Observing the Dardanelles outflow with an HF WERA Radar system

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Abstract

The Hellenic Centre for Marine Research and the University of the Aegean have jointly installed and operate a WERA high-frequency (HF) radar system at the eastern coast of Limnos island, Greece. The HF radar current measurements, after being processed using two different techniques in order to minimize observational errors, are used for the description of the principal characteristics of the surface flow field within a one year period (2010). The results show that the Black Sea Waters outflowing from Dardanelles have a dominant pathway to the northwest, which changes during the summer period when strong northerly winds prevail, pushing surface waters southwards.

Keywords: remote sensing, high-frequency (HF) radar, surface circulation, noisy and irregular data

1. Introduction

The North Aegean provides a link between the Mediterranean Sea and the Black Sea, two marginal seas with strong contrasts in their physical and biochemical properties. The Black Sea Water (BSW) inflow to the Aegean Sea, through the Dardanelles Strait, is the most significant water mass in the North Aegean. In addition, the rich in organic matter BSW largely determines the physical and biochemical characteristics of the area, potentially affecting the production and the general quality of the marine environment. Moreover, the BSW has been linked to inter-annual changes in the deep-water characteristics of the Eastern Mediterranean (Zervakis et al., 2000). Therefore, it is very important to study the development of the Dardanelles plume and its consequent route. For these reasons, the Department of Marine Sciences of the University of the Aegean and the Institute of Oceanography of the Hellenic Centre for Marine Research (HCMR) have jointly installed a WERA HF radar system (named "Dardanos") on the eastern coast of the island of Limnos, Greece.

The CORI system uses a WERA HF Remote Sensing system (Helzel Messtechnik GmbH, Germany). The HF CORI system has been installed and operating since October 2009, measuring surface currents in front of Dardanelles Straits every 30 minutes. It is comprised of two sub-systems deployed ~23 km apart in order to get the full 2D near surface currents field. The surface current radial velocity components measured by the two radar sites are then summed to determine the total surface current velocity vector. The system's working frequency is 13.5 MHz corresponding to a Bragg frequency of 0.37 Hz in deep water and an 11.08 m wavelength. The system emits a chirped continuous wave with a repetition frequency of 3.85 Hz and a 50 kHz bandwidth which gives a radial resolution of 3 km. Its operating range is approximately 70 km with a spatial resolution of 1.5 km that arises from interpolation performed by WERA software.

2. Materials and methods

This study focuses on the processing and analysis of surface currents fields measurements over the entire 2010, during which time both radar sites were operational and radar coverage was at its maximum extent. During this period, data were collected and averaged from the two HF radar sites at Plaka and Fisini (Fig. 1). Technological and environmental factors often combine to make HF radar measurements sparse in both space and time and hence limit their usage in several oceanographic applications that require time and space continuous data sets with minimized observational errors. Several approaches have been proposed in order to filter and interpolate gappy HF observations, as described in Kim et al. (2007). Here two techniques are tested for filtering and interpolating two-dimensional current data acquired by HF radar in Limnos Island, namely the Nearest Neighbor

Statistics (NNS) method (Halle, 2008) and the Open-boundary Modal Analysis (OMA) method (Lekien et al., 2004; Kaplan et al., 2007). It should be mentioned that a preliminary quality control is performed by WERA software at the stage of the radial velocity components, before the construction of the 2-D surface velocity vector fields. Our analysis constitutes a second level quality control procedure at the stage of total velocities, as the WERA software's preliminary quality control does not succeed to remove effectively spurious measurements.

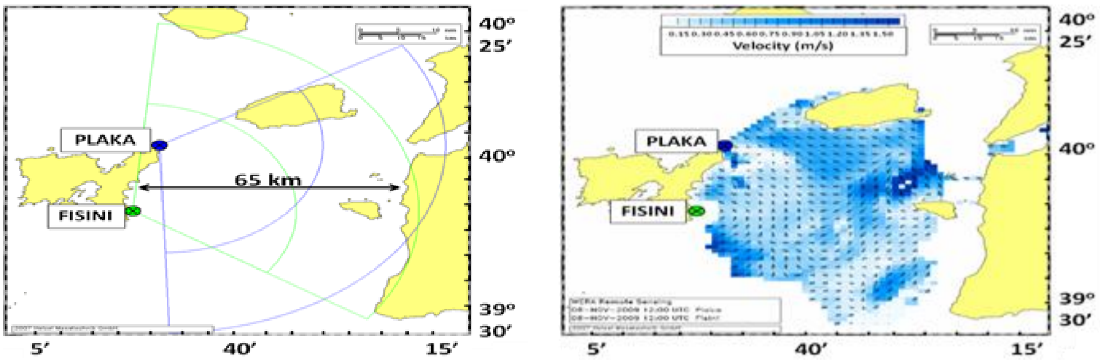

Fig. 1. Left: Map of WERA installation design along the east coast of Limnos Island, as provided by Helzel Messtechnik Gmbh. The blue and green arcs represent the 120° swath, which is covered by the WERA transmission. The blue circle refers to the location of Plaka station maintained by the Aegean University and the green circle refers to the location of Fisini station, maintained by the HCMR. Right: A footprint of the HF radar data in Limnos Island on 8 November 2009, at 12:00 UTC.

"Nearest-neighbor" statistics are used to screen the half-hourly surface currents for potential errors. A detailed description of the method can be found here: http://bml.ucdavis.edu/boon/pdf/MethodsPaperHalle.pdf. The NNS method uses a blend of temporal derivatives and spatial comparisons to quantify the acceptability of a given current measurement. Distances to the nearest valid measurements, angular differences between a given current measurement and currents measured nearby, magnitude differences are all used to flag currents as either acceptable or unacceptable.

The Open-boundary Modal Analysis method follows the procedure described in Lekien et al. (2004). The general idea of OMA is to generate a set of modes for a given domain which can be used to approximate any current field on that domain. The amplitudes of those modes are then fit to current measurements inside the domain. The modal series approximation is determined by minimizing a cost function to find the ideal combination of modes, which gives the best fit to available measurement data. These modes once they are calculated, they can be stored for repeated use on the same domain.

3. Results

NNS and OMA methods were applied to half-hourly surface currents as measured by the two radar sites in Limnos Island for the entire 2010. Daily-averaged surface velocity fields for the 27th of July of 2010 are presented in this study for the visual comparison of different methods. The surface velocity field as measured from the HF radar is shown in Figure 2. In the same Figure we can also see the quality of NNS, OMA and their combination's results for the same day. The NNS method effectively removes possibly erroneous measurements, but at the same time reduces significantly velocity's field range. RMS differences between radar total velocities and velocities filtered with NNS for the entire 2010, ranged from 0.05 to 0.22 m/sec and average directional differences were less than 11.23 degrees. The OMA method not only filters but also reconstructs velocity fields, preserving this way as much spatial coverage as possible and captures the structure of the flow throughout the domain.

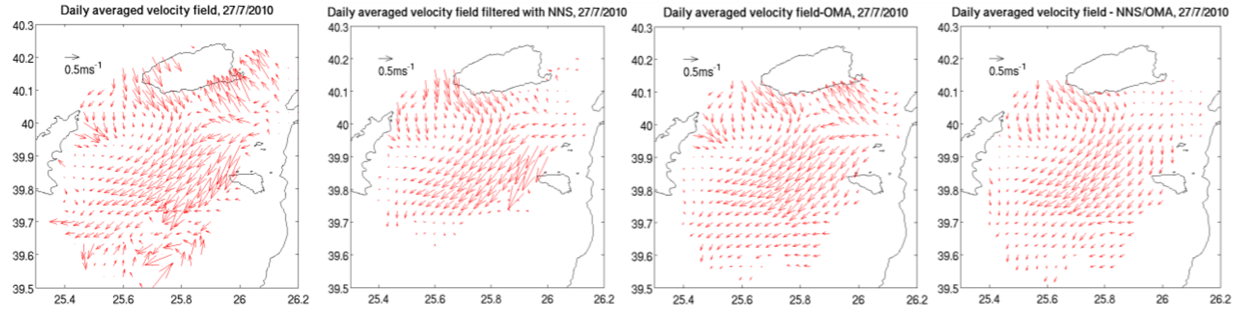

Fig. 2. From left to right: red vectors show daily-averaged surface velocity on 27 July 2010 before and after the application of different methods.

Mean RMS differences between fitted with OMA and total currents for the entire 2010 were of order 0.04-0.28m/sec and average directional differences were less than 11.8976 degrees. The NNS technique limits the footprint over which measurements are made. That's why we attempted to combine the NNS screening of data with a more sophisticated interpolation scheme, such as OMA and extend velocity's field range. Total current measurements screened with NNS were in turn passed to OMA method for further processing. Although the combination of NNS and OMA does not restrict spatial coverage, it seems to over smooth the velocity field, regarding velocity magnitudes. Mean RMS differences between filtered with NNS - fitted with OMA and total current velocities for the entire 2010 were of order 0.05-0.29m/sec and average directional differences were less than 11.8974 degrees.

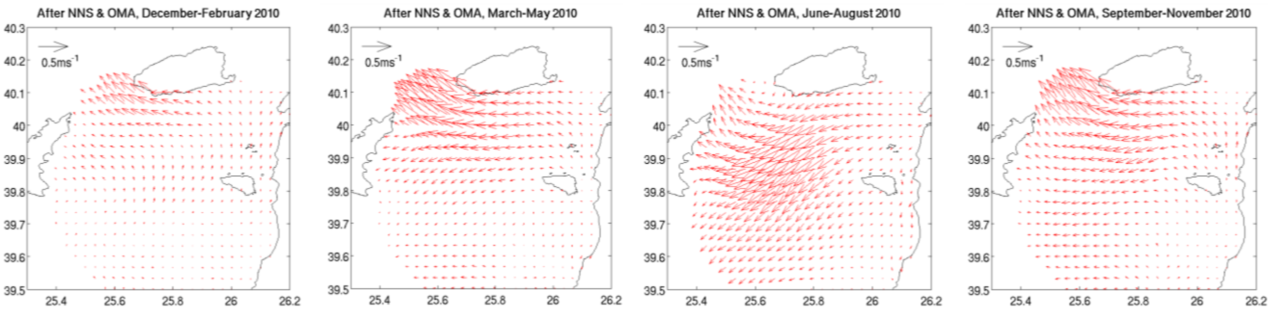

Fig. 3. From left to right: Seasonal velocity fields after filtering and reconstruction with the NNS/OMA for winter, spring, summer and autumn of 2010.

Regarding the seasonally averaged surface velocity fields throughout the entire 2010, after filtering and reconstruction, two major BSW pathways are identified in HF radar current fields: the northwest (NW Branch) and the southwest (SW Branch) pathways, bifurcating north and south of the Limnos Island respectively (Fig. 3). The analysis of HF radar observations shows that the NW Branch is an almost permanent feature in HF radar data throughout 2010, carrying brackish waters towards the north continental shelf. It is less dominant during summer. The SW Branch is enhanced by high Dardanelles inflows and northerly winds, especially during summer, when inflow rates reach their maximum and strong northerly winds ("Etesian") prevail in Aegean and it is quite limited over winter and spring of 2010. The SW Branch brings brackish waters directly to the Southwest, towards the Central Aegean. These results confirm previous studies in the area (Androulidakis et al., 2012; Kokkini et al., 2014).

4. Conclusions/Discussion

The NNS method effectively removes erroneous measurements but reduces significantly field's range. The OMA method filters successfully surface velocity fields, while preserving radar's field range. These two methods when combined result to over-smoothed and unrealistic velocity fields. Both methods and their subsequent combination fail in regions where the confidence in the total current measurements is relatively low, like in areas far from the radars or along the line of sight between radars. Fits with large data gaps are probably not recommendable under most circumstances and a real-time analysis should be restricted in regions with data coverage above a critical threshold (i.e. >20% availability), even if the latter significantly limits the range of currents field.

Regarding seasonal circulation in the study area using radar observations, we could state that the BSW flows in general in a northwesterly direction, except summer that strong northerly winds prevail, pushing surface water to the south. During winter when the BSW inflow is minimal, the circulation in the area is weak. During summer the increased BSW inflow rate induces a stronger circulation than in winter.

5. Acknowledgements

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