Synthetic Aperture Radar Imaging of Sea Surface Life and Fishing Activities

Michel Petit, Jean-Michel Stretta,
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***Abstract*— During the HAlieutics Radar Experimentation Mediterranean sea [1] (HAREM), conducted in August 1989 in the golfe du Lion off the western Mediterranean coast of Europe, synthetic aperture radar (SAR) images of the sea and lagoon surface and concurrent independent observations and measurements were collected in order to test the potential of some applications of SAR imaging theories to halieutics. These theories [2], [4]–[6] have been developed to explain the SAR signal modulation in relationship with small variations of water roughness induced by internal wave or current or wind field variations. Analysis of the HAREM data indicates, for the first time, that the marine surface life (here, tuna schools and marine mammals) and fishing activities (here, nets and fish traps) can generate a SAR signal modulation of comparable order of magnitude at the *C*-band (5.3 GHz). This has confirmed expectation for SAR, after the preliminary experiment made in *X*-band (9.6 GHz). From the HAREM data, the results of satellite simulations, considering ERS1 characteristics, are presented and show good promise for fishing activity surveys. This high sensitivity of SAR provides unique opportunities to obtain direct information on fishing and surface marine life activities in large survey areas. From that, we assume that the aerial SAR data and, under certain conditions, satellite SAR data may dramatically enhance and complement classical methods (statistics) used in fishery management, the essential goal in halieutics.**

***Keywords*— Remote sensing, SAR, tuna fisheries, marine mammals, survey, ERS1.**

I. Introduction

For several years, classical weather radars and *X*-band SLAR (Side-Looking Airborne Radar) has been used in aerial surveillance of fish schools, particularly for tuna. SLAR is relatively lightweight and low-cost in comparison with SAR but it has a resolution that is coarser by an order of magnitude at more. HAREM is the first experiment on the use of SAR for surveillance of fish and fishing activities, although the operation of the SAR itself is neither new nor novel and although the fact that the fish activity can be detected with an airborne SAR is

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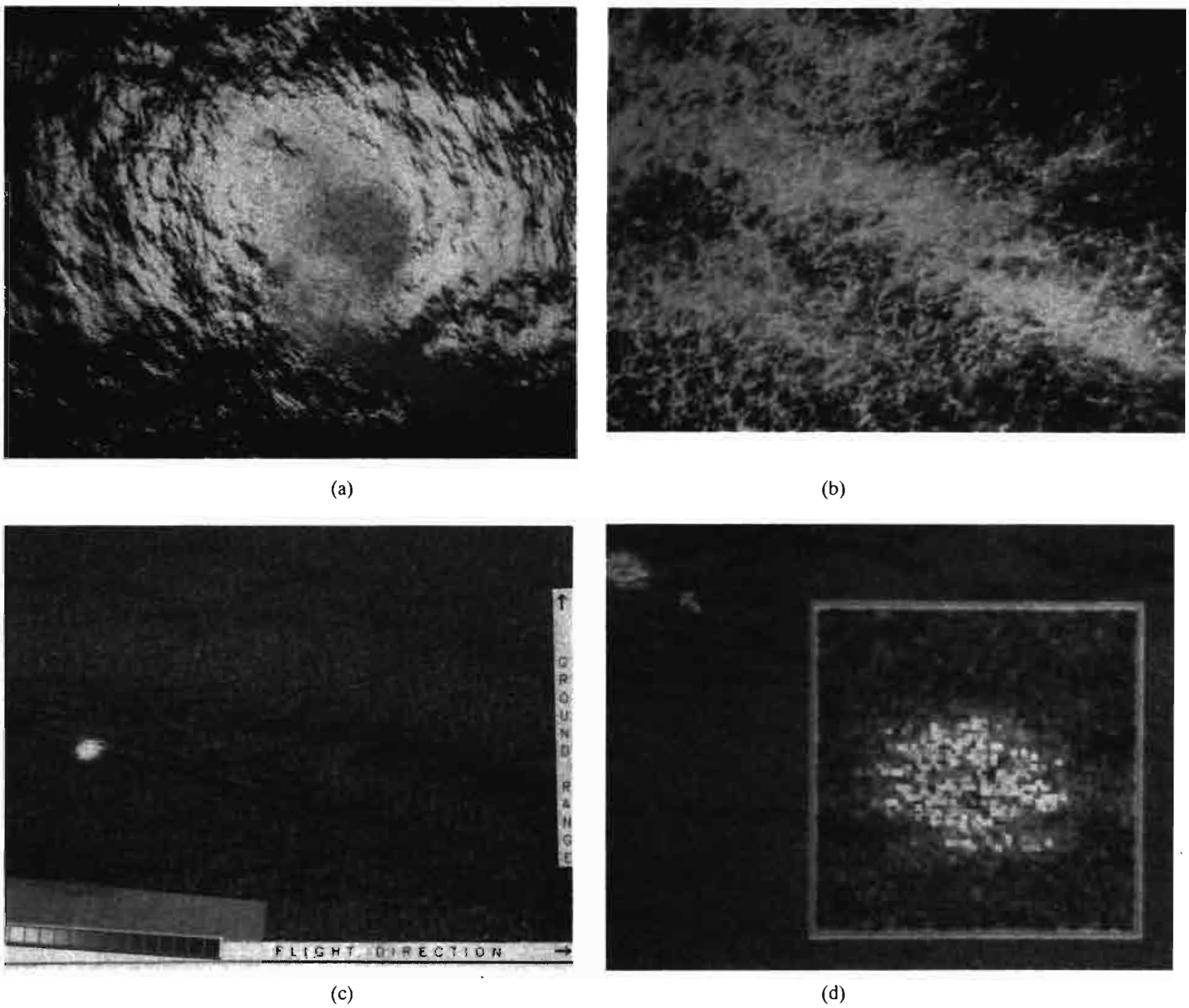


Fig. 1. (a) Bluefin tuna school from plane. This photo of characteristic tuna behavior, taken in the sunshine, gives a good idea of the physical phenomena which are able to be detected with SAR. (b) Another view of the "boiler" behavior of a tuna school on the surface. (c) Quick-look of SAR image of the tuna school, shown in (a). (d) After processing, the tuna school SAR image is desaturated and the structure of the school can be studied.

not surprising given our knowledge of how SAR works. As the SAR data can basically be translated in a map of sea surface roughness, on scales of the radar wavelength order (6 cm at C band and 3 cm at X band), they should be affected by fish and fishing activity that change the roughness of the surface at those scales.

The HAREM data include, for the first time, C-band VV-polarization SAR images of lagoon and ocean surfaces in fishery, tuna schools, and marine mammals activity areas. The SAR data have been provided by the aerial E-SAR/Dornier 228 high resolution radar device of German aerospace agency (DLR). Concurrent independent observations of tuna school size, cetacean identification, and fishing device positioning are also included for each scene, which allow a more rigourous interpretation of SAR signatures on these scenes. The ground-truth has been done by using the synchronous information from the Mediterranean French tuna purse seiner fleet and its aerial survey plane. A third small aircraft was used for low-altitude visual, photographic, and video observation of the small-scale fishery devices (nets, fish traps, and oysters beds) in lagoons.

Although most people have seen how a whale or a dolphin appears and breaks waves in the sea surface, the behavior of tuna schools close to the surface [7] has not been described very often. Most of the time, the fish are not breaking the surface but, if the school is reasonably compact, it causes a flattening of the surface. Fishermen call this behavior "breezing", which is easy to spot if the light and sun angle are correct as shown on Fig. 1(a). Sometimes, in relationship with feeding, this stable behavior turns into a myriad of jumps out of water, breaking the waves in a large area. This is the "boiler" or "smoker" school behavior (Fig. 1(b)).

So, in principle, the rough region produced by this behavior should change the radar's backscatter and should appear as bright features in a radar image. In agreement, Fig. 1(c) shows typical C-band images of the surface manifestation of a "boiler" school. The SAR incidence angle at this school is near 35°. Raw data have been motion compensated, following a German aerospace organization (DLR) method [8], to give a 2 x 2 m range and azimuth resolution image. This process corresponds to a four looks resolution degradation. It is possible to study the structure of the desaturated school signature (Fig. 1(d)).

This result could be the key to a new research direction, in so far as the jumping behavior of the fish is a feature of the species, and the number of jumps is related [7] to the tonnage of the school. For example, in boiler behavior, the bluefin tuna (*Thunnus thynnus*) "jump" is followed by a "come back". This is translated on the surface, as seen from the air, by a white line with an angle between 90° and 180°. And the larger the school, the more numerous are these jumps which tend to concentrate in the center of the school. This is translated in the tuna image by a radial gradient in the brightness. Presently, HAREM experiment data can give only indicative and qualitative information about the school in term of species and size. Several research programs will be necessary to increase accuracy in this type of assessment. We are at the same point in the state of the art as, several decades ago, with the beginning of the use of echosounders for halieutic surveys. However, the tools currently available, from a conceptual, mathematical [9] and software point of view, are much more advanced: Less time should be necessary to develop an operational technique. In particular, the relationship between the surface stock which is sampled by aerial methods and the actual abundance of biomass is now [9] known, and, currently is considered the basis of fish stock aerial monitoring.

The philosophy of the HAREM experiment is to use the SAR for surveys in fished or unfished Exclusive Economic Zones and for fishery management.

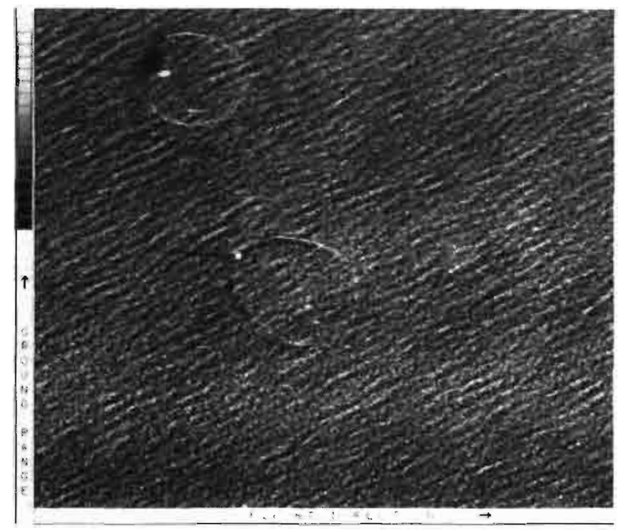
In the same spirit, the detection of nets and fishing devices has been studied for the tuna purse seining and small scale fishery in lagoons. Fig. 2 is processed as the scene of Fig. 1(c), and shows the major element in the purse seining *C*-band SAR image: The net's floats change the sea surface and consequently, produce a brighter ellipsod line which is included in a larger dark line. This dark ellipse corresponds to a smoothing of the waves when the seiner sets, as fast as it can, before the tuna school leaves. In the lee of the boat, the sea is calmer expressed in the image, as the dark spot near the boat. The straight dark line, parallel with the flight direction, is a well known artefact of this radar due to the strong return signal caused by the boat itself. All these features make the identification of purse seiner fishing activities easy and nonambiguous. Under appropriate sea state conditions, this suggests that the same kind of identification for large driftnets should be possible.

At a time when many of questions about the impact of driftnets on marine surface life are being asked, it appears timely to simulate a satellite SAR image of nets from HAREM data. While many ships have been observed using SAR's from space such as Seasat or the Shuttle (SIR-A and SIR-B), few detection of nets have been observed—or have interested the observers—and reported. As an example [3], the Colombia SIR-A coverage (0854 GMT, November 14, 1981, Rio de Oro Coast) shows a large group of fishing vessels of which many are small, traveling and working in pairs with a fishing net extended between them. Fig. 3 is a result of a degradation the aircraft SAR image of Fig. 2, following the radiometry, geometry, and other features of ERS1 with French space agency (CNES) software. Fig. 3, which would show the possibility of detecting the very characteristic signature of a purse seiner during the set from satellite SAR, could seem sufficiently indistinct to cast some doubt on this ability of satellite SAR's to detect such phenomena.

However, we must consider two essential points: First, the corresponding image of such a phenomenon is not at all of great utility in comparison with the identification and the localization of the setting seiner; and, second, this identification could be easily done with a pattern recognizing system, considering the size and the shape (circular) of the net and the extreme rarety of natural similar phenomena on the sea surface. Here too, we can imagine a new line of research: A simple expert system, on board future satellites, could automatically detect these signatures and send essential information for fishery management, containing the location of fishing activities.

In small-scale fishery management, the major problem is to collect statistics about distribution of fishing efforts, particularly in tropical zones where, very often, the classical enquiries are locally difficult to implement. If, by a flight, the complete inventory of fishing activities in an estuary or lagoon could be provided, the corresponding data would be an essential complement for the dynamic classical model [10].

(a)



(b)

Fig. 2. Tuna purse seiner in action and the corresponding SAR image.

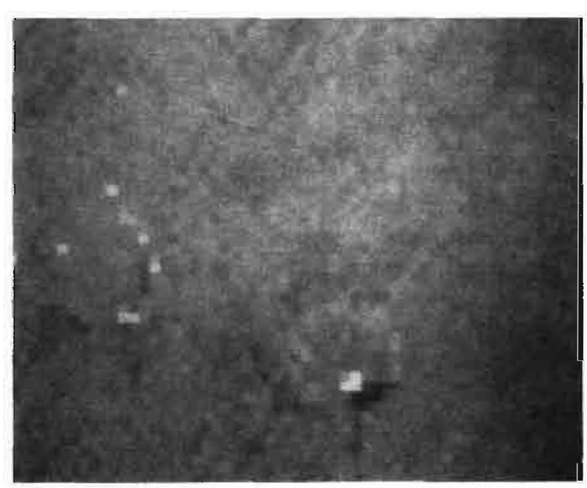
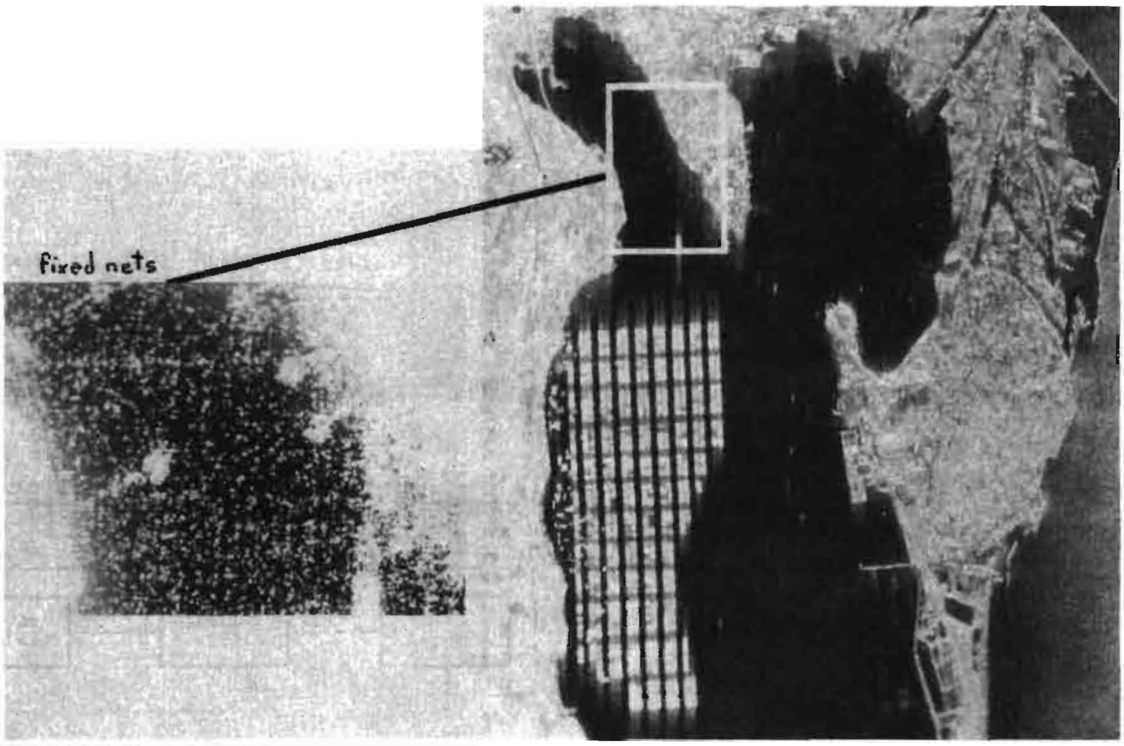
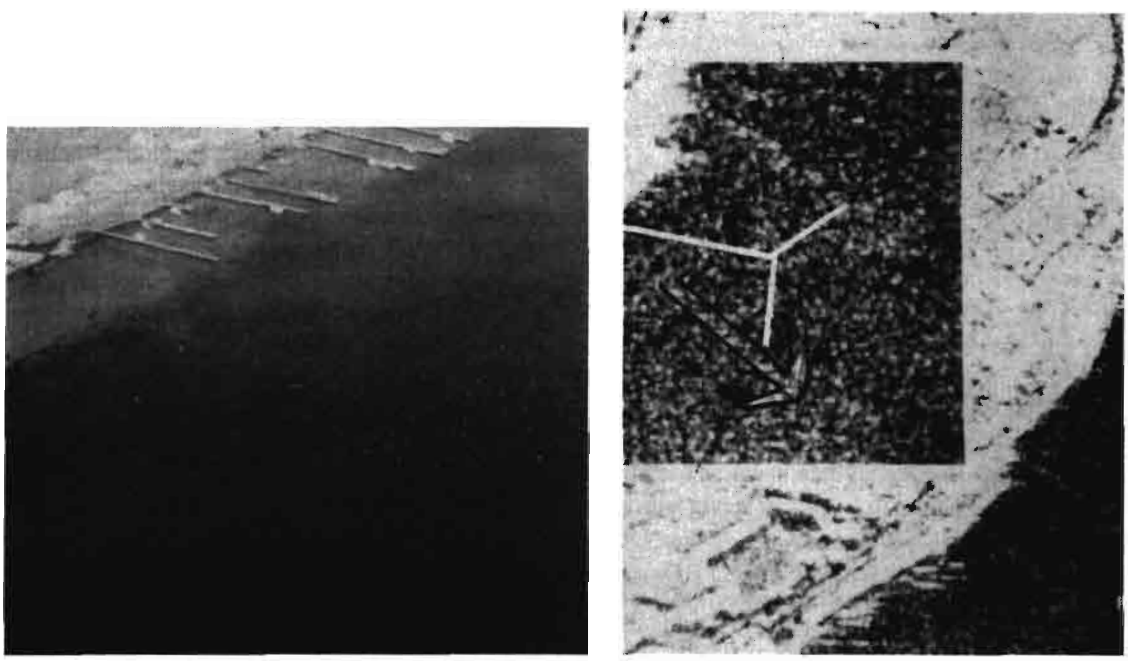


Fig. 3. ERS1 simulation of tuna purse seiner target from E-SAR data which corresponds to the processed image in Fig. 2.

Thus the lagoon part of the HAREM experiment has been to check if the fixed nets and fish traps in a small-scale fishery area change the water surface enough to be detected by the SAR sensor. Fig. 4(a) is a SAR *X*-band image of Thau lagoon (near Montpellier, France) recorded in a preliminary experiment in 1986 with French



(a)



(b) (c)

Fig. 4. (a) X-band SAR image of Thau lagoon (French Mediterranean coast) taken from the VARAN-S French radar in April 1986. Oyster table, fish traps and nets are detected. (b) Small- scale fishery coastal fixed net. This kind of net is present in numerous places, especially in the temperate and tropical waters. (c) C-band SAR image of Thau lagoon (as in (a)) from E-SAR German radar during HAREM. Details of fish nets in the same zone as in (a).

VARAN-S radar. This figure shows the oyster beds, well separated and with a nonhomogeneous brightness. The independent data [11] reveals that this is provided by a difference of material (wood or metal) of which the tables are made. More interesting is the detection of fixed nets. These targets are not easy to discern from boat or aerial photography (Fig. 4(b)). The SAR image identifies the backscatter changes provided by the "water emptiness" corresponding to wood stakes or floats. These fixed fishing nets are more difficult to detect with C-band, and HAREM data (Fig. 4(c)) does not give as good results as the VARAN-S preliminary experiment. Three reasons have been identified. First, for some scenes, a technical problem in the acquisition inverted the real parts and imaginary parts during the complex data generation. Secondly, the apparent radar surface roughness of targets are more adapted with X-band (3 cm) than with C-band (5 cm). Lastly, the peak power of VARAN-S is 30 times more powerful than the E-SAR one.

HAREM experiment data suggest a new line of research for fisheries management and the survey of marine surface life, in particular, for cetaceans and pelagic fish. Aiborne SAR could be more effective than any other monitoring technique, considering the large covered area, the noninfluence of clouds and the independence of the method facing of the fishery context. Now a large body of data on the geometric properties and radiometric signatures of these surface features should be collected during future aerial experiments and satellite simulations or actual satellite acquisitions (ERS 1), under a variety of wind, surface wave, and radar illumination and spectral band conditions. The next step is to improve the knowledge of the relationship between the schools' or nets' density and the radar image clues which would lead to conversion of schools or nets sensing into, respectively, abundance or fishing effort estimates, one of the major goals in halieutic surveys.

References

[1] M. Petit, J. M. Stretta, H. Farrugio, and A. Wadsworth, Etudes et thèses (Collection ORSTOM, 1990).
[2] W. Alpers, *Nature* vol. 314, pp. 245–247, 1985.
[3] J. P. Ford, J. B. Cimino, and C. Elachi, JPL Publication 82–95, 1983.
[4] B. A. Huges and J. F. R. Gower, *J. Geophys. Res.*, vol. 88, pp. 1809–1824, 1983.
[5] B. A. Huges, *J. Geophys. Res.*, vol. 83, pp. 455–465, 1978.
[6] R. F. Gasparovic, J. R. Apel, A. Brandt, and E. S. Kasischke, Tech. Digest. 6, 4, pp. 338–345, Johns Hopkins University Applied Physics Laboratory, 1986.
[7] M. Petit and J. M. Stretta, Collective vol. SCRS/88/32, 30, pp. 488–490, Int. Commission for the Conservation of Atlantic Tunas, 1989.
[8] R. Horn, *Proc. of IGARSS*, 1988.
[9] M. Petit, J. M. Stretta, and C. Dupouy, Doc. Tech. 302, pp. 127–140, FAO, 1989.
[10] J. F. Caddy and G. P. Bazigos, Doc. Tech. 257, FAO, 1985.
[11] A. Wadsworth, Doc. Tech. GDTA, Dec. 1986 Groupement pour le Développement de la Télédétection Aérospatiale, Toulouse, 1986.

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