→ 5th COASTAL ALTIMETRY WORKSHOP

ABSTRACT BOOK

16-18 October 2011 | San Diego, U.S.A.

Abstract Book

Last Updated on: 27 September 2011

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Opening Session

Keynote Talk: Improvement in Global Marine Gravity from CryoSat

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Marine gravity anomalies derived from radar altimeter measurements of ocean surface slope are the primary data for investigating global tectonics and seafloor bathymetry. The accuracy of the global marine gravity field is limited by the availability of non-repeat altimeter data. Current models, having accuracies of 3-5 milligals (e.g., S&S V18 and DNSC08), are based on the non-repeat data collected by Geosat (18 mo.) and ERS-1 (12 mo.) which use altimeter technology from the 70's and 80's, respectively. Over the next 3 to 5 years, a wealth of new marine gravity data will be provided by three currently operating satellite altimeters CryoSat, Jason-1, and Envisat. With careful processing of the data, in combination with data from past Geosat and ERS-1/GM altimeter missions, we expect to improve the accuracy of the global marine gravity field by at least a factor of two and in some areas a factor of four. In addition to track coverage, the accuracy of the recovered gravity field depends on the accuracy of the arrival time parameter. We have developed an optimized retracking algorithm for CryoSat in the LRM mode and show that the arrival time estimated from CryoSat is 1.4 times better than Geosat and ERS-1. This is consistent with a 2 times higher pulse repetition frequency for CryoSat. We are currently developing a retracking algorithm for CryoSat in the SAR mode and expect a factor of 2 or more improvement in the accuracy of the arrival time. CryoSat has been collecting ocean data for 1.5 years and the ground track density is now adequate to make significant improvements in the marine gravity field. We will construct an improved global gravity model based on these data and provide an evaluation at the Workshop.

Session 1:
Error Budget, Key Areas of Improvement and Draft Recommendations

Coastal Altimetry: Progress over Three Years – Revised Findings and Recommendations

P. Ted Strub[1] and 5th Coastal Altimetry Workshop Organizers
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At the conclusion of the first Coastal Altimetry Workshop (CAW-1) in February 2008, the participants wrote a list of recommendations and findings regarding the state of the art understanding of the nature of errors and correction terms needed to retrieve accurate values of SSH in coastal regions (http://www.agu.org/journals/eo/eo0840/2008EO400008.pdf, http://www.agu.org/pubs/eos-news/supplements/2008/smith_89_40.shtml).

During the CAW-5, it is appropriate to review the progress made over the past three years and update the original findings and recommendations. To this end, we will present a summary of the CAW-1 (and later CAW) findings during the first session of the workshop, in order to motivate discussions during the remainder of the workshop. During the last session of the workshop, we will review and revise these findings, based on results presented during CAW-5.

A Review of retracking Solutions for Coastal Altimeter Waveforms

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Over ocean surface, the altimetric echo has a well-defined shape, with a steeply rising leading edge followed by a gradual decline in power over the rest of the waveform. When the altimeter approaches the coast, this shape can be corrupted by land returns or by the summation of backscattered signals coming from inhomogeneous reflective surfaces. In recent years, several studies have been devoted to improve retracking algorithms efficient for those particular waveforms in order to move the altimetric measurements ever closer to shore.

In the frame of various CNES studies, coastal waveforms have been processed with dedicated retracking algorithms. I propose in this talk to review these different methods, pointing out their usefulness, applicability, qualities and drawbacks

Some retracking algorithms proposed in the CNES/Pistach products have been improved (retracking using a small part of the waveform, retracking using filtered waveforms, ...). Other retracking algorithms have been developed like those using external informations and those assuming that waveforms are the sum of a Brown echo and Gaussian peaks. An initial version of the algorithm assumed symmetric peaks. A updated version assumes altimetric signals corrupted by asymmetric peaks such as the ones observed at the end of the leading edge. I propose to present some results obtained with retracking handling asymmetric peaks. After defining the proposed model, I will show that the altimetric parameters can be estimated using a classical maximum likelihood method.

High Resolution Observations of Coastal Wet Path Delay Variability from the JPL High Altitude MMIC Sounding Radiometer

Brown, Shannon

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High resolution observations of wet path delay across several coastlines were acquired from the airborne JPL High Altitude MMIC Sounding Radiometer (HAMSR) during two recent deployments. HAMSR is a cross-track scanning passive microwave radiometer with 25 channels operating in three bands; 50 GHz, 118 GHz and 183 GHz. The instrument is similar to the Advanced Microwave Sounding Unit (AMSU), but has been recently upgraded using state-of-the-art receiver technology to enable observations of small-scale water vapor variability. Wet path delay is retrieved from the instrument using an algorithm that operates with the window channels in each band.

In August through September 2010, HAMSR participated in the NASA Genesis and Rapid Intensification field campaign to study tropical cyclones and in February through March 2011, HAMR participated in the NOAA Winter Storms and Pacific Atmospheric Rivers experiment. HAMSR flew on the NASA Global Hawk (GH) UAV during both of these campaigns. From the GH cruising altitude of 19km, HAMSR has a 1.5km spatial resolution and a 60km swath. These flights featured excellent observations of wet path delay in several coastal regions, ranging from the south coast of Alaska in winter to the Gulf of Mexico coast in the summer. An analysis of these coastal wet path delay measurements will be presented. The presentation will focus on the scales of wet path delay in the coastal zone derived from the HAMSR measurements compared to those in the open ocean. The radiometer derived wet PD variability will also be compared to the variability derived from a high-resolution WRF model off the coast of California. Finally, the data will be used to assess the errors that could be encountered using simple coastal path delay correction approaches that have been suggested in the literature, such as extrapolating clean open ocean data to the coast line.

Nested high-Resolution Data Assimilation Modeling of Ocean Tides in Coastal and Shallow Seas

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We describe efforts over the past few years at Oregon State University to improve tidal models in coastal and shallow seas areas of complex bottom topography. We use a nested data assimilation approach, implemented with the OSU tidal assimilation software (OTIS). First, basin-scale solutions (for the Atlantic, Pacific, Indian, Arctic and Southern Oceans were constructed by assimilation of all available altimetry data into a 1/12° shallow water equations (SWE) model, with boundary conditions taken from a fully global 1/4° inverse solution (TPXO7). Higher resolution regional solutions (1/30° or 1/60°) were then computed for selected areas, using the basin scale models for open boundary conditions. Even higher resolution solutions (e.g., 0.5 km or less) for selected individual coastal areas or bays have also been computed. Comparison to (un-assimilated) validation tide gauges (TGs) shows that inverse tidal solutions computed using accurate high resolution bathymetry results in substantial improvements in modeled tidal elevations, even though the density of altimetry ground tracks in the local domain is insufficient to directly map tidal elevations. We have now computed regional scale solutions for most shallow water areas

around the globe, and developed methods for patching these high resolution regional solutions into the basin-scale and global inverse solutions. These so-called "atlas" solutions are constructed at the coarse resolution of the larger-scale solution. Fine scale details of the regional solutions are lost through this smoothing, but the improved accuracy of larger scale features resulting from the high-resolution data assimilation is retained. To construct the atlas solutions the higher resolution local solution is smoothed onto the ocean grid used for the coarse resolution solution. Two approaches have been tried for combining the two models on the coarse grid. In the first approach, the smoothed local model elevations and volume transports are used for grid cells with depths below a fixed value H0 (usually 2000 m), with the values from the larger scale model retained for greater depths. The boundary is then smoothed slightly. In a variant on this scheme, we create a mask that is 1 for cells shallower than H0 and 0 otherwise. This is smoothed, resulting in a weight function w(x,y) that tapers smoothly to zero near the H0-isobath. The function w(x,y) is then used to form a weighted linear combination of the two solutions. This algorithm has been applied to compile new regional 1/12° Atlantic (AO-atlas), Pacific (PO-atlas), and Indian Ocean (IO-atlas) solutions as well as a new 1/4° global (TPXO7-atlas) solution. The atlas solutions dramatically improve fits to validation shallow water and coastal TGs. Much, but not all, of the improvement is retained even in the coarser global TPXO7-atlas solution. For example, on the East coast of North America, RMS misfit for a set of 9 TGs is reduced from 75.6 cm in the regional AO solution to 11.3 cm in the AO-atlas solution and 13.6 cm in the TPXO7-atlas solution. For Hudson Bay RMS misfits for 12 TGs for the three solutions are 56.8, 15.0, 21.1 cm.

Recommendations for the Future of Coastal Altimetry from COASTALT

Cipollini P[1] and the COASTALT Team

[1]National Oceanography Centre, UK

One of the most important outputs from the ESA-funded COASTALT project on development of radar altimetry in the oceanic coastal zone is a set of recommendations for the future of coastal altimetry. These will be presented one by one in this talk, with the aim of stimulating further discussion: 1. Further work is needed on the waveform retrackers, both theoretical and in terms of optimization and inter-calibration. "Theoretical" means improvement of the existing models (eg, by including the effect of white caps) or the development of new models (eg scattering from non-linear surfaces). "Optimization and intercalibration" include not only runtime optimization, but, most importantly, an assessment of biases and other differences amongst different retrackers, and the development of criteria for retracker selection. We believe that an international exercise for the intercalibration of the various retrackers would be extremely beneficial.

2. Innovative retrackers (which use information in adjacent waveforms) need further R&D to move from concepts to simulations and eventually confrontation with real data. This is a very promising field, already identified in COASTALT, and despite some difficulties in the implementation of some of the ideas put forward (Bayes Linear Retracker, 2-D retracker) it should be developed further, with the hope of achieving a full validation of these innovative techniques. 3. Coastal altimetry processors must be open, flexible, expandable, easily upgradable and fully documented, to facilitate the work of developers, testers, and the uptake of the data by 'expert users'.

4. The issue of filtering of the various corrections needs to be revisited. Correlation scales must be clearly identified and data screening and filtering schemes clearly recommended (these may depend on the application, to some extent). A good example is the work carried out in COASTALT regarding the correlation scales for the tropospheric corrections. Other corrections needing a better assessment of the optimal filtering scheme include the ionospheric correction and the Sea State Bias (SSB). A related issue is to establish which corrections, if any, need to be computed at full rate (18Hz) and which ones can be simply interpolated from lower rate data.
5. The SSB correction should be reassessed in the coastal zone, with investigation of dedicated models. This is a recommendation already agreed at previous Coastal Altimetry Workshops, and it continues to be perceived as scientifically challenging, but conducive to potentially very useful results.
6. Validation is crucial and should be supported further, by developing consistent validation protocols and assessments that can be applied to a number of locations with varying geographical and oceanographic conditions.
7. The techniques developed in COASTALT and similar projects, and the relevant processors, should be extended to ensure multi-mission and multi-domain capability. In particular they should be extended to the new and forthcoming Delay-Doppler altimetry missions (Cryosat-2, SRAL on Sentinel-3) and to AltiKa, all of which have intrinsically better capabilities in the coastal zone. In extending the techniques, coastal altimetry community need to work closely with the ice and inland water communities.
8. Coastal Altimetry applications should be supported and encouraged, with easy data access, outreach and training activities, and demonstration studies. The eSurge project (subject of a separate contribution to this Workshop) is a clear example of the transition to applications, but several other possible applications are listed and described in the OceanObs'09 Community White Paper on Coastal Altimetry, and more are emerging.

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Session 2: Application Highlights

Altimetry on the West Florida Shelf

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The usefulness of several coastal altimetry products, CTOH/X-TRACK, regional and global AVISO, and PISTACH, is explored over a wide continental shelf in the eastern Gulf of Mexico. Altimetry data quality is shown by the availability of the along-track sea level anomaly (SLA) data near the coast and by the average along-track power spectrum of the SLA, an indication of mesoscale variability. The altimetry-derived velocities are further compared with multiple-year ocean current observations by moored Acoustic Doppler Current Profilers (ADCP) at several sites and by High-Frequency (HF) radars on the West Florida Shelf. Quantitative statistics are reported on the differences between the estimated surface geostrophic velocities (with and without wind effect) and the observed subtidal currents. Potential applications of the coastal altimetry in the description of the currents on the West Florida Shelf are demonstrated. Challenges of such applications are also discussed.

Assess the Quality of Satellite Altimetry Data in the Arctic Ocean

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Continuous monitoring of sea level variability from satellite altimetry can be considered as one of the most fundamental steps for a better understanding of oceanic processes in the deep ocean. For sun-synchronous satellites (e.g., ERS-2 and Envisat), the complexity of environments, such as extension of ice, corrupts altimetry measurements and limits their use in the Arctic Ocean (65°N-90°N). In previously SSALTO/DUACS altimeter data set, the sea level mapping progress dismissed in the Arctic Ocean due to lack of confidence in mean sea level profiles. In 2010, its reprocessed data set (V3.0.0) was released, especially, sea level map coverage extended at high latitudes using the newer global mean sea level profiles, which referenced over the period 1993-1999 and integrate a precious information from the most recent altimeter missions and datasets.

The Sea Level Thematic Assembly Center (SL TAC) in the EU-FP7 (seventh framework program) MyOcean project aims to construct sea level service at a European level for Global Monitoring for Environment and Security (GMES) marine applications. In 2011, the sea level data over the Arctic Ocean was reprocessed under the grant of project MyOcean. Compared with the time delayed ‘Upd’ sea level products in V3.0.0 data set, the mapping of sea level was extended around the Queen Elizabeth Islands and over the Laptev Sea. Moreover, the resolution of sea level products improved from 0.25*0.25 degree to 0.125*0.125 degree in latitude by longitude.

This study assess the quality and performance of the newly processed weekly sea level products from TAC as well as SSALTO/DUACS time delayed 'Upd' sea level products V3.0.0 and its previous products. Comparisons with tide gauge records at 13 sites show that the 3 data sets are reliable to be study the variability of sea level over the Arctic Ocean with root mean square error of 3-4 cm and highest correlation coefficient larger than 95%. Moreover strong annual signals (root mean square of seasonal signal larger than 7cm) are found along the Norway and Russia coastlines (See the following page). Interannual signal is smaller than seasonal signal in the Arctic Ocean and root mean square of interannual signal larger than 5cm in the Norwegian Sea.

Comparing In Situ Current Data with Current Anomalies Derived from the PISTACH Products: the Loop Current Case

Cancet, M[1]; Le Hénaff, M[2]; Labroue, S[3]; Birol, F[4]; Jeansou, E[1]; Morrow, R[4]; Picot, N5; Guillot, A[5]; Dibarboure, G[3]

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Using geostrophic current anomalies derived from the altimeter data to observe the coastal currents or meso-scale structures is a real challenge considering the difficulties to retrieve good-quality altimetry data near the coasts. In the frame of the PISTACH project, funded by CNES, new processing methods and corrections dedicated to coastal applications were developed for the Jason-2 mission products. In order to demonstrate the gain owed to the PISTACH algorithms, the CNES supported the processing of level 3 products based on this dataset. The aim of this new study is to estimate the added value of these products in coastal zones, compared to classical SLA products.

One of the users' case zones that were chosen for the demonstration is the Loop Current, which flows along the South Florida coast before joining the Gulf Stream in the Atlantic Ocean. In this area, the current follows the continental shelf, being particularly well oriented to be monitored using along-track satellite altimetry data.

In order to establish the best "recipe" for the combination of parameters and corrections to be used to monitor the Loop Current, several SLA datasets were evaluated and confronted to in situ current measurements. A comparison to the classical DUACS products also showed the improvement owed to the PISTACH processing

Session 3: Trends and Variability in Coastal Sea Level and Currents

Change of Sea Level Trend around Sumatra from T/P and Jason

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The change of sea level trend, before and after marine earthquake, is an important research field both in geodesy and seismology. The 2004 Sumatra earthquake was a Mw9.3 earthquake, and there is obvious change both in the sea level and regional gravity field. Much observation, such as GPS and GRACE data, were used to analyze the deformation and gravity changes in Sumatra regions. Compared with satellite gravity data, satellite altimeter has a higher spatial resolution along the track and short repeated coverage. This article used T/P and JASON sea level anomaly (SLA), which provide by AVISO, to research deformation of Sumatra sea regions(80°E-105°E, 5°S-20°N). In the research, we believe that the sea level change trend which got from T/P sea level anomaly (1993.1-2002.10) is very stable. In here we can call it before earthquake trend, which may be caused by sea temperature or mass change. We believe that the sea level change trend which got from JASON sea level anomaly (2005.1-2009.3) is including a stable trend caused by temperature or mass and a trend caused by earthquake. We can call this sea level change trend after earthquake trend. The difference between before and after earthquake trend approximately equal the sea level change trend which only caused by earthquake. In the same way, we can approximately get gravity change trend only caused by earthquake. With the high precision and resolution of satellite altimeter data along the track, this paper use nearly two decades of T/P and JASON continuous altimeter data and calculate sub- satellite points trend of sea surface height before and after the Sumatra earthquake in Sumatra areas. Compared the results from satellite altimetry with the gravity changes from GRACE satellite observations in this region, this paper found that both of them had the similar trend along the track in most regions and the results from satellite altimetry can obtain more information in some small area.

Fine Scale Mapping from a Multi-Mission X-TRACK Data Set: Validation and Analysis

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The Bay of Biscay, in the North-East Atlantic, is a complex environment with a chaotic topography and a wide range of ocean dynamics, including a weak anticyclonic basin-wide circulation, a coastal poleward current, mesoscale propagating features and also high frequency shelf dynamics. The region has strong cloud cover, so visible and infra-rouge satellite observations are sparsely distributed. Satellite altimetry measurements are also limited near the coasts because of missing data, but also by the need for complex coastal dynamic atmospheric corrections and tidal models. However, the use of state-of-the-art de-aliasing models and improved data processing significantly increase the quality of the data in this region.

Recent studies have demonstrated the limitation of standard methodologies for mapping small scale features (<100km) in the Bay of Biscay area. As these small scale signals are observed in along-track data, here, we propose a mapping technique enabling a better representation of these processes. Different aspects of the method proposed are illustrated and discussed. For example, in the analysis process, we use decorrelation scales which vary spatially, in order to take into account the differences in scales between the coastal and the open ocean variability. The space and time evolution of mapping errors are also taken into account.

We have confronted the resulting gridded data set to independent observations (satellite imagery, drifters, current-meters and tide gauges). Comparisons with dynamical structures detected from visible and IR imagery, lagrangian statistics (drifter trajectories and Lyapunov Exponents) will be shown in order to underline the potential of fine scale sea level analysis on a regional basis.

Sea Surface Height Variability in the Rio de la Plata Estuary and the Adjacent Continental Shelf

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High standard deviation values of Sea Surface Height (SSH) of both gridded and along track satellite products in the Rio de la Plata estuary have been usually associated to the fact that non-appropriate corrections have been applied to altimetry data. In this work we first estimate the accuracy of the latest generation of gridded altimetry data produced by AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic data) and by CTOH (Centre de Topographie des Oceans et de l'Hydrosphere) along the T/P and Jason 1 tracks by comparison with in-situ data. Then we indentify the influence of the Rio de la Plata estuary's plume associated with the dominant wind’s variability in the SSH data. Decomposition in Empirical Orthogonal Functions (EOF) of the seasonal cycle suggests that the first two modes of variability correspond to the first two modes found with SST satellite data in the region (Simionato et al., 2010). The first mode is related to the radiative cycle while the second mode reflects the effect of the winds on the plume. On intraseasonal time scales negative anomalies along the northern coast of the estuary are observed, which seem to be related to upwelling events also identified on SST data. Interannual variability is also observed, displaying positve/negative anomalies in association with El Niño/La Niña events.

Simionato, C. G., M. L. Clara Tejedor, C. Campetella, R. Guerrero, and D. Moreira (2010), Patterns of sea surface temperature variability on seasonal to sub-annual scales at and offshore the Rio de la Plata estuary, Continental Shelf Research, 30(19), 1983-1997.

Regional Applications based on CTOH (Centre of Topography of the Oceans and the Hydrosphere) Altimeter Data

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The CTOH is an independant research service dedicated to satellite altimetry studies (http://ctoh.legos.obs-mip.fr). Its main objective is to maintain homogeneous altimetric data bases for the long-term monitoring of sea level, lake and river levels, the cryosphere, and the planet's climate. The CTOH data base includes the most recent altimetric corrections applied to a large number of altimetric missions (Topex/Poseidon, Jason-1, Jason-2, Envisat, Geosat-Follow-on). In parallel, the CTOH also provides a particular support for scientists working in the emerging fields of coastal altimetry, continental hydrology (over lakes, rivers and flood plains), and the cryosphere in order to develop new altimetric products

and applications. Using the X-TRACK processing software (Durand et al., 2008,2009; Bouffard et al., 2010; Birol et al., 2010; Roblou et al., 2010), the CTOH routinely produces regional along-track Sea Level Anomalies (SLA) research products which have already been distributed to many users (http://ctoh.legos.obs-mip.fr/products/coastal-products). In parallel, the CTOH continues to work on the optimal use of altimetry for the observation of sea level variability in coastal areas, in developing new regional products. As an example, in order to better resolve the complex spatial and temporal evolution of the coastal features, high sampling rate along-track SLA data are now routinely produced and analysed (i.e. 10Hz for T/P, 20 Hz for Jason-1,2, 18Hz for Envisat). Higher resolution regional multi-mission gridded products are also developed (Dussurget et al., 2011a-b). Here, we will illustrate some regional applications based on these experimental products.

Level-3 PISTACH Products for Coastal Studies

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

Near the coasts, satellite altimeter techniques are unfortunately limited by a growth of their error budget. This quality loss is due on one hand to the land contamination in the altimetric and the radiometric footprints until respectively 10km and 50km and on the other hand to inaccurate geophysical corrections (tides, high-frequency processes forced by atmospheric forcing).

In order to recover these data close to the coast that may contain useful information for coastal studies, the French Spatial Agency (CNES) funded the development of the PISTACH prototype dedicated to Jason-2 altimeter processing in coastal ocean. Since November 2008, these new satellite altimeter products have been providing new retracking solutions, several state-of-the-art or with higher resolution corrections in addition to standard fields.

In 2010, Dufau et al. (4th CAWS) evidenced the need of data post-processing (editing & filtering) of the PISTACH dataset to study ocean dynamics near the coasts of the North West Mediterranean Sea. In 2011, the PISTACH team has newly developed an adapted post-processing (editing, filtering) and produced level-3 PISTACH datasets along several tracks that cross the Agulhas Current and the Florida Strait.

This study gives the final recipe to be applied on the native PISTACH dataset for studying ocean dynamics of these coastal areas. Over each area, each step of the level-3 processing is explained and illustrated as well as the optimal choice of the Sea Surface Height solution.

Comparison of Coastal Altimetry and SAR derived Surface Current in the Coastal Region of the Agulhas Current.

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[1]CLS, France; [2]IFREMER, France

Recent studies using SAR derived Doppler shift have shown the potential of this emerging technique to provide a direct measurement of the across track component of surface current velocity at a resolution better than 10km. Demonstration has been made over strong and energetic current that appeared to be western boundary current which highest velocity appeared to be located quite close to the coast (less than 100km). Therefore traditional altimetric measurements failed to correctly represent the strength of these currents. However, coastal altimetric products, such as PISTACH, have been specifically designed to correctly represent the surface height in this coastal region, and are compared with SAR derived surface current estimates. Selected sites like the Agulhas current region have been chosen for this comparison, where the boundary current has a significant component in the across track direction and significant peak velocity above 1m/s.

Characterization of Oceanic Mesoscale and Submesoscale Energy Spectra

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Transition of oceanic scales in space is examined with currents observed from multiple platforms off the U. S. West Coast -- satellite altimeter (ALT), high-frequency radar (HFR), shipboard and stationary ADCPs. The wave-number spectra of HFR-derived surface currents agree with that of ALT-derived geostrophic currents at scales larger than 100 km, and decay with k-2 at high wave-number (less than 100 km), aligned with submesoscale spectra. Moreover, subsurface currents from shipboard ADCPs support continuous spatial scales in energy spectra. Coastal boundary effects on energy spectra and whether they are anisotropy are investigated with spatial covariance, equivalent to the wave-number spectra. The spatial covariance appears as an anisotropic exponential shape with decorrelation length scales of 20 km nearshore and 100 km offshore parallel to the shoreline. Their overall exponential shapes are consistent with submesoscale wave-number spectra of an approximate k -2 decay behavior.

On the Influence of Coastal Mesoscale Dynamics on the Jellyfish Trajectories and Distributions

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Oceanic mesoscale plays a key role in modulating large-scale circulation, heat fluxes transfer and primary production enhancement. Such hydrodynamic processes are also crucial for jellyfish transport and distribution along the Mediterranean coastal areas. Investigating the relationships between jellyfish distribution and mesoscale hydrodynamic processes therefore provides a rational to understand the influence of such physical structures on the dynamics of regional ecosystems, at the interface between the open ocean and the continental shelf.

Nevertheless, the high spatial and temporal variability associated with coastal mesoscale motions makes them difficult to study with sparse in-situ observations. Alternative options rely on developing methodologies based on the combination of multi-sensor platforms in conjunction with numerical simulations. In this respect, we use an advanced Lagrangian particle tracking code developed at LOPB (Marseille, France) to simulate jellyfish trajectories from both a 3D circulation regional model and currents derived from satellite observations. These are obtained by a high resolution altimetric current mapping tools developed at IMEDEA (Majorques, Spain). The large scale signals (~100 km) are removed by subtracting the gridded Sea Level Anomaly maps (AVISO) to improve along track data. In a second step, the residuals are submitted to an objective analysis scheme with correlation scales adjusted to smaller mesoscale and coastal dynamics. Our approach allows us to characterize the main mesoscale features and exchange between the Ligurian Sea and the Gulf of Lion and to infer possible main pathways of jellyfish trajectories.

Session 4: Synergy of Coastal Altimetry and Modelling

Ocean Surface Topography Estimates from the Oregon Coastal Ocean Forecast Model

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Our real-time coastal ocean prediction model provides everyday updates of 3-day forecasts of ocean conditions off Oregon (US West coast). To improve accuracy of initial conditions for forecasts, it has assimilated RADS alongtrack SSH data, high-frequency (HF) radar surface currents, and GOES SST. Assimilation proceeds in a series of 3-day time windows. In each window, the variational algorithm is utilized to provide dynamically based time and space interpolation and synthesis of the sparse data sets of different origin. Assimilation of data from different platforms in a coastal ocean model allows us not only to obtain an accurate estimate of SSH and other oceanic fields of interest, but also to understand connectivity of processes over the shelf and in the adjacent interior ocean, near surface and at depth. In a series of computational experiments, we assess the effect of assimilation of HF radar surface currents and hourly GOES SST on SSH variability in the coastal ocean, by comparing against AVISO and RADS SSH. Although the surface current assimilation provides an improved estimate of the shelf flows and associated SSH slope (depression near coast during upwelling and variability associated with jets), its can corrupt the current and SSH structure offshore of the HF radar area of coverage. Assimilation of alongtrack SSH in combination with HF radar surface currents helps to control eddy variability in that area, potentially providing surface velocity fields of spatially more uniform accuracy. While the hourly GOES SST imagery contains many gaps (primarily due to cloud covers), variational assimilation of this product in a series of 3-day windows allows time and space interpolation of these sparse data, filling the gaps and removing the noise. Despite the relatively low spatial contrasts of temperature in winter, assimilation of GOES SST positively affects SSH variability over the shelf and in a sea surface trough area separating northward downwelling-favorable coastal currents and the eastern boundary California Current, which continues to flow to the south in winter. Correction in the SSH is associated with correction in the paths of waters that reach the Oregon shelf in winter. In our ongoing research, using high-resolution (1-2 km) models, we are studying the SSH expression of eddy variability near coast in summer and winter, as well as the effect of the Columbia River discharge on the surface topography at mesoscales. These analyses will provide information on the utility of the wide-swath altimetry in the coastal ocean, when those data become available.

Real-Time Regional SSH Data Merging and Assimilation Modeling: Gulf of Mexico Demonstration

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This talk will describe a near real-time (NRT) regional merged SSH product using the sea surface height (SSH) data sets from Jason-1, OSTM/Jason-2 and EnviSat obtained from the Radar Altimeter Database System (RADS). The standard Optimal Interpolation (OI) method provided by AVISO is used as the baseline and compared with the 2D

variational (2DVAR) merging method. Although Gulf of Mexico is used for this initial demonstration, the data processing and merging are implemented with a goal to allow users to customize the data merging with on-demand configurations over any part of the world ocean. This regional NRT SSH data processing and merging will be integrated into a regional ocean modeling, data assimilation and forecasting system. Results of assimilating the merged SSH data products into Regional Ocean Modeling System (ROMS) using the multi-scale 3D variational (3DVAR) data assimilation method will be presented. Physical processes and predictability of the Gulf of Mexico Loop Current and the associated eddies will also be discussed.

Modeling and in situ Observations around the Florida Keys Coral Reefs: Potential Applications of Coastal Altimetry

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The seas surrounding South Florida exhibit strong dynamical and topographic complexities. The broad Southwest Florida Shelf and the narrow Atlantic Florida Keys Shelf communicate through islands and tidal passages. They encompass ecologically and economically important areas, such as: the Dry Tortugas Ecological Reserve (spawning grounds for several commercial fish species) and the Florida Keys National Marine Sanctuary (largest coral reef system in the continental U.S.). These areas are connected through both coastal flows and an oceanic current, namely the Florida Current, which is the Gulf Stream branch through the deep Straits of Florida, a continuation of the Loop Current in the Gulf of Mexico.

Meso-scale and sub-mesoscale variability are largely dominated by the meandering of the large scale current system and the associated eddies, especially the cyclones that are traveling along the main current front, connecting the reefs to the spawning grounds and impinging on the shelf, providing cool waters, fish larvae and nutrients.

Free running simulations over the South Florida domain have been carried out based on the Hybrid Coordinate Ocean Model (HYCOM), forced by the regional Gulf of Mexico HYCOM run by the Navy Research Laboratory with assimilation of mainly SSH and SST fields. Multi-year (2004-current) simulations with a new, very high resolution (1/100 deg., ~900m) HYCOM application covering South Florida and the Florida Straits (FKeyS-HYCOM, extending to Northern Cuba and the Western Bahamas) have revealed mesoscale and submesoscale features that are in qualitative agreement with ocean color imagery. In addition, new insights on eddy evolution have been revealed. Assessing the performances of these simulations would certainly benefit from a comparison with dedicated altimetry products, able to take into account the presence of the islands and the specific coastal scales.

The future outlook is to quantitatively assess the realism of the simulation and/or examine suitable data for assimilation in the nested domain. Of particular interest is to explore new methodologies that address altimetry challenges in areas of complex coastal to offshore interactions and in the framework of a downscaling, nested approach. First, the coastal altimetry data in the domain will have to be assessed by comparison with in-situ observations. A long record of ADCP data and ship-borne surveys exists, in tandem with a coral reef monitoring framework (Integrated Coral Observing Network/SEAKEYS). The data will also be analyzed to determine the processes they are able to capture, and to estimate the error level within the observation. Then, the use of coastal altimetry data for model evaluation and/or data assimilation will be determined. On the long-term, improved model predictions around South Florida and over the Florida Straits domain will be valuable for a range of applications, such as: enhancing a sustainable ecosystem management approach around the ecologically fragile, but economically important, South Florida coastal areas; improving the understanding of the connectivity between the Caribbean Sea and the Gulf of Mexico with the Atlantic Ocean (implications on fisheries); improving the predictability of transport and fate of pollutants from increased oil drilling activities (Cuba, Bahamas and eastern Gulf of Mexico).

Adjoint-based Ensemble Prediction in the Mid Atlantic Bight

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We describe recent advancements for an operational prediction system for the Mid Atlantic Bight. The system uses the 4-dimensional variational data assimilation algorithm of the Regional Ocean Modeling System (ROMS) to assimilate infrared sea surface temperatures, reprocessed coastal along-track altimeter data, and surface currents from a network of high frequency coastal radars. In an operational framework the model state at the end of the assimilation period is used as an initial condition to forecast a single integration of the non-linear ROMS model. It is shown that at short forecast lead-times (of the order of days) the divergence of model trajectories in the shelf and shelf-break regions is highly controlled by the surface forcing used in the deterministic forecast. Since this atmospheric variability is not known precisely in an operational framework, we explore the possibility of propagating the errors inherent to the chaotic atmospheric flow to the ocean state forecast via the adjoint model used in the variational system. The property of the adjoint model to act as a "sensitivity operator" allow us to measure the divergence of model trajectories (quantified by an index) without having to perform multiple integrations of the full non-linear model. The different atmospheric realization used in the ensemble forecast system are based on bootstrapped historical atmospheric analysis constrained to decorrelate at realistic lead times, and therefore offer a realistic forcing for the ocean model.

Session 5: Extreme Events and other Applications

Tropical Cyclone Yasi Observed by Jason-1 and Jason-2

Deng, X

The University of Newcastle, Australia

Severe Tropical Cyclone Yasi in early February 2011 was the most intense cyclone that hit north Queensland, Australia since 1918. It began developing as a tropical low northwest of Fiji on 29 January and started propagating on a general westward track. Yasi maintained its west-southwest movement and rapidly intensified from a Category 2 to Category 5 when making landfall on the north Queensland coast near Mission Beach between midnight and 1am early on 3 February (14:00 UTC on 2 February). During this period, Jason-1 and Jason-2 provided important sea level measurements along several ground tracks. In this paper, the Ku-band waveforms from Jason-1 (cycles 334 and 335) and Jason-2 (cycles 94 and 95) are used for monitoring of this extreme event. As expected, altimeter waveforms by the Ku-band radar are distorted near the core (or eye) of Yasi by heavy rain accompanying with the cyclone. To improve altimeter derived sea surface heights, the waveforms are retracked using both fitting and threshold algorithms. The formation of propagation of tropical cyclone Yasi is, then, traced using altimeter derived wind speed, wave height and sea level anomalies. The Yasi intensification over areas of anomalously high sea level has been observed through the analysis

Coastal Altimetry for Storm Surge Forecasting in the eSurge Project

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Storm surges are amongst the deadliest natural phenomena. Their understanding and realistic modelling supports both preparation and mitigation activities and should eventually bring enormous societal benefits, especially to some of the world's poorest countries (like Bangladesh). Earth Observation data have an important role to play in storm surge monitoring and forecasting, but the full uptake of these data by the users (such as environmental agencies and tidal prediction centres) must be first encouraged by showcasing their usefulness in demonstration studies, and then supported by providing easy access to the data themselves.

Having recognized the above needs, ESA has recently launched a Data User Element (DUE) project for 2011-2013 called eSurge. The main purposes of eSurge are a) to contribute through Earth Observation to an integrated approach to storm surge, wave, sea-level and flood forecasting as part of a wider optimal strategy for building an improved forecast and warning capability for coastal inundation; and b) to increase the use of the advanced capabilities of ESA and other satellite data for storm surge applications. The project is led by Logica UK, with NOC (UK), DMI (Denmark), CMRC (Ireland) and KNMI (Netherlands) as scientific partners. A very important component of eSurge will be the development, validation and provision of dedicated coastal altimetry products. Coastal altimetry has a prominent role to play as it measures directly the total water level envelope (TWLE), i.e. one of the key quantities required by storm surge applications and services. But it can also provide important information on the wave field in the coastal strip, which helps

the development of more realistic wave models that in turn can be used to improve the forecast of wave setup and overtopping processes. In this talk we will present examples of how altimetry has captured a few significant surge events in European Seas, and we will describe how a multi-mission coastal altimetry processor is going to be integrated in the eSurge system. The delayed-time reprocessed coastal altimetry data will be blended with tide gauge data to extract the main modes of variability in the coastal regions. Then data from the tide gauges can be used to estimate the water level in real time, based on the modes of variability found.

In a later phase of the project, the eSurge coastal altimetry processor will be extended to be able to ingest NRT raw altimetric waveforms and generate the relevant NRT products, a definite first for coastal altimetry. The pilot regions for this application will be the European Seas and the North Indian Ocean.

In summary, we expect eSurge to be one of the first pre-operational applications of coastal altimetry, in an area with huge impacts on society.

Airborne Remote Sensing for Ocean and Coastal Applications

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Satellite remote sensing has enabled remarkable progress in the ocean, earth, atmospheric and environmental sciences through its ability to provide global coverage with ever increasing spatial resolution. However, the temporal coverage of low earth orbiting satellites is not optimal. This temporal coverage may be sufficient for mesoscale ocean processes with time scales of a month, but is not sufficient for ocean processes that respond to atmospheric forcing with time scales of hours to days and other submesoscale ocean processes, especially coastal processes, both physical and biological, and air-sea-land interactions in the coastal zone. In addition, near-coast data are often discarded since it is difficult to interpret and model land effects on waveform altimetry, and we lack standardized corrections for various effects (e.g., path delays, coastal tides, high frequency atmospheric signals). For this range of phenomena and locations, satellite data need to be supplemented with higher resolution airborne data.

Over the past two years, built upon our experience conducting airborne experiments in support of physical oceanographic research since 1999, we have developed a novel, portable, high-resolution airborne remote sensing system specifically designed for quick response surveys. It is comprised of a scanning waveform LIDAR, a hyperspectral camera, a high-resolution video camera, and a Long-Wave Infrared (LWIR) camera, coupled to a high accuracy GPS/inertial measurement unit. We describe system performance, present preliminary results from recent coastal and oceanic surveys, and discuss the potential use of such system for providing independent measurements for in situ calibration of coastal reanalyzed satellite products.

Session 6: Retracking

Waveform Retracking Techniques for Quasi-Specular and Multi-Peak Echoes near the Coast

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This paper presents the waveform retracking technique for two waveform classes: quasi-specular and multi-peak echoes, which usually appear near the coastline. These waveform patterns do not conform to the Brown Model (1977); and thus cannot be effectively retracked by the physical retrackers, such as the Brown Model with either first or second order Bessel function. The aim of this study is to maximise the use of the Brown Model retracker because it is capable of giving precise geophysical parameters by considering the physical feature of the scattering surface. To apply the Brown Model to the quasi-specular echoes, change has been made in the Brown Model's scattering term by increasing the value of scattering term. The quasi-specular echoes are found to be well fitted to the modified model. In order to apply the Brown Model to the multi-peak echoes, the waveform is re-aligned based only on returns reflected from water surface without attempting to explain the full shape of the waveform. The retrackers are first applied to simulated waveforms and then Jason-1/2 waveforms in the Great Barrier Reef, Australia. The performance of both retrackers is analysed by comparing the sea surface heights derived from these retrackers and independent high frequency radar data.

Using HF Coastal Radar Currents to Correct Satellite Altimetry

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We use U.S. west coast HF radar (CODAR) surface currents to determine coastal altimetric waveform retracking methods. We first use this pairing of CODAR and altimetry in the open ocean with no land influence to determine how well a sea surface height inferred from the geostrophic portion of the CODAR surface currents agree with the sea surface height from coincident altimetry observations. High correlations between these two fields confirm the expectations that the CODAR and 1 Hz altimetric heights are similar using PISTACH altimetry corrections. Turning to 20 Hz altimetry data we make the same comparisons in the coastal ocean where we find cases where the CODAR and altimeter height do not agree. Looking at the individual altimeter waveforms we find that in each case there is a major deviation in the waveform. Looking more closely at the waveforms we find a surprising correlation between the Ku-band sigma0 and the tracker range relative to the Mean Sea Surface (MSS). Where this correlation drops off for Jason 2 it is found that the tracker is operating in the Diode/DEM mode. We found that the altimetry height retrievals based on waveform tracking are degraded by the occurrence of high radar return cross section called sigm0 blooms. We explore the influence of these sigma0 blooms for different waveform retrackers when compared to coincident CODAR retrievals

Session 7: Path Delay

Wet Tropospheric Correction: Filling the Gaps from Coast to Coast

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In the scope of the European Space Agency (ESA) funded project COASTALT, a method has been developed to compute the wet tropospheric correction in the coastal regions and applied to Envisat data -- the GNSS-derived path delay (GPD). At each point with invalid Microwave Radiometer (MWR) data, the method computes the wet tropospheric correction, by combining three data types: GNSS-derived path delays (PD) at coastal GNSS stations, valid MWR measurements in the vicinity of the point and PDs derived from a Numerical Weather Model such as the Deterministic Atmospheric Model of the European Centre for Medium-range Weather Forecasts (ECMWF). The data combination is performed by objective analysis.

In the scope of the ESA Climate Change Initiative (CCI) - Sea Level project the method is being further refined and applied to the whole Envisat mission.

This study addresses the latest developments aiming an efficient global implementation to any satellite altimeter mission which possesses an onboard microwave radiometer.

An inter-comparison between the three input data types (ECMWF, MWR and GNSS) has been performed for Envisat, using a global set of 190 GNSS stations, covering the various levels of variability of the tropospheric delay. This study shows that, overall, no significant biases or trends are identified between the various data types. It also shows that apparently valid MWR measurements can be quite noisy due to non-flagged ice and rain contamination and that identification of noisy MWR values is crucial since any noisy MWR measurement will induce large errors in the computed correction for the points in its vicinity. Following this study, strategies for an adequate data screening have been developed.

The algorithm is able to compute an estimate for every point along the satellite track. Therefore, although initially developed for coastal altimetry, it provides a global wet tropospheric correction that is continuous with respect to the MWR correction. Regions as the high latitudes (with ice contamination) and track portions with rain contamination in the MWR data will also have a valid and continuous correction.

Examples of the application of the method to various satellite missions will be presented. Performance of the GPD algorithm against existing alternative methods will also be presented for missions for which all corrections are available.

Wet Tropospheric Correction in Coastal Areas: Potential of Land Emissivity Maps / Neural Network Retrieval Algorithm

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On homogeneous water surfaces, the combination altimeter/radiometer for wet tropospheric correction estimation (dh) is satisfactory both in terms of accuracy (1 cm rms error) and spatial resolution (50 km). This is not the case in sea/land transition areas. Near coasts or islands, measured brightness temperatures may be highly contaminated by the presence of

land surface (with a strong and very time variable emissivity) in the radiometer footprint. Radiometer retrieval algorithms are all formulated with a sea surface emissivity model, and are therefore not suitable anymore. Other methods or data have to be considered.

Since a few years, new data or algorithms have been proposed. Alternative data mainly consist in GPS measurements available on the coast, allowing an alternative dh thanks to a specific processing (Fernandez et al, 2010). Meteorological models (global or regional to reach a better resolution) have shown to be a valuable source of information despite limited spatial and temporal resolution. Specific processing have been proposed, either at level 1 (decontamination of the brightness temperatures, Desportes et al, 2007) or level 2 (land proportion considered in the level 2 inversion, Brown et al, 2009). Finally optimal combinations have been proposed by different authors to take advantage of these different dh estimations (Fernandez et al, 2009, Mercier et al, 2007).

In this context, the objectives of this paper are the following. First we will review existing data and methods, highlighting the main issues raised by each of them. In a second step, we will present a new methodology to enhance the quality of the altimetry wet tropospheric correction in coastal areas. This new method is based on the development of a specific L2 algorithm like in Brown et al, but taking advantage of neural networks method for an optimal regression solution and a good knowledge of land properties (proportion and emissivity) acquired through the Pistach project. Preliminary results will be presented for the Envisat mission as well as potential application for future altimetry missions (Sentinel-3 topography and AltiKa missions)

Session 8: CryoSat and SAR Altimetry in the Coastal Zone

Contribution of CryoSat to Oceanography and Coastal Altimetry

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More than a year after the launch of CryoSat, its low-rate data have not been used much yet for oceanographic purposes, let alone in the coastal areas. This is partly due to the fact that the mission main goal is to support glaciology, not oceanography and consequential lack of focus on producing consistent high-quality ocean products. Secondly, the low-rate data is not available everywhere: significant areas are dedicated to running the instrument in SAR or InSAR mode. Not surprisingly, the ocean community has steered far from the standard CryoSat ocean products after the amount of negative press they received.
At NOAA, however, we have been able to show that the CryoSat data is intrinsically of high quality, and that the convention and SAR data can be combined. We have done this through:
• Combining final (LRM) and fast-delivery (FDM) products and splitting the segmented files into pass files.
• Retracking the conventional low-rate mode data and determine range, significant wave height, backscatter and off-nadir angle.
• Combining SAR waveforms into conventional waveforms and then retracking, or retracking the SAR waveforms with a dedicated retracker.
• Adding the usual corrections for ionospheric and atmospheric delays, tides, dynamic atmospheric correction, sea state bias, mean sea surface.
• Updating orbits and corrections whenever they become available.
These data were then all inserted into the Radar Altimeter Database System (RADS) for further analysis.
In this presentation we will show how the CryoSat data quality compares to other altimeters (Envisat, Jason-1 and Jason-2) by means of data distribution maps, histograms and crossover comparisons. In this we will particularly focus on coastal regions and discuss the possibilities of further improvements. Furthermore, we will show how the altimeter tracks line up a cover a region over time and discuss the relative precision of non-repeating orbits (in fact, the CryoSat orbit repeats after 369 days, but has a subcycle of 29 days).
NOAA already uses the significant wave height and wind speed (derived from the backscatter coefficient) from CryoSat in their hurricane forecasting models. The latency is such that we can turn around the data fast enough to have a positive impact on the forecasts.
Following this meeting we intend to publicly release our retracked and enhanced CryoSat data through the RADS server at the Delft University of Technology since we believe they provide a significant benefit to oceanographic users of satellite altimetry, in the open ocean and coastal region alike.

SAR Altimetry in Coastal Zone: Performances, Limits, Perspectives

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Up to now, any effort to retrieve the coastal zone phenomena from the space has been hindered by the intrinsic incapacity of conventional radar altimeters to sample all but largest scales involved in the coastal processes due to its insufficient along-track resolution.
However, nowadays, a new technology in Space-borne Altimetry has become reality: the Synthetic Aperture Radar (SAR) Altimeter.
The acquisition of altimetric data in SAR mode ensures a higher resolving

measurement power that shall enable scientists for the first time to aspire to measure even short-scale weak coastal phenomena, thanks to the 20-fold smaller along track radar resolution and 10 dB higher Signal to Noise ratio.
The secondary, but significant in coastal zone, effect of the radar footprint shrinking is the expected reduced impact of land contamination on the radar waveforms in the proximity of the shore.
As a consequence of this effect, the advent of SAR focusing promises to bring the satellite altimetry remote sensing closer to the shore up to around 500 meters. Anyway, this lower bound of 500 meter on coastal proximity is not always reachable, as the footprint shrinking occurs only in along track direction while the across track resolution shall remain basically unaltered. Hence, the orientation of the satellite ground-track with respect the coastline plays a role crucial for an effective filtering out of the off-nadir land-originated signals.
In the present work, utilizing the current CryoSat-2 Altimeter Dataset (SAR L1b) acquired over coastal sea water, and by retracking the SAR L1b waveforms, a performances study of SAR altimetry in coastal zone will be addressed and the benefits and limits of this new technology highlighted.
As particular study area, the Tyrrhenian Sea has been selected: statistics and metrics for sea surface height and significant wave height, as calculated from a cycle of passes, will be assessed, shown and interpreted.
Finally, employing the CryoSat Interferometric mode (SARin), it will be attempted to retrieve the origin direction of the radar returns in order to prove how, in SARin mode, the land-originated radar returns can be recognized and eventually discriminated from the pure nadir ocean return.

Some recent Investigations with CryoSat in Conventional and SAR Modes

Smith, Walter H F

NOAA, USA

The SIRAL altimeter on CryoSat, launched in 2010, can operate in three modes: the low-rate mode (LRM) behaves as a conventional altimeter; the SAR mode allows more precise range and more focused footprint through use of synthetic aperture radar (SAR), also known as delay-Doppler, processing; the SARIN mode, or interferometric SAR, also affords across-track slope determination from interferometry. I have been working on several CryoSat studies over this year and would like to present highlights of these.
For the conventional LRM mode, I have built a retracker that can process near-real-time (FDM: Fast Delivery Mode) and Level 1-B data to yield wind speed, wave height, and sea surface height anomaly. These data are being fed to NOAA's National Centers for Environmental Prediction.
Traditional retracking proceeds by iterative least-squares approximation, with Gauss-Newton iteration facilitated by the existence of analytic derivatives. I have derived an analytic expression for the SAR mode waveform and its derivatives with respect to the usual parameters (range, wave height, backscatter, etc.). This allows me to retrack the SAR mode waveforms with an MLE-style retracking algorithm.
I have Full Bit Rate (FBR) data in SAR mode for some ocean passes, including portions crossing coastlines, both from ocean to land and from land to ocean. FBR data includes all the raw I and Q samples of the raw radar echoes, prior to the range FFT that deramps the chirp, or the azimuth FFT that initiates the delay-Doppler SAR focusing calculation. I am currently working on these data with several applications in mind:

(1) I can use these data to trace exactly what happens as the instrument crosses a coastline.
(2) I can use these data to derive a LRM (conventional) waveform as well as a SAR waveform, and can compare the performance of these two modes under the same conditions (sea state, propagation, etc.)
(3) I can test a conjecture by J R Jensen (IEEE TGARS 1999 37(2), 651--658) that waveform sampling rates should be doubled prior to forming the summed squared power, since squaring doubles frequency. This will show whether higher resolution is potentially available from conventional altimeters.

Two forthcoming altimeter satellites, Sentinel-3 and Jason-CS, will have instrument heritage from CryoSat's SIRAL. Therefore the altimeter community should be interested in these new capabilities that we can test with CryoSat.

The SAMOSA Project Main Achievements and their Contribution to Coastal Altimetry

Cristina Martin-Puig[1]; Philippa A. M. Berry[2]; David Cotton[3]; Paolo Cipollini[4]; Chris Ray[1]; Lars Stenseng[5]; Christine Gommenginger[4]

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The application of Synthetic Aperture Radar (SAR) techniques to nadir-pointing radar altimetry offers the potential to significantly enhance Earth surface mapping. CryoSat-2 is the first satellite to provide such data. Although its primary mission aim is cryospheric applications, Cryosat-2 data shall be of great interest to the hydrosphere and oceanographic communities as they will allow the first quantitative assessment of the enhanced capabilities offered by SAR altimetry for high-resolution sea surface height measurements, coastal monitoring, ocean floor topography mapping, gravity field and inland water monitoring.

SAR altimetry was first proposed and described as Delay Doppler Radar Altimetry (DDA) by R. K. Raney in 1998.

The key innovation is the addition of along-track SAR processing that leads to increased resolution and improved signal-to-noise ratio through enhanced multi-looking.

The SAMOSA project team led by Satellite Oceanographic Consultants (SatOC, UK) included four additional scientific partners with a high level of relevant experience: The Danish University of Technology (DTU, Denmark), De Montfort University (DMU, UK), the National Oceanography Centre (NOC, UK) and Starlab Barcelona S.L (STARLAB, Spain). This consortium, with the external participation of Dr. R.K. Raney (Applied Physics Laboratory at the Johns Hopkins University, USA), has worked on the analysis of the potential capabilities of SAR Altimetry over ocean, coastal and inland water surfaces.

The project team succeeded in defining novel retracking techniques for SAR Mode (SARM) altimeter echoes over water surfaces and in evaluating the performance of SARM altimetry compared to conventional pulse-limited altimetry over identical sea state conditions. The performance of SARM in terms of range retrieval accuracy was analysed by retracking simulated Cryosat data, airborne data and CryoSat-2 data, and with estimates of achievable precision of SARM through the Cramér-Rao Lower Bound (CRLB) method. In addition, the "Berry Expert System" (BEST) was applied to simulated data over complex inland water scenarios to assess SARM performance over lakes, estuarine and wetlands.

This oral presentation intends to provide an overview of the main results achieved by the SAMOSA project focusing on those with greater impact to coastal areas.

Session 9: Data Processing and Products

Technical Achievements and Data from the COASTALT Project

Cipollini, P[1] and the COASTALT Team

[1]National Oceanography Centre, UK

The ESA-funded COASTALT project on development of radar altimetry in the oceanic coastal zone for Envisat is approaching completion in autumn 2011. This presentation will summarize the technical achievements and present the data coming from this innovative project.
The challenges faced during the development of a specialized processor for coastal altimetry stretch from the need for optimization of retracking over this particular domain to the need for specific corrections.
In the COASTALT processor, retracking is carried out by a suite of routines fitting the waveforms to physically-based models, that will be described with examples of their behaviour in the coastal environment. The results in terms of standard deviation of the retracked quantities and their differences with the SGDR data will be presented as a function of distance from coast and discussed. While the well-known Brown waveform model is robust enough to allow a meaningful estimation of the main parameters (sea level and significant wave height) up to ~10 km from the coast, we will present cases in which the adoption of specular and mixed retrackers allow a more realistic estimation in the coastal strip. This work is complemented by investigations of innovative retracking techniques based on a 2-D or Linear Bayesian approach, which are the subject of separate contributions to the Workshop.
The effect of specialized corrections, like the GPD Wet Tropospheric correction developed by Univ. Porto, will also be illustrated. For instance, in a comparison with the Newlyn Tide Gauge (W Britain), the adoption of the GPD correction instead of the MWR reduces the RMS difference in the heights from 3.7 to 3.2 cm.
Data from COASTALT (i.e. the Coastal Geophysical Data Records or CGDRs) are now available over a set of pilot tracks; these will be presented alongside the plans for extension to other tracks/regions in the framework of follow-on projects. A User Handbook complements the data and constitutes an extremely valuable document. In addition to being very useful to everyone wanting to use the COASTALT CGDR, it also serves as a general introduction to many of the technicalities of coastal altimetry, regardless of the specific mission.

The COASTALT Team: Susana Barbosa, Jérôme Benveniste, Machiel Bos, Valborg Byfield, Marco Caparrini, Peter Challenor, Paolo Cipollini, Henrique Coelho, Salvatore Dinardo, M. Joana Fernandes, Scott Gleason, Jesus Gómez-Enri, Christine Gommenginger, Clara Lázaro, Bruno M. Lucas, Cristina Martin-Puig, Laura Moreno, Alexandra Nunes, Nelson Pires, Graham Quartly, Andrea Scozzari, Helen Snaith, Mikis Tsimplis, Stefano Vignudelli, Luke J. West, Judith Wolf, Phil Woodworth.

Regional Sea Level Anomaly Processing in the Gulf of Mexico

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Sea level anomaly from satellites and tidal gauges are combined to demonstrate the feasibility of regional sea level anomaly processing in the Gulf of Mexico region. Similar to the global sea level anomaly processing conducted by AVISO, the regional sea level processing including the following steps: 1) Quality control and editing of altimetry observation, 2) Repeat track analysis, 3) Filtering the noise, 4) Optimal interpolation to merge satellite data and tidal gauge data. Two innovative improvements are introduced in the regional sea level anomaly processing. First, the Hilbert-Huang Transform method is used to filter the noise in the along track data. The Hilbert-Huang Transform separates the original data into intrinsic modes based on the characteristics of the data. When only higher modes are combined to conduct filtering, the high-wave number noise is effectively removed. The data at coastal region can be retained for regional sea level anomaly processing. Second, the regional sea level anomaly processing makes use all the available observations instead of sub-sampling the along track data as practiced in the producing of the global AVISO product. It is demonstrated that without including the tidal gauge data, the regional sea level anomaly processing reduces the RMS (Root Mean Square) error of AVISO product by 10% in the coastal region by comparing with the independent 10-day low-pass filtered tidal gauge observations in the northern part of Gulf of Mexico. By including the tidal gauge data, the RMS error between the regional sea level product and tidal gauge observation is around 2-3cm, which is a significant improvement from 10-11cm of AVISO product. Further work is needed to assess the regional sea level product in the open ocean.

Session 10: Cal/Val

Corsica: a Cal/Val Experiment to Link Offshore and Coastal Altimetry

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Observatoire de la Côte d'Azur, France

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 the reflector 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), due to a smaller time series, the standard deviation is 43 mm and the standard error is 10 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 buoy 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).

The proposed 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. Indeed, with the recent extension of the Corsica site (Capraia in 2004 and Ajaccio in 2005) and the ESA support, we are now able to perform absolute altimeter calibration for ERS-2 and EnviSat with the same standards and precision than for T/P and Jason missions. This will permit to improve the essential link between all these long time series of sea level observation.

Local Mean Sea Surface Models for Calibrating Jason-2 at the Gavdos Cal/Val Facility

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This work outlines an alternative methodology adopted for determining the satellite altimeter bias of Jason-2 using a locally determined mean sea surface (MSS) model at the Gavdos Cal/Val permanent facility. This local MSS has been determined using all available altimetric data in the region and replaces the local geoid used as a reference surface for calibration. The aim has been to extend the calibration area nearest to the coast where large underwater topographic gradients, south of Crete and around Gavdos, influence the estimation of sea level and the calibration process. Details regarding the methodology applied for the determination of the local MSS model, as well as comparative results against all other available reference models are provided.

Advances in the Validation of Coastal Altimetry Full Rate Wave Data (COASTALT Project)

Gomez-Enri, J[1]; Caballero, I[2]; Navarro, G[2]; Vignudelli, S[3]; Tejedor, B[1]; Cipollini, P[4]; Villares, P[1]

[1]University of Cadiz, Spain; [2]ICMAN-CSIC, Spain; [3]CNR-Pisa, Italy; [4]NOC-Southampton, UK

Ensuring a thorough validation of the nearshore altimetry information is a key activity for the significant impact of changing oceans on society, economy, ecology and climatology. The study presented here addresses the case of the continental shelf of Gulf of Cadiz (SW Iberian Peninsula). We validated significant wave height derived from ENVISAT RA-2 at full and low rates (18Hz and 1Hz respectively) from the COASTALT processor (18Hz) and Geophysical Data Records (1Hz), covering 8 years of data (2002-2009). We used ground truth in-situ measurements to check whether new improvements (reducing the uncertainties of the various terms concerning the coastal editing flag, tidal and atmospheric corrections, etc.) perform as good as standard altimetry in the open ocean. Our results using low-rate data demonstrate the potential for accurate geophysical parameter retrieval much closer to the coast than routinely achieved. We also observed an improvement in statistics (bias and rms) as we get closer to the coast when using COASTALT data respect to the standard GDR SWH data. At 9 km distance from coast, COASTALT/GDR data show an rms of 0.7/2.0 m and a bias of 0.6/1.9 m respectively.

Poster Session

Tropical Atlantic Western Boundary Currents from Satellite Altimetry

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[1]LOCEAN-IPSL; [2]ENSTA

The western tropical Atlantic region is investigated using newly processed coastal altimetric data between 1992 and 2009. This area is characterized by strong currents and important variability. This study focusses on the geostrophic component of this tropical circulation. Comparisons with in situ measurements are made to analyse the reliability of the satellite data. Analyses using numerical models are then conducted to characterize the low frequency variations.

COASTALT Product Validation at the Cascais Tide Gauge

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Validation is a crucial activity in the framework of development of satellite altimetry products for the coastal area. This work shows the latest validation results at the Cascais tide gauge (southern Portugal) for the final CGDR product resulting from the ESA-funded COASTALT project. The data at 18Hz are first subject to pre-processing and quality-control procedures, and a first assessment of the range height is performed along the track closest to the tide gauge, focusing on the coastalt Brown retracker. The temporal evolution of the geophysical corrections (including SSB, troposphere and ionosphere) is then described as a function of the distance to coast. Finally, along-track time series of sea-level anomalies are derived and compared with concurrent measurements of the height of the sea surface at the tide gauge. The use of 18Hz retracked data does allow to extract additional useful information from satellite altimetry measurements in the coastal area, with the agreement between tide gauge and coastal altimetry observations depending primarily on the quality of the retracked range.

New CryoSat Ocean Products

Bouzinac, C[1]; Féménias, P[2]; Parrinello, T[2]; Benveniste, J[2]; Dinardo, S[3]; Benveniste, J[2]

[1]ESRIN/RHEA; [2]ESA; [3]SERCO

This poster presents the Fast Delivery Marine Mode (FDM) products of ESA CryoSat mission, which will be improved in the next specialized processor version planned for the end of 2011. The FDM product is delivered in Near Real Time (70% in 3 hours after data acquisition). This poster introduces also to the new ocean products, in preparation. Generated on an independent production line, this new ocean production chain will be composed of the Intermediate Ocean Product (IOP) delivered about 3 days after data acquisition and the Geophysical Ocean Product (GOP) delivered about 30 days after data acquisition. With respect to FDM, which contains all the ancillary corrections available before the pass (e.g. tides), the following additional corrections will be applied to IOP and GOP: sea surface pressure, dry and wet tropospheric corrections and dynamic atmospheric correction (DAC). Also the orbit precision is not the same for FDM, IOP and GOP. The latter will benefit from the most precise orbit, delivered about one month after acquisition. The format of the IOP and GOP will remain identical to the FDM product format

Impact of the New Near-Land Radiometer Wet Path Delay Retrievals on Altimeter Tide-Gauge Comparisons

Brown, Shannon[1]; Beckley, Brian[2]; Mitchum, Gary[3]

[1]JPL; [2]SGT Inc., NASA GSFC; [3]University of South Florida

We present the results of a study to assess the impact of the recently released near-land wet path delays available on the JMR and AMR enhanced products on altimeter/tide gauge comparisons. Previously, land contamination of the radiometer retrievals significantly impacted the accuracy near land and the data were flagged as bad within 50km from land. Recently, a new algorithm was developed to retrieve path delays near land, significantly improving the accuracy in the coastal zone. In this study, we compare the altimeter SSH measurement to the tide gauges now including the altimeter measurements within 10km from land to those from the previous approach using altimeter data only at distances greater than 50km from land

Bayes Linear retracking in the coastal zone

Challenor, P; West, L

National Oceanography Centre

Current retracking methods treat altimeter data as single waveforms that are retracked individually. The order does not matter so that our knowledge that ocean parameters vary slowly across the sea surface is ignored. This is even more important in coastal areas where we expect bright targets to move through the waveform. One solution to this problem is to use Bayesian methods, treating the posterior from one waveform as the prior for the next. The computational overhead of calculating the full posterior probability density function makes these methods impractical in any but special circumstances. An alternative that avoids these computational problems is the Bayes linear retracker. Bayes linear methods work with only the first two moments (means and (co)variances) rather than the full density function. This means that they are extremely fast but still have the sequential advantages of the full Bayes solution. In this poster we present details of the Bayes linear retracker and show comparisons with an MLE tracker on both simulated and real waveforms in the coastal zone.

Effects of Altimeter Corrections on Linear Sea Level Changes Around Taiwan

Cheng, Y.C.; Andersen, O.B.

DTU Space

Multi-mission altimeter measurements from TOPEX/Poseidon, Jason-1 and Jason-2 satellites for the period 1993-2009 are used to characterize the sea level changes around Taiwan and the impacts of different geophysical and range corrections on linear sea level trend (LSLT) are investigated. The results show that the wet tropospheric correction, the dynamic atmospheric correction (DAC) and the tidal correction have significant impacts on the determination of LSLT from altimeter measurements around Taiwan. The misfit of LSLT with and without DAC is up to 2 mm yr-1 to the north of Taiwan, in the Taiwan Strait and in the coastal regions. Applying the selected optimal geophysical and range corrections to altimeter measurements, the mean LSLT for the period 1993-2009 around Taiwan without DAC applied is 3.63 mm yr-1, which is higher than the global average of 3 mm yr-1. With the DAC applied the LSLT is 3.31 mm yr-1 over the regions. Moreover, significant differences in LSLT are found in 8 selected regions around Taiwan. A comparison with LSLTs determined from

tide gauge records over the same period shows the best agreement in deep water.

Preliminary Result of Sea Surface Height Calibration/Validation for Multiple Satellite Altimeters in Taiwan

Cheng, Kai-chien

National Chung Cheng University

This study presents the calibration/validation (Cal/Val) activities in Taiwan for multiple satellite altimeters, including Jason-1/-2 and ENVISAT/AlitKa. The objective is to support the global effort in the multiple altimeter calibration by providing information of sea surface height bias in the coastal area of Taiwan. The calibration mechanism used in this study is basically established with a GPS-buoy, which is a simple and compact lifesaver or a waverider buoy equipped with a geodetic-grade GPS antenna. In addition, other techniques involved are Continuous GPS (CGPS) stations and coastal tide gauges. The locations for the absolute calibration in this study have been carefully selected based on the groundtracks of altimeters, the availability of tide gauges and CGPS stations in the area, and other factors such as instrumental and geophysical path corrections and sea state bias. Preliminary results of sea surface height bias of Jason-1/-2 in the southwest coasts of Taiwan, and the progress of establishing calibration for ENVISAT/AltiKa missions will be reported.

A New Parameter to Facilitate Screening of Coastal Altimetry Data and Corrections

Cipollini, P.

National Oceanography Centre, UK

One of the diagnostics used to measure the goodness of reprocessed coastal altimetry is ‘how closer to the coast’ we can get with respect to standard data, within agreed thresholds of accuracy and precision. Distance from coast, however, is often a too crude variable to perform this screening: for instance, the effect of land on the waveforms is likely to be lesser when the altimeter nadir is 3 km from a very small (~km-size) island than when it is at the same 3-km distance from the coastline but in a very recessed bay. The wave field is likely to be similar to open-ocean in the former case, and in the latter case we expect retracking to be more difficult, and the retrieved parameters and derived correction to be less accurate. In this example ‘distance from coast’ will not be a good independent (i.e. x-axis) parameter to screen those data against.

Within the ESA Sea Level CCI Project we are developing the algorithm for a new parameter, called Coastal Proximity, aiming at capturing the differences in coastal morphology (and,in a later phase, in coastal sea condition if that provesfeasible). In this poster we will first present examples of simulation of the effect of land on waveforms, which we have computed by flying a virtual altimeter over the 3-arcmin resolution ACE2 DEM (produced by De Montfort University, U.K). Then we will give details on the definition of the Coastal Proximityparameter, which we have computed globally, and present examples over some representative areas. Finally we will discuss how we are going to validate and fine-tune this new parameter so that it can became a useful everyday tool for the coastal altimetrists.

Level-3 PISTACH Products for Coastal Studies

Dufau, C.[1]; Collard, F.[1]; Peyridieu, S.[1]; Urvoy, M.[1]; Picot, N.[2]; Guinle, T.[2]; Cancet, M.[3]; Birol, F.[4]

[1]CLS; [2]CNES; [3]NOVELTIS; [4]LEGOS

Near the coasts, satellite altimeter techniques are unfortunately limited by a growth of their error budget. This quality loss is due on one hand to the land contamination in the altimetric and the radiometric footprints until respectively 10km and 50km and on the other hand to inaccurate geophysical corrections (tides, high-frequency processes forced by atmospheric forcing). In order to recover these data close to the coast that may contain useful information for coastal studies, the French Spatial Agency (CNES) funded the development of the PISTACH prototype dedicated to Jason-2 altimeter processing in coastal ocean. Since November 2008, these new satellite altimeter products have been providing new retracking solutions, several state-of-the-art or with higher resolution corrections in addition to standard fields. In 2010, Dufau et al.(4th CAWS) evidenced the need of data post-processing (editing & filtering) of the PISTACH dataset to study ocean dynamics near the coasts of the North West Mediterranean Sea. In 2011, the PISTACH team has newly developed an adapted post-processing (editing, filtering) and produced level-3 PISTACH datasets along several tracks that cross the Agulhas Current and the Florida Strait. This study gives the final recipe to be applied on the native PISTACH dataset for studying ocean dynamics of these coastal areas. Over each area, each step of the level-3 processing is explained and illustrated as well as the optimal choice of the Sea Surface Height solution. The L3 PISTACH data sets have been used to derive along track geostrophic currents and the altimetric currents are compared with two kinds of independent data: currents derived from SAR over the Agulhas Current and currents measured by a currentmeter located in the Florida Keys. The results obtained with PISTACH L3 products are also compared with standard AVISO L3 products.

High Resolution Altimeter Gridded Fields for Coastal and Regional Studies: Applications In The Western Mediterranean

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Previous studies have shown that the merging of multiple altimeter missions provide improved description of the mesoscale variability but they have also pointed out that the present configuration still lacks of enough resolution for correctly sampling regional and coastal features. In this context, we develop and test alternative methods to generate high resolution altimeter maps by using a two step method in which smaller scales are added close to the altimeter tracks. In a first step, the large scale signals (~100 km) are removed by subtracting the standard gridded Sea Level Anomaly maps (AVISO) to along track data (unfiltered and unsubsampled). In a second step, the residuals are submitted to an objective analysis scheme with correlation scales adjusted to smaller mesoscale dynamics. A method including bathymetric constraint has been tested to provide a pseudo-dynamical boundary condition and to increase reliability in the coastal region. SST data information from satellite sensors are also integrated in the covariance function to gain resolution. The methods are applied over the 2002-2010 period in the NW Mediterranean, a challenging area due to the low signal to noise ratio but where expertise and independent in situ data are available. As expected, the new fields display smaller features not present in the AVISO product with higher levels of Eddy Kinetic Energy close to the tracks. The mean power spectra (averaging all tracks and passes) also presents an increase in energy for wavelengths smaller than 200 km. Additionally, several tests were performed changing the correlation scales and altimeter, and the results did not present important sensitivity for small changes in the parameters. A correlation scale of 20 km and measurement noise variance of 9 cm^2 were finally selected. The dataset is then compared to independent data such as drifters launched in the area, several campaigns with in-situ data and glider information, revealing an improvement in the resolution of some small scale features. However, the method does not improve significantly the accuracy when statistical comparisons with drifters are performed in all the area. A crossvalidation with independent along track altimeter data shows a modest reduction of the differences between interpolated maps and along track measurements when the statistics are computed for interpolation errors smaller than 20% of the total variance. Finally we explore the potential of combining altimeter data with tide gauges located along the Mallorca coast in order to improve coastal features. Some illustrations of preliminary results will be presented

Sea Level Variation over the NE US Coast-Shelf Region from Altimetry

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In this study, coastal TOPEX and Jason-1 altimetric sea surface height anomaly (SSHA) data for the period from 1992 to 2008 will be analyzed to examine sub-tidal SSHA variability over the northeastern US coast/shelf/slope region from the Delaware Bay to the Gulf of Maine covering the Middle Atlantic Bight. The altimeter data have been filtered using a reprocessing methodology developed for the Northeast US coastal region (Feng and Vandemark, 2011) following recent best-practices for retrieving coastal altimeter SSHA estimates (Vignudelli et al., 2011). Within an overall objective are to investigate inter-seasonal and inter-annual variations in coastal SSHA from altimetry, we attempt to characterize the SSHA variation in the along-shelf and cross-shelf directions, and to identify sea level propagation along the shelf at these time scales. Data validation and investigation includes use of sea level measurements from the regional coastal tide gauge network

Validation of Altimetry Data Near Coast in the German Bight

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Altimetry data near coast are validated in the german Bight using a network of stations maintained by the German Federal Institute of Hydrology (BfG). The network consists of two measurements platforms off-shore and of other stations on islands and on the continent. All tide gauge stations are equipped with continuous GNSS. Some of the stations have additional instruments to measure sea waves and currents. An operational model run by the German Federal Maritime and Hydrographic Agency (BSH) is available. We compare the sea level variability derived from in-situ and model data to the standard altimetry products, to PISTACH coastal product and to Cryosat oceanographic LRM data.

Improved Altimetric Accuracy of SAR Altimeters over the Ocean: Observational Evidence from CryoSat-2 SAR data

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The CryoSat-2 SIRAL altimeter has been operating in SAR mode over a number of ocean sites and has been providing L1B SAR waveforms continuously to the science community since July 2010. The CryoSat-2 SAR mode is a precursor for the SRAL altimeter on the GMES Sentinel-3 Surface Topography Mission (STM) and provides the first opportunity to gather observational evidence about the altimetric performance of SAR altimeters over water surfaces compared to conventional pulse-limited instruments. Among a number of attractive features, SAR altimeters are expected to achieve improvement in range retrieval accuracy by a factor of 2 and finer along-track spatial resolution (~ 300m), making them particularly appealing for coastal and ocean bottom topography applications. This paper presents a comparative analysis of the retrieval accuracy for sea surface height (SSH) and significant wave height (SWH) from CryoSat-2 SAR mode and Jason-2 in the Agulhas region and the North Sea. The CryoSat-2 SAR mode SSH and SWH estimates are obtained by retracking L1B CryoSat-2 SAR mode waveforms over the ocean using the physically based SAR ocean waveform models developed in the ESA project "Development of SAR Altimetry Studies and Applications over Ocean, Coastal zones and Inland waters (SAMOSA)". Our observational results indicate an almost two-fold improvement in range retrieval accuracy for CryoSat-2 SAR mode compared to Jason-2, in support of previous theoretical and numerical findings. The SAMOSA project has so far produced two physically based models to compute SAR ocean waveforms, known as SAMOSA1 and SAMOSA2 models. The SAMOSA2 model offers more comprehensive formulation that addresses some of the limitations of the SAMOSA1 model, for example with respect to response to antenna mispointing. The paper reviews the various forms of the SAMOSA models and their performance against CryoSat-2 waveforms, to inform the definition of the SAR ocean waveform model to be used in the operational SAR ocean retracker for the Sentinel-3 Surface Topography Mission.

A Geometric Approach to Reducing Land Contamination in Coastal Altimetry Signals

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Coastal offshore radar altimetry suffers from a number of potential problems, but the one unique issue is the contamination of the marine radar reflection with signals reflected or diffracted from land topography. The objectives of this work are to map the effective shoreline gap caused by this contamination on a global basis and to develop methods derived from seismology to improve the signal resolution within that gap. The availability of high resolution SRTM digital topography for most land areas of the world allows the effects of onshore topography to be predicted. Using a simple geometric approach we can model the time of the first land-sourced arrival out to the presumed width of the altimeter beam. This shows that in many coastal areas the first arrivals would interfere with the main marine reflection, even in areas of moderate coastal topography. However,

although strong specular reflections will occur in some areas, most land reflections are likely to be diffuse, so this is the worst case scenario. The diffuse reflections could be modelled by Kirchhoff-Helmholtz integration, but this seems unlikely to provide a mechanism for actually removing the land signal due to the limited accuracy of SRTM data as well as the variation in the sea surface heights themselves. The digital topography may, however, be accurate enough to predict the likely time-distance shape of the diffracted arrivals, which may in turn allow the removal of those signals by transformation into an appropriate domain. Satellite tracks passing close to islands or promontories show the classic "side-swipe" signal from off-line reflections and allow the predicted geometry to be validated. This approach must next be transferred to the more difficult case of satellite tracks crossing from sea to land (and vice versa) where the full time-distance curve is not visible. One advantage of this situation, however, is that heights from land satellite altimetry could be used to predict the geometries of land contamination signals. Not only do these represent the relevant topographic reflection, but they may also have accuracy advantages. The wide spacing of onshore satellite altimetry heights make this data set unsuitable for Kirchhoff-Helmholtz integration, but the reflection geometry means that off-line topography will have the same effect on land and marine signals and need not be corrected. This contribution assesses the extent of contamination by land reflections and outlines a geometric approach to removing or reducing their impact, allowing greater confidence in nearshore radar reflection modelling.

Impacts of Hurricane Igor on the Grand Bank Sea Level, Currents and Chlorophyll Concentration

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On Sept. 21-22, 2010, Hurricane Igor passed by the Grand Bank of Newfoundland. In this study we used Jason-2 altimetry observations, tide-gauge measurements, and MERIS/MODAS ocean color data to study the changes of sea level, currents, and chlorophyll concentration before, during and after the storm. The significant sea level increase at St. John~{!/~}s from altimetry is consistent with tide-gauge measurements. Altimetric observations reveal salient cross-shelf variation of sea level and surface geostrophic currents during the storm. The MODIS and MERIS data indicate the initiation of the phytoplankton bloom after the passage of the hurricane.

Comparison of Envisat RA-2 Altimetry Radar Returns Versus Simulated Results at Pianosa Island

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[1] Foster City, CA

Satellite borne altimetric waveforms are easily simulated using raytrace algorithms with a high resolution DTM at Pianosa Island. A discussion of the dual-resolution, super-cover algorithm and raytrace performance is also given.

CryoSat-2 Low Rate and SAR Mode in the Coastal Zone – Limits and Possibilities with an Outlook to Sentinel-3

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The ESA Earth Explorer mission CryoSat-2 provides a unique opportunity for exploring a broad variety of scientific applications in the fields of Geodesy and Oceanography. Especially the coastal zones are of added value because of their socio-economic importance to mankind. The work of this paper is divided into two parts. Firstly, the assessment of the limits of pulse limited altimetry in the coastal zone with the standard CryoSat-2 Level 2 Low Rate Mode (L2 LRM) data. An ADT has been computed using the above mentioned data with geoid heights derived from the satellite-only GOCE time-wise geoid model. Secondly, a valuation of the upcoming possibilities, using data from the newly available Synthetic Aperture Radar (SAR) mode for ADT computations. As it can be expected from the experience with e.g. Jason-2 and Envisat, the errors of the sea surface heights from the altimeter in the pulse limited mode are far too high near the coast for a proper ADT determination. This is due to land contamination of the echoes received near the coast and the use of an insufficient atmospheric correction for the coastal zone. Bridging to the still experimental SAR-mode with its much smaller footprint size of about 300 meters, the effect of land contamination can be significantly reduced approaching near to the coast line. Thus a clear improvement of the quality of the ADT can be observed. Attention is also paid to the possibilities and limits of the use of GOCE derived geoid fields in the coastal zone. SAR-mode data from CryoSat-2 is only available in selected areas, which are used as samples to prepare for the launch of Sentinel-3 with its SAR-mode coverage in a global 300 km wide coastal zone

The Basic Radar Altimetry Toolbox for Oceanographers

Lucas, B[1]; BRAT, Team[2]
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The Basic Radar Altimetry Toolbox (BRAT) is a set of software tools and highly detailed and instructive collection of documentation. This project started in 2006 from the joint efforts of ESA and CNES and it is already on version 3.0.1 of the software. The software tools provide several ways to interact with the most common altimetry data formats, being the most used the Graphical User Interface (BratGui), this GUI is a front-end for the powerful command line tools that are part of the BRAT suite. A good feature of BRAT is that one can use its reading libraries to handle all the data formats and just obtain the desired data using Matlab, IDL, or even via an API that works for C/C++ and Fortan. The BratDisplay (graphic visualizer) can be launched from BratGui, or used as a stand-alone tool to visualize netCDF files – it is distributed with another ESA toolbox (GUT) as the visualizer. The most frequent uses of BRAT are quick data visualization/export and simple computation on the data fields. BRAT can be used for importing data and having a quick look at his contents, with several different types of plotting available. One can also use it 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 BratGui 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 (MSS, MSLA, etc.). The documentation collection includes the standard user manual explaining all the ways to interact with the set of software tools but the most important item is the Radar Altimeter Tutorial, that contains a strong introduction to altimetry, showing its applications in different fields such as Cryosphere, Geodesy, Hydrology among others, but with a focus on Oceanography. Included are also “use cases”, with step-by-step examples, on how to use the toolbox in the different contexts. For Oceanography the “use cases” are the Gulf Stream and its seasonal variation, Ocean eddies in the Kuroshio current, Computation of Geostrophic velocities (vector plots was one of the latest improvements of the toolbox), The North Western Mediterranean Sea (Coastal studies). The software is distributed under the GNU GPL open-source license and can be obtained, along with all the documentation, on the webstite: http://earth.esa.int/brat.

Application of a Mixed-Pixel Algorithm to TOPEX for Coastal Wet Tropospheric Delay Retrieval

Misra, S; Brown, S

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Current GDR processing for the TOPEX system is based on a standard path delay retrieval algorithm developed by (Keihm et al. 1995 - TGRS). The algorithm works on the unique principle of retrieving path delay information by applying binned retrieval coefficients to the measured microwave brightness temperature. The coefficients are binned with respect to retrieved wind speed and approximate path delay values.

A new algorithm developed by (Brown 2010 - TGRS), known as the mixed pixel algorithm, works on a similar principle for retrieval of path delay near the coastal regions. Contamination of the radiometer footprint due to mixed land and ocean scenes can contribute to retrieval errors. The mixed pixel algorithm retrieves path delays near such regions based on coefficients binned in land fraction and approximate path delay values. The above algorithm has already been successfully applied to GDR processing for the Advanced Microwave Radiometer (AMR) on Jason-2 as well as the Jason-1 Microwave Radiometer (JMR) for Jason-1. The new TMR coastal path delay data will be distributed as a TMR enhanced product as was done for AMR and JMR for Jason-1 and Jason-2 respectively.

This paper compares and contrasts the performance of the mixed-pixel algorithm applied to TOPEX with AMR and JMR. The algorithm results are validated with comparison to model path-delay data as well as ground-truth data from near-by GPS sites. The improvement of the new TOPEX coastal path delay retrieval with results from the previous open-ocean algorithm is also quantified. A brief description of the original open-ocean algorithm and mixed-pixel algorithm will be presented. Performance results from applying the algorithm to TOPEX will be presented, comparing retrieved path delays to model data as well as ground-truth.

Altimetry Observations of Coastal Kelvin Waves in the Bay of Bengal

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Kelvin waves originating in the equatorial Indian Ocean propagate along the equatorial wave guide until reaching the Sumatra coast and follow the coastal waveguide counter clockwise around the perimeter of the Bay of Bengal. We observed these coastal Kelvin waves using altimetry as well as model simulations from the HYbrid Coordinate Ocean Model (HYCOM) and Simple Ocean Data Assimilation (SODA) reanalysis for the period from 1993-2006. Sea surface height anomalies (SSHA) and surface currents are compared between altimetry measurements and model simulations. The wavelet analyses revealed the period and extent of these waves. The satellite and model simulations have similar cycles of an upwelling Kelvin wave propagating during the period from January to April of each year, and a downwelling Kelvin wave propagating during the period from May to August of each year. The beginning phase of the upwelling (downwelling) Kelvin wave is followed by strong currents blowing the opposite (same) direction of the propagation. Wavelet analysis of these coastal Kelvin waves shows a semiannual period off the coast of Sumatra, and transitions into an annual period as it continues around the perimeter of the Bay of Bengal. In this work we discussed these coastal Kelvin waves and upper ocean circulation in the Bay of Bengal.

Reconstruction of Sea Level Change in South East Asia Waters Using Combined Tide Gauge and Satellite Altimetry Data

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Low lying and densely populated coastal areas with thousands of small islands spreading across the South East Asia is highly prone to sea level rise affected by global warming. Accurate sea level maps in South East Asia, where the coastal tide gauge data record is too short and sparsely distributed to map sea level trends, is of great importance to scientists and decision makers in the region interested in past, present and future sea level change. Improving the near-coast altimetry processing will extend the coastal sea level record back in time and allow accurate mapping of sea level change in the region using existing reconstruction techniques.

Maps of global sea level change affected by global warming are reconstructed using Cyclostationary Empirical Orthogonal Functions (CSEOF) by fitting the satellite-derived sea level variability to coastal tide gauge observations. This method is an improved reconstruction technique, in comparison to methods based on fitting EOFs to global coastal tide gauge data for estimating the regional distribution of sea level rise over the last 60 years. However, further improvement is necessary to improve the accuracy of satellite in coastal area and shallow waters. The CSEOF method, applied to an improved satellite altimeter-data archive calibrated using coastal gauge stations in the region and incorporating the spatial data will improve mapping of Sea Level Change in the South East Asia Region.

The project will provide model for spatial map of sea level change in time series for sampling areas of Indonesia and Vietnam using reconstruction function derived based on CSEOF and coastal altimetry. The model could be the basic foundation to provide continuous improvement from sampling areas to other parts of the South East Asia region based on the development of land and marine spatial data archive adequate for coastal altimetry. The project will demonstrate multi disciplinary collaboration amongst scientists of various institutions as well as universities and government institutions in South East Asia. This will enhance human capacity development through the exchange of ideas, transfer of technology and upgrading of knowledge and skills. Reconstructing sea level change across the archipelagic regions, it is of importance for policy makers to have a spatial model that could show sea level change from the past to present and the model will be provided accessible to research communities and government as an input and an alternative data making a policy or regulation decisions.

Eastern Mediterranean Tide Gauge Network – eMACnet

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The eastern Mediterranean Altimeter Calibration network—eMACnet, is the result of collaborative efforts in the Aegean since 2001. Originally with one permanent absolute calibration facility (Gavdos) and recently with a second site at Kasteli, Crete, Greece, both of these sites in collaboration with a local team from the Tech. Univ. of Crete. Since 2008 our team expanded to include the Nat. Tech. Univ. of Athens (NTUA). The primary purpose of the extended network is the calibration and validation of altimetry missions. However, over the past years we have initiated a near real-time release of sea-level observations from our sites using EUMETCAST and the GTS. We hope that the availability of that data will help in other applications beyond altimeter calibration. The locations of our sites for example are also of interest to tsunami warning networks. We thus intend to provide our observations in near real-time to the European Tsunami Warning System (ETWS). At present, KASTELI in western Crete is delivering 1-minute sampled data every 15 minutes via EUMETCAST, and the original site at GAVDOS will follow by early September, 2011. Four more tide gauges are in operation at the sites of PALEKASTRO, eastern Crete (with CGRS), MANI-KARAVOSTASI, in southern Peloponnese, EMPORIO, Chios, and THASOS, in Northern Aegean. An additional system along with a CGRS receiver will be deployed at KYMI, north of Athens on the island of EVIA, followed by one on northern mainland Greece. Our cooperation with the Hellenic Navy Hydrographic Service (HNHS) will allow us to tap into the network of tide gauges that they operate, while they will benefit from the availability of our data, making the combined network one of the most complete in the Aegean area. Our future plans include in addition to installation of more stations the completion of CORS GNSS systems at all of the existing sites for a complete and absolute characterization of sea-level change in the area.

CryoSat Processing Prototype, LRM and SAR Processing on CNES Side

Picot, N.[1]; Thibaut, P.[2]

[1]CNES; [2]CLS

In the frame of the Sentinel-3 project, CNES is involved in the overall topography payload product quality. Like CryoSat, Sentinel3 embarks an altimeter including a conventional LRM mode and a SAR mode. While there is a long experience of LRM data processing, SAR nadir looking data are new and will need extensive prototype development and an in depth validation. Thanks to CryoSat project, acquisitions of SAR data are performed routinely over dedicated areas (Algulha current, North Atlantic, ...). Those SAR data are very valuable to assess the quality of the SAR processing methods currently under development. For example, a Cryosat Processing Prototype (C2P) has been developed on CNES side to prepare the CNES SAR ocean retracking study. In order to validate our prototype, the analysis has been conducted first on the LRM data, then on LRM_look_like data reconstructed on ground with the SAR data. C2P uses directly the LRM and SAR telemetry files and perform the whole processing steps required to derive sea surface information. It is so independent from the operational IPFs products. The C2P has been validated thanks to the use of Jason-2 data. This paper will focus on the prototype architecture and validation and will present the results obtained with CryoSat data during summer 2011. We have then experienced the processing on CryoSat products over November and December 2010 and we have performed cross comparison exercises with Jason-2 mission data and with multi mission DUACS maps. Specific attention will be paid in the coastal area were the CryoSat SAR data will improve the resolution of the ocean variability.

Implementation of the Hyperbolic Pretracker

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Small patches of the ocean surface with anomalously high backscatter lead to characteristic hyperbolic patterns in the altimeter waveforms. Such "bright targets" cause individual average waveforms to have a shape far from that consistent with the Brown model, and consequently lead to large errors in the application of standard waveform-fitting techniques. Sheltered bays with almost glassy surfaces are a particular cause of such features, and with the increasing interest in effective monitoring of the coastal zone, the continued discarding of such contaminated data is no longer acceptable.

There have been various attempts to model such complicated waveforms as a combination of a Brown plus a narrow peak, but such a model can be hard to fit, especially when the added peak is near the leading edge, and also such an approach neglects the contextual information available from neighbouring waveforms. The approach advocated here fits a hyperbola to the set of waveforms and removes that signal to leave a "cleaned" set of waveforms, which are amenable to conventional waveform-fitting techniques. This model has been tuned to work on Envisat waveforms, through accurate simulations of the altimeter's waveform record across backscatter anomalies. The retrieval has been optimised to work with realistic levels of Rayleigh (fading) noise, and the solution cast in matrix notation to enable efficient processing. Its effectiveness will be shown by application to case studies using real Envisat altimeter data.

Numerical Simulation of Radar Altimeter Waveforms – Foam Effects

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Conceptually at least, most sea parameter retrieval techniques for radar altimeters originate from Brown’s model of signal waveforms, together with appropriate calibration. Apart from the limits deriving from the necessarily simple forms of analytical sea wave spectrum (e.g. Pierson Moskowitz or JONSWAP), which do not allow the introduction of multimodal sea states, no information on the spatial distribution of the local backscattering coefficient over the sea surface is therefore normally taken into account. Since the roughness induced by the wind and the presence of whitecaps and floating foam have a great influence on the backscattering coefficient of the sea surface, errors are bound to arise in both Significant Wave Height (Sea State Bias) and Sea Level (Mean Sea Surface Bias). Such effects have been the object of intense research over the years (Gommenginger and Srokosz 2006) and analytical and empirical models have been produced over the years (Vandemark et al. 2005, Elfouhaily et al. 2000). However, such problems are so complex geometrically and physically that, in order to reconstruct the altimeter waveforms, a numerical rather than an analytical simulation of the sea surface and of its backscattering properties seems to presents some obvious advantages. Early attempts by Brüning et al. (1990) in the related field of SAR imagery analysis were not pursued with great success, presumably because of the inadequacy of computing power at the time. The numerical technique however presents a much greater flexibility, at the price of a heavy computational effort: more recently, Pugliese Carratelli and co-workers have produced some results based on the numerical simulation of the altimeter Significant Wave Height (Della Rocca and Pugliese Carratelli, 2000) as well as of SAR imagery (Pugliese Carratelli et al., 2006, 2007, 2008). The poster which will be presented at the conference will provide a detailed description of the algorithm used to simulate the altimeter waveform. In the first phase, starting from the description of sea surface and a number of physical assumptions, the backscattering coefficient is calculated for each value of the instantaneous water height, i.e. for each annular area of the sea surface, since circular symmetry is assumed. In the second phase, the evolution of the illuminated surface is followed in time, and therefore in elevation, during the whole pulse duration. As the EM wave front proceeds, annular surfaces are covered at different water heights, and the backscattered energy is computed as a function of the time. Obviously, while the second phase is conceptually well defined, if computationally delicate, the first part involves all the physical concepts and is therefore critical. The example to be shown in the poster is an attempt to investigate into the effects of whitecaps and floating foam on the formation of waveforms. This aspect is indeed relatively little understood, even if it is interesting to note that Zheng et al. (1983) took into consideration the effects of foam on altimeter response. A standard JONSWAP spectrum is assumed, and a sea surface realisation is randomly generated, very much like in Della Rocca & Pugliese Carratelli, (2000) and in the following papers by the Pugliese Carratelli et al. Within this framework, the trajectory of foam particles is simulated, from its birth (whitecap formation) through its decay, following Chapron and Reul's (2003) work on the evolution of foam layers. The percentage of foam covered sea surface, and the backscattering coefficient for each elementary annular surface are thus calculated. The connection between the thickness of the foam layer and the microwave reflectivity are connected by the law provided by Zheng et al. (1983). The algorithm provides, as it was to be expected, a bias on the estimated sea surface, since the reflection from the higher part of surface waves is stronger than from their troughs. Qualitatively, this is a classical result, but it is hoped that the availability of a flexible numerical model, with relatively few parameters, may help improve the understanding of the altimeter biases as well as of the whitecaps and foam movement mechanism.

Development of MMIC-based High-Frequency Radiometers to Improve Wet-Tropospheric Delay Correction in the Coastal Zone

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Current satellite ocean altimeters include nadir-viewing, co-located 18-37 GHz multi-channel microwave radiometers to measure wet-tropospheric path delay. Due to the area of the surface instantaneous fields of view (IFOV) at these frequencies, the accuracy of wet path retrievals begins to degrade at approximately 40 km from the coasts. In addition, they do not provide wet path delay estimates over land. A viable approach to meet these needs is the addition of millimeter-wave window channels at 90-170 GHz, with inherently

finer spatial resolution for a given antenna size. The addition of these millimeter-wave channels to current Jason-class radiometers is expected to improve retrievals of wet-tropospheric delay in coastal areas and to increase the potential for over-land retrievals. The principal objective of this technology development is to assess the ability of higher-frequency radiometers to meet the needs of the Surface Water and Ocean Topography (SWOT) mission recommended by the U.S. National Research Councilâ€™s Earth Science Decadal Survey and planned for launch in 2020. The primary objectives of SWOT are to characterize ocean sub-mesoscale processes on a 10-km scale and larger in the global oceans, and to measure the global water storage in inland surface water bodies, including rivers, lakes, reservoirs, and wetlands. Critical microwave component and receiver technologies are under development to reduce the risk, cost, volume, mass, and development time for high-frequency microwave radiometers. This project focuses on the design and fabrication of (1) low-power, low-mass and small-volume direct-detection millimeter-wave radiometers with integrated calibration sources operating from 90 to 170 GHz that fit within the overall SWOT mission constraints, and (2) a multi-frequency feed horn covering the same frequency range. The three key component technologies under development to achieve these objectives are a PIN-diode switch for internal calibration that can be integrated into the receiver front end, a high-Excess Noise Ratio (ENR) noise source and a single, tri-frequency feed horn. These new components are being integrated into a MMIC-based low-mass, low-power, small-volume technology-demonstration radiometer with channels centered at 92, 130 and 166 GHz. Finally, in a new project under the NASA Instrument Incubator Program, we will develop, build and flight test an internally-calibrated High-Frequency Airborne Microwave Radiometer (HFAMR) to reduce the risks associated with wet-tropospheric path delay correction over coastal areas and fresh water bodies. This instrument is designed to (1) assess wet-tropospheric path delay variability on 10-km and smaller spatial scales, (2) demonstrate millimeter-wave radiometry using both window and sounding channels to improve both coastal and over-land retrievals of wet-tropospheric path delay, and (3) provide an instrument for calibration and validation in support of the SWOT mission.

Tides in Shallow Water from Multi-Mission-Altimetry

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The tidal regimes in shallow water are significant less known than over the deep ocean. In shallow water the wave lengths of linear and non-linear tides are short and the ground track patterns of TOPEX and Jason are too coarse to estimate the complicated tidal spectra. In order to improve the spatial resolution and allow the estimation of more and smaller constituents additional data should be used. Although the altimeter data of ERS, ENVISAT, and GFO are suboptimal for the tidal analysis they can complement the time series of TOPEX and Jason data. Cross-calibrating altimeter data by means of multi-mission-crossover analysis appears as data of a single, virtual altimeter system and allows the combination of all missions without considering mission specific aspects. The auto-correlation functions – as one of the results of cross-calibration – are used to account for the strong correlation between along-track altimeter measurements. The aim of this paper is to show the potential of the multi-mission-altimetry for the modeling of linear and non-linear tides in shallow water areas. The tidal constants of independent sources like coastal tide gauges and bottom pressure gauges are used for the validation of results.

Satellite Altimetry over Inland Water: a New Tool to Detect Geoid Errors!

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Nowadays satellite altimetry is not only used over open ocean but also over inland waters. Some applications as, for example, investigations on inundation zones require to consider physical heights which tell you where water will flow. This implies to reduce geometric (elliptic) lake heights by an utmost precise geoid. Physical heights of a lake surface should exhibit a flat surface, as in general the water is in balance with gravity and the hydrodynamics of lakes can be neglected. In this paper we investigate physical heights over a few rather large lakes by using different geoid models. The high resolution EGM2008 model seems to be most convenient for this purpose. Physical lake heights, derived with EGM2008 are, however, not flat. The latest gravity field models from GOCE indicate significant errors of EGM2008 in particular over land areas. Therefore we generated a hybrid model by extending the GOCO02S model by the high frequency parts of EGM2008. This hybrid model improves the physical heights, but deviations from a flat surface remain. These deviations are too large to be explained as geostrophic currents. Thus the remaining variations of physical heights must be interpreted as residual geoid errors.

Bright Targets in the Coastal Zone: A Reconstruction Approach Applied to Envisat RA-2 Data

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Usage and availability of Sea Surface Height (SSH) information from satellite radar altimeters undergo known limitations in the coastal zone, where such data are of great importance and usefulness. In fact, coastal regions are a crucial zone to be investigated and monitored, due to the high impact of sea level and circulation changes on the environmental security and related economic and societal aspects. It is known that radar returns from the sea surface sometimes present target-like echoes (“bright targets”), especially in correspondence of particular features of the coastal zones, thus entailing a potential interference with SSH measurements. The hyperbolic patterns generated by such spiky echoes in the radargram domain have been tentatively explained as resulting from flat water areas in the proximity of the coastline, but their direct physical mechanism is still unclear. This poster describes the experimentation of a microwave tomographic reconstruction approach applied to Envisat RA-2 averaged waveforms, tested on selected passes over the Pianosa island (a 10 km2 island in the NW Mediterranean), with the aim of identifying the signal contamination sources in terms of their location and extent. The obtained results encourage the idea that the origin of such signatures is associated with particular conditions of the sea surface, that are easier to be found in the proximity of coastal closed areas, such as gulfs.

Agulhas Current Estimation from High Resolution Altimetry

Tournadre, Jean[1]; Collard, Fabrice[2]; Chapron, Bertrand[1]
[1]Ifremer; [2]CLS

The Topex/poseidon, Jason1 and Jason2 archive of high resolution (10 or 20 Hz) altimeter data have been reanalyzed along 4 passes intersecting the Aghullas current between Port Elizabeth and Durban to estimate the absolute geostrophic current. First the altimeter sea surface height data are corrected (geophysical corrections) and are then filterd for the high frequency noise. For each pass, the along-track mean sea surface height is then estimated and then subtracted from the sea surface height to compute the sea level anomaly . By adding the mean dynamic computed from the mean absolute velocity field obtained from SAR data to the along sea level anomaly we obtain the absolute along track dynamic topography.
Compare to the classical 1Hz data processing the use of the HR data allows to better preserve the along-track sea level gradient and thus to have a better estimate of the geostrophic current (compared to SAR data). We present the 20 year analysis of the Aghullas current speed for the 4 passes for which the distance between the current and the coast varie from 0 to 100 km.

Altimeter Analysis of Seasonal Circulation over the Patagonian Shelf

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We continue to investigate the use of altimeter data to look at seasonal changes in ocean circulation over the continental shelf along the SW margin of the Atlantic Ocean between 30°-50°S. This energetic region has strong tidal motions over the wide shelf and robust boundary currents and eddies in the deep ocean next to the shelf. Altimeter sea surface height (SSH) data have been used extensively to describe the current structures offshore of the shelf break. Over the shelf, however, the strong tidal SSH signals have deterred researchers from using the altimeter data. The assumption is that errors in the standard tide models will overwhelm the signals associated with shelf currents. In this study we test this assumption. Looking at along-track data, our previous studies have shown that long-term (17yr+) monthly and seasonal means reduce random errors enough to reveal coherent seasonal signals over the shelf. We extend that analysis here to include the standard AVISO gridded maps of SSH. While the along-track data are informative and allow tests of the most basic form of the altimeter data, they are also more ambiguous in their representation of shelf circulation. Two-dimensional maps of SSH, on the other hand, provide a more complete description of the flow's geostrophic circulation. Here we evaluate whether the widely-used gridded and mapped data produce fields consistent with our along-track results.

SAR Data over Ocean, Processing Strategy and Continuity with LRM Data,

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The nadir looking SAR altimeter concept has been studied in parallel in ESA and the US since the mid 1990s. This concept is now implemented in SIRAL instrument operating on board CryoSat-2 mission launched early 2010, and dedicated to ice topography observations. However, this novel altimeter concept can be very advantageous for observation of ocean surfaces, as it promises improved altimetric precision and better along-track resolution than conventional pulse-limited altimeters. This will allow to achieve high-resolution high-accuracy altimetric mapping of the ocean in regions of high mesoscale variability and in coastal areas. Several studies are ongoing to develop and test suitable processing algorithms for this new altimeter mode. This paper will present the ongoing study conducted by CLS under a CNES funding using simulated tools and Cryosat-2 flight data provided by the CryoSat project. In particular the continuity between SAR and LRM products will be addressed.

Radar Altimetry Waveform Retracking Applied to Coastal Ocean and Narrow Inland-Water Bodies

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Measuring sea surface height at coastal (< 30 km from coasts) and shallow (< 200 m in depth) water region has long been a challenge for researchers since the returned radar altimeter waveform is contaminated by complex land topographic surfaces and shorelines, as well as, stronger ocean dynamics including tides, resulting in much less accurate measurements if the altimeter is still on-lock. In addition, critical media and geophysical corrections, including wet and dry troposphere, ionosphere, and ocean tides, remain problematic, further degrading the measurement accuracy. Perhaps a more challenging research is to improve radar altimetry over small water bodies (< 1 km width, which is much smaller than the 1-Hz data sampling from a nadir altimeter, with footprints of several km), for the purpose of inland hydrologic or hydraulic studies. Here we demonstrate examples towards addressing the above challenging research problems using contemporary radar altimetry: (1) coastal retracking of TOPEX/Jason-1/Jason-2 altimetry over coastal Gulf of Mexico and coastal California, to examine the viability towards a comprehensive generation of improved coastal altimetry data, and (2) retracked radar altimetry data over Poyang Lake at Jiangxi, China, showing the unreliability of conventional backscattering coefficients (BCs) criteria for a footprint covering water and high-reflective sediments within the floodplain. For the latter example, observed radar altimetry water level change is validated by the MODIS data using the Modified Normalized Difference Water Index (MNDWI). Here we intend to demonstrate the advantage of combining altimetry and passive remote-sensing data to reduce the uncertainty of estimated water level and water surface extent. A technique of waveform editing based on empirical surface response and a migration of waveform peaks, known as the hooking effects, is also used towards estimating narrow (1~2 km in width) inland-water surrounded by terrains with steep gradients. The technique improves the accuracy to 1-meter level with high Improvement Percentages (IMPs) compared with onboard retrackers.