Surface circulation in the Algerian basin during 1984

Algerian basin
General circulation
Mesoscale

Bassin algérien
Circulation générale
Moyenne échelle

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ABSTRACT

The Algerian current observed during most of the summers between 1975 and 1983 appeared as a succession of eddies (diameter about 100 km) propagating eastward along the coast. In 1984, however satellite infrared imagery revealed two huge (diameter about 200 km) and driftless anticyclonic eddies occupying most of the Algerian basin. The Atlantic water was deflected seaward as far as the Balearic islands by the westernmost eddy located off Algiers, and was then dispatched by other eddies throughout the basin as if by a set of paddle-wheels. Nevertheless, and independent of the general situation, the occurrence of eddies induces secondary phenomena such as advections of surface water from the Liguro-Provençal basin into the Algerian basin, cool tongues and small-scale cyclonic eddies along the Algerian coast. In consequence, the circulation in the Algerian basin is mainly driven by mesoscale eddies and its temporal and spatial variability is thus very large.

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RÉSUMÉ

La circulation de surface dans le bassin algérien en 1984

L'observation du courant algérien pendant la plupart des étés de 1975 à 1983 a montré une succession de tourbillons (environ 100 km de diamètre) se propageant vers l'Est le long de la côte. Par contre, en 1984, deux grands tourbillons anticycloniques (environ 200 km de diamètre) occupaient une grande partie du bassin algérien. L'eau atlantique était alors déviée par le tourbillon le plus à l'Ouest vers le large jusqu'aux Baléares, où elle était ensuite reprise et distribuée dans tout le bassin par d'autres tourbillons comme par un ensemble de roues à aubes. Néanmoins, quelle que soit la situation générale, l'existence même de structures tourbillonnaires induit toujours des phénomènes secondaires tels que des advections d'eau de surface du bassin liguro-provençal vers le bassin algérien, des langues froides et des tourbillons cycloniques de petite échelle le long de la côte algérienne. Par conséquent, la circulation dans le bassin algérien apparaît surtout conditionnée par des structures de moyenne échelle, et sa variabilité spatiale et temporelle est donc très importante.

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INTRODUCTION

Until recently, the classical scheme of surface circulation in the Algerian basin depicted Atlantic water first flowing along the coast and then dividing into two branches, one continuing eastward through the Strait of Sardinia and the other being inflected toward the Liguro-Provençal basin. New conceptions of the circulation in the Algerian basin emerged as a result of synthetic analysis of the hydrological and satellite infrared data sets available for the period 1975-1983 (Millot, 1985). Near 1-2° E, the instability processes affecting the Algerian current commonly generate paired eddies : upstream cyclonic eddies are associated with downstream anticyclonic ones ; the divergence between them induces a coastal upwelling cell. The eddies are advected eastward by the mean flow, but only the anticyclonic eddies grow larger with age (diameter about 100 km, depth above 1 000 m). Since the energy required for this increase is provided by the mean current, the advection speed decreases, with the result that the eddies may leave the coastal zone and drift for weeks in the Algerian basin. Isolated eddies may reach the continental slope off Sardinia and thus draw Levantine Intermediate Water seaward. The instability of the Algerian current, through these eddies and upwelling cells, is therefore responsible for the large mesoscale variability which characterizes the Algerian basin. Millot (1985) suggested that this basin acts as a reservoir for water of Atlantic origin, thus disconnecting the incoming flow of Atlantic water from the exiting flows of highly modified Atlantic water.

The aim of the present paper is to describe elements of the Algerian basin circulation as recently deduced from the examination of more than one hundred infrared images of the 1984 spring-fall period. Analysis indicated the surface circulation to be somewhat different from that of preceding years, with two huge driftless anticyclonic eddies driving the circulation of the whole basin. Nevertheless, secondary phenomena observed in other years, such as surface water exchanges with the Liguro-Provençal basin and small-scale cyclonic eddies in the coastal zone, were still noted during the 1984 season. The 1984 situation will be described in Observations section and an analysis of both specific and common features will be made in Discussion section.

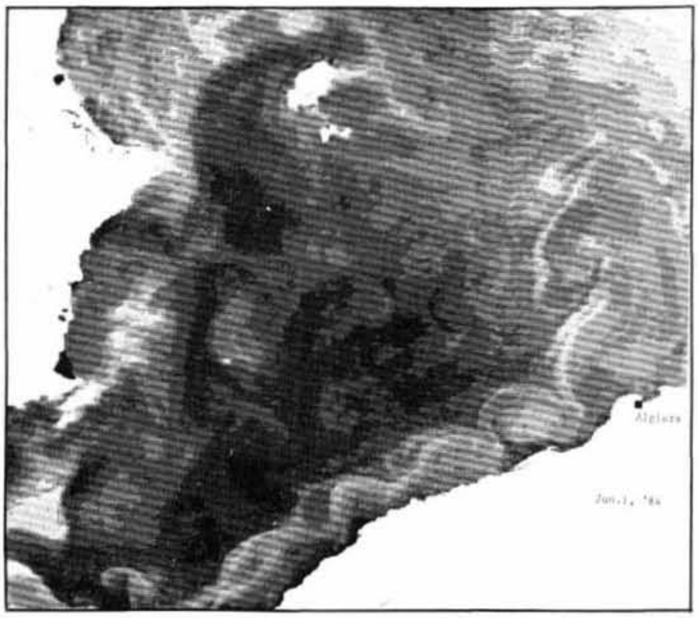


Figure 1
Le courant algérien. 1[er] juin 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
The Algerian current. NOAA AVHRR IR image on 1 June 1984 (processed at CTAMN).

OBSERVATIONS

The images of 1 and 12 June (Fig. 1 and 2) are representative of the situation in late spring 1984. In Figure 1, the Algerian current is shown by the lighter shades (*i.e.* colder waters) to meander alongshore between about 0° and 3° E, with the easternmost of these meanders (the wavelength of which is about 60 km) evolving into an anticyclonic eddy. Near 3° E, the Atlantic water surprisingly spreads seaward in a complex manner. In Figure 2, striking features are the two huge anticyclonic eddies located in the Algerian basin : the western one (eddy *W*) in the vicinity of 3° E and the eastern one (eddy *E*) in the offing near 6° E, with comparable diameters of 160-200 km. The Algerian current meanders are seen to be much sharper than earlier, and the flow appears to be deflected by eddy *W*. Since it lies close to the coast, eddy *W* acts as a paddle-wheel driving Atlantic water clockwise around its perimeter, first seaward in the vicinity of the Balearic islands, and then back towards the African coast. On the other hand, the lighter shades in Figure 2 display a continuity between the

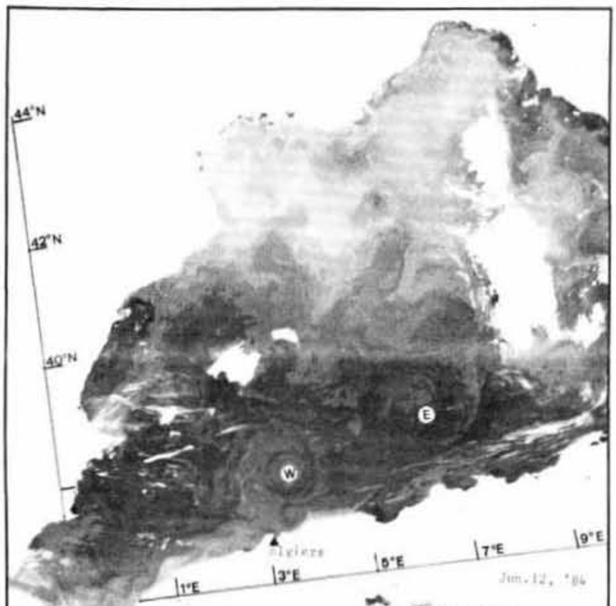


Figure 2
Méditerranée occidentale. 12 juin 1984 (provenance CMS).
The Western Mediterranean on 12 June 1984 (from CMS).

Liguro-Provençal basin and eddy *E*. The northern basin is known to have cooler superficial waters due to its doming structure, and it appears that these waters are swept along by eddy *E* as far as ≈ 80 km from the Algerian coast and in the vicinity of the Strait of Sardinia. Such entrainments are rather common features and contribute to the complex undulating outline of the North Balearic frontal zone.

Figure 3
8 juillet 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
NOAA AVHRR IR image on 8 July 1984 (processed at CTAMN).

On 8 July (Fig. 3), eddies *W* and *E* are still at the same location and have the same dimensions. They appear to induce between them a cyclonic circulation which is emphasized by a cooler water strip along its eastern edge (feature *D*). Although a large amount of Atlantic water is still deflected seaward on the west side of eddy *W*, the wedge-shaped patch of cool water between the coast and the eddy suggests that a fraction of this Atlantic water may succeed in propagating alongshore. While no large changes have affected the major structure of the eddies since their appearance in early June, miscellaneous features do appear in the Algerian basin, such as a patch of cool water (feature *A*) in the northwest of eddy *W*, and a tongue of cool water (feature *T*) spreading seaward from the cape at about 6°30 E. In the North, the temperature gradient linked to the North Balearic front reveals mesoscale structures such as a cyclonic-like loop (feature *B*), which contribute, together with eddy *E*, to the mixing of surface waters from the northern and southern basins.

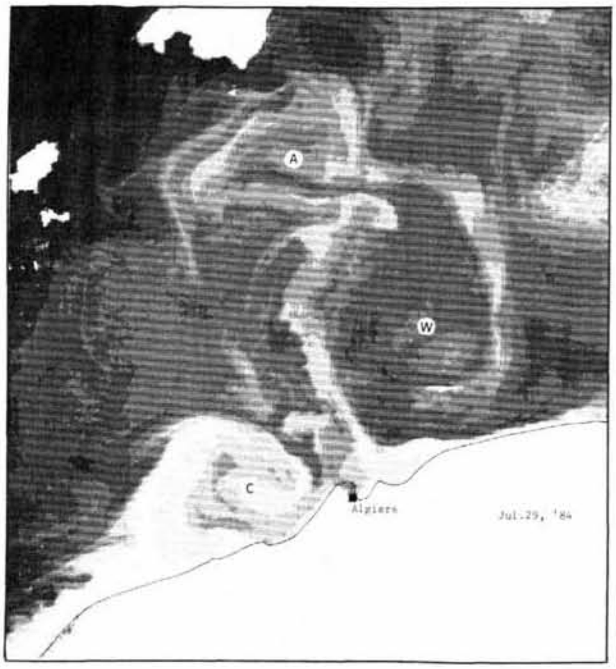
Since eddies *W* and *E* will only undergo slight modifications from mid July to late August, emphasis will be laid, as far as this period is concerned, mainly on the description of annex mesoscale features.

On 29 July (Fig. 4), two smaller structures are observed next to eddy *W*. The cool patch *A* observed on 8 July (Fig. 3) has moved around eddy *W* and proves to be an anticyclonic eddy, the size of which has increased to more than 100 km. A young anticyclonic eddy (feature *C*, diameter above 100 km) also appears west of eddy *W*. According to earlier images not shown here, its eastward drift-speed is 15-20 cm/s, and it is now situated less than 40 km from eddy *W*.

On 31 July (Fig. 5), eddy *A* has become more elongated (extent > 150 km) and now displays cooler patches at each end, seemingly forced to evolve into a double-cored eddy by being squeezed between the continental slope of Mallorca and eddy *W*. On 2 August (Fig. 6), isotherms mainly outline an anticyclonic motion around the eastern core. Meanwhile, eddy *C*, which has continued to drift rapidly, is alongside eddy *W* on 31 July (Fig. 5), and impinges on eddy *W* two days later (Fig. 6). In the eastern part of the basin, the cool tongue *T*, which first appeared in early July, is now swept along by eddy *E* as far as 120 km offshore. Note also the big anticyclonic eddy ($\varnothing \approx 150$ km) in the southern part of the Liguro-Provençal basin (Fig. 6).

The image of 7 August (Fig. 7) shows the drastic consequences of the impingement : the collision has reduced eddy *C* to a spiralled strip of cool water which now unites with the flow of deflected Atlantic water far offshore. Eddy *A* has become stretched to a length of about 200 km since its eastern core has been carried still farther away east round eddy *W*, its incurvate shape emphasizing the squeeze hypothesis. Eddy *W* conditions the evolution of the annex mesoscale phenomena, but the latter also modify the thermal signature of the former, as evidenced on this image by the angular outline.

On 1 September (Fig. 8), while eddy *E* has only slightly increased in size (from 160-200 to 200-220 km) eddy *W* shows several changes : its diameter has decreased from 160-200 to 100-120 km, but its core has moved northward (about 150 km from the Algerian coast instead of about 100 km) so that it still carries slightly modified Atlantic water as far as about 60 km from the Balearic islands. Moreover it is now mushroom-shaped, due to the cool water on its western side (this is the remaining signature of eddy *C*, as observed on two intermediate images not shown here). Compared to Figure 4, the deflection of the Atlantic water flow occurs about 40 km further west, and complex eddying features develop in the coastal flow, especially in the enlarged space between the



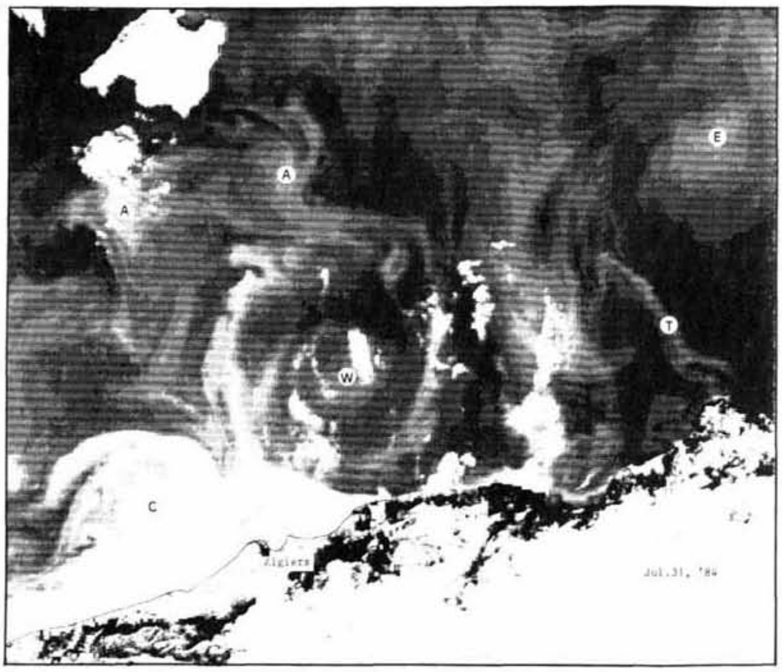


Figure 4
29 juillet 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
NOAA AVHRR IR image on 29 July 1984 (processed at CTAMN).

Figure 5
31 juillet 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
NOAA AVHRR IR image on 31 July 1984 (processed at CTAMN).

Figure 6
2 août 1984. Image infrarouge AVHRR NOAA (provenance CMS).
NOAA AVHRR IR image on 2 August 1984 (from CMS).

Figure 7
7 août 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
NOAA AVHRR IR image on 7 August 1984 (processed at CTAMN).

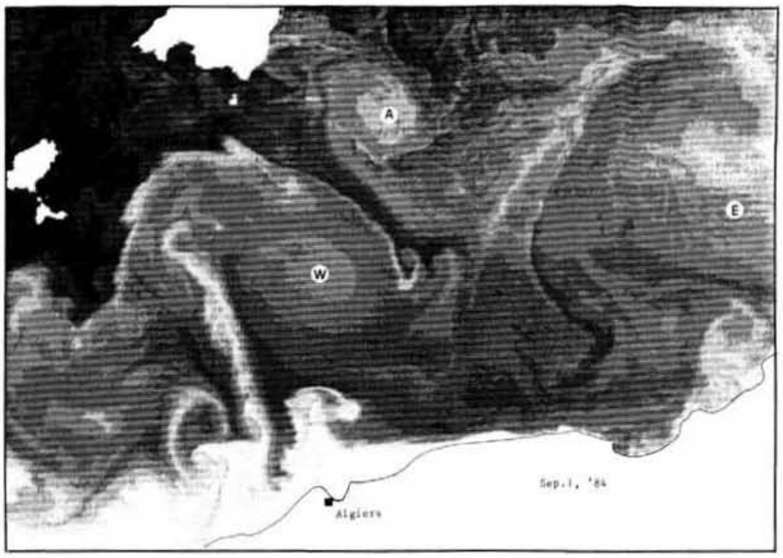


Figure 8
1er septembre 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
NOAA AVHRR IR image on 1 September 1984 (processed at CTAMN).

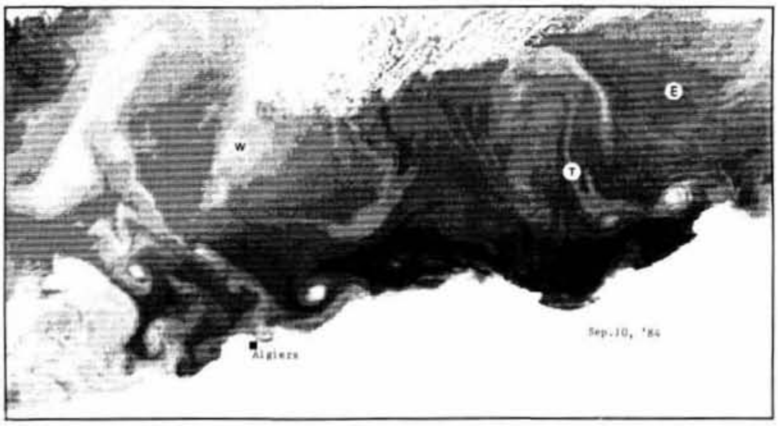


Figure 9
10 septembre 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
NOAA AVHRR IR image on 10 September 1984 (processed at CTAMN).

coast and eddy *W*. Concerning eddy *A*, although there is still some water left between Mallorca and eddy *W*, the greatest part has been carried away around the eastern core, so that eddy *A* is nearly reconstituted (diameter about 60 km). Its thermal signature now shows it to be more closely linked to eddy *E* than to eddy *W*, a further indication of its eastward entrainment by the paddle-wheel effect of eddies *W* and *E*.

On 10 September (Fig. 9), the striking features are the numerous lighter spots corresponding to small-scale cyclonic eddies (few km in diameter). Two of these are included in feature *T* (the cool strip already observed three months earlier) and the others (4 at least) can be seen in the vicinity of eddy *W*, close inshore. Such features appear in the images till the end of September (not shown).

The image of 19 October (Fig. 10) still displays eddy *W* with more or less identical characteristics, but the deflection of the Atlantic water occurs more to the West than before, and the cool signature vanishes quickly seaward. This might be linked to the fact that Atlantic water seems to be amassed upstream.

In summary, during at least five months in 1984, the Algerian basin has been occupied by two huge anticyclonic eddies (diameter about 200 km). While their

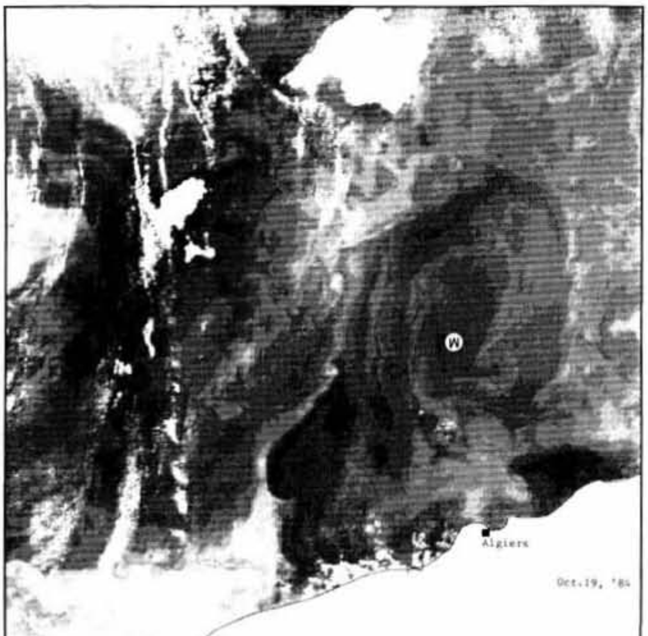


Figure 10
19 octobre 1984. Image infrarouge AVHRR NOAA (traitée au CTAMN).
NOAA AVHRR IR image on 19 October 1984 (processed at CTAMN).

overall shape has varied, their location has remained constant. Eddy *W* has deflected the Algerian current seaward as far as the Balearic islands, where the Atlantic water has then been dispatched through the entire basin by mesoscale eddies, as though by the action of a set of paddle-wheels. Eddy *W* has also swept structured features along : eddy *A* has been carried away round eddy *W* more or less undamaged, as has the structure derived from the impingement of eddy *C*. Important surface water exchanges with the Liguro-Provençal basin have been ascertained, together with the occurrence of small-scale cyclonic eddies.

DISCUSSION

The situation in the Algerian basin in 1984 as described in the previous section proved somewhat different from the preceding years, and will be discussed below under first heading. The secondary mesoscale phenomena related to the eddy-induced circulation can be observed each year, and will be discussed under second heading.

The Algerian basin in 1984

Between about 0° and 3° E, the Algerian current is as described by Millot (1985) : it takes a more or less meandering course alongshore (Fig. 1), sometimes giving birth to anticyclonic eddies, such as eddy *C*. The outstanding phenomena in 1984 is the occurrence of two large anticyclonic eddies, which remained essentially stationary for several months. There is no doubt that they are old stages of eddies originated by the instabilities of the Algerian current which may have drifted to their positions after being detached from the coast, according to the scenario proposed by Millot. Due to their size (diameter about 200 km and expected depth about 2 000 m), and since they have been observed for more than five months, these eddies are comparable to the warm rings associated with the Gulf Stream. Now, it is known from satellite and *in situ* data and from theoretical studies that the β-effect induces a westward motion on isolated eddies (*see* Robinson, 1983, for a review). Then, when looking at the bathymetry (Fig. 11), one observes that the Balearic continental slope rapidly stretches southward between 3 and 2° E. It may therefore be hypothesized that any westward motion of eddy *W* induced by the β-effect is blocked by the basin topography. Eddy *W* being blocked would then prevent eddy *E* from drifting westward.

Eddy *W* played a major role in the 1984 circulation. First, it deflected seaward the Algerian current, so that Atlantic water reached the vicinity of the Balearic islands in only slightly modified form. Yet, depending on the smaller size of eddy *W* and/or on the location of its core further to the North, a part of the Atlantic water succeeds in propagating alongshore and manifestations of instability can still be observed (Fig. 8). Second, eddy *W* also conditioned the trajectories and

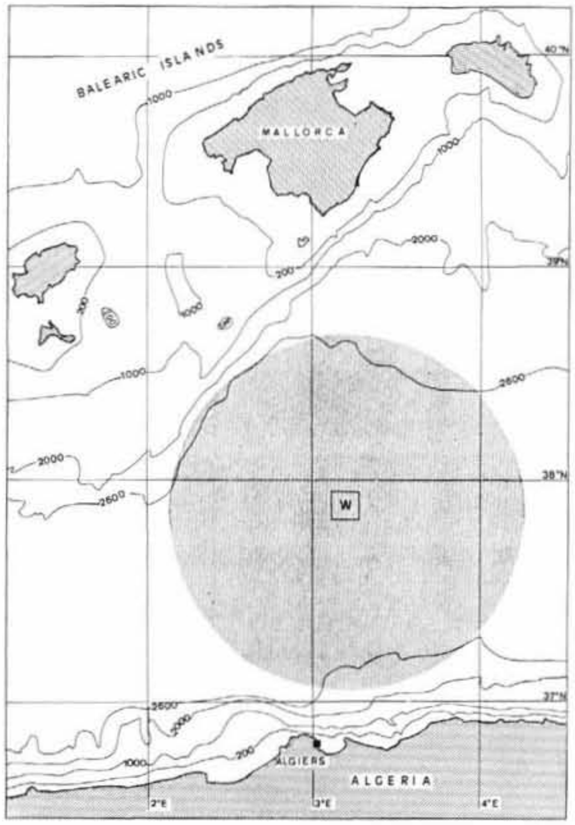


Figure 11

Carte schématique de la bathymétrie (profondeurs en mètres) autour du tourbillon Ouest figuré par la zone en pointillés.

Schematic map of the bathymetry (depths in metres) in the vicinity of eddy W, which is simulated by the dotted area.

evolution of smaller eddies ; for instance it has been seen to carry eddy *A* round its northern edge before relaying it to eddy *E*. The influence of eddy *W* is still more striking where eddy *C* is concerned : after the latter impinged on the former, it was destroyed and the remaining structure was also carried around. All these elements unite to evoke a circulation that functions like a set of paddle-wheels.

Common eddy-induced secondary mesoscale phenomena

Comparison of the 1984 data set with those of the previous years indicates that some features are common. The main feature is the surface water exchanges that often occur between the Liguro-Provençal and the Algerian basins. The thermal signature of the isolated eddies visualized in the vicinity of the North Balearic front is emphasized by the cooler superficial water of the northern basin (*see* feature *B* on Fig. 3, for instance). These isolated eddies may unite, as for example on 22 June, 1983 (Fig. 12) and on 12 June, 1984 (Fig. 2), to draw this cooler water as far as about 100 km from the Algerian coast. This accounts for a mixing between the newly-entered Atlantic water and the older superficial waters of the two basins which is obviously important and highly variable with both space and time.

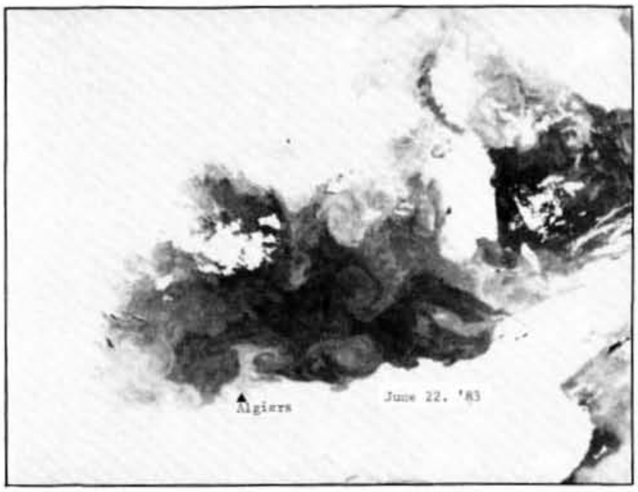


Figure 12
22 juin 1983. Image infrarouge AVHRR NOAA (provenance CMS).
NOAA AVHRR IR image on 22 June 1983 (from CMS).

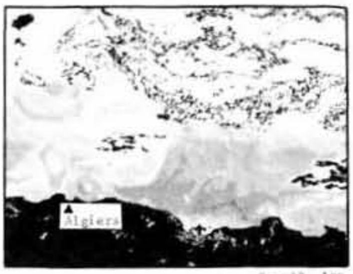


Figure 13
12 septembre 1983. Image infrarouge AVHRR NOAA (provenance CMS).
NOAA AVHRR IR image on 12 September 1983 (from CMS).

Small-scale cyclonic eddies as those presented on Figure 9 were observed up to the end of September 1984, and similar features also appeared in September 1983 (Fig. 13). These eddies are located between an anticyclonic eddy and the coast, and appear more energetic in the vicinity of a coastline break, sometimes associated with long-lasting features like feature *T* (Fig. 9). It is therefore supposed that they are shear-eddies resulting from the westward current induced along the shore by the rotary motion of the anticyclonic eddies.

Thus far, although the 1984 situation seemed rather unexpected, it may finally be considered as a variant of the general scheme of circulation in the Algerian basin previously proposed, *i.e.* in the sense that eddies remained in place instead of drifting. This analysis consequently reinforces the original conception of a general circulation mainly driven there by mesoscale phenomena. The impact of such eddies in both the open sea and the coastal zone appears to be important. Superficial waters issued from the Liguro-Provençal basin may be swept along as far as the African coastal zone. Likewise, cool tongues lasting several months and small-scale cyclonic eddies are generated, seemingly at coastline breaks. The vertical extent and the biological consequences of the mesoscale eddies are shown to be important by the preliminary results of a multi-disciplinary experiment (Médiprod V) conducted in the Algerian basin in June 1986.

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