EGU23-7610

Submarine cable drifting and landslide investigation based on ship noise recorded by seismometer

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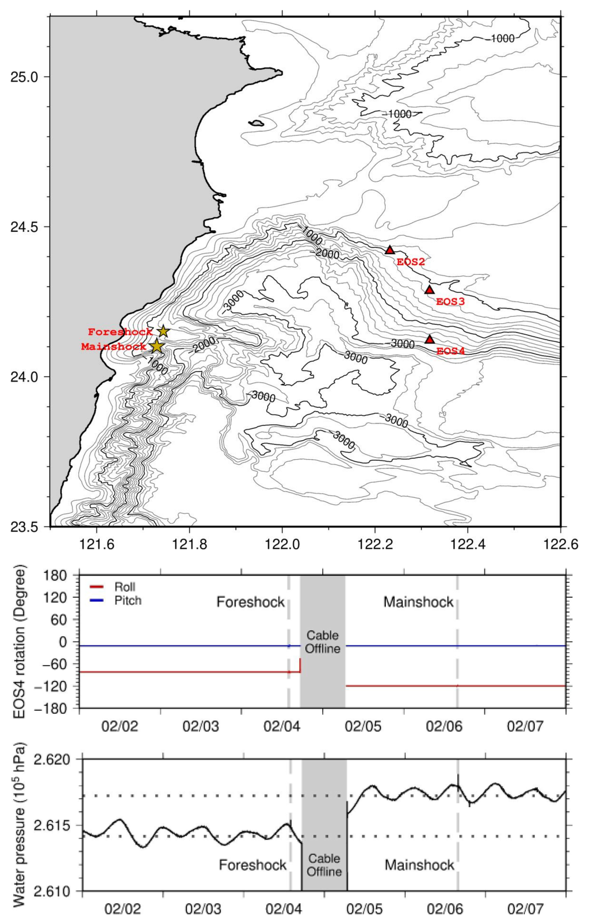
Abstract

After the Ml 5.8 Hualien earthquake occurred the 4 February 2018, the power of the submarine cable seismic and tsunami observation system of Taiwan's Central Weather Bureau (CWB) has been shut down for several days, and the attitude of one of the OBS, EOS4, shown 37° rotation and an increase of pressure by an equivalent of 4 meters in depth were observed after the power restoration. To find the actual position of this station, we applied the method of Trabattoni et al. (2020), which calculated the cepstrum based on the time difference between the direct and first reverberation wave of ship noise. However, the flat seabed assumption in this approach may not be suitable for EOS4 which is characterized by a dramatic topography variation. In our study, we developed a Fortran program to calculate the travel time curve by incorporating bathymetry variation and compared it with the result obtained by using active sources to assess the applicability of the program. The result shows the bathymetry variation does affect the OBS relocation. Apart from the position difference, the time difference between the observed and theoretical cepstrum curves could also be induced by bathymetry variation. In addition, the signal strength is related to the roughness and the material characteristics around the reflection point. To investigate the drift of EOS4, we select the AIS data of cargo ships within a radius of 30 km from the EOS4 for two different periods, which are 2/1-2/4 15:00 and 2/6-2/15, before and after the 2018 ML 5.8 earthquake, respectively. We select 27 and 76 ship traces significant signals. The minor change in the lateral direction of the cepstrum (i.e. horizontal distance) shows that the site location after the earthquake did not drift significantly, but the 0.2s time difference in the vertical direction of the cepstrum (i.e. travel-time; Tau) indicates that the site has been buried, which is in agreement with the pressure change of the station. The energy ratio of the hydrophone and the vertical channel of seismometer decreases at relatively lower frequencies and increases at higher frequencies. This phenomenon also supports our estimation. In addition, based on the cepstrum obtained from the ship tracks for a different direction, we obtained the time difference distribution in two dimensions, which may provide another constrain for bathymetry variation monitoring.

Introduction

EOS4 is an inline cable seismometer port of the Taiwan earthquake early warning system, located on the NW Taiwan ocean slope area. During the period between the foreshock and mainshock of 2018 Hualien earthquake, its attitude was rotated 37° clockwise and the pressure increased by around 4 m.w.d. To relocate its position, we used the noise of ship sailing as the sources.

Unlike seismic data, ship noise is a continuous signal that is difficult to separate into distinct phases. Therefore, previous studies used the similarity in characteristics between direct wave and first reverberation wave, which can be shown on the cepstrum, to calculate the travel-time difference, and to relocate the instruments. However, these studies simplified the influence of bathymetry, so we incorporate it as a parameter in our study.



(Guo and Lin., 2020)

Figure 1. (Top) Locations of the OBSs and the 2018 Hualien earthquake. (Bottom) Tiltmeter and pressure gauge plots of the EOS4 station.

Method

Source term * propagation term

$$x(t) = s(t) * g(t)$$

Fourier spectral density (spectrum):

$$|X(f)|^2 = |S(f)|^2 |G(f)|^2$$

Log spectrum:

$$log|X(f)|^2 = log|S(f)|^2 + log|G(f)|^2$$

Cepstrum: computing the IFT of the logarithm

$$C_X(\tau) \equiv \mathcal{F}^{-1}[\log|\mathcal{F}[x(t)]|^2]$$

$$C_X(\tau) = C_S(\tau) + C_G(\tau)$$

Direct path and first reverberated path:

$$g(t) = \alpha_d \delta(t - t_d) + \alpha_\gamma \delta(t - t_r)$$

$$G(f) = \alpha_d \exp(-j2\pi t_d f) + \alpha_r \exp(-j2\pi t_r f)$$

$$|G(f)|^2 = \alpha_d^2 + \alpha_r^2 + 2\alpha_d \alpha_r \cos(2\pi(t_r - t_d) f)$$

$$log|G(f)|^2 \approx log|\alpha_d^2 + \alpha_r^2| + \frac{2\alpha_d \alpha_r}{\alpha_d^2 + \alpha_r^2} \cos(2\pi\tau_{dr} f)$$

$$\tau_{dr} = t_r - t_d \ \text{(fundamental frequency)}$$

(Ferguson et al. , 2019)

The ship noise signal can be considered as the convolution of the source term s(t) and the propagation term g(t), and the intensity of the latter can be regarded as the intensity sum of direct wave α_d and first reverberation wave α_γ, both have similar waveforms. In addition, periodically occurring signals in similar frequency band can be clearly observed in cepstrum. Therefore, the time difference between two waves τ_{dr} can be differentiated after removing the source term $C_S(\tau)$.

The travel time of the first reverberation wave is determined by water depth and slope of the reflection point, which may result in multiple paths with similar arrival times.

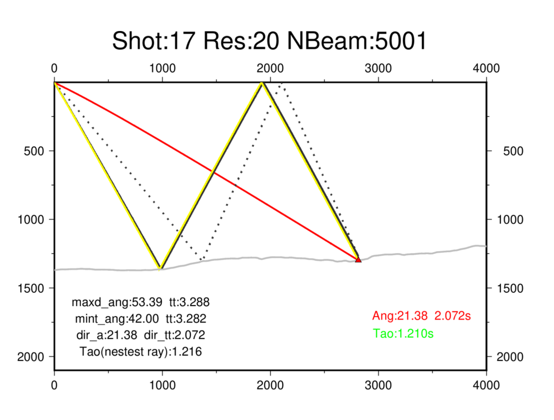


Figure 2. Two different propagation paths of ship noise in water column. Red and gray lines show the direct wave and the first reverberation wave, respectively. Yellow line represents the shortest path of the first reverberation wave.

Circular Seismic Survey

We use circular active-sources experiment for the calibration. The relocation of the OBS is performed based on the calculation of direct wave travel time by using a equivalent velocity for 1.51 km/s and the cepstrum with a flatten seabed condition. The result shows a drift distance of 145 m to the SW of the initial OBS position, with a rms of 4.7 ms by using the direct way. However, the result obtained from beamforming using the cepstrum method indicates an obvious difference (bright area in Fig. 2 Right).

Comparing the cepstrum intensity calculated with flat seabed to that with the theoretical travel time, the overall trend is similar, but some regions show less noticeable intensity (Fig. 3). In addition, there is also a slight shift in the slope towards the northeast direction of the seamount. According to the results of circular seismic survey, the influence of seabed topography on this method can be summarized as follows:

1. The relatively shallower seabed causes a decreased τ. Therefore, when using a flat seabed model for beamforming, it will cause a biased result towards the high bathymetry of the reflection point.
2. The surface condition (such as particle size, roughness, and slope) near the reflection point can affect the signal strength on the cepstrum when the distance is close.
3. The discrepancy between the observed and theoretical τ in the range of shot 350 - 400 indicates that the actual size of the seamount is larger than that observed from the bathymetry.

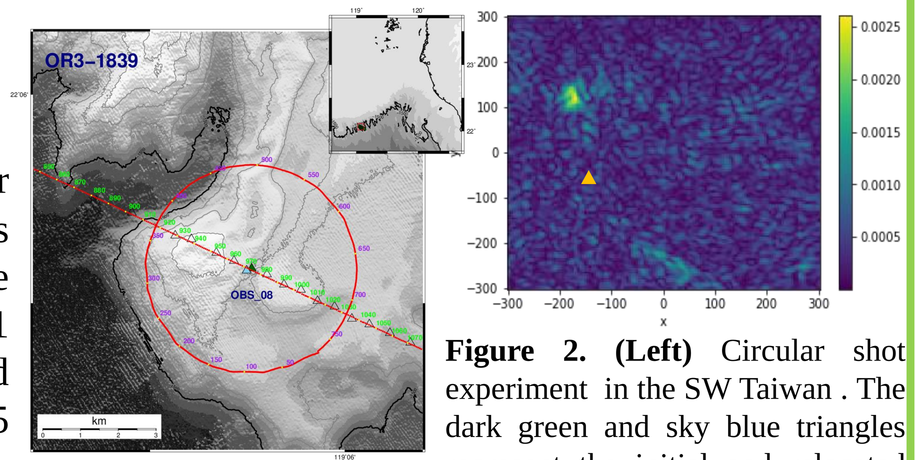


Figure 2. (Left) Circular shot experiment in the SW Taiwan . The dark green and sky blue triangles represent the initial and relocated locations of OBSs, respectively.

(Right) Intensity distribution relocated while relocating OBS with beamforming. The relocated location (the brightest area) is to the NW of the initial location which is different from the result of direct wave method (yellow triangle).

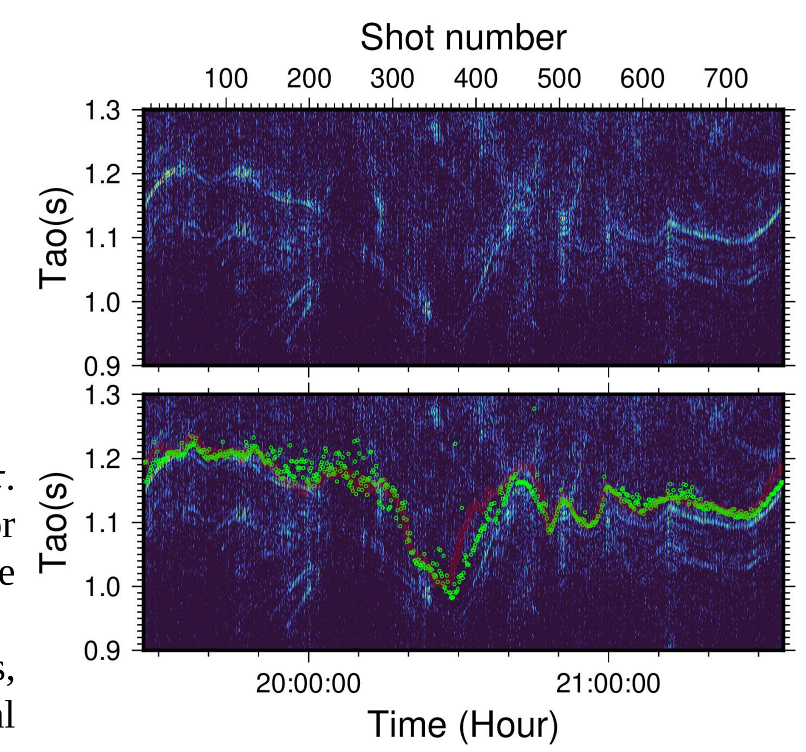


Figure 3. (TOP) Raw cepstrum intensity plot. **(Bottom)** After applying the theoretical travel times. The green circles represent the results by the Bellhop model, while the red line represents the data measured without considering the influence of slope on reflection.

CWB EOS4

To compare the differences before and after the event, the tracks of cargo ships within a radius of 30 km from the site during two time periods, from February 1st to February 4th 15:00 and from February 6th to February 15th were selected. Due to the limitations of shipping routes, most ships have a northeast-southwest direction of travel. There were a total of 89 and 291 ship tracks during the two time periods, respectively.

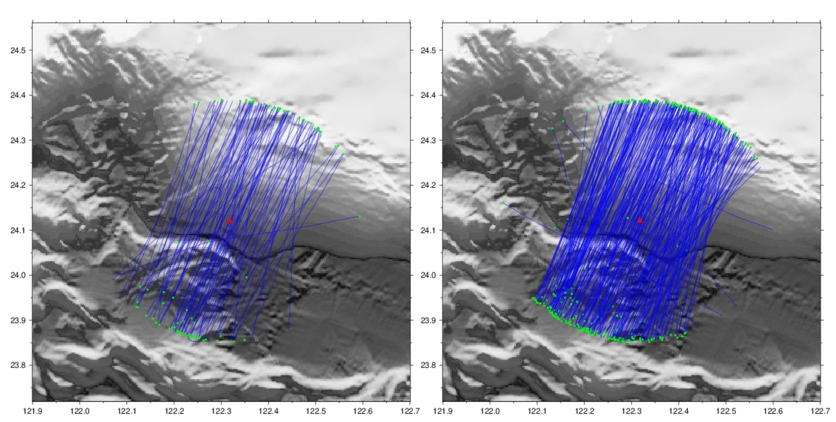


Figure 4. (Left) The track map of 89 paths within a radius of 30 kilometers from the EOS4 station since February 1st to February 4th 15:00. The green dots indicate the starting points of the paths. **(Right)** 291 tracks from February 6th to February 15th.

Site Location

Overall, there was minimal variation in the horizontal displacement of the station position between the two periods. The paths close to the station are expected to receive higher energy due to the near-vertical incidence angle. However, for most of the recorded tracks, the energy from the reflection point near the station is not clearly observable. Additionally, there is a decrease of approximately 0.2 seconds in τ values during the post-earthquake time period.

The decreased τ indicates that the path of the reflected waves has become shorter, suggesting that either a shallower depth of the reflector or of the receiver. This is contrary to the result of the pressure gauge recording an increase in depth by four meters.

Combining the energy loss and the spectral changes in H/V (hydrophone-to-vertical) ratio in the two periods, we speculate that there may have been a landslide or turbidity current passing through the station, resulting in sediment burial and causing such phenomena to occur.

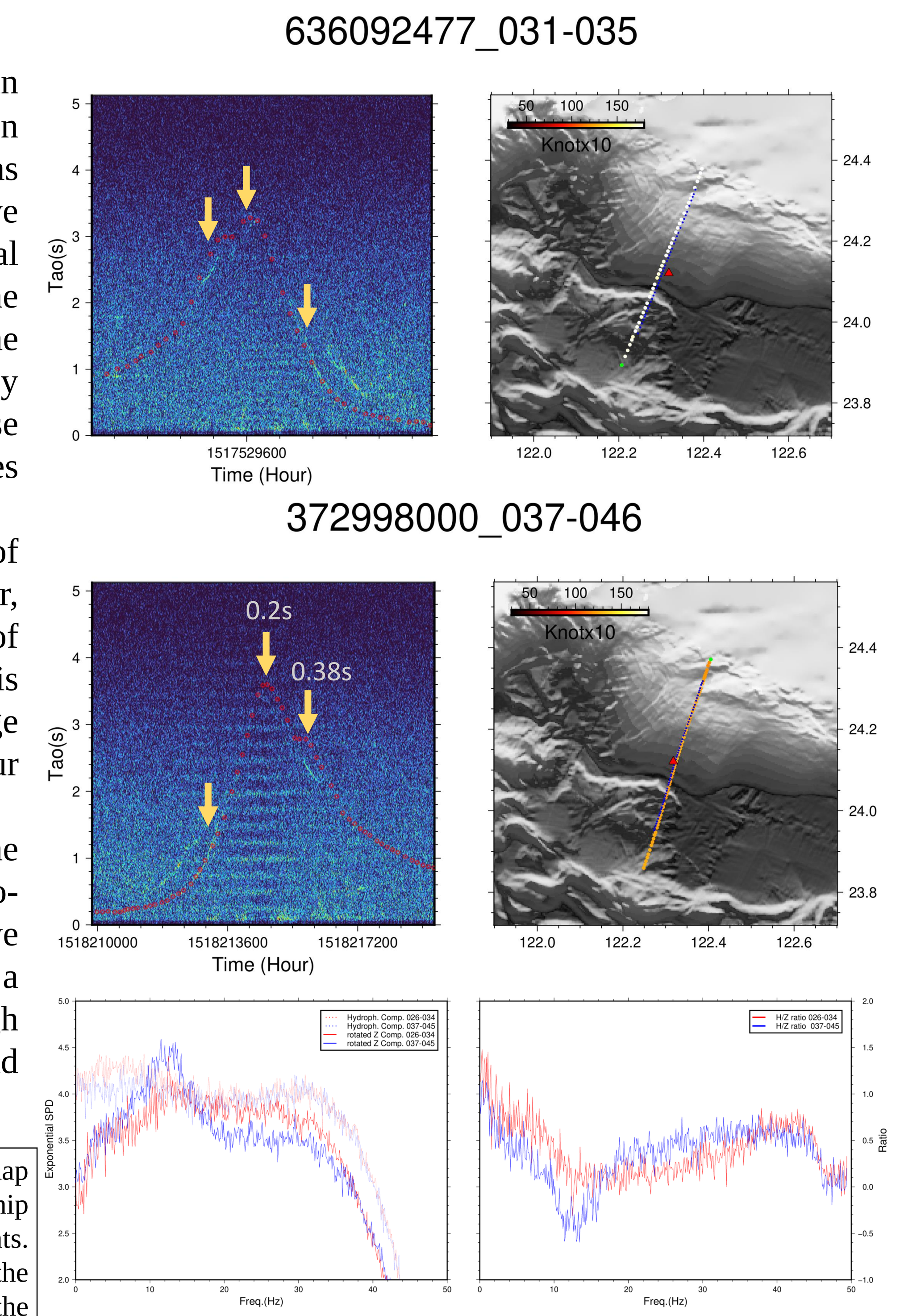


Figure 5. (TOP) The cepstral intensity and track map before the event. The color dots of track show the ship speed and small blue dots represent the reflected points. **(Middle)** The cepstral intensity and track map after the event. **(Bottom)** The spectra and H/V ratio along the vertical axis and hydrophone axis for two time periods.

τ different

Before the event, at the southeast foot of the slope near the station, the actual height of the canyons was higher than the bathymetry model. This may indicate that the accumulation of debris from the landslide was not caused by a single earthquake event.

On the other hand, there is a slight increase in τ in the northwest direction of site, indicating a deeper water depth. These two signs may indicate the directionality of underwater landslides.

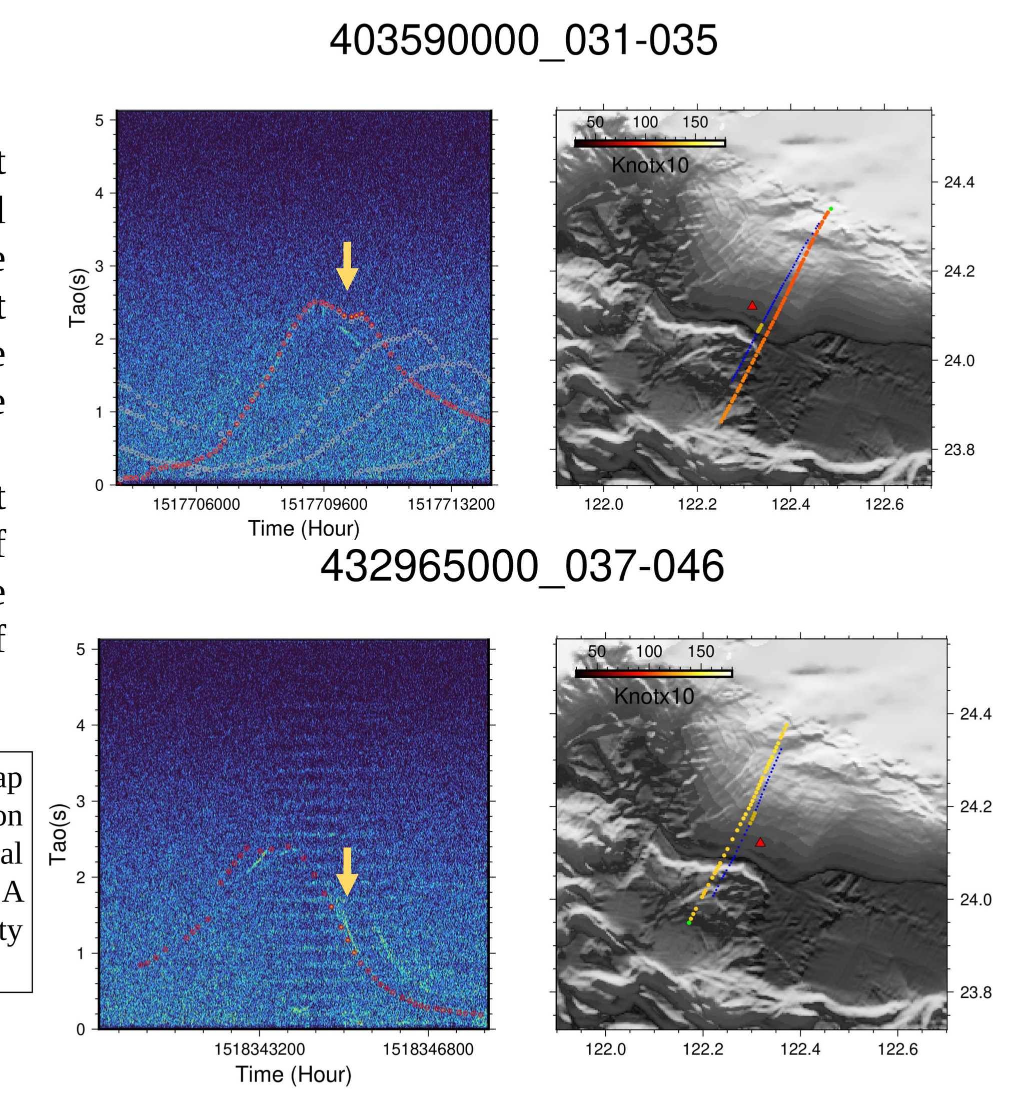
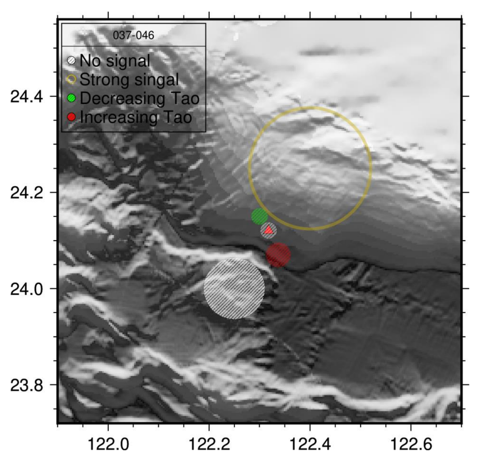


Figure 6. (TOP) The cepstral intensity and track map before the event. The khaki dots indicate reflection points with abnormal τ values. **(Middle)** The cepstral intensity and track map after the event. **(Bottom)** A distribution map was generated to the abnormal intensity and τ values.

Conclusions

1. The influence of bathymetry on localization was discussed, showing how local changes in seabed can affect the results of localization.
2. Local variations in travel times indicate changes in local bathymetry, which can be used to monitor alterations in nearby seabed, such as landslides or turbidity currents.
3. Comparing images from different time periods may reveal temporal changes over time.



Reference

Ferguson, Eric L., Stefan B. Williams, and Craig T. Jin. "Improved multipath time delay estimation using cepstrum subtraction." *ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, 2019.

Trabattoni, A., et al. "Orienting and locating ocean-bottom seismometers from ship noise analysis." *Geophysical Journal International* 220.3 (2020): 1774-1790.

Kuo, Ban-Yuan and Lin, Ching-Ren(2020)氣象局海底觀測網地震與傾斜儀資料之整合分析 (Report in Chinese). Central Weather Bureau, Taiwan