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TAKING THE PULSE OF OUR PLANET FROM SPACE

Exploitation of Fully Focused SAR (FFSAR) processing using S3/S6-MF over ocean

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Open Ocean Science Objectives

Analysis of new SAR configurations and processings to better exploit the altimeter performance and capability :

- Improved altimeter performances in global ?
- Mitigation of sea-state effects contributing to SSH retrievals uncertainty ? (increase of noise with SWH, impact through SSB, swell-induced aliasing, sea-surface motion effects)
- Benefit brought at mesoscale (better observability in 10-100km range) ?
- Capability to provide more details of the ocean surface structure ? : internal solitary waves (ISWs), swell detection, surface slope over trenches …

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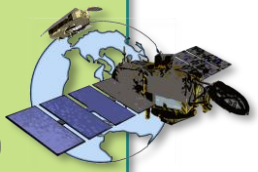
Objectives addressed in two ESA studies:



- **Multi-sensor synergy study for Sentinel-3C/D**
- **Sentinel-6MF and Jason-3 Tandem Flight Exploitation (S6-JTEX)**

notably focussing on FF-SAR processing (Egido and Smith, 2017)

Open Ocean Science Objectives

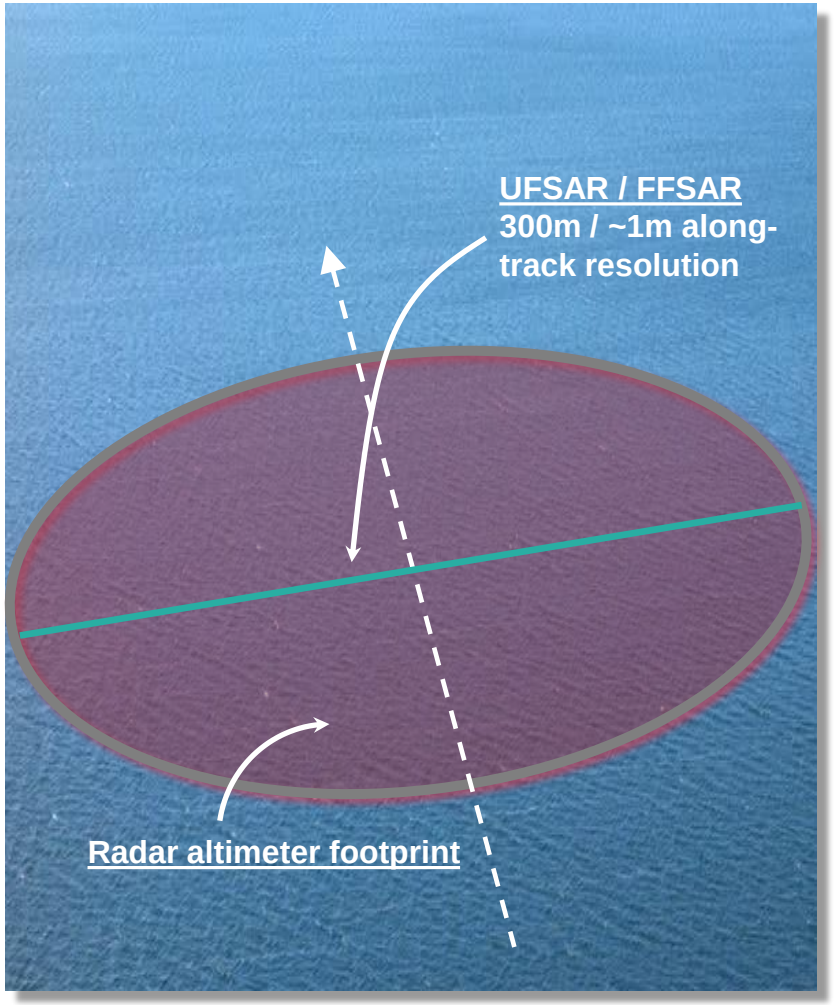
Expected benefit from FF-SAR processing :

More “(possibly) independent” single looks available

- improved noise level reduction
- better sampling of sea surface structures

FF-SAR data analysis:

- Analyze of different configurations: multilooking, along-track weighting function, Doppler bandwidth
- Processing of large data set and performance assessment over Open Ocean
- Evaluation of the FF-SAR benefit to capture ocean surface structures (swell and ISWs)



Data and Processings

Nature	Description	Institution
Sentinel-3 FF-SAR 160-Hz / 20-Hz	Data processed with SMAP tool based on Omega-k algorithm (Guccione et al., 2018)	ESA/CNES/CLS http://doi.org/10.5270/esa-cnes.sentinel-3.smap
Sentinel-3 UF-SAR 80-Hz / 20-Hz	Data processed with SMAP tool following 80-Hz waveform approach (Dinardo et al., 2014) and using Buchhaupt fast convolution retracker (2017)	ESA/CNES/CLS
Sentinel-3 Marine PDGS L2 products	Non-time critical L2 LRM/SAR altimeter products at 20-Hz/1-Hz	EUMETSAT available on COPERNICUS open access hub
Sentinel-3 S3PP LR-RMC	20-Hz/1-Hz L2E-HR Sentinel-3A data generated from CNES S3PP prototype in LR-RMC mode (Moreau et al., 2021)	CNES/CLS
Wave model	WWIII and MFWAM (mean peak period, wave height, and direction derived from wave spectra)	ECMWF and Meteo France

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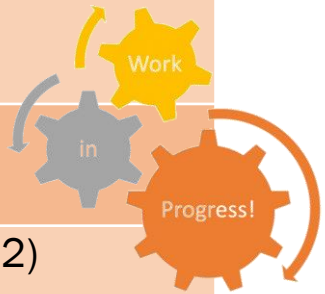
Sentinel-6MF FF-SAR 140-Hz / 20-Hz	Data processed with SMAP tool adapted to S6-MF mission	ESA/CNES/CLS
Sentinel-6MF UF-SAR 140-Hz / 20-Hz	Data processed with SMAP tool adapted to S6-MF mission	ESA/CNES/CLS
Sentinel-6MF PDAP L2 products	Non-time critical L2 SAR altimeter products at 20-Hz/1-Hz	EUMETSAT (Jun 2022)

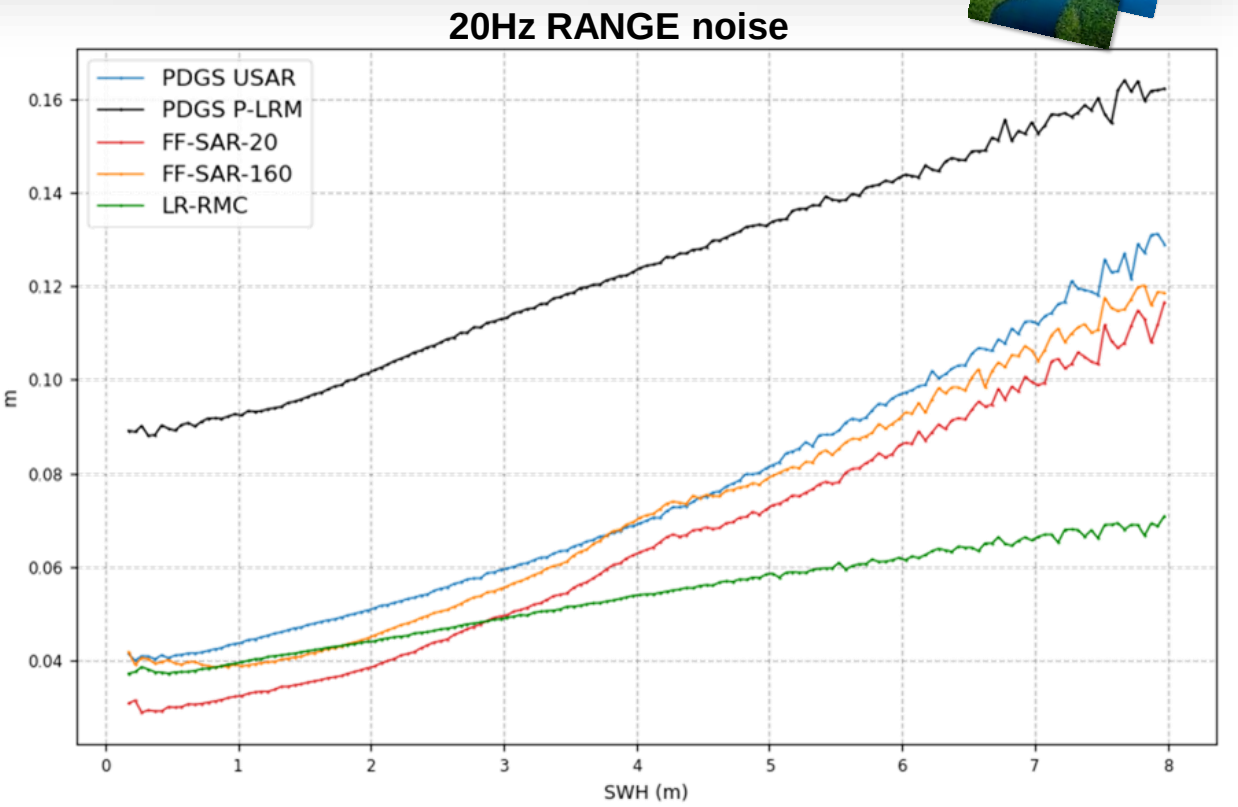


Analysis of S3 FF-SAR over Open Ocean

High frequency analysis: RANGE

- Similar dependency as for UF-SAR
- Smaller noise than UF-SAR and particularly LR-RMC for SWH<3m
- Slightly higher noise for FF-SAR 160Hz vs FF-SAR 20Hz

➔ **Better performance for FF-SAR**

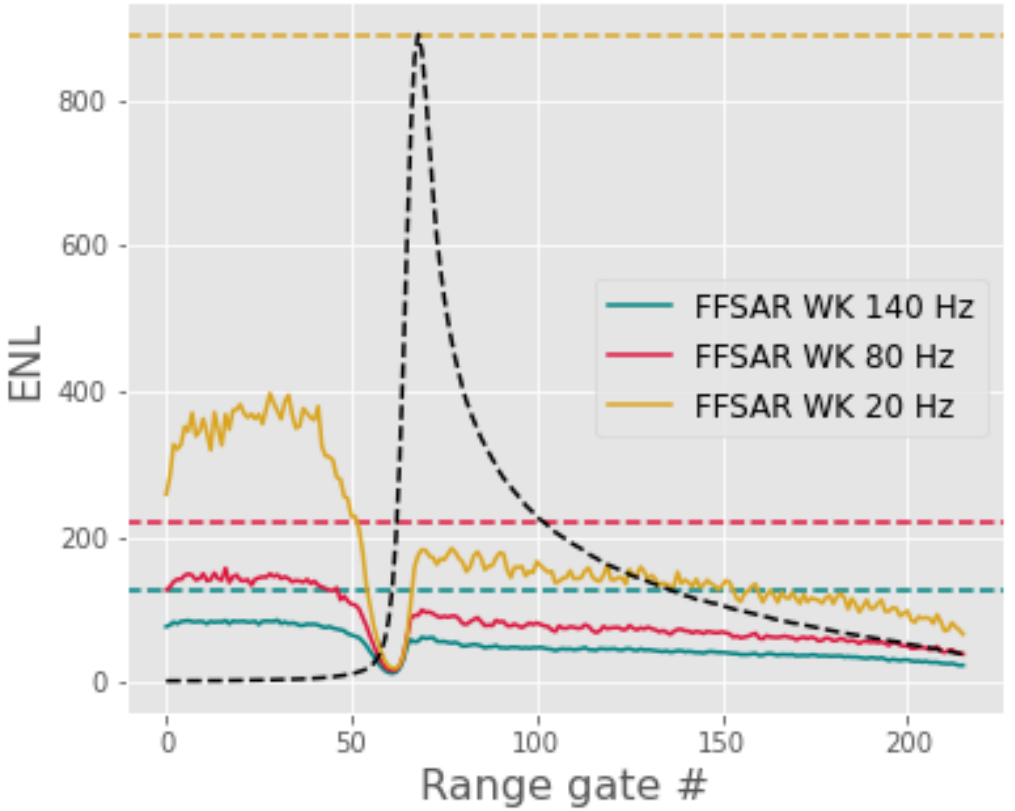


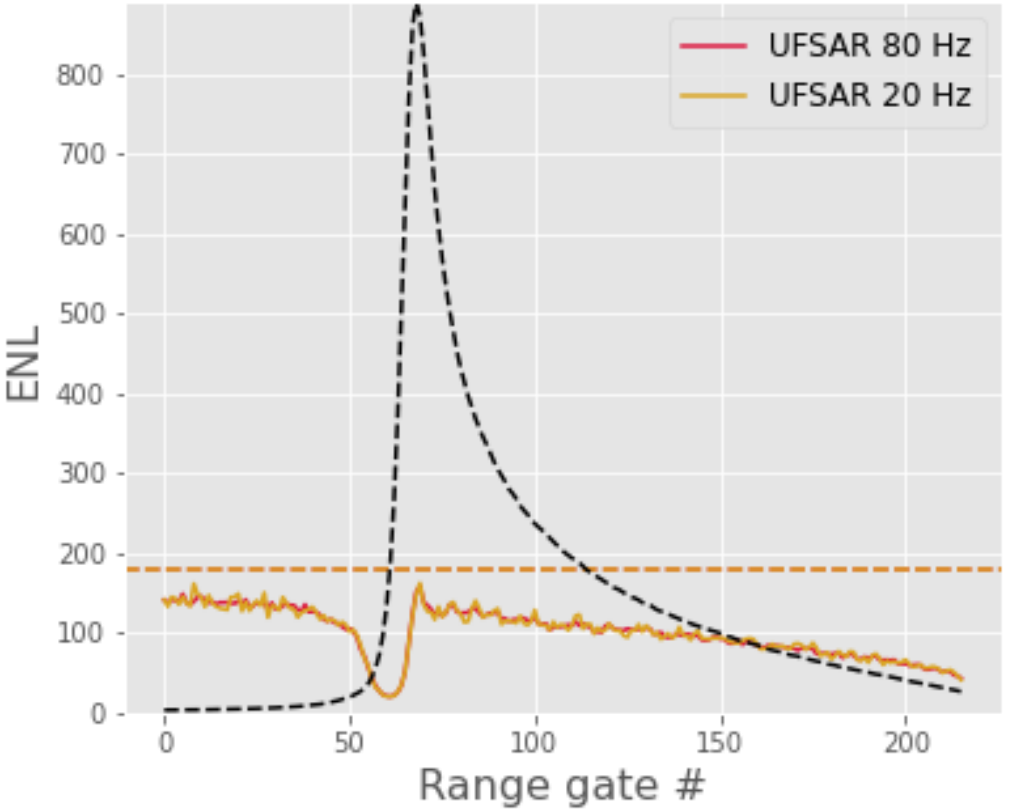
Processing	PDGS PLRM	PDGS SARM	FF-SAR-160	FF-SAR-20	LR-RMC
Noise at 2m-wave (cm)	10.2	5.1	4.5	3.8	4.4

Analysis of S3 FF-SAR over Open Ocean

High frequency analysis: RANGE

- Noise level improvement due to higher ENL for FF-SAR





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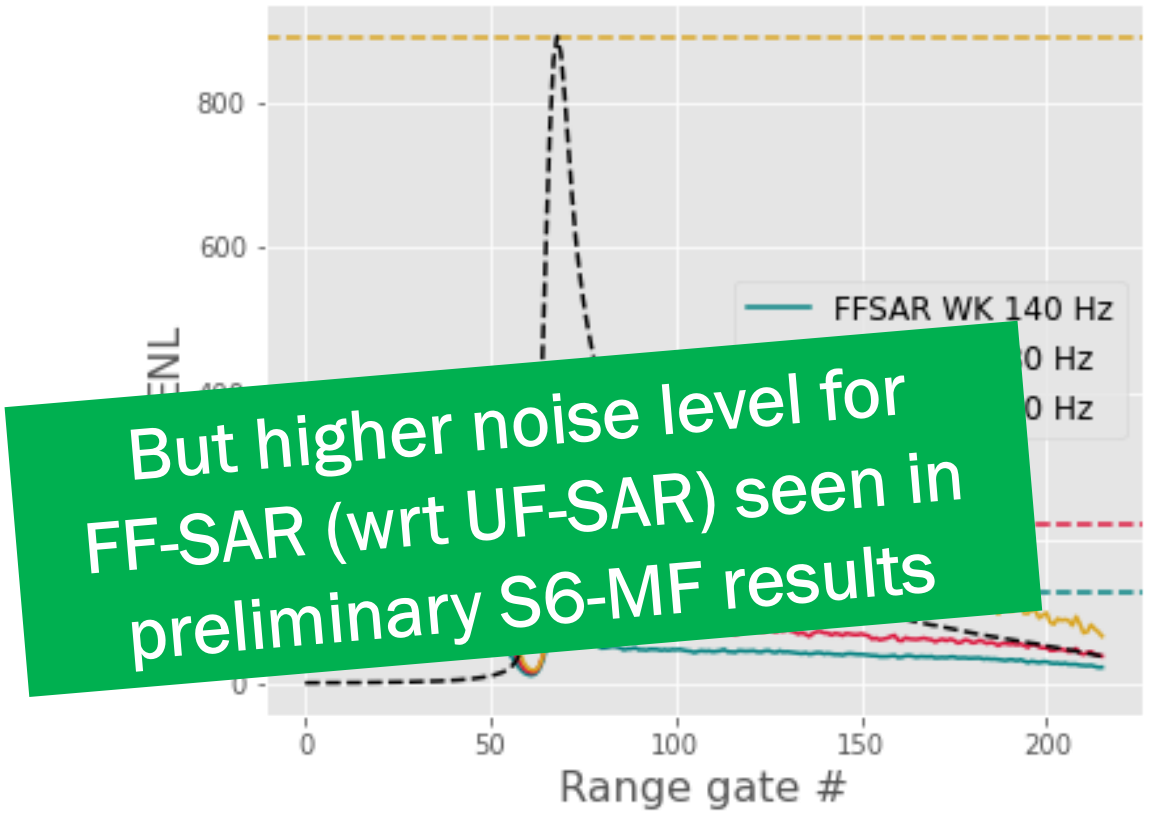
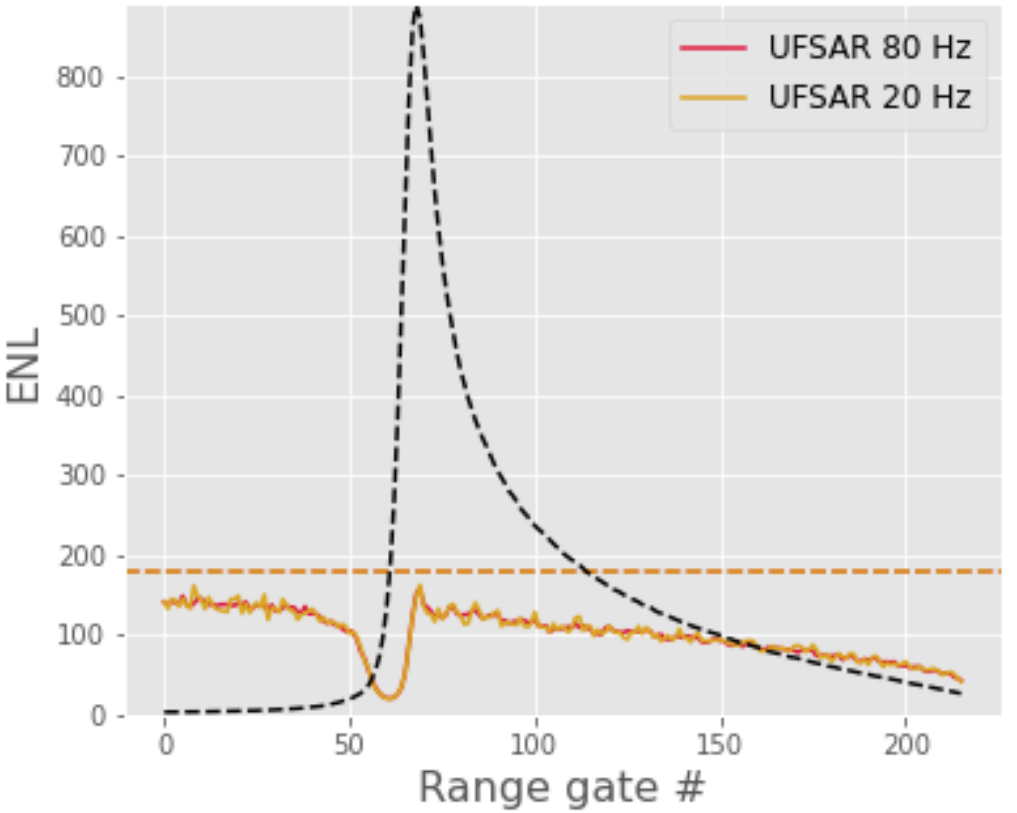


But higher noise level for FF-SAR (wrt UF-SAR) seen in preliminary S6-MF results



Analysis of S3 FF-SAR over Open Ocean

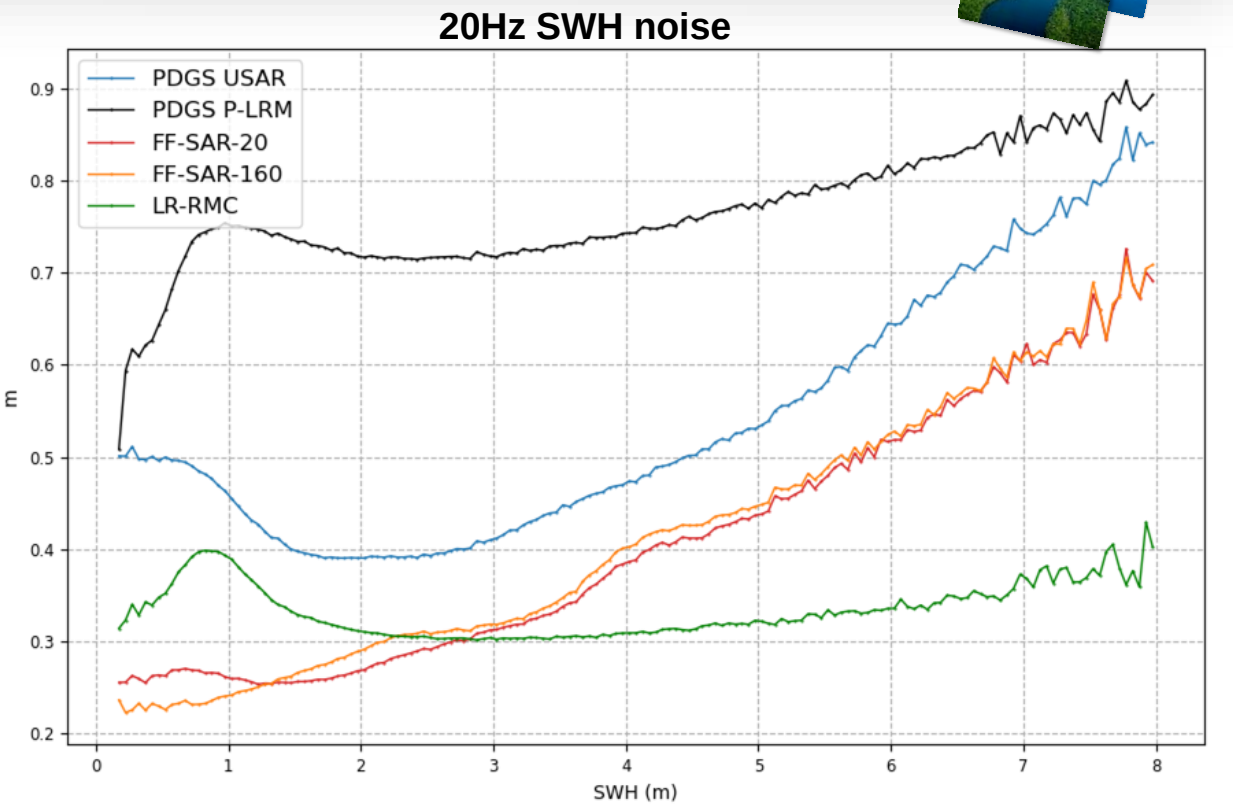
High frequency analysis: SWH

- Smaller noise than UF-SAR and especially than LR-RMC for SWH<3m
- FF-SAR-160 slightly higher than for FF-SAR-20

➔ **Excellent result for FF-SAR**

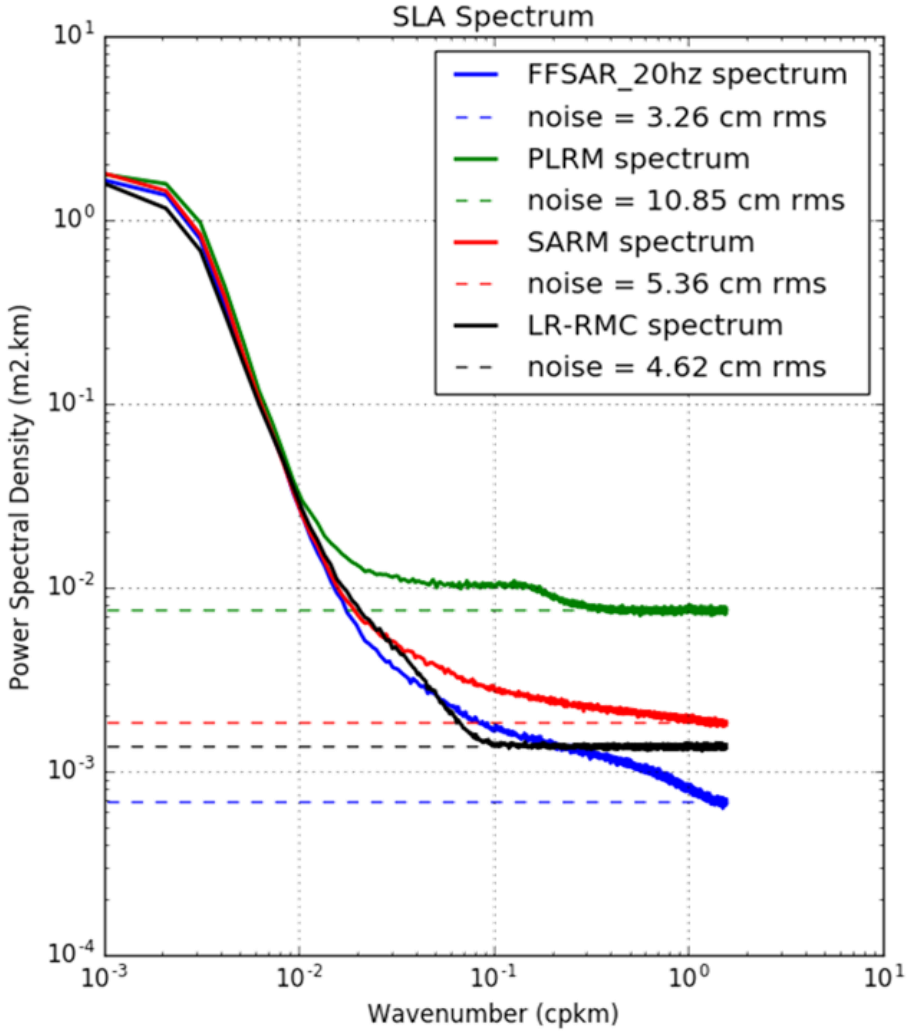
Long wavelength errors

SWH dependency with SWH similar to UFSAR suggesting similar vertical wave motion effects



Processing	PDGS PLRM	PDGS SARM	FF-SAR-160	FF-SAR-20	LR-RMC
Noise at 2m-wave (cm)	71.7	39.0	29.0	26.8	31.1

Analysis of S3 FF-SAR over Open Ocean



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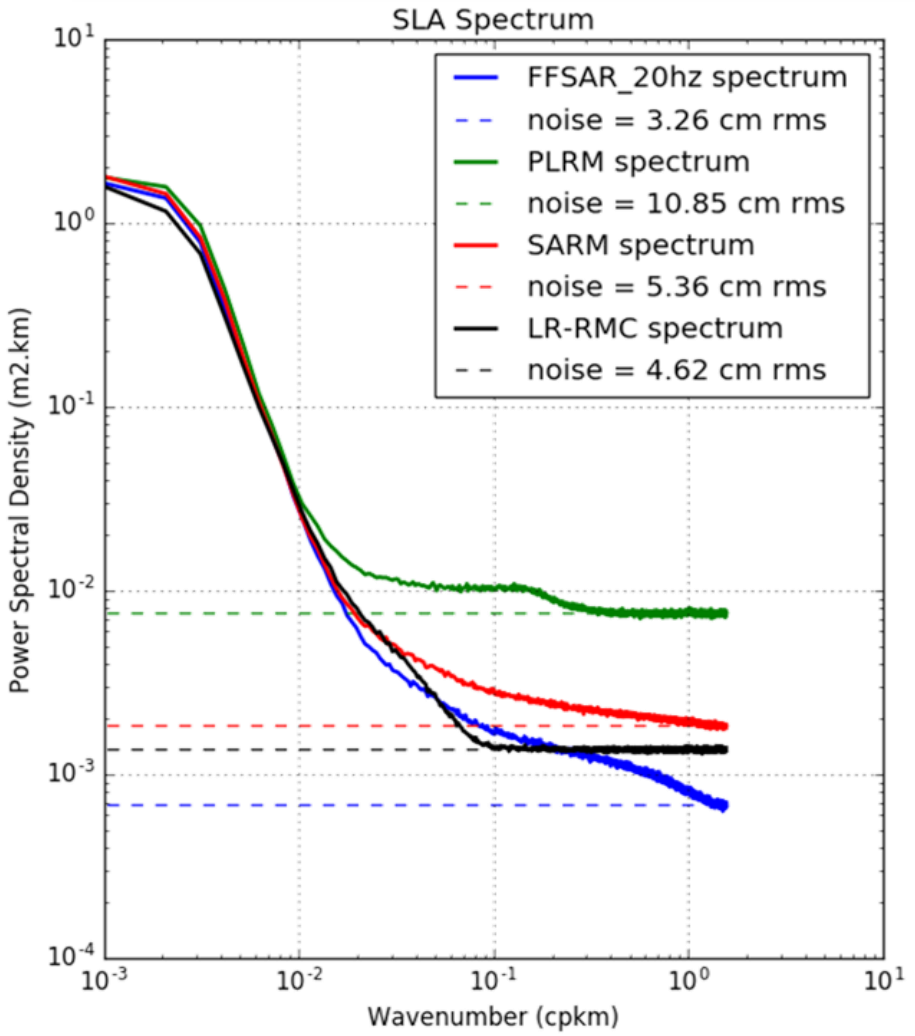
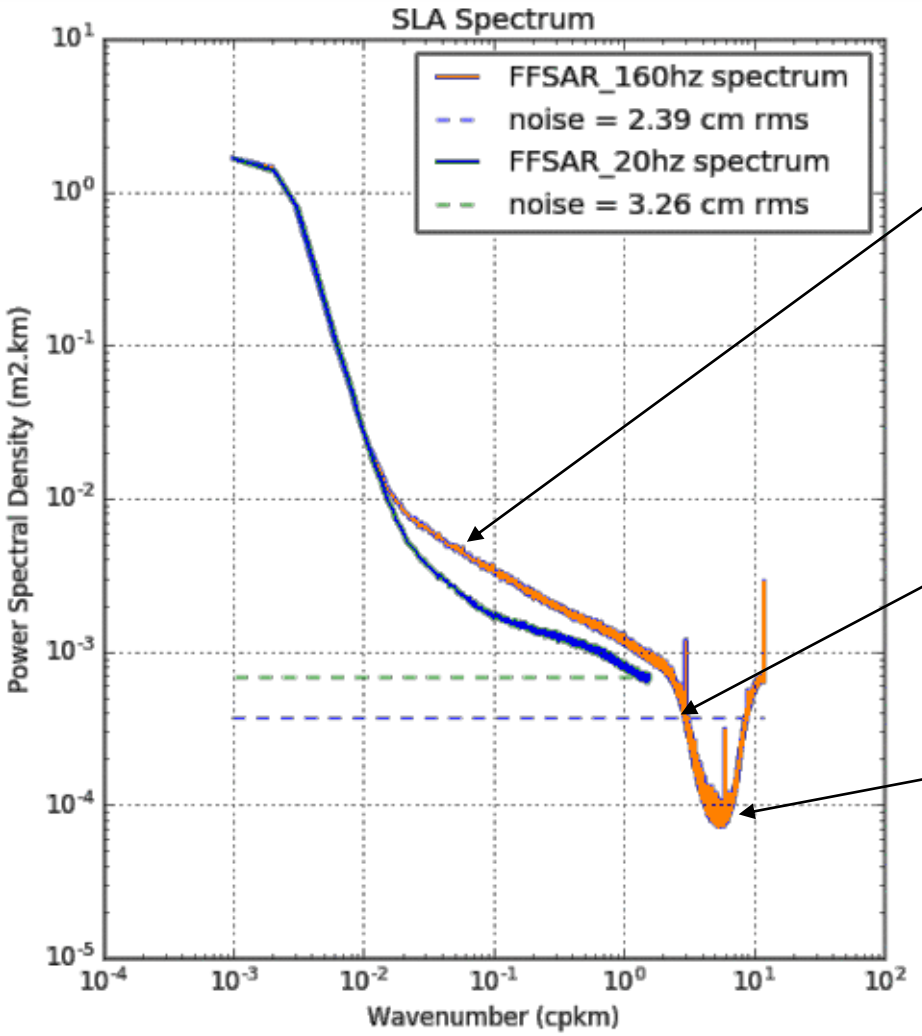




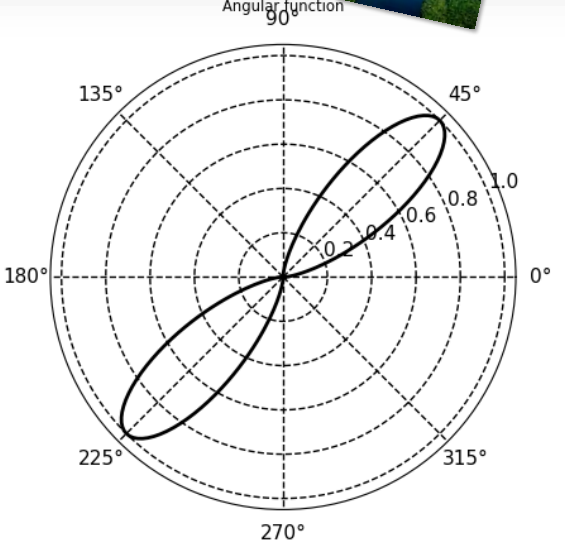
FF-SAR-160 PSD:

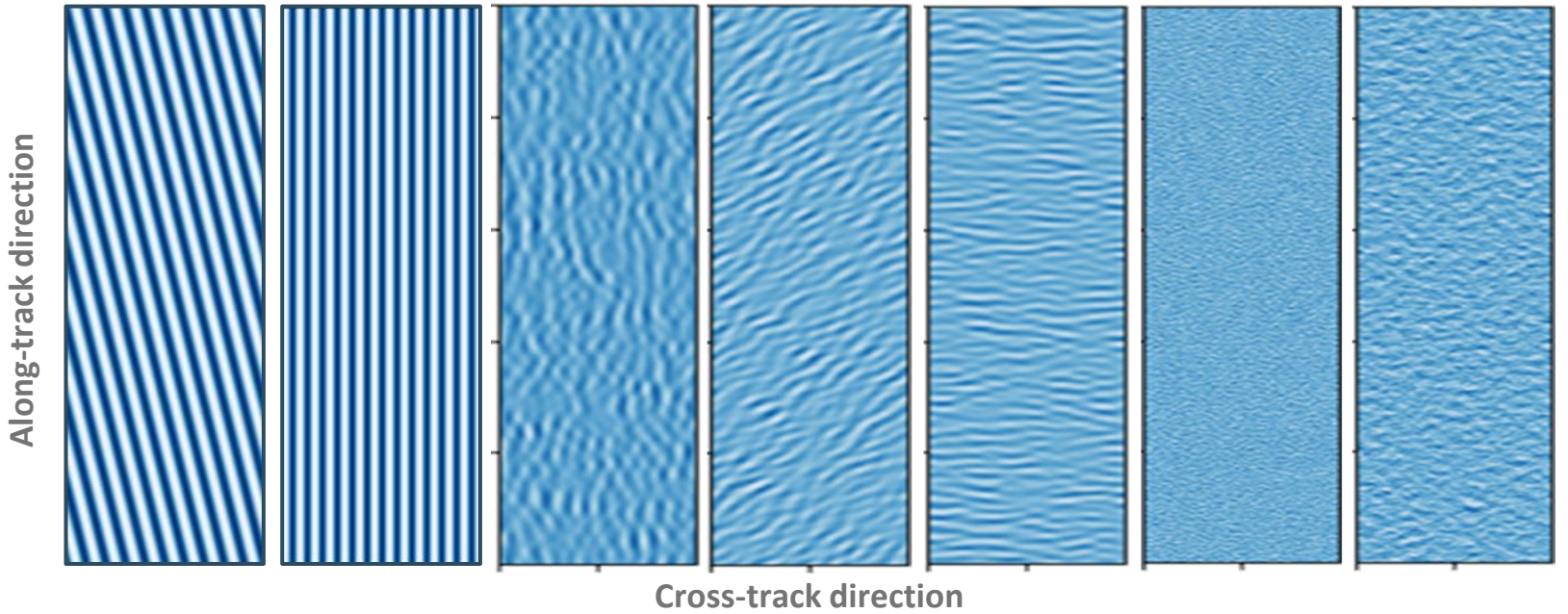
- Higher correlated error at mesoscales suggesting higher sensitivity to sea state (need different SSB for removing large-scale error correlation between SSH and SWH)
- Same PSD as for UFSAR @80Hz at small wavelengths (Rieu et al., 2021)
- Band-stop filter centered at 200m as expected due to azimuth grating lobes (closed burst)

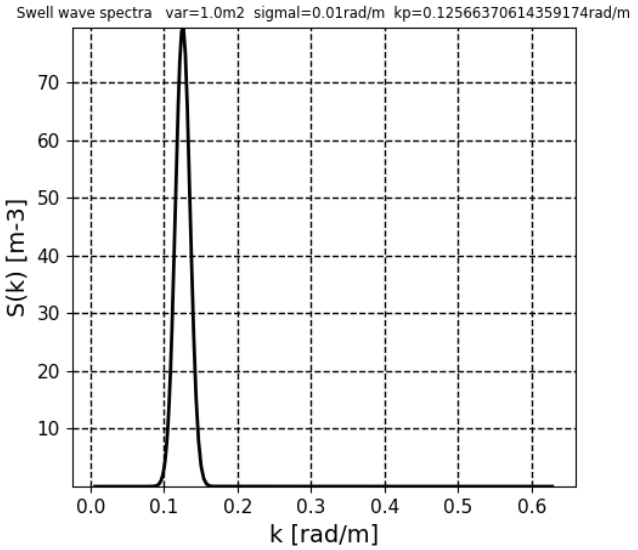
Swell Parameter Retrieval

Method assessment using simulated data

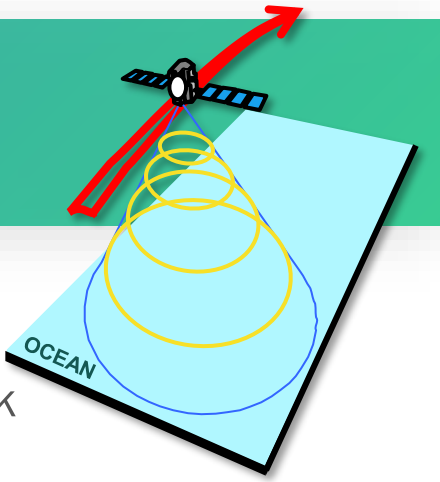
- Static scene generation for varying sea-state conditions:
  - sinusoidal wave spectra (for testing purpose only)
  - more realistic surface (swell and wind sea wave model)
- Simulated FF-SAR amplitude echoes then level-2 processing
- Computation of the SSH spectra (PSD) along simulated data segments and comparison with wave model





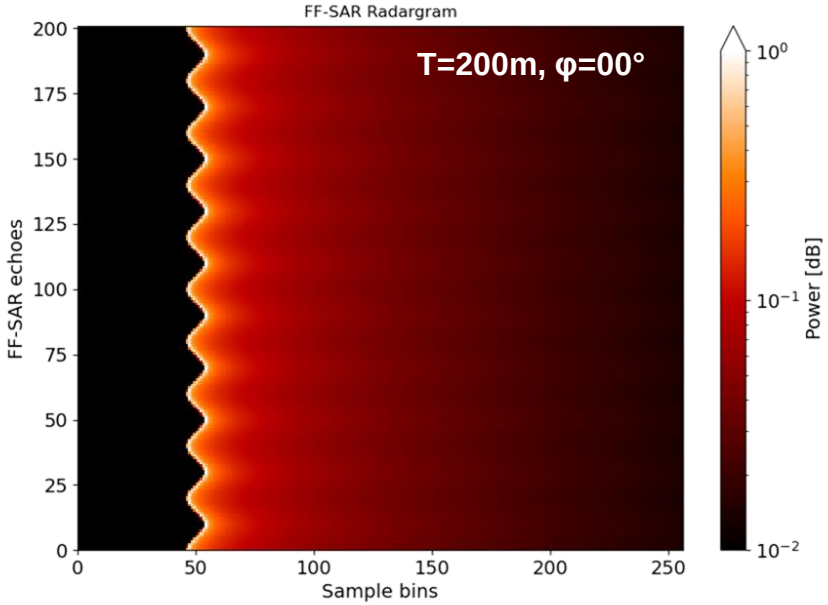


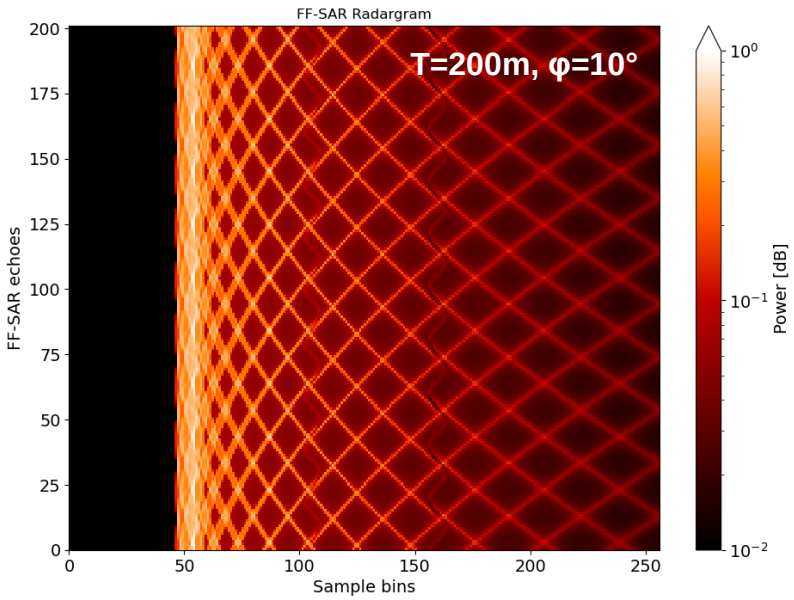
Swell Parameter Retrieval

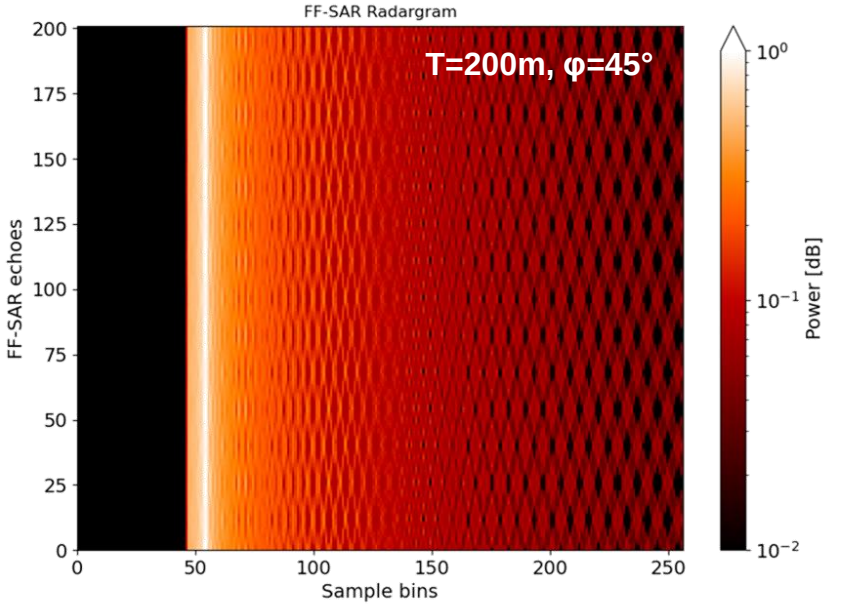


Scene with sinusoidal wave spectrum

- FF-SAR radargram for different wave periods and swell field directions wrt sat track







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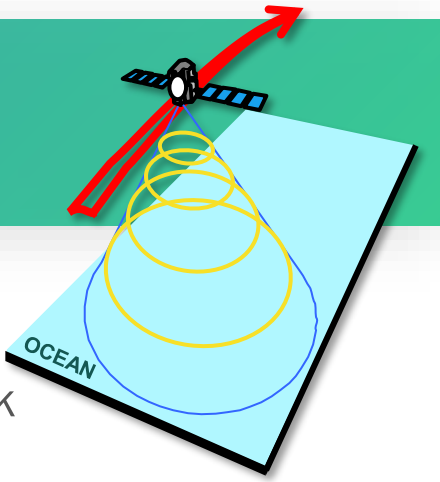
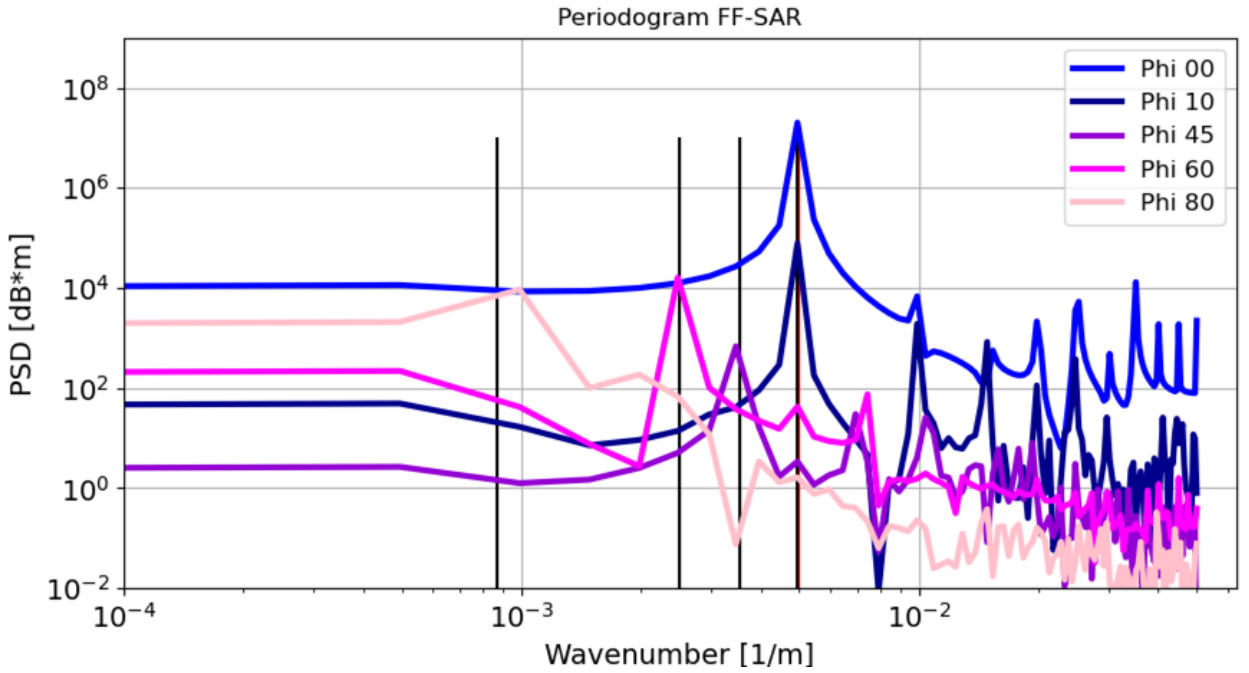
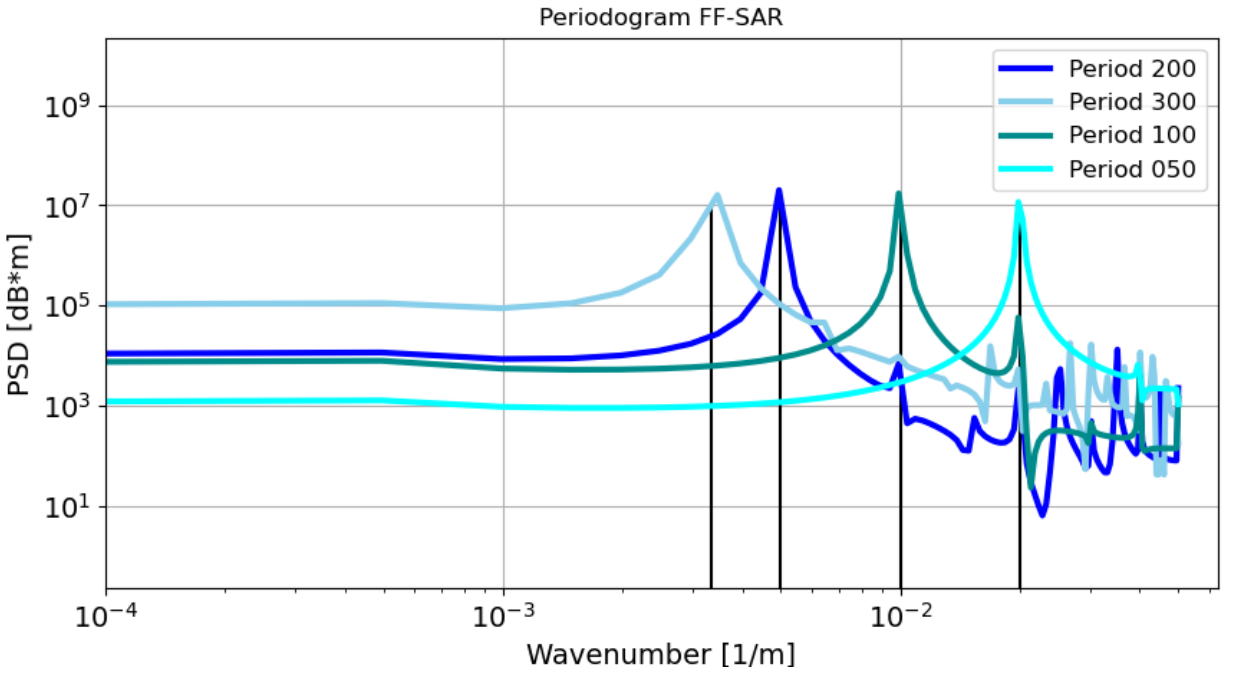


Scene with sinusoidal wave spectrum

- FF-SAR radargram for different wave periods and swell field directions wrt sat track
- Better performance achieved for swell propagating along the track
- Enable to retrieve low peak wave period as long as the Nyquist criterion is met (high sampling) and the HF noise level is sufficiently low not to degrade small-scale signal

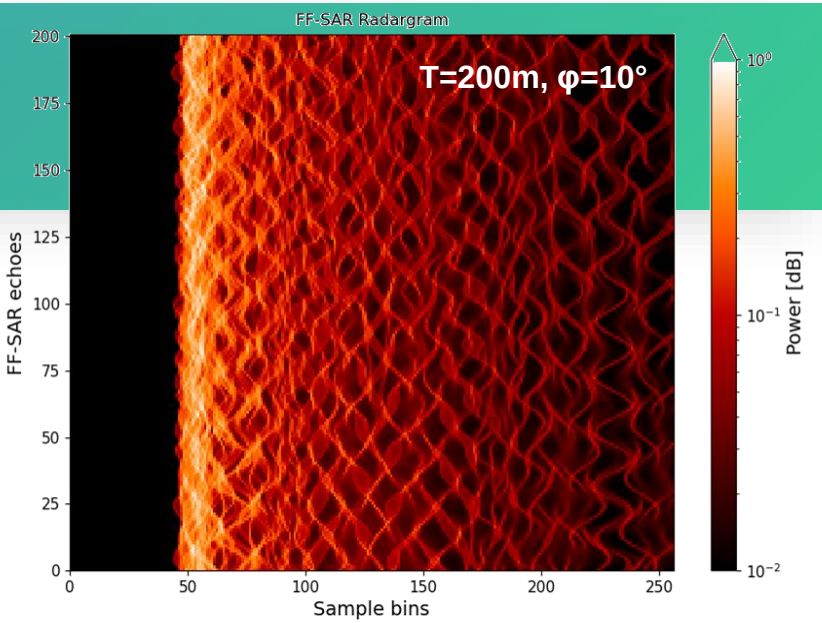


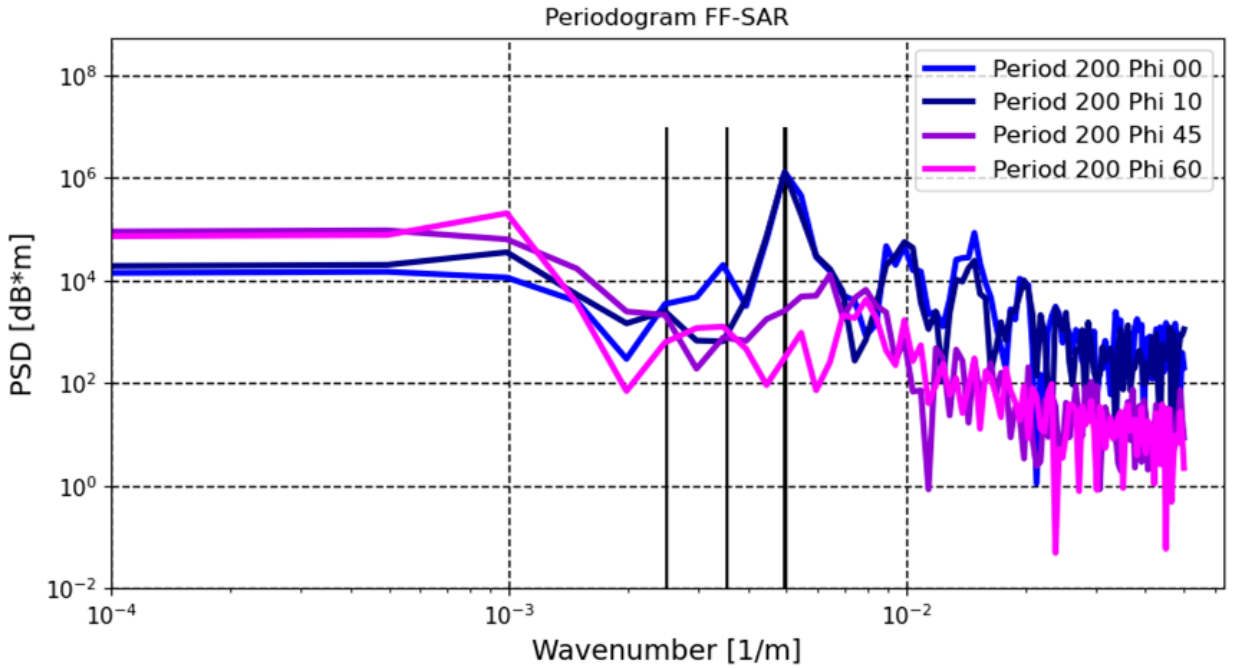


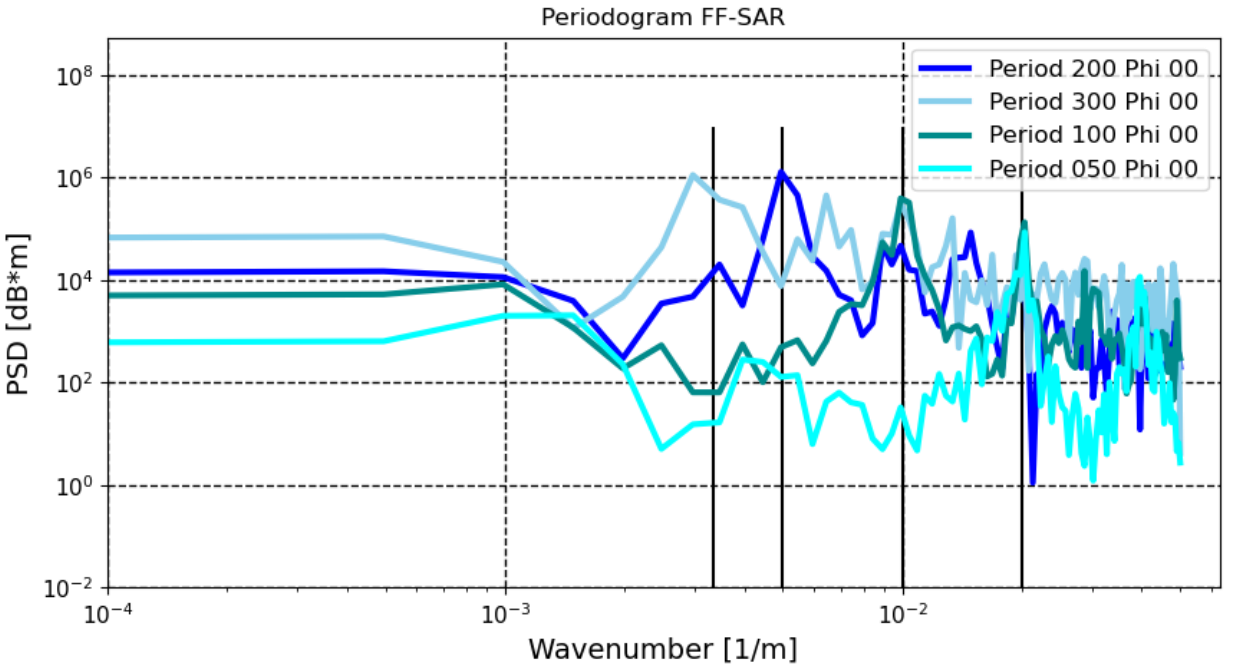
Swell Parameter Retrieval

Scene with wave spectrum model

- Well visible structures in the leading and trailing edge
- Peak retrieval method suitable for swell propagating along the track
- Complementary to the backscatter modulation method (Altiparmaki et al., 2022), limited by azimuth cut-off wavelength

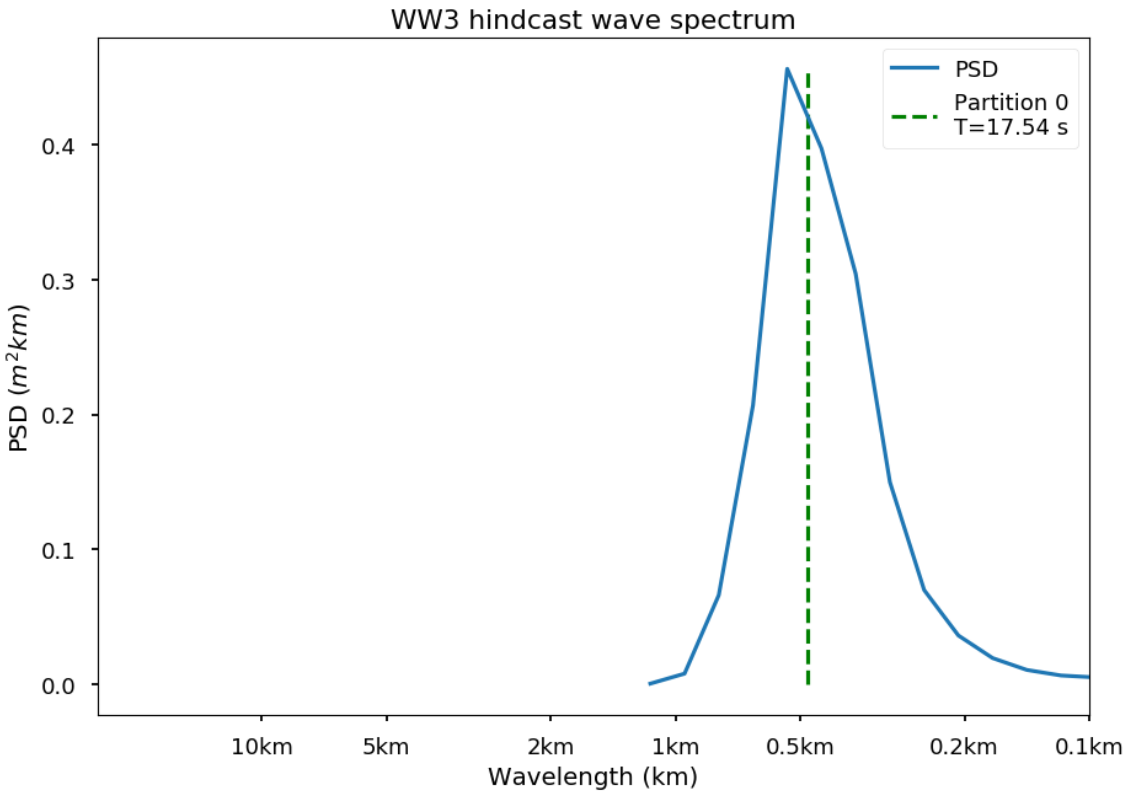






Swell Parameter Retrieval

- Good agreemennt with swell peak period (accounting for the incidence angle btw wave field and the sat track)



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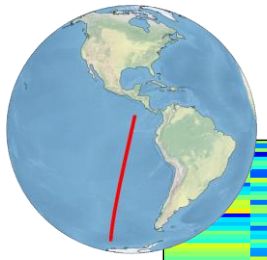
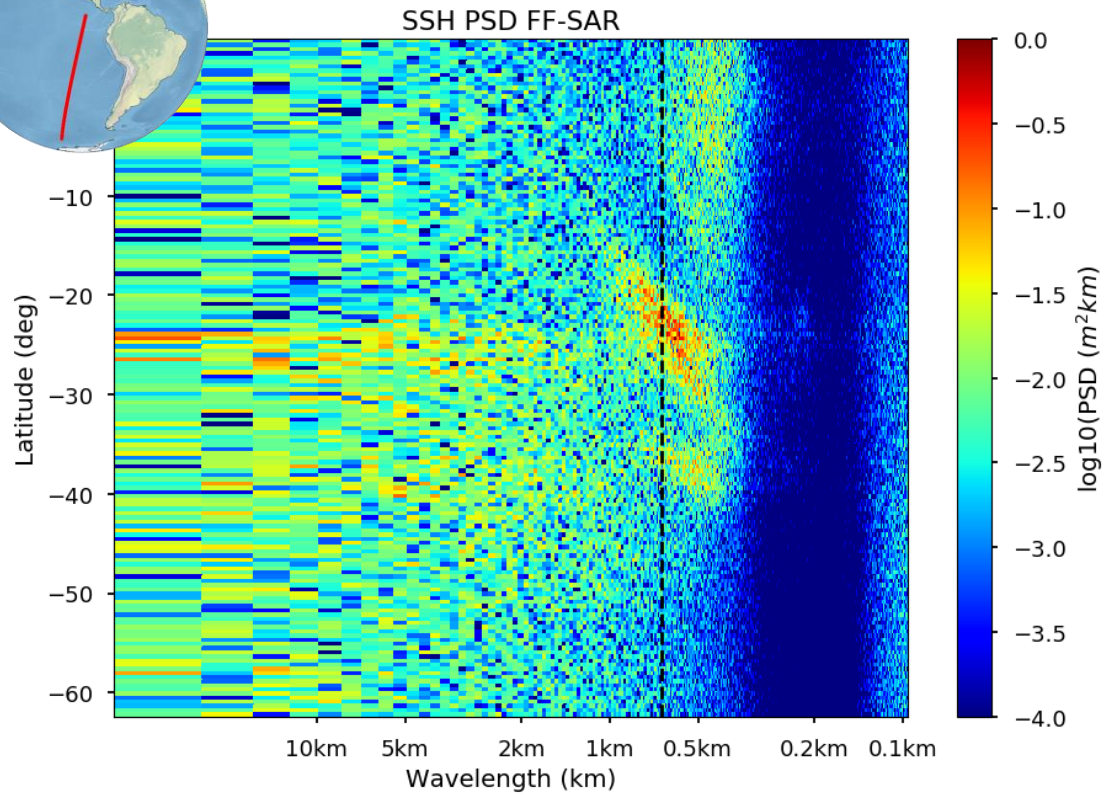
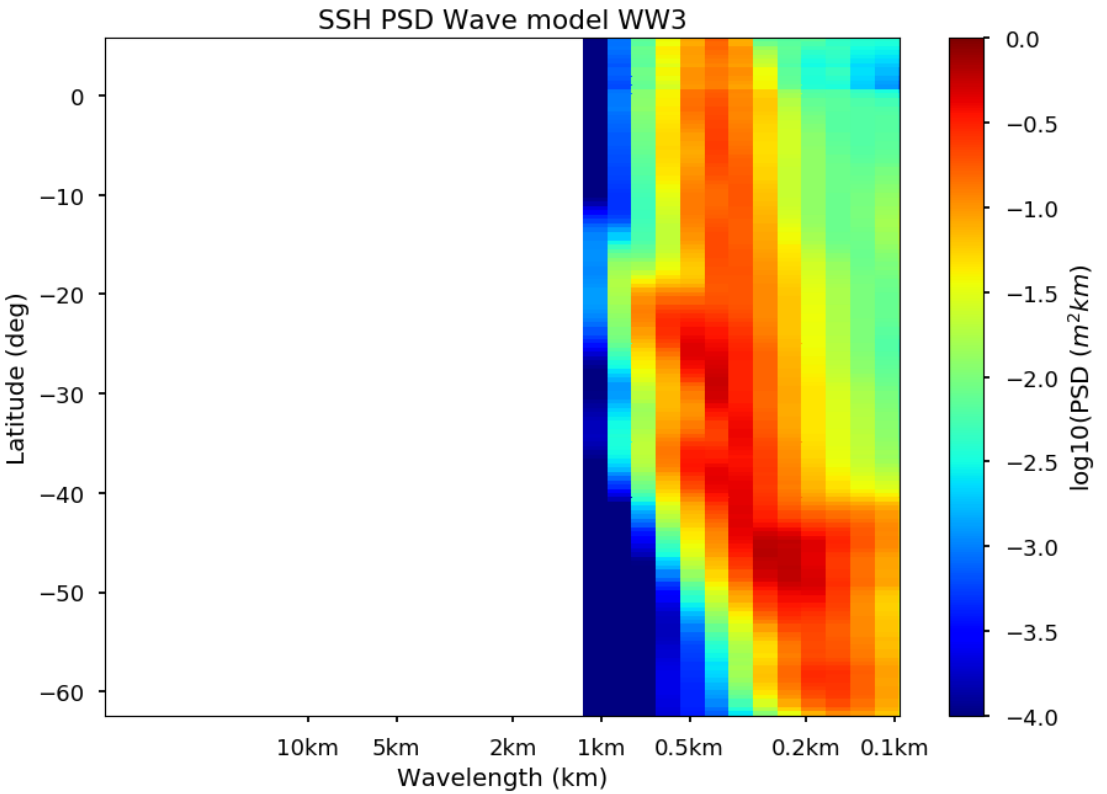
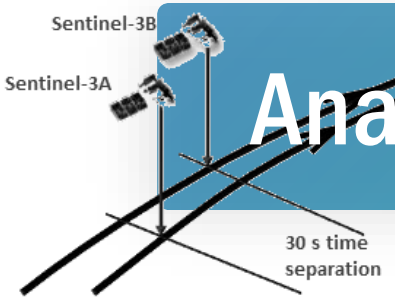




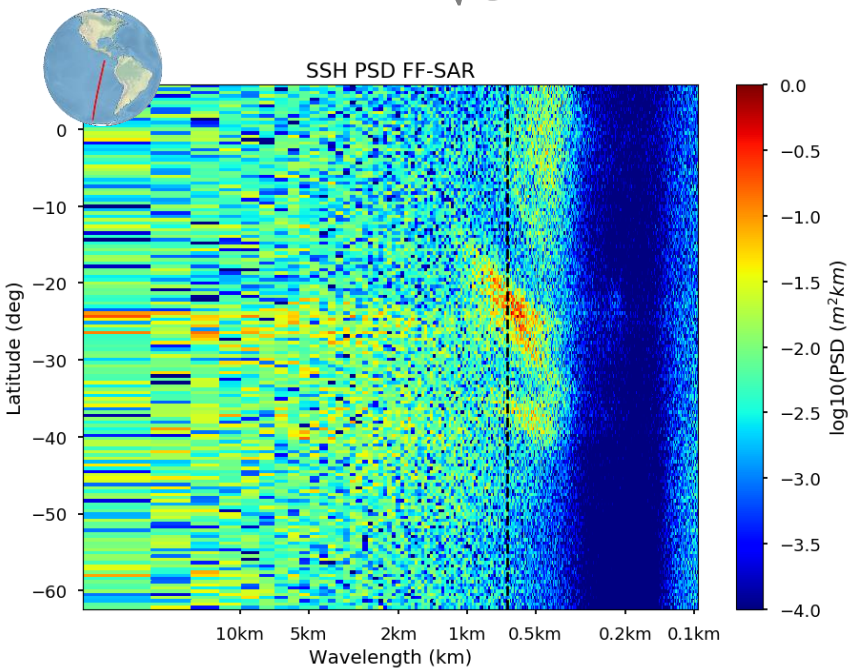


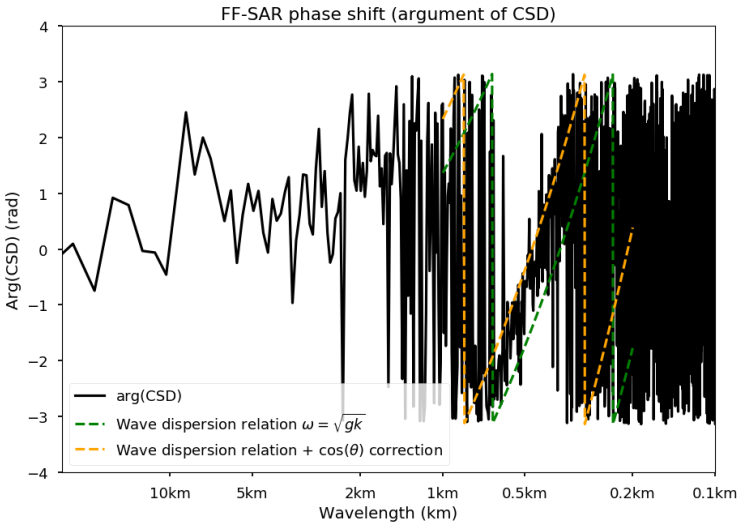


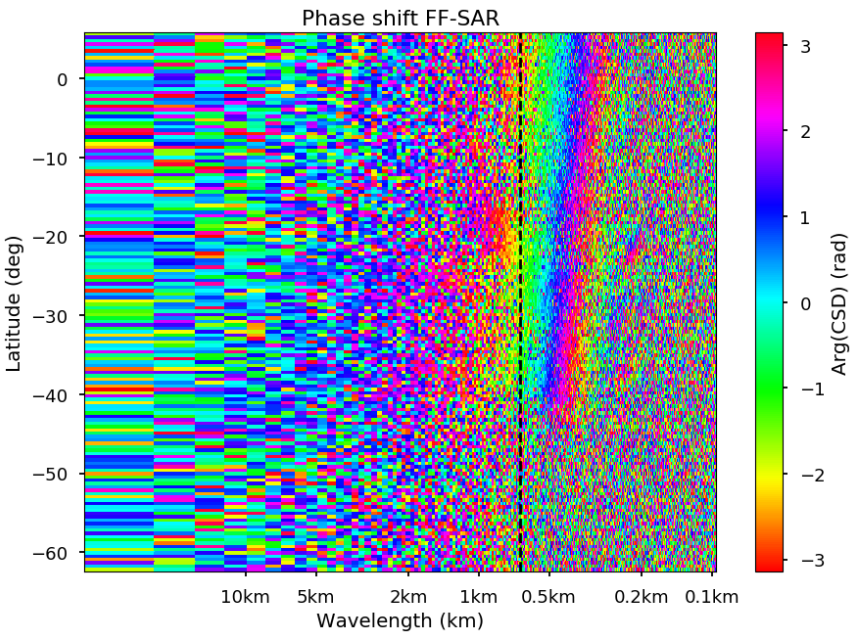
Analysis of FFSAR data over long ocean waves

Evidence of swell-induced signal in SAR altimeter data using 160-Hz FF-SAR during S3A/B tandem phase (as for UF-SAR @80-Hz in Rieu et al., 2021):

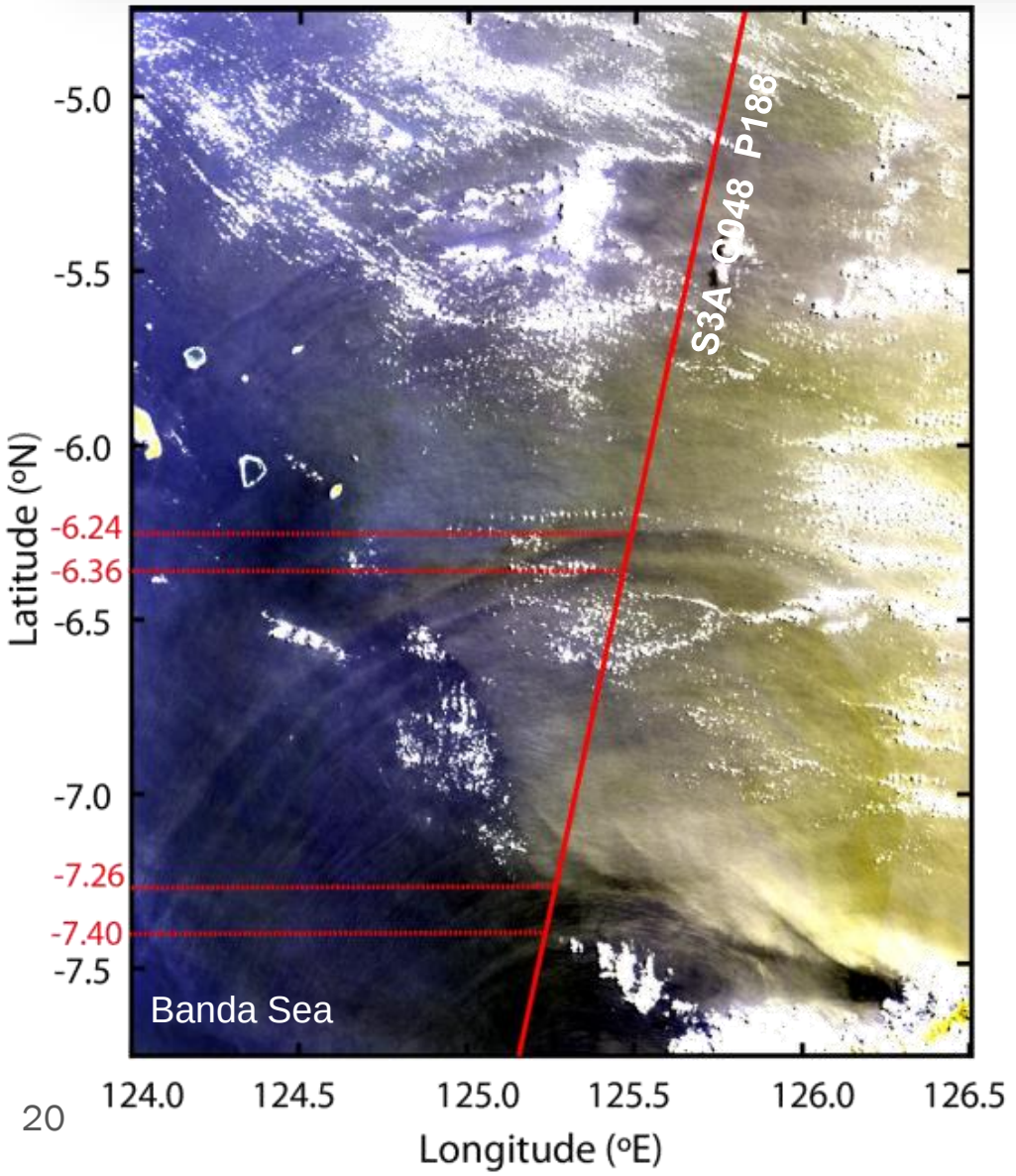
- long ocean waves are properly sampled
- peak wavelength corresponds to the dominant swell wavelength (and may possibly be recovered)
- phase shifts consistent with waves travelling according to the wave dispersion relation $\Delta\boldsymbol{\Phi} = \sqrt{\boldsymbol{gk}}\Delta\mathbf{t}$ at swell wavelength k and with a time lag Δt=30s



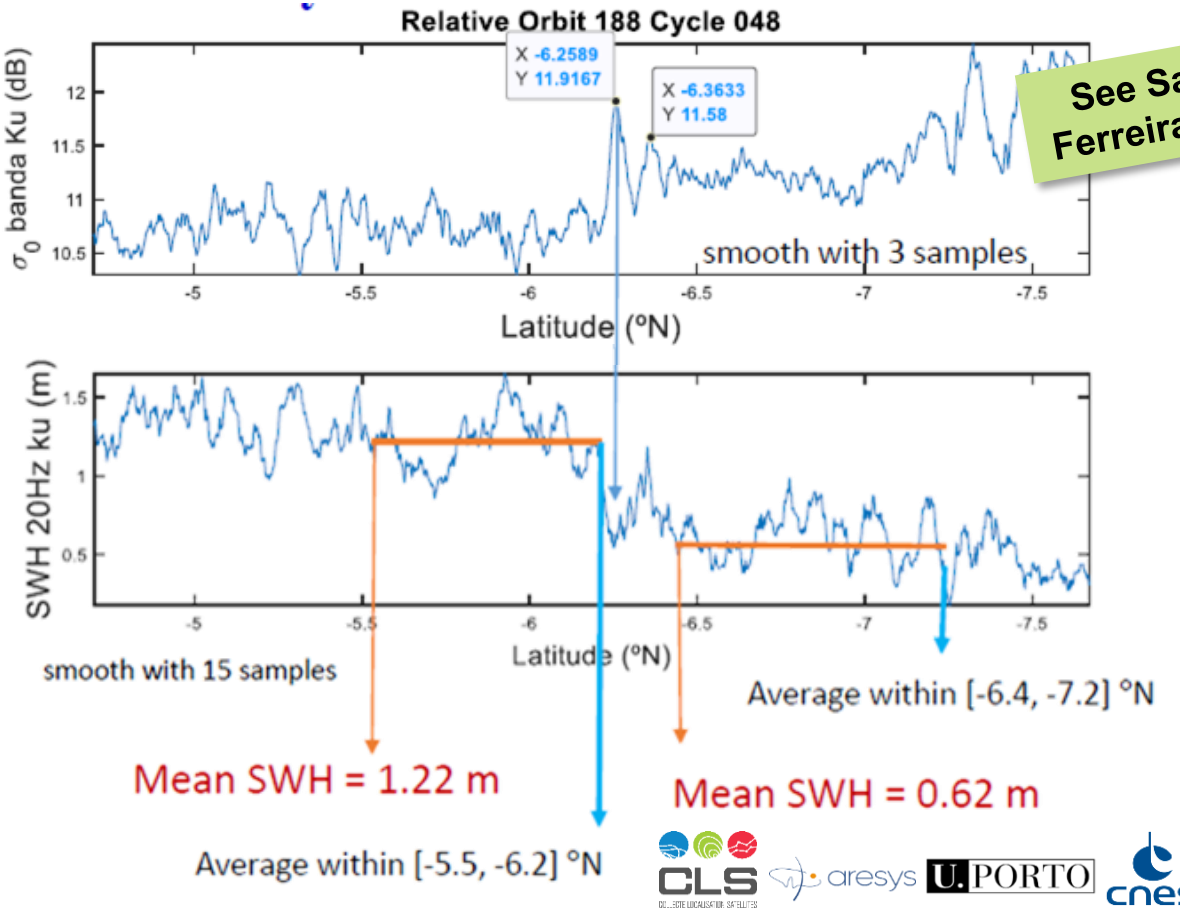




Internal Solitary Waves Detection (Univ. Porto)

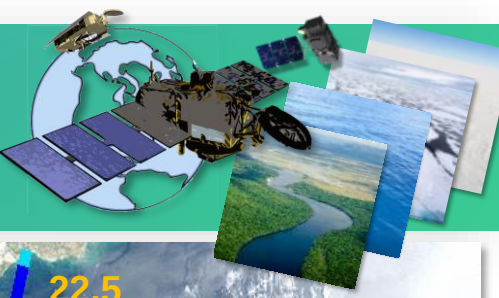


"Large scale" decay signature in SWH due to intense breaking waves and consequent energy dissipation occuring at the ISW front (Santos-Ferreira et al., 2022)



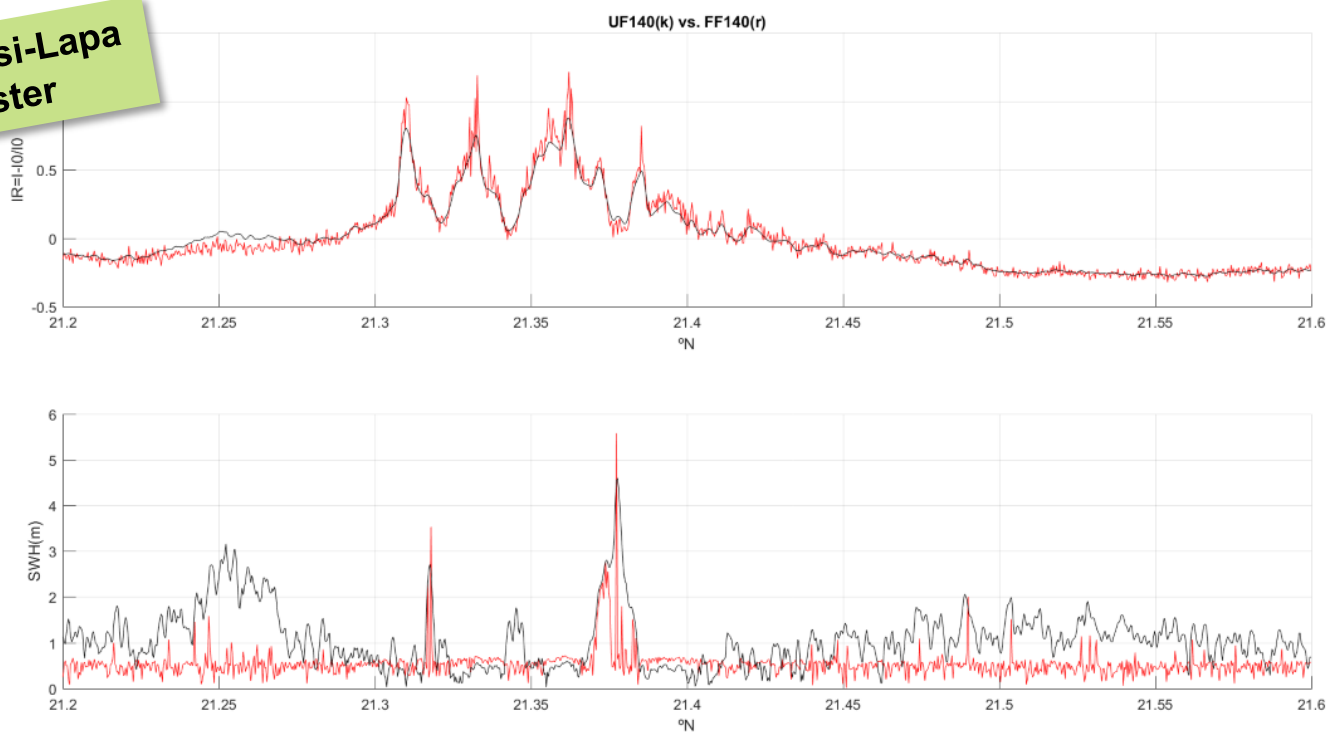
See Santos-Ferreira Poster

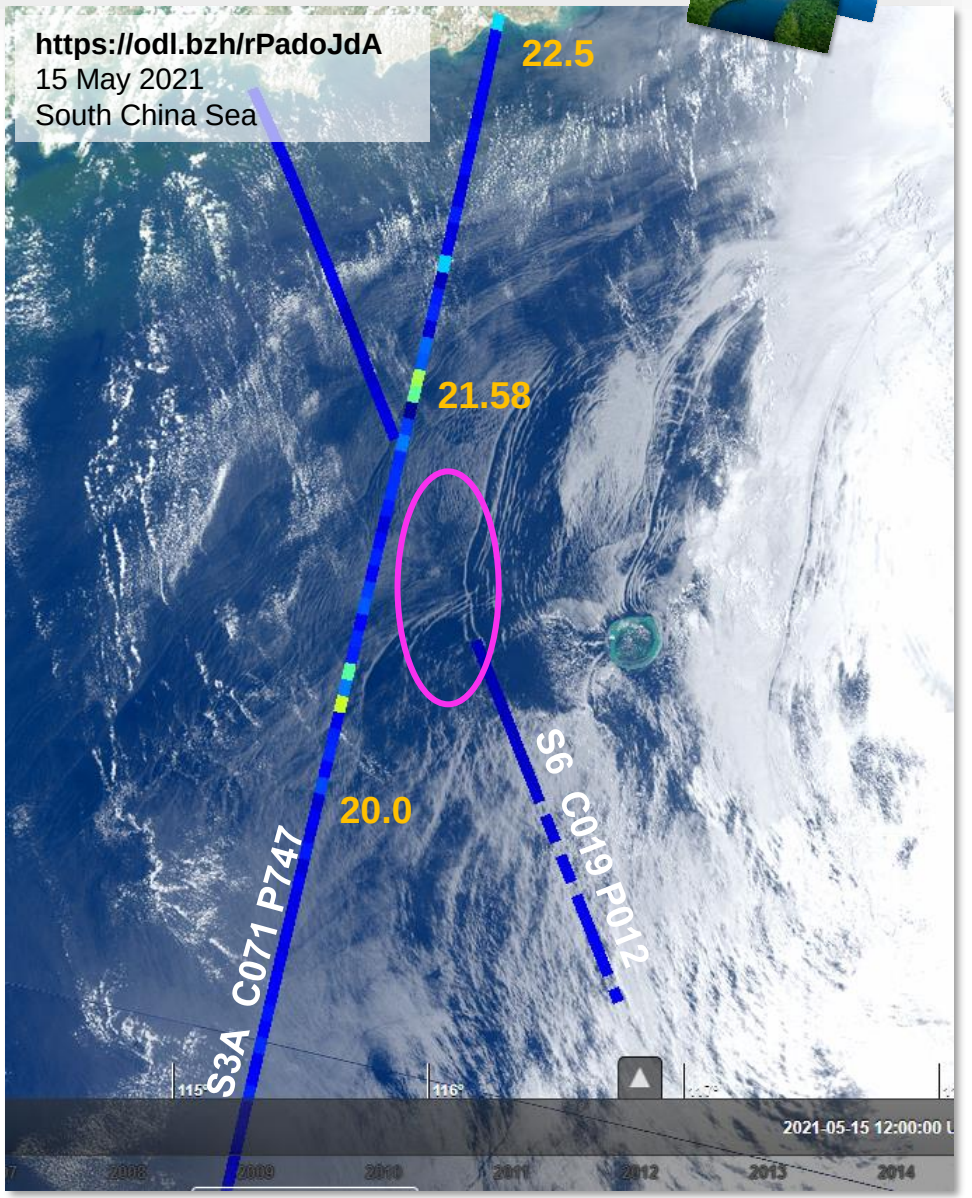
Internal Solitary Waves Detection (Univ. Porto)



- To apply automatic detection method in Santos-Ferreira et al. (2019) to detect ISWs in S6-MF SAR data
- To analyse ISWs signatures (intense wave breaking at the surface as reported in Santos-Ferreira)
- Compare sensitivity of signatures, specially SWHs, with J3 and S6-MF UF-SAR/FF-SAR data

See Grisi-Lapa Poster





Conclusions & Perspectives

- FF-SAR is a new coherent processing offering major improvement over open ocean
  - Better noise performances than UF-SAR (may not be the case for S6-MF)
  - Better sample short wavelengths (and prevent long-wavelength errors induced by spectral leakage as reported by Rieu et al., 2021)
  - But high posting rate increases sensitivity to sea state (as expected finally)
- Complementary operational solution to the current SAR-mode processing for ocean applications (i.e. swell detection and parameters retrieval)
- Ongoing analysis of large S6-MF data set through CalVal level-2 diagnostics and comparison to S3