Satellite Monitoring of Film Pollution of the Black Sea Surface

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Our experience in the satellite monitoring of the Black Sea

The technology of miltisensor satellite monitoring of the sea surface was developed and tuned by a consortium of research teams, including our team from Space Research Institute and the team from P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences.

1. ***1999 - 2005*** **(in summer periods) - Satellite monitoring of the coastal zone of the Black Sea in Novorossiysk – Gelendzhik area**

2. ***2006-2008*** **- Satellite monitoring of water conditions and pollution level of the Russian part of the Black Sea. The work was performed under a contract with the Russian Federal Service for Hydrometeorology and Environmental Monitoring jointly with specialists from the Research Center «Planeta»**

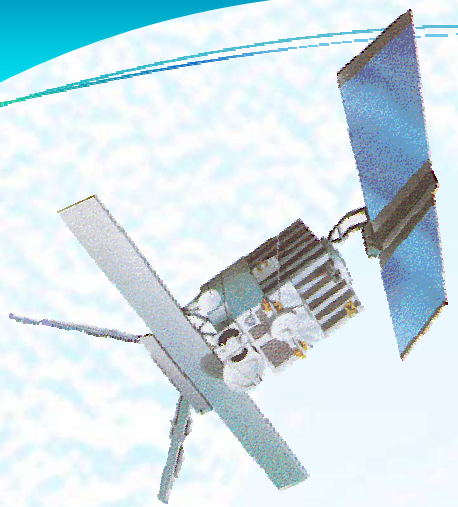
3. ***2009-2011*** **- Satellite survey of the total aquatic area of the Black Sea (Space Research Institute of RAS)**

Detection of anthropogenic and biogenic surface films by means of satellite radar data

4 main types of sea surface polluting films were investigated, caused by:

- oily wastewaters discharged by watercrafts;
- sewage discharge and rivers outflows, containing anthropogenic and natural pollutants;
- mud volcanoes activity and natural marine hydrocarbon emissions (methane seeps);
- increased biological productivity, including chlorophyll life cycle and intensive algal bloom.

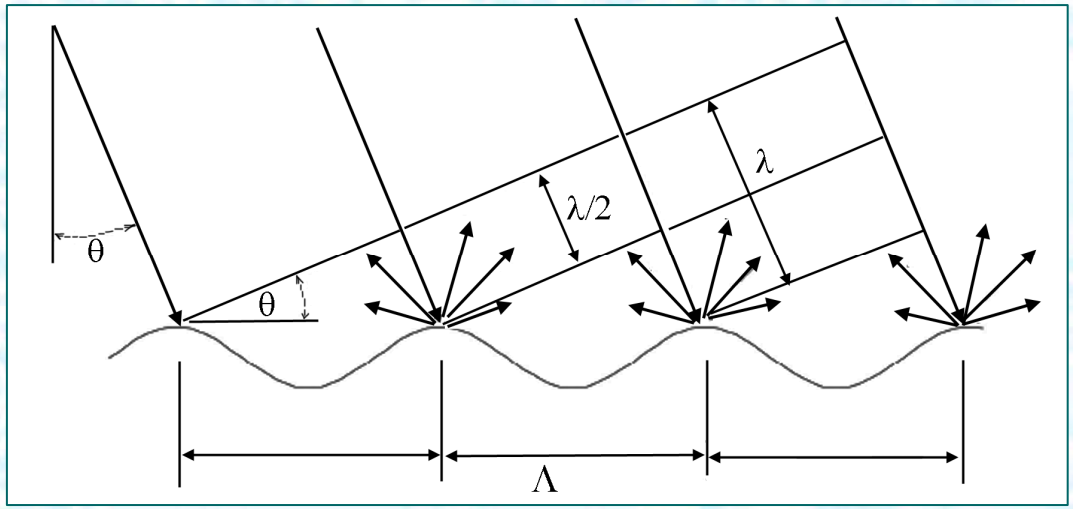
Satellite Radars



Among the many various sensors the Synthetic Aperture Radar (SAR) is definitely the most suited tool for oil spill monitoring, because of its high resolution and independence of cloudiness and solar-light conditions

- **24-hour operation capacity due to the use of active remote sensing , image parameters being independent on time of day;**
- **radar measurement can be performed under any weather conditions, as the atmosphere is nearly transparent for SAR microwave radiation;**
- **high spatial resolution (12 m/pxl – 75 m/pxl) of space SARs permits detecting even insignificant oil pollution with required accuracy as well as evaluating its parameters.**

Резонансный (брегговский) механизм рассеяния



Механизм формирования резонансного рассеяния радиолокационного сигнала на взволнованной морской поверхности, где
λ- длина зондирующей волны,
Λ-длина резонансной компоненты спектра поверхностного волнения,
θ- угол между направлением зондирования и надиром

$$\Lambda = \frac{\lambda}{2\sin\theta}$$

соотношение Вульфа-Брегга

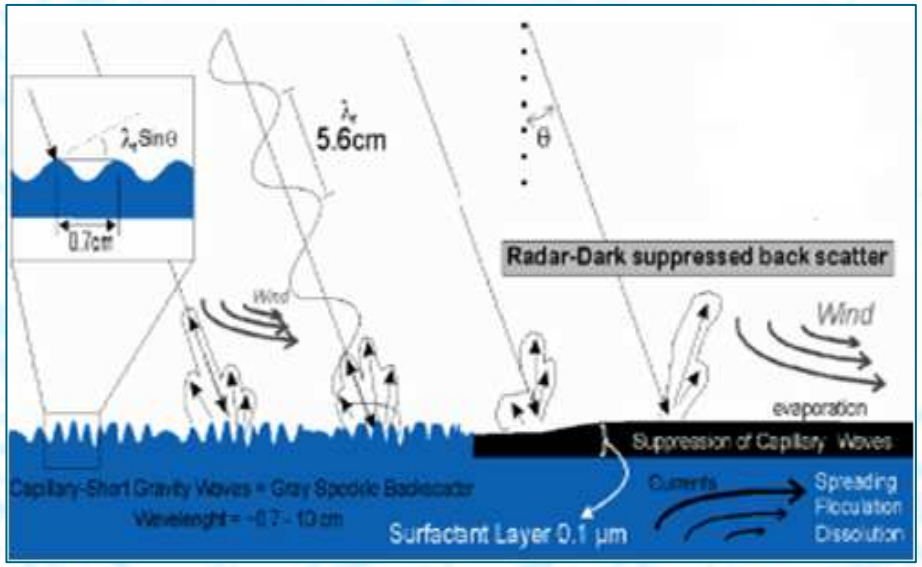
Определяет резонансную длину волны возмущения, которая селективно преобразует первичную волну, падающую под углом θ, в рассеянную волну, идущую в обратном направлении

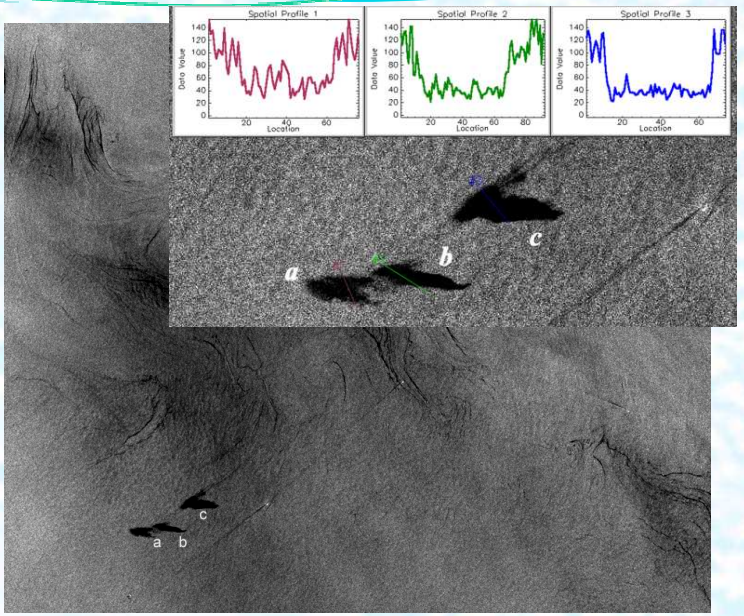
Для С-диапазона (длина зондирующей волны 5.6 см) – 7 ±1 см,

Radar imagery of surface films

Satellite monitoring of oil pollution of the sea surface is based on the capacity of radars to reveal sea surface areas covered by surfactant films and oil films in particular (so-called film slicks).

Oil appears as dark patches on SAR images because of its damping effect on capillary-gravity waves responsible for resonant backscattering and hence the backscattered radar signal.

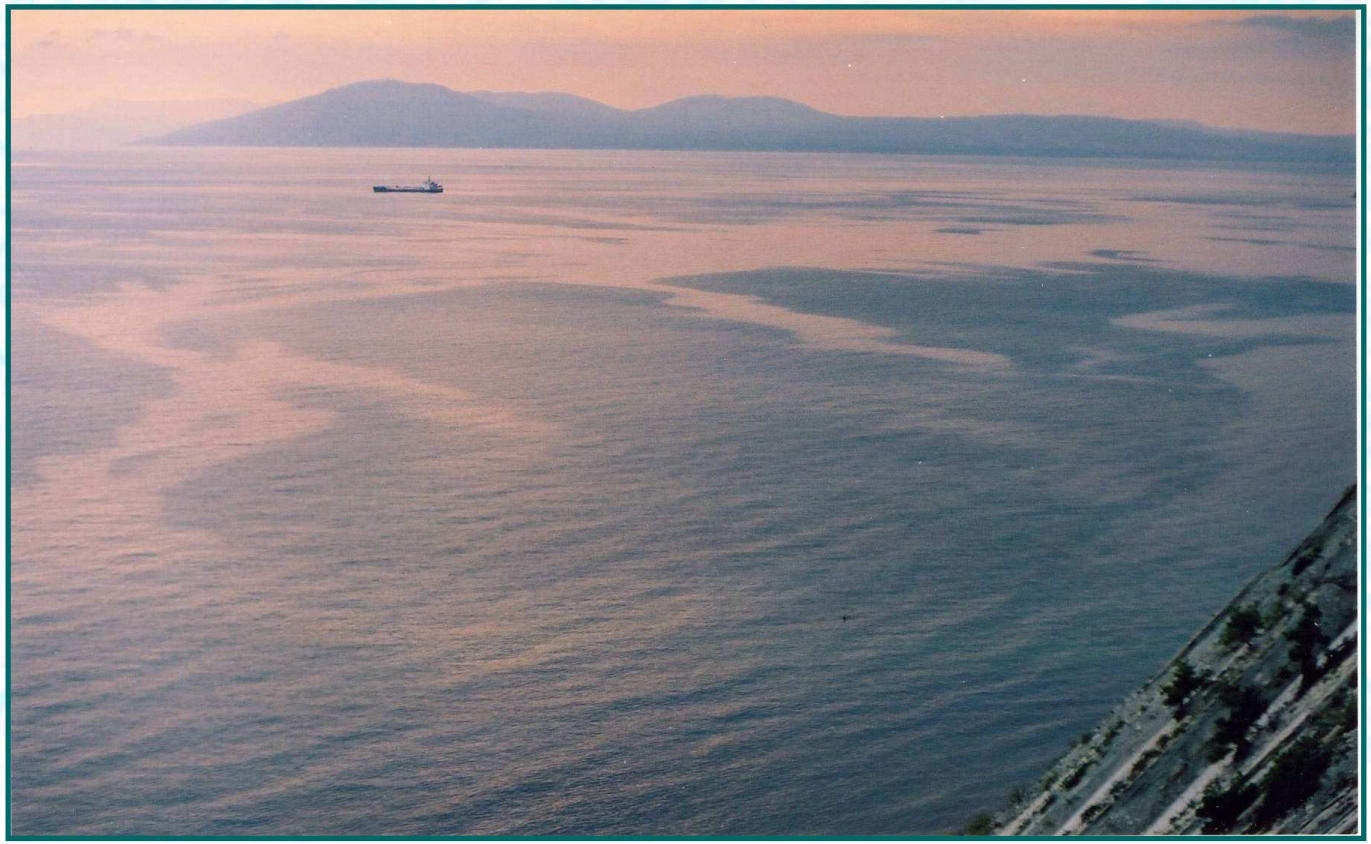




ERS-2 SAR, 31.07.02, 100x100 km.
Three consecutive oil spills and their signal variations compared.

The contrast between a spill and surrounding water, and therefore the probability of detecting pollution films, depends both on the amount and type of oil as well as on environmental factors such as wind speed, wave height, sea surface temperature (SST), currents, etc

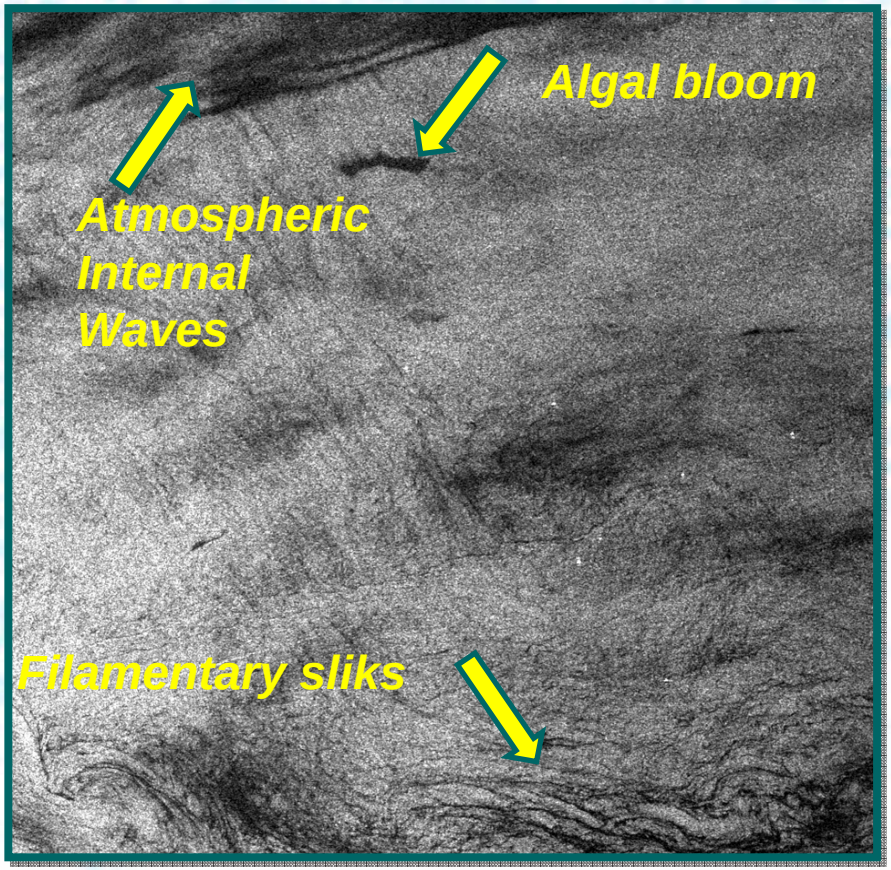
Slicks: patches and bands of short surface waves (ripples) of low intensity



- are observed under weak wind (up to 3-5 m/s) and become visible due to changes in reflection properties of sea surface caused by wind wave spectrum restructuring. Appear as sea surface smoothing

- Sea surface smoothing and emergence of slicks can be induced by various oceanic phenomena: internal waves, Langmuir circulations, ship wakes, algae bloom, oil spills, and surface currents.

Oil vs “Oil Look-alikes"



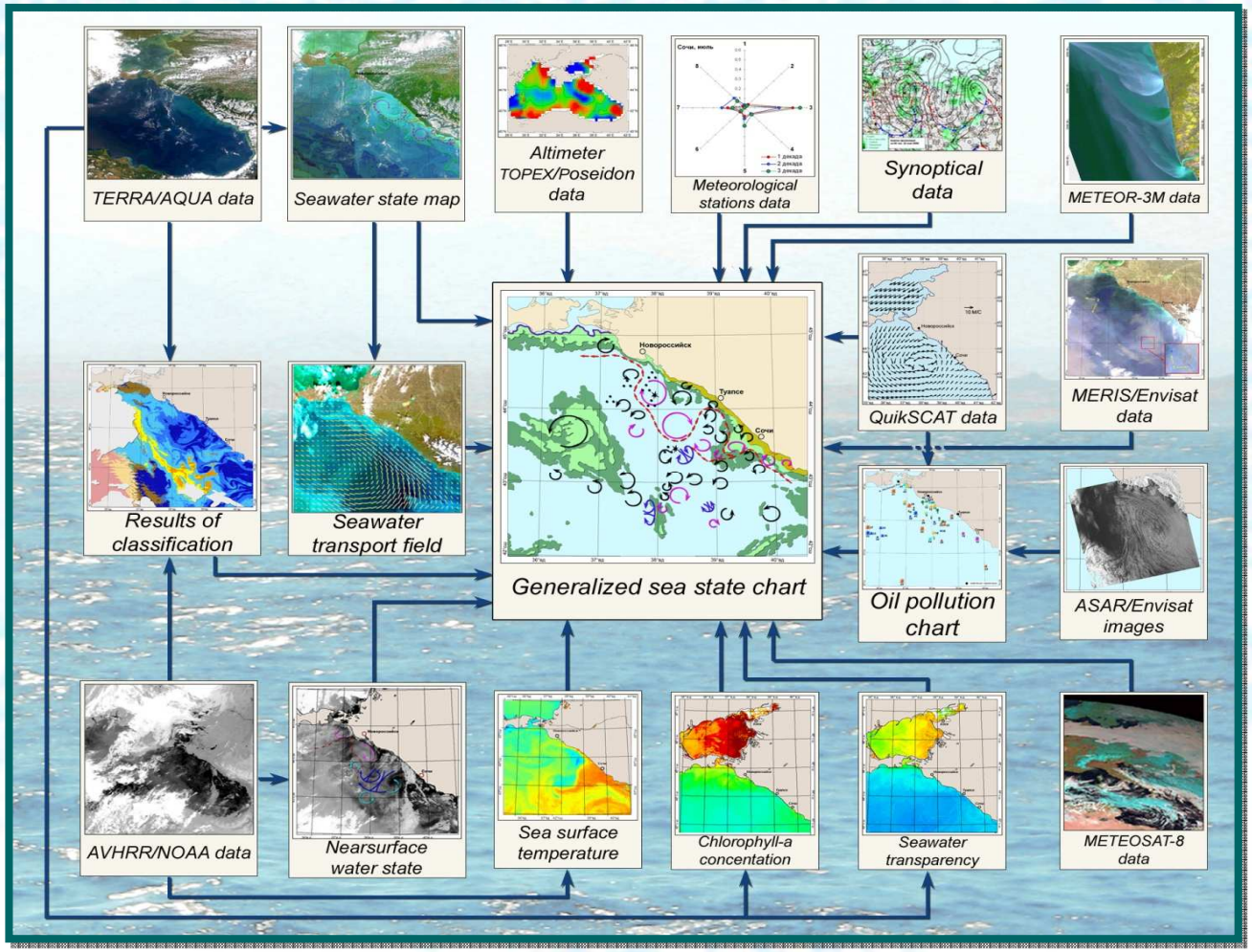
Monitoring of oil pollution of the sea surface on the base of the SAR data only is rather problematic because of the difficulty in distinguishing oil slicks, especially at lower wind speeds, from other phenomena known as look –alikes, such as:
biogenic films, areas of low nea-surface wind, convective cells, zones of upwelling, young ice, atmospheric internal gravity waves etc.

Our experience shows that this problem can be successfully solved on the base of combined use of satellite data taken in visual, IR and microwave ranges.

This data is obtained by different sensors mounted on board of different Earth observation satellites.

The key problem consists in combining data varying in physical nature, spatial resolution and image dimension.

The overall scheme of complex use of satellite data in the monitoring process



Combinations of various satellite data and resulting information products

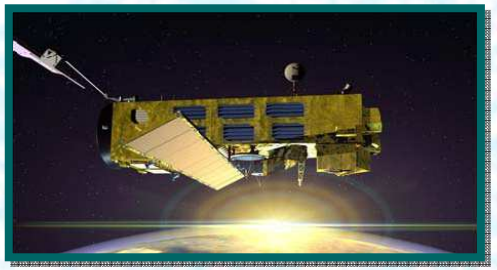
The technology of miltisensor satellite monitoring of the sea surface was developed and tuned by a consortium of research teams, including our team from Space Research Institute and the team from P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences.

Satellite sensors used

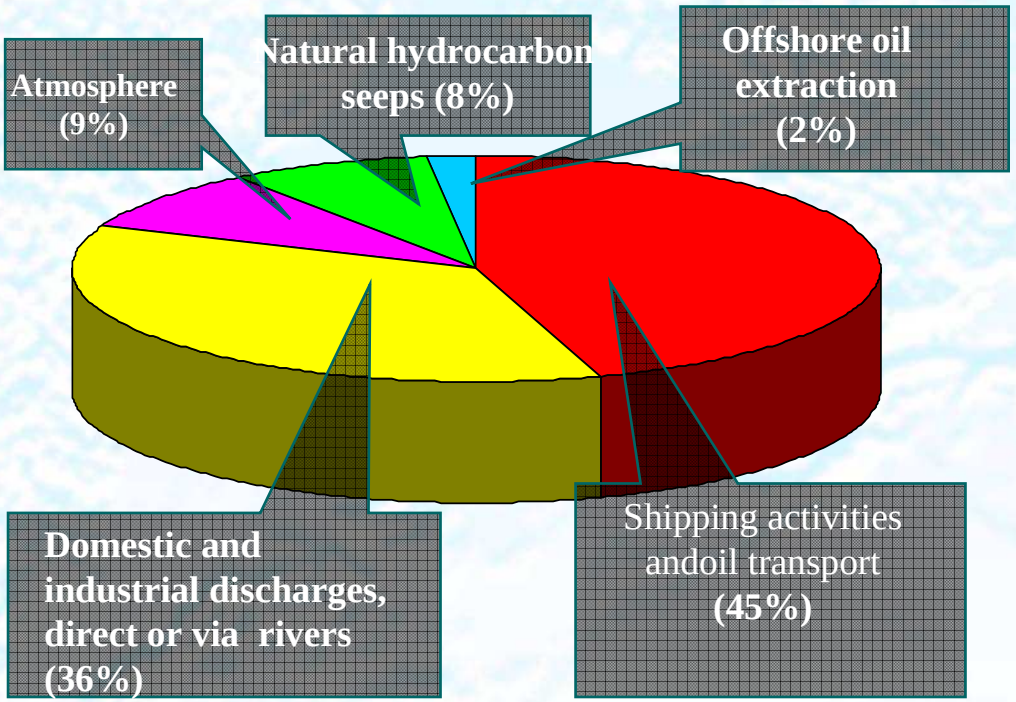
- Synthetic aperture radars Envisat ASAR, ERS-2 SAR spatial resolution 25 - 150 m;
- IR radiometers NOAA AVHRR, spectral bands 10,3 -11,3 μm, resolution 1 km;
- Imaging spectroradiometers:

  Terra/Aqua MODIS,

  Envisat MERIS; spectral bands: 0,622-0,672 μm, 0,546-0,556 μm and 0,438-0,448 μm; resolution 250 m;
- Scanning radiometers TM Landsat 5 and ETM+ Landsat 7



Oil in the Sea



Ship-related operational discharges of oil include:

- **discharge of bilge water from machinery spaces,**
- **discharge of fuel oil sludge,**
- **discharge of tank-washing residues and oily ballast water.**

The best way to monitore the chronic oil pollution of the sea surface is the continuous satellite monitoring

Oil in the Black Sea

The maximal limit volume of transfer of oil products is achieved now through the Bosporus, which is 146 million tons per year.

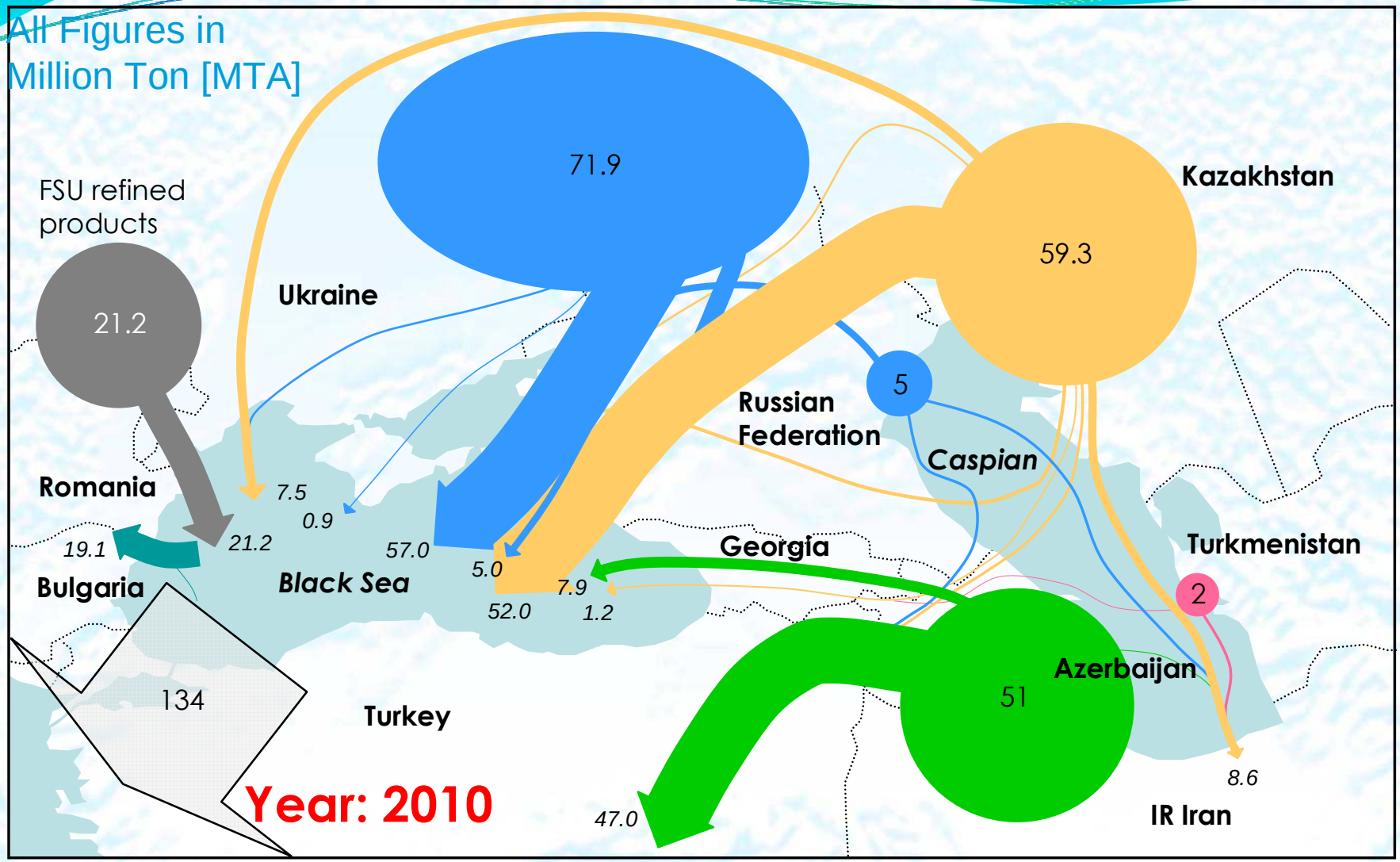
Oil shipping through Russian ports is increasing. Large tankers have been loaded on the raid of the Kerch channel for several years

Oil berth was built in Tuapse. Oil delivery line from Russian ports to Constance operates by «river-sea» vessels.

It is envisaged that the supposed carrying capacity of the Black Sea east coast oil terminals can make about 150 million t/year

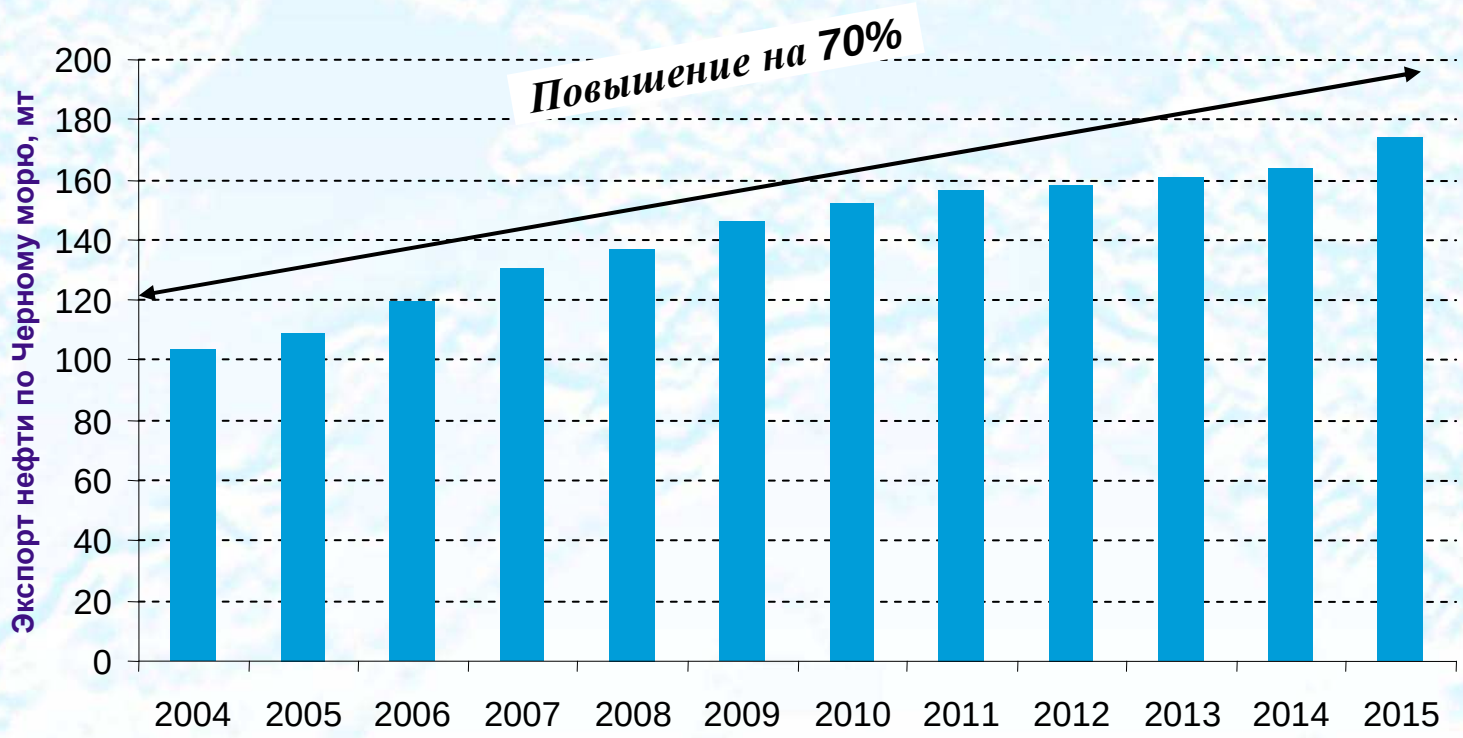
Practically all Black Sea countries aim to increase the transshipment of oil cargoes

Black Sea Oil Transport Volumes 2010



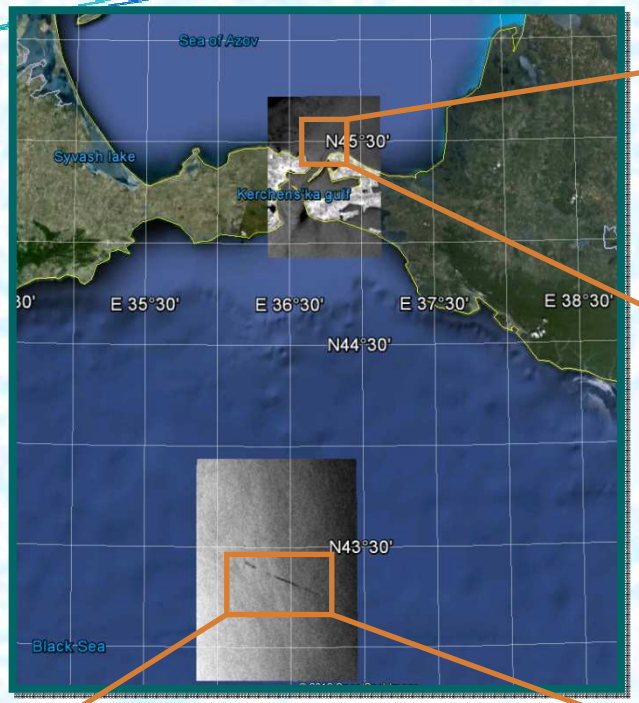
Data source: CERA

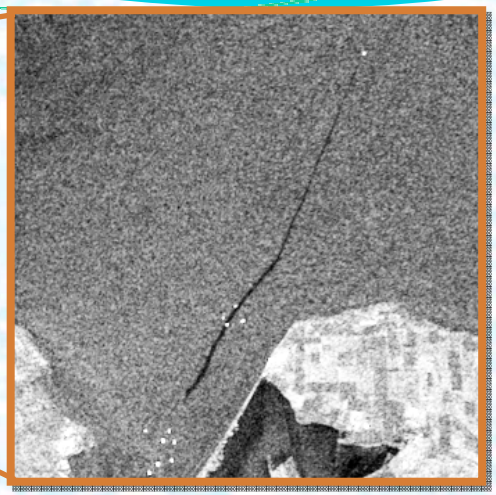
Прогнозируемый рост экспорта нефти через проливы Босфор и Дарданеллы



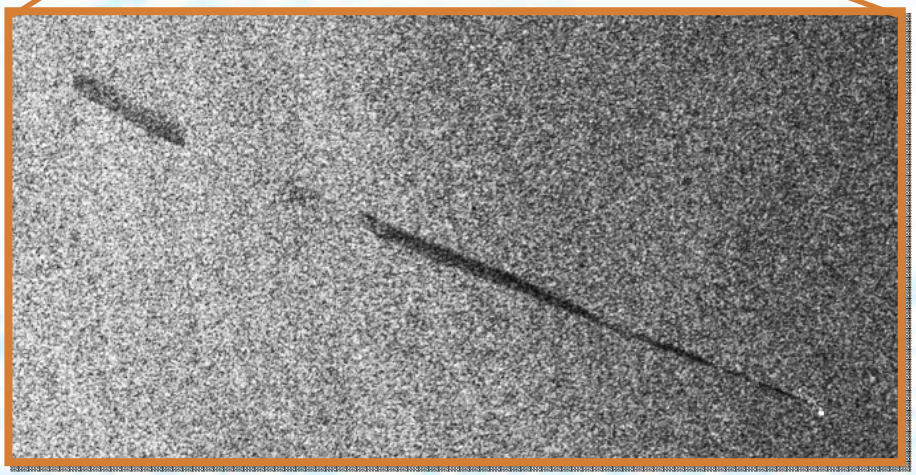
Центральный прогноз CERA на декабрь

Fresh spill from a moving vessel (1)



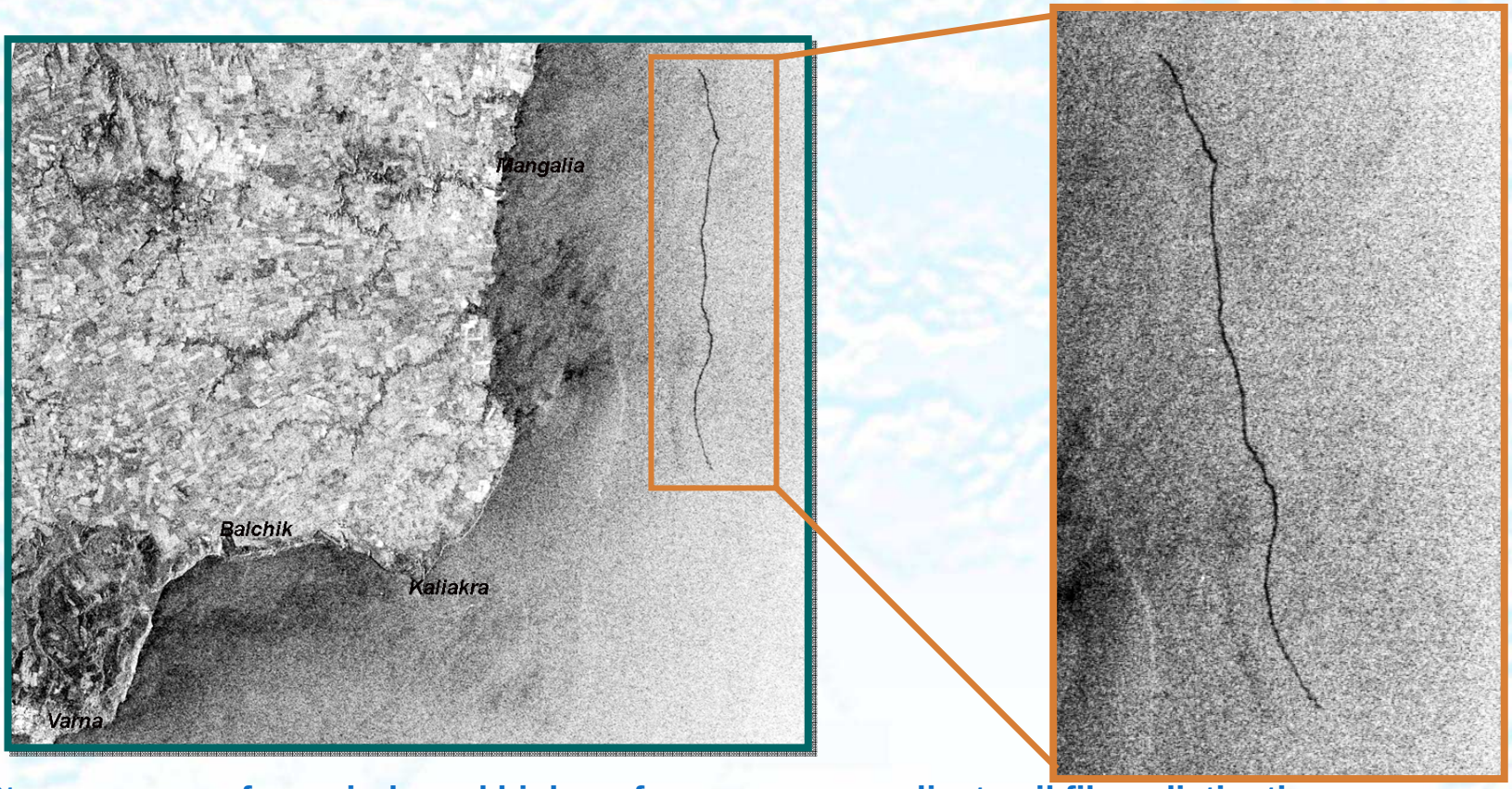


ASAR Envisat 10.06.2008, 19:18 UTC. Fresh oil spill from the moving vessel. Length – 21 km;



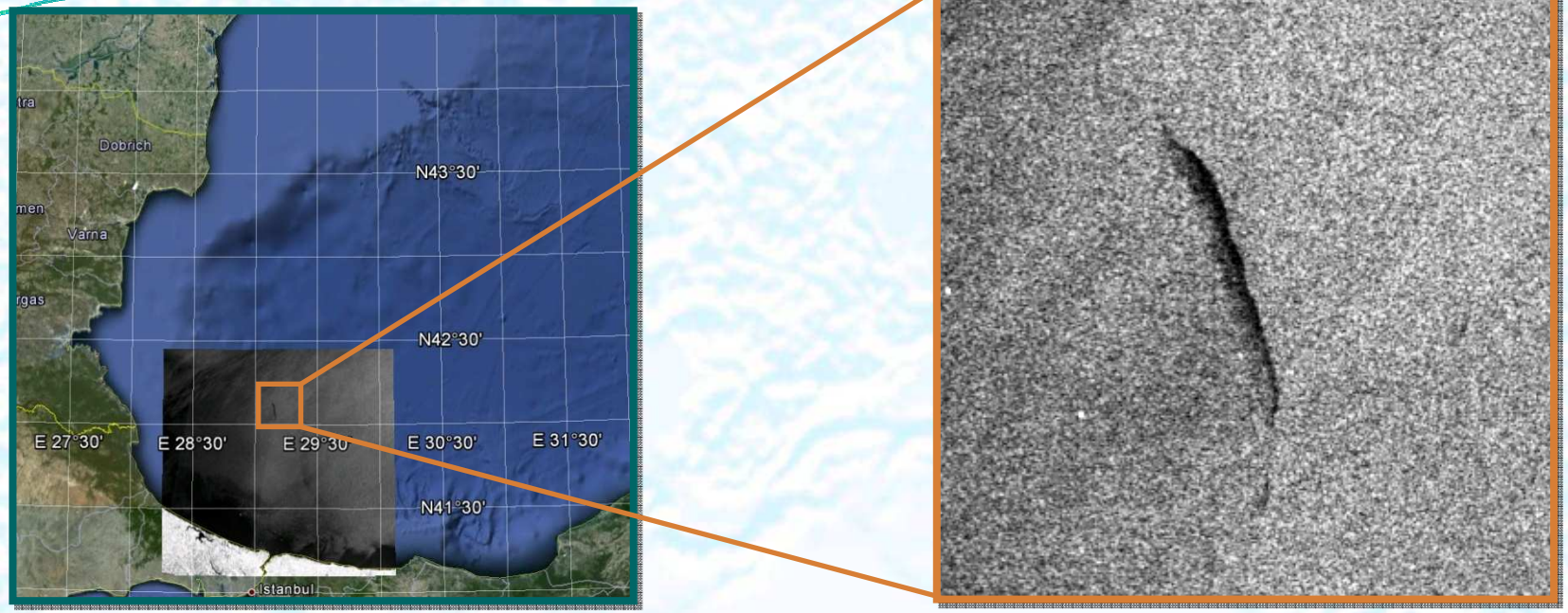
ASAR Envisat 10.06.2008, 19:18 UTC. Fresh oil spill from the moving vessel. Length – 45 km

Fresh spill from a moving vessel (2)



Strong near-surface winds and high surface waves complicate oil films distinction.
A fresh spill of 70 km length left by a moving ship in the western part of the Black Sea not far from the Cape Kaliakra.
The spill is distorted due to local currents and near-surface winds.
It is impossible to identify a ship responsible for a spill.
Another complicated factor is unstable stratification of the sea-atmosphere boundary layer which yields to the cellular-type radar patterns.

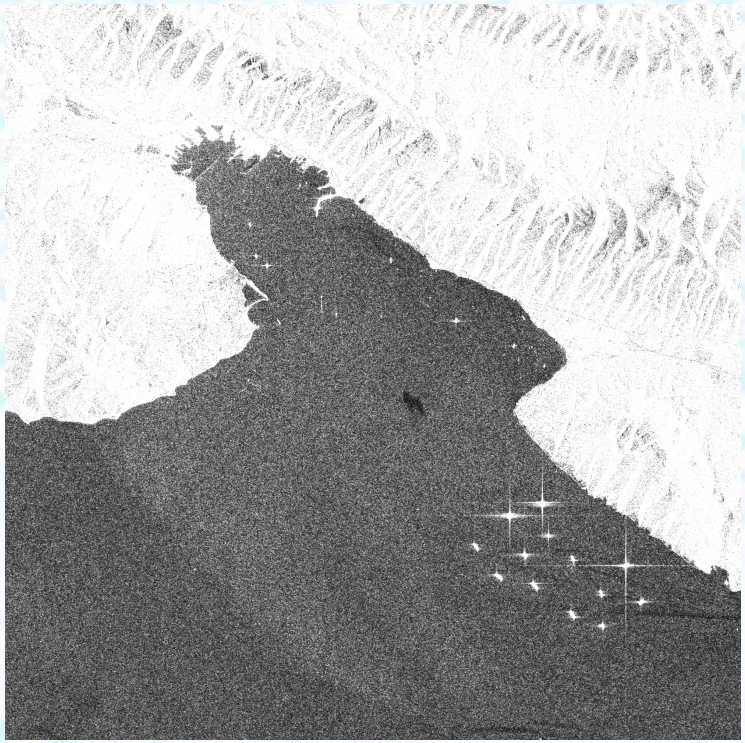
Weathered Oil Spill

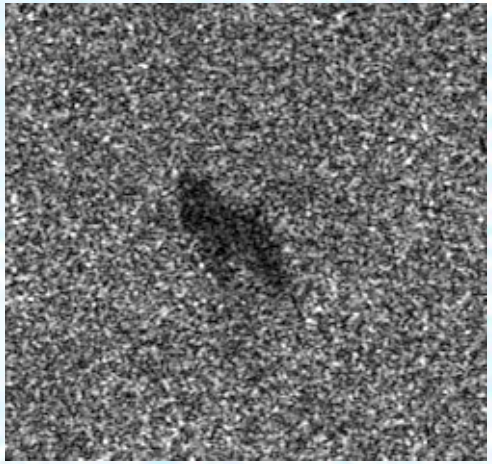


ASAR Envisat 08.04.2009. Weathered oil spill – «comb-like» structure. Surface – 8 km2;

Under the direct influence of the wind oil film shifts and accumulates on the leeward of the patch, forming a characteristic comb-like structure

Fresh spill from a motionless ship

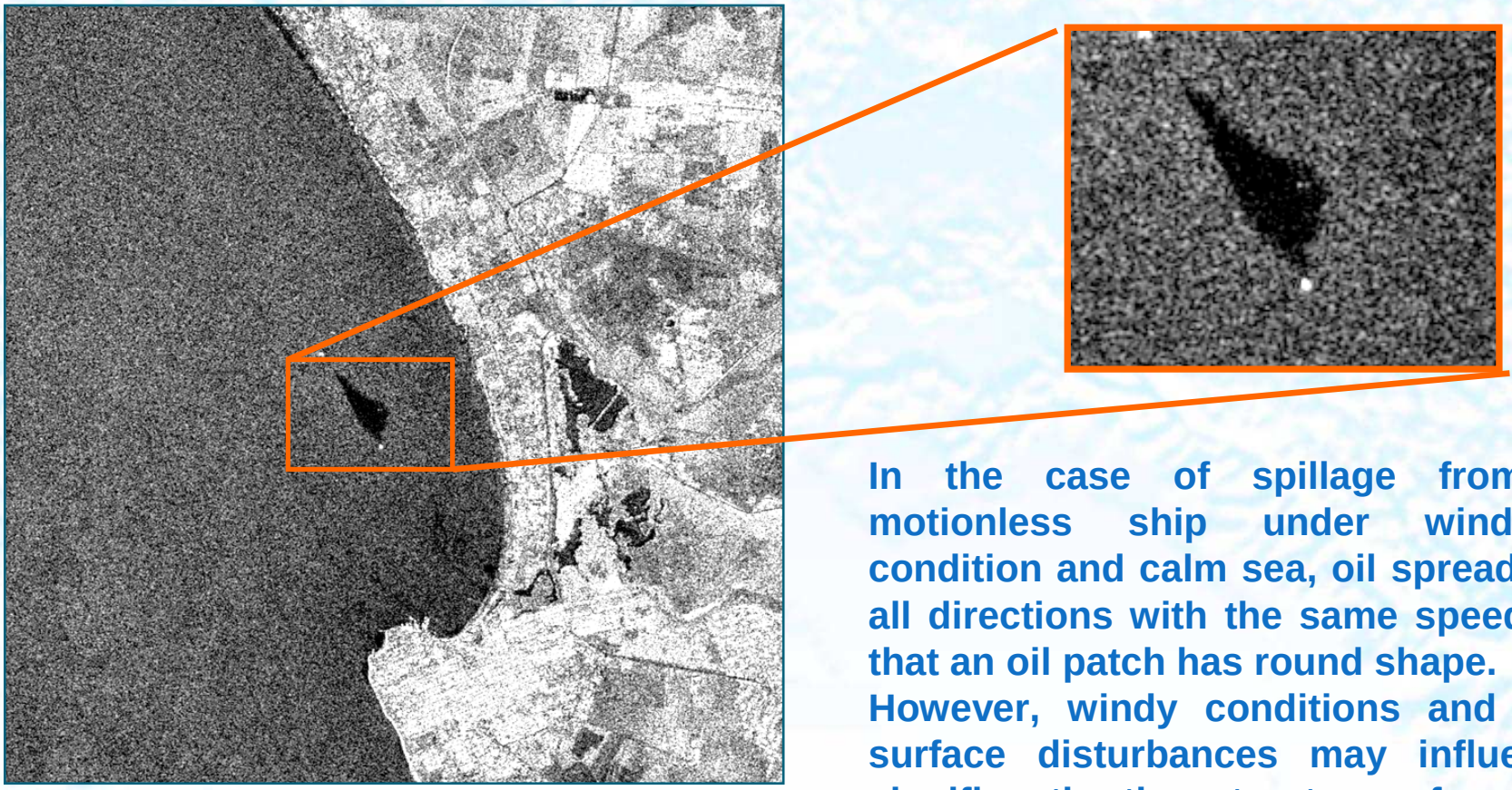




ASAR Envisat 01.08.2007, 07:29 UTC. The release of oil-containing waste waters in the Tsemeeskaya Bay. Surface – 0,6 km²;

In the case of spillage from a motionless ship under windless condition and calm sea, oil spreads in all directions.

Fresh spill from a motionless ship

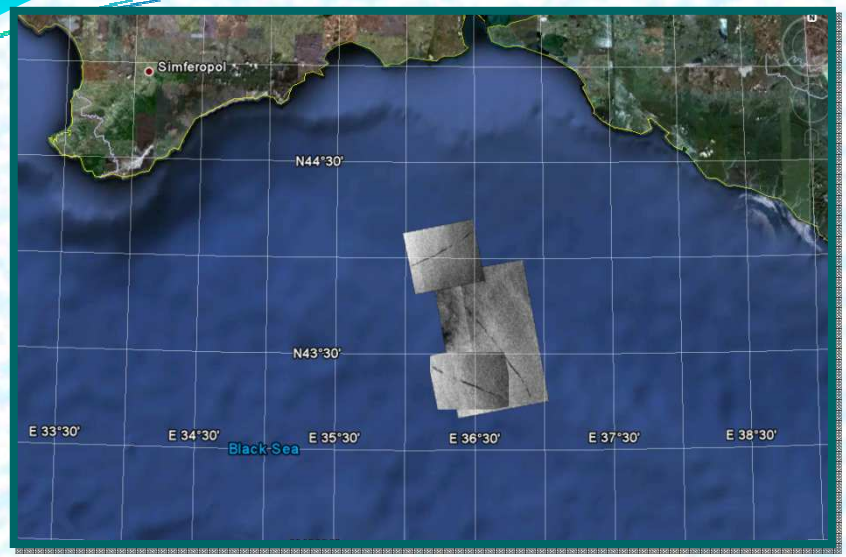


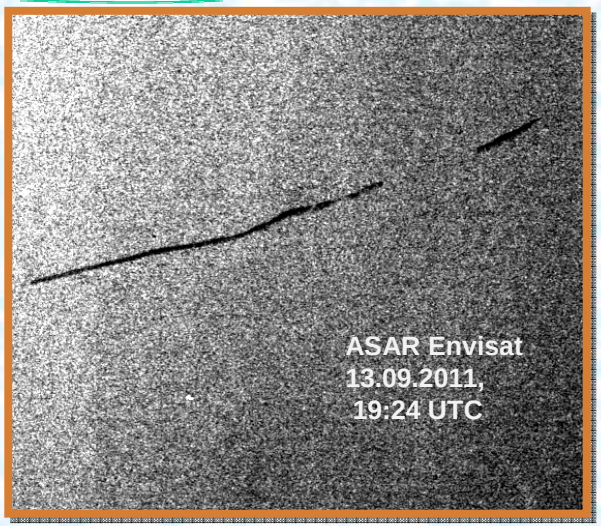
April 17 ,2007 . 19:19 GMT
Total polluted area 0.5 km²

In the case of spillage from a motionless ship under windless condition and calm sea, oil spreads in all directions with the same speed so that an oil patch has round shape. However, windy conditions and sea surface disturbances may influence significantly the structure of an oil patch

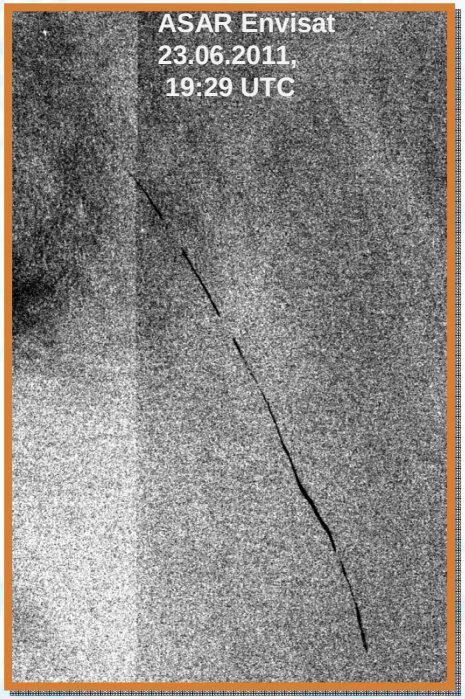
Spillage in the coastal area not far from the Anapa, the well know town of child resorts.

Multiple spillages from moving ships (1)

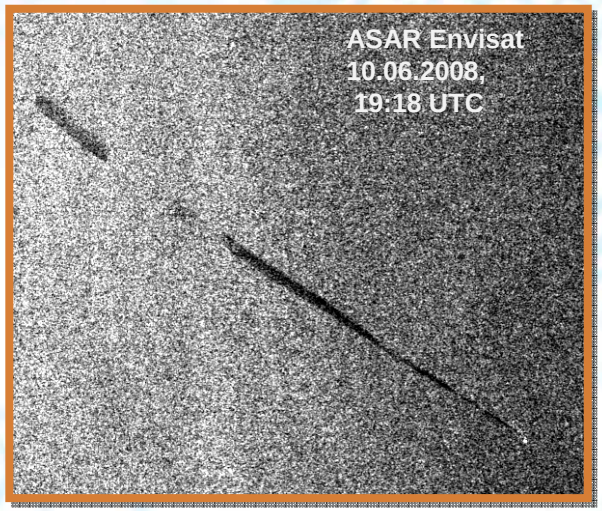




Length of the spill is 38 km,

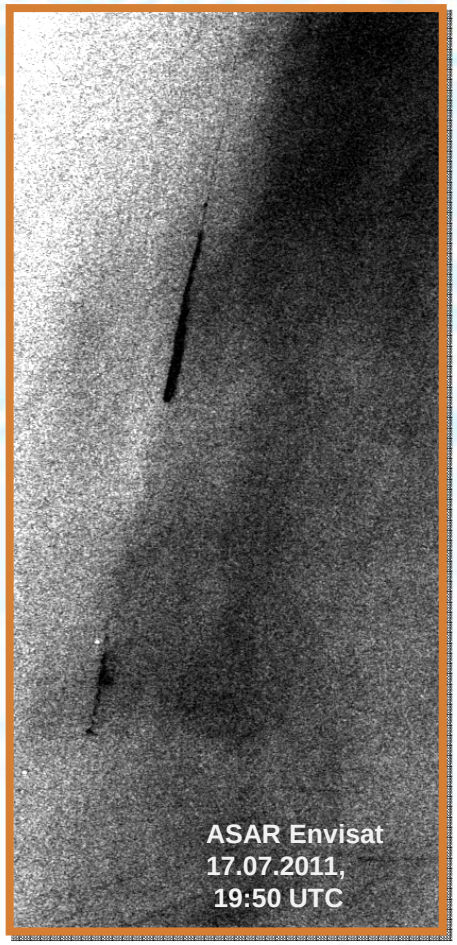


Length of the spill is 112 km



Length of the spill is 46 km, total area 20 km^2

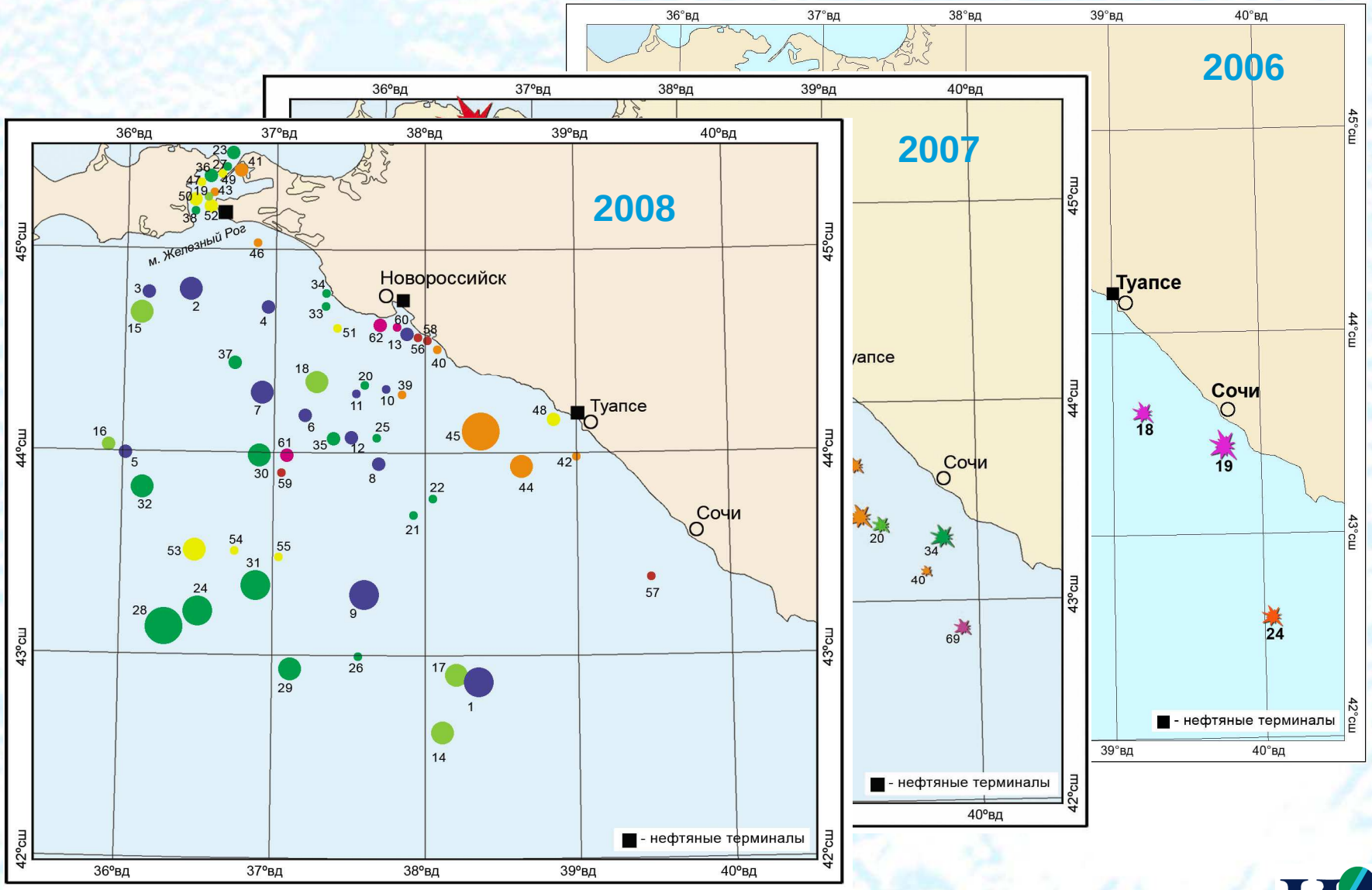
Multiple spillages from moving ships (2)



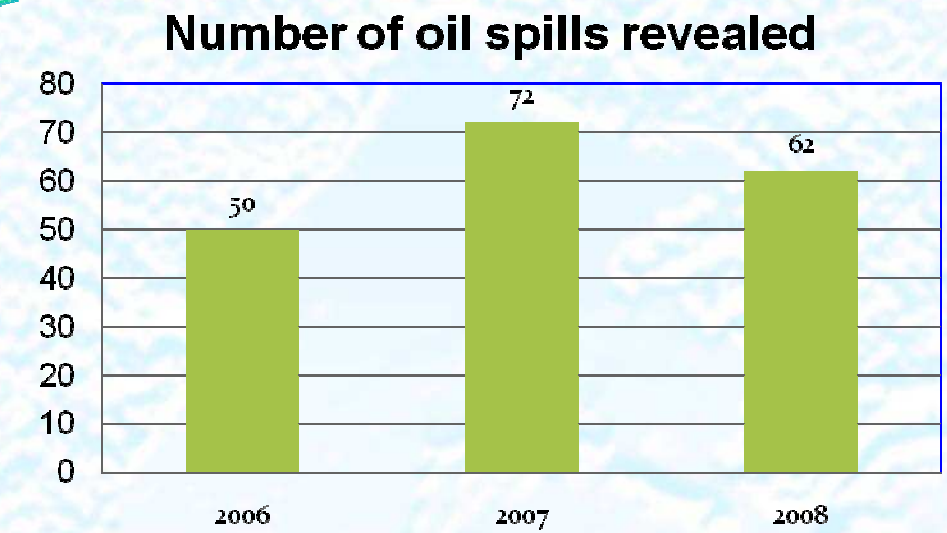
Length of the spill is 34,5 km, total area 9 km²

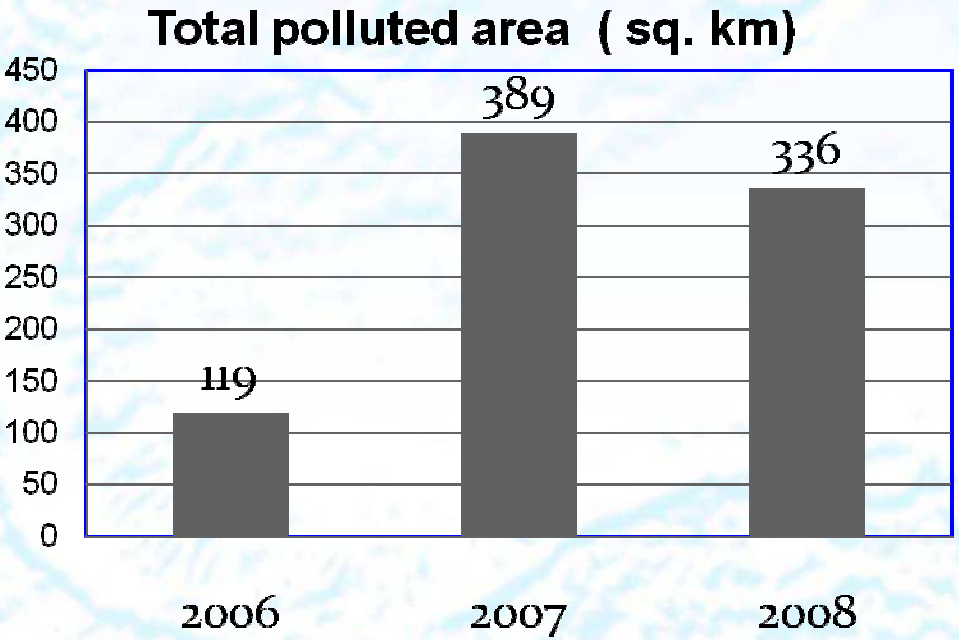
Length of the spill is 57 km, total area 7 km²

Summary charts of oil spills in the North-eastern Black Sea revealed from satellite SAR data



Summary of oil spills in the North-eastern Black Sea revealed from satellite SAR data





Over three years of observation, 184 events of sea surface oil pollution as a result of ship discharges have been detected.

Individual oil spill area varied from 0.1 to 30 sq.km.

Year-by-year numbers of oil spills are

50, 72, and 62, correspondingly.

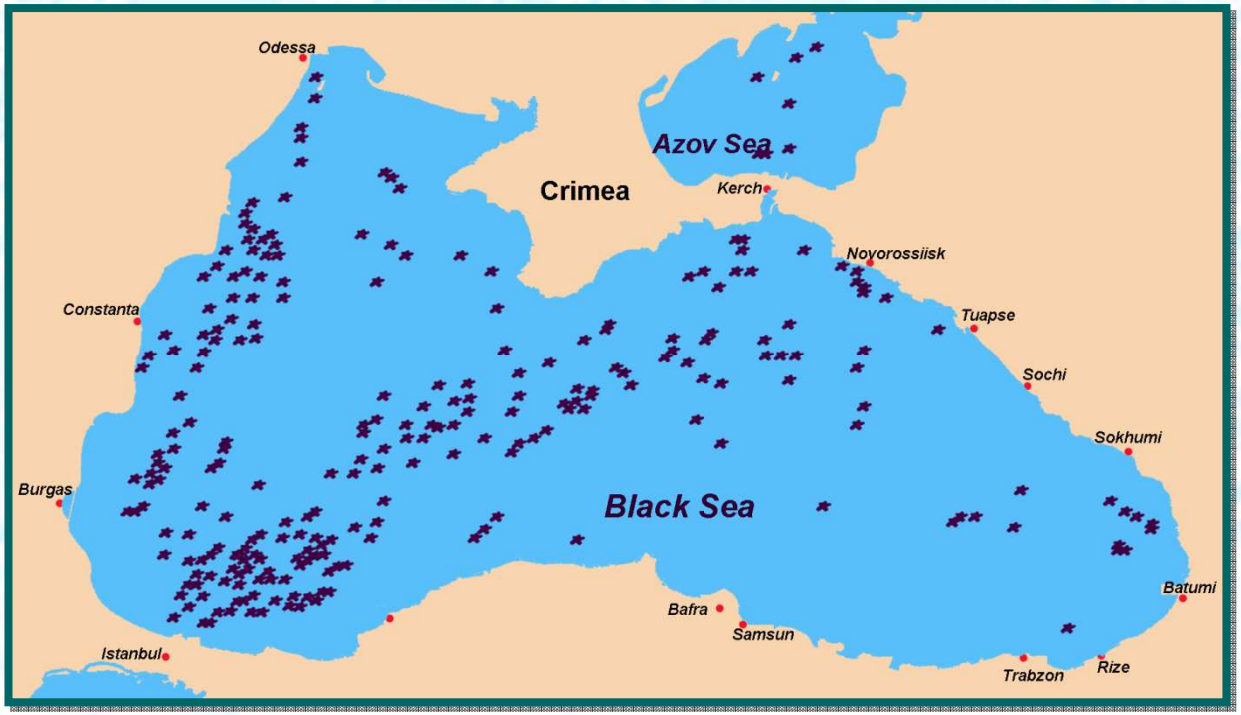
Total polluted areas are 119, 389, and 336 sq.km.

Sharp growth of polluted area in 2007 - 2008 is due to a catastrophic oil spill in the Kerch Strait occurred in November 2007 during a tanker catastrophe and its aftereffects in summer 2008.

Summary chart of oil spills in the Black Sea revealed from satellite SAR data in 2009

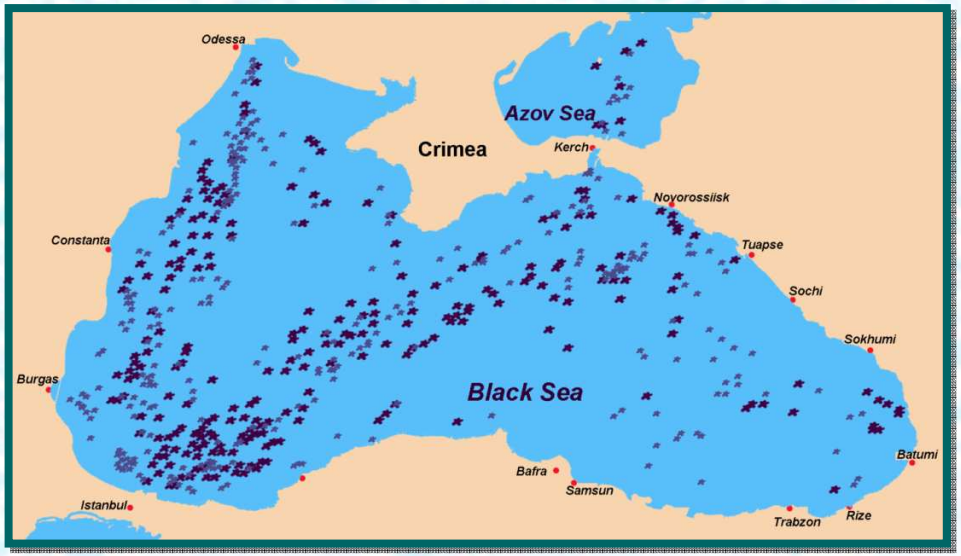
293 spillages were detected in 342 satellite radar images

Summary chart of oil spills in the Black Sea revealed from satellite SAR data in 2010

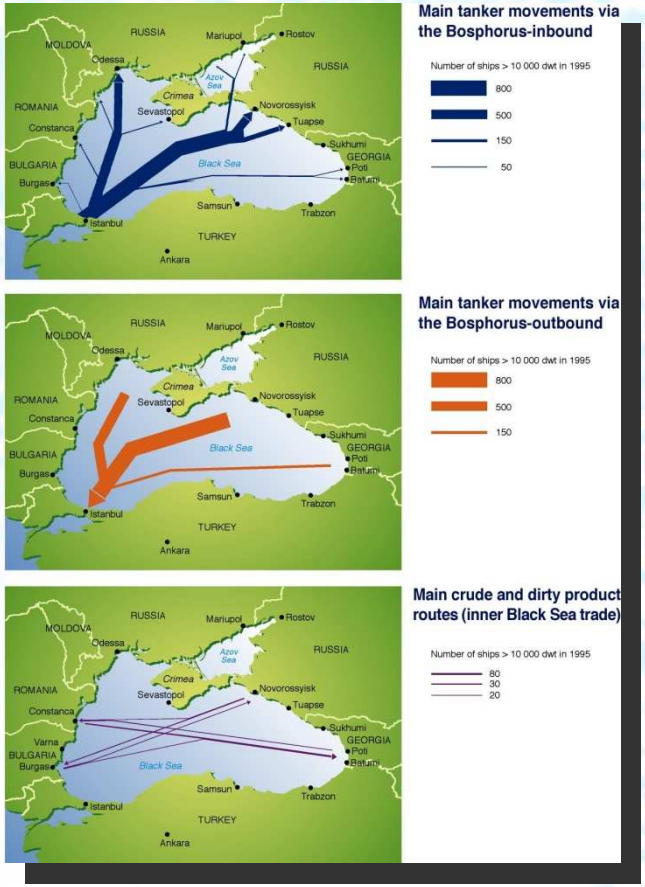


260 spillages were detected in 364 satellite radar images

Map of oil spills revealed from satellite radar imagery in the Black Sea aquatic area in years 2009-2010



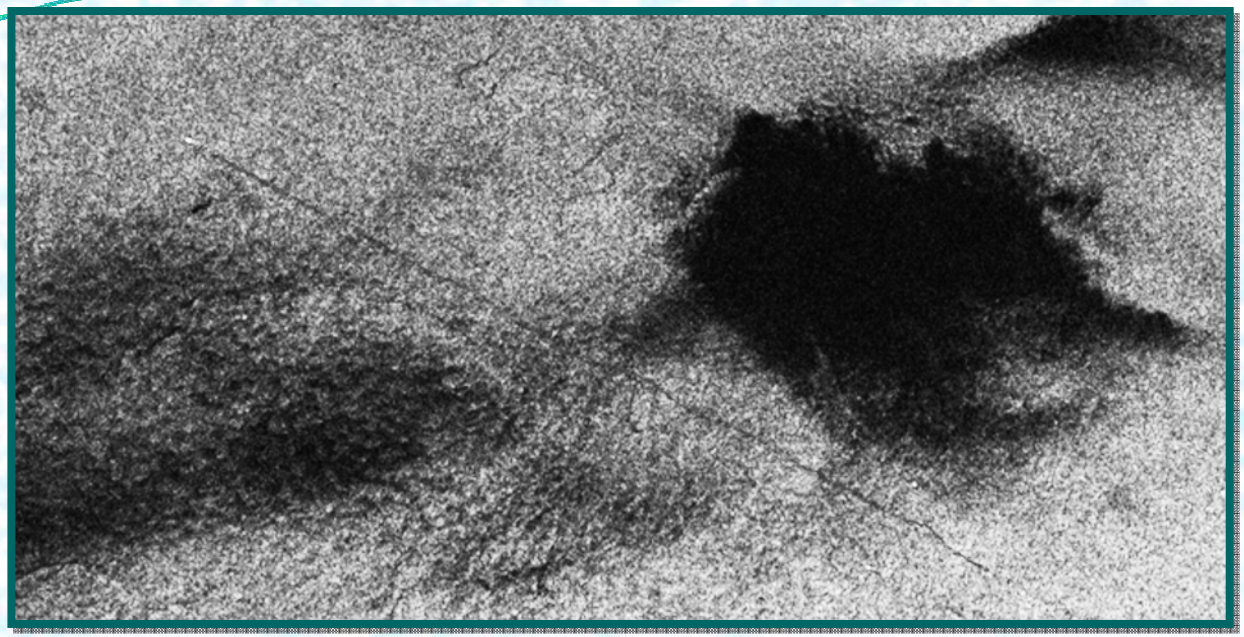
Oil transport in the Black Sea



The total 553 spills were detected in satellite radar imagery of the sea surface in 2009-2010

In *UNEP/GRID-Arendal Maps and Graphics Library*. Retrieved 17:00, February 22, 2012 from http://maps.grida.no/go/graphic/oil_transport_in_the_black_sea.

Radar signatures of biogenic films connected to ship wakes

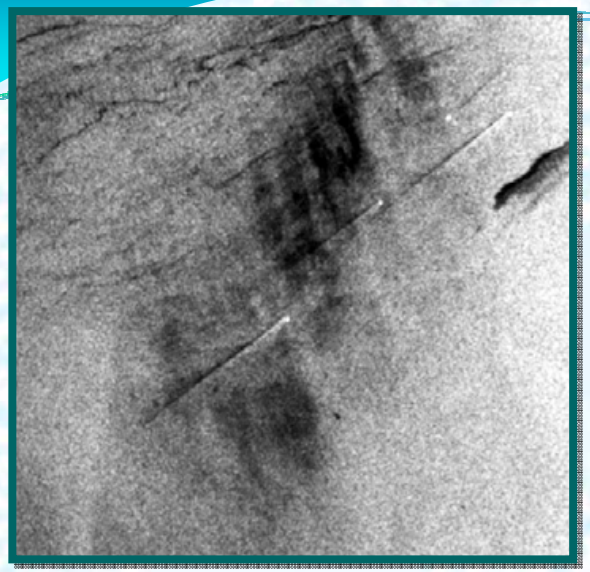


Clip (5 km x 25 km) from the Envisat ASAR image taken on 17.08.2010 over the western part of the Black Sea. The visibility of the ship wake in the ASAR image is due to presence of micro-bubbles in the wake. Wake length - 50 km

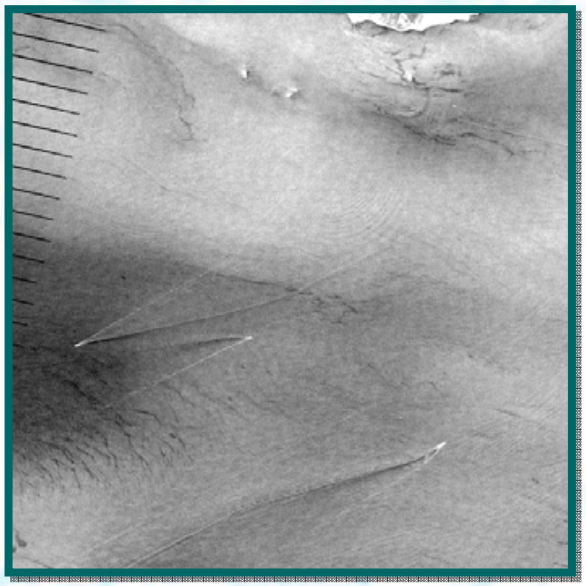
Most often when in radar image a dark stripe follows almost immediately a ship, depicted as a bright white dot, an inexperienced interpreter may definitely interpret this dark line as a spill from this ship. However, that dark stripe may result from intensive phytoplankton bloom and consequently cannot be considered as an anthropogenic pollutant

A great amount of air bubbles appear when ships are moving and waves are breaking. Bigger bubbles move faster towards the water surface but the most part of air bubbles of less than 1 mm size comes up to the surface with the velocities varying from 1 to 10 cm/s. For large-capacity vessels with water draft of 10-15 m the film wake appears on the sea surface about after 20-25 minutes or even more

Кильватерные следы за движущимися надводными судами



Фрагмент (25 км х 25км) Envisat ASAR изображения кильватерных следов за кораблями, полученного 23.05.2009 в 07:54 UTC.
Длина следов 8-10 км

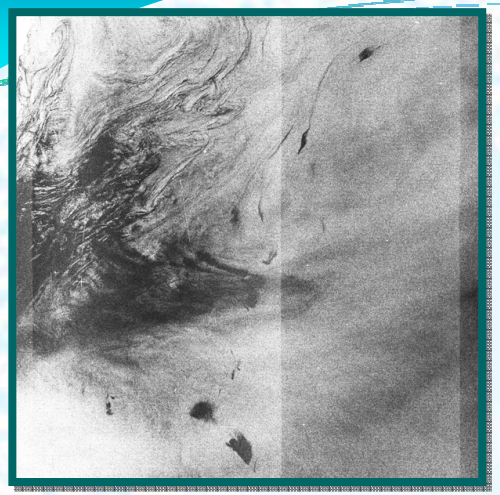


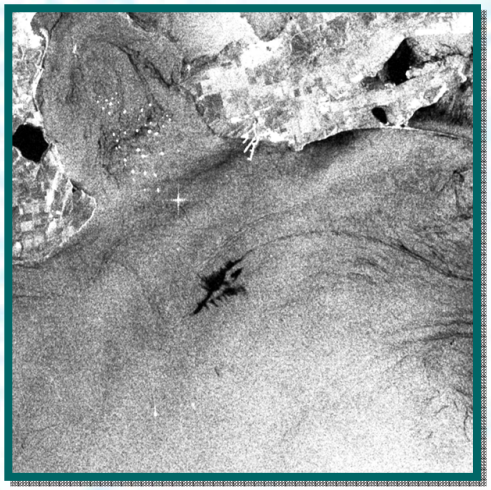
Фрагмент цветосинтезированного изображения (3,2,1 каналы) сенсора ETM+ ИСЗ Landsat 7, полученного 06.06.2009 в 08:04 UTC. Отчетливо выделяются кильватерные следы за кораблями длиной 9-10 км

Кильватерные следы отличаются хорошо узнаваемой структурой, которая подчиняется закону расширения и включает в себя центральную часть, и V-образные с «усы», Область пониженного рассеяния в кильватерном следе, присутствующая на РЛИ, соответствует зоне турбулентной струи, в которой воздействие турбулентности, порожденной винтами судна приводит к «выглаживанию» ветрового волнения и образованию сликов, различимых на РЛИ. V-образные структуры обусловлены волнами Кельвина, их отображение на РЛИ зависит от условий съемки, в частности, от взаимного расположения азимутального угла съемки и направления движения корабля, его размера, формы и скорости

ИКИ

Manifestations of natural films on the sea surface



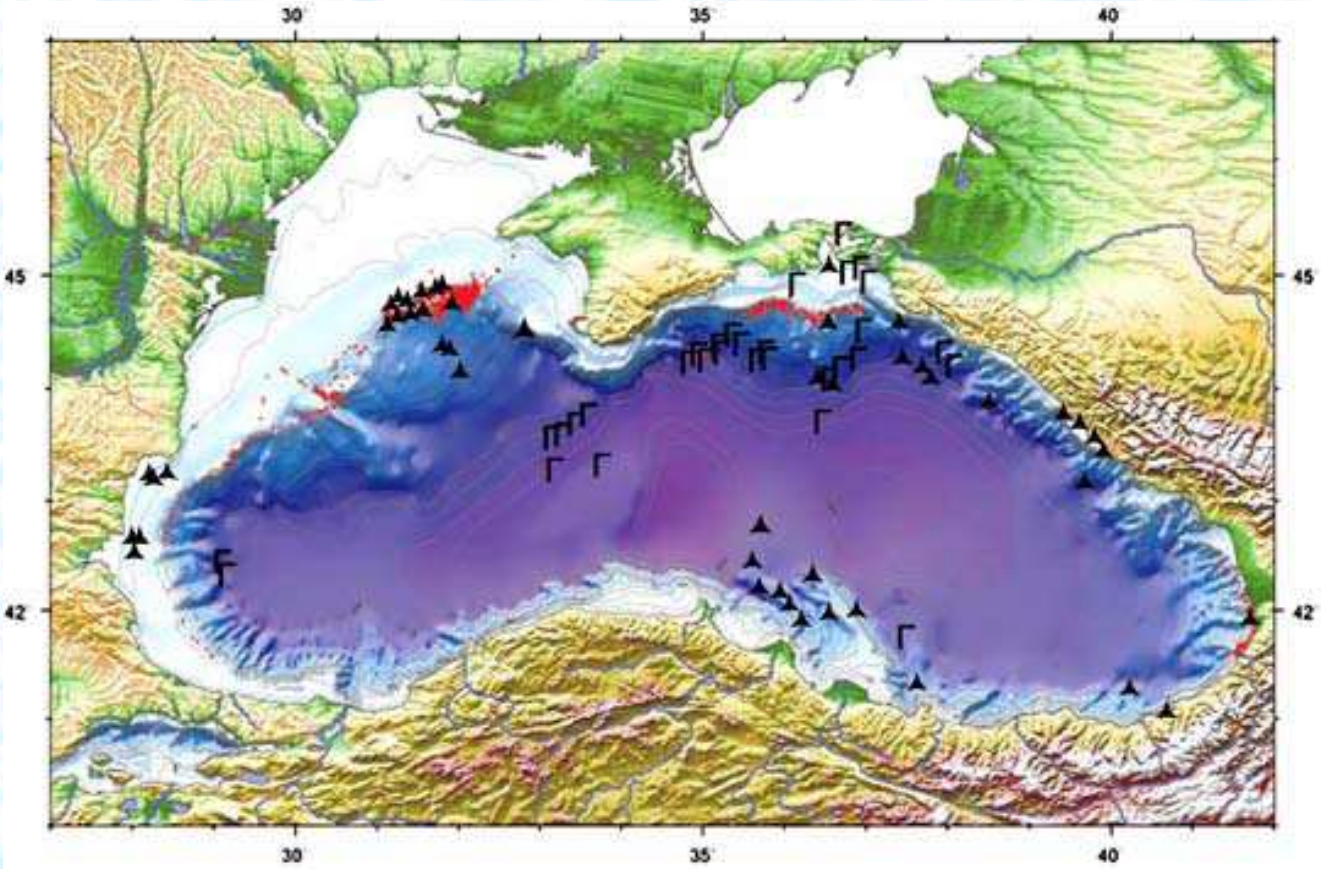


On the Black Sea water surface there regularly appears a great deal of slicks resembling oily wastewaters discharged by ships but having some specific features and caused by the presence of biogenic films on the sea surface. This biogenic films are produced in the sea during complex biochemical processes of life activity and decomposition of died sea organisms, thus in strict sense such films cannot be considered pollutants.

The biogenic films are sensitive to surface currents and reproduce the geometric shape of local circulation pattern. Under low winds organic films on the sea surface are retained in the form of slicks for a considerable time and start to disrupt at wind speeds of 6-7 m/s and higher. When the strong wind subsides, organic substances come up to the sea surface again and form slicks. Large conglomerations of phytoplankton in the Black Sea are observed during its most intensive “bloom”; the first acme takes place in the period from the end of spring till the beginning of summer, the second – in autumn. That times organic films are produced on the sea surface and most often they cover large sea areas.

Slicks due to algal bloom as seen in ASAR Envisat imagery:
(a) subscene (150x150 km) of the ASAR Envisat image collected on 03.07.10 at 17:52 UTC in the western part of the Black Sea;
(b) subscene (100x100 km) of the ASAR Envisat image collected on 18.09.10 at 19:32 UTC in the southern part of the Black Sea;
(c) subscene (50x50 km), of the ASAR Envisat image collected on 09.06.09 at 07:50 UTC в in the north-eastern part of the Black Sea near the Kerch strait

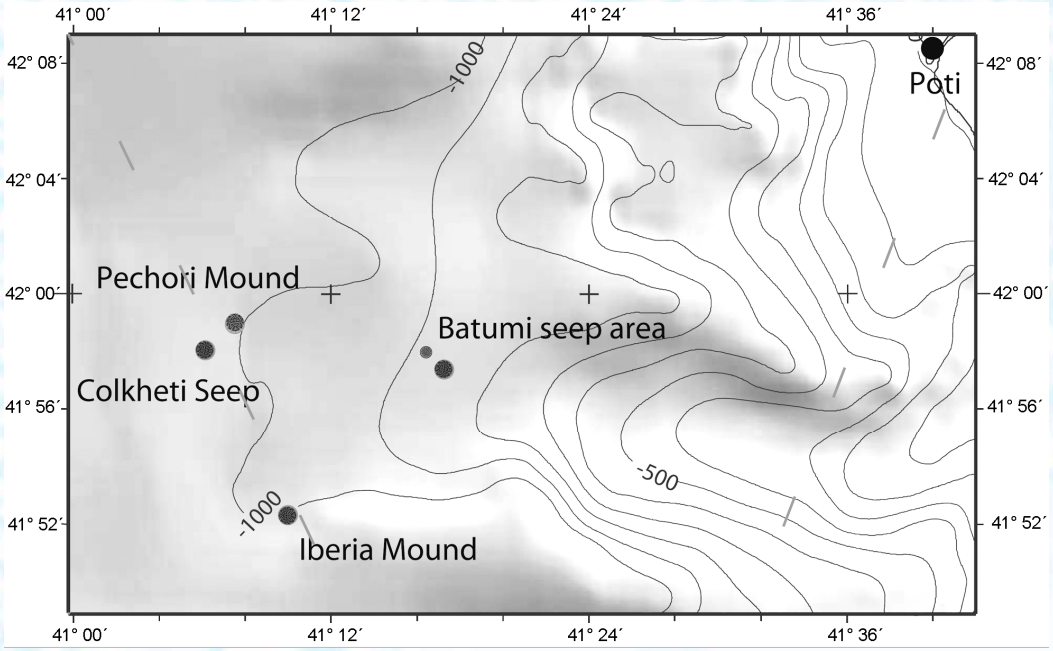
Slicks resulted from hydrocarbon seepage (1)



In case of the Black Sea as compared to other seas the monitoring of detection of oil spills caused by ship discharges is much more complicated due to not only intensive phytoplankton bloom but also to mud volcano activity and to natural hydrocarbons seeps that can be detected in many areas of the Black Sea

Карта-схема распределения струйных метановых газовыделений в Черном море:
красные точки — задокументированные метановые выделения;
черные треугольники — выходы нефти и газа на поверхность;
Г — грязевые вулканы

Slicks resulted from hydrocarbon seepage (1)



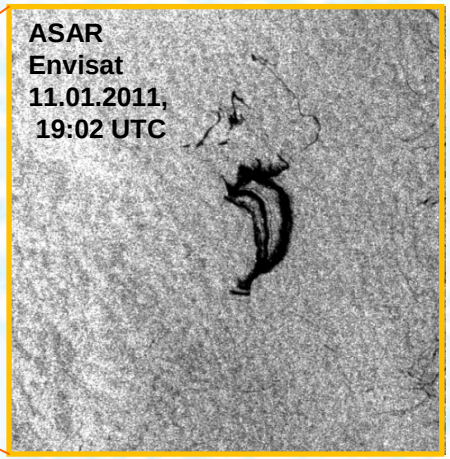
Bathymetric map of the study area offshore Poti (Georgia)

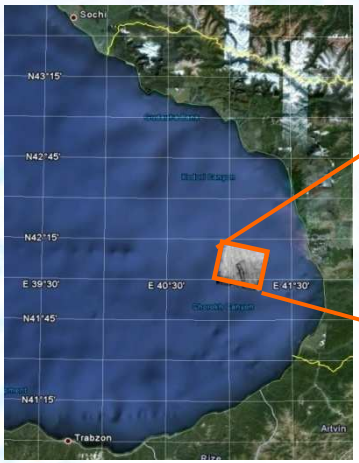
We analyzed all radar images of the Black Sea in the area of Georgian shelf and continental slope obtained for the period from January, 2009, to July, 2011.

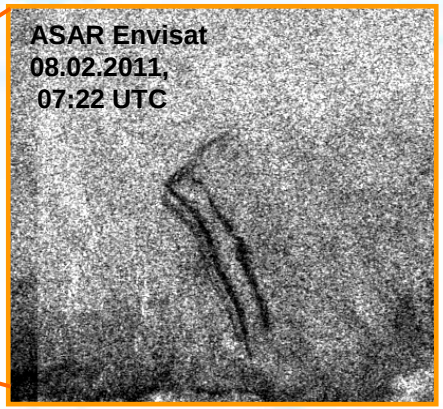
In general for this period 73 radar images of the test area have been obtained and 46 of them contained slick structures.

A relatively small area covering approximately 20 sq. km of the sea surface became something like a nature laboratory located near the Georgian continental slope where on the sea floor there are located 4 cold methane seeps. The presence of oil traces in bottom sediments is a distinguishing feature typical of these seeps.

Slicks resulted from hydrocarbon seepage (2)

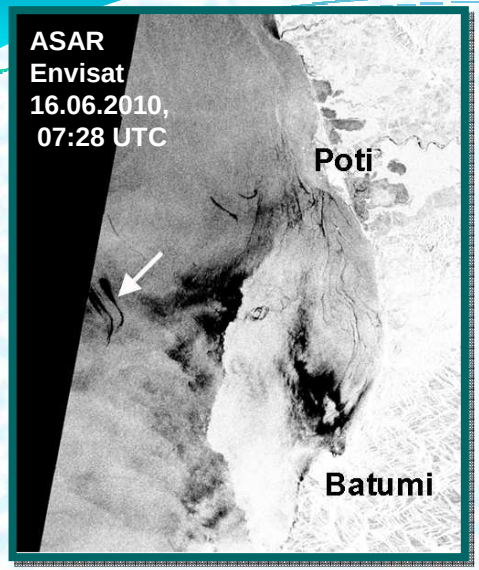


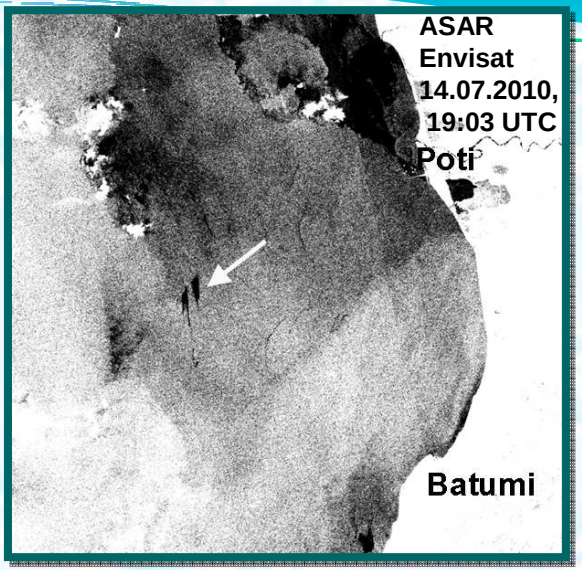


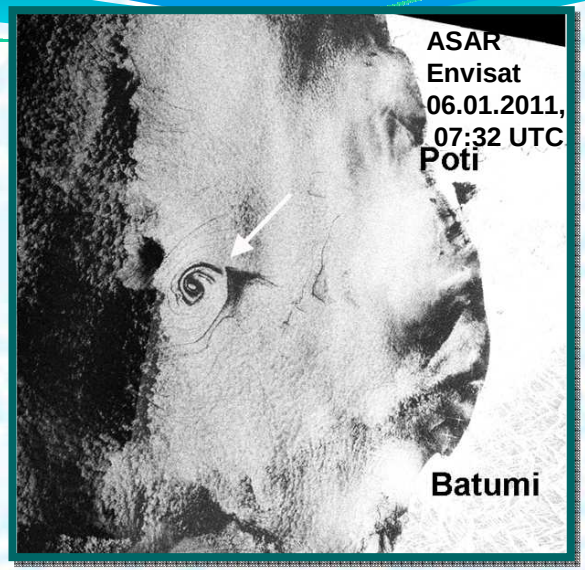


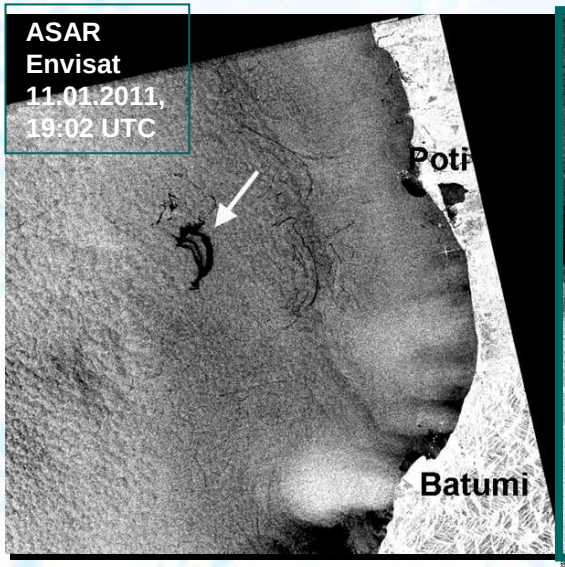
We analyzed all SAR ERS-2 and ASAR Envisat images of the Black Sea taken over the continental slope area offshore Georgia and continental slope obtained for the period from January, 2009, to July, 2011. For this period 73 radar images of the test area have been obtained and 46 of them contained slick structures.

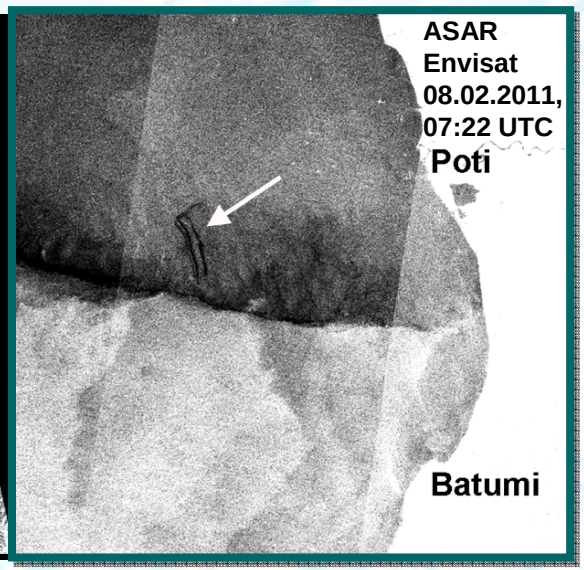
Slicks resulted from hydrocarbon seepage (3)

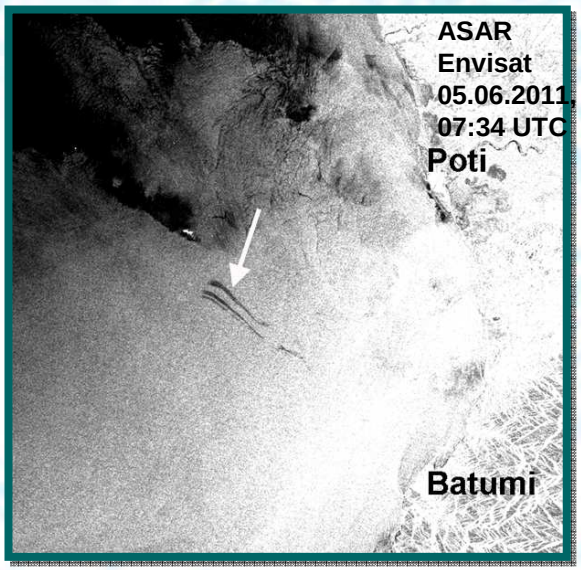






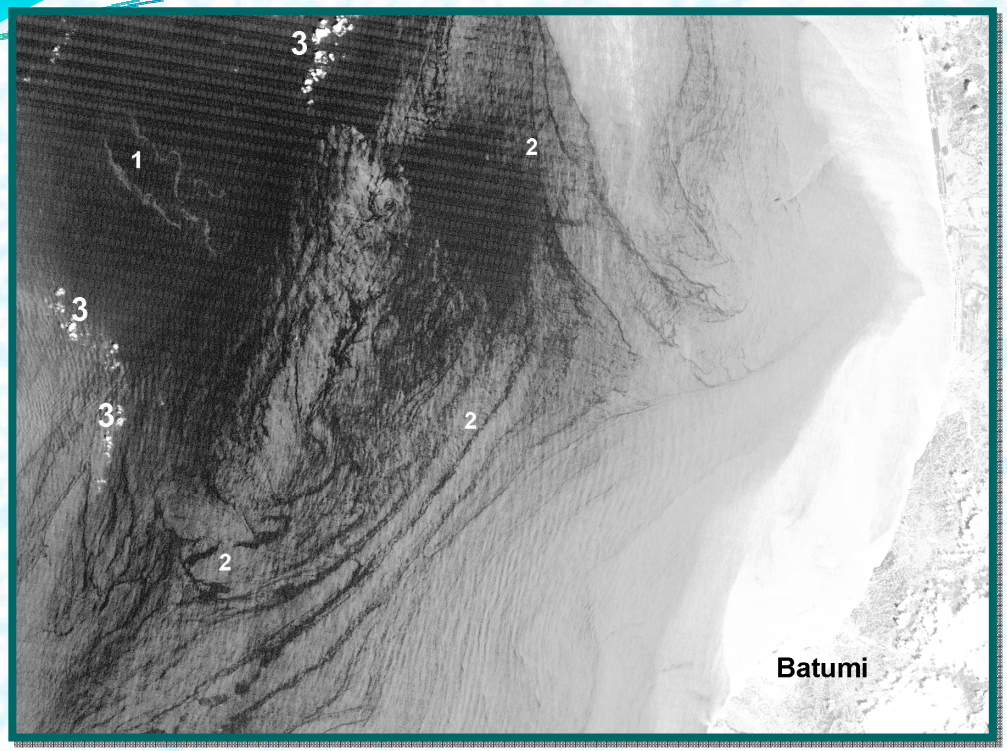






In the majority of cases the slicks appear in radar images as "coupled" structures.

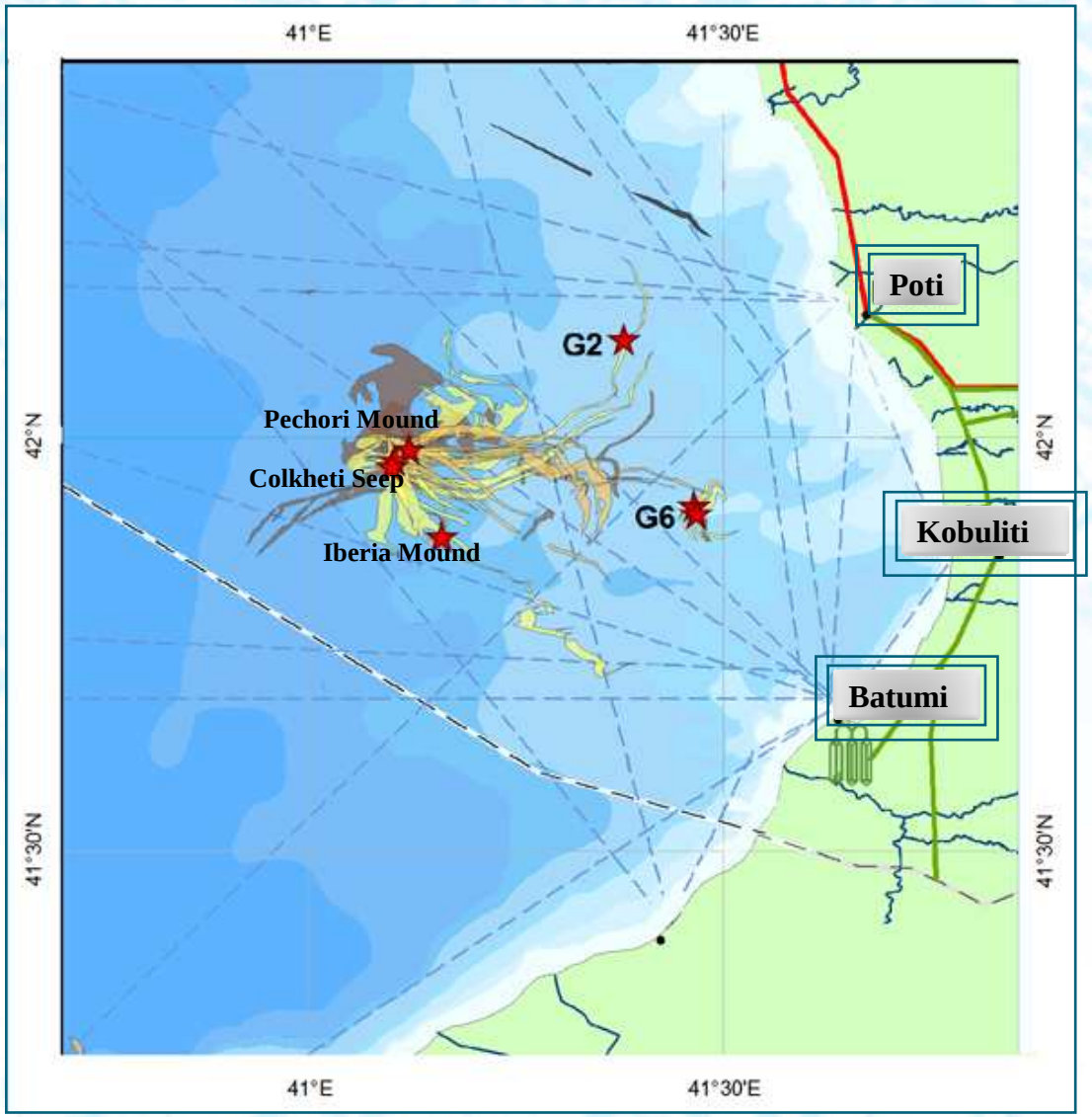
Slicks resulted from hydrocarbon seepage (4)



Subscene of the TM Landsat 5 image (composite of 3, 2 and 1 spectral channels) acquired on 01.07.201. 1- Surface slicks in the methane seeps area; 2- biogenic films; 3- clouds

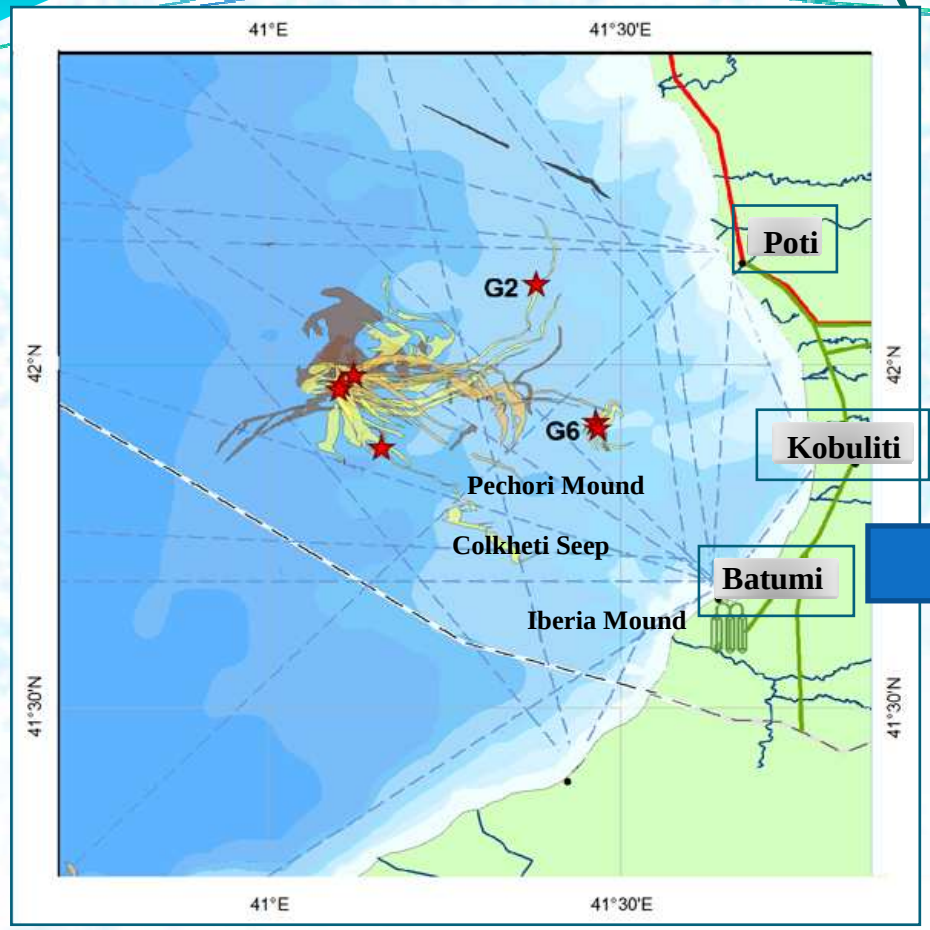
In order to find out whether the surface films registered in the area belong to oil pollution or have biogenic origin the satellite images obtained in different ranges of electromagnetic spectrum have been analyzed. In particular a complex analysis of satellite data derived from ASAR Envisat and data of TM Landsat 5 and ETM+ Landsat 7 was performed. In color composite TM Landsat 5 and ETM+ Landsat 7 images (composite of 3, 2 and 1 spectral channels) oil slicks are distinguished by bright-toned appearance in contrast to biogenic films which are visualized as pale patterns

Consolidated scheme of seepage slicks in the study area offshore Poti (Georgia)



Courtesy of V. Zatyagalova, research and development centre "Planeta"

Consolidated scheme of seepage slicks in the study area offshore Poti (Georgia)

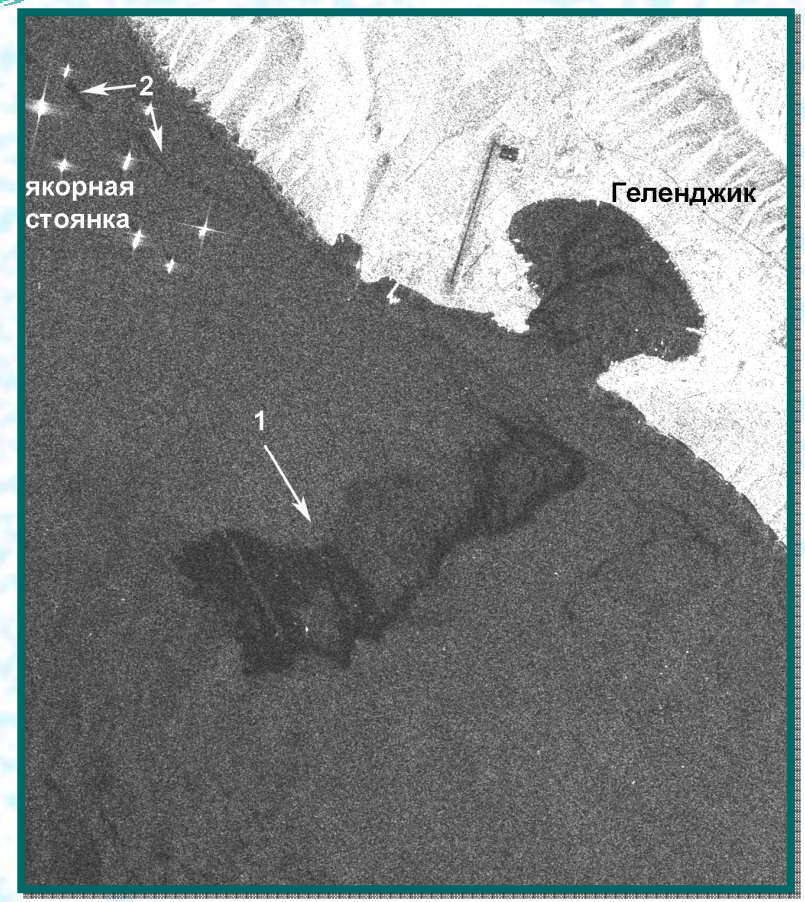


Batumi Oil Terminal is a sea point used for transportation of Caspian oil exports.

BNT also is the only terminal on the Caucasian Black Sea coast used for handling of liquefied petroleum gas.

Batumi Sea Port is located on the Black Sea in the western part of Georgia and is a transportation hub that brings together sea, rail, road and pipeline transport modes.

Slicks due to underwater leakages Slicks due to underwater leakages from sewage systems



SAR image obtained on 29 of September, 2010

Aerial photograph taken from a helicopter

Conclusions (1)

Our observations have shown that there has arisen a strong necessity to implement operational satellite monitoring of sea surface pollution which would allow :

- ✓ to determine the source of pollution,
- ✓ to make quantitative assessment of pollution scale
- ✓ to predict its drift parameters.

Satellite data can be recognized as evidence of environmental review on condition that relevant legislation enactment has been provided.
In this regard, the degree of credibility of satellite images interpretation is of greatest importance as it is used to infer information on anthropogenic pollution of the sea surface.

It is worth mentioning that the problem of anthropogenic and natural films discrimination in radar imagery is very complicated. Synergic use of data obtained from different sensors helps to solve the problem.

Conclusions (2)

The multisensor approach, combining analysis of ASAR/SAR data with other satellite remote sensing data on SST, suspended matter, sea level, chlorophyll-a concentration, mesoscale dynamics, wind and waves, is definitely an effective tool for operational monitoring of oil spills in coastal zones.

To increase the degree of credibility of satellite images interpretation it is necessary :

- **to use for complex analysis the complementary data obtained by various satellite sensors in optical and infrared spectrum ranges;**
- **to make a catalogue of the most frequent events and their visualizations in radar images that are typical of a specific region in order to facilitate interpretation of SAR imagery;**
- **to establish a database for a region of interest, which would contain information on characteristic processes and events that take place in the area depending on the time of year, time of day and directions of currents for the purpose of preventing a false alarm.**
- **Also radar images should be correlated to the map of potential regular pollution sources (deep-water sewage discharge, oil terminals, rivers outlets, submarine mud volcanoes etc.).**

Распределенный информационный ресурс коллективного пользования для комплексного анализа данных космического дистанционного зондирования в интересах исследования Мирового океана РФФИ 11-07-12025-офи-м-2011

Distributed Multi-User Information System for Combined Analysis of Satellite Remote Sensing Data for World Ocean Investigations

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