

MODELLING OF AMBIENT NOISE CREATED BY A SHIPPING LANE TO PREPARE PASSIVE INVERSION: APPLICATION TO USHANT

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Abstract: *The Ushant thermal front is a seasonal phenomenon which occurs from May to October in a shallow water environment (100m) of the Iroise Sea (off the coast of the north-western France). It corresponds to the boundary separating a well mixed inner shelf water from an open sea stratified water. To determine the dynamic of the front -or more basically the presence of a stratified or homogeneous water column- the possibility to use a shipping lane as a continuous acoustic source is studied. The originality of this work is to use a single receiver. Simulation results of sounds radiated by a shipping lane in a shallow water environment are presented, both for stratified and homogeneous water column. The corresponding pressure fields show a mean level difference in the frequency band 50-300 Hz. This feature will be used in the future as an observable to differentiate both environments, and thus passively detect the Ushant thermal front.*

One of the issue to get the mean level offset is to record the shipping lane noise without isolated ship interferences. As a consequence, an optimum mooring position to track the thermal front is suggested by the analysis of the vessel traffic from AIS data (Automatic Identification System).

Keywords: *Passive acoustic inversion, ambient noise, shipping lane, thermal front, shallow water.*

1. INTRODUCTION

Nowadays many facilities exist to understand the dynamic of the ocean, in particular on the coastal zones. Remote sensing data as SAR images can be interpreted to detect internal waves in shallow water, or Lagrangian drifter give the possibility to follow a specific coastal structure as eddies. Acoustical technologies are commonly deployed for the sub-bottom currents observation with ADCP sensor or for a wind observation through the ambient noise (WOTAN project) to estimate the wind speed from the energy of sound which is produced by the wind when it is propagating beneath the ocean surface [1]. In this study we investigate the use of a passive acoustic method to detect the Ushant front presence. Basically it consists in determining the stratified or homogeneous aspect of the water column from the analysis of an acoustic pressure field. Indeed, this field is greatly affected by the sound speed profile in the water column, and the latter suffers strong variations due to variations in temperature, salinity and density, characterizing the presence of a frontal zone as the Ushant thermal front [2].

The originality of our work is to use a single sensor, and to consider the noise radiated by a traffic lane as a source of opportunity. Most of the time, passive tomography applied to environment monitoring is performed using vertical line arrays [3]. This paper presents only a preliminary study of the tomography in such a restrictive context. However, the final aim of our work will be to provide in situ data to overcome the lack of data necessary in coastal modelling. Indeed oceanic models in shallow water run mainly with an assimilation data process fed with satellite measurements of the sea surface temperature [4], which fails when a cloud cover occurs. The assimilation of acoustic measurements into ocean models was first suggested by [5] and [6] and evolves toward applications presented in [7] and [8].

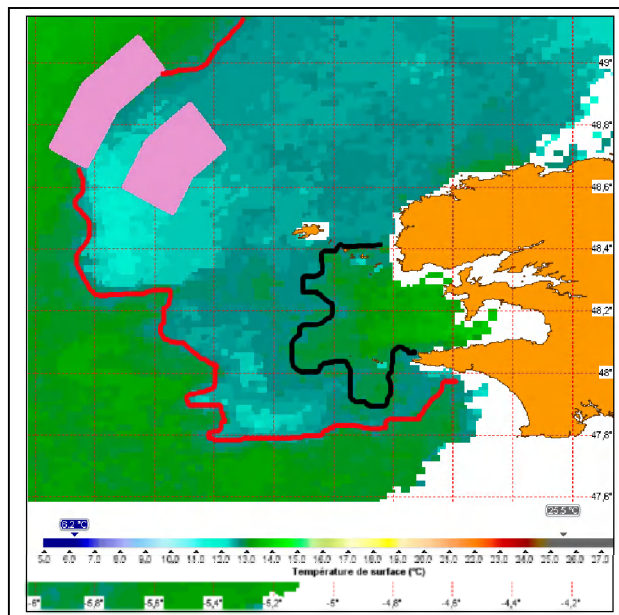
Coastal zones present a great interest for both environmental as well as war strategy fields. As a consequence, active acoustic systems present many drawbacks in this context: using active sonar contributes to the noisy pollution of the environment (dolphin colony living there), and secondly a main interest for defence applications is to use unobtrusive sensors. The passive tomography fulfils these tasks with the noise present in the ocean, and in particular the ability to use the ship noise as a source of opportunity has been already proved [9] [10] [11]. For this study, we consider the case of the Ushant traffic separation lane, with an average of 160 ships per day crossing this area.

The paper is organized in five sections: section II is dedicated to the Ushant front, its dynamic and the description of the traffic separation scheme. Section III presents an analysis of the propagation, simulation results, and proposes a basic tomography scheme. Section IV deals with complications arisen when considering real data, and operational application of the method. The last section concludes the paper and presents the outlooks of this work.

2. THE USHANT FRONT AND THE USHANT TRAFFIC LANE

The Ushant tidal front is a seasonal phenomenon which occurs from May to October off northwestern France. The main tidal front -the external front (here referenced as the red line on the figure 1) - corresponds to the boundary between a cold homogeneous water (around 10-11°C in May) close to the coast and an open sea stratified water (13-14°C in May). It is localized at the west of the Ushant island and the homogeneous layer spreads approximately in a range from 5°W to 6°W of longitude. Another front, close to the coast -the internal front (here referenced as the black line on figure 1) - spreads between the Pointe of Saint Mathieu and the Pointe du Raz. A typical situation of this period is presented in the figure 1 showing the structure of different fronts. Corresponding sound speed profiles describe a typical step for the stratified water column (represented by the blue line in figure 1-b), and a vertical line for the homogeneous water column (represented by the red dotted line in figure 1-b).

(a) AVHRR satellite measurement



(b) Synthetic sound speed profiles

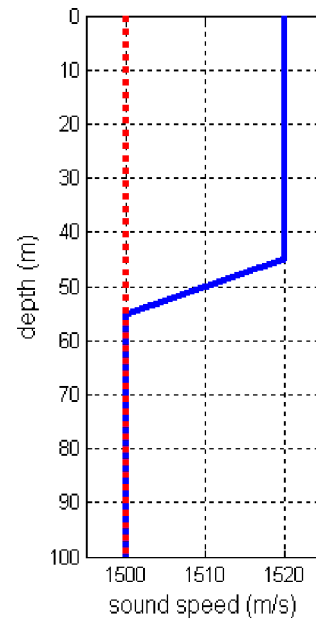


Figure 1. (a) AVHRR satellite measurement of the Sea Surface Temperature over the Ushant front area on the 22th of May 2007, 12h00. The external front corresponds to the red line, and the internal front to the black line. These lines separate homogeneous cold water in blue (11°C) from stratified water in green (13-14°C). The Ushant traffic separation scheme is marked out by two pink strips, northwestward of the Ushant island. (b) Synthetic sound speed profiles corresponding to homogeneous cold water (red dotted line) and stratified water (blue line)

The Ushant traffic separation scheme draws two main distinctive lanes (separated by the pink strips on Fig. 1-a), one upward nearest the coast, and one downward off the coast (and beyond the far-off pink strip). The ship traffic is constituted of an average of 160 ships a day. This traffic creates a heavy continuous source of noise, that

will be considered for our tomography scheme. However, it is interesting to point that all the traffic in the Ushant area is not concentrated on the two main lanes. This problem will be addressed in section IV.

3. A SIMPLE TOMOGRAPHY SCHEME

a. Modal propagation

In shallow water, at considered frequencies ($f < 1$ kHz), the propagation is described by modal theory. Considering a point source at depth z_s , the received pressure field at range r and depth z is [12]:

$$p(r, z) = \frac{1}{\sqrt{2\pi r}} \int_0^\infty S(f) \rho(z_s) \psi_m(z) \sqrt{k_{rm}} e^{-i k_{rm} r} dk_{rm} \quad (1)$$

where $S(f)$ is the source spectrum, $\rho(z_s)=1$ is the water density, ψ_m are the modal depth functions, and k_{rm} are the radial wavenumbers. The tomography scheme presented in next section is based upon modal consideration.

b. Tomography scheme

Our problematic is to distinguish between homogeneous and stratified water columns (see Fig. 1) using a single receiver. In this restrictive context, only straightforward tomography method could be developed. As a first step, the opportunity to use only the received spectrum amplitude is investigated.

In a stratified water column, the first modes are trapped around the sound speed profile minimum. In our context, the first modes are trapped in the deeper part of the water column, and thus interact more with the seabed than in an homogeneous environment. This phenomenon implies that the pressure field recorded in the stratified environment is more attenuated than the pressure field recorded in an homogeneous environment. As an illustration, Fig. 2-a presents the spectrum simulated in environments using sound speed profiles presented in Fig. 1-b. Simulation configuration is the following: source depth at 6 m, receiver depth at 90m, source/receiver range set at 30km, and source spectrum is flat. On the figure 2, one can see that the spectrum simulated in homogeneous water (in blue) is higher than the spectrum simulated in stratified water (in red) over the frequency band 0-500Hz. Note that the source/receiver configuration used for this simulation corresponds to our passive application. Indeed, the ship noise considered as the source, is close from the surface, while the receiver is close to the bottom. According to our own experiments, it seems to be the best place in the Ushant area, affected by strong currents, to limit the anchoring vibrations, and thus noise.

To link the attenuation phenomenon to our tomography context, the noise radiated by an horizontal source line is also simulated. The closest distance (CPA) between the receiver and the line source is 30 km, while the other simulation parameters are the same than previously. Corresponding simulated spectrums are presented in Fig. 2-b. Results are

equivalent to those obtained with the point source, although the spectrum variations have been smoothed by the range integration. Over the frequency band 0-130 Hz, both spectrums, point source as well as line source, differ by more than 10 dB. As this frequency band is greatly excited by radiated ship noise, this amplitude difference could be used as an observable to distinguish both stratified and homogeneous environments.

However, considering ship noise as a source also brings complications. Indeed, the source level is unknown and may vary. Nevertheless, according to Wales et al [13], ship radiated noise follows a statistical distribution around a known model. The standard deviation around this model is 5 dB for frequency below 350 Hz. Consequently, stratified and homogeneous environment should be distinguishable for low frequency when the received spectrum difference is higher than the source variability.

To improve the spectrum difference, one can simply increase the range. However, range should not be too large, indeed, if the range is too large, Signal to Noise Ratio (SNR), which is critical in this passive context considerably decreases.

In this study, the traffic noise in the Ushant area is considered as a line source. Next section will present a traffic analysis, showing that this assumption is justified if the receiver position is well chosen.

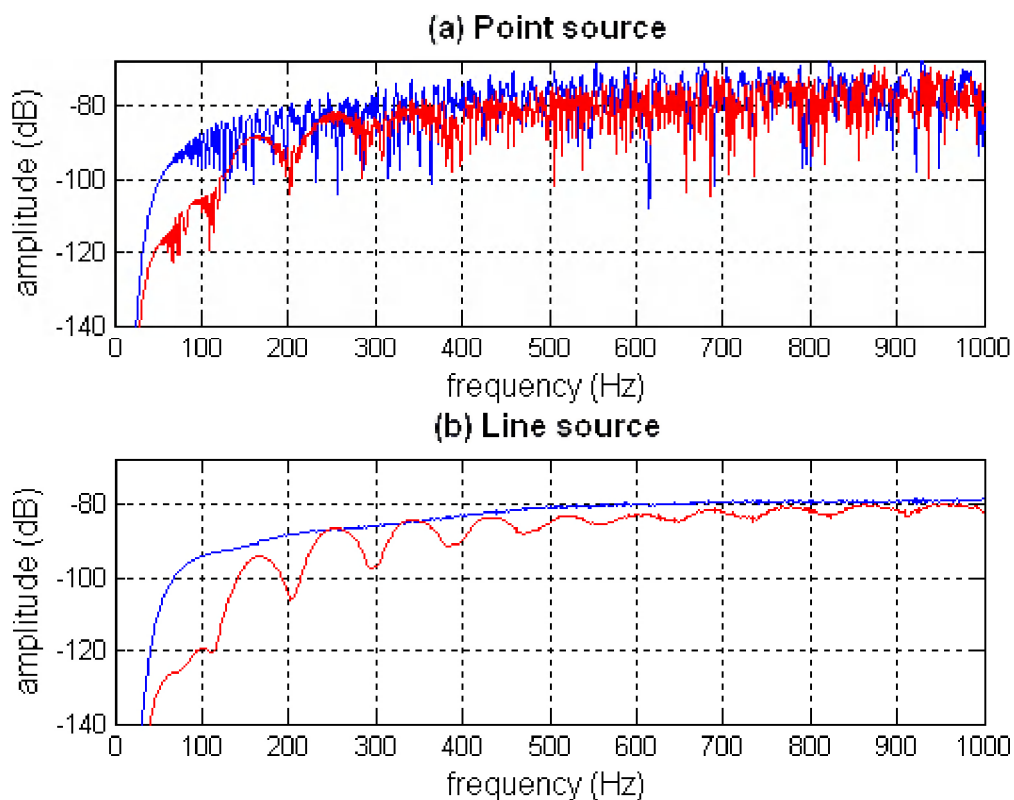


Figure 2. Simulated spectrum for homogeneous sound speed profile (blue) and stratified sound speed profile (red). Figure (a) corresponds to a point source and Figure (b) corresponds to a line source.

4. TOWARD AN OPERATIONNAL APPLICATION

To perform our operational tomography scheme, it is necessary to determine an optimum location for the receiver, allowing to record only shipping lane radiated sound, without any interference coming from a singular vessel. In this context, AIS data covering the period from March to August 2010, reveal the vessel distribution in this area (see figure 3). Note that AIS data provide information about ship identity, status (anchoring, fishing, etc...), and position allowing the vessel trajectory reconstruction.

In this experience, hydrophone characteristics allow to record ship radiated noise in the limit of 95 km for a 5 dB signal to noise ratio. Under this assumption, cumulative ship distributions is estimated on a six months period in the Iroise Sea, covering a $47.5^{\circ}\text{N} - 49.5^{\circ}\text{N}$, $6.5^{\circ}\text{W} - 4.5^{\circ}\text{W}$ limited area, as shown on figure 3. Density traffic is represented by the brightness scale. As a consequence, two parallel main lanes appear tagged with P, corresponding to the traffic separation scheme, while many vessels having a random trajectory, as fishing vessels, are cancelled. Secondary roads are tagged with S, and the two possible optimum receiver locations are tagged with R. R locations correspond to the centre of a one hour vessel free perimeter of 40 km, on a 24 hours period. Nevertheless, as previously mentioned, a long range is more appropriated to distinguish in term of amplitude, both spectrums corresponding to stratified and homogeneous water. Consequently, the optimum receiver location is the top R position of the image on the figure 3. In addition, the possibility to use a traffic shipping lane as a continuous line source is confirmed by AIS traffic statistics, showing on a 24 hours period, that the mean number of vessels per hour is constant, with approximately 50 vessels per hour.

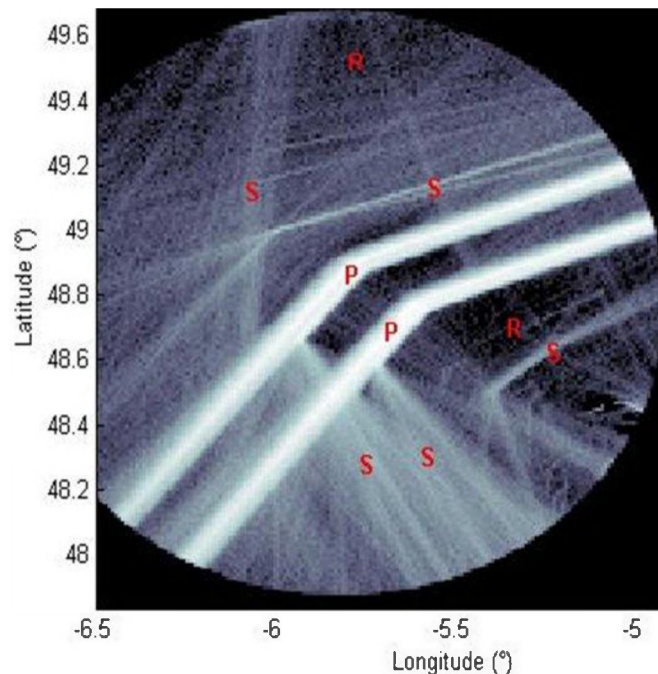


Figure 3. Shipping distribution in the Iroise Sea: cumulative ship positions from March to August 2010, with main SST traffic tagged with P, secondary traffic lanes tagged with S, and optimum hydrophone positions tagged with R.

5. CONCLUSION

In this paper we have presented theory, simulation results and data analysis that demonstrate that we can extract in operational conditions an observable, based on a passive acoustic analysis, to characterize the stratified or homogeneous aspect of the water column, and therefore the possibility to detect the presence of the Ushant thermal front. These results are conditioned by a particularly constraining framework which requires positioning the receiver in an optimum place, defined from a compromise between a far enough range to prevent interferences and an enough amplitude difference between stratified and homogeneous environment spectrum. In the future, we will deploy an autonomous hydrophone to get real acoustic data, allowing us to compare operational results with simulation.

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