→ CRYOSAT THIRD USER WORKSHOP

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ABSTRACT BOOK

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Opening Session

CryoSat : ESA's Ice Explorer Mission: Two Years in Operations: Status and Achievements

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CryoSat-2 was launched on the 8th April 2010 and it is the first European ice mission dedicated to monitoring precise changes in the thickness of polar ice sheets and floating sea ice over a 3-year period. CryoSat-2 carries an innovative radar altimeter called the Synthetic Aperture Interferometric Altimeter (SIRAL) with two antennas and with extended capabilities to meet the measurement requirements for ice-sheets elevation and sea-ice freeboard. Initial results have shown that data is of high quality thanks to an altimeter that is behaving exceptional well within its design specifications.
The first data was released to the scientific community in February 2011 and since then, products have been systematically distributed to more than 200 Principal Investigators and used by more than 500 scientists worldwide.
Scope of this paper is to describe the current mission status and the main scientific achievements since the start of the science phase. Topics will also include programmatic highlights and information about the extension of the mission data portfolio to include the new ocean products

Mission, Instrument and Data Processing

CryoSat-2: Three Years of Operations (almost)

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The CryoSat-2 spacecraft is one of the Opportunity missions of the ESA Living Planet programme. It is currently operated by the European Space Operations Centre, in Darmstadt. The Mission objective is to provide, thanks to its multi-mode interferometer radar, SIRAL, a global continuous measurements of the ice cover variations on the Polar caps and continental ice sheets.

In April 2013, CryoSat-2 will have achieved three years of operations, including six-months of commissioning and the follow on routine operations. Overall, the mission has proven to be very successful and the spacecraft overall performance very reliable.

The paper first provides an overview of the CryoSat-2 Ground segment and the implemented operational concept covering Ground Stations support and the payload operations planning cycle, followed by an overview of the mission and the in-flight operational status of the Satellite.

The remainder of the paper will present details of the main satellite operations carried out in flight, from the post launch corrective actions through to routine operations. The routine operations will be described, including their implications, for example data downlink automation, orbit maintenance manoeuvre execution, Star Tracker operations, debris collision monitoring, platform units maintenance, payload calibrations via Transponder passes. Special operations in support of the mission and also as a consequence of anomalies will be presented, addressing how and why these are executed and the issues encountered.

As conclusions, the need for stable operations to preserve data quality is highlighted and how the evolution of the current operational concepts allows the CryoSat-2 mission to fully support the user needs.

CryoSat-2 Precision Orbit Determination Including Altimeter Calibration and Validation

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CryoSat-2 was successfully launched in April 2010 to map the cryosphere with an advanced microwave altimeter system, including SAR and SARin capabilities. The mission goal is to observe sea ice freeboard and ice sheet elevation changes for a nominal period of 3 years. Precision orbit determination (POD) of CryoSat-2 relies on DORIS Doppler tracking and ground based satellite laser ranging (SLR). Here we show an update on the results of our CryoSat-2 POD efforts. The Delft orbits compare well with the MOE and POE trajectories computed by CNES and can be considered of Jason-class. We find RMS of SLR residuals around 2cm and RMS of radial differences around 1.5cm when compared to the CNES POE orbits. We address data sources, availability, latency, quality and editing, software, standards and methods and focus the discussion on possibilities to further improve the orbit, e.g. by the use of a dedicated satellite macro model. We also show an update on the results of our CryoSat-2 LRM CAL/VAL efforts. The SIRAL altimeter onboard CryoSat-2 perfectly samples the ocean surface. To be able to exploit these data it is necessary to assess and validate them. Another reason is that we want 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 very pressing, now Envisat stopped providing data and meanwhile its successor Sentinel-3 is 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), and verify the orbit accuracy. The present status of the absolute and relative calibration of LRM Level-2 data is discussed, also by comparison of CryoSat-2 with other satellites (crossover and grid analyses) and with tide gauge data. We provide estimates on range and timing biases and try to explain them. In this update of CAL/VAL results we focus on the latest ESA version of the product and compare with our own efforts to improve the ocean product.

CryoSat SIRAL FBR, Stack & L1b Calibration with TRP

Roca, M.[1]; Fornari, M.[2]; Garcia, A.[1]; García, P.N.[1]; Reche, Mercedes[1]
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The CryoSat mission is designed to determine fluctuations in the mass of the Earth's land and the marine ice fields. Its primary payload is a radar altimeter that operates in different modes optimised depending on the kind of surface: Low resolution mode (LRM), SAR mode (SAR) and SAR inteferometric mode (SARin). This radar is named SIRAL: Synthetic aperture interferometer radar altimeter [1].

Transponders are commonly used to calibrate absolute range from conventional altimeter waveforms because of it characteristic point target radar reflection. The waveforms corresponding to the transponder distinguish themselves from the other waveforms resulting from natural targets, in power and shape.

ESA has deployed a transponder available for the CryoSat project (a refurbished ESA transponder developed for the ERS-1 altimeter calibration). It is deployed at the KSAT Svalbard station: SvalSAT.

We are using the ESA CryoSat transponder to calibrate SIRAL's range, datation, and interferometric phase (or angle of arrival) to meet the missions requirements [2].

Ideally the comparison between (a) the theoretical value provided by the well-known target, and (b) the measurement by the instrument to be calibrated; provides us with the error the instrument is introducing when performing its measurement [3]. When this error can be assumed to be constant regardless the conditions, it will provide the bias of the instrument. And if the measurements can be repeated after a certain period of time, it can also provide an indication of the instrument drift.

In these calibrations, we are using 3 different types of data: the raw Full Bit Rate data, the stack beams before they are multi-looked (stack data) in the Level 1b processor, and the Level 1b data itself [4].

Data from the CryoSat thermistors have also been analysed, with the purpose of correlating the thermal evolution of the platform with the evolution of the interferometric phase error.

Due to equipment degradation over time, the transponder can have internal delay uncertainties from its initial measurement so it needs to be re-calibrated. The way of doing this calibration is by retrieving the range using RA-2 EnviSat data, as it has a well-known absolute range bias. The delta error in the range measurement should come from the error in the transponder internal delay estimation.

References:

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Measuring the Effective Along-Track Resolution of CryoSat

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The main payload of CryoSat is a Ku-band pulsewidth limited radar altimeter, called SIRAL (Synthetic interferometric radar altimeter), that transmits pulses at a high pulse repetition frequency thus making the received echoes phase coherent and suitable for delay/Doppler processing.

In delay/Doppler processing, that is used in SAR and SARin modes, the along-track footprint size is reduced by exploiting the coherence of the emitted pulses to synthetise a narrower antenna and in turns to obtain an improved along-track resolution with respect to conventional pulsewidth limited altimeters.
According to [1], the along-track resolution depends on the orbital parameters, such as altitude and velocity, as well as on instrument parameters, such as the carrier wavelength and the Pulse Repetition Frequency, as well as on the processing itself. After more than two years of mission, is now possible to verify the effective along-track resolution as function of the parameters listed above as they are read from the CryoSat products. This analysis has been performed allowing to verify that the along-track resolution, that is defined as the -3dB width of the azimuth Impulse Response Function, is approximately equal to 490 m and it is stable over the time. Moreover the geographic variations of the along-track resolution, due to its dependence on the orbit, have been studied highlighting that an higher resolution is obtained in the Arctic with respect to the Antarctica. Finally, an investigation has been started aimed at increasing the along-track resolution by selecting the optimal window that is used in the delay/Doppler processing without decreasing the clutter suppression, that is a relevant requirement to retrieve the correct elevation profile from ice sheets.

[1] R. Keith Raney, The Delay-Doppler Radar Altimeter IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, vol. 36, no. 5, September 1998.

Pending Anomalies and Problems in CryoSat Data Products

Bouzinac, C[1]; Fornari, M[2]; Mannan, R[3]
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This presentation details all the pending discovered problems and anomalies in CryoSat data products at the Level 1b and at the Level 2 of the operational processing chain for the different modes (Low Resolution Mode, Fast Delivery Marine Mode, SAR Mode and SAR Interferometric Mode). When possible, a solution to the problem is also explained.

Cal/Val Campaign Status

Davidson, M., Parrinello, T.
ESA

The overall objective of all CryoSat validation activities is to assess and quantify uncertainty in the CryoSat measurements of sea ice thickness and land ice thickness change. It is only through the detailed characterisation and

estimates of these uncertainties that the overall science objectives of the mission can be fully achieved. The principal means for achieving this objective has been through dedicated, independent, ground-based and airborne campaigns along with detailed investigations of retrieval methods applied to the satellite measurements. The Calibration, Validation and Retrieval Team (CVRT) composed of members selected through two ESA CryoSat cal./val. Announcements of Opportunity plays an essential role in the mission validation. The CVRT has helped ESA elaborate details of coordinated Cal/Val strategy and contributes through experiments and data analysis to Cal/Val efforts, providing feedback to ESA on the results.

The presentation will provide an overview of the CryoSat validation experiments, their objectives and some important first achievements. Synergies with parallel NASA activities and ESA/NASA collaboration will be highlighted and planning for future activities summarised.

An Improved Water Vapour Path Delay Correction for the CryoSat Mission over the Ocean

Stum, Jacques[1]; Delepoulle, Antoine[1]; Sicard, Philippe[1]; Soudarin, Laurent[1]; Guillot, Amandine[2]
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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 the atmosphere at frequencies near the 22.235-GHz water vapour 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 vapour 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 analysed, 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.

Cryosphere

Cross-Validating ICESat-1 and CryoSat-2 using Tide Gauge Measurements

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Center for Space Research

A quantitative link between the measurements obtained by ICESat-1, CryoSat-2, and future missions such as ICESat-2 is required in order to maintain data continuity. While the primary goals for the ICESat and CryoSat-2 missions are cryospheric in nature, both provide data globally. Availability of ICESat-1 and CryoSat-2 ocean data present several scenarios for cross-calibration and data-verification studies including crossover, mean sea surface (MSS), and tide gauge analyses. Radar altimetry measurement stability has long been successfully monitored using tide gauges as an independent set of globally distributed in-situ measurements (Mitchum 1994, 1998; Chambers et al., 1998). Building upon these and other investigations, a subset of tide gauges from the global network is examined to perform a cross-calibration of ICESat-1 and CryoSat-2. Each individual tide gauge provides a local, continuous time series of sea level change, and so provides just a single measure of local relative bias. Most powerfully, in aggregate the tide gauges provide an estimate of the global adjustment necessary to link time series of non-cotemporaneous missions. Furthermore, this method can tie incongruent mission parts (as for the 18 ICESat-1 campaigns) or instrument modes (as for the CryoSat-2 SIRAL, operating in different modes for different gauges around the globe). Therefore, the benefits of the tide gauge analyses include both inter- and cross-mission calibration.

A Comparative Analysis of the Sea Ice Freeboard from CryoSat, CryoVEx and IceBridge

Rose, S. K.; Skourup, H.; Forsberg, R.
DTU Space

Sea ice is crucial in the understanding of the Earth's climate, and since 1979, where satellites started to monitor the sea ice extend, it has been shrinking. CryoSat-2 has now operated in almost three years, and measures more of the Arctic ocean, than ever before due to its high sampling rate and geographical coverage up to 88ºN/S. CryoSat-2 is dedicated to monitor cryosphere changes, including changes in the sea ice thickness. The CryoSat Validation Experiment (CryoVEx) has been conducted by ESA, to examine the uncertainties in the satellite measurement of e.g. sea ice thickness.
In this study, we aim to estimate the sea ice freeboard from CryoSat-2, and compare it with the high-resolution Airborne Laser Scanner (ALS) measurements collected along CryoSat-2 ground tracks from the CryoVEx 2012 campaign, together with NASA's Operation IceBridge data. We will use the CryoSat SAR data level 1b and 2 to discriminate the leads and from this, estimate the sea ice freeboard. Furthermore, we aim to show an example of SARin data over sea ice from the Wingham box to examine the potential use of this method for sea ice freeboard estimation.

Sea Ice Thickness and Volume Changes from CryoSat-2

Giles, K[1]; Ridout, A[1]; Wingham, D[1]; Cullen, R[2]; Malcolm, Davidson[2]; Haas, C[3]; Hendricks, S[4]; Krishfield, R[5]; Farrell, S[6]; Kurtz, N[6]; Schweiger, A[7]; Zhang, J[7]; Kwok, R[8]
[1]University College London; [2]ESTEC; [3]University of York; [4]Alfred Wegener Institute; [5]Wood Hole Oceanographic Institute; [6]University of Maryland; [7]University of Washington; [8]Jet Propulsion Laboratory

Arctic sea ice has undergone major changes in recent years but there remains much uncertainty about its ultimate fate, in particular the timing of an ice-free Arctic in summer. Although satellite measurements of ice extent are well established, wide-area measurements of sea ice thickness are key to understanding the fate of Arctic sea ice cover in the future. Satellite altimeters can provide direct measurements of sea ice freeboard from which sea ice thickness can be calculated. We describe the CryoSat mission and present the first two full winters of data on sea ice thickness from CryoSat-2, validated using in-situ and aircraft data. We then calculate ice volume from CryoSat-2 and compare with earlier estimates from ICESat laser altimetry and current estimates of the PIOMAS sea ice model.

Using CryoSat-2 SARIn Mode Data Over Sea Ice to Correct for Off-Nadir Ranging to Leads

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[1]University College London; [2]

CryoSat-2's payload, the SAR Interferometric Radar Altimeter (SIRAL) is the most advanced space-borne radar altimeter ever flown; the along-track resolution is reduced to ~300m though SAR processing and the inclusion of a second antenna allows for across-track interferometry. Although SIRAL's interferometric mode (SARIn mode) was designed primarily for use in coastal areas of the large ice sheets, an area of SARIn mode acquisitions over sea ice to the north-west of the Canadian Archipelago has been included. In conventional sea ice altimetry highly reflective openings in the ice cover - leads - are picked out and their elevation is taken to be the instantaneous sea surface height. The elevation of the sea ice relative to this surface is the sea ice freeboard, which can be converted to sea ice thickness by application of Archimedes' principle. It is known that leads can dominate radar echoes despite being many hundreds of meters away from nadir, an effect known as 'snagging', as the onboard tracker 'snags' on the lead. This sensitivity to off nadir leads causes the radar to overestimate the range to the surface and hence underestimate the ocean surface elevation. Conventional pulse-limited altimeters cannot account for this error as they cannot distinguish the point of origin of power within a single footprint. Using Interferometric CryoSat-2 data, we demonstrate for the first time that it is possible to infer the across-track direction of return of off-nadir leads, determine their location in the footprint and correct for the associated height error. We find that leads can dominate the radar echo up to around 1800m away from nadir. This results in a elevation bias of between -1cm and -4.5cm when averaged over the SARIn mode acquisition area, depending on the level of filtering that is performed. Left unaccounted for, this represents a ~10-40cm overestimate of ice thickness using CryoSat-2. Using SARIn mode data to correct for off nadir ranging improves both the accuracy and precision of the sea surface elevation measured by CryoSat-2 in sea ice covered areas.

In-situ Calibration and Validation of CryoSat-2 Observations over Arctic Sea Ice North of Svalbard and in Fram Strait

Gerland, S.[1]; Renner, A.H.H.[1]; Spreen, G.[1]; Wang, C.[1]; Beckers, J.[2]; Dumont, M.[3]; Granskog, M.A.[1]; Haapala, J.[4]; Haas, C.[2]; Helm, V.[5]; Hudson, S.R.[1]; Lensu, M.[4]; Ricker, R.[5]; Sandven, S.[6]; Skourup, H.[7]; Zygmuntowska, M.[6]
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CryoSat-2's radar altimeter allows for the first time to continuously observe the pan Arctic sea ice thickness on a monthly basis. Calibration and validation are crucial for new satellite sensors like SIRAL, the radar onboard CryoSat-2, in order to substantially increase the understanding on limitations and accuracy. Since 2010, the Norwegian Polar Institute conducted, along with national and international partners, systematic calibration and validation studies north of Svalbard and in Fram Strait, using both helicopter-borne electromagnetic ice thickness profiling, and on ice in situ measurements. The data collected contributes to the calibration and validation of the SIRAL radar altimeter, which measures the freeboard of sea ice. Additionally this in situ data can be used to better quantify the uncertainties involved converting sea ice freeboard to ice thickness. In total seven ship-based campaigns were conducted (August/September 2010 (2), April/May 2011 (2),August/September 2011, July-September 2012 (2)) to the region north of Svalbard and Fram Strait. In terms of abundant ice classes, these two regions are substantially different; north of Svalbard, first year ice is dominant, whereas in Fram Strait usually a combination of first year ice and multiyear ice occurs. During the cruises, detailed measurements of snow and ice thickness, freeboard, and snow stratigraphy and density were performed on ice stations and from a helicopter. The collected data were integrated with satellite data, airborne observations from helicopter that measured ice thickness using an electromagnetic induction sounder (EM-bird) and conducted aerial photography, and for one case (spring 2012) with data from a Twin-Otter aircraft carrying the ESA Airborne Synthetic Aperture and Interferometric Radar Altimeter System (ASIRAS) system, the airborne radar altimeter designed to simulate the SIRAL radar on board CryoSat-2, as well as a laser scanner. Calibration and validation results will be presented with respect to (i) how in situ snow properties may affect the penetration of the satellite radar signal into the snow pack, (ii) how regional ice thickness distributions obtained from helicopter and ship-based measurements compare with satellite data, and (iii) how data compare along distinctive overpass/overflight lines.

Mass Balance of Sea Ice in both Hemispheres: Airborne Validation of CryoSat-2 and ICESat Freeboard and Thickness

Hendricks, Stefan[1]; Helm, Veit[1]; Ricker, Robert[1]; Schwegmann, Sandra[1]; Haas, Christian[2]; Herber, Andreas[1]
[1]Alfred Wegener Institute; [2]York University

The recent decline of Arctic summer sea ice extent underlines the necessity of a sea ice thickness climate data set for the understanding and potential prediction of these changes. CryoSat-2 is the present satellite altimeter mission for sea ice thickness retrieval, operating since 2010. However, it is necessary to cross-calibrate the results from different satellites to extent this time series over the lifetime of an individual mission. Data acquired from airborne campaigns can be used to realize this cross-calibration if direct data overlap is missing, as it is the case for CryoSat-2 and ICESat. Most of these airborne validation campaigns have focused on the Arctic, either as validation activities for CryoSat within ESA's CryoSat Validation Experiment (CryoVEx) or the Operation IceBridge of NASA . Besides these validation frameworks considerable sea ice data exists from airborne and ship-borne surveys from various institutions. Validation data for Antarctic sea ice has received less attention and effort, mostly due to logistical reasons, though it is necessary to understand and monitor the sea ice mass balance in both hemispheres.
We review recent validation activities in the Arctic and present plans for airborne satellite freeboard and thickness validation campaigns over sea ice of the Antarctic Ocean. Data acquisition will consist of two ship cruises in the Weddell Sea between June and September and one aircraft missions in the Weddell and Bellingshausen Sea in November 2013. During the ship cruises of the research vessel Polarstern we will collect sea ice thickness data with airborne EM surveys and physical snow properties on ice stations during Antarctic winter. The airborne campaign will feature direct ice thickness measurements with airborne EM and freeboard retrieval with radar and laser altimeters. The goal of these campaigns is to estimate uncertainties in the satellite freeboard retrieval and the freeboard to thickness conversion for both laser and radar altimeters and ultimately to contribute to a sea ice mass balance time series in both hemispheres

First Results of CryoSat-2 Performance over Multiyear and Seasonal Sea Ice

Beckers, J.[1]; Casey, J.A.[1]; Hendricks, S.[2]; Haas, C.[3]
[1]University of Alberta; [2]Alfred Wegener Institute; [3]York University

Arctic sea ice is undergoing a regime shift from primarily multiyear ice to seasonal ice. While the decline in extent is well quantified, accurate, validated measurements of sea ice thickness and thus ice volume remain spatially and temporally limited. The performance of CryoSat-2 over multiyear sea ice in the Lincoln Sea and the Canada Basin is assessed using extensive, coincident airborne electromagnetic induction and NASA Operation Ice Bridge laser altimetry surveys from the CryoVEx campaigns in March/April 2011 and 2012. In-situ measurements of snow and ice were performed to assess radar wave penetration into the snow cover and for validation purposes. Airborne electromagnetic induction surveys over seasonal sea ice in the Bay of Bothnia are compared to CryoSat-2 data from March, 2011. For both study sites SAR imagery was acquired coincident to the CryoSat-2 overpasses and airborne surveys to aid in the interpretation of waveforms and freeboard retrievals. Initial results suggest that strong returns from off nadir can result in across-track snagging affecting the range measurements and the resulting freeboard retrievals. The discrimination of open water and sea ice in the SAR mode surface type flag requires further refinement. Some of the observed deficiencies in the CryoSat-2 data are likely due to known issues in the original Level 2 processor. The results will be updated with the new Level 2 processor as soon as the new data become available.

Snow Radar Derived Surface Elevations and Snow Depths over Sea-Ice off Greenland During Three Icebridge Campaigns

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[1]Jet Propulsion Laboratory; [2]University of Kansas

This paper presents estimates of snow depth over sea ice from the NASA's Operation IceBridge [1] Greenland campaigns in April 2009, 2010, 2011 derived from the Kansas University's wideband Snow Radar [2]. We compare the estimates of the top surface interface heights between NASA's Atmospheric Topographic Mapper (ATM) [3] and the Snow Radar. We also derive snow depth estimates for all radar vertical profiles, which we compare to available in-situ snow depth measurements [4].
The Snow Radar backscatter returns allow for surface and interface layer types to be differentiated between snow, ice, land and water using a tracking and classification algorithm developed and discussed in the paper. The classification is possible due to different scattering properties of surfaces and volumes at the radar's operating frequencies (2-6.5 GHz), as well as the geometries in which they are viewed by the radar. These properties allow the returns to be classified by a set of features that can be used to identify the type of the surface or interfaces preset in each vertical profile.
We applied a Support Vector Machine (SVM) learning algorithm [5] to the Snow Radar data to classify each detected interface into one of four types. The SVM algorithm was trained on radar echograms whose interfaces were visually classified and verified against coincident aircraft data obtained by CAMBOT [6] and DMS [7] imaging sensors as well as the scanning ATM lidar data. Once the interface locations were detected for each vertical profile we derived a range to each interface that was used to estimate the heights above the WGS84 ellipsoid for direct comparisons with ATM and in-situ data.
Snow Radar measurements were calibrated against ATM data over areas free of snow cover and over GPS land surveyed areas of Thule and Sonderstrom air bases. To calibrate the radar against the GPS surveys and ATM we applied a number of corrections including: 1) The lever arm correction, 2) Radar time delay and resolution correction, derived from more precise calibration of the system delays, and 3) radiometric calibration of the radar backscatter data. Once all corrections were applied the radar measurements were verified against the ATM and the GPS measurements that were located in the estimated radar footprints, which resulted in an overall error of ~ 0.3 m between the radar and ATM overall. The agreement between ATM and GPS survey is within +/- 0.1 m over all areas.
For the purpose of this paper we will concentrate our analysis on flights of April 25th 2009 and April 15th 2011, which are within related region of the Arctic and were coincident with in-situ ice and snow measurements.

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First Results from a CryoSat-2 Calibration Experiment in the East Antarctic Sea Ice Zone, SIPEX-2

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The Sea Ice Physics and Ecosystems Experiment, SIPEX-2, was a ship-based sea ice science cruise and took place in East Antarctica between 63.5 S and 66.5 S, and 113 E and 123 E, in September to November 2012.

We have deployed an instrumented helicopter (AS 350 BA "Squirrel") off the Australian RSV Aurora Australis. This helicopter carried a scanning LiDAR (Riegl LMS-Q240i) in combination with a high-resolution digital still camera (Hasselblad H3D-II) and an IR pyrometer (Heitroniks KT-19). The scanning LiDAR measures surface elevation (that is freeboard in case of sea ice) from which ice thickness can be deduced. The still photos are used to derive surface characteristics and provide visual reference. The pyrometer measures skin surface temperature of the snow/ice surface and open water in leads or polynyas.

An Autonomous Underwater Vehicle, a seabed class AUV, was sent out at several ice stations and provided highly detailed maps of the underside of the sea ice, using a multi-beam upward looking sonar.

Also, during eight sea ice stations, we drilled 100m transects through the sea ice for snow and ice thickness measurements to calibrate and validate the airborne and underwater measurements. We also carried out snow and ice density measurements.

This paper presents first results from this voyage, highlighting heavily deformed sea ice, rafted up to several meters thickness, with a thick snow cover on top, exceeding one meter at times. We will discuss the implications of our findings on space-borne remote sensing products, particularly CryoSat-2.

CryoSat Cal/Val – Accuracy of the CryoSat Products

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The CryoSat mission is one of the European Space agency's (ESA) Earth Opportunity Programmes and was launched in April 2010. The primary scientific objectives for the mission are to determine changes of the ice sheet elevation and sea ice thickness within its nominal lifetime of five years to get a better understanding of the short-term response of the Cryosphere to climate change. In order to validate the scientific data products post-launch CryoSat Calibration/Validation Experiments (CryoVEx) were carried out since CryoSat's successful launch. The CryoVEx campaigns included co-coordinated field and airborne measurements at selected validation sites in the Arctic and Antarctica. Here we will present comparisons of CryoSat-2 data with data acquired during the CryoVEx campaigns. We will focus on CryoSat SARIn products compared with GPS data acquired at the Halvfarryggen in Dronning-Maud-Land (DML), Antarctica and airborne laser scanner data acquired in a Blue Ice area in DML and at Law Dome/Totten glacier. The GPS and laser scanner data will be used as reference elevation for the analysis. Results will be presented obtained from the Level 2 product as well as derived from Level 1B using own procedures.
The validation sites are situated close to the margins of Antarctica and show surface slopes of up to one degree. The sites show very different snow/firn properties,. This can be used to determine the depth

of the dominant scatterer of the Ku-Band signal. The areas around Halvfarryggen and Law Dome are characterised by a very strong east-west gradient in snow accumulation rate, ranging from 0.5 m to 3 m firn per year, whereas the surface at Novo is Blue Ice covered by small patches of snow. Therefore different backscatter mechanism will dominate the received radar signal, volume scattering at the Halvfarryggen and Law Dome and surface scattering in the Blue Ice area, respectively. In case for a dominant volume scattering a penetrating radar signal is assumed. We will investigate if the re-tracked radar surface elevations are formed some distance in the snow pack and if such a penetration can be determined within the error bars of the SARIn product. In the Blue Ice area no penetration is expected and though this site can be used as reference.
Next to the accuracy and penetration studies we plan to show first results of interferometric swath processing.

Ground Validation of CryoSat-2 on Austfonna, Svalbard

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Backscatter measured by CryoSat-2 over land-ice surfaces is related to variability within the near surface layers. We present a suite of ground truthing data from the Austfonna ice cap, Svalbard, collected coincident with CryoSat-2 data acquisition during spring 2011. The ground based and airborne ground truthing data is used to validate interpretation of the snow surface and previous summer surface from the CryoSat-2 radar altimetry data.
The ground based data consist of Ku-band and 800 MHz radar profiles, snow pits, firn cores and borehole videos. The airborne data includes Ku-band radar and laser scanner. The previous summer surface is tracked in the 800MHz radar data and used to validate retracking of this layer in the ground based Ku-band radar, airborne ASIRAS and CryoSat-2 data. Further identification of critical interfaces influencing the CryoSat-2 data are identified by down scaling the bandwidth of the airborne ASIRAS and ground based Ku-band radar data to that of CryoSat-2.
A decade time series of winter snow pack and glacier facies for the Austfonna ice cap interpreted from 800 MHz ground-penetrating radar data show it to consist of firn (a wet snow zone), superimposed ice and ablation ice. There has been considerable variation in both the firn area and the firn-ice transition over this period. It remains to be seen if, in addition to the winter snow pack, we can monitor the horizontal distribution of firn with CryoSat-2.

Greenland Ice Sheet Changes from CryoSat, IceSat and GRACE

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CryoSat data over the Greenland Ice Sheet are used to continue elevation height changes over the Greenland ice sheet, following a decade of detailed monitoring of ice sheet changes with GRACE and IceSat. The combination and validation of the different data for measuring changes is quantified by using available airborne lidar data from IceBridge and CryoVEx. There is a special challenge of using CryoSat as fill-in between EnviSat and Sentinel-3 for the long-term measurements of surface elevation changes, a key essential climate variable in the ESA Climate Change Initiative. Another challenge is the joint utilization of both altimetry and gravity field change measurements for consistent estimates of regional change patterns.

In the paper we analyze GRACE, IceSat and CryoSat data since 2003, and present consistent estimates of overall mass changes with average values around -240 GT/year, showing large variations from year to year, with 2012 being another record melt year for the Greenland ice sheet. Sources of the changes are mainly melt of the marginal ice zones in SE and NW Greenland, as well as changes in the major outlet glaciers.

Validation of CryoSat-2 Products over the Continental East Antarctic Ice Sheet

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One of the main goals of the CryoSat-2 mission is to observe the variations in the elevation of the continental ice sheets within a few centimetres accuracy. To fulfil these high quality claims the CryoSat-2 Level 2 products need to be validated against independent measurements.

We use several data sets to validate these products in central East Antarctica. Especially the remarkably flat terrain over the subglacial Lake Vostok yields an excellent opportunity for a comparison with the results of the laser altimeter mission ICESat. We present the results of these investigations like the estimated offset and accuracy as well as an intercomparison of both data sets with different elevation models.

Furthermore, we use several kinematic GNSS profiles which were recorded during the participation of members of the Institut fuer Planetare Geodäsie of TU Dresden in the Russian Antarctic Expedition (RAE) between 2001 and 2012. After 2007 these data sets also include 6 continental traverses with a length of about 1600km each between the coast and the Russian Antarctic research Station Vostok(78° 28' S, 106° 50' E). With an accuracy of less than 15cm we can use these data to show that the surface-height changes in this region are negligible small. Hence, these data sets are appropriate for a direct comparison of the CryoSat-2 products with ground based observations.

Constraining Ice Sheet Mass Balance Trends using CryoSat-2 and Laser Altimetry

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The mass balance of the Antarctic and Greenland is required to assess their contribution to sea level rise as well as evaluate their sensitivities to variable future forcings. There is general agreement that the ice sheets are losing mass and that loss may be increasing. However, the range of estimates and the uncertainty in those estimates is in many cases, larger than the signal measured, particularly in a regional sense. CryoSat-2 will improve on the legacy satellite measurements from ERS-1 and -2 and Envisat by using its interferometric model to determine elevation on steep slopes and through it's greater across – track resolution. The new technique will overcome many of the limitations of previous radar altimeters but elevations will still suffer from variable penetration in the firn and errors due to short-wavelength roughness.

Building on previous work comparing and combining laser and radar altimeter data, we attempt to assess the uncertainty in elevation. We use the NASA ICESat satellite altimeter to assess biases in elevation from CryoSat-2 data. We focus on the first 4 months of released data from the CryoSat-2 mission to determine the size of the bias and how it relates to geophysical and instrument parameters. Using independent elevation change estimates, we determine that the time difference between the two satellites does not affect the results seen. We observe modal differences between ICESat and CryoSat-2 of 1.10 m with larger difference in many areas and defined spatial patterns. Differences increase sharply over steep slopes and indicate possible residual slope based biases as well as smaller signatures of penetration into the top few metres of the snow pack. CryoSat-2 quasi-crossovers with other local CryoSat-2 data have a smaller modal difference of 7 cm, lower spread and no defined spatial patterns indicating repeatability in the data.

Analysis of Recent Mass Balance of Amery Ice Shelf Derived from CryoSat-2 Radar Altimetry

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This paper presents the results of mass balance change of Amery ice shelf derived from CryoSat-2 data combination with other existing polar monitoring data. The Antarctic is important in understanding present-day sea level change.CryoSat-2¡¯s SAR/ Interferometric Radar Altimetry (SIRAL) will improve estimates of ice sheet elevation. The altimetric approach can provide a vital component for

understanding long-term averaged vertical velocity (elevation change rate) and its impact on the climate with low costs of computation and data storage in Antarctic ice sheet, its higher resolution and latitudinal coverage (up to 88S), both spatial resolution and accuracy, particularly around the margins, and the largest dH/dt values occur over narrow, fast-flowing outlet glaciers. CryoSat-2 all-weather capability will provide more observations coverage under cloudy conditions on ice sheets, We used CryoSat-2 level 2 data, the synthetic aperture interferometric mode (SARinM) and low-resolution mode (LRM) data .We extend the crossover method to surface elevation reconstruction which include repeat track analysis, least-squares fitting of rigid planes to segments of repeat-track data assuming elevation change rate and volume change.
In order to estimate the Antarctic mass balance, we tested a combination of CryoSat-2 radar altimetry with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite stereo images and with laser altimetry (ICESat) for monitoring of glacier volume changes. The CryoSat-2 radar altimeter assumed penetration of the snow cover to the ice surface to measure ice elevation, while ASTER high-resolution (15-m) coverage can be obtained for the highly-textured (e.g., crevassed) surfaces at low elevations, the ICESat laser altimeter measures the upper snow surface elevation.
We used CryoSat-2 to extend time series until at least 2015, which can also help to validate coincidental gravity measurements from the GRACE satellite.

Mass Depletion of Glaciers on the Northern Antarctic Peninsula Observed by Altimeter and SAR Measurements

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The northern Antarctic Peninsula is a region that underwent a series of rapid cryospheric changes in the last couple of decades, most pronounced the sudden collapse of several large ice shelves which appear to be linked to a series of exceptionally warm summers. In the wake of the ice shelf disintegrations their former tributary glaciers started to retreat, thin and speed up, a condition which is still maintained today years after the collapse. A thorough understanding of these processes is a prerequisite for assessing the potential future response of nearby regions buttressed by ice shelves to climate warming.
Here we report on recent topographic changes of the major glaciers formerly feeding the Larsen-A, Larsen-B and Prince Gustav Channel ice shelves in the framework of GlacAPI (Multi-sensor Analysis of Glacier response to Climate Change on the Antarctic PenInsula). GlacAPI aims to give refined mass balance estimates and to analyze dynamic processes of Antarctic Peninsula glaciers. Of great interest hereby is to compare, validate and improve topographic products of various sensors.
The ESA CryoSat mission provides detailed surface elevation measurements that we compare and validate using satellite and airborne derived digital elevation data from other sources such as from the TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) mission of DLR, NASA ICESat GLAS (Geoscience Laser Altimeter System) and NASA Operation Ice Bridge ATM (Airborne Topographic Mapper) data. The synergy of altimetry data with spatially detailed DEMs from the TanDEM-X mission is of particular interest for precise retrieval of glacier volume changes. Combined these datasets allow for

a unique assessment of ice-volumetric changes in recent years that are compared with contemporary calving flux estimates derived using the Input/Output Method (IOM) for selected basins. The data show extensive mass depletion for all major glaciers in this region which is going on since the collapse of the ice shelves in 1995 and 2002. Recent data indicate for a few glaciers some decrease of ice export and volume change, associated with gradual slow-down of calving velocities.

The Evolution of an Antarctic sub-Glacial Lake from CryoSat Interferometric Mode Observations

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We use Synthetic Aperture Radar Interferometric (SARIn) mode data acquired by CryoSat to map the surface expression of a drained sub-glacial lake in East Antarctica. These observations provide a detailed picture of the full area extent and depth of this feature. We compare the CryoSat data to measurements made by the laser altimeter flown on-board the Ice, Cloud, and land Elevation Satellite (ICESat). By combining observations made from both platforms we chart the evolution of this surface feature and estimate the water volume which has drained from the sub-glacial lake. This estimate is evaluated using independent observations made by the SAR on-board the Advanced Land Observing Satellite (ALOS). This study demonstrates the capability of CryoSat to track off-nadir topographic features, and the benefits it can yield to a wide range of glaciological applications.

The Study of DEM and Height Change from CryoSat Data at Dome A and Grove Mountains, East Antarctica

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The CryoSat satellite provides us the elevation information for the Antarctic continental ice sheets and its margins with Low Resolution Mode (LRM) and SAR Interferometric (SARIn) mode respectively. The height change of the Antarctic ice sheet is also one of its important goals.

The real-time kinematic GPS survey was carried out at the summit of Dome A during 21st Chinese National Antarctic Research Expedition (CHINARE) 2004/05 austral summer season. The surface topography of Dome A was drawn up from the kinematic double-frequency GPS data covering an area of about 70 kilometres square. During the following 24th and 25th CHINARE expedition to Dome A, the extent was enlarged to 400 kilometres square. And for the Grove Mountains area, 400km away from Chinese Zhongshan Station, a field survey of the core area of 110 kilometres square was completed with GPS and total station surveys during the 16th CHINARE 1999/2000 austral summer season.

Based on the field data and other satellite missions, the accuracy of the DEM derived from the CryoSat data is studied for Dome A with LRM mode and Grove Mountains with SARIn mode respectively. In addition, height changes could be obtained with repeat tracks and cross tracks respectively. Unlike the traditional altimeter, SARIn mode can accurately determine the location of echo. And the tracks of the measuring points are not so regular. The irregular tracks make it much more difficult to locate the crossover points. Moreover, detection and elimination of gross errors is a critical step for CryoSat data processing. Height changes with LRM and SARIn modes are discussed.

Alpine Snow, Glaciers and Inland Water Bodies Study in Part of Indian Region using CryoSat-2 Radar Altimeter Data

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Water storage in alpine snow, glacier and inland water bodies (reservoirs, lakes and river) are a very significant part of catchment-scale water resources of any country including India. Remote sensing is quite useful to monitor land surface water and glacier conditions. Specially, Radar altimeters show great potentiality for directly measuring elevation changes of large icecaps as well as big alpine glacier along with water level variation in large rivers, reservoirs and lakes. We use in situ measurements of glacier elevation, water-surface stage and remotely-sensed (CryoSat-2 and Envisat-RA2) data to compute time varying storage changes in different inland water bodies in north and north eastern part of India, like Tehri, Hirakund and Sunderban area along with few large snow and glacier covered of North West Himalaya such as Gangotri, Bada shigri and Siachin. The CryoSat-2 data (SIRAL) in both SAR and Interferometric mode in level 2 was used for glacier and water level estimation study. The data was provided by ESA under Category-1 Proposal C1P.8847. The direct application of altimetry data to glacier dynamics and reservoir management is often preceded by validation of satellite altimetry data with reliable ground-measured data. A good to very less correlation and Root-mean-square errors has been found between insitu and remotely sensed data sets during time period of February to June of 2012 for few selected sites as compared with other elevation data from SRTM and ASTER GDEM. Also there is large difference between grid size of SIR_SIN mode based elevation data as compared to ground and other observations. Comparison of satellite-based water level and insitu measurement depends on the distance between in situ gauging station and satellite track, length of the overlapping records, glacier and river width and glacier and river morphology, etc. The present study also examines the lake's water level and temporal change using the CryoSat-2 altimetry data over the few of the reservoirs such Tehri, Bhakra, Hiarkud and Sunderban delta. It was observed that it is possible to monitor the seasonal and annual storage volume changes in reservoirs that might have significant effects on continent scale water cycling and other climatic parameters. Water level of wide rivers such as Ganga and Mahanadi are also being processed to find the water level changes and further correlation of river discharge by utilizing ground based gauge and altimeter. The present study shows that both radar altimeter (CryoSat-2 and RA2) data offer great potential for monitoring large alpine glaciers and water level in inland water bodies. Further extensive validation of derived elevation as well as re processing of level 1b data is needed for any operational use of such information in snow depth changes, glacier mass balance and water resources studies.

Outcome of the Antarctic CryoVEx Campaigns and First CryoSat-2 Validation Results

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To fulfil the main goals of the CryoSat-2 mission it is necessary to validate the different CryoSat-2 products against independent measurements. The objective of the CryoSat Validation Experiments (CryoVEx) is to collect and analyse airborne and ground-based measurements in order to get such independent data sets.

In 2008/09 and 2010/11 the Institut fuer Planetare Geodäsie of TU Dresden successfully realised CryoVEx campaigns in the blue-ice area south-east of Schirmacher Oasis, Dronning Maud Land, East Antarctica.

Since altimetric returns at blue ice will be dominated by the surface reflection especially such areas are well suited for calibration/validation activities.
The surface heights have been observed utilising kinematic GNSS measurements. Extensive ground-based observations along traverses covering the blue-ice area have been carried out since 1991 in order to determine long-term surface-height changes and surface velocities.

The two Antarctic CryoVEx campaigns provide an excellent continuation of the long-term observations.

In the presentation we will discuss the results of the accomplished CryoVEx campaigns, comparisons to the former measurements and possible inferences. Up to 2008 the repeated measurements yielded a decrease of the surface height of up to -15 ... -20cm/a in this area. In contrast to this, the rates of the surface-height change based on the results of the two CryoVEx campaigns, which cover even 2 years, register a positive trend in the same magnitude.

We detected the anomalous trend change on basis of the repeatedly observed traverse covering the blue-ice area as well as of several kinematic test grids. Additionally, we will compare our ground-based results with coordinated airborne measurements carried out by AWI including a collection of radar (ASIRAS) and laser altimeter data. Finally, first direct comparisons with CryoSat-2 data sets will be presented.

Ocean, Land & Inland Water

CryoSat Plus for Oceans: Ocean user Requirements, and Assessment of CryoSat-2 Data

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The ESA CryoSat-2 mission is the first space mission to carry a radar altimeter that can operate in Synthetic Aperture Radar (SAR) mode. Although the prime objective of the CryoSat-2 mission is dedicated to monitoring land and marine ice, the SAR mode capability of the CryoSat-2 SIRAL altimeter also presents the opportunity of demonstrating significant potential benefits of SAR altimetry for ocean applications, based on expected performance enhancements which include improved range precision and finer along track spatial resolution.

The "CryoSat Plus for Oceans" (CP4O) project is supported by ESA under the Support To Science Element Programme. CP4O started in June 2012, and will continue to December 2013. The objectives of CP4O are:

- to build a sound scientific basis for new scientific and operational applications of CryoSat-2 data over the open ocean, polar ocean, coastal seas and for sea-floor mapping.
- to generate and evaluate new methods and products that will enable the full exploitation of the capabilities of the CryoSat-2 SIRAL altimeter, and extend their application beyond the initial mission objectives.
- to ensure that the scientific return of the CryoSat-2 mission is maximised.

This work is to be carried out within four sub-themes: Open Ocean Altimetry, Polar Ocean Altimetry, Coastal Zone Altimetry, Sea Floor Altimetry.

The first activities of the project are to provide a summary of scientific requirements which take advantage of the new capabilities offered by the CryoSat SIRAL altimeter and to provide a comprehensive review of the state-of-the-art, which includes an assessment of the currently available CryoSat-2 data products

This presentation will provide an overview of the project, present the results from the first activities described above, and will look ahead to the next steps:

- The production and evaluation of demonstration data products produced specifically for application in the four sub-themes identified above,
- Assessment of their potential impact in terms of the identified user requirements,
- Production of scientific roadmap to ensure successful transfer of the results into scientific and operational activities.

The results of CP4O will also prove highly relevant to support the planning for future missions, including Sentinel-3 and Jason-CS which will also carry SAR enabled altimeters.

CryoSat-2 Ocean Wind and Wave Products: Global Validation and Assimilation

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The altimeter significant wave height (SWH) and the surface wind speed measurements are of considerable importance for weather prediction either for assimilation or verification. The ESA CryoSat-2 Fast Delivery Ocean Level 2 (FDM) is not an exception and therefore validation of this product is required. However, due to the delay in releasing the official FDM product, alternative unofficial products produced by other centres are used. Abdalla and Janssen (CryoSat Workshop, 2011) used the SWH product produced by Centre National d'Etudes Spatiales (CNES). The results from the unofficial CNES SWH product showed that the quality of the SWH from CryoSat-2 is very high.

The US National Oceanic and Atmospheric Administration (NOAA) distributes another (unofficial) CryoSat-2 product in near real time. This product is monitored and validated at ECMWF. Experiments to assimilate this product in the WAM model will be carried out soon. The results will be presented at the workshop.

The official ESA FDM product is expected to be released early 2013. If that product is made available in time, the results from its validation and assimilation will be also presented.

Observing the Ocean using CryoSat-2's Synthetic Aperture Radar (SAR) Mode

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The CryoSat mission is designed to measure changes in the polar ice fields. There is evidence that suggests that changes in the acceleration of the loss of ice from the Greenland and Antarctic ice sheets are a result of heat arriving at their periphery transported by the ocean. In the Arctic, as the sea ice cover retreats the Arctic Ocean circulation might also change, which could speed up the reduction of the sea ice cover and alter the storage and distribution of freshwater. Therefore, the ability to monitor changes in the polar oceans as well as the ice cover will increase our understanding of the system.

The method used to derive sea ice thickness estimates from CryoSat-2 produces measurements of the sea surface height in the ice-covered oceans, from which surface circulation can be derived. In this paper we demonstrate CryoSat-2's ability to measure the sea surface height in the Arctic. We also present results from an alternative model fit to the oceanographic returns that can provide estimates of significant wave height and backscatter (which is related to wind speed), in addition to sea surface height, for CryoSat's SAR mode data.

A Validation Exercise for CryoSat-2 in SAR Mode in the German Bight Area

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We present a validation exercise performed between Level 2 Altimetry Data acquired by the CryoSat-2 in SAR Mode near to the coast of the German Bight during the period 2011-2012 and a network of tide gauge stations and GNSS stations, maintained by the German Federal Institute of Hydrology (BfG) and by the Federal Agency of Cartography and Geodesy (BKG) in the same area.

The CryoSat Data have been Delay-Doppler processed as from the FBR (Full Bit Rate) Level until the Level 1b and subsequently re-tracked using the SAMOSA3's SAR Echo Model and a fitting scheme based on Levenberg-Marquard Least Square Minimization Algorithm. Sea Surface Height (SSH) and Significant Wave Height (SWH) at 20 and 1 Hz have been derived.

The in-situ network consists of two offshore measurement platforms and of other stations both on the islands and the continent. Tide gauge stations are equipped with continuous GNSS and instruments to measure sea waves and currents. In particular, the validation is carried out at the offshore platform FINO3 and at the coastal tide gauge Langeoog to highlight any eventual degradation in the behaviour of CryoSat passing from an open ocean regime to a coastal zone regime.

The low sea state conditions expected near coast is useful to assess the capacity of the SAR Altimetry to retrieve wave heights also at low sea state part of the sea spectrum.
Only CryoSat-2 tracks passing within 50 km from the in-situ platform are considered in the present analysis.

Pseudo pulse-limited (PLRM) data derived from CryoSat in SAR mode and provided via the RADS database will be compared with parameters derived from the CryoSat SAR Echo Model data to estimate possible biases occurring in SAR mode with respect to the LRM Mode and tune up the SAR re-tracking scheme.

As performance metrics to measure the quality of the results, scatter plots, cross-correlations, standard deviations, and biases between the in-situ and the CryoSat-derived measurements (Sea Level and SWH) will be presented.

A preliminary comparison made at the offshore platform FINO3 between in-situ wave heights and the SWH derived from CryoSat data in SAR mode using the SAMOSA's SAR Echo Model shows a good agreement for sea wave heights higher than 1 meter. Differences between observed and derived from CryoSat SWHs are higher for SWH smaller than 1 meter suggesting a possible CryoSat's inadequacy to measure in SAR mode low SWHs. This inadequacy might be due to the current operated multi-looking scheme that averages always almost all possible looks whereas over quasi-flat/specular surfaces it would be more sensible to limit the multi-looking average only to the near nadir looks.

Quality Assessment of CryoSat-2 Data Over Ocean in LRM&SAR Modes

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CryoSat-2 is ESA's ice mission which primary objective is to serve Cryosphere science. Nevertheless, CryoSat-2 has, in theory, 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.

Even if CryoSat-2 is not an optimised payload for mesoscale observation (no radiometer and single frequency altimeter, no repetitive ground track), Labroue et al. (2011) showed, with a few months of data, that the CryoSat-2 system gives very good performance in its traditional mode (Low Resolution Mode). The present study provides further results that confirm the quality of the system for ocean, based on the analysis of data processed with CNES prototype (CPP).

The CryoSat-2 altimeter is operated almost continuously over ocean, either in Low Resolution Mode (like conventional pulse-limited altimetry sensors) or in the so-called Doppler/SAR mode (higher-resolution and lower noise level). While the optimised SAR processing were not yet available, CNES developed a pseudo LRM processing that allows recovering data in all the SAR acquisition regions. Even if the noise is higher than the traditional LRM mode, this is a major achievement that provides a global continuous coverage in the operational SSALTO/DUACS system, especially over Europeans seas.

The next step is now the assessment of SAR dedicated processing to exploit all the potential of this new technique. In the frame of the ESA CryoSat Plus For Ocean project (CP4O), assessment of several SAR processing will be performed (CPP, SAMOSA processing...).
The different metrics are presented here, based on the analysis of the CPP SAR data. While promising results were presented at the 2012 OSTST in Venice (Boy et al), we analyse more deeply the main features to check the reliability and the improvements of the SAR processing (noise reduction, increased along track spatial resolution, check of the dependencies that may induce geographically correlated errors, continuity with LRM processing...).

All these analysis based on CryoSat-2 will also help us to prepare the methodology of the quality assessment for the next generation of altimeters (Sentinel-3 and Jason-CS). One of the key issues for validating SAR mode without a global coverage over open ocean, is to improve our capacity in detecting residual centimetre correlated differences between LRM and SAR zones.

The Performance of CryoSat-2 as an Ocean Altimeter

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Nearly three years after the launch of CryoSat-2, oceanographic applications of the CryoSat-2 data emerged, after several institutes, including NOAA, have made a dedicated effort to upgrade the official CryoSat-2 data products to a level suitable for monitoring open-ocean phenomena, such as mesoscale currents, wind speed and wave height. However, in coastal areas this is much less the case. This is largely a result of the fact that CryoSat-2 is running in SAR or InSAR mode in many of the research focus areas, such as the Mediterranean Sea.

We have shown that the CryoSat data is intrinsically of high quality, and for over a year now have been producing "IGDR" type data which is provided through FTP as well as through our RADS service. The processing steps include:

- Combine final (LRM) and fast-delivery (FDM) products and split the segmented files into pass files.
- Divide the 369-day repeat cycle into subcycles of 29 or 27 days.
- Retrack the conventional low-rate data to determine range, significant wave height, backscatter (and off- nadir angle).
- Add or replace the usual corrections for ionospheric and atmospheric delays, tides, dynamic atmospheric correction, sea state bias, and mean sea surface.
- Update orbits and corrections whenever they become available.

This way NOAA produces an "IGDR" product from the fast-delivery FDM and the CNES MOE orbit in about 2 days after real time, and a "GDR" product from the final LRM data and the CNES POE orbit with a delay of about 1 month.

In order to extend the data products to the coastal regime and fill other gaps in LRM coverage, we have developed a process in which the SAR data are first combined into "Pseudo-LRM" or "reduced SAR" wave forms, which are similar to the conventional pulse-limited wave forms. The reduced SAR wave forms are retracked and combined with the LRM data to form a harmonised product. Although this sounds relatively straightforward, many steps were needed to get this done:

- Combine the SAR wave forms into conventional wave forms, without loss of information.
- Reconstruct backscatter and significant wave height in a meaningful way, consistent with low-rate data.
- Cross-calibrate the conventional and Pseudo-LRM data.
- Validate the data quality of conventional and SAR mode data through crossovers and collinear track analyses.

There Pseudo-LRM data have been merged with LRM data and have been available via RADS since October 2012. Since then, NOAA has developed some other techniques to process the SAR data, taking advantage of the higher spatial resolution it can provide.

In this presentation we will demonstrate how the quality of the CryoSat-2 data processed by NOAA compares to other altimeters (Envisat, Jason-1 and Jason-2) by means of data distribution maps, histograms and crossover comparisons. We will also present comparisons with the standard Level 2 products and assess their quality.

ftp://ibis.grdl.noaa.gov/pub/cs2igdr/ and http://rads.tudelft.nl/

Sensitivity of SAR Mode Altimeter to Swell Effect

Moreau, T.[1]*; Amarouche, L.*[1]*; Thibaut, P.*[1]*; Boy, F.*[2]*; Picot, N.*[2]
[1]*CLS;* [2]*CNES*

The exploitation of in-orbit CryoSat-2 SAR-mode data over ocean has recently shown some key performance enhancements compared to those typically seen with conventional pulse-limited altimeters, such as improved range precision and finer along track spatial resolution. This will allow to achieve high-resolution high-accuracy altimetric mapping of the ocean surfaces, and might potentially enable to detect some features that are unresolved from low-resolution mode observations, in particular the long ocean surface waves (swell). Contrary to the classical altimeter, the illuminated area is not a surface-constant ring, but only a part of the area that is narrowed along the satellite track direction by the synthetic aperture processing to few hundreds of meters in width, equivalent to the wave number of typical directional wave spectra. Regarding this geometry, we might suggest that the SAR-mode retrieval will not measure the average height of the ocean's surface but a local topography of the swell, with small wavelength structures only. However 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 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). CLS has been conducting a study, under CNES funding, to characterize these effects. This study has been using 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. This paper will present this numerical study.

Contributions of CryoSat, Envisat, and Jason-1 to Improvements in Global Marine Gravity Accuracy

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Altimetry observations from the satellites CryoSat, Envisat, and Jason-1 have been contributing to improvements in the modeling of the marine gravity field. The latest version (v. 20) incorporates 2.5 years' worth of data from all three geodetic missions and builds upon previous gravity models that used only Geosat and ERS-1 records (v. 18). Enhancements in the accuracy of the marine gravity field rely mainly on the spatial density of ground tracks, as well as the range precision of measurements along these tracks. The authors have demonstrated in previously presented work that all three new altimeters have reduced range noise compared to the two older altimeters, and thus increased gravity accuracy is to be expected between the v.20 and v.18 gridded models. A comparison between these two grids and shipboard gravity collected in the northern Gulf of Mexico shows that v. 20 has an accuracy of 1.71 mGal, which is lower than 2.03 mGal for v. 18. In this work, we aim to characterize the refinements to the gravity grid on a global scale. We consider north and east directions of sea surface slopes, then subtract the old grid (v. 18) from an updated grid that includes all or a portion of the newly available data sets. The median absolute deviation of these differences are then calculated along latitudinal bands globally. In the case where all new data are incorporated (v. 20), and for the region between 60 S and 60 N, the differences between old and new grids are higher for the east slopes (~ 1 microradian) than for north slopes (~ 0.5 microradian). The greatest differences, however, are observed in the polar regions, with the residuals reaching as high as 4 microradian. We also generated 3 other alternative grids that each excluded CryoSat, Envisat, and Jason-1 data, so as to isolate the contributions that are specific to each mission. The analysis by differencing reveals that Jason-1, which has an inclination of about 66 degrees, is mainly helping to resolve the E-W component of the gravity field over most of its coverage area. As to be anticipated from their orbital inclinations, it is the grids that exclude CryoSat and Envisat which show considerable residuals with the old grids at high latitudes. However, when excluding Envisat data, there are differences greater than 2 microradian between 72 S and 81.5 S, whereas if CryoSat data is left out, the same large differences are only present from 72 N to 81.5 N. These suggest that while Envisat data are contributing mainly to supplementing the gravity accuracy in the Southern Ocean, it is the addition of CryoSat data that is leading to improvements in the Arctic marine gravity over the same range of latitudes.

Experiments with CryoSat2 FBR SAR Data over Ocean Surfaces

Smith, W
NOAA

CryoSat2 is showing the world new possibilities in advanced ocean altimetry. The future ocean altimeter missions Sentinel-3 and Jason-CS will carry altimeters with a SAR mode inherited from the CryoSat2 SIRAL SAR mode. The ocean science community is therefore eager to see what can be done with a SAR altimeter over ocean surfaces. Although the CryoSat2 mission was designed for ice measurement, it has been very helpful to the ocean community by providing the first opportunity to study SAR mode data over oceans in many forms, including the Full Bit Rate (FBR) data.

FBR data permit direct investigation of the echo-to-echo correlation in the complex electric field received at the antenna, putting theoretical results to a test not previously possible. If the echoes are averaged incoherently - that is, only the power in the echoes is averaged - one obtains a pulse-width-limited (so called LRM) waveform, as in a classical altimeter. If the echoes are averaged coherently - that is, the average of the complex electric field - one can synthesize a single Doppler-sharpened beam, which can be steered to look at nadir. By applying an FFT to a burst of complex echoes, a fan of Doppler-sharpened beams can be synthesized.

The standard processing employed by the mission when the instrument is in SAR mode is called multi-looking. Multi-looking combines views of a single ground position from multiple viewing angles obtained from Doppler-sharpened beams in FFTs of multiple bursts of echoes. We view this product as only one end-member in a suite of possible ways of looking at the ocean surface. We are investigating other ways of using FBR SAR echoes to look at the ocean. By varying the schemes employed for Doppler beam synthesis and echo and beam averaging, we can build a variety of ways of looking at the ocean. We hope to find a way that is optimal for measuring range to, and wave height on, the ocean surface. Our preliminary findings will be presented at this meeting.

CryoSat Ocean Processor : Presentation and Preliminary Validation Results

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A CryoSat Instrument Processing Facility (IPF) dedicated to Ocean products is under development by ACS and CLS, on ESA request. The objective of this new IPF is to support the generation of two additional Level 1B and Level 2 Ocean products: the Interim Ocean Products (IOP), available in 2-3 days, and the Geophysical Ocean Product (GOP), available in about 30 days after acquisition. In its first release, to be delivered in the first half of 2013, CryoSat Ocean IPF will be able to process both LRM and SAR data, SAR data being down-processed in a pseudo-LRM mode. The processing baseline is the CNES software used for the operational processing of the Jason-1, Jason-2 and ENVISAT missions (off-line processing only for ENVISAT mission).
The definition of the content of the new ocean products will be presented, together with a definition of the processing performed. First results from the validation phase will be presented as well.

Coastal SAR Altimetry Data from the eSurge Processor

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The SAR altimeter on board CryoSat-2 allows an intrinsically higher along-track resolution than conventional pulse-limited instruments. This has advantages for some open ocean applications, like in areas of strong submesoscale activities (filaments, very intense fronts across storms) and in areas affected by major oil slicks. The advantages are even more evident in the coastal zone, where the typical scale of dynamical phenomena is shortened.

When the track approaches the coast almost orthogonally, the waveforms conform well to the delay-Doppler Altimetry model (and give sensible results when retracked), up to 500 m from the coast or even closer, as already demonstrated by Dinardo et al. using CryoSat-2 data at the 5th Coastal Altimetry Workshop (2011).

Assimilation in, and validation of, storm surge models appear as a very promising application of the coastal altimetry data, that can bring tangible societal benefits. Altimeters observe directly the Total Water Level Envelope (TWLE), which is a key quantity for modelers and forecasters of storm surges. This particular application is being tested within the ESA Data User Element eSurge Project, where a multi-mission coastal altimetry processor (derived from the one developed for the COASTALT Project) generates reprocessed data for a number of past storm surge events. Long altimetric time series are 'blended' with tide gauge observations to allow TWLE prediction in real time based on the gauges; a demonstration of the direct near-real-time capabilities of coastal altimetry is also an objective of eSurge.

The eSurge coastal altimetry processor is able to process CryoSat-2 data on the basis of the SAMOSA3 SAR altimetry waveform model. We will present examples of the reprocessed coastal CryoSat-2 data over a few significant events in the North Sea, U.S. East Coast and North Indian Ocean, highlighting the improved information content with respect to conventional LRM data, and we will discuss how these data are integrated with other observations and model output within the eSurge system.

Analysis and Inter-Calibration of Wet Path Delay Datasets to Compute the Wet Tropospheric Correction for CS-2 over Ocean

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The loss of Envisat in April 2012 increased the use of CryoSat-2 (CS-2) data for applications beyond the primary objectives of the mission, including studies over oceans. Since CS-2 does not carry an onboard microwave radiometer (MWR), the wet tropospheric correction (WTC) is a model-based one, currently provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). Due to its high spatial and temporal variability, the WTC is still one of the major error sources in satellite altimetry, thus driving a need to develop an improved wet path delay correction for CS-2, particularly important for ocean applications.

In the scope of the CryoSat Plus for Oceans (CP4O) project, funded by the European Space Agency, a data combination (DComb) algorithm is being developed, based on the objective analysis of all available data sources (e.g. from MWR on board remote sensing (RS) satellites, Global Navigation Satellite Systems (GNSS) and the ECMWF ReAnalysis (ERA) Interim model). The scope of this study is the analysis and inter-calibration of all available datasets for the computation of the wet path delay of altimeter measurements over ocean, in preparation for their use in the DComb algorithm.

Two main data types are analysed: wet path delays derived from water vapour products of scanning microwave radiometers of various sensors (e.g. AMSU-A, SSMI/S, AMSR-E and TMI) on board over ten different RS missions and GNSS-derived path delays from coastal and island stations. Except for TMI, all MWR imaging sensors are on board near-polar sun-synchronous satellites possessing different local times of the ascending node (LTAN), thus allowing an almost uniform data coverage throughout the day. Since CS-2 orbit is not sun-synchronous, the number of MWR images available for the WTC computation (within pre-defined time and space domains centred at the instant and location of the CS-2 altimeter measurement) will vary throughout the satellite repeat cycle (369-days); for most cases, 2 to 4 images are available at mid-latitudes, these numbers increasing with latitude. All MWR are inter-calibrated with respect to the Advanced Microwave Radiometer (AMR) on board Jason-2, using the recent Geophysical Data Records version D (GDR-D) and the ERA Interim model. Special attention is given to the identification and removal of ice and land contaminated pixels in the MWR images.

The GNSS-derived path delays shall play a major role in the coastal zones, of particular relevance for the exploitation of CryoSat-2 Synthetic Aperture Radar (SAR) measurement mode in these regions. A brief summary of the major steps involved in the processing of these data to derive wet path delays for coastal altimetry will also be presented.

Applications of CryoSat-2 SAR & SARin Modes for the Monitoring of River Water Levels

Bercher, Nicolas[1]; Dinardo, Salvatore[2]; Lucas, Bruno[2]; Calmant, Stephane[3]; Crétaux, Jean-François[4]; Féménias, Pierre[2]; Picot, Nicolas[5]; Benveniste, Jérôme[2]
[1]LEGOS/CNRS; [2]ESA/ESRIN; [3]LEGOS/IRD; [4]LEGOS/CNES; [5]CNES

Regarding hydrology applications and particularly the monitoring of river water levels from space, the CryoSat-2 ice mission has two main valuable characteristics: (1) its drifting orbit and (2) the altimeter's SAR and SARin modes.

The benefits of the drifting orbit of the satellite have been illustrated in the frame of the "20 years of progress in radar altimetry" symposium (Venice, 2012). It has been showed that, with such an orbit, the way river water level was monitored using conventional altimeters had to be revisited. In particular, using LRM mode only, CryoSat-2 allowed us to build spatio-temporal time series of the river water level, map the river's topography and derive pseudo-time series and pseudo-profiles of the river.

This study will focus on the new ways to use altimetry instrument for the monitoring of river water levels. SIRAL's CryoSat-2 instrument SAR and SARin modes have the ability to deliver surface heights with an unprecedented along-track resolution of about 300 m. Moreover, using the SARin mode (involves two antennas), the across track angle of the retracked echo is also available in routine.

These two aspects of the SARin mode (high resolution and cross-track angle) make it a new tool to distinguish whether the retracked echo came from the a surface of interest (e.g., a river) or any other reflective object nearby the surface of interest (e.g., another river section, lakes or temporary lake after flooding events, any other specular surfaces, etc.).

We will introduce the multiple benefits of using the intermediate multi-look matrix (also known as stack matrix), among them: (1) to refine and select among the multiple doppler-beam waveforms before averaging and retracking them and (2) to be able to study the surfaces response according to their view angle. Custom products processed at ESA (ESRIN) in the perspective of Sentinel-3, as well as official CryoSat-2 L1b and L2 products will be used to illustrate these results. The study investigated on some specific areas, depending on the data availability for SAR and SARin modes. We focused on the Mekong river using SAR mode and Amazon main rivers using SARin mode. Several applications of these modes will be assessed, such as deriving instantaneous (single track) longitudinal and transverse profiles of river water levels and building pseudo-time series.

The results will show the extent of new applications and accuracy refinement brought by both SAR and SARin mode. It will emphasize on the need for the Sentinel-3 mission to implement SAR instrument mode over land waters. Finally, combined with its really tight and drifting orbit, CryoSat-2 can be seen as a mission for topography and intermediate step toward the SWOT mission.

This study is submitted to be presented as the second part of a two-talks series, the first one being “Inland Water SAR Altimetry: New techniques and methods for the hydrological exploitation of CryoSat Data” by Dinardo et al.

Performance of CryoSat-2 in SARIN Mode over Great Rivers

Calmant, Stephane[1]; Bercher, Nicolas[2]; Dinardo, Salvatore[3]; Lucas, Bruno[3]; Féménias, Pierre[3]; Benveniste, Jérôme[3]
[1]LEGOS/IRD; [2]LEGOS/CNRS; [3]ESA/ESRIN

In SARIN mode, CryoSat-2 will be the first altimetric satellite to ever provide direct measurement of water level by interferometry. SARIN data have been collected over the two largest rivers in the world, namely the Amazon and Congo rivers. These areas present a very interesting variety of measurement condition. We present the results obtained so far with the very limited set of data available today, both in terms of capability to pick up measurements according to the environment of the reflecting water body and in terms of accuracy on these measurements, assessed mostly in the case of the Amazon basin where in-situ readings are available. CryoSat-2 is placed on an orbit characterized by a low temporal sampling but a high spatial sampling. We also discuss the capability of such an orbit to be used to perform dense detection of river bodies that could be used to make wet/dry masks for automatic detections by further missions such as the SENTINEL-3 mission or the SWOT mission.

Inland Water SAR Altimetry: New Techniques and Methods for the Hydrological Exploitation of CryoSat Data

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The concept of SAR Altimetry has found immediate application and interest among the users principally over open ocean and coastal zone domains.
But a new applicative territory remains still basically unexplored: the inland water theme.

Indeed, the SAR/SARin technology looks very attractive for inland water users thanks to the resolution shrinkage in along-track direction that will now allow to monitor more efficiently small water bodies and to reduce the land contamination from the off-nadir land targets.

With respect to the SAR mode, the SARin Mode has the additional advantage of:

1) a better robustness of the on-board tracking system and a four time longer receiving window that will enable the radar to follow very steep topographic reliefs without loss of tracking
2) possibility to infer the echo origin's angle and distinguish between nadir and off-nadir return

The current Delay/Doppler processing, that is actually applied over open ocean, is suitable as well for inland water studies, provided that:

1) a weighting function is applied in azimuth before the beam forming operation is executed, in order to limit the azimuth ambiguities or "ghosting" effect.
2) an oversampling at least by factor 2 is applied during the range compression in order to properly sample the specular return echoes.

On top of this, clearly a standard open ocean SAR waveform physical model (like for instance SAMOSA) not always could be fully applicable for inland water studies as it is not able to cope with very peaky waveforms from still waters.

For this scope, at ESRIN, we developed a re-tracking scheme able to change and adapt the model's waveform to specular water conditions (still water) or diffusive water conditions (rough water).

In SAR mode, thanks to the high instrumental Pulse Repetition Frequency and to an accurate Delay/Doppler Processing, the real antenna beam-width (with a footprint of 16 km) can be split in a series of Synthetic Doppler Beams, each one with a footprint of 300 meters.

Since these Doppler Beams are synthetic, they can be steered to any point of the overflown ground - track and hence virtually a SAR Altimeter has the potentiality to provide an altitude measurement at any desired surface location along the ground-track. Because rivers and lakes are very localized targets, it seems sensible, in case of application of SAR Altimetry over inland water domain, to steer all the Doppler Beams exactly in the middle of the river/lake's water body in order to get a water level measurement the most clean and uncontaminated possible.

As secondary option, it could be also possible to over-sample the river/lake's crossing, fixing surface locations along the lake/river's cross at a space distance lesser than 300 meters (the intrinsic CryoSat's along track resolution) in order to increase the number of available water measurements at the lake/river's cross.

Poster Session – Mission, Instrument and Data Processing

The CryoSat Payload Data Ground Segment and Data Processing

Frommknecht, Bjoern[1]; Parrinello, Tommaso[1]; Badessi, Stefano[1]; Mizzi, Loretta[2]; Fornari, Marco[3]
[1]ESA/ESRIN; [2]Telespazio S.p.a; [3]Rhea S.p.a.

Selected as the first Earth Explorer Opportunity mission and following the launch failure of CryoSat-1 in 2005, the CryoSat-2 mission was launched on the 8th April 2010 and it is the first European ice mission dedicated to monitoring precise changes in the thickness of polar ice sheets and floating sea ice over a 3-year period. The main CryoSat-2 mission objectives can be summarised in the determination of the regional and basin-scale trends in perennial Arctic sea ice thickness and mass, and in the determination of regional and total contributions to global sea level of the Antarctic and Greenland Ice. Therefore, the observations made over the life time of the mission will provide conclusive evidence as to whether there is a trend towards diminishing polar ice cover and consequently improve our understanding of the relationship between ice and global climate change. Scope of this paper is to describe the CryoSat Ground Segment and its main function to satisfy the CryoSat mission requirements. In particular, the paper will discuss the current status of the L1b and L2 processing in terms of completeness and availability. An outlook will be given on planned product and processor evolutions, the associated reprocessing campaigns will be discussed as well.

Operational and Reprocessed CryoSat Product Quality Assessment

Wallum, M[1]; Bouzinac, C[2]
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This poster presents details of the Quality Control activities performed for CryoSat data products under the Instrument Data Evaluation and Analysis Service (IDEAS) contract.

IDEAS manages the operational quality control for ESA's space-borne Earth Observation instruments and is responsible for the quality assessment of both the operational and reprocessed datasets for CryoSat.

Details of the different QC procedures and tools deployed by IDEAS to assess the quality of L1B and L2 data products, in addition to some results from the quality assessment of the current Baseline B data are presented.

CryoSat-2 SIRAL Calibration: Strategy, Application and Results

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The main payload of CryoSat-2 is a Ku band pulsewidth limited radar altimeter, called SIRAL (Synthetic interferometric radar altimeter), that transmits pulses at a high pulse repetition frequency thus making the received echoes phase coherent and suitable for azimuth processing.

This allows to reach an along track resolution up to 250 meters which is a significant improvement over traditional pulse-width limited altimeters.

Due to the fact that SIRAL is a phase coherent pulse-width limited radar altimeter, a proper calibration approach has been developed.

SIRAL performs regularly four types of calibrations: (1) CAL1 in order to calibrate the internal path delay and peak power variation, (2) CAL2 in order to compensate the instrument transfer function, (3) CAL4 to calibrate the interferometer and (4) AutoCal, a specific sequence in order to calibrate the gain and phase difference for each AGC setting.

Internal calibration data are processed on ground by the CryoSat-2 Instrument Processing Facility (IPF1) and then applied to the science data. In this poster we will describe as first the calibration strategy and then how the four different types of calibration are applied to science data. Moreover the calibration results over almost 3 years of mission will be presented, analysing their temporal evolution in order to highlight the stability of the instrument over its life.

Poster Session - Cryosphere

Long-term Antarctic Surface Elevation Trends from Satellite Radar and Laser Altimetry

Brian C., Brian C.; Meister, R.; Didova, O.; Muir, A.; Shepherd, A.; Laxon, S.

The last decade has seen dramatic changes in the Antarctic ice sheet (AIS), which is home to over 60% of the world's fresh water reserve. The acceleration of Antarctica's outlet glaciers has led to a negative mass balance in Western Antarctica, while accumulation anomalies in the East suggest a positive mass balance in some areas. Monitoring these changes over long timeframes is critical towards understanding the impact that the AIS has on global sea-level rise, ocean currents, and weather patterns, particularly with regard to recent climate warming. This study seeks to explore this issue by examining the volume change of the AIS over the past decade using Envisat and CryoSat-2 satellite radar data, as well as ICESat laser altimetry data. These missions have all collected valuable information about the surface elevation changes of the AIS, but the spatial and temporal resolution of the individual measurements are substantially different, and the measurement signals themselves have varying levels of firn penetration. Despite these differences, the trends derived from the individual missions are highly correlated and, because each mission measures the same quantity (i.e., surface elevation), they provide the opportunity for cross-validation. This presentation will investigate the similarities and differences in the computed surface trends from each mission, and seek an optimal combination of the two measurements types.

Evaluation of CryoSat-2 for Height Retrieval over the Himalayan Range

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Climate warming over the 20th century has caused drastic changes in mountain glaciers globally, and of the Himalayan glaciers in particular. The stakes are high; mountain glaciers are the largest contributor to the increase in the mass of the world's oceans, and the Himalayas play a key role in the hydrology of the region, impacting on the economy, food safety and flood risk to a large population. Partial monitoring of the Himalayan glaciers has revealed a mixed picture; while many of the Himalayan glaciers are retreating, in some cases locally stable or advancing glaciers in this region have also been observed. Recent controversies around the future of the Himalayan glaciers, fuelled by projections reproduced in the 2007 *Intergovernmental Panel on Climate Change* report, have highlighted our limited knowledge of the evolution of Himalayan glaciers, and our limited understanding of the relationship between climate change and Himalayan glaciers' change.
In its interferometric mode, CryoSat-2 is designed to enable the retrieval of elevation over steep sloping terrain. If successful over mountain glaciers, height retrieval by CryoSat-2 could provide an invaluable datasets for the assessment of ice mass balance of the Earth's mountain glaciers. Here we present the first results of quality assessment of height retrieval by CryoSat-2 over the snow and ice covered Himalaya.

CryoSat-2's SARIn Mode in the Coastal Regions of Greenland

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TU Munich

The ESA Earth Explorer mission CryoSat-2 provides a unique opportunity for exploring a broad variety of

scientific applications in the fields of Glaciology, Geodesy and Oceanography. The implementation of all three measurement modes provided by CryoSat-2, especially the interferrometric SAR (SARIn) mode, promises better observability of glaciers, areas with higher surface slopes and the land-sea transaction zones.
In this context a comprehensive quality and performance analysis of the SARIn mode data was carried out to better understand the potential of this measurement mode and it's capabilities for contributing to a multi sensor observation system. This includes also a cross-comparison with results gained from other sources like altimetry missions, in-situ data and TerraSAR/Tandem-X SAR observations.

Cryosphere: Recognizing the Culture of Space-Based EO Application in Canada's Northern Regions Management

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Ice caps and glaciers occupy 150,000 km2 of the Canadian Arctic Islands which, collectively, represents the largest area of land ice outside of the Greenland and Antarctic ice sheets. Another 50,000 km2 of land ice covers Canada's western and Northern Cordillera. These land ice masses contribute significantly to the change of sea level and flow of rivers. The thickness and extent of marine ice fields, or sea ice, is also a critical aspect of the functioning of the Arctic marine ecosystem, the global climate system, marine navigation and issues related to sovereignty and protection of the environment. Today we see an ever-increasing number of demands on Arctic coastal zones and lands, ocean and their resources. While traditional fishing and marine transportation continue to be of prime importance, they are now joined by other uses, such as oil and gas exploration, aquaculture, eco-tourism, search and rescue operations, etc. With over $20 billion in annual economic activity, Canada's Arctic zones and their resources are significant contributors to the overall Canadian economy. Our need for tools to predict and monitor short and long-term environmental changes, especially in the Canadian Arctic, has never been greater. Improved, up-to-date environmental data is needed to plan for environmentally and economically sound growth and to develop more sustainable practices to protect our waters and lands. Space-based Earth Observation (EO), including RADARSAT-2 and CryoSat-2, provides us with unique and essential information to understand how our northern environments work, allowing, for instance, more accurate mapping, environmental monitoring, safety and emergency response. After the launch of CryoSat-2, the Devon Ice Cap in the Canadian Arctic is serving as the primary site for calibration/validation of the altimeter in Canada, while the Columbia Ice field in the Canadian Rockies is an airborne altimeter cal/val site for efforts that are parallel to the CryoSat MB retrieval goals. The Lincoln and Beaufort Seas is also used as test sites in the validation of the measurements of marine ice. Since 2000, the Canadian Space Agency (CSA) EO Applications and Utilization Division have managed over 200 projects and distributed over $45M in funding to Canadian OGDs, industry and universities. The poster will be review of CSA past & on-going EO initiatives related to the cryosphere and management in Canada’s Northern regions, focusing on existing applications programs, partners, coordinated activities, synergies and use of data and products (i.e. ice sheets margins and altitude, changes in sea ice thickness, etc.).

Potential Synergy of RADARSAT-2 and CryoSat-2 for Sea Ice Volume Flux Estimates in the Canadian Arctic Archipelago

Howell, S.E.L.
Environment Canada

Environment Canada's Climate Research Division is currently estimating the sea ice area budget of the Canadian Arctic Archipelago in collaboration with Canadian Space Agency and Canadian Ice Service. The Canadian Ice Service's record of RADARSAT-1 and RADARSAT-2 imagery is being utilized to generate sea ice area flux estimates from 1997 to present. Following determination of the Canadian Arctic Archipelago's sea ice area budget our next step is to investigate the potential of integrating CryoSat-2 ice thickness estimates with RADARSAT-2 ice area fluxes. This would allow for the generation of recent sea ice volume flux estimates between the Canadian Arctic Archipelago and Arctic Ocean. This presentation will illustrate the time series of RADARSAT derived sea ice area flux between the Canadian Arctic Archipelago and Arctic Ocean from 1997-2012, present a preliminary sea ice area budget of the Canadian Arctic Archipelago and then discuss the potential integrating of CryoSat-2 with RADARSAT-2 for estimating sea ice volume flux between the Canadian Arctic Archipelago and Arctic Ocean.

Application of CryoSat-2 GDR Data from DEM Generation of Antarctica

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Digital elevation models (DEMs) are crucial components of research on the Antarctic ice sheet. They are frequently used to calculate the elevation changes and regional mass balances of glaciers (Gardelle, Berthier et al. 2012). Research on terrain data collection and DEM generation has attracted substantial attention. It is difficult to obtain high-accuracy terrain data over large areas with field surveys and photogrammetry in Antarctica, especially for remote and high-altitude Antarctic inland glaciers.

Launched in early 2010, CryoSat-2 is equipped with SIRAL (Synthetic Aperture Interferometric Radar Altimeter) instrumentation, also termed a Ku band pulse-width limited radar altimeter. The inclination of the satellite's orbit is 92iã, and the orbit can approach latitude of 88iã. The repeat period of 369 days is formed by successive shifts of the 30-day repeat pattern (Wingham, Francis et al. 2006). So the temporal sampling of each crossover will be very poor but the crossover spatial sampling will be very dense, ten times more than EnviSat RA-2 (Remy and others, 2012) and dozens of times more than ICESat/GLAS. The new data product and dense data distribution make high precision and the most extensive coverage of DEM generated by CryoSat-2 GDR data possible.

We collect the Level 2A of GDR data of 2012. The height of the surface in Level 2A of GDR is fully corrected for instrument effects, propagation delays, measurement geometry, other geophysical effects such as tides and the slope-induced error caused by the large radar footprint. The off-nadir position of the retracked point is corrected by the slope model. The slope model is replaced with better model. We remove the incredible data that have some error in the measurement through the measurement quality flags of the 20Hz measurement parameters. And the GDR data near the coastline of the Antarctica removed largely have the cross-track angle error of SARIn mode. The new measurement mode using two antennas perhaps needs to be improved. A grid DEM is selected for terrain modeling in this study. According to the distribution of the point data, Kriging (ordinary Kriging) is a suitable interpolation method for DEM generation in this study. The grid resolution of 500m is recommended based on considerations of the spacing of these nearly parallel tracks. The DEM generated by CryoSat-2 GDR data will update the existing DEM products of Antarctica. And we will use the IceSat/GLAS data from 2005 to 2008 and the Icebridge data from NSIDC to verify the DEM generated by CryoSat-2 GDR data.

Sea Ice Measurements in McMurdo Sound, Antarctica for the Validation of Remotely Sensed Sea Ice Properties.

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The coastline of the Antarctic continent is largely fringed by ice shelves. The interaction of ocean water with ice shelves in the sub ice shelf cavity leads to outflow of very cold, partly supercooled water which significantly affects the sea ice formation process. It is estimated that sea ice in the vicinity of ice shelves is about 10 % thicker than it would be without the presence of ice shelves. The sea ice in McMurdo Sound is highly representative of this described phenomenon as investigations over the past 15 years show. McMurdo Sound is therefore thought to be representative of a large percentage of the Antarctic continental coastline. Logistical constraints have restricted these observations largely to the close vicinity of Ross Island near New Zealand's Scott Base. In this research we aim to extend information available on general sea ice conditions from this local area to the larger region using remote sensing methods including ICESat and CryoSat-2 data, as well as helicopter borne electromagnetic induction sounding. Here we concentrate on the observation of the freeboard height, which is validated by extensive ground measurements.

Comparison of Sea Ice Freeboard and Thickness Distributions from Aircraft Data and CryoSat-2

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Sea-ice thickness on basin-scale is an important variable in the polar climate system, however datasets are sparse. The only remote sensing technique capable of obtaining sea-ice thickness on that scale are satellite altimeter missions, such as the ICESat and CryoSat-2. The CryoSat-2 satellite was launched in 2010 and is equipped with the Ku-Band radar altimeter SIRAL. CryoSat-2 is part of the ESA's Living Planet Programme and was especially developed for the observation of changes in the cryosphere. This includes especially the determination of variations in sea-ice thickness in the Arctic Ocean. For that purpose it is essential to validate the CryoSat-2 products.

The CryoSat Validation Experiment (CryoVEx) combines field and airborne measurements in the Arctic and Antarctic in order to validate CryoSat measurements. Here we report the results from the first combined aircraft and satellite data acquisition over sea ice in the Arctic Ocean. During the CryoVEx 2011 campaign in the Lincoln Sea several CryoSat-2 underpasses were accomplished with two aircraft. One aircraft was equipped with ASIRAS, an airborne radar altimeter, and an airborne laser scanner; the second aircraft carried an electromagnetic induction device for direct sea ice thickness retrieval and an airborne laser scanner as well. Both aircraft flew in close formation at the same time of a CryoSat-2 overpass.

This is a presentation about the results from comparing sea-ice freeboard and thickness distribution of laser scanner, radar altimeter and electromagnetic sounding measurements with the CryoSat-2 product within the multi-year sea ice region of the Lincoln Sea in spring, with respect to the penetration of the Ku-Band signal into the snow and the effect of surface roughness on the radar range retrieval.

CryoSat Radar Altimetry over Antarctic Sea Ice

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Since its launch in 2010, analysis of satellite radar altimetry data from CryoSat has aided the production of sea ice thickness maps across the entire Arctic Ocean basin. Similar maps are not yet available for the Antarctic. In contrast to the widely reported decline in the Arctic, model predictions concerning the overall volume of Antarctic sea ice under a warming climate are ambiguous. Large-scale observation of Antarctic sea ice thickness and volume are required to determine trends and aid predictive models of future global climate change.

In the Antarctic the weight of snow cover is often sufficient to depress sea ice below the ocean level, forming negative ice freeboards and flooded and refrozen snow. This complicates the analysis of radar returns from sea ice as radar signals may be reflected from an undetermined point within the floe rather than the snow-ice interface. In addition, a detailed climatology of snow depth and density does not exist for the Antarctic and improved information on snow cover on sea ice would allow improved estimates of sea ice thickness.

We utilise satellite radar altimetry from CryoSat combined with, but not limited to, IceBridge snow radar and ICESat laser altimetry data to observe Antarctic sea ice. We investigate the nature of radar echoes over the ice, snow depth retrieval methods, and the possibility of combining these to obtain reliable values of Antarctic sea ice thickness.

Analysis of airborne synthetic aperture radar waveforms over arctic sea ice

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Sea ice thickness and its changes are one of the largest uncertainties in the Arctic climate system. To address these uncertainties CryoSat was launched in 2010. Onboard is the SAR/Interferometric Radar Altimeter (SIRAL) which uses the synthetic aperture radar technique to enhance the resolution along track. The new, improved sampling technique and the resulting changes in the signal shape lead to the question whether a distinction of different sea ice types may be possible. To answer this question we analyze airborne Ku-band radar altimeter data over different surface types in the arctic ocean from CryoSats' pre-launch validation campaigns. We define various parameters to account for the difference in strength and width of the returned power waveform and select the most appropriate parameters. With a Bayesian based method we are able to identify around 80 percent of the waveforms correctly. We further find that the use of the radar power echo maximum can minimize the rate of false detection of leads compared to the widely used pulse peakiness parameter. The ability to distinguish between different ice types makes it possible to improve the freeboard retrieval and the conversion into sea ice thickness by applying surface type dependent values for the sea ice density and snow load. More analysis however is required to test the method presented here for SIRAL onboard CryoSat.

CryoSat-2 Waveform Shape and Signal Penetration along the 2011 Greenland Inland Traverse

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The 2011 Greenland Inland Traverse (GrIT) provides a detailed elevation profile across 1120km of the Greenland Ice Sheet. Initial comparisons of GrIT Kinematic GPS elevations to CryoSat-2 Level-2 elevation measurements reveal a consistent vertical offset of 1.2m. Examination of Level-1b data with correction for datation errors and additional post-processing of GPS measurements improves comparisons of elevation measurements. GPS-validated CryoSat-2 elevation measurements lend confidence to a detailed analysis of waveforms, and signal penetration along the varying surface slopes and facies conditions crossed by GrIT.

Poster Session – Ocean: Mission, Instrument and Data Processing

Performance of ESA CryoSat-2 GDR Data over Open Ocean

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Although not part of the basic mission objectives the CryoSat-2 data acquired over ocean has already shown its suitability and value for a variety of ocean applications. Especially, the combination of this data with other altimeter systems is important to enhance the temporal and spatial resolution of sea surface height measurements. The majority of altimeter users presumably apply the official ESA Level 2 GDR product. Hence, the quality of this product and its consistency with other altimeter missions such as Jason-1/2 and Envisat is of particular interest.

In this contribution an analysis of ESA Level 2 GDR product from baseline B is presented. A comprehensive quality assessment is done by means of a global multi-mission crossover analysis. It reveals time variable radial errors of the mission together with its stochastic properties as well as a significant time tag bias and provides information on the orbit accuracy. Moreover the consistency of the different measurement modes (LRM, SAR, SARin) is investigated.

Quality Assessment of CryoSat-2 ESA Level 2 Products Over Ocean

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CryoSat-2 is ESA's ice mission which primary objective is to serve Cryosphere science. Nevertheless, CryoSat-2 has, in theory, the potential to be a mission of opportunity for oceanography. Even if CryoSat-2 is not an optimised payload for mesoscale observation (no radiometer and single frequency altimeter, no repetitive ground track), 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.

The CryoSat-2 altimeter is operated almost continuously over ocean, either in Low Resolution Mode (like conventional pulse-limited altimetry sensors) or in the so-called Doppler/SAR mode (higher-resolution and lower noise level). This study presents an overview of the quality of the Level 2 products over ocean, based on the analysis of the month of June 2012 (new version of the products delivered by ESA since February 2012). These results are focused on the data acquired in Low Resolution Mode only.

Preliminary Analysis Between CPP Retracker and SAMOSA Retracker Over Open Ocean in SAR Mode

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Two different methodologies to derive Sea Surface Heights (SSH) and Significant Wave Heights (SWHs) over open ocean from CryoSat L1b SAR waveforms have recently been devised and developed: the first one is the one currently implemented in the CNES/CLS CPP (CryoSat Prototype Processor) and is based on a purely numerical solution and second one is the one developed by the SAMOSA team and is based on a purely analytical solution.
One of the goals of the R&D Project CryoSat+ for Ocean (CP4O), supported under the ESA STSE (Support To Science Element) programme and by CNES, is to assess any eventual differences stemming from the two methodologies through an exhaustive round robin exercise.
The scope of the present work is to feature the very first preliminary results of an inter-comparison analysis operated between SSHs and SWHs derived by the SAR CPP Re-tracker and the SAMOSA re-trackers, run over L1b CPP waveforms , L1b SAR Kiruna PDGS waveforms (Baseline B) and ESRIN EOP-SER SAR L1b waveforms (SAR waveforms generated independently at the ESRIN by EOP-SER Altimetry Team).
This activity has been performed by the ESRIN EOP-SER Altimetry Team as a side task in the CryoSat for Ocean Project (CP4O) and the analysis carried out on

just one CryoSat SAR Pass (2012 05 30 Time 21:19:55) acquired over the Pacific Ocean.
The SAMOSA re-tracker and the CPP re-tracker, when applied on the same input waveforms (CPP) and with the same scenario conditions, seem to provide equivalent results with very minor differences in term of range/SWH noise and trends/biases.
The inter-comparison against the Kiruna PDGS waveforms demonstrates the significant and detrimental effect for open ocean studies, in term of noise and bias, caused by the application of the weighting function (Hamming function) in the Kiruna PDGS and by the truncation of the waveform trailing edge (CryoSat PDSG Baseline B).
This effect is sufficient to severely impact the utility of the currently produced Kiruna PDGS derived products over ocean and has led to the recommendation by the CP40 team to use CPP Products in the framework of the Project CP40. The inter-comparison against the ESRIN EOP-SER waveforms highlights that trends/biases in range can result from different approaches adopted in the application of stacking algorithms or in the Doppler Correction.
It is strongly recommended that the origin of such discrepancies is investigated and, in the end, to standardize the procedures of the stacking algorithms.

Even if the first results seem to be promising, it needs to bear in mind that they are not fully conclusive because they have been derived from just one CryoSat Pass but nonetheless they highlight the outstanding importance that holds an extensive inter-comparison exercise between the two existing re-tracking methodologies, based on at least two sub-cycle dataset in different sea state conditions (for example moderate and low sea state).
This last activity will be one of the major outcomes of the CP40 WP 5000.

Poster Session – Coastal Ocean

Coastal SAR Altimetry: An Experiment in the Northern Caspian Sea

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As it has been already shown by previous works (see Dinardo et al. at the 2011 5th Coastal Altimetry Workshop), the CryoSat-2 SAR Echoes behave very well in accordance with the waveform physical models even in very close proximity of the coastline in case of favourable conditions (ground-tracks orthogonal to the coastline) whereas they can be still heavily land-contaminated in case the ground-track runs parallel to the coast line.
This anisotropic effect is due to the shrinkage of the spatial resolution in SAR mode that occurs just in along-track direction, leaving unchanged the across-track resolution.
As a consequence of this footprint shrinkage, the advent of SAR Mode promises to revolutionize the coastal zone satellite altimetry.
Anyway, nowadays, all the current more mature SAR Re-tracking methodologies (SAMOSA and CNES/CLES CPP) are designed to offer the best performances over open ocean surfaces (diffusive surface scattering mechanism). Notwithstanding, they may perform also very well in coastal zones unless:

1) the echoes don't suffer a really "heavy" contamination from the surrounding land 2) the echoes are originated from very shallow and still coastal waters (specular surface scattering mechanism). This second case is not very frequent in coastal zones but it may be observed now more often since in SAR mode we have finally the possibility, in favourable conditions, to really reach the shoreline where a still waters scenario can be encountered.
Following the initial work presented at 6th Coastal Altimetry Workshop (2012), we will attempt to adapt the original open ocean SAMOSA Model to a coastal still waters scenario.
This adaptation will be operated estimating the water surface rms slope (RMSSS) from the backscattered power distribution vs. Doppler beam angle as achieved integrating the STACK's SAR power echoes.
This RMSS parameter is an indicator of how much specular or diffusive is the surface illuminated by the radar.
The RMSS parameter will be hence fed as input in the SAMOSA Physical Model in order to adapt the model itself automatically to the changed water scenario conditions, turning the model's classic long-tail SAR waveform into a very peaky waveform.
The benefit of this methodology is that we use either for open ocean conditions either for coastal still water conditions the same model and re-tracker scheme, avoiding hence any bias or discontinuity in height , typically occurring when one swaps waveform model or re-tracker during the same pass.
The experiment will be run at the wetlands of the Volga's Delta in the Northern Caspian Sea in summer time. CryoSat-2 is covering the area in SAR mode and along the passes, the instrument is facing an abrupt transition from diffusive open sea condition to very specular water conditions over the Volga's Delta wetlands. Hence, this seems to be the ideal environment where to test the proposed methodology.

Poster Session – Ocean Circulation

A Preliminary Arctic Ocean Mean Dynamic Topography Using CryoSat & GOCE

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The Arctic is a region of great significance to the global climate, and is currently undergoing major changes on a short timescale. It is crucial to improve monitoring of this region and our understanding of its climate. However, the polar environment makes gathering spatially & temporally comprehensive data via in-situ measurements highly impractical. Furthermore, our ability to use satellite-based techniques in the region has been limited by the inclination at which past missions have been flown.

CryoSat is unprecedented in providing continuous, high-resolution altimetry at latitudes of up to 88º, giving almost complete polar coverage. In addition to CryoSat's primary mission of surveying ice, this allows us to derive the mean dynamic topography (MDT) and hence geostrophic circulation of almost the entire Arctic Ocean by combination with new gravity data from the GOCE mission. Given the GOCE's high resolution, we may achieve excellent accuracy using this technique.

In this paper we describe how gridded gravimetric data is produced from the latest GOCE potential model and filtered to mitigate commission errors and the Gibbs phenomenon. We then describe how this is combined with a recent mean sea surface (MSS) derived from CryoSat altimetry to produce a solution for the Arctic Ocean MDT. The solution using this gridded method is presented along with the geostrophic currents calculated from it. We also present a preliminary comparison of these results with previous work. Finally we outline future work on a superior MDT solution by combining the MSS & geoid in spectral form, as well as some potential applications of this new data.

Poster Session – Land & Inland Water

CRUCIAL - CryoSat+ Inland Water and Land

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The CryoSat-2 SIRAL altimeter presents a unique opportunity for inland water height retrieval. In order to maximise the potential of this new dataset the ESA CRUCIAL contract has been set up to investigate the application of CryoSat-2 data over land and inland water.
When operating in SAR Full Bit Rate (FBR) mode CryoSat-2 captures waveforms at an unprecedented resolution alongtrack, allowing smaller inland water targets than possible with conventional altimetry to be measured. Prior work performed with the Envisat Individual echoes has shown that a high Pulse Repetition Frequency (PRF) allows successful measurements to be obtained from river targets as small as 25m across. SAR FBR data are acquired over the Mekong River area, including the Mekong Delta itself. This region provides the ideal test-bed for obtaining small target inland water measurements and early results of FBR waveform reconstruction and analysis are presented within this paper.
Whilst FBR data over land are available in a few test regions, over much of the Earth's land surface measurements are acquired in Low Resolution Mode (LRM). These data are comparable to those obtained by conventional altimeters, such as ERS-2 and EnviSat. The non-repeat orbit of CryoSat-2 presents a new challenge to inland water measurement by satellite radar altimetry, as repeat timeseries are no longer possible. However, CryoSat-2 data produce stage measurements from along the course of rivers more regularly than the 35-days of previous ESA missions. New methodologies must be investigated to allow hydrologists to harness the full benefit of these new data. This paper presents initial findings of investigations over major river systems captured in LRM mode.

Applications of CryoSat-2 SARin and LRM Modes for Lakes Monitoring

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The CryoSat-2 altimetry data in the two modes, SARin and LRM have been applied over a set of lakes in Eurasia and South America. The 1 Hz LRM data allow to estimate water level variations of large lakes, like Baikal, Onega and Ladoga (Russia), and Bakhash (Kazakstan), over which more than 100 different tracks have been processed. Despite the repeat cycle of Cyosat-2 (369 days) is not optimal for hydrology, for such lakes, through a crossover point analysis it is possible to calculate the water height variations every 2-3 days. Moreover, the spatial sampling of the measurements is well suitable to determine mean lake surface (linked to the form of the static geoid) of these large lakes, which is hardly achievable with other missions like Jason-2 or Envisat. In contrast the orbital cycle is not designed to perform survey of smaller lakes or reservoirs. The 20 Hz SARin mode would have a significant interest for studying small lakes or reservoirs, thanks to the measurements design as it allows catching very narrow area of water with high precision, but again the repeat orbit cycle limits the use for hydrology with too small number of passes every year. SARin mode is investigated here over the big lakes of South America (Argentino (Argentina), General de Carrera (Argentina), Titicaca (Peru) and Nicaragua (Nicaragua)) and is compared to radar altimetry data from Jason-1, Jason-2 and Envisat satellites. With the SARin mode we have also analyzed the results over the Lake Issykkul (Kyrgyzstan) which is a current Cal/Val site for radar altimetry, where several geodetic expeditions have been carried over the last 8 years. It has allowed mapping precisely the mean lake surface of Issykkul, with GPS vertical profiles over the lakes, and large set of In situ data are also available to perform error budget of various satellite missions. It has been applied to the CryoSat-2 SARin datasets.

CryoSat-2 SAR Mode over the Eastern Amazon Basin

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Since October, 2012, CryoSat-2 is collecting data in SAR mode over the eastern half of the Amazon basin. These data are of major importance in the process of assessing the interest of SAR data over rivers since several operational missions such as JASON/CS and the SENTINEL-3 constellation might also collect SAR data over rivers, potentially. In this area, the Amazon basin includes very large reaches in the central channel as well as very narrow ones, in particular on the left side, towards Guyanas. Given that the orbit does not permit to make time series at given locations, as it is required to compare heights with gauge readings, we focus on the detection capability, and on the potential to provide accurate slopes at various length scales, one of the intensively searched for hydrological parameters. Our results show that the acquisition of SAR data over rivers is such an improvement both in terms of potential density of the height measurements due to the high detection capability and in terms of accuracy of these measurements (as high as the decimetric level) that SAR mode would turn to be a major step in continental altimetry if scheduled for the missions to be launched in the near future.

Poster Session – Outreach and User Tools

A Toolkit for CryoSat Investigations by the ESRIN EOP-SER Altimetry Team

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The scope of this work is to feature the new toolkit for the exploitation of the CryoSat data, designed and developed by the Altimetry Team at ESRIN EOP-SER (Earth Observation - Exploitation, Research and Development).
The tool framework is composed of two separate components: the first one handles the data collection and management, the second one is the processing segment.
The CryoSat FBR (Full Bit Rate) data are downlinked uncompressed from the satellite, containing unaveraged individual echoes. These data are made available in the Kiruna CalVal server in a 10 day rolling archive. Daily at ESRIN all the CryoSat FBR data, in SAR and SARin Mode, are downloaded (around 30 Gigabytes) catalogued and archived in local ESRIN EOP-SER workstations.
As of November 2012, the total amount of FBR data is over 5 Terabytes, with CryoSat acquisition dates spanning January 2011 to October 2012 (with some gaps). This archive was built by merging partial datasets available at ESTEC and NOAA, that have been gently made available for EOP-SER team.
The on-demand access to this low level data is restricted to expert users with validated ESA P.I. credentials. Currently the main users of the archiving functionality are the team members of the Project CP4O (CryoSat Plus for Ocean), CNES and NOAA.
The second component of the service is the processing segment. On the EOP-SER workstations there is internally and independently developed software that is able to process the FBR data in SAR/SARin mode to generate multi-looked echoes (level 1b) and subsequently able to re-track them in SAR and SARin mode (Level 2) over open ocean, exploiting the SAMOSA model and other internally developed models.
The processing segment is used for research & development scopes, supporting the development contracts awarded confronting the deliverables to ESA, on site demonstrations/training to selected users, cross-comparison against third part products (CLS/CNES CPP Products for instance), preparation to Sentinel-3 mission, publications, etc.
Samples of these experimental SAR/SARin L1b/L2 Products can be provided to the scientific community for comparision with self-processed data, on-request.
So far, the processing has been designed/optimized for open ocean studies and is fully functional only over these kind of surfaces but there are plans to augment this processing capacity over coastal zones, inland waters and over land in sight of maximizing the exploition of the upcoming Sentinel-3 Topographic mission over all surfaces.
There are also plans to make the toolkit fully accesible trough an operation of software "gridification" to run in the ESrin GPod (Grid Processing on Demand) Service.
In this presentation, will be shown graphs and statistics about the spatial coverage and amount of FBR data actually archived on the EOP-SER workstations and some scientific results and the tests that have been produced and operated to validate the products (tests against CryoSat Kiruna PDGS Products and against transponder data).

BRAT: The Basic Radar Altimetry User Toolbox for CryoSat Products

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The Basic Radar Altimetry Toolbox (BRAT) is a collection of tools and tutorial documents designed to facilitate the processing of radar altimetry data, including CryoSat data in all three acquisition modes. This project started in 2006 from the joint efforts of ESA (European Space Agency) and CNES (Centre National d'Études Spatiales). The latest version of the software, 3.1, was released in March 2012. The tools enable users to interact with the most common altimetry data formats, being the most used way, the Graphical User Interface (BratGui). This GUI is a front-end for the powerful command line tools that are part of the BRAT suite. BRAT can also be used in conjunction with Matlab/IDL (via reading routines) or in C/C++/Fortran via a programming API, allowing the user to obtain desired data, bypassing the data-formatting hassle. The BratDisplay (graphic visualizer) can be launched from BratGui, or used as a stand-alone tool to visualize netCDF files – it is distributed with another ESA toolbox (GUT) as the visualizer. The most frequent uses of BRAT are quick data visualization/export and simple computation on the data fields. BRAT can be used for importing data and having a quick look at his contents, with several different types of plotting available. One can also use it to translate the data into other formats such as netCDF, ASCII text files, KML (Google Earth) and raster images (JPEG, PNG, etc.). Several kinds of computations can be done within BratGui involving combinations of data fields that the user can save for posterior reuse or using the already embedded formulas that include the standard oceanographic altimetry formulas (MSS, MSLA, etc.). The documentation collection includes the standard user manual explaining all the ways to interact with the set of software tools but the most important item is the Radar Altimeter Tutorial, which contains a strong introduction to radar altimetry, showing its applications in different fields such as the Cryosphere, Oceanography, Geodesy, Hydrology among others. Included are also “use cases”, with step-by-step examples, on how to use the toolbox in the different contexts. The upcoming release that is on the forge will focus on Sentinel 3 Surface Topography Mission that is built on the successful heritage of ERS, Envisat and CryoSat. The future version will provide, among other enhancements, support for reading the upcoming S3 datasets and specific “use-cases” for SAR altimetry in order to train the users and made them aware of the great potential of SAR altimetry for scientific applications in the Cryosphere, Ocean and coastal Ocean, land and inland water. The BRAT software is distributed under the GNU GPL open-source license and can be obtained, along with all the documentation (including the tutorial), on the website: http://earth.esa.int/brat