INTERANNUAL VARIABILITY OF LIW FORMATION : A HIGH RESOLUTION NUMERICAL STUDY

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Abstract

We study the interannual variability of LIW formation using an eddy resolving numerical model of the Levantine basin, forced by realistic atmospheric data from selected typical years. The strong interannual variability of winter heat loss modulates the characteristics of the formation process and the properties of the new water mass. During mild winters the formation rate can be significantly reduced compared to climatology. During severe winters the formation rate is not increased considerably but, instead, we observe simultaneous deep and intermediate water formation in the area. These experiments also revealed the significant role of extreme cooling events associated with the passage of storms over the basin.

Key-words : Intermediate waters, Levantine Sea, Air-sea interactions, Models

Introduction

Intermediate and deep convection processes at different locations of the Mediterranean sea are responsible for the formation of the various water masses of the basin. Among them and probably the most characteristic, is the Levantine Intermediate Water (LIW), the saline and warm water mass that occupies the intermediate layers of the basin (200-500m). Its is formed in the Levantine basin during winter-time cooling and evaporation. From its formation site, it spreads throughout the whole basin and exits through the straits of Gibraltar, being the main contributor to the Mediterranean outflow into the Atlantic ocean.

A wide range of "core" LIW temperature and salinity values can be found in the bibliography for the Levantine basin; minimum and maximum values reported are 14.5-16.4oC and 38.85-39.15 for T and S respectively [1]. This wide range of LIW core values is a first indication of the significant interannual variability of LIW characteristics. The second strong indication, comes from the different locations that have been reported in the past as possible LIW formation sites. Most observations indicate that the Rhodes cyclonic gyre, a permanent feature of the Eastern Mediterranean general circulation [2], is the formation site of LIW. There are, nevertheless, observations of intermediate water formation in the whole north Levantine [3], in the south Levantine [4] or in the SE Aegean sea

We describe results of numerical experiments that simulate the formation of LIW under different meteorological conditions. We apply the numerical model used in the past for the study of LIW formation under mean climatological conditions [5]. Those experiments proved that under such conditions, the Rhodes cyclonic gyre is the unique site of LIW formation. The duration of the event is typically 2 months (February-March) and the estimated annual formation rate 1.2 Sv. In the new experiments, we force the model by real 12hours atmospheric data from selected winter periods, instead of the monthly mean climatological forcing previously used. In these way, two new important factors are introduced : the interannual variability of atmospheric forcing and the effect of synoptic time scale events.

The Numerical Model

The numerical model we use is based on the Princeton Ocean Model (POM), a 3-D primitive equation ocean model widely used for both open ocean and coastal sea studies [6]. It is a free surface model that uses sigma coordinates in the vertical and a time splitting technique to calculate the 2-D and 3-D equations with different time step. The Mellor-Yamada scheme is used for computation of vertical mixing coefficients while horizontal diffusivities are calculated according to the Smagorinsky formula.

The model is applied in the Levantine using a 5.5x5.5 km eddy resolving grid. The same grid was capable to reproduce transient baroclinic eddies (20-50 km) associated with the instability of the rim current in the Rhodes gyre [5]. In the vertical, 30 sigma levels with logarithmic distribution in the top are used. Radiation boundary conditions are used along the western boundary of the domain that is considered to be open. The MED2 data base [7] is used for model initialization and for the T-S profiles updated seasonaly along the open boundary.

The surface boundary conditions are the fluxes of heat, fresh water and momentum. All of them are computed at each time step using the model's SST and atmospheric parameters from the 1980-1988 12hr NMC analysis (wind speed, air temperature and relative humidity). The cloud cover C is taken from the COADS 2x2 monthly mean data set for the same period, while precipitation is derived from monthly climatology.

For the interactive computation of surface fluxes we use the formulation developed in the framework of MERMAIDS [5] choosing a combination that gives realistic annual mean heat and water budgets for the Mediterranean and the Levantine : the formula of May for long wave back radiation, the formula of Kondo for sensible and latent heat and the formulation of Rosati & Miyakoda for solar radiation.

The Numerical Experiments

The scope of our numerical experiments was to study the formation of LIW under different winter conditions. We, therefore, decided to select from the 9 years period of available NMC data four winters with different characteristics. Our selection was based on the mean air temperature over the Levantine that can characterize each winter as "typical", "mild" or "severe". Each numerical experiment is a 5 months integration of the model during the cooling period of each year, *i.e.* from November to end of March starting from the same initial state, and using the same open boundary conditions; this means that we do not attempt to simulate the exact formation conditions or general circulation features of each specific year but to study the effect of different atmospheric forcing on the formation of LIW.

In figure 1 we present the five months long time series of total heat flux for the four numerical integrations. In all four cases, the variability of the surface buoyancy loss is composed by two time scales : the low frequency seasonal cooling and heating and the high frequency episodes associated with strong synoptic scale atmospheric events. The low frequency signal introduces in all cases an increasing buoyancy loss from November until mid January when we have the period of maximum cooling. The trend is then reversed and by the end of March we observe slightly positive heat budget that marks the beginning of the warming period for the sea.

On top of this common for all years low frequency variability, we have a number of short time scale events with variable intensity and duration. Most of them are related to the passage of atmospheric depressions over the area. The low air temperatures and strong winds associated with these systems increase the latent (mainly) and sensible heat loss to the atmosphere. Particularly effective are the north winds that follow these systems, since they bring over the sea very dry and cold air masses of Arctic origin. During these events, the heat loss can be as high as 500-600 W/m^2 which means 3-4 times above the typical value. Depending on its duration, the total amount of buoyancy lost during a single event can be equivalent to the heat loss during a whole month (*e.g.* events of January 1987).

Based on the mean heat loss during the 5 months of the experiments we can characterize the four winters as "mild" (1984 - 108 W/m^2), "typical" (1985 - 125 W/m^2, 1986 - 140 W/m^2) and "severe" (1987-171 W/m^2). The total budget of each winter is usually controlled by the characteristics of the short time scale events. The winter of 1987 is characterized as a very

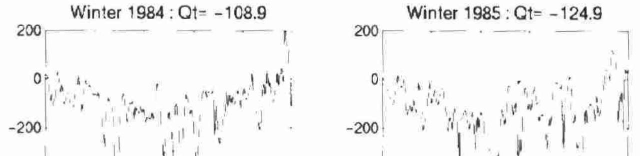

Figure 1 : Time series (November-March) of total heat flux (Q_{total})