

SAR Marine Applications

Wind and Waves

Martin Gade

Uni Hamburg, Institut für Meereskunde
martin.gade@uni-hamburg.de



Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

FAKULTÄT

FÜR MATHEMATIK, INFORMATIK
UND NATURWISSENSCHAFTEN

SAR Marine Applications

Friday, 9 Sep, Morning:

1 - History & Basics

Introduction

Radar/SAR History

Basics

Scatterometer

2 - Wind and Waves

SAR Wind Fields

Storms, Tropical Cyclones

Ocean Surface Waves

Oceanic Internal Waves

Marine Surface Films

Rain

Friday, 9 Sep, Afternoon:

3 - Currents and Objects

Surface Currents

Sea Bottom Topography

Ship Detection

Oil Pollution Monitoring

Sea Ice

4 - Practicals

SNAP Toolbox:

Georeferencing, Mosaics,

Image Interpretation

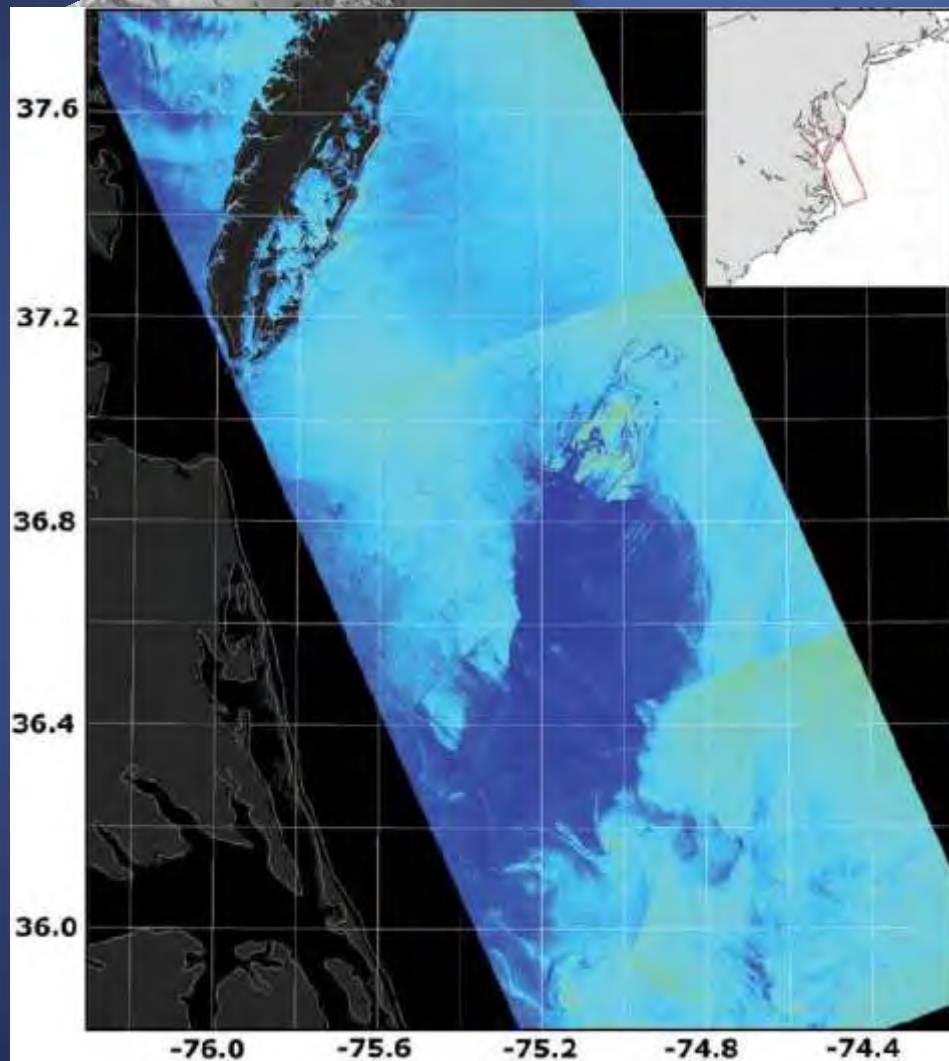
Wind Fields, Oil Pollution,

Sea Ice, Objects

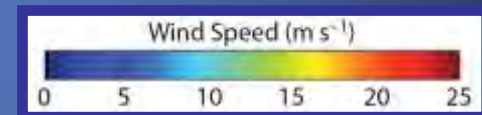


SAR Wind Fields

SAR Wind Fields



Ocean winds



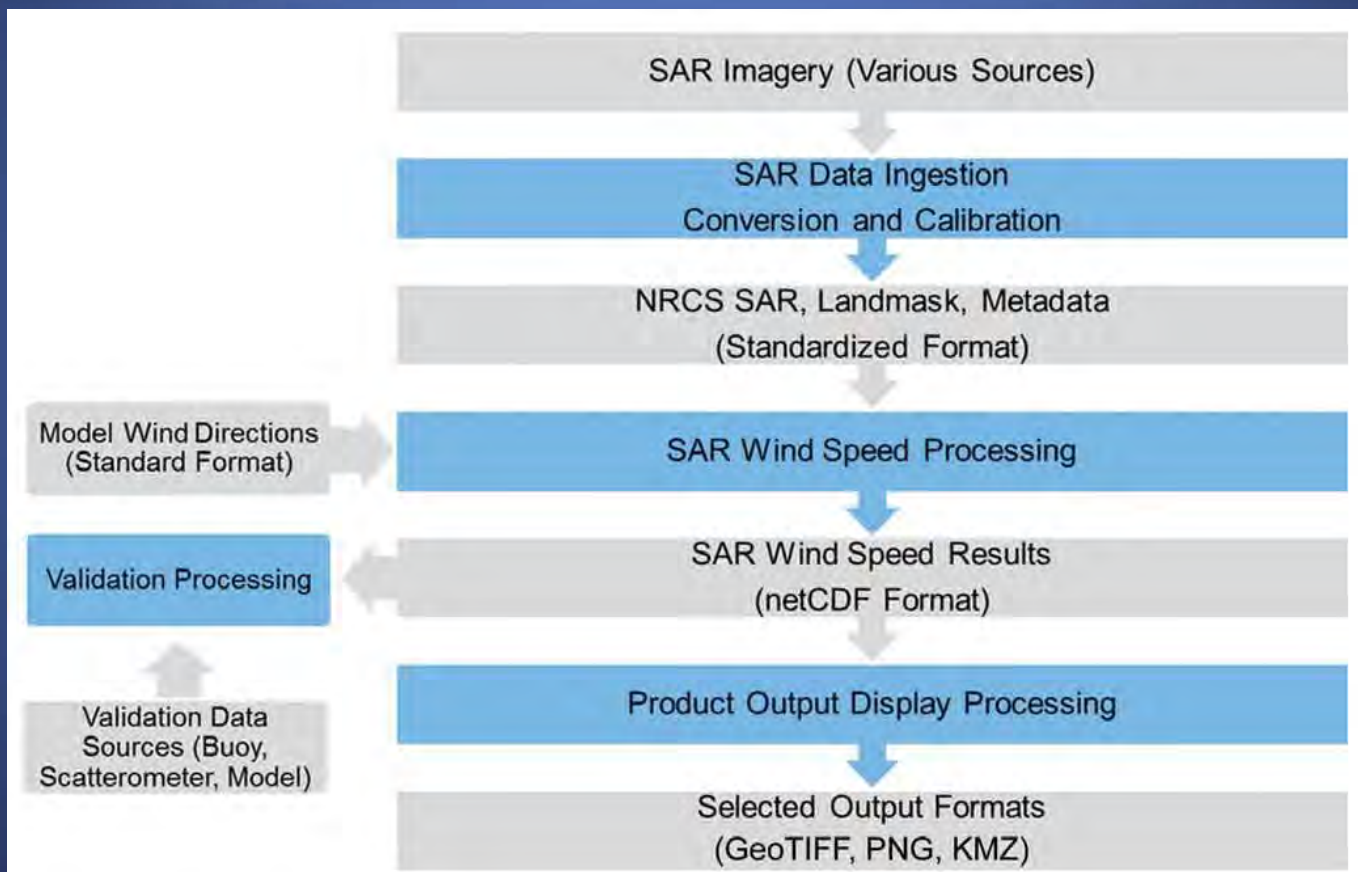
Data basis:

Seasat SAR Image (L-HH)
U.S. East Coast
(28 September 1978, 15:20 UTC)
© NASA

[Monaldo et al., 2013]

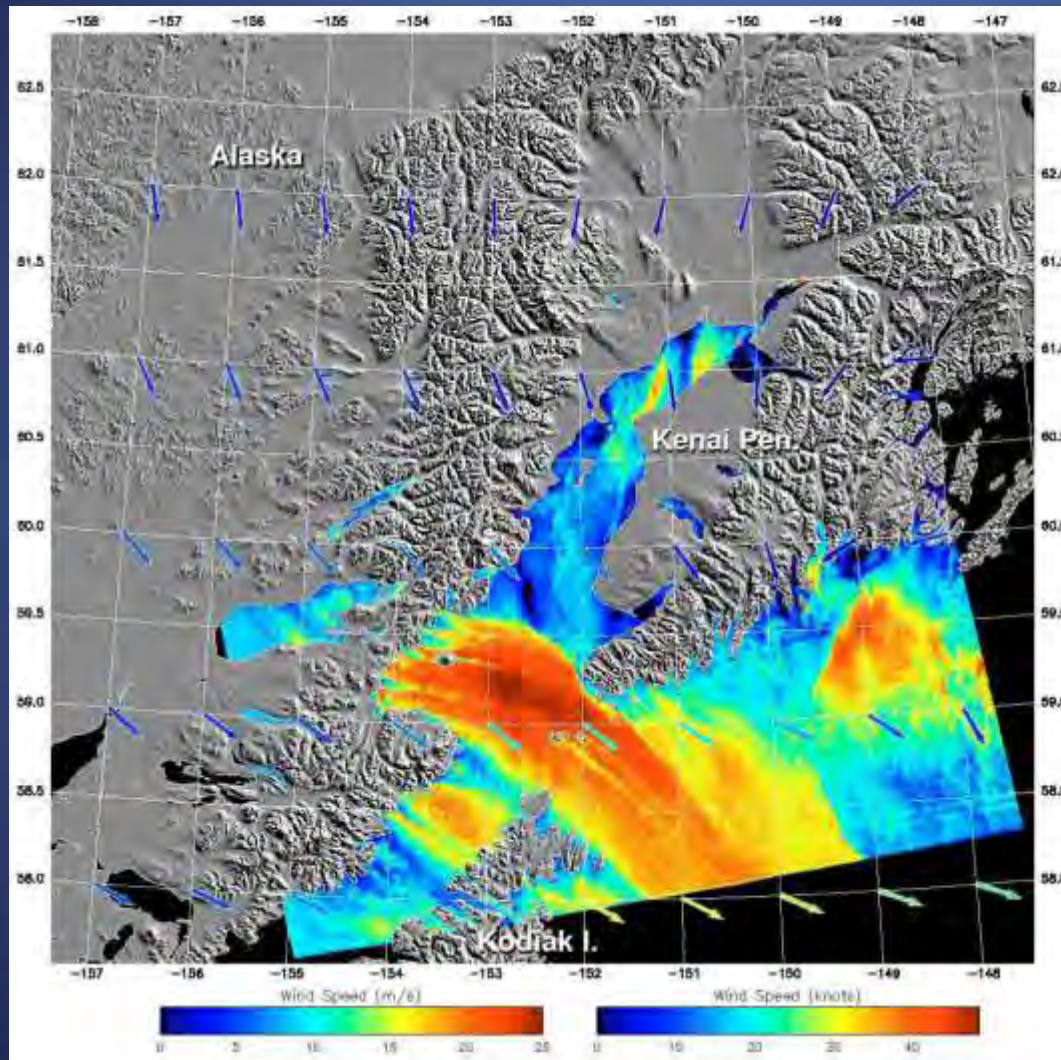
SAR Wind Fields

Processing flow (NOAA)



[Monaldo et al., 2013]

SAR Wind Fields



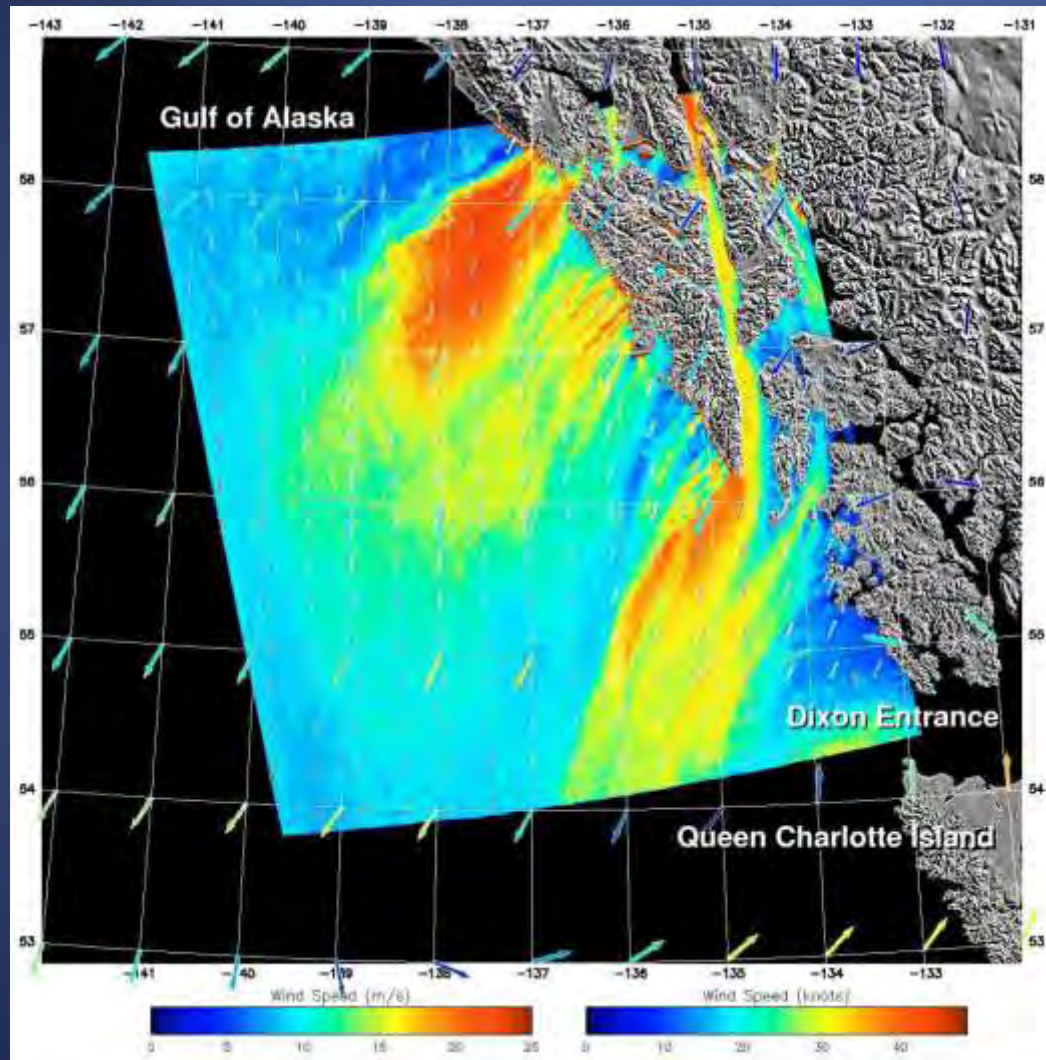
Ocean winds

Data basis:

Radarsat-1 SAR Image (C-HH)
Kodiak Island
(31 October 2000, 03:44 UTC)
  CSA

[Jackson & Apel, 2004]

SAR Wind Fields



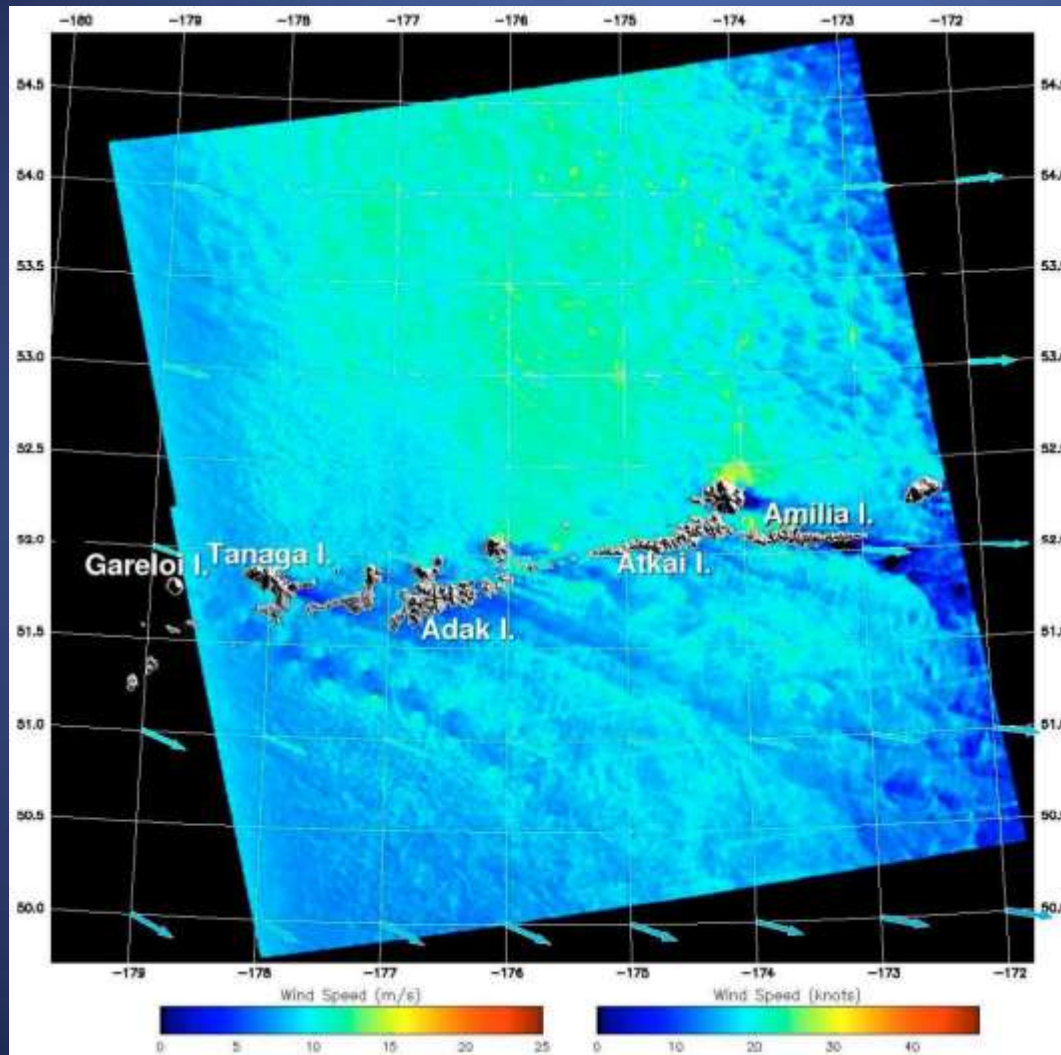
Ocean winds

Data basis:

Radarsat-1 SAR Image (C-HH)
Gulf of Alaska
(19 March 2001, 02:48 UTC)
© CSA

[Jackson & Apel, 2004]

SAR Wind Fields



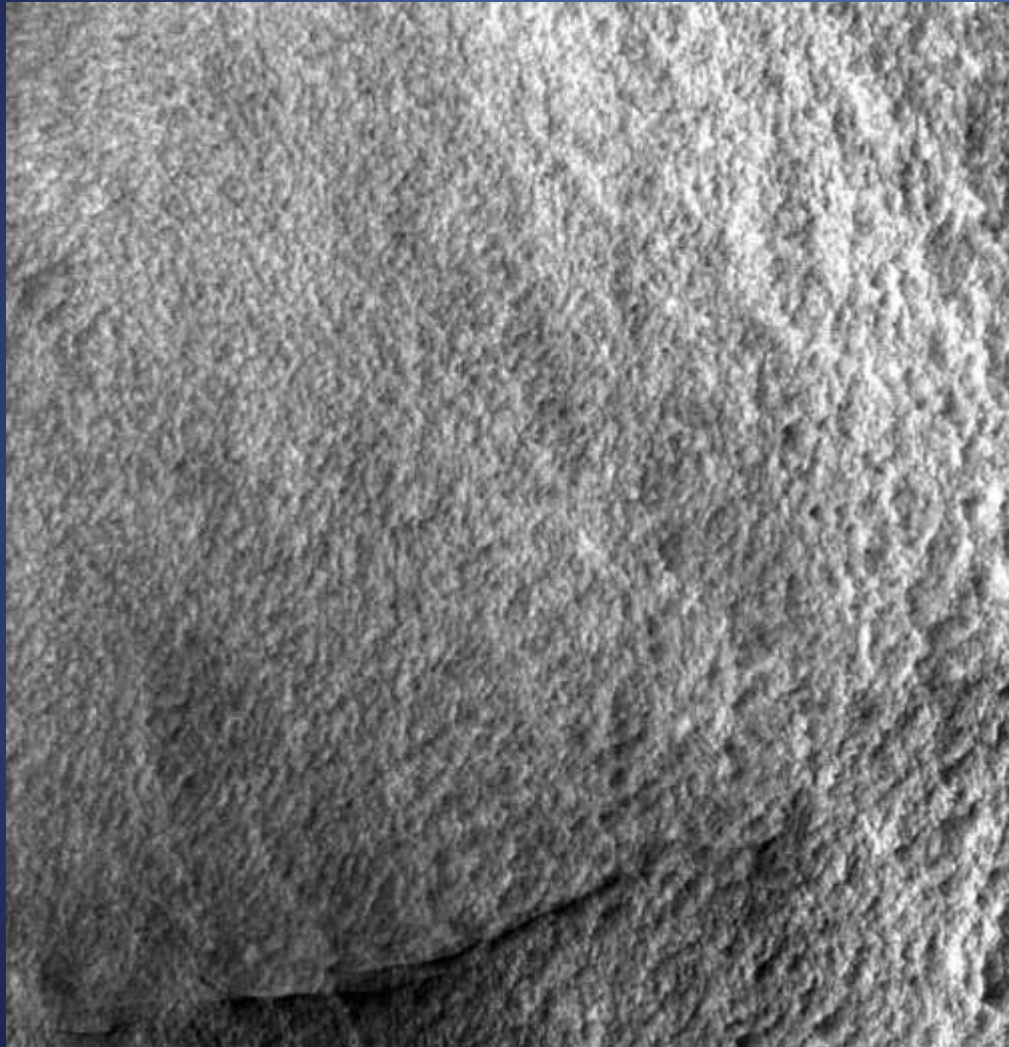
Ocean winds

Data basis:

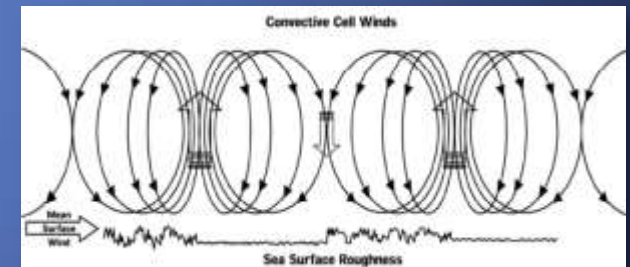
Radarsat-1 SAR Image (C-HH)
Aleutian Islands
(04 May 2001, 05:26 UTC)
  CSA

[Jackson & Apel, 2004]

SAR Wind Fields



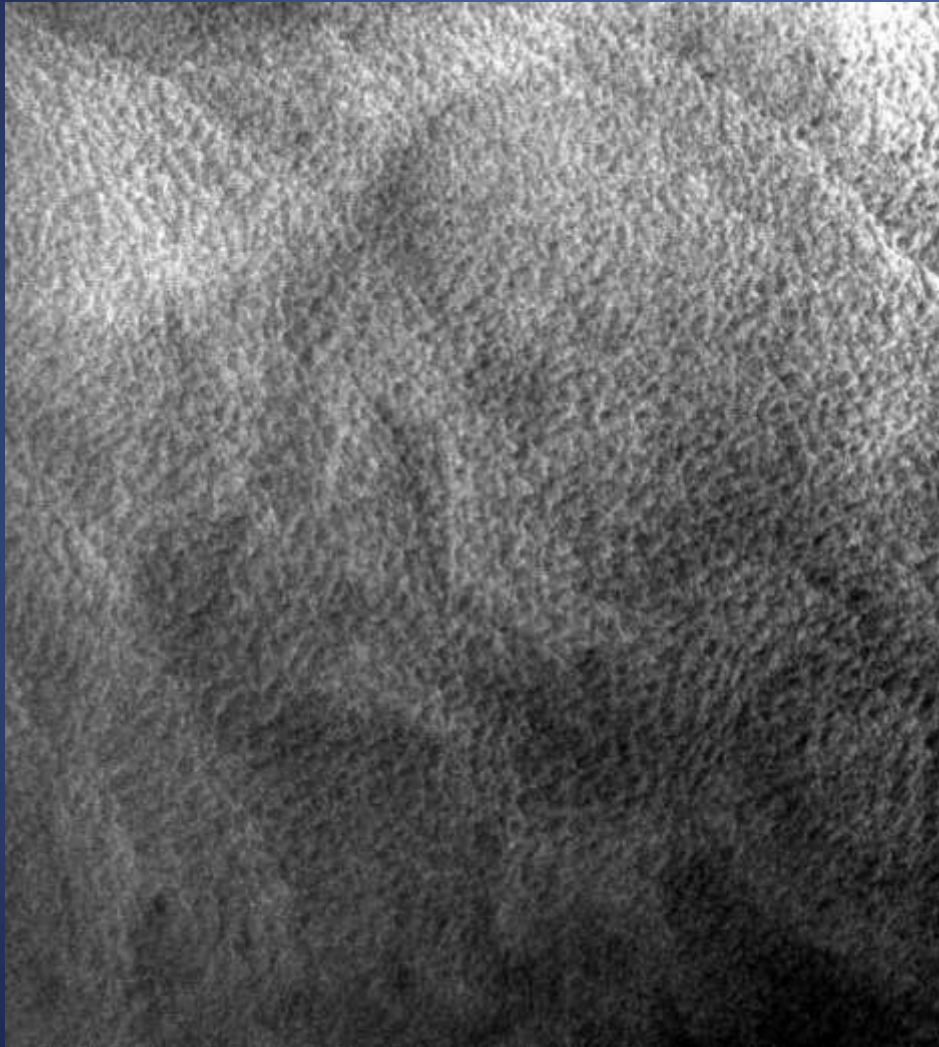
Atmospheric
convective cells



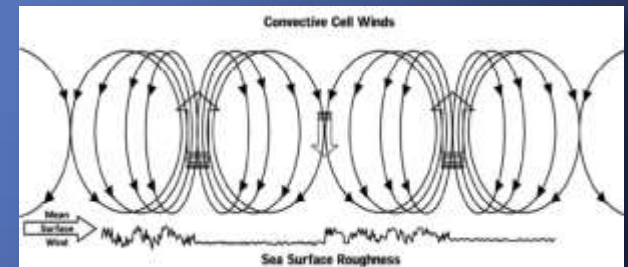
[Jackson & Apel, 2004]

Radarsat-1 SAR Image (C-HH,
300 km × 300 km) U.S. East Coast
(17 January 1997, 22:42 UTC, © CSA)

SAR Wind Fields



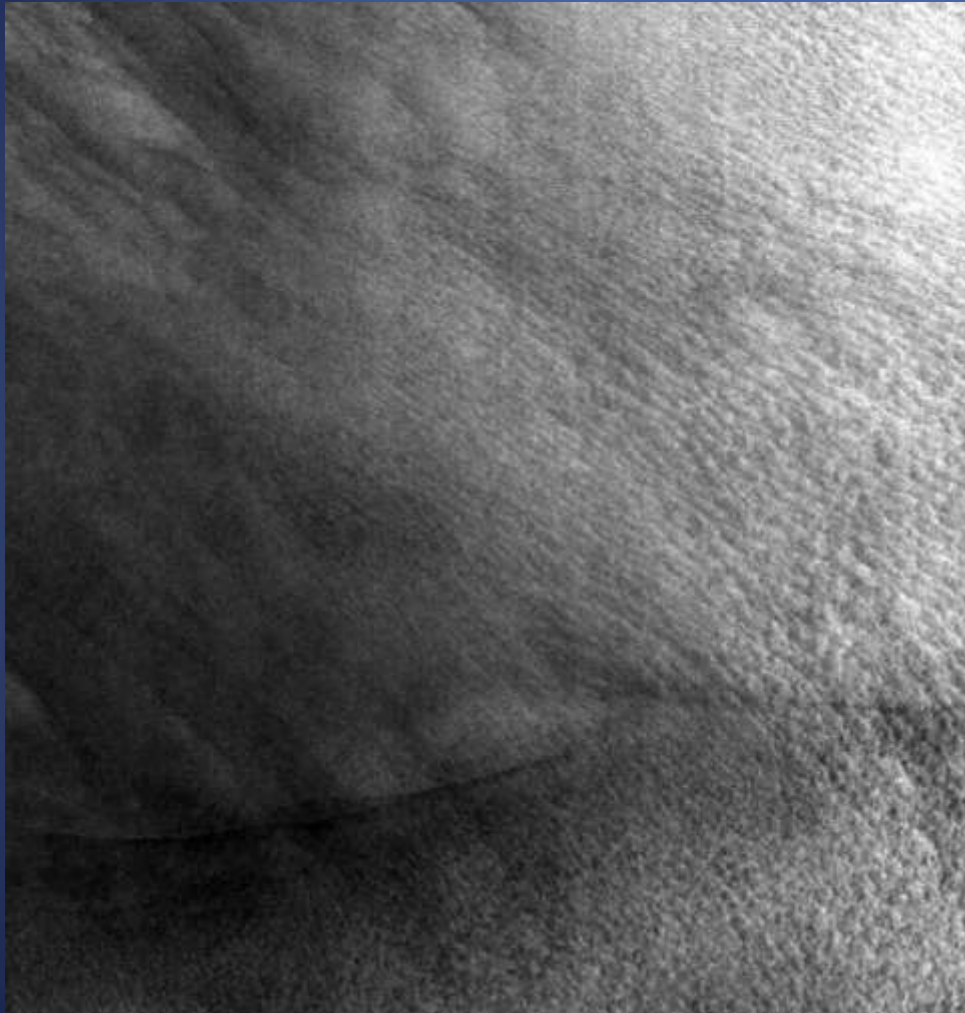
Atmospheric
convective cells



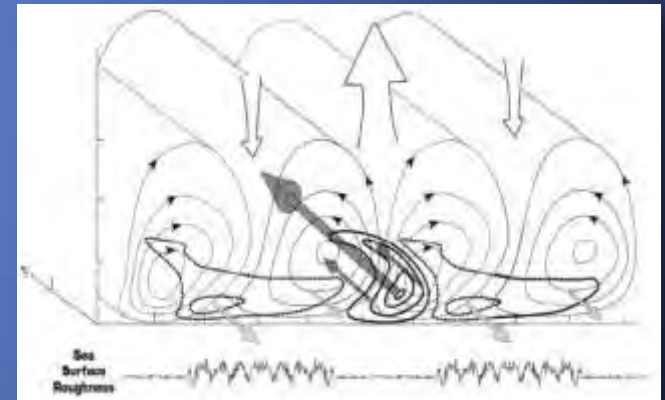
[Jackson & Apel, 2004]

Radarsat-1 SAR Image (C-HH,
300 km × 300 km) U.S. East Coast
(6 March 1997, 22:42 UTC, © CSA)

SAR Wind Fields



Atmospheric roll vortices

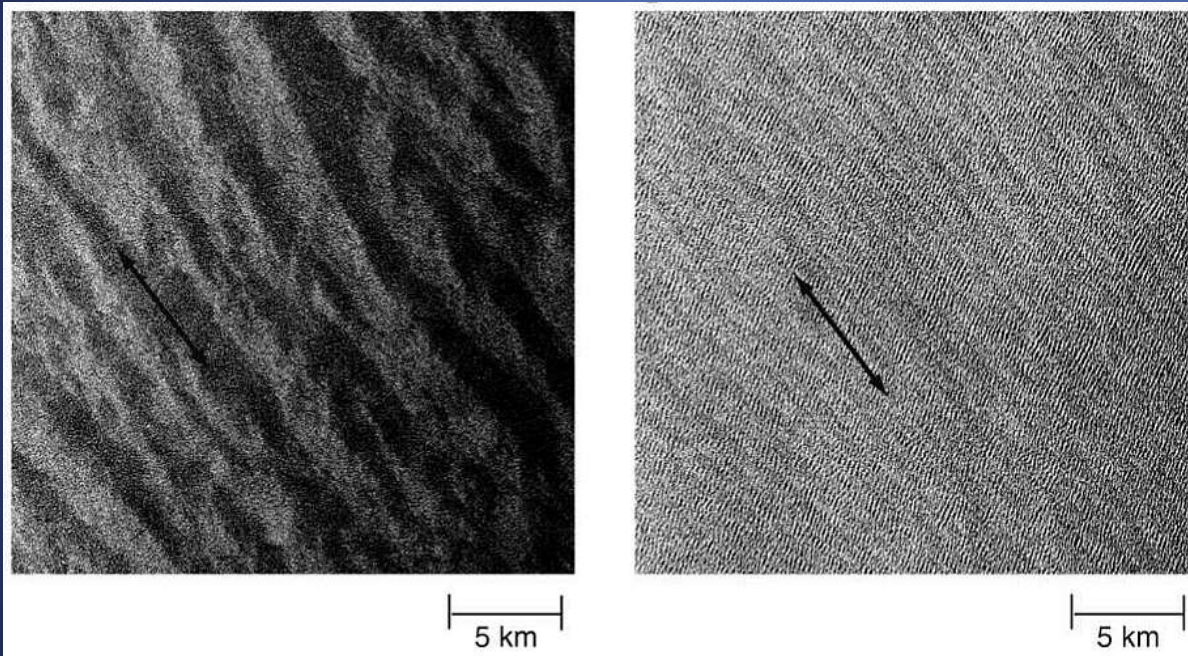


[Jackson & Apel, 2004]

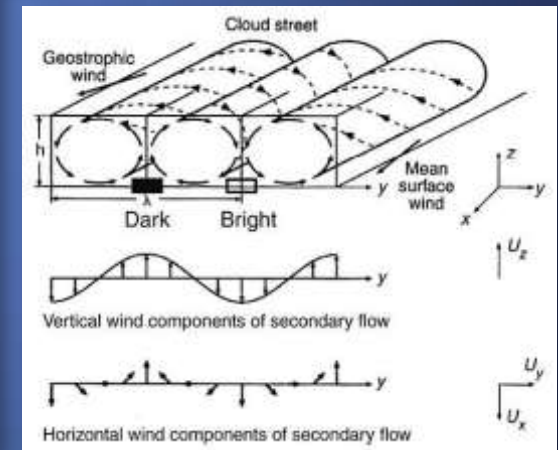
Radarsat-1 SAR Image (C-HH,
300 km × 300 km) U.S. East Coast
(6 March 1997, 22:42 UTC, © CSA)

SAR Wind Fields

Atmospheric roll vortices



Radarsat-1 Images (C-HH, 25 km × 25 km)
off Southern California
(left: 12 June 1999, right: 2 December 1998,   CSA)

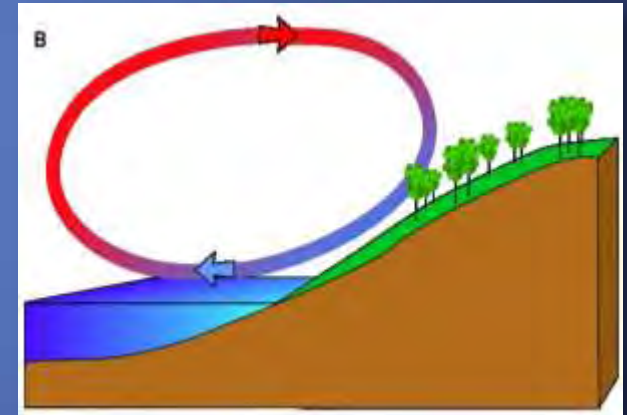


[Jackson & Apel, 2004]

SAR Wind Fields



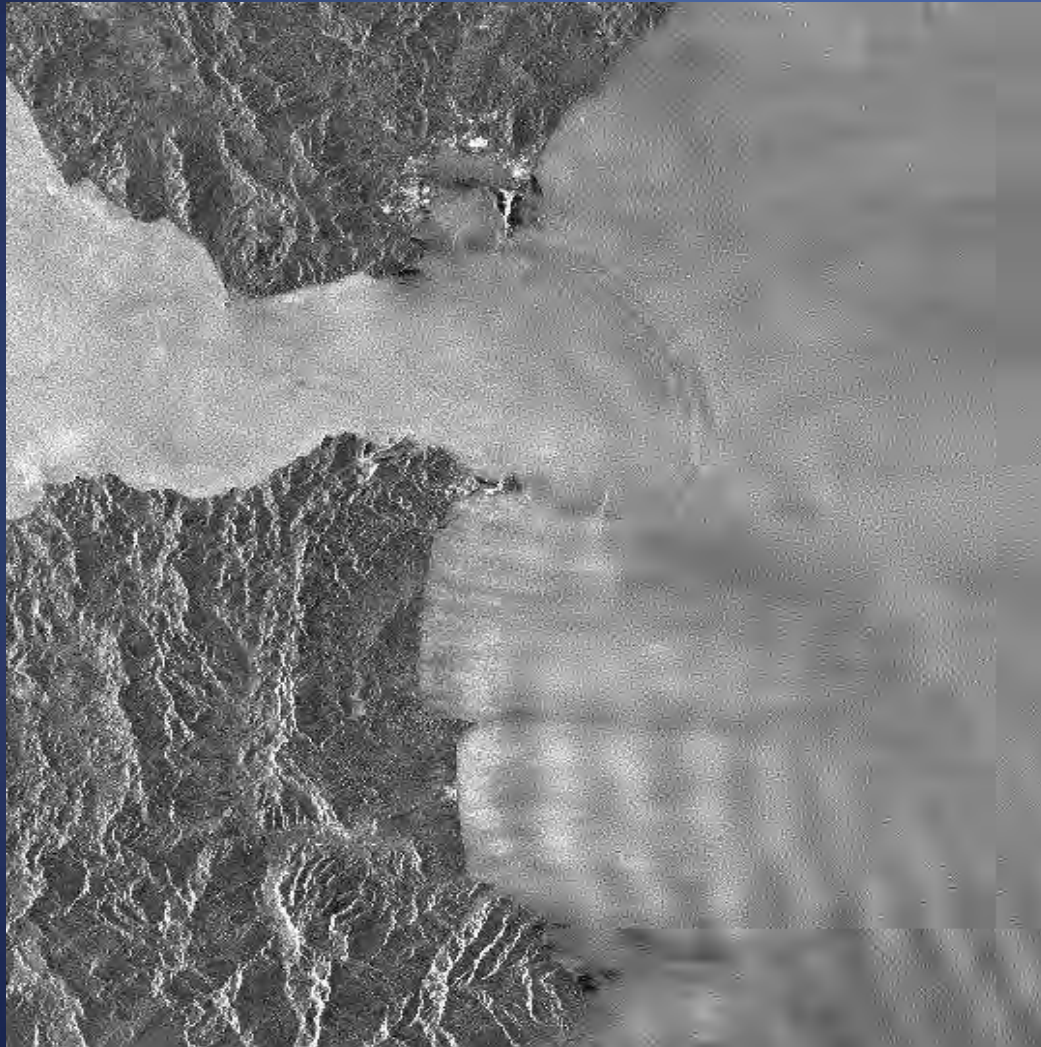
Katabatic winds &
Atmospheric convective
cells



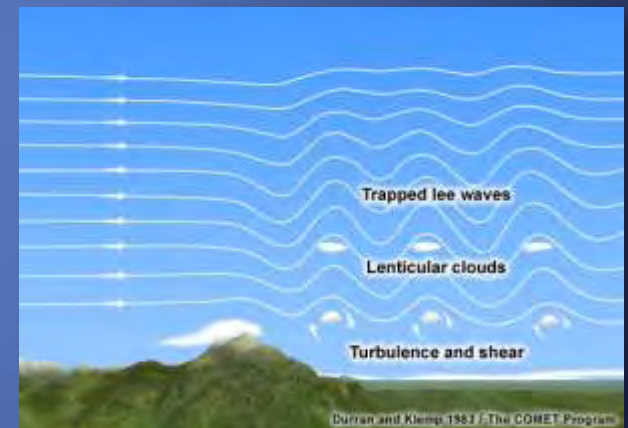
[Wikipedia, 6/2013]

ERS SAR Image (C-VV, 100 km × 100 km)
Strait of Messina
(8 September 1992, 21:13 UTC, © ESA)

SAR Wind Fields

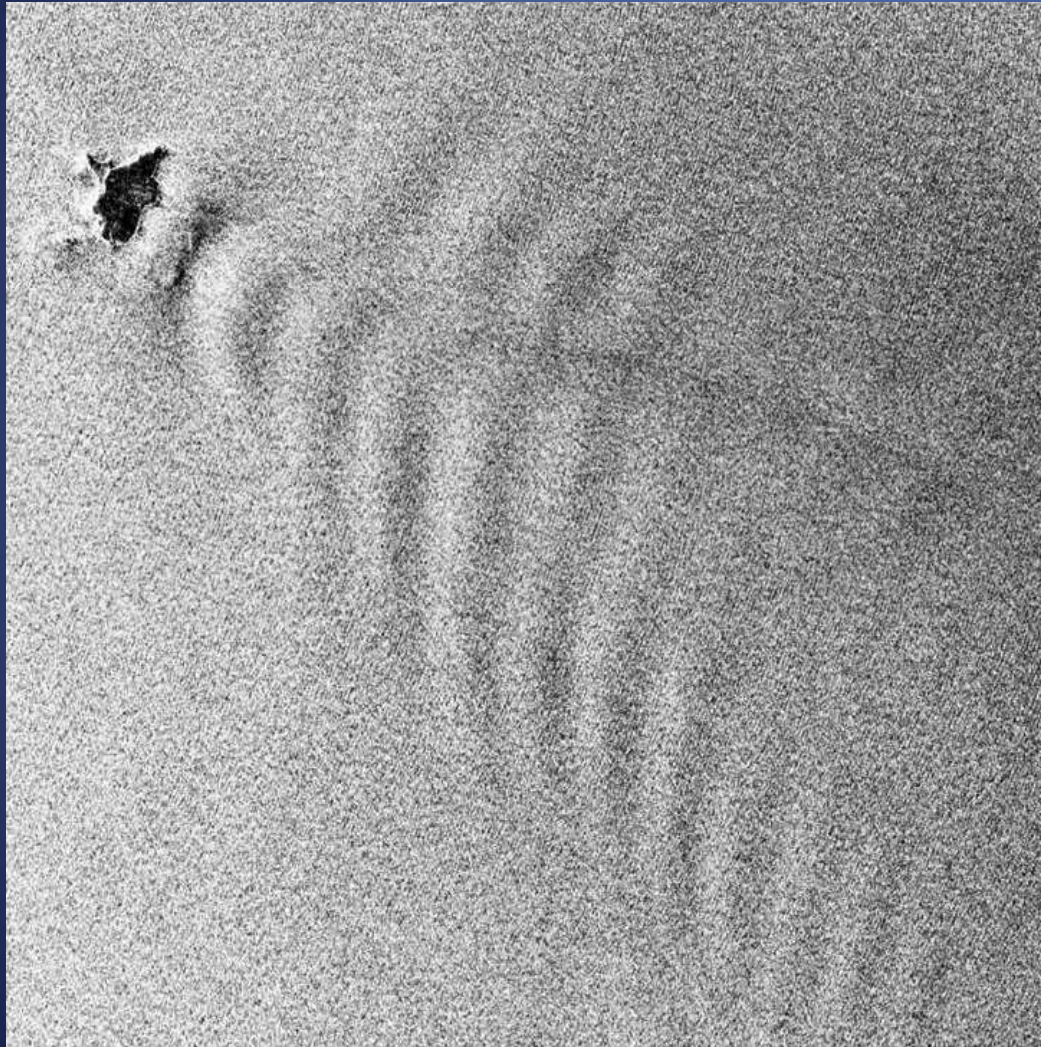


Internal waves
&
Atmospheric gravity
waves

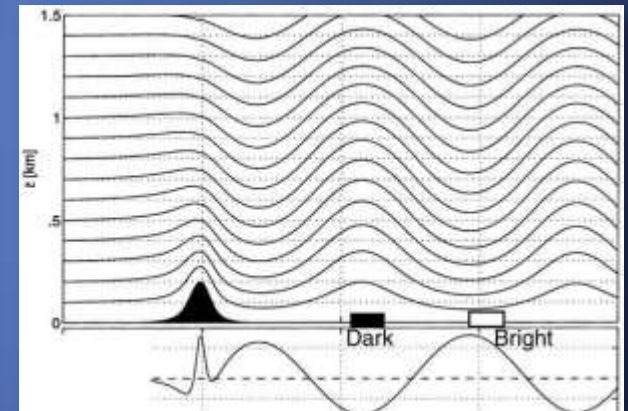


ERS SAR Image (C-VV, 100 km × 100 km)
Strait of Gibraltar
(3 September 1993, 22:39 UTC, © ESA)

SAR Wind Fields



Atmospheric lee waves
(gravity waves)



[Jackson & Apel, 2004]

Radarsat-1 SAR Image (C-HH, 20km × 20km)
Santa Barbara Island
(28 July 1998, © CSA)



SAR Wind Fields Take-Home Messages

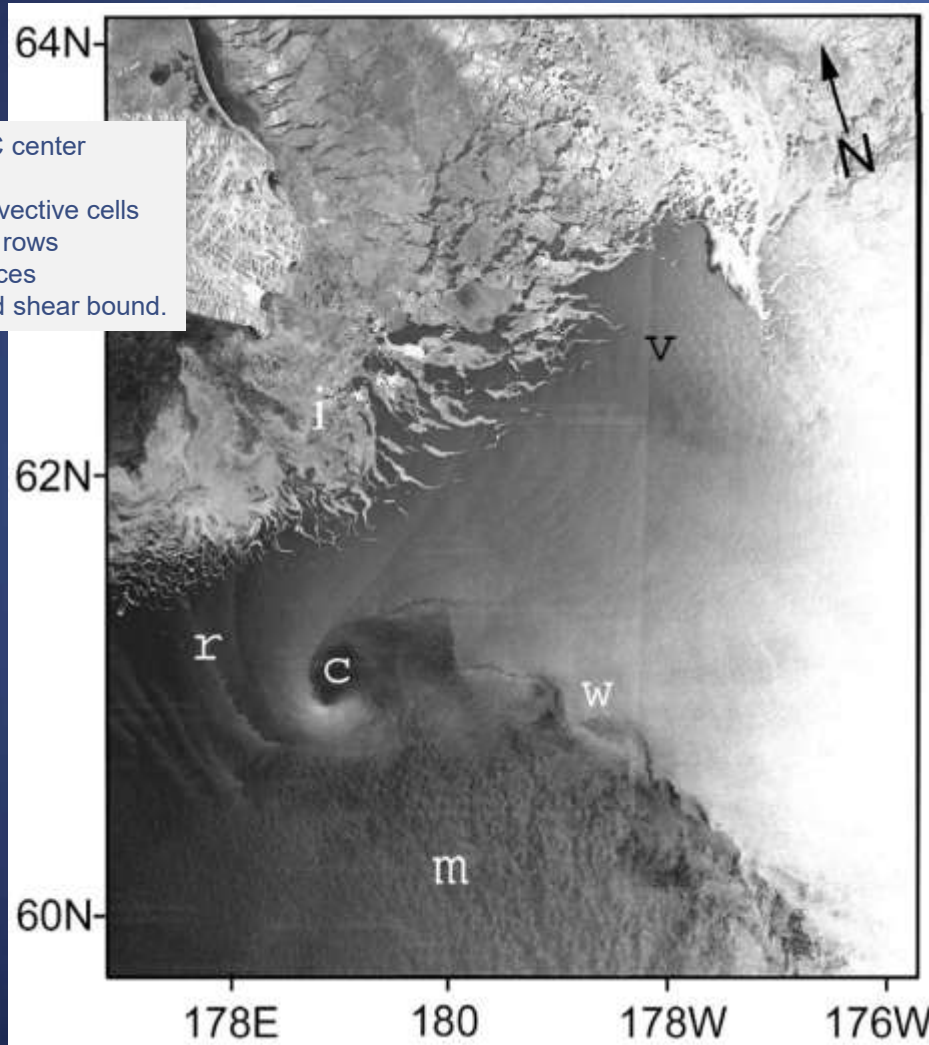
High-resolution wind fields
(Sub-) Mesoscale atmospheric dynamics
Convective cells, roll vortices, lee waves



Storms, Tropical Cyclones

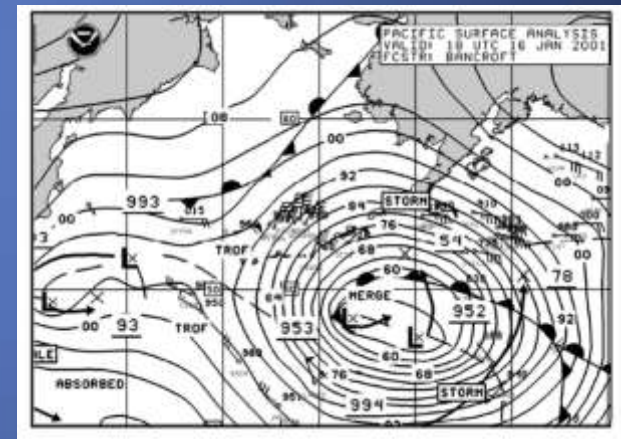
Storms & Tropical Cyclones

c: PMC center
i: ice
m: convective cells
r: wind rows
v: vortices
w: wind shear bound.



Polar mesoscale cyclone

Pacific Surface Analysis
16 Jan 2001 1800 UTC
(NOAA National Weather Service)



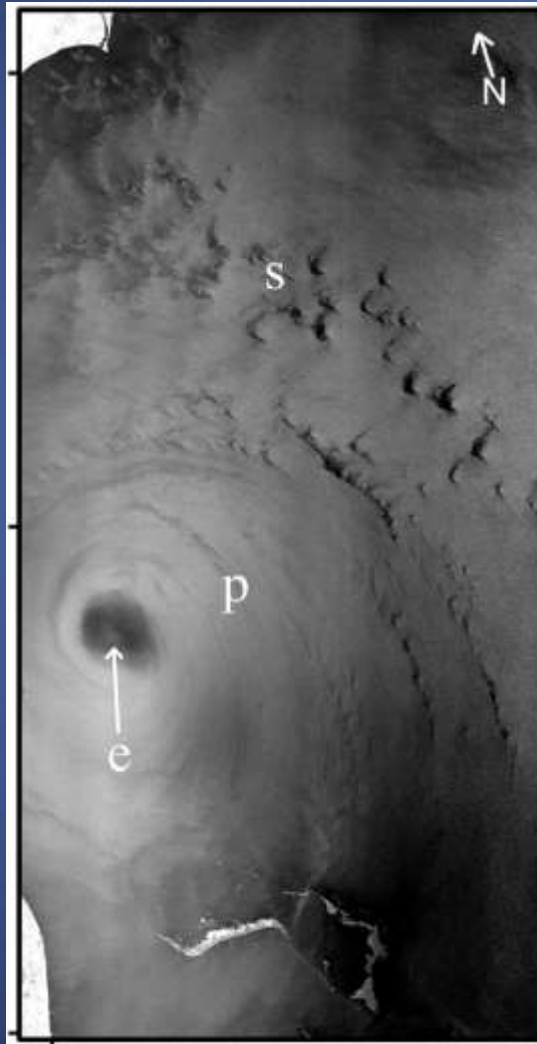
[Jackson & Apel, 2004]

Radarsat-1 ScanSAR Image (C-HH,
500 km x 600 km) - Bering Sea
(16 January 2001, 18:21 UTC,   CSA)

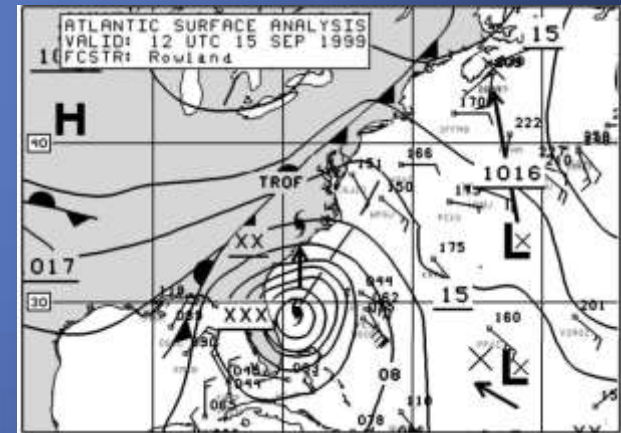
Storms & Tropical Cyclones

Hurricane *Floyd*

e: eye
p: precipitation
s: convective cells



Atlantic Surface Analysis
15 Sep 1999 1200 UTC
(NOAA National Weather Service)

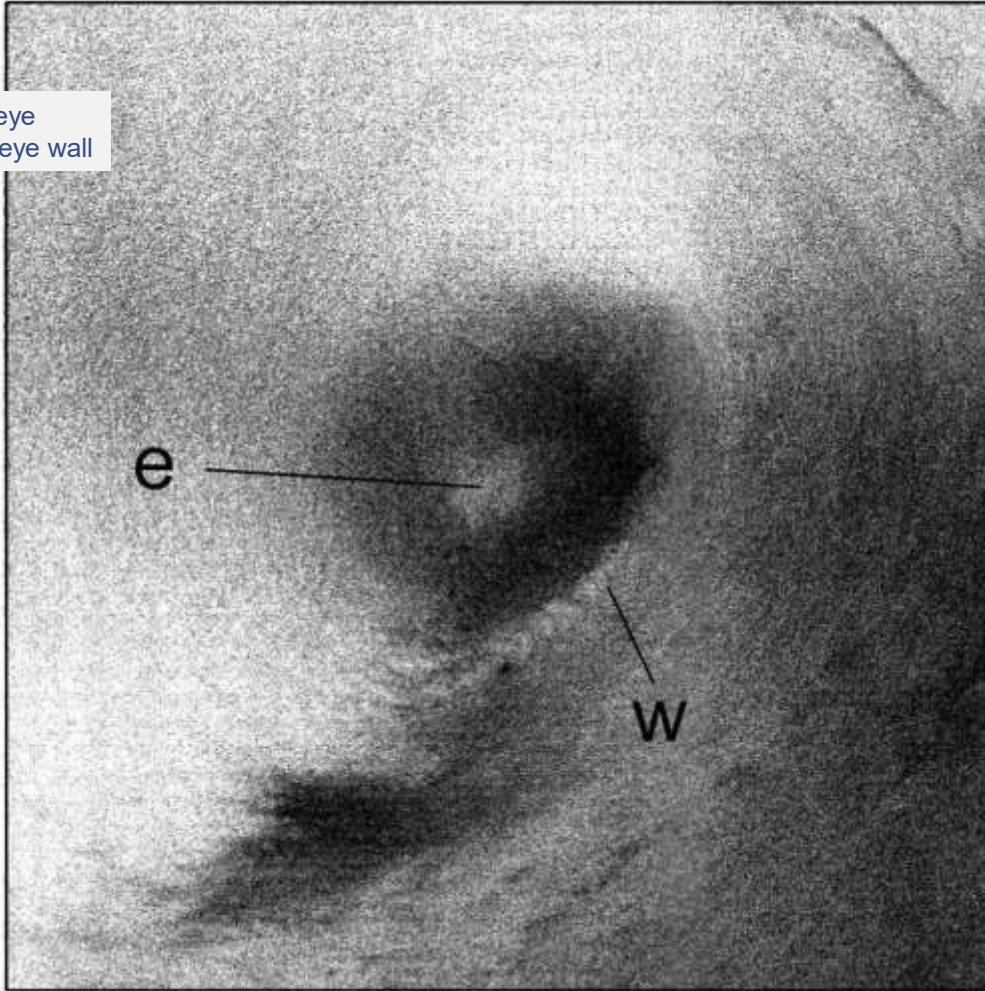


[Jackson & Apel, 2004]

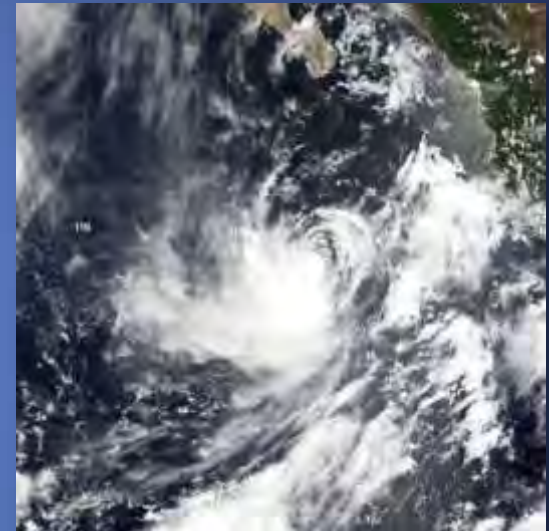
Radarsat-1 ScanSAR Image (C-HH, 500 km × 1000 km)
East of Florida
(15 September 1999, 11:08 UTC, © CSA)

Storms & Tropical Cyclones

e: eye
w: eye wall



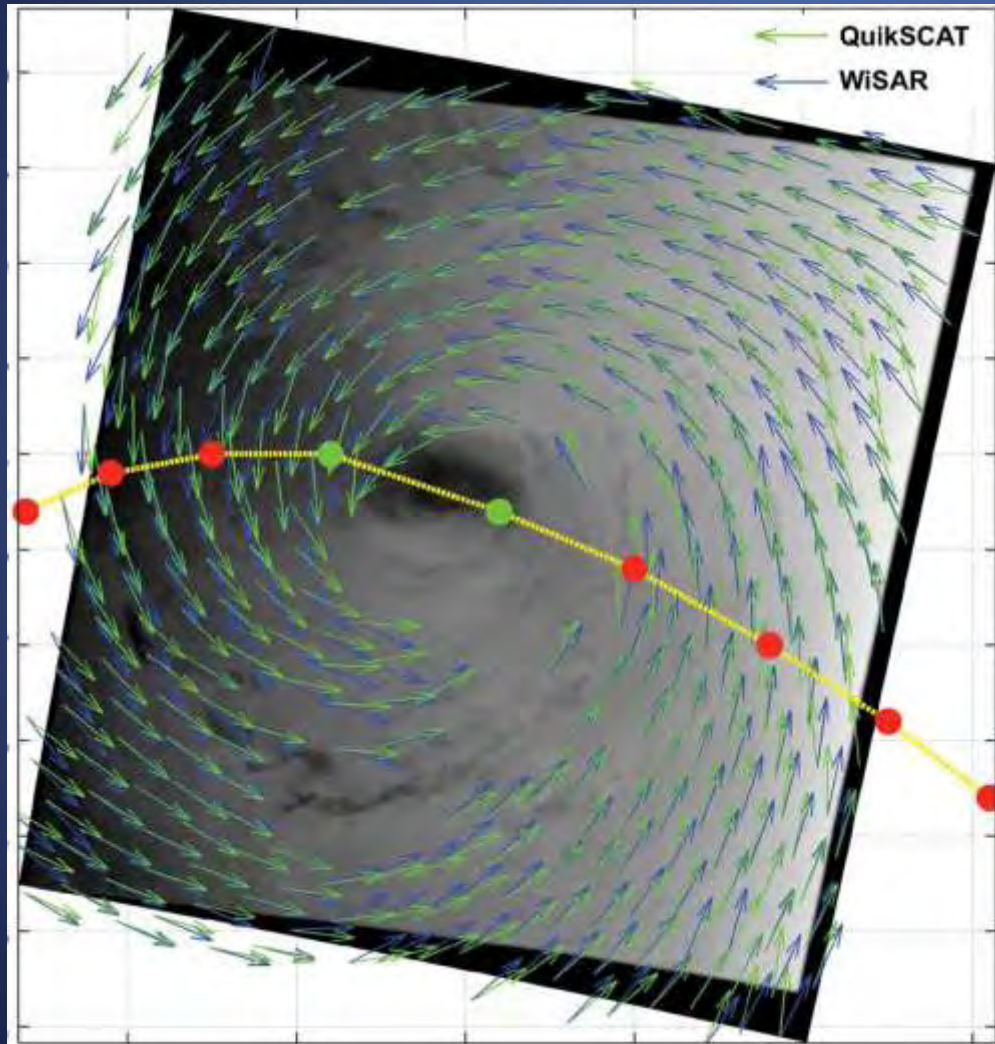
Hurricane *Dalila*



Radarsat-1 ScanSAR Image (C-HH,
100 km × 100 km) - Pacific
(26 July 2001, 01:24 UTC, © CSA)

[Jackson & Apel, 2004]

Storms & Tropical Cyclones



Typhoon *Fitow*

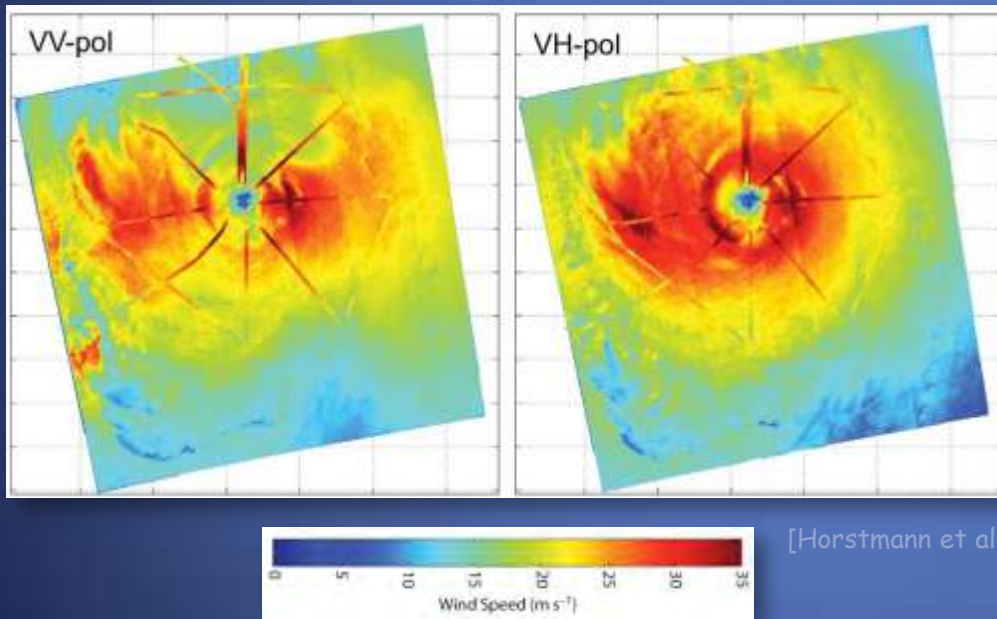


Radarsat-1 ScanSAR Image (C-HH)
Pacific
(31 August 2007, 19:43 UTC,   CSA)

[Horstmann et al., 2013]

Storms & Tropical Cyclones

Hurricane *Earl*



[Horstmann et al., 2013]

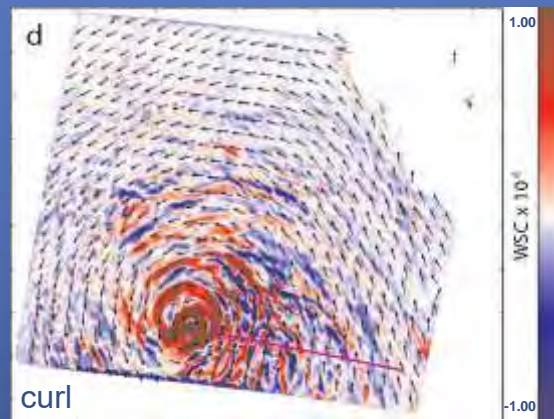
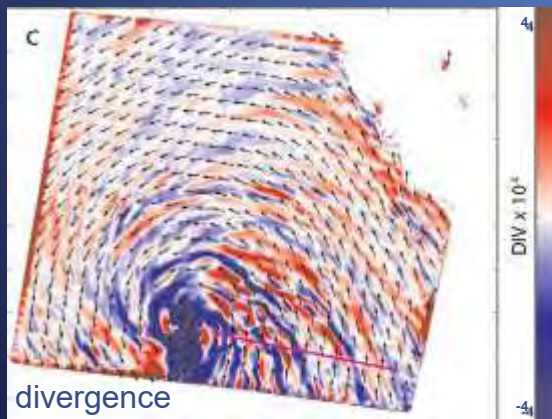
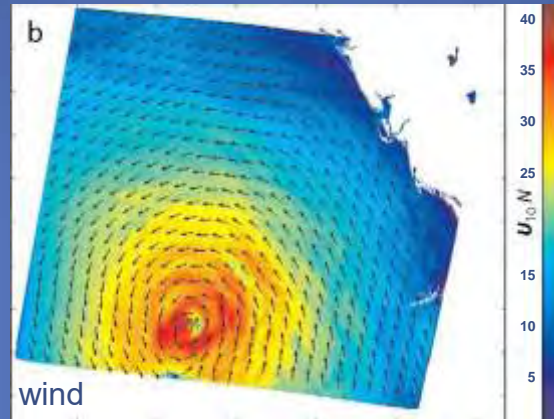
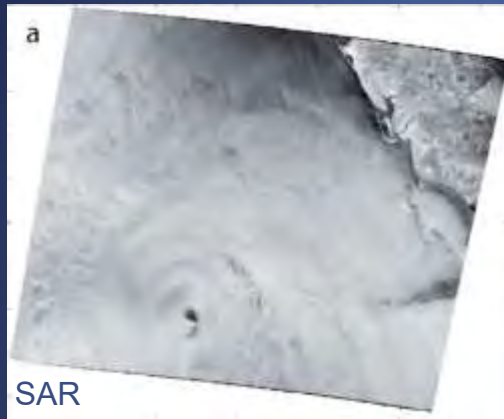


Data basis:
Radarsat-2 ScanSAR Image (C-VV/VH)
Bermuda
(2 September 2010, 22:59 UTC)

Tracks: Stepped Frequency Microwave
Radiometer (SFMR)

Storms & Tropical Cyclones

Hurricane *Katrina*



Radarsat-1 ScanSAR Image (C-HH)
Gulf of Mexico
(27 August 2005, 11:38 UTC,   CSA)

[Foster, 2013]



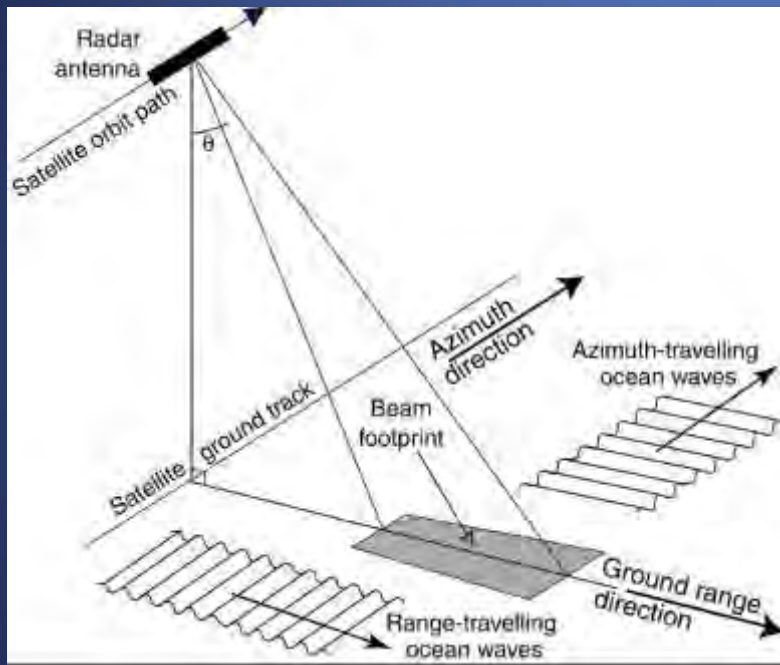
Storms, Tropical Cyclones Take-Home Messages

Detailed studies/observation of spatial
wind distribution in storms/cyclones

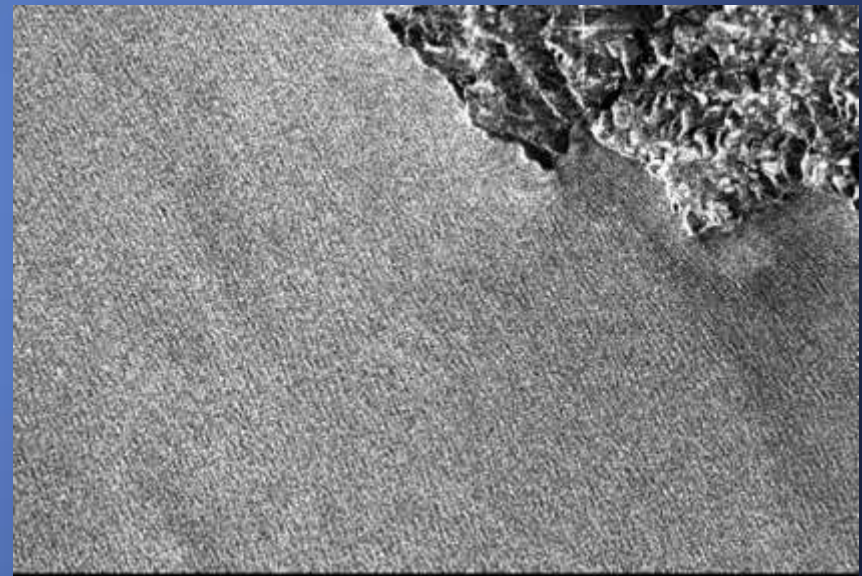


Ocean Surface Waves

SAR Imaging of Ocean Surface Waves



[Robinson, 2010]



Propagation direction of the ocean waves is important!

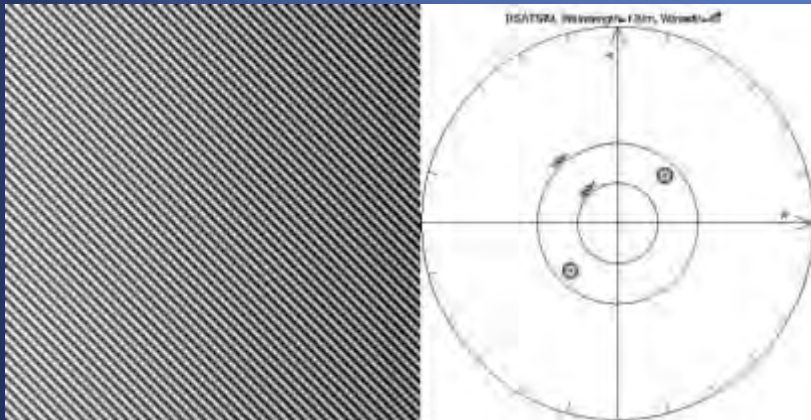
ERS-1 SAR Image (C-VV, 25 km × 17 km)
English Channel

SAR Imaging of Ocean Surface Waves

SAR Image Spectra

$$S_I(\vec{k}) \sim \Psi(\vec{k}) ?$$

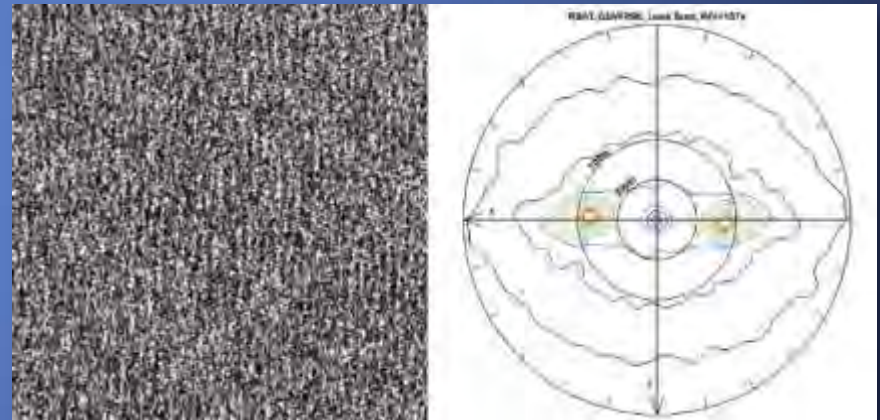
Image spectrum ocean wave spectrum



Simulated Image

Image Spectrum

6.4 km × 6.4 km, sinusoidal waves (120 m, 45°)



Radarsat-1 SAR Image

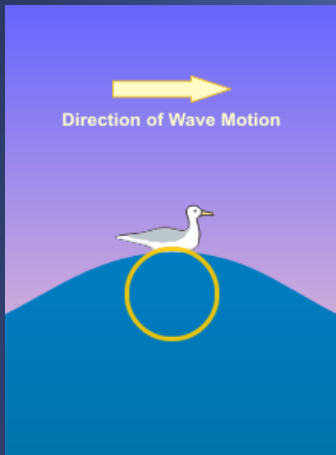
SAR Image Spectrum

6.4 km × 6.4 km, ocean waves (≈ 120 m, 0°)

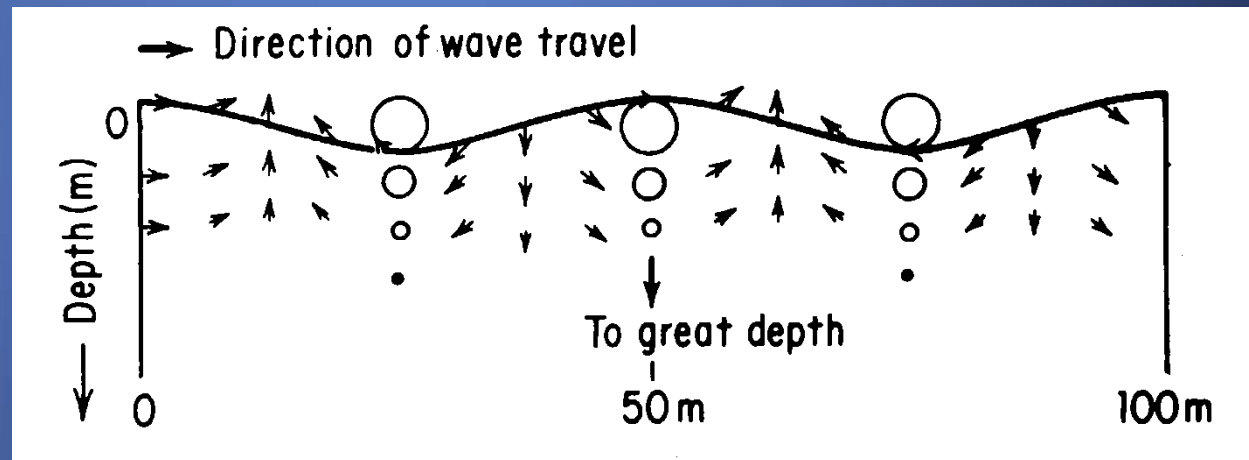
[Jackson & Apel, 2004]

Ocean Waves

Orbital motion of long ocean waves



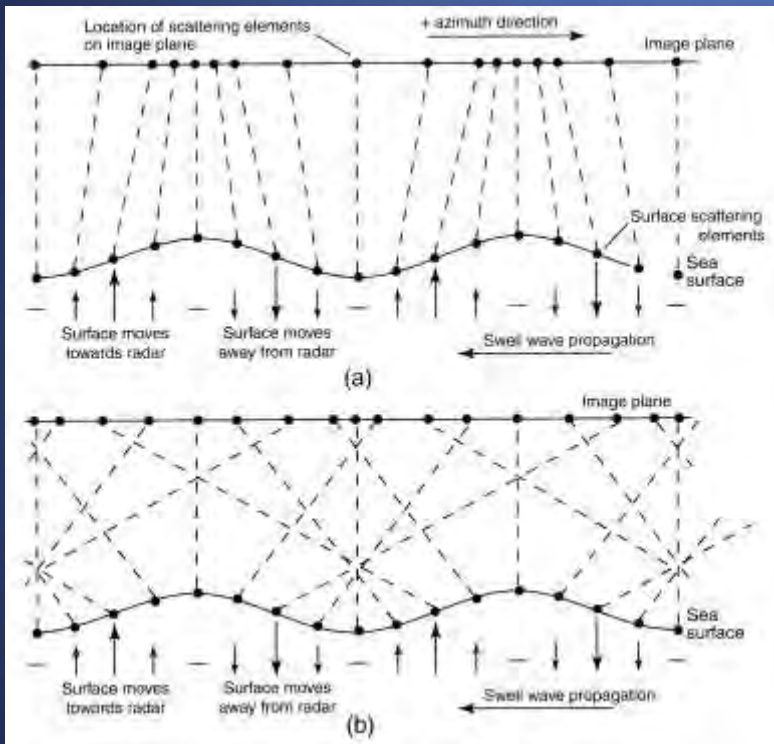
[NOAA]



[Jackson & Apel, 2004]

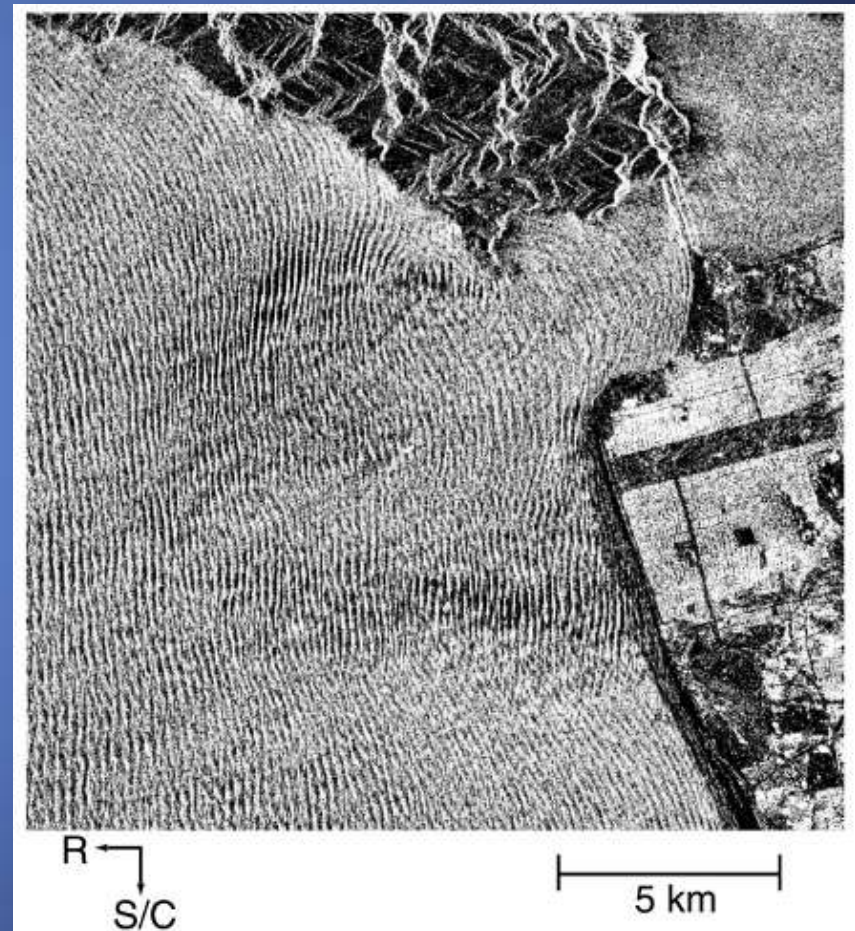
SAR Imaging of Ocean Surface Waves

Velocity bunching



[Robinson, 2003]

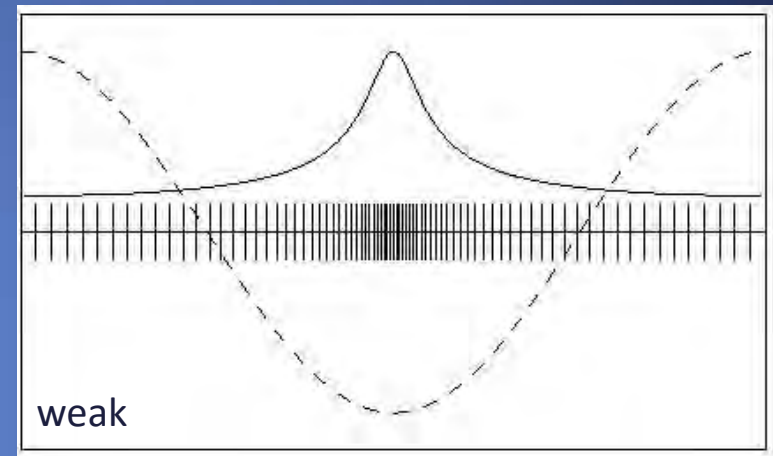
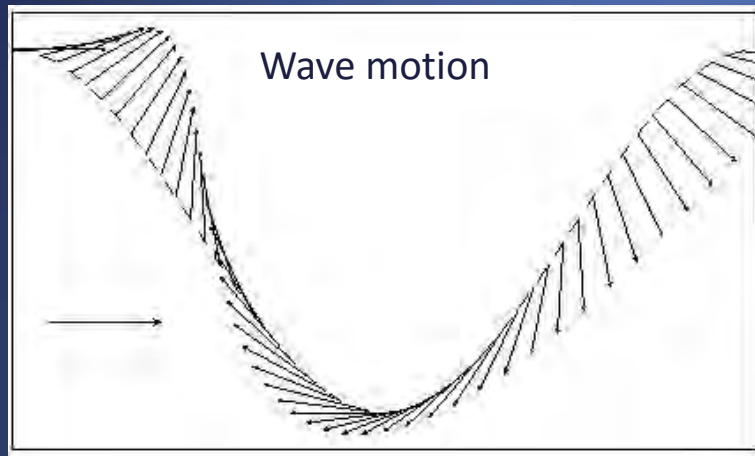
Propagation direction of the ocean waves is important!



[Jackson and Apel, 2004]

SAR Imaging of Ocean Surface Waves

Velocity bunching



Azimuthal cutt-off:

$$\lambda_{min} \cong \frac{R}{V} \sqrt{H_s}$$

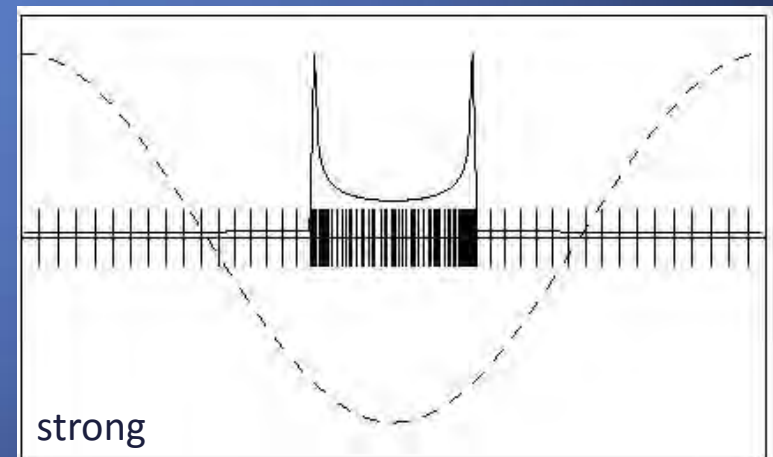
with

R : range (distance)

V : platform velocity

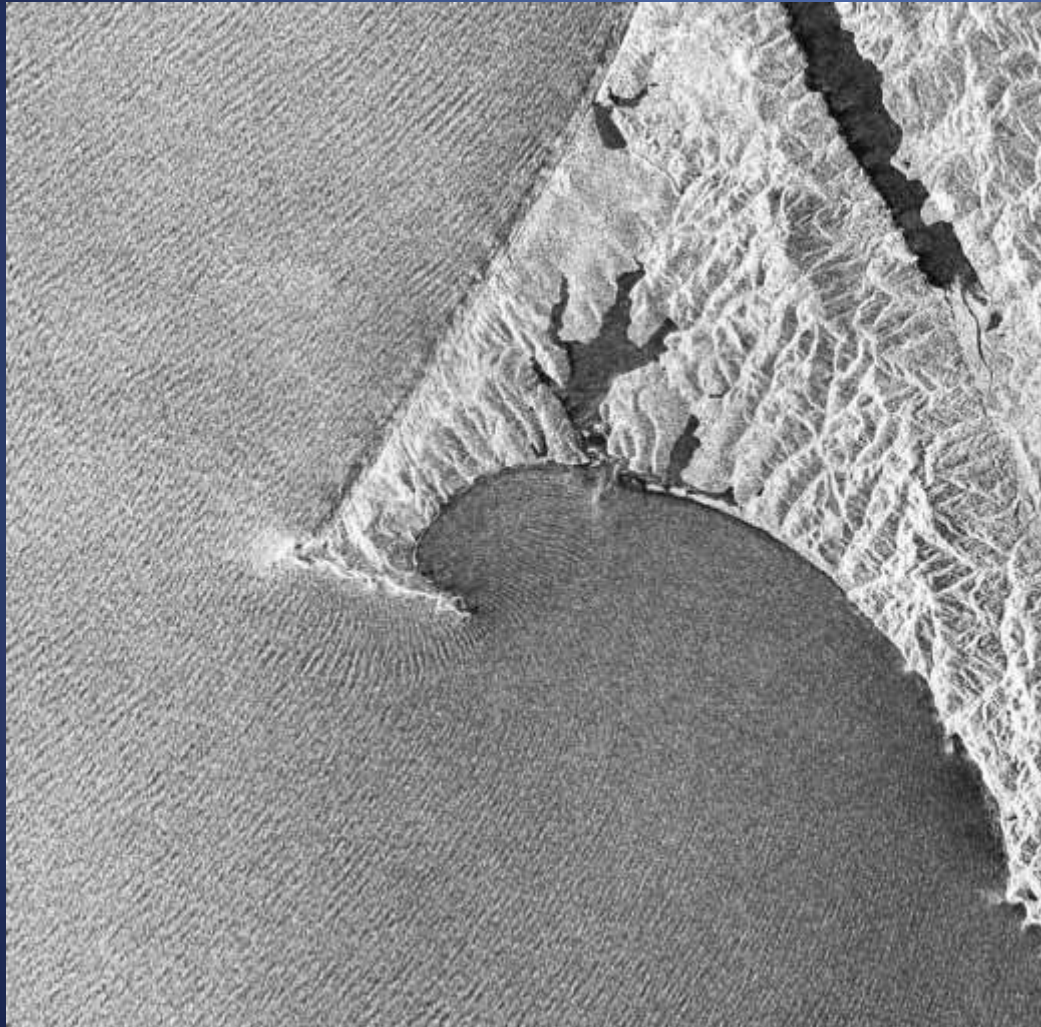
H_s : significant wave height

E.g., $R = 800\text{km}$, $V = 7\text{km/s}$, $H_s = 2\text{m}$: $\lambda_{min} \approx 162\text{m}$

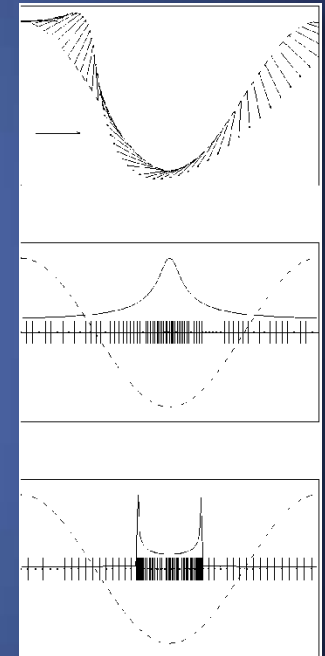


[Jackson and Apel, 2004]

SAR Imaging of Ocean Surface Waves



Wave refraction



[Jackson & Apel, 2004]

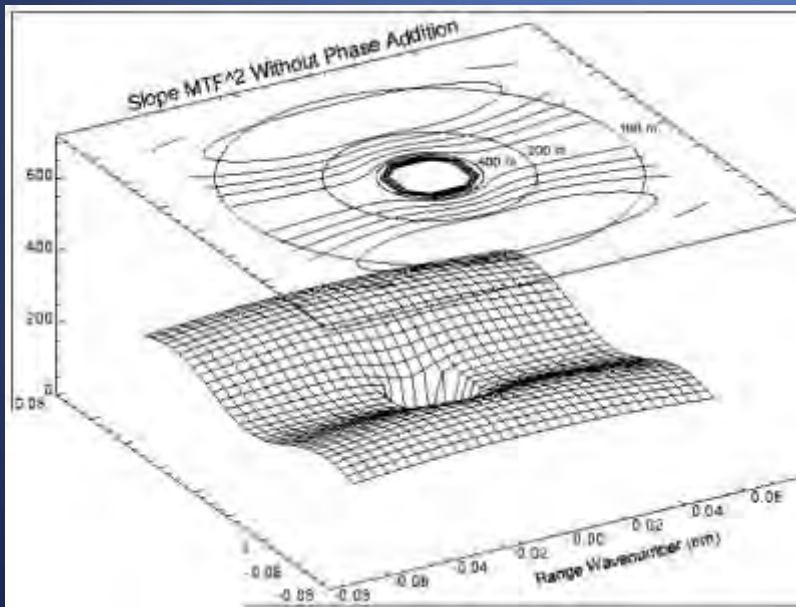
Radarsat-1 SAR Image (C-HH,
29 km \times 28 km) Point Reyes
(22 November 2001, 22:39 UTC,   CSA)

SAR Imaging of Ocean Surface Waves

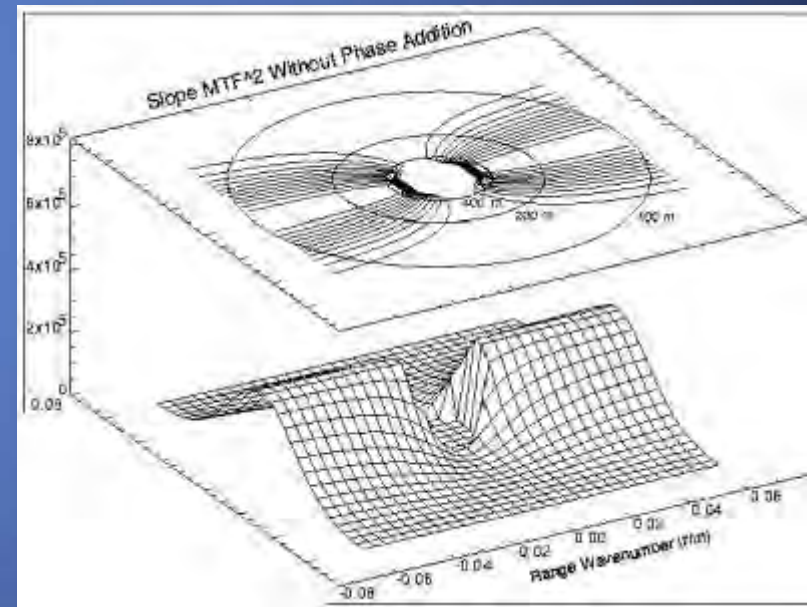
Dependence of SAR Image and Ocean Wave Spectrum

$$S_I(\vec{k}) = [H_D(\vec{k}) T(\vec{k}) \Psi(\vec{k}) + S_N(\vec{k})]$$

Image spectrum	dynamic response function	modulation transfer function	ocean wave spectrum	noise spectrum
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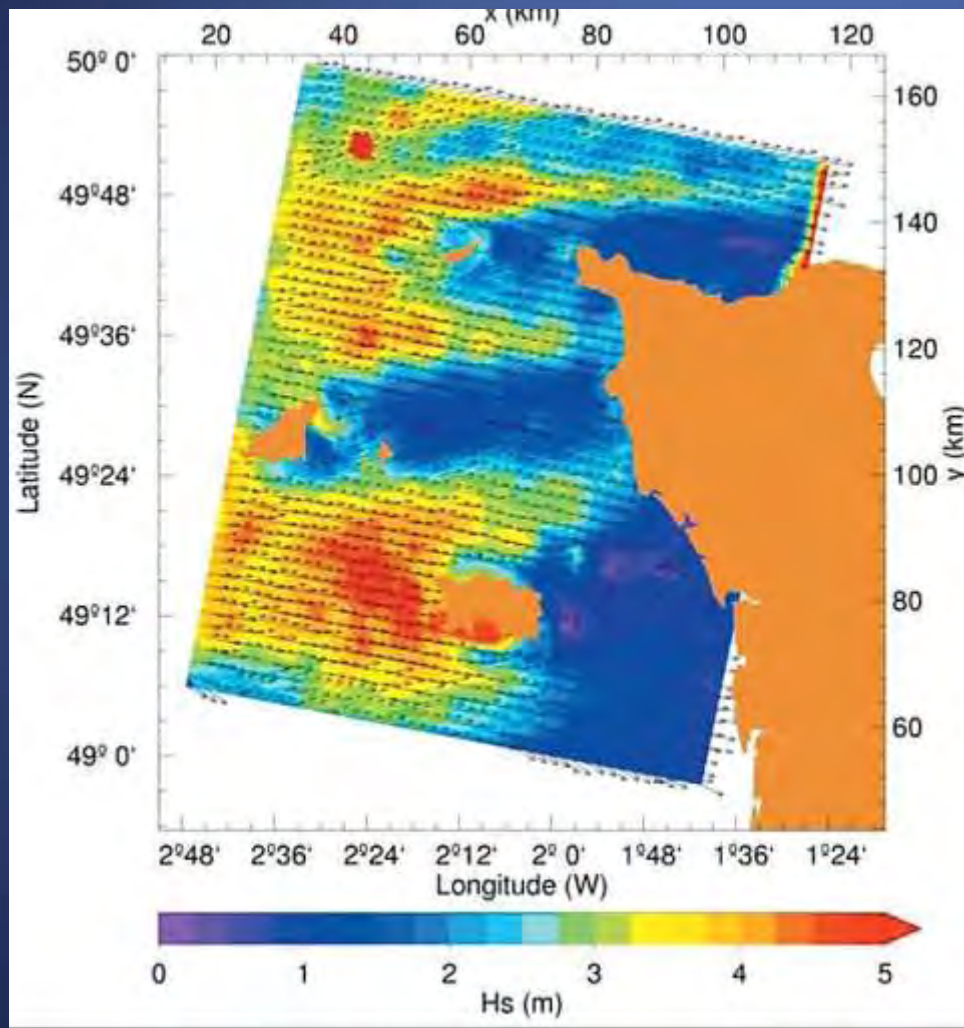
$\theta = 25^\circ$, $(R/V) = 30$ s, $H_s = 1$ m



$\theta = 25^\circ$, $(R/V) = 120$ s, $H_s = 1.6$ m

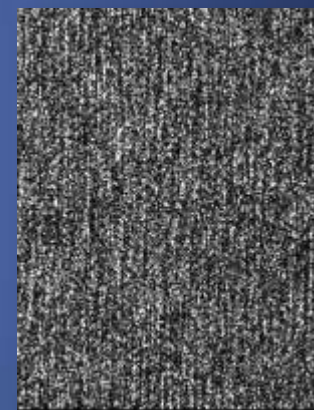
[Jackson & Apel, 2004]

SAR Imaging of Ocean Surface Waves



Wave field (height + direction)

basis:
 ENVISAT ASAR image (C-VV, SLC)
 Gulf of St. Malo, English Channel
 9 March 2003, 10:22 UTC



ENVISAT ASAR
 wave-mode imagedette
 (C-VV, SLC, 5 km × 6.7 km)

[Robinson, 2010]

SAR Imaging of Ocean Surface Waves

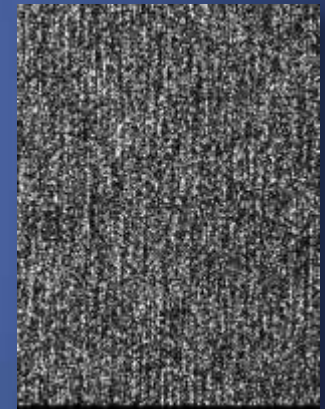
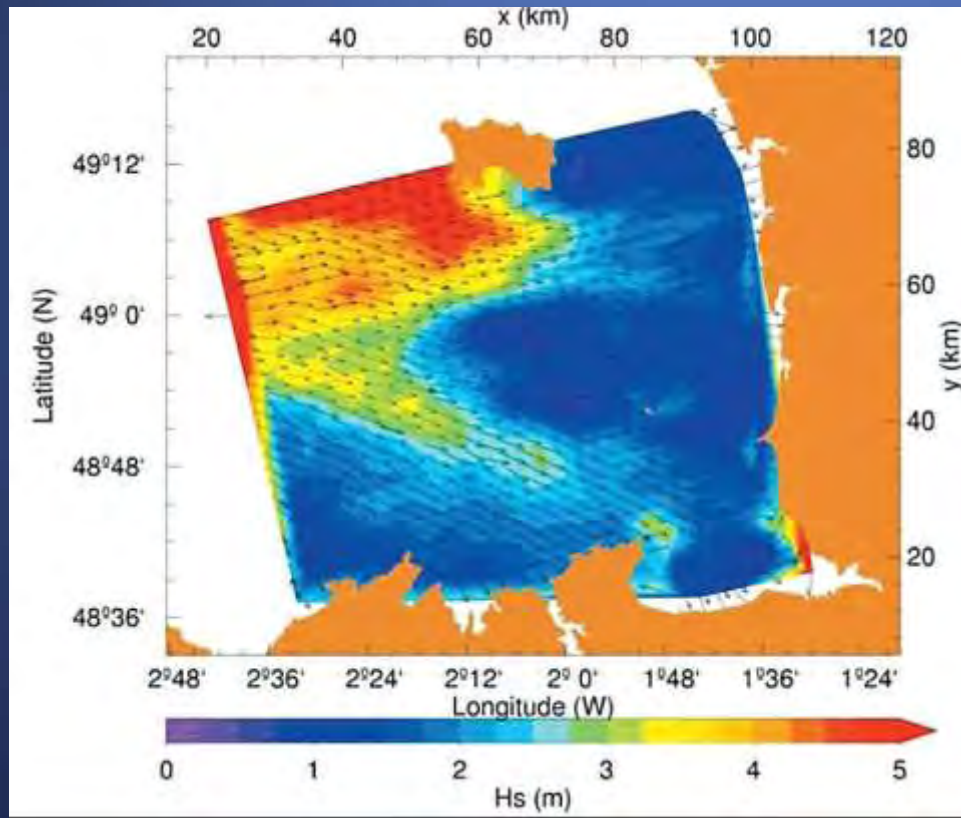
Wave field (height + direction)

basis:

ENVISAT ASAR image (C-VV, SLC)

Gulf of St. Malo, English Channel

9 March 2003, 21:44 UTC



ENVISAT ASAR
wave-mode imagette
(C-VV, SLC, 5 km × 6.7 km)

[Robinson, 2010]

SAR Imaging of Ocean Surface Waves

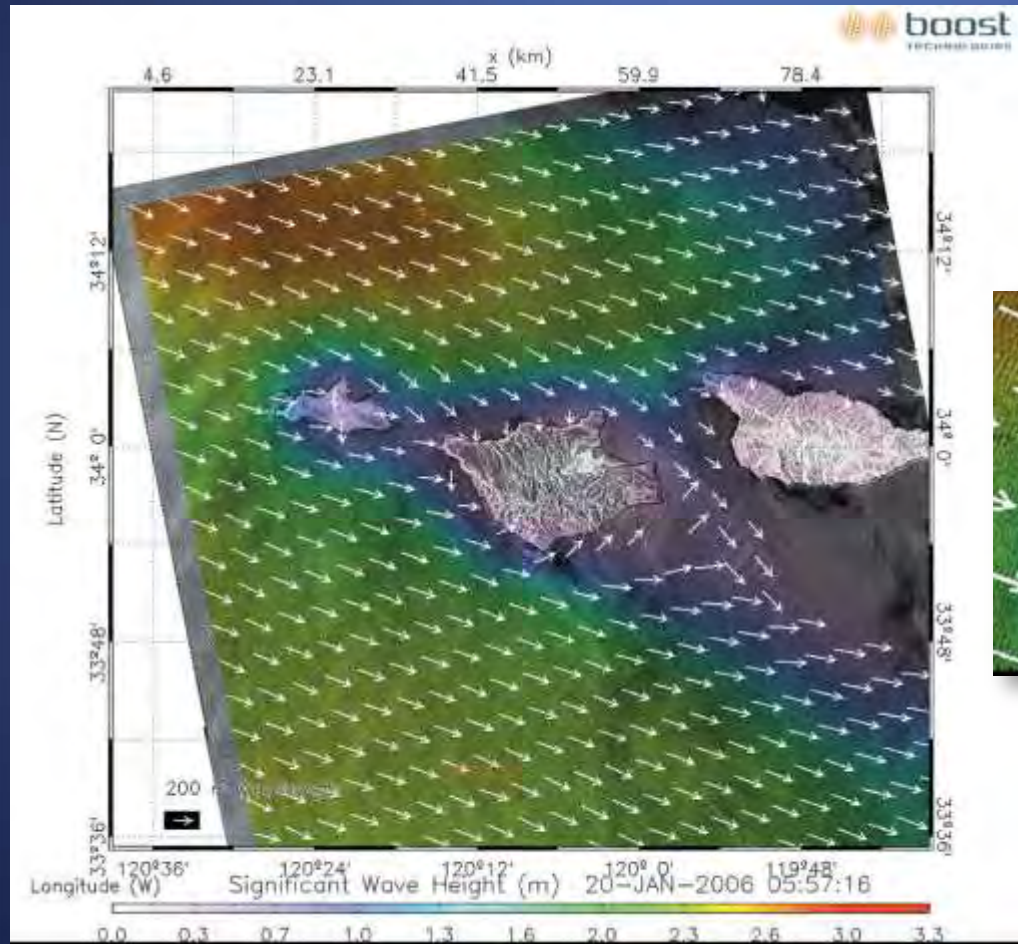
Wave field (height + direction)

basis:

ENVISAT ASAR image (C-VV, SLC)

Channel Islands, CA, USA

20 January 2006, 05:57 UTC



[Robinson, 2010]



Ocean Surface Waves Take-Home Messages

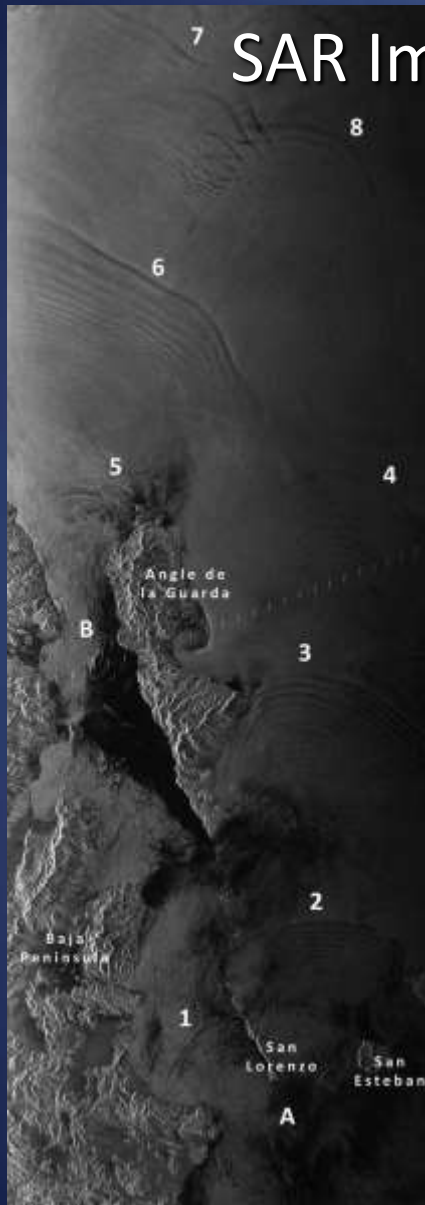
Wave orbital motion: velocity bunching
Non-linearity: azimuthal cut-off
Operational wave fields



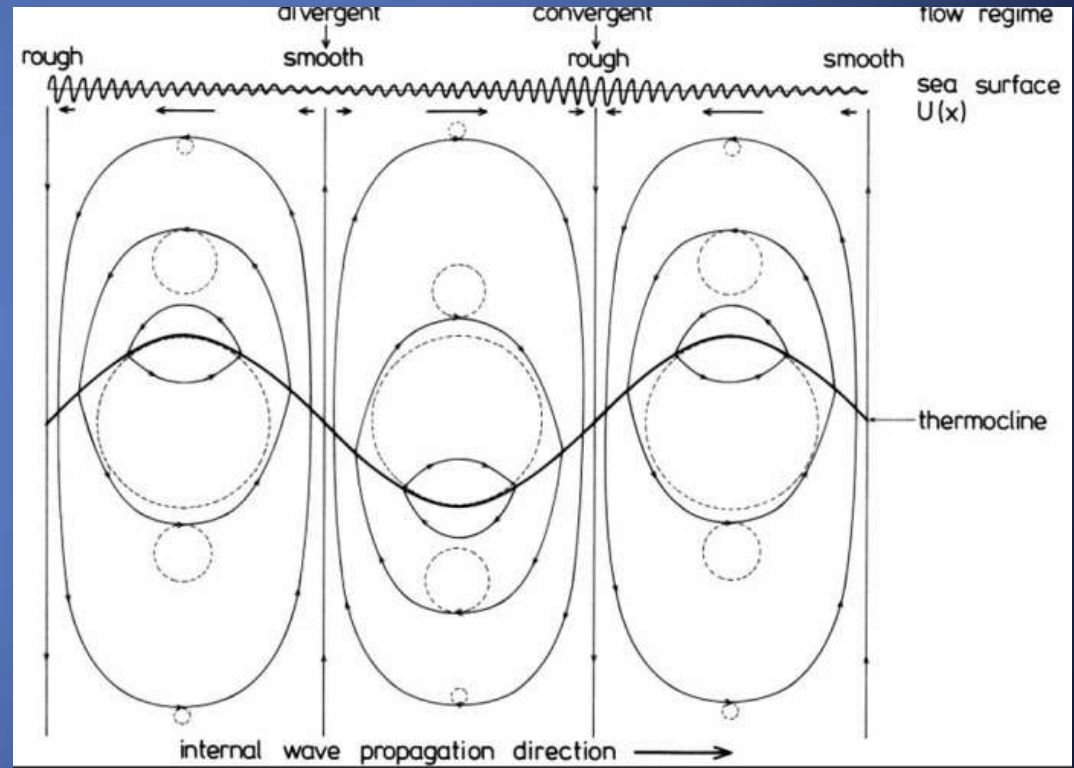
Oceanic Internal Waves

SAR Imaging of Oceanic Internal Waves

Seasat: First SAR Imaging of Internal waves



Seasat SAR Image (L-HH, 100 km × 270 km)
Gulf of California
(29 September 1978, 18:11 UTC, © NASA)

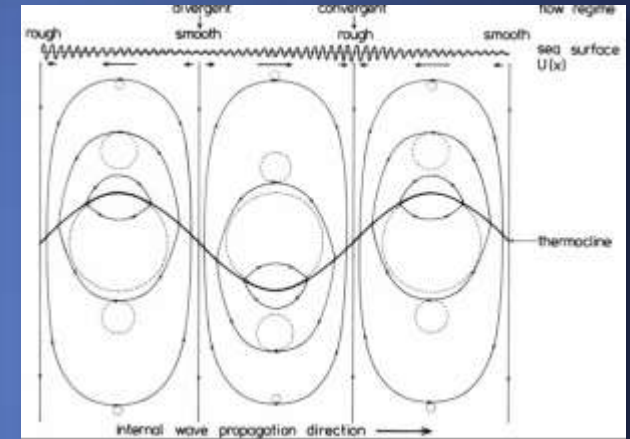


[Robinson, 2010]

SAR Imaging of Oceanic Internal Waves



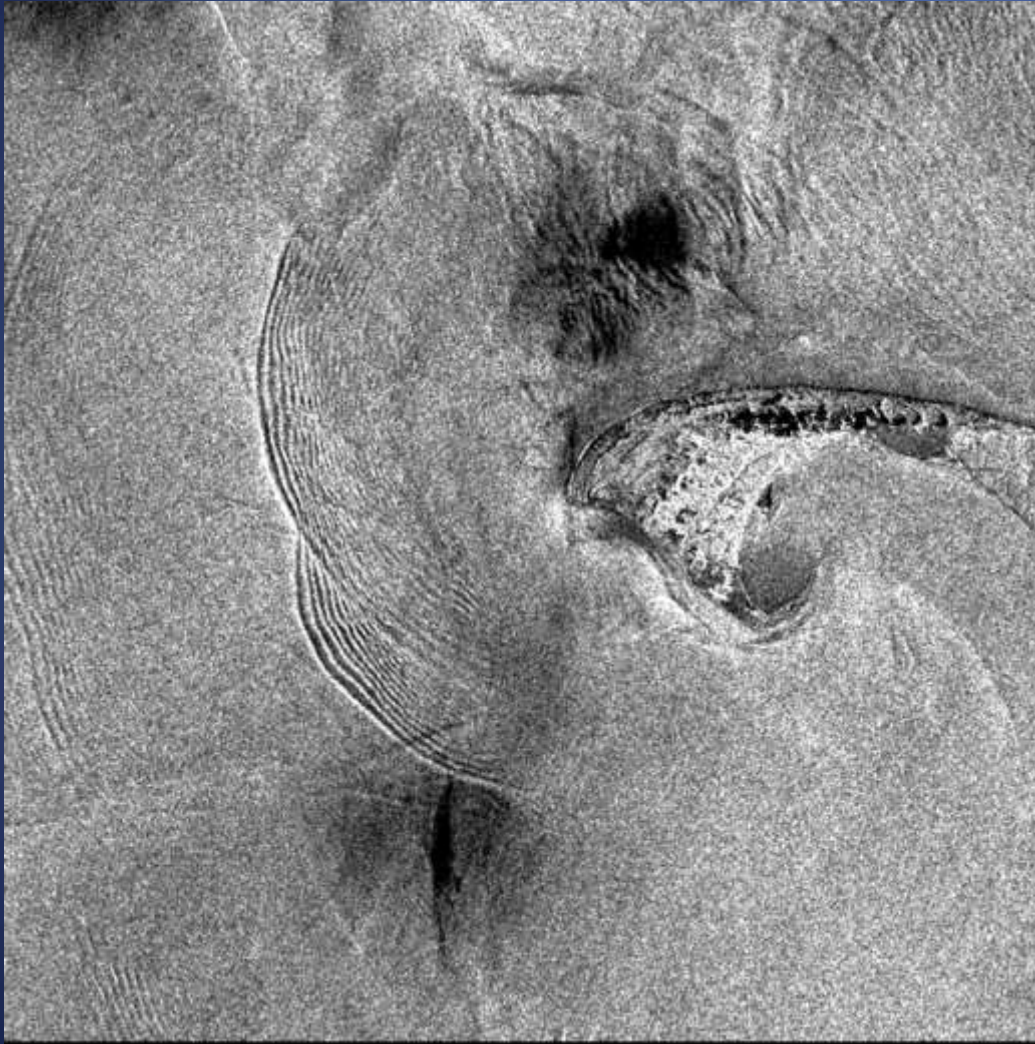
Internal waves



[Robinson, 2010]

ERS SAR Image (C-VV, 100 km × 100 km)
Strait of Gibraltar
(1 January 1993, 22:39 UTC, © ESA)

SAR Imaging of Oceanic Internal Waves



Roughness variations

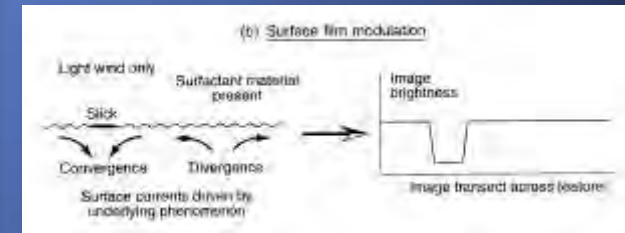
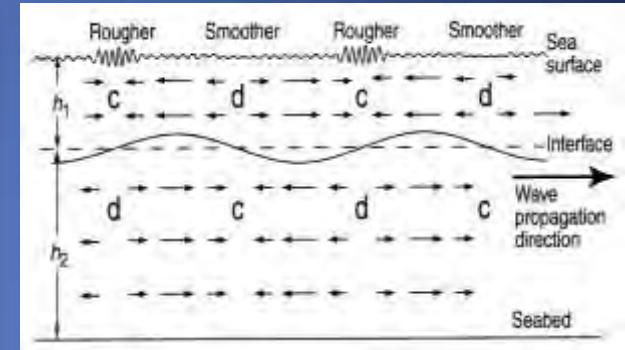
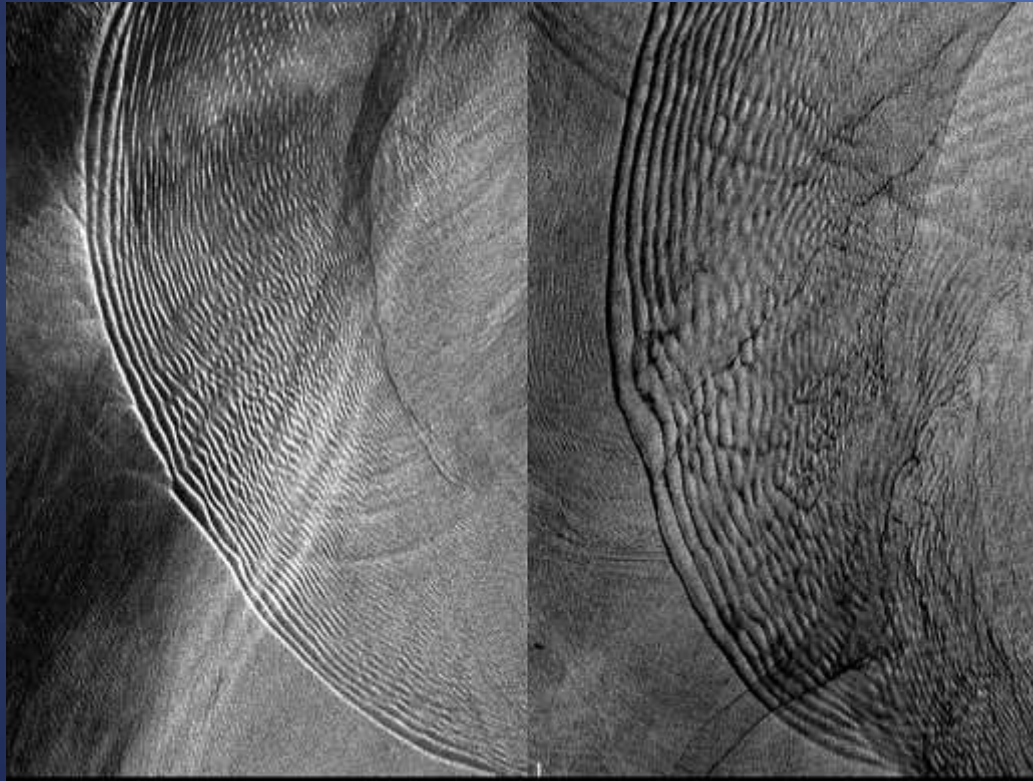


[Robinson, 2010]

ERS SAR Image (C-VV, 30 km × 30 km)
Cape Cod
(21 August 1994, 15:26 UTC, © ESA)

SAR Imaging of Oceanic Internal Waves

Roughness variations



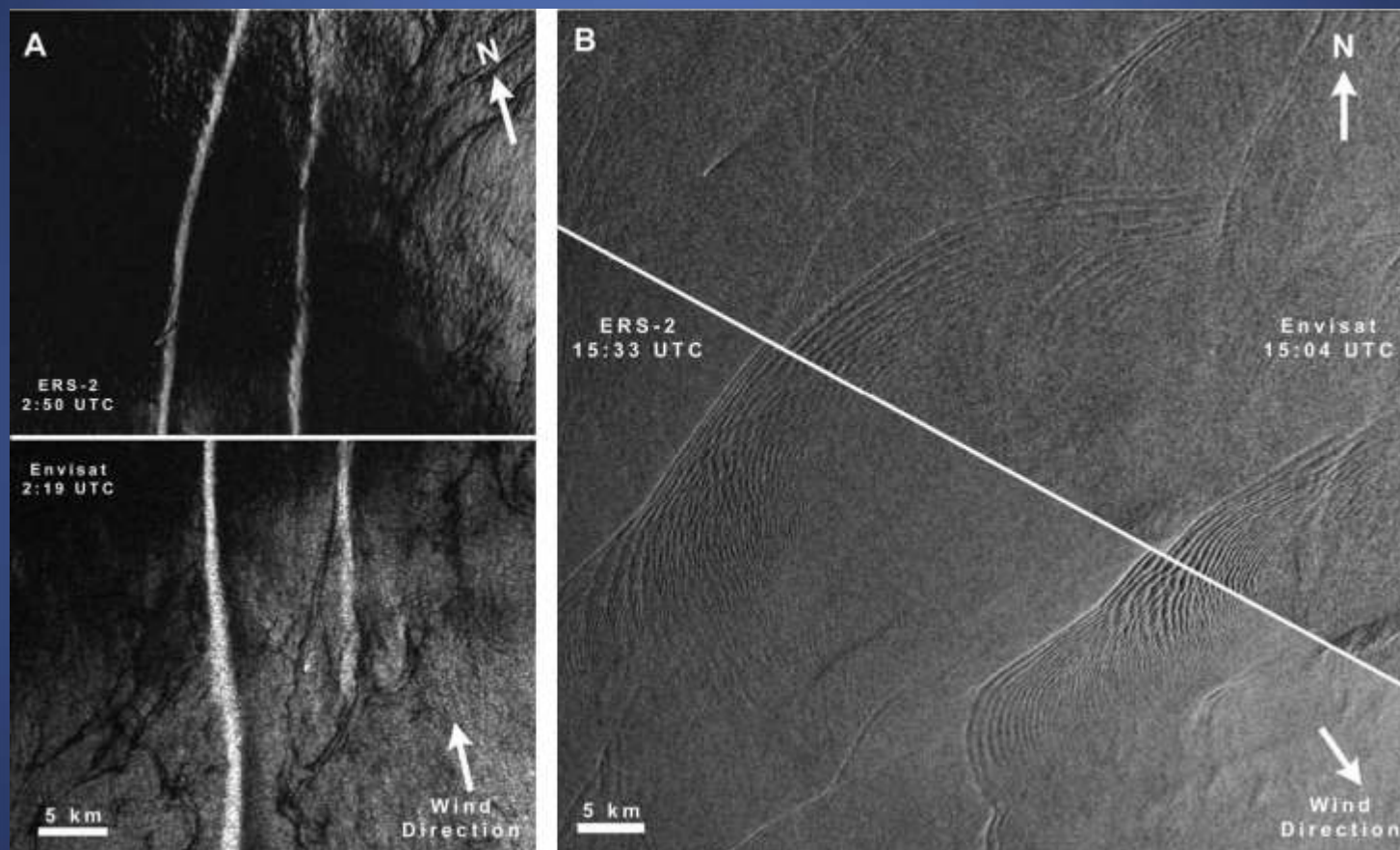
[Robinson, 2003]

[Robinson, 2010]

TerraSAR-X Images (X-VV, 11 km × 17 km)
U.S. East Coast
(23 June 2008, 22:26 UTC, 4 July 2008, 22:26 UTC, © DLR)

SAR Imaging of Oceanic Internal Waves

Propagation speed from pairs of ERS / ENVISAT images



ERS-2 SAR / ENVISAT ASAR Images
(C-VV, 35 km × 30 km) South China Sea
(28 March 2009, 02:19 / 02:50 UTC, © ESA)

ERS-2 SAR / ENVISAT ASAR Images
(C-VV, 65 km × 65 km) U.S. East Coast
(8 August 2006, 15:04 / 15:33 UTC, © ESA)

[Jackson
et al., 2013]



Oceanic Internal Waves Take-Home Messages

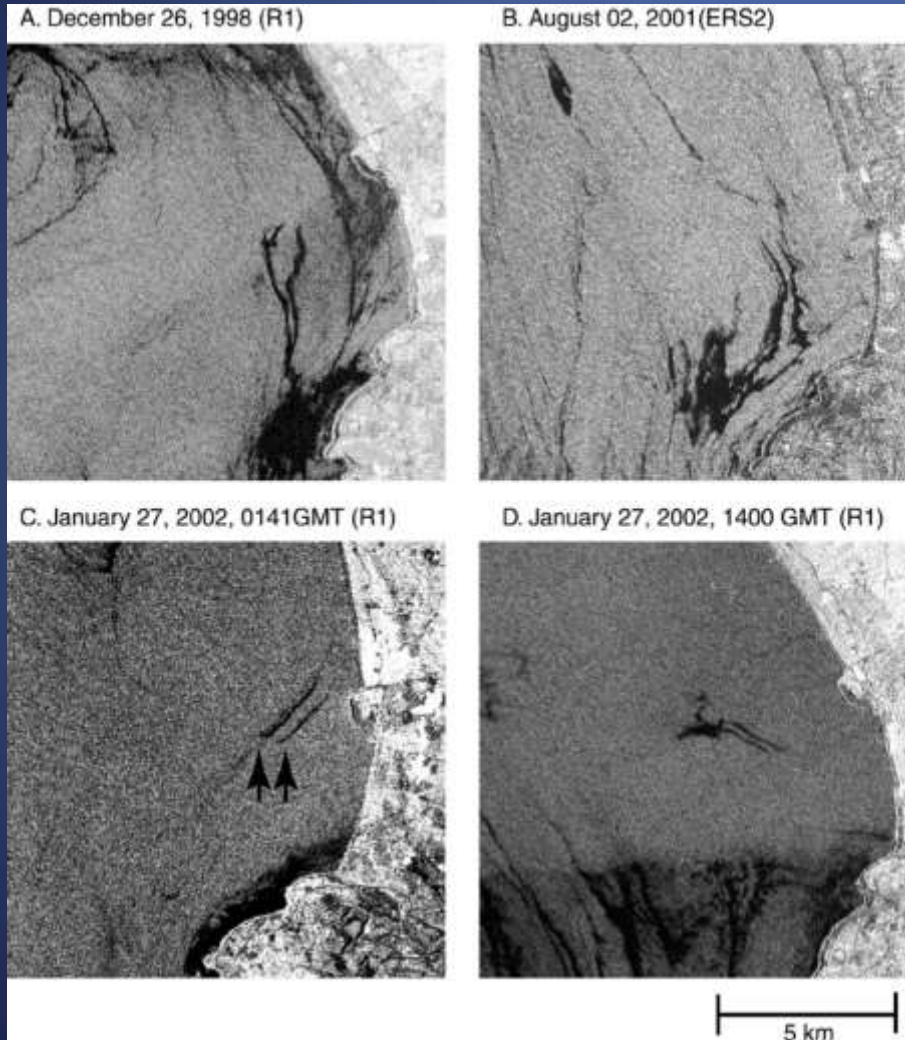
IWs at two-layer interface (pycnocline,
thermocline): mixing processes
Surface roughness variations



Marine Surface Films

Marine Surface Films

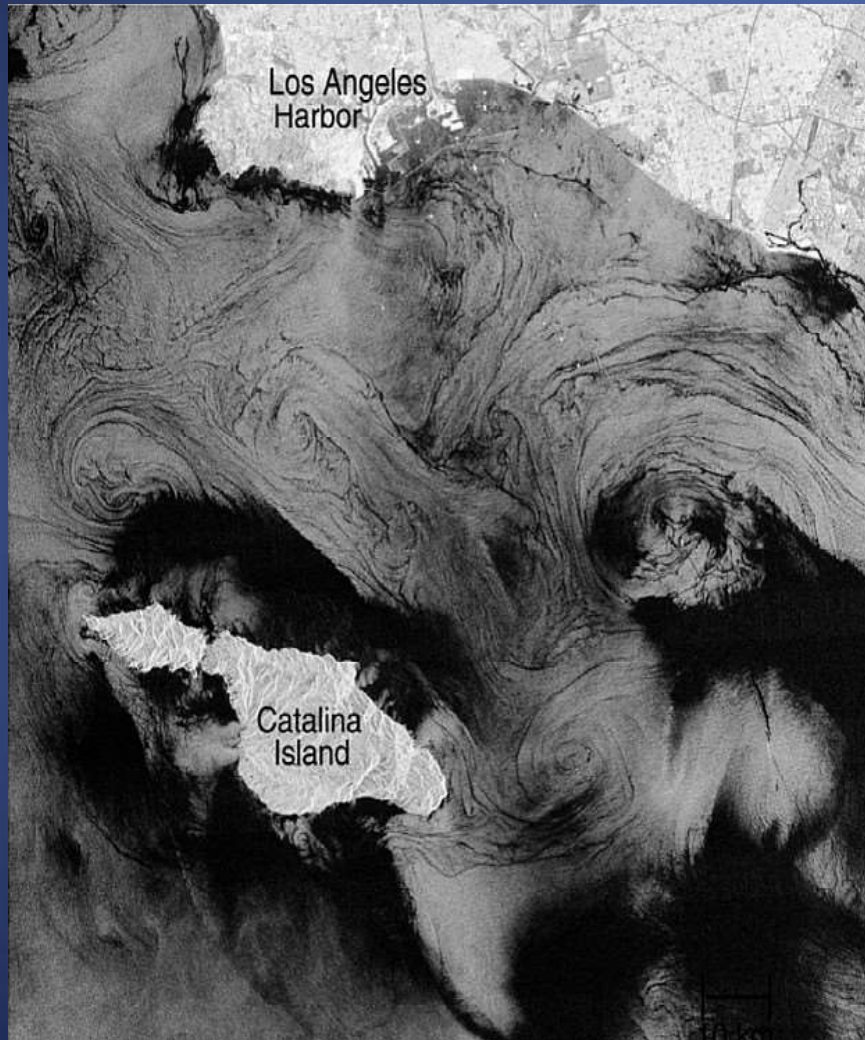
Natural oil seeps



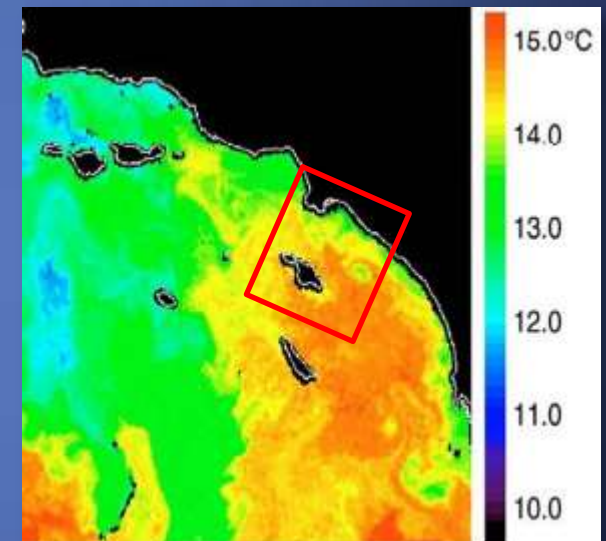
Radarsat-1 SAR Images (C-HH; 12.5 km × 12.5 km)
ERS-2 SAR Image (C-VV; 12.5 km × 12.5 km)
Redondo Beach, CA
(© CSA, ESA)

[Jackson & Apel, 2004]

Marine Surface Films



Slicks & eddies



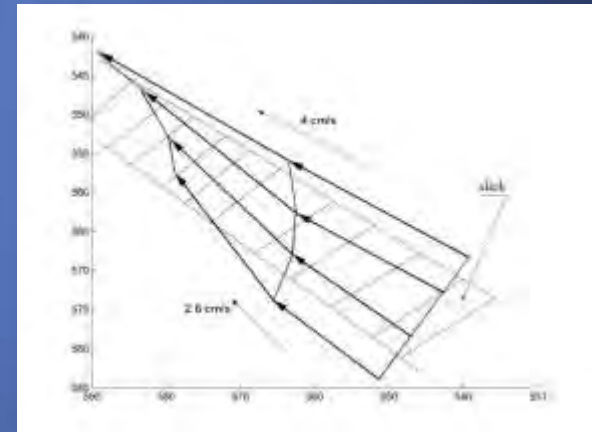
[Jackson & Apel, 2004]

Radarsat-1 SAR Image (C-HH)
Catalina Channel
(26 December 1998,   CSA)

Marine Surface Films



Slicks & eddies



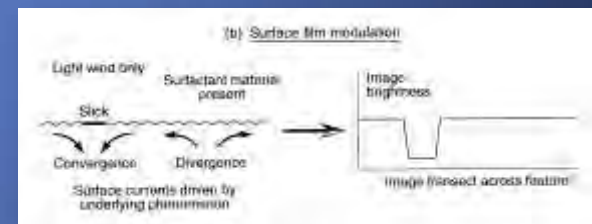
[Gade et al., 2014]

ERS SAR Image (C-VV; 70 km × 70 km)
Bering Strait
(24 June 1997, 22:30 UTC, © ESA)

Marine Surface Films



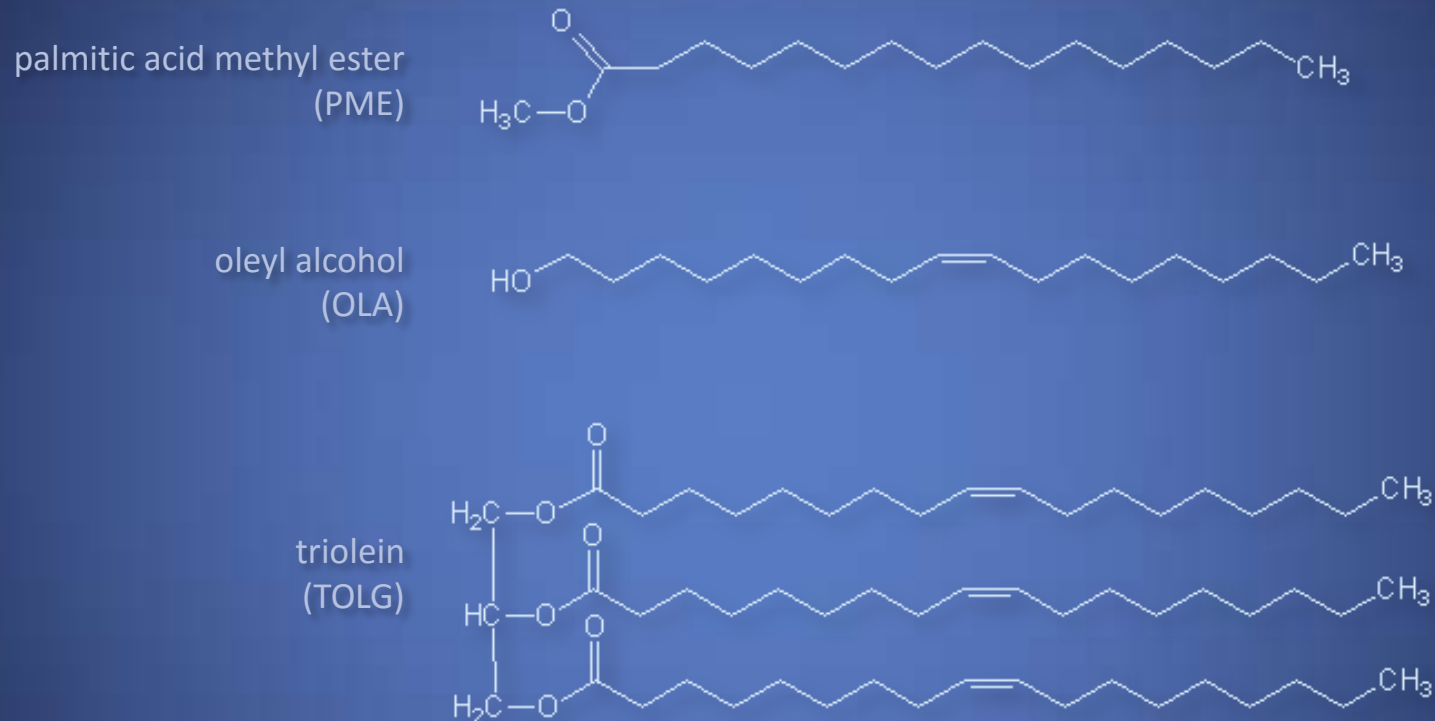
Slicks & eddies



[Robinson, 2003]

ERS SAR Image (C-VV; 100 km × 100 km)
Caspian Sea
(12 October 1993, © ESA)

Monomolecular Surface Films

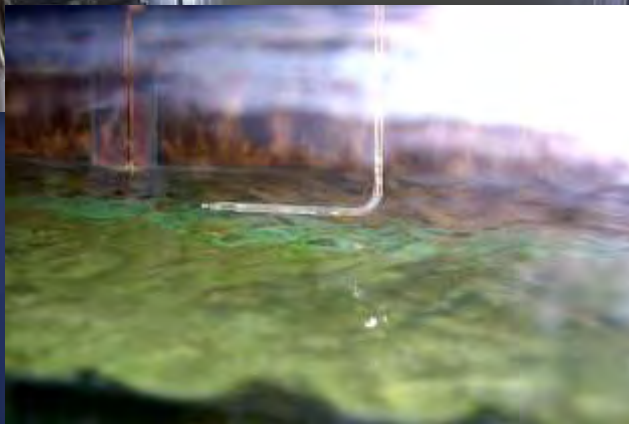


Model Substances represent main components of natural marine surface films

Hydrophobic part (long alacyl chain) – Hydrophilic head group

Substances accumulate at the water surface as monomolecular film

Wind-Wave Tank of the University of Hamburg



UHH's Wind-Wave Tank

Size: 24 m × 1 m × 1.5 m

Water depth: 0.5 m (freshwater)

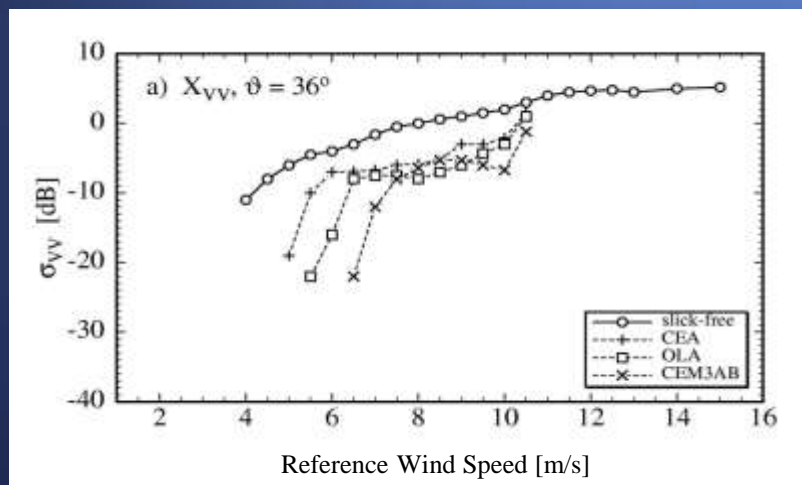
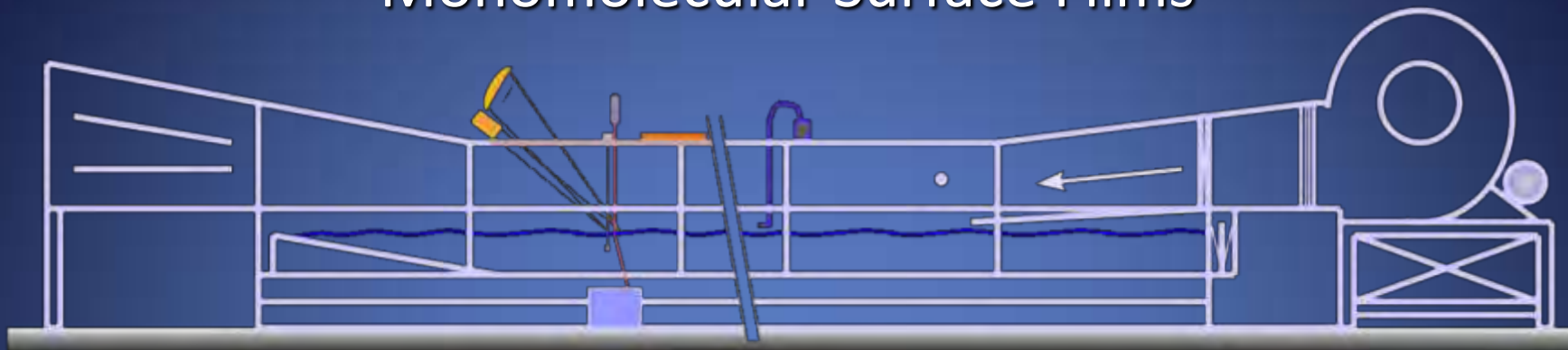
Wind: 2 – 20 m/s

Rain: up to 160 mm/h @ 12.5 – 14.8 m

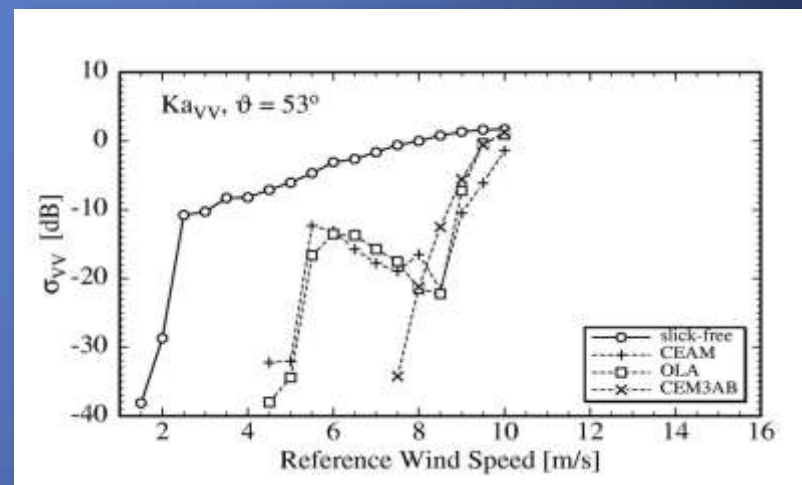
Monomolecular Surface Films



Monomolecular Surface Films



[Gade, 1998]



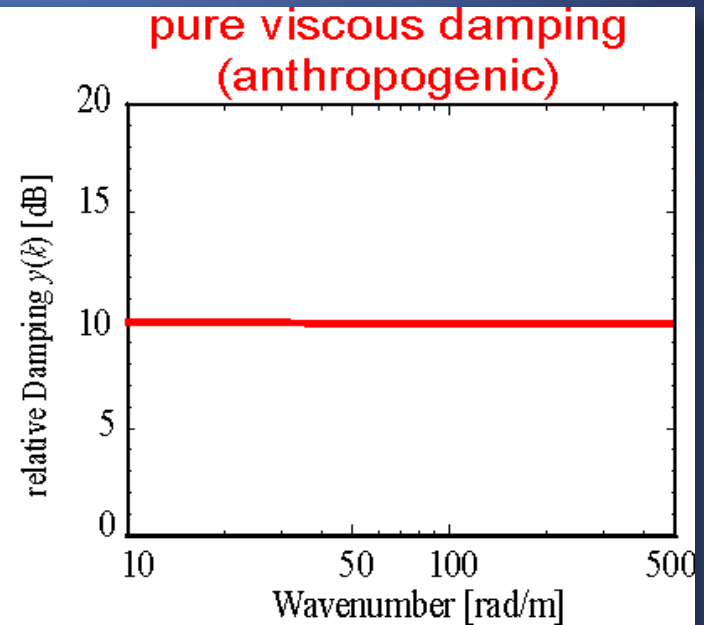
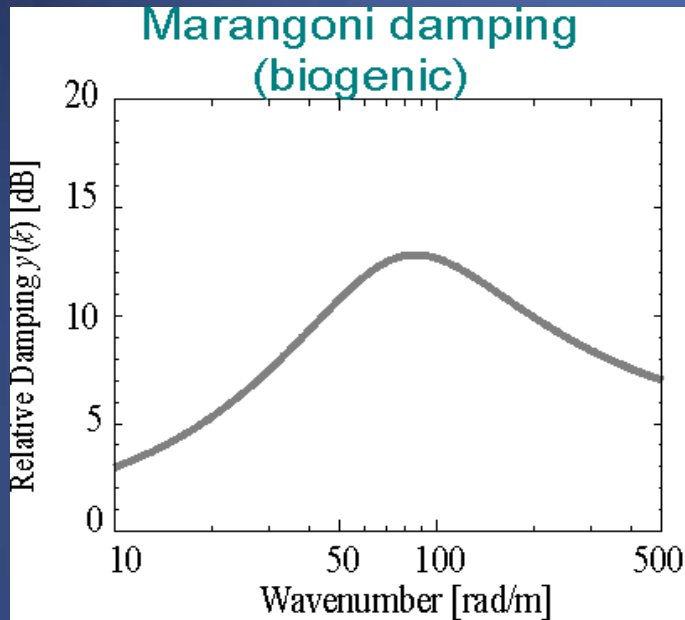
[Gade, 1998]

Measured radar contrast

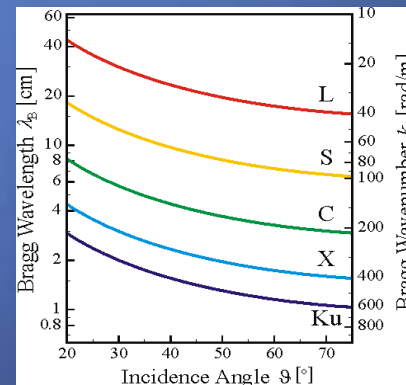
left: X band (9.8 GHz, $\lambda_B = 3$ cm)

right: Ka band (37 GHz, $\lambda_B = 0.8$ cm)

Wave Damping by Surface Films



Use multi-frequency radar techniques to discriminate between biogenic and anthropogenic surface films



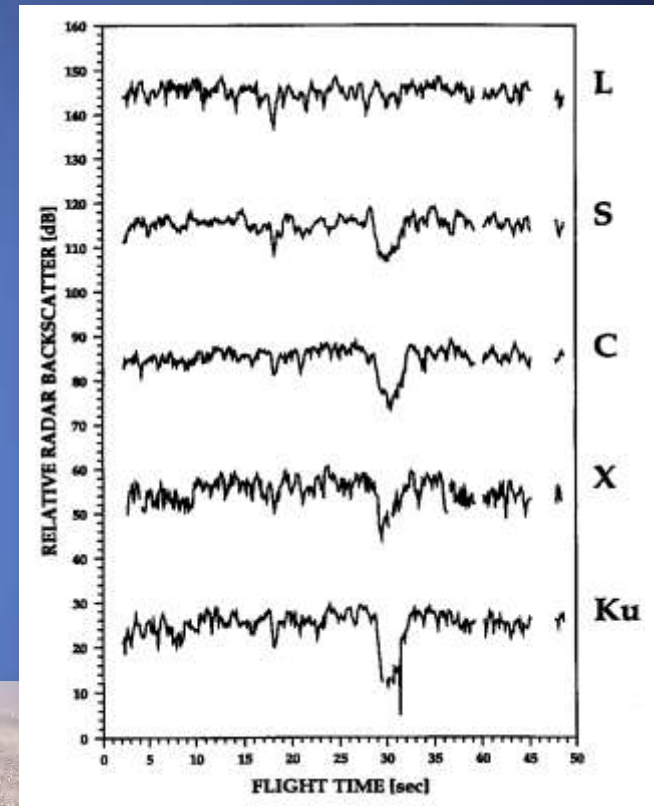
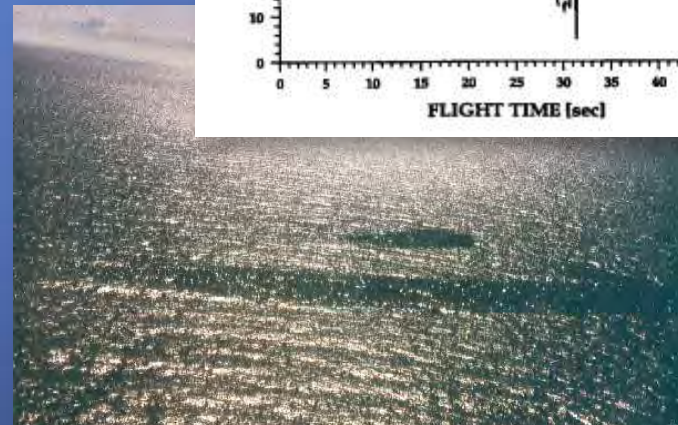
Scatterometer Experiments



MULTI³SCAT of Uni Hamburg

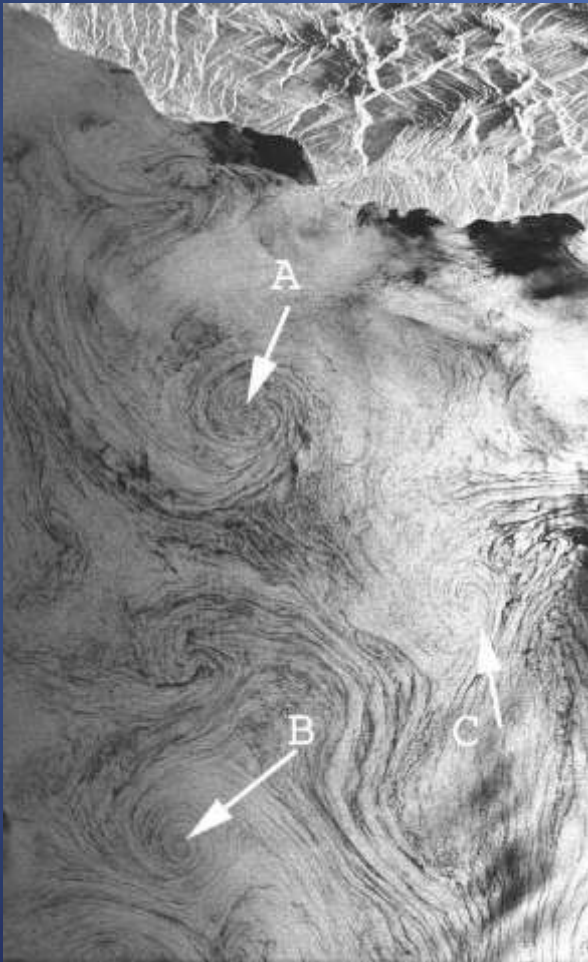
- flown on BO 105
- 5 frequencies: (L, S, C, X, Ku band)
- 4 polarisations (HH, HV, VV, VH)
- incidence angle: 23° ... 65°
- nominal flight height: 150 m
- Ø footprint: 1.6 m ... 128.9 m
- transmit power: 10 mW ... 150 mW

Marine Surface Films



Marine Surface Films

Detecting and tracking of sub-mesoscale oceanic eddies



ENVISAT ASAR WS Image (C-VV; 25 km × 25 km)
NE Black Sea
(15 August 2006, 19:18 UTC, © ESA)

ENVISAT ASAR WS Image (C-VV; 120 km × 200 km)
NE Black Sea
(10 May 2007, 07:37 UTC, © ESA)

[Gade et al., 2013]

Marine Surface Films

High-resolution surface current fields from pairs of Sar images

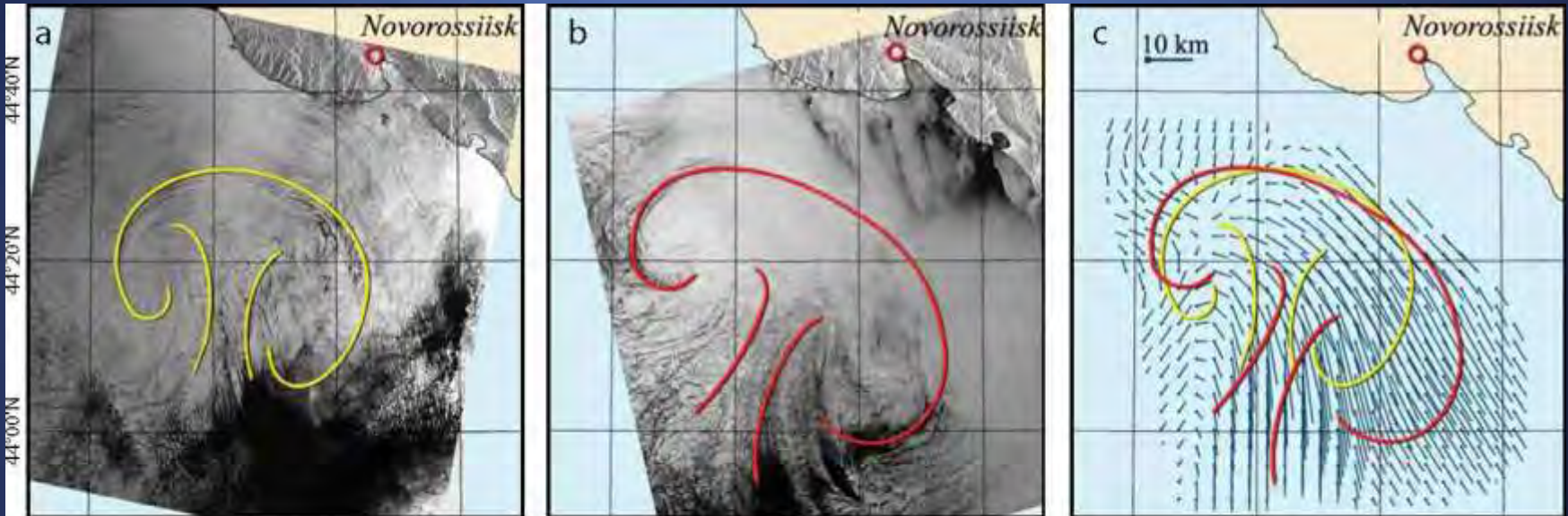
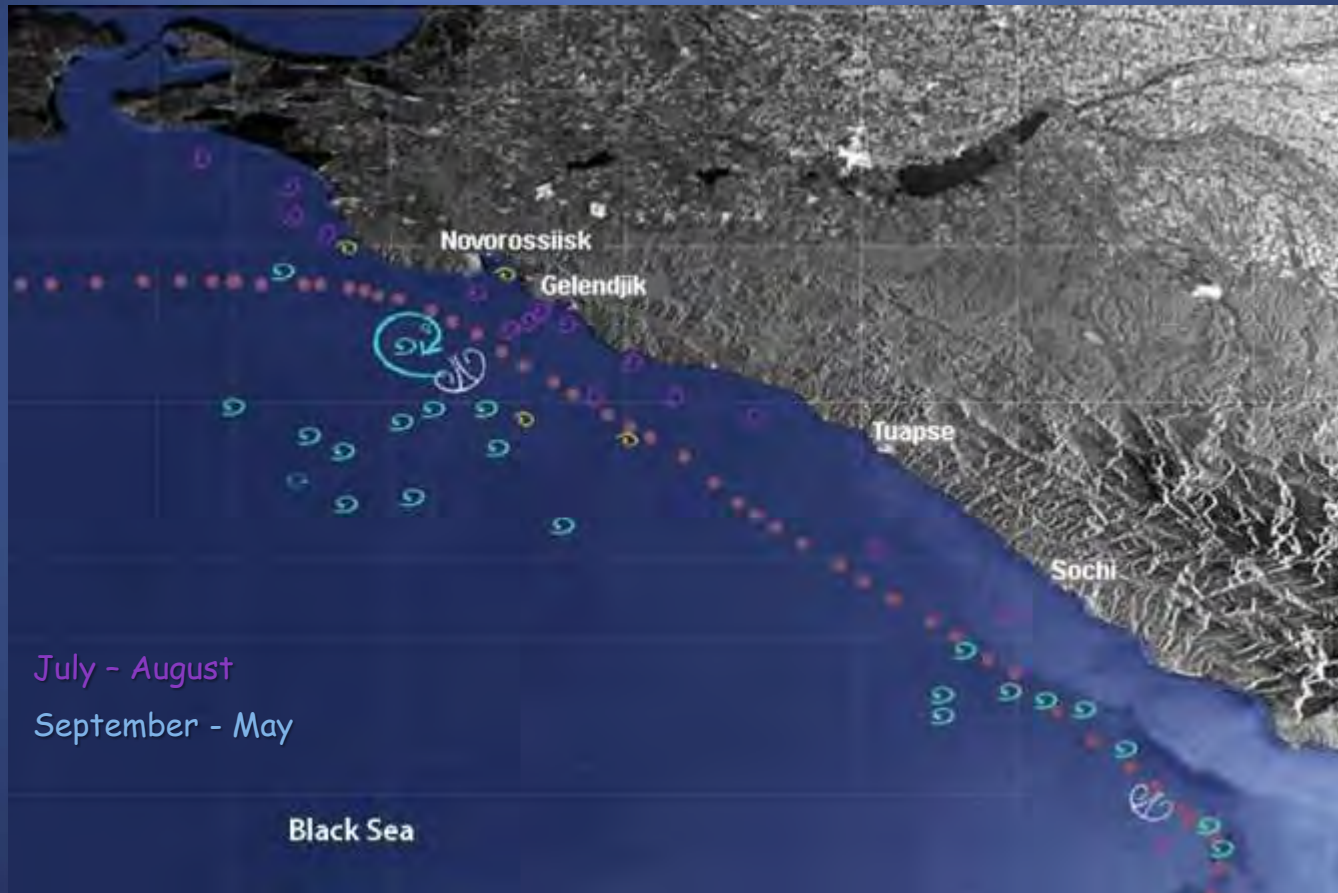


Figure 11. (a) Envisat ASAR Image obtained June 19, 2006, at 07:52 GMT showing a nascent dipole eddy. Dimensions are about 66 km x 62 km. © ESA, 2006 (b) Envisat ASAR image of a 92 km x 78 km dipole eddy obtained June 19, 2006, at 19:10 GMT © ESA, 2006 (c) Reconstruction of the local velocity field from analysis of images a and b.

[Gade et al., 2013]

Marine Surface Films

Eddy statistics for the northeastern Black Sea



[Gade et al., 2013]



Marine Surface Films Take-Home Messages

Monomolecular surface films

Strong wave damping

Tracers for turbulent features/processes
in upper water layer

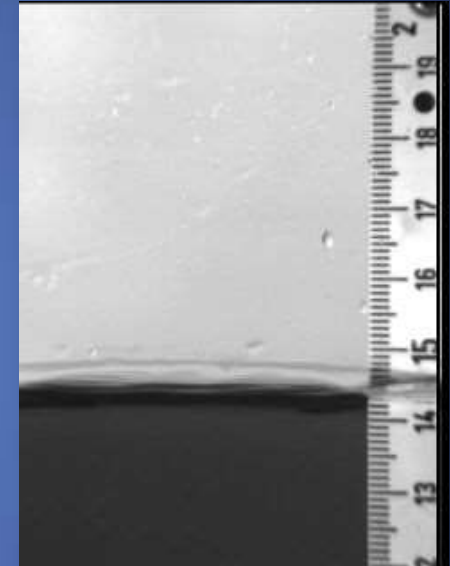


Rain

Heavy Rain

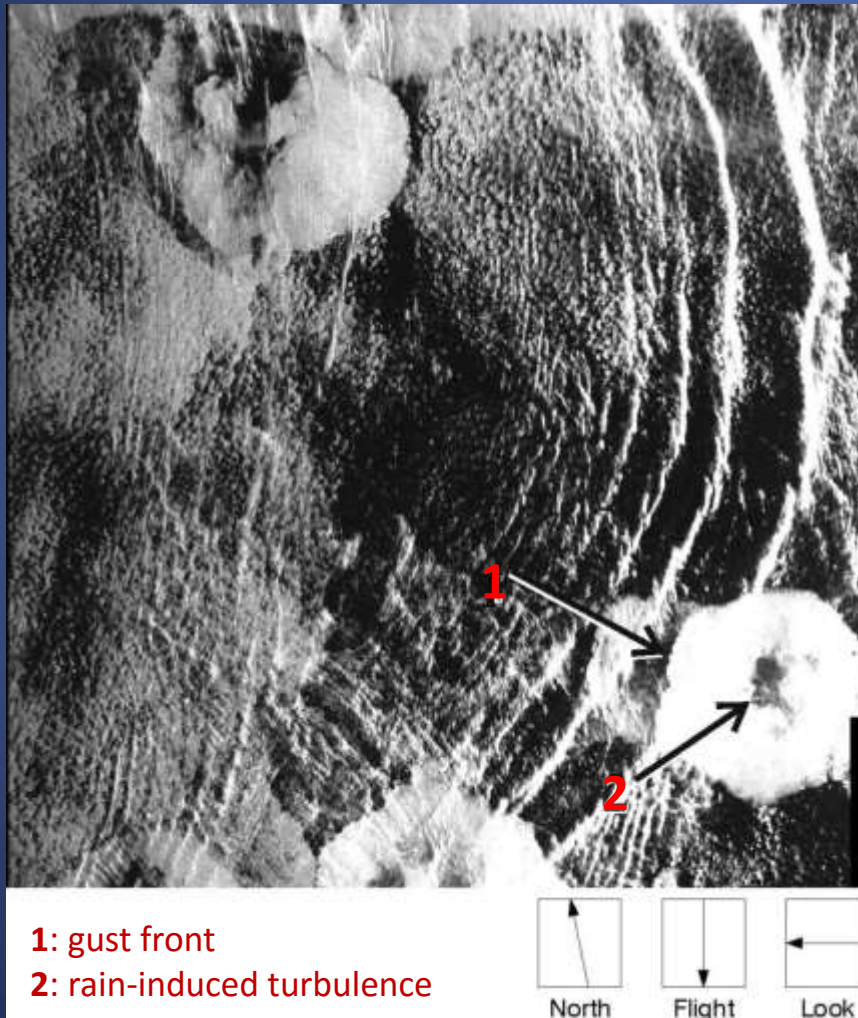


Impinging rain drop

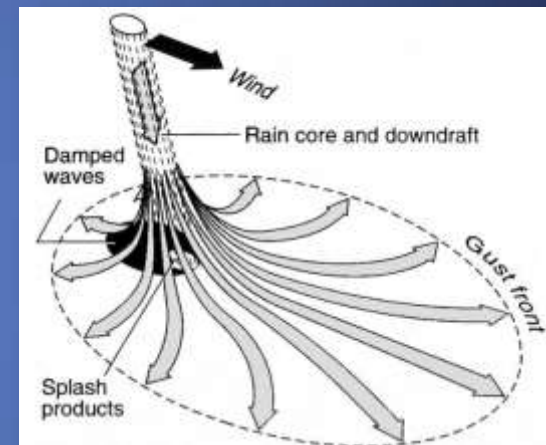


ERS SAR Image (100 km × 100 km)
South Chinese Sea
(14 May 1998, 02:52 UTC, © ESA)

Heavy Rain



Downdraft

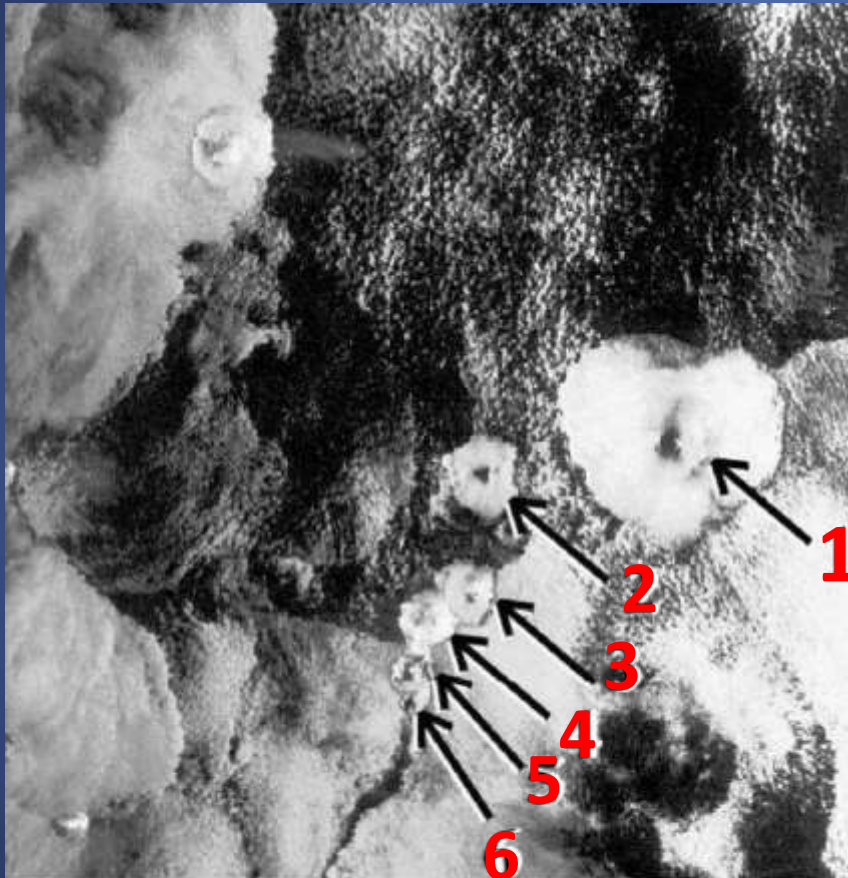


[Jackson & Apel, 2004]

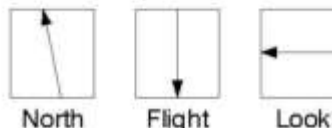
ERS-1 SAR Image (100 km × 100 km)
Andaman Sea
(3 April 1996, 12:34 UTC, © ESA)

[Jackson & Apel, 2004]

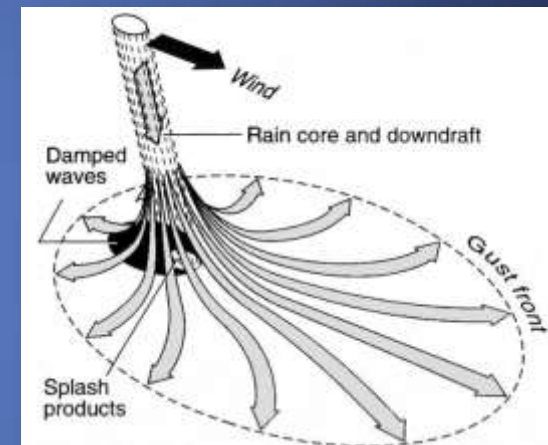
Heavy Rain



1-6: chain of rain cells
(from old to young)



Downdraft

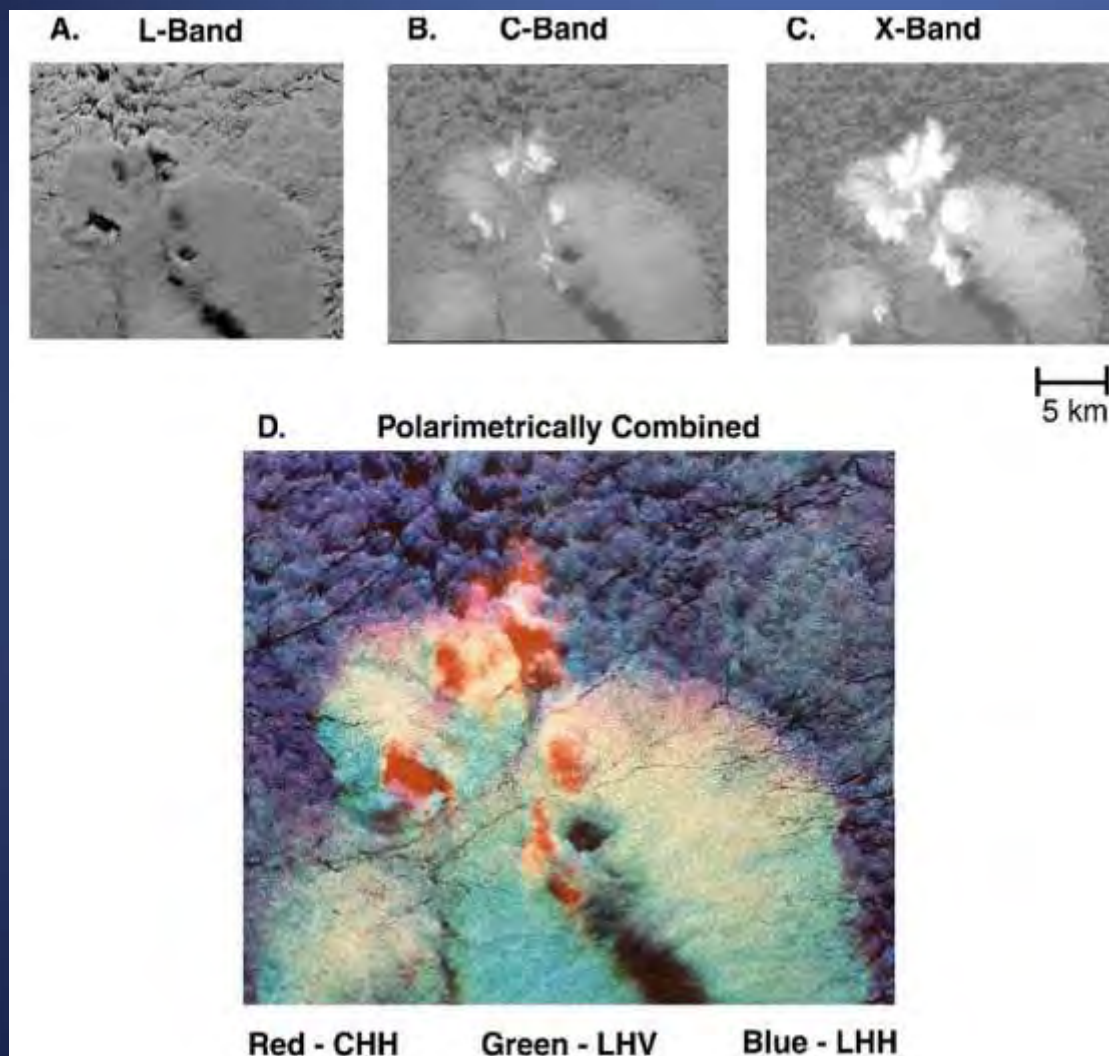


[Jackson & Apel, 2004]

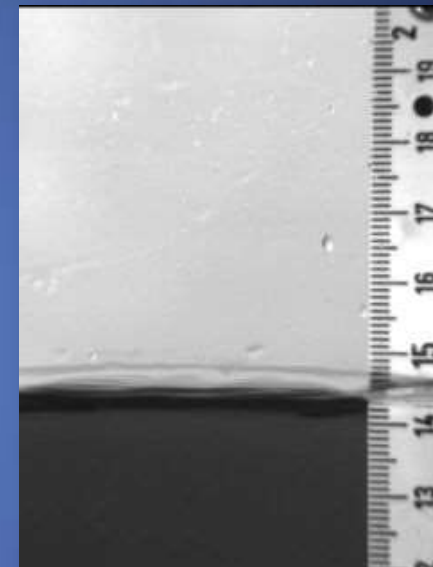
ERS-1 SAR Image (100 km × 100 km)
Gulf of Thailand
(18 April 1994, 03:42 UTC, © ESA)

[Jackson & Apel, 2004]

Heavy Rain



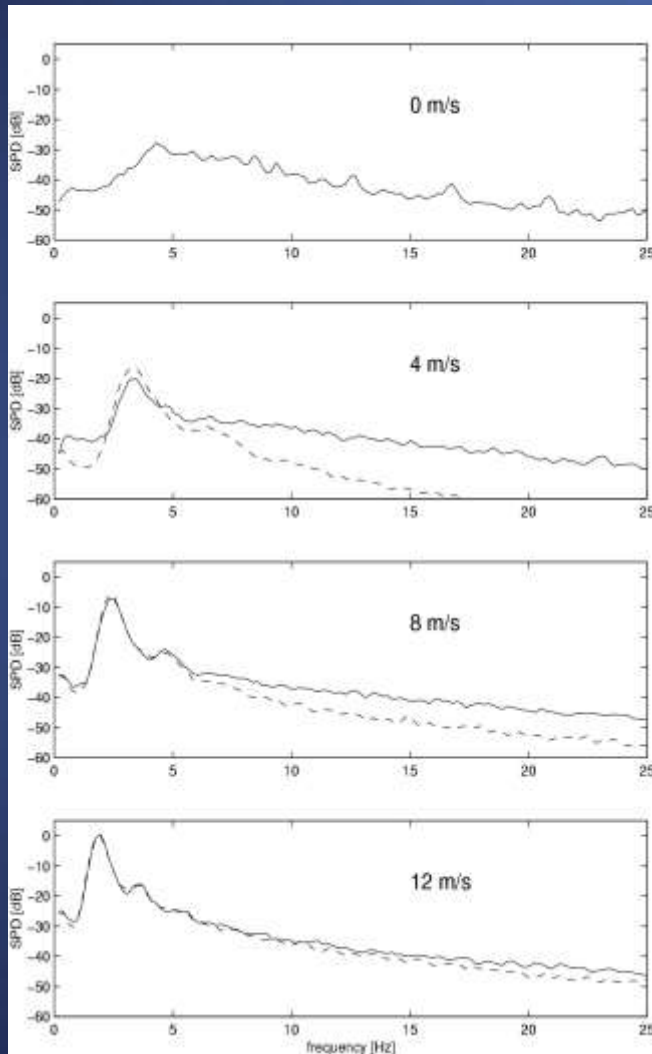
Impinging rain drop



SIR-C/X-SAR Images (5 km × 4 km)
Solomon Islands
(10 April 1994)

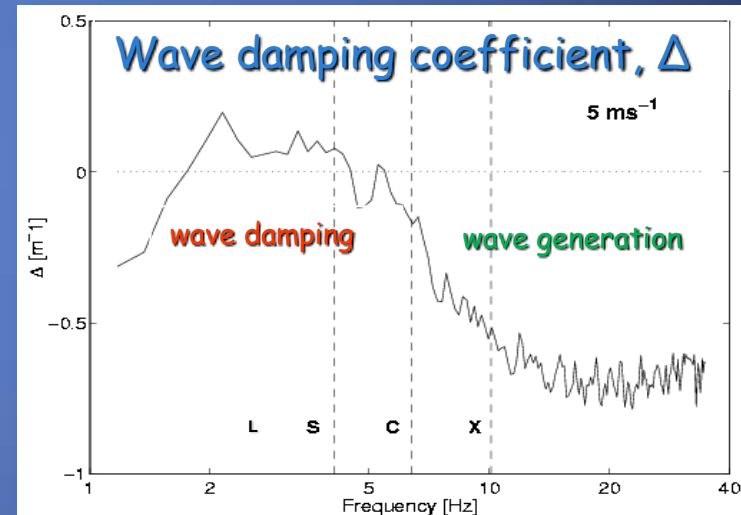
[Jackson & Apel, 2004]

The Action of Heavy Rain on the Water Surface



wind only

wind and rain

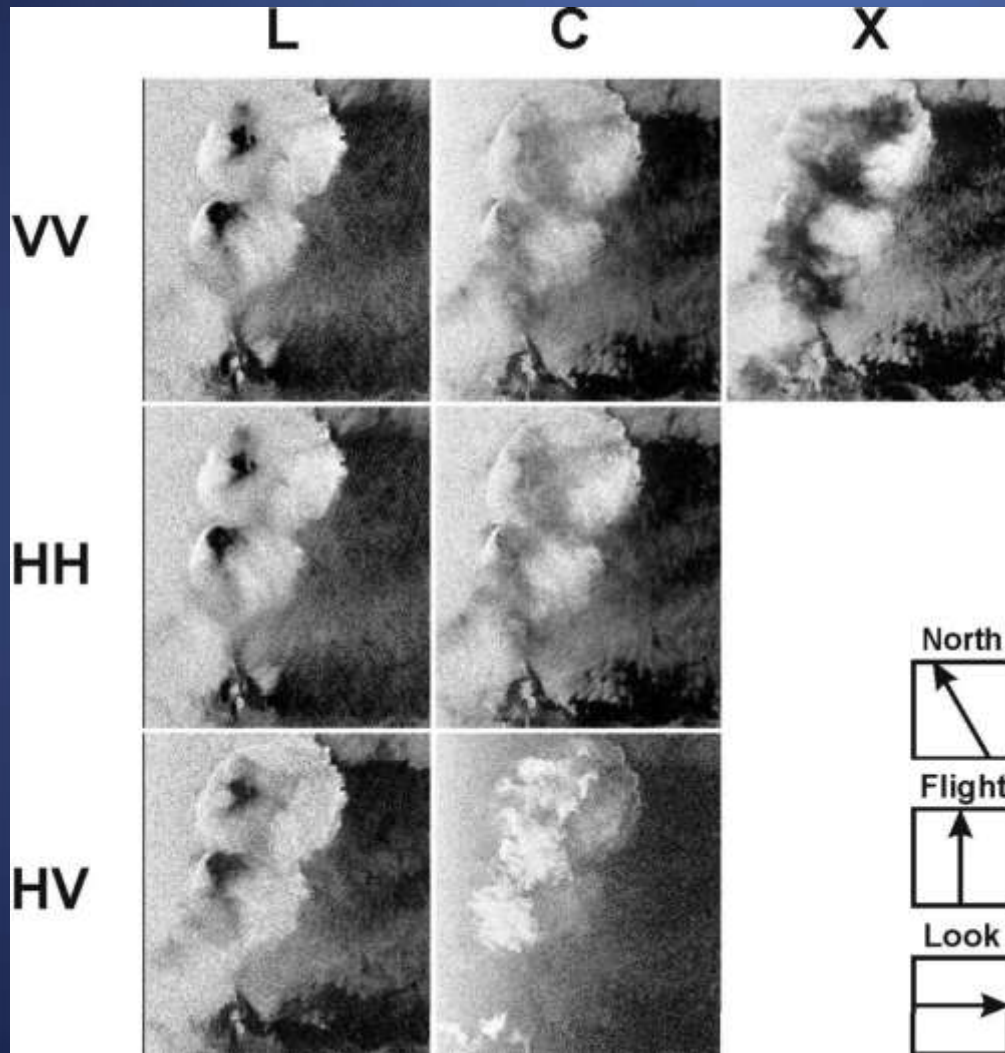


Damping of long waves ($f < 5$ Hz)

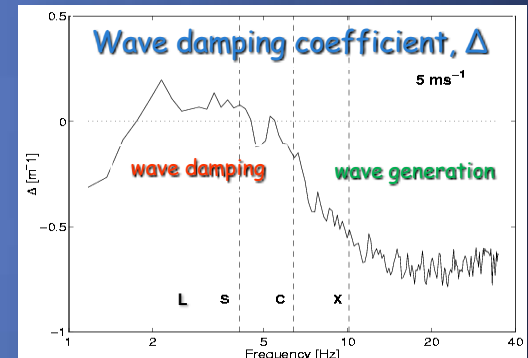
Generation of short waves ($f > 5$ Hz)

[Braun, 2002]

Heavy Rain



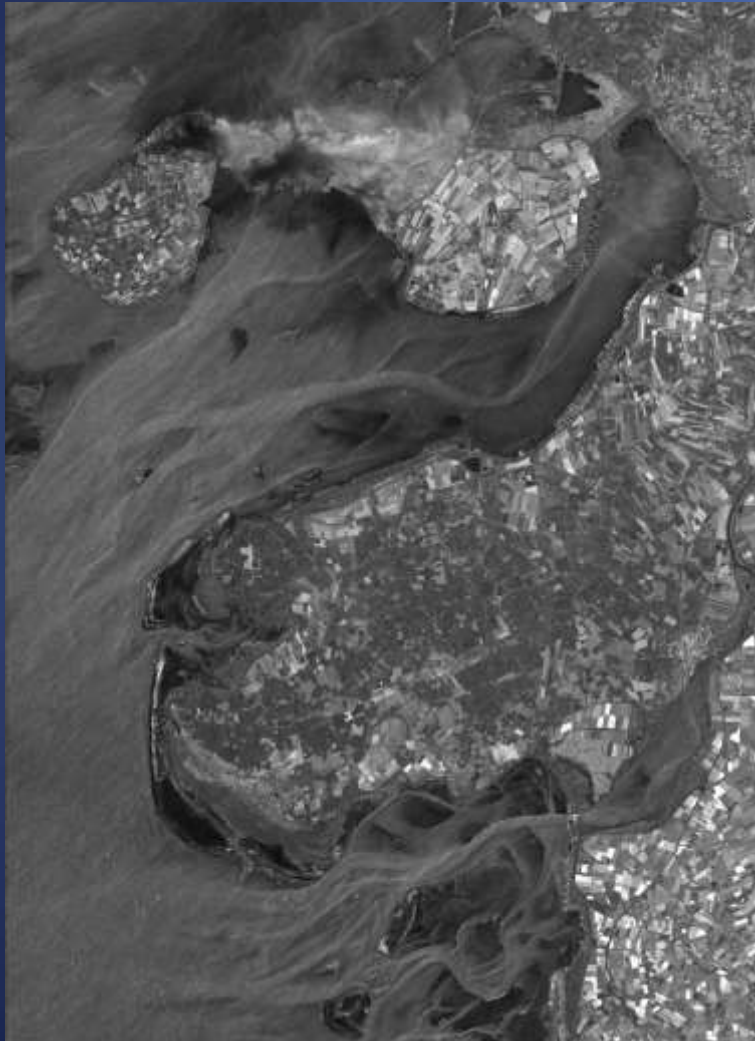
SAR Imaging at different radar frequencies and radar polarizations



SIR-C/X-SAR Images (16 km × 18 km)
Northern Straits of Malacca
(17 April 1994, 18:47 UTC)

[Jackson & Apel, 2004]

Comparison of SAR Imagery and Weather Radar



TerraSAR-X Image (X-VV, 30 km \times 40 km)
German Bight
21 August 2008, 05:50 UTC,   DLR



Rain

Take-Home Messages

Heavy rain visible (surface & atmosphere)
Turbulence: wave damping
Splash products: roughness generation





to be continued...