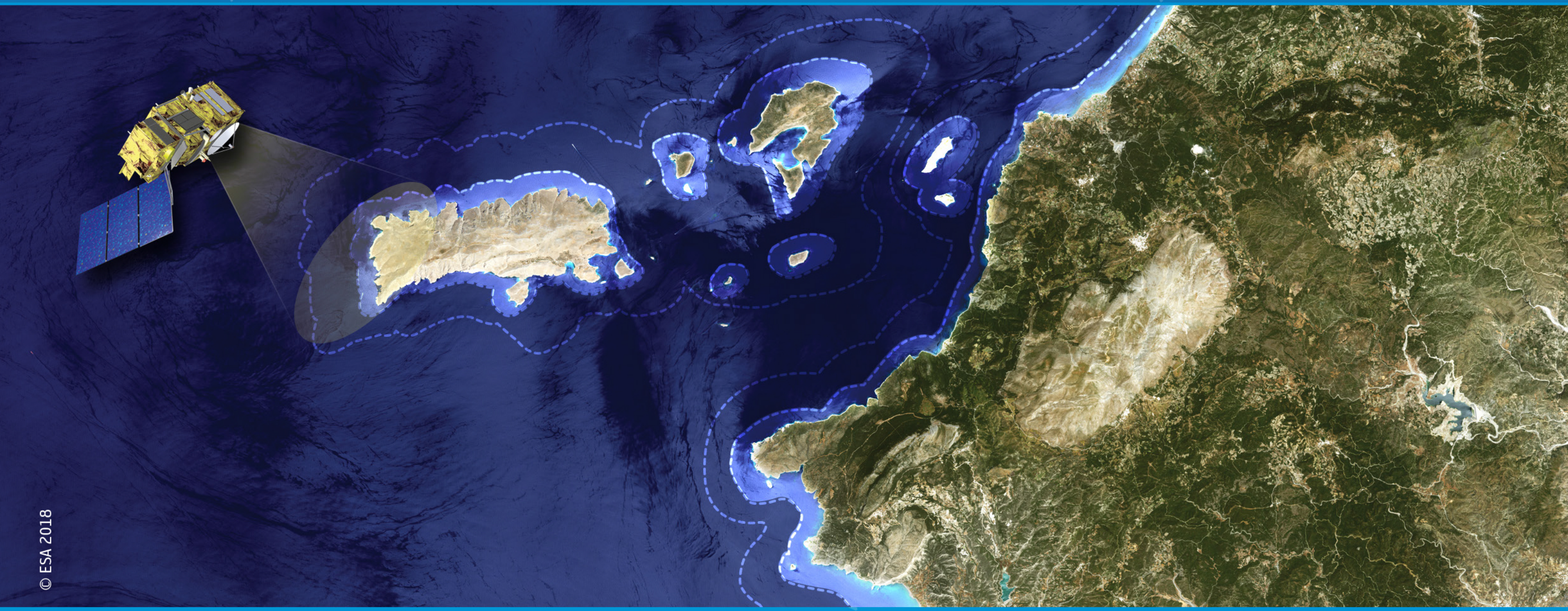
12th COASTAL ALTIMETRY WORKSHOP



FINAL REPORT

4–7 February 2020 | ESA–ESRIN | Frascati (Rome), Italy

12th COASTAL ALTIMETRY WORKSHOP (CAW12)

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CAW12 Final Report

Written, including contributions from CAW-12 participants, by

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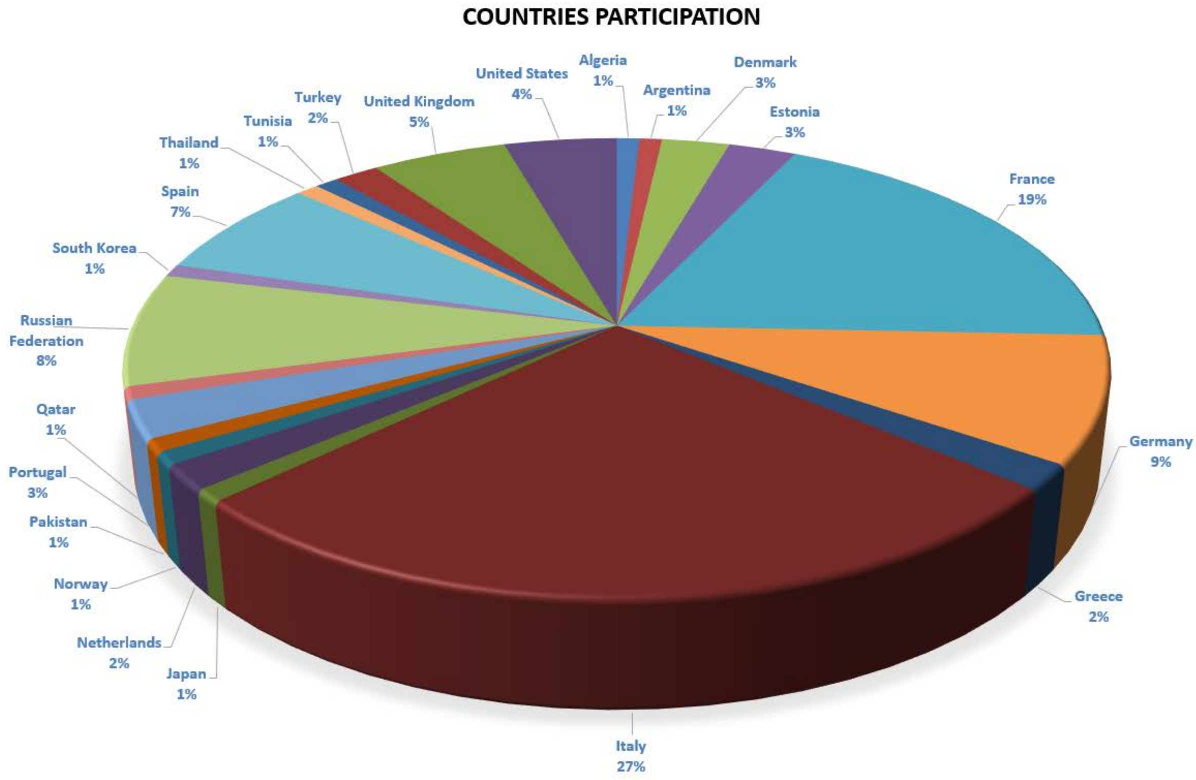
Introduction

The 12th edition of the Coastal Altimetry Workshop was organized by the European Space Agency (ESA) with the support from seven institutions. The workshop brought together 116 scientists from 26 Countries and included a Coastal Altimetry Training course for students and young researchers.



Key topics at the workshop covered 5 themes:

1. Retracking
2. Corrections, Calibration & Products
3. Application of Coastal Altimetry Data
4. Sea Level, Currents & Data Assimilation
5. Synergistic and Climate Studies

and were discussed in 3 sessions:

1. Technical issues in coastal altimetry
2. Applications of coastal altimetry data
3. Synergistic and climate studies

This final report includes the main recommendations, the summaries of all the presented contributions and a summary of the discussion slots. A section dedicated to the feedback provided by the participants ends the document.

All presentations (37 oral and 49 poster) given during the Workshop and the Coastal Altimetry Training course can be downloaded at www.coastalaltimetry.org

The University of Cádiz (Spain) candidates to host the next Coastal Altimetry Workshop in 2021.

Recommendations from the Workshop

- The CAW Community encourages studies focused on the development of gridded L4 coastal products, with a dedicated strategy, to facilitate the uptake by a wider range of users (including modellers).
- The CAW Community encourages studies to improve the sea state bias characterization, with particular focus on decoupling SLA-SWH correlated errors and solve the current limitations in the last ~4Km from the coastline.
- The CAW Community encourages studies focused on comparing ocean variabilities observed by coastal altimetry against remote sensing observations (SST/Ocean Colour in Sentinel-3, SAR and optical imagery in Sentinel-1/2) and model data.
- The CAW Community encourages synergies with in-situ coastal observation systems (e.g., tide gauges, HF radar), as the merging of the satellite-derived information and in-situ measurements is crucial to improve our understanding of the ocean processes that dominate the variability of the SSH in the coastal regions.
- The CAW Community recognizes the importance of research studies of extremes as one of the applications with the highest societal impact in the coastal zone. We encourage, therefore, new dedicated efforts in demonstrating the added value of coastal altimetry, also considering the increasing number of altimeters in orbit, which increases the possibility to observe these phenomena.
- Given the progresses and confidence of latest coastal altimetry dataset up to ~4km to the coast, the CAW Community encourages studies to use data in highly populated coastal areas of the world where there is insufficient coverage of in-situ data. The collaboration/formation with/of local expertise is also encouraged, being of high societal impact.
- To facilitate the exchange of knowledge and reach a broader non-expert audience, the submission of requirements for open-source and open access programs & tools should be encouraged by funding agencies. To tackle the increasing amount and complexity of data funding, agencies should provide services and capabilities that will enable and foster the synergistic usage of coastal altimetry data.
- The CAW Community recommends comparing unfiltered vs filtered data in order to separate the different signal components from the noise at different scales.
- The CAW Community encourages Cal/Val activities, more specifically:
    - Dedicated Cal/Val in-situ experiments should be accurately co-located in space and time with altimeter observations.

  - For existing observation networks, a careful selection of validation sites is required. New diagnostics/methodologies need to be developed to define how to proper select the data. We need to go beyond the simple the distance between Cal/Val site and satellite observations. Knowledge of local processes needs to be included in the definition/selection of the site.

- New corrections based on tide-surge models, rather than on tides and atmospheric models, should be explored to account for non-linearities.
- The provision of FF-SAR data for coastal, estuarine and river applications is required.
- The development of bespoke solutions for Sea State Bias in coastal zone and for SAR mode altimetry is also encouraged.
- The implementation of coastal retrackers in the operational processing chains of Sentinel-3 and Sentinel-6 is recommended.
- The development of constellations of satellites for coastal altimetry monitoring, to address the poor temporal sampling of existing systems, is recommended.

Session 1 – Discussion

- Update on SSB for Sentinel-3: for the operational products, the update of the SSB model is part of the planned evolutions by EUMETSAT.

- About SSB correction: the approach explained by M. Passaro works up to 3-4 km to the coast. Closer to the coast or with FF-SAR, a global SSB model is no more valid as the dynamics in coastal zone is totally different. A dedicated project is required to solve this issue.

- SAR altimetry coastal observations are quite noisy requiring smoothing, is there any recommendations to average & smooth the data properly? It depends by many factors, the coastal areas are very different and it is hard to provide a unique recipe working in all cases.

- There is agreement on the need of SAR coastal retrackers (e.g. SAMOSA+/++) to obtain reliable results at the coast. A coastal retracker is needed in official products (now only SAMOSA2 is available which is not successful at the coast). The CAW-12 Community recommends the implementation of coastal retrackers in the ground segment. For Sentinel-3 Inland Water products, users already made a similar recommendation to implement specific retrackers in the ground segment and guarantee the continuity of estimates at the estuaries.

- On sea level at the coast: we shall work on data contamination. In this regard, all corrections used should be checked as well as other data (moisture, precipitation, etc.). River discharge should be checked as well.

- The impact of sea level change will be in terms of extremes (sea level rise, storm surges & waves): at the moment CCI projects are decoupled, dealing with parameters in different projects and this complicates the situation (e.g. different regions of interest are studied). The ESA HYDROCOASTAL Project will soon start to put together hydrologists and coastal oceanographers and study the interactions between these two regions.

- Regarding the improvement in observing small scales, many progress has been seen in improving the spectral hump to see small scales. From oceanographers' point of view, we need practical examples confirming that we can actually see small features (smaller eddies & coastal currents) only when improved altimetry datasets are used in coastal observing systems.

- The exclusion of the highest waves at the coast in the altimetry data selection is filtering out many effects of interest. However, for validation, this has to be made to assess the quality of the data.

- Regarding round robin exercises to assess the best retrackers, as made for instance in the Sea State CCI project, the Community agrees that there is room to further improve the retracking algorithms for the coastal zone domain.

- We have seen new retrackers (SAMOSA+ & SAMOSA++, only available in the ESA GPOD online processing service, for more information see the thesis by S. Dinardo available at: https://tuprints.ulb.tu-darmstadt.de/11343/) but also new parameters like the vertical velocity of wave particles accounted in the modelling (see thesis by C. Buchhaupt available at: https://tuprints.ulb.tu-darmstadt.de/9015/). New formulation are therefore needed if we start considering new effects. Surely there are still a lot of work to do.

- About future methodologies for validation, for 2D altimeters in the future we could use HF data to validate the meridional and zonal components. However, HF measure velocities, which is a quantity that can be derived from altimetry. Therefore, it is a tricky point. For ocean transport, at L3 & L4, HF data could be used for validation.

- Spectral wave models are performing well at coastal zone and reliable simulations can be performed.

- Regarding SWOT, it will give 2D images. With altimetry we are limited to interpret what happens over just one narrow track. With SWOT, we will learn a lot more.

- Are we adding redundancy in the coastal domain with high posting rate data (e.g. 80 Hz) or does it actually bring new information? The sampling has to be improved but the corrections are not available at HF yet. The Community is still interpolating them and this is a severe limitation.

- Regarding the data editing methods, many of these are taken from ocean altimetry (e.g. threshold methods, detection of outliers based on standard deviation). Methods specific to coastal errors should be developed, in addition to filtering out contaminated waveforms. If the editing method is wrong, the comparison against TG is of very poor quality. There must be a compromise between the number of removed data and the minimum number of data needed to perform a reliable statistical analysis of the errors.

Session 2 – Discussion

- Gridded products working better at the coast are required. An interpolation taking into account the coastline would be a significant improvement. Actual products are not realistic by this point of view.

- In Oceanography, coastal TG data have been combined with altimetry data to produce a product bridging coastline and offshore areas and constraint sea level along the coast. One dataset alone is not sufficient for oceanographers. Smart interpolation and extrapolation methods taking into account water dynamics and coastlines shall be considered. This would lead to a better L4 product. This cannot be extended to global coverage as TGs are not present everywhere but it can be applied regionally. We should also keep in mind that from SSH we get only the geostrophic currents and processes close to the coast are far from being geostrophic. Output from regional models including assimilation could provide more reliable results.

- For gridded products, the right methodology shall be found without introducing uncontrolled smoothing/interpolation. In the Baltic+ SEAL project (http://balticseal.eu/), some coastal approach will be investigated but with specific efforts in this direction (i.e. a project on a regional thematic L4 product) the Community could do much more to improve and stimulate the use of L4 products. Providing not reliable L4 products would result in unsatisfied users who would think that such products bring no added value or contribution if compared to those made available in the past. For part of the potential users of these products (e.g. those working on storm surges prediction), they would not be supported by sea level anomaly from RA. We need near real-time along-track data to support this Community with an accurate description & quality check to allow the correct assimilation of RA data into models.

- About assimilation of the tides, at the moment the assimilation is in the frequency domain (tidal component by tidal component, harmonic by harmonic). The Community could propose a revival of the ESA eSurge and eSurge Venice Projects (http://www.storm-surge.info/). Back then, there were just a few altimeters available. Now the situation has changed. Artificial Intelligence and pattern recognition could be used to detect storm surges in the vast amount of collected data which are now available.

- The closer you get to the coast, the more data are needed. Especially a greater number of in-situ stations is needed to support altimetry and fill the gap due to the repeat cycle of altimetry missions.

- Regarding observations at the coast, it could be useful to have an increased network of HF radars (EU has a very limited and fragmented network in comparison to the USA). If not, analyses at the coast will be complex.

- The CAW Community promotes the creation of a network of HF radars to complement the RADAR altimetry dataset.

- SSB is of cardinal importance. The sea state bias model that does not work in the last km to the coast. SSB at the coast is, by the processing point of view, one of the most important limitations.
- Spatial and temporal sampling are also a limitation. This is a limitation over the open ocean but at the coast the situation is even worse. Integration of data of both different altimeters and independent data is a key point to try to partially cover the space and time domain that we are not capturing with a limited number of missions.
- The CAW Community promotes the production & validation of an L4 synergistic product at the coast integrating data from difference sources (multi-mission altimetry & independent datasets). This is surely more urgent than an L4 product in the open ocean.
- Considering what happened for open ocean altimetry: L2 tracks were available and then L4 gridded products were released attracting new users. Similarly, the Community shall aim at getting to a reliable L4 product at the coast to attract more scientists and increase the usage and impact of altimetry data & data from independent sources (TG, models, etc.).
- Biological oceanographers at the coast use satellite data (SST & OC), L4 gridded products would be beneficial to them, especially if these include multiple missions. Communities waiting for these data are many. Velocity products would be also highly appreciated for investigations on globe/coastal currents.
- Coastal processes include many effects (discharge, tidal mixing, etc.). The physical processes depend on the area of interest and the production of an L4 product could limit some geophysical component (e.g. geostrophic component). The product could result useful but users should be aware of the risks/limitations in using such a product.
- Multi-mission costal products could be used for extremes but we need to provide data with a shorter time delay.
- For extremes, it is important to have the sea level before the event (to be given in input to the model). Altimetry data shall be used in combination with models. When we think about users’ needs, they want not only to observe but also to make forecasts. Therefore, giving the state of the ocean before the extreme would be very useful. Sea level trends at the coast shall be also considered.

Session 3 – Discussion

- On how much we can get close to the coast: Sometimes we can get very close to the coast (1-2 Km), some other times the situation is very different (4-5 Km). It depends on the morphology of the coast. No general rule exists.

- More in-situ data would be beneficial to explore processes and understand what we see in trends and the difference between open ocean and coastal zone trends. In addition, the development of HR models over the time span of typical analyses of SL trends (15 years) is also an important point, and it is easier to be implemented.

- Climate records are long time series of inter-calibrated data released with a specific uncertainty. We recognise that we can reach good results up to 4 Km to the coast. The remaining challenges are those discussed: produce a dedicated hi-res gridded product. At the moment, with 0.25 degrees grid, the coastal information is too diluted or missed.

- Regarding the sea level variations we observe close to the coast, many progresses have been made but we do not know if what we see is related to coastal processes (lack of experience on these data) or to uncertainties. Independent observations of cross shore sea surface height profiles below some altimeter track could be used to improve the analysis if the right instrument/campaign is defined. An array of bottom pressure recorders along the track could also help this kind of analyses.

- For climate, is it indeed important to consider what happens within 5 km to the coast? Yes, it is because sea level budget closure in a key point and the contribution from the inland domain (rivers, glaciers melting, ground water discharge…) shall be accounted and properly evaluated. The other reason, which is related to the previous, is the impact on human activities due to sea level rise at the coast.

- Users living in places in which no data except altimetry data are available shall rely on coastal altimetry as a mean to provide estimates which are as reliable as TG data. In the future, it will be fundamental to demonstrate and convince on the benefits of using satellite radar altimetry in areas where no in situ data are available.

- Products having an along-track resolution of 100 m have been produced and compared to standard Delay Doppler-SAR (300 m resolution in along-track) by members the Community. No quality loss has been observed. The Community promotes further studies on FF-SAR and requires access to fully focused data through platforms such as the ESA GPOD Online and On Demand Processing Platform.

- The across shelf, perpendicular to the coast, resolution of the altimetry has been discussed and very good results presented. The other dimension, along shelf, is typically over much longer length scales but the challenge there is that we have the separation between the ground track of all this nadir-looking missions. To really use coastal altimetry for costal oceanography, we need to put together the whole constellation of missions. It is important that we account for all the differences in these missions to avoid having discontinuities that could jeopardise the use of the data in coastal oceanography or the production of L4 multi-mission products.

- The increase of resolution with FF-SAR could surely improve our knowledge of mesoscale features. However, increasing too much the resolution would probably lead to a point in which the SSH will be influenced not only by dynamical mesoscale features but also by other processes. No presentation has been given on this, but this is an important point. At a very small scale not everything can be converted into geostrophic currents.

- Increasing the resolution also means being able to resolve smaller scale processes. As a consequence, variability increases partially because of noise but also because of the presence of useful signal. Therefore, using higher posting rates and then apply a filter could be counterproductive as signal could be lost.

- Regarding Sentinel-6 data access from EUMETSAT, no specific data access for coastal zone data is planned.

- The Sentinel-3 ground segment has been updated (new L1 and L2 processors) and a full mission reprocessing is underway (two months are missing).

- The CAW community promotes the improvement of retrackers available in Sentinel-3. More retrackers are needed and SAMOSA+ & SAMOSA++, available in the ESA GPOD Online and On Demand Processing Service, are very good candidates to be considered. A round robin considering these and other retrackers is recommended.

Summaries from the Individual Sessions

Opening Session

Altimetric measurement of sea surface height with increasingly high resolution and its applications to the coastal oceans

Lee-Lueng Fu

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Session 1: Technical issues in coastal altimetry

CHAIRS: Jérôme Benveniste, Anny Cazenave

Improving sea level mapping methodology and high-resolution hydrodynamic model for altimetry calibration/validation in the "Pertuis Charentais" area (La Rochelle, FRANCE)

Clémence Chupin, Yann-Treden Tranchant, Laurent Testut, Valérie Ballu

Our project aims to improve the exploitation and validation of altimetry data in coastal area and prepare the validation of future altimetry missions. In case in situ measurements are not under satellite track, and to analyse gradients along and across tracks, we need to understand physical processes involved. On this project, we work on a high-resolution hydrodynamic model with SCHISM in our study area, « Les Pertuis Charentais ». We also improve SSH mapping methodology to link offshore altimetry measurements with coastal tide-gauge observations.

In LIENSs laboratory, we develop a marine ASV ('PAMELi') to collect a wide range of data near the coast. We combine GNSS Antenna and acoustic altimeter observations to measure SSH along track ('Mini-Cyclopee' system). Comparing to a GNSS carpet ('CalNaGeo'), this system provide similar observations at a cm-level. Both measurements also agree with tide gauge observations, but further investigation are still needed.
In coastal area, reliable in-situ measurements are necessary for altimetry validation. PAMELi could help us to compare multi-parameters (SSH, temperature, salinity …) during satellite overfly, which will be useful for validation of future mission SWOT.

Revisiting the small-scale variability in coastal areas thanks to altimetry constellation

M. Raynal, S. Labroue, M-L. Denneulin, B. Picard, G. Dibarboure, N. Picot

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Session 1: Technical issues in coastal altimetry (cont'd)

CHAIRS: Luciana Fenoglio, Francesco Nencioli

Proving that Sentinel-3 Altimetry can be a Shore Success

F. Nencioli, G. Quartly

In this work we assessed the enhanced performance of Sentinel-3 SAR near the coast with respect to those from conventional LRM processing. In our analysis, we compared significant wave height observations from Sentinel-3A with those from a network of coastal wave-buoys around the southwest of the UK. S3A significant wave height observations observations are from the processing baseline 2.33 (variables swh_ocean_20_ku and swh_ocean_20_plrm_ku from cycles 002 to 041 - March 2016 to February 2019). In-situ wave observations are from the Coastal Channel Observatory (http://www.channelcoast.org) and Western Channel Observatory (http://www.westernchannelobservatory.org.uk/) data portals spanning the same time period. The analysis included also output from the WWIII-AMM7 wave model available from CMEMS (product NORTHWESTSHELF_ANALYSIS_FORECAST_WAV_004_012).

The model results were used to define marine areas where the wave height will co-vary with that at the selected buoy. Within these coherent areas we find a strong correlation between our satellite and in-situ observations and can demonstrate improved performance for the SAR estimates approaching the coast (whereas the errors for the PLRM estimates increase). Our coastal analysis finds r.m.s. errors of 0.46 m, with no dependence upon swell direction or period.

Identifying which in-situ observations can be used for the cal/val of remote sensing observations by deriving coherent co-varying regions provides better results than simply using geographical distance. Furthermore, our approach could be readily replicated for other altimeters as well as extended to other regions of the globe.

Improving the Validation Technique for Coastal Sea Level Rates from Satellite Altimetry and Tide Gauge Observations

A. Shaw, F. M. Calafat, C. Gommenginger, C. Banks, N. Dayoub, J. Benveniste

The recent introduction of specialised retrackers, such as the Adaptive Leading-Edge SubWaveform (ALES), has raised the possibility of retrieving good quality

altimetry data closer to the coast. We use geostatistical tools to identify regions of long sea level length scales based on data from tide gauges and satellite altimetry in order to improve the validation technique for altimetry observations as part of a study conducted within the framework of the ESA Sea Level Climate Change Initiative. The performance of the coastal altimetry observations is assessed by comparing with tide gauges grouped according to their decorrelation values, which provides a valuable tool.
The sea level trends from tide gauges and altimetry agree (within error bars) but the standard errors are large mainly due to the short time series. A constant distance to the coast may not be the best criterion to ensure a good comparison with tide gauge data. The closest distance to the coast needs to be assessed at each location as sea level trends and variability vary regionally due to different ocean processes driving sea level changes. There are large differences between altimetry and tide gauge measurements and further work is needed to understand these differences and try to reconcile them.

The data for the period 2002 to 2016 used here are from XTrack/ALES altimetry v1.0 (supplied by LEGOS/TUM) and monthly mean values from the Permanent Service for Mean Sea Level tide gauge data network (https://www.psmsl.org). The following corrections are applied to the tide gauge observations : 1) the dynamic atmospheric correction from AVISO (https://www.aviso.altimetry.fr/); 2) Glacial Isostatic Adjustment using ICE-6G (https://www.psmsl.org/train_and_info/geo_signals/gia/peltier/); and 3) where GPS is available (https://www.sonel.org).

CalNaGironde: The Gironde Experiment

N.Ayoub, S.Barbot, L.Benoit, P.Bonnefond, C. Brachet, M. Calzas, C. Conessa, C. Drezen, L. Fichen, L.Froideval, J.Garcia, C.Giry, A. Guillot, G.Jan, F.Lyard, L. Magot, N.Picot, J.-C. Poisson, P.Ternon, G. Valladeau

In the frame of the SWOT mission, a mission with challenging objectives on surface height & slope accuracies, this experiment was a test campaign to better estimate which CalVal means shall be used.

In the proposed experiment, authors:

- Test and analyze ground means to measure the water height
- Analyze the actual water height variations along the river over 200 kms (influence of tides, currents, sand banks…)
- Analyze the actual water height variations across the river (identical)
- Analyze the accuracy of existing tide gauge network.
- Compute the local bathymetry and current velocity with ADCP

A previous similar campaign (with less instruments) was held on the Seine River in June 2017. Authors used Co-located measurements (time/space) by: CalNaGeo (“GNSS-carpet” developed by DT-INSU/CNRS), GNSS buoys (developed by DT-INSU/CNRS), Cyclopée (radar+GNSS+gyrostabilisation developed by DT-

INSU/CNRS), HyDrones, lidar+GPS on drone (initially developed by HyDrones/CLS (now by vortex-io), ADCP, 2 Tide gauges maintained by SHOM and 10 by DREAL, Airborn LIDAR (M2C, university of Caen). Algorithms involved mainly GNSS processing. The obtained results underlined a very good coherence with the different instruments at 1-2 cm rms. The benefit for the coastal altimetry community lies in an improved knowledge of estuaries phenomenology and future research will be about calval for SWOT and other altimetry missions.

Requirements and recommendations:

- Is in situ giving the truth? As shown, local effects can impact the comparisons with tide gauges:
    - Distance: strong effects (tens of cm) in particular conditions (river branches)
    - Datation: up to 10 cm for time tagging error of several minutes depending water level time gradient (strong tides in estuaries)
    - Geodetic referencing uncertainty: several cm (often only based on geoid grid instead of accurate levelling)
- Using existing networks of instruments is a good opportunity, but they were not designed to achieve our level of accuracy (SWOT or other FF-SAR nadir missions like JCS or S3A/B)
- If we want to safely verify satellite data accuracy we must end-to-end design, install and monitor our own in situ instruments (AdoptACoast as part of ADOPT-A-CROSSOVER International project)

SAR Altimetry performance and improved retrieval methods in the Coastal Zone. Results and recommendations from the SCOOP project.

D. Cotton, T. Moreau, M. Raynal, E. Makhoul, M. Cancet, L. Fenoglio-Marc, C. Gommenginger, M. Naeije,M. J. Fernandes, C. Lazaro, A. Shaw, M. Restano, A. Ambrózio, J. Benveniste

Presentation of the results of the SCOOP project which aimed, 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. Another objective is 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.

Data Sets and algorithms : Two SAR altimeter data sets were produced, a first data set with processing intended to be equivalent to Sentinel-3 baseline processing, and a second data set with modified processing including application of zero-padding (factor 2) and Hamming windowing. Sea Surface Height, Significant Wave Height and sigma0 were investigated.

Analysis and results:

- Analysis of performance of the two test data sets in the coastal zone, in terms of noise, validation against other products and in-situ data, appropriate methods for data selection and including an investigation of the effect of the "angle of arrival".
- Analysis of the performance of two further test data sets produced by isardSAT intended to improve performance at the coast, firstly using the first ocean window delay (when the altimeter ground track crosses from land to ocean) as a tracking reference, (2) using the mean sea surface as tracking reference.
- A study by NOC to investigate SAR data characteristics at the coast with the objective to develop and test potential improvements to coastal zone processing, including stack selection, sub waveform retracking, SAR stack optimal weighting.
- Main conclusion is that zero-padding and Hamming Windowing improved performance significantly in the open ocean for significant wave height, and slightly for Sea Surface Height. No improvement was seen for sigma0. Therefore, it was recommended to apply these two modifications in routine operational processing.
- isardSAT coastal processing, using the mean sea surface as a reference for retracking based around a reduced waveform was shown to reduce noise in SSH retrieval
- No difference in performance (noise) was found for different angles of arrival with respect to the coastline, though more data were lost for oblique angles (nearly parallel), due to selection based on waveform misfit.

Benefits:

- Confirmation of performance of SAR Mode from Sentinel-3 baseline applied to Cryosat in open ocean and at the coast
- Guidance for processing and data filtering (with detailed documentation on processing)
- SAR mode test data sets

Recommendation / Prospects for further research: available in SCOOP Road Map, main points:

SAR Mode Processing

- The use of the innovative SARM processing (Zero-padding and Hamming window) for Sentinel-3 mission is recommended to improve ocean altimetry products
- In situ measurements are needed to fine tune and calibrate the PTR settings.
- SSB correction dedicated to the SAR SSH is needed to compute accurate SSH.
- Further studies should be carried out into the development of coastal re-trackers for SAR mode echoes.
- Other approaches should (continue to be) developed and evaluated:

Stack characterisation / selection; Amplitude and Dilation Compensation (ACDC); Fully Focussed SAR processing; effect of vertical motion of wave particles.

RDSAR Processing

- Coastal re-trackers should be applied for coastal data sets.
- Further tests on MLE4 re-tracker on the RDSAR product should be carried out.

Wet Troposphere Correction

- The GPD+ correction clearly outperforms the ECMWF operational model-derived correction.
- The composite correction present in Sentinel-3 products is not suitable for use. The GPD+ WTC would be an added value for Sentinel-3A products

Documentation and reports at www.satoc.eu/projects/SCOOP/

Assessment of Sentinel-3 and Jason3 Altimetry Data in The Coastal Zone

N. Dayoub, C. Gommenginger, A. Shaw, C. Banks, H. Snaith

The Study focuses on assessing the S3A/3B SAR, PLRM data available on the standard SGDR product and the retracked ALES data in the coastal zone. It also investigates the impact of using 20Hz sea state bias model on noise reduction of consecutive differences of the uncorrected sea surface heights.

The assessment concluded that Sub-waveform retracking (ALES) brings many benefits for LRM and P-LRM data in the coastal zone. It also showed that the ALES noise reduction compared to SGDR date in the open ocean comes mainly from applying SSB at 20Hz. The study reported significantly better performance of S3 SGDR SAR in coastal zone compared to ALES and SGDR PLRM results. However, track orientation to the coast is critical for the S3 SAR achievable performance.

Session 1: Technical issues in coastal altimetry (cont'd)

CHAIRS: Jesús Gómez-Enri, Matthias Raynal

Retracker bias characterization in coastal zones

F. Niño, F. Birol, D. Blumstein, H. N. Ngo, F.Léger

This work is motivated by the need to quantify how well retrackers behave near the coast, and particularly if there is a way to predict if a bias exists in a particular coastal setting. There are very few instrumented calibration sites providing "ground truth", so this study presents a simulation environment in which retrackers can be tested and statistical properties assessed. We use a mature and well tested simulator of radar waveforms created at Legos and used since 2014. Using topography data from SRTM 3 and virtual stations obtained at the crossings of the AltiKa tracks with Mediterranean coastlines, we generate a dataset of ca. 139000 waveforms obtained at 3600 virtual stations, located from 10km up to the coastline (using distance to coast as calculated from GSHHG data). Waves were included in water areas, and backscatter is provided per type of surface: a specular and diffuse backscatter for water and a purely diffuse value for land. All of these waveforms have been retracked by the MLE4 algorithm (kindly provided by F. Boy from CNES). The success of retracking is assessed in terms of diffgate: the difference between the epoch given by the retracker and the true gate where the nadir's water level should be found.

No simple relationship was found between diffgate and the statistics of the topography inside the footprint area, nor for statistics of backscatter. The estimated probability density function of diffgate shows it is not gaussian distributed nor symmetrical and there is a bias of about 1/3 gate (or 10 cm) for our simple experiment setting. The distribution is also different for distances greater and those less than 10 km from the coast. This work could be useful as a retracker comparison benchmark, since it provides a "ground truth" with which results can be referred to. As further work, we need to test a wider spectrum of wave amplitudes, as well as diversify the backscatter properties used. A global dataset can also be generated instead of being limited to the Mediterranean.

Round Robin Assessment of Radar Altimeter LRM and SAR Retracking Algorithms for Significant Wave Height: A Coastal Point of View

F. Schlembach, M. Passaro, G. Quartly, F. Nencioli, A. Kurekin, G. Dodet, J. F. Piollé, F. Ardhuin, C. Schwatke, D. Dettmering, F. Seitz, P. Cipollini, C. Donlon

A comprehensive, objective comparison between different LRM and SARM retracking algorithms was conducted in the framework of a Round Robin exercise of the SeaState_cci project. Thereby, different metrics were extracted with respect to outliers, intrinsic noise, wave spectral variability, comparison against wave models and in-situ buoy data.

Datasets used: Jason-3 and Sentinel-3A. Buyo data from the CMEMS network was used. Also the ERA5 and an ERA5-based hindcast (increased resolution of 18km and no assimilation of altimetry data) were used for validation. The performance of the following algorithms were evaluated:

- LRM: MLE-3, MLE-4, Brown-Peaky, WHALES, WHALES_adj, WHALES_realPtr, WHALES_realPtr_adj, Adaptive, Adaptive_HFA, TALES, STARv2

- SARM: SAMOSA-based (SGDR), WHALES-SAR, DeDop-Waver, LR-RMC, LR-RMC_HFA, MLE-4-PLRM, TALES-PLRM, STARv2-PLRM

No such comparable assessment has been conducted so far in the past, comparing different retrackers in terms of various performance metrics. The dependence of the quality and quantity of satellite altimetry SWH measurements in the coastal zone has been shown. There are yet a lot of challenges for improving retracking algorithms, in terms of precision for high and low sea states and accuracy and number of valid measurements in the coastal zone.

Defining a retracking manifold within a radargram stack to improve satellite altimetric water level over coastal seas: A feasibility study

M. Tourian, O. Elmi, N. Sneeuw

Single-waveform retracking for satellite altimetry applications over coastal zones has reached its limits, obtaining decimeter-level accuracy. The existing retracking methods find a retracker offset in a waveform by analyzing the variation in backscattered power along the bin coordinate. This makes the retracking procedure strongly dependent on noise in backscattered power. Moreover, the success of such methods is only guaranteed for certain waveform types requiring cumbersome pre-processing steps including waveform classification.

With the launch of the operational Sentinel-3 series of the European Copernicus programme, the algorithms to obtain highly precise water level estimates over inland waters and coastal seas need to become more robust, efficient and fit for automated use. Therefore, the main objective of this study is to demonstrate the potential of developing a next-level retracking algorithm and, consequently, improve altimetric water level determination over coastal regions. To this end, neighboring waveforms are collected into a (single-pass) radargram and, then, such radargrams are stacked over time. These so-called (multi-pass) radargram stacks contain, unlike single waveforms, the full information on spatio-temporal variation of backscattered power over water surfaces.

The radargram stack eases the recognition of patterns like retracking gate, shoreline, tides, etc. Instead of a retracking gate as a point in the 1D waveform, in a 3D radargram stack a surface referred to as retracking manifold is to be determined. The potential of our new approach will be demonstrated using Sentinel 3B data, pass number 655, over the Cuxhaven tide gauge station at the Wadden Sea.

The algorithm is illustrated below. Within a radargram stack, a manifold will be defined, which acts like a retracker.

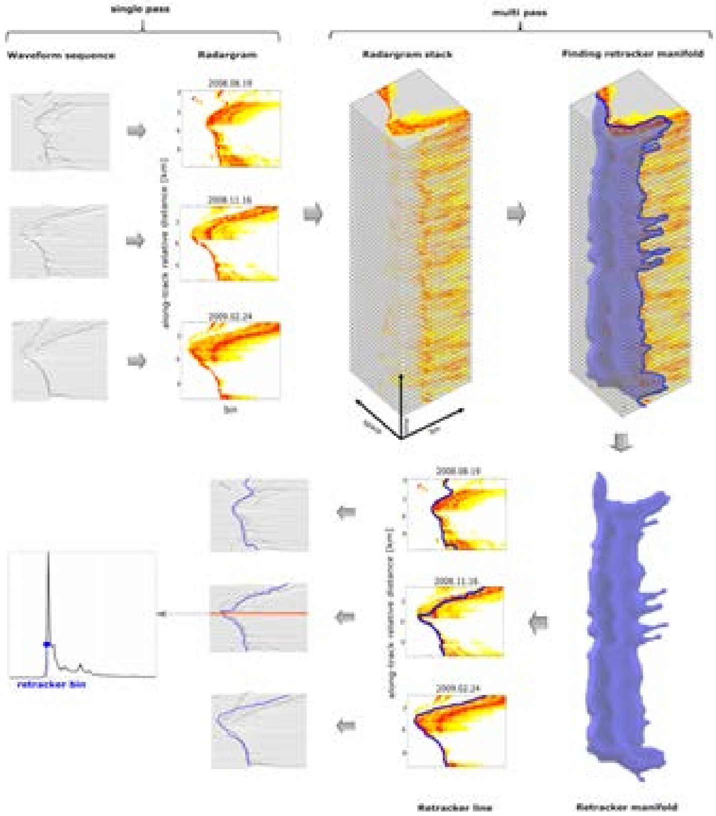


Figure 1: defining a manifold retracker over radargram stack

The standard retrackers do not provide satisfying results in the coast due to strong land contamination. The OCOG retracker outperforms Ocean and Sea-Ice retrackers with a poor performance of 0.56 correlation and 0.28 RMSE.

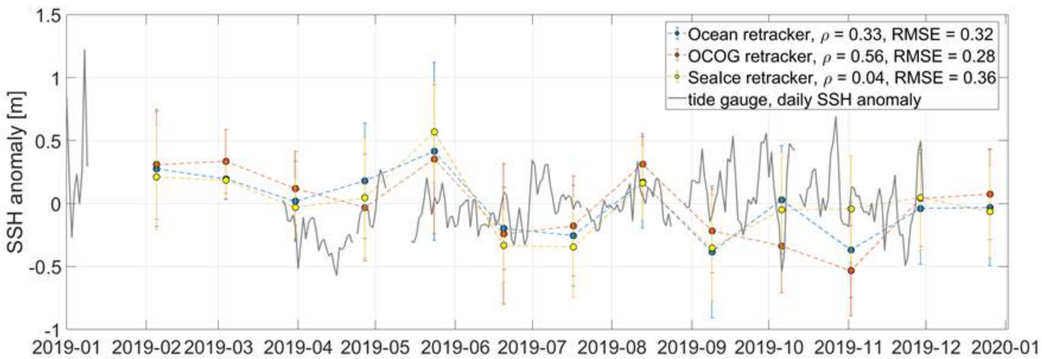


Figure 2: water level time series at the Cuxhave from 3 standard retrackers

In order to define a retracking manifold within a radargram stack, a Markov Random Field (MRF) model can be developed. The MRF model benefits from conditional models in bin-space, bin-time and space-time axes (radargram), which are sensitive to the characterized patterns. Then, the maximum a-posteriori solution will be found resulting the retracking manifold. To this end, the problem will be reformulated as an energy function minimization issue. Here, the performance of different classes of optimization techniques like max-flow, message passing, linear programming relaxations, move making and global optimal methods are investigated. We will also investigate a method to estimate the uncertainty in retracker manifold.

The developed retracker:

- Is not dependent on waveform type: Practically, each of the existing retracking algorithms has its best performance on a specified type of waveform (Deng and Featherstone, 2006). For instance, fitting algorithms are appropriate for the quasi-Brown model waveform and are not applicable to a quasi specular waveform. OCOG retracking method is sensitive to noise in the trailing edge, which deteriorates the estimation of the waveform mass center. Threshold retracking and the IP methods are only applicable to waveforms with a clear leading edge.

- Is not sensitive to blunder: The performance of existing methods is generally sensitive to blunders and strong variations in waveform. The correctness of estimated retracker offset is highly vulnerable in the presence of blunders in waveforms.

- Does not require pre-processing: The performance of retracking methods strongly depends on the waveform type. Therefore, pre-processing steps must be applied before retracking steps. This often includes excluding noisy waveforms and (un-, semi or supervised) classification of waveforms.

- Does not ignore the spatio-temporal information: The existing single-waveform retracking methods retrack the waveforms by analyzing the backscatter power variation in only bin-coordinate and ignore the spatio-temporal variation of waveform over a certain water object.

Outlook for future research: Investigating the best conditional model in bin-space axes (radargram) sensitive to shoreline pattern, off-nadir pattern and jumps in leading edge

Assessing the quality of 80 Hz Sentinel-3A SRAL sea level data around Spanish coasts

A. Aldarias, J. Gómez-Enri, I. Laiz, B. Tejedor, S. Vignudelli, P. Cipollini

Two and a half years (June 2016 - November 2018) of Sentinel-3a SRAL (S3A-SRAL) altimetry data were validated at selected sites around Spanish coasts. Three coastal sites were selected to do this work: Huelva (Gulf of Cadiz), Barcelona (Western Mediterranean Sea) and Bilbao (Bay of Biscay). Two tracks were selected in each site, one ascending and one descending. The altimetry data were obtained from the European Space Agency Grid Processing On Demand (GPOD) SARvatore (SAR versatile altimetric toolkit for ocean research & exploitation) service. In this work, we assess the new product with sampling rate of 80 Hz (equivalent to an along-track distance between two consecutive measurements of about 85 m). Data were validated using in-situ radar tide gauge data from the Spanish Puertos del Estado.
The altimeter-derived sea level anomaly time series were obtained using the corrections available in GPOD. The sea state bias correction (SSB) is not available at 80 Hz in GPOD; hence it was empirically approximated to a fraction of the significant wave height that

minimises the sea level anomaly RMSE with respect to the tide gauges, i.e. 5% of SWH. The validation was performed using two statistical parameters, the Pearson correlation coefficient (r) and the mean square error (rmse). In the 5-20 km segment with respect to the coastline, the results were 6-8 cm (rmse) and 0.7-0.8 (r) for all the tracks. This "distance of good quality" to shore reaches a minimum of 3 km for the tracks at Huelva and the descending track at Barcelona. Our results demonstrated that data screening plays a key role in the selection of the altimeter valid data. The comparison against tide gauges spotted anomalous sea level data not removed in the standard screening used in this work. This work will be extended to other zones with different characteristics, an also including Sentinel-3b SRAL

SWOT Datasets for the Coastal Areas

J. Hausman, M. Gangl, M. Gierach, C. Oaida, S. Vannan

Surface Water and Ocean Topography (SWOT) mission will measure water height for oceans and inland water. While no coastal specific datasets are currently planned for SWOT, it will measure waters in the coastal and estuarine areas, with a 21-days repeat. The datasets it will produce fall into two categories Low Rate (LR) and High Rate (HR). The level 2 LR data will be available globally and have oceanic corrections applied. It will come in 2 resolutions smoothed with 2 km spatial resolution on an Earth-fixed grid. The second resolution is unsmoothed, so not on an Earth-fixed grid, 250 m spatial resolution and is meant for experts. The HR datasets are designed for inland water and will only be produced for inland waters and nominally 1 km off the coast. These datasets will only have inland corrections, so no ocean tides or sea state bias. Level 2 datasets available over the coastal area are pixel clouds. The raster is on a 100 m x 250 m Earth-fixed grid. The regular pixel cloud will be on 100 m x 225 m native grid and is meant for expert users. SWOT will produce 20 TB of data per day so PO.DAAC will store these data on the cloud and migrate current service capabilities as well. Users will be able to search, discover, subset and visualize data, as the currently do. Reprojection and regridding services will also be made available, along with APIs. In this way, users can bring their code up to the cloud and compute next to the data or use the services to reduce the data volume and download. Either type of access is free to the user. Jason-CS/Sentinel-6 will be the first mission to be stored and distributed from the cloud.

Session 1 - Posters

Inland radar altimetry for intermediate scale water bodies with nadir specular echoes and a constellation of small satellites

R. Abileah, S. Vignudelli, A. Scozzari

We previously reported (8th Coastal altimetry Workshop, Lake Konstanz, 2014, and 25-years of Progress in Radar Altimetry, Ponta Delgada, 2018) on the prevalence of quasi-specular echoes from intermediate scale (50m to 250 m) inland water bodies. [Abileah et al., 2017], based on Envisat, showed range measurements of specular echoes with coherent 'zero-Doppler' summing of a few individual echoes (IEs), demonstrating the potentiality to get an accuracy of <1 cm. Land interference is virtually eliminated. This paper shows repeatability with Sentinel-3:

Abileah, R., Scozzari, A., Vignudelli, S. (2017). Envisat RA-2 Individua Echoes: A Unique Dataset for a Better Understanding of Inland Water Altimetry Potentialities. Remote Sensing, 9(6), 605.

Abileah et al., 2017 explained in Sections 2.1, 3.1 a new method to estimate water heights from Individual Echoes (that we now call "Precise Inland Surface Altimetry", PISA). Equation 1 is the PISA model of a complex radargram. Equation 2 is the PISA solver for water level. PISA uses a water map M to compute Z(h) that is the theoretical complex radar gram for water body M with water level (h).

We have examined a dozen locations worldwide: transponders, rivers, lakes, and the Salar de Uyuni. We have shown in the poster four case-studies: (1) Crete transponder; (2) Arno River, just wide enough (about 100m) to have one full Sentinel-3 (S3) burst over water; (3) Salar de Uyuni; (4) 800 m wide Sils Lake (Silsersee, Switzerland). We established with high confidence that 1) interpolation of the waveform peak is a potentially very accurate measure of water level to sub cm relative accuracy; 2) No need for ad hoc "retracking"; 3) Range rmse is ~1cm for IEs, <<1cm for burst integrated IEs. We investigated 3 sites along the course of the river between Florence and the sea. Castelfranco is the best location for consistent, unambiguous specular echoes. All passes have very similar radargram signature exhibit a similar water level of about 11 m.

Requirements and recommendations: validation plan to estimate water level accuracy with in situ data. It is fundamental to have simultaneous gauge measurements with altimeter passages and a rigorous selection of in situ gauge sites, which must be as much as possible representative of the "virtual" (satellite) gauge, under the hydraulic point of view.

Improving Conventional Altimetry in coastal area: Review of the performances derived from innovative LRM retrackers

M. Raynal, A. Guérou, H. Roinard, F. Birol, S. Labroue, P. Thibaut, F. Piras, N. Picot

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

SAR single and multi looks water level over small inland water bodies

S. Roohi, S. Dinardo, R. Scharroo

The contribution has been withdrawn.

Regional In Situ CalVal of Sentinel-3 Altimeter Range

M. Cancet, P. Bonnefond, C. Watson, B. Haines, F. Lyard, O. Laurain, P. Féménias

In situ calibration ensures regular and long-term control of the altimeter sea surface height (SSH) time series through comparisons with in situ tide gauge records. Usually, in situ calibration of altimeter SSH is undertaken at specific CalVal sites through the direct comparison of the altimeter data with the in situ observations. NOVELTIS has developed a regional CalVal technique, which aims at increasing the number and the repeatability of the altimeter bias assessments by determining the altimeter bias both on overflying passes and on satellite passes located a few tens of kilometres away from the calibration site. In principle this extends the single site approach to a wider regional scale, thus reinforcing the link between the local and the global CalVal analyses.

The regional method was initially developed at the Corsican calibration sites of Senetosa and Ajaccio in collaboration with OCA and OBSPM. It was successfully implemented at the Californian site of Harvest and at the Australian site of Bass Strait, in close collaboration with JPL and the University of Tasmania, respectively. The method was used to compute the altimeter biases of Jason-1, Jason-2, Envisat and SARAL/AltiKa at all these sites.

Today, the method is used to monitor the Sentinel-3A&B missions and shows high potential for the monitoring of any future altimetry missions. It is a means to assess the stability of the missions in coastal regions governed by very different ocean dynamics conditions and to evaluate the coastal performance of the various corrections that are available in the altimetry products.

A Regional Evaluation of Sentinel-3 SRAL Derived Geophysical Parameters in Open Ocean and Coastal Areas in The North Sea

H. Ranndal, O.B. Andersen, K. Nielsen

This work is part of the SIMOS project, which aims to advance the commercial application of existing metocean satellite data that are relevant for the maritime sector, with a main focus on the Sentinel-3 SRAL product.

From the official Sentinel-3a L2 data product delivered by Copernicus, we have derived the Total water level envelope (TWLE) as a measure of the observed sea surface height for data from launch and to the end of 2019. TWLE estimates, together with the altimetry derived Significant Wave Height (SWH) and wind speeds, were compared to in-situ data from the NWS Data Portal, at locations in open ocean as well as coastal areas.

From the results it is clear, that the Sentinel-3 product is very reliable in open ocean locations, but that care still needs to be taken near the coast, where the L2 data can be misunderstood if not treated correctly. The quality of the coastal data is very dependent on the simplicity of the coastlines, where e.g. mudflats give rise to erroneous results. In general, the altimetry derived wind speeds are underestimated in coastal areas, whereas the SWH estimates are overestimated near the coast. It should be investigated if perhaps these coastal biases can be avoided with a more appropriate post processing. To see the relative performance of Sentinel-3a, CryoSat-2, SARAL, and Jason-3, means of the RADS range rms for 2018 were compared.

The results revealed the mean range rms for Sentinel-3a is a couple of centimetres lower than the Jason-3 satellite. However, the RADS ranges for Sentinel-3a and CryoSat-2 do show some sensitivity near the coast, which is not seen for the conventional altimeters carried by SARAL and Jason-3.

More work should be put in to understanding these differences, and if it also applies to original SAR data without RADS processing.

Validation of Multi-Satellite Altimetry Data Utilizing a High-Resolution Marine Geoid for the Baltic Sea

M. Mostafavi, A. Ellmann, N. Delpeche-Ellmann

Most satellite altimetry (SA) products often reflect the Sea Surface height (SSH) with respect to a reference ellipsoid. In practicality, computations of the Dynamic Topography (DT) that is referenced to the geoid allows for a more stable reference frame and it also represents the mean and time varying ocean dynamics. In this study we examine and validate SSH from both SA and tide gauges. Whereby the tide gauges derived SSH are fitted to a high-resolution geoid for the Gulf of Finland, Baltic Sea.

For comparison between the SSH calculated from the SA and TG. The methodology required SA range deduced to SSH after applying corrections. Virtual station (VS) has been selected at specific intersection points of ascending and descending passes and represents TG Dynamic Topography that is corrected for geoidal height. TG data deduced to DT using high-resolution geoid. SSH discrepancies calculated between SA and VS in period of 2016−2018 in three modes: (a) at location of VS (b) MEAN of 7 points closest to the VS location and (c) MEDIAN of 7 points closest to the VS location and applied to SA data using standard deviation (S.D) and root mean square error (RMSE).

Datasets used:

- EST-GEOID-2017: Estonian quasi-geoid model, covering the region from with spatial resolution of 0.01° x 0.02° which is referred to the GRS80 ellipsoid.
- TG data provided by the Estonian Environment Agency with hourly DT measurements refer to Baltic 1977 height system. The overlapped time span of TG data with SA data has been considered.
- Sentinel-3A: SRAL Non-Time-Critical (NTC) Marine Level 2 products from 01 March 2016 to 26 January 2018 (Cycle 1-27), 20Hz Ku-band with standard measurement are used.
- Jason-3: Geophysical Data Records (GDRs) Level 2 data from 12 February 2016 to 09 August 2019 (Cycle 0 - 128) at 20Hz Ku-band are used.

Results:

- Sentinel 3A discrepancies varied from as high as 36cm at station Heltermaa to 10 cm at Dirhami. The most optimum method appears to be the mean of 7 closest points to the VS.
- Comparison of Sentinel-3A and Jason-3 at three locations (Dirhami, Kunda and Narva) show that the Jason-3 data to have better RMSE over GoF.
- Discrepancies between SA and TG show STD between 8-28 cm

Outlook for future research:

Further process over study area using different datasets (multi-mission SA data) and different retrackers seems to be necessary to obtain better agreement.

Monitoring marine litter with ocean current products in the North Atlantic Ocean

M. Lux, E. Sahuc, M. Cancet

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website

A new high-resolution coastal model in Kerguelen Island for CAL/VAL operations

Y. Tranchant, C. Chupin, L. Testut, V. Ballu, O. Laurain, P. Bonnefond

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Sentinel 3A approaching the coast: effects of track orientation and coastal topography

J. Gómez-Enri, A. Aldarias, S. Vignudelli, P. Cipollini

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Recalculation plan for altimetry measurements of Russian GEO-IK satellites No 1-9 ((1985–1995))

S. Lebedev

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Systematic Differences Between Tide Gauges and Altimetry Related to Coastal Tidal Dynamics

S. Esselborn, J. Illigner, T. Schöne

Motivation of the poster is to assess the accuracy of total water level envelope (TWLE) from altimetry at three tide gauge stations in the German Bight (SE North Sea) for the period 2010-2019. Special focus is put on systematic differences between the two data sets related to differences in the tides at the measurement locations of the two systems.

Datasets used:

1. altimetry at virtual stations derived from 20/40Hz GDR data from SARAL/AltiKa, Jason-2, Jason-2 and Sentinel-3A with careful editing applied. The virtual stations located at distances between 7 to 50 km from the tide gauges,

2. 1-min. tide gauge data from the FINO1-platform, the open water island Helgoland and the island Sylt located at intertidal flats.

We present a technique to settle systematic differences between the data sets related to the spatial inhomogeneity of the tidal dynamics. We assume a time shift and an amplitude scaling between virtual altimeter and tide gauge stations. The time shift and scale are estimated by optimizing RMS errors and correlation coefficients between collocated TWLEs.

The derived tidal correction significantly improves the RMS error between tide gauge and collocated altimeter TWLE for all missions in the German Bight by 25-70% (depending on location and mission). This is even the case for the location Sylt where the tides are not strictly linear any further.

The work will be extended with more and absolutely referenced tide gauge stations in the region. The period will be extended as well to the beginning of the 2000's.This will allow to monitor drifts and biases more accurately for all station and missions including as well Envisat and Jason-1.

The TUDaBo Processor for SAR and RDSAR Mode

L. Fenoglio, C. Buchhaupt

Improved RDSAR and SAR processor for L1 and L2 data are needed to derive more precise and accurate parameters from altimeter observations. TUDaBo SAR-RDSAR is a software processor prototype developed to experiment with SAR mode data from L1A (FBR) to L2. TUDaBo SAR-RDSAR is made available at ESA's G-POD service and enabled to registered users. Reduced SAR, unfocused SAR and Low resolution Range Cell Migration Correction (LRMC) mode data are generated for both CryoSat-2 and Sentinel-

3A. The user can experiment with different configurations, using various signal processing options and retrackers. All L1B/L2 products have the same geolocations and time tags, which make possible direct comparison without interpolation. An introduction on the GUI and examples of results are given.

The processing methodologies are: RDSAR (Reduces SAR mode), SAR unfocused, LRMC (Range Migration Corrected). Adopted algorithms for retracking are BMLE3, SINC and TALES (RDSAR) and SINCS (SAR). Optionally It is possible to account for the vertical motion of wave particles (VVWP), using the vertical velocity OV in the waveform model (SINCS-OV). Another option is to transform the samples in the stack to get a distribution close to normal distribution (zero skewness, ZSK)

TUDaBo in GPOD is a processing tool with several options and different outputs. The user can experiment with different configurations, using various signal processing options and retrackers. All L1B/L2 products have the same geolocations and time tags, which make possible direct comparison without interpolation. An introduction on the GUI and examples of results are given. TUDaBo provides RDSAR coastal product and is comparable to SARvatore SAMOSA+ in open ocean.

TUDaBo is a flexible tool. Save in space is granted thanks to online access to S3 and CS-2 archive. It is supported by GPOD Team for successive integration of versions, user authorisation and generic user support. The TUDaBo processor can be extended to add new modes (RCM-F, FF-SAR) and include new options.

It is recommended to provide precise documentation on processing steps from L0 to L2 both in official product and in published results. Names, definition and procedures should be consistent in all official documents and the project reports. A manual for newcomers and also for experts, to be used as reference, should be produced; this should be clear, precise and complete.

Fully Focused SAR Altimeter Processor for Assessing the Full Capabilities of SAR-mode Altimeter Missions

T. Moreau, P. Rieu, J-C. Poisson, F. Borde, F. Boy, S. LeGac, N. Picot

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

GEO-IK Space Geodetic System

V. Kosenko, V. Zvonar, V. Karnaukhov, D. Shapovalov

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Session 2: Applications of coastal altimetry data

CHAIRS: Mathilde Cancet, A. Abulaitijiang

Bathymetry Improvement and Tidal Modelling at Regional Scales

M. Cancet, F. Toublanc, F. Lyard, G. Dibarboure, N. Picot, T. Guinle

Coastal processes (tidal currents, storm surges, waves) directly impact offshore and coastal activities and studies. Many studies and applications lie on the quality of ocean modelling and the limited accuracy of bathymetry, especially on the continental shelves, contributes to degrade the numerical model performance despite significant use of in-situ and satellite data assimilation. In particular, the ocean tide models are very sensitive to the bathymetry accuracy on the shelves, where the ocean tides show the largest amplitudes and are highly non-linear.

Increasing the grid resolution and local model tuning are some of the means to improve the tidal model performance in the coastal regions, and large improvements have been achieved thanks to this approach. However, increasing the resolution of the model implies using bathymetry data of consistent quality and accuracy, which is today the main limiting factor to accurate high-resolution tidal modelling.

This has a direct impact on the quality of the coastal altimetry sea surface heights as the tide correction is one of the largest corrections on the shelves, ranging from several centimetres to several metres. It is of prime importance for the current and future satellite altimetry missions that already or will enable to retrieve high-resolution coastal observations of the sea surface height, such as Sentinel-3, Sentinel-6/Jason-CS and SWOT.

In this context, CNES funds a project that aims to improve the bathymetry and the tidal models in a number of regions, such as the North-East Atlantic Ocean, the Mediterranean Sea and the Arctic Ocean. The work consists in 1) inventorying the existing bathymetry datasets in these regions, 2) merging the collected datasets into a reference global bathymetry dataset, 3) evaluating this new bathymetry dataset through hydrodynamic regional tidal modelling and 4) improving the quality of the regional tidal model thanks to the assimilation of in situ and altimetry tidal observations.

The outputs of the project are high-resolution regional tidal atlases that show significant improvements at the coast compared to the most recent global tidal atlases. This work paves the way for the future global tidal atlas FES.

MSS improvement in the coastal zone - result from the Baltic Sea

O. B. Andersen, A. Abulatitijiang

As part of Baltic SEAL project funded by ESA, new mean sea surface (MSS) based on multi mission altimetry products are being developed. The altimetry missions include Topex from the 90s til the most recent Sentinel 3 series. The ALES+ retracker developed by M. Passaro et. al. (2018) is proved to be able to retrieve more valid measurements near the coast. Taking advantage of the new dataset, by temporal averaging the exact repeat track missions (for instance, Topex and Jason series), a new mean sea surface model (noted as MSSv1) of the Baltic Sea is developed. The difference between MSSv1 and DTU15MSS shows that the improvements are notable near the coastal lines (up to 5 km). This is attributed to good data coverage from ALES+ data (provided by TUM). Particularly, improvements are observed in the Danish Straits and Gulf of Bothnia where there are thousands of islands.

Merging a number of satellite missions to produce a mean sea surface model is not an easy task. Including the CryoSat-2 and recent missions (e.g., Snetinel-3 series) to already developed MSSv1 is not straightforward and not easy to implement due to the fact that the sea level is rising over time.

Moreover, a number of geophysical and range corrections are analyzed as a function of distance to coast. The mean of sea level anomalies and the mean of correction terms in the data should be consistent both near-shore and off-shore. Analyses show that ALES+ data is of good quality in terms of wet tropospheric corrections (WTC), sea state bias (SSB) and sea level anomalies up to 5 km from the coast. The same analysis is done for the data extracted from RADS (1 Hz only). The WTC correction and sea level anomalies for SARAL and Sentinel-3 series tend to be problematic, if the users extract the data by its default Radiometer WTC option.

We recommend the users to extract data with ECMWF or ERA Interim correction options to these satellites to have consistent sea level anomalies both near-shore and offshore.

Examining the Performance Sentinel-3A SAR Altimetry Retrackers and Hydrodynamic Models Using a High-Resolution Geoid Model in the Baltic Sea

N. Delpeche-Ellmann, M. Mostafavi, A. Ellmann

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

New CNES-CLS18 Mean Dynamic Topography of the global ocean from altimetry, gravity and in-situ data

S. Mulet, M.-H. Rio, H. Etienne, N. Picot, G. Dibarboure, M.-I. Pujol

The Mean Dynamic Topography (MDT) is a key reference surface for altimetry. It is needed for estimating the sea level above the geoid from altimeter Sea Level Anomalies (SLA) and thus monitor the full ocean dynamics (not only anomalies: an eddy in SLA map could be in fact a meander when the full signal is considered). Also, the MDT is the missing component for the optimal assimilation of altimeter data into operational ocean system.

CNES-CLS Mean Dynamic Topography solutions are calculated by merging information from altimeter data, GRACE and GOCE gravity data and oceanographic in-situ measurements from drifting buoy velocities and hydrological profiles. The objective of this communication is to present the newly updated CNES-CLS18 MDT. The main novelties compared to the previous CNES-CLS13 solution is the use of updated input datasets and improved data processing.

An evaluation of this new solution compared to the previous version and to other existing MDT is done through comparison to independent in-situ data. Further validation by “super-users” has also been performed. Compared to the CNES-CLS13 solution, the new CNES-CLS18 MDT shows improved performance everywhere and more significantly in coastal areas. Feedbacks from “super-users” were very valuable.

However, we still have to improve coastal areas. Indeed, toward the coast where in-situ measurements are sparse, mainly on the shelf, the global MDT solutions could be less accurate than in the open ocean. Perspectives are thus to include new observation sources like radar HF (see presentation from Caballero et al. about COMBAT project for instance) and go on improving the processing toward the coast. Interactions with the users are very important to help them using the product and to have feedbacks from them to implement improvements.

Session 2: Applications of coastal altimetry data (cont'd)

CHAIRS: Marcello Passaro, Florence Birol

Toward Higher resolution Level-3 altimeter products

Valladeau M.-I. Pujol, Y. Faugère, S.Dupuy, O. Vergara, Q. Dagneaux, G. Dibarboure

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

The New Generation of High-Resolution X-TRACK/ALES Regional Altimetry Product and the Coastal Applications Associated

F. Léger, F. Birol, F. Niño, M. Passaro, A. Cazennave, Y. Gouzènes, J.-F. Legeais, C. Schwatke(2), J. Benveniste(4)

Coastal observations are crucial to better understand and predict the behaviour of the coastal ocean. Altimetry provides a unique long-term and almost global observational dataset to characterize the evolution of sea level variability from the open ocean to the coastal ocean

In the context of the bridging phase of the ESA's climate change initiative sea-level project (SL_cci) and acknowledging user needs, we developed a new dataset based on X-TRACK L3 multi-mission product combining the better spatial resolution provided by high-rate data (20 Hz), the post-processing strategy of X-TRACK and the advantage of the ALES retracker.

ALES is a retracker developed in order to improve the availability and quality of coastal altimetry data and X-TRACK is a post-processing software developed with the same objective. Both algorithms have been combined to produce a new high resolution L3 coastal altimetry product.

In this product the number of near-shore sea level data available is significantly increased: 4 km closer to the coast compare with classical 1hz data. In average, the closest altimetry point with 80% of valid sea level data in the time series is located at a distance of less than 3 km, even 1 km at best case.

Extend the X-TRACK/ALES product to SARAL/AltiKa, ENVISAT and Sentinel-3 missions.

Recommendations: Continue to improve the quality of altimetry corrections near the coast, with a particular focus on the SSB correction. Have more studies that validate and try to understand the sea level variations observed in the first 10 km coastal band.

On the Use of Satellite Altimetry for Validating a Pan-European High Resolution Storm Surge Hindcast (ANYEU-SSL)

T. Fernández-Montblanc, P. Ciavola, M. Vousdoukas, L. Mentaschi

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Coastal Altimetry Circulation (CryoSat-2): Comparison with High-Frequency Radar

R. Mulero-Martinez, J. Gómez-Enri, M. Bruno

The present work assesses the study of mesoscale surface circulation in coastal areas (Gulf of Cadiz), using high-resolution altimetry data (20Hz) and High-Frequency radar (HFr). With this aim, across-track surface absolute geostrophic current (SAGC) velocities, derived from low pass filtered CryoSat- 2 SIRAL-SARM (20 Hz) sea level anomaly (SLA), are compared with HF radar data under different ocean-atmospheric conditions. Both observing systems detect the main mesoscale processes, with high correlation (up to r = 0.97) and absolutes differences lower than 10 cm/s, even for the evaluated points closer to the coast (<5 km). Furthermore, the addition of ageostrophic components, such as the wind-induced Ekman current and the bottom drag coefficient to the ASGC is assessed as a possibility for improving the altimetric measurements in coastal areas, improving the results under strong westerly wind conditions at the positions closer to the coast.

Session 2: Applications of coastal altimetry data (cont'd)

CHAIRS: Kaoru Ichikawa, Martín Saraceno

Assessment and application of Sentinel-3 fully-focused SAR altimeter range data for enhanced detection of coastal currents along the Northwest Atlantic shelf

H. Feng, A. Egido, D. Vandemark, J. Wilkin

Fully-focused Synthetic Aperture Radar (FFSAR) processing is a novel approach to Delay Doppler altimeter (DDA) signal analysis that involves optimal focusing of the complex radar echoes along the satellite ground track. The FFSAR approach has shown its improvement over UnFocused SAR (UFSAR) data in the open ocean in terms of sea surface height (SSH) noise reduction. The present study seeks to exploit such potential FFSAR improvements to better resolve near-shore and short-scale currents on the Northwest Atlantic (NWA) shelf, a connected system including the Nova Scotian Shelf, marginal sea Gulf of Maine, and Mid-Atlantic Bight. Along this extended coastline there are several persistent and narrow (scales < 10-30 km) coastally-trapped currents that conventional altimetry has failed to adequately capture.

Our overall goal is to improve regional monitoring and prediction by using most up-to-date altimeter SSH data. Specific objectives are to evaluate Sentinel 3A PLRM, UFSAR, FFSAR data to quantify: 1) data recovery rates near to the coast, 2) noise in SSH, SWH, and Sigma0 data across the shelf and (3) SSHA-derived geostrophic velocity estimations at scales of 10-40 km. This study has shown that FFSAR data are distinguished from the "standard" UFSAR with the following advantages: 1) SSH and SWH noise significantly reduced from offshore to nearshore (factor > 2 for SWH), 2) effective SSH (and SSHA) noise invariance to SWH (suggesting high-frequency retracker (or SSB) noise is likely very low), 3) FFSAR data continue up to the coastline with little degradation (inside of 5 km) in the coastline orientation, 4) derived geostrophic current estimates are less biased and exhibit the lowest noise, but are quite close to UFSAR performance in the bulk sense, and 5) fine-scale (~20 km) analysis across nearshore currents and small-scale gyres reveals the FFSAR data provides sharper and more realistic observations.

In the next work steps, we intend to develop an optimal FFSAR SSH dataset (5Hz, 10Hz) that can resolve geostrophic current estimates at 5-20 km scales this coastal shelf. These SSH-derived currents will be evaluated further with regional ROMS model output and coastal buoy ADCP measurements for FFSAR vs. UFSAR vs. PLRM data. Eventually, we will consider FFSAR vs. UFSAR data in ROMS model SSHA assimilations.

Wave-current interactions in the Agulhas current system

S. Ponce De Leon Alvarez, C. Guedes Soares, J. A. Johannessen

This work is devoted to wave current interactions in the Agulhas current system. Motivations of the present work are two: to better understand wave-current interactions and their effects on the spectral shape and to study the Stokes drift in the Agulhas current system. The scope is in line with previous studies. The study was conducted by performing high resolution spectral wave model simulations with and without currents during the winter of 2018 and the summer of 2016. The model adopted was the WAM model (Gunther and Berenhs, 2012). Boundary conditions were taken from the ERA-5 reanalysis wave model (ECMWF) and the ERA-5 ECMWF wind reanalysis (Hersbach et al., 2019).

The current field comes from the European Space Agency (ESA) funded GlobCurrent project (Johannessen et al., 2016) and from MERCATOR OCEAN. The validation of the numerical simulations was performed for the Significant Wave Height (Hs) using satellite altimetry data available from the altimeter missions of Jason3, Jason2, Saral-Altika and Cryosat (produced by AVISO). Wave spectra were analyzed both in deep and shallow water. Sentinel-1 wave mode Synthetic Aperture Radar (SAR) spectra were compared against WAM spectra from two different simulations: WAM&GlobCurrent and WAM&MERCATOR. The surface Stokes drift obtained from the WAM&GlobCurrent model during a 3-month summer period (2016) was studied.

The Agulhas Current System causes a highly variable Stokes drift map with increased intensity due to the frequency shift of the wave energy. The major limitations of the results are related to the lack of the Sentinel SAR wave mode near coastal zones. In these areas, shallow water together with coastal phenomena can alter the wave field and so improved satellite data from coastal regions is needed to better understand how the waves behave near the coast. In the future we are planning to extend the period of the study for several years and to incorporate the new recent spectra data from CFOSAT (Hauser et al., 2017) in order to compare modeled and measured wave spectra.

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Toward a New Coastal Altimetry-Based Algorithm for the Detection of Current Intrusions Into the Gulf of Lion

D. Casella, M. Meloni, A. M. Doglioli, A. Petrenko, J. Bouffard

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

The Zone of Influence: Matching along-track coastal altimetry data with high-frequent tide gauge observations for vertical land motion estimation

J. Oelsmann, M. Passaro, D. Dettmering, L. Sanchez, C. Schwatke, F. Seitz

The combined use of satellite altimetry and tide gauge observations can strongly complement vertical land motion measurements by GNSS. Thus, by enhancing the comparability of coastal satellite altimetry (SAT) and tide-gauge (TG) measurements, we improve the accuracies and uncertainties of vertical land motion (VLM) trend estimates at the coast, which is a substantial contributor to relative sea level change. We use multi-mission along-track altimetry, which features latest improvements of coastal retracking (based on ALES) and geophysical corrections combined with high-frequent GESLA tide gauge records (Woodworth, 2019). This set-up outperforms previously employed gridded and monthly combinations (Wöppelmann and Marcos, 2016) in terms of temporal and spatial resolution as well as in performance in coastal regions. Resulting trends are validated against ULR6-GPS measurements from https://www.sonel.org/.

Our data-set allows to capture and identify small-scale regions of coastal sea level variability, which strongly improves accuracies and uncertainties of associated derived VLM trends. By validation with GPS, we find an optimal definition to describe such 'Zones of Influence' which can then be applied at any tide-gauge for VLM determination.

Robust estimates of VLM trends are fundamentally important for reliable predictions of future coastal sea level change and thus for coastal security and adaption plans. Our results provide substantial improvements for estimating VLM with altimetry and tide-gauges. Future research could focus on a more advanced adaption to processes contributing to coastal sea level dynamics, which offers great potential for further improvements.

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Coastal Altimetry using ICESat-2 Photon-Counting Laser Altimeter

B. Wang, M. Tourian, N. Sneeuw

For radar altimeters, when the satellite nadir position approaches the coastline, more waveform samples become contaminated by land reflections, which causes poor accuracy of water level comparing to open oceans even some retracking methods may fail. Unlike radar altimetry, small footprint (~17 m) and dense sampling measurements (0.7 m) of ICESat-2 present an opportunity to measure the water surface directly, and to extract the long wave length from the point cloud.
Measurements of a single track include noise photons, which are from solar background radiations, system dark current and speckle effect. Therefore, we used a density-based algorithm, which called Density-Based Spatial Clustering of Applications with Noise (DBSCAN) to eliminate noise points to extract relatively clean water surface. Before applying DBSCAN algorithm, we need to modify the scale of horizontal direction because the surface reflections have higher density in the vertical than the horizontal direction. We can see the water surface has a thickness more than 1 m, which is caused by the reflections from the water volume under the surface. The next step is to extract the water surface precisely. For this case we used the method of sampling with different quantiles of a size of segments. The design a box with the width of 100/200/300 m moving along the track with a step of 5 m, and in each step different quantiles can be calculated. We found that the result of 99% quantile is the best comparing to the tide gauge station, which we achieve the accuracy of 1 to 3 cm, and segment of 200/300 m shows the same result of 100 m.

In the future work, we will use histogram-based methods to eliminate noise. We also try to extract significant wave height from the measurements.

The use of Sentinel-1, Sentinel-2, and SWOT-type data for monitoring the topography of coastal intertidal areas

E. Salameh, B. Laignel, F. Frappart, I. Turki

Intertidal flats lying as a buffer zone between land and sea provide critical services including protection against storm surges and coastal flooding. These environments are characterized by a continuous redistribution of sediment and changes in topography. Sea level rise, anthropogenic pressures, and their related stressors have a considerable impact on these areas and are expected to put them under more stress; hence the increased need for frequent and updated topography maps.

An improved approach of the waterline method was developed to derive intertidal Digital Elevation Models (DEMs). The changes include a faster, more efficient and quasi-automatic detection and post-processing of waterlines.

Sentinel-2 and Sentinel-1 images combined with sea level information were used to generate the DEMs using the waterline method.

The adopted algorithms is the waterline method + k-means segmentation and active contouring for edge detection.

The obtained results underlined DEMs with accuracies that reached 20 cm were obtained owing to the fine sampling of the tidal range provided by Sentinel-1 and Sentinel-2 Constellations. Major improvements were added to the waterline method rendering the method quasi-automatic

Reliable intertidal topography maps for hydrodynamic modelling. The generated DEMs provide useful and needed information for several scientific applications (e.g., sediment balance, hydrodynamic modelling), but also for authorities and stakeholders for coastal management and implementation of ecosystem protection policies.

Future research will be focused on assessing SWOT’s ability to generate intertidal DEMs using InSAR method.

Session 2: Applications of coastal altimetry data (cont'd)

CHAIRS: Mathilde Cancet, Martín Saraceno

The assimilation of high frequency altimeters wave data in the model MFWAM: a relevant perspective for wave submersion warning

L. Aouf, A. Dalphinet, D. Hauser, C. Tourain

This highlights the impact of the assimilation of high frequency altimetry in wave model. It is the first time that we showed an enhanced impact induced by level 2 wave products provided from Sentinel-3 (20Hz Significant Wave Height) and CFOSAT (5Hz SWH) in comparison with classical 1Hz data.

The main outcome of this study is that filtering technique of high frequency SWH is good enough to allow an efficient assimilation in operational coastal wave model. It is very important to account the variability of wave heights provided by high frequency altimetry, which describes physical processes in particular in coastal areas that not well represented in models. In the perspective we will pursue assimilation runs of high frequency altimetry from all satellite missions (Jason-3, CryoSat and SARAL/AltiKa). Then we can assess the performance of using high frequency SWH in coastal models.

This work will also lead the assimilation of high frequency SWH in the regional marine Copernicus service CMEMS-MFC.

CFOSAT Mission: A Proposal for Testing Sites in the North-Western Russia

Dayoub A. Kostianoy, S. Lebedev, S. Badulin, V. Grigorieva, A. Kouraev, V. Tcepelev

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Session 2 - Posters

Waveform retracking analyses of satellite altimetry data on shallow Natuna waters and its surrounding, Indonesia

B. Nababan, R.D. Permana, M.E. Sinurat, J.P. Panjaitan

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Identification Sea Ice Edge Position based on Satellite Altimetry

S. Lebedev, A. Kostianoy , D. Soloviev

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Coastal SWH : Supporting Future Operational Ina-WAVES Products using Sentinel 3B and HF RADAR Data Assimilation

K.R. Pratama, E.L. Siadari, B.E. Pratama

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Lake Monitoring Using Multi-Mission Satellite Radar Altimetry

R. Muzaffer, S.U. Haque

Lake monitoring is crucial in managing water demands sustainably if the temporal lake levels are variable. Satellite radar altimetry is an advanced method for monitoring water level change over oceans and inland water bodies. Extended observations are required to study water level variations, that are not available for each waterbody. Especially in a country like Pakistan, where river flow and lake level gauge network is insufficient, radar altimetry provides an adequate approach to fill these data gaps. This study derived and compared the water levels over Manchar Lake from Sentinel-3A with GRLM data (Global Reservoir and Lake Monitor).

The objective of this work is to compare results of two extreme end altimetric satellite tracks passing over the Manchar Lake.

Manchar Lake, is the source of fresh water and livelihood for the communities living around. This is the most prominent shallow waterbody in the district of Jamshoro, Sindh, Pakistan with an altitude of 34.14 m above the mean sea level (MSL).

Data of Jason Series & T/P was acquired from GRLM, while Sentinet-3A from G-POD. Both datasets (Water Levels) were compared and evaluated.

The results demonstrate the utilization of freely available multi-mission satellite data to overcome the gauge network issue. Two datasets used for the study gave comparable results showing similar trends which further can be integrate to have the extensive time series with short temporal resolution.

Requirements and recommendations:

Firstly, minimum 02 gages must be installed in lake (upstream and downstream) in order to have ground-based data as well. It is further required to have a bathymetric survey may be conducted to further investigate and verify lake capacity and estimation of actual water level data with Altimetry.

Altimeter Wave Data Used to Compare with the Data from the Offshore Wave Glider System

T. Kim, J. Lee

The offshore wave data are very important for verification of satellite altimeter wave data as well as numerical wave model results, but it is not an easy task to perform offshore wave measurement using a buoy system or ocean tower station. As an alternative to buoy or tower measurement, a wave glider system was chosen because it can observe waves in the open sea for a long period of time unattended. It operated from October 16, 2015, to October 21, 2016, and from January 2, 2017, to March 31, 2017, centered on the East Sea, 130.9 ° E and 36.48 ° N., and wave heights, periods and directions were measured with 30-minute intervals. For verification of significant wave heights, altimetry wave heights from Cryosat-2 phase_a, Jason-2 phase_a, Jason-2 phase_b, Jason-3 phase_a, SARAL/AltiKa phase_a, and SARAL/AltiKa phase_b were compared. Both data show similar trends of time series of wave height but altimeter data are lower than glider data in the peak most of the time. Wave periods from wave glider are to be compared and coastal wave information from the coastal tower stations is also studied using coastal altimetry in future research.

Observed sea level changes at different coastal sites from retracked altimetry over 2002-present

Y. Gouzenes, A. Cazenave, F. Léger, F. Birol, M. Passaro, F. Niño, J.F. Legeais, J. Benveniste

In the context of the ESA Climate Change Initiative project, we have reprocesses altimetry data from Jason-1, 2 and 3 using the ALES retracker combined with the XTRACK system to estimate sea level anomalies in the world coastal zones. This new coastal sea level product has been computed in 6 different regions: Western Europe, Mediterranean Sea, Western Africa, India, Southeast Asia and Australia. Along-track sea level anomalies time series have been produced over 2002-2018 and coastal sea level trends have been estimated within the last 15 km to the coast.

In this poster, we present coastal sea level changes along selected Jason tracks of the 3 regions: South East Asia, Australia, North Indian Ocean.

We used sea level anomalies from X-TRACK/ALES 20 Hz Jason-1, Jason-2, Jason-3 data from the CCI sea level project.

Results show that in some cases, it is possible to produce valid sea level anomalies very close to the coast (up to some hundred meters sometimes)

Specific behaviours of sea level trends are reported when the satellite approaches the coast, an observation already highlighted for previous regions (Mediterranean Sea, North Atlantic Ocean, and western Africa).

After thorough examination of the time series and severe editing, we observe in a number of cases an increase or a decrease of coastal sea level within about 5 km from the coast, compared to offshore. But in most cases, we also observe that coastal trends are the same as offshore.

Future work will be devoted to determine if the trend behaviour close to the coast is related to some pertinent parameters (such as coastal topography/bathymetry, shoreline morphology, ocean dynamics, etc.). It is also intended to improve the satellite track coverage using Envisat and SARAL/AltiKa data, and in a more distant future data from Sentinel-3A and -3B.

Synergy of Coastal Altimetry and Tide Gauge Data in Monitoring Sea Level. A Case Study in the Aegean Sea

N. Flokos

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Sea surface height variations in the slick-rich Sulawesi Sea determined by a new coastal retracking algorithm eliminating inhomogeneous smooth sea surfaces within footprints

K. Ichikawa, X.F. Wang, D. N. Wei

A new retracking algorithm (Wang et al.,2019) was applied to 20Hz Jason-2 data in the Sulawesi Sea, Indonesia, where strong echoes from large slicks often contaminate waveforms even away from coasts. By adjusting footprint sizes with referring waveforms of adjacent along-track points, it successfully suppresses anomalous SSHA at/around slicks. Significant ENSO signals are present in the estimated SSHA, but spatial distribution of their strength is revealed different in 2014/15 and 2009/10 El Nino events. In addition, variations with 3-4 month periods also show interannual modulations, which are not represented in a numerical model.

Potential Applications of the SWOT Mission to the Coastal Oceans

L.L. Fu

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Performance of Recent Global Tide Models at The Entrance of The Gulf of California With Application to Altimeter Data

J.Valle, J. Gómez, A. Trasviña

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

X-TRACK Regional Altimeter Products for Coastal Applications: 2020 Release

F. Léger, F. Birol, F. Niño, D. Allain

X-TRACK is designed to extend the use of altimetry data to coastal ocean applications. Today, X-TRACK is a mature 1 Hz product used worldwide by more than 700 users since 2007 formore than 60 papers concerning a wide range of coastal applications. We must continue to provide historical data but also continue to develop the software to integrate new missions in order to provide the best dataset to users. The dataset provided is composed of SLA along-track time series and along-track empirical tidal constant for different altimeter missions.

X-TRACK is a processing software dedicated to coastal altimetry data. It produces L3 SLA products. Then an harmonic analysis is applied on the SLA time series to derive a regional along-track tidal constant product. The benefit lies in the provision of long time-series of SLA from most altimetry missions, processed homogeneously. For tidal constant: independent data available in addition to tide gauge data for tidal studies, validation of tidal models or assimilation into tidal models.

Future improvements: Include new mission such as Sentinel-3A, use a new high-resolution dynamical atmospheric correction and extend X-TRACK to 20Hz SLA data.

Recommendations: Ensure the continuity and availability of long-term sea level data.

Wave Model Confidence Index: A metocean decision support tool

C. Skandrani, E. Munesa, L. Grignon, M. Cancet

NOVELTIS provides innovative services to the main economic operators in various sectors: Marine Renewable Energy, Oil & Gas, Shipping and Maritime Transport. These services overcome the limitations of current solutions and are based on forecasted and observed data.

A first service called WMCI "Wave Model Confidence Index" designed and developed by NOVETIS in the frame of the NEPTUNE Innovation European Support Program, provides a unique solution that addresses the following major need regularly expressed by maritime stakeholders:

« I need to know the accuracy of sea states forecasts in order to take a decision but do not have any easy/global solution ».

Due to the heterogeneity (formats/sources) of wave heights and sea states measurement information, no solution gathering all open source available information in near real time (NRT) was available. Valuable data already exist but they are disseminated in many servers across different institutions, since these data come from models, satellites and buoys, each of them being managed by separated entities. WCMI tackles this challenge, providing access to all the available NRT information concerning wave heights and sea states as well as multi models forecasts.
WMCI offers user friendly and intuitive comparison functionalities with the most relevant wave forecasting models (from CMEMS, NOAA…) at global scale including

Atlantic area to provide a synoptic view and an easy evaluation of the data reliability. This functionality support quick and reliable decision making.
WMCI solution exploits also near real-time altimetry data provided by CMEMS, with particular enhancement of the handling and presentation of satellite data made more accessible and easy to use for direct comparison with the forecasts through the service.

The number of incidents for maritime transport has been rising for several years due to the increase in traffic and the impact of climate change. An accurate and reliable prediction of sea-state and its threats is a major challenge in both economic and human terms, hence NOVELTIS implemented a service called SAVaS to forecast the risk of extreme sea state conditions.

The SAVaS service relies on a wave forecast, calibrated and validated with satellite and buoy data, and statistical indicators. The service provides at a global and regional scales continuous 7 day forecasts of the sea state updated every 6 hours, weather conditions, as well as synthetic indicators for wave dangerousness and for risk of occurrence of extreme and rogue waves. Probability of return of extreme waves is provided for 10, 20, 50 and 100 years.

River Water Level Monitoring from Satellite Radar Altimetry Multi Missions: A Case Study of the Amazon and Danube Rivers

M. Mostafavi, S. Roohi, A. Ellmann, N. Delpeche-Ellmann

This study examines results of Envisat and SARAL Satellite Altimetry (SA) standard waveform retracking procedures to monitor the water level of Amazon and Danube rivers between 2002 to 2012 for. In addition, the Jason-2 data has been used to study water level variation of Danube river
from 2008 to 2014. Validation of the SA data was performed by water level records of the tide gauge (TG) stations located near the satellite tracks.

The methodology entailed that for each satellite's overpass using different possible scenarios with the onboard retracking method. outlier detection was performed, to screen out low-quality data.
External models were applied to correct the range. This holds media and the geophysical corrections. Water level time series of SA data defined by merging all single passes and all tracks then a model has been fitted on it to eliminate the outliers. To find the most robust water level scenario SA data compared with TG data by calculating the of root mean square errors (RMSE).

Datasets used:

- Altimetry data including Envisat RA-2 GDR 18 Hz data from 2002 to 2010, SARAL/AltiKa SGDR 40 Hz data from 2013 to 2016 and Jason 2 with Poseidon-3 altimeter SGDR 20 Hz from 2008 to 2018.

- In-Situ gauge time series of stations were provided by Agencia Nacional de Aguas (ANA) over Amazon River and Orszagos Vizjelző Szolgalat (HHFS) over Danube River in Hungary. These overlaps of about 14 years with SA measurements.

Results of the comparisons within the test regions show that the RMSE are between 37 and 72cm. Formal errors are about 55 cm on average for Amazon and 56 cm for Danube river basin. A good agreement was obtained at Jatuarana station in the Amazon river using MEDIAN value for H-Ocean retracker of SARAL data.

Future outlook: Use of other missions such as CryoSat-2, Jason-3 or Sentinel-3 could improve spatial/temporal resolution and estimation quality over inland water bodies.

Recommendations:

Mostly using the MEDIAN values and sea-ice retracker provides the minimum values of STD and RMSE in water level determination of rivers. The ocean retracker is not reliable for inland water bodies.

Determination of Sea Level Trends of the Marmara Sea from Satellite Altimetry and Tide Gauges Data (2010-2019)

M.H. Erkoç, U. Do-an

The purpose of this study, to determine sea level changes from tide gauges and various satellite altimetry missions in the Marmara Sea. For this aim, relative sea level trends and tidal parameters have been estimated over period 2010-2019 by main tidal frequencies using least-squares harmonic estimation method from two tide gauge stations distributed in the Marmara sea operated by TUDES (Turkish National Sea Level Monitoring System). The Satellite altimetry mission data also have been used to estimate absolute sea level. The data have been obtained by AVISO, ESA-EO,Copernicus Open Access Hub data archive in the period of 2010-2019.

Additional comment from the Participant

I met with some institute and organisation representatives. We started some collaborations. Thanks to these collaborations, DAC, SLA and Tidal Parameters can be estimated more accurately. ESA Sea Level CCI Project data can be included near coasts of Turkey in Mediterranean Sea and Marmara Sea. With Erdemli Tide Gauge Station that lies near Jason tracks, we can be prepare new calibration report for altimetry data. In near time, I also will determine VLM rate in the region.

Coastal HF Radars and Remote Sensing Altimetry: Complementary Process for Wave Height Observations

I. Bué, A. Semedo, J. Catalão

West coast of Iberian Peninsula is strongly influenced, by low-pressure systems in mid-Atlantic Ocean, storms and severe sea states, mostly during winter. The combination of High Frequency Radar (HFR) and satellite altimetry measurements could improve continuous monitoring of coastal areas. These remote sensed techniques could also act as a complement for wave height observations at transition areas (open ocean to nearshore) and filling the information gaps of in situ sensors. In fact, satellite altimetry could be the only way to measure operational oceanography parameters (waves and winds) in open ocean. However, satellite altimetry measurements are inaccurate near shore due to land contamination.

The study area is located at West & South of Iberian Peninsula. Time window for the statistical analysis of the Significant Wave Height (SWH) hourly and monthly values comparisons (buoy vs SRAL & buoy vs HFR) from January 2017 to December 2019. Wave datasets used from L2P Sentinel 3 SRAL, CODAR Seasonde HFR stations in Iberian Peninsula and 12 oceanographic buoys. In situ measurements taken as "ground truth".

The major achievements/limitations are:

- Low number SRAL measurements (revisit time) and land contamination in near shore satellite altimeter measurements shown SRAL SWH overestimation;

- SWH monthly mean time series (HFR and SRAL) shown similar wave features and seasonal variability; '

- During summertime or in calmer sea states, second-order ocean spectrum is closer to noise floor, conducting HFR to estimate SWH with a lower precision (wave height overestimation);

- SWH homogeneity assumed over whole HFR range cell could also contribute to increase the differences detected (HFR SWH overestimation);

- Satellite altimetry & HFR wave data properly processed, can be used for coastal sea state monitoring, especially where there are no in situ sensors;

- Using remote sensing techniques to estimate SWH can increase the possibilities of obtaining a better space and time coverage, compared to buoy distribution over coastal areas, regarding other sensor input.

For future research, we intend to merge satellite altimetry and HFR SWH information for reinforcement in coastal areas monitoring; evaluate the use of wave parameters from HFR as input data for numerical models validation or assimilation into wave models and conduct an analysis of extreme wave height events using HFR and SRAL wave data

Access to Sentinel-3 Marine Center data

B. Lucas, R. Scharroo, C. Nogueira Loddo, C. Martin-Puig, S. Dinardo, I. Parodi

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Sentinel-3 Marine Centre status

B. Lucas, R. Scharroo, C. Nogueira Loddo, C. Martin-Puig, S. Dinardo

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Satellite Altimetry: Coastal Region Research to Applications

M. Srinivasan

This work is motivated by the desire to highlight key research areas in ocean altimetry that may support or lead to operational applications, specifically, and societal benefits, in general. It is of value to mission funding agencies that societal value be identified and shared with existing and potential user communities, and that awareness of the usefulness of these missions and data streams be identified and acknowledged. With existing potential for coastal applications of altimetry data, and expanded potential from the SWOT mission, scheduled to launch in late 2021, the timing of highlighting the research and operational uses of altimetry to the coastal research community at the 12th CAW is right.

A process has been initiated to mine the altimetry mission literature database (https://sealevel.jpl.nasa.gov/science/litdb/) for topical research papers that have 'applications value'—that is, value that may exist in the research for the non-research community and for societal benefit. This search is not complete, but more than 60 relevant papers have been identified to date. Expanded knowledge, awareness, and examples of research-to-applications activities will benefit the coastal community of researchers—to see value in their work beyond research—and to coastal communities, where data and information products can inform decisions-makers, potentially protecting life and property, now and in future planning.

Altimetry mission applications that are relevant to coastal communities include weather prediction, coastal impacts (storm surge, coastal currents), fisheries management, ecosystem functioning, marine transport, sea level rise (and related disaster risk management), flooding, and coastal impacts from ocean and surface water changes, among many others.

Highlights of Spatial Altimetry Activities in CNES Related to Coastal Processes

A. Collet, S. Pena Luque, A. Andral, N. Picot, A. Lifermann, D. Blumstein, T. Amiot, F. Gouillon, E. Bergsma, B. Laignel, R. Almar, N. Ayoub, F. Lyard.

The following activities have been presented:

SMall Altimetry Satellites for Hydrology (SMASH)

SMASH is a Phase A project with 10 nanosat on the same orbit. The Water level accuracy will be 10cm and the revisit time of 1 day instead of >10 days. The mission will improve the understanding of the spatial-temporal dynamics on coastal estuaries, lagoons and hydrological processes. Low spatial/High temporal frequency of SMASH is in synergy with High spatial/Low temporal frequency of SWOT

Surface Water and Ocean Topography (SWOT)

SWOT is one satellite among others to observe the dynamics. Work has been done to make a Pixel cloud representation of water mask geolocation and elevations based on simulated SWOT data. There is ongoing study with LEGOS of the coastal circulation variability from daily to interannual time scales and other about the use of the coastal Symphonie model and T-UGO model for tides

S2 surface reflectance images

CNES has a perspective of a new water color products in the coastal fringe based on Sentinel2 will allow a better insight of the continuum between rivers, estuaries and littoral processes. The objective should be to Switch to surface reflectances. According to thematic expert if will be Very useful addition to the network of in situ measurements available.

Hydroweb-NGa

It is a single tool to : Explore (Pangeo tools), Visualize, Process, Develop, Compare (datacube), Homogenize and Extract. It is the unique portal to access the SWOT HR data. It will integrate multi-sensor water variables (hydro/coastal) in a single system, gathering numerical models, in-situ data and altimetry derived products (river discharge, lake volume changes), water color, water surface dynamics, soil moisture, snow coverage, LULC of the surroundings and littoral DEMs. It has a Multi-satellite vision: the increase of satellite sensors to observe water processes (interferometry, SST, SAR imagers, color sensors) requires new methods to integrate them together to better understand water dynamics.

Bathymetry

Lead by Legos, CNES supports the development of bathymetry inversion algorithms in coastal waters through the measurement of ocean waves velocity field. The Algorithm use Sentinel 2 radon band or Pleiades satellite video imagery (12 images – 8s apart – res 0,5m).

Exploring the Trend of Sea Level Rise and Its Impacts on Coast of Pakistan Using Satellite Radar Altimetry

T. Naseer, A. Zaidi, S. Vignudelli

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Indus River Level Monitoring using Sentinel 3A data

A. Zaidi, R. Muzaffar, V. Panhwar, S. Zafar

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

2-D Flood Model Validation in the Lower Indus reach Using Satellite Altimetry

V. Panhwar, A.Zaidi, N. Babar

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Use of Sentinel3-A satellite altimeter data for Geoid determination over the Western Mediterranean

T. Benkouider

In this study, a method for the computation of the deflections of the vertical DOV from altimetric data of Sentinel-3A -PLRM derived records- of the year 2018, over the Western Mediterranean sea, is based on the use of the remove restore technique, the major argument of using this method is the fact that DOV values are less contaminated by long-wavelength errors.

the SSH value which, in addition to standard geophysical corrections, is corrected by local tidal correction using tide gauge data for the Algerian coastal zone. By removing a known reference geoid model like EGM 2008, the mean dynamic topography must also be removed ,a residual geoid field is obtained, which is converted to geoidal undulation by means of the inverse Vening Meinesz formula.

The calculated results obtained by computing standard deviations can be considered acceptable in the open ocean, but this results decreases rapidly over coastal areas when land enters the altimeter footprint.

The outlook for future study is using more accurate water level estimates such as the Adaptive Leading-Edge SubWaveform (ALES) and the European Space Agency Grid Processing On Demand (GPOD/SARvatore),also development of better corrections for the wet tropospheric and SSB corrections using more adaptive models.

SAR and SARin Altimetry Processing on Demand for Cryosat-2 and Sentinel-3 at ESA G-POD

J. Benveniste, S. Dinardo, G. Sabatino, M. Restano, A. Ambrózio

The scope of this presentation is to feature the G-POD SARvatore service to users for the exploitation of CryoSat-2 and Sentinel-3 data, which was designed and developed by the Altimetry Team in the R&D division at ESA-ESRIN. The G-POD service coined SARvatore (SAR Versatile Altimetric TOolkit for 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 and Sentinel-3 SAR data, from L1A (FBR) data products up to SAR/SARin Level-2 geophysical data products.

The G-POD graphical interface allows users to select a geographical area of interest within the time-frame related to the Cryosat-2 SAR/SARin FBR and Sentinel-3 L1A 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. Pre-defined processing configurations (Official CryoSat-2, Official Sentinel-3, Open Ocean, Coastal Zone, Inland Water (20Hz & 80Hz), Ice and Sea-Ice) are available. After the task submission, users can follow, in real time, the status of the processing. The output data products are generated in standard NetCDF format, therefore being compatible with the multi-mission "Broadview Radar Altimetry Toolbox" (BRAT, http://www.altimetry.info) and typical tools.

Initially, the processing was designed and optimized uniquely for open ocean studies. It was based on the SAMOSA model developed for the Sentinel-3 Ground Segment. However, since June 2015, the SAMOSA+ retracker is available as a dedicated retracker for coastal zone, inland water and sea-ice/ice-sheet. A new retracker (SAMOSA++) has been recently developed and will be made available in the future. The scope is to maximize the exploitation of CryoSat-2 and Sentinel-3 data over all surfaces providing user with specific processing options not available in the default processing chains.

Recent improvements include: 1) A Join & Share Forum to allow users to post questions and report issues (https://wiki.services.eoportal.org/tiki-custom_home.php); 2) A data repository to better support the growing Altimetry Community avoiding the redundant reprocessing of already processed data (https://wiki.services.eoportal.org/tiki-index.php?page=SARvatore+Data+Repository&highlight=repository); 3) The extension of the radar receiving window size, up to a factor 4, in the Sentinel-3 service, which is beneficial for inland water analyses over very steep topographic regions; 4) The CREODIAS cluster element to speed up the data processing.

To respond to the request of hydrologists, and simulate data that a rive gauge would provide, SARvatore will soon include a post-processing service to convert water level estimates in L2 data to virtual station water level values, which are typically required by hydrologists.

The service is open, free of charge (supported by the ESA SEOM Programme Element) for worldwide scientific applications and available at
https://gpod.eo.esa.int/services/CRYOSAT_SAR/,
https://gpod.eo.esa.int/services/CRYOSAT_SARIN/,
https://gpod.eo.esa.int/services/SENTINEL3_SAR/.

The BRAT and GUT Couple: Broadview Radar Altimetry and GOCE User Toolboxes

A. Ambrózio, M. Restano, J. Benveniste

The scope of this work is to showcase the BRAT (Broadview Radar Altimetry Toolbox) and GUT (GOCE User Toolbox) toolboxes.

The Broadview Radar Altimetry Toolbox (BRAT) is a collection of tools designed to facilitate the processing of radar altimetry data from all previous and current altimetry missions, including Sentinel-3A L1 and L2 products. A tutorial is included providing plenty of use cases on Geodesy & Geophysics, Oceanography, Coastal Zone, Atmosphere, Wind & Waves, Hydrology, Land, Ice and Climate, which can also be consulted in http://www.altimetry.info/radar-altimetry-tutorial/.

BRAT's last version (4.2.1) was released in June 2018. Based on the community feedback, the front-end has been further improved and simplified whereas the capability to use BRAT in conjunction with MATLAB/IDL or C/C++/Python/Fortran, allowing users to obtain desired data bypassing the data-formatting hassle, remains unchanged. Several kinds of computations can be done within BRAT involving the combination of data fields, that can be saved for future uses, either by using embedded formulas including those from oceanographic altimetry, or by implementing ad-hoc Python modules created by users to meet their needs. BRAT can also be used to quickly visualise data, or to translate data into other formats, e.g. from NetCDF to raster images.

The GOCE User Toolbox (GUT) is a compilation of tools for the use and the analysis of GOCE gravity field models. It facilitates using, viewing and post-processing GOCE L2 data and allows gravity field data, in conjunction and consistently with any other auxiliary data set, to be pre-processed by beginners in gravity field processing, for oceanographic and hydrologic as well as for solid earth applications at both regional and global scales. Hence, GUT facilitates the extensive use of data acquired during GRACE and GOCE missions.

In the current version (3.2), GUT has been outfitted with a graphical user interface allowing users to visually program data processing workflows. Further enhancements aiming at facilitating the use of gradients, the anisotropic diffusive filtering, and the computation of Bouguer and isostatic gravity anomalies have been introduced. Packaged with GUT is also GUT's Variance/Covariance Matrix (VCM) tool, which enables non-experts to compute and study, with relative ease, the formal errors of quantities – such as geoid height, gravity anomaly/disturbance, radial gravity gradient, vertical deflections – that may be derived from the GOCE gravity models.

BRAT and GUT toolboxes can be freely downloaded, along with ancillary material, at https://earth.esa.int/brat and https://earth.esa.int/gut.

Validation of Sentinel-3 Coastal Altimetry Data on the Baltic Sea and Estonian Lakes

A. Liibusk, T. Kall, S. Rikka, R. Uiboupin

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Session 3: Synergistic and climate studies

CHAIRS: Paolo Cipollini, Guillaume Dodet

Coastal Sea Level rise at Senetosa (Corsica), the calibration site of altimetry missions

Y. Gouzenes, F. Léger, A. Cazenave et al.

In the context of the ESA Climate Change Initiative project, we have reprocesses altimetry data from Jason-1, 2 and 3 using the ALES retracker combined with the XTRACK system to estimate sea level anomalies in the world coastal zones. This new coastal sea level product has been computed in 6 different regions: Western Europe, Mediterranean Sea, Western Africa, India, Southeast Asia and Australia. Along-track sea level anomalies time series have been produced over 2002-2018 and coastal sea level trends have been estimated within the last 15 km to the coast.

In this presentation, we focus on a particular coastal site where the Jason track crosses land, Senetosa, located south of Corsica in the Mediterranean Sea, for two reasons: (1) Senetosa is the calibration site for the Topex/Poseidon and Jason altimetry missions, equipped for that purpose with in situ instrumentation, in particular tide gauges and GNSS antennas, and (2) the rate of sea level rise estimated in this project increases significantly in the last 4-5 km to the coast compared to the open ocean rate.

We used sea level anomalies of X-TRACK/ALES 20 Hz Jason-1, Jason-2, Jason-3 data from the CCI sea level project.

Results:

We computed along-track sea level trends at each 20 Hz points from 15 km offshore to the coast. The reprocessing developed in this project allows us provide valid sea level data to up to 1 km to the coast. Estimated sea level trends over the 16 year study time span display a significant increase in the last 4-5 km to coast, about twice what is observed offshore.
Careful examination of all sources of potential errors (eg., due to geophysical corrections, intermission bias, mean sea surface height, etc.), possibly causing the increased rate of sea level rise close to the coast, has been carried out. However none of these factors seems able to explain the observed trend increase. We conclude that it may reflect real physical process occurring close to the coast.

We investigated the effect of waves and currents. While the ALES-based SSB correction may not work as well close to the coast as in the open ocean because of inadequate empirical formulation due to change in wave properties at the coast, it hardly explains the observed increase in sea level trend close to the coast. On the other hand, the presence of a coastal current at Senetosa may be at the origin of the observed trend. Further investigations are ongoing.

An article has been submitted to Ocean Sciences (January 2020).

Near future work will include:

- More detailed investigations on the SSB correction in the last 5 km to coast.
- Detained analysis of the coastal current at Senetosa using the high-resolution (400 m) MARS3Dnumerical model developed by IFREMER
- Synthesis of the 'best cases' for which precise coastal sea level time series and trends have been estimated in the 6 study regions and preparation of a publication in a high-impact journal
- Computation of new coastal sea level products using Envisat and SARAL/AltiKa

Coastal altimetry at high-latitudes: the Baltic SEAL project observing sea level among jagged coastline and sea ice

M. Passaro, F. Müller, A. Abulaitijiang, O. B. Andersen, D. Dettmering, J. L. Høyer, M. Johansson, J. Oelsmann, K. S. Madsen, L, Rautiainen, I. M. Ringgaard, E. Rinne4, J. Särkkä, R. Scarrott, C. Schwatke, F. Seitz, L. Tuomi, A. Ambrozio, M. Restano, J. Benveniste

This work is motivated by the need to exploit special processing techniques to study sea level trend and variability in the Baltic Sea, which is characterised by the most challenging conditions for satellite altimetry: the presence of a jagged coastline and the seasonal sea ice coverage.

The aim is to improve the current standards of sea level product in the region. A multi-mission cross-calibrated along-track and gridded dataset will be released within this year. Other products include a new mean sea surface and an experimental high-temporal resolution grid (1 to 5 days) over one year, to feed models for storm surge studies.

We start from the waveform data of the almost all altimetry missions that have been flying from TOPEX up to 2019. We use optical and SAR imaging for tailoring the classification approach to distinguish water returns from sea-ice returns. We also use tide gauge data for validation. Our quantity under investigation is the sea level height.
The main algorithms used to produce the dataset are:

- K-mean medoids unsupervised classification [1]
- ALES+ and ALES+ SAR retracking and sea state bias algorithms [2]
- MMXO cross-calibration [3]

Note that these algorithms are improved within the project itself.

In the current stage, we are just about producing first, preliminary products. The first version of the recomputed mean sea surface fills the gaps of previously unsampled areas.

This project serves as a laboratory for innovations in coastal altimetry. The approaches to go from waveform data to a user-friendly sea level product can be exported to other regions.

Future research shall involve the reprocessing of TOPEX data, whose documentation and availability right now hinders a full independent reprocessing, although this should change in the next months. The nature and shape of the Baltic Sea also suggest a possible sea level budget study focused on the region.

Given the ever-increasing number of altimeters flying, we recommend to foster new studies related to storm surges (such as the former ESA e-Surge project), which would be particularly beneficial for societal impact in the Baltic Sea region. We hope to highlight the potential of this application with our experimental high-temporal-resolution sea level grid.

Project website: http://balticseal.eu/

References:

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Session 3: Synergistic and climate studies (cont'd)

CHAIRS: Fabien Léger, Slim Gana

Coastal Extreme Sea Levels From Satellite Altimetry: A Global Study

H. Lobeto, M. Menendez

Sea level extreme events have a key role in coastal impacts such as erosion and flooding. The availability of +25 years of sea level data from satellite altimetry gives the possibility of using this information to understand these events and their behaviour. Thus, the main objective of this work is to develop a methodology to study non-tidal residual extreme events nearby the coast from satellite altimetry data, which is especially relevant at those places where we do not have in-situ information. This work is a continuation of a previous study developed along the east coast of North America (Lobeto et al., 2018).

First step consists in building a new NTR global database from satellite altimetry data. In particular, the SLA database considered here is obtained from CMEMS: SEALEVEL_GLO_PHY_L3_ REP_OBSERVATIONS_008_062. Also, a global dataset of tide gauges is used to calibrate the methodology.

After selecting the coastal extreme sample from both databases at every station considered, a non-stationary statistical extreme model is applied and then the results are compared. The differences obtained when comparing the outcomes from both sources are related to some geographical and morphological characteristics (coastal exposure, shelf width, latitudinal gradient and ocean wave correlation) in order to define a correcting factor (ESF) to modify the extreme statistics from altimetry. ESF successfully reduce the differences between altimetry and tide gauge data in most of the stations selected. The main conclusion derived is the possibility of using this methodology to obtain preliminary sea level extreme statistics (e.g. 50yr return sea level) at any coastal location only using satellite altimetry data.

Finally, the method is applied to 475 coastal units defined along all the world's coasts. Results are coherent with other climate studies concerning coastal climate variation patterns (i.e. seasonality and long-term trends).

Combining Coastal Altimetry Data With High-Frequency Radar and Drifter Data to Monitor the Dynamics in the South-East Bay of Biscay

A. Caballero, N. Ayoub et al.

The mean dynamic topography (MDT) is a surface of reference to compute absolute dynamic topography from altimetric sea level anomalies. The availability of accurate MDT is critical for research or operational systems that assimilate altimetric data into ocean circulation models. Global MDTs have been estimated in the last ~15 years and are frequently updated (e.g. the CNES-CLS MDT 2018, see the presentation of S. Mulet et al.).

Despite significant improvements, the global MDTs contain errors in coastal areas, partly due to the lack of high-resolution in situ observations to constrain locally the small scales of the MDT. The COMBAT project is supported by CMEMS in the framework of the CMEMS 2nd Service Evolution call; the objective is to compute a regional MDT in the south-eastern Bay of Biscay from the latest CNES-CLS product and from high-frequency radar measurements.

A preliminary study is performed using simulated sea surface elevations and currents from the Symphonie ocean circulation model to investigate methods to extract the geostrophic contribution from the total surface currents. This method is then applied to the high-frequency radar observations. A regional MDT over the whole Bay of Biscay (hereafter the COMBAT MDT) is then computed using the method of Rio and Hernandez (2004) and Rio et al. (2005, 2011, 2014).

The verification of the COMBAT MDT is in progress; first results based on AVISO altimetric maps and radar data not used for the MDT calculation suggest that the COMBAT MDT is indeed more realistic than the global one.

Case Study of Wind-Driven Waves in the White Sea During the Tandem Phase of Jason-2 and Jason-3 Missions

S. Badulin, V. Grigorieva, P. Shabanov, V. Sharmar, I. Karpov, S.Lebedev, A. Kostianoy

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Understanding Ocean Wave Climate Variability in the Open Ocean and at the Coast

C. Gommenginger, B. Timmermans

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Session 3: Synergistic and climate studies (cont'd)

CHAIRS: Christine Gommenginger, Marco Restano

Freshwater-induced coastal water level variability from SAR altimetry

C. Slobbe, F. Zijl, M. Verlaan, J. Pietrzak, M. Snellen, Y. Afrasteh, H. Guarneri, L. Keyzer, R. Klees

The presented study was a first attempt to quantify the freshwater induced water level variability in the Dutch Rhine Region of Freshwater Influence (ROFI) as obtained from Sentinel-3A SAR altimetry data and high-resolution background models. The Rhine ROFI, one of the largest ROFI's in Europe, is created by the fresh river water outflow from the Rhine and Meuse rivers. The discharge occurs during ebb tide. Every ebb tide, lenses of fresh-water are ejected that spread forming ever larger lenses that merge and interact with the lenses emitted on the previous tidal cycles. The Rhine ROFI is very dynamic, with significant tidal currents modified by baroclinic effects, due to the highly variable temperature and salinity. There is great interest to better understand these dynamics and to capture them by hydrodynamic models. Among the reasons is the need to study and predict salt intrusion events and the prediction of expected water depths for save and efficient navigation of large ships to the Rotterdam harbor.

In developing a high-resolution model that is able to capture the ROFI dynamics, validation data is needed. So far, the validation data are primarily in-situ measurements and satellite-derived sea surface temperature and ocean color data. Altimeter-derived water levels have never been used, because i) the spatial extent of the Rhine ROFI is small, and ii) the signal is small compared to tide and surge signals. By using SAR altimetry in combination with a high-resolution quasi-geoid model and a high-resolution 3D hydrodynamic model we believe it may become possible to isolate the discharge signal. The hydrodynamic model being used is the 3D Dutch Continental Shelf Model – Flexible Mesh developed by Deltares. The altimeter data being used were acquired by Sentinel-3A. In this study, we used all data acquired for one track that crosses the Rhine-ROFI in the year 2017. We used our own level-2 processor. The water levels were retracked using the SAMOSA+ retracking scheme proposed by Dinardo et al. 2018 with some small edits from our side. The edits affected the data editing scheme and some different choices we made in deciding what retracker options are used when. More particular, the waveforms are classified using some shape parameters and auxiliary data sets and based on the outcome different retracking options are applied. Moreover, we apply sub-waveform retracking. After the retracking, we assessed the quality of fit and based on that we used different options or ignored the waveform at all.

When compared to the model, we showed the presence of residual signals that when compared to wind fields can be interpreted as ROFI signals. There is a discrepancy between the model and the altimeter-derived ROFI signal; the latter being larger. In a future work, we will apply the FF-SAR processing scheme. We are also working on a new version of the hydrodynamic model that has a higher resolution in the Rhine ROFI. Finally, we will compare our results to SST and ocean color data.

Continuum of Waters and Estuaries

L. Fenoglio, M. Gärtner, B. Zohidov, J. Staneva, S. Dinardo, B. Uebbing, C. Buchhaupt, S. Melchionna, J. Kusche

The Coastal areas and estuaries are among the environments most affected by anthropogenic impact and climate change and are defined as multi-risk, due to coastline retreat, flooding by storms and river floods, and pollution. Estuaries, which connect ocean and land, salt and fresh water, have a complex hydrodynamics, with a strong variability of the water level at various temporal and spatial scales, due to the interaction of water bodies and phenomena. River variability in absence of tides is considered for comparison. Precise observations from space help in predicting their evolution at short and long term scales.

Limitation of LRM altimetry in these regions are well known and we investigate SAR altimetry with different processors. The main goal of this presentation is to investigate accuracy at the coast, estuary and river level.

We compare in-situ level height with multi-satellite data from SAR altimetry (height) and SAR imagery (water extension). We analyse simulated SWOT observations of water level in the same river. We consider the Copernicus Marine and Land altimeter data. In addition, we use the data derived by the dedicated Level 1 and Level 2 altimeter public processors SARvatore (SAMOSA+) and TUDaBo (RDSAR TALES). Moreover we use the UBonn processor which generates the RDSAR STAR data .

A toolbox OverVirtual performs a careful combination of altimetry and in-situ data. Adopted algorithms for retracking: STAR, TALES (RDSAR), SAMOSA+, SAMOSA++ (SAR) compared to official products (ocean and OCOG in RDSAR, SAMOSA2 in SAR).

The results show for SAR altimetry water level an accuracy of 2-4 cm in open ocean and of 15-20 cm in rivers of 200-300 km width. In estuaries and coasts with high tidal regimes the accuracy is 40 cm (r.m.s. with in-situ data). In the marine environment, the best values are reached in SAR by the SAR processor SARvatore (SAMOSA+ and SAMOSA++) and in RDSAR by the STAR processor. In in-land waters, SARvatore and the Copernicus processor with ocean re-tracker give comparable results.

The results show that in SAR mode the SAMOSA+ observations are usable at more than three Kilometers from coast; the same is seen in RDSAR mode with the RDSAR/STAR products, while RDSAR TALES is more noisy.

IN terms of future outlook, the new procedures in along-track SAR (RMC and Fully Focused SAR) are promising. SWOT has the advantage to give 2D observations with a comparable accuracy and is very interesting for all three regions of investigation.

It is recommended to add coastal retracker in Sentinel-3 and Sentinel-6 official products for all modes

SMASH: a mission concept to better monitor inland waters and estuaries

D. Blumstein et al.

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Session 3 - Posters

Satellite Altimetry and In Situ Observations: Estimating Relative and Absolute Sea Level Rise at the Adriatic Sea coast (Venice and Trieste)

F. De Biasio, G. Baldin, A. Papa, S. Vignudelli

The study aims at improving the methodology for estimating vertical land motion from tide gauge and altimetry measurements in the Mediterranean Sea with special focus on the Adriatic Sea.

In this analysis, the classical vertical land motion rates are derived by differencing tide gauge and altimetry measurements. Optimization of the error estimates are obtained solving an "inverse linear problem with constraints" [Menke, 1989]. The SL_CCI altimetry gridded sea level anomaly dataset v2 is used. PSMSL monthly means of sea level are used for the tide gauges, as well as specific dataset released by the Tide Forecast and Early Warning Center (Venice Municipality), by the Italian Institute for Environmental Protection and Research and by the Institute of marine Sciences (CNR) for some tide gauges. ERA5 dataset msl pressure is used for calculating the monthly means of inverted barometer effect to make altimetry SLA e Tide gauge SL comparable. In relation to previous studies [Kuo et al., 2004; Wöppelmann and Marcos, 2012] here we try to improve the methodology by using rates obtained by time series of differenced values and improving the choice of the constraints to solve the linear inverse problem.

All the errors on the vertical land movements have been reduced by a percentage between -46 and -71 % w.r.t. the classical methodology introduced by [Cazenave et al., 1999]. Limitations are the reduced number of very good and long tide gauge time series in the Med Sea, and particularly in the southern basin.

A clear identification of the potential of altimetry in terms of the dynamics of the coastal zone, and the identification of the different factors contributing to the relative sea level rise at regional scale.

Further improvements are expected in the methodology, as well as in the number of tide gauge time series, in the length of the altimetry time series now available (CMEMS 1993-today) and ERA5 reanalysis (1950-today). Being independent of the particular spatial region, this analysis can be used everywhere.

As the length and the quality of the tide gauge time series is fundamental, national and international authorities should focus in maintaining the existing tide gauges and adhering to international standards for their management. The southern side of the Mediterranean Sea should also be populated with tide gauges. GPS stations should also be installed and co-located with the tide gauge basement. There should also be a big effort in making more and longer consistent tide gauge data available to the community. As for the satellite altimetry data, the principal corrections should also be included in the dataset (DAC, TIDES) to make them comparable to tide gauges.

The Impact of the Large-Scale Atmospheric Patterns in the North Atlantic on the Northern European Sea Level

F. Mangini, L. Chafik, E. Madonna, C. Li, L. Bertino

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Exploring the Synergy between Optical Imaging Radiometry and Radar Altimetry for Inland Waters: an Experience on the Nasser Lake

A. Scozzari, S. Vignudelli, N. Galal, M. Khairy, A. Negm

This work proposes a combination of optical imagery and radar altimetry to estimate water storage variations in inland water targets, exploiting the simultaneous acquisition offered by SRAL and SLSTR instruments onboard Sentinel-3. Such simultaneous and independent measurements by the two instruments constitute an excellent opportunity for cross-validating the acquired data, especially in poorly gauged sites.

The developed algorithm starts from the assumption that a reduced subset of pixels may carry enough information for assessing the status of the observed water body, by selecting the pixels exhibiting the highest variability of the collected radiance, and comparing the obtained timeseries with altimetry data processed by the GPOD SARvatore processor.

Preliminary results show a promising correlation between the timeseries generated by the two measurements, in terms of both general trend and seasonal dependence. Thanks to the approximation proposed in this paper, a very light computational process can infer an estimation of water storage, especially when the natural system is fully identified on the basis of ground-truth data. Future research may regard the further exploitation of the short revisit time of SLSTR, which can be proposed to observe relatively fast phenomena in synergy with (and cross-validated by) the radar altimetry measurements.

On the Synergy Between Altimetric data and a WebGis Platform to Understand Coastal Hydrodynamic Processes: The ODYSSEA Project

S. Gana, D. Cebrian-Menchero and the ODYSSEA Consortium*

The ODYSSEA* consortium is currently building an innovative platform and network of Mediterranean marine and coastal observatories that will deliver in-situ ocean observing data and model outputs to fulfil tailored end-user needs and policy-maker requirement. By setting up this network of integrated marine observing systems, ODYSSEA is increasing the spatial and temporal coverage of oceanographic and ecological monitoring across the Mediterranean region, with focus on data-poor areas.

Thanks to the ODYSSEA system, it will be possible to compare the outputs of the models and in-situ monitoring with satellite data covering the coastal zone, especially regarding sea level variation, in order to validate either model outputs or altimetry data, based on what is already known about the observatories areas. As part of a synergistic approach, tests are carried out with and without altimetric data assimilation in coastal model and quantities as SSH and SLA are compared over a relevant period of time.

Thereby, the ODYSSEA will offer to the coastal community, and specially to the coastal altimetry community, a robust reference for satellite data validation and interpretation based on in-situ data and numerical model outputs. Besides the comparison with model output, glider data along Satellite tracks (Sentinel-3, SARAL, Jason-1-2-3) in key regions of the Mediterranean will be soon available, in order to shed light on the relation between sea surface signature of structures (in terms of Temperature and Sea-level) and what is occurring at depth.

In order for the synergies between altimetric and in-situ data provided by Odyssea to move towards an effective operational mode, it is required to ensure the availability of gridded satellite constellation products, especially regarding Fully Focussed SAR Altimetry (CryoSat-2, Sentinel-3, or Sentinel-6/Jason-CS).

(*): This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727277.

Quantification of the Signature of the Northern Current in Sea Level Variations or How Can We Optimally Use Altimetry Observations in Coastal Circulation Studies

A. Carret, F. Birol, C. Estournel

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Extreme Sea Level in the Coastal Zone – Pathway to Improved High-Temporal-Resolution Gridded Sea Level Product over the Baltic Sea

I.M. Ringgaard, J.L. Høyer, K.S. Madsen, A. Abulaitijiang, O.B. Andersen

This ongoing work is part of the Baltic+SEAL project. The aim is to obtain a gridded product combining tide gauges, satellite altimetry and storm surge model output into a gridded product for the Baltic Sea with a temporal resolution of 3 days. The short temporal resolution allows for extreme sea level events (i.e. storm surges) to be captured. The method will be based on previous work by Madsen et al. 2015 and Madsen et. al 2019 (the latter is part of the ESA DUE eSurge project). Using optimal interpolation, tide gauges and satellite altimetry will be weighted onto the storm surge model, resulting in an improved sea level product.
Data were processed and made available as part of the Baltic+SEAL project. Data includes tide gauges, satellite missions Jason-2, Jason-3, Cryosat-2 and Sentinal-3a and the storm surge model HBM run at DMI.

This gridded product highlights the synergy between the satellite altimetry community, the in-situ observational community (tide gauges) and the modelling community by combing the knowledge from these three different fields. As the Baltic Sea contains areas with many small islands and narrow straits, this is an ideal area to experiment on coastal altimetry.

The first step is to test the possibility and value of a high-temporal resolution gridded sea level product. On a longer time scale, the storm surge forecast would benefit greatly from having a near-real time gridded sea level product, as this could be used to improve the preconditioning before storm surges.

References:

Madsen, K. S., Høyer, J. L., Fu, W., and Donlon, C. (2015). Blending of satellite and tide gauge sea level observations and its assimilation in a storm surge model of the North Sea and Baltic Sea. J. Geophys. Res. 120, 6405–6418. doi:10.1002/2015JC011070

Madsen, K. S., Høyer, J. L., Suurrsaar, Ü., She, J. and Knudsen, P. (2019). Sea level trends and variability of the Baltic Sea from 2D statistical reconstruction and altimetry. Front. Earth Sci. 7:243.doi:10.3389/feart.2019.00243

The first four years of Sentinel-3 Altimetry – The latest Reprocessing

B. Lucas, R. Scharroo, S. Dinardo, C. Nogueira Loddo, C. Martin-Puig

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

The Sea-level Budget on the Northwestern European Shelf in the Satellite Era

C. Camargo, R. Riva, T. Hermans, A. Slangen

The contribution to the final report has not been provided by the author/s.
The presentation can be found on the Workshop website.

Feedback from CAW-12 Participants

The following points have been indicated by participants:

Training Day

- A 2-day training would be preferable to properly digest the content.
- Training material should be made available in advance on the CAW website.
- Video recording would be beneficial.
- BRAT & SARvatore demos should be given in training rooms with the involvement of attendants. This time, the combined lesson was too long and difficult to assimilate.
- Lessons on waves and on synergy with other sensors & models should be added.
- Examples with code should be made available.
- It should be better demonstrated how data are useful for coastal research.

Workshop

- More time for discussing posters is needed.