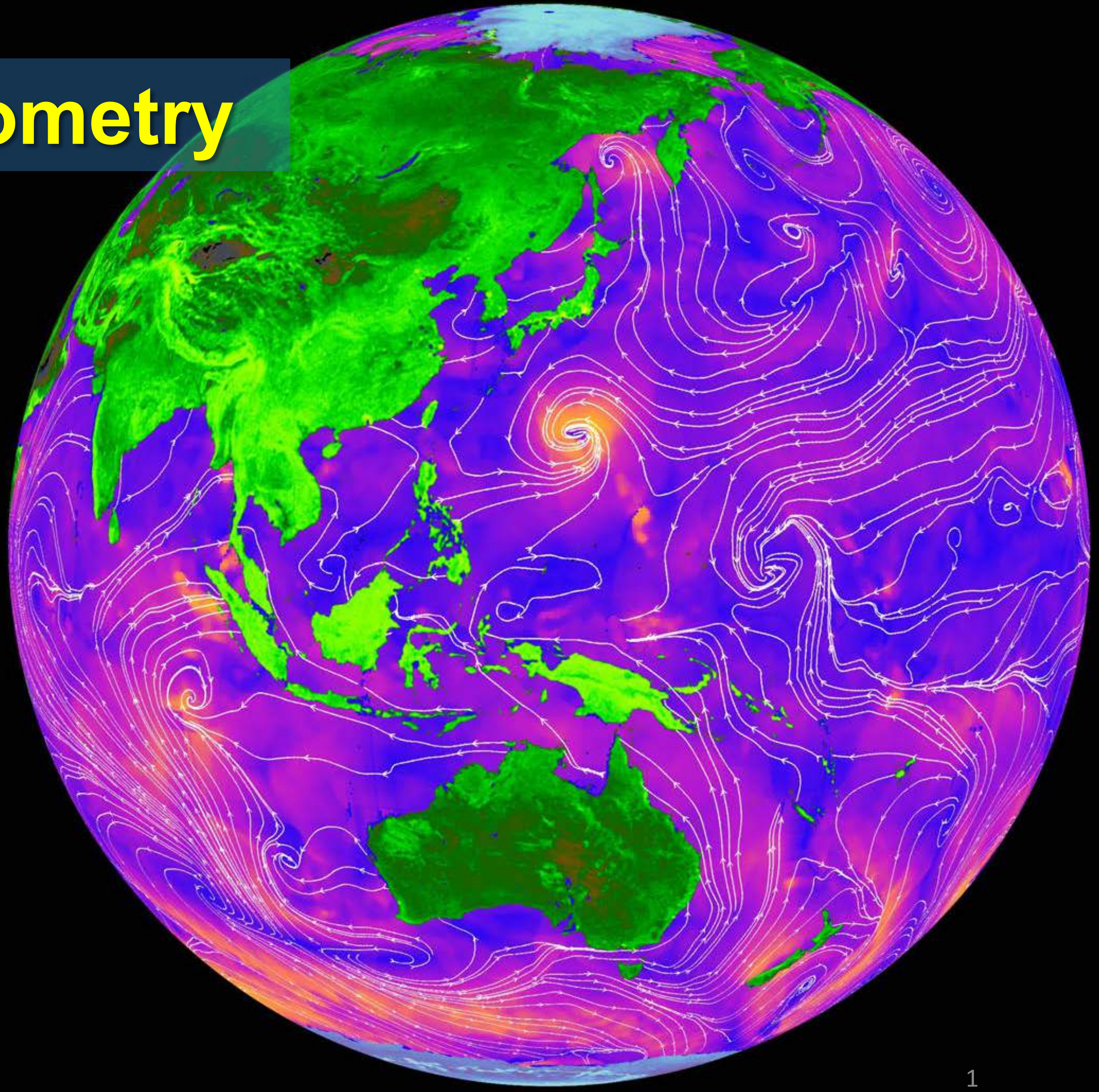
Introduction to Scatterometry



International Ocean Vector Wind Science Team (IOVWST) Meeting
29 May 2024

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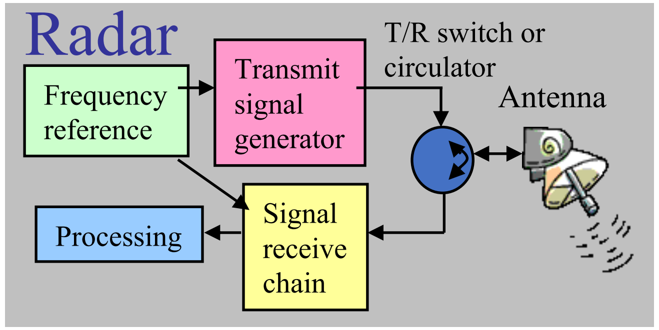
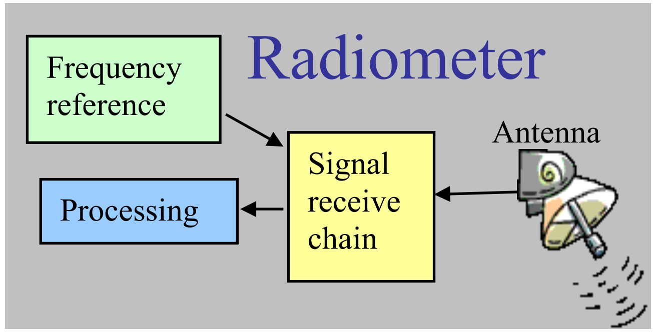
Brigham Young University

Microwave Remote Sensing





Sensor Classes

Active (radar)

- *Real Aperture*
  - **Scatterometer**
  - Altimeter
  - Side-looking radar
  - Weather radar
- *Synthetic Aperture*
  - SAR
  - Interferometric SAR

Passive (radiometers)

- *Real Aperture*
  - Radiometer
  - Sounder
- *Synthetic Aperture*
  - SA radiometer
  - Interferometer

Note: Current scatterometers only measure power. Future 'Doppler scatterometers' will use EM phase information to estimate surface current.

Key Scatterometer Equations

Radar Equation:

$$P_R = \frac{P_T G^2 \lambda^2 A_c}{(4\pi)^3 R^4} \sigma^o$$

where

P_R is the received power

P_T is the transmitted power

G is the antenna gain

λ is the transmit wavelength

A_c is the resolution cell area

R is the slant range

σ^o is the normalized surface backscatter

Noise Equation:

$$P_N = kT_S B_N$$

where

P_N is the noise power

k Boltzman's constant (1.38e-21)

T_S is the system noise temperature

B_N is the receiver bandwidth

Kp Equation: (radiometric accuracy)

$$K_P = \frac{\sqrt{var(\sigma^o)}}{\sigma^o}$$

$$K_P = \sqrt{a + \frac{b}{SNR} + \frac{c}{SNR^2}}$$

where a, b, c are constants that depend on the instrument and WVC

$$SNR = P_R / P_N$$

Note: "Noise" (P_N) is the 'signal' in radiometry. σ^o is the 'signal' in scatterometry.

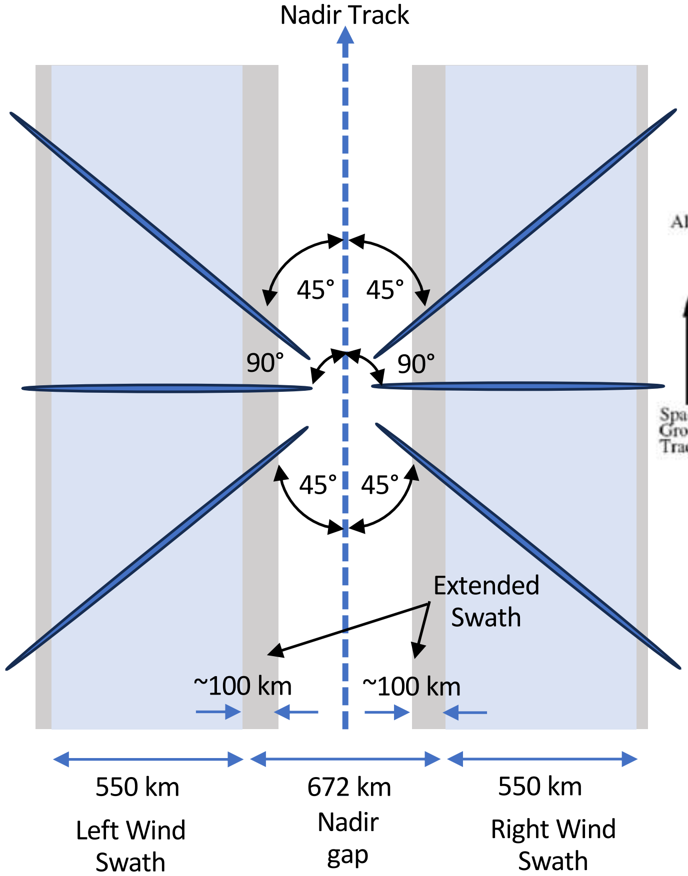
Fan-beam vs Scanning Scatterometers

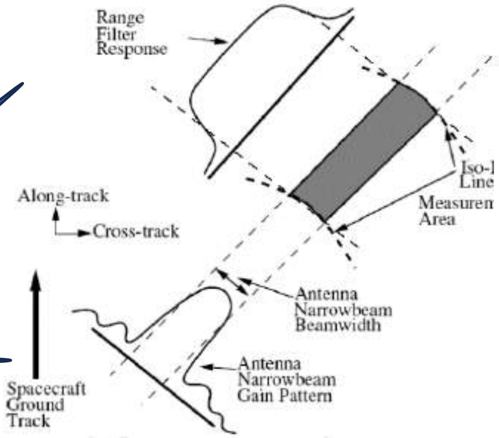
Fan-beam

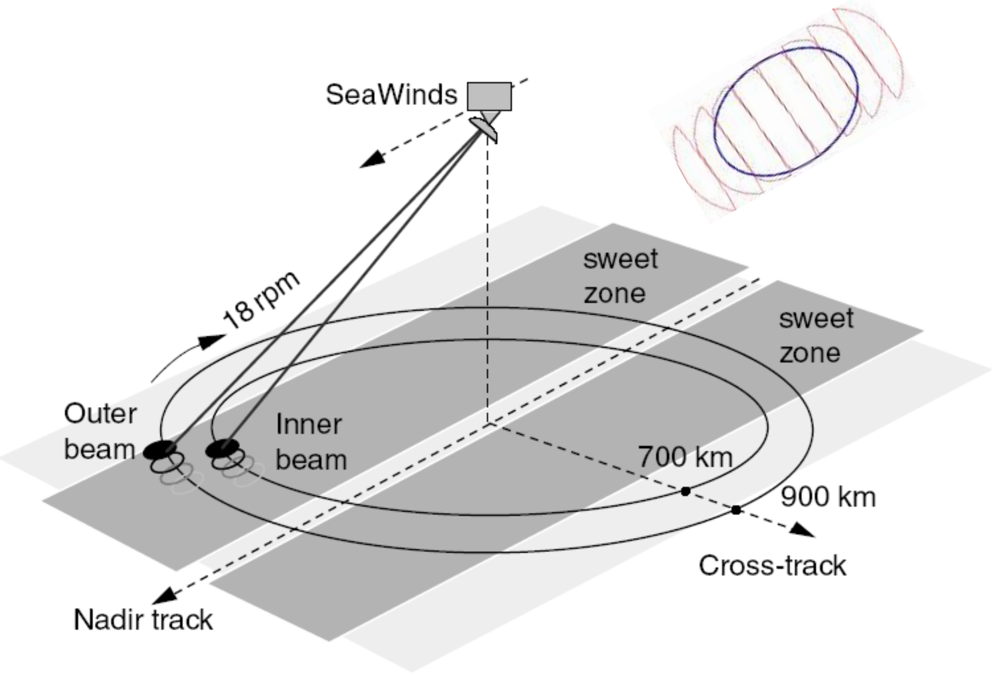
SASS/ERS/NSCAT/ASCAT resolution defined by beamwidth and Doppler or range gating in along-beam

Conically Scanning

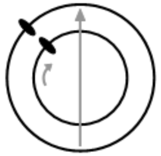
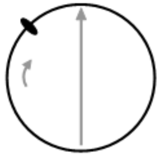
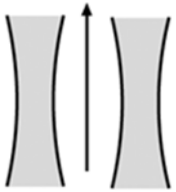
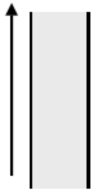
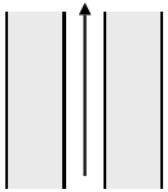
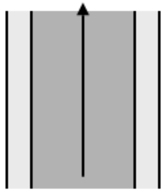
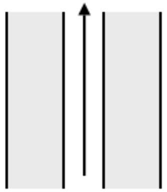
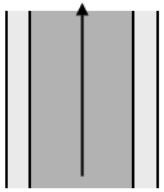
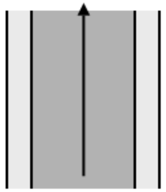
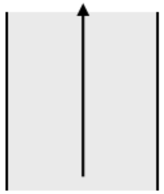
SeaWinds/QuikSCAT/OSCAT/HY resolution defined by beamwidth with range/Doppler processing to create "slices"



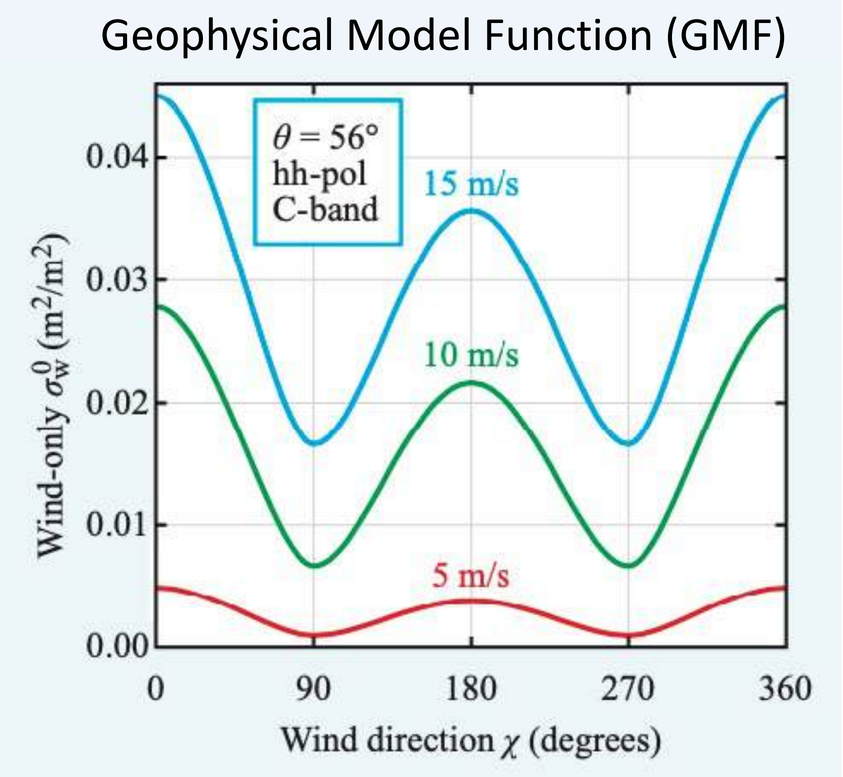




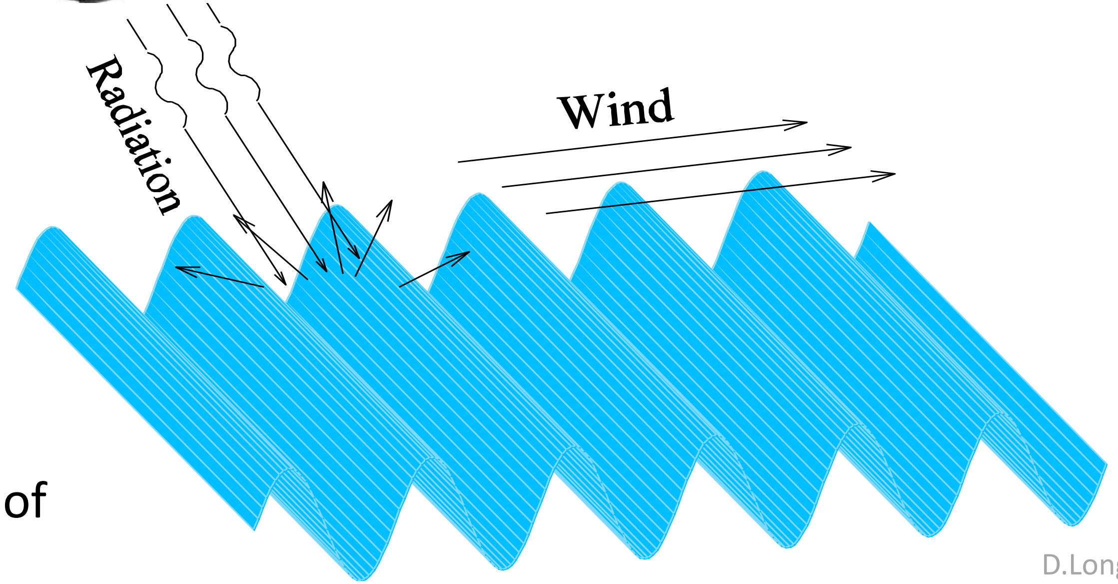
Wind Scatterometers- Past and present

	SASS	ESCAT	NSCAT	SeaWinds	ASCAT	OSCAT	HY-2A	SMAP (Radar)
Frequency & Band	14.6 GHz (Ku)	5.3 GHz (C)	13.995 GHz (Ku)	13.4 GHz (Ku)	5.3 GHz (C)	13.515 GHz (Ku)	13.255 GHz (Ku)	1.2 GHz (L)
Antenna Configuration								
Polarization	VV and HH	VV	VV, VV & HH, VV	VV-outer / HH-inner	VV	VV-outer / HH-inner	VV-outer / HH-inner	VV, HH, HV, VH
Beam Resolution	Fixed Doppler	Range gate	Variable Doppler	Pencil-beam	Range gate	Pencil-beam	Pencil-beam	Pencil-beam
Resolution (σ°)	Nominally 50 km	50 km	25 km	Egg: 25x35 km Slice 6x25 km	SZO:25/50 km SZF: 4x20 km	Egg: 30x68 km Slice: 6x30 km	Inner: 23x33 km Outer: 26x37 km	SAR: 1 km Egg: 1x30 km Slice: 6x18 km
Swatch Configuration & Width in km	 ~750 ~750	 500	 600 600	 1400,1800	 500 500	 1400,1836	 1350,1700	 1000
Incidence Angles	0° - 70°	18° - 59°	17° - 60°	46° & 54.4°	25° - 65°	49° & 57°	41° & 48°	40°
Mission & Dates	SEASAT: 6/78-10/78	ERS-1: 7/91-3/00 ERS-2: 4/95-5/11	ADEOS-I:8/96-6/97	QuikSCAT: 6/99-11/09* ADEOS-II: 1/02-10/02 RapidScat: 10/14-8/16	METOP-A: 6/07-11/21 METOP-B: 9/12- METOP-C: 8/21-	OceanSat-2: 2/10-2/14 ScatSat-1: 8/16-	HY-2A: 8/11- HY-2B: 10/18-	SMAP Radar: 4/15-7/15

Wind Scatterometry Theory

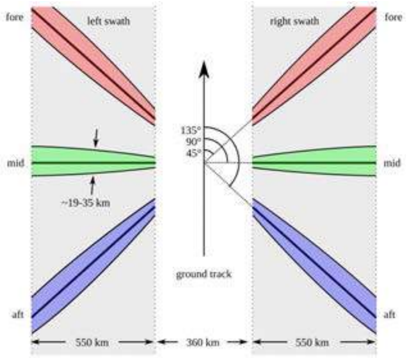


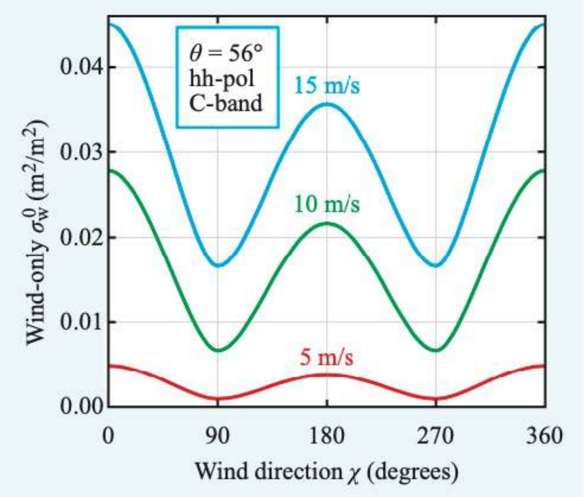
- Winds over the ocean create small capillary-gravity waves ("cat's paws") which roughen surface
  - Roughness is related to wind speed and direction
- A scatterometer measures surface roughness via measurements of the normalized radar cross-section (NRCS or sigma-0)
  - Sigma-0 measured at multiple azimuth angles
- Wind estimated ("retrieved") from sigma-0 with aid of geophysical model function (GMF)



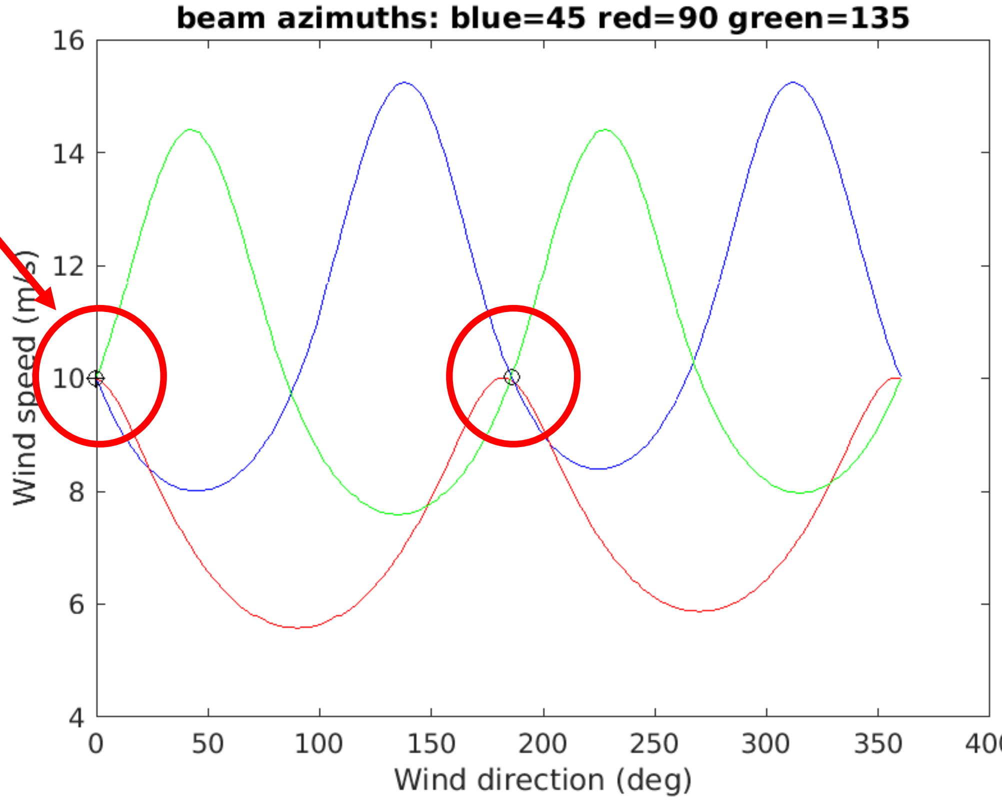
How does scatterometer wind retrieval work?

(a simplified illustration for ASCAT)





- ASCAT collects 3 sigma-0 measurements at different azimuth angles
- GMF gives wind/speed curve for each
- Wind estimate is where curves intersect
  - Determine by minimizing an "objective function"
- Multiple solutions called "ambiguities"
  - Typically, 1-4 ambiguities
  - Rank by "closeness" (1st, etc.)
  - First two about 180° deg apart, similar speeds
- Selection of unique wind uses nearby estimates ("Ambiguity selection")



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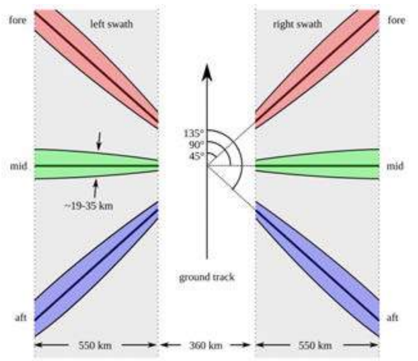
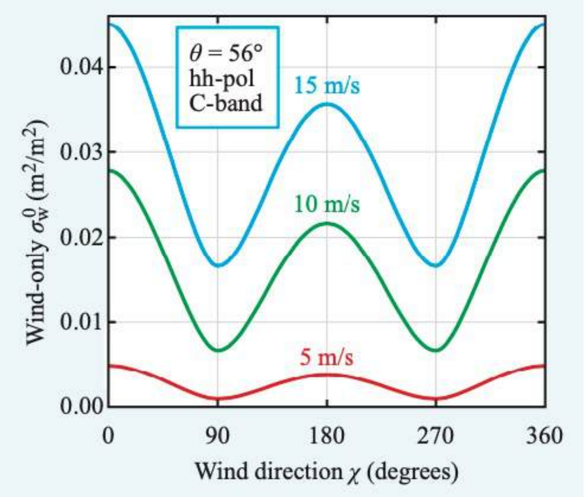
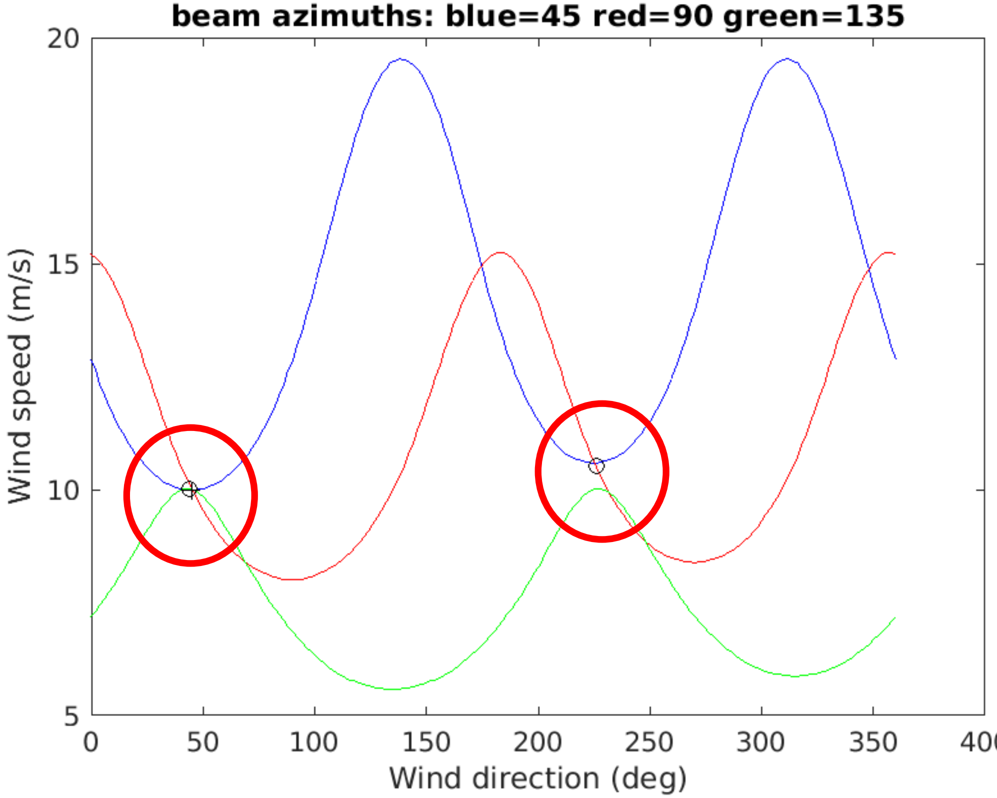
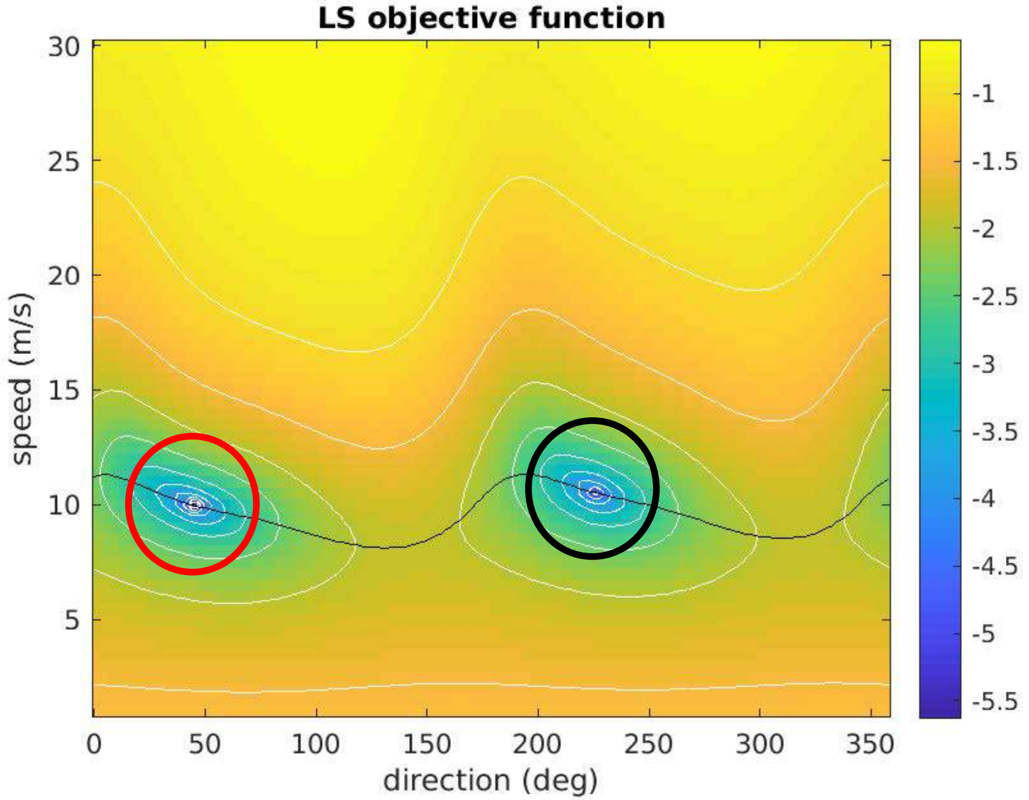


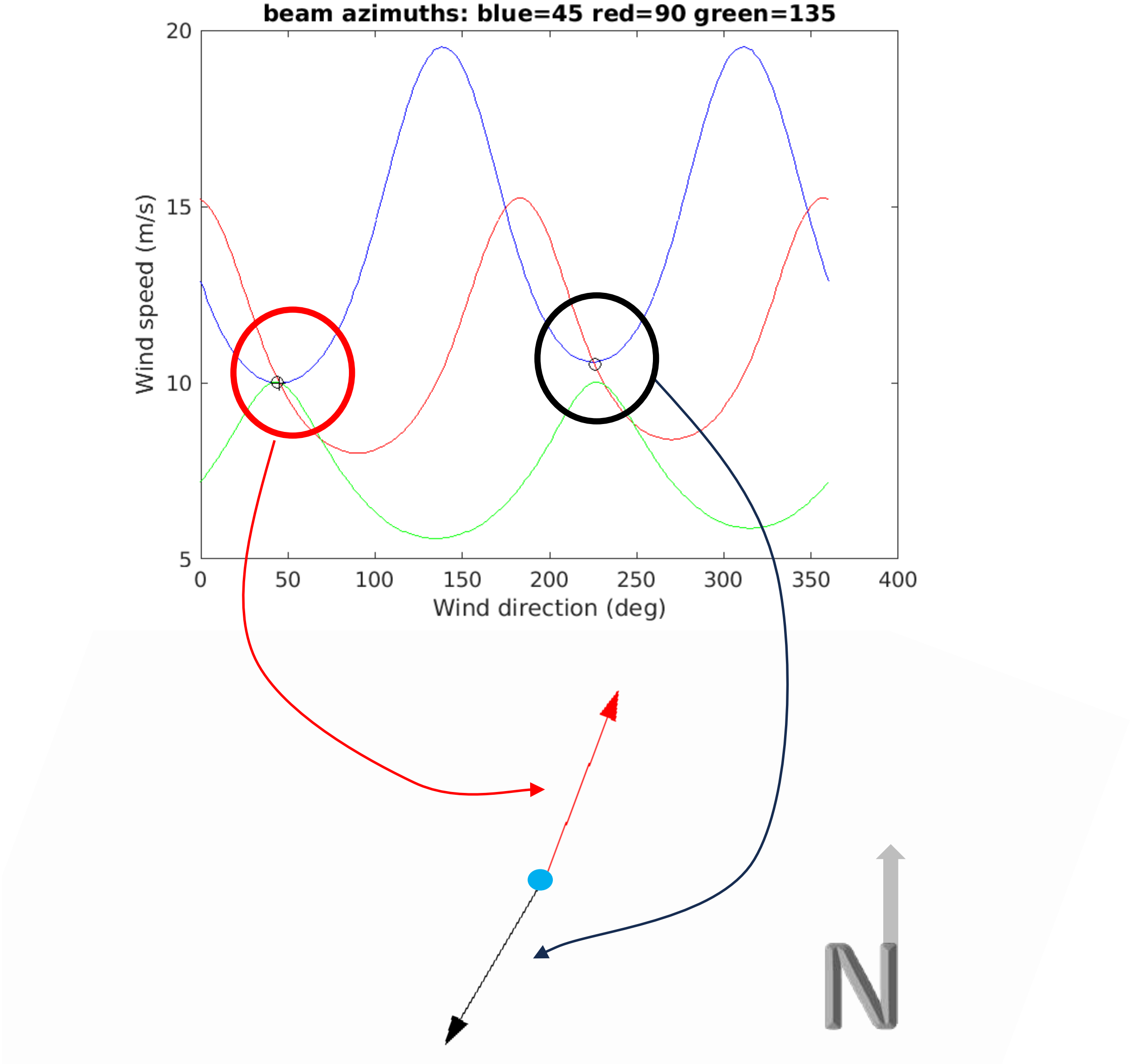




Objective function:

- Maximum Likelihood (MLE)
- Maximum Aposteriori (MAP)
- Least Squares, etc.

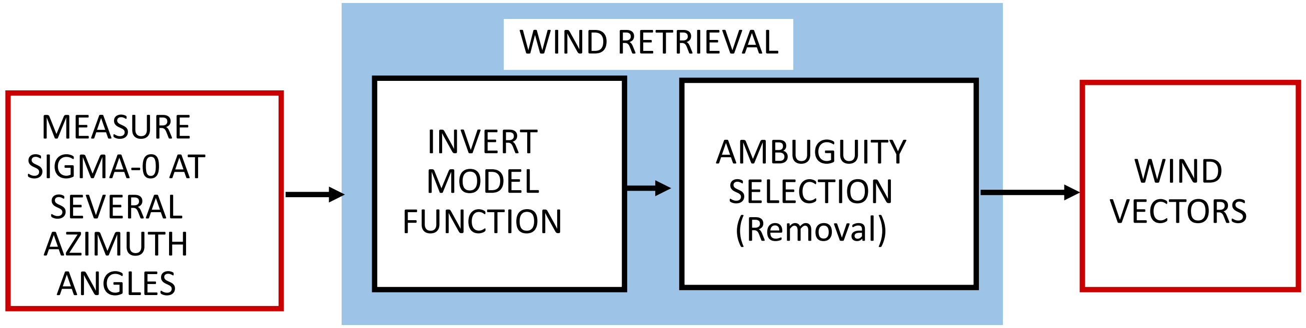


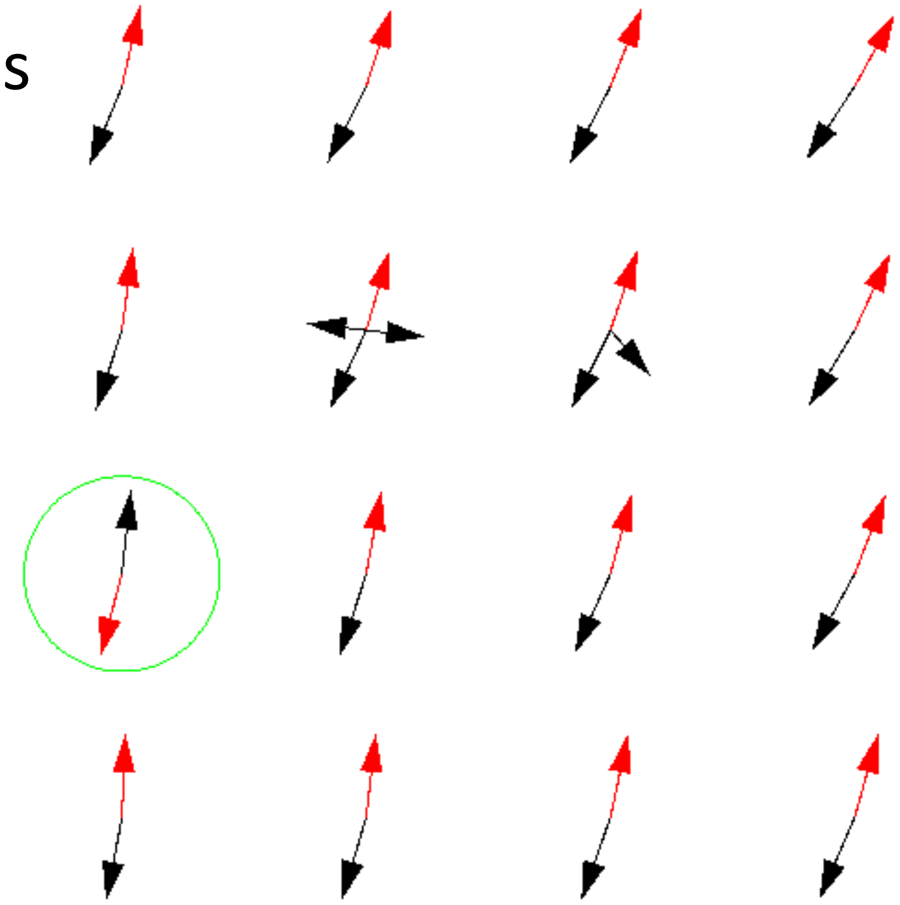


Wind ambiguity vectors

Ambiguity Selection

- Ambiguities generally have similar speeds
  - First and second differ by ~180°
  - Mostly 2, sometimes 3 or 4
- Many different methods to select unique vector at each WVC
- One: Median filter-based
  - Start with 1st ambiguities
  - Compute median of nearby area
  - Choose ambiguity closest to median





Red: First-ranked (most likely) ambiguity
Black: Other ambiguities

More information

F.T. Ulaby and D.G. Long, *Microwave Radar and Radiometric Remote Sensing,* University of Michigan Press, 2014.

- https://us.artechhouse.com/Microwave-Radar-And-Radiometric-Remote-Sensing-P1738.aspx
- https://www.amazon.com/Microwave-Radar-Radiometric-Remote-Sensing/dp/0472119354

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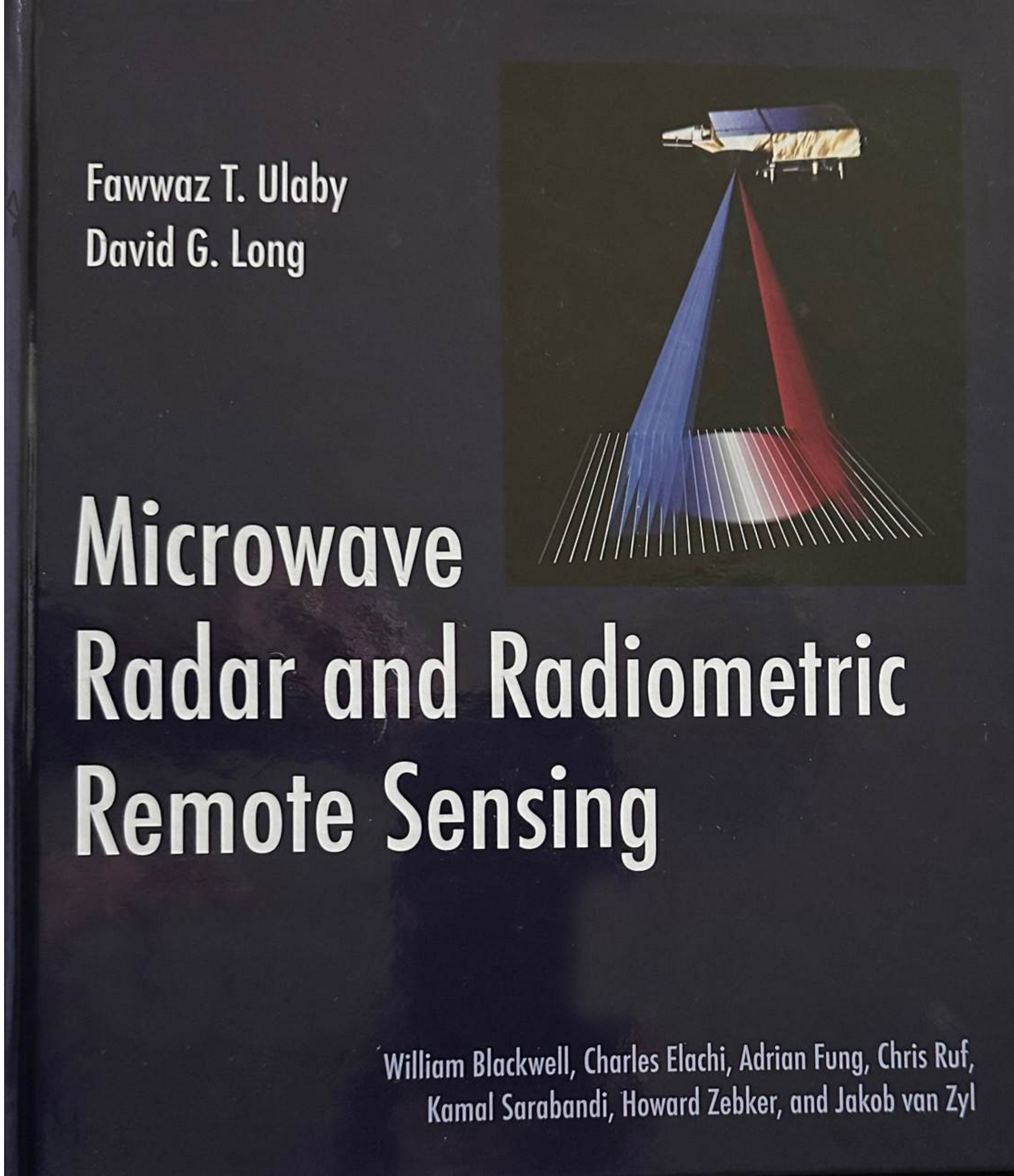
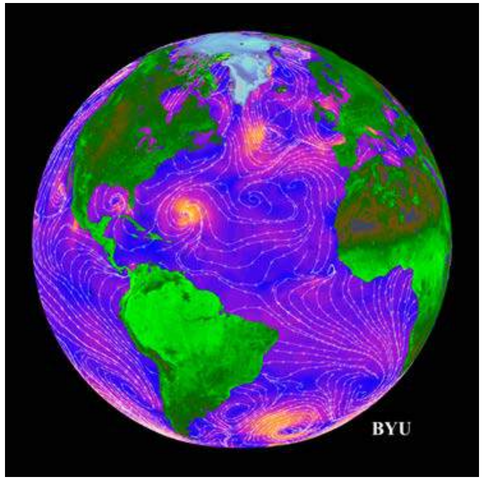
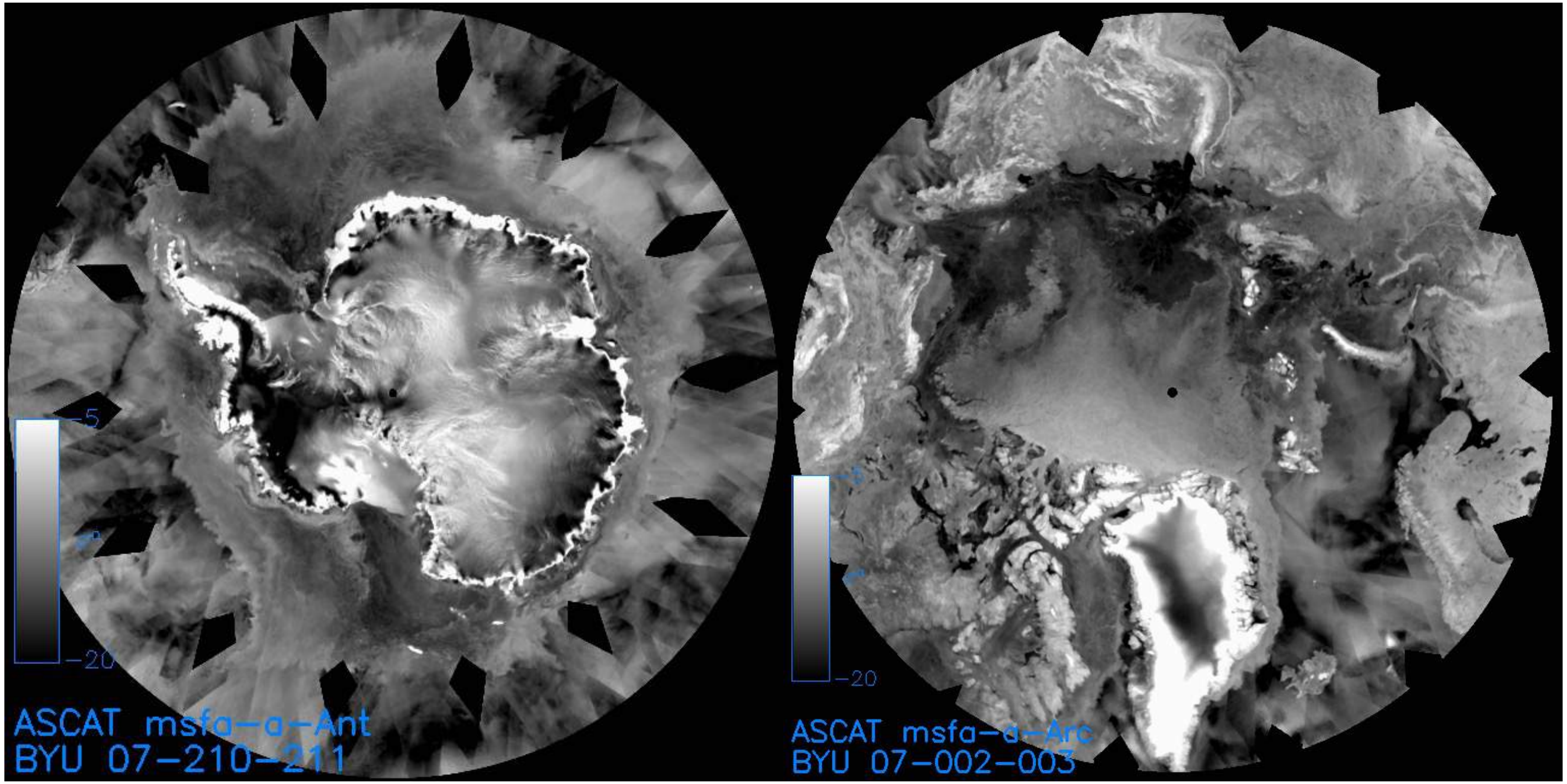




Non-Wind Scatterometer Applications

Key advantages of scatterometry:
- Frequent global coverage
- Multiple azimuth angles and polarizations

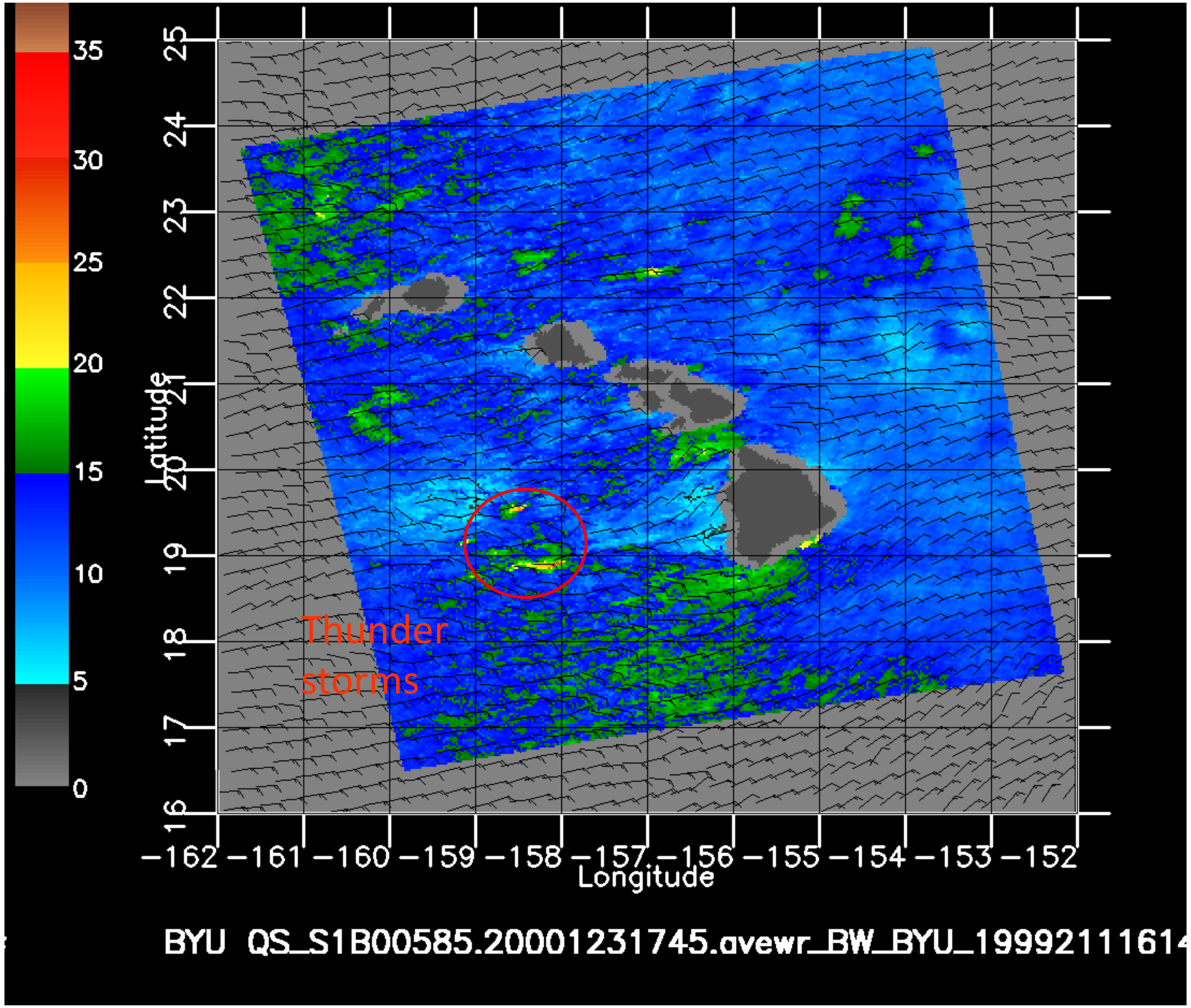
- Sea ice extent, age
- Freeze/Thaw conditions
- Flooding
- Oil spills
- Vegetation mapping
- Urban growth
- "Land/ice winds" (via sand and snow dunes)
- Greenland & Antarctica accumulation and melt



Hawaiian Winds & Rain

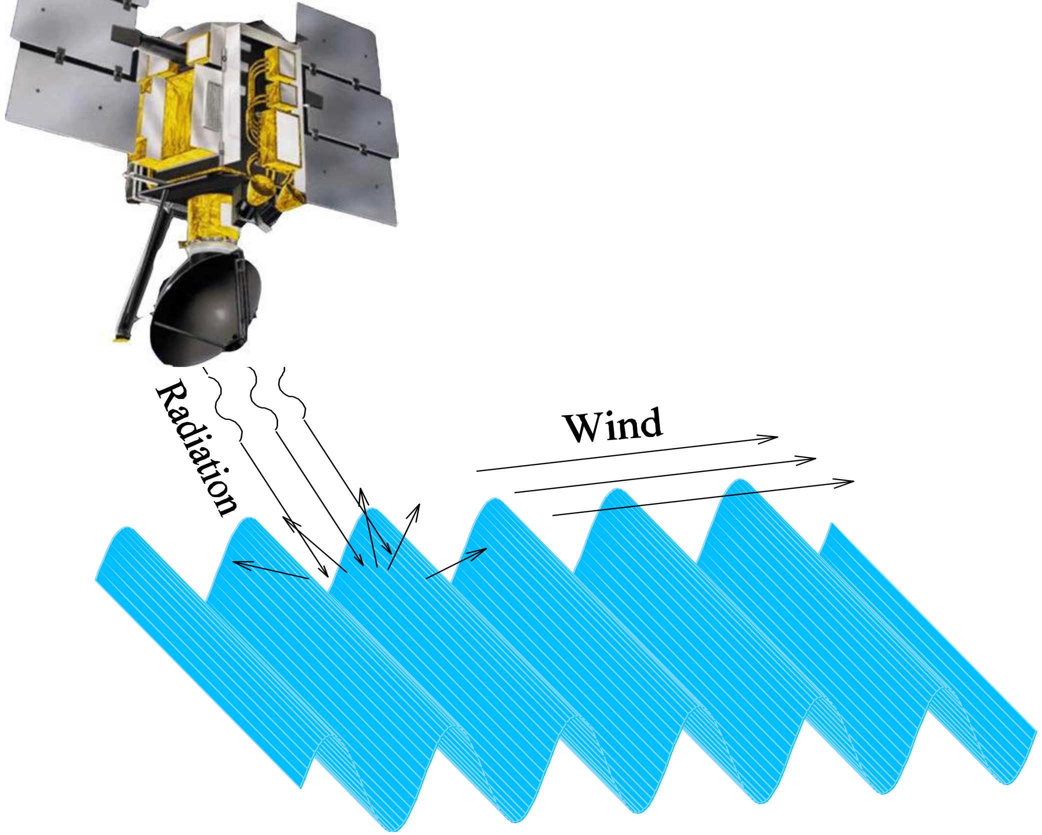
UHR (2.5 km) wind speed

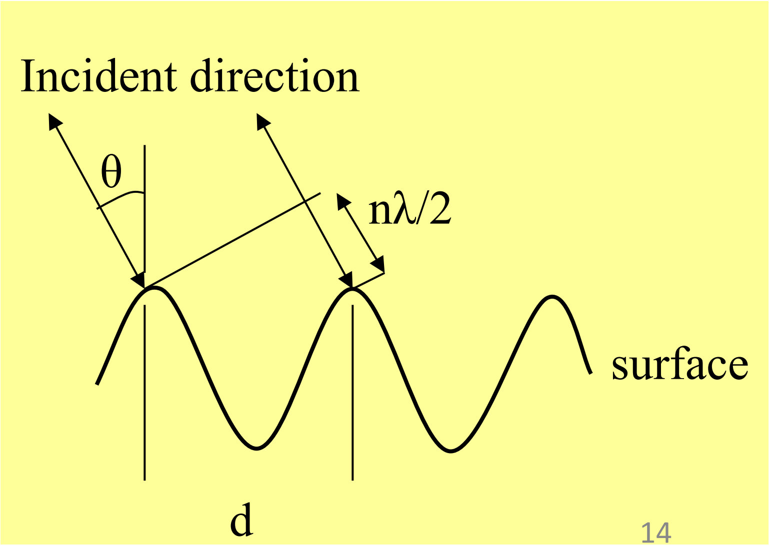
25 km barbs



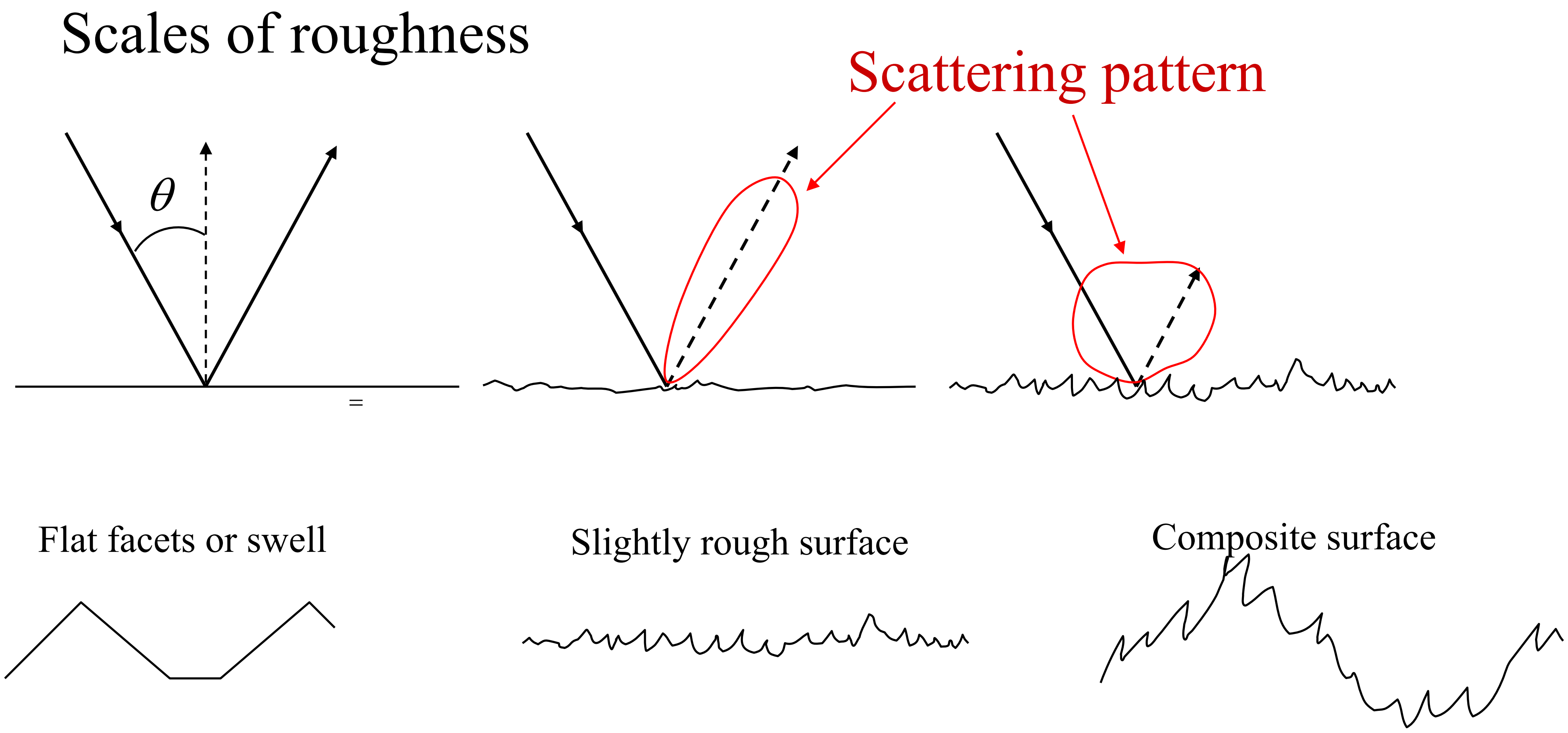
Bragg (Resonant) Scattering

- Bragg scattering can occur for periodic surfaces
  - Samples wave spectrum
- Reflections from peaks reinforce each other at particular incidence angles and cancel at other angles
  - Enhanced scattering in particular directions
  - Scattering is incidence and azimuth angle dependent
- Resonance condition $n\lambda = 2d\sin\theta$





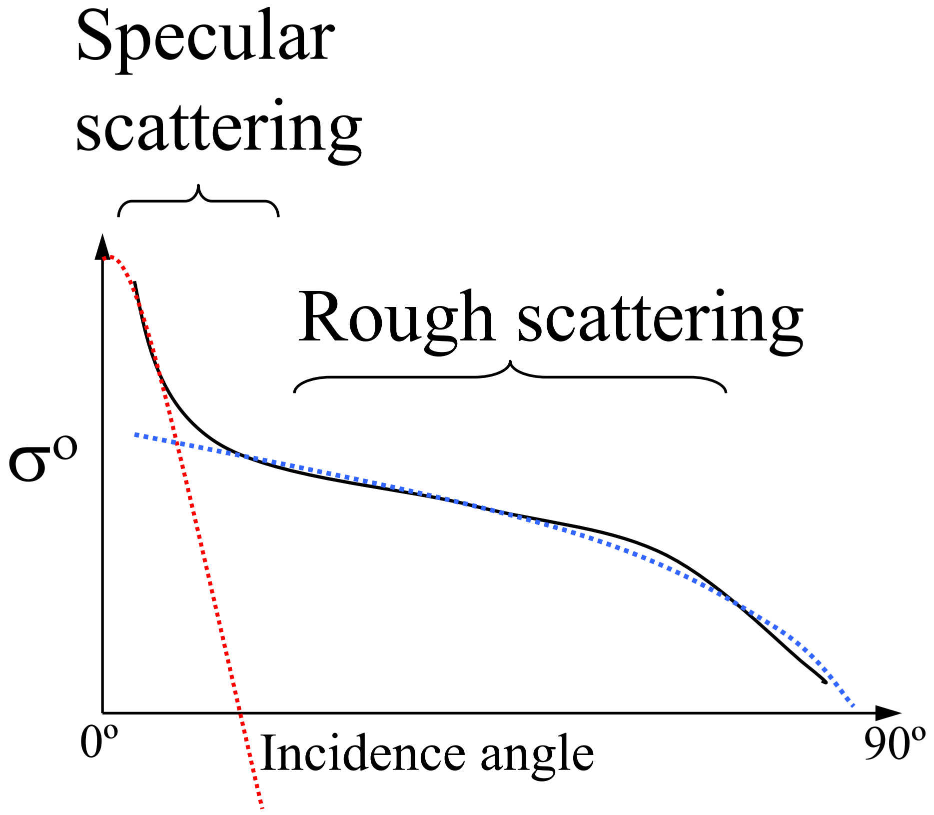
Multiscale Rough Surface Scattering



General Rough Surface Backscatter

- General scattering may be a combination of surface and volume scattering, which have a combination of specular and rough scattering characteristics

- Details depend on surface characteristics



Surface Scattering

- "Bistatic scattering" is the scattering in one direction when the illumination is from another direction
- "Backscatter" is the return back toward the source
  - Special case of bistatic scattering
  - σ^o is the normalized backscatter = backscatter/target area