Analysis of speckle noise impact on rotating near-nadir measurements. SWIM case

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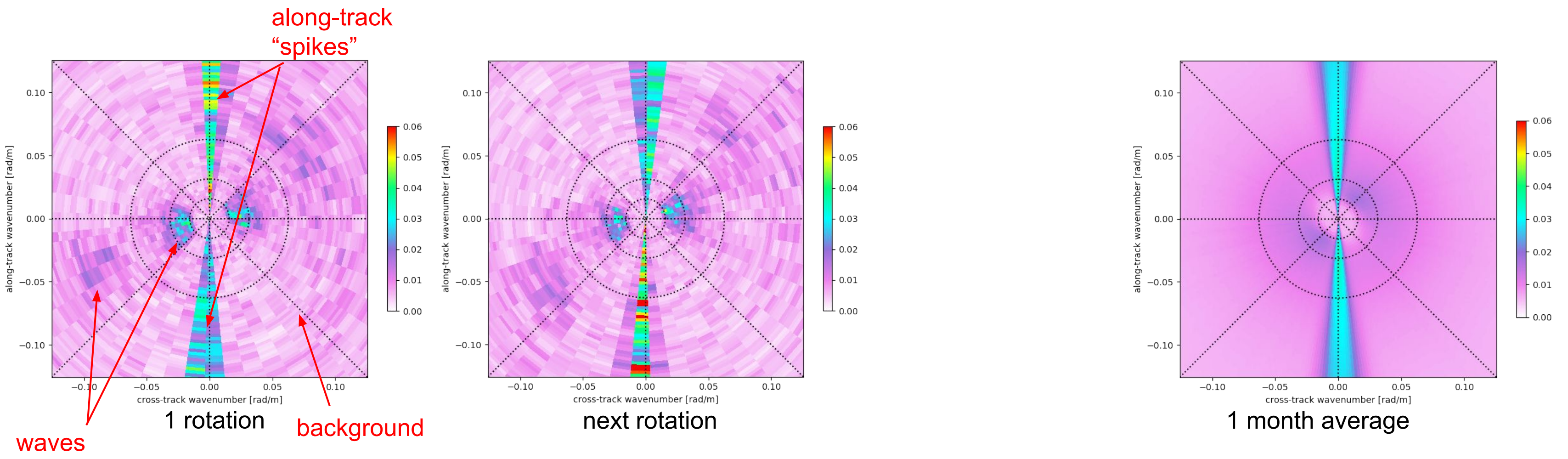
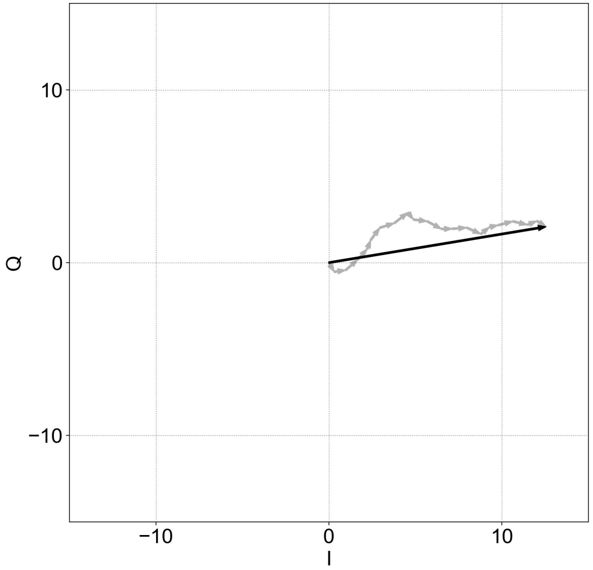
Speckle in the SWIM context



SWIM fluctuation spectra for 10° beam

The SWIM speckle noise is azimuth-dependent, with very conspicuous spikes in the along-track directions, and a continuous background in the other directions.
The spikes are very narrow in azimuth, strong enough to be clearly seen on 1-rotation plots (left figures).
The orientation of the spikes with respect to the track is stable and fixed, while the background is more isotropic, as can be seen on a month-average plot (right figure).

What is "speckle noise" in the first place?



Intensity (black arrow) is the sum of scatterers complex contributions (short grey arrows).

In active imaging instruments using phase-coherent illumination (acoustic, laser, microwaves), the recorded return signal is a sum of infinitesimal contributions from individual scattering elements in the scene, each with its own phase, very sensitive to its 2-way distance to the instrument.

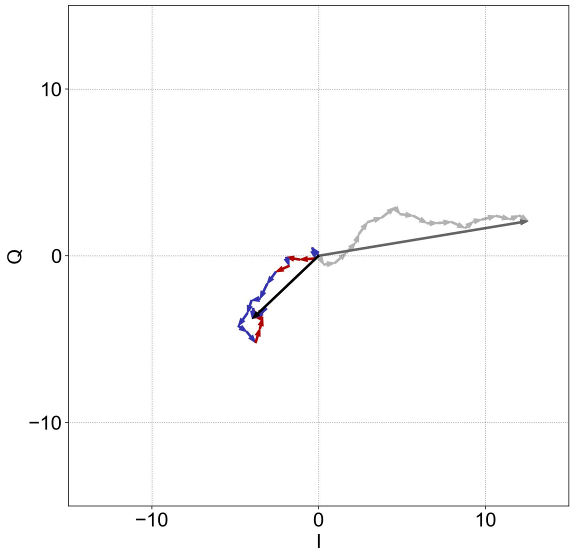
→ random modulation of the intensity due to constructive/destructive interferences.

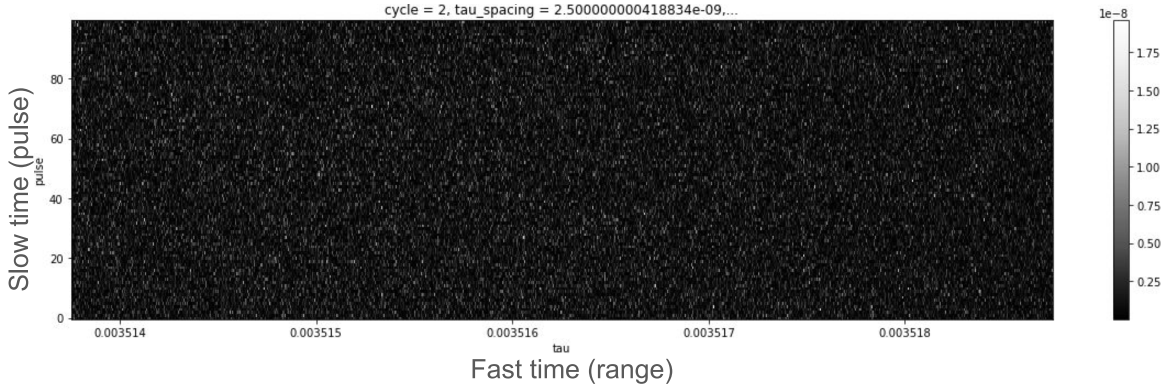
→ "speckle noise"

→ need to average over many realizations of the noise to retrieve mean intensity.

→ number of needed samples varies with geometry, hence with SWIM observation azimuth.

Cross-track speckle noise



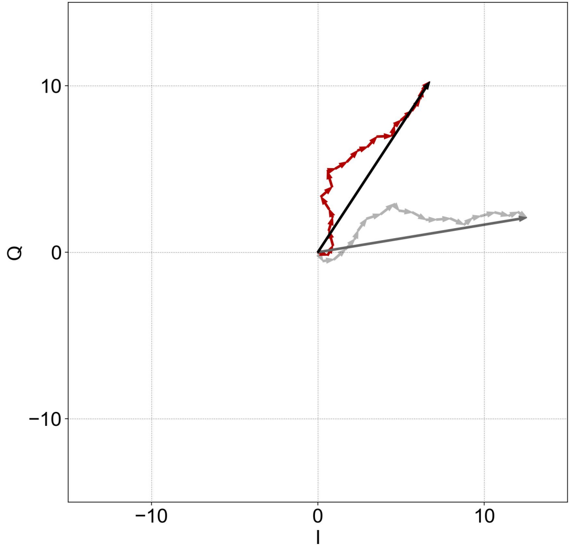


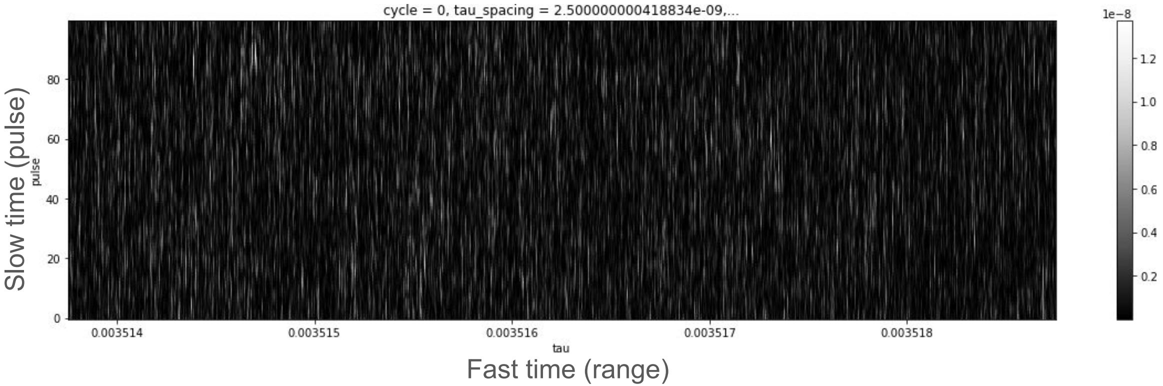
In cross-track observations, 2-way distance between instrument and scatterers evolves differently for scatterers that are fore/aft of the satellite

→ large diversity of phase changes between two pulses (large Doppler B/W)

→ speckle noise decorrelates fast→ getting enough samples is easy.

Along-track speckle noise





In along-track observations, all scatterers are either fore or aft of the satellite
→ much less diversity of phase changes between two pulses (small Doppler B/W)
→ speckle noise stays very correlated→ getting enough samples is long.

Azimuthal variation of speckle spectrum

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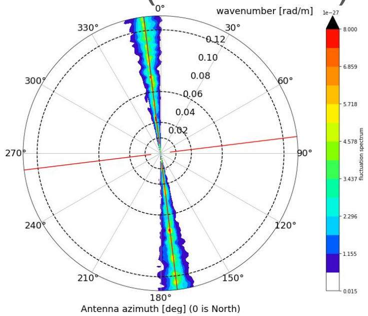
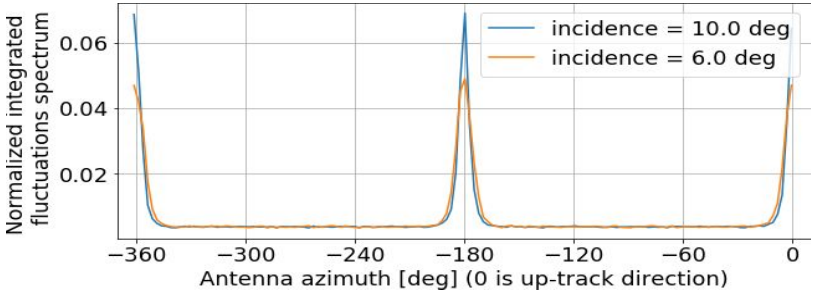
Simulated SWIM spectrum over flat surface (no waves). *Earth rotation disabled*



Speckle damping with pulse averaging method is strongly degraded in along-track directions due to long coherence time between pulses. Maximas occurs in along-track directions.

Quantitative variation (spectrum integrated over wavenumbers) of speckle level as a function of antenna azimuthal angle relative to up-track direction:



Measured one-month averaged SWIM spectra.

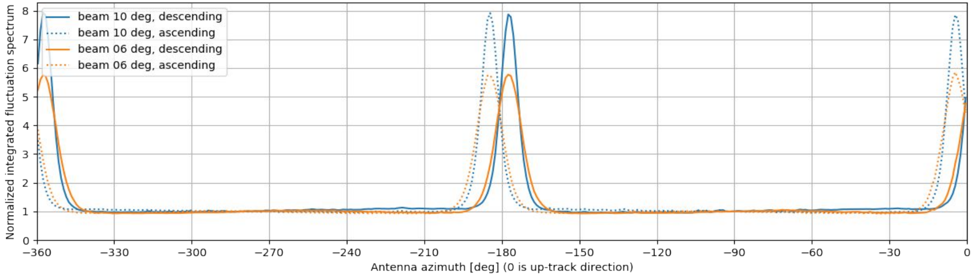


Figure above presents SWIM spectra integrated over wavenumbers corresponding to 25-35 m wavelength in order to remove waves impact. Maximum speckle level occurs at slightly different azimuthal locations than along-track directions depending on ascending/descending pass and latitude (shown in next slide) suggesting that Earth rotation speed is impacting speckle maximum location.

Location of maximum speckle azimuth

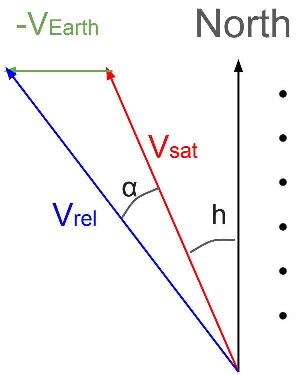
Azimuth of maximum speckle appears at angle of maximum relative velocity (minimum Doppler bandwidth)

Theoretical deviation of maximum speckle azimuth

$$\alpha = \arctan\left(\frac{R_e\Omega_e\cos(lat) + V_{sat}\cos(i)/\cos(lat}{V_{sat}\cos(h(lat))}\right) - h(lat)$$

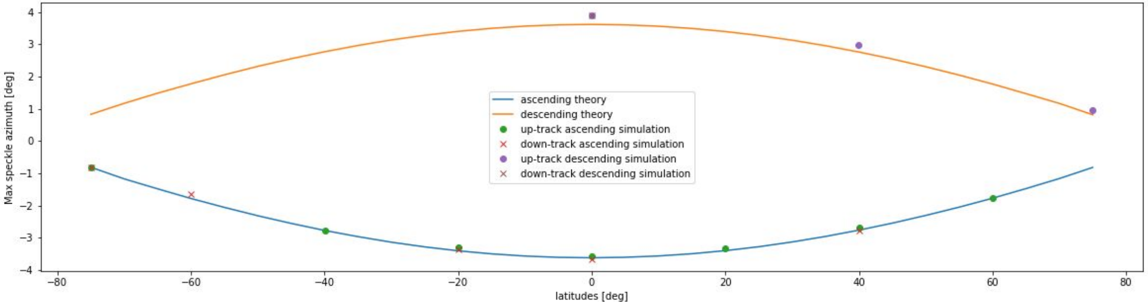
Satellite heading

$$h(lat) = \begin{cases} \arcsin\left(\frac{\cos(i)}{\cos(lat)}\right) & \text{in ascending pass} \\ \pi - \arcsin\left(\frac{\cos(i)}{\cos(lat)}\right) & \text{in descending pass} \end{cases}$$



- R_e: Earth radius
- i: Orbit inclination
- Ω_e: Earth rotation speed [rad/s]
- V_{sat}: Satellite ground velocity [m/s]
- lat: Satellite latitude
- h: Satellite heading

Deviation of maximum speckle level (α) as a function of latitude. Solid lines are derived from above equation and dots were obtained with SWIM numerical simulations.



Location of maximum speckle azimuth vs latitude

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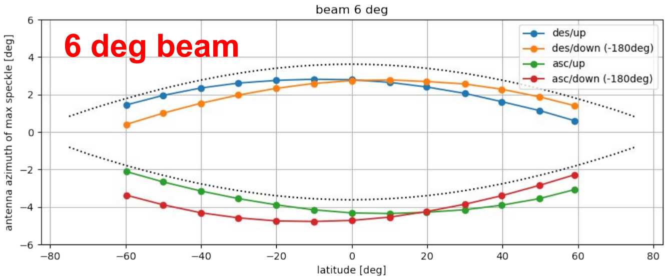
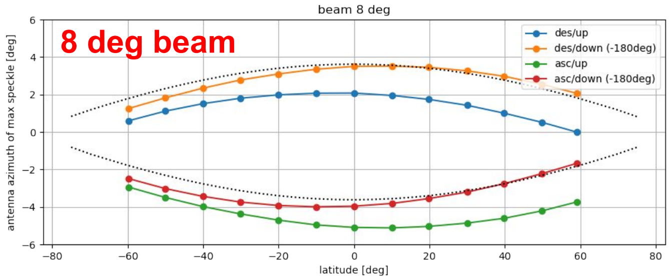
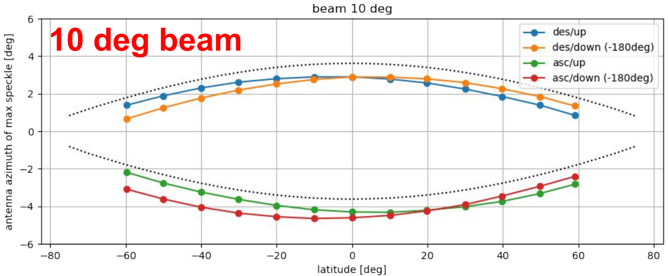




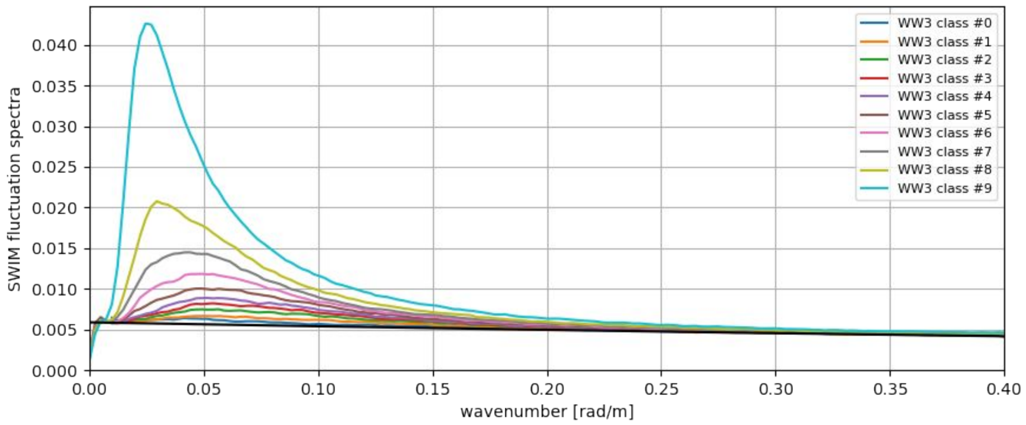


Black dots : Theoretical / simulation locations (No up/down-track difference)
Blue : measured up-track / descending
Orange : measured down-track / descending
Green : measured up-track / ascending
Red : measured down-track / ascending

Observation: Inconsistencies between 6, 8 and 10 deg beams behaviour reveal **non-physical origins**. Theory and simulation (black dot lines) also do not perfectly agree with SWIM data.

Explanation: Deeper inspection revealed that discrepancies between theory/simulation and SWIM data can been explained by ground processing errors introduced in the angle bias correction matrix where erroneous antenna azimuth angle has been used. This (small) error will probably be resolved in future products release.

Speckle sensitivity away from the along-track regime



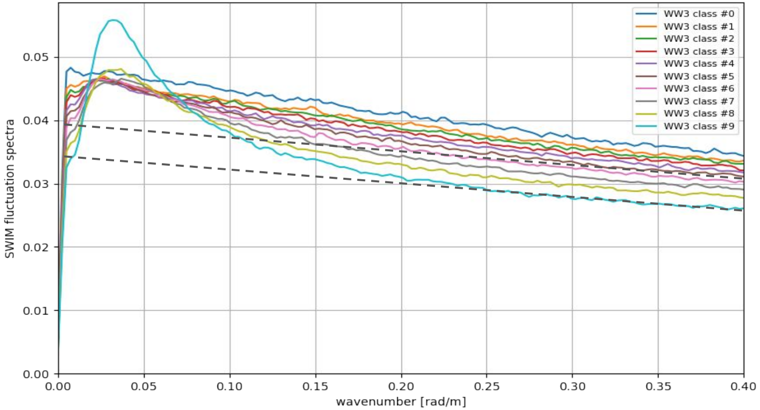
Mean SWIM fluctuation spectra ordered by energy in SWIM direction given by colocated wave model WW3.
In cross-track direction.
Black line indicates speckle function learned from spectra free of waves.

Speckle noise spectrum is:

- a slowly decreasing quasi-linear function of wavenumbers.
- independent of (considered) sea state parameters (insignificant impact).
- independent of antenna azimuth (insignificant impact). Not shown on this figure.

Speckle spectrum appears to be (almost) exclusively driven by fast scatterers phase decorrelation due to observation kinematics.

Speckle sensitivity in the along-track regime



Mean SWIM fluctuation spectra ordered by energy in SWIM direction given by colocated wave model WW3.
Figure obtained in the along-track domain (maximum speckle azimuthal direction).

Speckle noise spectrum (eg. black dashed curves) is:

- a decreasing quasi-linear function of wavenumbers.
- Dependent on considered sea state parameters (very similar sensitivity obtained when wind discrimination is considered).
- Strong sensitivity of spectrum level versus antenna azimuth in the along-track domain. (see slide 6)

Speckle spectrum level is high due to slow scatterers phase decorrelation driven by observation geometry. For a given azimuthal angle, temporal phase diversity decorrelation is dependent on geometrical properties of surface profile (sea state).

Conclusion

Speckle behaviour can be divided in **two distinct regimes**.
Each regime is driven by different speckle origin, level and sensitivities

Cross-track domain :

- Speckle level is fully driven by fast scatterers phase decorrelation between pulses: speckle level is low compared to along-track.
- Sea state impact (surface geometry) is negligible.

Along-track domain :

- Scatterers phase decorrelation between pulses is strongly reduced: speckle level is much stronger than across-track regime.
- Diversity of scatterers phase variation (decorrelation) between pulses becomes sensitive to geometric properties of the surface profile. Sea state impact is no more negligible and has to be considered.