SIMP: SLICKS AS INDICATORS FOR MARINE PROCESSES

Leonid M. Mitnik[1], Martin Gade[2], Stanislav A. Ermakov[3],
Olga Yu. Lavrova[4], José B.C. da Silva[5], David K. Woolf[6]

[1] Pacific Oceanological Institute, FEB RAS, 43 Baltiyskaya St., Vladivostok 690041, Russia, e-mail: lm_mitnik@mail.ru
[2] Universität Hamburg, 20146 Hamburg, Germany, e-mail: gade@ifm.zmaw.de
[3] Institute of Applied Physics, RAS, Nizhny Novgorod, Russia, e-mail: stas.ermakov@hydro.appl.sci-nnov.ru
[4] Institute of Space Research, RAS, Moscow, Russia, e-mail: olavrova@mx.iki.rssi.ru
[5] University of Lisbon, Lisbon, Portugal, e-mail: jdasilva@fc.ul.pt
[6] National Oceanography Centre, Southampton, UK, e-mail: dkw@noc.soton.ac.uk

ABSTRACT. ...SIMP is an international project funded by INTAS aimed at improving the information content, which can be inferred from multi-sensor satellite imagery of marine coastal areas. Scientific teams from Germany, UK, Portugal, and Russia focus on the development of novel tools for marine remote sensing of the coastal zone. In particular, the project teams' benefit from the fact that surface films may enhance the signatures of hydrodynamic processes such as plumes, internal waves, eddies, etc., on microwave, optical, and infrared imagery. The project's objectives are to develop a robust methodology for identifying slick-related phenomena/processes through their surface signatures and thereby, to improve the discrimination capabilities between slicks and other oceanic and atmospheric phenomena by taking into account information gained from satellite imagery quasi-simultaneously recorded at microwave, visible and IR wavelengths. The results of the two project years are summarized. Examples are given for the project's web presentation, laboratory and field experiments, and of the analyses of various satellite data.

KEY WORDS: Slicks, Remote sensing, multi-sensor satellite imagery, coastal zone, INTAS

1. INTRODUCTION

In order to improve the information content that can be inferred from multi-sensor satellite imagery of marine coastal areas, scientists from Germany, Portugal, Russia and UK, have formed the project SIMP whose main goal is the development of novel tools for marine remote sensing of the coastal zone. The basic idea of SIMP is to benefit from the fact that marine surface films, which are often present in coastal areas may enhance the signatures of hydrodynamic processes such as fronts, eddies, plumes, internal waves, etc., on microwave and optical imagery.

In this paper results from analyses of various satellite data over the Russian coast of the Japan/East Sea (JES) and Black Sea, as well as from joint dedicated field and laboratory experiments obtained so far are summarized. Laboratory and field experiments are being conducted in order to investigate the influence of variations in wind speed and surface currents on radar and optical signatures of biogenic and anthropogenic surface films. We will demonstrate how the interpretation of satellite radar imagery can benefit from a deeper knowledge of the very mechanisms responsible for slick signatures and from auxiliary information provided by sensors working at different electromagnetic frequencies.

2. SATELLITE IMAGES: IMPROVED ANALYSIS

Slicks structures driven by local hydrodynamic processes may be visible on radar and optical imagery, thus allowing for a monitoring of these processes via their surface manifestations (Figure1).

The presence of surface films reveals several mesoscale eddies, their spiral structure and is favorable for their

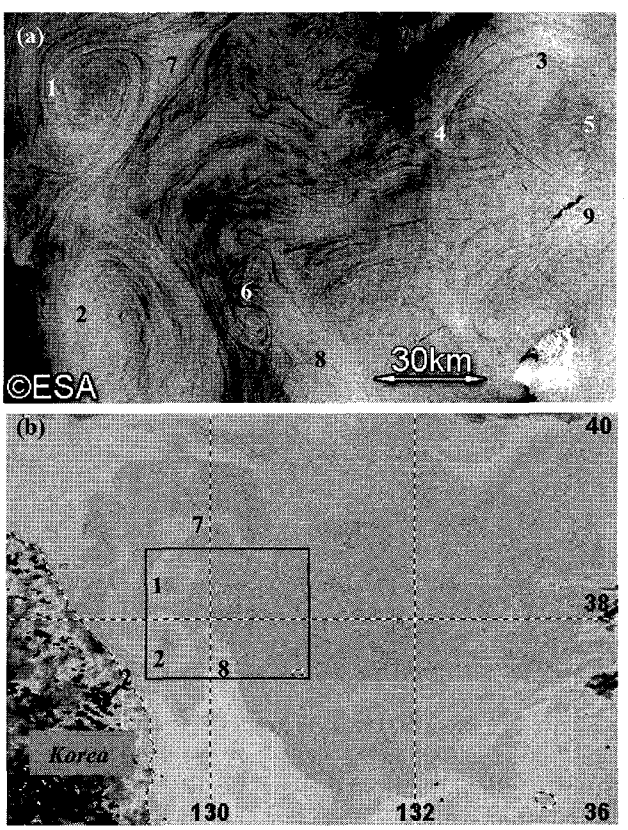

Figure1.Eddies 1-6, warm water flows 7, 8 and oil pollution 9 on Envisat ASAR (a) and AVHRR infrared (b) images taken on 14 April 2004 at 01:28 (a) and at 15:20 UTC (b).

manifestations on ASAR image. The location of the thermal gradients correlates very well with the location of SAR signatures caused by current shift at the boundaries of synoptic eddies, eddy-like features and frontal zones (Mitnik and Dubina, 2006).

A large number of ASAR images containing surface manifestations of vortex structures different in type and size were detected in the coastal zone of the Black Sea. Almost all of them are visible as slick patterns. The most striking features are the so-called mushroom flows, that are dipolar or quasi dipolar eddies. It is multisensor approach that provides the most comprehensive information on their size and origin (Figure 2).

An Envisat ASAR image acquired under weak southwest wind of 2-3 m/s and weak surface waves (Figure 2a) revealed an early formation stage of a dipole composed of a jet and a pair of cyclonic and anticyclonic eddies. The jet direction was about 10° to the east and its length was 110-120 km. Relative spatial uniformity of the wind field and its low speed coupled with the presence of biogenic films on the sea surface favored clear imprinting of filamentary slicks in the ASAR image.

The slicks are the result of ripple smoothing due to the surfactant films. The dipole is hardly discernable as in NOAA AVHRR IR images as in Aqua MODIS IR and visible images of May 15 and appears more distinct in such images only the next day, May 16 (Figures 2b,c,e,f).

It is easy to notice the presence of mushroom structures, surface temperature (SST) field. A less distinct structure can be detected in the processed water leaving radiance image. In the Chl *a* concentration chart, maximum contrast is registered along the dipole jet. Obviously, maximum Chl *a* concentrations roughly correspond to convergence zones of the mushroom structure.

Figure 2d presents a schematic co-location of radar, thermal and optical data obtained over two consequent days and revealing the evolution of the eddy dipole. For a considerable time, the dipole retained its shape and position, drifting slowly in the northwest direction due to the effect of the Rim Current in the Black Sea. Dynamic vortex structures of the kind regularly observed in this region of the sea are known to induce not only horizontal, but also vertical mixing of water. They contribute to hydrodynamic instability of the alongshore current and intensify coastal water transport to the open sea.

Different thermal and colour images appear to correlate strongly enough, however in a complex, indirect manner. These are quite typical situations of satellite data interpretation and retrieving practical results and conclusions. Comprehensive analysis of various available satellite data significantly contributes to the quality and detail of data interpretation and the reliability of the overall picture of intricate interaction of hydrodynamic, meteorological and biological factors.

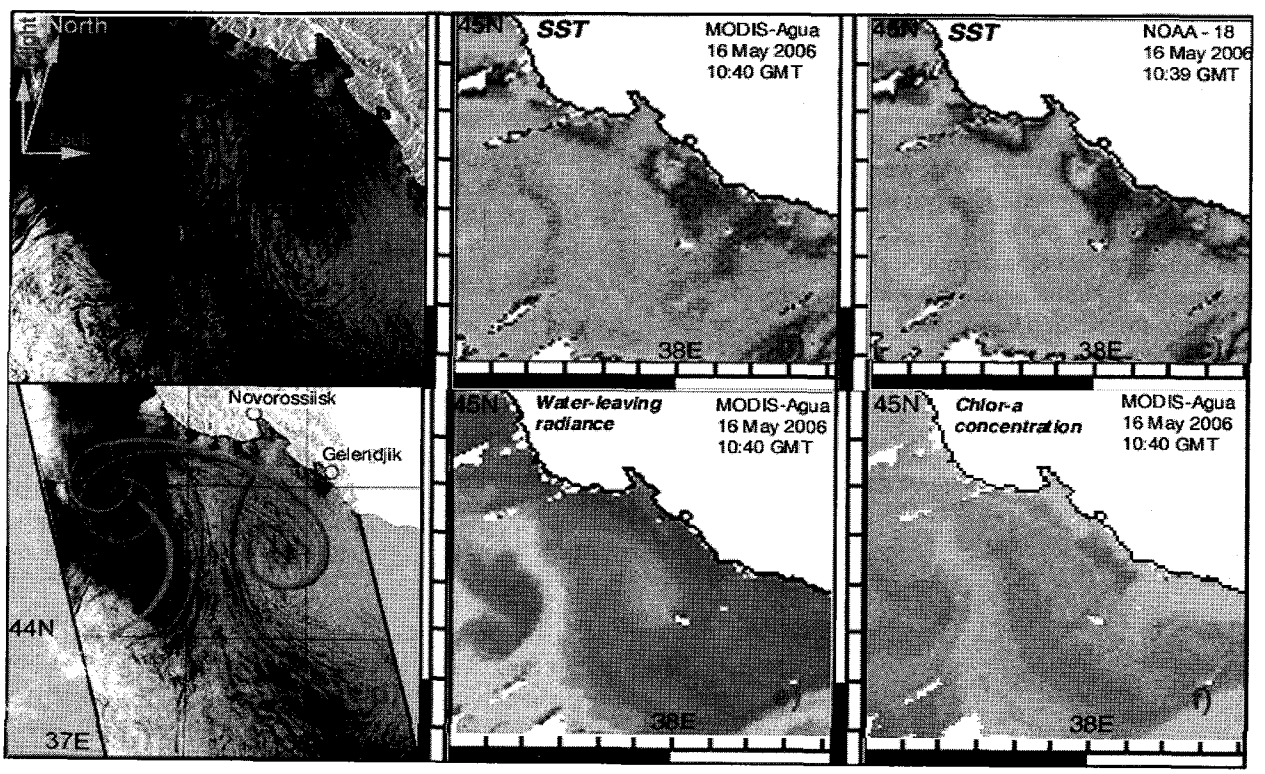

Figure 2. Mushroom flow manifested itself through bands of surfactant slicks on Envisat ASAR VV-polarization image for 15 May (a); SST fields derived from Aqua MODIS (b) and from NOAA AVHRR for 16 May (c); eddy dipoles schematic superimposed on geo-referenced Envisat ASAR image for 15 May (d); water leaving radiance chart (composite of seven channels) (e) and Chl *a* concentration chart (f) derived from Aqua MODIS data for 16 May 2006.

Both biogenic and anthropogenic slicks were detected on all SAR images. At wind speeds below 5-6 m/s slicks visualized the oceanic dynamic phenomena.
Envisat SAR images of the experimental areas were analyzed by IKI and POI teams. (SIMP, 2006a).

3. FIELD EXPERIMENTS

An important task within SIMP are field experiments that are designed to provide sub-satellite data during satellite overpasses, to study hydrodynamic processes inside and outside of slick-covered areas, and to evaluate results from laboratory studies. Experimental campaigns were conducted in 2004-2006 by the teams of IAP and IKI in the coastal zone of the Black Sea (summer time) and by POI in Peter the Great Bay of the JES (different seasons).

The objectives of these experiments were:
- to develop a better understanding of mechanisms of slick formation and of the relation between slick geometry and the structure of surface currents;
- to investigate the physical characteristics of marine films
- to investigate surfactant spreading regimes;
- to conduct in situ optical and hydrometeorological measurements to improve the interpretation of SAR data
- and to compare the measured and computed values of the normalized radar cross section.

New methodologies of surface current measurements in a thin surface layer (about 5 mm) were developed using special floats whose trajectories were traced or from a small boat equipped by GPS receivers (IAP) or from a coastal video camera (POI). Simultaneously, film sampling was carried out from slicks and surrounding "non-slick" areas. It was found that in the presence of spatially varying surface currents surfactants tend to accumulate in shear current zones where weak transverse currents are encountered. The resulting compression of the surfactants gives rise to a stronger damping behaviour. Figure 3 gives an example of trajectories of floats, two of them were placed initially inside a slick band and another two outside the band. These results show that there are current components in. the cross-slick direction which are responsible for the film compression.

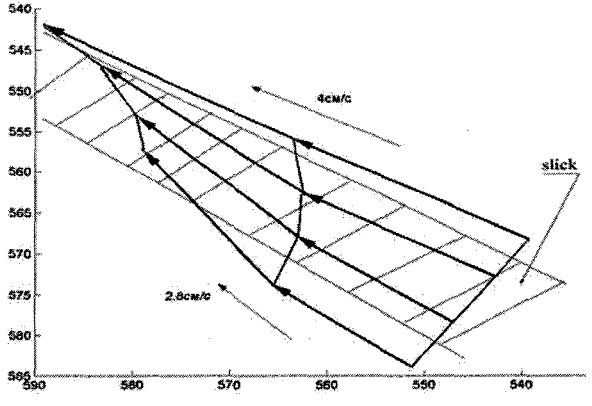

Figure 3. Trajectories of markers inside and outside a natural slick band (see text)

Spreading and drift regimes of artificial slicks created by oleic acid and vegetable oil were studied by their observations during several hours with simultaneous measurements of the sea surface wind by a cape anemometer and surface currents using man-made tracers.

Figure 4. Artificial slick created by oleic acid from a boat.

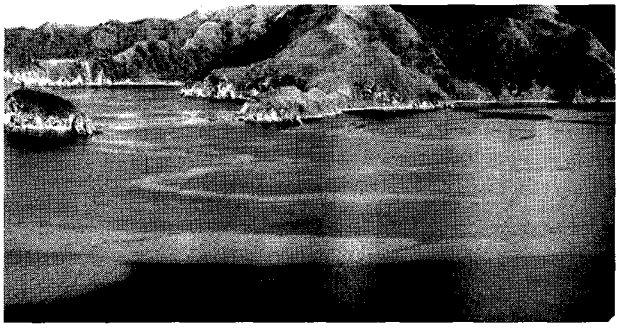

Figure 5. Image of the Vityaz' Bay in the JES taken by a video camera with polarization filter on 5 September 2005 at 01:30 UTC during Envisat ASAR sensing. A band at image bottom was created by oleic acid. Other slick bands and spirals were formed by biogenic films.

4. LABORATORY EXPERIMENTS

An important part of SIMP is basic research addressing open questions about hydrodynamic processes influencing on the spatial distribution of surface-active material on the water surface. Such basic research has been performed at the wind-wave tanks of the Institute of Applied Physics (IAP) and of the University of Hamburg (UHH).

Investigations of short wind waves and their variability due to long waves were carried out at IAP-RAS at low wind conditions and short fetches and in the presence of surface films consisting of oleic acid ("OLE") and a polymer (poly)oxyalcylene glycol ("Emkarox") at different concentrations (i.e., deployed amount of substance per time interval). It was shown that the phase velocities of short wind waves do not obey the linear dispersion relationship and thus bound waves (high order

harmonics) give significant contribution in the spectrum of short wind waves. A local balance model was modified and the effect of the generation of bound waves was described by an additional term in the kinetic equation for the spectrum of wind waves, thus allowing to explain the experimental results on short wave modulation, both in the lab and in the field (Figure 6).

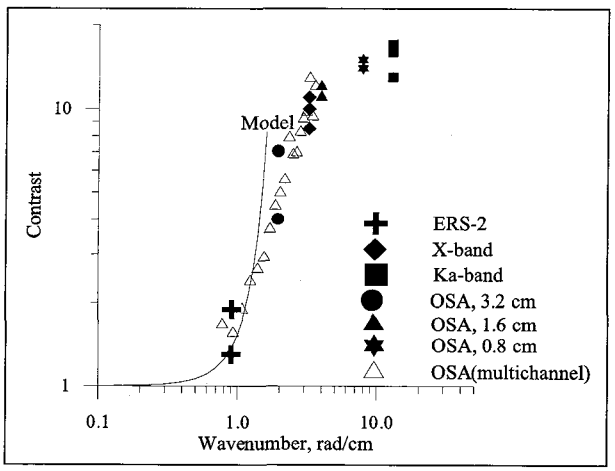

Figure 6. Radar and optical contrasts vs. wavenumber of wind waves for vegetable oil slicks at wind velocities W = 6 - 8 m/s. The solid line – LB-model for W = 7m/s and the elasticity 12 mN/m (results from field experiments).

5. SIMP WEBSITE, DATABASE AND MARINE GIS

Two websites, the SIMP project website and the SIMP database have been created in order to ensure a swift exchange of data and information amongst the project teams, and to allow an easy dissemination of results to interested parties outside the consortium.

The aim of the project website (SIMP, 2005a) is to (1) provide an overview of project activities and results to the public, (2) facilitate exchange of documents and information between project partners and (3) keep a transparent record of progress within the project. The website is split into two sections, one of which is open to the public whereas the other part allows access by password only.

A project database (SIMP, 2006b) has been installed on an FTP site accessible to all project participants and to the public in order to ensure a swift transfer of data of any type between all project teams. The concept of the presentation of slick images, the file structure, and the presentation layout has been developed in terms of an easy access to the data and to the corresponding information. The database is intended to feature various phenomena and processes visualized by slicks on the sea surface and imaged by different sensors.

The main purpose of the specialized GIS developed for the Northwest Pacific, including the coastal zones of the Japan/East and Okhotsk Seas is to provide access to satellite and in situ data as well as to the tools of their analysis.

The following data are in the GIS: ERS-1/2 SAR and Envisat ASAR images, NOAA AVHRR and Terra and Aqua MODIS images, the QuikSCAT-derived sea surface winds, weather maps, and also the ground-truth data collected at the POI Marine Station Cape Shults in the JES. GIS is realized as the Internet project (SIMP, 2006c).

5. CONCLUSIONS

During its two and a half year, SIMP has already proven to provide a wealth of new results on the influence marine surface films (slicks) on oceanic processes at different scales and, thus, on data from satellite-borne sensors. Public accessible websites have been built and maintained in order to allow a swift exchange of news and data and an easy dissemination of the main results obtained by the project consortium.

In order to improve the understanding of marine processes that are associated with marine surface films the project consortium has conducted laboratory and field experiments with artificial and natural surface films and has analyzed various satellite images of the marine coastal zone. Algorithms of oceanic and atmospheric phenomena classification based on multi-sensor satellite images has been developed and implemented.

The results obtained so far clearly demonstrate the benefit that can be taken from a deeper knowledge of the very processes that influence the accumulation of marine surface films at the sea surface and the imaging of marine surface films of different origin by space-borne microwave and optical sensors.

During the remaining project duration, the consortium will continue focusing on various marine processes whose imprints on satellite imagery are enhanced by marine surface films of biogenic and anthropogenic origin.

References

SIMP (2006a), Project website, http://www.soc.soton.ac.uk/lso/simp
SIMP (2006b), Project database, http://simp.iki.rssi.ru
SIMP (2006c), Project GIS, http://simp.poi.dvo.ru.

Acknowledgements

SIMP receives funding from INTAS under contract 03-51-4987. The work presented herein was carried out with the help of several colleagues at the participating institutions. The authors are grateful to Philipp Lange (UHH), Susanne Ufermann (NOC), Lev Gushchin (IAP), Eugeny Makarov (IAP), Irina Sergiewskaya (IAP), Yury Shchegolkov (IAP), Tatiana Bocharova (IKI), Anton Churyumov (IKI), Konstantin Litovchenko (IKI), Marina Mityagina (IKI), Denis Darkin (POI), Vyacheslav Dubina (POI), Vitaly Fishchenko (POI) and Oleg Konstantinov (POI). The ERS and ENVISAT satellite data used within SIMP were provided by the European Space Agency through Bear AO 2775, AO3-401, AO3-1291, and AO-ID-391.