CRyosat-2 sUCcess over Inland water And Land (CRUCIAL) Contract 1/6287/11/I-NB

D2200 Development and Validation Plan

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Abstract

The objective of WP2000 is to perform a comprehensive state-of-the-art review of all current initiatives, algorithms, models and EO based datasets relevant to the theme of Land and Inland water.

The review will include:

- A detailed review, assessment and cross-comparison of existing products, datasets, methods, models and algorithms, as well as related range of validity limitations, drawbacks and challenges.
- A detailed analysis of the suitable models and data integration approaches as well as their related limitations, drawbacks and challenges.
- A survey of all accessible associated data sets (space, airborne and in situ) which could be of use for development and validation activities (problems such as the lack of sufficient data sets will be investigated and practical solutions identified).
- An analysis and identification of the best candidate test areas to be used in later Work Packages. This shall include a complete analysis and description of the available data over those test areas.
- This will be obtained by performing a thorough review of the most current scientific publications in conjunction with drawing on the expertise of the consortium in related ESA projects, and other relevant research activities.

This report presents a Development and Validation Plan (DVP) resulting from the Preliminary Analysis Report (PAR) relevant to the theme of Land and Inland water. The document presents an initial overview of activities planned under work packages 3000 (WP3000) and 4000 (WP4000)

It is the second of two deliverables within Work Package 2000 (WP 2000) of the CRUCIAL project, the other deliverable is the PAR.

The document produces summary information to allow the reader to understand:

- What new products are planned to be delivered
- The input data which will be used to generate each product
- The geographic location for the validation of the product and the time period it will cover
- The steps needed to obtain the product and new techniques that need to be applied
- The likely risk in obtaining the product

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Abbreviations and Acronyms

Abbreviation	Meaning
ATBD	Algorithm Theoretical Basis Documents
BEST	Berry Expert SysTem
CRUCIAL	Cryosat-2 sUCcess over Inland water And Land
DHI	Independent, international consulting and research organization. Formally the Danish Hydraulic Institute
DTU	Danish Technical University
DVP	Development and Validation Plan
FBR	Full Bit Rate
FEWS-RFE	Famine Early Warning System – RainFall Estimate
EGM	Earth Gravitational Model
EGM08	Earth Gravitational Model 2008
ERS2	European Remote Sensing satellite 2
ENVISAT	Environmental Satellite
ESA	European Space Agency
EO	Earth Observatory
GRACE	Gravity Recovery And Climate Experiment – NASA satellite
GRDC	Global Runoff Data Centre
IPF	Instrument Processing Facility
Jason	US/French Altimeter Satellite
L1A	Level 1A

L1B	Level 1B
LOTUS	EU project called "preparing Land and Ocean Take Up from Sentinel-3"
LRM	Low resolution Mode
Mike-11	1 dimensional river model
NAM	Nedbør-Afstrømnings-Model. A lumped conceptual rainfall runoff model
NCL	Newcastle University
NOAA-GFS	National Oceanic and Atmospheric Administration – Global Forecasting System
NRT	Near Real Time
OCOG	Offset Centre Of Gravity
PAR	Preliminary Analysis Report
PMP	Project Management Plan
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar mode of Cryosat SIRAL
SARIN	Interferometric Synthetic Aperture Radar mode of Cryosat SIRAL
SIGDR	Sensor Interim Geophysical Data Records
SIRAL	SAR Interferometric Radar Altimeter
SWAT	Soil and Water Assessment Tool. A Hydrological model
TOPEX/Poseidon (T/P)	US/French Altimeter Satellite (1992-2006)
TRMM	Tropical Rainfall Measuring Mission
WOIS	Water Observation and Information System

WP	Work Package

1. Introduction

This document contains a development and validation plan (DVP) for the CRUCIAL project. This Deliverable 2200 (D2200) is part of Work Package 2000 (WP 2000). The other deliverable in WP 2000 is the Preliminary analysis report (PAR) – Deliverable 2100 (D2100).

In PAR a state-of-the-art review of all current initiatives under the theme of Land and Inland Water applications was carried out. As a result of this a DVP has been developed.

The document produces summary information to understand:

- What new products are planned to be delivered
- The input data that will be used to generate each product
- The geographic location for the validation of the product and the time period it will cover
- The steps needed to obtain the product and new techniques that need to be applied
- The likely risk in obtaining the product

2. Products – Usage

The initial process batch considered 3.5 months of data. Further batches are data are being acquired as a minimum of one year of data is needed in order to detect seasonal signals and to achieve complete spatial coverage from Cryosat-2.

Figure 1 shows the Cryosat-2 tracks and which mode it is in throughout the world. Clearly over land most of the world is in LRM mode. There are also larges areas in SAR and SARIN mode.

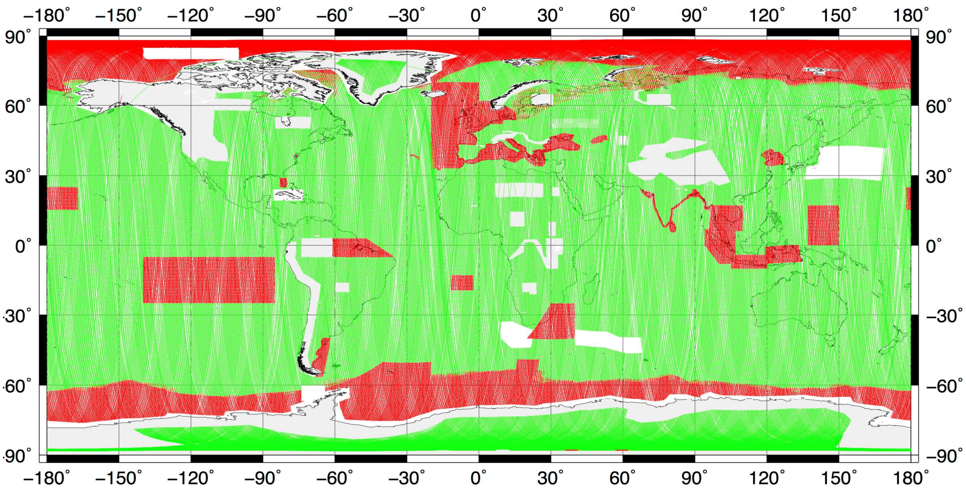

Figure 1 Cryosat-2 tracks. Red are in SAR mode, Green in LRM mode and the blank areas SARIN mode.

The PAR concluded that from initial analysis useable waveforms are being provided in LRM from Cryosat-2, and that a rough generic estimate would be that half of the records contain useable data over flat to moderate terrain. These waveforms had recognizable characteristics related to the terrain overflown. Retracking LRM data over land will require sufficient data to enable parameter tuning of existing algorithms specific to the hardware and antennae properties of Cryosat-2.

The CryoSat-2 SAR FBR and Level 1B (L1B), generated by the ESA Instrument Processing Facility (IPF), are distributed to users by ESA. The Full Bit Rate (FBR) product for SAR and SARIN modes is the output of uncalibrated individual echoes after deramping in the time domain. This data is also called the Level 1A (L1A) and is processed to form the L1B data. This is the lowest processing stage before information compression occurs. Level 1B data consists of multi-looked echoes at a rate of, approximately, 20 Hz at each point along the ground track of the satellite. CryoSat-2 SAR L1B products are currently available in Baseline B with Baseline C expected mid-2014. CRUCIAL has commenced with Baseline B data but will update to Baseline C when the archives are available.

Initial analyses has utilised LRM and the 20 Hz SAR L1B data. Our philosophy within the CRUCIAL project as detailed in this DVP is to fully understand and ingest LRM and SAR L1B data. LRM analysis shows a very high proportion of complex echoes, multi-target responses, in addition to problems/complexities resembling those from 'ocean mode' altimeters. Cryosat2 is not returning data over much rough terrain. For SAR L1B, the study of the Amazon (see Figure 12 and Figure 13) shows the complexity of SAR L1B waveforms over inland waters that deviate substantially from the standard Brown model expected over oceans. Some of the waveforms are ocean-like with others complex with multiple peaks revealing reflective components in the waveform from other bright targets such as still waters or wetlands in addition to the required inland water signal.

3. Products – Development and Validation

Cryosat-2 LRM/SAR data will be downloaded and stored on Newcastle servers prior to pre-processing into an internal form for retracking within the Berry Expert SysTem (BEST). Waveforms will be categorised into shape classes. Ocean-like or quasi-specular are immediately interpretable but as seen over the Amazon additional highly complex waveform shapes are observed. Detailed analyses will be necessary to both tune BEST to the Cryosat-2 waveform parameterisation based on the satellite specific altimetric hardware and to undertake a detailed investigation and categorisation of the waveform shapes. Algorithm tuning requires compilation of time series of waveform shapes across the test areas enabling the retracking to convert waveform shape to altimetric height.

Six rivers and lakes test regions have been selected in be included as part of the development and validation plan. This includes two lakes in Africa and four major rivers systems. A review of the study of lakes from satellite altimetry can be seen in Crétaux et al. (2011). The selection is determined somewhat by the operation mode (either LRM or SAR) of Cryosat-2 in these locations. The targets have also been selected for one of three reasons or a combination of all three. Firstly - capability to analyse the waveforms; secondly - retracking validation targets and, thirdly - river modelers targets. The six targets and Cryosat-2 SIRAL mode are

- Lake Tana (LRM)
- Lake Malawi (LRM)
- Amazon River and tributaries (LRM, SAR)
- Mekong (LRM, SAR)
- Brahmaputra - synergy with LOTUS (LRM)
- Zambezi - synergy with ESA Tigernet (LRM)

Other areas considered were the Syr Darya and Lake Issyk-kul but given a much lower priority as Cryosat-2 is in SARIN mode over these areas.

The objective of these studies is to utilize Lake Tana and Lake Malawi as validation targets for LRM data by comparison against contemporaneous Jason-2 altimetry. The river targets are either the subject of river modelling by members of the consortium, provide adjacent LRM and

SAR mode data for comparison, or synergistic with other ongoing programs. In situ gauge data is also available for the rivers.

Cryosat-2 presents new challenges to hydrodynamic river modelling as unlike previous satellite missions the orbit is non-repeating (repeat period 369 days) with a sub-cycle of 30 days. The orbital constraint will necessitate a change in hydrodynamic modeling approach. In particular, it is necessary to consider orthometric water height (height above mean sea-level) everywhere in the river. In particular it is not possible to consider the altimetric heights as a virtual station time series and hence conversion of altimetric height to depth and discharge by a rating curve is less straightforward. Conventional techniques bases on the river cross-section, river slope and altimetry only works for long time series as obtained from a repeat orbit. Thus, empirical schemes (e.g. Birkinshaw et al, 2010, 2014) are compromised while in hydrodynamic schemes based on rainfall-runoff models (e.g. Michailovsky et al, 2013; Michailovsky and Bauer-Gottwein, 2014; Finsen et al., 2014) the modelling will be non-linear and require the Extended Kalman Filter.

3.1 Lake Tana

3.1.1 Lake Tana – Introduction

Lake Tana (Figure 1) is the source of the Blue Nile and is the largest lake in Ethiopia. Located in the north-western Ethiopian Highlands, the lake is approximately 84 kilometers long and 66 kilometers wide, with a maximum depth of 15 meters, an average depth of 4m and a surface elevation of 1,788 meters. Its surface area ranges from 3,000 to 3,500 km,² depending on season and rainfall, so complex waveforms can occur especially near lake boundaries. The lake level has been regulated since the construction of the control weir where the lake discharges into the Blue Nile. Details of the hydrology of the catchment can be seen in Wale et al. (2009) and Chebud and Melesse (2013) and more details about the lake in Ayana et al. (2014). Satellite altimetry data has previously been used to obtain water levels in Lake Tana. It was one of 12 lakes considered by Mercier et al. (2002) in their analysis of 7 years of TOPEX/Poseidon (T/P) altimetry data acquired between 1993 and 1999. Lake Tana was one of three lakes considered by Duan and Bastiaanssen (2013). They used data from four satellite altimetry databases and validated it with in-situ data. Lake Tana was one of the lakes used by Ričko et al. (2012) when they tested water level products from different satellite altimetry. Pascual (2013) has carried out a validation study on altimetry data obtained from ENVISAT and T/P missions for Lake Tana with the in-situ data and found good agreement and low RMSE.

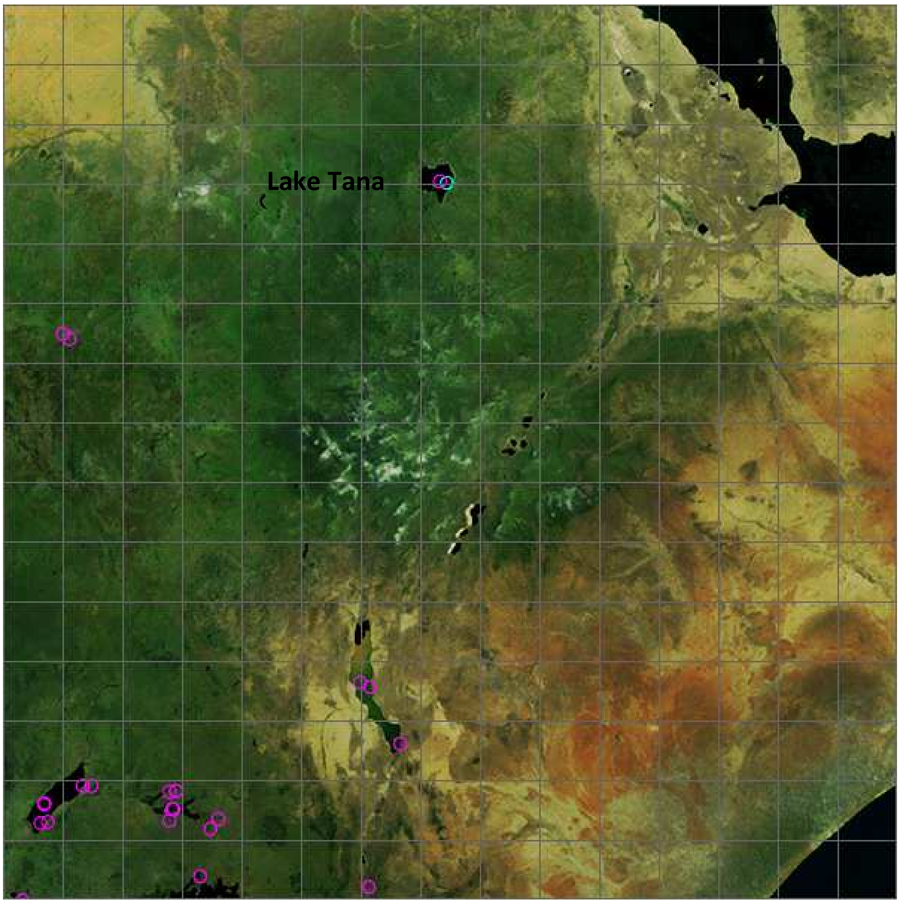

Figure 2 Lake Tana. The turquoise circle shows the NRT Jason-2 data. , the pink circle the historical ENISAT data

3.1.2 Lake Tana – Jason-2 data

The plan is to validate Cryosat-2 data from Lake Tana against Jason-2 data. Figure 2 shows that NRT altimetry data is available from Jason-2. There are clearly some outliers in the processed data but a distinct season pattern is visible with a 2-3m variation between dry season and wet season levels. The scenario is closer to a river scenario than the larger lakes.

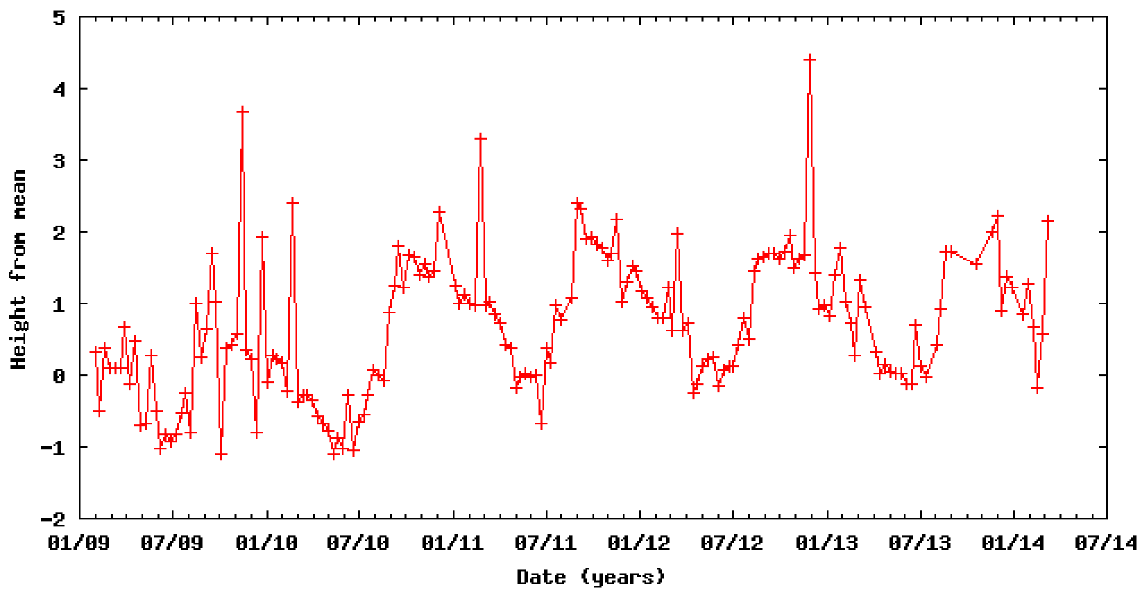

Figure 3 Jason-2 satellite altimetry data for Lake Tana from 2009-2014

3.1.3 Lake Tana – LRM Waveform analysis

Preliminary waveform analysis of four Cryosat-2 tracks has been carried out for Lake Tana (Figure 4). The colour scheme shows the preliminary waveform identifier. For the DVP it is sufficient to note that no single retracker is applicable along the satellite pass over the lake but that a number of ocean-like, single spike, double spike and complex uninterpretable waveforms are present. Problematic areas are apparent, as expected, when the waveform is affected by land. However, a change of retracker is noted mid-lake. This is possibly associated either with very shallow water or floating vegetation.

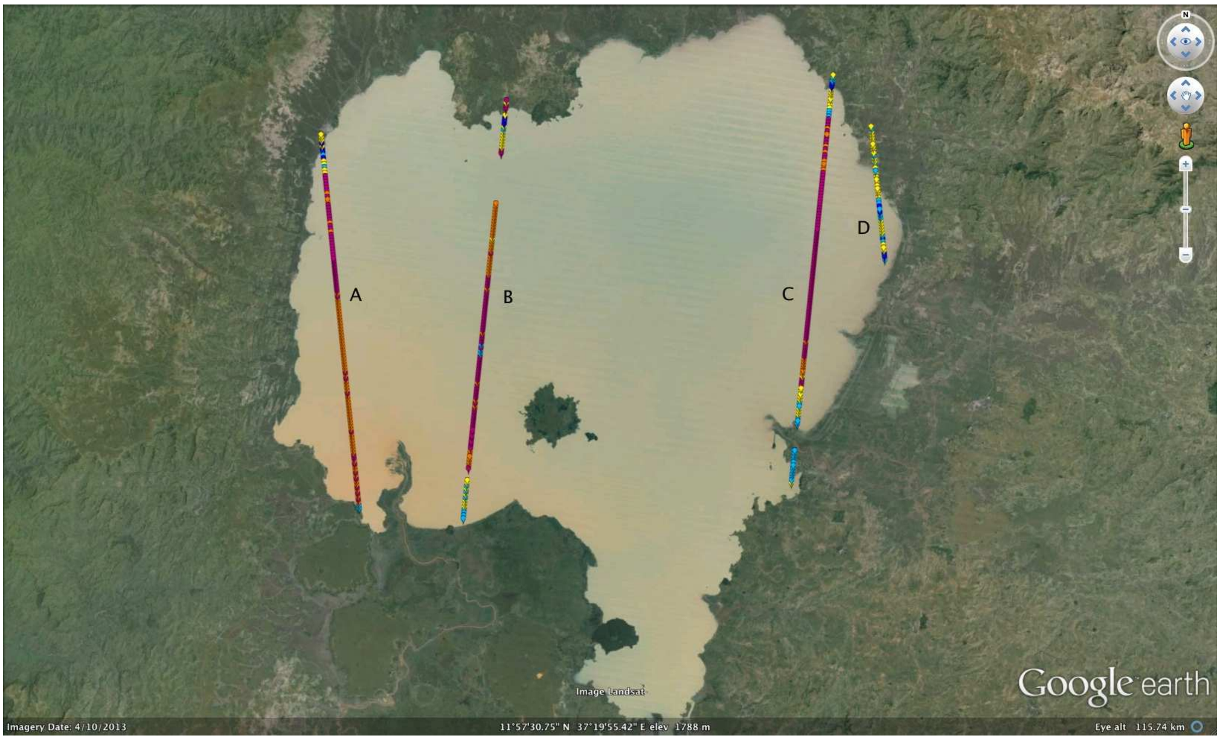

Figure 4 Cryosat-2 tracks over Lake Tana (A is track number 4488, B track 3540, C track 4351, D track 3648)

3.2 Lake Malawi

3.2.1 Lake Malawi – Introduction

Lake Malawi (Figure 7) is the southernmost lake in the East African Rift system. It is located between Malawi, Mozambique and Tanzania. Lake Malawi is the third largest and second deepest lake in Africa, it is also the ninth largest lake in the world. The lake is 580 km long and about 75 km wide at its widest point. The total surface area of the lake is about 29,600 km^2. The largest river flowing into it is the Ruhuhu River, and there is an outlet at its southern end, the Shire River, a tributary that flows into the Zambezi River in Mozambique. Details of the hydrology of the lake, including water levels and precipitation, can be seen in Lyons et al. (2011). Satellite altimetry data has previously been used to obtain water levels in Lake Malawi. Initial analysis was carried used using data from TOPEX/Poseidon (Ponchaut and Cazenave 1998;

Mercier et al. 2002). Berry et al. (2007) show satellite altimetry data for Lake Malawi from ERS2, ENVISAT, TOPEX and Jason-1. More recently Becker et al. (2010) used 16 years of satellite altimetry data from Lake Malwai,the three other largest east African lakes, together with GRACE data and rainfall observations to study the hydrological behavior in the region. Lake Malawi was one of the lakes Moore and Williams (2014) considered when using satellite altimetry and GRACE data to consider groundwater changes in Africa from 2003-2011. Lake Malawi was one of the lakes used by Ričko et al. (2012) when they tested water level products from different satellite altimetry.

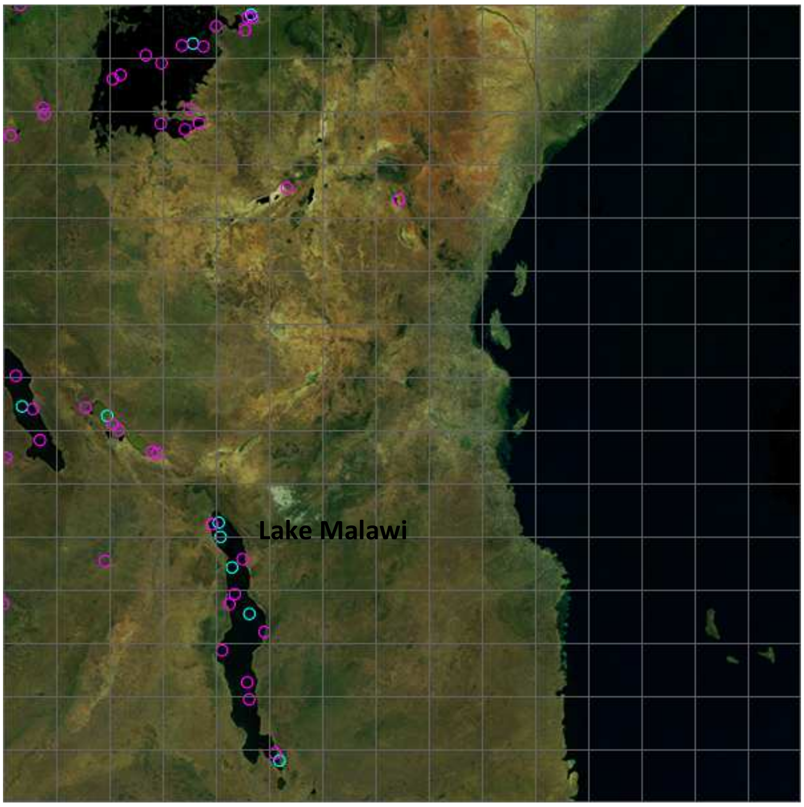

Figure 5 Lake Malawi. The turquoise circle shows the NRT Jason-2 data, the pink circle the historical ENISAT data

Given its size altimeter heights will need to be modified for differences in the lake level associated with the geoid**.** Figure 6 plots the geoid from two high resolution gravity field models; EGM08 as used on the "Rivers and Lakes" project; the replacement EGM08 and the difference between the two versions of EGM. Note that the difference can exceed 2m. A major problem with African lakes of this size is related to the accuracy of the geoid. Short-wavelength features in the EGM models rely on the availability of accurate and high resolution gravimetric data. Over Africa such data is sparse. To validate the geoid model over lakes such as Lake Malawi we will use ERS-2 and ENVISAT data to produce mean repeat track height profiles which can be used to validate or quantify the error in the geoid model.

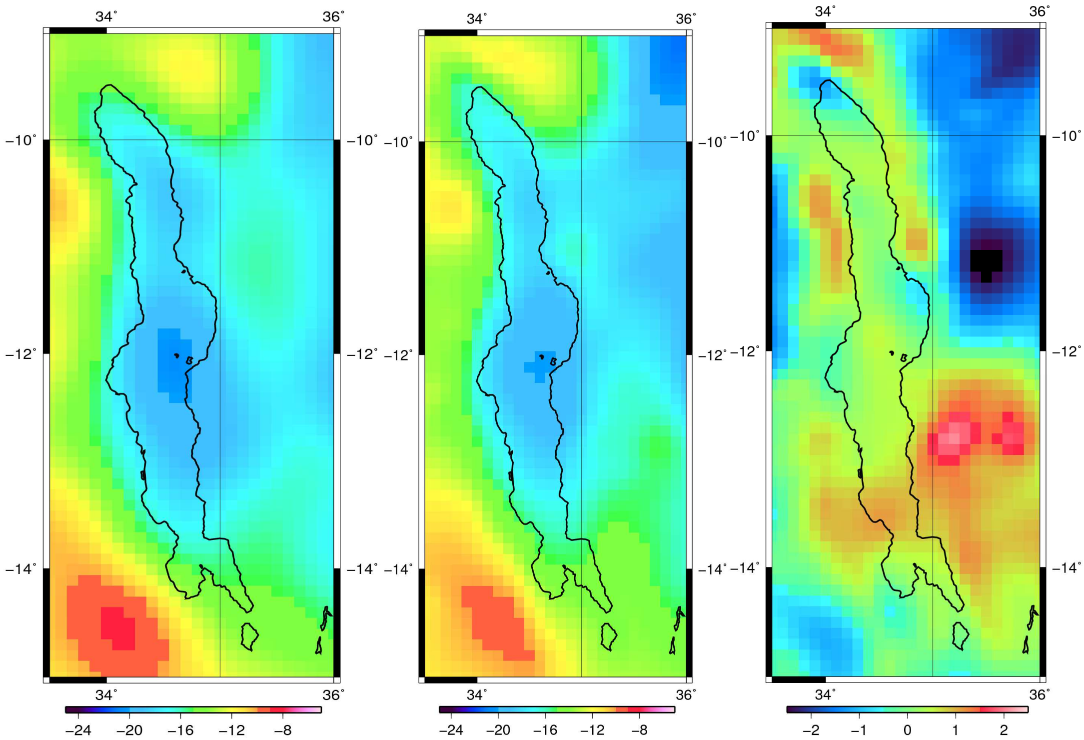

Figure 6 Geoid of Lake Malawi: EGM96 (left); EGM08 (centre); difference (right)

3.2.2 Lake Malawi – Jason-2 data

The plan is to validate Cryosat-2 data from Lake Malawi against Jason-2 data. Figure 7 shows useable NRT altimetry data is available from Jason-2 from four sites. There are clearly some outliers in the processed data but a distinct seasonal variation is visible together with a gradual drop over the 5 years. The site is good for validation as there is a substantial terrain variation in the surrounding areas.

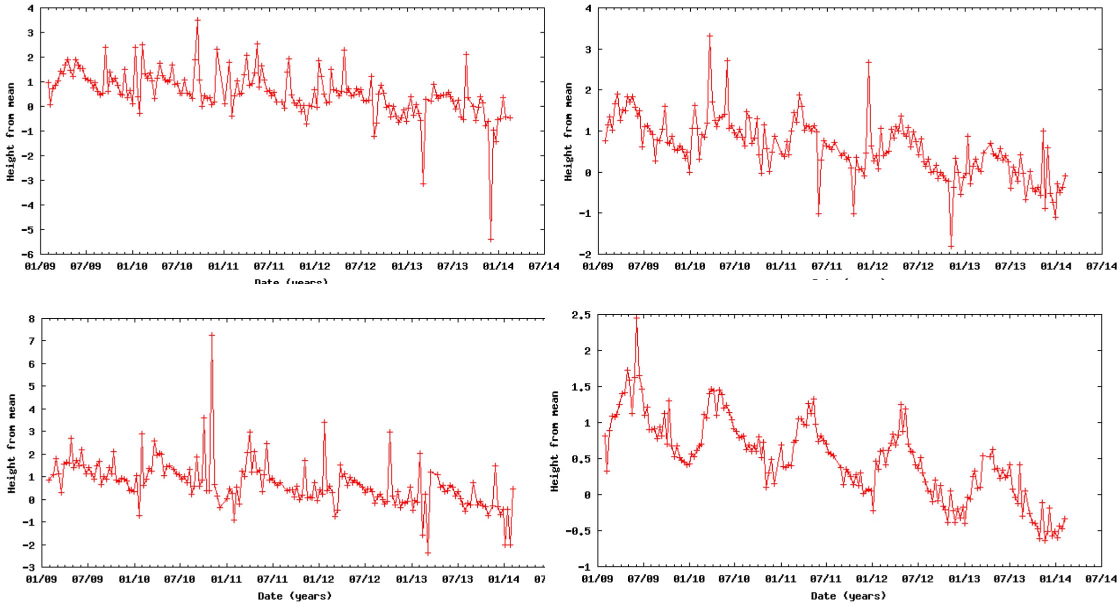

Figure 7 Jason-2 satellite altimetry data for Lake Malawi from 2009-2014

3.2.3 Lake Malawi – Waveform analysis

Preliminary waveform analysis of 11 tracks has been carried out for Lake Malawi (Figure 8). Again the colour scheme represents different waveform shapes. As with Lake Tana no single retracker is applicable along the satellite pass over the lake. There are a number of ocean-like, single spike, double spike and complex uninterpretable waveforms present. However, a single retracker covers most of the lake.

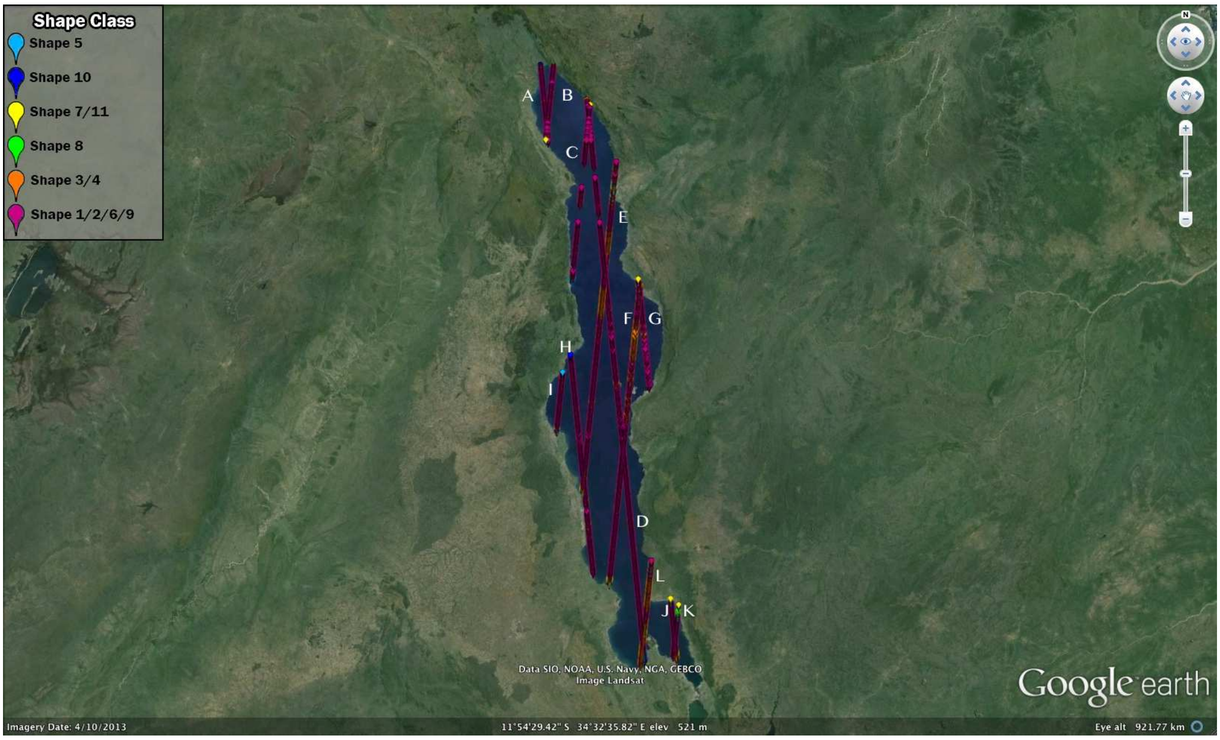

Figure 8 Cryosat-2 tracks over Lake Malawi (11 tracks which correspond to letters A-K)

3.3 Amazon River

3.3.1 Amazon River – Introduction

The Amazon River (Figure 9) in South America is the largest river in the world (by far) it terms of it discharge with an average discharge of 209,000 m^3/s, which is larger than the next seven biggest rivers combined. It also has the largest drainage area in the world of 7,050,000 km^2, which covers about 40% of South America. The width of the Amazon varies between around 1.6 and 10 km during the dry season but expands in the wet season to more than 48 km. Due to its size a lot of the earlier work on satellite altimetry in rivers was carried out in the Amazon (Birkett 1998; Berry et al. 2005; Frappart et al. 2006a; Zakharova et al. 2006; Coe et al. 2008) and much continues to take place there (Calmat et al. 2013; Getirana et al. 2013; Paiva et al. 2013).

Figure 9 Amazon River

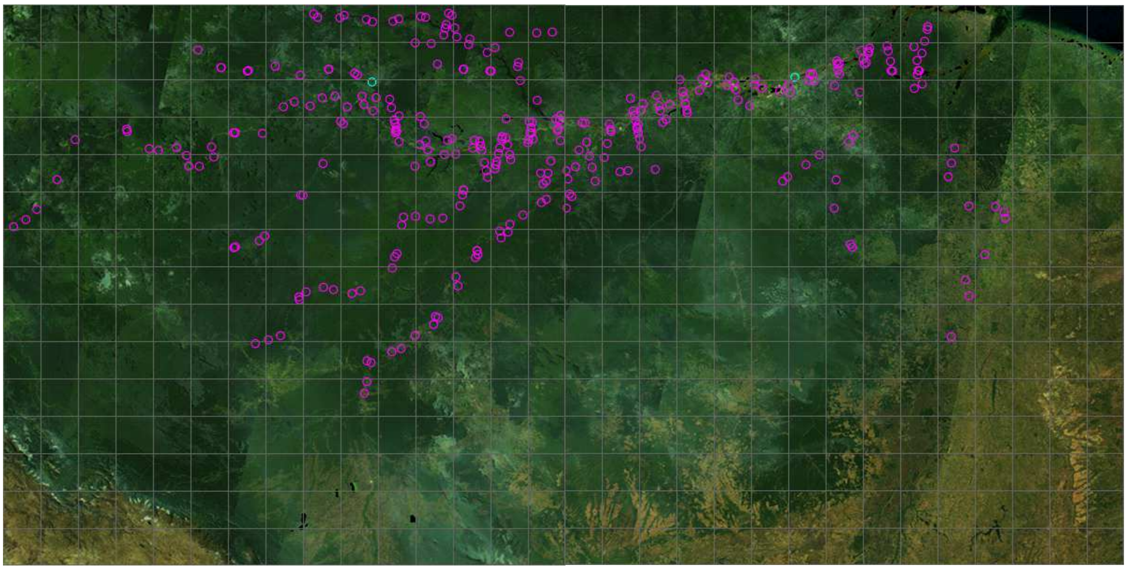

Figure 10 Amazon River. The two turquoise circle shows the NRT Jason-2 data, the pink circle the historical ENISAT data

3.3.2 Amazon river – Jason-2 data

The plan is to validate Cryosat-2 data from the Amazon River against Jason-2 data. Figure 10 shows there are a large number of historical ENVISAT data for the Amazon River but data is available from Jason-2 for only two crossings. Figure 11 shows the useable NRT altimetry data from Jason-2 for these two crossing of the Amazon river. The quality of the data does not appear to be good, therefore the plan is to see if this can be improved by re-processing the Jason2 Sensor Interim Geophysical Data Records (SIGDRs).

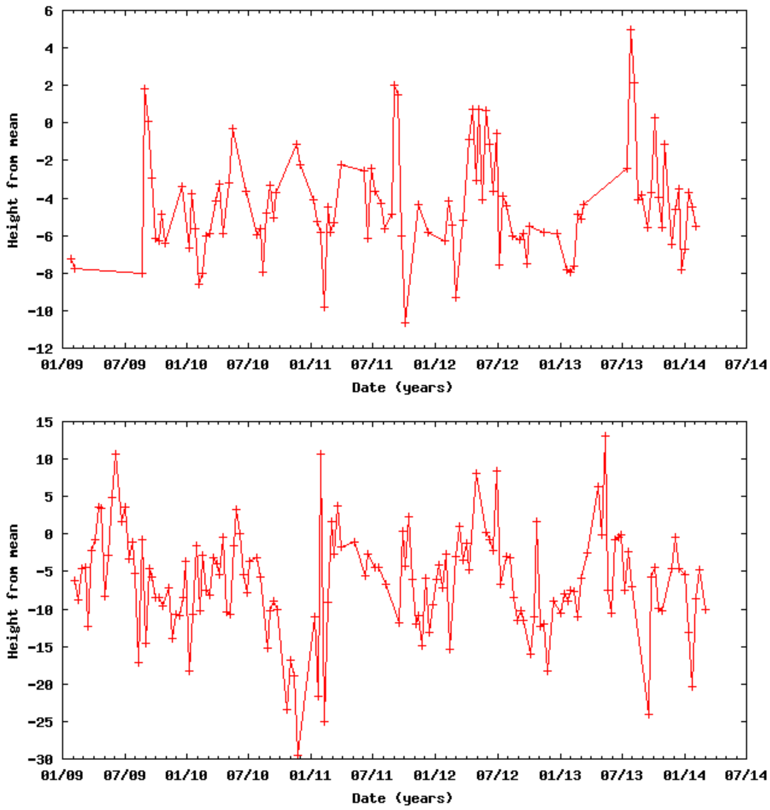

Figure 11 Jason-2 satellite altimetry data for the Amazon River from 2009-2014

3.3.3 Amazon River – LRM and SAR data

Figure 12 shows which mode Cryosat -2 is in over the Amaozn River. Green is LRM mode, RED is SAR mode and where there are no tracks it is SARIN mode. So for most of the Amazon river Cryosat-2 is in SAR mode. The eastern Jason-2 NRT altimetry data is in SAR mode and the western Jason-2 NRT altimetry data is in SARIN mode.

Figure 13 shows the preliminary waveform analysis of three tracks on an Amazon tributary. The analysis shows a combination of 'simple' quasi-specular returns and complex multi-target echoes. These multi-peak echoes far more numerous than from previous altimeters. While Figure 14 shows the SAR L1B waveforms in time sequence along track D.

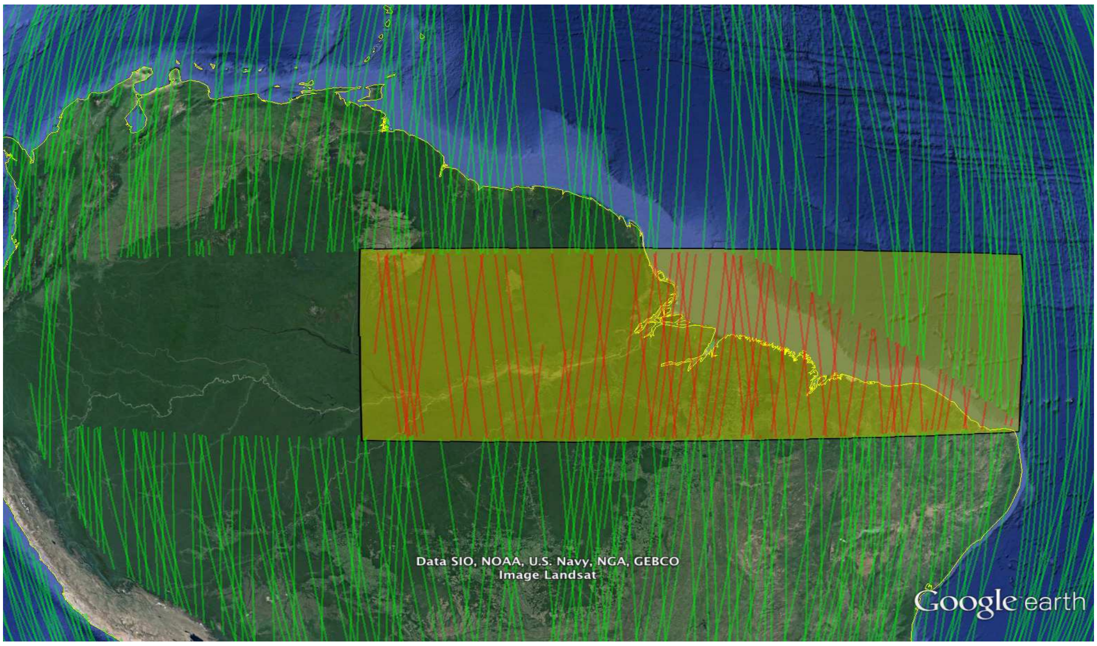

Figure 12 Amazon River Cryosat-2 tracks. Red shows the SAR tracks and green the LRM tracks

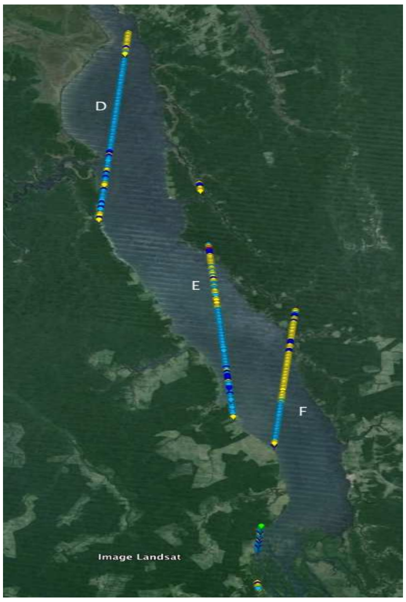

Figure 13 Amazon Tributary showing Track D, with (below) Track D SAR waveform echoes. Brightest echoes often complex shapes, multi-target responses

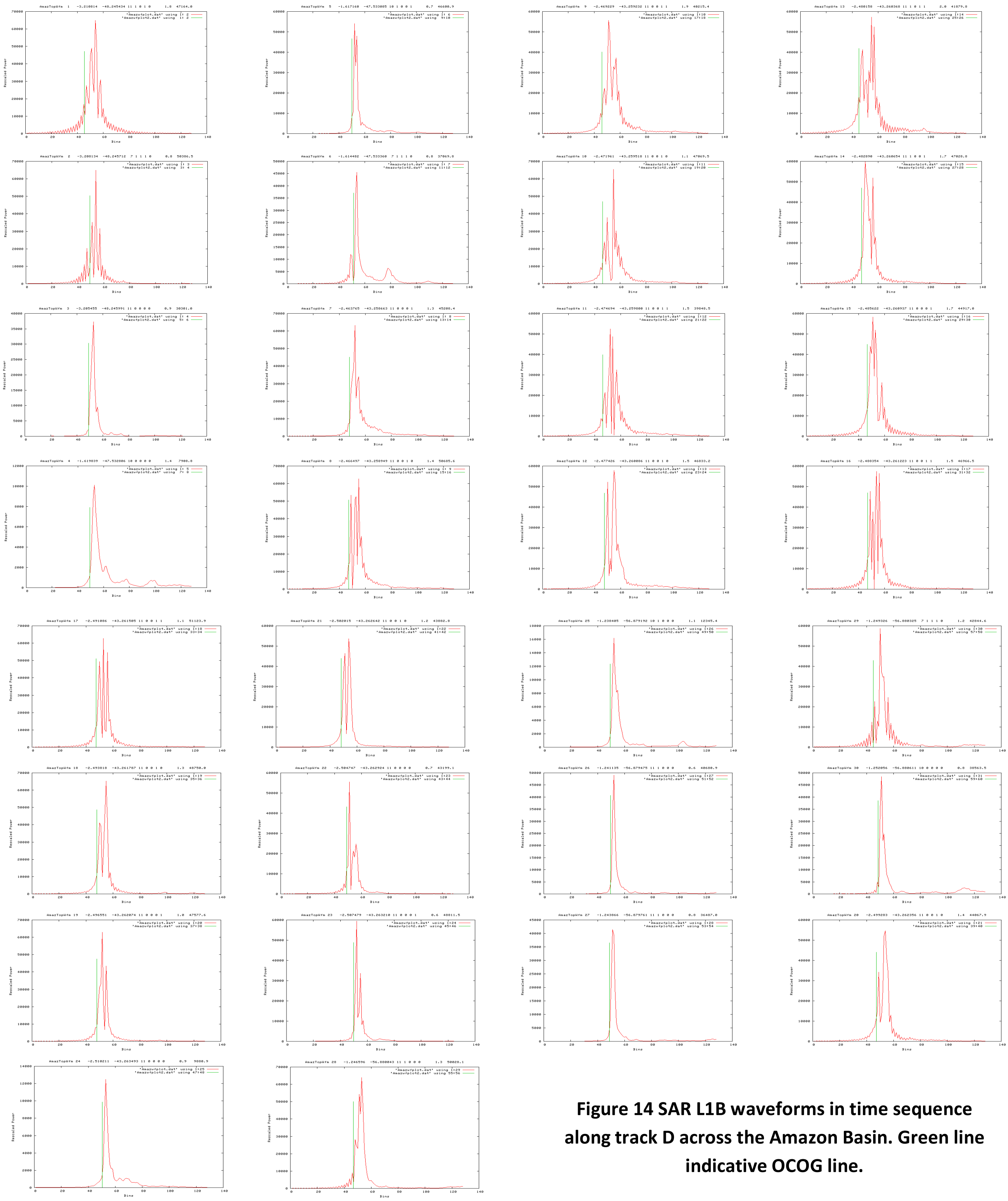

Figure 14 SAR L1B waveforms in time sequence along track D across the Amazon Basin. Green line indicative OCOG line.

3.4 Mekong River

3.4.1 Mekong River – Introduction

The Mekong River basin (Figure 15) is the sixth largest in the world in terms of discharge (ca 450 km3/ year) and the 11th largest in terms of length (ca 4800 km). It rises on the Tibetan Plateau and flows into the South China Sea after passing through China (21% of drainage area, Burma (3%), Thailand (23%), Laos (25%), Cambodia (20%) and Vietnam (8%). The climate is dominated by the southwest monsoon between mid-May and early October leading to a seasonal rise in May and peak in September or October and the lowest levels in March and April. A major component of the dry season flows (up to 30%) is from snow melt in the upper basin. Frappart et al. (2006b) have used satellite altimetry over the Mekong River. Birkinshaw et al. (2010) and Birkinshaw et al. (2014) have also used ERS-2 and ENVISAT satellite altimetry data and compared it to measured in-situ data. This shows that the altimetric measurements have a root mean square error (RMSE) of 0.44–0.65 m for ENVISAT and 0.46–0.76 m for ERS-2. They have also used this data to estimate discharge assuming the site is ungauged and compared it to the measured in-situ data.

Figure 15 Mekong river showing the location of Vientiane, Nakhon Phanom and Tonle Sap

3.4.2 Mekong river – Measured in-situ data

The plan is to validate Cryosat-2 data from the Mekong River against measured in-situ data. Hourly in-situ data has been obtained for both Nakhon Phanom and Vientiane for the period from 10/8/2010 to 20/11/2012 (Figure 18). These show the typical annual cycle in the Mekong with low flows and water levels during the dry season (November – May) and high flows and water levels in the wet season (June - October). The data for the rest of 2012 and 2013 will be available for download within the next six months. Other measured in-situ data is also available. The long term plan is to use the Cryosat-2 data to estimate discharge on the Mekong continuing the work carried out by Birkinshaw et al. (2014).

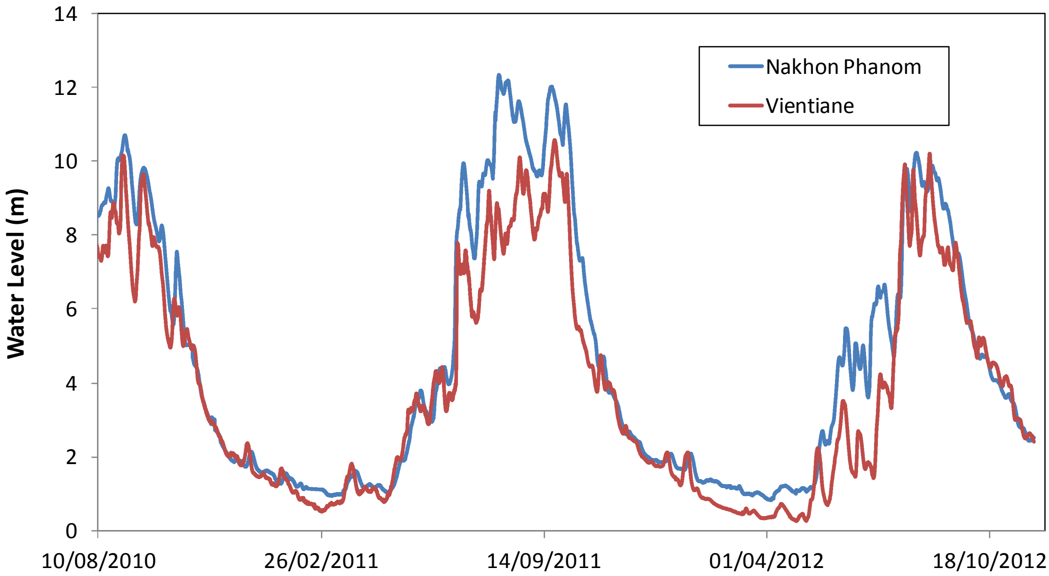

Figure 16 Measured in-situ water level data for Nakhon Phanom and Vientiane on the Mekong river. The location of Nakhon Phanom and vientiane can be seen in Figure 15.

3.4.3 Mekong River – LRM and SAR data

Figure 17 shows which mode Cryosat -2 is in over the Mekong River. Green is LRM mode, red is SAR mode. So for the lower Mekong Cryosat-2 is in SAR mode for the upper Mekong it is in LRM mode. Nakhon Phanom is within the SAR mode region (lower bounding box in Figure 17) and Vientiane is within the LRM mode region (upper bounding box in Figure 17).

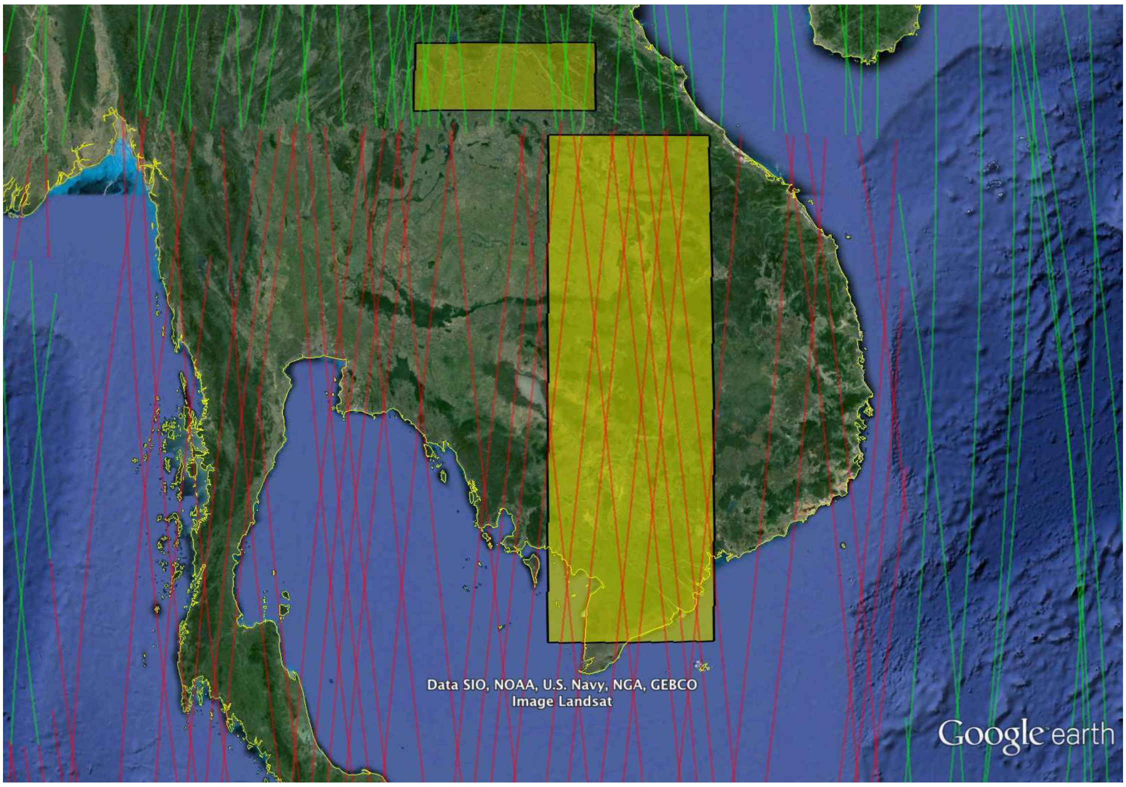

Figure 17 Mekong River Cryosat-2 tracks. Red shows the SAR tracks and green the LRM tracks. The upper bounding box contains Vientiane and the lower bounding box Nakhon Phanom.

3.5 Bramaputra River

3.5.1 Bramaputra – Introduction

The Brahmaputra River (Figure 18) is one of Asia's largest rivers, originating in the Tibetan highlands and flowing through China, India and Bangladesh to the Bay of Bengal. The River is known as the Yarlung Tsangpo in China and as the Jamuna River in Bangladesh. Discharge is highly seasonal and driven by heavy monsoon precipitation along the slopes of the Himalayas. Average low flow in the downstream areas is around 500 m^3s^{-1}, while peak discharge can exceed 80 000 m^3s^{-1}. The ~600 km east-west flowing downstream stretch in India/Bangladesh is highly braided and the width of the river system exceeds 10 km. The Brahmaputra is a high-profile transboundary river system. It is difficult to get access to in-situ monitoring data as such data is classified and not shared between the riparian countries. Remote sensing and earth observation thus have a key role to play as impartial and open sources of information (e.g. Biancamaria et al., 2011).

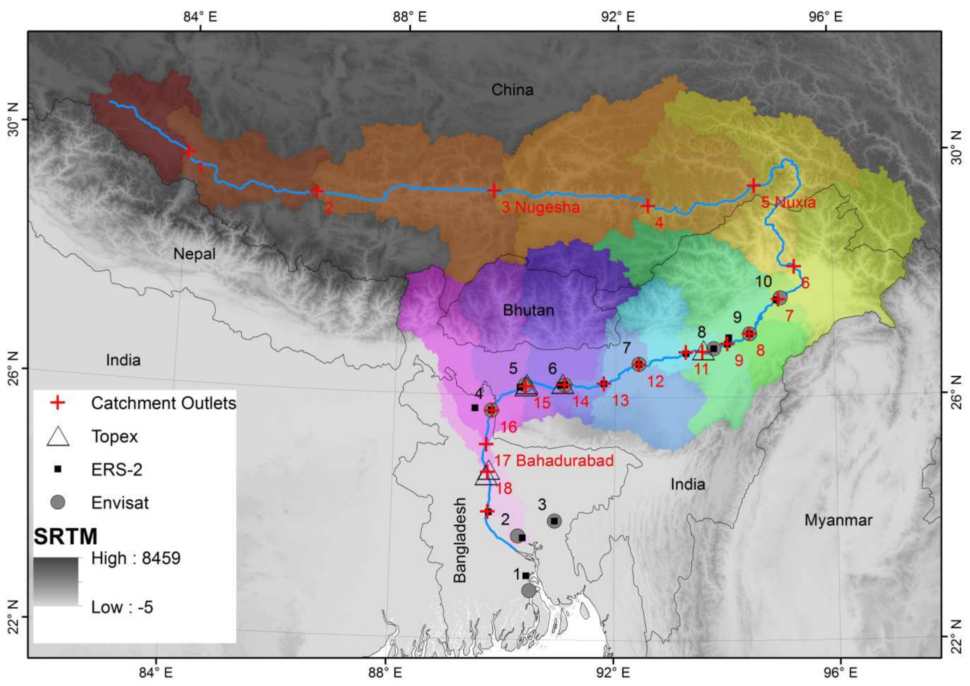

Figure 18 Brahmaputra River basin. The map includes in-situ gauging station locations and ERS-2/ENVISAT/ TOPEX-Poseidon virtual station locations

3.5.2 Brahmaputra – In-situ data

In-situ gauging station data is notoriously hard to obtain for this river system. The CRUCIAL consortium has access to historic time series of river discharge and water level from the stations Bahadurabad, Nuxia and Nugesha. However, these records have no overlap with the Cryosat-2 monitoring period. We also have access to a dataset of in-situ river cross sections measured on the lower Brahmaputra River. More data may be obtained in the future through research collaboration with partners from the Chinese Academy of Sciences and DHI India. However, progress on this front is unpredictable and uncertain.

3.5.3 Brahmaputra – River models

The CRUCIAL consortium has access to previous modeling and data assimilation studies performed on the Brahmaputra as part of the ESA River and Lake project (Michailovsky et al, 2013, Finsen et al, 2014). These studies used simple rainfall-runoff models in combination with Muskingum routing schemes. The extended Kalman filter was used for the assimilation of altimetric measurements. The models were forced with the TRMM-3B42 precipitation product, version 6. In the CRUCIAL project, a full 1-D hydrodynamic modeling approach will be used. The modeling work will be done in collaboration with the LOTUS project and the hydrodynamic simulation software DHI Mike-11 will be used. The rainfall-runoff modeling will be done with the software DHI-NAM and the models will be forced with TRMM-3B42, version 7. Preliminary results indicate a significantly improved model performance, which is probably due to improvements in the 3B42 precipitation product. The Ensemble Kalman Filter will be used for data assimilation. The research can take advantage of an existing generic data assimilation library developed by DHI (Ridler et al, 2014).

3.5.4 Brahmaputra – CryoSat-2 LRM data

Cryosat-2 is in LRM mode over the Brahmaputra. The lower Brahmaputra is flowing in approximate east-west direction over a distance of about 600 km. Due to the Cryosat-2 orbit configuration there are daily overpasses over the main river for about 10-15 days in each 30-day sub-cycle. The daily altimetric measurements are cascading in the downstream direction at a speed of about 50 km per day, which is less than the typical wave velocity in the river. There are no altimetric measurements from Cryosat-2 over the Brahmaputra for the remainder of each sub-cycle.

3.6 Zambezi River

3.6.1 Zambezi – Introduction

The Zambezi (Figure 19) is Southern Africa's largest and longest river. It flows from its headwater regions in Angola over a total distance of more than 2700 km to the coast of the Indian Ocean in Mozambique. Average discharge at the mouth is about 3400 m^3s^{-1}. The river links 9 countries and is heavily used for hydropower generation. Conflicting management objectives (e.g. hydropower vs. ecological flows) and conflicts between upstream and downstream riparian countries pose significant challenges for integrated water resources management. River discharge is highly seasonal due to the location of the basin on the fringes of the inter-tropical convergence zone. In-situ monitoring infrastructure in the basin is extremely weak.

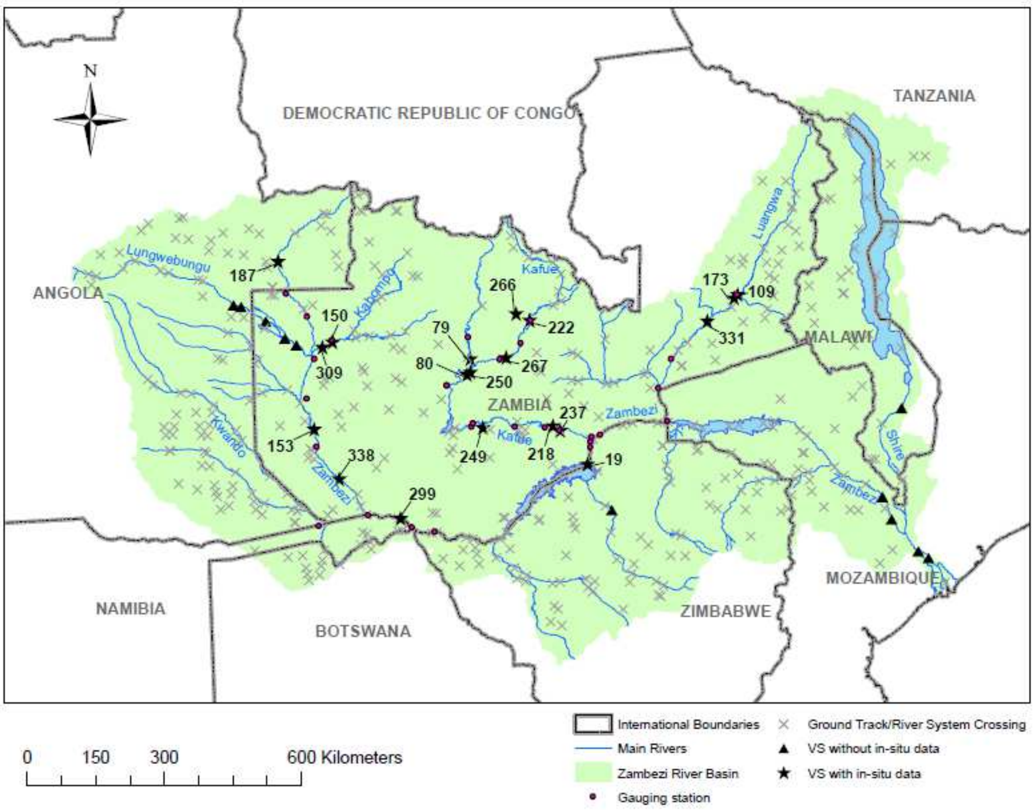

Figure 19 Zambezi River basin. The map includes in-situ gauging station locations and ERS-2/ENVISAT virtual station locations.

3.6.2 Zambezi – In-situ data

Historic in-situ measurements of water level and river discharge are available from the GRDC global database. However, data availability in this archive is extremely poor for the recent decades. The CRUCIAL consortium has access to a database of in-situ data maintained by the Zambian Department of Water Affairs. This archive has more recent data, but datasets are sometimes inconsistent and not quality-assured. The Zambian Department of Water Affairs and the Zambezi Watercourse Commission are joining the ESA-Tigernet project in phase 2 starting from 2014. More in-situ data may thus become available to the CRUCIAL consortium in the near future.

3.6.3 Zambezi – River models

The CRUCIAL consortium has access to previous modeling and data assimilation studies performed on the Zambezi as part of the ESA River and Lake project (Michailovsky et al, 2012, Michailovsky and Bauer-Gottwein, 2014). These studies used SWAT rainfall-runoff models in combination with Muskingum routing schemes. The extended Kalman filter was used for the assimilation of altimetric measurements. The models were forced with the FEWS-RFE precipitation product. In the Tigernet project, this modeling approach has been further refined and implemented in the open-source Water Observation and Information System (WOIS). Moreover, climate forcing variables are now derived from the NOAA-GFS global forecasting system to allow for operational river discharge forecasting, up to 7 days ahead. In the absence of operational radar altimetry datasets, the Tigernet forecasting system is presently informed with in-situ discharge observations only. Cryosat-2 altimetric water height measurements will be compared with WOIS model outputs. Assimilation of Cryosat-2 measurements into the WOIS modeling scheme will be explored.

3.6.4 Zambezi – CryoSat-2 LRM data

Cryosat-2 is in LRM mode over the Zambezi. The Zambezi is flowing in approximate west-east direction over a distance of about 2000 km. Altimetric readings from Cryosat-2 can therefore be expected to be available every day somewhere on the river system. However, in the upstream reaches, the river is relatively narrow (200-300 m). Availability of useable water returns will have to be investigated.

4. FBR Level 1A

Details of the processing strategy of FBR data from Level 1A (L1A) to Level 1B (L1B) is given in the CRUCIAL PAR. Conceptually, the SAR or Delay/Doppler altimeter utilises a burst of 64 echoes which because of the high pulse repetition frequency gives coherent correlation. Blocks of 4 such pulses are combined to form the 20 Hz L1B data. It is noted that the ground segment for Sentinel-3 will distribute L1A data. SAR FBR data corresponds to individual complex (I and Q) components. Each 64 echoes in a pulse comprise of 128 I and Q phase/amplitude pairs. Within the CRUCIAL project effort will be devoted to ascertain if significant enhancement can be gained by utilising the phase coherence over burst. It is to be noted that combinations of bursts as in the Level 1B product will lose phase coherence. The FBR data will be studied over two tests sites, with the primary being the Mekong.

5. Development and Validation cycle

The process of product development and validation will be carried out by each of the partners but coordinated by Newcastle University. The process will involve iteration as different approaches are tested, validated, revised and re-applied.

The steps to be carried out are as follows:

• Analyse, develop and validate the methods and algorithms needed to derive CryoSat-2 products fit for the theme of land and Inland water from LRM and SAR L1B data.

• Validate the methods and algorithms against independent data sources e.g Jason-2 data or measured in-situ data. Report the error analysis and cross - comparisons in the Product Validation Report (PVR).

• Document the selected methods and algorithms in the form of Algorithm Theoretical Basis Documents (ATBDs).

• Produce Experimental Data Sets needed in D4300. Table 1 summarises the planned dates for the provision for the deliverables.

Table 1 Planned dates of deliverables

Deliverable	Title	Due date
D3100	Data Set	25/9/14
D3200	Data Set User Manual	25/9/14
D4050	Algorithm Interim Report	25/4/15
D4100	Algorithm Theoretical basis Documents (ATBD)	25/8/15
D4200	Product Validation Report (PVR)	25/8/15
D4300	Experimental Data Set (prototype products)	25/8/15
D5400	Updated Data Set User Manual	25/10/15
D5000	Impact Assessment Report (IAR)	25/10/15
D6000	Scientific Roadmap (SR)	25/10/15

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