Nadir Scatterometry

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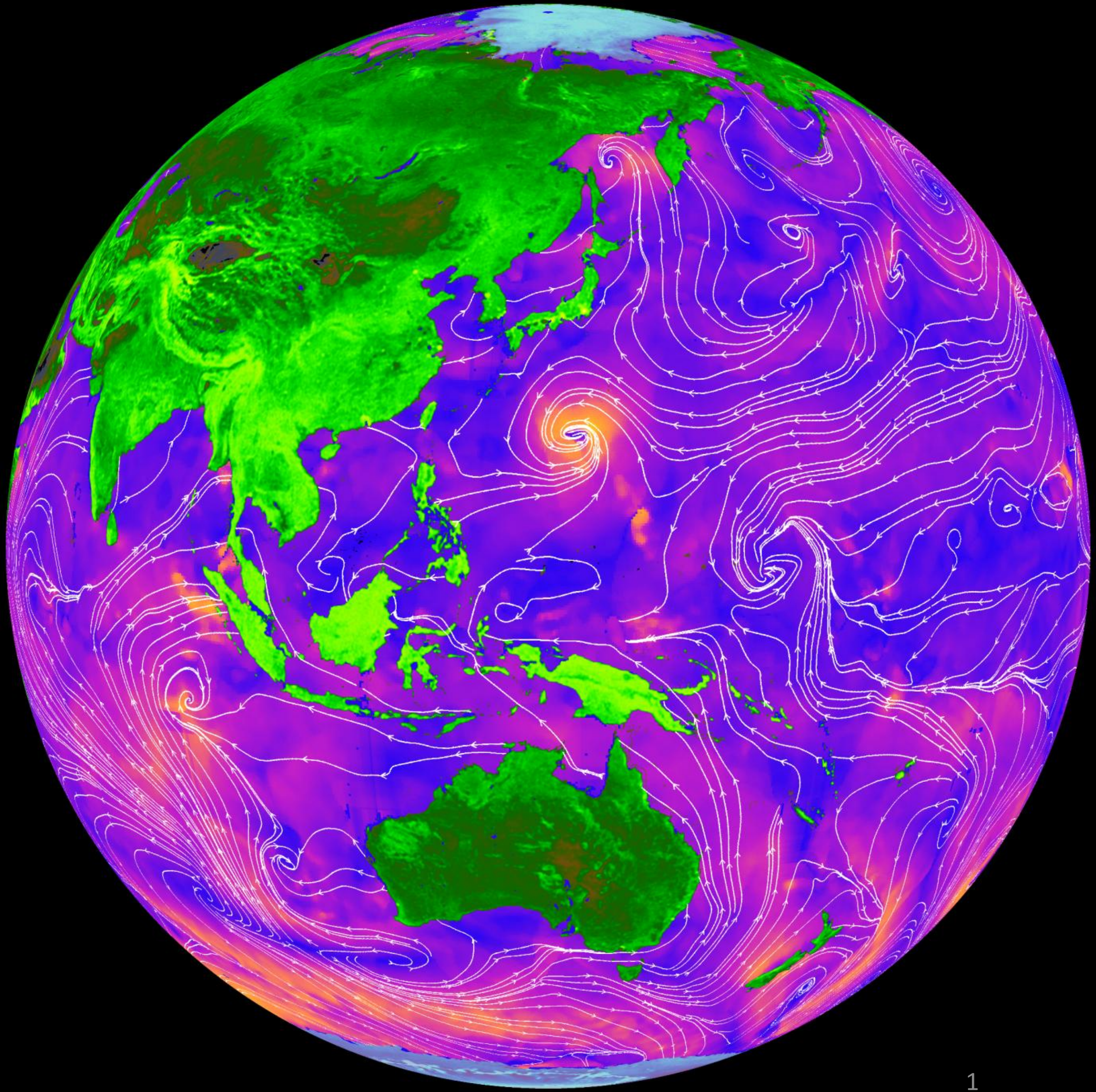
Care Weather Technologies



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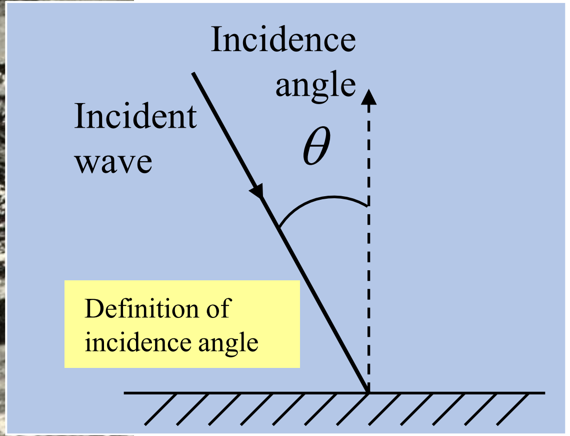
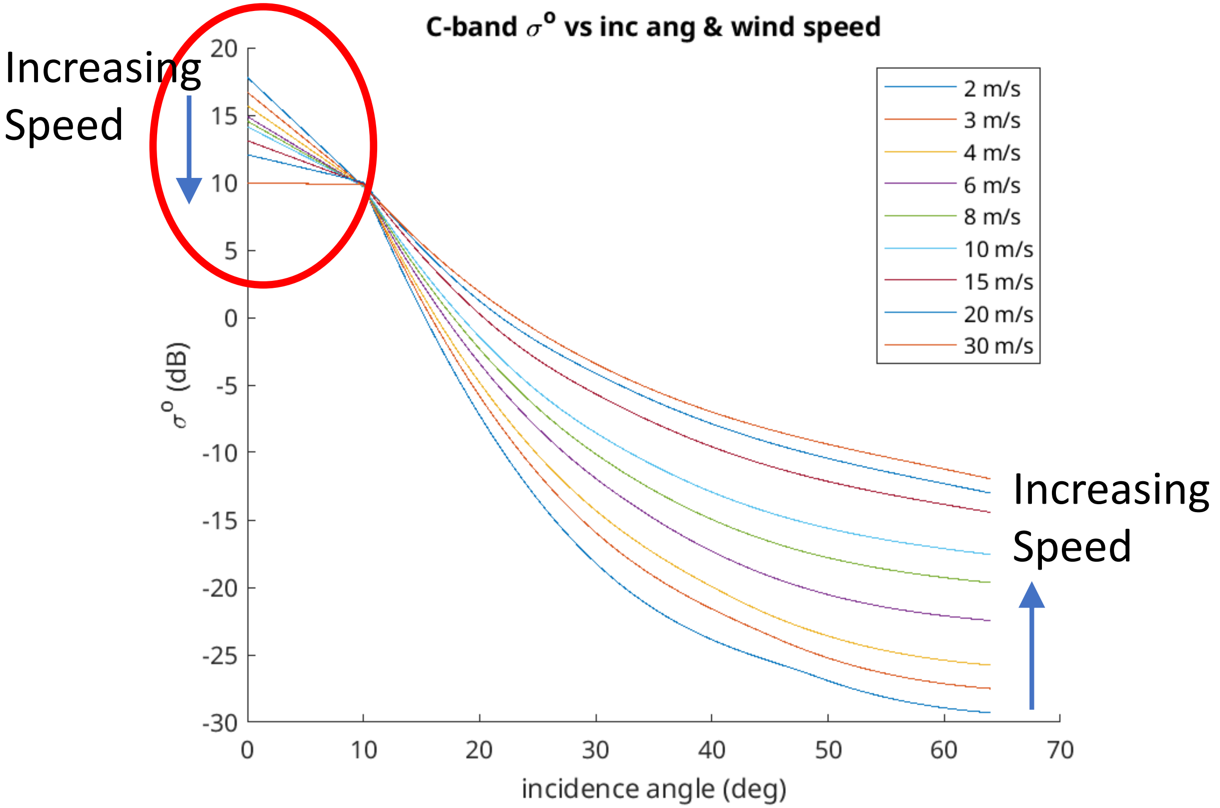
Nadir Surface Scattering

- "Backscatter" is the echo return toward the source transmitter
  - σ^o (sigma-0) is the normalized backscatter backscatter/target area



- Wind creates waves which roughen surface
  - Higher wind speed, rougher surface
- At off-nadir angles, sigma-0 *increases* with increasing wind speed
- At nadir, sigma-0 *decreases* with increasing wind speed



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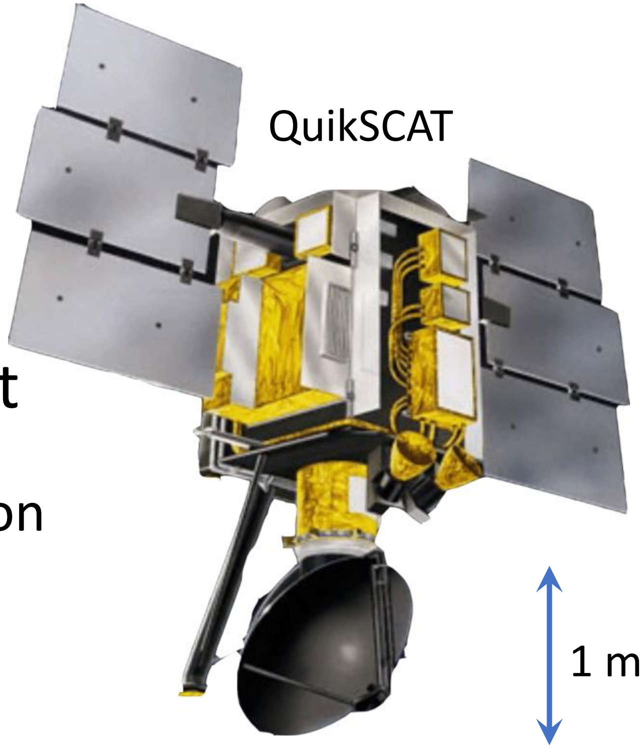
What is a "Nadir Scatterometer"?

- Classic wind scatterometers measure surface backscatter at moderate (20-60 deg) incidence angles
  - Can estimate the wind direction by exploiting the azimuth variation in backscatter with wind direction
  - Use scanning (multiple beams and/or rotating antennas) to measure wind over a wide (1600 km) swath
  - Very large SWAP requires large spacecraft = $$$ expensive

- A nadir scatterometer measures backscatter (only) at nadir (incidence angle of 0 deg)
  - Wind speed only
  - Narrow swath (~12 km)
  - Can use small antenna, low transmit power = small, $ inexpensive
  - Constellation enables broader coverage

QuikSCAT



1 m

Veery0.5

10 cm

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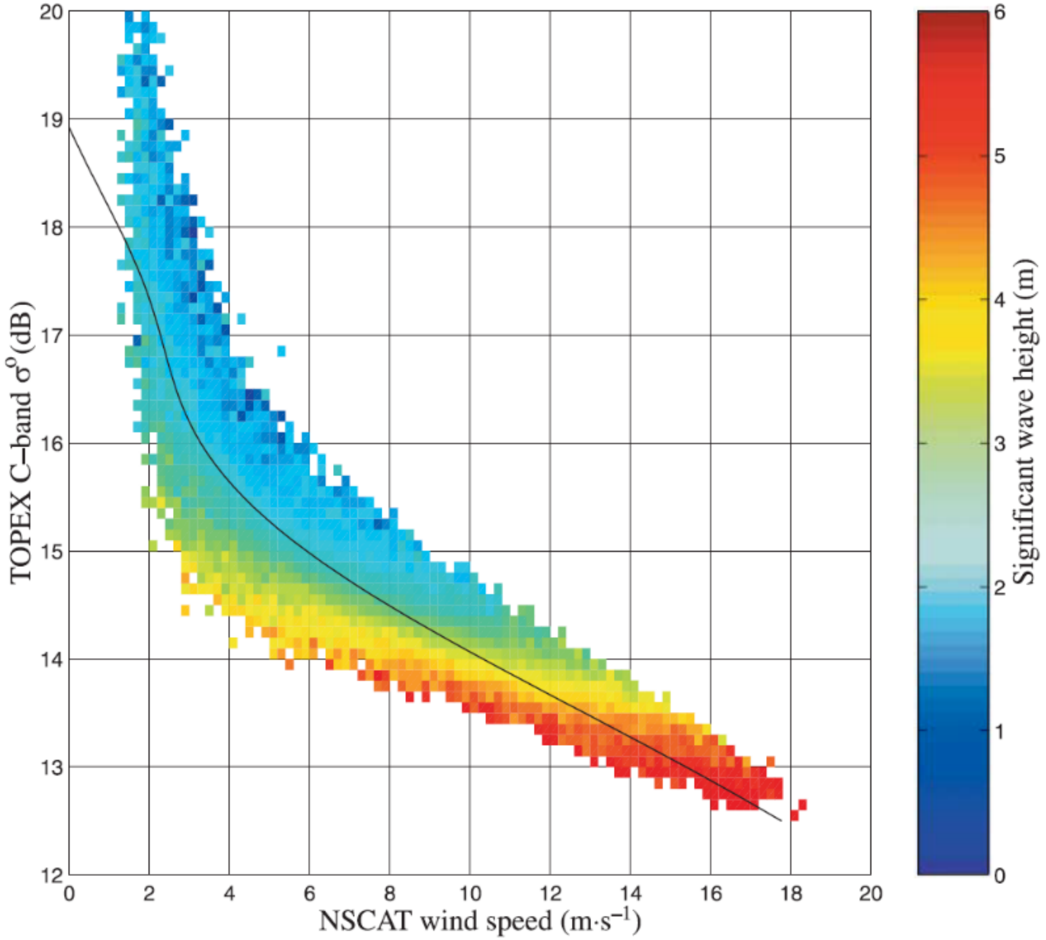
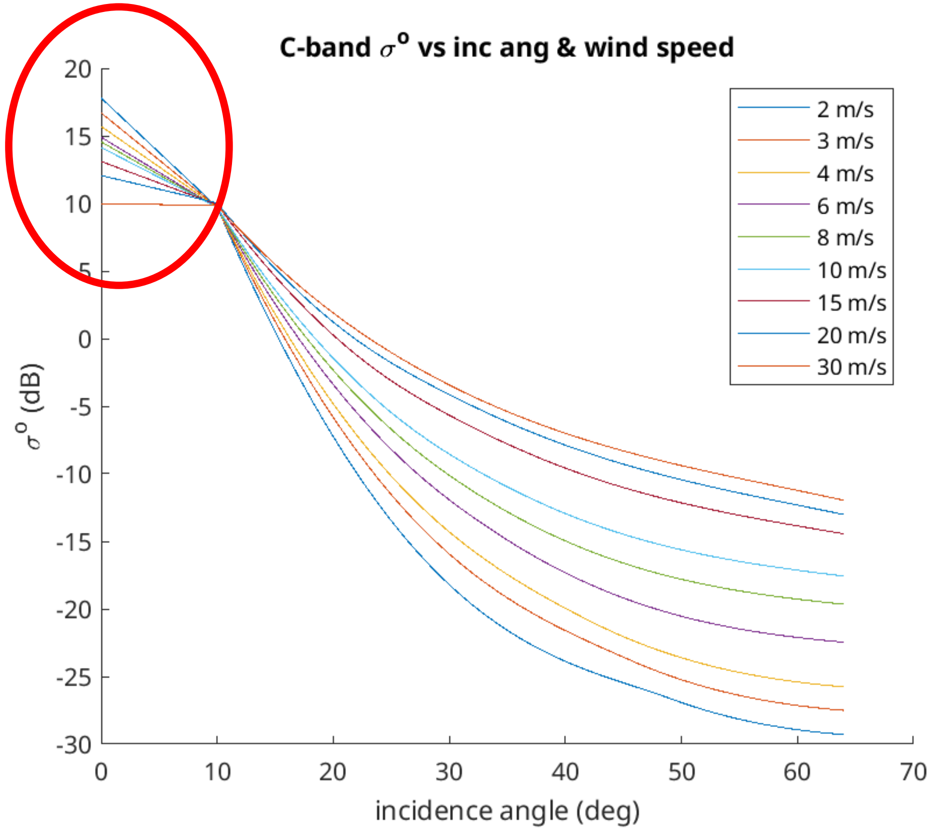
Satellite Altimeters and nadir GMF



- Designed to measure surface topography
  - High altitude (1650 km)
  - High bandwidth (320 MHz) to achieve centimetric accuracy
  - Large (~1 m) antennas for small footprint to measure Significant Wave Height (SWH)
  - High SNR
    - ~ 50 W transmitter, 102 us pulse , 2-4 kHz PRF
- Surface backscatter is a secondary measurement (high SNR)
  - Retrieve wind speed

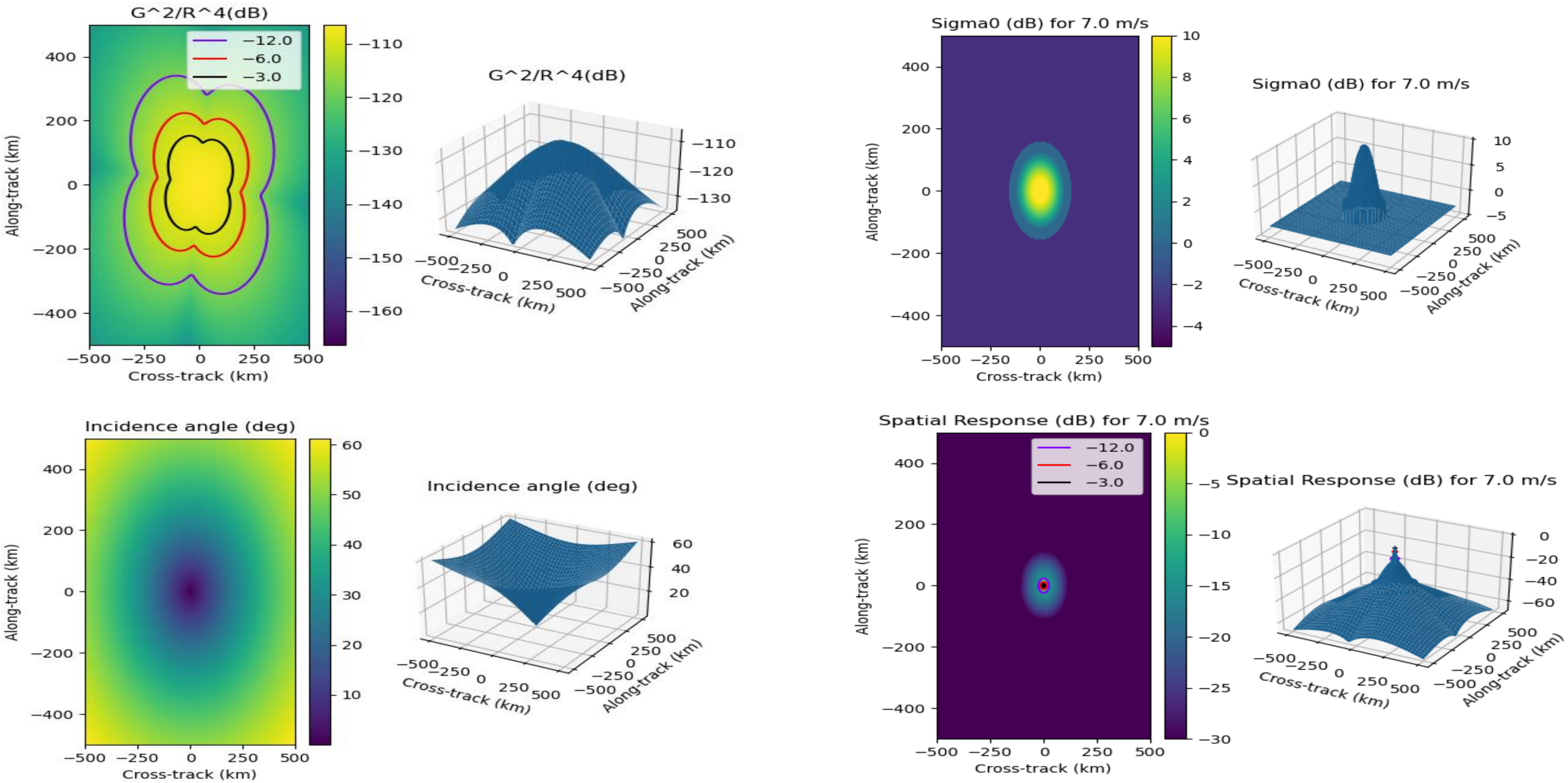
What if goal is to only measure backscatter at nadir?

- *Return echo from surface is dominated by nadir return*
- Exploit roll-off of sigma-0 versus incidence angle
  - Allows use of a wide beam (and therefore small) antenna
  - Precision pointing not required
- Lower altitude
  - Reduce radar range loss



This can be done from a small satellite! (but we don't get SWH)

Small* (4 patch) antenna pattern projected on surface**



* <10 cm by 10 cm at C-band

** model predictions for 450 km altitude, ellipsoidal earth

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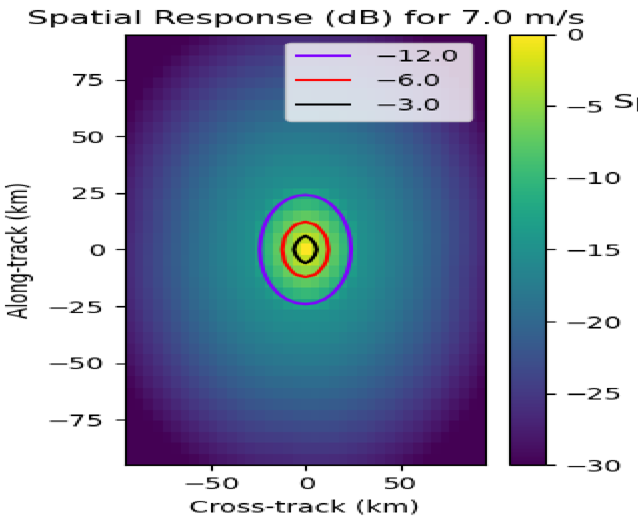
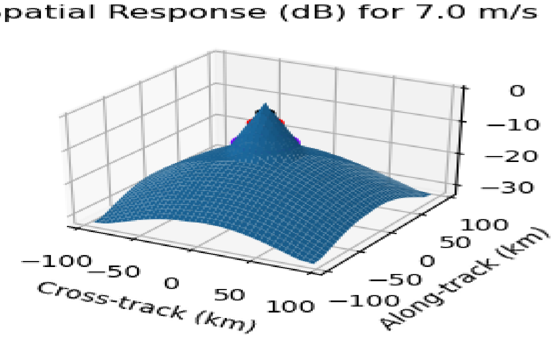
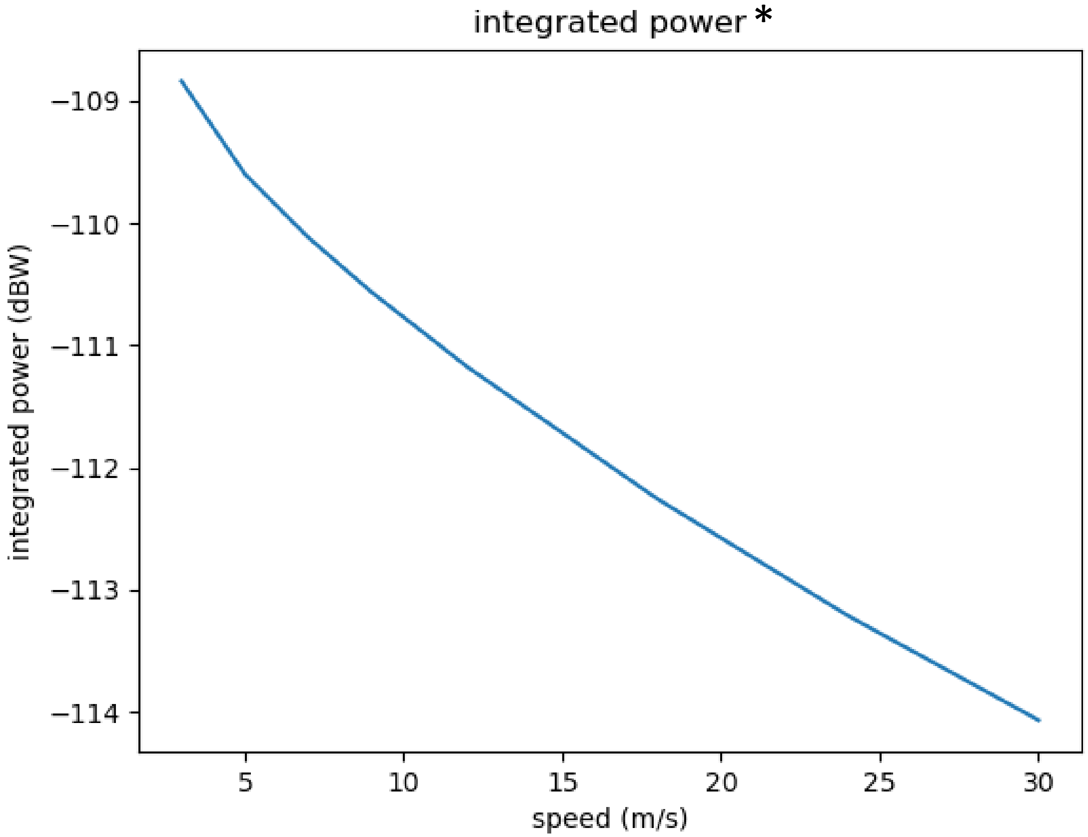
Nadir scatterometer Veery0.5

- Return echo from surface is dominated by nadir return
  - Defines spatial resolution
- Effective 3 dB footprint ~12 km





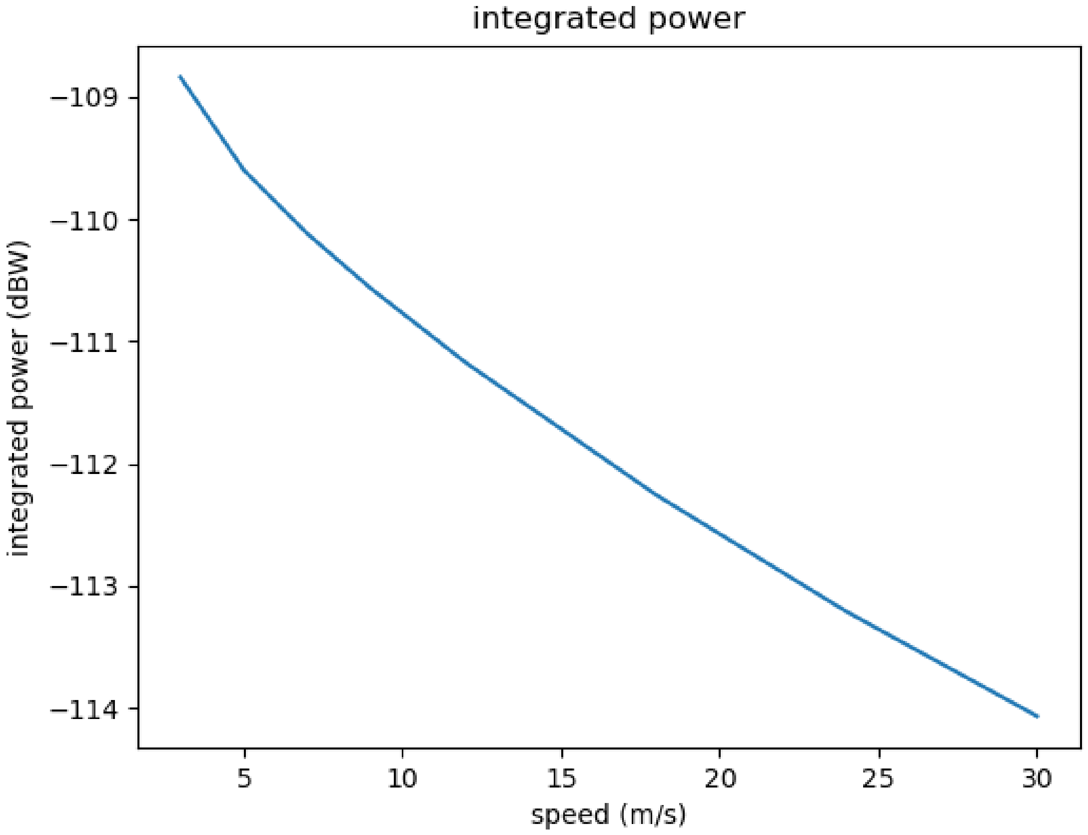


- 2 W transmit power, 2 ms pulse
- 10 kHz bandwidth FFT filter
- Noise floor < -147 dBW
- SNR > 35 dB

* model prediction for 450 km altitude, ellipsoidal earth

How does nadir scatterometry wind retrieval work?

- Limited dynamic range (5 dB) of return echo with high SNR (>35 dB)
  - Fall off of power with wind speed above 30 m/s assumed to follow trend, potentially enabling retrieval of very high winds speeds
- Basic idea:
  - Collect and average multiple pulses to improves Kp
  - “look up” wind speed on pre-computed power vs speed (“power GMF”) curve
- Simple, single solution, no ambiguities



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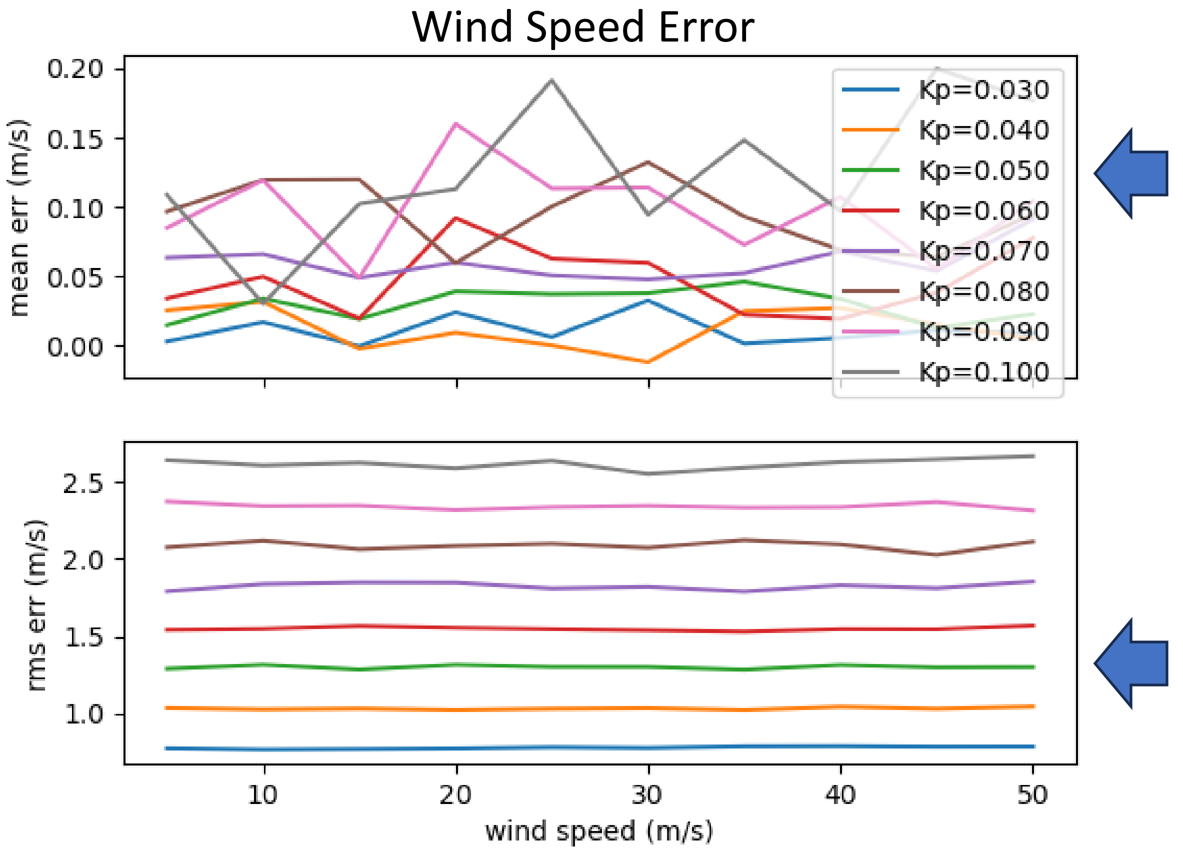
Veery0.5 Wind speed retrieval* performance

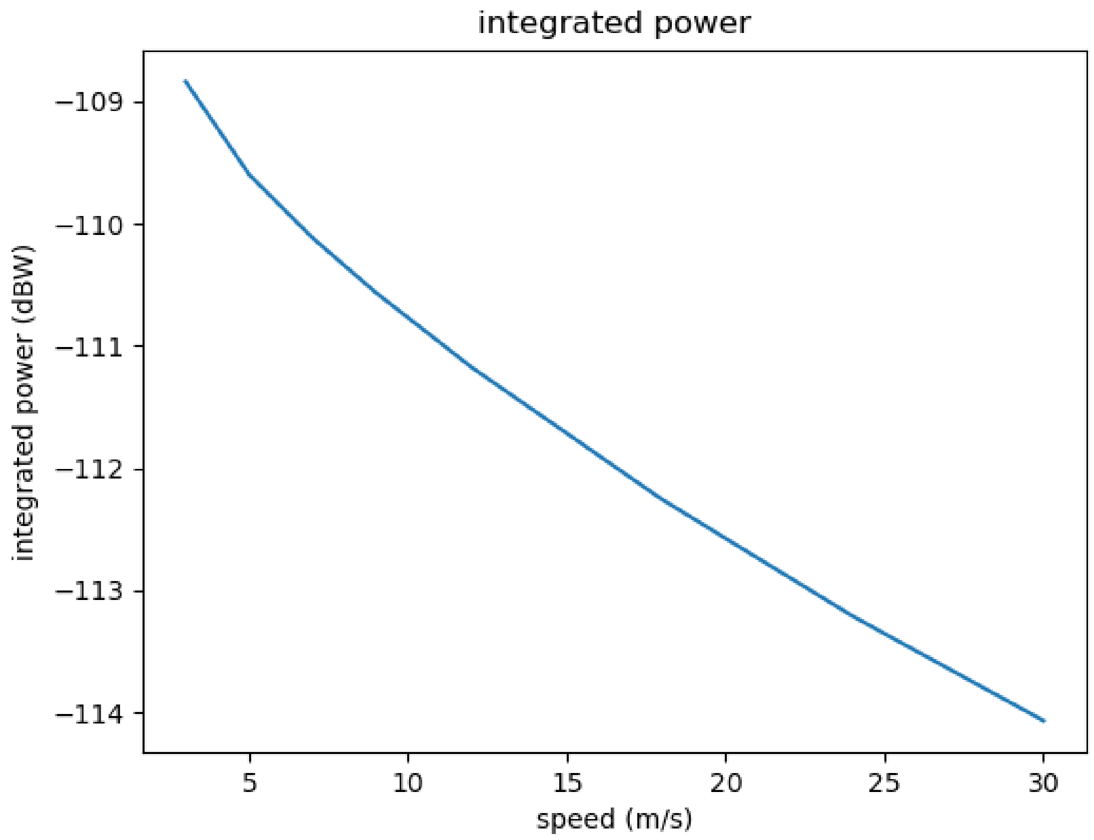
- Tradeoff between spatial resolution and wind speed accuracy
  - Average multiple pulses which smears spatial response pattern
- RMS speed error roughly flat with speed, driven by Kp
- Measurement Kp = 1/sqrt(T-B * Np)
  - Single pulse time-bandwidth product ~10, so Kp/pulse ~0.3
  - Np > 6 yields Kp<0.05
  - Minimum PRF of 12 Hz provides ~25 km resolution and RMS spd err < 1.5 m/s
  - Plan higher PRF to provide margin



* Monte Carlo simulation results with 5000 noise realizations for each case

Challenges – nothing comes for free

- Uncertainty in SWH dominates error
  - Estimate fetch to infer SWH using NWP and wave models
- Calibration of power measurements critical to minimizing biases in wind speed estimates
  - RF electronics temperature control
  - Antenna pointing knowledge



How is it possible that nadir scatterometry can be done from a small satellite when previous scatterometers were so large?

- Only measuring wind speed at nadir
  - Antenna scanning not needed, simplifying spacecraft and instrument
  - Slant range reduced in nadir direction
- Nadir return dominates echo
  - Conventional scatterometers minimize gain in nadir direction to avoid this
  - Sigma0 at nadir is 30 dB higher than off-nadir
  - Reduced sensitivity to antenna pattern
- Very narrow bandwidth operation minimizes noise
- Lower altitude reduces propagation loss
- Integrated spacecraft and instrument
  - e.g., shared communications transmitter and antenna

Backup Slides

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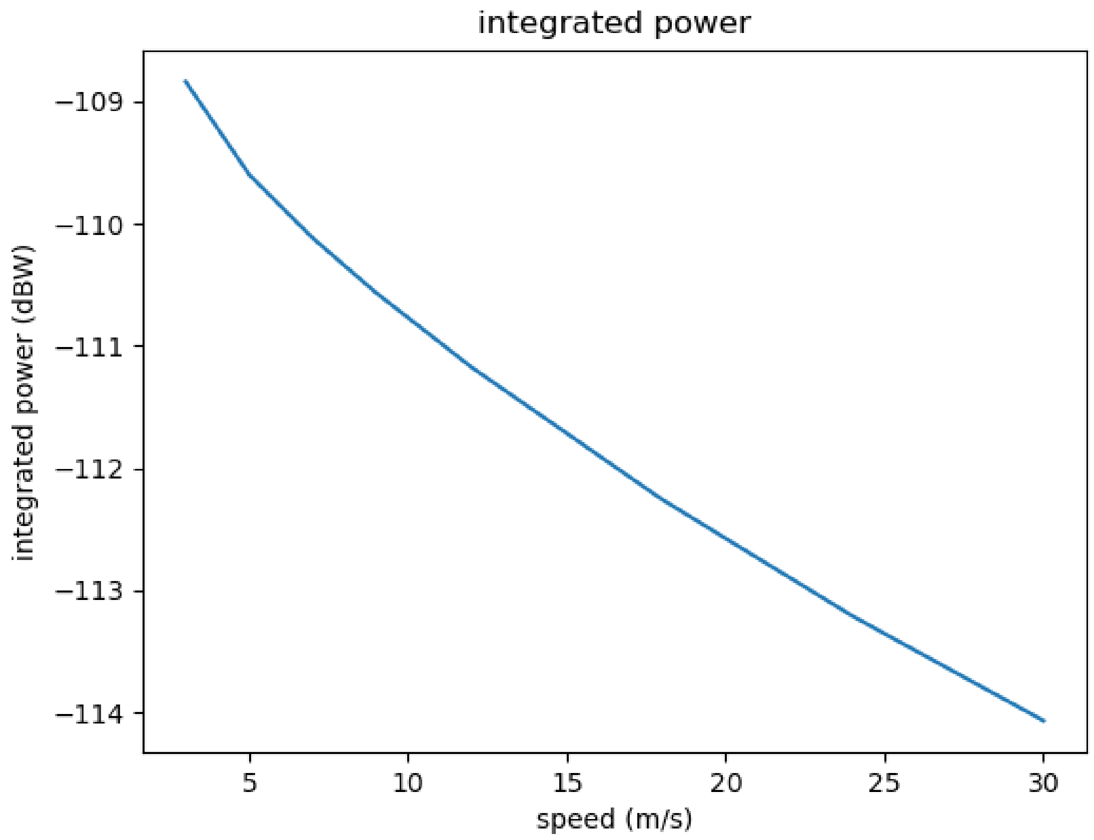
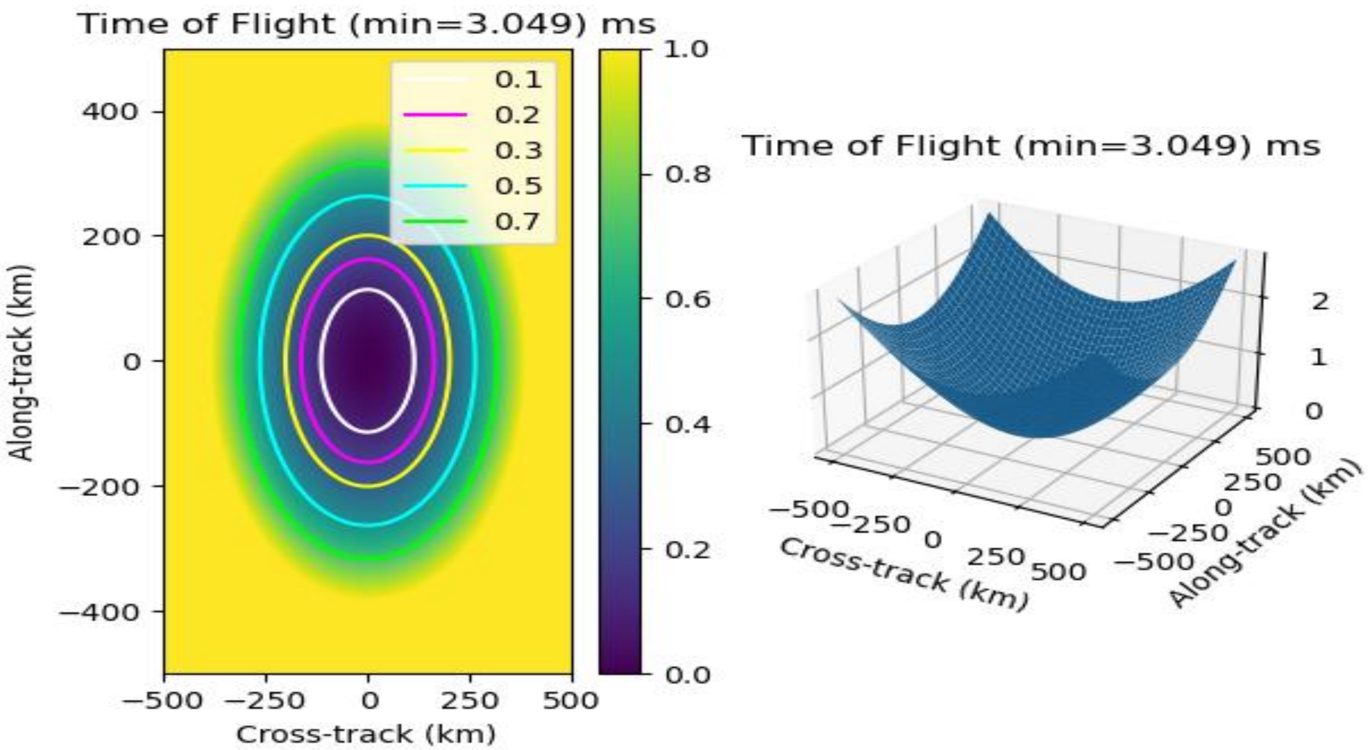
Cal/Val: Calibrating the "Power GMF"

- Power GMF curve can be computed prelaunch
  - General shape is constant so calibration is primarily adjusting just the vertical offset
- During Cal/Val, collocated power and surface winds from NWP products sets the mean offset
  - Can also make adjustments to curve shape if determined necessary
- Can be done automatically for each sensor potentially w/o dedicated in situ observations

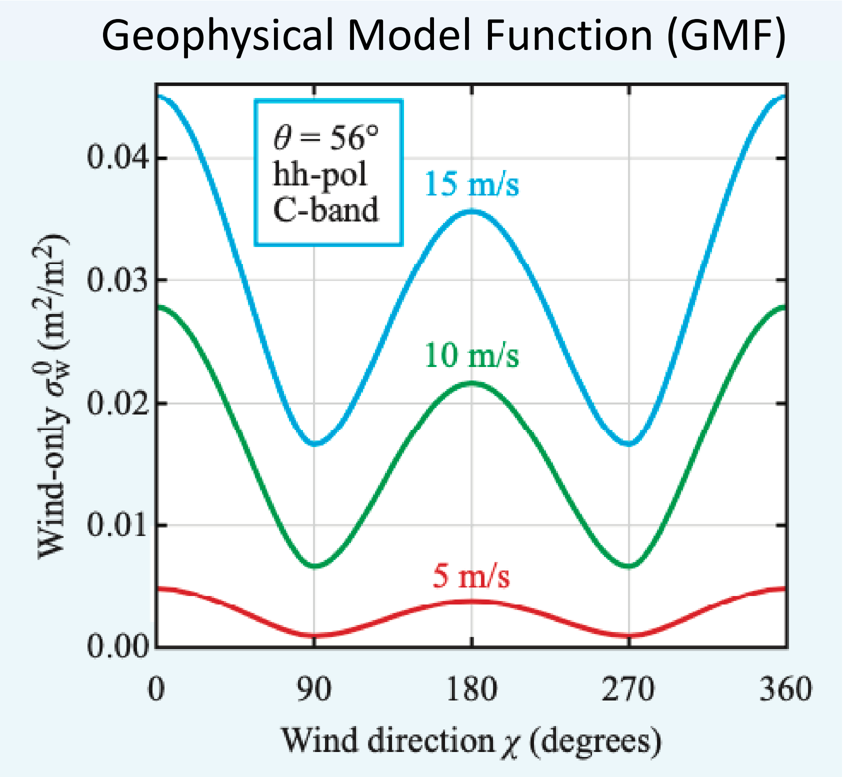


Slant range



Signal time of flight versus location on the surface from nominal 450 km altitude. The contours show the slant resolution contours for range bins near nadir.

Moderate Incidence Angle Scattering



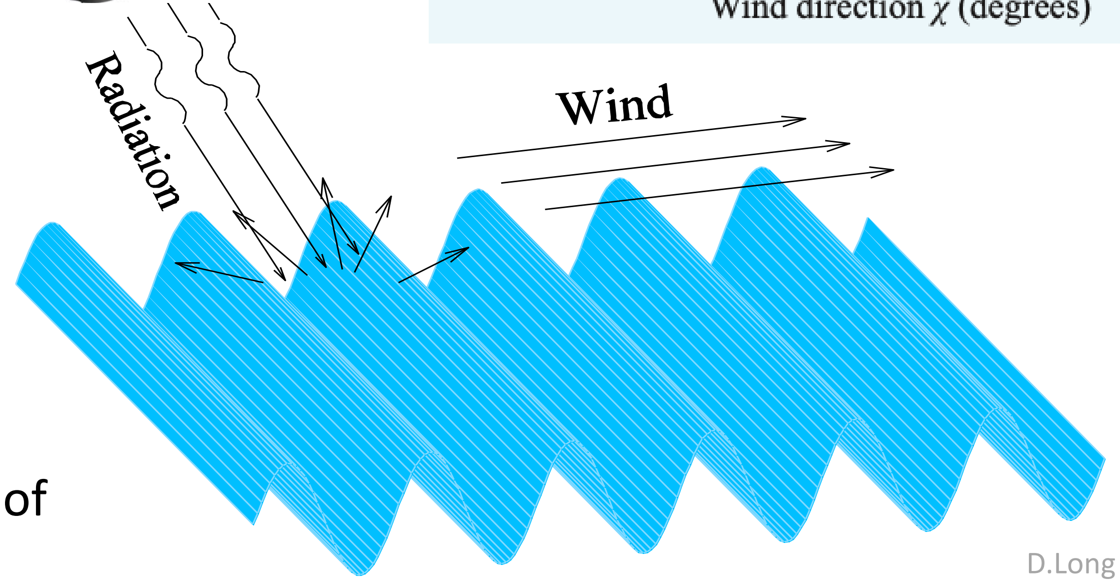
- Winds over the ocean create small capillary-gravity waves ("cat's paws") which roughen surface

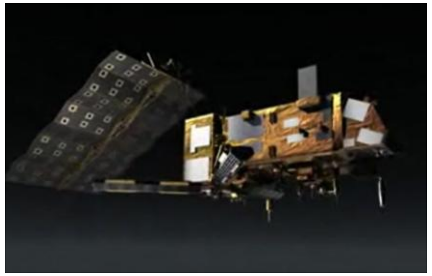
  - Roughness is related to wind speed and direction

- 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)

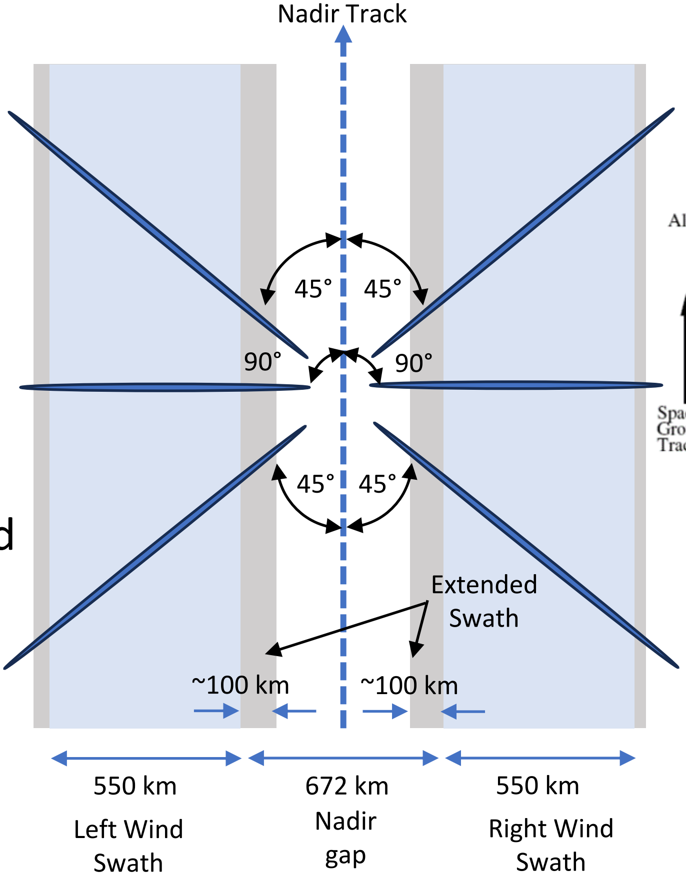




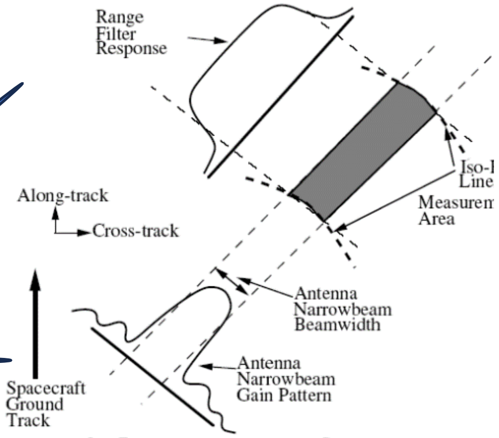
Fan-beam vs Scanning Scatterometers

Fan-beam

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

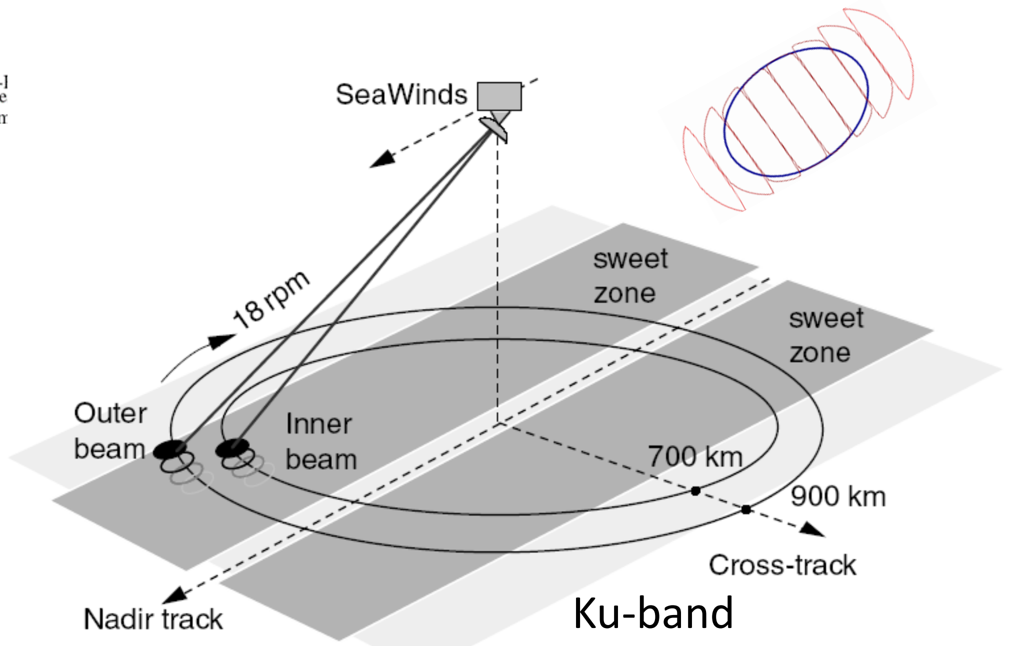


C-band ASCAT



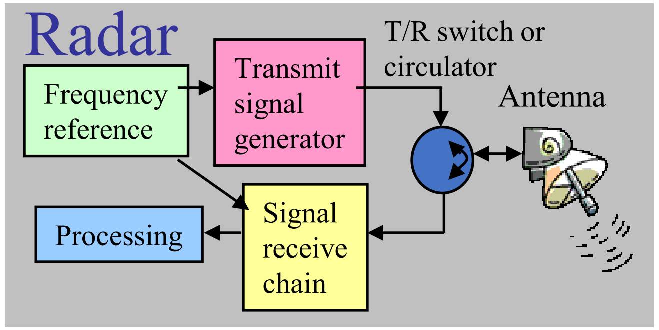
Conically Scanning

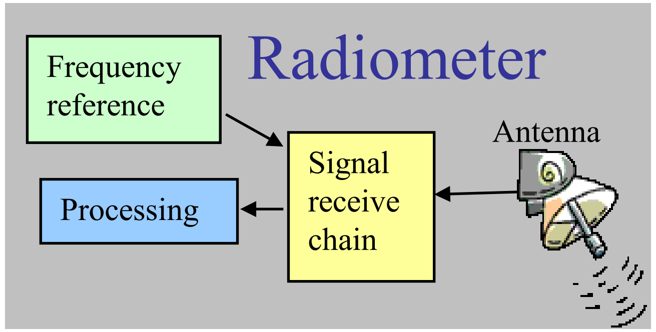
SeaWinds/QuikSCAT/OSCAT resolution defined by beamwidth with range/Doppler processing to create “slices”



Ku-band QuikSCAT

Microwave Remote Sensors





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 to estimate surface current. Nadir scatterometers are new.

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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

$$SNR = P_R / P_N$$

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

- Proportional to 1/T-B, the time-bandwidth product

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