2016 SAR Altimetry Workshop

Monday, October 31 2016 - Monday, October 31 2016
The objective of this workshop is to make a progress status about SAR altimetry processing and its applications notably in coastal areas but also for inland waters. The workshop will be organized around oral presentations and posters.

Abstracts Book
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Oral

Applications, SAR for science
Mon, Oct 31 2016, 16:00 - 17:30 - Auditorium

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16:15 - 16:30: SAR-mode altimetry performance over the Antarctic ice sheet: Jérémie Aublanc et al.
16:30 - 16:45: Characterization of SAR Mode Altimetry Data over Inland Waters – SHAPE project: Pierre Fabry et al.
16:45 - 17:00: Scientific Applications of Fully-Focused SAR Altimetry: Alejandro Egido et al.
17:00 - 17:15: On the assimilation of Sentinel-3A in the wave model MFWAM : global and regional scales: Lotfi Aouf
17:15 - 17:30: SAR altimetry in the Gulf of Bengal: Luciana Fenoglio-Marc et al.

Innovative SAR processing methods
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11:15 - 11:30: Some surprisingly wonderful aspects of fully focused SAR altimetry: Walter Smith et al.
11:30 - 11:45: Squeezing SARIn capabilities for complex scenarios: L1 & L2 processing improvements: Albert Garcia-Mondejar et al.
11:45 - 12:00: Evaluating the performance of Sentinel-3 SRAL SAR Altimetry in the Coastal and Open Ocean, and developing improved retrieval methods – The SCOOP Project.: David Cotton et al.
12:00 - 12:15: Results from observations to detect sea state bias from SAR mode altimetry.: Clare Bellingham et al.
12:15 - 12:30: DeDop: The tool to process altimetry data yourself: Mònica Roca i Aparici et al.

SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
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14:15 - 14:30: Sentinel-3a Delay Doppler Processing: Assessment over the Global Ocean.: Matthias Raynal et al.
14:30 - 14:45: Does Swell Impacts Significant Wave Height Measurements from SAR Altimetry?: Saleh Abdalla et al.
14:45 - 15:00: The coastal performance of SAR altimetry from CryoSat-2 and Sentinel-3: Paolo Cipollini et al.
15:00 - 15:15: Performance comparison of Sentinel-3 and CryoSat-2 Delay-Doppler (SAR) processing baselines over Open Ocean and Coastal zones: Eduard Makhoul et al.
15:15 - 15:30: Corsica: linking historical and current missions with Sentinel-3A: Pascal Bonnefond et al.

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Applications, SAR for science
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APPS_002: The Sentinel-3 Hydrologic Altimetry Processor prototype project: Pierre Fabry et al.
APPS_003: Cryo-SEANICE : CryoSat Science-oriented data Analysis over Sea-ICE areas: Pierre Fabry et al.
APPS_004: Impact of SAR Processing Parameters on Sea ice Floes and Leads Height Measurements : Sara Fleury et al.
APPS_005: Wave vertical orbital velocity effects on Doppler Altimeter waveform and SSH measurement: Eugenio Pugliese Carratelli et al.
APPS_006: Wave climate observed from altimeters: trends and extremes: Justin Stopa

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FUT_002: Sentinel-6 Poseidon-4 L1B simulator: a model based simulator for end-to-end performance evaluation: Michele Scagliola et al.
FUT_003: Analysis of particular aspects of the Sentinel-6 altimeter processing using Cryosat-2 data: Thomas Moreau et al.

Innovative SAR processing methods
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INN_002: SAR ALTIMETRY AT 80 Hz: Salvatore Dinardo
INN_003: Application and Evaluation of ACDC Delay-Doppler processing over CryoSat-2 for Open-Ocean zones: Eduard Makhoul et al.
INN_004: Methodology and Validation of SAR and SARin Full Bit Rate Altimetric Waveforms and Heights from the CRUCIAL Project: Philip Moore et al.

SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Mon, Oct 31 2016, 18:30 - 19:30 - Grande Halle
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SAR_003: Increasing the opportunities for the calibration of CryoSat interferometer by operational SARIn acquisitions over ocean: Michele Scaglioni et al.
SAR_004: The Sentinel-3A SRAL Instrument Calibration Monitoring: Pablo Garcia et al.
SAR_005: A Regional Assessment of the Sentinel-3 STM L1b & L2 SAR/PLRM Data Products with an enhanced processing baseline: Salvatore Dinardo et al.
SAR_006: Early Assessment of Sentinel-3A measurements over Arctic Sea Ice: Eric Leuliette et al.
SAR_007: First analysis of the Sentinel-3 SRAL data over inland water: Pierre Thibaut et al.
SAR_008: Validation of CryoSat-2 SAR and SARIn modes over rivers for the SHAPE project: Nicolas Bercher et al.
SAR_009: Coastal sea level in norway from cryosat-2 sar altimetry: Ole Baltazar Andersen et al.
SAR_010: Sentinel-3 mission: first results from the commissioning phase over ocean, coastal areas, inland waters and polar regions: François Boy et al.
SAR_011: Assessment of CryoSat-2 and AltiKa Sea Level Anomaly time series in the coastal strip of the Gulf of Cadiz: Jesus Gomez-Enri et al.
Abstract details
A review of topical issues in SAR Altimetry

Paolo Cipollini (National Oceanography Centre, United Kingdom); Eduard Makhoul (isardSAT UK, United Kingdom); M. Joana Fernandes (University of Porto, Portugal); Mônica Roca (isardSAT Barcelona, Spain); David Cotton (Satellite Oceanography Consultants, UK); Marco Restano (Serco/ESRIN, Italy); Jérôme Benveniste (ESA/ESRIN, Italy)

Session: Innovative SAR processing methods
Presentation type: Oral

Abstract:
The advent of SAR altimetry has prompted a radical reshaping of the amount of information contained in the altimetric echoes, and has brought along advanced processing techniques that exploit the Doppler information in the signal. Many groups around the world are at work to refine aspects of the processing with the aim of an improved (i.e. more accurate) retrieval of the traditional parameters (height, wave height, normalized backscatter and mis-pointing) or even new parameters such as the mean square slope. A review of the state of the art in SAR altimetry has been carried out recently within the ESA SCOOP project; this contribution summarizes the results of that review and describes the key progress points on which research is focusing, and the remaining challenges still faced by SAR altimetry. Recent improvements have been both in the L1A to L1B processing and in L1B to L2: they include the weighting of the SAR stack and the exploitation of the power distribution in the stack for new observables, the retracking of individual Doppler beams, the computation on a finer ground step, the fully focused SAR processing, the compensation of amplitude variations and look dilation in the stack, some improvements in the L2 retracking models and specific approaches to the retracking in the coastal zone. Those are accompanied by improvements in the range corrections required to account both for the path delay induced by the water vapour in the altimeter signal (Wet Tropospheric Correction) and for the sea state effects, with active research being carried out at present to derive a SAR mode Sea State Bias solution and to compensate for expected effects of swell on the SAR footprint.

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Some surprisingly wonderful aspects of fully focused SAR altimetry

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Session: Innovative SAR processing methods
Presentation type: Oral

Abstract:
We are experimenting with fully focused coherent processing of radar altimeter echoes. Our experiments to date use CryoSat2 FBR SAR data, but our methods could also be used with similar data from Sentinel-3 or Sentinel-6. We have presented previous results at the 2015 OSTST and the 2016 ESA Living Planet symposia. This presentation will present the method in more detail, and will discuss some intriguing aspects revealed by fully focused altimetry, including:

(1) the calculation is so sensitive to antenna motion that we can detect errors of a few microseconds in datation of pulse bursts in CryoSat FBR SAR data, and can properly correct for them.

(2) over small inland water bodies and small leads in sea ice, the calculation is very sensitive to the along-track dimension of the water surface. It appears that small smooth water bodies act as ideal radiators, in effect having their own antenna gain pattern or directivity, which can be exploited to measure their extent if fully focused processing is used.

(3) even over the ocean, a presumably homogeneously rough surface, coherent processing yields a better waveform than unfocused delay/Doppler processing (the process currently used in the ESA L1b and L2 SAR products), and it appears that the effective number of looks at the surface per length of track flown is much better with fully focused processing.

(4) the uncertainty in water surface height measurements is much smaller if fully focused processing is used than if unfocused d/D SAR is used. This is true in both open ocean and also leads in sea ice.

Additional results and applications will be in another presentation given by A E Egido.

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Squeezing SARIn capabilities for complex scenarios: L1 & L2 processing improvements

Albert Garcia-Mondejar (isardSAT Ltd., United Kingdom) ; Roger Escolà (isardSAT Ltd., United Kingdom) ; Eduard Makhoul (isardSAT S.L., Spain) ; Pablo Nilo García (isardSAT S.L., Spain) ; Mònica Roca (isardSAT Ltd., United Kingdom)

Session: Innovative SAR processing methods
Presentation type: Oral

Abstract:
The CryoSat mission is designed to determine fluctuations in the mass of the Earth’s land and the marine ice fields. Its primary payload is a radar altimeter that operates in different modes optimised depending on the kind of surface: Low resolution mode (LRM), SAR mode (SAR) and SAR interferometric mode (SARIn). This radar is named SIRAL: Synthetic aperture interferometer radar altimeter [1]. The SARIn mode uses two antennas allowing to compute cross-track angles at which signals arrives.

For scenarios with large topographical variations over short distances, a received SARIn waveform can sometimes have more than one peaks, so different elevations can be retrieved from a single waveform. Over certain regions with certain x-track slope conditions, the elevation profile x-track can be retrieved using the phase difference information.

Firstly with data from ASIRAS [2] and secondly with CryoSat-2 [3] data, the computation of surface elevation profiles over ice caps and glaciers using the so called "swath processing" proved the powerful capabilities of the SARIn mode, improving the spatial resolution of the elevation measurements.

Improvements to the L2-swath processing approach have been investigated and implemented within the ESA founded projects CryoSat+ for Topography and CryoSat+ for Mountain Glaciers. The processing improvements are not only focused in the retracking algorithms but also on the algorithms that are applied in the early stages of the processing chain in order to clean the stack data, multi-looked waveforms and phase difference information as much as possible.

These new algorithm and improvements, initially designed for glaciers, have now been evaluated over other areas such as Coastal and Inland Waters.


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Evaluating the performance of Sentinel-3 SRAL SAR Altimetry in the Coastal and Open Ocean, and developing improved retrieval methods – The SCOOP Project.

David Cotton (Satellite Oceanographic Consultants Ltd, United Kingdom); Thomas Moreau (CLS, France); Eduard Makhoul (isardSAT, United Kingdom); Mónica Roca (isardSAT, UK); Paolo Cipollini (National Oceanography Centre, UK); Mathilde Cancel (Noveltis, France); Francisco Martin (Starlab, UK); Luciana Fenoglio-Marc (University of Bonn, Germany); Marc Naeije (TU Delft, The Netherlands); M Joana Fernandes (University of Porto, Portugal); Marco Restano (SERCO/ESRIN, Italy); Américo Ambrósio (DEIMOS/ESRIN, Italy); Jérôme Benveniste (ESA-ESRIN, Italy)

Session: Innovative SAR processing methods
Presentation type: Oral

Abstract:
The ESA Sentinel-3 satellite, launched in February 2016 as a part of the Copernicus programme, is the second satellite to operate a SAR mode altimeter. The Sentinel 3 Synthetic Aperture Radar Altimeter (SRAL) is based on the heritage from Cryosat-2, but this time complemented by a Microwave Radiometer (MWR) to provide a wet troposphere correction, and operating at Ku and C-Bands to provide an accurate along-track ionospheric correction. Together this instrument package, including both GPS and DORIS instruments for accurate positioning, allows accurate measurements of sea surface height over the ocean, as well as measurements of significant wave height and surface wind speed.

SCOOP (SAR Altimetry Coastal & Open Ocean Performance) is a project funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme Element, started in September 2015, to characterise the expected performance of Sentinel-3 SRAL SAR mode altimeter products, in the coastal zone and open-ocean, and then to develop and evaluate enhancements to the baseline processing scheme in terms of improvements to ocean measurements. There is also a work package to develop and evaluate an improved Wet Troposphere correction for Sentinel-3, based on the measurements from the on-board MWR, further enhanced mostly in the coastal and polar regions using third party data, and provide recommendations for use.

At the end of the project recommendations for further developments and implementations will be provided through a scientific roadmap.

In this presentation we provide an overview of the SCOOP project, highlighting the key deliverables and discussing the potential impact of the results in terms of the application of delay-Doppler (SAR) altimeter measurements over the open-ocean and coastal zone. We also present the initial results from the project, including:

- Key findings from a review of the current "state-of-the-art" for SAR altimetry,
- Specification of the initial "reference" delay-Doppler and echo modelling /retracking processing schemes,
- Evaluation of the initial Test Data Set in the Open Ocean and Coastal Zone
- Overview of modifications planned to the reference delay-Doppler and echo modelling/ re-tracking processing schemes.

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Results from observations to detect sea state bias from SAR mode altimetry.

Clare Bellingham (National Oceanography Centre, United Kingdom) ; Christine Gommenginger (National Oceanography Centre, United Kingdom) ; Meric Srokosz (National Oceanography Centre, United Kingdom)

Session: Innovative SAR processing methods
Presentation type: Oral

Abstract:
Sea state bias is the largest unknown remaining in SAR altimetry measurements today as there is currently no solution available. Due to the asymmetric shape of the SAR altimeter footprint, SAR observations have the potential for sea state bias errors to be greater depending on the relative directions of the ground track and swell propagation. Our investigation has addressed this problem using observations from Envisat ASAR measurements of swell length, height and direction, through Globwave data, which we have collocated with Cryosat2 L1B data. The study area focused on SAR boxes in the North and West Atlantic, the Equatorial Atlantic and the Agulhas region. Averaged waveforms are ordered by swell direction, swell wavelength and wave height to form a matrix of results within similar conditions. We also show comparative results of the effects of the L1B processing to the collocated waveforms in this study.

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DeDop: The tool to process altimetry data yourself

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Session: Innovative SAR processing methods
Presentation type: Oral

Abstract:
The recent development of SAR altimetry, or more properly Delay Doppler altimetry, as implemented on CryoSat-2 and now recently on Sentinel-3, opens an exciting new era for the scientific community. This new approach offers to scientists an opportunity to develop new processing schemes and derive new and improved products, and so maximise the benefits of the measurements available from upcoming missions.

Historically, in conventional altimetry, the understanding of the Level 1B processor was in the hands of the instrument engineers with system expertise.

Due to the strong link between the Level 1B processing and the final geophysical retrievals through the retracking process, it is important that the SAR Altimetry scientific community gains a much better understanding the Level 1B processor, and is involved in new developments. And this is the focus of the ESA DeDop project.

The DeDop project provides the scientific community with the means to understand and use low level Altimetry data and how these data are processed, by providing them with a Fully Adaptable and Configurable DDP and a friendly user interface (The DeDop “Studio”) to help them to interact with the DDP. The proposed DDP has different options from which the user will be able to choose according to their particular field of interest. Examples of the new options are: surface focusing (particularly relevant for special targets like coasts, rivers or lakes), any kind of weighting along and across track, different azimuth processing approaches, stack masking, new stacking algorithms (e.g. ACDC), Sigma-0 at stack level, etc.

The DDP is open source and the code will be freely available, in such a way that users will be able to explore the code and its configurable possibilities and to modify it to their own needs. The key algorithms for the DDP were developed within the ESA Sentinel-6 project.

When fully developed, the DeDop studio will also include various demonstrations of new features that can be investigated and retrieved; implemented as case-studies:

1. Iceberg Detection: Detection of target emerging from the sea surface. Examples of this are: icebergs, ships, lighthouse, and small islands.
2. Ocean Wind / Wave Modelling: Exploitation of the high-resolution altimetry for ocean wind-wave modelling.
3. Sea Ice: To improve discrimination of sea-ice through the use of stack data.
4. Inland Water: Evaluate use of DDP IL1B-S and L2 products for monitoring rivers and inland waters, focussing on the Amazon basin.
5. Transponder: The calibration of the main scientific parameters of the altimeter: range, datation, and Sigma-0.

6. Attitude Estimation: Demonstrate the retrieval of pitch of the Sentinel satellite, independent of the star trackers.

7. ACDC (Stack L1B waveform modelling): ACDC is a new method of forming the Doppler delay map, named Amplitude Compensation and Dilation Compensation. The objective of this study is to evaluate the stability of the ACDC.

8. Polar Ocean Eddies: To improve the estimation of the SSH across mesoscale eddies, in the sub-polar Arctic along the West Spitsbergen Current.

9. 3D Stack Modelling: Perform 3D fitting, or fit of the overall stack to test and quantify if precision and accuracy of geophysical retrievals is improved.

The DeDop Studio will be used to create and manage named DeDop Processor configurations, invoke the DeDop core processor with a given configuration and finally to read in the processor outputs for exploration and comparison with former outputs. It will have a clear, comprehensive, intuitive and accessible graphical user interface and comprise a flexible and extendible set of data visualisations and analysis functions for the L1A, L1BS and L1B outputs. As stated before, the ultimate aim of the DeDop Studio is to attract community scientists to use and modify the processing code and let them become acquainted with the new Level-1 altimeter products.

We will present and demonstrate the capabilities of the current version of the DeDop Processor and Studio, and present early outcomes of the various case studies.

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Results over Ocean of the SAR Mode Processing in Sentinel-3A Products

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Oral

Abstract:
Sentinel-3A mission was successfully launched in February 2016. It is a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. We focus here on the observations acquired by the sea-surface topography payload that encompasses a dual frequency altimeter, a dual frequency radiometer and Doris and GNSS sensors. A specificity of the Sentinel-3A mission is that it embarks a Delay Doppler altimeter. The SRAL altimeter operates continuously in Delay Doppler mode (or the so-called SARM) over all surfaces since the 12 April 2016.

We will present the performance of the SARM observations over ocean through the assessment of the Sentinel-3A Level 2 products. The SARM processing within the Sentinel-3A operational ground segment is quite close to other existing ones (CNES processing and GPOD processing for instance) either for the Doppler processing or for the retracker. Different metrics will show the performance of the SARM sea level, wind and wave data by:

• comparing with other altimetry missions
• comparing with PLRM mode which is an LRM like processing that allows detecting very small residual errors on the SARM data
• comparing with other Delay Doppler processing such as the CNES processing already assessed over Cryosat time series and now on Sentinel-3A mission

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Sentinel-3a Delay Doppler Processing: Assessment over the Global Ocean.

Matthias Raynal (CLS, France); Sylvie Labroue (CLS, France); Marion Orszynowicz (CLS, France); Nicolas Picot (CNES, France); Amandine Guillot (CNES, France); François Boy (CNES, France)

Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Oral

Abstract:
The ESA (European Space Agency) mission Sentinel-3a was successfully launched in February 2016. Sentinel-3a is a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The mission will support ocean forecasting systems, as well as environmental and climate monitoring.

As the Cryosat-2 altimeter, the SRAL (Sentinel Radar Altimeter) radar differs from previous conventional pulse limited altimeter in that it is capable of operating in several modes. The conventional or low resolution mode (LRM) was activated during the first cycle in order to ensure the continuity with the Synthetic Aperture Radar mode (SARM) activated since the 12th April 2016 over the global Ocean.

The SARM (or Delay Doppler mode) full coverage is available for the first time in the altimetry history and it will allow to strengthen the past results obtained with Cryosat-2 and to better characterise the SARM benefits (noise reduction, smaller across-track footprint) using a more representative sampling and taking into account the regional specificities.

The Sentinel-3a Prototype Processing (S3PP) developed by CNES (Boy et al., 2015-2016) inherited from the Cryosat-2 Prototype Processing (CPP) (Boy et al., 2012-2013) starts from Sentinel-3a level-0 telemetry files and generate Sea Level Anomaly (SLA) measures for each record in LRM or SAR mode. The present study shows some results obtained with a half year of S3PP Delay Doppler data record. Data quality has been assessed through different metrics that are presented here. We analyse more deeply the main features to check the reliability and the improvements of the SARM processing (noise reduction, increased along track spatial resolution, check of the dependencies that may induce geographically correlated errors ...).

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Does Swell Impacts Significant Wave Height Measurements from SAR Altimetry?

Saleh Abdalla (ECMWF, United Kingdom); Salvatore Dinardo (EUMETSAT, Germany)

Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Oral

Abstract:
Significant wave height (SWH) product is the most robust measurement produced by radar altimeters. It was shown that SWH product from conventional altimetry (e.g. ENVISAT, Cryosat-2, Jason-2 and SARAL/AltiKa) is of excellent quality. The same was also found to be correct for the SWH measured using the Synthetic Aperture Radar (SAR) Mode (e.g. from Cryosat-2).

Since the impact of ocean swell on SAR altimetry, sea surface height in particular, has been a hot topic recently, it is worthwhile questioning the swell impact on SAR SWH measurements. For this, Cryosat SAR Mode SWH product produced using the SAMOSA ocean model processed in the ESRIN G-POD service open to the Community called SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation (SARvatore) covering the period from Sep. 2010 to Jun. 2014 is collocated with the ECMWF operational ocean wave model products. The collocated dataset will be examined to see whether the swell has any impact on SAR SWH. The results, however, will be limited to the areas where Cryosat is operating in the SAR Mode.

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The coastal performance of SAR altimetry from CryoSat-2 and Sentinel-3

Paolo Cipollini (National Oceanography Centre, United Kingdom); Francisco M. Calafat (National Oceanography Centre, UK); David Cotton (Satellite Oceanography Consultants, UK); Jérôme Benveniste (ESA/ESRIN, Italy)

Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Oral

Abstract:
SAR altimetry is expected to be particularly advantageous in the coastal zone, due to the much higher along-track resolution and the better signal to noise ratio of the SAR mode. This is confirmed by the results of an assessment of the performance of SAR altimetry around the coast of the UK using CryoSat-2 data and Sentinel-3 data, which we show in this contribution. This assessment has been carried out within the ESA-funded CryoSat Plus for Oceans Project (CP4O) and SCOOP projects. The diagnostic that we use as a measure of the instrumental noise is the absolute value of the difference amongst consecutive 20-hz samples, both for height and significant wave height. Results demonstrate that in favourable conditions at 2 km from the coast we get the same level of noise as over the open ocean, i.e. less than 5 cm noise for the 20-Hz data for SSH, and less than 45 cm noise for the Significant Wave Height, and noise figures at 1 km are only slightly greater if some screening based on waveform fitting is carried out. Specific processing configuration (Hamming filter in azimuth, pre-FFT zero padding) improves the noise characteristics. Validation of SSH against tide gauges is encouraging: with fine tuning of search radius (and sometimes outlier removal) we can get RMS < 10 cm with search radii ~20 km. We also demonstrate the important potential for SAR altimetry to help characterise the wave field close to the coast– with examples of sheltering of the waves in areas of complex morphology, and shoaling effects in areas where the coast is simple and the tracks are nearly orthogonal to the coastline, such as the region along the UK south coast close to Brighton.

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Performance comparison of Sentinel-3 and CryoSat-2 Delay-Doppler (SAR) processing baselines over Open Ocean and Coastal zones

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Oral

Abstract:
During the last decade the radar altimetry has entered in its golden age as demonstrated by the different number of missions (Jason-3, CryoSat-2, SARAL/Altika, Sentinel-3) currently operating and the forthcoming ones (Sentinel-6). The relatively new operational SAR mode in CryoSat-2 and Sentinel-3 missions, opens a new paradigm in the capabilities offered by satellite radar altimeter missions. The delay-Doppler processor (DDP), also known as SAR processor, coherently integrates a series of pulses to provide a series of Doppler beams with an improved along-track resolution (around 300 m) and focused to a specific location, which after being correctly aligned (compensating for the slant-range variation, among others) provide several looks that can be incoherently averaged. In this way, an improvement on the performance of the geophysical retrievals compared to a conventional altimetry operation is expected, whenever an optimised processing baseline is set up.

Within the framework of the SCOOP (SAR Altimetry Coastal and Open Ocean Performance) project funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme Element, and in order to characterise the potential performance of Sentinel-3 SRAL SAR mode altimeter products, a comparative study is undertaken in this presentation between the CryoSat-2 and Sentinel-3 SAR processing baselines. Such evaluation is performed over several regions of interest covering both the open-ocean and coastal zones, taking as input the recently released CryoSat-2 Baseline-C FBR data.

This comparative study is based on the validation of the different in-house developed DDP processing approaches through the inversion of the geophysical parameters (SSH, SWH and sigma0), exploiting an in-house implementation of the Chris et al 2015 analytical SAR retracker. This analytical retracker is adapted hand-in-hand to the L1B processing in order to create an L1B waveform modelling as accurate as possible.

The impact of the different processing options is evaluated and characterised across the different processing levels: first, within the L1 processing itself (stack level analysis), at L1B waveform and at L2 (geophysical retrieval). The performance of the geophysical retrievals (RMSE and goodness of fitting, among others) will be exploited comparatively over the different tracks and regions in order to identify the most suitable processing approach. The objective is to define a roadmap identifying potential improved processing options for the Sentinel-3 baseline and if possible to show some preliminary results based on the implementation of some upgrades.

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Corsica: linking historical and current missions with Sentinel-3A

Pascal Bonnefond (Observatoire de Paris - SYRTE, France); Pierre Exertier (OCA-GEOAZUR, France); Olivier Laurain (OCA-GEOAZUR, France); Thierry Guinle (CNES, France); Pierre Féménias (ESA-ESRIN, Italy)

Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Oral

Abstract:
In collaboration with the CNES and NASA oceanographic projects (T/P and Jason), the OCA developed a verification site in Corsica since 1996. CALibration/VALidation embraces a wide variety of activities, ranging from the interpretation of information from internal-calibration modes of the sensors to validation of the fully corrected estimates of Sea Surface Heights using in situ data. Now, Corsica is, like the Harvest platform (NASA side), an operating calibration site able to support a continuous monitoring with a high level of accuracy: a ‘point calibration’ which yields instantaneous bias estimates with a 10-day repeatability of around 30 mm (standard deviation) and mean errors of 3-4 mm (standard error). For a 35-day repeatability (ERS, EnviSat, SARAL/AltiKa), due to a smaller time series, the standard error is about the double (~7 mm).

The locations of the Ajaccio (ERS & Envisat legacy) and Senetosa (T/P & Jason legacy) calibration sites are overflown by the Sentinel-3A pass #741, allowing to determine the SSH bias from both sites within a distance of ~37 km and a time lag of ~5 s. This situation will allow to mitigate geodetic errors of each site and will allow linking the past and current other missions (T/P-Jason and ERS-Envisat series). In order to perform the calibration over a longer segment of pass, we plan to make the connection of the Ajaccio and Senetosa local geoids along the Sentinel-3A track.

A first data set from the PDGS has been delivered to the Sentinel-3A Validation Team (S3VT) in June and the first results from the Corsica site show:

- An improved data quality in coastal areas thanks to SAR
- A very good agreement between SARM and PLRM (SARM-PLRM = -4.8 ± 3.8 mm) over both sites
- The absolute SSH bias derived from Ajaccio tide gauge (for cycle 2 & 3): SARM = -31.0 mm / PLRM = -24.2 mm

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Exploiting Cryosat-2 stack data for nadir-lead detection in sea-ice regions

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Session: Applications, SAR for science
Presentation type: Oral

Abstract:
In the Arctic and Antarctic Ocean, part of the sea surface is seasonally or continuously covered by sea ice. In these areas, it is important to isolate the altimeter echoes that are reflected back by leads, long and narrow fractures in the ice. Lead echoes, coming from specular surfaces, have a very high backscatter coefficient that can dominate the altimeter return even if the lead is hundreds of meters away from the nadir position (off-nadir leads). The sea level computed from off-nadir leads reflections is therefore affected by biases and errors.

The recognition of leads is based on the classification of altimeter waveforms. The new SAR altimetry missions, in which the averaged waveform is formed by summing up several looks acquired at different look angles and stacked together, can be exploited to reduce the “false-lead detections”, i.e. the lead-like waveforms that correspond to off-nadir leads and are erroneously used for sea level estimation.

In this study, we analyse the Stack Product of Cryosat-2, available from the ESA GPOD service. We propose the adoption of a new parameter, the Stack Peakiness” (SP) and we show its behaviour along tracks orbiting above sea ice regions compared to the other Stack parameters that are currently available in the official product (Stack Kurtosis and Stack Standard Deviation). The SP compares the main return (expected to come from the nadir echo) w.r.t. the rest of the stack: when crossing a lead, SP grows, peaks and decreases, revealing the most likely location in which the lead is seen at nadir. The Stack Peakiness is then used as a parameter to classify the echoes into leads and ice and the results are quantitatively validated against SAR images from Sentinel-1. We propose the adoption of the Stack Peakiness parameter in the standard products of the SAR altimetry missions and we emphasize the importance of making the Stack Product of SAR altimetry freely available to expert users.

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SAR-mode altimetry performance over the Antarctic ice sheet

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Session: Applications, SAR for science
Presentation type: Oral

Abstract:
During the past 30 years, Earth’s polar region has been continuously monitored by satellite altimetry. Thanks to their wide spatial coverage and relatively high temporal sampling, radar altimeters have greatly improved our knowledge of the ice-sheets topography and our understanding of the ice sheets dynamics. Over that time period, all radar altimeter missions flying over ice-sheet surfaces (GeoSat to Altika) have been operating in conventional Low Resolution Mode (LRM). Despite constant improvements in resolution and precision, LRM instruments still suffer from several limitations and uncertainties, notably due to their large radar footprint: 10km to 20km (depending on mission).

Unlike its predecessors, the Cryosat-2 and Sentinel-3A satellites carry on-board a new generation of radar altimeter instrument operating in a Synthetic Aperture Radar (SAR) mode. This mode allows to reduce the along-track resolution to 300 meters, that would make it possible to capture finer-scale topographic variations of ice-sheet surfaces. The SAR-mode performances have been thoroughly analyzed in open ocean with Cryosat-2 data. However their abilities in monitoring of ice-sheet surfaces have still to be assessed.

SAR-mode radar altimeter data have been recently analyzed over the Antarctica continent, with sporadic Cryosat-2 acquisitions performed in winter 2014 and Sentinel-3A SRAL data acquired in spring 2016. Those data have been processed through the CNES prototype chains (the CPP for Cryosat-2 and the S3PP for Sentinel-3A) and the use of innovative and dedicated algorithms to this particular surface. This paper presents a comprehensive study of the SAR-mode performance over ice-sheet surfaces in comparison with LRM one, focusing on analyses of the waveform shapes, the accuracy of the retrieved surface elevation, its sensitivity to surface slope and penetration effects into the snow/ice layers. This work clearly demonstrates the improved ice-sheet surface measuring capability offered by SAR-mode altimetry with respect to conventional radar altimetry.

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Characterization of SAR Mode Altimetry Data over Inland Waters – SHAPE project

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Session: Applications, SAR for science
Presentation type: Oral

Abstract:
This work is the continuation of the work we presented at Hydrospace2015 as well as LPS2016 on the understanding of SAR mode altimetry in hydrology. It is part of the SEOM Sentinel-3 Hydrologic Altimetry Processor prototype (SHAPE) study which aims at boosting the use of “SAR” mode altimetry data in hydrology. The main reason why Space Hydrology is still not operational at global scale is the variety of inland water scenes and scenarios which cannot properly be taken into account via a fixed processing chain. The complexity coming from the spatial diversity is emphasized by the strong temporal variability related to seasonal trends, extreme events and human action. The radar backscatter properties of water depend on wind conditions, surface current and trophic phenomenons.

The key aspect of the SHAPE project that is addressed here is the qualitative and quantitative characterization of the existing SAR Mode Altimetry data (CryoSat-2) over the inland water domain.

We run our new conceptual framework that eases and partially automates the analysis of CryoSat-2 measurements over inland waters through the use of water masks and the altimeter footprints. This serves to analyse the altimeter data together with the information on the water fraction within the instrument footprint. Several improvements of our experiment makes it possible now to come with interesting results from the in-depth analysis of the following physical and statistical indicators:

- the Mean Individual Echoes, Stacks and Waveforms (SAR and RDSAR) as reference signals,
- the Kurtosis (peakiness), Skewness (asymmetry), Standard Deviation for Stacks and Waveforms (SAR and RDSAR),
- Specifically for the Stacks: Stack centre (mispointing and/or mean surface slope), Range Integrated Power (RIP) statistics, Stacks static & animated plots with a crossing over the non-water area, transition area and water area categories.

Among the improvements have been made in both the computations and the method to analyse the results:
- the 0% and 100% Water Fraction classes have been introduced
- the exercise has been run over 2 consecutive years (2014 and 2015) and over two different baselines (B and C)
- the Scaled Amplitude to Watt conversion has been applied to both waveforms and Stacks
- not only Beam-Doppler limited footprint is used but also Pulse-Doppler limited footprint to better locate water content,

The outcome of this work may impact future retrackers and ease the mapping of water bodies through water detection criteria. Results are provided over Amazon and Danube.

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Scientific Applications of Fully-Focused SAR Altimetry

Alejandro Egido (NOAA/CICS-MD, United States); Walter Smith (NOAA, USA)

Session: Applications, SAR for science
Presentation type: Oral

Abstract:
The delay/Doppler algorithm implemented in CryoSat-2 and Sentinel-3 applies a coherent processing the 64 echoes within each burst (about 3.5 milliseconds of flight), which allows narrowing the footprint in the direction along the track to about 300 m. However, by accounting for the phase evolution of the targets in the scene, it is possible to focus the complex echoes along the aperture, and perform inter-burst coherent integration potentially as long as the target illumination time. This process, similar to SAR imaging systems, reduces the along-track resolution down to the theoretical limit equal to L/2, where L is the antenna length. We call this the fully focused SAR Altimetry processing. For the development of the technique we have used the CryoSat-2 SAR Mode data, but our methods could also be used with similar data from Sentinel-3 or Sentinel-6/Jason-CS.

The footprint of a fully focused SAR altimeter measurement is an elongated strip on the surface, which is pulse-limited across-track and SAR focused along-track. The technique has been demonstrated using transponder data, showing an achievable along-track resolution of 0.5 meters. Despite the asymmetry of the altimeter footprint, the fully focused technique may be useful for applications in which one needs to separate specific targets within highly heterogeneous scenes, such as in the case of sea-ice leads detection, hydrology, and coastal altimetry applications. Applying this technique on CryoSat-2 data over land and sea-ice, we can correctly measure the along-track extent of water bodies and ice-leads only a few meters long in the along-track dimension. On a random rough surface, independent fully focused SAR waveforms can be obtained, potentially, every 0.5 meters, leading to an increase on the effective number of looks that can be obtained of the surface, with respect to delay/Doppler altimetry.

In this paper we concentrate on the different scientific applications of fully-focused SAR altimetry, and on the results that we have obtained so far by processing CryoSat-2 FBR SAR mode data. In hydrology and sea-ice applications the improved along-track resolution can be exploited to obtain a better representation of the surface features. In addition, we developed a simple retracker to estimate the sea surface height (SSH) estimations from sea-ice leads. The precision of the obtained SSH measurements is better by a factor of square root of two than the ESA L2 Baseline-C product, due to the higher multilooking capabilities of FF-SAR. We also demonstrate the use of the technique for the open ocean, where a similar result is obtained. In this case we determined that the effective number of looks of the multilooked echoes increases by a factor of 2 with respect to delay/Doppler, leading to a significant improvement in the estimation of the ocean geophysical parameters.

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On the assimilation of Sentinel-3A in the wave model MFWAM: global and regional scales
Lotfi Aouf (Division Marine et Océanographie Météo-France, France)

Session: Applications, SAR for science
Presentation type: Oral

Abstract:
The availability of Sentinel-3A (S3A) SRAL wave data will increase the coverage of observations over the oceans and the revisit of some areas will be certainly improved. The retrieval of S3A SRAL wave data is completely based on delay Doppler altimetry (SAR mode) technique. We can expect the assimilation of S3A wave heights impacting more coastal regions. The goal of this work is to assess the positive impact of the assimilation of S3A revealed by the preliminary results. We then need to evaluate further the assimilation of S3A in the global and regional operational wave models during longer period (~6 months). The validation of the results with independent wave data (altimeters and buoys) will be performed. We will investigate the bias of significant wave height from SRAL in the tropics. To this end a comparison between the assimilation of S3A SRAL wave data with the one of SAR directional wave spectra of Sentinel-1A is examined for dependency of the bias with swell regime. The persistency of the assimilation of S3A will be also investigated in the forecast period. Discussions and conclusions will be commented in the final paper.

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SAR altimetry in the Golf of Bengal

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Session: Applications, SAR for science
Presentation type: Oral

Abstract:
Sea level in the Bay of Bengal is perceived as a major threat to the densely populated coastal areas due to land subsidence, absolute sea level rise rates higher than the global mean and frequent cyclones.

Sea level change is here measured from SAR and pulse-limited satellite altimetry in the interval 2012 to 2016. Our goal is to investigate the additional knowledge that SAR altimetry from the Cryosat-2 and Sentinel-3 missions can eventually provide. We use CryoSat-2 and Sentinel-3 data in SAR mode, as well as conventional Jason-2 and SARAL-Altika low resolution mode (LRM) data. Cryosat-2 SAR data are from GPOD and Sentinel-3 data from EUMETSAT. The FBR data are processed to generate Reduced SAR (RDSAR) 20 Hz waveforms. RDSAR and LRM waveforms are retracted using various algorithms.

The accuracy of some environmental corrections to the altimetric measurement to derive sea level is expected to be low due to lacking of in-situ data and due to the intrinsic characteristics of the natural signal itself. Wet tropospheric correction from on-board microwave radiometer, model-derived and GPD+ from UPorto are here compared as well as the resulting sea level data.

SAR-derived parameters are evaluated by using in-situ hourly tide gauge data from the University of Hawaii Sea level Center, wind and wave models from European Centre for Medium-Range Weather Forecasts and from Wave Watch 3. Through the BanD-Aid consortium (Belmont Forum) additional tide gauges and modelled water levels are made available from the operational forecast system of the Institute of Water Modelling (IWM) in Bangladesh.

Spatially averaged and gridded monthly sea level variability and trends computed from SAR altimetry are compared to state of the art sea level datasets as the Climate Change Initiative ECV products and to monthly tide gauges of the Permanent Service of Mean Sea level. Finally swell and cyclonic events are investigated to detect differences between SAR and RDSAR observations.

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SAR altimetry processing on demand service for cryosat-2 and sentinel-3 at esa g-pod

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Session: Innovative SAR processing methods
Presentation type: Poster
Poster number: INN_001

Abstract:
The scope of this presentation is to feature the ESA-ESRIN G-POD SARvatore service to users for the exploitation of the CryoSat-2 data, which was designed and developed by the Altimetry Team at ESA-ESRIN EOP-SER (Earth Observation – Exploitation, Research and Development). The G-POD service coined SARvatore (SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation) is a web platform that allows any scientist to process on-line, on-demand and with user-selectable configuration CryoSat-2 SAR/SARin data, from L1a (FBR) data products up to SAR/SARin Level-2 geophysical data products. The Processor takes advantage of the G-POD (Grid Processing On Demand) environment, made available and operated by ESA RSS (Research and Service Support), to timely deliver custom-processed data products and to interface with ESA-ESRIN FBR data archive (155'000 SAR passes and 41'000 SARin passes - 118 TB of CryoSat data storage). The output data products are generated in standard NetCDF format (using CF Convention), therefore being compatible with the Broadview Radar Altimetry Toolbox (BRAT) and other NetCDF tools. By using the G-POD graphical interface, it is straightforward to select a geographical area of interest within the time-frame related to the Cryosat-2 SAR/SARin FBR data products availability in the service catalogue. The processor prototype is versatile allowing users to customize and to adapt the processing, according to their specific requirements by setting a list of configurable options (which can be augmented upon user request). After the task submission, users can follow, in real time, the status of the processing. From the web interface, users can choose to generate experimental SAR data products as Stack data and Range Integrated Power (RIP) waveforms.

The processing service, initially developed to support the development contracts awarded by confronting the deliverables to ESA’s, is now made available to the worldwide SAR Altimetry Community for research & development experiments, for on-site demonstrations/training in training courses and workshops, for cross-comparison to third party products (e.g. CLS/CNES CPP or ESA SAR COP data products), and for the preparation of the Exploitation of the Sentinel-3 Surface Topography Mission, by producing data and graphics for publications, etc. Initially, the processing was designed and uniquely optimized for open ocean studies. It was based on the SAMOSA model developed for Sentinel-3 Ground Segment using CryoSat data. However, since June 2015, a new retracker (SAMOSA+) is offered within the service as a dedicated retracker for coastal zone, inland water and sea-ice/ice-sheet. In view of the Sentinel-3 data exploitation, a new flavor of the service will be initiated, exclusively dedicated to the processing of Sentinel-3 mission data products. The scope of this new service will be to maximize the exploitation of the upcoming Sentinel-3 Surface Topography Mission’s data over all surfaces. Moreover, since June 2016, the high resolution EIGEN6C4 geoid based on GOCE DIR5 data is available in output products. The service is open, free of charge (supported by the SEOM Programme Element) for worldwide scientific applications and available at https://gpod.eo.esa.int/services/CRYOSAT_SAR/

More info can be read at:

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**SAR ALTIMETRY AT 80 Hz**

Salvatore Dinardo (HESPACE/EUMETSAT, Italia)

**Session:** Innovative SAR processing methods  
**Presentation type:** Poster  
**Poster number:** INN_002

**Abstract:**  
Thanks to the CryoSat-2 unique capacity to downlink unprocessed Full Bit Rate (FBR) data, different data-processing strategies and/or approaches can be attempted and implemented on ground.

This is particularly helpful, when operating in the coastal zone, inland water or land. On these particular domains, it seems sensible to have SAR-processed echoes treated at highest repetition frequency possible in order to capture all the short scale variability of the coastal scenario.

In the Delay-Doppler processing algorithm, the parameter controlling the echo posting frequency is the grid space step that conventionally has been fixed at frequency of 20 Hz (300 meter) in order to match the instrument along track resolution, but the grid space step can be arbitrarily defined to any desired value.

In the present work, we will attempt to Delay-Doppler process the FBR data with a finer space step, around 80 meter, that corresponds to a frequency of 80 Hz (Burst Repetition Frequency) and we will try to quantify the improvement, in term of precision and in term of observability of short scale signals, that is achieved from usage of that finer space step. It is worth to notice that, whereas the grid space step shrinks from 300 meters to 80 meter, the theoretical along-track resolution of 300 meter will remain unaltered.

Once that the L1B SAR echoes have been generated at 80 Hz, they will be re-tracked at 80 Hz using the SAMOSA model in order to retrieve the geophysical quantities: Sea Surface Height (SSH), Significant Wave Height (SWH) and Wind Speed at 10 meter (U10).

The experiment will be run in the waters of the North East Atlantic and it will consist in processing the same FBR dataset at 20 Hz (standard grid case) and at 80 Hz (overgrid case) and in spotting the differences between the two cases in term of statistics and resolving power.

Averaged wavenumber spectra will be produced at 80 Hz and 20 Hz and it will be proved the higher short-scale resolving power of the 80 Hz mode.

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Application and Evaluation of ACDC Delay-Doppler processing over CryoSat-2 for Open-Ocean zones

Eduard Makhoul (isardSAT, United Kingdom); Chris Ray (Saint Mary’s College, United States); Mònica Roca (isardSAT, United Kingdom); Albert Garcia (isardSAT, United Kingdom); Roger Escolà (isardSAT, United Kingdom)

Session: Innovative SAR processing methods
Presentation type: Poster
Poster number: INN_003

Abstract:
During the last decade there has been a tremendous evolution in radar altimetry from both technological and operational standpoints. This has been concreted in the development of the Synthetic Aperture Radar (SAR) altimetry, with CryoSat-2 as the reference mission and the follow-on Sentinel-3 mission for oceanographic purposes. Such framework represents a breakthrough in altimetry, offering the possibility to investigate new processing approaches in order to enhance the quality of the SAR altimetric products (especially in terms of geophysical retrievals).

In this line and from the experience gained within the Sentinel-6 project, this presentation is devoted to show the integration and operation of the ACDC (amplitude compensation and dilation compensation) technique in an in-house developed L1B processor based on the CryoSat-2 as well as Sentinel-3 baselines. Preliminary results on the ACDC performance on real FBR CryoSat-2 data over open ocean zones will be presented.

ACDC was originally proposed by Chris Ray and isardSAT team within the Sentinel-6 project. The basic idea is to perform a two-step compensation once the stacking has been performed and right after geometry corrections application: 1) along-track amplitude compensation to equalise the Doppler-dependent weighting induced by the acquisition geometry in combination with both antenna and surface radiation patterns; and 2) across-track dilation compensation to correct for the waveform widening when moving away from the central beam. In this way, a better alignment of the waveforms within the stack is obtained focusing the spread along-track energy into a single range bin, such that an improved speckle reduction and signal-to-noise ratio (SNR) are expected. This results in a simpler and more computationally efficient analytical retracker over ACDC L1B waveforms when compared to the conventional SAR analytical retracker on L1B waveforms. As proved over simulated Sentinel-6 data, the combination of the ACDC processing within L1B and the implementation of the simpler ACDC retracker provides improved (less noisier) geophysical retrievals.

Taking into account such considerations, the core of this presentation intends to show the potential capabilities of the ACDC method when integrate in the CryoSat-2 and Sentinel-3 processing baselines, comparing the retrieved geophysical parameters with the conventional SAR processing baselines for both missions over FBR CryoSat-2 data on several tracks over open-ocean. Taking into account that under ideal considerations (perfectly known attitude, antenna and surface radiation patterns) a flat response over the ACDC stack is expected. Therefore, deviations on such expected flatness could be potentially linked to wrong attitude information (already presented by Chris Ray in OSTST in 2015) and even related to specific characteristics on the surface backscattering itself (and so to specific geophysical parameters). In this line, this presentation will attempt to show preliminary analysis on these latter aspects as well.

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Methodology and Validation of SAR and SARin Full Bit Rate Altimetric Waveforms and Heights from the CRUCIAL Project.

Philip Moore (Newcastle University, United Kingdom); Stephen Birkinshaw (Newcastle University, United Kingdom); Marco Restano (SERCO/ESRIN, Italy); Americo Ambrozio (DEIMOS/ESRIN, Italy); Jérôme Benveniste (European Space Agency, Italy)

Session: Innovative SAR processing methods
Presentation type: Poster
Poster number: INN_004

Abstract:
CRUCIAL is an ESA/STSE funded project investigating innovative land and inland water applications from Cryosat-2 with a forward-look component to the future Sentinel-3 and Jason-CS/Sentinel-6 missions. The high along-track sampling of Cryosat-2 in its SAR and SARin modes offer the opportunity to recover high frequency signals over inland waters. A methodology has been developed to process the FBR L1A Doppler beams to form a waveform product using ground cell gridding, beam steering and beam stacking. Inland water heights from Cryosat-2 are derived by using a set of empirical retrackers formulated for inland water applications. Results of the processing strategy will include a comparison of waveforms and heights from the burst echoes (80 m along-track) and from multi-look waveforms (320 m along-track). SAR and SARin FBR data are available for the Amazon, Brahmaputra and Mekong for 2011-2015. FBR SAR results will be compared against stage data from the nearest gauge where applicable with heights from Tonle Sap also compared against Jason-2 data from the United States Department of Agriculture. A strategy to select the number of multi-looks over rivers will also be presented based on the rms of heights across Tonle Sap. Comparisons will include results from the empirical retrackers and from waveforms and heights obtained via ESA’s Grid Processing on Demand (G-POD) using the SAMOSA2 retracker. Results of FBR SARin processing for the Amazon and Brahmaputra will be presented including comparison of heights from the two antennae, extraction of slope of the ground surface and validation against ground data where appropriate.

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Monitoring Sentinel-3A: S3MPC activities to ensure a consistent accurate dataset

Graham Quartly (Plymouth Marine Laboratory, United Kingdom); Sylvie Labroue (CLS, France); Pierre Féménias (ESA/ESRIN, Italy); Remko Scharroo (Eumetsat, Germany); Carolina Nogueira Loddo (Eumetsat, Germany); Saleh Abdalla (ECMWF, United Kingdom); Mónica Roca (isardSAT, Spain); Pablo Nilo (isardSAT, Spain); Francesco Nencioli (Plymouth Marine Laboratory, United Kingdom); Marie-Laure Frery (CLS, France); Steven Baker (University College London, United Kingdom); Alan Muir (University College London, United Kingdom); David Brockley (University College London, United Kingdom); Andrew Shepherd (University of Leeds, United Kingdom)

Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_001

Abstract:
Sentinel-3A is the first altimeter to operate in delay-Doppler mode over all ocean surfaces, with the advantages of SAR altimetry expected to set new standards for the accuracy of global sea level records. To contribute usefully to the development of climate data records, the performance of the instrument needs to be fully monitored. This talk will give an overview of the processes undertaken by the Sentinel-3 Mission Performance Centre from the internal monitoring of calibration modes to the assessment of its geophysical estimates. With the wide remit of the mission, the validation activities will span consistency with other altimeters, comparison with dedicated ground observations and spectral analysis. Metocean observations, such as wind speed, wave height and total liquid water content will be contrasted with output from a high-resolution atmospheric model, and sea-ice and land-ice observations will be compared with Cryosat-2, Operation Ice Bridge, and in situ surveys.

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Transponder Calibration in SAR altimetry: from CryoSat-2 to Sentinel-3

Albert Garcia-Mondejar (isardSAT Ltd., United Kingdom); Marco Fornari (RHEA / ESA, The Nederthlands); Jérôme Bouffard (RHEA / ESA, Italy); Pierre Féménias (ESRIN / ESA, Italy); Mònica Roca (isardSAT Ltd., United Kingdom)

Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_002

Abstract:
Transponders are commonly used to calibrate absolute range from conventional altimeter waveforms because of its characteristic point target radar reflection. The waveforms corresponding to the transponder distinguish themselves from the other waveforms resulting from natural targets, in power and shape.

ESA has deployed a transponder available for the CryoSat project (a refurbished ESA transponder developed for the ERS-1 altimeter calibration). It is deployed at the KSAT Svalbard station: SvalSAT. Another transponder has been deployed by Technical University of Crete for the Sentinel 3 calibration in the island of Crete.

For CryoSat-2 [1], we are using the transponder to calibrate SIRAL’s range, datation, and interferometric baseline (or angle of arrival) to meet the missions requirements [2].

For Sentinel-3 we are using the transponder to calibrate SRAL’s range, datation to meet the missions requirements [3].

In these calibrations, we are using 3 different type of data: the raw L1A data, the stack beams before they are multi-looked (L1BS), and the multi-looked waveform products (L1B) [4].

Ideally the comparison between (a) the theoretical value provided by the well-known target, and (b) the measurement by the instrument to be calibrated; provides us with the error the instrument is introducing when performing its measurement [5]. When this error can be assumed to be constant regardless the conditions, it will provide the bias of the instrument. And if the measurements can be repeated after a certain period of time, it can also provide an indication of the instrument drift.

The performances of the CryoSat-2 altimeter, the SIRAL (Synthetic aperture interferometer radar altimeter), have been monitored since 2010 with the Transponder measurements. The range and datation biases from the processor have been corrected in the initial Baselines and now with the Baseline C the long-term trends can be performed in order to evaluate the aging of the instrument.

For Sentinel-3 altimeter, the first data with the Crete TRP have been analysed and the first performances assessment will be made before the end of the Commissioning Phase.

On this presentation the main results with the CryoSat-2 and Sentinel-3 altimeters will be shown.


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Increasing the opportunities for the calibration of CryoSat interferometer by operational SARIn acquisitions over ocean

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_003

Abstract:
The main payload of CryoSat is a Ku-band pulselwidth limited radar altimeter, called SIRAL (Synthetic interferometric radar altimeter). When commanded in SARIn (synthetic aperture radar interferometry) mode, through coherent along-track processing of the returns received from two antennas, the interferometric phase related to the first arrival of the echo is used to retrieve the angle of arrival of the scattering in the across-track direction. In fact, the across-track echo direction can be derived by exploiting the precise knowledge of the baseline vector (i.e. the vector between the two antennas centers of phase) and simple geometry.

In order to monitor the performance of the CryoSat interferometer along the mission, in orbit interferometer calibration campaigns following the approach described in [1] have been periodically performed. During those campaigns, the satellite is rolled from side to side of ~0.4 deg as it flies over ocean and the SIRAL is commanded to acquire in SARIn mode. As discussed in [1], the end-to-end calibration strategy for the CryoSat interferometer using the roll manoeuvres has been verified to be effective and it has allowed assessing the performance of the CryoSat interferometer from 2010. However, the drawback of this approach is that the complete end-to-end calibration of the CryoSat interferometer can be done only suspending the science acquisitions in correspondence of the roll manoeuvres and the calibration is thus commanded about every 18 months.

In this abstract it is presented a complementary approach for the calibration of CryoSat interferometer based on the analysis of the operational SARIn acquisitions for small ocean patches in order to increase the number of calibration opportunities. It is worth noticing that the advantage of this opportunistic end-to-end calibration of the CryoSat interferometer is that its impact on science acquisitions is minimized. By analysis of SARIn acquisitions of an ocean patch for 18 months, the calibration parameters for the CryoSat interferometer have been computed and then compared with those obtained from the calibration campaigns in conjuntion with the roll manoeuvres. Recalling that the calibration parameters for the CryoSat interferometer are a linear coefficient (a) and a bias (χ), the comparison has shown that

• The bias χ retrieved by operational SARIn acquisitions is comparable to the bias retrieved by calibration campaigns
• The linear coefficient retrieved by operational SARIn acquisitions is much more noisy than the linear coefficient retrieved by calibration campaigns, as it was expected since this parameter is computed by a linear fitting as function of the roll angle which varies by few tenths of degrees in operational acquisitions

In conclusion, operational SARIn acquisitions over open ocean can be used to increase the calibration opportunities for the CryoSat interferometer without any impact on the science acquisitions. The limitation of this approach is that it cannot allow to completely calibrate the interferometer because only the contribution addressed to the parameter χ in the calibration function can be measured with sufficient accuracy.


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The Sentinel-3A SRAL Instrument Calibration Monitoring

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_004

Abstract:
The Sentinel-3A is the most recent altimetric mission of a long historical series.

It is well known the crucial importance of the instrumental calibration when processing the altimeter data, in order to produce reliable and accurate L2 geophysical retrievals, such as sea surface height, significant wave height, or wind speed over the oceans.

isardSAT, as Expert Support Laboratory within the Sentinel-3A Mission Performance Centre team, is responsible for monitor the calibration parameters during the Sentinel-3A mission.

This talk will present the first cycles of Calibration Monitoring data acquired during the Commissioning Phase of the Sentinel-3A SRAL instrument in all calibration modes, along with a comparison with the on-ground reference values.

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A Regional Assessment of the Sentinel-3 STM L1b & L2 SAR/PLRM Data Products with an enhanced processing baseline

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_005

Abstract:
In the present work, we carry out a regional assessment of the quality of the Sentinel-3 (S-3) STM L2 SAR (Synthetic Aperture Radar) and PLRM (Pseudo-LRM) data products.

The work is structured in two parts.

In the first part, we will process the Sentinel-3 SAR data products from L0 until L2 in SAR and PLRM mode using a different processing baseline as defined in the S-3 STM Payload Ground Segment (PDGS).

The enhanced processing baseline includes a tailoring of the Delay/Doppler Processing and SAR Waveform Retracking: we will introduce new options, both in the L1b and in the L2 SAR chain, as zero-padding (in range and azimuth direction) and Hamming window in coastal zone and a double extension of the radar range window (for L1b chain) and a Delay-Doppler Stack Masking computed using the exact slant range correction (for L2 chain). We expect in this way to identify the positive impact of these changes in the S-3 data product quality.

TU Darmstadt/University Bonn will provide the PLRM L2 data (built from S-3 STM L1a) using a numerical retracker and zero-padding option, the SAR L2 data will be extracted from the ESRIN GPOD Sentinel-3 service.

In the second part of the work, we will proceed to validate the data.

The L2 altimetric geophysical parameters to be validated are the sea surface height above the ellipsoid (SSH), the sea level anomaly (SLA), the significant wave height (SWH) and the wind speed (U10), all estimated at 20 Hz. The selected test area is the North-East Atlantic Ocean and the North Sea (between -25 and +16 deg longitudes and between 43S and 63N deg latitudes). The products quality will be assessed in open sea and coastal zone. The data will be validated by cross-comparison between SAR and PLRM data, cross-comparison between PLRM/SAR data and ocean wave model (ECMWF) data, wavenumber spectral analysis and validation against in-situ tide gauge and buoys data.

The in-situ calibration and validation (CAL/VAL) in the German Bight is part of the GB_S3CVAL activities proposed by the University Bonn/TU Darmstadt as part of the Sentinel 3 Validation Team (S3VT).

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Early Assessment of Sentinel-3A measurements over Arctic Sea Ice

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_006

Abstract:
Launched February 16, 2016, the European Sentinel-3A mission builds on the heritage of the ERS-2 and Envisat satellites, measuring surface topography and temperature. Over the Arctic Ocean, Sentinel-3A will provide critical measurements of sea ice freeboard and sea surface height, providing coverage to a latitudinal limit of 81.5 °N. The measurement of sea ice freeboard from orbit is challenging owing to the small signal (< 0.35 m on average) and the complex sea ice environment that comprises rough sea ice floes, interspersed with open water, or re-frozen leads. Discrimination of waveform returns from floes and leads is required to determine freeboard, that portion of an ice floe floating above the local sea surface.

Since 2002, the NOAA Laboratory for Satellite Altimetry has cooperated with ESA, EUMETSAT, and NASA to conduct airborne validation experiments over the Arctic Ocean to assess how well sea ice freeboard (and hence ice thickness) can be measured from space using satellite altimetry. NASA’s Operation IceBridge (OIB) mission utilizes multi-instrumented aircraft to conduct annual surveys of the winter sea ice cover to monitor critical and rapidly-changing regions of the Arctic, so as to bridge gap in observations between the ICESat and ICESat-2 eras. Since 2009, OIB have conducted numerous validation experiments, under-flying Envisat, ICESat and CryoSat-2.

On 21 April 2016, just two months after launch, the OIB mission conducted an airborne survey over Arctic sea ice timed to coincide with an overpass of the Sentinel-3A (S3A) satellite. This was the first coordinated survey while S3A was operating in SAR mode. Spatially and temporally coincident data were collected in the eastern Beaufort Sea, in a study area that comprised large sea ice floes, interspersed with open and refrozen leads. The OIB instrument suite, including laser and radar altimeters, and high-resolution visible and infrared camera systems, provides measurements of sea ice freeboard, snow depth, and sea ice morphology. Here we present an early evaluation of S3A waveforms and sigma-0 measurements over Arctic sea ice using coincident OIB data and MODIS imagery. We verify sea ice lead and floe delineations in S3A waveforms, and the impact of snagging, via an assessment of S3A waveform parameters. We also assess the accuracy of S3A surface elevation measurements and, if available, we will present a first assessment of Sentinel-3A sea ice freeboard estimates via comparison with independent OIB freeboard and snow-depth measurements.

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First analysis of the Sentinel-3 SRAL data over inland water

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_007

Abstract:
The Sentinel-3 Mission (S-3), launched in December 2015, is part of the Global Monitoring for Environment and Security (GMES/Copernicus) European initiative. For oceanic applications, the S-3 mission delivers continuity to existing ESA ERS, Envisat and CryoSat-2 missions. The topography payload consists in a Delay Doppler altimeter (SRAL), a microwave radiometer MWR and 3 instruments for precise orbit computation purposes (GNSS, DORIS and laser reflector). The Sentinel-3 satellite flies on a new orbit with a 27-days cycle.

The SRAL instrument is a nadir Ku/C altimeter, with two operating modes: the low resolution mode (LRM), used for all past oceanographic missions and the high resolution mode (SAR) used for the first time on CryoSat-2. The LRM mode has been activated during one cycle at the beginning of the S-3 mission while the SAR mode is activated since then. The SAR mode (also called Delay Doppler mode) provides an improved along track resolution (around 320m) with respect to the LRM mode. During the commissioning phase (S3E1 phase), CNES has been in charge of the topography calibration and validation in support to ESTEC teams and with the support of CLS team.

In this paper, we will present a first data quality assessment focussed on inland water regions. This includes analyses of the coverage of the main inland water bodies, of the waveform centering for different tracking modes and of the evolution of the various parameters during the water surface overflight (waveforms, range integrated power, water level, etc..). The impact of the Level-1 processing on these parameters will be addressed.

The analysis will be based on S-3 data processed by the CNES prototype chains (Sentinel-3 Processing Prototype) as well as on S-3 ESA land products. The S3PP has been used to implement and test new algorithms and methods that would permit to better estimate water heights. In this study the importance to use innovative algorithms dedicated to hydrological zones have been clearly demonstrated. The results will be compared to products of other missions such as Jason-2/3 or SARAL/AltiKa focusing on the SAR mode added value for improving the observation of inland water bodies.

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Validation of CryoSat-2 SAR and SARin modes over rivers for the SHAPE project

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_008

Abstract:
In the frame of the preparation of Sentinel-3A SAR altimeter satellite, this study addresses the processing and validation of water levels derived from CryoSat-2 data over rivers. This work is part of the SHAPE project, the SEOM Sentinel-3 for Science Inland Waters activity. Meanwhile real Sentinel-3A data are available, the project focuses onto the use of CryoSat-2 data and try to mimic them as much as possible.

Previous studies have highlighted the benefits of the CryoSat-2 mission for the monitoring of river water levels. The on-board SIRAL altimeter implements altimetric SAR mode for the first time (as well as SARin mode), together with conventional low resolution mode (LRM). However, compared to conventional satellite altimetry missions, CryoSat-2 flies on an unusual geodetic orbit characterised by a long orbit period (369 days) and a dense spatial coverage (7km at equator).

This unusual orbit, for hydrology, induces an unusual sampling of the rivers path and make the water level measurements spread in space, along the river path, and in time. This exciting and challenging feature requires to develop and implement data processing in new and specific ways. One objective being to cancel the spatial component of the water level variations in order to retrieve the usual sampling pattern in which data are spread in time only (and thus are local time series).

One major topic developed in this work is what we call the migration of CryoSat-2 measurements along the river path. The migration is used to derive pseudo time series at given Arbitrary places. It involves a group of local CryoSat-2 measurements in which we try to cancel the local spatial variations, according to an estimated longitudinal river profile.

The presentation of this work is broke down into three parts, with an emphasis on performing the validation of drifting/geodetic orbit data. There are:

1. the estimation of longitudinal river profile from third party altimetry missions flying over the same river,
2. the migration of the CryoSat-2 measurements along the river path to built local "pseudo time series" (i.e., in which local spatial variations were removed),
3. the estimation of the errors that are attributable to the migration process itself, based in in situ data only.

In the end, validation results in SAR, and SARin mode for reference, against in situ data will be presented. The tools are implemented in the case of the Amazon river for which sufficient in situ data and gauging stations allow to perform the 3 points mentioned above.

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Coastal sea level in norway from cryosat-2 sar altimetry

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Session: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3
Presentation type: Poster
Poster number: SAR_009

Abstract:
Conventional altimeters determine the sea surface height with an accuracy of a few centimeters over the open ocean. Although satellite altimetry is a mature discipline, altimeter observations collected over coastal regions suffer from numerous effects which degrade their quality.

The Norwegian coast adds further complications, due to many islands, mountains, and deep, narrow fjords. The European Space Agency (ESA) CryoSat-2 satellite carries a Synthetic aperture Interferometric Radar ALtimeter (SIRAL). Due to the SIRAL instrument, CryoSat-2 is able to observe closer to the coast than conventional altimeters.

This motivates the current paper, in which we investigate the potential of CryoSat-2 data to provide improved observations in the Norwegian coastal zone. We make use of CryoSat-2 SARIn mode observations and determine sea surface heights at 23 tide gauges along the coast, and compare these with independent sea-level observations. Using standard CryoSat-2 geophysical (tide + IB) corrections gives a standard deviation of differences of