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The Mid-Mediterranean Jet Artefact

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[1] The Mid-Mediterranean Jet has been considered to be, since the 1990s, a more or less continuous surface current meandering across most of the eastern basin of the Mediterranean Sea, generating a series of eddies. This relatively recent view of the current, which was not found in earlier circulation diagrams and does not have any theoretical support, emerges more or less from simple statistics applied to any kind of in situ data. Here we use a relatively large set of surface drifter trajectories, which provide reasonable sampling of the area of interest, to show how mesoscale anticyclonic eddies generated elsewhere with specific diameters, locations and displacements, can provide a misleading picture by suggesting the occurrence of a mid basin jet which is actually nothing more than a data analysis artefact. **Citation:** Millot, C., and R. Gerin (2010), The Mid-Mediterranean Jet Artefact, *Geophys. Res. Lett.*, *37*, L12602, doi:10.1029/2010GL043359.

1. Introduction

[2] *Nielsen* [1912] clearly expressed what are, according to us [e.g., *Millot*, 1987; *Millot and Taupier-Letage*, 2005] also, the basic forcings of the circulation in the Mediterranean Sea: the sea is a concentration domain where the Coriolis effect forces the incoming Atlantic Water (AW) to circulate in an anticlockwise pattern. Even though *Nielsen* [1912] had a limited number of (bottle) data, the diagram he proposed is correct, albeit oversimplified with only a few arrows drawn in the eastern part of the eastern basin of the sea (all three historical diagrams discussed herein are reproduced by *Hamad et al.* [2005]). In the following decades, more data were collected here and there and from time to time with bottles and then CTDs. However, prior to the availability of satellite data, succeeding authors [e.g., *Ovchinnikov*, 1966; *Lacombe and Tchernia*, 1972] could only compute geostrophic currents from a data set that continued to remain still relatively sparse. Overall results indicated a large spreading of AW off Africa, which is correct even though actual features could not be evidenced.

[3] During the 1990s, a huge effort was made by the POEM (Physical Oceanography of the Eastern Mediterranean) group which collected a large amount of data that led the participants [e.g., *Robinson et al.*, 1991; *Malanotte-Rizzoli et al.*, 1997] to depict the occurrence of a Mid-Mediterranean Jet (known as MMJ) crossing the western part of the Ionian sub-basin and all of the Levantine one (Figures S1a and S1b in the auxiliary material), generating a series of eddies.[3] Even though such a mid basin jet emerges from simple statistics applied to any reliable in situ data set, one can note that this presupposition totally ignores the Coriolis effect, is not supported by any theoretical study and has never been described elsewhere. One can also note that these authors, who scarcely sampled close to Africa probably due to political reasons, could have imagined that AW did circulate where they did not sample, as indicated by the diagrams available to them. Finally, they could also have looked at the infrared satellite imagery that was easily available at the time, as was done for the western basin to study similar phenomena [e.g., *Millot*, 1985; *Taupier-Letage and Millot*, 1988]. In this paper, we show how simple statistics of a large set of data concentrated in a specific part of the basin can suggest the occurrence of such a jet. Because we think it is a data analysis artefact, we will call it MMJA hereafter.

[4] Starting from the premise that the major circulation features in the western and eastern basins of the sea are similar [*Millot*, 1992], the analysis of some 1000 infrared satellite images over the period 1996–2001 [*Hamad et al.*, 2005, 2006] led to the following picture. As in the western basin, AW actually circulates anticlockwise in the eastern basin, but markedly along-slope. It basically forms a basin-wide gyre (a few hundreds of metres thick) much more concentrated along-slope (a few tens of kilometres wide) than what *Nielsen* [1912], who did not have access to similar information, could have imagined. The thermal imagery also confirmed that the gyre is markedly unstable in the southern part of the basin, in particular off Libya and Egypt: its portion there, named the Libyo-Egyptian Current (LEC), generates anticyclonic eddies (the LEEs) with diameters of 100–150 km. The mesoscale LEEs first propagate downstream (i.e., eastward) while embedded in their parent current before detaching from it, probably since they get much larger vertically (several thousands metres) than the current itself and thus tend to follow deeper isobaths. As suggested by the 1996–2001 data set and schematized by *Millot and Taupier-Letage* [2005] (Figure S1c), the LEEs can then accumulate and interact in some specific places (such as Mersa-Matruh associated with the Herodotus trough) or eventually drift westward for months as in the western basin [*Puillat et al.*, 2002]. As expected and supported by data in the Algerian sub-basin, drifters are attached less to an eddy embedded in its parent current [*Salas et al.*, 2002] than to an eddy detached from it [*Salas*, 2003]. A difference between the western and the eastern basins is the occurrence in the latter of wind/Etesians-induced anticyclonic eddies such as

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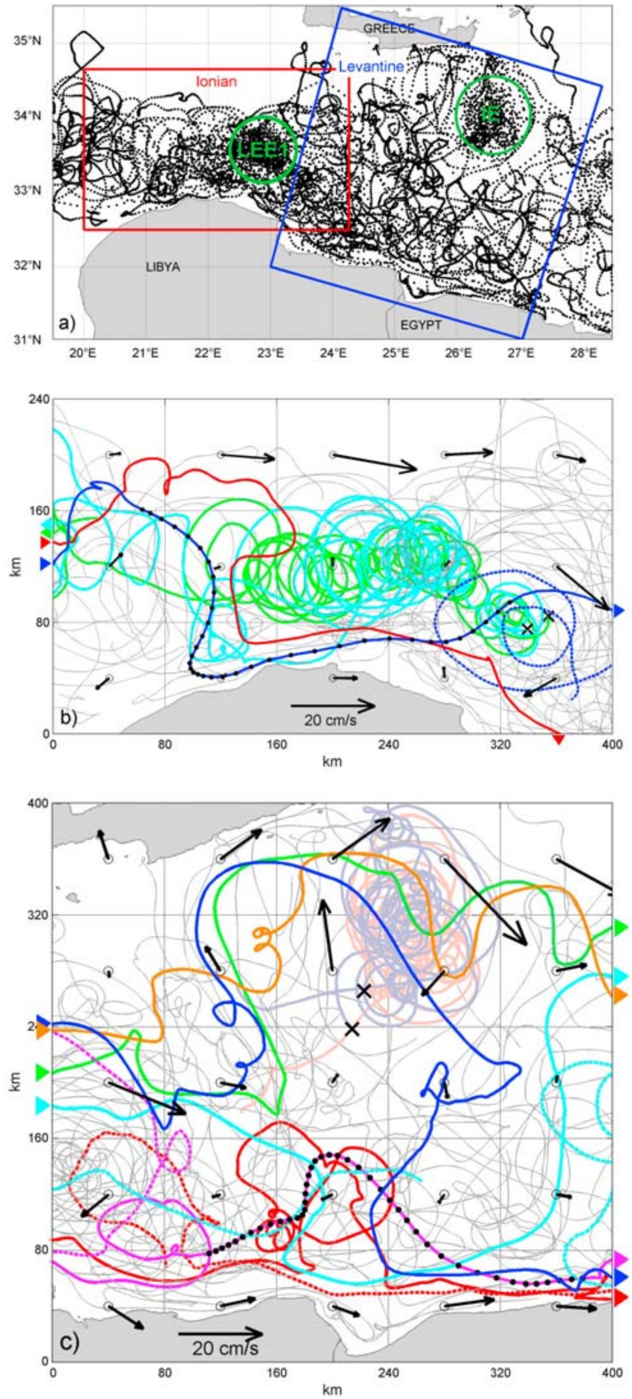

Figure 1. (a) The available trajectories in the study area, highlighting the (b) Ionian (red rectangle in Figure 1a) and (c) Levantine (blue square in Figure 1a) domains; the relatively motionless Ierapetra-05 and Ierapetra-06 (IE) eddies as well as the westward drifting LEE-1 eddy are located as in February 2006. In Figures 1b and 1c all available trajectories are in grey; the triangles specify the beginning and end of the coloured trajectories at the borders of the domains and the crosses specify launching locations in their interiors; parts of the coloured trajectories prior to or after crossing the domains are dashed; the 10-day largest eastward displacements are marked by (41) positions (black dots) plotted at 6-h intervals; the mean currents in each 80 km by 80 km box originate at the centre.

Ierapetra that have a surface signature similar to the LEEs [see *Hamad et al.* [2006] for details about appearance and trajectories).

[5] During the EGYPT-EGGITTO program [*Taupier-Letage and EGYPT-EGITTO Teams*, 2007], ~100 mini WOCE-SVP surface drifters were launched, providing trajectories analysed at the basin-scale by *Gerin et al.* [2009]. Here, we focus mainly on the MMJA, using the data only from the drogue-equipped drifters in the period spanning September 2005–July 2007. The trajectories were first edited, then low-pass filtered and finally sub-sampled (6 h). Some contextual aspects of the AW circulation are briefly illustrated with the analysis of specific trajectories, and a detailed statistical analysis of the current components has been performed with a view to throwing some light on the existence of this feature of the circulation.

2. Descriptive Analysis

[6] Winter and summer data were merged together since the MMJA is considered to be seasonally independent. Allowing for the fact that data are scarce eastwards of 30°E, the analysis is limited to the part of the eastern basin lying between Libya, Egypt and Crete (Greece). The resulting set of trajectories is shown in Figure 1a. Since the phenomena we wish to discuss roughly follow the African slope, we define two domains that extend roughly 400 km in the along-slope direction The cross-slope extensions are 240 km for the Ionian domain (Figure 1b) and 400 km for the Levantine one (Figure 1c). Therefore, 28 trajectories in the Ionian and 38 trajectories in the Levantine have been extracted, providing ~5600 and ~8000 current data, respectively; altogether some 3400 drifter*day are represented. Note that simple computations of mean currents over 80 km by 80 km boxes (Figures 1b and 1c) display a MMJA feature in most of the Ionian and in the western Levantine while it is masked in the eastern Levantine by the Ierapetra signal; note also that these computations clearly display the LEC in the Levantine. We first looked for visualisations of the most significant currents or jets, using those trajectories which have zonally crossed the whole (or nearly the whole) 400-km breadth of one of the two domains.

[7] In the Ionian (Figure 1b), the green and cyan drifters were launched on the same day at nearby locations in LEE-1 (named as in the companion papers) and remained trapped in it while it drifted westward, thus accounting for the efficiency of the drogue and the reliability of the resulting lagrangian current data. Drifters clearly had eastward velocities when they were at more than 120–150 km from the African slope (i.e., in the MMJA area) and left the domain after 6.5 (green) and 5.5 (cyan) months. The cyan drifter re-entered the domain and depicted a trajectory (shown in blue), with a 400-km crossing time of ~26 days corresponding to a mean along-slope speed of ~18 cm/s, similar to the trajectory of another drifter (shown in red), with a crossing time of ~44 days. Both drifters traced, though at different times (~9 months apart), small scale features when in the MMJA area and then an anticyclonic loop before being rapidly entrained along the African slope to the east, evidencing the LEC. Finally, note that the largest zonal displacements over 10-day intervals (~300 km) are in the LEC area.

Table 1. Number of Data, Mean, and Maximum Values of the E, W, N, and S Components in the Ionian and the Levantine Domains[a]

Parameter	E	W	N	S
		Ionian		
NoD	2994	2604	2829	2769
Mean (cm/s)	15.5	13.8	12.3	13.5
Max (cm/s)	83.2	57.6	51.0	59.3
		Levantine		
NoD	4308	3630	3821	4117
Mean (cm/s)	15.3	11.9	11.8	12.4
Max (cm/s)	84.4	80.5	79.8	85.2

[a]NoD, number of data.

[8] In the Levantine (Figure 1c), two drifters (shown in pink and pastel blue) launched on the same day at nearby locations, which described similar trajectories in and out from Ierapetra-06 and demonstrated similar lifetimes (~4 months), also account for the reliability of the current data. Several months before, when Ierapetra-06 had not replaced Ierapetra-05 yet, three trajectories meandered across the same area. The green and the orange trajectories that could represent the MMJA best had a 400-km crossing time of 33–35 days (mean along-slope speeds of 13–14 cm/s). The blue trajectory, similar to the green one in the beginning although ahead by ~2 months, veered from the north towards the south where it joined the LEC, yielding a 400-km crossing time of ~2.5 months. This trajectory was as slow as the red one whereas the cyan (33 days) and magenta (30 days) ones were the fastest (mean along-slope speeds of 14.5–15.5 cm/s). Note that two drifters entered and left the domain along the African slope while another four entered it in the MMJA area. Of these, two continued along the northward path and two joined the southern one. Here too, the largest zonal distances over 10-day intervals (~260 km) are in the LEC area.

[9] When considering both domains together, it is clear that the most rapid and direct eastward trajectories are due to the LEC, and hence confined along the African slope where the largest 10-day displacements are in the range 260–300 km (mean along-slope speeds of 30–35 cm/s). The trajectories in the MMJA area are either markedly meandering or even dominated by anticyclonic mesoscale eddies such as Ierapetra or the LEEs. Trajectories frequently shift from the MMJA area to that of the LEC.

3. Statistical Analysis

[10] We specify the characteristics of the current data in space considering the distribution, with respect to their distances from the southern and western borders of each of the two domains, of the current components in along-slope (E and W) and across-slope (N and S) directions. Note that the slope being less uniform in the Ionian than in the Levantine, computations close to the southern borders of both domains are less significant for the former than for the latter. In both domains (Table 1) the E component nearly always has the largest number of data (NoD), mean (median, not shown since providing very similar results) and maximum values. This is as it should be since the AW generally circulates eastwards but differences between E and W, as well as between E and either N or S are somewhat low. Note that a net mean along-slope speed of 2–3 cm/s for a 50–100 m thick AW layer in both domains gives transports in the order of a few tenths of Sv, which is well within the expected range.

[11] All current components are plotted in across-slope (Figure 2) and along-slope (Figure S2) directions. Their distributions are quantified by the computation of three parameters over 20-km intervals: the NoD (the thin green line), the mean (the thin blue line), and the sum (i.e., the NoD times the mean, represented by the thin red line). This last parameter is a significant piece of information provided by drifters since there can be areas where specific directions are frequently associated with relatively large speeds, which is a notion that takes into account both the NoD and the data range, i.e. not only the data mean. This parameter somehow quantifies the feeling of an experimentalist at sea who can hardly appreciate a mean current and will mainly retain the frequent occurrence of specific current directions in specific places, which could bias his/her schematisation of the circulation. Finally, we computed the net values for all three parameters (E–W and N–S, thick lines).

[12] In the Ionian (Figures 2a and 2b), the main result concerns the means of the E component (the thin blue line with plus signs as markers) that are relatively constant over the whole 240-km range, strongly suggesting that the MMJA is an artefact. To explain this, let us first consider the other 20-km averages. The NoDs are at their maximum at 130 km for both N and S, near 120–150 km for E and near 80–110 km for W, while E and W have similar NoDs (means and sums, as well) mainly near 120 km. This is clearly due to the LEEs anticyclonic eddies which are propagating westward at that distance of 120–130km (see the cyan and green trajectories in Figure 1b). The mean values display a similar slight doming (near 120 km) for N and S. They are relatively constant and a bit larger for E while they are larger in the south than in the north for W. Consequently, the net N–S component is relatively low while the net E–W component is significant and eastward mainly at distances greater than ~120 km. The simple 80 km by 80 km averages that evidence a MMJA feature in the northern part of the domain thus result more from scarce W data than from large E data. Note that the MMJA feature is emphasized by the distribution of the E–W net sum that displays a maximum at 130–150 km, much more pronounced than the slight one on the E–W net mean. Note also that the rare E data with magnitudes >60 cm/s occur not in the MMJA area (>120 km) but in the LEC one (<80 km), which is to be linked to the relatively large values of all three parameters for E at 60–80 km (as depicted by the blue and red trajectories). Finally, it must be stated that the large variations of the location of the slope with respect to the southern border of the domain prevent from getting more accurate information about the LEC.

[13] From the zonal perspective (Figures S2a and S2b), the most striking feature is the similarity between the E and W data distributions that is consistent with phenomena either flowing (the LEC) or propagating (the LEEs) in an along-slope direction. Differences between the distributions of the N and S data are simply due to an irregular propagation of the LEEs since a stationary anticyclonic eddy increases the NoD for the S (N) component at greater (smaller) distances from the western border of the domain. The evolution that frequently occurs from N to S data along-

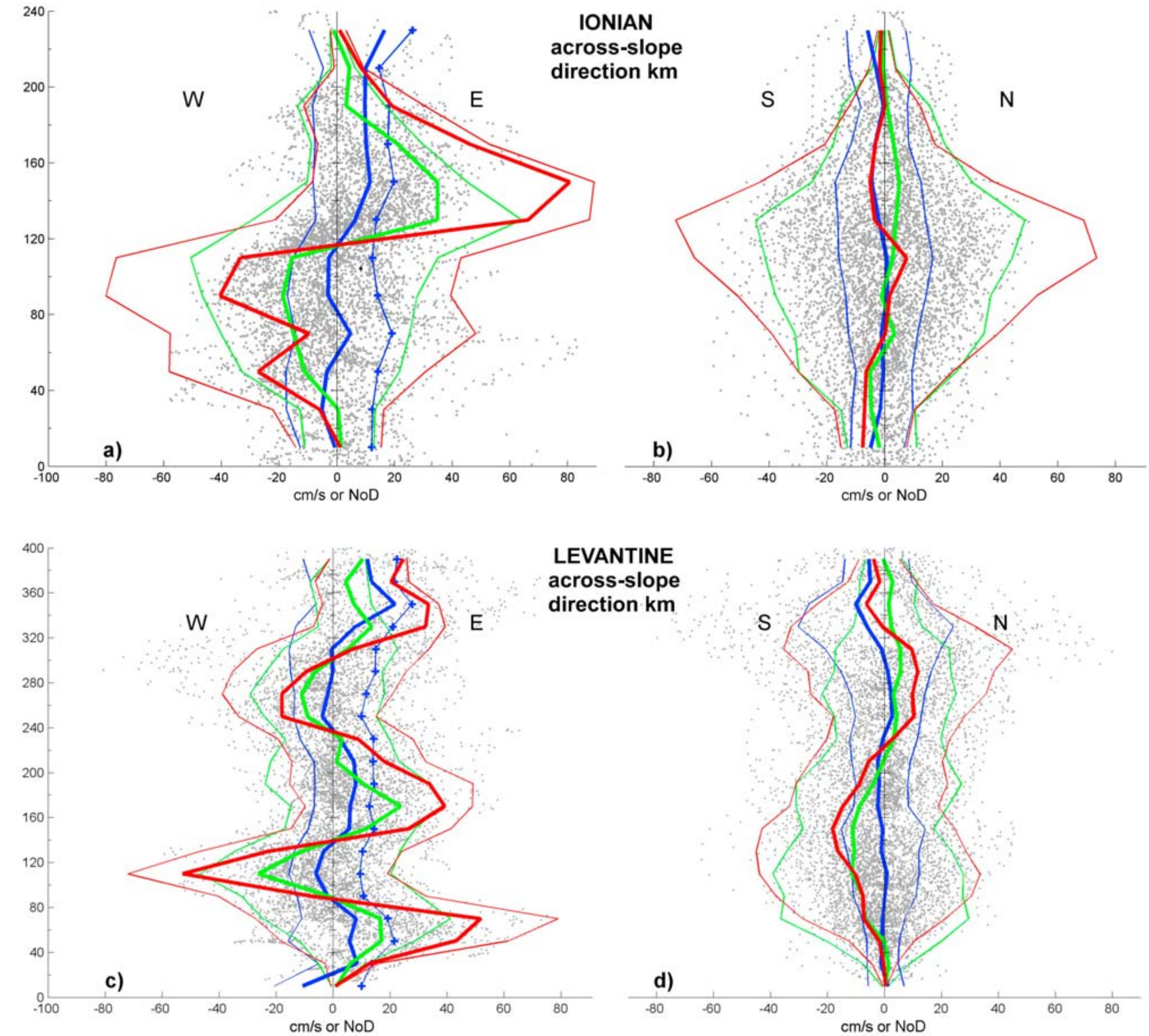

Figure 2. (a, c) E and W components and (b, d) N and S components in the Ionian an in the Levantine, respectively, plotted on the x-axis (cm/s) as a function of distance in the across-slope direction (y-axis, km). In all plots: available data are plotted as grey dots; thin lines link points representing 20-km averages of the Number of Data (NoD, green, x-axis numbers to be multiplied by 10), the mean (blue), the sum (red, x-axis numbers to be multiplied by 100); thick lines represent net E–W and N–S values.

slope (Figure S2b), as well as the one that occurs once from W to E data across-slope (near 120 km (Figure 2a)), is directly linked to the anticyclonic nature of the LEEs and to their along-slope propagation when offshore.

[14] In the Levantine too (Figures 2c and 2d), the main result concerns the means of the E component in an across-slope direction (the thin blue line with plus signs) that display two maxima (near 350 km and 50 km) associated with Ierapetra and the LEC, respectively, and relatively constant values in between (from ~300 to 100 km). Since the data themselves do not display specifically large values in the latter zone, there is definitively no reason to invoke the occurrence of even a markedly meandering mid basin jet. Even though the N–S distributions display less symmetry in the Levantine than in the Ionian, the overall situation is clearly depicted by the net E–W parameters. Indeed, in Figure 2c, all three curves cross the vertical axis at similar distances corresponding to the mean positions of the centre of Ierapetra (300 km), the limit between Ierapetra and the LEEs (240 km), the centres of the LEEs (140 km), the limit between the LEEs and the LEC (90 km) and the inner edge of the LEC (i.e. the coast/slope; 0–10 km). Ierapetra is relatively energetic and the largest component value in the whole domain is found there for S (85.2 cm/s (Table 1)), which is consistent with the eddy's forcing by northerly winds. The LEC is more clearly identified in the Levantine than in the Ionian, which is mainly due to the regularity of the slope there; indeed, computations performed at specific

distances from the southern border of the domain are more significant, leading to low parameter values for all components close to the slope.

[15] In the along-slope direction (Figures S2c and S2d), the most striking feature is the rough similarity between the E and W data distributions that evidences the almost stationary Ierapetra (mainly from the NoDs and the sums). Ierapetra and the western part of LEE-1 (the most energetic LEE) are also evinced by the distributions of the N and S data.

4. Discussion

[16] It has recently been proposed that the eastern basin of the Mediterranean Sea is characterised by a circulation feature of the Atlantic Water denominated the Mid-Mediterranean Jet (the MMJ). We explored this proposition with a relatively large number of lagrangian current measurements (~3400 drifter*day) shown to be reliable and providing an objective and efficient sampling of part of the study area where the so-called jet is presumed to exist.

[17] A descriptive analysis of the trajectories demonstrates that those corresponding to the most rapid 400-km long eastward crossings (27–30 days, mean along-slope speeds of 15–18 cm/s) or to the longest 10-day eastward displacements (260–300 km, mean along-slope speeds of 30–35 cm/s) all occur along the African slope, not in the middle part of the basin. These trajectories are associated with what we have called the Libyo-Egyptian Current [e.g., *Millot and Taupier-Letage*, 2005], which is part of the basin wide along-slope anticlockwise gyre traced by the Atlantic Water (Figure S1c).

[18] A statistical analysis of the distribution, with respect to their distances from the southern and western borders of two specific domains, of the current components in across-slope and along-slope directions, was also made. It shows that the largest velocities to the east are due to the Libyo-Egyptian Current, or to eddies such as Ierapetra, and not to some kind of mid basin jet. Furthermore, all current components are relatively large and frequent, demonstrating the importance of mesoscale anticyclonic eddies, in particular the Libyo-Egyptian Eddies induced by the instability of the Libyo-Egyptian Current. However, the east component is the largest and most frequent one, consistently with what is to be expected from a quantitative point of view for the net east-west transport.

[19] The Libyo-Egyptian Eddies have specific dimensions (diameters of 100–150 km) and propagate either eastward along the African continental slope when embedded in their parent current [see *Hamad et al.*, 2005, 2006] or westward when detached from it. Therefore, they induce velocities to the east in the middle part of the basin and velocities to the west in its southern part where these velocities tend to be opposite to those associated with the Libyo-Egyptian Current. Since the velocities to the north and to the south balance each other, simple statistical computations depict currents that are essentially zonal and correspond to features either actual (e.g. the Libyo-Egyptian Current) or fictitious.

[20] Clearly, drifters provide significant additional information about the occurrence of some circulation features as they are objectively and evenly distributed in a study area within a few days (computations not shown), contrary to ship-based or eulerian current observations. Obviously, observers can hardly appreciate mean currents and, when drawing circulation diagrams, they will tend to retain mainly the information regarding the largest and most persistent currents they encountered while at sea. Our study provides an example of the risks that are encountered.

[21] In any case, the Atlantic Water in the central part of the basin only displays eddy-like circulation features. Also, unless it is entrained from one eddy to the other (the paddle-wheel effect [e.g., *Taupier-Letage and Millot*, 1988]), hence meandering in the middle part of the basin (what can look like a MMJ), the Atlantic Water tends to reach the African slope again (due to the Coriolis effect) after describing a last anticyclonic loop. As a result, velocities to the east are significant all across the basin and mean values computed over 20-km intervals are roughly similar whatever the distance from the African slope; however, the maxima are clearly associated with both Ierapetra and the Libyo-Egyptian Current. Thus, it is clear that the Mid-Mediterranean Jet is an artefact, which led us to name it the MMJA.

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