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The 1987 Aegean dense water formation: A streamtube investigation by comparing theoretical model results, satellite, field, and numerical data with contourite distribution

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ABSTRACT

We here discuss a detailed investigation of the dense water formation, evolution and spreading in the Aegean Sea during the year 1987, immediately prior to the onset of the Eastern Mediterranean Transient (EMT). We use hydrologic data collected during the LIA cruise; satellite images for SST (Sea Surface Temperature), and PROTHEUS data (a coupled ocean–atmosphere numeric model) along with theoretical streamtube models. These hydrological analyses are related to late Quaternary sedimentary drifts in the Cyclades Plateau and in the Myrtoon Basin. Our analysis shows that streamtube dynamics provide a novel model of dense water evolution and spreading in the Aegean Basin. Applying this model to dense water masses observed in winter and spring 1987 near Samothrace and over the Limnos-Lesbos Plateau, results in a geostrophic flow of this dense, cold water towards the Limnos-Sporades Channel, in the North Aegean Sea. There it mixes with dense water from the Limnos-Lesbos Plateau and finally both move geostrophically towards the Cyclades Plateau. These results indicate that most of the dense water observed near the Cyclades, formed initially about 3 months earlier at Samothrace and Limnos shelves. During its long pathway it partially mixed with adjacent water masses. Although our analysis concerns only one year of dense water analyses, these results are thought to reflect a more general and recurrent phenomenon in the Aegean basin. Indeed, high-resolution (Airgun 10 in.) seismic-reflection data from the Cyclades Plateau reveal the presence of late Quaternary sediment drifts. These observations are concordant with results from our theoretical model. This suggests a direct link between such a dense-water cascading and contourite dynamics. The continuation of sediment drifts into the deep basin floor (≈900 m deep) of the Myrtoon Basin, moreover, indicates a cascading character of such bottom currents at the flanks of the basin, a feature that set further investigations.

1. Introduction

The idea that the Aegean Sea could be the source of the Eastern Mediterranean deep waters was first proposed by Nielsen (1912), but successive observations demonstrated the main role of the Adriatic Sea as source of such bottom waters (Malanotte-Rizzoli and Hecht, 1988, and references therein). Field observations from the Aegean Sea around the year 1990 revived the Nielsen hypothesis by demonstrating that the Cretan dense water (CDW) was observed on the Northern Aegean coasts and on the shallow shelves of the Cyclades islands, and then accumulated in the Cretan Sea (Zervakis et al., 2000; Gertman et al., 2006). CDW, later on, filled the bottom layers of both Mediterranean Sea basins (Roether et al., 1996; Klein et al., 1999) although, overflowing the Sicily Strait, this deep water results to be heavily modified (Ben Ismail et al., 2014).

During 1987, before the EMT event, an unexpected dense water was observed in the Aegean Sea. Its density ($\sigma_\theta \approx 29.25$–$29.35$) was indeed higher than the historical maximum value of 29.2 (Georgopoulos et al., 1992; Theocharis and Georgopoulos, 1993, two similar articles called G2T3 in the following).

Whereas the period 1992–1993 is generally considered as the real onset of a full EMT (Roether et al., 1996), the cold winter of the year 1987 is of some interest since modern field data are available and also because of a particularly severe 3–13 March storms (Lagouvardos et al., 1998) due to cold fronts passing over the Aegean Sea.

About the EMT event, during September 1987 the first Meteor-POEM cruise did not find any presence of the CDW outflow into the deep Eastern Mediterranean, while Gertman et al. (2006) evidenced a CDW outflow from the Island of Kassos in the Cretan Arc (Fig. 1) during

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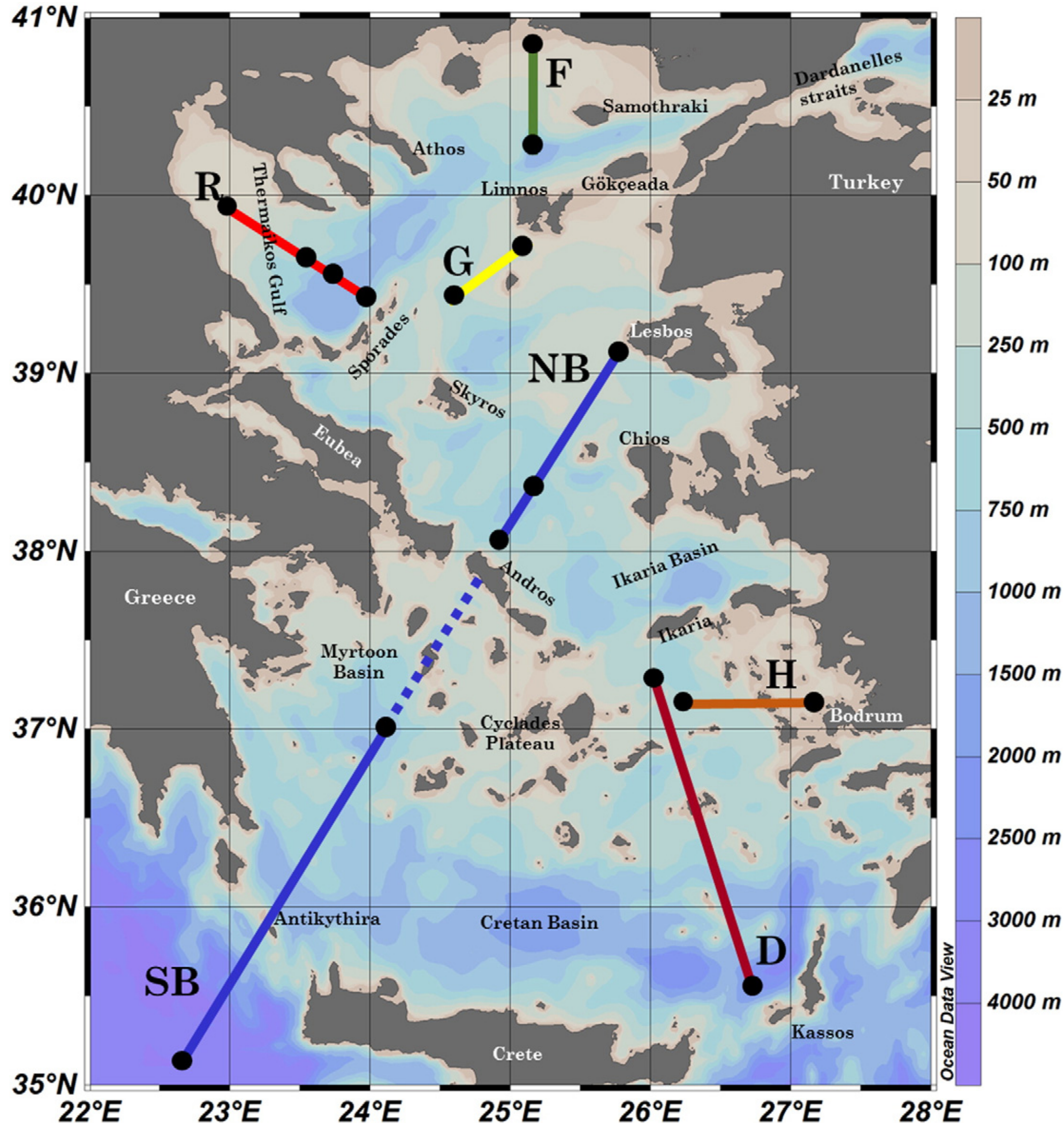

Fig. 1. General map of the Aegean Sea bathymetry, and the hydrologic transects F, R, G, NB, H, SB and D simulated by the PROTHEUS numerical results. Transect F, near Samothrace, corresponds to the C transect of G2T3. Transect R is along the Thermaikos Gulf, with remarkable river outflows. Transect G contains the sill between the Sporades plateau and the Limnos shelf, connecting the NAT and the Central Aegean Basin. Transect NB is from the Lesbos shelf to the northern Cyclades plateau (NB is the northern part of the B transect). Its southern part in the Cretan Sea is the SB transect, which goes from the Cyclades Plateau to the Eastern Cretan Sea. Transect H contain the sill between Central Chios Basin and the Cretan Sea. Transect **D,** with the southern shelf of Ikaria and intermediate (~1000 m) and deep (~2000 m) points, south of the Eastern Cretan Sea.

March 1988. Numerical simulations by Wu et al. (2000); Demirov and Pinardi (2002) among others, pointed out major winter events in the years 1981, 1983, 1987, and 1990.

We here focus on path and formation of dense water currents during the 1987 cold winter and spring, in order to infer recursive phenomena of geological interest. We pair field data (i.e., hydrographic data from G2T3) with theoretical models (i.e., the streamtube model by Smith, 1975; Killworth, 1977; Rydberg, 1980, and other viscous models by Shaw and Csanady, 1983; Shapiro and Hill, 1997; Killworth, 2001), numerical outputs (from the PROTHEUS numerical model; Artale et al., 2010), and satellite measurements (AVHRR time series; Josey, 2003; Marullo et al., 1999a, 1999b) to infer dense water formation sites. Such an approach aims to determine the possible pathway and spreading of the resulting bottom currents from the Northern Aegean Trough and the Limnos-Lesbos Plateau till the Cyclades Plateau, also in relations with contourite deposits in this plateau. All this is complemented by the analysis of a large set of high-resolution seismic-reflection data from the Cyclades Plateau and Myrtoon Basin in order to map late Quaternary sedimentary structures. The combination of marine geological data with oceanographic analyses provides relation between bottom-current activity and contourite drifts, as suggested by Rebesco et al. (2014).

This work is structured as follows: the study area is described in Section 2; data, methodologies, and both numerical and theoretical models are described in Section 3. Analyses and results from numerical simulations of temperature (T) and salinity (S) vertical transects as well as the analysis of the theoretical model for bottom current pathways are in Section 4, for both North Aegean Trough (NAT) and Central Basin. The bottom sediments of the Cyclades Plateau and the Cretan Sea hydrology are analyzed in Section 5. A short synthesis and conclusions are in Section 6.

2. Study area

The Aegean basin has a very complex structure of different local environments as canyons, river deltas, coastal or offshore sediments (Maley and Johnson, 1971; Zervakis et al., 2000).