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THE USE OF NEAR REAL TIME INFRARED AND SAR SATELLITE IMAGERY TO UPDATE THE SAMPLING STRATEGY OF AN OCEANOGRAPHIC VESSEL

Oscar Chic[1], Jordi Font [1], Stein Sandven[2]

1: Institut de Ciències del Mar, CSIC, P. Joan de Borbó s/n, E-08039 Barcelona, Spain
e-mail: ochic@icm.csic.es, jfont@icm.csic.es

2: Nansen Environmental and Remote Sensing Center, Edvard Griegsvei 3a, N-5037 Solheimsvik, Norway
e-mail: stein@nanvax.nrsc.no

ABSTRACT: Near-real time remote sensing (NOAA infrared and ERS-2 SAR) has been used to guide the *in situ* sampling in an oceanographic cruise on board the Spanish *RV Hespérides* in the western Mediterranean (October 1996). Mesoscale circulation structures evolve rapidly and require daily updated synoptic information to achieve the best efficiency in field measurements. The different characteristics of SAR and AVHRR in what concerns swath, revisiting time and dependence on atmospheric conditions, and the specific circumstances at the moment of the experiment, resulted in a much higher use of infrared information. At present SAR, although it can better resolve some features, is not yet an operational tool to drive the measuring strategy of an oceanographic ship in latitudes like the Mediterranean Sea.

INTRODUCTION

During the last decade, remote sensing and in situ studies have evidenced that mesoscale variability plays a major role in the Mediterranean Sea dynamics. The generation and evolution of meanders, eddies and filaments (time scales of days-weeks and spatial scales of few tens of km) are not only powerful mechanisms for shelf/slope exchanges, but can strongly influence and even modify the basin scale circulation. In October 1992, *in situ* sampling, quasi-simultaneous to ERS-1 SAR acquisition, showed that surface signatures of mesoscale circulation features can be identified in SAR images of the Alboran Sea. A very good correlation was found between shear lines in the border of large gyres and the direction of the corresponding frontal jet measured by an Acoustic Doppler Current Profiler (ADCP) from the *R/V García del Cid* (Font et al., submitted).

The high spatial resolution offered by SAR could be used for fine positioning of *in situ* measurements in mesoscale dynamics studies. This implies the need of an almost-real time satellite data acquisition and transmission to the research vessel, what can be easily done for infrared radiometers with a portable HRPT station, but is much more difficult for SAR. Studies performed by the Nansen Environmental and Remote Sensing Centre (NERSC, Bergen) in the Norwegian Sea achieved such near-real time SAR imagery availability on board: ERS-1 data were acquired at Tromsö satellite receiving station, rapidly processed at Bergen, and interpreted images faxed to *R/V Håkon Mosby* three hours after acquisition (Johannessen et al., 1992).

The encouraging results in detecting frontal structures in the Mediterranean, and the experience acquired in obtaining near-real time SAR images, were the reason for proposing an ERS-2 project in the southern region of the western Mediterranean. "ALGERS. The use of ERS sensors for the study of the dynamics of Modified Atlantic Water in the Algerian basin" (code AO2.E102, PI J. Font) was organised, among other objectives, to provide pre-cruise, post-cruise and near-real time SAR coverage to an interdisciplinary experiment to be done with the *R/V Hespérides* in the Alboran Sea and Algerian basin in autumn 1996. Simultaneous satellite synoptic information could strongly help in designing the *in situ* sampling of mesoscale structures

OMEGA-ALGERS CRUISE

The cruise took place from 30 September to 21 October 1996 in two legs on board the Spanish research vessel *Hespérides,* to fulfil the objectives of OMEGA project in the western Alboran gyre area, and to initiate the interdisciplinary study of the Algerian basin included in MATER project. OMEGA ("Observations and modelling of eddy scale geostrophic and ageostrophic circulation") and MATER ("Mass transfer and ecosystem response") are research projects of the Marine Science and Technology programme of the European Union.

During OMEGA, a box of 100 x 80 km in the northern half of the western Alboran gyre was sampled three times by undulating SeaSoar (CTD, fluorometer, light sensor, infrared backscatter sensor), ADCP and multibeam Simrad EK500 echosounding, and once in a regular grid of CTD (+oxygen, fluorescence, light transmission) stations. Differential and 3D GPS were used for precise navigation data., and water samples were taken for chemical and biological measurements. During ALGERS, a mesoscale meander developed in the Algerian current near 1°E, previously tracked by remote sensing, was sampled along cross-shelf sections. The sampling methodology was quite similar, plus launching of expendable XBT and XCTD probes, primary productivity and radiotracers determinations, and deployment of surface drifters to be tracked by satellite.

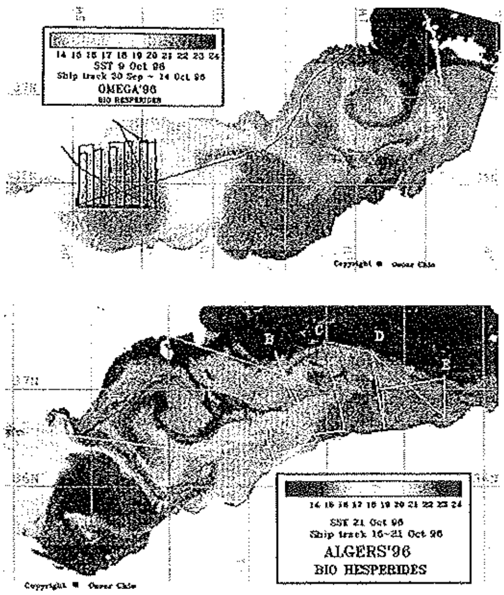

Figure 1. Alboran sea and western Algerian basin. NOAA sea surface temperature and ship track for both legs of OMEGA-ALGERS cruise in October 1996

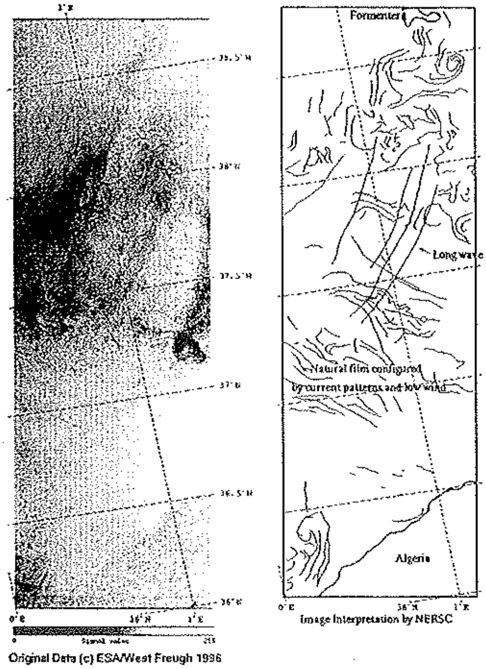

Figure 2. ERS-2 SAR image and its analysis received in near-real time on board *RV Hespérides* (orbit 7520, 27 September 1996)

The SAR acquisition was arranged with the British Defence Research Agency Satellite Ground Station, West Freugh (Scotland), through the Southampton Oceanography Centre, one of the OMEGA partners. SAR acquisition for both areas during the cruise had been requested to ESA within the ALGERS AO2 project. When ERS-2 SAR was observing the study area, data were especially recorded by West Freugh, that immediately generated QL5 products (50 m pixel size), then downloaded and analysed by NERSC at Bergen, and finally transmitted by Inmarsat link to the *Hespérides*. Compacted files of the SAR images, together with features detection analysis, were received on board during the day following the satellite pass.

From 21 September to 21 October a total of 17 ERS-2 passes were recorded with this procedure. Figure 2 is one example of these transmitted files. The same features detection analysis was done off-line by NERSC with other SAR data sets received from ESA during September.

Two specific cases studied during the cruise are presented here

REMOTE SENSING REAL TIME ACQUISITION

The availability of simultaneous satellite data was considered to be fundamental for both legs of the cruise: the optimal location of the OMEGA surveys in relation to the western Alboran gyre, and the permanent tracking of an evolving instability during ALGERS.

The remote sensing information acquisition during the cruise included infrared and SAR imagery. A SeaSpace portable HRPT satellite receiving station (Terascan TS300) was installed on board the *Hespérides* and obtained NOAA AVHRR infrared imagery four times a day all along the cruise. Sea Surface Temperature was computed, the images were georeferentiated and made immediately available to the oceanographers for analysis in comparison to field measurements. Figure 1 shows the study areas on this kind of images.

CASE 1: THE WESTERN ALBORAN GYRE

The Alboran Sea is the region of the western Mediterranean in contact with the Atlantic ocean through the strait of Gibraltar. A surface inflow of light Atlantic water occurs as a narrow northeastward jet that later forms a wave-like front, usually coupled to two large anticyclonic gyres and mesoscale eddies developing along the edge of these gyres. The very active front in the surface 0-200 m layer along the edge of the western gyre gives rise to a three-dimensional ageostrophic circulation at mesoscale, and then provides an enhanced transport route for heat, nutrients and biomass. Surface features (water mass distribution, roughness patterns) reflect the presence of this intense dynamics. The objective of OMEGA is to determine the three-dimensional motion in such an area.

The continuous reception of AVHRR during the weeks previous to the cruise allowed a monitoring of the Atlantic water jet, and hence a precise positioning of the oceanographic sampling to better capture the area of intense mesoscale circulation. The scarce SAR coverage for this pre-cruise period prevented from using it in fine tuning the sampling strategy.

Both the density distribution and current vectors, obtained from the second underway SeaSoar and ADCP survey on 6-8 October (Allen et al., 1997) indicate the presence of the anticyclonic gyre and its associated jet in the surface layer. The infrared images for this period clearly show the stability of the western gyre, with surface warm water accumulating in its center on the lighter side of the front.

Figure 3. Superposition of NOAA SST and ERS-2 SAR images of the western Alboran sea on 6 October 1996. © ESA / West Freugh 1996

On 6 October one ERS-2 SAR image of the area was acquired (orbit 7649). In the NOAA-14 SST map of the same date, cold water entrained from the coastal area traces the location of the jet along its N and NE borders. A pulse of Atlantic water can also be detected in the thermal image, and this was corroborated in situ by visual observation of colour and roughness differences in surface water. The SAR image, formed under a wind intensity of 2.5 m/s, shows the presence of bright and dark lines in its NE area, that could be initially interpreted as the signature of internal waves. A precise georeferentiation allows a superposition of both images (fig. 3) and the identification of these sea surface roughness singularities as shear lines depicting the frontal jet along the western Alboran gyre.

CASE 2: ALGERIAN CURRENT INSTABILITIES

Downstream the Alboran Sea, the jet of Modified Atlantic Water forms a well defined flow along the African coast: the Algerian current. Due to hydrodynamic processes, not yet fully understood, this alongslope current becomes unstable and develops meanders. These induce the formation of cyclonic and anticyclonic eddies, that can grow and play a major role in the configuration of the general circulation in the Algerian basin (Millot, 1994).

Until the end of September, 27 ERS-1 and ERS-2 passes with SAR acquisition (received from ESA) and daily AVHRR SST maps (retrieved from the German DLR ISIS server) were used to identify instabilities of the Algerian current and choose the most suitable area for the field work. In the weeks previous to the cruise a mesoscale meander was developed near 1°E. It appeared like an usual coastal anticyclonic eddy, with a well-marked secondary cyclonic circulation. Once the HRPT station was operative on the *Hespérides*, and thanks to the dominant clear weather, this specific structure was continuously monitored, and the *in situ* sampling organised to take the maximum advantage of the measurements for the best description of the phenomenon.

Besides some cloud covering during the cruise, the navigation and sampling sites were continuously updated from the satellite information. The different cross-shelf sections (fig. 1) were located to fully intersect the alongslope current upstream, downstream and in key positions of the cyclonic and anticyclonic parts of the instability. An authorisation to work in Algerian waters allowed a complete sampling of the coastal zone.

On 16 October a cloud free image of the complete instability was obtained (fig. 4), as well as one SAR image of its western part. One of the sampling transects was situated to cross the core of the cyclonic eddy on the afternoon of 17 October (no cloud free image available for this date). An examination of the surface water temperature and salinity record along this transect from the coastal zone to offshore waters (fig. 4) indicates a perfect match between the *in situ* decription of the vein of Atlantic water (colder and fresher than the ambient water) and its remotely sensed signature. Specific hydrographic stations, to collect water at several depths, were positioned to coincide with maxima or minima of surface variables (alongslope current, inner edge of the cyclonic eddy, cold core, outer edge). The corresponding SAR image (orbit 7792), as received on board, does not seem to highlight any surface structure related to the instability, maybe due to too high wind intensity, 10 m/s from the NNE. Full resolution (SAR.PRI) images provided by ESA will now be processed to improve the information on sea surface roughness.

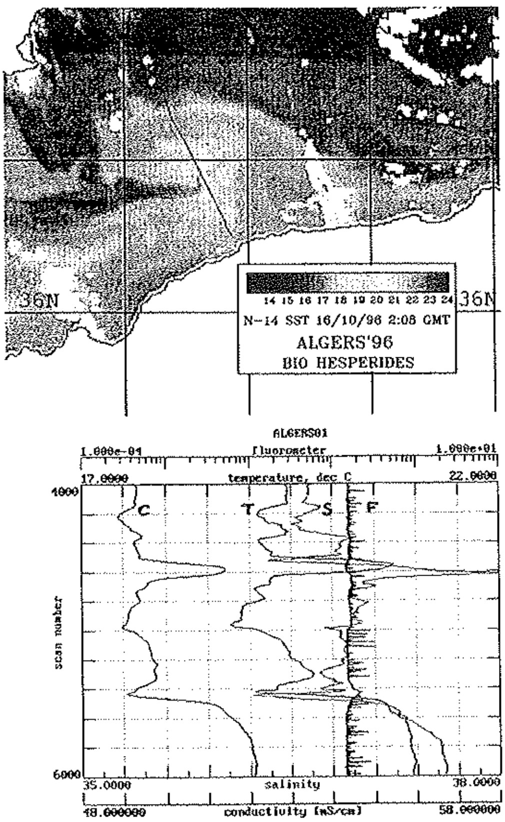

Figure 4. a) NOAA SST image of the Algerian current instability on 16 October 1996 with the ship track on 17 October. b) Surface variables recorded along this track from 13:48 (top) to 19:21 GMT (bottom)

CONCLUSIONS

The use of near-real time remote sensing has proved to be very efficient in the daily updating of sampling strategy for mesoscale circulation studies. The different characteristics of SAR and AVHRR in what concerns swath, revisiting time and dependence on atmospheric conditions, and the specific circumstances at the moment of the experiment, resulted in a much higher use of infrared information to guide the in situ sampling. At present SAR, although it can better resolve some features, is not yet an operational tool to drive the measuring strategy of an oceanographic ship in latitudes like the Mediterranean Sea.

For this kind of mesoscale studies, a SAR with lower spatial resolution (probably of the order of 50-100 m) but wider swath, would be of great help. An optimum solution would be an operational constellation of space borne radars to have a daily coverage of any ocean region. This could complement the lower resolution, and cloud depending, infrared radiometers, and allow a real all-weather all-time synoptic view of the ocean surface, a key issue for mesoscale dynamics.

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