Analysis of the C-band spaceborne scatterometers thermal noise

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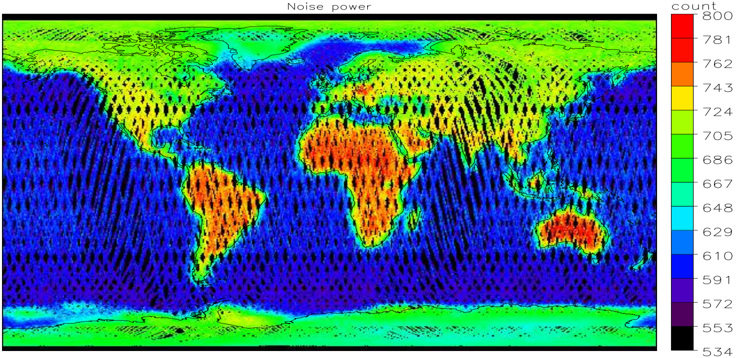
Introduction

- Scatterometer is a real aperture radar designed to determine the normalized radar cross section (σ_0) of the surface
- The scatterometer receives backscattered power + noise power
  - Noise power = receiver noise + thermal Earth radiance + RFI
  - Noise power measured separately in a transmit-free window in which the scatterometer works as a microwave radiometer
- Noise power is subtracted from the total received power to compute $\sigma 0$
  - Relevance of noise subtraction for $\sigma 0$, wind speed and the variance processing
  - The impact of the noise power misestimate (mis-subtraction) on σ_0
- ERS-2 and Metop-A scatterometers operating in C-band frequency (5.3/5.255 GHz) and VV polarization

Metop/ASCAT noise power map

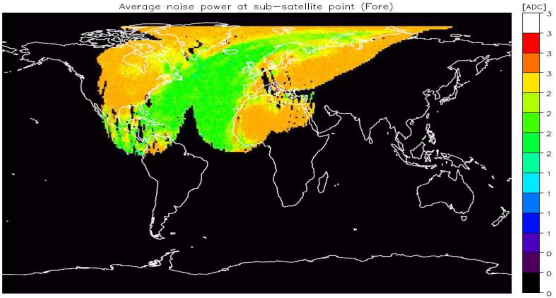
- Geophysical signature: signal power depends on surface type
- Noise power proportional to brightness temperature T_b
  - T_b depends on emissivity and physical temperature
  - Relatively good radiometric resolution
  - Coarse spatial resolution (antenna footprint)

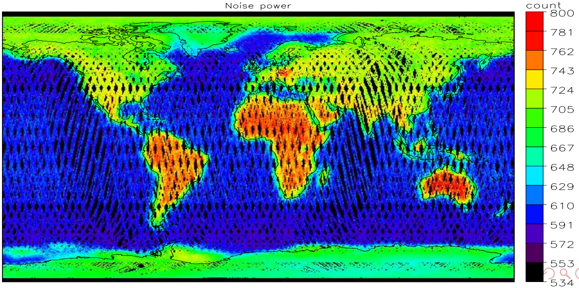


Data: 1-6 January 2011 (NH winter / SH summer)

ERS-2/AMI noise power map

- AMI data:
  - December 2008
- ASCAT data:
  - January 2011
- ERS-2/AMI (1995-2011) only distinguishes between land and sea
- Metop-A/ASCAT (2006-) higher radiometric resolution

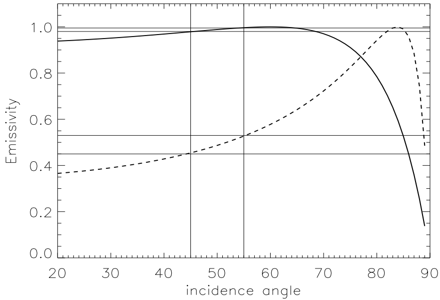




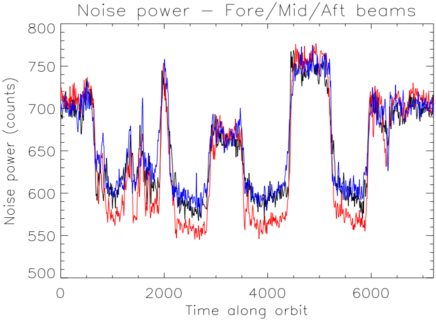
Viewing geometry effect

- Scatterometer employs 3 antennas (Fore/Mid/Aft)
  - Mid antenna illuminates the swath with lower incidence angles than side antennas (Fore/Aft)
- Mid antenna noise is lower than side antennas over ocean
  - T_b depends on emissivity which depends on incidence angle (θ)

Noise power difference due to incidence angle difference



Emissivity Vs θ - dashed: sea, solid:land

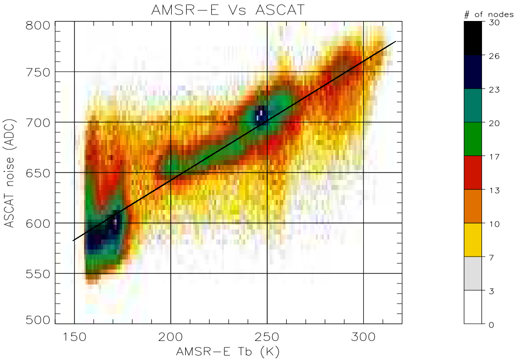


Black: Fore, Red: Mid, Blue: Aft

Comparison with AMSR-E radiometer

- AMSR-E microwave radiometer brightness temperature
  - 6.9 GHz channel
  - V-polarization
- Three main clusters: Sea, land and ice
- Other sub-clusters: polar waters, tropical waters, sea ice, land ice, SH continents etc.

Very good correlation ($\rho \approx$ 0.9)



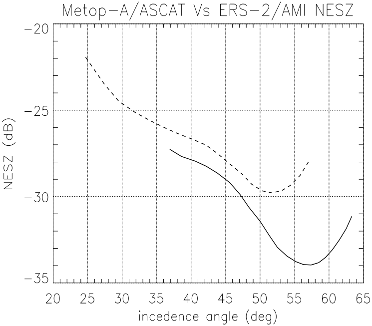
Noise Equivalent Sigma Zero - over ocean

- NESZ: sensitivity of the radar instrument

$$NESZ = \frac{(4\pi)^3 R^3 P_n}{P_t G_a^2(\theta) G_r \lambda^2 \rho \phi_0}$$

- NESZ depends on the instrument parameters, mainly $G_a(\theta)$
  - Hence the shape of the antenna gain pattern across-swath

ASCAT NESZ/SNR lower/higher than AMI



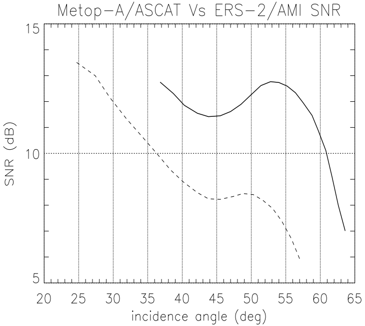


Figure: ASCAT (solid) Vs AMI (dashed) NESZ/SNR - Fore antenna

Noise subtraction effect on $\sigma 0$ and wind speed

- Comparison of σ_0 processed with noise subtraction against σ_0 processed without noise subtraction
  - Difference increases with decreasing σ_0 (max:1.4 dB/1.2 m/s)
  - Confirms the necessity and importance of noise subtraction

Lower backscatter more sensitive to noise

$\Rightarrow$ noise subtraction more important

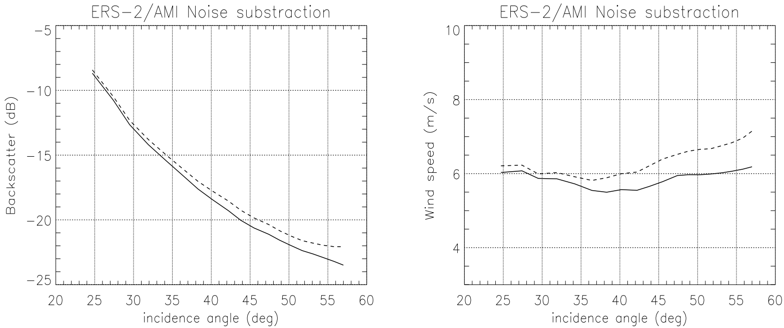


Figure: solid: with noise subtraction, dashed: without noise subtraction

Noise subtraction effect on the variance

- Noise subtraction ⇒ variance addition:

$$var[P_{s+n} - P_n] = var[P_{s+n}] + var[P_n]$$

  - Difference increases slightly across-swath: [0.45, 1.25] %
  - Similar trend observed in σ_0 and wind speed

Noise subtraction increases the variance

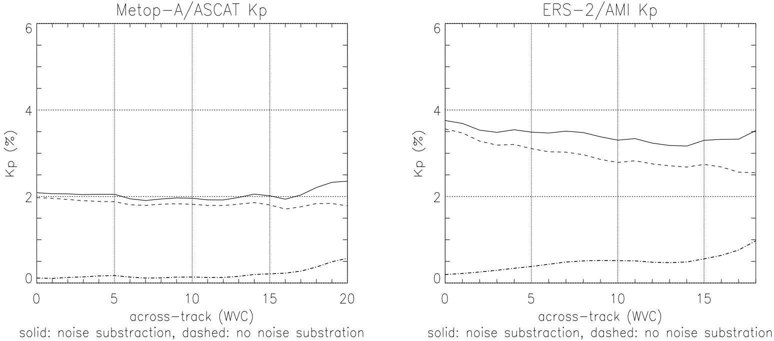


Figure: solid: with noise subtraction, dashed: without noise subtraction, dot-dashed: difference - left: ASCAT, right: AMI

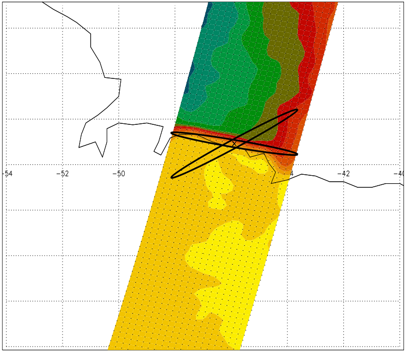
Spatial resolution - Land/sea transition

- ASCAT and AMI are fixed fan beam scatterometers
  - Antenna footprint: narrow in azimuth ($\approx$ 30 km) and wide in range ($\approx$ 500 km)
- σ_0 measurement (range gated): spatial resolution depends on the PSF
- Noise power measurement (not range gated): spatial resolution depends on the antenna footprint
  - Land contamination depends on the orientation of the antenna footprint
- Measurements near the transition between two different surfaces (e.g., land/sea or sea-ice/sea) are probably processed with over/under estimated noise power

Sea-land transition - $\sigma 0$

- Nominal $\sigma 0$ (25 km): range gated and spatially filtered
- PSF dominated by Hamming spatial filter (width $\approx$ 86 km)
- Step slope is inversely proportional to the width of the PSF
  - σ_0 small PSF $\Rightarrow$ sharp transition

Spatial resolution independent of footprint orientation



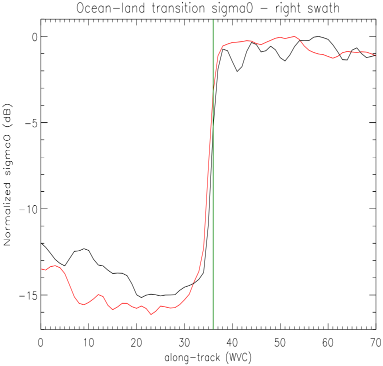
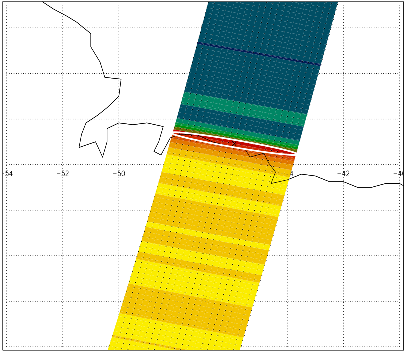


Figure: Land-sea transition, red: Mid antenna, black: Fore antenna

Land-sea transition - noise - mid antenna

- Noise signal not range gated (averaged along-track)
- PSF dominated by antenna footprint, orientation and along-track averaging
  - Antenna footprint parallel to the coast ⇒ sharp transition

Spatial resolution depends on footprint orientation



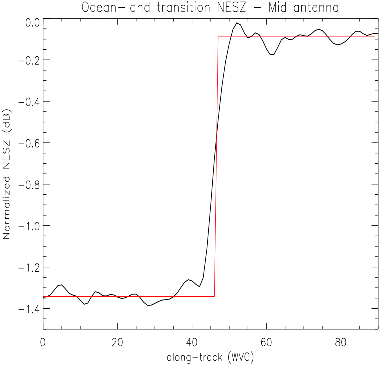


Figure: Sea-land transition, Mid antenna

Land-sea transition - noise - side antenna

- Antenna footprint quasi-perpendicular to the coast line
- PSF larger in this direction ⇒ smooth transition

Spatial resolution depends on footprint orientation

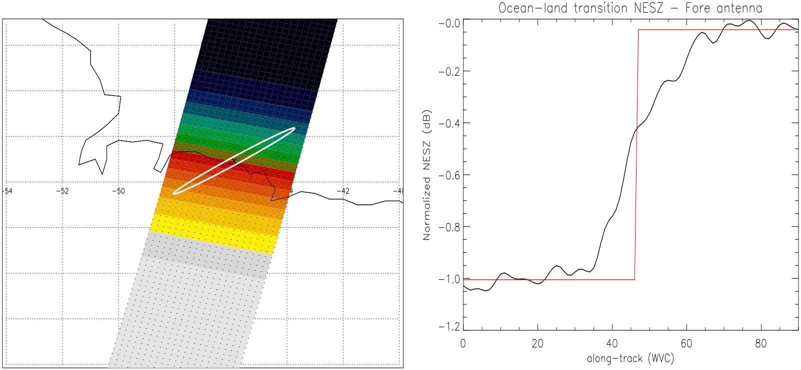


Figure: Land-sea transition, Fore antenna

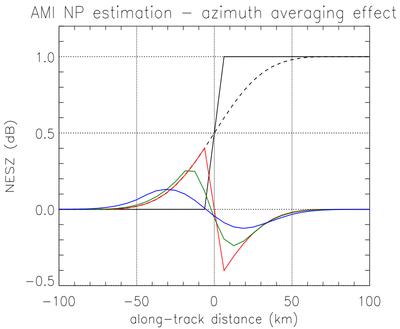
Impact of along-track averaging on noise subtraction

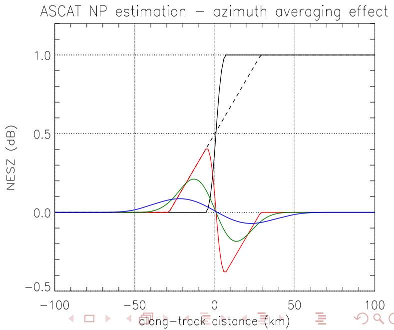
- Metop-A/ASCAT
  - σ_0 signal averaged over 8 along-track samples using trapezoidal filter
  - noise signal averaged over 40 along-track samples using rectangular filter
- ERS-2/AMI
  - σ_0 signal averaged on-ground over 32 along-track samples
  - noise signal averaged on-board over 28 along-track samples and on-ground over 21 along-track samples using Gaussian filter
- Noise signal varies spatially
  - **different averaging between σ_0 and noise signal $\Rightarrow$ impact on noise subtraction**
  - this impact is more important at the coastline because of the high contrast in noise level

Impact of along-track averaging on noise subtraction

- σ_0 error(red/green/blue) = ideal subtraction (black solid) - biased subtraction (black dashed)
- Nominal resolution product (blue): bias negligible (< 0.1 dB)
- Higher resolution products (Green and red): the bias might reach 0.2 and 0.4 dB.

This affects few measurements close to the coast





Conclusion

- Noise signal carries useful geophysical signature (proportional to brightness temperature)
  - Relatively good radiometric resolution, but coarse spatial resolution (particularly in range)
- Noise subtraction is important for $\sigma 0$ and wind speed processing, more important over ocean than over land
  - The effect of under/over subtraction of the noise power near the coast was assessed using land-sea transitions
  - The error on coastal σ_0 is probably negligible (< 0.1 dB) for nominal resolution products, for high resolution products the noise power misesimate could reach 0.4 dB
  - This affects only few measurements close to the coast