Acoustic Measurements of the Two-Layer Exchange Flow in the Strait of Istanbul

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Introduction

Acoustical methods are playing an increasingly important role in the study of oceanographic phenomena. Here we discuss recent results illustrating the power of combining acoustic Doppler profiling, back scatter acoustic imaging and GPS navigation in a study of the exchange flow in the Bosphorus.

The Bosphorus, Dardanelles Straits and Sea of Marmara constitute a system through which an exchange of water takes place between the Black Sea and Mediterranean Sea. Low salinity water from the Black Sea, formed as a result of excess precipitation and river discharge, flows along the surface through the straits to the Mediterranean. A return flow of more saline, denser Mediterranean water returns to the Black Sea as an under current. Complexities of the Bosphorus flow include secondary and eddy circulations induced by the tortuous geometry of the strait, along strait density variations, and entrainment of fluid from one layer into the other [2].

The study of the physical processes affecting the exchange flow in the Bosphorus has become more and more important over the years. Large vessel traffic is likely to increase in future if plans to ship oil from the Caspian Sea to the western countries through the Bosphorus become reality. Furthermore the constantly expanding population of Istanbul causes increasing pollution of the Bosphorus and the adjacent seas. Assessing the effects of the pollution on the seas requires a good knowledge of the physics of the flow in the Bosphorus.

Background

The Bosphorus is a meandering strait about 31 km in length, with widths varying from 0.7 to 3.5 km, averaging about 1.6 km. Average and maximum depth are 35 and 110 m. Its bed is a drowned river channel, on average more than 50 m deep. The important geometrical features affecting the flow are two sills and a contraction. The southern sill has a depth of 33m. The northern sill is located just north of the Bosphorus - Black Sea junction and has a depth of about 60m. At the contraction the strait is only 600m wide. This is also the deepest section ($\approx$ 110m).

The Bosphorus is a strongly stratified two-layer system. Highly saline ($S \approx 38$ psu) Mediterranean water flows north under fresher and therefore less dense Black Sea water ($S \approx 18$ psu) which flows into the opposite direction (see Figure 1).
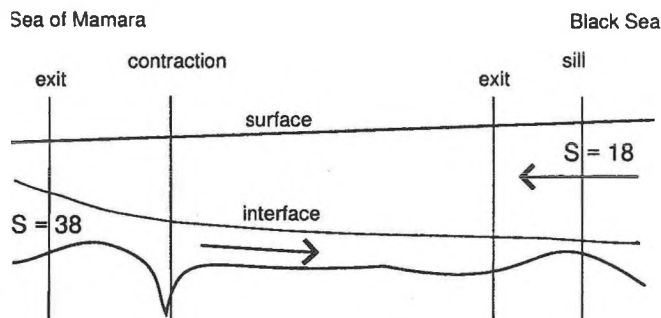

Figure 1: Sketch of the two-layer flow in the Bosphorus.

Experiment

In August 1998 we surveyed the strait with a 300 kHz broadband ADCP in bottom-tracking mode and a 120kHz echo-sounder together with GPS positioning. Available data include runs along the strait, plus several transects across the strait.

The vertical bin size of the ADCP was 2m and the first bin was 4.5m below the surface. With a beam angle of 20 degrees the ADCP missed only a few bins at the bottom. Sometimes high bubble concentrations in the Bosphorus limited the maximum depth of measurement.

High resolution images of the flow structure were obtained with the echo-sounder. The vertical bin size was 0.45m and the first bin was 1.3m below the surface. The beam-angle of the transmitter was 3.6 degrees which gives a good horizontal resolution at even the deepest points in the strait.

The acoustic measurements were supplemented with position data from a differential GPS system. The horizontal position accuracy was better than 2m.

Results

Position in the Bosphorus is given relative to the thalweg. Its origin is at the southern exit at the Sea of Marmara. The thalweg distance increases northwards so that the Black Sea begins at thalweg 32km.

Figure 2 shows the along channel component of the horizontal velocity along the entire strait and the ADCP backscatter intensity. The velocity of the upper layer was about $-0.1\,\mathrm{m\,s^{-1}}$ at the Black Sea side. While moving southward it increased, but varied depending on the width of the strait. Maximum surface velocities of up to $-1.7\,\mathrm{m\,s^{-1}}$ were reached at about 9 to 10 km, south of the contraction. It remained

fairly high (about $-1.3\,\mathrm{m\,s^{-1}}$) until it reached the Sea of Marmara, the reason being the relatively small thickness of the upper layer between the contraction and the Sea of Marmara.

The northward flowing lower layer moved with average speeds ranging from $0.4\,\mathrm{m\,s^{-1}}$ to $0.8\,\mathrm{m\,s^{-1}}$ with highest speeds near the northern exit.

The velocity data as well as the density profiles show that the depth of the interface decreased from north to south. The high vertical resolution of the current data enables us to use the current speed as definition for the interface depth; the interface is defined as the depth of zero current. Then the interface depths are $42\,\mathrm{m}$ at $30\,\mathrm{km}$, $40\,\mathrm{m}$ at $25\,\mathrm{km}$, $37\,\mathrm{m}$ at $17\,\mathrm{km}$, $35\,\mathrm{m}$ at $11\,\mathrm{km}$, $28\,\mathrm{m}$ at $9\,\mathrm{m}$, and $23\,\mathrm{m}$ at $3\,\mathrm{km}$. The interface depth is changing most rapidly between the contraction and the southern sill. While detailed analysis of the acoustic back-scatter images is not discussed here, the coarser resolution ADCP signal is consistent with the interpretation of intense mixing in this region.

The flow structure along the cross-channel transect TW6, which is located in a highly curved section of the strait, is shown in Figure 3. Because of the curvature the current not only had a vertical velocity gradient but also a horizontal one. The upper layer flow occupies the entire width of the strait but is strongest on the west side. On the other hand, the lower layer flow was confined to the west side. The high resolution echo-sounder image shows instabilities along the interface and also within the upper layer.
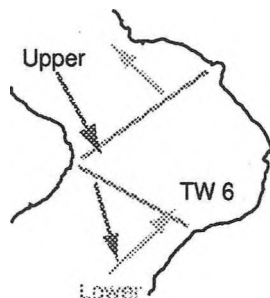
SUMMARY

Acoustical measurement techniques were used to study the two-layer exchange flow in the Bosphorus. The vertical resolution of the ADCP measurements is sufficient to clearly define the depth of the interface. The number of missing bins both at the surface and at the bottom is small. This is an important prerequisite for an accurate determination of the layer transports and the change of the layer transports along the channel [1]. The latter will allow us to estimate the amount of mixing and entrainment as a function of position in the Bosphorus. This is currently being undertaken.

The echo-sounder images reveal interesting details about the structure of the flow. Hence they can be used to identify regions of intense mixing and entrainment across the interface and, even more important, they can give insight into the physical processes that occur in the flow.

REFERENCES

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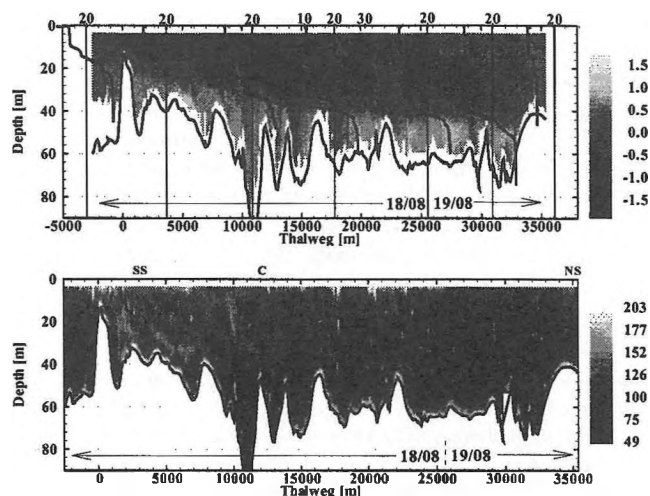
Figure 2: **Upper:** Along channel velocity $[\mathrm{m\,s^{-1}}]$ plotted versus depth and thalweg. Northward flow is positive and southward flow is negative. Vertical profiles of $\sigma_t[\mathrm{kg\,m^{-3}}]$ obtained at thalweg positions -3, 4, 11, 18, 25, 30, and 23 km are superimposed. The data are composed of sections acquired on two days. **Lower:** Average back-scatter intensity from the ADCP.
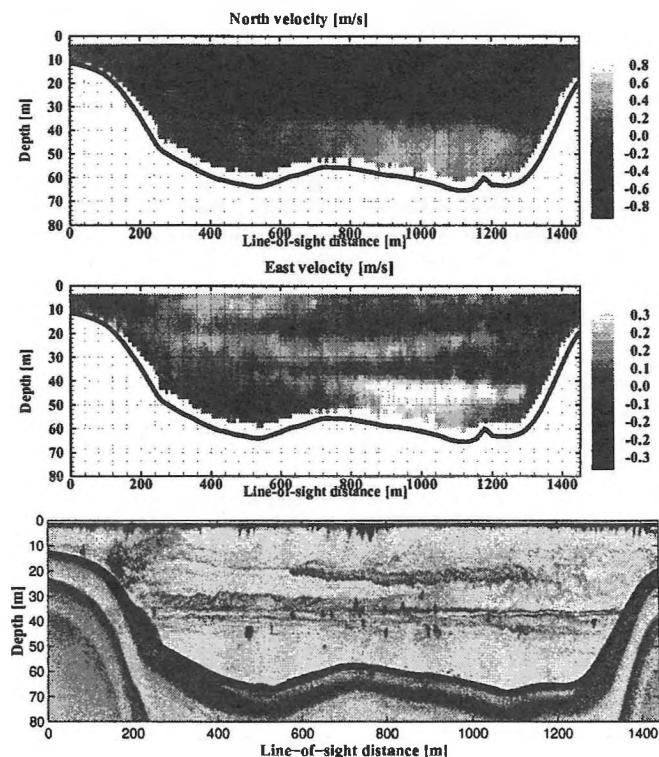

Figure 3: **Upper:** North component of horizontal velocity $[\mathrm{m\,s^{-1}}]$ plotted versus depth and thalweg. **Middle:** East component. **Lower:** Echo-sounder image of the flow.