ESA 2nd Advanced Training Course in Ocean Remote Sensing

Interpretation and Detection Capabilities in Support to Practical Analyses Tools

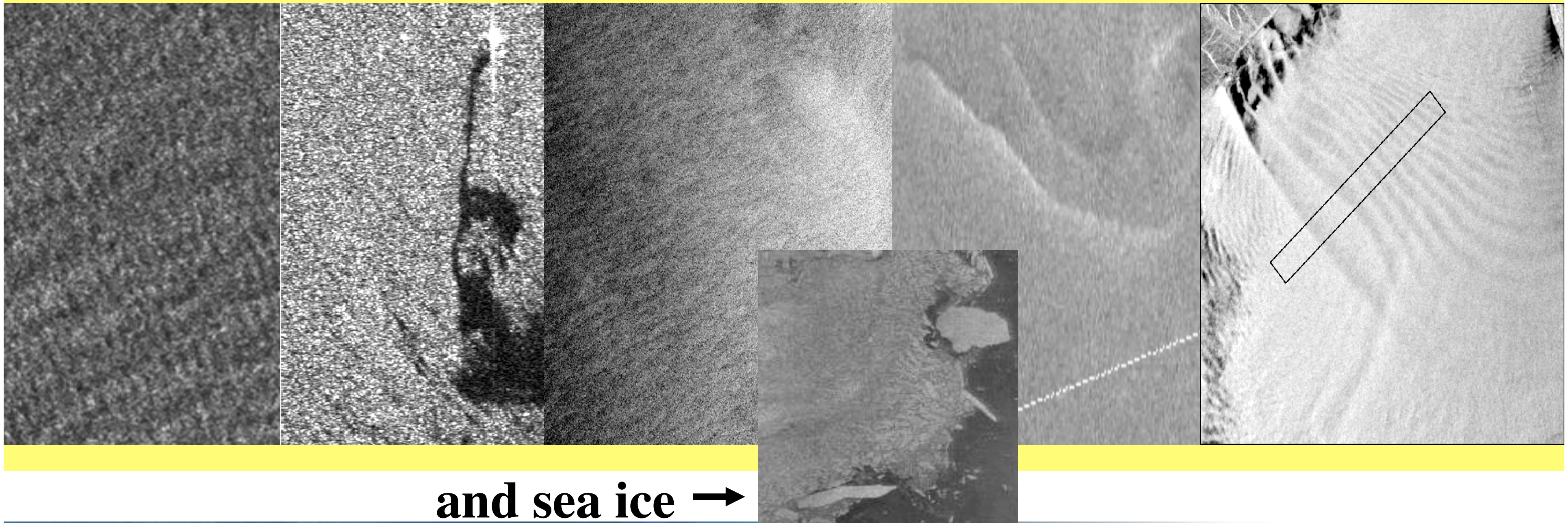
Johnny A. Johannessen (NERSC) and
Fabrice Collard (CLS)

The surface roughness is the source the SAR backscatter signal.

The ocean surface roughness is influenced by wind and waves, currents, surface slicks and sea ice and is often different in open ocean versus coastal or ice covered regions due to fetch effects

Although the SAR "sees" only the " Bragg waves", these waves are modulated by a large number of upper ocean and atmospheric boundary layer phenomena. This is the reason why SAR images manifest expression of:

Wave field   Oil spill   Wind field   Current front   Internal waves



and sea ice →

SAR CONTRIBUTION TO MARINE MONITORING

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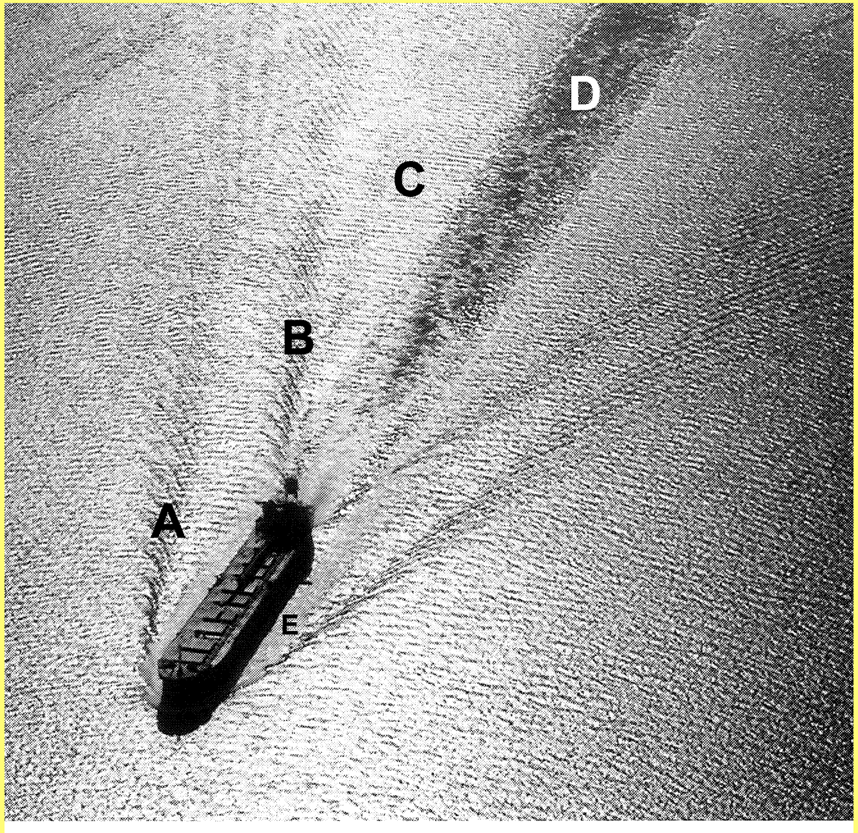
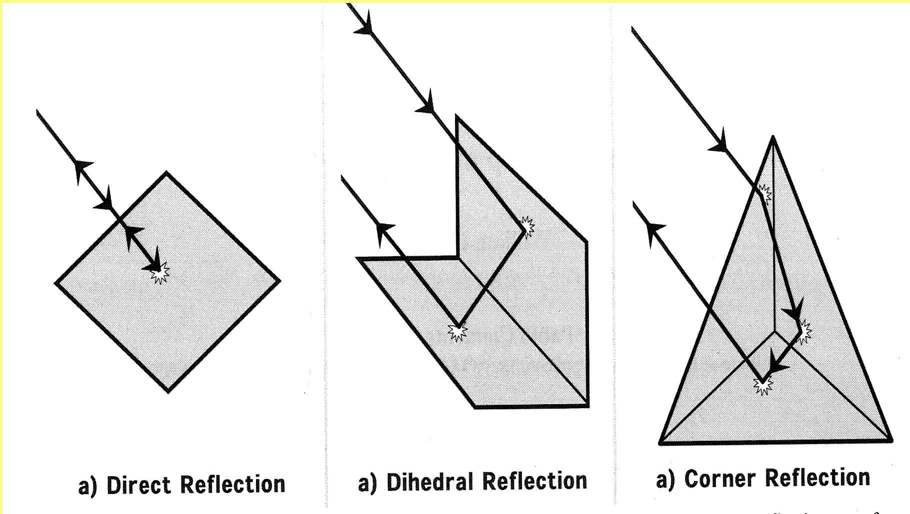
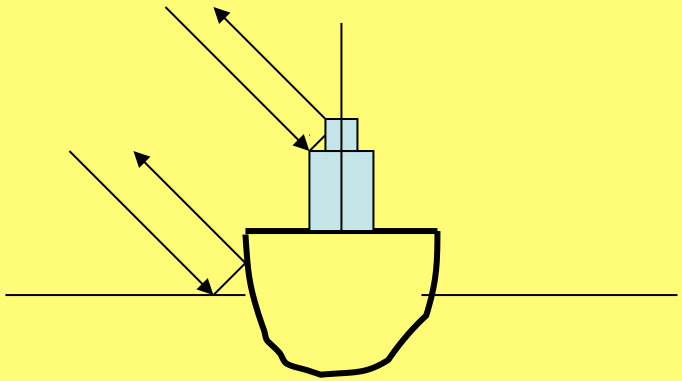
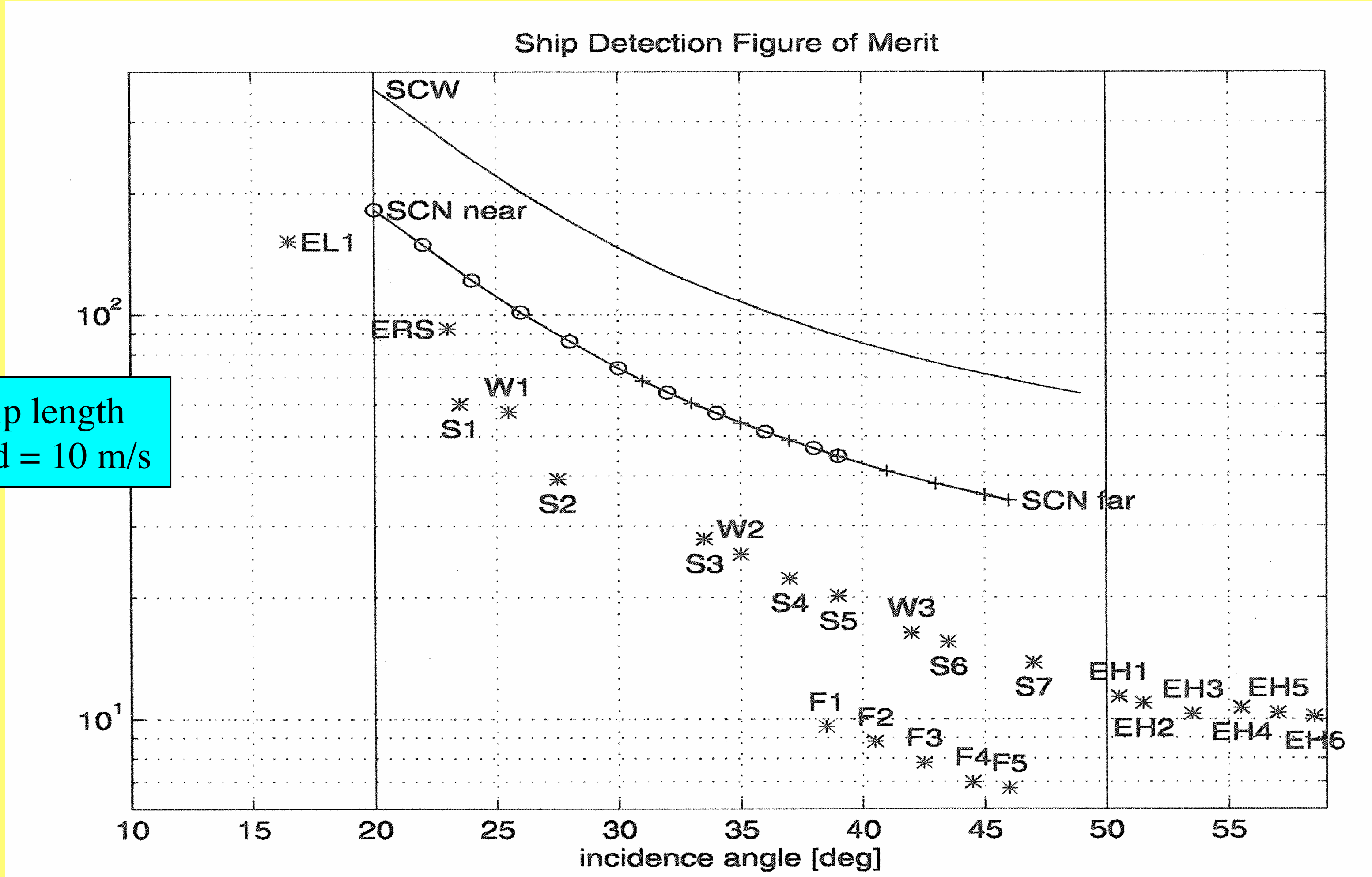
Possible radar pulse returns from ships





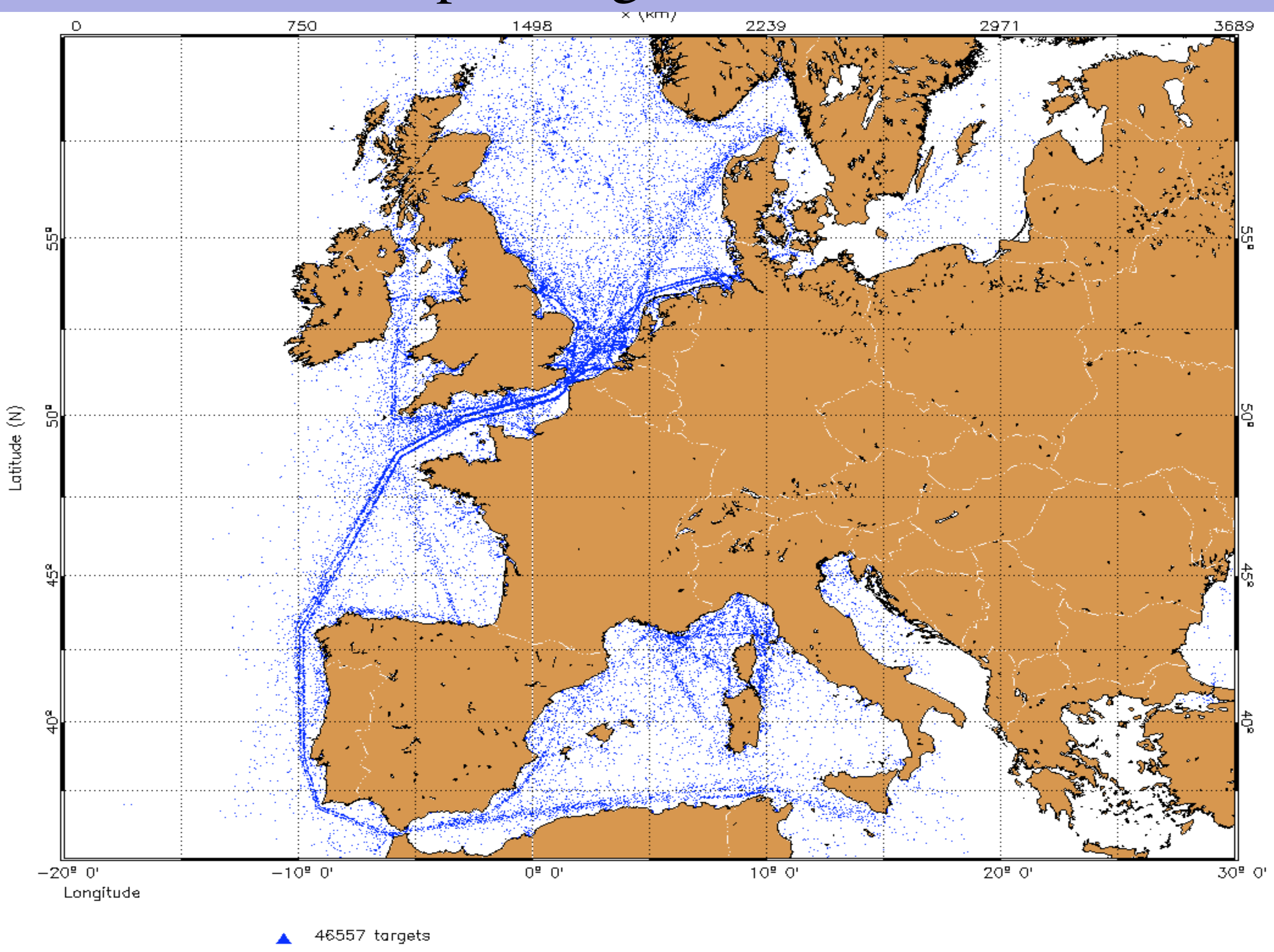


Ship detection as a function of incidence angle (Vachon et al., 1997)

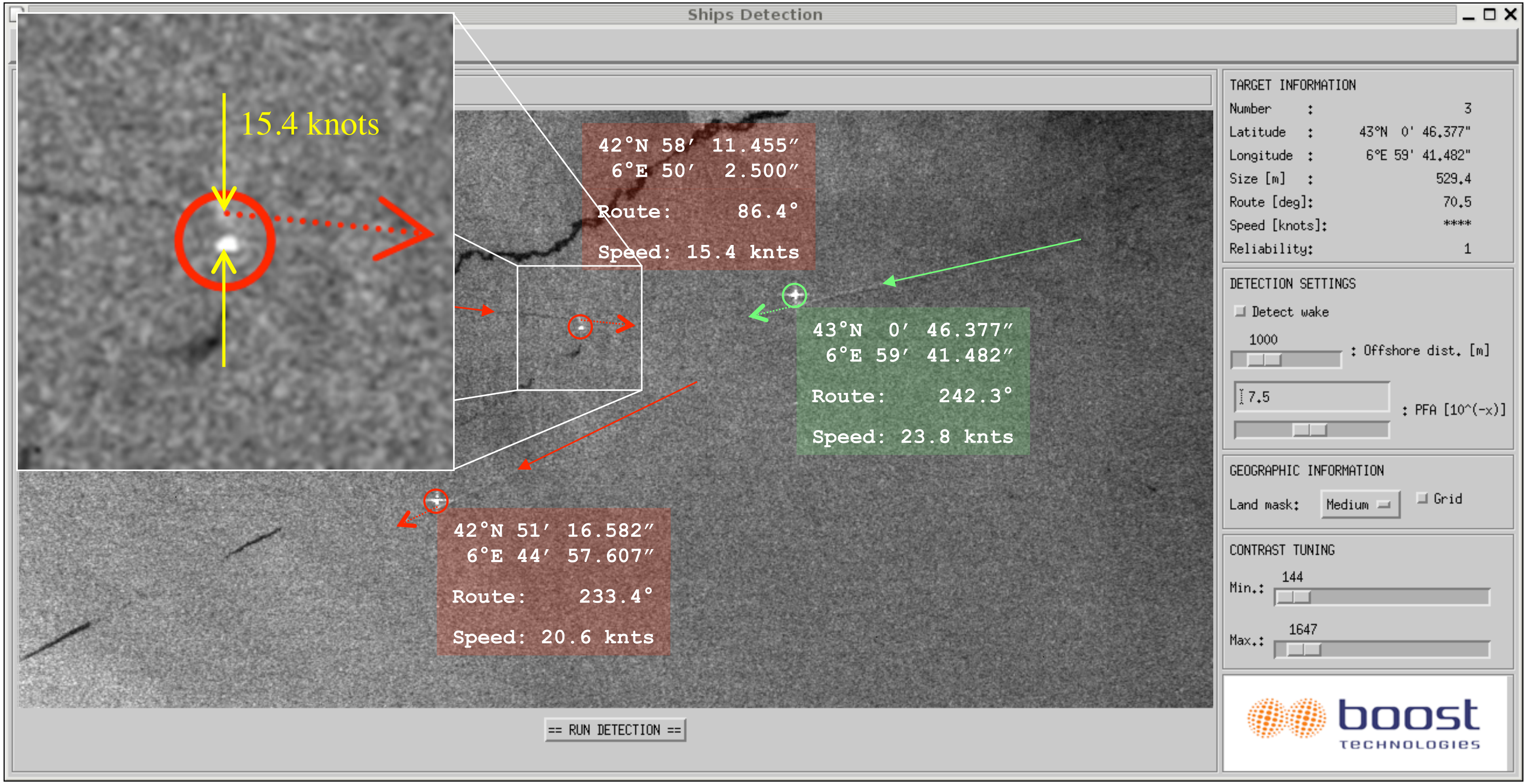


min. ship length
for wind = 10 m/s

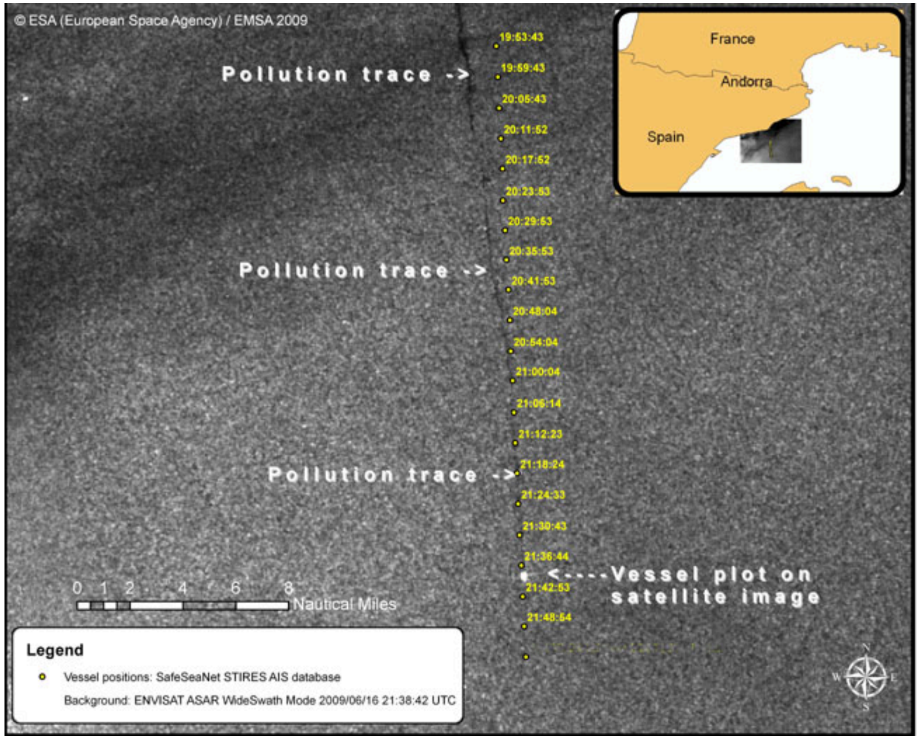
Ship Detection over Europe using Envisat ASAR Wide Swath products

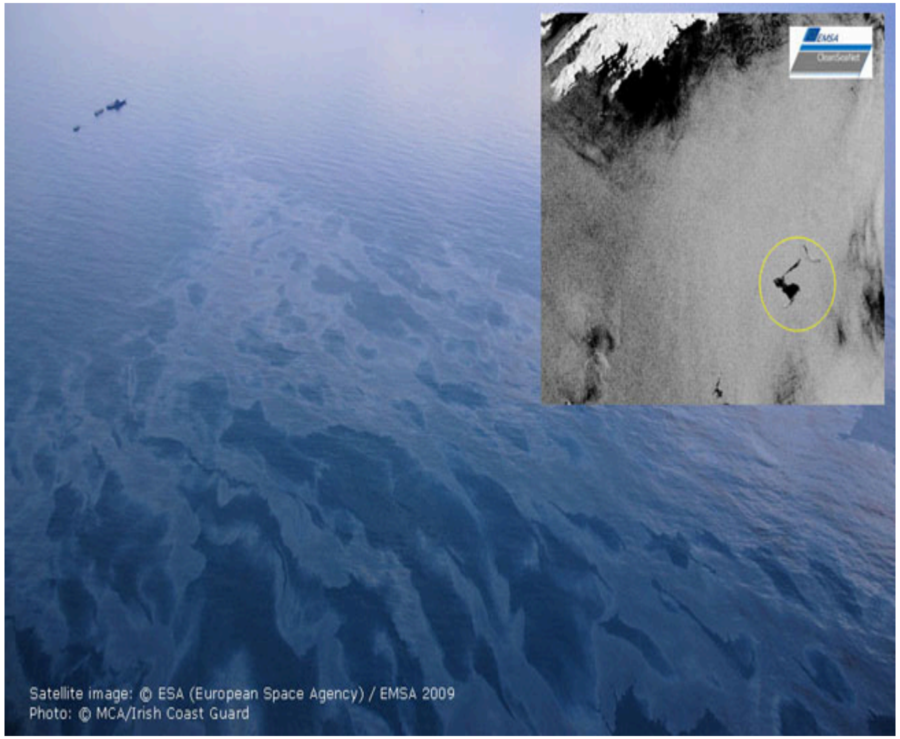


Measuring ship speed using SARTool



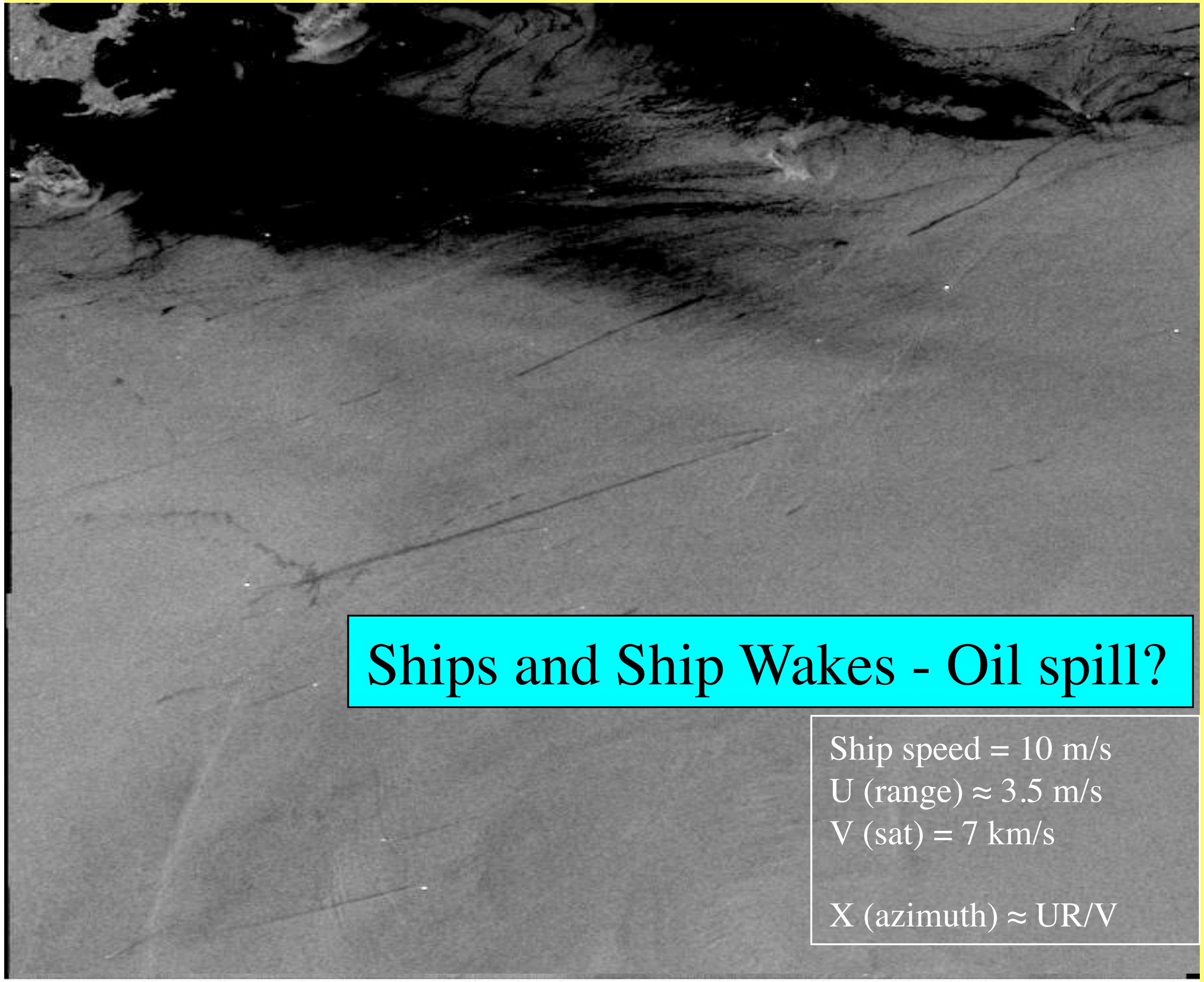
OIL SPILL





EMSA: CleanSeaNet - An oil spill detection service for European seas

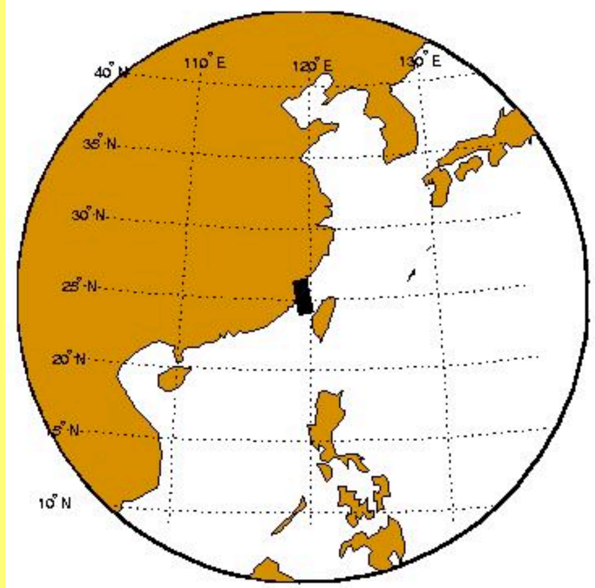
Ships and Ship Wakes - Oil spill?

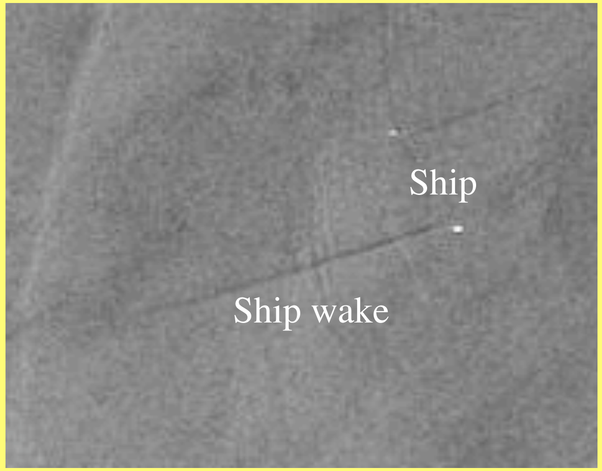


Ship speed = 10 m/s
U (range) ≈ 3.5 m/s
V (sat) = 7 km/s

X (azimuth) ≈ UR/V

Envisat ASAR APM V/V ASCENDING
10-AUG-2007 13:57:34





Showing compliance with IRTC (Internationally Recommended Transit Corridor)

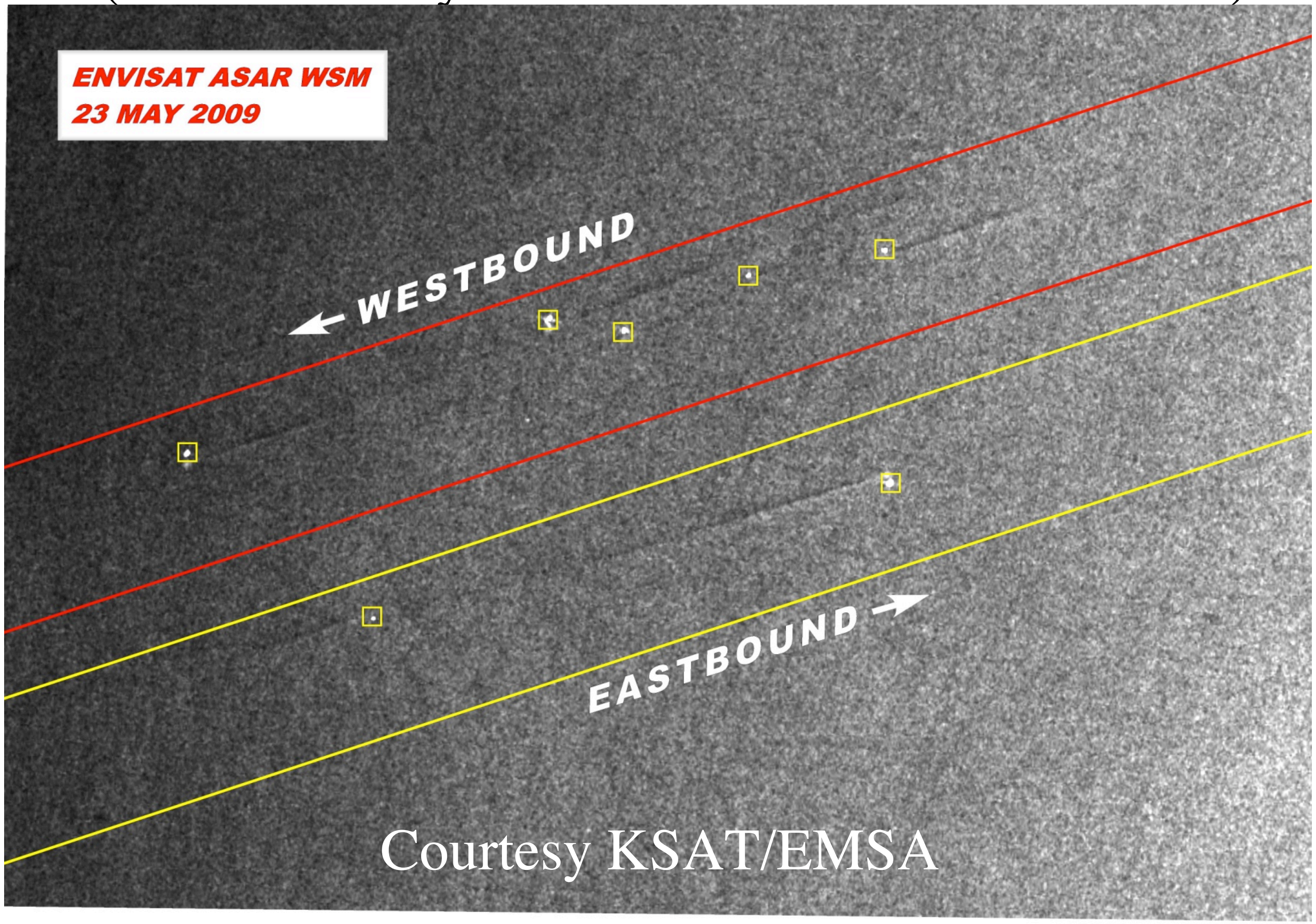


Figure 1. Ocean and coastal areas under Norwegian jurisdiction: Norwegian economic zone, Jan Mayen, and the Svalbard fisheries protection zone. The gray zone is claimed by both Norway and Russia.

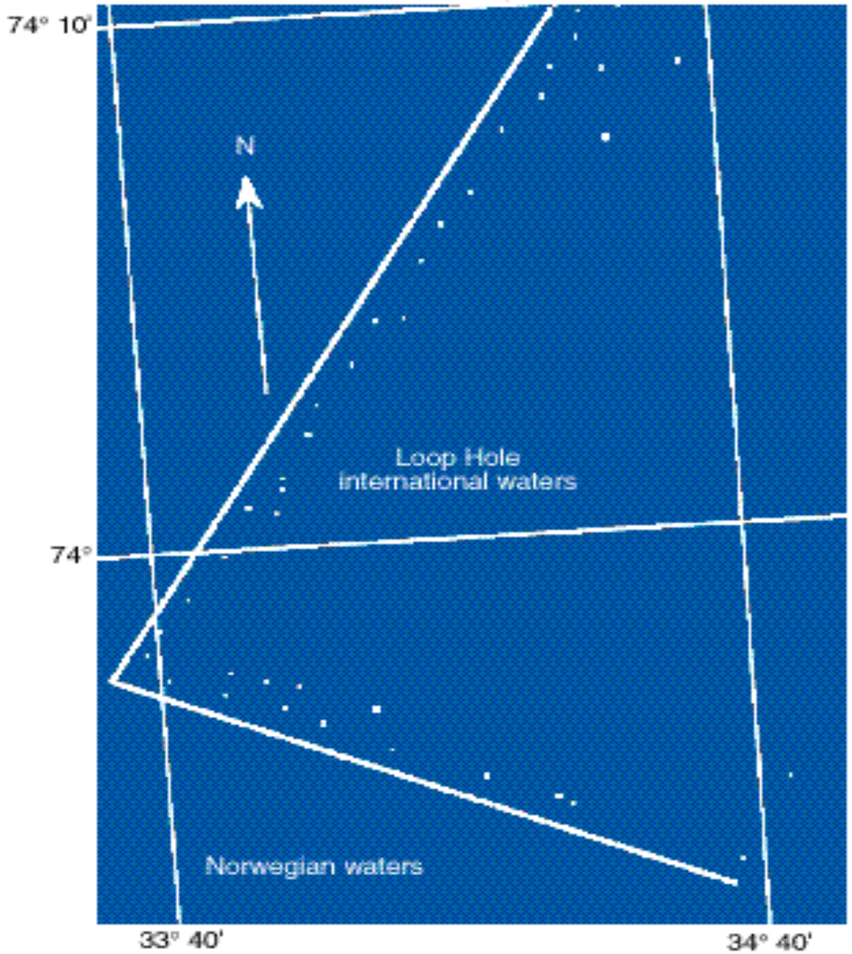
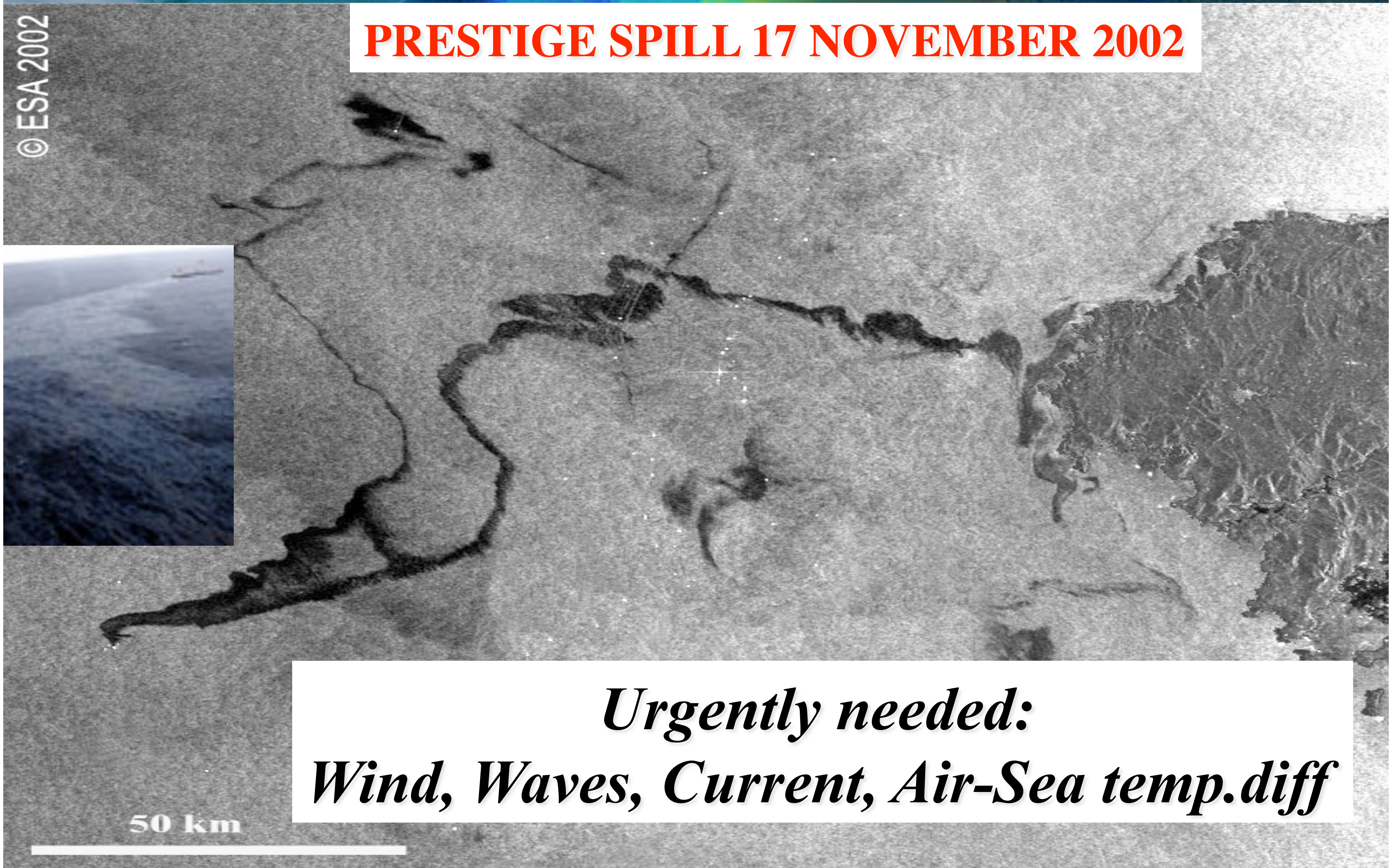


Figure 2. Radarsat-1 ScanSAR narrow-far image, 28 August 1996, showing foreign trawlers along the "Loop Hole" boundary. (© Canadian Space Agency.)

PRESTIGE SPILL 17 NOVEMBER 2002



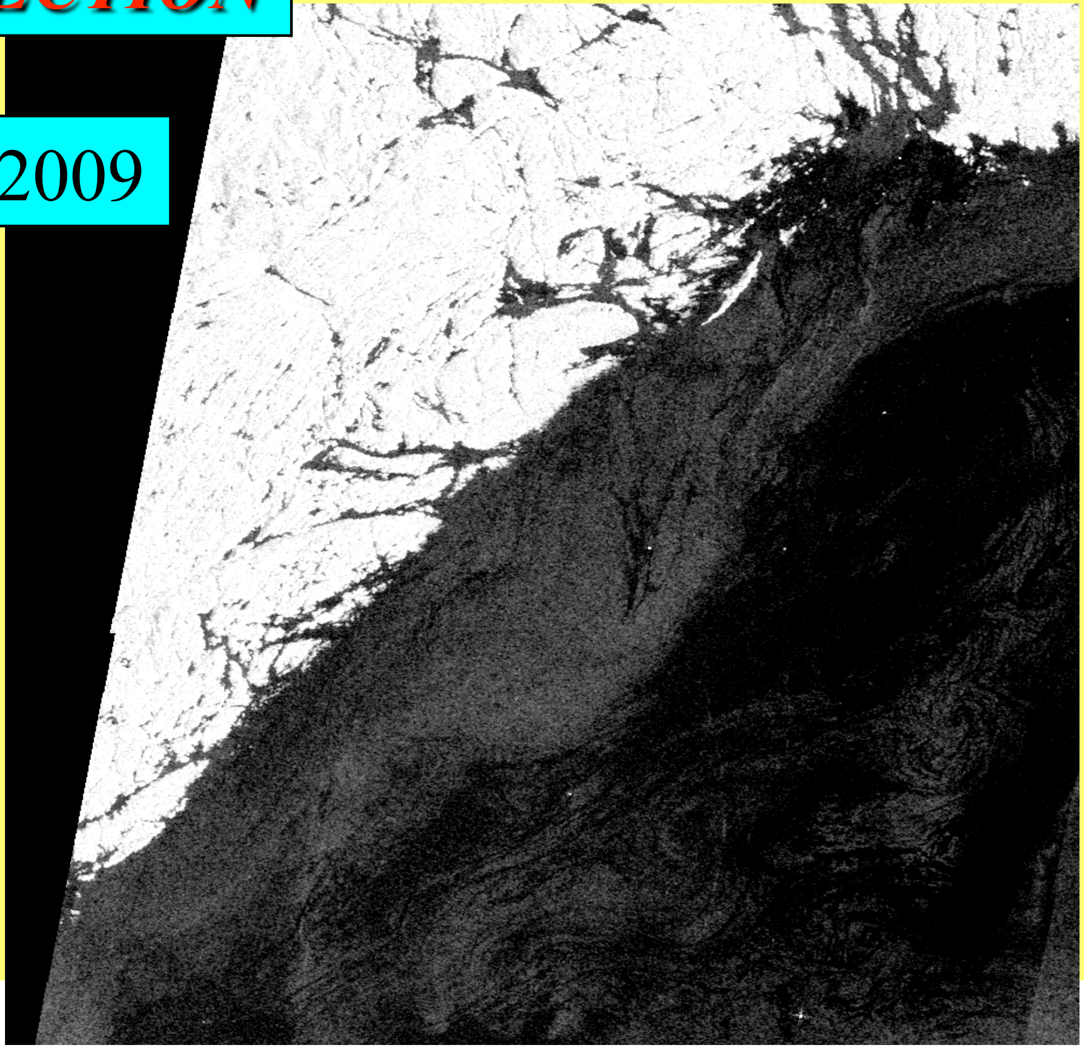
Urgently needed:

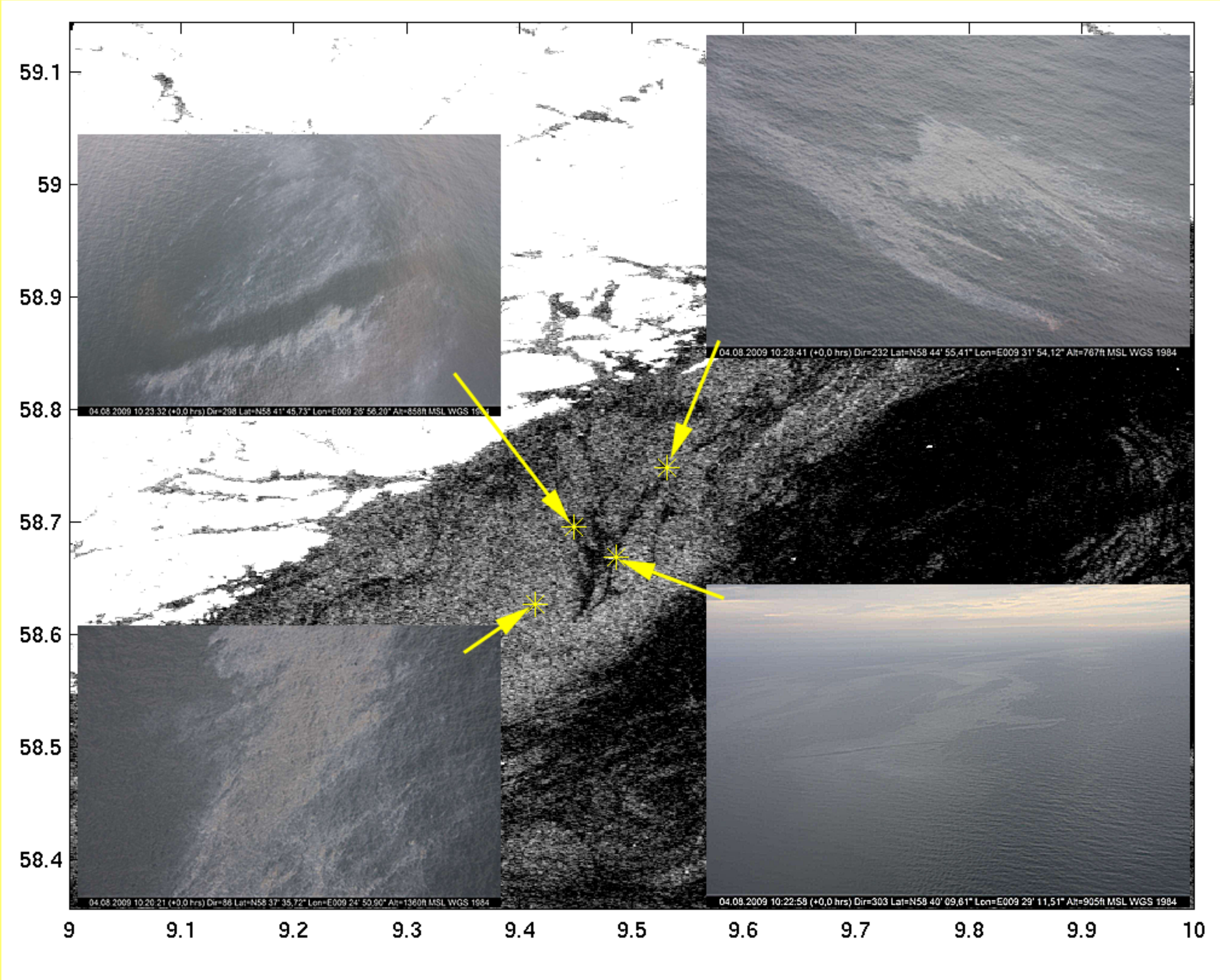
Wind, Waves, Current, Air-Sea temp.diff


OIL POLLUTION
FROM
"EXXON VALDEZ"
COMPARATIVE
AREA ON
NORWEGIAN COAST
Russland
Finland
Norge
Sverige
Estland
Latvia
Danmark
Litauen
Tyskland
Polen
0
250
500
Kilometers

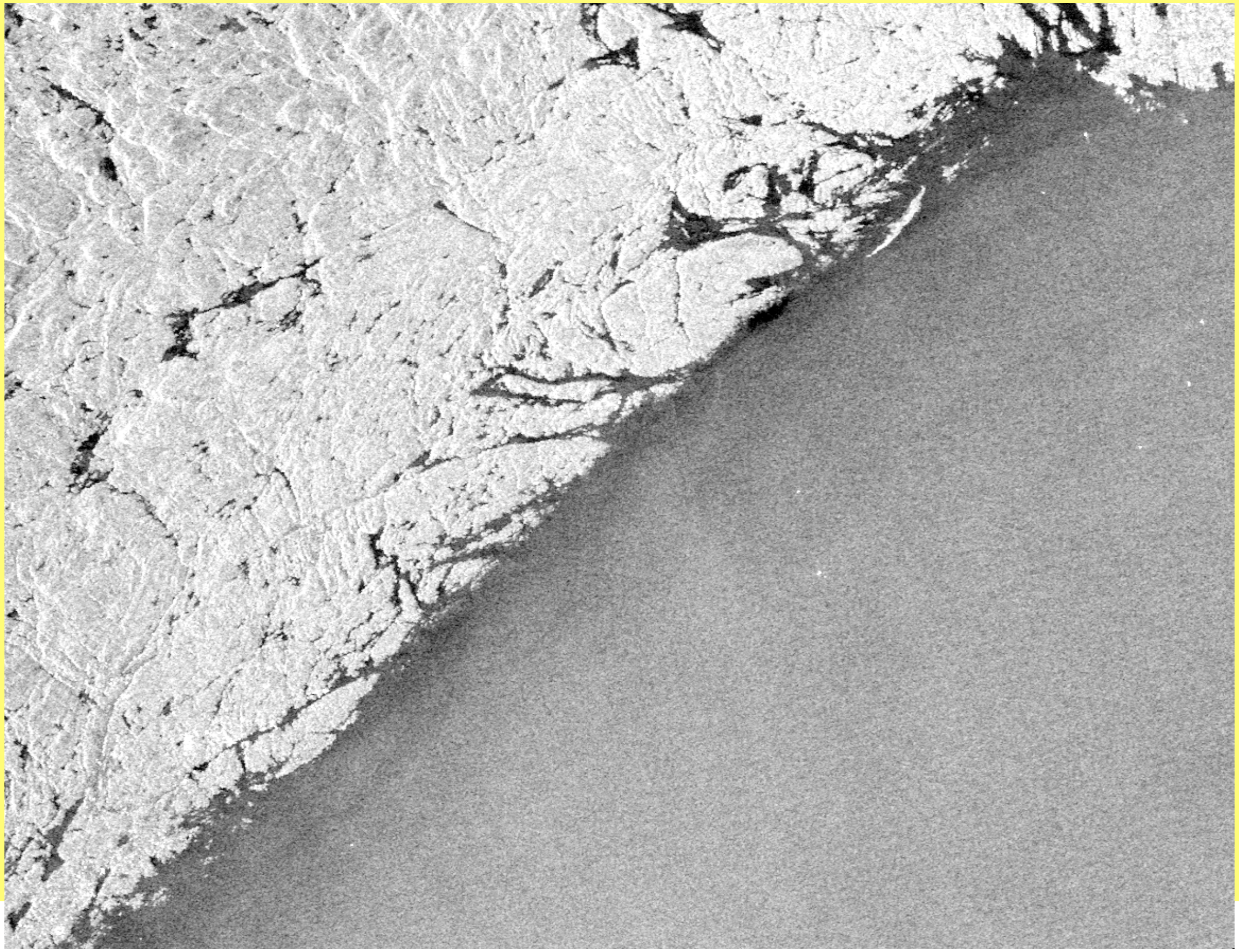
OIL SPILL DETECTION

Full City, August 2009

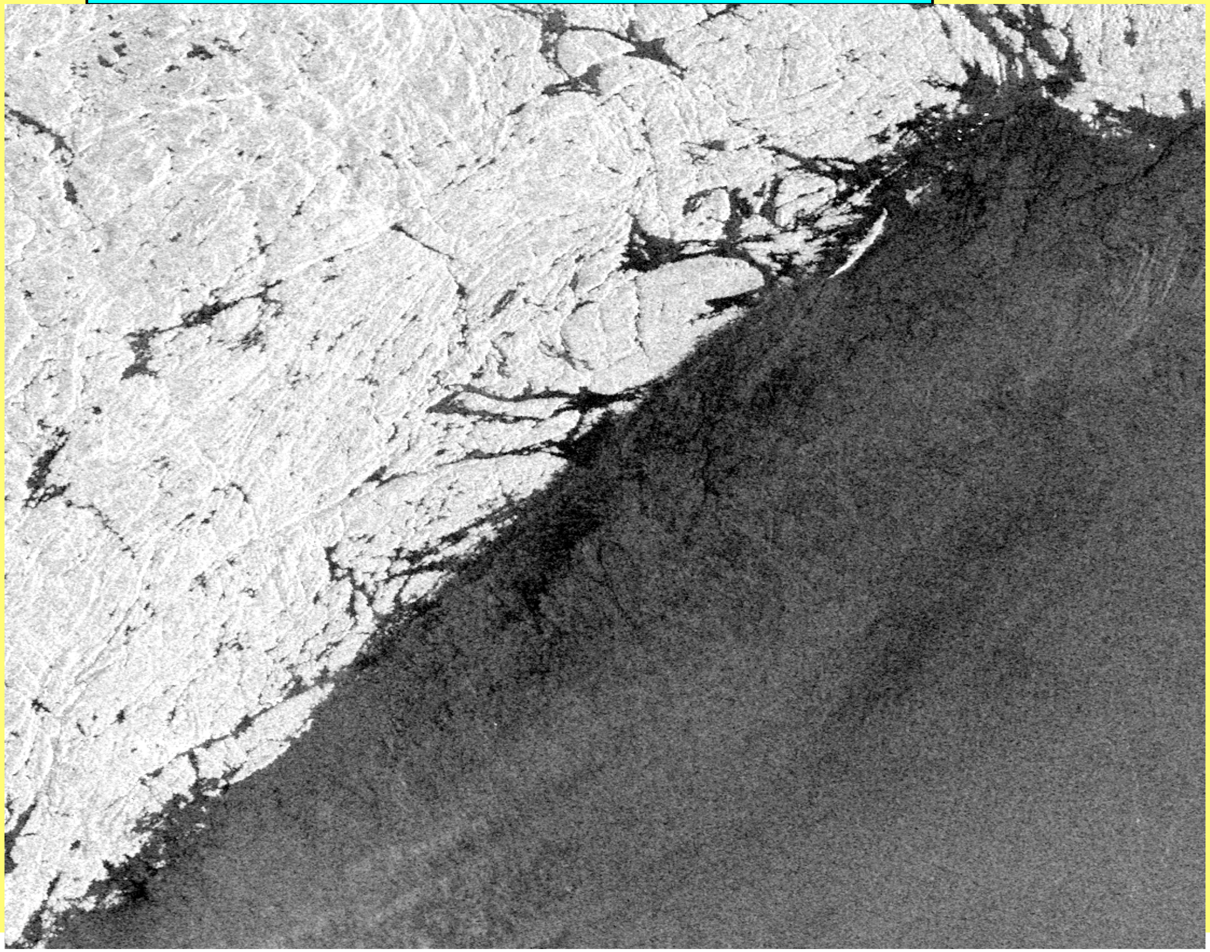



59.1
59
58.9
58.8
58.7
58.6
58.5
58.4
9
9.1
9.2
9.3
9.4
9.5
9.6
9.7
9.8
9.9
10
04.08.2009 10:23:32 (+0,0 hrs) Dir=298 Lat=N58 41' 45,73" Lon=E009 26' 56,20" Alt=858ft MSL WGS
04.08.2009 10:28:41 (+0,0 hrs) Dir=232 Lat=N58 44' 55,41" Lon=E009 31' 54,12" Alt=767ft MSL WGS 1984
04.08.2009 10:20:21 (+0,0 hrs) Dir=86 Lat=N58 37' 35,72" Lon=E009 24' 50,90" Alt=1360ft MSL WGS 1984
04.08.2009 10:22:58 (+0,0 hrs) Dir=303 Lat=N58 40' 09,61" Lon=E009 29' 11,51" Alt=905ft MSL WGS 1984

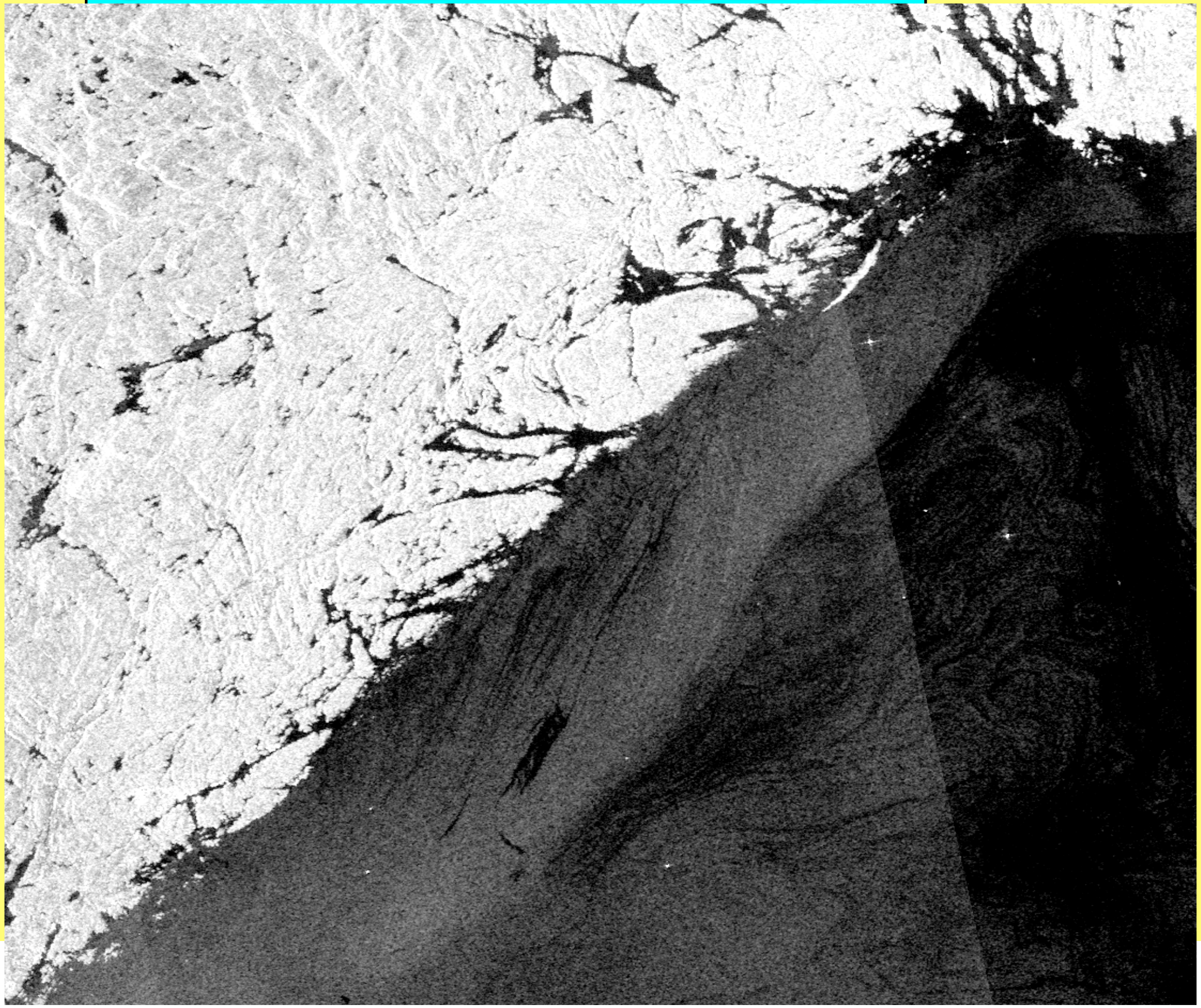
OIL SPILL DETECTION



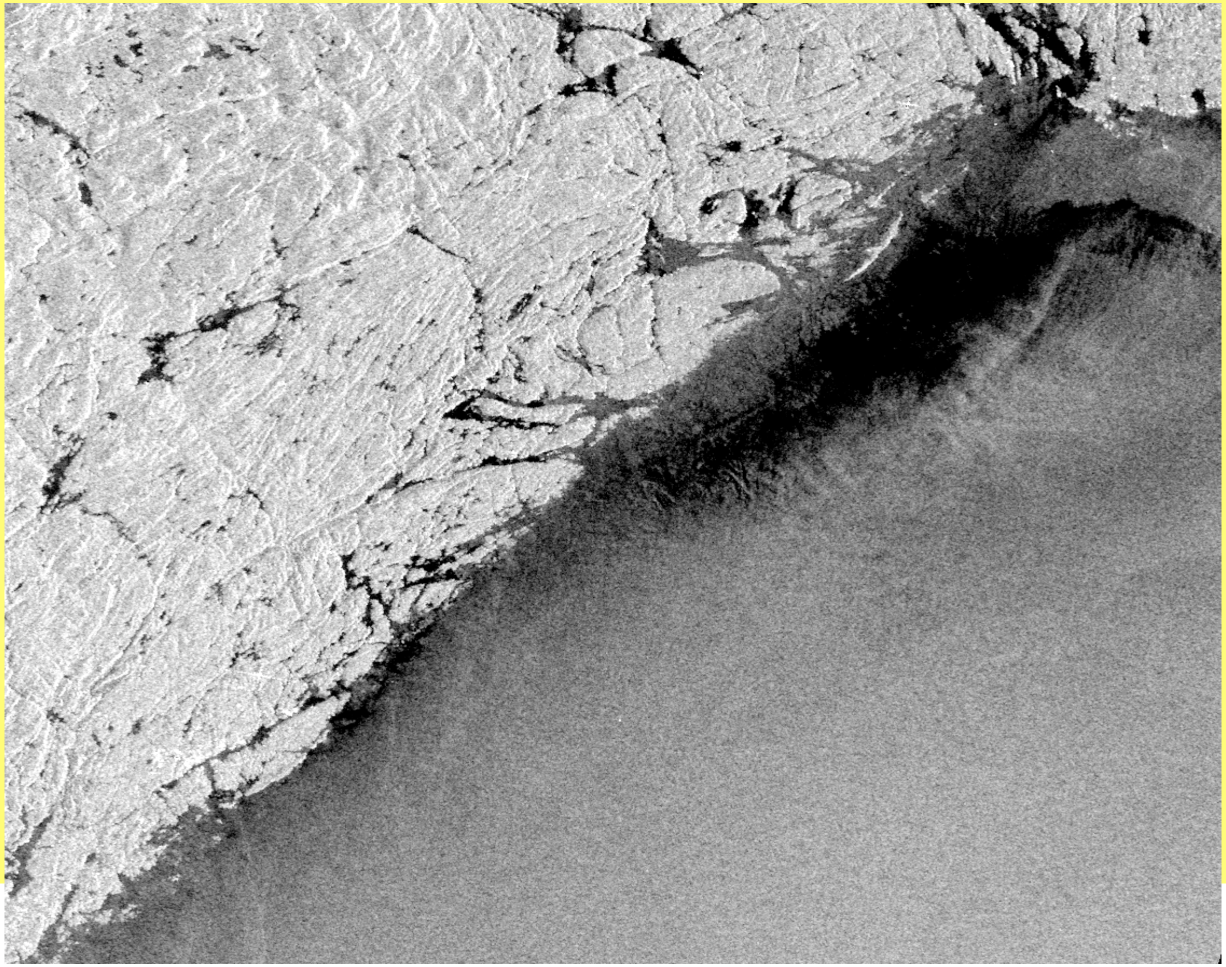
OIL SPILL DETECTION



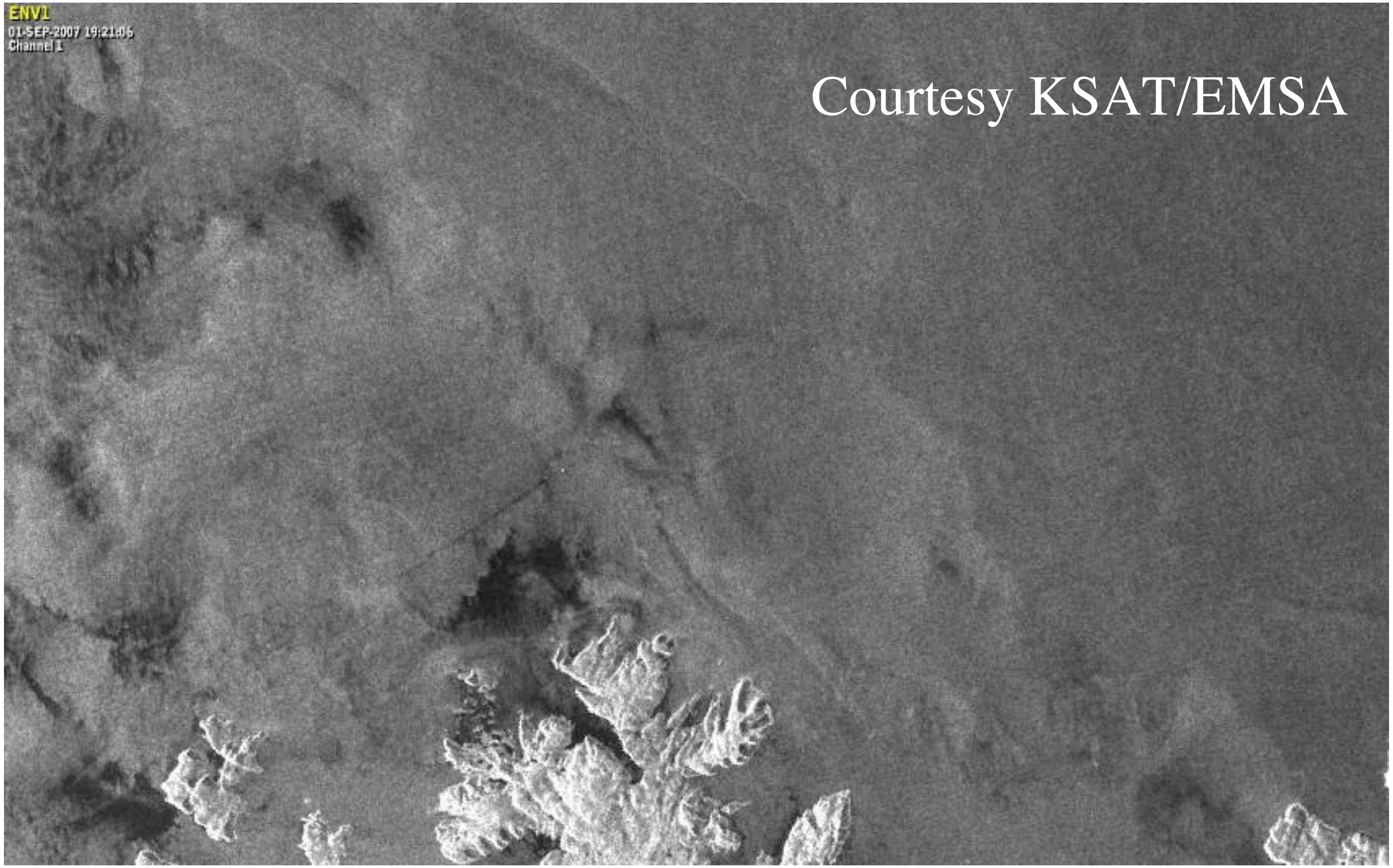
OIL SPILL DETECTION

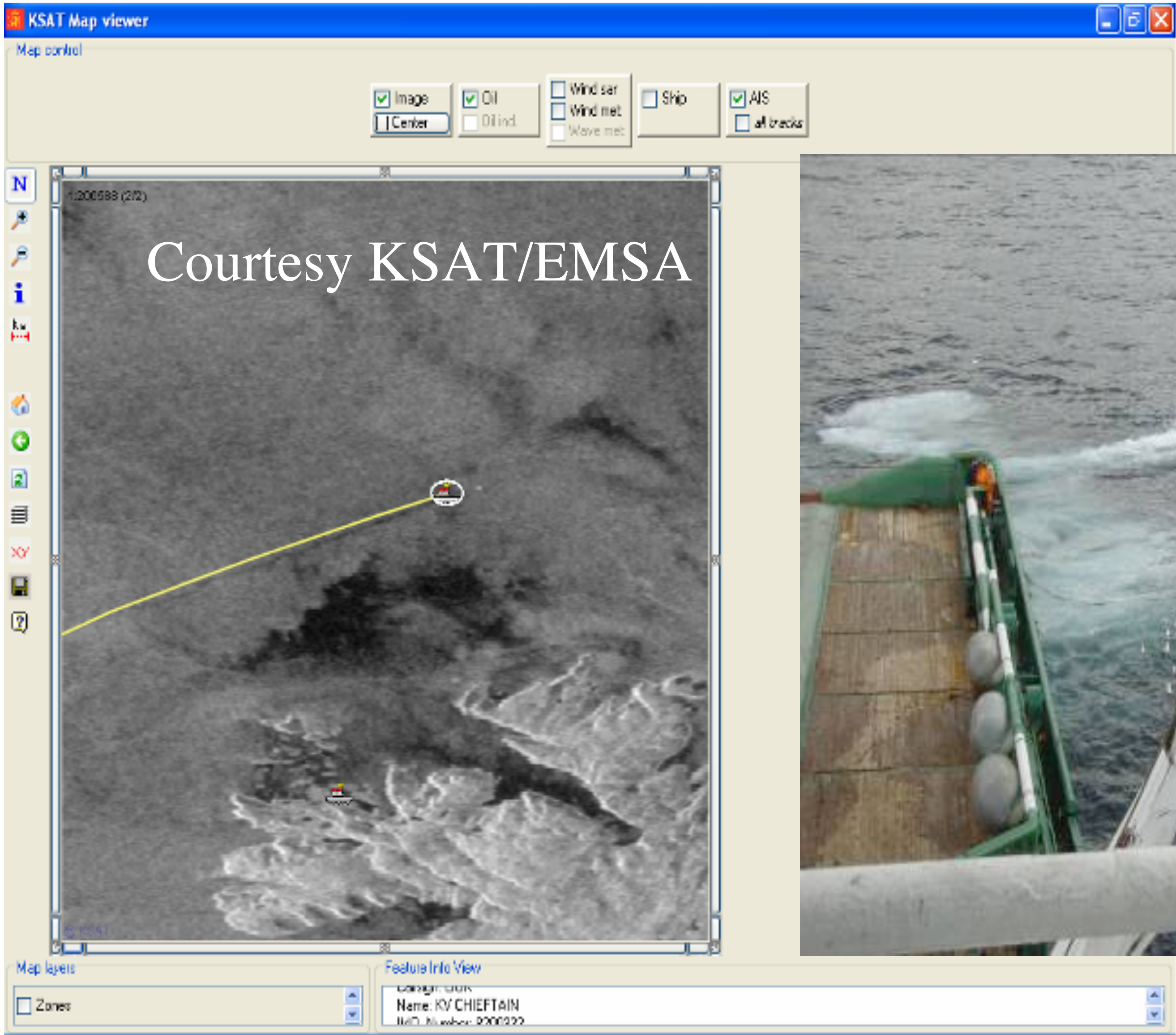


OIL SPILL DETECTION

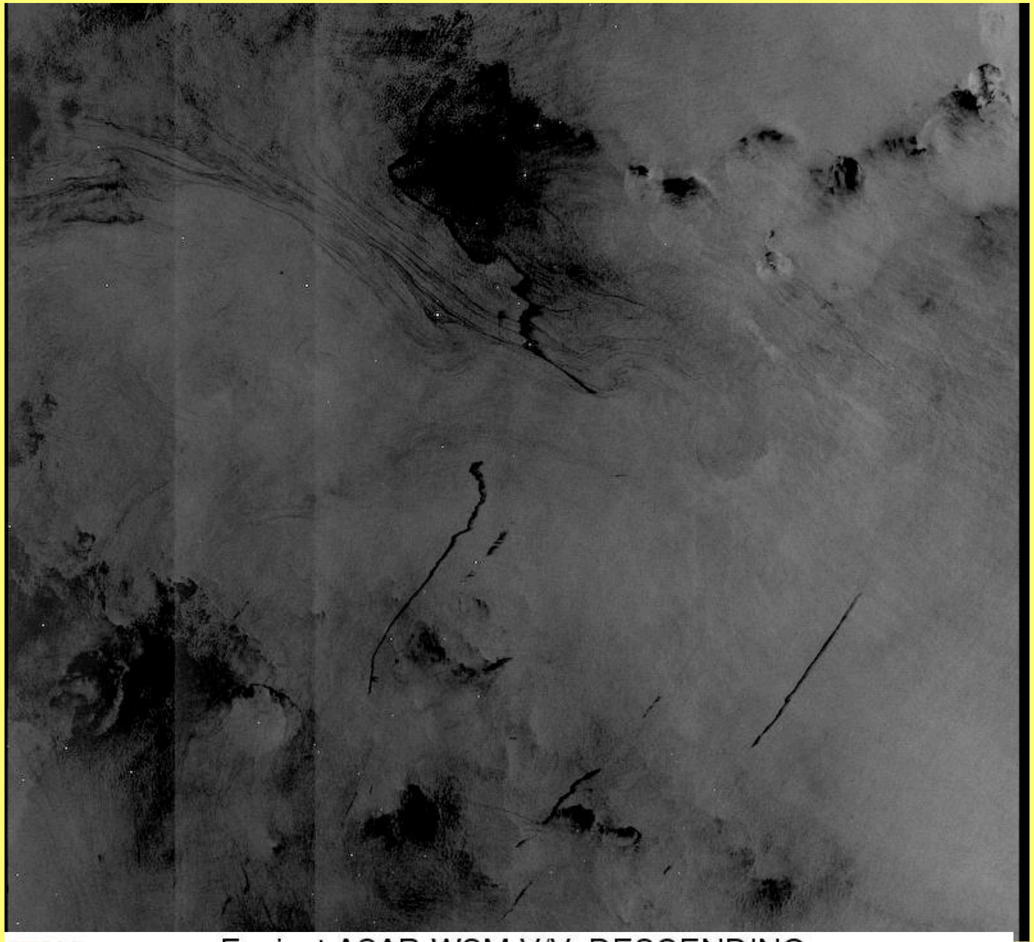


Black tail – but not always a real pollution




KSAT Map viewer
Map control
Image
Center
Oil
Oil ind
Wind sar
Wind met
Wave met
Ship
AIS
all tracks
Courtesy KSAT/EMSA
Map layers
Zones
Feature Info View
Name: KV CHIEFTAIN

Oil Spill, natural film, low wind speed



Envisat ASAR WSM V/V DESCENDING

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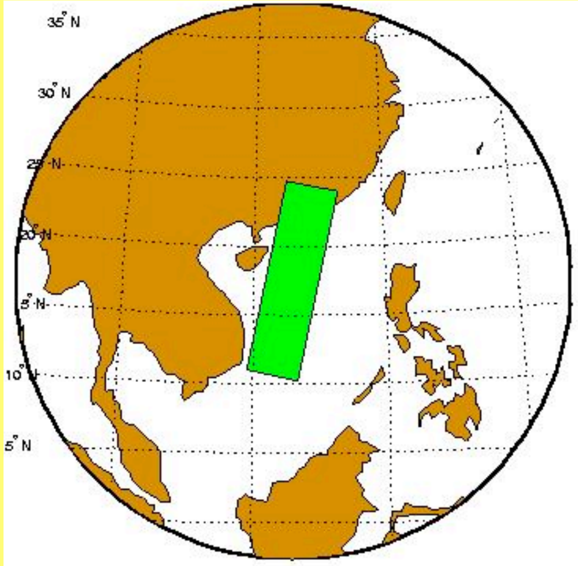
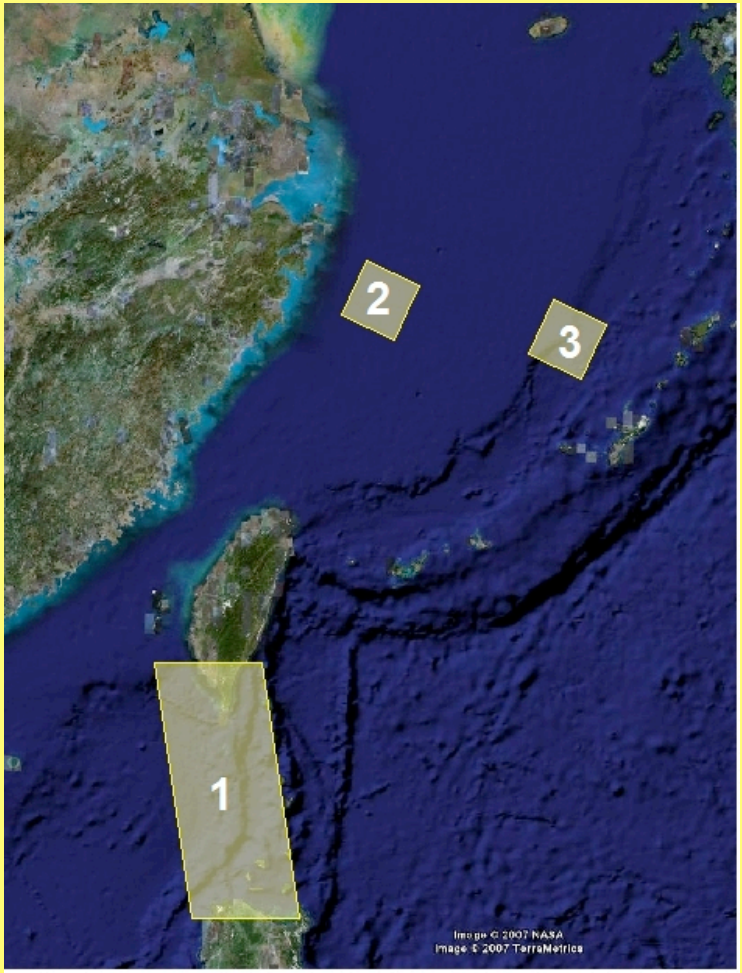
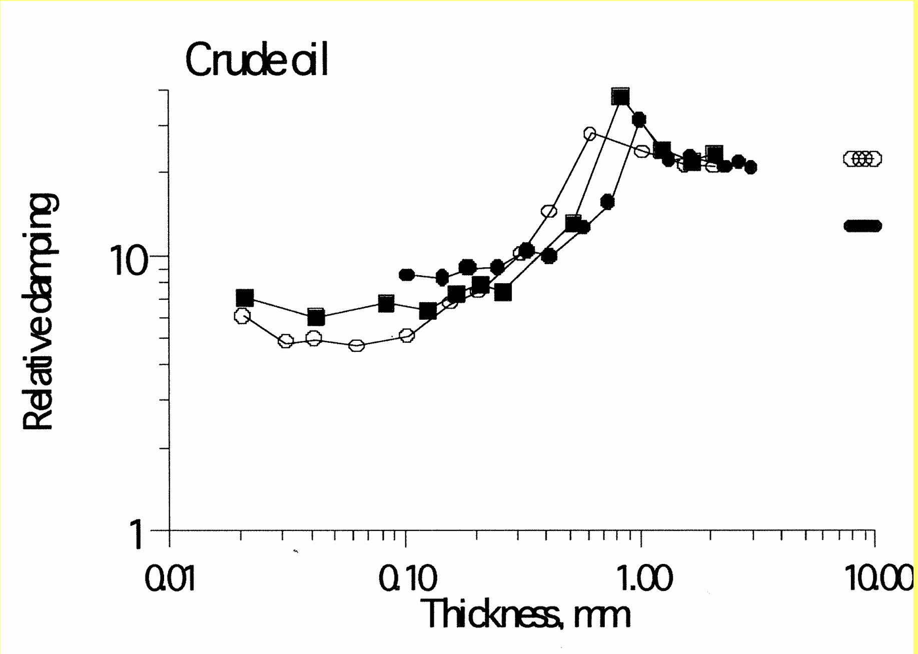


Natural film and eddy features

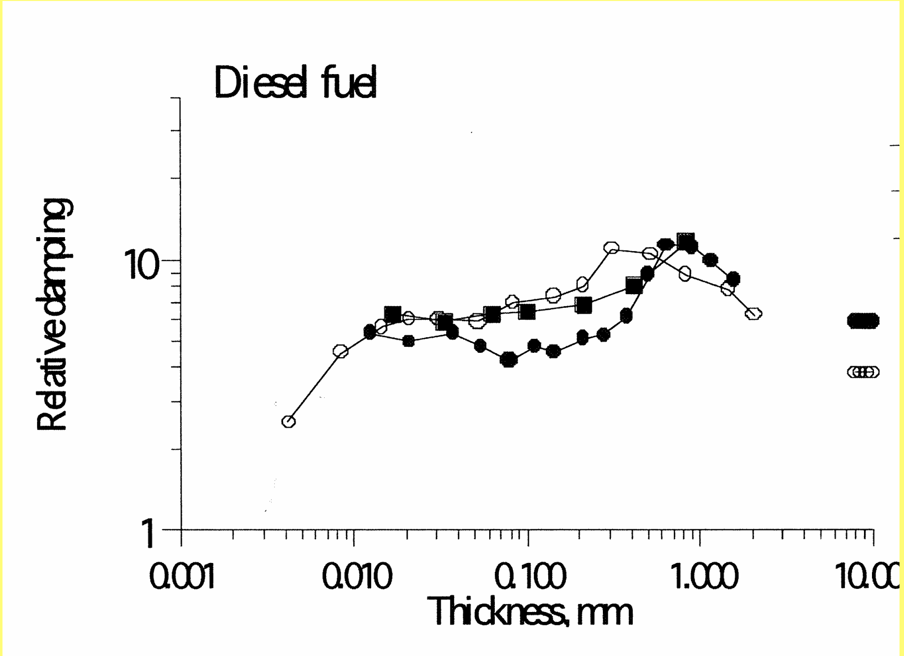


Oil spill damping



● 22-24°C
■ 5-7°C
○ 2- 3°C

at 15 GHz



ARTIFIAL SLICK DAMPING VERSUS WAVELENGTH

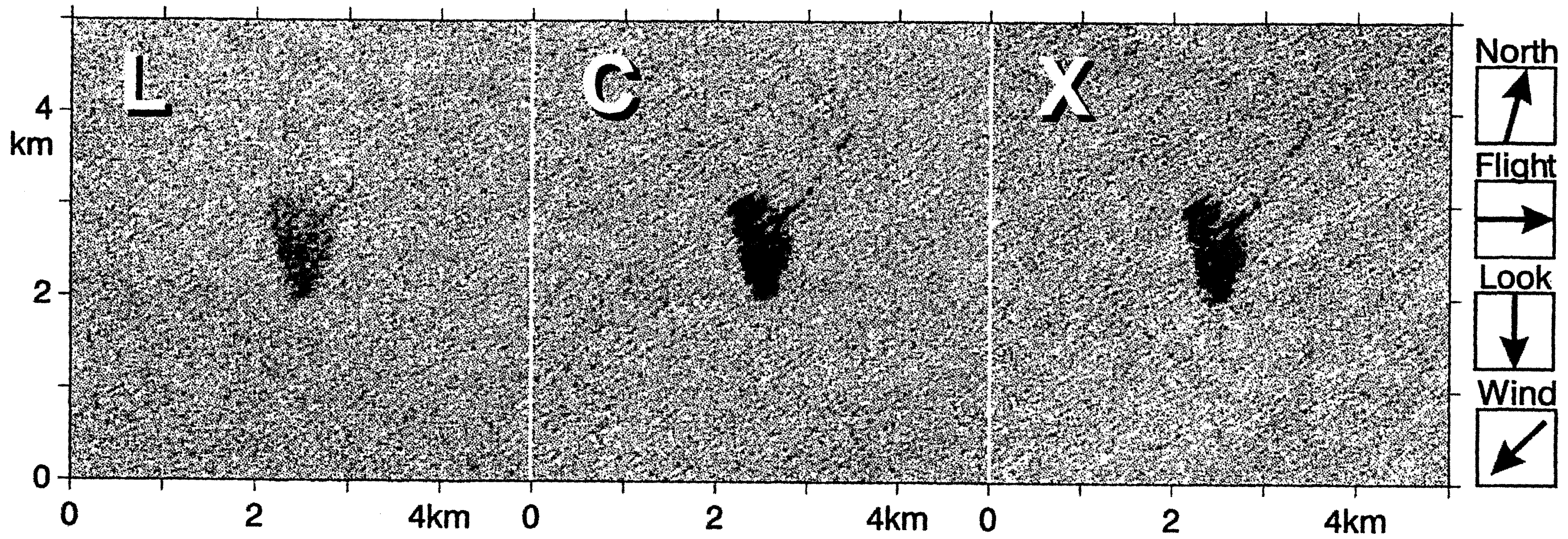
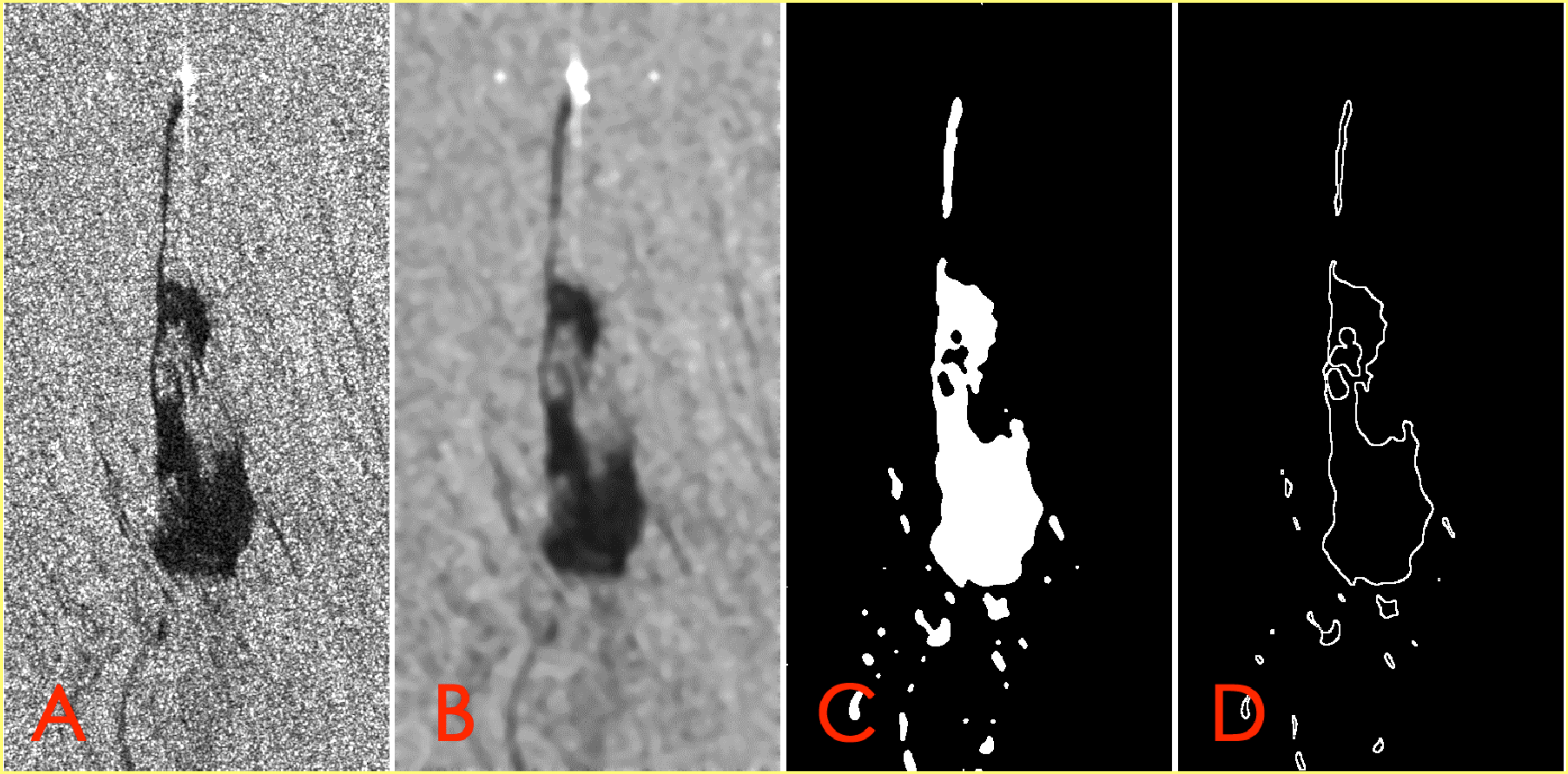


Figure 22. SIR-C/X-SAR images of artificial oleyl alcohol slick during the expermant in German Bight. The images are for VV polarization, L-, C- and X-bands. The illustration taken from Gade et al. Imaging of ocean surface films by SIR-C/X-SAR. J.Geophys. Res. 103. C9. 1998.

After Gade et al, 1988

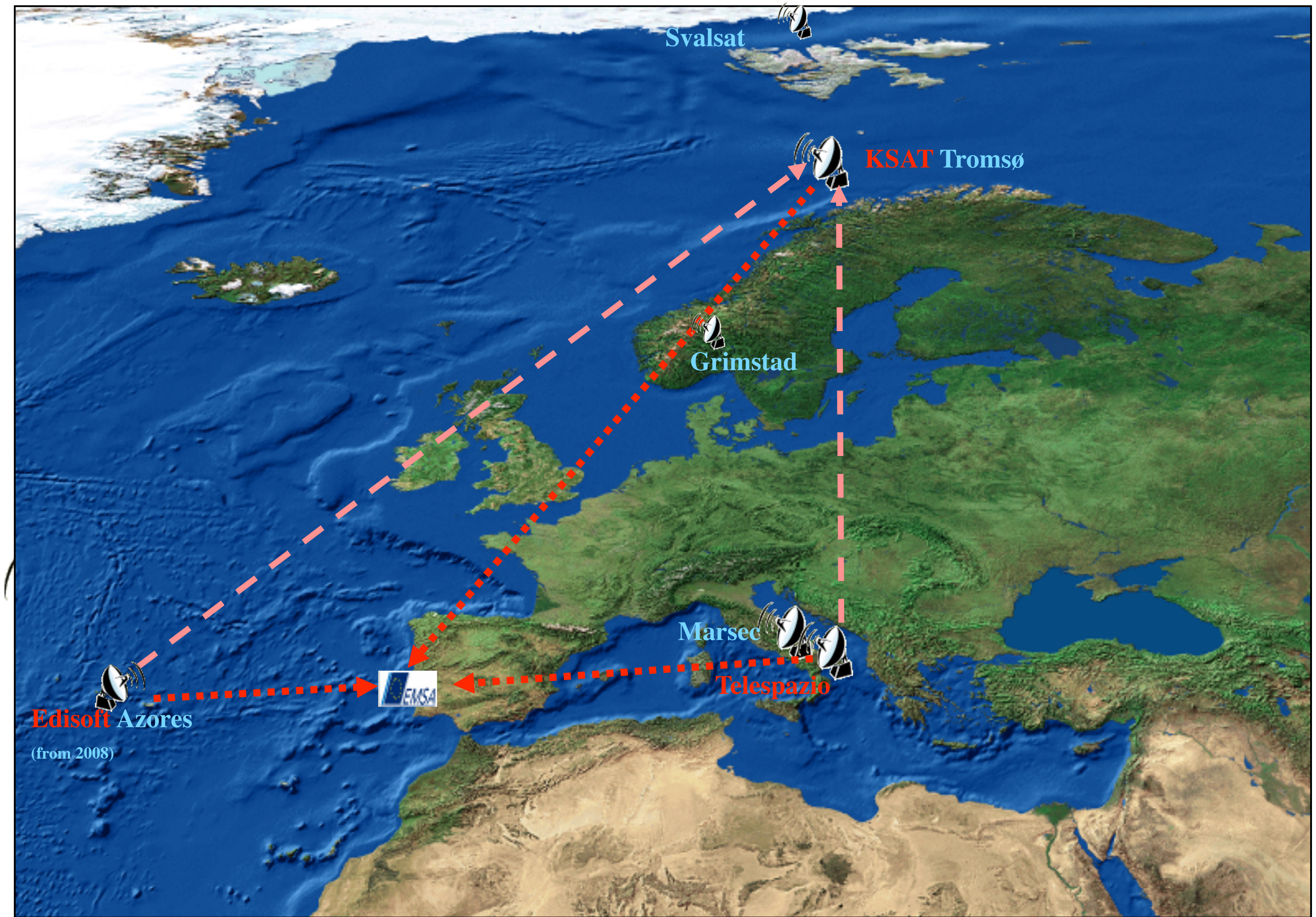
OIL SPILL DETECTION



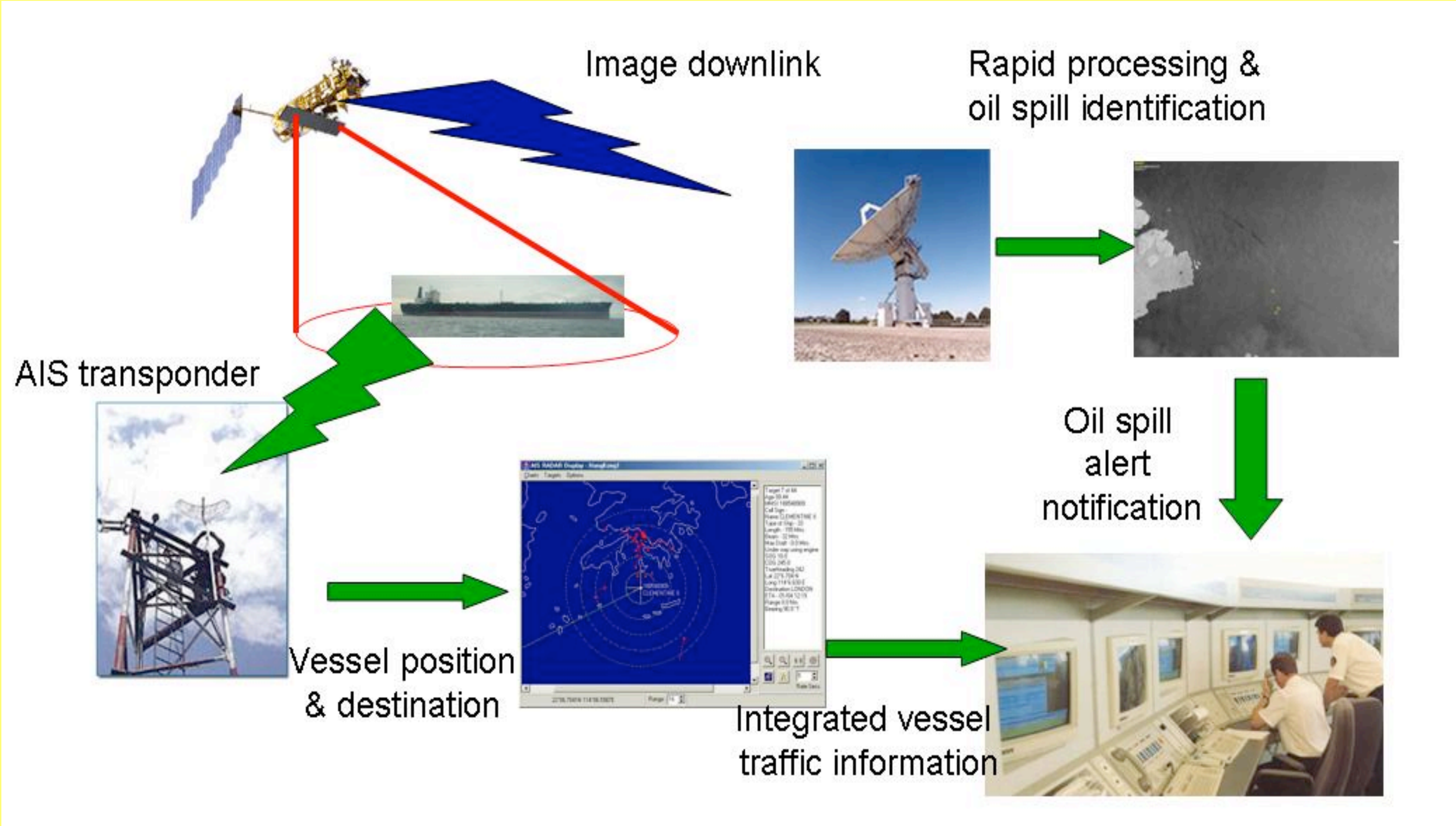
Typical shapes of oil spills originating from dumping of mineral oil from ships.
(courtesy of CRISP, Singapore)

GMES Service Network

- Ground stations
- Service providers
- Service centre:
  - Order handling
  - support
  - Service interface



Oil Spill detection system



SAR CONTRIBUTION TO MARINE MONITORING

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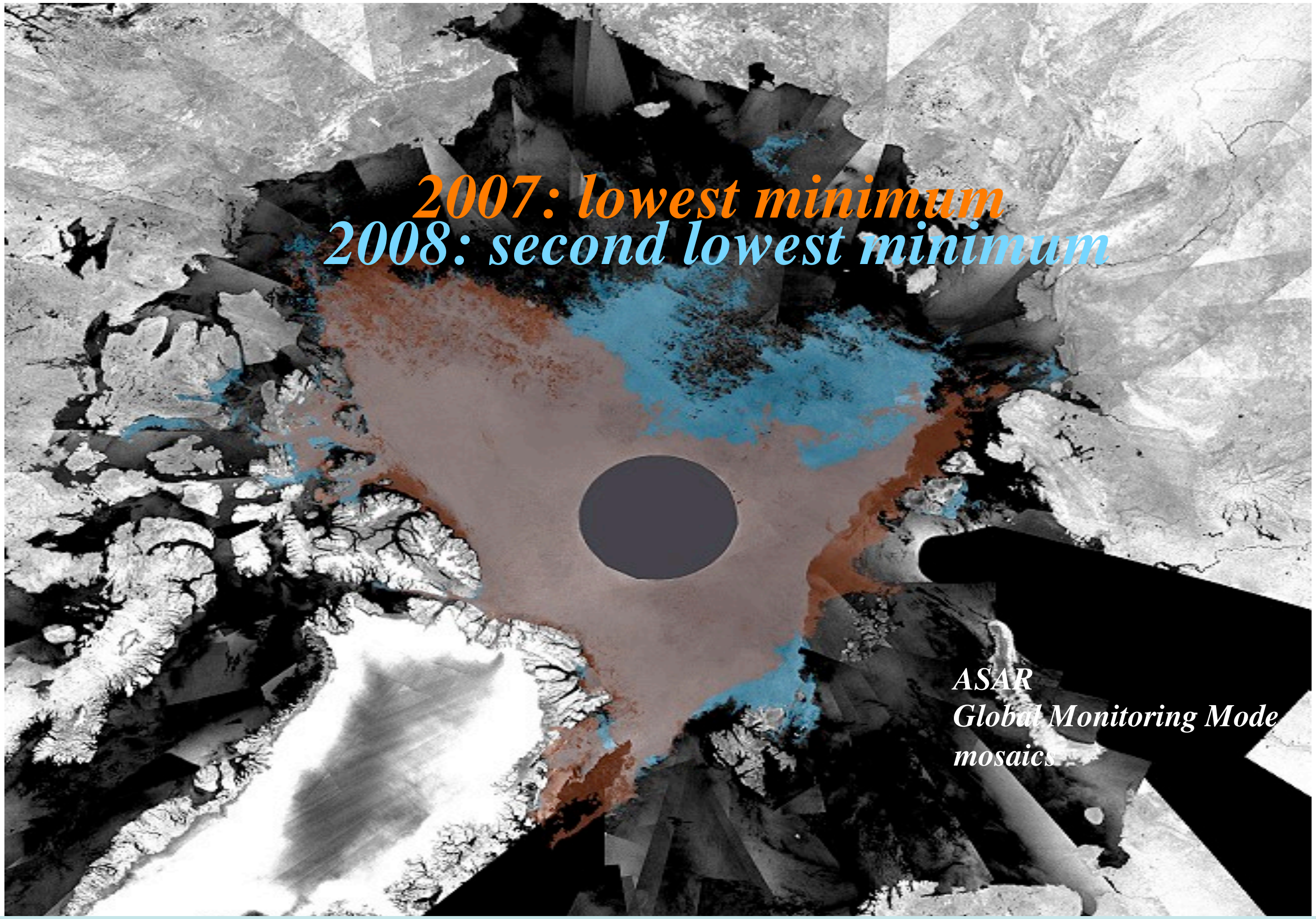
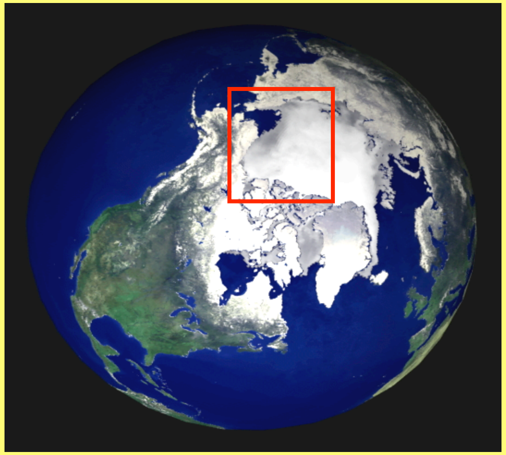


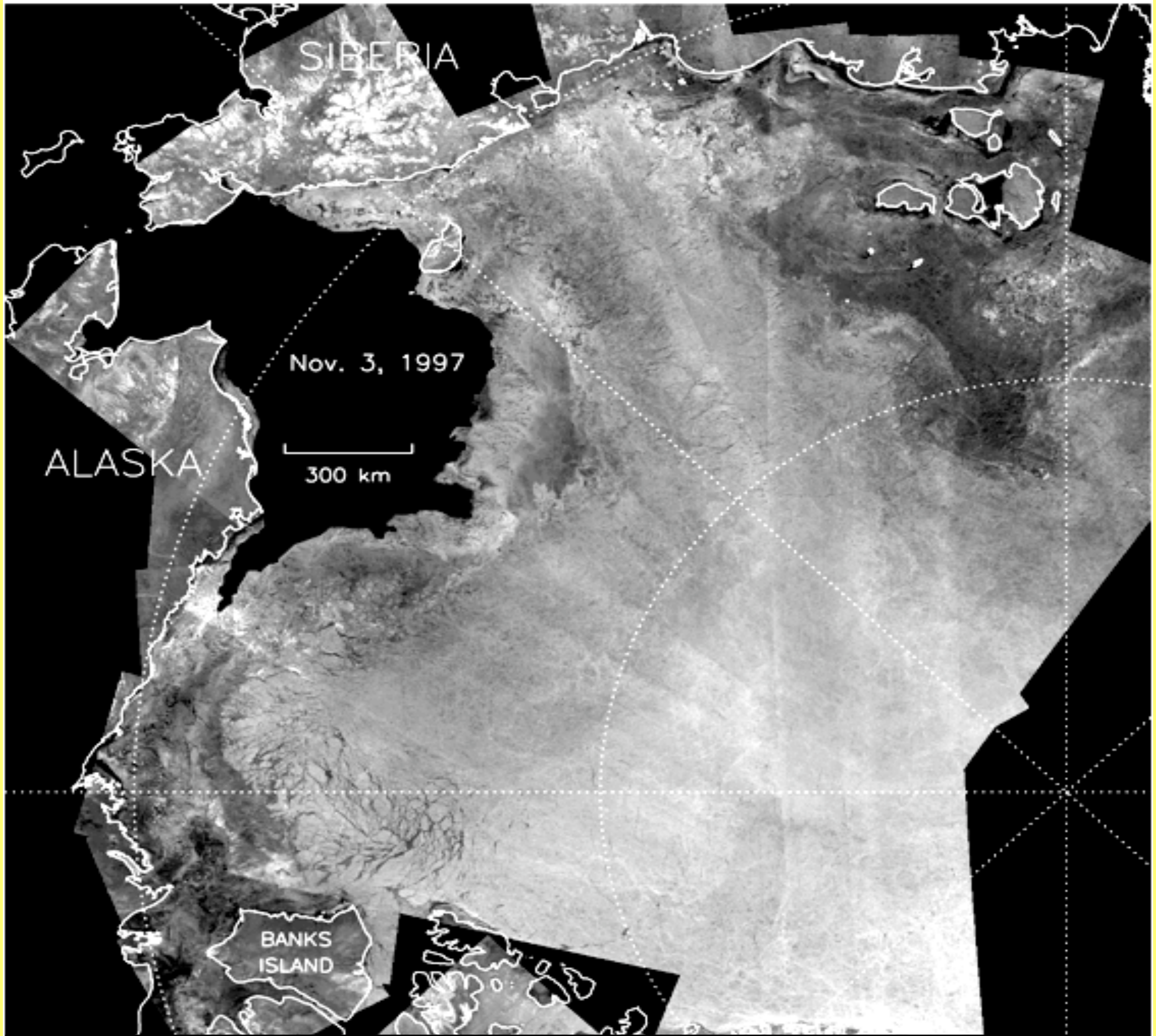
Arctic sea ice changes

Arctic Ocean

Mosaic of RADARSAT ScanSAR imagery



COURTESY RON KWOK JPL



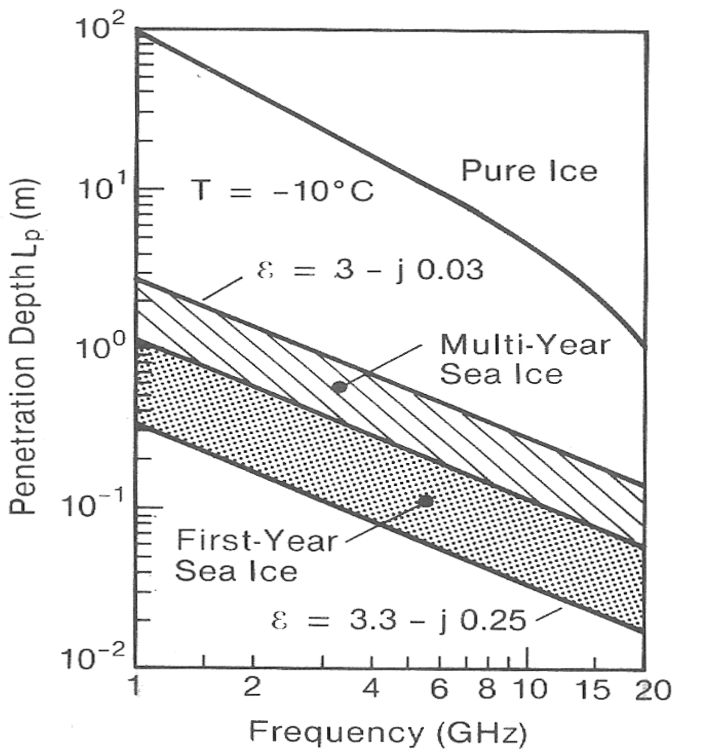
Backscatter = surface scattering + volume scattering

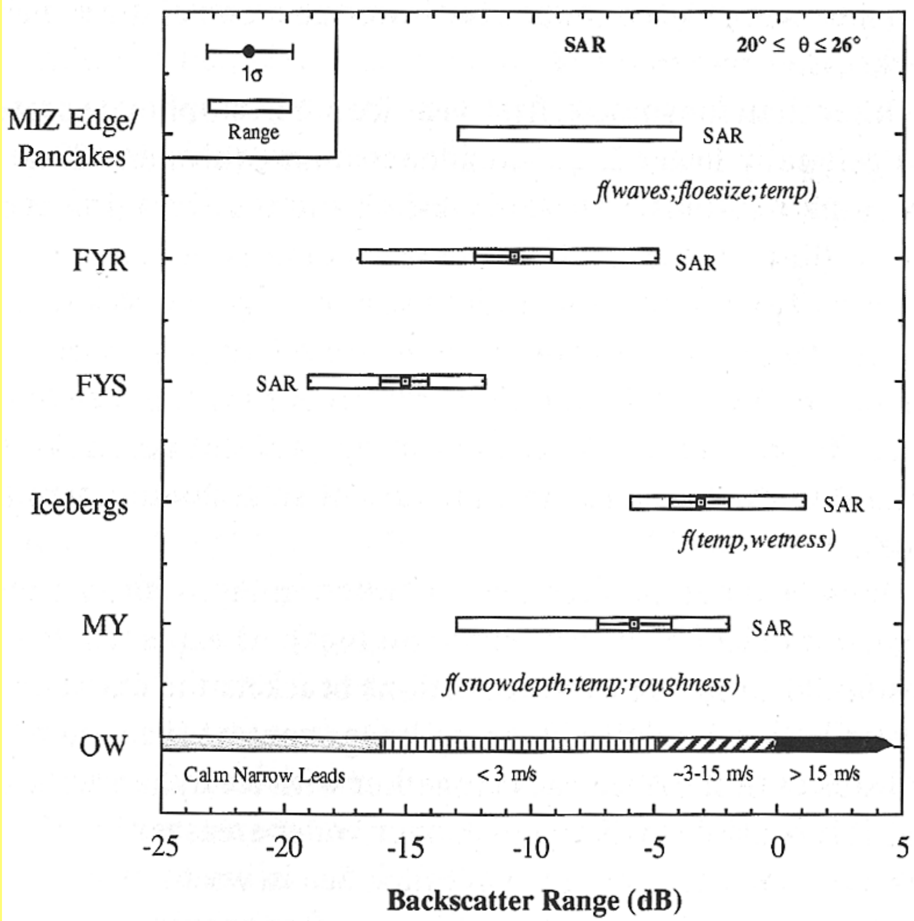
Surface and volume scattering

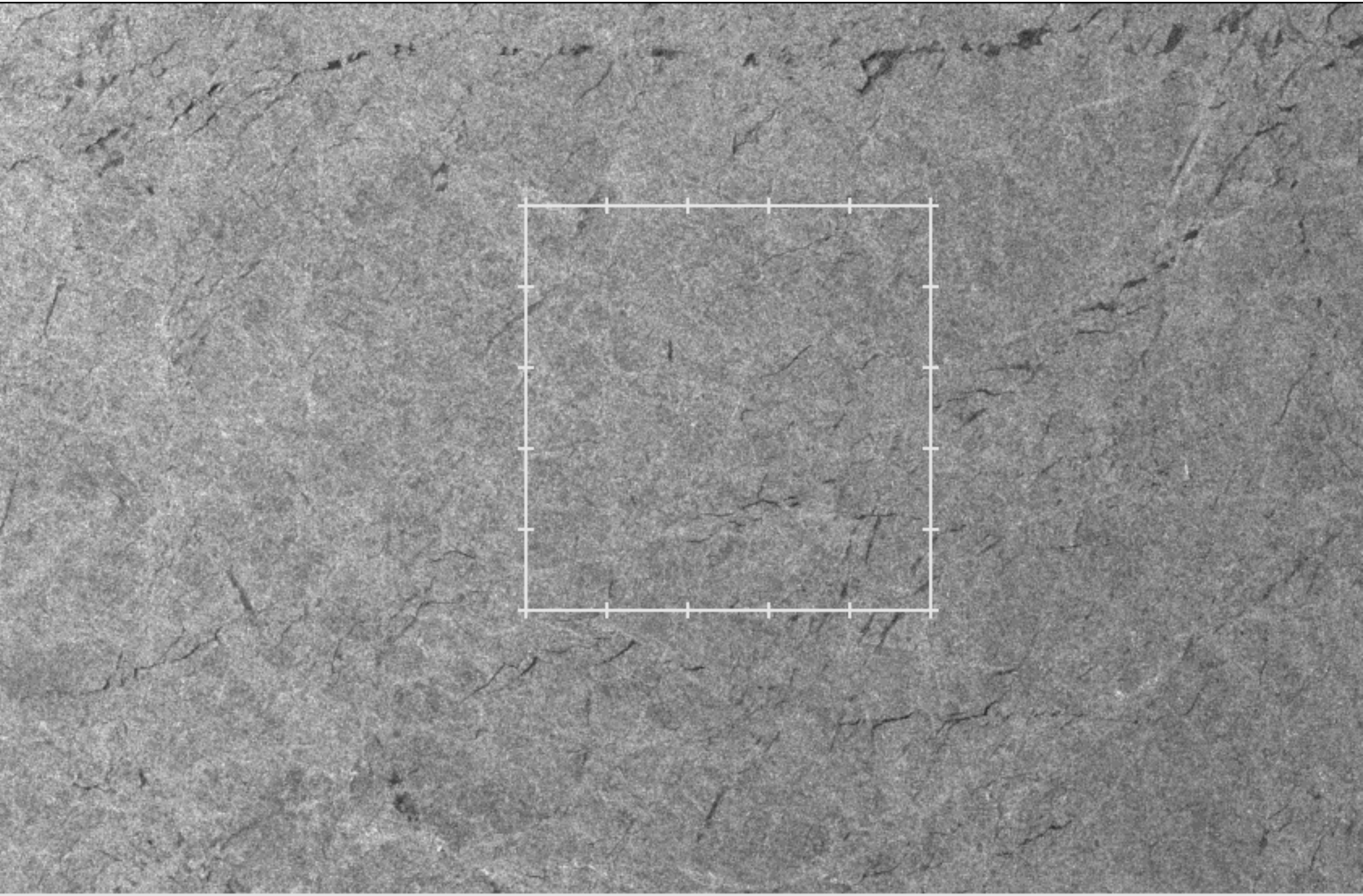
The importance of volume scattering is governed by the dielectric properties (dielectric constant) of the material:

High DE: surface scattering dominates

Low DE: volume scattering dominates

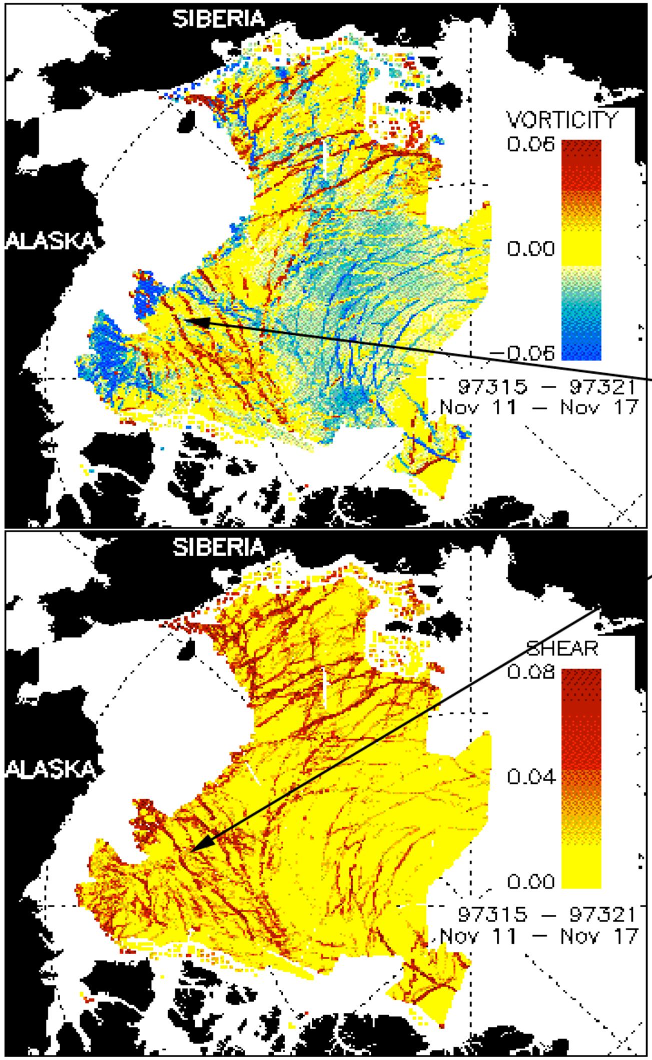


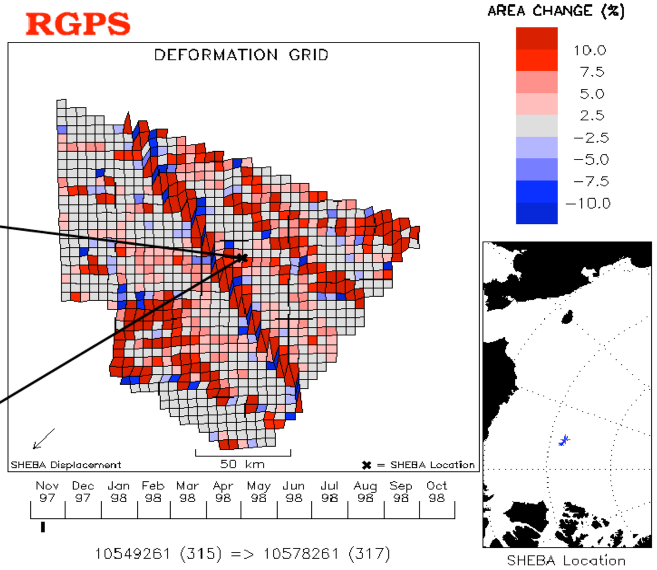




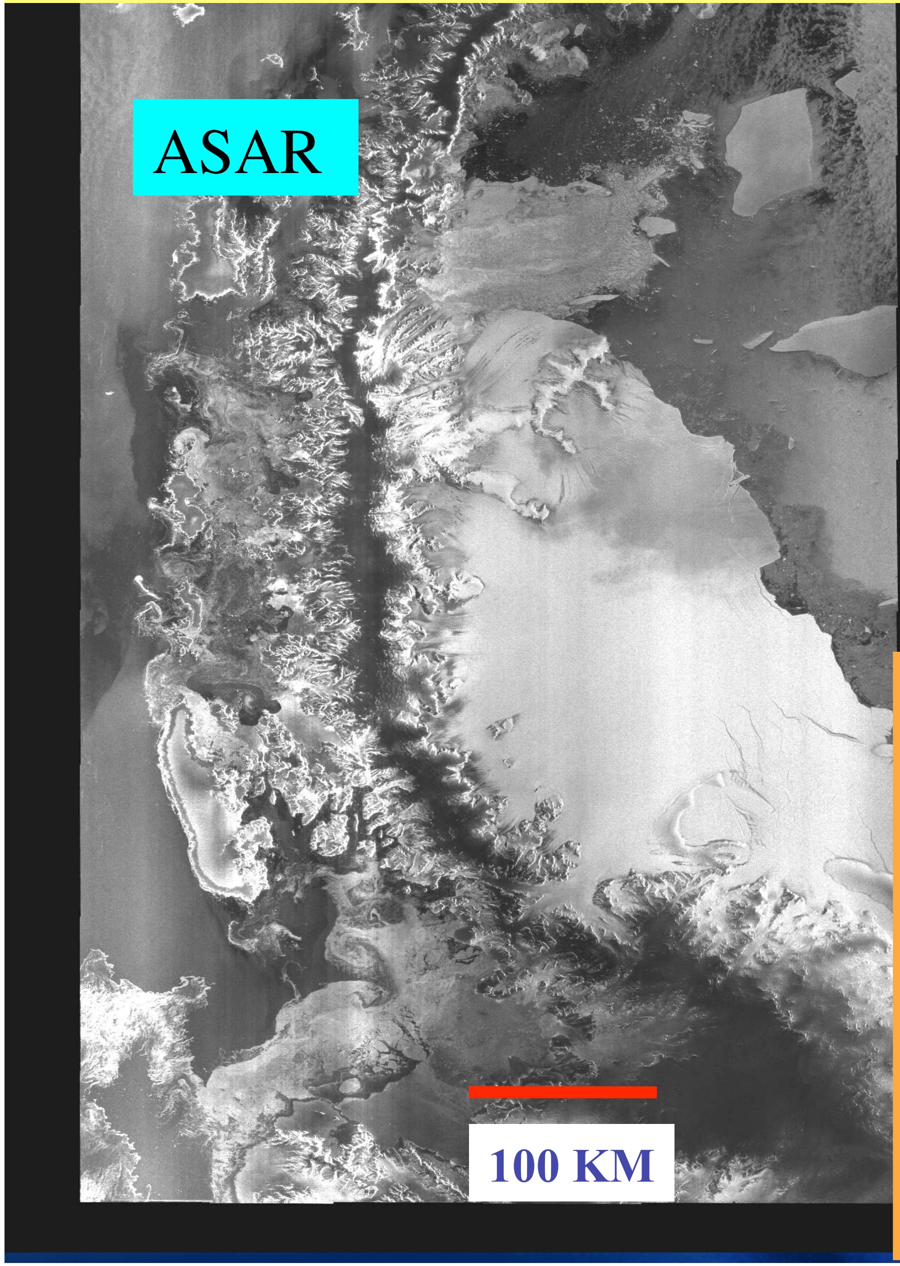
1998 Day of Year

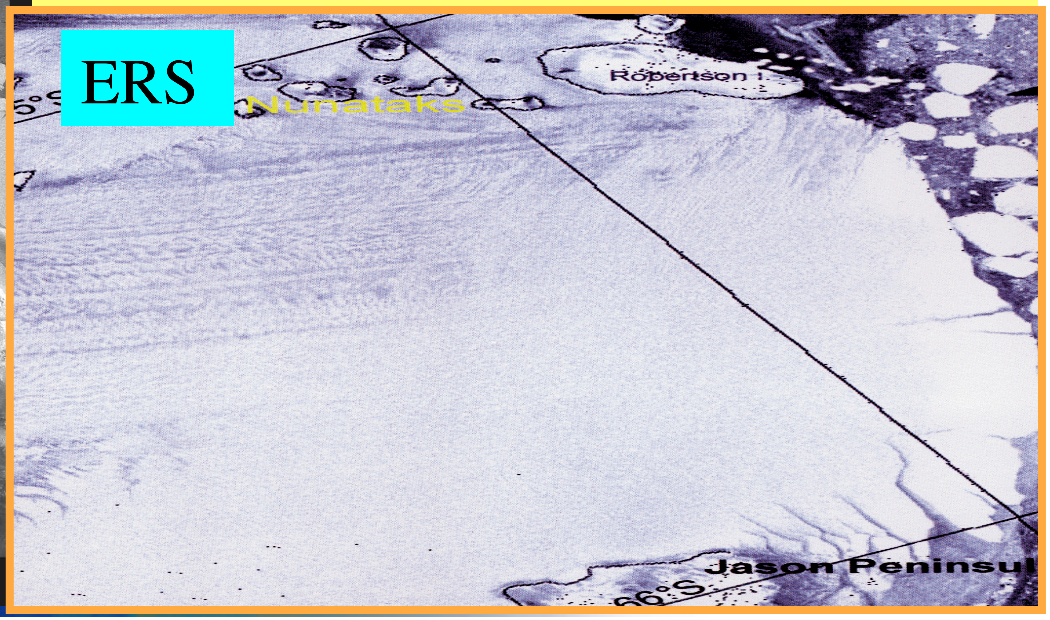
Location of SHEBA, Nov 97



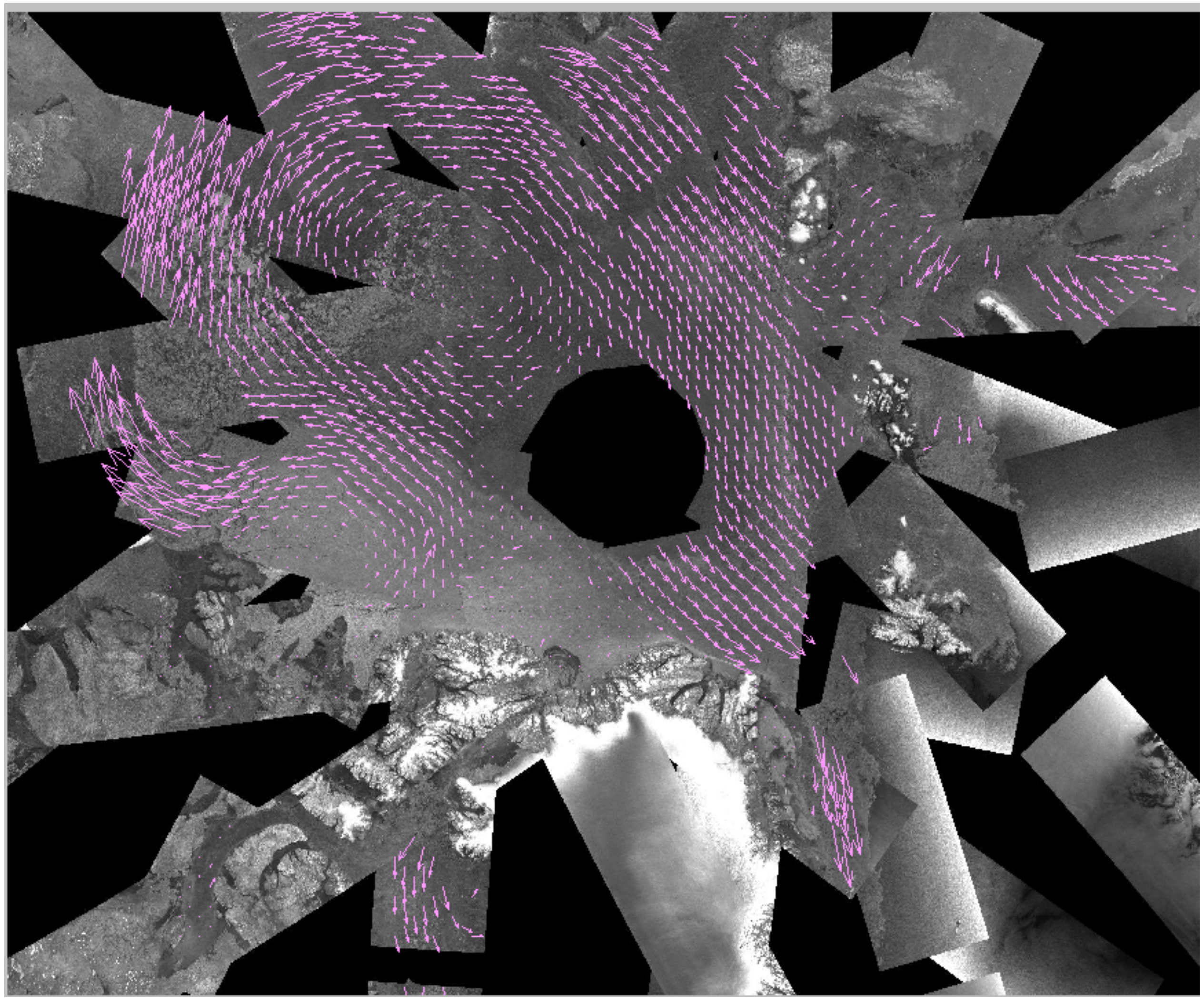


Large-scale Visualization Of Cell Deformation


ASAR
100 KM


ERS
Nunataks
Robertson I.
Jason Peninsul

ASAR: Arctic Sea Ice Drift



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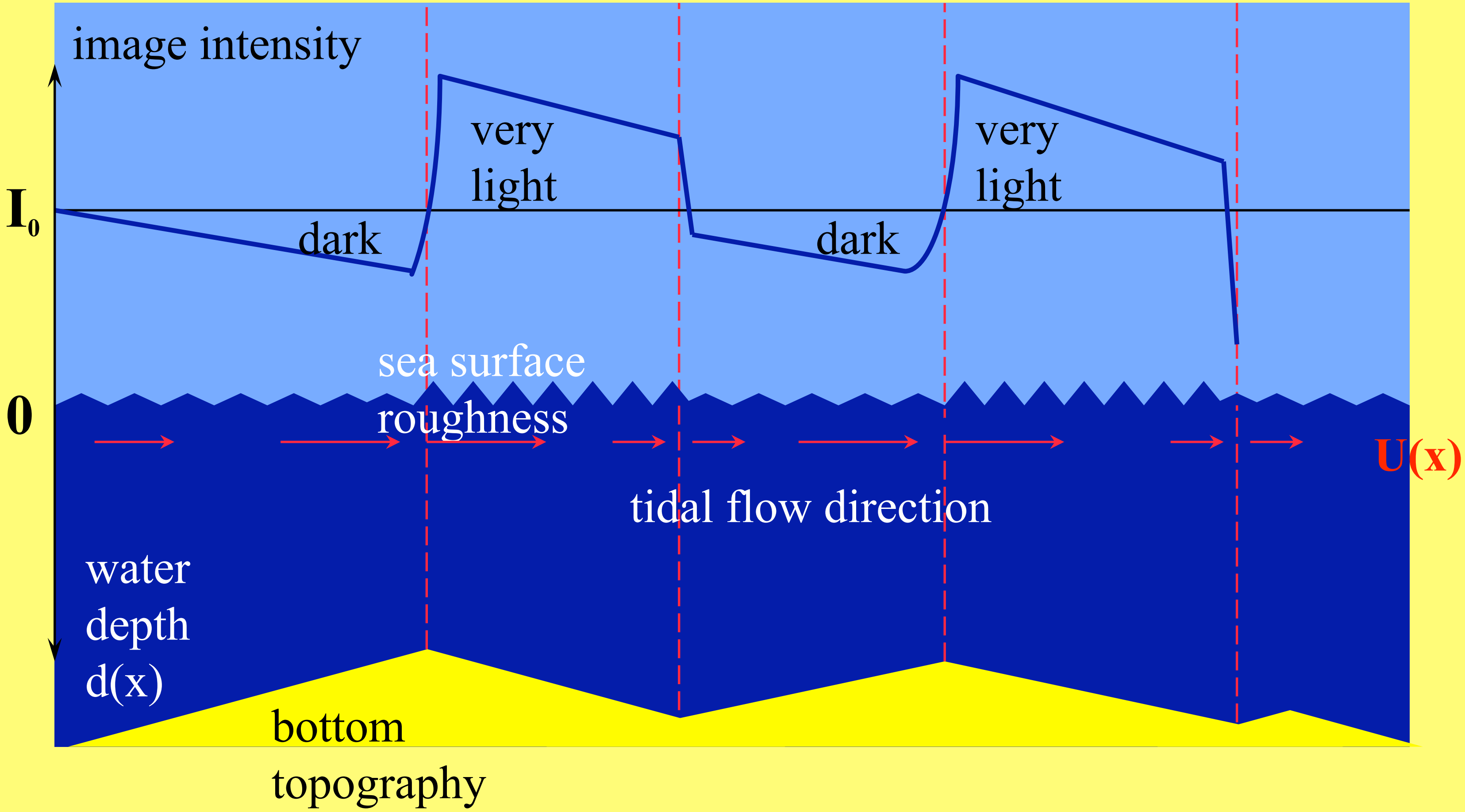
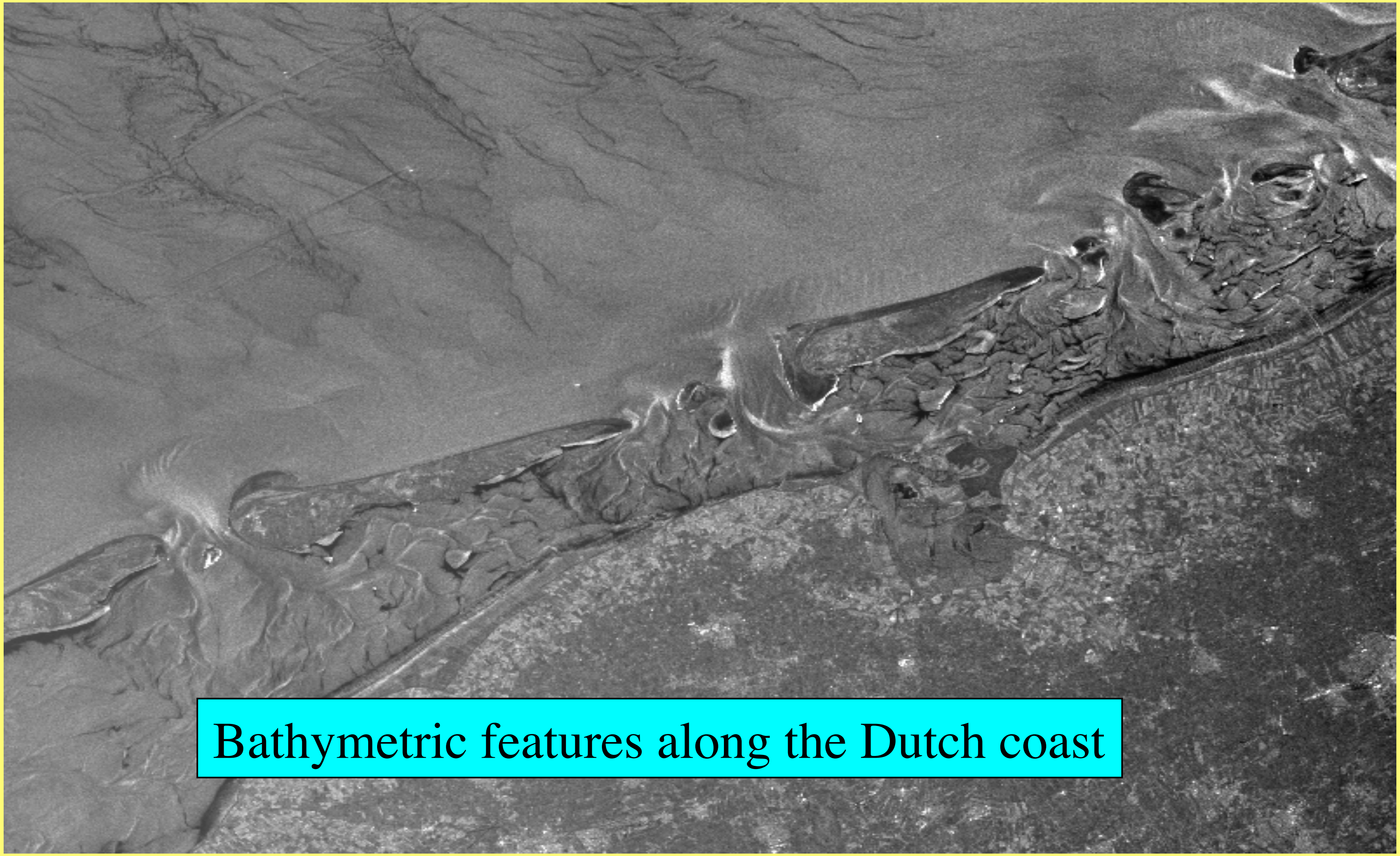
Bathymetry by imaging radar.



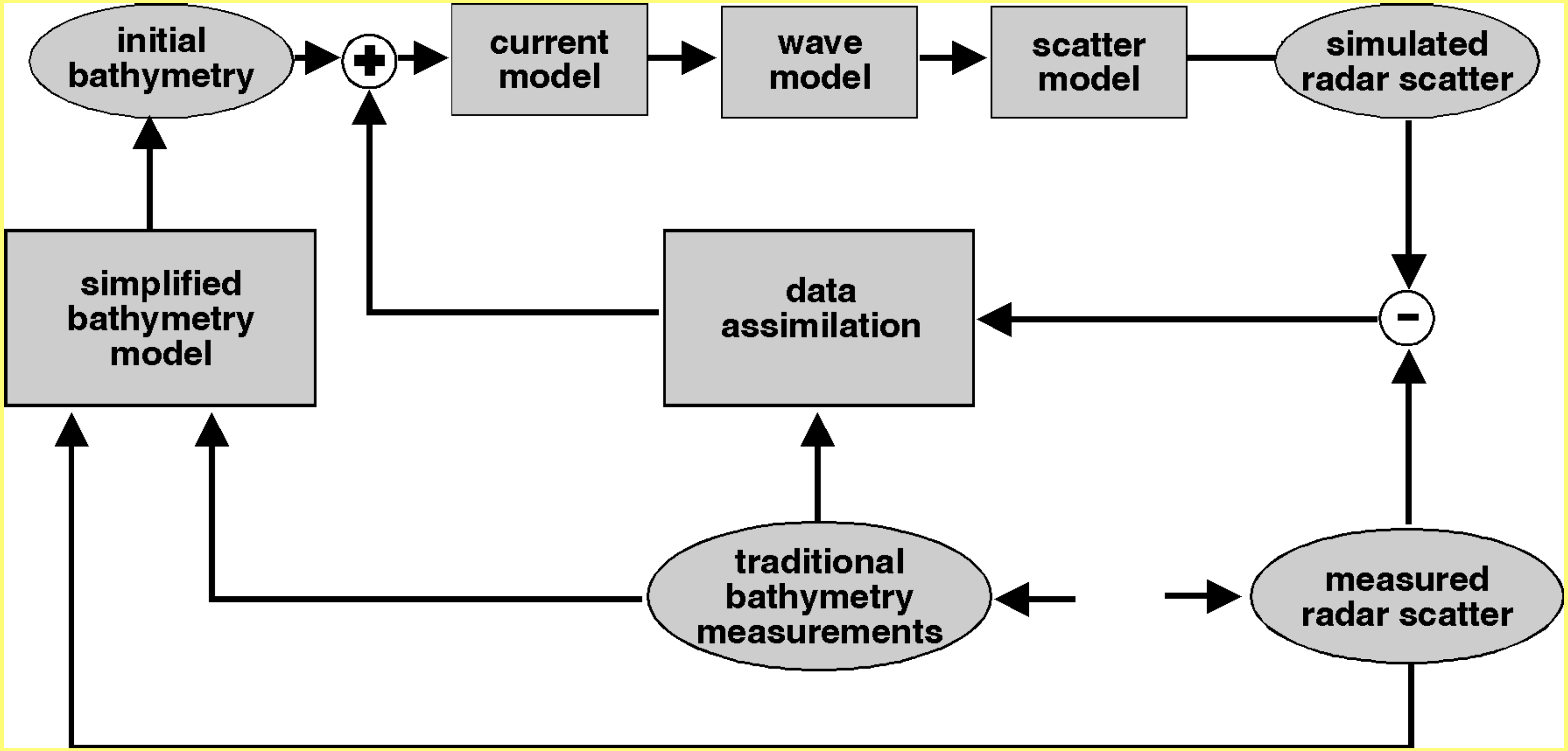
Bathymetric features along the Chinese coast

ERS-1 SAR image of the Xinchuan Gang Shoals at the east coast of China north of Shanghai. Part of the area falls dry during ebb tide (dark areas off the coast).



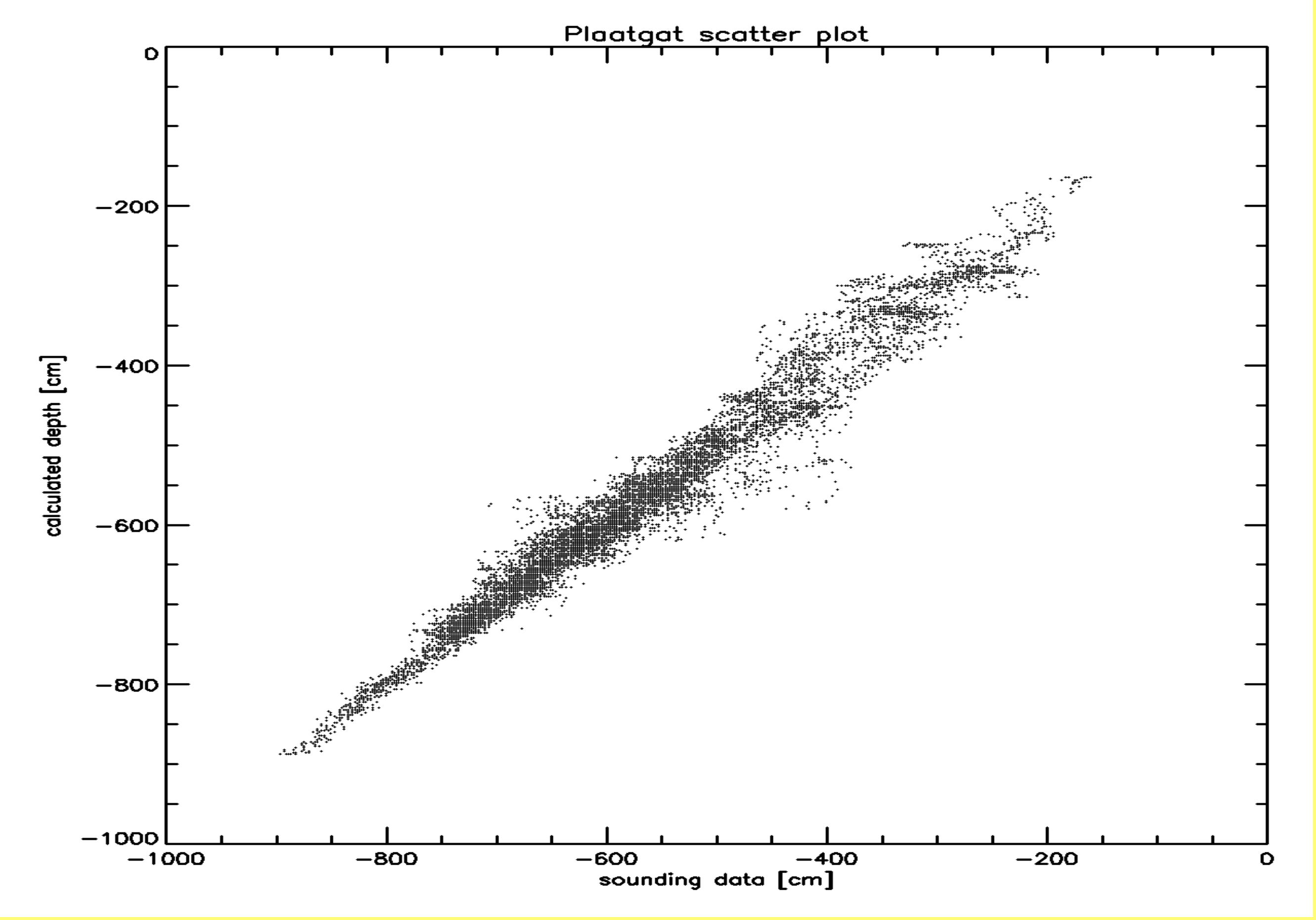
Bathymetric features along the Dutch coast

Bathymetric Assessment System



www.argoss.nl

COMPARISON SAR AND SOUNDING DEPTH DATA



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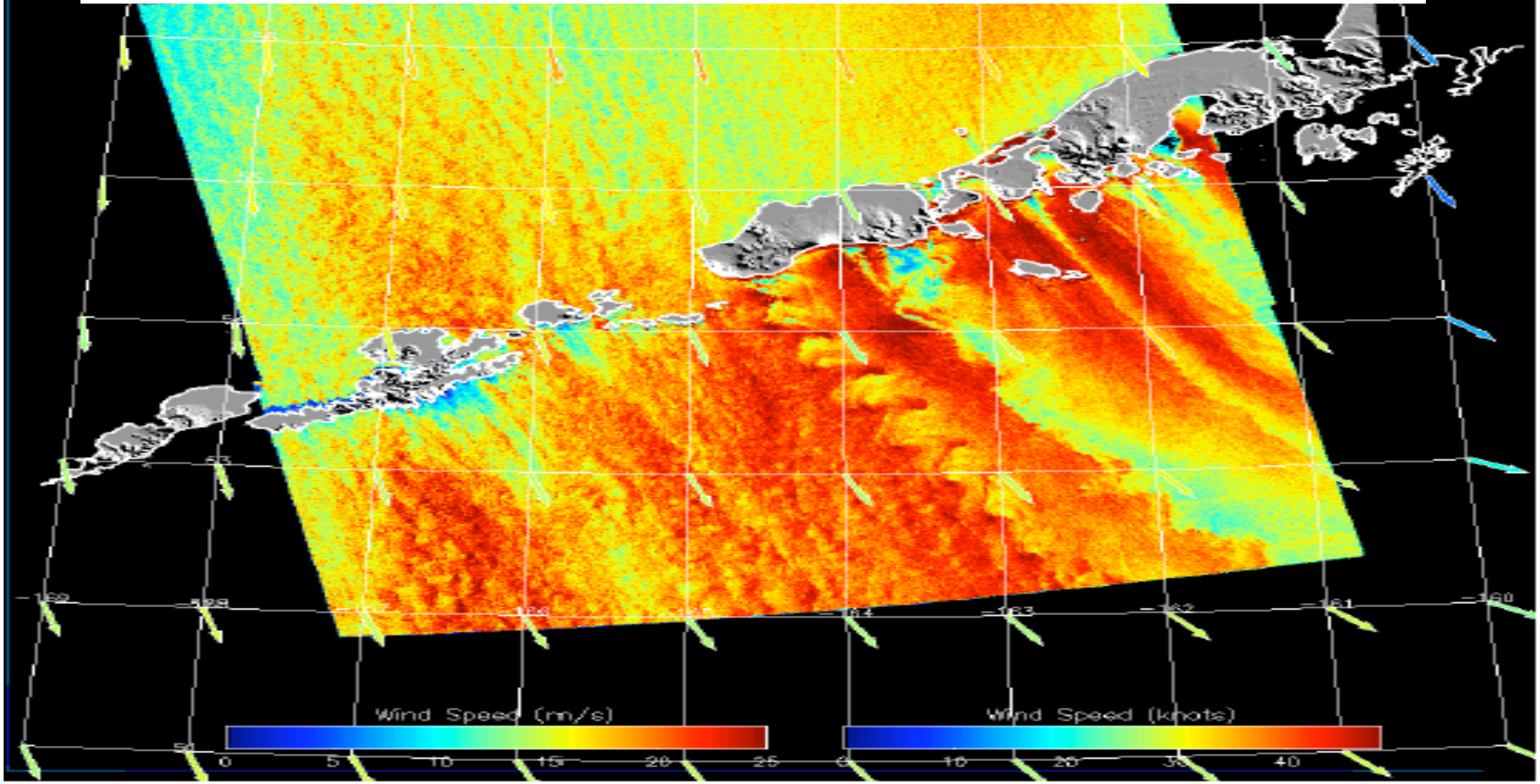
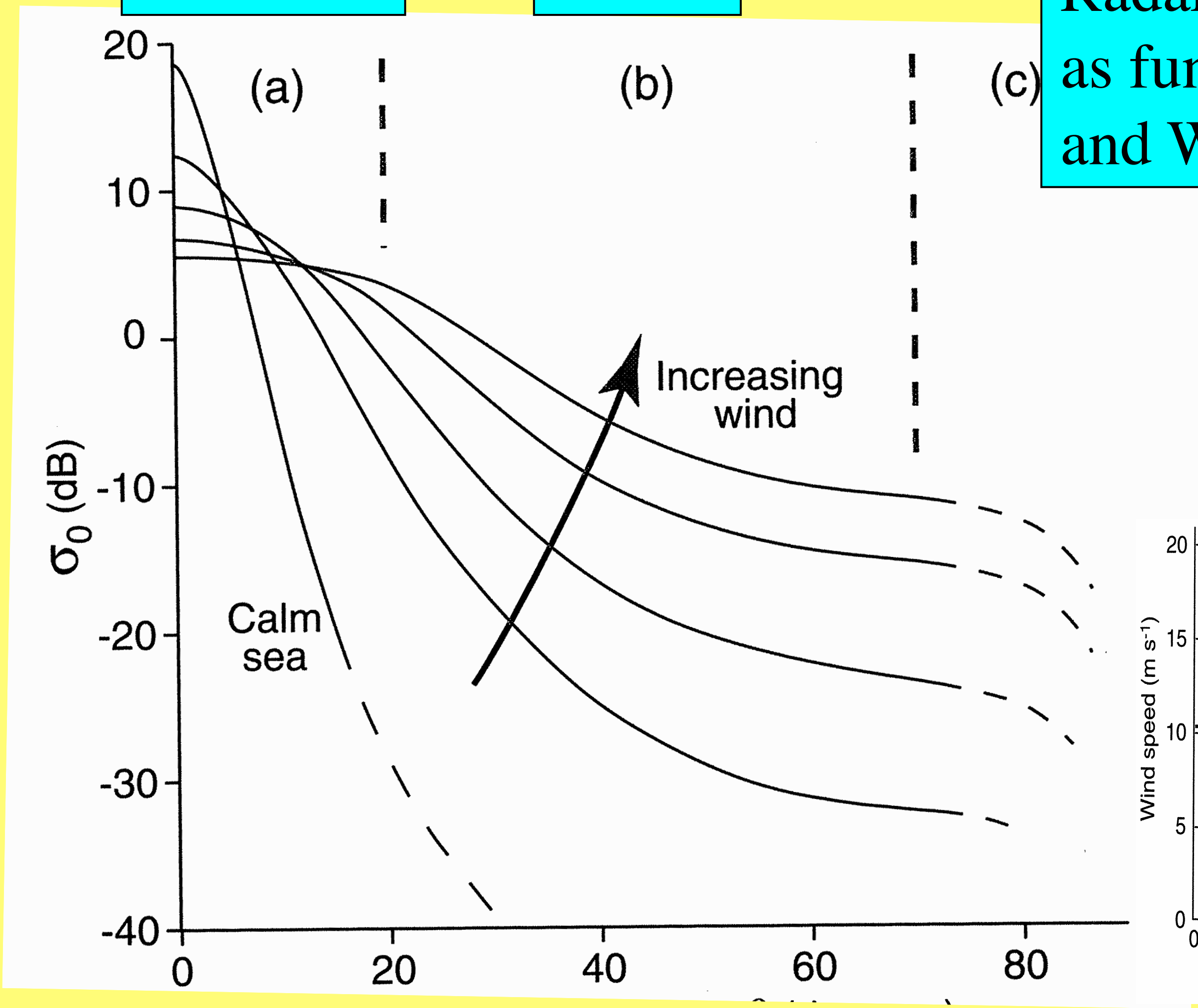
$$\sigma^{0}(U,\varphi) = A(\theta)U^{\gamma(\theta)}\left[1 + B(U,\theta)\cos\varphi + C(U,\theta)\cos 2\varphi\right]$$



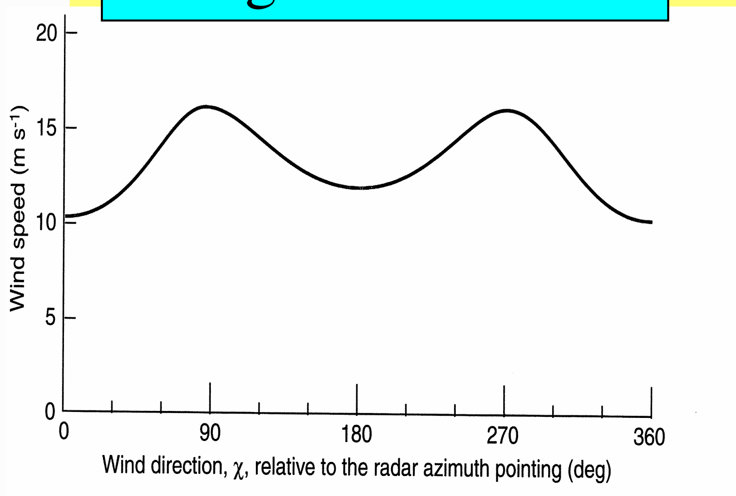
SPECULAR

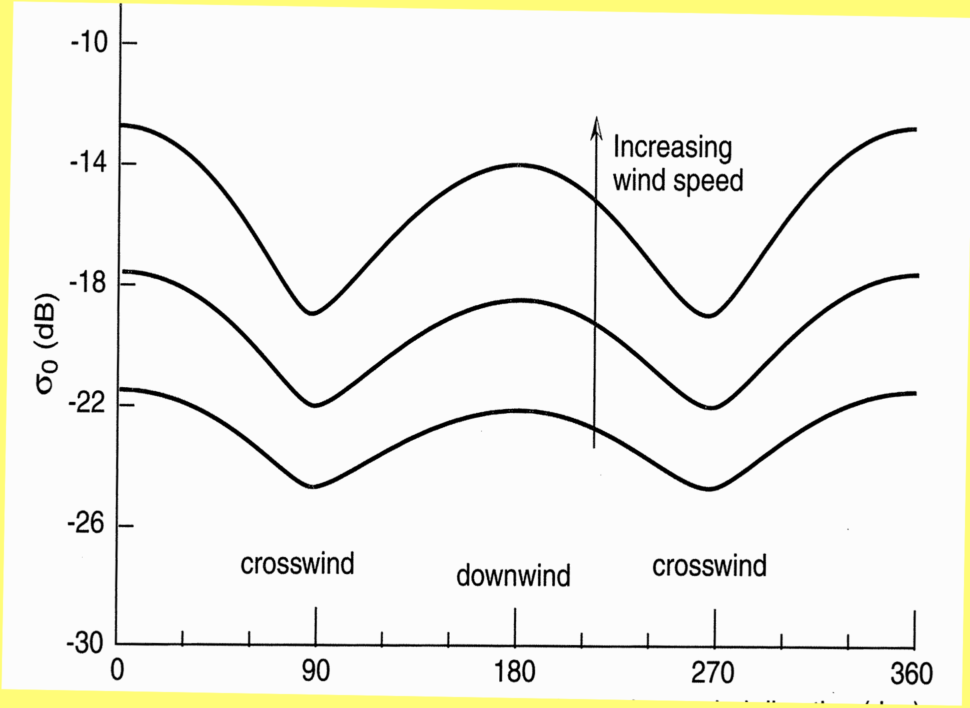
BRAGG

Radar signal strength as function of incidence angle and Wind speed



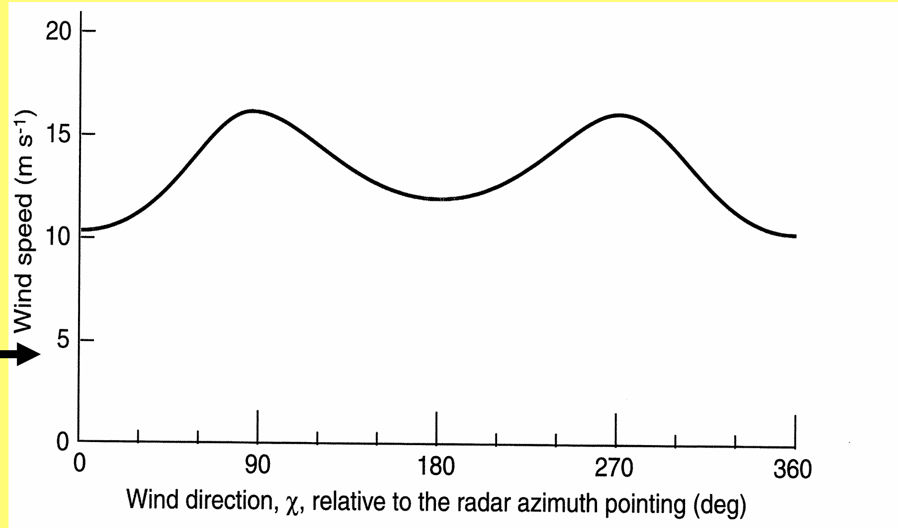
Wind speed changes with direction for a given radar signal strength



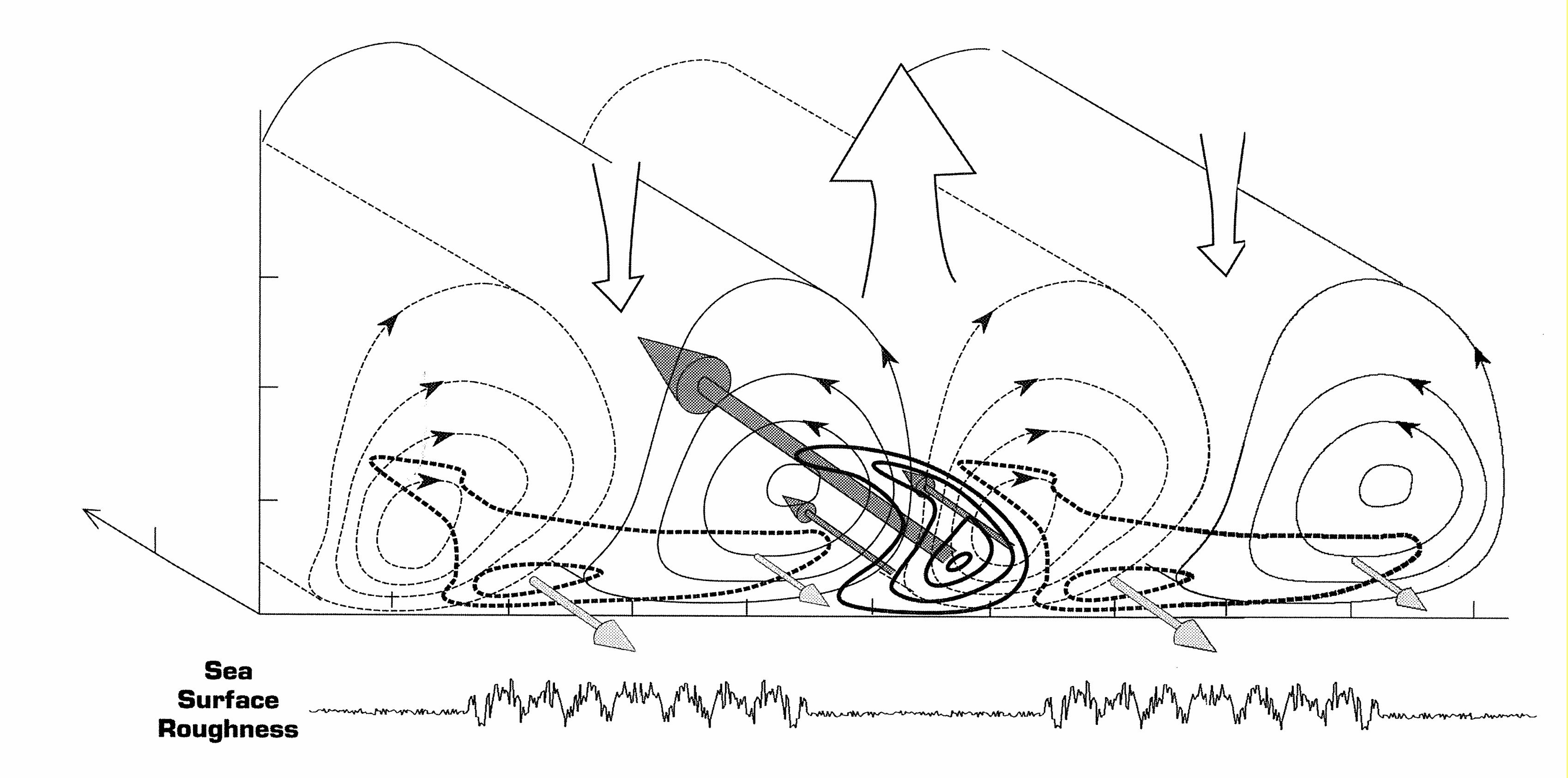


Radar signal strength as a function of wind speed and direction

Wind speed changes with direction for a given radar signal strength

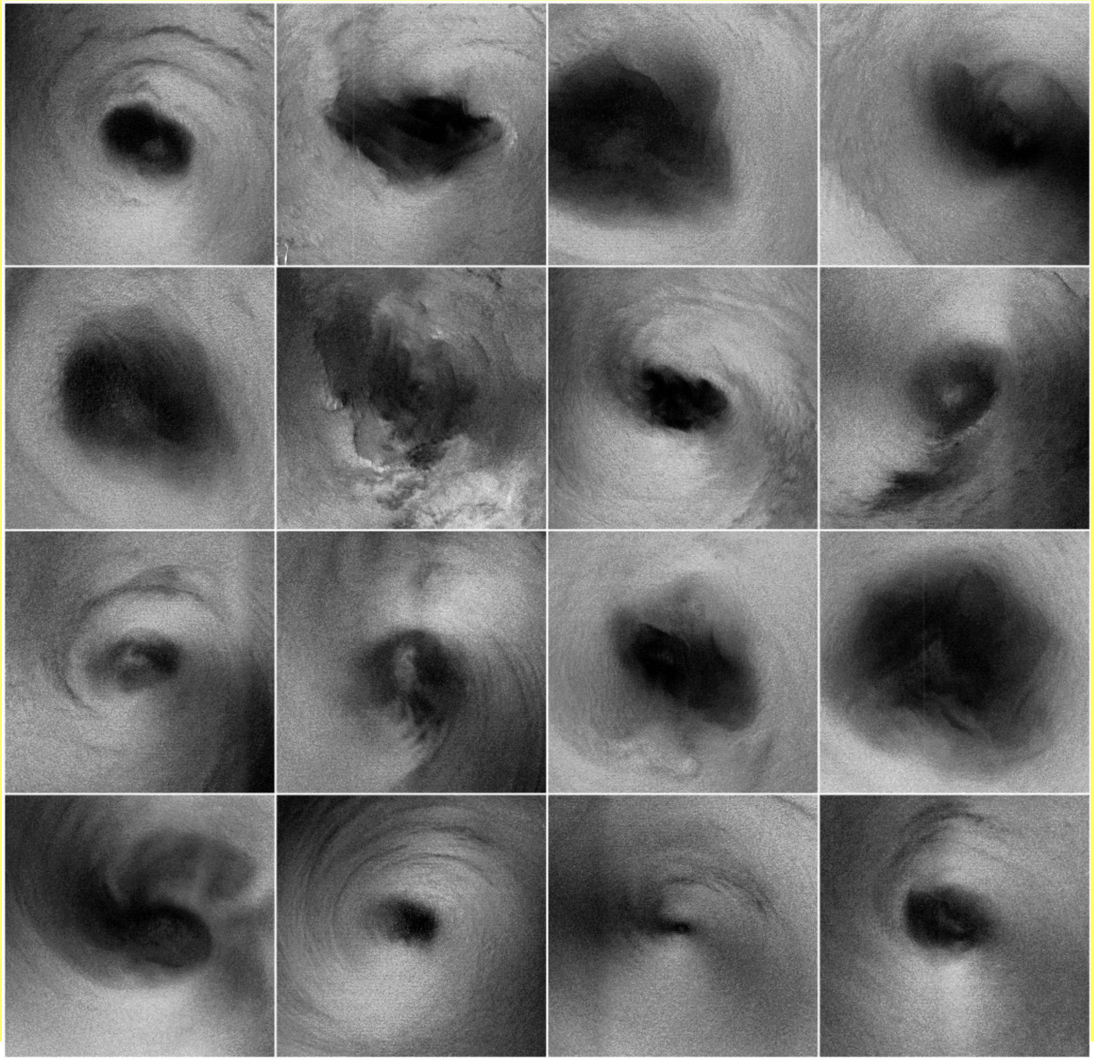


ATMOSPHERIC BOUNDARY LAYER ROLLS



Courtesy Ralph Foster, Univ. Of Washington

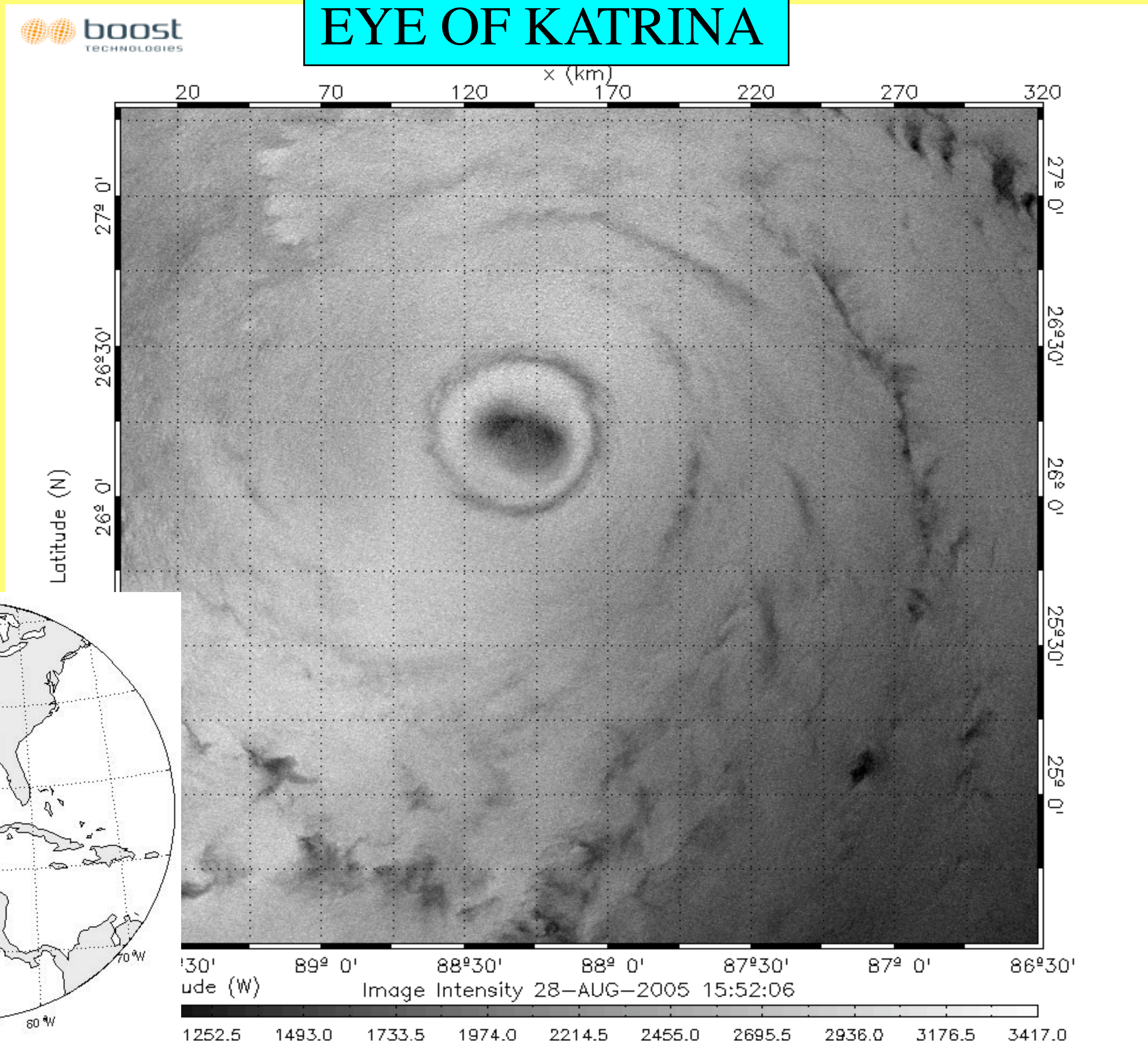
Hurricane Eyes

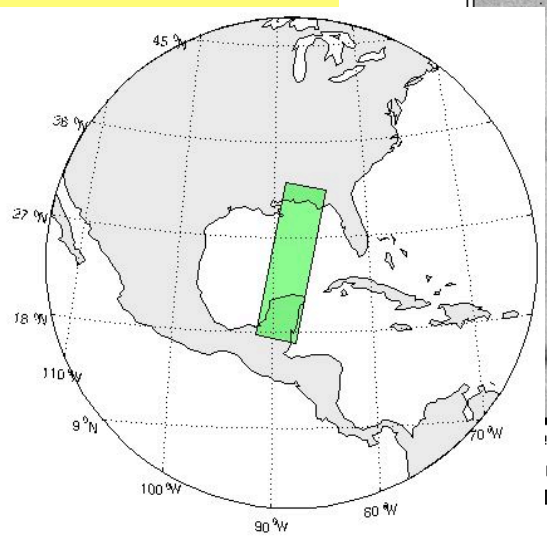


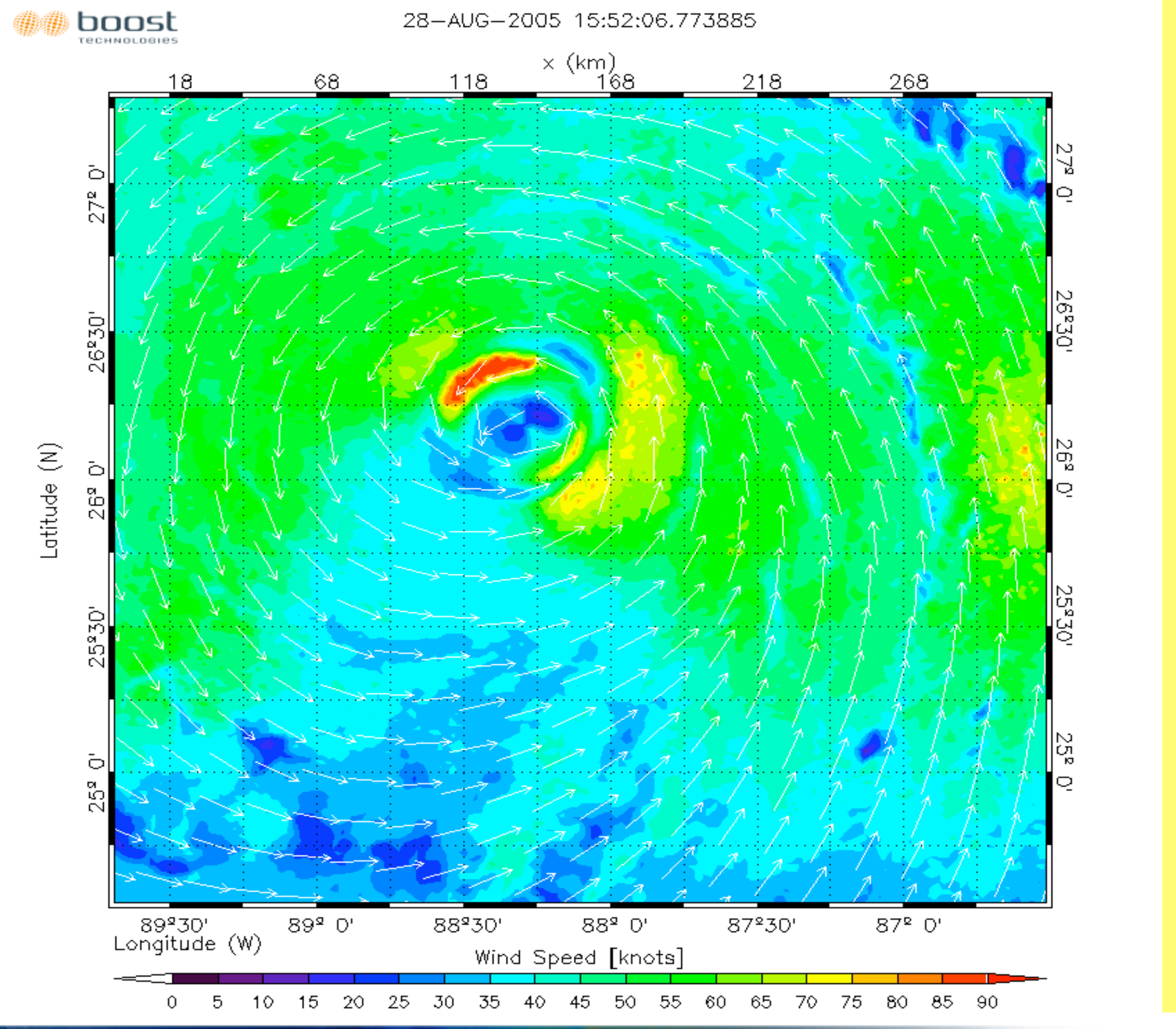
Danielle 31 Aug '98	**Dennis 27 Aug '99**	**Dennis 29 Aug '99**	**Dennis 31 Aug '99**
Floyd 15 Sep '99	**Alberto 17 Aug '00**	**Florence 13 Sep '00**	**Dalila 26 Jul '01**
Flossie 29 Aug '01	**Flossie 1 Sep '01**	**Erin 11 Sep '01**	**Erin 13 Sep '01**
Felix 17 Sep '01	**Humberto 26 Sep '01**	**Juliette 27 Sep '01**	**Olga 28 Nov '01**

100 km

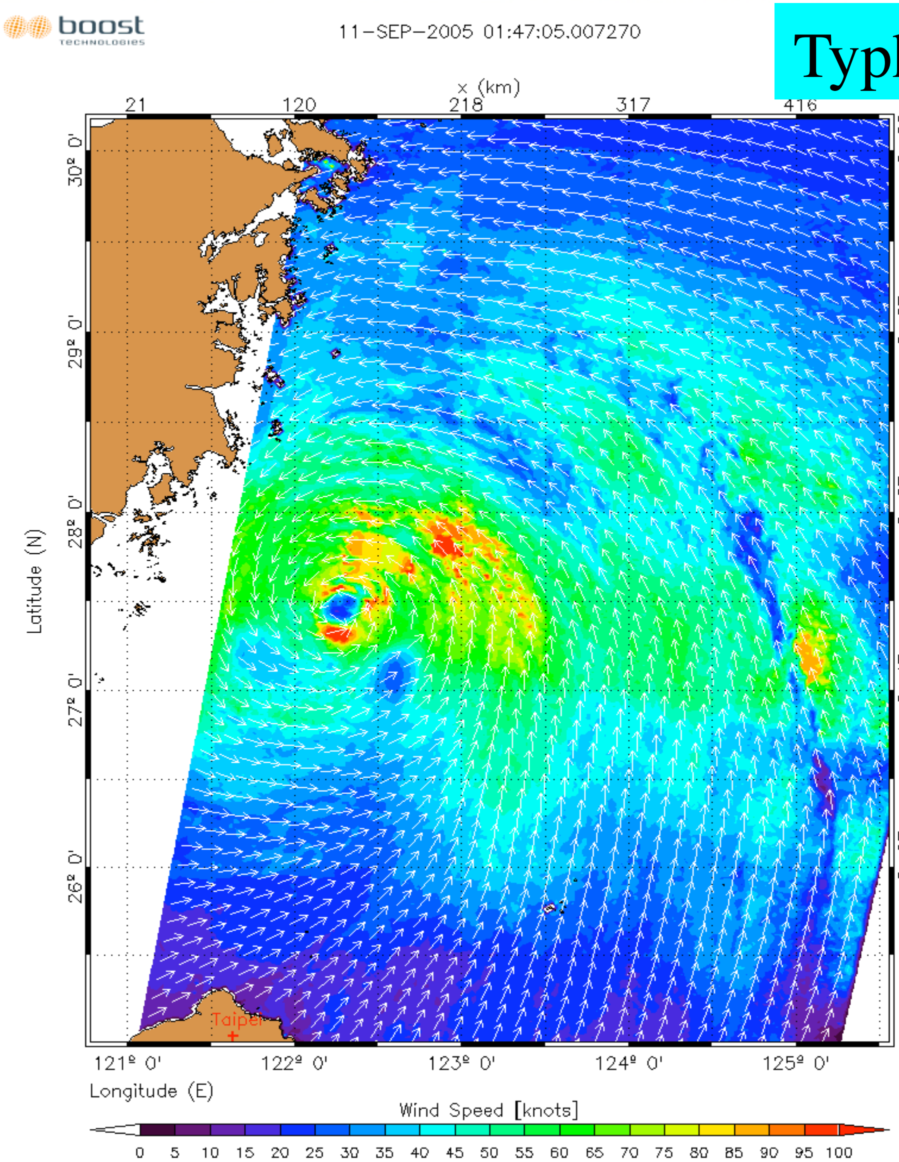
EYE OF KATRINA

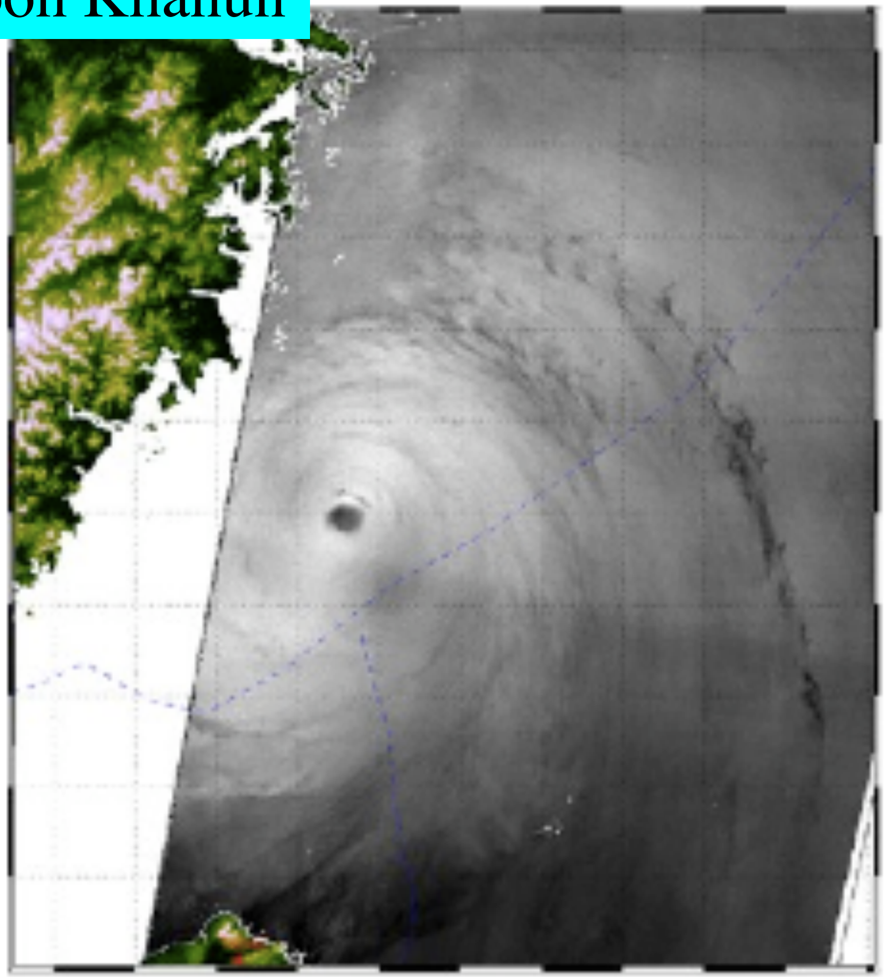




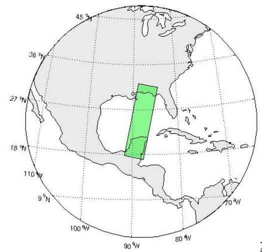

boost TECHNOLOGIES
28–AUG–2005 15:52:06.773885
x (km)
18
68
118
168
218
268
27º 0'
26º30'
26º 0'
25º30'
25º 0'
Latitude (N)
89º30'
89º 0'
88º30'
88º 0'
87º30'
87º 0'
Longitude (W)
Wind Speed [knots]
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90

Typhoon Khanun

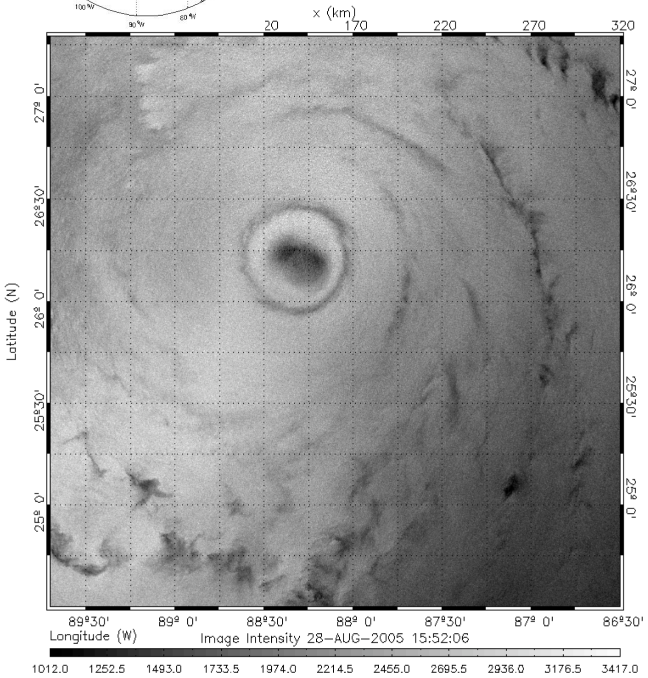


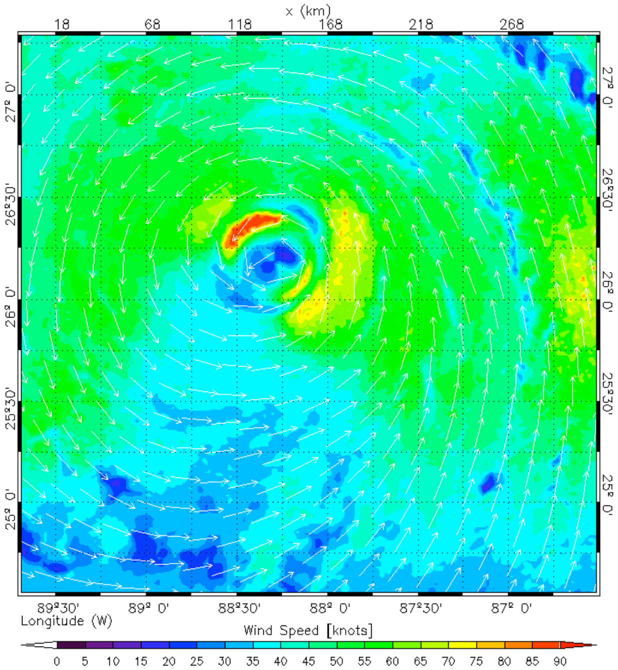


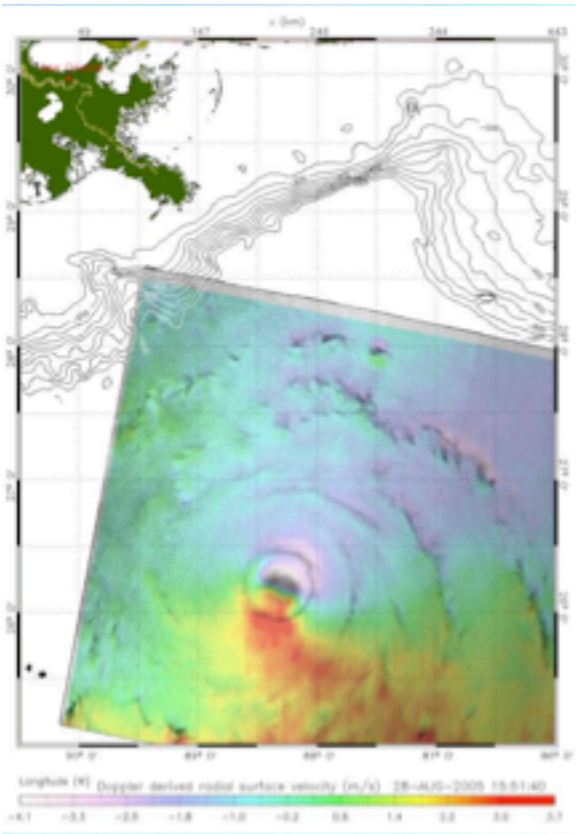
WIND



HURRICANE KATRINA





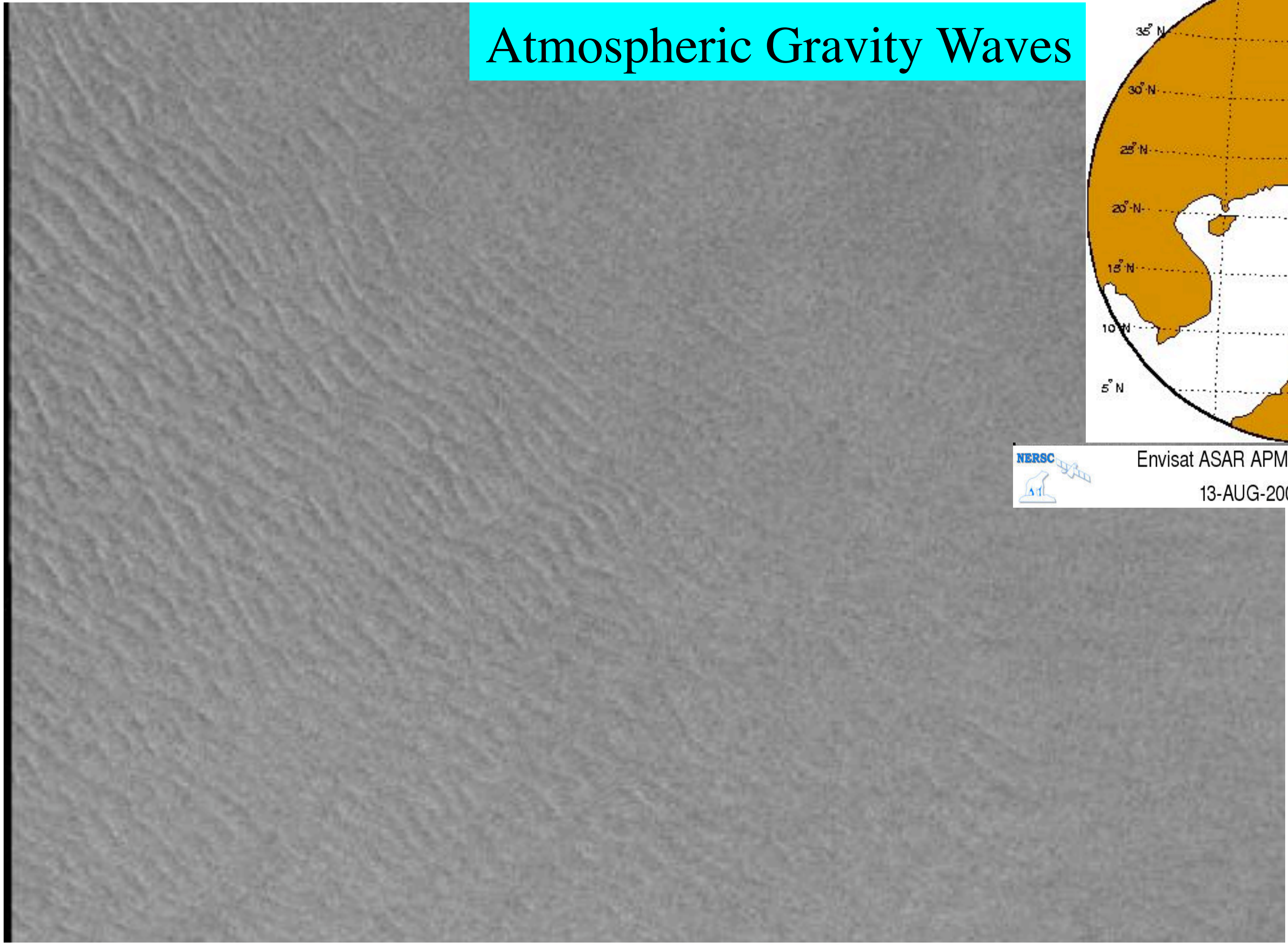


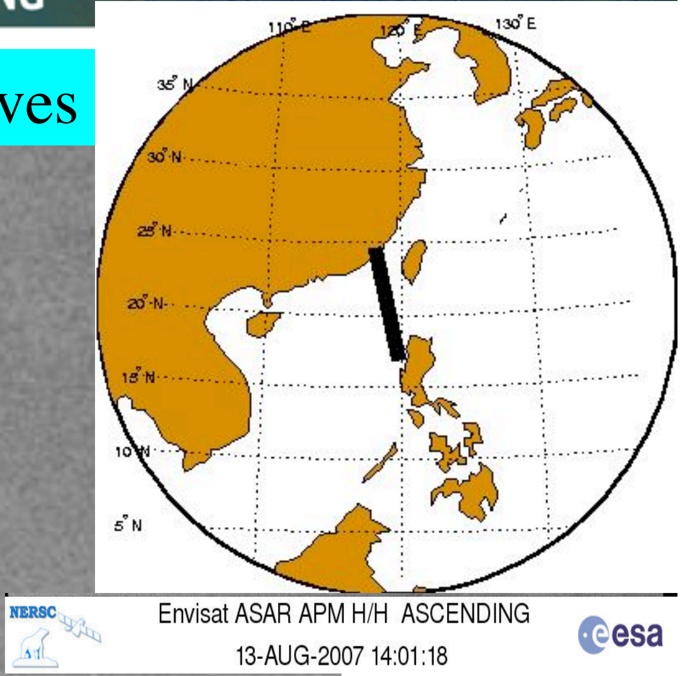
CROSS-SECTION

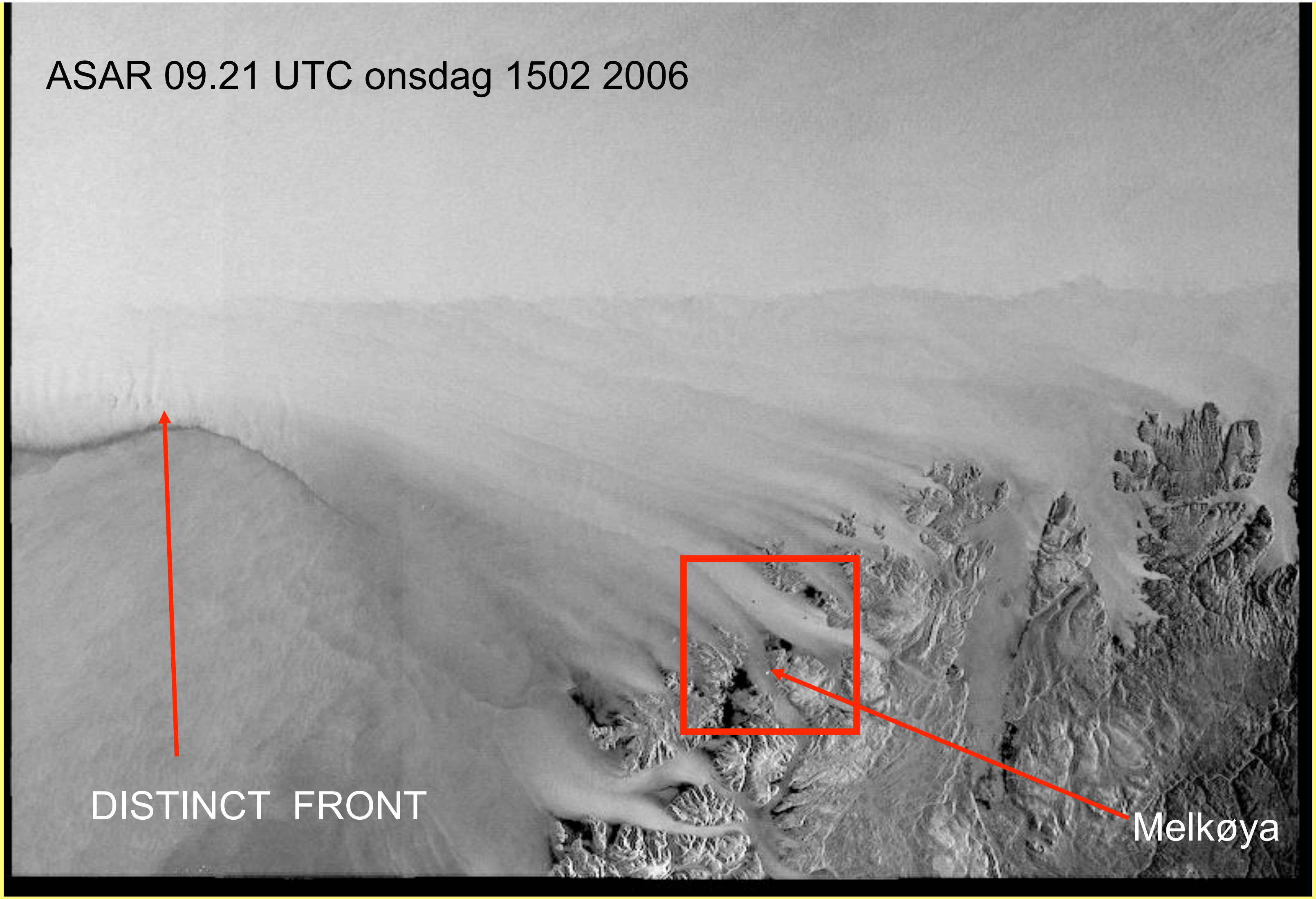
WIND SPEED

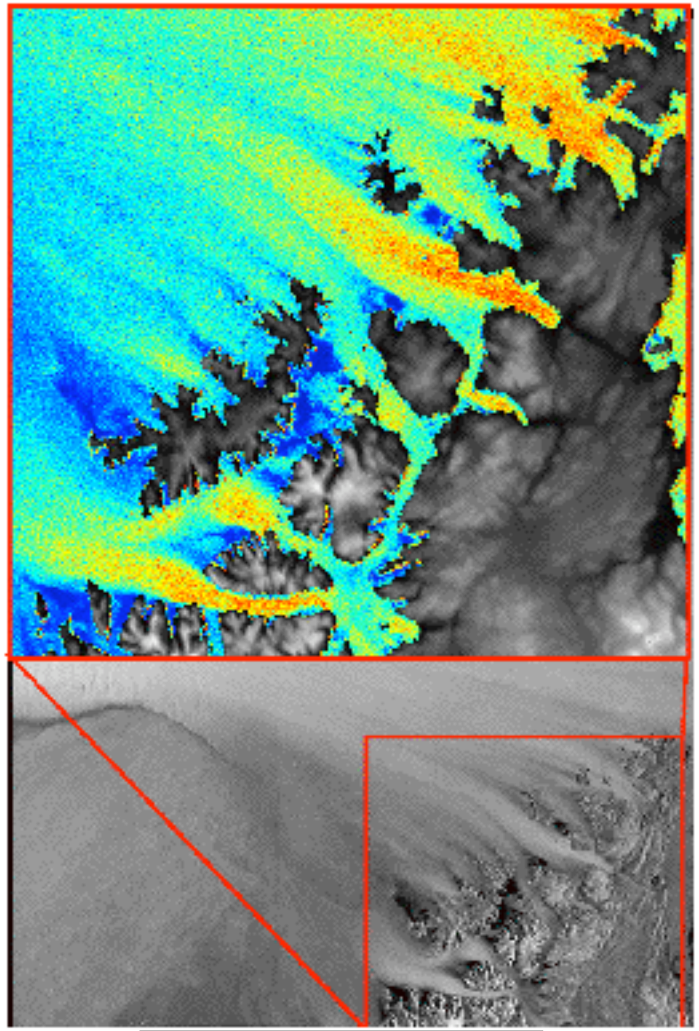
RANGE DOPPLER VELOCITY

Atmospheric Gravity Waves

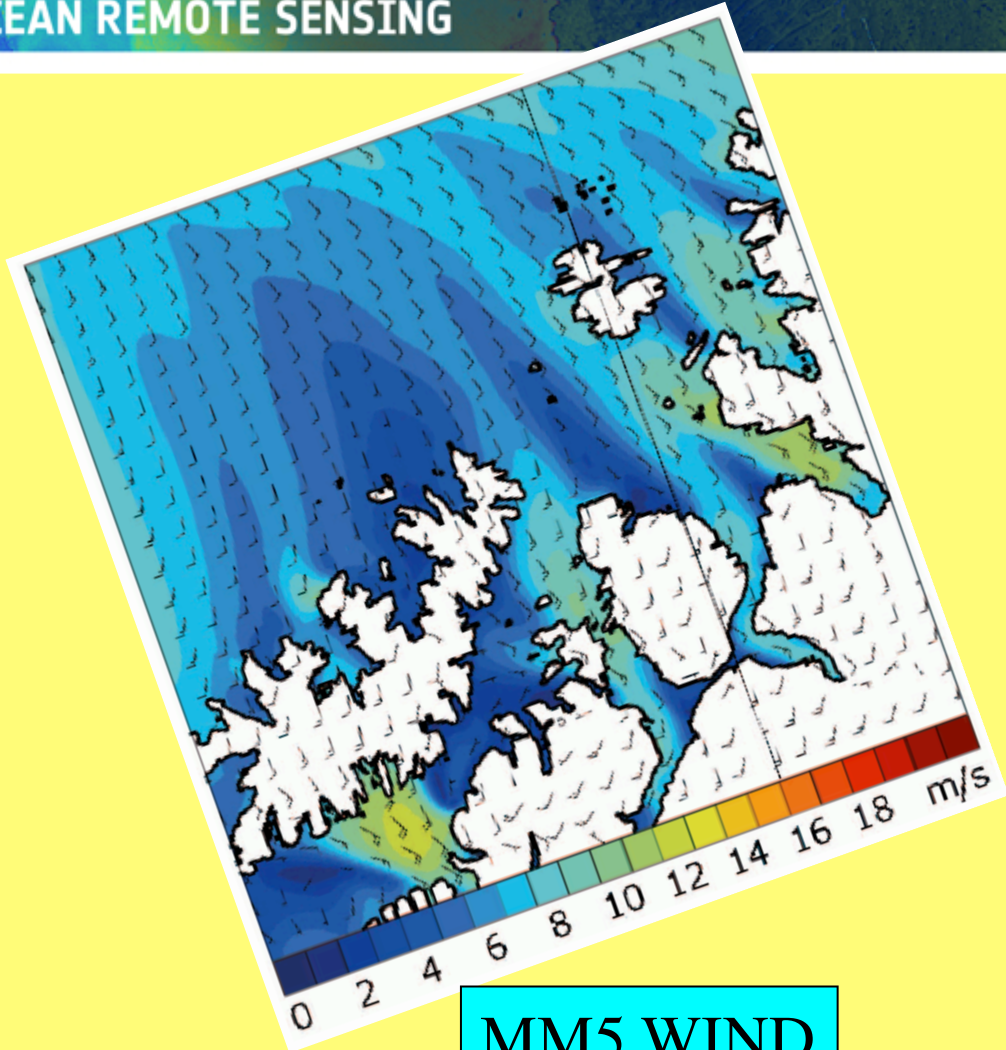





ASAR 09.21 UTC onsdag 1502 2006
DISTINCT FRONT
Melkøya

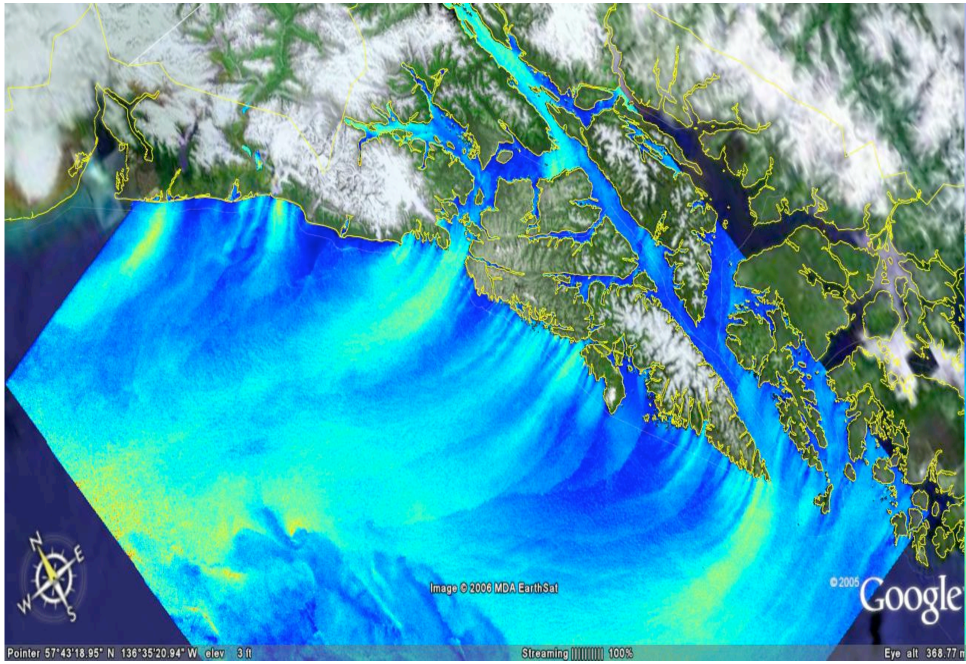


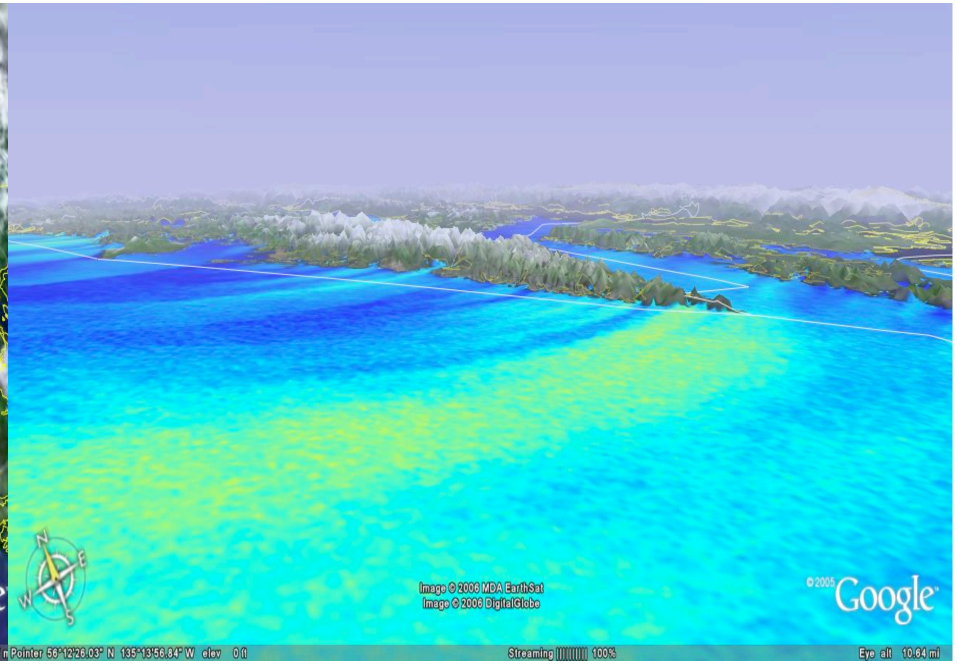
ASAR WIND



MM5 WIND

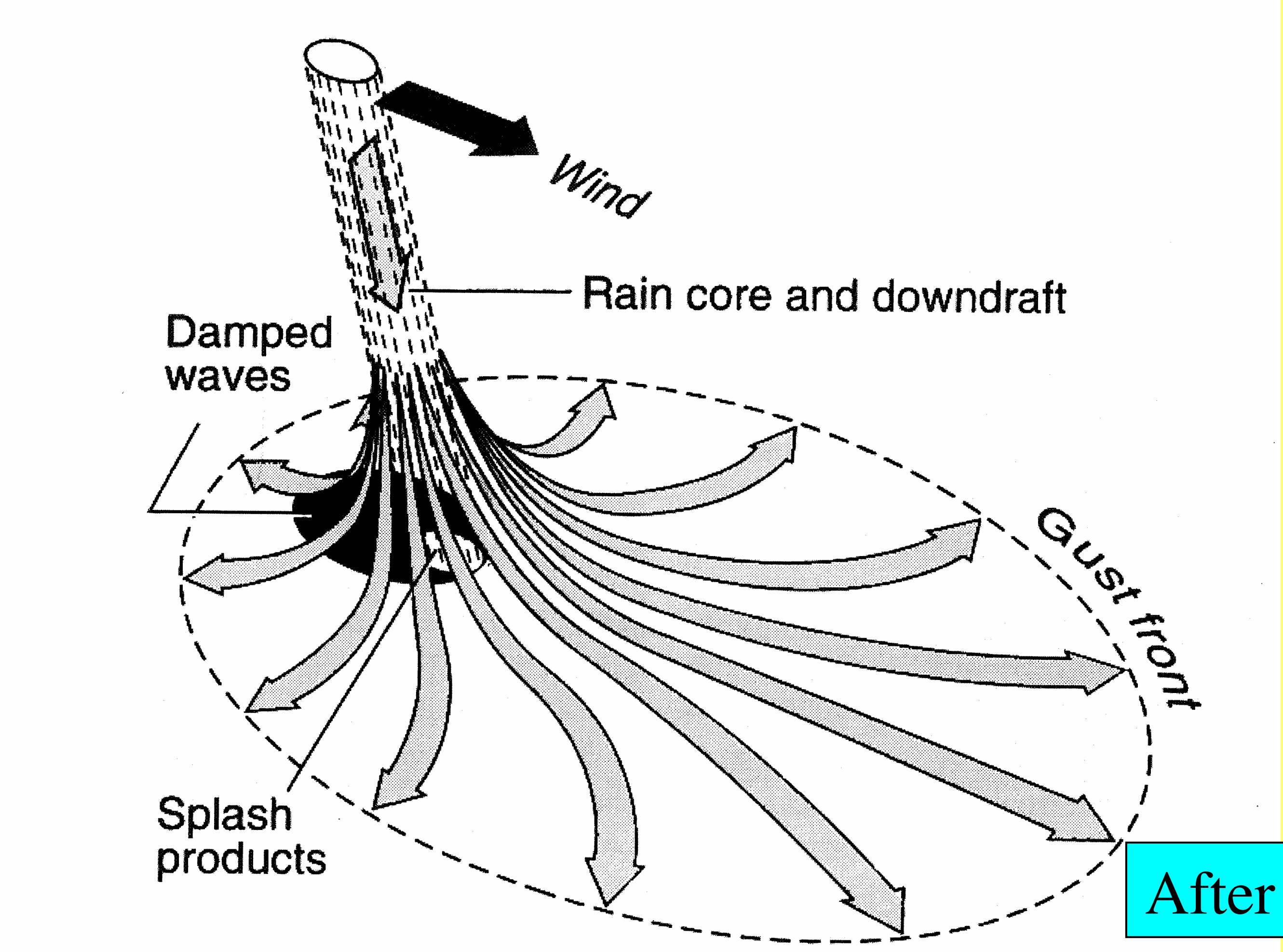
Envisat SAR Wind Image : Google Earth Format



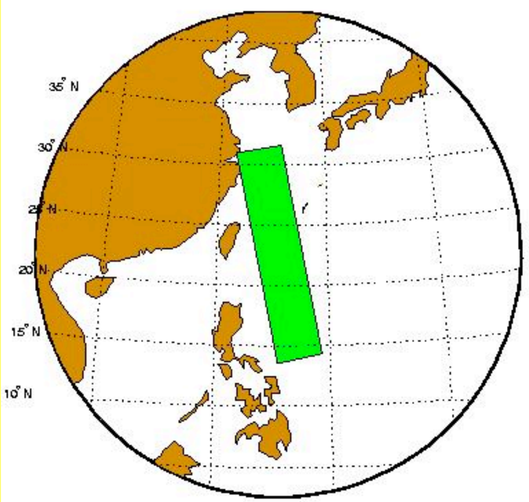


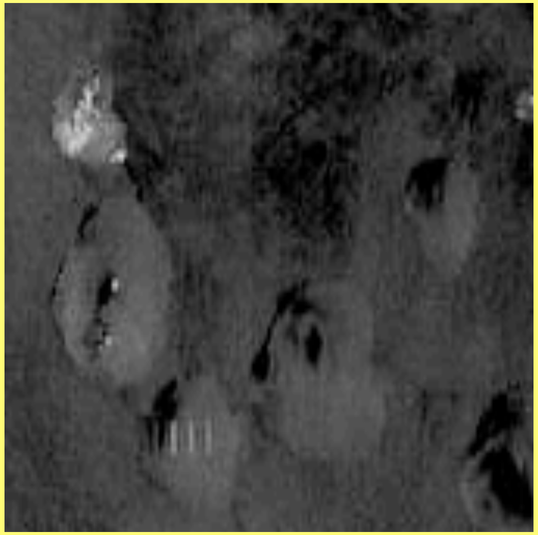
Courtesy Monaldo et al

SURFACE EXPRESSION OF RAIN CELLS IN RADAR IMAGES



After Atlas, 1994


35° N
30° N
25° N
20° N
15° N
10° N




NERSC
Envisat ASAR WSM V/V ASCENDING
01-AUG-2007 13:37:25
esa

SAR CONTRIBUTION TO MARINE MONITORING

Operational Surveillance	Emerging New Application	Routine Product and partly used in NWP	Research Dominated
Ship detection Oil spill detection Sea Ice Shallow water Bathymetry	Wind field retrievals	Ocean Waves and Ocean Spectra	Surface current fronts and eddies Internal Waves Atmospheric boundary layer Processes Film damping

SAR WAVE IMAGING MECHANISMS

- TILT MODULATIONS - HYDRODYNAMIC MODULATIONS - VELOCITY BUNCHING

- Longer waves locally modify the exact plan of incidence to produce a contrast corresponding to the local change in cross section

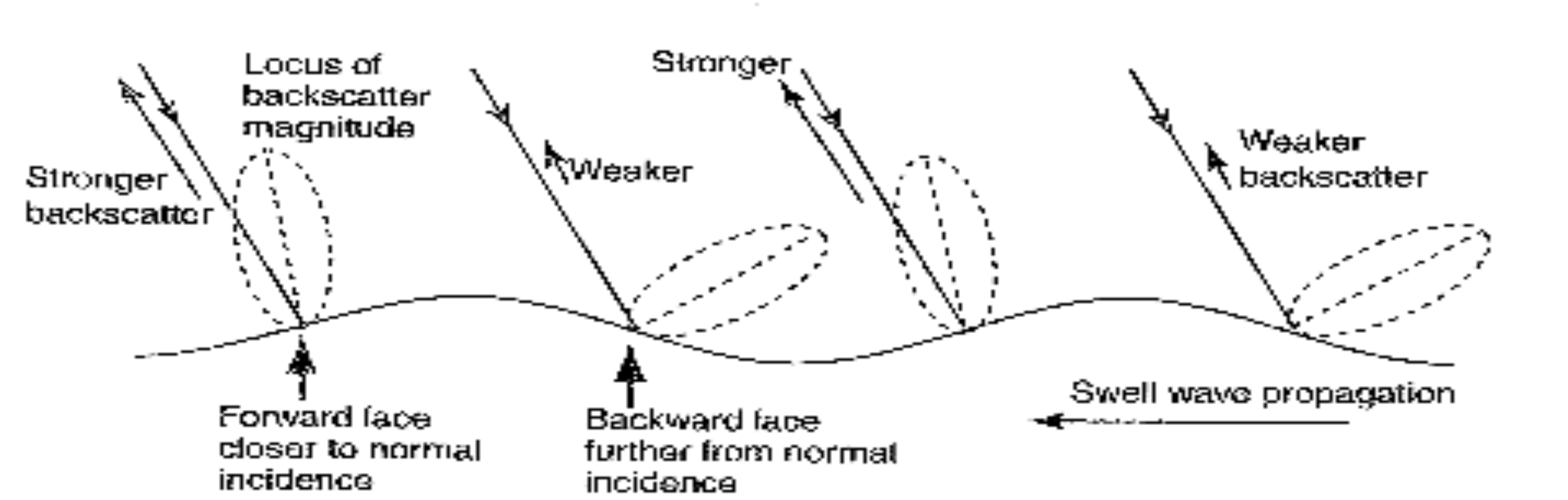
→ **Tilt Modulation** : a priori knowledge of the gradient of the relative cross section as a function of the small incidence angle deviation

$$T_t(k) = \left(\frac{1}{\sigma^o} \cdot \frac{\partial \sigma}{\partial \theta}\right)_{\theta = \theta_0} \cdot ik_r$$

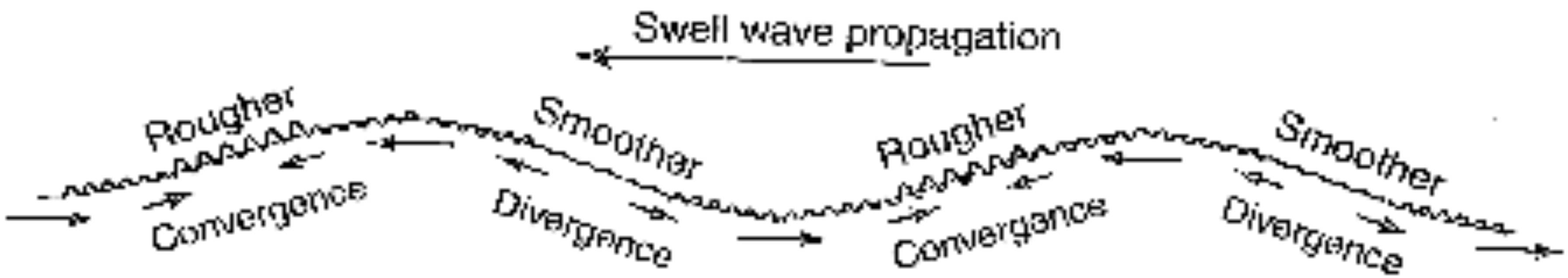
→ **Hydrodynamic Modulation** : a priori knowledge of the gradient of the relative cross as a function of the phase of the long wave

$$T_h(k) = \left(\frac{1}{\sigma^o} \cdot \frac{\partial \sigma}{\partial \varphi}\right) \cdot ik_r$$

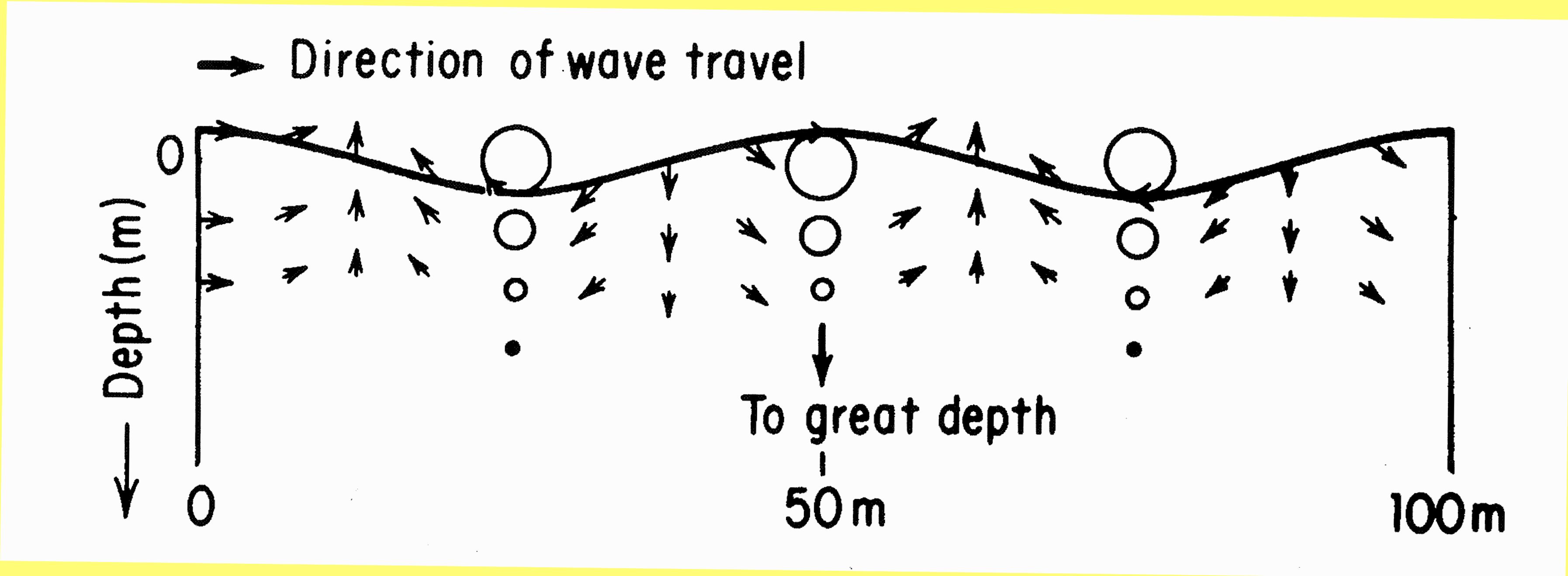
TILT MODULATION



HYDRODYNAMIC MODULATION

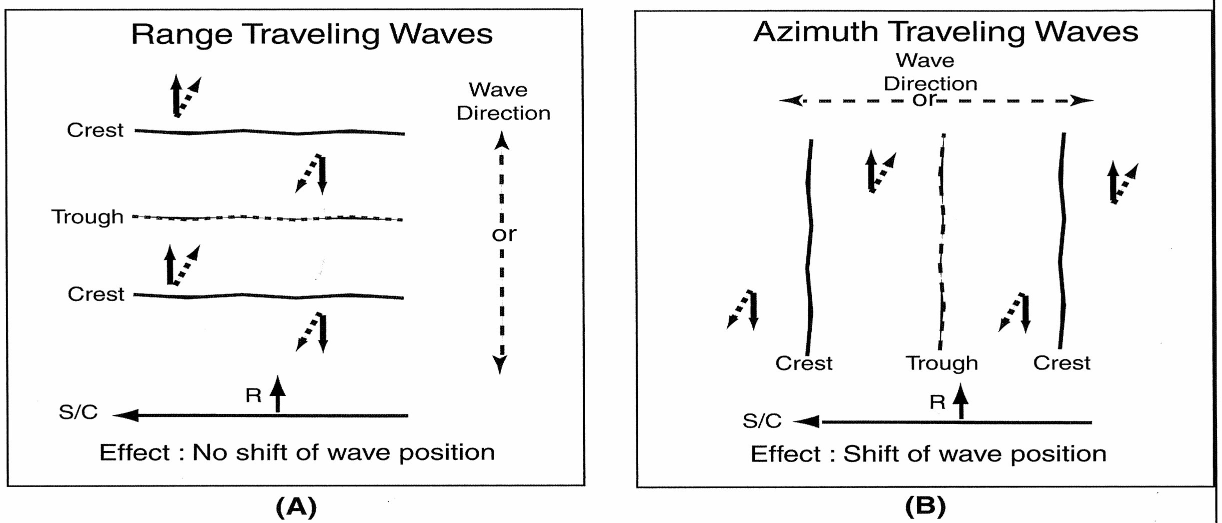


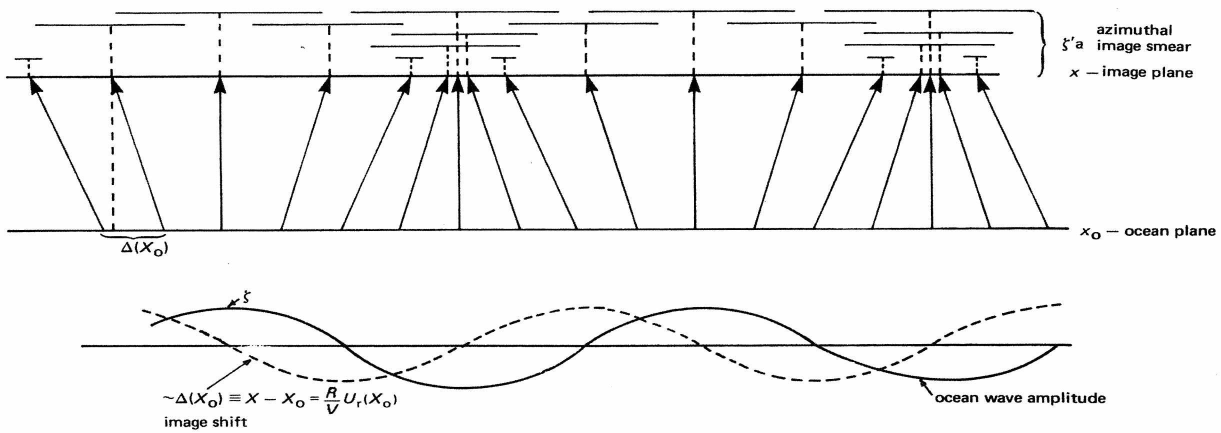
PARTICLE MOTION DUE TO TRAVELLING WAVES

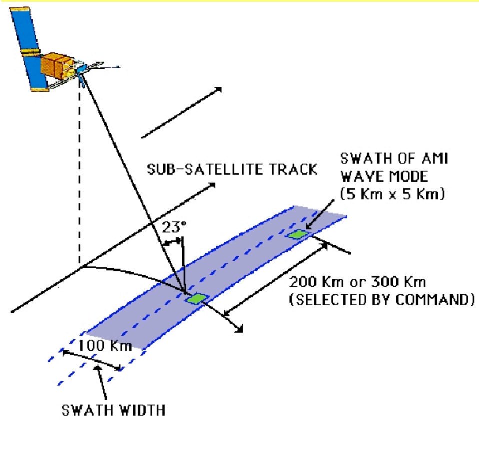


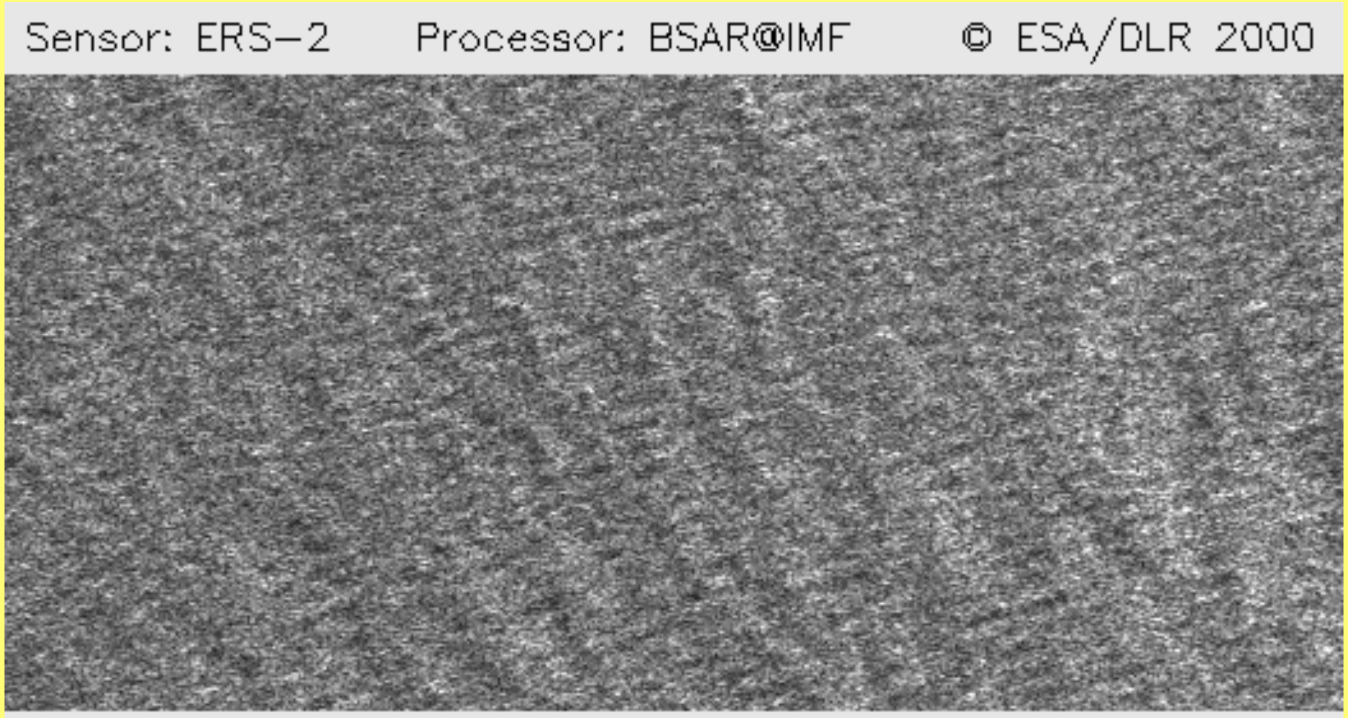
After Neumann and Pierson

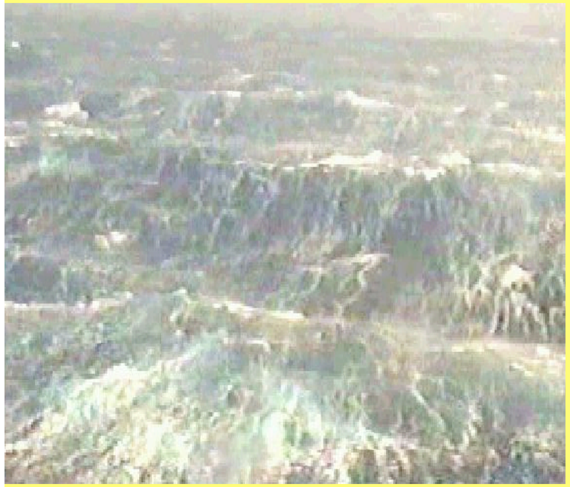
MOTION EFFECT - VELOCITY BUNCHING





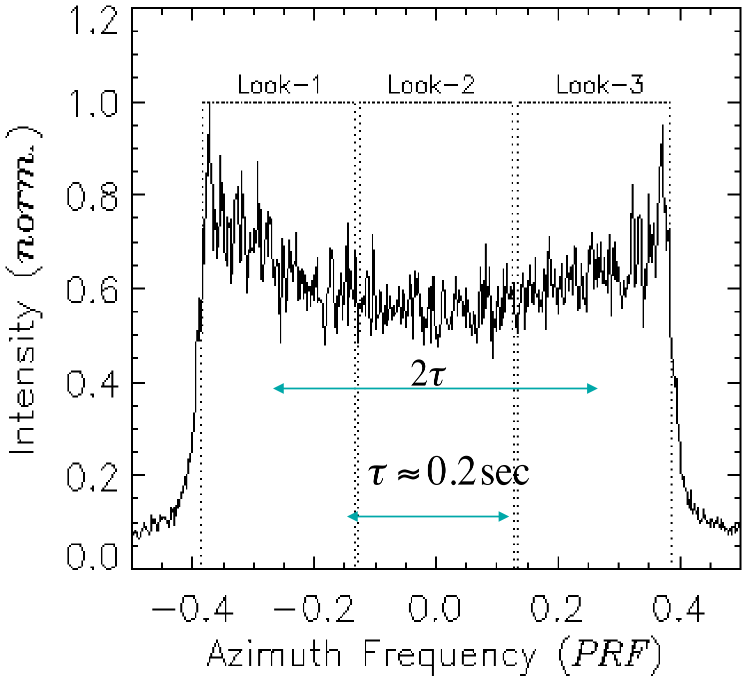


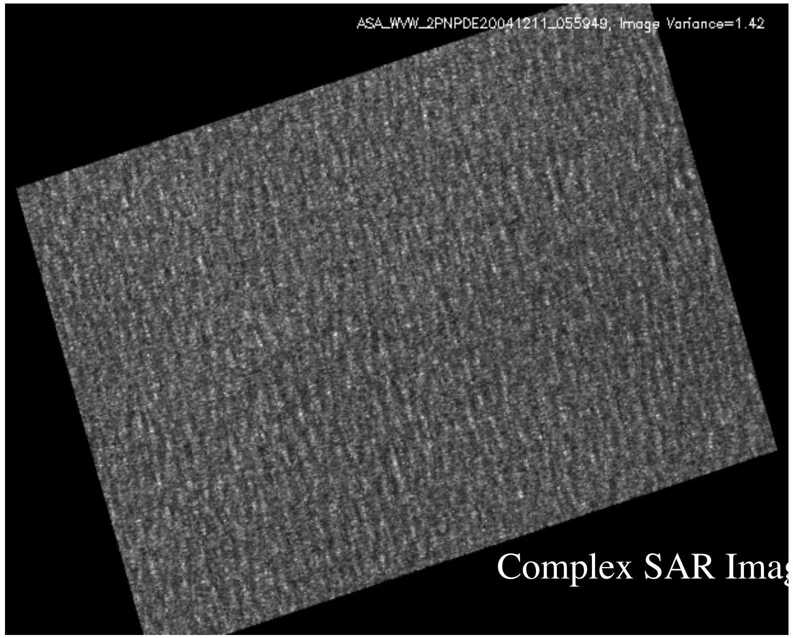




Ocean waves from SAR

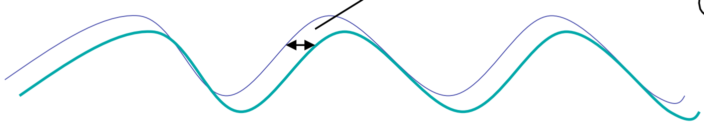
From Co- to Cross-Spectra Estimation: Ambiguity





-Look Extraction
-Intensity Detection

$$\Delta\varphi = \omega_k \cdot \tau \approx 10^o$$



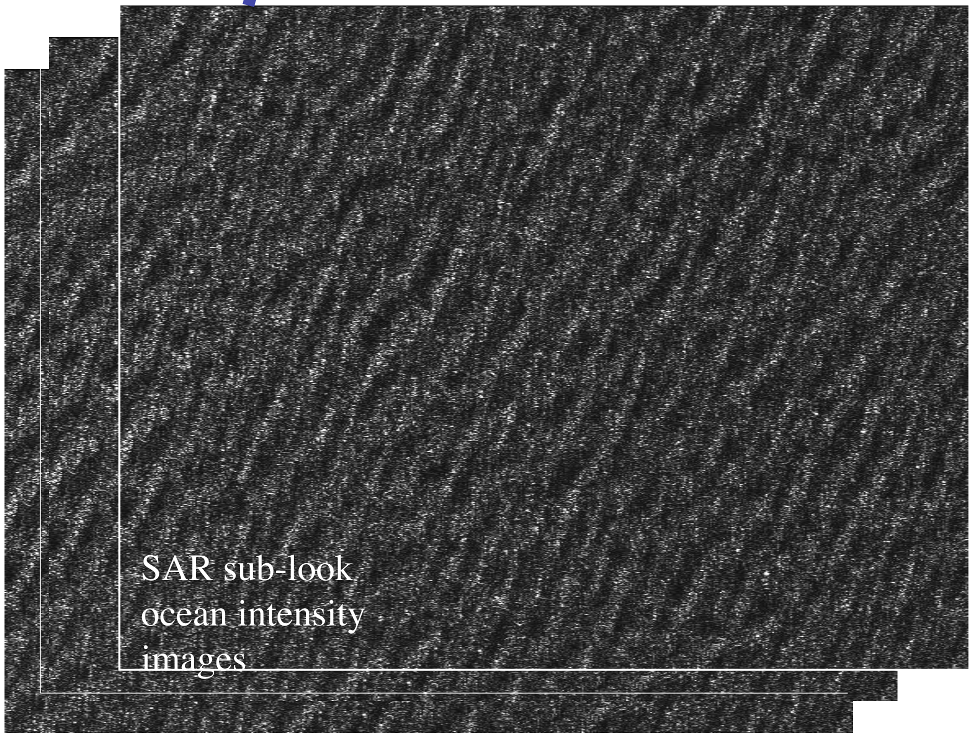
phase term resolves wave propagation direction

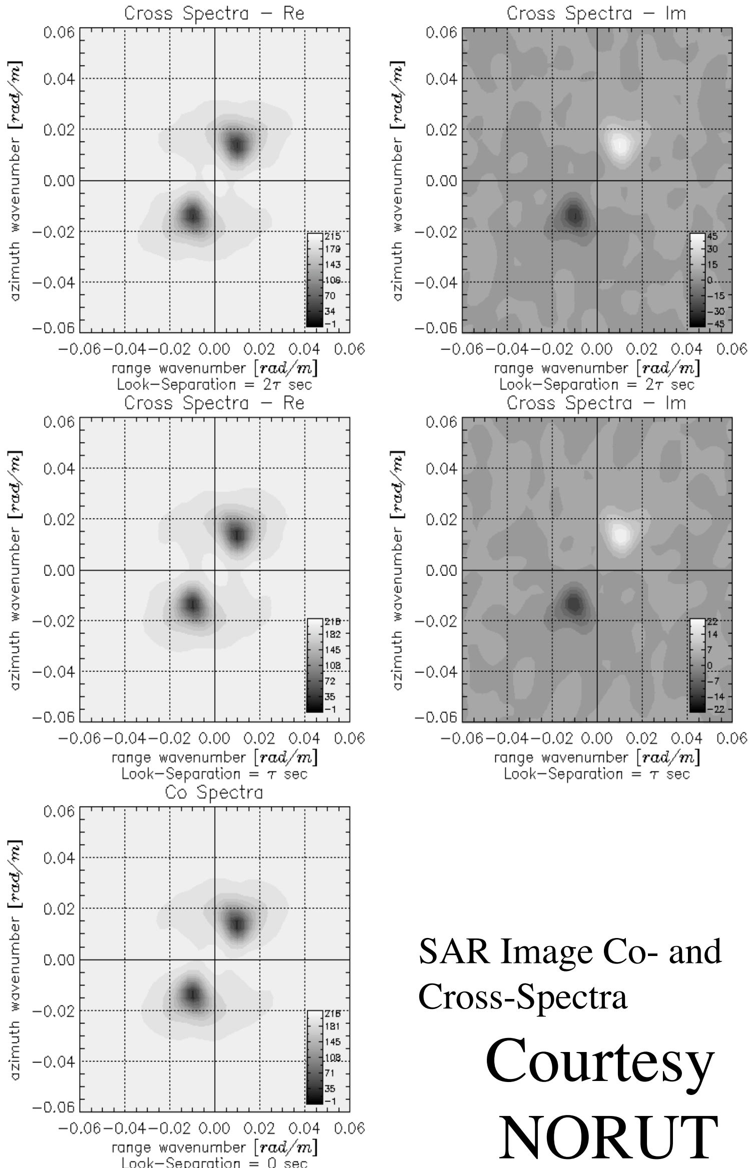
Courtesy NORUT

3 look intensity images

Spectral Estimation

$$P_{SAR}^{(m,n)}(\underline{k},\tau) = \frac{1}{\langle I^{(m)}\rangle\langle I^{(n)}\rangle}\left\langle I^{(m)}\left(\underline{k},\frac{\tau}{2}\right) I^{(n)^*}\left(\underline{k},-\frac{\tau}{2}\right)\right\rangle$$





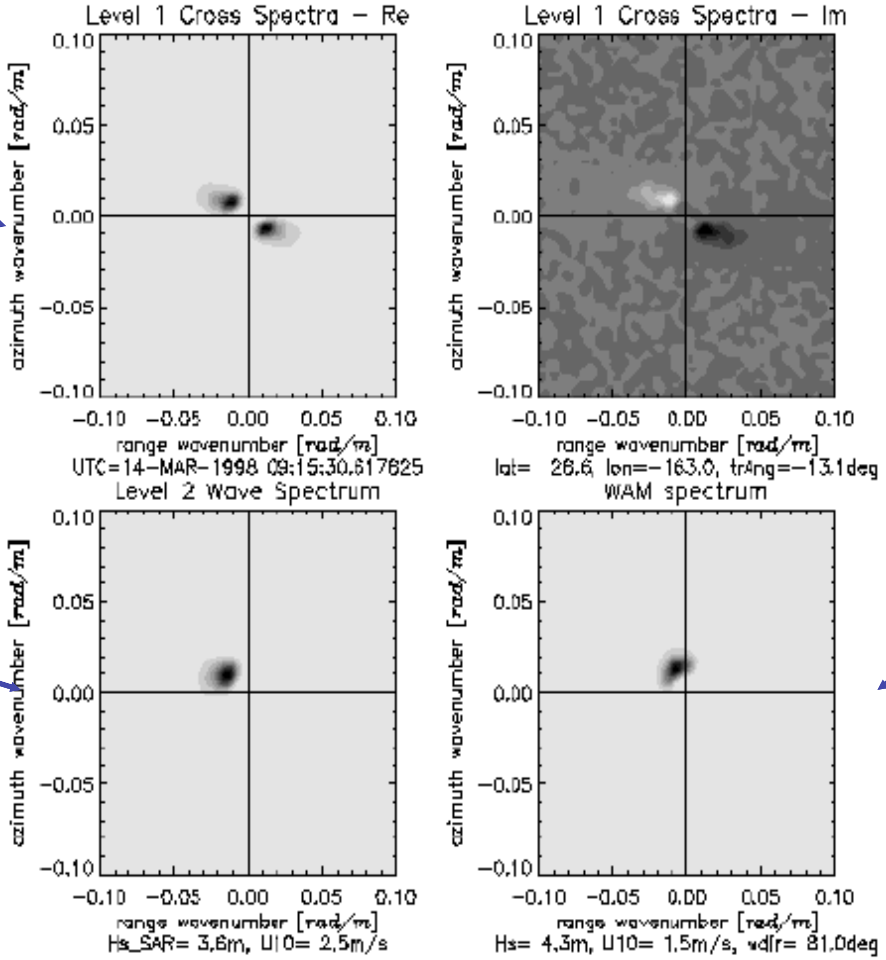
SAR Image Co- and Cross-Spectra

Courtesy NORUT

Inversion to SAR Ocean Wave Spectra

SAR image cross-spectra

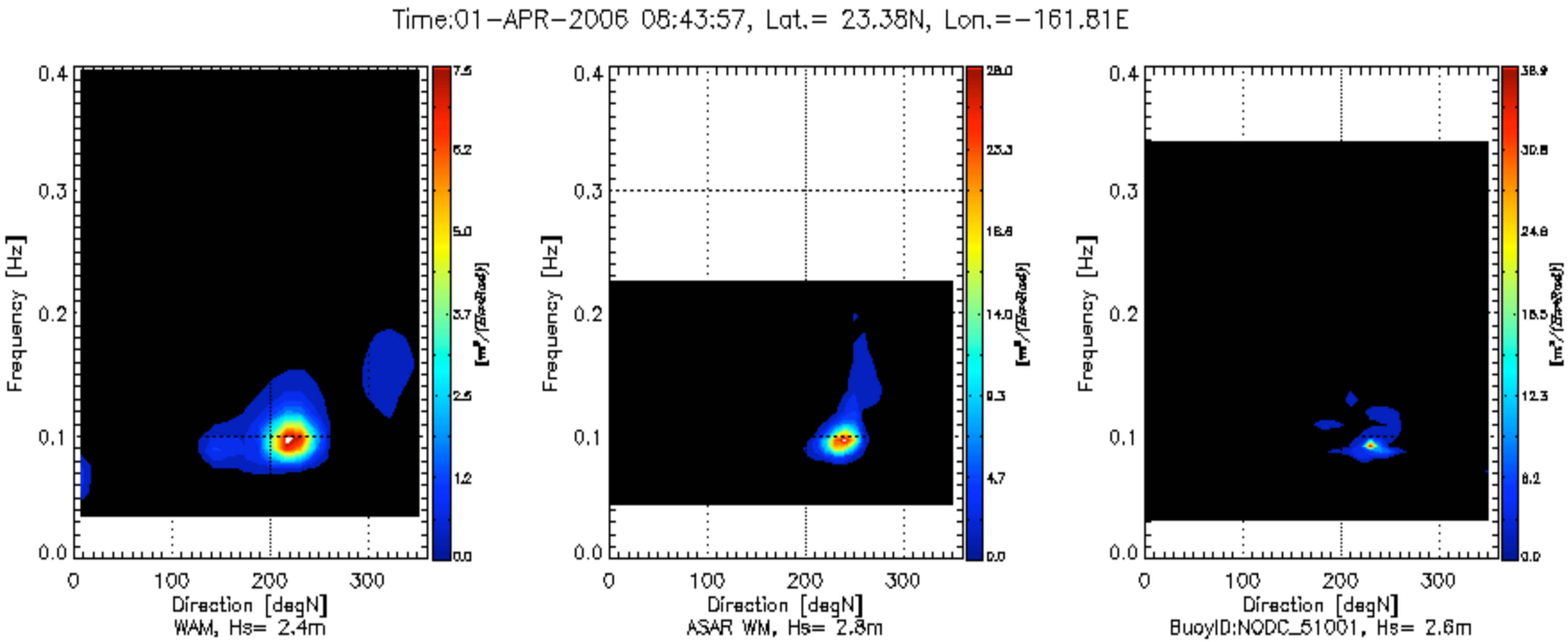
SAR ocean wave spectra



WAM (for comparison)

Courtesy NORUT

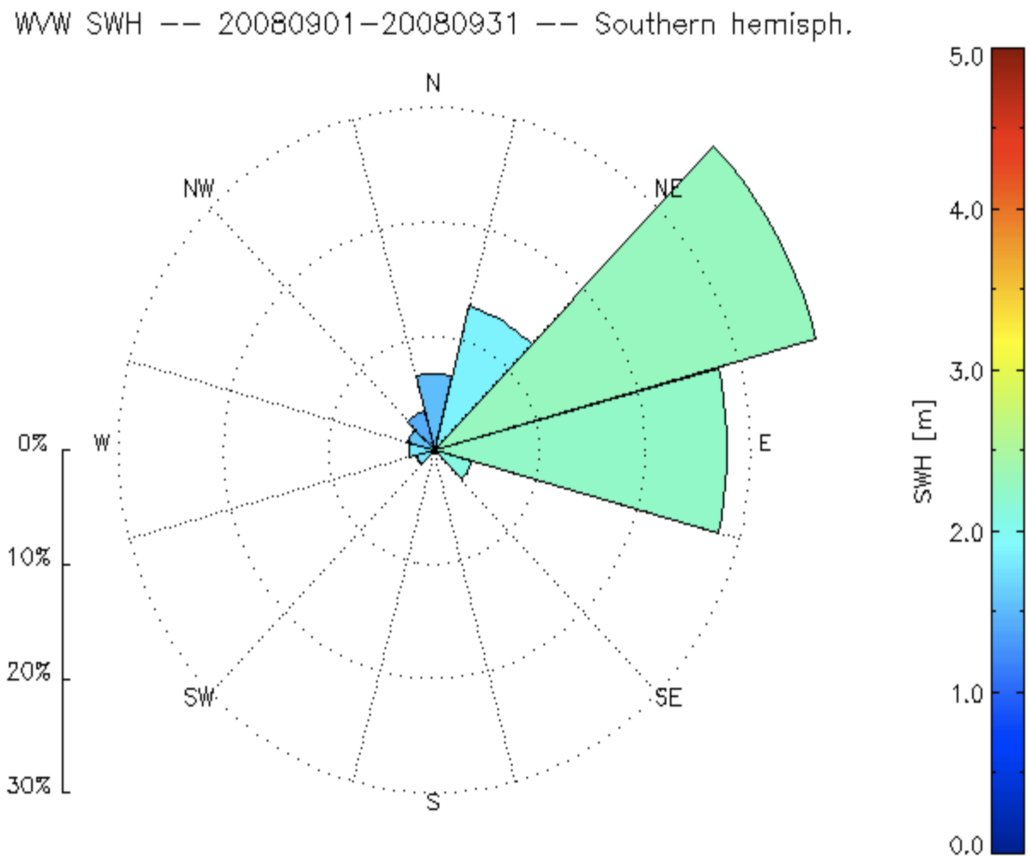
Validation - Performance



Courtesy NORUT

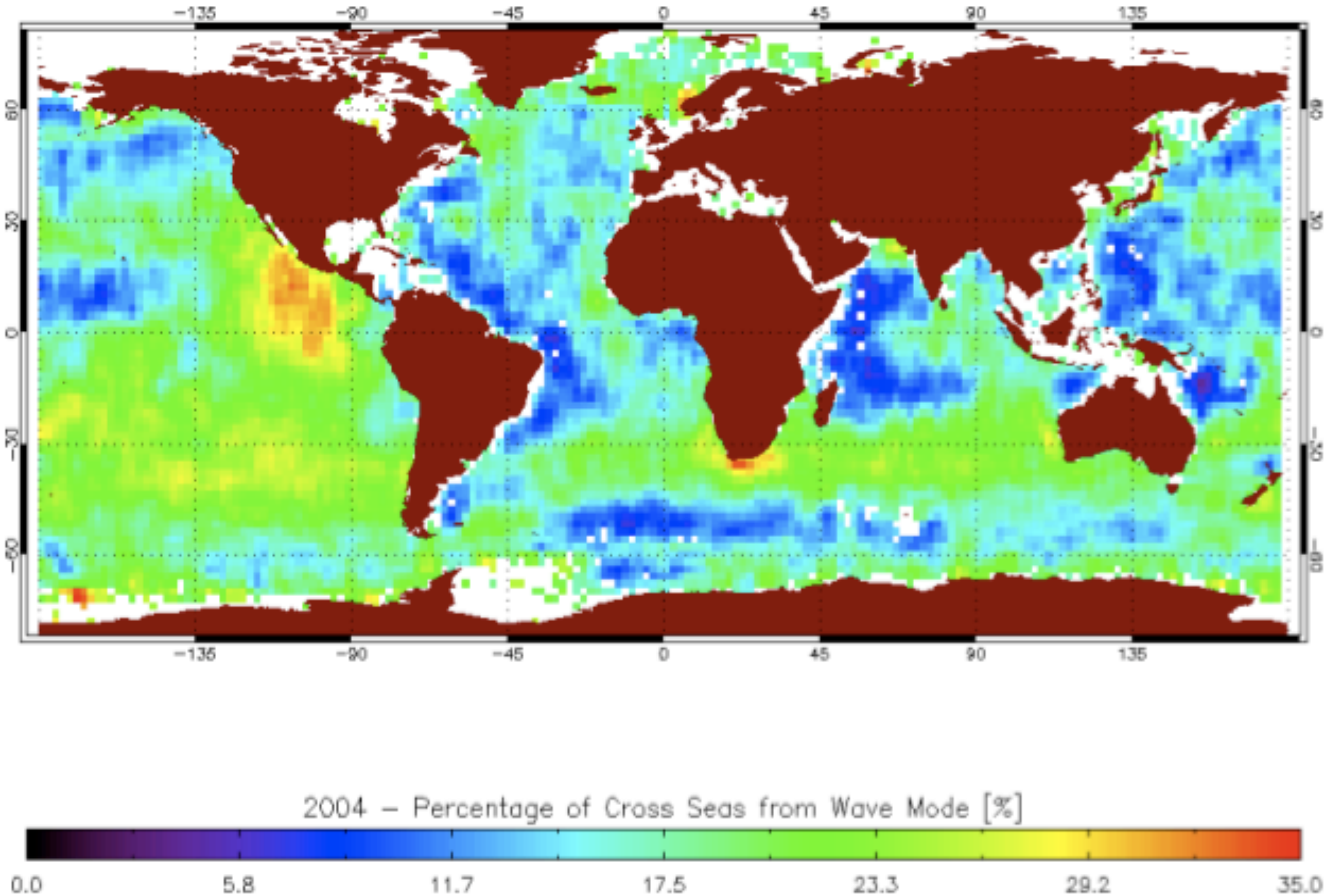
Swell RMSe: $H_s \approx 0.4$m, $T \approx 0.7$s, $D \approx 23^o$

Higher Order Products - Wave Rose

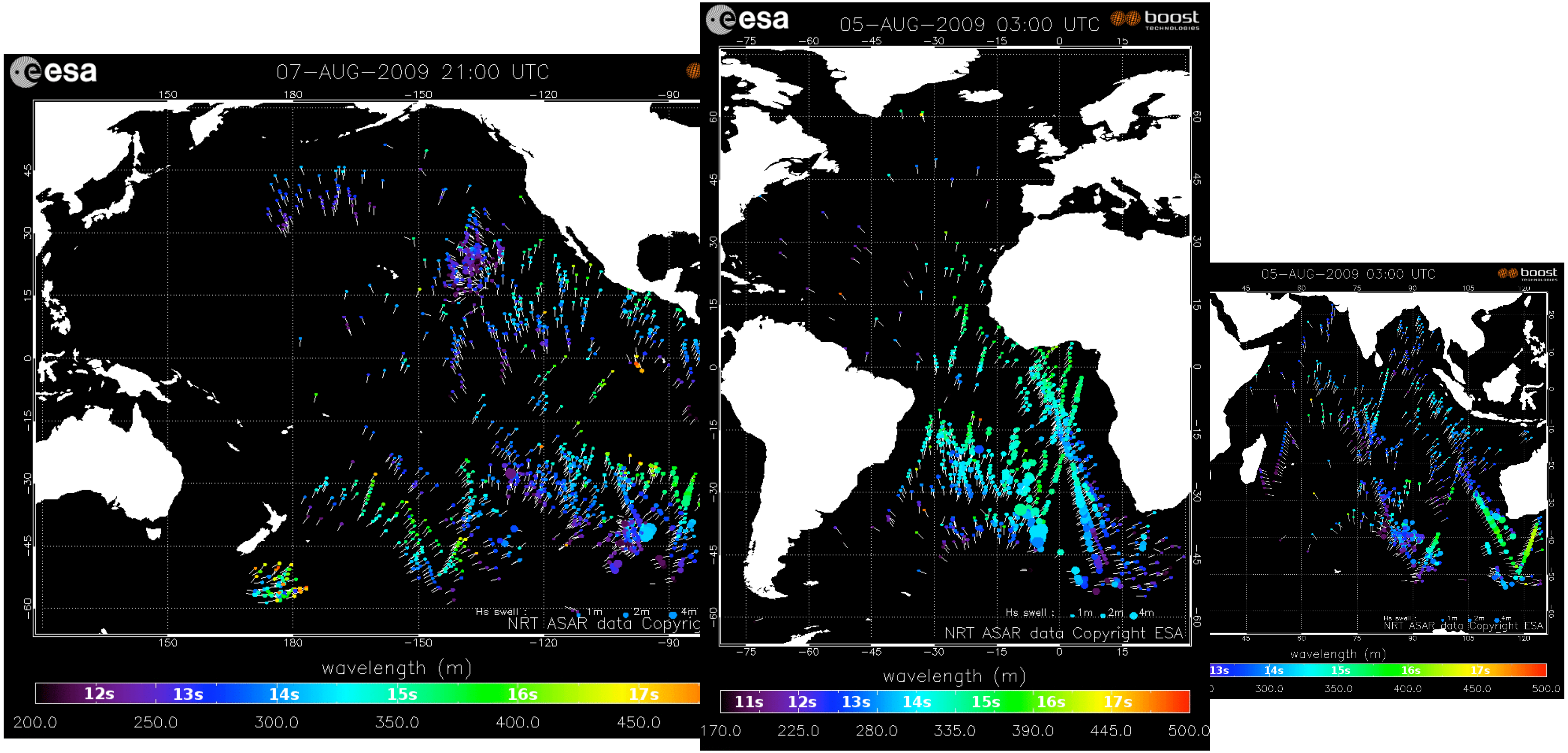


Courtesy NORUT

Higer Order Products - Crossing Seas



CourtesyCLS-NORUT



FIREWORKS: Global NRT ASAR Swell Wave tracking is a reality:

Courtesy Collard, Chapron (ESA WVC study) http://soprano.cls.fr

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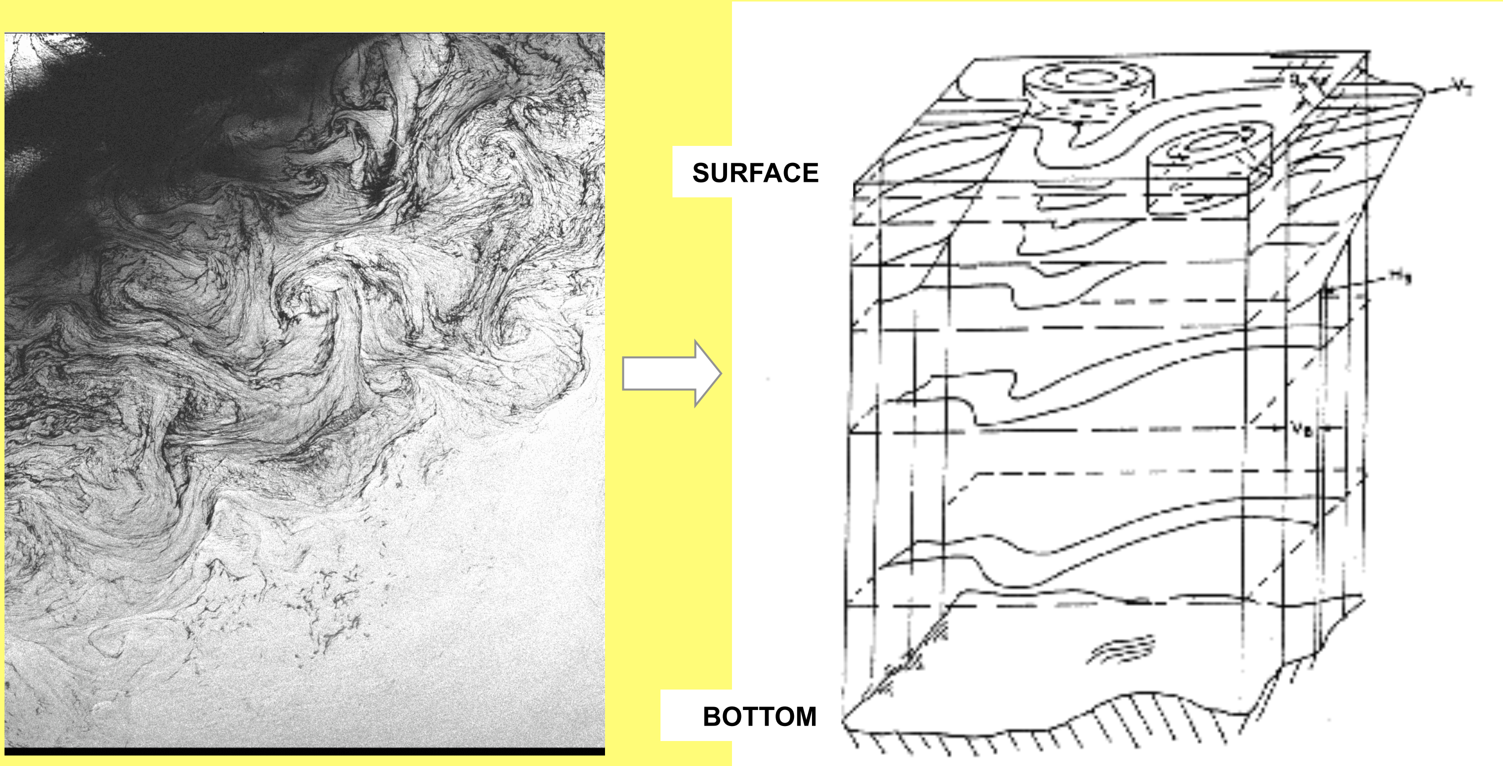
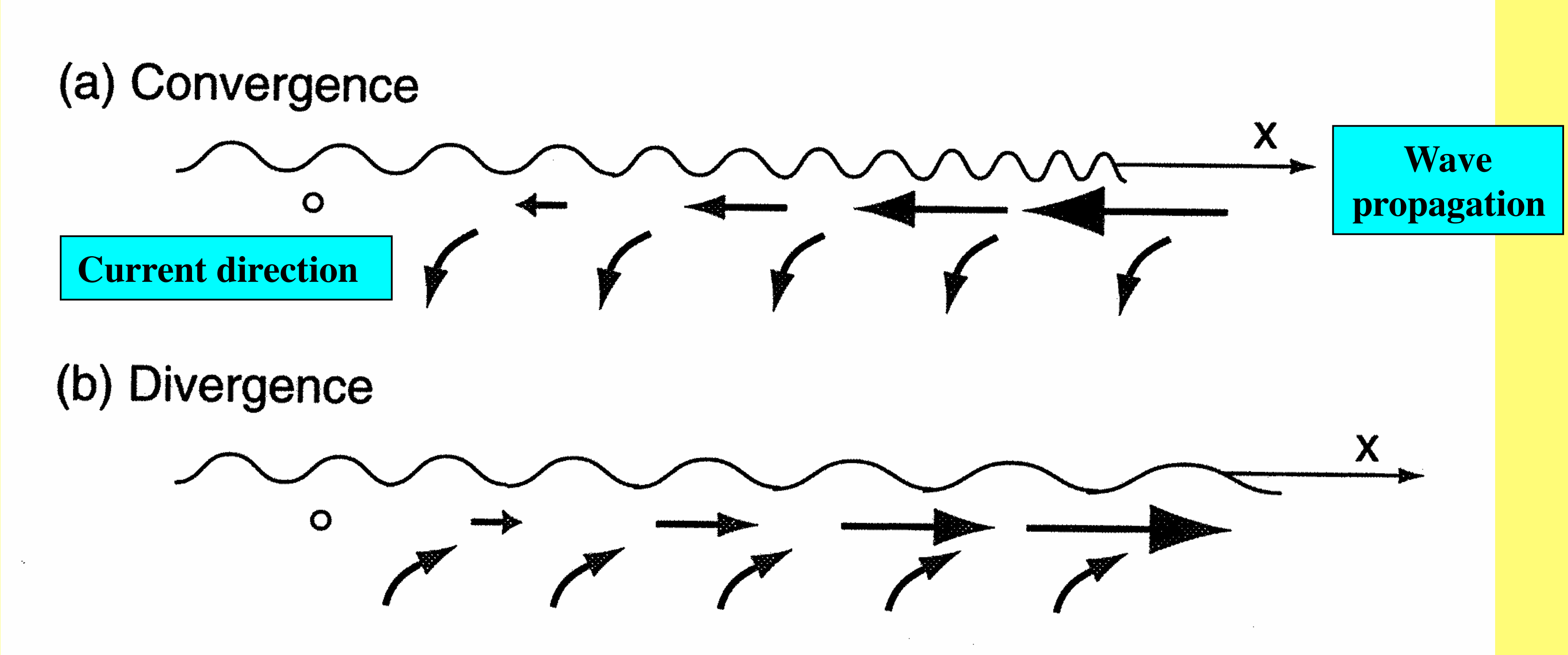
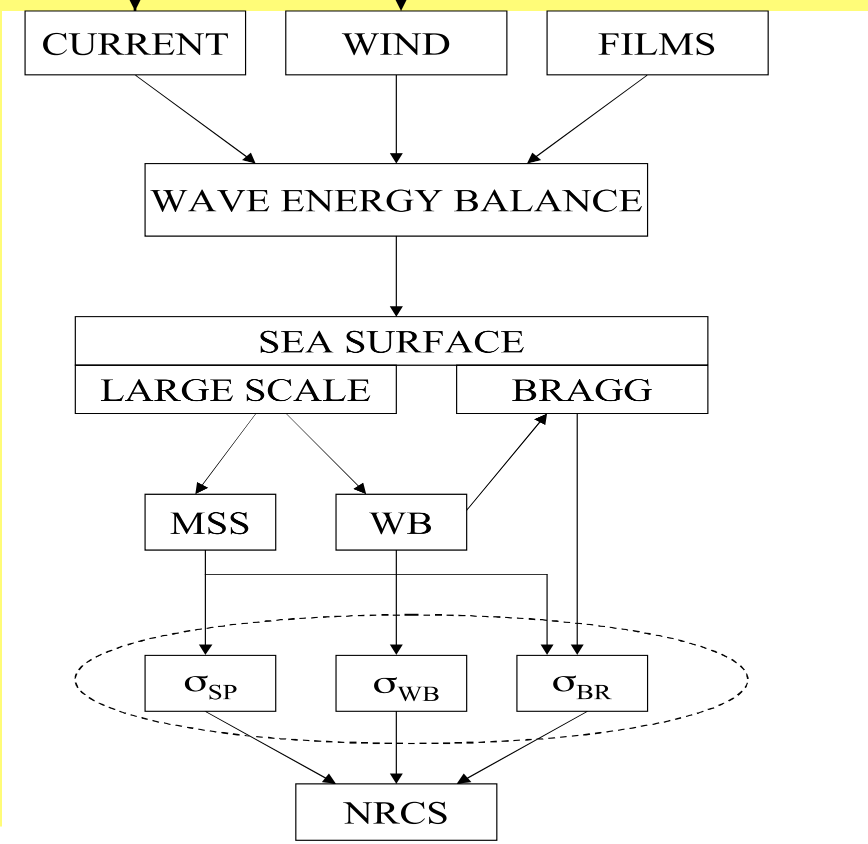
CHALLENGE: FROM SAR IMAGE TO QUANTITATIVE CURRENT ESTIMATE



CHANGING THE ROUGHNESS BY CURRENTS



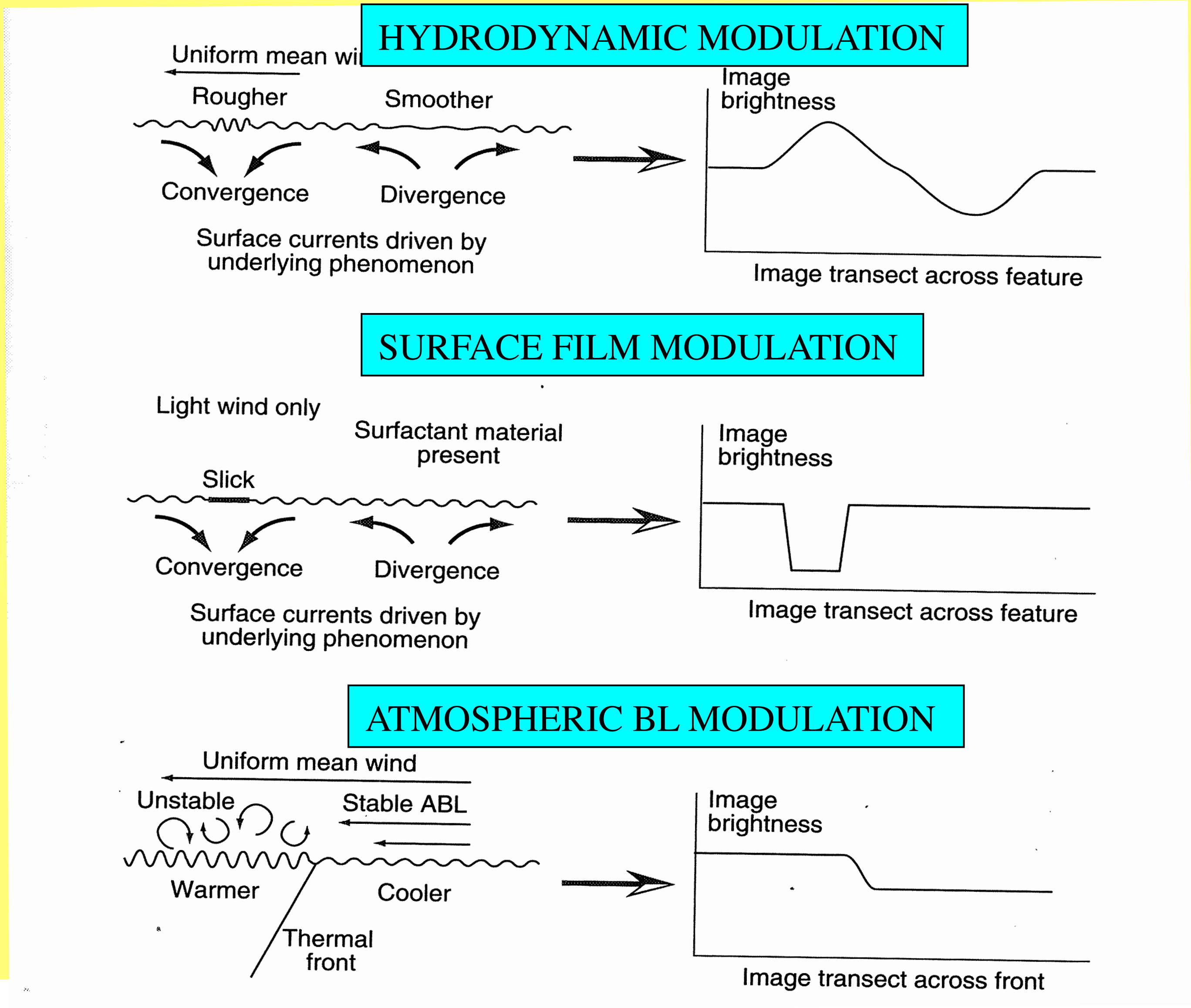
DOPPLER SENTROID SHIFT



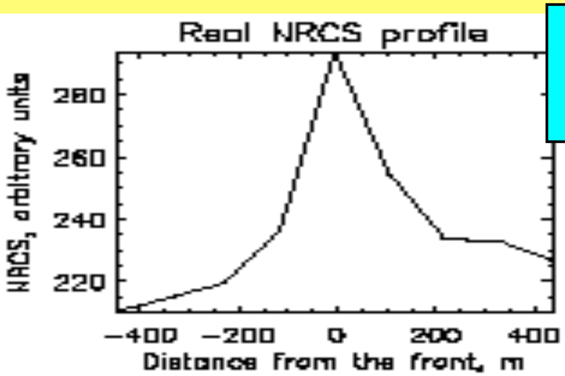
NEW SURFACE CURRENT VELOCITY ESTIMATES

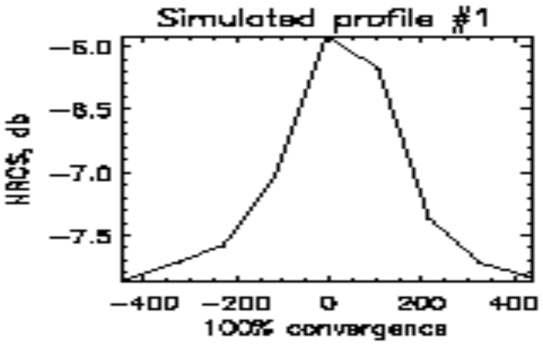
EMERGING NEW SAR CURRENT RETRIEVAL TOOL

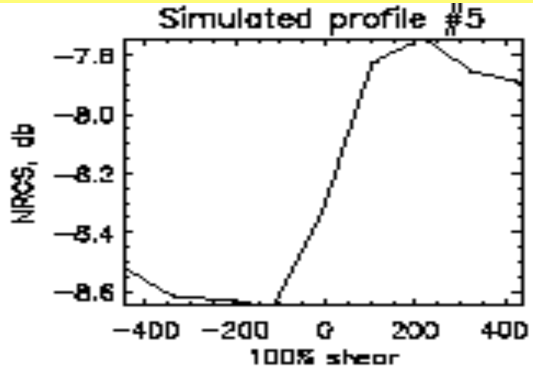
Kudryavtsev,Dmitry, Johannessen, Chapron, Collard et al.,

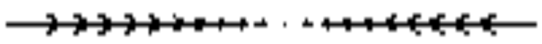

HYDRODYNAMIC MODULATION
Uniform mean wi
Rougher
Smoother
Convergence
Divergence
Surface currents driven by underlying phenomenon
Image brightness
Image transect across feature
SURFACE FILM MODULATION
Light wind only
Surfactant material present
Slick
Convergence
Divergence
Surface currents driven by underlying phenomenon
Image brightness
Image transect across feature
ATMOSPHERIC BL MODULATION
Uniform mean wind
Unstable
Stable ABL
Warmer
Cooler
Thermal front
Image brightness
Image transect across front

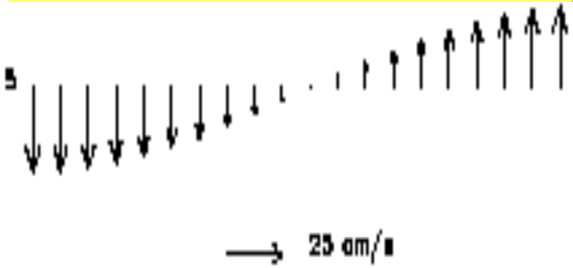
OBSERVED & SIMULATED SAR EXPRESSION OF CURRENT FEATURE

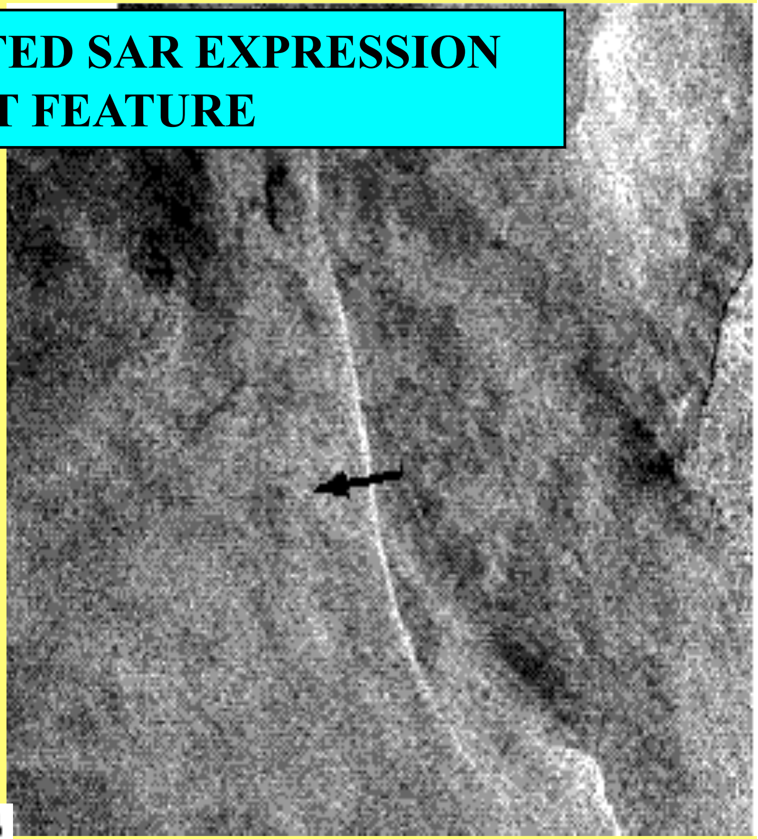






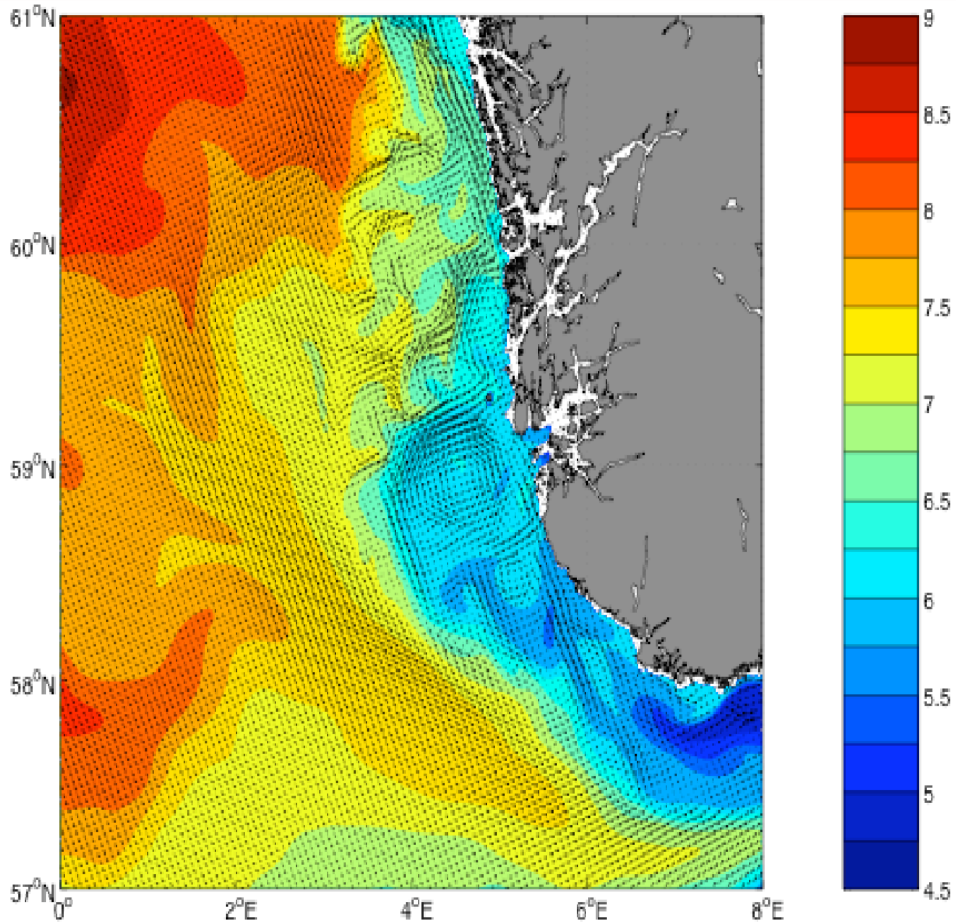


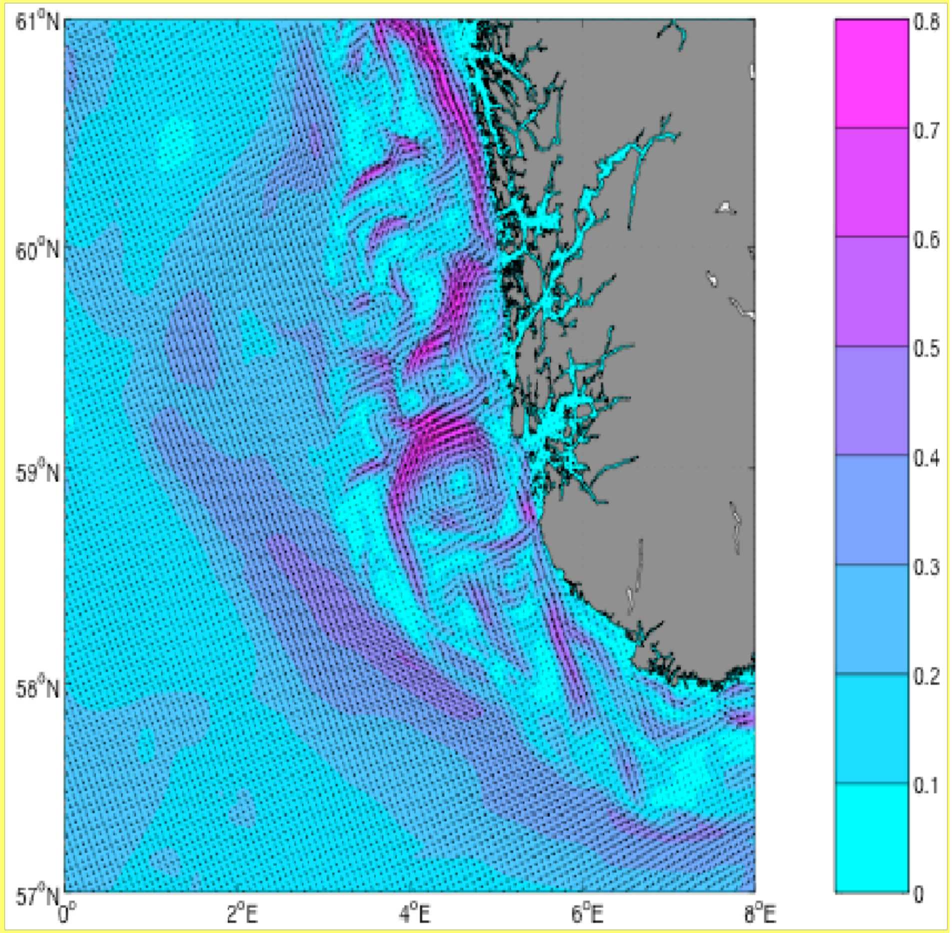




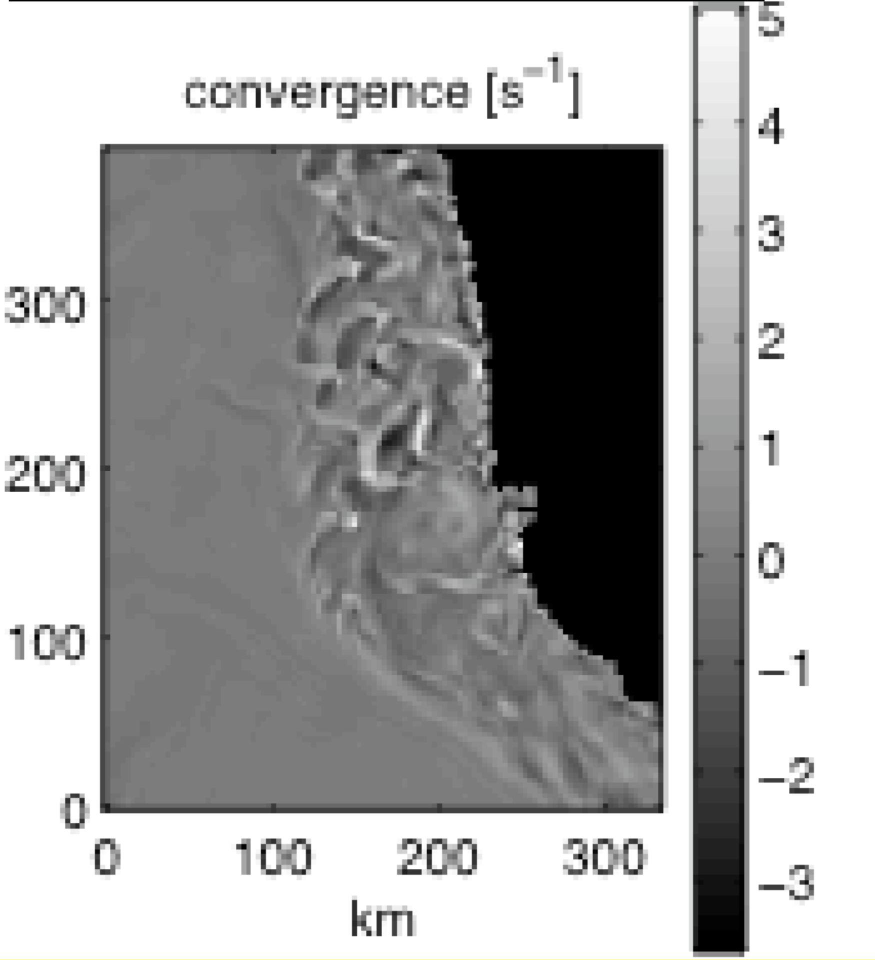
SST & SURFACE CURRENT

SURFACE DIVERGENCE

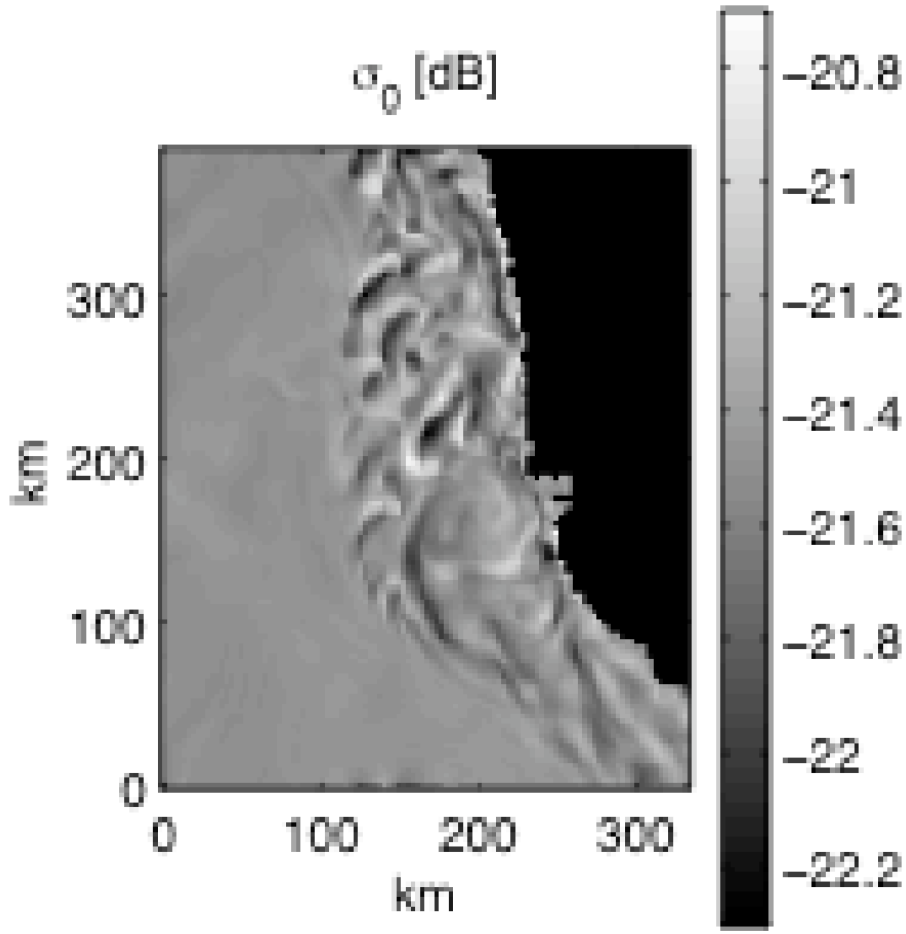




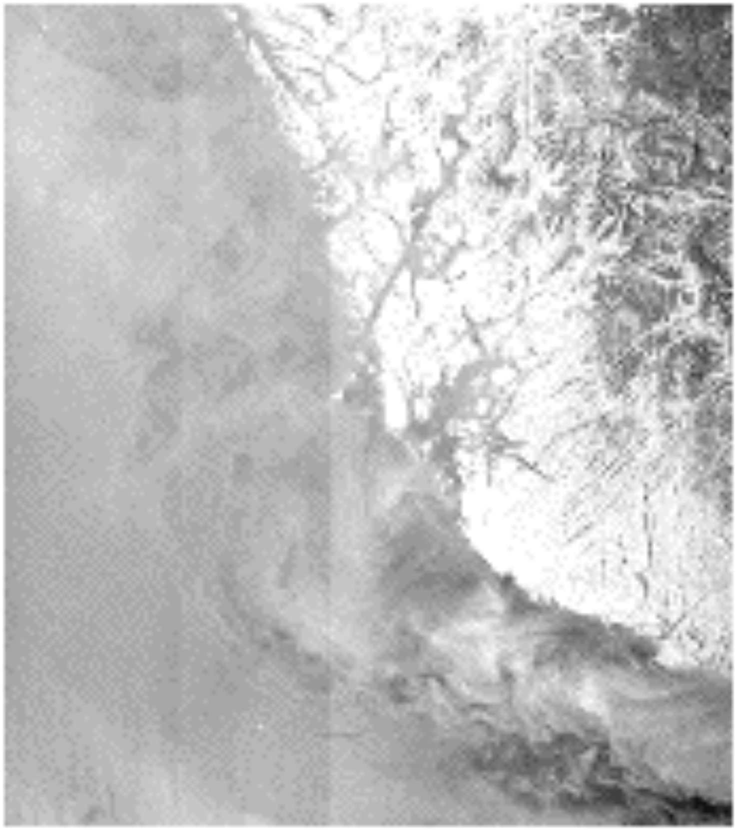
SURFACE DIVERGENCE



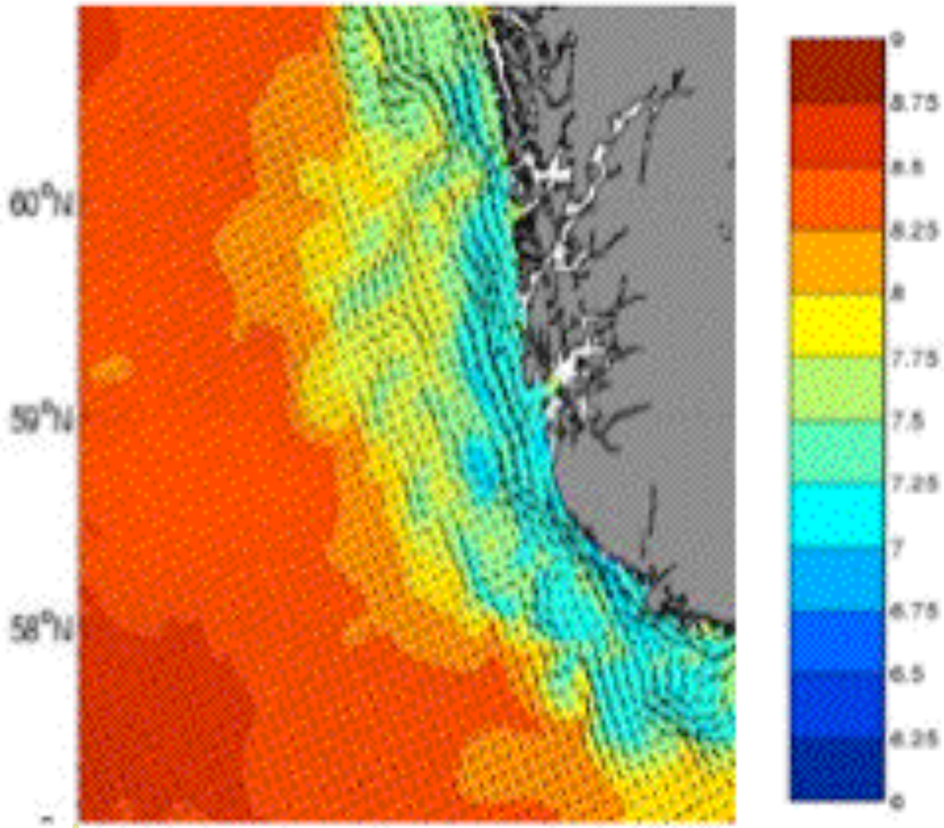
SIMULATED RADAR SIGNAL



ASAR IMAGE

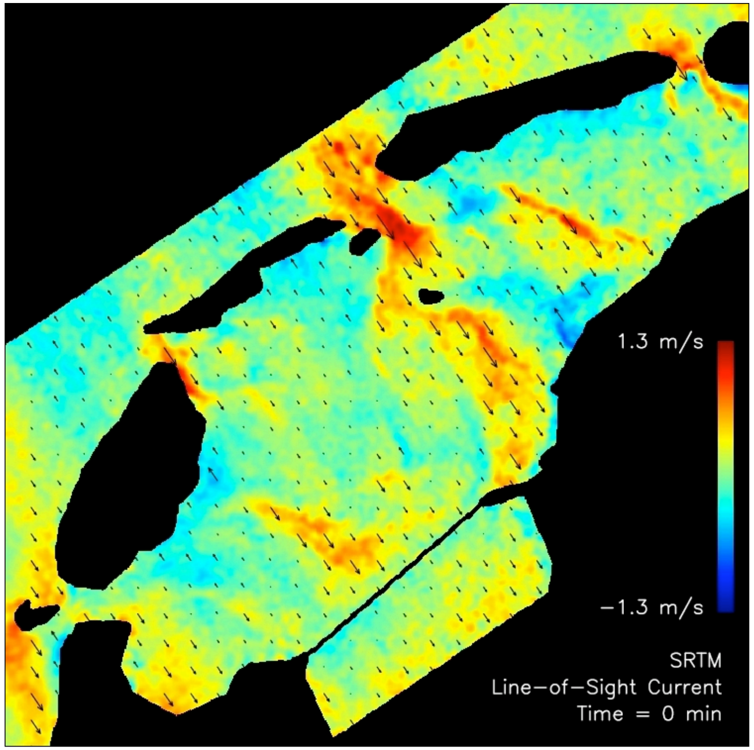


SURFACE CURRENT & SST

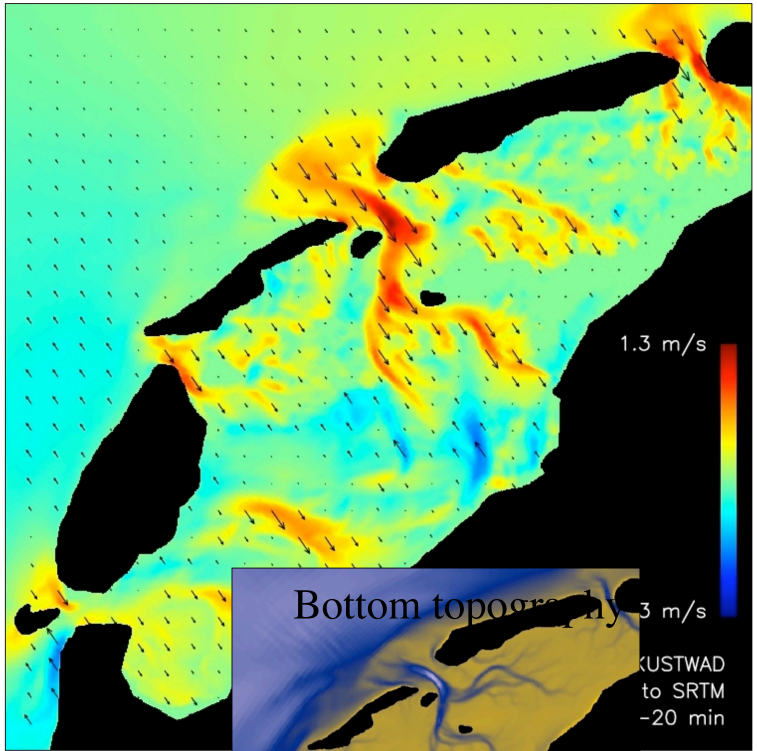


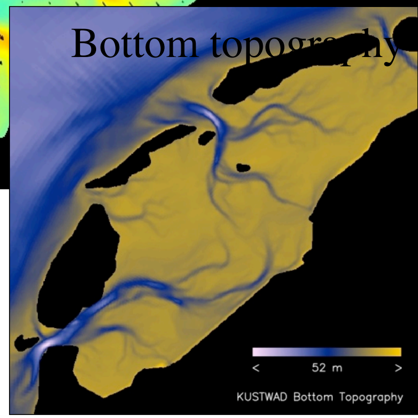
SRTM (X-SAR) Example: Wadden Sea (Netherlands)

Line-of-sight current from SRTM, (70 km)²



...and from circulation model KUSTWAD



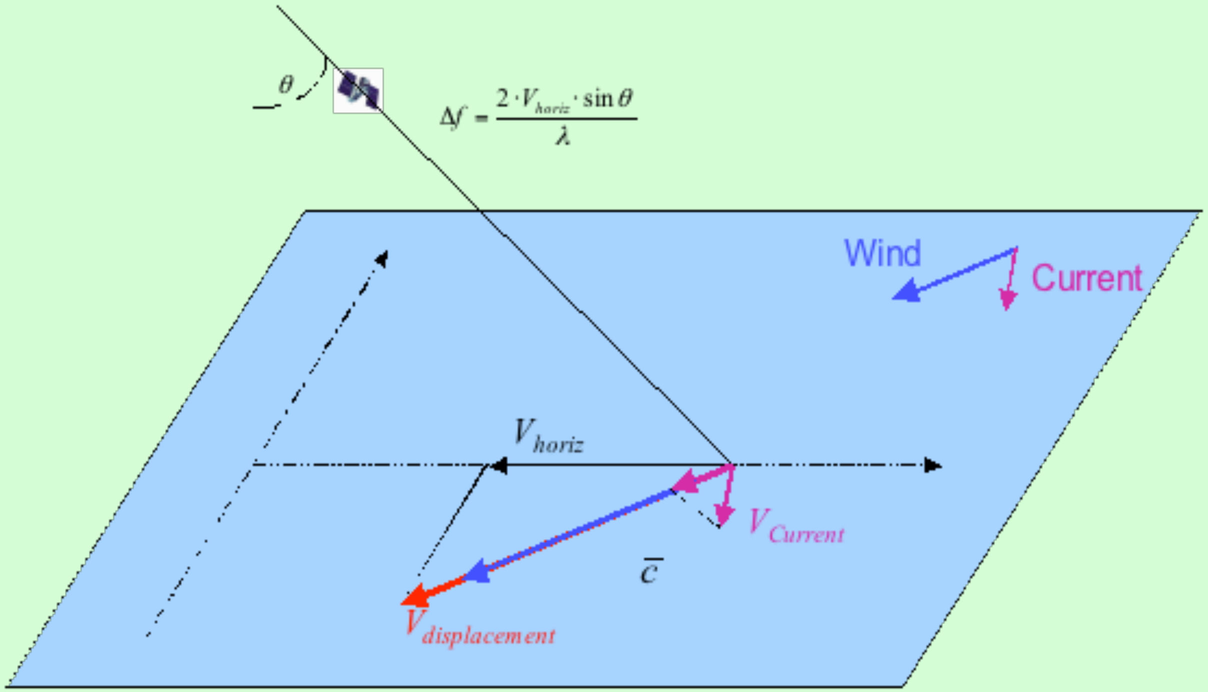


- Good qualitative and quantitative agreement
- Accuracy: About 0.1 m/s at 1 km resolution
- Data quality consistent with InSAR model

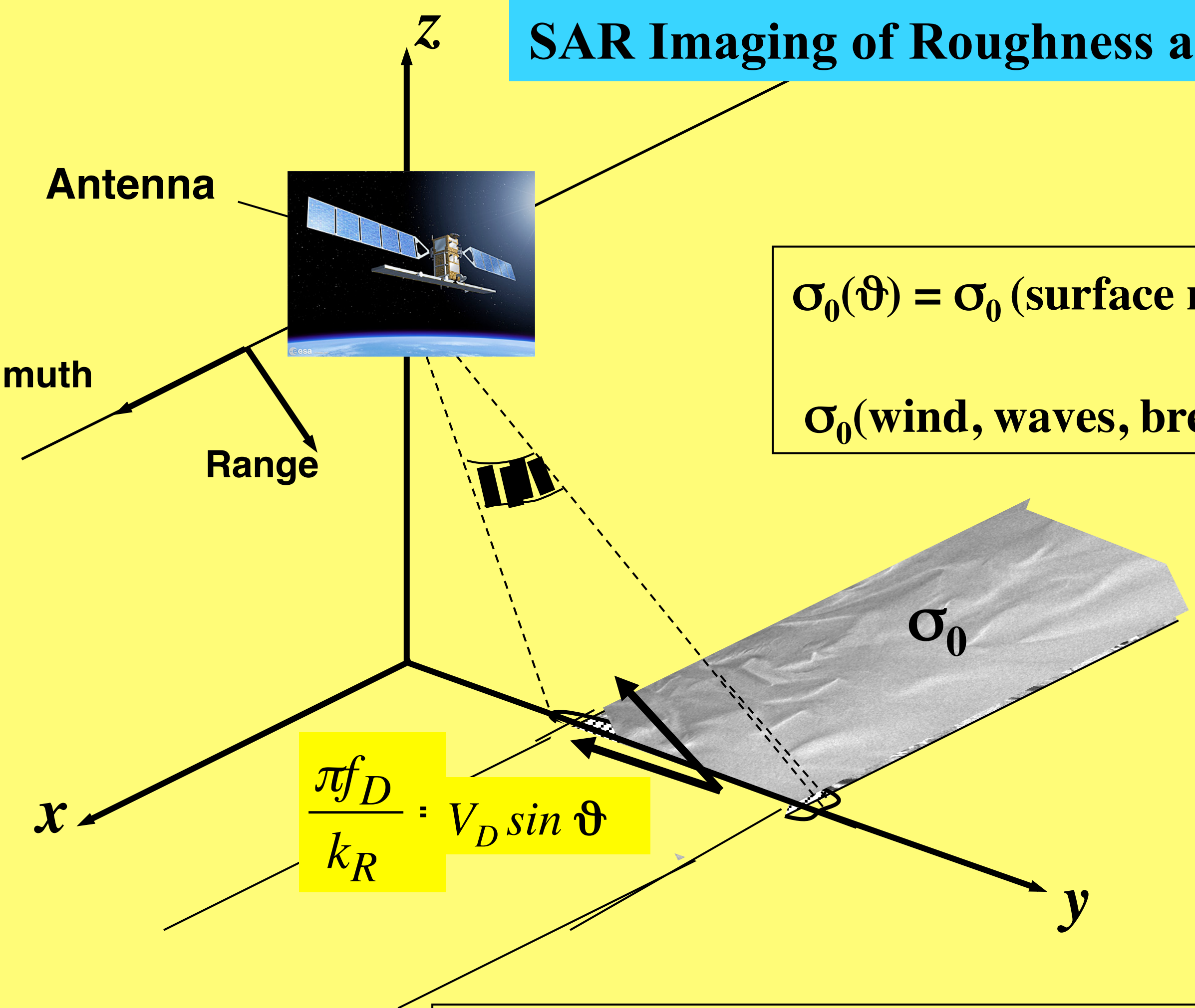
Courtesy R.Romeiser

DOPPLER ANOMALY METHOD

- Main principles



SAR Imaging of Roughness and Doppler Shift



$\sigma_0(\vartheta) = \sigma_0$ (surface roughness) =

σ_0(wind, waves, breaking, current

$V_D = V_D$ (wind driven scatterer, waves, breaking, current)

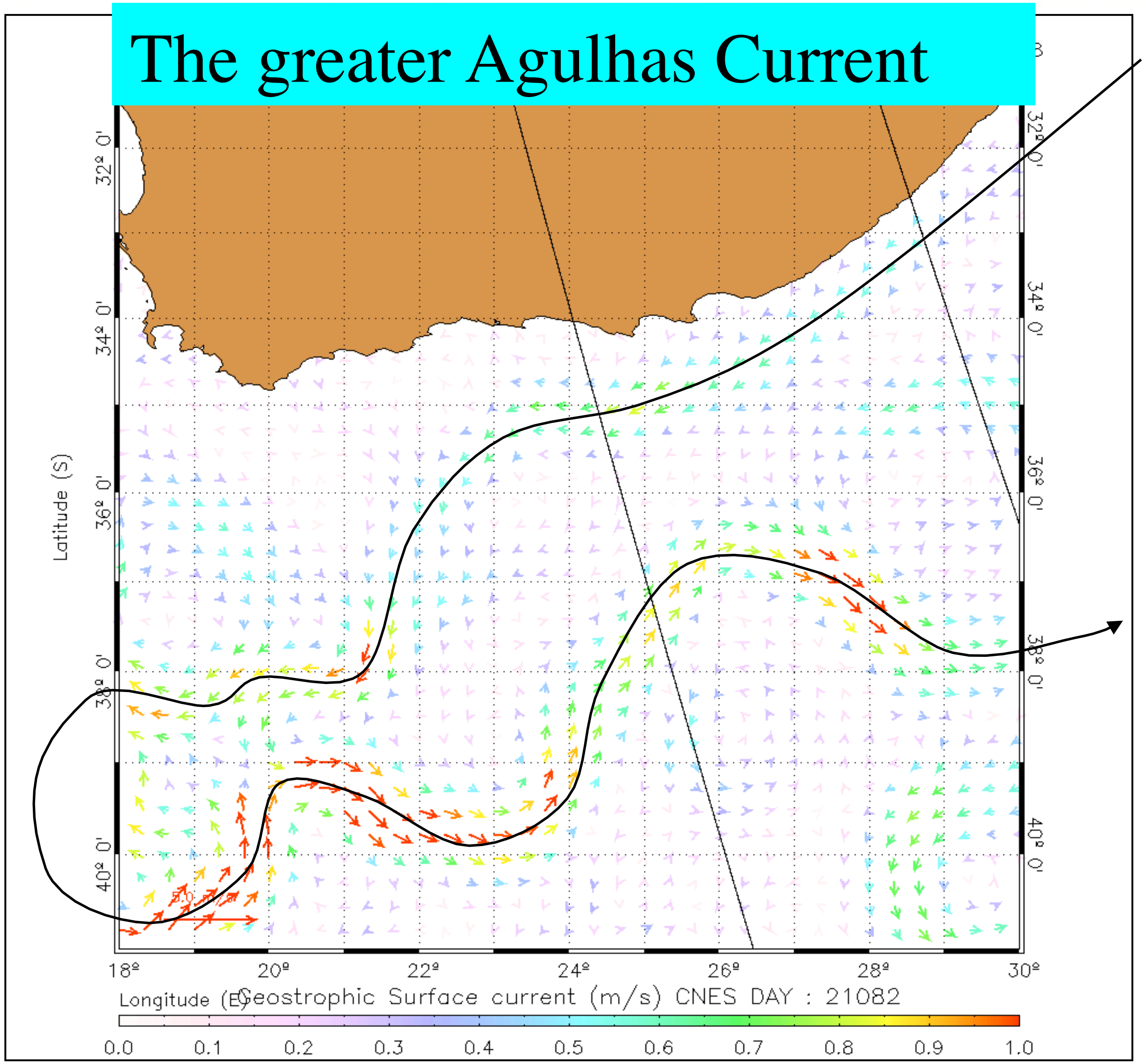
Estimation of Doppler anomaly

Anomaly (shift) = measured – predicted

$$\frac{\pi f_D}{k_R} = -\frac{\overline{(u \sin\theta - w \cos\theta)\sigma_0(\theta + \Delta\theta)}}{\overline{\sigma_0(\theta + \Delta\theta)}} = \boldsymbol{V_D}$$

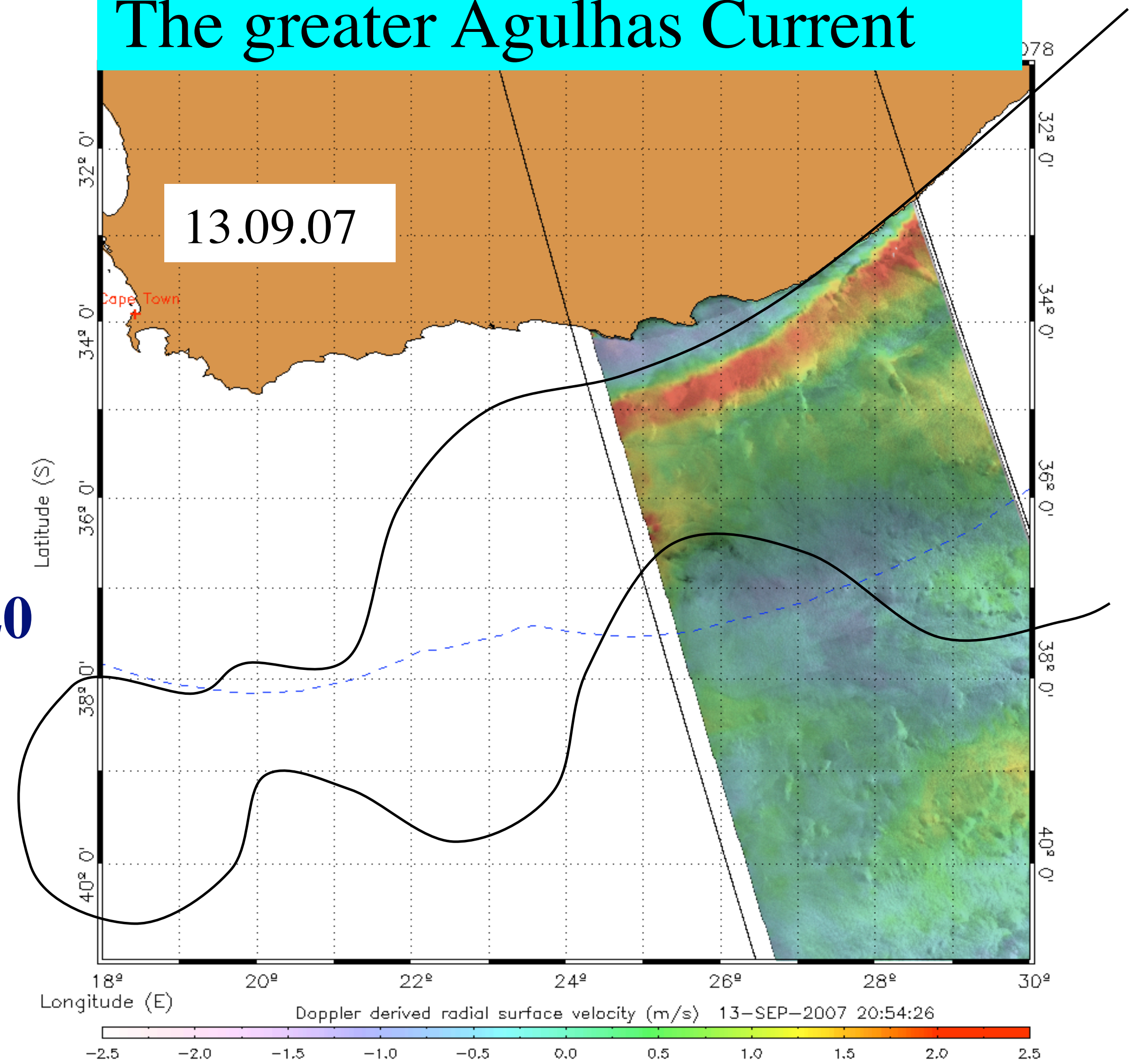
f_D: Doppler shift
K_R: Radar Wave number
θ : Incidence angle
U: horizontal velocity
W: vertical velocity
σ_0: radar cross section

Altimetry derived surface current : 7 days mean (13-20 September)



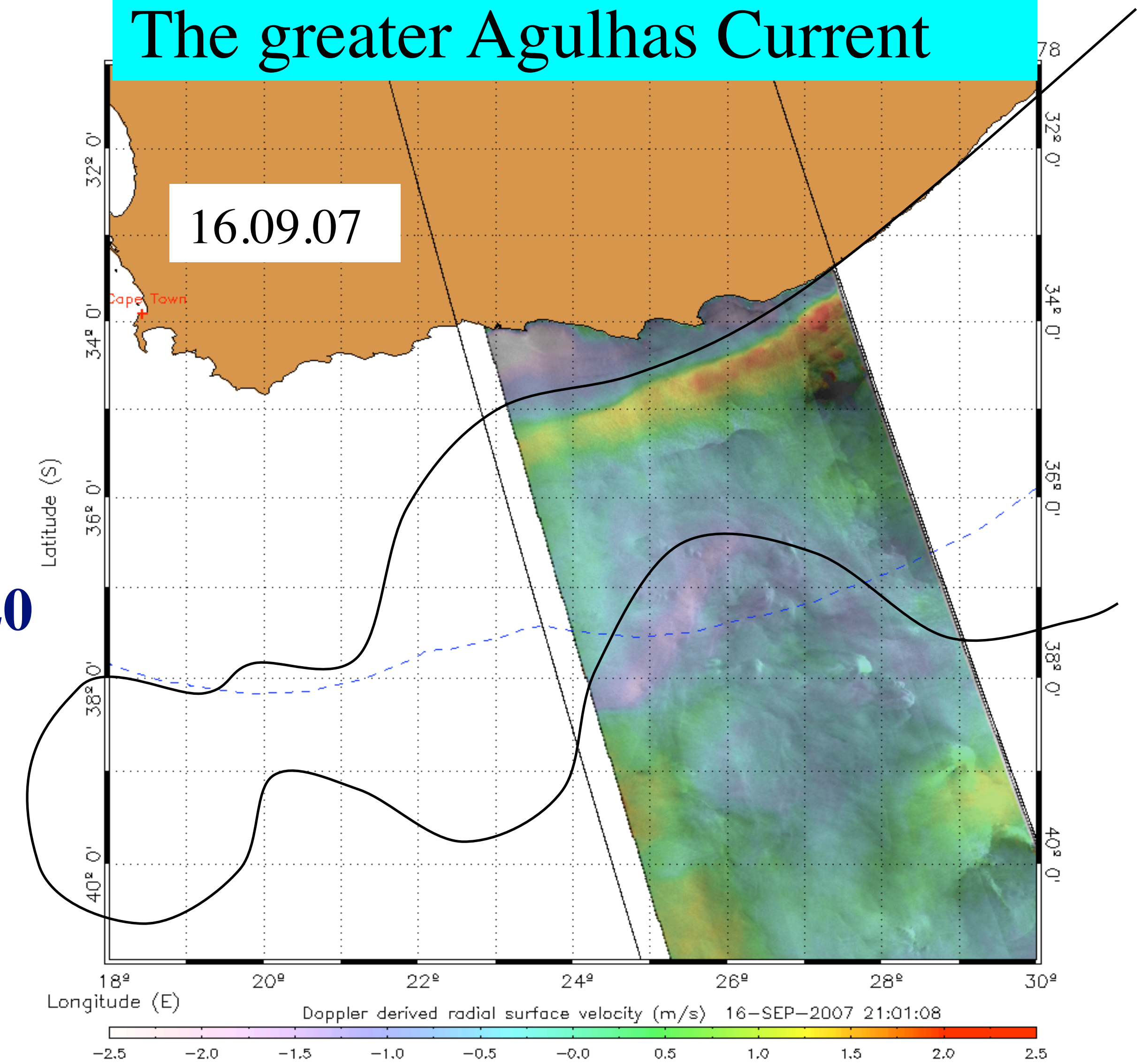
The greater Agulhas Current

Range directed surface Doppler velocity after removal of wind contribution (13-20 September)

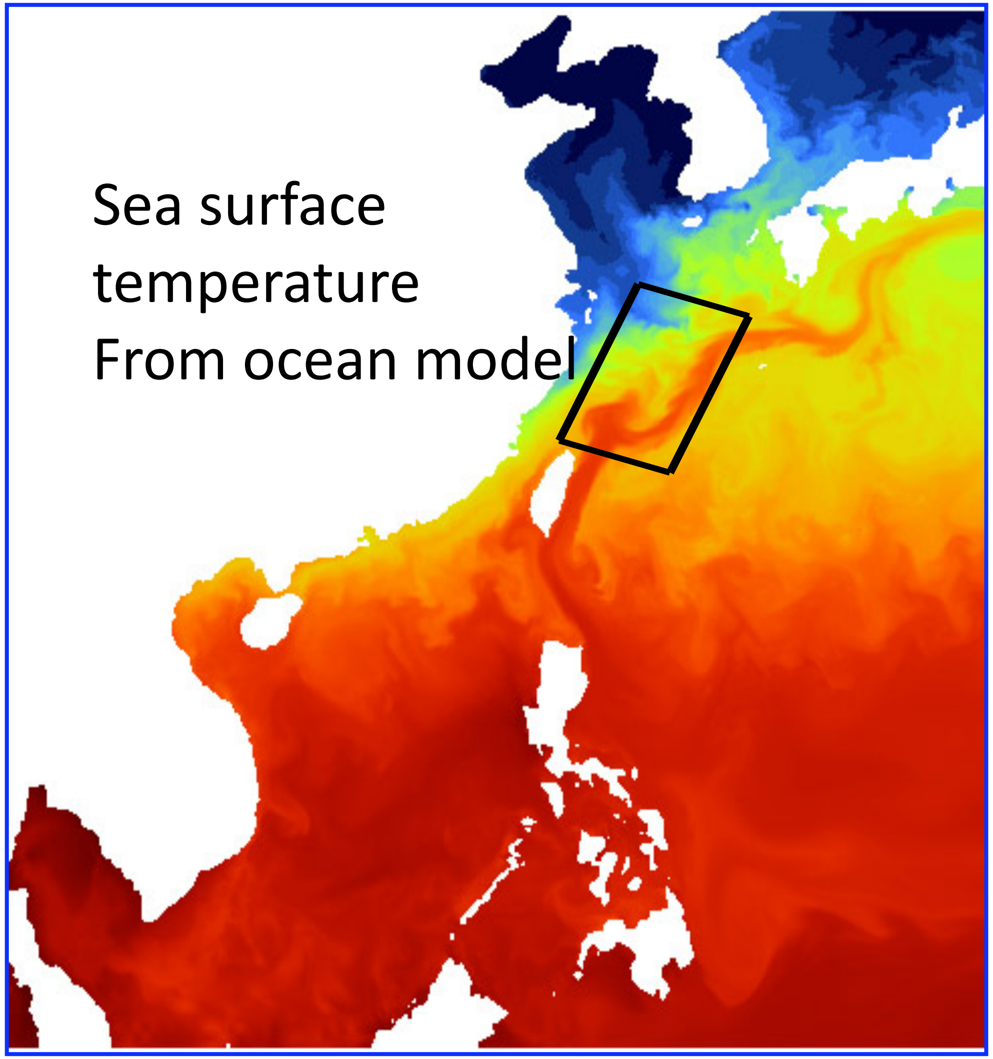


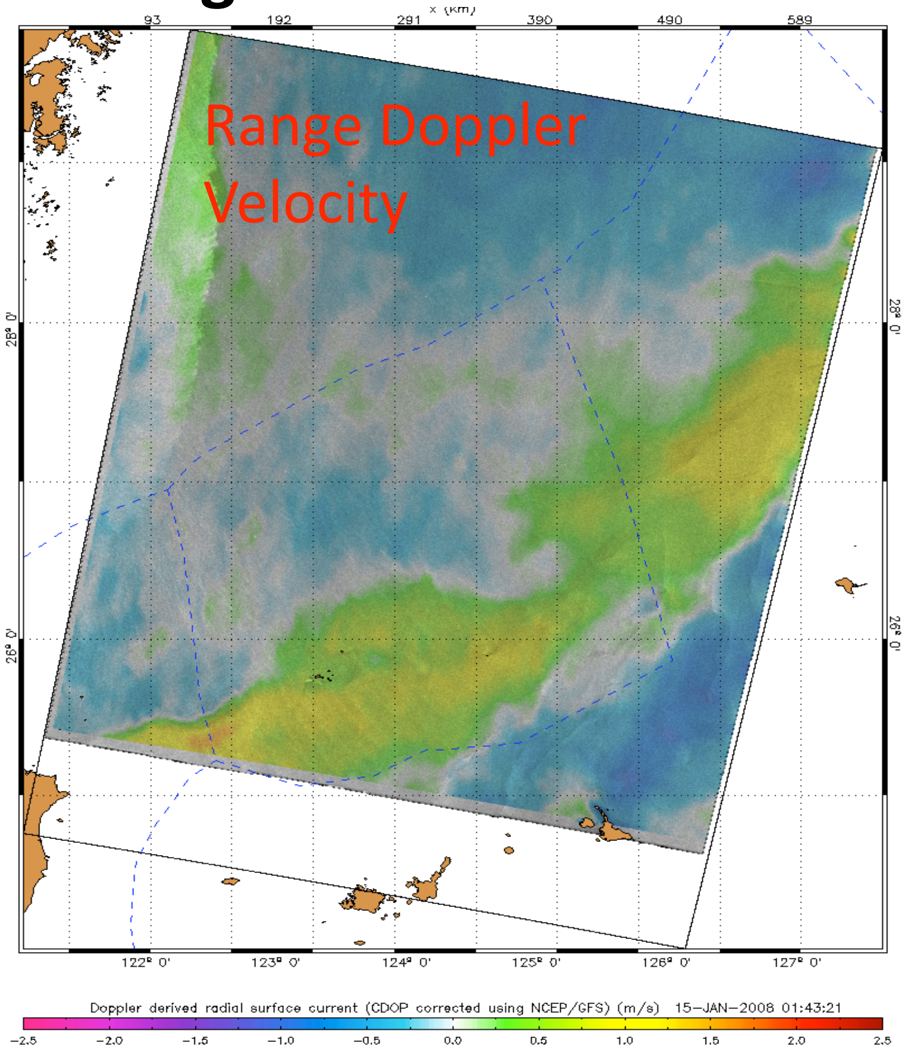
The greater Agulhas Current

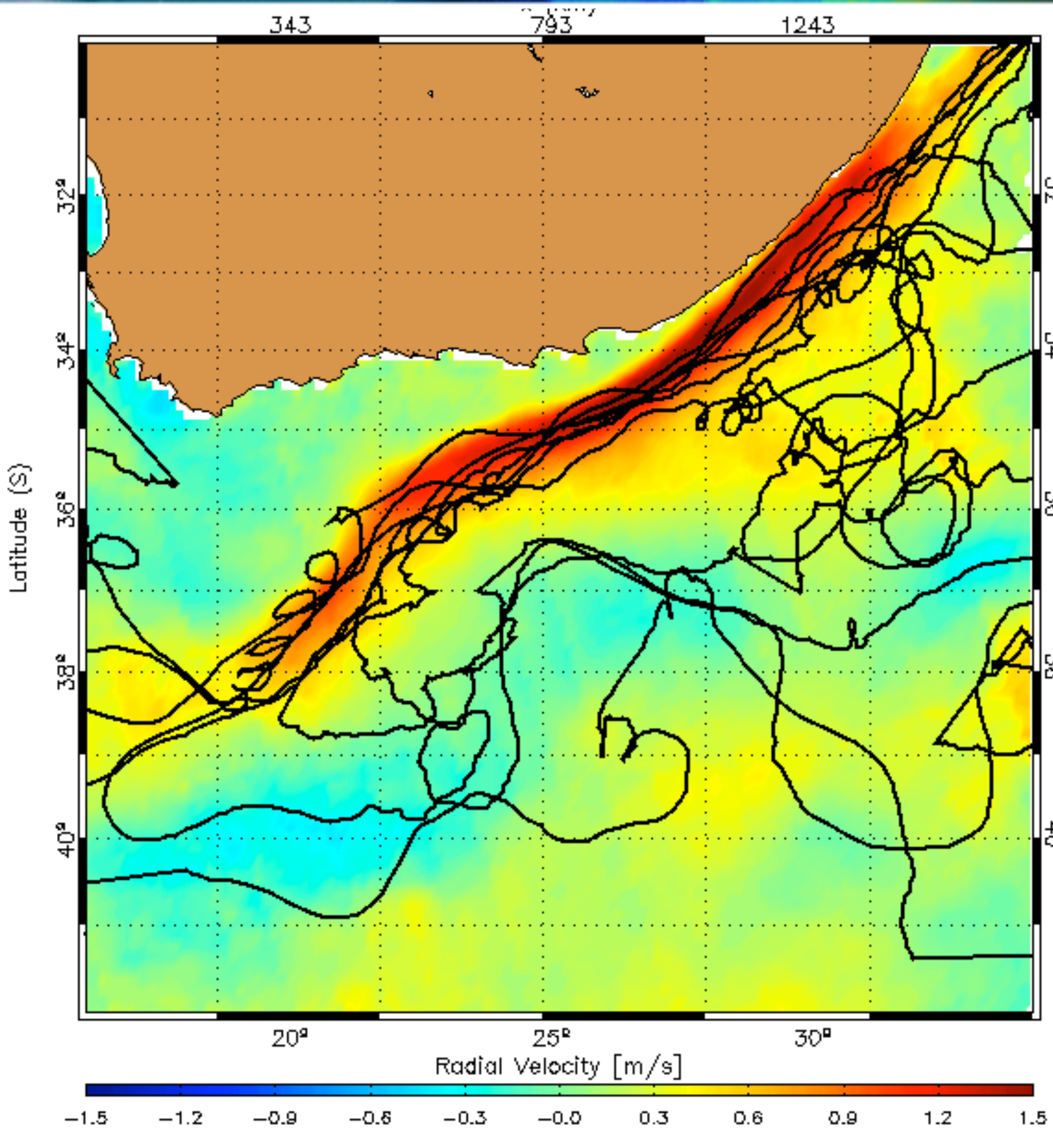
Range directed surface Doppler velocity after removal of wind contribution (13-20 September)



Kuroshio Monitoring

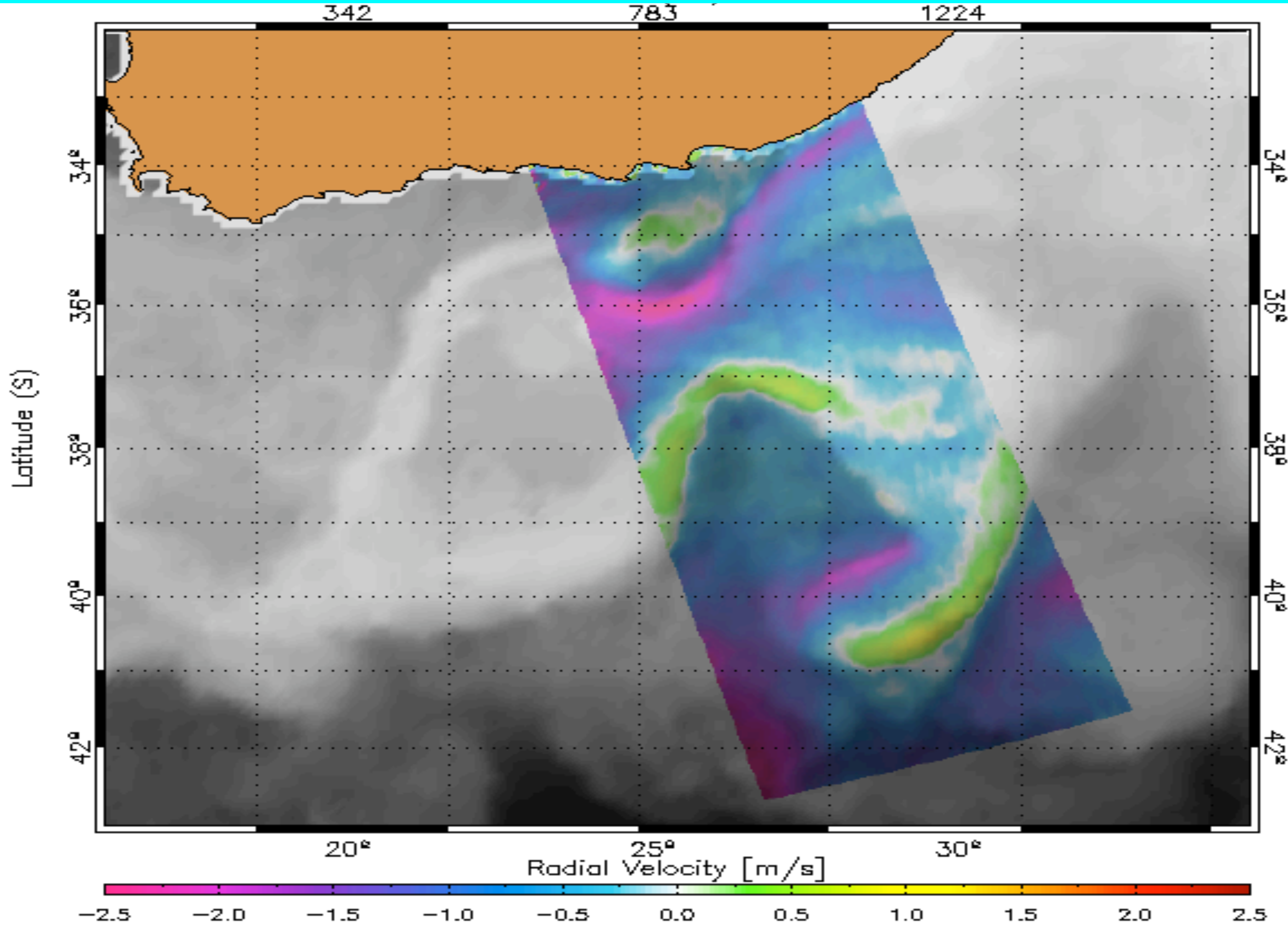






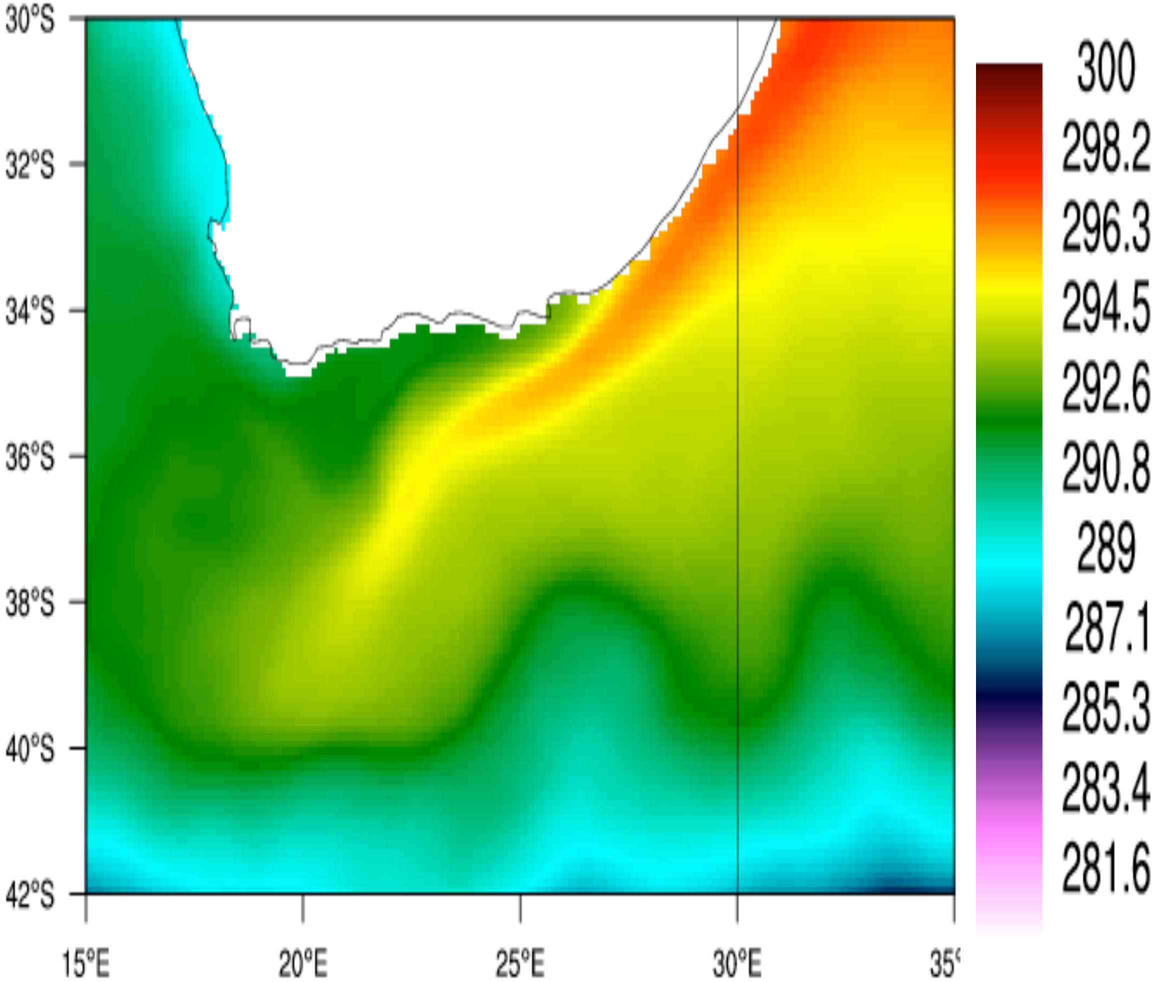
RANGE DOPPLER VELOCITY VERSUS SURFACE DRIFTERS

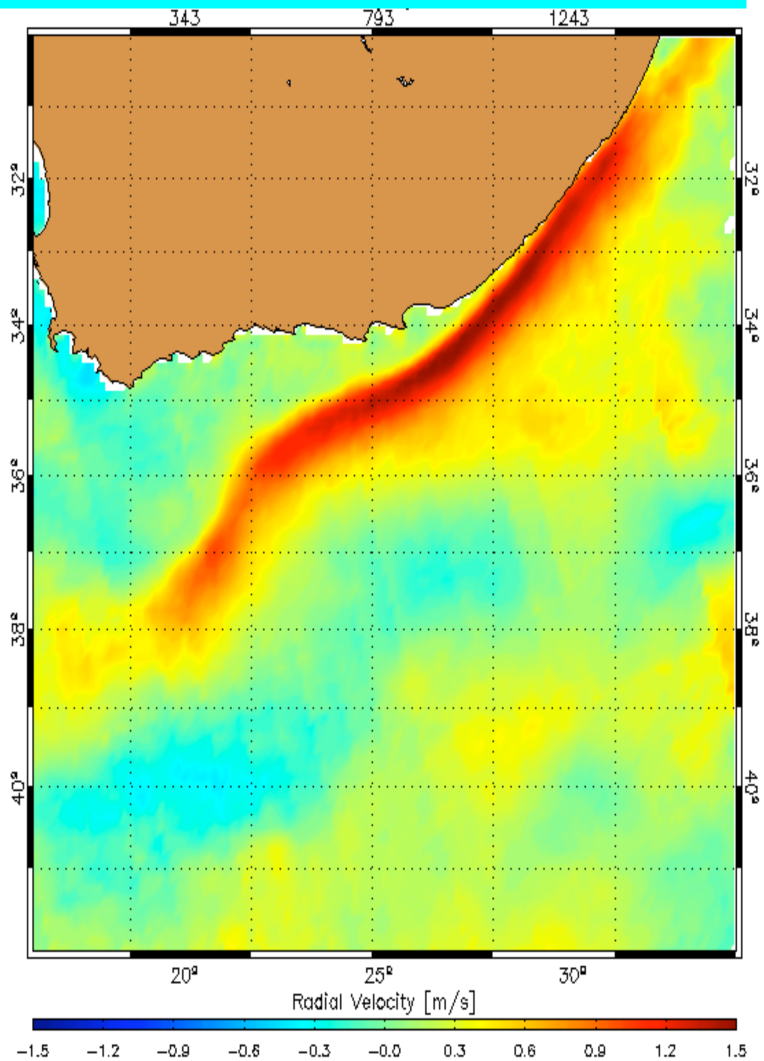
SST and range Doppler velocity overlay – 14 April 2009



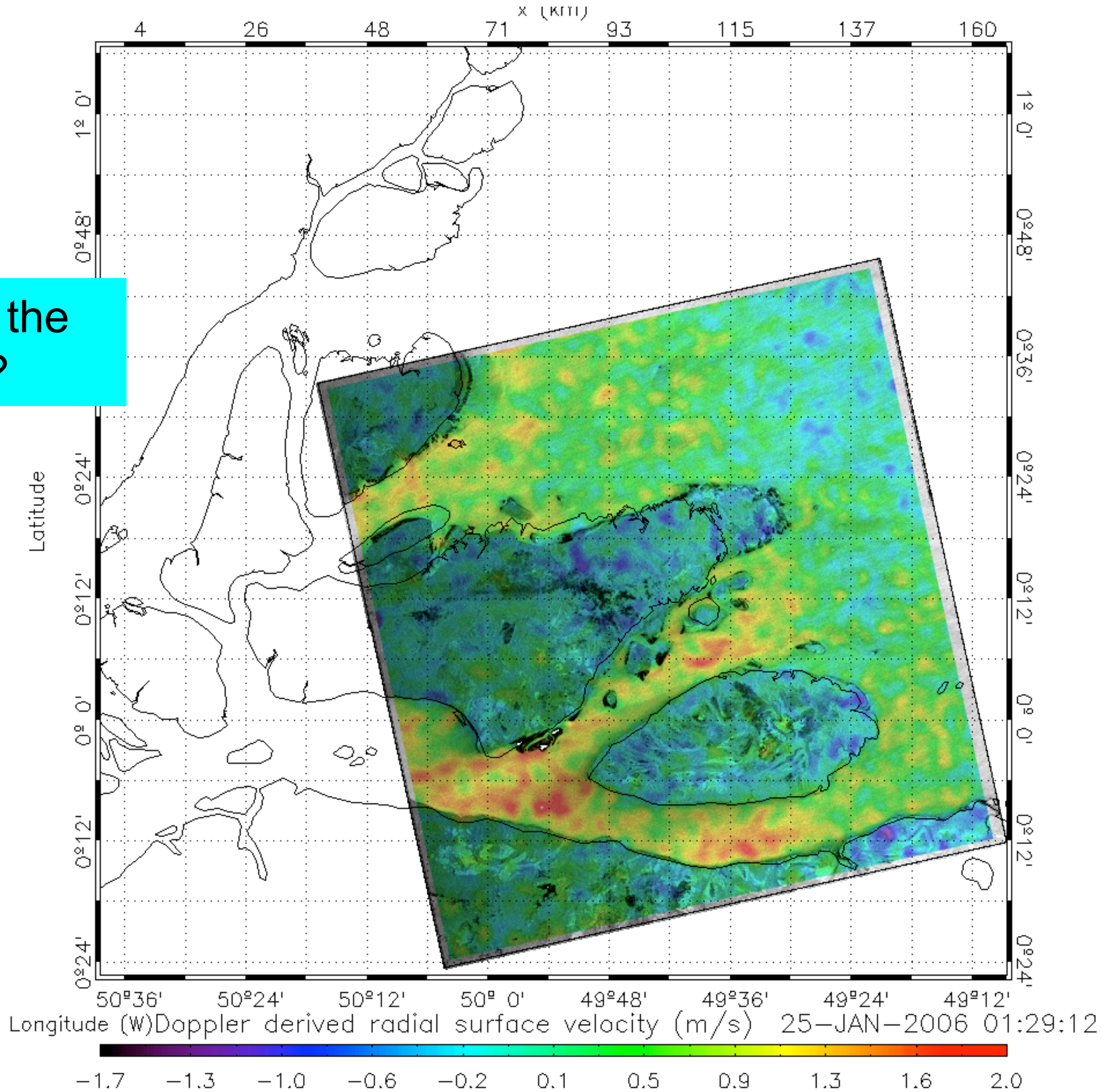
NERSC

Mean SST and range Doppler velocity





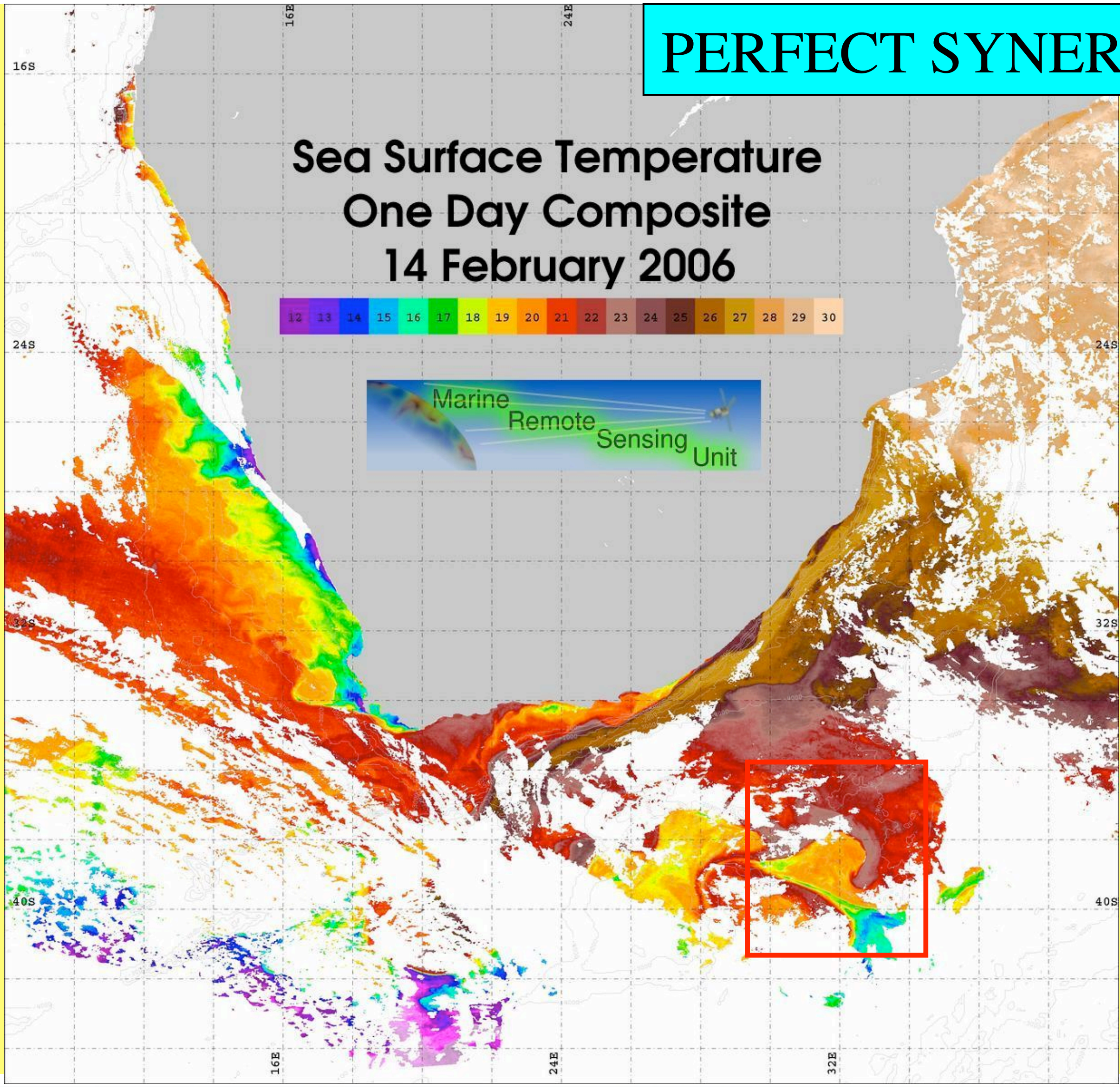
Can the river outflow from the Amazon be estimated?

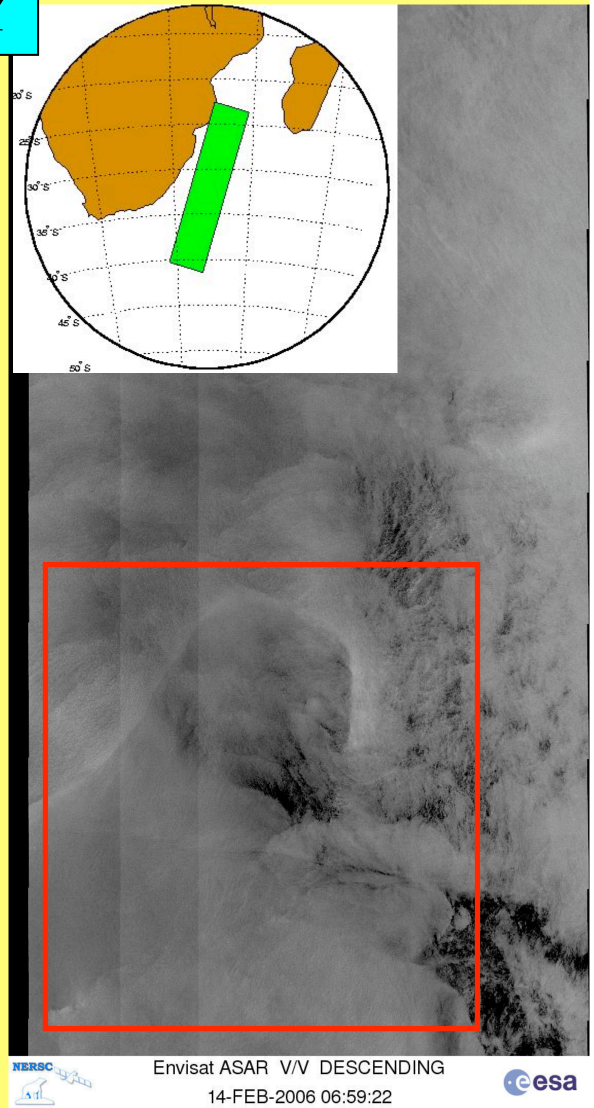


SAR CONTRIBUTION TO MARINE MONITORING

Operational Surveillance	Emerging New Application	Routine Product and partly used in NWP	Research Dominated
Ship detection Oil spill detection Sea Ice Shallow water Bathymetry	Wind field retrievals	Ocean Waves and Ocean Spectra	SYNERGY Surface current fronts and eddies Internal Waves Atmospheric boundary layer Processes Film damping

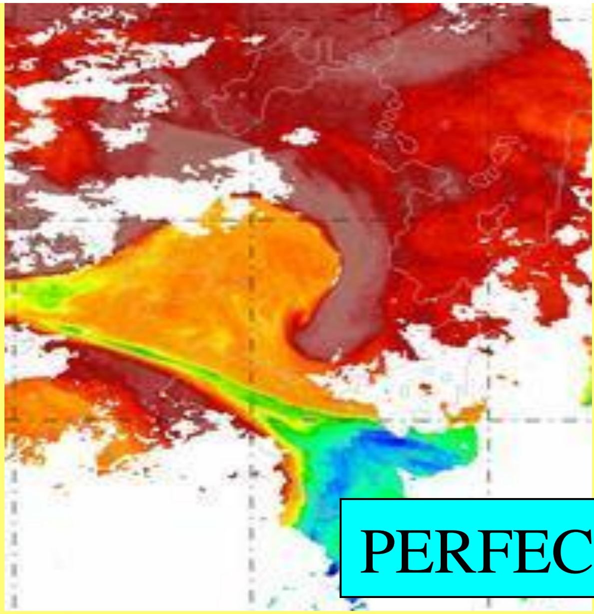
PERFECT SYNERGY

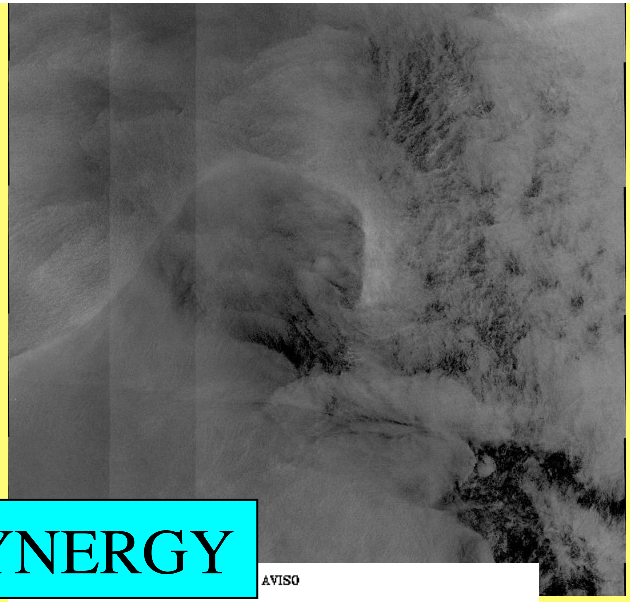




NOAA-16/17/18

AVHRR Sea Surface Temperatures





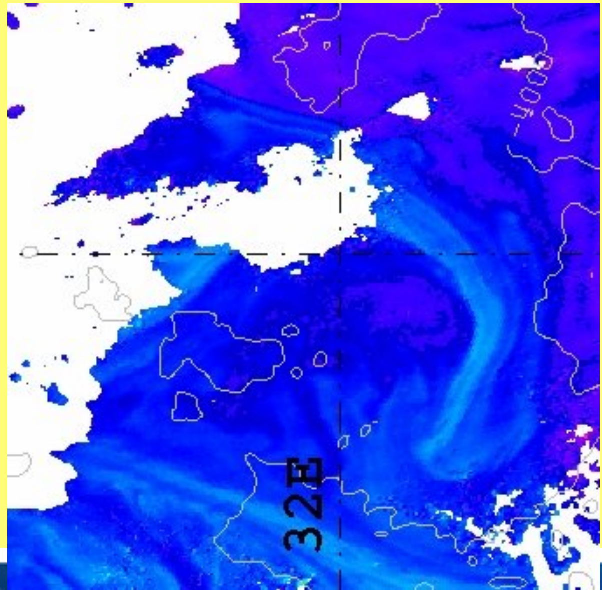
Envisat ASAR

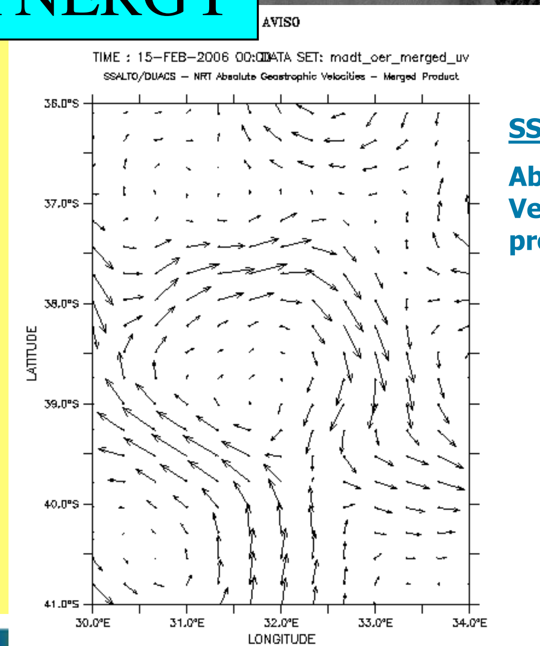
Sea Surface Roughness

PERFECT SYNERGY

MODIS Aqua

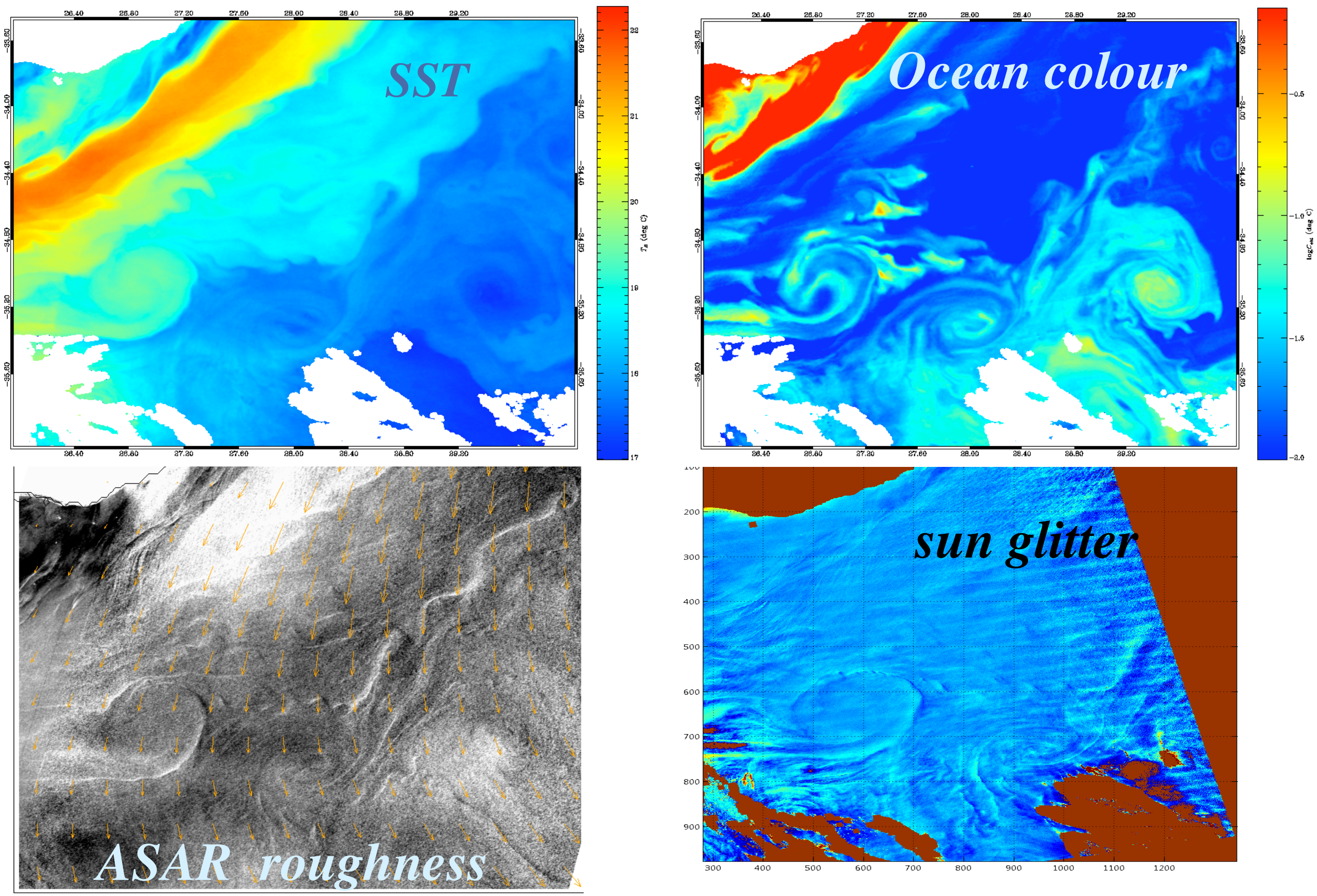
Chlorophyll-a concentration





SSALTO/DUACS Altimetry

Absolute Geostrophic Velocities – Merged product

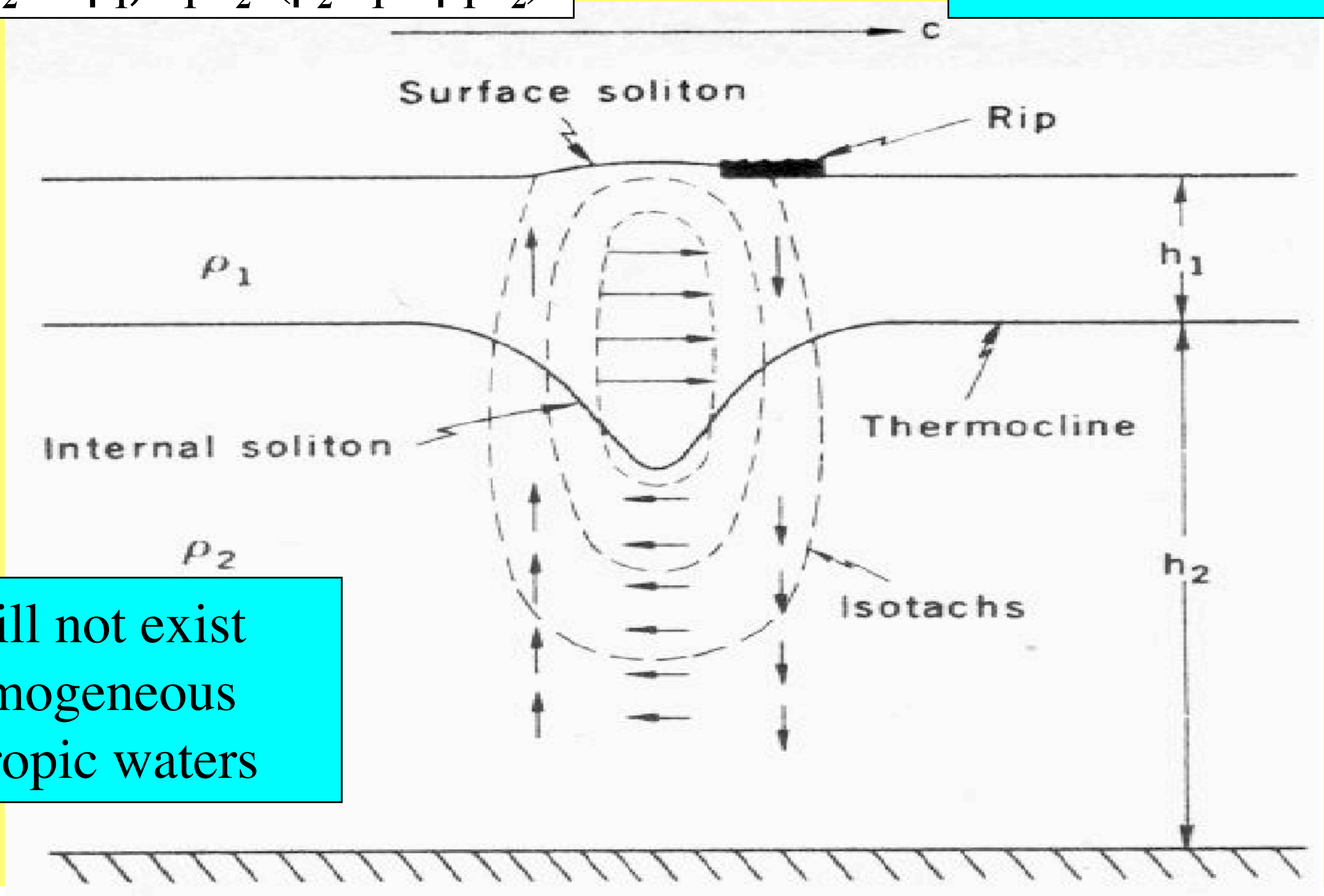

SST
Ocean colour
ASAR roughness
sun glitter

SAR CONTRIBUTION TO MARINE MONITORING

Operational Surveillance	Emerging New Application	Routine Product and partly used in NWP	Research Dominated
Ship detection Oil spill detection Sea Ice Shallow water Bathymetry	Wind field retrievals	Ocean Waves and Ocean Spectra	Surface current fronts and eddies Internal Waves Atmospheric boundary layer Processes Film damping

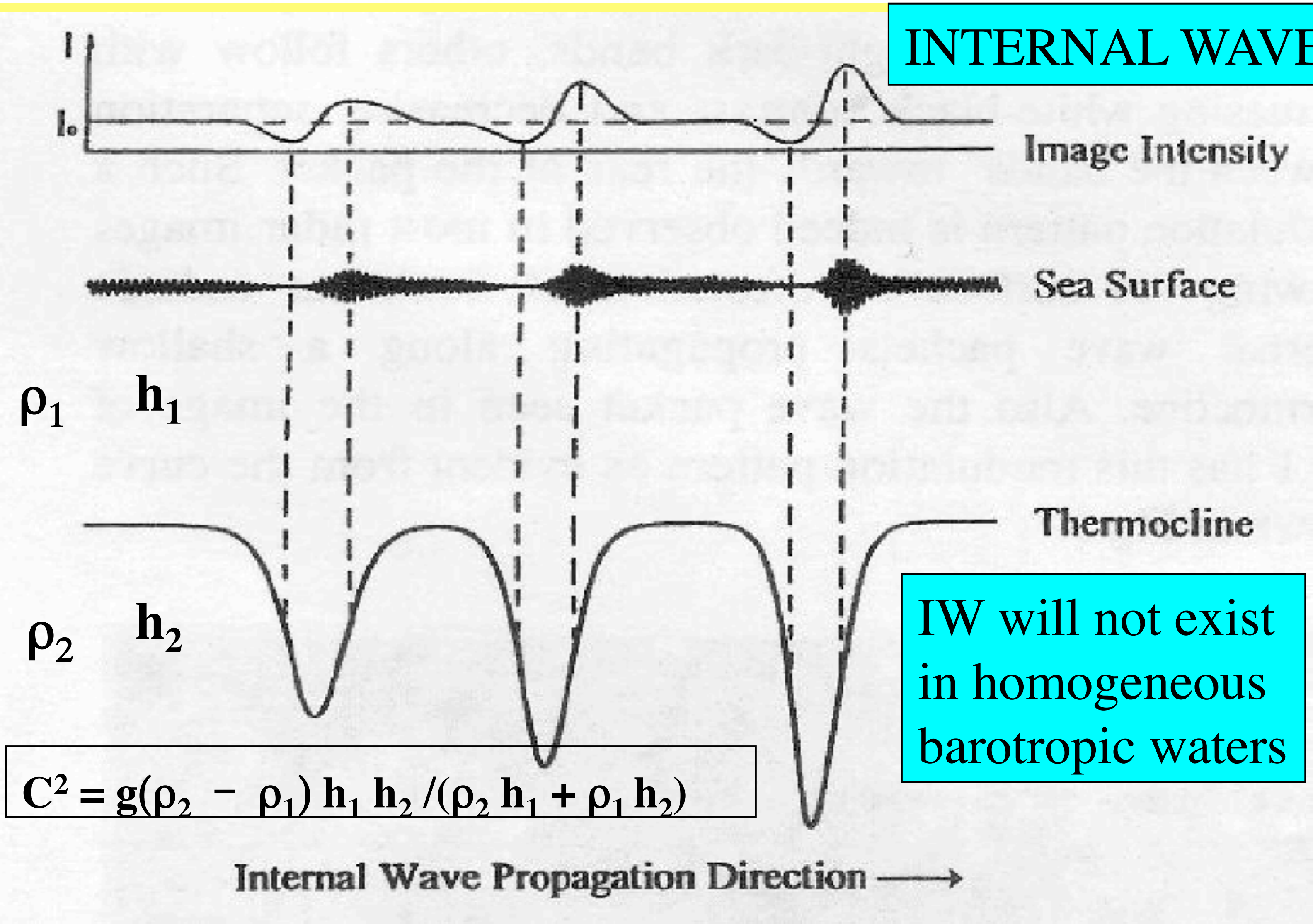
$$C = g(\rho_2 - \rho_1)\, h_1\, h_2 / (\rho_2\, h_1 + \rho_1\, h_2)$$

INTERNAL WAVES



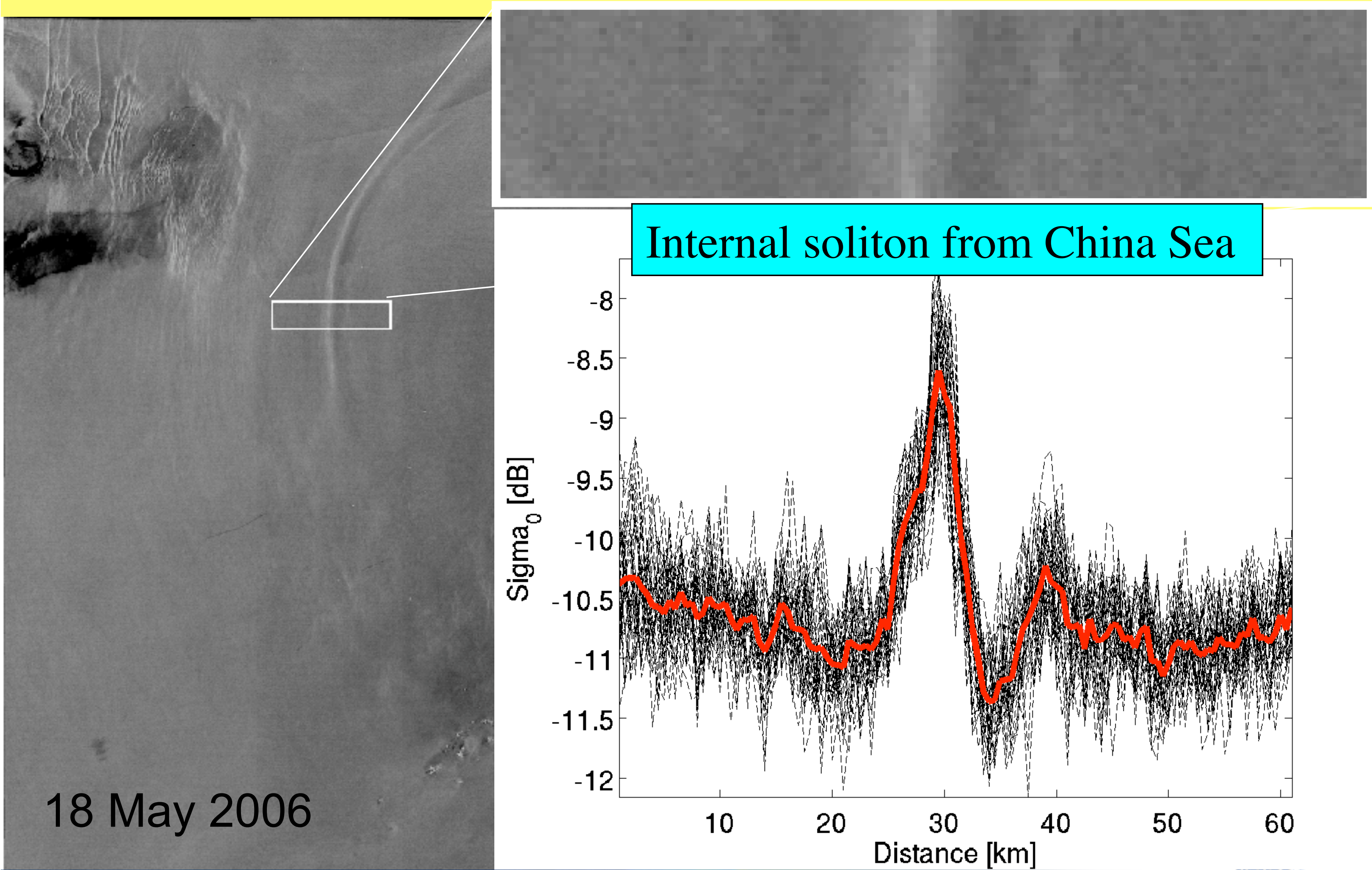
IW will not exist in homogeneous barotropic waters

INTERNAL WAVES

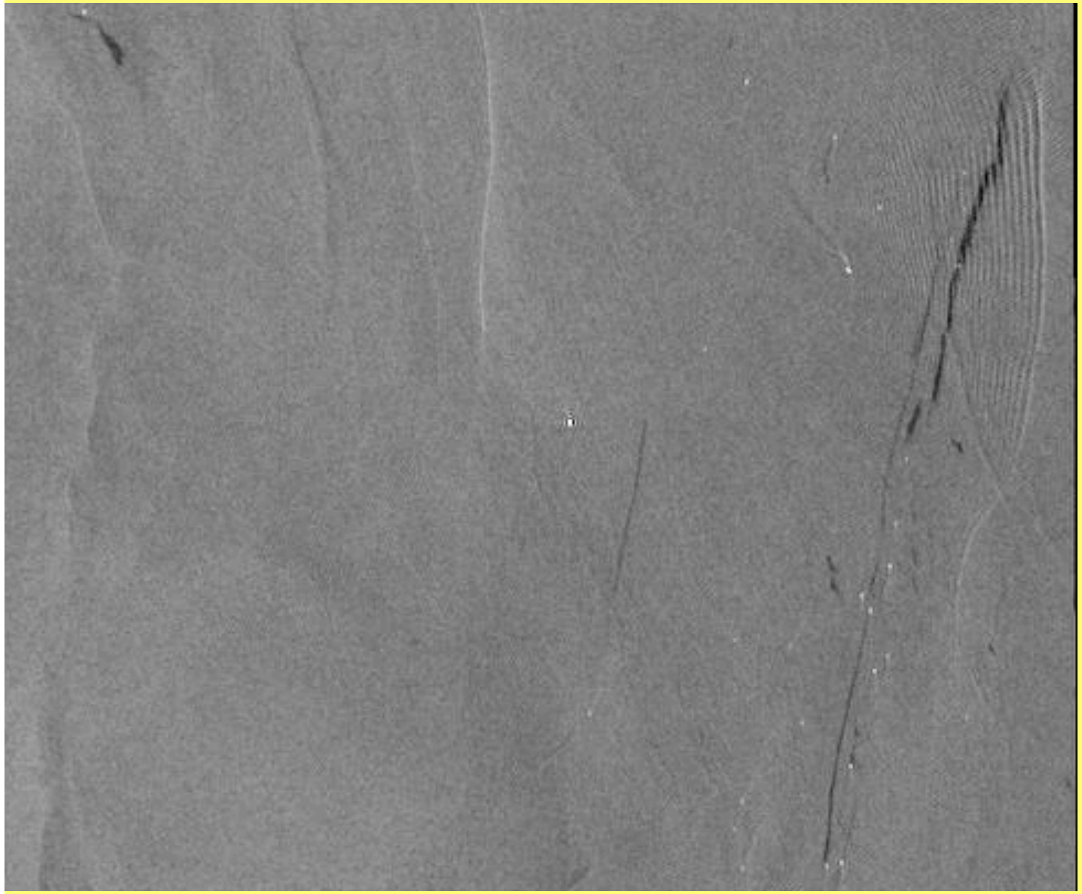


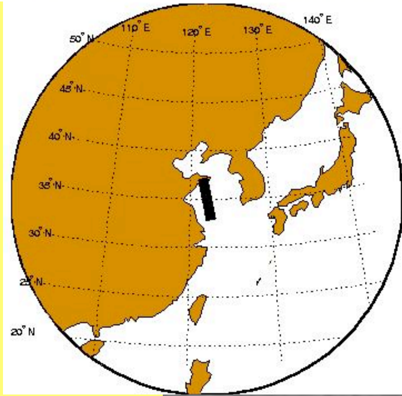
$$C^2 = g(\rho_2 - \rho_1)\, h_1\, h_2 / (\rho_2\, h_1 + \rho_1\, h_2)$$

IW will not exist in homogeneous barotropic waters


Internal soliton from China Sea
18 May 2006
Sigma0 [dB]
-8
-8.5
-9
-9.5
-10
-10.5
-11
-11.5
-12
10
20
30
40
50
60
Distance [km]

Internal Waves

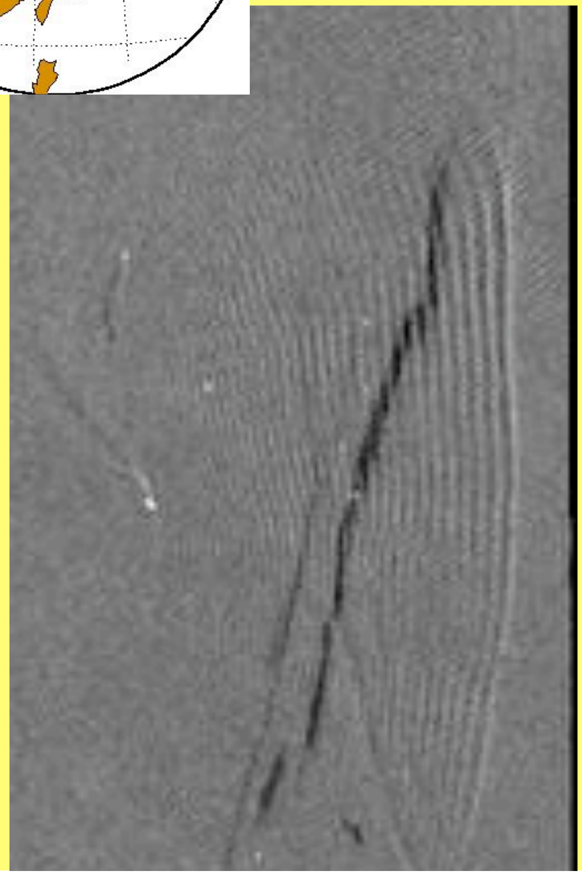




NERSC

Envisat ASAR APM V/V ASCENDING

17-AUG-2007 13:39:58



NERSC

Radar Imaging Model

- Wind speed
- Atmospheric stability
- Ocean surface current
- Surface dampening films

Hydrodynamic module →

Description of surface waves

↓

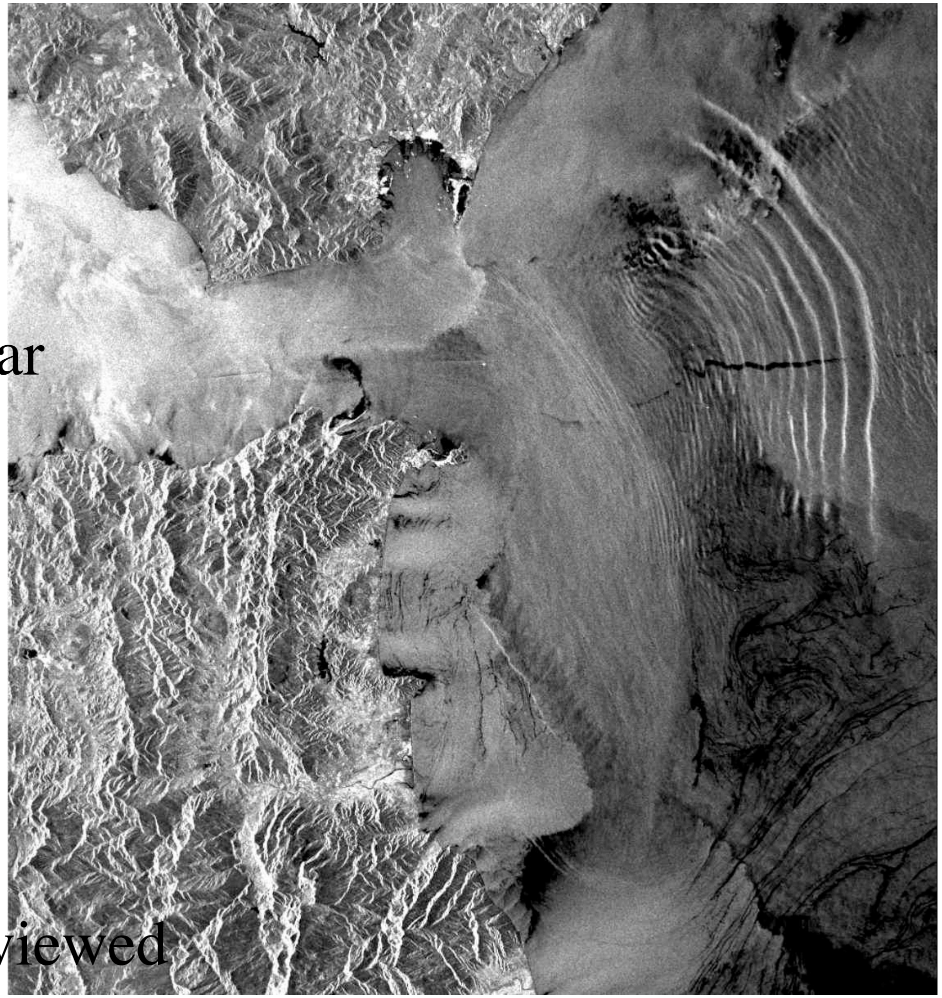
Radar parameters:
- Incidence angle
- wavelength
- polarization

← Radar module

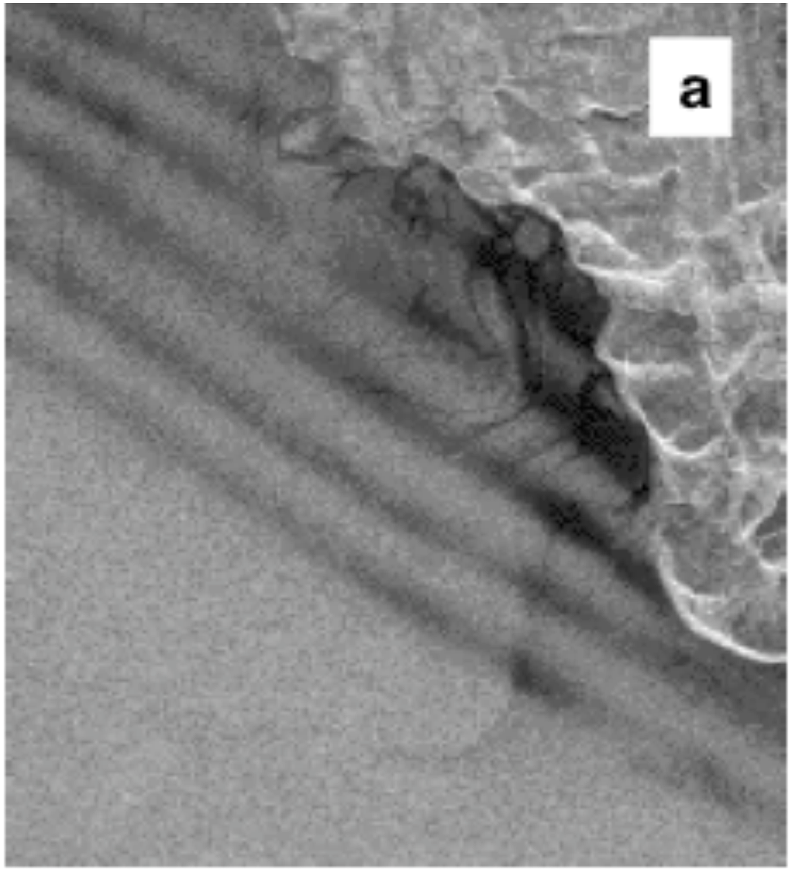
Bragg scattering
Specular scattering
Breaking waves

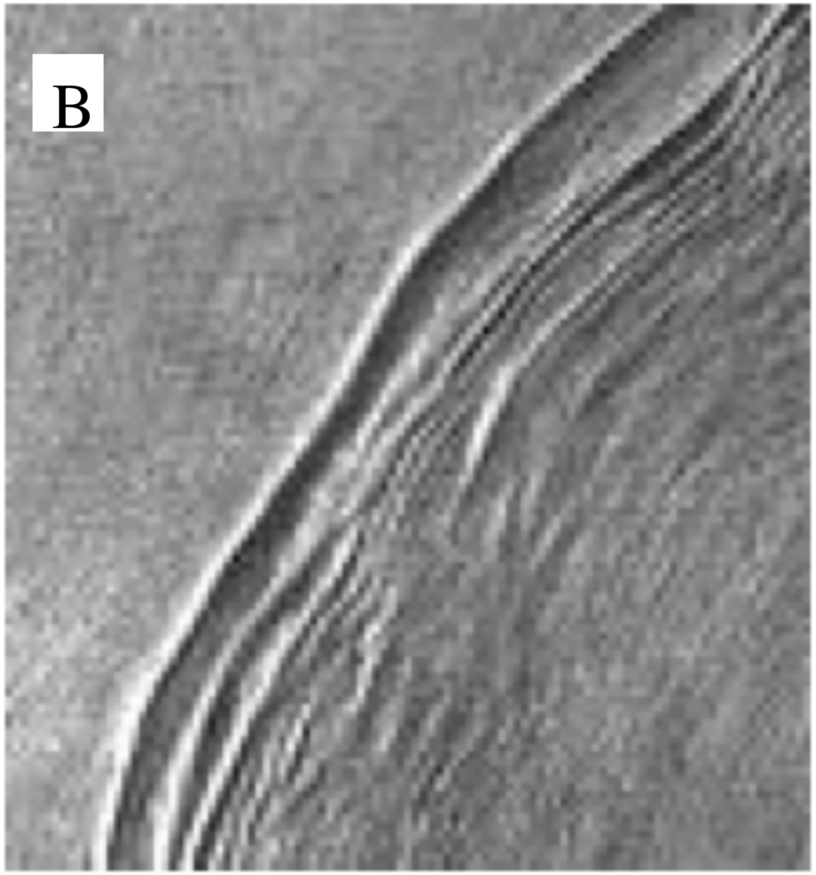
$\left.\begin{array}{r}\text{Bragg scattering}\\ \text{Specular scattering}\\ \text{Breaking waves}\end{array}\right\}\sigma_0$

IWs in the Straight of Gibraltar



Tropical and subtropical ocean viewed by ERS SAR (courtesy W. Alpers and ESA)
http://earth.esa.int/ers/instruments/sar/applications/ERS-SARtropical/

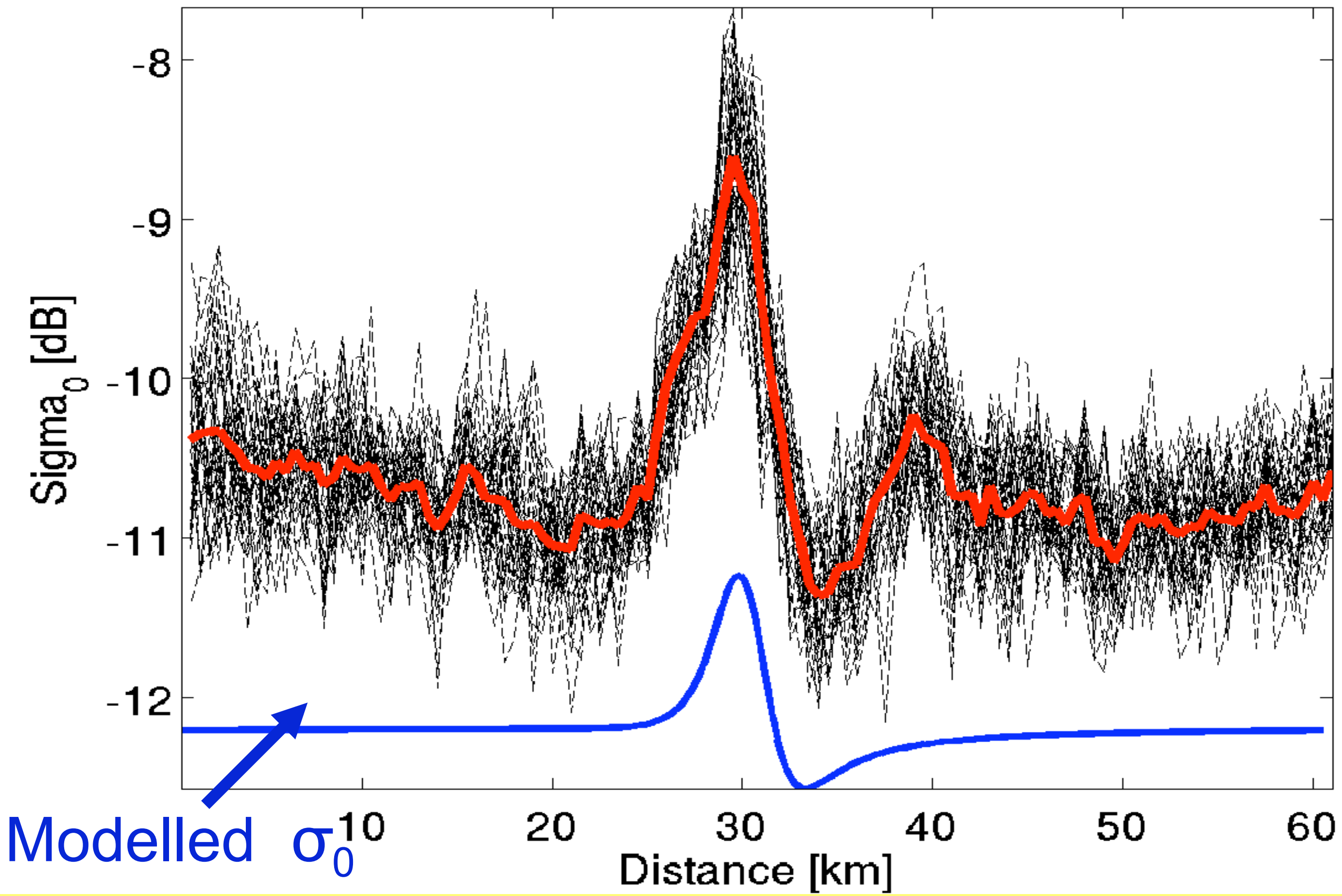




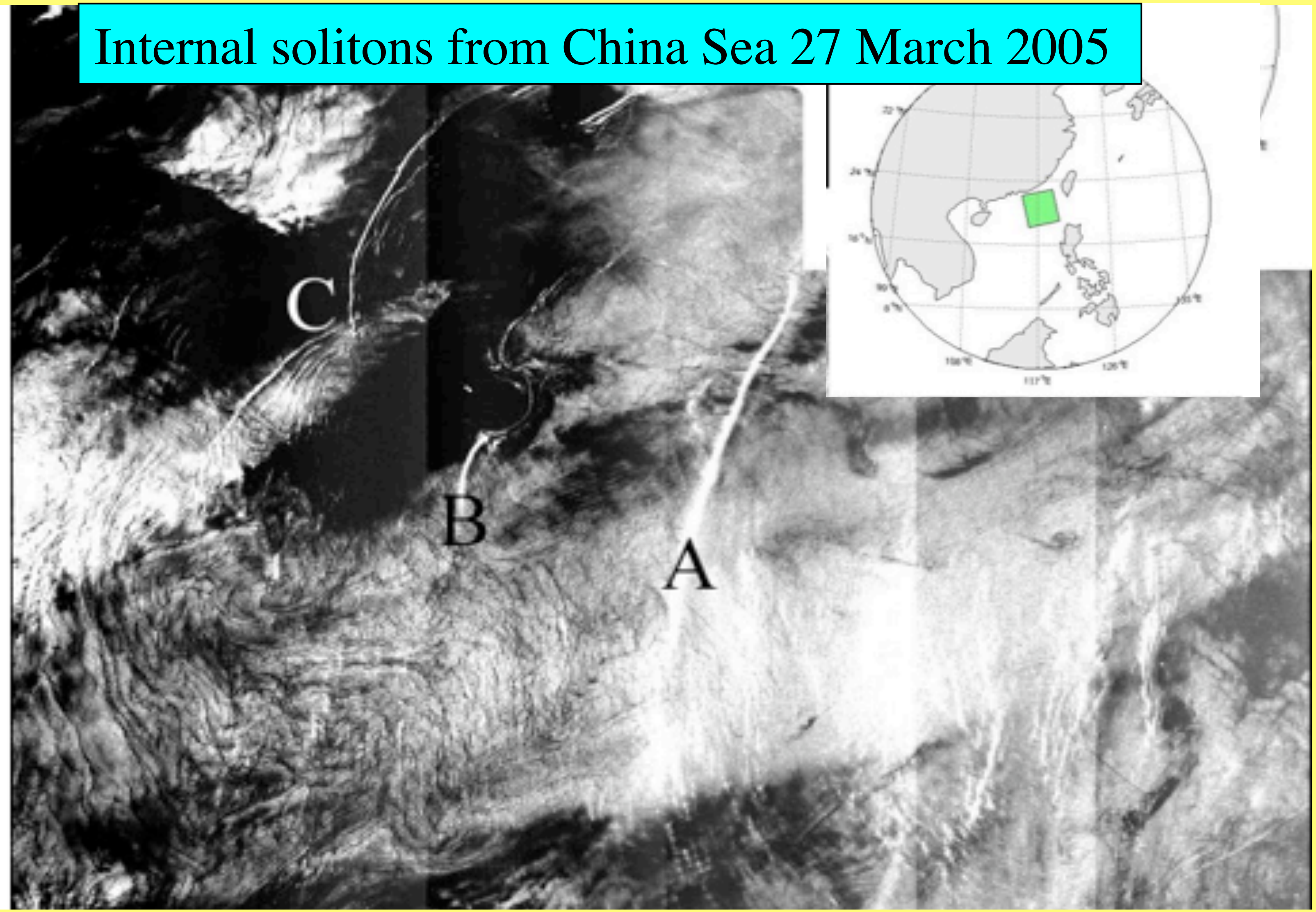
TYPICAL SAR SIGNATURE OF ATMOSPHERIC GRAVITY WAVES

TYPICAL SAR SIGNATURE OF OCEANIC INTERNAL WAVES

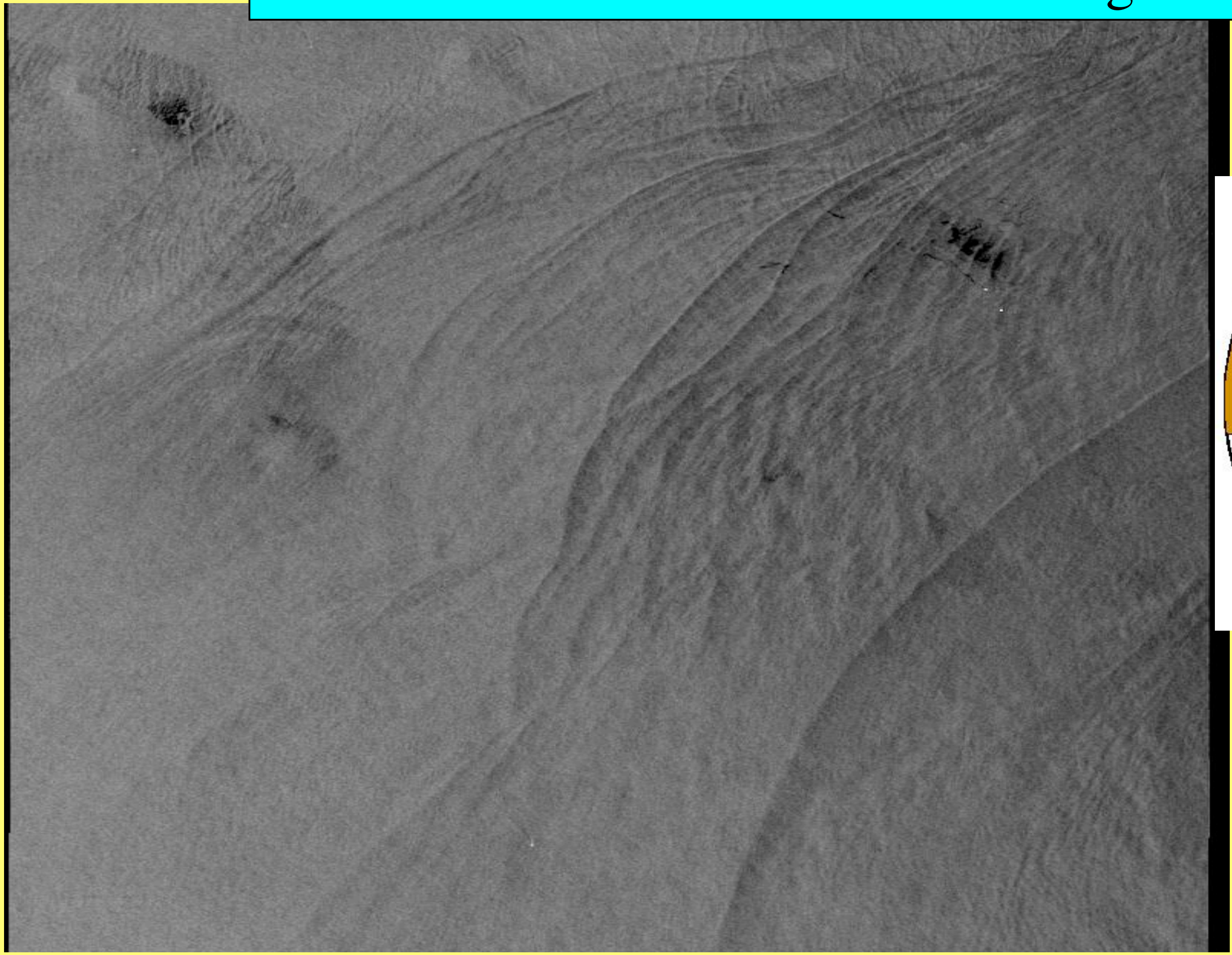
Simulation of backscatter anomaly due to presence of IW

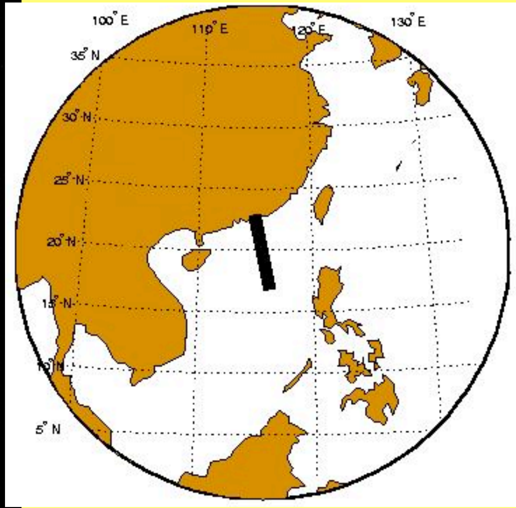


Internal solitons from China Sea 27 March 2005



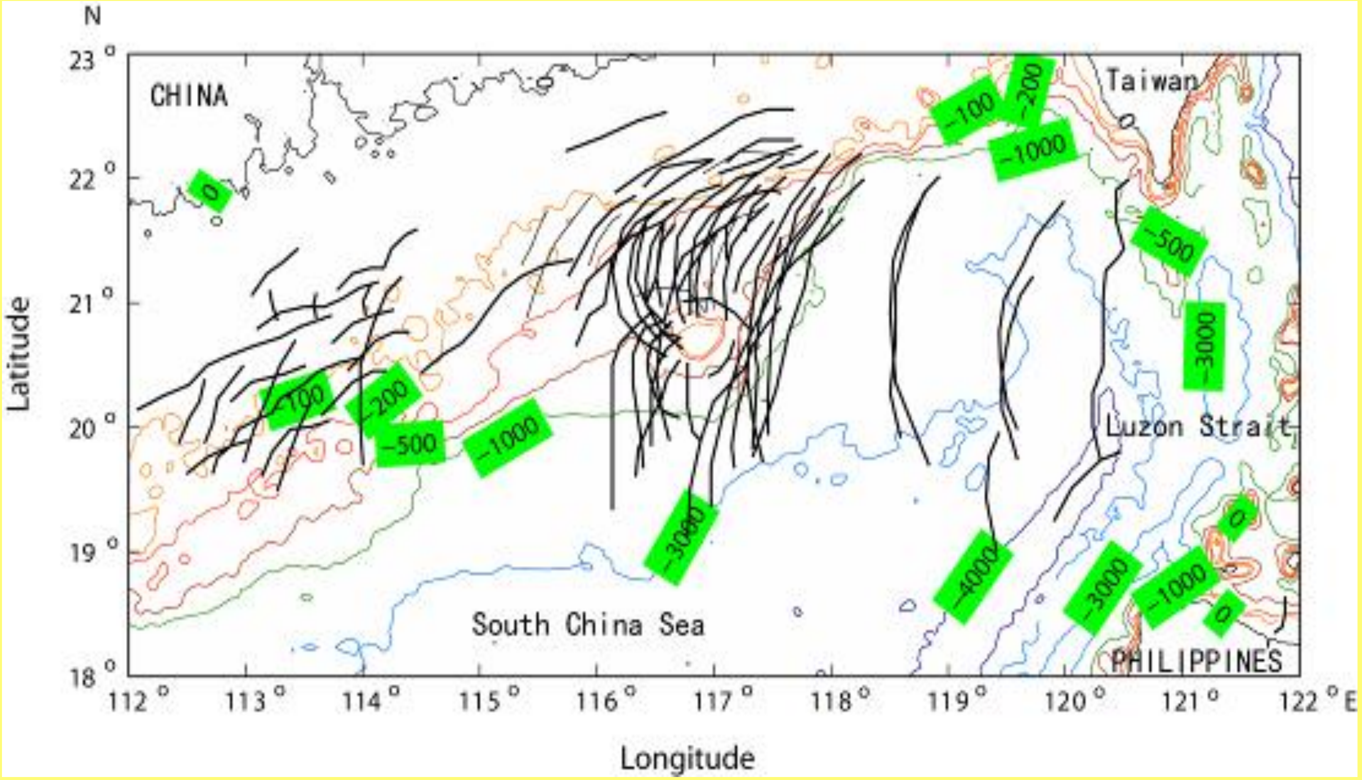
Internal waves from China Sea 3 August 2007





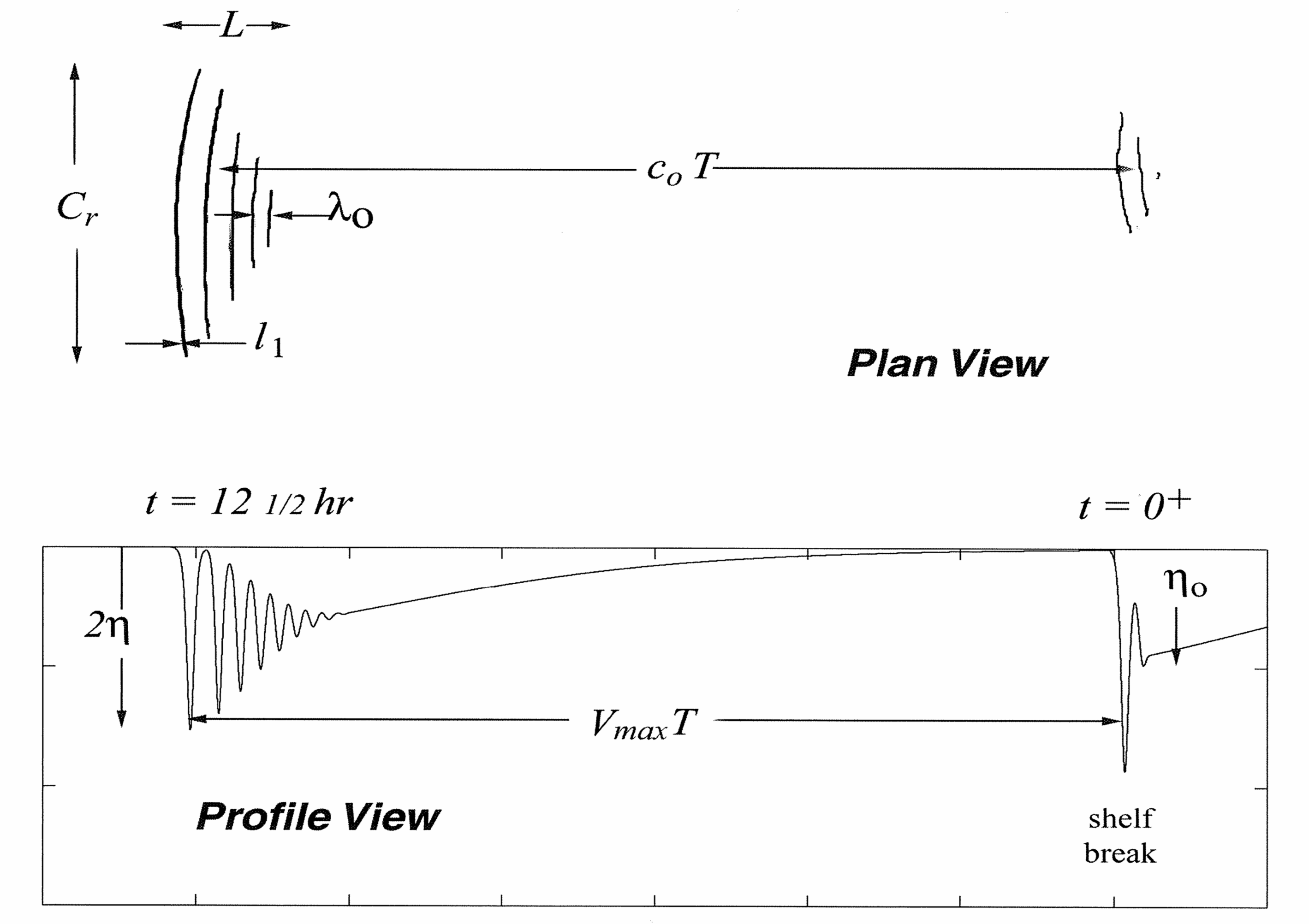
AP mode

Internal waves in the South China Sea from SAR images



After Xilin Gan

Schematic showing tidally generated solitons on shelf break



Characteristic summary of IW

Characteristic	Symbol	Scale
Packet Length	L (km)	1 – 10
Amplitude Factor	$2\eta_0$ (m)	-15
Upper Layer Depth	h_1 (m)	20 – 35
Lower Layer Depth	h_2 (m)	30 - 200
Long Wave Speed	c_0 (m s^{-1})	0.5 - 1.0
Maximum Wavelength	λ_{MAX} (m)	100 – 1000
Crest Length	C_r (km)	0 - 30
Internal Tidal Wavelength	$D = VT$ (km)	15 – 40
Characteristic Soliton Width	l_1 (m)	100

SAR CONTRIBUTION TO OCEAN RESEARCH & APPLICATION

Operational Services and NWP	Operational Surveillance	Emerging new applications	Research and Development
Ocean wave spectra Swell propagation and tracking	Sea Ice Oil Spill Ship Detection Shallow Water Bathymetry	**High resolution coastal wind field** **Hurricane Wind Speed Intensities**	Surface Current fronts and eddies Range Doppler Velocities Internal Waves ABL Processes Surfactants

SUMMARY

Wave spectra and swell propagation retrievals are robust without first guess input, but shorter waves and freak wave detection not generally possible. In use at NWPs and ECMWF

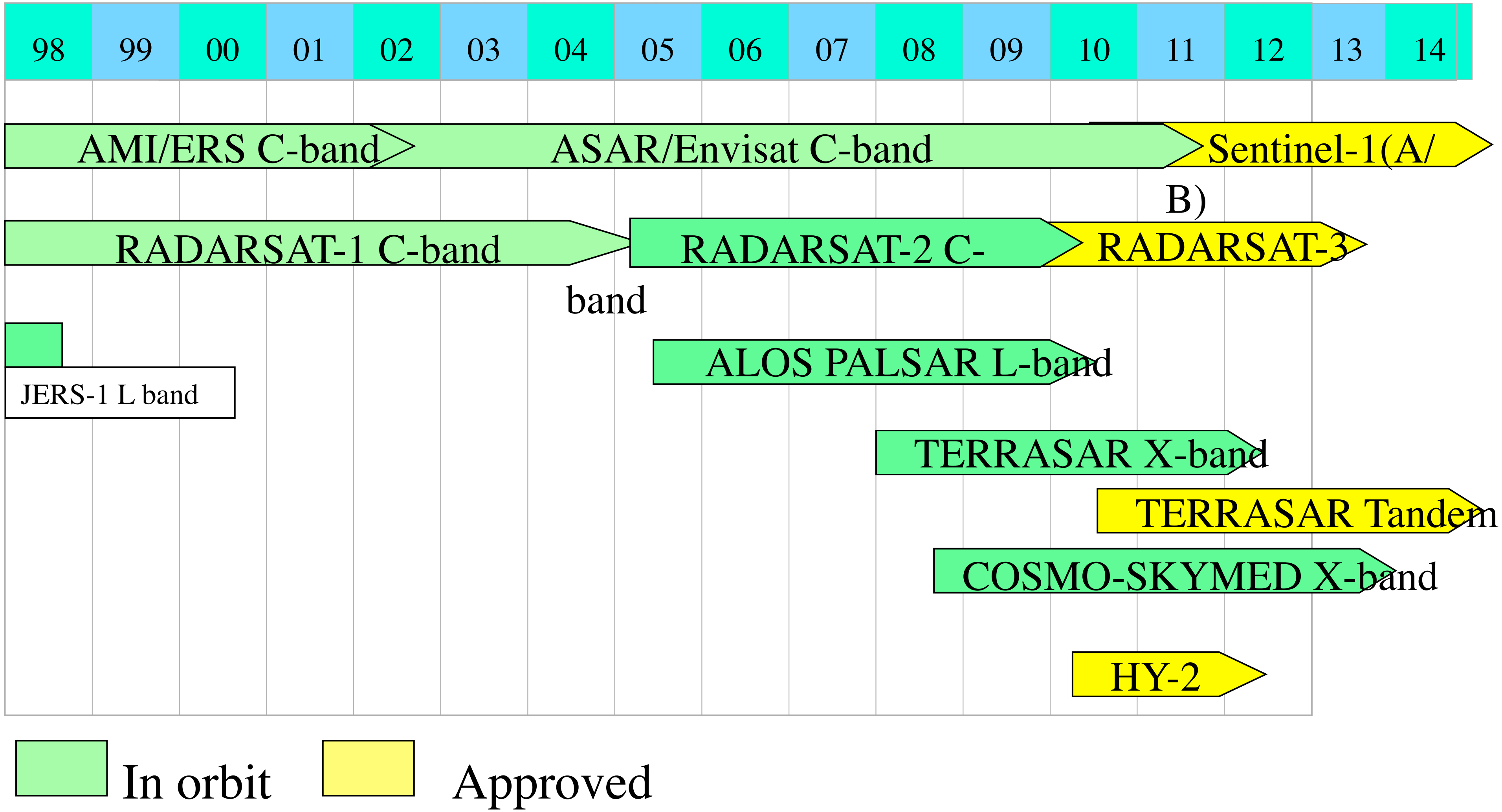
Oil spill and ship detection turned into operational services. But oil spill detection is based on statistical approach.

High resolution wind fields are retrieved, but repeat coverage too Infrequent to go into full operational NWP use

Surface current retrievals now emerging from range Doppler shift method and ATI

Consistent wind, wave and surface current retrievals not yet mature

Pure physical based scattering model still to be developed



TIMELINE OF SAR SATELLITES