Status of and the potential for the understanding of the western Mediterranean Sea

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This paper focuses on the circulation of the water masses because we now have relatively good data sets and seemingly efficient theoretical models, which allows us to expect a correct understanding of this basic phenomenon in the very near future.

The gross features of the circulation, at least in regions where it is relatively stable, and mainly for what concerns the surface layer of Modified Atlantic Water (MAW), have been established several decades ago from a quite-surprisingly very reduced number of hydrological casts. But, it is only since a few years that satellite data and long current time series have provided us with a significantly improved description of the mesoscale variability of the circulation and, to a lesser extent, of its seasonal variability.

We first review the most important results concerning the mesoscale variability, recently obtained in the Alboran Sea and in the Algerian and northern basins mainly. This variability manifests itself either as fluctuations of the major coastal currents, such as meanders, or as coherent structures resulting from instability processes affecting these currents, such as eddies. The space (some tens to a few hundreds of km) and time (a few weeks to several months) scales of these mesoscale phenomena, as well as their relatively intense signature in remotely-sensed and in situ measurements, allow an efficient description of their characteristics: it is obvious that the importance of these phenomena has been greatly underestimated for a long time. Now, even if they are easily measured and relatively well described, the understanding and modelling of the mesoscale phenomena are generally far from being satisfactory.

Interesting results have also been obtained concerning the seasonal variability, in the Straits of Gibraltar and Sicily and in the Corsican Channel as well. As the actual working of the whole sea -which basically transforms surface waters into deeper ones during the winter- is seasonal, one could expect a clear corresponding variability of the circulation. But this takes no account i) of the characteristics of the Strait of Gibraltar which constrains the exchanges with the ocean to be more or less maximal, ii) of the relatively large intensity of mesoscale phenomena and other subinertial variations of the flows and iii) of the fact that direct current measurements are neither numerous nor long enough to give an accurate estimation of the transports. Now, even if not easily estimated, the seasonal variability may be expected to be quite well understood with numerical models.

A better understanding of this seasonal variability is the primary objective of PRIMO, a several-year "International Research Programme in the Western Mediterranean" supported by IOC and ICSEM, in which most of the physical oceanographers interested in the western Mediterranean Sea are involved. Our strategy is to conceive an experiment aimed i) to specify more accurately the major characteristics of the seasonal variability of the circulation and ii) to check for all the mechanisms expected to be responsible for such a variability.

Another point to which it would certainly be fruitful to pay more attention concerns the mean paths described by the Levantine Intermediate Water (LIW) and by the western Mediterranean Deep Water (MDW). In fact, on the basis of hydrological and direct current measurements, it seems obvious that both water masses basically flow cyclonically along the continental slope in the whole sea. This is of primary importance, because such paths offer simple conditions to check for the validity of numerical models (for LIW) or because the forcing mechanisms are far from being obvious (for MDW); moreover, we suspect the circulation at depth to significantly influence, at least in some regions, the circulation of the surface layer.

Finally, we emphasize the relatively close similarities which exist with other semi-enclosed seas such as the eastern Mediterranean Sea and the Japan Sea, and we underline the various interests of companion studies.

Some recent aspects of the modelling of the Circulation of the Mediterranean Sea

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In this work, we present several process studies which have been obtained with the 3D primitive equation numerical model of LODYC prior to make a realistic model of the circulation of the Western Mediterranean Sea.

First, deep water formation is investigated with a high resolution three dimensional model. A rectangular basin is forced by various sea surface heat and salt fluxes. A 1,000 thick patch of dense water is formed within the forcing area, which is surrounded by a cyclonic vortex. Meanders develop at the periphery of the patch and then tend to occupy the whole patch area. Energy studies show that the meanders are generated through a baroclinic instability process. These features agree with observations. Sensivity studies of the space and time variability of the forcing are presented. It is found that these variabilities greatly affect deep water formation. Deep water formation appears to depend on a convective process parameterized by a simple non-penetrative convective adjustment and on the vertical motion induced by baroclinic instability. The two processes are strongly linked. Furthermore, deep convection induced by the thermohaline forcing drives an horizontal cyclonic circulation of the same order of magnitude as that estimated from observations. Hence it is found that thermohaline forcing is important in driving the Mediterranean circulation andthat it must be included in any numerical model of this area.

Second, the behavior of the Algerian current is investigated. The current is forced by an initial field of density in a periodic rectangular channel. After a long time which is of the same order as that observed on the physical simulations made on the large rotating table of Grenoble, meanders develop. Their wavelength is of the same order as those observed in nature and in the physical simulation. These meanders are due to baroclinic instability and their characteristics fit an analytical theory which has been developed.

Third, the generation of the flux through the strait of Gibraltar and the formation of the Almeria-Oran front is investigated. A fixed density gradient is imposed between the Mediterranean Sea and the Atlantic Ocean. It is maintained constant by a newtonian restoring on climatological values. This procedure generates a realistic flux through the strait which has some degrees of freeedom and allows variability linked to variations in the density gradient. Furthermore, the gyres of the Alboran Sea are generated and their behavior is discussed.