Determination of the shallow S-wave velocity structure and sediment thickness offshore central Chile using Distributed Acoustic Sensing

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ABSTRACT

1. CONTEXT

✧ From **October to December 2021**, we recorded thousands of earthquakes in **central Chile** along a 150km fiber-optic cable[1] (red line in Fig. 1). Using **Distributed Acoustic Sensing** (DAS), we obtained dense and long-distance measurements of ground deformation, with the equivalent of **37500 virtual seismic sensors**.

✧ Offshore central Chile, the **Valparaiso Forearc Basin** (VFB) is a significant geological feature that contributes to the complexity of the region. The basin is bounded to the north by the **Punta Salinas Ridge** (PSR). The fiber crosses several canyons with highly variable sediment thickness along its path.

✧ We estimated both the **thickness** and **S-wave velocity** of sediments beneath the DAS fiber using strain-rate recordings for twenty local earthquakes.

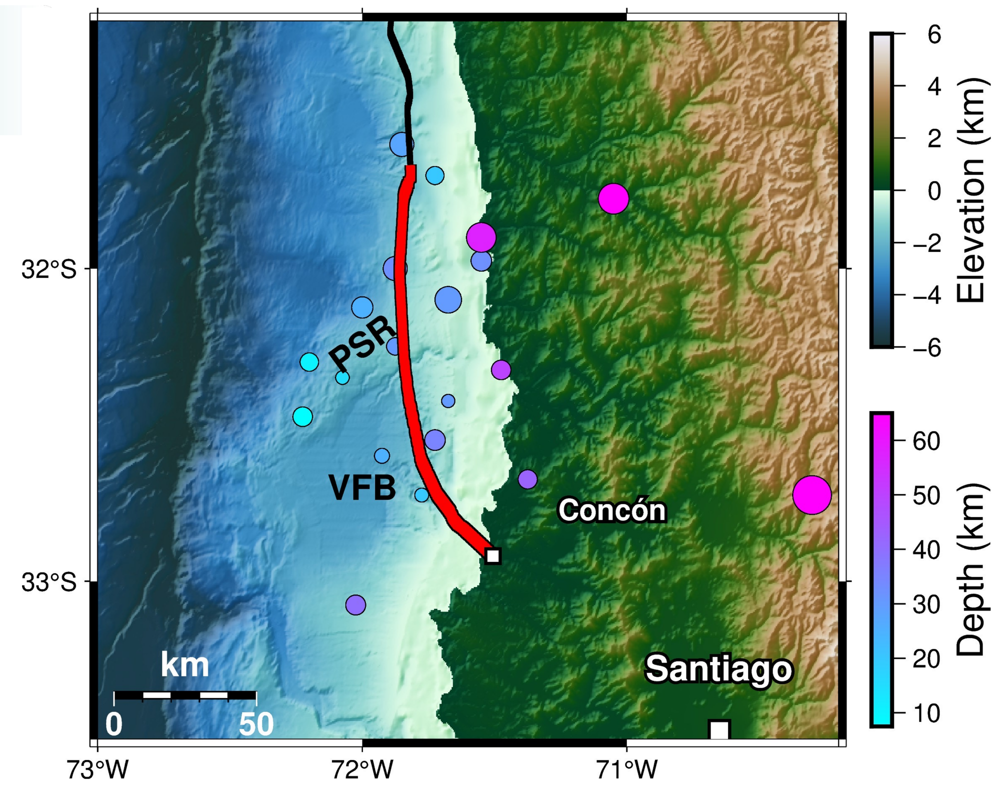


Figure 1: Central Chile map and DAS deployment with a frequency sampling of 125Hz and a spatial sampling of 4.08m. Coloured circles correspond to the earthquakes used in this study (from Ml1.9 to Ml5.6).

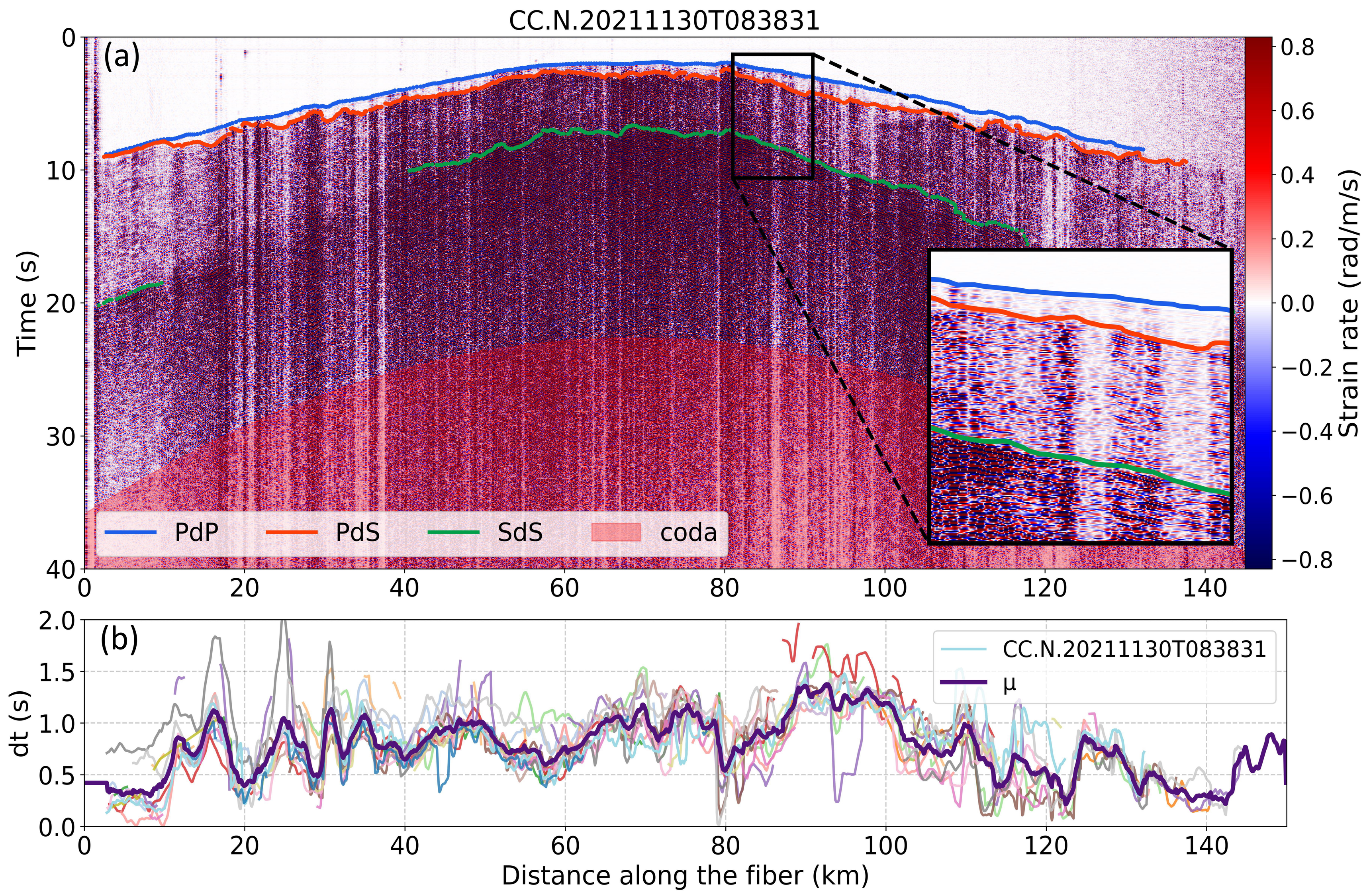
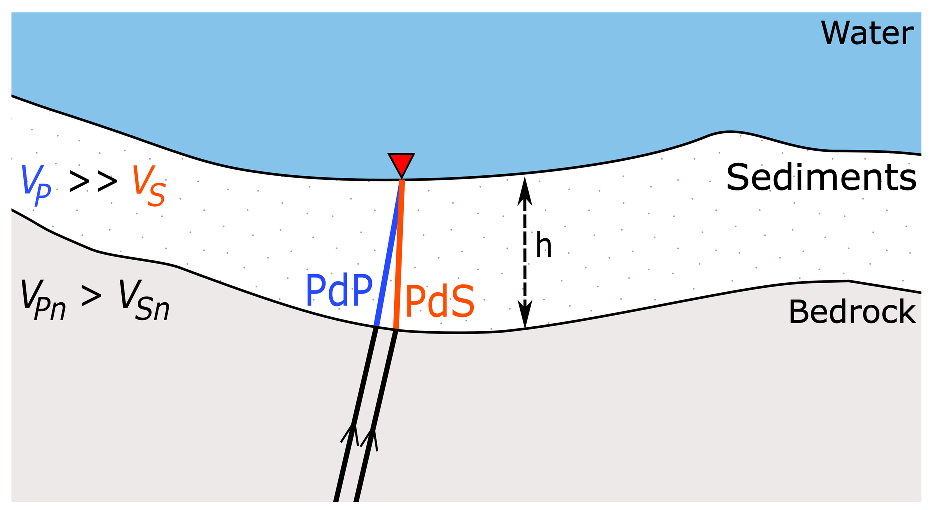


Figure 2: (a) Strain-rate of an earthquake that occurred on 11/30/2021 at 08:38:31 (UTC+01:00). Data decimated in time and space by a factor 5 and bandpass filtered between 0.5 and 25 Hz. (b) Travel time delays (dt) between the PdP and PdS phases converted at the bedrock/sediment interface.

2. TRAVEL TIME DELAY DUE TO SEDIMENTS

✧ We measure the **travel time delay** (dt) within the sediment using the travel time difference between the **direct PdP-wave** and the **converted PdS-wave** at the bedrock/sediment interface:



✧ Arrival times of the PdP, PdS and SdS are manually picked (Fig. 2a).

✧ dt is stable over the 20 earthquakes and can be used to **estimate sediment thickness and S-wave velocity** along the fiber-optic cable[2] (Fig. 2b).

3. SURFACE WAVE VELOCITY MEASUREMENTS

✧ The **seismic coda**, composed of highly scattered waves, is selected after the arrival of the SdS phase (Fig. 2a). It is used to identify the **fundamental mode** of the **Rayleigh wave phase velocity** on Frequency-Wave Number (FK) diagrams (Fig. 3).

✧ We generated FK diagrams for **2km** sections along the entire fiber, using a sliding window of **500m** (289 FK diagrams in total).

✧ We manually picked the lower dispersion curves to minimize the error due to the azimuth of the source[3].

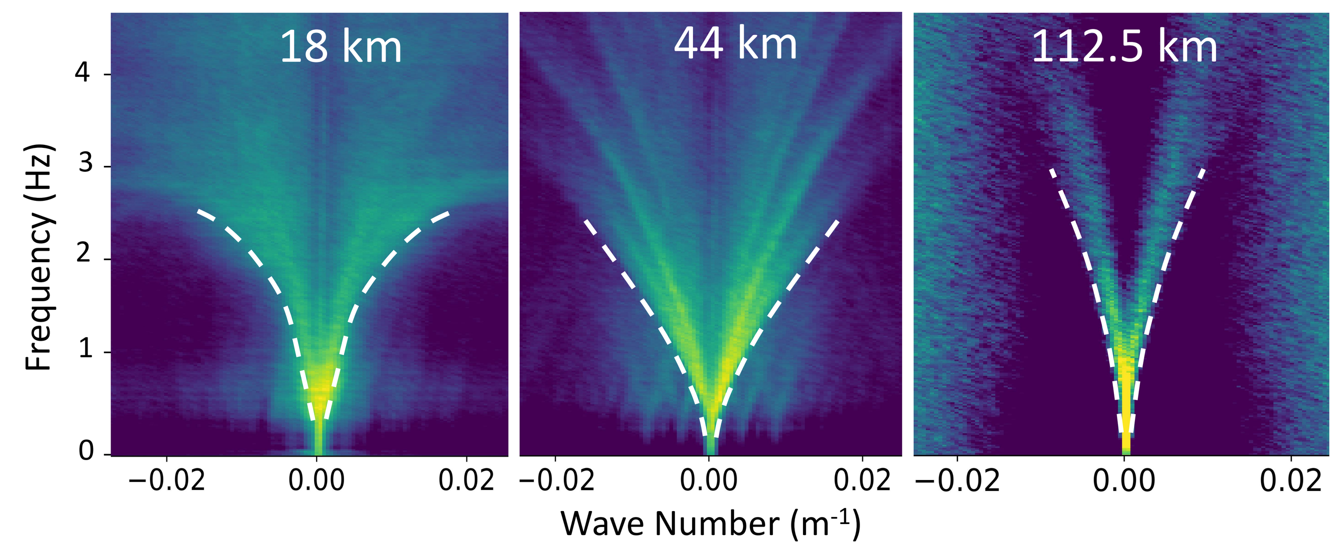


Figure 3: The fundamental mode, given by the lower frequency curve, has been manually picked, frequencies range from 0.2 Hz to 6Hz.

4. JOINT INVERSION OF THE SURFACE WAVE VELOCITIES AND TRAVEL TIME DELAYS

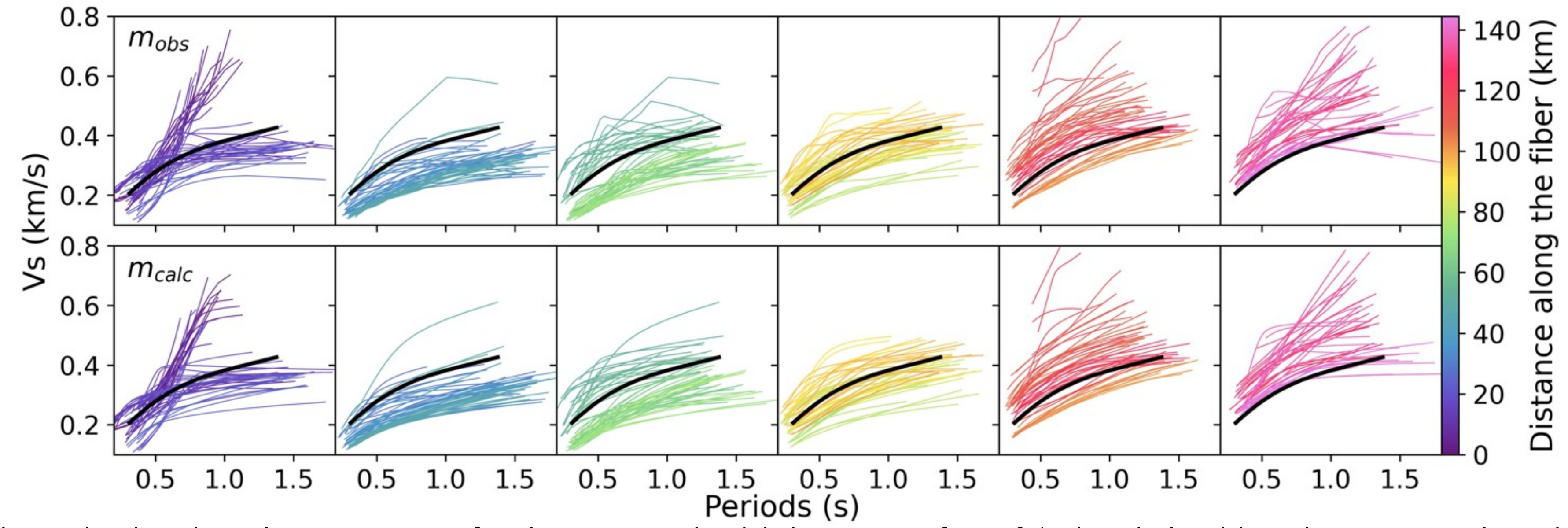
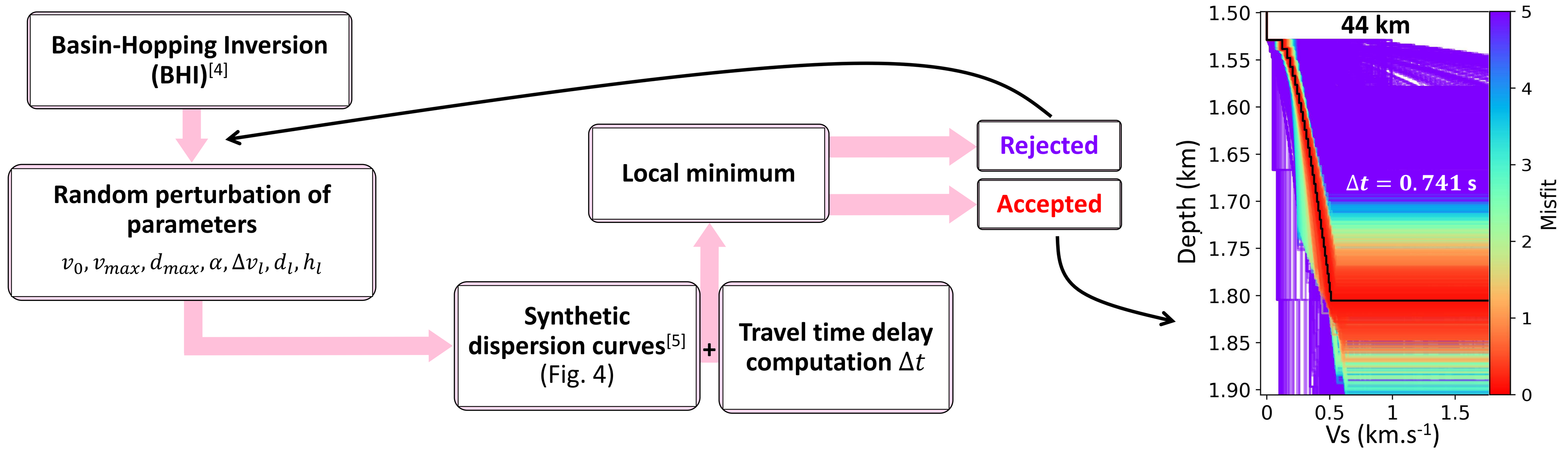


Figure 4: Comparison between observed and synthetic dispersion curves after the inversion. The global average misfit is ~0.1. The calculated Δt is always recovered exactly.



5. 2D VELOCITY MODEL

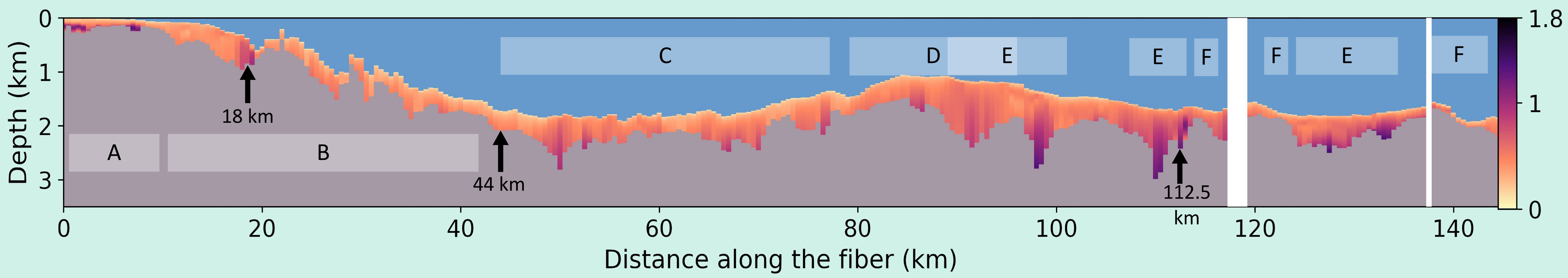


Figure 5: The final 2D velocity model is constructed by merging results of the 1D inversions every 500m. The blue area represents the sea. The minimum and maximum velocities of the sediment layers implemented in the inversion are set to 30m/s and 3500m/s respectively. The velocity in the bedrock layer (grey area) is set to 3500m/s.

Ⓐ **Continental shelf:** thin layer of sediments with high-velocity.

Ⓑ **Continental slope:** sediments filling up to 500m at the base of a steep relief with increasing velocity. Steep reliefs are located all along the slope.

Ⓒ **Edge of the VFB:** sedimentary deposits are present but do not clearly define the basin feature.

Ⓓ **PSR:** sedimentary incision by the canyon bordering the VFB. The PSR is divided between a thin sedimentary layer and sediment accumulation (basin-like).

Ⓔ **Basin features**, filled with higher velocity sediments.

Ⓕ Very thin layer of low-velocity sediments along small reliefs.

CONCLUSION

✧ The results show **significant differences** in **thickness** and in **Vs** along the cable, with values consistent with an **unconsolidated sediment layer.**

✧ The developed methodology confirms the potential of DAS for subsurface imaging purposes.

Next step: to image the sedimentary structure along a 300km cable to the north of this cable.

REFERENCES: [1]Baillet, M., et al.: A workflow for building an automatic earthquake catalog from near-real time DAS data recorded on offshore telecommunications cable in central Chile., (EGU 2024), [Session SM2.2]; [2]Trabattoni, A., et al.: Accounting for shallow sedimentary layers for accurate earthquake localization using submarine Distributed Acoustic Sensing, (EGU 2024), [Session SM2.2]; [3]Rivet, D., et al.: New perspectives on crustal imagery leveraging offshore submarine fiber optic cables, (EGU 2024), [Session SM5.2]; [4]Wales, D. J. & Doye, J. P. K. Global Optimization by Basin-Hopping and the Lowest Energy Structures of Lennard-Jones Clusters Containing up to 110 Atoms. J. Phys. Chem. A 101, 5111–5116 (1997). [5]Herrmann, R. B. Computer Programs in Seismology: An Evolving Tool for Instruction and Research. Seismological Research Letters 84, 1081–1088 (2013).