The influence of the mixed layer in the shallow water modal propagation Interference pattern

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Abstract

In this paper, we discuss the role of the mixed layer in the interference pattern of broadband shallow water modal propagation. Different size of mixed layer are used in order to obtain analytically values of the invariant β. An experimental Sound Speed Profile is fitted and the limits of this fit is used to estimated the β value and compared to its experimental value. Besides, discussion about the differences between experimental and theoretical value are introduced.

Introduction

The interference structure in the pressure field was first introduced by (Chuprov, 1982), this phenomenon is related to the theory of waveguide Invariants (D'Spain et al.,1999;Jensen et al., 2011; Harrison, 2011; Rouseff, 2002) where the relationship between the change in group speed with respect to change in phase speed for a group of normal modes in the waveguide is stated.

Some works (Harrison, 2011; Sell et al, 2011) demonstrated that the β value is 1 for a ideal waveguide with perfect reflectors boundaries, range independent environment and homogeneous Soun Speed Profile(SSP). For a uniform SSP gradient, β is equal to -3 and for other types of SSP the value is in the range -3 to 1.

The β may have a distribution of values in accordance of many rays paths and is variable for an environment that supports different types of propagation paths. The striations pattern in the propagation spectrum can be thought of as the result of range variation of the multi-path Impulse response (Harrison, 2011), and so they can be calculated from travel times and therefore ray cycles times and cycle distances.

The waveguide invariant β quantifies the range variation of these interference fringes and in (Chaves et al., 2011) some features of shallow water propagation are explained. The long range propagation and the interferometry between modes of adjacent order are explained in (Pessek et al, 2012).

Despite of the influence of others factors like depth of the waveguide and source and receiver depth, this work aims to highlight the crucial importance of sound speed profile, specially the mixed layer in the invariant parameter β and introduce a discussion about the theoretic and graphic β value.

Theory

The waveguide property o maintaining a robust interference pattern under a assortment of conditions is a consequence of an important relationship between the change in group speed with respect the change in phase speed for a group of modes in the waveguide (Jensen et al. , 2011).

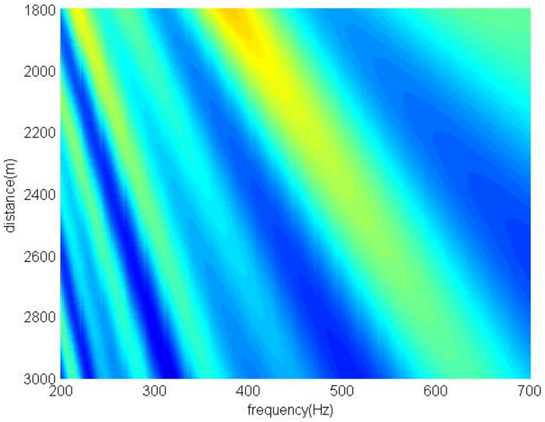

Figure 1: Interference Pattern

Figure 1 shows a spectrogram where the line represent the interference pattern related to situations of same acoustic intensity ($I(r,z,\omega)$ = constant) with respect to frequency and range. So, setting the acoustic intensity total derivative to zero we obtain the following equation (Chuprov, 1982):

$$\frac{d\omega}{dr} = -\frac{\partial I}{\partial r} / \frac{\partial I}{\partial \omega} \qquad (1)$$

In the normal mode picture (Chuprov, 1982), the intensity at the receiver can be written as:,

$$I(r,z,w) = I_0 \times (\sum_n B_n^2 + 2 \sum_{m \neq n} B_m B_n cos(\Delta k_{mn}(\omega) r)) \qquad (2)$$

where the constant I_0 is the reference intensity, $\Delta k_{mn} = k_{rm} - k_{rn}$ is the interfering differences of pairs of horizontal modal wave numbers and, $B_{m,n} = r^{-1/2} A_{m,n}$ are the mode amplitudes, so we can explicitly wright the following derivatives:

$$\frac{\partial I}{\partial r} = -\omega \sum_{m,n} B_n B_m \left(\frac{1}{v_m} - \frac{1}{v_n} \right) sin(\Delta K_{mn} r) \qquad (3)$$

$$\frac{\partial I}{\partial \omega} = -r \sum_{m,n} B_n B_m \left(\frac{1}{u_m} - \frac{1}{u_n} \right) sin(\Delta K_{mn} r) \qquad (4)$$

Consequently using these above equations it is possible calculate the normal mode result for equation 1. Besides, the relation between the distance, frequency and the parameter β is given by:

$$r = \frac{\beta \times \omega \times dr}{d\omega} \qquad (5)$$

In many practical situations it is suitable to fit the real SSP by a polynomial like formula (Harrison, 2011) in terms of the depth z, namely:

$$c^2 = c_0^2 (1 - (\frac{z}{L}))^p \qquad (6)$$

Where L is the water layer depth, while c_0 and p are the best fitting parameters. In addition, in this particular case it is possible to relate the invariant parameter β (Harrison, 2011) with polynomial power p:

$$\beta = \frac{3 - 2v}{2v - 1} \qquad (7)$$

where $v = 1 - 1/p$.

Some kinds of SSP with different mixed layer structure are shown in the figure 2 and the β associated with each profile are listed in the table I.

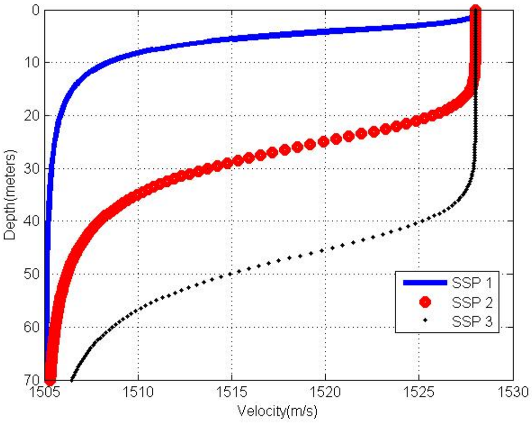

Figure 2: Different mixed layer structure

In the table bellow the values of β for each SSP from the figure 2 are listed:

SSP	p	β
1	4	3.0
2	8	1.7
3	12	1.4

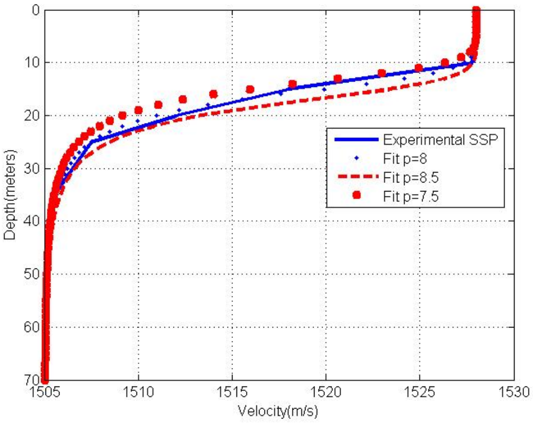

Figure 3: Experimental SSP fitted

Real Data examples

The data above are collected during a sea trial where source and receiver positions are controlled with GPS receiver. The SSP is measured (with a velosom equipment) and is plotted in figure 3. The experimental SSP was fitted for the best minimum square criterion and is plotted in figure 3, and in the table below the values of p associated at each β:

p	β
7.5	1.727
8.0	1.667
8.5	1.615

In the figure 4 we show the experimental interference structure received. This Structure is produced by a broadband source in shallow waters. We already know the distance source-receiver and we would like to estimate the β value from this area.

In figure 5 we show an interference pattern extracted from figure 4. The two lines represent the limits of the interference and using this limits we estimated the graphical β value. The value estimated is 1.7 ± 0.5 and the theoretical value is 1.67 ± 0.06.

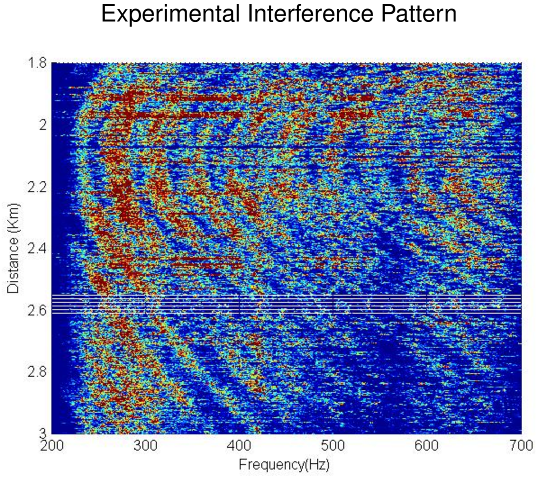

Figure 4: Acoustic Intensity(dB, Frequency x Range)

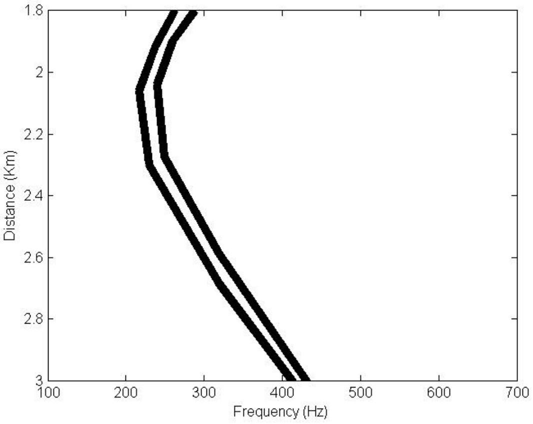

Figure 5: Interference Pattern

Summary and Conclusions

In this work we show that the SSP profile affect considerably the invariant β. Besides, we verify numerically and experimentally that the mixed layer plays a fundamental role in the β value.
Comparing the theoretical error with the experimental error we could conclude that exist other influences in the β value, this influences are associated with the bottom bathymetry, source and receiver depth and also for what modes can survive at large propagation distances.

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