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Discussions

Interactive comment on "Passive Acoustic Measurement of Bedload Grain Size Distribution using the Self-Generated Noise" *by* Teodor I. Petrut et al.

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NOTE: The authors did a change in the Eq. (7) which will slightly changes the results of numerical tests and field spectra inversion presented in this article. The change has the physical meaning of passing from power to energy representation of impacts and so it avoids the usage of time in the impact modeling. As the clarity of the presentation was invoked by the two referees, we did some changes regarding the system of notation in order to define easier-to-read equations. In consequence, some parts of the text change but the modifications still follow the pertinent advices of the referees. The resulted paper is also added in the supplement of this response comment.

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Discussion paper

Below, we are considering the referee's suggestions and corrections step by step.

1. P2/L3: Reference (Parker, 1990) must be mentioned here.

Correction applied. Thanks !

2. Put the citations: "The development of surface-based and mixed-size transport models concerned many scientists (Heimann et al., 2015; Kuhnle, 1993; Parker, 1990; Recking, 2016; Wilcock and Kenworthy, 2002; Wilcock and McArdell, 1993)."

3. Rephrasing :

"Therefore, measuring bedload leads not only to transport rates but also to bedload GSD to calibrate models. However, obtaining bedload samples during exceptional hydraulic events may be difficult by using traditional bedload sampling techniques (e.g., pressure-difference samplers). To measure a wide range of discharge flows, the scientific community has been interested in developing indirect, or surrogate, methods that achieve continuous measurements no matter the hydraulic conditions. This paper is dedicated to the monitoring of bedload GSD using the acoustic noise naturally generated by bedload transport in rivers."

to the following:

"Therefore, measuring bedload leads not only to transport rates but also to bedload GSD to calibrate models (Parker, 2002; Wilcock et al., 2009). However, obtaining bedload samples during exceptional hydraulic events may be difficult by using traditional bedload sampling techniques (e.g., pressure-difference samplers) (Bunte et al., 2010). To measure a wide range of discharge flows, the scientific community has been interested in developing indirect, or surrogate, methods that achieve continuous measurements no matter the hydraulic conditions (Gray et al., 2010; Hubbell, 1964)."

4. The remark ", so-called the bedload Self-Generated Noise (SGN)." is added at the end of the sentence. Thanks!

5. Replacement applied. Thanks!

6. Correction applied

7. Correction is applied:

“Measuring bedload GSD with passive methods has been achieved using plates (Barrière et al., 2015; Krein et al., 2014; Rickenmann et al., 2014; Wyss et al., 2016b)”.

8. Replacing SGN with “Self-Generated Noise (SGN)”

9. Rephrasing:

“The acoustic effect of accelerating rigid bodies is mathematically modeled by (Kirchhoff, 1883). A framework was constructed by (Goldsmith, 2003; Hertz, 1882; Hunter, 1957) to mathematically model acceleration profiles from elastic impacts between two solid rigid bodies like two spheres or a sphere and a slab. Mathematically, the acoustic pressure field generated from the acceleration of a rigid body is evaluated by the integral convolution from Eq. (1) (Akay and Hodgson, 1978; Koss and Alfredson, 1973; Thorne and Foden, 1988)”

to the following:

“The acoustic effect of accelerating rigid bodies is physically modeled by (Kirchhoff, 1883). A framework was constructed by (Goldsmith, 2003; Hertz, 1882; Hunter, 1957) to model acceleration profiles from elastic impacts between two solid rigid bodies like two spheres or a sphere and a slab. In a mathematical sense, the acoustic pressure field generated from the acceleration of a rigid body is evaluated by the integral convolution from Eq. (1) (Akay and Hodgson, 1978; Koss and Alfredson, 1973; Thorne and Foden, 1988)”

10. All this part containing the term explanation is reformulated according to the new system of notations.

Rephrasing:

“where t is the temporal variable and χ = t, if 0 $\leq$ t’ $\leq$ Tc, t’ is the delayed time due to sphere geometry, t’ = t - (r - a)/c, r – the distance of measurement of the sound from the contact point, see Fig. 1a-b, a – the radius of sphere, c – the sound celerity, χ = Tc, if t’ > Tc, and s – material density and U – the impact velocity. In Eq. (2), the constant ÏŚ(1) = 9.229, for the sphere-sphere impact where the spheres’ radii are equal, and ÏŚ(1) = 10.601, for the impact between sphere and slab (considered here). The material parameter ζ = (1-ν2)/(πE), where E – Young’s modulus, ν – Poisson ratio. The general form of acceleration profile is provided by (Goldsmith, 2003) and it is rewritten in a more convenient form for both impact models in Eq. (3).”

to the following:

“where χ is the time interval of convolution, with χ = t, if 0 $\leq \tau \leq$ Tc, and χ = Tc, if τ > Tc, with τ a delayed time due to sphere geometry, τ = t - (r - a)/c, r is the distance between the observation point and the impact, see also the Fig. 1a-b, a is the radius of sphere, c is the sound celerity and s is material density and Uimp is the impact velocity. The parameter ÏŚ(1) is a constant, ÏŚ(1) = 9.229 for the impact between two spheres of same radii and ÏŚ(1) = 10.601, for the impact a slab and a sphere. The parameter ζ = (1-ν2)/(πElong) is a material parameter and it contains the Young’s modulus (Elong) and the Poisson ratio (ν). The general form of acceleration profile is provided by (Goldsmith, 2003) and it is rewritten in an unified form for both sphere-sphere and sphere-slab impact models, see the Eq. (3).”

11. Acronym explained

12. The verb “is” is inserted. Thanks!

The definition of both frequencies is added at the end of the statement:

“(. . .) and ω is the angular frequency which is a measure of rotation rate, in radians per seconds, and it is equal to 2πf, f is the linear frequency, a measure of number of occurrences per second.”

13. The Eq. (7) represents the spectral analytic model of impact between sphere and slab and it is one of the contributions of this paper. In the paper of (Akay & Hodgson, 1978) we only find the temporal analytic model which is discussed in the Appendix 2 and which is used to model the temporal waveform of impact in the Fig. 2a.

14. On P6 Line 25 was given the argument for the use of slab-sphere impact instead of sphere-sphere impact. This means that the slab do not contribute to hertzian sound production as it does not oscillate; his role in the sound production is the reflection of the sound from the impactor particles, by which it allows the method of image modelling. As the impactee particles in the bed river are fixed and usually greater than moving particles, also depicted in the Fig. 1b, we may consider the bed river as a massive slab which reflects the hertzian sound pressure generated by impactor particles. In this way, we skip the task of determining the dimensions of impactee particles.

Rephrasing:

“This could justify the reason to use the sphere-slab impact physics instead of sphere-sphere impact, to reduce eliminate the need for the dimensions of the impactee object”

to the following:

“In this paper, we choose to use a slab model to model bedload SGN as it simplifies the inverse problem. Indeed, the task of determining the dimensions of impacted particles is skipped. Therefore, we consider that the riverbed could be modeled as a slab. This hypothesis could be supported when the riverbed is armored or paved, as in the Fig. 1b, but may be false when the river bed is totally mobile and when the impacts between particles of different diameters are very common.”

15. Rephrasing:

“The random variable of the GSD is the number of collisions N, and so the complete notation is ΓPMF(N = ni). However, one needs to transforms this variable to the weight (mass) of sediments M, to facilitate the comparison with the measured GSD by bedload samplers. Thus, the variable N from ΓPMF(N = ni) will be multiplied by Di3 , Eq. (10a) becoming ΓPMF(M = mi). Furthermore, the solution is written as a cumulative distribution form, ΓGSD(M $\leq$ mi), expressing the mass percentage of sediments finer than Di, as in Eq. (10b)"

to the following (according to the new system of notations):

"Therefore, the random variable here is probability of collisions γ, and so the complete notation is γ(I = Ii) because it is a discrete probability (we operate on size classes of 1-mm diameter). This probability is computed from histogram of number of impacts per second so one needs to transforms it into a histogram in mass of sediments M, to be compatible with the measured GSD by physical sampling. In consequence, γ(I = Ii) will be scaled by Di3, as in the Eq. (10a) in order to obtain γm(M = mi). Finally, the grain size distribution (GSD), or the cumulative distribution form of γm, will be Γm(M $\leq$ mi), expressing the probability of sediments finer than Di, as defined in the Eq. (10b)."

16. The sentence is completely removed to avoid the ambiguity.

17. The sentence including this line "The distance of measurement is also important, as it the phase shift Td used in the addition of two coherent acoustic fields and also the Poisson's ratio plays a decent role in this variation." is rephrased as it follows:

"The distance of measurement, r, and the material properties, s, ν and E, play also a role in fpeak variation".

18. Rephrasing :

"The computation of high order analysis could be made by Sobol's analysis (Sobol, 2001), but this type of analysis is beyond the scope of this article"

to the following:

"The computation of high order sensitivity indices can be made using Sobol's methodology (Sobol, 2001), but this type of analysis is beyond the scope of this article".

19. Replacement applied. Thanks!

20. As with the new Eq. (7), the values of sensitivity indices obtained by FAST analysis change a bit.

21. This part will be treated in the Discussion part of the paper (see also the referee's point #37)

22. Replaced "LS" with "Least Square (LS)"

23. Figure 2c added with modeled spectra

24. Replaced "solution" with "least square solution"

25. This part will describe the PSD formulation for stationary signals and energy formulation for energy signals

Rephrased from:

"A particular concern in the theory of statistical signal processing is the variance of computed PSD. In our work, Short-Time Fourier Transform has been used. Fourier transforms are applied on small temporal windows of signal (with an overlap of 50 %). These collections of local spectra are averaged over predefined frequency bins which are narrowband (Oppenheim and Verghese, 2010). If the signal is long enough then the averaging of a great number of local spectra diminishes the spectrum variance. In the same time a good spectral resolution is achieved and a great number of size classes may be correctly inferred from the PSD."

to the following:

"The signal processing tools in this paper refers to using the Power Spectral Density (PSD) as the method of spectral representation of bedload signal. The use of PSD is worthwhile because the type of bedload signal is a stationary random one. Random stationary signals are signals varying in time but whose average and standard deviation of amplitude values over some fixed periods are constant. A particular concern for the signal processing of random processes is the minimization of the variance on the PSD. In our work, we will use the periodogram approach of PSD estimation, which means applying the Fourier transform on local portions (windows) of random signal, with an overlap of 50%, and then averaging them in narrow bandwidths (Oppenheim and Verghese, 2010). Therefore, the averaging is useful because it mitigates the variance on the PSD. In this work, the quality of spectra is vital for accuracy of estimations. The uncertainty principle tells us that the smaller the temporal window, the bigger the uncertainty in locating two very close frequencies on the spectrum, so a trade must be made between the PSD variance and its spectral resolution. If the bedload signal is too short, the quality of spectra toward the low frequency bands is worsened because in one single bandwidth of the Fourier Transform there are spectral information of impacts from multiples grain sizes. Finally, the longer the signal the better the spectral resolution and the lesser the variance on the PSD curve."

26. Replacement applied

27. Rephrasing:

"The presented PSD curve shows two main bandlimited phenomena: (1) from 10 to 1000 Hz, which does not represent the bedload process but hydrodynamic processes; (2) from 1000 Hz to 50000 Hz which truly represents the bedload transport. The inversion procedure to estimate the GSD will be reliable as long as the bedload bandlimited region does not interfere with other extraneous noise source (hydrodynamic noise, turbulence)."

to the following:

"Two main sources of noise can be distinguished in the recordings: below and above 400 Hz (fig. 7). Bedload impacts can clearly be heard in the higher frequency band, it sounds like the crackling of the flames. Sounds occurring below 400 Hz are not propagating sounds as they are localized below the cutoff frequency of the river waveguide (Geay 2017b, Rigby 2016). They are related to turbulence induced noise around the sensor and to mechanical movements of the structure sharing the hydrophone.”.

28. We do not consider sparse grain size distributions, i.e. logarithmic size classes like the Wenthworth definition. The grain size distributions estimated in this paper have the fixed resolution of 1 mm and start from 1 mm (coarse sand).

29. Correction applied

30. The sentence containing the word “noisiest” is reformulated as it follows:

from

“Moreover, the most sediments were sampled in this position and the SPL map from Figure 7c showed that this position is the noisiest from all the cross-section.”

to

“In this position, it can be observed that a maximum bedload acoustic energy has been recorded. Additionally, a maximum flux of sediments was sampled in this position.”

31. Replacement applied

32. Replaced “a certain value” with “10 dB”

33. Modified as in the point #14 of RC 1: “1-2 mm” to “10-14 mm”. Thanks.

34. Removed “observed to be”

35. Rephrasing:

“The cross-sectional variation of the estimated D16, D50 and D84 by the NNLS algorithm follows quite decently the trend of bedload D50 measured by the TR sampler, Fig. 9b.”

to the following:

“The cross-sectional variation of the estimated D16, D50 and D84 by the NNLS algorithm follows the same trend of increasing values from left to right banks as the bedload

D50 measured by the TR sampler, Fig. 9b. However, the cross-sectional variability of sampled diameters is higher than the estimated one".

36. Rephrasing:

"The model Eq. (9) is valid if the acoustic propagation only takes into consideration the sound divergence models."

to the following:

"The proposed model (eq. 9) has been elaborating by assuming a simple geometrical spreading model of the acoustic waves in the river."

37. Discussion based on acoustic propagation study by (Geay et al.,2017b):

Rephrasing (the text from P15-L3 to P15-L15):

"Thus, the acoustic propagation has effects on the spectral amplitudes but not on the spectrum's shape. In nature, however, there are many other acoustic propagation models in the river. One of them is when the high frequencies are more attenuated than the lower ones. Also, higher frequencies are prone to scattering effects or to absorption, discussed in the context of river 5 soundscape in (Tonolla et al., 2009). In the case of Isère Rivers, even though the suspended sediment transport is important, these effects are assumed to be mitigated by the fact the sound production from the powerful acoustic source from the centre overtakes assures enough good SNR of recorded signal. Another propagation effect concerns the lower frequencies, which are attenuated by the frequency cutoff phenomena, due to acoustic propagation in shallow waters, or waveguides (Geay, 2013; Jensen et al., 2011; Rigby et al., 2016). During experimental fields, the Isère River has enough depth, 2.5 m, that the cutoff 10 phenomenon cannot affect the generate frequencies associated to SGN. The pebble-sized particles that are up to 64 mm give SGN of dominating frequencies well above 1000 Hz, whereas the channel's depth of 2.5 m fixes the cutoff frequency to about 148 Hz, assuming a perfect rigid bottom. Therefore, the spectra in the bedload bandwidth will not be exposed to frequency cutoff so this does not present any risk to inversion. Yet, SGN monitoring and inversion technique for GSD determination is particularly adapted to large rivers."

to the following:

"Bedload SGN spectra monitored by a hydrophone are not only dependent on bedload sizes but also affected by propagation effects. For example, an alpine river has been modelled as a Pekeris waveguide (Geay et al., 2017). Consequently, it has been shown that the monitored spectra were slightly dependent on the hydrophone position in the lower frequency band.Another propagation effect concerns the frequency cutoff phenomena, due to acoustic propagation in waveguides (Geay, 2013; Geay et al. 2017b; Jensen et al., 2011; Rigby et al., 2016). During experimental fields, the Isère River such a depth, i.e. 2.5 m, that the cutoff phenomenon is located below 1000 Hz which cannot affect the frequencies associated to the SGN. The pebble-sized particles that are up to 64 mm give SGN of dominating frequencies well above 1000 Hz, whereas the channel's depth of 2.5 m fixes the cutoff frequency to about 148 Hz, assuming a perfect rigid bottom. Therefore, the spectra in the bedload bandwidth will not be exposed to frequency cutoff so this does not present any risk to inversion. Yet, SGN monitoring and inversion technique for GSD determination is particularly adapted to large rivers. Generally, propagation effects are frequency dependent and higher frequency ranges are more affected by attenuation or scattering effects. A solution to the non-linear effects of acoustic propagation would be to determine the river's transfer function by active acoustic experiments (Rigby et al., 2016) and to construct laws of attenuation that will compensate the loss (Wren et al., 2015)."

38. The last sentence from P16/L29 is entirely removed

39. Tables and Figures: Overall, tables and figures support well the text. Event though not critical, legend and axis labels are too small and the arrangement of subfigures is not well balanced for most of the figures. Fig. 6c- Please consider to set the background color as white, as done for Fig. 6a. You could also report the cross-section on

this panel and keep the same y-axis direction between Fig. 6a and 6c. Two “in” in the caption (“in in units of dB. . .”). Fig. 10- replace “medallion” by “inset”. The title of table 3 is not enough explicit.

Captions revisited and replacement applied. Thank you !

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