Response to referee #1's interactive comment on the manuscript "Impact of Turbulence on Aeolian Sand and Dust Entrainment: Results from Wind-tunnel Experiment"

This paper aims to investigate the effects of atmospheric turbulence on sediment emission rates. This topic is a central issue in recent investigations by the community with various papers suggesting important effects of turbulence on dust fluxes and their size distribution.

This paper contains two major elements: it implements a simple technique to generate quasi-convective turbulence in a wind tunnel. This is an important advance because the lack of wind tunnel experiments on sediment movement has so far been carried out under neutral or near-neutral conditions which do not allow the study of the role of large eddies on wind erosion. The second major point, well illustrated by Figure 4, is that the results show that the sediment emission rates are higher during quasi-convective turbulence situations. These are significant contributions that deserve a publication of this paper.

Nevertheless, in its form, some parts need to be better detailed to improve understanding or to avoid unanswered questions. Most figures need to be enlarged.

Response: we are most grateful to Prof. Gilles Bergametti for his encouraging comments and constructive suggestions. The Referee pointed out the essential contributions of this work to elucidate the effects of atmospheric turbulence on sediment emission. The suggestions will be considered and the relevant text and figures will be modified accordingly.

Comments:

Lines 17-18: I agree that "it has been shown in numerous studies that equation 1 is valid in general" but some papers have also challenged its validity (e.g. Martin & Kok, Science Advances, 2017; Andreotti, J. Fluid Mech., 2004). It is not the purpose of this paper to discuss this but the wording used could suggest that this debate does not exist.

Response: thanks for the comment. We will modify the sentences to make relevant statements more precise.

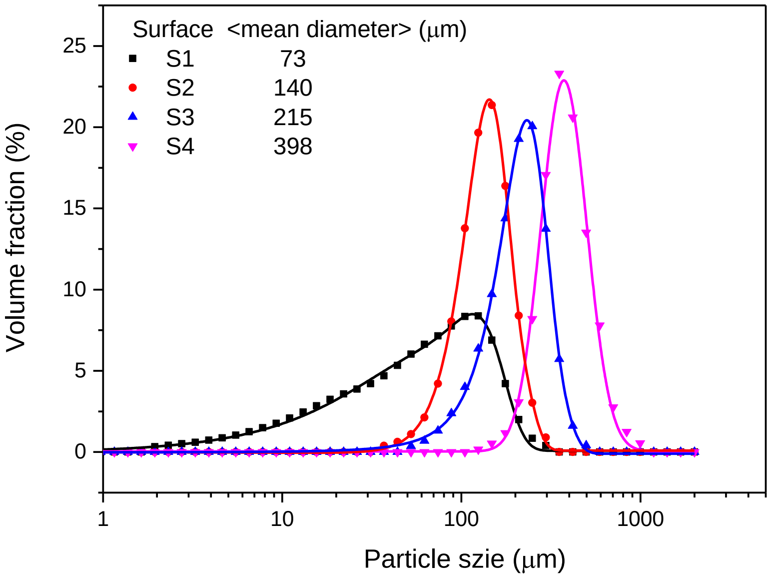
However, it should be note that the argument of the linear-relationship between saltation flux Q and shear stress τ (or u_*^2) is confined to saturated aeolian flow condition (or steady-state saltation condition) with splash-dominated particle entrainment. The majority of the existing measurements do not support the $Q \sim \tau$ linear relationship. In our study, aerodynamic entrainment is dominant and Eq. 1 should be reasonable to be used.

Lines 74-75: I understand the first part of the sentence, which seems sufficient in itself. What more do you mean by "by comparing the shear stresses measured by the two devices"?

Response: indeed, the latter part of this sentence is redundant. We will delete it in the revision.

Lines 92-94: The description of the soils is really limited. On reading, one gets the impression that only the average particle size differs and this is not sufficient to then understand why $\bar{\gamma}$ are so different in table 3.

Response: sorry for this negligence on the description of soil. We actually measure the size distribution of the employed four soils (as shown in follow) by using a Microtrac S3500 Laser Diffractometer (Microtrac, Montgomeryville, PA, USA). We will add this information to help for well understanding of reverent results. However, due to the wet method used at that time, these results don't necessarily reflect the true particle classification of the surface.



Line 141: the end of the sentence is not clear for me. When looking at figure2, the wind profile is not significantly modified for z<0.2m. The authors should be more explicit.

Response: the fluttering cloth not only enhances the turbulent kinetic energy (Fig. 2) but also modifies the wind profile close to soil surface. We focus on the wind condition close to surface ($z<0.2$ m) because the wind in this region directly drive soil erosion. Although the wind profile is not modified significantly, the change is recognizable. By fitting the wind profile data to Eq. 5, the friction velocity u_* (or shear stress ρu_*^2) could be evaluated. But if Ψ_m is set to 0 for the case of WP, the obtained u* obviously diverge from the data of Irwin sensor. Only when a non-zero Ψ_m is considered, the deduced u_* agrees with the data of Irwin sensor (Table 2). That is why we state that the wind profile for $z < 0.2$ m modifies to one more similar to wind profile in convective ABL.

We will modify the relevant sentence in the revised version to make it clear.

Table 2: This table needs to be strongly completed and better discussed. I do not retrieve the 25% and 15% difference in $\bar{\tau}$ for fan speeds 7000 rpm and 12000 rpm, respectively, as mentioned line 157, when comparing u_* from the NP and WP profiles.

Response: thanks for these suggestions which will be considered in the revised version.

In Line 156-157, the increase of shear stress (not friction velocity) from Irwin sensors is discussed (note that the data of NP is used to calibrate Irwin sensor, i.e. for the case of NP, the shear stresses measured by Irwin sensor and the one deduced from wind profile are same). The relative increase of $\bar{\tau}$ at fan speed 7000 rpm should be (0.32^2-0.29^2)/0.29^2=22%, and (0.55^2-0.51^2)/0.51^2=16% for the case of 12000 rpm. We apologize for being too rough with our previous estimates, and the exact numbers will be revised.

Are the u_* from Irwin sensors those obtained for the WP conditions. This should be clearer in the table (move WP to be centered).

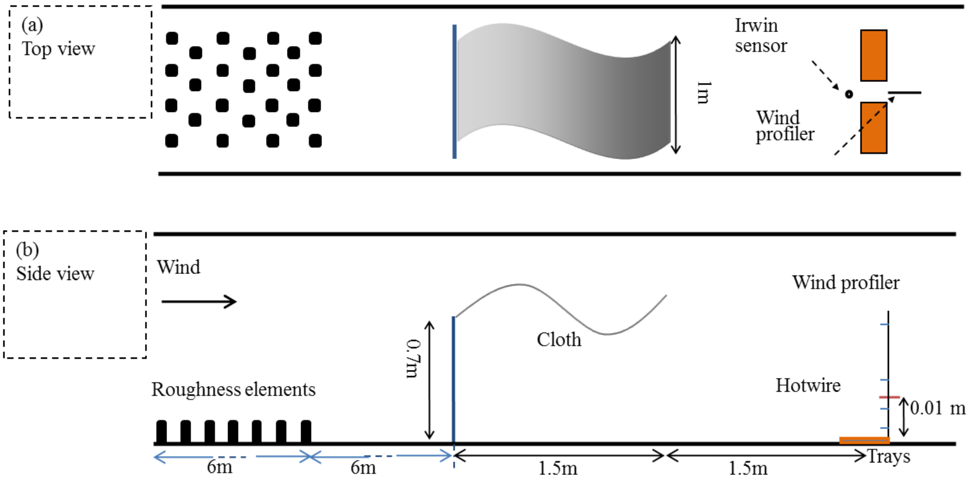
Response: yes, the table will be modified as follow:

Table 2: Friction velocity $\bar{u}_*$ and roughness length z_0 estimated for runs with and with no forced perturbation and different wind-tunnel fan speeds. The Irwin sensor is calibrated based on the data of wind profiles under the NP condition.

Fan Speed (rpm)	NP		WP			
	Profile ($\psi_m = 0$)		Profile ($\psi_m \neq 0$)			Irwin
	$\bar{u}_*$ (m s $^{-1}$)	z_0 (mm)	$\bar{u}_*$ (m s $^{-1}$)	z_0 (mm)	η_m (mm $^{-1}$)	$\bar{u}_*$ (m s $^{-1}$)
7000	0.29±0.0087	0.0133±0.0044	0.31±0.0077	0.0150±0.0034	-0.0229	0.32±0.0128
7500	/	/	0.34±0.0062	0.0153±0.0025	-0.0213	0.34±0.0064
8000	0.34±0.0068	0.0146±0.0024	0.36±0.0067	0.0159±0.0016	-0.0200	0.37±0.0101
8500	/	/	0.39±0.0051	0.0167±0.0013	-0.0188	0.39±0.0069
9000	0.38±0.0083	0.0159±0.0020	0.41±0.0087	0.0156±0.0022	-0.0178	0.42±0.0080
9500	0.40±0.0021	0.0129±0.0005	0.44±0.0038	0.0165±0.0007	-0.0168	0.44±0.0031
10000	0.43±0.0106	0.0164±0.0024	0.46±0.0083	0.0166±0.0016	-0.0160	0.47±0.0109
10500	0.47±0.0091	0.0207±0.0025	/	/	/	/
11000	0.47±0.0204	0.0175±0.0043	0.50±0.0067	0.0165±0.0010	-0.0146	0.51±0.0077
12000	0.51±0.0180	0.0166±0.0035	0.55±0.0033	0.0162±0.0008	-0.0133	0.55±0.0085

Moreover, there are 4 Irwin sensors in the wind tunnel: how do the authors use them? Is the reported data an average of the four sensors? If so, give the standard deviation.

Response: in fact, only the data of one probe is completely extracted and analyzed, and the others are used as backup probes. We will remove the other probes illustrated in Figure 1 to avoid misunderstanding.



More generally, give the standard deviations since there are several repetitions of each experiment. Add the emission rate for each experimental condition and the associated standard deviation.

Response: thanks for comment. We will add the associated standard deviation in Table 2. For the data of emission rate, relevant standard deviations have been illustrated as the error bars in the figure 4, 5 and 6.

Why does z_0 change significantly for NP experiments: it should be constant unless there is an additive saltation roughness but the WP experiments have an almost constant z_0 which rules out this assumption. How accurate is the recovery of u_* and z_0 from the wind profile? Does this accuracy depend on the regime (i.e. wind speed)?

Response: z_0 is actually the aerodynamic roughness which is depended not only on the roughness of surface but also on the wind regime. We obtained the u_* and z_0 by fitting the measured wind profile data to Eq. (5) (for the case of NP $\psi_m = 0$). For all of the cases, the coefficients of determination are almost 99%. There are two possible reasons for the deviations of z_0 at NP_95 and NP_105. The first is the less repeat times for these two cases (3 for NP_95 and 5 for NP_95). The other conjectured reason is a considerable change of weather condition outdoor. The wind tunnel is connected with outside, and obvious weather changes (strong wind or rain) will slightly influence the flow field in the wind tunnel. The results in Table 2 also show that the introduction of parameters ψ_m in the fitting equation is beneficial to obtain a more stable z_0.

We will add some explanations for the deviations of z_0 in the revised version.

Figure 4 is the key figure of the paper. It shows that the slight increase of $\overline{\tau}$ in quasi-convective conditions is not sufficient alone to explain the measured differences in the emission rates of the four soils. It implies that the perturbations of the shear stress, τ', are also responsible for a part of the differences in the emission rates. This is perfectly clear.
Response: yes it is.

However, the lack of information on the different soils (S1 to S4) complicates the understanding of why the emission rates of the different soils as reported in figure 4 do not follow the order of τ_t (as shown in table 3). According to equation 12, the only explanation for that is that the different soils have different values of $\bar{\gamma}$ (as suggested by table 3 for NP experiments) but reasons or at least hypotheses allowing to understand this should be given. Furthermore, what could be the possible explanation for such large differences in $\bar{\gamma}$ observed for S1 and S4 but not for S2 and S3 between the two sets of experiments? I can understand that $\bar{\gamma}$ is affected by quasi-convective turbulence but it is difficult to understand why it would affect the four soils so differently.

Response: thanks for comment. We will discuss this in the revised version.

In our opinion, τ_t represents the difficulty level of surface particles for emission, which depends on particle size, arrangement, moisture content and other surface properties. $\bar{\gamma}$ represents the ability of surface particles to respond to winds exceed the threshold, which is determined by the number of erodible particles and the sensitivity of these particles to local turbulence.

It's also important to note that, for surface with mixed-size particle, just like the ones employed in our experiment, all of the particles drove by an active force exceed relevant threshold should emit. We can imagine that particles with the lowest threshold are most prone to move, than the other particles with bigger or smaller size join the movement with the increase of wind. But the distribution of particle is non-uniform which may lead to a various threshold value obtained by regression analysis of emission flux data (Hard-to-move particles may dominate in mass and thus affect the regression value of critical wind).

There are a least three distributions which may influence the final emission flux, including the distribution of shear stress, the distribution of threshold and the distribution of the fraction of released particle. This makes it very difficult to analyze the data.

In order to better answer the reviewers' questions, we re-analyzed the data. First of all, we removed the measurement results of the lowest wind speed (7000 rpm), because the amount of emitted particles corresponding to this condition is very low, which leads to poor stability and greatly interferes with our analysis results. Regression analysis was performed on the remaining data based on the coordinate system of Log10 (F) vs τ, with Eq. (13) as the regression equation and τ_t and $\bar{\gamma}$ as regression parameters.

It is clear that the perturbations of the shear stress have significant influence on emission rate and these changes could be well expressed by Eq. (13) (R^2 very close to 1). But the increase of emission rate could be attributed to the increase of $\bar{\gamma}$ and the decrease of τ_t. Based on existing data, we can't clarify this issue better.

Table: Shear stress τ_t and empirical parameter γ for test surfaces.

	WP			NP			$\frac{\overline{\gamma_{WP}}}{\overline{\gamma_{NP}}}$	$\frac{\overline{\tau_{t\_WP}}}{\overline{\tau_{t\_NP}}}$
	τ_{t_WP} (N·m^{-2})	$\overline{\gamma_{WP}}$ (s^2·m^{-2})	R^2	τ_{t_NP} (N·m^{-2})	$\overline{\gamma_{NP}}$ (s^2·m^{-2})	R^2		
S1	0.17	9.96	0.92	0.08	2.10	0.97	4.74	2.13
S2	0.25	3282.92	0.96	0.28	4598.63	0.99	0.71	0.89
S3	0.28	2388.90	0.99	0.33	4317.70	0.99	0.55	0.85
S4	0.39	3130.74	0.96	0.34	502.10	0.99	6.24	1.15

For simplicity, we assign the average of τ_{t_WP} and τ_{t_NP} to $\tau_{t,}$ and re-performed the regression analysis by only considering $\bar{\gamma}$ as regression parameters, meaning that the influence of perturbations of the shear stress is artificially attribute to the change of $\bar{\gamma}$. The results are shown as follow.

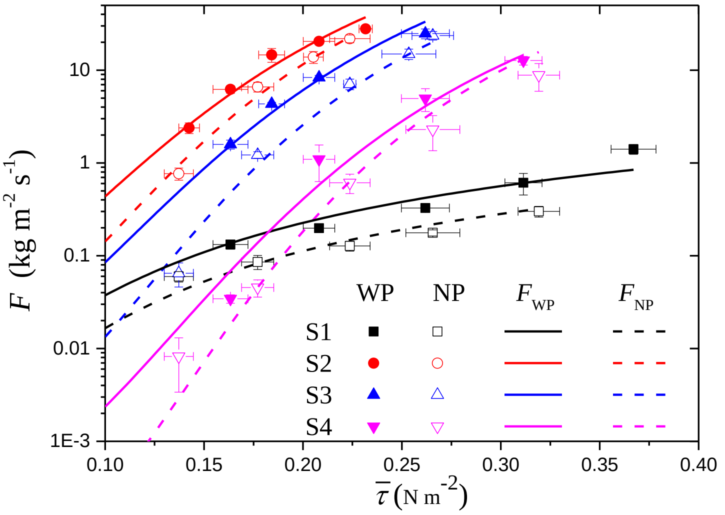


Figure 6. Estimated entrainment rates with and without forced perturbation. The dots are experimental data (remove 7000 rpm cases) and lines derive from Eq. (12).

Table: Evaluated threshold shear stress τ_t and regression parameter $\bar{\gamma}$ for test surfaces.

	τ_t (N·m^{-2})	WP		NP		$\frac{\overline{\gamma_{WP}}}{\overline{\gamma_{NP}}}$
		$\overline{\gamma_{WP}}$ (s^2·m^{-2})	R^2_{WP}	$\overline{\gamma_{NP}}$ (s^2·m^{-2})	R^2_{NP}	
S1	0.13	7.12	0.89	3.30	0.86	1.96
S2	0.27	4919.84	0.95	3605.29	0.99	1.29
S3	0.31	4675.62	0.97	2521.74	0.98	1.97
S4	0.37	1996.39	0.95	1713.19	0.95	1.34

In summary, as the threshold τ_t was first evaluated in our analysis, the factors affecting the emission rate were mainly attributed to γ and the effective shear stress (τ-τ_t). We discussed the influence from the forced perturbation to γ (Fig. 6 and Tab. 3) and (τ-τ_t) (Fig. 7). The forced perturbation almost double enhances the average γ(The effect is greater at lower shear stress).There is not much difference among the four soils.

According to the results of emission rate (as shown in Fig. 6), S2 and S3 are more erodible with more big value of $\bar{\gamma}$. S1 is the weakest-eroded surface. Despite start with very low shear stress, the mass of released particle is very limited, that leads to a low $\bar{\gamma}$. For the case of S4, we believe that the emission at low τ is mainly corresponding to the most-easy-moved particles (with diameter about 70-100 μm) with low τ_t and low γ. As the τ increase, the bigger particles with large mass (high γ) and τ_t start to move. Since we analyzed the final aggregate data, all of these effects are mixed together.

The number given in Table 3 are very precise with two significant digits for all parameters but we have no idea of the uncertainties and how are significant the differences in $\bar{\gamma}$.

Response: thanks for comment. We re-analyzed the data and the determination coefficients will be added to judge the uncertainty of regression parameters. There is no special meaning to the significant digits. We just want to keep consistent in the table.

Table: Threshold shear stress τ_t and empirical parameter γ for test surfaces.

	τ_t	WP		NP		$\frac{\overline{\gamma_{WP}}}{\overline{\gamma_{NP}}}$
	($N \cdot m^{-2}$)	$\overline{\gamma_{WP}}$ ($s^2 \cdot m^{-2}$)	R^2_{WP}	$\overline{\gamma_{NP}}$ ($s^2 \cdot m^{-2}$)	R^2_{NP}	
S1	0.13	7.12	0.89	3.30	0.86	1.96
S2	0.27	4919.84	0.95	3605.29	0.99	1.29
S3	0.31	4675.62	0.97	2521.74	0.98	1.97
S4	0.37	1996.39	0.95	1713.19	0.95	1.34

Moreover, the quality of the fits to equation 12 is not given while looking at figure 6 (and despite its small size), these fits seem worse for S1 and S4 than for S2 and S3.

Response: thanks for comment. The determination coefficients of the fitted lines will be added. That is right, the fits of S1 and S4 are slight worse.

Lines 200 -201: Does this suggest that the impact of convective turbulence should be rather limited on the total dust emission budget?

Response: we want to declare that: for the condition with mean shear stress much bigger than the threshold, the surface particle emission is dominantly influenced by the mean effect of convective turbulence; for the condition with mean shear stress close to the threshold, the change of the distribution of surface shear stress caused by convective turbulence significantly influence the process of surface particle emission. Considering that the approximated-threshold wind conditions may have a high temporal weight in natural conditions, we believe that this effect needs to be considered.