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

D1100 Requirement Baseline

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Abstract

This report presents a Requirement Baseline (RB) document resulting from the Scientific Requirements consolidation task within Work Package 1000 (WP 1000) of the CRUCIAL project. This present document aims to:

- Analyse the results from the user consultation with key institutions for the theme of Land and inland Water applications
- Use the results to characterize the limitations and drawbacks of existing products
- Use the results to inform the scientific and operational requirements for the Land and Inland water theme
- Incorporate any changes and suggestions as a result of the review by ESA

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Abbreviations and Acronyms

Abbreviation	Meaning
CRUCIAL	CRyosat2 sUCcess over Inland water And Land
DTU	Danish Technical University
ERS2	European Remote Sensing satellite 2
ENVISAT	Environmental Satellite
ESA	European Space Agency
LRM	Low Resolution Mode
JASON-2	US/French Altimeter Satellite
NCL	Newcastle University
NRT	Near Real Time
RA	Radar Altimeter
SAR	Synthetic Aperture Radar mode of Cryosat-2 SIRAL
SARIN	Interferometric Synthetic Aperture Radar mode of Cryosat-2 SIRAL
Sentinel-3	ESA Earth Observation satellite mission
SIRAL	SAR Interferometric Radar Altimeter
USDA	United States Department of Agriculture

1. Introduction

The objective of WP1000 is to consolidate the preliminary scientific requirements for the theme of Land and Inland Water applications. In conjunction with the relevant scientific communities an analysis of the current needs, along with limitations and drawbacks of existing products has been carried out. This will be used to inform the scientific and operational requirements for the Land and Inland Water theme. Included in this will be any technical and scientific constraints for any methods and models to be developed.

The scientific requirements have been derived in consultation with scientific users. This analysis will also draw on the considerable expertise and prior work of the consortium members (Newcastle University and Danish Technological University). For the inland water work, this will be augmented by the specialist knowledge of the river authorities involved in the sub-contractor studies.

This report constitutes the Requirement Baseline and includes a complete and detailed description of the information requirements concerning user requirements for inland water studies and represents the basis for all the activities to be carried out during the project.

This Requirement Baseline describes the user consultation process and reports the outcome.

1.1. Methodology

Cryosat-2 was launched on 8 April 2010. It follows on from previous ESA earth orbiting satellite radar altimeters (e.g. ERS2 and ENVISAT) that have been used for land surface applications including mapping (Berry et a.l, 2010a; Smith & Berry, 2011) and measurement of river and lake systems (Berry et al., 2009a; Wheeler et al., 2010). Cryosat-2's primary instrument is SIRAL (SAR Interferometric Radar Altimeter), which uses radar to determine and monitor the spacecraft's altitude. Although Cryosat-2 primary aim is to measure sea ice and ice sheets it can provide valuable data over the rest of the earth surface. SIRAL operates in one of three modes, depending on where (above the Earth's surface) CryoSat-2 is flying. The three modes are: the conventional altimeter mode or Low resolution Mode (LRM), Synthetic Aperture Radar (SAR) and Interferometric Synthetic Aperture Radar (SARIN). CryoSat-2's has a low-earth orbit and is not Sun-synchronous, and the ground tracks are non-repeating unlike the majority of previous

satellite missions; it has a period of 100 minutes. The Cryosat-2 mission is the first to operate a SAR mode Altimeter.

This study is investigating innovative land and water applications from Cryosat-2 with a forward-look component to the future Sentinel-3 mission. To achieve this objective a user consultation has been carried out as part of this research project asking users about the limitation and drawbacks of existing products and what new products they would like to see. The results of this consultation are summarised and analysed in this deliverable.

The user consultation was achieved by sending out a questionnaire to 600 verified users of the Rivers and Lake website (http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/shared/main). This website was set up under previous ESA contracts and it allows the users to download water levels in rivers and lakes from ENVISAT for the period 2002-2010 and Jason-2 2009 – present. This is a very important resource for water levels in rivers and lakes, so the vast majority of groups interested in using satellite altimetry data are registered.

Although the questionnaire was sent out to verified emails, this list still contained a considerable number of spam emails (even manually it was not easy to work out which were spam and which were not) so it was sent to all these potential users. Even for the non-spam emails it is expected that sending out a questionnaire to this large number of users will solicit only a small percentage of answers. It is a self-selecting group that have answered the questionnaire – generally those that have downloaded data and obtained useful results. Those that have failed to download any data or have not found the data useful will not fill in the questionnaire. Also, if several people from the same organization received the questionnaire general only one reply would be received.

We received responses from 37 people to the 15 questions in the questionnaire. Most people answered every question but a few did not.

1.2. Questionnaire

The questionnaire that was emailed out was an electronic form in which users selected from a list or filled in a text box. Screen dumps from this electronic version of the questionnaire can be seen in Annex 1. There were 15 questions in the questionnaire. The first three asked the users how easy they found using the Rivers and Lake website, using the data from the website and how often they used the data. The next three questions asked what they used the data for, if they use the Near Real Time (NRT) data or the historical data and at which locations in the world

they use the data. Then there were two questions asking if the users would like additional information about the data rather than just a mean water level. Following this there were questions that asked what improvements they would like to see in the existing data and the accuracy of the data that is needed. Three questions then asked about the users requirements for the current Cryosat-2 data and the future Sentinel-3 mission. Finally, the users where given the option to write any additional comments and details about their organization.

2. Questionnaire analysis

2.1.User Profile

The questionnaire was emailed to 600 users of the Rivers and Lake website who have had their emails verified. As mentioned in Section 1.1 an unknown number of these are spam emails. In total 37 responses were received covering a large range of organization throughout the world. Not all the users gave their institutions and affiliations but the 21 that did are listed below:

- Institute of Geodesy and Geoinformation (APMG), Bonn University, Germany
- HoverAid Charity, UK
- Delft University of Technology, Dept Water Management, Netherlands
- Deltares, Netherlands
- Kush insitute for space technology, Khartoum, Sudan
- Pacific Oceanological Institute, Vladivostok, Russia
- Nanjing Institute of Geography and Limnology Chinese Academy of Sciences, China
- Department of Geological Sciences, Jahangirnagar University, Savar, Dhaka, Bangladesh
- Research Institute for Geo-Hydrological Protection of the National Research Council, Italy
- Dept of Water Science & Engineering, UNESCO-IHE Institute for Water Education, Delft, Netherlands.
- Australian National University, CSIRO, Australia
- Brockmann Consult GmbH, Germany.
- CSIR, South Africa
- Pixalytics Ltd, USA

- Sao Paulo State University, Brazil
- Arba Minch University, Institute of Technology, Ethiopia
- Mekong River Commission, Cambodia
- International Commission for Congo-Ubangui-Sangha Basin, DR Congo
- TU Darmstadt, Germany
- Swedish Meteorological and Hydrological institute, Sweden
- Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), France

Of the 21 users who revealed their institutions and affiliations, 16 come from the public research sector, 3 from the public operational sector and 2 from the operational private sector. It can be seen from the list that someone from most of the key groups involved in satellite altimetry answered the questionnaire.

The electronic questionnaire provides details of the country where the form was filled in (even when the user did not supply their organization). These have been grouped into continents and are shown in Figure 1. The highest number is from Europe (43%) but it is good to see all the inhabited continents represented. Of the 48% from Europe the highest number (five out of 16) were from the Netherlands.

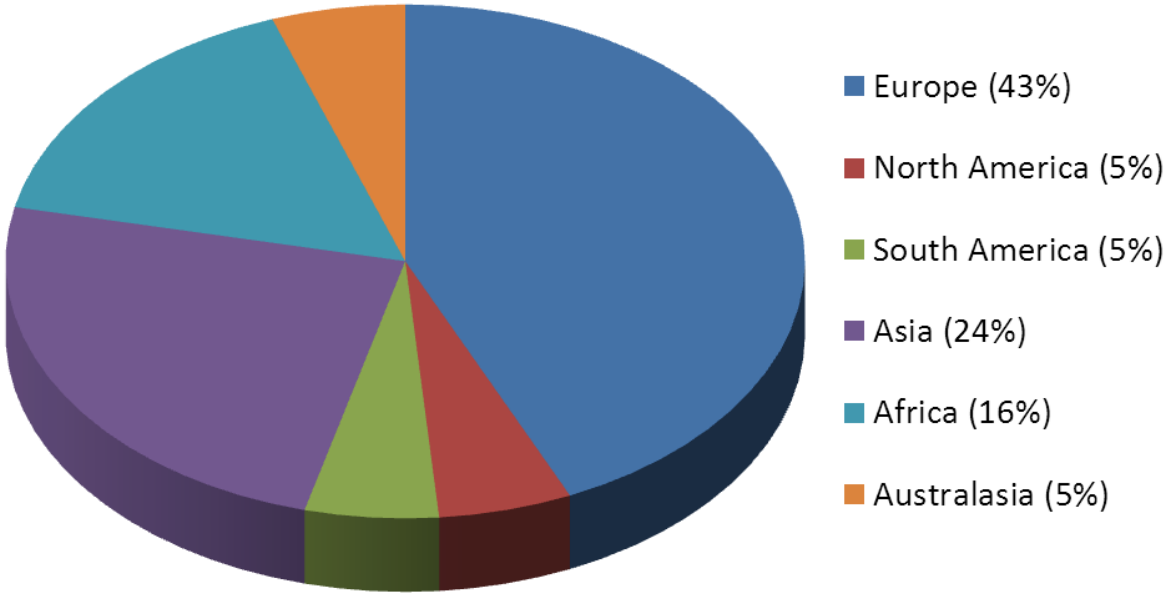

Figure 1 Continent of users of the satellite altimetry community

2.2.Ease of downloading data

The question asked here was “How did you find downloading the data from the rivers and Lakes website?”. There were five possible answers ranging from very easy to very difficult. Figure 2 shows the results. It can be seen there the majority of users found it either “Easy” or “Very Easy”. But a significant number found it “Difficult” or “Very Difficult”.

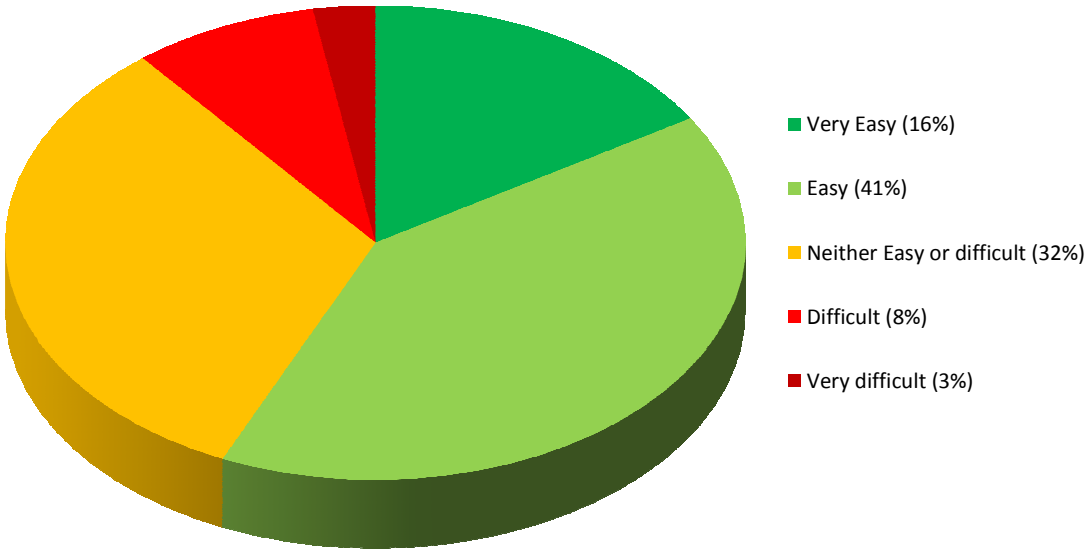

Figure 2 The Ease of downloading the satellite altimetry data

2.3.Ease of use of data

The question asked here was “How did you find using the data from the Rivers and Lakes website?”. There were five possible answers ranging from very easy to very difficult. Figure 3 shows the results. As with downloading the data it can be seen there the majority of users found it either “Easy” or “Very Easy”. But a significant number found it “Difficult” and one user found it “Very Difficult”. The results are very similar to those for the ease of downloading the data

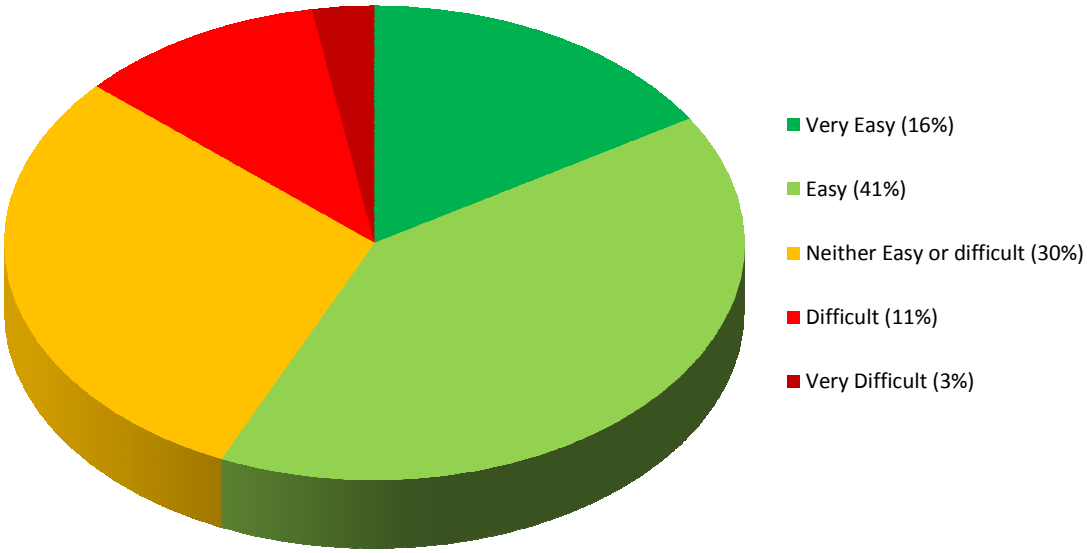

Figure 3 The ease of use of the satellite altimetry data

2.4.Frequency of use

The question asked here was “How often do you use data from the rivers and Lakes website?”. There were four possible answers: weekly, monthly, annually and never. Figure 4 shows the results. Clearly most users use the data annually (73%) with monthly the next most common (14%). 5% use the data weekly and 8% never use the data. It is encouraging that nearly all the respondents use the data. However, as mentioned in Section 1.1 the respondents are self-selecting with those using the data more likely to reply.

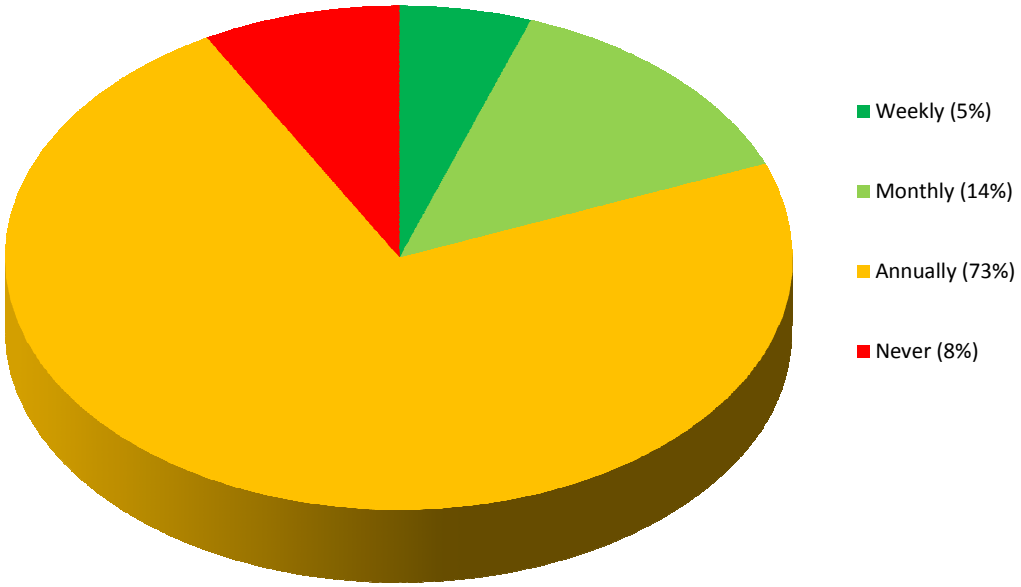

Figure 4 How often the satellite altimetry data is used

2.5.Purpose of use

The question asked here was “What do you use the Rivers and Lake data for?”. Users were given the option of selecting from four possible answers, but could choose all the relevant ones. These were: “water levels in lakes”, “water levels in rivers”, “to help estimate river discharge” and ”flooding extent”. They were also given the option of specifying another use. Figure 5 shows that the most common use was “water levels in lakes” and “water levels in rivers”. 14 users used the data to help estimate discharge in rivers and six for flooding extent. The other users were for the “water volume in lakes” and “water redistribution” as part of the ESA Diversity II project and as a comparison with other products.

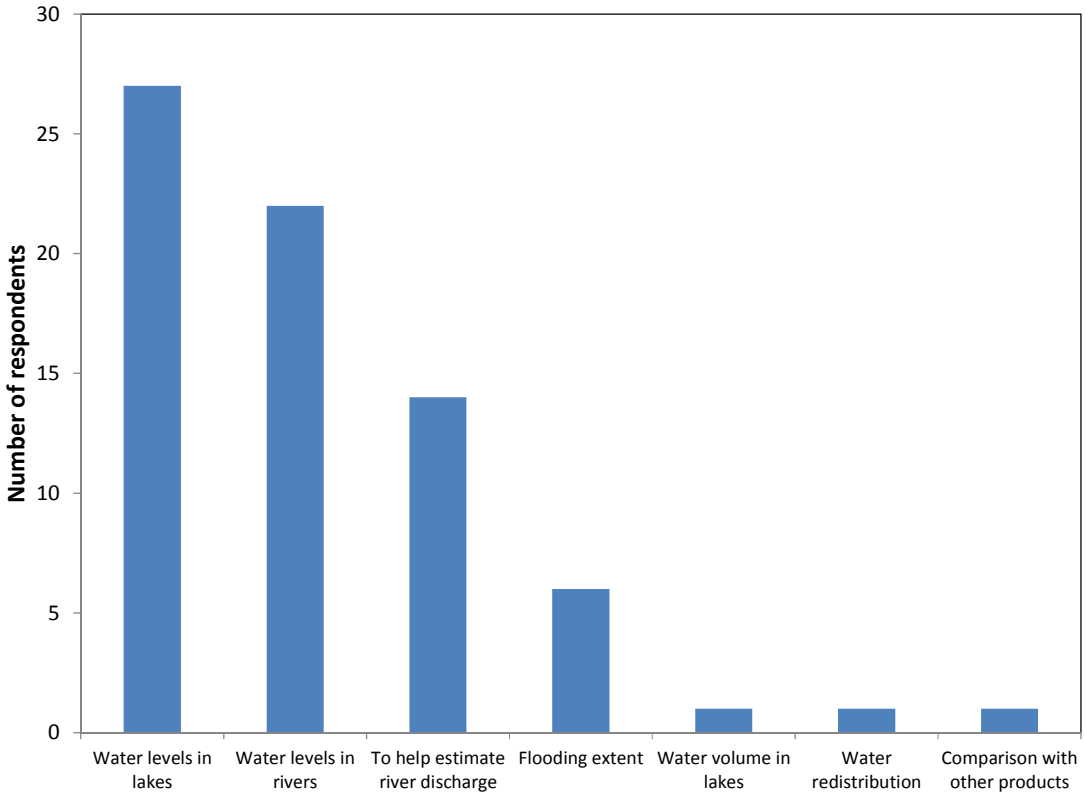

Figure 5 The purpose that the satellite altimetry data is used for

2.6.Type of data

The question asked here was "For the River and Lake data do you use the Near Real Time (NRT) data, historical data or both? For historical data there is the potential in the future to post-process the data to remove outliers". Figure 6 gives a summary of the type of data the users are interested in. Nearly all the users are interested in the historical data, with many commenting that they would like the outliers removed. Just over half the users (55%) are interested in the NRT data

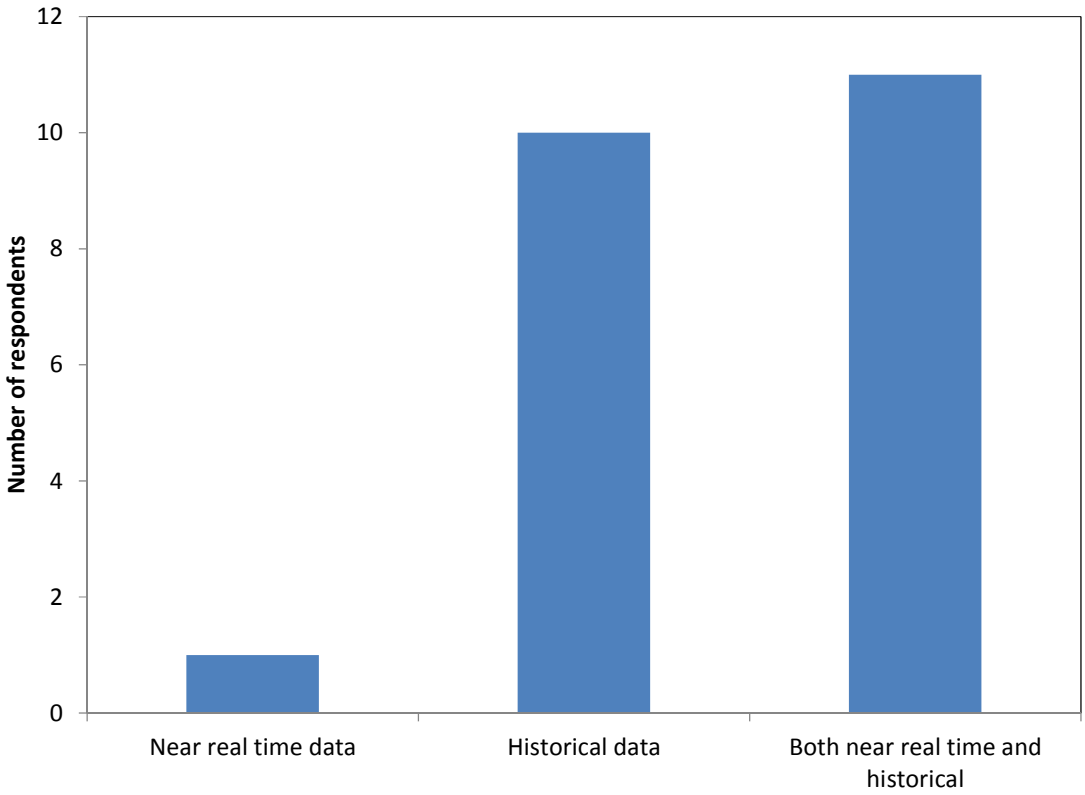

Figure 6 The type of data that the respondents use

2.7.Location of use

The question asked here was “Which locations or regions of the world have you used the Rivers and Lake data for?”. Users were given a text box to fill in. Figure 7 gives a summary of the continents where the data is used. Six users made use of the data globally. For a particular continent the data was most well used in Africa, which makes sense as the in-situ measured data is poorest in this continent. Table 1 summarizes particular regions, rivers or lakes which the users mentioned.

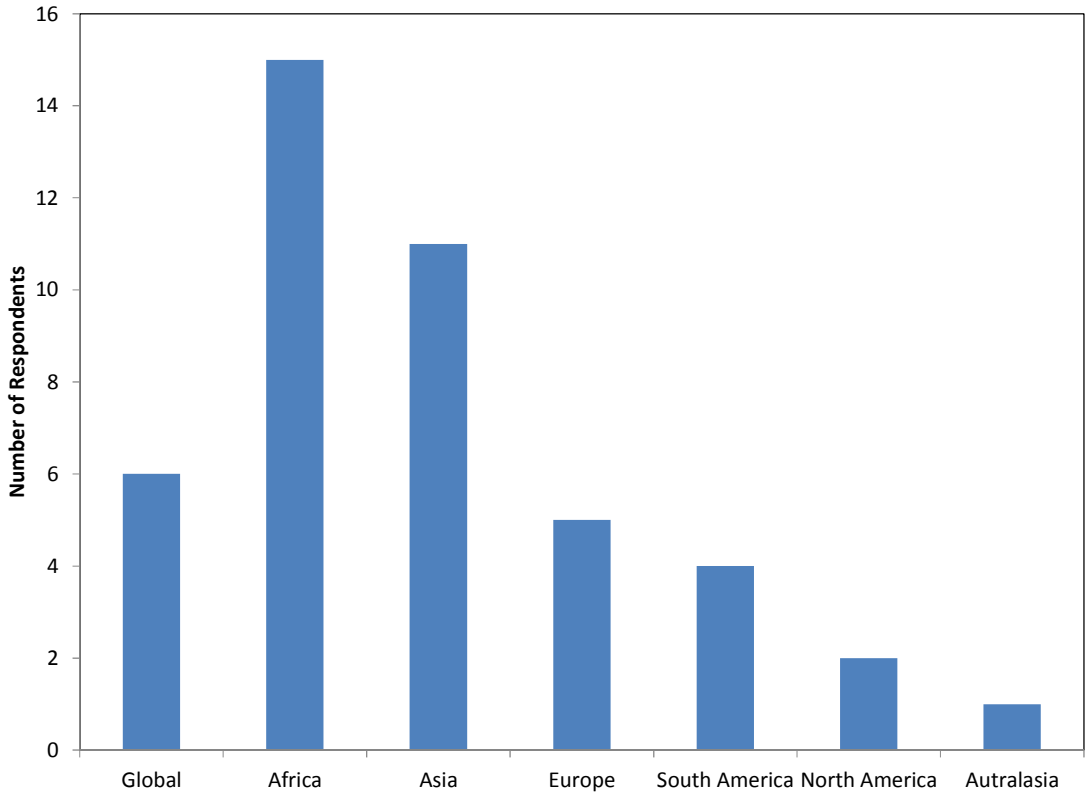

Figure 7 The continent the satellite altimetry data is used

Table 1 Locations where the satellite altimetry data is used

Lake/ river	Country/ Region
-	Mozambique
-	Madagascar
-	Rawanda
Blue Nile	Sudan
Ganges-Brahmaputra delta	Bangladesh
Danube River	Central/eastern Europe
Po River	Italy
Duero river	Spain
Niger river	Western Africa
Amazon river	Brazil
Mekong river	S.E. Asia
Ob river	Russia
Amur river	N.E. Asia
Okavango delta	Botswana
Zambezi river	Democratic Republic of Congo, Malawi etc
Congo river	Central Africa
Lake Peipus	Estonia/Russia
Lake Chad	Chad
Lake Tana	Ethiopia
Lake Victoria	Tanzania, Uganda and Kenya
Lake Michigan	USA
Lake Nicaragua	Nicaragua
Rift Valley lakes	East Africa
Lakes Balaton	Hungary
Lake Paijanne	Finland
Lake Tahoe	USA
Lakes Vaenern and Vattern	Sweden
Lake Nasser	Egypt
Lake Volta	Ghana

2.8.Auxiliary data

The question asked here was “The River and Lakes data provides the water level. Would full details about the auxiliary data used to obtain these values be of use? For example, you may wish to replace the wet tropospheric, dry tropospheric correction, instrument correction, orbital height etc. with your own values but you will need the values utilised in the height measurement to do this”. Figure 8 gives a summary of the responses. Most users (10) are just happy to obtain the basic water level data, a slightly smaller number (9) would like basic details on the auxiliary data used. These are the end-users that want the best available data but do not have the technical expertise to improve these values. Only four respondents want the full details of the auxiliary data so they can use their own data. These four are university research groups with the technical expertise to be able to carry out this sort of analysis.

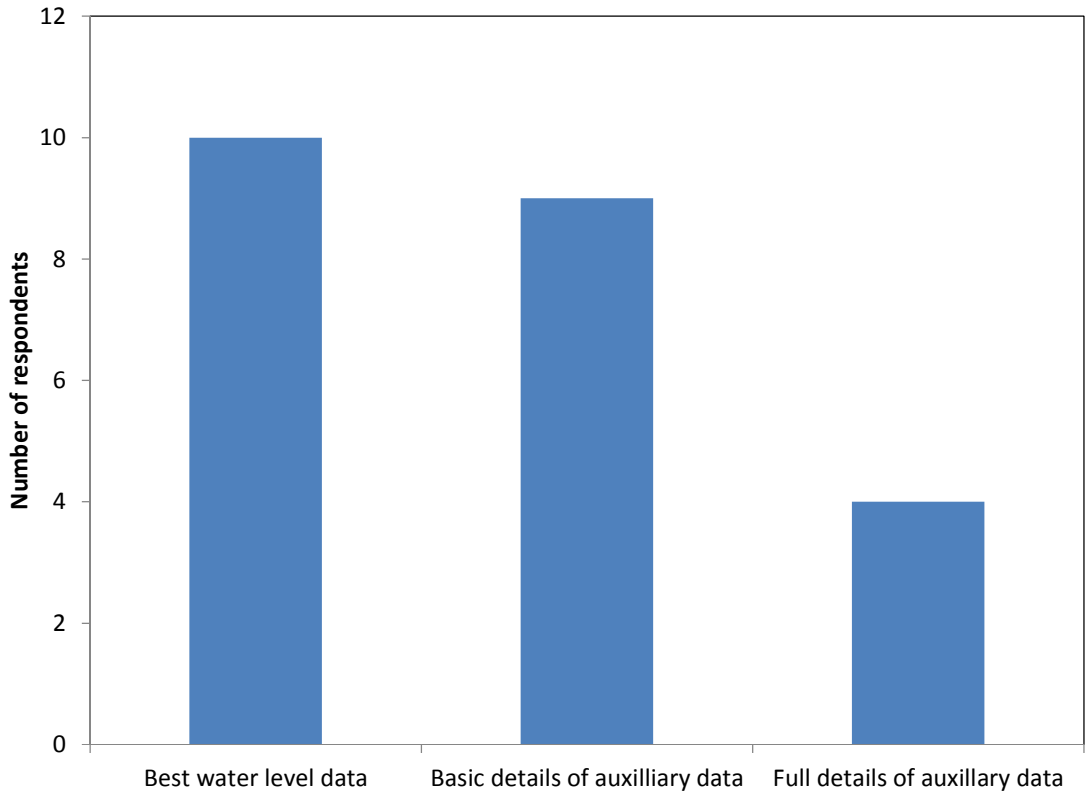

Figure 8 The auxiliary data required by the user

2.9.Individual or mean values

Another question was asked here about what sort of data the users require. The question asked was "The current Rivers and Lakes data from ENVISAT and Jason-2 gives the mean water level for a track across a river or lake. Are you interested in the individual values or just the mean value?". A similar number of users were interested in both individual values and mean values. So individual values are important for many users and it is something that we should aim to provide in future. Some of those interested in just the mean value would however like to see some sort of error estimate.

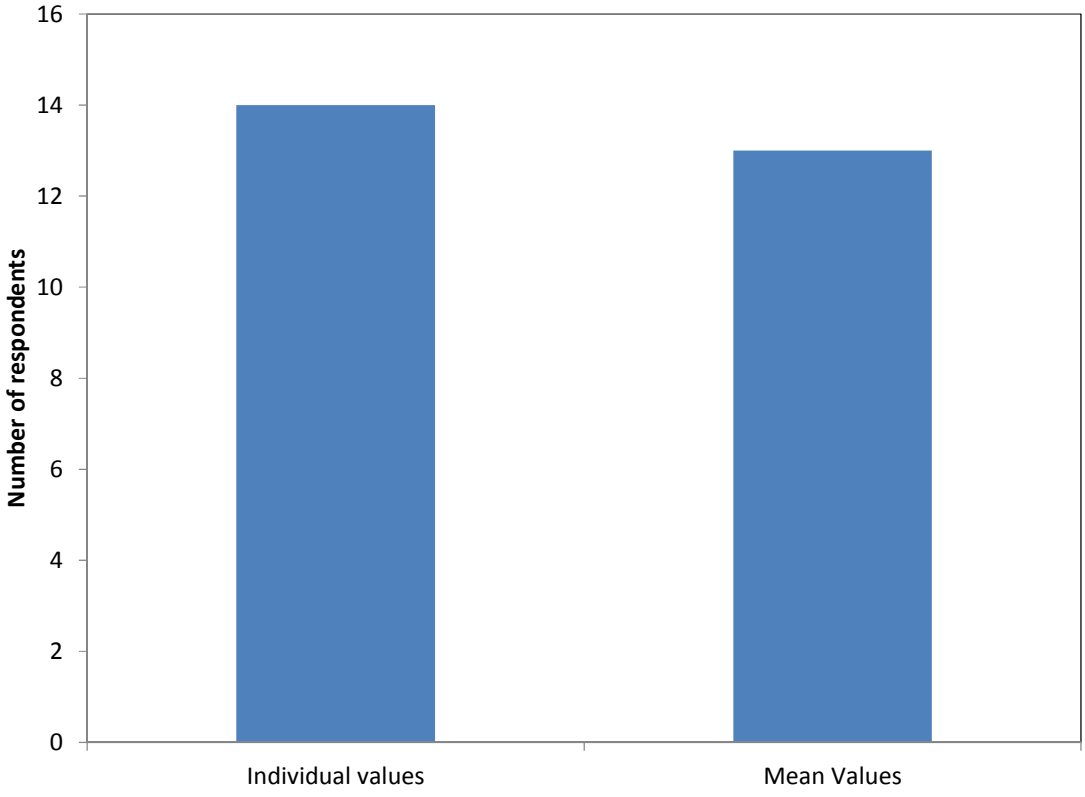

Figure 9 Whether individual or mean water level values are required by the user

2.10. Potential for improvement

The question asked here was “What improvements would you like to see to river and Lakes data and content?”. Users were given a text box to fill in. Figure 10 gives a summary of the responses. Seven users would like to see more River and Lakes targets. Comments included:

- Would be nice to have a global comprehensive and consistent database of all satellite altimetry over inland waters with the same ease of use as River & Lake but that may be a bit much to ask.
- River and Lake provides online data just for some rivers (often the largest), even if the data are available for many others. I'd like to find all the data on line.

Five users would like to see better quality control. Comments included:

- A clean filtered version of data, not containing false values as huge outliers.
- We found shifted and unrealistic timeseries in all cases, whereas it was usually quite obvious which ones to retain.

Two users would like to have some sort of uncertainty estimation of the data.

Seven other comments were made these were:

- Conduct capacity building through training and pilot studies.
- Some explanation on the data referencing, datum used and how it relates to measured data.
- Multi-location, multi-sensor merging to create a set of high quality long-term and updated time series.
- I think the way the Foreign Argriculture Service of USDA presents the water levels of various lakes around the world is very user friendly. One file per site and each new acquisition is appended to this file. I think that is rather elegant. So, I do hope that the Crucial project of NU will look at this way and may be get inspired.
- Concatenation of available data to make it easy to know when there is data at a site

- I think the way the Americans offer the data (Global Reservoir and Lake Monitor) is very elegant. The data is appended to a text file so you don't have to download every single measurement. I would like something similar, but with some extra basic details.
- You could publish a map showing all lakes suitable for this measurement method, simply by performing a GIS analysis of satellite tracks and lake area polygons.

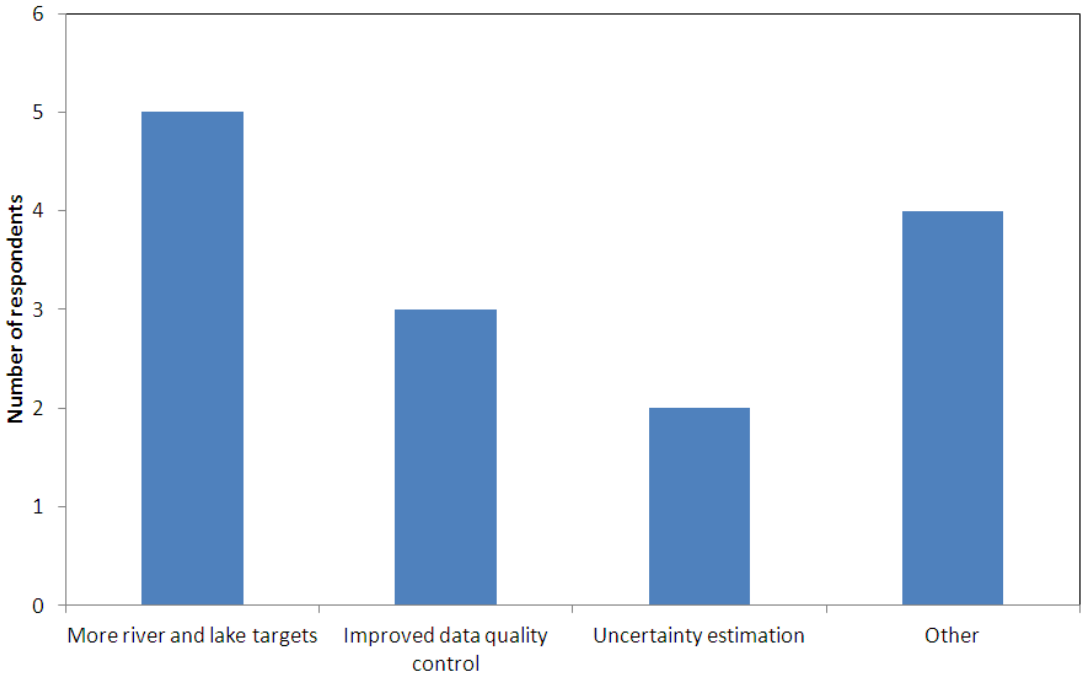

Figure 10 Potential improvements to the Rivers and Lakes data

2.11. Accuracy of data

The accuracy of water level data is clearly an important issue. The question asked here was "The obvious aim is that the water levels obtained from satellites should be as accurate as possible. It would be really useful if you could provide any information on the minimum accuracy level needed for your work or the potential scope for other work if the accuracy levels were improved". Figure 11 shows the accuracy requested by the users, whereas the current range is around 30-60cm (Birkinshaw et al. 2014). So clearly an improvement in accuracy would be important for many users. Other comments included the following:

- The data is useful if the variability is greater than the range
- Rivers 20cm and lakes 40cm
- The current accuracy is 70cm it would be good to improve this accuracy
- The lake accuracy is OK at the moment
- Better accuracy would improve discharge estimates

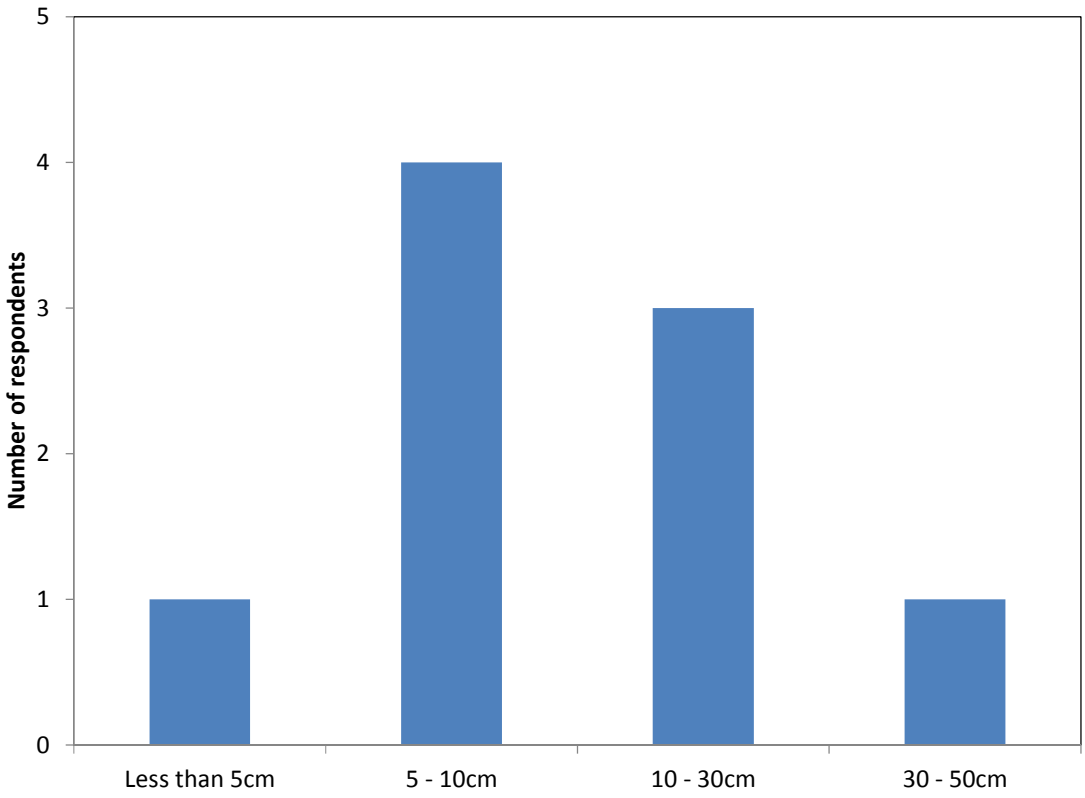

Figure 11 The accuracy of water level data the users need for their work

2.12. Cryosat-2 modes

The questions asked here was “We are currently working with Cryosat-2 data. This operates in three modes depending on its locations. These are the conventional altimeter or LRM mode, SAR mode and SARin. Which data are you interested in? Select all boxes that are relevant”. Figure 12 shows the users responses. Most users were interested in the LRM mode data followed by the SAR and SARin data. But it is also clear from the written responses that most of the end users had no idea what the three modes were.

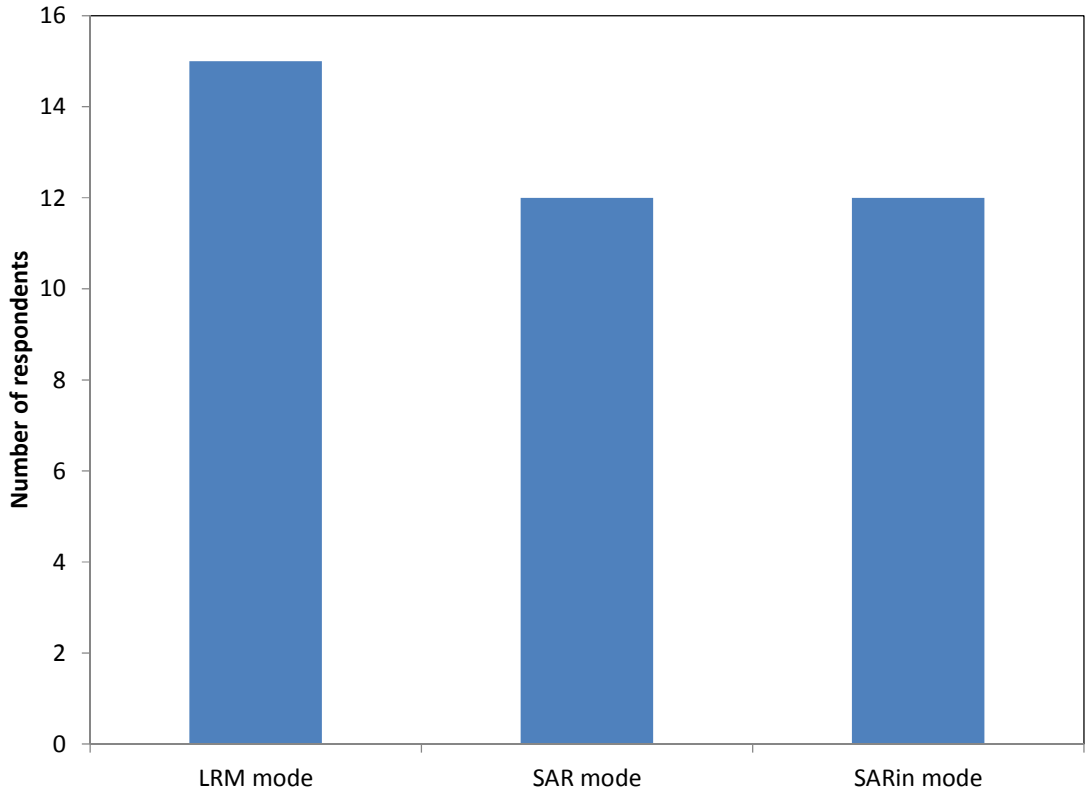

Figure 12 The Cryosat-2 modes that users are interested in

2.13. SAR mode data

The SAR mode in Cryosat-2 offers the potential for high quality data over narrower channels compared to the conventional LRM mode data. It is interesting to know how much information the users require about the data. So the following question was asked "We are currently working with Cryosat-2 and in the future we will be using Sentinel-3 data. Cryosat-2 is sometimes in SAR mode and Sentinel-3 will be in SAR mode. Are you interested in the parameters used to obtain the altimetry data in SAR mode?". Figure 13 shows that an equal number (12) would like more detail and would just like the best data available.

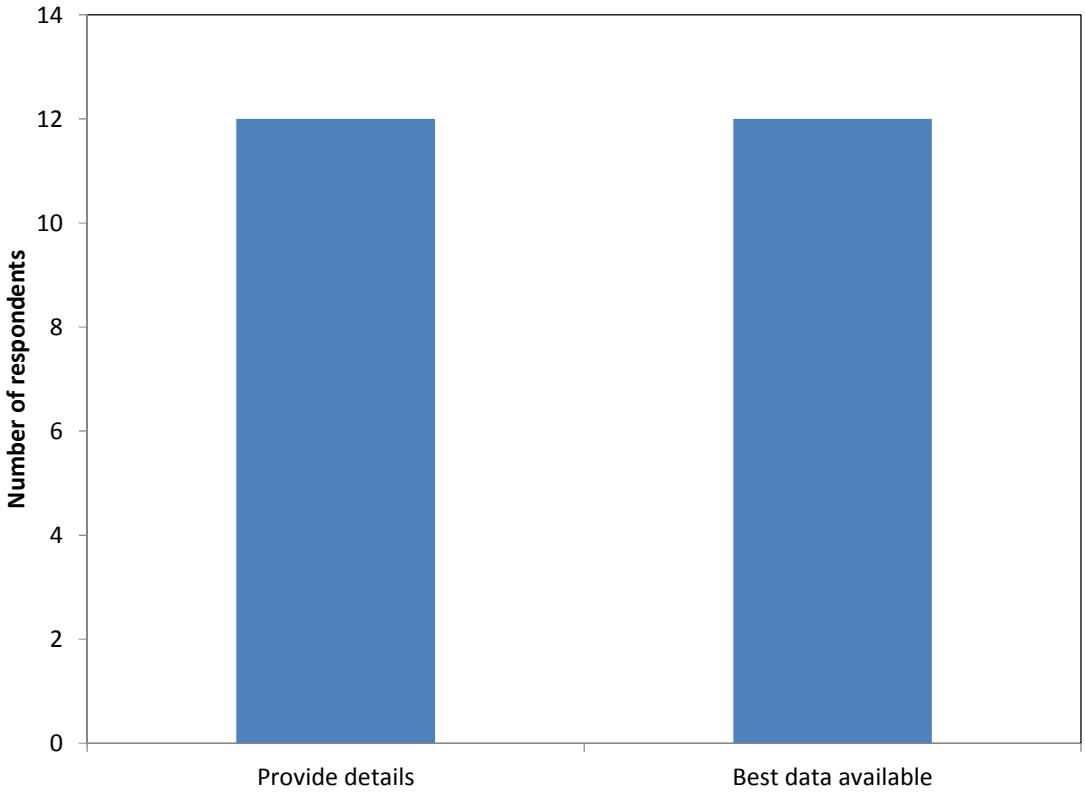

Figure 13 Whether the users would like details of the parameters used to obtain data in SAR mode

2.14. Sentinel-3 data

The question asked here was "We are currently working with Cryosat-2 and in the future we will be using Sentinel-3 data. Is there any particular data from these sources that would interest you?". Users were given a text box to fill in. The results were hard to generalise so all the comments are shown below:

- If possible higher resolution of flooded areas
- Water level, water extent
- Water levels
- River and lake water quality
- Altimetry data
- We developed a procedure that coupled measurements of river velocity derived from the spectroradiometer MODIS and of water levels derived from the altimeter RA-2 for river discharge estimation. This can be of particular interest for the forthcoming Sentinel-3 mission, in which a visible-near infrared multispectral and an altimeter sensor will be onboard the same satellite platform providing significant improvements in terms of vertical accuracy and spatial-temporal resolution.
- SAR data on the Lower Niger river. I am interested in creating/ interpolating river bathymetry using satellite imagery.
- Continuing longer-term time series where possible, and new effort into water level data for large ephemeral rivers and lakes, e.g. Okavango, Lake Eyre, etc.
- Surface temperature
- Definitely very interesting to have a greater density of data points
- As an end user I am not really interested in the source of the data. I do care about reliability and sustainability

- Narrower river channels
- Monitoring of water levels in major reservoirs throughout the Mekong region especially in parts that do not share data with other countries. Water level in the main Mekong river and Great Lake of Cambodia are already monitored to better accuracy locally and shared to all so the first phase has just been a proving of the method rather than of any practical use so far. The question needs a bit of explanation as to what might be available.
- The water level and water balance
- Glacier surface elevation data
- Both PseudoRL and SAR data are interesting

2.15. Other Comments

The final question asked was "If there are any other comments that you would like to make them please fill in the box below". The results were hard to generalise so all the comments are shown below:

- It would be nice to have systematic error estimates together with the water levels.
- Please give us tutorial exercise on flood mapping and river discharge estimation; effect of climate change.
- The river and lakes data I received has been very useful to me and enabled me build a hydrodynamic model of the lower Niger River within reasonable uncertainties. I think it is a worthwhile project and wish this new project with Cryosat-2 even more success.
- Despite the mentioned difficulties and suggestions for improvement, your data have been very beneficial to my research, so thank you very much for your great work!!
- Very useful and needed service! Availability of river related data (monitored data) is a large problem in Africa.
- I hope there could be some clear report showing the success of the first stage and then what is proposed next and what could be available, how often, how many points etc
- The majority of lakes in Europe (>80%) are located in the Scandinavian countries, but there is no information about these on the website. Please focus more on the lakes in northern Europe.

3. Analysis of Limitations and Drawbacks of Existing products

It is clear from the number of registered users and download of data from the Rivers and Lakes website (http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/shared/main) that the radar altimetry (RA) data is an important resource. The find out more about the users of this data an electronic questionnaire was sent out to which 37 users replied. Those who replied were a self-selecting group who all use the data at least annually. There were positive comments such as "Very useful and needed service" and "The river and lakes data I received has been very useful to me". The users come from a range of countries throughout the world.

Analysis of the comments received show that generally users find the data easy to download and use. The main use of the data is for water levels in lakes and water levels in rivers. As expected, the data is most used in countries and continents with poor in-situ measured data. So Africa is the continent where the data is most used. The main limitation and drawbacks of the existing data is the limited range of rivers and lakes for which the data can be downloaded on-line and also the quality of the data. For example, comments were that there are often outliers or unrealistic values. These two drawbacks are related as only those rivers and lakes which pass a quality control are available on-line. The scientific and user requirements for river and lake data are discussed in Section 4.

The only replies to the questionnaire were from people/organizations that used the rivers and lakes RA data, including most of the main groups worldwide using RA data It is unclear why other people/organizations did not use the data or the potential number of people who would use the data if it included more rivers and lakes and the quality control was better. But from the comments received adding more rivers and lakes and better quality control is important.

The SAR data from Cryosat-2 and in future from Sentinnel-3 has a lot of potential in regards to the Land and Inland Water theme. Not only has it the potential to extend the existing time series of data, which is really important for looking at the effect of climate change (see deliverable D2100), but also for additional targets and improved quality. Users are clearly exciting about the additional potential of this data.

From the replies the users of the RA data can be split into two main groups (although there is obviously some overlap between the groups): the RA experts and the end users. In general, they are experts in RA and are focused on obtained the best quality water level data. They want individual altimetry values (rather than mean value) and full details of how the water levels values were obtained (including corrections). They fully understand the different modes

available in Cryosat-2 and are excited about the potential of the SAR data in Cryosat-2 and Sentinel-3. On the other hand are the end-users. In most cases these users have little or no knowledge of RA. They just want the best available data with the smallest errors. These users are not really bothered about where the data comes from and do not usually understand the difference between LRM, SAR and SARin data and which data is available on Cryosat-2 or in future on Sentinel-3. What is clear from this questionnaire is that it is important to provide the data and information for both types of users.

4. Scientific and Operational User Requirements

The water levels in lakes and rivers obtained from satellite altimetry is used for two main reasons: firstly, for near Real Time (NRT) forecasting and, secondly, for historical analysis. Full details of how the water level data is used are given in Deliverable D2100 the Preliminary Analysis Report.

For the NRT data the Rivers and Lakes website (http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/shared/main) is an important resource. However, as this Deliverable has shown there are a limited number of targets, as the targets present have to pass quality control, and even for those sites that are available there are outliers/erroneous data for these targets. For example, there are some water levels in lakes well below the base of the lake bed. For NRT data these constraints are inevitable as such values may include systematic errors but still pass internal checks based on along-track consistency of heights .

However, for historical data there is the potential to carry out proper validation and hence to produce a datasets with more targets and without the outliers/erroneous values. The user's response to the questionnaire suggests that this is an important scientific and operational requirement. This would require a reanalysis of all existing data but would enable full use to be made of this exciting and unique dataset. Three possibilities are suggested for the validation

- A simple range test. For each site there is a maximum possible and minimum possible value. If the data is outside this range it can be removed
- A test for jumps in the data. It can be physically impossible for river water levels to drop more than a certain amount within a short period
- Analysis of nearby data. Birkinshaw et al. (2010) removed erroneous data by considering all the satellite altimetry along a stretch of river simultaneously.

In summary, any future website should include more targets, stringent quality control and single file downloads for a particular location for post-processed data perhaps by combining the best features of the River and Lakes websites and that of the USDA. Further, a single timeseries for a lake should be available. This is not intended as a criticism of the River and Lakes website as that was run under Near Real Time constraints. The high frequency rate of SAR altimeters should also facilitate quality control on NRT data. However, for non-real time usage the user requires

greater consistency, integrity and filtering where possible. For rivers sensible quality control needs to be imposed to remove systematic errors while for lakes assimilation into a single file based on reprocessed heights is the main requirement. Associated with quality control a measure of accuracy should be presented whenever multiple heights across the inland water permit its derivation – such a measure will need to use an empirical approach to identify spurious data. There is a strong requirement for timeseries of river and lake heights and more targets should be added to the database. Furthermore, the necessity for continuous time series throughout the year could be dropped to allowing inclusion of ice-bound rivers and lakes etc to be included.

Table 2 summarises the requirements for RA over rivers and lakes both for existing products and for future research and development from Cryosat-2

Table 2 List of user requirements for RA over rivers and lakes

Number	Requirements	Technical & Scientific constraints
1	NRT and historic water level data should be reprocessed and made available for more locations	For the NRT data this will allow locations with erroneous data/outliers to be included. For the historic data post processing (see number 2) should improve the quality
2	Historic water level data should be post processed to improve the accuracy and remove outliers	This would require a reanalysis of all existing data and improved algorithms to remove the outliers. The algorithm would include a range test, a jump test and that other nearby RA data are considered. A measure of the accuracy/errors in the data should also be produced.
3	A single time series for historic lake water level should be made available	Post processing of RA data from several locations will be required. A measure of the accuracy/errors in the data should also be produced.
4	Currently the mean water level for a river and lake is produced, individual values should also be made available to enhance spatial	There needs to be some thought about how this data can be put on a website for easy downloading.

	resolution.	
5	Modify the website for downloading of data	The other requirements will mean the website to download the data will need to be modified. Changing it to include the best features of the Rivers and Lakes and the USDA should be considered.
6	Full details on the auxiliary data (such as the wet and dry troposphere correction) should be made available	
7	Analysis of Cryosat-2 waveform for LRM, SAR and SARin data is needed.	Downloading of complete years of data for the validation locations and categorizing of the waveforms
8	Assessment of the accuracy of the Cryosat-2 data	Comparison with validation datasets. Development of atmospheric corrections for Cryosat -2
9	Details of the parameters used to obtain RA data in SAR mode	
11	Enhance the precision of SAR altimetric heights. Users state that 5-30 cm is the requirement for scientific use and hydrological applications.	Comparison with in situ data etc will almost certainly show that this is achievable over lakes and large rivers but perhaps ambitious for small rivers and complex targets.

Items 1-6 of Table 2 are suggested recommendations for a follow-on Cryosat-2/Sentinel-3 and upgrade to the present River and Lake system to enhance the user experience to a level of detail and efficiency beyond that users perceive with the USDA website. Items 7 onwards relate specifically to Cryosat-2 and Sentinel 3. The inference from the questionnaire is that applications of the River and Lake website will be projected into the Sentinel-3 era (Items 7-11) but with Items 1-6 addressed in the new system.

Table 3 User applications and realistic requirements for RA and other remote sensing data over rivers and lakes

	Application	Data	Requirement
1	Lake level	RA	NRT and post processed Height accuracy: <20 cm Distribution: Global Geoid ≈5cm (to connect adjacent or non-repeat passes) Suggestions: Scandinavian Lakes, ephemeral lakes
2	Lake extent	Microwave/optical	Post processed Accuracy in plan: 5-50 m
3	Lake volume	RA, microwave/optical digital terrain model	NRT and post processed
3	River level	RA	NRT and post processed Height accuracy: 5-30 cm but useful as long as accuracy less than variation Distribution: global Suggestion: ephemeral rivers
4	River width	Microwave/optical	NRT and post processed Accuracy in plan: 1m (mean over 20-30 km stretch) (SAR, altimetry)
5	River slope	RA, microwave/optical digital terrain model	Post processed Accuracy: cm/km
6	River discharge		NRT and post processed From river height, width and slope. Can be coupled with river velocity based on microwave sensors (e.g. MODIS, AMSR, Sentinel)
7	Flooding	RA, microwave/optical digital terrain model	NRT

The user applications, data and realistic requirements as inferred from the questionnaire are presented in Table 3. It was noted that most users downloaded the existing River and Lake data monthly or annually but with 5% downloading weekly. Assuming the latter are NRT most current users post-process the data. However NRT use is still significant and likely to be concentrated in Africa where for geo-political reasons communication between neighbouring countries may be limited. The requirement for NRT results is strong with further potential for development to include improved accuracy, targets and quality control. The development of tools for microwave/optical sensors for lake extent, river widths and flooding are outside the CRUCIAL remit but have been included for completeness and to illustrate the extensions necessary to move beyond the River and Lake concept and to inform the scientific and operational requirements for the Land and Inland water theme.

5. References

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Annex I – Questionnaire

The Questionnaire sent to the River and lake users contained nine questions can be seen below:

1 How did you find downloading the data from the River and Lake website (http://tethys.eaprs.cse.dmu.ac.uk /RiverLake/shared/main)?

2 How did you find using the data from the River and Lake website?

3 How often do you use the data from the River and Lake website?

4 What do you use the River and Lake data for? Select all the boxes that are relevant

- ☐ Water levels in lakes
- ☐ Water levels in rivers
- ☐ To help estimate river discharge
- ☐ Flooding extent

Other (Please Specify)

5 For the River and Lake data do you use the Near Real Time (NRT) data, historical data or both? For historical data there is the potential in the future to post-process the data to remove outliers

- ○ Near real time data
- ○ Historical data
- ○ Both near real time and historical data

6 Which locations or regions of the world have you used River and Lake data for?

7 The River and Lakes data provides the water level. Would full details about the auxiliary data used to obtain these values be of use? For example, you may wish to replace the wet tropospheric, dry tropospheric correction, instrument correction, orbital height etc with your own values but you will need the values utilised in the height measurement to do this.

- ☐ I am only interested in having the best water level data rather than how it was obtained
- ☐ I would like basic details on the auxiliary data used to obtain the water levels
- ☐ I would like full details of the auxiliary data used in the height measurments so I can apply my own corrections

Please specify which detailed auxiliary data you would like

8 The current Rivers and Lakes data from ENVISAT and Jason-2 gives the mean water level for a track across a river or lake. Are you interested in the individual values or just the mean value?

- ☐ Individual values
- ☐ Mean values

9 What improvements would you like to see to the River and Lake data availability and content? Please fill in the box with any suggestions.

10 The obvious aim is that the water levels obtained from satellites should be as accurate as possible. It would be really useful if you could provide any information on the minimum accuracy level needed for your work or the potential scope for other work if the accuracy levels were improved.

11 We are currently working with Cryosat-2 data. This operates in three modes depending on its locations. These are the conventional altimeter or LRM mode, SAR mode and SARin. Which data are you interested in? Select all boxes that are relevant

- ☐ Conventional or LRM mode
- ☐ SAR mode
- ☐ SARin mode

12 We are currently working with Cryosat-2 and in the future we will be using Sentinel-3 data. Cryosat-2 is sometimes in SAR mode and Sentinel-3 will be in SAR mode. Are you interested in the parameters used to obtain the altimetry data in SAR mode?

- ○ Yes, please provide details
- ○ No, I just want the best data that is available

13 We are currently working with Cryosat-2 and in the future we will be using Sentinel-3 data. Is there any particular data from Cryosat-2 and in future from Sentinel-3 that would interest you? Please fill in the box with any suggestions.

14 If there are any other comments that you would like to make them please fill in the box below.

15 It would be really useful if we could know more information about your organisation. If you could fill in details below that would be great (otherwise leave it blank).

Finish Survey