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

Science Activity Plan

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APPLICABLE DOCUMENTS

DA 1 Sentinel-6 Michael Freilich and Jason-3 Tandem Flight Exploitation (S6-JTEX), Statement of Work [EXPRO+], Ref. ESA-EOPSM-S6-SOW-3774, Issue 1, Revision 0, 04/12/2020

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ACRONYMS AND ABBREVIATIONS

CNES	Centre National d'Etudes Spatiales
ESA	European Space Agency
FF-SAR	Fully Focused SAR
HR	High Resolution
IR	Altimeter Impulse Response
J3	Jason-3 mission
LRM	Low Resolution Mode
L1	Level 1
L2	Level 2
MSL/GMSL	(Global) Mean Sea Level
MSS	Mean Sea Surface
MWR	Micro-Wave Radiometer
POS4	Poseidon-4 altimeter
PRF	Pulse Repetition Frequency
S6-MF	Sentinel-6 Michael Freilich
SAP	Science Activities Plan
SAR/SARM	Synthetic Aperture Radar (Mode)
SLA	Sea Level Anomaly
SSH	Sea Surface Height
SWH	Significant Wave Height
WSH	Water Surface Height

1 Introduction

1.1 Scope of the document

This document is the Science Activity Plan (SAP) providing an exhaustive list of S6-JTEX case studies of interest based on the exploitation of the Sentinel-6MF (S6-MF) and Jason-3 (J3) data acquired in tandem phase.

The objective of the document is to describe the implementation plan that will be carried out for performing the scientific activities of each S6-JTEX case study. These activities are described in detail, together with the method used to address these goals and the source data required to support the different studies.

2 SAP Implementation Plan

2.1 Objectives of the S6-MF and Jason-3 tandem flight exploitation

The Copernicus Sentinel-6 Michael Freilich (S6-MF) satellite is taking over the responsibility as the reference mission to continue the long-term record of sea-surface height measurements started in 1992 by the Topex-Poseidon satellite and then by the Jason series. The role of Copernicus Sentinel-6 Michael Freilich is not only to extend the record for climate studies, but also to monitor the changing height of the sea surface with greater precision than before (with an error on the trend of less than 1mm/year [Scharroo et al., 2016; Donlon et al., 2021]).

To achieve this objective, the S6-MF satellite carries a radar altimeter of new generation, Poseidon-4, supported by a new highly precise microwave radiometer, AMR-C (Advanced Microwave Radiometer-C). The Poseidon-4 altimeter evolves significantly from its predecessors (Poseidon-3A and -3B instruments on board Jason-2 and -3 respectively) and features higher performance than this previous generation. First it embeds a new operating mode, currently termed interleaved, that allows, for the first time, to make use of synthetic aperture radar (SAR) capability [Raney, 1998; Wingham et al., 2006; Boy et al., 2017] in the altimeter reference mission time series. Poseidon-4 also features a new architecture, increasing the use of digital functions which aims at enhancing the stability of the altimeter performances. Furthermore, Poseidon-4 performs a near continuous transmission of Ku-band pulses, that allows both conventional low-resolution mode (LRM) and SAR mode data to be generated simultaneously, ensuring compatibility with previous pulse limited altimeter missions. On top of that, Poseidon-4 includes an on-board RMC processing to reduce SAR mode data volume to be downlinked so that high-resolution observations could be made everywhere in global ocean, close to the coast and for mapping rivers and lakes for hydrology purposes.

The Poseidon-4 altimeter is designed to ensure enhanced continuity of the long time series of measurement. It is nonetheless a completely new instrument with a new architecture and new capabilities which need to be thoroughly commissioned. Any differences or discrepancies with other missions (in particular with respect to Jason-3, along with they form a tandem flight convoy formation) would have to be detected and strategies to be established to correct for any errors in the S6-MF data that might arise owing to this new radar instrument and design.

It is an objective of this Tandem phase study to better characterize the S6-MF POS4 instrument, compared to the Jason-3 one, to better understand the phenomena that can affect, corrupt, bias or noise the retrieval of the geophysical parameters of interest, and finally to better characterize the accuracy of these measurements that is key parameter to derive regressions on long term series for climate applications. Furthermore, different S6-MF operational modes (LRM, SAR RAW and SAR RMC) will be activated during the tandem phase, but low- and high-resolution observations will be performed simultaneously most of time, allowing S6-MF data to be directly cross-compared at the same surface sample location.

2.2 Overview of the SAP

The Science Activity Plan provides a comprehensive summary of the science and engineering activities that are foreseen to be conducted using the S6-MF and J3 data acquired in tandem phase to support the Sentinel-6 MF mission aims:

- To provide an exhaustive analysis of S6-MF measurements during the tandem flight opportunity with Jason-3 in order to build an accurate S6-MF altimeter climate data record over ocean (for the sea level and sea state), but also to ensure a seamless transition for inland water height,
- To develop a number of scientific studies that fully exploit the capabilities of the mission, and
- To make use of innovative processing (e.g., FF-SAR, increased posting rate in SAR processing, LR-RMC) to allow for new potential products and applications.

Specific SAP activities are listed in the next section, organised by surfaces and processing, and classified into core activities (to be completed during the course of the project) or optional activities (complementary activities requiring additional resources to accomplish them), knowing that this remains negotiable with ESA.

2.3 Candidate activities for implementation

It is the objective of the phase-one stage of the project and particularly the SAP review (at the final Down Selection Meeting hold at T0 + 3 months) to establish a prioritization of these activities and decide which activities will be addressed and completed during the Data Analysis phase studies (phase two).

In the table below, we provide the SAP activities list and the related status. The green background is used to highlight “core” activities, the blue background for “optional” activities, and the orange background for activities proposed in the SoW [DA 1] but not addressed in the project (given the limited resources of the project) and not provided as an option by the partner consortium neither.

Id	Title	Activity Theme	Status
0.1	Study of S6-MF uncertainty propagation for geophysical products while in tandem with J3	metrology	proposed in SoW but not addressed
1.1	Validation of the S6-MF measurements over open ocean and characterization of potential differences/discrepancies with respect to Jason-3	CalVal ocean	core
1.2	Evaluation of the performance of S6-MF measurements in coastal areas	CalVal ocean	core
2.1	Homogenization/mitigation of differences and/or discrepancies captured in ocean products available from S6-MF, Jason-3, Sentinel-3 and other satellite data	uncertainties and GMSL	core
2.2	Study of alternative approaches to inter-calibration of S6-MF and Sentinel-3 SRAL while in tandem	uncertainties and GMSL	core
3.1	Validation of S6-MF sea state measurements using triple collocation analysis	sea state	core
3.2	Exploiting differences and processing techniques to study ocean swell waves and high sea states and mitigate their impact on S6-MF SSH measurements	sea state	core
3.3	Study of new S6-MF capability to measure wind speed over the ocean	sea state	proposed in SoW but not addressed
4.1	Exploiting the S6-MF effective number of looks (ENL) for sea state applications	statistical analysis of L1 data	core
5.1	Exploitation of Fully focused SAR (FFSAR) processing using S6-MFover ocean and sea ice surfaces	FF-SAR processing	core
6.1	Characterization and exploitation of S6-MF and J3 in support of improved hydrology products	inland water analysis	core
7.1	Study of the S6-MF capability for estimating the Lake Ice Thickness	cryosphere surfaces	core
7.2	Study of new S6-MF capability over cryosphere surfaces (e.g. sea ice, icebergs, ice sheet margins)	cryosphere surfaces	proposed in SoW but not addressed
8.1	Study of new S6-MF capability in tandem with J3 and together with other satellite data sets to measure internal wave surface signatures over the ocean	internal waves detection study	core
	No identified optional activities at the present time		optional

Table 1: Table of SAP activities and related status. 1) activities in green background are those foreseen for implementation in the Data Analysis phase studies, 2) activities in orange background are those proposed in the SoW [DA 1] but not retained in the SAP list during the first phase of the review, and 3) activities in blue background are those proposed as an option for a possible implementation in phase 2 or at a later stage (to be discussed with ESA during the course of the project).

2.4 Phase two: implementation of the science activities

Progress meetings will be held on a regular basis, and periodic reporting will be performed to communicate on the implementation of the SAP activities to ESA, in order to raise any potential problem, technical difficulty, or unexpected results and set up quickly solutions to resolve them. In case of new findings or research results that might affect the operational processing chain, information would be reported to the relevant S6 MPC team following the general process as described in next section.

All results obtained during the implementation of the activities will be compiled in scientific papers and submitted to a peer-reviewed journal for publication, but also summarized in the Final Report.

2.5 Data comparisons and re-calibration

The S6-MF and Jason-3 tandem phase offers a unique opportunity to compare two different altimetry missions operating at the same frequency with different modes and using different scientific processing algorithms while observing exactly the same scenes a few seconds apart. Comparisons between the two missions include three different stages as it is currently applied in S6-MF commissioning activities:

- **The first stage (comparison)** consists in determining instrument and/or product biases through comparison and evaluating under which conditions such biases occur. This involves performing direct comparisons of the L1 and L2 data from the two satellites over different surface and atmospheric conditions and types of site and using these comparisons to understand biases and to test product uncertainties.
- **The second stage (interpretation)** understands the physical origin of any biases and uses the results of the comparison to improve our understanding of the instrument (L1) and/or product processing (L2) and/or to improve the estimates of uncertainties. This stage requires knowledge of the instrument and/or product processing. Note that this stage would also consider whether the third stage “recalibration” is needed by considering the impact of any observed differences at L1 on the L2 products.
- **The third stage (re-calibration)** then corrects for such biases if this were needed. Ideally such corrections would not be provided as pure “bias correction”, but through a reconsideration of the algorithms and information provided to L1 processing from L0 and to L2 processing from L1.

The outcome of the comparison and interpretation will be discussed with the Sentinel-6 Validation Teams and Sentinel-6 MPC (or equivalent under EUM responsibility) who holds the responsibility for re-calibration/reprocessing activities.

3 SAP Activities

3.1 CalVal Ocean

<table>
<tr><th>1.1</th><th colspan="2">CalVal Ocean</th></tr>
<tr><td colspan="2">Responsible: CLS
Participants: -</td><td>Objective: Validation of the S6-MF measurements over open ocean and characterization of potential differences/discrepancies with respect to Jason-3</td></tr>
<tr><td colspan="3">Rationale:
Thanks to the long duration of Sentinel-6A/Jason-3 tandem phase (12months+), a large amount of spatially and temporally collocated data are being collected. This unique opportunity allows a precise evaluation of Sentinel-6A performances with respect to Jason-3. The goal is to allow a seamless transition between Jason-3 and Sentinel-6A as the reference mission.

A complete CalVal assessment is performed in order to identify any discrepancies/differences between Jason-3 and Sentinel-6A LR over ocean. Residuals between Sentinel-6A LR and Jason-3 datasets are analyzed globally over ocean but also over specific geographical areas, specific atmospheric and sea state conditions to highlight any source of dependency. Thanks to the large dataset, the level of uncertainties is low. When identified, discrepancies are investigated to understand its origin and to propose correction if necessary.

Improvements brought by HR modes are also assessed in comparison to LR S6 and Jason-3's conventional mode and to other SAR data (from Sentinel-3A). Direct comparisons between HR RAW and RMC data have been performed over LX2 segments and over complete cycles thanks to the RAW2RMC on-ground converter.

This activity is strongly based on results obtained during CNES/EUMETSAT commissioning activities and during GPP project.</td></tr>
<tr><td colspan="3">Input / Data:
Sentinel-6 MF L2 LR and HR NTC data over ocean (and over transponders)
Janson-3 L2 GDR data over the tandem phase period
Sentinel-3A and/or -3B L2 marine NTC data over the tandem phase period
MFWAM wave model (by extracting the mean peak period, the mean propagation angle, and mean wave height) for supporting possible long ocean wave analysis,
Outputs from L2 GPP project
Outputs from CNES/Eumetsat commisioning activities</td></tr>
<tr><td colspan="3">Tools:
CLS internal tools dedicated to altimetry analyses</td></tr>
<tr><td colspan="3">Activity description:
<u>Task 1</u>: Compile and summarize the main outcomes obtained in the frame of the Sentinel-6 MF commissioning activities and identify the remaining open questions
<u>Task 2:</u> Perform investigations to fully assessed Seintinel-6A performances and discuss potential processing alternatives (L1B and L2 and post processing) that could allow to mitigate sensitivities and ultimately discrepancies between all acquisition modes of S6 and J3.
<u>Task 3:</u> Paper</td></tr>
<tr><td colspan="3">Outputs:</td></tr>
</table>

• Peer review paper [D-70] • Slides to report on the progress of the study [D-30]
References: •

1.2	CalVal Ocean

Responsible: TUM **Participants:** -	**Objective:** Evaluation of the performance of S6-MF measurements in coastal areas

Rationale:

The accuracy of altimetry measurements in the coastal areas is affected by the local departure of the radar signal from the known ocean response (due to inhomogeneities of the illuminated area) and the inaccuracy of the corrections, as well as of the tidal models, needed to isolate anomalies in the sea level variability (Cipollini et al., 2017).

Sea Surface Height (SSH) from Delay-Doppler (DD) instruments is generally more precise and reliable in the coastal zone if compared to previous standard low-resolution mode (LRM) altimetry missions, even without any specific coastal retracker. Despite the improvements, the quantity and the quality of sea state and sea level retrievals in the coastal zone is still significantly different than from the open ocean. For example, concerning Significant Wave Height (SWH), it has been observed that the amount of missing data and outliers in Sentinel-3 data for a distance to coast of less than 20 km amounts to almost 40% (Schlembach et al., 2020).

In the latest years, the reprocessing of Low Resolution Mode (LRM) missions with the ALES retracker (Passaro et al., 2014) has shown that meaningful information can be retrieved in general up to 3 km from the coast and in some cases until few hundreds of meters (Benveniste et al., 2020). ALES has been designed to improve the detection of sea level in the coastal zone by overcoming the difficulties in retrieving the information from contaminated radar waveforms. Despite the wide use, this retracker is not yet part of the ground segment of the Geophysical Data Records of the LRM missions and reprocessings, with the consequence that DD coastal performances are compared with LRM data that are not optimized for the coastal zone.

Given that the coastal zone is explicitly a focus of S6-MF, there is a need to understand how reliable the data provided to the users are and what are the improvements compared to the coastal-optimized LRM data. Moreover, in view of future reprocessings, the best strategy concerning possible additional dedicated retrackers and the different modes of operations have to be found. Considering the latter, in particular, it is important to understand from the early stage of the mission whether the on-board RMC processing (Kuschnerus et al., 2018), suggested in the open ocean since the current default ground station network cannot support operations in SAR RAW mode everywhere in the ocean, alters the performances of the retrieval algorithms in the coastal zone.

Input / Data:

- Sentinel-6 MF L1B LR NTC data over coastal areas
- Sentinel-6 MF L2 LR and HR NTC data over coastal areas
- Jason-3 SGDR data over the tandem phase period

Tools:

- TUM internal tools dedicated to altimetry analyses

Activity description:

The study aims at providing an internal comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and J3. The performances will be assessed in terms of range retrieval and significant wave height retrieval. In addition, considering the intercomparison of the products from the two missions, the consistency of the relevant geophysical correction (i.e. radiometer correction, dual-frequency ionosphere, sea state bias) will be checked. All the statistics will be referred to the 20-km limit from the global coastline, i.e. the area in which typically the general performance of satellite altimetry data is considered degraded.

The work is structured in three different tasks:

- Retrack the J3 and S6-MF LRM waveforms with specific retrackers: ALES and heritage from other ongoing projects (for example, WHALES from Sea State CCI)

- Performance assessment analysis in terms of intrinsic noise and outlier analysis in the coastal zone, for S6 LRM, SAR-RAW and SAR-RMC & retracked J3
- Intercomparison of S6 and J3 based on L2 products in the coastal zone will be performed focusing on bias, drift and their geographical patters

Outputs:

- Paper on coastal performance of S6_FM in coastal areas [D-80]
- Slides reporting on the progress of the study (at regular meetings with ESA) [D-30]

References:

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3.2 Uncertainties and GMSL

2.1	Uncertainties and GMSL
Responsible: CLS **Participants:** Magellium	**Objective:** Homogenization/mitigation of differences and/or discrepancies captured in ocean products available from S6-MF, Jason-3, Sentinel-3 and other satellite data

Rationale:

Sentinel-6 MF will play a key role to extend the Topex/Jason series that monitors the Mean Sea Level variations for more than 27 years. Such a long time series helps to characterise the pace of the sea level rise all over the globe which is now part of the Essential Climate Variables (ECVs) distributed by the Copernicus Climate Change Service. The long-term quality and stability of such variables is ensured thanks to precise inter-calibration of the successive altimetry missions that have flown on the historical Topex's orbit. Such in-depth inter-calibrations have been performed during tandem phases that helped to mitigate discrepancies between Topex/Jason-1 (Ablain et al., 2012) as well as Jason-1/-2 and -3, at the sensor parameters level (range, sigma-0, SWH) as well as for the geophysical corrections such as the Sea State Bias (Tran et al. 2010) that contribute to the SSH computation and thus to the MSL. In addition to the conventional LRM, S6-MF will use a SAR mode which has never been operated on previous reference missions and consequently will require specific attention to ensure a homogeneous transition. The bias estimation between S6-MF and Jason-3 will directly impact the global and regional MSL trends and their uncertainties. Zawadzki et al. (2016) showed that the Jason-2/Jason-3 GMSL bias uncertainty is of 1 mm (90%) and the resulting GMSL trend uncertainty (due only to the bias) is of 0.14 mm/yr over the last 10 years of these missions' operational time. In case of loss of the reference mission, they showed that switching to Sentinel-3A increases the GMSL trend uncertainty by a factor 3, mainly due to the change of orbit. It is important to notice that these figures are based on simulations of Jason-3 and Sentinel-3A data (real data were not yet available in 2016) and based on a method that assumed strong properties of the Jason-2/-3 and Jason-2/Sentinel-3A inter-comparisons (noise levels and inter-correlations). Recent studies performed in the S3TC ESA project proposed an update of their method based on actual Sentinel-3A/B data and showed that special care needs to be taken to connect two missions to obtain adequate GMSL trend uncertainties (Clerc et al. 2020). The S6-MF tandem phase with Jason-3, combined with the Sentinel-3 missions will give the opportunity to consolidate the current method of bias estimation based on a reference mission, as well as to explore new methods such as a multi-mission approach and/or the use of FRM data. This will allow quantifying how accurate these new methods are as compared to the one used so far.

Input / Data:

- Sentinel-6 MF L2 NTC over ocean
- Jason-3 L2 GDR
- Sentinel-3 A/B SRAL L2 marine NTC (SAR and LRM)
- Tide-gauge data from Gloss-Clivar and PSMSL databases

Tools:

- CLS internal tools dedicated to altimetry analyses

Activity description:

- Task 1: **Estimating the regional and global MSL biases between S6-MF and Jason-3 and their associated uncertainties**
  - For all available modes (LRM/LRM, LRM/SAR, etc.)
  - Use a statistical approach as done in Clerc et al. (2020) to estimate the GMSL bias uncertainties
  - Propagate these onto the GMSL trend uncertainty and characterize the long-term stability of the record.

- For the regional MSL, we will perform similar analyses at different regional scales, with a focus on the spatial correlation determination of the residual signals. We will be able to determine at which spatial scale the MSL data records is accurate enough for any scientific needs.

- Task 2: **Comparison to alternative methods (multi-mission approach, tide-gauge comparison)**
    - Quantify by how much the bias uncertainties are increased if one uses alternative approaches:
        - Multi-mission approaches with different orbits (Sentinel-3's)
        - Multi-mission approaches with and w/o tandem phases
        - Tide-gauge data
    - Determine what is the optimal approach to improve the uncertainty?"

Outputs:

- A peer review paper describing the work proposed [D-90]
- Contributions to the different S6JTEX meetings and writings [D-30]

References:

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2.2	Uncertainties and GMSL
Responsible: Magellium **Participants:** CLS	**Objective:** Study of alternative approaches to inter-calibration of S6-MF and Sentinel-3 SRAL while in tandem

Rationale:

Intercalibration studies allow differences between altimetry missions to be detected, enabling in-depth investigations to be carried out to understand their origin and then correct them. Several types of error signals such as biases, drifts or signals correlated in time and space can be detected for the main altimetry parameters (e.g. SWH, Sigma0), but also geophysical corrections (e.g. wet tropospheric correction) and, most importantly, sea surface height. This is possible in different satellite configurations: 1) when the satellites are on two different orbits, which is the most common situation; 2) during tandem phases, when two satellites are on the same orbit with a few seconds time lag. Thus, in the past, significant geographically correlated SSH biases have been detected between TOPEX and Jason-1 (Ablain et al., 2012) during the tandem phase of these missions. It was mainly due to errors in the orbit solutions but also to heterogeneous processing between missions (e.g. sea state bias correction). The correction of these errors made it possible not only to homogenise the two missions, but also to improve each of the two timeseries. Many other examples can be provided: for instance, the detection of significant GMSL drifts in the ENVISAT GMSL in 2003/2005 by comparison with Jason-1 (Olivier et al., 2012) and more recently in the S3A/S3B GMSL by comparison with Jason-3 and SARAL-Altika (Jugier et al., 2020; Guerou et al., 2020). By helping to detect and correct many important altimetry errors, intercalibration studies are therefore essential to ensure a good accuracy of all altimetry products, and especially the GMSL indicator. It is also very likely that the current tandem phase between Jason-3 (JA3) and Sentinel-6 Michael Freilich (S6-MF) will provide relevant information in terms of differences and discrepancies between the two missions as these potential differences will be very precisely estimated and certainly statistically significant. However, if such discrepancies are found, and despite their very good accuracy, the errors cannot be attributed to either of the two missions. Therefore, one of the most relevant ways to attribute the errors detected is to use other altimetry missions such as Sentinel-3 (S3A and S3B). Cross-comparisons between S3A and S3B with S6-MF and JA3 while in tandem will provide us with another source of information to analyse the discrepancies between all these missions.

Input / Data:

- Sentinel-6 MF L2 NTC over ocean
- Jason-3 L2 GDR
- Sentinel-3 A/B SRAL L2 marine NTC (SAR and LRM)

Tools:

- To be developed during the study

Activity description:

- *Task1 : specification of the alternative intercalibration method between Sentinel-3 SRAL and S6-MF.*
    - To find the best balance between, on the one hand, having accurate but few measurements and, on the other hand, having a lot of measurements but little accuracy due to ocean variability.
    - To carry out a sensitivity study on the uncertainties of the method, by progressively varying the spatial and temporal collocation criteria of the S6-MF and S3-A (or S3-B) measurements.

- *Task 2 : Analysis in depth the level of uncertainty obtained*
    - By calculating its evolution over time for both bias and drift estimates at global and regional scales, and for the main physical variables (e.g. ssh, swh, sigma0, ...).
    - By comparing these uncertainties with those obtained during a tandem phase, which is the optimal case (maximum number of measurements and very accurate).
    - By applying the approach to some concrete discrepancies found between J3 and S6 (SAP 2.1)

Outputs:

- A peer review paper will be submitted to provide the synthesis of this study [D-160]
- Slides will be provided at the various meetings with ESA to report on the progress of the study [D-30]

References:

- Ablain, M., Meyssignac, B., Zawadzki, L., Jugier, R., Ribes, A., Cazenave, A., et al. (2019). Uncertainty in satellite estimate of global mean sea level changes, trend and acceleration. Earth Syst. Sci. Data Discuss. 1–26. doi: 10.5194/essd-2019-10
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- Donlon C., OSTST, 2020: Altimetric Reference Transfer Standard (ARTS)
- Jugier R. et al., OSTST, 2020: What sea-level drifts can be detected at global and regional scales by comparing recent altimetry missions together: S3A, Jason-3 and Saral-Altika? Available here.
- Guerou et al., S3VT 2020, Investigating the Sentinel-3 SARM range drift
- A. Ollivier, Y. Faugere, N. Picot, M. Ablain, P. Femenias & J. Benveniste (2012) Envisat Ocean Altimeter Becoming Relevant for Mean Sea Level Trend Studies, Marine Geodesy, 35:sup1, 118-136, DOI: 10.1080/01490419.2012.721632

3.3 Sea State

<table>
<tr><td>3.1</td><td colspan="2">Sea State</td></tr>
<tr><td colspan="2">Responsible: NOC
Participants: -</td><td>Objective: Validation of S6-MF sea state measurements using triple collocation analysis</td></tr>
<tr><td colspan="3">Rationale:
The Sentinel-6/Jason-3 Tandem provides a unique opportunity for in-depth investigations of the uncertainties and error characteristics of altimeter sea state data. Given the high temporal and spatial variability of sea state, conventional inter-comparison methods (e.g. cross-overs) are unable to isolated the contributions to observed uncertainties due to natural variability, random instrument errors and systematic instrument/processing biases. In the case of Sentinel-6MF, with its key role in ensuring long-term continuity of the altimeter reference data record,

understanding these uncertainties and the consistency of its sea state measurements in the context of other satellites, and in different ocean conditions, is particularly critical. The S6-MF/Jason-3 Tandem will give the opportunity to evaluate, for the first time, the performance of the new S6-MF SAR Interleaved mode (Gommenginger et al., 2013) directly against S6-MF LRM and Jason-3 (LRM), and to explore the relative merits of difference modes and satellites (biases, random errors, continuity) in different oceanic conditions (e.g. high waves, swell, low winds).

This study uses triple collocation as the central methodology to assess data from Sentinel-6MF and Jason 3, different S6-MF operating modes, independent in situ fiducial data and global models. Triple collocation is a powerful statistical tool that makes it possible to quantify measurement uncertainties in three independent datasets, without assumptions about the quality of either data source. The method was applied successfully by NOC during the Sentinel-3A/B Tandem phase and served to establish the excellent consistency of sea state measurements from the two satellites (Clerc et al., 2020), and to quantify the instrument performance in LRM and SAR modes. In the case of Sentinel-3 however, the 6-months Tandem phase resulted in a relatively small number of collocations with buoys, and the study concluded that the triple collocation analyses would have benefitted (for the sake of robustness) from a longer tandem period. The longer, 12-months, Tandem between S6-MF and Jason-3 should provide a great opportunity to repeat and extend these analyses and achieve greater levels of confidence.</td></tr>
<tr><td colspan="3">Input / Data:
Sentinel-6 MF L2 LR and HR NTC data over ocean during the tandem phase period.
Jason-3 L2 GDR data during the tandem phase period.
Sea state observations from moored data buoys provided via NDBC and CMEMS.</td></tr>
<tr><td colspan="3">Tools:
Existing tools and infrastructure for data analysis at NOC.</td></tr>
<tr><td colspan="3">Activity description:
The proposed study comprises the following elements:

• Triple collocation applied to S6-MF LRM, Jason 3 (LRM) and wave buoy data obtained by match-up during the Tandem phase (Significant Wave Height and Wind speed). This will evaluate the consistency of S6-MF LRM data against Jason-3 and the same fiducial observations, with regards to the long-term reference data records (Timmermans etal., 2020a ; 2020b).</td></tr>
</table>

• Triple collocation applied to S6-MF SAR, Jason 3 (LRM) and wave buoys obtained by match-up during the Tandem phase (Significant Wave Height and Wind speed). This will examine the uncertainties of S6-MF interleaved SAR measurements against the common reference from Jason-3 and buoys.

• Triple collocation applied to S6-MF SAR, S6-MF LRM and Jason 3 (LRM) over different ocean regions during the Tandem Phase. These analyses complement the other tasks by providing a broader view of performance across the globe, including regions where in situ measurements are rare or absent (e.g. Southern Ocean, Central Pacific).

Outputs:

- A peer review paper will be submitted to provide the synthesis of this study [D-100]
- Slides will be provided at the various meetings with ESA to report on the progress of the study [D-30]

References:

- Clerc S, Donlon C, Borde F, Lamquin N, Hunt SE, Smith D, McMillan M, Mittaz J, Woolliams E, Hammond M, Banks C. Benefits and lessons learned from the Sentinel-3 tandem phase. Remote Sensing. 2020 Jan, 12(17):2668.
- O'Carroll, A. G., Eyre, J. R. and Saunders, R. W., Three-Way Error Analysis between AATSR, AMSR-E, and In Situ Sea Surface Temperature Observations. Journal of Atmospheric and Oceanic Technology (25) 2008.
- Gommenginger, C. Martin-Puig, L. Amarouche, and R. K. Raney, Review of State of Knowledge for SAR Altimetry over Ocean, Version 2.2, EUMETSAT, EUM/RSP/REP/14/74930421, November 2013.
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- Timmermans, B., A. G. Shaw, and C. Gommenginger (2020), Reliability of extreme significant wave height estimation from satellite altimetry and in situ measurements in the coastal zone, Journal of Marine Science and Engineering, 8(12), 1039.

3.2	Sea State

Responsible: CLS **Participants:** -	**Objective:** Exploiting differences and processing techniques to study ocean swell waves and high sea states and mitigate their impact on S6-MF SSH measurements

Rationale:

The S6-MF mission continues the innovative record of altimetric Delay/Doppler technique [Raney, 1998] started with the Cryosat-2 mission. While this latter operates only over selected oceanic regions, the S3-A/B missions perform this acquisition of such data worldwide. With the recent launch of the S6-MF satellite, this technological advancement with respect to traditional altimeters goes one step further by bringing new capabilities such as: (1) novel processing technics that enhance the SAR altimeter capability for providing topographic, wave and backscattering features of the surface at smaller scales and with even more lower measurements noise than what has already been achieved by S3-A/B from the interleaved operating mode; (2) simultaneous generation of both conventional low-resolution mode (LRM) and SAR mode data [Phalippou et al., 2012], but also (3) the provision of LR-RMC data [Moreau et al., 2021].

While various studies pointed out significant benefits of SAR over LRM in terms of improved measurement errors and finer along-track spatial resolution [Boy et al., 2017], some downsides specifically to SAR altimetry have also been highlighted. Indeed, the retrieved topography, wave and backscattering features are sensitive to long ocean waves. The impact depends strongly on the period of the waves and their energy, but also on the orientation of the satellite track with respect to them [Aouf et Phalippou, 2015; Abdalla and Dinardo, 2016; Moreau et al., 2018; Reale et al., 2018; Rieu et al., 2020]. Another important effect of swell is the increase of the high-frequency noise on the estimated parameters, but also of the SSH variance at longer wavelengths because of the aliasing [Reale et al., 2020; Rieu et al., 2020]. In addition, to this swell effect, orbital velocities [Boisot et al., 2016; Buschaupt, 2019; Egido et al., 2020, Amarouche et al., 2019; Tran et al., 2020] induced by all sea states and not limited to swell only, can also alter the SAR mode signal leading to observed biases in SWH data which can in turn induce a bias in SSH through the SSB correction. Other phenomena can furthermore affect the delay/Doppler measurement leading possibly to additional biases in SSH estimation. They may be related to nonlinear effects of waves leading to upwave/downwaves SSH and SWH biases and variability [Tran et al. 2020].

Sentinel-6 MF should be impacted by the same kind of limitations related to sea state than S3-A/B data. The preliminary analysis performed within the commissioning activities on the newly acquired data seems to confirm that so far. However, one can expect some differences of behavior due to differences in some instrument characteristics: pulse repetition frequency, altitude, integration time length …

Input / Data:

- Sentinel-6 MF L2 LR and HR NTC data over ocean
- Jason-3 L2 GDR data over the tandem phase period
- Outputs from L2 GPP project
- Outputs from CNES/Eumetsat commisioning activities
- ERA5 wave model

Tools:

- CLS internal tools for data analysis

Activity description:

- Three issues and corresponding analysis axes have been identified to answer to ESA questions:
    - **Sea-state impact assessment**: What is the potential impact of ocean wave conditions on the long-term sea state and sea level time-series?

- ○ **Swell detection**: Is it possible to detect swell by combining SAR altimeter data processed in different ways and then to define new products including additional swell information?
- ○ **SSH correction**: Is it possible to propose approaches to mitigate negative SSH impacts due to SAR processing and reduce regional biases that would enter into the sea level record?

- Assessment of the feasibility of each of them in terms of data availability, technical difficulties and workload
- Selection of the aspects to be further analyzed during the second phase and proposal of the corresponding work plan to be agreed by ESA
- Data analysis
    - Peer Review Paper preparation

Outputs:

- A peer review paper [D-110]
- Slides to report on the progress of the study [D-30]

References:

- Abdalla, S., S. Dinardo, ''Does swell impact SWH from SAR altimetry?", 2016 SAR Altimetry Workshop, La Rochelle, France, Oct. 31, 2016.
- Amarouche, L., Tran, N., Herrera, D., Guerin, C.-A., Dubois, P., Aublanc, J., Boy, F., 2019. Impact of the ocean waves motion on the Delay/Doppler altimeters measurements. OSTST Meeting 2019, Chicago, Illinois, United States, Oct. 21–25.
- Aouf, L. and Phalippou, L., ''On the signature of swell for the Cryosat-2 SAR-mode wave data", OSTST Meeting 2015, Reston, Virginia, USA, Oct. 20 – Oct. 23, 2015. Available online at https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/OSTST2015/IPM-02-ostst_Aouf_sarmode_2015_1.pdf.
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3.4 Statistical Analysis of L1 data

<table>
<tr><th>4.1</th><th colspan="2">Statistical Analysis of L1 data</th></tr>
<tr><td colspan="2">Responsible: Aresys

Participants: -</td><td>Objective: Exploiting the S6-MF effective number of looks (ENL) for sea state applications</td></tr>
<tr><td colspan="3">Rationale:

This case study is aimed at verifying the existence of a discrepancy in S6-MF geophysical parameters obtained starting from low-resolution mode waveforms because of the higher pulse repetition frequency. While conventional low-resolution mode altimeters like J3 operates at PRF around 2 kHz, S6-MF operates at PRF around 9 kHz, so that, according to the results in (Egido and Smith, 2019), significant sea-state-dependent biases are expected introduced during the retracking.

The first studies on the correlation properties of consecutive pulses from nadir-looking pulse-limited radar altimeters where mainly focused on determining the maximum pulse repetition frequency at which statistical independence could be achieved (Walsh, 1982). Following these studies, the pulse repetition frequency (PRF) for the Jason series was selected to be approximately 2 kHz.

Copernicus Sentinel-6 Michael Freilich is the first altimeter operating in a continuous high-rate pulse mode, i.e. interleaved mode. This design allows the simultaneous production of low-resolution mode measurements with a pulse repetition frequency of ~9KHz for Ku-band. S6-MF thus allows to obtain an elevated number of highly correlated single looks with respect to the fewer number of Jason-3 slightly correlated altimeter pulses.

Recent studies, (Scagliola, 2016) and (Egido and Smith, 2019), revealed that for LRM waveforms the averaging of higher number of correlated single looks (~9KHz) allows to obtain higher ENL with respect to the averaging of fewer almost uncorrelated single looks (~1.8KHz). Moreover, it was showed that despite the fact the at higher PRFs the noise in the estimation of geophysical parameters is reduced, the significant dependence of the statistical properties on the range gate also introduces significant biases in the retracked parameters. These biases have been found to be sea-state dependent and needs to be properly accounted for in order to integrate Sentinel-6 Michael Freilich measurements to Jason-3 data which is the current reference mission of the Ocean Surface Topography satellite series.</td></tr>
<tr><td colspan="3">Input / Data:
Sentinel-6 MF L1A and L1B LR data over sites of interest (Ocean patch)
Jason-3/POS-3B L2 GDR-F standard data over sites of interest (Ocean patch)</td></tr>
<tr><td colspan="3">Tools:
Aresys in house theoretical waveform model tool
Aresys in house ENL analysis tools
Aresys in house semi-analytical retracker</td></tr>
<tr><td colspan="3">Activity description:
<u>Task 1</u>: Evaluation of the autocorrelation properties of the echoes acquired by S6 Poseidon instrument by making use of a theoretical waveform model
<u>Task 2</u>: Comparison of the theoretical results with the ENL estimated from real S6-MF data
<u>Task 3</u>: Exploit the Aresys L2 geophysical parameters retrieval tool to verify the effect of the varying ENL on the precision of the retrieval of the geophysical parameters as a function of the multilooking posting rate
<u>Task 4:</u> Paper</td></tr>
</table>

Outputs: • Peer review paper [D-120] • Slides to report on the progress of the study [D-30]
References: • Walsh, E.J., 1982. Pulse-to-pulse correlation in satellite radar altimeters. Radio Sci. 17, 786–800. • M. Scagliola, L. Recchia, D. Giudici, and M. Kuschnerus, “Pulse limited waveforms from interleaved mode: An analysis on the achievable speckle noise reduction,” presented at the OSTST Meeting, La Rochelle, France, Oct./Nov. 2016. [Online]. Available: https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/IPM_05_scagliola_OSTST_2016_v3_17h15.pdf • Egido, A., Smith, W.H.F., 2019. Pulse-to-pulse correlation effects in high prf low-resolution mode altimeters. IEEE Trans. Geosci. Remote Sens. 57, 2610–2617. • Egido, Alejandro & Dinardo, Salvatore & Ray, Christopher. (2020). The Case for Increasing the Posting Rate in Delay/Doppler Altimeters. Advances in Space Research. 10.1016/j.asr.2020.03.014. • Wingham, D.J., Giles, K.A., Galin, N., Cullen, R., Armitage, T.W.K., Smith, W.H.F., 2018. A semianalytical model of the synthetic aperture, interferometric radar altimeter mean echo, and echo cross-product and its statistical fluctuations. IEEE Trans. Geosci. Remote Sens. 56, 2539–2553. • Recchia, Lisa & Scagliola, M. & Giudici, Davide & Kuschnerus, Mieke. (2017). An Accurate Semianalytical Waveform Model for Mispointed SAR Interferometric Altimeters. IEEE Geoscience and Remote Sensing Letters. PP. 1-5. 10.1109/LGRS.2017.2720847. • Amarouche, L., P. Thibaut, O. Z. Zanife, J.P. Dumont, N. Steunou, & P. Vincent, 2003: Improving the Jason1 ground retracking to cope with attitude effects. Marine Geodesy, Special Issue on Jason1 Calibration/Validation, Part 2. DOI:10.1080/01490410490465210

3.5 Fully-Focused SAR Processing

5.1	Fully-Focused SAR Processing
Responsible: CLS **Participants:** Aresys	**Objective:** Exploitation of the Fully focused SAR (FFSAR) processing using S6-MF over ocean and sea ice surfaces

Rationale:

Fully-focusing of radar altimeters is a recent concept that has been introduced in (Egido and Smith, 2017) to allow further improvement of along-track resolution in high pulse repetition frequency (PRF) radar altimeters. While in Delay/Doppler processing the coherent summation of pulses is performed over a limited number of successive pulses (i.e., bursts), the concept of coherent summation has recently been extended to the whole synthetic aperture. This is the so-called fully-focused synthetic aperture radar (FFSAR) concept, in which all the echoes within the antenna extent are coherently summed after phase compensation to increase the along-track resolution up to its theoretical limit (half the along-track antenna length) and to improve also the ENL with respect to Delay/Doppler.

It has to be recognized that exploitation of FFSAR waveforms in science application is just at the beginning, see (Kleinherenbrink et al, 2020) and (Egido et al, 2020) as well as that the already operational high PRF radar altimeters (CryoSat and Sentinel-3) have some limitations in the FFSAR processing:

- The closed burst timeline implies that the along-track FFSAR Impulse Response Function is affected by grating lobes that reduce the achivables accuracy of the resulting geophysical parameters
- The deramping-on-receive instruments introduce along-track phase distortion that have to be properly characterized to be then compensated to achieve a sufficient quality in the FFSAR waveforms

S6-MF Poseidon-4 instruments offer new capabilities to investigate on the real potential of FFSAR concept. In fact, due to the open burst timeline of the Poseidon-4 instrument, in the along-track FFSAR Impulse Response Function obtained by processing S6-MF L1A products the grating lobes are no more present. Additionally, the matching-filter-on-receive scheme for Poseidon-4 is expected to guarantee a higher phase coherence within the visibility time of each point target. On the other hand, the combination of the PRF and of the along-track antenna pattern in Poseidon-4 determines that Doppler ambiguities are expected to affect the Level1b FFSAR waveforms in case that the whole Doppler bandwidth is processed.

Input / Data:

- Sentinel-6 MF L1A, L1B and L2 HR data over sites of interest (transponder, inland-water, transponder, sea-ice, swell)
- Sentinel-6 MF L1A, L1B and L2 HR data over open-ocean (few cycles) for global analysis
- Sentinel-1 and Sentinel-2 images for supporting swell and sea-ice analysis (by leads collocation tool with S6-MF)
- MFWAM wave model (by extracting the mean peak period, the mean propagation angle, and mean wave height) for supporting swell analysis

Tools:

- CLS and Aresys internal tools dedicated to altimetry analyses
- Aresys Sentinel-6 processing tool (integrated in the GPOD platform) to generate FFSAR l1b with a coherent format with operational products
- CLS SMAP/S6PP Sentinel-6 FFSAR processing tool to generate FFSAR L1b and L2 data
- Lead detector tool developed by N. Longépé [Longépé et al., 2019]

Activity description:

- Task 1: Find an optimal configuration of FF-SAR on S6 data following the target type (specular or not specular targets) by an analysis over few test cases over different areas identified first. The most important configuration parameters to be determined are the posting rate (to have the best compromise noise/resolution), the doppler bandwidth (to remove aliasing), the illumination time (to possibly reduce the sea surface motion effect over dynamical targets).

- Task 2: Detection of leads on sea-ice areas by collocation with S1 (and S2) images. We want to take the opportunity of replicas absence with S6-MF interleaved mode to assess the FF-SAR capability to detect leads and to provide more precise surface height estimation compared to UF-SAR.
- Task 3: Analysis of large FF-SAR data set over open ocean with the optimal configuration found in the previous task and evaluate the possible interest of implementing the omega-kappa method in ground segment. Additionally, a study of sea state retrieval with FFSAR will be conducted and validated by comparison with wave model (MFWAM) over swells of different wavelengths.
- Task 4: Paper

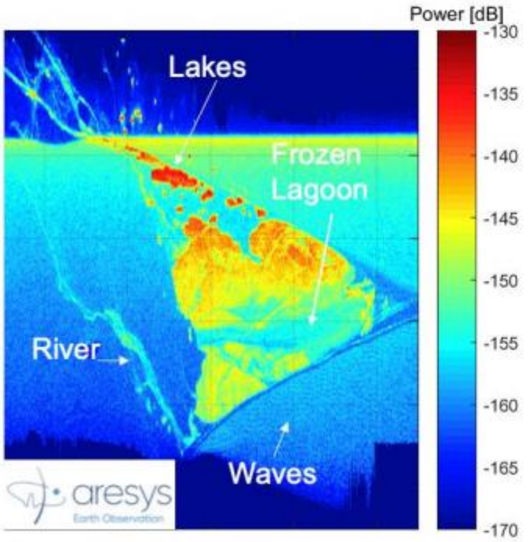

Figure 1. FFSAR S6-MF L1b radargram that images different targets.

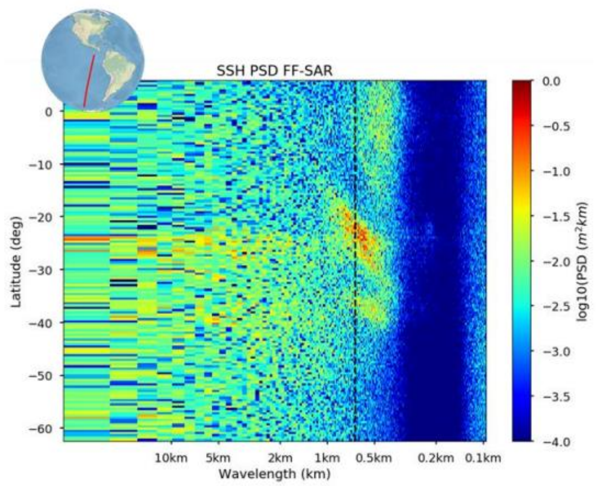

Figure 2. FFSAR S3A along-track SSH spectra over an open ocean pass, with a band stop limit for wavelengths around 200m due to azimuth replicas.

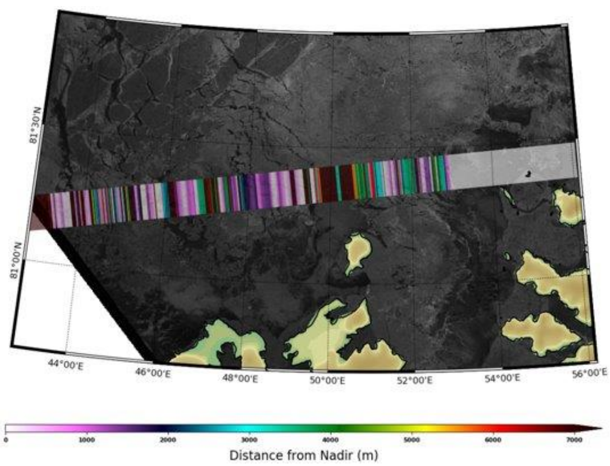

Figure 3. FFSAR S3A track over sea-ice and Sentine-1 image in the background (leads are in dark gray), with distance between S6 nadir and the closest lead by collocation with Sentinel-1.

Outputs:

- Peer review paper [D-130]
- Slides to report on the progress of the study [D-30]
- S6-FFSAR S6PP data processed on few cycles

References:

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3.6 Inland Water Analysis

6.1	Inland Water Analysis
Responsible: CLS **Participants:** -	**Objective:** Characterization and exploitation of S6-MF and J3 in support of improved hydrology products

Rationale:

The validation of the Sentinel-6 MF measurements over Inland Waters and the characterization of potential discrepancies and differences with respect to Jason-3 are particularly important to ensure seamless continuity for operational monitoring services (e.g., Copernicus Global Land Lakes and Rivers Water Level Service) as well as for climate applications (e.g. Copernicus Climate Change Service, Copernicus Climate Initiative Lakes).

Input / Data:

- Sentinel-6 MF L2 HR data over sites of interest (inland waters) [D-140]
- Jason-3/POS-3B L2 GDR-F standard data over sites of interest (inland waters) [D-30]

Tools:

- CLS internal tools for analyses over inland waters

Activity description:

- Task 1: Determine the potential biases on Water Surface Height retrievals in between J3 (LRM) and S6 for the different modes (LRM, SAR-RA, SAR-RMC). Investigation of possible dependency with water bodies size will be investigated.
- Task 2: focus on the benefits of S6-MF FFSAR, in particular regarding the improved along-track resolution compared to UFSAR

Outputs:

- a peer review paper will be submitted to provide the synthesis of this study [D-140]
- slides will be provided at the various meetings with ESA to report on the progress of the study [D-30]

References:

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3.7 Cryosphere Surfaces

7.1	Cryosphere Surfaces
Responsible: CLS **Participants:** -	**Objective:** Study of the S6-MF capability for estimating the Lake Ice Thickness

Rationale:

Lake ice thickness (LIT) is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS). LIT is a sensitive indicator of weather and climate conditions through its dependency on changes in air temperature and on-ice snow depth. The monitoring of seasonal variations and trends in ice thickness is not only important from a climate change perspective, but it is also relevant for the operation of winter ice roads that northern communities rely on. Yet, field measurements tend to be sparse in both space and time, and many northern countries have seen an erosion of in situ observational networks over the last three decades. Therefore, there is a pressing need to develop retrieval algorithms from satellite remote sensing to provide consistent, broad-scale and regular monitoring of LIT at northern high latitudes in the face of climate change. To date, few studies have investigated the potential of radar altimetry data for the estimation of LIT, e.g. Beckers et al 2017 (CryoSat 2 data), Yang et al 2020 (Jason data, Lake Water Level study). These are empirical methods based on thresholds, that rely on in situ validation (which is not always possible and difficult to compare) and hard to generalize to different targets. Mangilli et al 2021 developed a novel and efficient retracking approach, the LRM_LIT retracker, specific to LIT retrieval from conventional altimetry Low Resolution Mode (LRM) data. The method is based on the physical and analytical modelling of the radar waveforms that show a specific signature related to the ice and due to the double scattering of the radar wave at the snow-ice interface and at the ice-water interface. The LRM_LIT retracker has been validated on thermodynamical lake ice simulations (CLIMo, Duguay et al 2003) and in-situ data. The LRM_LIT analysis performed on Jason-2 and Jason-3 data over the Great Slave lake (GSL) in Canada yields robust and consistent LIT estimations over different winter seasons, capturing the LIT seasonal and inter-seasonal LIT variations. The Sentinel-6 mission offers an unique opportunity to ensure the continuity of the LIT observations between the LRM data set and the current and future SAR altimetry missions. This continuity is crucial in order to ensure the scientific exploitation of long time series for LIT trends and climatological studies. Within this context, the main goal of the project is to develop and validate a physical based LIT retracker for S6-SAR data and to assess the accuracy of the LIT estimation with both S6 LRM and SAR data.

Input / Data:

- S6-MF LRM and SAR data over chosen targets lakes during the tandem phase
- Jason-3 GDR data over the same targets and dates

Tools:

- CLS internal tools for the LIT analysis for both LRM and SAR data

Activity description:

- Characterization of the LIT signature on SAR S6 data over a target lake (e.g. the Great Slave Lake in Canada)
- Development of a new LIT modelling specific to SAR
- Development of the SAR_LIT retracker
- Assessment of the accuracy of the SAR LIT estimation
- Comparison of LIT LRM (J3 and S6) and LIT SAR retrievals over a target lake

Outputs:

- Peer review paper [D-230]
- Slides to report on the progress of the study [D-30]

References:

- J. F. Beckers, J. Alec Casey and C. Haas, "Retrievals of Lake Ice Thickness From Great Slave Lake and Great Bear Lake Using CryoSat-2," in IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 7, pp. 3708-3720, July 2017, doi: 10.1109/TGRS.2017.2677583.
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- A. Mangilli, P. Thibaut, C. Duguay, J. Murfitt, "A New Approach for the Estimation of Lake Ice Thickness from Conventional Radar Altimetry, IEEE Transactions on Geoscience and Remote Sensing 2021, in preparation
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3.8 Internal Waves Detection Study

8.1	Internal waves detection study
Responsible: University Porto **Participants:** CLS	**Objective:** Study of new S6-MF capability in tandem with J3 and together with other satellite data sets to measure internal wave surface signatures over the ocean

Rationale:

Internal waves are characterized by large-amplitude vertical displacements (typically 50-150 meters) near the largest density gradient in the water column. Their energy propagates for hundreds of kilometers perpendicularly to their crests, from generation sites near steep underwater topography to eventually breaking nearshore or dissipating offshore. They are also characterized by significant vertical velocities, mixing and associated vertical fluxes. These have implications in biological productivity and biomass observable from satellites, and can crucially affect the ocean up to the climate scale. Recent work (Magalhaes and da Silva, 2017; Santos-Ferreria et al, 2018; 2019; Magalhaes et al., 2021) demonstrates that internal waves can be observed by satellite altimetry. This study focus on an analysis of the signature of internal waves by inter-comparing S6-MF and J3 in tandem together with other satellite data sets (e.g. Sentinel-3 OLCI/SLSTR, Sentinel-2 MSI and Sentinel-1 SAR images). Subsurface internal waves alter the ocean surface roughness that is imprinted in sigma0 signatures as well as SWH impacts at small-scale (1-3 kms) to medium-scale (10s of kms). The signature of SAR and LRM on the same internal waves, collocated with other satellite data (e.g. Sentinel-1 SAR, Sentinel-3 OLCI sun glitter etc.) will form the basis of this work. An analysis of the SWH signatures in the same fashion of Magalhaes et al, 2021 is performed.

Input / Data:

- Sentinel-6 MF L1A, L1B and L2 HR data over sites of interest (identified hot-spots of internal solitary waves, such as Tropical West Atlantic and Banda Sea)
- Sentinel-6 MF L1A, L1B and L2 HR data over open-ocean (selected cycles) for global analysis
- Sentinel-1, Sentinel-2 and Sentinel-3 images for supporting internal wave analysis
- Possibly MITgcm numerical advanced modelling in 2D-configuration, fully-nonlinear and non-hydrostatic
- Jason-3 GDR-F @20-Hz in tandem with Sentinel-6 MF
- Sentinel-6 MF FF-SAR L1B radargram that images different phases of ISWs

Tools:

- To be developed and available from U.Porto as well as data pre-processing from CLS

Activity description:

- ISW signature comparison in L2 HR Sentinel-6 MF and Jason-3 20 Hz data, in parameters such as sigma0, SWH and SSHA.
- Multi-Scale analysis of SWH in L2 HR Sentinel-6 MF and Jason-3 20 Hz data.
- FFSAR S6-MF L1b radargram analysis over ISWs

Outputs:

- Paper on detectability of Internal Solitary Waves with Sentinel-6 MF analysis, and synergy with Jason-3 [D-150]
- Slides to report on the progress of the study [D-30]

References:

- Magalhaes, J. M., Alpers, W., Santos-Ferreira, A. M., & Da Silva, J. C. (2021). Surface wave breaking caused by internal solitary waves effects on radar backscattering measured by SAR and radar altimeter. Oceanography, 34(2).

- Santos-Ferreira, A. M., Da Silva, J. C., & Magalhaes, J. M. (2018). SAR mode altimetry observations of internal solitary waves in the tropical ocean Part 1: Case studies. Remote Sensing, 10(4), 644.
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- Magalhães, J. M., & da Silva, J. C. (2017). Satellite altimetry observations of large-scale internal solitary waves. *IEEE Geoscience and Remote Sensing Letters*, *14*(4), 534-538

4 SAP Data Access Requirements

4.1 Data access summary

The following table lists the data type, coverage and access requirements for performing the S6-JTEX studies as defined in the Phase 1.

S6-JTEX Activity Theme	Mission/ Instrument, FRM, model	Product Type	Temporal Coverage	Geographical Coverage	Product Provider	Access Details
CalVal Ocean (CLS)	Sentinel-6A/POS-4	L2 HR/LR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	Global ocean (and over transponders)	Eumetsat	available on CNES cluster
	Jason-3/POS-3B	L2 GDR-F standard	From: 18/12/2020 To: 31/03/2022	Global ocean (and over transponders)	CNES	available on CNES cluster
	Sentinel-3A/B/SRAL	L2 SAR marine NTC	From: 18/12/2020 To: 31/03/2022	Global ocean	Eumetsat	available on CNES cluster
	MFWAM	wave model	From: 18/12/2020 To: 31/03/2022	Global ocean	Météo France	available on CNES cluster
Coastal Assessment (TUM)	Sentinel-6A/POS-4	L2 HR/LR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	Coastal area	Eumetsat	S6-JTEX-DATA (and available on TUM facilities; S6VT)
	Sentinel-6A/POS-4	L1B LR NTC	From: 18/12/2020 To: 31/03/2022	Coastal area	Eumetsat	S6-JTEX-DATA (and available on TUM facilities; S6VT)
	Jason-3/POS-3B	SGDR-F data	From: 18/12/2020 To: 31/03/2022	Coastal area	CNES	available on TUM facilities
Uncertainties and GMSL (Magellium/CLS)	Sentinel-6A/POS-4	L2 HR/LR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	Global ocean	Eumetsat	available on CNES cluster
	Jason-3/POS-3B	L2 GDR-F standard	From: 18/12/2020 To: 31/03/2022	Global ocean	CNES	available on CNES cluster
	Sentinel-3A/B/SRAL	L2 SAR/LRM marine NTC	From: 18/12/2020 To: 31/03/2022	Global ocean	Eumetsat	available on CNES cluster
	Tide gauges		From: 18/12/2020 To: 31/03/2022	Global ocean	Gloss-Clivar / PSMSL	available on CLS facilities

Sea State (NOC)	Sentinel-6A/POS-4	L2 HR/LR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	Global ocean	Eumetsat	S6-JTEX-DATA (and NOC servers)
	Jason-3/POS-3B	L2 GDR-F standard	From: 18/12/2020 To: 31/03/2022	Global ocean	CNES	S6-JTEX-DATA (and NOC servers)
	Moored wave buoys	In situ		Global ocean (U.S. / Europe)	NDBC / CMEMS	
Sea State (CLS)	Sentinel-6A/POS-4	L2 HR/LR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	Global ocean	Eumetsat	available on CNES cluster
	Sentinel-6A/POS-4	L1A NTC	From: 18/12/2020 To: 31/03/2022	Global ocean	Eumetsat	available on CNES cluster
	Jason-3/POS-3B	L2 GDR-F standard	From: 18/12/2020 To: 31/03/2022	Global ocean	CNES	available on CNES cluster
	ERA5	Wave model	From: 18/12/2020 To: 31/03/2022	Global ocean	ECMWF	available on CLS archive
Statistical analysis of L1 data (ARESYS)	Sentinel-6A/POS-4	L1B LR NTC	Approx 1 month	Ocean patch	Eumetsat	available on S6 commissioning server
	Sentinel-6A/POS-4	L1A NTC	Approx 1 month	Ocean patch	Eumetsat	available on S6 commissioning server
	Jason-3/POS-3B	L2 GDR-F standard	Approx 1 month	Ocean patch	CNES	S6-JTEX-DATA
FF-SAR processing (CLS/ARESYS)	Sentinel-6A/POS-4	L2 HR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	Global ocean	Eumetsat	available on CNES cluster
	Sentinel-6A/POS-4	L1A NTC	2/3 cycles	Global ocean	Eumetsat	available on S6 commissioning server and CNES cluster

			S6A_P4_1A_HR______20201207T162550_20201207T163200_20201208T081248_0370_002_157_078_EUM__OPE_ST_F00.SEN6.tar	Sea ice test cases	Eumetsat	available on S6 commissioning server and CNES cluster
			From: 18/12/2020 To: 31/03/2022	Transponder test case	Eumetsat	available on S6 commissioning server and CNES cluster
			S6A_P4_1A_HR______20201207T162550_20201207T163200_20201208T081248_0370_002_157_078_EUM__OPE_ST_F00.SEN6.tar	Ocean test case	Eumetsat	available on S6 commissioning server and CNES cluster
	MFWAM	wave model	2/3 cycles	Global ocean	Météo France	available on CNES cluster
	Sentinel-1/SAR sensor	image	(where applicable)	Sea ice and over swells	ESA	https://scihub.copernicus.eu/dhus/#/home
	Sentinel-2A/B/MSI	image	(where applicable)	Sea ice and over swells	ESA	https://scihub.copernicus.eu/dhus/#/home
Inland water analysis (CLS)	Sentinel-6A/POS-4	L2 HR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	worlwide inland waters	Eumetsat	available on CNES cluster
	Sentinel-6A/POS-4	L1A NTC	From: 18/12/2020 To: 31/03/2022	worlwide inland waters	Eumetsat	available on CNES cluster
	Jason-3/POS-3B	L2 GDR-F standard	From: 18/12/2020 To: 31/03/2022	worlwide inland waters	CNES	S6-JTEX-DATA
	Hydrolakes	Water body database	static	worlwide lakes / reservoirs	HydroSHEDS	available from https://www.hydrosheds.org/page/hydrolakes
	SWOt River Database (SWORD)	database providing hydrologic variables (WSE, width, slope, ..), centerlines and contours	static	worlwide inland waters	SWOT project	available on CNES cluster

	ICESat-2/ATLAS	ATL13	From: 18/12/2020 To: 31/03/2022	worlwide inland waters	GSFC/NASA	https://icesat-2.gsfc.nasa.gov/science/data-products
Lake Ice Thickness (CLS)	Sentinel-6A/POS-4	L1B HR/LR NTC (reprocesssed in 03/22)	From: 18/12/2020 To: 31/03/2022	Great Slave Lake	Eumetsat	available on CNES cluster
	Jason-3/POS-3B	L1B GDR-F	From: 18/12/2020 To: 31/03/2022	Great Slave Lake	CNES	available on CNES cluster
Internal waves detection study (Univ. Porto)	Sentinel-6A/POS-4	L2 HR/LR NTC (reprocesssed in 03/22)	(where applicable)	Over ISWs to be identified	Eumetsat	S6-JTEX-DATA
	Sentinel-6A/POS-4	L1B HR NTC (reprocesssed in 03/22)	(where applicable)	Over ISWs to be identified	Eumetsat	S6-JTEX-DATA
	Sentinel-6A/POS-4	L1B FF-SAR	(where applicable)	Over ISWs to be identified	CLS	S6-JTEX-DATA
	Jason-3/POS-3B	L2 GDR-F standard	(where applicable)	Over ISWs to be identified	CNES	S6-JTEX-DATA
	Sentinel-1/SAR sensor	Image	(where applicable)	Over ISWs to be identified	ESA	https://scihub.copernicus.eu/dhus/#/home
	Sentinel-2A/B/MSI	Image	(where applicable)	Over ISWs to be identified	ESA	https://scihub.copernicus.eu/dhus/#/home
	Sentinel-3A/B/OLCI	Image	(where applicable)	Over ISWs to be identified	ESA	https://scihub.copernicus.eu/dhus/#/home
	MITgcm	Non-hydrostatic model of the ocean	(where applicable)	Over ISWs to be identified	MIT	available on Univ. Porto facilities

Table 2: Data Description: type, period and geographical coverage, and access requirements per case study

4.2 About S6-MF data reprocessing

Several activities and conclusions that will be drawn from the results emerging from these activities depend on the quality and homogeneity of the S6-MF data acquired during the tandem phase.

At the time of writing, the S6-MF data series is not of a sufficient quality to enable accurate altimeter radar assessment to be performed over the different surfaces targeted by the project. Several changes made on the S6-MF operational processing chain during the commissioning phase (updates of the wind and SSB models, changes of calibration bias on sigma-0, internal path delay, to name a few) have produced inhomogeneous S6-MF data series, making their scientific analysis and comparison with Jason-3 difficult. In addition to this, it was reported a delayed calibrations issue making the current operational products in NTC latency (and in STC at a lesser extent) not of a sufficient quality for GMSL study [Dinardo et al., 2021].

The opportunity to take benefit of the reprocessing campaign of the entire operational data series (foreseen in March 2022) arises and will be discussed with ESA before starting the data analysis. The purpose of this section is to question whether the upcoming reprocessed operational data is to be used to achieve the objectives of the different case studies or not.

5 SAP Interface Control Document

The following interfaces have been identified:

- Data Access interfaces
  - S6-MF products from EUMETSAT data centre (also available from S6 commissioning server, and mirrored on CNES cluster)
  - ESA Scihub for S3, S2 and S1 images
  - EUMETSAT data centre for S3 altimeter data (also mirrored on CNES cluster)
  - GSFC ICESat-2 ATL13 data (for water surface height over inland waters)
  - AVISO data access for Jason-3 GDR/SGDR products
  - MFWAM data access
  - ECMWF data access
  - Hydrolakes and SWORD database
  - In-situ data access (tide gauges, moored wave buoys)

- Consortium collaborative working environment interfaces
  - Access to the S6-JTEX-DB catalogue with user-friendly search and discovery interface
  - Interactive access to S6-JTEX-DATA through web OpenDAP protocol (also allowing data visualization)
  - Non-accessible local workstation for data reprocessing with innovative algorithms and data analysis

- Communication with other entities
  - If required, communication with EUMETSAT, CNES, commissioning team and S6 MPC will be performed by phone or webex sessions
  - Special operation requests and anomaly reports will be relayed through the S6-JTEX ESA Technical Officer (TBC).