VARIABILITY OF THE SOUND FIELD IN THE PRESENCE OF INTERNAL KELVIN WAVES IN A STRATIFIED LAKE

Uzhansky E.[1], Katsnelson B.[1], Lunkov A.[2], Ostrovsky I.[3]

[1] L. Charney School of Marine Sciences, University of Haifa, Israel, 3498838 Haifa,
[2] Prokhorov General Physics Institute of the Russian Academy of Sciences, 38 Vavilova str. Moscow, 119991, Russia,
[3] Israel Oceanographic & Limnological Research, Yigal Alon Kinneret Limnological Lab., P.O. Box 447, Migdal 1495001, Israel

Contact author: Ernst Uzhansky
Room 270, Multi-Purpose Blvd., University of Haifa, 199 Aba Khoushy Ave., Mount Carmel, Haifa 3498839, Israel
e-mail: ernstuzhansky@gmail.com

Abstract: *The spatiotemporal variability of low- and mid-frequency sound field in the presence of internal Kelvin waves (IKWs) was studied in Lake Kinneret (Israel). Experimental measurements of the sound field were carried out using a vertical line array (VLA) consisting of ten hydrophones with 3 m spacing. The VLA was deployed in the deepest (37 m) part of the lake. Signals were transmitted from the source deployed at peripheral lake location at the distance of 5.5 km from the VLA at 5-m depth. Chirp signals (300 – 2000 Hz) were transmitted with 5 sec intervals during >24 hours (the period of the IKWs). IKWs were registered using three thermistor chains (TCs) positioned along the northwest transect at 10-m, 20-m and 37-m station depths. This setting allowed us to characterize the variations of thermal structure and the corresponding sound speed profile along the transect. The vertical structure of sound field obtained with the VLA shows correlation with temporal variability due to IKWs. The modeling of sound propagation was done using Parabolic Equation (PE) method, taking into account the parameters of bottom, lake bathymetry and variation of water temperature. The PE results showed close agreement with experimental measurements. [This work was supported by Israel Science Foundation, grant 565/15].*

Keywords: *Internal Waves, underwater acoustics.*

1. INTRODUCTION

Internal waves (IWs) populate various stratified aquatic systems from small reservoirs, such as lakes to the ocean. Water motions caused by IWs lead to an increase in turbulence and diapycnal mixing at the peripheral lake zones, especially in areas where the metalimnion (the thermocline) touches the bottom [1]. It results in enhanced vertical transport of solutes from the nutrient-rich hypolimnion (water below the thermocline) to the upper productive water layer, leading to increased primary productivity rates [2]. From acoustical point of view, IWs are one of the most important factors influencing sound propagation in the ocean. The acoustic effect of IWs in negligible at very short ranges but becomes important for path lengths of several kilometers [3]. The capability of acoustical methods in studying IW dynamics was demonstrated on the shelf zone of the ocean [4], while no such measurements were done in lakes.

The presence of a sharp thermocline and respective gradient in water density in the metalimnion are important for the development of various types of Internal Waves (e.g. Kelvin waves, Poincare waves, high-frequency gravitational waves) e.g. [5], [6]. Rotational internal Kelvin waves (IKWs) showed the most significant contribution to the internal waves spectra [7].

It was shown in [8], remarkable influence of IKWs on the sound propagation and some specific features of variation of interference pattern of the sound field.

2. MESUREMENTS AND INSTRUMENTAION

The study is carried out in a warm monomictic Lake Kinneret. It possesses typical shallow water waveguide properties (depth of ≈10 to 40 m, sound speed profile with a slight negative gradient). The lake bottom is represented as a less than 1 m thick gas-rich layer with low compressional wave velocity (≈300-500 m s^{-1}) lying above gas-free thick bottom with relatively high sound speed (1550 m s^{-1}). Parameters of the bottom were estimated from direct sediment sampling and acoustical sediment characterization [9]. During the winter temperature of the whole water body is about 16° C, while during the summer lake is strongly stratified.

In the following work we consider sound field propagation along the acoustic track (Fig. 1) from the source deployed at 5 m depth at Station T (7.5 m bottom depth) to the receiving system, i.e. Vertical Line Array of 10 hydrophones with 3 m spacing positioned at Stn. A (36 m bottom depth).

Experiment

The experiment was carried out at the end of June 2018 when sharp thermocline is presented (Fig. 2). Linear-frequency modulation pulses (Chirp) at 300 – 2000 Hz frequency band with 5 sec duration were transmitted for > 24 hours (the period of the IKW). Each cycle of 10 consequent pulses was repeated every 30 minutes from 17:45 June 26 till 22:00 June 27. No pulses were radiated from 03:30 till 11:45 on June 27. The recorded signals were cross-correlated with the radiated signals to obtain pulse response. The Hilbert transform was applied to extract the experimental pulse envelopes.

Three thermistor chains were deployed at three stations (H, F, A) to register temporal evolution of the water temperature, and thus, temporal variability of the IKW.

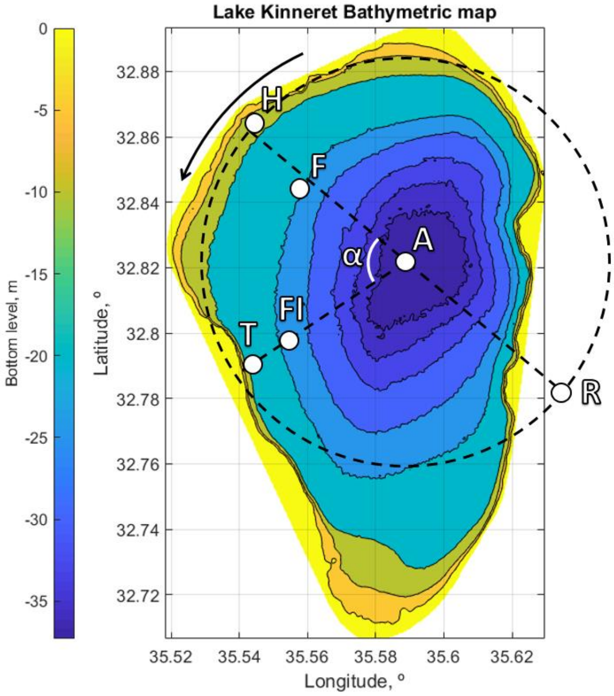

Fig. 2: Bathymetric map of Lake Kinneret and layout of the experiment. A – position of VLA. H, F, A – positions of thermistor strings. T denotes position of the sound source.

Simulation

Numerical modeling of the sound field was carried out for various thermocline positions for the full cycle of the IKW (i.e. 24 hrs). Temporal variability of the IKW was obtained from temperature data from thermistors chains. Sound field simulations were done with a Parabolic Equation approach using RAMs (M. Collins/NRL). Variation of bathymetry and layered structure of the bottom was considered as stationary (unperturbed) parameters. As a non-stationary (perturbed) component only water temperature variations were used. In our model we consider circular shape of the lake (dashed circle, Fig. 1) with radius TA, spatiotemporal variations of water temperature are similar for each radius of this circle (i.e. temperature variations at transect TA are the same as on the transect HA and have the corresponding shift in time).

Thermistor chains were deployed at the northwest transect, whereas acoustic track was positioned at the southwest. Considering period of the IKW 24 hours corresponding to 360º of phase shift, and the angle between these transects α, variations of the IKW at southwest transect were obtained from the +5 hours (i.e. 75º) phase shift of IKW from temperature sensors deployed at Stns. H, F, A.

3. RESULTS

Both simulated and experimental sound fields show similar behavior. First, sound field at the VLA is concentrated below the thermocline. Secondly, variability of sound field intensity is connected with vertical thermocline displacements. When thermocline is high, sound field is stretched and less intense. When thermocline is low, it presses the sound field down to the bottom, resulting in higher intensity of the sound field (Fig.3). Analysis of numerical modeling (Fig. 4) shows up to ≈1 km horizontal displacement of the sound field in vicinity to the VLA.

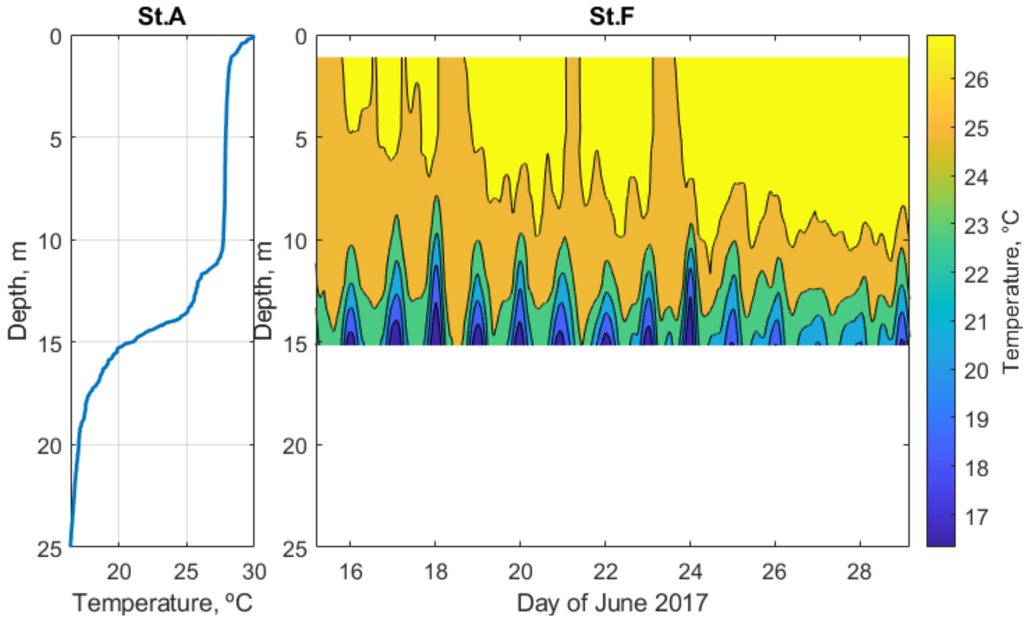

Fig.2: a) – temperature profile at Stn. A at the day of the experiment (26 June 2018) with CTD; b) – temperature profiles obtained at St. F in June 2017 with a thermistors chain.

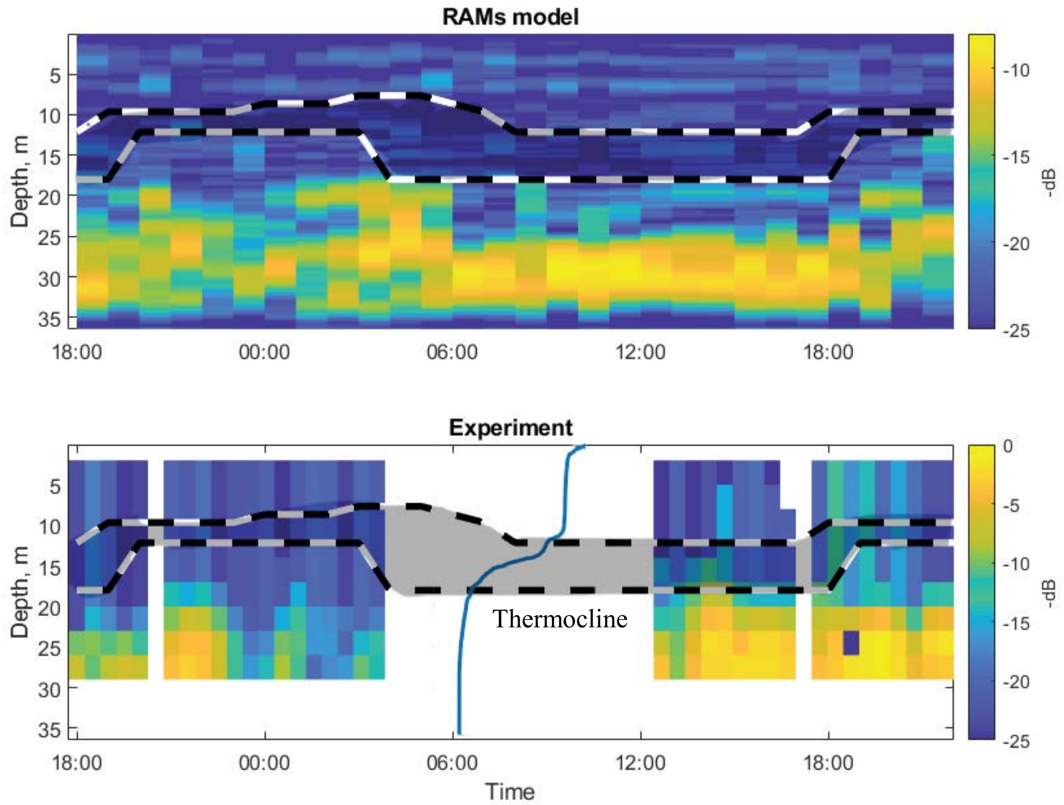

Fig.3: a) Transmission Loss at the VLA simulated with RAMs at frequency of 1 kHz, b) experimental sound intensity recorded on the VLA. White color depicts absence of data. Thermocline boundaries are depicted as dashed lines. In the center of is depicted typical thermocline curve.

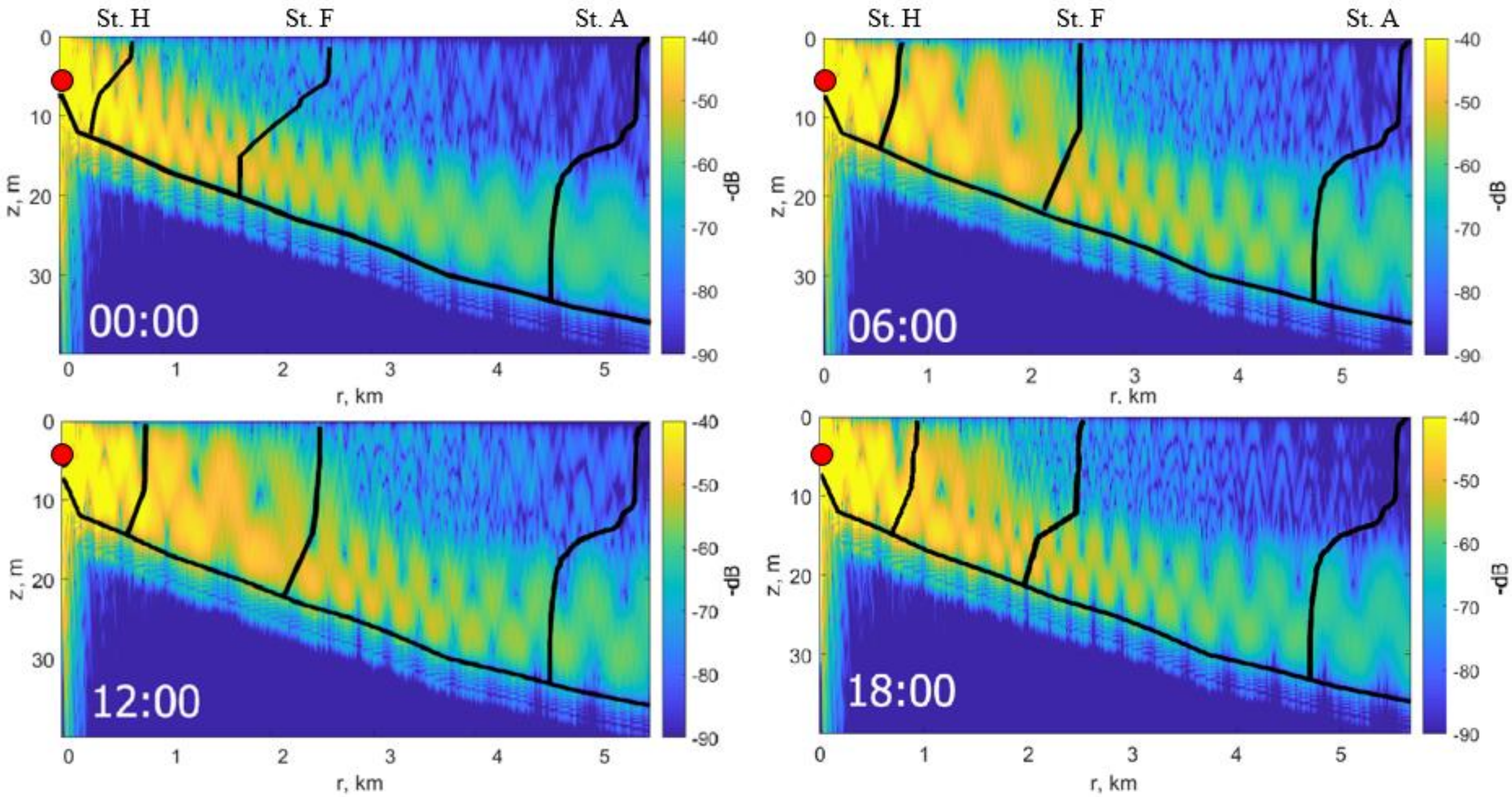

Fig4. Numerical model of Transmission Loss along the transect TA at four moments of time. Solid lines represent temperature profiles obtained with thermistors chain at Stations H, F, and A and shifted in time by +5 hrs. Sound source is depicted as a red circle

4. ACKNOWLEDGEMENTS

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