Project No. 031001

MONRUK

Monitoring the marine environment in Russia, Ukraine and Kazakhstan using Synthetic Aperture Radar

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT
SIXTH FRAMEWORK PROGRAMME
PRIORITY 4
Aeronautics and Space

MONRUK Publishable Final Activity Report

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Project coordinator organisation: Nansen Environmental and Remote Sensing Center

Revision 1

Contents

1 Project execution

Summary of project objectives

The overall objective of MONRUK was to develop and implement satellite Synthetic Aperture Radar (SAR) monitoring of the marine environment in Russia, Ukraine and Kazakhstan (the RUK area) as a contribution to development of GMES marine services in (1) the Barents and Kara Seas, (2) the Black Sea and (3) the Caspian Sea. Satellite SAR images for the three study areas were collected in order to develop and validate retrieval algorithms for ocean and sea ice parameters. In addition to SAR data, optical, infrared and scatterometer data have been used to observe sea surface temperature, ocean colour and surface wind.

In addition to SAR data analysis, optical and IR data, met-ocean data from models and in situ platforms were used. The main tools in the SAR analysis were the Radar Imaging Model (RIM) and the Atmospheric Boundary Layer (ABL) model provided by NIERSC and the SARTool provided by BOOST/CLS. These tools were distributed and used by the consortium partners as part of the data analysis in the project.

SAR monitoring exercises were conducted in the three study areas with support from other met-ocean and satellite data. The data analysis resulted in retrieval of geophysical information (wind, waves, currents, fronts, slicks, sea ice parameters). A number of users were involved in the project, receiving satellite data results. The users assessed the information obtained from the satellites and provide feedback to the consortium partners in order to improved satellite observations of the marine environment in the three study areas. The lessons learned from the user demonstrations will be used to develop future operational systems for SAR monitoring in the three regions.

One objective was to develop a prototype, web-based, marine information system with focus on SAR data. The main achievement of this work was the establishment of a SAR downloading, processing and archiving system used for selecting and distribution of SAR data to the consortium. Finally, MONRUK disseminated results to other related projects, organizations and agencies that are involved in developing operational oceanography services across Europe.

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Partners:

Coastal and Marine Resources Centre (CMRC), University College Cork, Ireland
BOOST/CLS, France
Nansen International Environmental and Remote Sensing Center (NIERSC), Russia
Marine Hydrophysical Institute (MHI), Ukraine

National Centre of Space Research and Technology of the National Space Agency Republic of Kazakhstan, Kazakhstan
JRC, Institute for the Protection and Safety of the Citizen, Italy

Summary of work performed and results achieved:

SAR data acquisition system
A system for downloading, processing and archiving ENVISAT ASAR images from ESA rolling archive has been established at NERSC. The access to SAR data has been secured through ESA AO projects, allowing the consortium to download all produced SAR images in the study areas to a server at NERSC. A copy of the archive was kept at NIERSC in St. Petersburg for distribution to the partners and users in the RUK region. This archive has made it possible to select interesting SAR images for further analysis and distribution to users. During the MONRUK project several thousand SAR images were collected, and several hundred were used in the project. This SAR downloading and archiving system is now run operationally at NERSC and is used in many projects. The system is available at http://sat.nersc.no and is presently password-protected.

Analysis tools and algorithms
The software package SARTool, provided by BOOST/CLS was the main software package used in the project to analyse SAR images from ERS, ENVISAT, TerraSAR-X and RADARSAT. SARTool has been developed over many years and was provided to all the partners. The software incorporates a number of auxiliary data sets to support the SAR analysis such as bathymetry, shoreline, wind and temperature data, currents from models and others. The partners were trained in use of the software and intend to use the software for analysis of SAR ocean images in future projects. Use of SARTool requires a licence issued by BOOST/CLS who is the owner of the system.

NIERSC has developed the Radar Imaging Model (RIM) which predicts background radar scattering from the sea surface at arbitrary atmospheric stratification, wind and wave conditions as well as radar signature of current features, surface temperature fronts and natural slicks or oil spills. By prescribing ocean surface conditions and SAR parameters, the model is used to produce simulated SAR images. The modelled SAR images are useful as a tool for interpretation of ocean features observed in real SAR images. This model has been used in studies of SAR signatures in the Barents and Kara Seas. NIERSC and NERSC own the IPR for the model.

Data analysis and retrieved products
The main scientific results of MONRUK are based on the analysis of numerous SAR images, combined with other satellite data and models, giving new information about open ocean and sea ice conditions in the study areas.

The SAR studies the Barents and Kara seas were mainly focused on sub-mesoscale ocean currents and fronts, internal waves and wind field. The studies are motivated by the need to understand features such as convergence and divergence zones, fronts, eddies and internal waves. Fronts are potential accumulation zones of nutrients and therefore important for fisheries. Internal waves and their energy is important for navy operations and ocean mixing processes. Monitoring of wind field with emphasis on polar laws is needed for better weather forecasting. The studies show that current features, fronts and internal waves can routinely be observed by SAR. These oceanic phenomena were classified, analyzed, mapped and interpreted with combine use of SARTool and the RIM model. The SAR analyses were supplemented by output from the operational ocean current model

HYCOM[1], as well as infrared and optical satellite images. The supplementary information was important for interpretation of the observed SAR signatures.

The work in the Black and Caspian Sea study areas was focused on oil spill detection by SAR. The SARTool provided by BOOST/CLS was chosen as software for processing and analysis of the SAR data. A number of SAR images were processed in order to establish the quantitative level of pollution of the seas by oil spills, statistical parameters of observed oil spills events, and to establish the origin and sources of the oil spills. In total 258 oil spills events were identified in 367 analyzed SAR images over the Black Sea. The spatial distribution of the spills showed that the most frequent occurrence of oil spills takes place along the main tanker routes, near offshore oil platform positions, and in the large ports.

In the Caspian Sea, about 100 SAR images were analysed and oil spills were observed in about 30 cases. The main contribution to oil spills in this area is not only industrial activities (oil platform, tankers and pipelines), but also natural sources such as hydrocarbon leakage from the seafloor. The analysis of SAR images in the northern Caspian Sea is particular difficult in the coastal zones due to varying sea level and very complicated configuration of the coastline.

The retrieval of Doppler surface velocity from SAR data is a new promising approach that has been demonstrated in the project. The Doppler velocity field contains both wind-driven and wave generated surface motion. Surface current is an important oceanographic parameter which could be derived from the total velocity if wind dependence of the Doppler velocity is established (analogy to CMOD4). The reconstruction of the surface current from the Doppler velocity field is presently investigated by a PhD student at NERSC.

The Kerch Strait oil spill accident in the Black Sea in November 2007 provided an opportunity to use the incident as a case study to assess how satellite SAR data could be a useful tool to map the extent of an oil spill. It was demonstrated that it is possible to use SAR from three different SAR satellites to monitor the oil spill: Envisat, RADARSAT and TerraSAR-X. Also Russian optical images were collected from the oil spill accident. The lesson learned from this accident was that there was no systematic SAR or optical data acquisition in the days following after the accident, so it was not possible to carry out a dedicated study of the spreading of this oil spill. In order to carry out a systematic study of oil spill detection from satellites, it is necessary to have daily images during the days following an oil spill event.

A neural network algorithm of sea ice classification was developed and tested for SAR images over the Barents and Kara Sea region. The algorithm of multiyear ice concentration retrieval consisted of sea ice classification using Bayesian approach, interactive delineation of zones of different partial concentration of multiyear ice and calculation of multiyear ice concentration within the boundaries of delineated areas. An algorithm of ice drift, based on cross-correlation technique, was developed and tested using a series of ENVISAT ASAR images. These algorithms will be used in future sea ice monitoring systems based on SAR data.

The polynya in Storfjorden in Svalbard was investigated by combined use of SAR and optical/infrared images. SAR images were used to classify ice types, while optical/infrared images were used to identify open water and thin ice. A method for ice thickness retrieval using thermodynamic balance between air, snow cover, ice and ocean was tested on MODIS infrared images. The SST data from MODIS were used as input to an algorithm

[1] HYCOM is the ocean model used in GMES marine core services for the Arctic regions (http://www.myocean.eu.org)

calculating the thickness of thin (< 0.5 m) ice. This method was a useful supplement to the SAR analysis, which does not provide direct information about ice thickness.

The capability of ENVISAT Alternating Polarization data (AP) to classify sea ice types was also investigated. Preliminary results shows that sea ice type classification can be improved by use of polarization data, but more studies are needed to establish which combination of co- and cross-polarization are optimal for specific ice types. ENVISAT AP and TerraSAR-X images were also studies for iceberg detection. Preliminary results show that the TerraSAR-X images have promising capability for detection of icebergs, at least in the Franz Josef Land area where most of the icebergs are less than 100 m in horizontal extent. Comparison between TerraSAR and ENVISAT AP images showed that the higher resolution provided by the TerraSAR-X images can improve the detection of icebergs considerably in this area.

Sea ice monitoring in the northern part of the Caspian Sea was conducted using ENVISAT ASAR and RADARSAT SAR data. ASAR images were received from NIERSC and RADARSAT images were received from CAR. Selected images were analysed for detailed characterisation of the sea ice in the area. The results of this analysis is useful for oil companies and other operators who need to know how ice conditions change during the winter months.

User demonstrations

The information derived from SAR images regarding oil spills and sea ice features has been positively assessed by many users who received examples of analyzed images. Further use of SAR for mapping ocean and sea ice features has been requested by most of the users. It will therefore be important to follow up the activities in MONRUK with new projects that can develop SAR monitoring further in these regions.

About 15 user institutions from Russia, Ukraine and Kasakhstan have been involved in the project, receiving SAR data and analysed information retrieved from the SAR data. About 200 ENVISAT ASAR images were selected and distributed to Russian users in the Barents and Kara Seas for supporting their work on sea ice monitoring. The major users are Marine operations headquarters of Rosatomflot and the Center for Ice and Hydro-meteorological Information of AARI. Rosatomflot used the SAR images for planning routes of navigation in the Arctic and for solving tactical tasks of navigation in the ice.

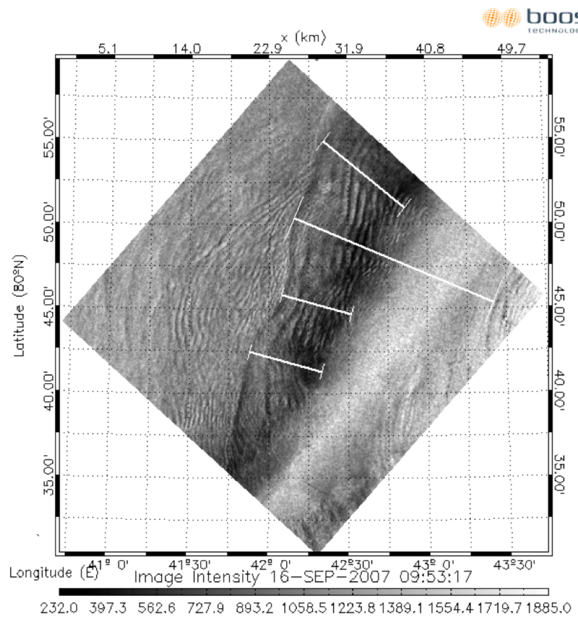
In the Black Sea, Marine Hydrophysical Institute (MHI) contacted (1) The Oceanographical Center in Sevastopol, who performs operational monitoring and forecasting of the ocean conditions in the Black Sea. The Center is particularly interested to use SAR for oil spill detection. (2) The Operational Center of National Space Agency of Ukraine. This Center is responsible for planning and design of new EO satellites in Ukraine, and is therefore interested all kind of results on SAR ocean monitoring in the Black Sea. (3) The Black Sea branch of Moscow State University, where students are educated in satellite technology and applications. The staff from MHI teaches students at this university and have recruited young scientists to work with earth observation.

In the Caspian Sea users were interested both in sea ice monitoring in the Northern Caspian Sea and oil spill monitoring in the whole region.

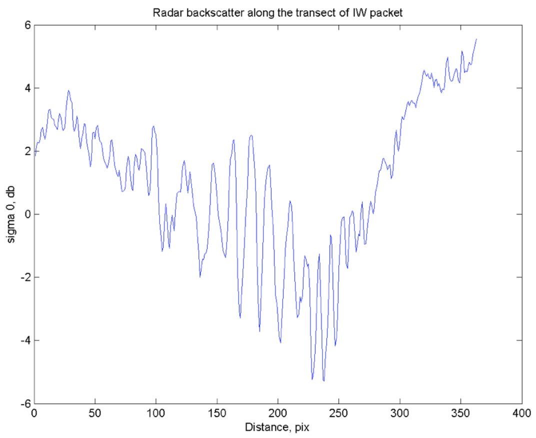
The users have in general been very interested in receiving the information, using the SARTool and learn how to analyse data. All the users have provided feedback and suggested how SAR monitoring could be implemented in the future. For many users, MONRUK was the first project demonstrating the capability of SAR data for ocean and sea ice monitoring. The users were very interested in a continuation of the activities that started in MONRUK. It is therefore important to establish follow-up projects where the SAR monitoring systems can be further developed in the regions. users suggested that future work should focus on: (1) Free access to satellite, meteorological, hydrological data and the products demonstrated in MONRUK such as oil spill analysis and sea ice classification; (2) Incorporating learning about the modern algorithms of data analysis developed within MONRUK project. Future work should also involve students in project activities in order to build up capacities in the study areas to analyse and use SAR-based information.

System for data dissemination

The original plan was to implement a web-based information system in MONRUK for distribution of data among the partners and to the users. It soon became clear that it was too ambitious to implement such system among the Russian, Ukrainian and Kazakhstan partners and their users. The communication by Internet was too slow for transmission of large data files. These partners did not have infrastructure and technical capacity to install and operate a web-based system. It was therefore decided to disseminate data by a more simple method such as using ftp-servers where data from the partners were placed and other partners could download data. The main result of the work was the establishment of the SAR downloading, processing and archiving system at NERSC, where all partners could search and download SAR images for the study areas. Another important result was the capacity building efforts provided by CMRC, NERSC and NIERSC to train personnel among the other partners how to exchange data in an efficient way and what infrastructure is needed to establish a web-based information system.



a



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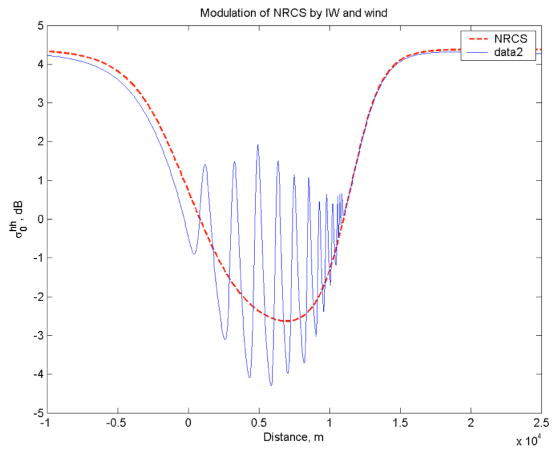
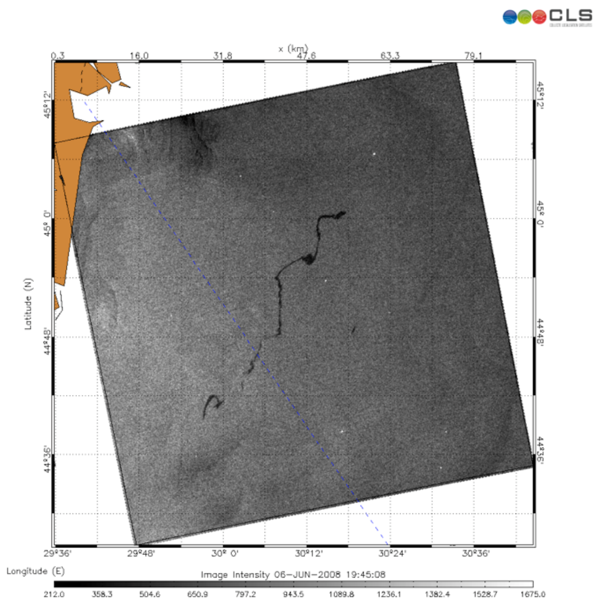


c

Figure 1, (a) SAR image of internal waves in the Barents Sea (16 September 2007); (b) SAR profile across the internal wave train; (c) radar image model of the internal wave train (blue) and the background signature (red).



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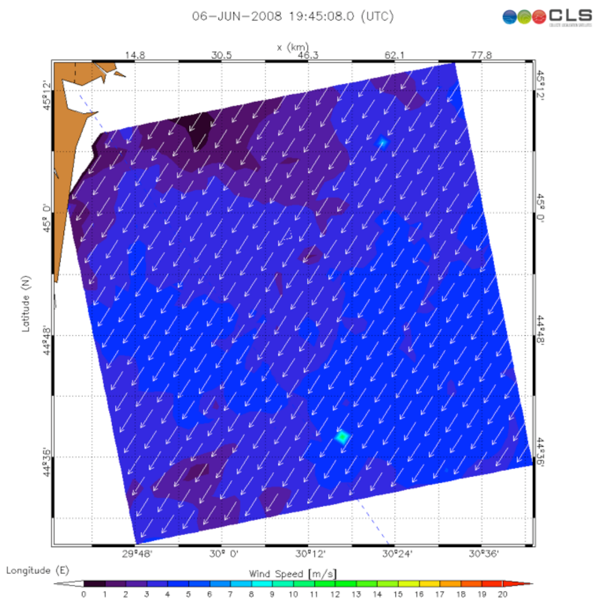

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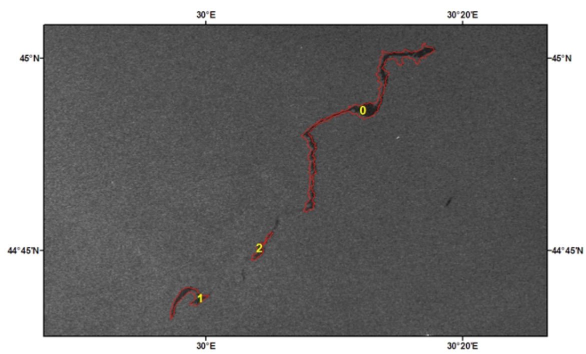

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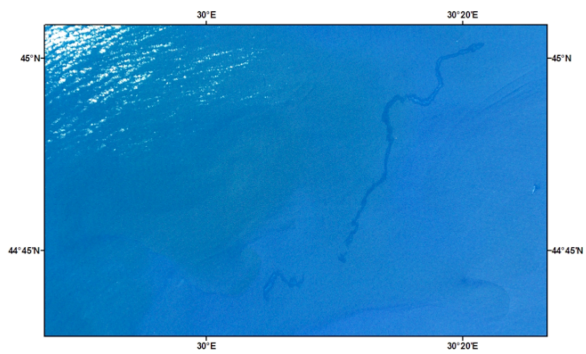

d

Figure 2. (a) SAR image from western Black Sea obtained on 06 June 2008 with an oil spill in the centre; (b) wind field based on SAR backscatter; c) analysis of the oil spill areas using SARTool, where the three polygons are described in the table below; (d) the same oil spill as seen in a Landsat image from the same day as the SAR image.

Table.1 Parameters of the oil spill presented in figure 2c

Oil spill area	Wind	Length	Perimeter	Area	Complexity	Contrast	PMR	B Gradient	Mean Out	PMR2	Spread	Slendernes	direction
0	6,14	27,28	85,46	24,43	23,79	1,47	0,26	685,97	759,51	0,12	707,97	661,87	85,65
2	5,36	5,25	18,55	4,82	5,68	1,52	0,23	917,47	904,07	0,13	95,65	39,22	69,64
1	5,36	4,47	11,15	2,18	4,54	1,39	0,17	880,32	838,54	0,13	49,82	46,81	96,45

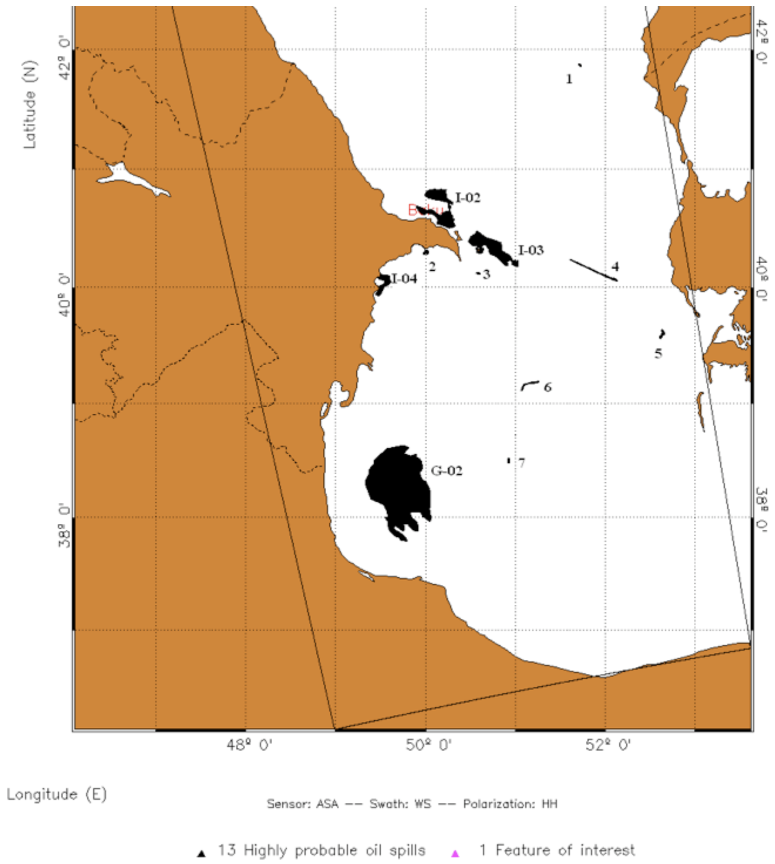

Figure 3. Upper graph: Map of oil slick clusters observed in the SAR image from 11 August 2008. Lower graph: detailed SAR image of oils spills in cluster G-02.

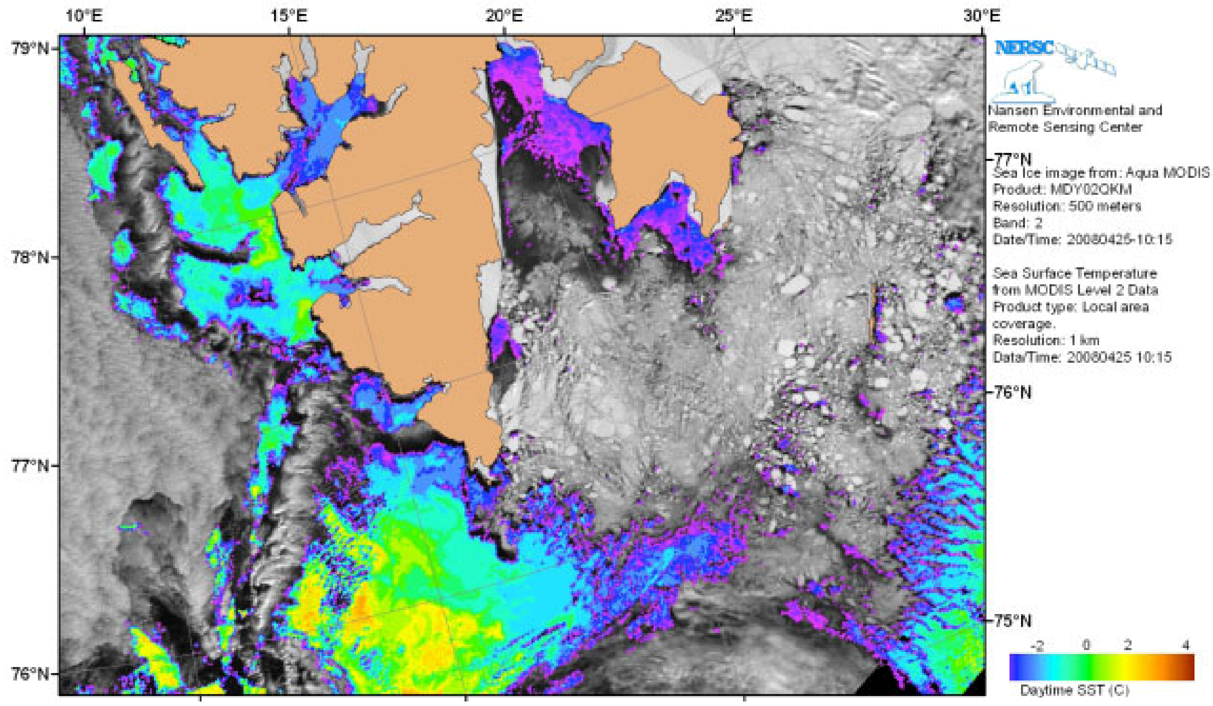

Figure 4. Merged SAR image from ENVISAT (greyscale) and sea surface temperature from MODIS on 25 April 2008 in the Svalbard area.

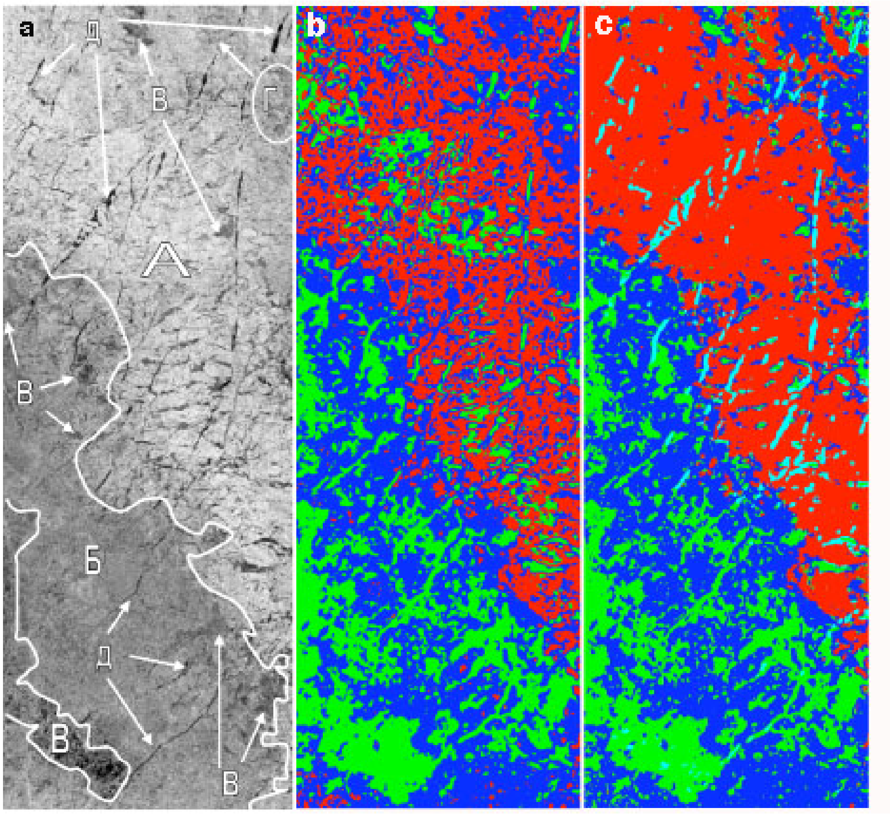

Figure 5. (a) SAR image with three zones of ice types; (b) ice type classification using the neural network algorithm: multiyear ice (red), deformed firstyear ice (dark blue) level firstyear ice (green) and open water/nilas in leads (light blue). (c) classification results after two iterations with the neural network algorithm.

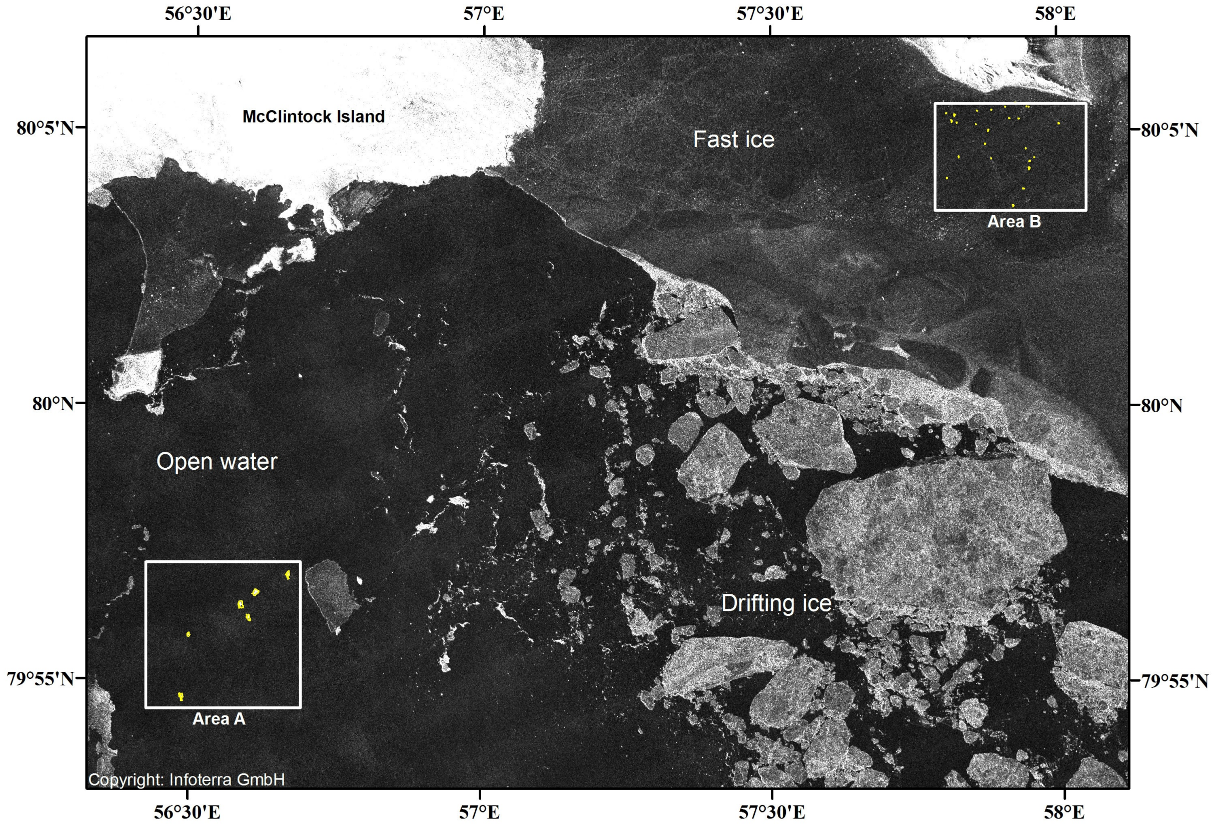

Figure 6. Iceberg detection in the northeastern Barents Sea in a TeraSAR-X image from 02 June 2008. The subareas A and B have been analysed with an iceberg detection method, and each detected iceberg is marked by yellow.

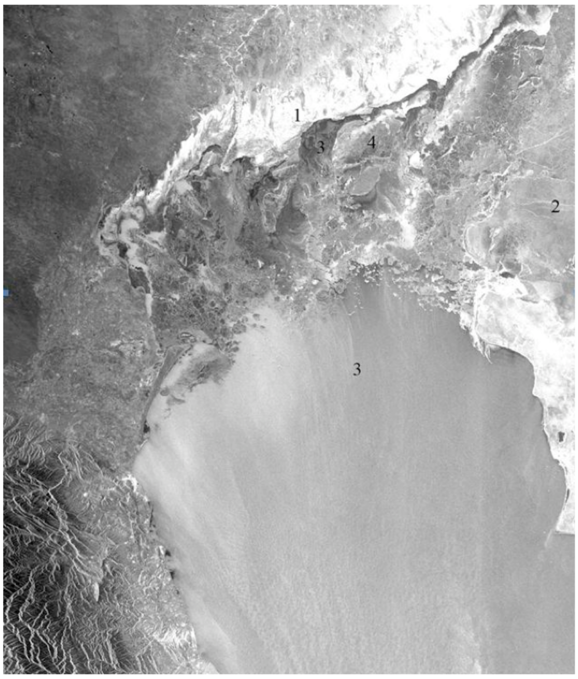

Figure 7. Analysis of sea ice in a SAR image in the Northern Caspian Sea obtained on 08 February 2008, where areas of different ice conditions are identified.   1 – fast ice; 2 – sea ice concentration 10/10; 3 - sea surface; 4 - ice concentration 8-9/10.

2 Dissemination and use

2.1 Dissemination to users

The project has demonstrated the capacity of SAR data to detect and monitor ocean surface features to many users in Russia, Ukraine and Kazakhstan. The users, including both governmental institutions, research institutions and companies, have expressed their interest to develop a SAR observing system as part of the environmental monitoring in the Barents-Kara seas, Black Sea and Caspian Sea. The need for improved monitoring in these areas is clearly stated. There is a large potential for further exploitation of satellite SAR data in these regions. The stress on the marine environment is increasing due to oil and gas exploration as well as transportation by tanker and pipelines. The need for improved monitoring and forecasting systems is evident. The next step can be to start a follow-up project where data acquisition, analysis and dissemination of results are done in a more systematic way with continuous involvement of users. A follow-up project needs to identify barriers preventing the development of satellite monitoring in the three regions and propose mitigation actions. The SAR data acquisition scheme established in MONRUK, based on ESA's contribution to GMES, will continue and secure provision of SAR data. A new project can therefore focus on the developing tailored products to different users where other satellite and in situ data are included.

2.2 Networking activities

The networking activities focused on linking MONRUK results to a broader group of organizations and projects. Those included among others, the Black Sea Commission (BSC), the European Group of Experts on satellite Monitoring of sea-based oil Pollution (EGEMP), the Arctic Regional Ocean Observing System initiative (Arctic ROOS) and the European Maritime Safety Agency (EMSA). The main efforts were focused in promoting collaboration with bodies, involved in issues related to the scientific objectives of the project.

A major networking event was the organization of the Maritime Satellite Surveillance Forum (Ispra, Italy, 11-13/June/2007), with the participation of more than 60 delegates from almost all EU maritime Countries, including also Secretariats of relevant Regional Agreements. This offered the unique opportunity to link MONRUK to the main relevant European initiatives in the field, such as MARCOAST, EGEMP and EMSA Clean Sea Net. The networking event included the MARCOAST (Marine & Coastal Environmental Information Services) oil spill workshop. MARCOAST is a three-year GMES project, funded by the European Space Agency, whose main objective is to establish of long term network, of marine and coastal information services. This event encompassed a User Federation meeting (11/June/2007) and a validation workshop (12/June/2007).

The third event was the 9th meeting of the European Group of Experts on satellite Monitoring of sea-based oil Pollution (EGEMP), which for the first time was opened to non-EGEMP members, such as MONRUK and MARCOAST partners. The fourth event was the 3rd EMSA Clean Sea Net User Group and finally the fifth event was devoted to the User Executive Board meeting of MARCOAST.

This 3 day broad forum, on the use of satellite SAR imagery to monitor oil spill pollution, offered the possibility to the MONRUK partners, to meet MARCOAST partners and official experts, appointed by competent national authorities, from Research (EGEMP) and from the operational sector (EMSA Clean Sea Net User Group), as well as from the industry (e.g. Thales Alenia Space, Telespacio, Kongsberg Satellite Services, etc).

2.3 Dissemination through Internet, conferences and literature

The project and its results were also broadly disseminated through Internet, conferences and workshops. Some of these dissemination events are described below.

Internet dissemination

http://monruk.nersc.no/ This is the official site of the project maintained on the Co-ordinator's web server (NERSC). Links to this site appear also in the web sites of the other partners.

http://ipsc.jrc.ec.europa.eu/showca.php?id=71 Brief description of the MONRUK project appears on the web site, of the Institute for the Protection and Security of the Citizen of the JRC.
http://ec.europa.eu/enterprise/policies/space/files/monruk.pdf A two page brochure of the MONRUK project appears in the official web site of the European Commission.

http://www.osce.org/documents/eea/2008/06/32337_en.pdf A presentation of the oil spill pollution related studies, carried out within the frame of the MONRUK project appears in the official web site of the Organization for Security and Co-operation in Europe.

http://www.gmes.info/pages-principales/projects/project-database/database-of-projects/?idproj=125&what=1&page=5&cHash=ca716093e5 A brief description of the MONRUK objectives appears in the web site of GMES.

http://www.pryroda.gov.ua/index.php?newsid=219 Activities of the MONRUK project were reported in the web site of the State Research and Production Centre "Nature" of Ukraine.

http://planet.iitp.ru/sea_monitor/archive/2007/12/02.htm The oil spill pollution activities over Russian seas, carried out in the frame of the MONRUK project, were reported in the April-November/2007 newsletters of the Russian Scientific Research Center of Space Hydrometeorology "Planeta".

http://ec.europa.eu/enterprise/policies/space/files/research/brochure_fp6_low_en.pdf
Description of the MONRUK project objectives appears in the brochure entitled "Space Research – Developing applications for the benefit of the citizens", European Communities, 2008 edition, EC-DG General Enterprise and Industry.

http://www.uagp.net/news/geonews/11090.html The research activities of the MONRUK project were reported at the web site of the Russian Federal State Unitary Enterprise under its Geodesy and Cartography news.

Conference and workshop presentations and papers

Presentations at national and international scientific events:

1) Sandven S., Kudriavtsev V. Malinovsky V. and Stanovoy V., (2008), Development of Marine Oil Spills/slicks Satellite monitoring System elements for the Black Sea, Caspian Sea and Kara/Barents Seas, Proc. 2nd International Workshop on Advances in SAR Oceanography from ENVISAT and ERS Missions SEASAR-2008 21-25 January 2008 ESA-ESRIN Frascati (Ro) Italy.
2) Novikova N. N., Pakhomov L. A., Feoktistov A. A., Zakharov A. I. and Denisov P. V., (2008), International projects DEMOSSS and MONRUK & development of work initiated under international projects OSCSAR and MONRUK, Proc. 6th Annual Conference of the All-Russia Conference, "Modern problems of remote sensing of Earth from space",10-14 November 2008, Moscow, Russia (in Russian).

3) Feoktistov A. A., Novikov N. N., Pakhomov L. A., Alexandrov V. Y., Zakharov A. I., Denisov P. V., (2008), The main results of monitoring of the ice cover of the Caspian Sea in the framework of international projects and DEMOSSS MONRUK, Proc. 6th Annual Conference of the All-Russia Conference, “Modern problems of remote sensing of Earth from space”,10-14 November 2008, Moscow, Russia (in Russian).
4) Feoktistov A. A., Novikova N. N., Pakhomov L. A., Zakharov A. I., Denisov P. V., (2008), Monitoring the sea surface of the Caspian Sea in the framework of international projects DEMOSSS and MONRUK, Proc. 6th Annual Conference of the All-Russia Conference, “Modern problems of remote sensing of Earth from space”,10-14 November 2008, Moscow, Russia (in Russian).
5) DEMOSSS • MONRUK, Proc. XXVI All-Russia National Symposium on radar study of natural environments, 19-20 May 2009, St. Petersburg, Russia.
6) DEMOSSS • MONRUK, Proc. XXVI All-Russia National Symposium on radar study of natural environments, 19-20 May 2009, St. Petersburg, Russia.
7) Novikova N. N., Pakhomov L. A., Feoktistov, A. A., Denisov, P.V., (2009), The monitoring of oil pollution of the Caspian Sea to the use of ASAR/ENVISAT in the framework of international projects DEMOSSS and MONRUK, Proc. IV All-Russia Scientific School and Conference, "Radiophysics Methods in Remote Sensing Media", 30/June – 03/July 2009 Murom, Russia (in Russian).
8) Muellenhoff O., Ferraro G., Topouzelis K. (2008), Monitoring the Marine Environment in Russia, Ukraine and Kazakhstan Using Satellite Synthetic Aperture Radar - The MONRUK Project, Proc. of Remote Sensing for International Stability and Security; 19 February 2008; Ispra (VA) (Italy), JRC46503
9) Sandven S., Hamre T. and Kudriavtsev V., (2009), MONRUK: Monitoring the marine environment in Russia, Ukraine and Kazakhstan, Proc. 33rd ISRSE 4-8 May 2009, Stressa, Italy.
10) Sandven S. and Hamre T, (2009), Interoperable GMES services for marine pollution monitoring and forecasting in European regional seas, Proc. 33rd ISRSE 4-8 May 2009, Stressa, Italy.
11) Sandven S., Johannessen O. M., Bobylev L. and Dahlin H., (2009), Arctic Regional Ocean Observing System, Proc. 33rd ISRSE 4-8 May 2009, Stressa, Italy.
12) Pavlakis P. and Ferraro G., (2009), Possibilities and limitations in using satellite SAR for oil spill monitoring in the Northeast Caspian Sea – Project MONRUK, Proc. 33rd ISRSE 4-8 May 2009, Stressa, Italy.

2.4 Potential impact

It is expected that the results of MONRUK will have impact on ocean monitoring and forecasting systems in the three study areas after the project is completed. SAR technology, combined with other satellite data, in situ data and modelling systems, can provide significant improvement of the ocean observing systems. This requires that SAR data becomes available on regular basis and derived products can be effectively disseminated to users. Improved monitoring and forecasting will be required as oil and gas exploration, tanker traffic and other industrial activities increases in the areas. The pressure on the marine environment will increase as a result of these activities. Both industries and governmental agencies will benefit from an improved monitoring system where SAR data play a central role.

3 Publishable results

The main exploitable results from MONRUK are: 1) SAR data acquisition and processing system, 2) SARTool software package, 3) Radar Imaging Model, and 4) SAR data analysis results in each of the three study areas.

SAR data acquisition and processing system

This is a system for downloading ENVISAT ASAR images from ESA's rolling archive where data are available for GMES monitoring projects and other research projects that need regular access to SAR data for marine areas. The system allows users to search in archive of SAR data, browse quicklooks and process selected images with relevant software tools. The system is non-commercial and made for use in operational SAR-based services. At present, the system calculates wind speed and Doppler velocity automatically, and ice classification is presently under implementation. It is planned to implement more algorithms for retrieval of ocean and sea ice parameters. At present the system is password-protected because of the data policy for SAR data. Future use of the system is expected to have open access and be adapted for exploitation of Sentinel-1 data. The system will be further developed in the Norwegian Satellite Earth Observation Database for Marine and Polar Research (NORMAP). This is a research infrastructure funded by the Research Council of Norway for 2010-2016.

SARTool software package.

This software package has been developed over several years by BOOST Technologies, and MONRUK has contributed to further development and implementation of the package. SARTool is designed for analysis of SAR images for marine studies, including retrieval of wind, detection of oil slicks, ship detection and inclusion of data from other satellites, bathymetry, coastline, and model output. Through user demonstrations BOOST has received feedback from users about improvement of the SARTool. Algorithms for retrieval of sea ice parameters and icebergs are under implementation. It is a commercial system where users purchase a licence and get support from BOOST.

Radar Imaging Model

This is a radar scattering model for simulation of SAR images of the ocean surface with prescribed wind, waves, temperature and slicks. The model is used to quantify the effect of varying surface conditions on the SAR signature. The model is useful for analysis and interpretation of signatures in real SAR images from all available SAR systems. The model is developed by NIERSC and NERSC and is available as non-commercial software. The model will be further developed and tested on SAR data with different frequency, polarisation and incidence angles.

SAR data analysis results

A number of scientific results using SAR data and the analysis tools have been obtained in the three study areas. The studies have shown that SAR is a useful data source for identification and retrieval of ocean and sea ice parameters and processes. This contributes to improved detection and monitoring of the marine environment and to build up new knowledge about the processes at the sea surface. Two topics are particular relevant in the study areas, namely the detection and mapping of oil spills and sea ice. These phenomena are essential to monitor from satellites because they have strong impact on the environment and human operations. Many users have requested that SAR monitoring systems should be established in the study regions, and follow-up projects to MONRUK should be initiated because of the need to obtain the information that SAR can provide. This shows that there is a demand for SAR monitoring systems and necessary step should therefore be taken to establish such system in the Barents-Kara Sea, the Black Sea and the Caspian Sea.