NOWPAP - PICES Joint Training course
on Remote Sensing Data Analysis

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Oil spill monitoring by remote sensing

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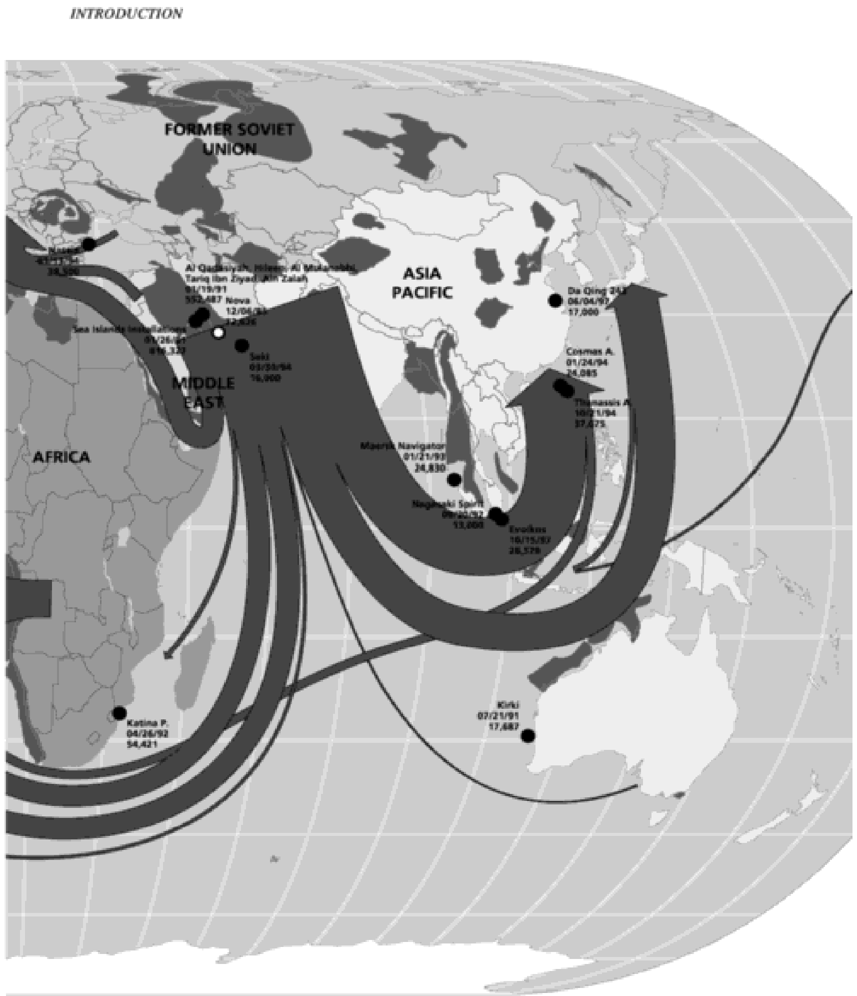


Oil in the Sea III: Inputs, Fates, and Effects (2003)

Even a small amount of oil in the sea can have severe effects on marine life. Changes in regulations and industry practices following the *Exxon Valdez* spill in 1989 have helped to reduce oil inputs from petroleum transportation and extraction. But most oil that enters the sea does not come from oil exploration, extraction or spills. In fact, nearly 85% of the 4 million tonnes of petroleum that enter North American ocean waters each year as a result of human activities comes from land-based runoff, polluted rivers, airplanes, and small watercraft, says the new National Academies report *Oil in the Sea*. The report, which is the third in a series, presents the most up-to-date estimates of major oil sources.

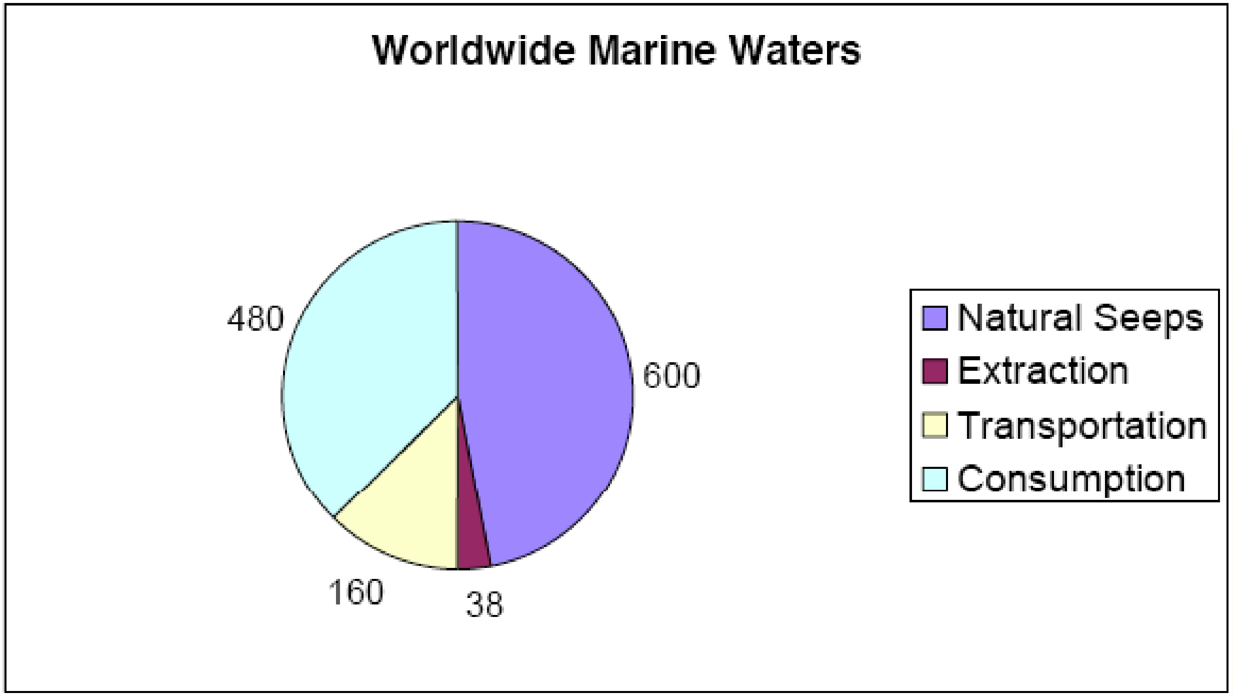
http://www.nap.edu/books/0309084385/html/

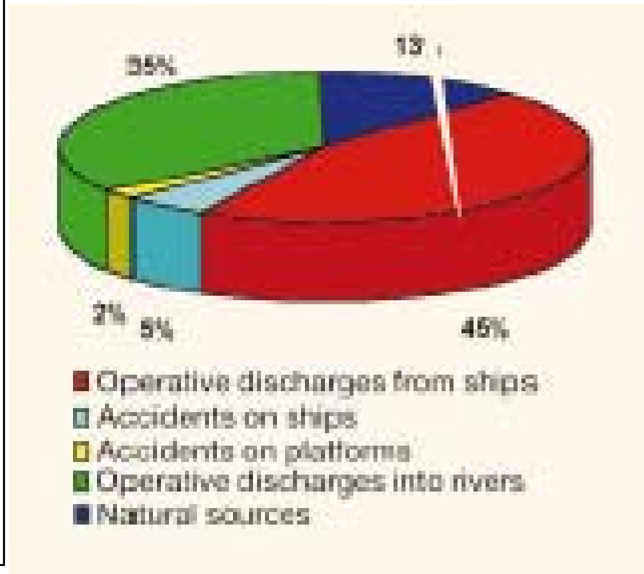
Global inputs of oil to marine environment

Types of oil pollution	Input tonnes	Percentage of the World total
Offshore drilling	50000	2.16
Large oil spills	120000	5.17
Natural seeps	200000	8.62
Up in smoke	300000	12.93
Routine maintenance	450000	19.40
Down the drain	1200000	51.72
Total World	2320000	100.00

Offshore drilling - operation discharges and drilling accidents during oil exploration.
Large oil spills typically oil tanker accidents such as collisions and groundings.
Natural seeps comes from seepage off the ocean floor and eroding sedimentary rocks (has occurred for thousands if not millions of years).
Up in Smoke - from oil consumption in automobiles and industry (atmospheric fallout).
Routine maintenance occurs from ship bilge cleaning and so forth.
The worst oil pollution - **oil dumped into the drains and road runoff** - dumping oils and oil products down storm drains after oil changes, urban street runoff and so forth.

Global inputs of oil to marine environment

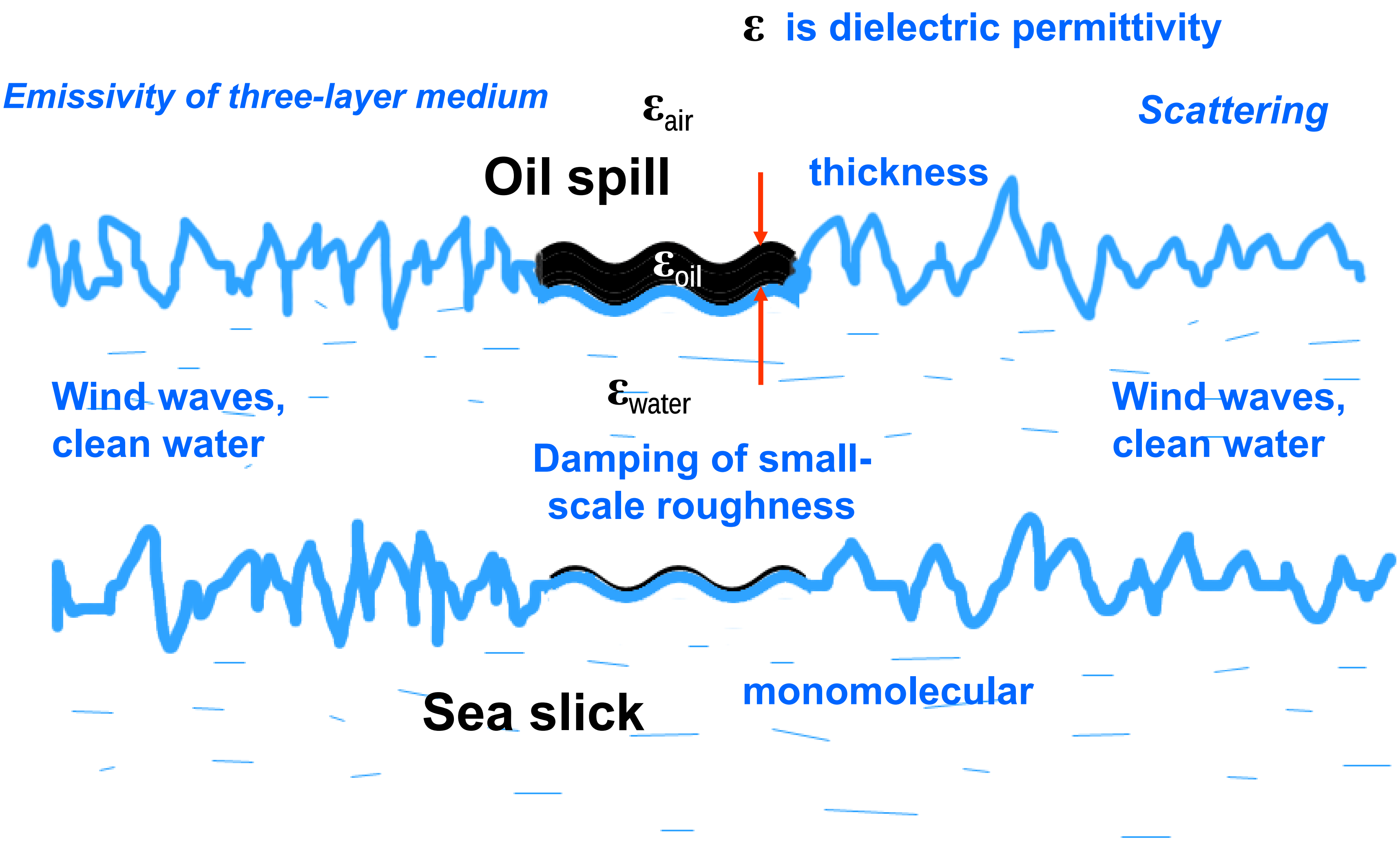


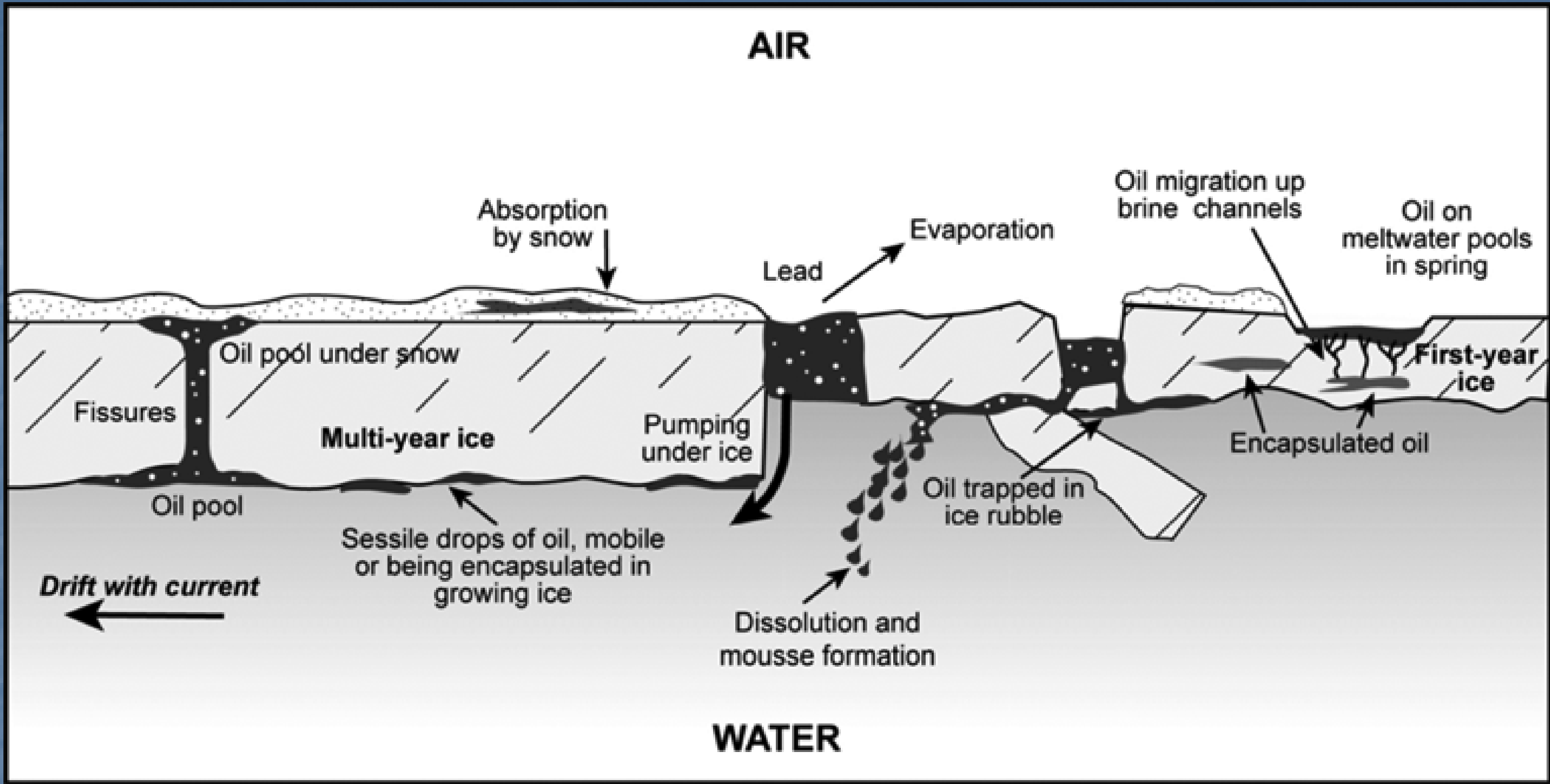


Average annual contribution to oil in the ocean (1990-1999) from major sources of petroleum in kilotonnes. (***Oil in the Sea III: Inputs, Fates, and Effects (2003)***, **National Academy of Sciences**).

http://books.nap.edu/openbook.php?record_id=10388&page=29

Remote sensing of oil spill and sea slick




AIR
Absorption by snow
Lead
Evaporation
Oil migration up brine channels
Oil on meltwater pools in spring
Oil pool under snow
Fissures
Multi-year ice
Pumping under ice
First-year ice
Encapsulated oil
Oil trapped in ice rubble
Oil pool
Sessile drops of oil, mobile or being encapsulated in growing ice
Drift with current
Dissolution and mousse formation
WATER

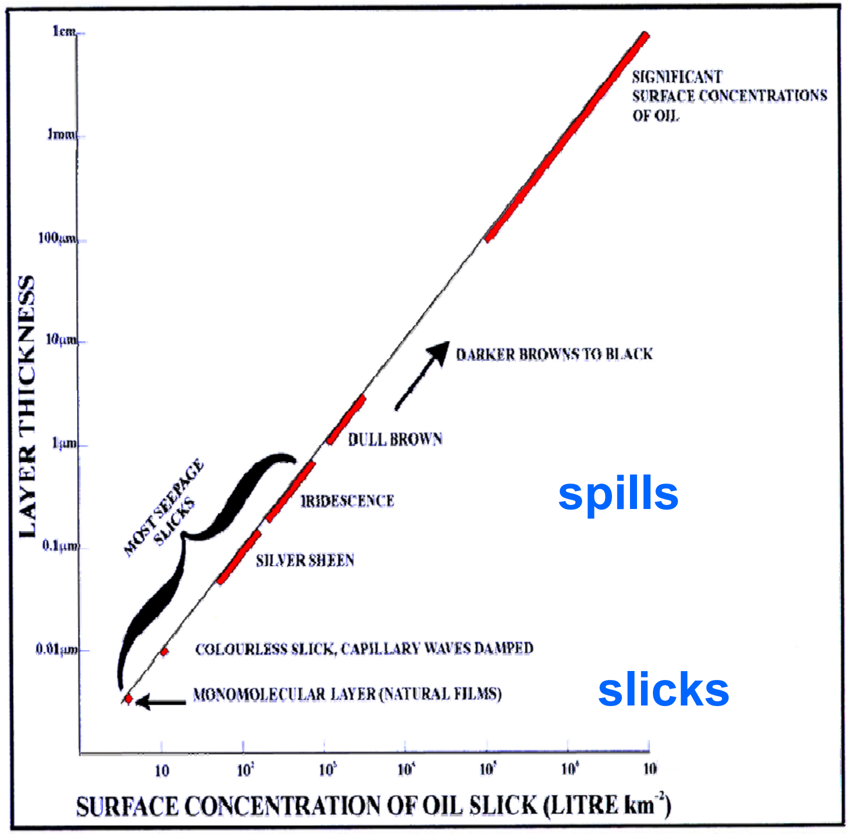
3. Summarizing characteristics and nomenclature for the sea slicks and crude oil spills

Marine Surface Films. Physico-Chemical Characteristics, Influence on Air-Sea Interactions, and Remote Sensing, M.Gade and H. Hühnerfuss, Eds. Universität Hamburg, Germany, Springer, 2006)

	Sea slicks	Crude oil spills
Chemical constituents	*surface-active substances* consisting of a *hydrophilic* head group and a *hydropholic* tail	alcanes, cycloalcanes and aromatics with *preferentially hydrophopbic* character, no hydrophilic head group
Distribution at the water surface	a) substances spread on the water surface; b) substances *are being spread* on the water surface; c) a sea slick *is generated (or produced)* at the surface	a) crude oil *is spilled* at the sea surface; b) a crude oil spill *is generated (or producing)* at the sea surface
Thickness	*monomolecular*, typically 2.4-2.7 nm	thicker layers, typically µm-range, if freshly spilled even cm-range (in connection with accidents)
Origin	both biogenic (secreted by plankton or fish) and man-made	nearly in all cases man-made, in few cases oil seeps
Water wave damping mechanisms	resonance-type wave damping in the short-gravity-wave region, (*Marangoni damping*)	damping by an interfacial layer of higher viscosity
Microbial or photochemical transformation of constituents	relatively fast: time scale hours or few days (→ soluble, highly polar substances that disappear in the bulk water)	very slow: several months (→ *weathered oil spills* → formation of surface active compounds → *slick* formation around thick spill centers)

From Bonn Agreement (2004, 2009)

Code	Description/appearance	Bonn, layer thickness (µm)	ASTM, layer thickness (µm)	liters per km^2
1	Sheen (silvery/gray)	0.04 to 0.30	0.1–0.3	40 to 300
2	Rainbow	0.30 to 5.0	0.3–0.5	300 to 5000
3	Metallic	5.0 to 50	~3	5000 to 50,000
4	Discontinuous true oil color	50 to 200	>50	50,000 to 200,000
5	Continuous true oil color	200 to >200		200,000 to >200,00



Spill thickness determines **appearance** at sea at given wind speed

Evolution of oil

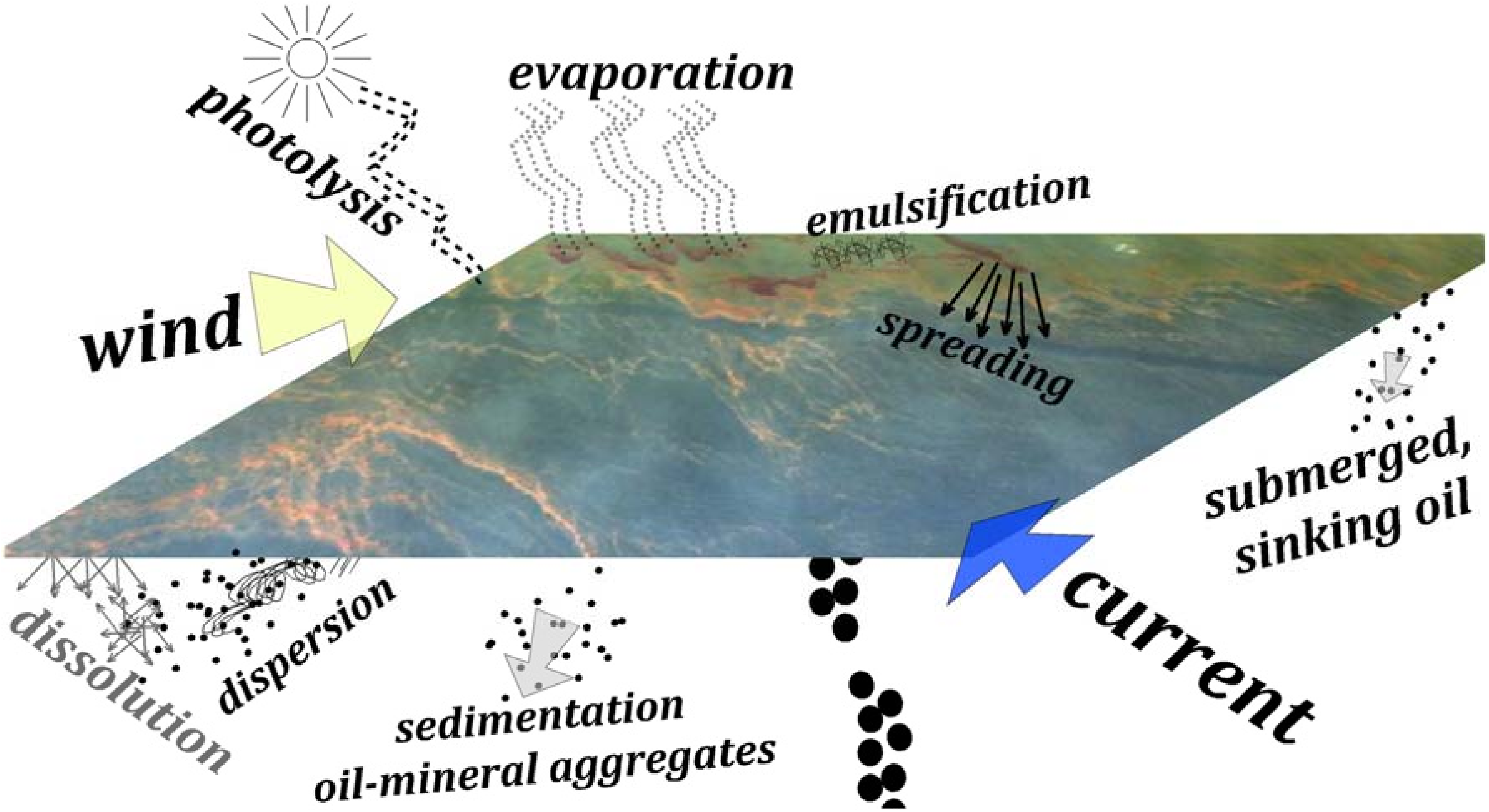
Spreading, Evaporation, Dispersion, Emulsification, Dissolution, Oxidization, Sedimentation and Biodegradation

The above processes combine to produce natural dissipation of oil into the marine environment.

Spreading, Evaporation, Dispersion, Emulsification and Dissolution **are most effective during early stages of a spill whilst** ***Oxidization, Sedimentation and Biodegradation*** **occur in the later stages.**

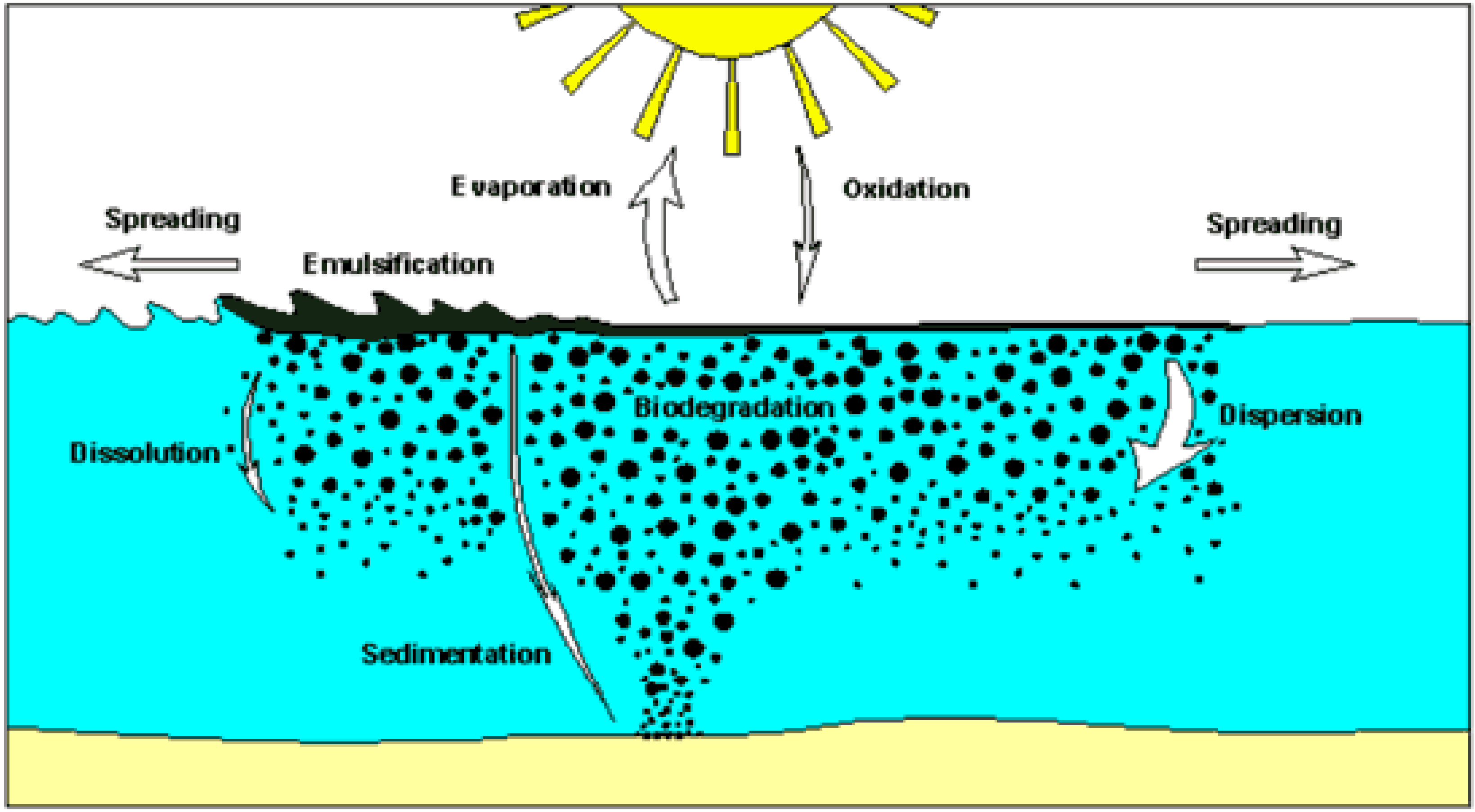
How long the process of natural dispersion takes is an almost unquantifiable figure as it is highly dependant on environmental conditions that are uncontrollable.

Oil slick processes



Schematic of important early oil slick processes on time-scales up to a few days for a subsurface hydrocarbon spill. ***Oil image from AVIRIS image of the Deepwater Horizon spill.***

2. Behavior of oil at sea (weathering)



The rate at which oil dissipates is greatly dependant on the type of oil, weather/sea conditions and whether the oil remains water borne or becomes land-bound. The processes involved in its evolution, collectively known as weathering, are *spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation and biodegradation*. The time scale however, of their relative importance, varies from few hours to months.

Life of a spill

What happens to oil when it is spilled at sea?

Any oil spillage will dissipate into the marine environment. Unfortunately the level of environmental damage caused during natural dissipation can be significant, depending on the location of the spill and whether it is likely to reach land or other sensitive areas. The rate at which oil dissipates is greatly dependent on the type of oil, weather/sea conditions and whether the oil remains water borne or becomes land-bound. There are eight distinct processes involved in the dispersion of oil, collectively known as 'weathering'.

Spreading

As soon as oil is spilled into water, it begins to spread over the surface. In the initial instance this will be in the form of a single mass or slick. Spreading is rarely uniform and the slick is likely to break up into a number of smaller slicks within a few hours if not contained. How quickly oil spreads is dependent on a number of factors:

1. ***The thickness or 'viscosity' of the oil.***

Lighter refined 'fuel oils' will spread a higher rate than heavy 'crude oils'

2. ***Weather conditions.***

Wind can significantly increase the spread of a slick. 'Swirling' wind conditions are likely to break up a slick faster than wind from a single direction

3. ***Sea Conditions.***

Rough seas will greatly enhance the rate of spread and break up the slick.

Emulsification

Emulsification occurs when two liquids that cannot be naturally mixed combine. One liquid will become suspended in the other forming an emulsion. You may be familiar with emulsification if you have suffered a head gasket problem on your car. The creamy white fluid that builds up on the oil filler cap is emulsified oil/water. Emulsification can increase the volume of pollutant (at this stage it is often called 'chocolate mousse') and also reduces the rate at which biodegradation will take place. Emulsions may separate back into oil/water if they become 'beached' in warm weather conditions.

Dissolution

Oil does contain water-soluble compounds that can dissolve into the sea. It is however more likely that these compounds would have been removed due to evaporation.

Oxidization

Oils react to head and oxygen and break down into soluble compound or persistent forms called tars. The rate of Oxidization is dependent on the type of oil and at best can be described as 'slow'. Heavier oils are more likely to form tars. Tar formation often occurs in the form of 'tar balls' consisting of a highly weathered outer crust covering an almost liquid core. This greatly increases the persistence of the oil contained within.

Sedimentation

Oil does not naturally sink. However, should water-borne sediments such as sand or organic material come into contact with oil particles, they may increase the weight of the oil sufficiently to cause sinking. This is more likely to occur if a slick is inshore and close to sandy beaches where there will be a high level of suspended sediment.

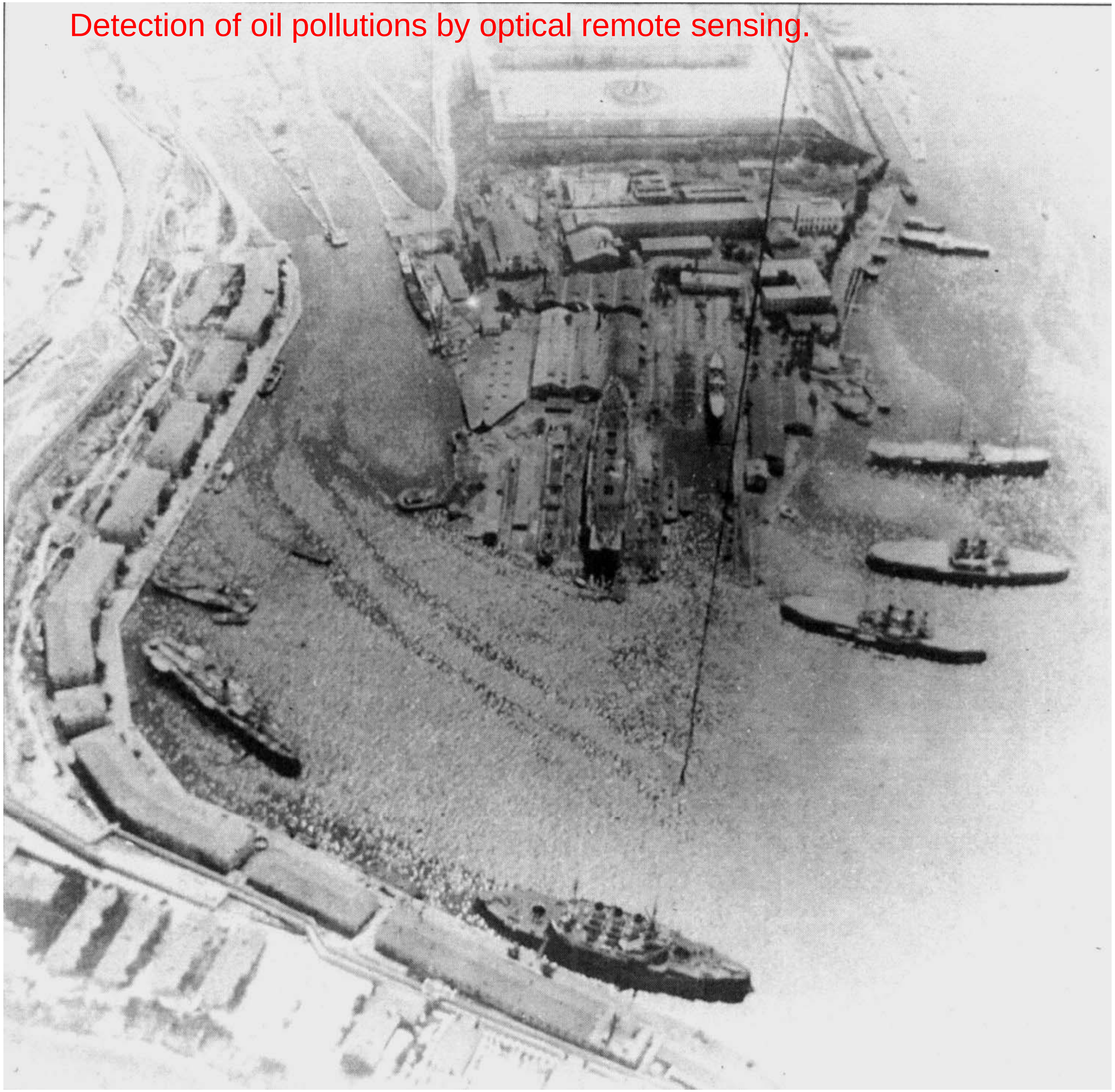
Biodegradation

Sea water contains a variety of microbes that can degrade oil either partially or completely. Whether this occurs is dependent on the concentration of nutrients in the area and the type of oil involved. Heavier oils contain components that are extremely resistant to microbes and less likely to degrade.

Combined effects - Weathering

The above processes combine to produce natural dissipation of oil into the marine environment. Spreading, Evaporation, Dispersion, Emulsification and Dissolution are most effective during early stages of a spill whilst Oxidization, Sedimentation and Biodegradation occur in the later stages. How long the process of natural dispersion takes is an almost unquantifiable figure as it is highly dependent on environmental conditions that are uncontrollable.

Detection of oil pollutions by optical remote sensing.

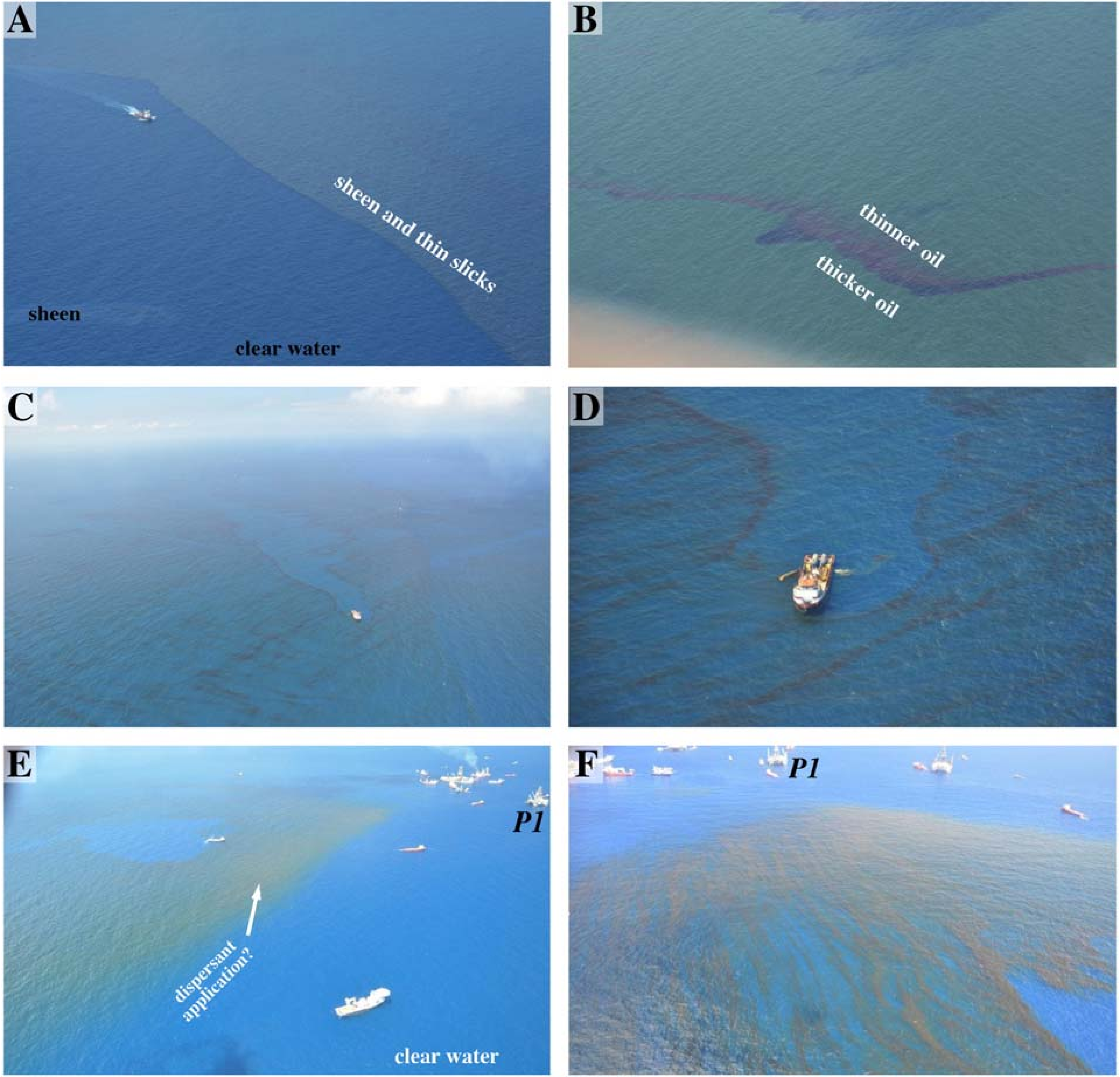


Sebastopol – Home of Remote Sensing

1902 Sebastopol Black Sea Photo.
(image credit: Stanichny, MHI, Ukraina)

Visible spectrum oil slick appearance: underlying spectroscopy

Thin sheen oil optical behavior is governed by light transmission and reflection through the slick. This light includes downwelling solar radiation and upwelling reflected light and scattered light rom the underlying water and oil. Oil identification is by contrast with seawater; and thus is most successful where sub-surface upwelling radiance is higher relative to specular sky radiance seawater reflection, in the range of 480–570 nm. These reflectances and transmittances have strong wavelength and angular dependencies with greater contrast for less oblique observations and shorter wavelengths. Thickness makes a difference for thinner slicks.
It was found a steeper fall off in crude oil reflectance (greater absorption) towards blue for spectra spanning 470 to 800 nm, with increasing slick thicknesses from 10 to 133 μm.



Sample Deepwater Horizon spill aerial photos on 23 June 2010 of
A Sheen and thin slick.
B. Fresh surfaced oil in thin slick.
C. Distant slick.
D. Same as **C**, but closer, showing wake bunch-up and sheen coverage asymmetry.
E. Dispersant application.
F. Possible weak Langmuir slick organization and cloud shadows.
Platform (P1) identified in E and F to aid orientation.
Images courtesy of Ben Holt.

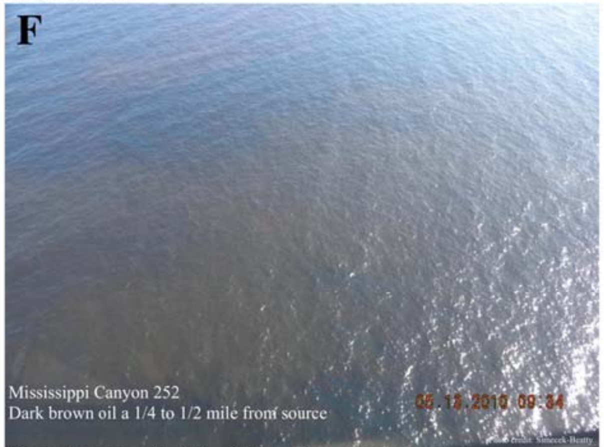
Dinoflagellate and boatwake

Red emulsified oil with dull and silver sheens in convergence

Sargassum

Red-orange emulsified oil in bands with windrows of silver and dull sheen

Brown Algae



Dark brown oil ~0.4 - 0.8 km from source

Deepwater Horizon aerial photos of (A,C,E) false positives and (B,D,F) similar looking oil slicks. Images courtesy of Debra Simecek-Beatty.

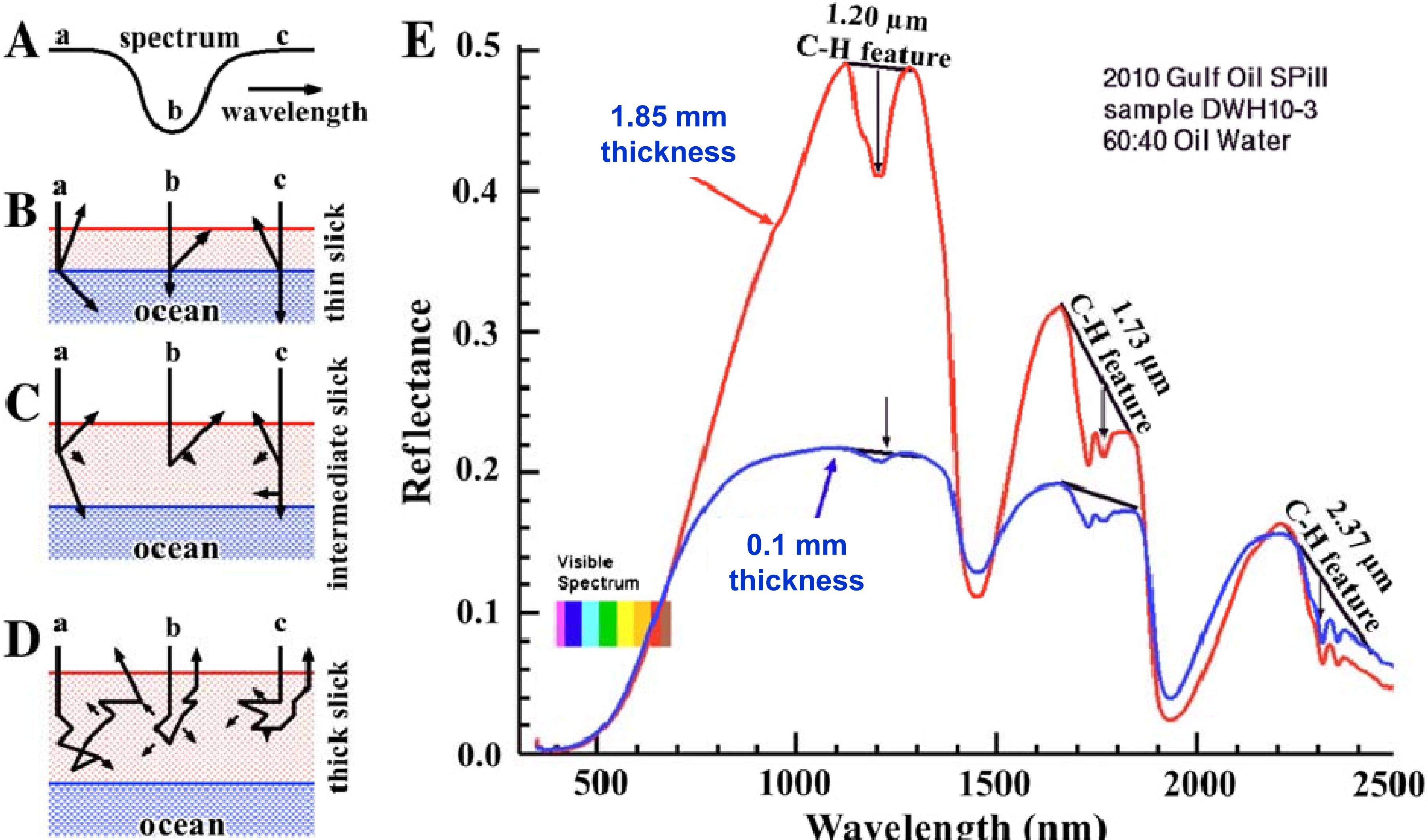

Vladivostok. Amursky Bay
22 July 2009.

An aerial photo, released by China's Xinhua news agency on July 17, 2010. An oil slick floating off the coast of Dalian after pipeline explosions at the northeastern Chinese port.

A Greenpeace activist surveys the damage of the oil spill at Dalian's port on July 21, 2010

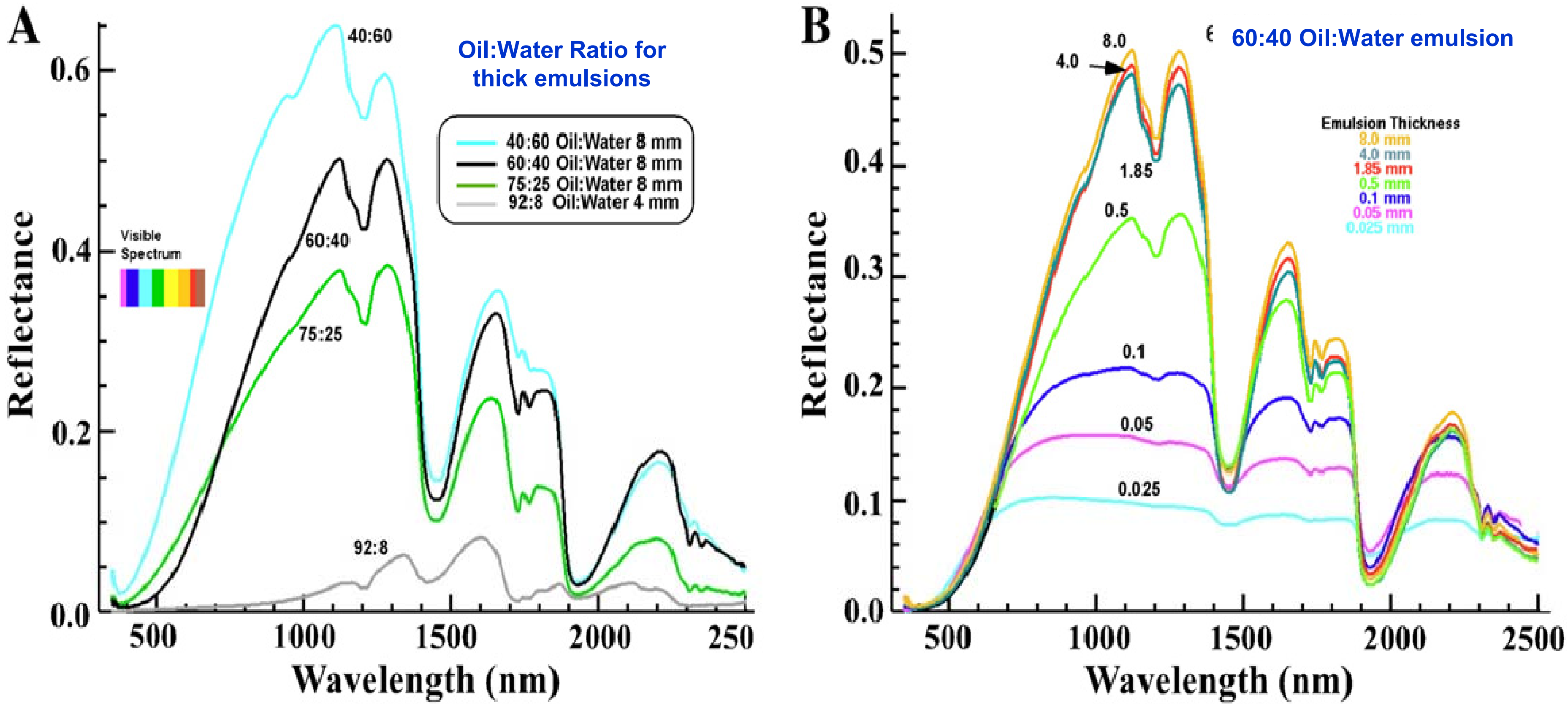
Near infrared oil slick appearance: underlying spectroscopy

Petroleum hydrocarbon spectral features in the near infrared (NIR) are dominated by a carbon–hydrogen bond, C¥H, stretch and also symmetric axial and angular deformations, with a mid-infrared (MIR) fundamental near 3300 nm. In reflectance, light at different wavelengths penetrates an absorbing layer to different depths due to varying absorption and scattering (Clark, 1999). This enables different wavelengths to probe an oil or oil-emulsion layer to different depths (Fig. 5), and can cause a slope or skew in an absorption feature, termed "shoulder-ness," see schematic in Fig. 4A–D. Furthermore, the continuum—i.e., the spectrum outside the feature, is shaped by nearby water absorptions, which are affected strongly by the oil to water emulsion ratio.



A–D. Illustration of light scattering in oil on water. Arrow length indicates amount of scattering intensity. E. Laboratory spectra of two different thicknesses of the same emulsions from a Deepwater Horizon oil sample. Spectra were recorded for samples in a quartz-glass window cell over a water substrate contained in a glass jar painted flat black on the inside. Black lines illustrate continuum endpoints. From Clark et al. (2010b).

Oil slick thickness and oil-to-water emulsion ratios are key spill response parameters for containment/cleanup and were derived quantitatively for thick (>0.1 mm) slicks from AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) data using a spectral library approach based on the shape and depth of near infrared spectral absorption features.



A. *Deepwater Horizon* oil:water emulsion laboratory spectra for a range of oil to water ratios for thick oil. B. Spectra of a 60:40 oil-to-water ratio emulsion over a range of thicknesses. From Clark et al. (2010b).

Thermal infrared oil slick appearance (emissivity)

Thermal InfraRed (TIR, 7–14 μm) oil slick remote sensing has focused on discriminating oil from seawater by identification thermal contrast spatial patterns. TIR oil slick detection works by identifying a thermal contrast between the emissivity of the oil slick with the background, oil-free water emissivity and complements daytime visible spectrum reflectance by being viable at night. The thermal contrast
arises due to the different emissivities of water versus oil, which depend on slick thickness (Salisbury et al., 1993). The contrast also arises from the oil's lower heat capacity, lower albedo in the visible, and different thermal conductivities. These thermal attributes manifest as an Apparent Thermal Inertia (ATI) or temperature change resistance, defined ATI=(1−a) / (Tday−Tnight), where a is albedo, normalized by the day, Tday, to night, Tnight, temperature difference. An oil slick's ATI is distinct from seawater's (Asanuma et al., 1986). During daytime, oil slicks thicker than 150 μm appear warmer than surrounding water while thinner, detectable slicks appear cooler. This reverses at nighttime (Tseng & Chiu, 1994) with a 50–150 μm transition. Thinner slicks appear cooler due to the decreased emissivity of the thin oil layer relative to water Thick slicks (>500 μm) appear warmer during daytime because they are effective solar radiation absorbers, but appear cooler at nighttime as they lose heat more rapidly than the surrounding water.

Infrared sensor

The IR sensor is used to provide relative, not absolute, thickness information of oil slicks on the sea surface, not rain, mist or fog.

The sensor detect IR radiation in the 8-12 mkm emitted by oil.

The oil layers are depicted as variations in gray level (or in defined colors).

Areas of relatively thin oil film are apparently cooler than the surrounding sea and areas of thicker oil films are actually warmer than the surrounding sea because they absorb the sunlight more rapidly. (*European Workshop Oil pollution Monitoring. Existing oil remote sensing means.* D. Mason. Aircraft and aerial sensors).

Spectral features of remote measurements

Wavelength range	Microwave		Infrared		Visible	
Regime	*Passive*	*Active*	*Passive*	*Active*	*Passive*	*Active*
Day / Night	+	+	+	+	-	+
Cloudiness	+	+	-	-	-	-
Spatial resolution	*low*	*low - high*	*medium*	*high*	*high-medium*	*High-medium*
Penetration depth	< mm - m	< mm - m	< mm	< mm	< mm (land) m (ice) < m – 20 m (water)	< mm (land) m (ice) < m – 20 m (water)

$$\lambda[cm] = \frac{30}{\nu[GHz]}$$

Three measurements are used to describe EM waves: wavelength (λ) in *μm*, *cm* or *m*, frequency (ν) in hertz (Hz) and velocity (*c*) in *m/s*. 1 GHz = 10^9 Hz.

$$\Delta\varphi_{0.5} = 70\frac{\lambda}{D}$$ **(degrees)**

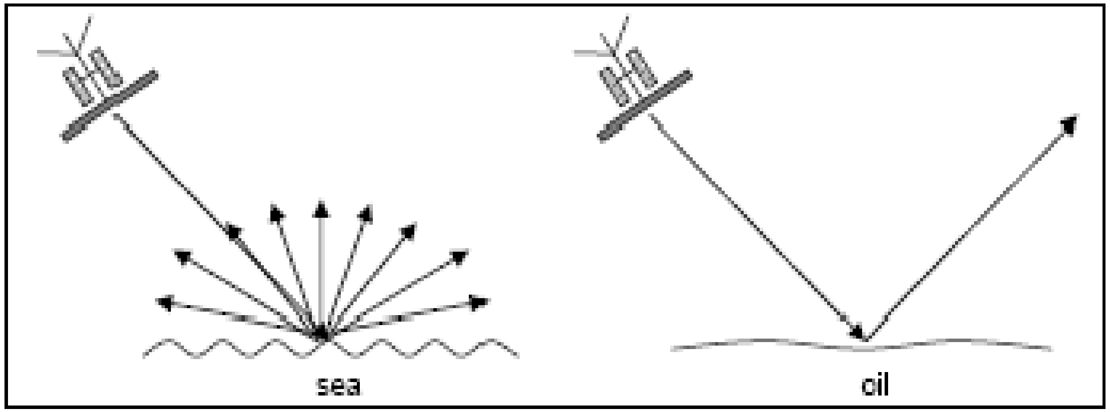
Target detection mechanism

Relationship between wavelength region and target detection mechanism

Wavelengths		Detectable parameter	Specific detection constraints
Ultraviolet	01.-0.4 μm	Spectral reflectance. Fluorescence	Strong atmospheric absorption band below 0.29 μm. Atmospheric scattering
Visible	0.4-0.76 μm	Spectral reflectance	Illumination required
Infrared Near IR Far IR Thermal IR	0.76-1000 μm 0.76-3 μm > 3 μm 7-14 μm	Spectral reflectance. Spectral thermal emission	Under illumination conditions, spectral reflectance masks out thermal effects below 3 μm. Atmospheric haze and clouds. Molecular absorption
Microwave	1mm – 1m	Spectral brightness. Temperature. Reflection/scattering cross section	Droplet clouds, rain. Molecular absorption. Polarization bias.

Why the SAR can detect an oil spill event?

- An oil spill may cover vast areas of the sea surface and damp some of these capillary waves.
- In this way, the water surface roughness is reduced and can be detected by the Normalized Radar Cross-Section (NRCS) on SAR images, since it appears as a dark area or an area in which there is an absence of sea clutter.

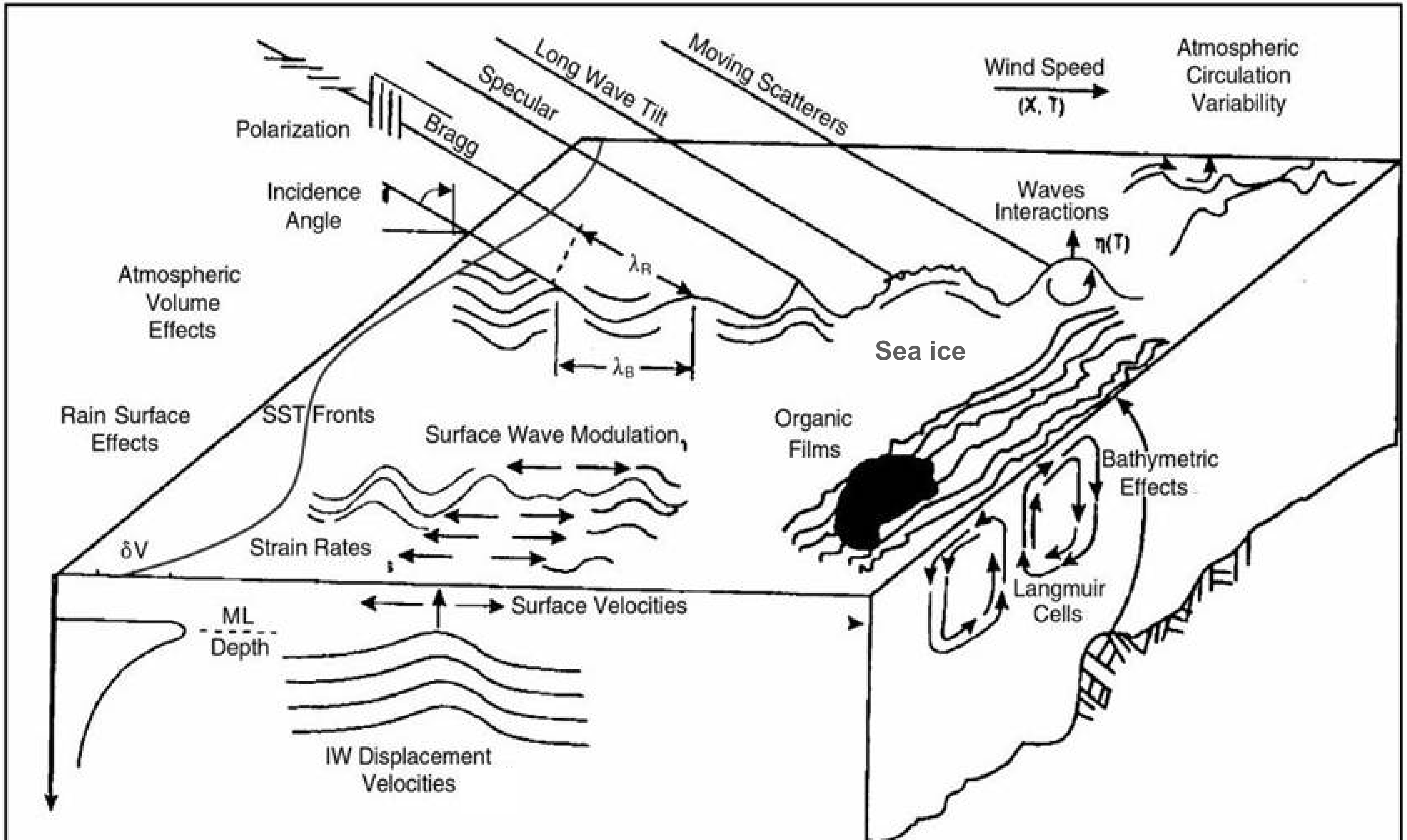


short gravity – capillary waves

Wind speed > 2m/sec…

http://serac.jrc.it/midiv

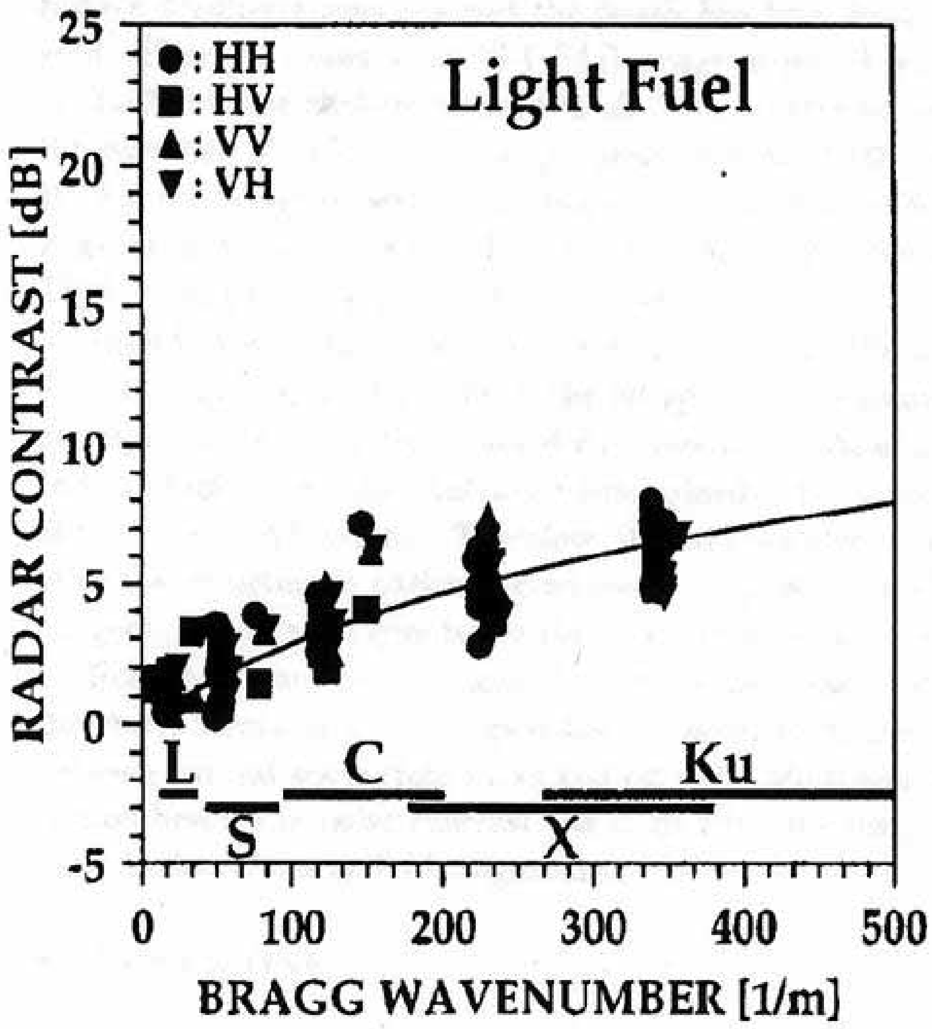
4.2. Processes involved in SAR ocean imaging

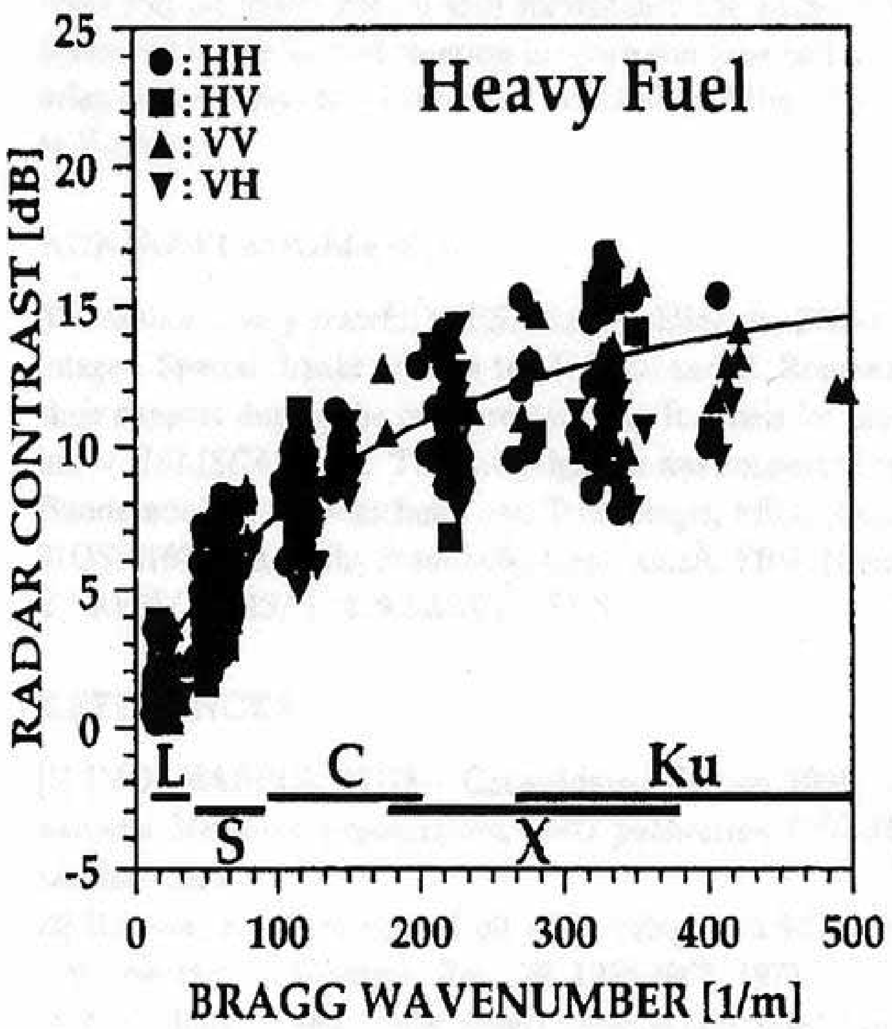


[adapted from Press et al., 1996]

Main SAR response from the ocean is from resonance of the radar microwaves with capillary and small gravity surface waves (i.e. Bragg waves), as well as modulation by longer waves.

SAR instrument characteristics also play a major role in the capacity to detect oil spills on the sea surface: radar frequency, polarisation, incidence angle, spatial resolution, etc.



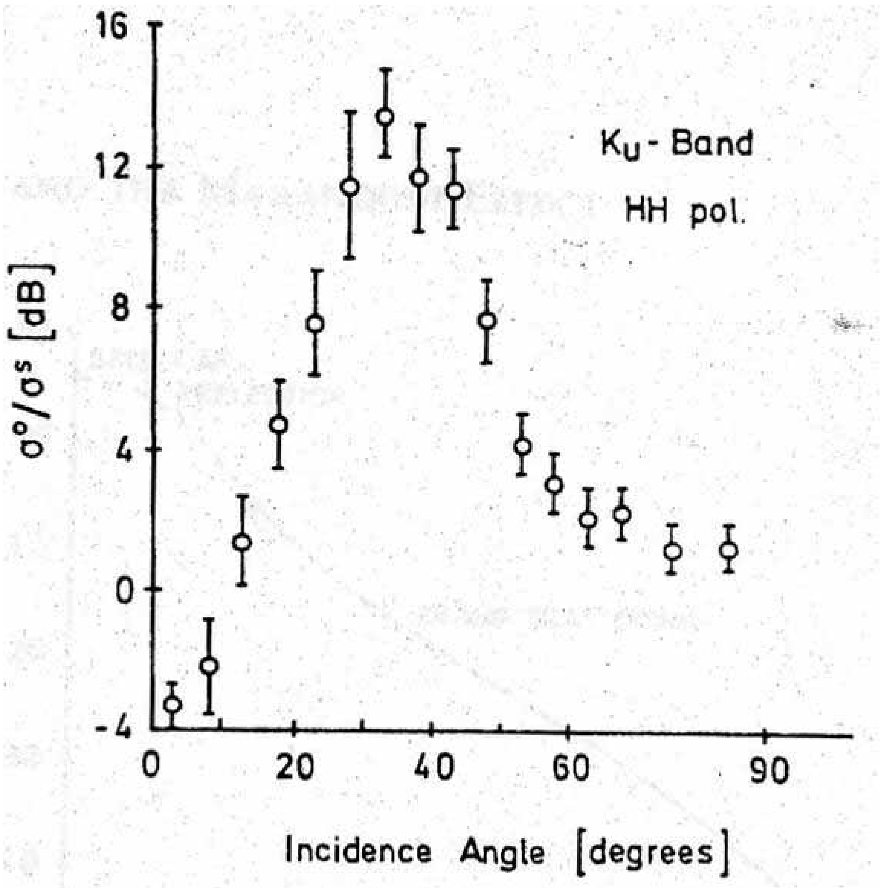


Radar contrast as a function of frequency for two kind of fuel

V. Wismann, R. Theis, W. Alpers, and H. Hühnerfuss, "The damping of short gravity capillary waves by experimental sea slicks measured by a multifrequency microwave scatterometer," in Proc. OCEAN, vol. II, Victoria, Canada, 1993, pp. 342–347.

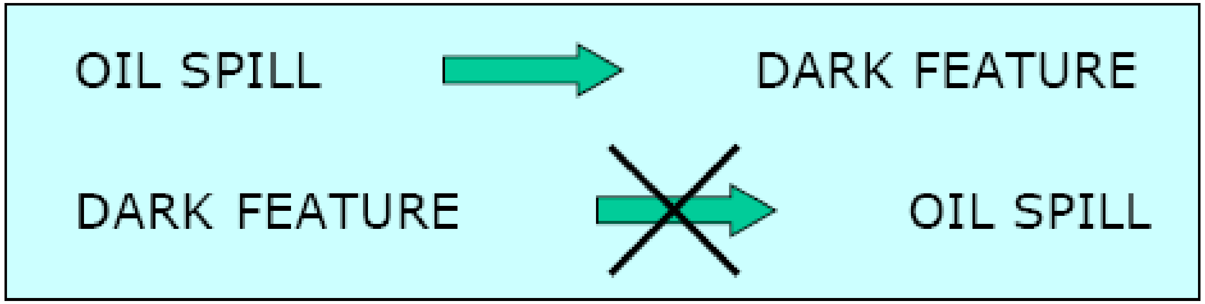
Radar contrast as a function of incidence angle in Ku-Band

The incidence angle (that is the angle between the transmitted electromagnetic (e.m.) waves and the normal of the sea surface) also changes the contrast ratio between oily areas and clean areas. The imaging mechanism varies as a function of incidence angle as well as the typical sea surface wavelengths that interact with e.m. signal. Since the latter react progressively to the wind forcing, with increasing energy when the wavelength increases, the contrast ratio will also change correspondingly. The influence of polarization in the SAR capability to detect oil spills is more difficult to assess. As stated by the radar theory, SAR backscattered signal is expected to be higher in VV-polarization that in HH-polarization. In practice, the vertical (VV) polarization for both transmission and reception will be preferred to any other configuration for oil-spill detection when this is available (e.g. ERS-1/2, ENVISAT).



Eventually, the spatial resolution is also of importance. Typically, SAR images products that offer wide coverage (e.g. Envisat ASAR WS or Radarsat-1/2 ScanSAR modes) usually have resolution between 50-150 m. Nevertheless, such products have revealed to be sufficient for normal operational surveillance of ship discharges. Indeed, this resolution allows detection as well as the possibility to measure the length of en route discharges (but not the width, this one being of the same dimension as the pixel size). Higher resolution products have limited swath but they will be preferred in case of the monitoring of widespread accidental spills as the area of interest is known a priori and exhaustive detailed reporting of potential slicks is wanted over this area.

Are all dark features in a SAR image oil spills?



- Oil spills are not the only phenomena which can appear as a dark feature.
- Under certain air/sea boundary layer conditions, other sea surface manifestations of natural origin may result to SAR expressions or false targets, similar to those due to an oil spill.
- They are usually referred to as look-alikes objects.

Look-alike

Natural slicks	Reflections of the bottom topography in shallow waters
Threshold winds (fronts)	Plumps of municipal sewage
Wind shadows behind islands and coastal mountains	Wave shadows behind land
Calm areas	Weed beds that calm the water just above them
Surface currents	Grease ice
Internal waves	Biogenic oils
Rain cells	Whale and fish sperm, etc.
Upwelling areas	

http://serac.jrc.it/midiv

Detection and identification of films in SAR images

Oil spills and natural films modify surface tension, therefore having a strong impact on radar backscatter level which is decreased and results in dark patches in comparison with the surroundings.

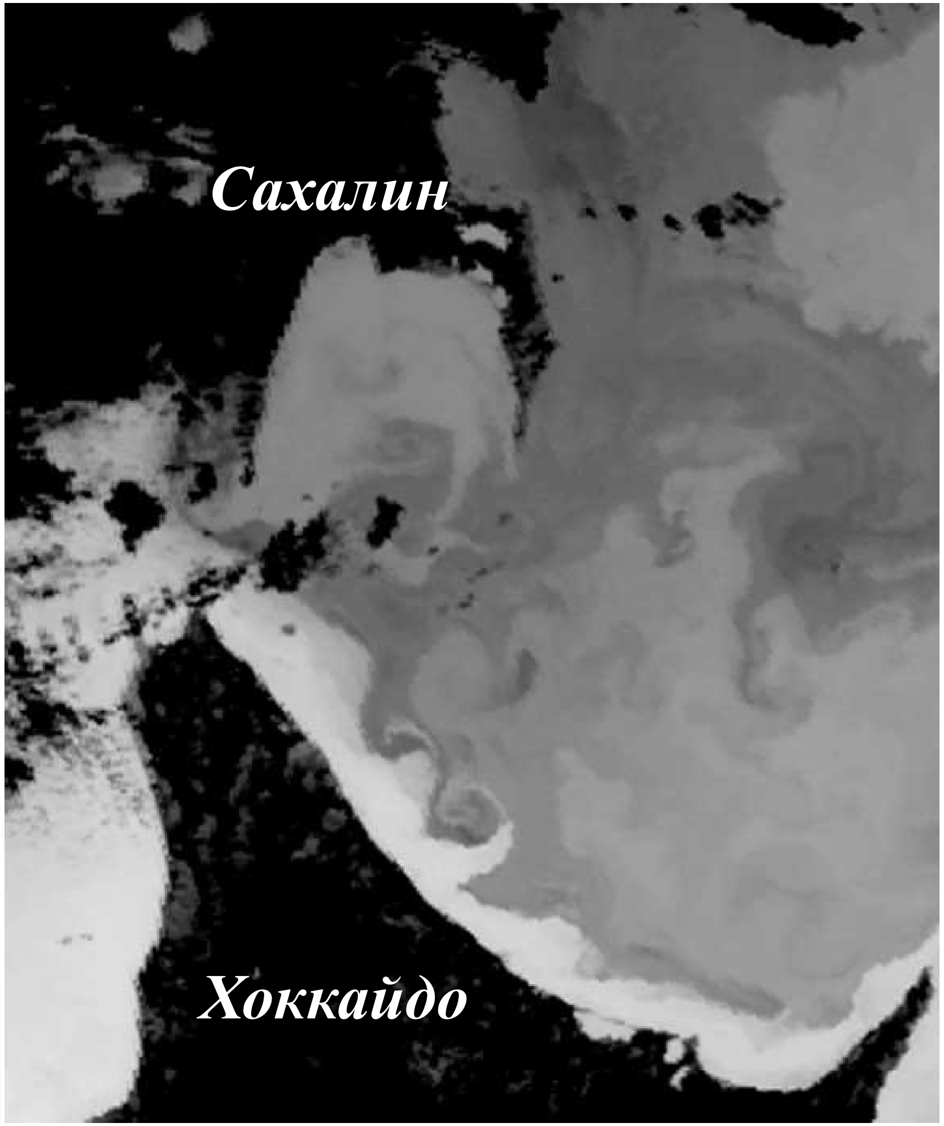
Low wind conditions **do not provide *enough signal contrast for detection*. Sufficient wind speed is required to allow enough contrast between spilled and clean areas. For the VV-polarized C-band SAR sensors, this minimum wind speed is about 2.5 m/s. Thus, low wind conditions are the major source of false negative alarms (situations where oil spills are actually present on the sea surface but could not be detected by SAR imagery).**

In the case of *high winds situations*, the radar inability to observe oil spills on the sea surface is due to physical process as surface turbulence and waves dispersion drag slicks into the ocean subsurface. The upper wind limit for oil spill detection ranges between 12-14 m/s.

In fact the ability to detect an oil slick will depend on the importance and nature of the slick but also on the evolution of the local conditions (wind, currents) from the very beginning of the spill. **But we seldom have the full history of those local conditions that are determining the detectability of the slick, as well as its drift).**

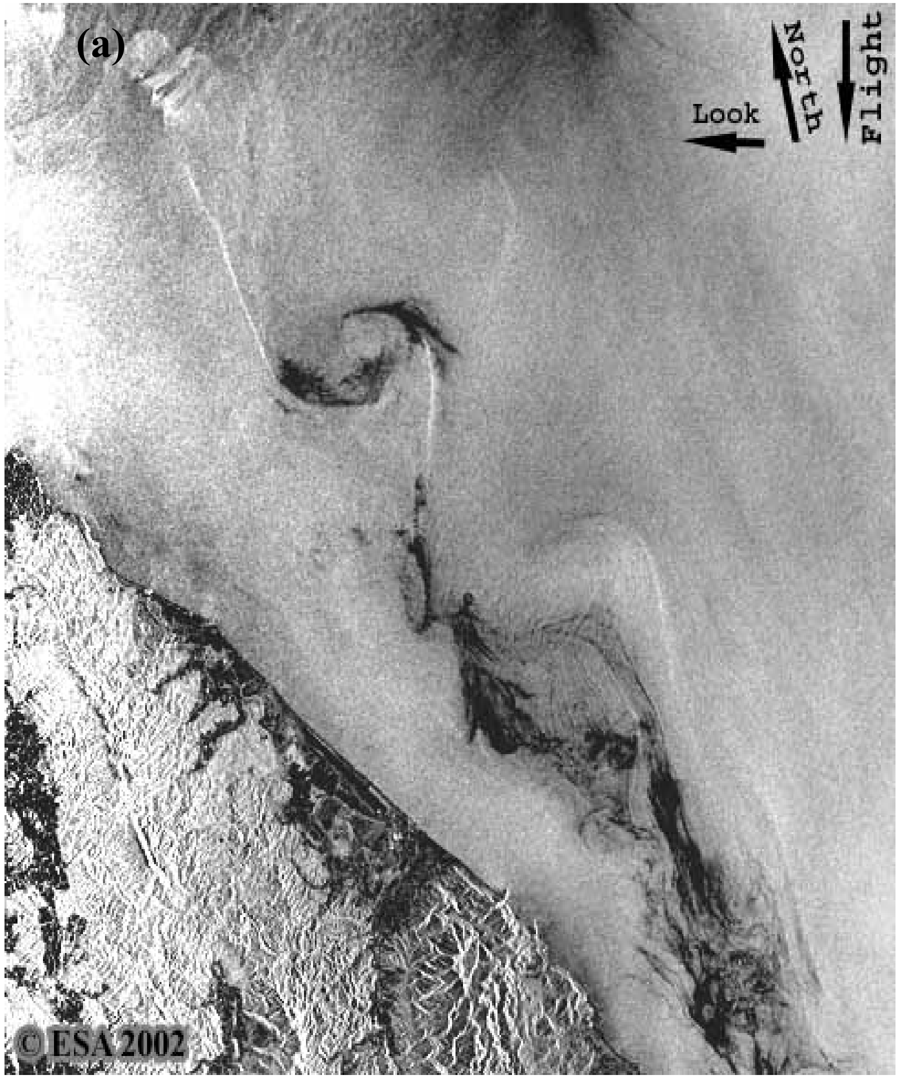
Vortex street on 14 October 2002

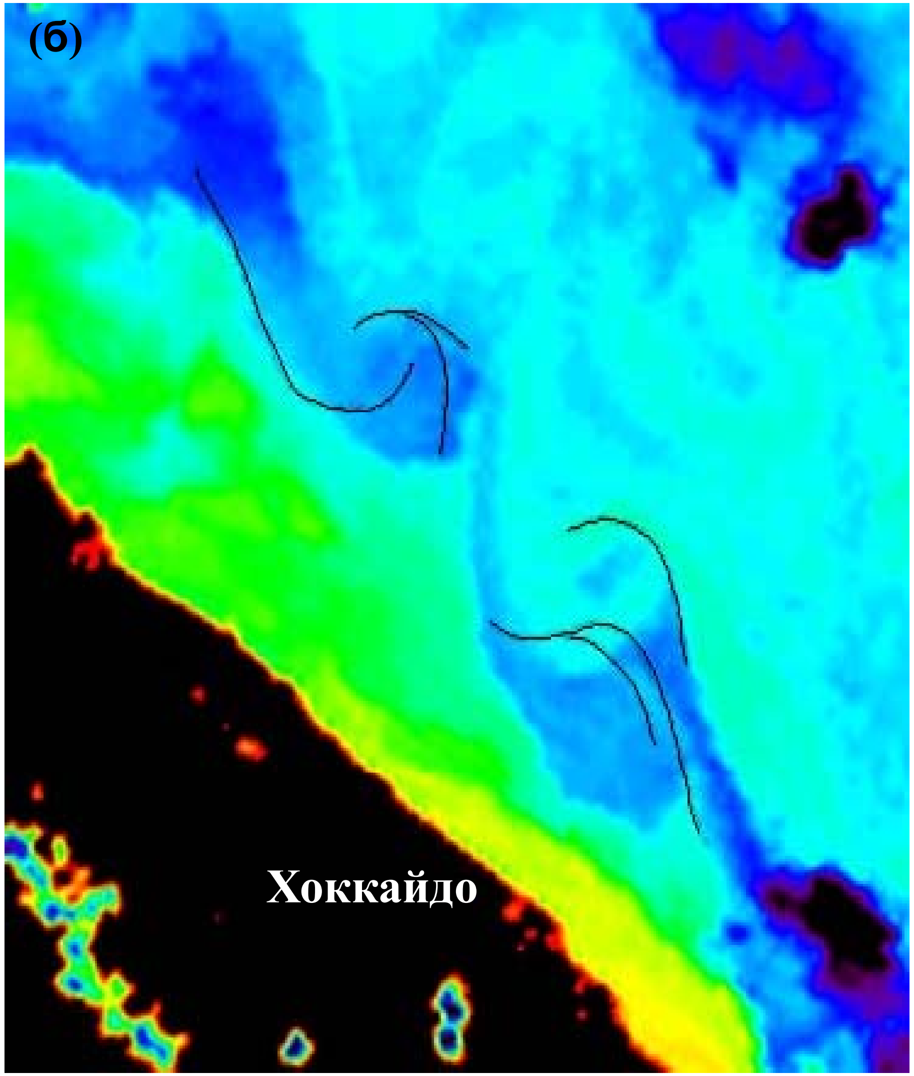
NOAA AVHRR за 06:14 Гр



NOAA AVHRR за 16:18 Гр

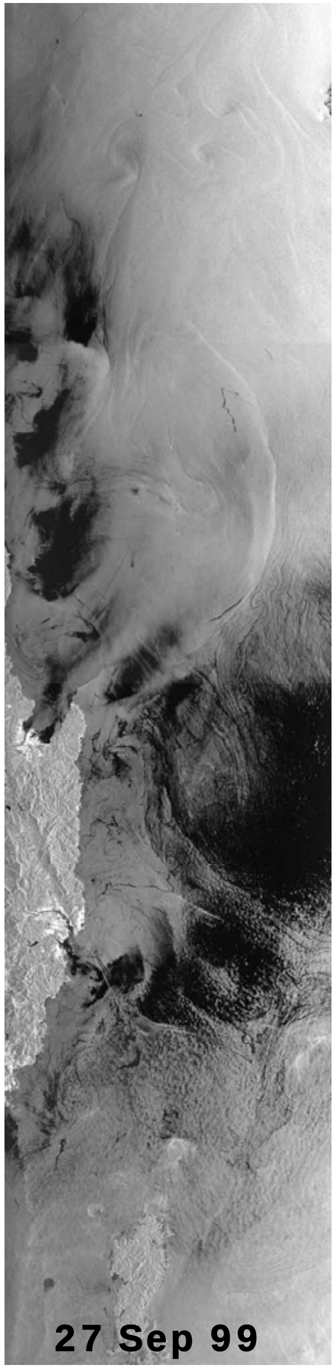
Soya Warm Current

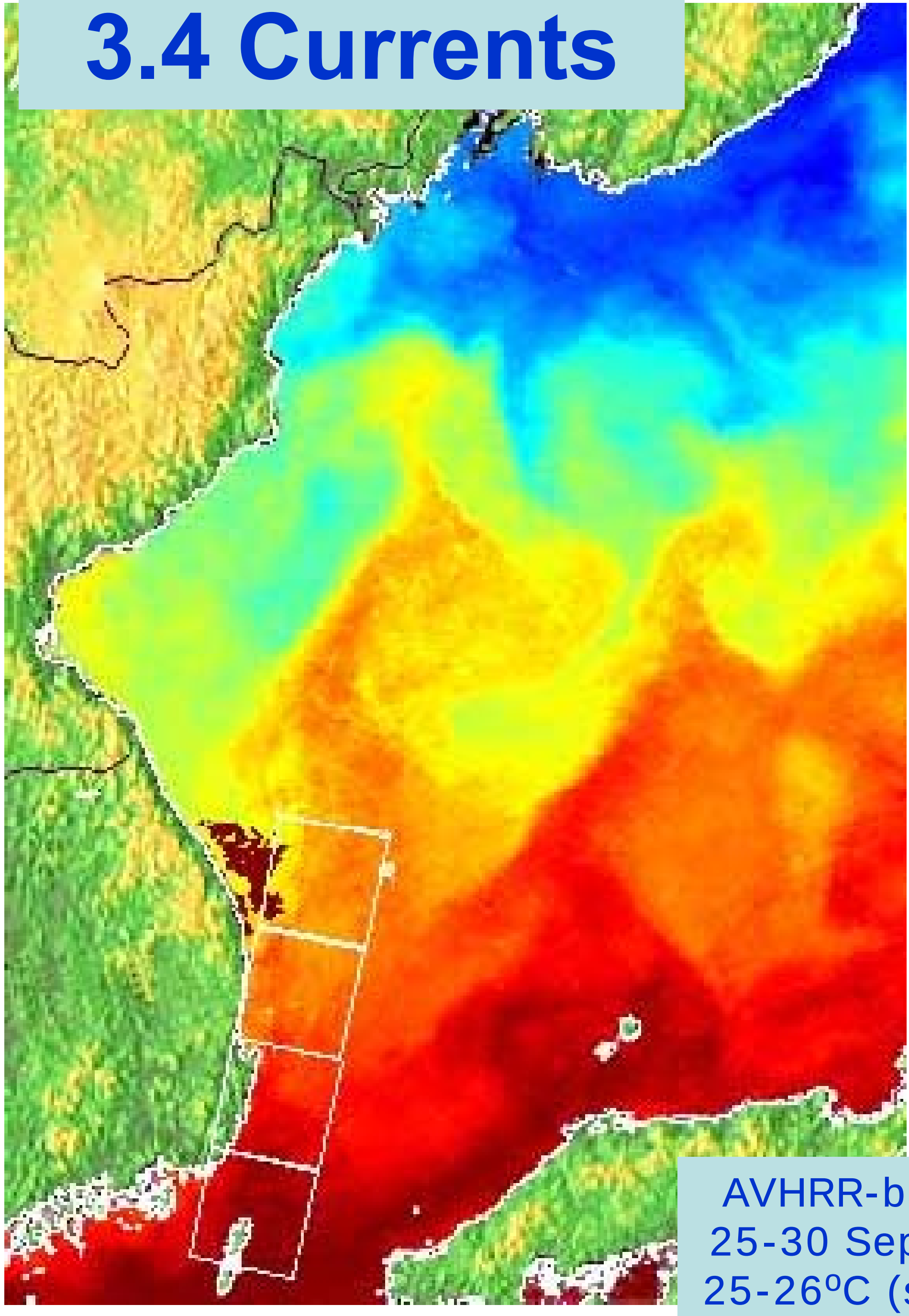




Radar and thermal contrasts in the Soya warm Current area as observed on 13 May 2002: (a) ERS-2 SAR image taken at 18 UTC and (б) NOAA AVHRR IR image taken at 03:50 UTC. Contours of SAR signatures are shown by dark lines.

3.4 Currents



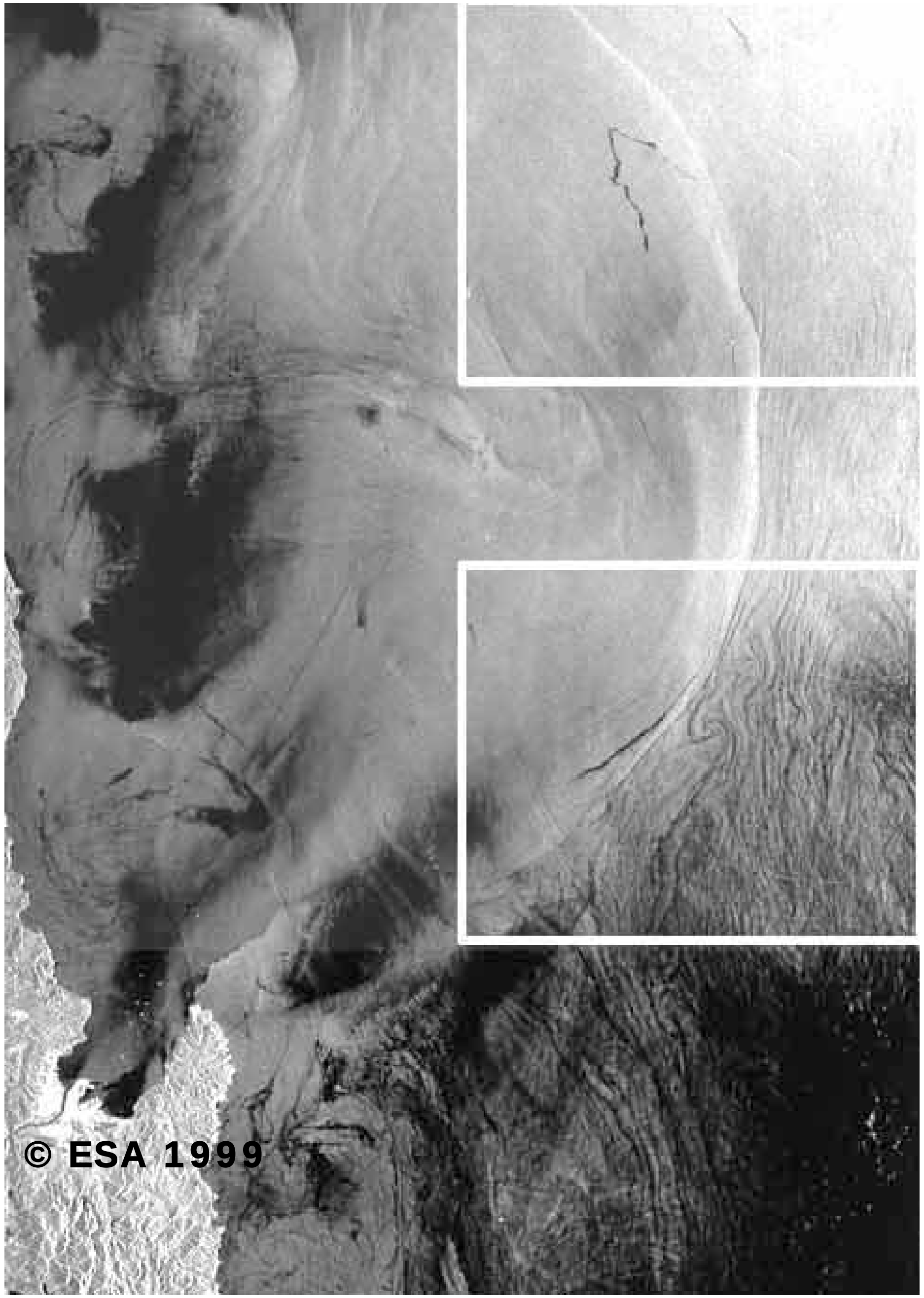


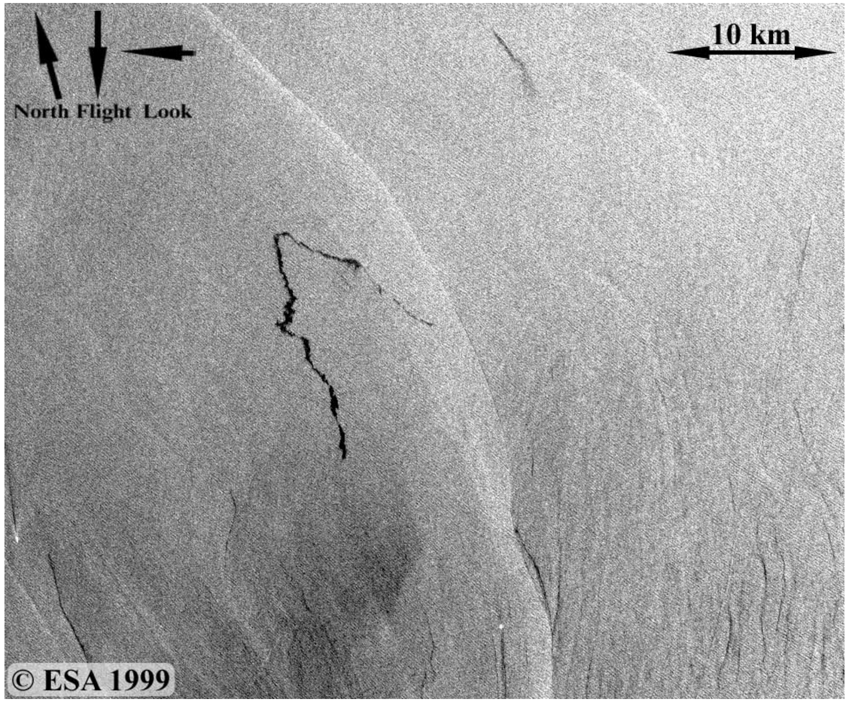
East Korean Warm Current

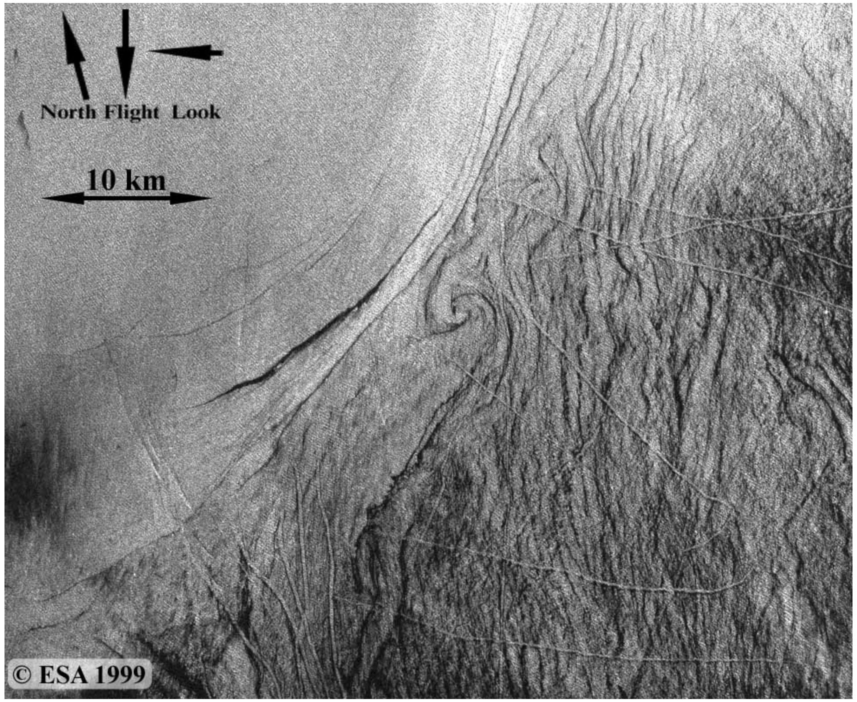
The EKWC flows to the north along the eastern coast of Korea. It is separated from the coast at 38-40°N and flows to the northeast where it meets the North Korean Cold Current and forms a subpolar front. AVHRR IR images revealed the currents, mesoscale eddies, streamers and other features of surface circulation.

AVHRR-based SST composition for 25-30 Sep 1999. SST changes from 25-26^{o}C (south) to 14-15^{o}C (north).

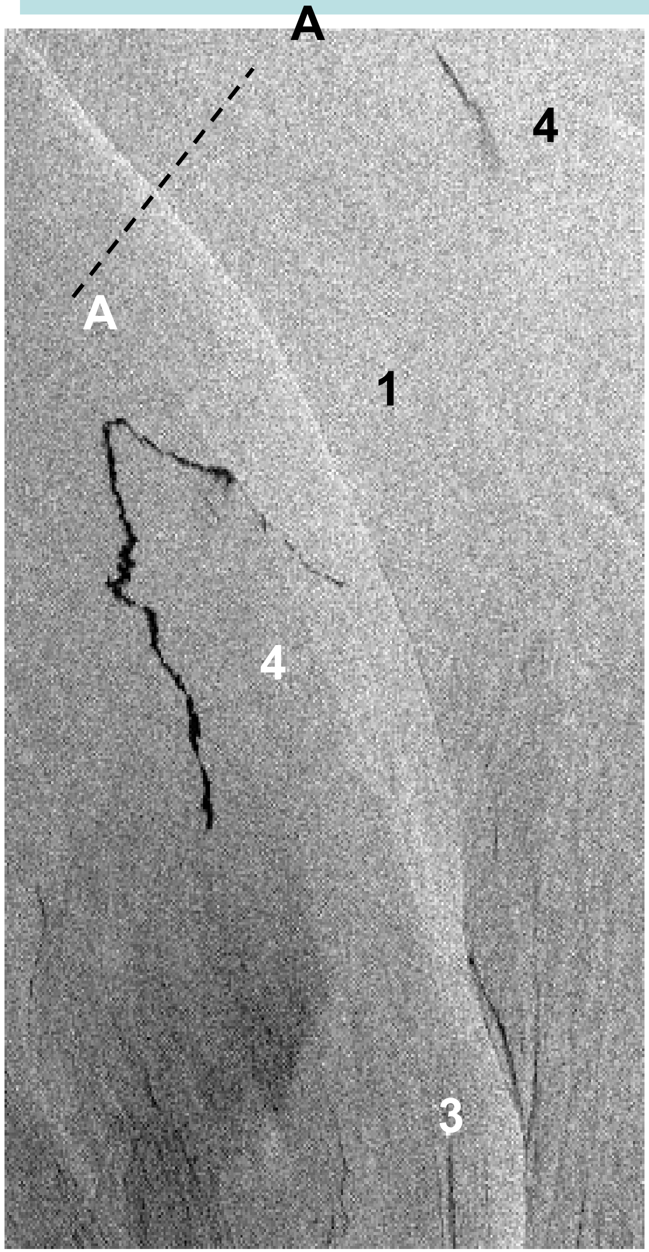
East Korean Warm Current

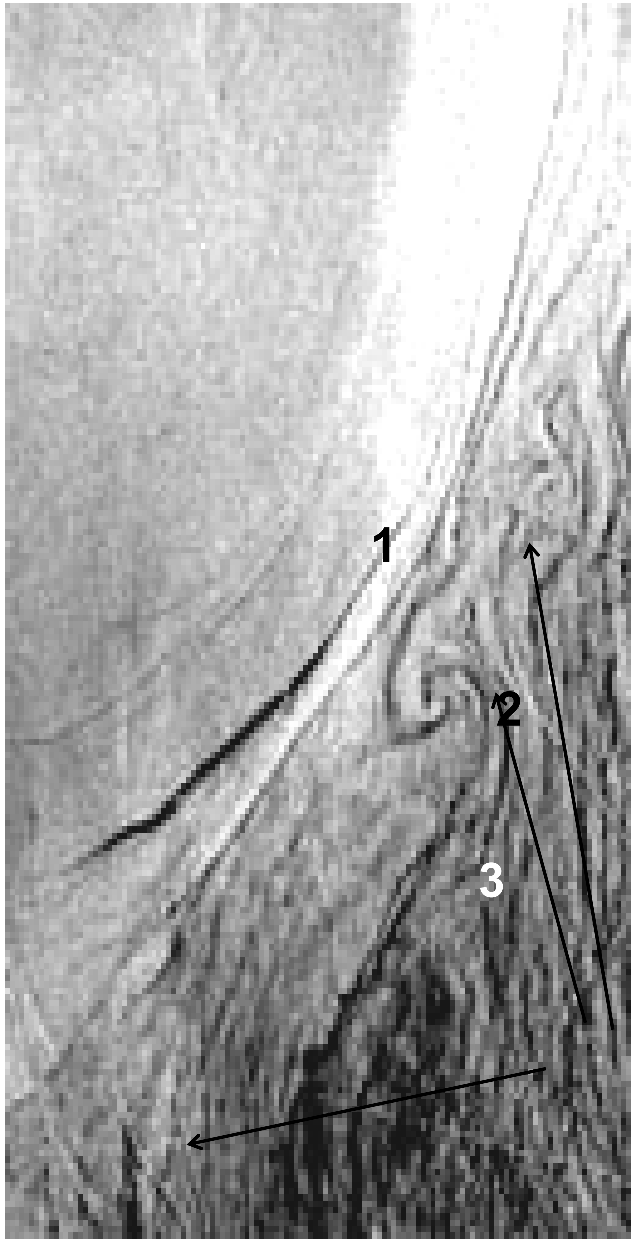






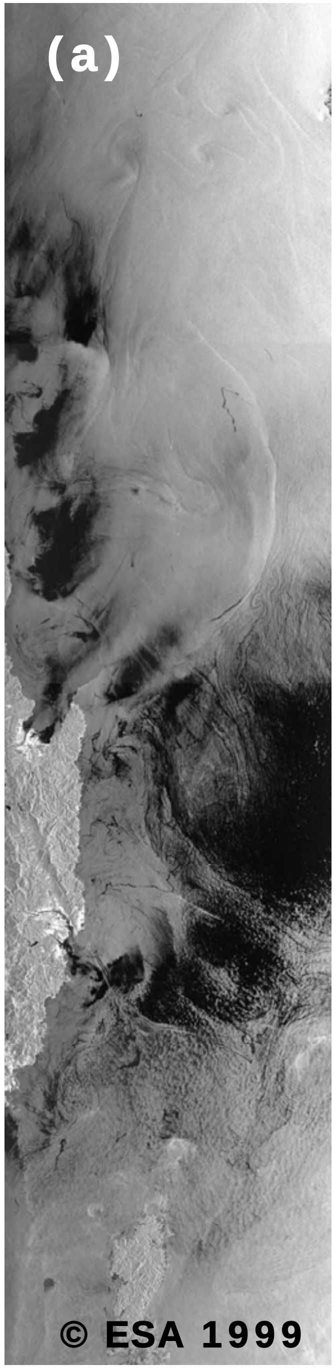
East Korean Warm Current

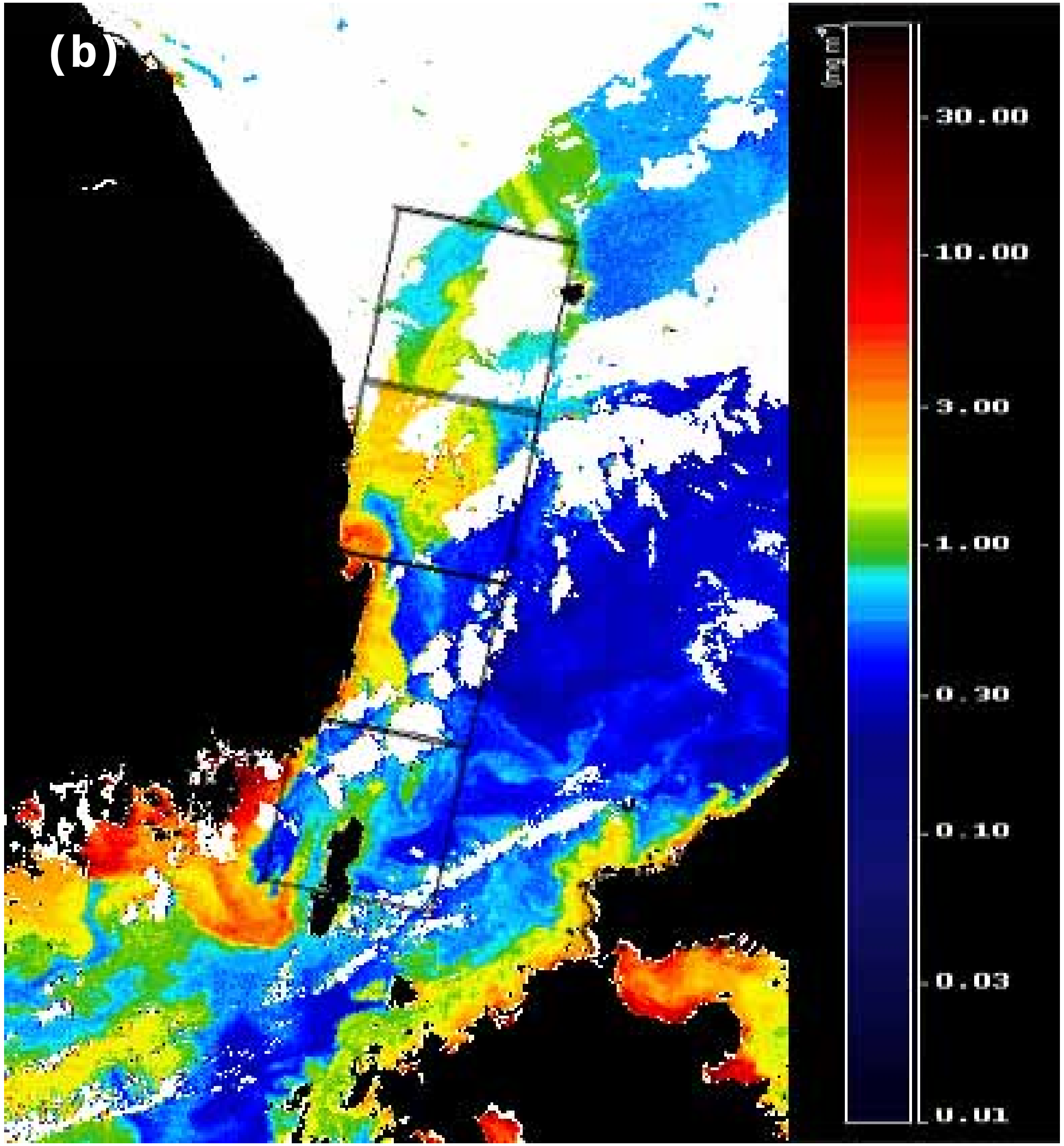




Fragments of ERS-2 SAR image (25x40 km) for 27 Sep 1999 at 02:02 UTC, showing the EKWC front (1), spiral eddies (2), ships (bright dots), ship wakes (3), filamentary slicks and oil slicks (4).

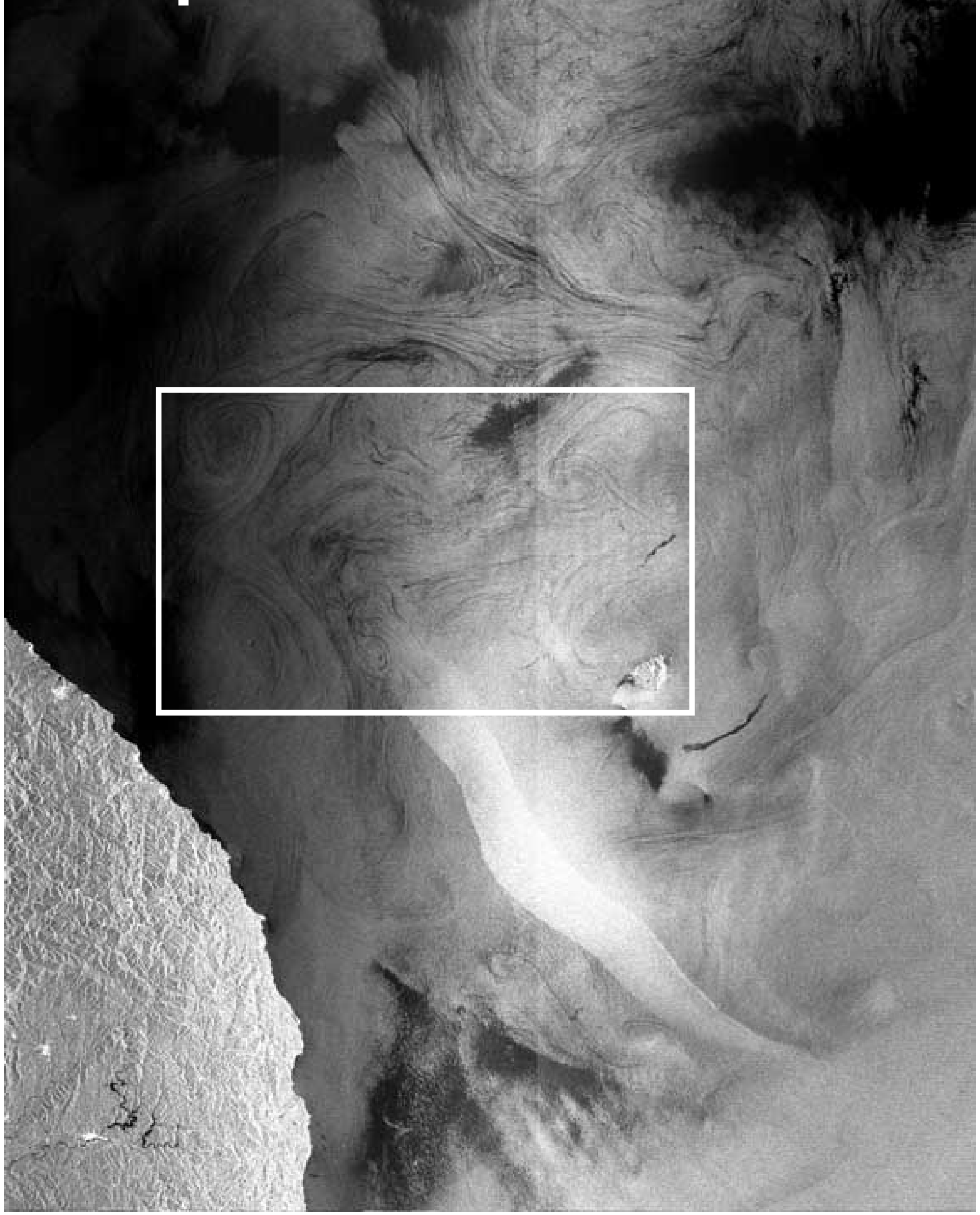
East Korean Warm Current

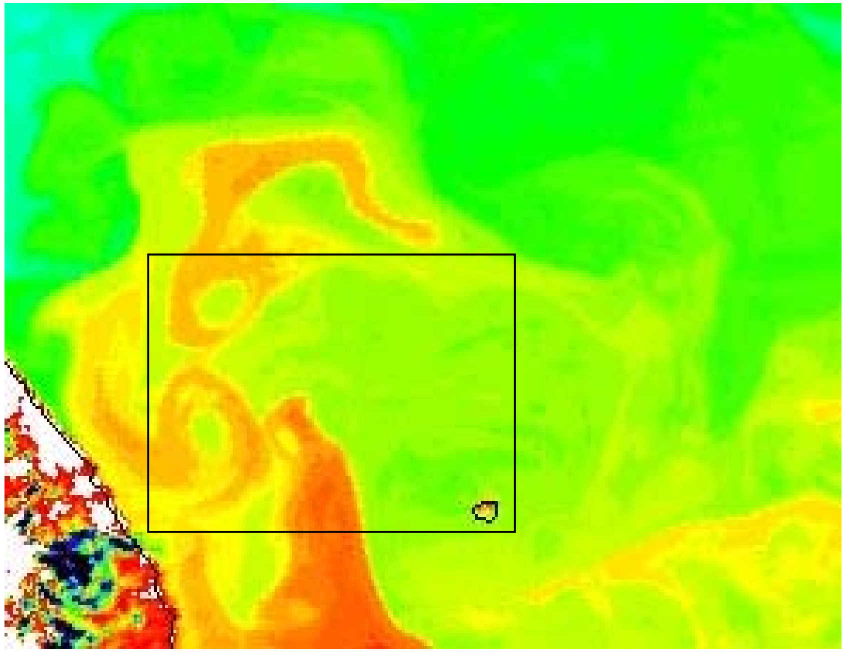


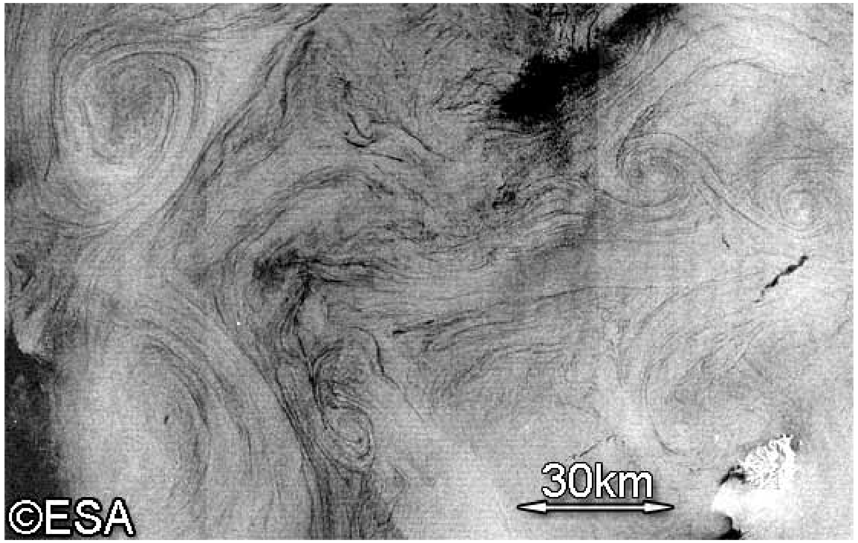


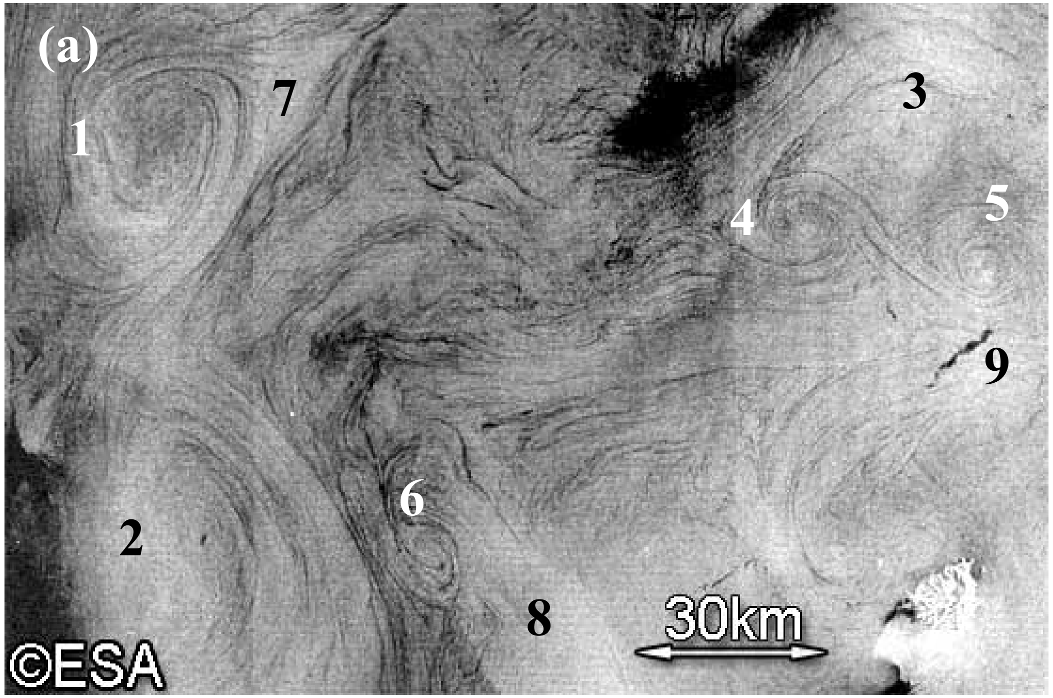
ERS-2 SAR image(a) and SeaWiFs-derived chl-*a* content taken on 27 Sep 1999 (b)

14 Apr 2004. Envisat ASAR and NOAA AVHRR

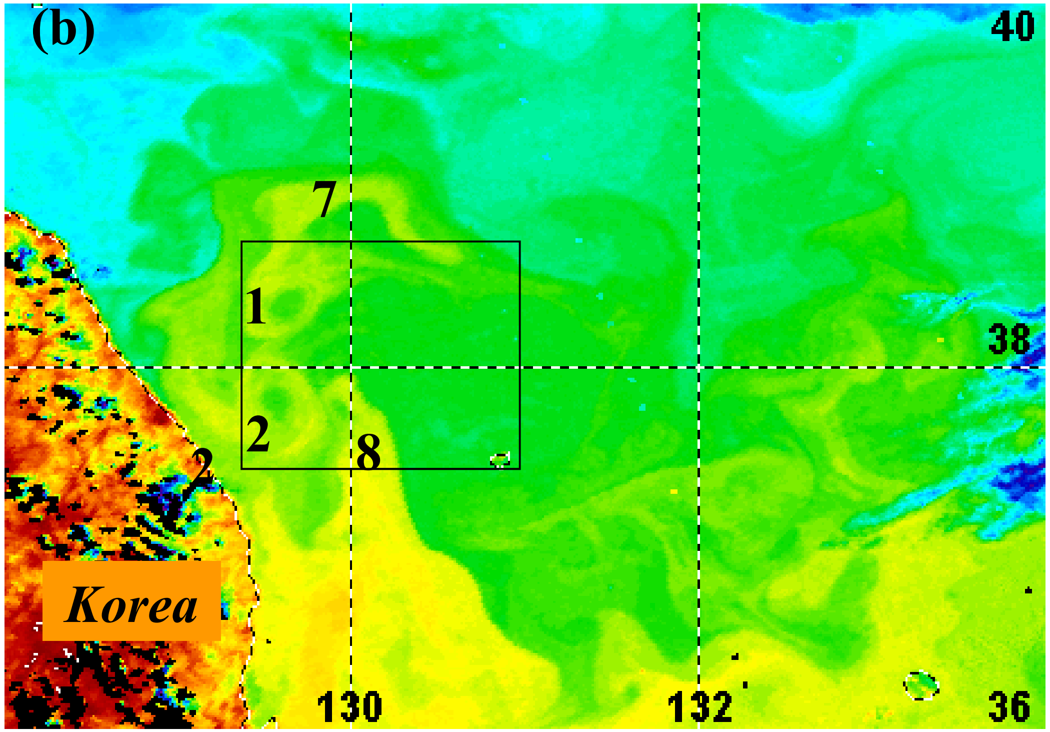




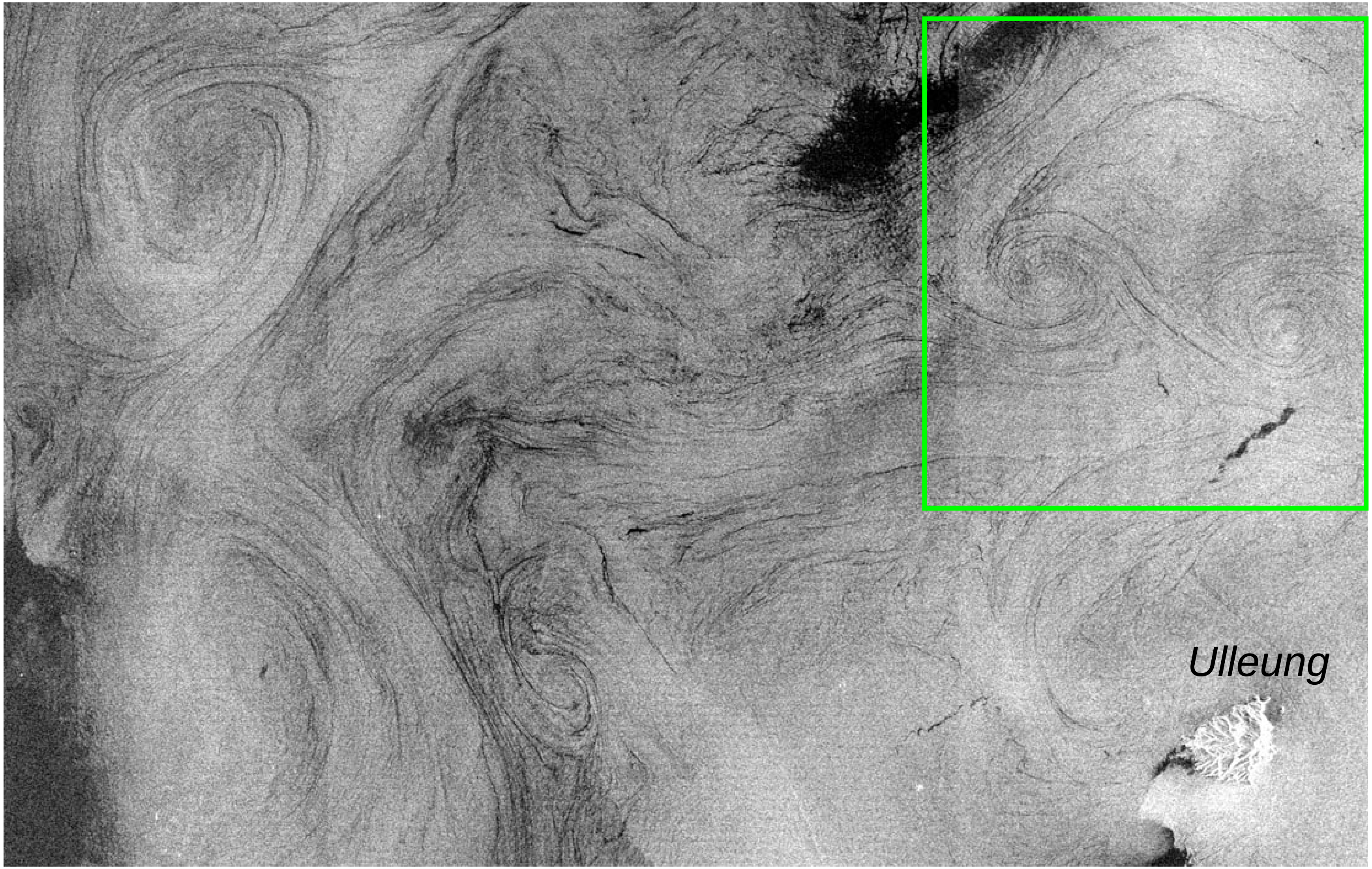




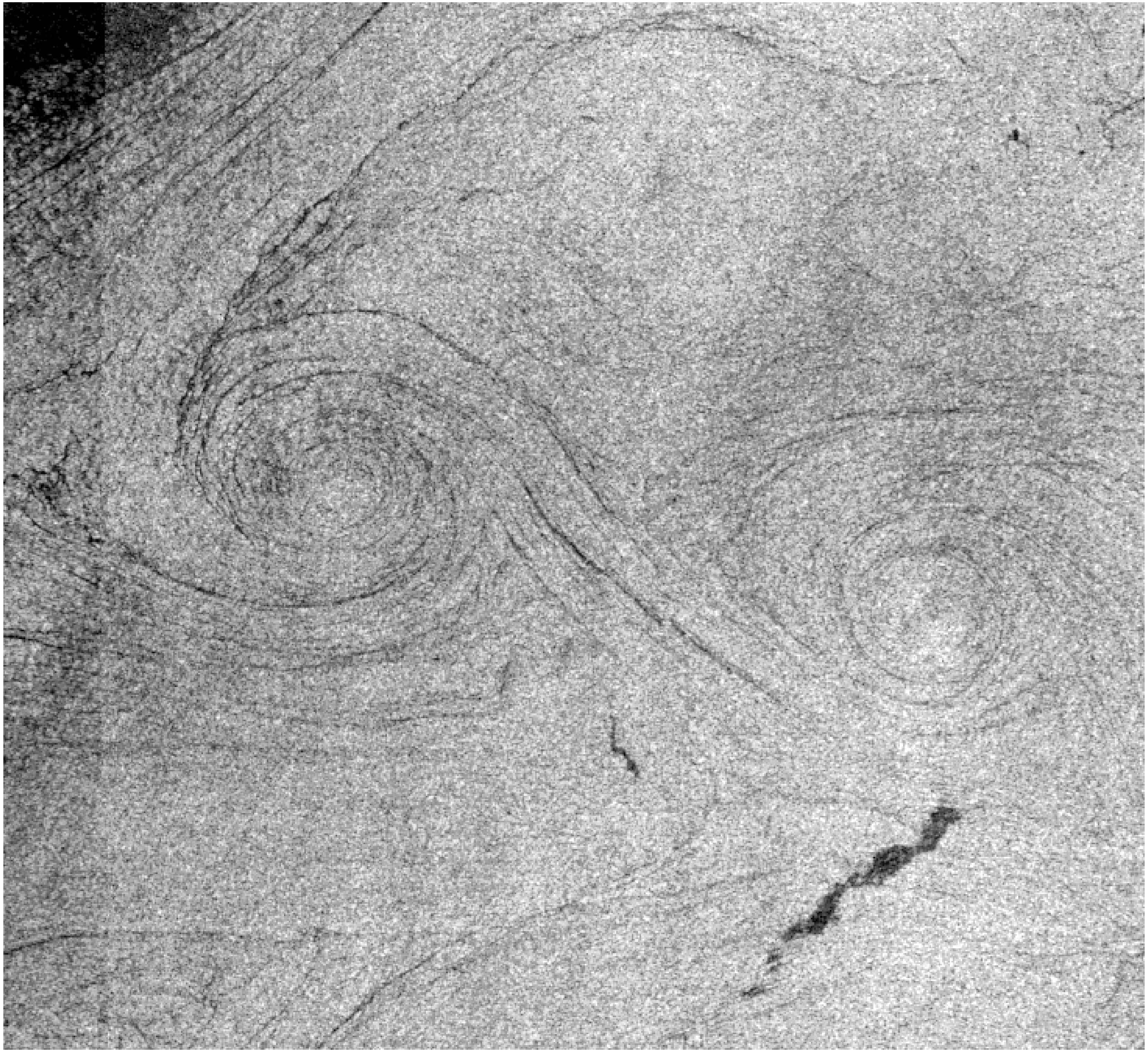
14 April 2004



Envisat ASAR (a) and NOAA AVHRR IR (b) images taken at 01:28 UTC (a) and at 15:20 UTC showing the mesoscale cyclonic eddies 1-6, warm water flows 7 and 8 and oil pollution 9.

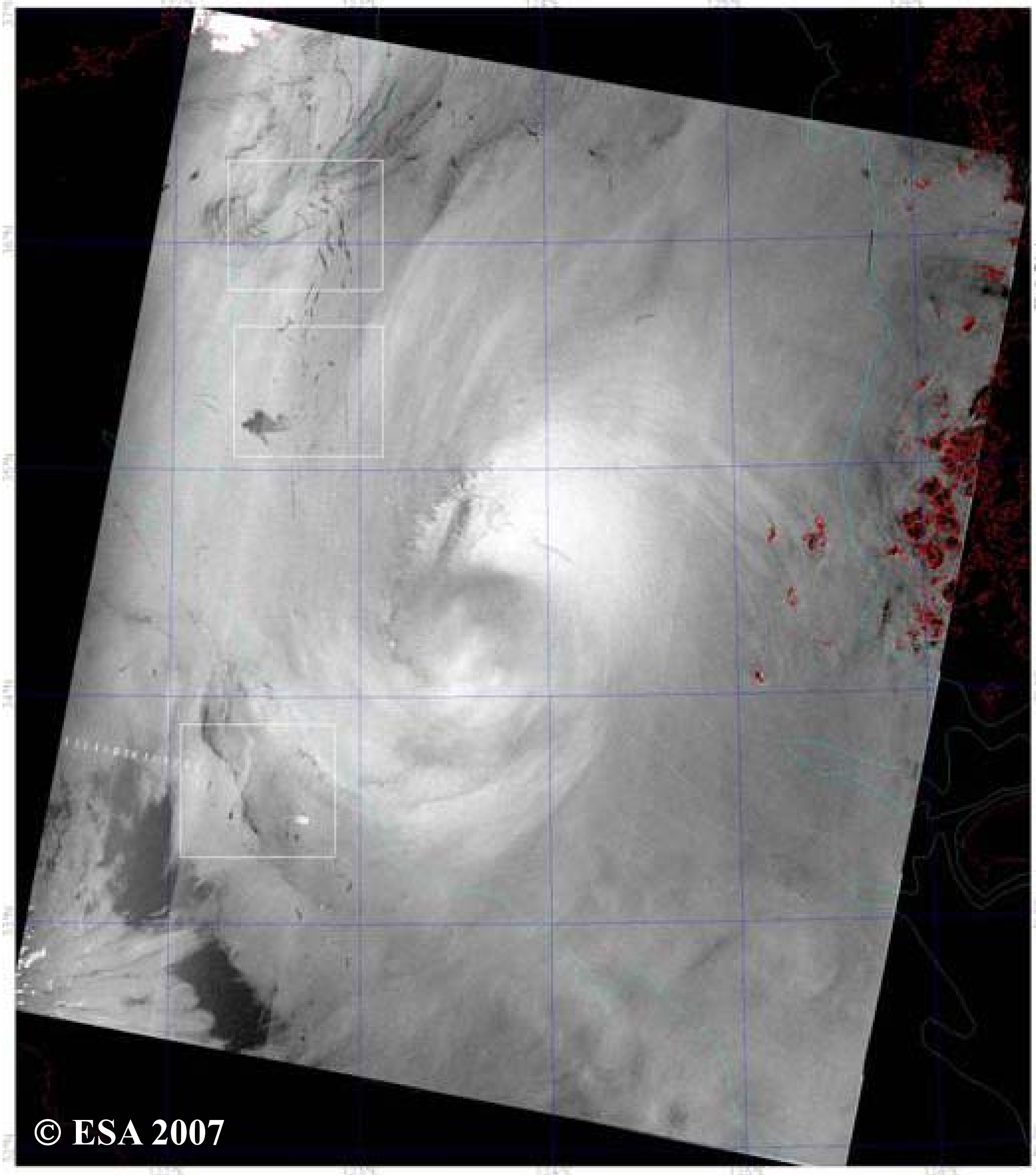


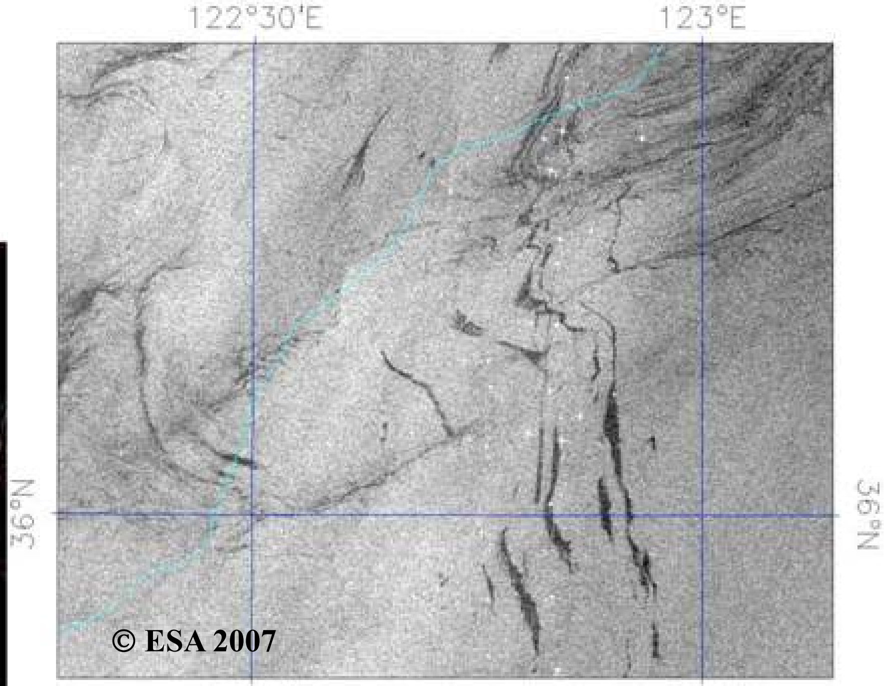
Filamentary slicks visualize the eddies of various scales.

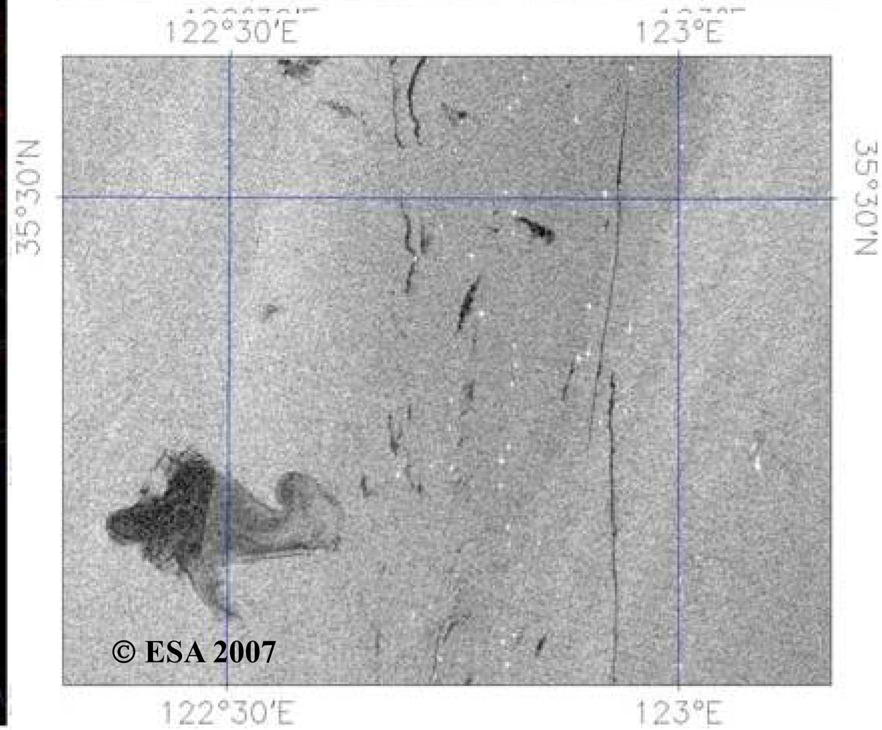


Spiral eddies and oil pollution

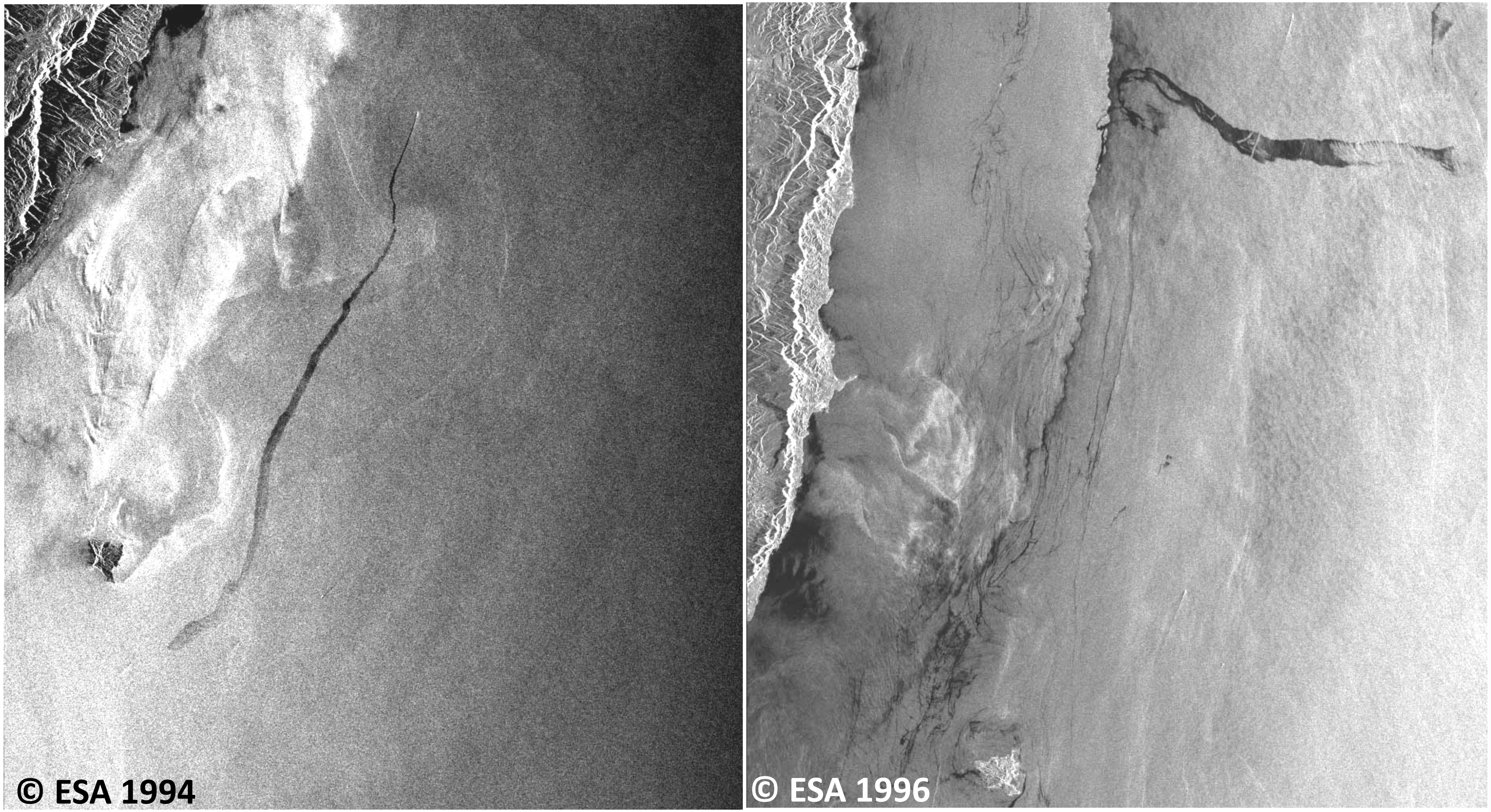
Yellow Sea.
15 Aug 2007, 01:41 UTC





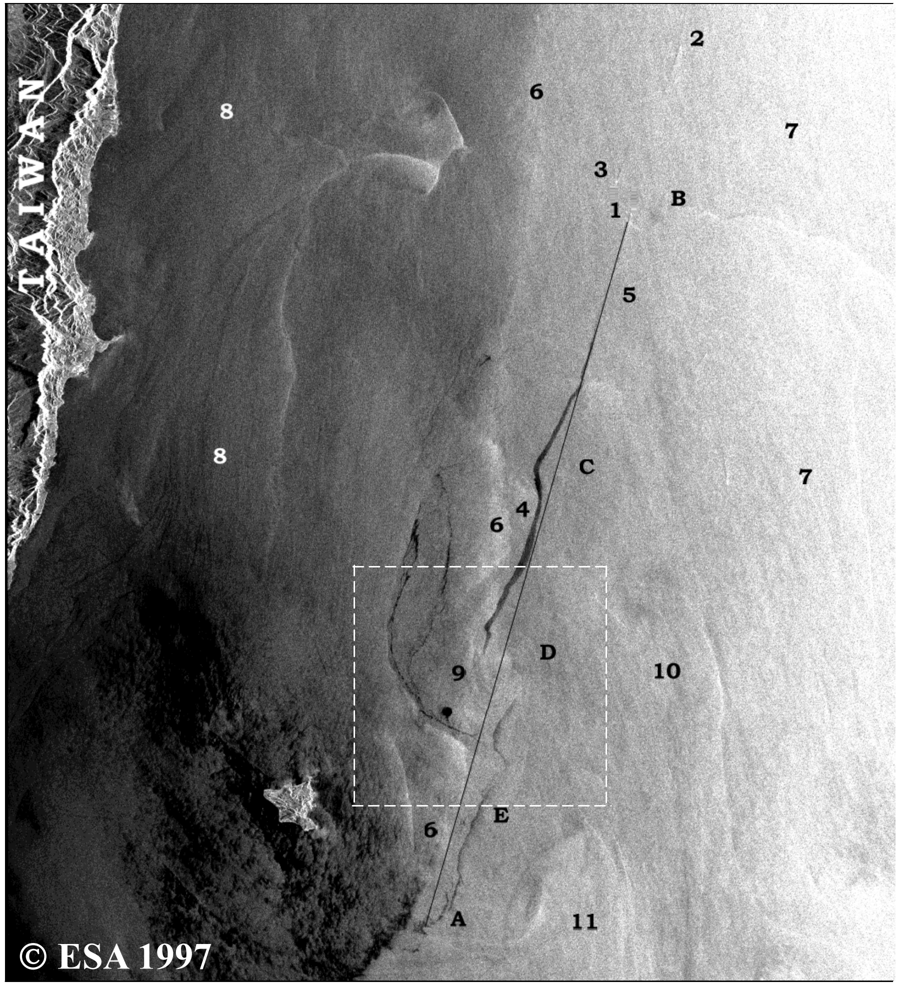


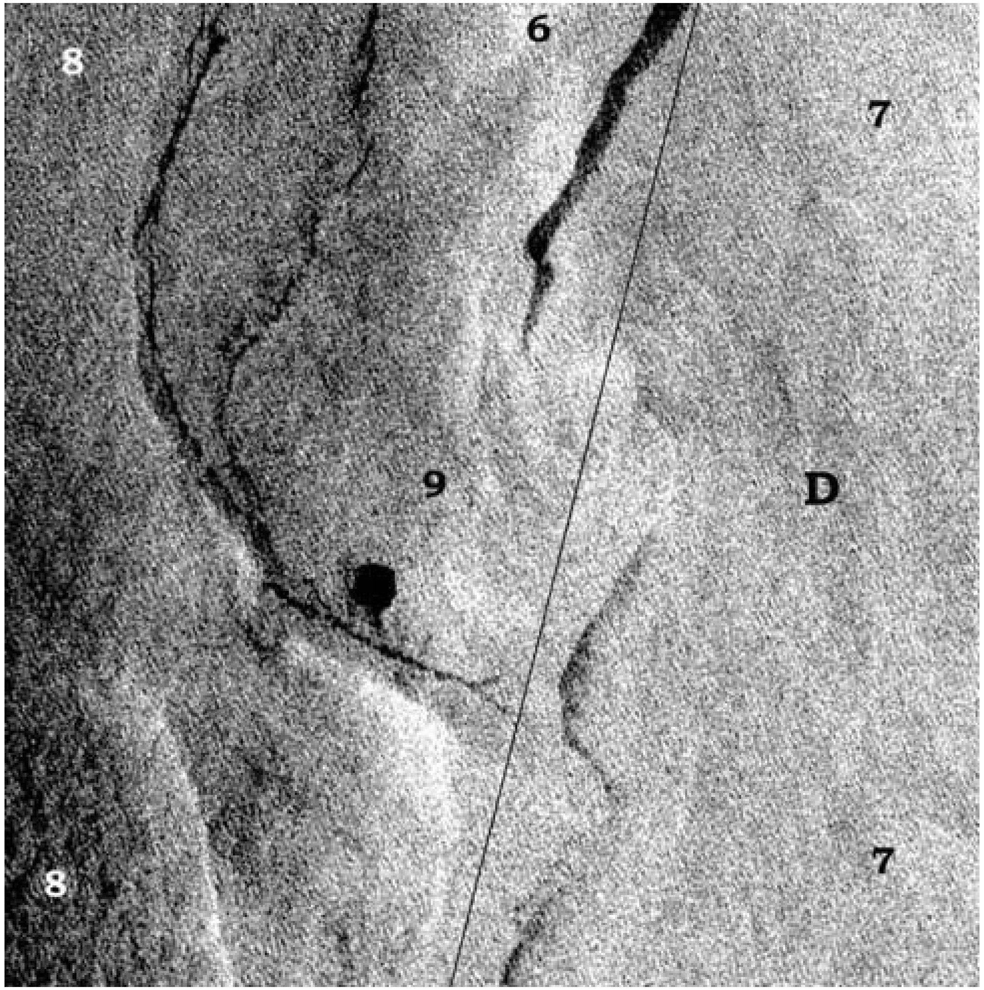
Transformation of oil spills in Kuroshio Current frontal zone east off Taiwan on:
ERS-1 SAR images taken on 20 May 1994 (left) and 7 April 1996 (right)



Mitnik L., Chen K.-S., Wang C.-T. (2006). Reconstruction of surface currents from ERS SAR images of oil-tank cleaning slicks. P. 315-336 in: *Marine Surface Films. Physico-Chemical Characteristics, Influence on Air-Sea Interactions, and Remote Sensing.* M.Gade and H. Hühnerfuss (eds). Universität Hamburg, Germany, Springer.

Oil pollution. Kuroshio east of Taiwan



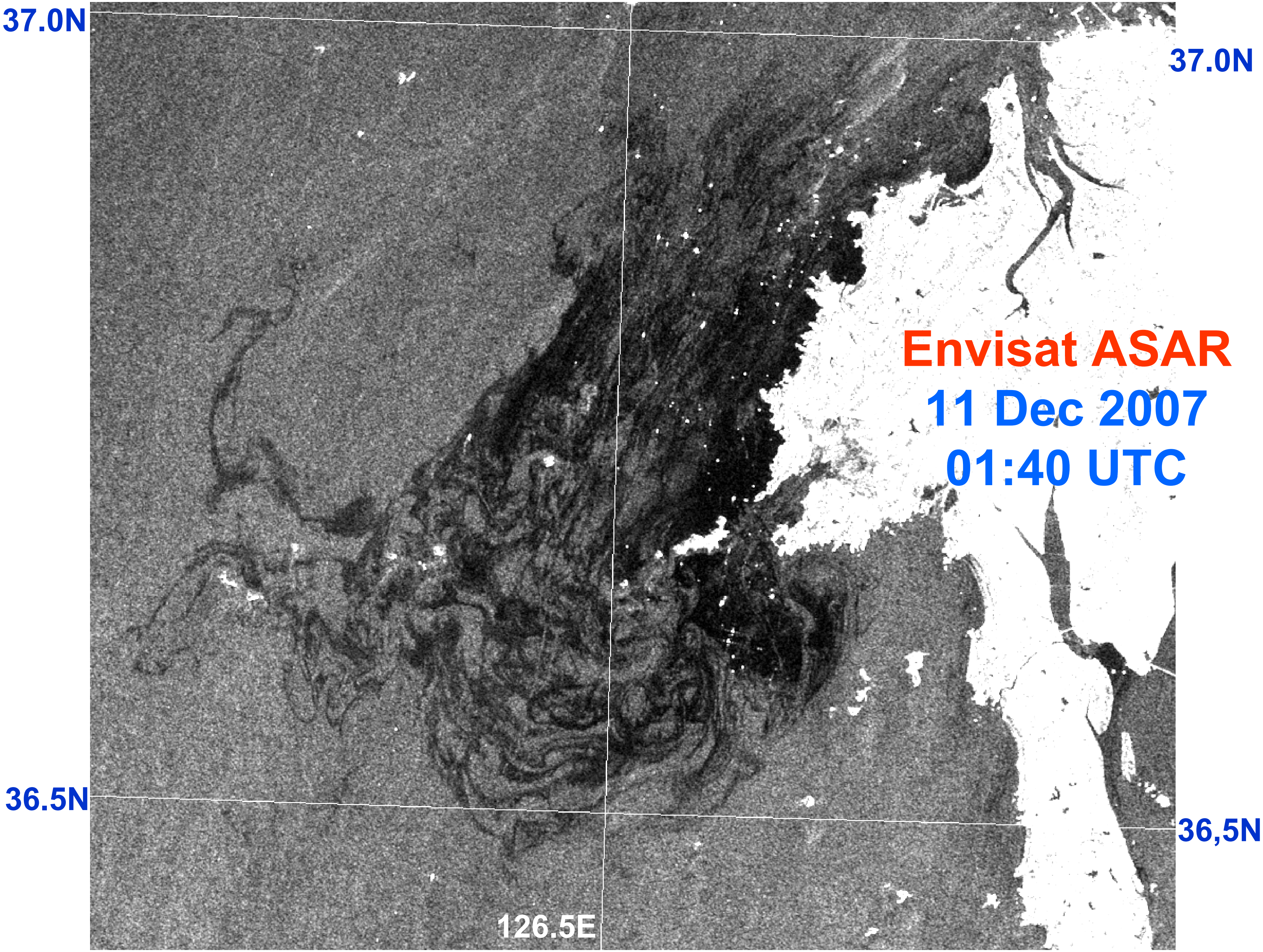


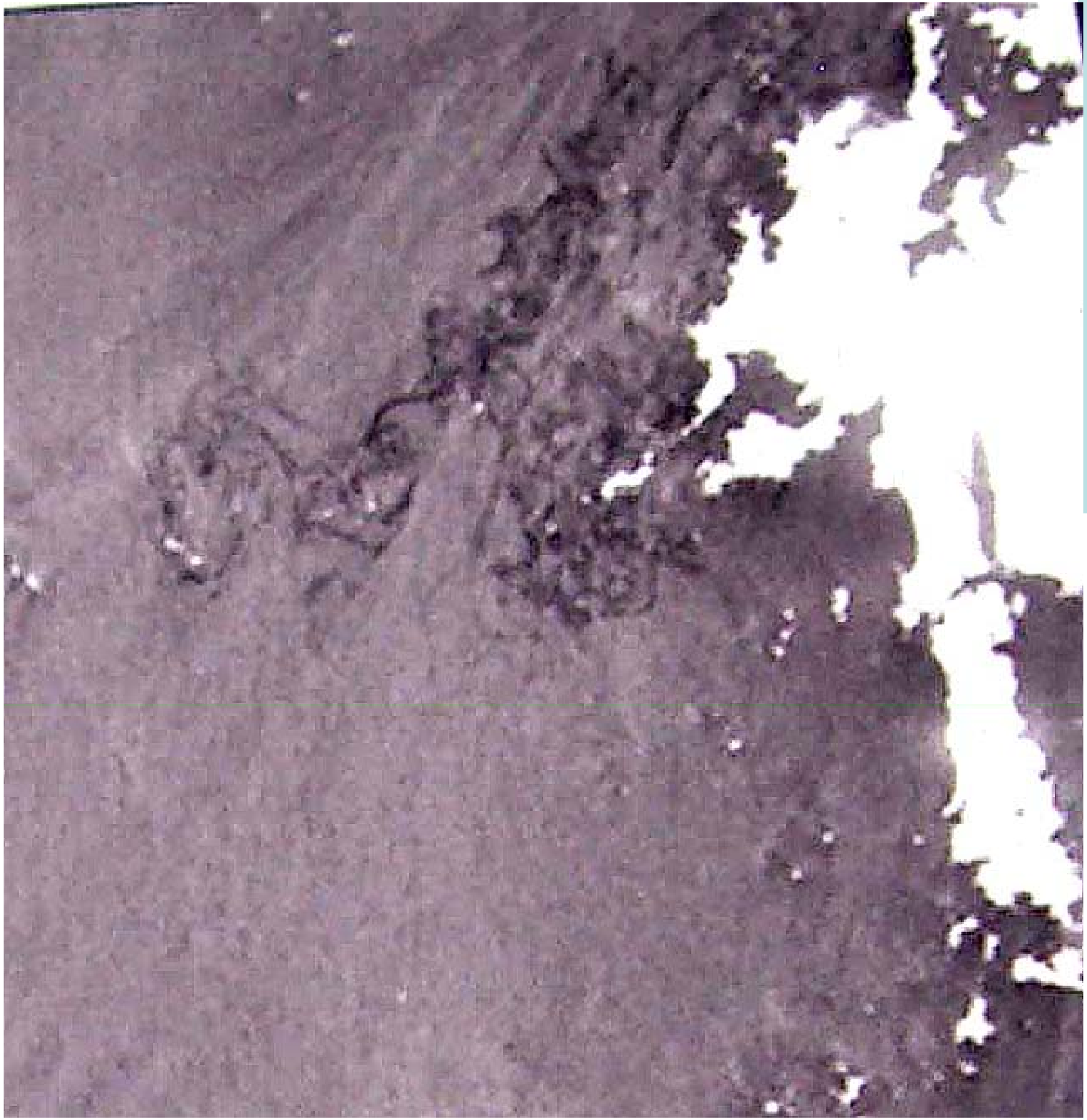
ERS-1 SAR. 29 December 1997

Mitnik L., K.-S. Chen, C.-T. Wang Reconstruction of surface currents from ERS SAR images of oil-tank cleaning slicks. P. 315-336 in: *Marine Surface Films. Physico-Chemical Characteristics, Influence on Air-Sea Interactions, and Remote Sensing*, M.Gade and H. Hühnerfuss, Eds. Universität Hamburg, Germany, Springer, 2006.

7 December 2007

The oil spill incident occurred about 6 miles off the Taean coastal area (36° 56.00´N, 126° 02.09´E) due to the collision of an oil tanker, the Hebei Spirit, with a towed barge, the Samsung 1, at 7:15 AM on *7 December 2007*. As on *9 December*, about 20 km of Taean coast (with 10 – 30 m width) has been blackened by the spilled oil. It was reported that fishing ground (2,100 ha) and 6 beaches (221 ha) were also polluted. The thin oil slicks are also spreading on sea surface to south, about 25 nm long and 1 nm width.


37.0N
37.0N
Envisat ASAR
11 Dec 2007
01:40 UTC
36.5N
36,5N
126.5E



RADARSAT

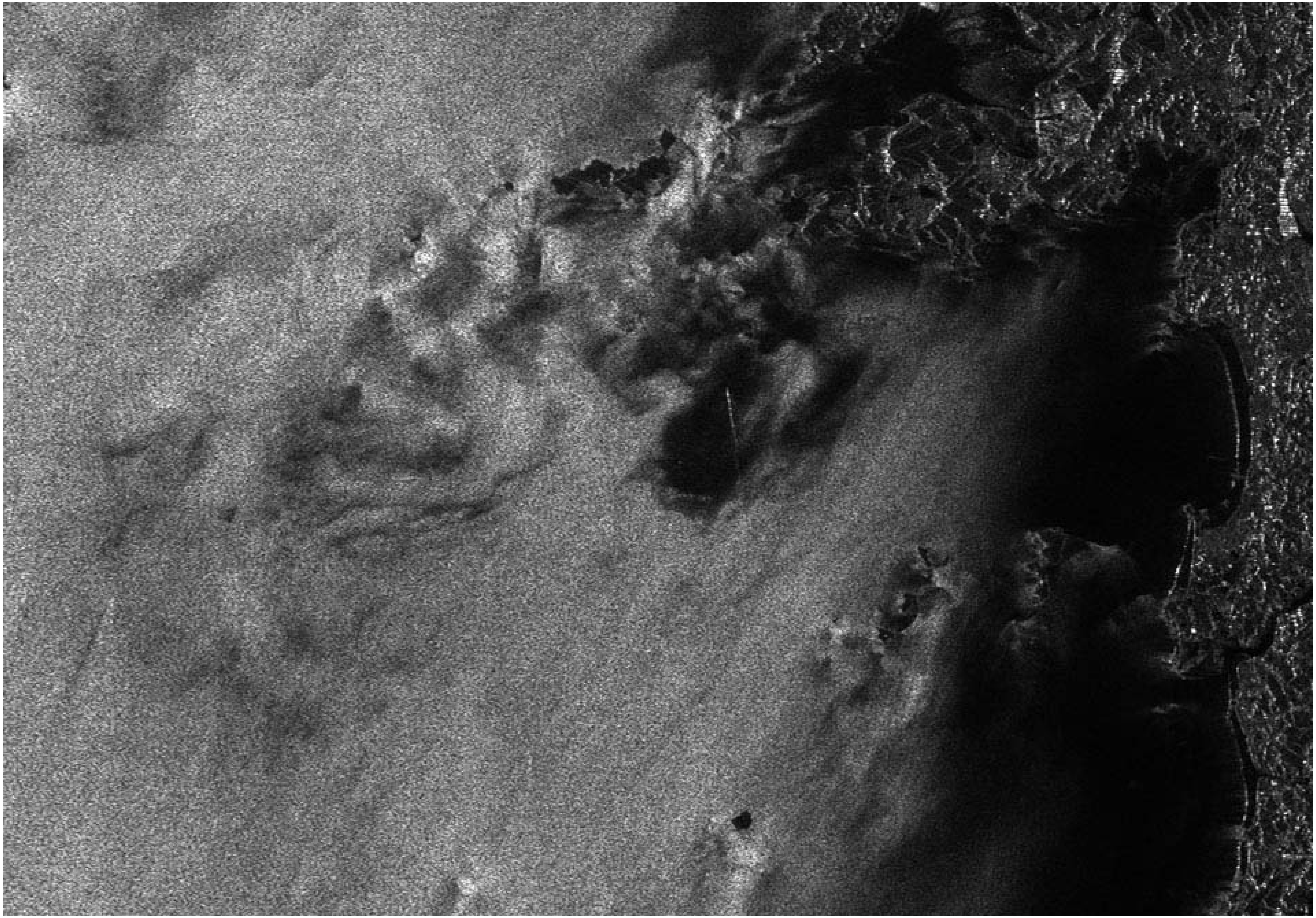
11 Dec 2007

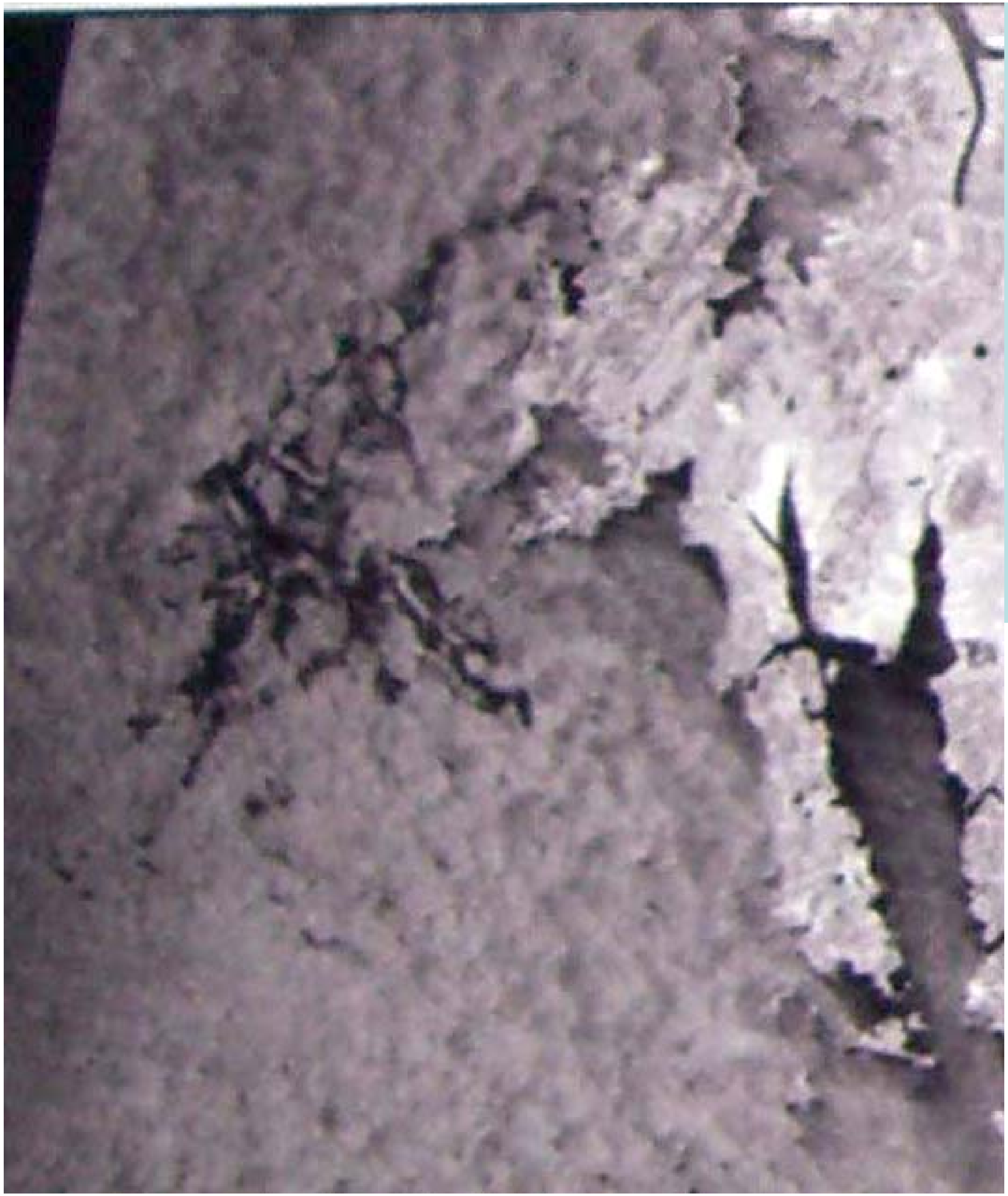
at 09:31 UTC

HH-pol

S = 700 km^2

ALOS PALSAR 11 Dec 2007at 13:46 UTC VV-pol





TerraSAR-X

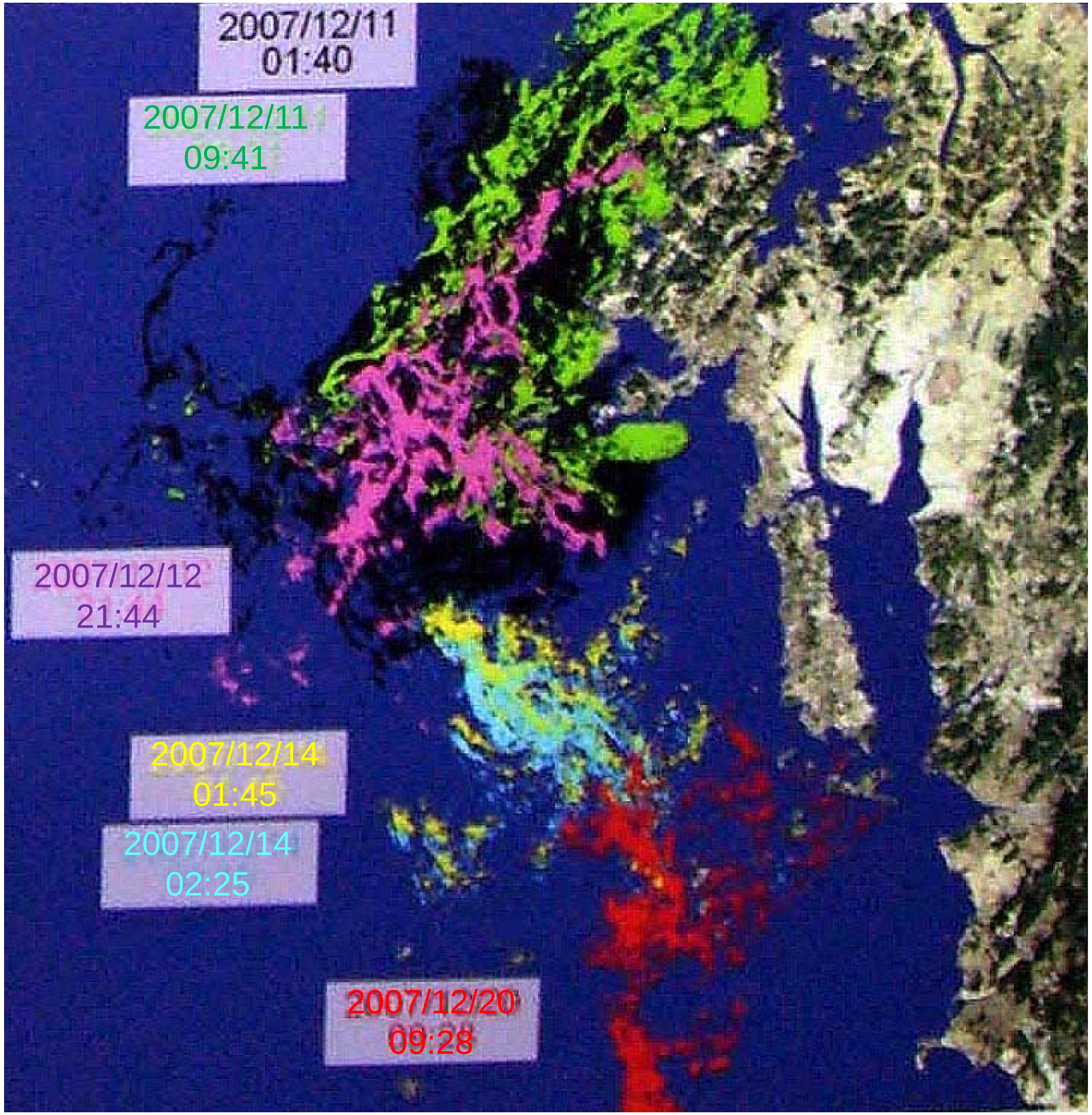
12 Dec 2007

at 14:43 UTC

VV-pol

S = 400 km^2

Satellite SAR observations of oil spill on the west coast of Korea



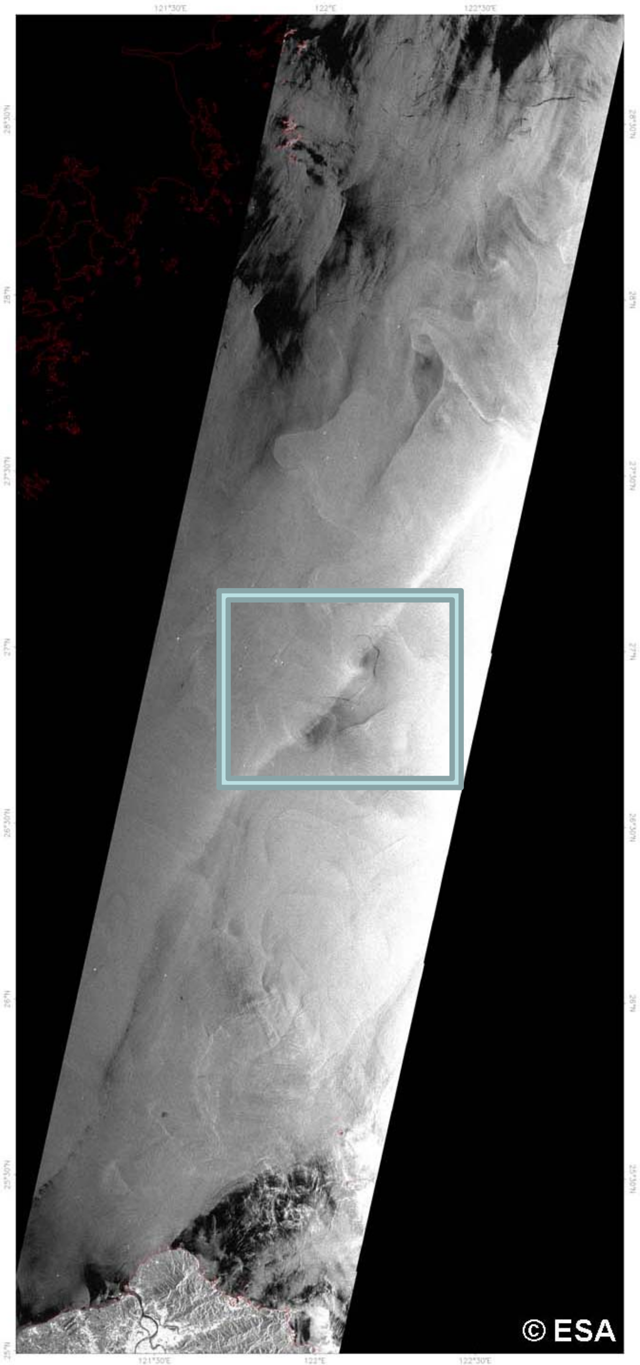
Duk-jin Kim, Jinho Kang, Boyeol Yoon, Younsoo Kim and Yongseung Kim. Observation of crude oil spill off the west coast of Korea using TeraSAR-X, Envisat, ERS-2, RADARSAT-1, and ALOS. *IGARSS'08. Boston, 6-11 July 2008.* Remote sensing Division, Satellite Information Research Institute, Korea Aerospace Research Institute

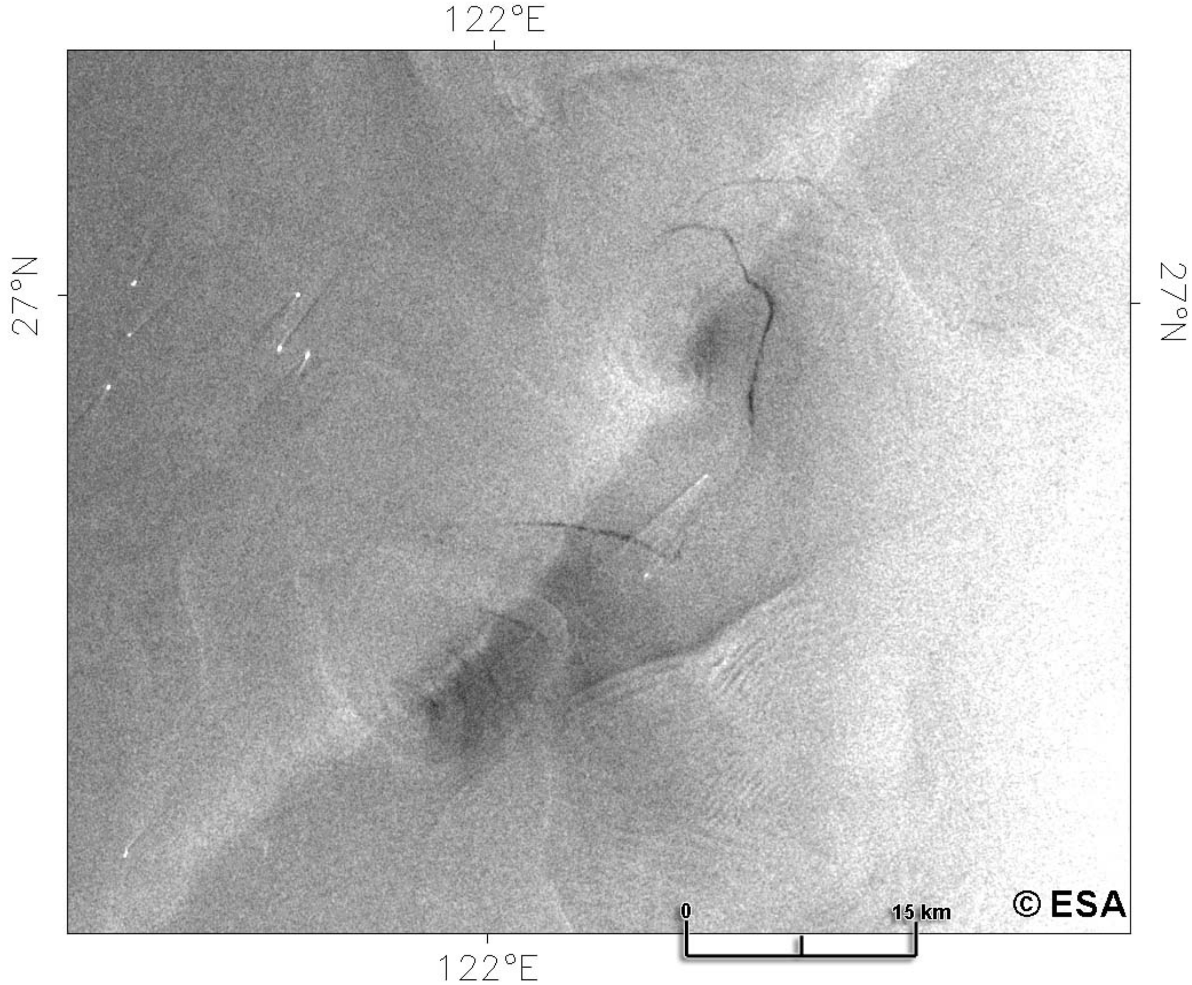
Satellite SAR observations of oil spill on the west coast of Korea

Date	9 Dec 14:03	11 Dec 01:40	11 Dec 09:31	11 Dec 13:46	12 Dec 21:44	14 Dec 01:40	14 Dec 02:15	20 Dec 09:28
Satellite	ALOS	Envisat	RADAR-SAT	ALOS	Terra SAR-X	Envisat	ERS-2	Terra SAR-X
Wavelength, cm polarization	23.5	5.6 HH	5.6 HH	5.6 HH, VV, HV, VH	3.15 VV	5.6 HH	5.6	3.15 VV
Wind speed, m/s direction		5.3 10°	5.9 13°		6.1 328°	6.6 347	6.6 345	5.1 349
Damping ratio, dB		6.9	4.5		7.1	2.2	3.4	3.3
Oil spill area, km^2		1300 (R) 1400 (K) 1555 (C)			400 (K) 550 (C)	350 (K) 332 (C)	340 (K) 420 (R)	>410

The first Envisat ASAR image was acquired on 10 December, however, it covers only a part of oil spill area.

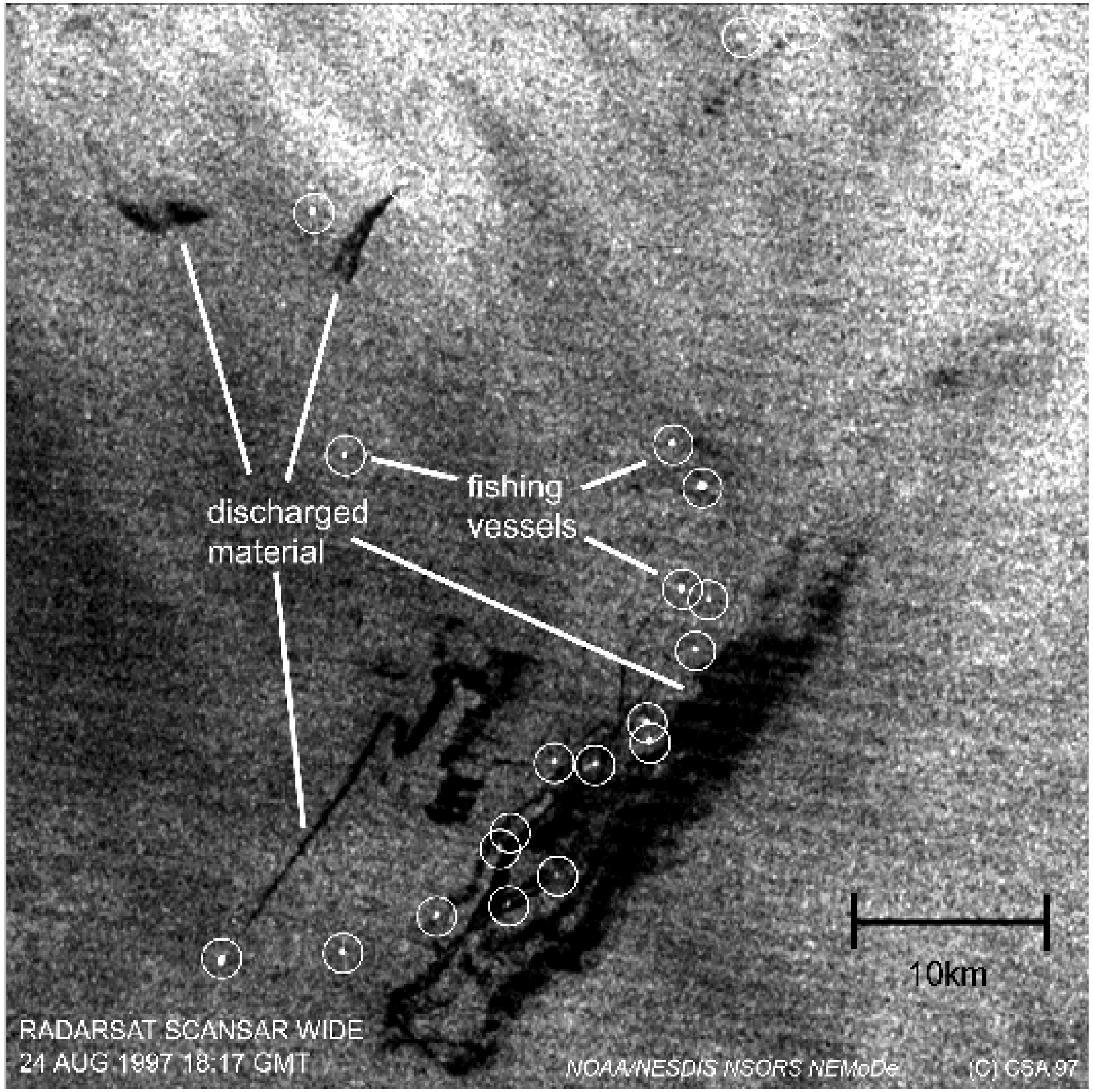
Duk-jin Kim, Jinho Kang, Boyeol Yoon, Younsoo Kim and Yongseung Kim. Observation of crude oil spill off the west coast of Korea using TeraSAR-X, Envisat, ERS-2, RADARSAT-1, and ALOS. *IGARSS'08. Boston, 6-11 July 2008.* Remote sensing Division, Satellite Information Research Institute, Korea Aerospace Research Institute





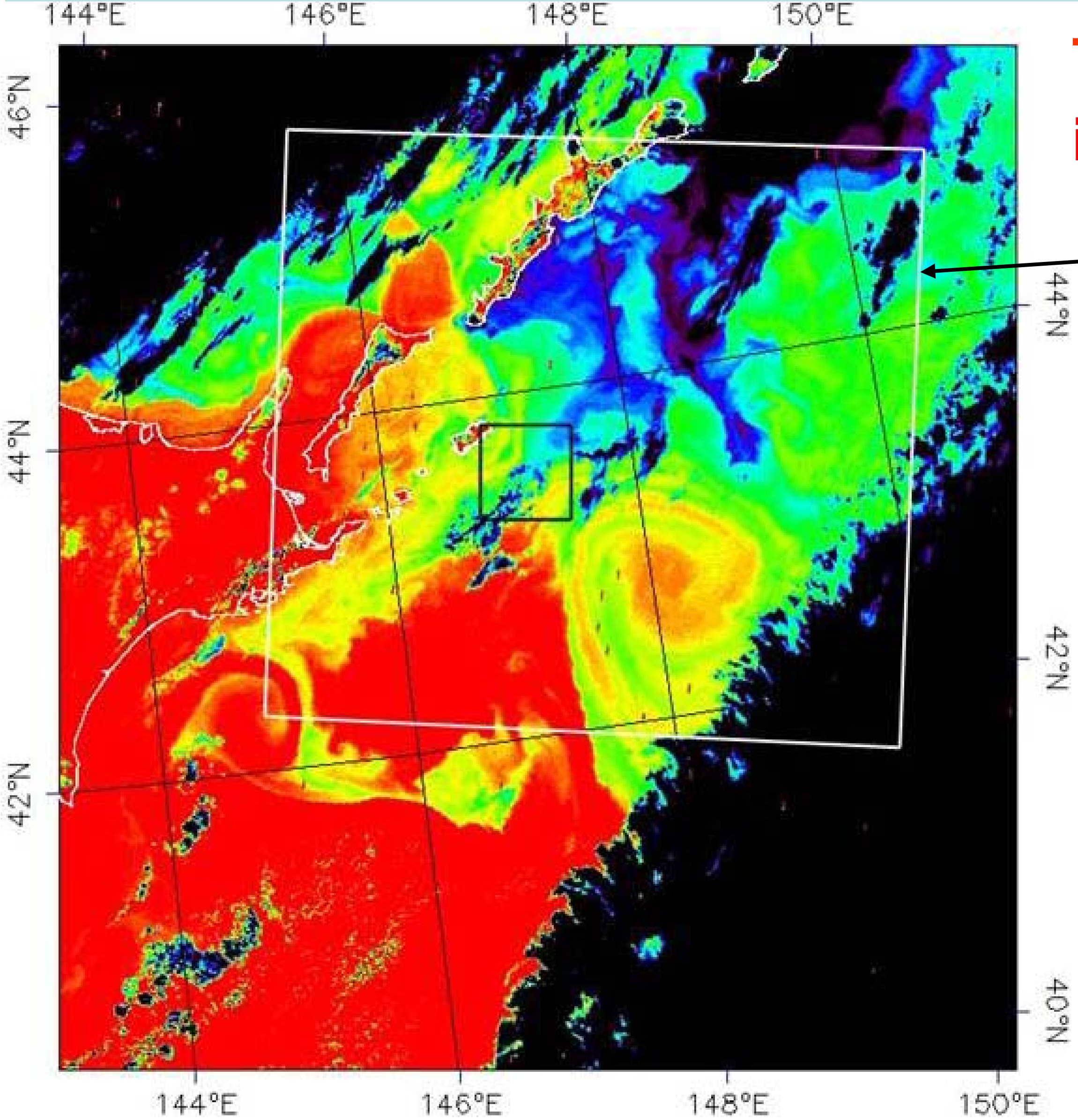
Envisat ASAR image acquired on 20 December 2008 at 01:57 UTC

Oil Release During Fish Processing



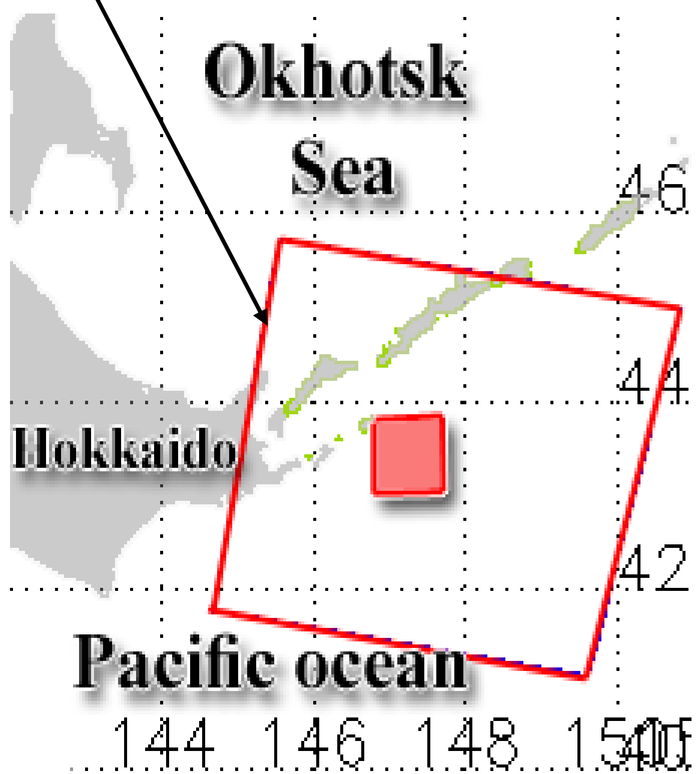
Bering Sea walleye pollock fishery

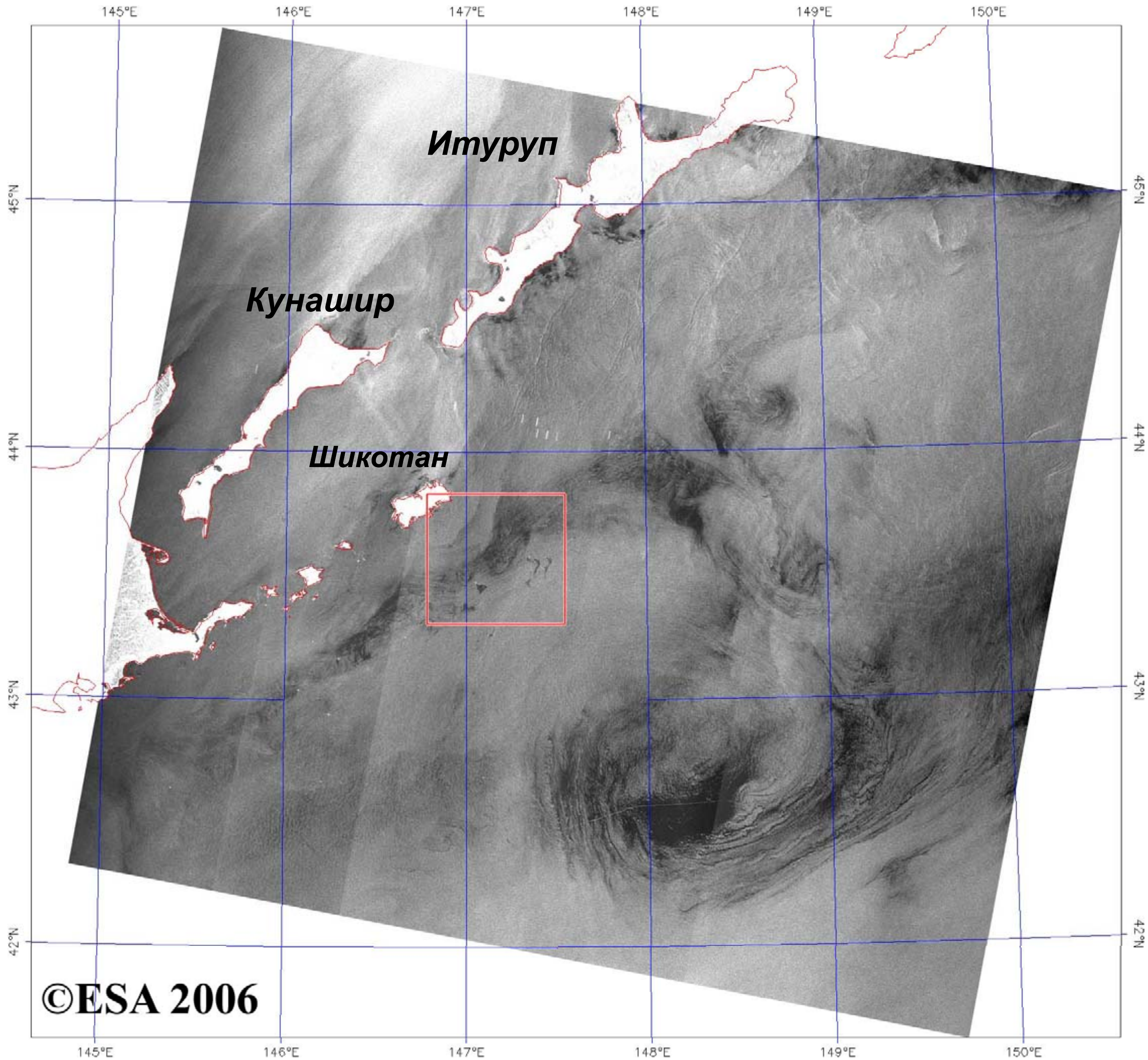
6. SAR signatures of biogenic slicks, oil spills, oceanic and atmospheric phenomena



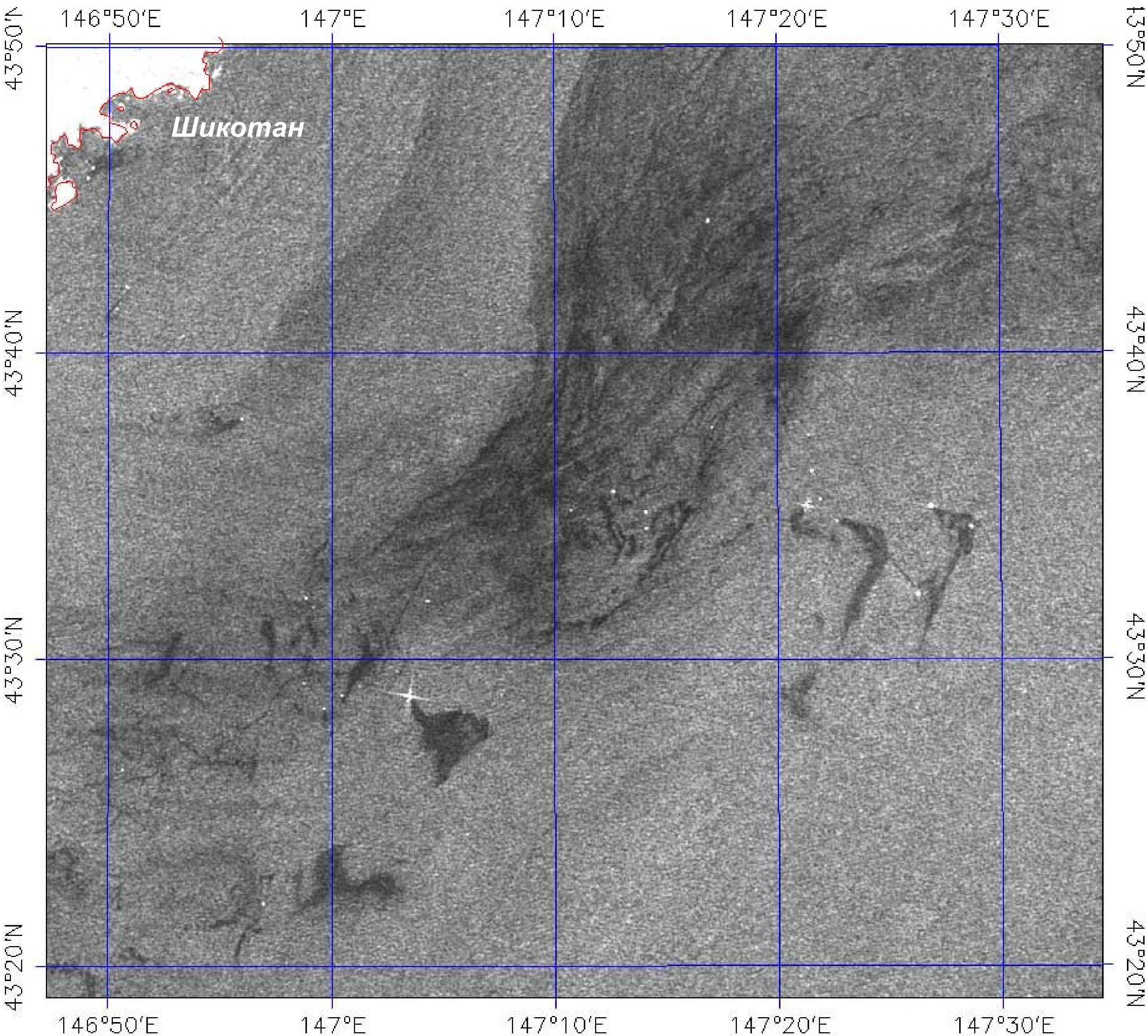
Terra MODIS infrared image. **24.9.06, 01:15 UTC**

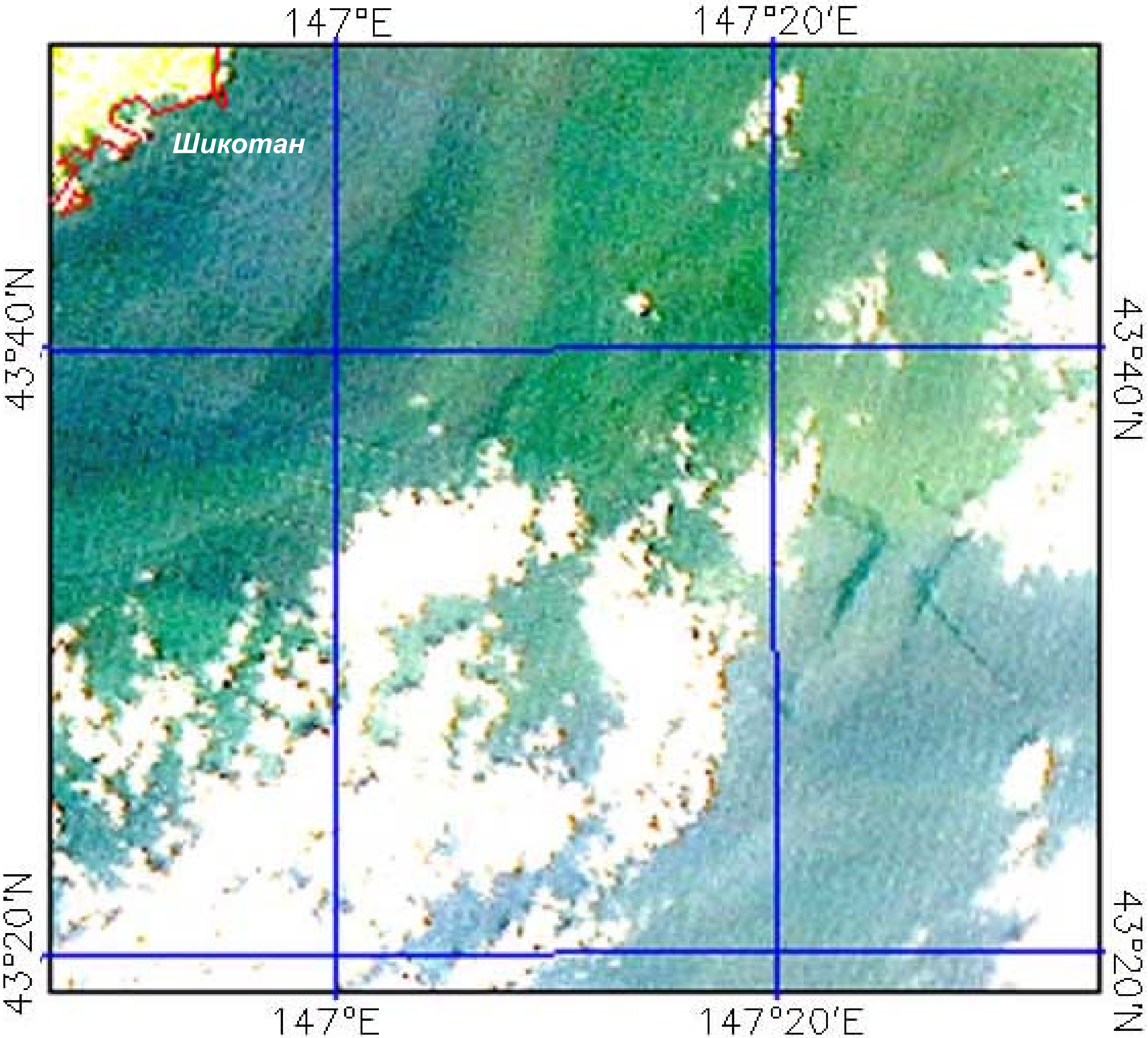
Boundaries of Envisat ASAR image at 00:21 UTC

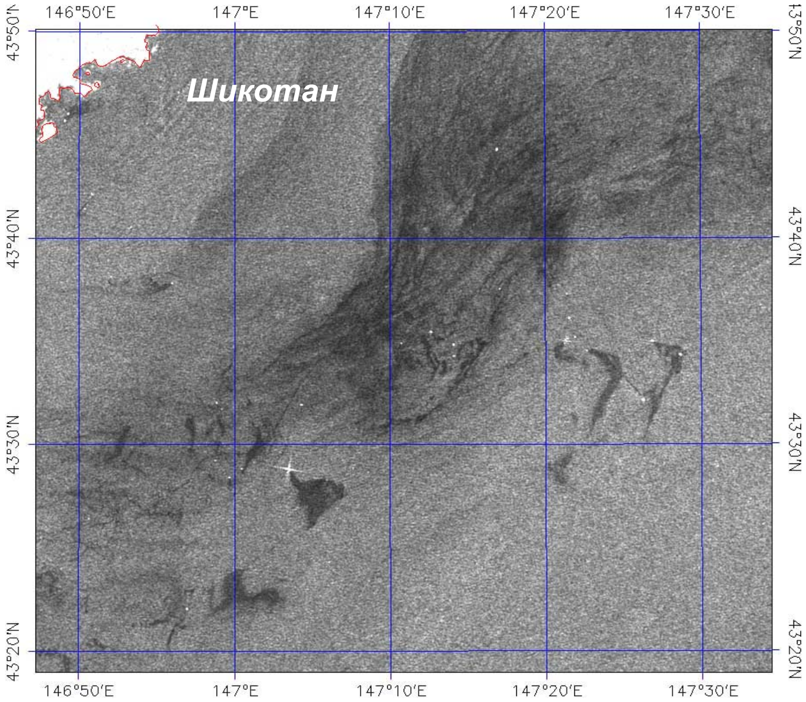


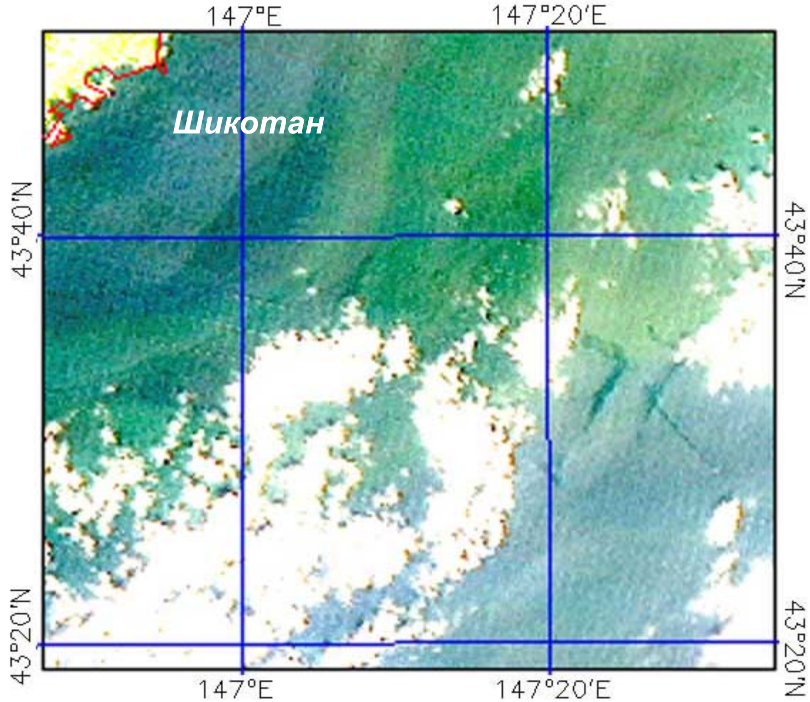


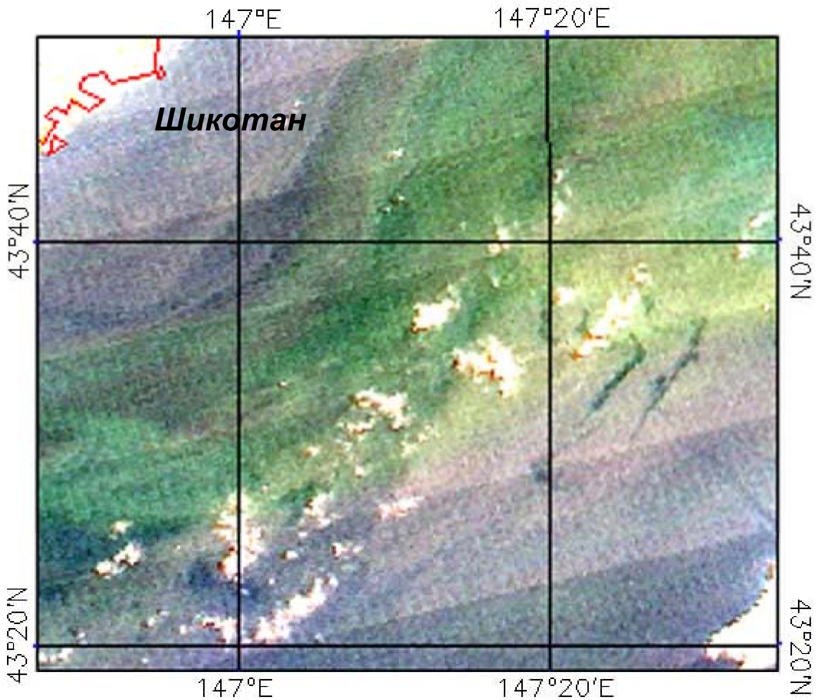
Изображение РСА со спутника Envisat за 24 сентября 2006 г. в 00:21 Гр.


146°50′E
147°E
147°10′E
147°20′E
147°30′E
43°50′N
43°40′N
43°30′N
43°20′N
Шикотан


147°E
147°20'E
Шикотан
43°40'N
43°40'N
43°20'N
43°20'N
147°E
147°20'E







Изображение РСА со спутника Envisat в 00:21 Гр. и изображения спектрорадиометра MODIS в истинном цвете со спутников Terra и Aqua в 01:15 и в 03:00 Гр. 24 сентября 2006 г.

CEARAC-POI web site “Oil spill monitoring by remote sensing” http://cearac.poi.dvo.ru

The following sections are in the website:

1. Introduction
2. Behaviour of oil at sea
3. Remote sensing techniques of oil pollution detection
4. Marine satellite remote sensing data used for oil spills monitoring
5. Algorithms of interactive and automatic detection of oil spills
6. Database of the georeferenced satellite SAR images of the Northwest Pacific. Database of the annotated georeferenced satellite SAR images with revealed oil pollution.
7. Environmental information that is important for oil pollution monitoring/evolution (winds, currents, ice, weather forecast) - Links to the China, Japan, Korea and Russia.
7. References.
8. Links.

Web site on oil spill monitoring

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NOWPAP
Working Group 4

Remote Sensing for Oil Spill Monitoring

POI

This website was developed as part of the CEARAC activity in the field of the oil spill monitoring by remote sensing.

CEARAC is responsible for implementing activities related to Working Group 3: HAB (Harmful Algal Blooms) and Working Group 4 (WG4): Remote Sensing of Marine Environment. In the First Focal Points Meeting of CEARAC in February 2003, the Meeting agreed on the main issues needed to be focused on by WG4. Developing website for public outreach is one of the issues. The same Meeting also agreed that eutrophication and oil spills should be the targets of marine environmental monitoring by remote sensing for the time being due to the fact that both of them are common environmental issues in NOWPAP region and both are expected targets of remote sensing applications.

One of the final goals of WG4 is to establish marine environmental monitoring systems by remote sensing in the NOWPAP region. Therefore, it is important to collect data and information, including satellite images, to forecast the development and behavior of eutrophication and oil spill, and then to disseminate data and information on the present conditions of eutrophication and oil spill and the forecasting results speedily.

However, data and information about the marine environment by remote sensing are actually scattered in different organizations in the NOWPAP region. In order to share their usability, to share existing research and development resources, and also to understand the future trends in marine environmental monitoring, developing remote sensing information network system, which integrates the scattered information, is the basic work to be implemented.

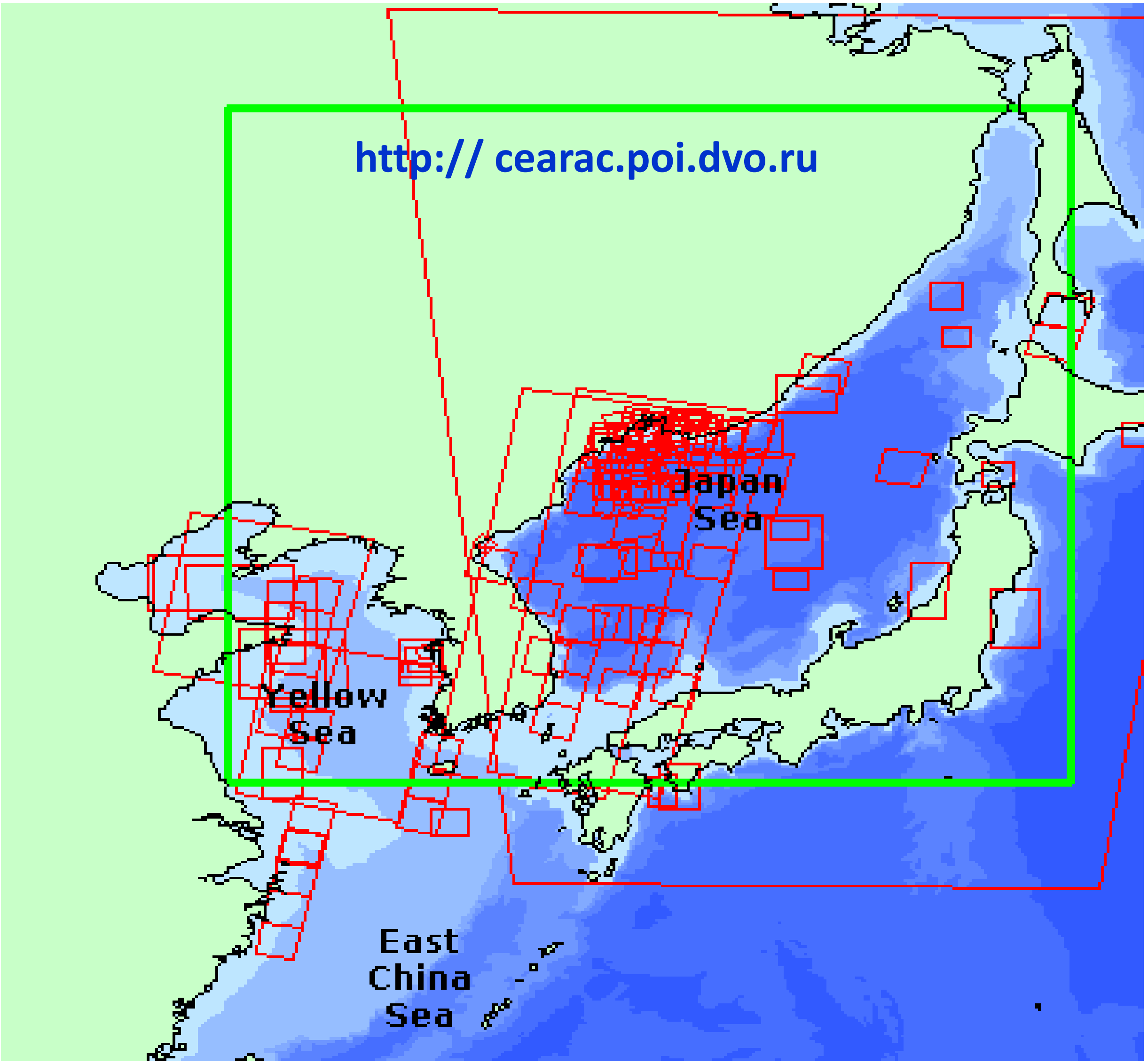
The First WG4 Meeting (Vladivostok, Russian Federation, 1-3 December 2003) agreed on the development of remote sensing information network system, including a portal site on remote sensing in the NOWPAP region and a website on remote sensing for oil spill monitoring. This website is the result of the collaborative work between CEARAC and POI, which is expected to make contributions to the implementation of NOWPAP activities.

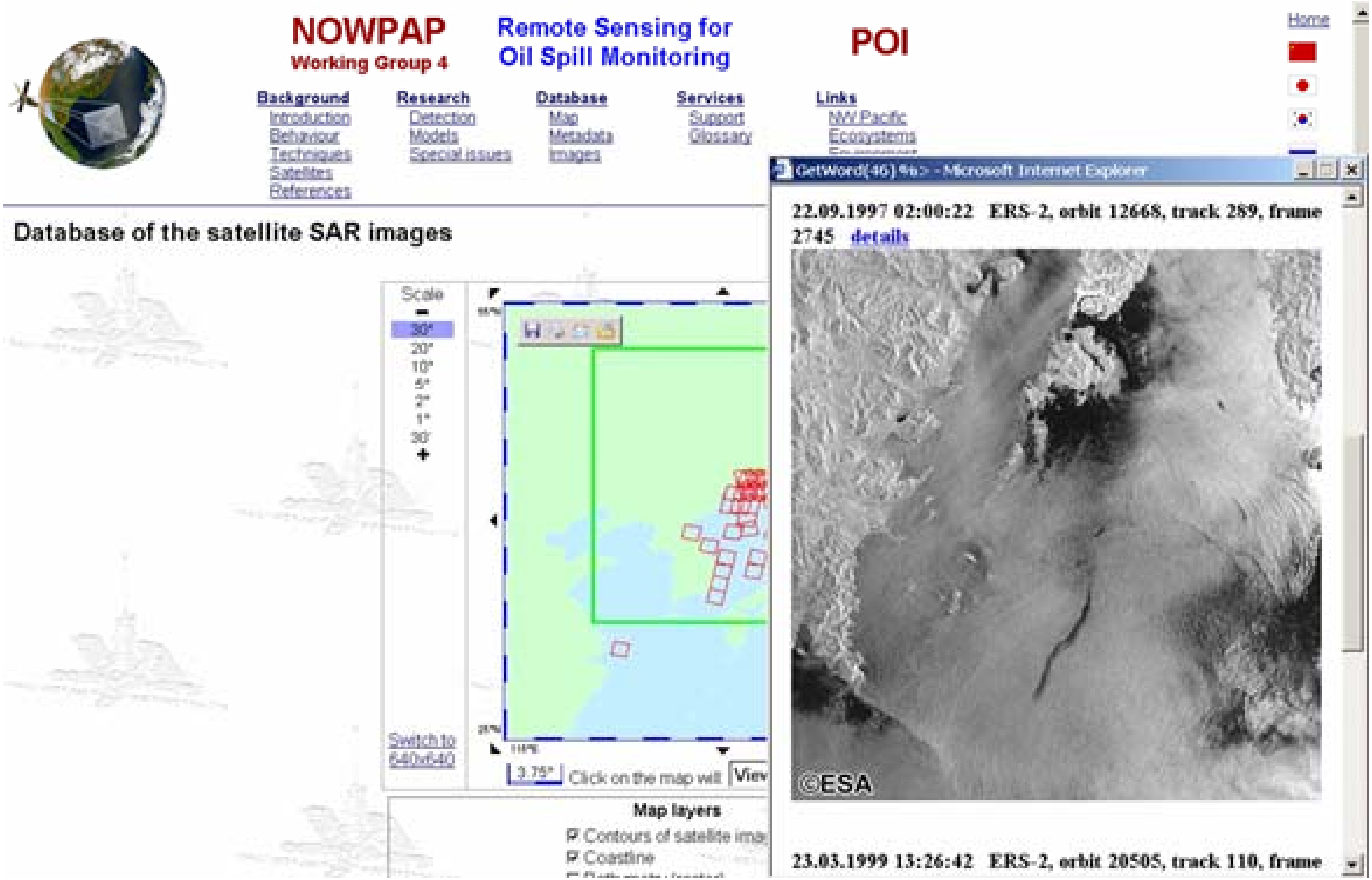
UNEP CEARAC MERRAC

Oil spill monitoring by remote sensing

NOWPAP Working Group 4

POI

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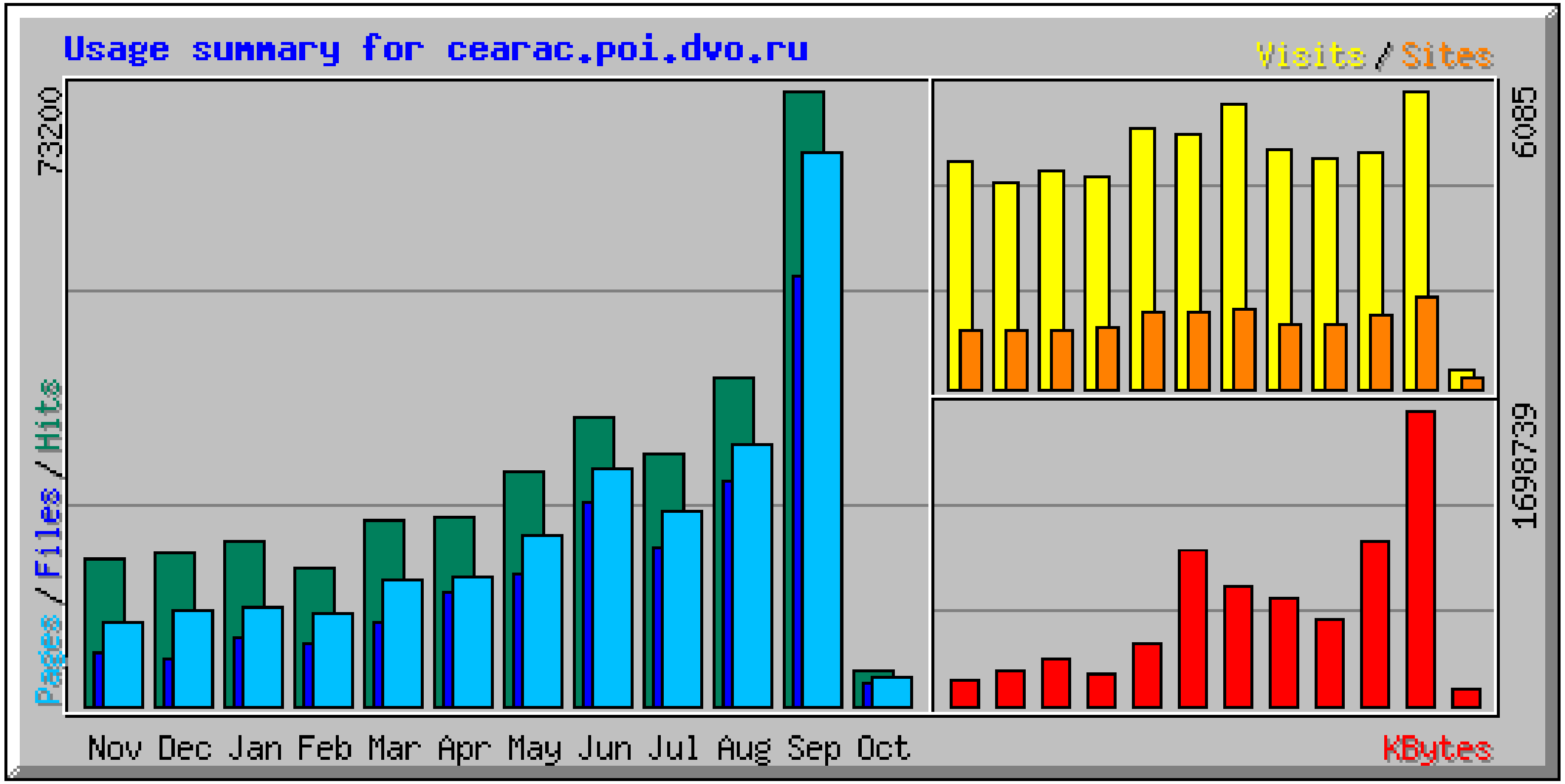
20°
10°
4°
2°
1°
30'
Switch to 640x640
Click on the map will
Map layers
Contours of satellite imag
Coastline
GetWord(46) %> - Microsoft Internet Explorer
22.09.1997 02:00:22 ERS-2, orbit 12668, track 289, frame 2745 details
©ESA
23.03.1999 13:26:42 ERS-2, orbit 20505, track 110, frame

Summary by Month

Month	Daily Avg				Monthly Totals					
	Hits	Files	Pages	Visits	Sites	KBytes	Visits	Pages	Files	Hits
Oct 2011	289	89	160	56	226	35421	511	1443	803	2603
Sep 2011	350	127	171	74	759	275686	2221	5136	3821	10510
Aug 2011	355	121	195	71	649	278640	2219	6051	3773	11035
Jul 2011	457	157	266	85	717	546878	2656	8246	4885	14168
Jun 2011	357	101	226	82	699	106031	2469	6786	3048	10714
May 2011	373	124	231	77	748	140366	2396	7171	3854	11578
Apr 2011	335	106	196	79	686	102135	2397	5883	3193	10056
Mar 2011	477	173	305	92	700	156564	2867	9466	5393	14814
Feb 2011	478	137	298	102	812	120342	2856	8350	3844	13395
Jan 2011	452	148	273	89	768	96248	2774	8477	4589	14031
Dec 2010	433	174	253	90	752	102466	2792	7864	5405	13431
Nov 2010	523	248	324	80	801	137227	2419	9726	7447	15715
Oct 2010	542	251	317	101	1053	274053	3143	9844	7785	16816

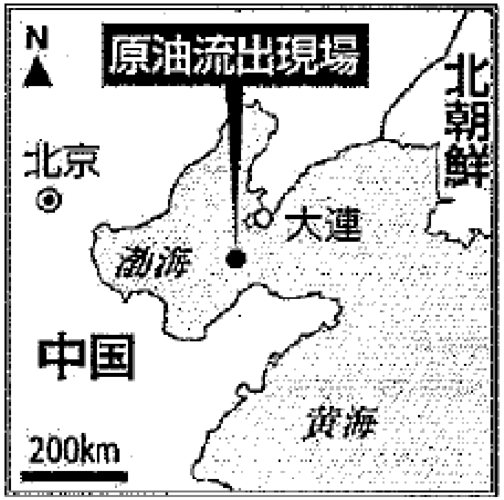
Oil spill monitoring by remote sensing



Month	Daily Avg				Monthly Totals					
	Hits	Files	Pages	Visits	Sites	KBytes	Visits	Pages	Files	Hits
Sep 2013	2440	1700	2194	202	1856	1698739	6085	65844	51014	73200
Aug 2013	1257	864	1006	154	1448	946974	4797	31204	26807	38976
July 2013	972	608	747	151	1279	485822	4700	23185	18877	30132
June 2013	1150	807	943	162	1262	618727	4861	28292	24227	34518

中国の海上油田で原油流出　隠蔽体質に非難集中

2011.7.6 00:02 (1/2ページ)

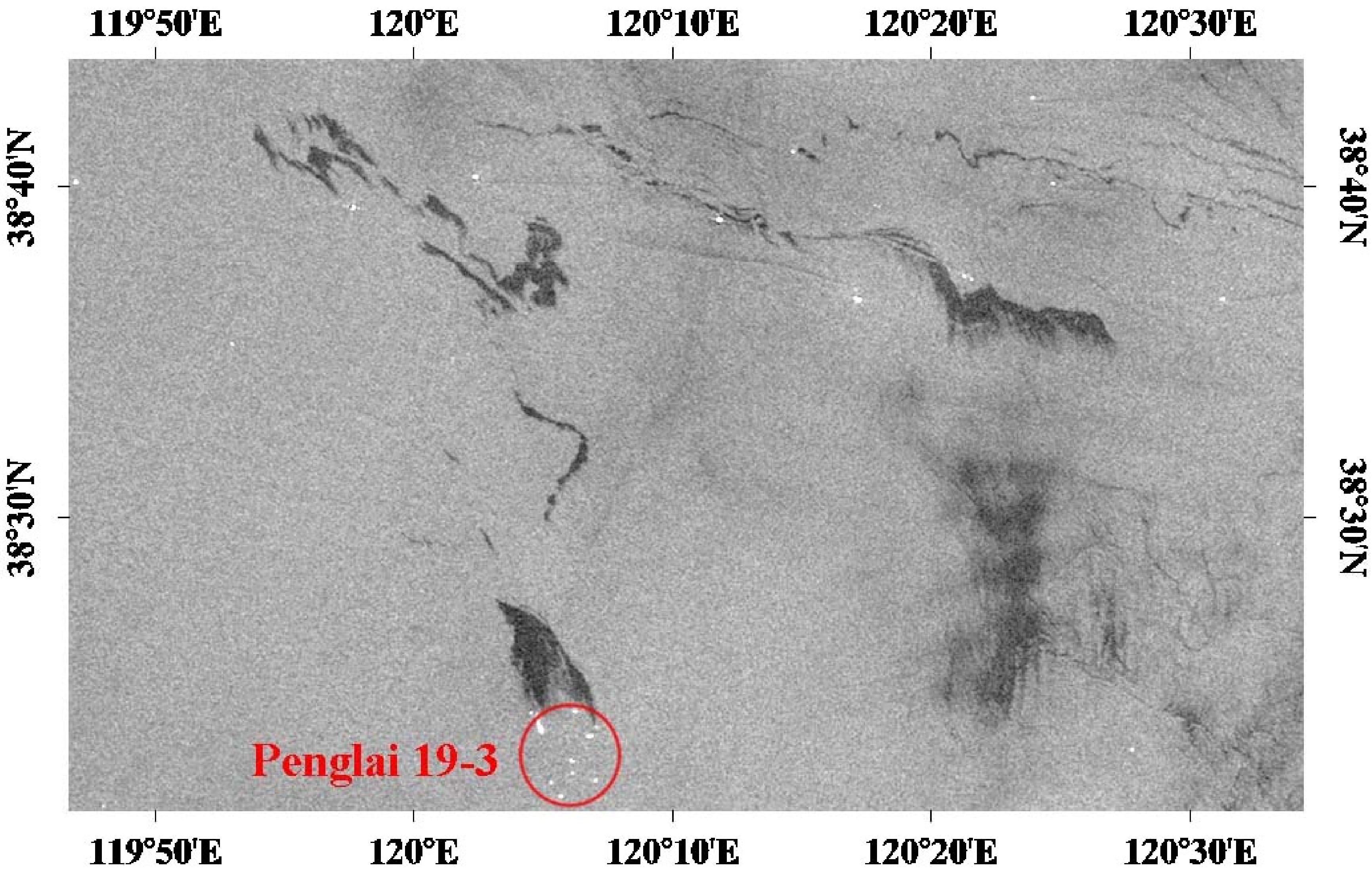


クリックして拡大する

【北京＝川越一】中国山東省沖の渤海にある同国最大の海上油田で6月上旬に原油が流出していたことが発覚し、国家海洋局は5日、初めて事故を公表し、原油が広がった面積は840平方キロにわたったことを明らかにした。汚染拡大が懸念されているにもかかわらず、発生から約1カ月も事故を隠蔽した当局や企業の姿勢に、国民の不信感が高まるのは必至だ。

同油田は、中国国有石油大手、中国海洋石油と米石油大手コノコフィリップスが共同開発した。原油が流出したのは6月4日。同月20日ごろ、インターネット上の書き込みで発覚した。中国海洋石油関係者による内部告発とみられている。

中国メディアからの問い合わせに沈黙を守っていた中国海洋石油は1日夕になって流出を認めた。3日には同社関係者が「油漏れの範囲はわずか200平方メートル程度だ。事故処理はすでに完了しており、現場海域の環境への影響は少ない」とコメントしたが、国家海洋局の発表によって、事態を著しく過小評価していたことも浮き彫りとなった。



Oil spills in Bohay Bay of the Yellow Sea from ships and two oil platforms in Penglai 19-3 area on Envisat ASAR image acquired on 11 June 2011. Total polluted area exceeds 65 km^2.

Image courtesy of ESA - European Space Agency

Detail from Envisat ASAR image identifying cluster of platforms assumed to be in the Penglai 19-3 offshore oil field; and likely oil slicks.

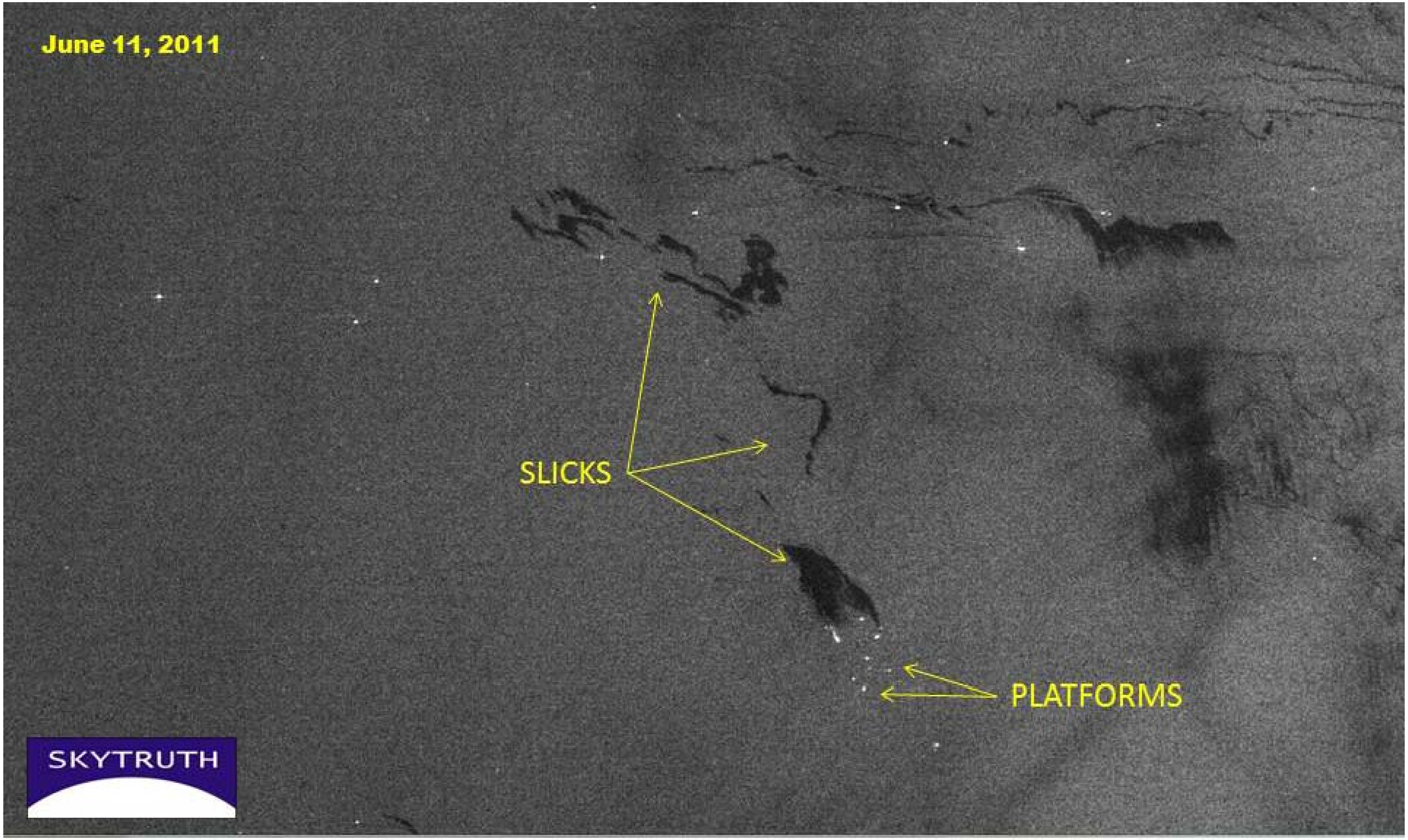
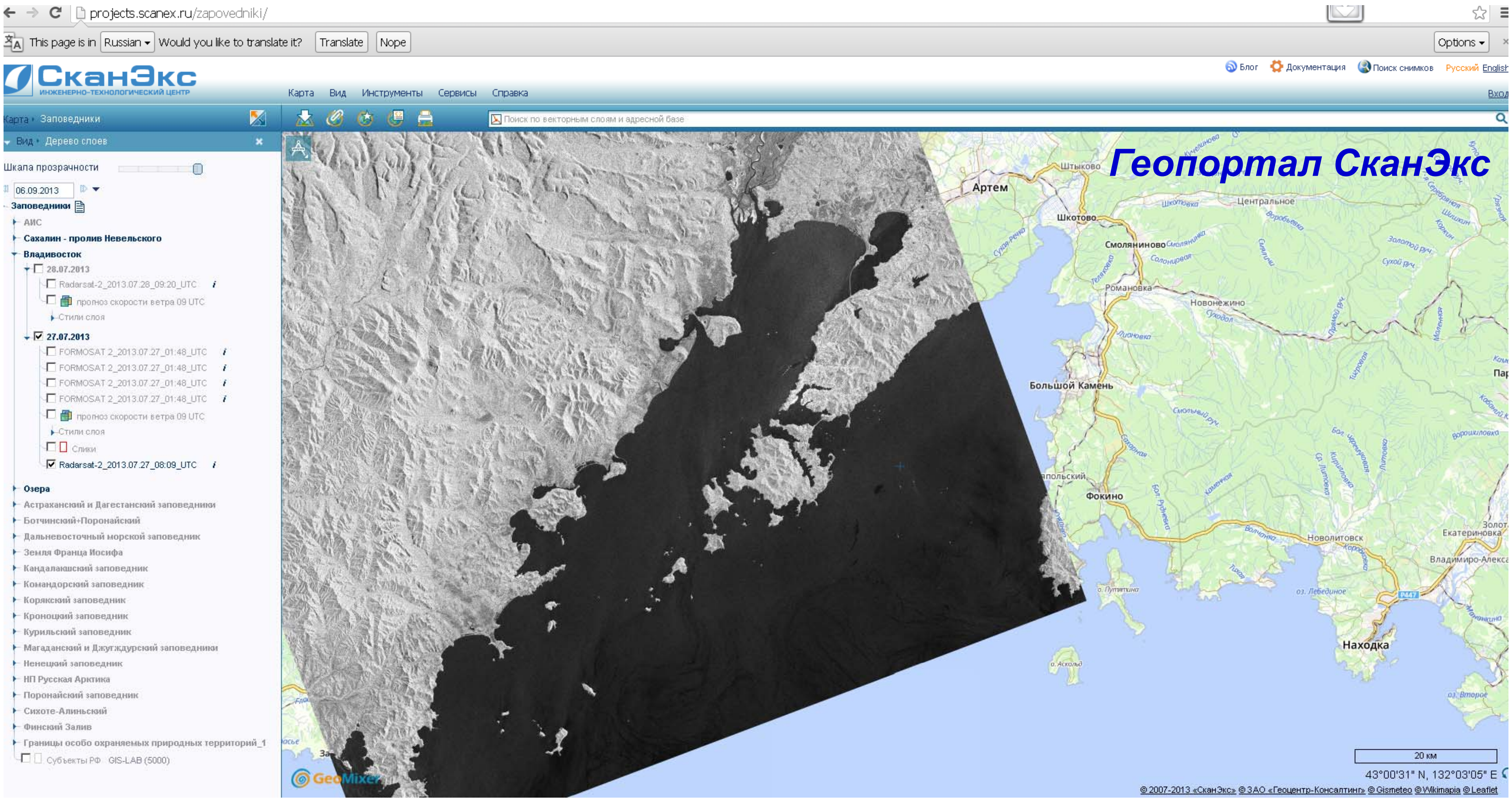
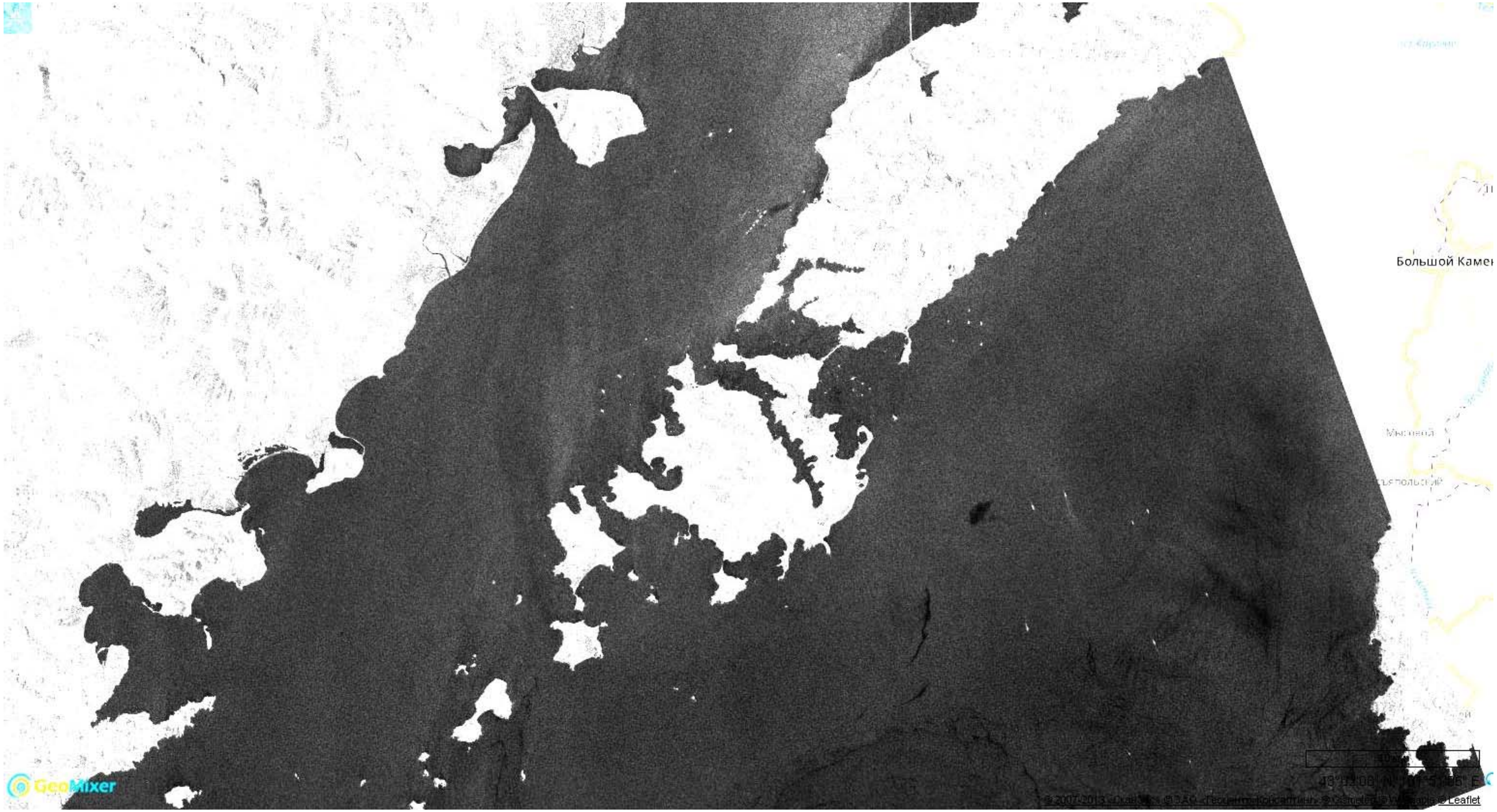


Image courtesy of ESA - European Space Agency

Oil spills are serious threats to marine environment. They can affect marine resources in several ways including surface contamination and disruption of natural marine cycles, including a wide range of subsurface organisms that are inked in a complex food chain that includes human food resources.

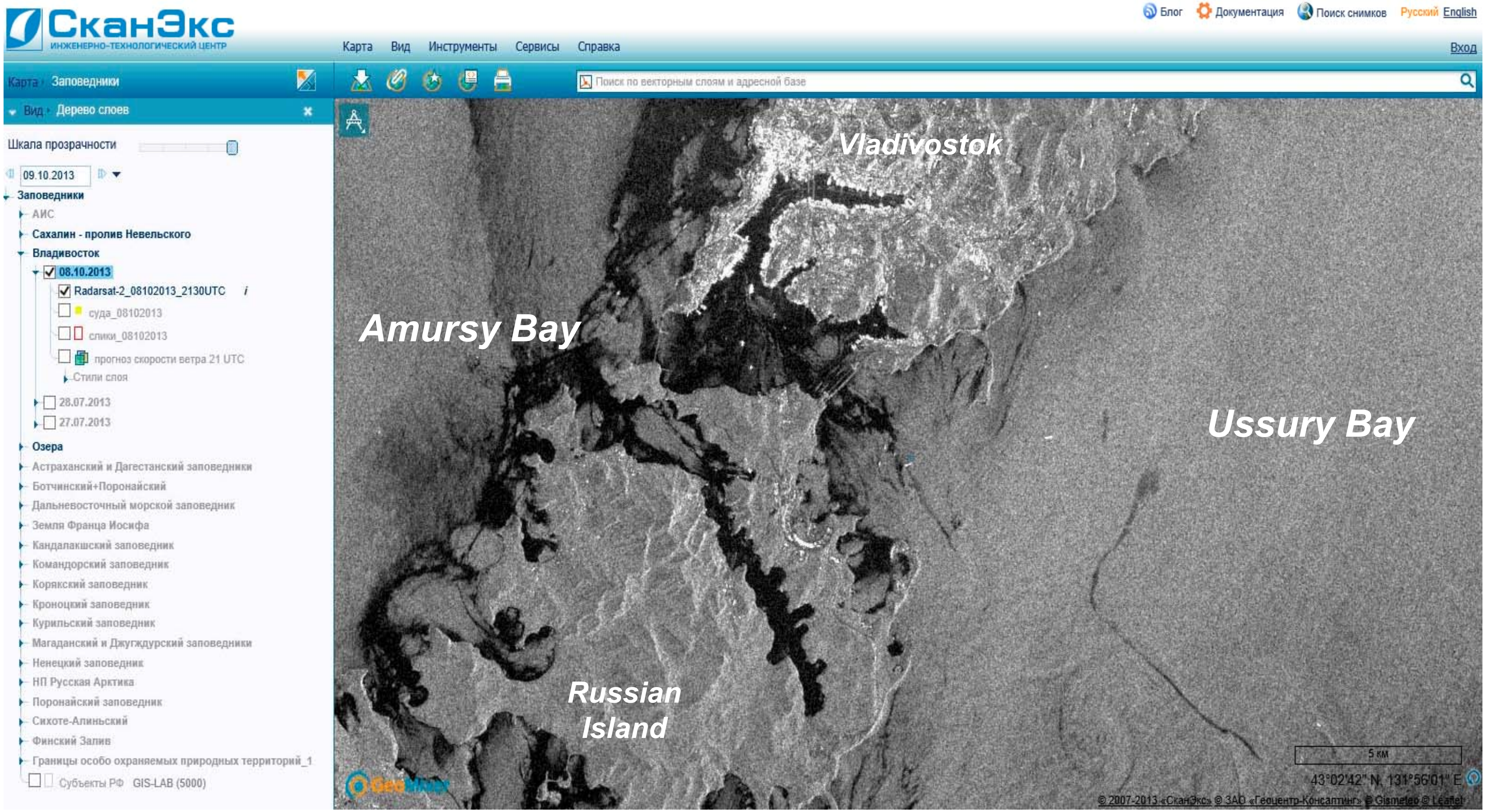


Radarsat-2 SAR, 27 July 2013, 09:09 UTC
Peter the Great Bay



ScanEX

Radarsat-2 SAR image, 8 October 2013, 21:30 UTC



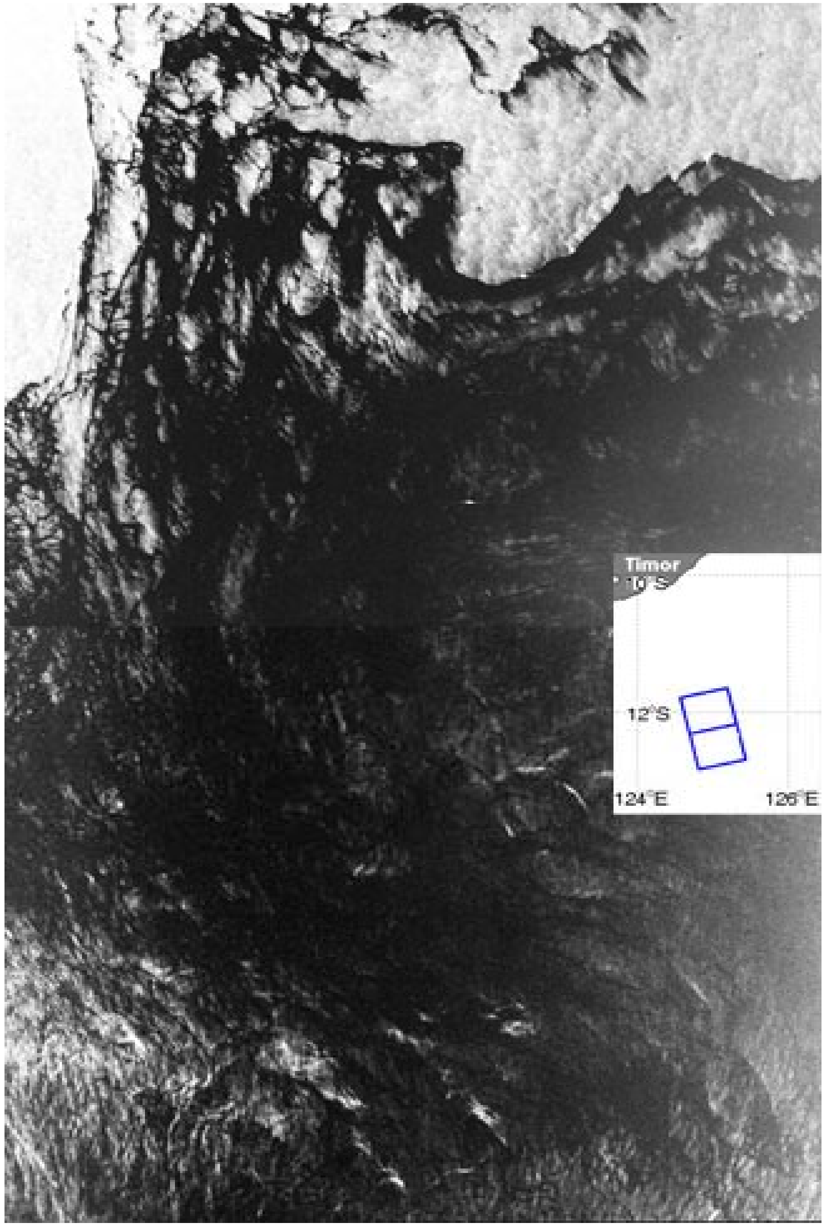
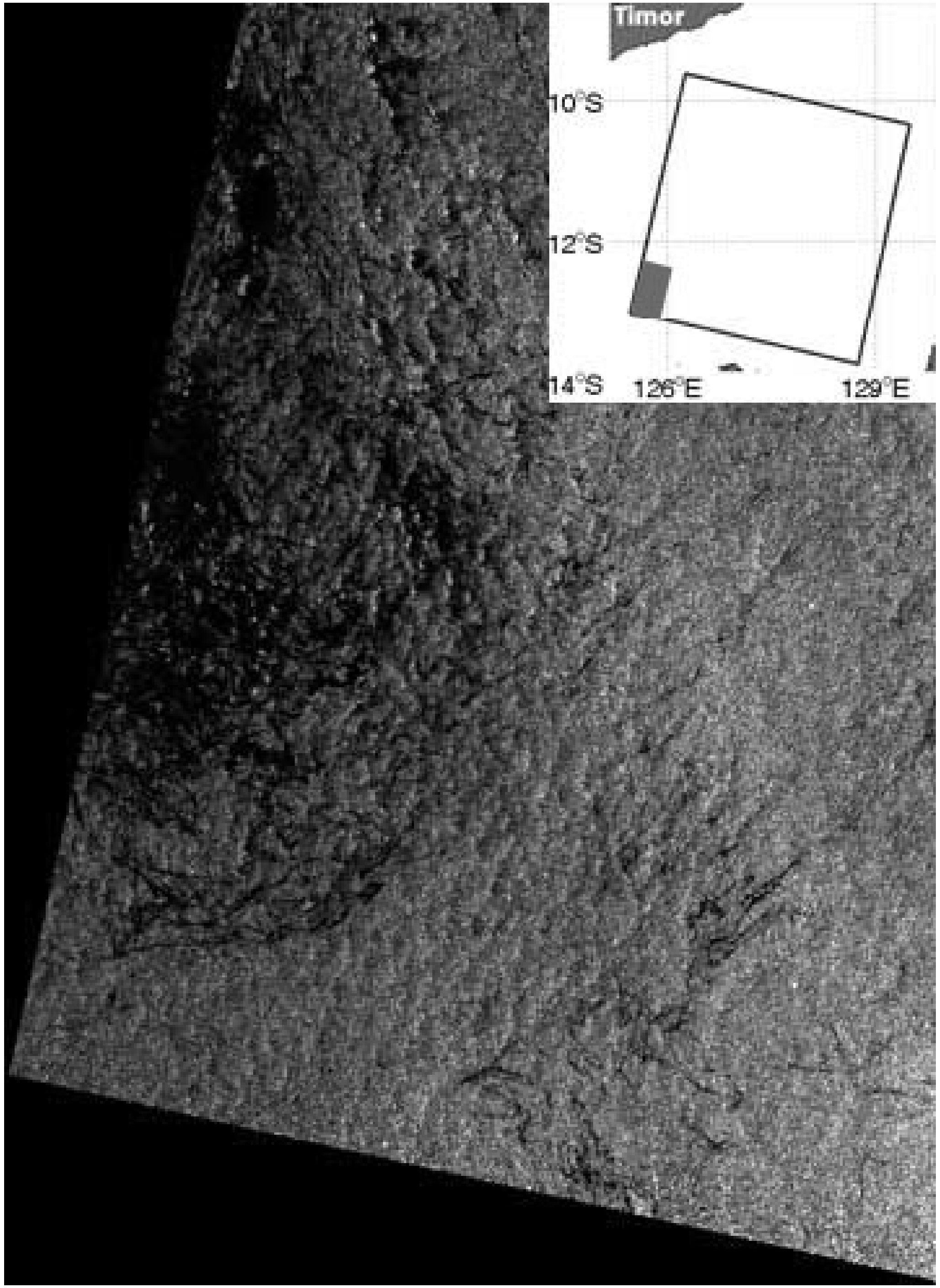


Fig. 2. Fragment of ALOS PALSAR image acquired on 2 September 2009 at 14:37 UTCwith HH-pol. The boundaries of two frames are given in an incertion.

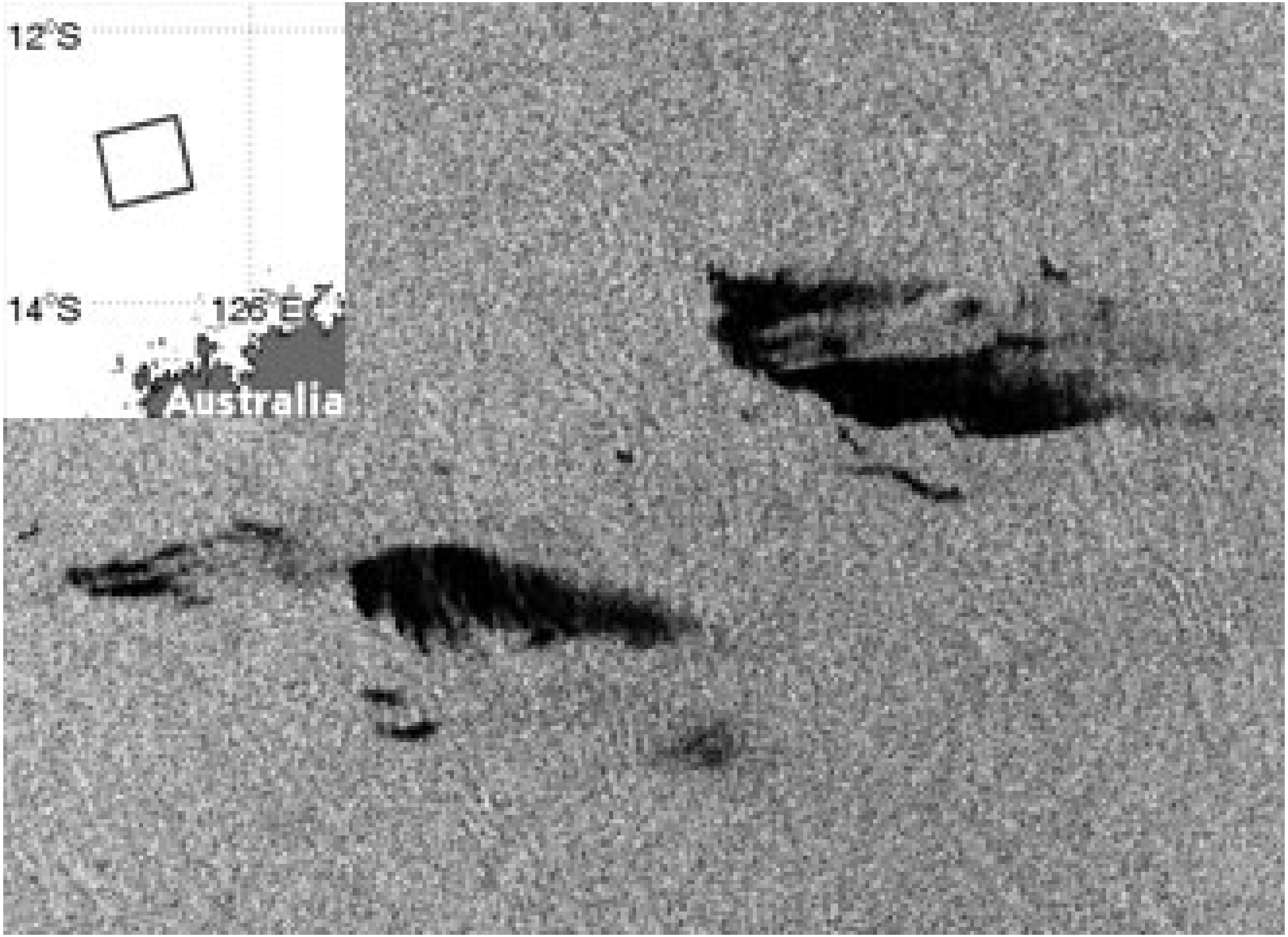
TIMOR SEA

On August 21, 2009, a well on the Montara oil platform in the Timor Sea off the northern coast of Western Australia blew out as a new well was being drilled on the platform by the West Atlas mobile drilling rig.

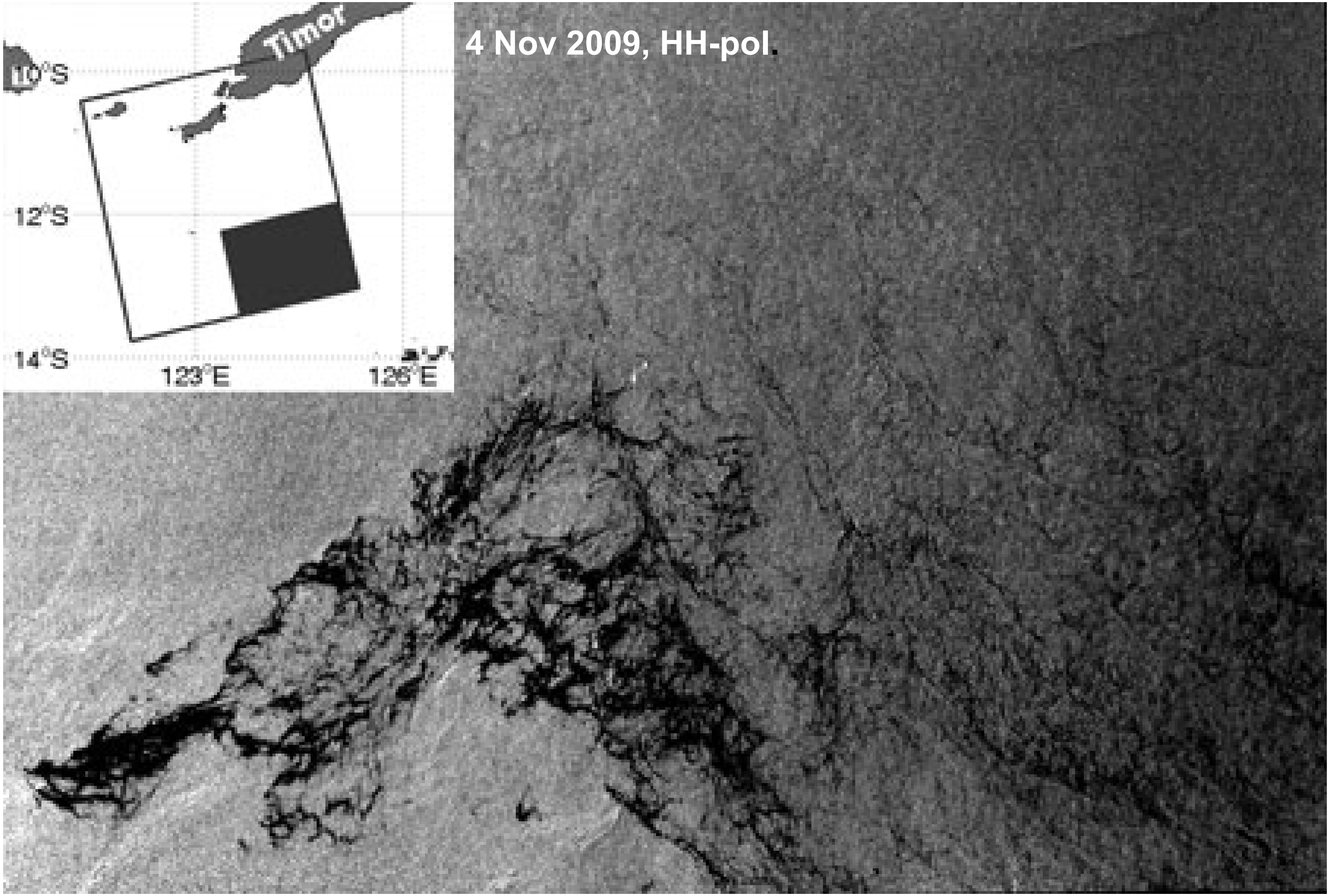
PALOS PALSAR images were acquired on 2 and 30 September, 18 October and 4 November 2009



Fragment of PALSAR image with HH-pol for 30 September 2009 at 01:40 UTC showing oil spill northeast of Montara platform. The square in an insertion marks the boundary of PALSAR frame and dark rectangle shows the location of the fragment.

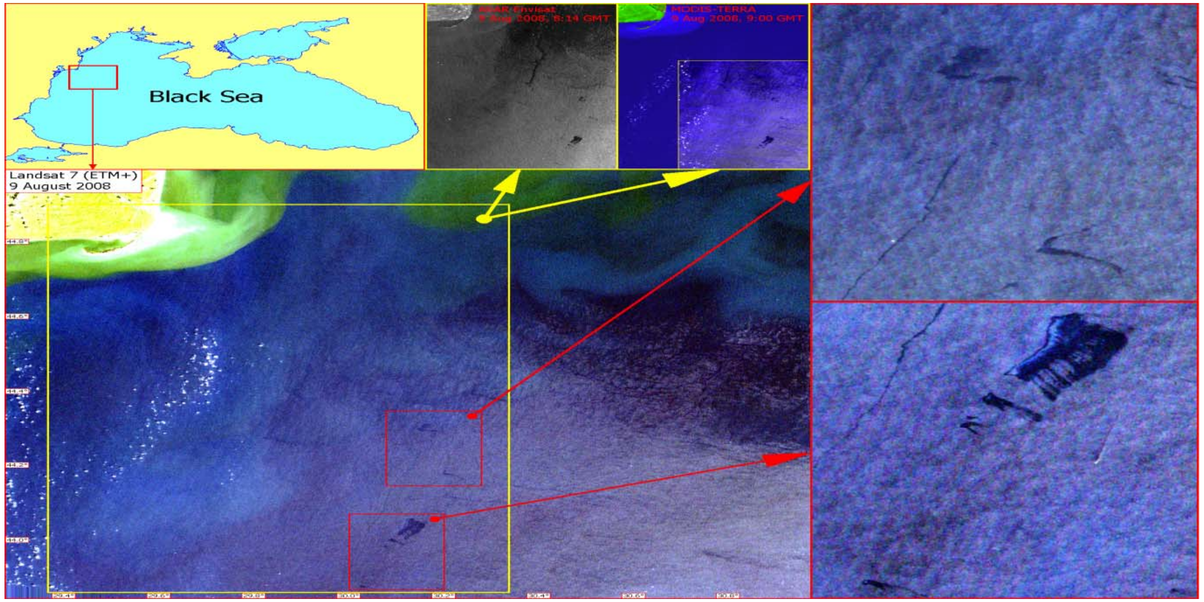


Fragment of ALOS PALSAR image. 18 October 2009, 14:37 UTC, HH-pol.



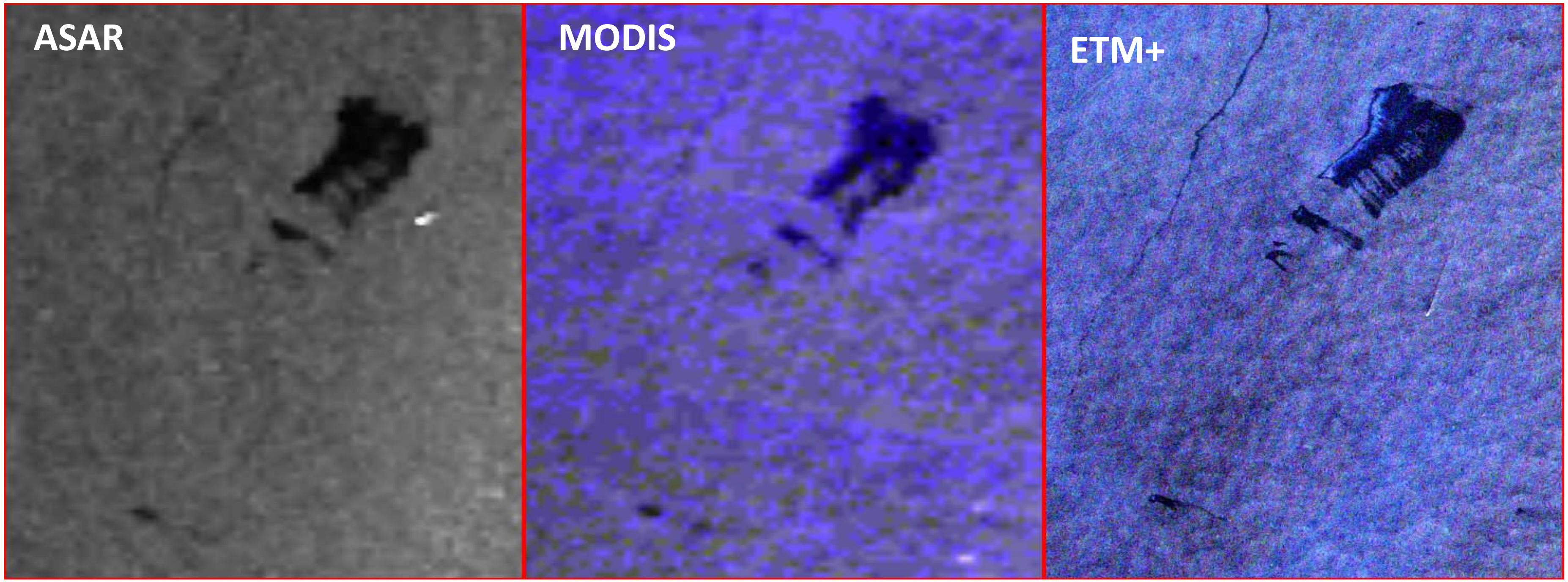
Leonid M. Mitnik. Oil spill detection and mapping in the Northwest Pacific Ocean by L-band ALOS PALSAR. PI 364

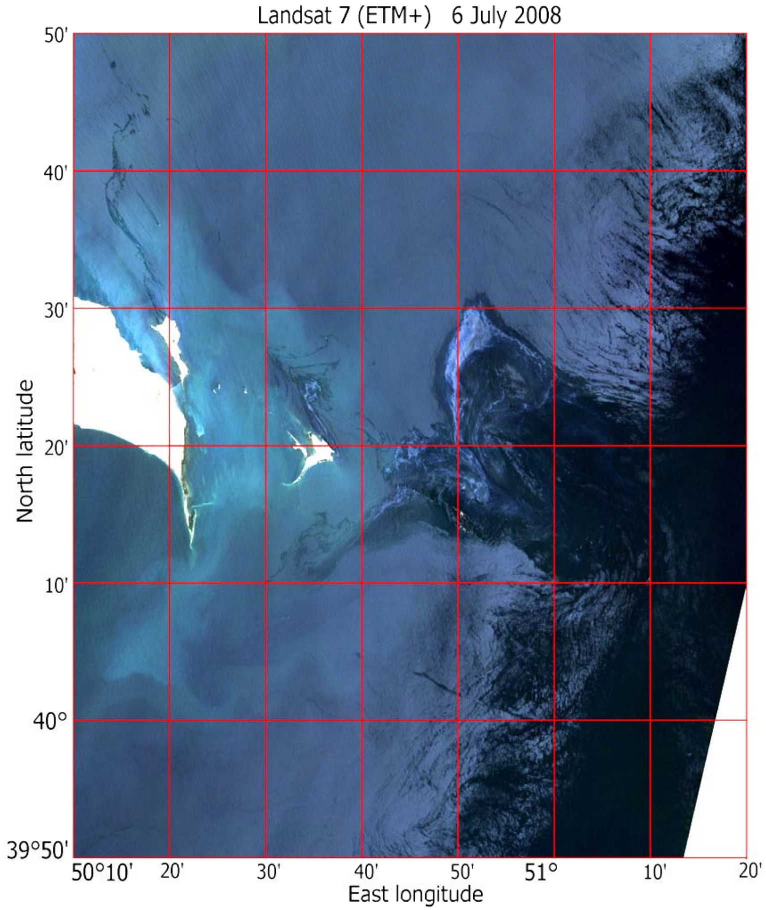
Multi-sensor detection of oil pollution Black Sea. 9th August 2008

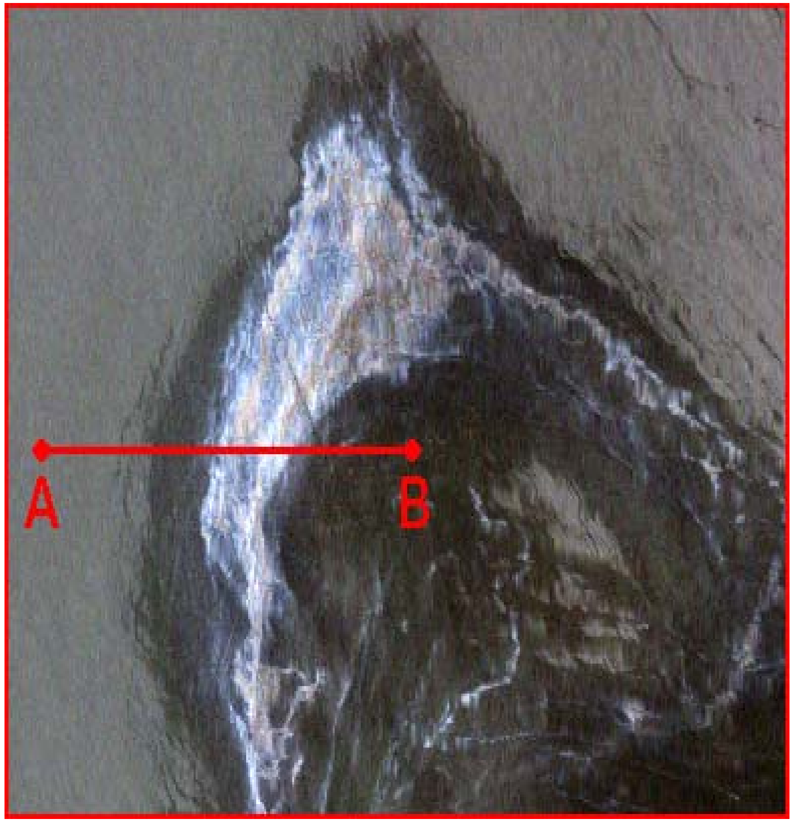


Optical images were obtained outside from “sun glitter” pattern and oil spills appeared like dark areas. Different sensors gave the same signature of the oil pollution like elongated from SW to NE stripe moving to NW. This direction corresponds to the SE wind (~5 m/s) registered by QUIKSCAT and NCEP data.

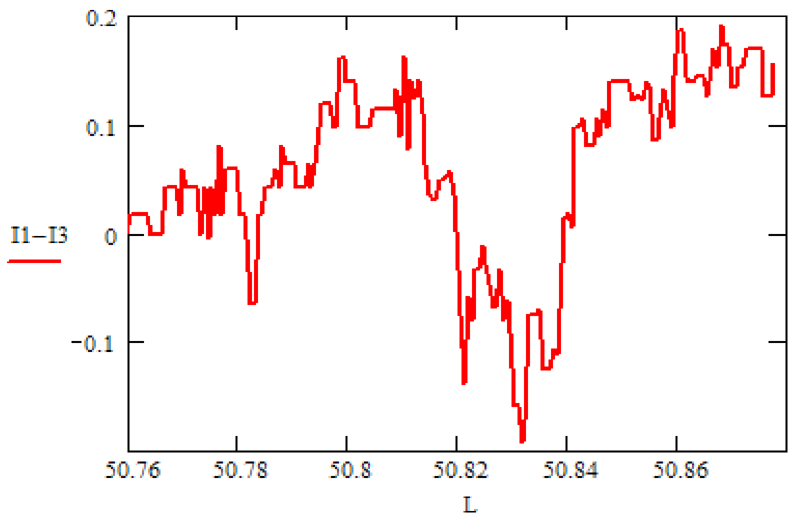
Landsat ETM+ data additionally detect area with “thick” oil appeared like bright stripe within dark spot. So, optical data allow to separate “thick” and “thin” films and give estimation of the oil thickness.



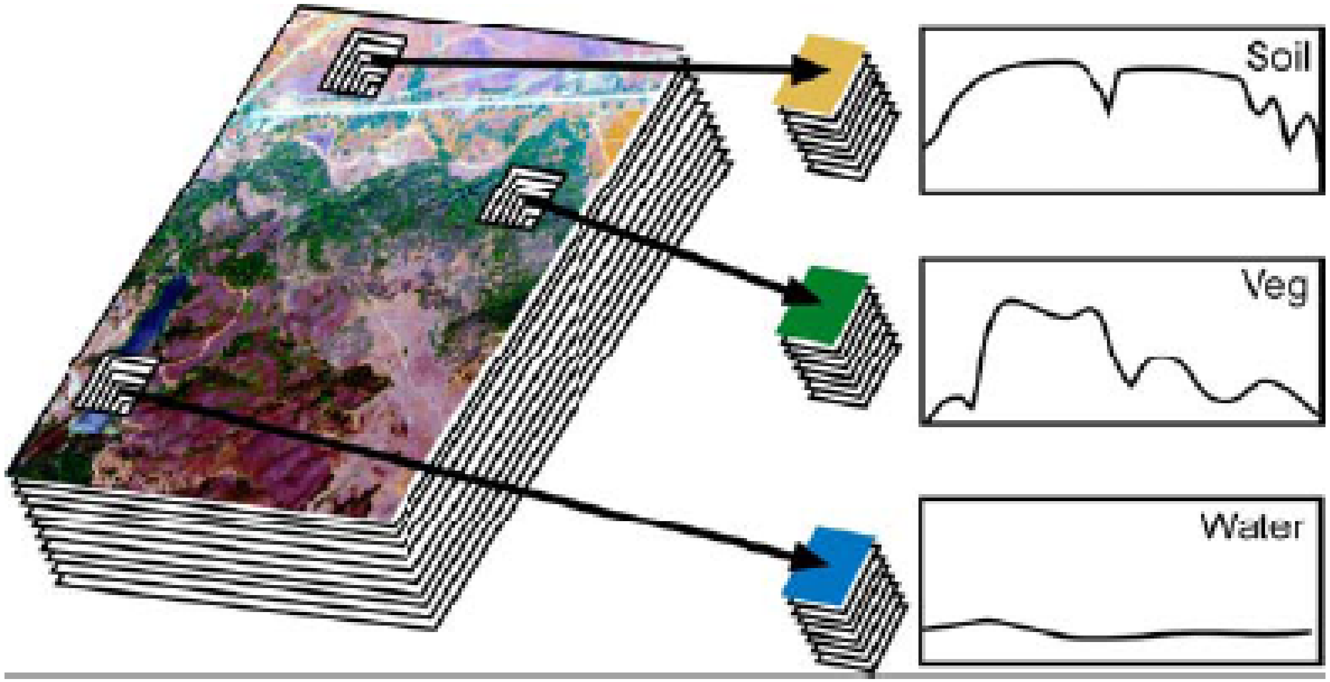




Thick" oil films (>0.5*10-6 m) increase reflection coefficient of the "water – film" system and appeared commonly like the areas with higher radiation. Landsat ETM + synthetic colors image for "Oil Rocks" area (Caspian Sea) demonstrates huge oil pollution northern from platforms field with "thick" film appearance, even with interference pattern within slick. Periphery of the slick consists from "thin" film (darker) of spreading oil. Multispectral approach allows to separate thin and thick oil films.
Difference of the band 1 and band 3 contrasts across section A-B presented on graph gives positive values for "thin" films and negative for "thick" films.



Hyperspectral imagery



The concept of **hyperspectral** imagery, when image are made at many narrow contiguous wavelength bands, resulting in a complete spectrum for each pixel.

Single sensors are unlikely to provide adequate temporal and spatial coverage at adequate resolution for pollution monitoring. Systematic routine monitoring of marine environment requires inputs of microwave. IR and visible data in ways that take advantage of their respective strengths. Satellies provide global statistical information: oil spills are observed all over the world seas.
Study with 1600 ERS SAR images taken over the Mediterranean Sea showed that a half of the images present at least one slick. Similar estimates were obtained for the Baltic Sea and for the South East Asia area.

Hyperspectral imagery

In the visible spectrum, crude oil and heavy refined oils are distinguished thanks to three optical properties which vary from oil to oil, and which make them detectable at sea by optical sensors:

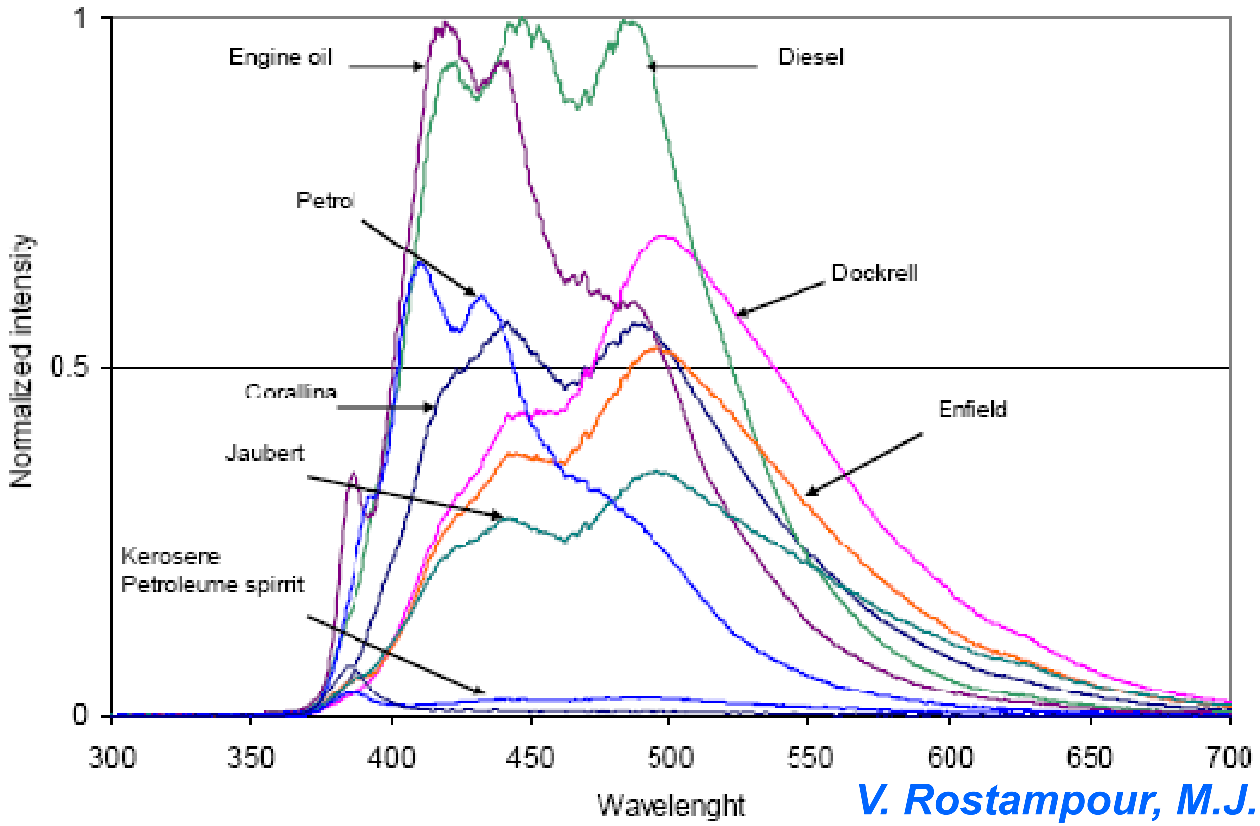
- Their refractive index is greater than that of seawater
- Their coefficient of light absorption is much stronger than that of water, particular at shorter wavelengths
- They fluoresce when subjected to bright natural light.

Hyperspectral imagery

Up-to-date, a laser fluorosensor is the most useful instrument in oil remote sensing, because of its capability to distinguish oil on backgrounds that include water, soil, weeds, ice and snow. It is the only sensor that can positively discriminate oil on most backgrounds. This type of active sensors takes advantage of the fact that certain compounds in petroleum oils absorb UV light and become electronically excited. This extinction is rapidly removed through the process fluorescence emission, primarily in the visible region of the spectrum. Since very few other compounds show this tendency, fluorescence is a strong indication of the presence of oil. Natural fluorescing substances, susch as chlorophyll, fluoresce at wavelengths that are different enough than oil to avoid confusion. As different types of oil yield slightly different fluorescent intensities and spectral signatures, it is possible to differentiate between classes of oil under ideal conditions.

Fluorescence behavior of the oil spills

Fluorescence-based monitoring systems are reliable and accurate means for quantifying and detecting a compound in all environments. Hydrocarbon oils indicate significant fluorescence response when they are exposed to UV radiation. The fluorescence emission measurement provides substantial information on the detection and monitoring of hydrocarbon oils. Chemical composition and aromatic compounds are mainly responsible for the fluorescence emission of mineral oils.



Fluorescence emission spectra of four Australian crude and five refined oils at 385 nm excitation wavelength..

V. Rostampour, M.J. Lynch. Ocean Optics'06

Oil spill detection and characterization by satellite SAR and airborne SLAR, hyperspectral and lidar data

- Satellite SAR and airborne SLAR systems are useful for regional-scale observation and detection. Airborne optical sensors are not convenient for that task because of their reduced swath.

- Microwave and fluorescence lidar sensors are complementary, regarding the different thickness ranges that can be estimated by both sensors.

- Hyperspectral and lidar sensors could be used in the same manner as IR/UV sensors for regional scale detection (compensation of the SLAR blind zone). Hyperspectral data would allow a better spatial resolution to be reached, but could not be used during night flights however.

- Thermal IR and hyperspectral VNIR sensors are complementary as far as their detection capabilities are concerned: thin oil slicks can not be detected by thermal IR sensor because of the sea surface thermal balance (they can be with an hyperspectral sensor) while thick oil slicks still influence the signal recorded by a thermal IR sensor (quick saturation of the signal as a function of oil thickness in the case of a n hyperspectral sensor).

- Joint use of hyperspectral and fluorescence lidar sensors allow high spatial resolution thickness distribution maps to be obtained, while SAR, SLAR, and IR/UV are only used for detection.

Conclusion

Clearly the appropriate time for developing new oil spill remote sensing approaches is not during the response. Many steps are required to validate technology in the appropriate environment, including integration with critical hardware and analysis software before reaching operational technology readiness.

Technologies with proven and accessible Rapid Response Products, like MODIS, are far more likely to contribute to spill response. Data fusion of ancillary data such as meteorology can be highly helpful; however, data coordination logistics during a spill are challenging.

Oil spills provide an opportunity to field test new approaches under real world conditions, as does the post-spill period for monitoring technologies. ***Although oil spills occur frequently, they are unpredictable and highly challenging for data collection mobilization, particularly for small oil spills.***

Large spills present a more feasible target; however, careful calibration/validation studies may be impossible during oil spills. ***A key step in most remote sensing applications is field validation, which generally requires a planned release*.**

Although large test facilities can play a role, they cannot recreate many real-world characteristics of a marine oil spill from a remote sensing perspective. In this regard, ***natural marine hydrocarbon seeps provide real world oil slicks for studying oil slick processes without release permits.***

Leifer I. et al. State of the art satellite and airborne marine oil spill remote sensing: Application to the BP *Deepwater Horizon* oil spill (2012). RSE. V.124. P. 184-209