

Identification of Internal Waves off Visakhapatnam from Thermister Chain

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Abstract

An analysis of Internal Wave (IW) signatures by in-situ observations off Visakhapatnam has been presented to study the impact of IWs on acoustic field. Temperature data were collected for 44 hours at an interval of 2 minutes off Visakhapatnam (17° 26.46' N and 83° 31.20'E, and sonic depth 100 m) during 18-20 October 2006 using indigenously developed thermister chain to study the Internal Wave (IW) characteristics. Sound velocity realizations (in space and time) in the observed high frequency (HF) IW field is generated utilizing Garret-Munk (GM) model. Acoustic modeling is carried out in the generated IW HF field to compute transmission loss anomaly for source-receiver configuration at the depth of 20 m and range of 9 km. The anomaly explains the impact of IW on acoustic propagation characteristics in HF IW field and it was found to be 9.98 dB.

1. Introduction

Physical variability occurs in the ocean with space (scales of millimeters to planetary) and time (from seconds to geological times) due to external and internal forcing (Robinson and Ding Lee, 1994). Physical oceanographers are interested to study variability of ocean environment rather than its mean. Oceanic changes relevant to underwater acoustics are classified into mean and fluctuating components (De Santo's 1979) with the following general model of the sound speed equation

$$C(r, t) = C_0(z) + \delta C_1(r) + \delta C_2(r, t)$$

z – depth, t -time, r - three-dimensional position

having characteristics: 1) a mean vertical profile $C_0(z)$ that represents local climatology ($C_0 \sim 1500$ m/s), 2) a meso scale component ($\delta C_1(r)$) (fronts, eddies) — deterministic with respect to the acoustic time scale ($\delta C_1/C_0 \sim 10^{-2}$), and 3) a statistical component ($\delta C_2(r, t)$) (i.e random with respect to the acoustic time scale, $\delta C_2/C_0 \sim 10^{-4}$) that represents small scale fluctuations caused by Internal Waves (IW) and fine and microstructure. The IW frequencies extend from inertial

frequency. The IW of semidiurnal frequency –internal tides- dominate the low frequency (LF) band of IW, while IW of >0.5 cph dominate the high frequency(HF) band of IW. In the present paper, we discussed the IW characteristics and its impact on the sound propagational characteristics off Visakhapatnam using time-series data of currents, CTD and thermister chain.

2. Methodology

2.1 Modeling of Internal Waves

The IW parameters vary with space and time. Their measurements at sea are too expensive. Therefore successful modeling of IW, provides the IW parameters at any interested site in the sea. Garret and Munk (GM) (1975) succeeded in modeling deep water IW-GM model – and later improved it for shallow water IW, (Munk , 1981). This GM model requires time-series data on temperature field for frequency analysis and CTD data for stratification parameter Brunt-vaisala frequency. Details on IW modeling for generation of HF IW field can be found in Krishna Kumar & Balasubramanian (2005). Internal wave simulation is carried out for identification and prediction of high-frequency internal waves with space and time utilizing the time series CTD, currents and thermister chain data. Internal wave eigen-frequencies and modes at a specified sequence of horizontal wave numbers are computed using “finite difference – Sturm sequence – bisection – inverse iteration method”, with mean profiles . From these modal calculations, sequences of sound speed realizations are obtained using the Garrett-Munk internal wave spectrum model . Using temporal and spatial distribution of sound speed realizations, the range-independent and range-dependent numerical ray tracing experiment is conducted to obtain eigen rays and transmission losses etc., to study the impact of internal waves on sound propagation.

3. Data

Temperature data (Fig.1) were collected for 44 hours at an interval of 2 minutes off Visakhapatnam ($17^{\circ} 26.46'$ N and $83^{\circ} 31.20'$ E, and sonic depth 100 m) during 18-20 October 2006 using indigenously developed thermister chain to study the Internal Wave (IW) characteristics.

4. Results and Discussions

4.1 IW Characteristics

Time-series data were Fast Fourier Transformed (FFT) to examine the spectral characteristics of the temperature oscillations in the study area off Visakhapatnam (Mahadevan et.al, 1987). The power spectra of temperature fluctuations at 7 vertical depths (5 m, 10 m, 25 m, 50 m, 60 m, 75 m, 100 m) were computed to study the short period internal waves with one ensemble and 3 ensemble data sets and are presented in Fig 2. The IW spectral energy in the thermocline is the highest compared to other depths (above and below). The dominant observed frequencies of IWs are found to be between 0.02-0.40 cph (LF) and 0.5-2.5 cph (HF), although

the upper limit of IW band is 24.57 cph . From these frequencies, overall period are computed and they found to be 0.081 hrs for LF whereas HF is 0.29 hrs. IW speed has been computed using mean density of top (MLD) and below layer using CTD data and it is found to be 0.029 km/hr following the methods reported earlier (Antony et.al 1985, Murty and Murty 1986). Knowing the IW dominant frequencies, periods and speeds, overall wave lengths are found to be 0.29 km (LF) and 0.0084 km (HF) respectively. HF IW field simulation is essential to study the impact of above said IW characteristics on sound propagation characteristics using GM model .

4.2 Internal wave simulation

The Buoyancy profile has been generated (Fig.3) using the observed temperature and salinity profiles on uniform mesh, with a depth increment of $\Delta z = 2$ m for the purpose of computing the internal wave modes and eigen-frequencies (Fig.4). In the present model, care is taken to see that the local Brunt-Vaisala Frequency is between 0.024cph (inertial frequency) to 24.57 cph (maximum frequency) and stratification scale ($B=1.3$ km) (Ramana Murty et.al,1989). A wave number sampling increment of $\Delta k = 0.01$ cycles/km was used with samples between 0.5 cycles/km (lower bound of HF) and higher bound of HF(1.5 cph) and the another same samples at negative wave numbers to compute normal modes . A total of 20 internal wave modes and eigen-frequencies were computed at each of the above said positive wave numbers. The dispersion relations between the wave number and eigen-frequencies are plotted and shown in Fig 5. An energy density factor of $E_0 = 4$ was used to generate realizations of displacements. Sound velocity profiles (C) were obtained by adding the fluctuations (δC_2) in the following equation (Munk and Zachariasen, 1976) to the background profile (C_0)

$$\delta C_2(r, z, t) \cong (dc_p / dz) \text{Re}[\zeta (r, z, t)]$$

where dc_p / dz is the potential sound velocity gradient (m/sec) and $\xi(r,z,t)$ the internal wave displacement function. Sound velocity profiles were generated for every 600 sec (10 minutes) between 0 and 3000 Sec (50 minutes) and every 0.1 km between 0 and 9 km. The temporal and spatial dependence of the sound velocity in the HF IW field in the contour form is shown in Fig.6 for a single realization (Flatte', et.al, 1979) . The range dependence of the sound velocity profile is the most important consequence of the internal waves, on the temporal and spatial scales selected. The spatial - independence (Without Internal Waves-WIW) and spatial -dependence(IW) of sound velocity profiles have been used as input(left panel of Fig 7) to trace the rays between source-receiver configuration at 20m depth, to compute eigen rays (middle panel of Fig 7) and their corresponding intensity losses(right panel of Fig 7).From Fig 7, one can conclude that 200 SR/R category eigen rays for range-independent and 103 rays for range-dependent

are seen among all possible 4 classes. The travel times are clustered may be due to the anticipated ray path degeneracy (Munk and Wunsch, 1979). To avoid ray path degeneracy, in the present simulation experiment, cumulative intensity loss (Moler & Soloman, 1970) also has been computed in the presence of IW and without IW considering the phase shift with sub-surface-duct frequency of 1031.9 Hz (Urick, 1975) instead of individual ray paths. The anomaly explains the impact of IW on acoustic propagation characteristics in HF IW field. From , one can conclude that the transmission loss anomaly with reference to mean is found to be 9.98 dB.

5. Conclusions

An analysis of Internal Wave IW signatures by in-situ observations off Visakhapatnam have been presented to study the impact of IWs on acoustic field. Acoustic modeling is carried out in the generated IW HF field (by GM model) based on in-situ observations to compute transmission loss anomaly for source-receiver configuration at the depth of 20 m and range of 9 km. The anomaly explains the impact of IW on acoustic propagation characteristics in HF IW field and it was found to be 9.98 dB.

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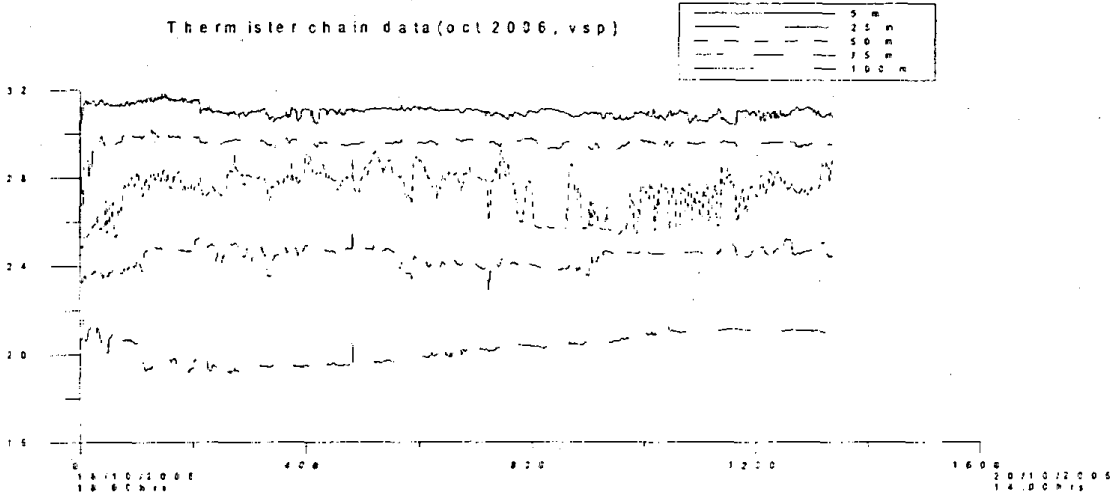


Figure 1. Time series data on temperature (2 minute) collected from thermister chain at off Visakhapatnam during 18-20 oct2006

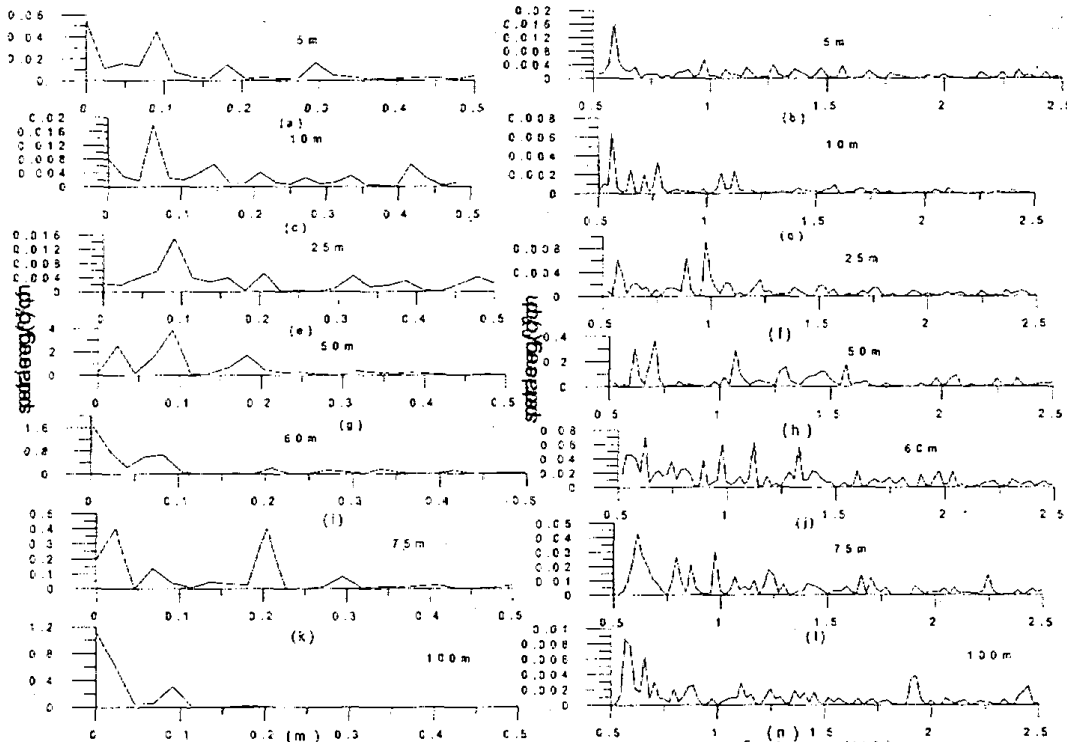


Figure 2. Energy spectra of temperature oscillations at depths 5m, 10m, 25m, 50m, 75m, 100m off Visakhapatnam (VSP) during 18-20 Oct 2006

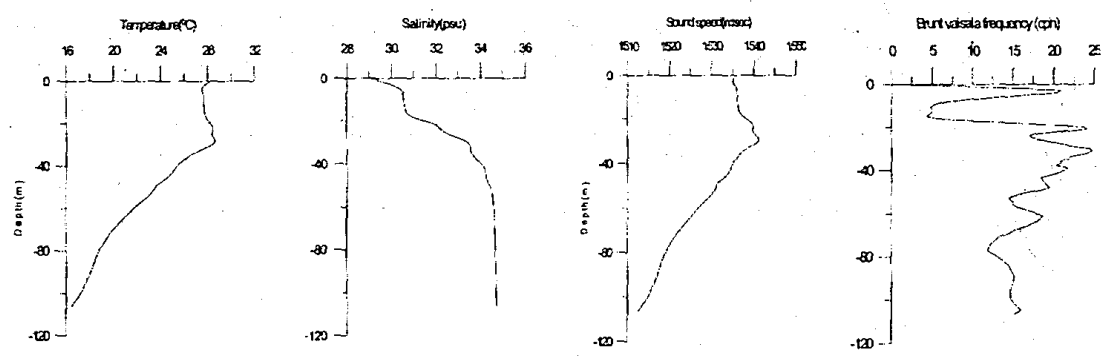


Figure 3. Mean vertical distribution of a) Temperature ($^{\circ}$ C) b) Salinity (psu) c) Sound speed(m/sec) d) Brunt-Viasala's frequency (cph) off Visakhapatnam during 18-20

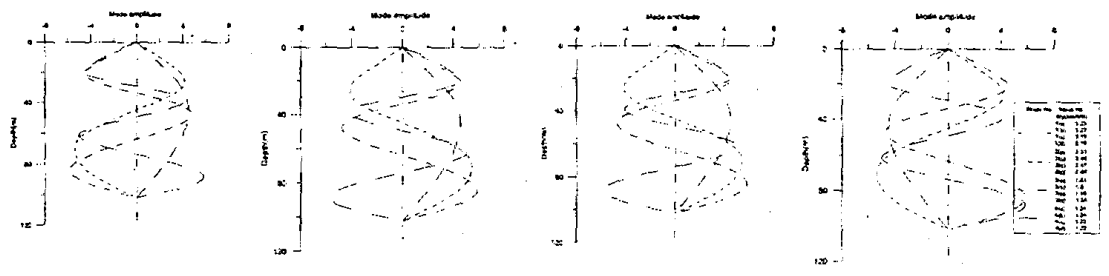


Figure 4. Internal wave modes for frequencies (cph) (a) 1.5 (b) 1.49 (c) 1.48 (d) 1.47 off Visakhapatnam during October 2006

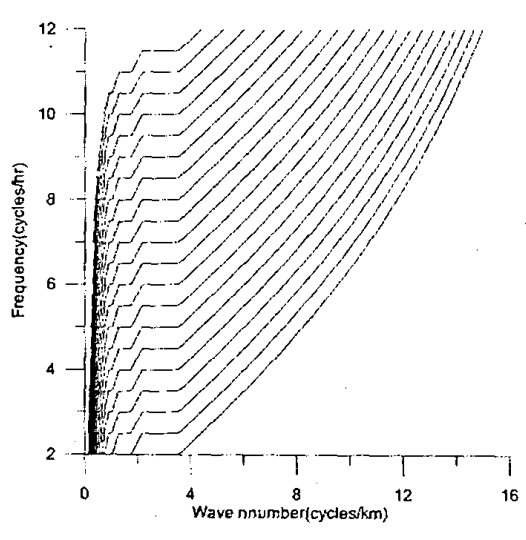


Figure 5. Internal wave dispersion relations

Oct. 2006

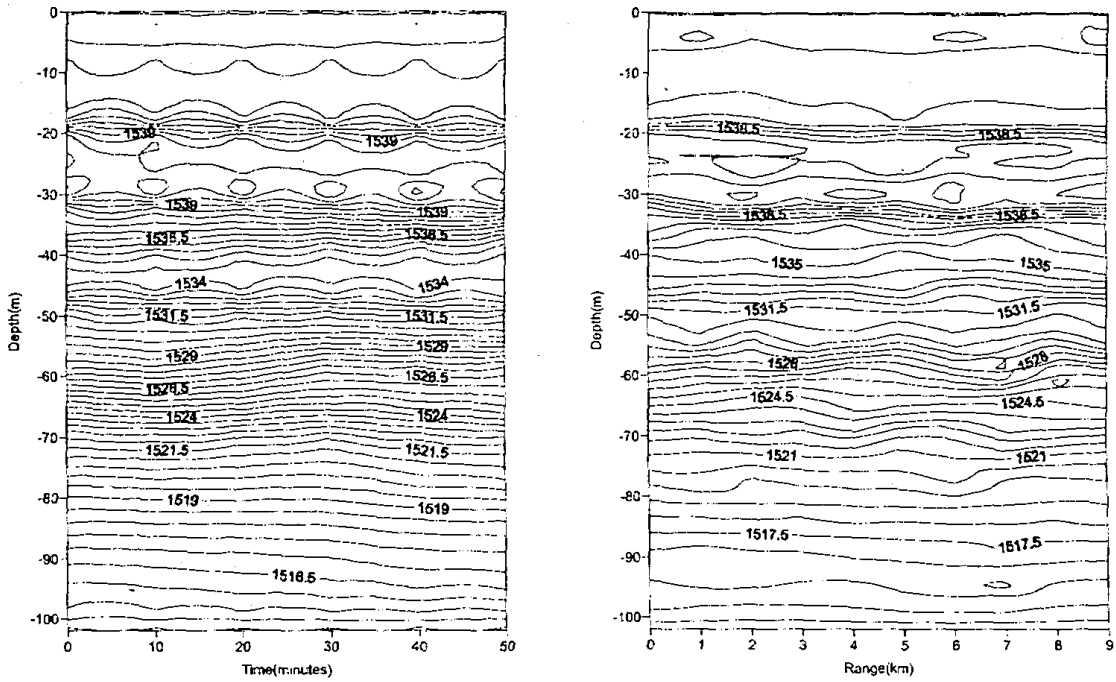
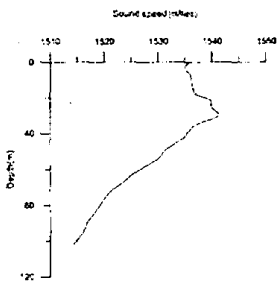


Figure 6. Temporal and spatial dependence of sound velocity distribution in the internal wave field (single & double realizations) off VSP

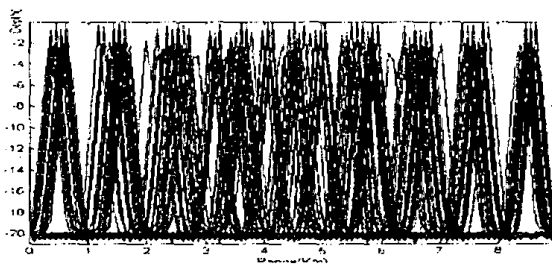
Sound Velocity

Eigen Rays

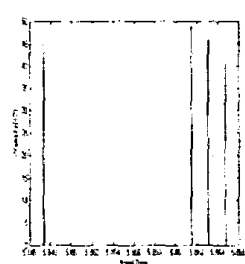
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Mean of HF IW field



Range (km)

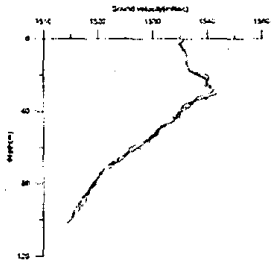


Travel Time (sec)

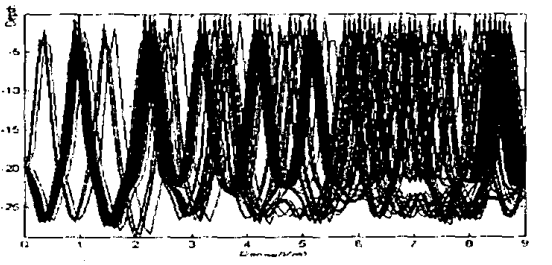
Sound Velocity

Eigen Rays

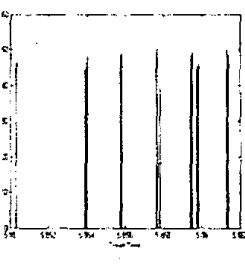
Intensity Oct 2006



Range -dependent of HF IW field



Range (km)



Travel Time (sec)

Figure 7. Eigen Rays Plot