Oil spill detection and mapping in the Northwest Pacific Ocean by L-band ALOS PALSAR

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Abstract
The Asian marginal seas and especially their coastal zones are strongly impacted by oil pollution. SAR seems to be one of the most suitable instruments for spill detection, in particular, to fight against illegal discharges. ERS-1/2 SAR and Envisat ASAR images and relevant data were analyzed to interpret SAR dark tone signatures caused by both oil spills and look-alikes, to advance algorithms of oil spill detection and to choose the areas for ALOS PALSAR sensing. Field experiments were conducted at the POI Marine Stations to study wave damping by natural and artificial films. Original polarization optical devices and systems of floats were developed to estimate wind wave spectra. Slick dynamics was studied by analysis of time series of sea surface images.

Keywords: Envisat ASAR, ERS-2 SAR, ALOS PALSAR, oil spill, natural slicks, radar signatures, optical polarization devices, wave spectra, detection algorithms.

1. INTRODUCTION

Oil pollution of the ocean is a major environmental problem, especially in its coastal zones. Oil spills are regularly observed in the Asian marginal seas. Oil and natural gas exploration and production areas, oil terminals, coastal refineries, and major oil tanker casualties and routes are sources of the pollution. Oil refineries are concentrated on the southeast coast of Japan, the south of South Korea, in China along the Bo Hai coast and in Shanghai area, around Taichung and Kaohsiung in Taiwan. There is heavy oil tanker traffic in the East Asian Seas from the Persian Gulf to Japan, Taiwan, and South Korea. Further development of the new oilfields in the Okhotsk and Yellow Seas as well as construction of new oil-pipe-lines from Eastern Siberia to the Japan Sea coast coupled with continuing releases of petroleum hydrocarbons in river waters increase marine water pollution. Recent oil spills near Primorye, Sakhalin, Hokkaido and Honshu coasts have demonstrated the high sensitivity of coastal ecosystems to oil contamination that imposed increased requirements upon detection and monitoring of polluted waters both in the open sea and in the coastal zone.

Main aim of the first stage of the project was selection the areas where oil spills are observed to estimate the potential of ALOS PALSAR images separately or in combination with other data for oil spill detection and discrimination of oil spills and natural slicks.

This aim was achieved by analysis of C-band ERS-1 and ERS-2 SAR and Envisat ASAR images together with ancillary information collected at the POI Satellite Oceanography Laboratory. In previous years, about 400 SAR and ASAR images of the Northwest Pacific Ocean were obtained from the European Space Agency in the frames of several ongoing research projects. Oil spills and films of natural surfactant materials (slicks) are readily observed as low-backscatter patches and lines in SAR images provided they are of sufficient extent.

Peter the Great Bay, East Korean Bay and Toyama Bay in the Japan Sea, eastern Sakhalin shelf, Aniva Bay and the Soya Warm Current area in the Okhotsk Sea, a central part of the Yellow Sea, Bohai Sea, China coastal zone and the Taiwan Strait were chosen for study of oil spills and look-alikes. Field experiments were conducting at the POI Marine stations in the Japan Sea with the usage of new optical polarization devices and systems of floats developed to get accurate estimates of wave heights, wave slope spectra for clean and film-covered sea surface. Dynamics of natural and man-made monomolecular slicks was studied by analysis of time series of sea surface images that allowed tracing the propagation of internal waves, formation and evolution of spiral eddies, and other mesoscale and microscale oceanic phenomena near POI Marine stations. Ground truth data were collected, in particular, during satellite SAR sensing and radar signatures were compared with optical images.

Below we will present several SAR images of the Asian marginal seas where oil spills were detected.

2. OIL SPILLS IN THE JAPAN SEA

On ERS-2 SAR image acquired on 22 September 1997 and shown in Fig. 1 dark features are seen in a central part of Peter the Great Bay (1, 2, and 4) and in Ussuriyskiy Bay (3). The features were classified as illegal oil spills from the ships. A ship can be seen as a light point to the west of a large oil spill). Ship wake appears as a narrow dark band behind the ship. The dark patches **A** and **B** to the east of the Muraviev-Amurskiy Peninsula and Russkiy Island and to the southwest of Gamov Peninsula were likely due to weak winds although effect of surface films must not be ruled out. The thin dark lines **C** are an example of natural biogenic slicks resulting from enhanced biological activity. POI Marine Stations where subsatellite experiments were conducted are on Popov Island) and at Cape Shults 6.

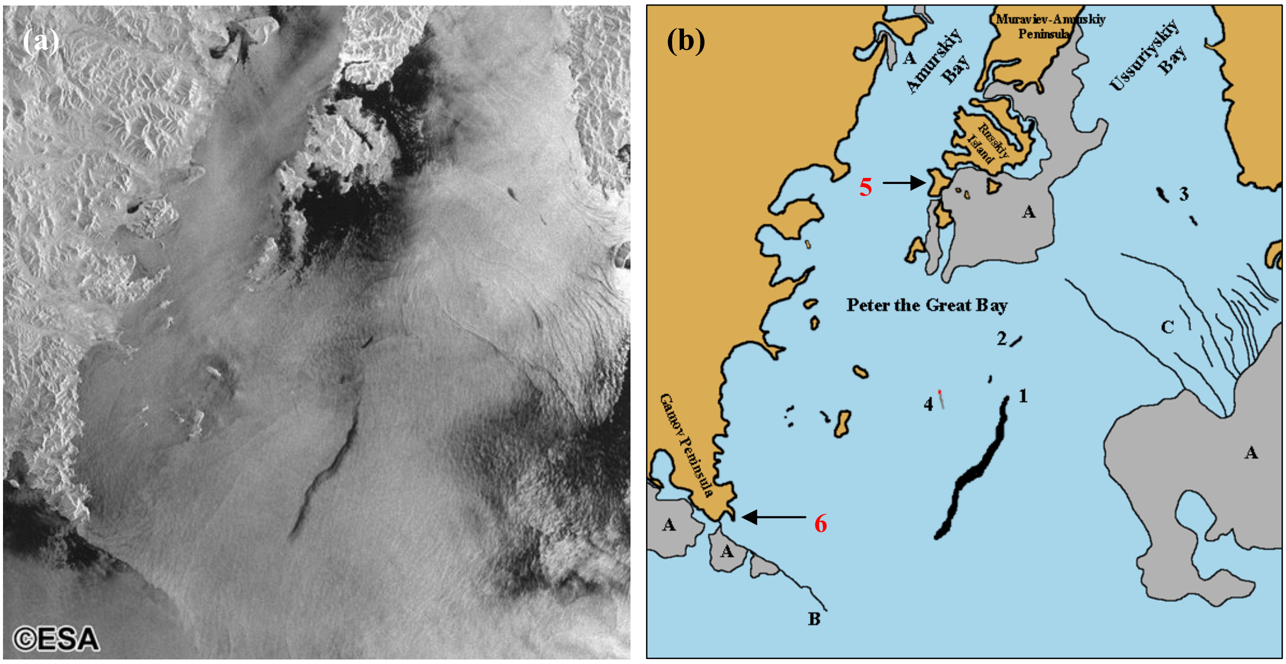

Figure 1. (a) ERS-2 SAR image of the Peter the Great Bay taken on 22 September 1997 at 02:00 UTC. The image size is about 100 km x 100 km. The spatial resolution of the image is 100 m x 100 m. (b) Interpretation scheme of the SAR image showing the location of the dark features and POI Marine Stations.

Illegal oil spills were found on other images of Peter the Great Bay, in particular, close to the Marine Reserve area. (Fig. 2). Oil spills were revealed also near Korean coast and in the open areas of the Japan Sea [1-5].

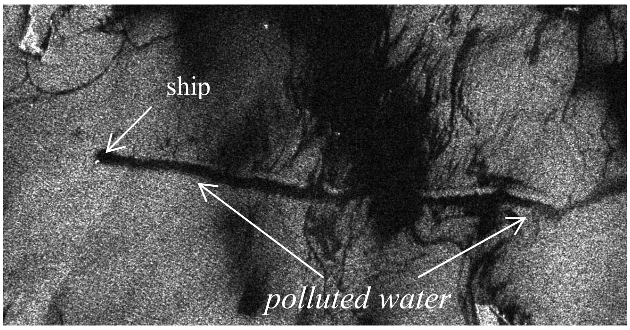

Figure 2. Detection of illegal waste water discharge from a ship (white dot) in Peter the Great Bay on ERS-2 SAR image taken on 23 March 1999 at 13:23 UTC. The size of a full-resolution fragment is 14.6 km x 7.5 km.

2. OIL SPILLS IN THE YELLOW SEA

Numerous oil spills are detected on almost each SAR image of the Yellow Sea where ship lines and fishery activity are observed. Fig. 3 shows Envisat ASAR image of the Yellow Sea acquired on 15 August 2007 at 01:41 UTC in a wide swath regime. A spiral feature is imprint of wind field of a tropical depression centered at 34.4ºN, 123.7ºE. Bright area 1 to the north of the cyclone center 2 corresponds to the strongest wind. White rectangles 3-5 mark the boundaries of fragments where oil spills were found. The fragments 2 and 3 are displayed in Fig. 4.

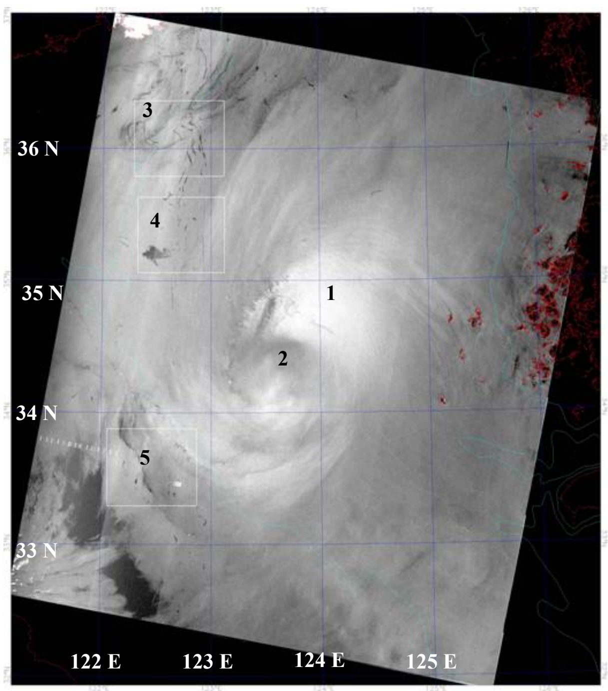

Figure 3. Envisat ASAR image of the Yellow Sea for 15 August 2007. Brightness variations are caused by cyclone's wind field. Dark patches and bands within white rectangles 3-5 are due to oil spills. Large dark area at the bottom left results very likely from weak winds and likely from damping of the surface roughness by natural films.

Analysis of full resolution SAR images shows that the sizes and shape of the dark features are changed significantly that can be used to improve discrimination of oil spills. In particular a broad elongated dark patches at the bottom left are likely due to weak winds or the presence of biogenic films damping the sea surface roughness. Two types of the narrow dark bands oriented approximately normal to each other are detected in Fig. 4. The longitude-directed darker bands originated very likely from illegal discharges of waste waters containing oil products. Numerous ships (white dots) are observed in the area of the dark bands and lines. It may be suggested that a part of them are responsible for oil pollution. The main orientation of gray lines in Fig. 4a is latitudinal one. These lines (filamentary slicks) are formed by natural films and indicates on the increased plankton concentration.

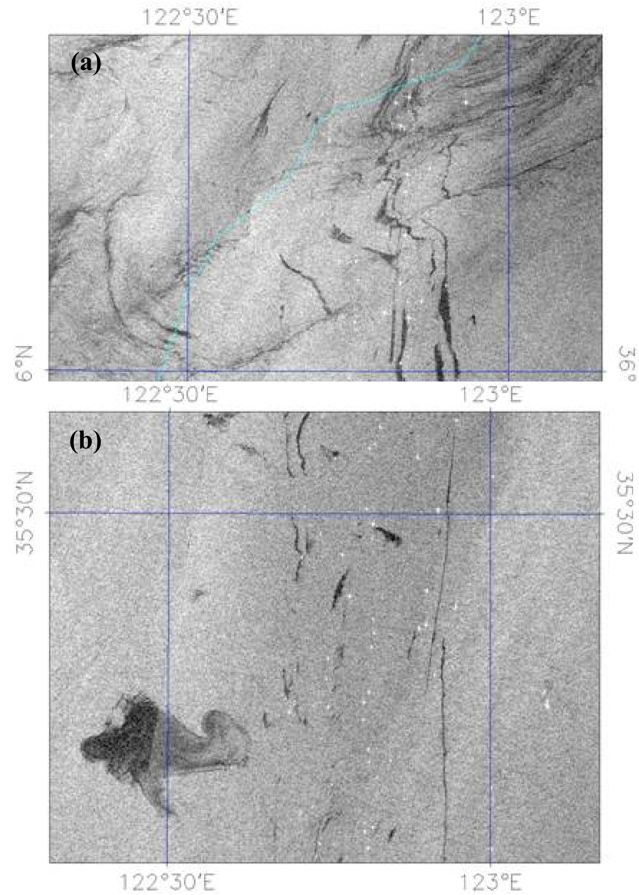

Figure 4. Fragments 2 (a) and 3 (b) of Envisat ASAR image of the Yellow Sea acquired on 15 August 2007 at 01:41 UTC. Dark features result from oil spills and biogenic slicks and numerous white dots are due to strong backscatter by ships. The boundaries of the fragments are shown by white rectangles in Fig. 3.

Oil spills and natural slicks are observed against the background, brightness of which is determined by simultaneous influence of the atmospheric (wind speed and direction, as in Fig. 3, rain cells, etc.) and oceanic (fronts, currents, sea ice, etc.) conditions. SAR image presented in Fig. 5 demonstrates oil spills in the Yellow Sea, which are observed against the swell background.

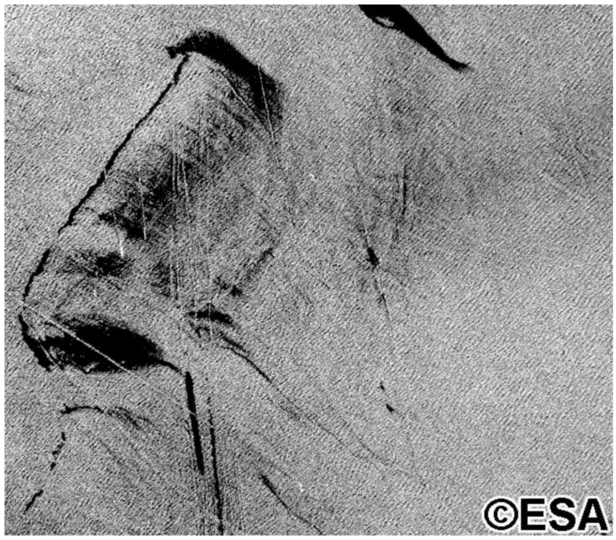

Figure 5. Oil spills, ships, ship wakes (low contrast light lines), biogenic slicks and swell with the wavelength of approximately 150 m on a fragment of ERS-2 SAR image acquired on 24 July 2003 at 02:27 UTC.

3. GROUND TRUTH OBSERVATIONS

Measurements of the sea surface slope distribution and the mean-square slope in the field experiments are significant for interpretation of the SAR signatures. Techniques based on light reflection ('shape from reflection') turn out to be most suitable to take wave slope images. It was shown that the measurements of the water surface shape are accurate enough to compute 2D wave number spectra. The original and standard optical devices (video cameras, polarization spectrophotometer, etc.) and techniques were used to derive the characteristics of gravity and gravity-capillary waves under variable environmental conditions in particular during ERS-2 SAR and Envisat ASAR sensing of Peter the Great Bay [4-6].

The characteristics of the sea surface roughness were estimated from registration of time series of brightness variations of a light white disk floating on the sea surface. The disk served as a filter of surface waves. They were also retrieved from the brightness variations of the sea surface images which were recorded at three polarizations with frequency of 6-50 Hz using advanced original software developed for processing of the time series of the images. Patches and narrow bands of artificial slicks were created from a boat. These slicks as well as natural biogenic slicks in Vityaz' Bay and in the open Japan Sea were recorded by video cameras and by a digital photo camera from the coast. Biogenic slick bands and spirals and artificial slicks in Vityaz' Bay created by oleic acid and sunflower oil pouring from a boat before Envisat ASAR sensing were detected simultaneously from Cape Shults by a video camera and from space (Fig. 6). Surface currents in the slick-covered areas were estimated by observations of tracers in a form of small contrast floats placed in slick areas.

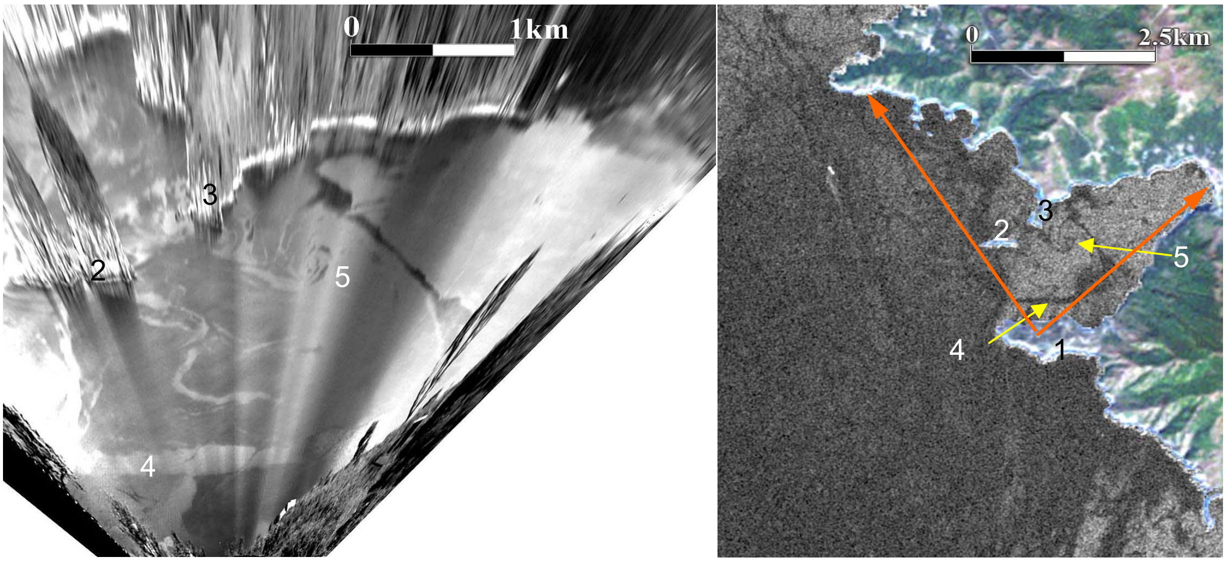

Figure 6. Simultaneous observation of biogenic and artificial slicks in Vityaz' Bay on 5 September 2005 at 01:30 UTC. (a) Panoramic image obtained by a video camera from Cape Shults and transformed on a plane and (b) fragment of Envisat ASAR image: (1) Cape Shults, (2) island, (3) cape on opposite side of Vityaz' Bay, (4) artificial slick band formed by oleic acid and (5) a cyclonic spiral slick formed by biogenic film. Red arrows in (b) mark the boundaries of panoramic image (a).

4. CONCLUSION

Several areas in the Northwest Pacific Ocean were chosen as the study sites by analysis of several hundreds of ERS-1 and ERS-2 SAR and Envisat ASAR images and taking into account the location of ports, oil terminals, oil platforms, shipping lines, rivers, as well as the ongoing programs of coastal zone monitoring in the NOWPAP area [1, 3]. They include the Peter the Great Bay, East Korean Bay and Toyama Bay in the Japan Sea, Sakhalin shelf, Aniva Bay and the Soya Warm Current area in the Okhotsk Sea, a central part of the Yellow Sea, Bohai Sea, China coastal zone and the Taiwan Strait and several areas in the East-China and South-China Seas. Results of SAR signatures analysis and interpretation show the advantages of multisensor approach, which allows to increase probability of oil spill detection against the variable background. Specialized field experiments with the usage of new optical devices developed at POI give a new insight in understanding of physical factors determining radar signatures of oil spills and biogenic films. This approach is supposed to apply to analysis of ALOS PALSAR images of the chosen sea areas.

ACKNOWLEDGMENT

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REFERENCES

[1] Web site Oil spill monitoring by remote sensing, http://cearac.poi.dvo.ru

[2] V. Dubina et al., "Mesoscale oceanic phenomena in Peter the Great Bay from multisensor satellite sensing data," *Abstracts of International Conference "Advances of Satellite Oceanography: Understanding and Monitoring of Asian Marginal Seas*, Vladivostok, Russia, 3-6 October 2007, pp. 31-32.

[3] L. Mitnik et al. Web-site "Oil spill monitoring by remote sensing" http://cearac.poi.dvo.ru, *ibid*, pp. 95-97.

[4]. L. Mitnik et al. "Remote sensing of surface films to study oceanic dynamic processes", *3rd KORDI-POI Workshop for the East Sea monitoring*, Jangmok, Korea, June 2007.

[5]. L.M. Mitnik "Monitoring of oil pollution with the use of satellite imagery," *The 1st NEAR-GOOS - NOWPAP Training Course on Remote Sensing Data Analysis*. Nagasaki, Japan, 2-7 September 2007.

[6]. L.M. Mitnik et al. "Envisat ASAR polarization experiments in the Peter the Great Bay, Japan Sea: Preliminary results," *EARSel eProceedings,* 2006, Vol. 5, No.2, pp. 199-207.