A REVIEW OF BOSPHORUS MEASUREMENTS DURING THE TÜRBO CAMPAIGN (1999-2000)

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1. Introduction

A detailed measurement program promoted by the İstanbul Technical University Foundation, Defense Studies Center (İTÜV/SAM) contracted by the Turkish Straits (TÜRBO) administration of the Turkish Government in the 1999-2000 period was carried out by the IMS-METU (1999) to investigate surface currents in the Bosphorus, a key element of enormous importance for navigation and shipping accident risks in the Turkish Straits.

A small ship specially fitted with on board ADCP was used to monitor currents in the Bosphorus, including its many small embayments, shallows and turns in channel orientation, while the research vessel R/V BİLİM collected CTD and ADCP data at stations and transects across the Strait. The experiments were performed on several days during 3-6 September 1998, 4-22 March 1999 and 22 July – 3 August 1999. The magnetic anomalies in compass direction created by the steel hull of the small ship ATMACA II hired from a diving company, as well as the GPS positions and consequently ship course had to be corrected for accurate positioning, by making use of independent measurements of the GPS and bottom tracking.

Current meter and sea-level measurements at fixed stations shown in Figure 1 provided additional information on the flow characteristics. A current-meter at 4.5 m depth was placed at Beylerbeyi near the Small Officers Preparatory School (station CM1/BL: 41º02’36”N 29º02’14”) in the southern Bosphorus and two current-meters at 5 and 11 m depths at the headland of Selvi Burnu in the northern Bosphorus (station CM2/SB: 41º08’42”N 29º04’12”E), all of which were Aanderaa RCM7 rotor type recording current-meters. Sea level stations close to these locations were established, installing Aanderaa Water Level Recorders of the WLR7 type on the coast of the Yusuf Kalkavan Mariner High School at Beşiktaş (station SL1/BS: 41º02’19”N 29º01’06”E) and at the pier of the Rumelikavağı Pilot Station (station SL2/RK: 41°10’33”N 29º04’22”E). The positions of the sea level instruments were levelled, yielding +0.818m for SL1/BS and +1.681m for SL2/RK stations. Currents and sea level were measured at 5 min nominal sampling and recording intervals.

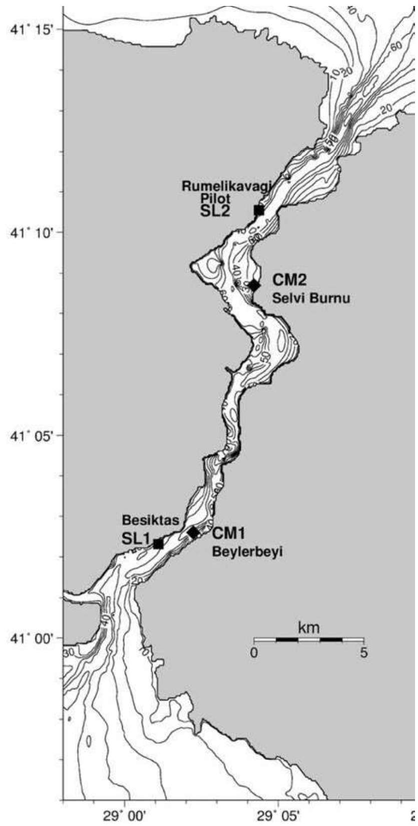


Figure 1. Positions of current-metering and sea level stations in the Bosphorus

2. ADCP measurements of surface currents

The primary aim of the measurements was to determine surface currents and the associated surface circulation in the Bosphorus, especially to collect elaborate information showing areas of rapid changes in direction and magnitude of currents, meandering and re-circulations in the various bends, corners, deep channels, shallow banks and embayments of the Strait, which are extremely important in general navigation and shipping in this critical high energy region. In order to collect the ADCP data used to construct maps of surface currents, the small boat had to enter shallow areas and travel along the Bosphorus along a route that challenged the very same dangers of navigation in the congested traffic of the Strait. The measurements actually represent near-surface currents at about a depth of about 5 m because of the loss of data near the surface.

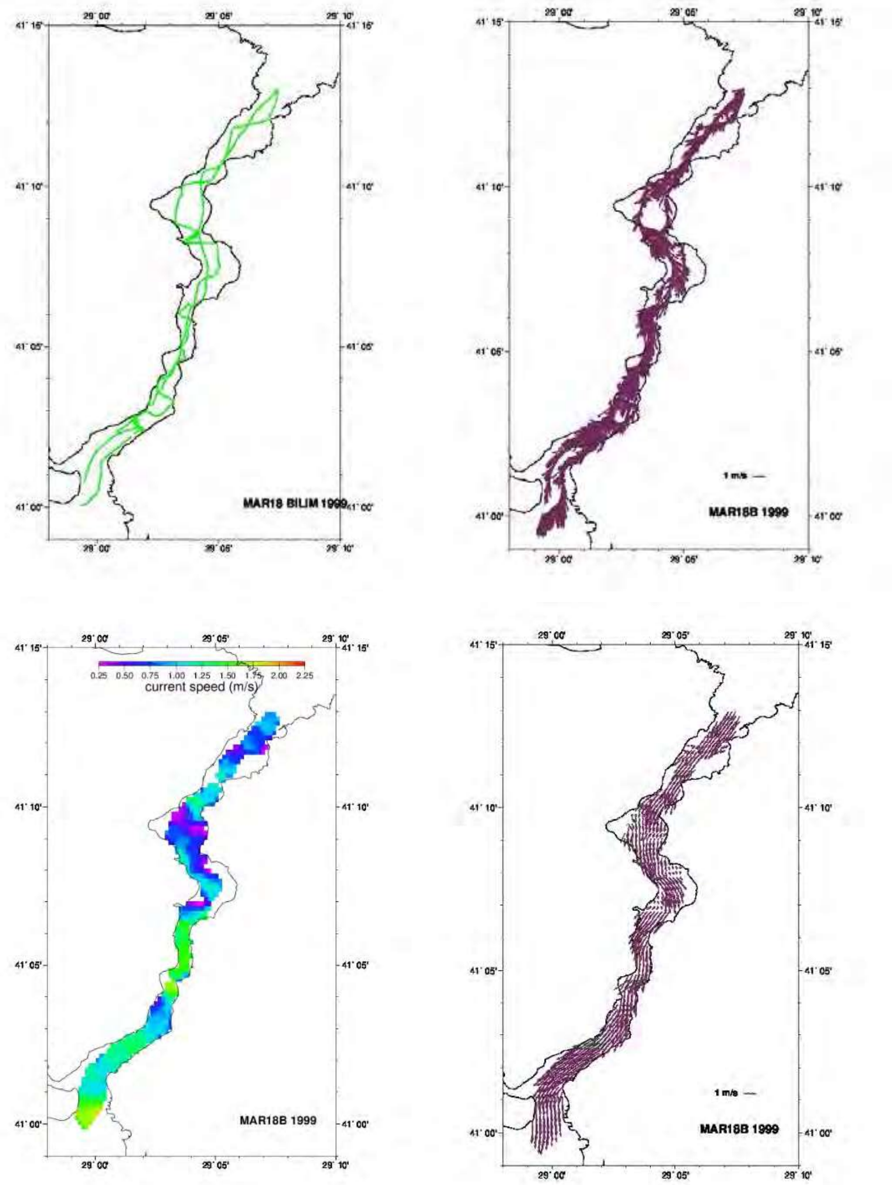


Figure 2. Example display of the travel path of the boat ATMACA II along the Bosphorus, the vectors of surface currents sampled along the route, and the interpolated amplitude and vectors of surface currents on March 18, 1999.

An example of the ADCP near-surface (10m) currents obtained by the boat along its path in the Bosphorus and the interpolated fields of current amplitude and vectors are provided in Figure 2. The series of daily surface current maps are provided in Figure 3.

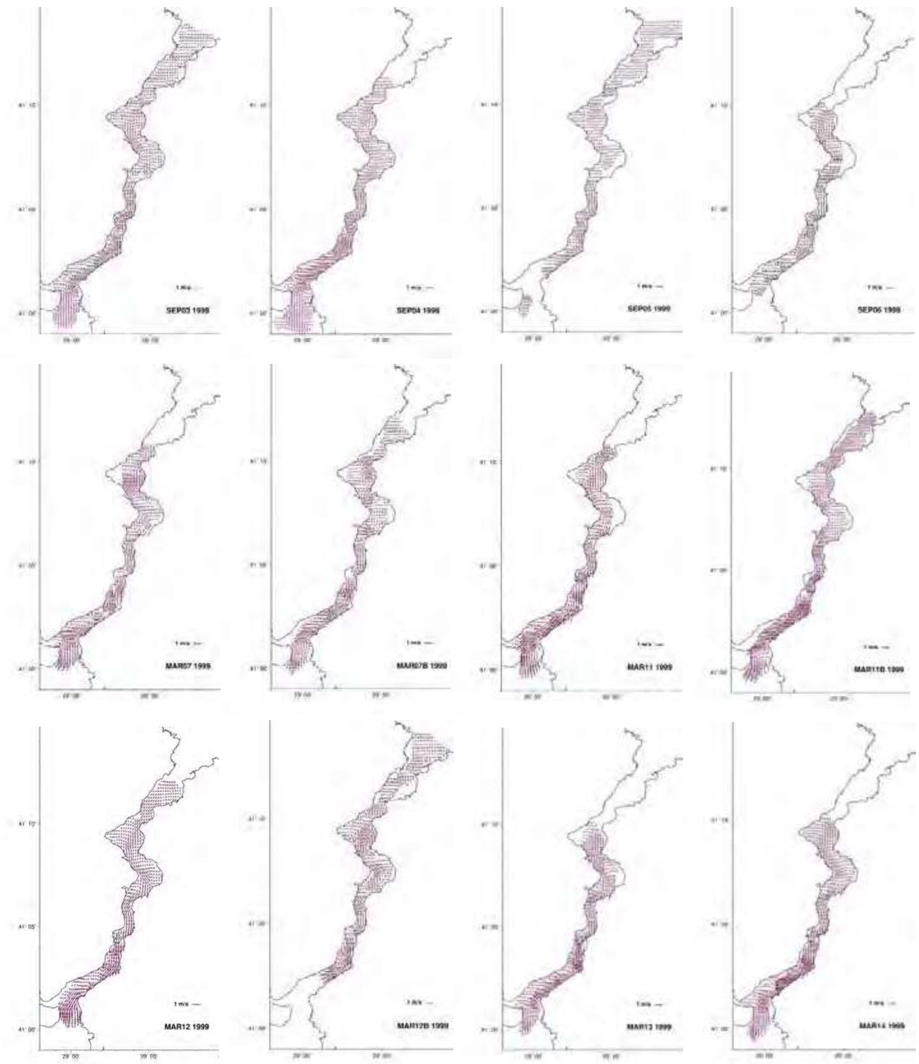


Figure 3. Surface currents based on daily measurements horizontally interpolated to the Bosphorus area.

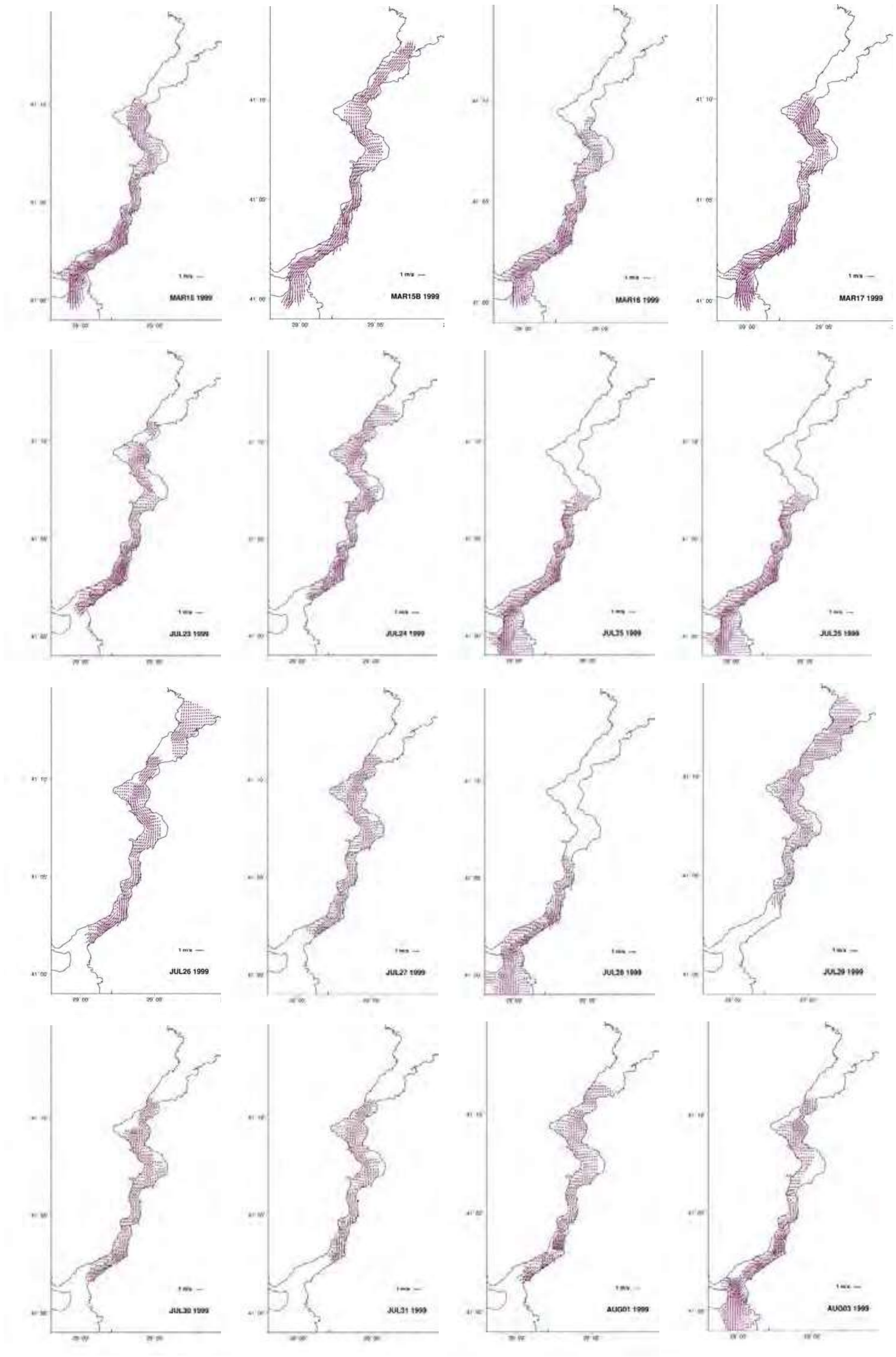


Figure 3. continued

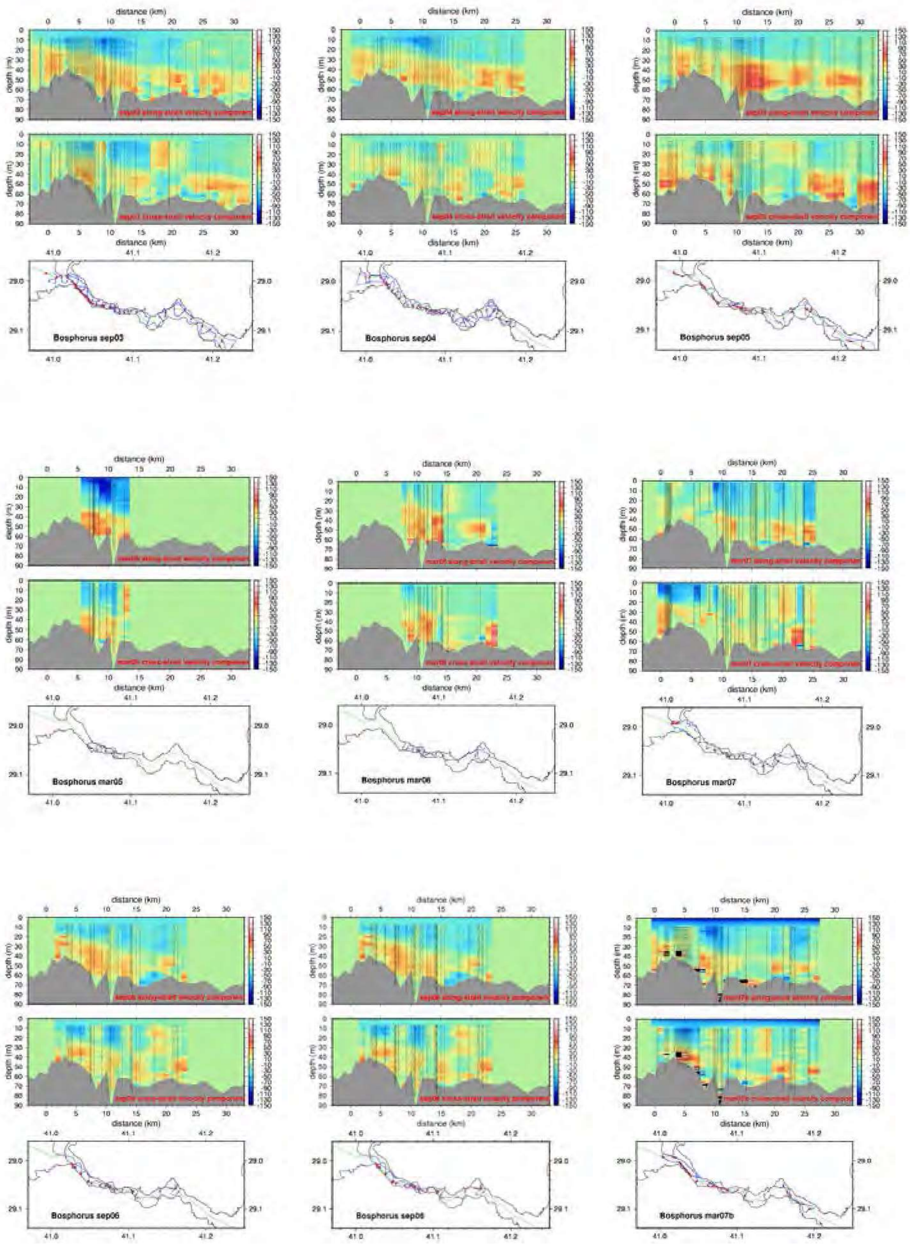
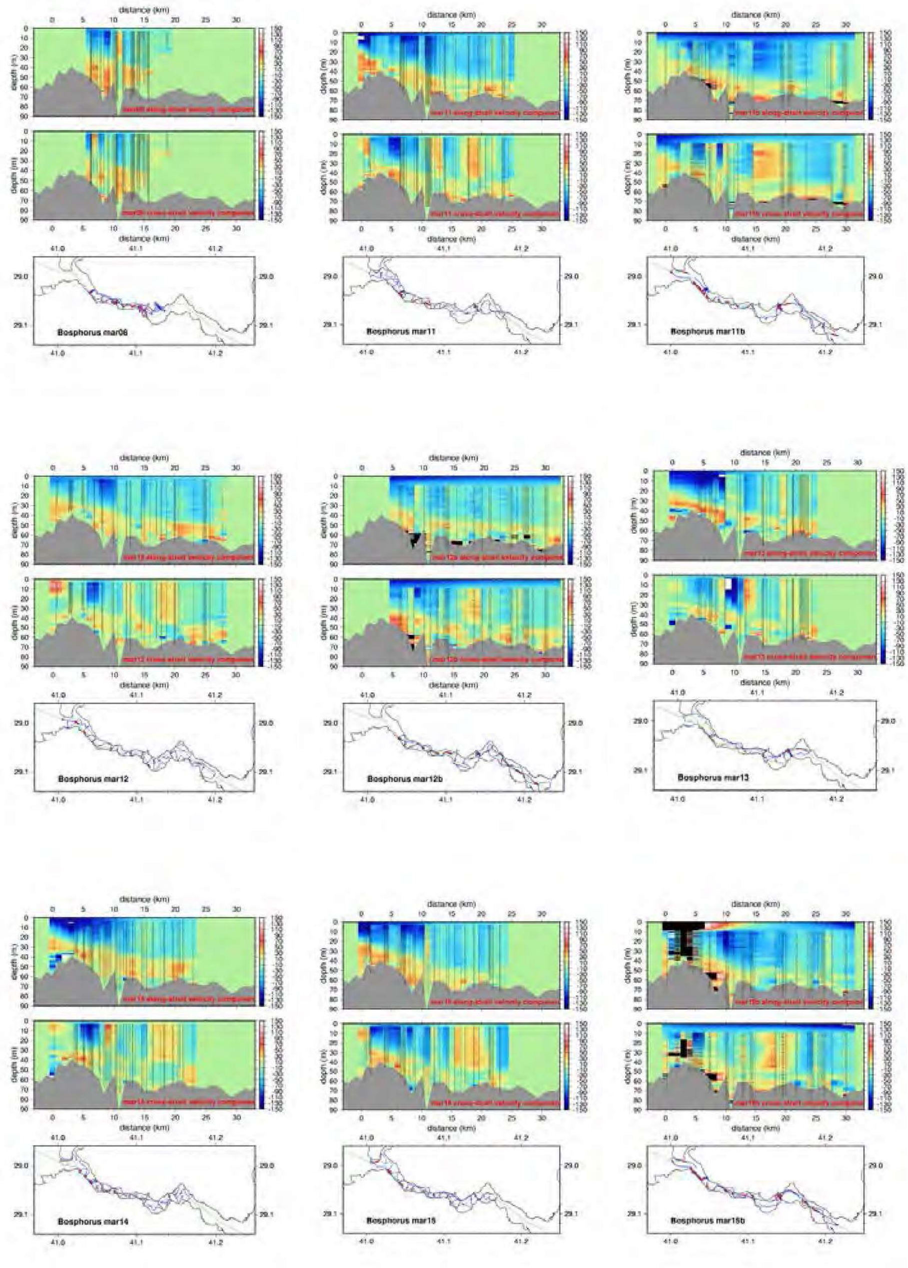


Figure 4. Transects of ADCP currents along the Bosphorus. The upper panel in each set is the along-strait component of velocity (positive towards the Black Sea) and the middle panel is the cross-strait component. The boat path, the thalweg line and crossing points (red) used in interpolation to transects are shown in the lower panel.



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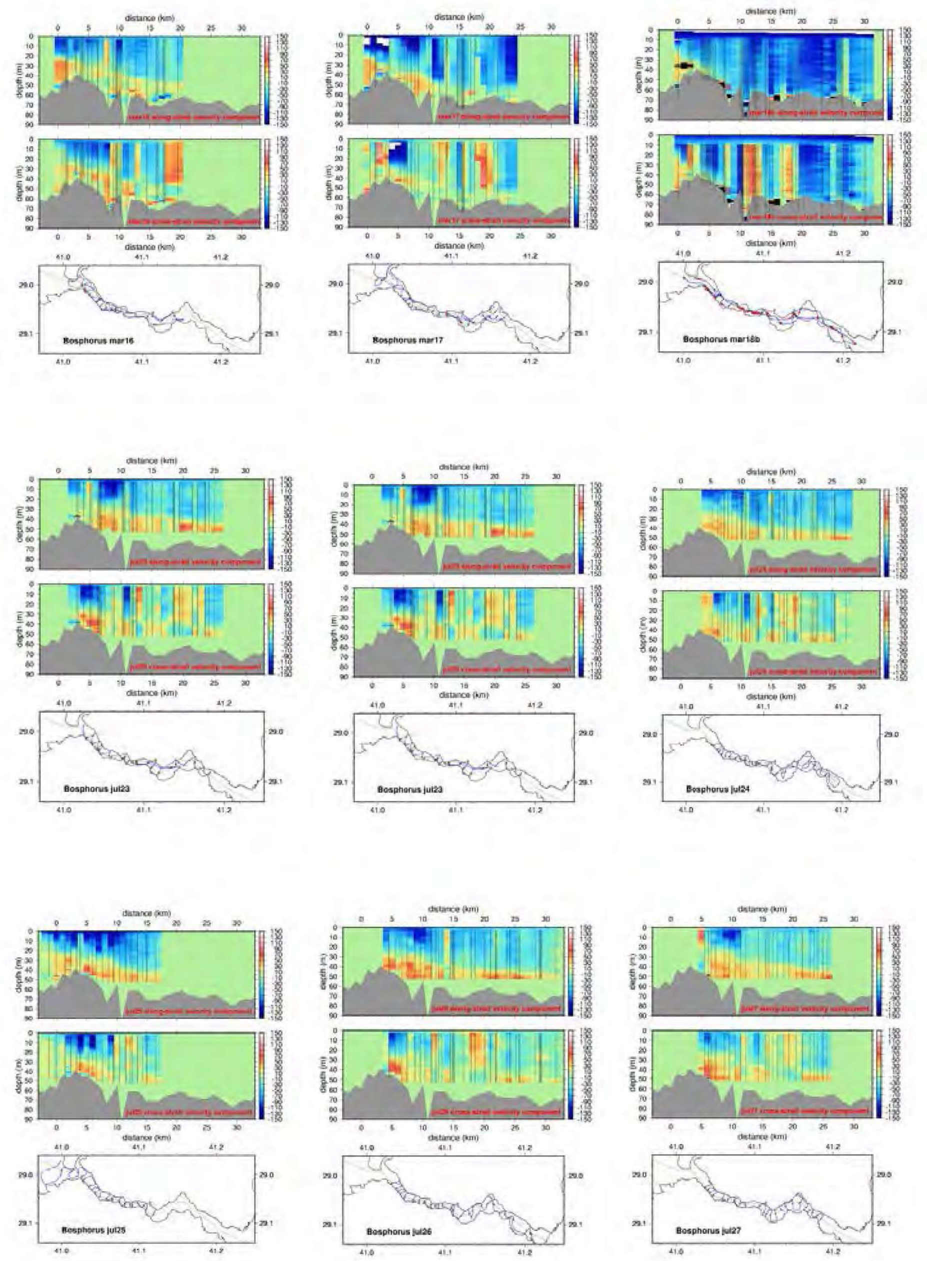

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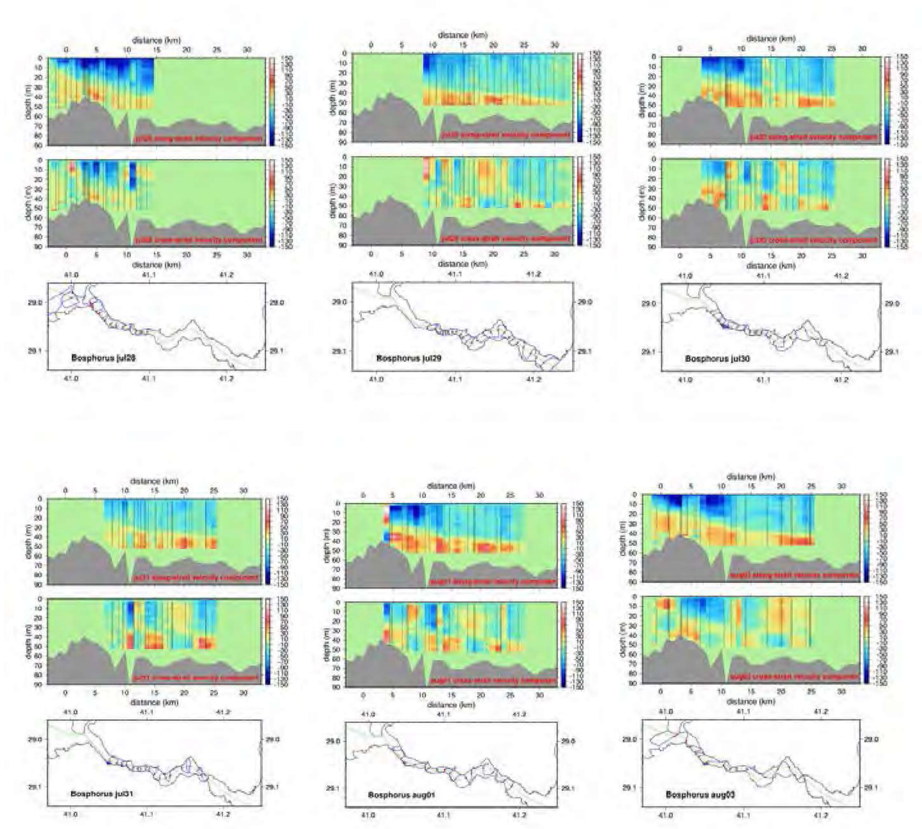

Figure 4. continued

3. ADCP and CTD sections

The ADCP current profiles obtained along the travel path of ATMACA II (e.g. Figure 2) were projected on the mid-Bosphorus transect following the thalweg, by using the data at the intersections of the boat path with the thalweg. The current vector data were then rotated to align the along-strait component to the thalweg line, and the other component perpendicular to it. The along-strait and cross-strait components are shown on the upper two panels in Figure 4, and the boat path crossing points with the thalweg are also shown.

A great variety of flow configurations are shown in Figure 4, with high currents of up to 1.5 m/s and higher are observed especially in the southern Bosphorus. In the lower layer, currents reaching 1 m/s in amplitude are observed. The measurements during March 15-18 demonstrate a case of lower layer blocking, with the emmmmntire Bosphorus swept by southward currents on March 18.

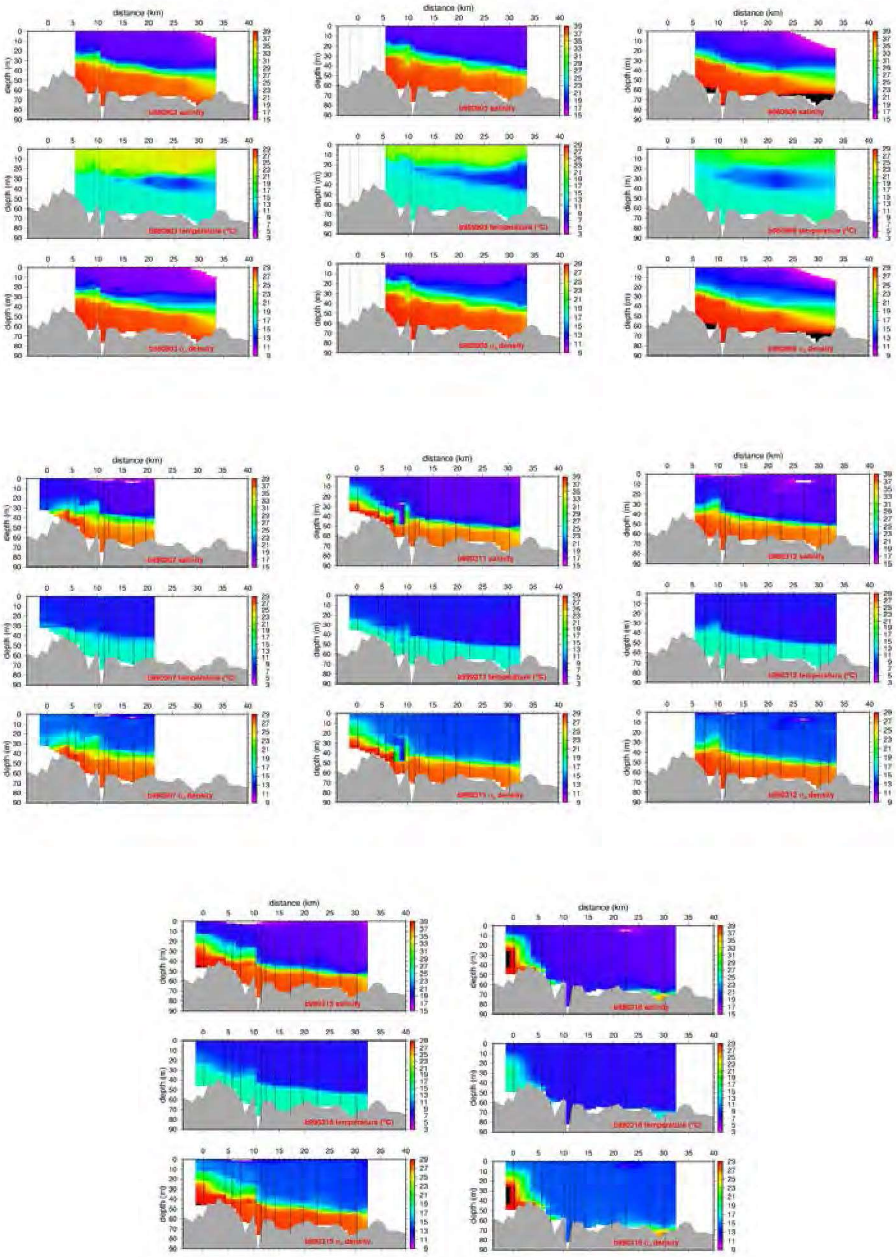

Figure 5. CTD cross sections along the Bosphorus obtained by R/V BİLİM on several days during which ADCP measurements of Figure 4 were obtained by ATMACA II. In each figure the upper, middle and lower panels respectively display salinity, temperature and density sections.

CTD data at stations were obtained by R/V BİLİM during some of the days when ADCP data from the boat ATMACA II. The temperature, salinity and density sections are provided in Figure 5 for comparison with the ADCP data in Figure 4. In most of the cases, two layer flow structure and the change in interface characteristics past the hydraulic control at the contraction in the southern part appear as well known features, except the last one on March 18, 1999 when the lower layer is blocked and pushed all the way to the south, past the southern sill of the Bosphorus.

ADCP measurements were also obtained in the Dardanelles Strait by the R/V BİLİM during its return to the Mediterranean Sea, as shown in Figure 6. A crossing pattern was followed along the Strait to enable horizontal interpolation of surface currents. The cruise path of the ship, its intersections with the thalweg line and the projected along-strait and cross-strait velocity componetns are shown on the left-hand side panels. The original velocity measurements and the horizontally interpolated surface circulation are shown on the right-hand side. The sections indicate the highest upper layer currents past the Nara Pass, while the lower layer currents are significantly lower in magnitude.

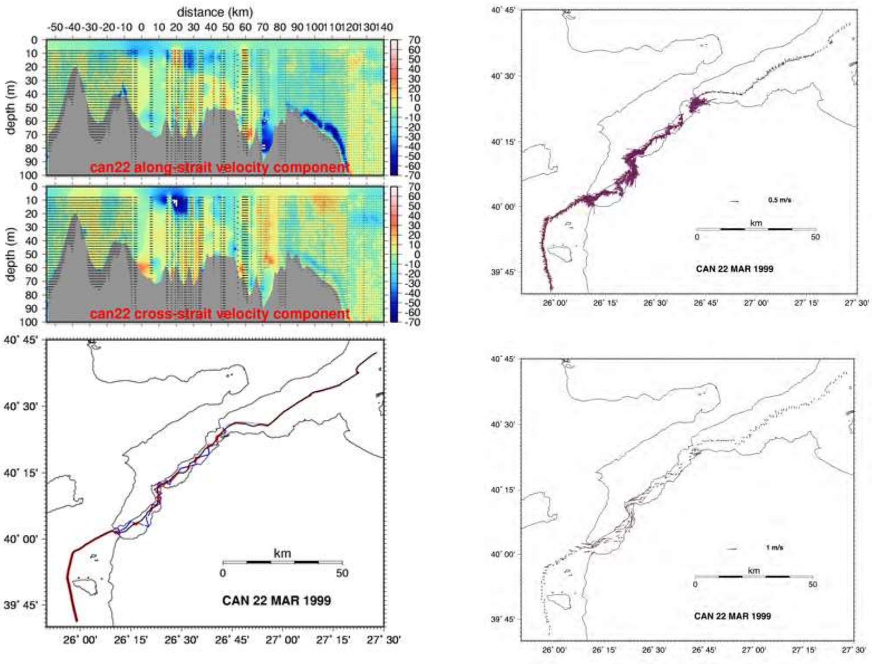

Figure 6. Along-strait (positive towards the Black Sea) and cross-strait velocity components along the Dardanelles Strait (upper two panels) and the path of R/V BİLİM intersecting the thalweg line (red) in the lower panel on the left hand side. The original velocity vectors sampled along the cruise path and horizontally

interpolated to show surface current distribution are shown on the two panels on the right-hand side.

4. Current and sea level measurements

Currents at fixed stations were measured for several monthly current-meter deployment periods. An example of current measurements at stations CM1 and CM2 is provided in Figure 7, with current components rotated to align with the main flow axis, temperature and salinity.

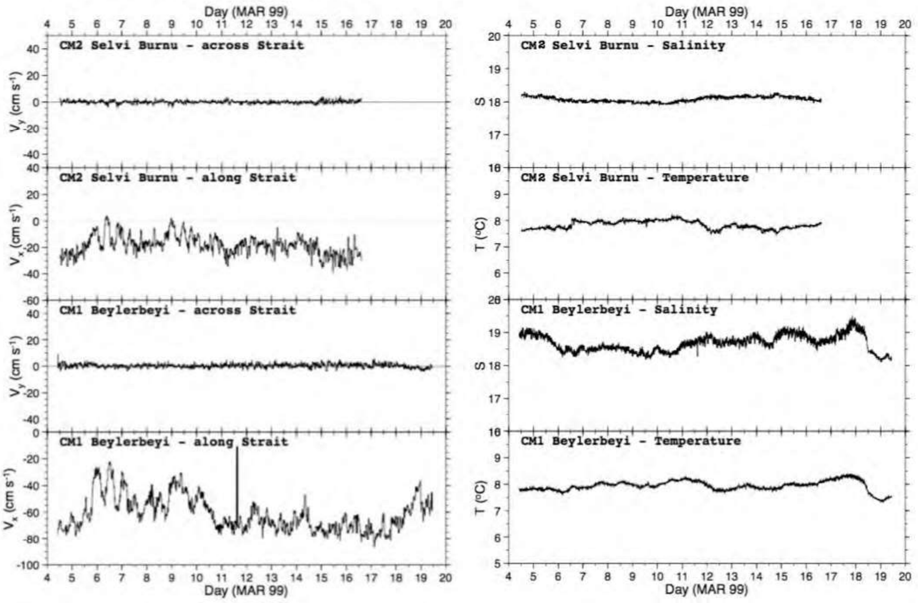

Figure 7. Current-meter measurements starting on 04 March 1999 of current components aligned along the main strait direction and temperature and salinity records.

Mean currents of 0.2-0.6 m/s and instantaneous values reaching up to 1m/s are observed in the records. Spatial and temporal correlations and spectral analyses provide estimates of spatial and temporal scales of motion. Spectral estimates using fft periodogram and maximum entropy analyses are given in Figure 8 for the currents displayed in Figure 7, showing diurnal and semi-diurnal tidal signals as well as 2-5 d periods corresponding to motions driven by meteorological factors, and small fluctuations in the high frequency band.

Sea level measurements obtained for about eight months by repeated deployments of tide gauges at Beşiktaş (BS) and Rumelikavağı (RK) stations show local and remote effects of the regional hydro-meteorology influencing the dynamics of the TSS as well as the neighboring seas. Spectra for sample records at the two stations are given in Figure 9.

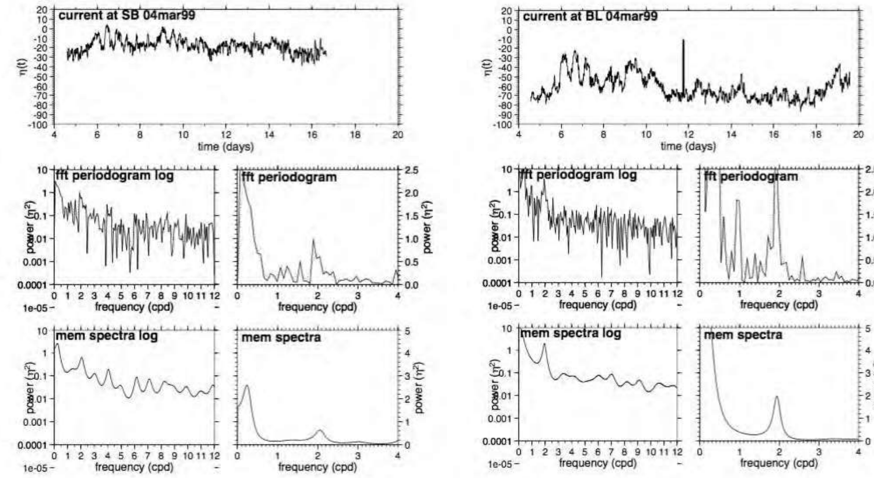

Figure 8. Time series, periodogram and maximum entropy spectra for the along-strait current components of time-series starting on 04 mar 1999 at the SB and BL stations.

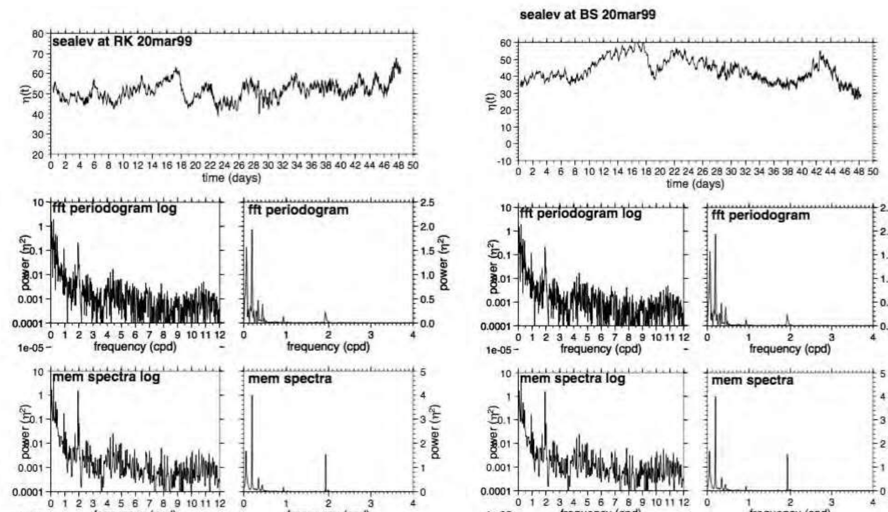

Figure 9. Time series, periodogram and maximum entropy spectra for the sea level time-series starting on 20 mar 1999 at the RK and BS stations.

5. Sea level annual time series

Sea level measurements were obtained for almost about a year by repeated deployments of tide gauges at Beşiktaş (BS) and Rumelikavağı (RK) stations along the

Bosphorus. The complete time series obtained by joining the various records are shown in Figure 10.

Sea level changes at the two ends of the Bosphorus are linked to local and remote hydro-meteorological driving factors such as the net water fluxes in the Black Sea that determine the net flux of the Bosphorus in an average sense, but also the dynamic loadings by winds, barometric pressure and tidal effects in addition to the net water budget. In fact the correlation and spectral analyses of the time series part of which are represented in the above section have shown oscillations at sub-inertial and tidal frequencies that are typical of such motions.

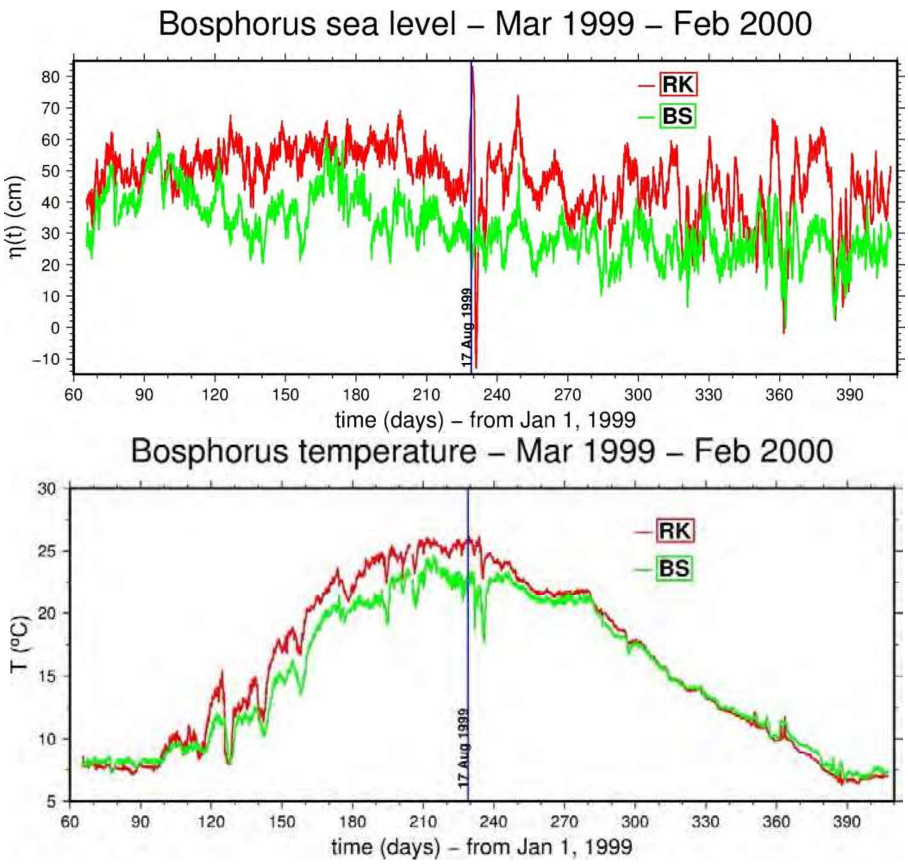

Figure 10. Time series of sea level and surface temperature at stations Rumelikavağı (RK) and Beşiktaş (BS) obtained from tide-gauges during March 1999 – February 2000.

What can be observed from these time series is the great oscillatory motions of the sea level on both the northern and the southern instrument sites in the Bosphorus. Oscillations of several days in period typically varying from daily to weekly frequencies typically resulting from hydro-meteorological events and tides are well known in the region. There is a long-term, seasonal sea level difference between the two stations possibly closely following the difference between the Marmara and Black Seas, that actually governs the transport through the Strait. The sea-level difference on the average is about 20-30 cm, but goes up to about 60 cm during dynamic changes. During certain occasions in winter and spring seasons the difference is seen to vanish, corresponding to upper-layer blocking or "Orkoz" events that are well known in the Bosphorus.

A spectacular event in the record is observed during the August 17, 1999 Richter scale 7.4Mw earthquake that struck the region and created great damage and loss of lives. While the measurements were primarily concerned with sea level variations linked to local and remote meteorological forcing and the water balance of the Black Sea, the measurements at Rumelikavağı revealed a completely different response that probably belongs to a process of tectonic origin connected with the 1999 Marmara earthquake.

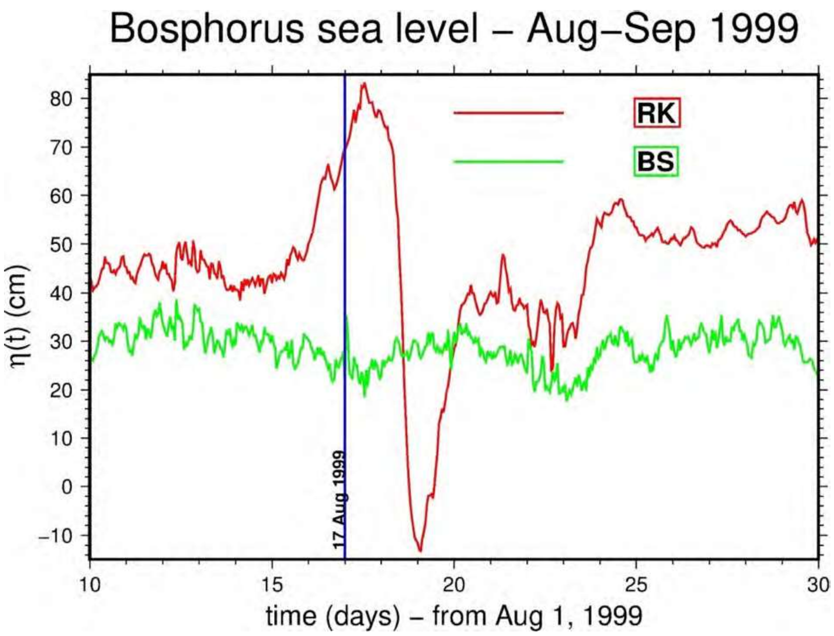

Figure 11. The sea level records at Rumelikavağı (RK) and Beşiktaş (BS) on and expanded time scale, covering the August 17, 1999 earthquake event.

The expanded scale plots of the sea level response at the two stations are shown in Figure 11. While the sea level at Beşiktaş (BS) fluctuates as often observed, the sea level at Rumelikavağı (RK) first starts to rise from a level of 0.40 m on 14th with increasing rate in the following three days to reach a peak of more than 0.84 m at about 3 am on the morning of the 17th, which is the exact time of one of the greatest earthquakes of the recent past, that took place in Gölcük, further south of the Bosphorus in the İzmit Bay area of the Marmara Sea. From then on a steady drop of sea level for the next two days follows, by about ~1 m to reach a minimum of -0.14 m past the midnight of the 19th, after which the sea level once again starts to recover until mid-day on the 20th, coming back to the constant level of 0.40 m, finally with a still further daily increment to reach about 0.60 m on the 23rd. This behavior is very different from other times shown in Figure 10, and could only be related to earth movements that are much slower than water movements.

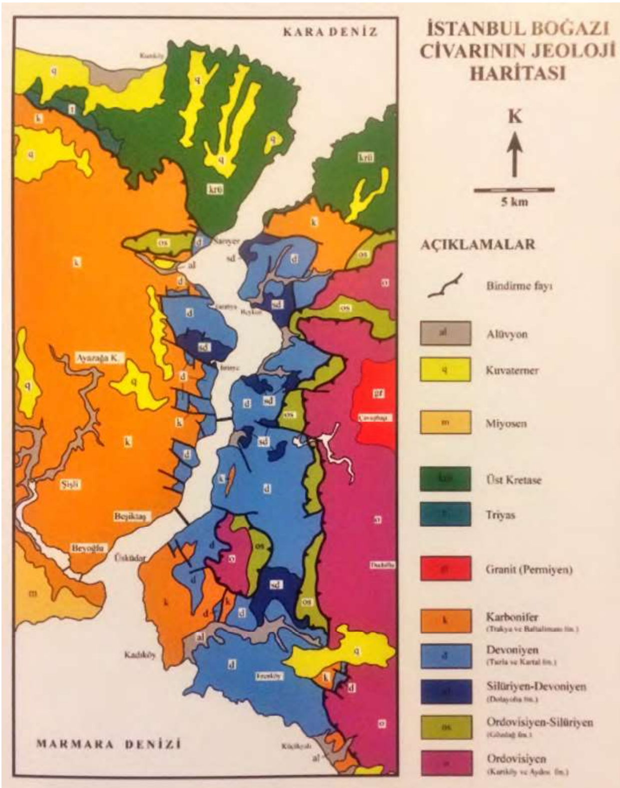

Figure 12. A summary of the geology of the Bosphorus Strait (İstanbul Technical University)

Because we could not explain such great variations at the time of the experiments, we did not publish them. The report on the experiment was given to the TÜRBO administration by taking out the set of measurements from the graphical displays of the results and details were not discussed of the particular period, in order to exclude and not claim responsibility for any scientific results that did not seem to be explicable. We believe that the phenomenon could only be evaluated and understood from the point of view of solid earth science, although no one has yet offered such an explanation. In this respect we only remark that, perhaps the overlaid fault line in Figure 12, passing through exactly the same point as the sea level measurements were made (compare Figure 1), or the sharp change in the rock structure across this fault could have a role to play, although the fault is not an active one.

We knew that the particular response that has been observed could not be associated with hydrodynamics because it was only observed at one of the two sea- level stations operating at the same time, and further, the great changes in sea level lasting for more than several days observed at the Rumelikavağı station north of the Bosphorus could not be explained by tsunamis or some similar process which should have been of higher frequencies of oscillation. Similarly, the observed record could not be related to some kind of instrument malfunction, because the pressure sensor of the WLR7 is a mechanical one and the recording system is an old-fashioned cassette type with stable electronics. However, our contacts with geologists and geophysicists to seek for a possible explanation at the time unfortunately did not produce any credible explanation.

It is striking that this different behavior has occurred more than 60km from the source of the earthquake and not concurrently observed at the Beşiktaş sea level station which was actually closer to the earthquake epicenter. Although a scientific explanation for this recording of anomalous sea level change has not been found to date, the event now deserves attention because it should be revealed possibly to trigger further investigations leading to a scientific explanation and possibly additional means to monitor the effects of earthquakes in the region.

Acknowledgements

We will always remember the primary roles of Admirals Güven Erkaya and Şevket Güçlüer for the TÜRBO initiative and Prof. Nejat İnce who acted on behalf of İTÜV/SAM to support this essential study to help set the basis for evaluating environmental conditions with respect to the critical influence of currents on navigation through the Bosphorus Strait. We thank all past personnel of the IMS-METU who took part in these studies at sea and at the office.

Reference

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