APLICATION OF REMOTE SENGING TECHNIQUES TO THE STUDY OF INTERNAL WAVES IN THE STRAIT OF GIBRALTAR

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Abstract - *The generation and propagation of internal waves is one of the most interesting oceanographic processes in the Strait of Gibraltar. In this paper, radar (ASAR) and ocean colour images (MODIS y MERIS) have been used in order to characterize this phenomenon. The processing of instantaneous colour images has allowed the analysis of the relationship between physical processes of the internal waves and the biological implications. During internal waves generation, MODIS and MERIS images show a chlorophyll maximum structures in the coastal areas of Camarinal Sill. When these waves are located in Alborán Sea, the colour images illustrate the presence of chlorophyll maximum associated to the waves front. The results seem to indicate that a suction of coastal water take place during the internal waves generation and this rich chlorophyll water entry in Alborán Sea travelling joint to the internal waves.*

Keywords - *internal waves, Gibraltar Strait, ASAR images, Ocean Colour images.*

I. INTRODUCTION

The high amplitude and short period internal waves are generated at the western side of Camarinal Sill of the Strait of Gibraltar (Fig. 1) during maximum tidal outflow (toward Atlantic Ocean) when the flows reach 1 m s^{-1} (Vázquez *et al.*, 2008). These remain there until the flow weakens and then, the internal waves propagate towards the Mediterranean Sea. The internal waves produce a sea surface signal of roughness bands, named boiling water, (Bruno *et al.,* 2002) which are detected from ASAR (Advanced Synthetic Aperture Radar) images.

The mixing processes associated to the internal waves are able to produce a recirculation of the Mediterranean Water nutrients towards Alborán Sea and, consequently, to increase the phytoplankton populations inside de Atlantic Jet (Macías *et al.*, 2008). The main objective of this work is to characterize the waves processes and its biological implications in the study area using instantaneous radar and ocean colour images.

II. MATERIAL Y METHODS

In order to achieve the objective of this study, three tools have been used:

- Instantaneous ASAR and ocean colour images (MODIS and MERIS) to characterize the generation and propagation of the internal waves processes in the Strait of Gibraltar.
- Tidal velocity prediction in Camarinal Sill to identify the state of the internal waves.
- CTD data obtained from GIBRALTAR 08 Cruise on board of R/V Sarmiento de Gamboa to confirm the remote sensing information (Fig. 1).

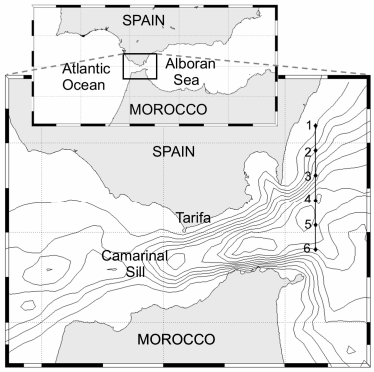

Fig. 1. Chart of the Strait of Gibraltar and location of CTD stations.

III. RESULTS

III.a. Generation

In the ASAR image of 2nd of June of 2008 (Fig. 2a) the roughness features confirm the generation of the internal waves in the Strait of Gibraltar. The tidal velocity prediction (Fig. 2b) shows that this image was captured during maximum outflow with a current intensity greater than 1 m s^{-1}, when hydraulics conditions are favourable for the generation. On other hand, in MERIS and MODIS images (Fig. 2c), it can be seen an increase of surface chlorophyll in coastal area of Camarinal Sill. This chlorophyll maximum structure travels eastward according to the propagation of the internal waves toward Alborán Sea.

III.b. Propagation

In the ASAR image corresponding to 1st of October of 2008 (Fig. 3a) can be detected waves train propagating in Alborán Sea. The tidal velocity prediction in Camarinal Sill (Fig. 3b) confirms that the internal waves have been approximately one cycle late in coming to Alborán Sea from its generation in Camarinal Sill. In MERIS image (Fig. 3c),

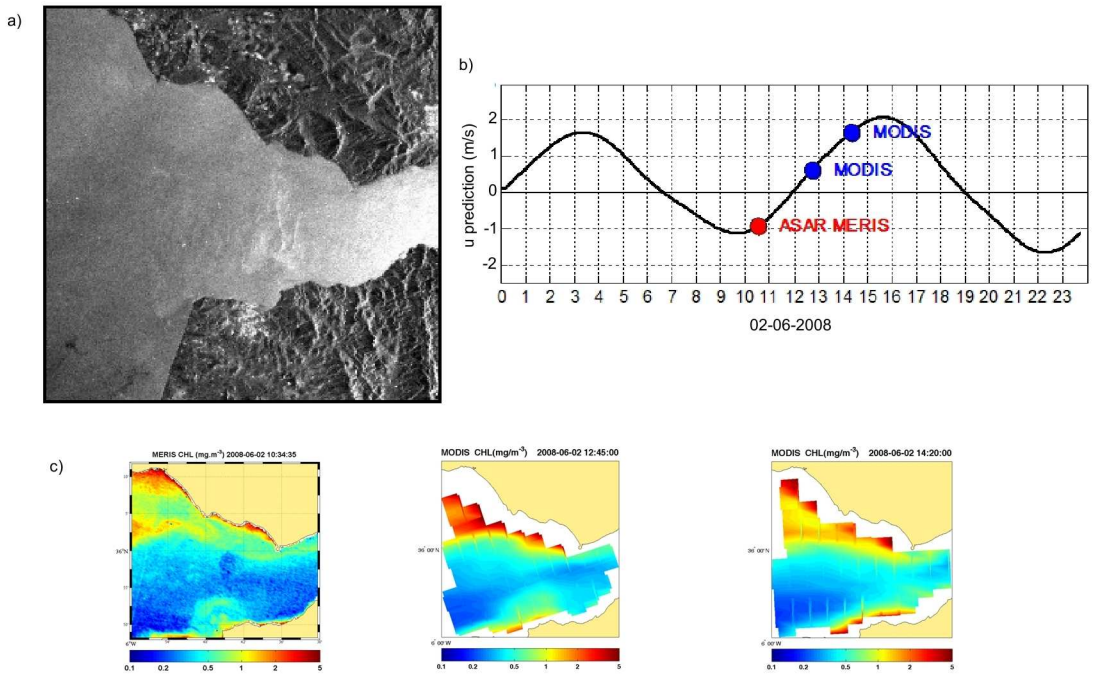

Fig. 2. (a) ASAR image on 2 June 2008. (b) Tidal velocity prediction of 2 June 2008, showing when ASAR and MERIS images (red circle) and MODIS (blue circles) were acquired. (d) Colour images on 2 June 2008.

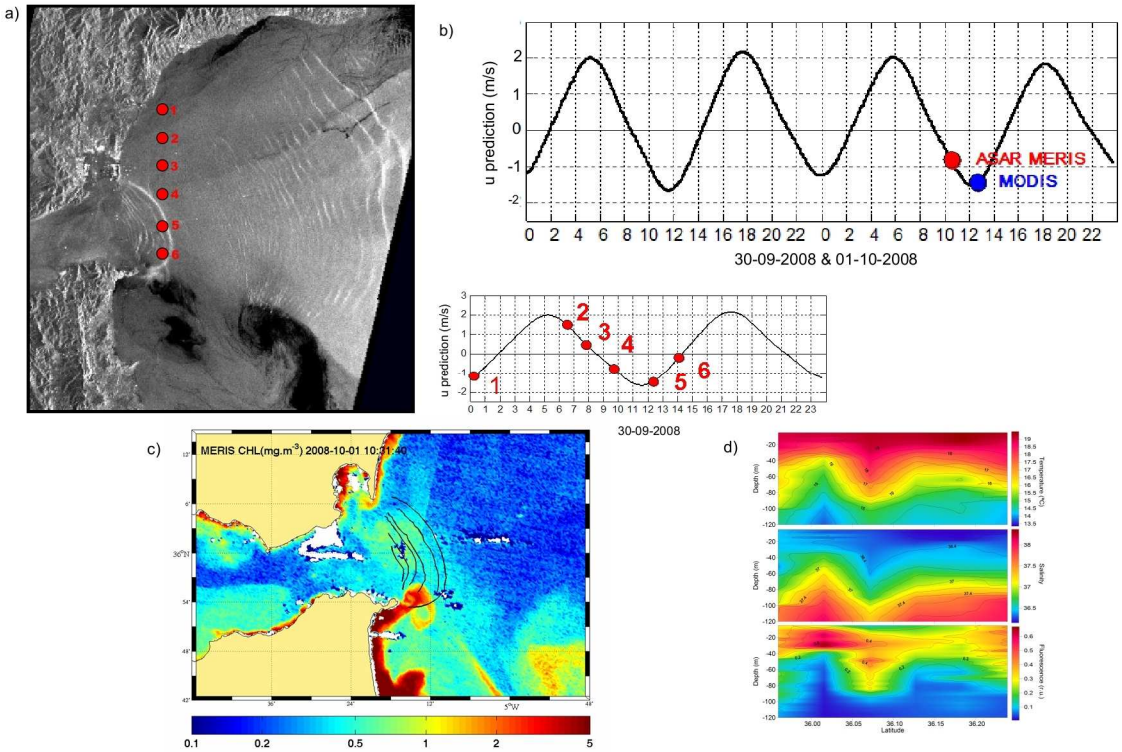

Fig. 3. (a) ASAR image on 1 October 2008. (b) Tidal velocity prediction of 30 September - 1 October 2008, showing when ASAR and MERIS images (red circle) were taken and tidal velocity prediction of 30 September showing when CTD cast (red dots) were taken. (c) Colour image on 1 October 2008. (d) CTD sections along line showing in figure 1a and 3a.

high chlorophyll values associated to waves train extracted of SAR image can be seen. In the CTD transect carried out 30 of September of 2008, a waves train in Alborán Sea was recorded. The isothermals and isohalines rise, joint to an increase of chlorophyll values (as colour images show) characterize the arrival of the internal waves in station 5 (Fig. 3d).

IV. CONCLUSSIONS

The combined analysis of images and *in situ* data reveal advection of North and South coastal water to the centre channel of the Gibraltar Strait and its entrance to Alborán Sea. This coastal water with higher chlorophyll concentration is incorporated to the Mediterranean Sea associated to the arrival of the internal waves train to this area.

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