SAR Maritime Applications

Wind and Waves

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SAR Maritime Applications

Friday, 3 June, 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, 3 June, Afternoon:

3 - Currents and Objects
- Surface Currents
- Sea Bottom Topography
- Ship Detection
- Oil Pollution Monitoring
- Sea Ice

4 - Practicals
- SNAP Toolbox:
- Calibration, Georeferencing,
- Image Interpretation
- Wind Fields, Oil Pollution,
- Objects

SAR Wind Fields

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

Wind-Roughened Water Surface

Geophysical Model Function

CMOD4 (Stoffelen and Anderson, 1997)

$$\sigma_0 = b_0[1 + b_1 \cos\chi + b_3 \tanh(b_2 \cos 2\chi)]^{1.6}$$

with

$b_0 = c_r \times 10^{\alpha+\gamma\cdot f_1(U_{10}+\beta)}$

$f_1(y) = -10$ for $y \leq 10^{-10}$ (negligibly small winds)

$= \log y$ for $10^{-10} < y \leq 5$ (low to moderate winds)

$= \frac{\sqrt{y}}{3.2}$ for $y > 5$ (moderate to high winds)

$\alpha = c_1P_0 + c_2P_1 + c_3P_2$

$\gamma = c_4P_0 + c_5P_1 + c_6P_2$

$\beta = c_7P_0 + c_8P_1 + c_9P_2$

$b_1 = c_{10}P_0 + c_{11}U_{10} + (c_{12}P_0 + c_{13}U_{10})f_2(x)$

$b_2 = c_{14}P_0 + c_{15}(1 + P_1)U_{10}$

$b_3 = 0.42 \cdot [1 + c_{16}(c_{17} + x)(c_{18} + U_{10})]$

$f_2(x) = \tanh[2.5(x + 0.35)] - 0.61(x + 0.35)$

$P_0 = 1$ $P_1 = x$ $P_2 = \frac{3x^2-1}{2}$ $x = \frac{\theta-40}{25}$

c_n: coefficients c_r: residual correction term

Microwave Basics

Radar backscattering from the sea surface

[Robinson, 2003]

(a) specular

(b) Bragg

(c) edges & shadowing

SAR Wind Fields

Measuring wind speed and direction

[Jackson and Apel, 2004]

SAR Wind Fields

Measuring wind speed and direction

[Jackson and Apel, 2004]

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 × 600 km) - Bering Sea (16 January 2001, 18:21 UTC, © CSA)

Storms & Tropical Cyclones

e: eye
p: precipitation
s: convective cells

Hurricane *Floyd*

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

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*

NOAA Weather Radar

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]

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

Propagation direction of the ocean waves is important!

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]

[Jackson and Apel, 2004]

Propagation direction of the ocean waves is important!

SAR Imaging of Ocean Surface Waves

Velocity bunching

[Jackson and Apel, 2004]

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

SAR Imaging of Ocean Surface Waves

Wave refraction

[Jackson & Apel, 2004]

Radarsat-1 SAR Image (C-HH, 29 km × 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

θ = 25°, (R/V) = 30 s, H_s = 1 m

θ = 25°, (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 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)
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

[Robinson, 2010]

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

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, 2010]

[Robinson, 2003]

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

[Jackson et al., 2013]

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)

Oceanic Internal Waves
Take-Home Messages

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

Surface roughness variations

Marine Surface Films

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

palmitic acid methyl ester (PME)

oleyl alcohol (OLA)

triolein (TOLG)

Model Substances represent main components of natural marine surface films

Hydrophobic part (long alcyl chain) – Hydrophilic head group

Substances accumulate at the water surface as monomolecular film

Monomolecular Surface Films

Monomolecular Surface Films

[Gade, 1998]

[Gade, 1998]

Measured radar contrast

left: X band (9.8 GHz, λ_B = 3 cm) right: Ka band (37 GHz, λ_B = 0.8 cm)

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]

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

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

[Jackson & Apel, 2004]

Downdraft

[Jackson & Apel, 2004]

Heavy Rain

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

[Jackson & Apel, 2004]

Downdraft

[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

[Braun, 2002]

wind only

wind and rain

Damping of long waves (f < 5 Hz)

Generation of short waves (f > 5 Hz)

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 × 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

"There've been reports of an increase in chatter among the women."

to be continued…