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The continuous water temperature monitoring by using Acoustic Tomography Technology

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ABSTRACT: Acoustic Tomography (AT) technology transmits reciprocal acoustic waves to measure the flow characteristics such as flow velocity, water temperature, suspended sediment concentration, salinity and the flow direction in rivers, dam storages, lakes, seas and the oceans. Although, this technique is widely applied in developed countries, it was not used in Iran yet. This research shows the first acoustic tomography experiment in Iran for measuring the flow velocity in a shallow lake located in the western of Shiraz City. Reciprocal sound transmissions were performed between the two acoustic stations located on both sides of the lake. The length of sound transmission line was 262 m and the central frequency was set to 30 kHz. The experiment period was 20 minutes and the acoustical data was collected at time intervals of 40s. The surface temperature was measured by a temperature sensor (accuracy= 0.1 oC) at four positions along the acoustical ray path. The results showed the arrival time of acoustic waves were approximately constant and it was 177 ms. Finally, the depth- and range-averaged sound speed and the water temperature along the ray path were estimated from the mean travel time. The temperature varied between 19.7 to 19.9 oC that was confirmed by temperature sensor data. The temperature resolution of AT technique was estimated around 0.04 oC that shows the more accuracy than the temperature sensor. The result of this study showed the ability of acoustic tomography technique to monitor the water temperature in natural aquatic environments.

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1. INTRODUCTION

Recent investigations show that the more frequent and extreme events are the consequences of climate change. For example, higher flood peaks lead to higher erosion rates and subsequently higher suspended sediment concentrations and turbidities in surface waters. Climate change also increases the air temperature and it may influence in-lake processes as well as the magnitude and timing of inflowing waters to lakes [1]. Furthermore, many water quality processes are temperature dependent. Generally, solutes are more soluble at higher temperatures while gases are less soluble [2]. For example, water temperature increment will increase kinetic rates, decomposition rates, biological oxygen demand (BOD), sediment oxygen demand (SOD) and algal metabolism. On the other hand, dissolved oxygen concentrations will diminish in higher temperature waters [3]. Many aquatic species have a small tolerance to low oxygen concentrations (hypoxia). During anoxic conditions, increased nutrient and heavy metal release from the sediments (e.g., phosphorus remobilization) can increase eutrophication and toxic conditions in water bodies. Therefore, Water temperature measurement is an important environmental factor in dam reservoirs, lakes, river and coastal planning/management, and environmental conservation.

A wide variety of techniques such as temperature sensors, numerical models and satellite imagery methods have been used to measure the water temperature. However, these methods have their own limitations. As an example, temperature sensors measure the water temperature locally (at one point) of water bodies, numerical methods have large uncertainties and the satellites only estimate the surface water temperature.

Acoustic tomography technology offer powerful technique for measuring the water temperature in oceans, seas, rivers and lakes. Ocean Acoustic Tomography (OAT) employs high-powered signals with frequencies less than 1 kHz to measure range-averaged ocean temperature. Coastal Acoustic Tomography System (CATS) applies OAT to coastal waters. Because CATS transmits signals at frequencies up to 10 kHz, it can be used in smaller water bodies. Hence, CATS monitors the flow temperature fluctuations in the seas and the straits. To use this technique in shallow aquatic environment and in the shorter ranges as much as hundred meters, these systems must transmit sound at much higher frequencies. As a result, Fluvial Acoustic Tomography System (FATS) uses a second-generation - CATS that transmits sound at a frequency of 30 kHz to measure flow velocity and water temperature in rivers [4]. Although, FATS is widely used to measure water temperature in rivers, it was never applied in the lakes. This study shows the result of first acoustical

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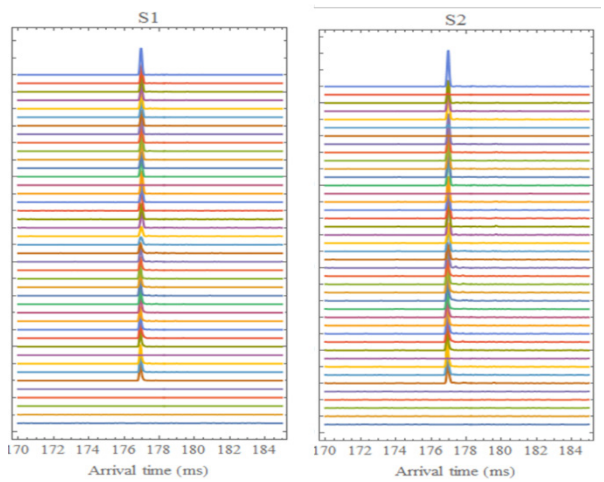

Fig. 1. Stack diagrams of correlation wave forms of transmitted from both stations.

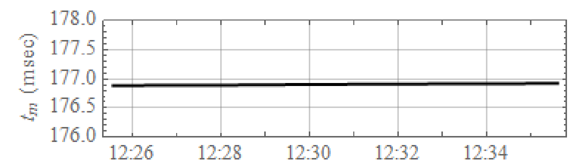

Fig. 2. The mean Arrival time at both stations (S1 and S2).

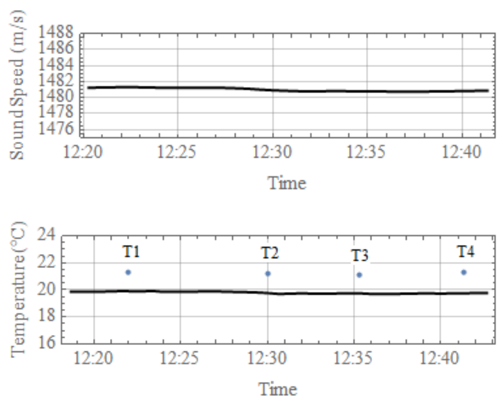

Fig. 3. Sound Speed in water and water temperature comparison.

tomography experiment in a one of the freshwater Haftbarm Lakes, located western part of Shiraz.

2. METHODOLOGY

This research shows the first acoustical tomography experiment in a lake to measure the water temperature. Reciprocal sound transmissions were performed between the two acoustic stations located diagonally on both sides of the lake during the period of July 7, 2017. The air temperature ranged from 32 °C to 33 °C and there was not meaningful wind. Sound pulses of the FATS were simultaneously transmitted from transducers every 40 second at a timing synchronized with a GPS clock. The length of sound transmission line was 262 m and the central frequency was set to 30 kHz. The temperature data was successfully collected.

3. RESULTS AND DISCUSSION

FATS uses travel-time tomography approach. Based on the arrival time of acoustic signals at the upstream and downstream stations, the sound speed and flow velocity along the sound ray path are computable. Based on the Medwin's formula, sound speed in water is a function of temperature T (˚C), Salinity (S) and depth (m) in the ranges of 0 ˚C ≤ T ≤ 35 ˚C, 0 ≤ S ≤ 45 and 0 ≤ D ≤ 1000m, (Equation 1) [5].

$$c = 1449.2 + 4.6T - 0.055T^2 + 2.9\times10^{-4}T^3 + (1.34 - 0.01T)(S - 35) + 0.016D \quad (1)$$

Since there is no saltwater intrusion at the experimental site, the water temperature can be estimated from the sound speed in water [6].

To accurately identify the arrival time of a traveling acoustic signal mixed with noise, the transmission signal is phase- modulated by applying a pseudo-random sequence called an M-sequence [7]. The FATS transmission signal is modulated with a 9th-order M-sequence (511 digits). A three cycles per digit (Q-value) is also selected as a suitable value to transmit the phase-modulated sound from the broadband transducers. The arrival times of the acoustic data were 176.96 and 177 msec at station 1 and station 2, respectively (Fig. 1). Therefore, the mean travel time of 176.98 msec was observed (Fig. 2).

The depth- and range-averaged sound speed and the water temperature along the ray path were estimated from the mean travel time. The results of calculations showed the speed of sound in water was about 1481 m/s during the experiment period and the temperature varied between 19.7 to 19.9 ˚C. The temperature measurement was confirmed by the temperature sensor data at four locations through the transmission line of acoustic waves (Fig. 3). The temperature resolution of Acoustic Tomography technique was estimated around 0.04 ˚C that shows the more accuracy than the Temperature Sensor.

4. CONCLUSIONS

Continuous measurements of the water temperature were conducted in a shallow lake using Fluvial Acoustic Tomography System (FATS), a state-of-the-art acoustic system. The FATS equipped with a couple of 30 kHz broadband transducers with horizontally omnidirectional and vertically hemispherical beam patterns can be used to estimate the cross-sectional average temperature from multiple ray paths that cover the cross-section of a water body. This outcome is confirmed by the previous studies that investigated about the temperature fluctuations in the rivers and estuaries. In conclusion, the result of this study showed the ability of acoustic tomography technique to monitor the water temperature in natural aquatic environments.

REFERENCES

[1] Coats, R., Perez-Losada, J., Schladow, G., Richards, R. and Goldman, C., 2006. “The warming of lake Tahoe”. *Climatic change*, 76(1-2), pp.121-148.

[2] Zouabi-Aloui, B., Adelana, S.M. and Gueddari, M., 2015. “Effects of selective withdrawal on hydrodynamics and water quality of a thermally stratified reservoir in the southern side of the Mediterranean Sea: a simulation approach”. *Environmental monitoring and assessment*, 187(5), p.292.

[3] Sadeghian, A., de Boer, D., Hudson, J.J., Wheater, H. and Lindenschmidt, K.E., 2015. “Lake Diefenbaker temperature model”. *Journal of Great Lakes Research*, 41, pp.8-21.

[4] Bahreini motlagh, M., Kawanisi, K., Danial, M.M., Al Sawaf, M.B. and Kagami, J., 2016. “Application of shallow-water acoustic tomography to measure flow direction and river discharge”. *Flow Measurement and Instrumentation*, 51, pp.30-39.

[5] Medwin, H., 1975. “Speed of sound in water: A simple equation for realistic parameters”. *The Journal of the Acoustical Society of America*, 58(6), pp.1318-1319.

[6] Kawanisi, K. Ishikawa, K. and Razaz, M., 2014. “Acoustic Measurements Of Streamflow and Water Temperature In A Mountain River”. *Proceedings of the 7th International Symposium on Environmental Hydraulics*. pp. 29–32.

[7] Zheng, H., Gohda, N., Noguchi, H., Ito, T., Yamaoka, H., Tamura, T., Takasugi, Y. and Kaneko, A., 1997. “Reciprocal sound transmission experiment for current measurement in the Seto Inland Sea, Japan”. *Journal of Oceanography*, 53, pp.117-128.

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