PAJ Oil Spill Symposium 2008

Application of Wavelet Spectrum Analysis to Oil Spill Detection by Using Satellite Observation Data

February 21, 2008

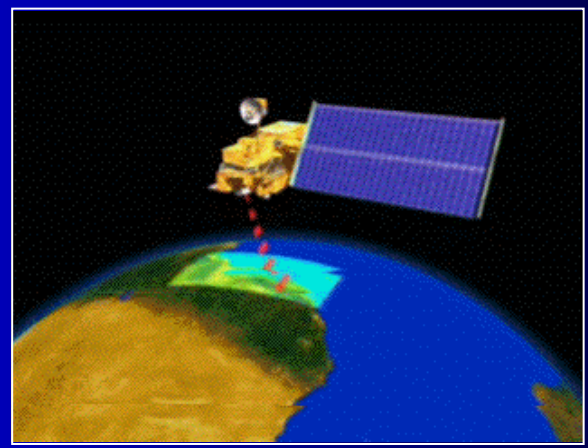
Tokyo, Japan

Masanao Hara Dr.,

VisionTech Inc.

1. Background

- Oil spill is one of the most critical issues for the marine environment.
- The most important thing to minimize the influence is how to find the area of the oil slick when it occurred.
- Spilled Oil is drifting and spreading in wide sea area every moment.
- Satellite Remote Sensing is one of the useful technology for the monitoring.

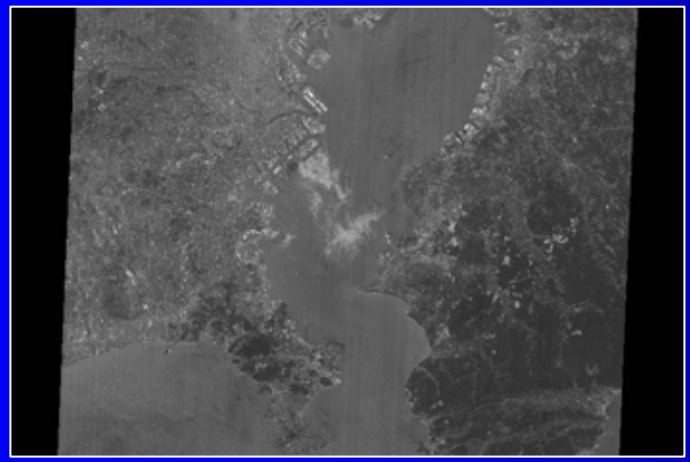


An example of oil spill disaster observed by an optical sensor

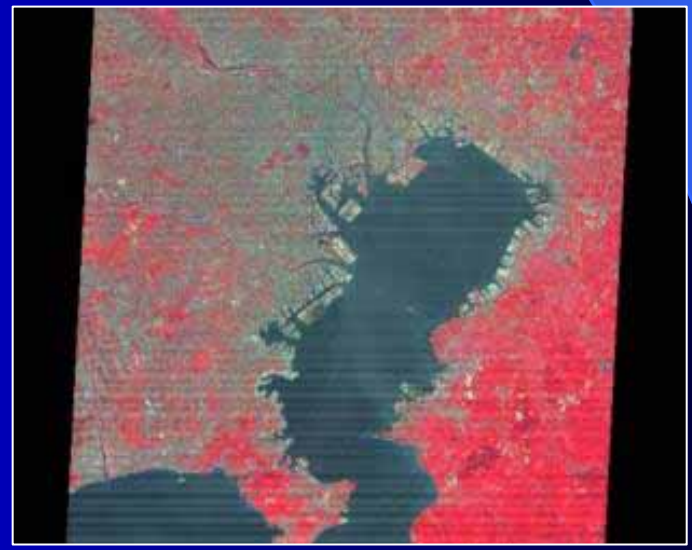
(Diamond Grace, Tokyo bay, July 02, 1997)

LANDSAT-5/TM July 03 ‘97

SPOT-2/HX July 03 ‘97



SPOT-2/Pan July 03 ‘97



JERS-1/OPS July 05, ‘97

The major oil spill disaster which observed by an optical sensor

Shipname / Location (Country)	Date & Time of the accident		Satellite / Sensor		Observation Date & Time		Cloud Cover	Type of pollutant / Quantity spilled		Conclusion
Diamond Grace / Tokyo (Japan)	**1997/7/2**	**10:20**	**JERS-1**	**OPS**	**1997/7/5**	**10:44**		**Crude oil**	**1550KL**	△
			LANDSAT-5	**TM**	**1997/7/3**	**9:45**				×
			SPOT	**PAN**	**1997/7/3**	**10:54**				○
			SPOT	**XS**	**1997/7/3**	**10:54**				○
The Russian tanker NAKHODKA / Oki Island, Shimane (Japan)	1997/1/2	2:51	LANDSAT-5	TM	1997/1/4	10:03	Yes	Heavy fuel oil	6240KL	×
			ADEOS	AVP	1997/1/3	11:09	Yes			×
Thousand Venture / Okino-Torishima, Tokyo (Japan)	1996/4/20		LANDSAT-5	TM	1996/4/27	9:30	Yes	Heavy fuel oil	700KL	×
			LANDSAT-5	MSS	1996/4/27	9:30	Yes			×
Toyotaka-maru / Wakayama (Japan)	1994/10/17	1:45	LANDSAT-5	MSS	1994/10/20	9:50	Yes	RABI Brend oil	570KL	×
			LANDSAT-5	TM	1994/10/20	9:50	Yes			×
			MOS	MESSR	1994/10/18	10:45	Yes			×
			SPOT	HX	1994/10/19	10:54	Yes			×
Taiko-maru / Fukushima (Japan)	1993/5/31	6:10	MOS	MESSR	1993/6/17	10:19		Heavy fuel oil (C)	521KL	×
Node Hope / Tomakomai, Hokkaido (Japan)	1993/1/26	23:44	MOS	MESSR	1993/2/2	10:24		Heavy fuel oil	437KL	△
			SPOT	HX	1993/2/4	10:16	Yes			×
			SPOT	PAN	1993/2/4	10:16	Yes			×
			LANDSAT-5	TM	1993/1/29	9:35	Yes			×
Showa Shell Tank / Kushiro, Hokkaido (Japan)	1993/1/15	20:06	LANDSAT-5	MSS	1993/1/22	9:29		Asphalt	246KL	×
			LANDSAT-5	TM	1993/1/22	9:29				×
Nippou-maru / Himeji, Nagoya (Japan)	1991/9/27		LANDSAT-5	MSS	1991/10/3	10:05		Heavy fuel oil	180KL	△
Kenhatsu No.11 / Yoanguni Island, Okinawa (Japan)	1990/5/23		MOS	MESSR	1990/5/23	11:16	Yes	Heavy fuel oil		×
Maritime Gardenia / Kyoto (Japan)	1990/1/26	17:50	LANDSAT-5	TM	1990/1/26	9:56	Yes	Heavy fuel oil	918KL	×
Eisei-maru / Muroran, Hokkaido (Japan)	1993/1/13		JERS-1	OPS	1993/1/19	10:38		Marine fire		△
			LANDSAT-5	TM	1993/1/13	9:36				×
			LANDSAT-5	MSS	1993/1/20	9:42				△
Taishoh-maru / Osaka (Japan)	1994/2/14		SPOT	PAN	1994/2/16	11:06		Chemicals	116KL	△
Mass Dike / The Island Sea (Japan)	1992/5/2		MOS	MESSR	1992/5/2	11:07		Chemicals	260KL	△
Kyouwa-maru / Omaezaki, Shizuoka (Japan)	1991/6/26		MOS	MESSR	1991/6/27	10:37		Chemicals	100KL	△
No.2 Chloe / Kanmon Straits (Japan)	1990/10/27		LANDSAT-5	TM	1990/10/30	10:13		Chemicals	200KL	△
			LANDSAT-5	MSS	1990/10/30	10:13				△
Hakuun-maru / Fukuoka (Japan)	1997/10/25		SPOT	HX	1997/10/25	11:02		Light oil	100KL	△
Ryouyou-maru / Shizuoka (Japan)	1993/7/23		LANDSAT-5	TM	1993/7/24	9:38	Yes	Chemicals	267KL	×
			LANDSAT-5	MSS	1993/7/24	9:38	Yes			×
Kotobuki-maru / Wakayama (Japan)	1992/11/5		MOS	MESSR	1992/11/11	10:39	Yes	Gasolene	100KL	×
Seihou-maru / Osaka (Japan)	1992/5/1		MOS	MESSR	1992/5/8	10:40	Yes	Gasolene	280KL	×
			LANDSAT-5	TM	1992/5/7	9:58	Yes			×
Taihou-maru / Iwate (Japan)	1989/6/28		MOS	MESSR	1989/7/2	10:16	Yes	Light oil	444KL	×

1. Background

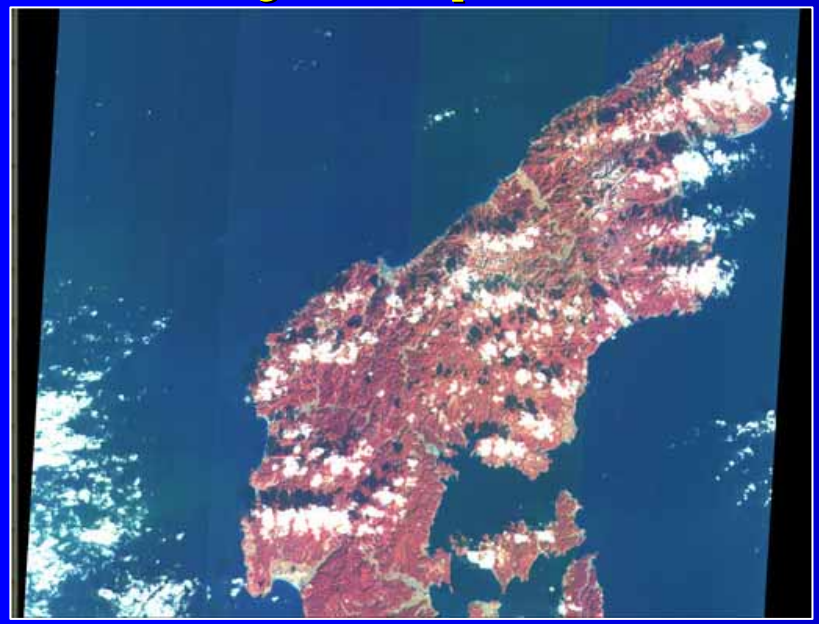
- Oil Slicks are not always easily visible in Satellite imagery from *passive sensor* like optical sensors.

- Instead of optical sensors, more often, Oil Slicks are observed with *active sensors* like SAR (Synthetic-Aperture Radar).
- SAR can be observed regardless of day and night, without being influenced by clouds.

- The SAR image interpretation is rather difficult than optical imagery, and the experience and the training are required for the information extraction.

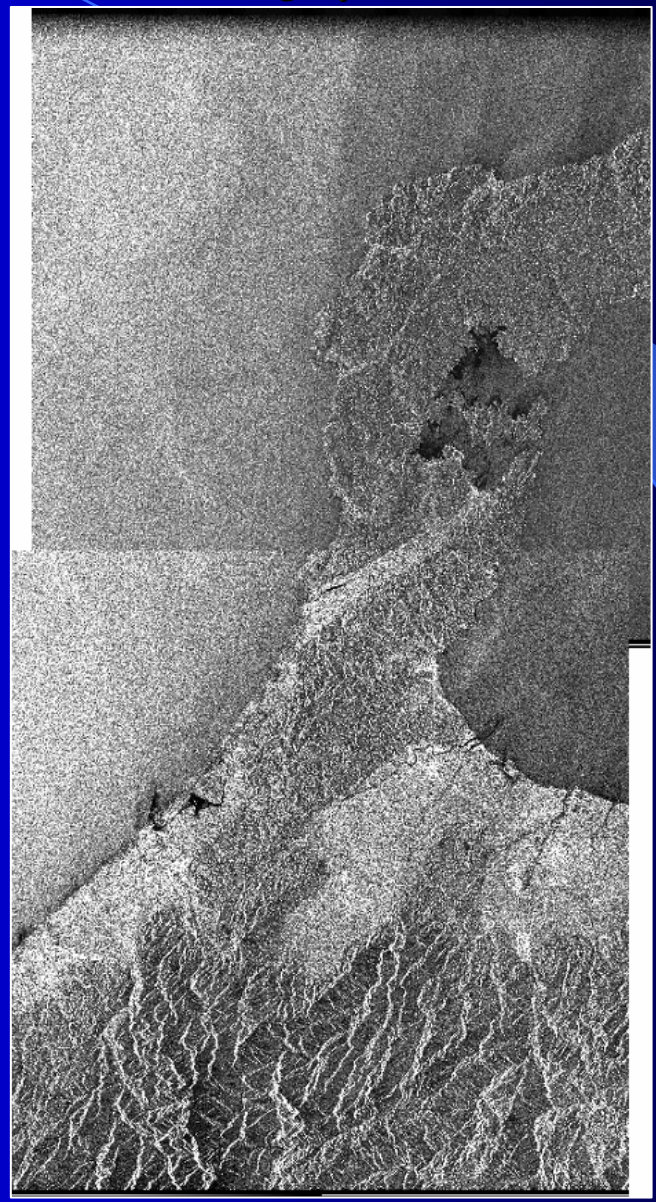
Comparison with an optical sensor imagery and a SAR sensor imagery

An image of an optical sensor



SPOT
Date: 1997/01/17
Sensor: HX
Path: 324
Low: 275

An imagery of SAR



ERS-2
ORBIT:0009125
Date: 1997/01/17

Frame center:
N 37.20
E 136.73

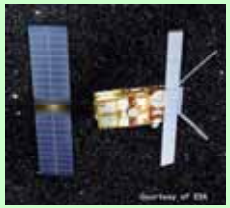
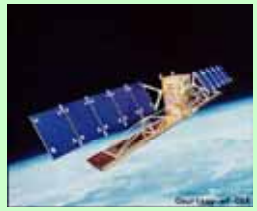
ORBIT:0009125
Date: 1997/01/17

Frame center:
N 36.60
E 136.88

2. Purpose

- Try to visualize the oil slick area more easily by applying Wavelet analysis to SAR data.
- And the final goal of this development is that an Automated Oil Spill Monitoring and Early Warning System will be constructed.

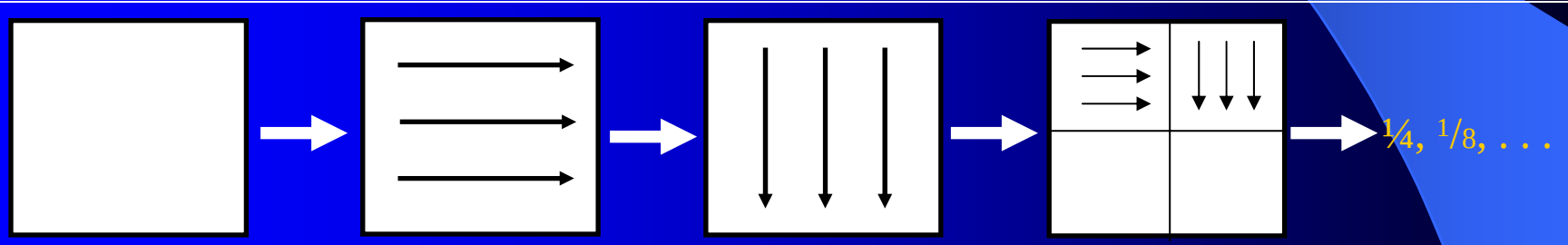
3. The specification of satellites and its equipped SAR sensor (in operation)

Satellite	ERS-2	RADARSAT	ENVISAT	ALOS		
						
Country	Europe	Canada	Europe	Japan		
Distributor	ESA	CSA	ESA	RESTEC		
Launch	April 21, 1995	November 4, 1995	March 1, 2002	January 24, 2006		
Altitude	780km	798km	799.8km	691.65km (at Equator)		
Orbital Category	Sun-synchronous sub-recurrent	Sun-synchronous sub-recurrent	Sun-synchronous sub-recurrent	Sun-synchronous sub-recurrent		
Life	6 years	5 years	5 years	3～5 years		
Repeat cycle	35 days	24 days	35 days	46 days		
Circling the earth	About 100.5 minutes	About 101 minutes	100.59 minutes	About 99 minutes		
Sensor	**AMI**	**C band SAR**	**ASAR (and 9 others)**	**PALSAR**	PRISM	AVNIR-2
Spatial resolution	30m	10～100m	30m	7～100m	2.5m (At nadir)	10m (At nadir)
Bands	5.3GHz(C-Band)	5.3GHz(HH polarization)	5.331GHz (C-Band)	1.27GHz (L-Band)	1 Band (Panchromatic)	4 Bands
Number of bands	1ch	1ch	6ch	1ch, 3 polarization	9ch	4ch
Sensor on board	AMI	SAR	ASAR	PALSAR	Optical sensor	Optical sensor
Mode	Image Mode Wave Mode Wind Mode	Fine Beam Mode Standard Beam Mode Wide Beam Mode ScanSAR Narrow Beam Mode Extended High Mode Extended Low Mode	Image mode Alternating polarization mode Wave mode ASAR ScanSAR mode Wide swath mode Global monitoring mode	Fine mode, ScanSAR mode, Polarimetric (Experimental mode)		
Swath width	80.4km	50～500km	56～100km(selectable)	30～350km	70km (Nadir mode) 35km (Triplet mode)	70km (Nadir mode)
Pointing angle / Incident angle	±23 °	20～60 °		8～60 °	±1.2 ° (Triplet mode, Cross-track)	±44 °

4. Methodology

Multi-resolution Analysis of the Wavelet Transform was applied.
The Haar wavelet was used as the Mother wavelet.

½	½	0	0
0	0	½	½
½	-½	0	0
0	0	½	-½



An original resolution

Low pass → Low pass
Low pass → High pass
High pass → Low pass
High pass → High pass

A half band Resolution

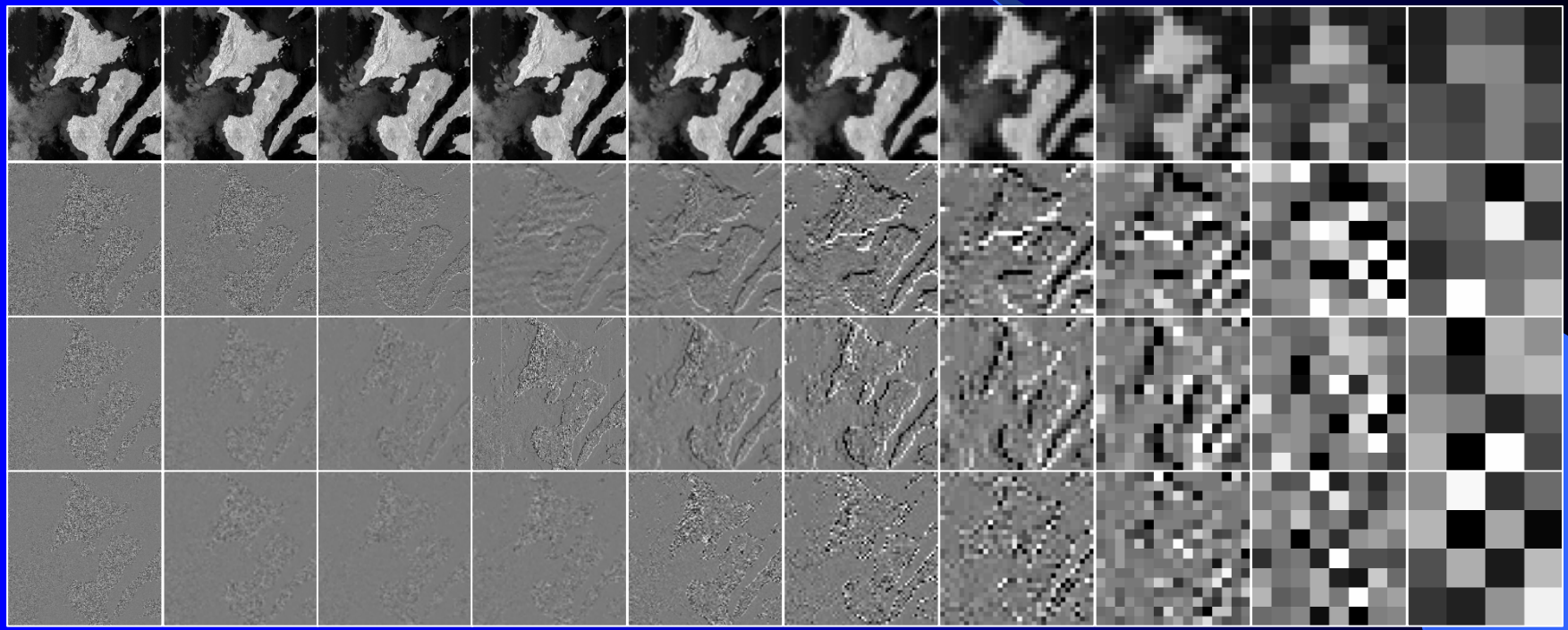
Change Resolution

¼, ⅛, . . .

Extract a gradient of wavelet spectral by each pixel

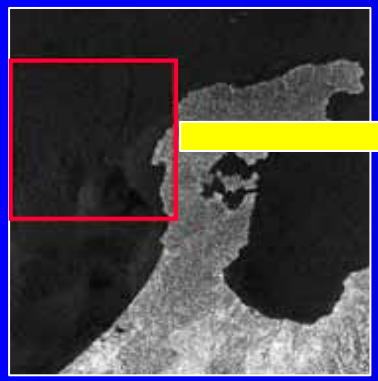
4. Methodology

Multi-resolution Analysis of the Wavelet Transform

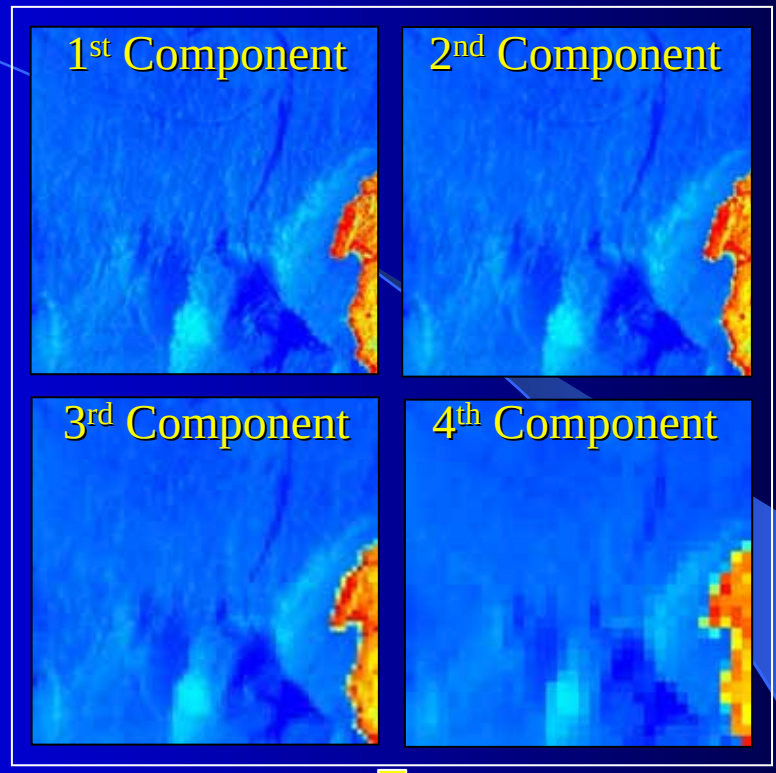


4. Methodology

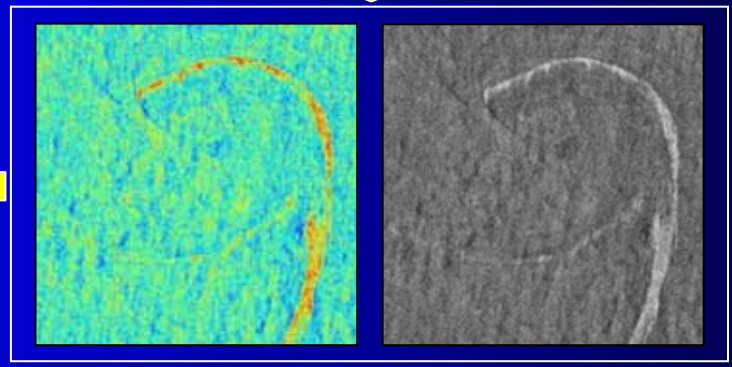
Wavelet Transform



RADARSAT
Jan.11, 1997



Detect Oil Spilled Area



Map the detected Oil Spill Area

5. Case Studies

1) The oil tanker "Solar-1"(Philippines), Aug. 11, 2006

The tanker was carrying about 2 million liters of oil, when it sank off Guimaras Island in Panay bay located in the central Philippines under rough weather condition and initially spilled 200k liters into the sea.

2) The oil Tanker "Prestige" (Spain), Nov. 13, 2002

The Prestige carrying more than 67,000 tons of oil encountered a violent storm at about 150miles off from Spain's Atlantic coast. The leak of spilled oil was at least 6,700 tons sunk early in the day of 19 November 2002.

3) An Unknown Oil-spill, (Sweden), May 09, 2005

A 97-kilometer oil slick was discovered off Sweden's South-Eastern coast in the Baltic Sea during a routine flight of Swedish Coast Guard. About 25tons of oil were located between the islands of Gotland and Oland, however it was not known where the oil came from.

4) Oil-fuel storage tanks of Power plant, (Lebanon), July 13,15, 2005

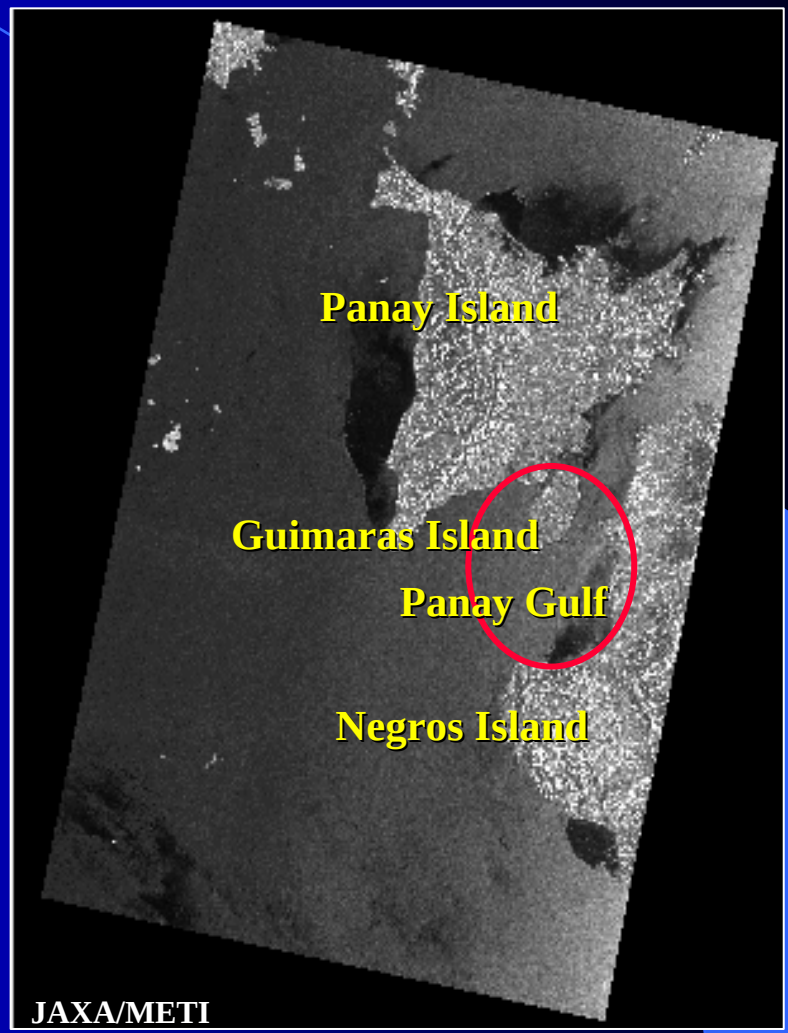
The oil-fuelled power plant of Jieh located on the coastline about 30 km south of Beirut was hit by bombs on July 13 and 15, 2006 in the course of the conflict of the Middle East. An estimated 30,000 tons of heavy fuel oil leaked into the Mediterranean sea.

5-1. Case Study : The oil tanker “Solar-1”(Philippines), Aug. 11, 2006

The tanker was carrying about 2 million liters of oil, when it sank off Guimaras island in Panay Gulf located in the central Philippines under rough weather condition and initially spilled off 200k liters into the sea.

5-1. Case Study : The oil tanker “Solar-1”(Philippines), Aug. 11, 2006

The disaster scene



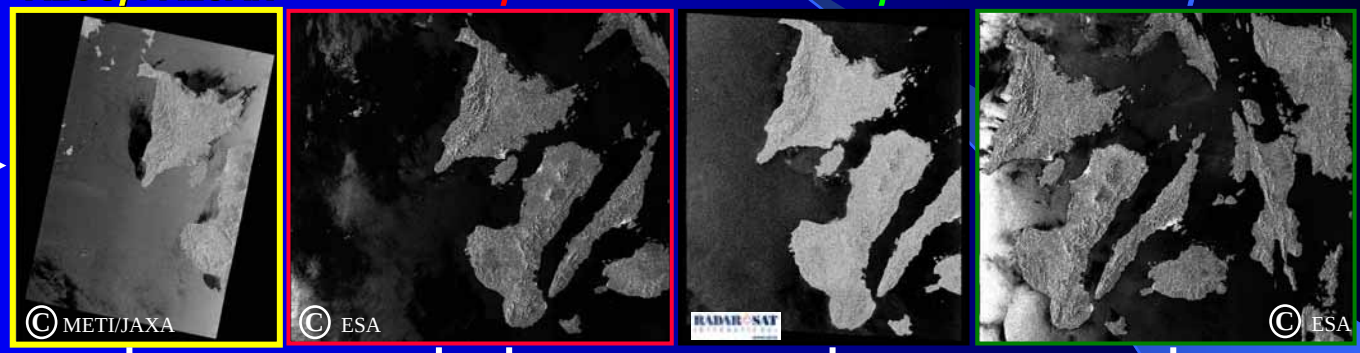
A flow of the analysis

Occurrence date:
Aug. 11, '06

Observation date and time

Observation data

Aug. 25, '06 02:13	Aug. 25, '06 13:53	Aug. 27, '06 10:02	Aug. 28, '06 13:58
ALOS/PALSAR	ENVISAT/ASAR	RADARSAT/SAR	ENVISAT/ASAR



Applying Wavelet Analysis

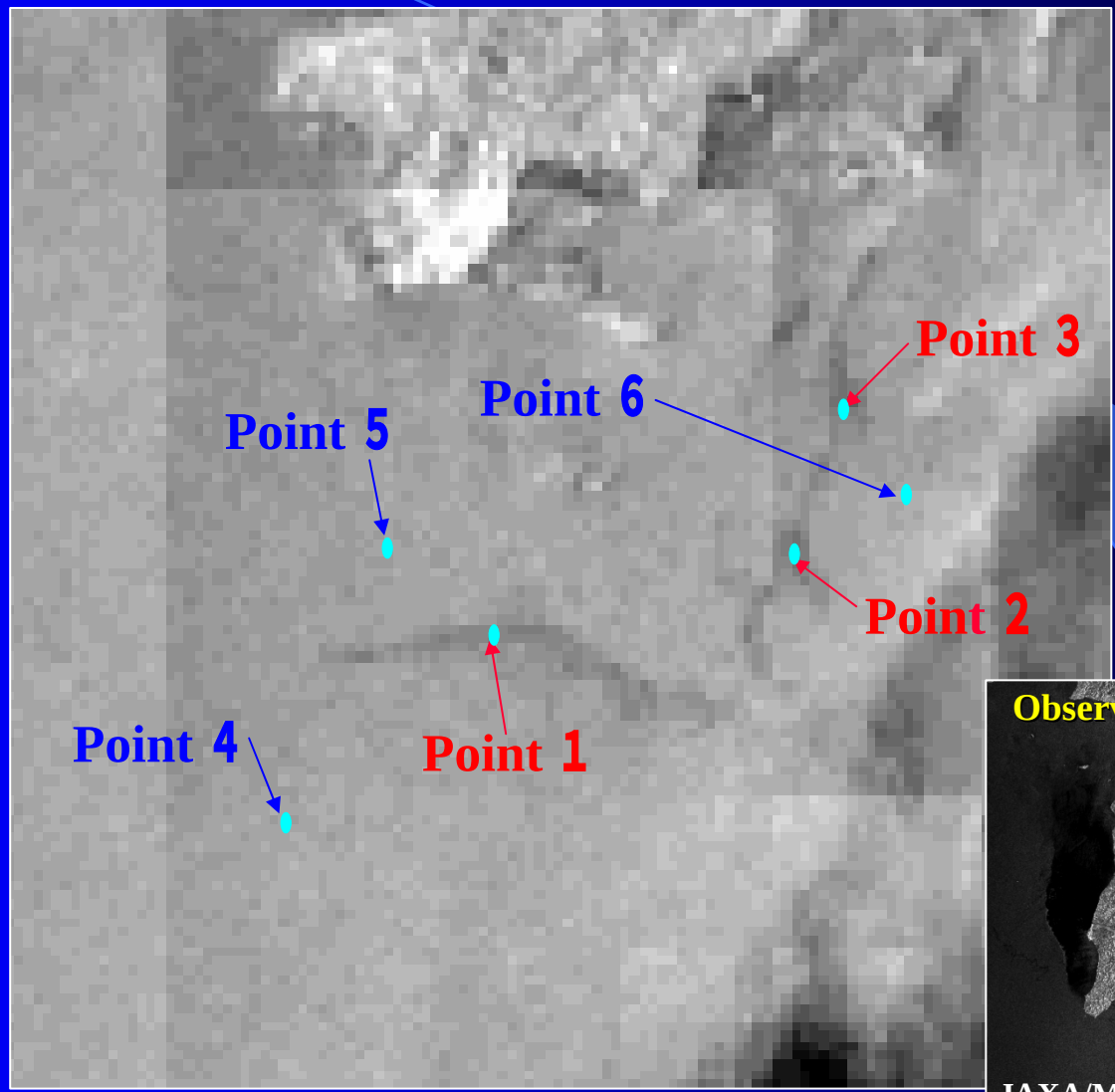
Mapping

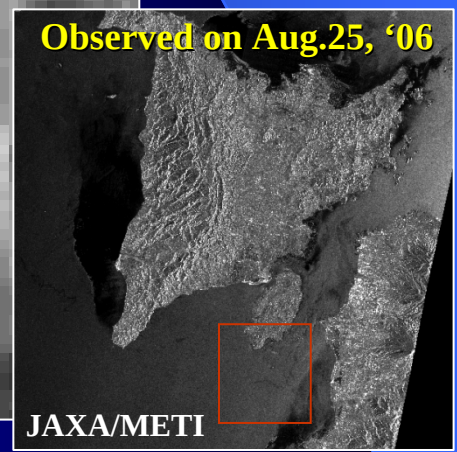
Analysis Example 1. ALOS/PALSAR (Observation date : Aug. 25, 2006)

LL 1st to 7 th component

Processing area (2048 * 2048)

The Result imagery of the Wavelet analysis of ALOS/PALSAR

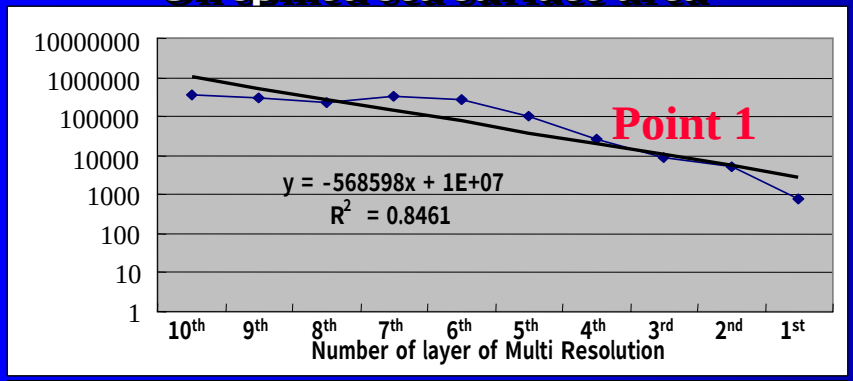


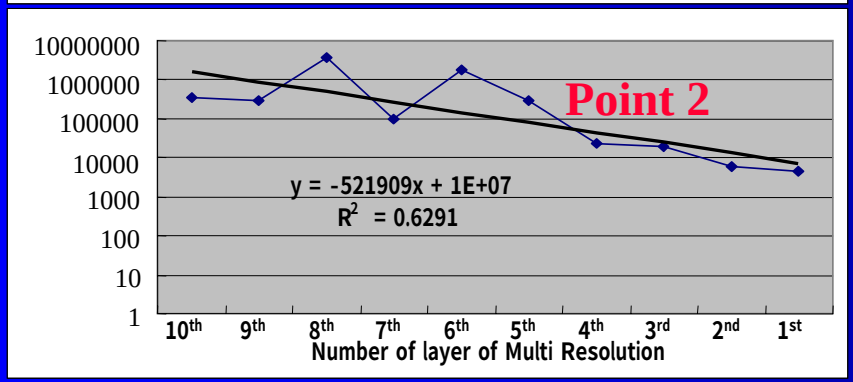


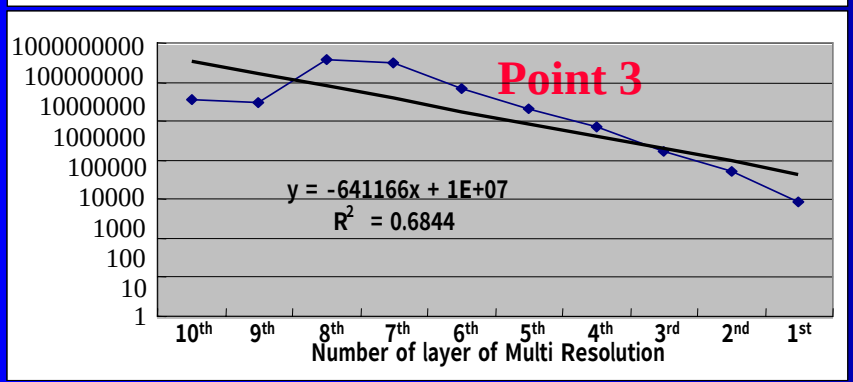
The sampling points are selected in the area detected as an spilled area : Point1～3
The sampling points are selected in the normal sea surface area : Point4～6

The Profile of Wavelet Spectrum between the spilled oil area and the normal sea surface.

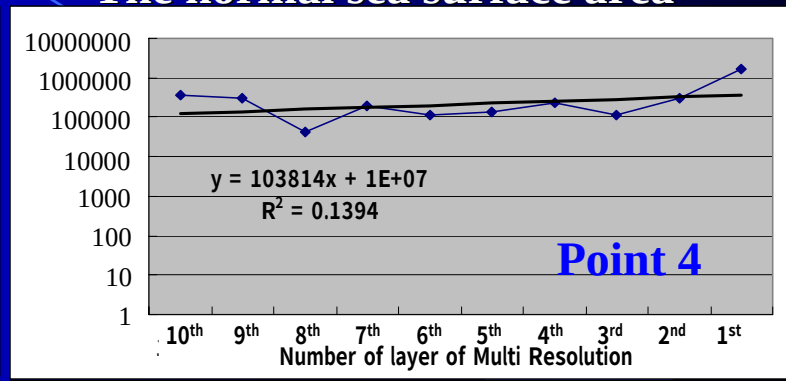
Oil spilled sea surface area

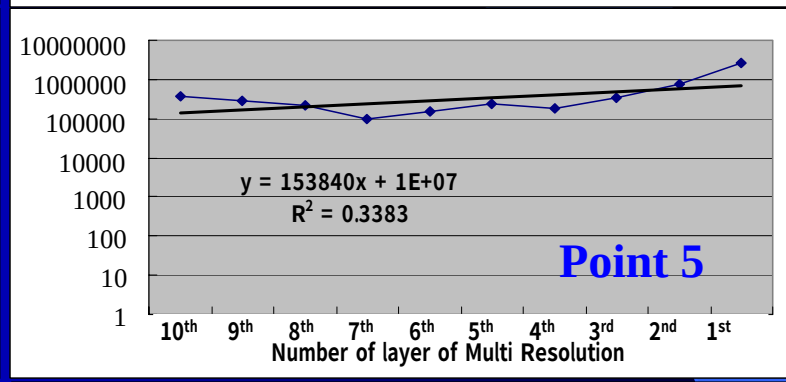


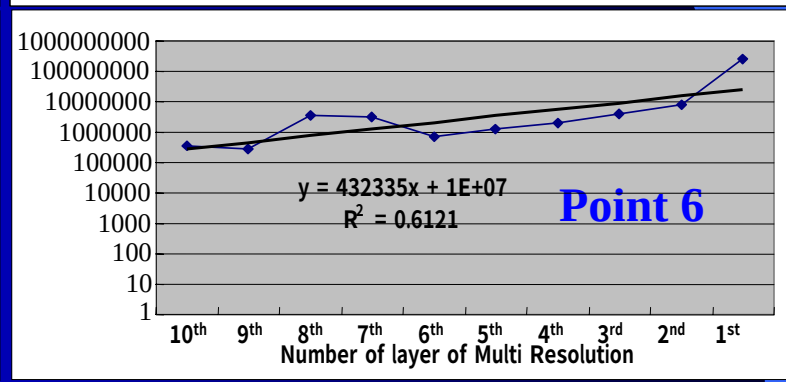




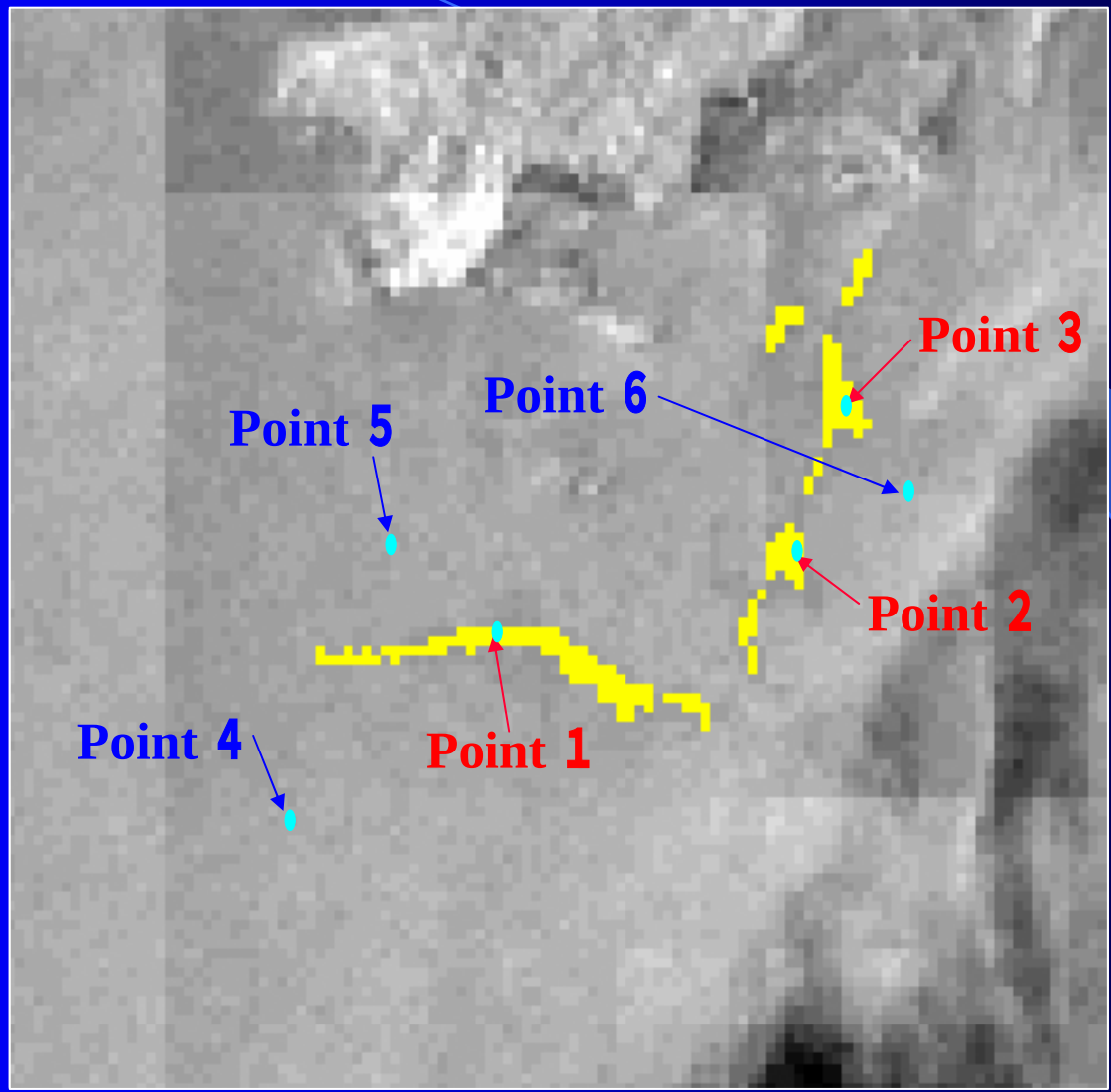
The normal sea surface area







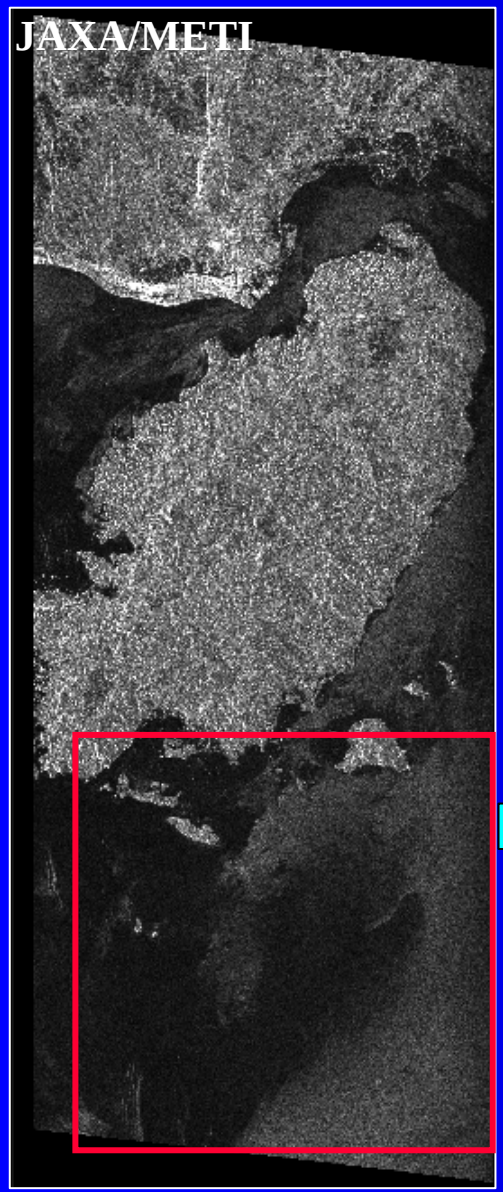
Mapping of the Oil-Spilled Area detected by Wavelet Analysis

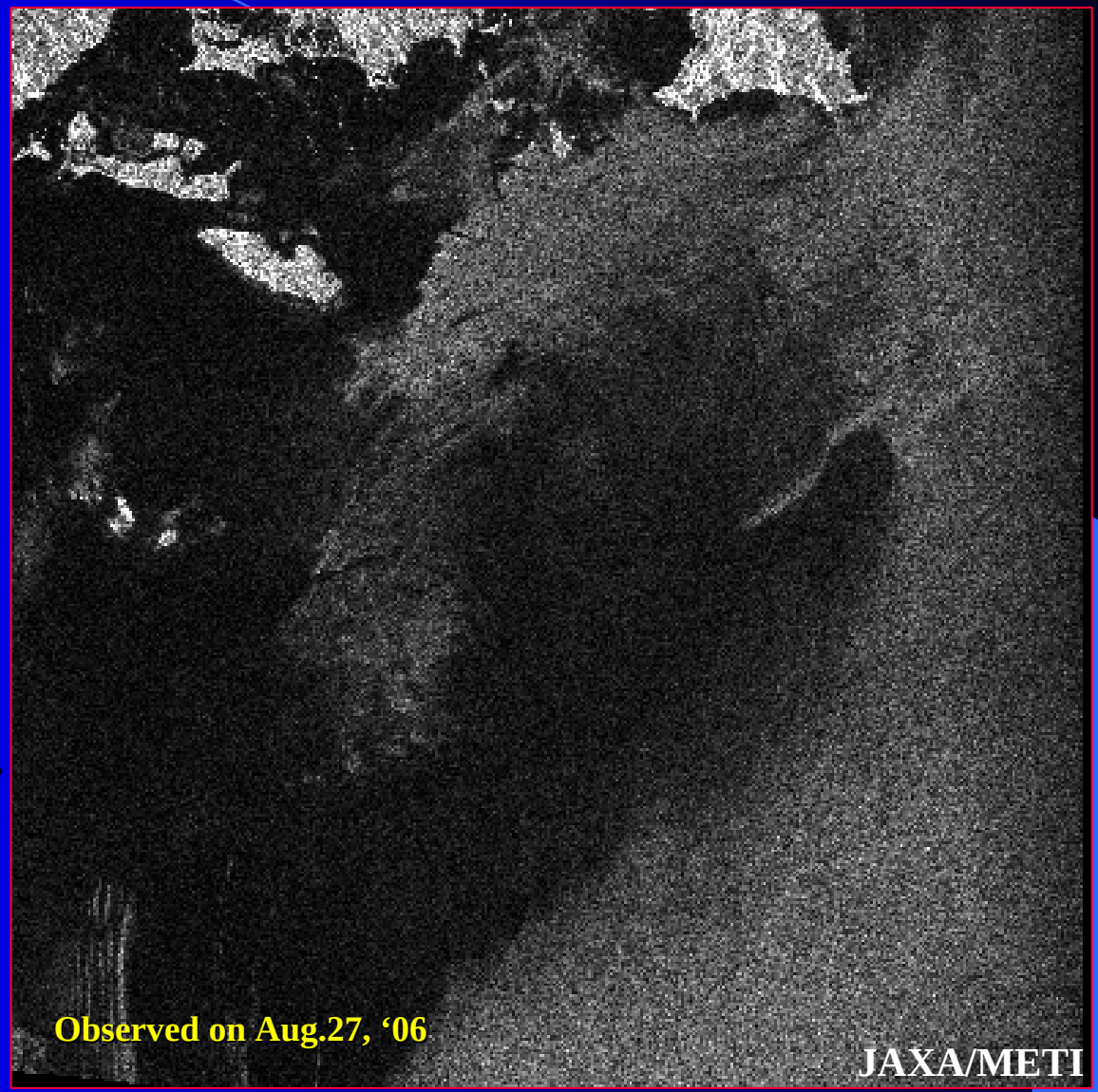


Estimated Oil Spilled Area

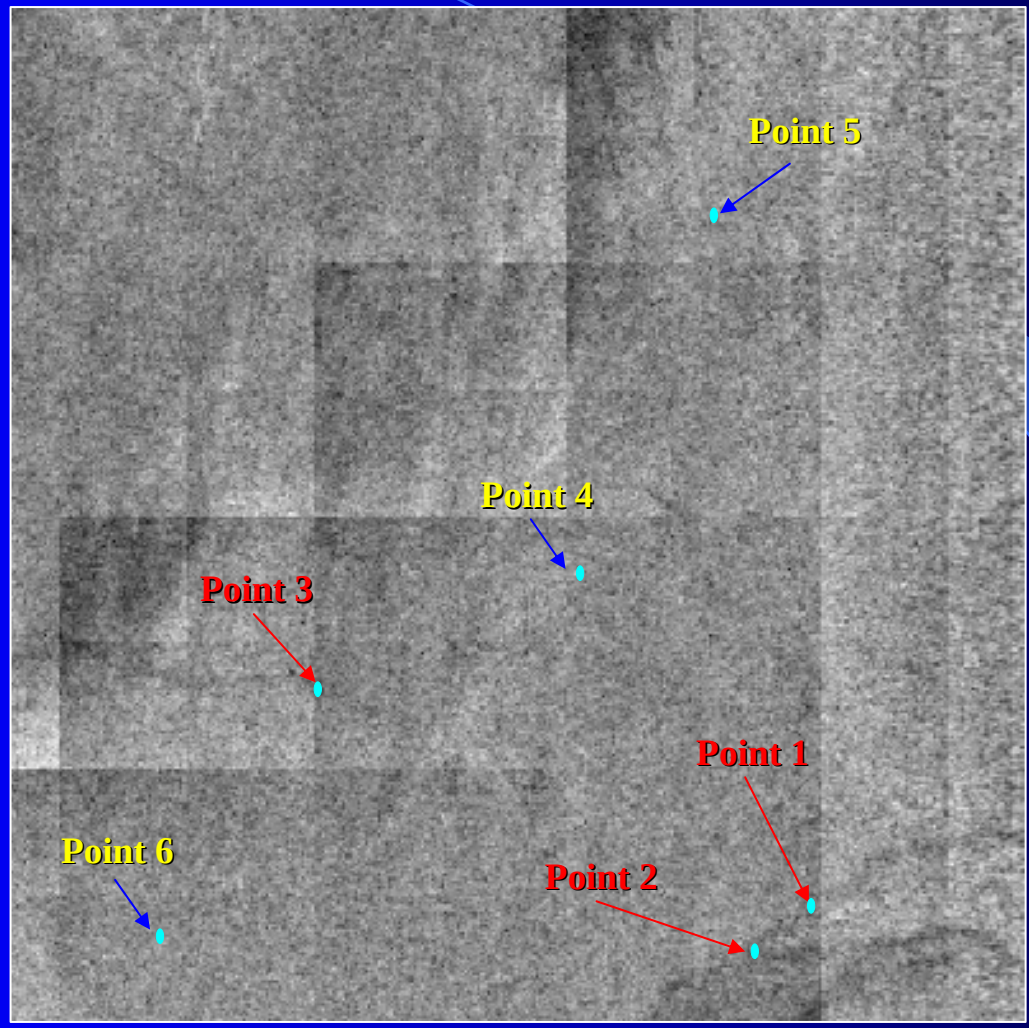
Estimated normal Sea Surface Area

Analysis Example 2. ALOS/PALSAR (Observation date : Aug. 25, 2006)





The Result Imagery of the Wavelet analysis of ALOS/PALSAR

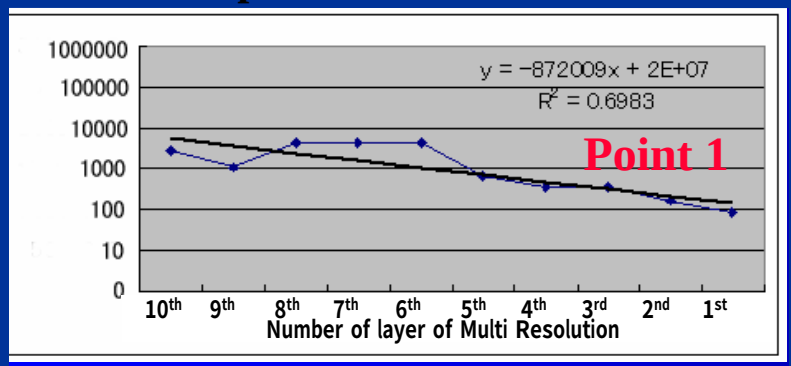


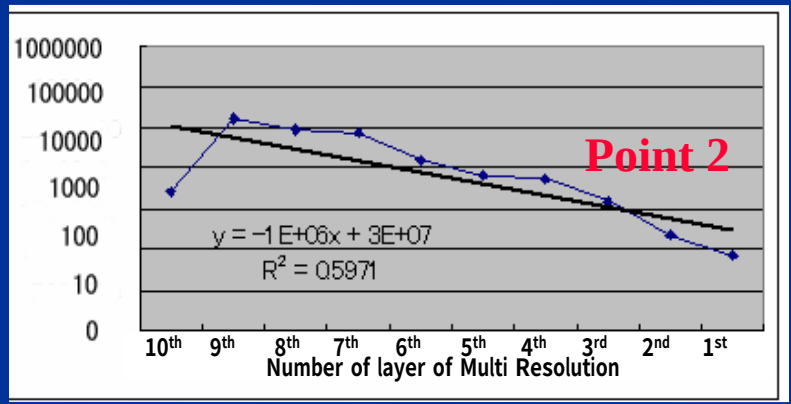
The sampling points are selected in the area detected as an spilled area ： Point 1～3

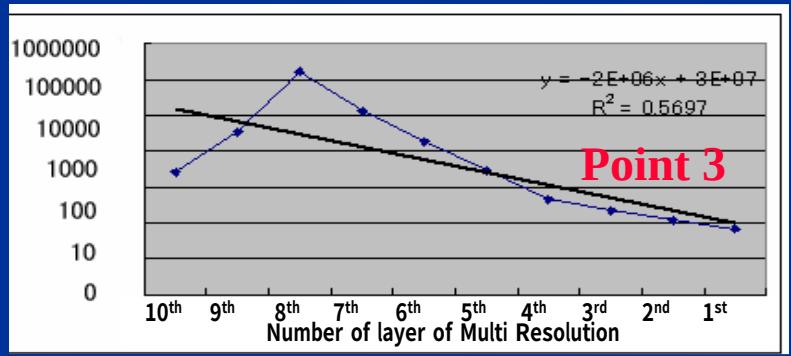
The sampling points are selected in the normal sea surface area ： Point 4～6

The Comparison of Wavelet spectrum profile between the spilled oil area and the normal sea surface.

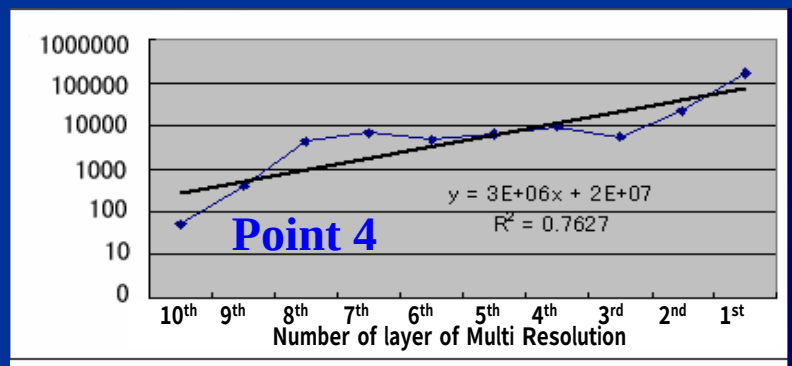
Oil spilled sea surface area

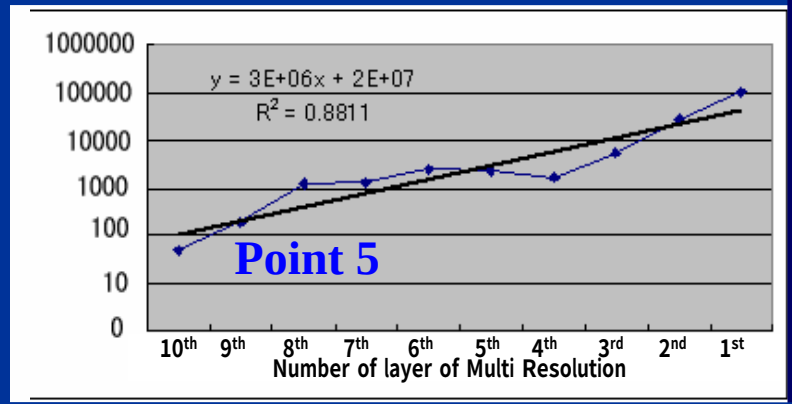


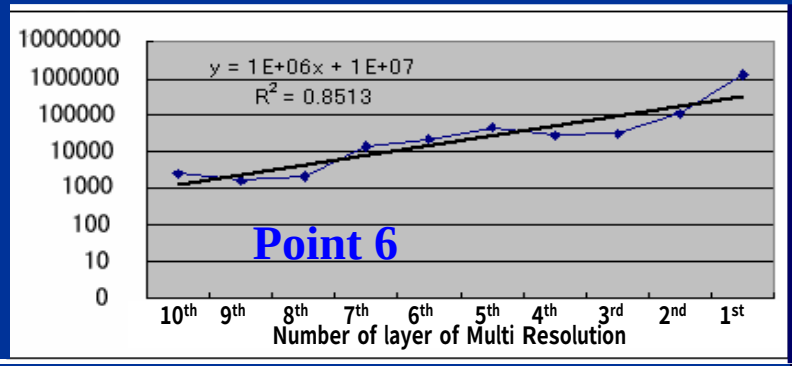




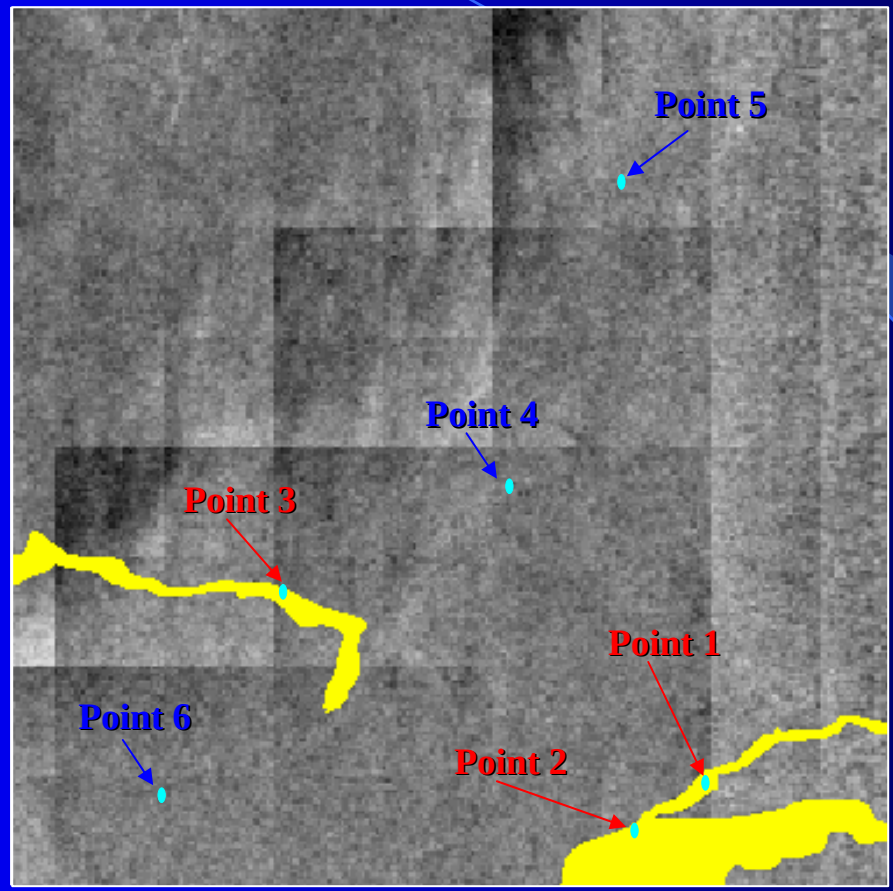
The normal sea surface area



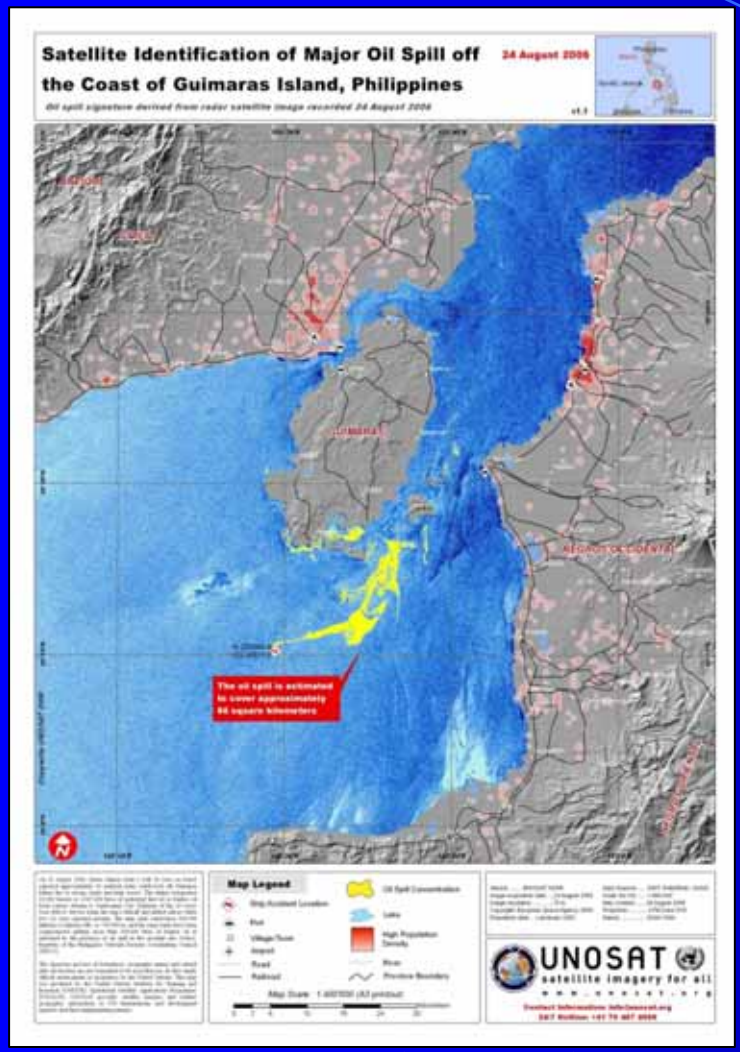




Mapping of the Oil Spilled Area detected by Wavelet Analysis



The Comparison with Map Products of UNOSAT

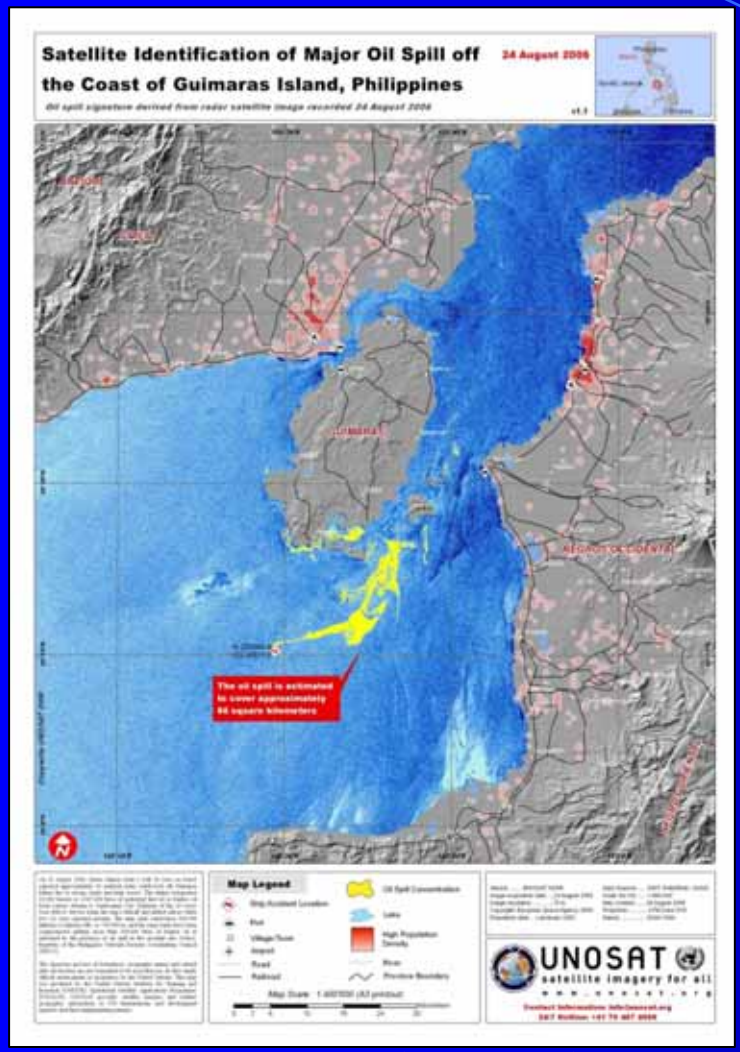


Aug. 24, '06 (UNOSAT)
ENVISAT/ASAR (Aug. 24, 2006)

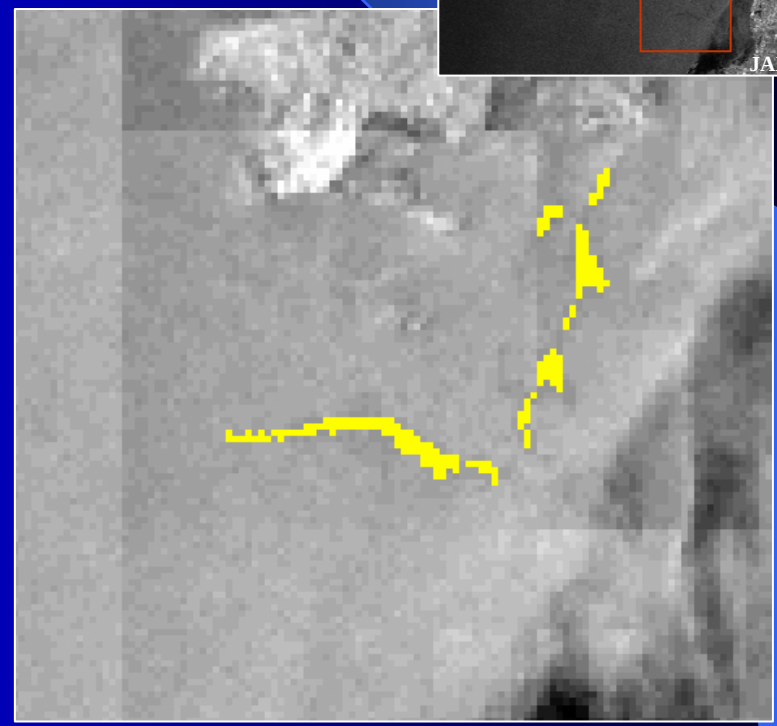
Aug. 27, '06 (UNOSAT)
RADARSAT (Aug. 27, 2006)

http://unosat.web.cern.ch/unosat/

The Comparison with Map Products of UNOSAT

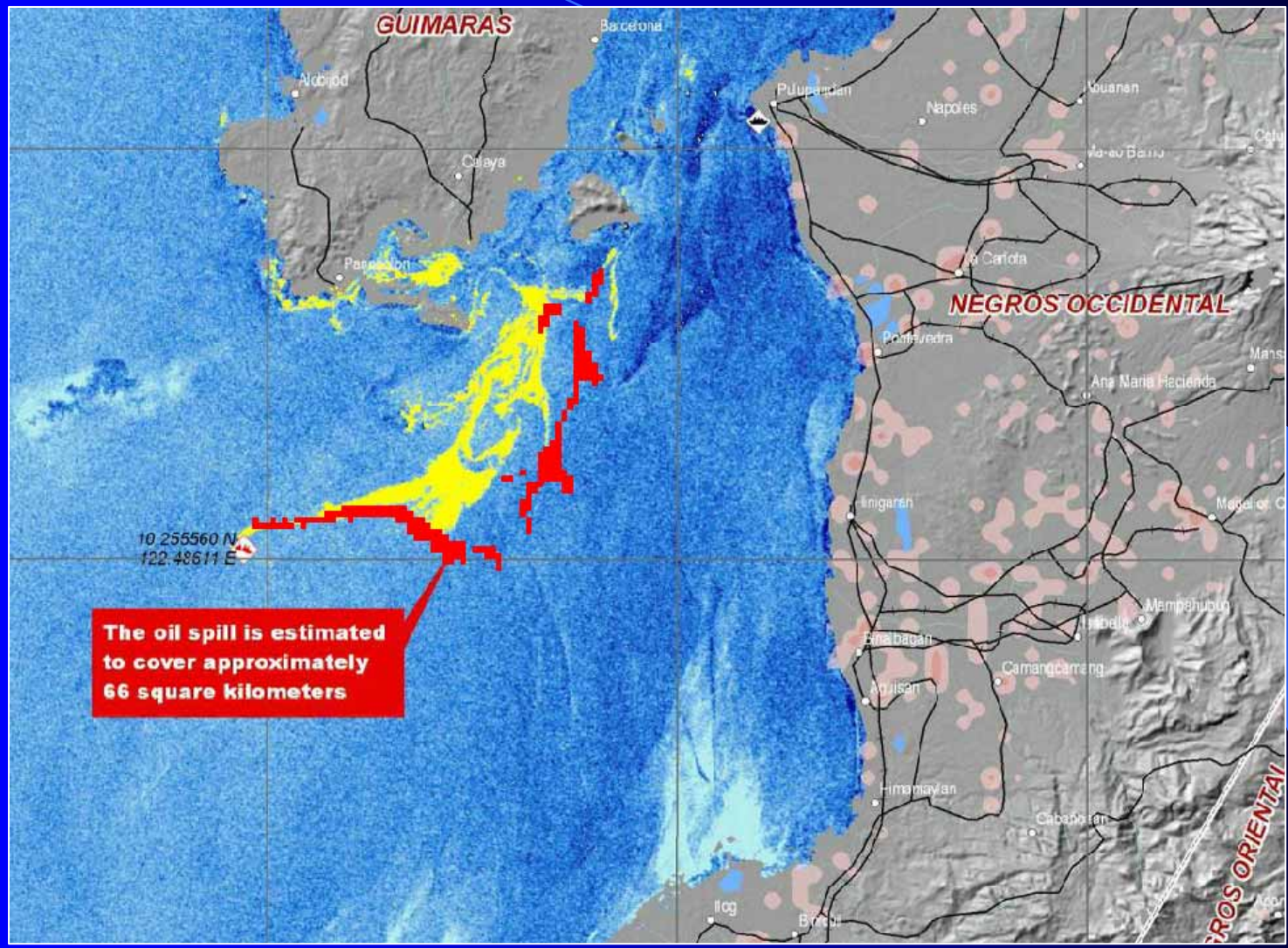


Aug. 24, '06 (UNOSAT)
ENVISAT/ASAR (Aug. 24, 2006)



ALOS/PALSAR (Aug. 25, 2006)

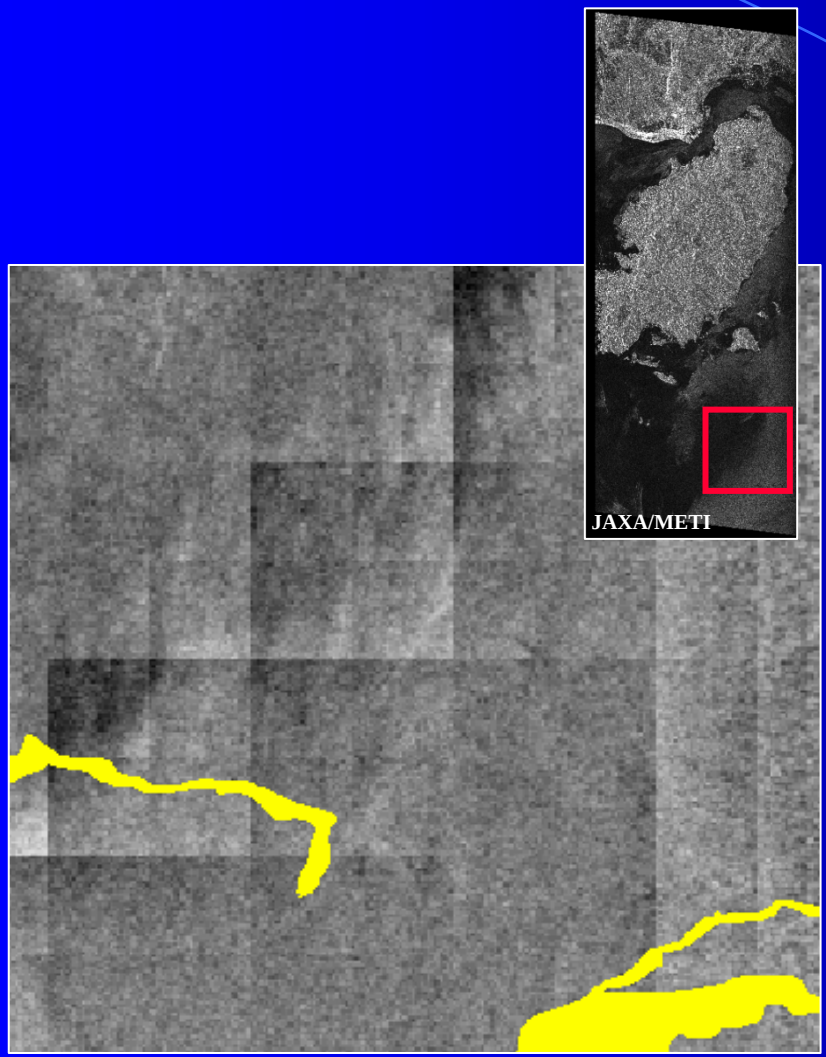
The Comparison with Map Products of UNOSAT



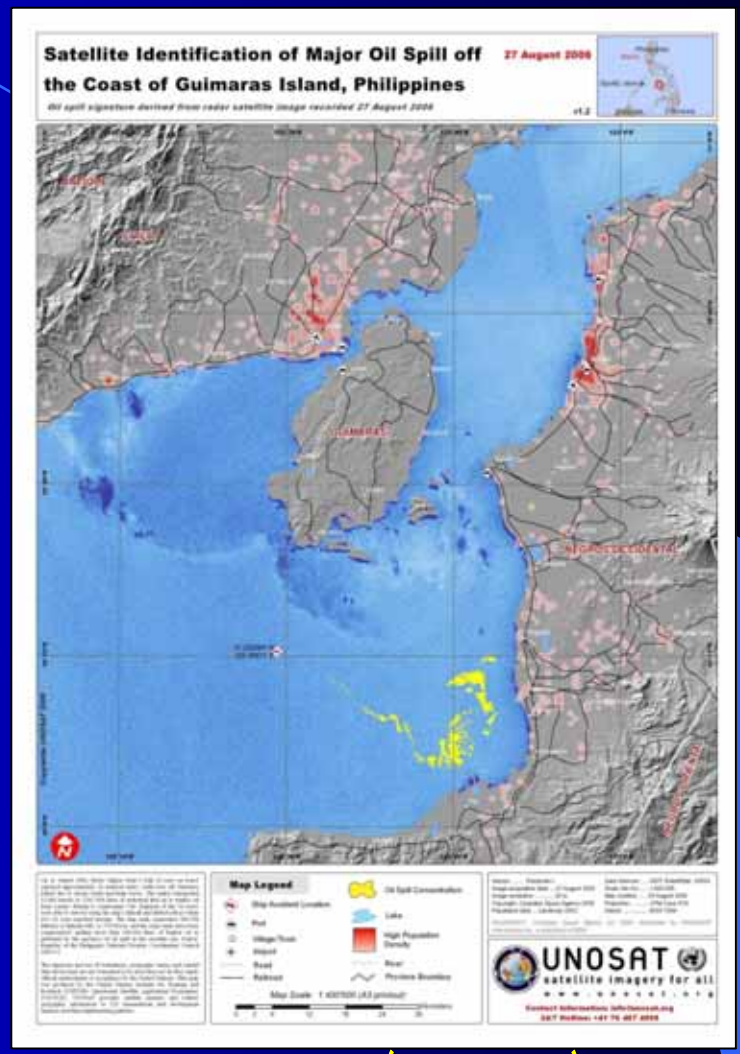
Aug.24, 2006 (ENVISAT)

Aug. 25, 2006 (PALSAR)

The Comparison with Map Products of UNOSAT

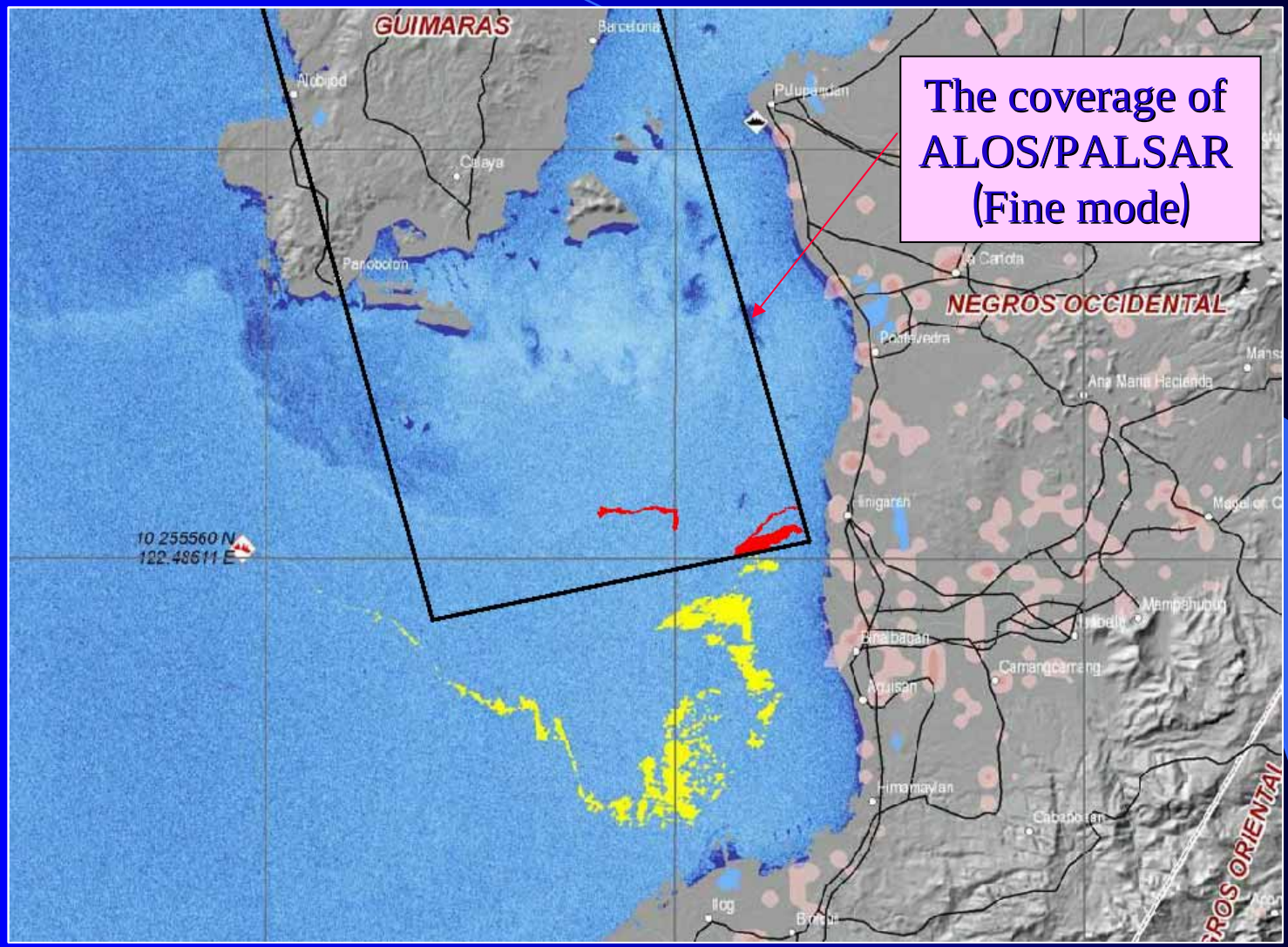


ALOS/PALSAR (Aug. 27, 2006)

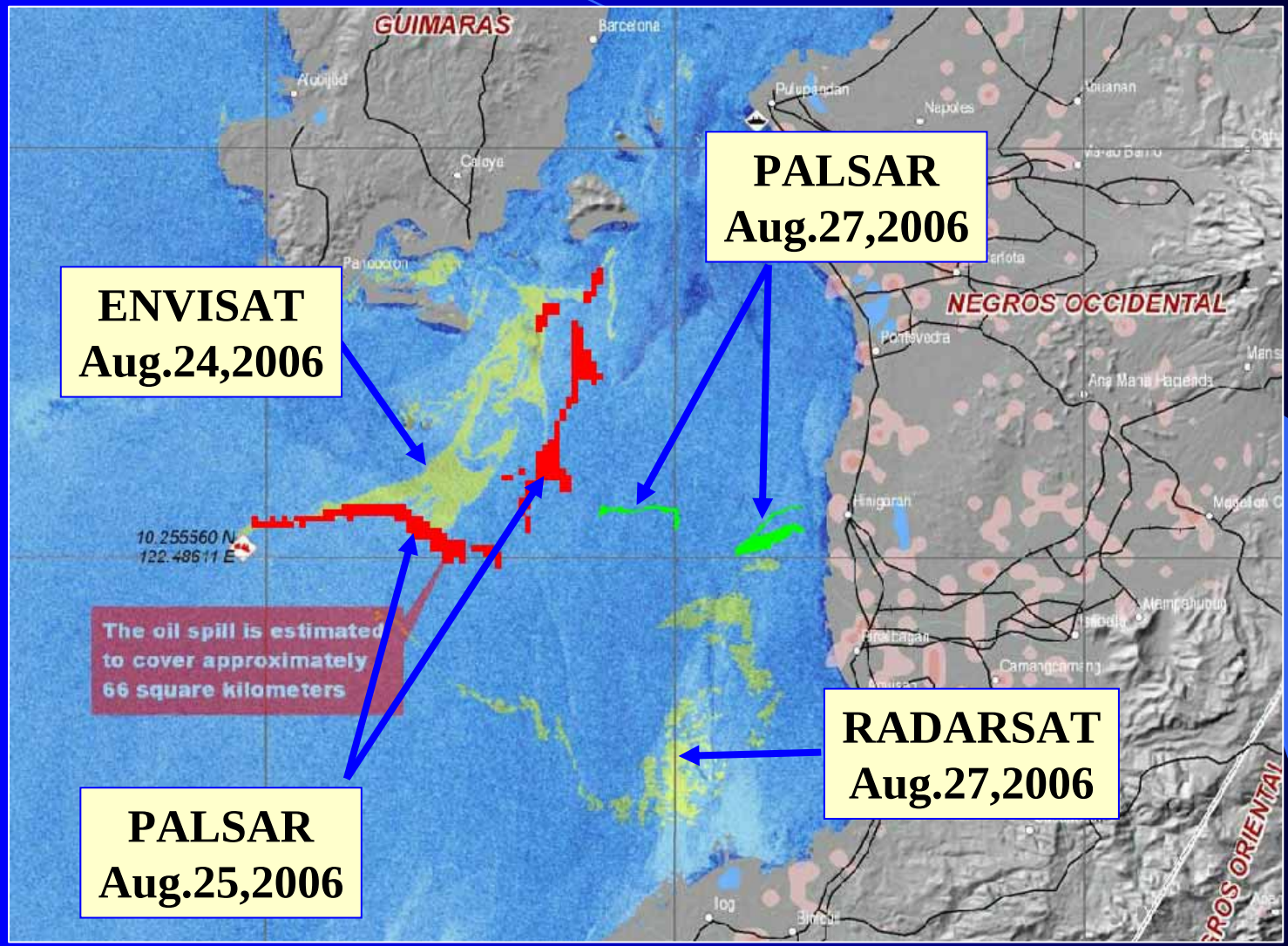


Aug. 27, '06 (UNOSAT)
RADARSAT (Aug. 27, 2006)

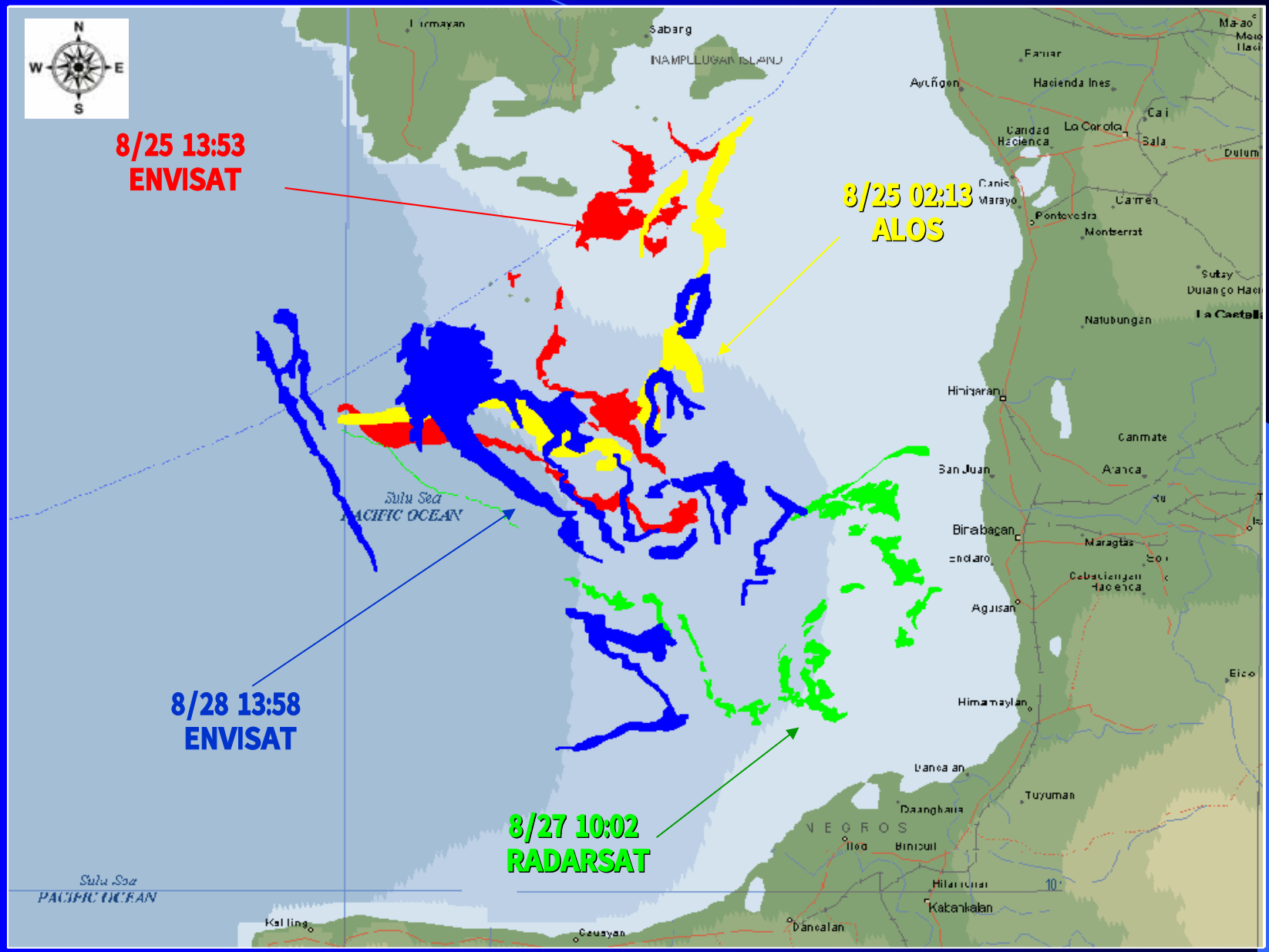
The Comparison with Map Products of UNOSAT



The Comparison with Map Products of UNOSAT



The Detected Oil-Spilled area from the satellite observation data



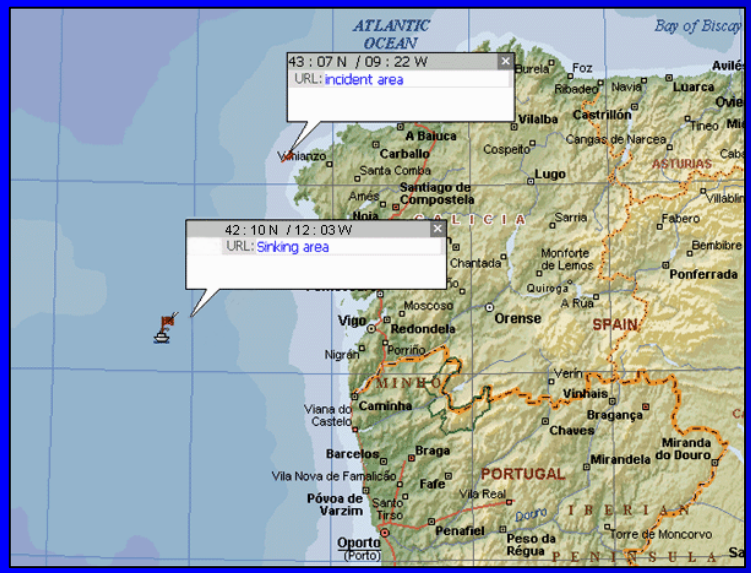
5-2. The oil Tanker “Prestige” (Spain), Nov. 13, 2002

The Prestige carrying more than 67,000 tons of oil encountered a violent storm at about 150miles off from Spain's Atlantic coast. The leak of spilled oil was at least 6,700 tons sunk early in the day of 19 November 2002.

Photos : http://www.cedre.fr/index_gb.html
http://earth.esa.int/ew/oil_slicks/galicia_sp02/ (copyright AP)

5-2. The oil Tanker "Prestige" (Spain), Nov. 13, 2002

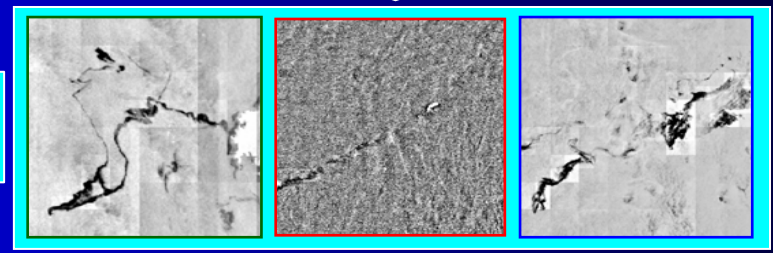
Disaster source



Occurrence date: Nov. 13, '02

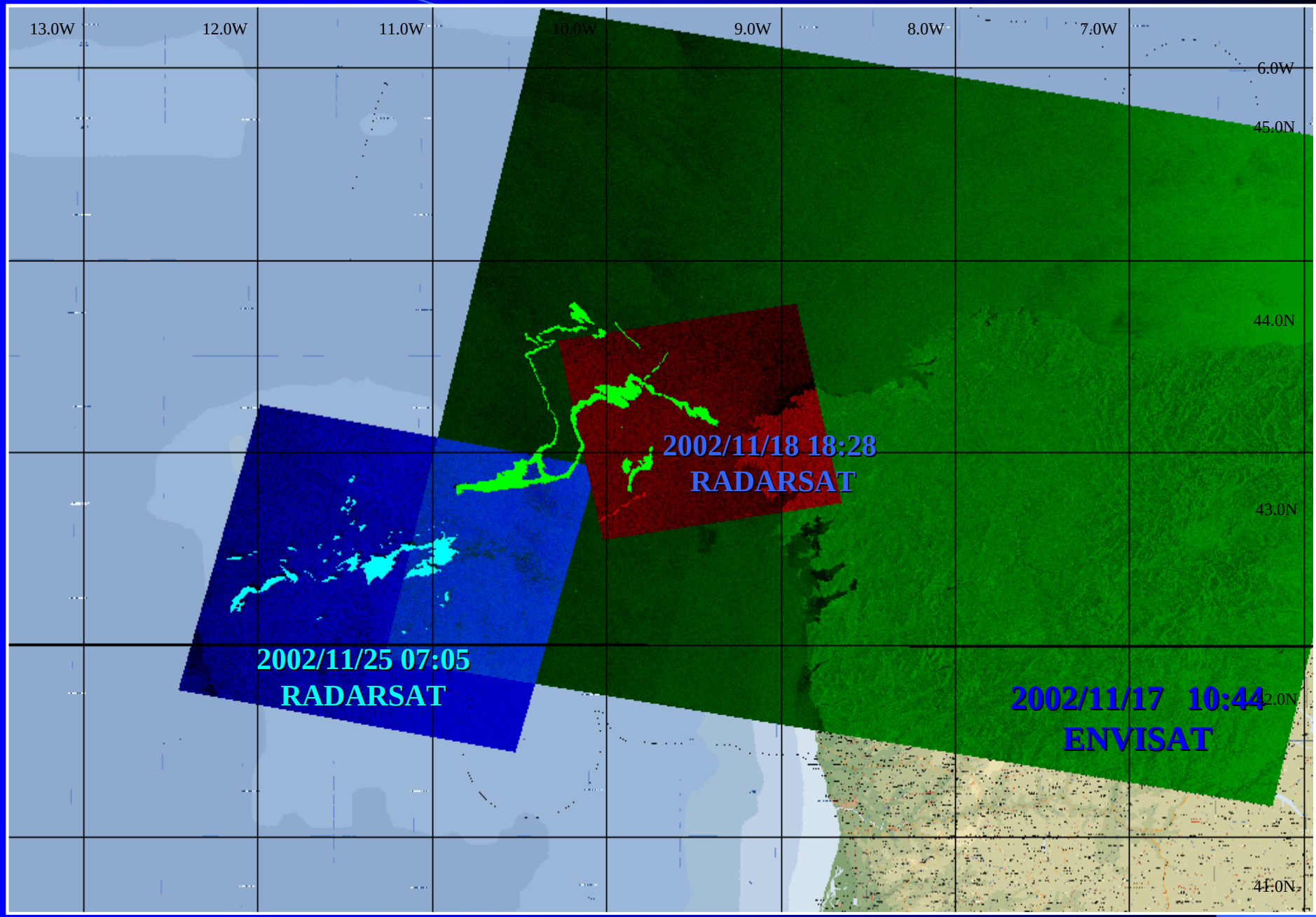
11/17/2002 ENVISAT | **11/18/2002 RADARSAT** | **11/25/2002 RADARSAT**

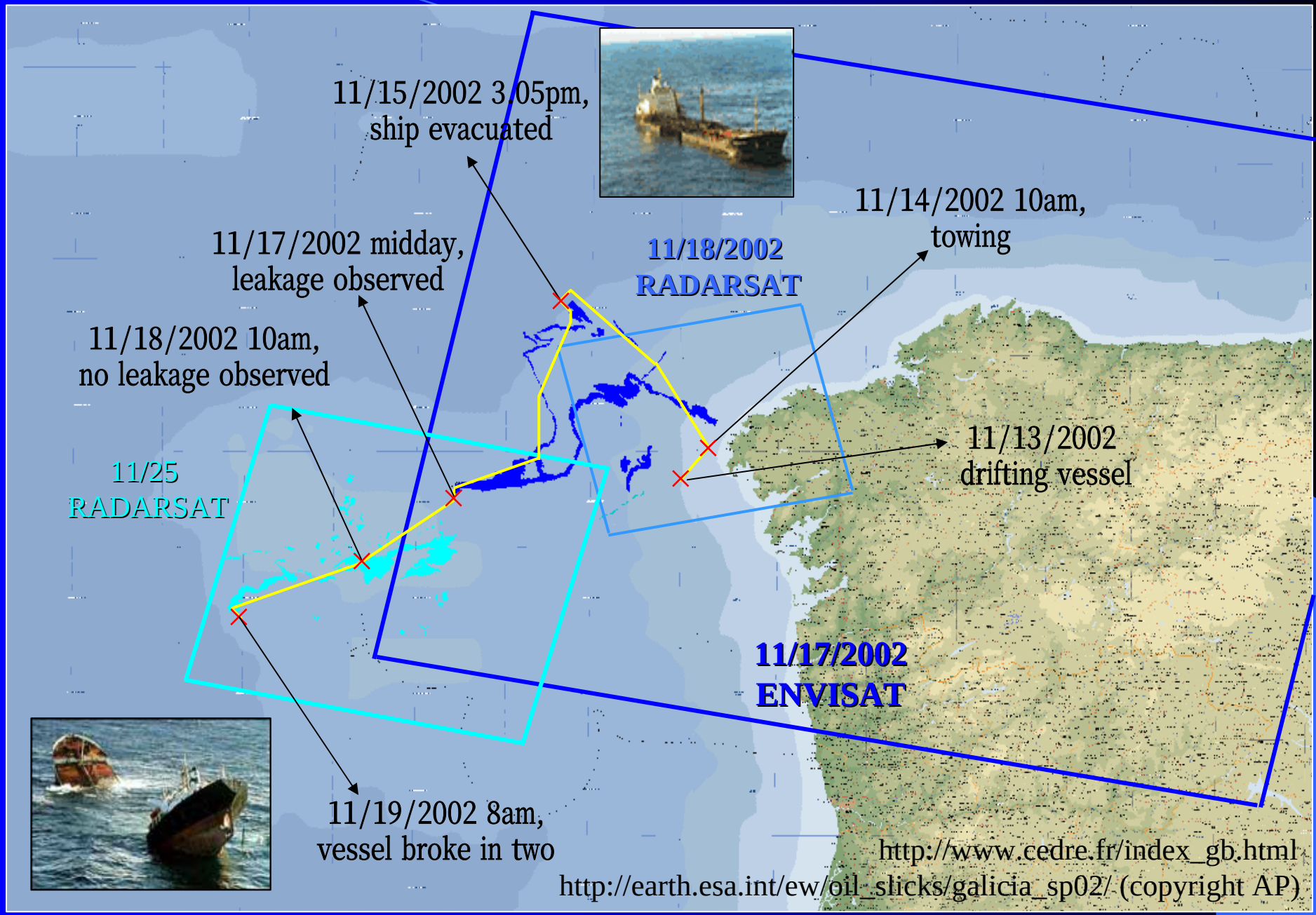
Oil-Spilled area detection by Wavelet Analysis



The result imagery of Wavelet Analysis

Mapping


13.0W
12.0W
11.0W
10.0W
9.0W
8.0W
7.0W
6.0W
45.0N
44.0N
43.0N
42.0N
41.0N
2002/11/18 18:28
RADARSAT
2002/11/25 07:05
RADARSAT
2002/11/17 10:44
ENVISAT


11/15/2002 3:05pm,
ship evacuated
11/14/2002 10am,
towing
11/17/2002 midday,
leakage observed
11/18/2002
RADARSAT
11/18/2002 10am,
no leakage observed
11/13/2002
drifting vessel
11/25
RADARSAT
11/17/2002
ENVISAT
11/19/2002 8am,
vessel broke in two
http://www.cedre.fr/index_gb.html
http://earth.esa.int/ew/oil_slicks/galicia_sp02/ (copyright AP)

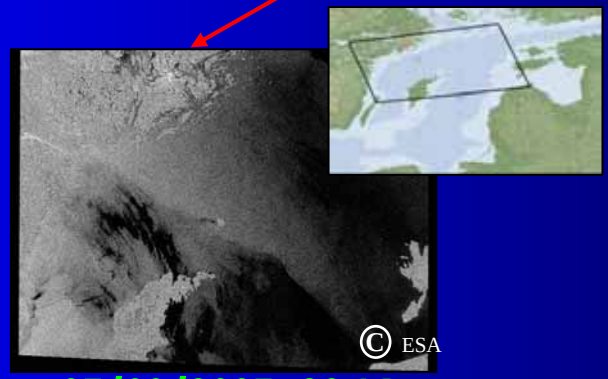
5-3. An Unknown Oil-spill, (Sweden), May 09, 2005

A 97-kilometer oil slick was discovered off Sweden's South-Eastern coast in the Baltic Sea during a routine flight of Swedish Coast Guard. About 25tons of oil were located between the islands of Gotland and Oland, however it was not known where the oil came from.

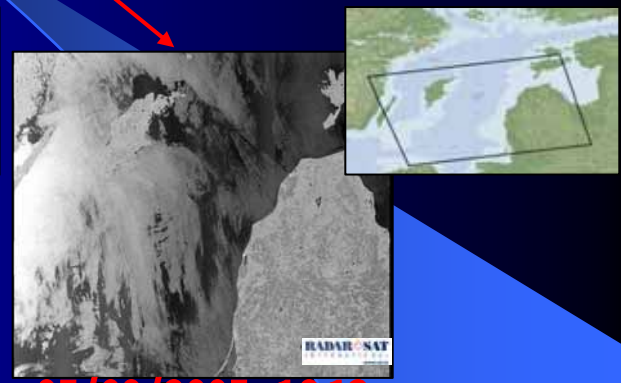
5-3. An Unknown Oil-spill, (Sweden), May 09, 2005

Disaster source

Occurrence date: May 09, '05

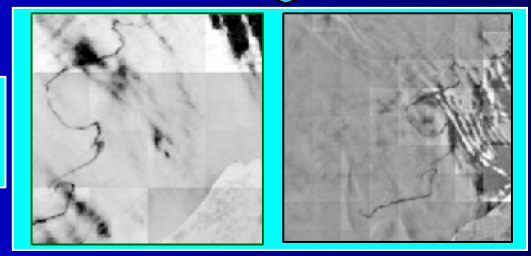


05/09/2005 20:14
ENVISAT



05/09/2005 16:13
RADARSAT

Wavelet Analysis



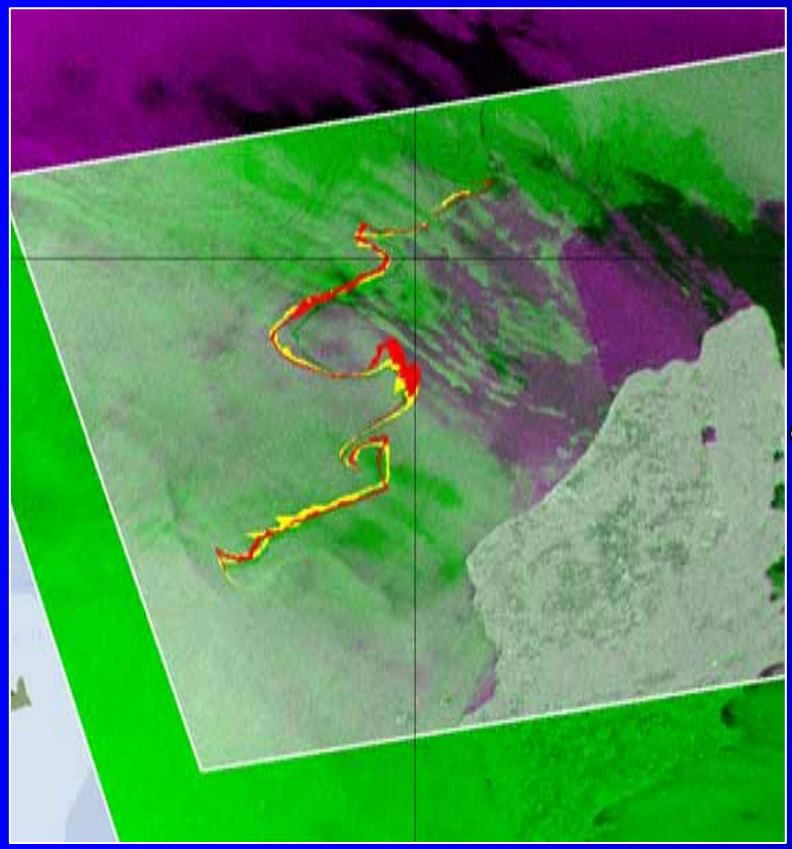
ENVISAT 05/09/2005

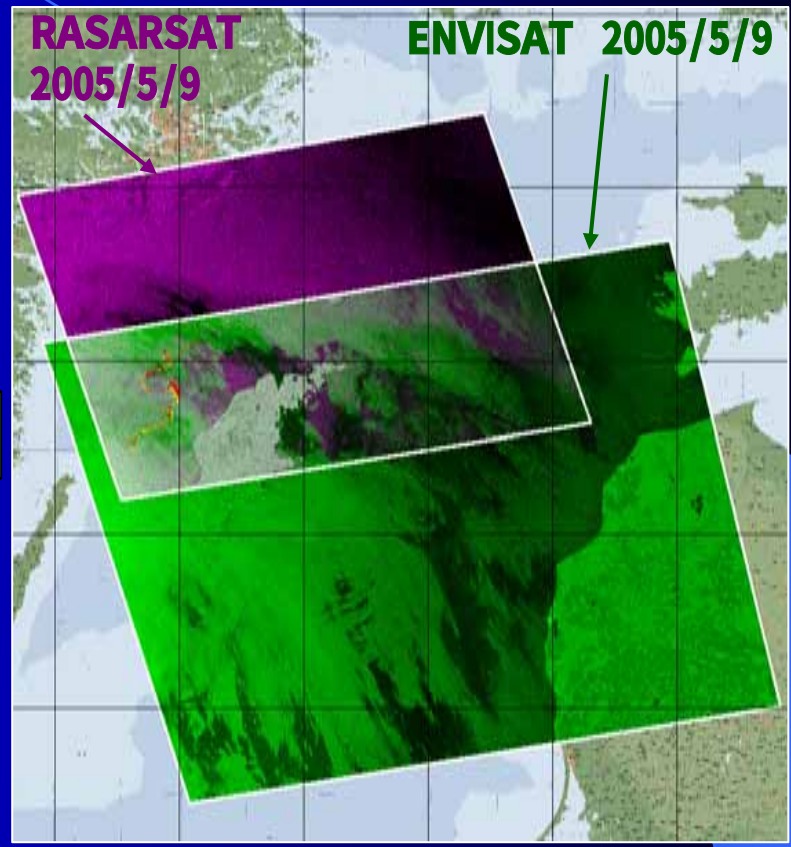
RADARSAT 05/09/2005

The result imagery of Wavelet Analysis

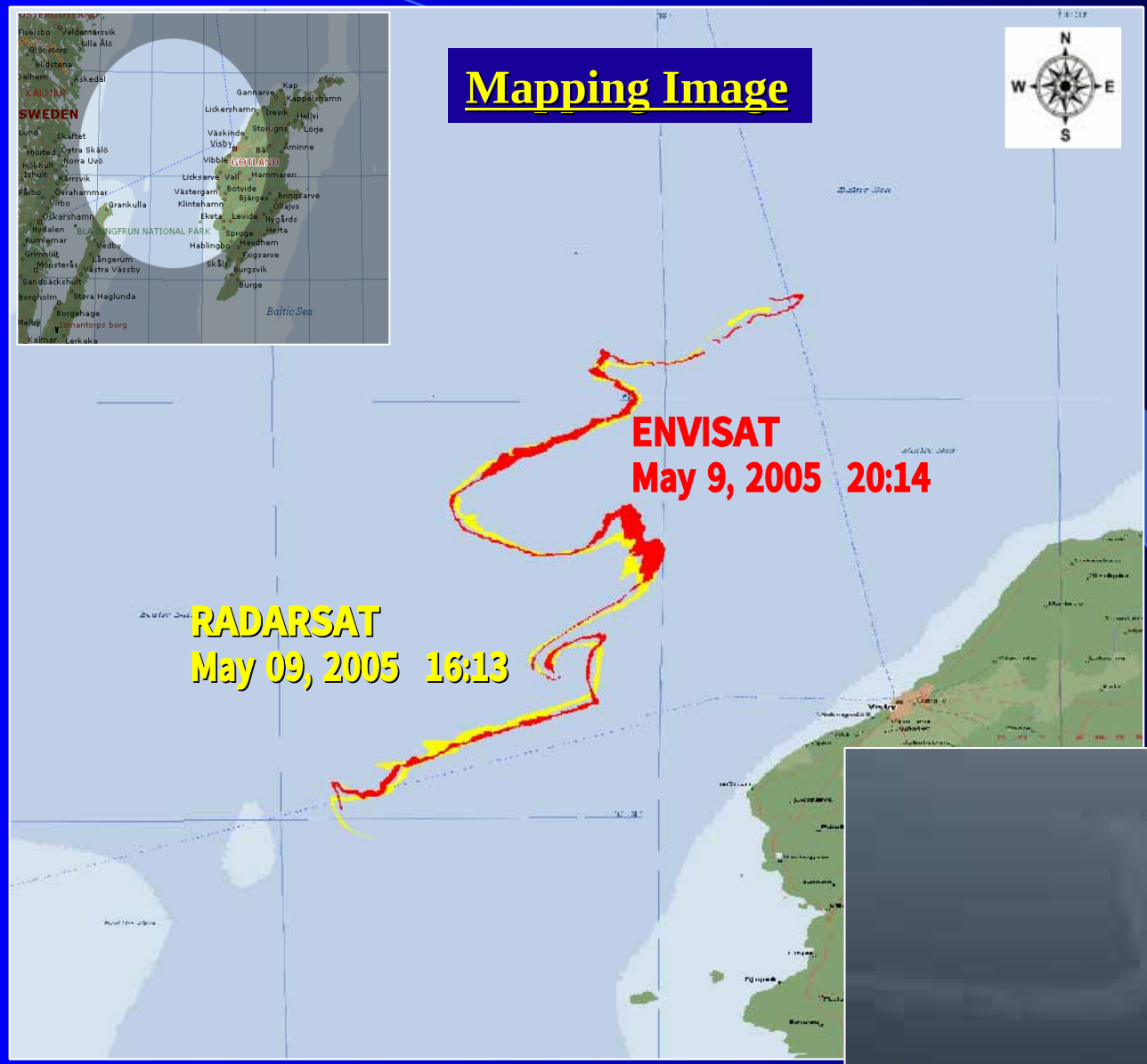
Mapping

The Result Imagery of the Wavelet analysis (Color Composite Imagery)





Observation Date and Time:
RADARSAT-1: May 09, 2005 16:13
ENVISAT/ASAR: May 09, 2005 20:14

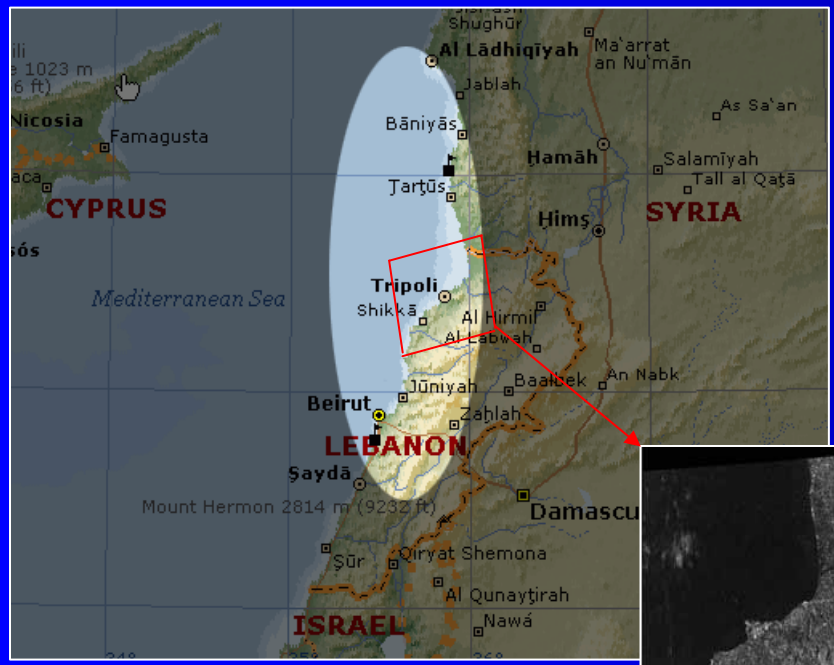

Mapping Image
N
W
E
S
SWEDEN
GOTLAND
Baltic Sea
ENVISAT
May 9, 2005 20:14
RADARSAT
May 09, 2005 16:13
Photo: Swedish Coast Guard

5-4. Oil-fuel storage tanks of Power plant, (Lebanon), July 13,15, 2005

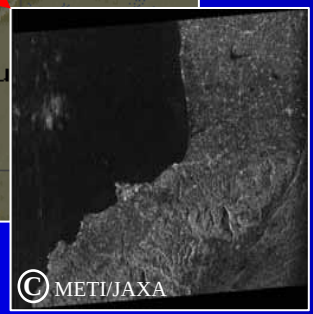
The oil-fuelled power plant of Jieh located on the coastline about 30 km south of Beirut was hit by bombs on July 13 and 15, 2006 in the course of the conflict of the Middle East. An estimated 30,000 tons of heavy fuel oil leaked into the Mediterranean sea.

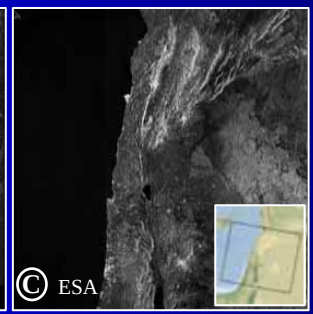
5-4. Oil-fuel storage tanks of Power plant, (Lebanon), July 13,15, 2005

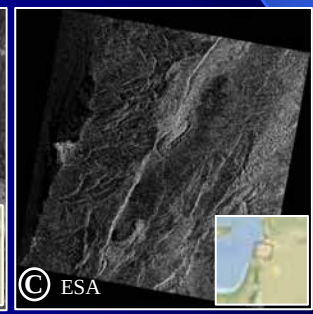
Disaster source



http://www.itopf.com/news.html
http://www.asahi.com/special/MiddleEast/TKY200607290517.html







Aug.16, 2006 20:10 ALOS/PALSAR

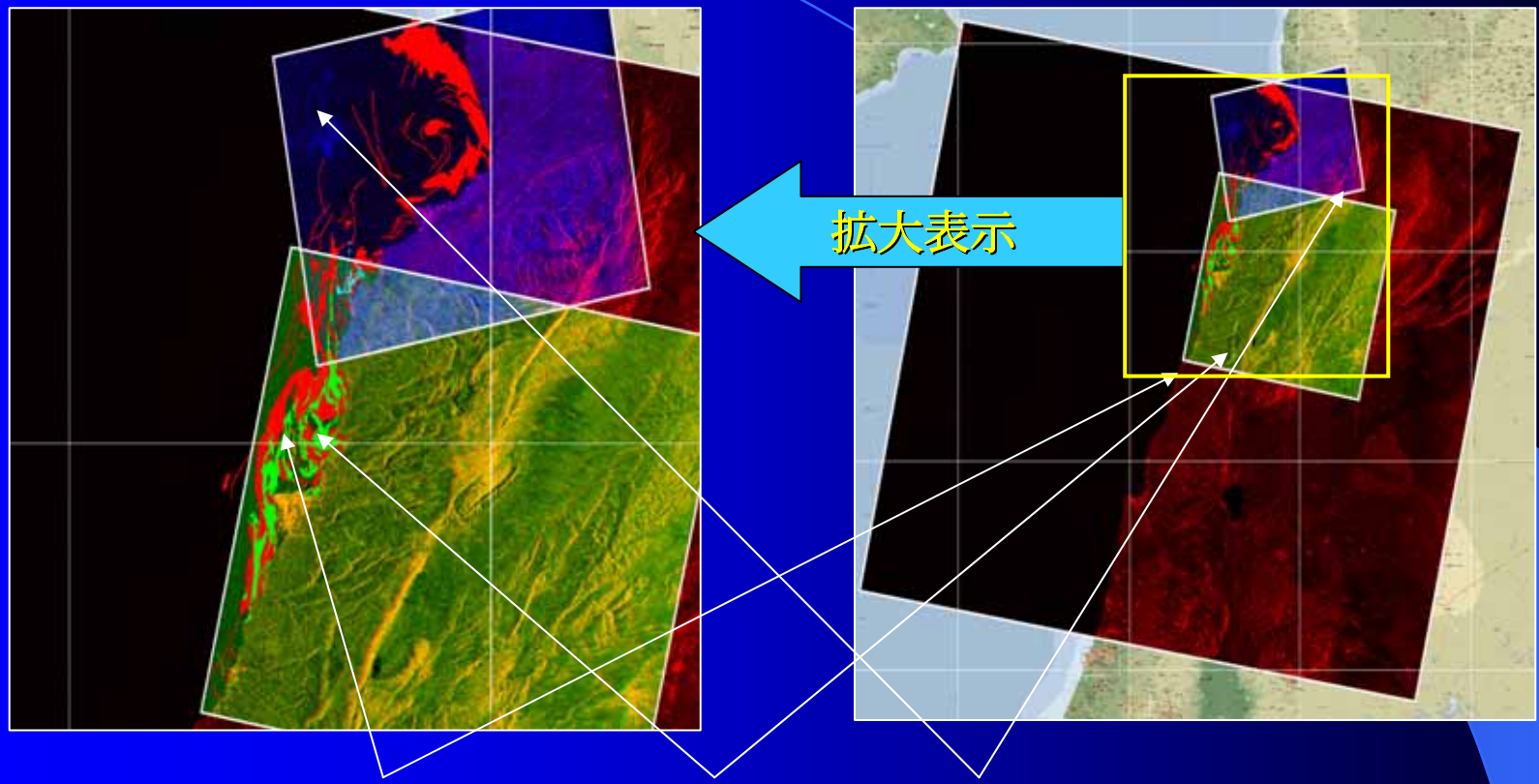
Aug.03, 2006 07:40 ENVISAT/ASAR

Aug.06, 2006 08:15 ERS-2/AMI

The result imagery of Wavelet Analysis

Mapping

The Detected Oil Spilled Area (Color Composite Imagery)

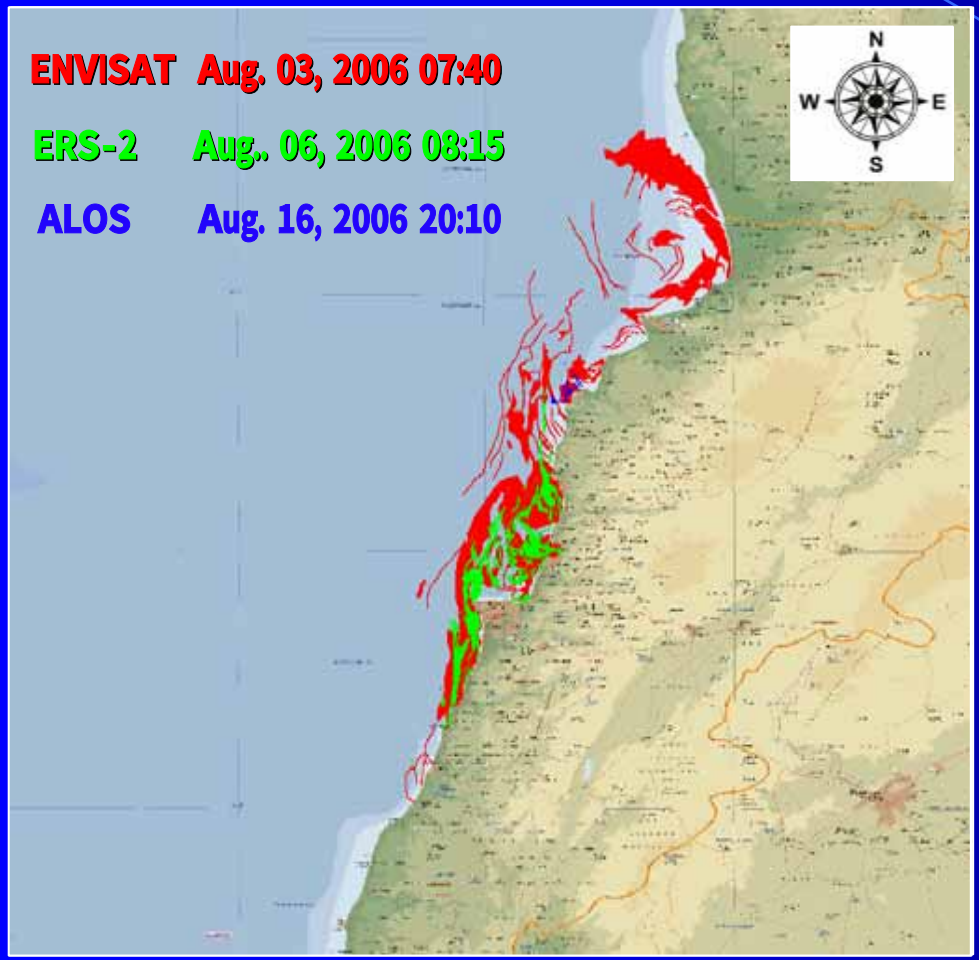


ENVISAT：	ERS2：	PALSAR：
Aug.03, 2006	Aug.06, 2006	Aug.16, 2006

Observation date and time：

ENVISAT/ASAR：Aug. 03, 2006 07:40
ERS-2/AMI：Aug. 06, 2006 08:15
ALOS/PALSAR：Aug. 16. 2006 20:10

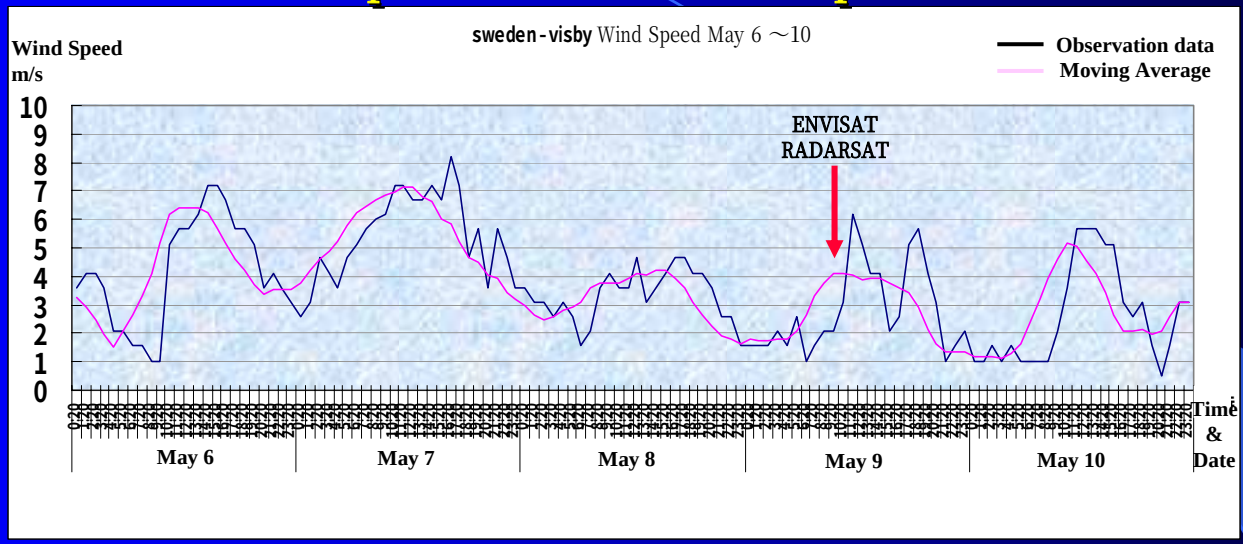
The Detected Oil-Spilled area from the satellite observation data

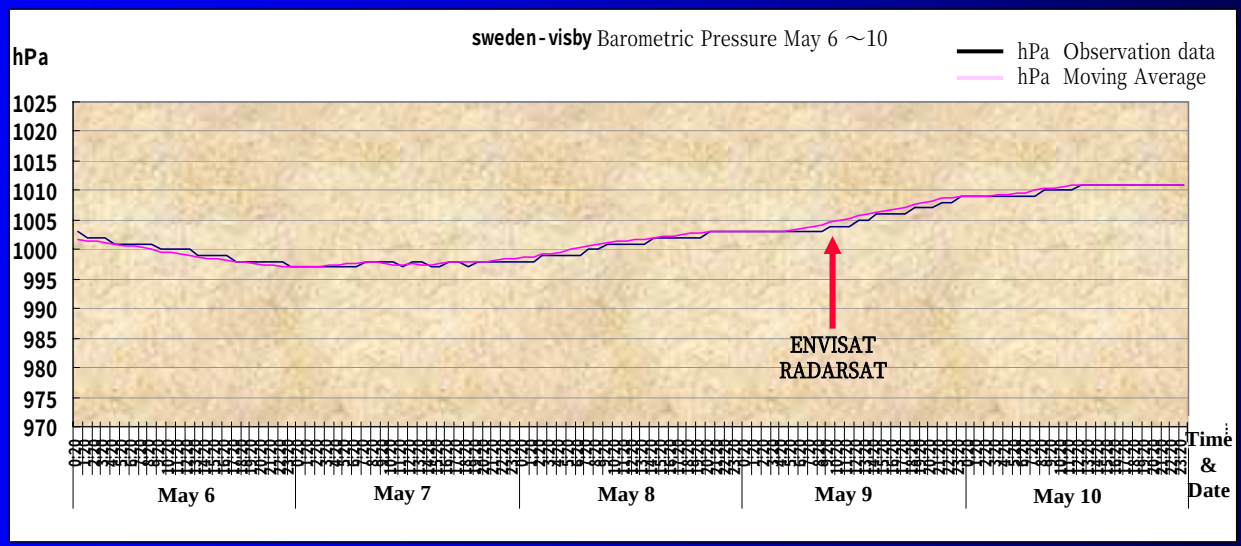


http://www.disasterscharter.org/disasters/CALLID_126_e.html

6. Weather and walrus's impact statements

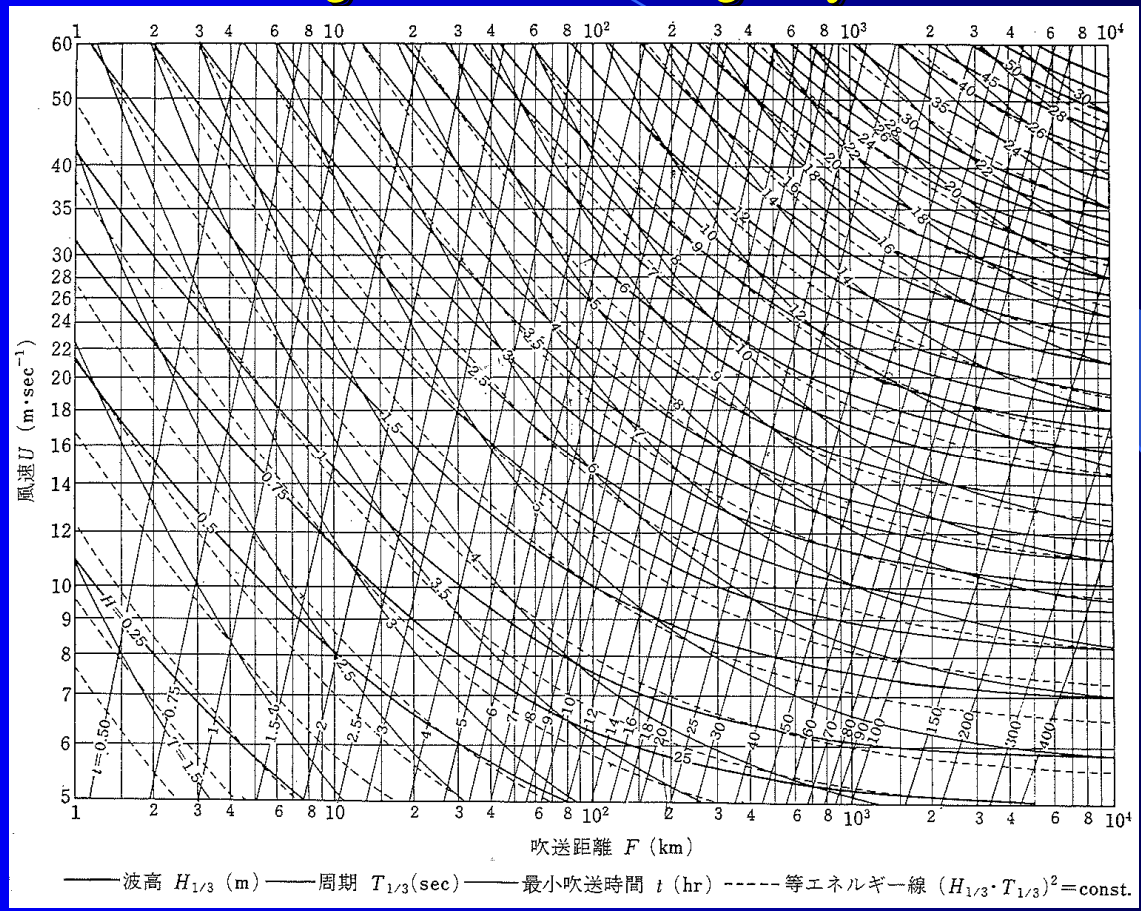
Wind speed and barometric pressure





6. Weather and walrus's impact statements

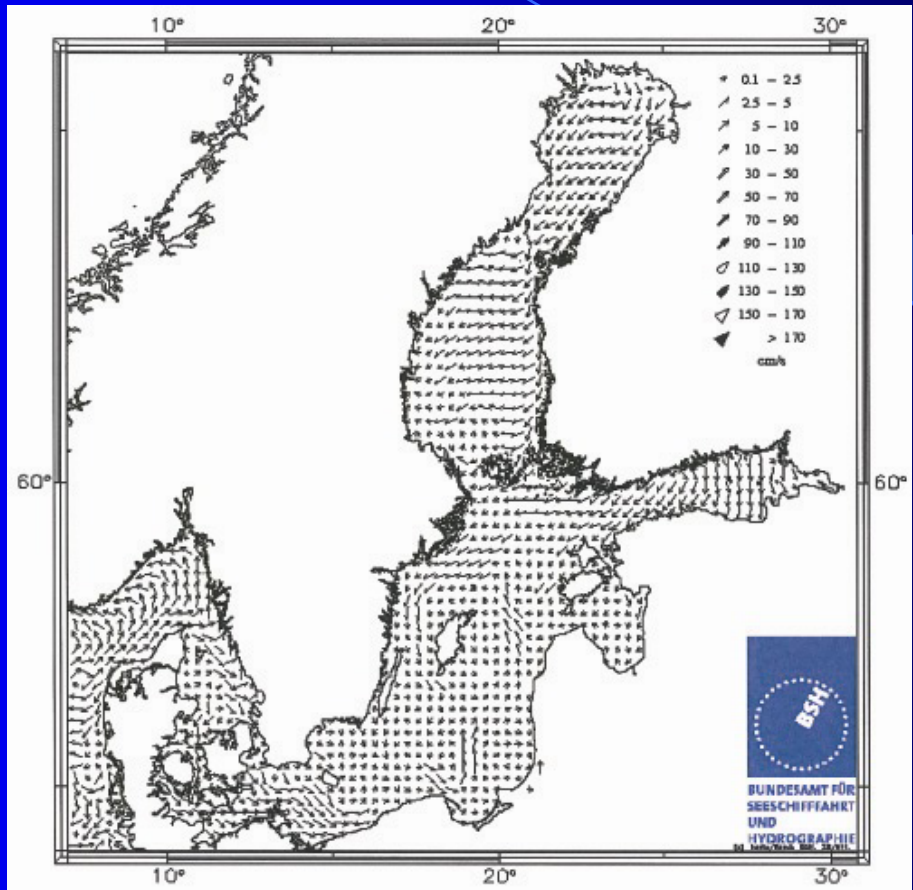
The estimation of significant wave height by formula of Wilson



$$gT_{1/3}/2\pi U_{10}{}^{2}=1.37\left[1-\left\{1+0.008\left(gF/U_{10}{}^{2}\right)^{1/3}\right\}^{-5}\right]$$

6. Weather and walrus's impact statements

Mean current in the Baltic sea



Mittlere Strömung am 9. 5.2005 1. Schicht (0– 8m)

Mean Current on 9. 5.2005 1. Layer (0– 8m)

6. Weather and walrus's impact statements

Sea Area	Satellite	Observation date	Time (GMT)	Wind Speed (Av)	Wind Speed (Mx)	significant wave height
				m/sec	m/sec	m
Sea Area of Guimaras Is. Panay Bay	RADARSAT	2006/8/27	10:02:26	0.8	3.9	0.11
	ENVISAT	2006/8/25	13:53:17	0.6	1.9	0.07
	ENVISAT	2006/8/28	13:58:17	0.6	1.9	0.07
	ALOS	2006/8/25	2:13:35	0.6	1.9	0.1
Spanish northwest offing in the Atlantic Ocean	RADARSAT	2002/11/18	18:28:30	2.2	6.1	0.21
	RADARSAT	2002/11/25	7:05:25	0.3	3.6	0.14
	ENVISAT	2002/11/17	10:44:32	2.5	5	0.15
	ERS-2	2002/11/26	11:31:33	2.5	7.2	0.35
The vicinity of Baltic Sea of Gotland Is.	RADARSAT	2005/5/9	16:13:35	1.1	6.1	0.34
	ENVISAT	2005/5/9	20:14:17	1.1	6.1	0.34
The coastline about 30 kilometers South of Beirut, Lebanon	RADARSAT	2006/7/26	15:47:15	—	—	—
	RADARSAT	2006/8/4	3:27:55	0.8	4.2	0.15
	ENVISAT	2006/8/3	7:40:41	0.8	3.1	0.15
	ERS-2	2006/8/6	8:15:05	1.4	4.7	0.32
	ALOS	2006/7/18	20:12:07	—	—	—
	ALOS	2006/7/18	20:11:59	—	—	—
	ALOS	2006/8/16	20:10:23	0.8	3.1	0.11

7. Conclusion

- By applying Wavelet analysis to a synthetic aperture radar imagery, it was shown that the possibility of the detection of the oil slicks could be performed in high probability.

- It is possible for automatic recognition of the oil slicks without human interpretation if this technique is established. And it can use as one of the method of the screening.

- Furthermore, using the SAR data under the conditions from which the weather and the sea surface differ, Oil Slick has been recognized by this method. It shows a possibility that it could use day and night under all-weather condition.

- The verification of the recognition probability by the difference such as the thinness (thickness) of oil and the wave height of the sea surface, will be also done as the next phase.

Thank you

M. Hara,
VisionTech Inc.
http://www.vti.co.jp