# Evaluation of ERS-1 microwave sensors capability in the study of oceanic fronts

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## RESUMEN

Un proyecto español, seleccionado por el primer ERS-1 Announcement of Opportunity de la ESA, ha estado desde 1991 hasta 1995 investigando la viabilidad del uso de los sensores de microondas del satélite ERS-1 en el estudio de frentes oceánicos en el Mediterráneo occidental. En esta cuenca marina los frentes de densidad son debidos mayoritariamente a gradientes de salinidad, con lo cual no siempre las imágenes infrarrojas son eficientes en identificar estructuras superficiales ligadas la circulación Además el Mediterráneo presenta a menudo una importante variabilidad de mesoescala (decenas de kilómetros) que puede dar lugar a fenómenos más intensos que las corrientes medias. El SAR del ERS-1 ha demostrado ser un sensor muy eficiente en identificar este tipo de fenómenos bajo ciertas condiciones meteorológicas. Tiene, el inconveniente de la dependencia de su capacidad de detección con la intensidad del viento local, y de cubrir una zona demasiado estrecha (100 km.). No existe de momento un método que permita discriminar automáticamente las señales debidas a la dinámica marina de otros fenómenos capaces también de modular la rugosidad de la superficie del mar. El altímetro del ERS-1 es útil para extraer información coherente sobra la evolución temporal de la circulación regional y de mesoescala en una zona de señales superficiales intensas como es el mar de Alborán. Se ha elaborado un sistema para corrección y análisis de datos altimétricos en entorno PC. Se han desarrollado diversas herramientas para el análisis de imágenes SAR de bajo nivel, incluyendo un microprocesador basado en el Chirp Scaling Algorithm. Se ha desarrollado también un método para la geocodificación precisa de imágenes SAR para aplicaciones cartográficas.

**PALABRAS CLAVE:** ERS-1, SAR, altímetro, Mediterráneo occidental, dinámica de mesoescala

## ABSTRACT

A Spanish project, approved by ESA under the first ERS-1 Announcement of Opportunity, has been investigating the feasibility of using ERS- 1 microwave sensors in the study of oceanic fronts in the western Mediterranean. In this basin density fronts are mainly due to salinity gradients, so not always satellite infrared imagery is an efficient tool to identify surface structures related to circulation. In addition, it usually presents an important mesoscale variability (order of tenths of kilometres) that can give rise to phenomena more intense than mean currents. ERS-1 SAR has demonstrated to be an efficient sensor in identifying this kind of phenomena under certain meteorological conditions. However, its detection capability depends on local wind speed and it has a too narrow swath (100 km). By now there are no methods to automatically discriminate between signatures of marine dynamics and other phenomena also able to modulate sea surface roughness. ERS-1 altimeter is useful to extract coherent information on the temporal evolution of regional and mesoscale circulation, in an area of strong sea level variability like the Alboran sea. A software package has been implemented for altimetric data correction and analysis in a PC environment. Several low level SAR imagery processing tools have been developed, that include a processor based on the Chirp Scaling Algorithm. A method for precise geocodification of SAR images for cartographic applications has also been developed.

**KEY WORDS:** ERS-1, SA.R, altimeter, western Mediterranean, mesoscale dynamics

## INTRODUCCIÓN

During the eighties satellite remote sensing became a very common tool for oceanographic research. AVHRR infrared and CZCS sea colour imagery were widespread used for open ocean and regional studies, as well as Landsat MSS and TM, and SPOT for coastal areas. The different penetrations associated to the wavelengths of these passive sensors, and their capability to image different marine phenomena, were adapted to fulfil a considerable range of experimental requirements. To track the characteristics of different water masses and of their particulate matter content, has been very useful to understand the dynamics of the ocean surface layer. However, cloud coyer was a limiting factor to all these radiometers.

In 1978 Seasat, a satellite equipped with active microwave sensors to observe the ocean, was operative for three months. Radars proved to be able to monitor open ocean conditions (surface winds, significant wave heights, geoid, large geostrophic currents) and to reveal many kinds of phenomena in regional and coastal seas (internal waves, frontal structures, slicks, shallow water bathymetry). Not only radars can operate in spite of any cloud cover or sunlight conditions, but they can detect or image sea surface phenomena not related to visible or infrared signals. Capillary or short gravity waves generated by the wind on the sea surface are imaged by a radar due to Bragg backscatter. Ocean phenomena interact with these waves and produce modulations of the sea surface roughness that can he imaged or measured in different ways.

In 1986 the European Space Agency issued the ERS-1 Announcement of Opportunity for proposals on scientific applications of the future ERS-1 satellite in the domain of oceanography and related fields. One of the accepted research projects was "Evaluation of ERS-1 microwave sensors capability in the study of oceanic fronts", submitted by a group of Spanish and British institutions leaded by the Institute of Marine Sciences (ICM-CSIC) from Barcelona. The scientific objective was focused on the use of ERS-1 radars to study the dynamics of surface density fronts in the Mediterranean region. In this region the general circulation is strongly affected by rnesoscale phenomena, and these structures are there of such a size (order of tens of kilometres) that can be easily detected and resolved by ERS-1 SA-R. The spacing between ground tracks (some 60 km at this latitude during the 35-d repeat cycle) and the general weakness of Mediterranean currents posed a challenge to the use of ERS-1 altimeter, but the availability of repeated data gave a clear possibility to analyse long-period temporal variability. In addition, the short distance from the investigated areas to the location of research institutions was an advantage to organise in situ experiments to compare classical oceanographic information with satellite data. The project aimed at integrating the experience on western Mediterranean offered by the Spanish partners, with the experience of the British partners in using Seasat SAR and altimeter in frontal studies. For the non-oceanographers Spanish scientists the aim was to acquire experience on satellite microwave data processing and interpretation by the contact with the UK colleagues.

This paper is a summary of the main results obtained by the end of the project in 1995, and gives a list of all the publications it has generated. Near 50 communications have been presented to Spanish and international congresses, symposia, workshops or courses from 1991 to 1995.

## SAR IMAGING OF FRONTAL MESOSCALE STRUCTURES

The imaging capability of SA.R has been used to detect structures in the sea surface that can be related to frontal circulation, that is motion associated to gradients in water density. The usually frequent periods of low cloud cover in the Mediterranean region had allowed in the past to verify the existence of considerable mesoscale phenomena (meanders, eddies, filaments) generated from the frontal boundaries and that were traced by temperature differences in satellite infrared imagery. However, and especially under some seasonal conditions, the Mediterranean fronts are mostly due to salinity gradients rather than to temperature. This is the reason why we expected that SAR could be more efficient than infrared radiometers in detecting mesoscale circulation structures. Seasat SAR had shown that changes in sea roughness can be imaged in correlation with frontal features.

The first SAR scenes obtained by ERS-1 in the Balearic has in during its 3-days repeat cycle Commissioning Phase (November 20, 1991, Ebro delta to Ibiza) confirmed our hopes: besides complex surface signals probably related to fresh water discharges and meteorological events, shear lines and mushroom-like eddies were clearly visible in the area of the Balearic front (Martínez et al., 1992). It became evident that ERS-1 SA.R can provide valuable information on the frontal mesoscale structures typically present in the western Mediterranean surface layer.

In May-June 1992. the acquisition of several kinds of in situ information (CTD, ADCP, continuous surface TS, lagrangian drifters, wind and ichtioplankton) around a submarine canyon (Palamós) in the shelf/slope region of the NW Mediterranean by an ICM cruise, allowed a first comparison to simultaneous SAR imagery (Font et al., 1993). The conceptual model of current shear identification as radar cross-section perturbations (backscatter intensity peaks by wave-current interaction or damping by natural slicks accumulation), as systematised and checked by the Nansen Environmental and Remote Sensing Centre (Bergen), was applied to extract signals of the alongslope and shelf circulation. The detailed analysis of the oceanographic parameters revealed that the situation was highly variable, with the density front oscillating between three consecutive surveys and a warm upper layer that permitted a decoupled dynamics of light fresh waters. In addition, the meteorological conditions also had an intense spatial and temporal variability, what strongly modulated the phenomena observed in SAR images.

During the first leg of the cruise the surface front was quite offshore from the narrow shelf. The very irregular and weak wind field during the ERS-1 pass coincident with this leg (15th May) originated a patchy backscatter intensity distribution. One. can observe a curved signature upstream the canyon and shear lines alineated with the bathymetry downstream of it (figure l). This indicates the topographic effect of the canyon on the alongslope current, as delineated by the dark lines and the velocity vectors. During the second leg the front was closer to the shore, but SAR imagery only revealed internal waves propagating offshore, while the wind distribution produced a more homogeneous backscatter intensity (figure 2). Full resolution zooms to several parts of this high backscatter area show a complex pattern of interacting


**Figure 1** ERS-1 SAR subscene 50 x 50 km on 15 May 1992 superposed to surface ADCP vectors and location of the canyon (500 m isobath). Pixel size is 100 m

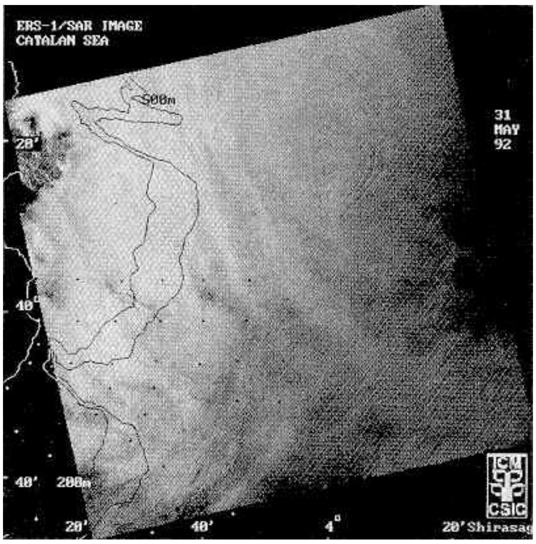


**Figure 2** Offshore Internal waves, alongslope shear lines end a possible area of low winds in a 200 m resolution georeferentiated full 100 x 100 km SAR.FDC image

small internal wave trains. An image between legs 2 and 3 (13th June), with half of the area affected by strong northerly winds, revealed the presence of a small eddy on the shelf upstream the canyon. During leg 3 no clear structures can be identified in the SAR scene, due to the high backscatter intensities recorded in the image. An in-depth study of this SAR imagery in relation to hydrographic and current measurements (Shirasago, 1996) has permitted an accurate description of different oceanographic phenomena in relation to the prevailing environmental conditions.

The Alboran Sea circulation is characterised by a wave-like front delineated by the incoming Atlantic waters (fresher and lighter than Mediterranean waters) that penetrate into the basin as a surface jet from Gibraltar. Two big anticyclonic gyres are coupled to this front and dominate the regional dynamics. They have been repeatedly observed by NOAA infrared imagery, while in situ measurements have revealed the occurrence of intense mesoscale motions, as for example small cyclonic eddies along the border of the big gyres.

From 17 September to 10 October 1992 an oceanographic cruise on board the CSIC R/V García del Cid covered the whole Alboran Sea. 134 CTD stations, plus ADCP profiles (continuously averaged every 5 minutes) and surface temperature and salinity (every minute) were recorded. For the first time a complete and systematic survey of the Alboran Sea, including Moroccan and Algerian waters, was achieved by an oceanographic ship. A study has been done integrating in situ data and SAR. FDC scenes, with the support of several ATSR SST images (Shirasago et al., 1994). 26 Alboran Sea SAR images from 12 to 28 September 1992 have allowed the construction of a mosaic for the whole sub-basin. The comparison of this picture to the oceanographic data indicates a very good correlation of the, shear lines with the major dynamic structures. Figure 3 shows the hydrographic stations location and the surface (10 m)

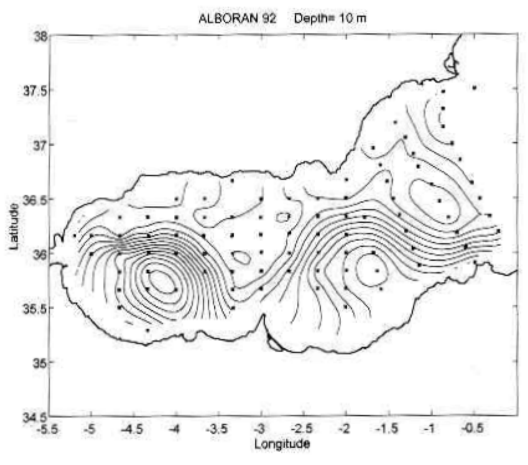


**Figure 3** The surface dynamic topography in the Alboran Sea derived from the 134 CTD profiles shows the wave-like front associated to the incoming jet of Atlantic water end the two big anticyclonic gyres.

dynamic topography calculated from the CTD casts. The two big anticyclonic gyres with the associated wave-like front are clearly identified, as what gives sharp discontinuities in some parts of the re- well as the origin of the Algerian current, in this representation of the surface geostrophic field.

Figure 4 shows the SA.R mosaic overlaid with A.DCP velocity vectors and bottom topography. Different levels of backscattering were recorded in the 9 satellite passes (almost always ascending), what gives sharp discontinuities in some parts of the resulting image. This is a result of the different wind states prevailing in the zone during the survey, or related to the different background oceanographic conditions, The western gyre (figure 5) appears, enlightened because of the general high

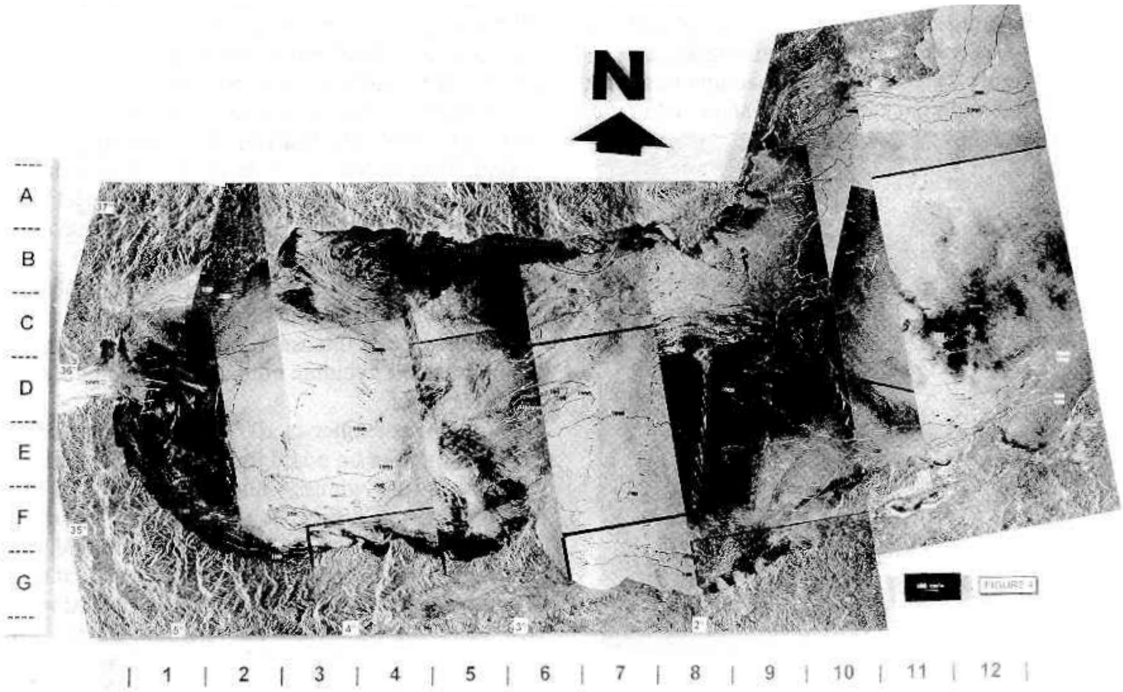


**Figure 4.** Alboran Sea: mosaic 01 ERS-1 SAR images contemporaneous to the sea campaign in September 1992. Surface layer ADCP velocity vectors and the 100, 200, 1000 and 2000 m isobaths have been superposed.

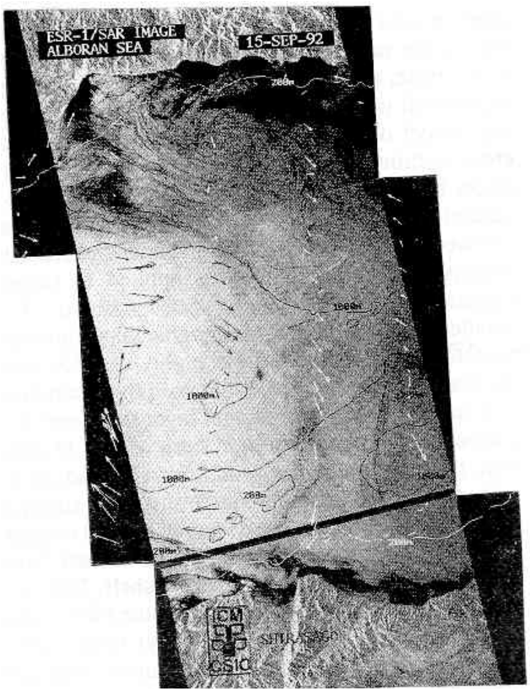


**Figure 5.** The western Alborsn gyre viewed by SAR imagery and ADCP in sltu measurements

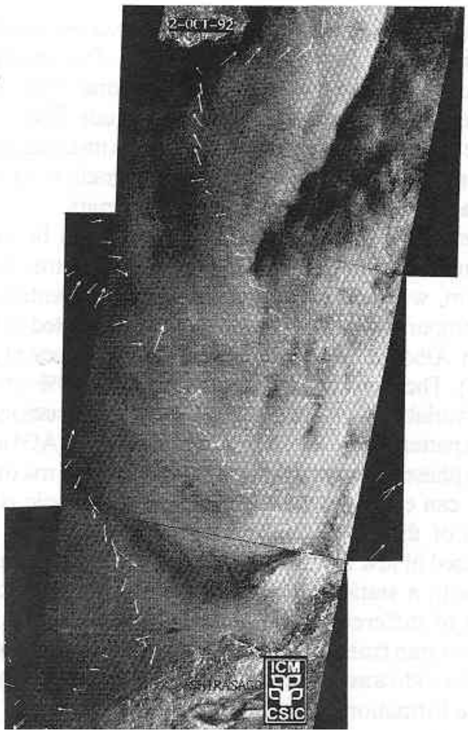


**Figure 6.** SAR backecattering shows the formation of the Algerian current near Oran. The effect of a wind front can be observed in the northern area


**Figure 7.** SAR detection of a cyclonic ocean rnesoscale eddy in the central Alboran Sea. The low backscatter (dark) spiral lines ore intersected by parallel bands corresponding to atmospheric signals.

backscattering measured in this three images (September 15). Some shadow parts at the border denote the gyre sense (clockwise). The ADCP vectors confirm such clockwise motion and indicate velocity values up to 100 cm/s in many places. The left border appears distorted because of the intrusion of a cyclonic eddy probably formed due to atmospheric phenomena prevailing in this day (October 1st), including possible atmospheric internal waves signatures reflected in the sea surface overlapped to this eddy. The "warm core" at the north-east of the western gyre is noticed by the presence of a cyclonic eddy revealed by smoothed-black lines, probably due to natural film formation.

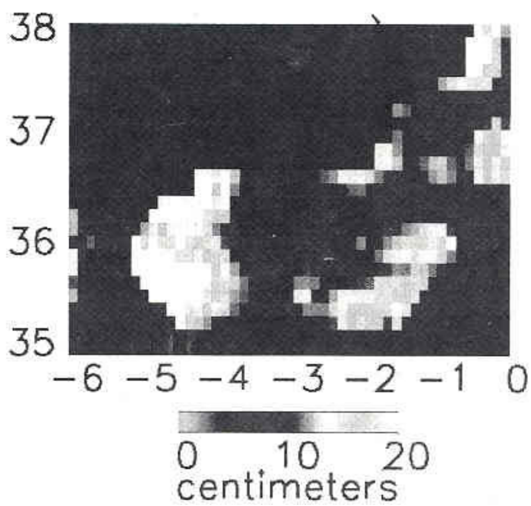


**Figure 8**. Total variability of sea surface height in Alboran during 1992-1993 computed from ERS-1 altimeter.

The second gyre is partially shadowed in the mosaic (three images dated September 28) with the ADCP vectors denoting the direction and magnitude of the velocity. The jet associated to the wave-like front is clearly detected in these images (upper and left part). It can be observed, at the easternmost zone of the Alboran Sea the jet directed towards the coast and the formation of the alongslope Algerian Current (figure 6), also confirmed by intense ADCP velocities. Figure 7 is an enlargement of the area in the trough between both gyres. A mesoscale cyclonic eddy is shown superposed to the signature of atmospheric internal waves.

## ALBORAN SEA SURFACE HEIGHT TEMPORAL EVOLUTION

The ERS-1 altimeter has been used in investigating a long time scale variability of the Alboran sea surface, under the direction of Dr. Jorge Vázquez from JPL, Pasadena. Alongtrack data were extracted in the area between 35$N to 38$N and 6$W to 0$ for the period February 1992 to December 1993. Atmospheric corrections including the wet and dry troposphere were applied. 'Me geoid and time independent part of the sea surface height was removed by along track interpolating with a bi-cubic spline. To remove tides in the area, a tidal model of the Mediterranean was interpolated in space-time to the required positions. The usual procedure of removing orbit error by a quadratic curve resulted not to be realistic. Instead, a linear tilt and bias were removed in the tracks over the Mediterranean. In order to obtain maps of sea surface height anomalies, an iterative successive correction technique was applied to interpolate the residuals to a regular series in space and time. To include an entire repeat, a 35-day e-folding time scale was applied in the spatial domain. These maps were created at a regularly spaced 10 day interval with 8 points per degree of latitude and longitude. Figure 8 represents the space distribution of sea surface variability during the two years of measurements, as derived from this series of maps. The computation of Complex Empirical Orthogonal Functions (CEOF) from a set of time series is a good technique to extract dominant signal in noisy data, as for example sea surface anomalies derived from altimeter measurements. Unlike real EOF, CEOF can detect propagating features in a two dimensional field. The variability of the analysed field is separated into spatially uncorrelated orthogonal modes, by first calculating a spatial covariance matrix at each grid point with complex time series, where the real part are the actual data values and the imaginary part their Hilbert transform. The resulting eigenmodes are represented by a temporal phase and amplitude and a spatial phase and amplitudes The slope, of the temporal phase is a measure of the instantaneous frequency, and the two-dimensional gradient of the spatial phase is a measure of the wavelength.

The CEOF analysis, that had resulted to be very efficient with Geosat altimeter data in the Gulf

Stream, was applied to our data set and evidenced the temporal variability to be mainly associated to the major Alboran Sea dynamic features (Vázquez et al., 1996). The first three modes account for 70% of the total variability. Mode 1 (45%) indicates a stationary wave pattern in the Western Alboran Gyre (WAG) area and a phase difference between two dominant maxima, what can evidence the formation of a cyclonic eddy north of the WAG. Strong temporal variations are detected at low frequency. Mode 2 (18%) is associated with a stationary high in the WAG and shows areas of different vorticity on both sides of the Almeria-Oran front (eastern border of the EAG). Mode 3 (7%) indicates a westward propagation in the area of the formation of the Algerian current.

Significant correlations are found between sea surface temperature and sea surface height variability in the region of the EAO, where cloud coyer was scarce during the studied period. ERS-1 altimetry at a 35-d repeat is not sufficient to resolve the temporal variability of the mesoscale gyres, however a combination of infrared imagery and altimetry can be a powerful tool to study western Mediterranean variability (figure 9). Further tests have demonstrated that a combination of different altimeters, as Topex/Poseidon with high temporal resolution and ERS with better spatial resolution, can provide an excellent mean for this kind of investigations.

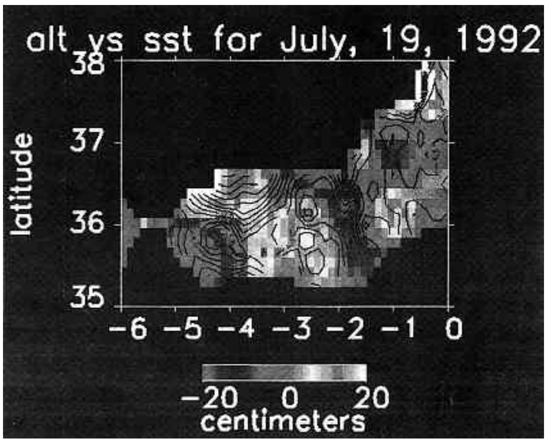


**Figure 9.** Superposition of NOAA/AVHRR sea surface temperature end ERS-1 altimeter sea surface height on 19 July

## ALTIMETER DATA PROCESSING ON A PC ENVIRONMENT

A new software for the analysis of altimetric data has been developed (Sánchez and Martínez Benjamín, 1994; Sánchez, 1995). it reads ERS-1 (OPRO2) CD-ROM data and selects and validates data in the desired window. The specification of the altimeter tracks within the desired window that includes the Western Mediterranean Sea and the Eastern North Atlantic Ocean, allows a fast processing on the validated information. Atmospheric and geophysical corrections are applied to obtain the altimeter profiles and the dynamic topography along the tracks. Different pro- cessing techniques are used by a processing editor. Different processing modules can be selected and connect them depending on the oceanographic features that would like to reveal. The data flows through the network to obtain finally the results. They have been obtained maps of sea surface topography, sea wave height and ocean variability for different cycles. Some visualisations have been obtained using AVS, Application Visualisation Software, on a Convex 3480.

Processing for altimetric data:

1. First remove of SSH (Sea Surface Height) points with a high variability value.
2. Iterative process to eliminate spikes in the data:

For each iteration, each data is compared with the results of a cubic spline interpolation based on the six closest points. lf the difference is greater than 5 cm, the point is corrected according to its interpolated value, and the new value is used for following iterations.

When convergence is achieved, points which have moved more than 30 cm are flagged, while the other points keep their initial value.

3. Data profiles are resampled every 10 km using a cubic spline (to provide regular sampling). Interpolation is performed only for points surrounded by two non flagged data points. In this case the immediate next valid points are chosen.
4. A first/second polynomial is fitted to each individual profile and removed (case SSH).
5. The mean profile is computed, and the residuals are calculated for each track

Processing for residuals (or SWH, corrections):

1. A first/second order polynomial is fitted to each individual profile and removed.

2.a. The residual level profiles are smoothed with a 40 km median filter and compared with the unsmoothed profiles. Points with a difference greater than 40 cm are replaced by:

2.a.l. The median value (in the original data).

2.a.2. Cubic spline interpolation based on the four closest points.

2.b. The residual level profiles are smoothed with a window smoothing routine and compared with the unsmoothed profiles. Points with a difference greater than 10 cm are replaced by:

2.b.l. The median value (in the original data).

2.b.2. Smoothed value.
2.b.3. Cubic spline interpolation based on the four closest points.

3. Mean profiles and residuals are recalculated.
4. A first/second order polynomial is fitted to each residual profile and removed.
5. The mean along track wavenumber spectrum is calculated for each residual track, and filtered with an appropriate cut-off wavelength (Lanczos filter).

Figure 10 is an example of this pure applied to an area that includes the western Mediterranean and the adjacent region of the northern Atlantic ocean.

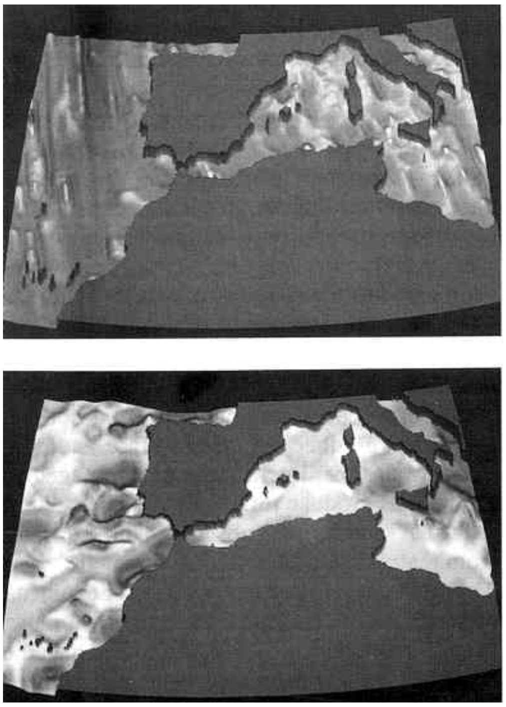

**Figure 10.** a) Backscattering coefficient for ERS-1 altimeter ascending tracks on cycles 15-16, summer 1993.
b) Computed dynamic heights, including geoid, for the same period.

## LOW LEVEL PROCESSING OF SAR DATA

Quality analysis is an important task in the development of SA.R image digital processing methods. A methodology for the analysis of both point target and extended target in SAR images has been developed (Martínez and Marchand, 1903). The main objective is to provide a tool for the study of the focusing performance, of different processing algorithms and the, influence of key parameters (peak intensity and amplitude, spatial resolution, peak side lobe ratio, integrated side lobe ratio, ambiguity level, radiometric resolution) in the quality of the final image. The utility of the proposed methodology has been demonstrated in the study of two practical situations: the correct focusing of images and the effect of the processed bandwidth on SAR images.

SAR is the remote sensing instrument with more future in the observational technologies development. The focusing of SAR raw data presents serious difficulties. These can be resolved with the CSA method, Chirp Scaling Algorithm that equalises the range migration trajectories of the whole data set with respect to a reference. Inisel Espacio has implemented a CSA processor (Martínez et al., 1995), integrated with extra functions in a work station. CSA-SLC processor has succeed a quality analysis of the produced imagery to agree with ESA specifications for SLC ERS-1 products. The first version of the processor produces Single Look Complex images. SLC. SA.R image quality assessment was performed using ERS-1 RAW data from Flevoland (official test site) and from the submarine canyon area studied in the present proposal, where both raw data and SLC image were available. CSA-SLC processor has succeed a quality analysis of the produced imagery to agree with ESA specifications for SLC F-RS-1 pro- ducts. Work is ongoing to get ground range projected imagery, similar to the PRI product.

The principal characteristics of this processor, compared to other classical processors, are:

-The CSA algorithm produces high quality SAR images, suitable for any kind of applications.
-Range compression is performed simultaneously to azimuth compression, what saves two FFTS.
-Computational efficiency, since it only requires 4 FFTS.
-The CSA algorithm is adequate to process SA.R data collected on complex geometries.

As a result of the experience gained in SAR raw data processing, two contracts were awarded to Inisel Espacio by ESA for the implementation of a graphical user interface and for the upgrade of the CSA SAR Processor (ESTEC contract 10516/93/NL/FM(SC) and ESRIN contract 11118/94/1-FGE).

## GEOCODIFICATION OF SAR IMAGES

Since the European Space Agency ERS-1 satellite was launched in July 1991, the Institut Cartográfic de Catalunya and the Department of Geology of the University of Barcelona have been working together on the SAR geocoding problem.

A method has been developed (Palá and Corbera,. 1994) that involves a keplerian modelisation for the satellite orbit based on the ephemerides orbital points and their velocities. The start time -

for the first image row-and increment time between rows may be extracted from the tape information or adjusted on the basis of Ground Control Point (GCPs). In the case of Ground-Range data, polynomial coefficients allowing transformation from Ground-Range to Slant-Range are needed and derived from GCPS, if not provided in the tape header. The rectification process need an accurate Digital Elevation Model and takes profit of locality when calculating the SAR position from the geocentric position. An orbital data table is used in order to improve the rectification speed. The known foreshortening and layover topographic effects on the original images are eliminated. An ERS-1 image over a rough area in southern Catalonia was rectified and compared with 1:50 000 SPOT panchromatic orthoimages over the same area, giving a successful overlapping. in the future, the aim is to integrate the ERS-1 SAR rectification model with the, available models for other imagery (SPOT, TM, Aerial photography, ...) and to allow a multiple SAR triangulation combined with other observable data when desired.

As an experiment, to offer to the users a new cartographic view compared to the usual spaceborne optical sensors, the ICC ha,, built a radar map of Catalonia at scale 1:250 000. (Institut Cartográfic de Catalunya, 1995). 14 SAR.PRI ERS- 1 images, from 5 different descending passes, have been corrected using orbital information and a ground Digital Elevation Model with an initial inter-pixel distance of 15 m. Near 10 GCPs were used for each image, and a filtering process was applied before combining the images in a mosaic, where radiometric transitions between adjacent swaths were minimised.

## GENERAL CONCLUSIONS AND RECOMMENDATIONS

Concerning the expected results for the oceanographic applications of ERS-1 sensors, as were indicated originally in the proposal, we can conclude after the completion of this research:

1) ERS-1 SAR is a powerful sensor to detect surface structures related to frontal mesoscale circulation in the western Mediterranean. Due to its high horizontal resolution, independence from cloud coyer and capability to image shear/not-thermal features, it represents a significant improvement compared to the classical optical or infrared remotely sensed imagery.

However some important problems difficult its operational use:

- The strong dependence on wind conditions. Too low winds produce a fiat sea surface and no waves-current shear interaction can be imaged. Too High winds produce rough seas with very intense radar backscatter that obscures any information from features related to density gradients
- The difficulty in discriminating the phenomena of different nature that can be imaged by a radar of such characteristics. Although models have been established and almost-automatic procedures implemented by several authors, it is not always easy to separate the signature of circulation dynamics from other marine or atmospheric processes capable of modifying sea surface roughness.
- The narrow swath of ERS-1 SAR (100 km) is an important limiting factor. SAR spatial resolution is more than excellent to study the mesoscale in the Mediterranean, but the time evolution is far from being adequately resolved. A periodicity of the order of 1 day would be necessary. The swath narrowness makes this impossible, as well as it difficult the simultaneous observation of several or large mesoscale structures in wide areas like the Algerian basin. This could be achieved with a compromise in a new kind of radar: a spatial resolution of 100 m would be probably enough for mesoscale dynamics purposes, while a swath of the order of 500 km and an adequate repeat cycle would significantly increase the temporal resolution.

2) ERS-1 altimeter has demonstrated to he useful to extract coherent information on the temporal evolution of re ional and mesoscale circulation characteristics in one region of the Mediterranean basin, what had not been possible with previous altimeters. It is clear that future improvements in altimeter measurements and orbit determination will significantly improve this usefulness, as shown yet by Topex/Poseidon.

The multiple corrections to be applied to altimetric data imply a complex processing. With the present experience, a systematic data distribution of fully processed sea level anomalies, as tested yet, would he an outstanding solution for the researchers interested in oceanographic applications. We were not able to adequately work until we implemented the high resolution Mediterranean tide model, and we are waiting for a good geoid to be able to calculate full dynamic topographies instead of only using temporal variability.

In addiction analyse mesoscale structures of the Mediterranean size it is necessary merge measurements from different altimeters to have the adequate spatial resolution. Several teams are working in this direction.

3) To oceanographers that use infrared imagery as a tracer of surface water mass distribution and circulation, ATSR appears to be a tool with a performance very similar to the well known AVHRR/NOAA. It provides a better determination of SST, but the simultaneous spatial coverage is smaller (500 km). In spite of having received a considerable amount of ATSR data sets, we have only used few of them for technical and logistical reasons. Some users, with limited hard- ware facilities, can have difficulties in

efficiently handling lots of images stored in exabytes. For our purposes it would be excellent the possibility of an on-line access to a ATSR ISST-quick-look data bank, where images could be selected by geographic coordinates and dates, viewed (the actual swath and cloud coyer are fundamental constraints) and, if adequate, formally ordered. It would increase significantly the benefit of the present ATSR data availability. 11 has been shown that a combination of infrared imagery with altimetry is a powerful approach for mesoscale dynamics studies.

Four years after the becoming of our work with ERS-1, sensors, the basic conclusion of project ERS-1 A.O. El, is that it has been the best satellite ever offered to the oceanographic community, and that we are really interested in continuing to have access, through agreements with ESA, to the different sets of data of the future ERS and similar platforms. The provided information is an exceptional mean to complement, and in several aspects critically improve, the research carded out by in situ experimentation and numerical simulator on many do- mal ns of the marine environment research.

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