FLOW PHENOMENA IN THE NORTH AEGEAN SEA DERIVED FROM SATELLITE DATA

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Abstract

The spreading pattern of Black Sea Water into the North Aegean Sea was studied using NOAA-AVHRR, thermal data obtained during one year, 1995-1996. A strong, seasonal variability of the spreading pattern was revealed in agreement with the wellknown physiodynamical structure of the NAS. Moreover extensive upwelling appeared to take place off the Asia Minor coast during summer/autumn 1995. Finally the Maximum Cross Correlation method was applied in selected occasions in order to derive surface advective velocity vectors.

Key-words: Aegean Sea, remote sensing, circulation

Introduction

The Black Sea is connected to the North Aegean Sea via the straits of Bosphorus and the Dardanelles respectively and the Sea of Marmara. There is a significant surface layer flow from the Black Sea to the North Aegean Sea and a subsurface, slow intrusion of Levantine water from the North Aegean Sea to the Black Sea. The discharge pattern of the Black Sea Water origin (BSW) into the surface layer of the North Aegean Sea (NAS) is important to understand due to several environmental problems related to the dispersion of pollutants from various sources in the Black Sea towards the Mediterranean. Therefore, the knowledge of the hydrodynamic properties of the North Aegean Sea and especially the transport and spreading patterns of BSW is essential for assessing the fate of pollutants, especially in case of accidental release. Satellite data can provide important, qualitative information on circulation patterns and also a potential to quantify surface advective velocity fields.

The surface water temperatures and temperature differences were used as a tracer to identify different water masses and water movements based on:
a) a qualitative description of the main hydrodynamic features of NAS, with emphasis on the discharge pattern of the BSW, analysed by a large number of NOAA-AVHRR data collected during one year, between 1995-1996
b) application of the Maximum Cross Correlation Method (MCC) to obtain quantitative information on surface advective velocities using sequences of NOAA-AVHRR data.

Satellite data for circulation studies and image processing

An alternative method to study the spreading pattern of BSW in the North Aegean Sea is the use of satellite thermal data related to the surface water temperature. The BSW, which is characterized by low salinity and low density, is well stratified in the surface layer of the North Aegean Sea. Consequently the BSW has a lower density and will remain in the surface waters of the North Aegean Sea even after intense mixing processes. Moreover, the BSW is much colder than the surrounding waters - a difference of up to 3-5°C. Thus surface water temperature could be utilized as a "tracer" for the transport and spreading of the BSW. A very limited study, based on only four NOAA scenes, has been reported earlier (1). However, no comparison was made with known flow patterns and no applications of the MCC method was reported.

For this study NOAA-AVHRR data was obtained from the NOAA receiving station at the Department of Physical Geography, University of Lund, Sweden during one year - March 1995 - March 1996. A total of about 50 scenes were analyzed, representing all the months of the studied period.

Maximum cross correlation method

The image processing technique of the Maximum Cross Correlation method (MCC) was utilized in order to determine surface advective velocity vectors. This technique provides the potential to derive surface velocity fields using sequences of NOAA images, separated by a certain time interval - say of the order of 24 h. The MCC is basically a statistical method to determine the displacement of small surface water temperature patterns during a given time interval - on the basis of known time and distance an average velocity is calculated in a straightforward way. A more detailed description of the MCC method is given in the literature, see for instance (2, 3).

The trace of BSW in the NAS

Approximately 50 NOAA-AVHRR scenes representing the period March 1995 - March 1996 were analyzed as to the spreading pattern of BSW in the North Aegean Sea. Due to the limited space available in this paper only two scenes - one typical summer situation and one typical winter situation can be shown (for a more comprehensive description, see (4).

The first scene, Fig 1, refers to a summer situation, 95-07-31, 0552 GMT, N-12, ch4 with a grey-scale coding comprising three digital levels for each grey-scale tone - see bottom of Fig 1. Dark areas correspond to cold water and bright to warmer water. One could notice vast areas of cold water south of the entrance of the Dardanelles most probably linked to upwelling. There is also a very distinct thermal front south of the islands of Imvros and Limnos separating the cold water in the Chios basin and the somewhat warmer water north of it. Outflow can be distinguished between the front and the island of Imvros as a surface water with temperatures between the upwelled water and the surface water of the Athos basin. There is also a distinct feature showing upwelled water being transported south of both the islands of Imvros and Limnos and then northwards to the west of Limnos towards the island of Thasos.

The second scene, Fig 2, refers to a winter situation, 96-01-18, 1652 GMT, SST, N-12. The surface water temperature is grey-scale coded with 0.5°C for each grey-scale tone - see bottom of Fig 2. A dark tone is cold water and a bright tone is somewhat warmer water. The coldest surface water occurs in a limited area just at the entrance of the Dardanelles. There is a flow from the Dardanelles westwards to the south of Imvros after which transport turns to the northwest between Imvros and Limnos approaching the northern Greek coast east of Thasos. Most parts of the Athos basin surface waters will thus be covered with relatively cold water. There is a very sharp thermal front between the outflow structure near the entrance and the Athos basin water north of it with a temperature difference of near 4.0°C. There is also a sharp boundary towards the south, however not as distinct as the northern one and with a temperature difference of about 2.7°C. There is no upwelling off the Asia Minor coast.

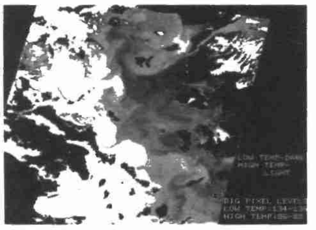

Figure 1.North Aegean Sea. 95-07-31, 0552 GMT, ch4, 8 LSB, N-12. Grey-scale code: three digital levels for each tone. Dark is coldest, bright is warmest

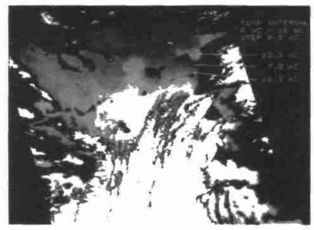

Figure 2.North Aegean Sea. 96-01-18, 1652 GMT, SST, N-12. Grey-scale code: 0.5°C for each tone. Temperature is about 7.3°C at the entrance (dark) of the Dardanelles and about 12.8°C just south (bright) of the entrance

The qualitative studies of the 50 NOAA-AVHRR scenes obtained during one year, between 1995-1996 in the NAS, are summarized as follows:

- at most occasions the BSW outflow from the Dardanelles is distinguished due to its low surface water temperature compared to the surrounding surface water temperatures of the NAS. Temperature differences of more than 4°C have been observed between the BSW and the surrounding NAS surface water. The outflow can be traced at least to the island of Imvros and passed it more or less as a jetlike structure with strong temperature gradients - *i.e.* a distinct boundary - towards the surrounding NAS surface water. At a number of occasions a distinct, colder surface flow with limited lateral extent can be traced from the entrance of the Dardanelles westwards and then heading to the northwest between the islands of Imvros and Limnos all the way to the coast of northern Greece.
- the surface waters of the Dardanelles and its entrance area are colder as compared to regions further off the entrance area for the period Oct/Nov up to May approximately. For the rest of the year the temperature structure is more complex most probably due to an interaction between the outflow and the upwelling phenomena off the Asia Minor coast. Thus there is often a situation during summer when the temperature appears to decrease along the outflow axis, at least up to a certain point.
- upwelling was observed over extensive areas off the Asia Minor coast south of the entrance region of the Dardanelles for all the scenes but one during the months July, August, September, October (altogether ether 18 scenes). During the months November, December, January, February, March, April, May no upwelling was observed except at one occasion (altogether 17 scenes). June and October appeared to be transition months with a more or less equal distribution of upwelling and no upwelling (altogether 12 scenes). Thus there is a strong seasonal component in the upwelling phenomenon which is in agreement with other observations. The cause of the upwelling is thus stated to be strong northeasterly winds (Etesian winds) during summer.
- there is a seasonal pattern as to the spreading pattern of the BSW outflow. On a monthly basis the observations were as follows:

Jan-March: Distinct discharge between Imvros and Limnos and then heading to the northwest. At one occasion the outflow seems to turn northwards along the Asia Minor coast immediately after discharge into the NAS.

April: Discharge reaches the southern part of Imvros and then heads northwest

May: Distinct discharge between Imvros and Limnos after which it is heading to the northwest. The outflow can be traced far away - all the way to the coast of northern Greece and even further.

June: Relatively distinct or distinct discharge between Imvros and Limnos and then heading to the northwest.