TITLE

Please change the title to a new one, not using the same as for the conference paper published in 2015.

Yes, it is done.

1-INTRODUCTION

1.1 The manuscript motivates controlled experimental measurements by noticing that both synthetic benchmarks and validations of imaging techniques are generally limited. This is an important aspect, however it would be great to provide further motivation and background about small-scale physical modeling by the MUSC laboratory.

We have reorganized introduction and the section about MUSC laboratory.

See responses to reviewer 1 section **1** for more details.

1.2 When introducing small-scale physical modeling (page 3), it omitted references to many previous studies using thin-plate models for this same purpose. I think it would still be worthwhile to mention some of this work (sometimes referred to two-dimensional, plate wave or Lamb wave modelling), like Oliver et al. (1954), Angona (1960), Healy and Press (1960), O'Brien and Symes (1971), Pant et al. (1988) or more recent Mo et al. (2015).

References have been added in the corrected manuscript.

1.3 A short explanation about the differences and limitations of 2-D versus 3-D physical modeling would be great to provide, in order to motivate the setup chosen of the MUSC laboratory.

Lines ! It is done in the corrected version (in Physical method section not in Introduction).

Text was added **Lines !** :
« 2D small-scale seismic laboratory exist (Oliver et al. (1954); Angona (1960); Mo et al. (2015)) and have several advantages compared to 3D laboratory: (1) the variety of materials which can be anisotropic and which are less expansive and easier to handle contrary to sometime huge 3D epoxy-resin models or (2) much less source energy requirement (Oliver et al. (1954); Mo et al. (2015)). However, this method is based on the propagation of pseudo-longitudinal waves which are, in fact, non-dispersive Lamb waves while 3D methods propagate the full wavefield through the model without proxy for propagation velocities and wavetypes. More, 3D methods are best suited to reflection, refraction and diffraction problems than 2D methods (Angona (1960)) which are critical in high-resolution seismic imaging. »

1.4 Also, the nomenclature and abbreviation used of "Physical small-scale Modeling Methods (PSM)" is somewhat new, where most other literature uses terms like "physical scale model", "physical modeling" or "scale model data". Thus, it would rather be "Small-scale physical modeling methods". The abbreviation PSM in the manuscript is hardly used and could be omitted altogether.

We use "Small-scale physical modeling methods" in the corrected version.

1.5 You mention modeling surface waves as a reason not to immerse the model in say a water

tank. However, you do not further discuss this important topic and the results presented in this study omit showing surface waves. It would be great to list limitations in physical modeling of surface waves and clarify what you refer to as ”reflection echoes”, mentioned in the conclusions.

Concerning « ommit showing surface waves »
Surface waves are presented but « wrongly » labelized as S-wave. Indeed, even in a homogeneous medium, the S-wave propagating along the free-surface is a Rayleigh wave. Consequently, we have relabeled direct S-wave as Rayleigh wave.

Concerning ”reflection echoes”
Our words were wrongly chosen here , “reflected echoes » in the conclusion refers to ringing effects of the source in fact. This ringing effect carried by the direct P and S/Rayleigh waves interfere with direct S/Rayleigh wave and reflected-wave arrivals respectively. This is corrected in the new version.

The findings presented on page 4 could be further structured. The manuscript mainly lists the following problem items addressed in this study: (1) line-source versus point-source modeling, (2) geometrical spreading corrections, (3) effective source time function, that is the transducer influence, (4) reproducibility of the experiment/measurement. These items could be separated into challenges related to the ”forward problem” of modeling wave propagation in 2-D (items 1,2), the ”inverse problem” of retrieving the correct source and model parameters (item 3), and finally the robustness, stability and precision of the measurement apparatus (item 4).

Lines ! This part has been restructured in the corrected manuscript taking into account the difficulties in organizing the results. We understand this remark but splitting into challenges would require, from our point of view, to rewrite largely the result sections. Indeed, these challenges are strongly linked to each other: (1) 3D-2D spreading correction and point-source versus line source, and (2) source reproducibility and source time function estimation. However, we try to clarify at best these different results and we now differentiate them in the introduction.

2-METHODS

2.1 Since the focus of the study is on physical modeling, it would make sense to start presenting the MUSC laboratory (section 2.2) rather than the numerical method used for comparison (section 2.1).

We have reorganized the manuscript to present the MUSC laboratory first.

2.2 Furthermore, when presenting the MUSC laboratory it would be helpful for readers to mention limitations which are expected. For example, it is known that ultrasonic transducers are resonant and narrow-band due to the physical properties of these devices. Also, the transducers are in general large compared to the minimum wavelength of the simulation, thus can impose directivity effects. Some of these effects have been studied by Fran¸cois Bretaudeau et al. (2011) already, but it would be great to further mention and justify the selected frequency-bandwidths of 20 - 200 kHz and 300 - 800 kHz.

These remarks are tackled in the corrected version in 3 separated parts as following :

1) For example, it is known that ultrasonic transducers are resonant and narrow-band due to the physical properties of these devices.

piezo-electrics components are indeed resonant. One of the difficulty to avoid the resonnant effect is the impedance adaptation of the transducer to the propagating medium. However, in MUSC, we use tranducers who have been built with well-adapted shape, backing element and suited material for the contact to the medium, in order to be adapted to the impedence of the material that we use, as much as possible (for exemple, they are not adapted to alluminium blocks). That is specially the case of those adapted to a central frequency of 100 KHz in the paper. In the case of the higher frequency one (not used in the tests described here), a conical adaptator in resin between the transducer and the model allow to weak the resonant effect. This aspect is already described in (Bretaudeau et al, 2011) and, to our mind, it should not be repeated with long developments in the present paper. However, it is recalled in the corrected version as recommended, at the end of the third paragraph. Moreover, even if the resonnant effect are avoided, the response of the transducer remains as a filtering effect to the electrical signal injected in input. This aspect is a critical point tackled in the present proposed article. For this reason, we complete the added sentence of the 3d paragraph by this aspect. The part added :

Lines ! « The piezo-electric transducers used are built to be adapted to the impedance of the resin model described in the next part. Thus the emitted signal, already presented in (Bretaudeau et al. 2011) is not resonant. However, the sensor response combined with the coupling effect to the model behaves as a filter for the source shape. This effect is a crucial point that has been firstly tackled in MUSC by (Bretaudeau et al. 2011) with an assumption of 2D propagation although in case of a punctual source. In the present paper, we propose to study further the impact of this source response on the data by taking into account the 3D effects of a punctual source and by simulating a 2D source line. Note that the transducer response and the coupling effect depend on the frequency of the emitted signal. We will tackle this frequency dependance by taking into account the entire waveform of the pulse . »

Concerning the narrow-band aspect, the following text has been added in the subsection « Characteristics of the scale models tested » :

Lines ! « As shown on figure 2, even if the emission properties of a piezo-electric transducer is narrow-band, the spectral bandwith of the pulse emitted by the piezo-electric transducer is large enough to simulate a seismic pulse emitted by a hammer fall in subsurface media, through the scale ratio used in table 2. »

2) Also, the transducers are in general large compared to the minimum wavelength of the simulation, thus can impose directivity effects. Some of these effects have been studied by Fran¸cois Bretaudeau et al. (2011) already, but it would be great to further mention

Precisions about this have been added in the corrected version in paragraph 4 through the following sentences :

Lines ! « Actually, as explained in Bretaudeau et. al. 2011, classical piezo-electrical transducers sizes are generally large compared to the emitted wavelength and provide a directional emission pattern whereas a hammer fall source used in subsurface field measurements behaves as a punctual impact and provides an omnidirectional emission pattern. For this reason, in the MUSC laboratory, two adapted sources have been tested in term of directivity pattern by (Bretaudeau et al.) who showed their capacity to simulate a thin piston effect. The first one, corresponding to the lower frequency band [20-200] is a commercial one with a small impact contact. The second one, corresponding tio the higher frequency band. ...

3) and justify the selected frequency-bandwidths of 20 - 200 kHz and 300 - 800 kHz.

It has been clarified in the corrected version through the following sentences whixh have been inserted in the 5th paragraph :

This two frequency bands have been chosen to allow both complying with the dimensional scale ratio shown in tables 1 and 2 and making easily the heterogeneities in the medium. That means : the heterogeneities should be not too small (1mm of minimal size) and the total model size should not be too big or too heavy (1m2 and 270 Kg max) for the supporting table. For simulating classical dimensions in the subsurface domain, we use preferentially the low frequency band which allows a dominant wavelength (at 100kHz) about 13 mm for the Rayleigh waves and 28 mm for the P waves, by taking into account the velocity in the models described below. The scale ratio principles are used as follows

2.3 Also, it would be great to evaluate the precision achieved of the measurements in the MUSC laboratory. For example, the precision of the positioning of the receiver position is stated as ±10µm which for a shortest wavelength of 1mm amounts to a precision of 1%. So does the vertical offset measurement by a laser beam with a 20µm diameter, thus the measurement is not exactly a point measurement but an average over a small surface fraction. One could briefly present for the chosen setups what error of the measurement would be expected. Since this is one of the advantages of laboratory settings, you could put error bars on the traces.

The following text has been added in the subsection « Characteristics of the scale models tested » :

Lines ! « The laser beam diameter is 20µm large. In the presented study, typical of experimentations in MUSC, the dominant wavelength (at 100kHz) equals about 13 mm for the Rayleigh waves and 28 mm for the P waves . Thus, the laser beam respectively equals lamda/650 and lamda/1400. At the field scale, and following the rules in table 1, those corresponds to a measurement surfaces of 20 mm and 2 mm respectively. These dimensions are lower or equivalent to the possibilities available by geophones holds. Thus, at the laboratory scale in MUSC, the measurement accuracy in term of the size of the recording surface is respected »

In parallel, the position accuracy of the receiving system is 10µm. This value is lower to the focal beam. It corresponds to the center position of the laser beam, which is 20µm large. In practice, the incremental displacement between two receivers positions used here equals mm. It is higher than the focal beam size

2.4 The same consideration also holds for the ringing of the transducers which will likely look different at different central frequencies. One could present the ringing for different central frequencies of the source, to better highlight in which frequency regime the transducers affect measurements and need to be treated more carefully as is then done in the following of this study.

The frequancial effects of the transducer is tackled thorugh the entire waveform, as added in the modified version (see the corrected part to answer to your comment 1)) of the Methods part above.

3-RESULTS

3.1 It would help to start clarifying which 2-D numerical result is compared against which 3-D experimental data and somehow introduce nomenclature for 3-D experimental point-source, 3-D experimentally constructed line-source and 2-D numerical line-source.

This has been taken into account and the proposed nomenclatures are now incorporated in the corrected version.

3.2 Section 3.2 would be great to further subdivide into new sub-sections: The first part deals with reproducing single measurements to validate the reproducibility of the source. The second part deals with the effective source time function estimation, starting at page 14, line 29 (”In the second step ...”). The third part introduces the new 2-layer model called BiAlt, thus deals with a new experimental setup (page 15, line 8) and comparison. It would help to put these into different sub-sections and discuss each result separately.

For convenience, the RESULTS section has been reorganized into three separate parts, hoping that this will allow for better understanding of the results.

3.3 Also, in your comparisons between different traces you use a correlation coefficient over the whole trace length. Since you already see and discuss different effects on P-, S-, PP- and PS-phases, it would make sense to further separate the comparisons into just comparing a single phase. This would make it clearer in how well a P-wave, S-wave or PP- or PS-reflection is treated in the geometrical spreading and 2D line-source approximations.

Additionnal correlation coefficients for P-, S/Rayleigh- and PP-reflected waves have been added to figures 8 and 9 (figures 9 and 10 in the previous version). Psv-reflected wave is difficult to locate on real data, so the correlation coefficient has not been calculated for it. Results are discussed **Lines !**

4-CONCLUSIONS

4.1 Would it be that you verified experimentally that you can construct a line-source using the MUSC laboratory? or would it be that the geometrical spreading transformation applied to 3-D data is only accurate for P- and S-phases, but not reflected ones like PP- or PS-phases?

I think that the most important result is the 3D constructed line-source since other publications have already shown limitations of geometrical spreading correction methods.

4.2 The very last sentence mentions the addition of new measurements in the MUSC laboratory by Valensi et al. (2015). It would be great to shortly explain this addition in the introduction and why it hasn’t been used for this study.

Valensi et al. (2015) have introduced horizontal component in the MUSC laboratory. However, when this study was realized the horizontal component was not fully calibrated and signal-noise ratio issues were persistant. Furthermore, some data were generated before the improvement of the laser interformeter. Consequently, we use only the vertical component.
comment – It is a work in progress that will require a little more time before being fully finalized.

5- OTHER REMARKS

Manuscript text

page 2, line 2: ”2 D and 3 D” please see if 2D and 3D or 2-D and 3-D could be used in a more coherent way throughout the text.

It's done.

page 2, line 49: ”algorithms innovations” just use e.g. ”algorithms”.

It's done.

page 3, line 56: ”sharp similarities” maybe better ”close ..”.

OK.

page 4, line 33: ”It is based on the following findings.” awkward ending of a paragraph.

Yes, it's awkward...corrected.

page 4, line 38: ”3D/2D geometrical spreading effects” it would be clearer saying ”3D-to-2D geometrical spreading corrections”.

OK.

page 6, line 56: ”Since the wave equation is linear” the sentence sounds a bit odd, maybe ”For the linearized wave equation, ..”

It's done.

page 8, line 24: ”finely” ? could be omitted

OK.

”In the far-field approximation, ..” You show the single-velocity transformation in eq. (10) and then state ”is recommended for small offsets”. This seems to contradict with the initial far-field assumption. Maybe you could clarify it.

I have no physical explanation for this. I can just refer to Schafer (2014) and Forbirger (2014) who have shown, on the basis of numerical tests, that single-velocity transformation is better for small-offset while direct-wave transform is better for large-offset. This “clarification” has been added to the manuscript (see appendix **Lines!**).

page 15, line 57: ”..to inverse crime.” the sentence sounds strange.

Indeed...

<u>Figures</u>

***Figure 2*: This figure is not referenced in the text. There is also no explanation of why the traces lack in the middle (closest to the source). Furthermore, the images all show glitches at different offsets which are not apparent in for example figure 6 (c). It would be nice to explain in the manuscript text what is shown here.**

Figure 2 shows three multireceiver acquisition for the BiAlt model. The traces lack in the middle is related to the position of the laser over the piezo-electric source so that no trace can be recorded. The glitches on figure 2 which are not present on other figures are related to interferometer wear during acquisitions shown in figure 2.

Figure 3 and 4**: The figures only show the BiAlt model. It would be great to also show the first model used which is the homogeneous one next to it, in both figures. This would make it clearer that the study is conducting experiments on two different models.**

Done for figure 3, figure 4 from the previous version has been removed.

Figure 9: there is no need to additionally label the image with (a) or reference it as Fig. 9(a). It then is just figure 9.

It's done. Figure 9 is now Figure 8.

References

Please note that in many references on page 17 - 19, the usage of 2D, 3-D or CO2 became 2d, 3-d and co2 and would need to be corrected.

It is done.