Ocean Surface Topography Science Team Meeting

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Millennium Harvest House Hotel
1345 28th Street
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Earth's energy imbalance and implications for ocean heat content

Kevin Trenberth, National Center for Atmopheric Research

Session theme: Science Results from Satellite Altimetry
Keynote

"Global warming" from increased greenhouse gases really refers to a global energy imbalance at the top-of-atmosphere (TOA). Global fluctuations in TOA energy of up to 0.2 W m-2 occur from natural variations in clouds, aerosols, and changes in the Sun. At times of major volcanic eruptions the effects can be much larger. An energy imbalance is manifested not just as surface atmospheric or ground warming, but also as melting sea and land ice, and heating of the oceans. An inventory of energy shows that over 90% of the imbalance is manifested as ocean heat content (OHC), and this with melting land ice, causes sea level to rise. For the past decade, over 30% of the heat has apparently penetrated below 700m depth that is traceable to changes in surface winds mainly over the Pacific in association with a switch to a negative phase of the Pacific Decadal Oscillation (PDO) in 1999. Surface warming was much more in evidence during the 1976-1998 positive phase of the PDO, suggesting that natural decadal variability modulates the rate of change of global surface temperatures while sea level rise is more relentless.
We use ORAS4 ocean reanalysis data and other OHC estimates to compare the OHC rates of change with model-based estimates of TOA energy imbalance (from CCSM4), and with TOA satellite measurements for the year 2000 onwards. Most of the ocean-only OHC analyses extend to only 700 m depth, have large discrepancies among the rates of change of OHC, and do not resolve interannual variability adequately to capture ENSO and volcanic eruption effects, all aspects that are improved with assimilation of multi-variate data. ORAS4 rates-of-change of OHC quantitatively agree with the radiative forcing estimates of impacts of the 3 major volcanic eruptions since 1960 (Mt. Agung 1963, El Chichón 1982, and Mt. Pinatubo 1991). Estimates (OHC and TOA) show that over the past decade the energy imbalance ranges between about 0.5 and 1 W m-2. By using the full-depth ocean, there is a better overall accounting for energy, but discrepancies remain at interannual timescales between OHC and TOA radiation measurements, notably in 2008-09.

Jason-1 : three successful phases of ocean monitoring

Rosemary Morrow, LEGOS / Observatoir-Midi-Pyrenees
Pascal Bonnefond, Observatoire de la Cote d'Azur – GEOAzur, Valbonne, France
Lee-Lueng Fu, 3. Jet Propulsion Laboratory, CALTech, Pasadena, California, USA
Josh Willis, 3. Jet Propulsion Laboratory, CALTech, Pasadena, California, USA
Thierry Guinle, CNES, Toulouse, France
Glenn Shirtliffe, 3. Jet Propulsion Laboratory, CALTech, Pasadena, California, USA

Session theme: Science Results from Satellite Altimetry
Keynote

The ocean observing satellite altimeter Jason-1 was launched from Vandenberg Air Force Base, Calif., on December 7th, 2001, and terminated its mission on July 2nd, 2013. With more than 11 years in orbit, Jason-1 became one of the longest-lived oceanographic satellites. Much smaller and lighter than TOPEX, Jason-1 was the first satellite to use the CNES-TAS PROTEUS platform, and the digital radar altimeter instrument Poseidon-2. With a 3-system precise orbit determination (laser retroreflector array, DORIS orbitography instrument, and GPS receivers), and its microwave radiometer, Jason-1 demonstrated that a lighter, precise, reference altimetry mission was possible, and these technological choices have continued with Jason-2 in 2008, and Jason-3 planned in 2015.

During its lifetime, Jason-1 provided a major contribution to the monitoring of sea level rise, an essential climate variable. This was due to its excellent measurement accuracy, the long-term stability of its instruments, and the continuous effort of calibration-validation. This precise calibration was assisted by two key periods of formation flying intercalibration, with its predecessor TOPEX in 2001, then with its successor Jason-2 in 2008, allowing us to maintain measurement uncertainty below the 0.5 mm/year mark.

Jason-1 was an exemplary and multi-faceted altimeter mission. Not only did Jason-1 extend the precise climate record established by Topex/Poseidon, it then made invaluable observations for mesoscale ocean studies on his second, interleaved orbit. Even when moved to a "graveyard" orbit, Jason-1 continued to make unprecedented new observations of the Earth's gravity field, with precise measurements right till the end.

Jason-1 observed the full spectra of ocean variations, including the near 4 cm rise in global sea level over that period, helped reveal the different flavours of El Nino in the early 20th century, extended the monitoring of mesoscale eddies over a 2 decade period, and even made precious observations of extreme events such as tsunamis or the ocean interaction with cyclones and hurricanes. Last, but not least, Jason-1 also played a key role in the transition of altimetry towards more operational applications, and accompanied the development of the global Argo program and the GODAE ocean forecasting programs.

This presentation will cover some of the many success and achievements of Jason-1 over the last 11.5 years.

Meso-submesoscale dynamics and their impact on sea-level: overview of recent studies and future perspectives

Patrice Klein, LPO/IFREMER

Session theme: Science Results from Satellite Altimetry
Keynote

Theoretical and numerical studies of the last ten years have higlighted the significant impact of the meso/submesoscale eddies and fronts (in particular in the scale range 10 km -100 km) on the larger-scale ocean dynamics and on the vertical transports of any properties. These meso/submesoscale structures have been found to represent a significant part of the ocean surface kinetic energy and, because of their aspect ratio (vertical to horizontal), to explain a large part of the 3D dynamics (including vertical motions) in the first 500 m below the surface.

The new class of wide-swath altimeters (such as SWOT and COMPIRA) should be able to monitor the surface dynamics of this meso/submesoscale turbulence. Furthermore, as pointed out by some recent studies, they may have the potential to estimate the 3D dynamics of the first 500 m (with the help of theoretical arguments and using some interior data at large-scale). As such these altimeters open a new exciting, very important and unique avenue not only for the ocean dynamics but also for the physical-biological - as well as the air-sea - interactions.

To be able to fully exploit the strong potential of these new altimeters when data will become available, some scientific questions have still to be addressed such as for example, the interactions between the mesoscale/submesoscale dynamics with the interior dynamics and, with the unbalanced motions (internal tides, inertial motions, mixed-layer dynamics ...). Other questions concern the potential synergy between these new altimeters and the existing satellite data. To address these questions in the next future, an international effort should be put in coordinating scientific research on ocean dynamics on scales between 10 km and 100 km.

This talk will review these recent results on mesoscale/submesoscale turbulence as well as the questions to be tackled in the next future. It will present some strategies to move forward. At last it will introduce the new international working group on mesoscale/sub-mesoscale processes (bringing together observationalists, modellers, theoreticians) whose mission is to further refine, extend and, coordinate these strategies.

Ocean Observations of Climate Change: Overview of the IPCC 5th Assessment Report

Don Chambers, University of South Florida, College of Marine Science

Session theme: Science Results from Satellite Altimetry
Keynote

The ocean influences climate by storing and transporting large amounts of heat, freshwater, and carbon, and exchanging these properties with the atmosphere. About 93% of the excess heat energy stored by the earth over the last 50 years is found in the ocean. More than three quarters of the total exchange of water between the atmosphere and the earth's surface through evaporation and precipitation takes place over the oceans. The ocean contains 50 times more carbon than the atmosphere and is at present acting to slow the rate of climate change by absorbing one quarter of human emissions of carbon dioxide from fossil fuel burning, cement production, deforestation and other land use change.

We summarize the observational evidence of change in the ocean, with an emphasis on basin- and global-scale changes relevant to climate, with a focus on studies published since the AR4. These include: changes in subsurface ocean temperature and heat content, evidence for regional changes in ocean salinity and their link to changes in evaporation and precipitation over the oceans, evidence of variability and change of ocean current patterns relevant to climate, observations of sea level change, and biogeochemical changes in the ocean, including ocean acidification.

Understanding and Projecting Sea Level Change: An Overview of the IPCC 5th Assessment Report (AR5)

R. Steven Nerem On Behalf of the Working Group I Chapter 13 Writing Team, University of Colorado at Boulder
John A. Church (Australia), Peter U. Clark (USA), Anny Cazenave (France),
Jonathan M. Gregory (UK), Svetlana Jevrejeva (UK), Anders Levermann (Germany),
Mark A. Merrifield (USA), Glenn A. Milne (Canada), R. Steven Nerem (USA),
Patrick D. Nunn (Australia), Antony J. Payne (UK), W. Tad Pfeffer (USA),
Detlef Stammer (Germany), Alakkat S. Unnikrishnan (India)

Session theme: Science Results from Satellite Altimetry
Keynote

The rate of global mean sea level rise (GMSLR) has accelerated during the last two centuries, from a rate of order tenths of mm/yr during the late Holocene, to about 1.7 mm/yr since 1901. Ocean thermal expansion and glacier melting were the dominant contributors to 20th century GMSLR, with relatively small contributions from the Greenland and Antarctic ice sheets. Process-based models suggest that the larger rate of rise since 1990 results from increased radiative forcing (both natural and anthropogenic) and increased ice-sheet outflow, induced by warming of the immediately adjacent ocean. Confidence in projections of global mean sea level rise has increased since the AR4 because of improved physical process-based understanding of observed sea level change, especially in recent decades, and the inclusion of future rapid ice-sheet dynamical changes, for which a quantitative assessment could not be made on the basis of scientific knowledge available at the time of the AR4. By 2100, the rate of GMSLR for a scenario of high emissions (RCP8.5) could approach the average rates that occurred during the last deglaciation, whereas for a strong emissions mitigation scenario (RCP2.6) it could stabilize at rates similar to those of the early 21st century. In either case, GMSLR will continue for many subsequent centuries. Although there has been much recent progress, projections of ice-sheet change are still uncertain, especially beyond 2100. Future sea level change will not be globally uniform, but models still exhibit substantial disagreement in projections of ice mass loss and ocean dynamics, which are the main influences on the pattern. Uncertainty in projections of future storminess is a further obstacle to confident projection of changes in sea level extremes.

SARAL/AltiKa: a Ka band altimetric mission

Jacques Verron, Laboratoire de Glaciologie et Géophysique de l'Environnement
Pierre Sengenes, CNES
CNES and CLS project teams and Contributions from SARAL/AltiKa PI's, CNES

Session theme: Science Results from Satellite Altimetry
Keynote

The SARAL-AltiKa satellite mission is an India-France ISRO-CNES joint project. The satellite has been put into orbit by a PSLV vehicle supplied by ISRO, and launched from Sriharikota, the main ISRO launch base, on Feb. 25, 2013.
The SARAL (Satellite for ARgos and ALtika) payload consists of an ARGOS instrument, and an altimetry payload including the AltiKa radiometer-altimeter. SARAL/AltiKa is intended to be a gap filler mission between the RA-2 on-board ENVISAT and Sentinel-3. As such, SARAL/AltiKa is flying on the same orbit as ENVISAT. The special feature of SARAL/AltiKa is that it is based on a wideband Ka-band altimeter (35.75 GHz, 500 MHz), which will be the first satellite altimeter dedicated to oceanography to operate at such a high frequency. The AltiKa instrument consists in a Ka-band altimeter based on already developed subsystems inherited from Siral (CRYOSAT) and Poseidon-3 (JASON-2) in particular, and an embedded dual frequency radiometer. The altimeter and the radiometer share the same antenna. Due to the single frequency Ka-band altimeter, the enhanced bandwidth leads to a better vertical resolution. The spatial resolution is also improved, thanks to the Ka-band smaller footprint and the increased PRF.
This talk will present the main characteristics of the mission and the first outcome on the data availability and the performances of the AltiKa products. In particular, SARAL/AltiKa already proved to be satisfying the expected performances or better and compare well to Jason-2 data. Also, the quality of SARAL/AltiKa data in terms of accuracy, data latency and availability has allowed to rapidly make the data available, leading especially to an efficient integration in several operational systems. First results show a lesser data loss/degradation than expected due to Ka-band sensitivity to rainy and cloudy conditions. Preliminary SARAL/AltiKa insights on mesoscale variability, coastal oceanography, inland waters and ice sheets monitoring will be shown.

SWOT mission design for advancing mesoscale oceanography

Lee-Lueng Fu, Jet Propulsion Laboratory
Clement Ubelmann, Jet Propulsion Laboratory
Rosemary Morrow, LEGOS CNES

Session theme: Science Results from Satellite Altimetry
Keynote

The Surface Water and Ocean Topography (SWOT) Mission is being developed jointly by NASA and CNES with contributions from the Canadian Space Agency. The mission's primary objectives are to map the elevations of land surface water and ocean topography with an instrument resolution of a few tens of meters for applications to land hydrology and mesoscale oceanography. A Science Definition Team was formed in late 2012 to work with the mission development team on the formulation of the mission's science requirements. A number of aspects on the mission design that are key to the success of the oceanographic objectives of the mission will be addressed in the presentation. These include the expected resolution of signals, the measurement error budget, and the calibration of the measurement performance against past record of ocean topography.

Bifrequency radiometer for Ka band altimetry mission: issues and way of improving retrieval algorithms

Estelle Obligis, CLS
Bruno Picard, CLS
Marie-Laure Frery, CLS
Nicolas Picot, CNES

Session theme: Instrument Processing
Oral

The altimeter measurement of the sea surface height is impacted by the delay due to humidity in the atmosphere. Therefore a microwave radiometer is added on board altimetry missions to determine accurately this wet tropospheric correction (dh). The inversion of a set of brightness temperatures (TBs) measured by a microwave radiometer at the location of the altimeter footprint allows the retrieval of this correction with a global accuracy around 1 cm rms (Ruf et al, 1994).
For NASA/CNES mission, the radiometer performs measurements around the water absorption line (21 or 23.8 GHz), around 35 GHz to take into account cloud liquid water content (37 or 34 GHz) and finally a low frequency channel (18 or 18.7 GHz) to take into account the surface contribution.
In the case of ESA missions (ERS-1, ERS-2, Envisat, and Sentinel-3), a bifrequency radiometer is used and the lack of the low frequency channel is partly compensated by the use of the altimeter wind speed (for ERS-1 and ERS-2 missions) or backscattering coefficient in Ku band (Envisat, Sentinel-3).
The SARAL AltiKa mission has been successfully launched 25th of February of this year. The AltiKa altimeter performs measurements in Ka band and the microwave radiometer at 23.8 GHz and 37 GHz.
The first objective of this paper is to present the performances of a standard neural algorithms based on the use of both TBs and altimeter backscattering in Ka band and the different issues that have been raised with in-flight measurements. The second one is to propose other retrieval algorithms using additional inputs (model or altimeter wind speed, SST...), and to assess their performances.

AltiKa Radiometer: first results of in-flight calibration

Marie-Laure Frery, CLS
Bruno Picard, CLS
Estelle Obligis, CLS
Laurence Eymard, Institut Pierre Simon Laplace
Pierre Sengenes, CNES
Nathalie Steunou, CNES
Nicolas Picot, CNES
Raquel Rodriguez-Suquet, CNES

Session theme: Instrument Processing
Oral

The AltiKa/SARAL mission is a complement of the Jason altimeter series. The use of a Ka band altimeter results in better performances in terms of spatial resolution and accuracy. A two-channels microwave radiometer (23.8 and 37 GHz) is combined to the altimeter in order to correct the altimeter range for the excess path delay resulting from the presence of water vapour in the troposphere. Brightness temperatures are also used for the estimation of the atmospheric attenuation of the backscattering coefficient, that is significant in Ka band. The radiometer performs measurements of brightness temperatures in both bands at the location of the altimeter footprint.

First results at instrumental level exhibit its very good thermal stability, its very fine sensitivity and its sharp spatial resolution, making of AltiKa radiometer one of the best in-flight radiometers.

Concerning the brightness temperatures, in-flight calibration during the commissioning phase aims at providing quantitative information on the accuracy and the precision of their measurements. In a long term point of view, it will be used to assess the stability of the instrument. However, the main difficulty for microwave radiometry lies in the lack of references: natural targets are neither well-known nor homogeneous enough and each in-flight instrument has its own calibration strategy. We have therefore based the calibration of AltiKa radiometer on a combination of comparisons to other instruments (AMR on Jason-2, AMSU-A) directly over specific areas (Amazonian forest, Antartica). Over ocean, double-differences using simulations as a common reference (using ECMWF analyses and UCL radiative transfer model) are used to compare AltiKa radiometer to other instruments.
We will present here the first results of the AltiKa in-flight calibration based on such comparisons.

Comparison of Retrieval Algorithms for the Wet Tropospheric Path Delay

Soulivanh Thao, CLS
Laurence Eymard, OSU ECCE TERRA
Estelle Obligis, CLS
Bruno Picard, CLS

Session theme: Instrument Processing
Oral

The exploitation of altimetry measurements over ocean relies on the feasibility to correct the altimeter range for different perturbations. One of them, the wet tropospheric correction (dh) is nearly proportional to the integrated water vapor and is provided by a dedicated instrument, a microwave radiometer.

The relationship between dh and the radiations measured by the radiometer is empirically established using a statistical regression. Three frequencies are generally used to build this relationship: around 18, 23 and 37 GHz. The main 23 GHz frequency, being close to the 22.235-GHz water vapor absorption line, is highly sensitive to water vapor. The 18-GHz and the 37-GHz channels are respectively used to eliminate the sea surface and cloud contributions from the signal to be retrieved.

Altimetry missions apply this principle to compute the wet tropospheric correction, but their algorithms notably differ on two points (excluding the learning database):

1) The method of regression used: two-step log linear regression for Jason-2/AMR and its predecessors (TOPEX/TMR and Jason1/JMR); neural network for ESA missions (ERS1/MWR, ERS2/MWR, Envisat/MWR) and ISRO/CNES mission AltiKa.

2) The number of available frequencies: 3 frequencies for NASA radiometers with a measurements at low frequency (18.7 GHz for the Jason missions) used as a source of information on the sea surface and only 2 frequencies (23.8 and 36.5 GHz) for ESA missions. In this case, the lack of a low frequency channel is partly compensated by the use of the altimeter backscattering coefficient in the retrieval algorithm.

This paper will present the performances of several retrieval algorithms, including those used in the operational processing of altimetry missions. The algorithms are built and compared on the same learning and test databases to determine which regression method is more appropriate. The importance of each input for the different algorithms is analyzed and the performances of the different algorithms are assessed in terms of error (bias and standard deviation) but also in terms of geographical distribution of the errors and correlation with other environmental variables.

AltiKa in-flight performances

Nathalie Steunou, CNES
Pierre Sengenès, CNES
Jocelyne Noubel, CNES
Nicolas Picot, CNES
Jean-Damien Desjonquères, CNES
Jean-Christophe Poisson, CLS
Pierre Thibaut, CLS
Frédéric Robert, TAS-F
Nicolas Taveneau, TAS-F

Session theme: Instrument Processing
Oral

The SARAL/AltiKa satellite has been launched the 25th of February 2013 from the launch pad of Sriharikota (India). Since this date, AltiKa provides measurements and affords the first altimetry results in Ka band. This paper recalls the instrument design and assesses the in-flight performance.
The SARAL/AltiKa mission has been developed in the frame of a cooperation between CNES (French Space Agency) and ISRO (Indian Space Research Organization). AltiKa is a single frequency Ka-band altimeter with a bi-frequency radiometer embedded. Both altimeter and radiometer share the same antenna. Altimeter expertise and routine calibrations performed during assessment phase demonstrate the stability of the instrument. Moreover the performance assessed over ocean are noteworthy such as 0.9 cm on epoch 1 Hz noise for 2 m of SWH, which is fully consistent with simulations and ground pre-flight tests results. The data availability is also very good and very few altimeter measurements are lost due to rain attenuation. Radiometer data analysis shows that the instrument is very stable and its performances are consistent with pre-flight tests results.

One and Two-Dimensional Wind Speed Models for Ka-band Altimetry

John Lillibridge, NOAA Lab. for Satellite Altimetry
Remko Scharroo, EUMETSAT
Saleh Abdalla, ECMWF
Doug Vandemark, University of New Hampshire

Session theme: Instrument Processing
Oral

SARAL/AltiKa is the first satellite radar altimetry mission to fly a Ka-band instrument. Ka-band backscatter measurements suffer larger signal attenuation due to water vapor and atmospheric liquid water than those from Ku-band altimeters. An attenuation algorithm is provided, based on radar propagation theory, which is a function of atmospheric pressure, temperature, water vapor and cloud liquid water content. Due to the nature of the air-sea interactions between wind and surface gravity waves, the shorter wavelength Ka-band backscatter exhibits a different relationship with wind speed than at Ku-band, particularly in the linear model regime at moderate to high wind speeds. Here we present a new one-dimensional wind speed model, as a function of backscatter only, and a two-dimensional model, as a function of backscatter and significant wave height, tuned to AltiKa's backscatter measurements, once corrected for attenuation. The performance of these new Ka-band altimeter wind speed models is assessed through validation with independent ocean buoy wind speeds and theory. The results indicate wind measurement accuracy comparable to that observed at Ku-band, with only a slightly elevated noise level in the wind estimates. The one-dimensional wind speed model has been endorsed by the SARAL/AltiKa project team for the next major product update to "version-D" in early 2014.

Assessing sea state bias correction models for differing frequencies and missions

Doug Vandemark, Univ. of New Hampshire/EOS
Hui Feng, Univ. of New Hampshire/EOS
Ngan Tran, CLS
Bertrand Chapron, IFREMER/Centre de Brest

Session theme: Instrument Processing
Oral

Accurate and drift-free ancillary range corrections continue to be critical in ocean altimetry both for climate data record production and many scientific applications. One objective for this study is to help solidify the choice of optimal sea state bias (SSB) models for application to satellite altimeter data from the Topex/Poseidon mission forward. To support the objective, we first present a new and more rigorous examination of the common 2D SSB estimators created using direct averaging and collinear differencing techniques. Robust uncertainty estimates for the direct-averaging model approach and derived models will be addressed to illustrate the accuracy of this method. It is shown that one can observe statistically significant agreement between wind and SWH dependencies in Ku-band SSB models for the T/P and Jason missions, indicating a self-consistent electromagnetic bias component across platforms within the overall SSB correction. We also investigate some apparent smoothing within the operational collinear SSB solutions that are likely due to data sampling limitations in data sparse portions of the two-dimensional domain used to develop these models. First assessments from SARAL/AltiKa data analyses will also be presented to compare and contrast Ku- vs. Ka-band SSB models as derived using summer 2013 AltiKa and Jason-2 datasets.

A generalized semi-analytical model for delay/Doppler altimetry and its estimation algorithms

Abderrahim Halimi, Toulouse University
Corinne Mailhes, University of Toulouse
Jean-Yves Tourneret, University of Toulouse
Pierre Thibaut, CLS
Thomas Moreau, CLS
François Boy, CNES
Nicolas Picot, CNES

Session theme: Instrument Processing
Oral

The concept of delay/Doppler radar altimeter has been under study since the mid 90's, aiming at reducing the measurement noise and increasing the along-track resolution in comparison with the conventional pulse limited altimeters. This paper introduces a generalized semi-analytical model for the delay/Doppler echo that accounts for antenna mispointing, as well as an associated least squares estimation algorithms. The mean power of a delay/Doppler echo can be expressed by a convolution of three terms that are the probability density function (PDF) of the heights of the specular scatterers, the time/frequency point target response (PTR) of the radar and the flat surface impulse response (FSIR). The first contribution of this paper is the derivation of a generalized analytical model for the FSIR that accounts for antenna mispointing. The proposed analytical expression for the FSIR also considers Earth curvature, a circular antenna pattern and a Gaussian approximation for the antenna gain. The two dimensional delay/Doppler map (DDM) is then obtained by a numerical computation of the convolution between the proposed analytical FSIR expression, the PDF of the sea wave height and the time/frequency PTR. The resulting DDM depends on five altimetric parameters that are the epoch, the significant wave height, the amplitude, the along-track and the across-track mispointing angles. Appropriate processing, including range migration and multi-looking, is applied to the resulting DDM yielding the Doppler echo (also known as the multi-look echo). The second contribution of this paper is the derivation of estimators for the five parameters associated with the multi-look echo. A least squares approach is investigated by means of the Levenberg-Marquardt algorithm. Moreover, the study of the effect of antenna mispointing shows high correlation between the along-track mispointing and the echo's amplitude. Thus, a four parameter estimation strategy has been proposed rather than the mere estimation of the five parameters of interest. In order to evaluate these strategies, we compare their estimation performance to that obtained using the three parameter model derived in a previous paper [1]. Validation of the proposed model and the corresponding algorithms is achieved on simulated and real Cryosat-2 data. The obtained results are very promising and confirm the accuracy of the proposed model.

[1] A. Halimi, C. Mailhes, J.-Y. Tourneret, P. Thibaut and F. Boy, "A semi-analytical model for delay/Doppler altimetry and its estimation algorithm," IEEE Trans. Geosci. and Remote Sensing, 2013, to appear

CryoSat-2 SAR mode over ocean: one year of data quality assessment

Francois Boy, CNES
Nicolas Picot, CNES
Jean-Damien Desjonqueres, CNES
Sylvie Labroue, CLS
Thomas Moreau, CLS
Pierre Thibaut, CLS

Session theme: Instrument Processing
Oral

In the frame of the Sentinel3 project, CNES is involved in the overall topography payload product quality. Sentinel3 embarks an altimeter including a conventional LRM mode and a SAR mode. The SAR mode propose enhanced performances compared to the conventional mode, thanks to a reduced along track resolution (from 10km to 300m) and a lower measurements noise level. However, 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. To contribute to those analysis, CNES took the opportunity of the availability of CRYOSAT-2 SAR data over ocean and started, three years ago, the development of a Cryosat Processing Prototype to generate Level2 product including Sea Level Anomaly and Significant WaveHeigh information from both LRM L1B and SAR FBR products. In the frame of the OSTST, we propose to present a global data quality assessment of SAR data over ocean using one year of SAR data. We will present the cross comparison between SAR and RDSAR (LRM reference built from SAR measurements) SLA and SWH estimates, we will analyze the data quality continuity when the altimeter switches from one mode to the other and we will also detail SLA spectrum analysis. In addition, the SAR processing techniques and the algorithms developed on CNES side will be recalled and the improvements from 2012 OSTST and AGU meetings will be summarized.

Validation of Open-Sea CRYOSAT-2 Data in SAR Mode in the German Bight Area

Salvatore Dinardo, SERCo
Luciana Fenoglio, TU Darmstadt, Institute of Geodesy, Physical and Satellite Geodesy Section, Darmstadt
Bruno Lucas, Deimos
Remko Sharoo, NOAA
Matthias Becker, TU Darmstadt, Institute of Geodesy, Physical and Satellite Geodesy Section, Darmstadt
Jerome Benveniste, ESA
Aron Roland, TU Darmstadt, Institute for Hydraulic and Water Resources, Germany
Mathieu Sikiric, Laboratory of Satellite Oceanography, Rudjer Boskovic Institute, Zagreb, Croatia

Session theme: Instrument Processing
Oral

Altimetry Data acquired by the CryoSat-2 in SAR Mode in the interval 2011-2012 are processed and validated in the area of the German Bight at distance to coast larger than 10 Kilometers.

Instantaneous sea surface height (SSH), significant wave height (SWH) and wind speed (U10) from altimetry are compared to in-situ measurements at platforms, buoys and tide gauges and to results from an operational circulation model run by the German Federal Maritime and Hydrographic Agency (BSH). The in-situ data are available from a network of stations having a good geographical distribution, which allows considering three relevant zones: (1) open sea, (2) coastal zone and (3) inland water. The network is maintained by the Waterway and Shipping Administration (WSV) and by the German Federal Institute of Hydrology (BFG, http://www.bafg.de). The relevant in-situ data are sea level, GPS coordinates and wave data. Wave and wind model data are compared to the SWH and Wind speed derived from altimetry.

The CryoSat-2 Data have been Delay-Doppler processed from the FBR (Full Bit Rate) Level 1A to Level 1B and subsequently re-tracked using the SAMOSA's SAR Echo Model and a fitting scheme based on Levenberg-Marquard Least Square Minimization Algorithm. Sea surface height, significant wave height and wind speed at 20 Hz and 1 Hz have been derived. The Delay-Doppler processing (L1B) and the re-tracking processing (L2) has been carried out by the EOP-SER Altimetry Team at ESA/ESRIN. Pseudo pulse-limited (PLRM) data derived from CryoSat-2 in SAR mode and provided via the RADS database are compared with parameters derived from the CryoSat-2 SAR Data to estimate possible biases and trends between SAR mode and LRM mode and tune up the SAR re-tracking scheme.

The low sea state conditions in this area are suitable to assess the capacity of the SAR Altimetry to retrieve wave heights also at low sea state part of the sea spectrum.

The wind speed is derived using the same wind model used in Envisat mission and correcting for a little sigma nought bias to align CryoSat absolute backscattering to Envisat absolute backscattering.

Performance metrics to measure the quality of the results, scatter plots, cross-correlations, standard deviations, regression slopes and biases between the in-situ and the CryoSat-derived measurements (SSH, SWH, U10) will be presented.

A very good agreement has been achieved between both PLRM and SAR processed altimeter and in-situ data for the SSH (mean bias 2 cm, standard deviation 20 cm, slope 0.94) and SWH (mean bias 2 cm, standard deviation 30 cm, slope 0.97) set.. In the comparison with two wave models, the best agreement is obtained with the regional LSM model of the Deutsche Wetterdienst (DWD) (9 cm /34 cm 0.98)

Jason-CS Poseidon-4 Ground Prototype Processor (GPP): Processor results using simulated raw data and in orbit CryoSat-2 data

Mònica Roca, isardSAT
Albert Garcia-Mondéjar, isardSAT
Roger Escolà i Jané, isardSAT
Cristina Martín-Puig, isardSAT
Chris Ray, isardSAT
Bernat Martínez Val, isardSAT
Pablo Nilo García Arlauld, isardSAT
Klaus-Peter Koeble, Astrium GmbH
Marco Fornari, ESTEC/ESA
Richard Francis, ESTEC/ESA
Robert Cullen, ESTEC/ESA

Session theme: Instrument Processing
Oral

Jason-CS is an operational oceanography programme of two satellites that will ensure continuity to the Jason series of operational missions. The main payload of the Jason-CS satellite is the Poseidon-4 radar altimeter that has evolved from the altimeters on-board the Jason satellites (Poseidon-2 of Jason-1, Poseidon-3A of Jason-2 and Poseidon-3B of Jason-3). Poseidon-4 also inherits the Synthetic Aperture Radar (SAR) Altimeter mode of CryoSat-2 SIRAL and Sentinel-3 SRAL now proven to reduce errors in elevation and SWH retrieval over ocean. Furthermore, Poseidon-4 will be the first radar altimeter embarked on a satellite that includes improved digital and radio frequency hardware and, in particular, open burst Ku-band pulse transmission (an operation currently termed the interleaved mode), that performs a near continuous transmission of Ku-band pulses, that will allow SAR and pulse limited data to be gathered simultaneously. As with the Jason series and Sentinel-3, the Poseidon-4 transmits C- band pulses in order to retrieve a correction for ionospheric path delay.
The mission is being developed by a multi Agency partnership consisting of ESA, EUMETSAT, NOAA, CNES and NASA-JPL. ESA is responsible for the Jason-CS Space Segment development along with Astrium GmbH as a prime contractor. isardSAT is developing the Ground Prototype Processor for the Poseidon-4 under Astrium. This prototype processes all the chains starting from the Instrument Source Packets, and up to the Level 1b (calibrated pulse- width limited or multi-looked SAR data). The prototype has been verified using simulated data generated by the Jason-CS mission performance simulator and also using in-orbit CryoSat data adapted in format to Jason-CS. These data have been provided by ESA.
This paper will present the Ground Processor Prototype developed for Jason-CS, and the results of its verification, focusing on the new features of the processing chain compared to previous altimeters. Typical examples concern: the assessment of performance improvement thanks to the interleaved mode; the un-correction of the Range Migration Correction (RMC) performed on-board in order to reduce the data rate; the weighting applied to the Doppler beams before the multi-looking to correct the different echo shapes as a function of the incidence angle; or the reconstruction of the waveform scaling factor in order to be able to compute the surface backscatter.

Waveform aliasing in satellite radar altimetry

Walter Smith, NOAA Lab for Satellite Altimetry
Remko Scharroo, Altimetrics LLC

Session theme: Instrument Processing
Oral

Beginning with Seasat and continuing through the design for Jason-CS, all satellite radar altimeters have employed a pulse compression scheme known as full-deramp of a linear FM chirp. The process by which all conventional altimeters create a waveform from digitized radar echoes can lead to aliasing of the waveform. This was first noted by Bob Jensen in a 1999 paper (IEEE TGRS 37(2):651-658, doi:10.1109/36.752182). We have examined the problem both theoretically and experimentally, using raw digitized echo samples from CryoSat's SAR mode.

We derive theoretically the chirp bandwidth necessary to resolve sea surface height (SSH) and significant wave height (SWH) in waveforms of echoes scattered by a Gaussian rough surface approximating the ocean. A chirp bandwidth of 320 MHz, as used in Ku-band altimeters, is not wide enough to fully record the echo when SWH is less than about 1 meter, and aliasing should occur. AltiKa's wider bandwidth, 500 MHz, should be prone to aliasing when SWH is less than about 64 cm.

This theoretical aliasing through a bandwidth limitation applies to the raw digitized receiver output of an altimeter. This output is then converted to a time series of complex echo amplitudes by a discrete Fourier transform (DFT). After the DFT, a conventional altimeter obtains the power by simply squaring the magnitude of the discrete sequence, without resampling. Since squaring a signal doubles its frequency, the sampling rate for power may under-sample the sequence, and it is this under-sampling of a squared sequence that is the potential source of aliasing that Jensen's 1999 paper notes. This problem can be fixed by zero-padding the digital receiver output prior to the DFT, which effectively doubles the sampling rate of the waveform gate samples. This resampling must be done prior to forming the power in individual echoes, and thus prior to forming the mean power echogram averaged over a radar cycle (nominally 1/20 of one second) known as the waveform.

We processed 29 days of CryoSat SAR mode data over oceans, forming simple pulse-limited (pseudo-LRM) waveforms at a 20-Hz rhythm by the conventional method and by the zero-padded and resampled method. Geophysical retrievals were then made by MLE3 retracking of both the conventional and resampled waveforms. SSH variance is reduced by about 10% and SWH variance is reduced by up to 22% when zero-padding is employed. The significance of the variance reduction is shown by the statistical F-test. The error reduction and its significance are functions of SWH, and show that zero padding is most useful for SSH estimation when SWH is less than 2 m, and for SWH estimation when SWH is less than 4 m. Zero-padding makes a very small but statistically significant change in backscatter estimates as well. The 20-Hz range uncertainty decreases by 5 mm and the 20-Hz SWH uncertainty decreases by 9 cm when zero-padding is employed. The bias in SSH is unchanged, SWH changes by up to 5 cm, and backscatter changes by 0.051 dB when zero-padding is employed.

When CryoSat is in SAR or SARIN mode it still employs the conventional (no zero padding) processing scheme to obtain a waveform known as the tracking echo, which drives the automatic gain control and range tracking feedback loops. These ultimately govern the digital echo samples that it can make available. We suggest that future altimeters should be designed to include zero-padding in the chirp deramp DFT so that the echo power sampling process does not introduce any aliasing.

However, for very low values of SWH, even zero-padding cannot overcome a fundamental limitation: the roughness of the surface can be too small for the bandwidth available to the altimeter. We conjecture that this aliasing may contribute to the phenomenon known as sigma-naught blooms, in which a very specular echo drives the altimeter loops to yield poor results.

Towards an Operational Use of HY-2A in SSALT/Duacs: Evaluation of the Altimeter Performances Using NSOAS S-IGDR Data

Nicolas Picot, CNES
Jean-Christophe Poisson, CLS
Jean-François Legeais, CLS
Anne Vernier, CLS
Pierre Thibaut, CLS
Jean-Michel Lachiver, CNES
Juliette Lambin, CNES

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Oral

HY-2 is a second generation ocean observation/monitoring satellite series supported by CNSA (China National Space Administration) and operated by NSOAS (National Satellite Ocean Application Service) which carries a dual frequency (Ku-Band and C-Band) radar altimeter among its scientific payload. The satellite was launched on August 15, 2011 and provides scientific data since the summer of 2012.
The CNES SSALTO/Duacs system processes data from all available altimetry missions to provide a consistent and homogeneous catalogue of products for varied applications, both for near real time applications and offline studies. They cover a large spectrum of operational oceanography needs, from ocean mesoscale observations to climate applications. These products are of great interest thanks to the combination of multiple satellites such as the Jason-1 & 2 tandem with Envisat and more recently CryoSat and SARAL/AltiKa. But the product's quality has been affected by the recent loss of the Jason-1 and Envisat missions. Hence the potential contribution of a new altimeter mission such as the Chinese HY-2A (HaiYang stands for \'ocean\' in Chinese) has to be examined.
In order to introduce HY-2A data into the SSALTO/Duacs system, a CNES/CLS prototype derived from the current Jason-2 algorithms has been developed. It processes the S-IGDR provided by NSOAS and builds intermediate RS-IGDR products. The purpose of this paper is to give an overview of the quality of the RS-IGDR data over ocean and through it, to evaluate the HY-2A altimeter performances. The main conclusion is that over ocean the RS-IGDRs data quality is close to the Jason-2 one, which makes of HY-2A a good candidate for the enrichment of the SSALTO/Duacs system.

Using Multi-Mission Satellite Altimetry for Estimating Water Level Time Series of Inland Waters – The new Database for Hydrological Time Series of Inland Waters (DAHITI)

Christian Schwatke, DGFI
Denise Dettmering, DGFI
Wolfgang Bosch, DGFI

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Oral

Since many years satellite altimetry is becoming increasingly important for hydrology. The fact, that satellite altimetry, originally designed for open ocean applications, can also contribute reliable results over inland waters helps to understand the water cycle of the system earth and makes altimetry to a very useful instrument for hydrology. In this presentation, we introduce a new approach for estimating water level time series derived from multi-mission satellite altimetry data. The estimation is based on altimeter data from Topex, Jason-1, Jason-2, Geosat, IceSAT, GFO, Envisat, Cryosat-2, HY-2A, and Saral/Altika. Depending on the extent of the investigated water body we use 1Hz, high-frequent or retracked altimeter measurements. Classification methods such as Support Vector Machine (SVM) and Support Vector Regression (SVR) are used for the classification of altimeter waveforms and for rejecting outliers. For the estimation of the water levels we use a Kalman filter approach applied to the grid nodes of a hexagonal grid covering the water body of interest. After applying an error limit on the resulting water level heights of each grid node, an average water level per time interval is derived referring to one reference location.

The computed water level time series for about 180 globally distributed lakes, rivers, and wetlands are provided by the new database DAHITI (Database for Hydrological Time Series of Inland Waters) available via http://openadb.dgfi.badw.de. The time series have temporal resolutions of 30 days, 10 days or 1 day depending on the data coverage.
For validation of the time series, we compare our results with gauges and other altimeter data sets. Hereby we achieve very high correlations between absolute water level heights of time series from altimetry and gauges.

Altimetry impact studies on global ocean analysis and forecasts at Mercator Ocean

Joel Dorandeu, Mercator Ocean

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Oral

Operational ocean analyses highly rely on satellite altimetry observations. The sea level height integrates information over the whole water column. As the numerical model physic and resolution improves, the need of accurate and high resolution observation array appear to describe the mesoscale variability. Characterization of the sensitivity of ocean analyses to the SLA observations is an important issue. Different approaches are developed at Mercator Ocean to assess the impact of the sea level observations on the analysis and also insure a proper use of the observations.

Dedicated experiments, such as Observing System Evaluations (OSE) and Observing System Simulation Experiments (OSSE) allow precise estimation of the impact of observations. Such experiments are carried out to assess the impact in our analysis of the current and future altimeter constellation and instrumental changes (error reduction, drifting orbit altimeter observations, large swath altimeter). Studies can be performed at global and regional scales. Those approaches are illustrated with the ongoing studies.

The quality of the operational analysis highly relies on the altimetry constellation. The SARAL mission has been recently launched and already delivers highly valuable data. The AltiKa SLA have been successfully assimilated since the end of July: the observation misfit is consistent with the Jason2 observations. Further evaluation is still needed but the first assimilation results in the Mercator Ocean global 1/12° system are very encouraging. It is a meaningful example of quick and efficient data production and delivery by space ground segments. These data could then be assimilated quickly by ocean models, which is important in the context of operational oceanography

Real-time Data Assimilative Modeling of the U.S. Mid-Atlantic Bight Shelf

John Wilkin, Rutgers University
Julia Levin, Rutgers University
Javier Zavala-Garay, Rutgers University

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Oral

Hydrodynamic models are used in coastal oceanography to simulate the circulation of limited-area domains for studies of regional ocean dynamics, biogeochemistry, geomorphology and ecosystem processes. When operated as real-time now-cast or forecast systems, these models offer predictions that assist decision-making related to water quality and public health, coastal flooding, shipping, maritime safety, and other applications.

Here we describe the configuration and operation of such a modeling system for the shelf waters of the Mid-Atlantic Bight (MAB) – a region with a diversity of real-time models in sustained operation and a dense in situ observational data set for assimilation and skill assessment. MAB circulation is influenced by winds, tides, buoyancy input from rivers, a steady along-shelf sea level gradient, and mesoscale eddies that impinge upon the shelf edge. This spectrum of forcing, the relatively wide and shallow shelf, and the dynamic shelf edge frontal zone, makes the region and interesting test-bed for data assimilation methodologies.

The MAB is relatively densely observed, with much of the local data acquisition coordinated by the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) – a component of the U.S. Integrated Ocean Observing System (IOOS) network of regional coastal observatories. MARACOOS operates an extensive CODAR (Coastal Ocean Dynamics Applications Radar) network observing surface currents from the coast to the shelf edge, and deploys autonomous underwater glider vehicles (AUGV) to acquire subsurface temperature, salinity and biogeochemical data along transects throughout the MAB.

The Rutgers University Ocean Modeling Group sustains a real-time forecasting system for the MAB using the ROMS model (Regional Ocean Modeling System; www.myroms.org) with 4-dimensional Variational (4D-Var) data assimilation to adjust initial conditions, boundary conditions, and surface forcing in each analysis cycle. The data that are assimilated include CODAR velocities, satellite sea surface height anomalies (with coastal corrections), infrared and microwave satellite surface temperature, in situ temperature and salinity from AUGV and National Marine Fisheries Ecosystem Monitoring voyages, and all in situ data reported via the WMO GTS network.

The Mean Dynamic Topography that augments altimeter sea level data is derived from a complementary ROMS 4D-Var analysis constrained by mean surface fluxes, hydrographic climatology, long-term mean CODAR currents, lengthy mooring deployments, and a decade of ADCP data on a New York to Bermuda ship transect.

We describe the design and operation of the real-time system, and quantify the modeling system skill in comparison to other MAB real-time systems, in situ current-meter data, and U.S. Coast Guard Lagrangian drifters.

Improved Representation of Eddies in Regional Realtime Forecasting Systems Using Multi-Scale Data Assimilation of Satellite Altimetry

Zhijin Li, JPL

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Oral

A newly developed multi-scale three-dimensional variational data assimilation (MS-3DVAR) system has been employed to deal with multiple spatial scales in high resolution regional models and observations, and thus to more effectively assimilate multi-satellite altimetry data alongside sparse in-stiu observations, shore-based high-frequency radar velocities, and satellite sea surface temperatures (SSTs). Leveraging the capability developed to assimilate a variety of observations, a set of observing system experiments (OSEs) have been conducted to quantify the impact of the existing multi-satellite altimetry observations on ocean eddy representation and prediction on top of other available observations within the framework of an advanced observing system for the California coastal ocean and during the Salinity Processes in the Upper Ocean Regional Study (SPURS) field campaign in the North Atlantic Ocean. The result demonstrates a significant impact and provides insights in how the assimilation of multi-satellite altimetry improves the representation and prediction of meso-scale eddies.

Merging of in-flight radiometers for an alternative wet tropospheric correction estimation

Estelle Obligis, CLS
Jacques Stum, CLS
Amandine Guillot, Philippe Sicard, CLS

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Oral

Permanent gases in the atmosphere induce propagation delay to pulses emitted by satellite-borne radar altimeters to the ocean surface : the range measurement has to be corrected for this effect. The path delay due to water vapour (PD) varies from 1 cm in dry, cold air, to 40 cm in wet, hot air, and is highly variable in space and time. It has long been recognized that the most accurate way to measure it is to fly a microwave radiometer together with the radar altimeter, sensing theatmosphere at frequencies near the 22.235-GHz water vapor absorption line, along the altimeter path (i.e., nadir viewing). A second possibility is to compute the PD from meteorological models, but with poorer accuracy because such models often cannot map the atmospheric humidity short space and timescales. An alternate approach has recently been proposed by Stum et al. (IEEE Trans. Geosci. Remote Sens., 2011): it combines, through an objective analysis (OA) method, all existing scanning radiometer columnar water vapor observations, to derive the PD for any altimeter mission. This approach is motivated by the need to offer an improved PD correction for altimeter missions that do not embark a microwave radiometer, but also by the potential benefit to sea level rise studies using altimeter missions for which the long term stability of both the aboard radiometer PD and the meteorological model PD are uncertain. Improvements of the method will be presented, taking into account more sensors, refinements of the calculation of the statistical properties of the field of (sensor – ECMWF) PD anomalies to be analyzed, and of the sensor errors. More extensive validation results will also be shown, including statistical crossover analysis and spectral analysis. Its applicability to near real time altimeter processing (including Jason-2 and Cryosat-2) will be assessed. The potential of this type of products for large swath mission or for climate applications will be also discussed.

The 7th Continent Expedition: International Student Participation in a Voyage to the "Great Pacific Garbage Patch"

Danielle De Staerke, CNES
Annie Richardson, NASA/JPL

Session theme: Outreach, Education and Altimetric Data Services
Oral

To meet their demands for its use, humans produce more than 300 million tons of plastic each year, approximately 10% of which ends up in the ocean. Due to ocean currents, this plastic waste collects in particular areas of our global ocean. Solely a result of human activities, plastic pollution has environmental consequences for both marine and non-marine ecosystems, but few people are aware of it.One such region of accumulated plastic debris is the North Pacific Subtropical Gyre, where the prevailing ocean currents have created a large mass of very small particles of plastics, which have resulted in a "plastic soup" commonly referred to as the "Great Pacific Garbage Patch". French yachtsman Patrick Deixonne has organized the first French, "7th Continent' Expedition", sailing with his crew from San Diego, California to this "garbage patch". The goal of the expedition is to obtain precise scientific data about the marine environment in this area, and to increase international public awareness of the problem to decrease its impact, or even to stop it if we can. Middle and high school students at schools in France and the United States are participating in this expedition through the CNES-developed Argonautica educational project. Using data collected by drifting buoys via the Argos satellite system, Argonautica students and others interested, can access buoy data, and also sea surface height and current data from altimeter satellites like Jason, and surface wind data from other sensors. Students will use telecommunications to interact with the crew during the voyage, and will use tools on the Argonautica website, to examine the buoy and satellite data to better understand the currents at the heart of the North Pacific Subtropical Gyre where the plastics accumulate. At the same time, the students will learn more about the problem of microplastic and other marine debris, and about the usefulness of satellites for global oceanography.

Outreach in a Changing Budget Climate: More or Less, Doing More with Less

Annie Richardson, NASA/JPL OST Outreach

Session theme: Outreach, Education and Altimetric Data Services
Oral

As federal budgets shrink and funds for education and public outreach are reallocated, NASA outreach teams are faced with figuring out how to continue providing for the public's need and right to know how NASA is improving their daily lives. The Ocean Surface Topography (OST) outreach team is leading, or is involved in some new outreach activities and is maintaining some historical ones. Over the past year we have organized and/or participated in many events that focus on thematic Earth science outreach, especially in the area of climate change literacy, but have still made sure that the events include specific information about, and references to, oceanography from space, ocean surface topography, and the Jason radar altimetry missions.

In April 2012 and October 2012, Earth Public Engagement hosted Girl Scouts of Greater Los Angeles Earth Science Patch events at JPL. 80 scouts at each event rotated through a series of four activities, two of which were Jason related, which helped them earn JPL/GSGLA Earth Science patches.

In April 2013, the OST and GRACE outreach leads developed and coordinated a workshop for the University of Southern California and University of California, Riverside student chapters of the Society of Women Engineers and Minority Engineers groups. Twelve JPL engineers, including two from the Jason missions rotated through five roundtable discussions with 32 engineering undergraduates. This was the first time the JPL Earth Public Engagement organization had undertaken a workshop that focused not on science, but on engineering and technology. The event was so highly regarded by the students and the professional engineers, that a repeat workshop is being discussed for 2014.

In 2012 as part of our continued partnership with the French outreach team and with the CNES-sponsored Argonautica program, we had planned to support a class of San Diego, California students who, in conjunction with their study of marine debris, would follow the "7th Continent Expedition". The expedition was to set sail from San Diego to examine and take samples in the area of accumulated micro-plastics, known as the "Great Pacific Garbage Patch", in and around the North Pacific Gyre. The students were to receive daily updates from the crew, and were to use the Argonautica web site and Jason data to track buoys drifting in the area. We had hoped to have a subset of the students present their work at the OSTST meeting. Unfortunately the 2012 expedition was cancelled.

The 7th Continent Expedition was rescheduled and conducted in May 2013, and the JPL OST Outreach Lead joined members of the expedition team to visit San Diego's Wangenheim Middle School to talk about the expedition and their participation, and about the Jason satellite. However, the 2013 Expedition operating budget was much smaller, precluding most real-time interaction, and some JPL EPO activities were put on hold pending resolution of the U.S. federal budget, so student participation in the OSTST will have to wait for a future science team meeting.

Also victims of the budget, two major activities (JPL Open House and NASA/JPL Climate Day), were conspicuously absent from our 2013 outreach calendar. However we still managed to keep busy with old and new events. The presentation will give highlights of some of those events, what's on tap for the near future, and how EPO plans might change in this changing budget climate.

AVISO: online data extraction service for all altimetry users

Frederic Briol, CLS
Florence Birol, LEGOS
Emilie Bronner, CNES
Gerald Dibarboure, CLS
Thierry Guinle, CNES
Olivier Lauret, CLS
Rosmary Morrow, LEGOS
Clara Nicolas, CNES
Fernando Nino, LEGOS
Vinca Rosmorduc, CLS

Session theme: Outreach, Education and Altimetric Data Services
Oral

AVISO: online data extraction service for all altimetry users

F. Briol, F. Birol, E. Bronner, G. Dibarboure, T. Guinle, O. Lauret, R. Morrow, C. Nicolas, F. Niño, V. Rosmorduc

Altimetry users have a wide variety of needs ranging from research to operational applications. Standards datasets provide a robust base to meet most of them but research-grade algorithms and corrections are not easily accessible to the general audience. Similarly, classical distribution channels make it difficult to provide ad-hoc datasets in a convenient way especially when product size and bandwidth are a concern.

To address such evolving user needs, AVISO developed a new distribution channel, the Online Data Extraction Service (ODES), in order to provide users and applications with a wider range of altimetry-derived data (including high-resolution and coastal data).

The platform is designed to distribute both operational products from CNES and partner Agencies (Eumetsat, ESA, NOAA, NASA) but also research-grade data from LEGOS/CTOH and CLS and other contributions from the OSTST research community. Accessible products include GDR-class level 2 data, PISTACH coastal and hydrology demonstrators and XTRACK level 3 data. Various research-grade parameters (e.g. alternative geophysical corrections...) from the OSTST PI community are also available.

Most importantly, the ODES system provides flexible interfaces and an ad-hoc response. To illustrate, ODES users can use a user-friendly web interface to download along-track altimetry data only over their area of interest, choose their period of interest in a multi-mission context, limit the parameters and variables they wish to download (e.g. select only significant wave height-related variables) and apply more complex selection criteria. Most features aim at streamlining the data acquisition in an intuitive way.

The extraction service is also "on-the-fly", with no delay nor cache necessary, so that users can immediately begins their download. Lastly the ordering and downloading process can be automated and scripted for operational users with a custom and ad-hoc environment containing only the products they want.

Thanks to this framework, AVISO will now be able to include up-to-date corrections and information (e.g. updated tide model, results from a new or alternative algorithm to compute significant wave height, etc.) to streamline the reprocessing strategy and provide intermediate releases phased with the research advancement of OSTST research and other users.

ODES is available for OSTST testing first.

Its public opening is planned to be phased with the opening of the new altimetry portal, Aviso+.

NOAA Archive and Access Services for Jason-2/3 Products

Deirdre Byrne, 1NOAA National Oceanographic Data Center, Silver Spring, MD
Yongsheng Zhang, NOAA National Oceanographic Data Center-CICS/ESSIC/UMD, Silver Spring, MD

Session theme: Outreach, Education and Altimetric Data Services
Oral

In its role as the US archive for oceanographic data, the NOAA National Oceanographic Data Center (NODC) provides scientific stewardship of the data including near real-time and delayed-mode product distribution, rigorous archive services, custom products, and long-term data stewardship for the Jason-2/Ocean Surface Topography Mission (OSTM) and future satellites in the Jason series including Jason-3 and Jason-CS. Our presentation outlines our basic services, highlighting the following upgrades:

• Primary Datasets: O/I/GDR. Within the past few years, NODC has instituted a mirror service, replicating all GDRs directly from NOAA's Data Distribution Service. This has reduced the latency of providing the OGDR to the public to under an hour. The OGDR is currently distributed through NODC and experimentally, through Amazon Web Services (cloud). Service of all level-2 X-GDR products continues to be provided through ftp, http, OPeNDAP, and THREDDS Data Sever (TDS).

• Enhanced Data Rich Inventory (RI): Data Quality Monitoring (DQM) of 23 variables in the Jason-2 GDR/IGDR is provided on a per-pass basis. Eight statistical indices are computed at the time of ingest of each data file into the archive and stored in CF-compliant NetCDF format. Visualization of these statistics is provided via a Live Access Server (http://data.nodc.noaa.gov/las/) and Jason-2 DQM homepage (http://www.nodc.noaa.gov/SatelliteData/Jason2/qa.html), and they are publicly accessible via ftp, http, OPeNDAP and TDS at data.nodc.noaa.gov. DQM was instituted for the OGDR this year and is currently experimental.

• Derived products: Our Data Quality Monitoring system also automatically generates cycle-mean 3.0°x1.0° and 0.25ox0.25o grids for the monitored I/O/GDR variables (including SLA and SWH). The 3.0°x1.0° gridded I/GDR data (in NetCDF format) are accessible via ftp, http, OPeNDAP and TDS (http://www.nodc.noaa.gov/SatelliteData/Jason2/).

• Data discovery: While Jason-2/OSTM products news and RSS-feed webpages have been developed for improved data access, data discovery has been enhanced by implementation of a Geoportal server (http://data.nodc.noaa.gov/geoportal). Experimental file-level search for the OGDR, including cloud access, is also being tested.

• Preparation for future Jason missions: Archive, access and quality monitoring tools developed for Jason-2 are being generalized into NOAA the Jason Ground System (NJGS) to support Jason-2 and Jason-3 simultaneously in the future. This will allow for a consistent, integrated access to data from the two satellites.

Reformatted SEASAT Data and Improved Tools at PO.DAAC

Jessica Hausman, JPL

Session theme: Outreach, Education and Altimetric Data Services
Oral

The Physical Oceanography Distributed Active Archive Center (PO.DAAC) is NASA's data center responsible for data management and distribution of satellite oceanographic data, as well as providing support for its scientific user base. PO.DAAC's data holdings relevant to OST include sea surface height and significant wave height from TOPEX/Poseidon, Jason-1, OSTM/Jason-2, and gravity measurements from GRACE. PO.DAAC also archives data from Seasat, NASA's first oceanographic satellite mission that lasted 90 days during 1978. In honor of Seasat's 35th anniversary PO.DAAC has reformatted the flat binary Seasat data into easy to read data records in NetCDF format. This includes the altimeter (ALT), scatterometer (SASS), and microwave radiometer (SMMR) data. All of the reformatted data will be available via anonymous ftp from PO.DAAC.

PO.DAAC continues to provide users with improved abilities to access and visualize its data holdings by updating several current tools, and developing new ones. Most users are familiar with PO.DAAC's State Of The Ocean (SOTO) that utilizes Google Earth. There is now a 2-D, flat map version with the same functionality as the Google Earth based SOTO, so users now have a choice of a 3-D globe or a 2-D map. There have been several improvements to our subsetting tools. The old subsetter, POET, has been retired, but its functionality still exists in a swath subsetter, HiTide, and a gridded subsetter, LAS. HiTide has been given a sleaker welcome page so the layout is more intuitive to first time users. PO.DAAC has continually been adding more datasets into LAS, including OSCAR and the reconstructed sea level anomalies from Hamlington et. al. The webpage has been given a minor facelift so it is not as cluttered and information regarding datasets and/or missions are more obvious.

Status of GDR orbits for ocean topography missions and prospects for future improvements

Luca Cerri, CNES
Alexandre Couhert, CNES
Flavien Mercier, CNES
Sabine Houry, CNES

Session theme: Precision Orbit Determination
Oral

GDR-D orbit standards were defined at the San Diego OSTST meeting in October 2011, including for the first time in the operational precise orbits of several altimeter missions a GRACE-based linear model to account for the long-term variations of the geopotential.
We assess the status of the current solutions for the Jason-2 and Saral missions, and indicate what are the prospects for the subsequent generation of orbits foreseen for next year. While waiting for the next release of the International Terrestrial Reference Frame (ITRF2013), several improvements are already available and have been tested on Jason-2, including: a calibrated solar radiation pressure model; the EIGEN6S2 gravity field, that makes use of more GRACE data and accounts for the interannual variability of non-tidal gravity; improved parameterization techniques to mitigate force model errors in the operational orbits, those due to time varying gravity in particular.

Status of the GSFC precise orbit ephemerides for Jason-2, Jason-1 and TOPEX/Poseidon

F. Lemoine, NASA GSFC
N.P. Zelensky, SGT Inc.
S. Melachroinos, SGT Inc.
B.D. Beckley, SGT Inc.
D.S. Chinn, SGT Inc.
D.E. Pavlis, SGT Inc.
J.T. Wimert, SGT Inc.

Session theme: Precision Orbit Determination
Oral

Stable and precise orbits over the entire time span of available altimeter data are essential for analysis of altimeter data, and the interpretation of periodic, aperiodic and long-term oceanographic signals. Important issues for precision orbit determination relate to the stability and quality of the tracking systems and of the precision force and measurement models that underpin the POD analysis. We provide an update on the latest POE's computed by GSFC, which include the following updates: (1) Use of a new low-degree 5x5 series to model the variations in the geopotential over the entire time period, 1993-2013; (2) The application of the Vienna Mapping Function (VMF) as a standard troposphere correction for the radiometric data; (3) The impact of corrections to the DORIS frequency modeling. We review the impact of time-variable gravity modeling on the altimeter satellites, comparing and contrasting the 5x5 solution with those available from other sources, and assess their impact in the Jason-2 era with respect to trends in mean sea level. We review the stability of the tracking systems, primarily SLR and DORIS, and assess other prospects for model improvement.

Precision Orbit Determination For JASON2 With GPS

Willy Bertiger, JPL
Shailen Desai, JPL
Angie Dorsey, JPL
Bruce Haines, JPL
Felix Landerer, JPL
Dah-Ning Yuan, JPL

Session theme: Precision Orbit Determination
Oral

For the 2013 OSTST meeting we focused on assessing the changes in GPS determined orbit of JASON2 due to time variable gravity and changes in the GPS transmit antenna calibrations by the IGS effecting low earth orbiters.

For time variable gravity, we will evaluate the orbit quality based on two fields, EIGEN6S (includes GRACE data to 2009), and a fit to the JPL determined GRACE field over the time frame of the full JASON2 mission. For the high frequency effects of the ocean and atmosphere, we use either the current GRACE product release of Atmosphere and Ocean De-aliasing product (AOD1B) , a time series of spherical harmonics every 6-hours or 3-hour time series for ITRF2013 covering through 2010. We will evaluate the effects of these new models in terms of altimeter cross-overs and differences with other POD center determined orbits as well as the GDR.

The International GNSS Service (IGS) has recently changed the antenna calibrations (phase center as a function of azimuth and elevation) in a region only seen by low Earth orbiters. For JASON2 (and other low Earth orbiters including JASON and Topex), we have empirically determined antenna calibrations for the receiving antenna, based on a linear extrapolation of the previous IGS antenna calibrations to the JASON2 field of view. The recent IGS changes are inconsistent with a linear extrapolation. We have re-estimated the JASON2 antenna in a consistent manner. The new calibrations result in a small improvement in altimeter cross-over tests.

Towards the 1 mm/y Stability of the Radial Orbit Error at Regional Scales

Alexandre Couhert, CNES
Luca Cerri, CNES
Flavien Mercier, CNES
Sabine Houry, CNES

Session theme: Precision Orbit Determination
Oral

The focus of this presentation will be on the long-term stability of the orbit time series, for mean sea level applications, on a regional scale.
We discuss various issues related to the assessment of radial orbit error trends; in particular the impact of method on the inference of Geographically Correlated Errors is examined as well as the significance of trends vs. the time-span of the analysis. Thus a long-term error budget of the 10-year Jason-1 and ENVISAT GDR-D orbit time series is provided at two time scales: interannual, decadal.
The variations of the geopotential being still one of the primary limitations in the POD, the overall accuracy of the Jason-1 and Jason-2 GDR-D solutions is evaluated through comparisons with external orbits, using different time-variable gravity modeling options.
We will also review orbit errors depending on the tracking technique, aiming at monitoring the long-term stability of all available measurement systems operating on Jason-1 and Jason-2.

Impact of recent time variable geopotential models on precise orbits of altimetry satellites, global and regional mean sea level trends

Sergei Rudenko, Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany; Department of Geodesy and Geoinformation Science, Technical University Berlin, 135, 17th June St., 10623 Berlin, Germany
Denise Dettmering, Deutsches Geodaetisches Forschungsinstitut (DGFI), Alfons-Goppel Str. 11, 80539 Munich, Germany
Saskia Esselborn, Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany
Tilo Schöne, Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany
Christoph Förste, Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany
Jean-Michel Lemoine, Centre National d'Etudes Spatiales (CNES) / Groupe de Recherches de Geodesie Spatiale (GRGS), BPI 3200, 18, avenue Edouard Belin, 31401 Toulouse cedex 4, France
Michael Ablain, Collecte Localisation Satellites (C.L.S.), 8-10 rue Hermes, Parc Technologique du Canal, 31520 Ramonville Saint-Agne, France
David Alexandre, Collecte Localisation Satellites (C.L.S.), 8-10 rue Hermes, Parc Technologique du Canal, 31520 Ramonville Saint-Agne, France
Karl-Hans Neumayer, Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany

Session theme: Precision Orbit Determination
Oral

Determination of precise orbits of artificial Earth satellites is a complex and challenging task. The accuracy of precise orbits of altimetry satellites depends on many factors, such as diverse models and algorithms, the reference frame realization, various corrections and tracking data, the applied parameterization and some minor effects. Since the orbits of altimetry satellites are of altitudes between 700 and 1400 km, the motion of these satellites is strongly effected by the inhomogeneous structure of the Earth gravity field. In this paper we present the results of the investigation of the influence of the recent time variable geopotential models EIGEN-6S and EIGEN-6S2 on altimetry satellite orbits. Furthermore two modified versions of EIGEN-6S2 (EIGEN-6S2A and EIGEN-6S2B), a static version of EIGEN-6S and the static model EIGEN-GL04S were included in our investigations. All these models have been jointly developed by GFZ German Research Centre for Geosciences and Space Geodesy Research Group (GRGS) Toulouse. We computed precise orbits of the altimetry satellites ERS-1, ERS-2, Envisat, and TOPEX/Poseidon over 20 years time between 1991 and 2011 using Satellite Laser Ranging (SLR), single satellite altimeter crossover and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) data. We evaluated in particular the influence of the different geopotential models on the root-mean-square (RMS) fits of the observation data as well as on two-day orbital arc overlaps in radial direction, RMS and mean of single satellite altimeter crossover differences, geographically correlated errors, range biases, center-of-origin realization, stochastic properties of radial errors, global and regional mean sea level trends. A key aspect is the consistency of the derived orbits over the full length of the altimetry series. From our detailed study, we conclude, that EIGEN-6S2A time variable geopotential model performs best for all four satellites tested. This model provides, besides the geopotential coefficients up to degree and order 260, also a yearly time series of the drifts of the geopotential coefficients for degrees 2 to 50 for the Gravity Recovery And Climate Experiment (GRACE) period (2003 - 2012) and a yearly time series of the drift of three geopotential coefficients of degree 2 from 1985 till 2003 computed using LAGEOS-1 and LAGEOS-2 SLR observations and zero drift before 1985 and after 2012. This model includes also annual and semiannual variations of the geopotential coefficients for degrees 2 to 50 over the whole possible time span (1950 - 2050).
We recommend this model also as a background geopotential model for precise orbit determination to compute individual solutions to be used for the generation of a new realization of the International Terrestrial Reference Frame ITRF2013.

Orbit error due to time variable gravity and impact on mean sea level trend estimates and tide gauge calibration

Nikita Zelensky, SGT / GSFC
Frank Lemoine, nasa/gsfc
Stavros Melachroinos, sgt/gsfc
Brian Beckley, sgt/gsfc
Douglas Chinn, sgt/gsfc
Scott Luthcke, nasa/gsfc
Gary Mitchum, University of South Florida
Oleg Bordyugov, sgt/gsfc

Session theme: Precision Orbit Determination
Oral

The stability and accuracy of the satellite orbit through time is essential to altimeter data analysis. Studies have shown the previously applied simple POD modeling of time variable gravity (TVG) has become increasingly less adequate since about 2005, and have suggested the recent increase in ice melt as one of the causes. Several new TVG models have emerged showing progressive improvement over the simple model as indicated by the Jason-1/2 and Envisat SLR and Crossover residuals. The new models include GRACE-derived 50x50 gravity coefficient 10-day snapshots, SLR+DORIS 4x4 7-day snapshots, and the application of the reduced-dynamic technique. Regardless of the improvement in SLR and Crossover residuals, the models differ considerably in their orbit projections affecting regional estimates of mean sea level and changes in mean sea level. Such differences can also impact tide gauge calibration analysis. This study compares the Jason-2 SLR/Crossover residuals and projected Jason-2 orbit difference trends considering the GDRD, JPL Rlse11a, and several new orbits from GSFC. The new GSFC orbits include SLR+DORIS reduced-dynamic processing using the GRACE-derived 50x50 and SLR+DORIS 4x4 snapshot TVG models. The study examines the sensitivity of the reduced-dynamic SLR+DORIS orbits to TVG, potential impact on tide gauge calibration using the various TVG models, and the question of identifying the best TVG model.

Development Status of GPS-Based Precise Orbit Determination System for Japanese Ocean Surface Topography Mission (COMPIRA)

Kyohei Akiyama, Japan Aerospace Exploration Agency (JAXA)
Sachiyo Kasho, JAXA
Norimasa Ito, JAXA

Session theme: Precision Orbit Determination
Oral

Japan Aerospace Exploration Agency (JAXA) has proposed the first ocean surface topography mission in Japan, named COMPIRA. In the mission, JAXA will deliver near real time products to users within 6 to 12 hours(TBD), as well as precise products which require a radial orbit accuracy of 3cm RMS within 60 days (TBD). In order to meet these requirements, JAXA has developed a GPS-based Precise Orbit Determination (POD) software, which can estimate orbits of Low Earth Orbit (LEO) satellites with an accuracy of a few centimeters. This poster provides a brief overview of the POD software and accuracy evaluation results of the existing LEO satellite missions.

Assessment of Orbit Quality through the SSH calculation New insight in resolving long term and inter-annual signal for climate studies

Annabelle Ollivier, CLS
Sabine Philipps, CLS
Michael Ablain, CLS
Luca Cerri, CNES
Nicolas Picot, CNES
Sergei Rudenko, GFZ

Session theme: Precision Orbit Determination
Oral

The quality of the orbit ephemerides is crucial for the computation of the Sea Surface Height (SSH). Conversely, analyzing the impact of precise orbit ephemerides on SSH performances enables to describe their impact at different temporal scales and to detect remaining weakness in the orbit solution with a very fine precision.
In this study, we focus on the effect of different orbit solutions on long term trends and inter-annual signatures observed on the Sea Surface Height. This is conducted through several analysis using orbit solutions provided by the CNES (Centre National d'Etudes Spatiales) and GFZ (German Research Centre for Geosciences).
First, an analysis is performed on the SAA effect on the Jason-1 DORIS receiver. This particular processing impacts the geographical Mean Sea Level Trends through the merging of Jason-1 and 2 missions. This effect is quantified and discussed.
Then, another point with a known impact on the Mean Sea Level Trends concerns the gravity field. Strong efforts were recently made in the modeling of the static and variable gravity fields.
For Topex and Envisat mission, sensitivity studies between GFZ solutions based on different gravity fields are presented.
Finally the new CNES solution of orbit, based on recent gravity field including inter-annual variability in addition to the static, annual and linear terms are presented. Their impact on SSH is quantified for Jason-2 mission. This solution will be discussed as a possible future standard for altimetric products.

Empirical Solar Radiation Models for Altimeter Satellites

Flavien Mercier, CNES
Luca Cerri, CNES
Alexandre Couhert, CNES
Sabine Houry, CNES

Session theme: Precision Orbit Determination
Oral

The empirical accelerations that are estimated to obtain the precise orbits used in the Geophysical Data Records often show systematic signatures that indicate errors in the prelaunch satellite model, represented as a set of plates of known surface, orientation, optical and infrared properties. Although the impact of such errors on the final solution is relatively small, orbits that are dynamically constrained can benefit from the adoption of empirical models that include these systematic features. Also, such models could eventually help in stabilizing the time series of DORIS station coordinates used for the realization of the terrestrial reference frame.
We propose an empirical modeling approach in which the acceleration is expressed in a reference frame aligned with the sun direction. In such a frame, the radiation pressure accelerations are very stable, with small periodic variations whose amplitudes depend on the beta angle. This facilitates the overall observability of the model parameters to be identified. We tested this method using the GPS measurements available for the Jason satellites; we present the results, and discuss the prospects for the implementation in the precise orbit solutions of all the DORIS-based altimeter missions.

SARAL/AltiKa Orbit Quality Analysis Through Short-arc Technique

Pascal Bonnefond, OCA-GEOAZUR
Olivier Laurain, OCA-GEOAZUR
Pierre Exertier, OCA-GEOAZUR
Amandine Guillot, CNES
Nicolas Picot, CNES
Luca Cerri, CNES
Christian Jayles, CNES
Cédric Tourain, CNES

Session theme: Precision Orbit Determination
Oral

We have developed a short-arc orbit technique for the validation of altimeter satellite precise orbits. It is based on SLR data, and on rigorous geometrical adjustment criterions. The goal is to permit the validation of altimetric missions orbits.
SLR sites around the world (Europe, US, Australia, Asia) largely contribute to the tracking of the altimetric mission, thanks notably to the role of the International Laser Ranging Service (ILRS) through its recommendations, its data storage and distribution, and its monitoring of the up-to-date activity (qualitative and quantitative monitoring).
Thanks to a selective choice of SLR measurements, taking into account their intrinsic precision/accuracy, and the precision of the station coordinates of the SLR network, the proper error budget of the method has been reduced to few mm.
This has allowed us to study the radial orbit error of SARAL/AltiKa for POE, MOE and DIODE orbits above a given area. For the radial component, stability is better than 2 cm for MOE and POE and better than 4 cm for DIODE. Geographically correlated radial orbit errors are small (below 1 cm for MOE and POE, 2 cm for DIODE).

What do errors between altimeters tell us about the length of the Jason-3/Jason-CS calibration phase?

Eric Leuliette, NOAA
Walter Smith, NOAA
John Lillibridge, NOAA

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Oral

The tandem calibration phases for TOPEX/Poseidon and Jason-1 and for Jason-1 and Jason-2 provided crucial opportunities to compare instrument performances, geographically-correlated errors, and regional and global biases between missions. These phases have been essential for establishing a high confidence in the climate data record from the reference series of altimeter missions. When the Jason series makes the transition to a new platform of instruments with Jason-CS, the tandem calibration phase with Jason-3 will need to be of sufficient length to ensure the integrity of the climate data record.

Early in the Jason-2 mission, the residual differences in global mean sea level between Jason-1 and Jason-2 during the calibration phase were shown to have a 1 mm rms for the 10-day cycles. Differences during the Jason-1 interleaved and geodetic phases have essentially the same scatter, which we show is due to random altimeter errors, radiometer errors, and differences in sampling on different orbits. We will present sampling error bounds estimated from output of the assimilated ECCO model sampled with Jason, Envisat, and CryoSat ground tracks. These results suggest that a relatively short calibration phase can determine any intermission bias.

However, Jason-2 and Jason-1 were largely identical platforms, and common systematic errors may not be apparent. For example, errors in global mean sea level at the S2 aliasing period (59 days) largely cancel in the Jason-1/Jason-2 differences.
We can construct global mean sea level from an independent mission, Cryosat, and compare with Jason-1 and Jason-2. The residuals in global mean sea level between CryoSat-2 and Jason-2 have an rms of 3.6 mm, with the two largest variations (~2 mm) at the S2 aliasing periods for each of these two satellites (59 days for Jason and 244 days for CryoSat). These results suggest that errors associated with a solar day (e.g. errors in the S2 ocean and atmosphere tides, ionosphere corrections, heating of the instruments, etc.) are present in all missions.

Two issues argue for a calibration phase of at least six months. First, geographically-correlated errors between missions remain despite common orbit determination standards. We will show an analysis from the calibation phase that finds that at least 6 months of observations are necessary to determine the spatial pattern of the errors. Second, differences in sea state bias models between missions suggest that the length of the calibration phase should be long enough to sample the seasonal variations in wind and wave fields, in order to separate the true EM-bias from other sea state errors, such as tracker bias.

Effect of the processing methodology on satellite altimetry-based global mean sea level rise over the Jason-1 operating period

Olivier Henry, LEGOS/CNRS
Michael Ablain, CLS, Toulouse, France
Benoit Meyssignac, LEGOS/CNES
Anny Cazenave, LEGOS/CNES
Dallas Masters, CCAR, University of Colorado, USA
Steve Nerem, CCAR, University of Colorado, USA
Gilles Garric, MERCATOR Ocean, Toulouse, France

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Oral

Determining how the global mean sea level (GMSL) evolves with time is of primary importance to understand one of the main consequences of global warming and its potential impact on populations living near coasts or in low-lying islands. Five groups are routinely providing satellite altimetry-based estimates of the GMSL over the altimetry era (since late 1992). Because each group developed its own approach to compute the GMSL time series, this leads to some differences in the GMSL interannual variability and linear trend. While over the whole altimetry time span (since 1993), good agreement is noticed for the computed GMSL linear trend (of 3.1 +/- 0.4 mm/yr), on shorter time spans, trend differences are larger than the 0.4 mm/yr uncertainty. Here we investigate what could cause these trend differences. We focus on outputs from two different groups: the Colorado University (CU) and Archiving, Validation and Interpretation of Satellite Oceanographic Data (AVISO) because associated processing of each group is largely representative of all other groups. For this investigation, we use the high-resolution MERCATOR ocean circulation model with data assimilation (version Glorys2-v1) and compute synthetic sea surface height (SSH) data by interpolating the model grids at the time and location of "true" along-track satellite altimetry measurements, focusing on the Jason-1 operating period (i.e., 2002-2009). These synthetic SSH data are then treated as “real” altimetry measurements, allowing us to test the different averaging methods used by the two processing groups for computing the GMSL: (1) averaging along-track altimetry data (as done by CU) or (2) gridding the along-track data into 2°x2° meshes and then geographical averaging of the gridded data (as done by AVISO). We also investigate the effect of considering or not SSH data at shallow depths (<120 m) as well as the editing procedure. We find that the main difference comes from the averaging method with significant differences depending on latitude: in the tropics, the gridding method overestimates the GMSL trend while at high latitudes (above 60°N/S), the along-track averaging method underestimates it. Potential causes of these differences are explored and discussed.

Investigating short wavelength correlated errors on low resolution mode altimetry

Gérald Dibarboure, Collecte Localisation Satellite
Pierre Thibaut, CLS
Jean-Christophe Poisson, CLS
Yannick Lasne, CLS
Sylvie Labroue, CLS
François Boy, CNES
Nicolas Picot, CNES

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Oral

Although conventional radar altimetry products (Jason1, Jason2, LRM CRYOSAT2, etc) have a spatial resolution as high as 300 m, the observation of ocean scales smaller than 100 km is limited by the existence of a “spectral hump”, i.e. a geographically coherent error. In the frame of the future altimetry missions (SAR for Cryosat -2 and Sentinel-3 missions and interferometry for the SWOT mission) it becomes crucial to investigate and to better understand the signals obtained at small scales by conventional altimeter missions.
We show by simulation that heterogeneous backscattering scenes can result in the corruption of the altimeter waveforms and retracked parameters. The retrackers used in current ground processors cannot well fit the Brown model during backscattering events because this model has been designed for a homogeneous scene. The error is also propagated along-track because of the size and shape of the low resolution mode (LRM) disc-shaped footprint.
On real data, the hump phenomenon is shown to be almost ubiquitous in the ocean, yet more intense at low latitudes and in the Indian Ocean and Western Pacific Ocean, where backscattering events are more frequent. Its overall signature could be a Gaussian-like random signal smooth for wavelengths smaller than 15 km, i.e. white noise on 1 Hz products.
The analysis of current data from 8 altimetry missions (ERS-1/2, ENVISAT, JASON-1, JASON-2, CRYOSAT-2, SARAL and HY-2) highlights the influence of the instrument design and altitude, and the influence of the retracker used. The spectral hump is a systematic response to random events and it is possible to mitigate it with new processing.
Simulations and geographically limited datasets from the synthetic aperture radar mode (SARM) of Cryosat-2 show that the thin stripe-shaped synthetic footprint of SARM might be less sensitive to the artifact.

Wavenumber spectrum of estimated uncertainty in Jason-2 sea surface height measurement

Clement Ubelmann, JPL/CALTECH
Lee-Lueng Fu, JPL
Shannon Brown, JPL
Bruce Haines, JPL
Alexandre Couhert, CNES
Flavien Mercier, CNES

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Oral

Satellite altimeter observations of sea surface height (SSH) have wide-ranging applications. Many of them require the knowledge of the measurement errors, not only their magnitudes but also distribution of variance in wavenumber space. For instance, such wavenumber spectrum is needed for optimal constraint in state estimation via data assimilation by models. We analyzed the tandem mission observations from Jason-1 and Jason-2 for estimating the random errors. The POD error was estimated from the difference between the Jason-2 GDR D orbit and the JPL GPS orbit. We also estimated the errors in the corrections from the media effects of the wet troposphere, the ionosphere, and the dry troposphere, as well as the correction for the sea-state bias. The estimated wavenumber spectrum for the total uncertainty of SSH will be presented.

Accuracy Assessment of Global Ocean Tide Models

Detlef Stammer, CEN, Universität Hamburg

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Oral

Our knowledge of the dynamics of ocean tides as well as their impact on the general circulation has improved considerably since the launch of Topex/Poseidon twenty years ago. Very precise satellite altimeter data have been essential for improving empirical and hydrodynamic tide models. The geophysical applications of these new models have been widespread, including the provision of tidal corrections to altimetry, thereby enabling the study of non-tidal oceanic motions. This paper provides an accuracy assessment of state-of-the-art global tide models, including purely empirical, purely hydrodynamic, and dynamical models constrained by observations. The goal of the paper is to quality-assess modern global tide models and to understand some of their limitations by comparing them against a number of independent test data sets representing both the deep ocean and shallow seas. Tests are provided in terms of comparisons against bottom-pressure data, selected coastal gauges (primarily in polar regions), independent satellite altimeter data, and satellite gravimeter data. Long-wavelength components of models bearing implications for precise orbit determination are tested by analyzing laser ranging measurements to special geodetic satellites. Also for the first time we provide an assessment of tidal currents available from (selected) models by comparing against tidal velocities estimated from current meters located in the deep ocean and from acoustic tomography. A high-resolution 3-D model is used to assess limitations from inadequate vertical sampling at moorings. In several cases the tidal models have revealed flaws in the test data, including in some historical measurements long in use.

This talk will provide an overview about the joint work; detailed results will be presented in form of posters by several co-authors.

Sampling errors in the decomposition of vertical modes from current meter data estimated using an eddy-resolving ocean circulation model with embedded tides

James Richman, Oceanography Division, Naval Research Laboratory, Stennis Space Center, MS
Brian Arbic, Dept of Earth and Environmental Sciences, University of Michigan, Ann Arbor MI
Gregg Jacobs, Oceanography Division, Naval Research Laboratory, Stennis Space Center, MS

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Oral

An “eddying” global ocean general circulation model with high horizontal and vertical resolution and astronomical tidal forcing in addition to atmospheric forcing is used to examine the errors in the vertical mode decomposition of oceanic flows estimated from historical current meters with relatively sparse vertical resolution. The model barotropic and internal M2 tides agree well in amplitude with the tides estimated from aliased altimetric sea surface heights as shown in Shriver et al. (2012). The model barotropic M2 tidal velocity agrees reasonably well with other barotropic tidal models. However, barotropic tidal velocities are not directly measured in the ocean, but are estimated from moored current meters. The vertical distribution of meters on the moorings are not optimal for estimating the barotropic velocity and prior estimates have made substantial approximations to get estimates. In the numerical model, the sampling of velocity in the vertical is much greater allowing for error estimates in the barotropic velocity to be obtained. For the model, coarse sampling at the observation depths leads to ~11% underestimate in the amplitude of both the major and minor axes of the M2 barotropic tidal ellipse. The model overestimates the M2 barotropic tidal ellipse axes by ~20% compared to the data-assimilative TPXO 7.2 barotropic tide. The spatial correlation between the model and both the sampled and TPXO M2 barotropic tide is high. The ellipse axes estimated from the current meter moorings are much weaker than the model, typically ~60%, with a much lower spatial correlation. For the first baroclinic mode, the sampling leads to an overestimate of the model ellipse axes, but the current meter ellipse axes are still weaker than the model. The presence of higher vertical modes in the observations, which are missing from the model in deep water, appears to the cause for the difference.

Ongoing monitoring of absolute bias from the Australian In-Situ Calibration Sites: Bass Strait and Storm Bay

Christopher Watson, University of Tasmania
Neil White, 2. Centre for Australian Weather and Climate Research, A Partnership Between CSIRO and the Australian Bureau of Meteorology
John Church, 2. Centre for Australian Weather and Climate Research, A Partnership Between CSIRO and the Australian Bureau of Meteorology
Jack Beardsley, University of Tasmania
Matt King, University of Tasmania
Richard Coleman,
nstitute of Marine and Antarctic Studies, University of Tasmania

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

The Australian absolute calibration site located in Bass Strait (40° 39'S, 145° 36' E) continues to provide cycle-by-cycles estimates of absolute bias for Jason-class precision altimetry. This continues a time series now over two decades in duration, with successful monitoring of TOPEX/Poseidon, Jason-1 and OSTM/Jason-2 missions from this location. With support from the Australian Integrated Marine Observing System (IMOS), the Bass Strait facility has been augmented with a secondary site in Storm Bay, located within 350 km on the same descending pass (pass 088), but subject to significantly different ocean conditions. The Storm Bay site has on average twice the significant wave height as Bass Strait, allowing investigation of sea state effects on absolute bias.

In this contribution we present updated results from our single-pass multi-site approach. Our strategy at each site remains centred on the use of repeat deployments of oceanographic moorings (including high accuracy pressure gauges and associated instrumentation) combined with episodic GPS buoy deployments, and utilisation of coastal tide gauge data and land based GPS reference stations.

The Long-term Altimeter Calibration Record from the Harvest Platform

Bruce Haines, Jet Propulsion Laboratory, California Institute of Technology
George Born, Colorado Center for Astrodynamics Research, University of Colorado, Boulder, USA
Shailen Desai, Jet Propulsion Laboratory, California Institute of Technology

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

Located about 10 km off the coast of central California, the Harvest oil platform has hosted a dedicated altimeter calibration facility since the launch of TOPEX/POSEIDON (T/P) in 1992. Harvest is located in the path of the 10-d repeat ground track for the primary reference (Jason-class) altimeter missions, enabling the development of a continuous calibration record based on direct (overhead) passes of the platform. The experiment has produced a continuous, two-decade calibration time series spanning the T/P, Jason-1 and OSTM/Jason-2 missions and their combined climate record.

Over the past year, we have focused on the analysis of data from OSTM/Jason-2 overflights of the platform, the first of which occurred on July 13, 2008. At this writing, Jason-2 had passed over the platform 190 times, providing the basis for long-term monitoring of both bias and drift in the sea-surface height (SSH) measurements on the latest (D) version of Geophysical Data Records (GDR). Reflected in these GDR-D data are several important improvements that impact the bias at the decimeter level (Picot et al., 2012). Most noteworthy among them is a correction for an inconsistency (180.92 mm) in the interpretation of the altimeter antenna reference point (mechanical plane vs. aperture plane). In view of these improvements, the Harvest calibration record for Jason-2 depicts residual bias and drift of +12 ± 2 mm and +0 ± 2 mm yr-1 respectively (one standard error with N = 143). In consideration of systematic errors, such as uncertainty in the platform position and subsidence rate, neither estimate is considered statistically distinguishable from zero. We provide updates to these estimates based on the latest overflights, and also discuss any enhancements to the overall calibration record that bears on the interpretation of data from the legacy T/P and Jason-1 missions.

Finally, we describe preliminary results from the recently launched Indian/French SARAL mission, which carries a Ka-band altimeter (AltiKa). While this mission is on a different (35-d) repeat ground track, regional calibration methods (e.g., Cancet et al., 2013) can be used to relate the satellite geophysical record to the Harvest site.

Corsica: a multi-mission absolute calibration site

Pascal Bonnefond, OCA-GEOAZU
Pierre Exertier, OCA-GEOAZUR
Olivier Laurain, OCA-GEOAZUR
Thierry Guinle, CNES
Pierre Femenias, ESA/ESRIN

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

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, SARAL/AltiKa), due to a smaller time series, the standard error is about the double (~7 mm).
In-situ calibration of altimetric height (SSH for ocean surfaces) is usually done at the vertical of a dedicated CAL/VAL site, by direct comparison of the altimetric data with in-situ data. Adding the GPS 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).
Our CAL/VAL activities are thus focused not only on the very important continuity between past, present and future missions but also on the reliability between offshore and coastal altimetric measurement. With the recent extension of the Corsica site (Capraia in 2004 and Ajaccio in 2005), we are now able to perform absolute altimeter calibration for ERS -2, EnviSat, HY-2A and SARAL/Altika with the same standards and precision than for T/P and Jason missions. The upcoming Sentinel-3 mission will naturally be included in our CAL/VAL activities. This will permit to improve the essential link between all these long time series of sea level observation.
The presented results will be focused on the full set of TOPEX/Poseidon, Jason-1 and Jason-2 GDR products. Updated values of the altimeter biases for Jason-2 (GDR-D) will be presented as well as detailed studies on the various corrections. Recent results of SARAL/AltiKa based on the latest process cycles (1-6) will be also presented.

Latest Results for the absolute calibration of Jason and HY-2 satellites using the Gavdos/Crete permanent calibration facility

Stelios Mertikas, Technical Univesrity of Crete, Greece
Antonis Daskalakis, Space Geomatics Ltd., Greece
Hailong Peng, National Ocean Satellite Applications Service, Beijing, China
Ilias N. Tziavos, Department of Geodesy and Surveying, Aristotle University of Thessaloniki, Greece
Xinghua Zhou, First Institute of Oceanography, State Oceanic Administration, QuingDao, China
George Vergos, Department of Geodesy and Surveying, Aristotle University of Thessaloniki, Greece
Vasilis Zervakis, University of Aegean, Greece
Ole Baltazar Andersen, Danish Space Centre, Copenhagen, Denmark

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

This work presents the calibration methodology conducted at the Gavdos/Crete calibration/validation facilities along with the latest altimeter calibration results for the Jason-2 and the Chinese HY-2 mission. A new approach for integrating four in-situ tide gauge measurements in Gavdos will be presented, while the most recent altimeter bias results for Jason-2 will be reported based on the GDR-D products. Furthermore, the altimeter bias for the Chinese HY-2 satellite will be introduced using the CRS1 permanent site in south west Crete and the descending HY-2 Pass No. 280, at 20 Hz. Additionally, altimeter biases as determined by locally developed Mean Sea Surface model will be presented and compared with the conventional sea-surface calibration methodology.

Regional CalVal of Jason-2 and Envisat in Corsica and at Harvest

Mathilde Cancet, NOVELTIS
Bruce Haines, JPL
Pascal Bonnefond, OCA/GEOAZUR
Eric Jeansou, NOVELTIS
Florent Lyard, LEGOS
Pierre Féménias, ESRIN

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

In situ calibration insures regular and long-term control of the altimeter sea surface height (SSH) time series through comparisons with independent records. Usually, in situ calibration of altimeter SSH is done at the vertical of a specific CalVal site by direct comparison of the altimeter data with the in situ data.

However, for more than ten years, Noveltis has been developing a regional CalVal technique, which aims at increasing the number and the repeatability of the altimeter bias assessments by determining the altimeter bias both on overflying passes and on satellite passes located far away from the calibration site. The strong interest of this principle is to extend the single site approach to a wider regional scale, thus reinforcing the link between the local and the global CalVal analyses. It is also a mean to keep on calibrating a mission when good-quality in situ data happen to be missing at its dedicated calibration site.

The regional method was initially developed at the Corsican calibration sites of Senetosa and Ajaccio. The method was used to compute the biases of Jason-1, Jason-2 and Envisat (before and after the orbit change in 2010) at both sites, and proved its stability and generality through this cross-calibration exercise.

In 2013, the regional method was successfully implemented at the Californian site of Harvest, in close collaboration with JPL. This study gave the first Envisat absolute bias estimates in the Pacific Ocean, which showed high consistency with the analyses of the global CalVal teams. These results highlight the numerous advantages of this technique for monitoring missions on any orbits such as SARAL/AltiKa, CryoSat-2, HY-2A or the future Sentinel-3, Jason-3 and Jason-CS missions.

Analyses of altimetry errors using in-situ measurements: tide gauges and Argo profiles

Pierre Prandi, CLS
Guillaume Valladeau, CLS
Jean-François Legeais, CLS
Michael Ablain, CLS
Nicolas Picot, CNES
Pierre Femenias, ESRIN

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

Since the first altimeter missions and the improvements performed in the accuracy of sea surface height measurements from 1992 onwards, the importance of global quality assessment of altimeter data has been increasing. Global CalVal studies usually assess this performance by the analysis of internal consistency and cross-comparison between all missions. In this study, in-situ measurements are used as a complementary approach to analyze the altimetry errors, especially for climate scales.

Two types of in-situ measurements are considered: tide gauges and Argo profiling floats. Tide gauge data derived from several networks (GLOSS/CLIVAR, PSMSL) provide sea-level heights with a physical content comparable with altimetry sea level estimates. They cover the whole altimeter period but only on coastal areas. Therefore, Argo profiles are complementary data since they are more evenly spread out in the open ocean, but with enough spatial coverage since 2004 only. However, they measure vertical profiles of temperature and salinity, providing only the steric contribution to the total sea level content measured by altimeters. The mass contribution can be estimated from the GRACE data from 2003 onwards.

In this study, in-situ measurements are compared with altimeter sea level for the main altimeter missions: Jason-1, Jason-2, Envisat and CryoSat. If altimeter time series are long enough, tide gauge data provide a relevant estimation of the global Mean Sea Level (MSL) drift calculated for all the missions. Meanwhile, Argo profiles are able to detect MSL drifts at basin scales thanks to better ocean coverage. Correlation, variance differences between altimeter and in-situ sea level are also estimated accurately, separating the temporal scales (high, medium, low frequencies). Comparisons with sea level products merging all the altimeter missions together have also been performed using several datasets, among which the AVISO delayed-time Sea Level Anomaly grids.

Global Calibration and Validation of the Jason-2 and SARAL Geophysical Data Records

Shailen Desai, Jet Propulsion Laboratory, California Institute of Technology
Bruce Haines, Jet Propulsion Laboratory, California Institute of Technology

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

We present updated results on the global calibration and validation of the Jason-2 version D Geophysical Data Records (GDRs), and the first test release of SARAL/Altika GDRs. We focus in particular on temporal and geographically correlated errors, and the analysis of inter-satellite differences of various components of the two sea surface height measurement systems at ground-track crossing locations (crossovers). A valuable approach for evaluating geographically correlated errors is segregating the inter-satellite differences by quadrant, namely ascending and descending ground tracks in the northern and southern hemisphere. We also consider systematic differences in the altimeter measurements as a function of significant wave height and wind speed, noting that calibration of the backscatter coefficient, wind speed, and sea state bias is most likely needed for the SARAL/AltiKa measurements at this early stage of the mission. In doing so, one of our objectives is to develop an estimate for the overall sea surface height measurement system error budget for SARAL.

Global Jason-2 / Jason-1 Data Quality Assessment

Sabine Philipps, CLS
Hélène Roinard, CLS
Michael Ablain, CLS
Nicolas Picot, CNES

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

Long-term monitoring of the Jason-2 and Jason-1 altimetric systems is routinely performed at CLS, as part of the CNES SALP (Système d'Altimétrie et Localisation Précise) project. The main objective of this activity is to provide an estimation of the mission performances for oceanic applications such as mesoscale or climate studies. The monitoring of all altimeter and radiometer parameters is routinely performed in order to detect jumps or drifts. The objective of this presentation consists in giving an overview of Jason-2 and Jason-1 data coverage and data quality concerning altimeter and radiometer parameters, but also the performance of delayed and real time products (GDR, IGDR, OGDR/OSDR) at mono-mission crossovers and along-track.

Cross calibration between altimetry missions or with in-situ measurements is also systematically performed in order to estimate altimetry errors at different spatial and temporal scales. Jason-1 mission switched to a geodetic orbit in May 2012 and stopped to send data on 21st June 2013. Therefore cross-calibration between Jason-2 and Jason-1 is no longer possible.

As Jason-2 is the reference mission used in operational applications or for delayed time studies and especially for monitoring of the Global Mean Sea Level, the assessment of Jason-2 data quality is particular important and we pay special attention to the long-term stability of Jason-2 Global Mean Sea Level (GMSL).

Intermission and tide gauge comparisons with Jason-2

Eric Leuliette, NOAA
Gary Mitchum, University of South Florida
Remko Scharroo, Altimetrics, LLC

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

Because Jason-2 is designated as the sea level reference mission of the CEOS Virtual Altimetry Constellation, it requires particularly careful evaluation of its stability to ensure the integrity of the sea level climate data record from altimetry. We present an update of how well the 1-mm/year stability goal has been met with the official data products. In particular, we will present cross-calibrations of Jason-2 with Jason-1, SARAL/AltiKa, and CryoSat-2, and comparisons with the independent network of tide gauges.

With over three years of overlap between CryoSat-2 with Jason-2 observations, we have an opportunity to compare altimeters in two different, non-sun-synchronous orbits. The residuals in global mean sea level between the missions have an rms of 3.6 mm with the largest variations (~2 mm) at the S2 aliasing period for Jason-2 (59 days) and the period of a half revolution of CryoSat's nodal plane with respect to the earth-sun line (244 days).

We use tide gauge comparisons to show the impact of orbits with GDR-D standards (ITRF2008) for Jason-1 and Envisat, and these show that geographically-correlated errors are the largest remaining intermission differences.

We will review some issues in the tide gauge comparison, including the impact of the applying the 18.6-year lunar nodal tide to the 20+ year record of sea level identified by B. Beckley.

Global SARAL Data Quality Assessment of IGDR and GDR data

Sabine Philipps, CLS
Pierre Prandi, CLS
Vincent Pignot, CLS
Nicolas Picot, CNES

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

The SARAL mission was successfully launched on 2013-02-25, and cycle 1 started on 2013-03-14. SARAL has a single frequency altimeter (the first altimeter in Ka-band) and a dual-frequency radiometer on-board. It was expected that the Ka-band induces some changes, such as a reduced data availability due to higher sensitivity to rainy or cloudy conditions. About 6 months of OGDR and IGDR data products will be available, as well as at least 4 cycles of GDR products. Within the first months of the Altika mission, a first patch (P1) was developed to correct for some anomalies in the products and to account for the in-flight calibration data in the ground processing. This patch was applied for the GDR since cycle 1, and for the IGDR from cycle 4 pass 395 onwards.

Since the start of the IGDR data of SARAL, analyses of OGDR and IGDR were performed at CLS, as part of the CNES SALP ("Système d'Altimétrie et Localisation Précise") project. GDR products are also analyzed as soon as the cycles are available.

Hereafter some results of these analyses are presented. A focus is done on the data availability and validity. Indeed the data availability is less impacted by rain events as previously expected. Furthermore the main altimeter and radiometer parameters are analyzed and compared to other altimeter missions such as OSTM/Jason-2. The system performance at mono-mission crossovers is analysed. Furthermore multi-mission crossovers (with Jason-2) are presented and large-scale regional biases analysed. Our analyses are focused on the data produced with the patch 1.

Early look at SARAL/AltiKa data

Remko Scharroo, EUMETSAT
John Lillibridge, NOAA / Lab. for Satellite Altimetry
Saleh Abdalla, ECMWF
Doug Vandemark, Univ. of New Hampshire/OPAL

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

The launch of the SARAL satellite last February added a new tyke to the string of altimeters that has been operating continuously since 1991. While its orbit mimics that of ERS-1, ERS-2 and Envisat, its altimeter instrument, AltiKa, does none of that. AltiKa is the first Ka-band altimeter, and is also the first to provide 40-Hz elementary measurements, twice the rate we were used to. With a smaller footprint, higher range precision (even at 40-Hz) and higher range rate, everything appears cued to provide an excellent altimeter, particularly for applications where along-track high resolution matters. The high spatial resolution of the 35-day repeat orbit is an additional bonus over the 10-day repeat orbit of the Jason series.

The novelty of the altimeter as well as the radiometer causes some setbacks too: we need to totally relearn how to deal with the impact of the atmosphere. For example, the absorption of the signal by the dry troposphere is about 3 times as large in Ka-band as in Ku-band. The absorbtion by water vapour and cloud liquid water is even 6 to 7 times larger than we have been used to. In addition, the new radiometer design requires the development of new neural network algorithms for the determination of the parameters generally derived from the radiometer brightness temperatures, i.e., wet tropospheric path delay, backscatter attenuation, water vapour content, and liquid cloud water vapour.

The relationship between backscatter and wind speed in Ka-band also departs from that in Ku-band. We thus developed our own 1- and 2-dimensional wind speed models. Likewise, the sea state bias is expected to differ from what we have traditionally used.

This presentation highlights some of the “novelty” aspects of SARAL. We will show some of the recent developments to improve or enhance the SARAL data sets, evaluate the quality in terms of the inclusion in a climate data record, and give some detailed views of SARAL’s performance over the global oceans.

Performance and consistency of different satellite altimeter systems assessed by means of global multi-mission crossover analysis

Denise Dettmering, Deutsches Geodätisches Forschungsinstitut (DGFI
Wolfgang Bosch, Deutsches Geodätisches Forschungsinstitut (DGFI)

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

A rigorous inter-mission calibration is mandatory in order to use multi-mission altimeter data for sea surface monitoring with high spatial and temporal resolution and to enable a seamless connection between time series of different missions, mainly between TOPEX, Jason-1, Jason-2, and its successors.
The multi-mission cross-calibration (MMXO) developed and routinely executed by DGFI provides time series of radial errors for each mission included in the investigation with respect to a reference mission. These time series are used for correcting each altimeter measurement and to derive one consistent long-term altimeter data set with high spatial and temporal resolution.
By analyzing the calibration results detailed information on the quality and deficiencies of the different altimeter missions and on their consistency are revealed. In addition to relative range errors, stochastic properties of the time series as well as geographically correlated errors and information on the realization of the center-of-origin can be computed.
This presentation will show the latest results of DGFI's multi-mission cross-calibration (MMXO14) which is based on most resent data sets, correction products, and orbits. Special focus will be given to reprocessed Jason-2 GDR-D data, on Jason-1 measurements from geodetic mission phase, and on the new missions Saral and HY-2A.

An End-of-Mission Climate Quality Calibration for the JMR – Inter-satellite Calibration with the SSM/I Fundamental Climate Data Record

Shannon Brown, JPL
Sidharth Misra, JPL

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

The Jason-1 sensor provided more than a decade of sea level measurements and with the conclusion of the mission, the job is now to ensure the final mission product contains the highest quality climate calibration. In this paper, we describe the end of mission calibration process planned for the Jason Microwave Radiometer (JMR). The first step in the process is to ensure the long term stability of the brightness temperatures. To maintain the radiometer brightness temperature calibration on long time scales requires that it be referenced to stable sources external to the radiometer, where the long term calibration is then dependent upon the stability of these external sources. Using several independent external references and demonstrating consistency between them increases the confidence in the resulting long term WPD record and hence GMSL record.

The previous end-of-mission calibration for the Topex Microwave Radiometer relied on natural on-Earth references. Recently, a complimentary inter-satellite calibration approach was developed and applied to the Jason-2 Advanced Microwave Radiometer calibration. This approach essentially transfers the long term calibration from other stable externally calibrated satellite microwave radiometers to the altimeter radiometers. A newly developed fundamental SSM/I TB fundamental climate data record (FCDR) (Kummerow et al., 2010) will now allow us to extend this inter-satellite calibration approach back to the start of the altimetry record to validate and improve upon the long term calibration that we previously performed for the TMR and the JMR. The SSM/I FCDR was developed by Colorado State University (CSU) for NOAA and extends from 1987 to the present, covering the altimeter time period. Applying the inter-satellite calibration approach to the JMR using the new SSM/I FCDR will provide a second independent reference (in addition to the natural reference method) which will improve the long term WPD calibration and reduce the uncertainty in the GMSL trends on shorter time periods, improving the data for studies looking at interannual variability.

This paper will describe the inter-comparison between the JMR and the SSM/I FCDR calibration and discuss the re-calibration process for the JMR. An error estimate of the JMR PD stability over the mission will be provided.

The DTU13 Global marine gravity field – first evaluation

Ole Baltazar Andersen, DTU Space
Per Knudsen, DTU Space
Steve Kenyon, NGA
John K Factor, NGA
Simon Holmes, SGT International

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Oral

Since the release of the DNS08 and DTU10 global marine fields numerous new satellite missions important to global marine gravity field mapping have started delivering new and interesting data that will seriously improve global high resolution gravity fields.
GOCE delivers unprecedented accurate geoid/gravity field data in the 200-400 km range. Cryosat-2 LRM and SAR data delivers new high resolution sea surface height observation and since May 2012 the Jason-1 satellite has been operating in geodetic mission as part it end of life mission. This is a fantastic new source of altimetric data supplementing the recent released Cryosat-2 data. With nearly 3 years of data Cryosat-2 has completed more than 3 repeats along it primary tracks in it's 369 days repeat. In principle the satellite should continue to measure along these repeat However it is currently under investigating how exactly this repeating cycle actually is and as a consequence the Cryosat-2 data have been used for the DTU13 as non-repeating.
Extensive testing and improvement in methods to handles, process and derive gravity from the new class of data has been investigated and the first result from selected regions throughout the worlds ocean will be presented

New Marine Gravity from Jason-1 and CryoSat-2 Reveals Tectonics, Seamounts, and Abyssal Fabric

David Sandwell, Scripps Institution of Oceanography
Emmanuel Garcia, SIO
Walter H. F. Smith, NOAA
Khalid Soofi, ConocoPhillips Co.
Paul Wessel, Univ. of Hawaii
Michael Chandler, Univ. of Hawaii
Karen Marks, NOAA

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Oral

Marine gravity from satellite altimetry has become a primary tool for investigating the tectonics of the remote ocean basins as well as unexplored continental margins. Gravity field accuracy depends on three factors: spatial track density, altimeter range precision, and diverse track orientation. Recently two new non-repeat altimeter data sets have become available, resulting in a factor of 2-4 improvement in maps of the global marine gravity field. In June 2013, Jason-1 completed its 406-day geodetic phase. Given its relatively low inclination, the data from Jason-1 have increased the accuracy of measuring the marine gravity field's E-W component. Meanwhile, the nearly polar orbit of the ongoing Cryosat-2 mission has provided 3 years of non-repeat profiles so far, which have dramatically refined the marine gravity field's N-S component. The combined result is a spectacular improvement in the 12 to 40 km wavelength band, which is of interest for investigation of seafloor structures as small as 6 km. The current version of the altimeter-derived gravity field has an accuracy of 1.6 mGal in the Gulf of Mexico and 2.4 mGal in the Canadian Arctic. (1 mGal corresponds to a slope of 1 microradian or 1 cm per 10 km.) Unlike terrestrial gravity where coverage is uneven, these accuracies are available over all marine areas and large inland bodies of water. At the meeting we will present the latest gravity model and discuss new tectonic features revealed by Jason-1 and CryoSat-2. A global poster is available at:
ftp://topex.ucsd.edu/pub/global_figs/grav_gradient_V22.jpg

The DTU13 global mean sea surface from 20 years of satellite altimetry

Ole Baltazar Andersen, DTU Space, Denmark
Lars Stenseng, DTU Space
Per Knudsen, DTU Space

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Oral

The DTU13MSS is the latest release of the global high resolution mean sea surface from DTU Space.
Two major advances have been made in order to release the new mean sea surface.
The time series have been extended to 20 years from 17 years for the DTU10MSS creating a multi-decadal mean sea surface for the first time.
Secondly, the DTU13MSS ingest Cryosat-2 SAR Lead data in order to map the high latitude parts of the Arctic Ocean.
In the high latitude regions a combination of joint ERS-1&ERS-2/ENVISAT and Cryosat-2 altimetry have been used. Also the Jason-1 geodetic mission has been used for the DTU13MSS. The new geodetic mission of C2 and J1 present fantastic new source of altimetric data which can be used to replace the older ERS-1 and GEOSAT geodetic mission for the mean sea surface as the new data have far better range precision.

A 20-Year Reference Period for SSALTO/DUACS Products

Marie-Isabelle Pujol, CLS
Yannice Faugere, CLS
Jean-François Legeais, CLS
Marie-Helene Rio, CLS
Philippe Schaeffer, CLS
Emilie Bronner, CNES
Nicolas Picot, CNES

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Oral

Altimeter data processing involves the use of a Mean Sea Surface (MSS). This static field, computed using the whole altimetry time series, contains the signature of the Geoid and the height induced by the mean circulation over a given period. This period is called hereafter the reference period of the Mean Sea Surface. Through the use of this MSS, the reference period impacts the other deduced geophysical fields, Mean Dynamic Topography (MDT) and Sea Level Anomaly (SLA). Today the Ssalto/DUACS (AVISO multi-mission merged) products are referenced on a 7-year mean [1993;1999].

This notion of reference period is an important issue for the use of altimeter products. This presentation aims at presenting this issue, showing the interest of changing the current reference period to a 20-year period and describing how it will impact the Ssalto/DUACS reprocessed products available in early 2014.

New global Mean Dynamic Topography from a GOCE geoid model, altimeter measurements and oceanographic in-situ data

Sandrine Mulet, CLS
Marie-Helene Rio, CLS
Nicolas Picot, CNES
Ananda Pascual, IMEDEA

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Oral

The use of recent GOCE geoid models together with an altimeter Mean Sea Surface significantly improves the estimate of the ocean Mean Dynamic Topography at 100 km resolution compared to the use of previous GRACE geoid models. However, at scales shorter than 100km, the combined effect of geoid omission and commission errors prevents from directly using such models to estimate the ocean MDT and additional information is needed.
In this study, the methodology used by (Rio et al, 2012) to estimate the CNES-CLS09 MDT is applied to compute a new, high resolution Mean Dynamic Topography for the global ocean.
First a GOCE geoid model from the fourth official ESA release is subtracted from the CNES-CLS11 altimeter Mean Sea Surface. An optimal filtering technique is applied on the obtained noisy raw MDT to remove the noise due to the geoid omission error and the commission MSS and geoid errors. A ~100km resolution Mean Dynamic Topography is obtained. Then synthetic estimates of the mean heights and corresponding geostrophic velocities are built from in-situ measurements of the ocean state (heights and surface velocities) from which the temporal variability as measured by altimetry is removed. The in-situ measurements dataset consist in hydrological profiles measured by ARGO floats and CTD/XBT casts as well as 15m drogued SVP drifting buoy data for the period 1993-2012. The in-situ data are processed in order to match the altimeter data physical content. In particular, the surface velocities derived from the drifting buoy trajectories are corrected from the Ekman current contribution and the direct wind slippage, that might be quite significant in case of drogue loss.
The synthetic mean heights and velocities are then used to improve the 100km resolution MDT based on GOCE data through a multivariate objective analysis. A new, high resolution, global MDT (the CNES-CLS13 MDT) is obtained that also includes the Mediterranean Sea for which specific data processing and analysis parameters are used.
Improvements over the previous CNES-CLS09 MDT are quantified through comparison to independent in-situ velocities induced from ARGO floats surface displacements. Also, the potential impact of using the new MDT for assimilating altimeter Sea Level Anomalies into the Mercator-Ocean operational forecasting system is assessed.

Assessing Mean Dynamic Ocean Topography Using State Estimation Constraints

Sarah Gille, Scripps Institution of Oceanography
Matthew Mazloff, Scripps Institution of Oceanography
Bruce Cornuelle, Scripps Institution of Oceanography

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Oral

The latest gridded geoid products and altimeter-derived mean sea surface height fields are combined to constrain the mean dynamic ocean topography (MDT) in an observational assimilating ocean model, the Southern Ocean State Estimate (SOSE). Uncertainties in the small-scale MDT are accounted for with a prescribed error variance. Large-scale MDT errors are accounted for by solving for a smooth adjustment field. This adjustment field minimizes the impact of correlated errors in the geoid on the optimization, while providing a consistency estimate of SOSE to the MDT constraints. Structure in the estimated adjustment field is due to errors in the mean sea surface, the geoid, inconsistencies with the other constraints (e.g. Argo), or model errors (e.g. in the bathymetry). The adjustment field is negligible in regions where the model can be brought into consistency with the MDT constraint without having to alter the geoid or mean sea surface. The structure of the adjustment field highlights several prominent bathymetric features, including the Argentine Shelf, the Campbell Plateau, and the Kerguelen Plateau. However other notably complex areas, e.g. the Agulhas retroflection region, do not stand out. These results suggest a new way to merge MDT estimates with ocean state estimation.

Large scale Sea Level variation in the Arctic Ocean from Cryosat-2 SAR altimetry

Ole Andersen, DTU Space
Lars Stenseng, DTU Space
Yongcun Chen, DTU Space
Per Knudsen, DTU Space

Session theme: Science Results from Satellite Altimetry
Oral

Cryosat-2 SAR altimetry is becoming routinely processed at DTU using a suite of empirical retrackers that can handle the presence of sea ice within the radar echo.
We have processed 3 years of Cryosat-2 data quantified as either Lead or Ocean data within the Cryosat-2 SAR mask in the Arctic Ocean.
One of the problems encountered in the use of Cryosat-2 for oceanographic purposes in the Arctic is the fact that the mask discriminating SAR from other type of data and the quatification of the various data types changes with time so there are only very sparse regions with continous data of the same type. Furthermore the orbit configuration is such that the repeat is around 1 year. Consequently we applied binning of the data in order to increase the temporal resolution for the analysis of temporal changes in the Arctic Ocean from Cryosat-2.

Mapping the ocean's surface circulation from altimetry

Steven Jayne, Woods Hole Oceanographic Institution
Breck Owens, Woods Hole Oceanographic Institution
Bruce Cornuelle, Scripps Institution of Oceanography

Session theme: Science Results from Satellite Altimetry
Oral

We present an extension of the statistical mapping technique, optimal interpolation, based on the Guass-Markov theorem that incorporates additional constraints beyond simple geostrophy to compute the surface velocity field. In particular, we include additional covariances that allow the estimation of the equatorial velocities from the observed sea surface height. Near the equator, the traditional estimation of the geostrophic velocity from the pressure field using relations becomes ill-defined as Coriolis parameter goes to zero. However, using our technique the resulting velocity field is continuous and smooth between the off-equatorial geostrophic velocity and the equatorial beta-geostrophic velocity. This is uniquely different than method that is currently used by AVISO which also provides an operational velocity field derived from the sea surface height field, however, they apply beta geostrophy over the band of 5°N/S that is discontinuous with the higher latitudes, and results in distinct change in the eddy kinetic energy at those latitudes. Our methodology overcomes this disadvantage and can be combined with other constraints, such as no flow through topography, to create a dynamically-constrained, mapped surface velocity field.

Meridional Changes of the South Atlantic Meridional Overturning Circulation

Gustavo Goni, National Oceanic and Atmospheric Administration (NOAA), Atlantic Oceanographic and Meteorological Laboratory (AOML), Physical Oceanography Division (PHOD)
Shenfu Dong, University of Miami and NOAA/AOML
Francis Bringas, NOAA/AOML/PHOD

Session theme: Science Results from Satellite Altimetry
Oral

The Atlantic component of the Meridional Overturning Circulation (AMOC) is characterized by a northward flow of warm water in the upper layers from the South Atlantic into the North Atlantic, sinking and formation of North Atlantic Deep Water at high latitudes, and a southward return flow of cold water at depth. The AMOC carries a significant fraction of the total global ocean-atmosphere northward heat flux. The majority of this heat is lost to the atmosphere in the mid-latitudes where warm water meets cold, dry continental air masses. Several underway efforts involve in situ observations and numerical models seeking to design and establish a sustained observational system for the South Atlantic MOC. We incorporate satellite altimetry into these analyses to demonstrate how satellite measurements complement and expand the estimates of MOC from in situ observations in space and time in the South Atlantic. Of particular interest is to assess how well altimetry can be used to investigate the spatial and temporal variability of the MOC and Meridional Heat Transport (MHT) in this region. Previous results from hydrographic observations showed that the geostrophic component dominates the MOC/MHT at 35°S. We present here the time series of the geostrophic and Ekman components of the MOC/MHT between 20°S and 35°S estimated from altimetry observations and NCEP winds. The MOC/MHT time series show that the geostrophic component dominates the interannual variability of MOC/MHT during 1993-2005, with Ekman component plays a large role after 2005. The mean values of MOC (MHT) are 18.77 Sv (1.23 PW), 22.10 Sv (1.10 PW), 22.73 Sv (0.76 PW) and 23.06 Sv (0.72 PW) at 20°S, 25°S, 30°S, and 35°S respectively; denoting an increase in MHT towards the Equator, which is consistent with the very few estimates available in the region. The time series exhibit a long-period variability with high (low) values in the mid 2000's (1990's). The larger variability is observed at 20°S and 35°S, and it is lower in the center of the subtropical gyre. Consistent with previous results from XBT measurements, both geostrophic and Ekman components exhibit statistically significant annual cycle at 35°S with maximum anomalous values of approximately 4 Sv (0.5 PW). However, the seasonal cycles of the geostrophic and Ekman components are out of phase. Results for the other three latitudes are similar to that at 35°S, but with weak annual cycle.

The Contributions of Ekman Heat Advection to Meridional Heat Transport Anomalies in the Atlantic Ocean

Kathryn Kelly, University of Washington
Jinting Zhang, University of Washington
LuAnne Thompson, University of Washington

Session theme: Science Results from Satellite Altimetry
Oral

Observations of thermosteric sea level (TSL), equivalent water thickness (EWT) from GRACE, and sea surface height (SSH) are assimilated into a simple model forced by surface heat fluxes to construct a heat budget for the Atlantic for 1993-2010. Heat transport convergence (HTC) anomalies are estimated as a residual of the budget using a Kalman filter. Anomalies of HTC are combined with direct estimates of meridional heat transport (MHT) at 41N from Willis (2010) to estimate MHT anomalies throughout the Atlantic. The monthly MHT anomalies agree well with MHT from the RAPID/MOCHA program at 26.5N (the RAPID line). Our analysis shows that anomalies in MHT comparable to or those observed in 2010-2011 also occurred in 1999-2001. MHT anomalies are highly coherent between 35S and 40N with no obvious temporal lag. Positive anomalies in coherent MHT correspond to increased heat loss in the subtropical gyre highlighting the linkage between air-sea coupling in the North Atlantic subtropical gyre and large-scale ocean circulation. The high level of coherence in MHT, as well as the large contribution of Ekman advection to MHT at 26.5N, suggest forcing by large-scale wind anomalies. We compute estimates of Ekman heat advection from observations for comparison with model HTC and MHT and quantify the contributions of Ekman advection to meridional coherence. Ekman advection anomalies reverse sign across 40N, consistent with a decrease in MHT coherence there.

Satellite-based ocean analysis for the MidAtlantic Bight

Javier Zavala-Garay, Institute of Marine and Coastal Sciences, Rutgers University
John L. Wilkin, Institute of Marine and Coastal Sciences, Rutgers University
Julia Levin, Institute of Marine and Coastal Sciences, Rutgers University

Session theme: Science Results from Satellite Altimetry
Oral

We present an evaluation of 7 years (2006-2012) of ocean analysis for the Mid-Atlantic Bight. The analysis was produced by assimilating Sea Surface Height Anomalies along the Jason1/Jason2 tracks and individual passes of AVHRR Sea Surface Temperature using 4-Dimensional Variational (4-DVar) data assimilation in the Regional Ocean Modeling System (ROMS). The analysis is compared with a varied collection of not-assimilated surface and subsurface observations such as surface HF-Radar currents, drifter data, buoy SST, subsurface temperature and salinity from gliders and CTD casts (both in the shelf and deep ocean), and mean subsurface currents from current-meters and ADCP transects. The general circulation of the resulting analysis is described, and the performance of the system in extraordinary events such as Hurricane Irene (2011) and Hurricane Sandy (2012) is presented. It is shown that overall the system has a good degree of hindcast/forecast skill both in the shelf and the deep ocean, demonstrating how the combination of models with satellite observations via variational methods could be useful to infer the subsurface variability in other parts of the world.

Integrated multi-mission Satellite Altimetry data in Climatic Studies- Detection of the Madden-Julian Oscillation

Subrahmanyam Bulusu, Dept. of Earth and Ocean Sciences, University of South Carolina, Columbia
Gary Grunseich, Department of Meteorology, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu

Session theme: Science Results from Satellite Altimetry
Oral

The scientific value of satellite altimetry data has grown dramatically over time in oceanographic studies, but has not been fully utilized in climate-related studies. The Madden-Julian Oscillation (MJO) impacts a wide range of weather and climate phenomena such as monsoon onset and break, El Niño – Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) interactions, and tropical cyclone modulation. Despite the important role of the MJO in our climate and weather systems, current global circulation models (GCMs) exhibit considerable shortcomings in representing it. A lack of in situ observations in the tropical oceans, especially in the Indian Ocean, has impeded progress on the study of the MJO, specifically its initiation. This study shows that the MJO signal is observed in Sea Surface Height (SSH) data, indicating that satellite altimetry data can provide useful measurements of MJO activity, particularly in regions where there is a lack of observations.

In this study the role of air-sea interaction on Madden-Julian Oscillation (MJO) propagations across the tropical Indian Ocean is analyzed using integrated multi-mission satellite measurements of Sea Surface Height (SSH) and Outgoing Longwave Radiation (OLR). MJO-related activity is observed in both parameters in the eastern equatorial Indian Ocean indicates that in the eastern Indian Ocean, atmospheric conditions appear to aid the generation of equatorial Rossby waves while in the central and western Indian Ocean, different phases of oceanic Rossby wave propagations seem to have a strong influence on atmospheric conditions associated with the MJO. The downwelling phase of equatorial Rossby waves corresponds to strengthening of OLR anomalies in spatial extent and magnitude across the equatorial Indian Ocean, while the upwelling phase appears to weaken atmospheric MJO activity.

Two Decades of Global and Regional Sea Level Observations from the ESA Climate Change Initiative Sea Level Project

Michaël Ablain, CLS
Larnicol Gilles, CLS
Cazeanve Anny, LEGOS/CNES
Faugère Yannice, CLS
Benveniste Jérôme, ESA
Dinardo Salvatore, ESA
Lucas Bruno.Manuel, ESA
Johannessen Johnny, NERSC
Stammer Detlef, Univerty of Hamburg
Thierry Guinle, CNES

Session theme: Science Results from Satellite Altimetry
Oral

Sea level is a very sensitive index of climate change and variability. Sea level integrates the ocean warming, mountain glaciers and ice sheet melting. Understanding the sea level variability and changes implies an accurate monitoring of the sea level variable at climate scales, in addition to understanding the ocean variability and the exchanges between ocean, land, cryosphere, and atmosphere. That is why Sea Level is one of the Essential Climate Variables (ECV) selected in the frame of the ESA Climate Change Initiative (CCI) program and kicked-off in July 2010. This program aims to provide an adequate, comprehensive, and timely response to the extremely challenging set of requirements for highly stable, long-term satellite-based products for climate, that have been addressed to Space Agencies via the Global Climate Observing System and the Committee on Earth Observation Satellites. In order to achieve this, the objectives of the Sea Level CCI Project are: to involve the climate research community to collect their needs and feedbacks on product quality, to develop, test and select the best algorithms and standards to generate a climate time series, to provide a complete specification of the production system, and to produce and validate the Sea Level ECV product.

We will present the current status of the ESA CCI Sea Level Project. The 2013 OSTST will be the opportunity to unveil the 18 years climate time-series based on satellite altimetry measurements. We will also describe the different activities that were necessary to deliver the ECV products: collect and refine the user requirements, develop, test and select the best algorithms for climate applications. The production system and a brief description of the main product characteristics are provided as well as results of the product validation and its use, one year after its release.

The Phase of the Pacific Decadal Oscillation (PDO) and Sea Level Trends in the North Pacific

Gary Lagerloef, Earth & Space Research
ChuanLi Jiang, Earth & Space Research
Scott Springer, Earth & Space Research

Session theme: Science Results from Satellite Altimetry
Oral

In the Proceedings of the 20 Years of Progress in Radar Altimetry Symposium (2012) we noted that the map of the 20-year sea level trend measured by satellite altimetry bears a clear imprint of the PDO spatial pattern in the North Pacific. Here we investigate this further and show that, after the global mean sea level (GMSL) trend (~3.2 mm/yr) is removed, most of the residual trend in the North Pacific matches the pattern produced by projecting the sea surface height onto the PDO index. The negative trend of the PDO index during this period, coupled with this pattern, has suppressed the mean sea level rise in the eastern North Pacific (ENP), and enhanced it in the central North Pacific. Thus, the ENP sea level trend has been moderated by the PDO to be near zero or slightly negative, in contrast to positive GMSL rise. There is also a strong positive sea level trend in the western tropical Pacific during this period. We then examine a possible future scenario with a shift of the PDO from a negative to positive phase, with similar magnitude trend as the past 20-years. In such a situation, the ENP sea level rise could become two to three times greater than the global average, with potential implications for accelerating long-term sea level rise along the west coast of North America and Alaska.

Pacific Decadal Oscillation Contribution to Global and Regional Sea Level

Benjamin Hamlington, University of Colorado
Robert Leben, University of Colorado
Mathew Strassburg, University of Colorado
Steve Nerem, University of Colorado
Kwang-Yul Kim, Seoul National University

Session theme: Science Results from Satellite Altimetry
Oral

Understanding and explaining the trend in global mean sea level (GMSL) has important implications for future projections of sea level rise. While measurements from satellite altimetry have provided accurate estimates of GMSL, the modern altimetry record has only now reached twenty years in length, making it difficult to assess the contribution of decadal to multi-decadal climate signals to the global trend. Tide gauges, on the other hand, provide a much longer record albeit with very poor coverage of the ocean. By combining the two datasets, sea level reconstructions provide a possible solution to the respective shortcomings of the satellite altimetry and tide gauge datasets. Here, we use a sea level reconstruction relying on the use of cyclostationary empirical orthogonal functions (CSEOFs) to study the twenty-year trends in sea level since 1900. In particular, we show that the Pacific Decadal Oscillation (PDO) contributes significantly to the twenty-year trends in GMSL over the past 110 years. We estimate the PDO contribution to the GMSL trend over the past twenty years to be approximately 0.49 ± 0.25 mm/year, and find that removing this PDO contribution changes the estimated acceleration observed in GMSL. We discuss the implications of removing known climate variability like the PDO from the sea level record, and the extent to which it can improve the understanding of the underlying trends in global and regional sea level.

Sea level in ocean reanalyses and tide gauges -- how similar?

James Carton, University of Maryland
Gennady Chepurin, University of Maryland
Eric Leuliette, NOAA Laboratory for Satellite Altimetry

Session theme: Science Results from Satellite Altimetry
Oral

Tide gauge sea level records have interannual to multi-decadal variability which is correlated with meteorological variability and which can overwhelm the signal associated with global sea level rise. Removing this variability will improve global sea level estimates, while knowing the spatial and temporal structure of this variability is interesting from a straight science prospective.

This talk will compare sea level from an ensemble of seven ocean reanalysis and synthesis products with gauge time series from a representative set of 87 tide gauge station locations. The comparison is carried out for both a half-century base period and a century long extended period. We find generally good agreement for the half-century period with ensemble average correlations in excess of 0.55 and RMS differences of 2.2 cm, reducing to a correlation of 0.5 for the extended period. A significant fraction of the difference between tide gauge sea level and product sea level is associated with meteorological variability currently represented by the reanalysis/synthesis products. We interpret this result as indicating that there are residual errors in current atmospheric reanalyses that are contaminating current ocean reanalysis/synthesis products. The broader conclusions, though, are the positive statements that 1) much of the interannual to multi-decadal variability that appears in the tide gauge records is meteorologically driven and 2) that ocean products can be used to isolate this variability from the signal associated with the underlying global sea level rise.

Australia's unique Influence on global sea in 2010-2011

John Fasullo, NCAR
Carmen Boening, JPL
Felix Landerer, JPL
R. Steve Nerem, University of Colorado

Session theme: Science Results from Satellite Altimetry
Oral

In 2011, a significant drop in global sea level occurred that was unprecedented in the altimeter era and concurrent with an exceptionally strong La Niña. This analysis examines multiple data sets in exploring the physical basis for the drop's exceptional intensity and persistence. Australia's hydrologic surface mass anomaly is shown to have been a dominant contributor to the 2011 global total, and associated precipitation anomalies were among the highest on record. The persistence of Australia's mass anomaly is attributed to the continent's unique surface hydrology, which includes expansive arheic and endorheic basins that impede runoff to ocean. Based on Australia's key role, attribution of sea level variability is addressed. The modulating influences of the Indian Ocean Dipole and Southern Annular Mode on La Niña teleconnections are found to be key drivers of anomalous precipitation in the continent's interior and the associated surface mass and sea level responses.

Observations and Mechanisms of Near-Uniform Sea Level and Ocean Bottom Pressure Fluctuations Spanning the Arctic Ocean and the Nordic Seas

Ichiro Fukumori, Jet Propulsion Laboratory/Caltech
Ou Wang, Jet Propulsion Lab/Caltech
William Llovel, Jet Propulsion Lab/Caltech

Session theme: Science Results from Satellite Altimetry
Oral

Near-uniform variations of the ocean in the Arctic region from intra-seasonal to inter-annual time-scales are studied using satellite and in situ observations in conjunction with a global ocean general circulation model. The spatially coherent fluctuations extend across the deep ocean basins of the Arctic Ocean including the Nordic Seas with coincident variations in ocean bottom pressure and sea level. The variations are found to be associated with barotropic fluctuations of the ocean forced by changing winds at the shelf break along the continental margins of the Arctic domain. Observations of these variations will be described and the dynamics underlying the fluctuations discussed.

Submesoscale prediction and effects on surface dispersion during the Grand Lagrangian Deployment (GLAD) Experiment

Gregg Jacobs, Naval Research Lab
Bartels, QNA
Boguki, TAMU
Baron-Vera, RSMAS
Chen, RSMAS
Coelho, UNO
Crucic, RSMAS
Griffa, RSMAS
Gough, RSMAS
Haus, RSMAS
Haza, RSMAS
Hogan, NRL
Huntley, U Del

Session theme: Science Results from Satellite Altimetry
Oral

G. Jacobs
B. Bartels-Qinetiq NA
D. Bogucki –Texas A&M Univ.
J. Beron-U.Miami
S. Chen-U.Miami
E. Coelho-UNO/NRL
M. Curcic-U.Miami
A. Griffa-U.Miami
M. Gough-U.Miami
B. Haus-U.Miami
A. Haza-U.Miami
P. Hogan-NRL
H. Huntley-U.Delaware
M. Iskandarani-U.Miami
F. Judt-U.Miami
D. Kirwan-U.Miami
N. Laxague-U.Miami
A. Levinson-U.Florida
B. Lipphardt-U.Delaware
A. Mariano-U.Miami
G. Novelli-U.Miami
J. Olascoaga-U.Miami
T. Ozgokmen-U.Miami
T. Prasad-NRL
A. Poje-City Univ.NY
A. Reniers-U.Miami
E. Ryan-U.Miami
C. Smith-U.Miami
P. Spence-Qinetiq NA
M. Wei-NRL

GLAD is part of the Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE) designed to understand the dispersion of surface materials under the action of ocean surface processes. As part of the experiment, ocean environment forecasts were used to aid in the initial deployment of 300 surface Lagrangian drifters in the northeastern coastal Gulf of Mexico during July 2012.

The performance of the ocean predictions relative to the drifter observations indicates the present level of skill in predicting development of the physical processes controlling environmental conditions in such areas.

The predictions were based on numerical model forecasts, and in this case the Navy Coastal Ocean Model (NCOM) is used covering the Gulf of Mexico at both 3km and 1km resolutions nested into the global NCOM at 1/8 degree resolution. All publicly available satellite and in situ data were assimilated into the ocean model daily. Just prior to the experiment time period, the ocean community suffered loss of the satellite altimeter on ENVISAT, and the Jason-1 satellite was in the process of moving to a new orbit leaving only the Jason-2 data stream. Just prior to the experiment started on July 20 2012, the Jason-1 data stream was reestablished in its geodetic orbit, and the CryoSat2 data stream was added. These changes in the altimeter constellation presented an extreme challenge for the experiment, and did impact the forecast accuracies.

Post analysis indicated that the models were not generating the details in frontal positions of eddies that were observed in the satellite altimeter data and in gridded maps. The features were also observed in the drifter trajectories. A series of experiments were initiated in which variations in the correlation scales and background errors of the assimilation process were systematically changed. It was found that a key aspect is that a long time decorrelation is required for the altimeter data to properly affect the model forecast performance. Typical cycling assimilation systems use the most recently received observations through an analysis to correct the model initial condition or the model trajectory over one day's time. The implication is that the time decorrelation function is a delta function in the case of just resetting the initial condition or a 24 hour boxcar function if inserting the analysis over 1 day. The errors are much longer time scale just as the features of the ocean are, and increasing the temporal data influence reconstructed the features in the observations with much greater fidelity.

The submesoscale frontogenesis structure is predictable conditioned on accurate prediction of the mesoscale flow field that forces the ageostrophic secondary circulation. Experiments with the model results shows that surface divergence is much stronger than divergence at 40m depth, and this leads to different behavior in the dispersion of particles at each depth initially placed on an evenly spaced 1km grid. At 40m depth, the particle density remains relatively uniform even out to 40 days' time. At the surface after only 3 days, the particles aggregate along lines of surface convergence driven by the submesoscale frontogenesis.

This experiment is the first time ocean forecasts played such an integral part in the placement of such a grand Lagrangian data set. It provides a good reference point for the systems' performance. Assimilation of the drifter velocity observations has been examined to demonstrate the impact of this data source that is not presently used. The drifters are sampling the geostrophic velocity or surface height slope. The drifters provide information very similar to the altimeter satellites for an area of high interest with persistent coverage.

A 20-year analysis of Alboran sea ocean current from high resolution altimeter data

Jean Tournadre, IFREMER
Marjolaine Krug, FCSIR
Jordi Isern-Fontanet, IC3
Nicolas Reul, IFREMER
Bertrand Chapron, IFREMER

Session theme: Science Results from Satellite Altimetry
Oral

The water from the Altantic ocean flows near the surface through the Strait of Gilbraltar into the western Alboran Sea where the light Atlantic waters meet the dense Mediterranean ones. This meeting gives rise to intense density fronts and energetic meso-scale features such as two semi-permanent anticyclonic vortices known as the western and eastern Alborán gyres (WAG and EAG). This circulation is strongly variable in both time and space, with episodes where neither the western Alborán gyre nor the eastern Alborán gyre are present. We present a new approach to the analysis of the variability of the Alboran Sea circulation based on the combined analysis of different satellite data, i.e. SAR, Altimeter, Sea surface temperature and scatterometer. Firstly, about 1000 Synthetic Aperture Radar images over the Western Mediterranean sea have been analyzed in terms of surface currents (estimated from Doppler ship). The results have then been averaged to compute the mean surface current. The mean circulation is characterized by strong WAG with mean current speed of the order of 1 m/s and and weaker EAG with mean speed of the order of 50 cm/s. This mean circulation has been used to compute a high resolution mean dynamic topography, the necessary base for the estimate of absolute dynamic topography from altimeter data. The absolute dynamic topography for the three Topex/Jason1/Jason2 that overfly the Alboran Sea has been estimated to create an homogeneous series covering 20 years. Because of the narrowness of the Alboran sea , the number of conventional 1Hz altimeter data usable is limited (~25) and does not allow a good estimate of geostrophic speed. It is necessary to consider the high resolution 20Hz data to have a better estimate of the current speeds. Using Lee filter we estimate the geostrophic current from the absolute dynamic topography for the three altimeter passes that cover the alboran sea.This analysis based on Topex, Jason1 and Jason2 data shows the high spatial and temporal variability of the WAG and even an increase of the inflow of Atlantic water on pass 20 (the closet to the Gibraltar straight that need to be further confirmed and validated. The velocities are compared to the sea surface temperature variability as estimated from the NASA pathfinder data and to the short scale variability of scatterometer winds.

Processes Connecting Coastal to Basin-Scale Ocean Circulation: SW Atlantic Ocean

P. Ted Strub, College of Earth, Ocean and Atmospheric Sciences, Oregon State University
Ricardo Matano, College of Earth, Ocean and Atmospheric Sciences, Oregon State University
Vincent Combes, College of Earth, Ocean and Atmospheric Sciences, Oregon State University
Corinne James, College of Earth, Ocean and Atmospheric Sciences, Oregon State University

Session theme: Science Results from Satellite Altimetry
Oral

The focus of our OST-ST project is on the exchange of water mass and properties between the shelf and the deep ocean along the east and west coasts of South America (Argentina-Uruguay-Brazil; Peru-Chile). Our first region of interest is in the SW Atlantic, where the two opposing boundary currents (the Brazil and Malvinas Currents) converge and create an energetic eddy field offshore of the wide continental shelf. The serendipitous location of the strong freshwater outfall from the Rio de la Plata inshore of the confluence provides a salinity tracer that is detected by satellite surface salinity data collected by the new Aquarius mission. Here we use the combination of altimetry, scatterometry and satellite salinity fields, along with nested ocean circulation models, to investigate the onshore-offshore transport of water mass and salinity between the shelf and deep ocean in this dynamic system. Although taking place on the mesoscale, the transport is part of the basin-scale circulation and affects the salinity and biological fields (as seen in ocean color imagery) of the South Atlantic portion of the Southern Ocean.

Regional Variations in the Influence of Mesoscale Ocean Eddies on Near-surface Chlorophyll

Peter Gaube, WHOI
Dennis McGillicuddy, WHOI
Dudley Chelton, OSU
Michael Behrenfeld, OSU
Peter Strutton, OSU

Session theme: Science Results from Satellite Altimetry
Oral

Eddies influence biogeochemical cycles through the excitation of vertical velocities within their interiors and the horizontal advection of nutrients and ecosystems, either around the eddy periphery by rotational currents, or by the trapping of fluid within eddy interiors. In this study, we present an analysis of the influence of mesoscale ocean eddies, identified and tracked by their sea surface height signatures observed by a series of satellite altimeters on near-surface chlorophyll (CHL) as estimated from ocean color measured by the SeaWiFS sensor.

The influence of mesoscale eddies on CHL varies regionally, with cyclonic eddies generating positive CHL anomalies and anticyclonic eddies generating negative CHL anomalies in most boundary current regions. In some regions, such as the South Indian Ocean and oligotrophic South Pacific Ocean, anticyclonic eddies generate positive CHL anomalies and cyclonic eddies generate negative CHL anomalies. The observed regional variability of the influence of eddies on CHL is analyzed in an eddy-centric frame of reference in a series of six study regions.

Mechanisms by which eddies can influence phytoplankton communities are described and regions where the observed CHL response to eddies is in agreement with any subset of these mechanisms are discussed. This study does not attempt to definitively link the observed regional variability to any particular mechanism, but provides a global overview of how eddies influence CHL anomalies and presents an observations basis upon which coupled bio/physical ocean circulation models can be assessed.

Randomness, symmetry and scaling of mesoscale eddy life cycles

Roger Samelson, Oregon State University
Michael Schlax, Oregon State University
Dudley Chelton, Oregon State University

Session theme: Science Results from Satellite Altimetry
Oral

Time series of eddy amplitude from an automated eddy identification and tracking analysis of the nearly two-decade merged satellite altimeter record of global sea-surface height (SSH) are analyzed. It is found that the resulting amplitude life cycles of nonlinear mesoscale eddies, a major component of low-frequency ocean physical variability, have a characteristic structure that differs fundamentally from that which would be expected on the basis of classical interpretations of ocean eddy evolution in terms of mean-flow instability followed by frictional, radiative or barotropic decay, or of vortex merger dynamics in quasigeostrophic turbulent cascades. Further, it is found that these life cycles can be accurately modeled in terms of the large-amplitude excursions of a stochastic process. The ensemble mean and standard deviation time series of normalized eddy amplitude have several striking and unexpected characteristics, including time-reversal symmetry and approximate self-similarity. The basic qualitative and quantitative statistical properties of these series can be remarkably well reproduced with an extremely simple stochastic model, in which the SSH increments between successive time points are random numbers, and the eddy life cycles are represented by excursions exceeding a given threshold. The stochastic model is found also to predict accurately the empirical autocorrelation structure of the underlying observed SSH field itself, when the autocorrelations are computed along long planetary (Rossby) wave characteristics.

New perspectives for future high-level Ocean Altimetry products

Clement Ubelmann, JPL/CALTECH
Patrice Klein, IFREMER
Lee-lueng Fu, JPL/CALTECH

Session theme: Science Results from Satellite Altimetry
Oral

The next generations of altimeters (e.g. SWOT) are expected to perform two- dimensional SSH mapping at unprecedented resolutions (15km wavelength) with typical time revisits of 10-20 days. However, the short mesoscales not yet adequately observed with conventional altimetry (eddies between 15km and 100km) have time scales on the order of a few days that are much shorter than the revisit intervals, as opposed to the large and slowly-evolving mesoscale eddies currently observed by altimeters with similar or shorter time revisit. Therefore, the short-mesoscale dynamic signals will be inadequately sampled in time by missions like SWOT.

For the purpose of producing high-level products for the general user community, new strategies need to be developed to address the temporal sampling problem. Because of the significant mismatch between the time scales of the signals and the sampling intervals, the classic optimal interpolation methods successfully used so far to produce the altimetry maps by Aviso will probably not work well.

In this study, we apply the concept of dynamic interpolation to reconstructing the time evolution between two high-resolution SSH images, based on the basic principles of geophysical fluid dynamics. The conservation of interior potential vorticity or surface potential vorticity (through buoyancy anomalies) has been investigated in a quasi-geostrophic framework. We will show, from preliminary experiments based on a high-resolution 3D model as the truth, that such approach produces drastic improvement over classical interpolation.

As opposed to the advanced OGCMs, the dynamic interpolator does not rely on external parameters (e.g. forcing) and 3D state initialization (not observable at the scales of interest). It is highly efficient and self contained for producing gridded products for research and applications. Practical issues in the implementation of the method to SWOT as well as existing altimetry missions will be discussed.

Mean vertical and horizontal structure of the subtropical circulation in the South Atlantic from three-dimensional observed velocity fields

Claudia Schmid, NOAA/AOML

Session theme: Science Results from Satellite Altimetry
Oral

An analysis of the three-dimensional circulation in the subtropical South Atlantic based on velocity fields derived from Argo data and AVISO sea surface heights provides new insight into the mean zonal and meridional transports in the subtropical gyre. The velocity fields reveal the reduction of the latitudinal extent of the subtropical gyre with increasing depth that is mainly due to a southward shift of the westward branch of the subtropical gyre that is most pronounced near the western boundary. A joint analysis of zonal and meridional transports in the subtropical gyre in five 400m thick layers from the surface to 2000m reveals an interior pathway from the South Atlantic Current (SAC) to the Southern South Equatorial Current (SSEC) between 18W and 1E. At 35S the northward transport in this longitude band ranges from 6.8Sv in the shallowest layer to 3.9Sv in the deepest layer, and adds up to total transport of 26.0Sv in the upper 2000m. Within the uncertainty of the estimated transports, these northward transports are consistent with the west-to-east weakening of the SAC and the east-to-west strengthening of the SSEC in 18W and 1E. With respect to the boundary currents that are part of the subtropical gyre, the southward transport of the Brazil Current in the upper 2000 m increases from 5.4Sv at 29S to 29.0Sv at 34S. From there on the transport decreases to 7.3Sv at 36S before increasing again to 24.0Sv at 38.5S. The latitude-dependence north of 35S may be due to the small recirculation of the Brazil Current that has a northward transport of 14.8Sv at 35S in the upper 2000 m. Along the eastern boundary, the Benguela Current, is 23.9Sv in the upper 1200 m at 35S. To the east of this current, the Benguela Poleward Undercurrent can be detected in the velocity field as well as in the salinity field derived for the core of the Antarctic Intermediate Water. This current extends as far south as 30S and potentially even to 33S.

Northern North Atlantic sea surface height and ocean heat content variability

Sirpa Hakkinen, NASA Goddard Space Flight Center
Peter Rhines, University of Washington
Denise Worthen, NASA Goddard Space Flight Center

Session theme: Science Results from Satellite Altimetry
Oral

Strong connections between altimetric sea-surface elevation and heat-content in the upper 700m of the N. Atlantic are found in decadal to multidecadal variability. Altimetric SSH continues to be dominated by an increase of about 14 cm in the Labrador and Irminger seas from 1993 to 2011, while the opposite has occurred over the Gulf Stream region over the same time period. During the altimeter period the observed 0–700 m ocean heat content (OHC) in the subpolar gyre mirrors the increased SSH by its dominantly positive trend. Over a longer period, 1955–2011, fluctuations in the subpolar OHC reflect Atlantic multidecadal variability (AMV) which can be attributed to advection driven by the wind stress ''gyre mode'' bringing more subtropical waters into the subpolar gyre. The anomalous heat content in the recent 5 years wraps in a warm arc around the subpolar gyre, while accompanied by slowing surface cyclonic circulation. The warmth extends more than 800m below the surface, in both lobes of the warm arc.

The extended subpolar warming evident in SSH and OHC during the altimeter period represents transition of the AMV from cold to warm phase. In addition to the dominant trend, interannual anomalies propagate westward and are expressed strongly in the Gulf Stream recirculation and North Atlantic Current region. The first empirical orthogonal function SSH time series shows an abrupt change 2009–2010 reaching a new minimum circulation in 2010 which continues to persist. This coincides with the change in the meridional overturning circulation at 26.5N as observed by the RAPID project, showing it to be a basin-wide event, and with extreme behavior of the wind stress gyre mode and of atmospheric blocking. While the general relationship between northern warming, Atlantic meridional overturning circulation (AMOC) and atmospheric storm track variability remains undetermined, there are increasing signs of correlation among them, with model results suggesting upward influence of OHC anomalies on the atmospheric storm track.

Estimates of Geostrophic Transport in the Southern Ocean by Combining Satellite Altimetry and Temperature/Salinity Profile Data

Michael Kosempa, University of South Florida
Don Chambers, University of South Florida

Session theme: Science Results from Satellite Altimetry
Oral

We present estimates of volume transport for the Southern Ocean for 2004-present based on zonal geostrophic velocity fields computed from sea surface topography from altimetry and Argo autonomous floats. The data are combined to estimate the current at 1975 dbar, and then the relative geostrophic currents are computed from the Argo data and integrated from 1975 dbar to the surface along with the reference current at depth and surface current from altimetry to determine the total transport. Transport is computed between 29.5°S and 58.5°S. Velocities at depth are first compared to those estimated from Argo drift trajectory at 1000 dbars available from the Asia Pacific Data Research Center (APDRC). The inferred velocities agree with those from the Argo drift within the estimated sampling error of the latter, but have fewer gaps in space and time. Transport means across two choke points – south of Africa (131.9 ± 29.2 x 106 m3 s-1) and Tasmania (124.3 ± 13.1 x 106 m3 s-1) - are in good agreement with previously published results. The true utility of this method is found in the capability of generating time series as well as means transports. These observed transport fields could be used to validate conclusions drawn from computational models to better understand climate dynamics.

Western Boundary Current Velocity and Transport: Combining Altimetry, XBT, and Argo

Nathalie Zilberman, Scripps Institution of Oceanography
Dean Roemmich, Scripps Institution of Oceanography
Sarah Gille, Scripps Institution of Oceanography

Session theme: Science Results from Satellite Altimetry
Oral

Western Boundary Currents (WBCs) play an essential role in the meridional distribution of heat, mass, and freshwater of the global ocean. They constitute the primary pathway for basin-scale heat exchange between the tropics and the midlatitudes. Because they are highly variable narrow meandering jets, estimating the transport of WBCs poses signicant challenges. Our first goal is to provide state of the art estimates of the volume transport in the subtropical gyre WBC regions of the Pacific, Atlantic, and Indian Ocean using a combination of high-resolution expendable bathythermograph (HRX), Argo float profiles and trajectories, and altimetric datasets. Transport estimates are made both for the poleward WBCs and for their local recirculations. Quarterly HRX sections similarly occupied from the 1990s to 2013 provide 0-800 m temperature profiles. Argo temperature profiles are used to expand HRX temperature data to 2000-m. Altimetric height provides a correction of profile anomalies to mean fields in the upper 2000-m. Large-scale salinity adjustments to the 2004-2013 mean temperature/salinity relation are determined using Argo monthly anomaly fields of temperature and salinity. Absolute geostrophic velocity is assessed using Argo float trajectories at parking level. Our second objective is to study the time-variability of the transport in WBC regions in all three basins. WBC transport variability prior to the Argo era is addressed using combined altimetry/Argo data.

Large-Scale Pacific Ocean Sea Level and Circulation Changes vs. the PDO Forcing

Bo Qiu, University of Hawaii at Manoa
Shuiming Chen, University of Hawaii at Manoa

Session theme: Science Results from Satellite Altimetry
Oral

Satellite altimeter data of the past two decades are used to investigate the large-scale sea level and circulation changes in the North Pacific Ocean on decadal timescales. The variability has three centers of action: one in the tropical western Pacific of 2N~18N, the 2nd in the central subtropical gyre along the Subtropical Countercurrent (STCC; 18~30N), and the 3rd in the Kuroshio Extension (KE) region of 30~40N. While all changes in the three regions are induced by the PDO wind forcing, the ways the sea level and circulation respond in these three regions are dynamically different. In the tropical western Pacific, large regional sea level rise and the southward migration of the tropical-subtropical gyre boundary are caused by enhanced trade winds through the low-latitude manifestation of the PDO forcing. Along the STCC band, the PDO-related Ekman flux forcing alters the baroclinic vertical shear of the STCC, resulting in a clear decadal modulation in the regional eddy kinetic energy field. Decadal fluctuations in the KE system, on the other, are caused by the remote PDO forcing in the eastern North Pacific Ocean. Affected circulation changes include the path location, the surface jet intensity and stability, and the recirculation gyre.

The Annual Cycle of Steric Height and Sea Surface Height in the Equatorial Pacific

Dean Roemmich, Scripps Institution of Oceanography, UCSD
John Gilson, Scripps Institution of Oceanography, UCSD
Florent Gasparin, Scripps Institution of Oceanography, UCSD
Bruce Corunelle, Scripps Institution of Oceanography, UCSD

Session theme: Science Results from Satellite Altimetry
Oral

The close relationship of Argo steric height (SH) and altimetric sea surface height (SSH) is revisited in the equatorial Pacific, focusing on the annual cycle because of its large contribution to the total variance, its relationship to interannual ENSO variability, and its unique equatorial wave phenomena. Using either 9-year (2004-2012, SH and SSH) or 20-year (1993-2012, SSH) time-series for averaging, the westward propagating annual Rossby wave described by Kessler and McCreary (JPO,1993) stands out clearly. Eastward intraseasonal Kelvin wave propagation along the equator is strong enough in individual years to leave residuals in the 9-year or 20-year averages, particularly in October/November at around 160°W. In the eastern and central equatorial Pacific, the amplitude of annual variability is much greater at 5°N than at 5°S, as noted by Kessler and McCreary (1993). West of the dateline the variability is nearly symmetric about the equator with strong maxima at 5°N and 6°S. Gridded SH and SSH are well correlated throughout the domain with SSH anomalies approximately 1.1 times SH. The Argo profile data reveal the vertical structure and vertical phase propagation corresponding to the SH annual cycle. Argo trajectories at 1000 m show large annual zonal displacements along the equator of 1000 -2000 km. Annual steric variability extends below 2000 m, where the deep steric signal is significant but weaker due to decreased vertical property gradients. The spatial pattern of the SSH-minus-SH annual cycle is noisy but resembles that of mass variability from GRACE.

This report anticipates a field experiment beginning in late 2013 in which Argo resolution will be doubled in the equatorial Pacific. Using high bandwidth 2-way communications, Argo floats can now leave the sea surface in about 20 minutes, minimizing the sea surface equatorial divergence caused by much longer surface times in earlier floats. Information content in Argo and altimetry will first be investigated separately for comparison. In subsequent work we will consider them in combination, and together with wind stress, using multivariate optimal interpolation and then ocean state estimation to add dynamical constraints. The equatorial Pacific is a favorable test-bed because of the importance of optimizing the ENSO observing system and because the scales of variability are longer there than at higher latitudes, providing more robust statistical results.

Coastal and Inland Water SAR Altimetry at 80 Hz

Salvatore Dinardo, SERCO
Bruno Lucas, DEIMOS
Jerome Benveniste, ESA

Session theme: Instrument Processing
Poster

Thanks to the CryoSat-2 instrumental capacity to downlink unprocessed Full Bit Rate (FBR) data, different data processing strategies can be attempted and implemented on ground.
This is particularly helpful, when operating in the coastal zone, inland water or land. It seems sensible to have SAR-processed echoes treated at highest repetition frequency possible in order to capture all the short scale variability of the coastal scenario.
In the Delay-Doppler processing algorithm, the parameter controlling the echo posting frequency is the grid space step that conventionally has been fixed at frequency of 20 Hz (300 meter) in order to match the instrument along track resolution, but the grid space step can be arbitrarily defined to any desired value.
In the present work, we will attempt to Delay-Doppler process the FBR data with a finer space step -around 80 meter, that corresponds to a frequency of 80 Hz (Burst Repetition Frequency)- and we will try to quantify the improvement, in term of precision and in term of observability of short scale signals, that is achieved from usage of that finer space step. It is worth to notice that, whereas the grid space step shrinks from 300 meters to 80 meter, the theoretical along-track resolution of 300 meter will remain unaltered.
Once that the L1B SAR echoes have been generated at 80 Hz, they will be re-tracked at 80 Hz using the SAMOSA model in order to retrieve the geophysical quantities: Sea Surface Height (SSH), Significant Wave Height (SWH) and Wind Speed at 10 meter (U10).
The experiment will be run in the waters of the German Bight (Wadden Sea) and Northern Caspian Sea and it will consist in processing the same FBR dataset at 20 Hz (standard grid case) and at 80 Hz (overgrid case) and in spotting the differences between the two cases in term of statistics and resolving power.
The current work is a feasibility study, preparatory for the data exploitation of the Sentinel-3 Topography Mission over coastal zone and inland water.

Progress in Retracking TOPEX for the Climate Data Record

Philip Callahan, Jet Propulsion Laboratory
Brent Williams, Jet Propulsion Laboratory

Session theme: Instrument Processing
Poster

We will report on progress in understanding the waveform leakages and PTR changes that affected TOPEX Alt-A data. In addition, we will briefly report on studies of some numerical issues in retracking.

The effects of the leakages were found to have a limiting effect on the range of data that could be reliably used in the CalSweep measurements of the PTR. This also affects the Cal-1 data that are available throughout both Alt-A and Alt-B lifetimes. Possible methods of extending the PTR beyond the approximately seven usable lobes are being considered as it has been suggested previously that it is necessary to about 30 lobes to reach full accuracy. This suggestion is also being revisited.

A physical model of the PTR change based on changes in phase between the I and Q channels as originally suggested by R. Jenson of APL has been investigated. The model can reproduce much of the observed behavior, but the remaining differences make it unclear whether the model can be used to predict the temporal behavior better than the Cal-1 data.

Testing of waveform weights, masking, and PTR variations are continuing.

Inversion of Saral/AltiKa waveforms over different surfaces

Denis Blumstein, CNES / LEGOS
Fernando Niño , LEGOS
Sara Fleury, LEGOS
Nathalie Steunou , CNES
Francois Boy, CNES
Frederique Remy, LEGOS
Stéphane Calmant, LEGOS
Florence Birol, LEGOS

Session theme: Instrument Processing
Poster

The SARAL program is a joint mission conducted by ISRO and CNES dedicated to environment monitoring. The satellite, which was successfully launched on the 25th of February this year, carries the first altimeter using the Ka band: AltiKa. This instrument provides new opportunities for understanding altimetry in the coastal region thanks to its reduced footprint, improved range resolution and excellent measurement noise but it also poses new challenges linked to the new frequency band. The Cal/Val phase of the system has been conducted successfully and the first results are very promising.
We analyse the inversion of waveforms provided by the AltiKa instrument over various surfaces covering the whole range of applications of radar altimetry (ocean with strong non uniformities of the sigma0, coastal regions, hydrology and glaciology) and compare the result of these inversions (height and sigma0) with those of the classical retrackers. The application to other missions is also analyzed.
This work is performed in the frame of the OSTST/TOSCA project RESIPE/AltiWaveforms.

First SARAL/AltiKa Results: Overview of the Altimeter Performances

Jean-Christophe Poisson, CLS
Sophie Peyridieu, CLS
Pierre Thibaut, CLS
Nathalie Steunou, CNES
Nicolas Picot, CNES

Session theme: Instrument Processing
Poster

The SARAL/AltiKa mission was successfully launched on February 25, 2013 and provides high quality data since March 14, 2013. The AltiKa altimeter is an innovative 40Hz mono-frequency Ka-band radar, dedicated to provide accurate measurements of ocean surface topography. As SARAL/AltiKa is the first altimetry mission operating at 35.75 GHz and knowing that the future SWOT mission will use the same frequency, a careful consideration is given to the Ka-Band performance assessment with a special focus on the backscattering measurements (sensitivity to rain cells, wind speed, etc …).
In this paper, we propose to give an overview of the instrument and processing behavior, based on the first AltiKa measurements. Various aspects are covered such as the impact of the 480 MHz bandwidth, the comparison of the different tracker modes, the spectral error budget and the analysis of the Sigma0 measurements compared to the Ku ones.

Analyze of the effects of swell on SAR-mode measurements

Thomas Moreau, CLS
Laiba Amarouche, CLS
Pierre Thibaut, CLS
François Boy, CNES
Nicolas Picot, CNES

Session theme: Instrument Processing
Poster

The SAR-mode altimeter differs from the conventional radar altimeter in that it uses notably an along-track processing for increasing the spatial resolution of the measurements. On board the Cryosat-2 mission, the synthetic aperture processing creates doppler bins as narrow as 300 meters in width. This allows to achieve high-resolution (but also high-accuracy) altimetric mapping of the ocean surfaces, and might potentially enable to detect submesoscale structures (from 0.1 to 1km) that are unresolved from low-resolution mode observations, in particular the ocean surface waves (swell). For example, it is currently unknown how the retrieved sea surface height elevations and other surface parameters derived from the SAR-mode are impacted and at what accuracy these data are in the presence of directional ocean waves, especially those whose wavelengths are close to the SAR along track sampling. Very few studies have investigated the sensitivity of the SAR-mode altimeter data to the swell, which is of high importance for the next missions (Sentinel-3 and Jason-CS). Similar questions are likely to come up with the LRM mode data.
CLS has been conducting a study, under CNES funding, to characterize these effects through both simulation and flight data analysis. First, this paper presents the numerical study based on the use of an end-to-end simulation tool including a SAR simulation capability with a generator of realistic models of long ocean surface waves and a SAR retracking algorithm. In particular, we will examine the effects of different swell spectrum characteristics (in direction and frequency) on the surface geophysical estimated parameters. Second, the paper will address a methodology to track some Cryosat-2 SAR-mode data related to swell features and some examples.
These first results will be useful in the near future to develop specific retracking algorithms or improve the current ones for the specific cases where SAR mode altimeter data affected by swell.

ALES, the multimission Adaptive Leading Edge SubWaveform Retracker, design and validation

Marcello Passaro, School of Ocean and Earth Science, University of Southampton, U.K
Paolo Cipollini, National Oceanography Centre, UK
Stefano Vignudelli, Consiglio Nazionale Delle Ricerche, Pisa, Italy
Graham Quartly, Plymouth Marine Laboratory, U.K
Helen Snaith, British Oceanography Data Centre, U.K

Session theme: Instrument Processing
Poster

Satellite altimetry has revolutionized our understanding of ocean dynamics thanks to high repetition rate and global coverage. Nevertheless, coastal data has been flagged as unreliable due to land and calm water interference in the altimeter and radiometer footprint and high frequency tidal and atmospheric forcing. Our study addresses the first issue, i.e. retracking, presenting ALES, the Adaptive Leading Edge Subwaveform Retracker. ALES is potentially applicable to all the pulselimited altimetry altimetry missions and its aim is to retrack with the same precision both open ocean and coastal data with the same algorithm. ALES selects part of each returned echo and models it with a classic 'open ocean' Brown functional form, by means of least square estimation whose convergence is found through the NelderMead nonlinear optimization technique. By avoiding echoes from bright targets along the trailing edge, it is capable of retrieving the majority of coastal waveform up to 2 to 3 Km from the coasts. By adapting the estimation window to the significant wave height, it aims at preserving the precision of the standard data both in open ocean and in the coastal strip. ALES is validated against tide gauges in the Adriatic Sea and in the Greater Agulhas System for three different missions: Envisat, Jason1 and Jason2. Considerations on noise and biases provide a further verification of the strategy.

ERS reprocessing at CTOH for extended applications

Blarel Fabien, CNRS/Legos
Fernando NIÑO, IRD/Legos
Benoit Legresy, CNRS/Legos
Sara Fleury, CNRS/Legos

Session theme: Instrument Processing
Poster

The ERS altimetry data are historically distributed at level 2 only for open ocean applications. CTOH has used the ERS WAP data provided by ESA to develop its own processing chain. This processing adds the ice2 retracking and in-house corrections. We set up homogeneous and updated corrections for both ERS and ENVISAT including, for example, the tropospheric correction (blarel and legresy 2013), the doppler correction (blarel and legresy, 2012), and echo shape change corrections (legresy et al., 2006) making it compatible with altimetry applications out of the open ocean, including coastal altimetry, land ice, land hydrology and land surface monitoring. Here we show the first results of the reprocessing, with a comparison of the retracking outputs on the echo shape, namely Backscatter, Leading Edge Width, Trailing Edge Slope as defined in the Ice2 retracking (Legresy et al., 2005). We show maps of the results over the globe for both ERS2 and ENVISAT while they followed the same orbit at a 30 minute interval. We can observe the agreement and differences between both satellites measurements. We also show the results of validation on ERS and ENVISAT on an earlier version of the processing on limited areas exemplifying the interest for a number of applications. This dataset should be well adapted to non open-ocean applications and to compare to ESA's ongoing reprocessing of ERS data (Reaper product).

Comparisons of CryoSat-2 and Altika altimeter measurements of the ocean and Antarctic ice-sheet.

Natalia Galin, LSA/NOAA
Walter H. F. Smith, LSA/NOAA

Session theme: Instrument Processing
Poster

In February, 2013, the joint French/Indian altimeter mission SARAL was launched. The main payload of this mission is AltiKa, a pulse-limited altimeter which breaks away from previous altimeter design in that: its center frequency is in the Ka-band (35.75GHz), it has a transmit/receive bandwidth of 500 MHz, and a higher spatial sampling frequency of 40 Hz. These pertinent differences are hoped to improve knowledge of the small (mesoscale) ocean processes. Back in April, 2010, ESA had also launched a unique altimeter mission CryoSat-2 which also has some different characteristics to current and past altimeter missions. The main payload of CryoSat-2 is SIRAL - a Synthetic Aperture Interferometric Radar Altimeter, which breaks away from conventional altimeter missions in that it exploits coherence between its transmitted pulses to effectively increase the illumination time for any given object within its antenna, leading to increased spatial resolution in the along-track direction.

Both CryoSat and SARAL furnish new ways of measuring the Earth's surfaces, and may be expected to surpass conventional pulse-limited Ku-band altimetry. Their backward-compatibility with legacy measurements is also a concern for the study of climatological time series of ocean dynamics, sea level, and ice sheet elevation. We aim to assess the performance of CryoSat and SARAL in these areas. In particular, we are looking at ocean surface height, SWH and backscatter, and the comparison of AltiKa and SIRAL data to legacy EnviSat data over the Antarctic ice sheet.

Considering SARAL/AltiKa altimeter data for coastal zones and hydrology: the PEACHI project

Guillaume Valladeau, CLS
Pierre Thibaut, CLS
Nicolas Picot, CNES
Amandine Guillot, CNES

Session theme: Instrument Processing
Poster

SARAL/AltiKa ground processing and associated user products are directly derived from the Jason-2 ground processing chains (GDR-D standards). Even if this standard is state of the art for current altimeter systems in orbits and for deep ocean applications, the processing of the innovative Ka-band altimeter (40 Hz variable PRF system and mono-frequency) coupled with dual frequency radiometer slightly differs from the Jason-2 one (typically their frequencies and associated bandwidths). Thus, one of the challenges concerning SARAL is to benefit from other in-flight or past missions to improve our knowledge on altimetry and further investigate climate systems derived from Ka-band measurements. Consequently, the ground processing has to be enhanced to provide to the altimeter community the most reliable and relevant data for scientific studies and applications.

In particular, the reliability of AltiKa measurements for coastal and hydrology studies is of main interest in the frame of the PEACHI project (Prototype for Expertise on AltiKa for Coastal Hydrology and Ice). This project is a CNES (Centre National d'Etudes Spatiales) initiative to provide end-users reliable Ka altimeter measurements over coastal areas and in open ocean but also in continental and sea ice domains, and also linked to the CNES PISTACH and ESA Coastalt projects.

The prototype developed in the frame of the PEACHI project first aims at improving the reliability and the accuracy of the geophysical parameters thanks to new or improved algorithms. Preliminary results of the improvements performed on the main corrections (retracking algorithms, new radiometer corrections, improved tide models …) applied to SARAL/AltiKa measurements in the frame of the PEACHI project are presented here and especially focus on coastal zones.

The good quality of the measurements obtained with SARAL mission is compared with previous (ESA ENVISAT) and/or current missions like Jason-2 and the ESA CryoSat mission. These developments intend to demonstrate the advantage of the innovative Ka band for scientific studies.

The assimilation of CFOSAT synthetic wave data in the wave model MFWAM

Lotfi Aouf, Division Marine et Océanographie, Météo-France
Jean-Michel Lefèvre, Division Marine et Océanographie, Météo-France
Danièle Hauser, LATMOS/IPSL/CNRS

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

The CFOSAT satellite mission will provide the directional wave spectra from the real aperture radar SWIM and the wind vectors from the scatterometer SCAT at the same location. It is challenging for wave modelers to use such data in order to understand and better describe the physical processes at the ocean-atmosphere interface. To prepare our wave forecasting system of using such data, assimilation tests in the wave model MFWAM have been performed by using synthetic wave spectra provided by the simulator of SWIM developed by CNES. The sensitivity to the wavelength cut-off on the wave spectra is examined. The complementary use of SWIM, SAR (synthetic aperture radar) and altimeters is also investigated. Assimilation parameters in terms of correlation model are adjusted in order to improve the impact.

GMES-PURE: Shaping the Marine GMES/Copernicus User

Hans Bonekamp, EUMETSAT
Patrick Gorringe, EUROGOOS
Yota Antoniou, EUROGOOS
Peter Albert, EUMETSAT

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

The Copernicus/GMES Marine Core Service (MCS) as currently implemented by MyOcean-2 will become operational in 2014. In 2013, the European Commission (EC) has started the two-year project called GMES-PURE (Partnership for User Requirements Evaluation), to define and apply a structured process for the elaboration of the future MCS user requirements and their translation into service specifications, service data and technical requirements. While the focus for service data requirements is on space observations, high-level data requirements for in-situ observations will be captured and delivered as well. The GMES-PURE project constitutes a unique opportunity for MCS users to ensure that their current and emerging requirements are captured in time and to influence the future evolution of the MCS. The establishment and maintenance of long-term user driven operational services requirements and related coherent service specifications include a weighing of evolving user needs, scientific and technological capabilities, cost-effectiveness and affordability. This presentation will explain GMES-PURE approach, the Ocean Surface Topography User requirements and how end users can get and will be furhter involved in the project.

Improving the dynamic atmospheric correction for operational applications of altimetry

Loren Carrere, CLS
Frédéric Briol, CLS
Antoine Delepoule, CLS
Isabelle Pujol, CLS
Yannice Faugère, CLS
Stéphanie Dupuy, CLS
Emilie Bronner, CNES

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

Given its current accuracy and maturity, altimetry is considered a fully operational observing system dedicated to various applications such as climate studies or operational oceanography. Altimeter measurements are corrected for several geophysical effects in order to isolate the oceanic variability, and the dynamic atmospheric correction (DAC) is an important one; this correction allows for the removal of high frequency variability induced by the atmospheric forcing and aliased by the altimetric measurements.

The high frequency part of the DAC is based on a barotropic model simulation forced by atmospheric pressure and winds (MOG2D; Carrère and Lyard 2003); the low frequency part is an inverse barometer response. A 20-day cutoff-period was chosen because it corresponds to the Nyquist period of T/P-Jason reference altimeters' sampling and because the variability is mostly barotropic in this high frequency band.

The purpose of the study is to improve the performances of the DAC for users of altimetry, and particularly for operational altimetry. Indeed, some errors remain in the Near Real Time/Real Time DAC corrections due to the use of a degraded filtering window (window decentered in past) or even the use of an IB instead of the DAC for the RT.

Model forecasts are now generated in RT using ECMWF operational forecasts. These model forecasts are used to improve the quality of the NRT correction, by re-centering the filtering window of the DAC, and to produce a new forecasted DAC which can be used for DUACS-RT products.
The impact of these new DAC corrections on altimeter level-2 products has been estimated and results show a strong improvement both for the NRT and the RT. The impact on higher levels products has also been investigated and preliminary results will be presented.

Comparison and validation of multi-mission coastal altimetry around Venice

Paolo Cipollini, National Oceanography Centre, UK
Marcello Passaro, School of Ocean and Earth Science, University of Southampton, U.K
Stefano Vignudelli, Consiglio Nazionale Delle Ricerche, Pisa, Italy

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

Following on the coastal altimetry work for Envisat started in the COASTALT project (2008-2012), the NOC coastal altimetry processor is being extended to process data from multiple altimetric missions within the ESA DUE eSurge project for the provision of Earth Observation data in support of storm surge monitoring, modelling and forecasting.
An important calibration and validation site is the area around Venice, where storm surges (locally called 'acqua alta') are particularly frequent.
For this validation activity we have processed Envisat and Cryosat data in the area, as well as Jason-2 and Jason-1 (in interleaved orbit) over a wider area in the Northern Adriatic, and compared them with data from the CNR tide gauge at the "Acqua Alta" platform ~14 km from the coast of Venice Lido.
Envisat, Jason-2 and Jason-1 have been processed with the new ALES retracker (see the contribution by Passaro et al. in this meeting), which is included in the eSurge processor. Cryosat-2 data have been retracked with the SAMOSA3 model also included in the eSurge processor. All the comparisons are done at high-rate (20Hz).
The comparison of our retracked data against the standard data in the Envisat and Jason GDRs shows that with the dedicated ALES retracker we can retrieve more and better data closer to the coast. Correlations with the tide gauge data improve especially in the coastal strip (~10-20 km from the coast) but also, slightly, in the open ocean region, as many waveforms in this area suffer from the presence of bright-target-like artefact and therefore do not conform well with the Brown model. 20-Hz noise levels for the ALES-retracked Envisat are flat until about 3 Km from the coastline, as opposed to ~5 Km for the SGDR data. RMS values between ALES and tide gauge are at ~10 cm order of magnitude on the absolute water level (i.e. NOT using anomalies) which is a good result indicating a substantial closure of the SSH equation. Cryosat-2 data show an even better performance very close to the coast, with noise levels compared to the offshore ones up to less the 1 km from the coast, even if unresolved bias problems prevent an absolute RMS calculation so far: the RMS difference with the tide gauge, computed with anomalies, is of the order of 8 cm.

The contribution of altimetry to storm surge modelling in the eSurge project

Paolo Cipollini, National Oceanography Centre, UK
Kevin Horsburgh, National Oceanography Centre, UK
Phillip Harwood, CGI, Leatherhead, U.K
Craig Donlon, ESA/ESTEC, Noordwijk, The Netherlands

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

A promising emerging application of reprocessed coastal altimetry data is to storm surges. The European Space Agency, recognizing the potential of this technique, has given coastal altimetry a primary role in the Data User Element eSurge Project which aims to improve the modelling and forecasting of storm surges through the increased use of advanced satellite products.

In this contribution we give an update on the latest developments in the eSurge Project and provide details of the coastal altimetry data products generated within the Project from reprocessing Envisat, Cryosat-2 and Jason-2 altimeter echoes. We show examples of how coastal altimetry successfully extends the open ocean measurements to the coastal strip, and then we discuss the possible uses of these measurements in storm surge models, and the experiments planned to demonstrate these uses. The reprocessed data are useful for assimilation, when blended with Tide Gauge data; for verification of model output; and for ensemble pruning. We conclude by illustrating the eSurge-Live initiative for the provision of data in Near Real Time, showing examples of NRT Cryosat-2 data reprocessed by the eSurge processor over the Indian Ocean coast.

High-Accuracy Sea Surface Height Data in Near-Real-Time from the SARAL and Jason-2 Missions

Shailen Desai, Jet Propulsion Laboratory, California Institute of Technology
Bruce Haines, Jet Propulsion Laboratory, California Institute of Technology

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

Near-real-time (NRT) sea surface height (SSH) data from satellite altimeter missions become increasingly valuable to operational applications when they are available with high spatial density and accuracy. The SARAL/Altika mission is an especially valuable new opportunity for high accuracy NRT SSH measurements given that the Jason-1 and ENVISAT missions are no longer active. We describe our approach to improving the accuracy of NRT SSH measurements from SARAL, that adds to our existing respective measurements from Jason-2. For Jason-2, we continue to generate the so-called GPS-OGDR-SSHA value-added product by combining altimeter and radiometer data from the Operational Geophysical Data Record (OGDR) with NRT GPS-based precise orbit determination. For SARAL, we similarly combine altimeter and radiometer data from the OGDR products, but determine high accuracy orbit altitudes using SSH differences with respect to those from the Jason-2 GPS-OGDR-SSHA product at ground-track crossing locations (crossovers). This approach has the added benefit of leveling the SARAL and Jason-2 NRT SSH measurements, thereby facilitating seamless combination with no additional effort.

In this presentation, we provide updated results on the performance of the NRT GPS-based orbit solutions for Jason-2, showing that they continue to achieve radial accuracies of 1 cm (RMS). We also provide results on the performance of our inter-satellite crossover-based orbit altitudes for SARAL, showing that they are achieving accuacies of < 2 cm (RMS).

Ssalto/DUACS : The Jason1 / Altika unexpected handover

Yannice Faugere, CLS
Isabelle Pujol, CLS
Frederic Briol, CLS
Antoine Delepoulle, CLS
Gerald Dibarboure, CLS
Nicolas Picot, CNES
Emilie Bronner, CNES

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

DUACS-NRT provides GODAE, climate forecasting centers, the MyOcean EU FP7 project, and real time oceanographic research (e.g.: in-situ campaigns) with directly usable, high quality near real time altimeter data. Regional products (Mediterranean Sea, Mozambic, Arctic, European Shelves …) are also delivered to operational projects.

This year, Jason-1, the oldest satellite of the altimeter constellation used in the Duacs multimission system, was impacted by a severe anomaly and was definitively stopped on the 21 June 2013. Fortunately, the data from the Altika mission, launched in February, were released publicly in July 2013. As soon as they were available, the OGDR and IGDR merged with Jason-2 and Cryosat-2 have been used in the system allowing us to maintain the system resilience and product quality. The first analyses on Altika data demonstrated their potential to even improve the DUACS products in terms of resolution.

Another flying satellite, HY2A, could also be included soon in the system and still strengthen the system. In parallel, some processing improvements are foreseen on the processing, such as the use of a Dynamic Atmospheric Correction for real time products. Later, early 2014, some improvement will also been applied in terms of content and format. A full reprocessing will be released in the mean time to have an homogeneous data set over the entire altimetry period, more than 20 years.

A multiscale analysis from satellite altimeter observations

Gregg Jacobs, Naval Research Lab
Michael Wooten, QNA

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

Data-only products intend to provide information on ocean state without the presumption of a prescribed dynamical constraint. This is valuable for testing dynamical hypotheses to determine if the observations are consistent or if the observations invalidate the hypothesis. However, a regularly gridded dataset from irregularly spaced observations automatically presupposes a spatial relation. The gridding process is similar to applying a convolution integral to the observations with delta functions at their space/time locations. The most important aspect when using a regularly gridded product is to understand this convolution function, which can also be expressed as a filtering process. The filtering process imposes its own spectral response on the gridded data. In order to ensure proper conclusions are reached, the filter response function in the wavenumber/frequency domain of interest should be carefully considered.

Typically, spatial and temporal scales are prescribed and used in an optimal estimation process. In the past, such length scales have been estimated using historical altimeter observations through a binned space/time lagged autocovariance that is allowed to change over latitude and longitude. In the development process, the large scale sea surface height variations were removed so that the mesoscale characteristics would be estimated. It is possible to iterate this process. Using the mesoscale characteristics, the data may be interpolated and subtracted leaving the residuals. Residuals are subsequently used in a second time/space lagged autocovariance estimation of the next order length scales.

The results are the appropriate information to be used in a multiscale analysis, and this information may be used with either a data-only product or within a cycling numerical model assimilation system. The process of estimating the scales and application to a data-only analysis are examined in this presentation. Work is under way to use the scales in a cycling model assimilation system. The data-only analysis products from this multiscale analysis are now being generated and made available. These products include the regularly gridded information using both first mesoscale characteristics and the multiscale characteristics and both in a real time estimation and a reanalysis estimation for greater accuracy. A consistent reconstruction of the data-only products is under way.

An EM-bias correction estimate for AltiKa

Gregg Jacobs, Naval Research Lab
James Richman, Naval Research Lab

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

The AltiKa instrument was launched on the SARAL spacecraft 25 February 2013. Initial performance indicates that instrument noise is as good or lower than Jason-2 instrument noise. The water vapor radiometer calibration remains to be completed, and ECMWF moisture estimates are used for atmospheric correction in addition to the dry troposphere correction from surface pressure estmiates. With the Ka band altimeter, ionosphere influence is minimal. Orbit solutions in near real time show 10 cm amplitude errors at 1 cycle per orbital revolution. Data latency is very good with a large fraction of observations available within 24 hours of observation time.

The EM-bias correction has not yet been estimated, and a test of an automatically updating estimation algorithm has been applied to the initial data. In this algorithm, the EM-bias is initially set to 3.5% of the significant wave height. Observed sea surface height anomalies are binned as a function of significant wave height and wind speed with wind speed based on the algorithm from Abdalla, Scharroo and Lillibridge. The algorithm makes a daily estimate as new data arrives, and constructs a moving average with the prior estimate from yesterday. The weighting in the averaging results in a half amplitude in time of 30 days. The EM-bias development over the first 6 months of data indicates the instrument is quite stable and performing as expected. The EM-bias estimation algorithm for AltiKa is compared to the same algorithm applied to Jason-2 to understand the differences between performance at the Ku and Ka bands. The general shape of the corrections are similar with the Ka band showing smaller variation over significant wave height and wind speed and slightly more sensitivity to smaller surface waves as the Ka frequency of 35.75 GHz is more affected by surface gravity and capillary waves than the Ku 13.6 and 5.3 GHz on Jason-2.

Southwestern Atlantic currents from in-situ and satellite altimetry data

Martin Saraceno, UMI-IFAECI/CONICET-UBA-CNRS
Christine Provost, LOCEAN-IPSL
Alberto Piola, UMI-IFAECI, SHN, CONICET, UBA
Nathalie Sennéchael, LOCEAN-IPSL
Alejandro Bianchi, UMI-IFAECI, SHN, UBA
Diana Ruiz-Pino, LOCEAN-IPSL
Elbio Palma, UNS, CONICET
Raul Guerrero, INIDEP

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

Space and time scales are smaller than in the open ocean over continental shelves, shelf-breaks and close to the coast. The Patagonian continental shelf (PCS) and Malvinas Current (MC) environments not being an exception, on the contrary, large non-linear interactions are expected due to strong tides and winds and a complex bathymetry.Because of the large size of the PCS and shelf-break regions, satellite altimetry data combined with in-situ observations offer a unique dataset to study oceanic processes and validate altimetry data. In-situ time-series measurements are necessary to provide information on the vertical structure of the ocean and quantify the missing portion of the high-frequency variability that cannot be determined from the altimeter because of its limited time and space sampling. Scarcity of in-situ data prevented such quantification in the PCS and shelf-break regions.

A recently project approved and funded by EUMETSAT/CNES, presented here, will deploy an array of current meter moorings, bottom pressure recorders (BPR), conductivity-temperature (CT) sensors and a fully equipped oceanographic buoy during two years to simultaneously monitor the PCS and MC flows. The new data will allow accurate CAL/VAL exercises for the variety of satellite altimetry data. Furthermore, data analysis will improve understanding on the dynamics of both regions. It is expected that such analysis will have an important socio-economical impact since the PCS and adjacent shelf-break are one of the most productive areas of the World Ocean. The importance of obtaining accurate measures of flow variability on both environments resides on the fact that analytical studies indicated that the PCS circulation is dominated by a cross-shelf pressure gradient imposed by the MC.

Near-real time production of gridded SLA in the Mediterranean Sea using the Data-Interpolating Variational Analysis (DIVA)

Charles Troupin, IMEDEA (UIB-CSIC)
Arancha Lana, IMEDEA (UIB-CSIC)
Ananda Pascual, IMEDEA (UIB-CSIC)

Session theme: Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
Poster

The spatial interpolation of Sea-Level Anomalies (SLA) along-track data to produce gridded map has numerous applications in oceanography, such model validation, data assimilation or eddy tracking. Optimal Interpolation (OI) is often the preferred method for this task, as it leads to the lowest expected error and provides an error field associated to the analyzed field. However, the numerical cost of the method (due to the inversion of covariance matrices) as well as the isotropic covariance function, generally employed in altimetry, may stand in the way of a systematic application to SLA data.

The Data-Interpolating Variational Analysis (DIVA) is a gridding method based on the minimization of a cost function using a finite-element technique. The cost function penalizes the departure from observations, the smoothness or regularity of the gridded field and can also include physical constraints (advection, diffusion, ...). It has been shown that DIVA and OI are equivalent (provided some assumptions on the covariances are made), the main difference is that in DIVA, the covariance function is not explicitly formulated. The technique has been previously applied for the creation of regional hydrographic climatologies, which required the processing of a large number of data points.

In this work we present a implementation of Diva for generating high-resolution daily maps of SLA, ADT and geostrophic currents in the Mediterranean Sea. The procedure for the productions of the gridded products is as follow:
1. The download and formatting of AVISO NetCDF data files. This step is performed with bash scripts with the help of NCO toolbox.
2. The interpolation of SLA measurements using the DIVA tool and the generation of NetCDF files.
3. The computation of geostrophic velocity using the new SOCIB-CLS Mean Dynamic Topography (MDT).
4. The preparation of graphics for the region of interest. This step is performed with a script in Python using the Matplotlib plotting library.

The generated maps were used in the frame of G-ALTIKA (see poster by Pascual et al.) experiments carried out in the southwest of Ibiza island in August 2013. The results for this region show a good agreement with AVISO near-real time products for the Mediterranean Sea, while some differences are observed in the representation of eddies and meanders.

HF Radar data partially covering G-ALTIKA domain as well as drifter are used for further validation and comparisons.

Argonautica: behind the scenes

Vinca Rosmorduc, CLS
Danielle De Staerke, CNES

Session theme: Outreach, Education and Altimetric Data Services
Poster

The Argonautica educational project makes actual oceanographic data available to primary and secondary students. This helps understanding the oceans, their relation to environmental change and the effects on the living world. It is a chance for them to undertake a real investigation by taking part in a scientific project that alerts them to the evolutions in society and make them aware of the major challenges facing humanity and what is needed to protect the planet. The Argonautica project, in relation to various events and/or with help from scientific partners, proposes the following activities:
- monitoring of drifting buoys, some of which are made by the classes, or Argos beacon. This enables the students to understand oceanic circulation, the links between ocean and environment (climate?) and how they vary, by comparing the data with that supplied by the Jason satellites.
- showing the impact of these variations on marine animals, by monitoring their migrations with Argos transmitters.
At the end of the school year, the students come together to report back on their work.

We've been talking for more than ten years of the enthusiasm of students and teachers participating to the project; of the possibilities of the project; of the achievements of the participants...
Now we'll lift the veil on what's happening behind the scenes: data used, processing needed, tricks and problems, evolutions done… and sketch some perspectives on how it could further evolve in future years.

Enhancing science and promoting practical applications of high-resolution altimetry measurements

Margaret Srinivasan, Caltech Jet Propulsion Laboratory
Craig Peterson, Mississippi State University at Stennis Space Center

Session theme: Outreach, Education and Altimetric Data Services
Poster

NASA's Earth Science Mission Directorate Applied Sciences Program (ASP) is supporting a formal effort to optimize the value of upcoming NASA Earth missions to a broad user community and to society at large. The objective of the Surface Water and Ocean Topography (SWOT) Applications program is to pave the way for operational use of SWOT data products soon after the mission launches in 2020.
A wide range or existing and potential oceanography applications utilizing current altimetry data products will be enhanced with the introduction of high spatial resolution data from SWOT. With time series of surface water measurements provided by SWOT, a broad range of hydrology applications will inform water managers for river commerce, drought, floods, transboundary river issues, reservoir storage, and much more.

As part of the SWOT applications effort, several studies have already been proposed to ASP that will provide valuable demonstrations, data sets, and outcomes which will highlight the applications potential of SWOT for a broad range of users. The studies proposed to date include the development of an altimetry toolbox for forecasting floods in remote areas, the use of remote sensing measurements to improve the understanding, monitoring and management of estuaries and deltas, and the use of simulated SWOT data to assess the quality and potential value of SWOT measurements to both oceanography and hydrology applications.

Planned strategies to enhance science and practical applications of SWOT data will be discussed, including methods of engaging with the science community, operational users, and mission planners.

Sea Level Course and Experiments for High School Students

Benjamin Hamlington, University of Colorado at Boulder
Kyra Fitzpatrick, University of Colorado at Boulder
Robert Leben, University of Colorado at Boulder

Session theme: Outreach, Education and Altimetric Data Services
Poster

The Colorado Association of Black Professional Engineers and Scientists (CABPES) is a non-profit organization dedicated to encouraging African-American and underrepresented youth to pursue careers in the engineering and applied science professions. The goal is to increase the number of minority scientific and technical professionals to a level that better represents the minority population, while assisting in meeting the growing demand for engineers and scientists. CABPES works primarily with underrepresented students from grades 6 through 12 and offers assistance with schoolwork as well as counseling for students preparing for college. Professional engineers and scientists volunteer their time and effort to provide this help to students.

While CABPES offers several after-school courses focusing on engineering and math, there is considerable interest in educating and informing students about the growing field of climate science. CABPES, however, lacks the resources and advisors capable of teaching students climate science. To meet this interest and to fill a gap in their curriculum, we are providing resources and materials to the students and instructors at CABPES that will increase their interest in research and scientific activities, develop their knowledge of climate science (specifically sea level change and variability), and provide them with research and hands-on experience that will aid them in future scientific endeavors. The main thrust of this project involves providing 8-week courses on climate change and sea level change twice yearly to CABPES students. Here, we discuss the ongoing development of this course, including new experiments designed to teach students about sea level, satellite altimetry and climate change. The creation of a website intended to share the course and experiments with a wider audience is also presented. Finally, results from the most recent course are discussed, and the successes and failures are considered in terms of the future direction of the course.

CTOH: from L1 to L4 altimeter data

Sara Fleury, LEGOS/CTOH
F. Blarel, LEGOS/CTOH
D. Blumstein, LEGOS/CTOH
Florence Birol, LEGOS/CTOH
C. Delebeque, LEGOS/CTOH
Fernando Niño, LEGOS/CTOH
Rosemary Morrow, LEGOS/CTOH
M. Rogé, LEGOS/CTOH

Session theme: Outreach, Education and Altimetric Data Services
Poster

The Center for Topography of the Oceans and Hydrosphere (CTOH) is a French Observation Service created in 1989 and dedicated to satellite altimetry studies. Its objectives are to 1) maintain and distribute homogeneous altimetric databases for ocean, hydrosphere and cryosphere applications, 2) help scientific users develop new altimetry derived products and 3) contribute to the development and validation of new processing approaches of the altimetric data for emerging research domains.

The CTOH maintains homogeneous altimetric GDR data bases for the following missions : Topex/Poseidon ; GFO ; ENVISAT ; Jason-1; Jason-2 ; Saral/Altika ; Cryosat2. Retracking of ERS-1 and ERS-2 waveform with the ICE-2 algorithm is underway (see dedicated poster). Both 1Hz and 10-20-40Hz data are available over all possible oceanic and continental surfaces.

In addition we add about 20 recent corrections in a homogeneous way to all of the missions. These include tide models, DAC, MSS, geoids, and new tropospheric corrections. In addition, the CTOH works on developing and distributing new altimetric products which today can be accessed from the web site (http://ctoh.legos.obs-mip.fr/products). In the future, these will be distributed via the new AVISO ODES Online Data Extraction Service (see dedicated poster). These include :
Coastal products : Alongtrack data are available in a dozen regions, with specific X-TRACK processing in the coastal band. SLA are available on a nominal groundtrack (1hz and 20hz for some regions), as well as a high-resolution MSS (…/products/coastal-products). This product includes tidal constants : amplitude and phase lag with error estimations for each tidal constituent (see dedicated poster).

Continental hydrology products : including the “Hydroweb” data base for monitoring river and lake levels (…/products/hydroweb). Hydroweb now integrates the CASH project Topex reprocessed data over terrestrial surface waters.

Global SubMesoscale filaments. Amplitude and position of sub-mesoscale filament barriers calculated from gridded AVISO surface currents using the Finite-Size Lyapunov Elements (d’Ovidio et al., 2009), at 4 km resolution from 1993 to today (…/products/submesoscalefilaments).

Advection products: Surface tracer fields, such as SSS and SST, are stirred by AVISO surface currents. This allows us to simulate submesoscale structures in observed large-scale tracer fields (see dedicated poster).

The CTOH also provides altimetric expertise to users and the space agencies based on waveform analyses over all surfaces, and analyses of corrections and algorithms adapted to different surfaces, for past, present (Jason-2, Cryosat-2 and SARAL), and future altimetric missions such as SWOT.

The ESA LearnEO! Project for Stimulating Earth Observation Education

Vinca Rosmorduc, CLS
Chris Banks, NOC
Valborg Byfield, NOC
Fabio Del Frate, Tor Vergata University
Malcom Dobson, Bilko Develoment Limited (BDL)
Pierre-Philippe Mathieu, ESA/ESRIN
Matteo Picchiani, GEO-K

Session theme: Outreach, Education and Altimetric Data Services
Poster

For society to benefit fully from its investment in Earth Observation, EO data must be accessible and familiar to a global community of users who have the skills, knowledge and understanding to use the observations appropriately in their work. Achieving this requires considerable education effort. LearnEO! (www.learn-eo.org) is a ESA education project that contributes towards making this a reality.

LearnEO! has two main aims: to develop new training resources that use data from sensors on ESA satellites to explore a variety of environmental topics, and to stimulate and support members of the EO and education communities who may be willing to develop and share new education resources in the future. The project builds on the UNESCO Bilko project, which currently supplies free software, tutorials, and example data.

The LearnEO! tutorial and peer-reviewed lessons are designed to teach satellite data processing and analysis skills at different levels, from beginner to advanced - where advanced lessons requires some previous experience with Earth observation techniques. The material is are aimed at students and professionals in various branches of Earth sciences who have not yet specialised in specific EO technologies. The lessons are suitable for self study, university courses at undergraduate to MSc level, or for continued professional development training. Each lesson comes complete with data, analysis tools and background information required to complete the suggested activities and answer the study questions. Model answers are supplied for users working on their own or with limited specialist support.
Several lessons deal with altimetry, with ERS or Envisat data but also in combination with Jason-2 (along-track), or using gridded multi-mission data. Those data are part of a multi-sensors approach, so as to provide non altimetry users with an insight on what altimetry could bring them.

The web site also provides access to annotated data sets and a lesson developers resource library, both designed to support users who wish to develop their own lessons and tutorials and share these with others. Registered users are encouraged to become involved with the project by providing support for future software and lesson development, testing, and peer review.

This poster will present LearnEO! early achievements, and present the next steps, including the lesson-writing competition.

Aviso products & services: what's new?

Francoise Mertz, CLS
Emilie Bronner, CNES
Caroline Maheu, AKKA/CLS
Vinca Rosmorduc, CLS

Session theme: Outreach, Education and Altimetric Data Services
Poster

Since the launch of Topex/Poseidon, more than 19 years ago, satellite altimetry has evolved in parallel with the user community and oceanography. As a result of this evolution, we now have:
- A bigger choice of products, more and more easy-to-use, spanning complete GDRs to pre-computed sea level anomalies and gridded datasets and indicators such as MSL index or ENSO index.
- a mature approach, combining altimetric data from various satellites and merging data acquired using different observation techniques, including altimetry, to give us a global view of the ocean;
- data available in real or near-real time for operational use.
Different services are available either to choose between the various datasets, or to download, extract or even visualize the data.

2012 – 2013 saw changes (new regional data, FES2012, but also the end of Jason-1, the arrival of Saral), even though the major ones are planned for the beginning of next year (reprocessing of the whole multimission time series with a serious re-thinking of the whole set of gridded data, and also the public opening of the Online Data Extraction Service, and a new altimetry portal, restyling Aviso web and adding CTOH information and data)

Basic Radar Altimetry Toolbox: tools to teach altimetry

Vinca Rosmorduc, CLS
Jerome Benveniste, ESA/ESRIN
Emilie Bronner, CNES
Sander Niemeijer, S&T

Session theme: Outreach, Education and Altimetric Data Services
Poster

The Basic Radar Altimetry Toolbox is an "all-altimeter" collection of tools, tutorials and documents designed to facilitate the use of radar altimetry data, including the next mission to be launched, CryoSat. It has been available from April 2007, and had been demonstrated during training courses and scientific meetings. More than 2000 people downloaded it (January 2013), with many "newcomers" to altimetry among them. Users' feedbacks, developments in altimetry, and practice, showed that new interesting features could be added. Some have been added and/or improved in version 2 and 3. Others are in discussion for the future, including addition of the future Sentinel-3.

The Basic Radar Altimetry Toolbox is able:
- to read most distributed radar altimetry data, including the one from Saral,
- to perform some processing, data editing and statistic,
- and to visualize the results.

It can be used at several levels/several ways, including as an educational tool, with the graphical user interface
As part of the Toolbox, a Radar Altimetry Tutorial gives general information about altimetry, the technique involved and its applications, as well as an overview of past, present and future missions, including information on how to access data and additional software and documentation. It also presents a series of data use cases, covering all uses of altimetry over ocean, cryosphere and land, showing the basic methods for some of the most frequent manners of using altimetry data.

Example from education uses will be presented, and feedback from those who used it as such will be most welcome.

BRAT is developed under contract with ESA and CNES. It is available at http://www.altimetry.info and http://earth.esa.int/brat/

OpenADB: An Open Altimeter Database providing high-quality altimeter data and products

Christian Schwatke, DGFI
Denise Dettmering, DGFI
Wolfgang Bosch, DGFI

Session theme: Outreach, Education and Altimetric Data Services
Poster

OpenADB is a database for satellite altimeter data and high-level products developed by the German Geodetic Research Institute (Deutsches Geodätisches Forschungsinstitut, DGFI).
At the moment, OpenADB contains Sea Surface Heights (SSH), Sea Level Anomalies (SLA), Instantaneous Dynamic Ocean Topography Profiles (iDOT), Empirical Ocean Tide Model Corrections (EOT), and Vertical Total Electron Content (VTEC). All products are provided along the altimeter ground tracks. OpenADB works with a graphical user interface where users can choose their preferred data set after a short registration process. The desired data sets are provided in NetCDF format for download immediately after computation.
Furthermore, the “Database for Hydrological Time Series of Inland Water” (DAHITI) which contains about 180 time series of water level heights of inland waters is provided via OpenADB.
The database also provides meta information about all altimeter missions (e.g. satellite information, orbit parameters, etc.). Furthermore, a tool named “Pass Locator” which can be used to display satellite tracks of altimeter missions on a map.
The website of OpenADB is available at http://openadb.dgfi.badw.de.

Status of GDR orbits for ocean topography missions and prospects for future improvements

Luca Cerri, CNES
Alexandre Couhert, CNES
Flavien Mercier, CNES
Sabine Houry, CNES

Session theme: Precision Orbit Determination
Oral

GDR-D orbit standards were defined at the San Diego OSTST meeting in October 2011, including for the first time in the operational precise orbits of several altimeter missions a GRACE-based linear model to account for the long-term variations of the geopotential.
We assess the status of the current solutions for the Jason-2 and Saral missions, and indicate what are the prospects for the subsequent generation of orbits foreseen for next year. While waiting for the next release of the International Terrestrial Reference Frame (ITRF2013), several improvements are already available and have been tested on Jason-2, including: a calibrated solar radiation pressure model; the EIGEN6S2 gravity field, that makes use of more GRACE data and accounts for the interannual variability of non-tidal gravity; improved parameterization techniques to mitigate force model errors in the operational orbits, those due to time varying gravity in particular.

Orbit error due to time variable gravity and impact on mean sea level trend estimates and tide gauge calibration

Nikita Zelensky, SGT / GSFC
Frank Lemoine, nasa/gsfc
Stavros Melachroinos, sgt/gsfc
Brian Beckley, sgt/gsfc
Douglas Chinn, sgt/gsfc
Scott Luthcke, nasa/gsfc
Gary Mitchum, University of South Florida
Oleg Bordyugov, sgt/gsfc

Session theme: Precision Orbit Determination
Oral

The stability and accuracy of the satellite orbit through time is essential to altimeter data analysis. Studies have shown the previously applied simple POD modeling of time variable gravity (TVG) has become increasingly less adequate since about 2005, and have suggested the recent increase in ice melt as one of the causes. Several new TVG models have emerged showing progressive improvement over the simple model as indicated by the Jason-1/2 and Envisat SLR and Crossover residuals. The new models include GRACE-derived 50x50 gravity coefficient 10-day snapshots, SLR+DORIS 4x4 7-day snapshots, and the application of the reduced-dynamic technique. Regardless of the improvement in SLR and Crossover residuals, the models differ considerably in their orbit projections affecting regional estimates of mean sea level and changes in mean sea level. Such differences can also impact tide gauge calibration analysis. This study compares the Jason-2 SLR/Crossover residuals and projected Jason-2 orbit difference trends considering the GDRD, JPL Rlse11a, and several new orbits from GSFC. The new GSFC orbits include SLR+DORIS reduced-dynamic processing using the GRACE-derived 50x50 and SLR+DORIS 4x4 snapshot TVG models. The study examines the sensitivity of the reduced-dynamic SLR+DORIS orbits to TVG, potential impact on tide gauge calibration using the various TVG models, and the question of identifying the best TVG model.

Development Status of GPS-Based Precise Orbit Determination System for Japanese Ocean Surface Topography Mission (COMPIRA)

Kyohei Akiyama, Japan Aerospace Exploration Agency (JAXA)
Sachiyo Kasho, JAXA
Norimasa Ito, JAXA

Session theme: Precision Orbit Determination
Oral

Japan Aerospace Exploration Agency (JAXA) has proposed the first ocean surface topography mission in Japan, named COMPIRA. In the mission, JAXA will deliver near real time products to users within 6 to 12 hours(TBD), as well as precise products which require a radial orbit accuracy of 3cm RMS within 60 days (TBD). In order to meet these requirements, JAXA has developed a GPS-based Precise Orbit Determination (POD) software, which can estimate orbits of Low Earth Orbit (LEO) satellites with an accuracy of a few centimeters. This poster provides a brief overview of the POD software and accuracy evaluation results of the existing LEO satellite missions.

Comparisons to in situ data and estimation of errors in the Dynamic Atmospheric Correction

Loren Carrère, CNES
S. Dupuy, CBES
R. Ponte, CNES
Y. Faugère, CNES
E. Bronner, CNES

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

Comparisons to in situ data and estimation of errors in the Dynamic Atmospheric Correction

L. Carrère1, S. Dupuy1, R. Ponte, Y. Faugère1, E. Bronner 2
1 CLS, Space Oceanography Division, Toulouse, France. lcarrere@cls.fr
2 CNES, Toulouse, France

Given its current accuracy and maturity, altimetry is considered a fully operational observing system dedicated to various applications such as climate studies or operational oceanography. Altimeter measurements are corrected for several geophysical effects in order to isolate the oceanic variability. In particular, the dynamic atmospheric correction (DAC) allows for the removal of high frequency variability induced by the atmospheric forcing and aliased by the altimetric measurements.

The high frequency part of the DAC is based on a barotropic model simulation forced by atmospheric pressure and winds (MOG2D; Carrère and Lyard 2003); the low frequency part is an inverse barometer response. A 20-day cutoff-period for the high frequency part was chosen because it corresponds to the Nyquist period of T/P-Jason reference altimeters' sampling and because the variability is mostly barotropic in this high frequency band.

The purpose of the study is to estimate the quality of the dynamic atmospheric correction on the global ocean. For this purpose, comparisons with several in situ databases (tidal gauges and bottom pressure records) have been performed, considering different frequency bands (0-20 days, 20-30 days, 30-60 days and over 60 days). The results show the good performances of the DAC for high frequencies and for high latitudes and lower performances at low latitudes as expected; the residual signal allows an estimation of the DAC error for the high frequency band.

Assessment of long-term errors of wet tropospheric correction for altimetry missions: a mean sea level issue

Estelle Obligis, CLS
Michael Ablain, CLS
Soulivanh Thao, CLS
Jean-François Legeais, CLS
Bruno Picard, CLS
Laurence Eymard, CNRS/LOCEAN

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

The assessment of long-term errors of altimeter sea level measurements is of crucial importance for studies concerning the Mean Sea Level (MSL) evolution. One of the main contributors to the long-term sea level uncertainties is the correction of the altimeter range from the wet troposphere path delay, which is provided by onboard microwave radiometers for the main altimeter missions.
The first part of the study is dedicated to the wet tropospheric correction (WTC) estimated from microwave radiometers. Nowadays, water vapor products from microwave radiometers are rather consistent but important discrepancies remain. Understanding these differences can help us to improve the retrieval of water vapor and reduce at the same time the error on the mean sea level. Three radiometers are compared: Advanced Microwave Scanning Radiometer for EOS (AMSR-E), JASON-1 Microwave Radiometer (JMR) and ENVISAT Micro-Wave Radiometer (MWR). Water vapor products are analyzed both in terms of spatial and temporal distribution over the period 2004-2010, using AMSR-E as a reference. Overall, the study confirms the general good agreement between the radiometers: similar patterns are observed for the spatial distribution of water vapor and the correlation of the times series is better than 0.90. However, regional discrepancies are observed and a quantitative agreement on the trend is not obtained. Regional discrepancies are driven by the annual cycle. The JMR product shows discrepancies highly dependent on water vapor, which might be related to calibration issues. Furthermore, triple collocation analysis suggests a possible drift of JMR. MWR discrepancies are located in coastal regions and follow a seasonal dynamic with stronger differences in summer. It may result from processing of the brightness temperatures.
These discrepancies explain why the operational ECMWF atmospheric model is usually used as a common reference for mean sea level studies. However, due to several major improvements on the processing, this model is not homogenous over the altimetry period (from 1993 onwards) preventing the detection of errors on radiometer wet tropospheric correction especially on first altimetry decade. The second part of this study aims at determining the quality of WTC provided by ERA interim atmospheric model reanalyzes (ECMWF) in comparison with ECMWF operational fields and also with reanalyzes derived from National Centers for Environmental Predictions / National Center for Atmospheric Research (NCEP/NCAR). Separating our analyses on several temporal and spatial scales, we demonstrate that ERA interim is the best model WTC for the altimeter sea level at climate scales.
Overall, this work demonstrates the relevance of the feed-backs that the “altimetry” and “atmosphere” communities can bring to each other.

Retracking Jason-1 Altimeter Waveforms for Marine Gravity Recovery

Emmanuel Garcia, Scripps Institution of Oceanography
David T. Sandwell, Scripps Institution of Oceanography
Walter H.F. Smith, National Oceanic and Atmospheric Administration

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

In order to construct improved maps of marine gravity anomalies, we have developed and tested retracking methods for determining sea surface slopes from radar altimeter return waveforms collected by the Jason-1 mission. The accuracy of marine gravity models derived from satellite altimetry depends mainly on two factors: first, the density of ground tracks covered by the mission, and second, the precision of range measurements obtained by retracking the return waveforms. The geodetic phase of the Jason-1 mission, which occurred over 406 days from May 2012 - June 2013, resulted in a 7-8 km track spacing at the equator almost globally, thus providing excellent coverage. Meanwhile, a double retracking method originally developed for ERS-1 and Geosat data was also applied to the Jason-1 return waveforms. In this approach, we perform a least-squares fit of the altimeter waveform power to a mathematical model with three unknown parameters: arrival time, rise time, and amplitude. After smoothing the rise time along track, the waveforms are then retracked again to recover arrival time and amplitude, thereby reducing the problem to the retrieval of two parameters. From the retrievals of arrival time we compute the noise in the range measurements over the 20 Hz sampling frequency of Jason-1. The noise levels are 1.6 times higher for 3-parameter retracking compared to 2-parameter retracking, implying that an increase in precision accompanies the double retracking approach. We also compare the noise levels in our 3-parameter retracked data to the values of standard deviation in range provided in the official GDR data product, which are processed using an MLE4 algorithm. The GDR noise levels are slightly lower for values of significant wave height (SWH) less than 3 m, but at high SWH the GDR noise levels are higher than the results from our 3-parameter retracker. In addition to estimating the noise by computing the deviations in range about a mean, we also perform a power spectral analysis on residual sea levels, which we obtain by subtracting the EGM 2008 mean sea surface model from our best estimates of sea surface height. We extracted segments of Jason-1 tracks from two regions in the Pacific: one is in the South Pacific where high SWH is typical, and another is in the Equatorial Pacific, which has characteristically low SWH. For both these areas, the power spectral density of the 3-parameter retracked data is higher in the 10-100 km wavelength band, compared to the 2-parameter retracked data. We believe that this corresponds to a decrease in noise levels in range due to double retracking.

Reducing altimetry small-scales errors to access (sub)mesoscale dynamics: dream or reality?

Claire DUFAU, CLS
Sylvie Labroue, CLS
Gérald Dibarboure, CLS
Jean-Christophe Poisson, CLS
Yannice Faugere, CLS
Isabelle Pujol, CLS
François Boy, CNES
Nicolas Picot, CNES

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

The purpose of along-track space filtering applied to Sea Level Anomalies (SLA) currently distributed through AVISO and MYOCEAN is two-fold: (1) removing the non-oceanic small-scale signals (error, noise) and (2) keeping ocean dynamics that can be monitored by the satellite constellation. If it is suited for computing afterwards maps of SLA over the global ocean, it is clearly too radical for applications focused on (sub)mesoscale dynamics. We propose here to revisit the along-track filtering applied to SLA by using spectral analysis to determine the reachable length scales
After a short status on the current filtered SLA products, this paper will focus on the small-scale errors contained in the raw SLA (1hz). A new specification of filtering cut-off length to reduce these errors and access (sub)mesoscale dynamics will be detailed as well as an estimation of the remaining error to be prescribed in data assimilation systems that will use this new data.

Analysis of fine scale coastal process in the Gulf of Lion

Sekma Hela, CNRS/LEGOS/OMP, Toulouse, France
Morrow Rosemary, CNRS/LEGOS/OMP, Toulouse, France
Birol Florence, CNRS/LEGOS/OMP, Toulouse, France
Chaigneau Alexis, 2. IRD/LEGOS/OMP, Toulouse, France
Testor Pierre, 3. CNRS/LOCEAN/IPSL, Paris, France

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

Eight years of weekly sea level anomalies (SLA) regional maps in the Western Mediterranean are analyzed, using automated eddy detection and tracking methods, in order to understand the smaller mesoscale variability and its regional dynamics. Results show that eddies in the region seem to propagate following the main current. The areas of higher eddy amplitude correspond to areas of higher eddy kinetic energy calculated from altimetry SLA. Seasonal changes in eddy anticyclonic/cyclonic frequency are shown, with distinct seasonal changes especially in the coastal zone. In the Gulf of Lion, anticyclones are more frequent in winter, and cyclones occur more in summer. The eddy generation sites also vary seasonally, and study is underway to understand their relation to seasonal wind forcing, slope current intrusions onto the shelf, or seasonal Rhone river variations.
Eddy detection from the mapped satellite altimeter data is then used to better understand the finer-scale variations. This is first done using information from the CTOH/LEGOS along track coastal altimetric product, which uses the higher-frequency sampling associated with new filtering techniques. These altimetry products are also compared with in situ data collected by gliders. The objective of this comparison is to test the signal to noise of the alongtrack altimetric data sets as they pass over distinct mesoscale structures, to enable future improvements in filtering and editing. Preliminary results show a general good agreement between the structures observed from glider trajectories and the velocity fields obtained from along track Jason-2 SLA data, when observing large mesoscale structures (100-200km; r=0.8), although a good agreement is also detected between gliders data and DUACS/AVISO regional Mediterranean maps (r=0.9). When the gliders pass over smaller structures (20-50 km), lower correlation values are obtained when comparing glider and altimetry data (r=0.7 for the along track Jason-2 product corrected by the CTOH group and r=0.45 for the DUACS regional product). This work is ongoing to better understand the observability of the smaller mesoscale structures in alongtrack data, and will be extended in the future to SARAL/AltiKa and Cryosat-2 data.

Asymmetries between along- and across-track velocity spectra from tandem-mission altimetry

Martin Scharffenberg, Institut für Meereskunde, Centrum für Erdsystemforschung und Nachhaltigkeit (CEN), Universität Hamburg, Germany
Cimarron Wortham, Ocean Physics Department, Applied Physics Laboratory-University of Washington, Seattle, Washington, USA
Jörn Callies, MIT/WHOI Joint Program in Oceanography, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

Satellite altimetry has proven to be one of the most useful oceanographic datasets, providing a continuous, near-global record of surface geostrophic currents, among other uses. One limitation of observations from a single satellite is the difficulty of estimating the full velocity field. The three-year Jason-1-TOPEX/POSEIDON tandem-mission, with two satellites flying parallel tracks, promised to overcome this limitation. Velocities estimated from the tandem-mission, however, suffer from three important limitations. First, as anticipated, the distance between the tracks limits the resolution and reduces the observed velocity variance. Second, there is a fundamental asymmetry between along- and across-track velocity spectra estimated from a tandem-mission, even given the same measurement resolution in the two directions (i.e. along-track sample spacing equal to track separation). The finite sample spacing acts as a low-pass filter in wavenumber for the across-track velocity. The same sample spacing, however, attenuates the along-track velocity at all wavelengths. Finally, the sampling pattern steepens spectral slopes a factor of k^-2 at wavelengths smaller than the track separation for both velocity components. We show that all these effects a direct consequence of the filtering implied by the sampling pattern.

Why Mean Sea Level errors on the first altimetry decade [1993-2002] are higher than in the second one [2003-2013]?

Michael Ablain, CLS
Annabelle Ollivier, CLS
Sabine Philipps, CLS
Nicolas Picot, CNES

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

With the satellite altimetry missions, the global mean sea level (GMSL) has been calculated on a continual basis since January 1993. 'Verification' phases, during which the satellites follow each other in close succession (TOPEX/Poseidon--Jason-1, then Jason-1--Jason-2), help to link up these different missions by precisely determining any bias between them. Envisat, ERS-1 and ERS-2 are also used, after being adjusted on these reference missions, in order to compute Mean Sea Level at high latitudes (higher than 66°N and S), and also to improve spatial resolution by combining all these missions together.
The global mean sea level (MSL) deduced from TOPEX/Poseidon, Jason-1 and Jason-2 provides a global rate of 3.2 mm from 1993 to 2013 applying the post glacial rebound (MSL AVSIO website http://www.jason.oceanobs.com/msl). Besides, the regional sea level trends bring out an inhomogeneous repartition of the ocean elevation with local MSL slopes ranging from +/- 8 mm/yr. But for users, it's also crucial to know as much as possible the errors impacting the MSL calculation in order to analyze the MSL variations and in fine to interpret correctly the geophysical mechanisms at the origin of these variations.
In last OSTST (Ablain et al., Venice 2012), the characterization of these errors was performed over all the altimetry period separating several time scales as the long-term evolution (mean sea level trend), but also the inter-annual and periodic signals. However, it has been also underlined that these errors are not homogenous on time. Indeed they are most of the time more important on the first altimetry decade [1993-2002] than in the second one [2003-2013]. In this paper, we propose to describe in details the multiple causes explaining the MSL error budget differences between both decades. We also provide the MSL error budget for both decades separately.

Using CTOH Tidal Constants for Coastal Studies

Caroline Delebecque, CTOH/LEGOS
Florent Lyard, CNRS/LEGOS
Florence Birol, CTOH/LEGOS
Nadia Ayoub, CNRS/LEGOS
Laurent Testut, LEGOS
Laurent Roblou, CNRS/LEGOS

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

Since 2012, the Centre de Topographie des Océans et de l'Hydrosphère (CTOH) is using altimetry data to provide the community with a large collection of tidal constant estimates over more than 23 coastal regions and continental shelves (http://ctoh.legos.obs-mip.fr/products/coastal-products/coastal-products-1/tidal-constants). Taking advantage of the long time series of altimetry data, the regional CTOH Sea Level Anomalies database has been harmonically analysed to derive an empirical tidal correction. It provides tidal experts and coastal modelers with amplitude, phase lags and accuracy estimates for a wide spectrum of tidal constituents, every 6-7 km along the satellite ground tracks. It also takes advantage of the re-processing of coastal altimetry datasets using the X-TRACK processing tool (Roblou et al., 2011).

This presentation aims to highlight the performance of this regional tidal product through various case studies over coastal and shelf seas around the world. The performance of an empirical tidal correction derived from the CTOH along-track tidal constants database is compared to classical tidal corrections (provided by models) in terms of altimetry sea level variance reduction. In the Bay of Biscay, such strategy is expected to improve the observation of a seasonal slope current, the so-called Iberian Poleward Current. The coastal dynamics along the West coast of India, including this empirical tidal correction, is also studied.
Case studies of tidal modeling applications are also presented here. The recently-issued FES2012 global tidal model as well as several regional models have been validated using this independent tidal constants database. It has been used for constraining a regional tidal model using data assimilation techniques and for feeding back direct hydrodynamic modeling.
This tidal constants data base provided a complete set of tidal estimates for prescribing open boundary conditions in local tidal models.

Bumps and Wiggles: Making Sense of Sea Level Climate Record Variability

Dallas Masters, University of Colorado
R. Steven Nerem, University of Colorado
James Choe, University of Colorado

Session theme: Quantifying Errors and Uncertainties in Altimetry Data
Poster

The 20-year global mean sea level (GMSL) climate record made possible by the TOPEX and Jason altimeter missions is an important indicator of climate change. It is being increasingly relied upon for determining evidence of changing rates in the climate system (both accelerations and decelerations). Therefore, understanding the variability within the GMSL time series and also among the different estimates produced by various institutions is becoming more important. Decomposing the record into a long-term and seasonal components leaves a signal with variability on different time scales, from seemingly random short fluctuations to interannual and possible decadal periods. Previous work (Masters et al., 2012) showed that the differences among the GMSL time series produced by various institutions are mainly due to processing methods, such as employing shallow water editing and different averaging techniques (gridding versus non-gridding of the sea surface anomalies). Since then, some institutions have revised their time series to correct errors and improve the ancillary data that go into the sea surface anomaly calculations. In this work, we summarize new processing at the University of Colorado and its effects on the estimated GMSL time series. We also repeat the comparison of the different institutional time series and investigate the remaining causes of discrepancies between them. In order to further understand climate system signals reflected in the time series, we investigate the variability of derived rates of sea level change over interannual and decadal time scales and look at their possible causes.

Impact of revised time variable gravity realizations on geocentric sea level estimates derived from the TOPEX/Poseidon/Jason Climate Data Record

Brian Beckley, SGT Inc.
Frank Lemoine, NASA GSFC
Nikita Zelensky, SGT Inc.
Gary Mitchum, University of South Florida
Richard Ray, NASA GSFC
Xu Yang, SGT Inc.
Stavros Melachroinos, SGT Inc.
Doug Chinn, SGT Inc.
Oleg Bordyugov, SGT Inc.

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

Global and regional mean sea level trends derived from TOPEX/Poseidon, Jason-1, and Jason-2 (OSTM) altimetry (TPJAOS) are reassessed based on estimates employing recent advances in the time variable gravity and ITRF2008-based terrestrial reference frame realizations in the Precise Orbit Determination (POD). Global mean sea level (GMSL) estimates derived from the 20-year altimeter record are shown to have recent significant departures from the relatively stable long-term linear trend of 3.2 mm/yr. A brief period in which GMSL dropped nearly 1 cm from the linear trend is observed (Boening et al., 2012) followed by a pronounced rapid recovery exceeding 2 cm over the last two years. Regional sea level trend comparisons for the first and last 3-years of Jason-2 observations reveal basin scale reversals, with global means rising from 1.3 mm/yr to 7.1 mm/yr. Many of the obstacles previously impeding the measurement and validation of estimates of GMSL from satellite altimetry have been overcome (Fu and Haines, 2012). Nevertheless, due to the dynamic nature of the Earth rendering an unstable terrestrial reference frame (TRF), and error in modeling regional variations in the geopotential, the challenges of measuring geocentric sea level will persist. Case in point is the prior underestimation of recent regional trends by as much as 3 mm/yr in the North Atlantic, which are shown to be primarily a direct consequence of earlier POD omission error in modeling the complex time variable gravity. In this paper we assess the impact of revised POD standards on global and regional MSL estimates derived from the TPJAOS sea surface height record, in particular recent trends from the Jason-2 period, and the subsequent impact on validation results generated from tide gauge comparison analysis.

Preparatory steps for a permanent infrastructure in West Crete to calibrate Sentinel-3, Cryosat-2 and Jason missions with a prototype microwave transponder

Stelios Mertikas, Technical Univesrity of Crete, Greece
Constantin Mavrocordatos, European Space Research and Techology Center, The Netherlands
Nicolas Picot, CNES, France
Pierre Femenias, European Space Agency, Italy
Tommaso Parrinello, European Space Agency, Italy
Antonis Daskalakis, Space Geomatica Ltd.

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

To extend and strengthen Gavdos operations, three Cal/Val facilities have been developed at several other locations, all on the mainland of West Crete. At first, the RDK1 site has been established in the Central-West Crete and which lies along the Jason No. 109 ascending track, while it serves as extension and validation of the Gavdos Cal/Val procedures. Secondly, in the South-West Crete, the CRS1 site has been created for the calibration of the Chinese HY-2 satellite. Finally, a site, called 'CDN2', located on a triple cross-over of the Jason, Sentinel-3A (orbit 14) & 3B (orbit 335) and AltiKa satellites, has already been identified, tested, and selected for altimeter calibration. Also, observations from tide gauges and other dedicated scientific sensors (i.e., GPS-Glonass-EGNOS-BeiDou receivers, meteorological, DORIS, SLR, etc.) installed at various Cal/Val facilities over the broader Crete/Gavdos region, will be used to provide a time series of absolute calibration values and drifts for the Sentinel-3 altimeter and radiometer. A new prototype microwave transponder has been developed and delivered in 2011 to serve as an alternative and independent technique for calibration of, mainly, European altimetric missions. Calibration of the transponder itself has been conducted at the Compact Payload Test Range facilities in the European Space Agency, in 2012. The operational capabilities of the microwave transponder have been already tested employing the Cryosat-2 satellite on TUC campus.

This work will present the preparatory steps taken, and the procedures to be followed for the establishment of a permanent calibration site for Sentinel-3 in the south west of Crete using the developed transponder. Calibration of both Sentinel-3A and Sentinel-3B as well as Jason satellites (and possibly AltiKa) will be performed with this ground infrastructure.

Baleares 2013 Calibration Campaign for Jason-2 and Saral/AltiKa

Juan Jose Martinez-Benjamin, Technical University of Catalonia
RichardBiancale, CNES/GRGS
Jose Martin Davila, Real Instituto y Observatorio de la Armada en San Fernando (ROA)
Jorge Garate, Real Instituto y Observatorio de la Armada en San Fernando (ROA)
Begoña Perez, Puertos del Estado
Josep Gili, Technical University of Catalonia
Rogelio Lopez, Technical University of Catalonia
Ana Tapia, Technical University of Catalonia
Carlos Gracia, Technical University of Catalonia
Frederic Frappart, LEGOS/OMP
Nicolas Roussel, LEGOS/OMP

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

A Baleares calibration campaign in Spanish-French cooperation is being prepared for mid September 2013 for the altimeters of Jason-2 and Saral/AltiKa in the Ibiza island area. A similar Spanish/French experience with Jason-1 was made in June 2003 in this geographical area under IBIZA 2003 campaign.

In this local/regional campaign focusing in bias, we foresee to calibrate the altimeter of Jason-2 and Saral satellites by means of GPS buoys. 4 buoys will be used near a node from Jason-2 (September 15 about 9:38 in ascending track) and Saral (September 15 about 7:30 in ascending track) satellites to get the slope of the sea in along track and cross track directions, what is necessary to interpolate the exact nadir point of the satellite. It will be used Argos floating transmitters from CLS to be tied to the buoys with a long rope. We have thought over different configurations. The crossover point between Jason-2 and Saral North of Ibiza (around 40 nm) and West of Mallorca island seems to be optimal in order to have a comparable layout of buoys at the same place for both satellites, of couse at one day interval. This would allow moreover cross calibration between Jason2 and Saral. The GPS receivers will be at 1Hz. It will be used the CGPS at Ibiza harbour from Puertos del Estado. A description of the actual geodetic infrastructure of Ibiza site will be presented.

This campaign Baleares 2013 is founded from the Ministerio de Ciencia e Innovacion of Spain under National Project I+D+i ref:CGL2009-13435/CLI.

Global Calibration and Validation of the Jason-2 and SARAL Geophysical Data Records

Shailen Desai, Jet Propulsion Laboratory, California Institute of Technology
Bruce Haines, Jet Propulsion Laboratory, California Institute of Technology

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

We present updated results on the global calibration and validation of the Jason-2 version D Geophysical Data Records (GDRs), and the first test release of SARAL/Altika GDRs. We focus in particular on temporal and geographically correlated errors, and the analysis of inter-satellite differences of various components of the two sea surface height measurement systems at ground-track crossing locations (crossovers). A valuable approach for evaluating geographically correlated errors is segregating the inter-satellite differences by quadrant, namely ascending and descending ground tracks in the northern and southern hemisphere. We also consider systematic differences in the altimeter measurements as a function of significant wave height and wind speed, noting that calibration of the backscatter coefficient, wind speed, and sea state bias is most likely needed for the SARAL/AltiKa measurements at this early stage of the mission. In doing so, one of our objectives is to develop an estimate for the overall sea surface height measurement system error budget for SARAL.

Global Jason-2 / Jason-1 Data Quality Assessment

Sabine Philipps, CLS
Hélène Roinard, CLS
Michael Ablain, CLS
Nicolas Picot, CNES

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Oral

Long-term monitoring of the Jason-2 and Jason-1 altimetric systems is routinely performed at CLS, as part of the CNES SALP (Système d'Altimétrie et Localisation Précise) project. The main objective of this activity is to provide an estimation of the mission performances for oceanic applications such as mesoscale or climate studies. The monitoring of all altimeter and radiometer parameters is routinely performed in order to detect jumps or drifts. The objective of this presentation consists in giving an overview of Jason-2 and Jason-1 data coverage and data quality concerning altimeter and radiometer parameters, but also the performance of delayed and real time products (GDR, IGDR, OGDR/OSDR) at mono-mission crossovers and along-track.

Cross calibration between altimetry missions or with in-situ measurements is also systematically performed in order to estimate altimetry errors at different spatial and temporal scales. Jason-1 mission switched to a geodetic orbit in May 2012 and stopped to send data on 21st June 2013. Therefore cross-calibration between Jason-2 and Jason-1 is no longer possible.

As Jason-2 is the reference mission used in operational applications or for delayed time studies and especially for monitoring of the Global Mean Sea Level, the assessment of Jason-2 data quality is particular important and we pay special attention to the long-term stability of Jason-2 Global Mean Sea Level (GMSL).

Improving the tide gauge validation for the altimeter sea level climate record

Christopher Watson, University of Tasmania
Neil White, 2. Centre for Australian Weather and Climate Research, A Partnership Between CSIRO and the Australian Bureau of Meteorology
John Church, 2. Centre for Australian Weather and Climate Research, A Partnership Between CSIRO and the Australian Bureau of Meteorology
Matt King, University of Tasmania
Reed Burgette, New Mexico State University

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

The global tide gauge network provides the only independent validation of trends in global mean sea level (GMSL) derived from satellite altimetry. The technique requires computing the difference between altimeter and tide gauge sea surface heights at many different comparison points, increasing degrees of freedom and allowing the precise estimation of bias drift in the altimeter climate record. Key components of the technique include the mitigation of energy at tidal frequencies between the tide gauge and comparison point, as well as accounting for vertical land motion (VLM) at the tide gauge. As estimates of VLM improve, and as refinements in the validation approach are made, it is important to revisit the validation of the entire Jason-class sea level climate record.

We present the development of a refined strategy that is insensitive to outliers such as sites affected by earthquakes or unresolved datum changes, and not overly influenced by any specific small subset of sites in the network. We assess the sensitivity of the technique to a range of processing strategies used to mitigate effects such as tides and across track sea surface slopes. The impact of using a new GPS-derived vertical land movement correction for TGs is also investigated. We apply our bias drift estimation strategy to asses a number of different variants in altimeter datasets across TOPEX, Jason-1 and OSTM/Jason-2, beginning with standard GDR processing and then applying combinations of a number of other commonly used corrections (orbits, SSB and wet and dry troposphere). Results suggest subtle differences in bias drift between different altimeter datasets, with implications approaching the 1 mm/yr level for parts of the climate data record depending on the chosen mission and dataset.

Validation of altimeter data in the German Bight area

Luciana Fenoglio-Marc, Technische Universität Darmstadt
Aron Roland, Technische Universität Darmstadt
Mathieu Dutour Sikiric, 3Laboratory of Satellite Oceanography, Rudjer Boskovic Institute, Zagreb
Becker Matthias, Technische Universität Darmstadt

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

The scope of this study is a regional analysis and inter-calibration of the current and legacy altimeter products in the German Bight against in-situ data and model results both in open sea and in coastal zone (i.e. at distances larger/smaller than 10 Kilometers). The geophysical parameters to be validated are the sea surface height above the ellipsoid (SSH), the significant sea wave height (SWH) and wind speed (U10).

The in-situ data are from a network of tide gauges and platforms which are also GNSS stations.
The wave model data are from two models, namely the Wave Watch III model run within the IOWAGA project and the LSM model that is run operational at DWD/BSH. Beside resolution, the main difference is the physical description of the wind input and dissipation that is used in the wave models and the fact that the LSM model is nested in a global model which is assimilating altimeter wave height measurements.

In order to carry out this task and validate the results, special metrics will be applied.

The ultimate work objective is to monitoring the accuracy of the long-term sea level change in the German Bight area. Intermediate objective the discussion the quality of models analysed through dedicated model-data intercomparison studies.

The network and analysis method has been used successfully for the validation of the Cryosat data and now be extended for other missions.

Global and regional altimetry CAL/VAL: a closer look at Cryosat-2

Marc Naeije, Aerospace Engineering TUDelft, Delft, The Netherlands
Ernst Schrama, Aerospace Engineering TUDelft, Delft, The Netherlands
Remko Scharroo, EUMETSAT, Darmstadt, Germany
Yuchan Yi, Earth Sciences OSU, Columbus (OH), United States
Pieter Visser, Aerospace Engineering TUDelft, Delft, The Netherlands

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

CryoSat-2, in orbit since April 2010, maps the cryosphere with a dedicated altimeter system, with SAR and SARin capability. It now already surpassed its nominal 3 year mission of observing sea ice freeboard and ice sheet elevation change. Precision orbit determination (POD) of CryoSat-2 relies on DORIS Doppler tracking and ground based satellite laser ranging (SLR). We show an update of the results of our POD computations. These CryoSat-2 orbits compare very well with the trajectories computed by CNES and by ESOC and are of Jason-class. We find RMS of SLR residuals around 2cm and RMS of radial differences around 1.5cm. We address data sources, availability, latency, quality and editing, software, standards and methods and focus on the differences with CNES POE, MOE and DIODE navigator orbits, on the empirical acceleration parameters, and on the thermospheric density scale factors.
We also show an update of the results of our CryoSat-2 LRM and pseudo-LRM CAL/VAL efforts. In addition to ice, the SIRAL 2 altimeter onboard CryoSat-2 perfectly samples the global ocean surface. To be able to exploit these data it is necessary to assess and validate them. Another reason is that we want to to complement the Radar Altimeter Database System RADS with this dataset to improve the combined altimeter sampling resolution both in time and space. This has become important now Envisat and Jason-1 stopped providing data and meanwhile successors like Sentinel-3 and Jason-3 are not yet in place. So, we validate and calibrate the LRM data, add and improve corrections (including modeling of corrections that are not directly available from the CryoSat-2 platform), add pseudo-LRM (compressed SAR) to complement the global coverage, and verify the orbit accuracy. The present status of the absolute and relative calibration of LRM data is discussed, also by comparison of CryoSat-2 with other satellites (crossover analyses) and with tide gauge data. We focus on the latest ESA version of the ocean product and compare that with our own efforts to improve the product, which incorporates re-tracking of the wave forms and the determination of a dedicated hybrid sea state model. In addition we review the capacity of Cryosat-2 data and recent AltiKa data to reestablish the altimetric mesoscale variability measuring capability from before the demise of Envisat and Jason-1.

Cryosat-2 altimeter performance assessment over ocean

Annabelle Ollivier, CLS
Sylvie Labroue, CLS
Nicolas Picot, CNES

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

Cryosat -2 mission is dedicated to Cryosphere sciences. Nevertheless, it has the potential to be a mission of opportunity for oceanography. Indeed, the satellite embarks an innovative radar altimeter, and high-precision orbit determination (POD), which are expected to be at least as accurate as ENVISAT's. At the end of the year, the IOP/GOP new ESA products dedicated to ocean (Intermediate and Geophysic Ocean Products) will be available to the community.
Yet, since 2011, an ocean Prototype Product (CPP) is delivered by CNES and included in DUACS system. These data enables to demonstrate that the quality of this mission over ocean is indeed of great interest. They will also insure the time continuity before the period of availability of IOP/GOP products.
For this mission, the potential of innovative SAR mode is undoubtable, however, LRM (Low Resolution Mode) mode is also of interest. It complements the other satellite altimetry missions, it provides high latitudes coverage Currently only 3 altimeter satellites are available as inputs of the SALP/DUACS system, making CryoSat data vital to insure level3 and level4 data quality in near real time.
This poster focuses on the LRM data and assesses Cryosat-2 data quality over ocean (using CPP). It quantifies the system performances for the sea level calculation for large and mesoscales… Stability of the different parameters including the Sea Level is also analyzed in order to anticipate the potential of this mission to complete the altimetric time series (when the period is long enough) for the climate studies (notably Sea Level Rise). It also includes preliminary comparisons to other precise altimetric missions (Envisat and Jason-2). They are essential to assess data quality, as well as to allow combination of altimeter for applications and operational oceanography purpose. Finally, concerning the zones where the instrument works in SAR mode, a global assessment is presented, using the Pseudo LRM (PLRM) data. This enables to assess the fact that, with an adapted processing applied on SAR data, the same level of information as LRM can be obtained. Biases and seamless transitions between these modes are discussed.

Comparison of MLE3 and MLE4 retracking performances using Jason-2 GDR-D dataset: impact on Sea Surface Height estimation.

Hélène Roinard, CLS, Space Oceanography Division, Toulouse, France
Sabine Philipps, CLS, Space Oceanography Division, Toulouse, France
Michael Ablain, CLS, Space Oceanography Division, Toulouse, France
Pierre Thibaut, CLS, Space Oceanography Division, Toulouse, France
Nicolas Picot, CNES, Centre National d'Etudes Spatiales, Toulouse, France

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

In 2012, the whole JASON-2 mission data were reprocessed in GDR-D products version. In addition to the parameters computed by the MLE4 retracking algorithm, several parameters computed by the MLE3 retracking are also provided. Both retracking are based on the same least square principle. MLE3 algorithm estimates three parameters (range, significant wave height, and power) whereas MLE4 estimates four parameters (the three previous ones and the slope of the waveform trailing edge). The aim of this paper is to provide a synthesized overview of the relative performances of the two retracking algorithms highlighting their advantages and weaknesses.
The difference of behavior of the MLE3 and MLE4 parameters will be detailed thanks to various Cal/Val statistics over Jason-2 cycles 1 to 145. The impact on parameters and on valid SSH measurements will also be presented. Concerning the system performance, the variance of SSH crossovers and along-track SLA shows higher values for MLE3 than for MLE4. Our results highlight an important improvement of the performances at time scales less than 10 days when considering a MLE4 rather than a MLE3 algorithm. This study confirms that using a MLE4 retracking is recommended in the case of Jason-2 measurements. It mainly allows an improvement of the high physical content of SLA for along track distances between 10 and 70 km.

Envisat ocean altimetry performance assessment. End of life and overview of a successful mission

Annabelle Ollivier, CLS
Marielle Guibbaud, CLS
Yannice Faugere, CLS
Nicolas Picot, CNES
Pierre Femenias, ESA

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

In 2012, ENVISAT mission was interrupted, after 10 years of altimetric measurements over ocean. While in orbit, Envisat not only ensured the continuity of the observations provided by ERS-1 and ERS-2, but significantly improved the data quality compared to its elder sister mission. The quality assessment of these data was routinely performed at the CLS Space Oceanography Division in the frame of the CNES Segment Sol Altimétrie et Orbitographie (SSALTO) and ESA French Processing and Archiving Center (F-PAC) activities. This paper presents the main results in terms of Envisat data quality over ocean: verification of data availability and validity, monitoring of the most relevant altimeter (ocean1 retracking) and radiometer parameters, assessment of the Envisat altimeter system performances for the sea level calculation (for several scales : climate, mesoscales, costale areas, high latitudes,…) .
It also traces the improvements of the dataset from 2001 to 2012 thanks to an ever improving ground processing and an accurate validation and performance assessment validation exercise. Indeed, thanks to several improvements of the different terms used for the Sea Level Computation (new orbit, new tide models, new sea state bias, wet tropospheric corrections…), the quality of RA2 system keeps improving. This improvement is sensible in terms of geographically correlated biases, consistency at crossover points and regarding the long-term stability.
This work also includes a cross-calibration analysis of Envisat data with other flying precise altimetric missions (ERS, T/P, Jason-1 and Jason-2 and Cryosat 2). To complete these analyses, in situ external reference is often very useful and enables to give some absolute metrics of drifts and or geographically correlated patterns. These comparisons are essential to assess data quality and performances, as well as for allowing combination of altimeter datasets as required by applications and operational oceanography.
This paper intends to compare the mission performances to other past and current missions. It will also constitute a reference for the expected behavior of the very young or future missions such as AltiKa or Sentinel 3.

Significant Wave Height evolution and link to climate

Pierre Matton, CLS
Annabelle Ollivier, CLS
Michael Ablain, CLS

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

Since 20 years, the spatial altimetry allows to observe very precisely the regional and temporal evolutions of the sea surface height. With this technique, we can follow the evolutions of currents and mean sea level which is one of the indicators of global warming. (Leuliette et al. 2011, Cazenave and Llovel, 2010). Outside this informations, altimetry provides us measures about wind strength and wave height. The role of the wind as climatic indicator was already proved and its stability has already made the object of studies (Ablain et al. 2012). On the other hand, the significant wave height (SWH) from altimetry wasn't so used yet for climate studies purpose.

This day, the significant wave height derived from altimetry is used in the sea level measure via the Sea State Bias correction. That's why it's important to characterize this parameter in order to improve our knowledge of the error budget on different spatial an temporal scales. In addition, a better knowledge of its long term behaviour can help use in physical explanations about oceans evolutions of the last decades. As an example, the number of waves of 5 meters and more is increasing every year.

In this poster, resuming a 6 months training course, we focus on the characterization of Significant Wave Height from different altimetric missions like Envisat, Jason-1, Jason-2, Topex/Poseidon, ERS-1, ERS-2, Geosat Follow On and Cryosat-2. Their behaviour is analysed and characterized in terms of long term and interannual trends. For a finer analysis, comparisons to ECMWF ERA Interim model (Abdalla and Hersbach 2004) were also used as an external reference. This study enables to better characterize some discontinuities in the altimetric dataset (for instance on Topex Poseidon). It also highlights the fact that ECMWF ERA Interim model could not be used straight forward for trend analysis because it assimilates Real Time altimetrics data, affected by some inhomogeneity of processing. It therefore highlights the fact that for Climate orientated models, climate orientated altimetric products should be assimilated instead of Real Time series.

Finally, preliminary studies are shown to propose such climate altimetric SWH product. Once the short length inhomogeneities between missions are filtered, the long term evolution is rather consistent and could constitute a reliable series for physical interpretations.

SSALTO/DUACS: the Reprocessing of the 20 Years of Data is On Going

M.-Isabelle Pujol, CLS
Yannice Faugère, CLS
Annabelle Ollivier, CLS
Jean-François Legeais, CLS
Emilie Bronner, CNES
Nicolas Picot, CNES

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

During the last 20 years, altimeter Level 3 (along-track cross-calibrated SLA) and Level 4 products (merging multiple sensors as maps or time series) were developed in parallel with L2 (a.k.a GDR) processing improvements. Directly usable and easier to manipulate, L3/4 products are now vastly used in the user community. They contribute to various studies in different fields that cover the ocean, from climate and meteorological phenomena, to geophysics and biology.
The quality and precision of these products has been periodically improved, taking advantage of new missions with advanced altimeter technology, improved L2 processing, but also from a better understanding of the ocean stemming from the analysis of past records. Moreover, as applications become more and more diversified, L3/L4 products are evolving to better fit users' needs.
A full reprocessing of the 20 years of altimeter data is on going. This reprocessing will take into account all the recent improvements in order to generate a consistent altimeter data set. The altimeter standards will be updated with the more accurate standards available for the different missions. The inter-calibration process, allowing us to reduce the bias between the different missions, will be improved, taking into account the global MSL consistency. An important improvement will be the use of a new reference period, taking into account the 20 years of altimeter data now available. This will lead to more pertinent sea level anomalies, without impact on the absolute topography. Additionally, the mapping process will also be improved, with amongst others, the use of tuned correlation scales and adjusted altimeter errors. Preliminary validation results are encouraging and show improvements at climatic scales as well as mesoscales. The full reprocessed data sets will be available early 2014.

Global Quality Assessment of updated Geosat Dataset

Koch Vincent, CLS
Sabine Philipps, CLS
Michael Ablain, CLS

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

The U.S. Navy GEOSAT altimetric mission was the first mission to provide global altimeter data over a long period (from 1985 to early 1990). During the first 18 months, Geosat was on a geodetic orbit, afterwards it was on a 17-day exact repeat track. The last official release of Geosat data was in 1997 (http://ibis.grdl.noaa.gov/SAT/gdrs/geosat_handbook/). Even if the data set is less precise than data sets from recent altimeters such as Jason-2, the Geosat data are the only global altimeter data available before the 1990's and are therefore very interesting. Furthermore over the years updated geophysical standards (ionospheric model, wet and dry tropospheric correction from models, …) are available. A recent release of precise orbit ephemeris from the National Aeronautics and Space Administration is also available (GSFC 0905). In addition, the geodetic phase was retracked and is available as "20th Anniversary GEOSAT Geodetic Mission Product" (Lillibridge et al. 2006).

Hereafter we used the Geosat 1-Hz data set from the RADS database (http://rads.tudelft.nl/rads/rads.shtml) which contains already the updated standards. The quality of the updated data set is analysed and compared to the previous dataset (1997). Among others, analyses of sea level anomaly and sea surface height differences at mono-mission crossovers are done.

From Global Cal/Val over ocean to Global Cal/Val over ice sheets: quality assessment of SARAL/AltiKa for Antarctica and Greenland

Aurelie Michel, CNES / CLS / LEGOS
Annabelle Ollivier, CLS
Frédérique Remy, CNRS / LEGOS

Session theme: Regional and Global CAL/VAL for Assembling a Climate Data Record
Poster

Altimetry is an efficient tool to assemble a climate data record for oceans for more than 30 years but other types of surfaces can be studied thanks to satellite altimetry such as inland waters or sea ice.
Since 1991 and ERS1 launching, ice sheets are monitored and the long-term altimetric observations enable us to compute electromagnetic models, to help describe snowpack properties or to estimate volume balance and the contribution to the sea-level rise which is known to be 1mm/yr.
Saral/AltiKa was succesfully launched in February 2013 on the same orbit than previous satellites (Envisat, ERS series)in order to understand the whole new characteristics of SARAL and their impact on the altimetric waveforms and what can be deduced from them.
We thus here present a first global Calibration/Validation performed over ice sheets during the first 6 months of SARAL exploitation. Global/Calval methodology is similar to the one performed on oceanic surfaces with Jason and Topex/Poseidon, it helps us conqequently to use accurate and efficient analysis our Cal/Val on ice sheets. But we have to take into account differences such as different atmospherical attenuations and various effects inducing a bias in our analysis and that are non-predominant in ocean altimetry : the slope effect, the surface roughness at various scales and the penetration of the radar wave into the snowpack.
Knowing all of this, we assess that SARAL/AltiKa is an innovative mission for the ice sheets monitoring and provides us with precious informations just like Jason 1,2,Topex/Poseidon did over ocean.
We compared with the former altimetric mission Envisat which provided more than a decade record.
We see a +3dB difference between Envisat and Saral backscatter coefficient and a +1m difference between Envisat and Saral leading edge width (analog to SWH) which confirms us the less penetration effect.
Moreover we are able to do a cross comparison and compared the SARAL track from the mean Envisat profile or with Icesat.
All of these methods whose results are detailed in this presentation show the importance of the ice sheets monitoring to assemble an accurate climate data record to complete with the informations from ocean altimetry.

Instantaneous Profiles of Dynamic Ocean Topography (iDOT-profiles) – updated with GOCO03S

Wolfgang Bosch, Deutsches Geodätisches Forschungsinstitut (DGFI), Munich
Denise Dettmering, DGFI, Munich

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Poster

Usually 'geodetic' estimates of the Dynamic Ocean Topography (DOT) are performed with a long-term Mean Sea Surface (MSS), already implying a significant temporal smoothing. By the profile approach, developed at DGFI it has been demonstrated that DOT estimates can also be achieved if along-track sea surface heights are reduced by geoid heights, derived from the latest GOCE-based gravity field models. Both, the sea surface heights and the geoid heights are to be filtered in the same way in order to ensure spectral consistency of both quantities. We apply a Gauss-type filter (with no side lobes neither in the spatial nor in the spectral domain) with filter length of some 70 km, corresponding to a spherical harmonic series up to degree 210. This way we obtain instantaneous profiles of the dynamic ocean topography (iDOT-profiles) approaching meso-scale resolution.
After a new, careful multi-mission cross-calibration (MMXO13) we have now re-computed these iDOT-profiles for all passes of Topex, Poseidon, Jason1/2, ERS1/2, Envisat, and GFO with GOCO03S (Mayer-Gürr et al. 2013), one of the latest gravity models, combining GRACE and GOCE data. First iDOT-profiles for CryoSat are also available. All together the iDOT-profiles of these altimeter satellites realize a multi-mission sampling of the DOT with rather dense spatial and temporal resolution. The geostrophic velocity field of gridded iDOT-profiles show much more details and significant stronger velocities than an MSS-based DOT. In addition, the iDOT-profiles realize (smoothed) snapshots of the DOT and allow to construct (for the period up to 1993) a two decade time series of the DOT and the associated geostrophic velocity field, which exhibit the temporal evolution of the DOT, in particular the Eddy formation in the strong western boundary currents.

A Global Mean Ocean Circulation Estimation using GOCE - DTU12MDT

Per Knudsen, DTU Space
Ole Andersen,
DTU Space

Session theme: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Poster

The Gravity and steady state Ocean Circulation Explorer (GOCE) satellite mission measures Earth's gravity field with an unprecedented accuracy at short spatial scales. Preliminary results have already demonstrated a significant advance in our ability to determine the ocean's general circulation. The improved gravity model provided by the GOCE mission has enhanced the resolution and sharpened the boundaries of those features compared with earlier satellite only solutions. In this study, more recent gravity models from GOCE are combined with the DTU10MSS mean sea surface to construct a global mean dynamic topography (MDT) model. Calculation of the geostrophic surface currents from the MDT reveals improvements for all of the ocean's major current systems. Furthermore, the finer scale features, such as eddies, meanders and branches of the current system are visible.

The Application of Multiple Satellite Radar Altimetry Data Sets to Serve Inland Surface Water Projects

Charon Birkett, University of Maryland
David Bjerklie, USGS
Claudia Carabajal, SIgma Space Corp at NASA/GSFC

Session theme: Science Results from Satellite Altimetry
Poster

This program includes several inland water science investigations that utilize a suite of archival (T/P, Jason-1, ERS), current (Jason-2/OSTM, ENVISAT) and potential future (Jason-3, SARAL, Sentinel-3) radar altimeter data sets. The science focus includes river and wetland hydraulics and dynamics, and the utilization of lake levels as a proxy indicator of climate change. A multi-altimeter approach provides a more global and long-term outlook, combining the temporal and spatial resolution merits of each instrument, while the exploration of additional synergistic data such as NASA's ICESat-1 mission offers a multi-sensor approach for the determination of river discharge. A strong instrument performance and validation theme runs throughout the proposed program. This includes addressing the problems inherent in the merger of multiple datasets, and seeking refined radar echo interpretation methods to improve target detection and elevation accuracy. Technical results feed directly into several new pilot projects as well as a near real time NASA/USDA operational program that monitors large lakes and reservoirs around the world for drought and water resources issues. This presentation explores the main objectives which include investigating Jason-2/OSTM and SARAL instrument performance and developing data evaluation methods that maximize elevation accuracy and resolution. The Yukon River (USA), the Balonne River (Queensland, Australia), the Sudd wetlands (Africa), and the Usangu Wetlands (Africa) are the specific case study regions, while large lakes and reservoirs around the global are the focus for examining the correlations between observed lake height variations and climatic indices (e.g. ENSO, NAO).

Aspects of Wave Radiation in the World Oceans

Theodore Durland, College of Earth, Oceand, and Atmospheric Sciences, Oregon State University
J. Thomas Farrar, Woods Hole Oceanographic Institution
Steven R. Jayne, Woods Hole Oceanographic Institution
Jim Price, Woods Hole Oceanographic Institution

Session theme: Science Results from Satellite Altimetry
Poster

Our overall goal is a better understanding of the extent to which mid-ocean mesoscale variability can be attributed to remotely generated, radiating barotropic and baroclinic waves. In particular, we will examine the altimetric records for evidence of radiation from the most energetic and unstable flows: western boundary currents and their extensions, and the equatorial current systems. The observations will be compared with our best understanding of the generation mechanisms, radiation patterns and the extent to which the remotely generated energy can contribute to the mid-ocean eddy kinetic energy. This will be done with both analytical models and Global Circulation Models.

Using gridded sea-surface height (SSH) anomaly products from satellite altimetry, Farrar (2011) provided convincing evidence for barotropic Rossby waves coherent with and radiating away from Tropical Instability Waves to as far as 20 degrees north. With an enhanced analysis we show evidence that such radiating variability may be observable throughout most of the North Pacific. The phase and amplitude patterns of the observed coherent variability show a striking resemblance to those predicted by theoretical ray tracing of barotropic Rossby waves over the variable bathymetry of the North Pacific.

Combined Use of High Resolution Satellite Images and Altimetry to Estimate Volume of Small Lakes

Frédéric Baup, Université de Toulouse
Frédéric Frappart, Université de Toulouse
Jérome Maubant, Université de Toulouse
Florence Birol, Université de Toulouse

Session theme: Science Results from Satellite Altimetry
Poster

This study presents an approach to determine water volume of small lakes (<100 Hectares) by combining satellite altimetry data and high resolution (HR) images. The studied lake is located in the South West of France, and is only used for agricultural irrigation purposes. Altimetry satellite data are provided by the RA-2 sensors onboard Envisat, and high resolution images (<10m) come from optical (Formosat-2) and Synthetic Aperture Radar (SAR) antennas (Terrasar-X and Radarsat-2) satellites. Altimetry data (one every 35 days) and HR images (77) have been respectively available since 2003 and 2010. In situ data (water levels and volumes) have been provided by the manager of the lake since 2003. Three independent approaches are developed to estimate lake volume and its temporal variability. The first two are empirical and use synchronous ground measurements of volume and satellite data. Results demonstrate the good capability of altimetry and imagery to monitor the time-variations of the lake with a good accuracy (R^2 ALTIMETRY=0.97, RMSE ALTIMETRY=6,4%, R^2 IMAGERY=0.88 and RMSE IMAGERY=10%). The third method, which consists in combining altimetry (level of the lake) and satellite images (surface of the lake) to estimate volume changes of the lake, provides even better results (R^2=0.99), and demonstrates the potential of future Sentinel and SWOT missions for agricultural and irrigation applications through the monitoring of small lakes and reservoirs.

Current Status of the Japanese Altimetry Mission, COMPIRA

Akihisa Uematsu, Japan Aerospace Exploration Agency (JAXA)
Norimasa Ito, Japan Aerospace Exploration Agency (JAXA)
Ryoko Nakamura, Japan Aerospace Exploration Agency (JAXA)
Yukie Yajima, Japan Aerospace Exploration Agency (JAXA)
Yasuo Sudo, Japan Aerospace Exploration Agency (JAXA)
Naoki Miyashita, Japan Aerospace Exploration Agency (JAXA)
The JAXA COMPIRA Team, Japan Aerospace Exploration Agency (JAXA)

Session theme: Science Results from Satellite Altimetry
Poster

COMPIRA (Coastal and Ocean Measurement mission with Precise and Innovative Radar Altimeter) is a new Japanese altimetry mission by the Japan Aerospace Exploration Agency (JAXA). COMPIRA will carry a wide-swath altimeter named SHIOSAI (SAR Height Imaging Oceanic Sensor with Advanced Interferometry), X-band interferometric SAR having 80 km swath in both left and right sides, with resolution of 5 km. There are three fields which consist of the COMPIRA mission. The first one is ocean currents forecast; to aim to improve the ocean currents forecast, expecting to help various human activities over the ocean, for example, for efficiency of marine navigation through operational oceanography. The second field is fishery, to aim to observe the ocean surface topography linked to estimate fishing places related to sea surface height and ocean salinity/temperature. The third field is science; to aim to improve TSUNAMI forecast model using inversion method with the observation of TSUNAMI waves. We have been discussing specification of the mission through a user team called “COMPIRA team”. Also, we recently constructed two additional user teams, “Science team” and “Coastal forecast core team”. Especially, other than TSUNAMI forecast, COMPIRA is expected to obtain various useful data applied to various scientific fields over the ocean. Therefore, the “Science team” began to discuss about maximization of scientific outcome using COMPIRA data by Japanese scientists. Three new scientific outcomes are being intensively discussed; sea-level rise phenomena, mesoscale and submesoscale phenomena, and processing, outputs and applications of ocean currents forecast. The other team, “Coastal forecast core team”, is aimed to develop coastal forecast system through pre-launch activities toward COMPIRA. In parallel, we are now working on a conceptual design of the satellite system and payloads, and experiments. We conducted aircraft experiments of the sea surface height measurement with an airborne interferometric SAR along Jason-2 orbit over the Kuroshio current during Dec 2012-Jan 2013. In the paper, we will present current status of COMPIRA-related mission studies, activities including discussion of scientific outcomes, and some experimental results.

Generation of COMPIRA simulated data

Osamu Isoguchi, Remote Sensing Technology Center of Japan
JAXA COMPIRA team, Japan Aerospace Exploration Agency (JAXA)
Coastal forecast core team, JAMSTEC, Kyushu University, MRI

Session theme: Science Results from Satellite Altimetry
Poster

Japan Aerospace Exploration Agency (JAXA) is working on a conceptual study of altimeter mission named Coastal and Ocean measurement Mission with Precise and Innovative Radar Altimeter (COMPIRA), which will carry a wide-swath altimeter named Synthetic aperture radar (SAR) Height Imaging Oceanic Sensor with Advanced Interferometry (SHIOSAI). Capturing meso/submeso-scale phenomena and operational oceanography are one of COMPIRA's main objectives. Orbit specifications are thus designed to be better for operational oceanography including coastal forecast. That is, a spatial grid sampling is 5km and an observation times per revisit period (about 10 days) is 2 to 3 times. In order to meet both sampling frequency and spatial coverage requirements in mid-latitudes as much as possible, orbit inclination was set relatively low, 51 degrees. Although this sampling frequency is, of course, not enough high to capture time evolution of coastal phenomena, an assimilation process would compensate its time evolution if 2D SSH fields was observed at least once within decal time scale of phenomena. JAXA has launched a framework called "Coastal forecast core team" to aim at developing coastal forecast system through pre-launch activities toward COMPIRA. Assimilation segment as well as satellite and in situ data provision will play an important role on these activities. As a first step, simulated sea surface heights (SSH) are generated from regional ocean numerical models and the COMPIRA orbit and error specifications. The several regional model data around Japan were provided by Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Kyushu University, Meteorological Research Institute (MRI). Their specifications are as follows: spatial and temporal grid interval range from 1.5km to 3km, and 30 minutes to 3 hours, respectively. Some models incorporate tidal components. The generated simulation data will be used to develop an optimal method to generate mapped data products using and tide models using COMPIRA. Identical twin experiments are also planned to not only investigate the effect of wide-swath SSH measurements on coastal forecast but also develop an assimilation method that can be applied to 2D SSH measurements. In the workshop, the characteristics of the simulated data, which include a comparison of snapshots and its temporal evolution, and effective resolutions etc., are presented.

Predicting surface heat flux with sea level anomalies in the North Atlantic

LuAnne Thompson, University of Washington
Kathryn Kelly, University of Washington
James Booth, City College of New York

Session theme: Science Results from Satellite Altimetry
Poster

On interannual times scales, the ocean plays an important role in controlling surface heat flux, with stored heat leading to exchange of heat between the ocean and the atmosphere. A correlation analysis between both interannual sea surface height (SSH, as a proxy for upper ocean heat content) and sea surface temperature (SST) with surface turbulent heat flux (OAFLUX, Objectively Analyzed Air-sea Flux) shows that throughout much of the North Atlantic, SSH and SST are lagged correlated with surface turbulent heat flux, with both SSH and SST leading surface turbulent heat flux by several months throughout much of the North Atlantic Basin, with the predictive skill of SST slightly better than SSH. In general, a warm ocean leads to heat from the ocean to the atmosphere so that the turbulent fluxes damp the heat anomaly in the ocean. A seasonal analysis shows that for spring and summer, SST does marginally better than SSH in predicting turbulent heat flux. However, in fall and winter (October through February) SSH gives a more robust prediction of turbulent heat flux in a region that extends from the western boundary south of the separated Gulf Stream (70W, 28N) and to the Northeast (35W and 45N), with the location depending on the month of the year. In these regions in fall and winter, SSH predicts turbulent heat flux one to two years in advance. The regions of high predictive skill also track the seasonal evolution of the maximum mixed-layer depth and the atmosphere can access water subducted near the subtropical/subpolar gyre boundary. This analysis provides evidence that changes in the atmosphere can be forced by anomalies in subtropical mode water (eighteen degree water).

PHANTOM: Poleward heat flux and ACC variability at choke points

Young-Hyang Park, LOCEAN - MNHN
Christine Provost, LOCEAN CNRS
Ramiro Ferrari, LOCEAN UPMC/CNRS

Session theme: Science Results from Satellite Altimetry
Poster

The PHANTOM project is addressing some climate-relevant subjects at selected choke points in the Southern Ocean using in situ observations, altimetry, and numerical model outputs. It results from the fusion of two previous independent projects, DRAKE (PI, Christine Provost) and TRACK (PI, Young-Hyang Park), into a single bigger project to share the common methodology and personals around the central themes of the poleward heat flux and the Antarctic Circumpolar Current (ACC) variability in hitherto not well-documented, but dynamically and thermo-dynamically utmost important, choke point regions. It is designed to explore efficiently already-made in situ observations in Drake Passage and the Fawn Trough of the Kerguelen Plateau, to extend the experiments to other outstanding choke points such as the Udintsev Fracture Zone in the South Pacific and the Shackleton Fracture Zone upstream of Drake Passage via a French-Korean collaboration, and to validate and use the global datasets from altimetry and the eddy-resolving, data assimilating model MERCATOR outputs for better documenting and monitoring the Southern Ocean heat budget and the ACC variability.

The oceanic poleward heat flux in the Southern Ocean constitutes an important climate component connected with the meridional overturning circulation and has attracted ever increasing interest because of its peculiarity related to the presence of the strong eastward flow of the ACC. In contrast to subtropical regions where poleward heat flux is largely controlled by the geostrophic mean flow of the western boundary current system, the quasi zonal flow of the ACC in the Southern Ocean greatly isolates Antarctica from direct contact with warmer waters from lower latitudes (Rintoul et al., 2001). However, as the subpolar region south of the ACC loses a substantial quantity of heat to the overlying atmosphere by 0.5-0.65 PW (1 PW = 1015 Watts) south of 60°S (Gordon and Owens, 1987; Hastenrath, 1982), there should be a compensating oceanic heat flux poleward across the ACC. There are two competing but complementary views about how this occurs, i.e., by eddies or by mean flow.

Recently, we have conducted oceanographic cruises with long-term current meter moorings across two choke point sections: one across the Drake Passage in 2006-2009 (Provost et al., 2011) and the other across the Fawn Trough of the Kerguelen Plateau in 2009 (Park et al., 2009). The current meter data from these sites were analyzed in terms of poleward heat transport and ACC variability. Results from the Fawn Trough current meter data (Sekma et al., 2013) and from the Drake Passage data (Ferrari et al, in prep) indicate the overwhelming importance of time-mean flow for the local poleward heat transport due to a significant turning of velocity vectors with depth, revealing a highly non-equivalent barotropic structure.

We expect a similar situation can be observed in other topographically constricted regions with strong flow across prominent submarine ridges, such as the Udintsev Fracture Zone in the South Pacific where mooring will be deployed late 2014 from Araon Korean icebreaker in collaboration with colleagues from KIOST (Korean Institute of Ocean Science and Technology), KOPRI (Korean Polar Research Institute) and URI (University of Rhode Island, USA).

How sensitive is generalised linear Rossby wave theory to uncertainties in the determination of the background mean flow?

Angela Maharaj, Climate Change Research Centre, University of New South Wales, Australia
Remi Tailleux, Department of Meteorology, University of Reading, United Kingdom

Session theme: Science Results from Satellite Altimetry
Poster

It is now well established that both the bathymetry and the background mean flow can significantly affect the propagation of linear Rossby waves, and that both effects are important for correctly interpreting satellite observations of Rossby wave speeds. However, rigorously testing theoretical predictions of Rossby wave propagation against satellite observations is challenging, due to the notorious difficulty of estimating the background
mean flow from observations, which introduce significant uncertainty into the problem. We investigate the sensitivity of theoretical dispersion relations for linear Rossby waves in the presence of mean flow to uncertainties in the determination of the background mean flow, which are then evaluated against empirical dispersion relations obtained from the spectral analysis of sea surface height data for eight previously examined regions of the South Pacific Ocean. To this end, three different ways of estimating the background mean flow are tested, respectively, based on using the dynamic method on the World Ocean Atlas 2009 and WOCE database, as well as averaged velocities from the ECCO2 state estimation product. We also assess to what extent the theoretical dispersion relations in the presence of mean flow based on Killworth and Blundell (JPO,2003,2004)'s theory are affected by the error reported in Tailleux (JPO,2012).

The Tropical Atlantic North Equatorial CounterCurrent revisited from altimetry and SMOS satellites

Sabine Arnault, LOCEAN UMR CNRS/IRD/UPMC/MNHN
Marie Swatek, UPMC
Jacqueline Boutin, LOCEAN UMR CNRS/IRD/UPMC/FR
Fabienne Gaillard, LPO
Olga Hernandez, LOCEAN UMR CNRS/IRD/UPMC/FR
Nicolas Martin, LOCEAN UMR CNRS/IRD/UPMC/FR
Jean Luc Melice, LOCEAN UMR CNRS/IRD/UPMC/FR

Session theme: Science Results from Satellite Altimetry
Poster

The tropical Atlantic North Equatorial CounterCurrent (NECC) is investigated using altimetry and Sea Surface Salinity (SSS) provided either by the recent SMOS (Soil Moisture and Ocean Salinity) satellite or by the ISAS (In Situ Analysis System) reanalysis. The two SSS data present similar results that confirm the robustness of the new technology to capture ocean salinity. The satellite high resolution help in understanding the NECC development between 2010-2012 and in separating the eastern from the western characteristics. The current variability described from altimetry is in agreement with previous works. The existence of two different cores is confirmed in the western basin but only suggested in the East. These cores follow the Inter-Tropical Convergence Zone (ITCZ) displacements tracked as a SSS minima and those of a secondary and northern line. The SSS minima structure, either shown as a broad and diffuse area or a well marked line, also plays a role.

Exploring the behavior of a Ka-band altimeter in the Arctic Ocean

Pierre Prandi, C. L. S.
Sabine Philipps, C. L. S.
Jean-Christophe Poisson, C. L. S.
Bruno Picard, C. L. S.
Nicolas Picot, CNES

Session theme: Science Results from Satellite Altimetry
Poster

SARAL/AltiKa has been launched on February, 25th 2013, its first cycle has started on March 15th and the mission has been collecting high quality sea level data since then. This is the first time that a nadir looking conventional altimeter operates in the Ka-band, and differences were expected with respect to other altimetry missions that operate in the Ku-band (higher sensitivity to rain cells but also better performance in coastal areas). Differences were also expected over ice bodies where the Ka band should be less affected by penetration.
In this study we explore SARAL/AltiKa's behavior over the Arctic Ocean sea ice, with a focus on the backscatter coefficient. The first months of SARAL/AltiKa data are used to explore this year's Arctic melting season. Comparing SARAL/AlitKa to CryoSat-2 and Envisat shows that Ku and Ka-band backscatter over sea-ice present different behaviors, the Ka band seems to be much more sensitive to changes of the sea-ice surface which translates as a high variability of the backscatter coefficient. Possible explanations for the observed differences include: a different interaction with the sea or ice surface or effect of the smaller footprint of SARAL/AltiKa.
We present the first results of this exploratory work conducted under the CNES SALP contract, showing that the SARAL/ AltiKa mission might well provide new and useful information in the Arctic region over sea ice.

Synergistic use of remote sensing data for the study of the Azores and St. Helena current systems

Clara Lazaro, Universidade do Porto, Fac. Ciencias; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR) - Porto, Portugal
Alexandra L. Nunes, Instituto Politecnico do Porto, ISEP; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR) - Porto, Portugal
M. Joana Fernandes, Universidade do Porto, Fac. Ciencias; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR) - Porto, Portugal
Miguel Salgado, Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR/CIMAR) - Porto, Portugal

Session theme: Science Results from Satellite Altimetry
Poster

The Azores and St. Helena currents (AzC and StHC, respectively, the latter also known as Tristan da Cunha current), in the North and South Subtropical Atlantic Ocean, have been subject of a few studies using in situ data, that pointed towards a number of similarities between them regarding intensity, depth penetration and volume transport, and the latitudes at which their main cores are found (34°N and 34ºS for the AzC and StHC, respectively). Moreover, it is known that both systems have associated subsurface adjacent countercurrent flows.

In this study, nearly two decades of satellite altimetry are used in synergy with SST (Sea Surface Temperature) and in situ data to inspect the congeneracy of the AzC and StHC and their associated fronts. This work also aims at achieving a better description of the ocean circulation variability over the North and South Subtropical Atlantic basins on meso and large scales, with focus on the study of the congeneracy between both current systems.
Satellite altimetry, in combination with a mean dynamic topography (MDT) model computed from in situ data, was previously used to derive a time series of absolute dynamic topography (ADT), which allowed the study of the AzC variability over 1995-2006, namely the existence of inter-annual variability in its axis position. In addition to extending the previously used altimetric data set to the whole 1992-2011 period for the AzC, a similar study for the StHC is performed to assess possible resemblances between both currents in what concerns their inter-annual variability.

Both SLA and eddy kinetic energy (EKE) time series show the existence of interannual variability on both current systems, being significantly larger for the StHC region. Furthermore, the surface thermal signatures of the two currents/fronts, derived from available SST optimally interpolated microwave and infrared products (AMSR and AVHRR daily grids with 0.25° spatial resolution, Jun 2002 – Sep 2011), are also inspected and compared to the corresponding ADT-derived signatures for the overlapping period. These preliminary results are expected to improve the knowledge of the South Atlantic variability, the Atlantic inter-hemispheric connections and the correlation of long-period variability of the above referred oceanographic fields with the known phenomena of coupled atmosphere-ocean variability that affect the Atlantic, which are expected to occur on inter-annual to decadal time scales.

Variability of the Antarctic Circumpolar Current transport through the Fawn Trough, Kerguelen Plateau, monitored from 20 years of altimeter data.

Frédéric Vivier, CNRS, LOCEAN-IPSL, Université Pierre et Marie Curie
Young-Hyang Park, LOCEAN-IPSL, Muséum National d'Histoire Naturelle
Hela Sekma, LOCEAN-IPSL, Muséum National d'Histoire Naturelle
Julien Le Sommer, CNRS, LEGI, Université Joseph Fourier

Session theme: Science Results from Satellite Altimetry
Poster

The Kerguelen Plateau is a major topographic obstacle to the eastward flowing Antarctic Circumpolar Current (ACC). Whilst approximately two thirds of the ACC transport is diverted to the North, most of the remaining flow engulfs in the Fawn Trough, the only deep passage across the plateau. As part of the TRACK (TRansport ACross the Kerguelen plateau) project, three mooring lines of current meters were deployed in the Fawn Trough for one year in February 2009, underneath ground-track 94 of the Jason-2 satellite altimeter. Full depth CTD-LADCP casts carried out during the deployment cruise were previously analyzed to provide a comprehensive description of the regional circulation, featuring in particular a volume transport of ~43Sv across the Fawn Trough (Park et al., 2009). Here we present a time series of the transport in the Fawn Trough estimated from current meter observations, featuring a mean eastward transport of 34 Sv (possibly biased low by at most 5 Sv) and a root mean squared variability of 6 Sv, consistent with LADCP estimates (43 Sv in February 2009 and 38 Sv in January 2010). In addition, we analyze to what extent the transport can be directly monitored from along-track satellite altimeter data, which would enable study of the variability of the Fawn Trough Current from a now 20-year long archive.

The ability to reconstruct the flow from a limited set of moored instruments as well as from altimeter derived surface geostrophic velocity is further assessed from synthetic data extracted from a high resolution peri-Antarctic simulation. While a canonical method to derive transport from altimetry, previously applied to the Malvinas Current, gives here unsatisfactory comparisons with in situ estimates, an ad-hoc approach using only the two northernmost mooring lines yields an estimate well correlated (~0.8) with in situ transport at subseasonal time scales during the one year period of observations.

At interannual time scales, however, both methods provide significantly correlated (0.7) transports estimates, suggesting that long-term transport fluctuations across the Kerguelen Plateau can be confidently estimated from altimetry. These consistently indicate a measurable impact of the outstanding 1997-98 El Nino Southern Oscillation(ENSO) event, yielding an increase of the annual mean transport of ~3 Sv, possibly with a one year lag. The transport estimate based on the ad-hoc approach is significantly correlated (0.6) with the Southern Annular Mode (SAM) index at interannual time scales, suggesting that an intensification of the circumpolar winds drives an increase in the transport across the Kerguelen Plateau.

On the relationship between North Pacific sea level trends and Pacific Decadal Oscillation

ChuanLi Jiang, Earth & Space Research
Xuebin Zhang, CSIRO/Australia
Scott Springer, Earth & Space Research
Gary Lagerloef, Earth & Space Research

Session theme: Science Results from Satellite Altimetry
Poster

Accurately understanding and estimating sea level trends along the Pacific coasts are critical to risk management and policy decisions. The magnitudes of the sea level rise based on long-record tide gauge and satellite altimetry measurements fluctuate with different time spans of data, resulting in controversial conclusions. In this study, we utilize 60-year Church & White sea level reconstruction data set to examine the relationship between the global mean sea level rise and sea level variations associated with the aliasing of the decadal variability. Specifically, we systematically test the sensitivity of the relation between the sea level trends and trends in Pacific Decadal Oscillation (PDO) index to the time span of the data records in the entire North Pacific. Preliminary results show that the PDO trends are significantly negatively (positively) correlated with the sea level trends in the western (eastern) Pacific. These sensitivity tests have significant implications for the Pacific coastal risk management. The possible 'worst scenario' when the long-term sea level change works in accordance with the sea level trends due to aliasing of decadal-to-interdecadal sea level variations will also be addressed.

Regional ocean mass contribution to sea surface height variations with seasonal timescale

Tsurane Kuragano, Japan Meteorological Agency/Meteorological Research Institute
Yosuke Fujii, Japan Meteorological Agency/ Meteorological Research Institute
Takahiro Toyoda, Japan Meteorological Agency/ Meteorological Research Institute
Norihisa Usui, Japan Meteorological Agency/ Meteorological Research Institute
Koji Ogawa, Japan Meteorological Agency/ Meteorological Research Institute
Masafumi Kamachi, Japan Meteorological Agency/ Meteorological Research Institute

Session theme: Science Results from Satellite Altimetry
Poster

Many previous studies indicated that deviation of global mean seasonal variations between altimetric sea surface height (SSH) and thermal steric height was comparable to the global ocean mass variation, which is caused by total water flux between ocean and atmosphere and by total runoff. While, in a regional aspect, redistribution of the ocean mass caused by barotropic responses to wind stress and surface-pressure variations also plays an important role.
SSH caused by mass variation is simulated using a barotropic global ocean model forced by seasonally varying surface water flux, wind stress and surface pressure. The results indicate that the SSH varies homogeneously in the global ocean by surface water flux, while the SSH variations by wind stress are larger than those by surface water flux in the mid- and high-latitudes. Seasonal fluctuation of the altimetric SSH corrected by the model SSH forced by the above all three forcings is similar to that of steric SSH above a pressure level larger than 300 dbar.
The main factor of the seasonal SSH variation is the seasonal cycle of thermal steric variation by heating and cooling of upper-layer oceans. The homogeneous SSH variation by surface water flux and barotropic response to the wind stress are the secondary factors. Baroclinic response to the seasonally varying wind stress has a small effect on the SSH variation because the baroclinic response has a long response time over basin scale and could not follow the seasonally varying wind stress curl.

Multidecadal Sea Level Variability in East Asian Seas

Bob Leben, CCAR/University of Colorado at Boulder
Mathew Strassburg, CCAR/University of Colorado at Boulder
Ben Hamlington, CIRES/University of Colorado at Boulder
K.-Y. Kim, Seoul National University

Session theme: Science Results from Satellite Altimetry
Poster

Multidecadal sea level variability in East Asian seas is examined using satellite altimetry and sea level reconstructions to better understand long-term sea level trends in the western Pacific. The 25 East Asian seas are grouped into two regions: Southeast Asian Seas (SEAS) and Northeast Asian Seas (NEAS) as defined by the Limits of the Ocean and Seas published in 1953. The SEAS span the largest archipelago in the global ocean, the Indonesian Archipelago, and provide a complex oceanic pathway connecting the Pacific and Indian Oceans. This is the only existing tropical interoceanic throughflow and is comprised of a total of 20 seas, straits, and gulfs. SEAS regional sea level trends are some of the highest observed in the modern satellite altimeter record that now spans two decades. In contrast, the five Pacific marginal seas that comprise the NEAS of the western North Pacific exhibit significantly lower trend rates with the exception of the Philippine Sea. Initial comparisons of different global sea level reconstructions over the past 60 years find that 17-year sea level trends exhibit good agreement in areas and at times of strong signal to noise associated with multidecadal variability forced by low frequency variations in Pacific trade winds. Forcing of the sea level trends in the SEAS and NEAS regions, and coupling between the two regions, will be discussed further in the poster.

Global and Regional Past Sea Level From an Ensemble of 2D Reconstructions

Benoit Meyssignac, CNES/LEGOS/OMP
Olivier Henr, CNES/LEGOS/OMP
Hindumathi Palanisam, CNES/LEGOS/OMP
Anny Cazenave, CNES/LEGOS
C. K. Shum, JPL

Session theme: Science Results from Satellite Altimetry
Poster

For the past decades, information about sea level is sparse and essentially based on tide gauge records along islands and continental coastlines. This dataset cannot alone inform on open ocean regional variability. But it is important to know the dominant modes of the global and regional sea level variability on interannual/decadal/multidecadal time scales in order to understand the physical processes which drive them. For this purpose, several two-dimensional (2-D) past sea level reconstructions over the last century have been developed (e.g., Chambers et al., 2002a, b, Church et al., 2004, Berge-Nguyen et al., 2008, Llovel et al., 2009, Church and White, 2011, Calafat et al. 2010, Meyssignac et al., 2011, 2012, Ray and Douglas, 2011, Hamlington et al., 2011). In this presentation we use the Empirical Orthogonal Function – EOF- approach to reconstruct past sea level. This approach uses EOFs to combine long tide gauge records of limited spatial coverage and 2-D sea level patterns based on the altimetry dataset or on runs from Ocean General Circulation Models (OGCM). We developed 5 past sea level reconstructions based on EOFs from OGCMs with data assimilation, 2 reconstructions based on EOFs from OGCMs without data assimilation and 1 reconstruction based EOFs from satellite altimetry. Compared to previous reconstructions in the literature these reconstructions use data corrected for glacial isostatic adjustment (both tide gauge records and Altimetry) and tide gauge records corrected for vertical crustal motion with GPS measurements when available. The 8 reconstructions are based on more than 400 tide gauge records and cover the period 1900-2012 on a monthly basis. Performances of the 8 reconstructions are discussed in comparison with independent tide gauges not used in the reconstruction process. We also discuss the differences between the different reconstructions in terms of global mean sea level over the period 1900-2012 and in terms of sea level trend patterns over the period 1950-2012. Then, we present a ‘mean’ reconstruction based on the ensemble average of the 8 individual reconstructions. The dominant modes of temporal variability and the spatial trend patterns of this mean reconstruction are discussed.

The anatomy of recent large sea level fluctuations in the Mediterranean Sea

Felix Landerer, Jet Propulsion Laboratory / Caltech
Denis Volkov, CIMAS / University of Miami & NOAA - AOML / PhOD

Session theme: Science Results from Satellite Altimetry
Poster

During the boreal winter months of 2009/2010 and 2010/2011, Mediterranean mean sea level rose about 10 cm above the average monthly climatological values. The non-seasonal anomalies were observed in sea surface height (from altimetry), as well as ocean mass (from gravimetry), indicating they were mostly of barotropic nature. These relatively rapid basin-wide fluctuations occurred over time-scales of 1-5 months. Here, we use observations and re-analysis data to attribute the non-seasonal sea level and ocean mass fluctuations in the Mediterranean Sea to concurrent wind stress anomalies over the adjacent subtropical Northeast Atlantic Ocean, just west of the Strait of Gibraltar, and extending into the strait itself. The observed Mediterranean sea level fluctuations are strongly anti-correlated with the monthly North-Atlantic-Oscillation (NAO) index.

The ESA Climate Change Initiative Sea Level project: validation phase

Gilles Larnicol, CLS, Toulouse, France
Yanice Faugere, CLS, Toulouse, France
Michael Ablain, CLS, Toulouse, France
Anny Cazenave, CNES-LEGOS, Toulouse, France
Jerome Benveniste, ESA, Frascati, Italia
Detlef Stammer, University of Hamburg, Hamburg, Germany
Magdalena Balmaseda, ECMWF, Reading, United Kingdom
Johnny Johannessen, NERSC, Bergen, Norway

Session theme: Science Results from Satellite Altimetry
Poster

Precisely measuring sea level is a major objective for climate change studies. Since about two decades, sea level is routinely measured from space using altimetry techniques. But to address a number of important questions relevant to sea level studies (is sea level rise accelerating? Can we close the sea level budget? What are the causes of the regional and interannual variability? What are the coastal impacts of sea level rise? etc.), the accuracy of altimetry-based sea level measurements at global and regional scales need to be improved. This was the goal of the ESA CCI Sea Level project that started 3 years ago. Using multi-mission satellite altimetry data, the project developed a new satellite altimetry-based sea level processing system, with dedicated algorithms and data processing strategies, in order to generate high-accuracy altimetry-based sea level products for the last two decades. Here we present validation results of the ESA CCI Sea Level products. Validation includes comparison with tide gauges-based sea level, sea level budget closure studies, and comparisons with ocean reanalyses and coupled climate model outputs at global and regional scales. Impacts of assimilating the ESA CCI sea level products in numerical ocean models are also discussed. Plans for future improvements are presented.

A comparative study of sea level reconstruction techniques using the 20-year satellite altimeter data record.

Mathew Strassburg, Colorado Center for Astrodynamics Research, Department of Aerospace Engineering Sciences, University of Colorado, Boulder, CO
Benjamin Hamlington, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO
Robert Leben, Colorado Center for Astrodynamics Research, Department of Aerospace Engineering Sciences, University of Colorado, Boulder, CO

Session theme: Science Results from Satellite Altimetry
Poster

Sea level reconstruction is an active area of climate research that is focused on extending the relatively short sea level data record provided by satellite altimetry into the past. Questions persist, however regarding how best to reconstruct sea level variability and trends from historical observations using the satellite altimetry. In this work we analyze two basic methods of sea level reconstruction that differ only in the choice of basis functions used to fit to the historical tide gauge measurements. We examine the use of empirical orthogonal functions (EOFs) versus cyclostationary EOFs (CSEOFs) as the basis of the reconstructions, and evaluate techniques based on each of these bases for estimating climate signals and regional sea level trends. Additionally, the reconstructions' sensitivities to tide gauge sampling, both in space and time, will be investigated. In these tests, the 20-year satellite altimeter data record is treated as "truth" and used for idealized tests of the reconstruction techniques. EOF and CSEOF basis functions will be calculated from the satellite altimeter and both observed and synthetic tide gauge data will be used to optimally interpolate sea level over the 20-year altimeter data record. The resulting reconstructions will be compared with the actual satellite altimetry data to determine which, if either, method captures certain signals and variability better in this idealized setting. Global correlations, relative amplitudes and trends of observed climate signals in the sea level reconstructions will be compared, including the Pacific Decadal Oscillation, El Nino-Southern Oscillation, and Atlantic Multidecadal Oscillation. A primary goal will be to keep the comparisons as consistent and realistic as possible. Comparisons of this nature have not been performed to date and will yield valuable insight into two basic techniques of sea level reconstruction.

Multi-decadal regional sea level shifts in the Pacific over 1958-2008

Tony Song, Jet Propulsion Laboratory
Jae-Hong Moon, JPL
Peter Bromirski, Scripps Institution of Oceanography, La Jolla, California
Arthur Miller, Scripps Institution of Oceanography, La Jolla, California

Session theme: Science Results from Satellite Altimetry
Poster

Altimeter data have significantly improved our understanding of regional sea level variability and trends, but their relatively short records do not allow either evaluation of the ocean state prior to 1993 or multi-decadal low-frequency signals in the ocean. Here, we characterize and quantify the multi-decadal regional sea level rise (rSLR) and related ocean heat content in the Pacific from a non-Boussinesq ocean circulation model in comparison with datasets from altimeters, two sea level reconstructions, and in situ ocean profiles from 1958 to 2008. We show that the rSLR trends have undergone two shifts, during the mid-1970s and in the early 1990s, with an east-west dipole pattern in the tropical Pacific. In each of these phases, rSLR accelerated on one side of the Pacific, but decelerated on the other side. The multi-decadal sea level shifts can be explained by the dynamical (steric) upper-ocean responses to the surface wind forcing associated with the Pacific Decadal Oscillation (PDO), with negligible contributions from internal (depth-integrated) ocean mass changes. Additional model experimentation further confirms that the Pacific wind stress trend over the recent two decades has played an important role in strengthening the rSLR in the western Pacific while suppressing the rSLR in the eastern Pacific. The climate-forced large-scale rSLR variability imposes a long-term impact on coastal communities.

Non-seasonal fluctuations of the Arctic Ocean mass observed by GRACE

Denis Volkov, University of Miami / NOAA-AOML
Felix Landerer, Jet Propulsion Laboratory / California Institute of Technology

Session theme: Science Results from Satellite Altimetry
Poster

Time variable gravity observations from the GRACE satellites reveal strong non-seasonal bottom pressure variability in the Arctic Ocean on 2 to 6 months time scales and a record-high bottom pressure anomaly in February of 2011. Here, we examine the nature and driving forces behind those variations. Our findings indicate that the non-seasonal variability of the Arctic Ocean mass is strongly coupled to wind forcing. The zonal wind pattern is correlated with a di-pole pattern of Arctic Ocean mass changes. Westerly wind intensification over the North Atlantic at about 60°N and over the Russian continental shelf break causes the ocean mass to decrease in the Nordic seas and in the central Arctic, and to increase over the Russian Arctic shelf. The time evolution of this pattern is significantly correlated with the Arctic Oscillation index. Basin-wide Arctic Ocean mass fluctuations are related to northward wind anomalies over the northeastern North Atlantic and Nordic seas, and over the Bering Sea. We show that positive (negative) Arctic Ocean mass anomalies are associated with anticyclonic (cyclonic) anomalies of the large-scale ocean circulation pattern. Based on an ocean model output, we conclude that the observed non-seasonal Arctic Ocean mass variability is mostly explained by the net horizontal wind-driven transports, and the contribution of fresh water fluxes is negligible. We demonstrate that the net transport anomalies across the North Atlantic (Bering Strait) contributed about 3 cm (1 cm) to the record-high mass-related sea level anomaly in February 2011.

Quantifying the respective contribution of wind stress and diabatic forcing to decadal temperature changes and regional sea level trends over 1993-2010 based on ECCO solutions

William Llovel, JPL/NASA/Caltech
Ichiro Fukumori, JPL/NASA/Caltech
Ou Wang, JPL/NASA/Caltech

Session theme: Science Results from Satellite Altimetry
Poster

Since 1993 and based on satellite altimetry data, sea level trends display a large regional variability. Some regions experience a sea level rise (e.g., the west tropical Pacific ocean, the subpolar north Atlantic ocean …) whereas other regions experience a sea level drop (e.g., the east tropical Pacific Ocean, golf of Alaska …). Those sea level trends appear to be steric in nature. Moreover, steric changes appear to be mainly thermosteric, although halosteric effects can reduce or enhance thermosteric changes in some specific regions (Stammer et al., 2013). Understanding and quantifying the processes involved in regional sea level changes are important tasks to better constrain and ascertain the physical processes involve in regional sea level changes and then, improve future predictions to anticipate potential impacts. In this study, we analyze the ocean heat content change and its origin by analyzing Estimating the Circulation and Climate of the Ocean (ECCO, Wunsch et al., 2009). We run different experiments to estimate and quantify the respective contribution of each atmospheric forcing (e.g., wind stress and diabatic forcing) to heat content change and regional sea level trends.

The control of non-linear mesoscale ocean circulation through altimetric data assimilation revisited using a variational approach.

Pierre-Antoine Bouttier, OSUG-LGGE/CNRS
Jacques Verron, LGGE/CNRS
Eric Blayo, LJK/Université Joseph Fourier-INRIA
Pierre Brasseur, LGGE/CNRS
Arthur Vidard, LJK/INRIA

Session theme: Science Results from Satellite Altimetry
Poster

A long-term challenge for data assimilation (DA) in oceanography is the adequate representation of meso- and smaller-scale dynamics into numerical models used to simulate the ocean general circulation, variability and energy budget. However this small-scale activity, which is typically seen from altimetric satellites, is strongly linked to the nonlinear character of the flow whereas DA methods are generally less efficient in such contexts than in (almost) linear ones.

The purpose of this presentation is to address this problem specifically, by exploring the behavior of an incremental 4D-VAR DA method in a non-linear ocean model, based on NEMO and NEMOVAR modeling frameworks. More specifically, we investigate the impact of different altimeter observational networks based on JASON 1-2-3 and SARAL/AltiKA missions, by looking at the performances of variationnal DA system at eddy-permitting resolution. A simplified double-gyre ocean circulation model is implemented using the NEMO SEABASS configuration at 1/4° and 1/12° resolution. This idealized configuration is a common benchmark further used in the frame of the SANGOMA (Stochastic Assimilation for the Next Generation Ocean Model Applications) EU project dedicated more specifically to stochastic assimilation methods.

We have performed three twin experiments, without model error, with different simulated observation sets: one based on JASON-1 satellite tracks, one based on SARAL/Altika tracks and one taking in account both simulated satellites. Among others, we will present results characterizing scales and structures of the analysis error along the assimilation process, as well as potential connections with small scale activity. In order to study qualitatively and quantitatively the convergence of the algorithm and the structure of analysis and forecast errors, a broad spectrum of diagnostics have been considered: classical spatial and temporal RMSE, cost function characteristics and energy spectrum.

In our experiments, it appears that the incremental 4DVAR algorithm gives the best results in reducing analysis and forecast errors for one-month assimilation windows. This variational DA system also appears to be very sensitive to the observational sampling.The difficulty of convergence for the incremental 4DVAR algorithm at this spatial resolution is tackled with an observational network based on multiple altimeter satellite. In this case, this variational DA system is more efficient to reduce analysis error. Moreover, our results indicate that higher spatial resolution of the observational network (SARAL/Altika) is more efficient to achieve this goal than a higher temporal resolution (JASON-1).

Towards an ensemble stragtegy for altimetric data assimilation into eddy-resolving ocean circulation models

Guillem Candille, LGGE/CNRS
Jean-Michel Brankart, LGGE/CNRS
Pierre Brasseur, LGGE/CNRS

Session theme: Science Results from Satellite Altimetry
Poster

The objective of this project is to develop advanced methods suitable for addressing along-track altimetric data assimilation into eddy-resolving ocean circulation models needed for operational and research applications. This work is carried out jointly with the SANGOMA (Stochastic Assimilation for the Next Generation Ocean Model Applications) consortium, funded by EU under the GMES umbrella over the 2012-2015 period. In this framework, a realistic circulation model of the North Atlantic ocean at 1/4° resolution (NATL025 configuration) has been adapted to include effects of unresolved scales on the dynamics. This is achieved by introducing stochastic perturbations of the equation of state to represent the associated model uncertainty (Brankart 2013). Assimilation experiments are designed using altimetric data from past and on-going missions (Jason 1, Envisat but also SARAL/Altika missions) to better control the Gulf Stream circulation, focusing on the frontal regions which are predominantly affected by the non-resolved dynamical scales. An ensemble based on such stochastic perturbations is then produced and evaluated using the model equivalent of along-track altimetric observations. These three elements (stochastic parameterization, ensemble simulation and 4D observation operator) are used together to perform optimal 4D analysis of along-track altimetry over 10-day assimilation windows. In this poster, we will demonstrate the statistical properties of the pdfs : dispersion analysis and reliability rank histogram and RCRV, and global probabilistic properties through CRPS (Candille and Talagrand 2005, Candille et al. 2007). Further, we will discuss the relevance of using such improvements of conventional assimilation methods for re-analyses and real-time operational assimilation systems based on NATL025 or higher resolution configurations.

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Exploring the mesoscale activity in the Solomon Sea: a complementary approach with a numerical model, altimetric and glider data

Lionel Gourdeau, LEGOS
Jacques Verron, CNRS
Frederic Marin, LEGOS-Nouméa
William Kessler, NOAA/PMEL
Angélique Melet, GFDL
Russ Davis, scripps

Session theme: Science Results from Satellite Altimetry
Poster

This study aims at documenting the mesoscale activity in the Solomon Sea for the first time. The Solomon Sea represents a transit area for the LLWBCs connecting the subtropics to the equatorial Pacific and playing a major role in ENSO dynamics. It has been shown that the Solomon Sea circulation is complex with well-marked seasonal and interannual cycles, and a high level of eddy kinetic energy. At this stage, we examined the relation between the eddy kinetic energy and mesoscale eddy activity, and how they are related to the main currents and their variability.
Our analysis is mainly based on altimetric data to take advantage of the 19 years of observations. This synoptic time series at the surface is complemented by occasional in situ glider observations providing at-depth information. The good consistency between both measurements gives confidence in the analysis. Moreover, the analysis of in situ observations is completed by an analysis of model outputs since both model and observation provide similar diagnostics of the mesoscale activity in the Solomon Sea.
The highest eddy kinetic energy (EKE) is observed in the northern part of the basin and extends southward to the central basin. Both the EKE level and the eddy activity in the Solomon Sea are related to variations in the strength of the different currents entering the Solomon Sea, namely the GPC and the NVJ feeding the LLWBC through the southern boundary and the SEC through Solomon Strait. The type of instability that leads to the eddy growth in the Solomon Sea has not been determined so far. Both barotropic instability associated with horizontal shears between the northward LLWBC and southard SEC inflow and baroclinic instability associated with vertical shear between the highly variable surface current overlying the LLWBCs are possible méchanisms.
Most of the cyclonic eddies are generated in the southern Solomon Sea along the LLWBC and are advected northward. As for anticyclonic eddies, they are generated in the eastern part of the Solomon Sea and propagate westward until reaching the LLWBCs and being dissipated. Observations from gliders show that the signature of eddies on the temperature and salinity fields is visible down to about 300 m depth. Cyclones are responsible for an upwelling of the thermocline water up to the surface, whereas anticyclones lead to a downwelling of the warm surface water and to a depression of the thermocline. If eddies are predominantly cyclones, the eddy variability at seasonal and interannual time scales is dominated by the anticyclonic eddies. The SEC inflow variability through Solomon Strait appears as a main trigger of the mesoscale variability in the Solomon Sea, and the interannual variability of the anticyclonic activity is in phase with ENSO. Since anticyclonic eddies are generated in a region where the T, S water characteristics are different from that of the LLWBCs and dissipate in the LLWBCs, they could participate in the modification of water masses characteristics of the LLWBCs.

On the joint use of high resolution tracer images and altimetric data for the control of ocean circulations

Lucile Gaultier, CNRS / LGGE
Jacques Verron, CNRS / LGGE
Pierre Brasseur, CNRS / LGGE
Jean-Michel Brankart, CNRS / LGGE

Session theme: Science Results from Satellite Altimetry
Poster

Over the past two decades, altimetric satellites observed turbulent features of ocean dynamics at the mesoscale. High resolution sensors of tracers such as the Sea Surface Temperature or the Ocean Color reveal even smaller structures at the submesoscale, which are not seen by altimetry. The role of the submesoscale in the ocean may be very important for the dynamic at larger scales. Therefore, we must benefit from the two types of observations (mesoscale dynamic and submesoscale tracer image) to refine the estimation of the ocean circulation.

The goal of this study is to explore the feasibility of using tracer information at the submesoscales to complement the control of ocean dynamic fields that emerge from altimeter data analysis at larger scales. To do so, an image data assimilation strategy is developed in which a cost-function is built that minimizes the misfits between image of submesoscale flow structure and tracer images. In the present work, we have chosen as an image of submesoscale flow structure the Finite-Size Lyapunov Exponents (FSLE). The choice of FSLE as a proxy for tracers is motivated by d'Ovidio et al (2004), where similar patterns between tracers and FSLE images are evidenced.

A prerequisite to the study is that the relation between the ocean dynamics and FSLE can be inverted, in other words that the submesoscale information transmitted through the intermediate FSLE proxy is effective in controlling the ocean system. This assumption has been successfully tested on several regional pieces of the ocean. Using a strategy similar to the one used in Data Assimilation, the sensitivity of FSLE horizontal patterns to velocity errors is investigated. To do so, a Gaussian velocity error field is created using fifteen years of altimetric data. A cost function is then defined to measure the misfit between the FSLE computed using velocities with errors and the FSLE derived from a 'true' (error free) velocity.
It is found that a global minimum can be identified in the cost function proving that the inversion of FSLE is feasible. The next step is the inversion of submesoscale tracer information to correct a mesoscale altimetric field using real observation. The ocean dynamical variable to be corrected is the mesoscale altimetric velocity field using a high resolution tracer image. The strategy is similar to the one used to invert FSLE. The cost function measures the misfit between the FSLE derived from the altimetric velocity and the high resolution tracer image. Several test cases have been studied and demonstrating the success of the inversion of submesoscale tracer information to correct a mesoscale altimetric velocity field.

A high resolution physico-biogeochemical coupled model of process and a high resolution realistic model of the Solomon sea have been used to assess the error associated with the inversion. The efficiency of the correction on the oceanic circulation has also been demonstrated using these models.

These results show the feasibility of assimilating tracer submesoscales into ocean models for the control of mesoscale dynamics and larger scales as deduced from altimetry and therefore the benefit of the joint use of tracer image and altimetric data for the control of ocean circulations.

Lagrangian connectivity of near-surface ocean studied with in situ and satellite observations

Nikolai Maximenko, IPRC/SOEST, University of Hawaii
Jan Hafner, IPRC/SOEST, University of Hawaii
Oleg Melnichenko, IPRC/SOEST, University of Hawaii

Session theme: Science Results from Satellite Altimetry
Poster

Presented are preliminary results of the study, in which feasibility for floating matter to travel between a pair of selected locations is characterized on a global scale, using trajectories of Lagrangian drifting buoys. Low-connectivity areas are identified and role of major fronts, strong currents, and the equator as barriers are discussed. Lagrangian time scales of the exchange are assessed and shown to be much larger than Lagrangian velocity time scales in the mesoscale eddy field. Empirical SCUD (Surface CUrrents from Diagnostic) model, forced by satellite altimetry and QuikSCAT and ASCAT winds, is used to study Lagrangian trajectories longer than the characteristic life time of a drifter. Applied to the problem of marine debris, generated by the 2011 tsunami in Japan, the study suggests that pathway, linking the source to a particular destination, may be narrower than one might expect from the advection-diffusion model. Knowing these pathways could help optimize the use of limited resources available to monitor safety of critical sites (such as Midway Islands or big harbors).

Mesoscale Eddy Impact on the Gulf Stream, Shelf Circulation and Marine Ecosystem

Ruoying He, North Carolina State University

Session theme: Science Results from Satellite Altimetry
Poster

The interaction of shelf circulation with an open-ocean boundary current and mesoscale eddies can be of tremendous importance as it often results in significant export of coastal water to the deep ocean. However, the dynamics of this interaction are not well understood, and may not be well represented in regional or larger scale numerical models of ocean circulation. We used long-term satellite altimeter data, coastal sea level and shelf hydrography observations, as well as numerical modeling experiments to examine the dynamics of shelf circulation and biomass variability and their responses to the Gulf Stream (GS) meanders and open-ocean eddies. Case study results of an extremely large offshore meander of the GS, its causes and impact on shelf waters off the Southeast U.S. will be discussed.

SeaGoLSWOT: an oceanographic campaign in support of the AirSWOT mission in the Northwestern Mediterranean

Francesco Nencioli, Aix-Marseille University, Mediterranean Institute of Oceanography (MIO)
Francesco d'Ovidio, Laboratoire d'Océanographie et du Climat: Experimentation et Approches Numeriques (LOCEAN), IPSL
Andrea Doglioli, Aix-Marseille University, Mediterranean Institute of Oceanography (MIO)
Anne Petrenko, Aix-Marseille University, Mediterranean Institute of Oceanography (MIO)
Jérôme Bouffard, Aix-Marseille University, Mediterranean Institute of Oceanography (MIO)

Session theme: Science Results from Satellite Altimetry
Poster

One of the main goals of the Surface Water and Ocean Topography (SWOT) mission is to provide measurements of sea surface height at a resolution of few km over a swath of 100 km.
Such observations will allow to reconstruct the dynamics associated with (sub)mesoscale structures, characterized by spatial scales on the order of tens of km.
The SWOT mission will be particularly important for coastal regions, where traditional altimetry observations are currently inaccurate.
SWOT observations will allow a more reliable analysis of coastal transport and dispersion, which will provide key information for the development of a sustainable management of those regions.

The launch of the SWOT satellite is currently scheduled for Fall 2020.
Before then, the performance of the SWOT altimeter will be tested within the AirSWOT program.
AirSWOT will be based on an airborne version of the SWOT sensor, and will consist in a series of flight missions over key coastal regions.
Each mission will be associated with an accompanying oceanographic campaign, which will allow to compare and calibrate/validate the high-resolution altimetry measurements with in-situ observations.

SeaGoLSWOT is the field campaign associated with the AirSWOT mission over the Gulf of Lion (Northwestern Mediterranean) currently scheduled for Fall 2014.
The main goal of the campaign is to collect a series of three-dimensional mappings of physical and biological variables across identified (sub)mesoscale features.
The campaign will be based on an adaptive sampling strategy which will allow to design/optimize the sampling pattern of each mapping according to the characteristics of the local dynamics retrieved from the near-real time analysis of satellite imagery and previous mappings.

The in-situ measurements will include Lagrangian drifter trajectories, which will provide information on the local and larger scale surface transport patterns;
vertical sections of physical and bio-optical variables from gliders and a ship-towed profiler, which will be used to reconstruct the quasi-synoptic three-dimensional structure of the observed (sub)mesoscale features;
and surface phytoplankton assemblages from a bench flow cytometer, which will allow to reconstruct the horizontal distribution of different phytoplankton groups.

Integrated together, the observations from the various platforms will allow to address three key objectives within the AirSWOT program:
(i) Provide AirSWOT measurements with a ground truth of the physics at ~1 km horizontal resolution in the upper 100 m of the water column;
(ii) Test and tune novel in-situ sampling strategies and instrument configurations to be used during future AirSWOT flights;
(iii) Investigate the link between the ~10 km horizontal surface structures to the dynamics and the biogeochemical processes within the upper layer of the water column by integrating in-situ and AirSWOT measurements.

Evaluating Wavenumber Spectra in Drake Passage with ADCP and Altimeter Measurements

Sarah Gille, Scripps Institution of Oceanography
Teresa Chereskin, Scripps Institution of Oceanography

Session theme: Science Results from Satellite Altimetry
Poster

The first baroclinic Rossby radius in the Southern Ocean is estimated to be as small as 10 to 20 km (implying eddies with a typical diameter as small as 60 km). Features on these lengthscales can be difficult to detect, either from traditional hydrographic sampling or from gridded altimetric products, which typically smooth over 100-200 km lengthscales. In Drake Passage, the US Antarctic supply vessel ARSV Laurence M. Gould traverses Drake Passage approximately 20 times per year, and since 1999 on each crossing the ship has collected acoustic Doppler current profiler (ADCP) with horizontal resolution of 5 km. These ADCP observations provide a valuable tool for assessing wavenumber spectra in the Southern Ocean and for evaluating the open ocean performance of high wavenumber altimeter products (such as those designed to capture small scale features in coastal regimes) and may eventually help evaluate newer altimeters designed to provide higher spatial resolution data (e.g. AltiKa or Cryosat). In Drake Passage, ADCP data consistently indicate velocity spectra with spectral slopes of -3, in agreement with ADCP-derived velocity spectra computed in other energetic regions. In the mixed layer, where wind and waves may influence velocities, spectral slopes are slightly flatter (-2.5), and in the thermocline spectral slopes are about -2.7. These spectra are somewhat steeper than analogous spectra computed from altimetric products.

Low-frequency intrinsic variability of Sea Surface Height in the global turbulent ocean: spatio-temporal scales.

Guillaume Serazin, LGGE/CNRS
Thierry Penduff, LGGE/CNRS
Laurent Terray, CERFACS/CNRS
Sandy Gregorio, LGGE/CNRS
Bernard Barnier, LGGE/CNRS
Jean-Marc Molines, LGGE/CNRS

Session theme: Science Results from Satellite Altimetry
Poster

Recent high-resolution (e.g. 1/4° and finer) Ocean General Circulation Models (OGCMs) simulate the observed low-frequency sea surface variability with appreciable skill. In addition, mesoscale eddies are resolved and no longer parametrized in such highly non-linear models: a substantial amount of the simulated low-frequency variability appears spontaneously (i.e. without direct forcing by atmospheric variability) and imprints several observed quantities (SSH, SST, QNET, MOC, etc). Penduff et al. (2011) showed that this intrinsic part may account for most of the low-frequency SSH variance in eddy-active regions. Several idealized studies have been conducted with academic process-oriented models (e.g. Berloff et al., 2007, Djikstra and Ghil, 2005, etc), but the structure, scales, and origin of low-frequency intrinsic variability remain poorly-known in the global eddying ocean.

A 327-year seasonally-forced global ocean simulation (no interannual forcing) is compared to its 50-year counterpart driven by the full range of atmospheric timescales (with interannual forcing). Outputs are band-passed filtered in time and space. Our results suggest that the low-frequency SSH variability at small scales (< 6°) is largely intrinsic and colocated with mesoscale (short time and space scales) activity. We are currently examining whether this may result from inverse energy cascades towards large spatial and temporal scales, as suggested in Arbic et al. (2012). Over most of the global ocean, large-scale (> 12°) low-frequency oceanic variability is mostly driven by atmospheric variability. However, this variance is largely intrinsic in three hotspots (Gulf Stream, Kuroshio, ACC) where it reaches 50 – 80% of the total SSH variance. We argue that such OGCM-based investigations may provide useful information on the intrinsic fraction of low-frequency variability in the real ocean, which is mostly interpreted as directly responding to the atmospheric forcing.

Coastal Altimetry with the Ka Band

Fernando Niño, IRD/Legos
Florence Birol, Legos
Denis Blumstein, CNES/Legos
Da Nguyen Dac

Session theme: Science Results from Satellite Altimetry
Poster

The Saral/AltiKa mission, launched in February 2013, is the first oceanographic altimeter using a Ka-band frequency. The use of the Ka-band is expected to supply more accurate measurements (better signal/noise ratio, improvement of the spatial and vertical resolution) enabling a better observation of ices, coastal areas, continental water bodies as well as the waves' height. We will revisit the problem of extending satellite altimetric products into the shelf and coastal seas with these new data, and consider three specific points:
- AltiKa/Saral SSH altimeter measurements, as compared with traditional Ku altimeter data;
- The characteristics of altimeter waveforms near the coast;
- Editing criteria for Ka-band altimetry.
- Spatial scales observed (through some examples of physical processes).

This study will present the results of two regional test cases with very different weather and ocean conditions: the northwestern Mediterranean Sea and along the coast of Vietnam. Both the conventional 1-Hz data (i.e a resolution of ~6-7 km along the track) and the original high-rate altimetry data (40 Hz i.e. ~150m for AltiKa, a lower 20 Hz frequency i.e. ~300m in the case of Jason missions) will be analysed.

A Probabilistic Description of the Mesoscale Eddy Field of the Ocean

Martin Scharffenberg, Centrum für Erdsystemforschung und Nachhaltigkeit (CEN), Universität Hamburg, Germany
Stavroula Biri, Centrum für Erdsystemforschung und Nachhaltigkeit (CEN), Universität Hamburg, Germany
Detlef Stammer, Centrum für Erdsystemforschung und Nachhaltigkeit (CEN), Universität Hamburg, Germany

Session theme: Science Results from Satellite Altimetry
Poster

Probability Density Functions (PDF) for both (zonal and meridional) velocity components are presented which were inferred from the 3-year long Jason-1 - TOPEX/POSEIDON Tandem Mission (JTP). Results are compared with those obtained form longer time series of geostrophic velocities and SSH inferred form the 19-year 1/3° weekly AVISO SSH anomaly fields from the TOPEX/POSEIDON, Jason-1 and Jason-2 (TPJJ) missions. The differences in the zonal and meridional components are found to be evident, with a slightly wider shape for the zonal velocity component due to the larger variability in zonal direction.
Our results confirm that the exponential shape of the global velocity PDF is a consequence of the spatially inhomogeneous EKE distribution over the global ocean. Hence, the exponential shape is the result of averaging Gaussian PDF with differing PDF-width. As a result, regions that only have a small variance in EKE, have a Gaussian shaped PDF, whereas regions that have a large variance in EKE, show a rather exponential shaped PDF. Accordingly, normalizing any regional velocity PDF with their standard deviation also results in a gaussian PDF independent from the regional extend.
To further describe the behavior of the PDF, skewness and kurtosis is calculated for the first time for both velocity components individually as well as for the underlying SSH. The skewness and kurtosis of the velocity and SSH fields appear to identify the mean path of unstable ocean jets as well as regions dominated by eddies and they complement each other in the description of the actual structure of the eddy field. Using the longer 19-year time series of SSH and velocity results in clearer structures of skewness and kurtosis.

Multi-sensor observations towards coastal and mesoscale characterization: SARAL/AltiKa, HF radar, glider and drifters

Ananda Pascual, IMEDEA(CSIC-UIB)
Marc Torner, SOCIB
Charles Troupin, IMEDEA(CSIC-UIB)
Arancha Lana, IMEDEA(CSIC-UIB)
Simó Cusí, SOCIB
Carlos Castilla, SOCIB
Emma Heslop, IMEDEA(CSIC-UIB)
Joan Pau Beltrán, SOCIB
Kristián Sebastián, Sebastián Lora, SOCIB
Irene Lizarán, SOCIB
Simón Ruiz, IMEDEA(CSIC-UIB)
Joaquín Tintoré, IMEDEA(CSIC-UIB) and SOCIB

Session theme: Science Results from Satellite Altimetry
Poster

We present preliminary results of a recent multi-sensor experiment (G-ALTIKA, hereinafter) performed in August 2013 in the Western Mediterranean Sea. The two main objectives of G-ALTIKA are: (1) to process, validate and intercalibrate multi-platform datasets dedicated to coastal ocean and (2) to use an integrated approach to improve the monitoring and understanding of dynamical processes in the Western Mediterranean Sea.

During G-ALTIKA, a deep glider followed almost simultaneously a SARAL-AltiKa satellite track (no. 16) located close to Ibiza Island. This track benefits from the SOCIB HF Radar facility, which provides hourly surface currents in the Ibiza Channel, with a 3 km spatial resolution and a range up to 60 km. A Lanczos filter with a 36-h cutoff frequency removed inertial oscillations from radar data. The trajectories of surface drifters deployed in the area of interest were interpolated, low-pass filtered with a 36-h cutoff, and subsampled every 6 h to remove high-frequency components, especially tidal and inertial currents not resolved by altimetry data.

Initial comparisons reveal a relative good agreement between all platforms (drifter, along-track SARAL/AltiKa and HF radar). Dynamic height (DH) was estimated from the glider CTD. Test with different reference levels (ranging from 300 to 900 m) evidences a weak sensitivity of DH to this parameter. After the filtering of scales smaller than 10-15 km, not well resolved by altimetry, the gradient of dynamic height is only of the order of 2-3 cm, but indicates the presence of a coherent cyclonic meander with a diameter of around 25 km, located southwest of Ibiza.

Absolute Dynamic Topography (ADT) is obtained by combining 1 Hz, along-track near real-time SLA from SARAL/AltiKa with the new SOCIB-CLS Mean Dynamic Topography. Surprisingly, SARAL/AltiKa records also capture the weak cyclonic meander, with consistent size, amplitude and position compared to glider observations. Furthermore, SARAL/AltiKa is able to capture the northward edge of the meander, a northwestward current that lies on a shallow bathymetry (less than 100 m) and flows very close to the coast (distance to Ibiza < 10 km). However, 1 Hz along track data fail to depict the fine-scale signals sampled by the glider, which are typical in the Mediterranean Sea (Rossby radius around 10km).

As expected, the resolution of standard gridded altimetric maps is not sufficient for the detection of small mesoscale and submesoscale features present in the glider data, the drifter and the HF radar. High-resolution gridded maps have been generated using the Data-Interpolating Variational Analysis (DIVA), a gridding method based on the minimization of a cost function using a finite-element technique (see poster by Troupin et al.). The application of this method combining SARAL/AltiKa, Jason-2 and Cryosat -2 data allows us to well resolve this meander.

In summary, this study highlights that: (1) SARAL/AltiKa is providing reliable data very close to the coast with weak associated gradients, representing a challenge for the new era of satellite altimetry observations and (2) there is a clear need of high resolution ocean surface topography measurements, by the development of synergic approaches through the combined use of observing systems and model simulations and by the launch of the Surface Water and Ocean Topography (SWOT) mission.

G-ALTIKA was carried out in the frame of MyOcean2 EU FP7 funded project and is a contribution to the SARAL/AltiKa science team under the proposal: 'On the use of SARAL/Altika products for coastal and MEsoscale studies in the BAlearic Sea: synergy with other sensors (SAMEBA)'.

Wind-driven coastal sea level variability in the Northeast Pacific

Philip Thompson, Department of Oceanography, University of Hawaii
Mark Merrifield, Department of Oceanography, University of Hawaii

Session theme: Science Results from Satellite Altimetry
Poster

The rate of coastal sea level change in the Northeast Pacific (NEP) has decreased in recent decades. The relative contributions to the decreased rate from remote equatorial wind-stress, local longshore wind-stress, local wind-stress-curl are examined. Regressions of sea level onto wind-stress time series and comparisons between NEP and Fremantle sea levels suggest the decreased rate in the NEP is primarily due to oceanic adjustment to strengthened trade winds along the equatorial and coastal waveguides. The roles of longshore wind-stress and local wind-stress-curl are found to be of minor importance in comparison to equatorial forcing. The predictability of decadal sea level change rates along the NEP coastline is therefore largely determined by tropical variability. In addition, we demonstrate the importance of accounting for regional, wind-driven sea level variations when attempting to calculate accelerations in the long-term rate of sea level rise.

Mesoscale eddies in the South Atlantic Bight

Renato Castelao, University of Georgia, Department of Marine Sciences
Ruoying He, North Carolina State University

Session theme: Science Results from Satellite Altimetry
Poster

Satellite-derived sea level anomaly fields constructed by combining measurements from simultaneously operating altimeters are used to quantify properties and propagation characteristics of eddies in the South Atlantic Bight (SAB). Eddy detection and eddy tracking algorithms are applied to 19 years of high-resolution observations available at weekly intervals. Inshore of the 800 m isobath, eddies are most frequently observed at and downstream of the Charleston Bump (a major topographic feature located at 31°-32°N), a region where the amplitude of most eddies is increased. The bump is also a preferred region for eddy generation. The amplitude of eddies is found to increase with water depth. Eddies generated in the SAB tend to propagate westward toward the coast and to the northeast, presumably due to the influence of the strong mean northeastward flow of the Gulf Stream. Those eddies are highly nonlinear, with potential to trap water in their interior as they propagate. Since a large fraction of the eddies that at some point in their histories are found inshore of the 800 m isobath experience large bathymetric changes along their trajectories, they can potentially serve as efficient mechanisms for cross-isobath transport in the SAB. Analysis of temporal variability in eddy activity suggests that cross-isobath transport due to nonlinear eddies may be significant during all seasons, but will likely be characterized by large interannual variability.

Sea Surface Height Frequency and Wavenumber Spectra in the Atlantic Ocean, estimated from satellite altimetry and a hierarchy of numerical simulations

Stavroula Biri, CEN, Universität Hamburg
Nuno Serrra, Martin Scharffenberg, Detlef Stammer

Session theme: Science Results from Satellite Altimetry
Poster

Frequency and wavenumber spectra computed from altimetric sea surface height (SSH) anomalies are being compared with a hierarchy of MIT OGCM regional simulations performed for the Atlantic Ocean with spatial resolutions varying from 32 km (1/3 degree) to 4 km (1/24 degree). Also included in the comparison are results from the STORM-NCEP simulation, which is based on the MPI/OM model configured globally with close to 1/10 degree spatial resolution. All model runs are driven by fluxes computed with 6-hourly NCEP forcing fields and bulk formula. Results of the frequency spectra reveal that in some regions of the Atlantic the highest-resolution model simulation is capable of simulating observed SSH variability. However, there are many other regions where this does not hold, especially on periods smaller than 100 days. Discrepancies remain larger for wavenumber spectra, especially on scales smaller than the mesoscale eddy scales, over which model wavenumber spectra tend to fall off steeper than observed; nevertheless, showing a similar "noise tail" as observed by altimetry. A comparison is performed with respect to geostrophic zonal and meridional model velocity spectra, revealing a continuous increase in variability level with spatial resolution, especially on short time scales.

Signature of the seasonality of submesoscales on the SSH in the Kuroshio region between 25N and 45N

Patrice Klein, LPO/IFREMER
Hideharu Sasaki, ESC/JAMSTEC
Patrice Klein, LPO/IFREMER
Bo Qiu, Departement of Oceanography/UH
Yoshikazu Sasai, RICG/JAMSTEC

Session theme: Science Results from Satellite Altimetry
Poster

We use a high-resolution realistic simulation of the North Pacific to characterize the evolution of both the mesoscales (200 km – 300 km) and submesoscales (10 km – 100 km) in a large box region around the Kuroshio Extension (150–160°E and 25–45°N). Results reveal that the rms values of the relative vorticity (mostly captured by submesoscales) exhibits a conspicuous seasonal evolution with large values observed in winter (principally explained by mixed-layer instabilities). In contrast, the rms SSH (mostly captured by mesoscales) exhibits a very different time evolution with maxima occuring during the summer or later. Since the relative vorticity can be well estimated from SSH using a Laplacian operator, this means that these conspicuous differences between mesoscale and submesoscale activities can be captured by the spectral characteristics of the SSH (including the spectral slope).
As such, these results highlight the strong potential of the future satellite altimeter missions (such as SWOT and COMPIRA) -whose resolution should be ten times higher than that of conventional altimeters - to capture the submesoscales and their impact on the large-scale ocean dynamics.

Ageostrophic components in the coastal sea surface height obtained from the GPS on a ferryboat

Kaoru Ichikawa, Res Inst for Appl Mech, Kyushu University, Japan
Yutaka Yoshikawa, Kyoto University, Japan
Ken ichi Fukudome, Japan Sea Nat Fish Res Inst, Fish Res Agency, Japan
Akihiko Morimoto, HyARC, Nagoya University, Japan
Jong Hwan Yoon, RIAM, Kyushu University, Japan

Session theme: Science Results from Satellite Altimetry
Poster

As recent progresses in high-resolution altimeters such as SIRAAL-2 and AltiKa and promising plans of NASA/CNES SWOT and JAXA COMPIRA missions, coastal altimetry is one of the major targets in the altimetry community. However, we do not have sufficient knowledge about high-resolution sea surface height (SSH) in coastal areas where significant ageostrophic phenomena are present. In this study, the GPS system mounted on a ferryboat is used to obtain coastal SSH in the Tsushima/Korea Strait between Japan and Korea.
After removing the remained error in a local tide model by the harmonic analysis, the daily SSH along the ship track is obtained with sufficient spatial resolutions since September 2011.
By further removing the temporal mean SSH, temporal sea surface dynamic height anomaly (SSDHA) are further determined.
For variations longer than about 30 km, the GPS-obtained SSHA agrees very well with the SSDHA that is estimated from the 18-m depth velocity observed by the ADCP mounted on the same ferryboat, assuming the geostrophic balance.
Meanwhile, smaller-scale SSDHA variations with approximately 20-km wavelength are found sometimes present with amplitudes of the order of 0.1m, which are not present in the ADCP-obtained SSHA.
Time series of the surface currents observed by the ocean radar system in the southern part of the Tsushima/Korea Strait indicates that surface currents are highly temporally variable at the locations of such smaller-scale SSDHA, suggesting their ageostrophic nature.

Multiple, Migrating Quasi-zonal Jets in the Eastern North Pacific

Oleg Melnichenko, International Pacific Research Center, University of Hawaii, Honolulu, Hawaii
Nikolai Maximenko, International Pacific Research Center, University of Hawaii, Honolulu, Hawaii
Hideharu Sasaki, The Earth Simulator Center, Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan

Session theme: Science Results from Satellite Altimetry
Poster

Low-frequency motions in the eastern part of the subtropical North Pacific are dominated by multiple, alternating quasi-zonal jet-like features (striations), which slowly, at a speed of about 0.3 km/day, propagate toward the equator. Their structure and energetics are studied using three data sets: satellite sea level anomaly observations, historical hydrographic data, and output of the Ocean general circulation model For the Earth Simulator (OFES). We find that the striations' energy cycle is dominated by two dynamically distinct components. The first one is attributable to baroclinic instability of the large-scale, weekly-sheared meridional flow in the eastern limb of the subtropical gyre. Potential energy stored in the large-scale flow is accessible for conversion directly to the zonal striations. The latter, therefore, may have a profound effect on the thermohaline structure of the subtropical gyre and the mean circulation. The second component arises from the nonlinear interactions between the zonal striations and eddies and can be put into the context of the geostrophic turbulence theory. While the baroclinic conversion from the mean state to the zonal striations occurs throughout the layer between 200 and 600 m depth, the eddy effects are primarily confined to the upper 200 m.

Has the eddy kinetic energy of the Southern Ocean increased over the last twenty years?

Don Chambers, University of South Florida, College of Marine Science

Session theme: Science Results from Satellite Altimetry
Poster

A previous study by Meredith and Hogg (2006) found no evidence of an increase in eddy kinetic energy (EKE) in the Southern Ocean between 1992 and 2002. Here, we return to this issue using twenty years of observations and eddy kinetic energy calculated from both crossovers and from AVISO gridded data. We find that the EKE computed from crossovers is substantially larger than that computed from the gridded data, by approximately 40%. Both calculations do indicate a positive trend in the Indian and Pacific Oceans. When converted to relative change from the 1993 to 2000 mean, the change is 6% per decade. Sampling the gridded data to crossover locations does not change the result, suggesting the reduced sampling of crossovers are not to blame for the difference in magnitude. The more likely explanation is attenuation of signal due to the gridding process.

Use of a Lagrangian advection technique with altimetric velocities to reconstruct fine scales in large scale surface tracer fields in the Pacific Ocean

Marine Rogé, CTOH/LEGOS/OMP
Guillaume Dencausse, LPO/Ifremer
Rosemary Morrow, CTOH/LEGOS/OMP

Session theme: Science Results from Satellite Altimetry
Poster

Lagrangian lateral advection with altimetric geostrophic velocities can be used to stir large scale tracer fields at the ocean surface, and reconstruct mesoscale fronts and eddies. Dencausse et al, (2013) have tested this technique in the energetic Southern Ocean region south of Tasmania. Here we apply and evaluate the technique's performance in three different regions of the tropical and subtropical Pacific Ocean.
The technique is based on the passive horizontal stirring of a tracer field with altimetric velocities. The tracer field we use is based on large scale gridded Coriolis SST and SSS fields, produced from an objective analysis of in-situ data. Independent high resolution satellite SST and underway in-situ thermosalinograph data are used to evaluate our advected fields. One parameter that must be set is the advection time. While the study south of Tasmania concluded on an optimal advection time of ~2 weeks to best represent the finer scales, different values seem to apply in these new regions. These differences are mainly explained by the specific dynamics of each region. Also, physical processes other than geostrophic stirring that can affect the tracer evolution are neglected with this technique. These biases introduced in the advected fields can vary depending on the region and time of year. This is particularly true in areas experiencing heavy rainfall or warming/cooling periods. To limit the biases owing to the physics neglected by the method, it is possible to introduce corrections (Ekman, diffusion, air-sea flux…). But another approach is to exclude the contribution of physics other than geostrophic stirring using a “backward and forward” advection technique. We find a significant bias reduction when using this latter technique.

Black holes and eddies: How on Earth are them related?

Francisco Beron-Vera, RSMAS, University of Miami
George Haller, ETH Zurich, Zurich, Switzerland

Session theme: Science Results from Satellite Altimetry
Poster

Eddies are often envisaged as rotating bodies of water, traveling as coherent islands in an otherwise incoherent ocean flow. This Lagrangian view is appealingly simple, yet challenging to apply in actual eddy detection. The main difficulty is to classify fluid particle paths systematically as coherent or incoherent. Here we show that coherent eddies can be uncovered from altimetric sea surface height data based on a mathematical analogy linking them to black holes. Specifically, coherent belts of water around eddies are found to be analogous to photon spheres surrounding black holes in cosmology. The oceanic photon spheres are obtained around black-hole-type singularities of water deformation by solving differential equations for relativistic light propagation. This new approach reveals previously unknown eddies, such as super-coherent Agulhas rings in the South Atlantic, with unprecedented accuracy. These massive black-hole eddies transport material over large distances, thereby influencing marine life and global ocean circulation. Knowing their exact number and shape should help in assessing the recently proposed mitigating impact of long-range temperature and salinity transport on climate change.

What causes the model-data differences in seasonal variations of the South Atlantic Meridional Overturning Circulation?

Shenfu Dong, CIMAS/Univ. of Miami and NOAA/AOML
Molly Baringer, NOAA/AOML
Gustavo Goni, NOAA/AOML
Silvia Garzoli, CIMAS/Univ. of Miami and NOAA/AOML

Session theme: Science Results from Satellite Altimetry
Poster

The meridional overturning circulation (MOC) and meridional heat transport (MHT) in the South Atlantic from numerical models have shown differences from observational based estimates. Both the geostrophic and Ekman contributions to MOC/MHT estimated from XBTs, Argo floats, and satellite altimetry show significant seasonal variations, but the two components are out of phase. However, the seasonal variations of geostrophic component from models are minimal, and the seasonal cycle in modeled MOC/MHT is dominated by Ekman component. To better understand and to investigate the causes for those differences, same methodology is applied to temperature and salinity monthly climatology from observations and from models to estimate the MOC/MHT at 34°S. The MOC from model T/S fields show strong transport in the ocean interior region compared to the MOC estimated from Argo T/S fields. The geostrophic component of the MOC estimated from Argo data shows a seasonal variation with the maximum value in January and minimum value in August. However, the seasonal variations of the geostrophic contributions to the MOC from model T/S fields is very weak. Differences are seen in all three regions: western boundary, interior region, and eastern boundary, with the largest difference in the eastern boundary. Examination of the density field suggests that the difference in the eastern boundary is related to the vertical coherent density variations in the Argo measurements, which is not shown in the model field. Possible causes for those differences are discussed. Wind stress curl from models and observations show strong differences in the eastern boundary, which could explain why the models are unable to reproduce the seasonal variations in geostrophic component of the MOC. Another contributor for the Ekman-dominated seasonal variations in the models is that the seasonal variations in zonal winds is stronger than those from remote sensed ocean surface winds, which resulting in a stronger seasonal cycle in Ekman transport.

Vertical thermohaline structure of mesoscale eddies in the four major Eastern Upwelling Boundary Systems

Cori Pegliasco, LEGOS
Alexis Chaigneau, LEGOS
Rosemary Morrow, LEGOS
Yves Morel, LEGOS

Session theme: Science Results from Satellite Altimetry
Poster

The four major Eastern Boundary Upwelling Systems (EBUS) are characterized by the presence of numerous mesoscale eddies. They are preferentially formed along the continental coasts and then propagate westward to the open ocean where they progressivly dissipate. Thus, mesoscale eddies actively participate to the zonal redistribution of physical and biogeochemical properties from near-coastal upwelling regions to the open ocean. Although the main eddy caracteristics (size, duration, formation areas, propagation, etc) have been largely studied in the four EBUS, little is known about their physical vertical structure and the associated heat and salt contents. The main goal of this study is to merge 12 years (2000-2012) of satellite altimetry data with temperature and salinity profiles acquired by Argo floats in order to describe the vertical thermohaline structure of mesoscale eddies in the four EBUS.
In each EBUS, eddies are detected on sea-level altimetry maps and all available Argo profiles are classified into 3 categories depending whether they surface in anticyclonic eddies, cyclonic eddies or outside eddies. The vertical temperature and salinity anomalies associated with both anticyclonic and cyclonic eddies are depicted for each EBUS, showing clear differences in terms of eddy-core position and intensity. For instance, eddy vertical temperature anomalies in the Peru-Chile Upwelling System presents an anticyclonic eddy-core in subsurface (~300m) and a cyclonic eddy-core centered in the thermocline (~100m depth) ; in the California Upwelling System, both types of eddies are centered in the thermocline ; in the Canary Upwelling System, eddy-cores exhibit on average a deeper vertical extent and the signature of Meddies can sometimes be observed between 1100 m and 1600 m ; in the Benguela Upwelling Sytem, the maximum anomalies are found between 100 and 600 m, influenced by the passage of Agulhas Rings carrying Indian Ocean water in relatively deep layers. Furthermore, each EBUS is divided in subregions, where vertical temperature and salinity anomalies can be related to several processes and mecanisms such as large-scale water-mass distribution, front locations, wind-induced vorticity or near-coastal dynamics.

Evaluation of CMIP5 dynamic sea surface height multi-model simulations against satellite observations

Felix Landerer, NASA Jet Propulsion Laboratory

Session theme: Science Results from Satellite Altimetry
Poster

We evaluate the representation of dynamic sea surface height (SSH) fields of 33 global coupled models (GCMs) contributed to the fifth phase of the Coupled Model Intercomparison Project (CMIP5). We use observations from satellite altimetry and basic performance metrics to quantify the ability of the GCMs to replicate observed SSH of the time-mean, seasonal cycle, and inter-annual variability patterns. The time-mean SSH representation has markedly improved from CMIP3 to CMIP5, both in terms of overall reduction in RMS differences, and in terms of reduced GCM ensemble spread. Biases of the time-mean SSH field in the Indian and Pacific Ocean equatorial regions are consistent with biases in the zonal surface wind stress fields identified with independent measurements. In the Southern Ocean, the latitude of the maximum meridional gradient of the zonal mean SSH CMIP5 models is shifted equatorward, consistent with the GCMs' spatial biases in the maximum of the zonal mean westerly surface wind stress fields. However, while the Southern Ocean SSH gradients correlate well with the maximum Antarctic Circumpolar Current transports, there is no significant correlation with the maximum zonal mean wind stress amplitudes, consistent with recent findings that the eddy parameterisations in GCMs dominate over wind stress amplitudes in this region. There is considerable spread across the CMIP5 ensemble for the seasonal and interannual SSH variability patterns. Because of the short observational period, the interannual variability patterns depend on the time-period over which they are derived, while no such dependency is found for the time-mean patterns. The model performance metrics for SSH presented here provide insight into GCM shortcoming due to inadequate model physics or processes. While the diagnostics of CMIP5 GCM performance relative to observations reveal that some models are clearly better than others, model performance is sensitive to the spatio-temporal scales chosen.

Internal Tide Refraction and Attenuation in the North Pacific

Matthew Alford, Applied Physics Laboratory and School of Oceanography / University of Washington
Zhongxiang Zhao, Applied Physics Laboratory/University of Washington
Luc Rainville, Applied Physics Laboratory and School of Oceanography / University of Washington
Harper Simmons, University of Alaska
James Girton, Applied Physics Laboratory and School of Oceanography / University of Washington

Session theme: Science Results from Satellite Altimetry
Poster

Internal tides are thought to supply a large fraction of the power needed to keep the abyssal oceans stratified. However, because they often propagate 1000's of kilometers from their sources, determining the spatial distribution of their dissipation is a challenge. Toward this goal, we use multiple altimetric satellites and a global eddy-resolving model with tides to examine the attenuation of the mode-1 M2 internal tide from three major sources in the North Pacific: the Aleutians, the Hawaiian Ridge and the Mendocino Escarpment. The model is first used to compute the coherent fraction of the signals, which decreases with range owing to refraction by time-varying mesoscale eddies. The observed altimetric fluxes are then corrected for this coherent loss, since altimeters can only detect the coherent portion and therefore cannot distinguish reduction due to loss of coherence from true dissipation and scattering to higher modes. Signals remain 85\% coherent at 2500 km range north of Hawaii, where eddies are weak, compared to only 50\% coherent where eddies significantly refract the internal tide. The corrected fluxes are then integrated in wedges extending outward from the sources to account for radial spreading. No reduction in flux is detected over 2000 km for sources north of the critical latitude for parametric subharmonic instability (PSI), and over smooth bathymetry. Those south of the critical latitude and/or over rough bottoms experience much stronger attenuation, with reductions of about a factor of two over 2000 km. computed in this manner decays appears strongly dependent on rough bathymetry and parametric subharmonic instability. The results suggest that both PSI and rough topography can remove energy from the internal tide, but in their absence the internal tide can propagate nearly loss-free across entire basins.

Tidal currents of global tidal models tested using estimates from ocean acoustic tomography

Brian Dushaw, Applied Physics Laboratory, University of Washington

Session theme: Science Results from Satellite Altimetry
Poster

As part of a project led by D. Stammer for assessing the qualities, relative merits, etc. of a dozen or more global tidal models (Stammer et al., Richman et al., this conference), harmonic constants of tidal currents derived from recent tidal models are compared to harmonic constants estimated from acoustic tomography. Data from four acoustic tomography arrays deployed for various experiments over the past 30 years in the North Pacific and North Atlantic are used. As a measurement technique employing reciprocal acoustic signals that cycle throughout the water column and traverse O(500-km) distances, acoustic tomography offers a high-precision measurement of barotropic currents, tidal currents in particular. Baroclinic tidal currents negligibly influence these measurements. Previous comparisons of tidal current harmonic constants to tidal models have shown that tomography can accurately measure the harmonic constants of at least the eight largest tidal constituents. While some of the tidal models are constrained by observations, and some are hydrodynamic, so that tidal currents are inherently a part of the tidal solution, none of the tidal models are constrained by measurements of tidal currents. The new comparisons between measured and model tidal harmonic constants are generally favorable, with most models being "about" right. In some regions, small systematic differences between measured and modeled harmonic constants (amplitude and phase) suggest some aspect of the tidal models may be improved (missing or deficient physics), but the reasons for those differences are unknown at this time. In any case, insofar as these "spot" comparisons can determine, predictions of tidal currents derived from many of the modern global tidal models appear to be reasonably accurate, in the open ocean at least.

Can Geodetic-Mission Altimetry be used for High-Resolution Mapping of the Internal Tides?

Edward Zaron, Portland State University

Session theme: Science Results from Satellite Altimetry
Poster

The sea-surface expression of internal tides is spatially-variable, reaching a maximum of about 10cm near generation sites associated with submarine topography. Model results indicate that the internal tide wave field in the open ocean is a complex superposition of waves generated at multiple sites. Long time series obtained from exact-repeat missions (Topex, Jason-1, Jason-2, GFO, ERS) resolve the low-mode internal tide field at the scale of the inter-track separation. Here we attempt to make improved, higher-resolution, maps by combining exact-repeat and non-repeat altimetry. The approach involves combining sea-surface height from exact-repeat missions and sea-surface slope from non-repeat missions (geodetic missions and long-repeat orbit missions) in order to reduce the impact of different error characteristcs in the two data sources. The tides are modeled as a tensor product of spatial thin-plate splines and harmonic time dependence. Current results utilize exact-repeat data from the Topex/Poseidon and Jason-1 missions, and non-repeat data from the Geosat geodetic mission, the Jason-1 geodetic mission, and Cryosat. The answer to the question, "Can Geodetic-Mission Altimetry be used for High-Resolution Mapping of the Internal Tides?", is shown to depend on which and how much geodetic mission data is used, and the properties of the tidal fields to be estimated.

FES 2012, a new tidal model – validation results and perspectives of improvements

Loren Carrere, CLS
Florent Lyard, LEGOS
Mathilde Cancet, NOVELTIS
Amandine Guillot, CNES

Session theme: Science Results from Satellite Altimetry
Poster

Thanks to its current accuracy and maturity, altimetry is considered as a fully operational observing system dedicated to scientific and operational applications. In order to access the targeted ocean signal, altimeter measurements are corrected for several geophysical parameters among which the ocean tide correction is one of the most critical. Global ocean and loading tide models GOT and FES are operationally used in present altimeter GDRs. FES is a finite elements hydrodynamic model which assimilates altimeter and in situ data, while GOT model is build as an empirical adjustement based on altimeter data of a prior atlas (such as FES).
The accuracy of tidal models has been much improved during the last 20 years. Still, significant errors remain mainly in shelf seas and in polar regions. A new global tidal model FES 2012 has developed taking advantage of longer altimeter time series, improved modelling and data assimilation techniques, and more accurate ocean bathymetry. Special efforts have been dedicated to address the major non-linear tides issue and to the determination of accurate tidal currents.
Several validation diagnostics have been performed, versus in situ data and altimetry (Jason missions, ENVISAT), and will be presented in detail. Global spectral validation versus tidal gauges and along-track analyses, shows a clear improvement on M2 compared to DTU10 and GOT4V8 models, particularly on shelves regions, although FES2012 does not assimilate tidal gauges yet. Temporal validation versus tidal gauges and altimetry (crossovers and along-track residuals) also shows a clear improvement compared to FES2004, and a weaker improvement compared to GOT4V8 model, still with a stronger variance reduction in some continental shelves regions. We have identified a few regions were the new model tends to raise the residual variance; some of these problems can be explained by some local bathymetric issues (such as the Hudson bay). Concerning climatic purposes, FES 2012 allows reducing the residual signal at the 58.74 days period if compared to both FES2004 and GOT4V8.
We also present the future improvements envisioned in a forthcoming FES 2014 version. First, FES 2014 will benefit from recents developments in the physical and numerical modelling (T-UGOm) and that already allow for dividing the error of the pure hydrodynamic model by a factor 2. Additional upgrades will be carried out, such as a larger assimilation dataset (including tidal gauges), and local increases of the resolution, which would be of great interest for coming SWOT mission.
Note that FES2012 tidal atlas (elevations and currents) is available on a regular grid of 1/16° and can be downloaded on the AVISO website.

Improving storm Surge Hindcast: assimilation of satellite altimetry and tide guage data in the Baltic Sea

Høyer Jacob, Danish Meteorological Institute
Weiwei Fu, Danish Meteorological Institute
Kristine Madsen, Danish Meteorological Institute

Session theme: Science Results from Satellite Altimetry
Poster

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. It is sensitive to the changes in storm intensity, forward speed, size, angle of approach to the coast and the shape and characteristics of coastal features such as bays and estuaries. Along the coast, storm surge is often the greatest threat to life and property. In this study, the three-dimensional HBM model of DMI is used to conduct hindcast experiments in the Baltic Sea. Wind forcings from operational HIRLAM and its climatology version HIRHAM are used to examine their effects on surge predictions for several storm surge cases during 2002 and 2005. Moreover, the satellite altimetry and tide gauge sea level data are assimilated into the HBM model with Ensemble Optimal Interpolation (EnOI). The ensemble-based background error covariances are multivariate and inhomogeneous and can reflect the length-scales, the anisotropy and the covariability of mesoscale oceanic processes. The altimetry and tide gauge data are blended to account for both spatial
and temporal coverage. It is found that the assimilation is caple of statistically reducing the bias and root-mean-square error of sea level by 2-4 cm in the Baltic Sea. Comparisons with ICES temperature and salinity profiles show that the assimilation can decrease the RMSE of temperature and salinity by 0.3°C and 0.18 psu, respectively. In addition, the
assimilation run could outperform the free run for the next 24 hours forcasting.

Global Internal Tides from Multi-Satellite Altimetry

Zhongxiang Zhao, Applied Physics Laboratory, University of Washington
James Girton, Applied Physics Laboratory, University of Washington
Matthew Alford, Applied Physics Laboratory, University of Washington

Session theme: Science Results from Satellite Altimetry
Poster

Internal tides are internal gravity waves of tidal frequency originating from barotropic tidal flow over rough seafloor bathymetry. Globally, about 1 TW of power is input into internal tides, most of which is transported far away from generation sites as low-mode internal tides (with 50–200 km wavelength). Their ultimate breaking provides about half of the mechanical energy required for deep ocean mixing, with important implications for large-scale ocean circulation and heat transport.

Satellite altimetry offers a revolutionary observational tool for internal tides by detecting their centimeter-scale displacements in sea-surface height (SSH). However, the task is challenging because: (1) In general, any given location can contain multiple internal tides propagating in different directions (forming a complex interference pattern). (2) Internal tides have multiple baroclinic modes (with different wavelengths and vertical structures) in the continuously stratified oceans. (3) Broad-band mesoscale motions contain significant energy at the tidal aliasing frequencies, adding uncertainties to internal tide estimates. (4) Internal tides lose coherence as they propagate through the time-varying mesoscale fields, whereas satellite altimeters can only observe the coherent (tidally phase-locked) components. (5) Internal tides and their interference patterns have short wavelengths compared to the wide inter-track spacing of satellite altimeters.

Some of these issues have been addressed in our recent work: (1) We have evolved a plane-wave fit technique to separately resolve internal tides traveling in multiple directions. (2) We have separated mode-1 and -2 internal tides using different band-pass filters. (3) We have improved spatial resolution by using the merged SSH data from multi-satellite altimetry (TOPEX/Poseidon, Jason-1/2, Geosat Follow-On, ERS-1/2, and Envisat). Here we present our latest global maps of mode-1 M2 internal tides, which reveal a number of strong generation sites and well-defined internal tidal beams traveling over 3000 km. We also discuss planned future improvements. Our results may provide constraints and guidance to numerical model simulations. In particular, the removal of internal tide signals from altimetric SSH estimates has the potential to benefit the study of other mesoscale and submesoscale processes.

Towards Global Predictions of the Mode-1 Internal Tide

Brian Dushaw, Applied Physics Laboratory, Seattle

Session theme: Science Results from Satellite Altimetry
Poster

A frequency–wavenumber tidal analysis for deriving internal-tide harmonic constants from TOPEX/Poseidon (T/P) measurements of sea-surface height (SSH) has been developed, taking advantage of the evident temporal and spatial coherence and the weak dissipation of internal tides. The approach is a close cousin to Fourier series or objective mapping methods for fitting and interpolating data, but employing basis functions of traveling waves. Previous analyses consisted of simple tidal analysis at individual points, with resulting harmonic constants that were inconsistent with the dispersion relation and not self-consistent at altimeter track crossover points. Such analyses have difficulty in distinguishing between the effects of interference, incoherence, and dissipation. The frequency–wavenumber analysis provides an objective way to interpolate the internal tides measured along altimetry tracks to arbitrary points, while leveraging all available data for optimal tidal estimates. Tidal analysis of T/P data from 2000 to 2007 is used to predict in situ time series measured by tomography during the 2001–2002 Hawaiian Ocean mixing experiment (HOME), the 1987 Reciprocal Tomography Experiment (RTE87), and the 1991 Acoustic Mid-Ocean Dynamics Experiment (AMODE), demonstrating both the temporal coherence and the lack of incoherent elements to this wave propagation. The temporal coherence is directly evident in time series measured by acoustic tomography. Further, after correcting for changes in background stratification, it is evident that the internal-tide waves experience little attenuation as they cross the Northe Pacific basin. A significant fraction of the variability of internal waves, that component associated with mode-1 internal tides, appears to be predictable over most of the world's oceans, using harmonic constants derived from satellite altimetry.