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Modification of Receiver Operating Characteristic Curve due to Internal Waves

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1. Introduction

Curves of receiver operating characteristics, ROC curves, express detection probability (*Pd*) and false alarm probability (*Pfa*) as a function of detection index. There is an assumption in the conventional ROC curves, which is that the signal is steady in stationay Gaussian noise and large bandwidth-time products. In real ocean, the sound speed is changing with time and it cuase the acoustic signal fluctuation. This study attempts to investigate the fluctuation of acoustic signal due to internal waves and estimate the fluctuation parameter to apply for ROC curve modification.

2. Sea Experiment

On October 18-19, 2011, the sea experiment was performed in continental shelf break area bounded by 37°30N to 37°34N and 129°9E to 129°23E. The experiment area is located 8km offshore from the coastline. The experiment area is chosen because small scale oceanographic variability such as internal wave is observed frequently which propagates toward the east coast of Korea. The water depth is approximately 130m and the bottom is described in a geologic survey of the area as consisting of mud. Winds were calm and the sea state was nearly zero. **Fig1** Shows the area map of the experiment.

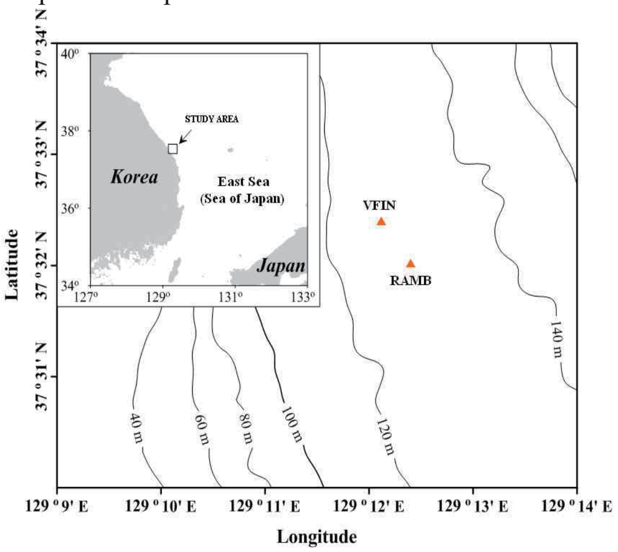

Fig. 1 Area map of the experiment off the east coast of Korea

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For acoustic data acquisition, sound source (VFIN) and vertical line array (RAMB) are placed 1 km apart. The acoustic signal was composed of 12 narrow band continuous waves at a frequency of 200 to 800 Hz in every 50 Hz .The source level of each tonal is 170 dB and set at a depth of 25m. 5 Hydrophones are equally spaced at a distance of 10m in the array from 15m to 55m water depth. The Thermistor sensors are attached on vertical line array at a depth of 10, 25, 30, 35 and 45 m. Temperature time series were collected during the experiment. Source and receiver positions were determined from the global positioning system (GPS) coordinates measured. Acoustic signal and ocean temperature were measured by one and half hour (18 22:20 – 19 00:50)

3. Analysis

In order to investigate the motions of the internal waves, the temperature data was converted to vertical displacements of isotherms as shown in **Fig2**.

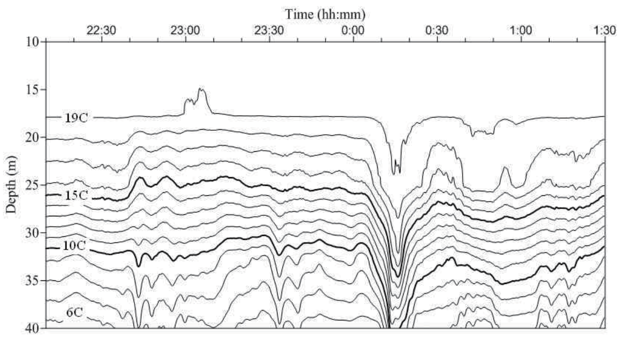

Fig. 2 A time series of isotherm depths from the temperature data (upper curve 19°C, 1°C interval)

The kriging interpolation method was used with a search radius of 0.5 minute and 7 meter in conversion. The maximum displacement reached about 9m downward. The internal waves are analyzed to move from offshore to coast at the speed of 70 cm/sec. The observed internal waves have characteristics of typical periods of 10 minutes, average amplitute of 5m and it continued about 2 hours. As temperature structure varies with time, it may cause travel time difference of acoustic signals. This travel time difference causes fluctuation of acoustic signals.

To analysis signal fluctuation, the sound pressure level as a function of time at a source frequency. The received acoustic signal from the hydrophone is pre amplified, filtered in the frequency band of 100-1000 kHz, transformed to a digital signal and stored in an internal memory of the receiver system. In post signal processing, the calculations of pressure level in the stored signals are conducted taking into account the hydrophone sensitivity, preamplifier gain and transfer function of the filter. The number of fast Fourier transforms (FFTs) was 1024 with a 50% overlap in the rectangular window. The moving average method is used to smooth the pressure level curve. The numbers of spans are selected to have a small value at a smaller depth, and a large value at a larger depth. The purpose of these selections is to provide the best fit for the smoothened plot to the original pressure level plot. For this study, sound pressure at a frequency of 350 Hz was chosen to analysis because large fluctuation was observed than other frequencies.

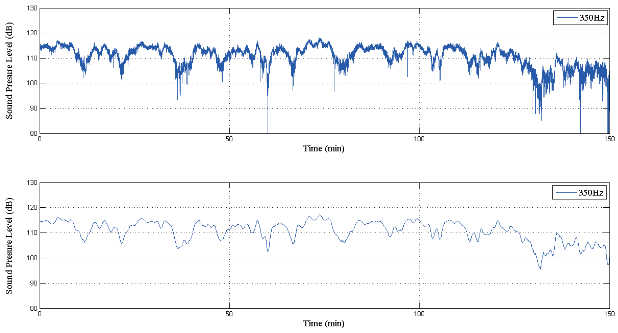

Fig. 3 Fluctuation of received signal at a frequency of 350 Hz.

Through the analysis on the acoustic signals, fluctuations periods of 10 minutes are located in time domain at a frequency of 350 Hz. Spectrum characteristics of acoustic signals shows the possibility that acoustic waves may react to the internal waves through some mechanisms like mode coupling and travel time fluctuation. As shown in **Fig. 3**, the signal fluctuation presents, so the ROCs must be modified to an extent dependent on the magnitude of the fluctuations. The ROC curves can be expressed by the equation

$$p(D) = \frac{1}{2} erfc \left[\frac{1}{\sqrt{2}} \cdot \frac{1}{k}\left(\frac{T}{\sigma_N} - d^{1/2}\right)\right]$$

$$p(FA) = \frac{1}{2} erfc \left[\frac{1}{\sqrt{2}} \cdot \frac{T}{\sigma_N}\right]$$

Where *erfc* is the complementary error function, *T* is the threshold setting, *d* is the detection index. *d* gives an indication of how easy it is to see the signal in the noise. The fluctuation parameter *k* is defined as $\sigma(S+N)/\sigma N$. Where $\sigma(S+N)$ is the standard deviation of the signal plus noise distribution and σN is the standard deviation of the noise distribution. *k* = 1 corresponds to a stable signal and Increasing *k* corresponds to increasing the signal fluctuation.

From the measured sound pressure data at a frequency of 350 Hz, signal fluctuation parameter can be calculated as *k* = 3.9. To calculate *k*, it is assumed that the standard deviation of noise distribution is unity 1.

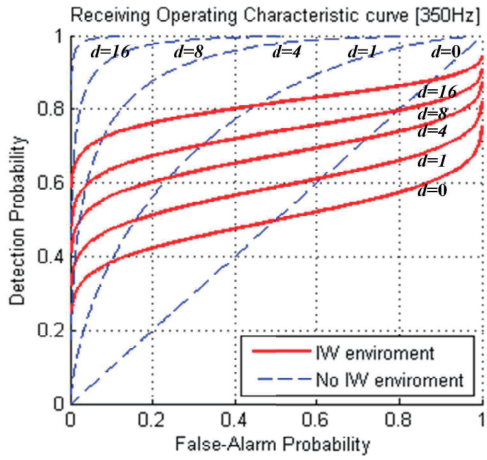

Fig. 4 ROC curves (Separate sets of curves appear for the fluctuation index *k* =1 and *k* = 3.9)

Fig. 4 shows the modified ROC curves with *k*= 3.9 and *k* =1 on double probability coordinates. At a fixed value of *Pfa*, the effect of fluctuation is to increase *Pd* when the signal is weak (lower value of *d*) indicating that the detection performance has been improved due to the signal variability causing detectable spikes in the signal to noise ratio. However to decrease *Pd* when the signal is strong (higher value of *d*), this indicates that the detection performance has become worse due to the signal variability causing dropouts in the signal to noise ratio. Having *k* = 3.9, at *Pfa* = 0.1, detection performance *Pd* increases from 0.1 to 0.38 for *d*=0 and decrease from 0.99 to 0.79 for *d* = 16.

4. Results

In this study, we analyse the internal wave structure which is observed in sea experiment and examine the influence that cause acoustic signal fluctuation. The value of fluctuation parameter *k* are derived from acoustic signal measurement and modify the ROC curves using the parameter. And We demonstrate the detection performance change according to fluctuation parameter.

References

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2. Robert J. Urick: Principles of Underwater Sound (McGraw-Hill Book Company, 1983) p.381.