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Evaluating the performance of the space-borne SAR sensor systems for oil spill detection and sea monitoring over the south-eastern Mediterranean Sea 1

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Synthetic Aperture Radar (SAR) images have been extensively used for the detection of oil spills in the marine environment as they are independent of local weather conditions, cloudiness and sun illumination. The objective of the study was to provide the users with specific knowledge on SAR image availability over a target area and assess the monitoring capability (visibility of an area) with respect to the requirements for oil-spill detection and marine environment protection over the south-eastern part of the Mediterranean Sea. For this purpose, a web GIS tool was been implemented, enabling the user to submit their queries and receive answers in the form of reports and statistics, concerning the current image acquisition capability over the area of interest. It also provides the user with graphic representations of the sensors' swath coverages over the same geographic location. The system has been tested over the Hellenic Seas and the resulting figures denoting the temporal resolution in the observation are analysed and discussed. The analysis shows that the operation of the Envisat satellite, in conjunction with ERS-2 and Radarsat satellites, has significantly improved the monitoring capability. As shown, the increase in the number of observations over a target location can reach theoretically a level of 130%. In conclusion, the study provides the user with an assessment of the remaining technological gaps and unmet user needs in the domain of marine environment protection. 2

1. Introduction

The Mediterranean is a semi-enclosed sea with land-locked waters of very low renewal rate. As the ship traffic is very important in its waters, the Mediterranean is extremely sensitive to pollution (Pavlakis *et al.* 2001). Activities, often illegal, such as dry-docking, marine terminals, ship cleaning and tanker accidents result in the release of large quantities of crude oil in the sea, which can vary between 300 000 and 1200 000 tones per year (Pavlakis *et al.* 1996, http://www.panda.org/about_wwf/where_we_work/mediterranean/threats.cfm). This renders the problem of marine pollution extremely important, considering that every oil spill, regardless of its size, may result in considerable environmental damage, depending on the season, geographic location, weather conditions and type of oil spilled. Figure 1 shows clearly the problem and shows why there is great political and scientific interest in serving the affected communities.

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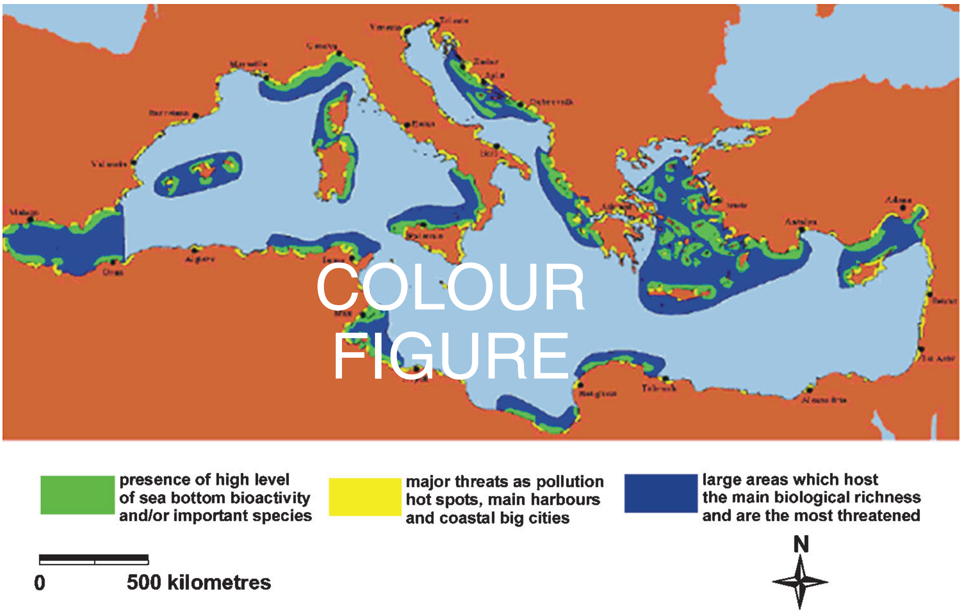

Figure 1. Map showing the ecologically sensitive areas in the Mediterranean Sea (in green), the areas historically affected by oil spills (in yellow), as well as the areas that are considered as highly endangered for oil spilling (in blue) (Gemelli and Volden 2001). 3

The protection of the marine environment has been the subject of several international co-operation frameworks such as the Bonn Agreement (1969), the Helsinki Convention (1974), the Barcelona Convention (1976), the MARPOL Convention (73/78), and the Mediterranean Action Plan (MAP) 75/95. In 1987, the sixth EU Ministerial meeting adopted a resolution in the form of the Open Partial Agreement, which foresaw the use of space technology in the operations. As a consequence, several studies attempted an assessment of the contribution of Earth Observation in the routine detection and surveillance of the marine environment such as the European-funded projects RAMSES, OILWATCH, ROSES, CLEANSEAS, COASTMON, RAPSODI, OCEANIDES, DISMAR, COASTWATCH and MARSAIS (Pedersen *et al.* 1996; Trivero *et al.* 1998, Espedal and Wahl 1999, Jolly *et al.* 1999, Espedal and Johannessen 2000, Johannessen *et al.* 2000, Vogt 2003, Fiscella *et al.* 2000a,b), leading to the conclusion that satellite sensor derived data can be useful for a number of reasons. The integration of radar sensor data with optical imagery provides a clear picture of the extent of disaster and assists the implementation of cleaning practices (Johannessen *et al.* 1994, Pavlakis *et al.* 1996, Jones 2001, Pollock and Bauna 2001, Pavlakis *et al.* 2001). Moreover, radar sensors on board satellites perform better compared with airborne ones, due to their wide area coverage and their capability of operating day and night independently of cloud conditions. Finally, a monitoring service, which has been based on the combined use of space-borne with 4 airborne sensors is by far much more cost-effective than the single operation of aircrafts (e.g. the SFT—Norwegian Pollution Control Authority operations). It is worth noting here that due to the high operation costs, an aircraft cannot be used for more than 200–300 hours per year. A good overview of the possibilities provided by the combined use of space-borne Synthetic Aperture Radar (SAR) and airborne

Sideward Looking Airborne Radar (SLAR), Laser-Fluoro Sensor (LFS), UltraViolet (UV) and MicroWave Radiometer (MWR) sensor systems is given by Al Kudhairy (2002).

However, there are still important limitations on the use of space-derived SAR observations, mainly relating to the poor temporal resolution of the data and the susceptibility of the imaging systems to lookalike artefacts and sea conditions. Moreover, the SAR imaging systems onboard satellites cannot be used for determining the physical and chemical properties of the pollutants and the likely pollution culprit. In practice, due to the limited number of SAR sensor platforms, monitoring from space has become operational only at polar latitude areas. In these areas the satellite coverage is twice as good as for the Mediterranean Sea.

However since 2003, the space-based monitoring capability has significantly improved after the successful launching and operation of the Envisat satellite. This increased interest in further studying the newly offered opportunities for near real-time surveillance, by combining the Envisat Advanced Synthetic Aperture Radar (ASAR) sensor together with the other two operational SAR sensors on board the ERS-2 and the Radarsat satellites. This paper examines the potential of the combined use of the three SAR sensors for efficient monitoring over the Mediterranean Sea. It describes a web-based geographic information system (GIS) tool that has been implemented to assist the user with several reporting facilities in order to assess the availability of image data over any geographic location. A description of the system, its operating modes and the implemented user interfaces, are given in §2 of this paper. The testing of the system over a representative part of the south-eastern Mediterranean Sea, which has been selected to be the Hellenic Seas, and the analysis of the returned figures denoting the current temporal resolution in the observation, are described exhaustively in the §3 of the paper. This analysis provides the basis to further explore the remaining technological gaps and unmet user needs in the domain, and draw conclusions on the specifications for the future satellite and sensor developments.

2. Implementation of a web interface informing on the occurrence of a space-borne SAR sensor over a target area

There are few user-oriented tools informing on the satellite coverage and the most suitable sensor configurations that provide the maximum surveillance rates over a target area. Beaudouin and Nicolas (2003) proposed a theoretical model for estimating the revisiting time over a target area, by using satellite ephemeris data and orbital parameters in conjunction with the geographic location of the area of interest.

This paper describes a module that has been developed to inform the user of the availability of any of the existing space-borne SAR sensors over a user-defined target location in a specific time frame. The core of the module is a GIS tool developed on a common ESRI/ArcGIS platform incorporating specifically customized user interfaces. It helps assessing the degree for systematic monitoring at any geographic location and time. This module makes part of a more complicated system accessible through the web, which is designed to cover the following tasks (http://spin-pc.space.noa.gr):

- Consult the user on the availability of any of the existing satellite SAR sensors over a target area.

- Apply automatic oil spill recognition on selected SAR images.
- Make systematic forecasts for the dispersion of the oil spilled. For this purpose, the system integrates models that account for sea-state conditions in the affected area. It provides the user with a series of images and reports, representing the dynamic change of the damaging event within user pre-defined time frames that may vary from 30 min up to 3 days.

The system's databases integrate a variety of graphic layers and attribute information relating to the following.

2.1 *The sensor*

Currently three satellites carrying SAR sensor instruments are supported. These are as follows.

2.1.1 **ERS-2 operating its SAR sensor in the image mode.** A set of vector layers and attribute tables, informing on the full ERS-2 coverage from the ascending and descending passes of the satellite, has been integrated. These graphic layers show the projected footprints of the scenes acquired within the 35-day period of the satellite, with each date being represented by a separate graphic layer.

2.1.2 **Radarsat operating its SAR sensor in the ScanSar Narrow A beam mode.** This particular operating mode has been widely used for the detection of oil spills and the surveillance of passing ships in the seas. The sensor's spatial resolution and incidence angle characteristics are best suited for this type of applications, while allowing for wide area coverage (300 km × 300 km). It has been used for years in the operational monitoring of the North Sea, the Barents Sea, the Atlantic, the Irish Sea, and the Baltic Sea (e.g. Tromso Satellite Station (http://www.tss.no/tssweb/services/), Canada Centre for Remote Sensing (http://www.ccrs.nrcan.gc.ca/ccrs/rd/apps/marine/oilspill/details_e.html), Vogt 2003)). Therefore, as for the ERS-2 satellite, the full-frame coverage corresponding to the complete 24-day period of the satellite has been integrated as a set of graphic layers in the system's database.

2.1.3 **Envisat operating the ASAR sensor in the Wide and Narrow swath modes.** As before, the full-frame coverage resulting from the ascending and descending passes of the Envisat satellite in its 35-day period has been integrated in the graphical database of the system. As for the other two cases mentioned previously, a separate graphic layer was used to represent the frame coverage for a single day. The two ASAR operating modes known as 'wide' and 'narrow' were taken into consideration (http://Envisat.esa.int/dataproducts/availability/). Also for compatibility purposes, the ASAR sensor has been considered as working in the so-called 'ERS-2 like' operation mode, meaning that the incidence angle of the beam is in the same range as for the ERS-2 SAR sensor.

For the user's convenience some additional layers were also integrated as follows.

2.1 *Port Authorities map*

This represents the areas under the responsibility of the Port Authorities in the entirety of the Hellenic Seas.

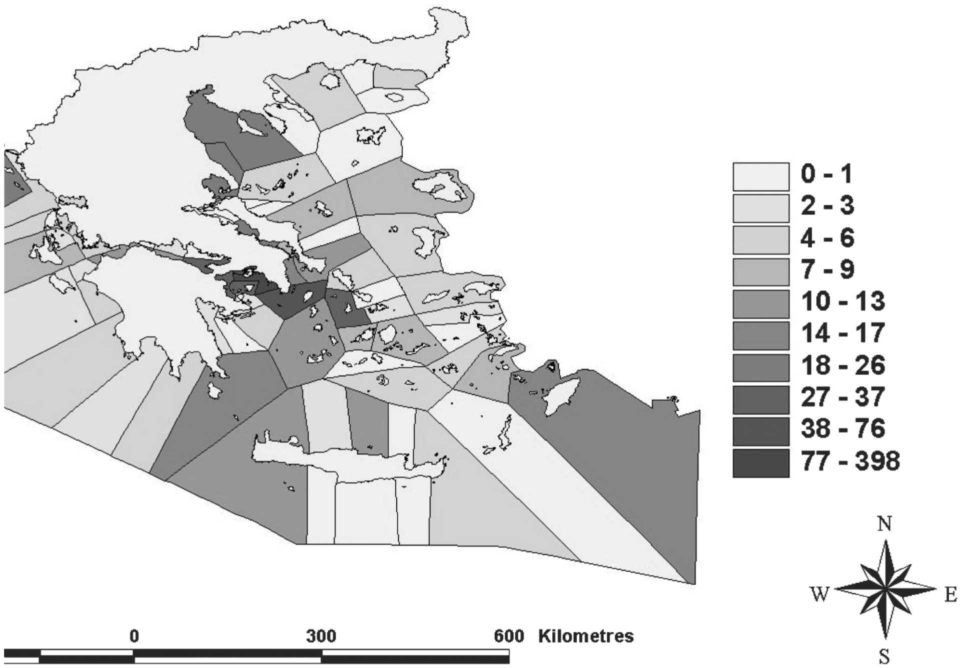

Figure 2. Map showing the oil spill accidents as reported by the Hellenic Port Authorities during the last 7 years.

2.2 *Accident map*

This is a layer denoting the number of accidents reported per Port Authority during the last 7 years (e.g. type of oil spill, date of the accident, area affected, etc.). Figure 2 is a thematic representation of these two layers.

2.3 *Sensitivity index map*

This is a layer representing an index providing insights into the most endangered and prompt to pollution seas throughout the Hellenic territory. 5

As mentioned, the developed system makes use of a set of reference swaths corresponding to a single satellite period. This is the basis for 'predicting' any satellite pass over a target area. It is assumed that any specific to the acquisition date and time, corresponds to a unique moment *K* in the satellite's period of *N* days, and that the same acquisition will be repeated in *K*+*N* days. Therefore by launching an internal calculation, the system returns a detailed list reporting the availability of the three satellites over a specific area for any user-defined date. To confirm the validity of the results, the predicted acquisitions were compared with the ones available in the ESA's and Radarsat International (RSI) archives, from past ERS-2 and Radarsat SAR sensors acquisitions, showing that the two datasets were in perfect conformity.

In practice the user of the system is prompted to enter the single date(s) or entire time frame(s), the target area(s), and the satellite system(s) of interest. They can also customize their queries by combining data from various graphic layers. The system returns a set of graphical representations, illustrating all satellite passes over the target area together with reports about the sensor identity and its characteristics

Table 1. An example of a report provided to the user. It shows all satellite passes over a randomly selected 2 km × 2 km area in the Aegean Sea located at 37°20.4′ N, 23°5.4′ E. It corresponds to the period from 4 January to 30 January 2003. A comparison with the ESA's archives showed absolute coincidence between the archived and the predicted acquisitions. EW-a and EW-d stand for Envisat Wide swath ascending (-a) and descending (-d) passes, respectively; SNA-a and SNA-d stand for Radarsat ScanSar Narrow A mode ascending (-a) and descending (-d) passes, respectively; E2-a and E2-d stand for ERS-2 ascending (-a) and descending (-d) passes, respectively. The columns 'Area' and 'Perimeter' represent the size (in km^2) and the perimeter (in km) of the part of the target area covered by each satellite pass. The column 'Coverage' represents the percentage of the total target area being covered by each satellite pass.

Area	Coverage (%)	Perimeter	Mission	Orbit	Track	Frame	Time	Date	ULX	ULY	URX	URY	LLX	LLY	LRX	LRY	CCX	CCY
4.00	100	8.00	EW-a	3933	372	756	20:11	04 Jan.	26.9500	40.4333	27.7167	36.8833	22.1667	39.7167	23.1500	36.1667	25.0500	38.3000
4.00	100	8.00	E2-a	37801	372	747	20:41	04 Jan.	23.1000	38.0000	24.2000	38.1833	23.3333	37.1167	24.4333	37.3000	23.7667	37.6500
4.00	100	8.00	EW-d	3940	379	2844	8:25	05 Jan.	23.6333	40.1667	28.4167	39.4500	22.8833	36.6167	27.4333	35.9000	25.5333	38.0333
4.00	100	8.00	SNA-a	37–318A	29.08	–	16:17:37	06 Jan.	21.4333	39.0500	24.9167	39.5833	22.1667	36.3333	25.5333	36.8667	23.5167	37.9667
4.00	100	8.00	EW-a	3976	415	756	20:17	07 Jan.	25.5167	40.4333	26.2833	36.8833	20.7167	39.7167	21.7167	36.1667	23.6167	38.3000
4.00	100	8.00	SNA-d	97–325D	29.08	–	4:32:09	07 Jan.	22.7000	39.4500	26.1667	38.9333	22.0833	36.7500	25.9333	36.2167	24.1000	37.8500
4.00	100	8.00	EW-d	3983	422	2844	8:30	08 Jan.	22.2000	40.1667	26.9833	39.4500	21.4333	36.6167	25.9833	35.9000	24.1000	38.0333
4.00	100	8.00	EW-a	3518	458	756	20:23	10 Jan.	24.0833	40.4333	24.8500	36.8833	19.2833	39.7167	20.2833	36.1667	22.1833	38.3000

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Table 1. *(Continued)*

Area	Coverage (%)	Perimeter	Mission	Orbit	Track	Frame	Time	Date	ULX	ULY	URX	URY	LLX	LLY	LRX	LRY	CCX	CCY
4.00	100	8.00	EW-d	3525	465	2844	8:36	11 Jan.	20.7667	40.1667	25.5333	39.4500	20.0000	36.6167	24.5500	35.9000	22.6500	38.0333
4.00	100	8.00	E2-d	37894	465	2853	9:07	11 Jan.	23.4667	37.9167	24.5667	37.7500	23.2333	37.0333	24.3167	36.8500	23.8833	37.3833
4.00	100	8.00	SNA-a	98–75A	29.08	–	16:13:26	13 Jan.	22.4667	39.0833	25.9500	39.6167	23.2167	36.3833	26.5667	36.9000	24.5500	38.0167
4.00	100	8.00	SNA-d	98–82D	29.08	–	4:27:59	14 Jan.	23.7333	39.3833	27.2000	38.8500	23.1167	36.6667	26.4667	36.1333	25.1333	37.7667
4.00	100	8.00	EW-a	3661	100	756	20:08	20 Jan.	27.6667	40.4333	28.4333	36.8833	22.8833	39.7167	23.8667	36.1667	25.7667	38.3000
4.00	100	8.00	EW-d	3668	107	2844	8:22	21 Jan.	24.3500	40.1667	29.1333	39.4500	23.6000	36.6167	28.1500	35.9000	26.2500	38.0333
4.00	100	8.00	EW-a	3704	143	756	20:14	23 Jan.	26.2333	40.4333	27.0000	36.8833	21.4333	39.7167	22.4333	36.1667	24.3333	38.3000
4.00	100	8.00	SNA-a	98–218A	29.08	–	16:21:48	23 Jan.	20.4000	39.0000	23.8833	39.5333	21.1333	36.2833	24.4833	36.8167	22.4667	37.9167
4.00	100	8.00	EW-d	3711	150	2844	8:27	24 Jan.	22.9167	40.1667	27.7000	39.4500	22.1667	36.6167	26.7167	35.9000	24.8167	38.0333
4.00	100	8.00	SNA-d	98–225D	29.08	–	4:36:21	24 Jan.	21.6667	39.5000	25.1333	38.9667	21.0500	36.8000	24.4000	36.2667	23.0667	37.9000

Table 1. *(Continued)*

Area	Coverage (%)	Perimeter	Mission	Orbit	Track	Frame	Time	Date	ULX	ULY	URX	URY	LLX	LLY	LRX	LRY	CCX	CCY
4.00	100	8.00	EW-a	3747	186	756	20:20	26 Jan.	24.8000	40.4333	25.5667	36.8833	20.0000	39.7167	21.0000	36.1667	22.9000	38.3000
4.00	100	8.00	EW-d	3754	193	2844	8:33	27 Jan.	21.4833	40.1667	26.2667	39.4500	20.7167	36.6167	25.2667	35.9000	23.3833	38.0333
4.00	100	8.00	EW-a	3790	229	756	20:26	29 Jan.	23.3667	40.4333	24.1167	36.8833	18.5667	39.7167	19.5667	36.1667	21.4667	38.3000
4.00	100	8.00	EW-d	3797	236	2844	8:39	30 Jan.	20.0500	40.1667	24.8167	39.4500	19.2833	36.6167	23.8333	35.9000	21.9333	38.0333
4.00	100	8.00	SNA-a	37–318A	29.08	–	16:17:37	30 Jan.	21.4333	39.0500	24.9167	39.5833	22.1667	36.3333	25.5333	36.8667	23.5167	37.9667

(e.g. operation mode, viewing angle, ascending, descending, etc.), the time and date of the predicted acquisitions, their geographical extent, the percentage of the target area covered by each acquisition, etc. (table 1). From the above it becomes evident that although this system has been designed to meet the needs of the Hellenic Port Authorities, it can be easily expanded to cover the whole Mediterranean Sea or any other place in the globe. 6

3. Assessment of the observing temporal resolution over the south-eastern Mediterranean Sea

The following two system configurations have been used in the calculations: (1) ERS-2/SAR image mode+Envisat/ASAR image mode Wide swath+Radarsat ScanSar Narrow A, hereafter denoted as E2ESEW sensor configuration. (2) ERS-2/SAR image mode+Envisat/ASAR image mode Narrow 2 swath+Radarsat ScanSar Narrow A, hereafter denoted as E2ESEN sensor configuration.

Two test sites were randomly identified to assess their visibility; the one located in the Aegean Sea at coordinates (37°20.4′ N, 23°5.4′ E) and the second in the Ionian Sea at coordinates (38°54′ N, 20°21′ E). Actually, two types of test site have been accounted for in the study. One has been defined to be of the size of $4\,km^2$ ($2\,km \times 2\,km$). The reason for using such a small test site comes from the need to assess the monitoring capability over a specific target, which remains stable over time (e.g. an oil platform or a refinery site along the coast line). In the second case, the test site has been defined to be a rectangular area of size $10\,000\,km^2$ ($100\,km \times 100\,km$) (figure 3).

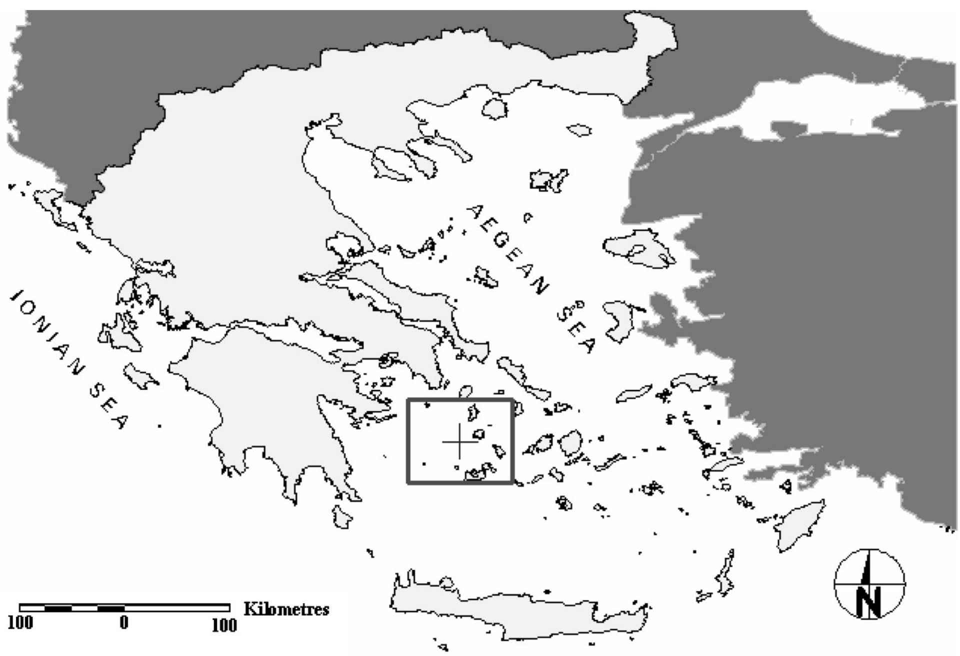


Figure 3. Map showing the types of the test sites selected to assess the observation capability over the Hellenic Seas. The square represents a target area of $10\,000\,km^2$. The $4\,km^2$ area, representing mainly a target position, is represented by a cross.

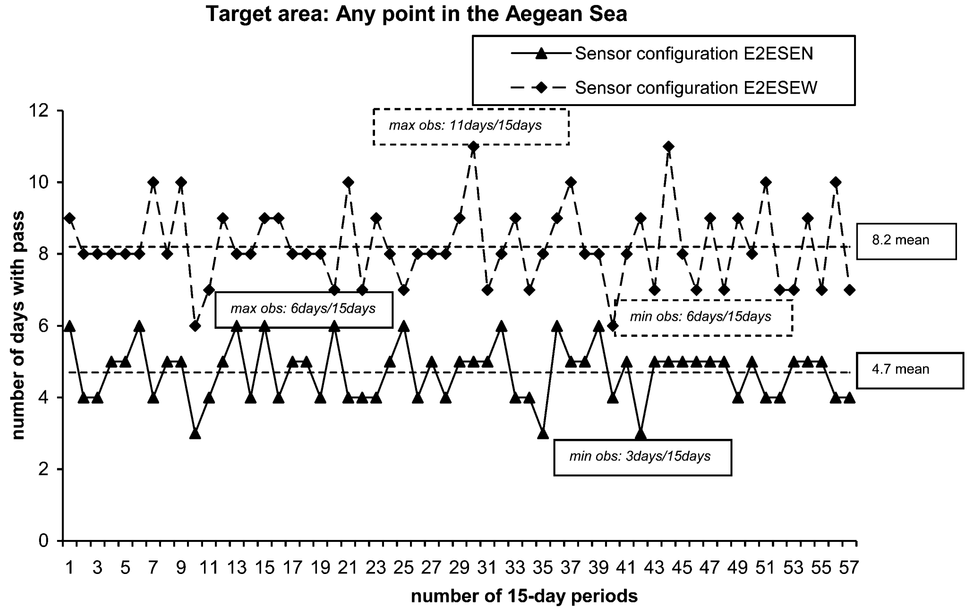
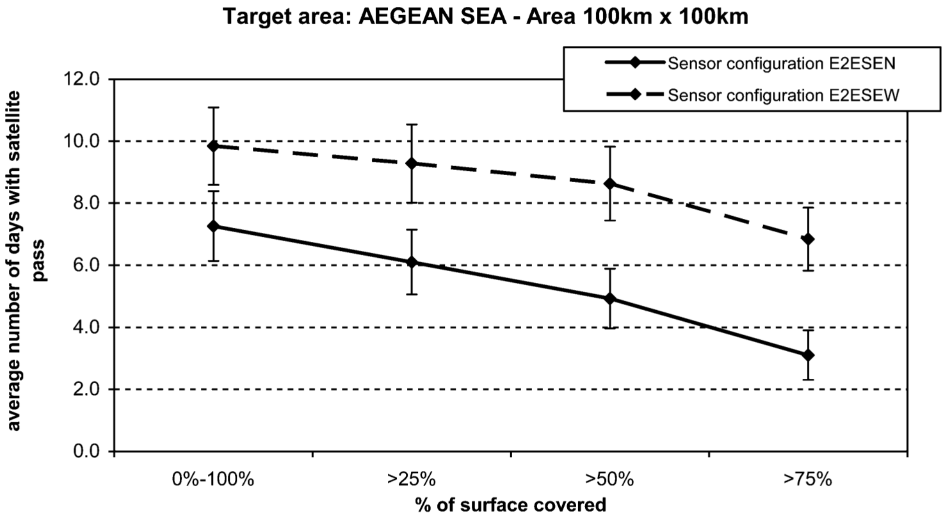


Figure 4. Plots representing the mean, maximum and minimum observation capability over the Hellenic Seas in the period from 1 January 2003 to 30 April 2005. The dashed line corresponds to the E2ESEW sensor configuration, while the continuous line corresponds to the E2ESEN sensor configuration.

The study spans the period from 1 January 2003 to 30 April 2005. This period has been selected to be large enough to confirm that any possible combination of satellites over a target area has been accounted for in the assessments. Calculations on satellite availability over a specific study area and estimations on the coverage percentage were carried out on a daily basis, but the resulting figures have been averaged to 15-day time frames (figure 4). It has been also calculated the number of times a 10 000 km^2 test area is covered for more than 25%, 50% and 75% in respect to its total extent, within a 15-day period. The results are illustrated in figure 5. It is to be noted that the resulting assessments were very similar in any of the two test sites. The x-axis in figure 4 represents the 15-day time frames corresponding to the studied period, numbered from 1 up to 57. The y-axis shows the number of distinct days within the 15-day period, for which there is at least one satellite pass and therefore at least one observation over the target area. As shown in figure 4, the mean temporal resolution in the observation of a target area can be defined either as 'at least one image every 2 days', or 'at least one image every 3 days', depending on the sensors' configurations. In other words, within a period of 15 consecutive days, the E2ESEW sensor configuration (dashed line plots) can image a target for 8.2 distinct days and often for more than once per day. Similarly, the E2ESEN configuration (continuous line plots), views the same target for 4.7 days within the same 15-day period. It is evident that the improvement in the monitoring capability from 4.7 to 8.2 days is possible only when switching the Envisat/ASAR sensor to operate in the 'wide' instead of the 'narrow' swath mode, thus affecting the image spatial resolution and discrimination capability. 8 9

A careful study of figure 4 shows, however, that the temporal resolution in the observations can deviate significantly from the mean values previously presented.



	ERS2-RadarSat ScanNarrowA – ENVISAT/ASAR Narrow swath		ERS2-RadarSat ScanNarrowA – ENVISAT/ASAR Wide swath	
Surface coverage %	average number of days	standard deviation	average number of days	standard deviation
0%-100%	7.3	1.1	9.8	1.3
>25%	6.1	1.0	9.3	1.3
>50%	4.9	1.0	8.6	1.2
>75%	3.1	0.8	6.8	1.0

Figure 5. Mean number of days in the 15-day time period for which the 100 km × 100 km target area is covered for a percentage greater than >25%, >50% and >75%. The plotted mean numbers are estimated over the whole study period spanning from 1 January 2003 to 30 April 2005. Both satellite configurations, E2ESEW and E2ESEN, are represented, denoted by the dashed line and the continuous line, respectively.

Indeed, considering the E2ESEW sensor configuration, the monitoring capability can reach a maximum value of at least one observation every 1.3 days (achieved in the 30th and the 44th 15-day periods studied). In contrast (during the 10th and 40th 15-day periods), the temporal resolution reaches its lowest value, namely an observation every 2.5 days. Also, considering the E2ESEN sensor configuration, the temporal resolution in the observation of the same target varies between two limits, defined as 'at least one observation every 2.5 days' to 'at least one observation every 5 days', respectively.

Figure 5 shows the evolution of the monitoring capability over a 10 000 km^2 area, as a function of the percentage of the area illuminated by the sensor. This capability is expressed as the mean number of days within a 15-day period, for which sensor configuration (E2ESEW or E2ESEN) provides an area coverage extending for more than a specific percentage value. As expected, the observation capability decreases as the coverage requirements change from any value between 0 and 100% to the requirement for having at least 75% of the total area covered. Indeed, as shown in figure 6, the E2ESEW sensor configuration may cover any percentage greater than 25% of the target area for 9.3 days in the 15-day period. However, this figure turns to the lower values of 8.6 days and 6.8 days in the 15-day period when the requirement for the percentage of the area to be covered becomes greater than 50% and 75%, respectively. Similarly, considering the E2ESEN sensor configuration, the

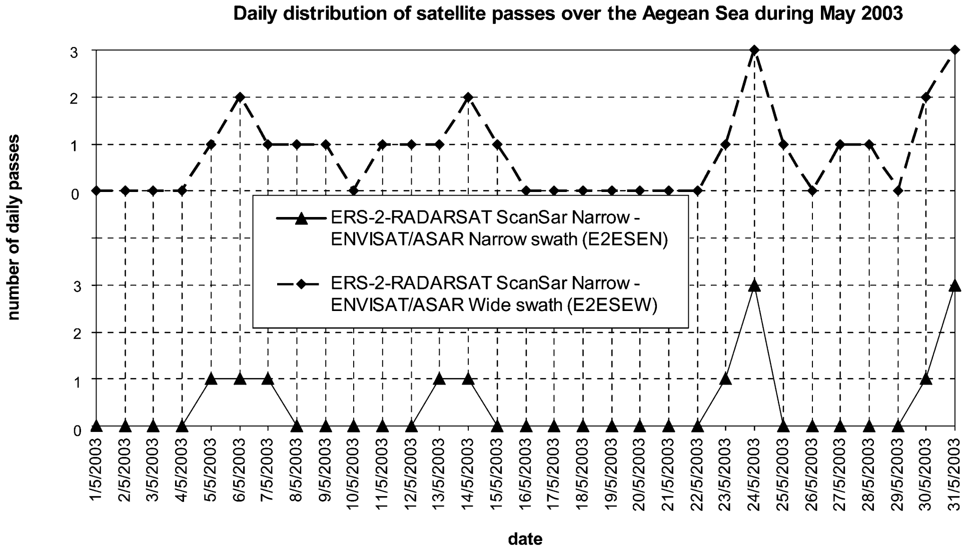


Figure 6. Daily pass/no-pass distribution for the two satellite configurations, E2ESEW and E2ESEN. The illustrated daily distribution corresponds to two randomly selected 15-day periods between 1 May and 30 May 2003.

observation capability is estimated to be 6.1 days, 4.9 days and 3.1 days in the 15-day period when the requirement for area coverage changes from any percentage greater than 25% to the percentage of 50% and 75%, respectively.

It is interesting, however, to note that the number of satellite passes on a daily basis, varies significantly in the 15-day period. As noted before, the assessed observation capability is expressed as the number of days for which there is at least one satellite pass in a 15-day period. However, there are dates for which the user is not provided with any image and others for which the number of the scenes acquired can be up to three over the same target location. Figure 6 is a representative example of two consecutive 15-day periods spanning from 1 May to 30 May 2003. The pass/

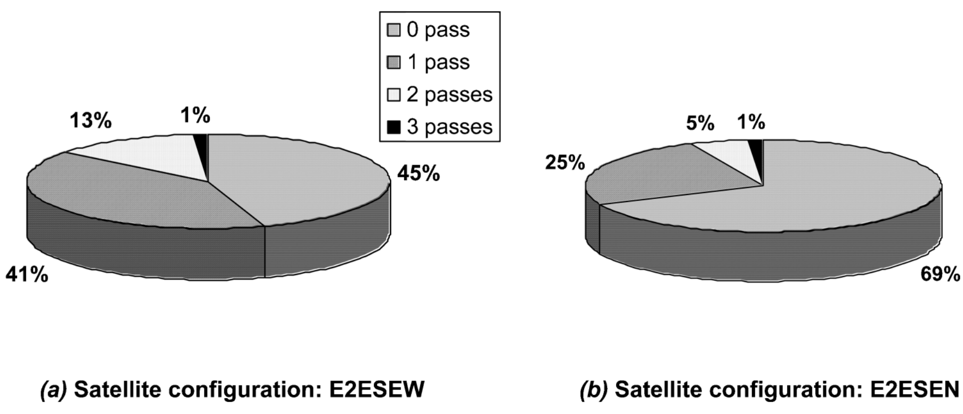


Figure 7. Percentages of time in the period from 1 January 2003 to 30 April 2005 with no satellite pass, as well as with one, two and three satellite passes in the same day over a target area in the Aegean Sea. Both satellite configurations denoted as E2ESEW and E2ESEN are represented.

no-pass daily distribution and the number of images acquired per day in the two 15-day periods are provided for both satellite configurations.

The pie charts in figure 7 illustrate percentages of time in the period from 1 January 2003 to 30 April 2005 with no pass, as well as with one, two and three satellite passes within the same day over the Aegean Sea. As is illustrated, the E2ESEW sensor configuration (figure 7(*a*)) ensures a target monitoring for around 50% of the time under consideration. Moreover, for 14.5% of the time the user is furnished with more than one scene per day. Similarly, figure 7(*b*) shows that the E2ESEN sensor configuration is capable of providing scenes over the target area for around 30% of the time. However, the percentage of time the user is furnished with more than one scene in the same day is reduced to about 6.5–7%.

4. Discussion

It is generally accepted that the current space-borne Earth Observation capability does not meet the needs of those responsible at European level to develop policies and implement strategies for environmental management. Also at regional and local scale the decision-makers lack real-time monitoring in the appropriate temporal resolution, which is the basis for setting up operations against any occurring disastrous phenomenon and any threat to the environment and citizens' lives. There is a further acceptance that significant improvement can only come through combining capabilities at European and international level.

In this context the European Commission jointly with the European Space Agency and their Member States initiated the Global Monitoring for Environment and Security (GMES) initiative, aiming at co-coordinating existing as well as new technologies, observation systems, scientific results, modelling capabilities and networking facilities, to better meet a structured demand for information on the part of European, national, regional and local decision-makers and users (http://www.gmes.info/projects/). Towards this direction and as far as the satellite sensor data are concerned, the European Space Agency has initiated discussions on the implementation of a unifying strategy for the current and future Earth Observation activities in Europe. It is well known that today there are in operation many data receiving facilities, including primary stations, national and regional mobile stations and 'user entities', assuming the role of ground segment. These facilities are often mission specific and they are developed independently of one another, forming a complex network and making it difficult for the user to find the right path to the required data. But even worse is the fact that users when asking for data, and mission planners when deciding about new developments, do not have visibility of the 'acquisition possibility' across the various missions. However, this knowledge, if available, can offer essential help to these people to move forward and draw conclusions in their domains of interest in a coordinated manner, avoiding unnecessary investments and deciding for complementary rather than redundant missions.

This paper is a trial to provide some insights to this problem, giving to the users, service providers, mission planners and decision-makers, in the domains of space and environment, answers about the existing monitoring capabilities, day and night, for the sea environment. Although the general feeling today is that space technology can serve the domains of sea monitoring and sea protection against pollution phenomena, there is a lack of knowledge of the degree to which it is feasible using

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Table 2. Contribution of the Envisat ASAR sensor in the enhancement of the monitoring capability over a target area in the Aegean Sea during the period 1 January 2003 to 30 April 2005.

		Satellite configuration		
	Number of daily satellite passes	ERS2–Radarsat	ERS2–Radarsat–Envisat ASAR Narrow	ERS2–Radarsat–Envisat ASAR Wide
	0	601	583	382
	1	238	212	346
	2	12	44	111
	3	0	12	12
Total number of passes		262*	336†	604‡
Absolute increase in total number of passes			74	342
% Increase in total number of passes			28%	130%
Number of days with at least one satellite pass in the studied period		250	268	469
Mean observation capability		at least one scene every 3.4 days	at least one scene every3.2 days	at least one scene every 1.8 days

*262=238+2 × 12; †336=212+2 × 44+3 × 12; ‡604=346+2 × 111+3 × 12.

the current and planned space systems. This makes the users reluctant to invest in this technology.

However, as the study shows, there is a higher potential today due to the fact that the offered monitoring capability has improved, after the launch of the Envisat satellite. The mean observation capability has increased from at least one satellite pass every 3 days to at least one satellite pass every 2 days due to Envisat's capability of operating in the wide swath mode (table 2). But even more important is the increase in the absolute number of observations over the target area in the studied period (1 January 2003 to 30 April 2005), due to the enhanced capability for acquiring more scenes in the same day. Indeed, the number of possible observations has increased by 28% when using the Envisat ASAR in the Narrow operating mode and by 130% when the Envisat ASAR sensor operates in the Wide mode.

Of course, this is still far from users' expectations for real-time monitoring. It is obvious that to achieve this there is a need for additional satellite systems operating in synergy with the existing ones.

Figure 6 shows that very little emphasis has been given in the past towards a coordinated operation and exploitation of the designed satellites. This explains why we report a number of consecutive days with more than one and up to three acquisitions in the same day, which are followed by important gaps in the acquisition. Therefore, Europe should focus on the amelioration of this situation, and take measures for a sustained operation and continuity of the current missions. Keeping in orbit to the maximum of their life the existing systems like ERS-2 and Envisat together with their ground segment facilities is of primary importance. In addition, specific decisions should be taken soon for their successive missions, if there is a real will to provide operational services within the next decade, as described in the frame of the GMES programme.

However, apart from the need to increase the temporal resolution in the acquisitions, another important parameter that should be taken into account when evaluating the performance of a satellite constellation for sea monitoring is the data spatial resolution. At this stage, it is worth noting that the mean observation capability has in fact increased to approximately one scene every 2 days by employing the ASAR sensor of the Envisat satellite. However, this requires the sensor to be operated in the wide swath mode, thus reducing the data spatial resolution. In the latter case, an oil spill can be detected when it has reached a size of approximately 10–15 Ha.

The authors believe that evaluations of this type should be repeated for a number of similar environmental applications. Moreover, these evaluations should consider synergies of optical and radar sensors of medium to high spatial resolution, depending on the observed parameters and phenomena. In this study the evaluations were based on the sole use of the existing satellite SAR sensors, considering them as best suited for sea pollution applications. For the time being the main problem is setting up the appropriate framework for discussions between the satellite constructors and operators and reaching the appropriate level of agreement that will allow the user to have direct access to their data in a coordinated and easy manner. This is the most challenging issue for Europe in the years to come.

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