather systems are classified into these four sub-systems.

Re: We added more analyses on meteorological characteristics of dust storms in this revision. Major difference of four types is associated with surface wind speed and the

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spatial range of the wind, which are determined by the associated weather systems. For instance, the cold front usually causes strong surface wind in an area of thousands of sq miles, while the downburst only occurs in an area of hundreds of sq miles. As a result, the dust storms caused by cold fronts are usually over a larger area than that for dust storms caused by downbursts. Other weather systems usually do not cause dust storms over the western US. For instance, the warm/stationary front, which usually features precipitation and weak winds, may depress the dust blowing. But if storms occurs in the warm region, it may produce strong downburst and cause dust stroms.

5. In Figure 2, I don't know how authors can associate a specific observation site with one dust storm type. Does it mean one dust storm type always occurs in the selected site? Or you only analyzed one dust storm for each type and selected one observation site most representative in that storm. In this case, I don't think you conclusion is statistically important. This is most confused and critical in your study. Please clarify it.

Re: No, it does not mean one dust storm types always occur in the selected site. We analyze each dust storms on an associated observation site most representable in that storm. The locations and sites changes for storms in each type. Figure 2 only shows four typical dust storm cases selected in linking the air quality observations with satellite and AERONET observations. We improve the expression to clarify this point.

6. If different observation sites are selected for different types of dust storms, how can you wipe off the influence from the different observation sites? That is, different observation sites may be affected differently by the dust storms. Therefore, the different measurements from different observation sites may not be due to the different characteristics of dust storms. Instead, they are different because the observation sites are affected differently. In addition, different observation site may also have different components for PM10 (e.g., some observation sites may have larger contribution from dust than others).

Re: Yes, you are right. That is one of challenges for dust storm identification and the

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reason for this study and future studies. Now, we have to notice that we only have limited stations spreading over the western US, which cannot be changed. We considered in this study is to find possible clues for dust storm identification based on this condition. We considered following problems that may challenge the dust identification in current condition and also previous studies.

(1) Previous suggested PM levels cannot be used as individual indicator. In addition to the problem you mentioned, different area may have different base-levels for PM. The normal day PM level in AZ may higher than the dust storm day PM level in WA.

Solution: in this study, we "first time" point out that the indicator "[PM10]peak/[PM10]normal" may be a good indicator for dust storms in addition to the high PM10 level. It indeed represents the curve (variation) of PM during dust storm. This may remove the effect by relative location of observational sites to dust storm area (the one you mentioned), and the local base-level variation.

(2) Due the distribution of stationary sites, dust storms occurring in limited area may be missed; dust storms covering large area may be recounted as several dust storms in the previous studies.

Solution: in this study, we try to link the satellite products with stationary observations. We understand that satellite products may contain large biases. But dust storms are extreme weather events. We use the spatial distribution of high values in satellite AOD linked with stationary records to compensate this defect in stationary data.

In sum, these problems occur due to the spatial distribution of stationary network. We can only base on these stations and we do find solutions to conquer the potential problem.

7. Comparing Figure 4 and 5, why high AOD in D3 lasts longer than its high PM10 concentration?

Re: They recorded different physical items for the same dust storm event. The station-

ary mass observations capture the air concentrations near surface, in which the large particles take a major part. While AOD captures the optical property above the ground. Smaller particles in higher levels suspend in air longer than large particles.

8. The way to identify the satellite observed dust AOD needs to be clarified in pages 14205 and 14206. It seems that some dust storms shown in satellite AOD are not selected. If there are local records, please provide detailed references. For example, in Figure 6, the bottom right panel shows a dust signature near the Gulf of California that is not selected.

Re: Yes, we follow your comments to add discussion on this part. In the revised paper, we made better explanation on these figures.

9. It's difficult to understand how you use the satellite AOD to derive the statistic information in Figure 7. The methodology should be better clarified.

Re: Yes, the satellite data provide AOD mean value, min value, maximum value and standard deviation value. These statistic values describe the uncertainty in the AOD values. The uncertainty may be caused by retrieval algorithm, satellite instrument biases, and surface process itself. This information can help us in better using satellite data to identify dust storms. We just make the use of this information in figure 7.