10th COASTAL ALTIMETRY WORKSHOP SUMMARY AND RECOMMENDATIONS[1]

WORKSHOP HIGHLIGHTS

This section describes the main outcomes resulting from the sessions and plenary discussions.

Highlights from session 1 - Waveforms and Retracking:

1) The continuing improvement of retracking techniques for LRM missions and the availability of Delay-Doppler processing in CryoSat-2 and Sentinel-3 have increased the precision and the reliability of high-resolution data in the coastal zone.
2) The high-resolution data allow observation of previously poorly resolved signals, such as internal solitary waves; further advances are expected from improvements in the coastal and shelf seas MSS and atmospheric corrections, and from the exploitation of the altimetric constellation to maximise the temporal sampling.

Highlights from session 2 - Range and Geophysical Corrections:

1) The main errors in the coastal areas still come from the wet tropospheric correction and the tide correction; the wet tropospheric correction is the most investigated and several options exist to improve it; the improvement of the tidal correction requires more accurate bathymetry datasets than what is available today to the scientific community
2) The Mean Sea Surface (MSS) is also an important source of errors in the retrieval of the sea surface height anomalies. Sentinel-3A and soon Sentinel-3B are on a new set of ground tracks, not previously surveyed, resulting in a lower accuracy of the present-day MSS for these missions. A few years of data will be necessary to reduce the errors for these ground tracks.

Highlights from session 3 - Performance and Cal/Val of Coastal Altimetry:

1) Improvements of SAR processing is still work in progress, and depends on the particular target, the most advanced example being fully-focused SAR processing for small water bodies and near-shore retrievals.
2) An unexplained bias in the significant wave heights of CryoSat-2 in the coastal zone needs to be investigated further.
3) Results that were presented at the workshop show a clear improvement in the coastal area thanks to the SAR and SARin modes, even in the 0–4 km band from the coast, which is half the “blind” zone in LRM. Studies have shown that

[1] Collated by Jérôme Benveniste, Paolo Cipollini, Stefano Vignudelli with the input of the CAW-10 Session Chairs: Marcello Passaro, Walter Smith, Mathilde Cancet, M. Joana Fernandes, Marie-Laure Frery, Pascal Bonnefond, Luciana Fenoglio-Marc, Remko Scharroo, Claire Dufau, Ole Roggenbuck, John Wilkin, Jerome Bouffard, Jessica Hausman, Svetlana Karimova, David Cotton, Kaoru Ichikawa and Guy Wöppelmann

this improvement also depends on the angle between the coastline and the satellite track.
4) The data retrievals in the 0–4 km band remains challenging and performance depends also on the options used in SAR processing, however, the improvement with reference to standard LRM is confirmed.
5) Absolute calibration requires a very well defined datum, as it is the case for the Corsica site. This datum is less well defined for other sites. Many sites in different regions are required.
6) The very small scales of ocean dynamics, i.e. those at the high resolution offered by the SAR and SARin modes, are poorly known: in situ data provide high temporal resolution but poor spatial resolution and this is the reverse for altimetry. It is then crucial to notice that the poor agreement often seen between in-situ data and altimetry can be due to sampling mismatch, not just to errors in one or the other of the two independent measurements.

Highlights from session 4 - Altimetry for Regional and Coastal Models:

1) The visibility of coastal altimetry products can be enhanced through a Wiki or User Forum where experts could offer help for novice users; demonstrate the value added by comprehensive use of coastal altimetry (emphasizing processes not platforms); encourage a greater focus on sea level in model analysis, e.g., for exploring synergies between altimetry and tide gauge data for coastal inundation; identify coastal regimes (river plumes, fronts, internal waves, estuaries) potentially informed by altimetry.
2) A focus on Sea Level processes in the coastal ocean appears to be the starting point to increase the synergy between altimetry and coastal and regional modelling communities;.
3) There is clearly a growing interest in sub-mesoscale dynamics, which is a trend that is re-unifying coastal and open ocean altimeter communities;
4) The present practice of combining the inverse barometer (IB) and high-frequency (HF) atmospherically forced effects on Sea Level into a single Dynamic Atmospheric Correction (DAC) mixes different dynamic processes that coastal oceanographers view as distinct;
5) The outcome of this Session at CAW-10 will be presented during the ARCOM session at the 5th ICM COSS-TT in April 2017.

Highlights from session 5 - Applications I – Currents, Waves and Winds:

1) Data on sea level anomaly (SLA) (e.g. the ones provided by ALES and CTOH/X-TRACK) are successfully used for studying temporal and spatial variability of surface currents in various coastal areas (e.g., North-Western Atlantic, South-Western Atlantic, Mexican Pacific, Northern Bay of Bengal, Arabian Sea, area of the Norwegian Coastal Current, Mediterranean Sea and Korean coastal waters).
2) Surface currents extracted from altimetry-derived products are validated against some in situ derived measurements of surface currents speed (moorings, ADCP, HF-radar, etc.). Although the comparisons are quite good in terms of correlations, there are still some disagreements in terms of absolute current values that need to be better understood.
3) Special attention still needs to be paid to an assessment of performance of SLA data in observing mesoscale rotational structures (vortices);

4) There are a great variety of altimetry products being currently used for different oceanographic applications. Among them there are both conventional and relatively well-known products (such as AVISO/CMEMS, OSCAR, GlobCurrent, etc.) and more innovative, mostly coastal-oriented datasets (ALES, CTOH/X-TRACK, PEACHI, SARAL/AltiKa, CryoSat-2 custom processed with ESA-ESRIN GPOD SARvatore service, etc.). The general tendency observed in the data usage is that the new data sources are expected to provide new exciting horizons for resolving small-scale circulation patterns comparing to the conventional datasets. Thus, through an analysis of both SLA and waveform signals captured by the new generation SAR altimeters (e.g., CryoSat-2 and Sentinel-3), there is hope to resolve smaller-scale near-coastal flows which cannot be observed using just conventional SLA products, meso- to submesoscale vortical structures, near-coastal upwelling events, internal soliton waves, etc.

Highlights from session 6 - Applications II - Sea Level and Extreme Events:

1) The largest number of presentations considered different aspects of the nature and character of sea level rise, globally, and in different coastal regions around the world. Examples of applications include investigating upwelling events on the Great Australian Bight, coastal defence around UK, vulnerability around Slovenia, Croatia, Montenegro and Albania, sea level trends around Australia and Indonesia, fiords and Arctic region. Examples of data analysis include CCI products, VLM estimation and small scale gravity changes.
2) The potential of swath altimetry to support improved surge monitoring was discussed. This includes the SWOT mission, but also the “SWOT-like” instrument on board the Chinese Space Station (Tiangong 2), whose data is due to be released in 2017. An investigation of number of case studies of individual storms (including Sandy, and Igor) on the East Coast of North America, using satellite altimeter data to derive parameters including surge magnitude and cross shelf decay scale;
3) The synergy of altimetry/tide gauges/modelling improves storm surge monitoring in the Baltic Sea;
4) Validation of Coastal Seal Level Measurements has been done in the German Bight;
5) Applications of data from Interferometric SAR (SAR-In) mode in areas characterised by complex topography and coastline (Fjords of Greenland and Norway leads to better results than with LRM or SAR modes.

RECOMMENDATIONS FROM THE WORKSHOP

From the plenary discussion the main recommendations from the workshop are:

1) High-resolution along-track should be made more accessible to non experts, with well-documented manuals in user-oriented formats. Some ‘best choices’ in terms of corrections should be already made by data producers (and clearly documented) so that high-resolution sea level measurements can be used directly by oceanographers without the need to recompute the sea surface height, and data user support should be provided. [This recommendation is detailed in Annex 1.]

2) A "REAPER-style" update of the TOPEX SGDR should be produced i.e. one that includes calibrated waveforms and updated instrumental corrections, with the relevant documentation.
3) Developers of coastal altimetry data sets should complement the traditional statistics based on the standard deviation of the estimations within a 1-Hz block with new "measures of reliability" based on the quality flags available in L1-L2 SGDR datasets and on the outcome of specialized retrackers.
4) The Mean Sea Surface and Mean Dynamic Topography in the coastal zone should be improved with the integration of Delay-Doppler processed data. The CryoSat-2 mission could be used to resolve the MSS details in the coastal regions with its SAR and SARin modes. SAR and SARin would add valuable information for improving MSS and MDT in coastal regions.
5) Acquiring SARin mode data with CryoSat-2 over open coastlines, estuaries and marginal seas would be valuable in preparation for future missions such as SWOT and a future SARin mission that ESA is studying. SARin mode is required for the "difficult" coastlines and to cover the requirement to drastically increase the spatial and temporal resolution to catch the small-scale signals on the shelves and very near shore. Also a future SARin mission should provide a better retrieval of the wet tropospheric correction near the coast.
6) In line with the previous recommendations, a request should be made to ESA for changes in the mode mask in order to sample all coastal areas either in SAR or SARin mode (depending on the coast type)[2].
7) New research aimed at demonstrating that improved coastal altimetry data sets can lead to more oceanographic knowledge of the small scales of variability must be promoted and supported.
8) The attention of the national authorities should be drawn onto the importance of making accessible bathymetry data sets to the scientific community, in particular regional bathymetry models and their updates, needed for getting high-accuracy tides and DAC corrections.
9) The application of the Dynamic Atmospheric Correction correction should be re-evalued. Potential inconsistent application of the DAC and issues with regional coastal geodetic datum makes using altimeter data in conjunction with tide gauges not obvious; moreover the Inverse Barometer and DAC should be provided separately as they are seen by oceanographers as distinct dynamics phenomena.
10) Further studies of the dependency of SAR measurement on swell should be encouraged

CONCLUSIONS

The technical development in coastal altimetry is continuing. Advances in LRM retracking and data processing are complemented by advances in corrections, and the whole field is receiving further impetus from the availability SAR mode data from CryoSat-2 and Sentinel-3. Integration of coastal altimetry with in situ observations and models remains crucial and has been a central topic at CAW10, and we should continue to feature it in future CAWs. The new scenarios for remote processing are especially interesting for helping this integration. Projects such as Co-ReSyF (funded by EU) and C-TEP (funded by ESA) are going to provide users with an environment

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[2] If the resources available on CryoSat-2 pose a limitation on the amount of SAR/SARin data, those regions where there are complementary in situ data from evolving coastal ocean observing systems of the Global Ocean Observing System (GOOS) Regional Alliances should take priority.

to merge different data sets, to raise collaborative data science, to develop and validate new applications, and to share these applications with other users.

The need for high-resolution and high-precision bathymetry appears to be more and more crucial to improve ocean modelling at high resolution (from a few km to a few hundred m). Tides and storm surge modelling are in particular much impacted by the quality of the bathymetry that is used in models, which may have direct impact on the accuracy of the coastal altimetry data if these model outputs are used as corrections for the SSH. This is even more crucial today and in the near future, with the improvement of satellite altimetry performances at the coast in terms of precision as well as resolution (SAR altimetry and SWOT mission).

Finally, user-friendly data access is central to the further development of coastal altimetry: data providers, research programme managers, space agencies should implement data processing training courses, especially now that there are new high resolution data; so that many researchers and students can process the data for their respective area of interest.

ANNEX I: DATA ACCESS AND USER SUPPORT

This section provides further details on the requirements for user-friendly data and user support that stemmed from the discussion at the workshop.

The coastal oceanography community (not only modellers) needs access to:

- 'rich' 20 Hz level-2 data, i.e. with corrections, to facilitate multi-platform synthesis (the ingredients of advanced analysis), recognizing that in coastal regimes it is still always necessary to test products to identify biases and errors;
- 'simple' 20 Hz level-2 i.e. with a limited set of recommended and documented (the recipes for advanced analysis) defaults selected by experts to the benefit of non-experts ;
- validated' 20Hz level-3, projected onto fixed along-track points , enriched with recommended defaults for tides, DAC, and other corrections to facilitate easy adoption by coastal oceanographers seeking a "first look" at time series of coastal altimeter products.

All of these data should be available, ideally, as centralised products (encompassing multiple missions and re-tracking analyses), in a common format and together with community tools in support of applications (e.g. by creating a repository for codes that undertake pre-processing tasks for typical coastal oceanography analysis, and/or prepare data for ingest into community modelling and model-data assimilation systems, including tools/scripts for near-real-time forecast systems). There is a clear search for unity/consistency in multi-platform products and formats, but it is recognized that the inhomogeneity and anisotropy of space and time scales in coastal waters argues against attempting to offer L4 merged products.
Steps that should be taken to improve data access to the end users include:

- Create a unified coastal altimetry platform which would provide
  - a generalised objective review of currently available coastal altimetry products with mention of the primary area of application, advantages and drawbacks of each product.
  - recommended roadmaps for obtaining and processing different types of data.
  - a forum for discussing scientific and technical issues related to the usage of the coastal altimetry product.
- Reduce the number and increase technical quality of user manuals for already-existing and newly-arriving products.
- Introduce spatial/temporal data subsetting facilities at the earliest possible stages.
- Standardise wherever possible the data formats, data access policies, data exploring/processing toolboxes, etc., for all products.
- Provide a regularly-updated summary or webpage of the available corrections and coastal altimetry products.
- Enhance the collaboration between modellers and coastal altimetry in order to share data sets and validate the corrections and coastal altimetry products.
- Prepare consensus recipes for coastal altimetry in order to guide novice users in the coastal oceanographic community.

- Organize training sessions for novice users and a coastal altimetry summer school in order to demonstrate hands-on uses of the data in applied situations, and foster the creation of instructional materials that could be made available beyond the summer school.

A standardised quality assessment should also be provided with coastal altimetry data, this in turn leads to a requirement for an agreed and robust approach to error characterisation. The example of the protocol developed in the CCI-Sea Level project was seen as an excellent example
It was noted that a flexible approach was needed when identifying the most appropriate altimeter data for comparison against Tide Gauge data, which depends on the local coastline topography and local oceanographic features. Sometimes the closest point will not provide the best results and other options must be explored, e.g. the point where the data are most correlated, or altimeter measurements averaged over a search radius. The best approach is best determined on a case by case basis, as characteristics and scales of variability are highly location / phenomenon dependant.

ANNEX II: SUMMARIES FROM THE INDIVIDUAL SESSIONS:

SESSION-1 - Waveforms and Retracking

Chairs: Marcello Passaro, Walter H. F. Smith, Pierre Thibaut

SUMMARY

The session was composed of 5 oral presentations and 2 posters. The discussion of Session-1 was mainly focused on the status of the high-frequency (HF) products, i.e., delivered at a 20 Hz frequency, in the coastal zone. The user community is eager to use these data, as they could reveal details at mesoscale and sub-mesoscale levels. Indeed, applications of HF data have already been presented either in the past (such as iceberg detections) or in this CAW (variation of retracked parameters in connection with internal solitary waves).
Nevertheless, one of the main points of criticism is the accessibility of HF coastal products. Currently, most of them are delivered in Level 1 or Level 2 products and the non-experts are often not able to retrieve the sea level datum by adding all the necessary corrections to the retracked range. One of the challenges for the community will be therefore to deliver HF products in which some choices in terms of corrections are already made, so that the oceanographers can access directly the HF sea level measurements. Such choices shall be clearly documented in the user manuals.

It is clear that the improvement of retracking techniques for LRM missions and the availability of Delay-Doppler (DD) processing in CryoSat-2 and Sentinel-3 have increased the precision and the reliability of HF data in the coastal zone. It is not yet clear whether this improvement can lead to more oceanographic knowledge of the small scales of variability for the following reasons:

1) Most of the atmospheric corrections are still delivered at 1-Hz rate ;
2) The quality of the mean sea surface (MSS) used to derive sea level anomalies from the retracked range is likely not to be sufficient in the coastal zone. Indeed, the mean sea surface models are based on altimetry data that are not reprocessed with coastal retrackers. A significant improvement of the MSS should come with the integration of DD data.
3) The temporal sampling rate of current altimetry missions is still insufficient to allow the observation of many sub-mesoscale processes.

Another point of discussion focused on the methods that are available to the users in order to assess the quality of an HF retrieval. The statistics based on the standard deviation of the estimations within a 1-Hz block are indeed of limited usefulness when dealing with HF data. In the L1-L2 SGDR dataset several quality flags are available. The developers of coastal altimetry dataset should start from these quality flags and release some “measures of reliability”.

It was noted that the new SGDR data delivery of past missions (such as the REAPER project for ERS-1 and ERS-2) is of great help for the community, since it allows the production of a coastal dataset that can go back at the beginning of the altimetry era. The community suggests therefore a “REAPER style” update of the TOPEX SGDR, i.e. including waveforms and instrumental corrections, and the relative documentation (which currently dates back 1993) in line with the newest reprocessing (currently only new orbits and new SLAs are distributed), in order to allow experiments with coastal retracking.

To summarise, the coastal retracking techniques of LRM altimetry and the improved data quality of Delay-Doppler data justify the attempt of exploit coastal sea level measurements also at rates higher than the traditional 7-Km averages. While further improvements are requested, it is time to improve the delivery of coastal data in user-oriented, well-documented formats.

SESSION-2 - Range and Geophysical Corrections

Chairs: Mathilde Cancet, Joana Fernandes, Marie-Laure Frery

SUMMARY

The session was composed of 6 oral presentations and 5 posters. A summary of each presentation and poster is presented.

Oral Presentations

1. *Validation of Sentinel-3 Wet Tropospheric Correction (Fernandes, M. Joana; Lázaro, Clara)*

Assessment of the Sentinel-3A (S3A) MWR-derived Wet Tropospheric Correction (WTC) (Reprocessed version 1 available in RADS) was presented, by means of comparison with GMI and the MWR on board J1, J2 and SARAL, comparison with GPD WTC solely based on external data (no on-board MWR used) and SLA variance analysis. Overall, performance is good in terms of long-term stability. RMS differences with respect to GMI, J1, J2 and AltiKa is 1 cm, 1.3 cm, 1.4 cm and 1.6 cm respectively. Calibration factors between 0.97 and 1.03 and offsets between 0.3 cm and -1.2 cm were found. The results also suggest that improvements are still required, particularly at the high latitudes.

2. *Performance of Sentinel-3A Surface Topography Mission Microwave Radiometer in Coastal Areas (ML. Frery, M. Siméon, P. Féménias, C. Goldstein)*

A status of performed and on-going developments was provided. For all studies, S3A is systematically compared to other instruments: J2, AltiKa, MetopA/AMSUA. The calibration of the MWR has been performed using a three-point approach over the full range of observable brightness temperatures. A bias between ascending and descending tracks is observable for S3A when comparing measurements and simulations, but not for the other instruments (J2, AltiKa, MetopA/AMSUA). This point still needs to be addressed. The WTC from the classical retrieval algorithm (three parameters) shows very good results by the metric of variance of SSH at crossover points (-2.2 cm²), with J2 around -2 cm² over the same period. Results of the new interpolation scheme based on Envisat and AltiKa were also presented and showed an improvement in the comparison of MWR-ECMWF difference close to the coast. An understudy algorithm was presented, that takes into account the land contamination in the MWR footprint for the retrieval of the WTC. This new algorithm needs more analysis and in-depth validation but already shows very promising results in the coastal areas.

3. *Exploitation of AIRWAVE for retrieving the wet tropospheric correction for coastal altimetry (Clara Lázaro et al.)*

The objective of this work is to develop, assess and validate a GPD+ WTC computed with the AIRWAVE dataset of Total Column Water Vapour retrieved from the series of Along-Track Scanning Radiometer on board ERS-1/2 and ENVISAT. It is intended to take advantage of the high spatial resolution of these data (1×1 km^2) and of the existence of data up to the coast. Results for the North-West Mediterranean Sea and for ENVISAT were presented. Based on several SLA variance difference diagnostics (computed cycle by cycle, function of the distance from the coast, along-track and at crossovers), it has been concluded that GPD+ with AIRWAVE shows an improvement in coastal regions (0-100 km) when used instead of MWR- and ERA-derived WTC. Overall, the results underline the potential of AIRWAVE data for coastal altimetry applications. The implementation of several algorithms for the improvement of AIRWAVES data accuracy is on-going.

4. *ACCRA: A study on future Microwave Radiometers for Atmospheric Correction of Radar Altimeters on Coastal regions (B. Picard, J. Charlton, L. Eymard, F. Karbou, L. Hermozo, M. Martin-Neira, ML. Frery)*

The study aimed to find the best microwave radiometer instrumental design and retrieval algorithm for future operational radar altimetry missions. The proposed design shall include the classical low frequency channels for ensuring observation continuity, augmented by a set of high frequency channels to enhance the retrieval in the coastal areas and over inland waters. The optimal set of frequencies has been defined using simulations and a final set of frequencies has been chosen after consideration of cost and volume constraints. A preliminary design has been developed with high constraints on the weight, volume and consumption, on the antenna performances to reduce side lobe and on the sensitivity. Finally both cold and hot calibrations have been recommended. Two types of retrieval algorithms have been tested to get the best of the new HF channels: an empirical neural network trained on ocean and land measurements and a 1DVar approach using a dynamical estimation of the emissivity. Both types of algorithms show good performances but the 1DVar approach seems very promising as it is able to downscale the WTC.

5. *Assessment of the FES2014 tidal currents on the shelves of Australia (M. Cancet, F. Lyard, D. Griffin, L. Carrère, N. Picot)*

In addition to the classical global validation of the tidal elevations from the FES2014 global model, an assessment of the FES2014 tidal currents was done, using 48 ADCP in situ observations located on the shelves all around Australia and provided by IMOS. The comparison between the model and the observations was done both in the frequency domain (vector differences on the amplitude and phase lag, for each tidal component and in each current direction, current ellipses) and in the temporal domain (time series of tidal current predictions). All these analyses are quite complementary and show the very good agreement between the FES2014 model and the ADCP data, in regions of various tidal regimes ranging from micro-tidal to macro-tidal. At a few ADCP stations, larger misfits are observed between the model and the observations. In these regions, generally characterized by very shallow waters, the resolution of the model is not sufficient to accurately model the tidal currents and regional configurations would be more appropriate. On very steep bathymetry gradients, the resolution of the model grid is sometimes too coarse, which can generate very local artefacts in the tidal current solutions. These results confirmed the general very good quality of the FES2014 tidal model, in particular in the coastal regions, and also highlighted some possibilities of improvements to the model.

6. *Assessment of Altimetric Range and Geophysical Corrections and Mean Sea Surface Models—Impacts on Sea Level Variability around the Indonesian Seas (Eko Y. Handoko, M. Joana Fernandes and Clara Lázaro)*

The best set of range and geophysical corrections and Mean Sea Surface models to use with TOPEX/Poseidon, Jason-1 and Jason-2 altimetric data for the Indonesian Seas region has been achieved after the assessment of the accuracy of the various available corrections and models through several sea level anomaly variance analyses. The sea level anomaly time series for the period 1993-2016, generated with the selected corrections, shows an increase in sea level of 4.2 $\pm$ 0.2 mm/year. The inter-annual component of sea level variation around the Indonesian seas is dominated by the ENSO phenomenon. The ccomparison between the detrended SLA time series and the Multivariate ENSO Index (MEI) shows a strong negative correlation (-0.74) during the analysed period.

Posters

1. *Enhance Coastal Tide Modeling Using Cryosat-2: A Feasibility Study (Piccioni et al.)*

The monitoring of tides normally requires repeating-orbit altimetry missions. In the case of the very long-term repeating orbit of Cryosat-2, the tidal signal is sampled at very long aliased periods. However, some methods enable to successfully identify these aliased signals in the Cryosat-2 data for the main tidal components, as shown in this study.

2. *Tidal downscaling in a 3D circulation model: a new approach based on tailored 2D simulations (Toublanc et al.)*

A study on the downscaling of tides in a 3D circulation model is proposed in the Bay of Biscay. The different tests have shown that the best large-scale 2D tidal solution (FES2012 global model in this study) is not always the best forcing solution for downscaling, as it can induce strong errors when used “as it is” to force a nested 3D circulation model. A tidal downscaling based on “tailored” 2D simulations with the same grid and bathymetry as the 3D high resolution simulations is used to avoid inconsistencies at the open boundaries due to resolution and/or bathymetry differences.

3. *Recent development in MSS and Gravity in the Arctic Region (Andersen and Knudsen)*

A new Geodetic MDT is derived from DTU15 MSS and a new experimental combined GOCO5CX (based on DTU15 GRAVITY from d/o = 360). DTU15 MSS is based on DTU13 model with the use of 6 years of CryoSat-2 measurements, which leads to improvements in the Arctic Ocean. Moreover, with its new geodetic track, SARAL/AltiKa will be a good asset for improvement in coastal areas due to its smaller footprint with respect to other altimeters.

4. *Evaluation of the Dry and Wet Tropospheric Corrections for CryoSat-2 and Sentinel-3 Over Inland Waters (Fernandes et al.)*

The DTC and WTC errors present in CryoSat-2 products were analysed for 4 regions of interest: Amazon and Danube Rivers, Lake Titicaca and the Caspian Sea. The DTC and WTC available in the CryoSat-2 products were compared against those derived from ECMWF, computed at the level of the ACE2 DEM, at the ECMWF orography and at the mean river or lake profile. An independent assessment of the corrections was performed by comparison with DTC derived from in situ surface pressure measurements and WTC retrieved from GNSS data. Errors up to several hundreds of meters have been identified in the surface elevations, which directly induce systematic DTC errors of several centimetres (11 cm in the Danube River) and WTC errors up to 2-3 cm, thus strongly affecting the retrieval of accurate water level profiles. Once computed at the correct surface elevation, the errors are expected to be less than 1 cm for the DTC and less than 2 cm for the WTC.

5. *Analysis of Altimetry Range and Correction in a Flat Coastal Environment at Aix Island Sea-Level Observatory, France (Testut et al.)*

The Aix Island sea-level observatory is a well-instrumented site for satellite altimetry calibration using in situ data such as tide gauge and GPS. Due to the specific location of the Aix island, between the two flat and elongated islands of Ré and Oléron, the usual methods of correction extrapolation from less contaminated offshore zones do not give accurate results. An analysis of the local conditions (SWH) and of the land contamination in the altimetry corrections (WTC) is performed with local models and GNSS measurements. A local geoid mapping is also underway.

Discussion and rcommendations

The higher spatial resolutions offered by the new altimetry techniques should give access to the mesoscale structures. But to fully exploit these higher spatial resolutions, high-resolution accurate corrections shall be provided up to the coast. To date, the main errors in the coastal areas still come from the wet tropospheric correction and the tide correction.
Several options are under development for the wet tropospheric correction, through the exploitation and/or the combination of various sources of information such as on-board MWR, GNSS data, imaging microwave radiometers and thermal infrared radiometers, through innovative retrieval algorithms for the current in-flight radiometer instruments and through the innovative design of new radiometer instruments using HF channels.

Regarding the ocean tides, the use of grids at higher resolution was recommended for the computation of the tidal corrections in the altimetry products. For instance there is no correction from GOT4.10 close to the coasts due to the coarse ½° grid. In the case of models implemented on unstructured grids (such as the FES models), the tidal predictions could be computed directly from the original grid in order to benefit from the full resolution of the model. In addition, the coasts are areas that would take the most benefit of regional/local tidal models. Finally, in macro-tidal regions it would be better to consider wetting/drying effects in the hydrodynamic models. However, increasing the resolution of the tidal models in the coastal regions requires more accurate bathymetry datasets than what is available today and an effort should be put on this aspect. In particular, in some regions such as river estuaries, the bathymetry changes over the time, which has a large impact on the tidal processes and should be also taken into account in the models.

The MSS is also an important source of errors in the retrieval of the sea surface height anomalies. Some missions such as S3A and soon S3B are on untracked orbits, leading to a lower accuracy of the MSS for these missions. A few more years of data will be necessary to reduce the errors for these orbits. In general, computing high-resolution coastal MSS from high-resolution reprocessed coastal altimetry datasets should be considered in order to take the most benefit of these datasets. Finally, the Croysat-2 mission could be used to resolve the MSS details in the coastal regions with its SAR and SARin modes. A request has been made to the Cryosat mission, to consider the possibility of changing the mode mask in order to sample all coastal areas in SAR and SARin modes .

In order to further validate the corrections and altimetry products, the collaboration between modellers and coastal altimetry should be reinforced. Both communities would take benefits from working more closely and sharing data. Finally, more information was asked by the users regarding the corrections and the altimetry products. A regularly-updated summary or webpage of the available corrections and coastal altimetry products was suggested.
Although not discussed to the workshop, it should be highlighted that acquiring updated bathymetry on a regular basis in coastal areas is performed by the most developed countries using eco sounding methods (multi-beam sounding) but these data are usually property of the national Hydrographic institutes and they don't

provide them to the tide developers. The only thing the scientific community can do is to continue the efforts in order to draw the attention of the national authorities to the importance of making accessible these valuable data sets to the scientific community, in particular for usage in the tide models.

SESSION-3 - Performance and Cal/Val of Coastal Altimetry

Chairs: Pascal Bonnefond, Luciana Fenoglio-Marc, Remko Scharroo

SUMMARY

The session was composed of 5 oral presentations and 14 posters. The Cal/Val approach can be mainly divided into two parts: (i) closed loop, being as close as possible to other means (other space sensors, in-situ data, etc.) and (ii) open loop, broaden the closed loop to regional and global Cal/Val by the means of models. The contributions to the session highlighted both approaches. Two oral talks were on global validation of the Sentinel-3, two other oral talks were on regional validation of CryoSat-2 and SARAL/AltiKa (Eastern North Atlantic shelf and Spanish Atlantic coast), one oral talk was on in-situ calibration at the Corsica site. Of the fourteen posters four were dedicated to regional analysis respectively in the North Sea, Mediterranean, Patagonia, South West Bass Strait. The others were addressing global analysis and related to improved data and projects (SHAPE, Scoop, DUACS, X-track), toolboxes (BRAT, GUT, G-POD) and mission status (Sentinel-3), validation with models (MACS).

Six seed questions were addressed and tentative answers were given:

1. What are the current limits and limitations of SAR altimetry and how are they expected to change in the near future?

Promising improvements of SAR processing are in progress, depending on the target, like fully-focused SAR for small water bodies and near-shore retrievals. Further investigations are needed to study the dependency of SAR measurement to swell.

2. Are we confident enough with SAR data to map coastal ocean surfaces, currents, wave heights, and wind speeds?

An unexplained bias in the significant wave heights of CryoSat-2 in coastal zone needs to be investigated further. The first analysis of Sentinel-3A data looks promising, but more investigation is needed as the ramp-up phase continues.

3. Can we quantify (as a function of distance from coast and direction) the reduction of land contamination in SAR mode compared to LRM?
It is difficult to give a clear number but the presented analyses shows a clear improvement in the coastal area thanks to SAR, even in the 0–4 km band from coasts, which is half the “blind” zone in LRM. Studies shown that this improvement also depends on the angle between coastline and satellite track.

4. How close to the coast can SAR altimetry be effectively used?

The results shown suggest that retrievals in the 0–4 km band remain challenging, and that performance depends also on the options used in SAR processing (e.g. Hamming window). Although the PLRM measurements are not completely comparable to standard LRM because they are noisier, the improvement thanks to SAR processing appears clearly in the coastal band when compared to PLRM.

5. How can we proceed to prepare for SWOT technology?

Data from CryoSat-2 with a small roll of 0.5° were acquired and need to be investigated. The CryoSat-2 project (T. Parinello) proposed to plan a CryoSat-2 campaign with roll up to 6° to simulated the SWOT conditions (incidence angles from 0.6 to 4°).

6. It has been observed that the absolute calibration of altimetric sea level at dedicated sites gives insights about measurement biases at the mm level. Can we explain the discrepancies and improve our confidence in the calibration?

It is well known that absolute calibration requires a very well-defined datum; therefore GPS data and a highly accurate geoid in the area are needed. This is the case for the Corsica site. However, other sites where a very precise dedicated geoid in the area is still not available could be involved trying to use the geoid information available or improve the geoid based on available altimeter data on coincident and crossing tracks.

In the final discussion open questions on the spectral content of SAR measurements, coastal band, and calibration/validation issues were further raised and discussed. It was agreed that the spectral content of SAR measurements, but also the ocean dynamics, at lengths smaller than 10 km is still not fully understood.

Also, our knowledge of the coastal band needs to be improved. The coastal band within few kilometers is an almost unexplored territory. Some areas have very well-defined in-situ instrumentation, but the studies involving those instruments are invariably related to local phenomenon. In conclusion, altimetry is at his infancy in this small band, CryoSat-2 has provided some insights. This insight is now being extended thanks to Sentinel-3, but not everywhere.

Moreover, it has been pointed out that the missing agreement between in-situ data and altimetry does not mean that one or the other is in error. In particular the very small scales dynamics at this high resolution are poorly known: in situ data provide high temporal resolution but poor spatial resolution and this is the reverse for altimetry.

It was also discussed if the calibration and validation made at well-instrumented locations over small areas can be extrapolated elsewhere. Also here careful analysis is needed.

SESSION-4 - Altimetry for Regional and Coastal Models

Chairs: Claire Dufau, Ole Roggenbuck, John Wilkin

SUMMARY

ARCOM is a joint initiative of the GODAE OceanView Coastal Ocean and Shelf Seas Task Team (COSS-TT) and the Coastal Altimetry Workshops. ARCOM aims to establish links between the altimetry and coastal modeling communities to foster the greater use of altimeter data for studies of coastal sea level processes within coastal and regional models through data assimilation, assessment, and analysis. Launched in 2015 during the 4th international Coordination Meeting (ICM) of the COSS-TT, there are two ARCOM activities in 2017. The first, as reported here was during the CAW-10 meeting; the second will be part of the 5th ICM-COSS-TT in April. COSS-TT is an opportunity to present developments in altimetry to a large number of coastal and regional modelers.

This CAW-10 session gathered 12 technical presentations about data products for modelling systems (Dufau et al. high resolution custom product for Canadian Arctic), sea level processes studies with models and/or altimetry (Borrione: AUV-based dynamic topography compared to altimetry, assimilation in models, Hirose: Tsushima Strait dynamics, Wakamatsu: Tsugaru Warm Current dynamics, Meloni: Northwest Mediterranean integrated observing system compared to models, Wilkin: wavenumber and frequency spectra; comparison to nested models, Roggenbuck: altimeter, tide gauge & ship-based sea level dynamics) and altimeter Data Assimilation (DA) (Moore: Quantifying impact of DA on circulation metrics, Kamachi: downscaling DA-constrained estimates, Olita: DA within a nested model for Sardinia, Bonaduce (Passaro): Black Sea 3DVAR DA, Brandini: Tuscan coastal observing system).

The seed questions prepared for the discussion were developed along three themes:

1) the visibility of coastal altimetry products and their current use;
2) the quality of SLA and SSH in coastal areas;
3) the synergy with regional/coastal modeling.

Regarding the visibility of coastal altimetry products, the feedback is that they clearly need more visibility. Several propositions were made for the purpose of raising visibility and use:

- A Wiki or User Forum where experts could offer help for novice users was proposed;
- Demonstration of the value added by comprehensive use of coastal altimetry (emphasizing processes not platforms);
- Encourage a greater focus on sea level in model analysis, e.g., for exploring synergies between altimetry and tide gauge data for coastal inundation;
- Identify coastal regimes (river plumes, fronts, internal waves, estuaries) potentially informed by altimetry.

A request for higher-level products was made. In fact, today coastal altimetry products vary in ease of use and coastal and regional oceanographers need help from expert altimetrists. The coastal oceanography community (not only modelers) needs to access to:

- 20 Hz level-2 to facilitate multi-platform synthesis (the ingredients of advanced analysis), recognizing that in coastal regimes it is still always necessary to test products to identify biases and errors;
- 20 Hz level-2 with limited set of recommended and documented defaults (the recipes for advanced analysis);
- 20 Hz level-3 enriched with recommended defaults for tides, DAC, etc. corrections to facilitate easy adoption by coastal oceanographers seeking a "first look" and coastal altimeter products.

All of these data would be available, ideally, as centralized products (encompassing multiple missions and re-tracking analyses), in a common format and together with community tools in support of applications (e.g. by creating a repository for codes that undertake pre-processing tasks for typical coastal oceanography analysis, and/or prepare data for ingest into community modelling and model-data assimilation systems, including tools/scripts for near-real-time forecast systems). There is a clear search for unity/consistency in multi-platform products and formats, but it is recognized that the inhomogeneity and anisotropy of space and time scales in coastal waters argues against attempting to offer L4 merged products.

The quality of altimetry in coastal regions was not addressed during this discussion, as this was the focus of Session 3. The emphasis was on the dynamics of interest in coastal regions. There is clearly a growing interest in sub-mesoscale, which is a trend that is re-unifying coastal and open ocean altimeter communities. In term of geophysical correction, the present practise of combining the inverse barometer (IB) and high-frequency (HF) atmospherically forced effects on Sea Level into a single Dynamic Atmospheric Correction (DAC) mixes different dynamic processes that coastal oceanographers view as distinct. It is suggested that OSTST re-evaluate how this correction is applied. Potential inconsistent application of the DAC, and issues with regional coastal geodetic datum, makes using altimeter data in conjunction with tide gauges is not obvious.

Regarding the synergy between altimetry and coastal and regional modelling communities, a focus on Sea Level processes in the coastal ocean seems to be the best approach that could foster the link between these two communities. Sharing the latest advances in altimetry processing and missions and carrying these through to delivering examples of altimetry use in coastal and regional oceans would motivate future uses of altimetry in those areas.
Outcomes from this Session at CAW-10 that will be communicated during the ARCOM session at the 5th ICM COSS-TT in April 2017 (https://www.godae-oceanview.org/outreach/meetings-workshops /task-team- meetings/coss-tt-workshop-2017) are:

- A talk will be given about the latest advances in altimetry processing that could be useful for studying the coastal and regional processes (Action: Paolo Cipollini and Claire Dufau);
- Examples of altimetry use in coastal regions from this CAW-10/ARCOM session will be collected (Action: John Wilkin);

– Details and Information on available coastal altimetry products (ALES, PEACHI, X-track etc…) will be collected and proposed through posters (1 poster/product). (Action: Claire Dufau);

During the final discussion at the conclusion of the CAW-10 meeting, the following significant points of interest were raised:

- Regarding Cryosat-2 satellite, acquiring SAR data "everywhere" over the coastal ocean would add valuable information for improving MSS and MDT in coastal regions. (M. Idžanović demonstrated this in a Session-4 poster on the Norwegian Coastal Current). To accomplish this, the ESA decision-making process on Cryosat-2 operations needs a clear recommendation issuing from the coastal user communities (CAW and COSS-TT groups, for instance). Discussion also highlighted that SARin mode data over estuaries and marginal seas would be valuable in preparation for future missions (SWOT). Further experimentation with SARin data would give information, and develop expertise, about analysis of across-track, off-nadir targets. The CAW-10 community recommends that a request be made to ESA for expanded global coverage of coasts with SAR and SARin mode, perhaps emphasizing regions where there are complementary in situ data from evolving coastal ocean observing systems of the Global Ocean Observing System (GOOS) Regional Alliances.
- Regarding tides and DAC correction, regional bathymetries are needed for getting high-accuracy corrections. In addition, in dynamic coastal regimes (e.g. Bay of Bengal) the bathymetry may not be stationery. A partnership with coastal modelers/oceanographers is mandatory in these areas.
- Consensus recipes for coastal altimetry are needed to guide novice users in the coastal oceanographic community. This advice/experiences/recommendations need to be pushed out to users and/or hosted through recognized/respected (and searchable) sources, e.g. the NASA PO.DAAC portal and/or the Cryosat User Forum.
- It may be time for organizing training sessions for novice users instead of, or in addition to, the SAR training sessions that have been held in conjunction with CAW. A Coastal Altimetry Summer School would demonstrate hands-on uses of the data in applied situations, and foster the creation of instructional materials that could be made available beyond the summer school.

SESSION-5 - Applications I – Currents, Waves and Winds

Chairs: Jerome Bouffard, Jessica Hausman, Svetlana Karimova

SUMMARY

The session was composed of 5 oral presentations and 6 posters. Altimetry-derived currents in the coastal zone: challenges, solutions, and perspectives. Based on high-quality works presented in the framework of Session 5 we arrive at following conclusions.

Data on sea level anomaly (SLA) (e.g. the ones provided by ALES and CTOH/X-TRACK) are successfully used for studying temporal and spatial variability of surface currents in the coastal areas. Among the regions of interest used in the works presented at the session there were North-Western Atlantic (work presented by Vandemark et al.), South-Western Atlantic (Saraceno et al.), Mexican Pacific (Torres Hernandez et al.; Valle Rodriguez and Trasviña Castro), Northern Bay of Bengal (Ishaque), Arabian Sea (Qazi et al.), area of the Norwegian Coastal Current (Idžanović et al.), Mediterranean Sea (Bouffard et al.; Jebri et al.; Karimova), and Korean coastal waters (Yoo and Kim).

Certain efforts are being undertaken by the oceanographic community for validating surface currents extracted from altimetry-derived products against some in situ derived measurements of surface currents speed (moorings, ADCP, HF-radar, etc.). Such validating campaigns typically gather that in general there was quite good correlation between the values provided by the two techniques (Saraceno et al.; Valle Rodriguez and Trasviña Castro). Nevertheless, there can be some disagreements between the absolute values of current velocities retrieved in both cases. Such differences are reported to be higher in the shelf zones than in the open and deep ocean (Saraceno et al.). The observed discrepancies are supposedly explained by the fact that the velocity of Ekman currents is not observed by standard altimetry-derived products on surface currents.

Special attention still needs to be paid to an assessment of performance of SLA data in observing mesoscale rotational, also called vortical structures. The analysis performed showed that the conventional SLA products should be used with care while extracting statistics on mesoscale eddies, because only the largest (D>70 km) anticyclonic eddies can be more or less sustainably represented by closed contours in the fields of SLA retrieved from conventional products (see Karimova's talk).

There is a great variety of altimetry products being currently in use for different oceanographic applications. Among them there are both conventional and relatively well-known products (such as AVISO/CMEMS, OSCAR, GlobCurrent, etc.) and more innovative, mostly coastal-oriented datasets (ALES, CTOH/X-TRACK, PEACHI, SARAL/AltiKa, CryoSat-2 custom processed with ESA-ESRIN GPOD SARvatore service, etc.). The general tendency observed in the data usage is that the new data sources are expected to provide new exciting horizons for resolving small-scale circulation patterns comparing to the conventional datasets, as it was shown by a combined usage of CTOH/X-TRACK and SARAL/AltiKa data (Jebri et al.). Thus, through an analysis of both SLA and waveform signals captured by the new generation SAR altimeters (e.g., CryoSat-2 and Sentinel-3), it is supposed to resolve:

(i) smaller-scale near-coastal flows which cannot be observed using just conventional SLA products (Jebri et al.; Idžanović et al.);
(ii) meso- to submesoscale vortical structures (Karimova),
(iii) near-coastal upwelling events (Qazi et al.),
(iv) internal soliton waves (da Silva et al.), etc.

The users' feedback gained in the course of the after-session discussion witnessed that during recent years, there was a tremendous progress achieved in making altimetry products available to general oceanographic community. Nevertheless, some newly introduced products (e.g., provided by CryoSat-2) still have some lack of meticulously written user manuals, which are needed for allowing oceanographers to organize the data processing in an optimal way and thus to get the best of SAR altimetry datasets. Among other major concerns of the oceanographic user community, there was mentioned a lack of standardization among the altimetry products and a great divergence of existing datasets, approaches, retracking techniques, ways of the data access, etc. Such emulation among different scientific groups for sure favours a general progress in the data processing techniques, but at the same time it is putting some additional difficulties to the oceanographic public on a way to an effective and correct usage of coastal altimetry products.

Taking into account the feedback expressed in the course of the Workshop, the following recommendations have been proposed by the user community:

- to create a unified coastal altimetry platform which would provide
  - a generalised objective review of currently available coastal altimetry products with mentioning the primary area of application, advantages and drawbacks of every of the products;
  - recommended roadmaps for obtaining and processing different types of data;
  - a forum for discussing scientific and technical issues related to the usage of the coastal altimetry product;
- to reduce the number and increase technical quality of user manuals for already-existing and newly-arriving products;
- to introduce spatial/temporal data subsetting facilities at the earliest possible stages;
- to standartise wherever possible the data formats, data access policies, data exploring/processing toolboxes, etc., for different products.

SESSION-6 - Applications II - Sea Level and Extreme Events

Chairs: P David Cotton, Kaoru Ichikawa, Clara Lázaro

SUMMARY

The session was composed of 6 oral presentations and 9 posters. The topics covered came under four broad headings:

- To characterise and understand the nature and impact of sea level rise in different regions;
- Surge modelling and monitoring;
- Processing and validating coastal measurements of sea level, waves and winds;
- Use of the Interferometric SAR mode (“SAR-In”) at complex coastlines

We present key points of the presentations under these headings below:

The Nature and Character of Sea Level Rise

The largest number of presentations considered different aspects of the nature and character of sea level rise, globally, and in different coastal regions around the world.

1. *Validating Altimeter Estimates of Sea Level Along the Southern Coast of Australia, M. L. Cahill (CSIRO, Australia), B Legresy, H.B de Oliveira*

This paper compared AltiKa data from AVISO's PEACHI product against tide gauges on the Great Australian Bight, with particular interest in investigating upwelling events at the Bonney Coast at the eastern end of the shelf.

2. UK Sea Level Space Watch – Monitoring Regional Sea Level Variability around the UK from Satellite Altimetry. P. D. Cotton (SatOC, UK), E. Ash, P Cipollini, F. M. Calafat

This paper presented a demonstration service developed for coastal defence managers, in which sea level data from the NOC "ALES" coastal processor were processed and analysed to provide regional inter-annual and long-term sea level trends around the UK coastline, to supplement projections of sea level change provided by climate change models. The analysis showed good agreement between Tide Gauge and altimeter data, and new information on the variability of the annual cycle in sea level around the UK Coast.

3. *The Estimation of Sea Level Rise Impact on Coastal Zones of the Eastern Adriatic Sea, M. Grgić (University of Zagreb), R.S. Nerem, T Bašić*

The Eastern Adriatic coastline, which includes Slovenia, Croatia, Montenegro and Albania contains a number of areas potentially vulnerable to sea level rise within the range predicted by climate models. This study bought together information from a wide range of sources, including Sea Level Climate Change Model Projections, Tide Gauge data, Satellite altimeter data, Digital Elevation Models, Shuttle Radar Terrain Model (SRTM), and Land Cover models, to assess the potential impact of sea level rise in these areas.

4. *Accurately Measuring Sea Level Change from Space in the Coastal Zone: an ESA Climate Change Initiative, A Cazenave (LEGOS, France), J. F. Legeais, M. Ablain, G. Larnicol, J. Johannessen, M. Scharfenberg, G. Timms, O.B. Andersen, P.Cipollini, M. Roca, S. Rudenko, J. Fernandes, M. Balmaseda, G. Quartly, L. Fenoglio, A. Ambrosio, M. Restano, J. Benveniste*

The ESA Climate Change Initiative (CCI) was established to use satellite data to derive a number of "Essential Climate Variables" (ECVs). One of the key outputs of the CCI Sea Level project was to set up a protocol to develop, validate and select the best algorithms to optimize the homogeneity and stability of the Sea Level ECV. This included geophysical corrections, orbit solutions, tidal corrections, instrumental corrections.

5. *Combining Tide Gauge and Satellite Altimetry Data: Towards Monitoring Vertical Land Motion at the Coast. G Wöppelmann (University of La Rochelle, France), M. Marcos.*

This paper reviewed the combined use of satellite altimeter and tide gauge data to derive land motion data, a major challenge in monitoring sea level change at the coast. A new combined satellite altimetry and tide gauge data set has been developed and used to estimate vertical land motion at a large number of coastal sites around the world. The results were then compared to GPS derived measurements. These results are available through a demonstration service on the SONEL web site.

6. *Sea Level Trends, Variability and Processes Around the Australian coast, S Royston (University of Tasmania, Australia), C. Watson, M. King, B Legresy.*

In this study trends in sea level around the coast of Australia were derived from "Standard" or MLE4 retracked TOPEX/Jason series altimeter products, and from Jason-2 data re-tracked with the ALES coastal processor. The two time series showed similar variance characteristics. Also, for the period 2008-2014, the linear trend is largest > 40km away from the coast. Climate indices were seen to have a greater effect on trend away from the coast, with greater high frequency variability at the coast masking the open ocean signal.

7. *Mass Redistribution from Satellite Altimetry. L Bao (Chinese Academy of Sciences, People's Republic of China)*

This study focusses on the use of satellite data to investigate small scale gravity changes, and hence small scale mass redistribution which is important to explain regional geophysical phenomena.

8. *Assessment of a Coastal Altimetry Data Product in the Indonesian Coastal Waters, J. Lumban-Gaol (Bogor Agricultural University, Indonesia), S. Vignudelli, R.R. Leben, T. Osawa, B. P. Pasaribu, A. Mansawam, A. Manuputty.*

In this poster the CTOH altimeter product (primarily Envisat data) was used to establish key characteristics in regional, seasonal and inter-annual variability in Sea Level Anomaly across the Indonesian coastal region.

9. *Coastal Altimetry in Support of NASAs Oceans Melting Greenland (OMG) Project. J Larson (University of Colorado, USA), D. Masters, J Willis, R. S. Nerem*

Using altimeter data in the Greenland coastal region provides a number of challenges, due to floating ice, wind forced sea surface height changes, poorly resolved tide models, and a lack of tide gauges for measurement validation. However, this is a key area in terms of characterizing ocean forcing at Greenland's marine terminating glaciers. This poster presents a case study from a fjord leading to one of Greenland's retreating tidewater glaciers.

10. *The Importance of Sentinel-3 for Extending the Arctic Sea Level Record. O Andersen (DTU Space, Denmark), S. K. Rose, C. Ludwigsen, L. Stenseng.*

Seasonal ice cover in the Arctic Ocean causes severe limitations on the use of altimetry and tide gauge data for sea level studies. Special processing / editing is needed to retrieve sea level information from altimeter data. With Cryosat-2 data, the time series now covers almost 25 years (1991-2015), and these data have been analysed to provide estimates of mean sea level trend of 2.1 ±1.3 mm/year between

66°N to 82°N, with a significantly higher trend in the Beaufort gyre region. The addition of Sentinel-3 data to this data set is particularly important to support studies of Arctic Freshwater flows, and for continuing studies of long term trends.

Surge Modelling and Monitoring

There were two papers on surge monitoring and modelling:

1. *Monitoring Storm Surges using Satellite Altimetry, G. Han (Fisheries and Oceans Canada, Canada)*

This paper presented a number of case studies of individual storms (including Sandy, and Igor) on the East Coast of North America, using satellite altimeter data to derive parameters including surge magnitude and cross shelf decay scale. The potential of swath altimetry to support improved surge monitoring was discussed. This includes the SWOT mission, but also the “SWOT-like” instrument on board the Chinese Space Station (Tiangong 2), whose data is due to be released in 2017.

2. *Assimilation of Blended Altimetry and Tide Gauge Observations in a North Sea – Baltic Sea Hydrodynamic Model for Storm Surge Forecasting. K Madsen (Danish Meteorological Institute, Denmark), J. L. Hoyer, W. Fu, C. Donlon.*

This poster presented an approach which combines satellite altimeter and tide gauge data in a statistical model of sea level, which provides hourly sea level at each point along satellite tracks, and which is then interpolated onto a 2D field of Near Real Time sea level. This product is then assimilated into the DMI storm surge modelling system, and assessments show improved performance of the model, especially in the semi-enclosed Baltic Sea.

Validation of Coastal Seal Level Measurements

There was one paper on Validation of Coastal Seal Level Measurements:

1. *Coastal SAR and PLRM Altimetry in the German Bight and West Baltic Sea with Sentinel-3A and CryoSat-2. S. Dinardo (EUMETSAT, Germany), C. Buchhaupt, L. Fenoglio-Marc, R. Scharroo, J. Fernandes, M. Becker, J. Benveniste.*

In this study a number of different processing “recipes” for CryoSat-2 and Sentinel-3 SAR mode data were explored, including an optional inclusion of Hamming Windowing, zero-padding, and the implementation of a SAMOSA based coastal re-tracker – SAMOSA+. A “Pseudo LRM” (PLRM) product, generated by TU Darmstadt, was used as the baseline for comparison. The “dynamic” inclusion of Hamming windowing (i.e. applied at the coast but not in the open ocean), and application of zero padding was found to provide the best results. Also SWH / Range noise was seen to be slightly higher for Sentinel-3 than for Cryosat-2, it was suggested this is due to the larger number of valid bins sampled by the on-board re-tracker in Cryosat-2, as the leading edge is located earlier in the window. It was noted however that the Sentinel-3 Sea Level Anomaly (SLA) showed a lower standard deviation than the Cryosat-2 SLA. It was suggested this could be due to different space / time sampling of the SLA field.

Applications of data from Interferometric SAR (SAR-In) mode.

There were two papers on Applications of data from Interferometric SAR (SAR-In) mode:

1. *The Value of SAR-in Altimetry for Gravity Prediction in Coastal Regions. O.B. Andersen (DTU Space, Denmark), A Abulaitijang*

The fjords of Greenland offer a particular challenge to coastal altimetry, because of the complexity of the topography of the coastline. The SAR–In mode allows the measurements of sea level where it was previously not possible. This improvement in the spatial density of measurements is particularly important for the retrieval of gravity field.

2. *Coastal Sea Level from CryoSat-2 SARIn Altimetry in Norway, M. Idžanović (Norwegian University of Life Sciences, Norway), V. Ophaug, O.B. Andersen.*

The SAR-In mode allows sea level measurements in the complex coastline of Norway, where the islands, mountains and deep, narrow fjords make it difficult to retrieve valid data. SAR-In mode measurements of Sea Surface Height were compared to measurements from 22 local tide gauges, and the improvements resulting in the application of local ocean tide and dynamic atmosphere corrections demonstrated.

Seed Questions / Discussion

In the session discussion, the following issues were raised:

- The research presented in this section has made use of data from a range of different coastal products (e.g. PEACHI, ALES, CTOH, SAR/SARin).
- A standardised quality assessment should be provided with coastal altimetry data, this in turn leads to a requirement for an agreed and robust approach to error characterisation. The example of the protocol developed in the CCI-Sea Level project was seen as a good example.
- Should there be a recommended approach for provision of Coastal Altimetry data, in terms of format, corrections applied, etc.?.
  - Could recommendations for corrections be provided (MSS, tide models, …..)?
  - It was suggested that the Inverse Barometer and Dynamic Atmospheric Correction should be provided separately, as they are due to different processes and generated from different models.
- It was noted that a flexible approach was needed when identifying the most appropriate altimeter data for comparison against Tide Gauge data, which depends on the local coastline topography and oceanography. Sometimes the closest point will not provide the best results and other options must be explored, e.g. the point where the data are most correlated, or altimeter measurements averaged over a search radius. The best approach is best determined on a case by case

basis, as characteristics and scales of variability are highly location / phenomenon dependant.

ANNEX III: LINKS TO ADDITIONAL MATERIAL

Objective of the workshop, seed questions, programme, presentations, posters, and summaries can be found at following web sites

www.coastalaltimetry.org

www.coastalt.eu