Operational Satellite Monitoring Systems for Marine Oil and Gas Industry

A.G. Kostianoy[a], D.M. Solovyov[b*]

[a] Ocean Experimental Physics Laboratory, P.P. Shirshov Institute of Oceanology, 36, Nakhimovsky Pr., Moscow, 117997, Russia – kostianoy@gmail.com
[b] Remote Sensing Department, Marine Hydrophysical Institute, 2, Kapitanskaya Str., Sevastopol, 99011, Ukraine – solmit@gmail.com

Abstract - Shipping activities, oil production and transport in the sea, oil handled in harbors, construction of oil and gas pipelines have a number of negative impacts on the marine environment and coastal zone. We elaborated several operational satellite monitoring systems for oil and gas companies in Russia and performed complex satellite monitoring of the ecological state of coastal waters, which included oil pollution, suspended matter, and algae bloom, in a fully operational regime. Our experience includes: (1) monitoring of the Lukoil D-6 oil rig in the southeastern Baltic Sea in 2004-2005; (2) monitoring of the underwater gas pipeline "Dzhubga-Lazarevskoe-Sochi" construction in the eastern Black Sea (2010); (3) monitoring of the "Nord Stream" underwater gas pipeline construction in the Baltic Sea (2010); (4) elaboration of the structure and principles of the complex satellite monitoring system organization for all coastal seas of Russia (2009-2010).

Keywords: Satellite monitoring, Oil and gas industry, Oil pollution, SAR, Numerical modelling

1. INTRODUCTION

Detection of oil pollution is among most important goals of monitoring of a coastal zone. Public interest in the problem of oil pollution arises mainly during dramatic tanker and oil platform catastrophes such as *"Amoco Cadiz"* (France, 1978), *"Ixtoc I"* (Gulf of Mexico, 1979-1980), *"Exxon Valdez"* (Alaska, 1989), *"The Sea Empress"* (Wales, 1996), *"Erica"* (France, 1999), *"Prestige"* (Spain, 2002), and *"Deepwater Horizon"* (Gulf of Mexico, 2010). However, tanker and oil platform catastrophes are only one among many causes of oil pollution. Oil and oil product spillages at sea take place all the time, and it would be a delusion to consider tanker accidents the main environmental danger. According to the International Tanker Owners Pollution Federation (ITOPF), over the period of 1974-2002, spillages resulting from collisions, groundings, tanker holes and fires amounted to 52% of total leakages during tanker loading/unloading and bunkering operations. Discharge of wastewater containing oil products is another important source, by pollutant volume comparable to offshore oil extraction and damaged underwater pipelines. The greatest, but hardest-to-estimate oil inputs come from domestic and industrial discharges, direct or via rivers, and from natural hydrocarbon seeps. The long-term effects of this chronic pollution are arguably more harmful to the coastal environment than a single, large-scale accident.

Shipping activities in the sea, including oil transport and oil handled in harbors, have a number of negative impacts on the marine environment and coastal zone. Oil discharges from ships represent a significant threat to marine ecosystems. Oil spills cause the contamination of seawater, shores, and beaches, which may persist for several months and represent a threat to marine resources. One of the main tasks in the ecological monitoring of the inland and coastal seas is an operational satellite and aerial detection of oil spillages, determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport. Oil pollution monitoring in the Mediterranean, North and Baltic Sea is normally carried out by aircrafts or ships (Kostianoy, 2008). This is expensive and is constrained by the limited availability of these resources. Aerial surveys over large areas of the seas to check for the presence of oil are limited to the daylight hours in good weather conditions. Satellite imagery can help greatly identifying probable spills over very large areas and then guiding aerial surveys for precise observation of specific locations. The Synthetic Aperture Radar (SAR) instrument, which can collect data independently of weather and light conditions, is an excellent tool to monitor and detect oil on water surfaces. This instrument offers the most effective means of monitoring oil pollution: oil slicks appear as dark patches on SAR images because of the damping effect of the oil on the backscattered signals from the radar instrument. This type of instrument is currently on board the European Space Agency's ENVISAT and ERS-2 satellites, the Canadian Space Agency's RADARSAT-1 and -2 satellites, and a German Earth observation satellite TerraSAR-X. The ENVISAT satellite was launched in March 2002 by the European Space Agency (ESA). Operational systems, which include 10 instruments, have been developed to monitor oceans, ice, land and atmosphere. ENVISAT has 35day repeat cycle, but due to wide swaths by some of the instruments, the Earth is covered within a few days. ASAR (Advanced Synthetic-Aperture Radar) instrument is used for mapping sea ice and oil slick monitoring, measurements of ocean surface features (currents, fronts, eddies, internal waves), ship detection, oil and gas exploration, etc. Users of remotely sensed data for oil spill applications include the Coast Guard, national environmental protection agencies and departments, oil companies, shipping, insurance and fishing industries, national departments of fisheries and oceans, and other organizations.

Since 2003 in cooperation between P.P. Shirshov Institute of Oceanology, Russian Space Research Institute, Geophysical Center (Moscow, Russia), and Marine Hydrophysical Institute (Sevastopol, Ukraine) we elaborated several operational satellite monitoring systems for oil and gas companies in Russia and performed complex satellite monitoring of the ecological state of coastal waters in a fully operational regime (24/24 and 7/7) (Kostianoy et al., 2009). Our experience includes: (1) elaboration of the complex satellite monitoring system and monitoring of the Lukoil D-6 oil rig in the southeastern Baltic Sea in 2004-2005; (2) elaboration of the complex satellite monitoring system (2007) and monitoring (2010) of the underwater gas pipeline "Dzhubga-Lazarevskoe-Sochi" construction in the eastern Black Sea; (3) elaboration of the complex satellite monitoring system (2006) and monitoring (2010) of the "Nord Stream" underwater gas pipeline construction in the Baltic Sea; (4) elaboration of the complex satellite monitoring system for the underwater gas pipeline "Bovanenkovo-Ukhta" construction in the Baydaratskaya Guba, the Kara Sea (2007); (5) elaboration of the complex satellite monitoring system for the Caspian Sea (2008); (6) elaboration of the structure and principles of the complex satellite monitoring system organization for all coastal seas of Russia (2009-2010). The accident on the BP oil platform «Deepwater Horizon» on 20 April 2010 in the Gulf of Mexico showed that absence of such a permanent complex satellite monitoring system makes low effective all efforts related to cleaning operations at sea and on the shore during the first days after the accident (Lavrova and Kostianoy, 2010). Examples from the above mentioned projects in the Baltic Sea are shown in the paper.

2. SATELLITE MONITORING OF THE LUKOIL D-6 OIL PLATFORM IN THE BALTIC SEA

Since 1993 there is no regular aerial surveillance of the oil spills in the Russian sector of the southeastern Baltic Sea and in the Gulf of Finland. In June 2003 *LUKOIL-Kaliningradmorneft* initiated a pilot project, aimed to the complex monitoring of the southeastern Baltic Sea, in connection with a beginning of oil production at continental shelf of Russia in March 2004. Operational monitoring was performed in June 2004 – November 2005 on the base of daily satellite remote sensing (AVHRR NOAA, MODIS, TOPEX/Poseidon, Jason-1, ENVISAT ASAR and RADARSAT SAR imagery) of SST, sea level, chlorophyll and suspended matter concentration, mesoscale dynamics, wind and waves, and oil spills (Kostianoy et al., 2005; 2006, 2009). As a result a complex information on oil pollution of the sea, SST, distribution of suspended matter, chlorophyll concentration, sea currents and meteorological parameters has been received. General goals of the satellite oil pollution monitoring in the Baltic Sea were:

(i) Detection of oil spills in the vicinity of D-6 oil platform as well as in the large area of the southeastern Baltic Sea;
(ii) Identification of sources of pollution;
(iii) Forecast of oil spills drift;
(iv) Data systematization and archiving;
(v) Cooperation with authorities.

Operational monitoring of oil pollution in the sea was based on the processing and analysis of ASAR ENVISAT (every pass over the southeastern Baltic Sea, 400x400 km, 75 m/pixel resolution) and SAR RADARSAT (300x300 km, 25 m/pixel resolution) images received from KSAT Station (Kongsberg Satellite Services, Tromsø, Norway) in operational regime (1-2 hours after the satellite's overpass).

For interpretation of ASAR ENVISAT imagery and forecast of oil spills drift IR and VIS AVHRR (NOAA) and MODIS (Terra and Aqua) images were received, processed and analyzed, as well as the QuikSCAT scatterometer and the JASON-1 altimeter data. Satellite receiving station at Marine Hydrophysical Institute (MHI) in Sevastopol was used for operational 24 hours/day, 7 days/week receiving of AVHRR NOAA data for construction of sea surface temperature, optical characteristics of sea water and currents maps. SST variability and intensive algae bloom (high concentration of blue-green algae on the sea surface in the summertime) allow to highlight meso- and small-scale water dynamics in the Baltic Sea and to follow movements of currents, eddies, dipoles, jets, filaments, river plumes and outflows from the Vistula and the Curonian bays. Sequence of daily MODIS IR and VIS imagery allows to reconstruct a real field of surface currents (direction and velocity) with 0.25-1 km resolution, which is very important for a forecast of a direction and velocity of potential pollution drift including oil spills. Combination of ASAR ENVISAT images with high resolution VIS and IR MODIS images allows to understand the observed form of the detected oil spills and to predict their transport by currents.

Sea wind speed fields were derived from scatterometer data from every path of the QuikSCAT satellite over the Baltic Sea (twice a day). These data were combined with data from coastal meteorological stations in Russia, Lithuania, Latvia, Estonia, Sweden, Denmark, Germany, Poland, and numerical weather models. Satellite altimetry data from every track of Jason-1 over the Baltic Sea were used for compilation of sea wave height charts, which include the results of the FNMOC (Fleet Numerical Meteorology and Oceanography Center) WW3 Model. Both data were used for the analysis of the ASAR ENVISAT imagery and estimates of oil spill drift direction and velocity.

In total 274 oil spills were detected in 230 ASAR ENVISAT images and 17 SAR RADARSAT images received during 18 months. A map of all oil spills detected by the analysis of the ASAR ENVISAT imagery in the given area of the southeastern Baltic Sea from 12 June 2004 till 30 November 2005 is presented in Figure 1. A real form and dimension of oil spills are shown. Green square shows location of the D-6 oil platform. Oil spills clearly revealed the main ship routes in the Baltic Sea directed to Ventspils, Liepaja, Klaipeda (routes from different directions), Kaliningrad, and along Gotland Island. No spills originated from D-6 oil platform were observed.

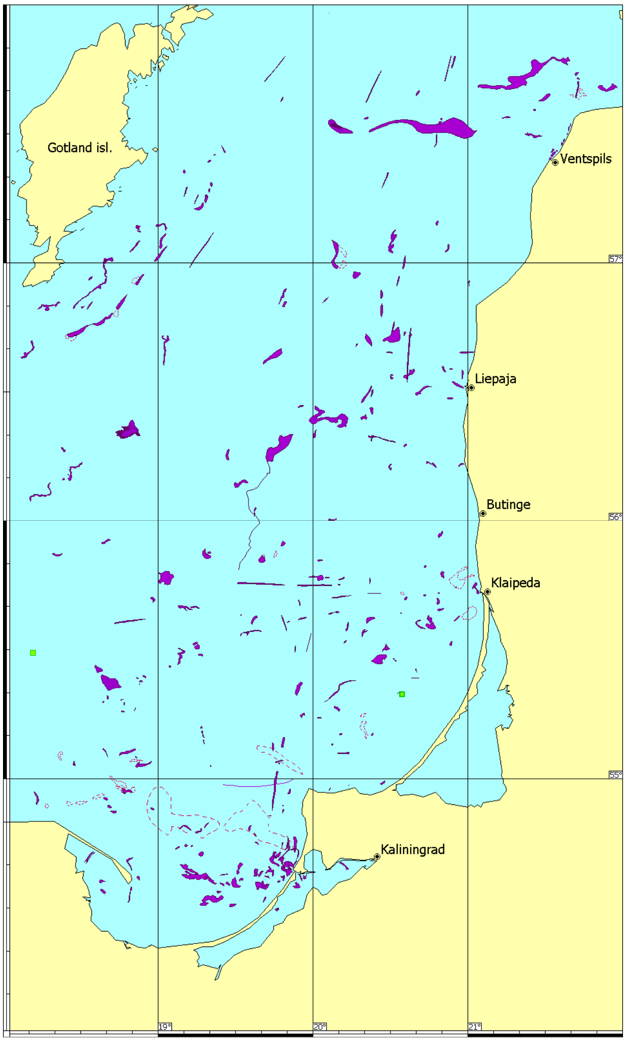

Figure 1. Map of all oil spills detected by the analysis of the ASAR ENVISAT and SAR RADARSAT imagery in June 2004 – November 2005.

3. NUMERICAL MODELLING

The interactive numerical model Seatrack Web of Swedish Meteorological and Hydrological Institute (SMHI) was used for a forecast of the drift of (1) all large oil spills detected by ASAR ENVISAT in the southeastern Baltic Sea and (2) virtual (simulated) oil spills from the D-6 platform (Figure 2). The latter was done daily for operational correction of the action plan for accident elimination at the D-6 and ecological risk assessment (oil pollution of the sea and the Curonian Spit).

This version of a numerical model on the Internet platform has been developed at the Swedish Meteorological and Hydrological Institute in close co-operation with Danish authorities (Ambjörn, 2006). The system uses two different operational weather models ECMWF and HIRLAM (HIgh Resolution Limited Area Model, 22 km grid) and circulation model HIROMB (HIgh Resolution Operational Model for the Baltic Sea, 24 layers, driven by the two weather models respectively), which calculates the current field at 3 n.m. grid. The model allows to forecast the oil drift for five days ahead or to make a hind cast (backward calculation) for 30 days in the whole Baltic Sea. When calculating the oil drift, wind and current forecasts are taken from the operational models. An oil spreading calculation is added to the currents, as well as oil evaporation, emulsification, sinking, stranding and dispersion. This powerful system today is in operational use in Sweden, Denmark, Finland, Poland, Estonia, Latvia, Lithuania and Russia (Ambjörn, 2006). Statistics, based on daily forecast of the oil spills drift from the D-6 oil platform in July-December 2004, shows potential probability (%) of the appearance of an oil spill in any point of the area during 48 h after an accidental release of 10 m^3 of oil (Figure 2). Probability of the oil spill drift directed to the Curonian Spit (150˚-sector from D-6) equals to 67%, but only in a half of these cases oil spills reached the coast.

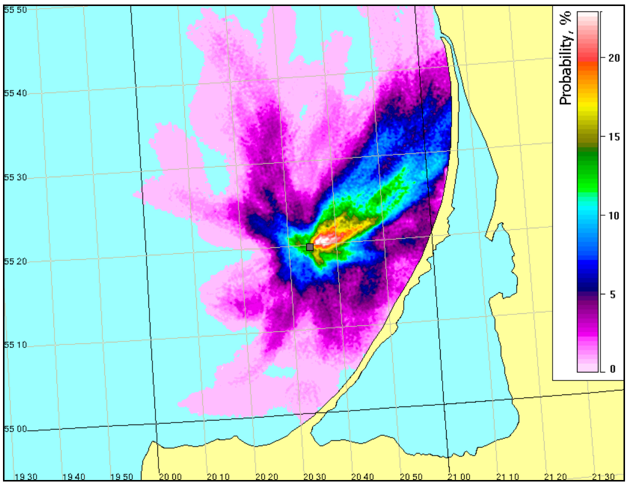

Figure 2: Probability of observation of potential oil pollution from D-6 platform during the first 48 hours after an accidental release of 10 m^3 of oil (basing on 6 months daily release of oil spill from the oil platform).

4. SATELLITE MONITORING OF THE NORD STREAM GAS PIPELINE CONSTRUCTION

The Nord Stream is a more than 1200-km long gas pipeline that will link Russia to Europe via the Baltic Sea from Vyborg in Russia to Greifswald in Germany. It will carry 55 billion m^3 of natural gas each year to supply both businesses and households. The construction in the sea has started in May 2010. The first line of the Nord Stream is scheduled to be completed in 2011. The second, parallel pipeline will be constructed in 2012. The pipeline has been planned with deep awareness of the environmental issues and specific conditions of the Baltic Sea, basing on the comprehensive Environmental Impact Assessment program that was conducted before implementing the project (Ermakov et al., 2007; Kostianoy et al., 2008).

The construction process of the pipeline may cause, in particular, the following impact on the marine environment: (i) oil pollution due to the operation of ships, pipe lay ships, dredge ships and mechanisms in the sea; (ii) increase of suspended matter concentration due to dumping of sand and gravel, and dredging operations; (iii) provoking of local algal bloom events in summertime due to vertical mixing resulted from dumping and dredging works.

But in many parts of the Baltic Sea the pipeline coincides with the main ship route crossing the sea from the Gulf of Finland to the southwestern part of the Baltic Sea. Along this ship route we have already been yearly observing the maximum of oil spills discharged from ships well before the Nord Stream construction (Helcom, 2002). Besides, in many parts of the Baltic Sea, which will be crossed by the pipeline, we observe very large areas of water with a high concentration of suspended matter and areas of very intense algal bloom. Both are observed yearly and have natural reasons. Thus, there are two very important and interrelated tasks: (i) to monitor in the operational regime the ecological state of the sea at the site of the pipeline construction, and (ii) to discriminate between natural effects and anthropogenic impacts, related to the construction itself. Moreover, oil spills must be distinguished between "own" pollution and "alien" pollution belonging to the transient ships. Complex satellite remote sensing of the sea surface in the operational regime can solve these problems.

In 2006 we elaborated and proposed a detailed plan of the complex satellite monitoring of the Nord Stream gas pipeline construction in the operational regime, which is based on our previous experience in the complex satellite monitoring of the ecological state of the Southeastern Baltic Sea, related to the operational control of oil pollution around the D-6 oil platform operated by *Lukoil-Kaliningradmorneft* (Kaliningrad, Russia) (Kostianoy et al., 2005, 2006).

The route of the Nord Stream gas pipeline coincides exactly the main ship route, and a line with a highest concentration of oil spills in the Baltic Sea. This fact leads to a supplementary task: oil spills must be distinguished between potential "own" pollution and "alien" pollution belonging to the transient ships. Thus, the ecological monitoring of the Nord Stream gas pipeline in the Baltic Sea has to include the operational satellite monitoring of all oil spillages detected in the vicinity of the site of the pipeline construction – determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport.

The construction process of the pipeline will cause the development of local plumes of sedimentary material resulted from dumping of material on the seabed or induced by dredging activities. From the other side, satellite imagery shows very large areas with high concentration of suspended matter which is a natural phenomenon resulted from the mixing of coastal waters.

Owing to the strong wind events, the material in the shallower areas is brought into suspension and advected by the currents. Usually, the transport of fine material starts in the shallow coastal regions when the wind speed exceeds a value of 10 m/s. Thus, the transport of fine material is weak during the summer and early autumn.

Since May 2010 in the framework of the contract signed with the Nord Stream Company we perform daily satellite monitoring of the suspended matter distribution on the sea surface in the Gulf of Finland. Discrimination between natural and anthropogenic effects as well as numerical modeling of suspended matter transport was included in the list of tasks of the proposed complex satellite monitoring of the gas pipeline construction.

5. CONCLUSIONS

The ecological monitoring in the field of marine oil and gas industry (construction and exploitation of oil and gas pipelines, platforms, terminals and ports) in the inland and coastal seas has to include the operational satellite monitoring of: (i) all oil spillages detected in the vicinity of the site of the construction – determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport; (ii) suspended matter – determination of its spatial and temporal characteristics, determination of suspended matter concentration, discrimination between natural and anthropogenic effects; (iii) algal bloom events – determination of their spatial and temporal characteristics, discrimination between natural and anthropogenic effects.

ASAR ENVISAT and SAR RADARSAT provide effective capabilities to monitor oil spills, in particular, in the Baltic Sea. Combined with satellite remote sensing (AVHRR NOAA, MODIS-Terra and -Aqua, MERIS Envisat, Landsat, Jason-1, etc.) of SST, sea level, suspended matter and chlorophyll concentration, mesoscale dynamics, wind and waves, this observational system represents a powerful method for long-term monitoring of ecological state of the inland and coastal seas especially vulnerable to oil pollution. Such an operational satellite monitoring system must be accompanied by an operational numerical model for forecasting of the drift of the detected oil spills in the vicinity of the construction for assessment of ecological risks related to potential oil pollution of the neighboring coasts and marine protected areas. Daily meteorological information and weather models are of vital importance for the system.

In 2004-2005 we elaborated and performed such a complex approach to operational monitoring of the Southeastern Baltic Sea in connection with a beginning of oil production on the Lukoil D-6 oil platform at continental shelf of Russia in March 2004. Today, we use the same system for a complex satellite monitoring of the Nord Stream gas pipeline construction in the Baltic Sea and “Dzhubga-Lazarevskoe-Sochi” gas pipeline construction in the Black Sea.

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REFERENCES

C. Ambjörn, “Seatrack Web, forecast of oil spills, the new version 2.0”, Abstracts, US/EU–Baltic Int. Symp. on “Integrated Ocean Observation Systems for Managing Global & Regional Ecosystems Using Marine Research, Monitoring & Technologies”, May 23-25, 2006, Klaipeda, Lithuania.

P.N. Ermakov, E.O. Cherevichenko, and A.G. Kostianoy, “Industrial environmental monitoring and control of the environmental legislation in construction and operation of the offshore section of the North-European Gas Pipeline”, Proc., VIII International Environmental Forum “Baltic Sea Day”, St.-Petersburg, 21-23 March 2007, “Dialog” Publ. House, St.-Petersburg, pp. 236-240.

HELCOM, 2002 (www.helcom.fi).

A.G. Kostianoy, “Satellite monitoring of oil pollution in the European Coastal Seas”, OCEANIS, vol 34, N 1/2, pp. 111-126, 2008.

A. Kostianoy, P. Ermakov, and D. Solovyov, “Complex satellite monitoring of the Nord Stream gas pipeline construction”, Proc., US/EU Baltic 2008 International Symposium “Ocean Observations, Ecosystem-Based Management and Forecasting”, May 27-29, 2008, Tallinn, Estonia.

A.G. Kostianoy, O.Yu. Lavrova, and M.I. Mityagina, “Integrated satellite monitoring of oil pollution in the Russian seas”, In: “Problems of Ecological Monitoring and Modelling of Ecosystems”, Yu.A. Izrael (Ed.), vol 22, pp. 235-266, 2009 (in Russian).

A.G. Kostianoy, S.A. Lebedev, D.M. Solovyov, and O.E. Pichuzhkina, Satellite monitoring of the Southeastern Baltic Sea. Annual Report 2004. Lukoil-Kaliningradmorneft, Kaliningrad, 36 p., 2005.

A.G. Kostianoy, K.Ts. Litovchenko, O.Yu. Lavrova, M.I. Mityagina, T.Yu. Bocharova, S.A. Lebedev, S.V. Stanichny, D.M. Solovyov, A.M. Sirota, and O.E. Pichuzhkina, “Operational satellite monitoring of oil spill pollution in the southeastern Baltic Sea: 18 months experience”, Environmental Research, Engineering and Management, N 4(38), pp. 70-77, 2006.

O.Yu. Lavrova, and A.G. Kostianoy, “A Catastrophic Oil Spill in the Gulf of Mexico in April-May 2010”, Russian Journal for Remote Sensing (Issledovanie Zemli iz Kosmosa), N 6, pp. 67-72, 2010 (in Russian).