International Hydrographic Review, Monaco, LXXIII(2), September 1996

HOURLY OCEANOGRAPHIC AND ACOUSTIC VARIATIONS IN THE STRAIT OF GIBRALTAR, AND MULTIBEAM ECHOSOUNDER TECHNOLOGY

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1. INTRODUCTION

The Strait of Gibraltar connects the North Atlantic Ocean and the Mediterranean Sea. The Strait has a length of approximately 60 km and at its most narrow section (Pt. Cires section) the width is of 12 km (Fig. 1). The main sill

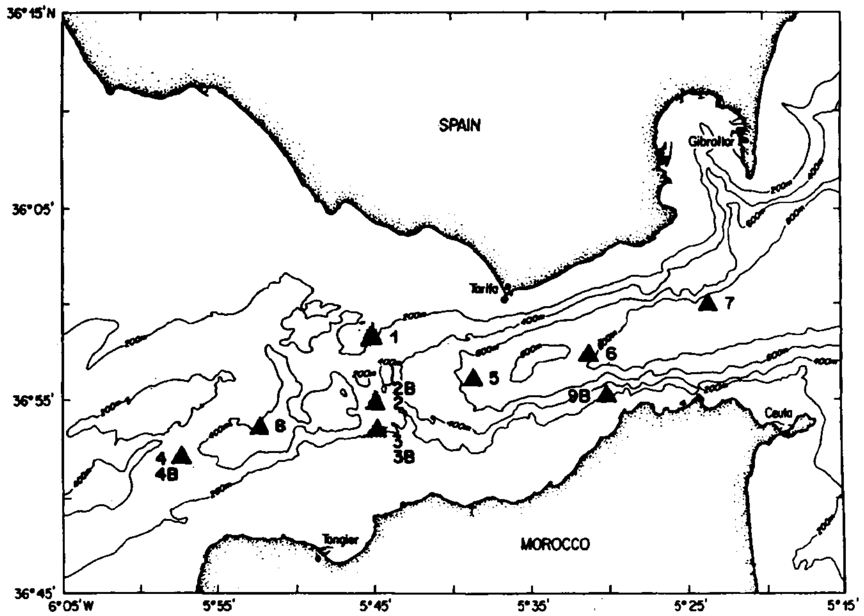

FIG. 1.- The Strait of Gibraltar.

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between Punta Paloma (Spain) and Punta Malabata (Morocco) has a depth of about 300 m; East of the sill the channel deepens to near 600 m at the Tarifa Section, and to 900 m at the Algeciras-Ceuta section. West of the sill the depth reaches 500 m north of Tanger,but further west a secondary sill in front of Cape Spartel is shallower (near 350 m) and then the depth increases gradually down toward the deep North Atlantic.

The Strait plays an important role in determining the water mass characteristics in the Mediterranean Sea because it acts as a constriction limiting the free water exchange between the two connected basins.

Data taken in the course of the Gibraltar Experiment (October 1985 to October 1986) shows clearly in several sections of the Strait of Gibraltar the different water masses and the interface between Atlantic and Mediterranean waters. (RUIZ et al. 1988). (Fig. 2). In addition to the Gibraltar Experiment, other data shows and relates the variability of the interface and the internal tide contribution.

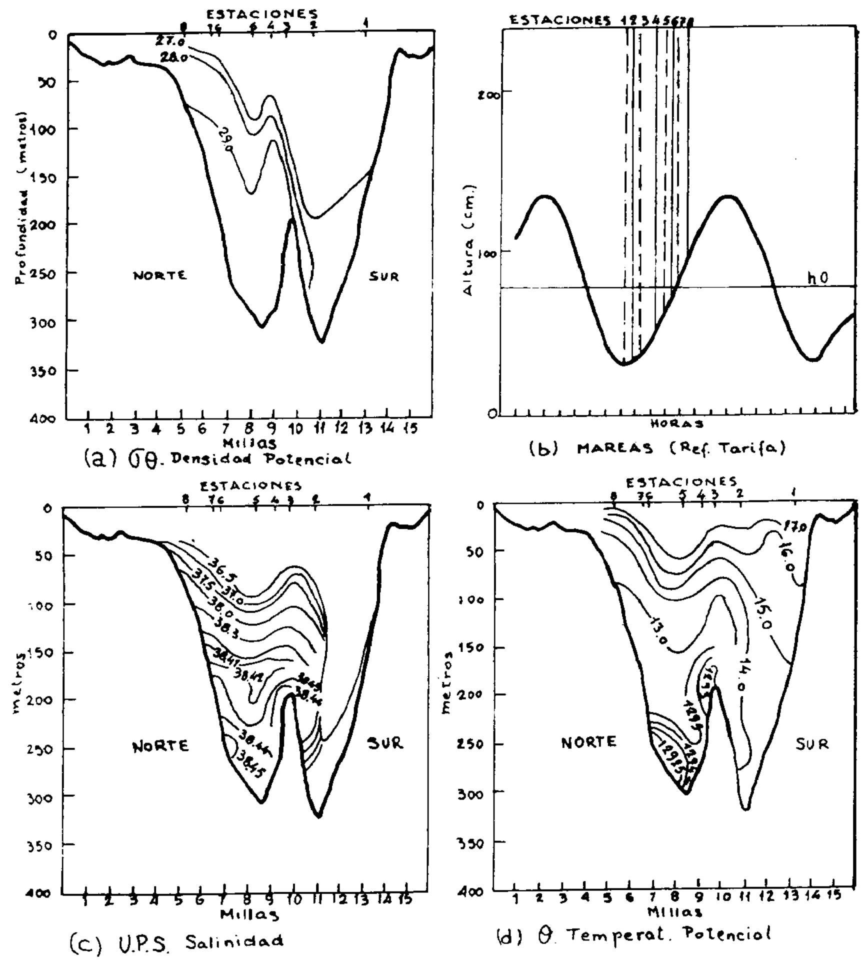


FIG. 2.- The different water masses and the interface between Atlantic and Mediterranean waters.

The oceanographic variability leads to acoustic variability, and in the multibeam echosounder technology application, for example, both are in the same spatial and temporal scales. It has been found that sound velocity variation with time and position is one of the major contributors to limiting usable coverage of multibeam echosounders (HAMMERSTAD, 1995). As a matter of fact the accuracy of the mapping system is determined by errors not only due to the multibeam instrument but also from other parameters including the sound velocity. Hence, it is extremely important in areas of high oceanographic (and acoustic) variability in which multibeam echosounder operations are performed, to closely monitor of the Sound Speed Profiles (SSP's) for the area of operation, or alternately to develop a model able to predict (in both, time and position) the SSP variability in that region.

What follows is a characterization of the oceanographic and acoustic variations in the Strait of Gibraltar, where undoubtedly they should have been taken in to account with multibeam echosounder operation, in order to minimize the error of the mapping system to meet IHO standards (equivalent to 18 cm RMS of errors for depths less than 30 m and RMS errors less than 0.6 percent of the water depth for deeper waters), although better accuracy will be required in the future by IHO and is demanded by some users today.

2. INTERNAL TIDE OBSERVATIONS

Internal waves associated with the tides in the Strait of Gibraltar have been noted and studied by many mariners and scientists in the past. The observations performed by the Spanish Navy Hydrographer Vicente TOFIÑO during 1783 and 1784 and published in 1789 show an interesting and reasonably accurate description of the tides and currents in the Strait of Gibraltar, as well as the effects on surface of the internal waves ("boiling water" north- south lines or tide rips), (Tofiño 1789), having been observed from ships, aircraft and even on both ship and land based marine radars (LA VIOLETTE et al, 1986).

Other reports (SACLANTCEN Technical Reports 127 and 147; ZIEGENBEIN, 1968,1969) conclude finally that "statistical information on internal wave activity in a certain area provides a knowledge of the range of variability of the ocean parameters in that area. The timing and spacing of sound velocity profile measurements, if based on this information, would avoid too many measurements, which would waste time, or too few, which would fail to represent the environment ". For multibeam echosounder mapping purposes the acquisition of this dynamical statistical information in different areas might therefore be one reason to include internal wave investigations in the variability studies of the oceans.

According to recent studies, internal waves are generated at the Camarinal Sill and propagate in groups or packets eastward with the following typical wave parameters (WATSON 1989) given in Table 1.

Table 1
Typical wave parameters

Period	6-20 min
Wavelength	0.5-2.5 km
Phase speed	1-2 m s^{-1}
Amplitude	up to 60 m.(peak to trough)
Packet width	up to 15 km
Packet duration	4 h
Waves per packet	up to 12

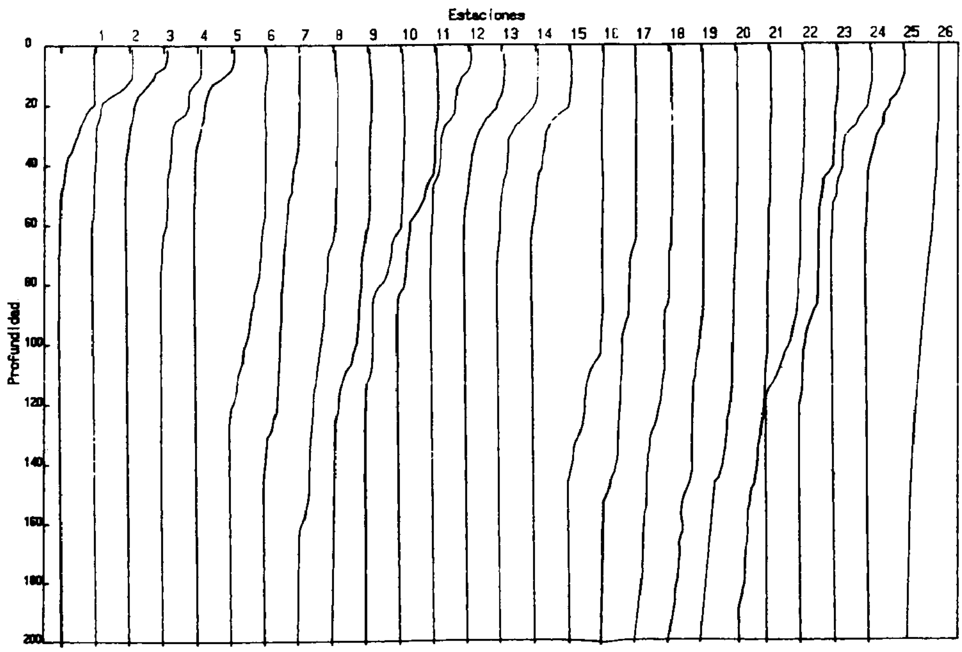


FIG. 3.- Data taken from yo-yo CTD stations.

The waves propagate from the sill between approximately high-water and low-water and they are generated at an interface depth of about 20 m or less as is evident from the data taken from yo-yo CTD stations (Fig. 3). Using only the downcast and computing the sound speed from the data, it is presented 25 SSP (Sound Speed Profile) corresponding to 25 hours of observations. Roughly, the picture represents the hourly variation of the SSP, with the superficial Atlantic water separated from the deep Mediterranean water by a clear transition zone corresponding to the interface. The data were obtained in 35° 56'N, 5° 42'W aboard the Spanish Hydrographic Ship MALASPINA on 29 and 30 November 1989. The first profile SSP1 was taken at 1115Z, on the day 29 while the rest were taken with an interval of 1 hour +/- 5 minutes except for the SSP17, where the interval was of about 2 hours from the preceding one (SSP16).

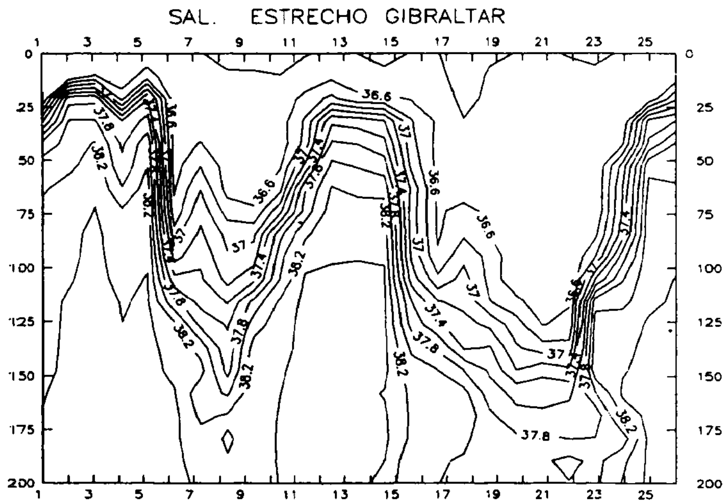


FIG. 4.- Salinity variations with depth.

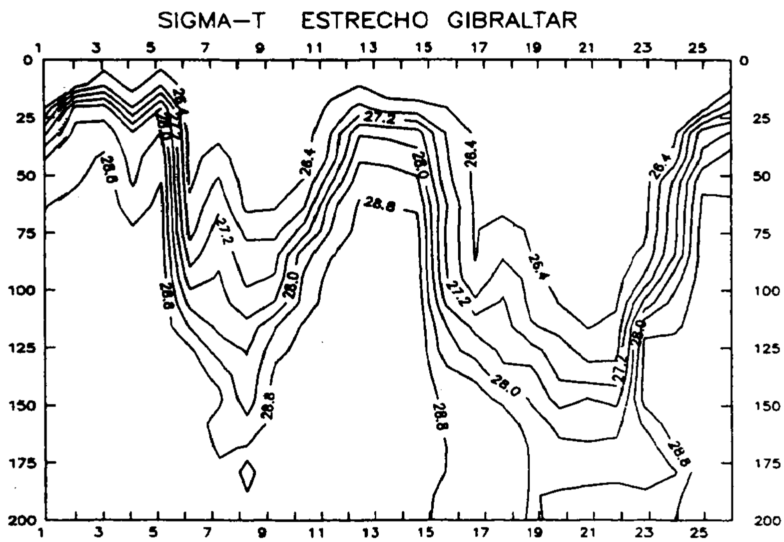


FIG. 5.- The Sigma-t parameter.

The interface in some profiles appears to be very shallow (about 10 m in SSP5, SSP12 and SSP25) and deeper in other (about 160 m in SSP8 and SSP19), marking those values the range of the interface depths for the data.

While many authors adopt as the interface the isopynal σ_θ = 28.0, under the dynamic point of view is more useful to work with the 37.0 ppt isohaline being the salinity average in the depths where the current u-component (East-West) becomes zero. Working with 37.0 ppt isohaline time series depths, it is possible to perform a harmonic analysis obtaining constituents that will allow the prediction for those depths.

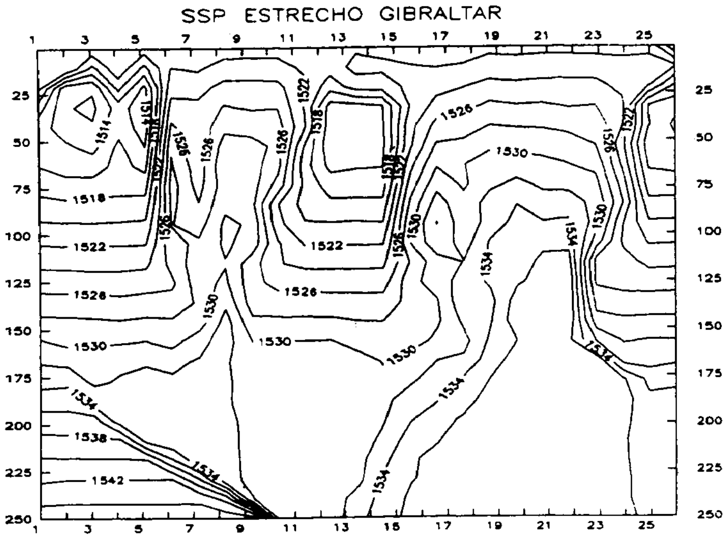


FIG. 6.- Description of the sound speed behaviour.

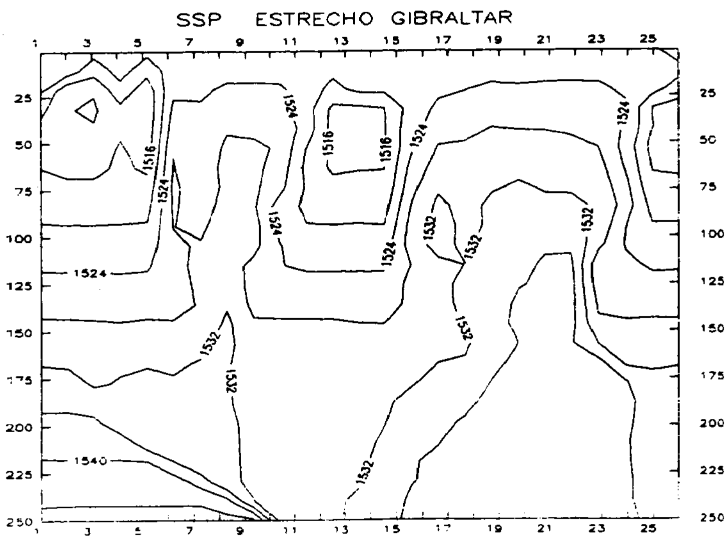


FIG. 7.- Data from Fig. 6 with less isovelocity contours.

In addition, the interface region exhibits a vertical motion with periodic swelling. It is possible, as well, to predict that effect taking two isohalines as boundaries of the region and performing harmonic analysis of the corresponding time series.

The interface upward motion is produced when the upper layer current to the west increases, so that when the internal wave appears, the current speed inhibits the wave propagation, creating the "boiling zone" in the Camarinal Sill. When the current speed decreases down to a point where the wave can propagate, internal wave packets are produced.

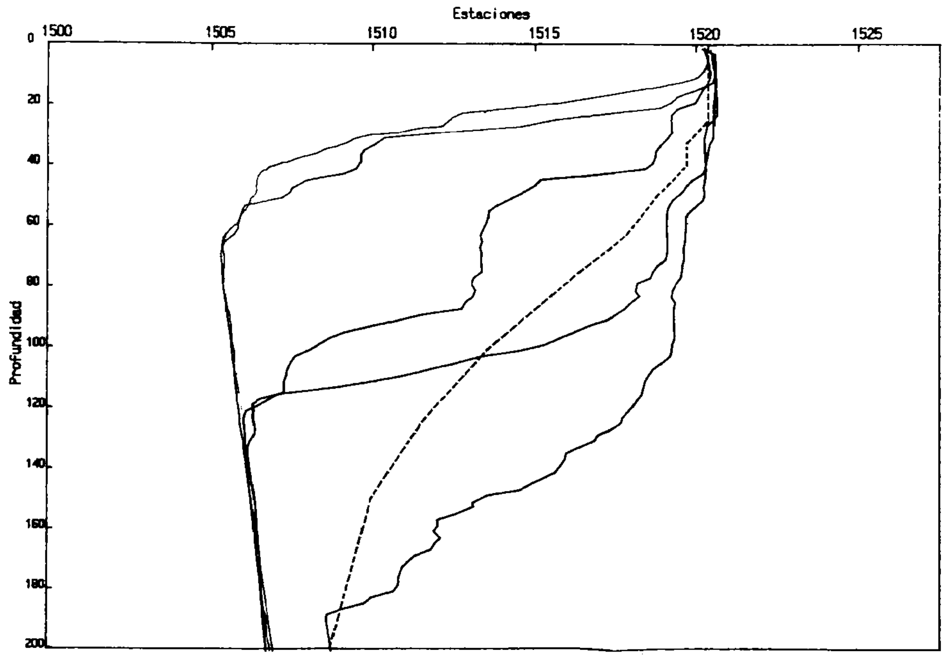


FIG. 8.- Half a period of the internal tide.

3. VARIABILITY IN THE PROPAGATION

In an acoustic context, it is evident from Figure 2 that in the case of the Strait of Gibraltar where two very different masses of water exist plus an interface zone that exhibits a semidiurnal tidal period, it is necessary either to know at least hourly the actual SSP or alternately to be able to make accurate predictions of the internal ware. Figure 4 shows the salinity variations with depth, in metres, and Figure 5 the sigma-t parameter, in the same conditions, for the analysed data. The horizontal axis represents the time scale, in hours. The semidiurnal character of the internal tide is quite clear from the pictures.

Computing the Sound Speed for the data and picturing the result as previously, we obtained Figure 6. In this picture the sound speed behaviour is clearly described, showing in addition to other expected characteristics, the existence of periodic semidiurnal minima at shallow depths (around 50 meters) that will produce transient very shallow Sound Channels at certain times of the day, times that can perfectly be predicted just with the internal tide information.

In Figure 7 we have the same information that in Figure 6 but with less isovelocity contours to neatly show the mentioned minima.

To physically demonstrate the hourly acoustic variations in the propagation we have selected SSP numbers 21 to 25 from Figure 2, corresponding to about half a period of the internal tide (Fig. 8), and using a simple ray tracer with two source

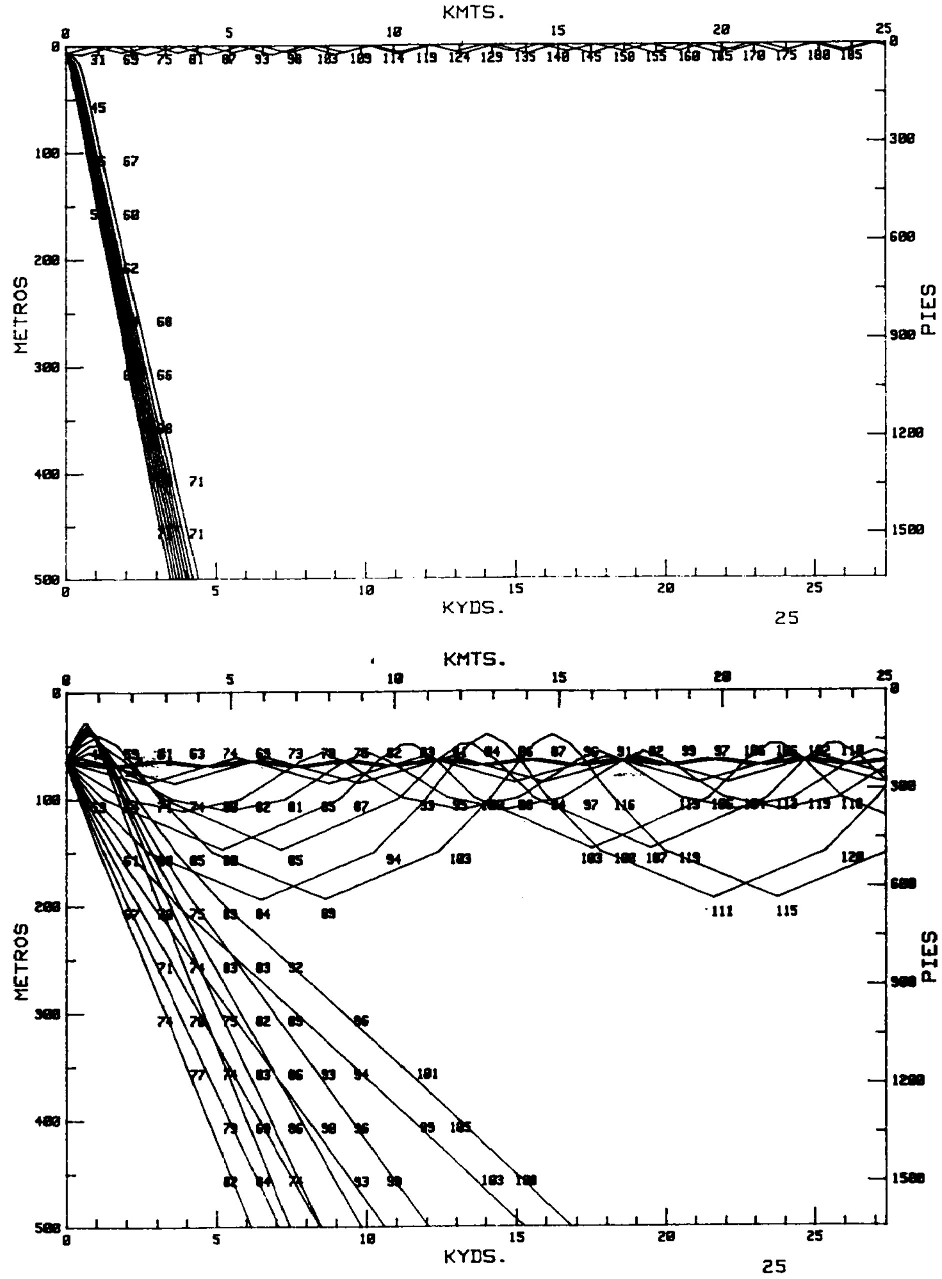


FIG. 9/10.- Comparison of propagation graphs using SSP25.

depths: surface and Variable Depth Sonar depth, we have obtained the respective graphs.

Comparing the propagation graphs using SSP25 (Fig. 9 and 10) and SSP21 (Fig. 11 and 12) we can see very significant differences. The existence of a Shallow Sound Channel is one of them.

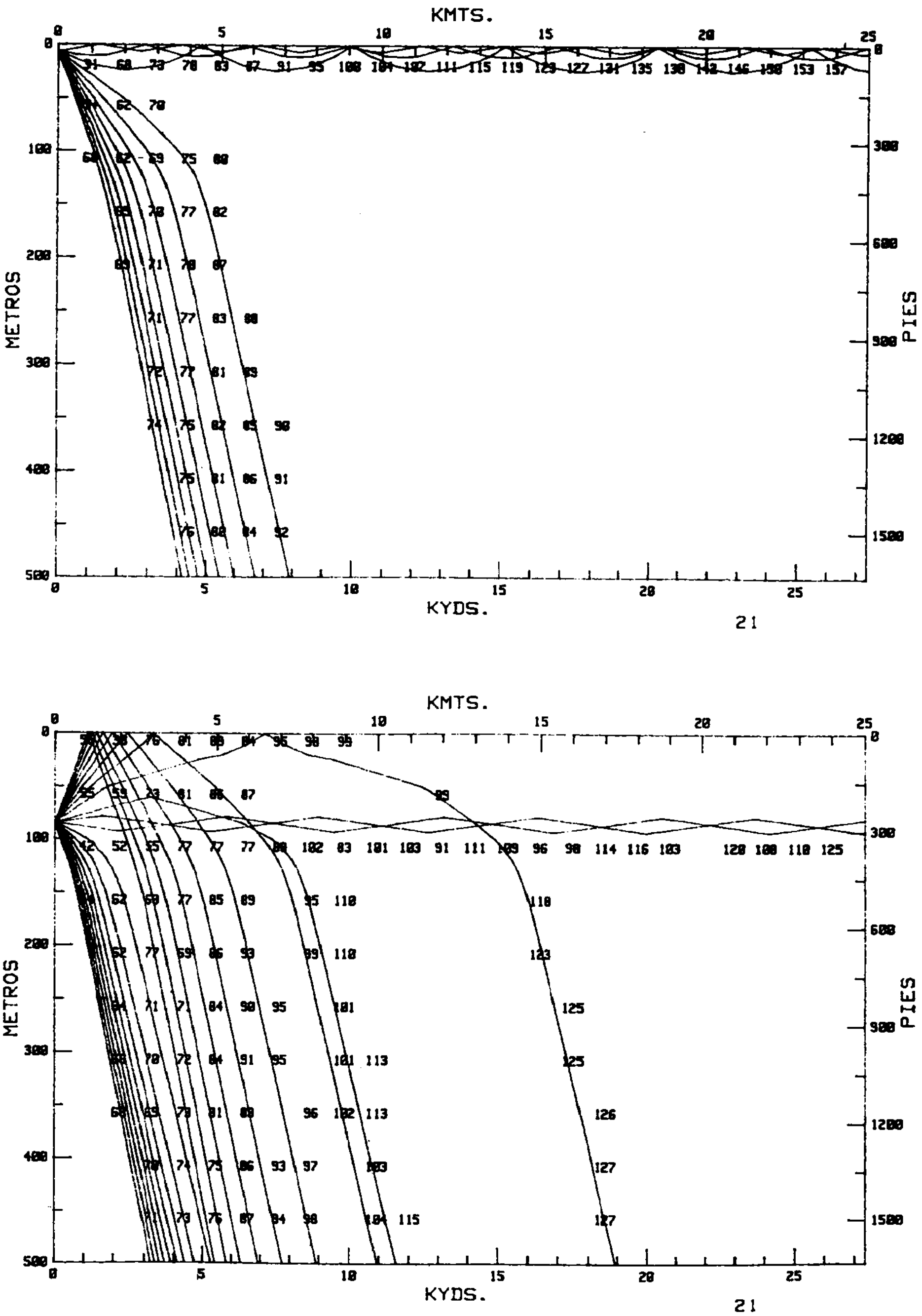
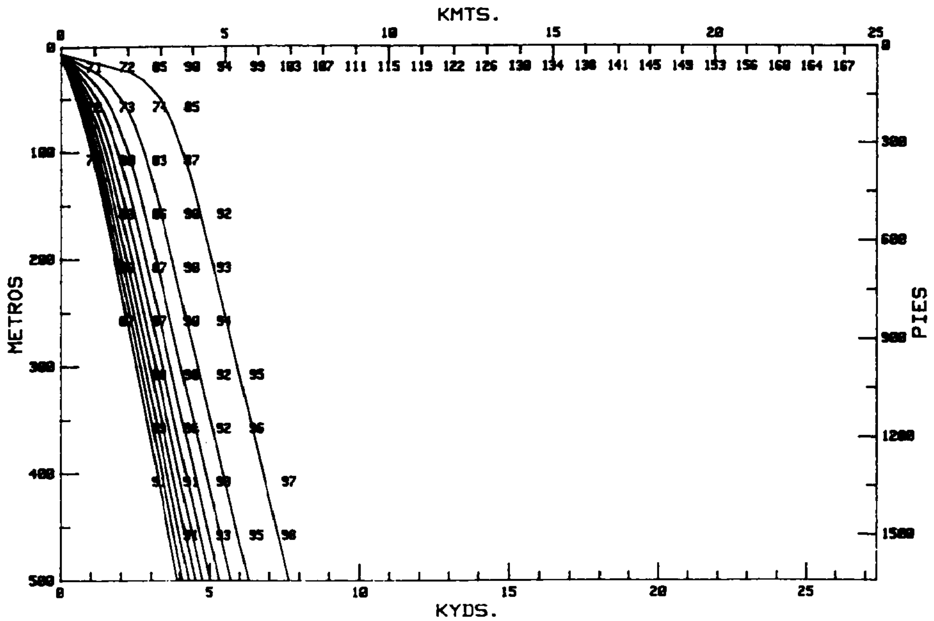


FIG. 11/12.- Comparison of propagation graphs using SSP21.

If we take a statistically average profile, as is the case of SSP26, the results are even more poorly correlated (Figure 13 and 14). SSP 26 represents an average of the total SSPs, but lack their real hourly features it cannot be taken as representative of the actual SSP for any multibeam operation, in this region.



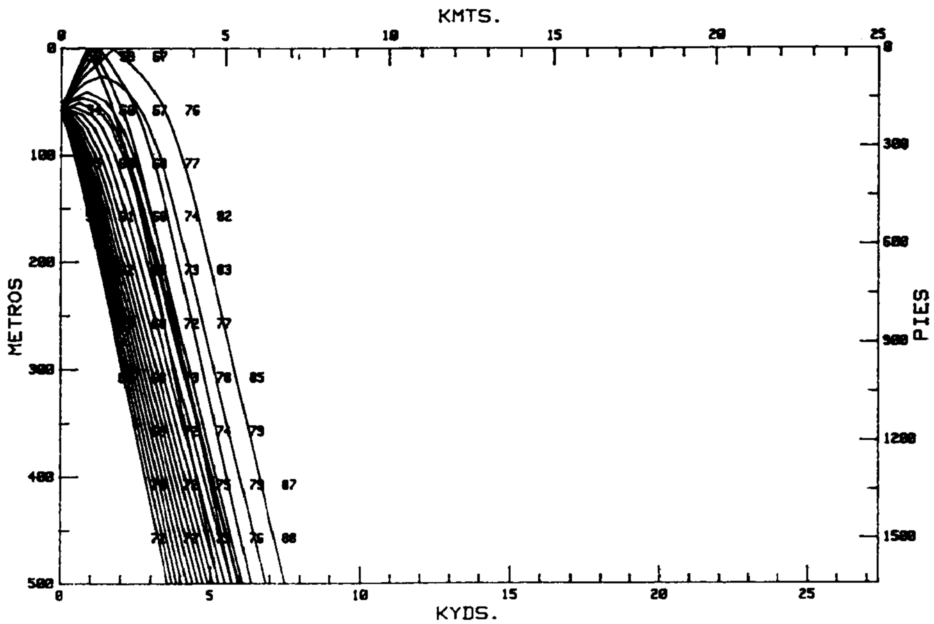


FIG. 13/14.- Statistically averaged profile.

4. CONCLUSIONS

1. The SSP high variability in the Strait of Gibraltar because of the physical characteristics of the local oceanography makes it very difficult to accept as valid any non dynamic statistically based prediction.

2. The importance of the internal tide contribution to this hourly variability added to the very different physical characteristics of the water masses in the Strait (specially with respect to the different salinities) makes it necessary to use CTD's, undulating CTD's, XCTD's or similar devices to compute the SSP's.

3. The use of models to predict the internal tides coupled to the physical parameters input of temperature and salinity to create a reliable and accurate hourly SSP will undoubtely benefit the multibeam echosounder operations performance in the Strait of Gibraltar and possibly other areas of high oceanographic variability .

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