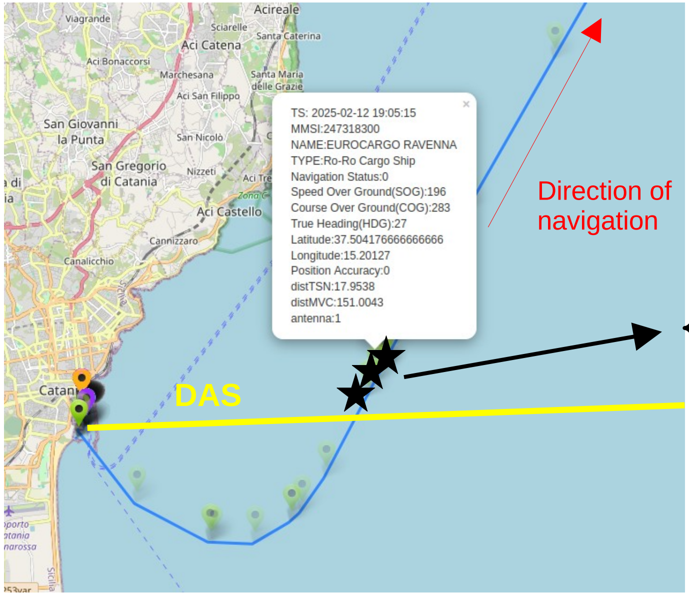
Frequency – wave-number (f – k) analysis of ships

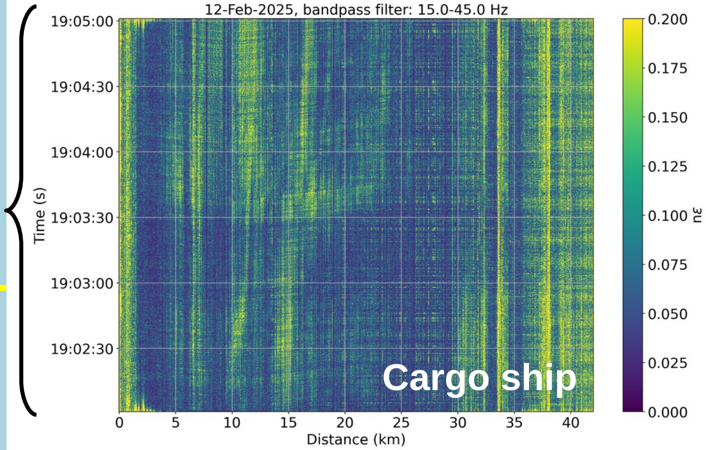
- **What?** Decomposition of different signals in the f – k domain with different apparent velocity ($v_{app} = f/k$)
- **Why?**
  - Denoise signals
  - Get relative orientation between the signal and the cable (angle + direction of the wave propagation)
  - Track moving signals (ships, whales, etc)
- **How?**
  - 2D FFT in time and space of DAS data
  - $v_{app} = v_{true} / \cos \theta$, where v_{app} is higher for higher v_{true} ($0º \leq \theta \leq 90º$),

    considering $v_{true} = 1.5$ km/s => relative orientation of an underwater acoustic signal

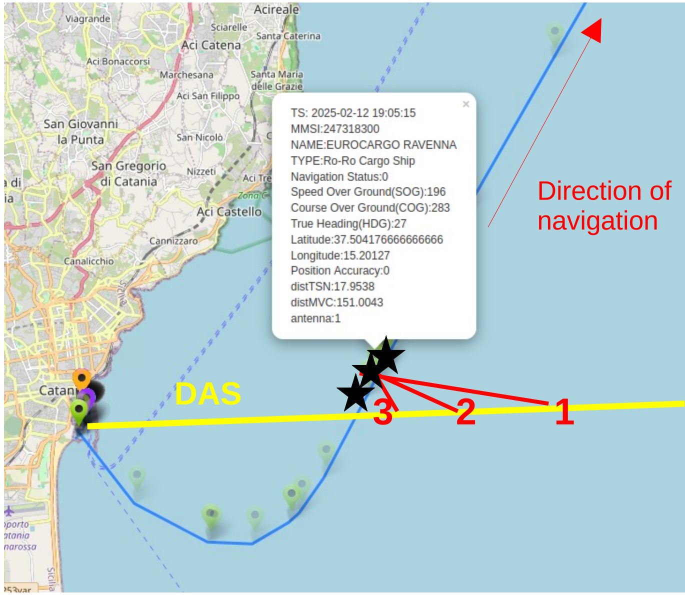
AIS (automatic identification system) positioning data



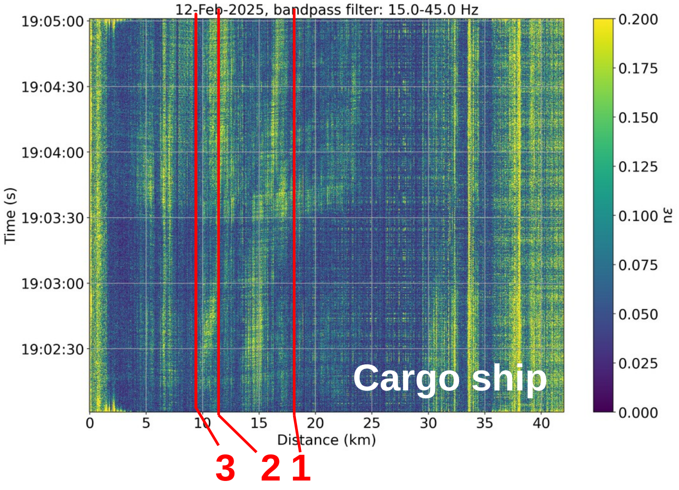
Time – Distance plot



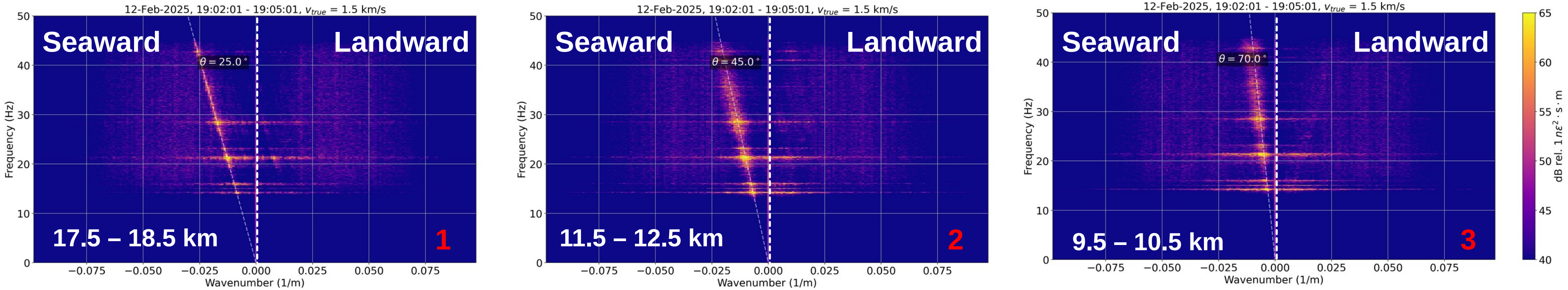
AIS (automatic identification system) positioning data

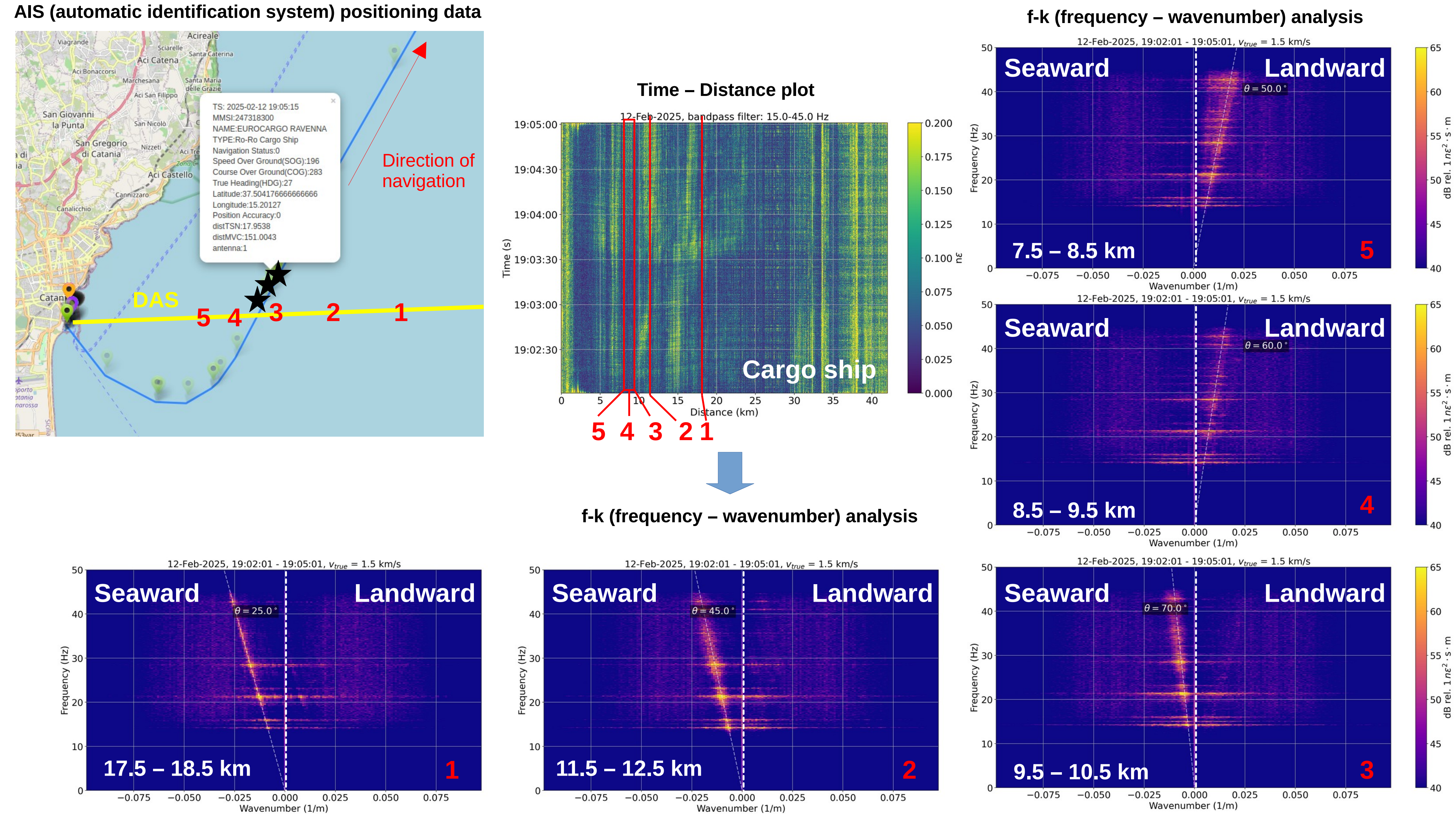


Time – Distance plot

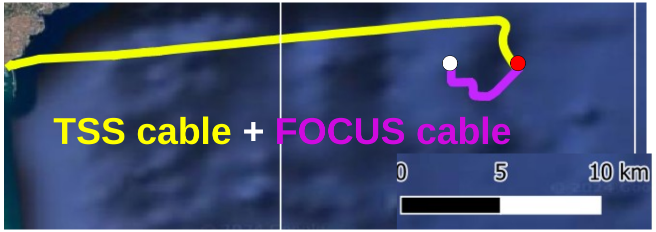


f-k (frequency – wavenumber) analysis

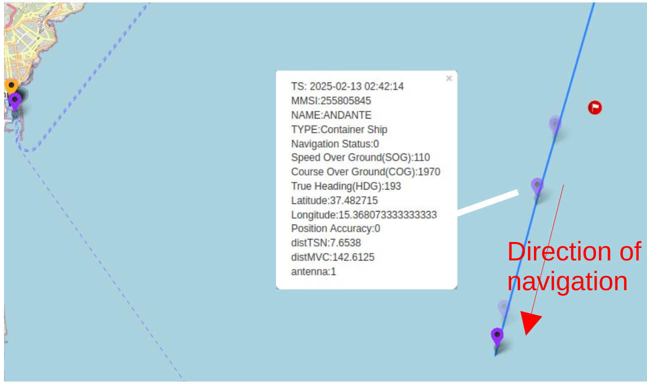


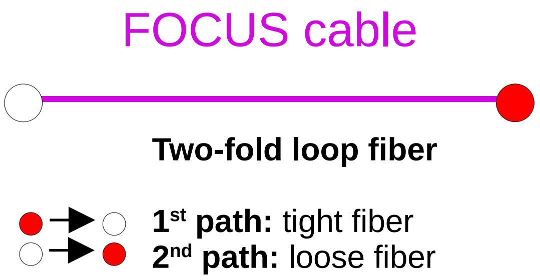


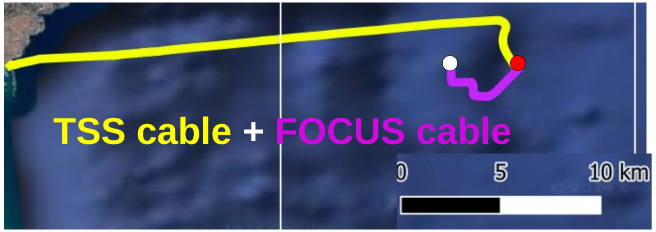
AIS (automatic identification system) positioning data
TS: 2025-02-12 19:05:15
MMSI:247318300
NAME:EUROCARGO RAVENNA
TYPE:Ro-Ro Cargo Ship
Navigation Status:0
Speed Over Ground(SOG):196
Course Over Ground(COG):283
True Heading(HDG):27
Latitude:37.504176666666666
Longitude:15.20127
Position Accuracy:0
distTSN:17.9538
distMVC:151.0043
antenna:1
Direction of navigation
DAS
5 4 3 2 1
Time – Distance plot
12-Feb-2025, bandpass filter: 15.0-45.0 Hz
Time (s)
Distance (km)
Cargo ship
nε
5 4 3 2 1
f-k (frequency – wavenumber) analysis
12-Feb-2025, 19:02:01 - 19:05:01, v_{true} = 1.5 km/s
Seaward
Landward
$\theta = 25.0°$
17.5 – 18.5 km
1
$\theta = 45.0°$
11.5 – 12.5 km
2
$\theta = 70.0°$
9.5 – 10.5 km
3
$\theta = 60.0°$
8.5 – 9.5 km
4
$\theta = 50.0°$
7.5 – 8.5 km
5
Frequency (Hz)
Wavenumber (1/m)
dB rel. 1 $n\varepsilon^2 \cdot s \cdot m$



AIS (automatic identification system) positioning data

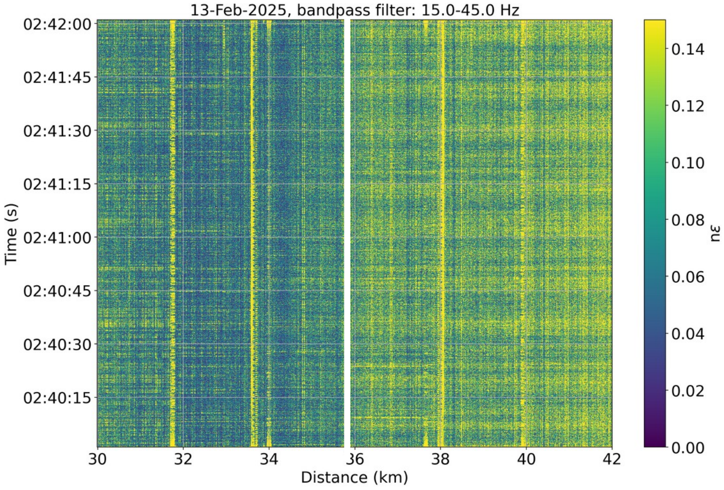






AIS (automatic identification system) positioning data

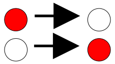
Time – Distance plot



Where is the ship?

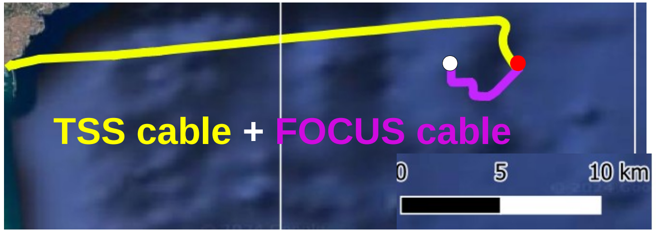
FOCUS cable

Two-fold loop fiber



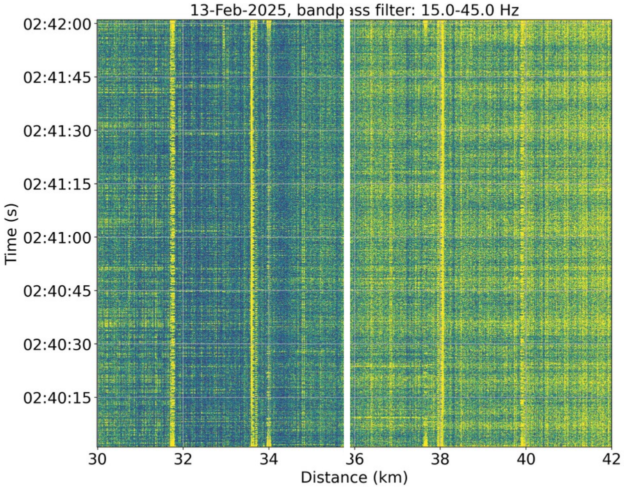
1st path: tight fiber
2nd path: loose fiber

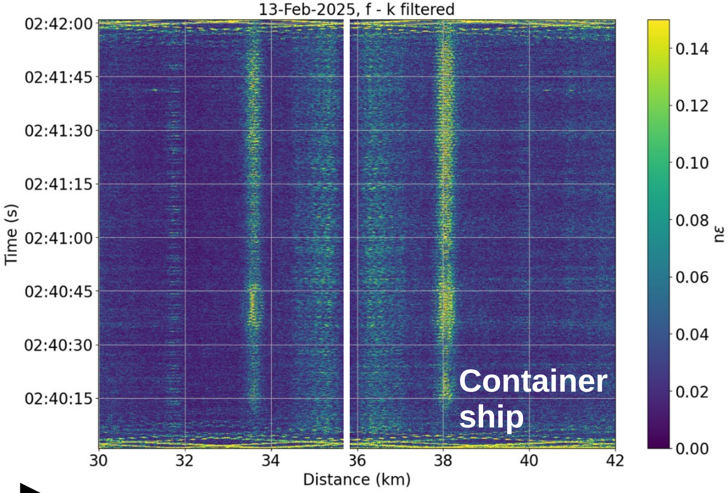
- Coupling of the fiber WITHIN the cable matters: variations on the SNR



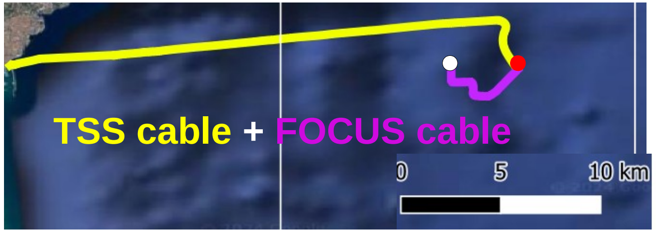
AIS (automatic identification system) positioning data

Time – Distance plots

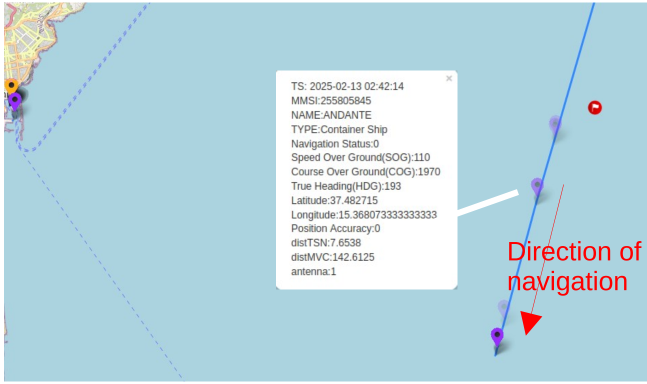




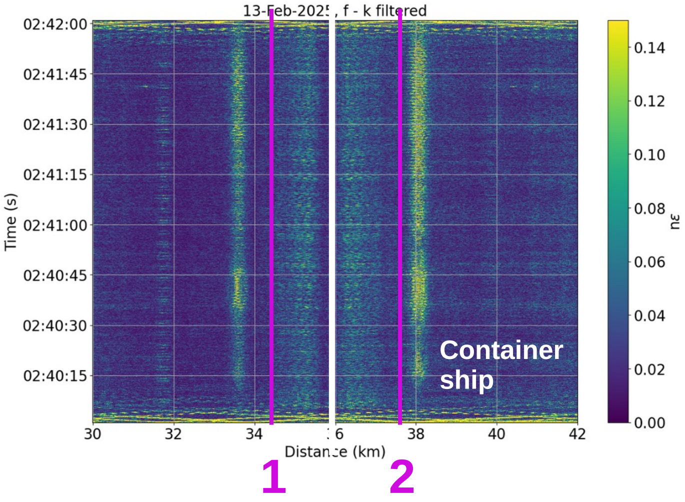
De-noised via f-k analysis



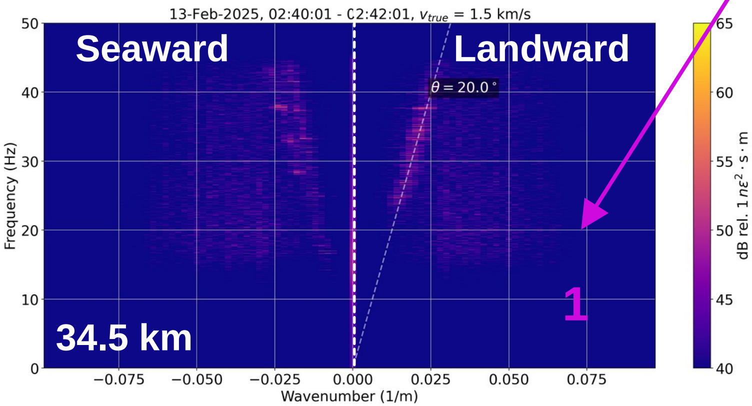
AIS (automatic identification system) positioning data

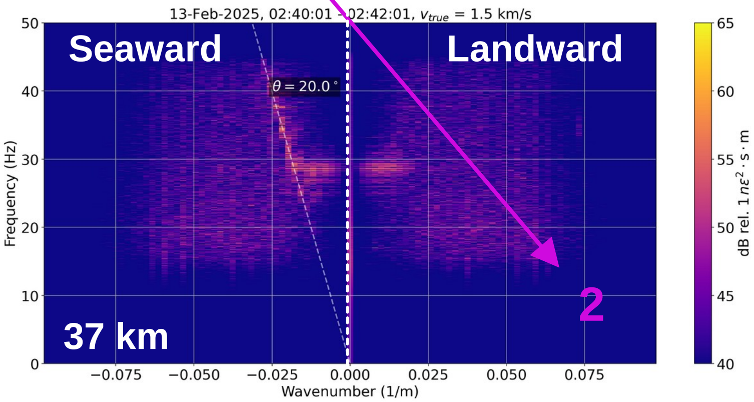


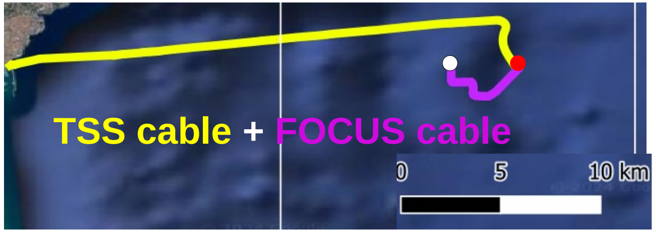
Time – Distance plot



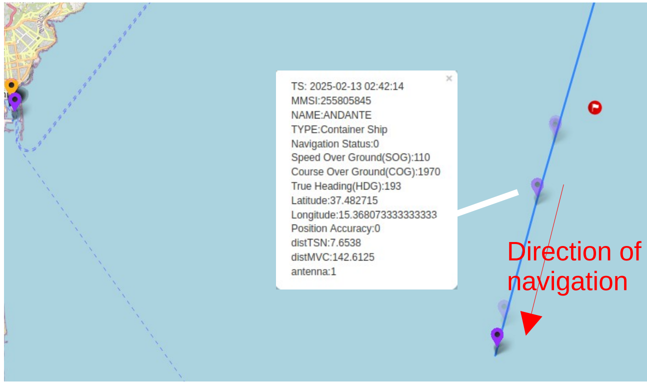
f-k (frequency – wavenumber) analysis



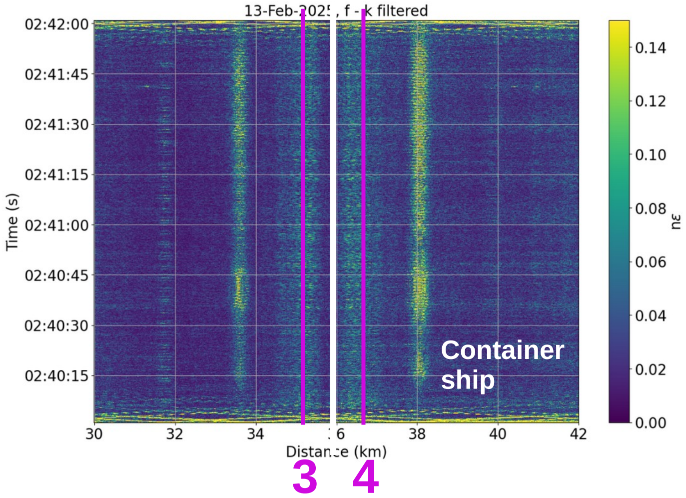




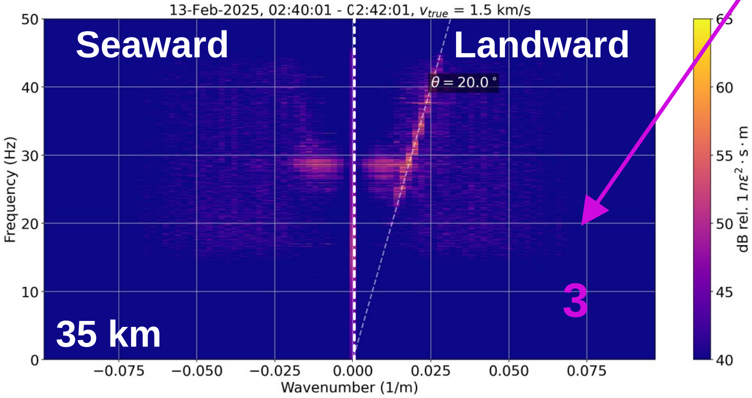
AIS (automatic identification system) positioning data

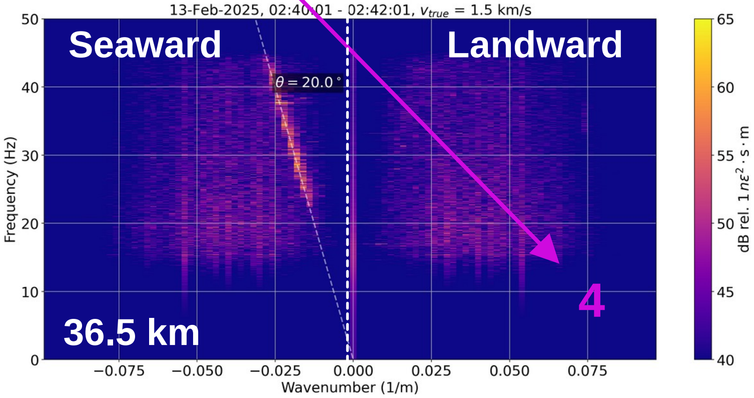


Time – Distance plot



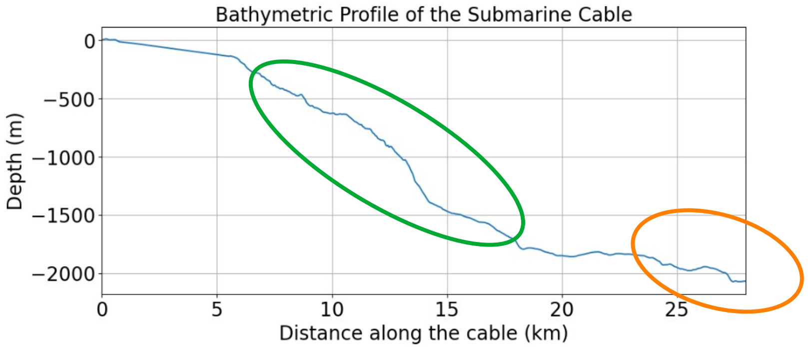
f-k (frequency – wavenumber) analysis





Preliminary observations

- At **shallow to intermediate depths** heavy boats at high speed (~ 19 knot) are visible along many kilometres:
  - Easy to obtain the relative orientation from the FO cable at different distances
  - Tracking is “possible” with a left-right ambiguity because the cable follows a straight line in this area
- At **deep waters**, heavy boats signals are hard to spot and are constrained to short distance ranges => difficult to track them
  - Signal not strong enough to propagate at those depths?
  - Need to focus on lower frequencies?
  - Coupling effects of the fiber within the cable and/or with the ground floor?
  - Acquisition parameters not suitable for this type of signals at these depths?



Improvements and next steps

- Try the method with more energetic signals: other type of heavy boats? higher constant speed? Other type of signals?
- Quantify the distance between the signal and the cable assuming constant speed
- Try different time windows for the analysis
- Beamforming for tracking