Response to reviewers

Dear Reviewers,
Dear Topical Editor and Editor-in-Chief CharLotte Krawczyk,

We sincerely thank both reviewers for their fair and constructive reviews, which greatly improved our manuscript. We appreciate the feedback given on the manuscript and carefully incorporated all points risen. Please find below our answers for each comment in green coloured text.

Kind regards,
Yueyang Xia on behalf of all co-authors

Referee 1: Nathan Bangs

Submitted on 17 Nov 2021
Referee #1: Nathan Bangs, nathan@ig.utexas.edu

Suggestions for revision or reasons for rejection (will be published if the paper is accepted for final publication)

Here are my remaining issues:

1) The presentation in the introduction on velocity model building and the technique developed here is confusing. I think I understand, but only after reading several times. The problem is that the description of the model building process and problems, and their approach to the solution, blur together. Some of the issue is too much use of the passive voice. For example, in each instance highlighted (in square brackets) below, it is not clear who is doing these actions, other researchers, or the authors, etc….:

"Several workflows [have been established] for velocity estimations depending on the different acquisition types and seismic wavefields available. Long streamer acquisitions with respect to the target depth in shallow water depth [offer the possibility] to invert for complementary wavefields, the near-vertical reflected events and the horizontal propagating refracted arrivals from the same dataset. Gras et al. (2019) used selected reflected arrival times and the refracted arrivals for a travel time tomography to estimate an initial velocity. This velocity [was used] for a subsequent full wavefield inversion followed by PSDM. To image crustal structures in a deep-water environment, Górszczyk et al. (2019) used complementary wavefields from streamer data and ocean bottom stations (OBS) recordings. A first arrival tomography of the OBS data [produced] an initial velocity for a full waveform inversion of the OBS recordings. To minimize the RMO of CIP gathers of the PSDM data with the waveform inversion velocity, a slope tomography of local reflector elements [was used] to further improve the velocity model for a final migrated image."

The confusion for me arises because they present their technique within a general description of the problem and it is hard to tell what the specific issues are that they are concerned with here and how they are addressing them. Line 79 states what they have done more specifically, but I'm not sure what "these issues" are and why the focus is on the depth error estimation as stated in the sentence that follows. Some clarification in the introduction would make it easier to understand the rest of the paper.

Thank you for the detailed comments.

We were restructuring the introduction and remove unnecessary detailed information.

2) Along the same lines as #1 above, additional explanation would help in a few spots. In my first review I asked for an explanation for why the NRM displacement field was determined (my comment # 1 in the previous review), which was answered in the author's response, but not in the revised text. Knowing that this approach provides a smoother depth error and improves stability helps explain why they have used this approach.

We missed to include this information (it was too obvious for us … sorry). We included it in the chapter: 2.2 Methodology of the ray-based grid tomography with CIP depth errors and in chapter 3.4 Data examples.

3) The heart of this technique is matching the traces to determine the displacement shift, but I don't see how this is done exactly. What criteria are they using to determine when traces align? The only description I found is on Line 153, and it only states that they "match and align" without explaining matching criteria. An explanation here would also help.

Yes, we fully agree. We included in chapter 2.1 Non-rigid and warping matching techniques, the basic equations and explain the method in more detail.

We further corrected all the sticky notes included in the manuscript and made small corrections for easier understanding.

We further shortened chapter 4.1 Final velocity model and reflectivity structure as this paper should focus on the method we applied. A more detailed discussion of the structure is in preparation in a follow-up paper, dealing with the geology of this line and other reprocessed lines nearby in this area.

Thanks for your help improving the manuscript.

Referee Report: se-2021-40-referee-report.pdf

Referee 2: César R. Ranero

Submitted on 01 Dec 2021
Referee #2: César R. Ranero, cranero@icm.csic.es

Suggestions for revision or reasons for rejection (will be published if the paper is accepted for final publication)
I think the authors have addressed reasonably well technical comments and the manuscript is currently more robust and the method clearer. The removal of the example from New Zealand also helps to focus the message.

They provide images of the shallow structure where their method is producing the largest Vp changes, given the limitations imposed by a 3-km streamer length. However, it would be expected that the changes in the shallow Vp structure also influences the image of deep structure. This is because, even though the final Vp at several km below the seafloor has not changed much, the changes in shallow ray-path bending should be transferred to the deep images and potentially improved them.

Therefore, I suggest that now they finalize the work by adding images of their improved PSDM results from the region that is possibly of the most geological interest, and this is the plate boundary zone. Plate boundaries fault zones are structurally complex and contain variable amount of fluids. The fault zone and fluids are typically imaged as reflections of variable geometry and amplitude, and often of reverse polarity, and these changes appear to relate to earthquake phenomena (e.g. Bangs et al., 2015).

The plate boundary in a nearby region along the trench is relatively well imaged with PSDM on much older data (Sallares and Ranero; 2019). These images were used to infer a long term tectonic model and its relation to seismogenesis. Thus, it would be very convenient to see the quality of the images on the more modern seismic data and whether the improved Vp produces also an improved image along the plate boundary fault.

After such moderate change with addition of image(s) of a key region of the subduction system the work should have a considerable increased scope and impact and would be really for acceptance.

Bangs, N. L., K. D. McIntosh, E. A. Silver, J. W. Kluesner, and C. R. Ranero, Fluid accumulation along the Costa Rica subduction thrust and development of the seismogenic zone, J. Geophys. Res. Solid Earth, 120, 67–86, doi:10.1002/2014JB011265. 2015.

Sallares V. & Ranero C.R., Depth-varying elastic properties of the upper plate determine mega-thrust earthquake rupture characteristics. Nature. https://doi.org/10.1038/s41586-019-1784-0 2019

Thank you for the detailed comments.

We looked in more detail to the plate boundary reflections as suggested. In the screenshots below are displayed the pre-stack migrated stacks with the velocity models from the OBS, the initial velocity for the reflection tomography, and the final velocity from the reflection tomography. At the location marked in the stacks additional surrounding CIP-gather from the individual velocity models are displayed. The velocity comparison can be found between OBS and initial model in Figure 6 and between the initial and the final velocity in Figure 14 in

the manuscript. In all the raster images black correspond to positive amplitudes and white to negative amplitudes.
An additional wiggle plot is included comparing the waveform of the seafloor in the reflection pattern between the two CIP location.

Observation stacks:
1. Due to the different velocity models the depth positions of the reflector changed with marginal wavelet / polarity change.

2. The first CIP-gather location:
On the first location the sediment velocities were significantly reduces from the OBS model to the final velocity model. Strong under-corrected events below the basement are from side echo scattering.

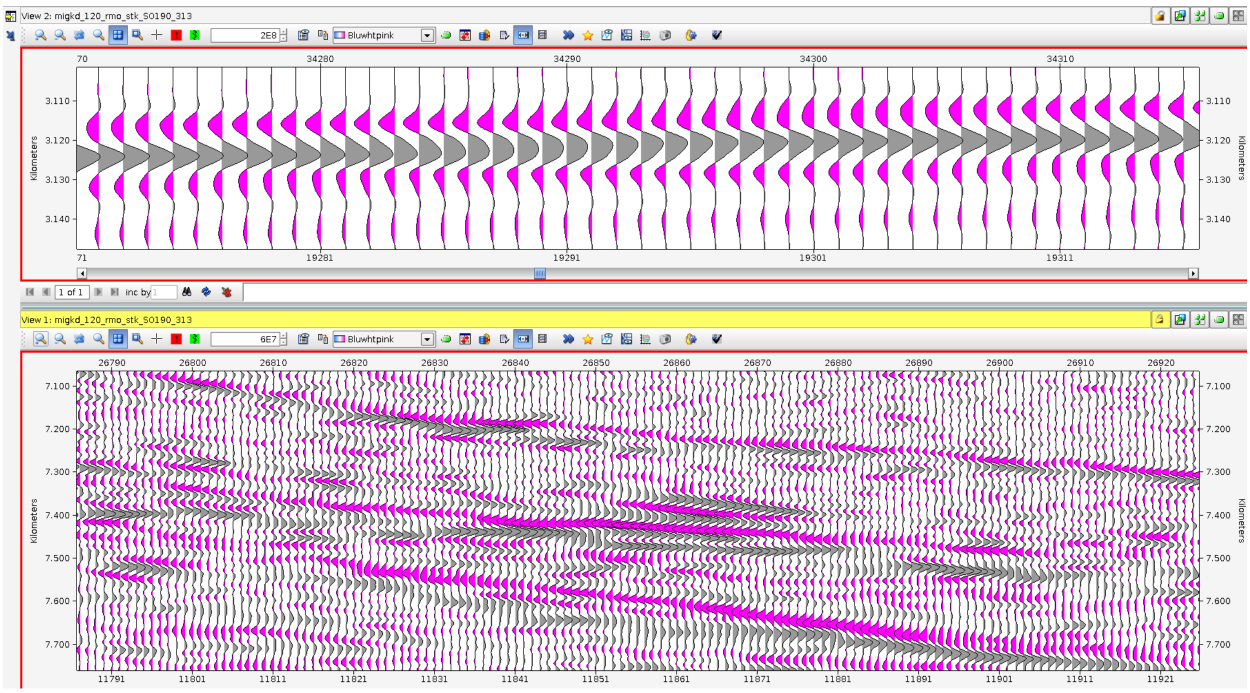
3. The second CIP-gather location:
The horizontal misalignment is reduced at the initial and final CIP gathers relative to the OBS velocity.
Further can be seen by comparing the initial and final gathers, that the individual events move spatially e.g. the energy is transferred to neighbor locations and offsets due to the ray-path bending even by velocity changes smaller than 10% at the near surface. But the stacks look very similar from their reflectivity.

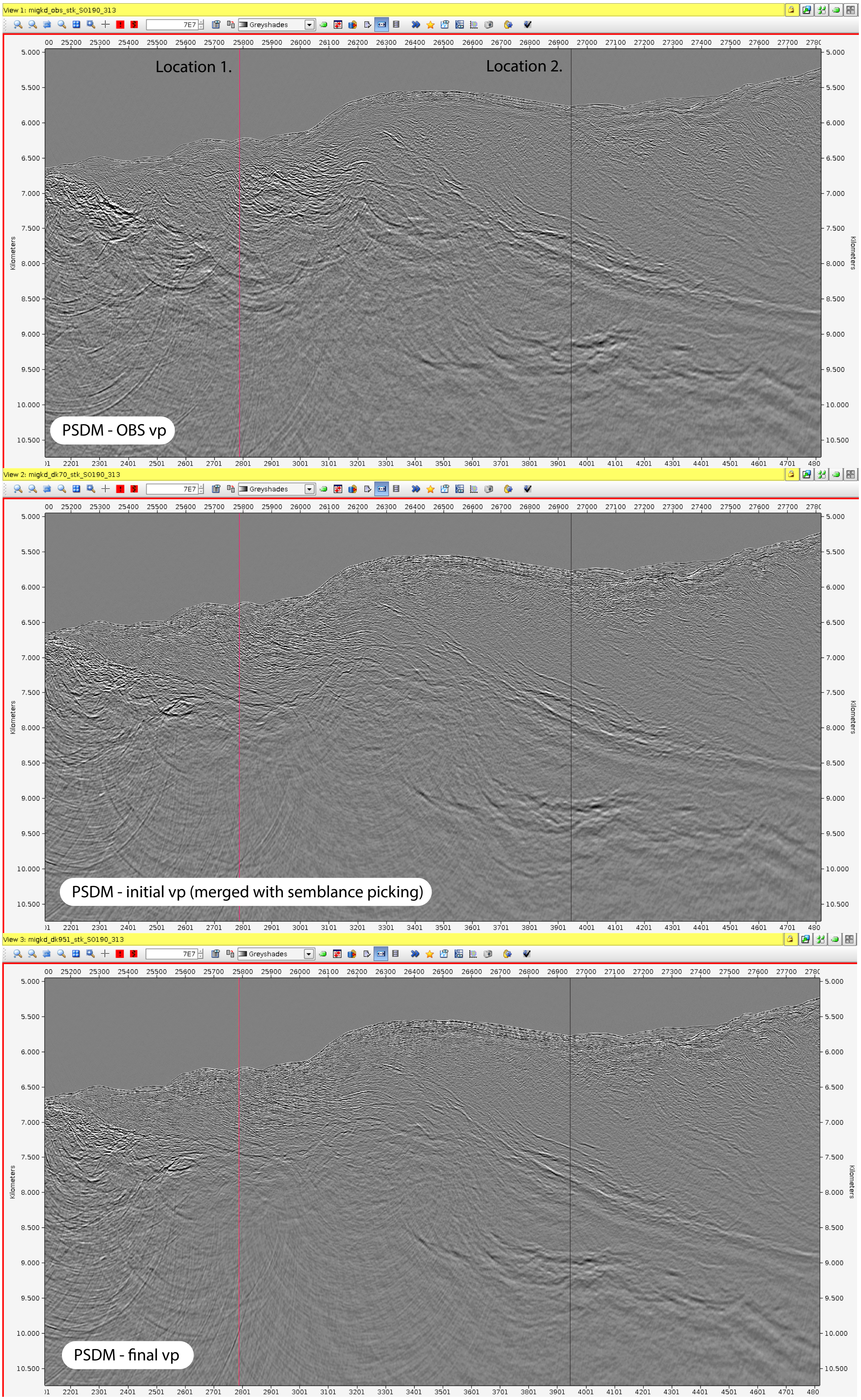
Based on that, an AVO analysis of CIP gathers must be carefully analyzed with respect to the overburden velocity structure.
From technical side a single value (max energy or shortest ray-path) Kirchhoff migration could amplify this situation. Here a comparison of a Finite-Difference migration with downward continuation of the full wavefield may help to verify this situation.

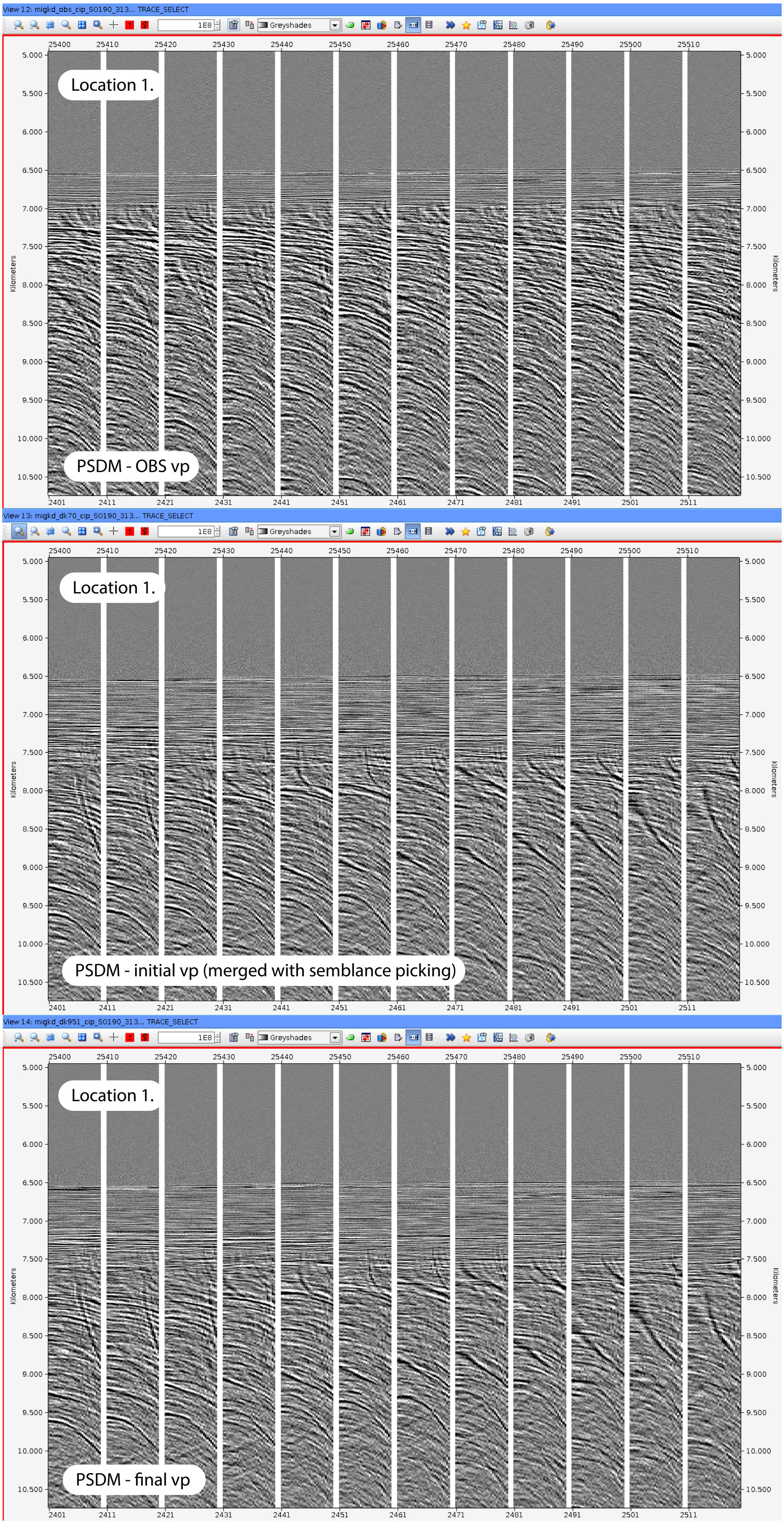
As we are already at the limit of the file size for the publication and are not able to include more high-resolution images. Further we are working on a follow-up paper, dealing with the geology of this line and other reprocessed lines nearby in this area.

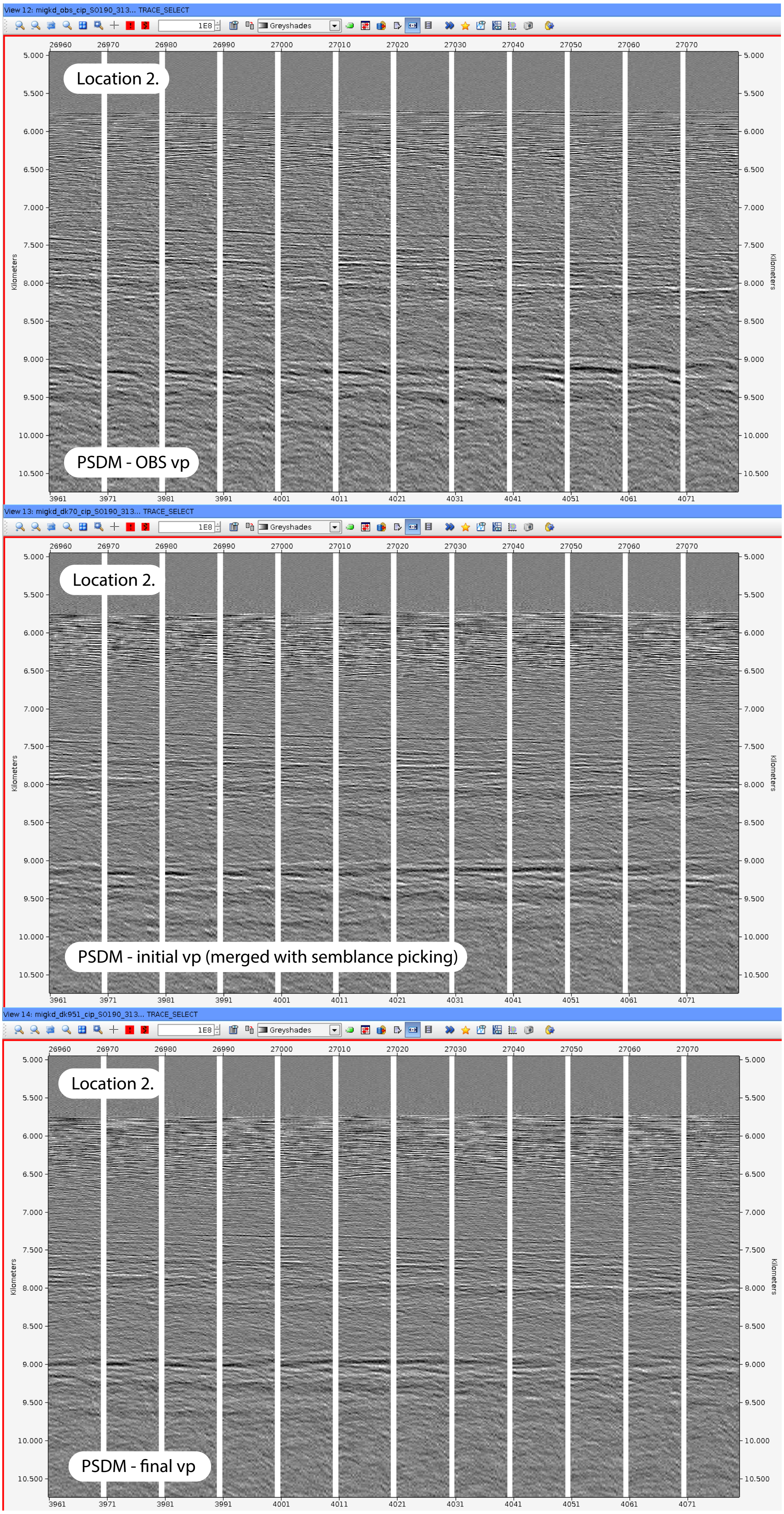
Regarding the discussions above, we added a new paragraph and the corresponding citations into the manuscript from Line 787 to 795 (in change-track PDF). A streamer data with a longer offset will favour the amplitude and fluid migration quantification topic in the future.

Thanks for your help improving the manuscript.




View 1: migkd_obs_stk_SO190_313
Location 1.
Location 2.
Kilometers
PSDM - OBS vp
View 2: migkd_dk70_stk_SO190_313
Kilometers
PSDM - initial vp (merged with semblance picking)
View 3: migkd_dk951_stk_SO190_313
Kilometers
PSDM - final vp


View 12: migkd_obs_cip_SO190_313... TRACE_SELECT
Location 1.
PSDM - OBS vp
Kilometers
View 13: migkd_dk70_cip_SO190_313... TRACE_SELECT
Location 1.
PSDM - initial vp (merged with semblance picking)
Kilometers
View 14: migkd_dk951_cip_SO190_313... TRACE_SELECT
Location 1.
PSDM - final vp
Kilometers


View 12: migkd_obs_cip_SO190_313... TRACE_SELECT
Location 2.
PSDM - OBS vp
View 13: migkd_dk70_cip_SO190_313... TRACE_SELECT
Location 2.
PSDM - initial vp (merged with semblance picking)
View 14: migkd_dk951_cip_SO190_313... TRACE_SELECT
Location 2.
PSDM - final vp
Kilometers
Greyshades