On the value of direct measurements of the water velocity offshore Brazil

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Abstract

We analyzed a large dataset comprising direct measurements of the speed of sound in the ocean, a. k. a. water velocity, that was acquired during a deep-water ocean-bottom node (OBN) survey offshore Brazil. We showed how these measurements are complementary to the seismic data for estimating water velocity variations.

The availability of underwater acoustic position measurements at the deployment and retrieval of the seabed receivers enabled us to assess the uncertainty in the position accuracy and to compare them with the expected values.

Introduction

Recent technology developments have enabled more cost-effective deployment of nodes - enabling the acquisition of full-azimuth long offset OBN data that can significantly benefit the imaging of many targets (Roende et al., 2020; Vigh et al., 2021), whether used in isolation or in conjunction with existing underlying streamer data, that is of more limited offset and azimuth coverage.

The spatio-temporal variation of the water velocity is a challenge for 3D seismic processing and even more so for 4D processing. Fortunately, in the case of OBN surveys, the deployment of the nodes in deep water is carried out using remotely operated vehicles (ROVs) on which sensors for directly measuring the water velocity can be installed. The variable accuracy of the reported node locations and the time drift of the clocks integrated into the nodes without real-time telemetry with the recording vessel are two additional challenges.

We present a case study based on a deep-water OBN dataset acquired offshore Brazil that highlights the value of two types of direct measurements of the water velocity that have complementary features. In the second part of this abstract, we share some observations on the accuracy of the reported locations of the nodes.

Method

Pressure Inverted Echo Sounders (PIES) are autonomous instruments that are often deployed at the seabed in deep water OBN surveys to estimate the average speed of sound in water and the height of the water column (Wang et al., 2012). The estimation is based upon the acoustic two-way flight time between the PIES and the sea surface, and the pressure and the temperature at the location of the device.

Sound Velocity Profilers (SVPs) are another type of measurement of water velocity. SVPs measure the acoustic time-of-flight using sensors that, in deep water OBN surveys, are typically attached to the basket containing the nodes that are deployed to the seabed by a remotely operated vehicle (ROV). SVPs provide densely sampled measurements along the trajectory of the ROV and coarsely sampled measurements in space and time.

Pressure-temperature-conductivity (PTC) sensors deliver the water velocity at sampling intervals comparable with the SVPs but the estimation is based upon empirical formulas rather than the time-of-flight. PTC measurements are also called CTD measurements, which stands for conductivity-temperature-density. The abbreviation CTD highlights that a deliverable of a PTC sensor is the density estimated using empirical formulas from temperature and conductivity measurements at locations that are finely sampled along the depth axis. The depth of the measurement is estimated using the pressure sensor.

SVPs (or PTCs) and PIES are complementary measurements that, if used jointly, provide spatio-temporal variations of the water velocity in deep-water OBN surveys. The method for the joint processing and visualization of PIES and SVPs, which has been applied to the examples in this abstract, is described in Bagaini et al., 2021.

Case study

The joint processing was applied to the 21 PIES and 477 SVPs that were acquired during an OBN survey over the Santos basin field offshore Brazil. This survey took place between December 2021 and March 2022. Figure 1 shows the average water velocity in the depth interval between 0 and 1100 m obtained by jointly processing PIES and SVPs. This graphical representation enables identification of temporal and/or spatial variations of the water velocity. In this case, both PIES and SVPs show a steady decrease in the water velocity in the first 60 days of the survey.

Figure 2 highlights the similarity between the temporal variations of water velocity obtained with PIES and the temporal variations of the temperature measured by the PTC sensors. The PIES measured the largest values of the water velocity from approximately the second week of

January to the first week of February (day range between 20 and 40) as shown in Figure 2a. The largest water velocities are very well correlated with the largest values of the sea temperature shown in Figure 2b. ROV trips to the seabed, and therefore PTC measurements, were suspended for about three weeks from the third week of January because of the COVID pandemic. When the PTC measurements resumed, the downwards trend in water velocity measured by the PIES is well correlated with the downward trend of the temperature measured by PTCs. This negative trend is reversed towards the end of the survey when again both PIES and PTC are in good agreement. The observer logs report rough seas and strong winds towards the end of the survey that, if associated with warm currents, explain this upward trend.

Water velocity variations estimated with direct measurements can be used to constrain the inversion based on seismic measurements following the method described in Muyzert et al., 2021 and applied to a large scale OBN survey by Seymour et al., 2021. Alternatively, these independent measurements can be used to validate the results obtained with seismic inversion. The outcome of this second approach is shown in Figure 3. The trend and the absolute values of the water velocity estimated with the seismic are in good agreement with the direct measurements in the period when both measurements are available. The exceptions are the measurements (purple dots) from one of the PIES that became faulty a few weeks after the acquisition started.

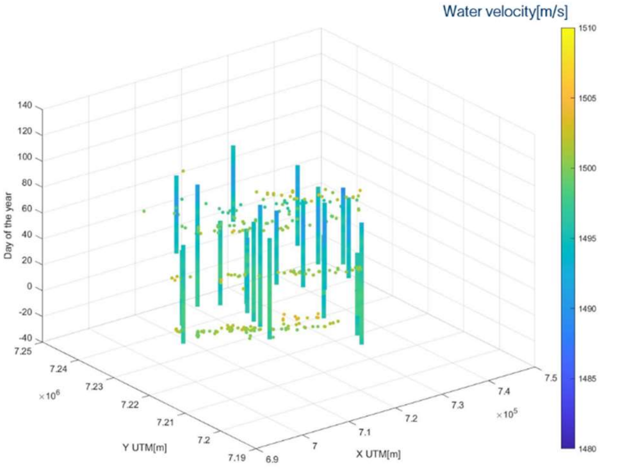
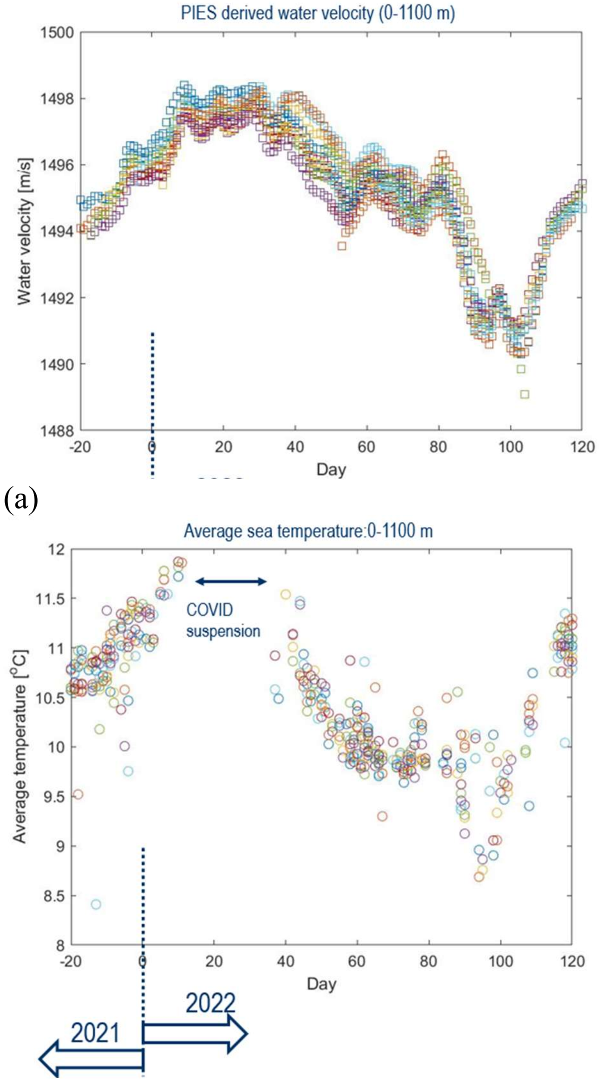


Figure 1. *Average water velocity in the depth interval between 0 and 1100 m computed using PIES and SVP measurements. Negative days indicate measurements made in December 2021, whereas positive ones indicate measurements made in January to March 2022.*



(a)

(b)

Figure 2. *(a) Average water velocity in the depth interval between 0 and 1100 m derived with PIES. (b) Average water temperature in the depth interval between 0 and 1100 m measured by the PTC sensors.*

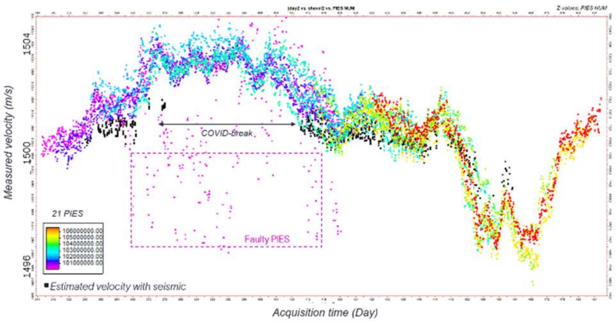


Figure 3. *Average water velocity estimated with PIES (color coded) and seismic measurements (black dots).*

The success of deep water OBN surveys, particularly when acquired for 4D purposes, depends on several factors; the accuracy of the reported source and node positions is one of them. When ROVs are used, the nodes' positions estimated with acoustic positioning methods, typically ultrashort baseline (USBL), are available at deployment and retrieval. Figure 4 shows the difference in the reported node depths at retrieval and deployment. The mean is approximately zero and the standard deviation is about 0.3 m. This is reassuring because the standard deviation of the USBL depths is expected to be less than 0.5 % of the water depth, which is between 2100 m and 2250 m in this example. However, the reported node depths at retrieval are greater than those at deployment in the northern part of the prospect, whereas the reverse is true in the southern part. This may be due to the assumptions on the water velocity made by USBL systems. The acquisition started in the northern part and finished in the southern part of the prospect. As observed when analyzing the direct measurements of the water velocity, the average water velocity decreased in the first three months of the acquisition. This may have caused this change in sign of the node depth difference. These differences are most likely of a magnitude that is acceptable when processing a single survey, but it may deserve further scrutiny during a 4D processing project.

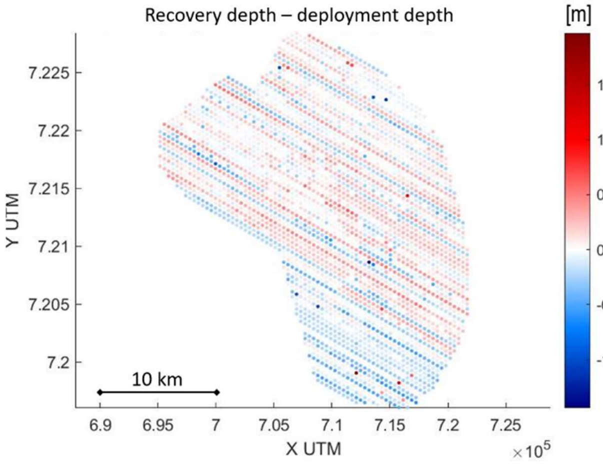


Figure 4. *Difference in the reported node depths at retrieval and deployment.*

Figure 5 shows the vectorial differences between the reported horizontal coordinates of a few nodes in the north-west of the survey at retrieval and deployment. The nodes shown were all deployed with the same ROV and retrieved with another one. The orientation of the vectors shows a behavior correlated with the receiver line.

The comparison of Figure 6 and Figure 7 provides additional insights. Figure 6 is the magnitude of the vectors in Figure 5, Figure 7 shows the difference in the azimuth directions of the ROVs that deployed the nodes in Figure 5 and Figure 6. The nodes on the receiver lines (or fraction of them) that were deployed and retrieved by ROVs moving with the same azimuth show a smaller magnitude of the difference vectors. We argue that this phenomenon is due to the offset between the arm of the ROV that deployed the nodes and the responder beacon used for the USBL measurements. The exception is denoted by the red question mark in Figure 6 and Figure 7.

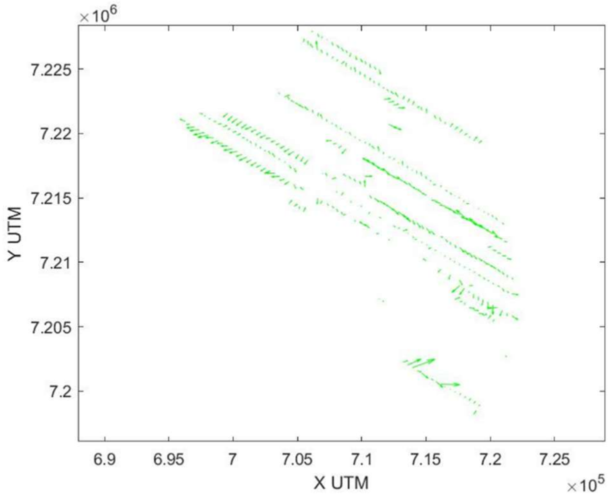


Figure 5. *Difference (vector field) of the reported horizontal coordinates at retrieval and deployment. Close-up in north-west part of the survey.*

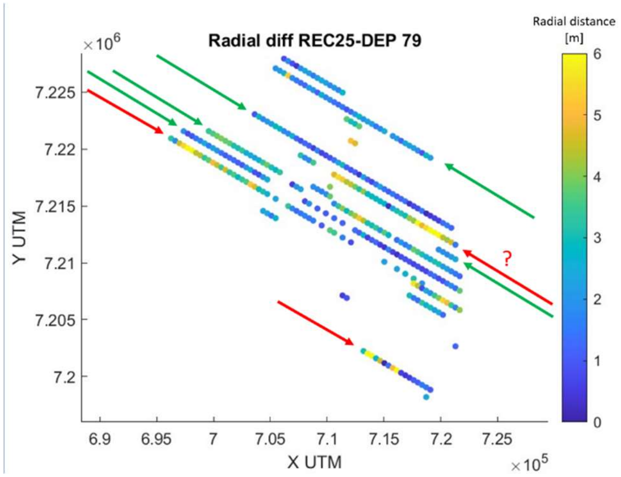


Figure 6. *Magnitude of the vectorial difference in the horizontal coordinates (Figure 5).*

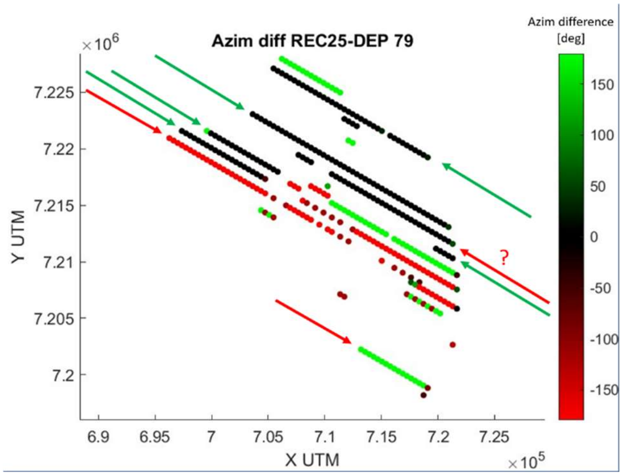


Figure 7. *Difference in the azimuth direction of the ROVs that deployed and retrieved the nodes.*

PTC measurements are used along with empirical formulas to obtain an independent estimation of quantities such as water density and water velocity. The conductivity is used to estimate the salinity, which is then used to compute the water density that along with the temperature enables the estimation of the water velocity. The water velocity from PTC measurements can then be compared with that obtained with time-of-flight sensors, as shown in Figure 8. The comparison of the two panels highlights an overall excellent agreement between water velocity estimated with time-of-flight and PTC sensors. However, some differences, particularly in deep water, deserve further investigation. Figure 9 is a close-up of Figure 8 in deep waters. The color coding distinguishes measurements made from sensors installed on three ROVs. The close-up highlights that one of the conductivity sensors (blue solid line) was not properly calibrated. The consequence is that salinity, density and water velocity derived from that sensor were over-estimated. However, two facts are reassuring: a constant factor is easy to estimate and compensate for; the effect on the water velocity does not exceed 2 m/s.

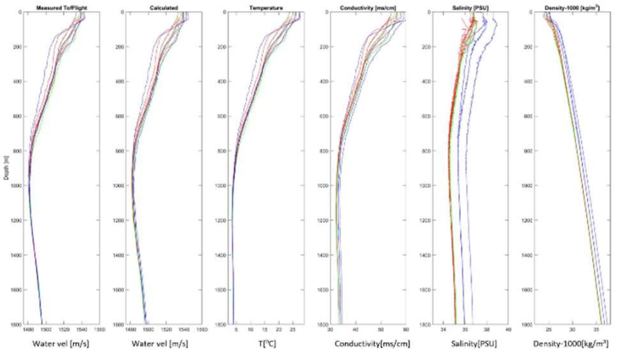


Figure 8. *The six panels from left to right. Water velocity from time-of-flight; water velocity from PTC; temperature; conductivity; salinity and density. Blue, red and green solid lines correspond to measurements made by three different ROVs.*

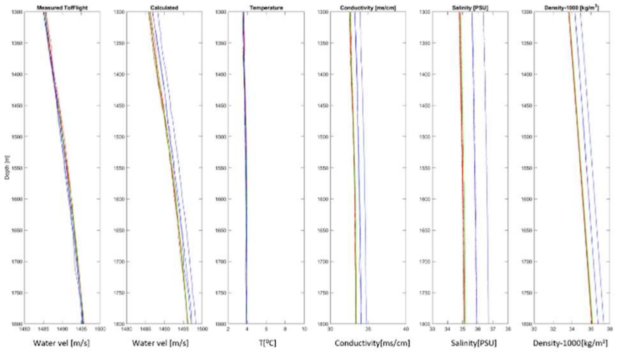


Figure 9. *Close-up of Figure 8 in deep waters.*

Conclusions

The frequent ROV "trips" to the seabed are precious to estimate acquisition quantities (node depths and water velocity) that can be used for deterministic processing of OBN datasets acquired in deep waters. We have developed a method that jointly processes several direct measurements of the water velocity acquired during these ROV trips. The results of this processing can either be used as a constraint for the processing of the seismic data or as independent results for the validation of the seismic processing results. We have shown the results of the latter approach based on a dataset acquired in deep waters offshore Brazil.

The difference between the reported node depth at deployment and recovery is approximately zero mean with a std of 0.3 m. This is within the expected USBL accuracy for the water depth of this survey.

We observed that the differences in the reported horizontal locations of the nodes at deployment and retrieval are larger for nodes that were deployed with ROVs moving in a direction which is opposite to the direction during the retrieval.

Modern oceanographic sensors can measure CTD and directly water velocity (SVPs) with time-of-flight sensors. Calibration of CTD sensors is important. However, the richness of the dataset used for this example enabled us to work out that one of the three conductivity sensors was not properly calibrated and compensate for this.

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