Title: **Satellite surveillance for maritime border monitoring**	
Author: H. Greidanus	**Number:**
File: GMOSSBordMon1-2.doc	**Version:** 1-2
Project: GMOSS	**Date:** 25 Aug 2004
Distribution:	

Abstract

Present day remote sensing satellites could be used to supplement maritime border monitoring in some specific cases. In combination with airborne surveillance they can serve to extend the effective patrol area. Furthermore they can be used to survey the less visited border areas for increased suspect vessel movements. The sensors of choice are either RADARSAT in its Fine beam mode, guaranteeing coverage but providing little information on ship type, or SPOT-5 2.5 m resolution panchromatic, which functions only in cloud-free daylight but has a much higher capability of recognizing vessel types.

1. Introduction

The monitoring of border crossings is one of the prime issues in security, as a significant number of security threats enter a country from abroad. For many countries, part of the border is on the sea; this is especially the case for Europe as a whole. There is, therefore, a need for maritime border monitoring.

At present, the maritime borders are guarded in several ways:
- Controls of ships coming into ports, mainly in the ports themselves;
- Inspections by ships on the sea within territorial waters;
- Inspections from aircraft (helicopter or fixed wing);
- Radar from coastal sites.

Different European countries use the above means in different mixes, and organizationally the controls are carried out by various bodies such as Customs, Coast Guard, Navy, Police, etc.

Given the above situation, and the recent availability of satellites with earth observation capability, a short exploration was carried out as to the suitability of satellite observation for maritime border surveillance.

2. Method

Satellite images from the Straight of Gibraltar were collected. This site was chosen because it is a constricted area with maritime traffic, it is a European border, there are two large ports on the European side (Algeciras and Gibraltar) and there are large current problems with border security related to smuggling and illegal immigration. As a consequence of the latter, already quite some effort is concentrated in this region to counter these illegal transports, in the form of strict customs controls in the ports supported by various high tech methods, and an array of coastal radar stations for detection of suspect ship traffic, plus the means of following up these detections by launching and directing patrol boats on the water as well as automotive patrols on the shore.

The satellites from which images were collected are listed in Table ##T1.

Satellite	Type / sensor	Resolution	Area	Images
RADARSAT	Radar / Fine beam	8 m	50 x 35 km^2 50 x 50 km^2	2 2
SPOT-5	Optical / Multi-spectral	10 m	60 x 60 km^2	1*
	Optical / Panchromatic	5 m	60 x 60 km^2	3*
	Optical / Panchromatic	2.5 m	60 x 60 km^2	2*
EROS	Optical / Panchromatic	1.8 m	11 x 11 km^2	2

Table ##T1. Satellite images collected over Gibraltar Straight.
*: The SPOT images pertain to a total of 4 different acquisitions, some of them simultaneously imaged in different modes.

The images were collected in the period 27 Aug 2003 – 26 Sept 2003 plus one image on 10 June 2003.

At the same days also data on ship traffic from coastal and port radars were collected. The coastal radar was the "SIVE" array of coastal radar operated by the Spanish Guardia Civil. This system consists of several radar posts along the South Spanish coast that continually survey the coastal waters, and relay their data to a central command post in Algeciras. This central command is able to launch intercept vessels in case a suspicious track is detected by the radar.

The port radar was the VTS from Algeciras port, i.e., the Vessel Traffic System that operationally manages all ship traffic in the harbor of Algeciras.

3. Results

3.1 Results from the SIVE coastal radar

The SIVE radar produced images of detected ships plus their tracks approximately in the same area as was covered by the satellite images. An example is shown in Figure ##F1. Unfortunately, there were timing problems which prevented a perfect synchronization between the SIVE radar images and the satellite images. Therefore, it has up to now not been possible to perform detailed correlations between the ship traffic in the coastal radar images and in the satellite images.

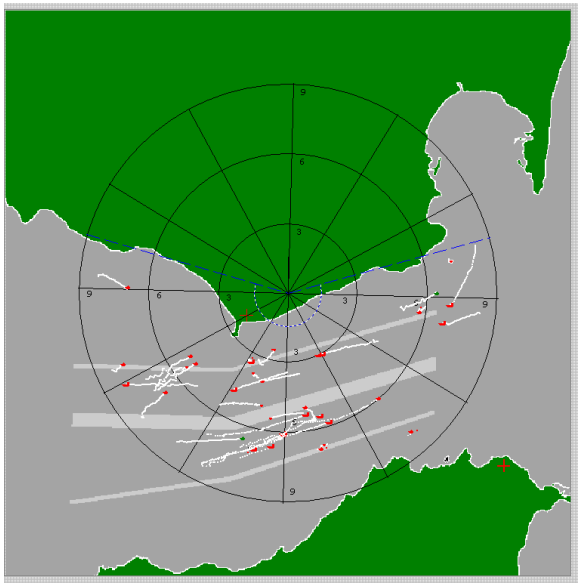

Figure ##F1. SIVE screen dump of one of their radar stations of 27 August 2003. Land is green, Spain to the North (up), Morocco to the South (down). The red and green dots are ships.

3.2 Results from the Algeciras port VTS

The Algeciras port VTS provided the positions and identities of ships that were in Algeciras harbor and registered with the port authorities at the times of satellite image acquisition. In addition, it gave screen dumps of the situation; one is shown in Figure ##F2.

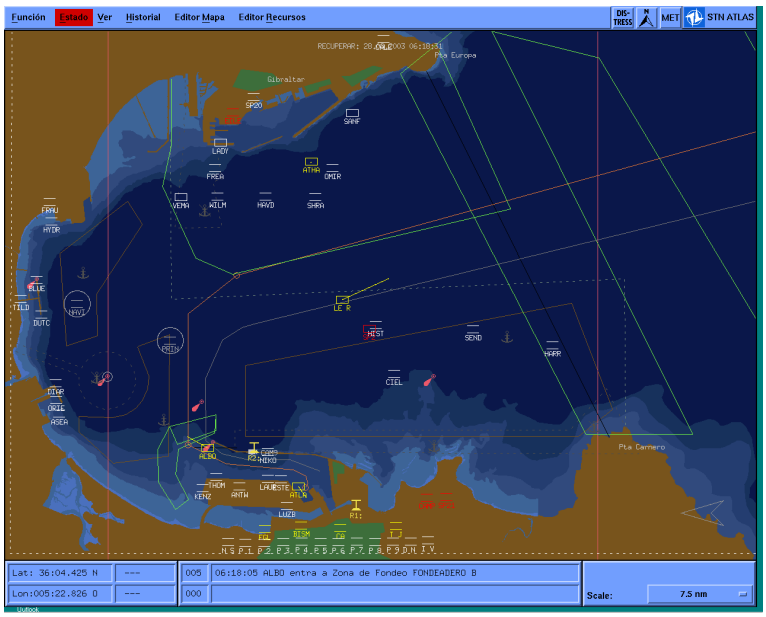

Figure ##F2. Screen dump from the Algeciras port VTS, 28 August 2003. (North is to the left, the region is the Bay of Algeciras with the Gibraltar peninsular above and Algeciras below.)

3.3 Results from RADARSAT

The four RADARSAT images show many ships. Figure ##F3 shows one of the images. At the 8 m resolution, the larger ships reveal their shape, and their length and width can be estimated. It is possible to make a rough classification based on that, but a detailed classification is beyond the capabilities of the radar image. Fast moving ships are distorted, as is expected from Synthetic Aperture Radar (SAR) imagery. Figure ##F4 shows some examples of how ships appear in the radar image. Figure ##F5 shows a comparison of a part of a RADARSAT image with the concurrent Algeciras port VTS screen.

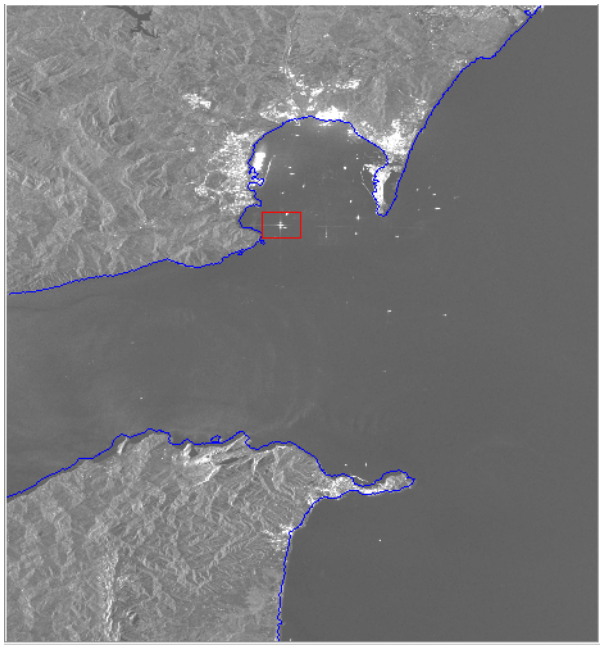
Figure ##F3. RADATSAT image of 26 September 2003. The coast line is overlaid. North is approximately up.

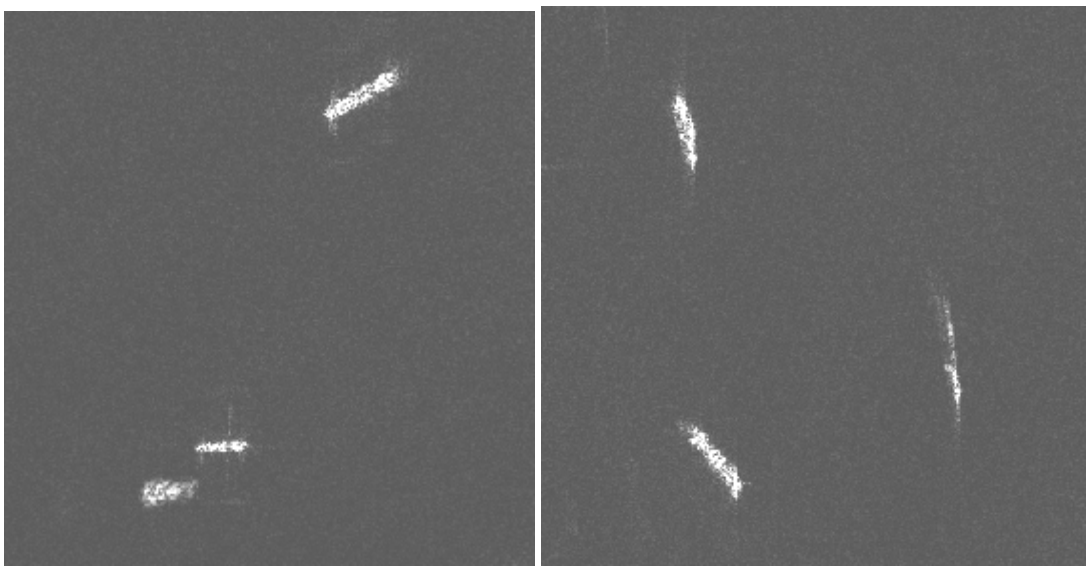

Figure ##F4. Details of RADARSAT images showing ships. The rightmost target resembling a streak is a fast moving ferry and its shape is distorted. The dimensions of the ship below left of that one are 350 x 50 m.

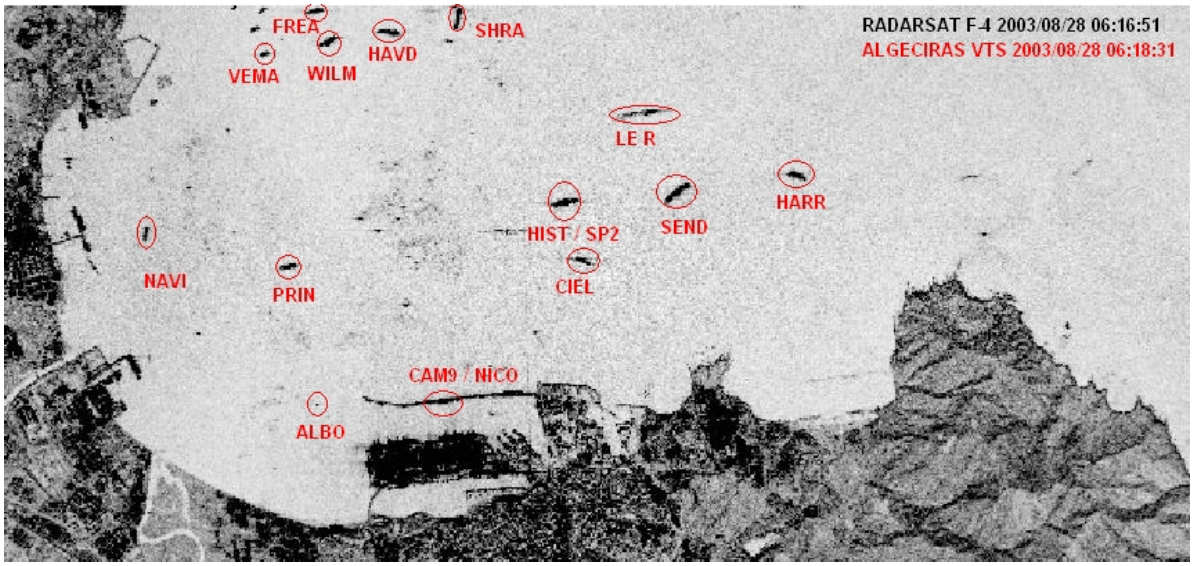

Figure ##F5. The Bay of Algeciras as imaged by RADARSAT on 28 August 2003, with the ship identifications from the port VTS system (ref. Fig. ##F2) overlaid in red. (Compared to Figures ##F3 and ##F4, this image is negative.)

3.4 Results from SPOT

The SPOT multi-spectral images contain four spectral bands (corresponding to blue, green, red and near infrared) at 10 m resolution. The panchromatic images are available at 5 m resolution and 2.5 m resolution. The multi-spectral and 2.5 m panchromatic are compared in an example in Figure ##F6. It would seem that the higher resolution provides more relevant information than the color, as far detecting and recognizing ships is concerned.

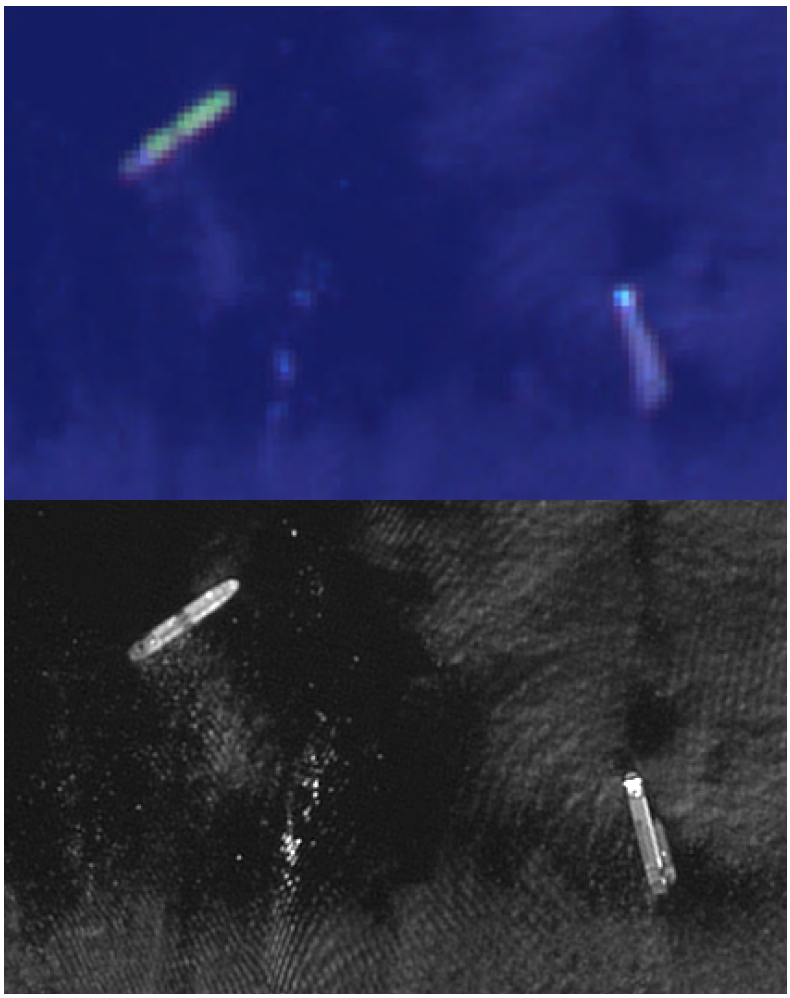

Figure ##F6. Part of a SPOT-5 image; the same scene in 10 m resolution multi-spectral (red, green and blue channels) on top, and in 2.5 m panchromatic on the bottom.

3.5 Results from EROS

An example of EROS is shown in Figure ##F7. With its 1.8 m resolution, this sensor provides the most information of those used in this study. It is easy to detect ships, also smaller ones; to recognize that ships are moored together; and to classify the larger ships as cargo, tanker, etc. However, the EROS image size is only rather small, 11 x 11 km^2.

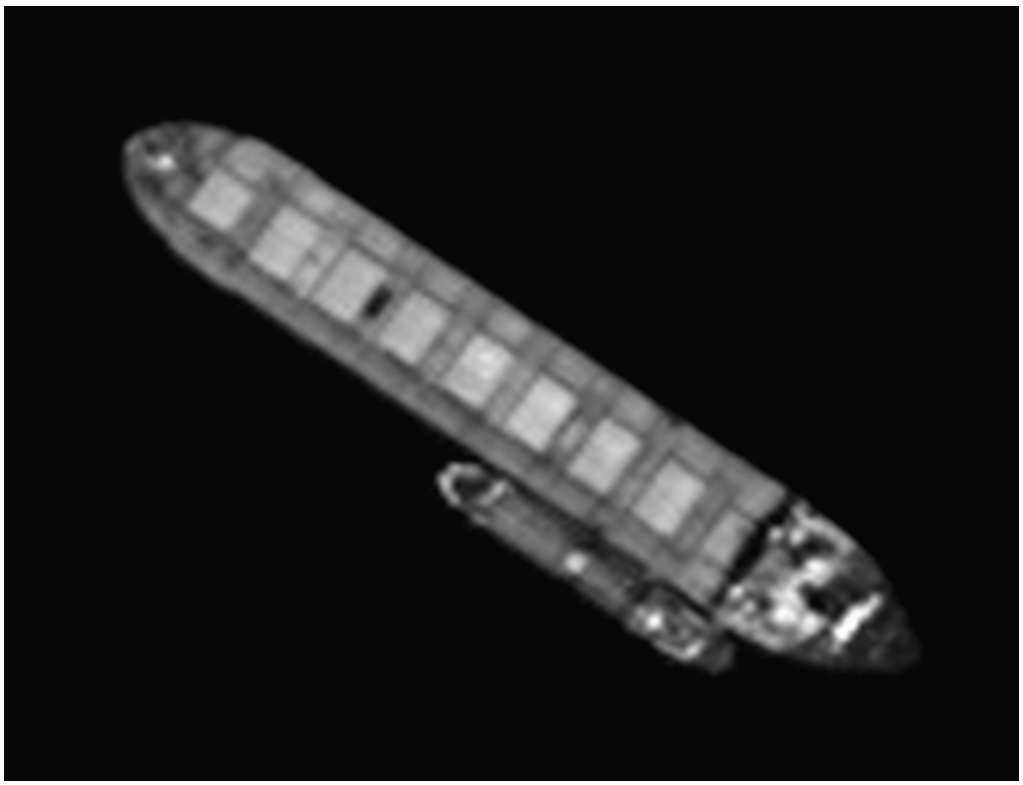

Figure ##F7. EROS image detail. Bicubic interpolation was carried out here in order to obtain a smoother image.

4. Discussion and main conclusions

The study is not completed at this time. Much of the data remains unexplored yet. Unfortunately it was impossible to make detailed correlations between the radar images and the coastal radar data due to synchronization problems.

Notwithstanding the above, the main conclusions are already clear.

RADARSAT in Fine beam mode and SPOT cover areas that are marginally large enough for maritime border monitoring. One or a few images with their 50 – 60 km linear size can cover specific areas which are known to be vulnerable to security risks. They are too small, however, to monitor more extended sea borders and coastal zones. In any case, with the present earth observation satellite configurations, the monitoring will never be continuous, but only of a snapshot nature, with a repeat frequency of the order of once per few days. This situation will remain the same in the foreseeable future, except that the repeat frequency will improve. Of these two satellites, RADARSAT (and similar SAR satellites) have the advantage that they are cloud and daylight independent, so one is guaranteed an image, but ship classification power is very limited. SPOT (and similar satellites) on the other hand provide much more information on ship type, but only work with clear skies and in the daytime.

For SPOT, the best choice seems to be 2.5 m resolution panchromatic. The extra color information in the multi-spectral images does not outweigh the loss of resolution from 2.5 m to 10 m. Also the 2.5 m panchromatic is preferable over the 5 m panchromatic (no examples were shown here to demonstrate this); the factor 2 extra resolution is very helpful for the recognition, both for smaller and larger targets. The SPOT-5 panchromatic 2.5 m resolution combines a high resolution with a large (60 x 60 km^2) field of view; these data sets are correspondingly large, and unfortunately also correspondingly expensive in terms of their list price.

EROS, and similar very high resolution optical satellites such as IKONOS and QUICKBIRD, are limited by their very small field of view. They are not really suitable to monitor border areas or border lines, only to monitor spots (such as ports). Also they are limited to clear weather and sunlight. On the plus side, they do give superior recognition capability.

Compared to the traditional means of surveillance for maritime border monitoring, satellite imaging can for sure not replace any of them at the moment. Any local or close-in inspection – in ports and from inspection ships and aircraft – is able to provide much more detailed information. Coastal and port radars are able of continuous

monitoring, which satellite observation is not. However, all these means are only locally available. Land based radars have a limited range, inspection ships only move slowly, and also surveillance aircraft can only be in one place at the time and are costly to operate. The niche for satellite imagery in border monitoring must be found in *supplementing* the existing surveillance spectrum. Satellite images can be used in conjunction with patrol flights, to extend the coverage of the aircraft. Alternatively, satellite images can be used to survey areas which are out of range of coastal radar stations and usual patrol areas, in order to assess shipping activity and give warning of increased potentially suspect vessel movements.

Acknowledgments

Several entities have made this research possible, and they are all gratefully acknowledged here for their help. The SIVE project of the Spanish Guardia Civil provided the radar data from the SIVE system. Mondragon Sistemas de Information of Maliaño, Spain, provided the radar data from the Algeciras port VTS. RADARSAT International provided the RADARSAT data free of charge. SPOT Image provided the SPOT data at favorable cost. ImageSat International provided good service with the EROS data.