Acoustic Tomography Experiment in the Lake of Geneva

Winter Cooling - Stage I

Xavier Falourd
LEMA, Ecole Polytechnique Fédérale de Lausanne, CH - 1015 Lausanne, Switzerland
Email: xavier.falourd@epfl.ch

Introduction

Physical limnology in lake of Geneva tries to identify the dominant processes of transport and mixing which influence the water quality of the lake. In order to achieve this, a nearly continuous observation of the movements of the water masses and the development of the thermal stratification is required. Based on ocean acoustic tomography principles [1], an acoustic experiment is performed in the Lake of Geneva so as to define future developments for limnological phenomena observations. By measuring sound travel times in two directions between arrays of hydrophones, placed at the boundary of the lake, we expect to infer, using tomography inversions techniques, the stratification and hydrodynamic state at lake basin scale.

The paper presents the results of an experimentation carried out during the winter 2003-2004 in the lake of Geneva, between two linear arrays of four hydrophones laid around the Grand Lac in order to observe the winter cooling.

Lake Acoustic Tomography

In Lake Acoustical Tomography (LAT), acoustic sources and receivers are strategically distributed around a lacustrine basin. One or more of each can be combined in a system and they simultaneously emit and receive coded signals. A comparison of the structure of the emitted and received signals allows for the acoustical characterization of the lacustrine environment between the sources and the receivers. However, high quality travel time data series can only be attained if the received signals possess stable, resolvable and identifiable arrivals. Stable arrivals are those which show up in repeated transmissions over an extended period of time. Arrivals are identified if the measured arrival structure resembles the predicted arrival structure in such a way that the measured arrivals can be associated with the different paths of propagation. Different from open-ocean applications, the realization of stable, resolvable and identifiable arrivals in a coastal environment is not always guaranteed. This is due to the existence of more irregular acoustic multipaths resulting from a fully or partially bottom-limited, range-dependent propagation condition.

Physical limnology of the Lake of Geneva

An overview of mixing and transport processes which have been observed in the Lake of Geneva based on the research by the LHE is given in [2]. From these studies it has become obvious that during recent years the lake remains stratified throughout the year. An analysis of time series of water level fluctuations at twelve stations around the Lake of Geneva during summer stratification has demonstrated the counterclockwise progression of internal Kelvin waves around the basin. Spectral analysis of these data has shown that only the first (Kelvin wave) and the tenth (Poincaré wave) mode internal waves are always excited. Internal seiches with shore hugging Kelvin waves and offshore Poincaré waves dominate the basinwide water movement (Fig. 1). In the near shore regions, these waves are omnipresent throughout the stratified period. In the offshore region, these waves often break, opening up temporary mixing windows between the epilimnion and the hypolimnion.

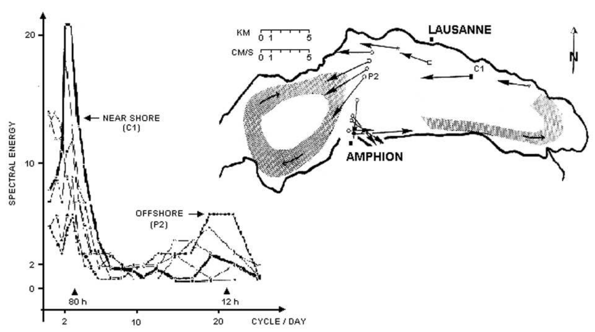

Figure 1: Top, Direct circulation pattern during summer stratification in the Lake of Geneva; bottom, Power density spectra of currents along the north shore [2]

Acoustic Set Up

Since the lake of Geneva is of commercial and tourist interest, the acoustic set up (locations of emitters and receivers) must require the expectations of fishering and commercial activities. Hence both emitters and receivers, in the nearshore of Lausanne and Amphion, are connected to permanent shore stations by reinforced cable of up to a 1000 m length. Both fixed at 30 m above the bottom of the lake at 45 m depth and at a distance of 13.175 km. Emitted signals are coded signals in the 10-20 kHz band. Measurements at pulse rate of twelve per hour, controlled by GPS clocks, are carried out so as to observe the finescale thermal stratification.

Acoustic experimentation

Let us denote $e(t)$ the emitted signal. The received signal is modelled as the noisy output of a linear system. It is given by $r(t) = (e * h)(t) + \nu(t)$ where $\nu(t)$ is a gaussian additive noise and $h(t)$ is the lake impulse response. $h(t)$ is given by :

$$h(t) = \sum_{p=1}^{P} \alpha_p \, \delta(t - \tau_p), \tag{1}$$

$$r(t) = \sum_{p=1}^{P} \alpha_p \, e(t - \tau_p) + \nu(t), \tag{2}$$

where α_P and τ_P are respectively the attenuation and the arrival time associated to the p^{th} path, and P is the number of paths.

The analysis of the travel time (τ_p) perturbations, derived from a classical cross correlation method shows the high heterogeneity of the thermally stratified propagation medium (Fig. 2). As a whole, Figure 2 shows distinctive traces representing stable, resolvable arrivals. From this figure, different evolutions of the different resolvable ray paths in time and in amplitude can be observed, describing the temporal evolution of different water masses. Amplitude and phase fluctuations are the results of surface seiches, internal seiches, internal progressive seiches and others phenomenon within the lake basin. To validate the preliminary measured results, we used a ray tracing software package. The simulated results are computed from bathythermic profiles measured during the acoustic experiments (Fig. 3). Comparison between ray-tracing and measurements shows that three major groups of rays dominate the impulse response. These rays are composed of:

1. refracted - surface reflected rays (R-SR),
2. refracted - bottom reflected rays (R-BR),
3. surface reflected - bottom reflected rays (SR-BR),

R-SR rays propagates in the upper homothermic layer the cooling of which is described by the increase of their travel time (polar-like profile). R-BR rays propagate in the metalimnion and hypolimnion describing the thermal stratification of deep water (temperate-like profile). The third one (SR-BR) describes the whole water column.

The observed coherence in time between the measured results and simulated validates the method. Once these rays classified and identified, their inverse interpretations are of interest for limnologists.

The reciprocal acoustic transmission allows to separate currents effects on acoustic propagation from the effects of sound-speed structure. Time series of currents data and temperature data is of great interest to qualify the evolution of the lake basin during the winter cooling. Throughout the recording period, correlated oscillations with a period of 12 h are observed in the acoustic data sets. This period is close to the inertial period for Lake Geneva. Previous work has indicated that this is the period of Poincaré waves for the observed stratification.

Following these encouraging results, the study will engage the resolution of the forward and the direct problem of tomography.

The final step should succeed in two ways of interest:

- one shot analysis to define the thermal stratification,
- multi-shot analysis to track internal waves .

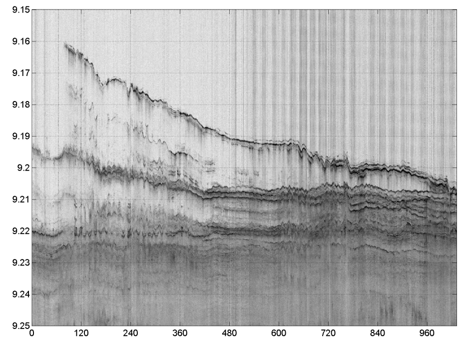

Figure 2: 42 days travel time series during the winter cooling; y-axis: travel time in second, x-axis: time of measurement in hour

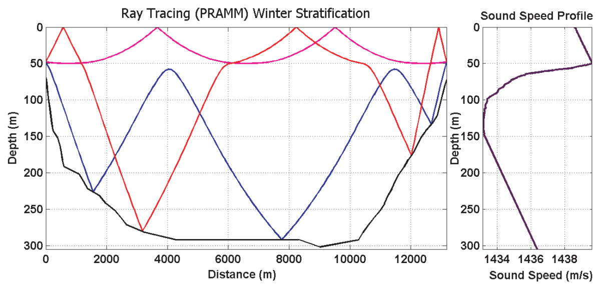

Figure 3: left: ray tracing between Amphion & Lausanne; right: sound-speed profile.

Conclusion

The analysis of travel time fluctuations, derived from classical cross correlation method, shows the high variability of the propagation path induced by internal waves and other currents within the field of study during the experimentation. It has been shown that repeated transmissions of the signal over an extended period of time can yield long-term high resolution time series of the evolution of the multipath propagation medium. In addition, we have found in the acoustic data, indications for basinwide phenomena (Poincaré waves) and the winter cooling of the upper water masses. A complete analysis of the forward and inverse problem is actually in study using acoustic and hydrodynamic database for winter and summer stratifications.

References

[1] W.Munk, P.Worcester, and C.Wunsch. *Ocean Acoustic Monography.* Cambridge University Press, 1995.

[2] U.Lemmin, *Courantologie lémanique.* Archs Sci. Genève, 51, 103-120.