Progress in Oceanography 135 (2015) 113–124

Contents lists available at ScienceDirect

Progress in Oceanography

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

Recurrent intrusions of transitional waters of Eastern Mediterranean origin in the Cretan Sea as a tracer of Aegean Sea dense water formation events

Dimitris Velaoras *, George Krokos, Alexander Theocharis

Hellenic Centre for Marine Research, Institute of Oceanography, Anavyssos, Greece

ARTICLE INFO

Article history:
Received 23 December 2014
Received in revised form 18 March 2015
Accepted 20 April 2015
Available online 25 April 2015

ABSTRACT

Available temperature and salinity data in the Cretan Sea from 1955 up to 2014 as well as literature sources were revisited in order to trace the appearance of low salinity, temperature, oxygen and nutrient-rich waters inside the basin at depths below the intermediate layer. First appearing as far back as 1961 in literature, these waters were found originating in the layers that separate intermediate and deep waters of the Eastern Mediterranean Sea (EMed) and were named Transitional Mediterranean Water (TMW) in the 1990s. Data analysis showed that the appearance of TMW in the Cretan Sea is a recurrent phenomenon connected to water mass exchanges between the Aegean Sea and the EMed. In particular, the inflow of TMW in the Cretan basin acts as compensation for the outflow of equally dense or denser masses from the Aegean. This export is a result of dense water formation (DWF) events taking place inside the Aegean Sea triggering TMW compensatory inflow into the Cretan Sea through the Cretan Straits. In this context, TMW intrusions in the Cretan basin can be used as a tracer of DWF in the Aegean Sea while the depth of the intrusion can provide valuable information about the intensity of the DWF event. The importance of TMW intrusions is not solely restricted to the tracing and evaluation of DWF events but could additionally expand to the impact on local ecological processes as TMW is a nutrient carrier for the oligotrophic Cretan Sea.

Introduction

The Aegean Sea is one of the four major sub-basins of the Eastern Mediterranean Sea (EMed), the other ones being the Levantine, Ionian and Adriatic Seas. The southernmost part of the Aegean Sea is the Cretan Sea which occupies the area south of the Cyclades Islands plateau and up to the south natural boundary of the Aegean Sea i.e. the island of Crete (Fig. 1). The Cretan Sea is the deepest Aegean basin with a mean depth of about 1000 m and maximum depth of roughly 2500 m at its eastern depressions (Theocharis et al., 1993, 1999a). Bounded to the north, east and west by land masses and to the south by Crete, the Aegean Sea communicates with the EMed solely by the Cretan Straits system i.e. the West and East Cretan Straits. These consist of a complex system of successive small islands and straits that separate Crete from the adjacent land masses of the Hellenic Peninsula and Asia Minor. The most important Cretan straits are the Antikythira Strait (about 30 km wide and 700 m deep at the sill) in the west and the Kassos and Karpathos Straits (about 65 km wide, 900 m deep and 40 km wide, 850 m deep at the sill respectively) in the east (Kontoyiannis et al., 1999). Crete along with the Cretan Straits creates an almost crescent shaped geological complex called the Cretan Arc. South of the Cretan Arc the EMed bathymetry steeply plunges to depths of 3000–4000 m.

The Cretan Sea exchanges water masses with adjacent EMed basins and acts as a large heat and salt repository that accumulates water masses originating from various Aegean Sea sub-basins (Theocharis et al., 1993; Velaoras et al., 2014). Furthermore the Cretan Sea itself is an active intermediate and occasionally deep water formation basin. A well-documented extreme event called the Eastern Mediterranean Transient (EMT) caused a unique thermohaline change in the EMed between the late 1980s–early 1990s (Roether et al., 1996, 2007; Klein et al., 1999; Theocharis et al., 1999b). During this period large amounts of very dense water masses of Aegean origin were exported from the Cretan Sea, estimated to about 7 Sv for the whole period (Roether et al., 1996) of which 2.8 Sv outflowed during the peak period of the EMT event between 1992 and 1994 (Roether et al., 2007). The potential density (σ_θ) of Cretan Deep Water (CDW) masses at the peak of the event reached values of more than 29.35 kg/m^3 inside the Cretan basin, while outflowing masses where characterized by $\sigma_\theta > 29.2$ kg/m^3

* Corresponding author.
E-mail address: dvelaoras@hcmr.gr (D. Velaoras).

http://dx.doi.org/10.1016/j.pocean.2015.04.010
0079-6611/

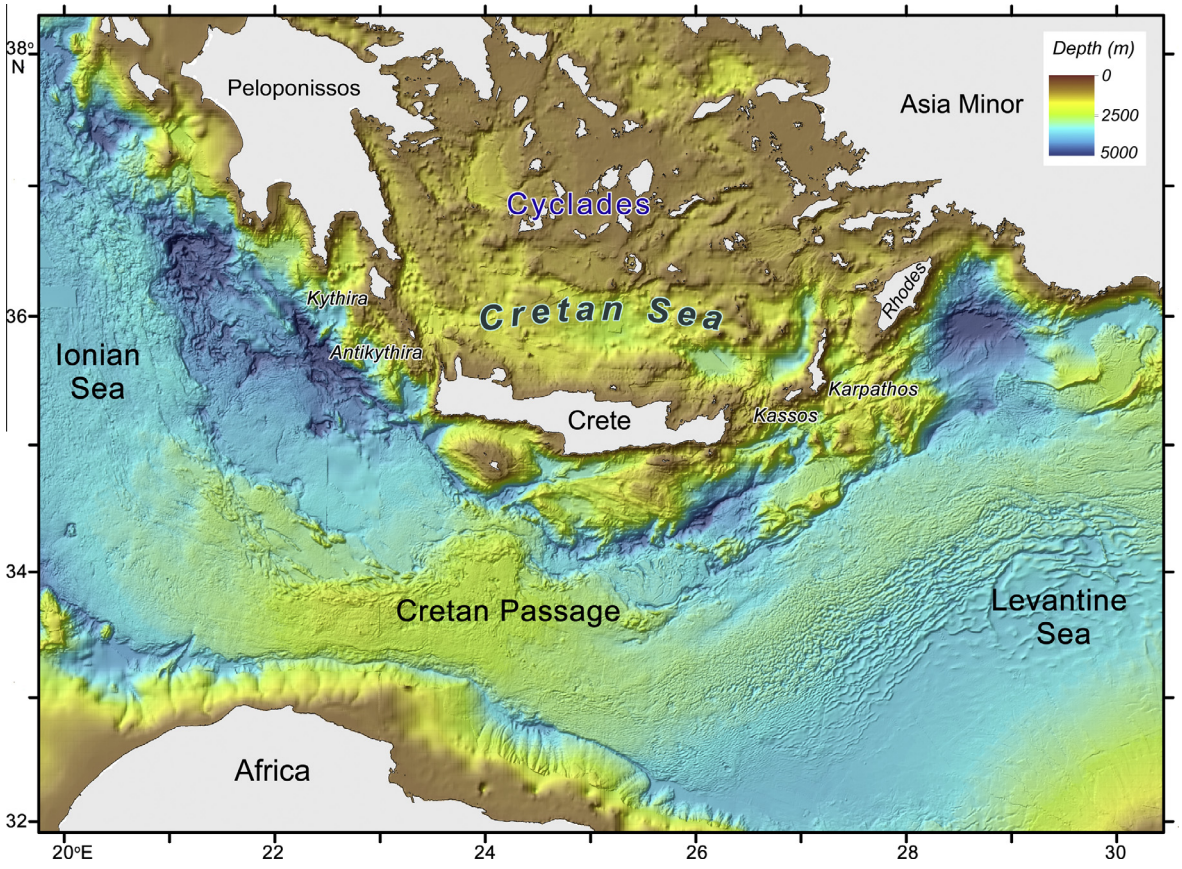

Fig. 1. Bathymetric chart of the South Aegean Sea, the Cretan Sea and adjacent Eastern Mediterranean basins.

(Theocharis et al., 1999b) which was higher than that of the existing Eastern Mediterranean Deep Water (EMDW) of Adriatic origin hitherto occupying the EMed bottom layers. As a consequence of this extreme dense water discharge through the Cretan Straits, deep/bottom layers of the EMed were replaced by the well oxygenated, more saline Aegean intrusion which uplifted all water masses by several hundred meters (Klein et al., 1999).

In this work, data in the Cretan Sea from various data sources will be revisited in an effort to trace the appearance of water masses of EMed origin that occasionally enter the Cretan basin and have their origin in EMed layers found below the saline intermediate water masses horizons. Furthermore, we will attempt to link these intrusions with dense water formation (DWF) events in the Aegean Sea and consequent outflows. Section 'Review of the Cretan Sea hydrology. The appearance of low salinity water masses below the intermediate layer in the Cretan Sea' presents a review of the Cretan Sea hydrology focusing on the appearance of low salinity water masses of EMed origin in the basin. Section 'Data and methods' presents the data and methods used herein. Section 'Results' presents the results of the data analysis followed by discussion in Section 'Discussion'. Final concluding remarks are made in Section 'Concluding remarks'.

Review of the Cretan Sea hydrology. The appearance of low salinity water masses below the intermediate layer in the Cretan Sea

Surface/subsurface and intermediate water masses in the Cretan Sea

Surface/subsurface layers in the Cretan Sea are occupied by three different water masses: (i) Atlantic Water (AW) entering the basin mainly through the western straits but occasionally from the eastern straits too, (ii) Black Sea Water (BSW) advected from the Central Aegean Sea and (iii) Levantine Surface Water (LSW) originating in the Levantine basin and entering through the eastern straits. Intermediate layers approximately below the first 100 m and up to 300–400 m are occupied by a mixture of Levantine Intermediate Water (LIW) and Cretan Intermediate Water (CIW). The former enters into the Cretan Basin through the eastern straits while the latter is ventilated locally on an annual basis. A more detailed study of masses and circulation in the Cretan Sea can be found in Zodiatis (1993), Theocharis et al. (1993) and Theocharis et al. (1999a).

Presence of low salinity water masses below the intermediate layer in the Cretan Sea during the EMT event

Prior to the peak-EMT period, layers below intermediate depth in the central part of the Cretan Sea were considered to be occupied by a rather homogenous water mass with lower salinity and temperature in comparison with the overlying intermediate masses but more saline and warmer than the water masses found at the same EMed horizons out of the Cretan Arc (Lacombe et al., 1958; Özturgut, 1976; Theocharis et al., 1993). The salinity of these deep masses has been reported as $\leqslant$38.9 while salinity at the same layers in the EMed was <38.8. Fig. 2 shows a salinity transect of 1986 along 36°N in the Cretan Sea, positioned in time just before the EMT onset. The CTD data originate from LIA4 Hellenic Centre for Marine Research (HCMR) cruise of November 1986, provided by the Hellenic National Oceanographic Data Centre (HNODC) of HCMR. Below intermediate depth, the Cretan basin is occupied by a rather homogenous mass with $38.85 < S \leqslant 38.9$.

In late 1987 which marks the onset of the EMT event, some sporadic presence of water masses from the 500–1000 m EMed layers