Observing the Mediterranean variability from meso- to decadal scales: how can we get the right picture?

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Abstract :

The overall functioning of the Mediterranean Sea, which transforms Atlantic Water (AW) into Mediterranean Waters (MW), has been comprehended for decades now, and so is the process of dense water formation (DWF), which leads AW to sink in specific offshore northern zones of both basins. However, some circulation features are still being debated, as are the impacts of climate change. This is mainly due to the lack of adequate data, especially of long-term time series. Indeed, the intense mesoscale activity of the Mediterranean requires a fine coverage in both space and time, and the variability over decadal (and more) scales requires monitoring over a long period to achieve an actual description, a proviso for a correct understanding. Adequate monitoring is only within the reach of an integrated system of Mediterranean marine observatories.

1. Introduction

One of the main scientific challenges of the XXIst century will be to answer societal demand about climate change issues, such as trends in temperature, sea level rise, occurrence of high impact weather events (flash floods, hurricanes, droughts…) etc[1]. While in the field of meteorology the observations are long enough to enable testing and validating the models of forecasts, in the field of climatology one has to rely mostly on proxies. Although the time scales accessible (for instance with ice cores) are well within climatic range, the potential variability in both space and time may raise questions about the generalization and validity of the proxies (e.g. Wunsch, 2006; Toggweiler and Russel, 2008). It is even worse in the field of oceanography *s.l.*, where only a few data sets of observations (in and above the sea) are longer than a few decades. It is thus impossible to test and validate the models dealing with changes in the circulation at climatic scale (e.g. Somot et al., 2006). Efforts have yet to be made, hence, to present the results (scenarios) with the errors and uncertainties estimated at best (e.g. Wunsch, 2007; Wunsch et al., 2007). Moreover, climatic changes in the ocean are most often apprehended through the study of the changes of the ocean circulation, taken as the Meridional Overturning Circulation[2] (MOC, also Mediterranean Overturning Circulation in Tsimplis et al., 2006). But recent works tend to show that eddies affect the mass and volume transport too, at a time scale of ~4years: since the MOC also reacts on such time scale, impact

[1] Most of these items will be addressed in the framework of the HyMEx program (2010-2020): http://www.cnrm.meteo.fr/hymex/
[2] Also known as the “conveyor belt”

of mesoscale activity on climate simulations should be considered (Stammer et al., 2006; Wunsch, 2008).
Satisfying outcomes to these issues rest for a large part on a concerted effort to collect comprehensive observations on the long term. The Mediterranean is no exception. The functioning of the Mediterranean is basically known and established for decades (for a review see *e.g.* Millot and Taupier-Letage, 2005a). However several points remain to be either refined or definitely settled, as adequate observations (both remote and in situ) are lacking yet. First we review briefly the main processes and scales of variability that hinder our forecasting ability. Then we sketch, for discussion purposes, the outlines of a Mediterranean-wide concerted observing strategy.

2. Sources of variability

a. Mesoscale activity

The mesoscale activity is represented mainly by meanders and eddies, and. Horizontal dimensions range from ~50km up to 150km, vertical ones from ~100-1000m (often reaching the bottom: ~3000m), with lifetimes from few weeks to one year (up to 3). This activity is ubiquitous in the Mediterranean (Fig. 1.), while more intense in the southern parts of both western and eastern basins. It generates a high variability in both space and time, and thus such a complexity that it requires for instance at least 4 altimeter missions to monitor the mesoscale circulation. Its importance of must be considered, since it can modify locally and temporally the circulation of the water masses (*e.g.* Taupier-Letage, 2008), for instance by entraining water off its normal path, up to reversing the mean circulation at depth (Millot and Taupier-Letage, 2005b). It is also likely that it contributes to the variability of the basin-wide mass and volume transport.
When overlooked, the interpretation of identical data sets can diverge, as in the case of the debated existence of a westward vein of Levantine Intermediate Water (LIW) circulation off Algeria (compare Millot and Taupier-Letage, 2005a and Fig. 79 of Tsimplis *et al*., 2006), or in the case of the much debated schema of the surface circulation in the Eastern Basin (compare circulations schemas in figure 1 of Hamad *et al.*, 2006).
On a much shorter scale, a CTD moored ~10m above the bottom at 3200m deep off Libya revealed episodes few-day long when the temperature dropped by a 10^{th} of a degree C (Fig. 2.). Whatever its origin[3] such a variability must be properly described when addressing climatological issues, where the signal (trend) looked for is a 100^{th} of a degree °C/year (*e.g.* Salat and Pascual, 2005).

b. Seasonal variability

Seasonal variability is generally well understood, if not well described. It is more marked in the northern parts of both basins, by an intensification of the Northern Current and an increase of its mesoscale activity (meanders), in relation to Dense Water Formation (DWF) processes. Note however that in the southern part of the Ionian sub-basin the surface circulation has yet to be precised. It is strongly dependant on the wind regime, and seems to be reversed during summertime. Because of its complexity (2 circulation cells), the recent efforts with surface drifters (Gerin et al., 2007b) do not provide definitive results yet.

[3] Most probably mesoscale phenomena, however data analysis is still underway.

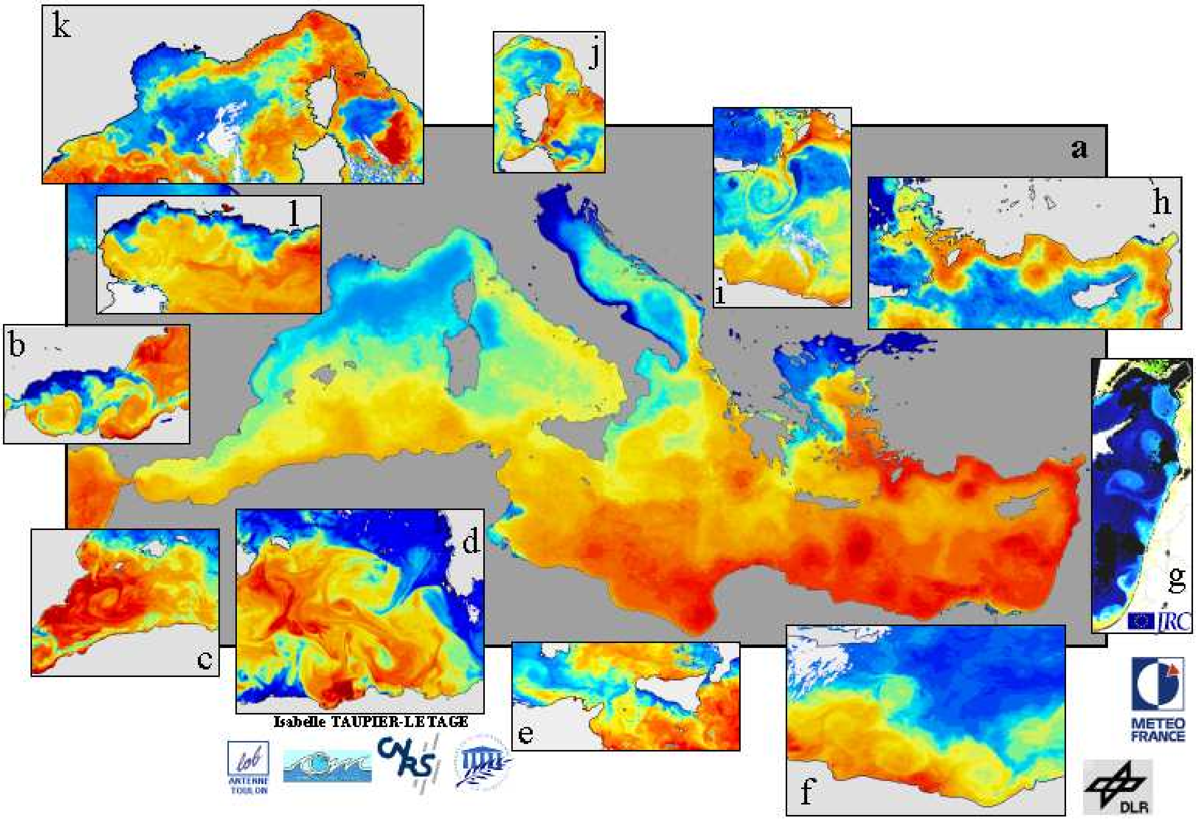

Figure 1: Illustration of the mesoscale dynamics in the Mediterranean with thermal NOAA/AVHRR images from SATMOS/MétéoFrance and DLR (but *g:* ocean colour/chlorophyll content from SeaWiFS, from *ies*). Images have been selected at different dates. Temperature increases from blue to red, but all images have an independent colour scale. a: **the monthly composite of January 1998 for the whole Mediterranean.** b: **the Alboran, in its classic situation of two gyres filling the sub-basin.** c: **the jet of AW on the western half of the eastern Alboran gyre reaches the algerian slope near 0° and continues as the Algerian Current, which can be seen (colder signature) propagating alongslope as far as ~4°E (south of Menorca), where it veers offshore (due to eddies interactions, not shown). An algerian eddy (warmer isotherms) can be seen south of Ibizza.** d: **Algerian eddies interacting strongly in the eastern part of the Algerian sub-basin, the accumulation zone ΣA_E. The strong shear between 2 close anticyclones creates small cyclonic shear eddies. Upwelling cells (dark blue tongues) are generated on the southwestern side of the AEs, where the current is directed offshoreward.** e: **the channel of Sardinia with an AE (blocked) at the entrance, and the channel of Sicily (the upwelling cells along the southern coast of Sicily are typical of summertime conditions).** f: **The western Levantine, with libyo-egyptian eddies (accumulation zone ΣL_W).** g: **The Middle-East, with coastal instabilities revealed by their chlorophyll content (SeaWiFS "ocean colour" image; situation not characteristic of the accumulation zone ΣL_E).** h: **The Northern Current off Turkey, showing sharp meanders and an eddy pinching off.** i: **Most of the Northern Current is feeding the wind-induced Ierapetra eddy, east of Crete.** j: **The Ligurian subbasin, with a vortex dipole (mushroom-like structure) north of Corsica; the cold patch east of the strait of Bonifacio reveals the divergence induced by a strong (past) mistral wind event.** k: **the Liguro-Provencal subbasin: the Northern Current flows close to the coast since the slope is steep east of the gulf of Lions; there it skirts the continental shelf along the ~200m isobath, and thus crosses the gulf; the cold area off the gulf of Lions (and probably the one east of the strait of Bonifacio too) reveals the area where wintertime deep convection occurs, forming dense water (image typical of wintertime situation).** l: **Upwelling cells in the gulf of Lions induced by strong Mistral events.**

c. Inter-annual variability

The process to monitor especially is DWF. During mild winters (no long-lasting intense episodes of northerly dry winds) only the formation of intermediate water occurs. Otherwise deep convection occurs, mixing surface and intermediate waters, resulting in a denser water that can reach the bottom. In the Eastern Basin the formation of Levantine Deep Water has yet to be described and fully observed. In the Western Basin, some intense episodes have been recently described (e.g. Puig *et al.*, this issue), at places that appeared unusual a priori: in the Ligurian and the eastern Catalan subbasins (Smith and Bryden, 2007). The question of whether it is a failure to look for and observe the DWF in the whole northern part of the basin, or whether such places are truly unusual remains open.

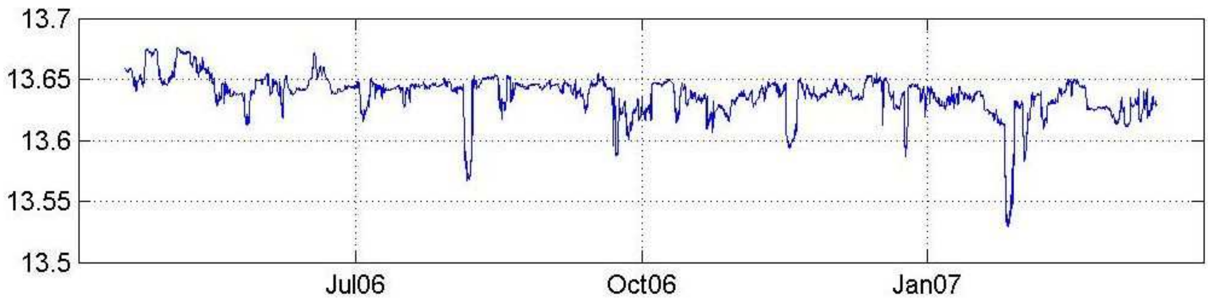

Figure 2: Time series of temperature recorded off Libya at ~3200m, about 10m above the bottom. The high variability shows that it is irrelevant to use the deepest layer to intercalibrate CTDs, that isolated measurements are likely not to be representative of the mean value –and that a mean value may be delicate to use (relevancy?). This Hydro-Change autonomous CTD was put on the mooring G1 of the EGYPT (Eddies and Gyres Paths Tracking) experiment (www.ifremer.fr/lobtln/EGYPT).

d. Multi-year up to decadal variability

This is for instance the case of the Eastern Mediterranean Transient (EMT: the main source of deep water suddenly switched from the Adriatic to the Aegean; see *e.g.* Tsimplis *et al.*, 2006). Because such a phenomenon (event?) was not predicted there was no dedicated monitoring, and because also of its quasi-decadal scale data appropriate are scarce. As the EMT signal propagates in the Western Basin, it also progressively modifies the characteristics of the dense water formed there (e.g. Schröder *et al.*, 2006; Gasparini, this issue).

In some places a definitive increase of temperature was observed, allowing to the time series length. This was for instance evidenced by a ~30-year long record of the surface temperature around the Medes Islands (NW Mediteranean, Pascual and Salat, 2005), as well as downstream close to Cartagena (Plaza et al., 2008).

In the same way, knowledge of the connexions of the Mediterranean to the Atlantic has yet to be improved. While it is mostly discussed in terms of the Mediterranean overflow water (MOW) fluxes and impact on the Northern Atlantic (for a review see *e.g.* Artale *et al.*, 2006), the acquisition of time series in the Strait of Gibraltar within the framework of the Hydro-Changes program recently showed that the temperature of MOW had increased as a result of the modification of its composition (Millot *et al.*, 2006). Most importantly, while modifications in the Mediterranean are most generally ascribed to internal (mediterranean) forcings, these time series evidenced a continuous increase in salinity of the Atlantic Water (AW) entering at Gibraltar of ~0.05 /year in 2003-2007: the AW yearly trend is dozens times larger than the Mediterranean waters (MWs) decadal one (see Millot, 2007, and references therein).

3. Outlines of a Mediterranean-wide concerted observing strategy

a. Requisites

- Cover the whole Mediterranean: both basins, offshore and coastal zones
- Sample from the surface to the bottom (several layers and/or water column)
- Consider the exchanges at Gibraltar and with the Black Sea
- Consider the exchanges between the sub-basins (Channels of Sicily, Sardinia, Corsica, Otranto (see Gasparini, this issue))
- Consider the exchanges with the Suez Canal to determine their significance (see Rosen, this issue)
- Be designed from the beginning to have a lifetime of 10 years at least (aiming at the century)
- Include both remote and in situ observations
- Have core parameters homogeneously measured in both space and time, that will be the backbone for other parameters observation (multidisciplinarity)
- Resolve time scales ranging from the hour to inter-annual and decadal
- Resolve space scales ranging from the km to the basin scale
- Encompass networks of platforms (e.g. gliders, gliders, moorings, ferries, drifters…) and specific programs of observation at fixed stations
- Have links (2-way communications) with meteorological and hydrological-continental networks and observatories
- Have links (2-way communications) with operational oceanography centers (operational oceanography, assimilation)

b. Main bottlenecks

- Legal issues : for now the restrictions to sample off the 12 miles of the territorial waters of many countries, even without taking samples (e.g. drifting buoys), do not allow any Mediterranean-wide system of observations to develop
- Areas undersampled (mainly southern parts of the Eastern Basin)
- Lack of dedicated staff: the regular activity of data acquisition cannot be that of a scientist over time (scientist = data analysis)
- Data exchange (time embargo if network run by scientists)
- Recurrent funding lacking for long term (target is usually ~3 years)
- Management for rescuing platforms (funding, staff, shiptime…)

c. Some solutions

- Perennial funding of the observation activity and means (for the sake of debate see some perspectives by Baker *et al.*, 2007).
- Develop and promote autonomous platforms and devices (e.g. a moored profiler for high-frequency CTD casts)

- Increase and combine complementary networks[4] (improve synopticity and spatial coverage), cf Fig.3:
    - network of moored CTDs (cf CIESM program Hydro-Changes) and other sensors
    - networks of multi-instrumented buoys
    - network monitoring the surface with thermosalinometers (+ meteorological sensors) installed on ferries[5] (cf CIESM program TRANSMED[6])
    - network of gliders
    - network of periodic CTD and XBT transects (e.g. across the straits and DWF)
    - periodic releases of ARGO CTD profiler and surface drifters

  Whenever possible additional measurements and/or samples must be taken to insure the multidisciplinarity (e.g. towed plankton recorders, … cf executive summary). Aside these routine networks, "networks of opportunity" should be considered, such as CTD profiles or transects in key places (Fig. 3).

- Promote the use of homogeneous devices/installations
- Periodic (yearly?) meetings of technical staff for training and "recipes" exchanges
- Develop 2-ways communications with platforms for intelligent sampling (event-triggered)
- Develop/fund real-time communication of data whenever relevant
- Develop structures hiring staff dedicated to "observation"
- Improve the data banking capability: increase/create centers for QA/QC, improve requests functions … (more dedicated staff)

4. A first sketch

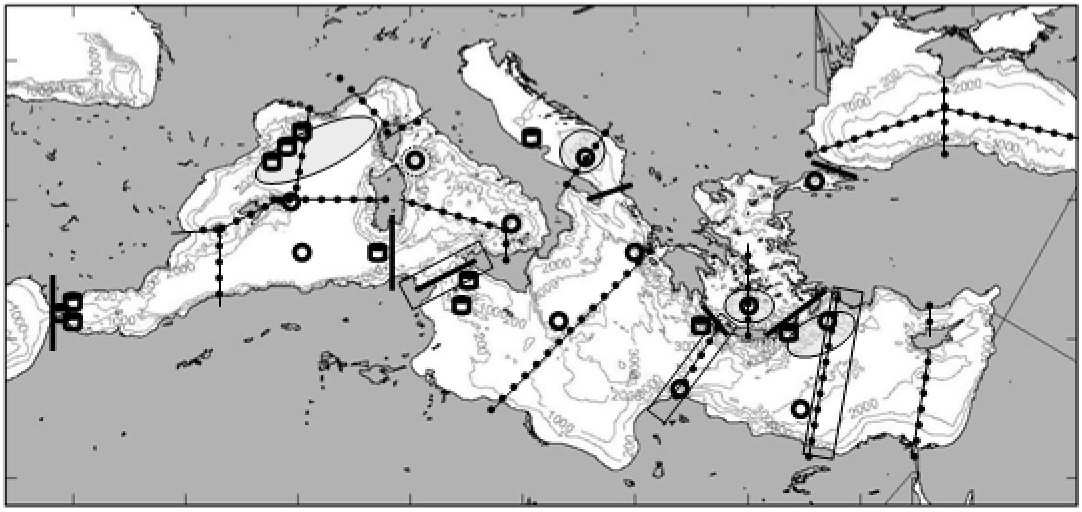

Figure 3: A first sketch of a Mediterranean-wide concerted observational effort.

Ellipses: areas of DWF; squares : CTD moorings of the Hydro-Changes program; circles: additional key points where to monitor deep water characteristics with CTD (in the future preferably with a profiling CTD to address the water column); thick lines: recurrent 2D monitoring of the straits; dotted lines: 2D

[4] This list doest not pretend to be exhaustive, and disregards the regional observatories, considered in the executive summary.
[5] Contribution of southern riparian countries to a concerted effort could especially take advantage of the ferries (more generally Volunteer Observing Ships), which offer a highly cost-efficient platform.
[6] See the figure representing the potential network on http://www.ciesm.org/marine/programs/transmed.htm

monitoring during "cruises of opportunity" (even partial sections are of interest); rectangles: high priority areas where to release surface drifters in a recurrent way (~1 every 6 months during ~2 years).

The 2D monitoring of the sections could be performed using CTD, gliders or XBT. As a general rule, all sections perpendicular to the slope/current, and spanning the shelf to the open sea, crossing the current, are highly valuable.

NB: The map of a potential network of ferries for surface monitoring is available on http://www.ciesm.org/marine/programs/transmed.htm . ARGO Profiler floats are not represented here but are definitely part of the required observations.

5. Conclusion

Considering the lack of (long) time series and the numerous places where in situ data are simply lacking (southern part of the Eastern Basin), one can only conclude that the data bases constructed with measurements isolated in both space and time and pooled for climatological studies need at least to be improved. This effort must be conducted along with an analogue effort to collect and analyse meteorological and continental hydrological observations.

There is now a general agreement about the need to improve the monitoring of the marine areas, from the global ocean to the coastal seas, and many efforts are being done at the international level (e.g. GMES, GOOS…). It is in theory easier to set up an integrated system of marine observatories in the enclosed Mediterranean than at global scale. However its accomplishment will face many national and trans-national issues, not withstanding the financial ones. But our better understanding and forecasting abilities are at stake.

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