

Resolution and Accuracy of Short-Offset Processed 3D Seismic Data for Seabed Mapping in Deep Water in Makassar Straits, Indonesia*

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Abstract

This article presents a case study from the ENI operated Muara Bakau (Jangkrik) PSC on the East Kalimantan shelf edge and the west slope of the Makassar straits. The article discusses the resolution and accuracy of Short-Offset Processed 3D Seismic Data (SOPS) and the applicability of the resulting Digital Terrain Models (DTM) for seabed mapping and initial field development planning.

The utilization of SOPS for seabed hazard evaluation in deep water has been steadily gaining popularity globally due to the SOPS DTMs regional coverage, sufficient resolution and accuracy for well planning and for initial oil field development design, availability of additional attributes such as seismic amplitude, phase and AVO, and relatively low cost. It is therefore of interest to better understand the resolution and accuracy of SOPS DTMs and their applicability and limitations for oil field exploration and development.

For this case study a SOPS DTM of 12.5x12.5 m grid spacing was generated covering a total area of 330 Km². A somewhat smaller area was later surveyed utilizing an Autonomous Underwater Vehicle (AUV). The resulting AUV DTM was of 1x1 m grid spacing. A number of exploration wells had already been drilled within the area and accurate water depth measurements had been performed from three of those wells. This provided the opportunity to evaluate the SOPS DTM accuracy and resolution. The results of the evaluation are presented in this paper.

Suitability of the SOPS DTM for Initial Planning of Seabed Facilities

Before we discuss in detail the accuracy and resolution of the SOPS DTM we present three examples of the SOPS DTM visualization:

[Figure 1](#) shows the Jangkrik NE (170 Km²) illuminated color coded SOPS DTM. A preliminary design of some of the seabed facilities is also shown. It can be seen that at 12.5x12.5 m grid spacing the SOPS DTM clearly depicts the seabed relief and all major seabed features such as the potentially unstable steep shelf edge, a terrace with rugged relief and exposed hard soils, terrace edge marked by steep slump scarps and canyon headwalls, seabed canyons with steep flanks and seabed slumps. The SOPS DTM is thus suitable for initial planning of seabed facilities.

[Figure 2](#) shows the color coded seabed gradient derived from the SOPS DTM. This visualization is useful as it maps areas of steep slope that can be an issue for drilling and for field development. The contrasting color boundary between white-blue and green-red colors was chosen at 6°, which in this case represents the maximum acceptable slope for exploration drilling.

[Figure 3](#) shows the color coded seabed seismic amplitude draped over the SOPS DTM of the Jangkrik Field (160 Km²). High seismic amplitudes are represented by red and yellow colors and mark the presence of coarse sediments deposited by debris flows within seabed canyons. Low seismic amplitudes are represented by shades of gray and correspond to soft clays covering the intercanion ridges.

Accuracy

In deep water SOPS DTMs are generally more accurate than DTMs from ship mounted multibeam echosounders (MBES). Better results can only be achieved by MBES operated close to the seabed as is the case with Autonomous Underwater Vehicle (AUV) mounted MBES. SOPS DTMs, however are much cheaper than AUV DTMs.

SOPS DTM accuracy depends on a number of factors, the most important of which are seismic data quality, accurate picking of the seabed horizon and accurate time-to-depth conversion. Seismic data quality depends on the water depth, on the seismic acquisition parameters, on acquisition quality and on the short-offset processing parameters. For example, picking of the seabed horizon in relatively shallow water and on very steep slopes may be difficult, may require significant manual correlation and may thus be of relatively low accuracy ([Figure 6](#)).

Accurate time to depth conversion depends on the accuracy and resolution of the velocity model used. As SOPS gains popularity it is expected that it will become common practice to acquire full water column velocity profiles during seismic data acquisition. Time to depth conversion accuracy can also be improved if the velocity model is calibrated by existing reliable water depth measurements such as from drill rigs and high quality echosounder measurements.

The 3D seismic data used for this case study was of good quality and the acquisition parameters were suitable for short-offset processing. A proprietary short-offset processing sequence was applied by PGS to improve the resolution of seabed imaging. Some of the data was acquired on the continental shelf where the water depth was too shallow for good quality seabed imaging ([Figure 7](#)). Additional uncertainty on the shelf was introduced by the presence of a soft unconsolidated mud layer at the seabed that was almost acoustically transparent within the available frequency range. In deeper water uncertainty was only introduced in areas of very steep slopes at the shelf edge and at the

terrace edge, at the flanks of seabed canyons and at fault and slump scarps. Outside of such areas the dominant factor defining water depth accuracy was time-to-depth conversion. On average the SOPS DTM accuracy was better than ± 2 m, better than IHO Survey Order 1a.

For time-to-depth conversion a sound velocity profile was derived from seabed stacking velocities picked at 100 ms interval through the full depth range throughout the study area. The velocity function was generated by statistically averaging a large number of individual velocity picks. This velocity function was found to be very accurate, only a 0.75% adjustment was needed to match the SOPS DTM to the water depth measured at three existing well locations. [Figure 11](#) shows the measured versus SOPS DTM water depth at the three well locations after adjusting the seismic velocities by 0.75%. A comparison was also performed between the SOPS DTM and the AUV DTMs. The results of those comparisons at the three wells are also shown in [Figure 11](#).

Assuming that the water depth measurements from the drill rig are the most accurate, it can be seen that the AUV depths are on average 0.71 m (0.16%) shallower than the drill rig and the SOPS depths are 1.26 m (0.30%) shallower. The average difference between the SOPS and AUV DTMs at the three well locations is only 0.55 m (0.13%), which raises a question about the accuracy of the drill rig water depth measurements. In any case all three difference pairs are less than 1.5 m, which is an excellent result given the water depth.

On [Figure 4](#) below, negative numbers indicate that the SOPS DTM is deeper than the AUV DTM (blue colors). Positive numbers indicate the reverse relationship (green, yellow and red colors). White color shows areas where the difference between the two DTMs is within ± 2 m.

The average difference between the two DTMs is less than 5 cm and the median difference is 38 cm. This is an excellent match and it confirms the high accuracy of the SOPS DTM and the relevance of using SOPS for seabed mapping in deep water. The standard deviation is less than 5 m, but that number is negatively affected by outliers on the shelf and terrace edges (Profile 2) and by errors in the AUV DTM (Profile 3). It can be seen on [Figure 5](#) that if these outliers and AUV DTM errors are excluded, the standard deviation decreases to less than 2 m.

[Figure 5](#) is a comparison between the SOPS DTM and the AUV DTM along Profile 1. It can be seen that the average difference between the two profiles is 35 cm, the median difference is 14 cm and the standard deviation is 1.74 m. It can be seen that deeper than approximately 450 m the seismic velocities are a bit too high resulting in a SOPS profile that at 750 m water depth is about 3 m deeper than the AUV profile.

[Figure 6](#) is a comparison between the SOPS DTM and the AUV DTM along Profile 2 across the shelf edge. Assuming that the AUV DTM is accurate, it can be seen that there is a large error in the SOPS DTM at the shelf edge. This error is due to uncertainty in picking the abrupt shelf edge from seismic data. It can also be seen that the error magnitude depends much more on the scarp height and steepness than on the water depth.

Vertical Resolution

It can be seen on [Figure 7](#) below that the Jangkrik SOPS has resulted in a clear seabed reflector with a dominant frequency of about 106 Hz. The first zero crossing of the seismic wavelet (green line) is used for seabed picking and provides better than 2 m vertical resolution (in this case at about 450 m water depth). This is approximately 1/8 of the dominant wavelength.

Horizontal Resolution

It can be seen on [Figure 8](#) that the theoretical horizontal resolution of the 3D migrated data used for this project is smaller than the 12.5 m bin size. Therefore the horizontal resolution is defined by the bin size. In reality a seabed feature would need to be at least a couple of 12.5 m x 12.5 m pixels or larger in order to be resolved. Therefore small pockmarks, boulders, etc. seabed features would not be imaged if they were smaller than about 25 m in length or in diameter. This is demonstrated by [Figure 9](#).

[Figure 10](#) illustrates the significant improvement of vertical seismic resolution that can be achieved by new broadband acquisition technologies that are gradually becoming mainstream. A SOPS broadband seismic DTM was not available to the authors, but it was felt reasonable to believe that, combined with a denser streamer separation of 75 m or less, there is potential also for improved horizontal resolution compared to the conventional SOPS DTM.

Conclusions

Within the Jangkrik and Jangkrik NE areas the Short-Offset Processed 3D Seismic DTM has:

- Approximately 25 m horizontal resolution
- Better than 2 m vertical resolution
- Average ± 2 m accuracy except on the shelf and on very steep slopes

Short-Offset Processed Broadband marine 3D seismic data will have even better resolution. Thus the SOPS DTM is suitable for initial field development planning and can reduce the time and cost for precision AUV surveys by limiting the AUV surveys to preferentially selected areas. Targeted AUV surveys can be conducted to accurately map steep slopes and small scale seabed features such as individual rocks, boulders, pockmarks, etc.

References

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Nenov N., D. Lundqvist, and S. Hay, 2011, Regional Interpretation of Shallow Geohazards from Deep Water 3D Seismic Data in the Makassar Straits, Indonesia: 35th IPA Conference in Jakarta, May.

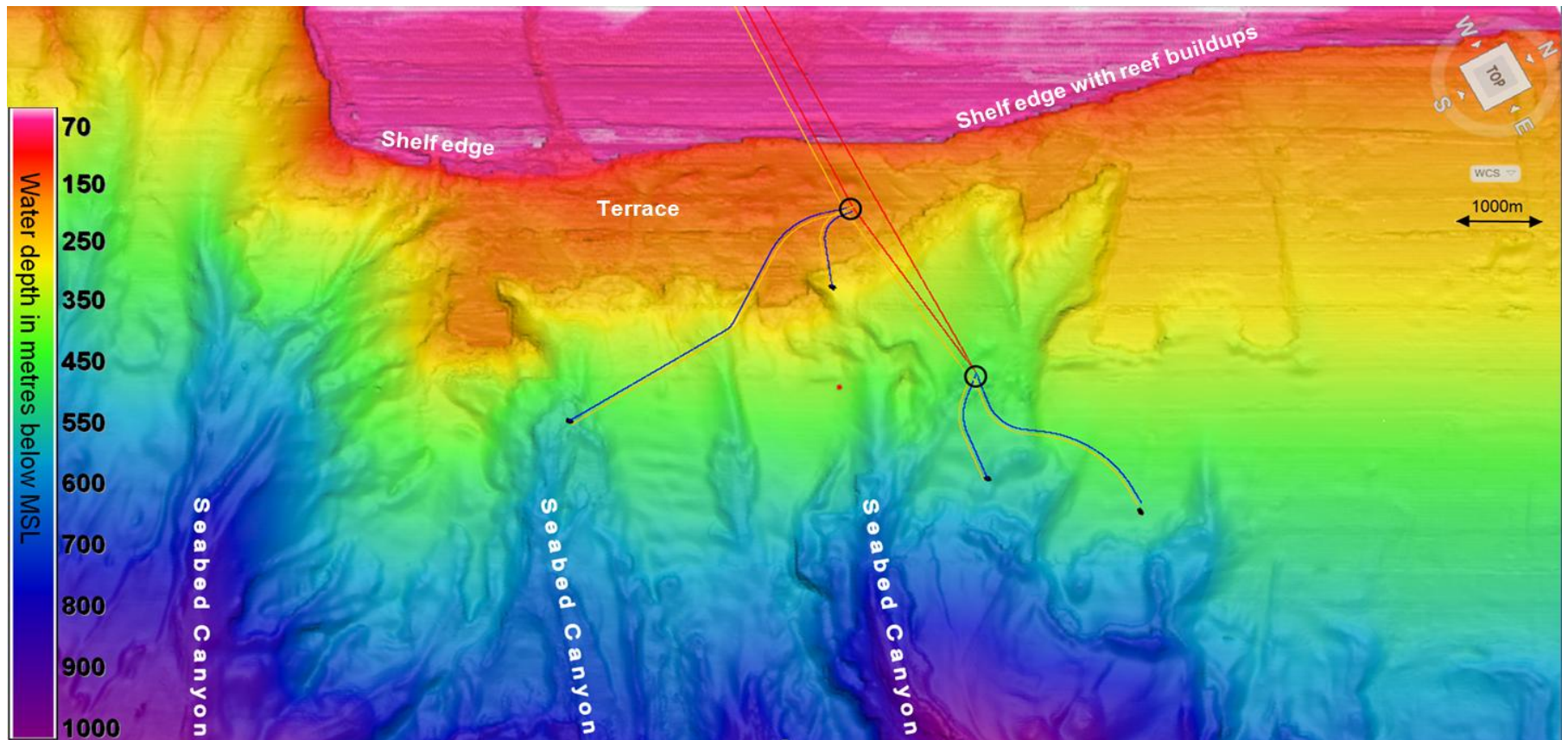


Figure 1. Jangkrik NE illuminated color coded Short-Offset Processed 3D Seismic (SOPS) Digital Terrain Model.

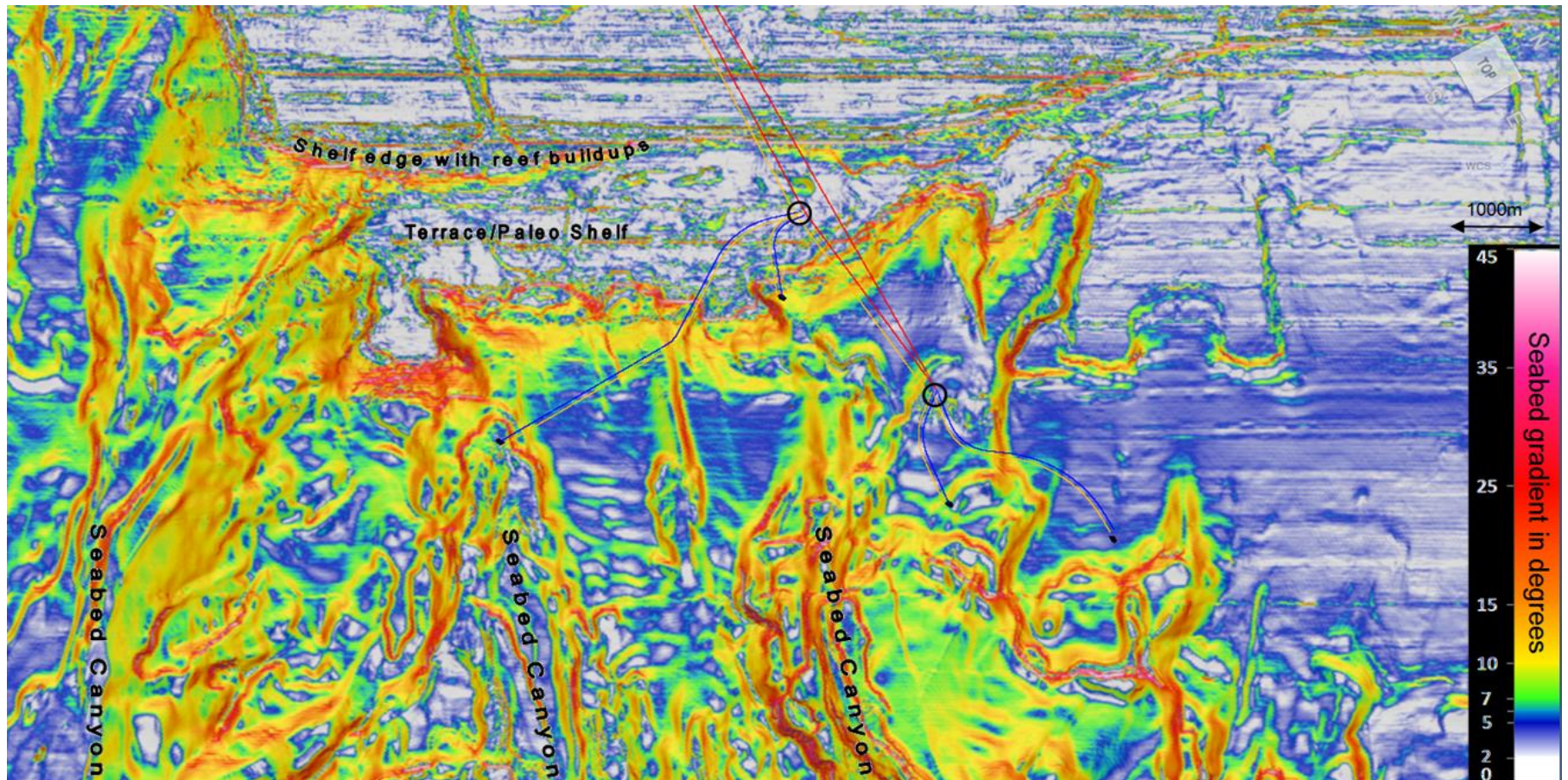


Figure 2. Jangkrik NE color coded seabed gradient derived from the SOPS Digital Terrain Model.

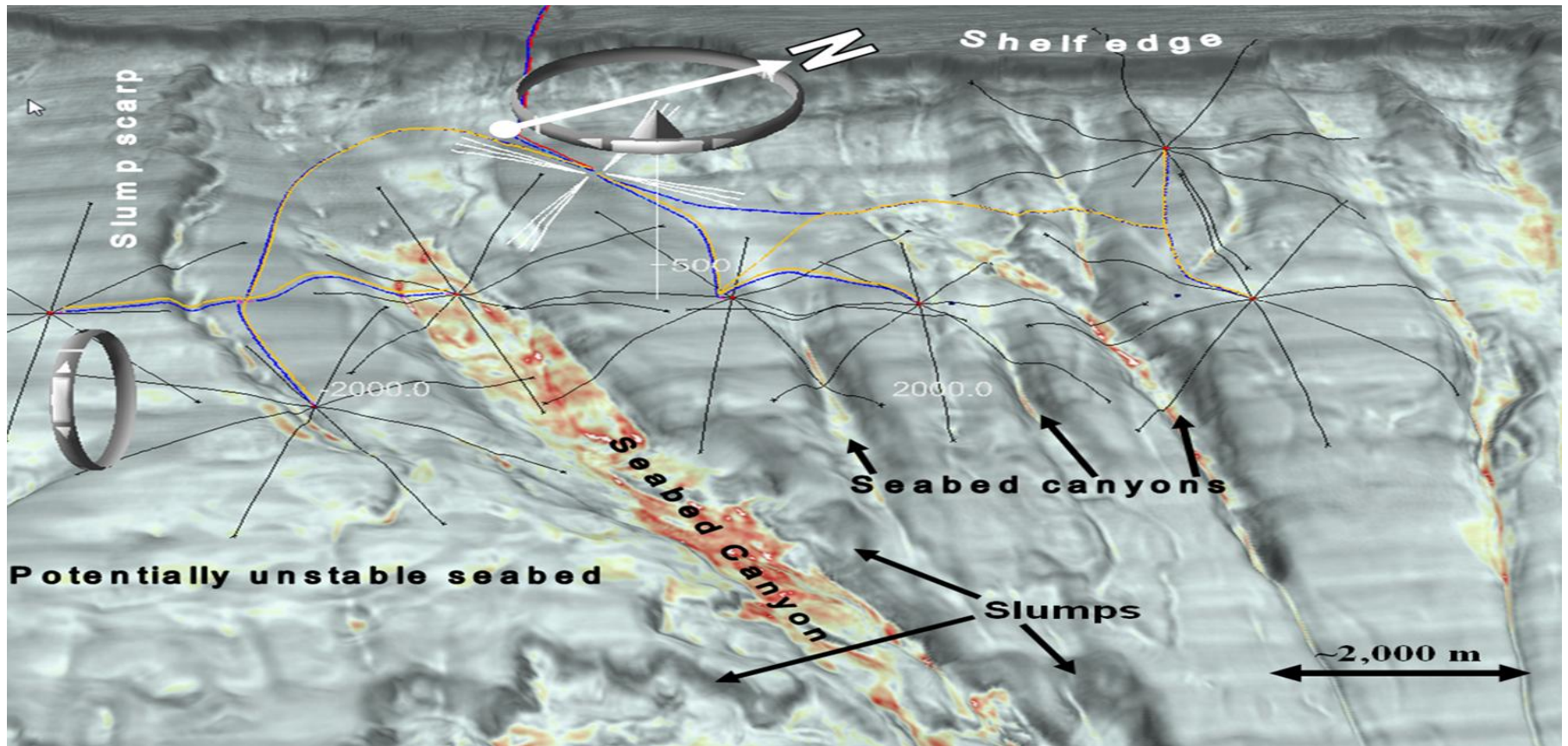


Figure 3. Color coded seabed seismic amplitude draped over the SOPS Digital Terrain Model of the Jangkrik Field.

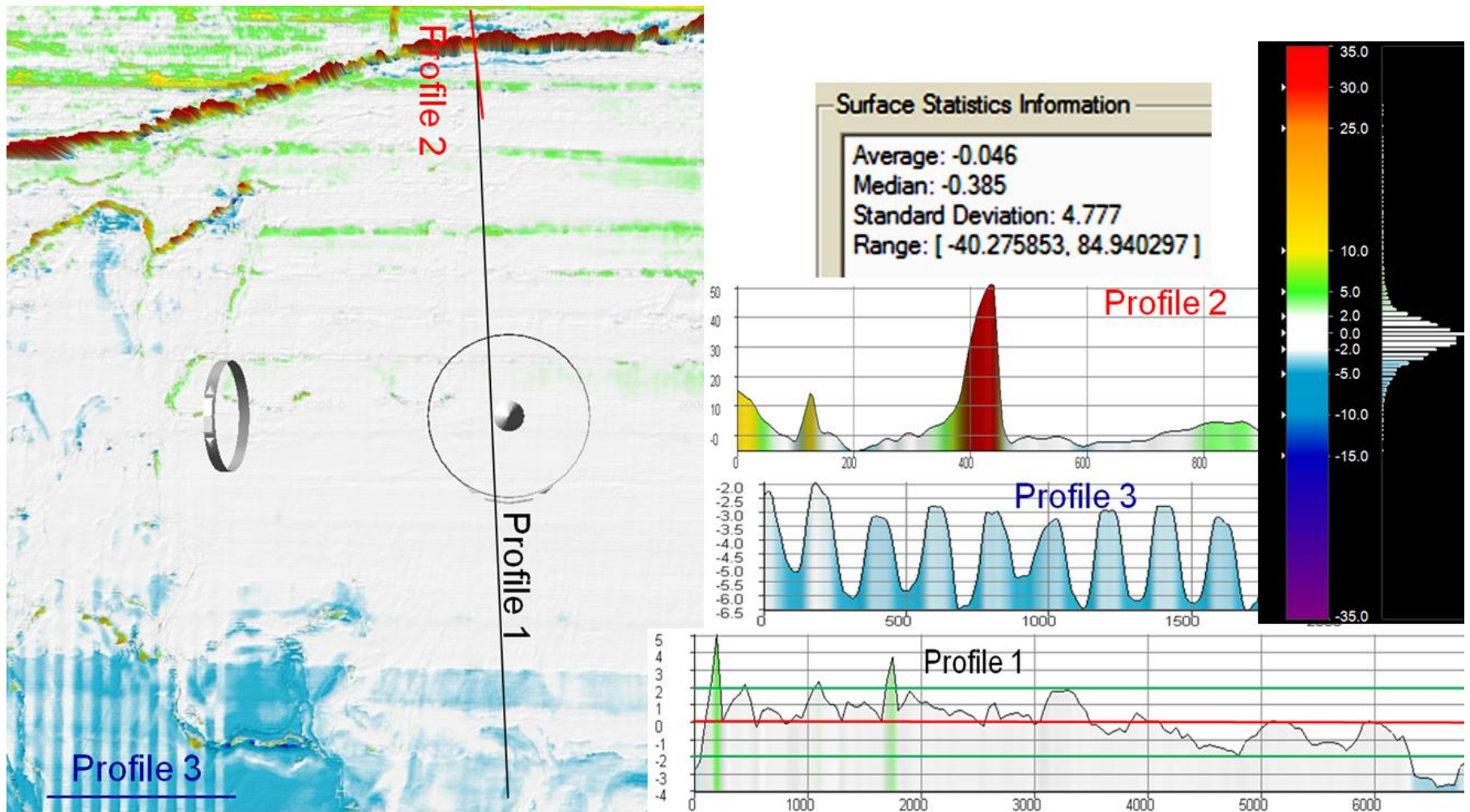


Figure 4. Jangkrik NE difference Digital Terrain Model (SOPS – AUV).

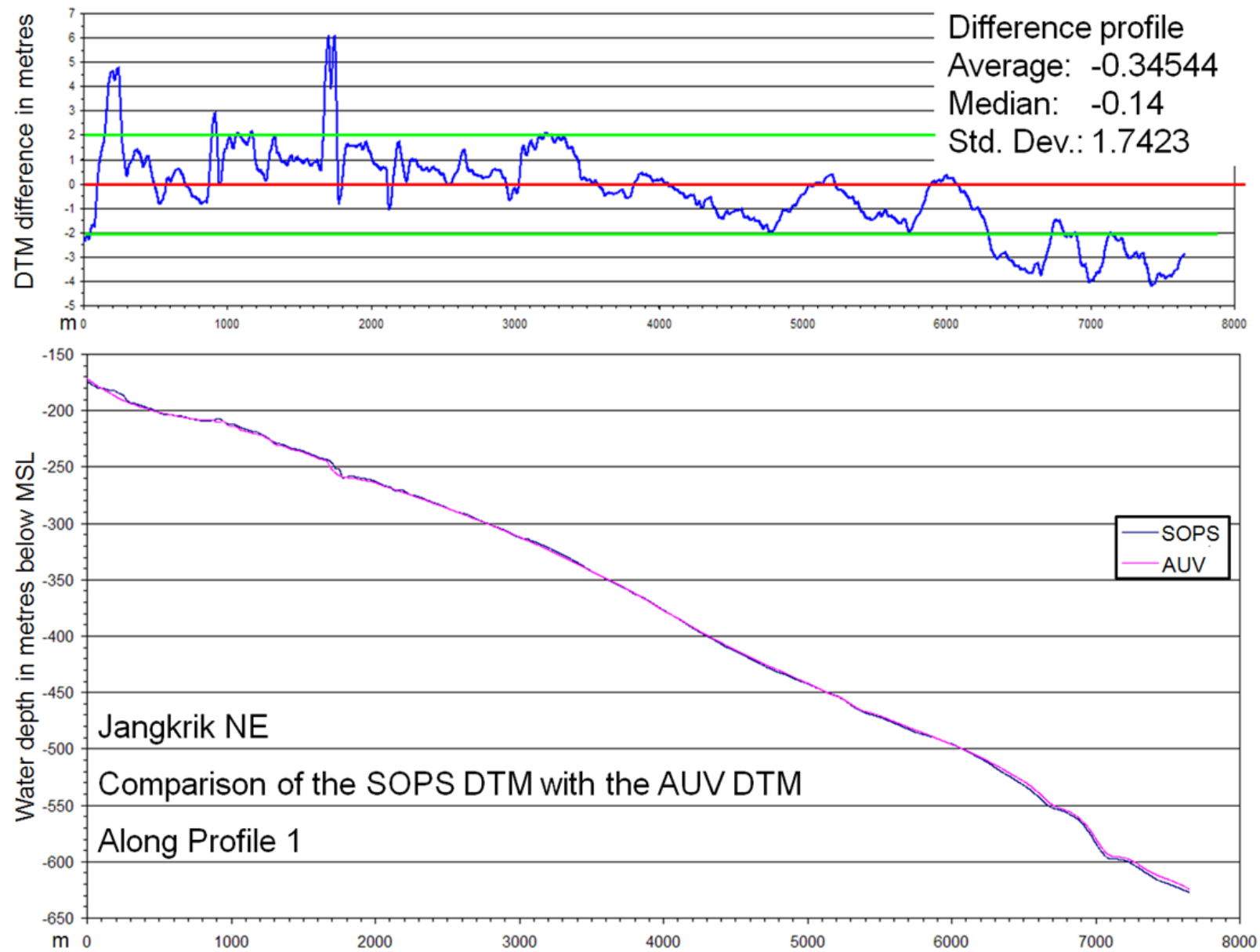


Figure 5. Comparison between the SOPS Digital Terrain Model and the AUV Digital Terrain Model along Profile 1.

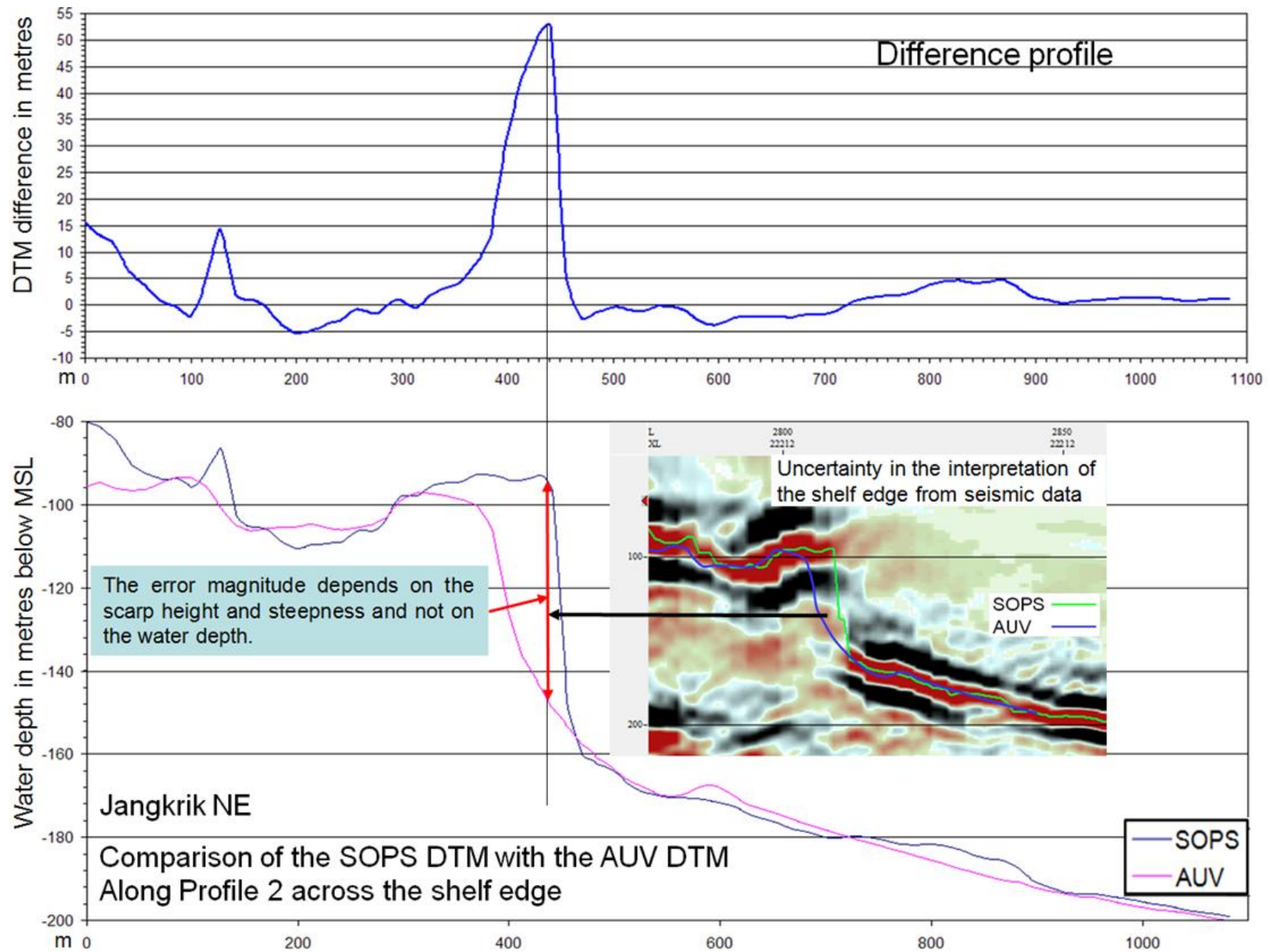


Figure 6. Comparison between the SOPS Digital Terrain Model and the AUV Digital Terrain Model along Profile 2 across the shelf edge.

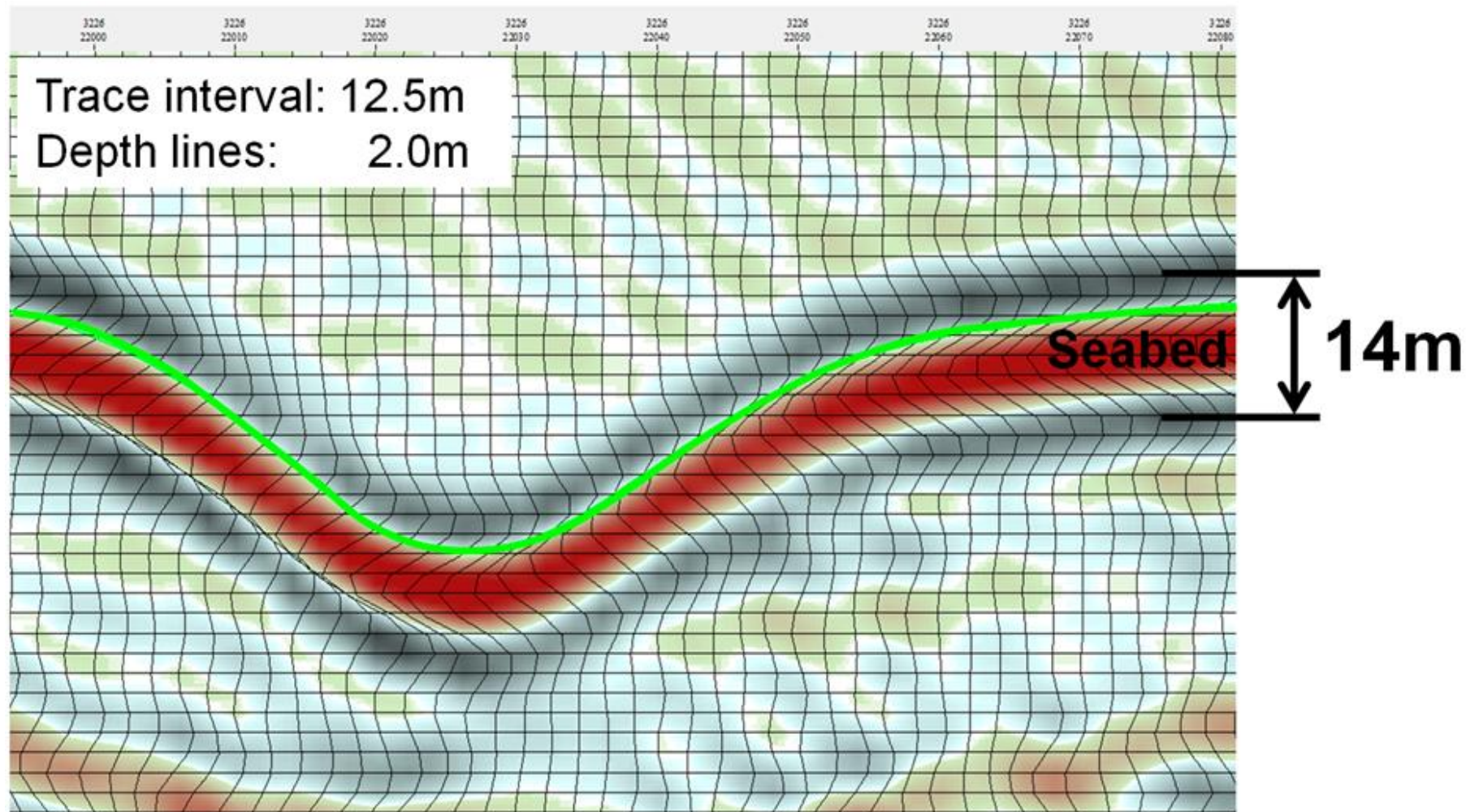
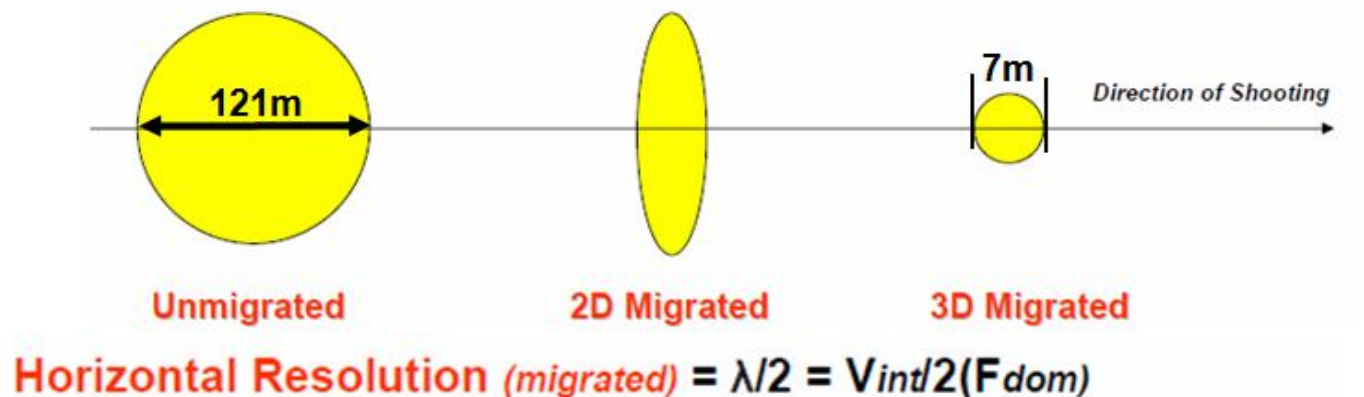


Figure 7. Jangkrik SOPS seabed reflector at approximately 450 m water depth.

Horizontal Resolution

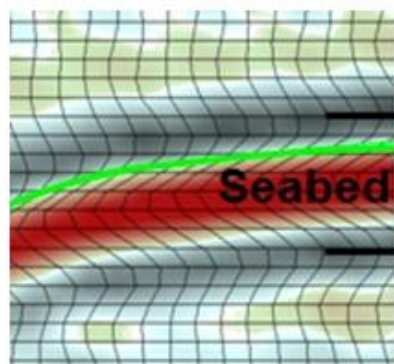
Migration Collapses the Fresnel Zone:



where: λ = wavelength of dominant frequency

V_{int} = interval velocity

F_{dom} = dominant frequency



14m

→ Horizontal Resolution (migrated) = $\lambda/2 = 7m$

Figure 8. Jangkrik SOPS horizontal resolution at approximately 450 m water depth.

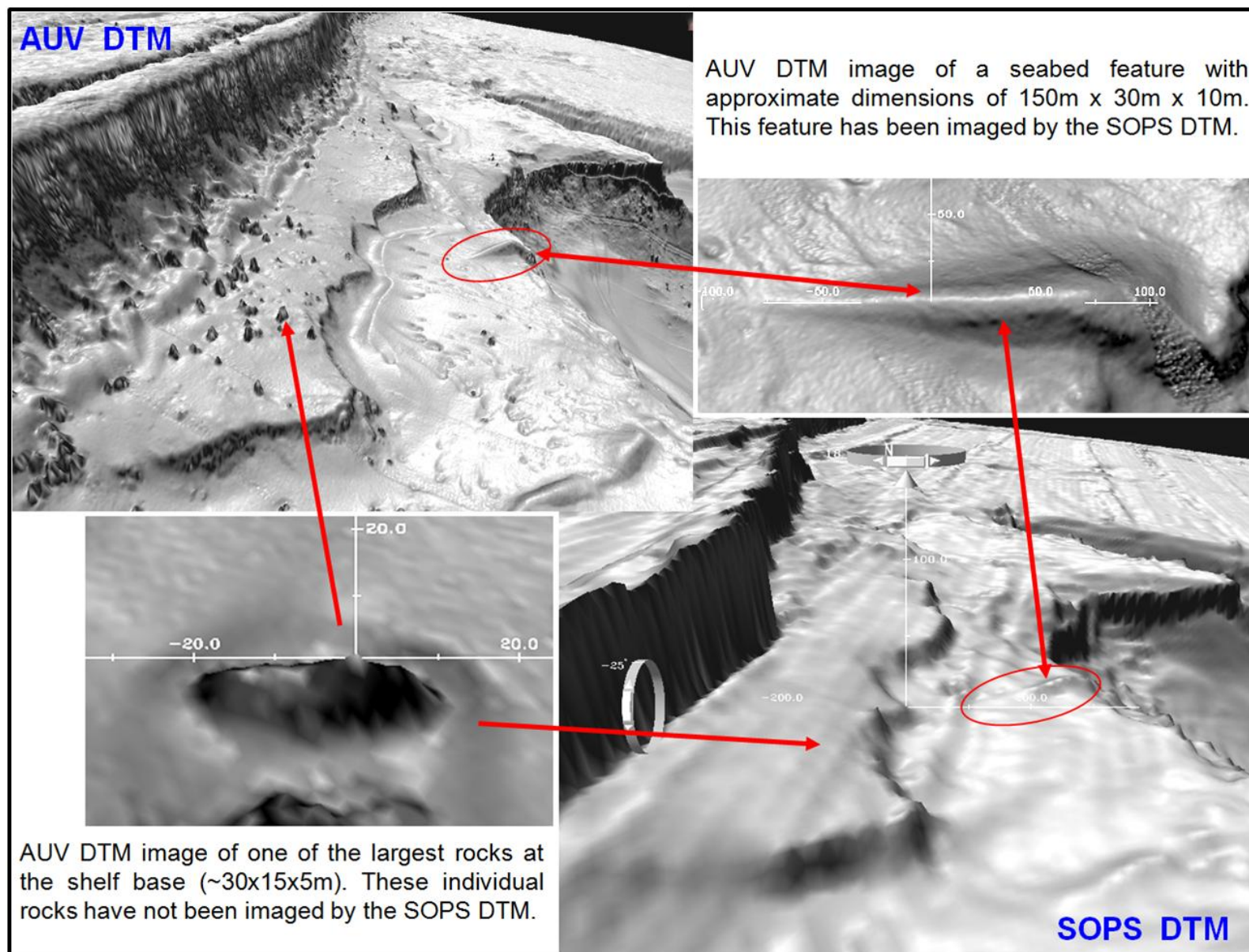


Figure 9. Comparison of the SOPS and AUV Digital Terrain Models (DTM). The SOPS DTM grid spacing is 12.5 m x 12.5 m and the AUV DTM spacing is 1.0 m x 1.0 m. Both images were generated by draping the color coded seabed gradient over the illuminated seabed DTM.

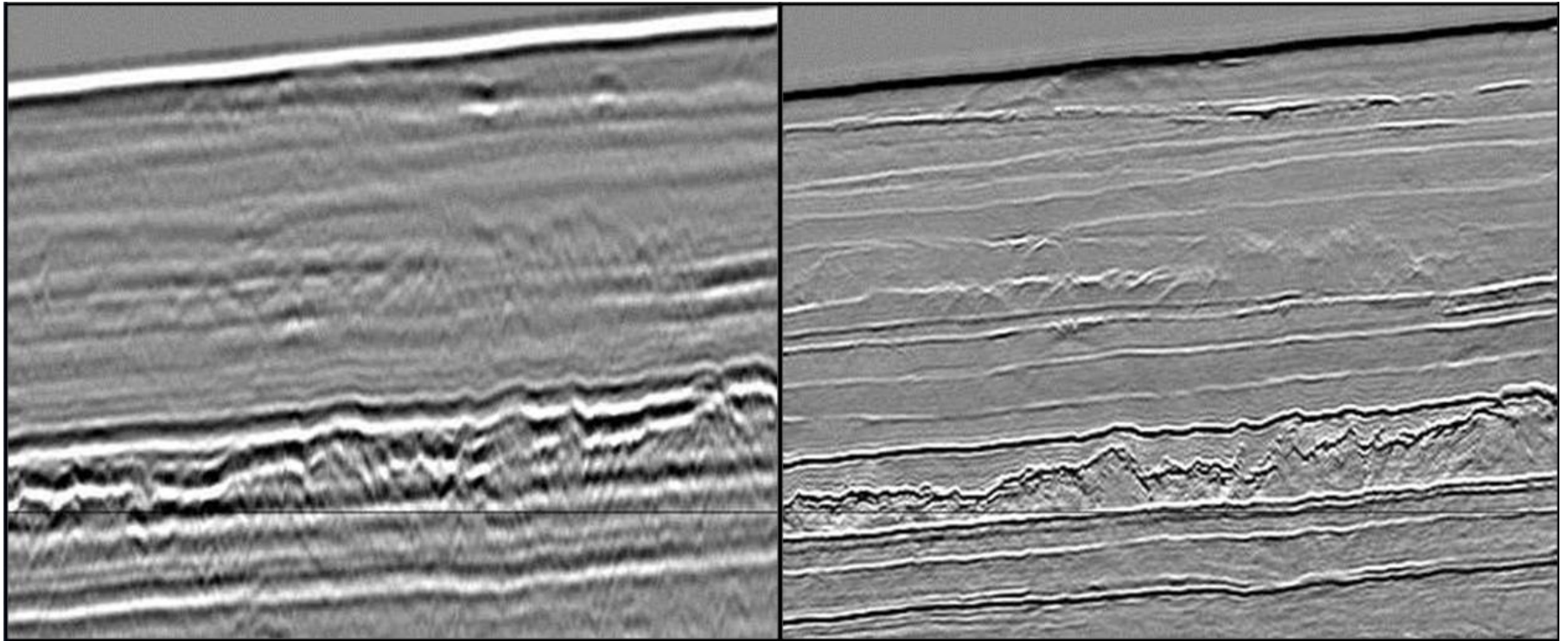


Figure 10. Example of true broadband data resulting from the precise de-ghosting of both the receiver ghost (via dual-sensor streamer) and the source ghost (via time and depth distributed source array).

Depth MSL	1	2	3	
Rig [m]	439.82	423.00	416.00	
SOPS [m]	439.72	420.92	414.41	
AUV [m]	438.52	422.82	415.36	Average
Rig-SOPS [m]	0.10	2.08	1.59	1.26
Rig-SOPS [%]	0.02%	0.49%	0.38%	0.30%
AUV-SOPS [m]	-1.20	1.90	0.95	0.55
AUV-SOPS [%]	-0.27%	0.45%	0.23%	0.13%
Rig-AUV [m]	1.30	0.18	0.64	0.71
Rig-AUV [%]	0.30%	0.04%	0.15%	0.16%

Figure 11. The measured versus SOPS Digital Terrain Model (DTM) water depth at the three well locations after adjusting the seismic velocities by 0.75%. A comparison was also performed between the SOPS DTM and the AUV DTMs.