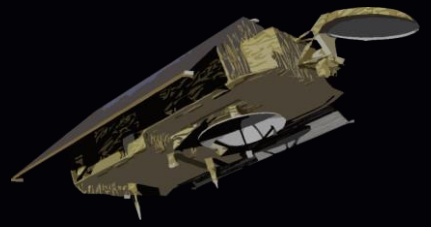
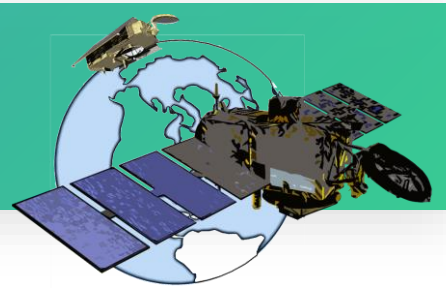


Sentinel-6 Michael Freilich and Jason-3 Tandem Phase Exploitation (S6-JTEX)

T. Moreau[1], L. Amarouche[1], S. Amraoui[1,2], E. Cadier[1], A. Mangilli[1], P. Prandi[1], V. Quet[1], N. Taburet[1], N. Tran[1], M. Ablain[3], M. Passaro[4], F. Schlembach[4], J. Oelsmann[4], D. Dettmering[4], P. Guccione[5], L. Recchia[5], J. Magalhaes[6], J.C.B. da Silva[6], A.M. Santos-Ferreira[6], B. Timmermans[7], C. Gommenginger[7], C. Banks[7], C. Donlon[8], C. Maraldi[9], C. Bignalet-Cazalet[9] F. Boy[9]

[1] CLS, [2] BIOceanOR, [3] Magellium, [4] TUM, [5] ARESYS, [6] Univ. Porto, [7] NOC, [8] ESA/ESTEC, [9] CNES

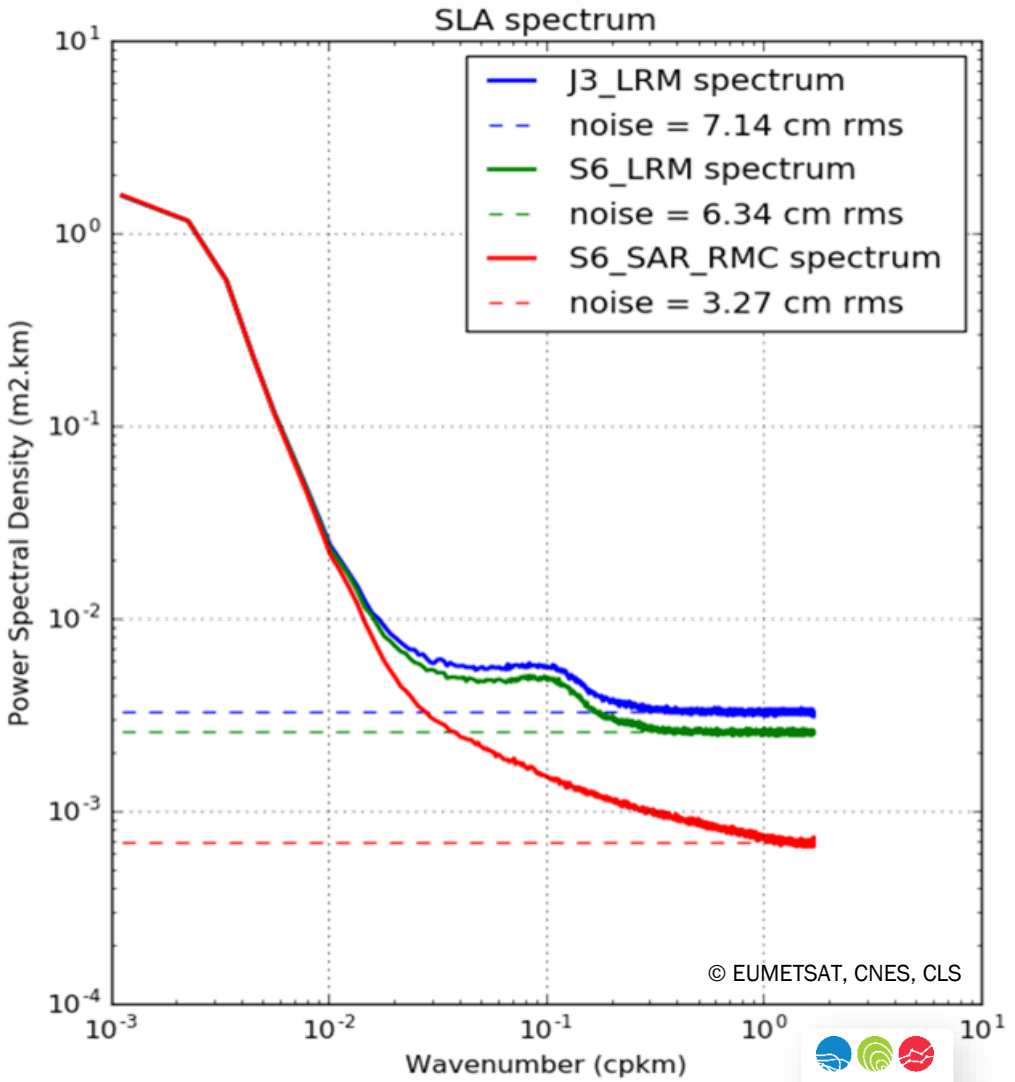
S6-JTEX Science Objectives



- To exploit the tandem phase between S6-MF and Jason-3 to demonstrate the high benefit of this new altimeter reference mission to extend the legacy of sea-surface height measurements
- To gain understanding of the different sea state effects contributing to the sea surface height retrievals uncertainty, but also impacting the quality of SWH quantities
- To develop a number of scientific studies that fully exploit the S6-MF capabilities and make use of innovative processing (higher posting-rate UFSAR, FF-SAR) to allow for new potential products and applications
- To report these results to the science community in peer-reviewed journal articles and present them in conferences, also available on the project website (https://www.s6-jtex.org/)

1 CalVal Ocean

- To compile and summarize the main results obtained during the commissioning activities, and identify the remaining open questions
- Investigations still ongoing to fully assessed S6-MF performances and discuss potential processing alternatives (L1B, L2 and post processing) that could allow to mitigate sensitivities and ultimately discrepancies between all acquisition modes of S6 and J3
- Particular attention focused on the F08 Processing Baseline including LR numerical waveform retracking that accounts for inflight PTR (altimeter ageing effects) to ensure enhanced continuity of the long-term data record for climate studies
- E. Cadier et al., *in prep.*

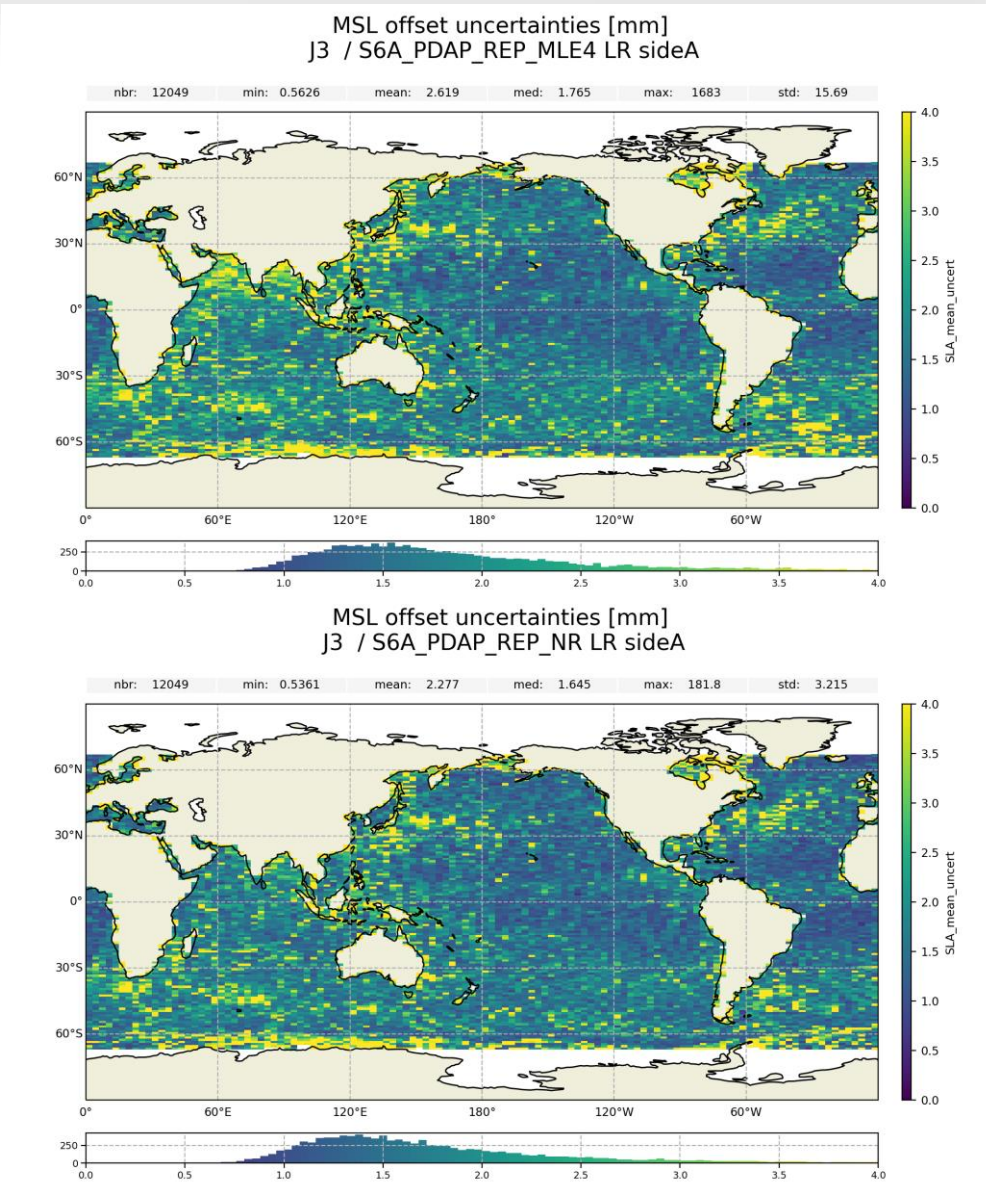


2 Uncertainties and GMSL

- Complementary to the F08 data CalVal, GMSL analysis is performed (included in E. Cadier et al., *in prep*.):

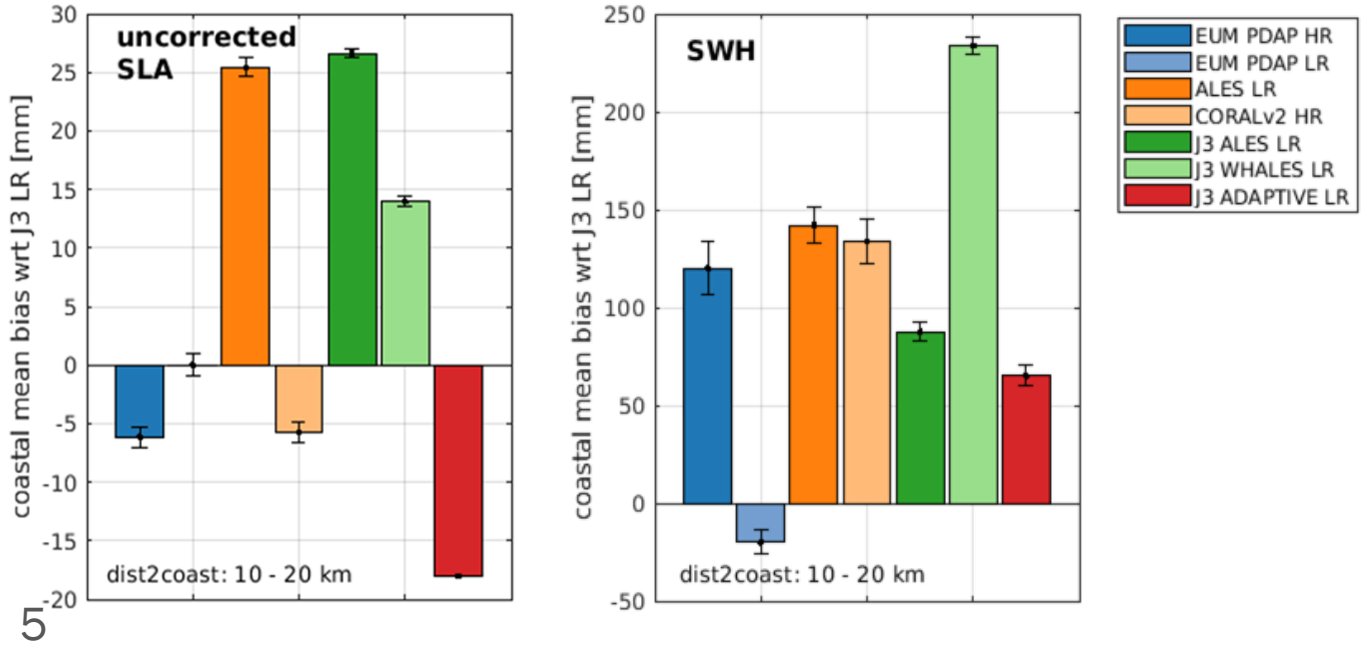
  - To homogenize and mitigate MSL discrepancies between S6-MF and Jason-3, with a focus on the LR num data
  - To consolidate the current method of bias estimation for “reference” missions, at the global and regional scales
  - To analyze in depth the level of uncertainty obtained

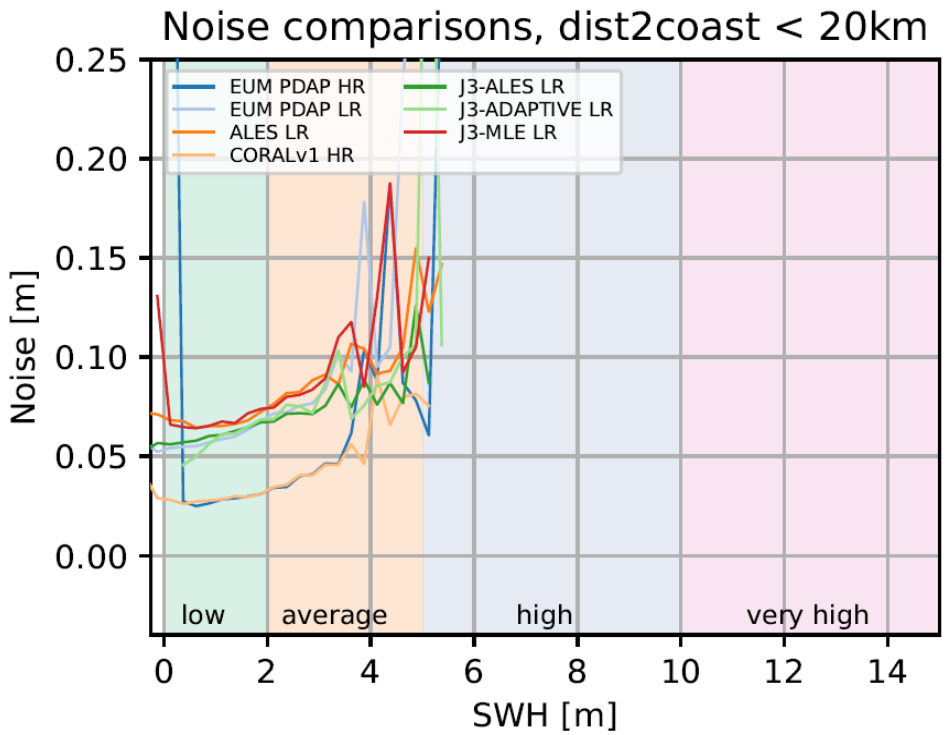
- To assess the benefit of a second calibration phase to estimate the relative global and regional mean sea level drifts between S6-MF and Jason-3
- M. Ablain et al., *in prep.*



3 Coastal Assessment

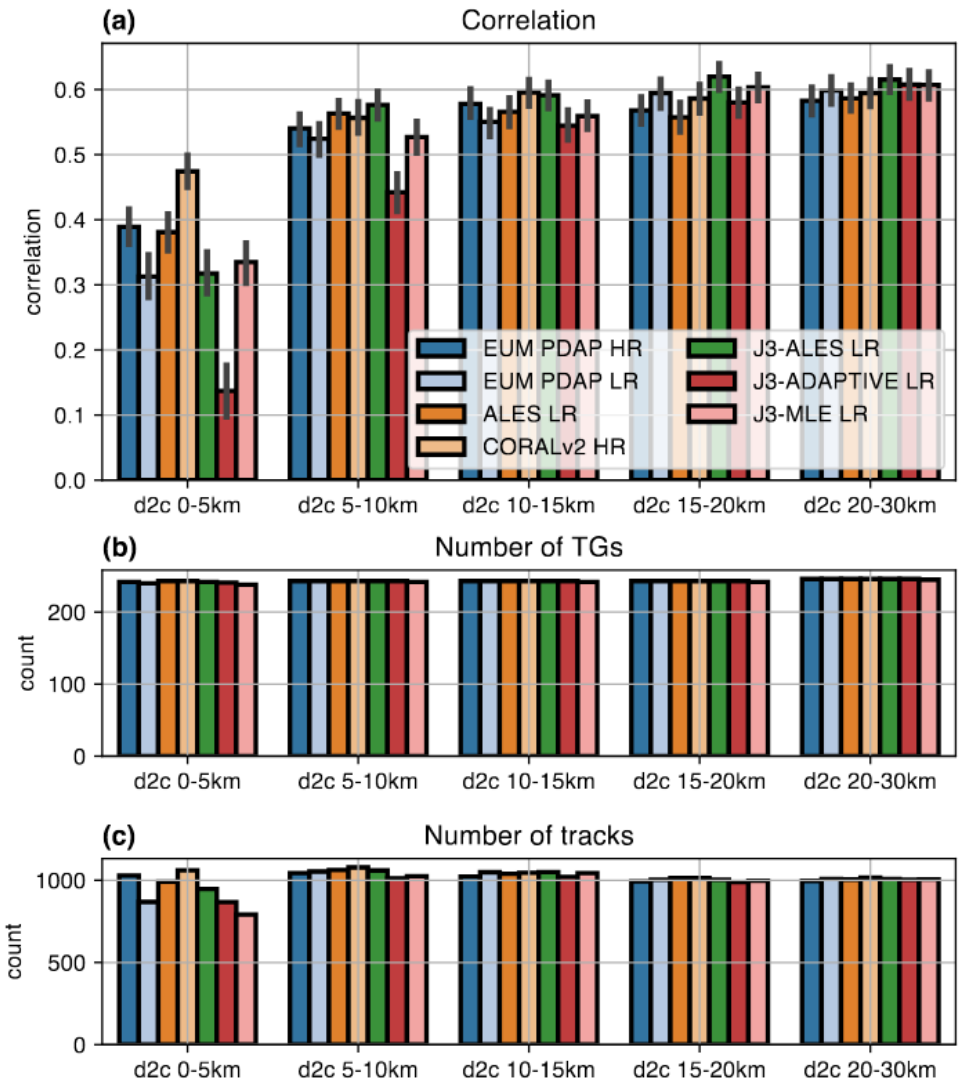
- Coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) wrt J3, making use of specific retrackers (ALES, WHALES, ..)
- Intercomparisons performed on range and significant wave height (in terms of bias, noise, drift and outliers) within the 20-km limit from the global coastline
- Large improvement in precision is observed with SAR altimeter data which can be further improved using dedicated coastal retracking (CORALv2 HR)





3 Coastal Assessment

- Analysis also including a comparison against tide gauges to assess the best performing dataset (in terms of correlation and amount of valid data) in the coastal zone
- This points to the conclusion that dedicated coastal retracking of SAR altimetry substantially improves the performances
- And that dedicated coastal retracking of LR altimetry is able to perform at least as good as non-coastal SAR altimetry retracker
- Passaro, M.; Schlembach, F.; Oelsmann, J.; Dettmering, D.; Seitz, F. Coastal Assessment of Sentinel-6 Altimetry Data during the Tandem Phase with Jason-3. *Remote Sens.* **2023**, *15*, 4161. https://doi.org/10.3390/rs15174161

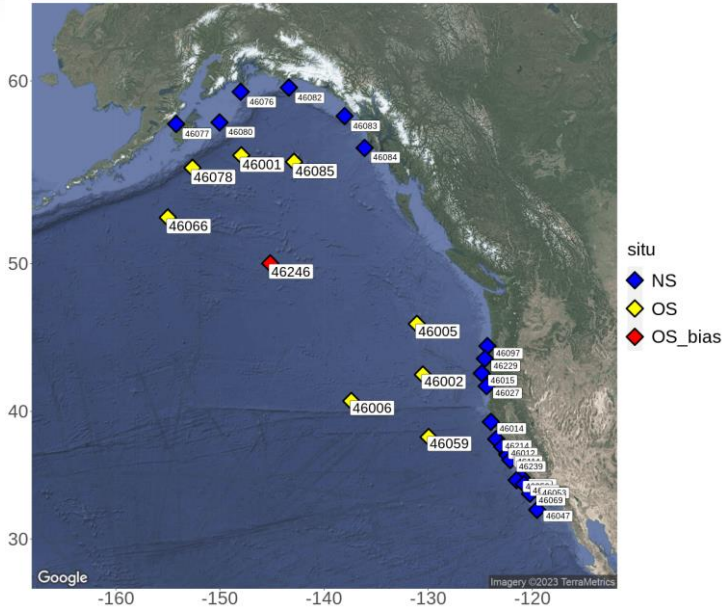


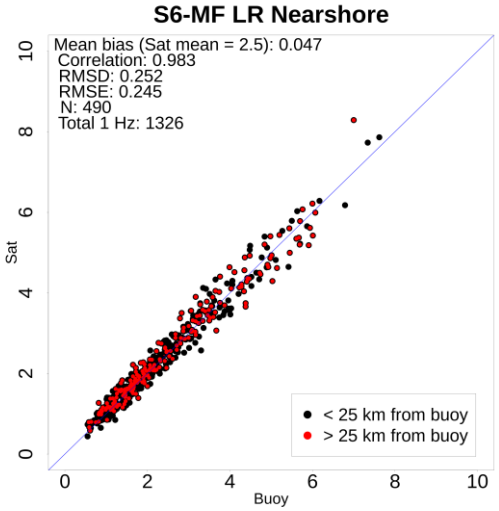
4 Sea State

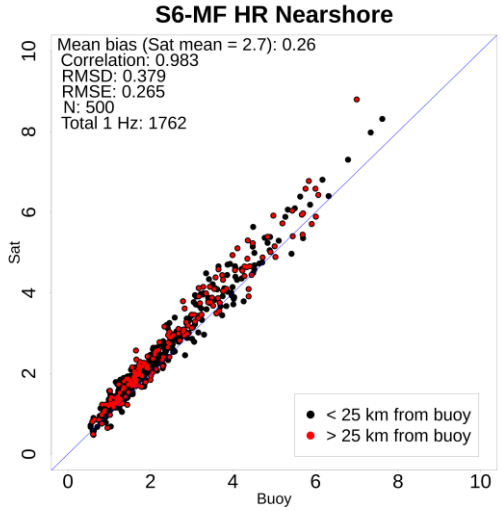
See B. Timmermans in Coastal Altimetry (Forums sessions)

National Oceanography Centre

- Collocated S6-JTEX (rev F06) data (J3, S6-MF LR S6-MF HR) found to be strongly characterized by near identical performance of J3 and S6-MF LR, and extremely high correlation between LR and HR modes.
- Performance against buoys (NDBC / CDIP) is examined using a novel altimetry sampling methodology that accounting for local spatial sea state gradients, particularly in dynamic seas nearshore (NS).
- Subsequent coastal analysis reveals very little difference in performance for both Jason-3 and S6-MF LR, at nearshore buoys (map, blue diamonds), compared with deep water offshore (OS) buoy (map, yellow diamonds).
- S6-MF HR is found generally to exhibit sea state dependent bias, which appears stronger nearshore (fig. bottom right), while correlation remains very similar to S6 LR.
- B. Timmermans et al., *in prep.*





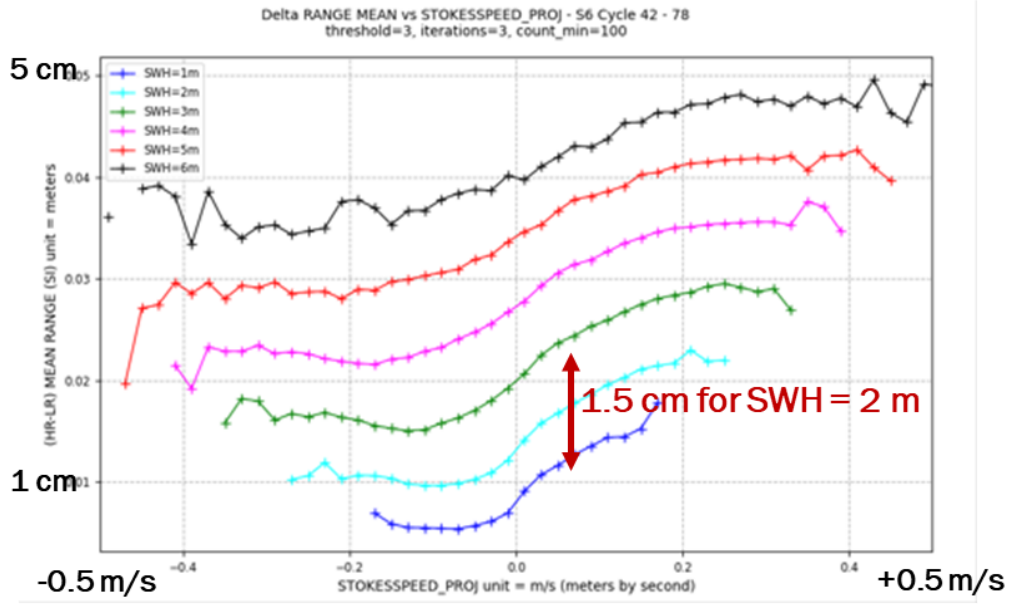


5 Sea State

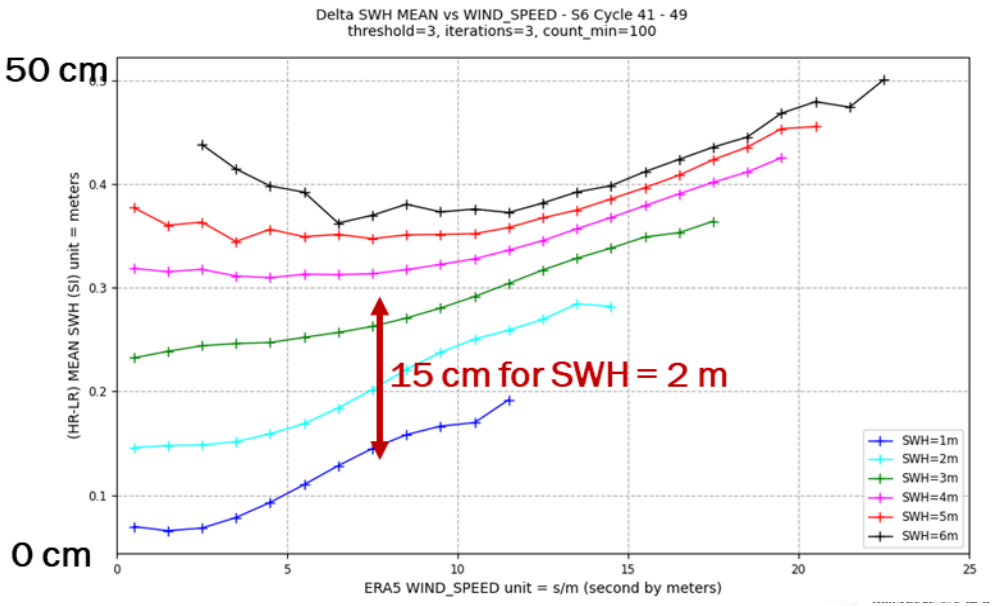
See L. Amarouche in Instrument Processing: Propagation, Wind Speed and Sea State Bias (Forums sessions)

- Characterization of S6-MF HR data sensitivity (on SWH and range) wrt different geophysical parameters (from model data): Vertical velocity, wind speed and along-track currents component
- Theoretical analysis is also performed to explain how the altimeter signal is impacted by the combination of these three phenomena and how the combination of all of them may explain the observed differences between HR and LR estimates
- L. Amarouche et al., *in prep.*

Range Diff HR–LR wrt
ERA5 Stokes Drifts Velocity Proj Sat Dir

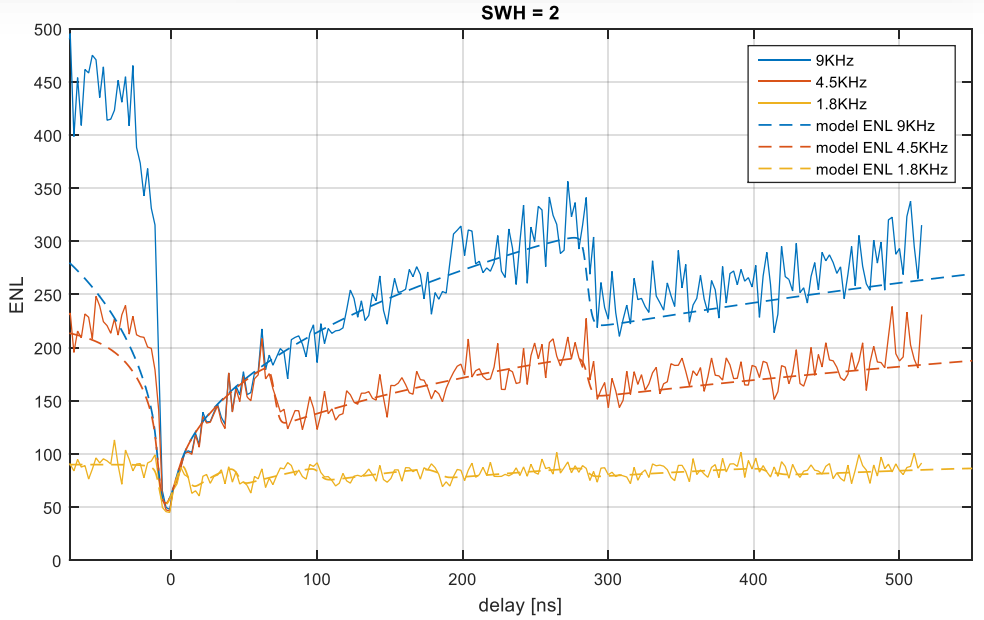


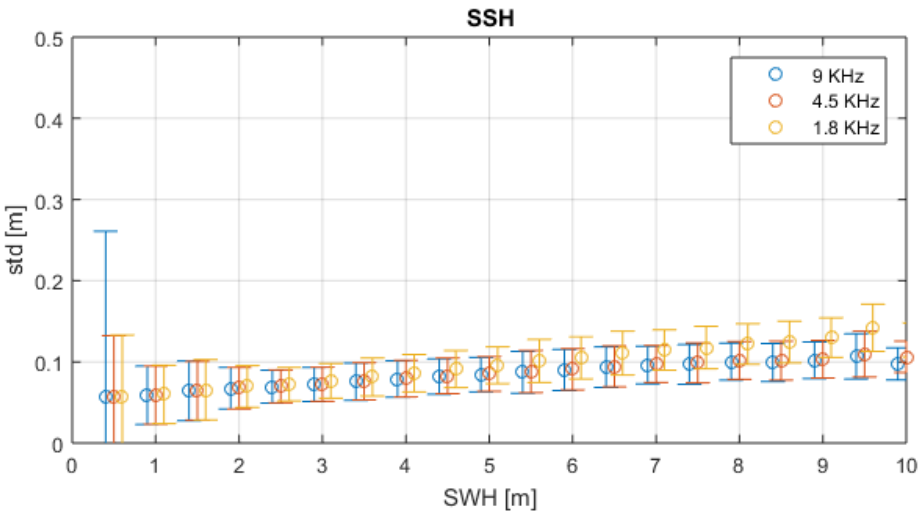
SWH Diff HR–LR wrt
ERA5 Wind Speed

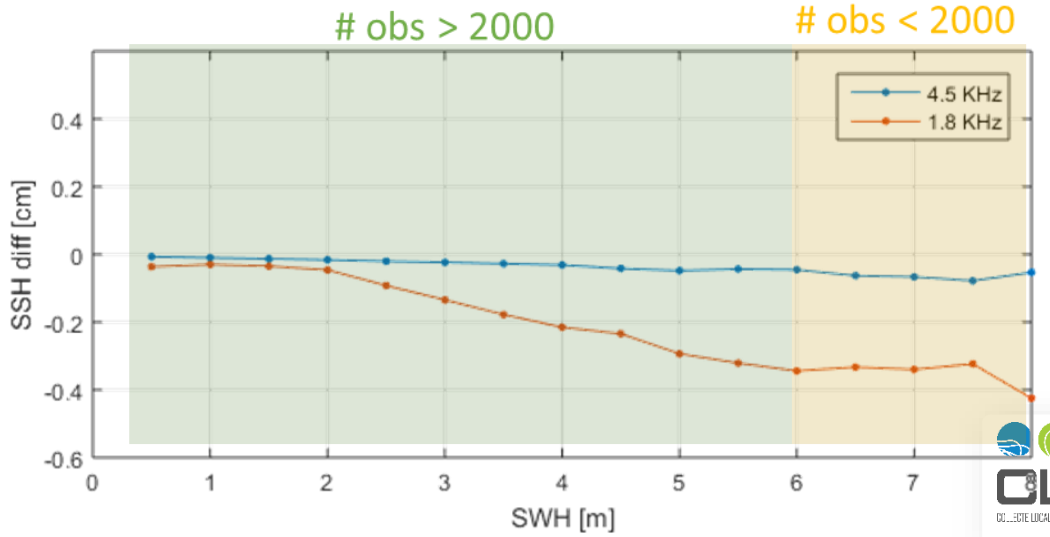


6 Exploiting the S6-MF ENL

- Evaluation of the autocorrelation properties by making use of a theoretical waveform model
- Good consistency between model and ENL estimated from S6-MF data
- Impact of the varying ENL (aka pulse-to-pulse effect) on the precision and accuracy of the geophysical parameters is characterized as a function of the multilooking posting rate (PRF)
- L. Recchia et al., *in prep.*



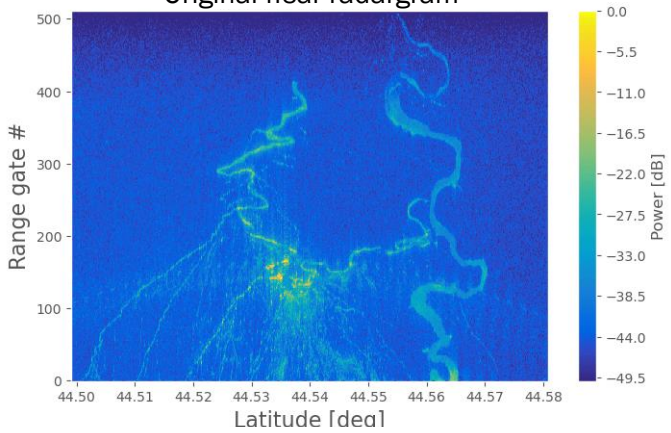


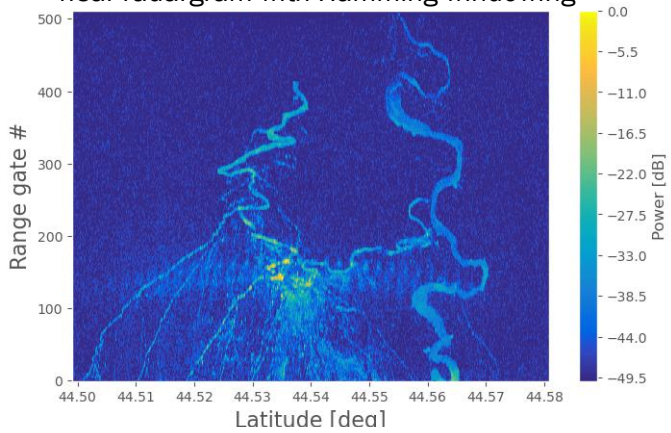


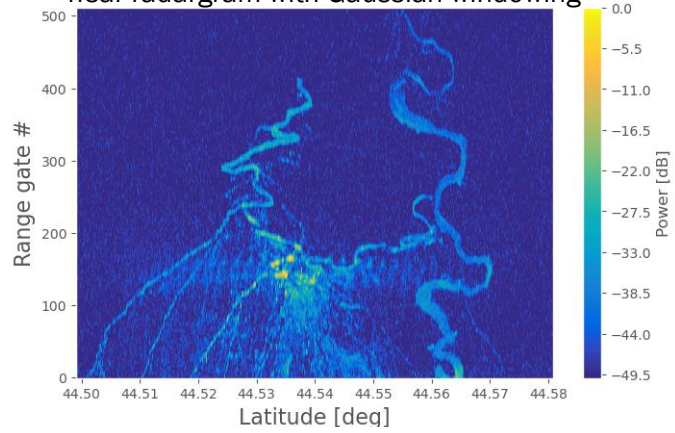
7 FF-SAR Processing

- Optimal configuration for FF-SAR WK processing is determined for diffusive (open ocean) and specular surfaces (inland waters, sea-ice leads) by tuning the parameters: Percentage of Doppler bandwidth, integration time, Doppler windowing, replica mitigation, multilooking

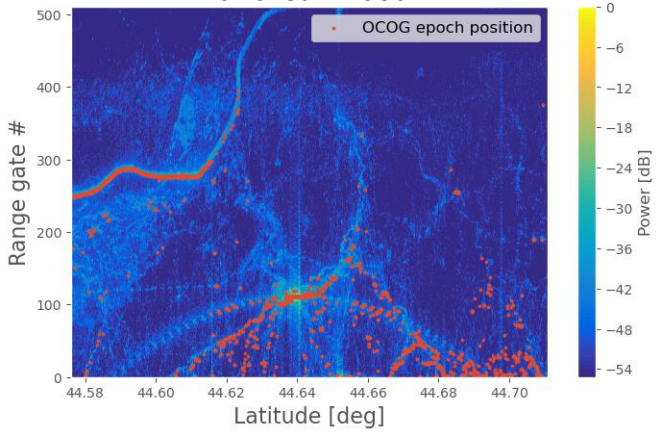
Doppler windowing

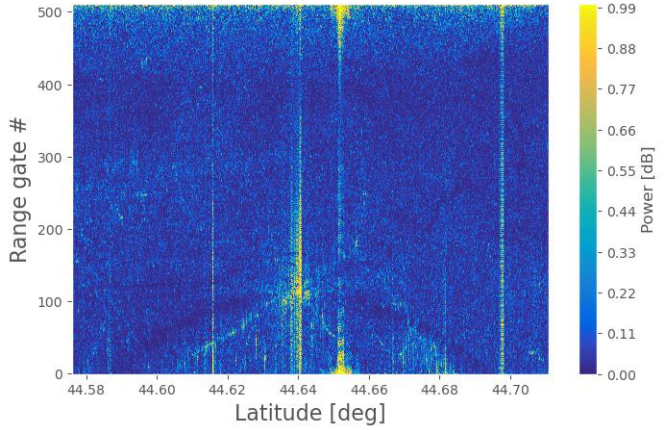


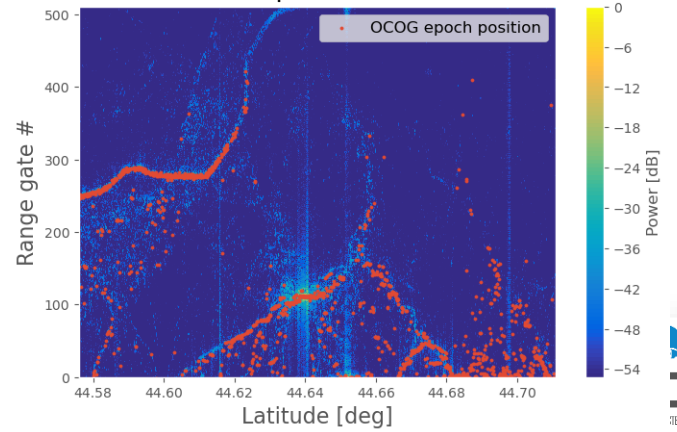




Replica mitigation

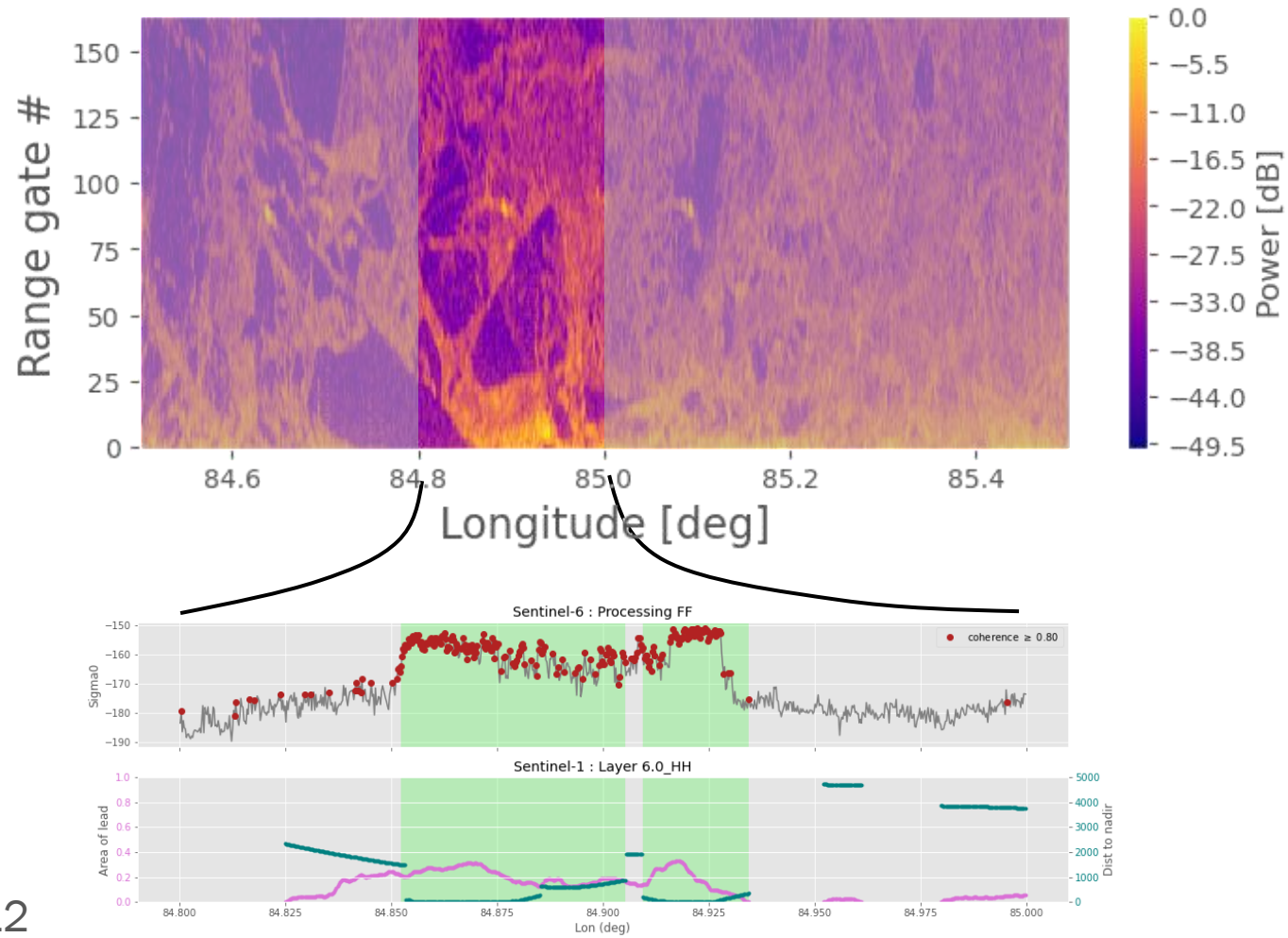


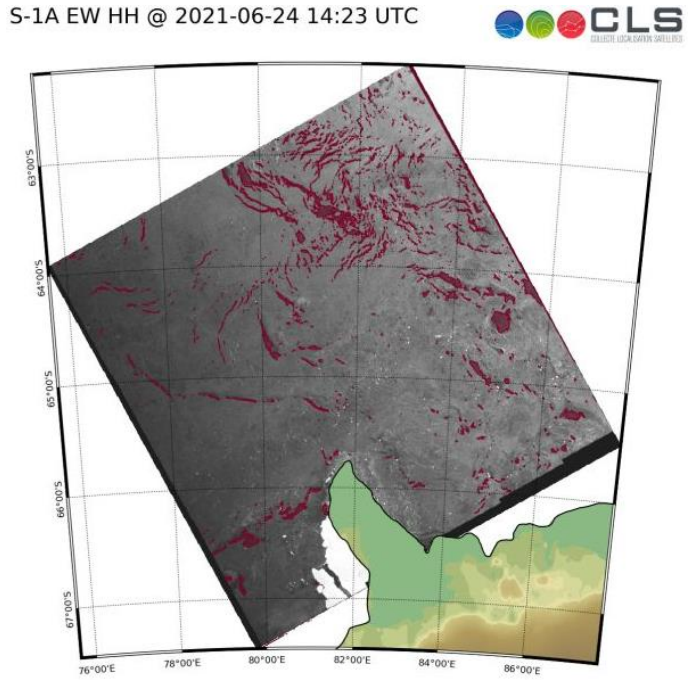




7 FF-SAR Processing

- Benefit of using FFSAR over sea-ice areas: Synergy with Sentinel-1 for lead detection





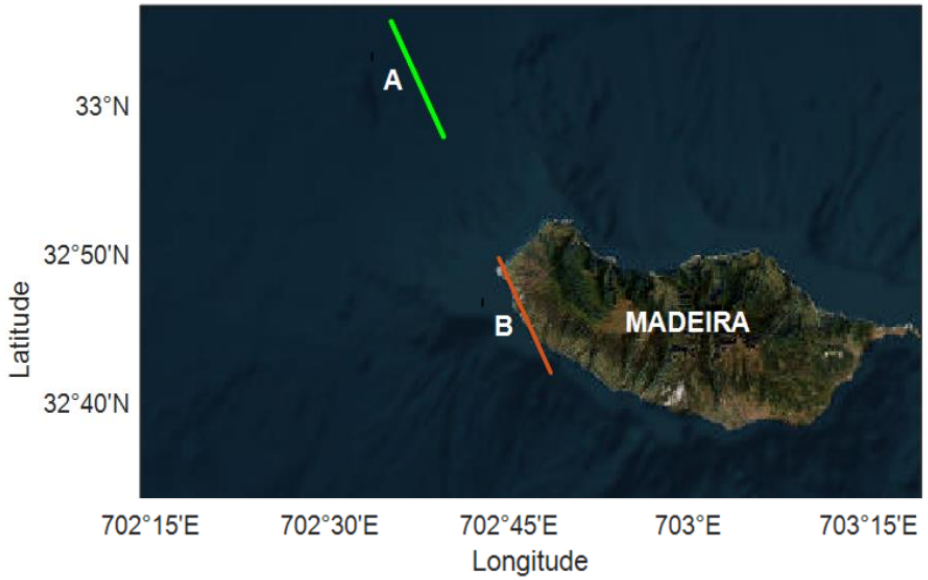
Sentinel-1 lead : area of lead <40% and distance to nadir <1500m

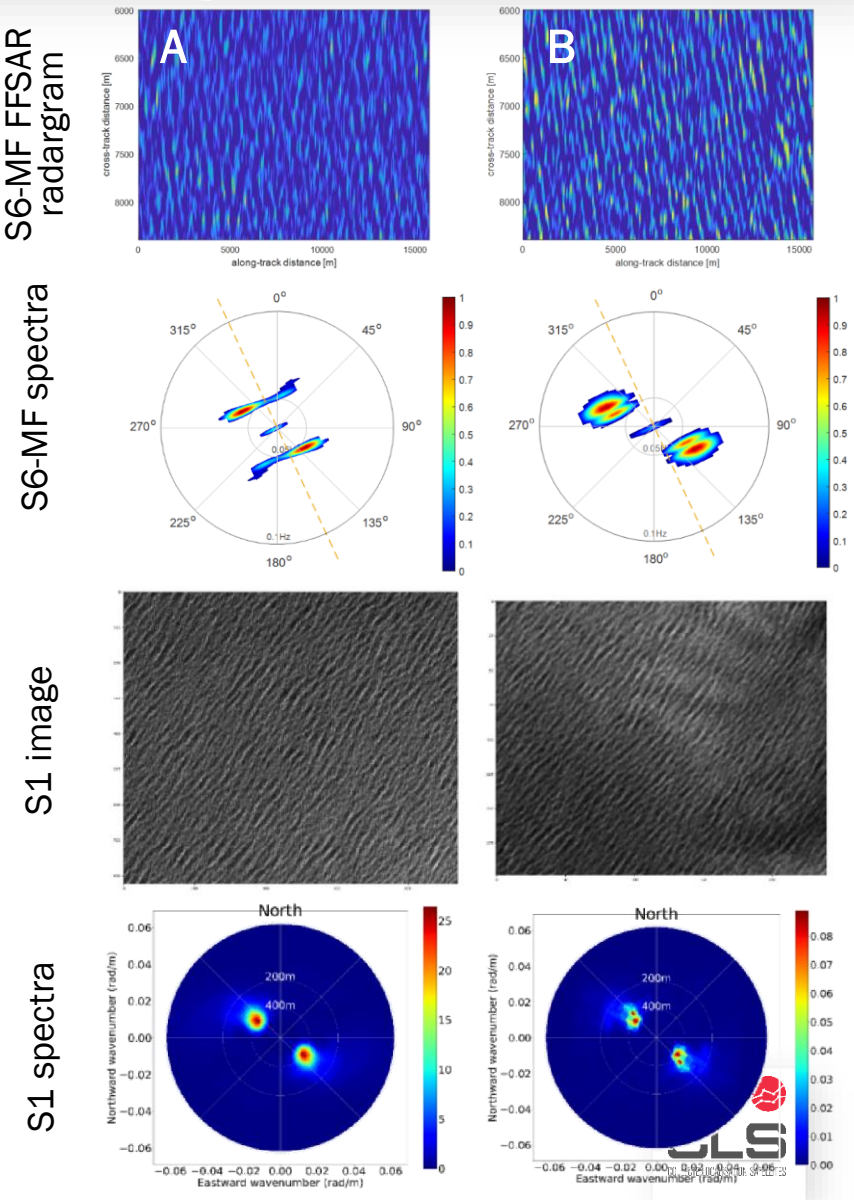
Sentinel-6 lead : coherence>0.8

7 FF-SAR Processing

See S. Amraoui in Instrument Processing: Measurement and Retracking

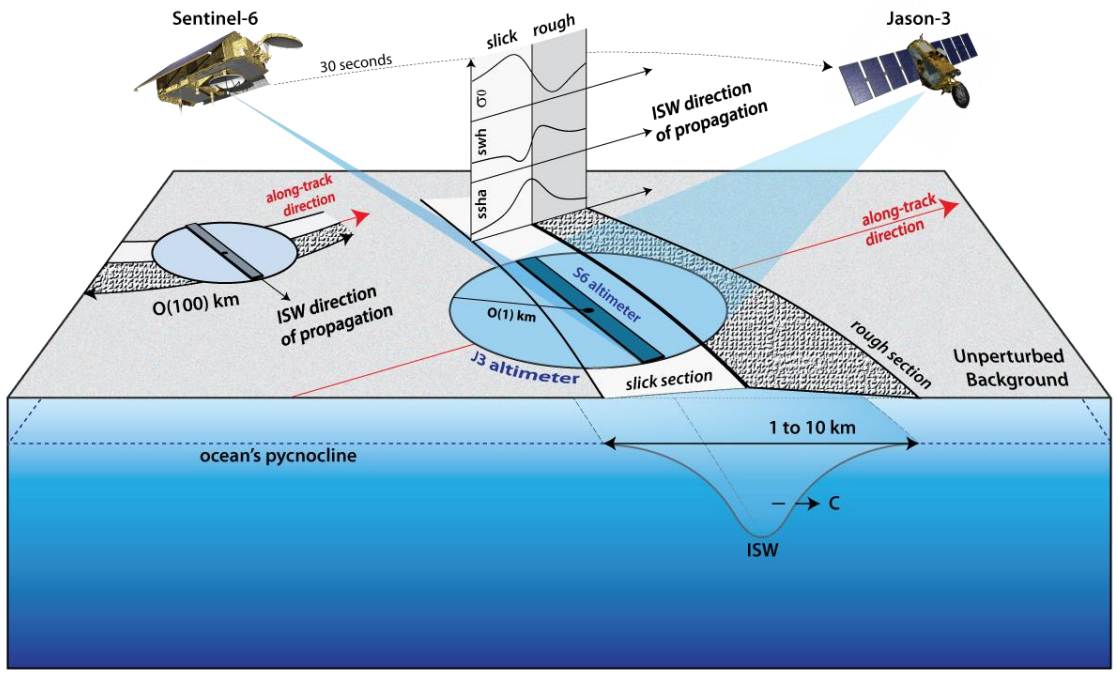
- Analysis of 2D modulation spectra extracted from S6-MF FFSAR data (from which is derived swell direction, amplitude and period), and comparison with Sentinel-1 spectra (in collaboration with O. Altiparmaki)





- Such analysis demonstrated the high interest of using FFSAR to allow for new potential products and applications
- S. Amraoui et al., *in prep.*

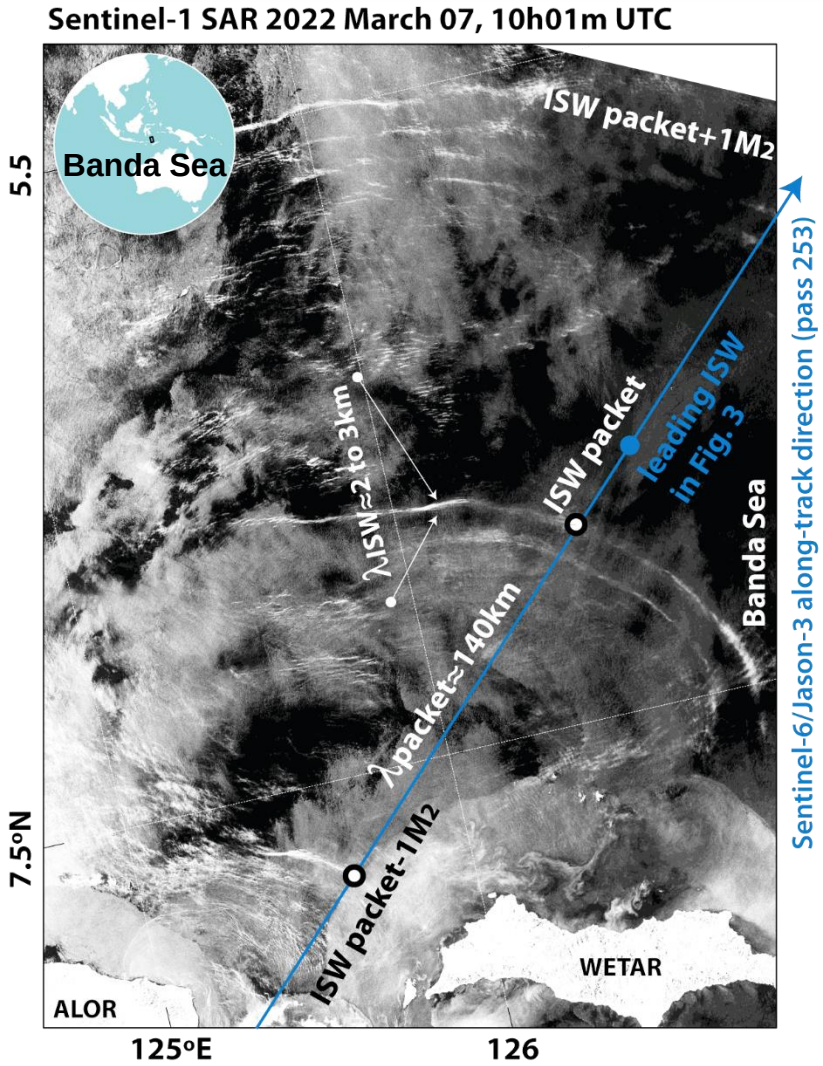
8 Internal Waves Detection



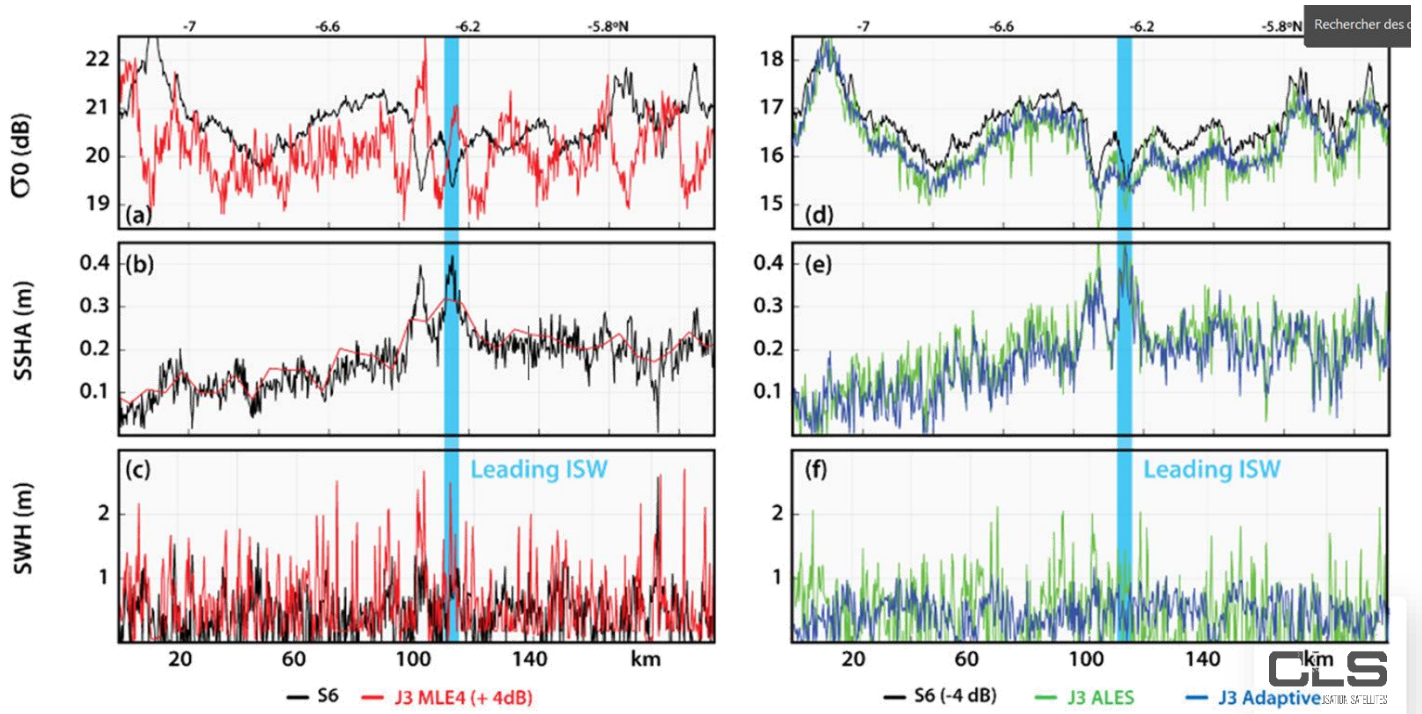
- S6-MF was set in a tandem orbit with J3, i.e. lagging just 30 seconds behind it
- In practice, there are observing the same phenomena with the same environmental conditions (i.e. surface wind and surface wave field)
- Any differences between their measurements should be instrumental (which is neglected) and/or related to their different ground resolutions (which is explored herein)
- This multisensor study explored simultaneaous measurements of internal solitary waves (ISWs) between SAR and conventional altimetry, and compare sigma0, SSHA and SWH signatures

- Magalhaes, J.M. et al., *Using a Tandem Flight Configuration between Sentinel-6 and Jason-3 to Compare SAR and Conventional Altimeters in Sea Surface Signatures of Internal Solitary Waves*. Remote Sens. 2023, 15, 392. https://doi.org/10.3390/rs15020392

8 Internal Waves Detection

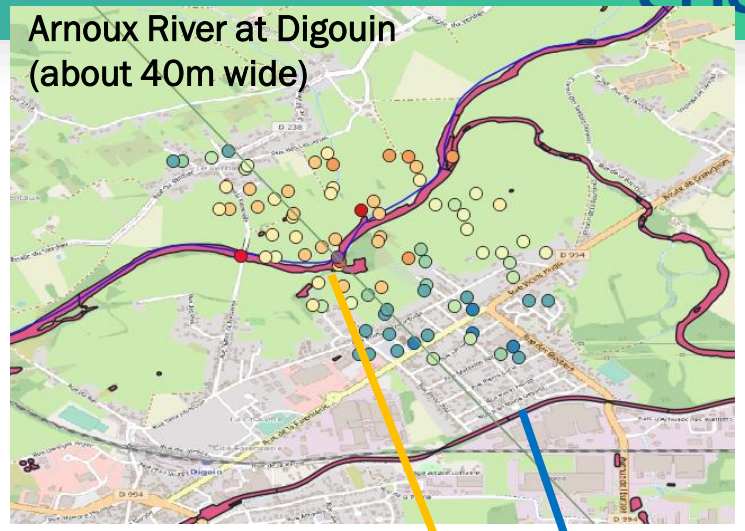


- S6-MF SAR altimeter can detect sharp ISW-signals in sigma0, SSHA and SWH, whereas conventional altimetry shows loss in detail
- In addition, standard MLE4 exhibits erroneous opposite sigma0 signatures, suggesting the need to use alternative algorithms (Adaptive, ALES) that perform in the same level of SAR altimeters when dealing with sharp transitions in ocean radar backscatter

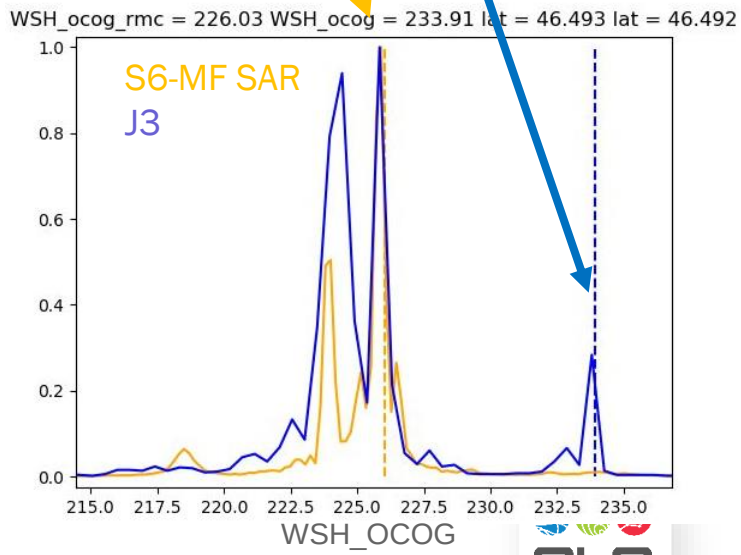


9 Inland Water Analysis

- Benefits of SAR altimetry wrt conventional altimetry fully demonstrated:
  - **Precision improvement by a factor of 3 over rivers** ~9.7cm with S6-MF SAR vs 29 cm with J3 (InSitu Comparisons over stations covering rivers from 10 to 300 m width)
  - **SAR reduced footprints** = less contaminating peaks in the waveforms => **outliers in WSH timeseries decreased by 27% with SAR wrt LRM over complex VS**
  - Excellent consistency in between RAW and RMC acquisitions
- S6-MF SAR and FF-SAR comparisons yielded the following results:
  - **4-5cm u-RMSE wrt in situ can be achieved on rivers down to < 20m in SAR**, reaching retracking noise limit
  - **Higher posting rate** (20 to 140 Hz) **improves by 15-20% the precision** of WSH retrievals in SAR.
  - **Benefits of FFSAR appear in complex configurations** (surrounding contaminants, steps/locks on river) where no a priori knowledge of the peak to retrack is needed
- N. Taburet et al., in prep.

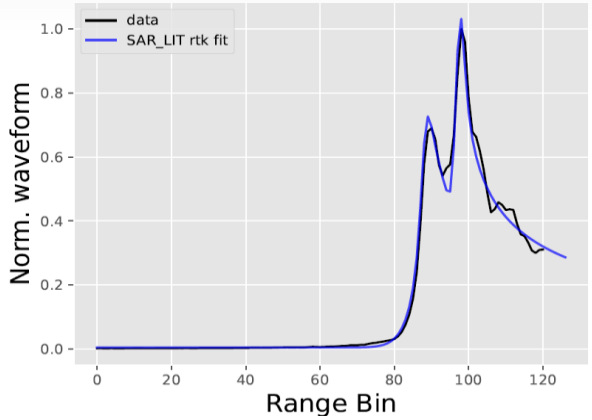


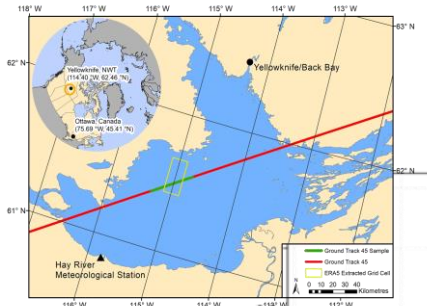
J3 observations with larger footprint are trapped by other water bodies

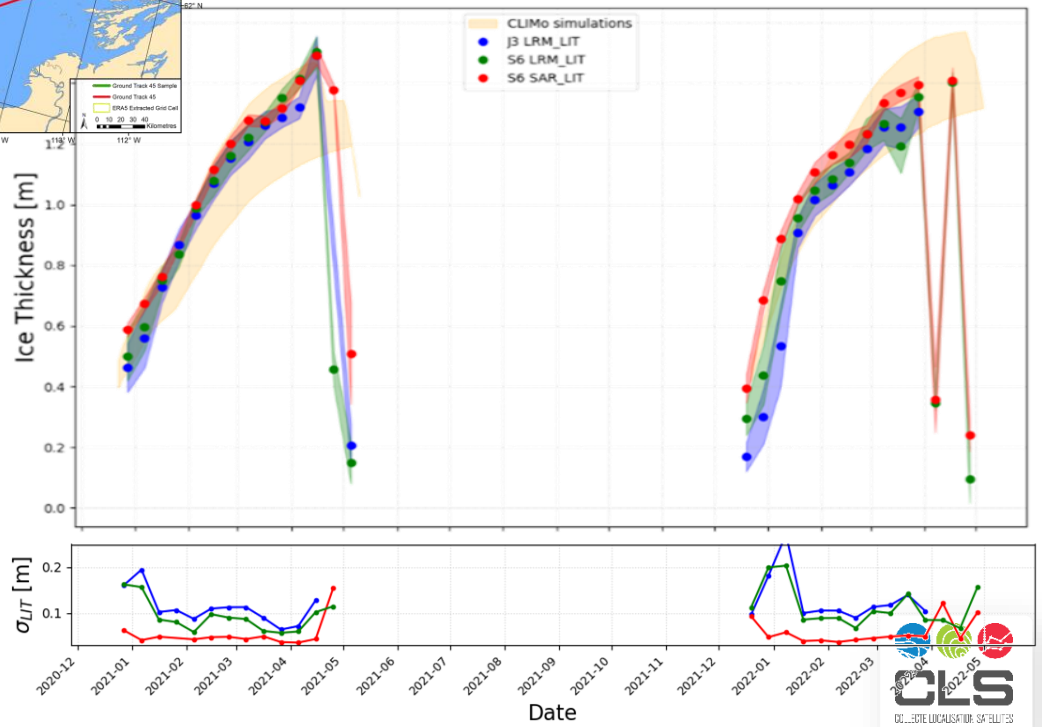


10 Lake Ice Thickness (LIT)

- As for conventional altimetry (Mangilli et al., 2022), a SAR LIT retracker based on the SAMOSA model has been developed for iced covered lake measurements (also tailored for use with FFSAR data)
- Comparison of LIT retrievals between S6-MF LR, S6-MF SAR and J3 are consistent in terms of LIT evolution and accuracy (over the Great Slave Lake)
- S6-MF LR exhibits a better accuracy than J3 (~20-30% improvement thanks to the higher PRF and range sampling)
- Improved accuracy with S6-MF UFSAR 20Hz (factor of ~2–3 wrt S6-MF LR)



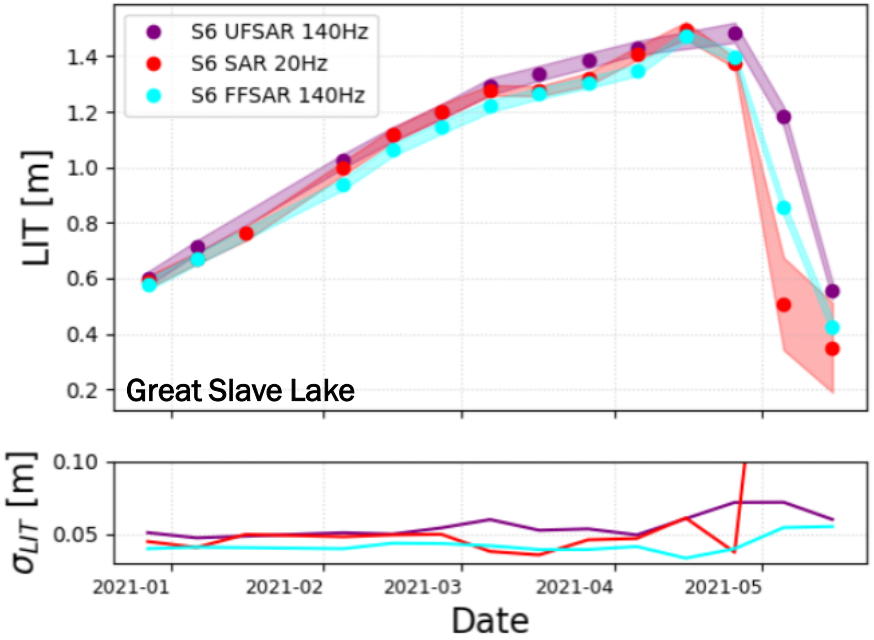


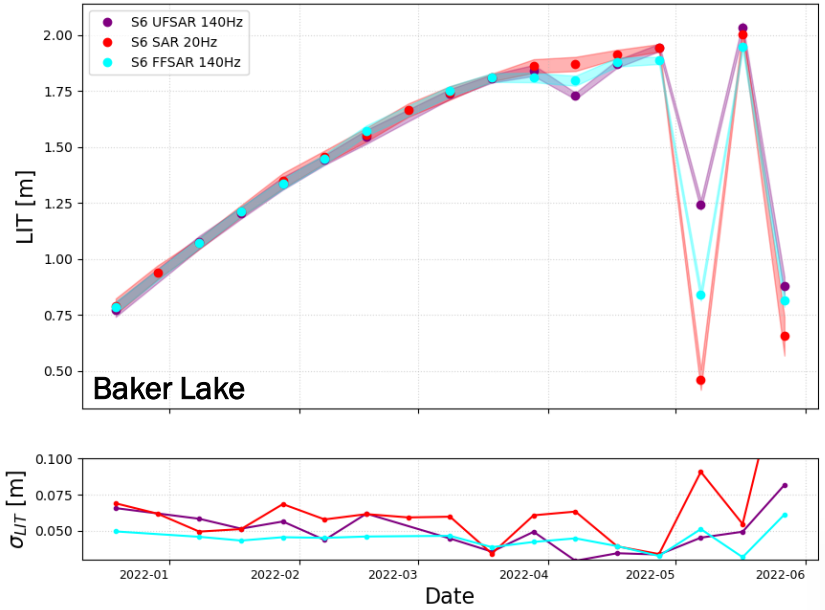


10 Lake Ice Thickness (LIT)

See A. Mangilli, Science IV: Altimetry for Cryosphere and Hydrology

- Overall consistent results among S6-MF SAR 20Hz, S6-MF 140Hz and S6-MF FFSAR 140Hz
- Increased performance with data at higher posting rate (140 Hz), notably at the melting transition
- At equivalent posting rate, FF-SAR 140 Hz allows to further improve the LIT analysis: double peak LIT signature seen at higher resolution and with a better precision (as seen over the Great Slave Lake, and the smaller and more challenging Baker Lake)
- A. Mangilli et al., *in prep.*





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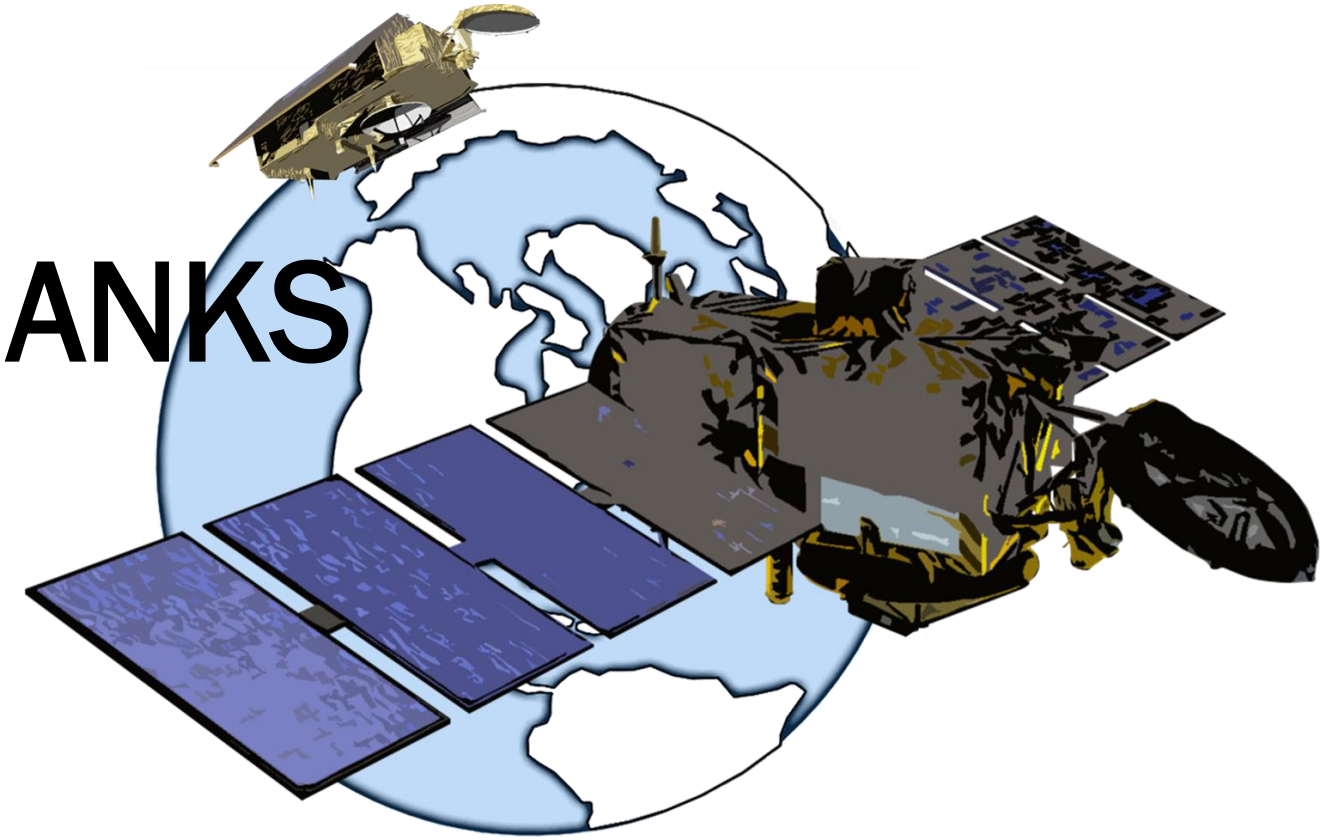
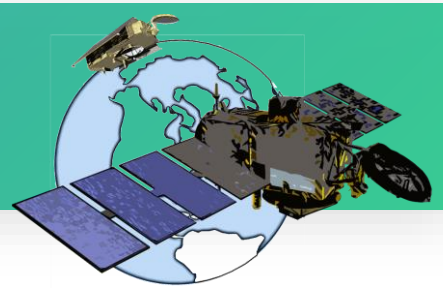


Sentinel-6 Mission

Copernicus Sentinel-6 Michael Freilich (S6-MF)

- New reference mission to ensure enhanced continuity of the long-term data record for climate studies
- New sensors: Highly precise radiometer (AMR-C) and new radar altimeter (POS4) with a new architecture and new capabilities currently commissioned to assess:
  - Continuity of LR mode with previous Jason series
  - Consistency between LR and SAR mode data
  - Consistency between SAR RAW and SAR RMC
  - Also analysis of new LR and SAR configurations and processings to better exploit the altimeter performance
    - mitigating any possible GMSL error, sea state effects and mesoscale error
    - benefit of using higher resolution processing over inland waters, cryosphere surfaces but also over ocean

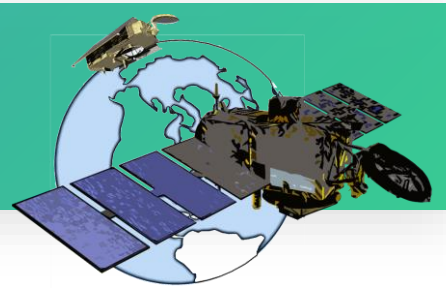
S6-JTEX Science Objectives



Tandem from a Climate perspective

- To perform very accurate calibration of the S6-MF altimeter (for the two chains) and radiometer against the reference mission
- To identify discrepancies between missions and different operating modes, but also drifts or periodic signals and establish strategies to correct for these errors
- To produce homogeneous and unbiased time-series observations and allow a precise estimate of uncertainties (with an error on the trend of less than 1mm/year) for long term climate data records and applications
- To also ensure the continuity of the long-term radiometric correction time series

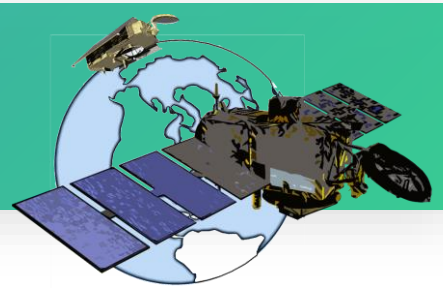
S6-JTEX Science Objectives



Expected impact of the Tandem for sea state

- To provide accurate SWH quantities for marine weather and sea state forecasting but also growing interests in long-term multi-mission altimeter records of sea state
- To gain understanding of the different sea state effects contributing to the sea surface height retrievals uncertainty
  - Increase of measurement noise on SSH with SWH
  - Sensitivity to long ocean waves (T02, energy, orientation):
    - High-frequency noise on altimeter estimates
    - Increase of SSH variance at long wavelengths (spectrum aliasing)
  - SWH bias induced by orbital wave velocities which can in turn impact SSH through SSB correction
  - Other phenomena affecting SAR altimetry signals (surface currents, wind speed)

S6-JTEX Science Objectives



Expected benefit from innovative processing and applications

- To make use of innovative algorithms to improve the altimeter performances:
  - SAR processing at higher sampling to better sample water targets (leads, river/lakes, frozen lakes), but also to mitigate swell-induced aliasing artifacts
  - Use of customized solutions for more challenging applications as coastal zone, inland water and sea-ice
  - Benefit of new delay-Doppler processing at mesoscale, ..
- To assess the enhanced fully focused SAR (FF-SAR) capabilities to better map inland waters (and sea ice leads) but also provide more details of the ocean surface structure