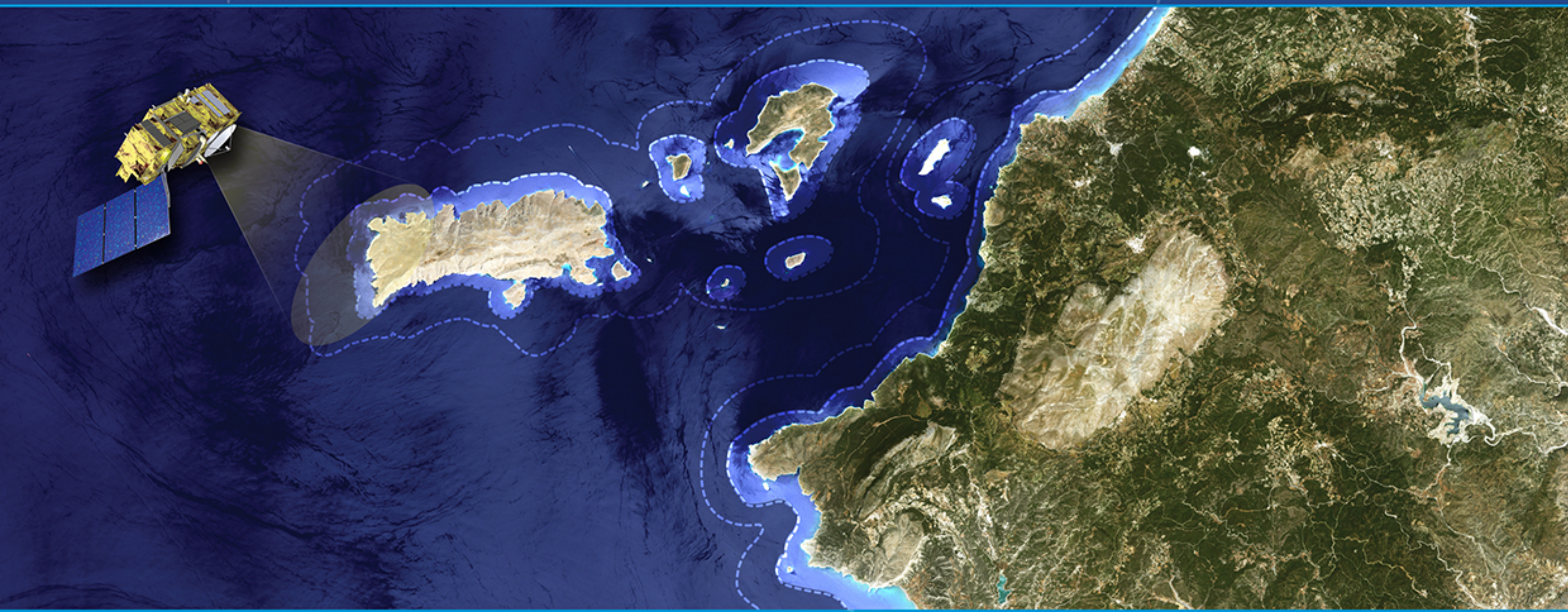
# → 10th COASTAL ALTIMETRY WORKSHOP

## SAR Altimetry Training Course



# ABSTRACTS

21–24 February 2017 | Florence, Italy

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# 2 Committees

### ORGANISING COMMITTEE

| | |
|---|---|
| Jérôme Benveniste | *European Space Agency – ESRIN*, Italy |
| Hans Bonekamp | *EUMETSAT*, Germany |
| Paolo Cipollini | *National Oceanography Centre*, U.K. |
| Laury Miller | *NOAA*, USA |
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| Nicolas Picot | *Centre National d'Etudes Spatiales*, France |
| Ted Strub | *Oregon State University*, USA |
| Doug Vandemark | *University of New Hampshire*, USA |
| Stefano Vignudelli | *Consiglio Nazionale delle Ricerche*, Italy |

### SCIENTIFIC COMMITTEE

| | |
|---|---|
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| Madeleine Cahill | *CSIRO,* Australia |
| Mathilde Cancet | *Noveltis*, France |
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| Jessica Hausman | *NASA Jet Propulsion Laboratory*, USA |
| Kaoru Ichikawa | *Kyushu University*, Japan |
| Andrey Kostianoy | *P.P. Shirshov of Oceanology*, Moscow, Russia |
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| Raj Kumar | *Space Applications Centre, ISRO*, India |
| Cristina Martin-Puig | *EUMETSAT*, Germany |
| Ananda Pascual | *IMEDEA,* Spain |
| Martín Saraceno | *University of Buenos Aires*, Argentina |
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| C. K. Shum | *Ohio State University*, USA |
| Walter H. F. Smith | *NOAA*, USA |
| Pierre Thibaut | *Collecte Localisation Satellites (CLS),* France |
| John Wilkin | *Rutgers University*, USA |

# 3 Programme

| | | | Day 1, Tuesday 21 February 2017 | | |
|---|---|---|---|---|---|
| 08:00 | 08:30 | 30 | Registration | | |
| 08:30 | 08:35 | 5 | Welcome to the SAR ALTIMETRY TRAINING COURSE | Jérôme Benveniste | |
| 08:35 | 08:55 | 20 | Radar Altimetry - Introduction to missions and applications | Marco Restano/Jérôme Benveniste | |
| 08:55 | 09:35 | 40 | Overview on LRM, SAR, SARin & RDSAR Altimetry | Mònica Roca | |
| 09:35 | 10:55 | 80 | SAR and SARin L1A to L2 processing; Strategies for different applications; options in SARvatore | Salvatore Dinardo | |
| 10:55 | 11:25 | 30 | Coffee Break | | |
| 11:25 | 11:45 | 20 | Delay Doppler Altimeter Instrument Calibration | Michele Scagliola | |
| 11:45 | 12:10 | 25 | Overview on corrections to be applied & on validation against TG and other datasets | Paolo Cipollini/Marcello Passaro | |
| 12:10 | 12:35 | 25 | Future Processing Innovations from ESA projects | Marco Restano/Jérôme Benveniste | |
| 12:35 | 13:00 | 25 | Fully focused SAR processing / Swath Processing | Walter Smith | |
| 13:00 | 14:00 | 60 | Lunch | | |
| 14:00 | 14:05 | 5 | Welcome to CAW-10: Introduction to the 10TH COASTAL ALTIMETRY WORKSHOP | Chair: Paolo Cipollini Chair: Jérôme Benveniste | |
| 14:05 | 14:05 | | S1: Waveforms and Retracking | Chairs: | |
| 14:05 | 14:10 | 5 | Session Introduction and Seed Questions | Chairs | |
| 14:10 | 14:30 | 20 | From Deep Ocean to Inland Water: Homogeneous Retracker Solution for Continuous Observations | Thibaut, Pierre | CLS |
| 14:30 | 14:50 | 20 | ALES Coastal Processing Applied to ERS: Extending the Coastal Sea Level Time Series | Passaro, Marcello | Deutsches Geodätisches Forschungsinstitut der Technischen Universität München |
| 14:50 | 15:10 | 20 | A New Retracking Technique for Brown-Peaky Altimetric Waveforms | Peng, Fukai | University of Newcastle, Australia |
| 15:10 | 15:30 | 20 | Mission-Independent Classification of Altimeter Waveforms for Applications in the Open Ocean, at the Coast Zone and Over Land | Schwatke, Christian | DGFI-TUM |
| 15:30 | 15:50 | 20 | High-Rate Radar Altimeter Waveform Signatures of Internal Solitons in Tropical Marginal Seas | Da Silva, Jose Carlos | Universidade do Porto |
| 15:50 | 16:10 | 20 | S1 Poster Flashes (5') + Discussion (15') | | |
| | | | Advancements in the Usage of Envisat Individual Echoes (IEs) | Vignudelli, Stefano | CNR |
| | | | Comparison with the Coastal Sea Surface Height Retrieved from Along-Track Jason-2 Continuous Waveforms and the HF Ocean Radar Data in the Tsushima Strait | Ichikawa, Kaoru | Kyushu University |
| 16:10 | 16:40 | 30 | Coffee Break | | |
| 16:40 | 16:40 | | S2: Range and Geophysical Corrections | Chairs: | |
| 16:40 | 16:45 | 5 | Session Introduction and Seed Questions | | |
| 16:45 | 17:05 | 20 | Validation of Sentinel-3 Wet Tropospheric Correction | Fernandes, M. Joana | Universidade do Porto |
| 17:05 | 17:25 | 20 | Performance of Sentinel-3 Surface Topography Mission Microwave Radiometer in Coastal Areas | Frery, Marie-Laure | CLS |

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|---|---|---|---|---|---|
| **17:25** | **17:45** | 20 | Exploitation of AIRWAVE for Retrieving the Wet Tropospheric Correction for Coastal Altimetry | Lázaro, Clara | Universidade do Porto |
| **17:45** | **18:05** | 20 | ACCRA : A Study on Future Microwave Radiometers for Atmospheric Correction of Radar Altimeters on Coastal Regions | Picard, Bruno | CLS |
| **18:05** | **20:00** | 115 | Ice breaker and Poster Session cocktail | | |
| | | | | | |
| | | | **Day 2, Wednesday 22 February 2017** | | |
| **08:30** | | | **S2: Range and Geophysical Corrections (cont'd)** | **Chairs:** | |
| **08:30** | **08:50** | 20 | Assessment of Range and Geophysical Corrections and Mean Sea Surface Models - Impacts on Sea Level Variability around the Indonesian Seas | Handoko, Eko Yuli | INSTITUT TEKNOLOGI SEPULUH NOPEMBER |
| **08:50** | **09:10** | 20 | Assessment of the FES2014 Tidal Currents on the Shelves Around Australia | Cancet, Mathilde | NOVELTIS |
| **09:10** | **09:40** | 30 | S2 Poster Flashes (15') + Discussion (15') | | |
| | | | Analysis of Altimetry Range and Correction in a Flat Coastal Environment at Aix Island Sea-Level Observatory, France | Testut, Laurent | LEGOS/LIENSs |
| | | | Enhance Coastal Tide Modeling Using Cryosat-2: A Feasibility Study | Piccioni, Gaia | DGFI-TUM |
| | | | Evaluation of the Dry and Wet Tropospheric Corrections for CryoSat-2 and Sentinel-3 Over Inland Waters | Fernandes, M. Joana | Universidade do Porto |
| | | | Recent Improvement in MSS and Gravity field in Coastal and Arctic Regions | Andersen, Ole Baltazar | DTU Space |
| | | | Tidal Downscaling in a 3D (Structured) Circulation Model: A New Approach Based on Tailored 2D (Unstructured) Simulations | Toublanc, Florence | CNES |
| **09:40** | | | **S3: Performance and Cal/Val of Coastal Altimetry** | **Chairs:** | |
| **09:40** | **09:45** | 5 | Session: Introduction and Seed questions | | |
| **09:45** | **10:05** | 20 | Sentinel-3 Close to the Coasts: Performances and Perspectives. | Boy, Francois | CNES |
| **10:05** | **10:25** | 20 | Performances over Coastal areas of the SAR Mode Processing in Sentinel-3A Products | Raynal, Matthias | CLS |
| **10:25** | **10:55** | 30 | Coffee Break | | |
| **10:55** | | | **S3: Performance and Cal/Val of Coastal Altimetry** | **Chairs:** | |
| **10:55** | **11:15** | 20 | Coastal Altimetry for the North-Eastern Atlantic Shelf | Fenoglio-Marc, Luciana | University Bonn |
| **11:15** | **11:35** | 20 | Validation of CryoSat-2 and AltiKa Sea Level Anomaly in the Coastal Strip of the Gulf of Cadiz | Gomez-Enri, Jesus | University of Cadiz |
| **11:35** | **11:55** | 20 | Corsica: A Multi-Mission Absolute Calibration Site | Bonnefond, Pascal | Observatoire de Paris |
| **11:55** | **12:55** | 60 | S3 Poster Flashes (40') + S3 Discussion (15') | | |
| | | | Satellite Altimetry in South-West Bass Strait | Cahill, Madeleine | CSIRO |
| | | | Validation of Sentinel-3A Altimetry Data by Using In-Situ Multi-Platform Observations near Mallorca Island (Western Mediterranean) | Sánchez-Román, Antonio | CSIC-IMEDEA |
| | | | A Novel Method for Lakes Water Level Measurement from SAR-SARIN Mode Altimetry – SHAPE Project | Fabry, Pierre | ALONG-TRACK SAS |
| | | | Broadview Radar Altimetry Toolbox | Escolà, Roger | isardSAT Ltd. |
| | | | Evaluating the Performance of Sentinel-3 SRAL SAR Altimetry in the Coastal Zone, and Developing Improved Retrieval Methods. Early Results from the SCOOP Project. | Cotton, P David | Satellite Oceanographic Consultants Ltd |
| | | | X-TRACK Regional Altimeter Products for Coastal Applications: 2016 release | Léger, Fabien | LEGOS/CTOH |
| | | | A New Era of Altimeter Products Towards High-Resolution | Dufau, Claire | CLS |
| | | | Sentinel-3 Surface Topography Mission: Overview and | Féménias, Pierre | ESA ESRIN |

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|---|---|---|---|---|---|
| | | | Status of Operations | | |
| | | | GOCE User Toolbox and Tutorial | Restano, Marco | SERCO c/o European Space Agency |
| | | | A Synergy Approach for the Validation of Coastal Altimetry Data in the Baltic Sea | Delpeche-Ellmann, Nicole | Tallinn University of Technology |
| | | | Improved Sea Surface Height from Satellite Altimetry in Coastal Zones: A Case Study in Southern Patagonia | Lago, Loreley Selene | University of Buenos Aires |
| | | | Inter-Comparison Between Different Along Track Altimeter Products, Numerical Ocean Models and In Situ Measurements: Development of a Dedicated Software. | Soleilhavoup, Isabelle | LEGOS |
| | | | SAR Altimetry Processing on Demand Service for CryoSat-2 and Sentinel-3 at ESA G-POD | Restano, Marco | SERCO c/o European Space Agency |
| | | | Ships-Squat – A Prominent Effect and How It Can Be Calibrated | Roggenbuck, Ole | Jade University of Applied Sciences Oldenburg |
| **12:55** | **14:00** | 65 | Lunch | | |
| **14:00** | | | **S4: Altimetry for Regional and Coastal Models** | **Chairs:** | |
| **14:00** | **14:05** | 5 | Session Introduction and Seed Questions | Chairs | |
| **14:05** | **14:30** | 25 | ARCOM, Enhancing the Link between Altimetry and Coastal Models | Dufau, Claire | CLS |
| **14:30** | **14:50** | 20 | Velocity and Sea Level Anomaly Wavenumber Spectra in the Coastal Ocean: Observations from HF-Radar and Altimetry Compared with Nested High-Resolution Models | Wilkin, John | Rutgers University |
| **14:50** | **15:10** | 20 | The Impact of Satellite Altimeter Observations on Estmates of Cross-Shelf Fluxes in the Mid-Atlantic Bight | Moore, Andrew | University of California Santa Cruz |
| **15:10** | **15:30** | 20 | A Multi-Technique Combination Method for Altimeter, Tide Gauge and Ships Data | Roggenbuck, Ole | Jade University of Applied Sciences Oldenburg |
| **15:30** | **15:50** | 20 | Impact of Coastal Altimetry Data in the Black Sea Physical Ocean Analysis System | Bonaduce, Antonio | CMCC/Mercator Ocean |
| **15:50** | **16:10** | 20 | Understanding Altimetry Signals in Near-Coastal Areas Using Underwater Autonomous Vehicles | Borrione, Ines | NATO STO CMRE |
| **16:10** | **16:40** | 30 | Coffee Break | | |
| **16:40** | | | **S4: Altimetry for Regional and Coastal Models - part II** | **Chairs:** | |
| **16:40** | **17:00** | 20 | Integration of Coastal Altimetry Data in the Tuscan Coastal Observing System | Brandini, Carlo | Consorzio LaMMA |
| **17:00** | **17:20** | 20 | High-Resolution Altimetry for the Eastern Canadian Shelf Regional Model | Dufau, Claire | CLS |
| **17:20** | **18:00** | 40 | S4 Poster Flashes (20') + S4 Discussion (20') | | |
| | | | Coastal Sea-Level Variabilities in Downscaled Models Controlled by an Eddy-Resolving Variational Estimation System | Kamachi, Masafumi | JAMSTEC |
| | | | Impact of 4D-Var Assimilation of Coastal Altimetry Data in the Sicily Channel Model | Olita, Antonio | CNR |
| | | | Intercomparison of Sea Level Variation Across the Tsushima Strait Among Tide Gauge Data, a Coastal Altimetry Product and an Ocean Reanalysis FORA-WNP30. | Hirose, Nariaki | Meteorological Research Institute |
| | | | Inter-Annual Variation of the Tsugaru Warm Current Revealed from the Long-Term Coastal Ocean Reanalysis | Wakamatsu, Tsuyoshi | Japan Agency for Marine-Earth Scinece and Technology |
| | | | Multi-Scale Analysis of Coastal Altimetry Data, Multi-Sensor Observations and Numerical Modelling Over the North Western Mediterranean Sea | Serco | Meloni, Marco |
| **18:00** | **20:00** | 120 | POSTER SESSION (and cocktail) | | |

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| | | | **Day 3, Thursday 23 February 2017** | | |
| **08:30** | | | **S5: Applications I – Currents, Waves and Winds** | **Chairs:** | |
| **08:30** | **08:35** | 5 | Session Introduction and Seed Questions | Chairs | |
| **08:35** | **08:55** | 20 | Coastal Mesoscale Structures at the Entrance to the Gulf of California | Torres Hernandez, Maria Yesenia | Center of Investigation and Education Superior of Ensenada |
| **08:55** | **09:15** | 20 | Satellite Altimetry in the Continental Shelf of the Southwestern Atlantic, Argentina | Saraceno, Martin | University of Buenos Aires |
| **09:15** | **09:35** | 20 | Performance of Different Altimetry-Derived Products and Techniques for Manifesting Mesoscale Eddies in Coastal Areas | Karimova, Svetlana | University of Liege |
| **09:35** | **09:55** | 20 | Surface Winds off Peru-Chile: Observing Closer to the Coast from Radar Altimetry | Astudillo, Orlando | Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile & Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Toulouse |
| **09:55** | **10:15** | 20 | Coastal Altimetry in Support to Marine Observatory and Marine Observatory in Support to Coastal Altimetry: Multi-Platform Validations of Altimetry for Monitoring the Variability of Coastal Fronts | Bouffard, Jerome | ESA / RHEA |
| **10:15** | **10:45** | 30 | Coffee Break | | |
| **10:45** | **11:25** | 40 | S5 Poster Flashes (25') + S5 Discussion (15') | | |
| | | | Poleward Currents from Coastal Altimetry: The West Coast of Southern Baja California, Mexico | Valle Rodriguez, Jonathan Bruno | CICESE |
| | | | Illustration of the High Performance of SARAL Ka-Band Altimeter in Observing the Mesoscale and Coastal Oceanic Features - Example of the Central Mediterranean Sea | Jebri, Fatma | LEGOS / MIO / INSTM |
| | | | Utilizing SAR Imagery, Ocean Color, SST, and Radar Altimetry to Study Upwelling and Ocean Circulation in the Coastal Arabian Sea | Qazi, Waqas Ahmed | Institute of Space Technology |
| | | | Use of Coastal Altimetry Data in Submesoscale Process Studies | Yoo, Jang Gon | Korea Advanced Institute of Science and Technology |
| | | | Evaluation of Operational Altimeter-Derived Ocean Currents for Shelf Sea Applications - a Case Study in the NW Atlantic | Vandemark, Douglas | University of New Hampshire |
| | | | Seasonal Circulation in the Northern Bay of Bengal with Special Reference to Shelf-Slope Region | Ishaque, Marufa | University of Dhaka |
| | | | The Norwegian Coastal Current Observed by CryoSat-2 SARIn Altimetry | Idžanović, Martina | Norwegian University of Life Sciences |
| **11:25** | | | **S6: Applications II - Sea Level and Extreme Events** | **Chairs:** | |
| **11:25** | **11:30** | 5 | Session Introduction and Seed Questions | | |
| **11:30** | **11:50** | 20 | Validating Altimeter Estimates of Sea level Along the Southern Coast of Australia | Cahill, Madeleine Louise | CSIRO |
| **11:50** | **12:10** | 20 | UK Sea Level Space Watch – Monitoring Regional Sea Level Variability around the UK from Satellite Altimetry | Cotton, David | Satellite Oceanographic Consultants Ltd |
| **12:10** | **12:30** | 20 | The Estimation of Sea Level Rise Impact on Coastal | Grgić, Marijan | University of |

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| | | | Zones of the Eastern Adriatic Sea | | Zagreb Faculty of Geodesy |
| **12:30** | **12:50** | 20 | Coastal SAR and PLRM Altimetry in the German Bight and West Baltic Sea with Sentinel-3A and CryoSat-2 | Dinardo, Salvatore | HeSpace/Eumetsat |
| **12:50** | **14:00** | 70 | Lunch | | |
| **14:00** | | | **S6: Applications II - Sea Level and Extreme Events (cont'd)** | **Chairs:** | |
| **14:00** | **14:20** | 20 | Accurately Measuring Sea Level Change from Space in the Coastal Zone: an ESA Climate Change Initiative | Cazenave, Anny | LEGOS |
| **14:20** | **14:40** | 20 | Combining Tide Gauge and Satellite Altimetry Data: Towards Monitoring Vertical Land Motion at the Coast | Wöppelmann, Guy | University of La Rochelle |
| **14:40** | **15:20** | 40 | S6 Poster Flashes (25') + S6 Discussion (15') | | |
| | | | The Value of SAR-in Altimetry for Gravity Prediction in Coastal Regions | Andersen, Ole Baltazar | DTU Space |
| | | | Sea Level Trends, Variability and Processes Around the Australian coast | Royston, Sam | University of Tasmania |
| | | | Coastal Sea Level from CryoSat-2 SARIn Altimetry in Norway | Idžanović, Martina | Norwegian University of Life Sciences |
| | | | Monitoring Storm Surges using Satellite Altimetry | Han, Guoqi | Fisheries and Oceans Canada |
| | | | The Importance of Sentinel-3 for Extending the Arctic Sea Level Record | Andersen, Ole Baltazar | DTU Space |
| | | | Mass Redistribution from Satellite Altimetry | Bao, Lifeng | Institute of geodesy and geophysics, Chinese Academy of Sciences |
| | | | Assessment of a Coastal Altimetry Data Product in the Indonesian Coastal Waters | Lumban-Gaol, Jonson | Bogor Agricultural University |
| | | | Assimilation of Blended Altimetry and Tide Gauge Observations in a North Sea – Baltic Sea Hydrodynamic Model for Storm Surge Forecasting | Madsen, Kristine S | Danish Meteorological Institute |
| | | | Coastal Altimetry in Support of NASA's Oceans Melting Greenland (OMG) Project | Larson, Jacob | University of Colorado |
| **15:20** | **16:30** | 70 | **Extended Coffee Break and Final Look at Posters** | | |
| **16:30** | **17:30** | 60 | **Report from Session Chairs (10' each)** | | |
| **17:30** | **18:30** | 60 | **Final Discussion, Recommendations and Closing Remarks** | | |
| **19:30** | **22:00** | 150 | Social Dinner (Non Hosted) | | |
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| | | | Day 4, Friday 24 February 2017 | | |
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| | | | SAR ALTIMETRY TRAINING COURSE | | |
| 09:00 | 09:40 | 40 | SAR Altimetry Processing for Open Ocean, Sea Level Monitoring,/SLCCI Multi Mission datasets | Luciana Fenoglio-Marc | |
| 09:40 | 10:20 | 40 | SAR Altimetry Processing for Coastal Oceanography | Luciana Fenoglio-Marc | |
| 10:20 | 10:50 | 30 | SAR Altimetry Processing for Sea Level in Polar regions (e.g. CS-2 data as input to Tide Models | Ole Andersen | |
| 10:50 | 11:20 | 30 | Coffee Break | | |
| 11:20 | 11:50 | 30 | SAR Altimetry Processing for Inland Water: Lakes | Nicolas Bercher | |
| 11:50 | 12:30 | 40 | SAR Altimetry Processing for Inland Water: River Monitoring (more oriented to discharge and floods monitoring, large basins) | Nicolas Bercher | |
| 12:30 | 13:30 | 60 | Lunch | | |
| 13:30 | 14:30 | 60 | SARvatore Demo and Hands-On | Salvatore Dinardo and Marco Restano | |
| 14:30 | 15:30 | 60 | DeDop Demo and Hands-On | Mònica Roca | |
| 15:30 | 16:00 | 30 | Coffee Break | | |
| 16:00 | 16:45 | 45 | BRAT Demo | Américo Ambrózio | |
| 16:45 | 17:15 | 30 | GUT Demo | Américo Ambrózio | |
| 17:15 | 17:45 | 30 | Future Missions: Sentinel-6, SWOT, CryoSat Follow On | Mònica Roca / Jérôme Benveniste | |
| 17:45 | 18:45 | 60 | Wine & Cheese | | |

# 4 Abstracts

## S1: Waveforms and Retracking

### From Deep Ocean to Inland Water: Homogeneous Retracker Solution for Continuous Observations

*Thibaut P.[1], Poisson J.C.[1], Moreau T.[1], Piras F.[1], Le Gac S.[2], Boy F.[2], Picot N.[2]*

*[1]CLS, France; [2]CNES, France*

Until now and for all altimetry missions, operational ground processing chains are implementing retracking solutions different for inland water and deep ocean surfaces. Physical retrackers are used for deep ocean (Hayne, Samosa). Threshold retrackers (OCOG or derivatives) are used for hydrology. Similar discrepancy is also observed between deep ocean and sea iced surfaces. The consequence of that dual processing schema is the introduction of potential water topography biases between areas upstream and downstream estuaries.

New physical model accounting for water surface roughness, associated with new numerical techniques provide us with a powerful solution, homogeneous whatever the overflown water surface. The aim of this talk is to illustrate the benefits of such a solution over selected estuaries and coastal regions.

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### ALES Coastal Processing Applied to ERS: Extending the Coastal Sea Level Time Series

*Passaro M.[1], Calafat F.M.[2]*

*[1]Deutsches Geodätisches Forschungsinstitut der Technischen Universität München, Germany; [2]National Oceangraphy Centre Liverpool, UK*

The Adaptive Leading Edge Subwaveform (ALES) retracked dataset of Envisat and Jason time series, together with updated geophysical corrections, tidal and mean sea surface models, has shown that coastal altimetry is now in a mature stage in which it can be used for sea level variability studies. However, the relatively short period (2002-2015) covered by the current ALES dataset still represents a limitation to trend and long-term variability analyses. This study is dedicated to the application of the ALES concept to the ERS-1 and -2 satellite missions, which extends the time series up to 10 years, guaranteeing more than 20 years (1991-2012 along the same Envisat ground tracks) of coastal altimetry. The reference dataset, on which the reprocessing is based, is the ESA REAPER project, which provided updated ERS data with state-of-the-art waveform fitting (retracking) and corrections.

The first part is dedicated to the retracking strategy. The ALES algorithm selects only a portion of the altimetric signal (waveform), in order to estimate the distance between the satellite and the sea surface (range) while avoiding the noise in the tail of the signal. The ALES design based on the relation between estimated sea state, achievable precision and width of the subwaveform is adapted to ERS sampling characteristics. The dataset obtained with the adapted algorithm is then validated against tide gauge observations and the noise performances are analysed. Preliminary results show the possibility to improve the sea level estimation compared to the REAPER reprocessing currently available, but a specific compromise has to be found between the desired precision and the portion of the signal considered in the retracking, given the lower sampling frequency of ERS compared to Envisat and Jason.

In the second part, joint Envisat+ERS time series are built in the North Sea and in the Mediterranean Sea to investigate seasonal variability and trends in sea level at a regional scale. Estimates of the annual cycle and trends from the altimetric time series are used in combination with tide gauge observations to characterize the magnitude and the geographic variability of these two components of sea level. The new coastal altimetry dataset enables us to explore coastal sea level changes in regions where very few tide gauge stations are available such as along the North African coast in the Mediterranean Sea. Furthermore, by providing sea level observations closer to the coast, it allows us to investigate differences between coastal and open ocean sea level along the entire coast.

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### A New Retracking Technique for Brown-Peaky Altimetric Waveforms

*Peng F., Deng X.*

*School of Engineering, The University of Newcastle, New South Wales, Australia*

Waveform retracking technique has been developed for many years to process the corrupted altimetric waveforms which do not conform to the Brown model.

The peaky waveform shows a combination of the Brown-like waveform with single or multiple peaks. It usually appears near coastlines when land topography is partly covered by the altimeter footprint. Many attempts have been tested to reduce the effect of the peak on waveforms, such as the modified Brown model and sub-waveform retrackers. Here, we propose a new retracking method to retrieve high quality estimates of altimeter ranges from peaky waveforms. The method first detect the location of the peak(s), and then retracks the waveform using the weighted least squares estimation. The corrupted waveform gates are assigned to lower weights, from which the effect of peaks can be effectively reduced. When taking an accuracy criteria of the 1 cm tolerance with respect to the full waveform retracker for the Epoch estimates by Passaro et al. (2014), the new retracker can achieve the required accuracy with up to 30 gates corresponding to the width of the peak assigned to lower weights.

The new retracker has been applied to the simulated and real Jason-1 waveforms. The simulated results show that not only the Epoch estimate can achieve 1cm accuracy level, but also the estimated significant wave height (SWH) is in the order of several centimetres. The results also show that the ALES (Passaro et al. 2014) cannot handle selected sub-waveforms affected by the peak, resulting in the estimation accuracy degraded significantly. The results of retracked Jason-1 waveforms have been compared to those from MLE4 and ALES, as well validated against in-situ tide-gauge observations. Four tide gauges (Darwin, Burnie, Lorne and Broome) are chosen around the Australian coastal zone. The comparison results with MLE4 and ALES show that all retrackers have similar performance over open oceans with the correlation coefficient of ~0.7 between altimetric and tide-gauge sea-level anomalies (SLAs). While near the coast, especially within ~7km to the coast, the performance of our new retracker is superior to MLE4 and ALES for that it can extend high correlated SLAs to 2.5km off the coast at the study area.

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**Mission-Independent Classification of Altimeter Waveforms for Applications in the Open Ocean, at the Coastal Zone and Over Land**

*Schwatke C, Dettmering D.*
*DGFI-TUM, Germany*

Altimeter waveforms are the basis for range and water level determination, which are estimated by waveform retracking. But waveforms also contain additional information about the surface type covered by the footprint of the radar measurement. Depending on the surface, the waveform shapes vary strongly between brown-like, brown-like with peaks, specular, etc. The knowledge of the waveform shape can be very helpful for different applications. For example, this information can be used for detecting sea-ice areas in the open ocean. In coastal regions, the classification can be used to distinguish between ocean, land, and corrupted ocean waveforms. Over land, the waveform classification can be used to identify inland water bodies such as lakes, reservoirs, rivers, and wetlands.

In this contribution, we present our new approach for a mission-independent classification of altimeter waveforms that separates different waveforms by its shapes into more than 50 different classes such as ocean-like, specular, etc. Hereby, a combination of function fitting and statistical criteria is applied for classifying the altimeter waveforms. An advantage of our classification method is that it works for all altimeter missions because it is independent from the waveform length and the measurement band. We demonstrate our approach by using waveforms of classical altimeter missions such as Envisat, SARAL, and Jason-3 but also input data from the SAR missions Cryosat-2 and Sentinel-3A. The performance of our classification will be shown in detail for different study cases such as ocean, coast, lakes, rivers, etc.

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**High-Rate Radar Altimeter Waveform Signatures of Internal Solitons in Tropical Marginal Seas**

*Da Silva J.C., Magalhaes J.M., Cerqueira A.F., Vieira E.*
*University of Porto, Portugal*

We report efforts for detection and recognition of short-period internal waves, also many times described in the literature as Internal Solitary Waves (ISWs), in high-rate along-track waveform records of the Jason-2/3 altimeters and SARAL Altika. A synergetic observation approach is developed for the identification of ISWs in altimeter data, based on validation with imaging radars and high-resolution optical sensors (measuring sun-glint patterns on the water surface). Geophysical parameters obtained from available SGDRs were processed and analyzed for regions of tropical marginal Seas where the existence of high-amplitude ISWs is known, namely: Andaman Sea, Sulu Sea, Celebes Sea, South China Sea, Red Sea, Northwest Australian Shelf, and Strait of Gibraltar. Evidence of modulation of several geophysical parameters is presented, namely: the “off-nadir-angle” available from the MLE4 retracking algorithm; sigma0 as retrieved from MLE4; significant wave height (SWH); and the differenced mean square slope calculated from the dual-band Jason-2/3 sigma0 measurements. The ISW signatures are sometimes recognized as parabolic-like shape sigma0 anomalies in the along-track radargram. These anomalies are mostly recognized as sigma0 positive anomalies which are related to short-event sigma0 blooms that have been reported in the literature (Mitchum et al., 2004; Tournadre et al., 2006; Dibarboure et al., 2014). On some occasions however, sigma0 negative anomalies with parabolic-like shape have also been observed back-to-back with the positive anomalies. We suggest that these consecutive negative/positive anomalies are associated to enhanced and decreased surface roughness produced by ISWs. This is consistent with some of our records of differenced mean square slope calculated from the dual-band Jason-2/3 altimeters. It is suggested that the improved MLE4 Brown model provides the capability to absorb the waveform distortion as ‘‘off-nadir angle’’ and sigma0, since the true pointing of Jason-2/3 is very good, so the retracked off-nadir angle is only apparent. With MLE4 the slope of the trailing-edge parameter and the sigma0 estimate are absorbing the bulk of the backscattering ISW event, for the case of pulse-limited altimeters, when the outer rings of the waveform footprint are affected. Hence, oceanography users interested in short-period internal wave signals may find useful information in 20-Hz rate Jason-2/3 current altimeter products. Development of better editing and postprocessing algorithms on the 20-Hz rate of current products is needed if we want to account for ISWs in coastal regions. New SARAL altimeter waveforms are compared with Jason-class high-rate altimeter waveforms related to ISWs.

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# S2: Range and Geophysical Corrections

### Validation of Sentinel-3 Wet Tropospheric Correction

*Fernandes M.J.[1,2], Lázaro C.[1,2]*

*[1]Universidade do Porto, Faculdade de Ciências, Portugal; [2]Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR), Universidade do Porto, Porto, Portugal*

Launched on 16 February 2016, Sentinel-3 (S3) carries a two-band microwave radiometer (MWR) similar to that of Envisat, aimed at the precise retrieval of the wet tropospheric correction (WTC) through collocated measurements withe the SRAL instrument.

Due to their instrumental characteristics and retrieval algorithms, the two-band MWR deployed on the European Space Agency (ESA) altimeter missions are known for their good performance in the open-ocean. However, when they approach the coast, the retrieval algorithm, which was designed for surfaces with ocean emissivity, generates very noisy values as the footprint encounters surfaces with different emissivity. The same happens at high latitudes in regions covered with ice.

This study is a contribution to the Sentinel-3 Validation Team project ID 13769, titled “Validation Of Coastal ALtimetry from Sentinel-3, by assessing the MWR-derived WTC present on S3 products, released for validation purposes.

The validation is performed by means of comparisons with independent data sets namely: scanning imaging microwave radiometers (SI-MWR) such as the Special Sensor Microwave Image Sounder (SSM/IS) or the GPM Microwave Imager (GMI); Global Navigation Satellite Systems (GNSS) derived path delays determined at coastal stations; wet path delays from the MWR on board Jason-2 and Jason-3.

Moreover, the overall along-track performance is compared against estimates obtained from the GNSS-derived Path Delay Plus (GPD+) algorithm and from atmospheric models. For this purpose, GPD+ wet path delays are derived by combining, through space-time objective analysis, all available measurements but not including S3 MWR, i.e. using only SI-MWR and GNSS observations.

Once the S3 MWR-derived WTC has been examined, the GPD+ algorithm is tuned to S3 by an appropriate detection of the invalid measurements due to land or ice contamination or any additional error source. Subsequently, new GPD+ estimates are obtained, now only for the points with invalid MWR values, by combining all available observations, this time also including valid measurements from the S3 MWR.

In addition to the statistical comparisons between the S3 MWR-derived WTC and the various WTC sources, the correction is also evaluated by means of sea level anomaly variance, both along-track, at crossovers and function of distance from coast.

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### Performance of Sentinel-3 Surface Topography Mission Microwave Radiometer in Coastal Areas

*Frery ML.[1], Siméon M.[1], Picard B.[1], Féménias P.[2], Goldstein C.[3], Helge Rebhan[4]*

*[1]CLS, France; [2]ESA (ESRIN); [3]CNES; [4]ESA (ESTEC)*

The Sentinel-3A Surface Topography Mission has been launched in February 2016. The topography payload aboard Sentinel-3A has measurements requirements over ocean as well as coastal areas, sea ice, and inland waters, these latter with enhanced performances benefitting from the dual-frequency SAR altimeter (SRAL). We present here the measurements acquired by the microwave radiometer (MWR) supporting the SRAL for the retrieval of the wet tropospheric correction.

The MWR is a two-channel microwave radiometer (23.8 and 36.5 GHz) similar to the Envisat MWR. The radiometer will perform measurements of brightness temperatures in both bands interpolated at the location of the altimeter footprint.

For the retrieval of the wet tropospheric correction, two algorithms based on simulated parameters (brightness temperatures and altimeter backscattering ratio) and neural networks are proposed in the Sentinel-3A products. First a classical approach, similar to Envisat’s algorithm is using both brightness temperatures and altimeter backscattering coefficient to take into account the surface roughness. Secondly, an innovative algorithm is using additional inputs such as the sea surface temperature and temperature lapse rate to improve the retrieval over specific areas such as upwelling regions.

We will present the performance of the Sentinel-3A MWR performances over coastal areas and compare its measurements to other radiometers in these regions.

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**Exploitation of AIRWAVE for Retrieving the Wet Tropospheric Correction for Coastal Altimetry**

*Lázaro C.[1,2], Fernandes M.J.[1,2], Casadio S.[3], Castelli E.[4], Papandrea E.[4], Dinelli B.M.[4], Burini A.[5], Bojkov B.[5], Bouffard J.[6]*

*[1]Universidade do Porto, Faculdade de Ciências, Portugal; [2]Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR), Universidade do Porto, Porto, Portugal; [3]SERCO, ESA/ESRIN, Frascati, Italy; [4]CNR, Istituto di Scienze dell'Atmosfera e del Clima, Bologna, Italy; [5]EUMETSAT, Darmstadt, Germany; [6]RHEA System SA, ESA*

AIRWAVE (Advanced Infra-Red WAter Vapour Estimator) Version 1 is an algorithm that has been expressly developed for the retrieval of Total Column Water Vapour (TCWV) from the measurements of the Along Track Scanning Radiometer (ATSR) on board ERS and Envisat missions. It is fast and independent from external constrains. The current version of the algorithm works on ocean/cloud-free scenes by combining advanced radiative transfer models and a sea surface spectral emissivity database. The simultaneous use of forward and nadir measurements minimise the impact of the knowledge of the sea surface temperature and of the atmospheric radiation on the quality of the retrieved TCWV. Exploiting only the TIR channels of the instrument, the algorithm enables the estimation of TCWV both in the day and night part of the orbits and the full exploitation of the ATSR instrument series, spanning from 1991 to 2012. One of the features of AIRWAVE V1 is that it enables the retrieval of cloud-free TCWV very close to the coastline, which is of paramount importance in Coastal Altimetry science.

This study focus on the exploitation of AIRWAVE for retrieving the wet tropospheric correction (WTC) for coastal altimetry. Wet path delays (WPD) derived from the AIRWAVE TCWV dataset have been incorporated in the Global Navigation Satellite System (GNSS) derived Path Delay Plus (GPD+) algorithm aiming at the generation of a new WTC for each altimetry mission. They are combined by optimal interpolation with WPD observations derived from the microwave radiometer (MWR) on board each altimeter missions, except for CryoSat-2, from a set of scanning imaging MWR on board Remote Sensing missions (e.g. the Special Sensor Microwave Imager (SSM/I) and the SSM/I Sounder (SSM/IS)) and from a network of coastal and island GNSS stations, with the representation and quality of each dataset taken into account by the interpolation. In this way, the GPD+ WTC is expected to benefit from the high spatial resolution of AIRWAVE data, with an impact on the effectiveness of the retrieval of coastal altimetry parameters such as Sea Level Anomaly (SLA).

The AIRWAVE-derived GPD+ WTC has been firstly released for 1-Hz ENVISAT data, taking advantage of AATSR and MWR data simultaneity. Results from the validation of this new GPD+ WTC by statistical analyses of SLA variance (along-track, at crossovers and function of distance from coast) and by direct comparison with independent sources such as GNSS data not used in the computations are shown. To fully exploit the high spatial resolution of AIRWAVE data and their availability closer to the coast, the GPD+ WTC for ENVISAT has also been computed for high-rate altimetry data from e.g. the Adaptive Leading Edge Subwaveform (ALES) rectracker. Results from the validation of this high-rate WTC are also shown for comparison.

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**ACCRA : A Study on Future Microwave Radiometers for Atmospheric Correction of Radar Altimeters on Coastal Regions**

*Picard B.[1], Charlton J.[2], Eymard L.[3], Karbou F.[4], Hermozo L.[1], Martin-Neira M.[5]*

*[1]CLS, France; [2]JCR, UK; [3]IPSL, France; [4]CNRM, France; [5]ESA/ESTEC, Netherlands*

The wet tropospheric correction (WTC) is a major source of uncertainty in altimetry budget error, due to its large spatial and temporal variability: this is why the main altimetry missions include a microwave radiometer (MR) The commonly agreed requirement on WTC for current missions is to retrieve WTC with an error better than 1cm rms.

With the introduction of the along-track synthetic aperture processing, first implemented in CryoSat-2, and now in the upcoming operational altimetry missions such as Sentinel-3 and Jason-CS, more accurate altimetry data are anticipated for coastal and inland waters.

Nevertheless, the quality of data in those areas are expected to be degraded with respect to those of the open oceans due to the rather wide field of view of the MR (-3 dB beam-width of ~20 km). As a matter of fact, the MR observations over those waters are subject to contamination by land brightness temperatures which fall within the MR footprint.

The present team has been selected by ESA/ESTEC to work on a MR instrument design for future operational radar altimetry missions. Such a design shall include the classical MR channels for ensuring observation continuity, augmented by a set of high frequency channels for enabling accurate altimetry over coastal and inland waters.

In this study team, the extensive systems and radiometric engineering experience of JCR Systems is complemented by a significant expertise of LOCEAN , CLS and CNRM in water vapour retrievals, a considerable experience in design and development of microwave and millimeter wave radiometer front ends from RAL and a substantial knowledge of SMT Consultancies in microwave and millimeter-wave antenna design.

We will present the final results of this study. First, the selection of an optimal set of observation frequencies based on an analysis of both potential horizontal resolution and the value of the physical information provided. Then, the instrument design selected in consistency with the selected channels. And finally, the results of a dedicated 1D-VAR retrieval approach with a specific strategy over coastal areas, using the best of each observation frequency. These results using the ACCRA configuration are discussed against the configuration of Jason-CS.

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### Assessment of Range and Geophysical Corrections and Mean Sea Surface Models - Impacts on Sea Level Variability around the Indonesian Seas

*Handoko E.Y.[1,2], Fernandes M.J.[1,3], Lázaro C.[1,3]*
*[1]Faculdade de Ciências, Universidade do Porto, Porto, Portugal; [2]Department of Geomatics Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia; [3]Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR), Universidade do Porto, Porto, Portugal*

Due to their unique characteristics and large complexity the Indonesian seas are a very interesting area for coastal altimetry studies. The determination of sea level variation for this region requires precise knowledge of all range and geophysical corrections needed to correct the altimeter range for the effects of the atmosphere, the sea state and the geophysical phenomena that need to be removed from the signal of interest. In addition, due to the large gradients of the mean sea surface (MSS) in this part of the ocean, the choice of a suitable MSS is also of relevance. For this purpose, the selection of the best range and geophysical corrections and mean sea surface models is important to estimate precise sea level anomalies around Indonesia.

The focus of this study is twofold (i) to assess the accuracy of range and geophysical corrections and mean sea surface models in the Indonesian seas, (ii) to determine sea level variation in this region by selecting the best choice of corrections and models for each mission.

For this purpose, three-reference missions were used, TOPEX/Poseidon, Jason-1 and Jason-2, over the 23 years (1993-2015) period. All altimeter data, including the corrections and MSS models, were used as they are made available in RADS, except for the wet tropospheric corrections from the GNSS-derived Path Delay Plus (GPD+) algorithm, provided by the University of Porto. The assessment of the various corrections and MSS models is performed using analyses of sea level anomaly (SLA) variance differences, function of distance from coast and at altimeter crossovers with time difference less than 10 days.

The selected set of corrections and MSS have been used to estimate the SLA time series. The rate of sea level rise for the Indonesian seas was found to be 4.2 ± 0.2 mm/year over the 23-year period (1993-2015) with very strong inter-annual variability.

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### Assessment of the FES2014 Tidal Currents on the Shelves Around Australia

*Cancet M.[1], Lyard F.[2], Griffin D.[3], Carrère L.[4], Picot N.[5]*
*[1]NOVELTIS, France; [2]LEGOS/CNRS, France; [3]CSIRO, Australia; [4]CLS, France; [5]CNES, France*

The accuracy of the ocean tide correction is crucial for altimetry data, especially in the coastal regions, where the ocean tide signal shows the largest amplitudes.

The FES2014 global tidal model benefits from a high resolution mesh, improved hydrodynamic modelling and data assimilation techniques, as well as a 20-year-long altimeter time series and a large dataset of tide gauge observations for data assimilation. The validation of the FES2014 tidal elevations has shown the very good performance of this atlas, and particularly on the shelves.

In addition to the tidal elevations, the FES2014 global tidal atlas provides the tidal current velocity, which is of particular interest for many scientific (ocean circulation analysis, ocean dynamics modelling…) and industrial (offshore activities, tidal energy site assessment…) applications. Validation of the tidal currents is challenging as it requires long and accurate time series of current-meter observations. Luckily, for more than 10 years Australia has been maintaining a network of about 50 ADCP instruments all around the country, principally through its government-supported Integrated Marine Observing System (IMOS). The Australian continental shelf has a wide range of tidal regimes ranging from macro-tidal to micro-tidal, thus providing ideal conditions to thoroughly test a model.

This paper presents an assessment of the FES2014 tidal current atlas against the tidal constituents computed from the IMOS current meter data around Australia. The results show the very good agreement between the FES2014 tidal currents and the measured tidal currents, in most of the regions around Australia. Some differences have also been noticed and analysed and some potential improvements to the model have been identified.

This study provides new insights on the FES2014 tidal model quality and possibilities of improvements that would benefit to both the tidal currents and the tidal elevations, and subsequently to the coastal altimetry observations.

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## S3: Performance and Cal/Val of Coastal Altimetry

### Sentinel-3 Close to the Coasts: Performances and Perspectives.

*Boy F.[1], Picot N.[1], Thibaut P.[2], Poisson JC.[2], Raynal M.[2], Desjonqueres J.D.[1]*
*[1]CNES, France; [2]CLS, France*

The series of Sentinel satellites mark a major step forward in the collection of Earth Observation data with the commitment to a series of spacecraft and sensors to construct long time series of data suitable for both climate applications and widespread operational use. Amongst its many sensors, Sentinel-3 is carrying a SAR altimeter (SRAL), providing global high-resolution data for the first time.

**The SRAL altimeter improves the along-track resolution (approximately 300 m) in SAR mode using a delay/Doppler technique. In addition, the instrument is operating in Open-Loop Tracking mode.** In this mode, the tracking operations are not anymore based on the echoes analysis, but use an *a priori* information from a Digital Elevation Model stored on-board. This mode allows to acquire waveform of potential interest when a classical tracker would fail, in particular when the surface of interest does not cover the entire radar footprint. It is particularly interesting when approaching the coast.

**Using SAR mode and OLTC tracking, Sentinel-3 facilates sea surface height measurement close to the coast and gives better accuracy and performances than other altimetry missions**.

**This paper demonstrates this statement. Sentinel-3 SRAL data quality has been assessed through different metrics that are presented here**. We analyse more deeply the main features (accuracy, noise, quality index respect to distance and direction to the coast) to check the reliability and the improvements of the SAR measurements when approaching the coast.

Then, **we will present current studies driven by CNES aiming at proposing enhanced processing solutions,** both for SAR echoes retracking and geophysical models (new FES models).

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### Performances over Coastal areas of the SAR Mode Processing in Sentinel-3A Products

*Raynal M.[1], Labroue S.[1], Urien S.[1], Amarouche L.[1], Jourdain S.[1], Quartly G.[2], Féménias P.[3], Benveniste J.[3], Boy F.[4], Dinardo S.[5]*
*[1]CLS, France; [2]PML; [3]ESA; [4]CNES; [5]EUMETSAT*

Sentinel-3A mission was successfully launched in February 2016. It is a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. We focus here on the observations acquired by the sea-surface topography payload that encompasses a dual frequency altimeter, a dual frequency radiometer and Doris and GNSS sensors. A specificity of the Sentinel-3A mission is that it embarks a Delay Doppler altimeter. The SRAL altimeter operates continuously in Delay Doppler mode (or the so-called SARM) over all surfaces since the 12 April 2016.
Thanks to the reduced footprint coupled with a lower instrumental noise, the SARM technique should provide improved sea level observations over coastal regions.
We will present the performance of the SARM observations over different coastal regions through the assessment of the Sentinel-3A Level 2 products. The SARM processing within the Sentinel-3A operational ground segment is quite close to other existing ones (CNES processing and GPOD processing for instance) either for the Doppler processing or for the retracker. Different metrics will highlight the performance of the Sentinel-3A SARM sea level over the specific case coastal areas and more specifically the behavior of different SARM retrackers (SAMOSA 2.3, SAMOSA 2.5 and S3PP).

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### Coastal Altimetry for the North-Eastern Atlantic Shelf

*Fenoglio-Marc L.[1], Dinardo S.[3], Buchhaupt C.[2], Uebbing B.[1], Scharroo R.[3], Kusche J.[1], Becker M.[2], Benveniste J.[4]*
*[1]University Bonn, Germany; [2]Technical University Darmstadt; [3]EUMETSAT; [4]ESA/ESRIN*

Several studies have demonstrated the potential of conventional low resolution mode (LRM) altimetry in the coastal zone when waveforms are reprocessed and corrections optimized. SAR altimetry is expected to provide even better measurements of sea surface height, significant wave height and wind speed in the coastal zone than conventional altimetry Current projects like SCOOP (SAR Altimetry Coastal & Open Ocean Performance), SLCCI (Sea Level Climate Change Initiative) and the GOCE++Dycot (GOCE++ Dynamic Topography at the Coast and Tide Gauge Unification) are actually investigating the performance of coastal altimetry data produced by standard and improved processing schemes. Improved processing include consideration of sub-waveform CA re-trackers as well as various approaches in SAR altimetry, as Hamming Weighting Window on the burst data prior to the azimuth FFT, Zero-Padding Technique prior to the range FFT, doubling of the extension for the radar range swath, improved thermal noise estimated from beams in Stack data.

We investigate the North-Eastern Atlantic shelf from Lisbon to Bergen to verify the increase in coastal performances with SAR processing.

We consider SAR CryoSat-2 altimetry products from GPOD and SCOOP project, SAR altimetry Sentinel-3 PDGS products from ESA/EUM. We build pseudo-LRM (PLRM) from the SAR products mentioned above. As conventional altimetry data we use Envisat and Jason-2 data retracked by a sub-waveform retracker and the ESA Sea Level Climate Change Initiative products.

We inter-compare and compare the various products with in-situ sea level data from the German Federal Institute of Hydrology (BfG) and Système d'Observation du Niveau des Eaux Littorales (SONEL) databases to reach three specific goals. First we assess the improved accuracy of the SAR altimetry measurements by near-simultaneous comparison with the tide gauge stations Then we assess the long-term performance of SAR altimetry by comparison with tide gauge records corrected for the vertical motion, estimated by GPS. Finally we assess the contribution of SAR in deriving an improved coastal mean dynamic topography by point-wise comparison with mean sea level topography derived from in-situ observations.

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### Validation of CryoSat-2 and AltiKa Sea Level Anomaly in the Coastal Strip of the Gulf of Cadiz

*Gomez-Enri J.[1], Cipollini P.[2], Vignudelli S.[3], Coca J.[4]*
*[1]University of Cadiz, Spain; [2]National Oceanography Centre, UK; [3]Consiglio Nazionale delle Ricerche, Italy; [4]University of Cadiz, Spain*

Four and half years of CryoSat-2 SIRAL data in SAR mode (at 18-Hz posting rate) and 2 years of AltiKa SARAL data (at 1 Hz) have been validated using two radar MIROS tide gauges in the Gulf of Cadiz: Huelva (HU), located close to the Tinto-Odiel river system, and Bonanza (BN), at the mouth of the main tributary in the study area, the Guadalquivir River. Tide gauge data were provided by Puertos del Estado (https://www.puertos.es/) at 5-minute interval. Data from CryoSat-2 SIRAL (processed according to baseline B) were provided by the European Space Agency (ESA) Grid Processing On-Demand (GPOD) **SAR**vatore (**SAR v**ersatile **a**ltimetric **t**oolkit for **o**cean **r**esearch & **e**xploitation) service available at: https://gpod.eo.esa.int/. The data selection was made considering the track segments in a radius of 50 km from the tide gauges. AltiKa data, from two exact-repeat tracks in the vicinity of the tide gauge, were obtained from the Radar Altimeter Data System (RADS) available at: http://rads.tudelft.nl/rads/rads.shtml. Time series of Sea Level Anomalies (Cryo_SLA and AltK_SLA) were compared against in-situ SLA data: HU_SLA (Huelva) and BN_SLA (Bonanza). We estimated the root mean square error (rmse) between satellite and tide gauge data. Time series of Cryo_SLA were built selecting the locations at six different along-track distances to the coast: 1 - 3 - 5 -10 -15 - 20 km. Our results show that rmse increases getting closer to the coast at both stations. The rmse at Bonanza is twice than Huelva. The standard deviation observed in the 5-minutes time series at Huelva/Bonanza is 8/18 cm, respectively. This might indicate a larger signal due to the the Guadalquivir River where Bonanza tide gauge is located: part of the difference found between Cryo_SLA and BN_SLA might be attributed to this dynamic, which is concentrated in the estuary mouth and is not captured by the altimeter instrument as no valid Cryo_SLA data were found in that particular zone. The analysis of AltiKa data shows rmse smaller than 8 cm along the track segment close to Huelva station. The rmse is bigger than 18 cm in the track segment around Bonanza station, also suggesting the river output as source of the noise.

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### Corsica: A Multi-Mission Absolute Calibration Site

*Bonnefond P.[1], Laurain O.[2], Exertier P.[2], Guinle T.[3], Féménias P.[4]*
*[1]Observatoire de Paris - SYRTE, France; [2]Observatoire de la Côte d'Azur - Géoazur, France; [3]CNES, France; [4]ESA/ESRIN, Italy*

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

In-situ calibration of altimetric height (SSH for ocean surfaces) is usually done at the vertical of a dedicated CAL/VAL site, by direct comparison of the altimetric data with in-situ data. Adding the GPS-based sea level measurements to the "traditional" tide gauges ones, it offers the great opportunity to perform a cross control that is of importance to insure the required accuracy and stability. This configuration leads to handle the differences compare to the altimetric measurement system at the global scale: the Geographically Correlated Errors at regional (orbit, sea state bias, atmospheric corrections...) and local scales (geodetic systematic errors, land contamination for the instruments, e.g. the radiometer).

Our CAL/VAL activities are thus focused not only on the very important continuity between past, present and future missions but also on the reliability between offshore and coastal altimetric measurement. With the extension of the Corsica site (Capraia in 2004 and Ajaccio in 2005), we are now able to perform absolute altimeter calibration for ERS -2, EnviSat, HY-2A, CryoSat-2 and SARAL/AltiKa with the same standards and precision than for T/P and Jason missions. The Sentinel-3 mission is also naturally included in our CAL/VAL activities. This will permit to improve the essential link between all these long time series of sea level observation.

The presented results will include the full set of TOPEX/Poseidon, Jason-1 and Jason-2 GDR products. Updated values of the SSH bias for Jason-1 based on GDR-E will be also presented. However, this presentation will be focused on Jason-3 data and the comparison with Jason-2 over the Formation Flight Period. Preliminary results for Sentinel-3A will be also presented and the improvement thanks to SAR will be estimated.

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## S4: Altimetry for Regional and Coastal Models

### ARCOM, Enhancing the Link between Altimetry and Coastal Models

*Dufau C.[1], Wilkin J.[2], Mourre B.[3], Kourafalou V.[4], De Mey P.[5]*

*[1]CLS, France; [2]Rutgers University, USA; [3]SOCIB, Spain; [4]RSMAS, USA; COSS-TT co-chair; [5]LEGOS, France; COSS-TT co-chair*

In 2015, a pilot workshop called Altimetry for Regional and COastal Models (ARCOM) was organized within the 4th International Coordination Workshop of the GODAE Coastal Oceans and Shelf Seas Task Team (GOV COSS-TT). Its main objective was to foster the use for validation and/or assimilation of altimetry data in coastal models. ARCOM was a successful event, breaking new ground in the potential for long-lasting synergy between the CAW and COSS communities. In particular, ARCOM helped explain the data and products that CAW has been advancing, while addressing practical aspects for data use and data value for COSS user applications. The tutorial session was the foundation for fruitful discussions about the quality of altimeter measurements and the applied geophysical corrections, the choice and computation of reference surfaces, the capability of the different altimeter sensors in different areas and circulation regimes. Some examples of use of altimetry data in COSS systems were shown, which gave confidence in the value of altimeter data for studying COSS dynamics.

This paper, as an introduction to the “synergies of coastal altimetry and modeling” session, will provide information on the available coastal altimetry datasets and propose concrete actions towards synergistic advances of nadir and wide-swath coastal altimetry on one side, and regional/coastal modeling and prediction on the other side, involving the COSS community and the regional altimetry groups.

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### Velocity and Sea Level Anomaly Wavenumber Spectra in the Coastal Ocean: Observations from HF-Radar and Altimetry Compared with Nested High-Resolution Models

*Wilkin J., Hunter E.*

*Rutgers University, United States of America*

A CODAR HF-radar network has been observing surface currents in the Mid Atlantic Bight (MAB) continental shelf ocean for several years. CODAR observes the component of velocity along a radial view direction from a single antenna, geo-located by range and azimuth. Vector velocity is computed by combining radials observed by multiple sites. The concave geometry of the MAB coastline enables us to select radial view transects that are substantially along or across isobaths, and compute wavenumber spectra for both along-shelf and across-shelf components of velocity. Comparing radial view spectra to vector component spectra reveals that the optimal interpolation vector combiner significantly damps energy for wavenumbers exceeding 0.03 $km^{-1}$.

We further computed SSHA wavenumber spectra using coastal altimeter data from CryoSat-2 for ensembles of tracks in the same region that were predominantly across- or along-shelf. While CODAR-derived velocity spectra exhibit power law dependence close to $k^{-5/3}$ down to the limit of resolution, the SSHA spectra are somewhat steeper.

Wavenumber spectra from observations are compared to results from hydrodynamic model simulations with increasing resolution achieved by 2-way synchronous nesting (for two and three levels of nested grids). Spectral shapes generally agree well, but with comparable energy levels not achieved until model horizontal grid resolution approaches ~700 m.

The results have implications for specifying observational error and error-of-representation in data-assimilative modeling systems that exploit CODAR and altimeter observations in the coastal ocean.

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### The Impact of Satellite Altimeter Observations on Estmates of Cross-Shelf Fluxes in the Mid-Atlantic Bight

*Moore A.[1], Laughlin B.[1], Wilkin J.[2], Levin J.[2], Arango H.[2]*
*[1]University of California Santa Cruz, United States of America; [2]Rutgers University, United States of America*

Satellite altimeter observations form an important component of ocean observing systems in the coastal ocean, and along with other satellite and in situ measurements, can be used to constrain ocean models using data assimilation methods. We present here a quantitative assessment of the impact that various recent altimeter missions have on estimates of cross-shelf fluxes of mass, heat and salt in the Mid-Atlantic Bight when these data are assimilated into the Regional Ocean Modeling System (ROMS). The data assimilation method used is a 4-dimensional variational (4D-Var) approach, and using techniques employed routinely in numerical weather prediction, we can partition the 4D-Var transport increments into contributions from each observing platform. Particular attention will be paid here to the impact of the coastal satellite altimeter measurements on the cross-shelf transport.

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### A Multi-Technique Combination Method for Altimeter, Tide Gauge and Ships Data

*Roggenbuck O., Reinking J.*
*Jade University of Applied Sciences Oldenburg, Germany*

Reliable information of the instantaneous sea surface height (SSH) and its behavior are important for all geosciences and the human society in itself. The two standard data sources are tide gauge readings and satellite altimetry measurements. Additionally ships, equipped with geodetic GNSS antennas and receivers can be used for SSH measurements. All three techniques have their individual characteristics such as spatial- and temporal resolution. It is most likely that a multi-technique model will profit from each technique.

Within a PhD project at the Jade University in Oldenburg a new combination method is under development. With this method it will be possible to combine altimeter data, tide gauge readings and ship based SSH measurements in one empirical model. The estimation of various parameters like the mean height, the trend and tidal amplitudes and phases will be possible. The calculation is done on a grid. Coastlines and islands were taken into account during grid generation. The introduction of auxiliary constraints ensures an invertible normal equation matrix.

First tests of this approach were done with simulated data in the North Sea region. This conference contribution will explain the combination approach and show the combination results using the simulated observations.

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### Impact of Coastal Altimetry Data in the Black Sea Physical Ocean Analysis System

*Bonaduce A.[1,2], Passaro M.[3], Storto A.[1]*
*[1]CMCC (Italy); [2]Mercator Ocean (France); [3]DGFI-TUM (Germany)*

The Black Sea physical ocean assimilation system used in this study implements a three-dimensional variational data assimilation scheme at a nominal resolution of 3 km, which assimilates observations from Argo profiling floats, SST measurements from infrared sensors and along-track altimetry data, usually taken from CMEMS (i.e. CLS/AVISO). Altimetry data are assimilated by means of local hydrostatic adjustments, i.e. the altimetry misfits are covariated onto increments of temperature and salinity profiles. In order to look at the impact of coastal altimetry data in the system, Jason-2 data were reprocessed using the ALES retracking algorithm. ALES is a specialised coastal subwaveform retracker (i.e. an algorithm that fits the received altimetric signal for precise sea level estimation), which analyses only a portion of the received altimetric echo, in order to avoid coastal signal corruption while keeping a precision comparable to the open ocean measurements. After processing Jason-2 data with ALES, a set of four experiments was designed. We consider a control experiment, represented by a free simulation (1) of the Nucleus for European Modelling of the Ocean (NEMO)Ocean General Circulation Model (OGCM) implemented in the Black Sea; a reference (2) experiment obtained using classical 1 Hz along-track altimetry data. Finally, two experiments where coastal altimetry data from Jason-2 satellite mission sampled at 1 Hz (3) and 20 Hz (4) were performed. Preliminary results show how the ocean assimilation scheme used in this work is suitable for coastal altimetry data, giving consistent results with the reference experiment, even when 20 Hz data are considered within the system.

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### Understanding Altimetry Signals in Near-Coastal Areas Using Underwater Autonomous Vehicles

*Borrione I., Oddo P., Russo A., Coehlo E.*
*NATO STO CMRE, Italy*

During the LOGMEC16 (Long-Term Glider Mission for Environmental Characterization) sea trial carried out in the eastern Ligurian Sea (Northwestern Mediterranean Sea), two deep oceanographic gliders (maximum depth up to 1000m) were operating continuously from 3 May to 27 June 2016. Where and when possible, glider tracks were synchronized in space and time with the footprints of spaceborne altimeters crossing the Ligurian Sea during the sea-trial (i.e., Jason 2, Altika and Cryosat 2). Objectives of the sea trial included the definition of new methods for a more adequate projection along the water column of satellite derived

SLA (or SSH) and their effective assimilation in coastal/near-coastal ocean models.

Using temperature and salinity measurements from glider tracks that were co-localized with the altimeter passages, we calculated the dynamic height, and then compared it with the CMEMS near-real time absolute sea level using the TAPAS (Tailored Product for Data Assimilation), where the SLA dataset is available with all the terms used in the correction (i.e., Dynamic Atmospheric Correction, tides, long wavelength error) and the associated Mean Dynamic Topography.

A preliminary comparison between the glider-derived dynamic heights and the altimeter products (with and without corrections) shows that the agreement between the compared datasets is variable and seems to depend on the spatial scales considered. As an effective assimilation of altimeter measurements could be extremely beneficial for the quality of current modelling systems in coastal and near-coastal areas, it is important to understand the causes of the disagreements, and how these may be related to the geographical and/or oceanographic conditions.

Sensitivity experiments with an ocean model based on the Nucleus for European Modelling of the Ocean (NEMO), configured to assimilate satellite-derived SLA, have been also carried out using different altimeter datasets.

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## Integration of Coastal Altimetry Data in the Tuscan Coastal Observing System

*Brandini C.[1,2], Doronzo B.[1,2], Fattorini M.[1,2], Lapucci C.[1,2], Taddei S.[1], Ortolani A.[1,2], Cipollini P.[3]*

*[1]Consorzio LaMMA, Italy; [2]CNR Ibimet, Italy; [3]NOC, UK*

Ocean circulation modelling at regional/coastal scales provides information that is crucial not only to many socioeconomic activities (including safety at sea) but also to support improved sea monitoring procedures (as required in Europe by the Marine Strategy Framework Directive 2008/56/EC).

A major limitation of models, either used for forecasting and long retrospective analysis, is their reliability. This can only be improved by a proper use of observations for the validation and calibration of the models and, if possible, for data assimilation. A number of recently established Coastal Observing systems attempt to make the best possible use of in-situ and satellite data, and to integrate this information in coastal circulation models.

In Tuscany, a coastal observing system was recently established under the SICOMAR project It includes, in addition to traditional in-situ data (buoys and tide gauges), automatic samplers onboard ships, autonomous marine vehicles, and most of all HF radars. The information obtained is used by a coastal circulation model to allow for a better description of the hydrodynamic circulation at short time and spatial scales. The area under investigation, between the Thyrrenian and Ligurian seas, is characterized by significant exchange of water masses through the Corsica Channel and, further north, by the well-known convergence zone of the eastern and western Corsica currents which form of the North Mediterranean current. This dynamics has been repeatedly studied using Coastal Altimetry data, which allowed a better understanding of the processes and their seasonal variability (Vignudelli et al., 2000, 2002, 2005; Bouffard et al., 2014).

Coastal Altimetry data can be integrated in hybrid monitoring systems (Wilkin and Hunter, 2013) alongside HF radars and hydrodynamic models, even to describe sub-seasonal circulation scales. In this contribution we show how a combination of different data, including reprocessed Jason-1 and Jason-2 data from the ALES processor run at NOC, can improve the description of circulation features that are still scarcely known and that are considered responsible for phenomena of accumulation of floating debris (such as, for example surface microplastic). Such circulation features are in turn confirmed by a number of independent observations in this area.

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## High-Resolution Altimetry for the Eastern Canadian Shelf Regional Model

*Dufau C.[1], Smith G.[2], Davidson F.[3]*

*[1]CLS, France; [2]Environment and Climate Change Canada, Canada; [3]Fisheries and Oceans Canada, Canada*

A multi-mission high-resolution altimetry chain has been set up over the Canadian Eastern Seas, from the US border to the Baffin Bay [95°W-43°W; 42°N-82°N]. A regional tuning has been done in terms of corrections and reference surface. Issued from the most recent research activity in altimetry field, a new estimation of the satellite-sea distance based on the waveform classification has been proposed for the satellite mission Jason-2 and SARAL/Altika missions. For the satellite mission Cryosat-2, data measured by its Synthetic Aperture Radar (SAR) mode have locally been used when available. A dedicated data selection strategy has been developed for this regional production in order to take more precisely into account the seasonal ice coverage. It provides a good compromise between the quantity of observations and their variance reduction. A dedicated spatial filtering has been applied on native 20Hz/40Hz observations to remove their noise level. The choice of the cut-off length has been done on the basis of a regional spectral analysis. Each mission has been considered separately.

This paper will present a quality assessment of the high-resolution altimetry data set optimized for the observation of small scale oceanic structures near the Eastern Canadian coasts and in sea ice areas, with a particular attention on to the Gulf of St Lawrence area and the Grand Banks area. This paper will also present the use of this dataset in the Canadian Regional Ice-

Ocean Prediction circulation regional modeling System (RIOPS).

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# S5: Applications I – Currents, Waves and Winds

## Coastal Mesoscale Structures at the Entrance to the Gulf of California

*Torres Hernandez M.Y., Trasviña Castro A., Pallas Sanz E., Rivas Camargo D.A.*

*Center of Investigation and Education Superior of Ensenada, Mexico*

The Cabo Pulmo National Park is the northernmost coral reef community of the Mexican Pacific. It is located on the gulf coast of the Baja California Peninsula, approximately at 23.5 ° N, in a privileged position to study the coastal dynamics of the entrance to the Gulf of California. We study various mesoscale phenomena that interact with the coast and modulate the coastal circulation. In this work we focus on the physical mechanisms capable of enhancing the productivity of a subtropical coastal ocean. We use sea surface temperature maps from GHRSST, chlorophyll maps from MODIS and COPERNICUS to document and describe offshore filaments that generate cross-shelf transport and export significant amounts of mass, momentum and nutrients (and presumably net productivity). Sea level coastal altimetry from the Adaptive Leading-Edge Subwaveform retracking procedure, and for JASON-2 and Envisat, is used to estimate coastal currents for some of these filaments. The coastal altimetry estimates are validated using a 7-year time-series of *in situ* currents in the Cabo Pulmo National Park. We present case studies of different types of filaments and an analysis of their evolution and of their contribution to the coastal productivity.

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## Satellite Altimetry in the Continental Shelf of the Southwestern Atlantic, Argentina

*Saraceno M.[1,2,3], Lago L.S.[2,3], Paniagua G.F.[1,3], Ferrari R.[1,3], Provost C.[4], Artana C.[4], Martos P.[5], Guerrero R.[5]*

*[1]Centro de Investigaciones del Mar y la Atmósfera (CIMA/CONICET-UBA), Ciudad Autónoma de Buenos Aires, Argentina; [2]Departamento de Ciencias de la Atmósfera y los Océanos (DCAO/FCEN-UBA), Ciudad Autónoma de Buenos Aires, Argentina; [3]UMI-IFAECI CNRS-CONICET-UBA, Ciudad Autónoma de Buenos Aires, Argentina; [4]Laboratoire d'Océanographie Dynamique et de Climatologie (LOCEAN), Université Pierre et Marie Curie, Paris, France; [5]Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP), Mar del Plata, Argentina*

This study shows preliminary results of the data obtained along the northern transect of the Franco-Argentinean CASSIS (Southwest Atlantic Currents Satellite In-Situ) project. Between December 2014 and November 2015, five moorings recorded direction and speed of currents, temperature, salinity and pressure. The five moorings were deployed under the Jason track #26: two in the continental shelf (A1 and A2) and three in the shelf-break (A4, M1 and M2). Correlation with satellite altimetry data is statistically significant within all the moorings, being significantly larger over the shelf-break than over the continental shelf. Here we focus on the results obtained from A1 and A2, trying to understand the reason of the lower performance of the altimetry data over the continental shelf than over the shelf-break. A preliminary analysis suggest that the ageostrophic component imposed by the dominant NNW winds is likely to be responsible of the lowest correlation found between the meridional components over the shelf. Coastal altimetry products (CTOH, ALES), new products from CLS with 1/8 of degree spatial resolution and that include Ekman currents, numerical model outputs and other satellite data (SAR, SST, ocean colour) are being analysed. Geophysical corrections are also examined.

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## Performance of Different Altimetry-Derived Products and Techniques for Manifesting Mesoscale Eddies in Coastal Areas

*Karimova S.*

*University of Liege, Belgium*

Altimetry-derived data open wide opportunities for assessing global and mesoscale circulation of the World Ocean through an inspection of the gridded fields of sea level anomaly (SLA). Nevertheless, for small marine basins there exist some discrepancies in mesoscale eddy statistics provided by the analysis of SLA, on one side, and direct observations of eddies in satellite imagery, on the other side. Thus, satellite imagery usually reveal that cyclonic and anticyclonic eddies are having different dynamical and morphological properties, while on analysis of SLA such differences are not well represented.

The aim of the present study is to compare the performance of the different altimetry datasets (e.g. provided by the CMEMS and Legos) as well as of different eddy detection techniques such as a geometrical method and some variations of a closed-contour approach based on analysis of the SLA, relative vorticity, Okubo-Weiss parameter, etc. As a region of interest, the Western Mediterranean Basin is being used, due to its intensive mesoscale eddy activity. The time coverage is from 2011 to 2013. As a 'ground truth', sea surface temperature (SST) fields are being used, a visual analysis of which allowed to detect more than 2200 eddies with diameters in the range 30-160 km.

Preliminary results of application of the closed-contour approach allowed to suppose that only anticyclonic eddies with a diameter exceeding 70 km could be sustainably represented by closed contours in the fields of SLA and relative vorticity. Cyclonic eddies, due to their smaller spatial scale and non-geostrophic nature, could not be resolved by the fields of SLA.

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### Surface Winds off Peru-Chile: Observing Closer to the Coast from Radar Altimetry

*Astudillo O.[1,2], Dewitte B.[2,1], Mallet M.[3], Frappart F.[2,4], Rutllant J.[5,1], Ramos M.[6,7,8], Bravo L.[7], Goubanova K.[9,1], Illig S.[2,10]*

*[1]Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile.; [2]Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Toulouse, France.; [3]Laboratoire d'Aérologie, Toulouse, France.; [4]Géosciences Environnement Toulouse (GET), Toulouse, France.; [5]Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile.; [6]Departamento de Biología, Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Chile.; [7]Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile.; [8]Centro de Innovación Acuícola Aquapacifico, Universidad Católica del Norte, Coquimbo, Chile.; [9]CERFACS, Toulouse, France.; [10]Departament of Oceanography, MARE Institute, University of Cape Town, South Africa.*

The near-shore surface mesoscale atmospheric circulation in the upwelling systems off Peru and Chile is influential on the Sea Surface Temperature through Ekman transport and pumping. There has been a debate whether or not the so-ca ed "wind drop-off", that is a shoreward decrease of the surface wind speed near the coast, can act as an effective forcing of upwelling through Ekman pumping. Although the wind drop-off has been simulated by high-resolution atmospheric models, it has not been well documented due to uncertainties in the scatterometry-derived wind estimates associated with land contamination. Here we use the along-track altimetry-derived surface wind speed data from ENVISAT, Jason-1, Jason-2, and SARAL satellites, to document the spatial variability of the mean wind drop-off near the coast as estimated from the inversion of the radar backscattering coefficient. The data are first calibrated so as to fit with the scatterometer observations of previous and current satellite missions (QuikSCAT, ASCAT). The calibrated data are then analyzed near the coast and a wind drop-off scale is estimated. The results indicate that the wind drop-off takes place all along the coast, though with a significant alongshore variability in its magnitude. Differences between products are shown to be related both to the differences in repeat cycle between the different altimetry missions and to the peculiarities of the coastline shape at the coastal latitudes of the incident tracks. The relative contribution of Ekman pumping and Ekman transport to the total transport is also estimated indicating a comparable contribution off Chile while transport associated to Ekman pumping is on average ~1.4 larger than Ekman transport off Peru. Despite the aliasing effect associated to the weak repetitivity of the satellite orbit and the high frequency variability of the winds in this region, the analysis suggests that the seasonal cycle of the surface winds near the coast could be resolved at least off Peru.

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### Coastal Altimetry in Support to Marine Observatory and Marine Observatory in Support to Coastal Altimetry: Multi-Platform Validations of Altimetry for Monitoring the Variability of Coastal Fronts

*Bouffard J.[1], Melonie M.[2], Fernandes J.[3], Lázaro C.[3], Casadio S.[4], Doglioli A.[5], Petrenko A.[5], Femenias P.[6]*

*[1]ESA / RHEA, Italy; [2]SERCO, Italy; [3]University Of Porto, Portugal; [4]ESA / SERCO, Italy; [5]MIO, France; [6]ESA, Italy*

The space-time variability of coastal slope currents plays a key role on the across-shore transport of natural and anthropogenic elements. It is therefore of critical importance to monitor the variations of their front position and intensity, in particular along densely populated coasts such as the littoral zone of the Mediterranean Sea. Our paper proposes to address this issue by giving an overview of integrated multi-sensor approaches aiming at monitoring the multi-scale variability of the Mediterranean Northern Current. Beside this scientific objective, our purpose is also to refine validation approaches for coastal altimetry, by analyzing the potential sources of disagreement between Coastal Altimetry and the Fiducial Reference Measurements (e.g. measurement/correction errors, physical content inhomogeneity, non exact collocations). To achieve this goal, several altimetric datasets and multi-platform observations from oceanographic campaigns and Marine Observatories are analyzed in conjunction with a regional circulation model. This R&D initiative, supported by ESA, is firstly based on an original exploitation of conventional pulse-limited altimetry data. The main outcomes should pave the way for designing validation approaches to assess/optimize improved geophysical corrections and processing algorithms dedicated to future missions whose the on-board technology will more suitable for coastal applications (e.g. Sentinel-6, SWOT).

REVISED ABSTRACT submitted 28/11 after query by OrgComm:

The space-time variability of coastal slope currents plays a key role on the across-shore transport of natural and anthropogenic elements. It is therefore of

critical importance to monitor the variations of their front position and intensity, in particular along densely populated coasts such as the littoral zone of the Mediterranean Sea. Our paper proposes to address this issue by presenting the first outcomes of an integrated multi-sensor approach aiming at monitoring the multi-scale variability of the Mediterranean Northern Current. The paper focuses on the scientific exploitation and validations of multi-mission coastal altimetry, by analysing the potential synergies and sources of disagreement with respect to *in situ* observations; especially regarding measurement errors, physical content inhomogeneity, synopticity issues and the non exact collocations between the different observing systems. To achieve this goal, several altimetric datasets (XTRACK, PEACHI, AVISO) and complementary *in situ* measurements (e.g. Moving Vessel Profilers, Gliders, CTD, ADCP, HF radar) from Marine Observatories (JULIO, MOOSE) and an oceanographic campaign (OSCAHR) are post-processed and analysed in conjunction with a 10-year regional simulation (SYMPHONIE). This R&D initiative, supported and funded by ESA, is firstly based on the original analysis and validation of pulse-limited Ka and Ku –band coastal altimetry data. The obtained outcomes are promising and pave the way for new multi-sensor approaches aiming at better characterising the coastal ocean dynamics hidden behind small-scale altimetric signals. Indeed, the thorough knowledge of local oceanographic processes appears to be THE key component in order to properly validate and continuously improve geophysical corrections and innovative coastal processing algorithms dedicated to past, new and future high-resolution altimetric missions.

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# S6: Applications II - Sea Level and Extreme Events

### Validating Altimeter Estimates of Sea level Along the Southern Coast of Australia

*Cahill M.L.[1], Legresy B.[1], Bastos de Oliveira H.[1,2]*
*[1]CSIRO, Australia; [2]University of Tasmania, Australia*

The southern coast of Australia along the Great Australian Bight is an east-west shelf extending for thousands of kilometers. The shelf is a known waveguide for large amplitude Coastally Trapped Waves (CTWs) that often contribute to creating extreme sea levels in the more populated gulf regions. At the eastern end of the shelf, the Bonney Coast, is Australia's only deep-reaching coastal upwelling system, drawing water from over 300m and extending along 800km of coastline. Upwelling occurs 2-3 times during the summer at the Bonney Coast, principally due to upwelling favourable winds but events are enhanced by the passage of correctly phased CTWs.

In previous work we found that estimates of sea level along the Bonney Coast, using AVISO's PEACHI product, were highly self-consistent in identifying upwelling events. The work has been extended now to compare altimetric sea level with data from two (National Tidal Centre) tide gauges along the southern coast, each of which is in the path of both an ascending and descending AltiKa pass. The propagating nature of the CTW signal provides the opportunity to incorporate heights from all altimeter tracks crossing the shelf – greatly increasing the number of altimeter/tide gauge comparisons that can be made.

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### UK Sea Level Space Watch – Monitoring Regional Sea Level Variability around the UK from Satellite Altimetry

*Cotton D.[1], Ash E.[1], Cipollini P.[2], Mir Calafat F.[2]*
*[1]Satellite Oceanographic Consultants Ltd, United Kingdom; [2]National Oceanography Centre, United Kingdom*

UK Sea Level SpaceWatch is a service designed to support the UK agencies responsible for the management and planning of national flood defences and for the preservation of coastal habitats threatened by sea level change.

Using data from satellite altimeters together with tide gauge data, Sea Level SpaceWatch provides, through an easy to use web-interface, the latest figures on observed sea level around the UK, supported by careful analyses of these data in terms of long-term trends, regional variability and confidence intervals showing the lower and upper limit for the current mean sea levels. The service complements and supplements the sea level change scenario information available from UK Climate Projections, offering planners the opportunity to verify the regional variability of sea level around the UK at multiple time scales and observe the presence of any significant inter-annual changes.

In the past it has been difficult to retrieve useful data from satellite altimeters close to the coast, because of land contamination of the return waveform. To address this problem, NOC has developed the "ALES" altimeter re-tracker for coastal regions. With this re-tracker, altimeter data from Jason-1, Jason-2, Envisat and Altika has been reprocessed to generate a 14 year times series of sea level data for the UK coastal zone (2002-2015).

This multi-year sea level data set has been validated against tide gauge data and then further analysis carried out to provide a characterisation of regional variability in sea level, in terms of the annual cycle, and inter-annual variability.

Key findings are:

- There is preliminary evidence of a geographical structure in the long-term trend, larger on the South and East than in the North-West.

- There was clear consistency between the annual cycle parameters (amplitude and phase) from tide gauge and altimeter data, with some localised differences. The annual cycle peaks between early October in the south-east and early November in the west coast and has an amplitude ranging from 5 to 9 cm.

- There is good agreement between the de-trended de-seasoned sea level from altimetry and from the tide gauges.

- There is significant spatial coherence in sea level on inter-annual timescales, with the leading EOF capturing over 50% of the variability.

The Development of Sea Level Space Watch has been funded by the UK Space Agency under the Space for Smarter Government Programme.

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### The Estimation of Sea Level Rise Impact on Coastal Zones of the Eastern Adriatic Sea

*Grgić M.[1], Nerem R.S.[2], Bašić T.[1]*
*[1]University of Zagreb, Faculty of Geodesy, Croatia; [2]University of Colorado Boulder, Colorado Center for Astrodynamics Research, USA*

The mean rate of global sea level rise is estimated to be ~3.1 mm yr−1. Those rates are routinely calculated from tide gauge measurements and satellite altimetry. However, regional rates that are driven by local geophysical processes can vary significantly. Thus, the impact of sea level change in the areas that adjoin the oceans should be evaluated through the local perspective. That includes modeling the sea level change with regards to the local vertical land motion and coastal relief combined with specific local sea level change rates. This study aims to model the future sea level change in relation to the coastal specifics of the eastern Adriatic Sea, which mostly covers Croatian coastline. The area of interest covers the northernmost part of the Mediterranean Sea, which contains over 1300 islands and is one of the most indented sea coasts in the world. The study encompasses sea level modeling from tide gauge measurements and satellite altimetry along with its comparison to the Shuttle Radar Terrain Model (SRTM) of the proposed area combined with vertical land movement trends. The satellite altimeter data processed include measurements captured by the Topex/Poseidon, Envisat, Jason-1, Jason-2, (Jason-3), Cryosat-2, and Saral altimetry missions. These data were combined with monthly solutions from the tide gauge measurements. The vulnerability of the coastal areas was evaluated through the analysis of the coastal relief, land cover in the coastal areas and terrain slopes. Finally, an insight into the expected absolute and relative sea level change and its impact throughout the 21st century is provided for the coastal areas of the eastern Adriatic area. The study provides numerical and graphical analyses along with the advantages and disadvantages of the employed modeling method.

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### Coastal SAR and PLRM Altimetry in the German Bight and West Baltic Sea with Sentinel-3A and CryoSat-2

*Dinardo S.[1], Buchhaupt C.[2], Fenoglio-Marc L.[2,3], Scharroo R.[6], Fernandes J.[4], Becker M.[2], Benveniste J.[5]*
*[1]HeSpace, Eumetsat, Darmstadt, Germany; [2]TU Darmstadt, Institute of Geodesy, Physical and Satellite Geodesy, Darmstadt, Germany; [3]University of Bonn, Institute of Geodesy, Bonn, Germany; [4]University of Porto, Faculty of Science, Porto, Portugal; [5]ESA-ESRIN, Frascati, Italy; [6]EUMETSAT, Darmstadt, Germany*

The scope of this study is a regional analysis and inter-comparison between CryoSat-2 and Sentinel-3 SAR altimeter data against in-situ data and regional model results at distances to coast smaller than 10 km. The in-situ data are from a network of tide gauges and GNSS stations. The validated geophysical altimeter parameters are the sea surface height above the ellipsoid (SSH), the significant sea wave height (SWH) and wind speed (U10).

We have carried out, from the CryoSat-2 FBR (L1a) product, a Delay-Doppler processing and waveform retracking tailored specifically for coastal zone by applying Hamming Window and Zero-Padding, using an extended vertical swath window in order to minimize tracker errors and a dedicated SAMOSA-based coastal retracker, named SAMOSA+. SAMOSA+ accepts the mean square slope as a free parameter and the epoch's first guess fitting value is decided according to the peak in correlation between 20 consecutive waveforms, in order to reduce land off-ranging effect.

Exactly the same processing baseline has been considered to process Sentinel-3A L0 data using the most accurate possible orbits (POE) and platform files (PCP) available.

Since the highest remaining uncertainties in the altimeter parameters derived in coastal shallow waters arise from residual errors in the applied corrections, we use a regional ocean tide and high resolution geoid and mean sea surface models (TPXO8 for tides, EIGEN-6C4 for the geoid and DTU13 for the mean sea surface). We also apply a regional improved wet tropospheric correction computed from the GNSS-derived Path Delay Plus (GPD+) algorithm at the University of Porto.

In parallel with SAR measurements, in order to quantify the improvement with respect to pulse-limited altimetry, we build PLRM (pseudo-LRM) data from CryoSat-2 FBR and Sentinel-3 L1a and retrack them with a numerical convolutional Brown-based retracker. PLRM is used as a proxy for real pulse-limited products (LRM), since there is no direct comparison of SAR and LRM possible otherwise. Both the CryoSat-2 and the Sentinel-3A SAR L2 ocean data are generated and extracted from the ESA-ESRIN GPOD service, whereas the CryoSat-2 and Sentinel-3A PLRM data are built and retracked by the Technical University of Darmstadt (TUDa). The regions of interest are the German Bight and West Baltic Sea, the latter being a very challenging area due to its complex coastal morphology and high tide dynamics. The epoch of interest is the complete mission duration for Cryosat-2 and and as much data as we can gather before the Workshop for Sentinel-3A.

The analysis will be based both on geometric parameters, such as the distance-to-coast parameter and the sea floor bathymetry and radar waveform parameters (misfit and entropy).

The final objective is to verify the ability of SAR Altimetry to measure accurately in the coastal zone the sea level annual cycle and the sea level trend. By the time of workshop, we will use 6 years of data for CryoSat-2 and the longest available dataset for Sentinel-3A to attempt the first assessment of whether Sentinel-3A and CryoSat-2 measure the same sea level annual cycle in open ocean and coastal zone.

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**Accurately Measuring Sea Level Change from Space in the Coastal Zone: an ESA Climate Change Initiative**

*Cazenave A.[1], Legeais JF.[2], Ablain M.[2], Larnicol G.[2], Johannessen J.[3], Scharffenberg M.[4], Timms G.[5], Andersen O.B.[6], Cipollini P.[7], Roca M.[8], Rudenko S.[9], Fernandes J.[10], Balmaseda M.[11], Quartly G.[12], Fenoglio L.[13], Ambrózio A.[14], Restano M.[15], Benveniste J.[16]*

*[1]LEGOS; [2]CLS; [3]NERSC; [4]University of Hamburg; [5]CGI; [6]DTU; [7]NOC; [8]isardSAT; [9]GFZ; [10]University of Porto; [11]ECMWF; [12]PML; [13]University of Bonn; [14]DEIMOS/ESRIN; [15]SERCO/ESRIN; [16]ESA-ESRIN*

Sea level is a major climate index because it integrates the response of oceans, mountain glaciers, ice sheets and land waters to external forcing factors and internal climate variability. Understanding sea level variability and changes implies an accurate monitoring of sea surface height variations at different spatio-temporal scales. This is why the 'Sea Level' Essential Climate Variable (ECV) was selected in the frame of the ESA Climate Change Initiative (CCI) programme. The main objective of this initiative was to provide long-term sea level time series at global and regional scales, with regular updates, as is required for climate studies.

The CCI is now in its 3 year long second phase, following a first phase that spanned 2011 to 2013. It has contributed to the reinforcement of collaboration of the European sea level community, refined their needs, and collected their feedback about product quality. It has also served to develop, test and select the best algorithms and standards needed to generate an improved sea level time series. This has led to the production of the Sea Level ECV that now covers the period 1993-2014.

The efforts conducted during the Sea Level CCI project will be extremely useful for future developments of sea level products in specific regions (e.g., the Arctic) and in coastal zones. Because sea level rise will aggravate the vulnerability of low-lying, highly-populated coastal regions of the world, providing accurate coastal sea level products is now a major goal and a scientific challenge. In coastal zones, 'absolute' sea level variations are the combination of the global mean rise, regional variability and short-scale oceanographic processes. Improvement of the first two factors in the open ocean has been the main objective of the Sea Level CCI project. In addition to summarizing what has been learnt during the project, the presentation will also address future needs, focusing especially on coastal issues.

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**Combining Tide Gauge and Satellite Altimetry Data: Towards Monitoring Vertical Land Motion at the Coast**

*Wöppelmann G.[1], Marcos M.[2]*

*[1]University of La Rochelle, France; [2]IMEDEA - UIB, Spain*

Vertical land motions are a key element in understanding how sea levels have changed over the past century and how future sea levels may impact coastal areas. Ideally, to be useful in long-term sea level studies, vertical land motion should be determined with standard errors that are one order of magnitude lower than the contemporary climate signals of 2-3 mm/year observed on average in sea level records, either using tide gauges or satellites. This metrological requirement constitutes a challenge in geodesy.

Here we review the use of the combination of satellite radar altimetry with tide gauge data to derive vertical land motion data. This method is independent from GPS, and enables to overcome some limitations associated with the use of GPS (number of stations and data availability, local leveling).We update previous data analyses and assess the quality of global satellite altimetry products available to the users for coastal applications. In particular, we carefully examine the uncertainties. Various satellite altimetry products are considered from the major data suppliers (Archiving, Validation, and Interpretation of Satellite Oceanographic data (AVISO), Climate Change Initiative (CCI), Commonwealth Scientific and Industrial Research Organization (CSIRO), Colorado University, Goddard Space Flight Center (GSFC)). The time span covered by the satellite altimetry data considered here extends at maximum from 1993 to 2016, although the final year depends on the particular data set. We investigate the linearity of the differenced (satellite minus tide gauge data) time series and evaluate their noise content. Finally, we use the new combined satellite altimetry and tide gauge data set to estimate vertical land motion at nearly500 coastal sites around the world and compare the results with the a GPS solution dedicated to tide gauge monitoring.

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## Poster Session

**Advancements in the Usage of Envisat Individual Echoes (IEs)**

*Vignudelli S.[1], .Abileah R.[2], Scozzari A.[3]*
*[1]Consiglio Nazionale delle Ricerche (CNR-IBF) Italy; [2]Jomegak; [3]Consiglio Nazionale delle Ricerche (CNR-ISTI) Italy*

The Envisat radar altimeter had a PRF of around 1800 Hz, which was intended to provide the maximum number of independent observations per second. The conventional processing and analysis of sea surface returns uses incoherent sums for noise averaging. Standard Envisat altimeter data are averaged at a rate of 20 Hz. However, a provision was made in Envisat for an 'Individual Echoes' (IE) recording mode that collects 1-second bursts of 1984 x 128 range bins of individual complex echo returns every 3 minutes. This acquisition mode was designed to support experiments beyond the conventional methods. A large collection of IE data packets has been provided by the European Space Agency and is now catalogued on disk. The available IE data cover almost all sorts of water targets, including open ocean, coastal zone and inland water. The analysis was primarily conceived for inland water study, but it's clear that the development of tools for the inland water context also supports the observation of the coastal zone. Matlab routines were developed for processing IE data in order to investigate ways of exploiting the complex data. In this work, we explain the current implemented capabilities, show evidence of observed features from selected case-studies in coastal zone, rivers and estuaries, discussing the impact of those aspects, such as the variability of the surface roughness, which are peculiar to the coastal zone.

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**Comparison with the Coastal Sea Surface Height Retrieved from Along-Track Jason-2 Continuous Waveforms and the HF Ocean Radar Data in the Tsushima Strait**

*Wang X.F.[1], Ichikawa K.[2]*
*[1]ESST, Kyushu University, Japan; [2]RIAM, Kyushu University, Japan*

A new algorithm is proposed to retrieve sea surface height (SSH) from Jason-2 waveforms contaminated near coastal areas. Unlike the other algorithms such as ALES that detect contamination in each single waveform independently, continuous waveforms along a track are used at once to detect contamination referring consistency with adjacent points. In this study, Jason-2 waveforms near Tsushima Island, Japan are processed and found closer SSH retrieval to the coast than the other algorithms. The obtained SSH is compared with surface velocity observed by the HF ocean radar data in which tidal and wind-driven current components have been removed separately. Spatial smoothing is found necessary for better comparison, which emphasises importance of closer SSH retrieval in coastal areas, especially in narrow channels where the number of altimeter data tends to be insufficient.

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**Analysis of Altimetry Range and Correction in a Flat Coastal Environment at Aix Island Sea-Level Observatory, France**

*Laurent Testut[1,2], Valérie Ballu[2], Médéric Gravelle[2], Pascal Bonnefond[3], Olivier Laurain[4], Etienne Poirier[2]*
*[1]LEGOS, France; [2]LIENSs, France; [3]SYRTE, France; [4]GEOAZUR, France*

Satellite altimetry in coastal areas is a challenging task due to both altimeter and radiometer contamination by land. However, the ability to use satellite altimetry data as close as possible to the coast would be invaluable and would benefit numerous applications such as local sea-level monitoring or hydrodynamic modeling and coastal oceanography.

Aix island is located between the two flat elongated islands of Ré and Oléron, which define a >10km wide inlet, sufficiently large for most altimetry mission to provide some measurements.

The Ile d'Aix sea-level observatory provides in-situ data, such as tide gauge and GPS, which can be used to validate final altimetric heights and improve specific corrections. In this work, we will investigate the quality of the SSB corrections provided by the altimeter by comparison with significant wave height provided by a local hydrodynamic model and an offshore wave gauge. Due to the site configuration and the sheltering of Ré and Oléron islands, methods based on the extrapolation of corrections from the less-contaminated offshore zones is not adequate.

We also look at the improvement of the tropospheric delay correction when using local tropospheric delay modeled from the GPS stations of Ile d'AIX (ILDX) and La Rochelle (LROC), with respect to using the tropospheric delay estimated from the land-contaminated radiometer.

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## Enhance Coastal Tide Modeling Using Cryosat-2: A Feasibility Study

*Piccioni G., Dettmering D., Bosch W., Seitz F.*
*DGFI-TUM, Germany*

During the last years significant improvements have been achieved in coastal altimetry. Advances in observational techniques, data processing and corrections brought to a higher accuracy in sea level estimations, reaching remarkable results within few kilometers from the shore. In particular, geophysical corrections have a significant impact on coastal products and therefore their constant improvements are crucial. Tide correction is the principal contributor in sea level determination and its solutions have dramatically improved through the last years. However, discrepancies of around 1 meter are still found among different tide models at short distances from the coast. With the unprecedented design of CryoSat's radar altimeter, high-performance observations over littoral areas are reached, showing higher resolution and Signal to Noise Ratio up to 2 km from the coast. Indeed, these promising features appear as a good opportunity for improving coastal tide representation. The aim of this work is to investigate on the possibility to exploit CryoSat-2 data within a tide model, focusing on the enhancement over coastal areas. This study is based on the Empirical Ocean Tide (EOT11a) model released by DGFI-TUM in 2012, which was developed with the spherical harmonic method. The difficulty in implementing this technique with CryoSat stays in the fact that short-repeat orbits are required in order to compute the aliasing periods of single constituents. In the case of CryoSat the same principle cannot be applied because of its long repeat cycle. However, alternative approaches such as a gridding strategies and the comparison of local sampling with major tide oscillations will be presented. The preliminary experiment will be carried out in the open ocean and the results will be compared with external models and values from short-repeat missions.

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## Evaluation of the Dry and Wet Tropospheric Corrections for CryoSat-2 and Sentinel-3 Over Inland Waters

*Fernandes M.J[1,2], Lázaro C.[1,2], Vieira T.[1]*
*[1]Universidade do Porto, Faculdade de Ciências, Porto, Portugal; [2]Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR), Universidade do Porto, Porto, Portugal*

Errors of up to few centimetres are presently associated with the dry and wet tropospheric corrections (DTC and WTC, respectively) given in Level 2 (L2) altimeter products over inland water regions, mainly because these corrections are usually referred to other than the appropriate height reference. These errors have been analysed in the scope of the Sentinel-3 Hydrologic Altimetry PrototypE (SHAPE) project, aiming at developing improved corrections for CryoSat-2 (CS-2) and Sentinel-3 (S3) L2 products. For this evaluation, regions of interest (ROI) covering rivers and lakes where CS-2 is operating in SAR and SAR-In modes, e.g. Amazon and Danube rivers and Titicaca and Baikal lakes have been selected.

For CS-2, the tropospheric corrections provided by Level 1B products have been compared against corrections computed from the ECMWF operational model at: i) the level of ECMWF model orography; ii) the level of the ACE2 digital elevation model; iii) the mean lake level, derived from Envisat data, or river profile derived in the scope of this project by AlongTrack (ATK) from Jason-2 data. Whenever GNSS data are available in the vicinity of the ROI, a GNSS-derived WTC is also generated and used for comparison. For S3, model-derived WTC are also compared to Envisat derived WTC in the central parts of the lakes, where radiometer data are valid.

The obtained results show that the model-derived corrections present in CS-2 products are referred to the model orography, which can depart from the mean river profile or mean lake level by hundreds of metres. ACE2 DEM is a better reference when compared to ECMWF orography, but height errors of the same magnitude are still found for some of the analysed regions e.g. Amazon and Lake Titicaca. Systematic errors up to 3-5 cm in the DTC are generally found for most of the selected regions, which can induce significant errors e.g. in the determination of mean river profiles or lake level time series. The effect of ECMWF surface pressure uncertainty propagation into DTC error has been found to be negligible from the analysis of surface pressure observations. Height-dependent errors of smaller magnitude, up to a few centimetres, have been found for the WTC for the selected ROI.

Results from this evaluation show that in general the magnitude of DTC and WTC errors is around 1 centimetre, when the corrections are referred to the proper reference: mean river profile, derived using the height of the closest point in the profile, or mean lake level determined from satellite altimetry. The evaluation of model-derived WTC errors using GNSS and MWR derived path delays is in progress and shall be extended to regions of higher WTC variability.

This analysis is currently being extended to S3 data samples accessed under the scope of Sentinel-3 Validation Team project ID 13769, titled "Validation Of Coastal ALtimetry from Sentinel-3 (VOCALS3)" and the first results will also be presented.

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**Recent Improvement in MSS and Gravity field in Coastal and Arctic Regions**

*Andersen O.B, Knudsen P.*

*DTU Space, Denmark*

The latest release of the global high resolution mean sea surface and free air gravity from DTU Space are increasing dependent of the Cryosat-2 LRM, SAR and SAR-In data with its more than 6 years in orbit.

Recently the SARAL/AltiKa was shifted from its nominal 35 days repeat track into a geodetic orbit. With its smaller footprint compared to conventional altimeters. As this satellite continue to collect 1-2 years of geodetic data it will further improve coastal mplete 1-2

Here we perform sevel local coastal studies of the influence and importance of Cryosat-2 and the first SARAL/AltiKa for coastal and Arctic region in preparation for the release of the global high resolution DTU16/DTU17 MSS and Free Air Anomaly maps.

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**Tidal Downscaling in a 3D (Structured) Circulation Model: A New Approach Based on Tailored 2D (Unstructured) Simulations**

*Toublanc F.[1], Ayoub N.[2], Lyard F.[2], Marsaleix P.[3], De Mey P.[2], Ghantous M.[2], Duhaut T.[3], Allain D.[4]*

*[1]CNES/LEGOS, France; [2]CNRS/LEGOS, France; [3]CNRS/LA, France; [4]Celad/LEGOS, France*

Modeling the 3D ocean circulation in coastal areas requires an accurate representation of the tidal dynamics. This is particularly true in the Bay of Biscay, where tides are highly energetic over the shelf, with tidal ranges reaching 6m at the coast. Although tidal dynamics are dominated by semi-diurnal constituents, nonlinear interactions occurring between these constituents and the topography result in the generation of overtides such as M4. Downscaling the tidal dynamics in a coastal model from a larger scale solution raises several methodological issues, especially in terms of currents. In particular, the choice of the large scale solution is crucial; the impact of likely inconsistencies in bathymetry and grid resolutions between the large scale model and the coastal one should be evaluated.

In this study, we propose a new approach to tidal downscaling for coastal modelling by using two numerical models, T-UGO and SYMPHONIE, on the same rectangular mesh and bathymetry at the nodes. The unstructured grid model T-UGO 2D spectral model is adapted to perform these simulations, and provide tidal boundary conditions to the 3D circulation model SYMPHONIE. The latter is set-up on a variable mesh grid that allows us to represent the different physical processes, including tides, that influence the dynamics of the bay, from the deep plain scale to the estuarine scale. The horizontal grid resolution varies between approximately 3km at the oceanic open boundary and less than 300m in the Gironde estuary and the Pertuis Charentais. Three types of tidal boundary conditions are tested for the SYMPHONIE model: the FES2012 atlas, T-UGO 2D spectral simulations, and SYMPHONIE 2D clamped simulations. Complex errors, taking into account both the amplitude and the phase of the M2 tidal constituent, are reduced by more than 75% with a regional forcing (SYMPHONIE or T-UGO 2D), compared to a global forcing (FES2012).

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**Satellite Altimetry in South-West Bass Strait**

*Legresy B.[1], Watson C.[2], Cahill M.[1]*

*[1]CSIRO, Climate Science Center, Australia; [2]University of Tasmania, Australia*

In this presentation we will detail our study area for improved understanding of coastal/SAR altimetry in the south west part of Bass Strait, Australia. This area hosts an absolute in situ calibration facility for the Jason-series satellite altimeters, having commenced operation in 1992 following the launch of TOPEX/Poseidon. In view of the new and upcoming SAR and InSAR satellite altimeters (Jason-CS/Sentinel-6, Sentinel-3A, Sentinel-3B and SWOT) we are expanding activity to capture data at multiple in situ comparison points that include our historical nadir altimetry comparison point, as well as two cross overs for the Sentinel-3A and 3B mission. We have developed an observation strategy that includes in situ equipment (pressure gauges, current meters and 3D wind/wave ADCPs, GNSS equipped buoys) complemented by a high resolution ocean model in order to deliver quality calibration and validation of satellite observations. While expanding the study area, we are able to interpret and validate measurements from the various satellite instruments (LRM, SAR, and in the future, InSAR). After presenting our cal/val system developments, we will show the updated results for the Jason series as well as case studies on early measurements by Sentinel-3A and Jason-3. In particular, we will illustrate the benefit of the SAR mode onboard Sentinel-3 in this area were numerous islands and challenging coastline make classical nadir radar altimetry more challenging close to the coast.

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**Validation of Sentinel-3A Altimetry Data by Using In-Situ Multi-Platform Observations near Mallorca Island (Western Mediterranean)**

*Sánchez-Román A.[1], Heslop E.[2], Reeve K.[2], Rodríquez D.[2], Faugère Y.[3], Torner M.[2], Tintoré J.[1,2], Pascual A.[1]*

*[1]IMEDEA (CSIC-UIB), Balearic Islands, Spain; [2]SOCIB, Balearic Islands, Spain; [3]CLS, Toulouse, France*

In the frame of the Copernicus Marine Environment Monitoring Service (CMEMS) Sea Level Thematic Assembly Center (SL-TAC), a glider mission was undertaken between May and June 2016 along the same track as the overpass of the Sentinel 3A satellite in the Southern Mallorca region. Moreover, a one-day ship mission on May 30, synchronous with the overpass of the satellite, captured two transects of moving vessel ADCP close to the coastal area. The aim was to compare the along track altimeter products and multi-platform in-situ observations in the southern coastal zone of the Mallorca Island and the Algerian Basin. In addition, we explored the potential of the Synthetic Aperture Radar Mode (SARM) instrumentation of Sentinel-3 mission, which enables the satellite to measure nearest the coasts with both higher spatial resolution and higher precision than previous missions. With the ultimate goal of contributing to a more complete understanding of both ocean and coastal physical processes and the biogeochemical impacts.

The analyses presented here are conducted through the comparison of Absolute Dynamic Topography (ADT) obtained from the Sentinel-3A altimetry measurements along ground-track #713 and Dynamic Heights (DH) derived from temperature and salinity profiles measured by the glider along the trajectory followed by the satellite. Moreover, currents derived from altimetry and in-situ glider data along the track followed by the satellite; and from ADCP data collected in the coastal region are analysed. Results show a good agreement between ADT from altimetry and DH from glider data with maximum differences lower than 3 cm that promote a root mean square error of 2.08 cm. The correlation coefficient between both datasets is 0.85. As a consequence, satellite data strongly resembles the geostrophic velocity pattern observed by the glider measurements along the Algerian Basin and also by the ADCP data in the coastal zone.

This mission is part of a study focused on mesoscale variability and comparison of the along-track and gridded interpolated maps altimetry products in the western Mediterranean Sea using in-situ data including Argo, ADCP, gliders, drifters, HF radar and tide gauges data. We also take advantage of both the high spatial resolution and the region covered by these datasets to investigate the variability of physical processes in the coastal area. This experiment also contributes to the preparatory cal/val activities of the forthcoming wide-swath satellite altimeter (SWOT) that will provide daily high-resolution sea surface height measurements during the fast phase after launch around the Balearic Islands.

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## A Novel Method for Lakes Water Level Measurement from SAR-SARIN Mode Altimetry – SHAPE Project

*Fabry P.[1], Bercher N.[1], Garcia Mondejar A.[2], Fernandes J.[3], Lázaro C.[3], Gustafsson D.[4], Ambrózio A.[5], Restano M.[6], Benvéniste J.[7]*

*[1]ALONG-TRACK SAS, France; [2]IsardSAT, UK; [3]Univ. Porto, Portugal; [4]SMHI, Sweden; [5]Deimos/ESRIN, Italy; [6]Serco/ESRIN, Italy; [7]ESA/ESRIN, Italy*

This work is part of the SEOM Sentinel-3 Hydrologic Altimetry Processor prototypE (SHAPE) study which aims at boosting the use of "SAR" mode altimetry data in hydrology. Meanwhile real Sentinel-3A data are available, the project focuses onto the use of CryoSat-2 data and try to mimic them as much as possible. While the study deals with both river and lake water height measurements, the work presented here is focused on medium to large size lakes.

One important challenge regarding the use of SAR mode data from CryoSat-2 is to estimate the local geoid from measurements which are spread aver the lake surface due to the space-time coverage of the geodetic orbit of the mission.

A novel methodology for the production of multi-mission water level time series is defined and employed. Various processing steps are impacted among which:

- for each lake crossing (coastline to coastline) water level measurements of consecutive records are combined together in a moving average filter to smooth out the noise component coming, for example, from windstress effects on lake surface. A water mask is used to constrain, in space, the domain of application of the moving average filters ;

- The geodetic orbit of CryoSat-2 is exploited in order to address tracks inter-calibration.

- The water elevation measurements, w.r.t. the ellipsoid model, obtained with this method are locally averaged within a given time interval and geobox to produce a mean lake surface impacted by the local geoid.

- Optionally, the production of time series can be done via what we call the "migration of CryoSat-2 measurements over the lake mean surface" for the period of interest

- The time series are then assessed via a standard validation procedure. In the end, validation results in SAR mode against in situ data are presented for lake Vänern; a medium size lake but the largest one in Europe.

- We then discuss the choices of the space and time windows at several stages of the process. We also discuss the potential of this approach that eases and partially automates the production of lake water heights time series from CryoSat-2. In the end we discuss the integration with LRM and multi-mission time series over lakes.

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## Broadview Radar Altimetry Toolbox

*Escolà R.[1], Garcia-Mondéjar A.[1], Moyano G.[1], Roca M.[1], Terra-Homem M.[2], Friaças A.[2], Martinho F.[2], Schrama E.[3], Naeije M.[3], Ambrozio A.[4], Restano M.[5], Benveniste J.[6]*

*[1]isardSAT Ltd., United Kingdom; [2]DEIMOS Engenharia, Portugal; [3]TU Delft, Faculty of Aerospace Engineering, The Netherlands; [4]Deimos/ ESRIN , Italy; [5]Serco / ESRIN , Italy; [6]ESA / ESRIN, Italy*

The universal altimetry toolbox, BRAT (Broadview Radar Altimetry Toolbox) which can read all previous and current altimetry missions' data, incorporates now the capability to read the upcoming Sentinel-3 L1 and L2 products.
ESA endeavoured to develop and supply this capability to support the users of the future Sentinel-3 SAR Altimetry Mission. BRAT is a collection of tools and tutorial documents designed to facilitate the processing of radar altimetry data.
This project started in 2005 from the joint efforts of ESA (European Space Agency) and CNES (Centre National d'Etudes Spatiales), and it is freely available at http://earth.esa.int/brat. The tools enable users to interact with the most common altimetry data formats. The BratGUI is the front-end for the powerful command line tools that are part of the BRAT suite. BRAT can also be used in conjunction with MATLAB/IDL (via reading routines) or in C/C++/Fortran via a programming API, allowing the user to obtain desired data, bypassing the data-formatting hassle. BRAT can be used simply to visualise data quickly, or to translate the data into other formats such as NetCDF, ASCII text files, KML (Google Earth) and raster images (JPEG, PNG, etc.). Several kinds of computations can be done within BRAT involving combinations of data fields that the user can save for posterior reuse or using the already embedded formulas that include the standard oceanographic altimetry formulas.
The Radar Altimeter Tutorial, that contains a strong introduction to altimetry, shows its applications in different fields such as Oceanography, Cryosphere, Geodesy, Hydrology among others. Included are also "use cases", with step-by-step examples, on how to use the toolbox in the different contexts. The Sentinel-3 SAR Altimetry Toolbox shall benefit from the current BRAT version. While developing the toolbox we will revamp of the Graphical User Interface and provide, among other enhancements, support for reading the upcoming S3 datasets and specific "use-cases" for SAR altimetry in order to train the users and make them aware of the great potential of SAR altimetry for coastal and inland applications. As for any open source framework, contributions from users having developed their own functions are welcome.
The Broadview Radar Altimetry Toolbox is a continuation of the Basic Radar Altimetry Toolbox. While developing the new toolbox we will revamp of the Graphical User Interface and provide, among other enhancements, support for reading the upcoming S3 datasets and specific "use-cases" for SAR altimetry in order to train the users and make them aware of the great potential of SAR altimetry for coastal and inland applications. As for any open source framework, contributions from users having developed their own functions are welcome.
The first Release of the new Radar Altimetry Toolbox was published in September 2015. It incorporates the capability to read S3 products as well as the new CryoSat-2 Baseline C.
The second Release of the Toolbox, in September 2016, will have a new graphical user interface and other visualisation improvements.

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## Evaluating the Performance of Sentinel-3 SRAL SAR Altimetry in the Coastal Zone, and Developing Improved Retrieval Methods. Early Results from the SCOOP Project.

*Cotton P.D.[1], Moreau T.[2], Makhoul-Varona E.[3], Roca M.[3], Cipollini P.[4], Cancet M.[5], Fenoglio-Marc L.[6], Naeije M.[7], Fernandes M.J.[8], Restano M.[9], Ambrózio A.[10], Benveniste J.[11]*
[1]Satellite Oceanographic Consultants Ltd, United Kingdom; [2]CLS, France; [3]isardSAT, Catalonia; [4]National Oceanography Centre, NERC, UK; [5]Noveltis, France; [6]University of Bonn, Germany; [7]Delft University of Technology, The Netherlands; [8]University of Porto, Portugal; [9]SERCO/ESRIN, Italy; [10]DEIMOS/ESRIN, Italy; [11]ESA_ESRIN, Italy

SAR (or Delay Doppler) mode altimetry is expected to be particularly advantageous in the coastal zone, due to the much higher along-track resolution and the better signal to noise ratio provided in this mode, and this has been confirmed in recent years by analysis of CryoSat-2 data.

SCOOP (SAR Altimetry Coastal & Open Ocean Performance) is a project funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme Element, started in September 2015, to characterise the expected performance of Sentinel-3 SRAL SAR mode altimeter products, in the coastal zone and open-ocean, and then to develop and evaluate enhancements to the baseline processing scheme in terms of improvements to ocean measurements. There is also a work package to develop and evaluate an improved Wet Troposphere correction for Sentinel-3.

This presentation will provide an overview of the SCOOP project, and present results of an analysis on the expected performance of the Sentinel-3 SRAL SAR mode products in the coastal zone, before considering possible modifications to the processing scheme that could enhance performance in the coastal zone. These potential enhancements include modifications both in the Delay Doppler Processing stage (L1A to L1B) and in the development and application of new waveform re-trackers (L1B to L2) designed to optimise performance in the coastal zone.

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## X-TRACK Regional Altimeter Products for Coastal Applications: 2016 release

*Léger F.[1], Birol F.[1], Fuller N.[1,2], Niño F.[1], Fleury S.[1]*
*[1]CTOH/LEGOS, France; [2]Meudon Observatory, France*

X-TRACK, has been developed by CTOH (Center of Topography of the Ocean and Hydrosphere) and LEGOS (Laboratoire d'Etudes en Géophysique et Hydrologie Spatiale) in order to optimize the completeness and the accuracy of the sea surface height information derived from satellite altimetry in coastal ocean areas. It is tailored for extending the use of altimetry data to coastal ocean applications and provides freely available along-track Sea Level Anomaly time series that cover today all the coastal oceans.

X-TRACK code was entirely rewritten in 2015/2016 in order to gain consistency and efficiency in the data processing workflow. We also revisited several aspects of the processing, as the altimetry corrections or the data editing strategy which has been significantly improved in order to obtain a better data quality for the points closest to the coast. We present here the new developments made in version 2016 of X-TRACK and the resulting improvement in terms of near-coastal sea level data availability and accuracy. Comparisons with the previous release of X-TRACK, with AVISO data and in-situ measurements are also shown. Discussions on the resulting cross-track surface geostrophic currents are also included.

Once more, the editing strategy will be now completely revised in order to systematically extend X-TRACK products to high-sampling rate SLA data depending on the altimeter mission (10 or 40 Hz). It should further improve the resolution of altimeter sea level observations near the coasts.

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**A New Era of Altimeter Products Towards High-Resolution**

*Dufau C.[1], Dibarboure G.[1], Ablain M.[1], Pujol MI.[1], Ubelmann C.[1], Faugere Y.[1], Picot N.[2], Desjonqueres JD.[2]*
*[1]CLS, France; [2]CNES, France*

The Sea-Level Thematic Assembly Center (SL-TAC) of the European Copernicus Marine Environment Marine Service (formerly known as DUACS/AVISO) currently ingests altimeter L2P products from 4 nadir missions: Jason-2, SARAL, Cryosat-2, HY-2A. The along-track spatial resolution of these missions is limited by the Low Resolution Mode (LRM) altimeter technology, except for SARAL whose performances are really higher. Current algorithms of the SL TAC provide operationally altimeter products with a spatial resolution about 200km and 14 days for the grids (L4) and locally 100km for the along-track products (L3).

In 2016, a new operational mission, Sentinel 3-A, has been launched. It is globally operated in the so-called Synthetic Aperture Radar Mode (SARM, or Delay-Doppler). CNES and ESA have used the regional SARM patches Cryosat-2 to demonstrate the possibility to gain in precision and resolution, typically up to 50km along-track. In parallel, the new operational Copernicus missions (Jason-3 then Jason-CS, Sentinel-3A/B) are going to increase the cross-track and temporal resolution of the altimeter constellation.

Through the development of new mapping techniques, the use of SARM missions and improvement of LRM processing, particularly with the SARAL mission, CNES and CLS work today on the development of a new higher resolution altimeter product (100 km / 7 days) to better serve environmental applications in regional and coastal regions. This paper will present a first status of this ongoing work.

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**Sentinel-3 Surface Topography Mission: Overview and Status of Operations**

*Féménias P.[1], Scharroo R.[2], Nogueira Loddo C.[2], Labroue S.[3], Quartly G.[4], Fernandez Sanchez J.[5], Picot N.[6]*
*[1]ESA ESRIN, Italy; [2]EUMETSAT, Germany; [3]CLS, Toulouse; [4]PML, UK; [5]GMV, Spain; [6]CNES, France*

The Copernicus Programme, being Europe's Earth Observation and Monitoring Programme led by the European Union, aims to provide, on a sustainable basis, reliable and timely services related to environmental and security issues. The Sentinel-3 mission forms part of the Copernicus Space Component. Its main objectives, building on the heritage and experience of the European Space Agency's (ESA) ERS and ENVISAT missions, are to measure sea-surface topography, sea- and land-surface temperature and ocean- and land-surface colour in support of ocean forecasting systems, and for environmental and climate monitoring. The series of Sentinel-3 satellites will ensure global, frequent and near-real time ocean, ice and land monitoring, with the provision of observation data in a routine, long-term (up to 20 years of operations) and continuous fashion, with a consistent quality and a high level of reliability and availability.

The Sentinel-3 mission is jointly operated by ESA and EUMETSAT. ESA is responsible for the operations, maintenance and evolution of the Sentinel-3 ground segment on land related products and EUMETSAT for the marine products. All ground segment facilities supporting the Sentinel-3 operations have been operated over the last months and the science products qualified and assessed by the Mission Performance Framework team.

The Sentinel-3 Mission Performance Framework (MPF) has been established by ESA and EUMETSAT to ensure, over the mission lifetime, the required operability and fitness-for-purpose of the core science products generated by the Payload Data Ground Segment (PDGS) and delivered to the Copernicus Services and the science community.

The Sentinel-3 Mission Performance Framework embraces ESA and EUMETSAT 'in-house' expertise and experts as well as the Mission Performance Centre (MPC) Team, the Sentinel-3 Validation Team (S3VT), the Copernicus POD service and the CNES team.

This paper will provide an update on the status of the ground segment operations for the Sentinel-3 Topography Mission since launch, including results on the S-3 mission PDGS Altimetry products quality, Cal/Val results as well as early plans related to the upgrade of the Instrument Processing Facilities.

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**GOCE User Toolbox and Tutorial**

*Knudsen P.[1], Ambrozio A.[2], Restano M.[3], Benveniste J.[4]*
*[1]Technical University of Denmark, DTU Space; [2]Deimos/ESRIN; [3]SERCO c/o European Space Agency, Italy; [4]ESA-ESRIN*

The GOCE User Toolbox GUT is a compilation of tools for the utilisation and analysis of GOCE Level 2 products. GUT support applications in Geodesy, Oceanography and Solid Earth Physics. The GUT Tutorial provides information and guidance in how to use the toolbox for a variety of applications. GUT consists of a series of advanced computer routines that carry out the required computations. It may be used on Windows PCs, UNIX/Linux Workstations, and Mac. The toolbox is supported by The GUT Algorithm Description and User Guide and The GUT Install Guide. A set of a-priori data and models are made available as well. Without any doubt the development of the GOCE user toolbox have played a major role in paving the way to successful use of the GOCE data for oceanography. The GUT version 2.2 was released in April 2014 and beside some bug-fixes it adds the capability for the computation of Simple Bouguer Anomaly (Solid-Earth). During this fall a new GUT version 3 has been released. GUTv3 was further developed through a collaborative effort where the scientific communities participate aiming on an implementation of remaining functionalities facilitating a wider span of research in the fields of Geodesy, Oceanography and Solid earth studies. Accordingly, the GUT version 3 has:

An attractive and easy to use Graphic User Interface (GUI) for the toolbox, Enhance the toolbox with some further software functionalities such as to facilitate the use of gradients, anisotropic diffusive filtering and computation of Bouguer and isostatic gravity anomalies. An associated GUT VCM tool for analyzing the GOCE variance covariance matrices.

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**A Synergy Approach for the Validation of Coastal Altimetry Data in the Baltic Sea**

*Delpeche-Ellmann N.[1], Pindsoo K.[1], Kudryavtseva N.[1], Soomere T.[1,2]*
*[1]Tallinn University of Technology, Estonia; [2]Estonian Academy of Sciences*

The introduction of SAR altimetry, now allows satellite altimetry data products to be available with a higher spatial resolution and precision that was previously not available in coastal and shelf sea areas. It is expected however that the satellite altimetry data products available will still be affected by some inaccuracies that are most likely due to land contamination and inadequate corrections applied (e.g. instrumental, atmospheric, geophysical) and possibly other sources. Thus validation on the reliability and accuracy of the data is necessary in order to establish certainty and confidence especially in complex sea areas such as the Baltic Sea (surrounded by different land masses and extensive archipelago regions). In this study a case study is performed for the Gulf of Finland (eastern Baltic Sea) whereby a validation of satellite altimetry data is performed for the sea level and currents data products. This validation consists of a statistical analysis that employs the synergy of satellite data (altimetry, ocean colour and surface temperature data) along with available in-situ (water level gauges, current meters and surface current drifters) and various model data. For reasonable error estimates of the combined data set a synergy of all the data is applied for given applications. Whist for high error estimates careful examination using statistical techniques into the possible sources and solutions of usage is illustrated.

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**Inter-Comparison Between Different Along Track Altimeter Products, Numerical Ocean Models and In Situ Measurements: Development of a Dedicated Software.**

*Isabelle Soleilhavoup[1], Florence Birol[1], Fernando Nino[1], Caude Estournel[2], Nicolas Fuller[1], Yannice Faugère[3], Claire Dufau[3]*
*[1]CTOH/LEGOS, OMP, 14 avenue E. Belin, 31400 Toulouse, France; [2]Laboratoire d'Aérologie, 14 avenue E. Belin, 31400 Toulouse, France; [3]CLS, 11 Rue Hermès, 31520 Ramonville-Saint-Agne, France*

Over the last decade, great progress has been made in both coastal altimetry and high resolution ocean modeling. Their use (together or separately) is rapidly evolving. One fundamental issue is then to understand the capabilities of the different coastal altimetry data products and of the different models for coastal applications. In this work, the purpose is the definition of diagnoses which can be computed from coastal alongtrack sea level anomaly products and are adapted to the monitoring of the coastal ocean dynamics. In the framework of the Copernicus program, a new software is under development at the Laboratoire d'Etude en Géophysique et Océanographie Spatiales (France), in collaboration with CLS. The two complementary objectives are:

- the development of new altimetry data validation/intercomparison methods, adapted to the finer scales of the coastal dynamics.

- the analysis of the performance of different high resolution numerical models thanks to alongtrack altimetry measurements.

This tool is based on the inter-comparison between coastal altimetry data sets, model outputs and in-situ measurements. Among these comparisons it is possible to focus on sea level, absolute surface currents or geostrophic surface currents. Different and complementary diagnoses are available. Their combined analysis provides information on the temporal and spatial variability of the coastal ocean dynamics which are captured by altimetry and models, respectively.

In this work, the project will be introduced, some example of diagnoses will be presented and results will be discussed.

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**SAR Altimetry Processing on Demand Service for CryoSat-2 and Sentinel-3 at ESA G-POD**

*Benveniste J.[1], Dinardo S.[2], Sabatino G.[3], Ambrózio A.[4], Restano M.[5]*

*[1]ESA-ESRIN; [2]He Space/EUMETSAT; [3]Progressive Systems/ESRIN; [4]Deimos/ESRIN; [5]SERCO c/o European Space Agency, Italy*

The scope of this poster is to feature the G-POD SARvatore service to users for the exploitation of the CryoSat-2 data, which was designed and developed by the Altimetry Team at ESA-ESRIN EOP-SER (Earth Observation – Exploitation, Research and Development). The G-POD service coined SARvatore (SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation) is a web platform that allows any scientist to process on-line, on-demand and with user-selectable configuration CryoSat-2 SAR/SARIN data, from L1a (FBR) data products up to SAR/SARin Level-2 geophysical data products. The Processor takes advantage of the G-POD (Grid Processing On Demand) distributed computing platform to timely deliver output data products and to interface with ESA-ESRIN FBR data archive (155'000 SAR passes and 41'000 SARin passes). The output data products are generated in standard NetCDF format (using CF Convention), therefore being compatible with the Multi-Mission Radar Altimetry Toolbox and other NetCDF tools. By using the G-POD graphical interface, it is straightforward to select a geographical area of interest within the time-frame related to the Cryosat-2 SAR/SARin FBR data products availability in the service catalogue. The processor prototype is versatile allowing users to customize and to adapt the processing, according to their specific requirements by setting a list of configurable options. After the task submission, users can follow, in real time, the status of the processing. From the web interface, users can choose to generate experimental SAR data products as stack data and RIP (Range Integrated Power) waveforms. The processing service, initially developed to support the development contracts awarded by confronting the deliverables to ESA's, is now made available to the worldwide SAR Altimetry Community for research & development experiments, for on-site demonstrations/training in training courses and workshops, for cross-comparison to third party products (e.g. CLS/CNES CPP or ESA SAR COP data products), and for the preparation of the Sentinel-3 Surface Topography Mission, by producing data and graphics for publications, etc. Initially, the processing was designed and uniquely optimized for open ocean studies. It was based on the SAMOSA model developed for Sentinel-3 Ground Segment using CryoSat data. However, since June 2015, a new retracker (SAMOSA+) is offered within the service as a dedicated retracker for coastal zone, inland water and sea-ice/ice-sheet. In view of the Sentinel-3 launch, a new flavor of the service will be initiated, exclusively dedicated to the processing of Sentinel-3 mission data products. The scope of this new service will be to maximize the exploitation of the upcoming Sentinel-3 Surface Topography Mission's data over all surfaces. The service is open, free of charge for worldwide scientific applications and available at https://gpod.eo.esa.int/services/CRYOSAT_SAR/

More info can be read at:

http://wiki.services.eoportal.org/tiki-index.php page=GPOD+CryoSat2+SARvatore+Software+Prototype +User+Manual

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**Ships-Squat – A Prominent Effect and How It Can Be Calibrated**

*Roggenbuck O., Reinking J.*

*Jade University of Applied Sciences Oldenburg, Germany*

In addition to satellite altimetry and tide gauges, ships can be used to gather sea surface height (SSH) data. Such data can be used for the calibration and validation of satellite altimeters or as an additional data source for empirical ocean models.

GNSS observations of at least three antennas aboard the ships are used for the precise positioning and attitude calculation. The resulting height has to be corrected for different systematic effects. The most prominent effect is the squat which describes the hydrodynamic sinkage of a ship when sailing through water. It depends on the vessels speed through water, the shape of the ships hull and the under keel clearance. In restricted waterways the effect can reach more than 1 meter. If this effect is calibrated, precise in-situ SSH measurements can be realized.

Within a PhD project at the Jade University in Oldenburg the squat of the research vessel WEGA was measured. The experiment took place near the East Frisian Island Langeoog. The SHIPS method (Shore Independent Precise Squat observation) was used. This method uses kinematic GNSS, is independent of facilities at the shore and takes advantage of an escort boat which represents the undisturbed sea surface. This conference poster will explain the experiment in detail and show the results of the calibration.

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**Coastal Sea-Level Variabilities in Downscaled Models Controlled by an Eddy-Resolving Variational Estimation System**

*Kamachi M.[1], Usui N.[2], Nishikawa S.[1], Sakamoto K.[2], Fujii Y.[2]*

*[1]JAMSTEC, Japan; [2]JMA/MRI, Japan*

We have developed an assimilation system toward coastal prediction around Japan. The system consists of a four-dimensional variational (4DVAR) assimilation scheme with an eddy-resolving model in the western North Pacific (MOVE-4DVAR-WNP) and fine-resolution coastal models covering western part of the Japanese coastal region around the Seto Inland Sea (MOVE-Seto) and covering all Japan coastal region (SICAT02). An initialization scheme of Incremental Analysis Update (IAU) is incorporated into MOVE-4DVAR-WNP to filter out high-frequency noises. During the backward integration of the adjoint model, it works as an Incremental Digital Filtering. Coastal models MOVE-Seto and SICAT02 are nested within the eddy-resolving model of MOVE-4DVAR-WNP. Temperature and Salinity fields of the two coastal models are forced by MOVE-4DVAR-WNP analysis fields using the IAU scheme.

The MOVE-4DVAR-WNP improves mesoscale variability compared to the 3DVAR version. In particular, short-term variability such as small-scale Kuroshio fluctuations is much enhanced. Using MOVE-Seto with MOVE-4DVAR-WNP we also performed a case study focused on an unusual tide event that occurred at the south coast of Japan in September 2011. MOVE-Seto succeeds in reproducing a significant sea-level rise associated with this event, indicating the effectiveness of the system for coastal sea-level variability. Newest version of the coastal model SICAT02 will be adopted in experiments of sea level variability such as rapid tide (Kyucho) under climate change in a national project of the adaptation to global warming (SICAT). Preliminary result for the analysis of Kyucho shows a relationship to the Kuroshio variability.

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**Impact of 4D-Var Assimilation of Coastal Altimetry Data in the Sicily Channel Model**

*Olita A.[1], Iermano I.[2], Sorgete R.[1]*

*[1]CNR, Italy; [2]Parthenope University, Naples, Italy*

The present study focuses on the impact of the assimilation of coastal products (Altika), in respect to their oceanic counterpart (Jason), in the reproduction of the circulation of the Sicily Channel (Central Mediterranean) by an assimilative sub-regional model.

The Sicily Channel Model is a regional implementation of ROMS (Regional Ocean Modeling System). The assimilation system is a 4D-Var assimilation (Moore et al. 2011) developed for ROMS. The experimental setup simulated the year 2014. We performed three experiment: NA) control run with no assimilation; AC): assimilation of coarse resolution data ; AH) Assimilation of high resolution data. All the three simulation have in common the same parameterizations and surface and boundary conditions. Surface forcing is provided from ECMWF (ERA-interim) while boundaries are provided by the Mediterranean Forecasting System (MFS) thorugh the Copernicus service.

Outputs of the three setup are intercompared and evaluated vs an independent set of data including CTD and optical/infrared satellite products able to provide the signature of the circulation features we focus on.

One of the main goal is to correctly reproduce the behavior and path of the Atlantic Ionian Stream (AIS) a meandering current flowing eastward south of Sicily towards the Eastern Mediterranean.

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**Intercomparison of Sea Level Variation Across the Tsushima Strait Among Tide Gauge Data, a Coastal Altimetry Product and an Ocean Reanalysis FORA-WNP30.**

*Hirose N.[1], Usui N.[1], Wakamatsu T.[2], Tanaka Y.[2], Toyoda T.[1], Fujii Y.[1], Takatsuki Y.[1], Kuragano T.[1], Kamachi M.[2]*

*[1]Meteorological Research Institute, Japan; [2]Japan Agency for Marine-Earth Science and Technology, Japan*

The Japan Sea is a semi-enclosed marginal sea of the North Pacific Ocean connected to the adjacent seas with shallow and narrow straits. Warm saline water enters the Japan Sea through the Tsushima Strait (TSM) and flows mostly out through the Tsugaru and Soya Straits. The surface circulation of the Japan Sea is largely affected by the variations of heat, salt, and moment through the straits.

Recently, an ocean reanalysis FORA-WNP30 (Four-dimensional variational Ocean ReAnalysis for the Western North Pacific over 30 years) has been produced using a 4-dimensional variational ocean data assimilation system, MOVE-4DVAR (Usui et al., 2015) with an eddy-resolving ocean general circulation model. FORA-WNP30 successfully reproduces not only the major ocean currents such as the Kuroshio and Oyashio but also the associated meso-scale phenomena such as eddies, fronts and meanders. We found that low-frequency variability of volume transport through the TSM is largely in phase with that of the ocean heat content (OHC) in the Japan Sea on interannual to decadal time scales, implying that the variation in volume transport through the TSM is a major cause for the OHC variations in the Japan Sea.

In order to evaluate the reproduction of volume transport through the TSM in FORA-WNP30, we compare the sea levels in FORA-WNP30 with independent data such as tide gauge data and altimetry data around coastal areas. Since sea level difference across the TSM is strongly related to the volume transport through the TSM, tide gauge data are useful for evaluation the volume transport through the TSM.

Sea level variation in FORA-WNP30 is largely consistent with tide gauge data around the Japan coast. In addition, we plan to intercompare the sea levels across the TSM among tide gauge data, a coastal altimetry product and FORA-WNP30.

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**Inter-Annual Variation of the Tsugaru Warm Current Revealed from the Long-Term Coastal Ocean Reanalysis**

*Wakamatsu T.[1], Hirose N.[2], Tanaka Y.[1], Nishikawa S.[1], Usui N.[2], Takatsuki Y.[2], Kuragano T.[2], Kamachi M.[1], Ishikawa Y.[1]*

*[1]Japan Agency for Marine-Earth Scinece and Technology, Japan; [2]Meteorological Research Institute, Japan Meteorological Agency*

The Tsugaru warm current (TWC) is a buoyant outflow from the Tsugaru Strait in northern Japan. TWC carries warm, saline subtropical water which goes through the Sea of Japan as part of the northward Tsushima Warm Current and spreads over cold, less saline subarctic water at the eastern mouth of the Tsugaru Strait. The path of the TWC outflow is known to exhibit bimodal patterns, the coastal mode and the gyre mode (e.g., Conlon 1982, Mizuno 1984). The transition between two modes occurs regularly in seasonal cycle with inter-annual variations. Dynamics behind its typical seasonal transitions between the two outflow modes are relatively well understood and documented in the previous studies. However, its long term inter-annual variation and dynamics are yet poorly known due to a lack of long term observational record that can resolve the coastal circulation scale of order 10km. Since the variation of TWC has a strong connection with a formation of fishing ground of the pelagic fish downstream along the Sanriku coast, to understand and predict the variation of TWC outflow has important value for the local fishery communities.

We have compiled an eddy-resolving, long-term ocean reanalysis data, FORA-WNP30 (Four-dimensional variational Ocean ReAnalysis for the Western North Pacific over 30 years), based on variational ocean data assimilation system, MOVE-4DVAR (Usui et al., 2015) recently and its coastal downscaled product has been started to be produced. In the preliminary studies conducted for the period from 2009 to 2011, the coastal ocean reanalysis data reveals a realistic inter-annual variation of TWC outflow which is inferred from high resolution satellite sea surface temperature data. In this presentation, we will make a report on analysis of long-term inter-annual variation of TWC and its validation against independent coastal observation data from tide gauge, high-frequency radar and coastal altimetry.

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**Multi-Scale Analysis of Coastal Altimetry Data, Multi-Sensor Observations and Numerical Modelling Over the North Western Mediterranean Sea**

*Meloni M.[1], Bouffard J.[2], Doglioli A.[3], Petrenko A.[3]*

*[1]Serco, Italy; [2]Rhea, Belgium c/o ESA/ESRIN; [3]MIO (Mediterranean Institute of Oceanography), France*

The proposed paper addresses the issue of exploiting and cross-comparing coastal altimetry, in situ data and model-based approaches to monitor the positioning and intensity of the Mediterranean Northern Current (NC). The approach is based on the combination of several tracks from different altimetric missions (lasting more than 12 years), in order to reduce the residual noise and detect the NC position. To achieve this goal, several multi sensor platforms (MVP (Moving Vessel Profiler), ADCP (Acoustic Doppler Current Profiler) and CTD) from marine observatories and cruise campaign (OSCAHR: Observing Submesoscale Coupling At High Resolution) as well as a numerical simulation (SYMPHONIE model), have been conjointly used in order to validate and optimize the altimetry processing methods . Across-track geostrophic currents derived from several altimetric datasets (PEACHI (Experimental Products), X-Track, AVISO) have been cross-compared to the SYMPHONIE model in order to statistically characterize the NC position and intensity over the Ligurian Sea and the Gulf of Lion. MVP , CTD and ADCP measurements from the OSCAHR cruise campaign as well as the JULIO (Judicious Location for Intrusion Observation) current meter have also been processed and compared with geo-located altimetric tracks. The obtained results show a good agreement and pave the way for the definition of new science oriented diagnostics particularly relevant for next altimetric satellite missions (Sentinel-3, Sentinel-6).

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**Poleward Currents from Coastal Altimetry: The West Coast of Southern Baja California, Mexico**

*Valle Rodriguez J.B., Trasviña Castro A.*

*CICESE, Mexico*

The west coast of Southern Baja California is subject to intense seasonal variability. Lowest temperatures occur from February to April partly due to the upwelling but also to cold water advection associated to the California Current. From July to October, the advance of a coastal poleward current carries warm water from the south and is responsible for the coastal seasonal temperature maxima. Analysis of twenty years of coastal altimetry data, 20 to 40 km from the coast, reveal a persistent seasonal equatorward/poleward flow during winter/summer months. We use a time series of currents from moored Acoustic Doppler Profiler (ADP) to validate coastal altimetry data from CTOH/X-TRACK (track 169), in order to study seasonal and interannual coastal current variability. During winter the flow is mainly towards the equator. Speeds obtained from altimetry between February-April reach maxima of 0.4 $ms^{-1}$while the ADP recorded maxima around 0.6 $ms^{-1}$. The poleward flow advances against the climatological wind in a narrow coastal band about 100 km wide, occupying the surface to 80 m depth and with speeds between 0.2 and 0.3 $ms^{-1}$ in the coastal altimetry, compared to 0.6 $ms^{-1}$ in the ADP record.

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**Illustration of the High Performance of SARAL Ka-Band Altimeter in Observing the Mesoscale and Coastal Oceanic Features - Example of the Central Mediterranean Sea**

*Jebri F.[1,2,3], Birol F.[3], Zakardjian B.[1], Bouffard J.[4], Sammari C.[2]*

*[1]Université de Toulon, CNRS/INSU, Aix Marseille Université, IRD, Mediterranean Institute of Oceanography (MIO), UM 110, 83957 La Garde, France; [2]Institut National des Sciences et Technologies de la Mer (INSTM), 28 rue 2 Mars 1934, 2035 Carthage Salammbô, Tunisia; [3]Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), OMP, 14 avenue Edouard Belin, 31400 Toulouse, France; [4]RHEA for European Space Agency, Earth Observation Directorate, ESRIN/EOP GMQ, Italy*

In this study, the performance of along track SARAL/AltiKa data with regard to standard altimetry is analyzed for the first time over the Central Mediterranean Sea. Such a key coastal region connects the eastern and the western sub-basins of the Mediterranean Sea and holds a number of significant dynamical processes covering the full spectrum of temporal and spatial scales. The relative performance of SARAL/AltiKa and Jason-2 data is assessed using comparisons with tide gauge measurements, and surface current observations from a ship Acoustic Doppler Current Profiler. The SARAL/AltiKa altimeter-derived geostrophic velocities are also compared to those derived from the research regional altimetric X-TRACK data set (already validated and analyzed in details by Jebri et al., 2016 over the study area). Results indicate the good potential of Ka-band satellite altimetry to capture higher resolution oceanic features. The analysis is further extended to the study of mesoscale processes associated to the surface circulation observed between April 2013 and September 2015. The evolution of the surface oceanic features is also analyzed by using remotely sensed sea surface temperature observations. The synergy of these combined data sets (i.e. SARAL/AltiKa, X-TRACK and sea surface temperature) allows a relatively good spatial coverage and clearly reveals mesoscale features never observed before with standard altimetry solely (in addition to the known Atlantic Tunisian Current, the Atlantic Ionian Stream, the Atlantic Libyan Current, and the Sidra Gyre).

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**Utilizing SAR Imagery, Ocean Color, SST, and Radar Altimetry to Study Upwelling and Ocean Circulation in the Coastal Arabian Sea**

*Qazi W.A., Javad A., Abbas A.*

*Geospatial Research and Education Lab, Institute of Space Technology, Pakistan*

The surface circulation of the Arabian Sea (AS) is primarily driven by ocean surface winds, which follow the Monsoon seasonal pattern. During the summer months, winds blow northward towards Pakistan, carrying moisture from the Arabian Sea, and also cause significant upwelling along the Oman and Eastern Arab coast. There are not many regular in-situ observations performed in the AS, and no long-term archive of in-situ observations of physical oceanography parameters exists. Present methods of observing coastal upwelling in the AS with SST and OC have limitations due to cloud coverage and dust storms. Microwave sensors offer the advantage of day-night coverage in nearly all weather conditions at high resolution; SAR imaging sensors can offer the resolution of a few meters, while the upcoming delay-Doppler / SAR altimeter missions can provide resolutions on the scale of 100 meters.

The interation of microwaves with the ocean surface at moderate incident angles results in Bragg scattering from short-scale waves, modulated by long-scale waves. Monomolecular biogenic slicks, byproducts of photosynthesis (enhanced due to upwelling), show low-backscatter in SAR intensity images due to Bragg wave damping. The same slicks can be observed in altimeter backscatter data too, however their wave damping causes the normal-incident altimeter backscatter brighter. Exploration of coastal upwelling using altimetry has been problematic because of the problems of coastal altimetry, along with lower resolution. The upcoming higher resolution delay-Doppler / SAR altimeters can open new vistas to explore coastal upwelling. We will present our current research results on detecting coastal upwelling and biogenic slicks in the coastal AS during summer monsoon months using L-band ALOS PALSAR SAR intensity imagery, and will discuss how SAR altimetery can be useful in this work also.

In the Arabian Sea, the significant variability of ocean surface currents has largely been missing in trying to understand the physical oceanography here. One established method for ocean surface currents generation from sequential SST and OC imagery is the Maximum Cross Correlation (MCC) method *(Crocker et al., 2007)* and the application of this method over the AS can generate a long-term record of ocean currents. *Qazi et al. (2014)* have also shown that advection of biogenic slicks can be tracked in sequential SAR imagery to determine ocean surface currents. This can be supported by deriving geostrophic current fields from radar altimetry and ocean surface winds from satellite scatterometry. Work to derive ocean surface current fields in the AS has just been started by our research group, and we will discuss the implications; we also expect to learn more about

eddies in this region by deriving surface circulation *(Qazi et al., 2014)*.

*Crocker, R. I., Matthews, D. K., Emery, W. J., & Baldwin, D. G. (2007). Computing Coastal Ocean Surface Currents From Infrared and Ocean Color Satellite Imagery. IEEE Trans. Geosc. & Rem. Sens., 45(2), 435–447. Qazi, W. A., Emery, W. J., & Fox-Kemper, B. (2014). Computing Ocean Surface Currents Over the Coastal California Current System Using 30-Min-Lag Sequential SAR Images. IEEE Trans. Geosc. & Rem. Sens., 52(12), 7559–7580.*

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**Use of Coastal Altimetry Data in Submesoscale Process Studies**

*Yoo J.G., Kim S.Y.*

*Korea Advanced Institute of Science and Technology (KAIST), Korea, Republic of (South Korea)*

This work evaluates feasibility and capability of the use of coastal altimetry data in submesoscale process (hourly and km-scale) studies with comparisons among independent mesoscale and submesoscale observations including sea surface heights (SSHs, or sea surface elevations) obtained from coastal altimetry, tide gauges, and coastal radar-derived surface currents, and passive tracer maps obtained from geostationary ocean color imagery. The coastal surface currents are decomposed into current components associated with stream functions and velocity potentials, and their stream functions are comparable with mesoscale SSHs and contain finer scale features, i.e., submesoscale fronts and eddies, which are supported by Chlorophyll maps having hourly and 500-m resolution. Some of coastal altimeter data exhibit consistent mesoscale and submesoscale features and have a reasonable agreement with passive tracer maps as well.

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**Evaluation of Operational Altimeter-Derived Ocean Currents for Shelf Sea Applications - a Case Study in the NW Atlantic**

*Vandemark D.[1], Feng H.[1], Wilkin J.[2]*

*[1]University of New Hampshire, United States of America; [2]Rutgers University*

It is now possible to examine long-term coastal ocean circulation dynamics as measured using in situ and space-based platforms by using a decade plus of data collected along the shelf of the NW Atlantic. Here we seek to evaluate the strengths and weaknesses of direct application of gridded altimeter-based ocean surface current products (OSCAR and GlobCurrent) in coastal process studies even though these products are expressly developed with open-ocean assumptions and applications in mind. In situ data come from platforms within the US Integrated Ocean Observing System (IOOS) and include upper ocean currents and hydrography. Several recent studies of the region suggest strong connections between variable geostrophic currents and water mass advection along the shelf and shelf-slope fronts. This investigation will intercompare currents derived from along-track altimeter data with those from OSCAR and GlobCurrent in their application to several regional process evaluations including mean and time-variable circulation in the Scotian-Gulf of Maine system, cross-correlation analysis with subsurface hydrography and currents, and cross-shelf gradients in derived currents.

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**Seasonal Circulation in the Northern Bay of Bengal with Special Reference to Shelf-Slope Region**

*Ishaque M.*

*University of Dhaka, Bangladesh, People's Republic of*

The Bay of Bengal is very dynamic. One of the reasons is the huge quantities of fresh water and sediment that Bay receives annually from its adjoining river systems. Also the coastal as well as open Bay bathymetry is different and complex. The seasonal monsoonal rains and the seasonal cyclones are important attributes of this region which adds to the complexities of the regional oceanography. Though there are a large body of research work on the basin-wide hydrographic characteristics in the Bay of Bengal, especially on the seasonal time-scale, the several aspects of circulation is largely unexplored. The most explored circulation in the Bay of Bengal is the East India Coastal Current (EICC). In this study, to determine the current pattern, altimetry data of 1999-2014 have been used. The data has been analysed using a variety of tools including band-pass filtering, chi-square test, mean, standard deviation and linear trend analysis. In addition, to infer the circulation pattern geostrophic current and Ekman currents were computed. Also, sea surface temperature and salinity were examined in conjuncture with current pattern. The domain-averaged monthly mean sea surface height anomaly (SSHA) for the study period showed large inter-annual variability. The monthly mean climatology showed a distinct seasonality. However, the shelf-slope circulation in the northern Bay of Bengal remains largely unknown. It is in this context that the present study investigates the seasonal cycle of circulation with special focus on shelf-slope region in the northern Bay of Bengal.

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**The Norwegian Coastal Current Observed by CryoSat-2 SARIn Altimetry**

*Idžanović M.[1], Ophaug V.[1], Andersen O.B.[2]*

*[1]Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, Ås, Norway; [2]DTU Space, Technical University of Denmark, Kgs. Lyngby, Denmark*

The Norwegian Coastal Current (NCC) transports warm and relatively fresh water along the Norwegian coast and into the Barents Sea, with its origin in Baltic water entering Skagerrak. Along its way northward it is fed by additional freshwater discharge. The NCC is important for the regional marine ecosystem and contributes to the poleward transport of warm Atlantic Water, maintaining the relatively mild climate in northwest Europe.

Although satellite altimetry is a mature technique, globally observing the sea surface height with an accuracy of a few centimeters, numerous effects degrade the observations in the coastal zone. For example, the radar footprint is contaminated by land and bright targets, and the range and geophysical corrections become difficult to model. The rugged Norwegian coast presents a further challenge, and the NCC, at times only a few tens of kilometers wide, typically falls into a zone where conventional altimeters do not deliver reliable observations.

The European Space Agency's CryoSat-2 (CS2) satellite is the first to carry a SAR altimeter instead of the conventional pulse-limited system, resulting in higher range precision and along-track resolution. This allows for tracking finer structures of the sea surface and get closer to the coast. We use CS2 low resolution and SARIn observations, for the period 2012-2015, along the Norwegian coast and determine a mean dynamic topography (CS2MDT) that is validated using tide gauges. In turn, geostrophic surface currents are derived from both the CS2MDT and the operational coastal numerical ocean model of MET Norway and compared. For the first time, the NCC is revealed by space-geodetic techniques, giving confidence in the new-generation SAR altimeters for coastal sea-level recovery.

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### The Value of SAR-in Altimetry for Gravity Prediction in Coastal Regions

*Andersen O.B., Abulaitijang A.*
*DTU Space, Denmark*

Cryosat-2 offers the first ever possibility to perform coastal altimetric studies using SAR-Interferometry as well as SAR altimetry. With this technological leap forward Cryosat-2 is now able to observe sea level in very small water bodies and also to provide coastal sea level very close to the shore.

We perform an investigation into the retrieval of marine gravity in several of the fjords in eastern Greenland. Among the fjords are the Scoresbysund Fjord which is the largest and deepest fjord in the World. In the marginal zone of Greenland the SAR-in is mainly used because of the huge topographic changes as Cryosat-2 is designed to map the margins of the ice-sheet.

For retrieval of marine gravity and also mean sea surfaces, the main important parameter is the spatial density of the sea level data. With only a few points in the fjords from Envisat, the new retracked Cryosat-2 SARin data offers a huge step forward in terms of data quality and data availability. We employ data from the first 5 years (summers) of Cryosat-2 to quantify the improvement that be achieved.

By comparing the data with and without the off-nadir correction we can furthermore study the improvement that can be expected from the SAR-in w.r.t. SAR data from gravity field retrieval in complex coastal regions.

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### Sea Level Trends, Variability and Processes Around the Australian coast

*Royston S.[1], Watson C.[1], King M.[1], Legresy B.[2]*
*[1]University of Tasmania, Australia; [2]CSIRO, Hobart, Australia*

There have been a number of recent improvements in coastal altimetry that offer the potential for improved understanding of coastal oceanographic processes, and their dynamic link between the coastal and open ocean. These processes affect our inference of sea level variability and trends as observed at coastal tide gauges and with offshore satellite altimetry.

Here, we investigate sea level trends and variability around the Australian coast using standard release TOPEX, Jason-1 and OSTM/Jason-2 data. We implement a novel multivariate noise analysis to assess the contribution of climate-mode variability to the data observed in the open ocean, as well as at coastal tide gauge sites. In an attempt to assess the nature of differences observed in a coastally retracked altimeter dataset, we use the Adaptive Leading-Edge Sub-waveform retracker (ALES) dataset spanning the OSTM/Jason-2 mission, together with the improved GPD+ wet tropospheric correction. We apply a variant of the noise analysis technique applied to the open ocean data to quantify differences in trend and variability between the tide gauge and coastal altimeter data points at various distances from the coast. Processes affecting these differences are discussed.

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### Coastal Sea Level from CryoSat-2 SARIn Altimetry in Norway

*Idžanović M.[1], Ophaug V.[1], Andersen O.B.[2]*
*[1]Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, Ås, Norway; [2]DTU Space, Technical University of Denmark, Kgs. Lyngby, Denmark*

Conventional altimeters determine the sea surface height (SSH) with an accuracy of a few centimeters over the open ocean. However, in coastal areas the noise is seriously increased from numerous effects, which degrade the quality. The Norwegian coast adds further complications to the use of satellite altimetry, due to its very complicated coastlines with many islands, mountains, and deep, narrow fjords. The European Space Agency (ESA) CryoSat-2 (CS2) satellite carries a synthetic aperture interferometric radar altimeter (SIRAL) which is able to observe sea level closer to the coast than conventional altimeters, without degradation. In this work, we investigate the potential of CS2 data to provide improved observations in the Norwegian coastal zone.

Initially we evaluate the performance of SAR altimetry by comparing CS2 SARIn observations with 22 tide gauges, and evaluate the two major geophysical corrections applied to CS2 data for the determination of the SSH. We demonstrate that we can significantly improve the comparison with tide-gauge observations if we substitute the standard CS2 geophysical correction for the ocean tide and dynamic atmosphere corrections with local corrections.

Secondly, we compare CS2 with conventional altimetry at the Stavanger tide-gauge, revealing an improvement of ~2-3 cm.

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**Monitoring Storm Surges using Satellite Altimetry**

*Han G.*

*Fisheries and Oceans Canada, Canada*

Storm surges are the main factor that causes coastal flooding, resulting in catastrophic damage to properties and loss of life in coastal communities. Thus it is important to enhance our capabilities of observing and forecasting storm surges for mitigating damage and loss. In this talk we provide examples of storm surges observed by nadir satellite altimetry, during Hurricane Sandy, Igor, and other cyclone events. The satellite results are evaluated against tide-gauge data. The storm surges are discussed for dynamic mechanisms. We also discuss the potential of a wide-swath altimetry mission to be launched in 2021, the Surface Water and Ocean Topography (SWOT), for observing storm surges.

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**The Importance of Sentinel-3 for Extending the Arctic Sea Level Record**

*Andersen O.B., Rose S.K., Ludwigsen C., Stenseng L.*

*DTU Space, Denmark*

Seasonal ice cover in the Arctic Ocean causes severe limitations on the use of altimetry and tide gauge data for sea level studies. In order to overcome this issue we reprocessed conventionel altimetry data with editing tailored to Arctic conditions, hereby more than doubling the amount of altimetry in the Arctic Ocean recovering up to 10 times the amount of data in regions like the Beaufort Gyre region compared with conventional datasets. With recent data from the Cryosat-2 SAR altimetry the time-series now runs from 1991-2015 a total of nearly 25 years.

We here present a new multi-decade altimetric dataset looking at the importance of the recent released Sentinel-3 datasets for extending this. Sentinel-3 SAR altimetry is particularly important in order to study in and out flow of the Arctic Freshwater in the future but also for continuing the sea level monitoring and studies of long term changes.

Out sea level record exhibit a mean sea level trend of 2.1±1.3 mm/year (without Glacial Isostatic Adjustment correction) since 1991 covering the Arctic Ocean between 66°N and 82°N with significant higher trend in the Beaufort Gyre region showing an increase in sea level up to 2011.

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**Mass Redistribution from Satellite Altimetry**

*Bao L.*

*Institute of geodesy and geophysics, Chinese Academy of Sciences, China, People's Republic of*

The gravity field changes in the oceans can be derived from the mass redistribution, which is the major driving forces of geodetic variations. Much works on combining GRACE, satellite altimetry and steric changes from oceanographic observations, have present large-scale mass redistribution in the oceans. Due to the limitation of the GRACE filter and steric model, less works on small-scale mass redistribution, which is key and important to explain some regional geophysic phenomena. In this study, we only focus on the gravity change from satellite altimeters, and those small-scale mass redistribution. Analysis on the errors of the marine gravity anomaly changes havs been discussed, also its potential impact on the final explain has been estimated. Further research on the derived gravity anomaly change and the progress of Chinese satellite altimetry for improving data resolution are introduced.

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**Assessment of a Coastal Altimetry Data Product in the Indonesian Coastal Waters**

*Lumban-Gaol J.[1], Vignudelli S.[2], Leben R.R.[3], Osawa T.[4], Pasaribu B.P.[1], Mansawan A.[1], Manuputty A.[1]*

*[1]Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Indonesia; [2]Consiglio Nazionale delle Ricerche, Istituto di Biofisica, Area Ricerca CNR San Cataldo, 56127 Pisa, Italy; [3]Colorado Center for Astrodynamics Research, Colorado University, Boulder, CO 80309-0431, USA; [4]Center for Remote Sensing and Ocean Sciences, Udayana University, Bali, Indonesia*

Indonesia is the largest archipelagic nation in the world, as around 70 percent of its total territory is water, and it has 17,480 islands. Its coastline is some 92 thousand kilometers long, making it the second longest after Canada. Therefore, coastal monitoring of sea level variability at all spatial and temporal scales is very important around Indonesian coastal waters. Satellite altimeter data and related applications for coastal studies are still developing in Indonesia. In this study we assess a satellite altimeter data product available from the Centre of Topography of the Oceans and the Hydrosphere (CTOH). The focus in on along track Envisat data collected over the Indonesian coastal region during 2002 to 2010. We compute the root mean square (RMS) of the Sea Level Anomaly (SLA) and percentage of valid CTOH Envisat data for 184 tracks over the Indonesian coastal waters. The average percentage of valid data on the first footprint from the coastline in shallow water such as the Java Sea (50%) is lower than the coastal deep sea (90%) such as eastern Indian Ocean. The RMS of data near the coast is higher than open seas. The SLA variability on annual time scales clearly shows that the SLA is negative during July to September and is positive during December to February in the coastal region. The highest amplitude of SLA occurred during Indian Ocean Dipole (IOD) positive phase in 2006. The fluctuation of SLA shows that the seasonal and interannual variability is affected by monsoons and global climate such as IOD. Sea level trends along track during the Envisat record shows that the Indonesian coastal waters region has experienced rising sea levels at rates more than the global mean. Trends in the region over this time period are positive and approach values greater than 5 mm $yr^{-1}$ in some tracks.

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## Assimilation of Blended Altimetry and Tide Gauge Observations in a North Sea – Baltic Sea Hydrodynamic Model for Storm Surge Forecasting

*Madsen K.S.[1], Høyer J.L.[1], Fu W.[2], Donlon C.[3]*
*[1]Danish Meteorological Institute, Denmark; [2]Department of Earth System Science, University of California, Irvine, USA; [3]European Space Agency/ESTEC, Noordwijk, Netherlands*

One of the main challenges of assimilation of coastal altimetry is that the data frequency does not match the short time scales of the coastal ocean. We have addressed this issue by combining altimetry and tide gauge observations in a statistical model of sea level. The statistical model provides hourly sea level in each point along charted altimetry tracks and is routinely interpolated to a 2D field of near real time sea level, independent of numerical weather prediction models and hydrodynamical models. In this study we investigate the benefit of assimilating the statistical model into our hydrodynamical storm surge modelling system, allowing frequent adjustments of modelled sea level inaccuracies. Results show improved overall performance of the model, especially in the semi-enclosed Baltic Sea, giving improved preconditioning for forecasting of storm surges. RMS improvements range from 6% to 34%. Combined with near-real-time verification of sea level forecasts during storm surge situations, this has the potential for improving storm surge warnings, saving life and property.

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## Coastal Altimetry in Support of NASA's Oceans Melting Greenland (OMG) Project

*Larson J.[1], Masters D.[1], Willis J.[2], Nerem R.S.[1]*
*[1]University of Colorado, United States of America; [2]JPL/NASA, United States of America*

Recent increases in ice discharge from marine-terminating glaciers on Greenland’s margins appear to have coincided with a warming of the oceans in these same regions. This discovery has led to the understanding that ocean heat content is playing a major role in the mass balance of Greenland’s marine-terminating glaciers and their subsequent contribution to global sea level rise. The spatial and temporal variability of the warmer water reaching Greenland’s marine-terminating glaciers and fjords is highly uncertain due to limited in situ and remote sensing measurements. Accurate coastal altimetry measurements could allow for the determination of ocean heat content changes both on Greenland’s continental shelf and in fjords. Using altimetry in coastal Greenland, however, presents numerous challenges due to floating ice, wind forced sea surface height changes, poorly resolved tide models, and a lack of tide gauges for measurement validation. Increased interest in Greenland’s coastal processes from the scientific community though makes it important to try and recover potentially valuable signals from the available altimetry. Here we present a case study from a fjord leading to one of Greenland’s rapidly retreating tidewater glaciers. Using data from Cryosat-2 and SARAL/AltiKa, we attempt characterize measurement and correction uncertainties to better understand whether an ocean forced signal can be recovered. This signal is compared to limited in situ temperature profiles taken by NASA’s Oceans Melting Greenland mission. This case study is meant to serve as a ‘proof of concept’ and investigate whether costal altimetry should be further explored as a means to characterize ocean forcing at Greenland’s marine terminating glaciers.

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