CEOF ANALYSIS OF ERS-1 AND TOPEX/POSEIDON COMBINED ALTIMETRIC DATA IN THE REGION OF THE ALGERIAN CURRENT

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ABSTRACT

Maps of Sea Level Anomalies (SLA) relative to the annual 1993 mean sea level combine the data from the ERS-1 and TOPEX/POSEIDON (T/P) altimeters. These regular maps in space and time are used in the region of the Algerian current, where the mesoscale eddies are of primary importance to the circulation of all the Mediterranean water masses. One of these anticyclonic eddies revealed by the SLA maps is confirmed with an ERS-1/ATSR image. Complex Empirical Orthogonal Functions (CEOF) analysis is performed on the SLA data set. The first resulting two modes explain nearly 85% of the variability, with 80% of the total variance for the first one and 5% of the total variance for the second one. The temporal phase of the first mode indicates that a constant frequency of 1 cycle per year is clearly dominant corresponding to the seasonal signal. The temporal amplitude and the temporal phase of the second mode show a periodicity of about 6 months which appears associated with the variability of the Algerian current.

INTRODUCTION

In the western Mediterranean sea, the superficial eastward flow of Modified Atlantic Water (MAW) forms a well defined jet along the Algerian coast called the Algerian current which is driven by the density difference between the Atlantic and the Mediterranean surface waters [ref. 7]. The Algerian current is hence a coastal current which flows eatsward along the north African coast and drives the MAW from the Alboran basin until the channel of Sardinia and the strait of Sicily. Meanwhile, part of the MAW is lost in the Algerian basin by instabilities of the current which begins to meander at 1 or 2E [fig. 1 in ref. 8]. The meanders can then generate cyclonic and anticyclonic eddies. However, the cyclonic ones desappear rapidly while the anticyclonic ones can develop and detach from the main current [ref. 10]. Indeed, large anticyclonic eddies with diameter of 200 km have been observed in the Algerian basin during several months [ref. 11]. These huge eddies could be old stages of eddies generated by the Algerian current instabilities. They are of primary importance to the circulation of all the water masses in the western Mediterranean sea [ref. 9], due to their deep extension [ref. 3]. In the surface layer, the MAW circulation is affected by this mesoscale activity and its temporal and spatial variability is thus very large. To obtain adequate resolutions in space and time adapted to the Mediterranean scales, it was necessary to combine data from ERS-1 (with a repetition cycle of 35 days and an intertrack of about 60 km) and TOPEX/POSEIDON (T/P) (with a repetition cycle of 10 days and an intertrack of about 250 km) altimeters.

DATA SETS

The radial component of the T/P orbit is determined to within 5 cm, while ERS-1 orbits are only determined to within 15 cm. However, since T/P and ERS-1 are flying simultaneously, the more precise T/P data have been used to correct the ERS-1 orbit error [ref. 6]. After all the typical corrections, including the inverse barometer effect, the data of ERS-1 and T/P have been merged on a common period, which begins on October 1992 and ends on December 1993, by ref. 1. The lack of knowledge of the geoid impedes the use of the absolute heights of the sea level. So, they have calculated the Sea

Level Anomalies (SLA) relative to the annual mean sea level. Then, they have gridded the SLA every 10 days with a spatial resolution of 0.2° using an objective analysis. For the present study, the data in the area of 0-15ºE in longitude and 35-40ºN in latitude have been extracted, to focus on the MAW flow until its entry in the eastern Mediterranean sea. The resulting 44 regular maps in time and space also provide an excellent database to make comparisons with Sea Surface Temperature (SST) images from the Along Track Scanning Radiometer (ATSR) of ERS-1.

To allow a direct comparison between altimetric data and ATSR images, vectorial maps of surface turbulent geostrophic velocities or Geostrophic Velocity Anomalies (GVA) have been calculated, computing the SLA gradient in both directions (East and North) at each grid point. The resulting vectorial eddy-like structures are cyclonic for a SLA minimum or anticyclonic for a SLA maximum, as a consequence of the geostrophic equilibrium.

COMPARISON WITH AN ERS-1/ATSR IMAGE

Some Algerian eddy characteritics can be pointed out with the comparison of GVA maps and ATSR instantaneous images. Fig. 1 presents an example of such comparison with an ATSR image taken on 28-Oct-1992 at 22h. The SST image is first presented as is (fig. 1a), with the 1000 and 2000 m isobaths, to allow a better observation of the thermal gradients. An anticyclonic eddy of cooler superficial water is well visible just between two masses of clouds, centered at about 4.5E and 37.5N with a diameter of about 100 km. In fig. 1b, the GVA map of 27-Oct-1992 is superimposed on the SST picture. The velocities are in good agreement with the cooler temperatures on the northern edge of the eddy. The strongest GVA is 32 cm/s at 3.8E, 37.6N for the western edge and 38 cm/s at 4.8E, 37.4N for the eastern edge. Coherently, both maxima are located in the coolest vein of the eddy. These velocities are of the same order of magnitude than the ones obtained by ref. 2 from hydrology who reported 30 cm/s eastward in the northern part of a smaller coastal anticyclonic eddy of about 50 km in diameter at 4ºE. The evolution of this anticyclonic anomaly can be followed on the consecutive SLA maps. First, it moves eastward along the coast until December 1992. Then, from January to February 1993, it deviates progressively toward the center of the basin at about 6ºE and desappears.

CEOF ANALYSIS

1. Methodology

Oceanic phenomena are usually the result of the association of various parameters difficult to dissociate with the interaction of many different time and space scales. The decomposition in principal components is advantageous because it is built on modes calculated from the data themselves, hence proper to the data set and not imposed. The empirical eigenfunctions are useful in analysing large data sets. Their principal virtues are that they provide the most efficient method of compressing data (they allow to reduce the amount of data keeping only the most significative phenomena), and they may be regarded as uncorrelated modes of variability of the field. The CEOF analysis has given good results on the Gulf Stream [ref. 12] and in the Alboran basin [ref. 13].

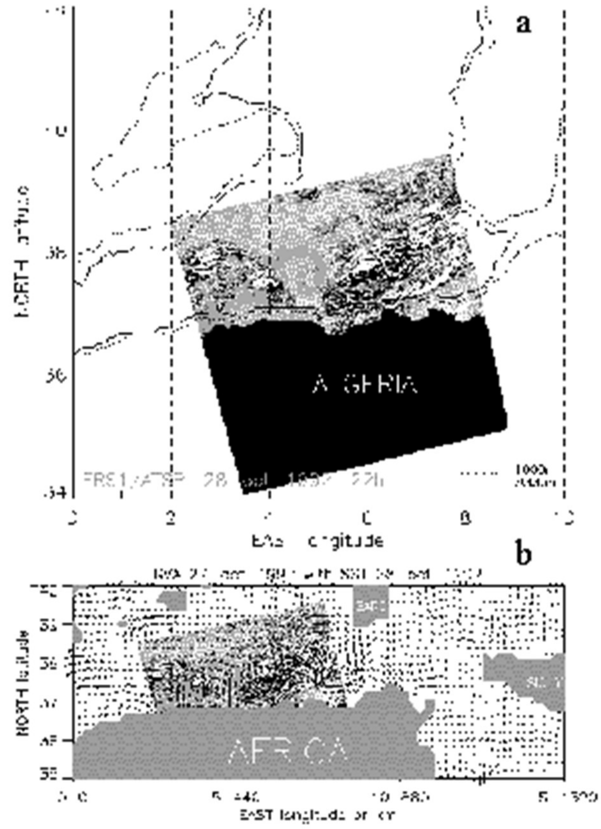

Fig 1 : (a) ERS-1/ATSR/SST image of 28-oct-1992 (b) with altimetric Geostrophic Velocity Anomalies of 27-oct-1992.

Complex time series are formed from the original time series and their Hilbert transforms. The real part of is simply the value of the residual sea level while the imaginary part is the Hilbert transform of the original data field where the amplitude remains unchanged but where the phase is shifted by /2. Mathematically, the rest of the procedure is similar to real EOF analysis except that the statistics are performed on the complex time series.

Since the covariance matrix is hermitian, it possesses real eigenvalues which give the variance associated with each mode. Unlike real EOF where the modes represent standing wave patterns, CEOF can resolve propagating waves [ref. 4]. The decision to apply CEOF instead of real EOF is appropriate because of the wave propagation associated with the instabilities of the Algerian current.

2. Results

The spatially correlated signal in the study area was found to be dominated by the first two CEOF. These first two modes explain nearly 85% of the variability, with 80% of the total variance contained in the first one and 5% of the total variance in the second one. The temporal phase of the first mode (fig. 2b) indicates a constant frequency of one cycle per year corresponding to the seasonal variability. The strongest

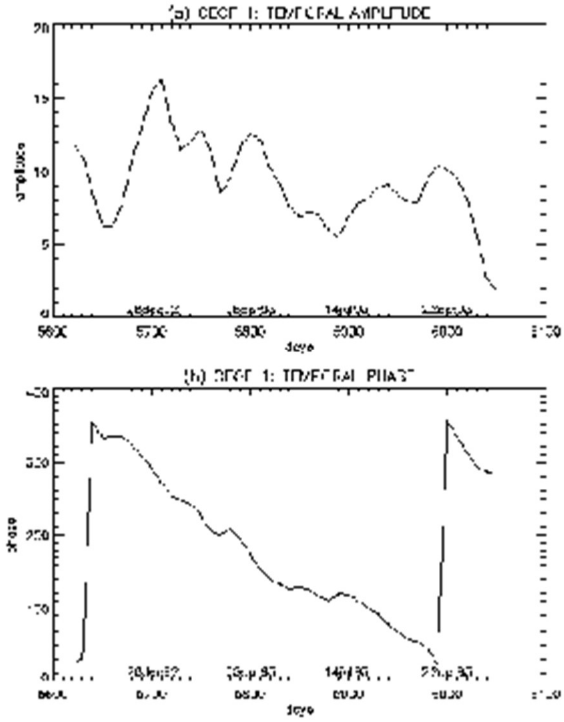

Fig 2 : CEOF 1 (a) Temporal amplitude (normalized units). (b) Temporal phase (degrees).

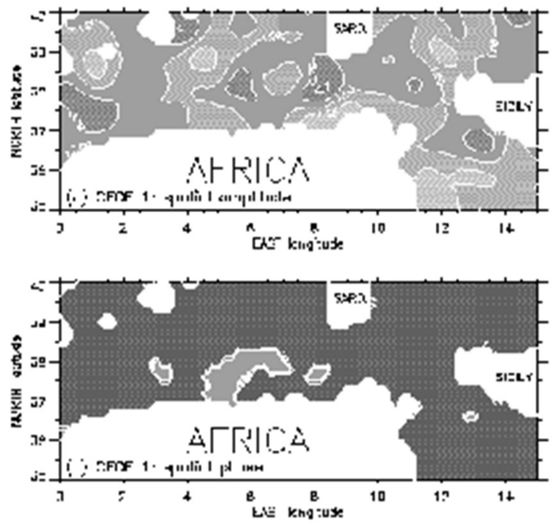

Fig 3 : CEOF 1 (a) Spatial amplitude (normalized units, c.i. of 0.25). (b) Spatial amplitude (degrees, c.i. of 90)

signal is observed in the southern part of the channel of Sardinia, south of the strait of Sicily near the Tunisian coast, at the entrance of the Tyrrhenian sea and south-east of Mallorca (fig. 3a). The spatial phase (fig. 3b) is homogeneous, indicating a stationary seasonal oscillation in all the study area. The maximum normalized amplitude is obtained at the beginning of January 1993 while the minima are observed in November 1992 and July and December 1993 (fig. 2a).

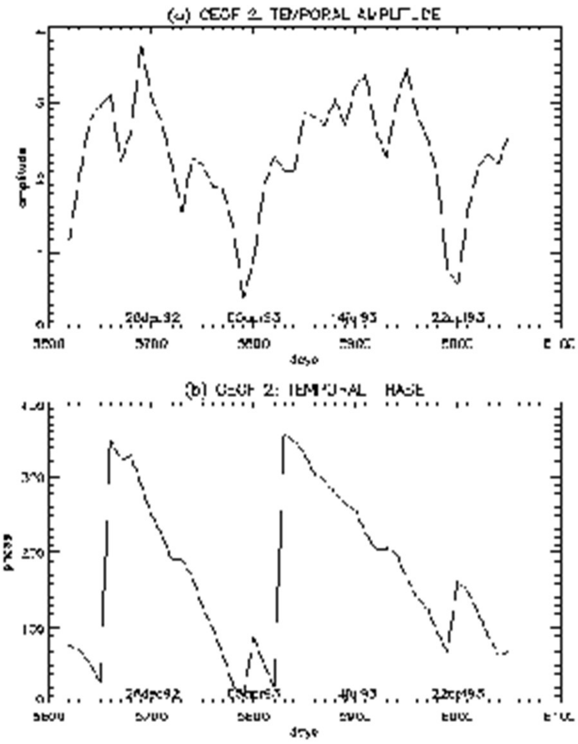

Fig 4 : CEOF 2 (a) Temporal amplitude (normalized units). (b) Temporal phase (degrees).

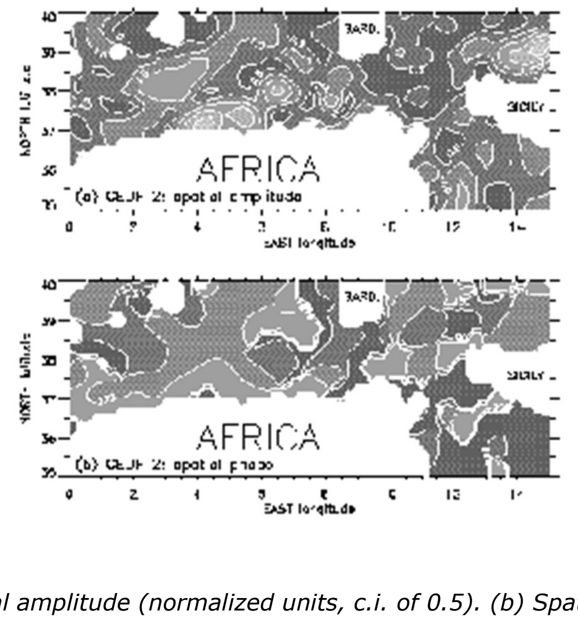

Fig 5 : CEOF 2 (a) Spatial amplitude (normalized units, c.i. of 0.5). (b) Spatial phase (degrees, c.i. of 90).

According to ref. 5, who analyzed T/P data in the whole Mediterranean sea and characterized changes in the mean level, roughly half of the seasonal signal is related to the steric effect of contraction and dilatation of the surface waters due to the heat exchanges at the ocean-atmosphere interface. The other half could bedue to a slight seasonal imbalance between inflow and outflow at the straits of Gibraltar and Sicily and evaporation and precipitation.

The temporal normalized amplitude (fig. 4a) and the temporal phase (fig. 4b) of the second mode show a periodicity of about 6 months which appears associated with the variability of the Algerian current, as the phase isolines are parallel to the mean path all along the Algerian coast until the channel of Sardinia (fig. 5b). The strongest amplitude of the second mode is located near the African coast between 4°E and 6°E and north of Sicily (fig. 5a). The phase isolines all along the coast (fig. 5b) show a deviation off-shore at 4E that corresponds to a maximum in amplitude. From this point, the spatial phase decreases north-eastward. In the western channel of Sardinia (8-9ºE), the amplitude presents a secondary maximum and the spatial phase decreases from south to north.

The highest values of the real spatial amplitudes (cm) of the second mode are located at 4ºE near the coast and at 8-9ºE in the southern part of the channel. Looking at the amplitude maps of this mode like a movie, both areas of maximum variability evoke wave propagation eastward and northward, since positive and negative anomalies alternate, with wavelengths of 14030 km and phase velocity of about 1 or 2 km/day

CONCLUSIONS

Both CEOF modes are associated to two very different physical phenomena which are the steric effect and the mesoscale variability.

The path of the Algerian current in the southern channel of Sardinia could be strongly affected by the seasonal variability as the first CEOF amplitude is important in this area with the maximum seasonal mean value obtained in autumn. This can be related to the seasonal variability of MAW flux observed in the strait of Sicily by the fact that these positive SLA could be linked to the MAW circulation around the cape of the Tunisian coast and its direct path toward the strait of Sicily. However, the 14 months of altimetric data used in this study are a too short period to get any solid conclusion on the seasonal variability.

The second CEOF reveals two points of higher variability along the Algerian current path. In the western part of the channel, the decreasing phase from south to north could correspond to the propagation of eddies. This is in agreement with the hypothesis that some anticyclonic eddies could detach from the African coast, at the entrance of the channel, as events of about 3 months. In the same way, such detachments could occur at about 4-5ºE. The amplitude and phase isolines let suppose a north-east propagation of the eddies. This is supported by the anticyclonic eddy observed at the end of October 1992 visible in fig. 1. After visual comparison between the CEOF 2 anomaly shapes and some contemporaneous infrared images from ERS-1/ATSR, the positive anomalies often correspond to anticyclonic eddies while the negative anomalies do not seem associated with cyclonic eddies, in spite of their equal amplitudes in SLA.

The 6 month periodicity of the mesoscale activity do not appear in the previous studies of the Algerian current with in-situ and infrared observations. Anticyclonic eddies have been detected in spring, summer and autumn [ref. 11], and during more than 6 months for the largest ones [ref. 9]. The frequent cloudy conditions of winter impede the infrared information during this season. It is therefore impossible to confirm this periodicity revealed by the second mode of the CEOF analysis, whereas the propagation characteritics fit quite well with the reality. In the future, it would be necessary to detect these eddies on a longer time period with the same nearly continuous synoptic view to ascertain wether or not the mesoscale variability is subject to a semiannual cycle. This will be possible using the combined altimetric data of T/P and ERS-2.

An extended version of this contribution has been submitted to the ERS-1 special issue of the Journal of Geophysical Research.

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