STUDY OF MESOSCALE FEATURES AND SEASONAL VARIABILITY IN THE CANARY BASIN FROM GEOSAT, ERS-1 AND TOPEX/POSEIDON ALTIMETERS DATA

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SUMMARY

Three series of altimeter data of the GEOSAT (1987-1989), ERS-1(1992-1993) and TOPEX/Poseidon satellites are used to identify and analyze the main mesoscale oceanographic features that appears in the oriental edge of the Atlantic Ocean, 20^{o}-40^{o} N, -19^{o}- -9^{o} W. The variability maps of the altitude of the sea surface and eddy kinetic energy have been computed by a process of objective analysis. Although the flow in this area is not so intensive as in the west frontier, like the Gulf Stream, it has been possible to compare the altimeter results with those from other remote sensing sensors and with in situ data. It has been estimated the correlation among the different types of data to detect eddies from the Mediterranean Sea and those generated in the south of Gran Canaria, as well as the identification of filaments from the NW African upwelling.

1. INTRODUCTION

The geographical situation of the area that we are studying, 20^{o}-40^{o} N - -19^{o}-9^{o} W, (fig. 1) situated between the continental platform and the open ocean has different nature that generate oceanographic features as: the presence of the Canary Current that flows to the Equator through the Canary Archipelago; the coastal upwelling of the northwest of Africa is intensified during the summer and the mesoscale eddies from the Mediterranean.

The Canary Islands work too as barriers to the continuous atmospheric and oceanic flows, modifying the velocity of the water mass and the wind field to leeward of the islands.

The main objective of this study is, first at all to see if it is possible to detect mesoscale ocean features in weak ocean currents by means of GEOSAT (1987-1988), ERS-1 (1992-1993) and TOPEX/Poseidon (1993) altimeters and secondly the achievement of the study of the seasonal, semiannual and annual variability of the sea surface altitude in the different periods. So we analyze the residual height and the geostrophic speed variance obtained from the altimeter data.

2. OCEANOGRAPHIC FEATURES OF CANARY BASIN

The general circulation in Canary Basin makes an anticyclonic gyre connected to the Gulf Stream through the Azores Current. This system is situated in the eastern edge of the subtropical north Atlantic and is defined by the Azores Current, the Canary Current and the North Equatorial Current (fig. 2). The Canary Current is a weak and cold stream that flows to the south going along the edge of the African Coast and through the Canary Archipelago.

By the way through this area generate to leeward of Gran Canaria Island some anticyclonic and cyclonic eddies with a great physical and biological interest (Aristegui et al., 1994).

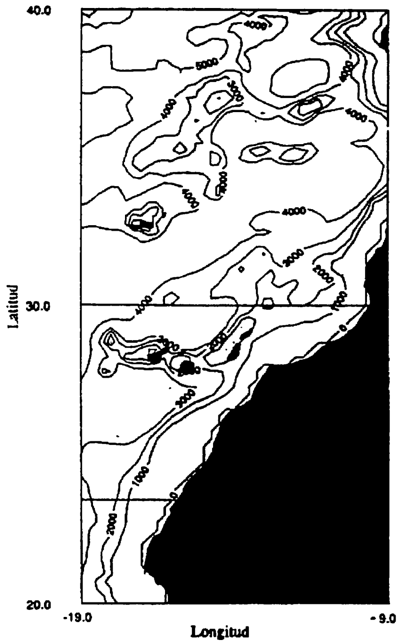

Figure 1. Study area.

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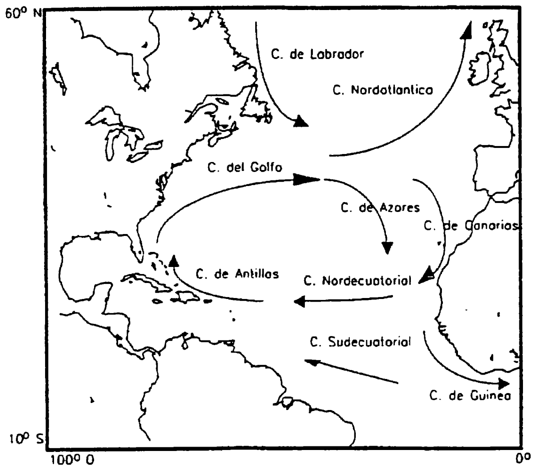


Figure 2. North Atlantic currents system.

Another features of the water that surrounds Canary Island are the wakes of warm waters that have been observed to leeward of islands of the archipelago with a high relief. That is just because of the obstacle that represents these natural elements to the field of the representative winds of this area (trade winds - NE direction). That produce a decrease of the intensity of themselves in the southeast of the Islands and a warming of the sea surface in these areas.

The wakes have been detected by means of sea surface temperature (SST) images of the sensor Advanced Very High Resolution Radiometer (AVHRR) (Hernández Guerra, 1990) as well as with in situ measurements (Aristegui et al., 1994).

In other way one of the representative oceanographic appearance in the coastal eastern edge is the presence of upwelling areas of cold and deep water masses, rich in nutrient and near to the coast, that makes that these areas have a great biological productivity. This is the case of the NW upwelling of the African Coast. Some authors have analyzed the regional and seasonal variability in relation to the wind field variations and they have characterized the upwelling in different areas, paying special attention to the area between 20° and 30° N where the maximums are appeared during the spring, the summer and the autumn (Mittelstaed, 1991).

Due to the proximity of the Canary Archipelago to the African Coast and thanks to the SST images of this area it can have been observed spreading of the upwelling noted as filaments advanced to the ocean around some kilometers, and sometimes they can reach the south of the more eastern islands of the archipelago.

3. DATA PROCESSING AND METHODOLOGY

In this study some data sets have been used from the altimeters installed in the satellites: GEOSAT, with a repetition period of 17 days (1987-1988), ERS-1 with a period of 35 days (May 1992-April 1993) and TOPEX/ Poseidon with 10 days of orbital repetition (1993).

Different corrections are applied to the data due to the errors originated by different sources, and they can be included in three groups:

Instrumental, atmospheric errors and the ones due to the interaction of the altimeter pulse with the air-sea interface. On the other hand, the first ones can be eliminated by the imposition of some requirements to the data during the analysis, that are specified in Table 1. In this case a data is refused when its value is out of the range previously specified.

Symbol	Name	Criterion
H	Sea level height	H ≥327.67 m
σ_h	Standard deviation of H	$\sigma_h \geq 0.12$ m
σ^o	Backscattering coefficient	$\sigma^o \geq 20$ db
σ_{AGC}	Antenna automatic control	$\sigma_{AGC} \geq 0.1$ db

Table 1. Parameters definition and data analysis criterion.

With regard to the second and third ones are eliminated using the corrections included or derived in the Geophysical Data Records (GDR) specified in the table 2.

Satellite	Correction	Method
GEOSAT	Dry Troposphere	ECMWF - GDR
	Wet Troposphere	TOVS/SMMI - GDR
	Ionosphere	GDR
	Tides	Cartwright & Ray (1990)
	Em. Bias	2.5% H
	Inv. Barometer	GDR
ERS-1	Dry Troposphere	ECMWF - GDR
	Wet Troposphere	TOVS/SMMI - GDR
	Ionosphere	GDR
	Tides	Cartwright & Ray (1990)
	Em. Bias	2.5% H
	Inv. Barometer	GDR
TOPEX/POSEIDON	Dry Troposphere	ECMWF - GDR
	Wet Troposphere	TOVS/SMMI - GDR
	Ionosphere	GDR
	Tides	Cartwright & Ray (1990)
	Em. Bias	2.5% H
	Inv. Barometer	GDR

Table 2. Geophysical corrections applied to the sea surface height for different satellites.

The effects about the pulse of the altimeter that have the components of the dry and wet troposphere are calculated one by one. To the correction due to the first ones a model proposed by the European Center for Medium- range Weather Forecasting (ECMWF) is generally applied, but to the second ones havé been used the climatological values averaged monthly obtained by the sensor Scanner Multichanel Microwave Radiometer (SMMR) on board of Nimbus-7 satellite, or with the TOPEX Microwave Radiometer (TMR). The ionospheric correction, which tries to compensate the delay of the signal produced by the free electrons, is made using Klobuchar's model (1987) or the Dual-frequency Doppler tracking receiver system (DORIS).

To eliminate the effect of the tides in the signal it has been used Cartwright and Ray's model (1990) instead of Schwiderski's (1980) because it has been shown that it doesn't work properly in the areas of the continental platform (Thomas y Woodworth,, 1990) and it is less precise too.

As a consequence of the interaction of the pulse with the sea surface it appears one extra mistake knowing as bias due to the sea state or electromagnetic bias. The waves in the ocean usually have narrow summits and wide valleys that make that the reflection of the altimeter pulses from the valleys are more intensive and dominant than those from the summits. So the theoretic measurement of the sea level will be little than the real one. Related to this phenomenon is the bias due to the assumption that the probability distribution of the scattering is symmetric, it means that we are considering the ocean processes as Gaussians. Even thought this interaction is not well studied, it is suggested that this error is eliminated adding the 2,5% of the significant wave height to the height value (Cheney et al., 1991).

To conclude, Ray et al., (1991) have shown that including the effect of the inverse barometer it is reduced the variation of the global standard deviation of the residual height over the ocean although this phenomenon isn't well studied and some oceanographers prefer don't apply it.

In this way the height of the sea surface as result of the application of the different adjustments it would be the following one:

H (corr) = H - tides - ionospheric correction - tropospheric correction - correction of inverse barometer + 0,0025 * Hs

where H is the height of the sea surface measured by the altimeter.

Subsequently the data of the sea height are interpolated to a net of geographic points separated 7.4 Km (0.06^{o} of latitude) approximately, along the trajectory.

Despite having removed the main error sources described before, there is still in the signal the influence due to the geoid and to the average sea surface, as well as the orbital error.

The first can be eliminated applying the method of the differences along the trajectory (Chelton et al., 1990), (Tokmakian and Challenor, 1993), it is very effective also when there are gaps in the data. This method instead of working with the height of the sea surface works with the mean of the slopes of the sea surface along the trajectory.

With the purpose of eliminating the second one we apply the lineal method tilt / bias because it is just to the arcs sizes lower than 3.000 Km (our case) it has been demonstrated that this method is more effective than other ones that use more sophisticated fittings of higher polynomial degrees or sin/cos. Zlotnicki et al., (1989) and Tai (1991), among others, discuss the effects about the variability of the sea surface has the application of the different orbital error elimination techniques to the arcs of different longitude.

With the purpose of getting an estimation of the variability of the sea surface two oceanographic parameters are calculated starting from the residual height obtained from the previous steps: standard deviation of the height and the variance of the eddy speed (known as Eddy Kinetic Energy) (EKE) . The last one it is evaluated using Menard's technique (1983).

Finally it is applied the method of the successive corrections (MCS) to the data of eddy speed in order to present them in maps every 15 days and 0.5 degrees. In this way on the one hand it can be identified mesoscale features and in the other hand to estimate quantitative and qualitatively semiannual and annual seasonal variations of the sea surface relative topography and of EKE in the studied area.

4. RESULTS ANALYSIS

The study of the GEOSAT data, ERS-1 and TOPEX/Poseidon have been divided in two sections: the first one it is identified and examined the mesoscale features as upwelling's filaments in the northwest coast of Africa from the satellite GEOSAT data, eddies from the Mediterranean Sea and the generated in the south of Gran Canaria Island. In the second one it is established an analysis of the seasonal variability of the signal during 1987-1988, and 1993 with GEOSAT and ERS-1 satellites, respectively.

4.1. Detection of mesoscale features

In this section it is examined first at all, the mesoscale features in the study area, as for example filaments from the upwelling of the northwest of the African Coast, from GEOSAT Satellite data and cyclonic and anticyclonic eddies generated to leeward of Gran Canaria Island by the use of ERS-1 satellite.

In the second place it is analyzed the viability of the use the TOPEX/Poseidon altimeter to the study area due to the distance among the satellite trajectories in this area.

Some studies made in this area by SST images (García Weil et al., 1994) have shown sometimes filaments from the NW African upwelling (fig. 3).

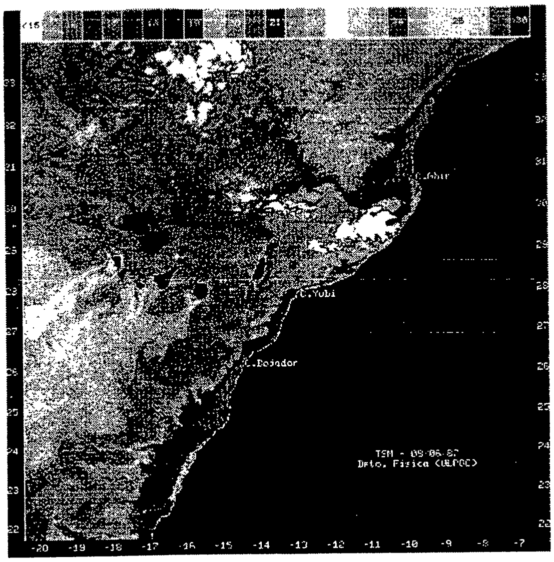


Figure 3. Sea surface temperature image in Spring 1987 (08/JUN/87)

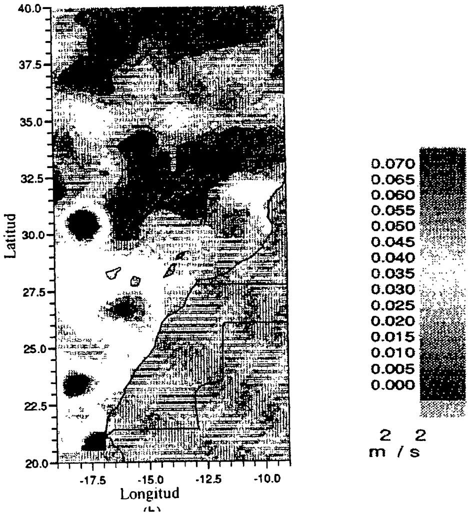


Figure 5. Eddy kinetic energy in Summer 1992 with ERS-1 data.

The variability of the sea surface level observed during spring 1987 with GEOSAT data (fig. 4) in cape Ghir and in the south of capes Yubi and Bojador make the presence of two filaments flowing west to the open ocean, the one in Cape Ghir being stronger (0.040 m) than the other at Cape Bojador. These features can be identified too at the same time with sea surface temperature maps.

Through the oceanographic cruises made in the south of Canary Archipelago on different times and using different instruments to make in situ measurements (CTD, AXBT, fluorometer) (Aristegui et al., 1994) as well as chlorophyll images from Coastal Zone Color Scanner (CZCS) and SST, it can be detected some eddies when the flow of the Canary Current is disrupted as it pass the channel between Gran Canaria and Tenerife Islands (Sangrá, P., 1995).

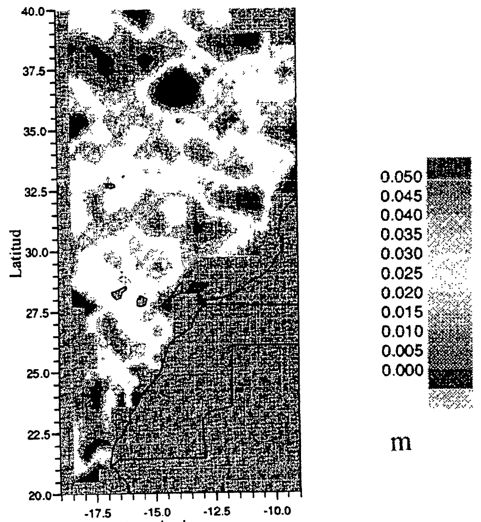


Figure 4. Variability sea surface height in Spring 1987 with GEOSAT data.

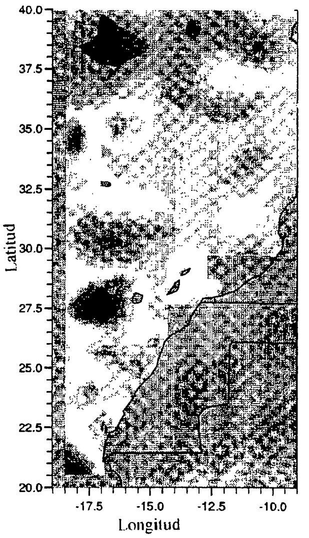
The EKE map of the summer 1992 (July) (fig. 5) shows a nucleus with energy value of 0,040 m^2s^{-2} in the southwest of Gran Canaria Island. At the same dates but through SST it is detected a cyclonic eddy in the same area of the altimeter signal that identified it. That is the reason why it could be associated with the oceanographic feature already mentioned.

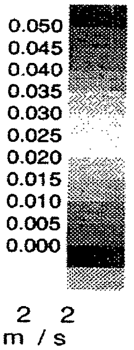
As it happened in the summer 1992, the following summer a nucleus with maximum EKE appears again at the southwest of Tenerife island with values that exceed 0.050 $m^2 s^{-2}$ for the ERS-1 (fig. 6) and 0.040 $m^2 s^{-2}$ for TOPEX (fig. 7). In both cases it is estimated that the south area of Hierro, Tenerife and Gran Canaria Islands are the most energetics one.

In order to estimate the variations of EKE during the year 1993 there have been used data of the altimeters on board of ERS-1 and TOPEX/Poseidon Satellites. In general the results through the TOPEX show less energetic variability that the ones from ERS-1. It is due to the gap of the satellite trajectories in relation to the extension of the studied area, that is the reason why the final results appear more smoothed. Even so, the regions that present the maximum values of energies are exposed when we use both types of data, with higher esteems in the case of ERS-1, as it might be expected.

4.2. Sea surface variability study during 1987-1988 with GEOSAT satellite

Next the variability of the sea surface observed during 1987 and 1988 will be analyzed with the altimeter on board





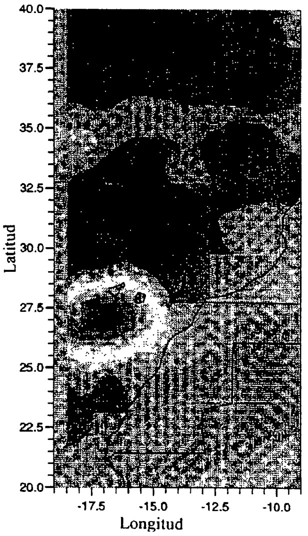


Figure 6. Eddy kinetic energy in Summer 1993 with ERS-1 data.

Figure 7. Eddy kinetic energy in Summer 1993 with TOPEX/POSEIDON data.

of GEOSAT satellite, paying special attention to the oceanographic features as eddies coming from the Mediterranean Sea and filaments developed from the NW African upwelling.

Winter

During the winter there are in the two years three nucleus of great variability situated in a stripe that goes from 33.0°-37.0° N and -16.0°-10.5° O of the studied area, being the ones from 1987 more intensive (0.040 m) than the ones from the following year. The results obtained in 1988 seem to be in concordance with the ones from Stammer et al., (1991). These ones made a study with hidrographic (March 1998) and altimeter data (GEOSAT 1987-1988) and they identified, through the anomaly maps of the sea surface, a serie of cyclonic and anticyclonic eddies from the Mediterranean Sea with both series of data, finding great correlation among the results obtained with the altimeter and with the hidrographic measurements.

On the other hand, around the Canary Archipelago are established differences referring to the locations in which are found the maximum variabilities. This way, at the northeast of the most oriental island of the Archipelago, Lanzarote, it is shown in 1987 a structure in a lenticular way that could proceed from the African Coast, while at the next year the values of variability of the sea surface relatively high are registered near the Islands of Tenerife and Gran Canaria. In the same way, it is evident that in the north area of the region the variability is maximum during the winter in 1987, and minimum around the Archipelago, while in 1988 happens the opposite.

Spring

Spring during two years is distincted by the attendance again of nucleus situated in the north area, which appears on winter time located eastwards that spread the maximum variability, going from 0.050 m in 1987 to 0.035 m in 1988. In the same way while during this last year it is shown at the south of the Tenerife Island the maximum value (0.050 m) in this period, in 1987 features near the African Coast are observed with values around 0.030 m. The ones situated at the height of Cape Ghir (30° N-10.5° O) and the one situated among 23.5° and 27.0° N and -16.0° and 14° O are pointed out.

In this same area and at the same time with anomaly maps of the height of the sea surface obtained with the altimeter, analogous features to the observed ones in the temperature maps have been identified.

Summer

In the summer time of 1987 the nucleus of maximum variability of the sea surface topography observed in winter as well as in spring, it also appears at the north of this area and displaced towards the southwest and its presence the following year although being less intense, it is registered.

In the other hand, at the west of La Palma Island and at the south of Tenerife Island it is shown another extreme value in the topography variation of the sea surface (> 0.050 m) in 1987, meanwhile in 1988, and though being shown a decrease in energy around the Archipelago in relation to the previous year it is found certain variability (0.030 m) as features shapes which seems originated in Cape Yubi (27.0° N) and Cape Bojador (26.0° N) and again it could be associated to filaments from the upwelling which has been already mentioned.

Autumn

In this season there are pointed out in 1987 variabilities of the sea surface between Gran Canaria and Fuerteventura

Islands (superior to 0.050 m). In 1988 the maximum variability is observed at two consecutive nucleus at the north of the region and another one at the south of the Tenerife Island (0.045 m). As a difference with previous seasons, the filaments are not observed in this period.

5. CONCLUSIONS

In this study the variability of the height of the sea surface and the Eddy Kynetic Energy (EKE) in the region located between 20.0°-40.0° N and -19.0° -9.0° W has been studied, through the data of the altimeters on board GEOSAT, ERS-1 and TOPEX/Poseidon satellites. It has been demostrated that the results obtained through this sensor can be useful for the detection and temporal analysis of the oceanographic features present in oceanic regions which variability is not very intense.

Filaments from the NW African upwelling and mesoscale eddies originated in the Mediterranean Sea and generated at the south of the Gran Canaria Island by the disruption of the Canary flow as its pass between Tenerife and Gran Canaria Island they can be identified. The same way the identification of these structures using other remote sensing techniques as SST and chlorophyll pigment concentration images and in situ data have been contrasted.

With GEOSAT satellite it has been observed that the filaments of upwelling are detected in the spring and summer seasons mainly, periods in which favorable conditions are given to the upwelling intensification and so the development of filaments of cold water directed towards the open ocean. It is also in this period in which the maximum values of variability of the sea surface at the south of the Tenerife and Gran Canaria Islands are found.

On the other hand, it has been seen that the variability of the signal in the north zone of the area it is presented in an annual way (GEOSAT 1987, 1988), so we could affirm that the Mediterranean eddies are features which are shown during the whole year, with a greater intensity in the spring and summer, besides being superior in 1987 than in 1988, and which displace to the southwest in the course of time.

To conclude for the same period of time there have been analyzed the values of eddy kinetic energy obtained by the ERS-1 and TOPEX/Poseidon (1993) altimeters disclosing that for the study of this area is more appropiate the use of ERS-1 data even though its precision is lower, its greater spatial coverage allows the detection of the mesoscale features present in the studied region.

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