Response to anonymous referee #1's interactive comment on the manuscript "Surface Renewal as a Significant Mechanism for Dust Emission"

General comments:

Zhang et al. 2016 present an analysis of wind tunnel experiments to examine the role of three dust emission mechanisms. While the authors try to address the role of surface renewal in dust emission, they also place much emphasis on the importance of aerodynamic entrainment compared to other emission mechanisms. I think this is the first study to address the surface renewal process based on wind tunnel experiments. I find that the paper is generally well written although some sections need to be restructured. The methods need improvements in several places. Often, I feel that the statements drawn by the authors lack sufficient evidence. More proper interpretations and in-depth discussions on the experimental data are needed in many places to support their conclusions. One big issue is that, although the wind tunnel experiments are well designed, the collected data sample is too small to tell real differences between the regression fitting of various dust flux formulations. Plus, no statistics are given by the authors to judge the performance of regression analysis. I recommend publishing this paper after the following issues are addressed.

Response: we much appreciate the positive and insightful comments from the anonymous referee #1. These comments have motivated us to examine and revise the manuscript. Some sections of the manuscript will be restructured, according to the suggestions of referee. The details of responses are shown as following.

Detailed comments:

(P-page, L-line; note that the ACPD public version is used in this review)

My very first comment is that, please use continuous line numbering (instead of restarting numbering on every page) in your future manuscripts. This really helps the review process. Regardless whether the journal has such a requirement or not, using continuous line numbering is always a good practice.

Response: thanks for the reminding, the advice will be accepted.

Section 2 reads more like literature review, rather than a well-organized methods section. I encourage the authors to add a few sentences right after the section heading to explain how section 2 is organized before diving into the subsections. Another serious issue of section 2 is the use of symbols and abbreviations that are difficult to follow, because the authors give a review of so many dust schemes. Are they all necessary to be included in the paper? The authors need to make it clear why having an entire section for literature review of these specific dust flux methods is needed, and how they are going to connect with the wind tunnel experiments.

Response: thanks for the suggestions, section 2 will be restructured. Some sentences will be added before the section heading; the symbols and abbreviations will be checked and to be made clear.

Equation 2: Why do the authors refer to the Gillette & Passi vertical flux parameterization, and then relate it to the Marticorena & Bergametti method of the F-Q relationship? Marticorena & Bergametti had their own parameterization for Q and F. That being said, equation 3 only applies for the Q parameterization in Marticorena & Bergametti, not necessarily the schemes from other studies.

Response: we listed typical achievement on vertical flux parameterization here. Marticorena & Bergametti considered F was a fraction of Q and the value of F/Q being imposed by the soil clay content. It was indeed that Marticorena & Bergametti had their own parameterization which was not employed in the manuscript. So we'd like to remove Eq.(3) to avoid misunderstanding.

Equation 4: Is this Fb or Fc? Later in eq. 8, you used Fc, but never defined Fc.

Response: Eq. (4) is the result of Fb and Eq. (7) including the contributions of Fb and Fc. We will make the Equations clear and define the variables before use.

Equation 5-7: Should all the F in these equations be Fc? Also explain what F(di) and F(di, ds) are.

Response: Eq. (7) including the contributions of Fb and Fc, we will make all of the variables clear.

Equation 8 is questionable. My expression is that there are no distinct differentiations between the three emission mechanisms in the model parameterizations. After all, they are mostly derived from wind tunnel experiment data, which most likely represent all three dust emission schemes. It is difficult to separate the different processes in field measurements or wind tunnel experiments. Even if Fa, Fb and Fc are specifically defined for the three processes, they formulations share the same parameters. However in fact, the validity of these formulations is only limited to certain conditions (e.g., wind speed, soil sizes), which are not discussed in the paper at all.

Response: that is true that dust emission mechanism is conceptually divided into three parts and it is hard to distinguish the contributions of these three sub-mechanisms from experimental data. Based on previous measurements, the vertical dust flux F is found to be proportional to u_*^n with varying values of n. That may be caused by the different contributions of the sub-mechanisms under different conditions. But we still don't know the actual reasons in detail, which limits the knowledge of dust emission. In this paper, we design an experiment to separate the contributions of the three sub-mechanisms and should improve the understanding on dust emission. Anyway, it is acceptable that we need to add some necessary explanation and discussion in the paper.

Equation 9: I think it is necessary to show a plot on regression analysis on calculating u* and z0 for all three experiments. Show the statistics from the regressions as well.

Response: yes, we will add the results of wind profiles and the information of regression analysis.

Equation 10: You never explained what the Pm(d) and Pf(d) are, and where they come from. I suppose that they come into play in Eq. 6. If so, define them after Eq. 6.
Response: actually, Pm(d) and Pf(d) are defined in line 11-12 of page 6. The variable p(ds) in Eq.

6 is also related to Pm(d) and Pf(d). Some adjustments will be made.

P6L3: How long does it take the fan to reach the target wind speed?

Response: several seconds.

Section 3.1: Explicitly describe the purpose of the three experiments, for example, what dust emission mechanism(s) are each experiment corresponding to? What real-world conditions (e.g., supply limited in S1, supply limited but with renewal in S2, unlimited supply in S3?) do the experiments represent? I think having one or two statements like that can help readers easily understand the purpose of the experiment setup.
Response: accepted.

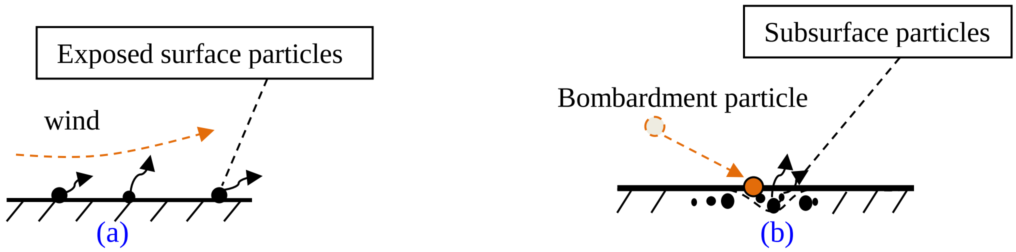
Equation 15 and Figure 3: Equations (15-19) should not be in the Results section. Move them to Section 2. I encourage the authors to rewrite Section 2 and logically introduce the dust schemes/equations (remove those not needed).
Response: accepted.

In Fig. 3: Why are there only 4 u*/Q values (same for other figures)? I do not think 4 runs for each surface type is sufficient to provide a meaningful data sample for regression analysis. Also, no statistics of regression (e.g., RMSE) are given. You can show them in the Fig.3. In P7L25, it is hard to "see" performance difference of two regression methods because of lack of statistical metrics. And the statistics should make more sense if a larger data sample is collected. If the wind tunnel can be configured to reach any target wind speeds, it should not be difficult to make more measurements at variable wind speed conditions in order to collect a sufficiently large data sample. I think this is a big weakness of the paper.

Response: our experiment is mainly limited by the amount of prepared soil material. To satisfy the requirement of experiment, the surface is made of soil material, with size of 9m length, 1m width and 5cm depth. Every surface is disposable and the soil material could not be used again, because of the changed dust content. That's why we only set 4 runs for each surface type. In the paper, we have 2 regression coefficients, and we thought the data of 4 runs were enough to run the regression analysis. But we still agree that the performance of regression analysis should be better, if more data sample is collected. The advice should be applied in future studies. Of course, we should add more statistics information of regression in this paper, such as the coefficient of determination R^2. Then, that will be easy to judge the performance difference of two regression methods

P8L15: The way the aerodynamic entrainment is calculated (F0-3min minus F3-10min) is not convincing. Please explain why there is no significant difference between the saltation flux between 0-3 min (unlimited supply condition) and 3-10 min (supply limited condition)?

Response: based on the definition of aerodynamic entrainment and saltation bombardment (as shown in the following picture), the emitted dust via aerodynamic entrainment depends on the amount of exposed surface dust, and saltation bombardment dust relates to the dust content of subsurface. For the case without surface renew (i.e. S1 in the paper), with the development of dust emission, the exposed surface dust is exhausted and supply-limit happens. But the content of subsurface should not change obviously during the total measurement time (10 mins), because of few motion of big surface particle (no surface renew). So there should be acceptable to consider that there is no significant difference between the emission flux via saltation bombardment between 0-3 min and 3-10 min.



Sketch map of (a) aerodynamic entrainment and (b) saltation bombardment

P9L1-7: This part of discussions is questionable. The authors state that "with intensified surface renewal from S1 to S3, the relationship between dust flux and friction velocity increasingly resembled the aerodynamic entrainment under unlimited supply." The authors show that the vertical dust flux is proportional to u*ˆ10 in S1 strong saltation condition, u*ˆ4 in S1 week saltation condition, u*ˆ6 in S2, and u*ˆ7 in S3. These n values still substantially deviates from the n=3 in Eq. 1. That means the F-u* relationship does not fall in the aerodynamic entrainment regime. By the rule, S1 supply limit state (n=4) is most close to the aerodynamic entrainment regime.

Response: that may be a misunderstanding of the referee. The vertical dust flux, which is proportional to u*ˆ10 in S1 (0-3 min, under unlimited supply), is actually caused by aerodynamic entrainment, but not saltation bombardment (the contribution of saltation bombardment has been subtracted). For the case of weak saltation condition (S1, 3-7 min), the vertical dust flux is proportional to u*ˆ4 (only caused by saltation bombardment and aggregates disintegration, aerodynamic entrainment is exhausted because of supply-limit). For the case of strong saltation condition (S2, 3-7 min), the vertical dust flux is proportional to u*ˆ6 (mainly caused by saltation bombardment, but includes the contribution of aerodynamic entrainment). And for the case of strong saltation and surface renew condition (S3, 3-7 min), the vertical dust flux is proportional to u*ˆ7 (caused by saltation bombardment and aerodynamic entrainment). The value of n changes from 4 to 7, and is closed to 10 (aerodynamic entrainment under unlimited supply). So we state that "with intensified surface renewal from S1 to S3, the relationship between dust flux and friction velocity increasingly resembled the aerodynamic entrainment under unlimited supply." Eq. 1 (n=3) is not the reference of aerodynamic entrainment in our paper. And also we note that our result of aerodynamic entrainment dust is obviously bigger than the value of LH2000 (i.e. Eq.1, the comparison is shown in Fig. 5). That divergence may be caused by different experimental conditions, such as surface roughness and surface particle distribution. The exactly reason will be exposed in future study.

The authors also states that "From this point of view, dust emission can be considered to be mainly driven by aerodynamic entrainment, whereas saltation and creep are responsible for surface renewal which restores the availability of dust for emission. In general, dust emission can be seen as the result of restricted aerodynamic entrainment." I agree that saltation and creep is responsible for surface renewal; but that does not lead to the conclusion that during that process, aerodynamic entrainment is the main mechanism for dust emission. Saltation and aggregates disintegration are contributing to emission while they replenish the surface at the same time. The conclusion by the authors is not supported by any quantitative analysis that can prove the dominant role of aerodynamic entrainment in dust emission. Also, explain what ‘restricted aerodynamic entrainment’ means.

Response: we will add some conceptual explanation for that. The regression curve of Fig. 5 (the modified version is shown in following) could be considered as the general formation for dust emission. The coefficient C relates to available dust content and the powder n relates to the mechanism of emission. Based on our measurements, n equals to 10 for aerodynamic entrainment and to 4 for saltation bombardment (also including the contribution of aggregates disintegration which is not identified in our work). Then the total dust flux could be expressed by

$$F = F_a + F_{b+c} = c_1 \cdot u_*^{10}\left(1-\frac{u_{*t}}{u_*}\right) + c_2 \cdot u_*^4(1-\frac{u_{*t}}{u_*}) \qquad *$$

where c_1 relates to exposed dust content and c_2 to subsurface dust content and impact energy of saltators. The first part of the right of Eq. * is contributed by aerodynamic entrainment and the second part by saltation bombardment (and aggregates disintegration). We can use Eq. * to predict vertical dust flux over three different surfaces. The values of u_{*t} are the same as in Fig. 5 and c_1, c_2 could be obtained by regression analysis. As shown in Fig. *, the results of Eq. * agree with the experimental data very well. And based on the existing value of c_1, c_2, it’s easy to give the ratio of F_a/F, shown as the dashed lines in Fig. *. The results show that, sometime (high u_* over S2 and S3) the contribution of aerodynamic entrainment excess saltation bombardment (F_a/F >50%). For that condition, aerodynamic entrainment becomes an important mechanism for dust emission. Saltation not only causes dust emission, but also is responsible for surface renewal which restores the availability of dust for emission (retrieve c_1 to a high level). For the first 3 mins of dust emission period over S1 (fully disturbed surface), aerodynamic entrainment is considered to be unlimited and c_1=9.88e6 is corresponding to ‘fully aerodynamic entrainment’. For S2, the limitation of aerodynamic entrainment is relieved by intense saltation. But the value of c_1 (=7.80e6) is less than 9.88e6, which represents aerodynamic entrainment does not achieve the level of ‘fully aerodynamic entrainment’ and is considered as ‘restricted aerodynamic entrainment’. Anyway, we will make some modifications for this part to ensure the conclusions are tenable.

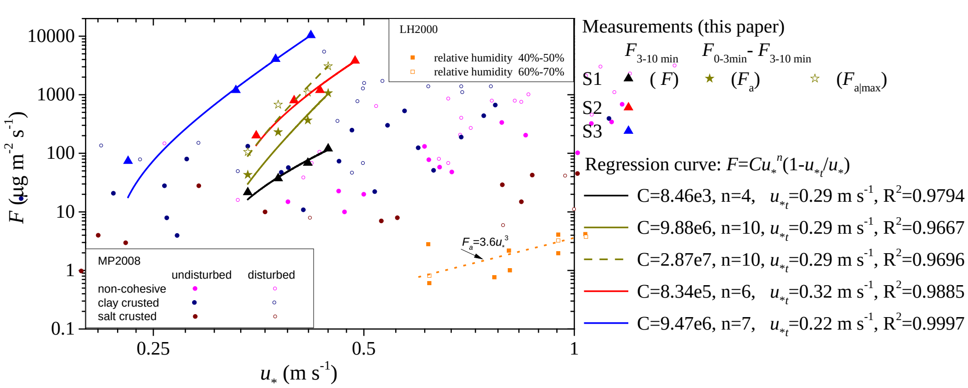


Figure 5: Measured dust emission fluxes over the three different surfaces in the wind-tunnel experiment (triangles), together with the measurements of Loosmore & Hunt (2000, LH2000) and Macpherson et al. (2008, MP2008), labeled as LH2000 and MP2008, as well as the various regression curves.

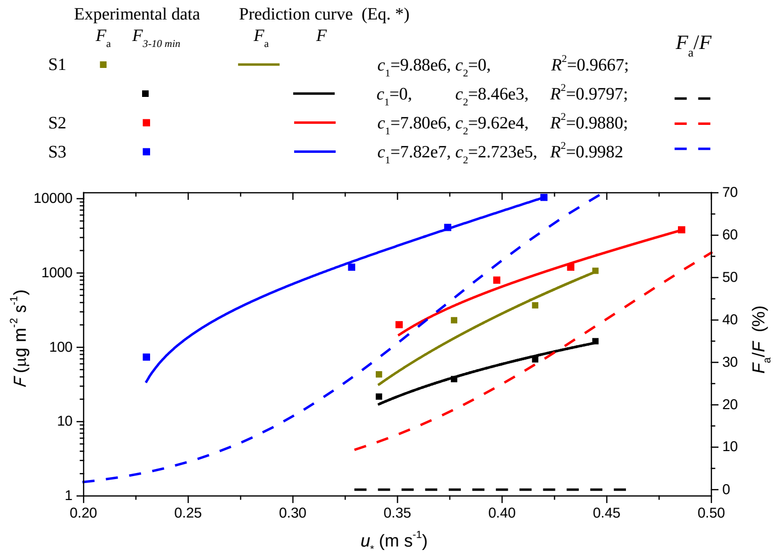


Figure *: predictions of Eq. * and the contribution of F_a over different surfaces.

P9L32, the authors' claim that "the last stage of S2 must be due to the contribution of aerodynamic entrainment" is not convincing. I understand that at high u* (last state of S2), surface renewal provides more erodible materials which increases the dust vertical flux. However, it is not necessarily due to the mechanism of aerodynamic entrainment. I think the authors are trying to emphasize the role of aerodynamic entrainment, but their analysis is groundless.

Response: the results of Fig. * shown above should support this statement.

Considering the above comments, the abstract and conclusion sections of this paper must be rewritten. The summary #2 in the Section 5 is groundless and misleading. The authors state that n = 10 in the case of aerodynamic entrainment, but Eq. 1 shows n = 3 in the aerodynamic regime (Eq.1 was used throughout the paper to separate the aerodynamic entrainment regime). The authors state that aerodynamic entrainment is even a dominant process under certain circumstances. Please elaborate on that. What specific circumstances are they? I think the authors made lots of efforts to relate their experiments to aerodynamic entrainment, but the focus of this paper is on surface renewal. Many issues around that are not addressed, such as the renewal rate, dependence on wind speed/soil texture/soil size distribution/vegetation, biases in current dust schemes due to lack of surface renewal, and possible ways to introduce to dust schemes.

Response: we didn't use Eq. 1 to separate the aerodynamic entrainment regime, but via $F_{0\text{-}3\ min}$ - $F_{3\text{-}10\ min}$ over S1. And as we stated before, the divergence between Eq. 1 and our results will be study in future work. The results of Fig. * should be good to prove the statement 'aerodynamic entrainment is even a dominant process under certain circumstances' and the relevant expression will be rewritten.

We appreciate that the referee give us some good advices on surface renew research in future. But the main work of this paper is to point out the significant of surface renewal in dust emission mechanism. The detail study of surface renewal will be implemented in next.

Minor comments:

Section 2.1, explicitly state that F is the vertical dust flux.
Response: accepted.

P1L24: there is -> there are.
Response: accepted.

P2L14: uplifted->uplift.
Response: accepted.

P2L15: inconsequential->insignificant.
Response: accepted.

P3L3: in equation 3, η_c is the soil clay content in percentage101.
Response: accepted.

Equation 4: η is already used in eq.3, use a different symbol.
Response: accepted.

P3L20: you already defined u*t above.
Response: that will be removed.

P5L21: if -> of.
Response: accepted.

P5L25: use dust vertical flux (not dust emission rate) to be consistent throughout the manuscript.
Response: accepted.

P9L9: η is already used in other places. use a different symbol.
Response: accepted.

P9L20: limit->limited.
Response: accepted.

Comments on Figures and figure/table captions:
Add S1, S2, S3 labels on the Fig. 2.
Response: accepted.

Add regression equations in Fig. 3.
Response: accepted.

Describe the horizontal dash lines in Fig. 4 caption.
Response: accepted.

Change ‘dust emission’ to ‘dust vertical flux’ in the Fig. 6 caption.
Response: accepted.

Table 2: Explain the meaning of the symbols in the caption (i.e. the parameters in the log normal size distribution).

Response: accepted.