SAR Marine Applications

History and Basics

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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 History

Radar History

1864	**J.C. Maxwell**: EM Field, Maxwell Equations
1885-88	**H. Hertz**: classical experiments with radio waves (455 MHz)
1900s	**C. Hülsmeyer**: first monostatic pulse radar
1919	**R.A. Watson-Watt**: patent for radio detection of objects
1922	**S.G. Marconi**: radio detection of targets **A.H. Taylor & L.C. Young**: detection of wooden ship on Potomac river
1930s	radar „rediscovered“ in frame of pre-WWII armament operational military radar to detect bigger ships and aircraft (bombers) independent research in Germany, U.K., U.S., Italy, USSR, France, Japan, Netherlands
1940s	microwave magnetron (higher frequencies = smaller antennas) military applications during WWII and shortly after
1950s	Doppler radar Synthetic Aperture Radar (SAR) invented at Goodyear Aircraft Corporation Pulse compression Phased array antenna
after	Growing civil and scientific applications Digital signal processing

Radar Basics

Band Designation	Nominal Frequency Range	Specific Frequency Range (ITU)
HF	3 - 30 MHz	
VHF	30 - 300 MHz	138 - 144 MHz 216 - 225 MHz
UHF	300 - 1000 MHz	420 – 450 MHz 850 – 942 MHz
L	1 – 2 GHz	1215 – 1400 MHz
S	2 – 4 GHz	2300 – 2500 MHz 2700 – 3700 MHz
C	4 – 8 GHz	5250 – 5925 MHz
X	8 – 12 GHz	8500 – 10680 MHz
Ku	12 – 18 GHz	13.4 – 14.0 GHz 15.7 – 17.7 GHz
K	18 – 27 GHz	24.05 – 24.25 GHz
Ka	27 – 40 GHz	33.4 – 36 GHz
V	40 – 75 GHz	59 – 64 GHz
W	75 – 110 GHz	76 – 81 GHz 92 – 100 GHz
mm	110 – 300 GHz	126 – 142 GHz 144 – 149 GHz 231 – 235 GHz 238 – 248 GHz

[Skolnik, 2001]

SAR History

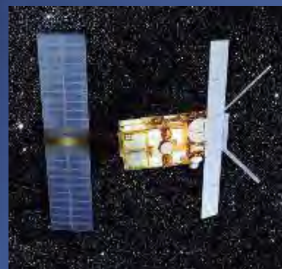
1951	**C. Wiley** (Goodyear): Postulation of Doppler beam-sharpening concept
1952	Beam-sharpening concept demonstrated at U Illinois
1957	First SAR imagery (U Michigan; optical correlator)
1964	Analog electronic SAR correlation (U Michigan)
1969	Digital electronic SAR correlation (Hughes, Goodyear, Westinghouse)
1972	Real-time digital SAR demonstrated; motion compensation (aircraft systems)
1978	Spaceborne SAR aboard SEASAT (analog downlink, optical processing, non-real time)
1981	Shuttle Imaging Radar (SIR) -A (optical processing on ground, non-real time)
1984	SIR-B (digital downlink, digital processing, non-real time)
1986	Spaceborne SAR real-time processing (JPL)
1987	Soviet 1870 SAR
1990	Magellan SAR imagery of Venus
> 1990	More spaceborne SAR sensors in orbit

Spaceborne SAR History

Year	Satellite	Band	Incid.Angle	Polarization
1978	SEASAT (USA)	L (1.3 GHz)	23°	HH
1981	SIR-A (USA)	L (1.3 GHz)	50°	HH
1984	SIR-B (USA)	L (1.3 GHz)	15°-65°	HH
1991	ERS-1 (Europe)	C (5.3 GHz)	23°	VV
1991	ALMAZ-1 (USSR)	S (3.0 GHz)	30°-60°	HH
1992	JERS-1 (Japan)	L (1.3 GHz)	39°	HH
1994	SIR-C/X-SAR (USA, Germany)	L (1.3 GHz), C (5.3 GHz), X (9.6 GHz)	15°-55°	HH, HV, VV, VH (SIR-C), VV (X-SAR)
1995	ERS-2 (Europe)	C (5.3 GHz)	23°	VV
1995	Radarsat-1 (Canada)	C (5.3 GHz)	20°-50°	HH
2000	SRTM (USA, Germany)	C (5.3 GHz), X (9.6 GHz)	54°	HH, VV (C), VV (X)
2002	ENVISAT (Europe)	C (5.3 GHz)	15°-45°	HH, HV, VV, VH
2006	ALOS-1 (Japan)	L (1.3 GHz)	8°-60°	HH, HV, VV, VH
2007	TerraSAR-X (Germany)	X (9.7 GHz)	15°-60°	HH, HV, VV, VH
2007	Radarsat-2 (Canada)	C (5.3 GHz)	10°-60°	HH, HV, VV, VH
2007-10	COSMO-SkyMed 1-4 (Italy)	X (9.6 GHz)	20°-59°	HH, HV, VV, VH
2010	TanDEM-X (Germany)	X (9.7 GHz)	15°-60°	HH, HV, VV, VH
2014	ALOS-2 (Japan)	L (1.3 GHz)	8°-70°	HH, HV, VV, VH
2014	Sentinel-1A (Europe)	C (5.4 GHz)	20°-45°	HH-HV, VV-VH

Spaceborne SARs

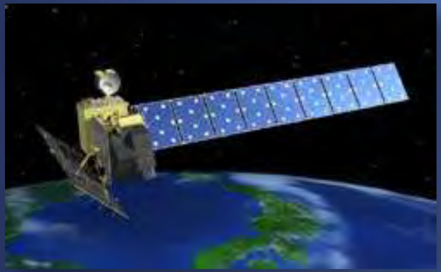

Seasat (1978)

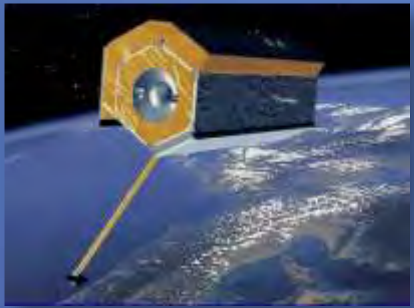

ERS-1/2 (1991/1995)


SIR-C/X-SAR (1994)

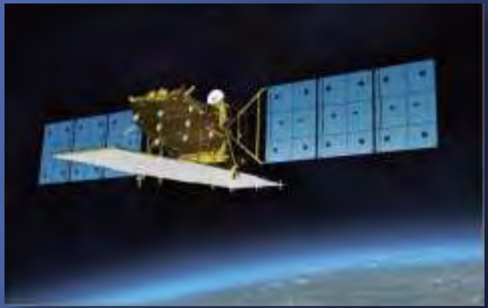

RADARSAT-1 (1995)


ENVISAT (2002)


ALOS-1 (2006)


TerraSAR/TanDEM-X (2007/10)


RADARSAT-2 (2007)


ALOS-2 (2014)


Cosmo Skymed 1-4 (2007-10)


Sentinel-1A (2014)

more SARs on, e.g., Indian, Chinese, German, Russian satellites

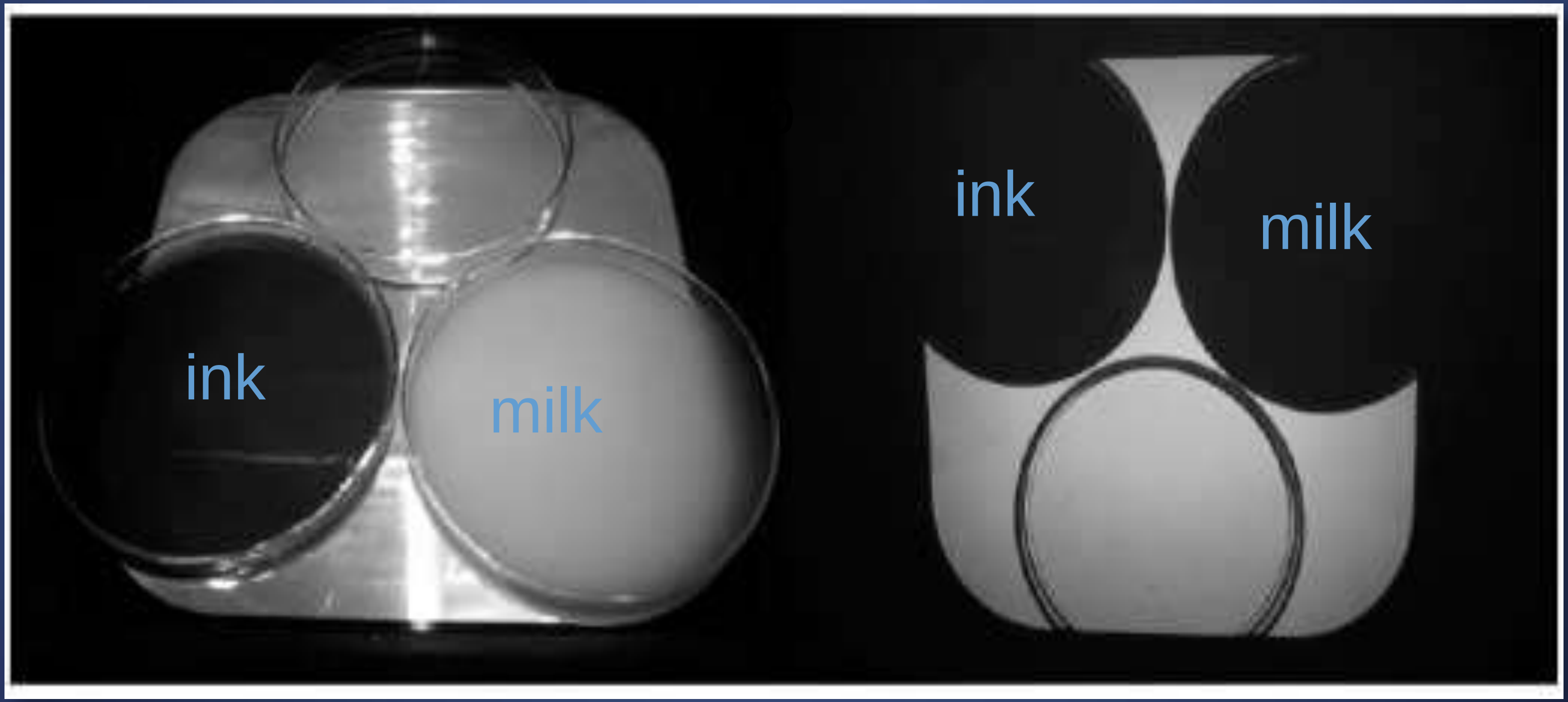
SAR History
Take-Home Messages

SAR ~ 60 years
1978 Seasat
>1991 continuous spaceborne SAR

Some Basics

Basics

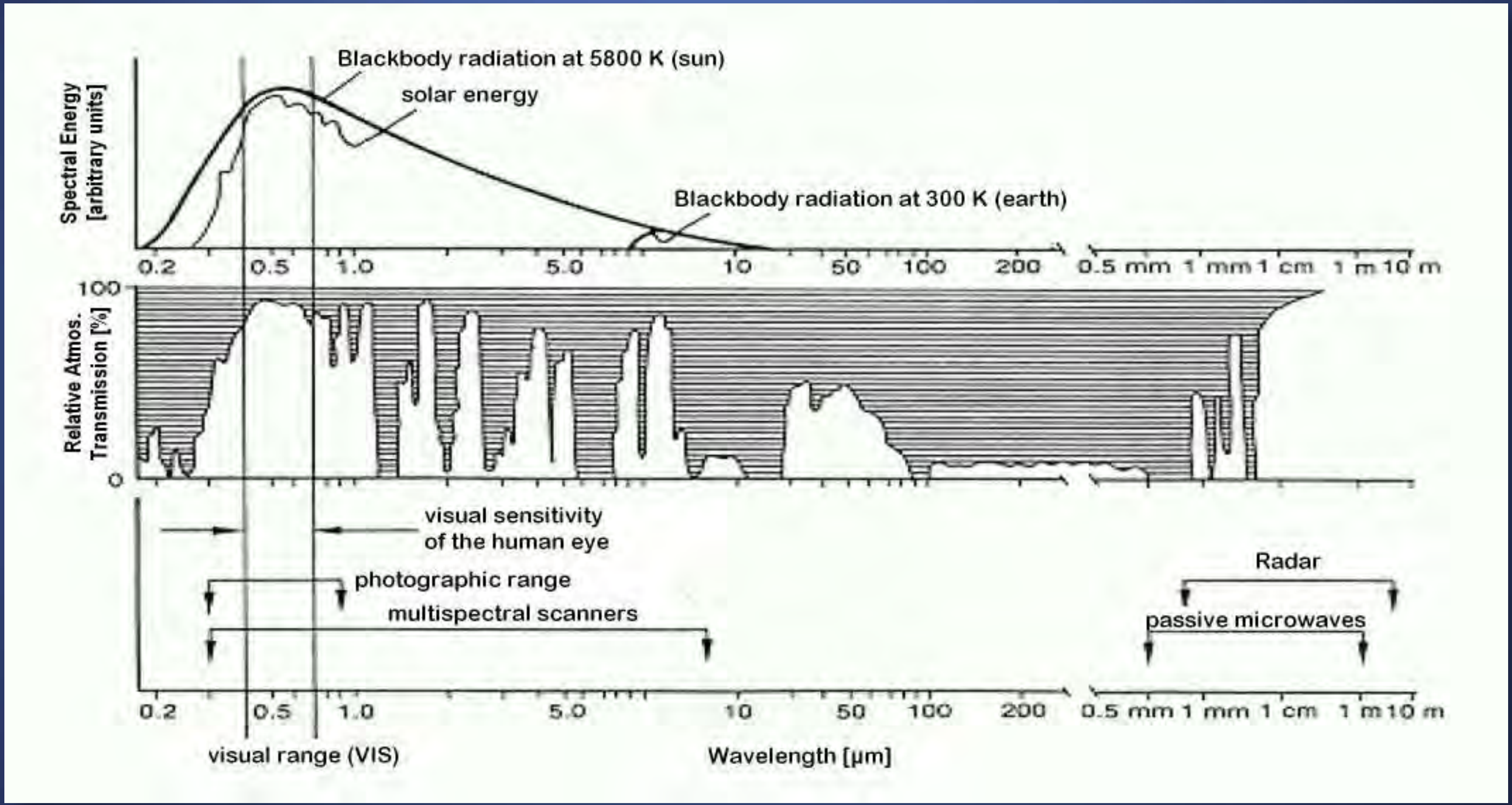
Absorption / Transmission / Scattering



[Petty, 2006]

Basics

Absorption of e/m waves in the atmosphere

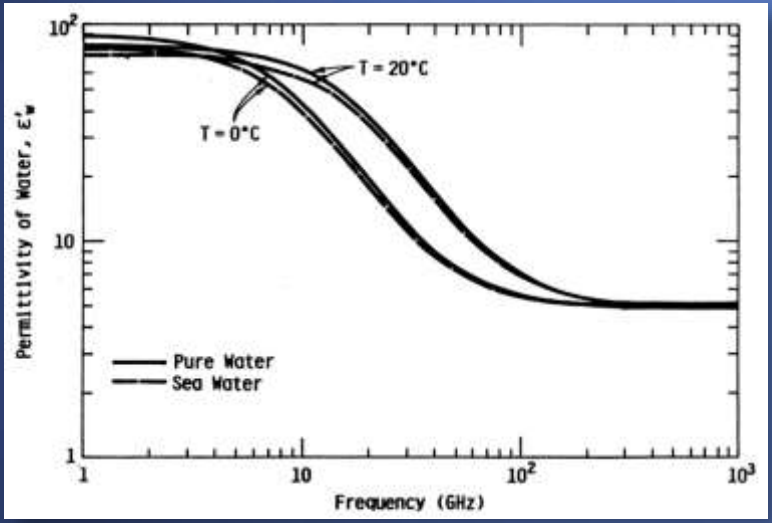


[Kappas, 1994]

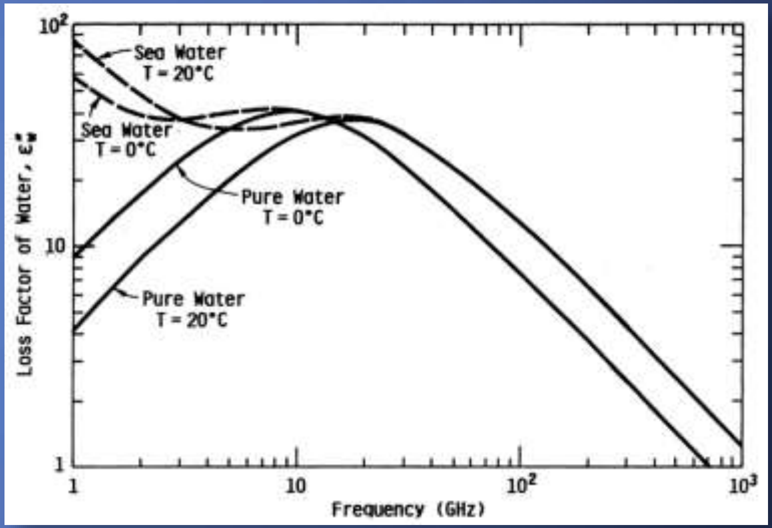
Microwave Basics

Complex dielectric constant of pure and sea water (32.45 ‰)

Real part (permittivity), ε'_w



Imaginary part (loss factor), ε''_w



[Jackson & Apel, 2004]

Complex dielectric constant, $\varepsilon_c = \varepsilon' - i\varepsilon''$: response to electromagnetic field

Loss tangent, $\tan\delta = \varepsilon''/\varepsilon'$: good ($\tan\delta$>>1) or poor ($\tan\delta$<<1) conductor

Microwave Basics

Penetration depth into water (1)

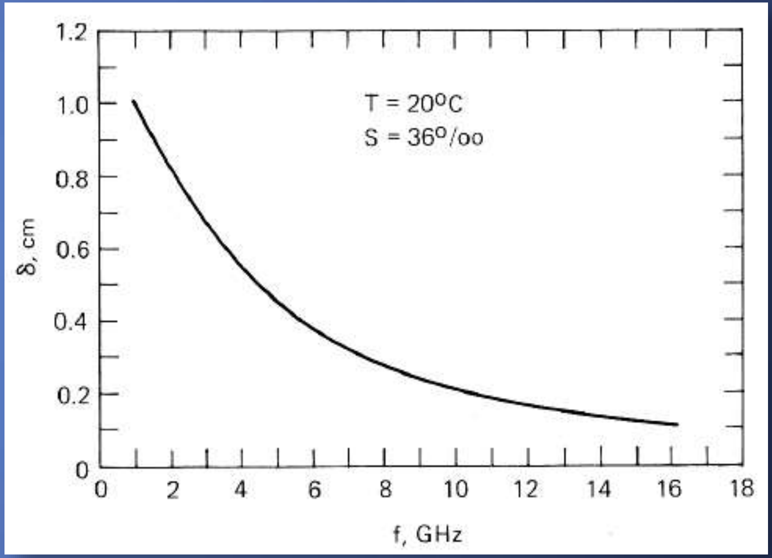
Plane wave propagation in lossy media, along direction ζ :

$$e^{-i\kappa\zeta} = e^{-\beta\zeta + i\alpha\zeta}$$

with attenuation coefficient β:

$$\beta = {}^{2\pi\,\Im(\sqrt{\varepsilon})}\big/_{\lambda_0}$$

Penetration depth δ = 1/β:
depth, at which power is reduced by e^{-2}.



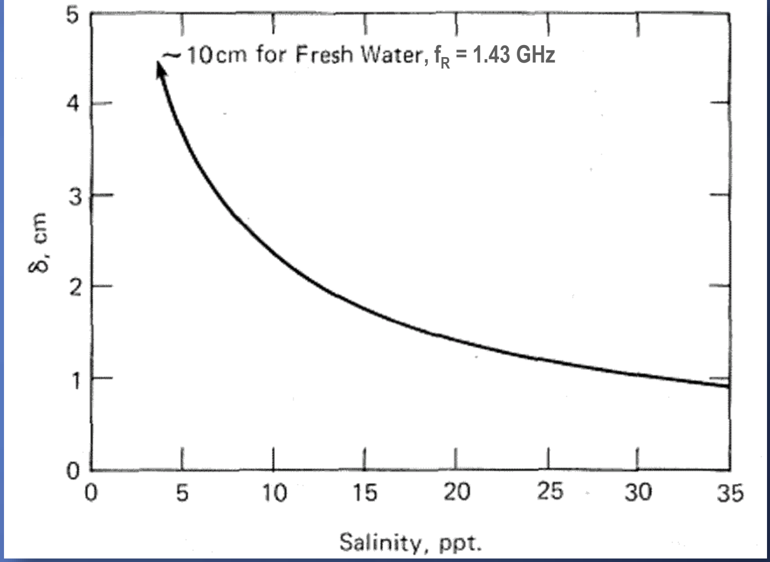
[Swift, 1980]

Microwave Basics

Penetration depth into water (2)

Penetration depth depends on
dielectric properties of sea water
and radar wavelength

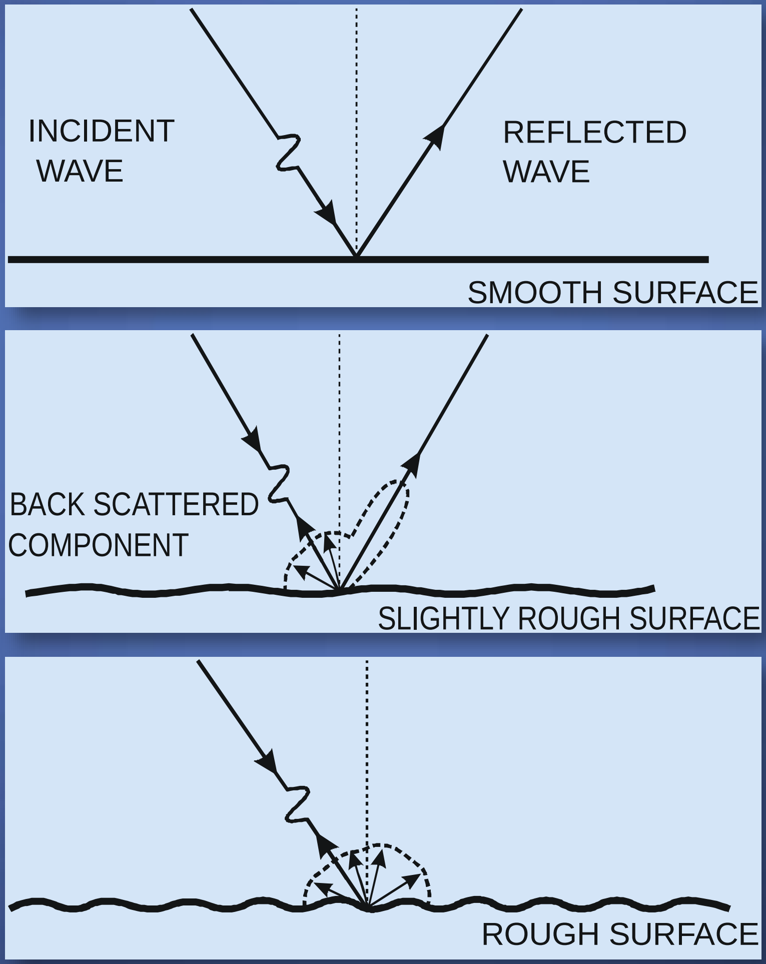
Dielectric properties depend on salinity
and temperature



[Swift, 1980]

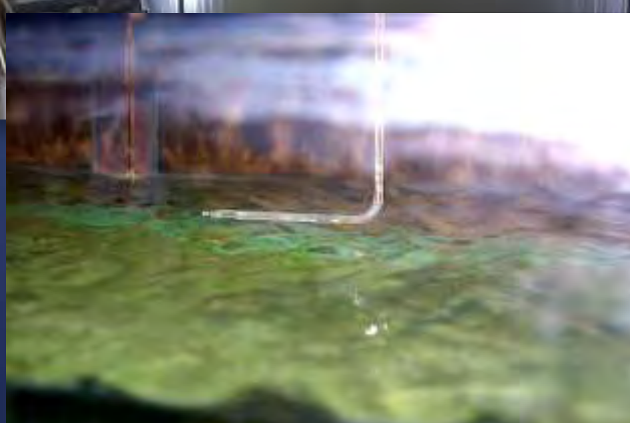
Microwave Basics

Surface scattering mechanisms



[Barale & Gade, 2008]

Wind-Wave Tank of the University of Hamburg



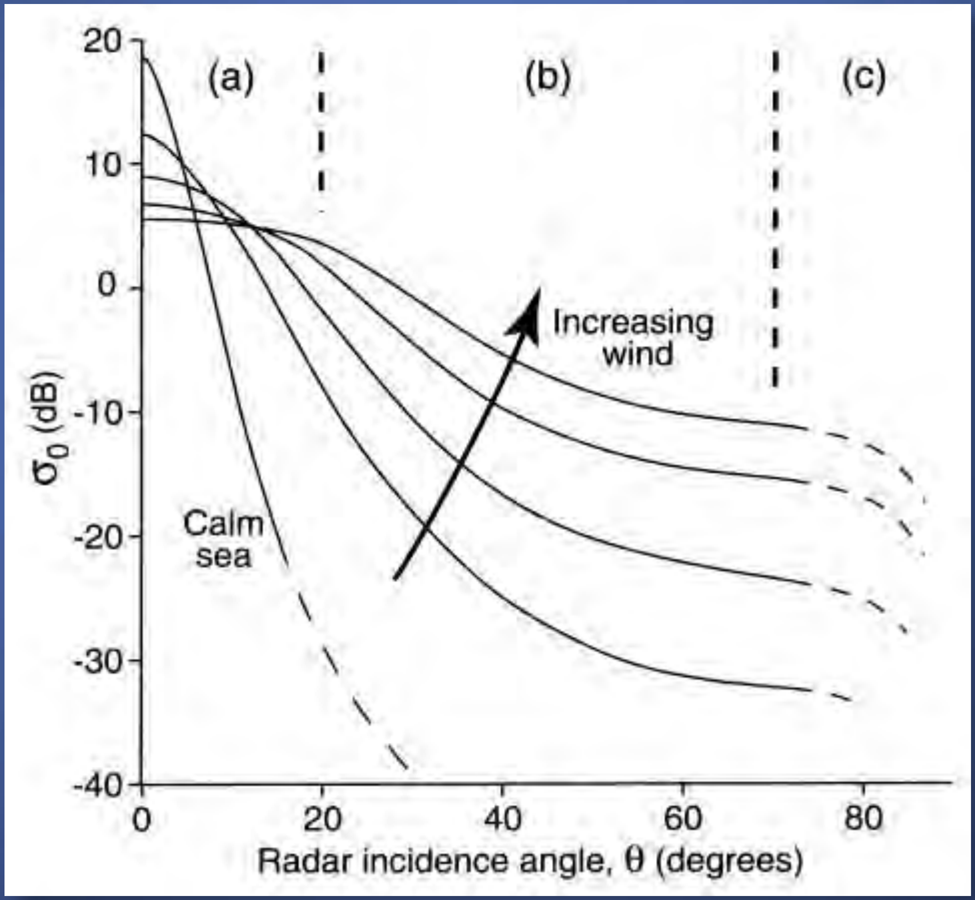
UHH's Wind-Wave Tank

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

Microwave Basics

Radar backscattering at the sea surface



[Robinson, 2003]

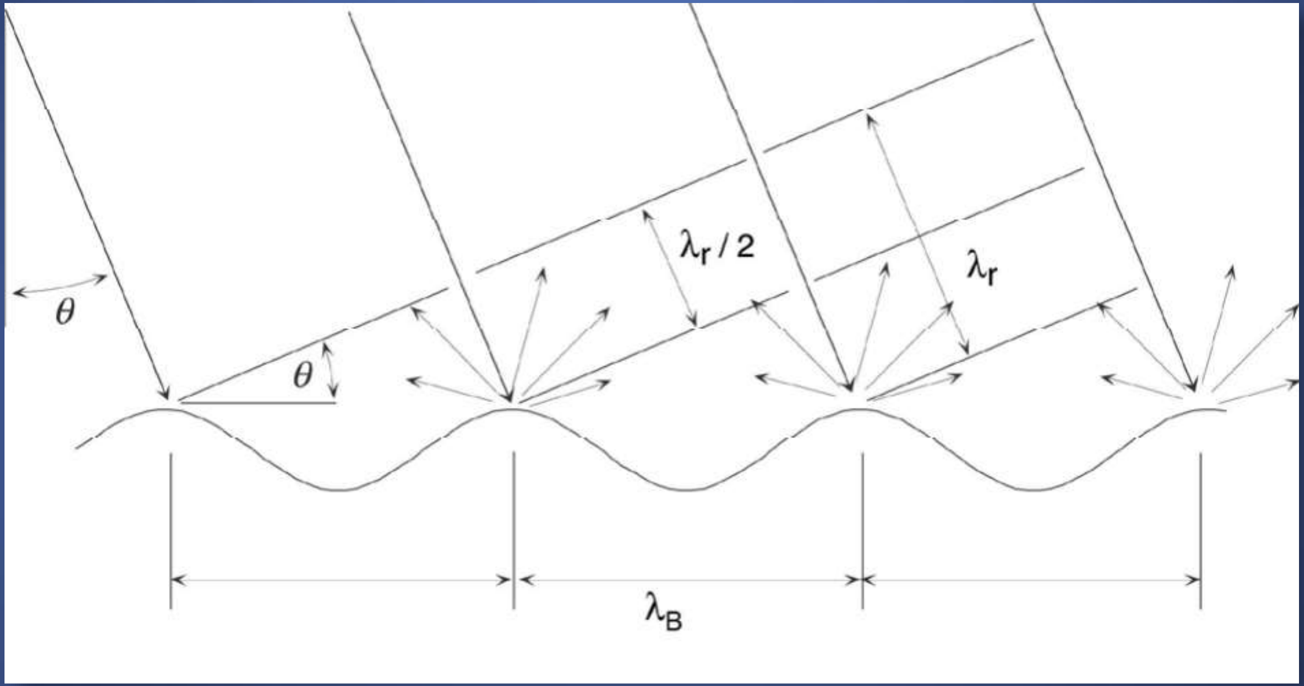
(a) specular

(b) Bragg

(c) edges & shadowing

Microwave Basics

Bragg Scattering

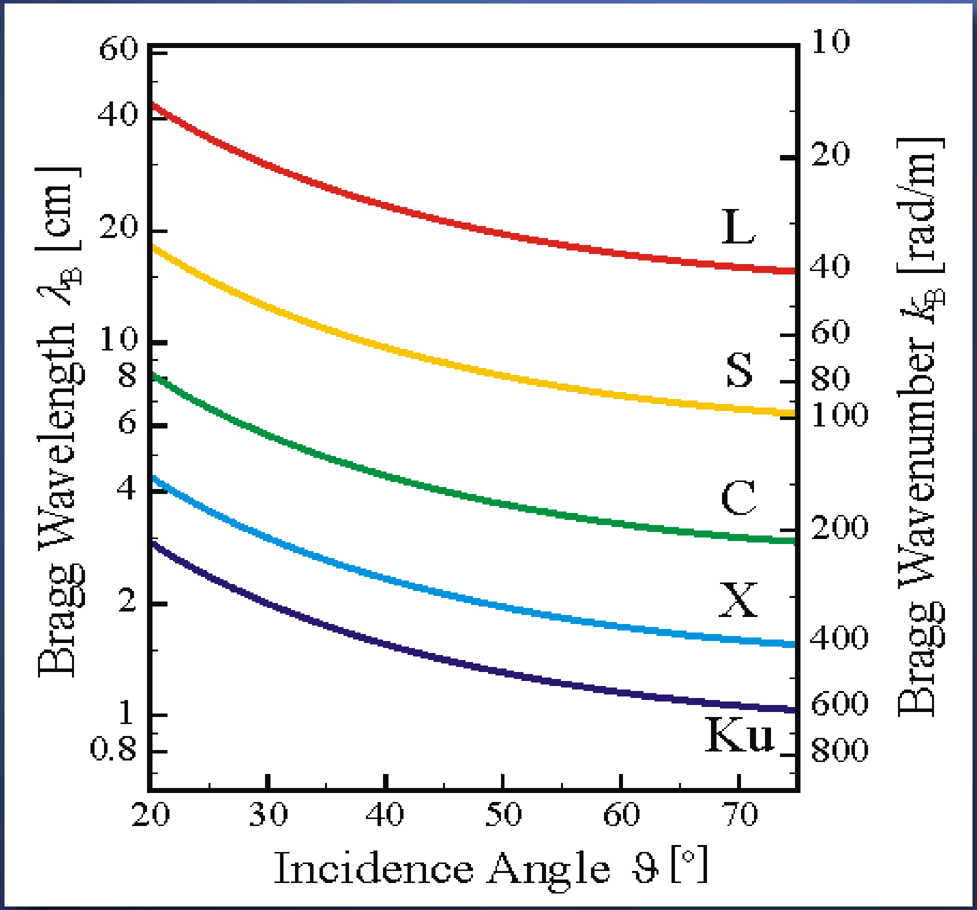


[Jackson & Apel, 2004]

$$k_B = \frac{2\pi}{\lambda_B} = \frac{4\pi \sin\theta}{\lambda_r} = 2k_r \sin\theta$$

Microwave Basics

Bragg Scattering



L : 1.25 GHz
S : 2.40 GHz
C : 5.30 GHz
X : 10.0 GHz
K_u : 15.0 GHz

$$k_B = 2k_r \sin\theta = \frac{4\pi \sin\theta}{\lambda_r}$$

Microwave Basics

Bragg Scattering

$$\sigma_0 = 8\pi k_e^4 \cos^4\theta_0 \left|b_{pp}(\theta_0)\right|^2 \left[\Psi\left(\vec{k}_B\right) + \Psi\left(-\vec{k}_B\right)\right]$$

k_e: electromagnetic wavenumber

θ_0: nominal incidence angle (20° .. 70°)

$\Psi(\vec{k})$: waveheight spectrum

Bragg wavenumber $k_B = 2k_e \sin\theta_0$

Polarization coefficients $b_{HH} = \frac{\varepsilon}{(\cos\theta_0 + \sqrt{\varepsilon})^2}$; $b_{VV} = \frac{\varepsilon^2(1+\sin^2\theta_0)}{(\varepsilon\cos\theta_0 + \sqrt{\varepsilon})^2}$

[Wright, 1968]

Geophysical Model Functions

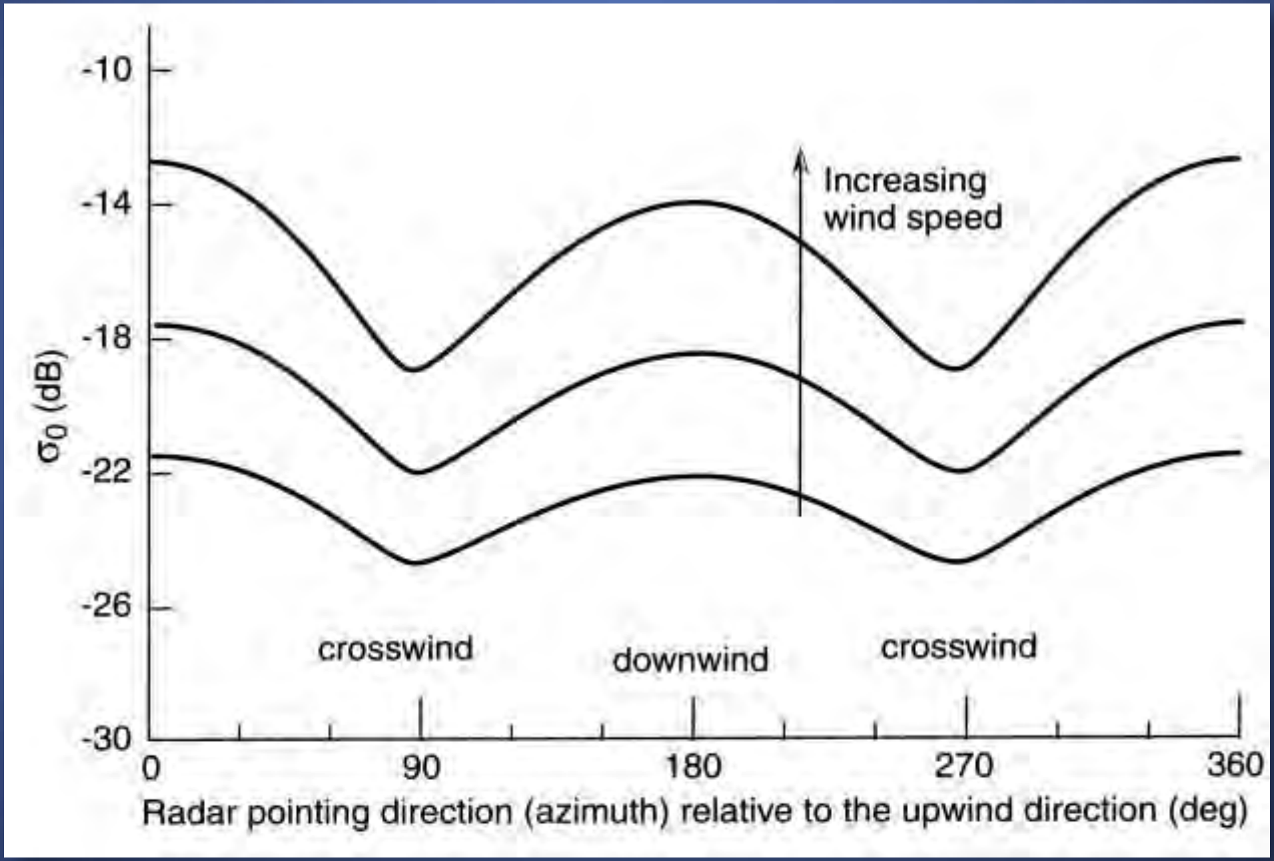
Dependence between radar cross section and wind speed and direction

$$\boldsymbol{\sigma_0 = A(f,p,\theta) \cdot U^{\gamma(f,p,\theta)} \cdot [1 + B(f,p,\theta)\cos\chi + C(f,p,\theta)\cos 2\chi]}$$

with
f : radar frequency
p : radar polarization
θ : incidence angle
U : wind speed (usually at 10m height)
χ : azimuth angle

Geophysical Model Functions

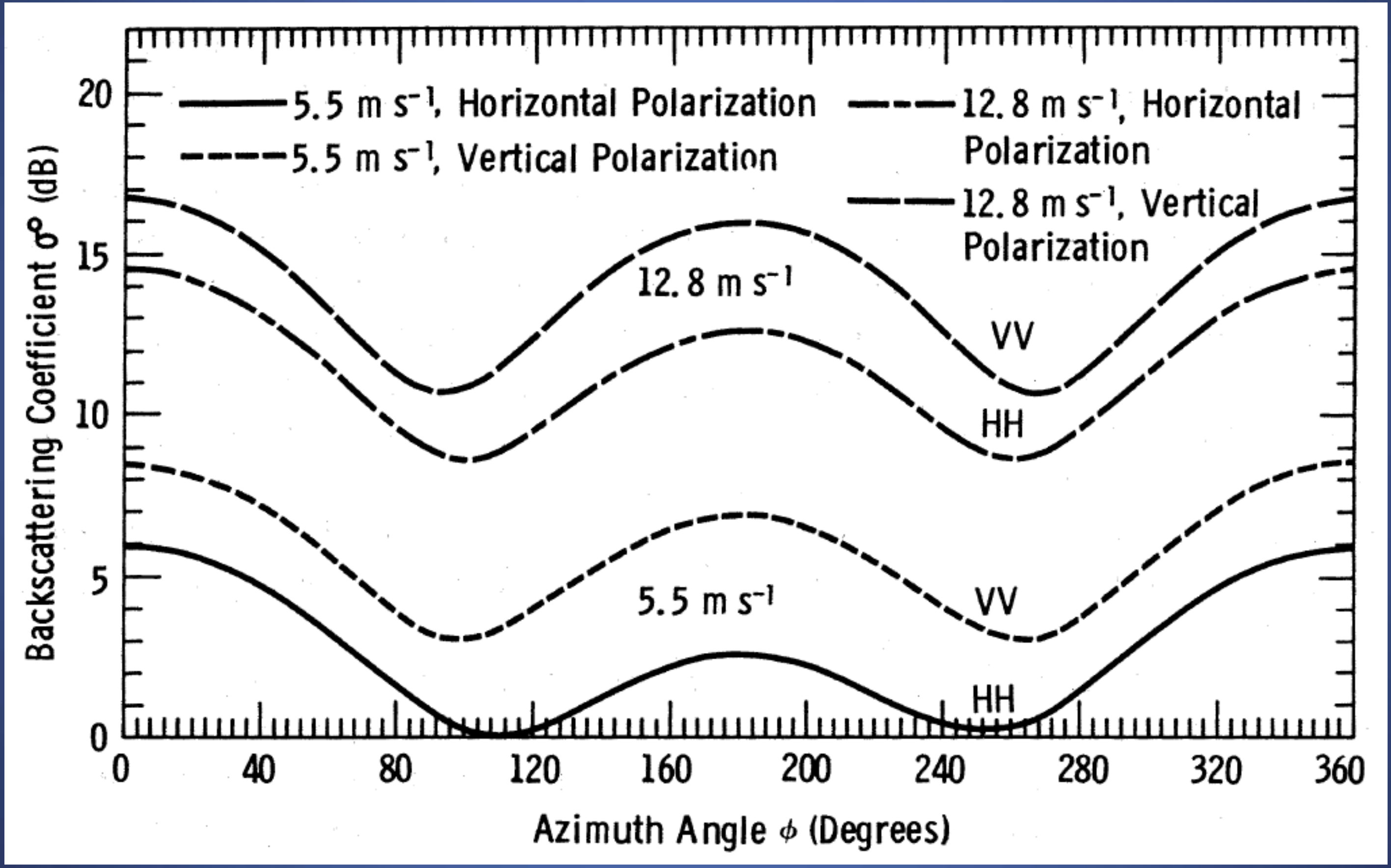
Measuring wind speed and direction



[Robinson, 2003]

Geophysical Model Functions

Measuring wind speed and direction



[Jackson and Apel, 2004]

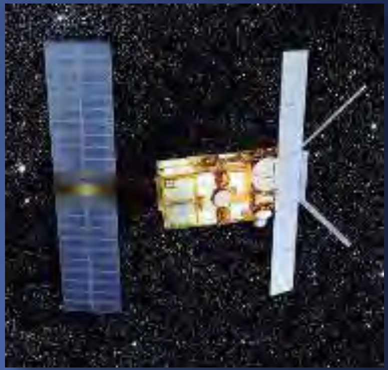
Excursion: Scatterometer

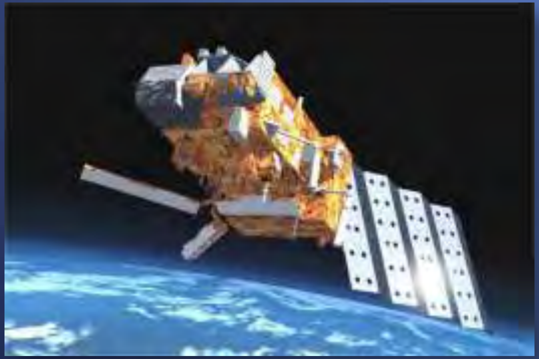
Scatterometer

Scatterometers aboard satellites


Seasat (1978)


QuikScat (1999)

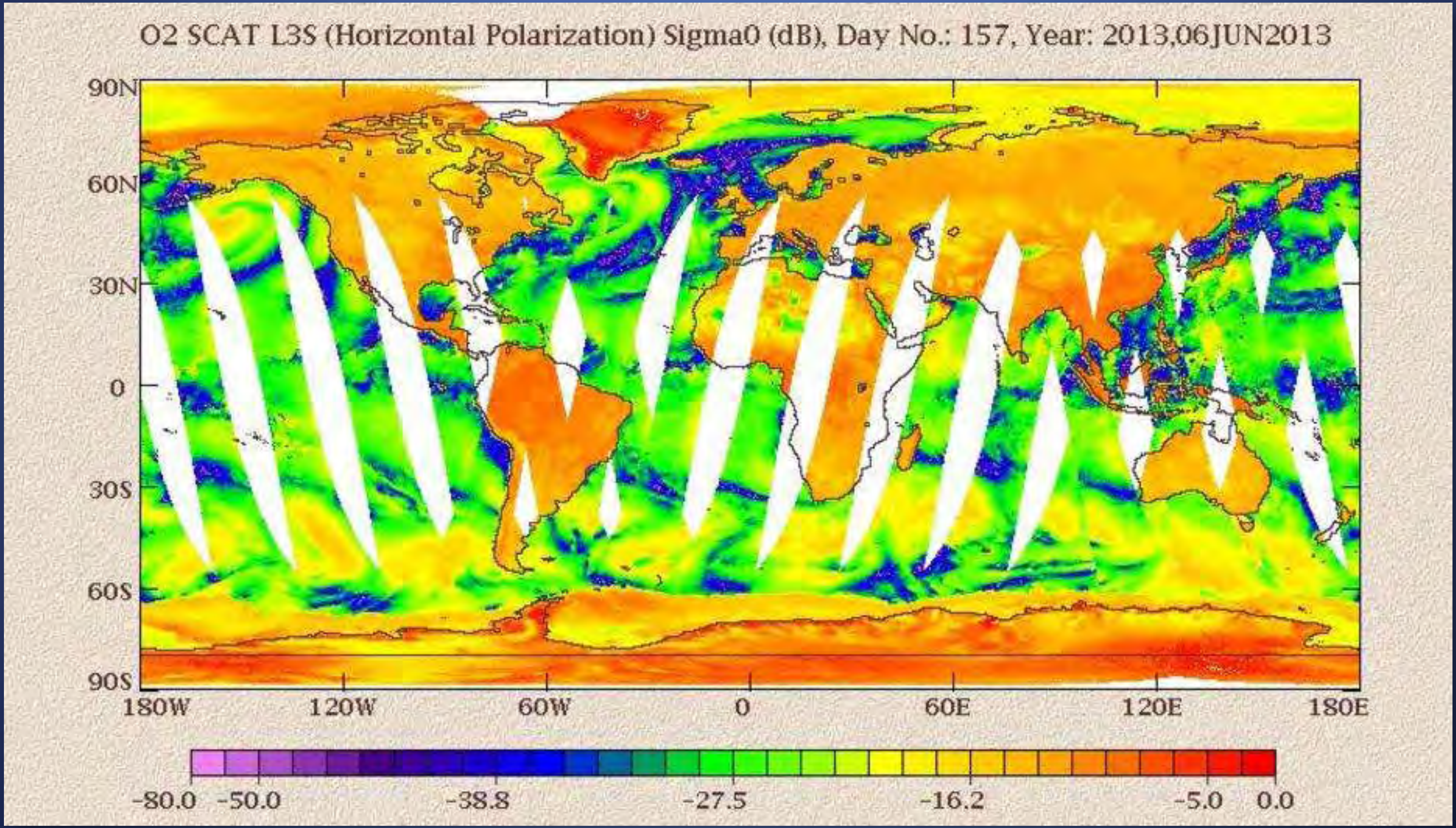

ERS-1/2 (1991 / 1995)


MetOp-A/B (2006 / 2012)


Oceansat-2 (2009)

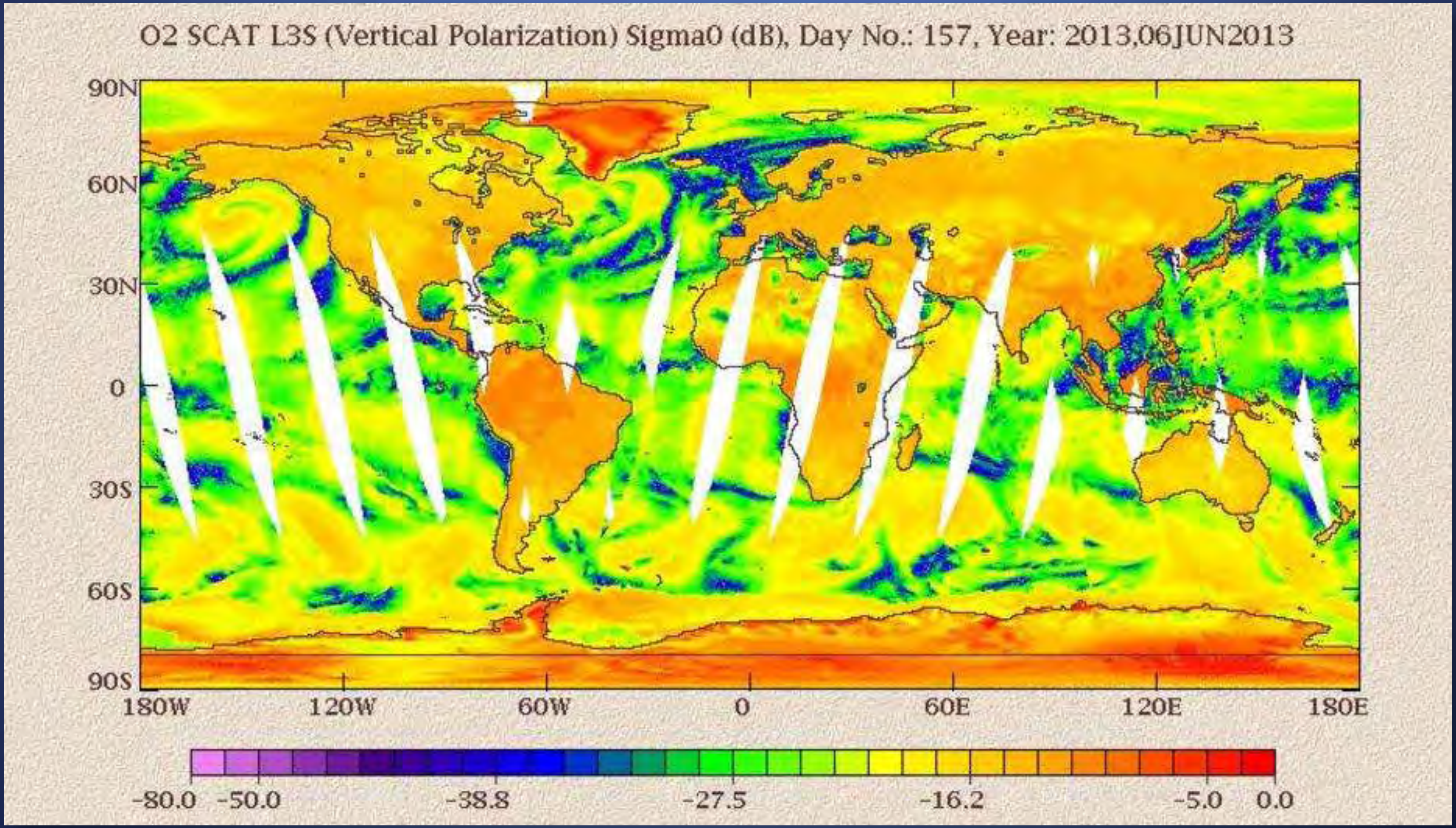
Scatterometer

One single day of Oceansat-2 NRCS (HH)



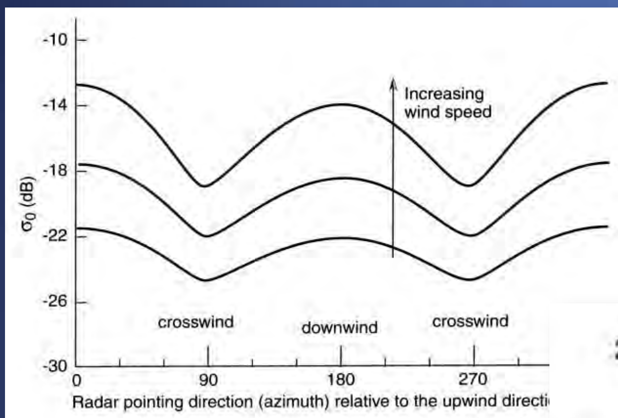
Scatterometer

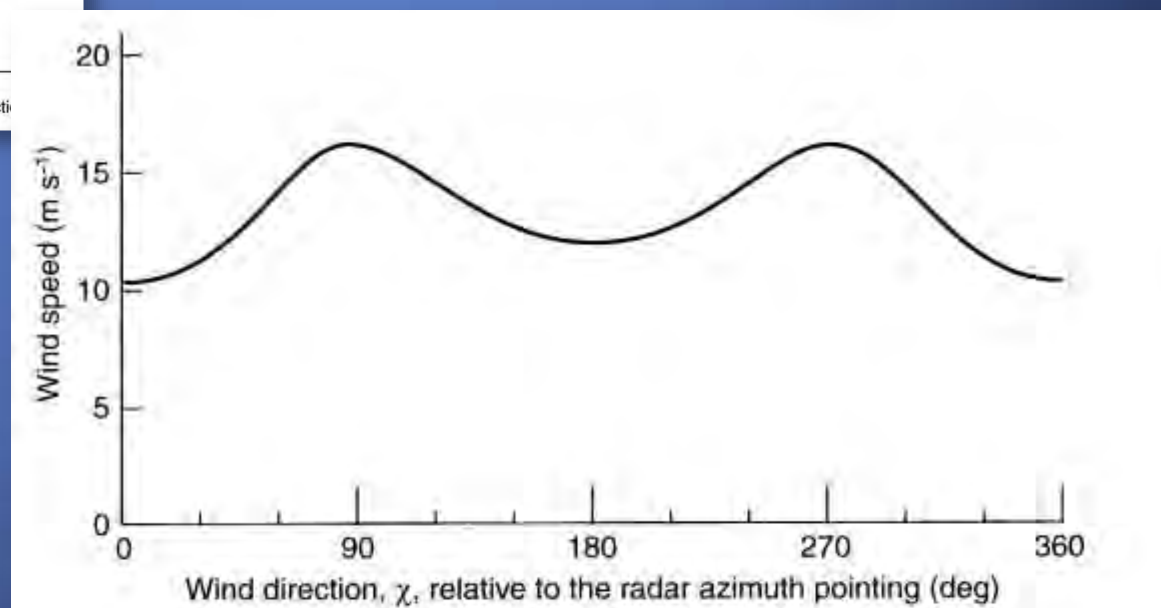
One single day of Oceansat-2 NRCS (VV)



Scatterometer

Measurement principle

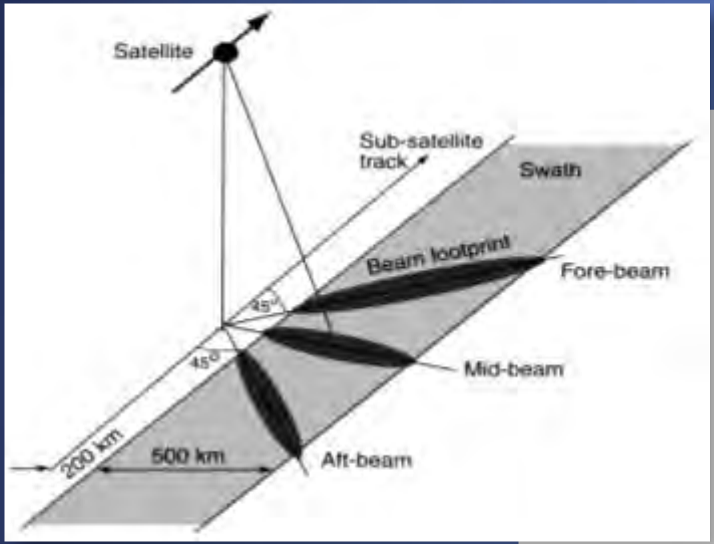


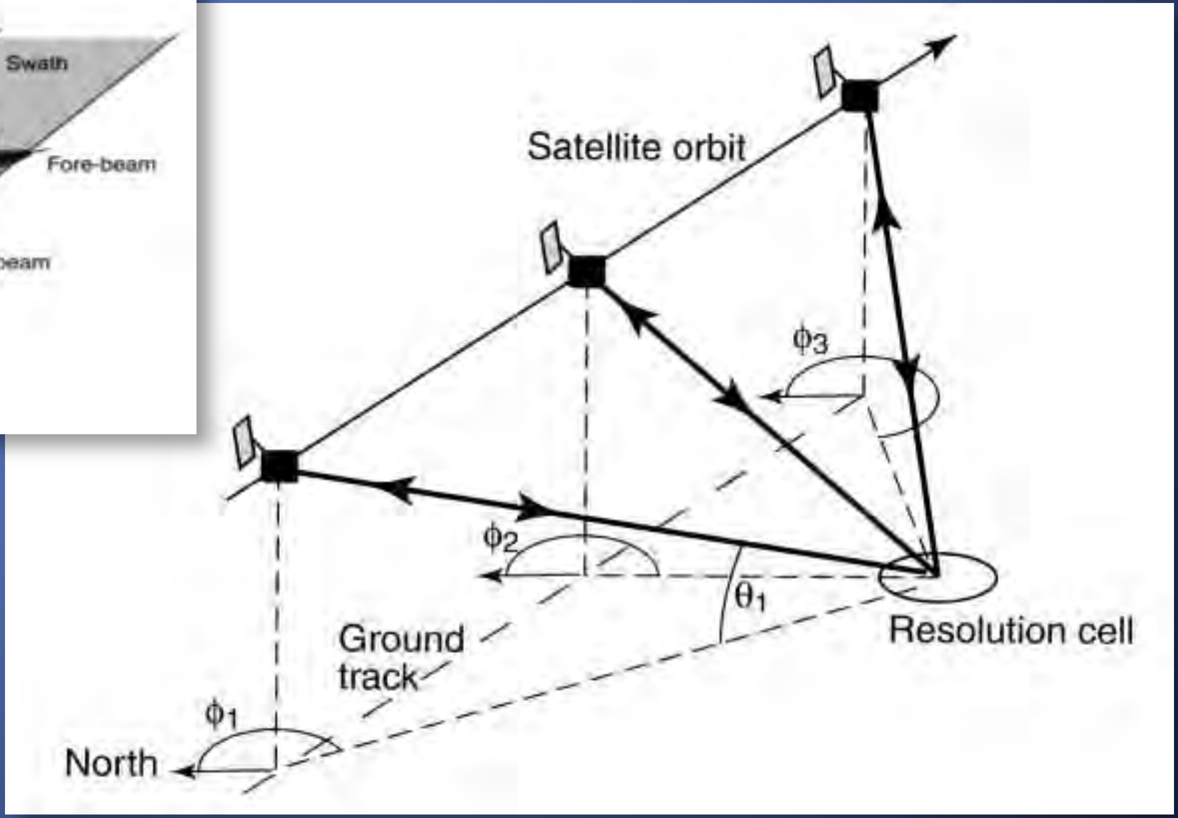


[Robinson, 2003]

Scatterometer

Measurement principle

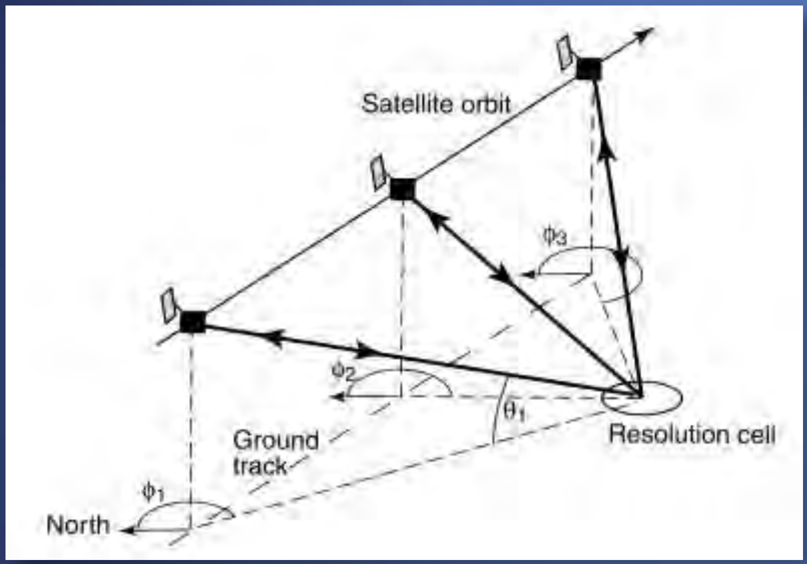


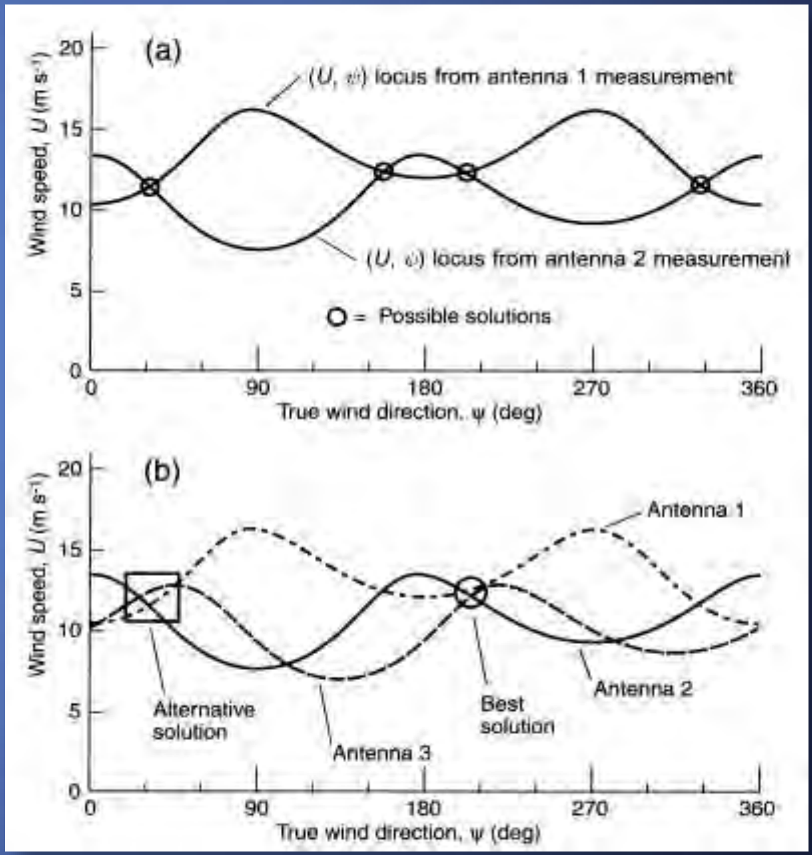


[Robinson, 2003]

Scatterometer

Measurement principle, ERS Scat

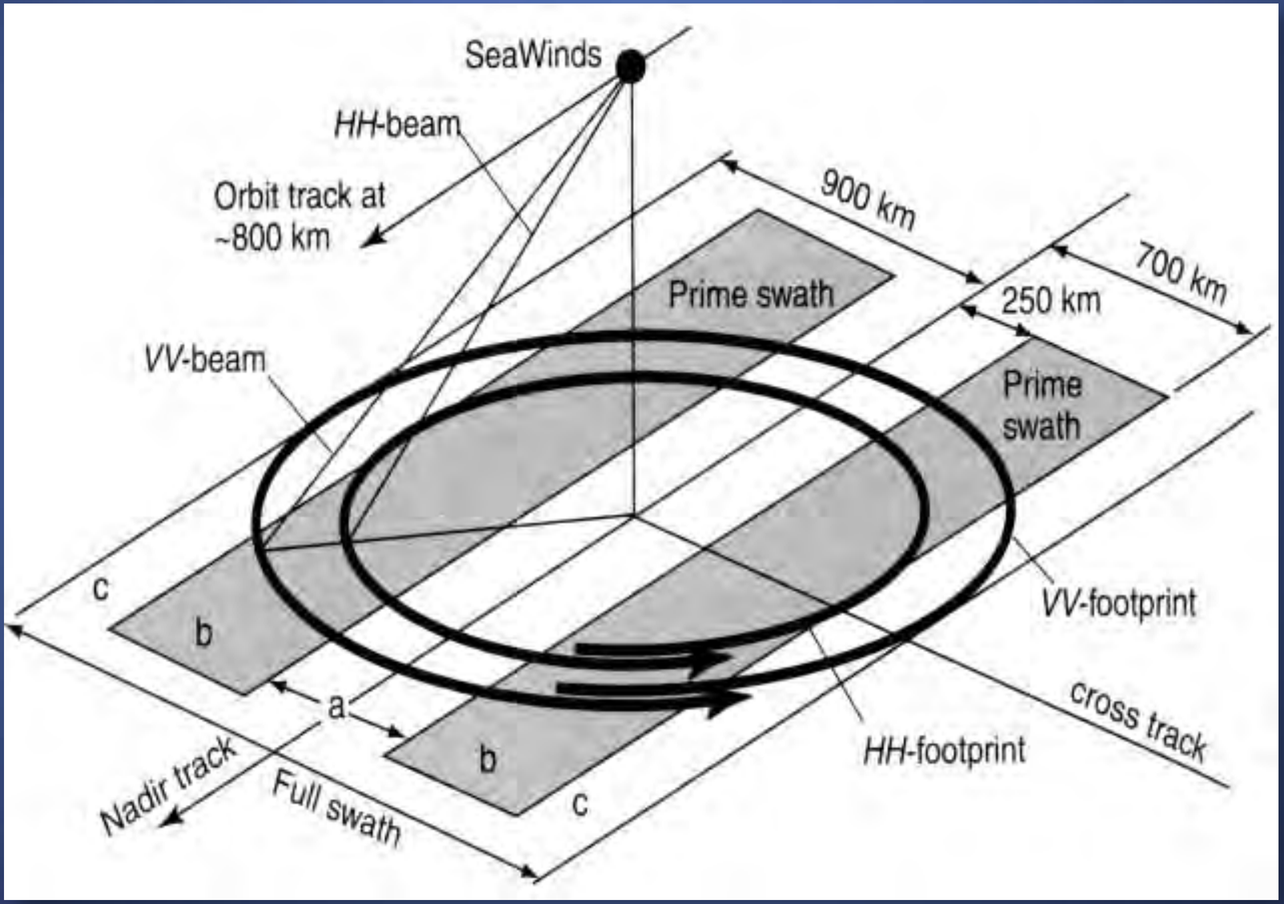




[Robinson, 2003]

Scatterometer

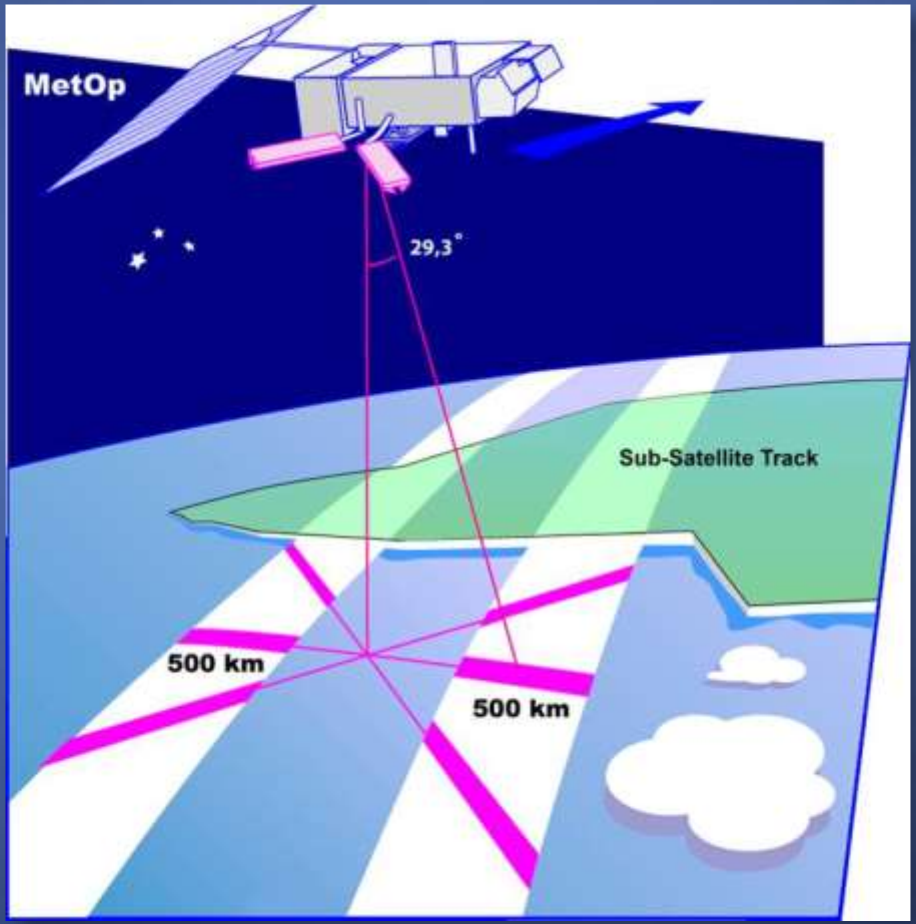
Measurement principle, Seawinds (QuikScat, OSCAT)



[Robinson, 2003]

Scatterometer

Measurement principle, ASCAT (MetOp)



[Eumetsat]

Geophysical Model Function

e.g. CMOD4 (Stoffelen and Anderson, 1997)

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

with

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

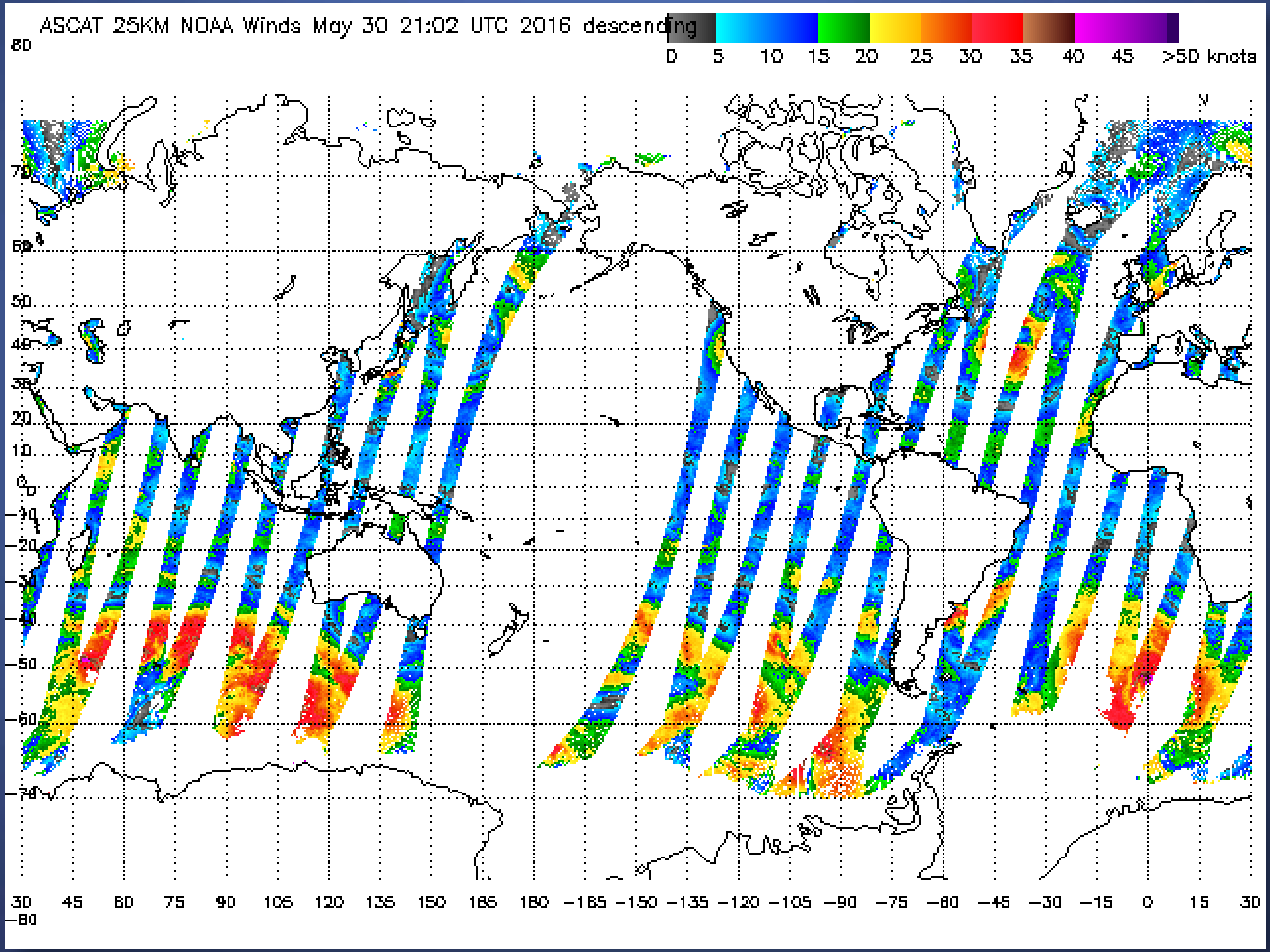
$f_1(y) = -10$	for $y \le 10^{-10}$	(negligibly small winds)
$= \log y$	for $10^{-10} < y \le 5$	(low to moderate winds)
$= \frac{\sqrt{y}}{3.2}$	for $y > 5$	(moderate to high winds)

$$\alpha = c_1 P_0 + c_2 P_1 + c_3 P_2$$
$$\gamma = c_4 P_0 + c_5 P_1 + c_6 P_2$$
$$\beta = c_7 P_0 + c_8 P_1 + c_9 P_2$$
$$b_1 = c_{10} P_0 + c_{11} U_{10} + (c_{12} P_0 + c_{13} U_{10}) f_2(x)$$
$$b_2 = c_{14} P_0 + c_{15}(1 + P_1) U_{10}$$
$$b_3 = 0.42 \cdot [1 + c_{16}(c_{17} + x)(c_{18} + U_{10})]$$
$$f_2(x) = \tanh[2.5(x + 0.35)] - 0.61(x + 0.35)$$
$$P_0 = 1 \qquad P_1 = x \qquad P_2 = \frac{3x^2 - 1}{2} \qquad x = \frac{\theta - 40}{25}$$

c_n: coefficients $\qquad$ c_r: residual correction term

Scatterometer

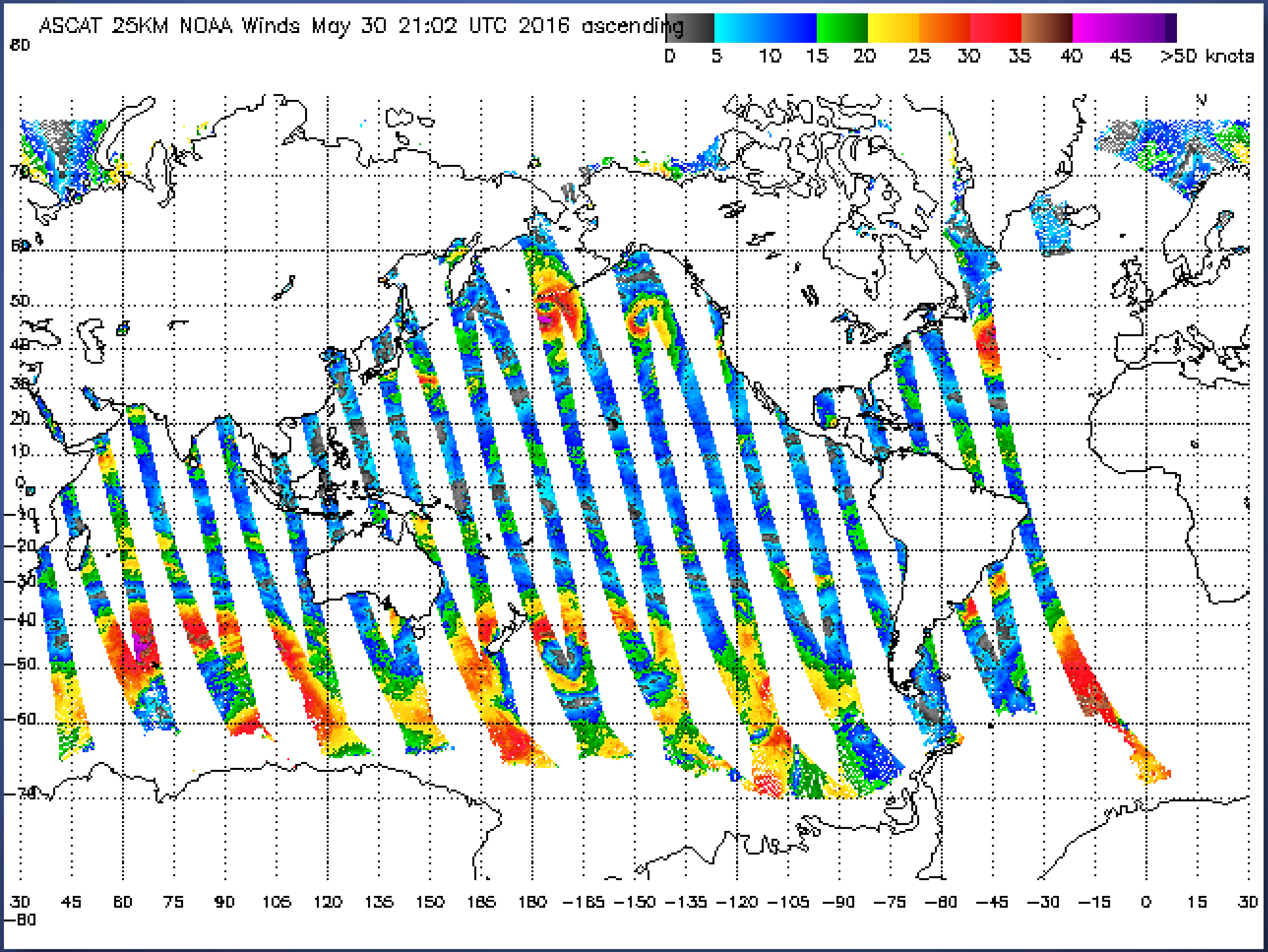
One day, descending orbits – MetOp-A ASCAT winds



[NOAA]

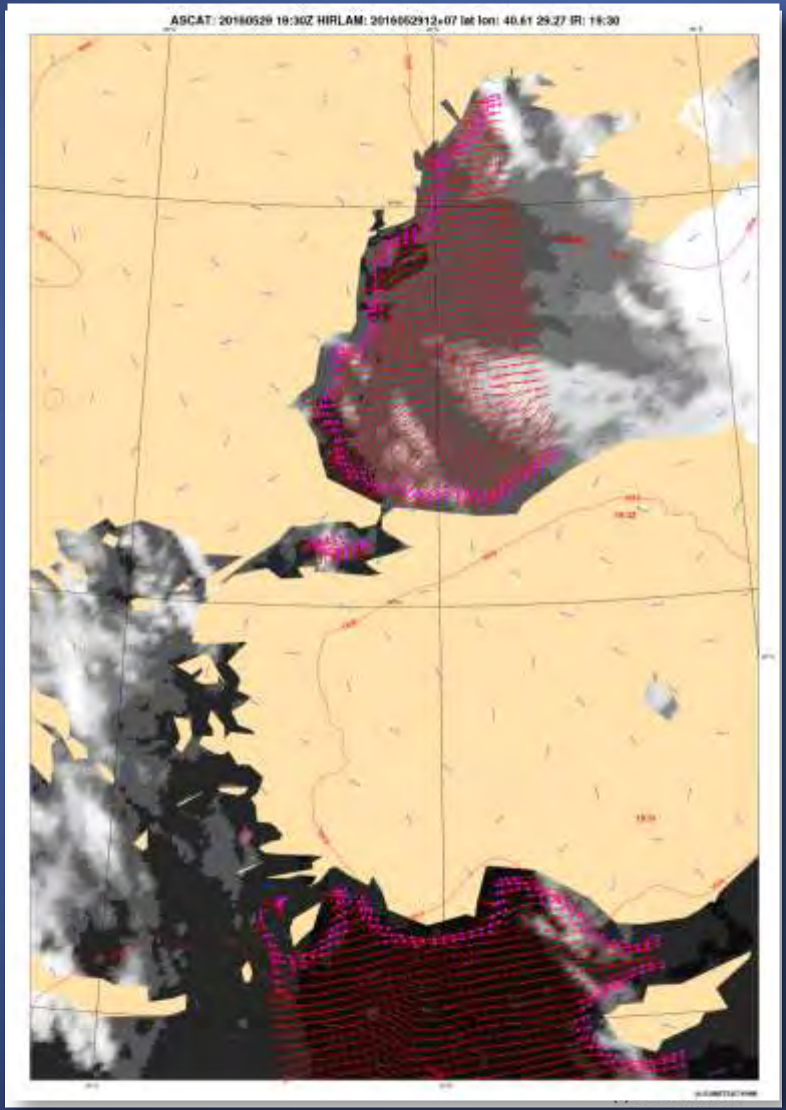
Scatterometer

One day, ascending orbits – MetOp-A ASCAT winds



[NOAA]

Scatterometer



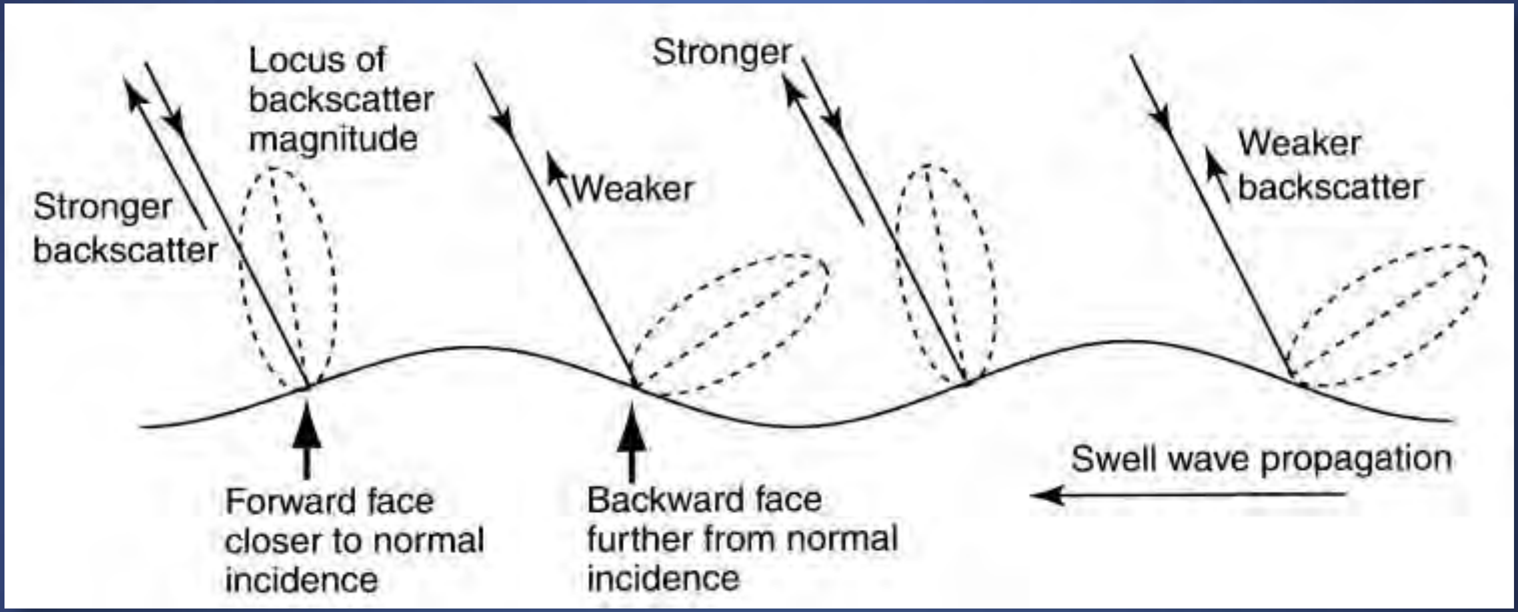
One ascending orbit
ASCAT coastal winds

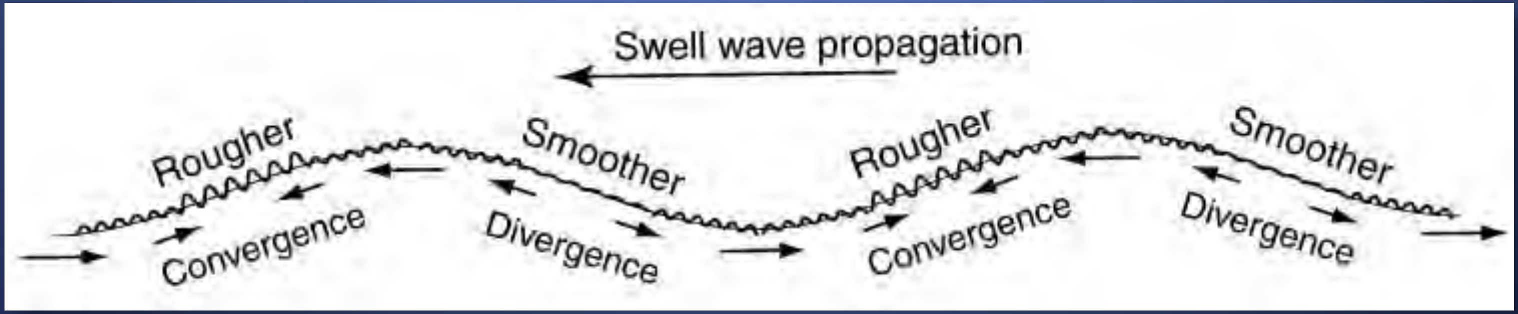
[EUMETSAT/KNMI]

back to Radar & SAR

Radar Backscattering from the Sea Surface

Tilt and hydrodynamic modulation

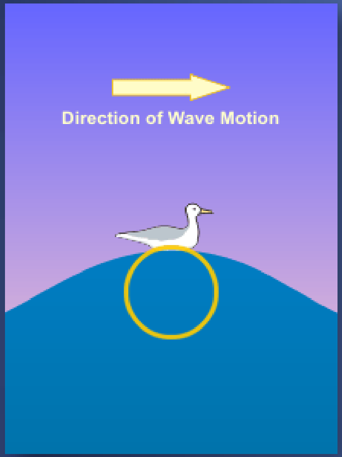




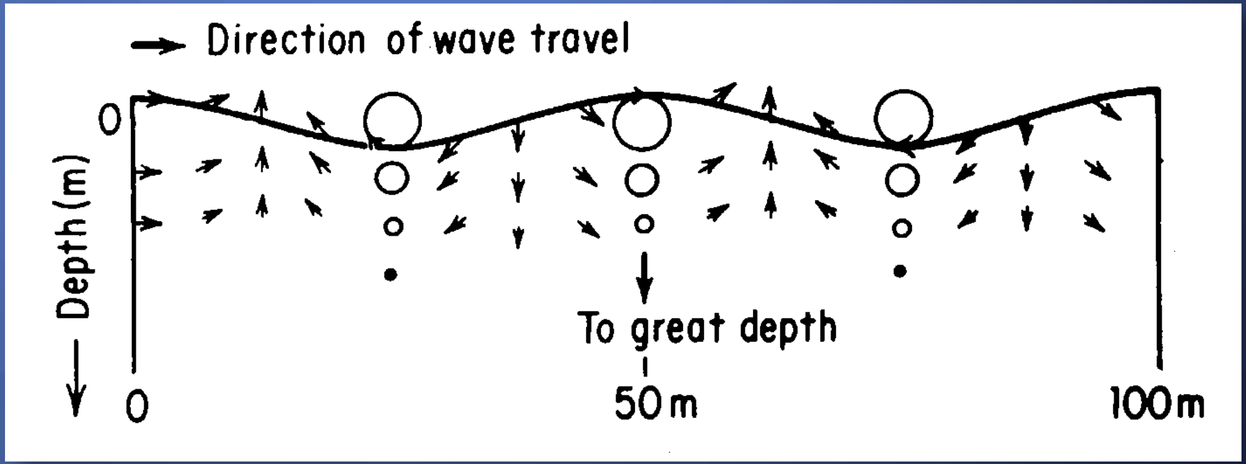
[Robinson, 2003]

Ocean Waves

Orbital motion of long ocean waves



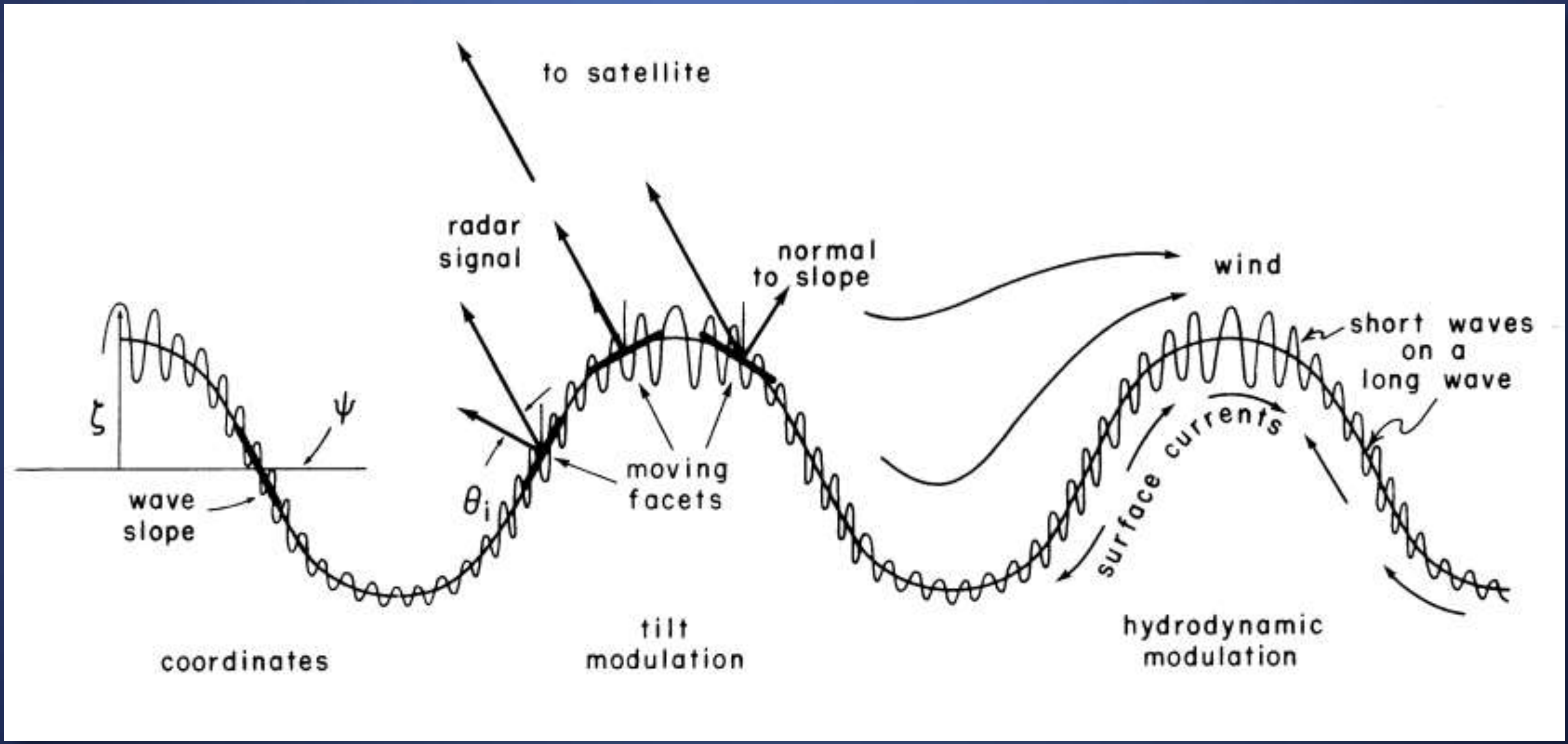
[NOAA]



[Jackson & Apel, 2004]

Radar Backscattering from the Sea Surface

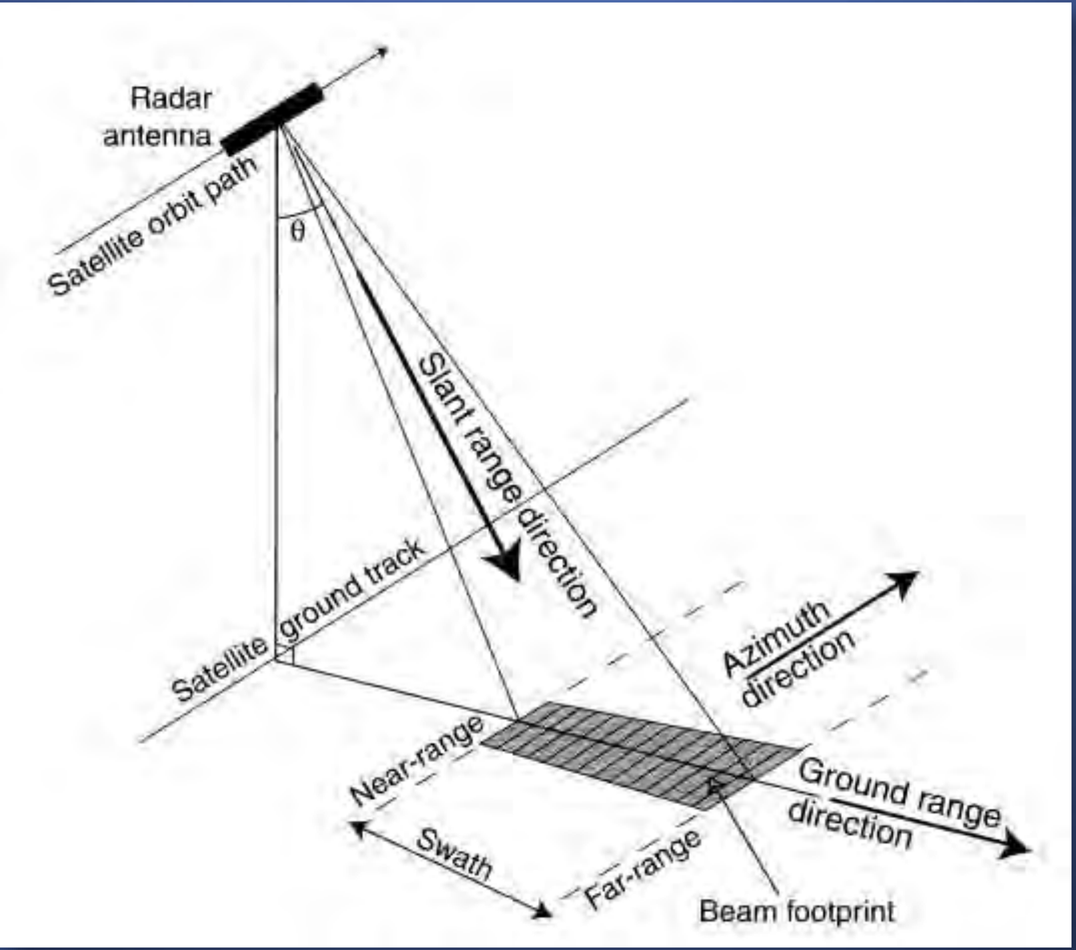
Tilt and hydrodynamic modulation



[Jackson & Apel, 2004]

SAR

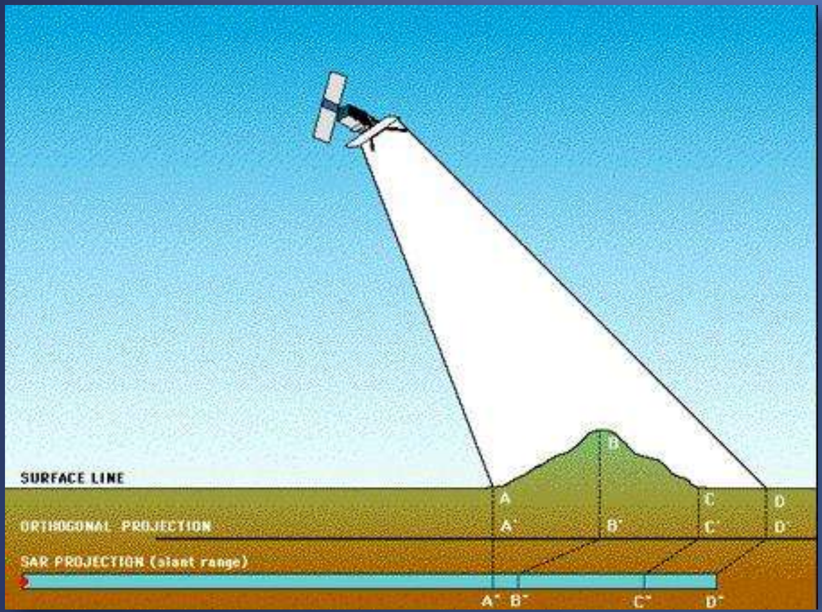
Definitions



[Robinson, 2003]

SAR Artifacts

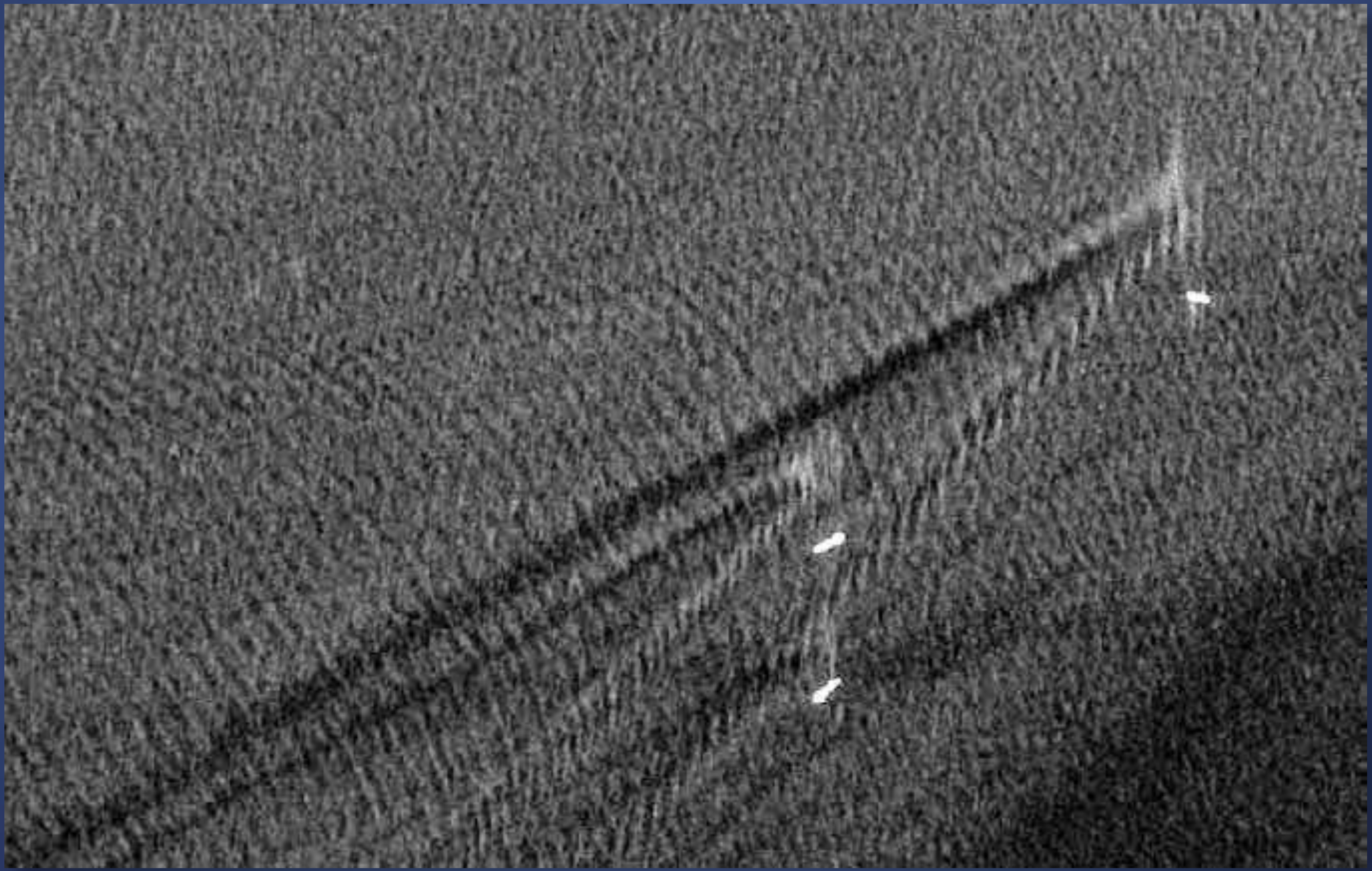
Foreshortening



[ESA]

SAR Artifacts

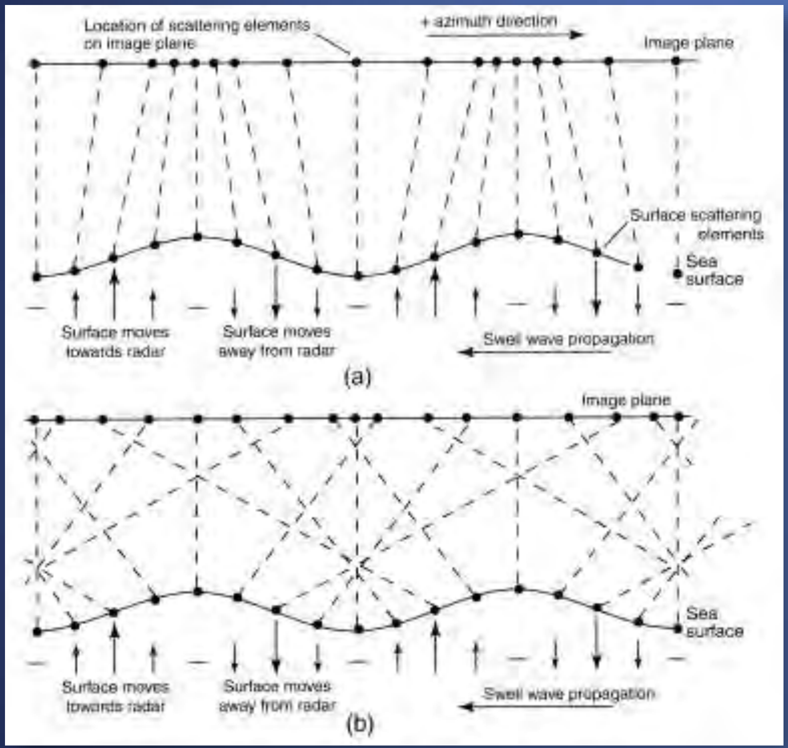
Azimuthal shift (“Ship-off-the-Wake Effect“)



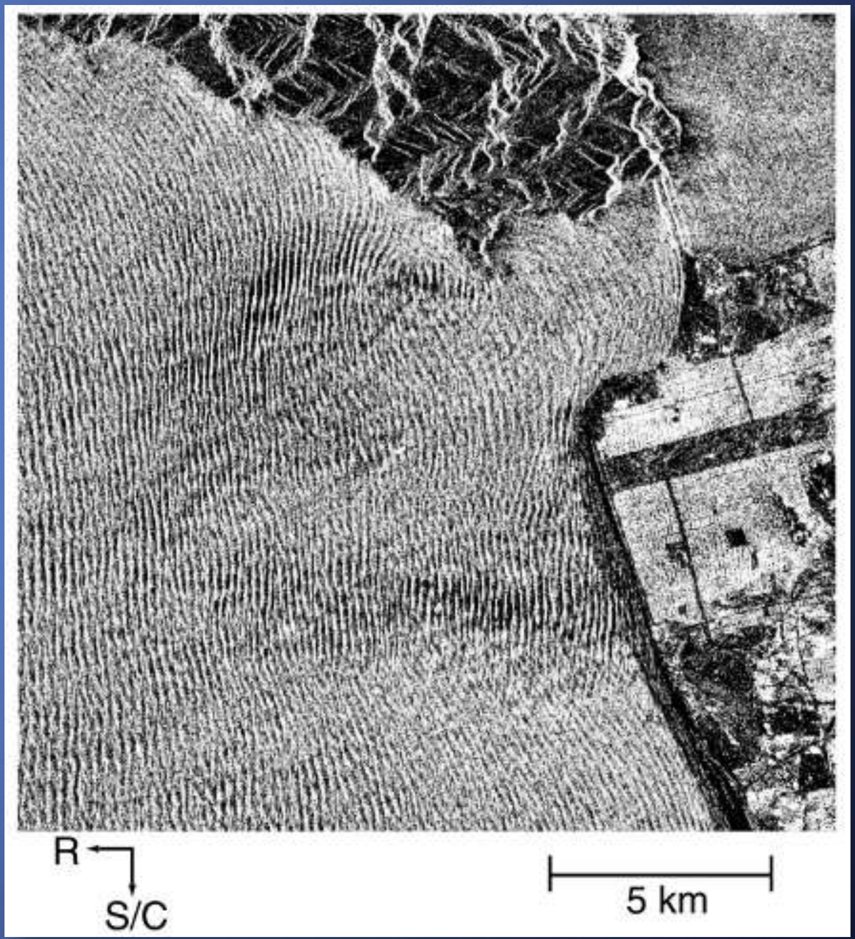
[Mallas & Graber, 2013]

SAR Artifacts

Velocity bunching



[Robinson, 2003]



[Jackson and Apel, 2004]

Propagation direction of the ocean waves is important!

Some Basics
Take-Home Messages

Radar backscattering from water surface
Bragg scattering
surface roughness important
GMF: wind-speed dependence

"It may be wrong, but it's how I feel."

to be continued…