Estuarine, Coastal and Shelf Science 163 (2015) 84–92

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Mapping of oceanographic properties along a middle Adriatic transect using Self-Organising Maps

Ivica Vilibić [a, *], Hrvoje Mihanović [a], Grozdan Kušpilić [a], Ante Ivčević [b], Vesna Milun [a]

[a] Institute of Oceanography and Fisheries, Šetalište I. Meštrovića 63, 21000 Split, Croatia
[b] Student at Geophysical Department, Faculty of Science, University of Zagreb, Horvatovac 95, 10000 Zagreb, Croatia

ARTICLE INFO

Article history:
Received 20 November 2014
Accepted 28 May 2015
Available online 6 June 2015

Keywords:
oceanographic data
Self-Organising Maps
seasonal changes
trends
decadal variability
Adriatic Sea

ABSTRACT

This paper examines oceanographic properties along the northern portion of the Palagruža Sill, middle Adriatic Sea, from 1998 to 2011. Temperature, salinity, dissolved oxygen (DO), total inorganic nitrogen (TIN) and orthophosphate concentrations were collected at four stations on a seasonal basis and monthly basis, spanning from coastal waters to the deepest part of the sill. Seasonal profiles and variances were computed, exhibiting no strong seasonal variability in either coastal or open Adriatic waters, except for temperature. The transect profiles were analysed using the Self-Organising Maps (SOM) method, which extracted two regimes with several transitional patterns characterized by an anomaly in one or more variables. These regimes match the Bimodal Adriatic-Ionian Oscillation (BiOS) regimes in the northern Ionian Sea, which are found to drive decadal oscillations in oceanographic parameters in the Adriatic. As the transect mainly encompasses the euphotic zone, no strong connection was found between BiOS regimes and DO, TIN and orthophosphate concentrations. This suggests that, in addition to basin-wide circulation, other physical and biogeochemical processes are more important for nutrient dynamics in the euphotic zone. The use of the SOM method in ocean coastal studies is discussed.

1. Introduction

The Palagruža Sill, a 170-m deep ridge separating the 1200-m deep South Adriatic Pit (SAP) from the 275-m deep Jabuka Pit (Fig. 1) has been recognized as an important location for tracking Adriatic-wide processes and dynamics (Zore, 1956). All Adriatic water masses are interchanged in this area (Zore-Armanda, 1963). North Adriatic Dense Water (NAdDW), the densest Mediterranean water mass, which is characterized by very low temperature, moderate salinity and high dissolved oxygen content, is generated at the northern Adriatic shelf and flows as dense bottom current over the western and central parts of the sill (Vilibić and Supić, 2005). Middle Adriatic Deep Water (MAdDW), which carries old waters from the deep Jabuka Pit toward the SAP, is characterized by higher nitrate and nitrite values (Grilli et al., 2013). Adriatic Deep Water (AdDW) is generated at the central SAP through deep-convection processes (Vilibić and Orlić, 2001). It then flows toward the Ionian Sea but also enters the middle Adriatic. Finally, Levantine Intermediate Water (LIW), which is characterized by high salinity, high temperature and low dissolved oxygen values, is generated in the Eastern Mediterranean and enters the middle Adriatic Sea over the eastern and central parts of the sill, especially during ingression years (Buljan, 1953). The flow is driven by cyclonic circulation in the northern Ionian Sea (Gačić et al., 2010). All of these water masses exhibit low levels of orthophosphates (Grilli et al., 2013), which are generally low in the Eastern Mediterranean (Krom et al., 1991). For these reasons, regular monitoring activities along the sill were initiated in the early 1950s (Buljan and Zore-Armanda, 1966) and continuously executed over the last 60 years, providing a long-term dataset of different physical, chemical and biological parameters.

This dataset has been used to assess different oceanographic properties and processes in the area. Interannual salinity variations were detected in the early 1950s (Buljan, 1953) and were used for the first definition of the Adriatic water masses (Zore-Armanda, 1963), which were then widely used to describe Adriatic oceanography (e.g., Buljan and Zore-Armanda, 1976; Orlić et al., 1992; Artegiani et al., 1997; Vilibić and Orlić, 2002). Mediterranean-wide processes, such as the Eastern Mediterranean Transient (Klein et al., 1999) and Bimodal Adriatic-Ionian Oscillation (BiOS, Gačić et al., 2010), have also been detected by the series. Monitoring has led

* Corresponding author.
E-mail address: vilibic@izor.hr (I. Vilibić).

http://dx.doi.org/10.1016/j.ecss.2015.05.046
0272-7714/

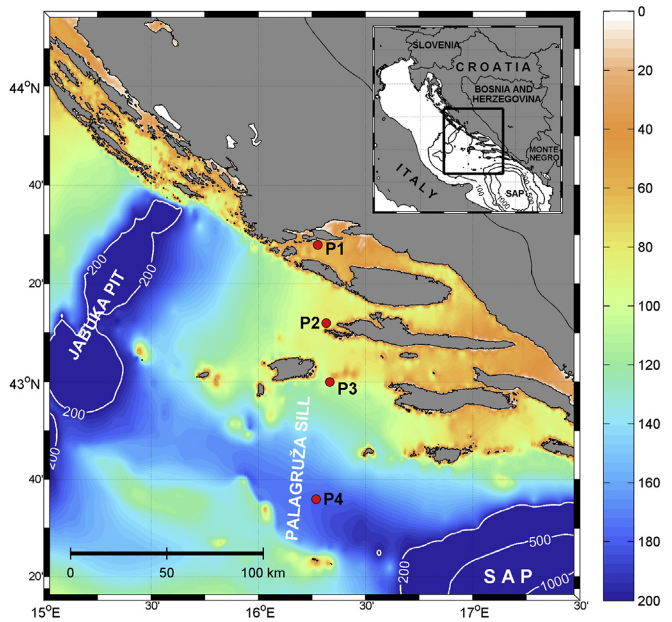

Fig. 1. Map of the investigated area with position of sampling stations. Depths are in meters.

to the discovery of new findings and updates to existing theories, such as the strong inflow of intermediate Western Mediterranean waters to the Adriatic (Vilibić et al., 2012). Long-term trends and weakening of the Adriatic thermohaline circulation were also documented from these measurements (Vilibić et al., 2013). The Bimodal Adriatic-Ionian Oscillation (BiOS) was found to be responsible for large decadal variations in physical and biogeochemical Adriatic properties (Gačić et al., 2010; Civitarese et al., 2010; Vilibić et al., 2012) and recognized as a dominant decadal process driven by internal dynamics in the northern Ionian Sea. This oscillatory pattern has a normal period, which is approximately a decade in length, but can change depending on the rate and intensity of dense water generation and properties of adjoining water masses from the Western and the Eastern Mediterranean (Gačić et al., 2010, 2011, 2014).

The study of water masses and properties in the central Adriatic has identified different biogeochemical, ecological and fisheries variabilities and trends in the basin. Numerous chemical and biological parameter variations were detected along the sill. They were ascribed to the variability of Adriatic water masses and the influence of coastal processes, such as freshwater nutrient loading (Marasović et al., 2005; Šolić et al., 2008). The assessment of primary production over the sill revealed the connection between region-wide atmospheric processes and biological parameters in the area (Grbec et al., 2009). These data were eventually used to connect fisheries parameters to environmental conditions (Zorica et al., 2013). The long-term variability in Adriatic hydrographic properties and water masses has been found to play a significant role in affecting the natural variability of commercial pelagic fish species in the Adriatic (Vilibić et al., 2013).

All of the aforementioned oceanographic studies conducted at the Palagruža Sill used different data analysis techniques, but none utilized neural network algorithms, such as the Self-Organising Maps method (SOM, Kohonen, 2001). The SOM was recently introduced to Adriatic oceanography as a useful tool for classifying patterns of different oceanographic parameters (Solidoro et al., 2007; Vilibić et al., 2011; Mihanović et al., 2011; Rako et al., 2013; Kovač et al., 2014). In addition, SOM has been widely used in the global oceanographic community (Liu et al., 2006; Liu and Weisberg, 2011). It has been successfully applied to a variety of problems in which a reduction of dimensionality (Murtagh and Hernandez Pajares, 1995), extraction of patterns (Kopp et al., 2010) or detecting outliers (Munoz and Murazabal, 1998) was performed. Although the method prefers large datasets, which are provided via remote sensing techniques (e.g., satellites, Richardson et al., 2003) or climate studies (e.g., Morioka et al., 2010), SOM has been successfully applied to limited datasets, such as *in situ* oceanographic data, from which patterns have been extracted and connected to driving processes and forces (e.g., Fendereski et al., 2014).

The motivation for this research is to assess the applicability of the SOM method to extract characteristic oceanographic profiles from a limited *in situ* oceanographic dataset. Physical and chemical parameters that were measured along the transect spanning the northern part of the Palagruža Sill, from coastal waters along the eastern Adriatic coastline (characterized by a large freshwater load) toward the deepest parts of the sill, were used in the analyses. The study period spanned from 1998 to 2011, when the transect was regularly surveyed on a monthly or seasonal basis. Section 2 introduces the data and SOM method. A seasonal analysis and extraction of SOM-based characteristic patterns are presented in Section 3. The results, their implications and our major conclusions are discussed in Section 4.

2. Data and methods

2.1. The data and data processing

Temperature, salinity, dissolved oxygen (DO), total inorganic nitrogen (TIN), which is the sum of nitrate, nitrite and ammonia, and orthophosphates were collected at four stations (P1 to P4, Fig. 1) at standard oceanographic depths (0, 5, 10, 20, 30, 50, 75, 100, 150 and 170 m) between 1998 and 2011. The very first measurements at these or nearby stations were executed in the early 1950s (Buljan and Zore-Armanda, 1966) and aimed to establish a permanent monitoring of coastal and open sea areas in the Palagruža Sill region. The monitoring programme has been quasi-continuous over the last 60 years (Vilibić et al., 2012). The outer stations (P3 and P4) are positioned to capture the inflow branch of the saline and warm LIW, which normally enters the northern Adriatic at the central and northern sections of the sill. The coastal stations (P1 and P2) are strongly influenced by the freshwater load, primarily from the Neretva River (average discharge of 234 m^3/s, Janeković et al., 2014). They are prone to coastal pollution from the largest eastern Adriatic coastal city, Split. The period from 1998 to 2011 was extensively monitored by several coastal monitoring programmes, with only minor gaps in the time series, enabling a thorough analysis using state-of-the-art methods. The measurements were conducted on seasonal or monthly bases, depending on the season. The programme included 12 cruises during winter (JFM), 26 cruises during spring (AMJ), 28 cruises during summer (JAS) and 14 cruises during autumn (OND). A single cruise encompassed the data from at least three out of four stations sampled during the 10-day interval.

Temperature and salinity data were recorded using Idronaut 316 and Seabird 25 CTD probes, with accuracies of 0.002 °C and 0.003 °C for temperature, 0.0003 S m^{-1} and 0.0003 S m^{-1} for conductivity and 0.1% and 0.05% of the full-scale pressure range, respectively. Dissolved oxygen was determined using classical Winkler titration (Grasshoff, 1976). Dissolved inorganic nutrient concentrations, including orthophosphates, nitrates, nitrites and ammonia salts, were determined using Auto Analyzer II and III