6.1: River and Lake level downstream added value services

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1. Abstract

This document describes the river and lake services based on CryoSat-2 SAR altimeter data defined in the scope of the LOTUS project.

River and lake level monitoring is a key parameter for various applications. State water agencies are definitely interested in such information since they want to prevent from natural disasters such dryness and floods. That information helps them to regulate the distribution of water in their respective areas. Hydroelectric companies controls part of the water retention areas to regulate their energy generation systems. River and lakes levels estimations allow them to prevent from water scarcity.

Currently, river and lake level retrieval from altimeter has already proved to be effective for large structure. Existing initiatives such as PISTACH or Hydroweb in Europe already distribute river and lake level products, based on conventional altimetry measurements. In the framework of LOTUS, has been demonstrated that with SAR altimeters the size of the water structure where water level can be estimated is reduced significantly.

A SAR altimeter uses delay Doppler techniques to obtain a finer ground footprint in the along track direction. The level of smaller water structure can be then estimated as their corresponding waveforms are not or less perturbed by the presence of land closeby. Moreover, the 20Hz measurements from conventional altimeter remain very noisy, only up to 5Hz products can be exploited. But, using SAR techniques the noise reduce largely; the delay-doppler compression combines waveforms from the same target, during nearby radar emission-reception beams.

Based on the results obtained in LOTUS, a dedicated service to propose to end-users a direct solution to visualize and download river and lake levels products has been developed: “AltWater”. Moreover the developed new river and lakes levels products will be supplied to existing services (Hydroweb, PISTACH), to prepare them for Sentinel-3 future exploitation.

Additionally, a Copernicus Global Land service will start in 2016 to provide the European Community with operational services for various parameters including river and lakes levels. Since, the planned products will be based on conventional altimetry, such future operational service could take advantage of LOTUS progresses using SAR altimeter instruments to estimate river and lake levels.

2. Review of user needs and requirements

2.1.Introduction

The satellite altimetry technique was mainly developed and optimized for ocean study purposes, i.e. for a better knowledge of these vast and deep blue areas on Earth, less well know than Venus' topography in the late 1970's. Satellite altimetry products (the GDR – Geophysical Data Record- being the first widespread product's class) were rapidly adopted by a fast growing community of scientific researchers, gathered under the "Space Oceanography" banner, and developing close and active interactions with spaces agencies (NASA, ESA, CNES). Starting almost from scratch in terms of global remote sensing of the oceans (in 10 days, Topex/Poseidon sampled a larger area than several decades of oceanographic in situ missions), this "Space Oceanography" community was completely receptive to this wealth of data and rapidly developed strategies of smart calibration and validation of the data, as well as their valorization in terms of scientific publications and value added services.

The context is completely different for the use of remote sensing (and especially altimetry) for continental hydrology for numerous reasons. In developed countries, the in situ monitoring of water resources is generally well established and usually performed at the catchment basin scale by public or para-public organisms/institutions. However, numerous countries suffer from water scarcity, which, "in fine", gives a sensible geopolitical dimension to the monitoring of the water resource. Consequently, in situ hydrological measurements are merely widely disseminated, or disseminated with a significant (and sometimes prohibitive) latency.

Hydrologic research is a field of activity that is quite old, very large and highly specialized. Therefore, long lasting work habits and practices, based on in situ measurements that meet the needs pretty well in developed countries, are difficult to change. The remote sensing (which for most hydrologists means optical imaging, with high resolution SPOT-type images) does not seem always relevant, at the noticeable exception of the mapping of wetlands during a flood event. Moreover, the monitoring of water resources at the local and regional scales is an important need expressed by the civil society and consequently, many sophisticated services already exist, often in a competitive market. Therefore, the remote sensing data must be totally relevant and accurate in order to improve these applications.

Note however that the situation is slightly different for river basins in developing countries: the in situ measurement networks are often insufficient and then the monitoring from space, even imperfect, makes sense, but still has to fit with historical existing practices.

Regarding more specifically the space altimetry technique, the resulting observable, i.e. the height of the water surface, corresponds to the main physical/hydrological parameter that is measured in situ with limnimeters. But, whereas the in situ measurement is usually realized several times per day, with an accuracy on the order of the centimeter (or a few centimeters), the equivalent measurement from space is acquired once every 10 days for Jason-2, or 35 days for AltiKa, with an accuracy hardly better than a few tens of centimeter for large rivers. For Cryosat-2, with its pseudo drifting orbit, the pertinence of its water level measurement is even more difficult to compare with in situ measurements and requires new strategies of exploitation/valorization.

In order to enhance the use of altimetry products over hydrological targets, it appeared necessary to some spaces agencies to take into account the needs of the hydrological community which may be skeptical with respect to conventional altimetry products. Therefore, several studies were initiated, either (non exhaustive list):

- with the compulsory participation of representative end users within the consortia ("DUE Innovator TIGER", ESA 2005),
- with a dedicated task aiming at gathering the user's needs and requirements ("River and Lake", ESA 2002; "PISTACH", CNES 2008)
- with a dedicated task of training and capacity building ("DUE Innovator TIGER", ESA 2005).

These studies are complementary to other initiatives that go beyond altimetry alone and investigate in a more comprehensive manner the contribution of space to hydrology:

- Space for Hydrology Meetings: 1st organized by LEGOS in Toulouse in 2003, 2nd organized by ESA and WMO in Geneva in 2007, 3rd to be held in ESA Frascati in September 2015.
- A study, funded by CNES in 2012 and realized by Artelia, CLS and Alcimed, and aiming at drawing the state of the art of the applications and services derived from space techniques for the management of water resources.

The objective of the paragraphs below is to provide a synthesis of the most relevant points from the studies mentioned above.

2.2. Users need enquiry for the PISTACH Project

Since CLS teams were actively involved in the PISTACH project, we draw below a synthesis of the "Quantification of the needs and requirements from the users' community" task performed at the beginning of the PISTACH project (2008).

The core of the PISTACH (Prototype Innovant de Système de Traitement pour les Applications Côtières et l'Hydrologie) prototype consists in several algorithms dedicated to the processing of Jason-2 altimetry data over coastal areas and continental waters. The PISTACH "hydrological" products are based on official IGDR Jason2 products, but are enriched with state-of-the-art retracking outputs and geophysical parameters/corrections (geoid, DEM, land cover class, Land/water mask, …), in addition to a high resolution sampling.

A questionnaire had been sent to more than 90 people from 15 different countries, which list was compiled from:

- personal contacts from the PISTACH consortium members (CNES, LEGOS, IRD, CEMAGREF, CLS)
- List of participants of the ESA "2nd Space for Hydrology Workshop" (Geneva, Nov 2007)

- List of registered users of HydroWeb

The presentation letter of this questionnaire is reproduced below in Figure 1.

On the use of altimeter products for continental hydrology

In the perspective of the Jason-2 mission scheduled for launch in June 2008, the PISTACH project "***Prototype Innovant de Système de Traitement pour les Applications Côtières et l'Hydrologie***" is funded by CNES to prepare a new altimeter data processing system dedicated to coastal seas and continental water bodies (rivers, lakes and reservoirs).

This survey aims at gathering feedback from hydrologists on their needs and requirements in terms of altimeter products in the domain of continental hydrology. These users requirements will guide the development of new altimetry products through improved product definition and data processing.

For those who are not yet fully familiar with altimetry products, you will find a detailed description of these products in annex, as well as on the http://www.altimetry.info/ web site.

PISTACH will only generate so-called "Level 2" products: these are altimetry products and it is to the users to reconstruct water levels.

Higher level products (hydrological water level products, such as those found on HYDROWEB* or River and Lake ** web sites) would certainly better meet the requirements of the hydrology community, but they have to be derived from pertinent Level 2 products. Therefore, this enquiry is not strictly limited to the needs related to a Level 2 product.

We thank you for spending some of your time to answer our questions.

Please feel free:

- to skip questions that you find too specific, especially if you are not (yet) familiar with space techniques and products,
- to contact us if you require any additional information,
- to forward this document to those of your colleagues that could be interested by this survey.

For the PISTACH team

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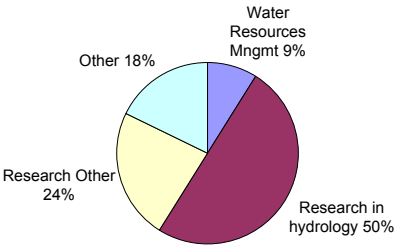
*HYDROWEB: http://www.legos.obs-mip.fr/fr/soa/hydrologie/hydroweb/

**River and Lake: http://earth.esa.int/riverandlake/

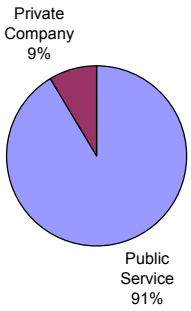
Figure 1: presentation letter of the user's requirements enquiry of the PISTACH project

The response ratio was around 25%, which is low but however common for that kind of enquiry. Half of the people who answered were working in research in Hydrology and 85% of them already practiced altimetry.

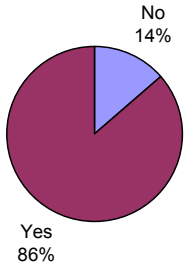
- **Users**



Activity field

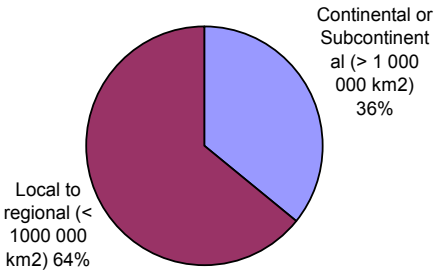


Type of structure

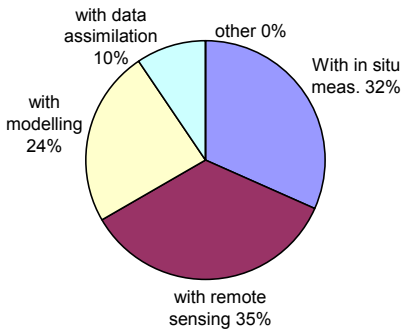


Practice of altimetry

Users familiar with altimetry indicates preferentially use the GDR (all missions) while others prefer Hydroweb and River and Lake water level time series products. The difficulties encountered are: datum that does not correspond with those used locally, insufficient spatial sampling, no parameters (eg Sigma0) associated with the measures (for Hydroweb and R & L), no uncertainty associated with the measurements.



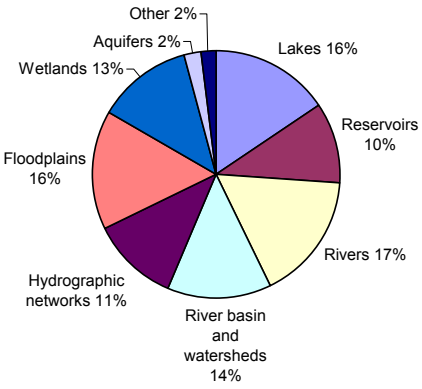
Scale of study



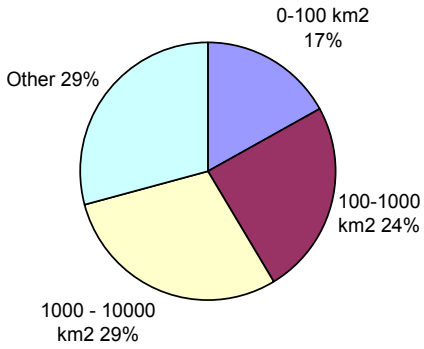
Study tools

In general, the users are working on a local to regional scale (basin). The continental scale especially concerns those working on climate change and on the water cycle on a global scale. Remote sensing is widely used, which makes us think that our users are rather part of "the new generation" of hydrologists. The use of in situ measurements, however, remains essential.

- **Areas of interest**



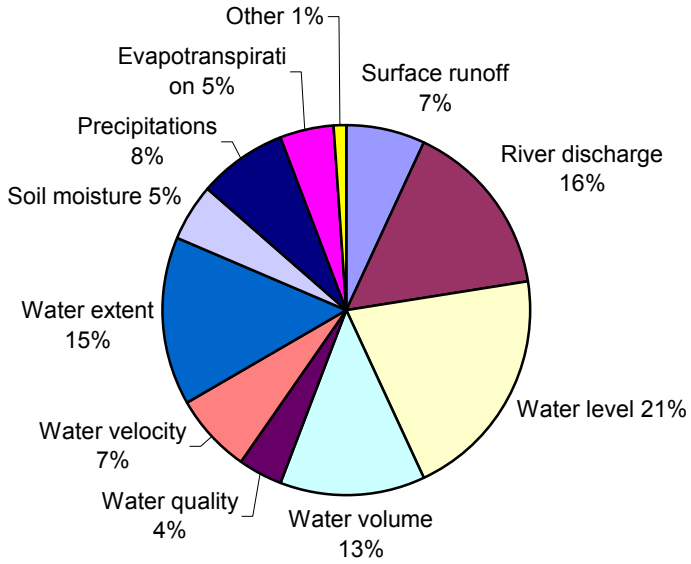
Types of targets



Typical size of study areas

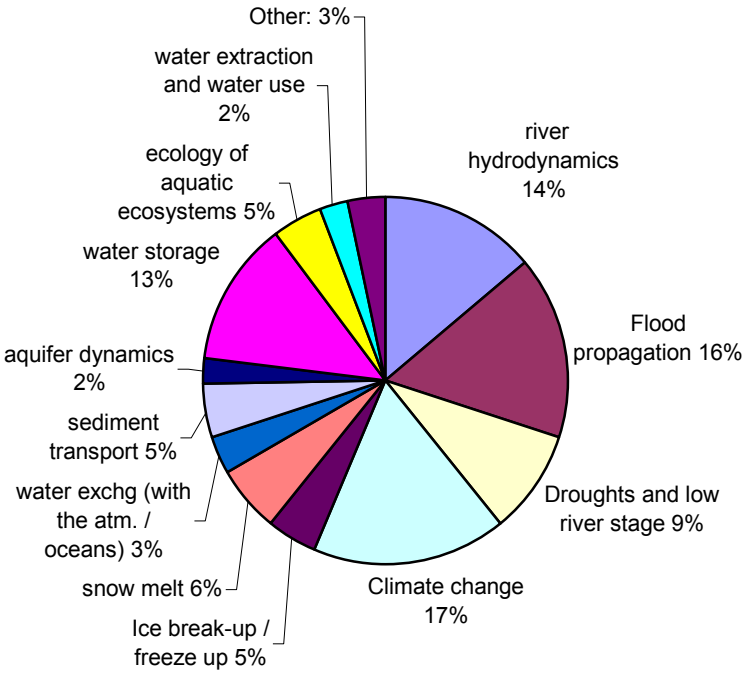
It is interesting to notice that the various types hydrological objects are studied in equal proportions, as well as the geographical scales of these objects.

- **Investigation of hydrological processes**



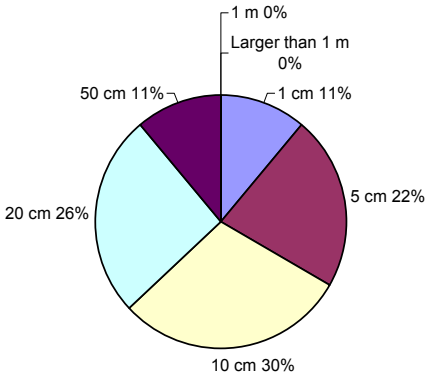
Hydrological parameters of interest

Water level is the hydrological variable that is mostly exploited: it is probably because it is the easiest variable to be measured. This is an "input" variable from which some of the other proposed variables can be deduced. Hydrological in situ practices are also based on frequent measurements (daily, twice daily, hourly, ...) of the water level, that are periodically associated with flow measurements at some river sections (a few times a year). From height/flow couples, one can construct rating curves for estimating the daily discharge from the measurement of the water level.

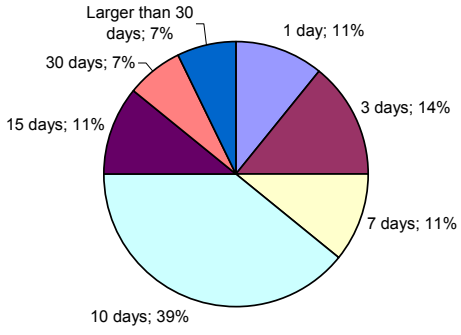


Physical processes

Among the studied physical processes, we distinguish those related to exceptional events (floods, extreme levels: 26%) from the other physical processes more closely related to the observation of the normal operation of water systems and water resources management (river hydrodynamics, water storage, 27% in total). Finally, climate monitoring is a major concern, and altimeter technology, thanks to its global coverage, fills this need.



Required accuracy

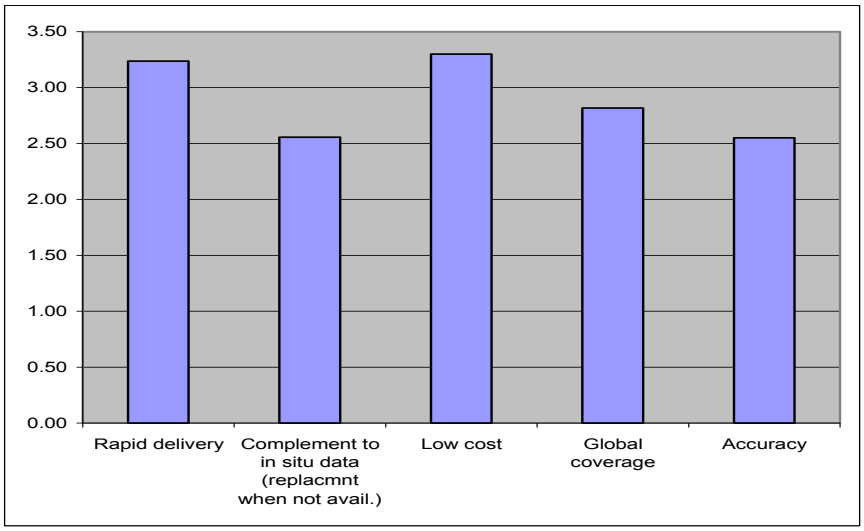


Required repetitivity

In general, users are satisfied with a level of accuracy equal or worse than 10 cm (66% total) and even 20 cm ¼ of them. These figures are certainly skewed by the fact that many of the users are aware of the limitations of the technique: ideal or realistic expression of need?

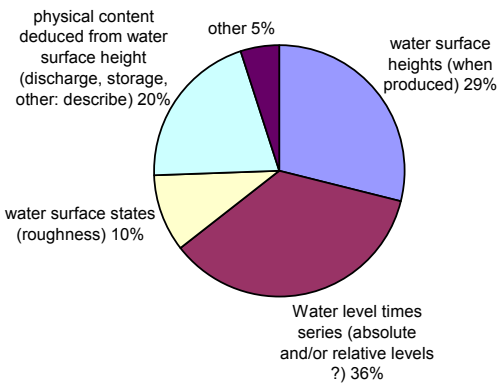
Regarding the frequency of measurement, a desired repeatability of about 10 days (and possibly less) certainly reflects in part a habit with TP and Jason data. The fact remains that a repeatability of 10 days is much better suited to the monitoring of hydrological processes than a repeatability of 35 days, as for ENVISAT.

- **An altimetry product for continental hydrology**

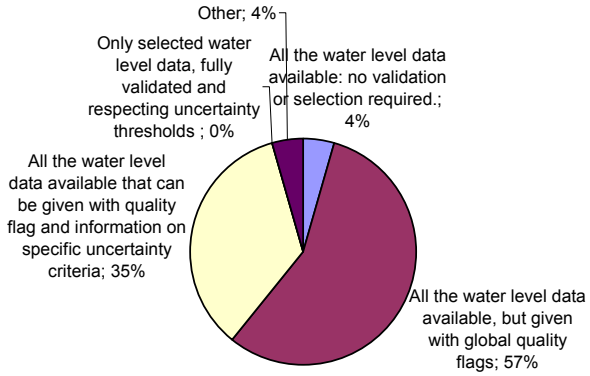


Main characteristics required for an altimetry product dedicated to continental hydrology (1 is for highest priorities, 5 for the lowest).

Users want in priority a product that is accurate and can complement, or even replace, in situ measurements. Surprisingly, the cost and delay of availability are not strong constraints.

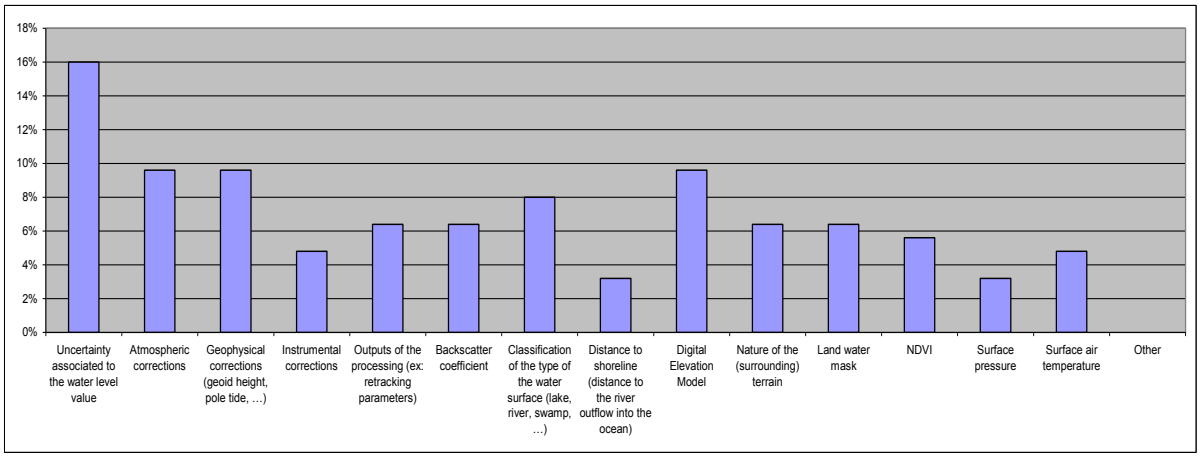


Physical content



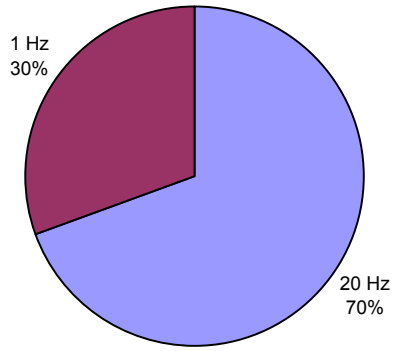
Level of validation

In terms of physical content, the water level time series would be appreciated (meaning Level3 products). Other derived quantities more or less directly from the altimeter measurement and water level are also sought. Users overwhelmingly want to have access to all the data acquired and a quality indicator associated with these data is expected. They seem to be ready (and voluntary) to access / use information on the quality of the data, but feel that this information should not be used by the producer to "clean" the product. The proportion of users who want to have a product "cleaned" however, is not negligible (35%).



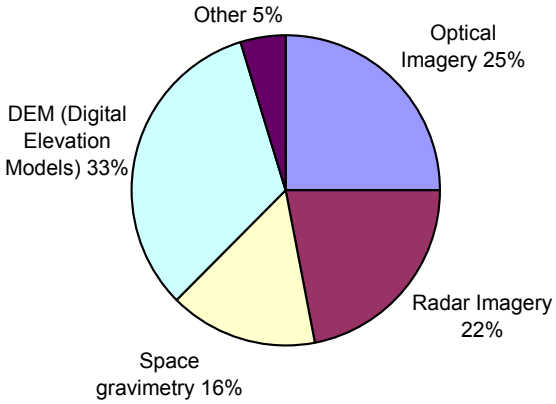
Ancillary data within the product

In confirmation of the previous question, users wish that the product contains an indicator of quality/accuracy/uncertainty. Then come the "usual" atmospheric and geophysical corrections, presumably in order to be able to correct the altimeter measurements in different ways. Information on the topography (DEM) and hydrological classification of the surface are considered useful. To a lesser extent, sigma0 and retracking parameters are required (advanced users) as well as contextual information (terrain, vegetation index, land / water mask).



Sampling rate of the product

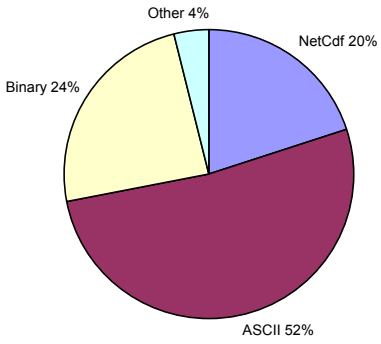
And of course, users prefer the highest sampling rate as possible.



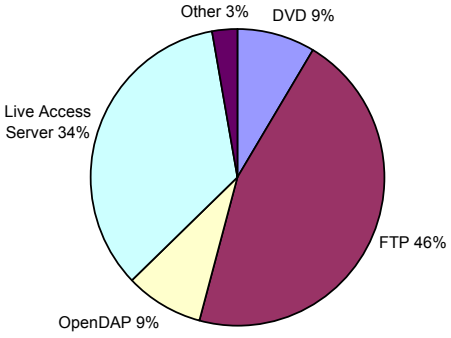
Synergy with other remote sensing data

In terms of synergy with other remote sensing data, the knowledge of a DEM appears very useful, if not essential. Imaging data (optical or radar) are also acclaimed, because it certainly helps to better understand the environment and context of the measurement (limit of the water bodies and if possible temporal variations of these limits) and also to better understand the interaction of the water systems without the need, at least to a first approximation, to go on the field.

- **Data Format**



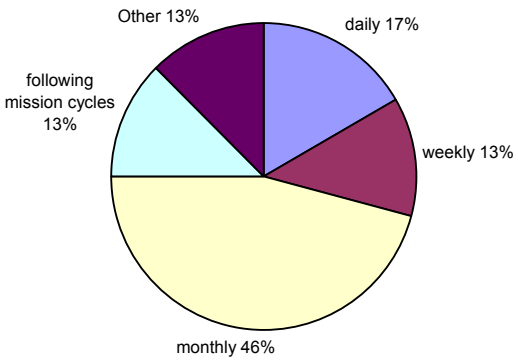
Data format



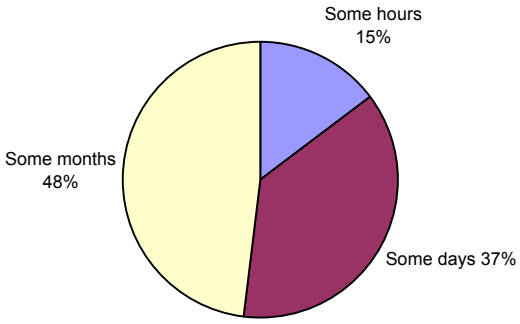
Dissemination of the data

-

Regarding the data format: hydrologists are obviously much less familiar with NetCDF (and more generally with the concept of interoperable file formats) than oceanographers. This point also concerns those already familiar with the altimetry products. FTP is acclaimed for data distribution, but more interactive solutions would also be welcome.

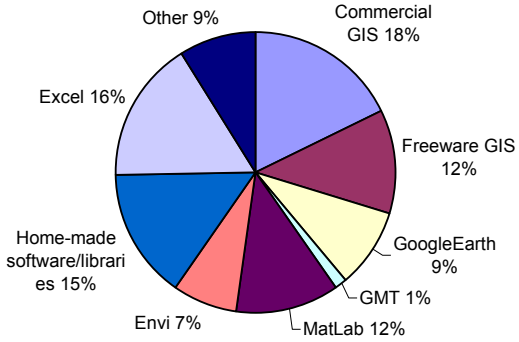


Update frequency



Delay of delivery

These two graphs clearly illustrate that the users are mostly not preoccupied by strong operational constraints that require a quick frequent update.



Software used

And finally, the users often use GIS, commercial or not (30% total). Excel is also widely used, and we note that about 15% of users develop their own processing chains.

Summary of the Users need enquiry for the PISTACH Project

The use of altimetry for continental hydrology is still mostly limited to non-operational uses, rather research-type application, and largely through public organisms/institutes. The uses for modeling, from global to regional scale, and for the climate and the surface water part of the water cycle are still prevailing. It is likely that this type of use will remain for some time the only possible use of altimetry products. Users of altimetry data, or those who intend to use them, although fully aware of their current limitations, however, have fully identified their potential: to complement in situ data or other satellite data sources, to measure water levels in lakes, rivers and in flooded areas.

If the fact of not being demanding for the data delivery in near real time can be explained by the non-operational nature of the uses of these data, the results of this enquiry concerning the data accuracy and repeatability is interesting. This confirms that the water levels data can be used as they are, preferably accompanied by all parameters that assess their relevance and / or validity / uncertainty. All improvements that can be made in the two most critical areas of repeatability and accuracy are certainly welcome, but the survey shows that this data is already useful in a varied number of hydrologic applications.

2.3. Synthesis and recommendations from the Second Space for Hydrology Workshop, Geneva (Switzerland) 12-14 November 2007

Another significant expression of requirements with respect to Earth Observation for hydrology was realized during the 2nd Space for Hydrology Workshop organized by ESA and WMO in 2007. (A sequel meeting is scheduled in September 2015).

The paragraphs below correspond to the draft version of a synthesis written by Pascal Kosuth (CEMAGREF, now IRSTEA) in collaboration with Jérôme Benveniste (ESA). It is not certain that this document was finalized.

Second Space for Hydrology Workshop

WMO, Geneva (Switzerland) 12-14 November 2007

Synthesis of recommendations and actions

(draft-v0 Pascal Kosuth and Jérôme Benveniste 01/12/2007)

The second "Space for Hydrology" workshop (HydroSpace'07) took place in Geneva (Switzerland) November 12-14 2007. It gathered 103 participants from 27 countries, one half from the Hydrology domain and the other half from the Space techniques domain.

80 abstracts were submitted by 138 co-authors leading to 36 oral presentations (4 sessions) and 38 poster presentations (1 common session).

The sessions were :

1. Global Hydrological modelling (oral and poster)
2. Monitoring spatio-temporal chanes of surface waters (oral and poster)
3. Space techniques to monitor hydrological variables (oral and poster)
4. Data assimilation of space observation applied to hydrology (poster)
5. Strategic combination of satellite and ground based data (oral and poster)
6. Current and future challenges in hydrology (poster)

Recommandations and actions

(round discussion on wednesday November 14th)

Debates about recommendations and actions for the further development of interactions between Hydrology and space techniques have been organized according to 5 major issues :

1. Access to satellite data and archives by hydrologists
2. Calibration, validation and quality of satellite products for hydrology
3. Development of the interactions between the two communities (Hydrology and Space techniques)
4. Modeling and assimilation of satellite data in hydrological models
5. Needs for space data and priorities for new satellite missions dedicated to continental hydrology

1. Access to satellite data and archives by hydrologists (P. Berry and others)

R-1-1 : Inform the Hydrological community on available satellite products : *The Hydrology community should be better informed on available satellite products and the inputs and insights that space techniques are potentially able to provide for hydrological studies.*

This should be done through workshops, capacity building and websites

R-1-2 : Web portal for "Hydrology and Space Techniques" *: dedicated to hydrologists to help them identify and access relevant satellite data, and to space scientists and engineers to access information on hydrological concepts and requirements.*

Strong support was given to the idea of a web portal

R-1-3 : Standards *: data formats and standards should be defined to exchange between multiple data sources (water level data, river discharge…)*

There is a lack of common standards to exchange water level data and river discharge data (see experience by WMO, GRD Global Runoff Data Center)

R-1-4 : Long term archiving of satellite products *:*

Archiving satellite data after the end of a satellite mission and maintaining these archives is a major problem. It should be addressed by Agencies and international organiszations.

2. Calibration, validation and quality of satellite products for hydrology (Alexander Braun, Pascal Kosuth)

R-2-1 : Data quality *: Satellite products (hydrological variables derived from satellite measurements) must be accompanied by uncertainty information.*

Satellite products too often consist in values, or time series of values[1], with no information on the uncertainty. Hydrologists cannot use such data in a proper way as they cannot assess the final uncertainty on their results. An additional risk is that "over-optimistic" estimations of accuracy (ex. a

[1] This was the case for the majority of the presentations during the workshop and is the case of a majority of the websites that provide such products

few decimeters for river water levels) lead some decision makers to assume that satellite techniques can replace in situ measurement.

Relevant quantification of the uncertainty will help in 3 complementary directions :

- it will allow hydrologists to properly use these products in complementarity with in situ data
- it will allow to assess the improvement of the products along time (new algorithms, new filtering methods,…) and therefore guide researchers in their developments
- it will guide further technological developments in sensor design and mission design

Uncertainty information should consist in error bars associated to values, with proper description of the method used to estimate the error (see recommendation 2-2). When such result is not available the product should be accompanied with the outputs of the CAL/VAL study on reference systems with a statistical relevance. When no Cal/Val results are available it should be indicated and the mission specifications should be given.

R-2-2 : Error assessment methods *: For each type of satellite product, the two communities (space techniques and hydrology) should work out a commonly agreed protocol for validation and quantification of accuracy/uncertainty*

R-2-3 : Scaling effects and errors *: Changing scale (time series, spatial fields) induces loss of information, bias and increase of uncertainty. We need to document scaling methods and their effects, and to inform the hydrological community*

A debate was initiated on these recommendations and more generally on the topic of product uncertainty. Although all agreed on the importance of quantifying the accuracy of hydrological variables derived from satellite (particularly for hydrologists to use these variables), the difficulty to achieve that task through unified methodologies was pointed out :

- in the case of radar altimetry the errors deriving from the geoid models, the lack of available in situ observation or the heterogeneous quality of these observations make the issue difficult : it is probable that a single methodology cannot be implemented to assess accuracy in the diversity of cases
- in the case of gravimetry or soil moisture, the spatial scale of the satellite measurement does not allow any direct comparison with in situ measurements. Consistency between satellite data and in situ measurement can only be assessed through modelling

It was emphasized that the methods to quantify accuracy could be diverse as long as they are clearly documented. (ex. of WMO)

WMO (Wolfgang Grabbs) proposed that the "accuracy of hydrological variables derived from satellite observation" topic could be a specific one addressed at the 2009 WMO Congress to be held in Brazil.

Another proposal was to establish benchmark areas, regions where specific works could be done to quantify the accuracy of satellite observation (ex. European rivers and basins, Amazon basin…)

3. Mechanisms for co-operation between the two communities (Hydrology and Space techniques)
(Paul Bates, Wolfgang Grabbs)

The obstacles for the hydrological community to make better use of the information provided by satellite Earth Observation techniques are various :

- lack of awareness on available data
- difficulties in accessing the existing data (lack of information on how to access these data "accessing satellite data is difficult"; cost problems…)
- difficulties to access funding to develop satellite data based methods
- lack of capacity
- from the point of view of the managers there is still a limited number of applications that are currently available

Hydrologists do not really know which type of information they could get from satellite data (estimation of water quantity, flood extent, flood and reservoir volume…)

R-3-1 : Capacity building : *capacity building for hydrologists to access and use satellite products*

The lack of capacity (by hydrologists) to use satellite products should be addressed through Capacity Building (workshops, summer schools) : this requires specific funding for capacity building. The FP6 had some funding possibilities, for instance on "Grid Computer Exchange". Similar funding could be mobilized for Space techniques for Hydrology.

R-3-2 : Exchange of information amongst hydrologists *on the applications of satellite products*

Although there is still a limited number of hydrological applications making use of satellite products, this workshop has shown a significant development in this direction. All opportunities should be used to divulgate these applications and stimulate exchange amongst hydrologists. This can be done

through websites, through participation to Water Resource and Hydrology Congress, workshops, conference, through capacity building and education.

R-3-3 : Stimulate expression of hydrologists requirement

It is important for space scientists to both develop satellite products and be open to requirements expressed by hydrologists. All possibilities for space scientists to

Contacts should be made by WMO with Regional HYCOS (HYdrology Cycle Obersving Systems) to inform them on available hydrological data from satellites and to inventory their requirements, particularly in the field of radar altimetry information.

A specific session of the 2009 WMO Congress should be dedicated to the complementarity between in situ data and satellite data

4. Modelling and assimilation of satellite data in hydrological models

A major driver of the use of satellite products in domains such as meteorology and oceanography has been the need to use these products in models. Scientists of these domains have developed a strong experience and capacity to assimilate satellite products in models, which is not the case for hydrologists : current researches in hydrology are far from able to assimilate near-real time satellite data.

R-4-1 : research on assimilation of satellite products in hydrological models *: Research should be supported to enhance assimilation capability of models (special funding program?)*

Specific research works are needed to enhance the assimilation capability of models (flood propagation models, surface hydrology models).

R-4-2 : Exchange of experience in the modelling approaches :

Opportunities should be developed to facilitate exchange of modelling experience between groups. Various issues have to be considered:

- sensitivity approaches
- spatial and temporal resolution, multi-scale approaches and inter-scale consistency
- real-time forecasting and adaptive management (great demand and potential in cooperation with actual end users)

5. Needs for space data and priorities for new satellite missions dedicated to continental hydrology (Jérôme Benveniste)

Up to now, no specific mission was dedicated to continental hydrology. Hydrologists have had to develop specific methods to extract relevant information from satellite missions that were initially designed for other purposes (ocean monitoring, solid earth monitoring, atmosphere monitoring).

R-5-1 : Priority to an along-track interferometry mission for continental waters

An along-track interferometry mission dedicated to continental water surfaces appears to be the number one priority in the field of hydrology. This would provide repetitive spatial coverage of water levels and slopes, water extent and delineation and inform on river and floodplain hydrodynamics and prepare the way to estimation of river discharges.

R-5-2 : GRACE follow-on

Preparing a GRACE follow-on mission with highest spatial resolution and increased accuracy (medium size river basins 10 000 km²) would provide information for hydrologists and monitoring tools relevant for water managers. Research on such developments are necessary.

A soil moisture sensor with higher resolution than SMOS would allow to take into account soil moisture dynamics on smaller catchments.

Conclusions for Action

- Action 1 : Develop a **"Space for Hydrology" web portal** dedicated to hydrologists to help them identify and access relevant satellite data, and to space scientists to understand hydrological concepts and requirements.
- Action 2 : Develop **capacity building for hydrologists** in order to enable them to access, analyse and use hydrological variables derived from satellite missions
- Action 3 : Support preliminary researches for the **development of an along-track interferometry mission** dedicated to continental water surfaces
- Action 4 : initiate a common work between space scientists and hydrologists to **quantify the uncertainty of satellite products for hydrology**
- Action 5 : Adapt, design, develop **standards for exchange** of hydrological data (to be done in close relation with WMO), and apply them for satellite products dedicated to hydrology
- Action 6 : Facilitate all means of exchange of information on successful applications of satellite products for hydrological studies (research and management).
- Action 7 : prepare a joint WMO-Space for Hydrology session at the next WMO Congress (2009 Brazil)

2.4. State of the art of the applications and services derived from space techniques for the management of water resources

Below is a synthesis of the enquiry realized in 2012 among French actors of the water resource management (Courtesy of CNES)

This study was funded by CNES in 2012 and realized by Artelia, CLS and Alcimed.

The people who were interviewed and their domain of activities

More than 60 people were contacted with respect to their activities in the water management domain. Most of them are French and work in French companies or institutions.

These activities are:

1. Water Governance
2. Management of Risk
3. Agriculture
4. Energy
5. Aquatic Ecosystem
6. Drinking Water

7. Research
8. Transportation
9. Impact on civil engineering structures
10. Health
11. Integrated Management estuaries

Their actual practices in terms of data used

The actors are organized at different levels: local, regional, national and / or international level and sometime interact with each other by various processes including the regulation.

When working on the French territory, the people that where questioned rely overwhelmingly on their in-situ measurements (60%). They use the in-situ measurements (sampling, measuring stations and airborne tools) in particular for their high accuracy (e.g. centimeters for the water level). The actors interviewed also use databases (30%). Satellite data are used at the margin (10%), primarily by users already familiar with these techniques.

Outside France, the satellite tool is more frequently used (50%), or is used to supplement the in-situ data, or to compensate for their absence due to difficulties accessing it, for geographical or political reasons or in case of lack of cooperation for their dissemination.

Needs and expectations

The actors interviewed mentioned two types of needs: generic needs that do not refer directly to a measurement of physical parameters and specific needs in terms of new concrete services. On the needs and expectations on a more general point of view, they stress the importance of regionalized visualization (2D) coupled to the temporal visualization (movie), but also the importance of standardization and capacity building to space technologies in terms of cost and technical possibilities. For new services in France, the needs cover relatively demanding services, mainly on the themes of mapping of wetlands and of the water resources storage:

Service identified	Description / Objective
Mapping of water storages	Mapping of the surface network for the resource management
	Mapping of ground water resource for resource management
	Mapping of the surface network for the flood risk management
	Mapping of ground water resource for the flood risk management
	Mapping of snow cover

Mapping of wetlands	Mapping of wetlands for protection of natural areas
	Mapping of wetlands for the flood risk
Decision support for irrigation	Fine quantification of water needs for agriculture
Monitoring of vegetal transport in rivers	Monitoring of sediments and other particles for evaluation of siltation
Plan land use	Density of population for evaluation of water demand and risk assessment
Mapping of water pollution	For anticipation of water pollution for sanitation of drinking water and bathing areas
Mapping of surface temperature	Identification of water resurgence in wetlands
Elevation profiles of the rivers	Improvement of hydraulic models and discharges
Maximum extent of floods	Improvement of models and prevision of floods

For applications abroad, most of the need is "basic" information to which should be added a few specific services:

Service identified	Description / Objective
Access to "basic" information	Objective and homogeneous over one given area (topography, imagery, altimetry, mapping, water height, discharge, …
	Information to define DEM, identification of river networks, creation of land use maps
Mapping of water storages	Estimation of levels and associated stored volumes for resource availability management: surface and underground storage
Localization and identification of water pollution	Detection of blooms of algae and other microorganisms
River water level from altimetry	Anticipation of floods Security of navigation
Currents and fresh water plumes in estuaries	Improvement of offshore structure dimensioning and securitization of operations

Regarding the use of satellite data, the actors interviewed are particularly sensitive to the possibility of optimizing resources and associated costs. The main obstacle cited by the actors is the cost of access to spatial data, being either real or psychological.

Analysis of the most pertinent services

Relevance of the identified services could be into 3 categories with respect to their level of maturity:

1. The existing services and completely filling (or in a relatively large portion) the expectations of users

2. The existing services that do not meet all expectations (e.g. lack of accuracy, cost, availability of information, ...)

3. Service unavailable at present

Service	Service already existing satisfying the expectations of the users	Existing services but not fully satisfactory	Service unavailable at present
Mapping of the hydrographical network, of wetlands and of surface reservoirs for the management of the resource	x		
Mapping of underground reservoirs for water resource management			x
Mapping of snow cover and snow water equivalent		x	
Land Use		x	
Localisation and identification of water pollution		x	
Decision making support for irrigation			x
Monitoring of the transport of vegetal particles in rivers			x
Mapping of water surface temperature		x	
Mapping of maximum flood extent in forests			x
River water level from altimetry		x	
Lakes and reservoirs water levels from altimetry	x		
Water level in flooded forests from altimetry		x	
Currents and river water plumes in estuaries		x	

3. Review of the state of the art technologies

This chapter provides below a comparative description of the data sources of inland water level derived from altimetry.

For most of the databases mentioned hereinafter, the data sets are freely accessible (usually after a registration process) via a clickable web map interface. These databases have a global coverage. Water level time series are usually provided as simple text files for download.

3.1. Hydroweb

The pioneering service **Hydroweb** was created at CNES/LEGOS (Toulouse, France) in the team of Anny Cazenave in the early 2000's. The (historical) Hydroweb web site is accessible via the following URL: http://ctoh.legos.obs-mip.fr/products/hydroweb

The first objectives of Hydroweb were to provide users with freely accessible water level time series derived from satellite altimetry over a large number of hydrological targets. The first products were computed over large lakes with Topex/Poseidon data. The number of studied objects rapidly increased as well as the number altimeter missions used in the processing (ERS-2, Envisat, GFO, Jason-1, Jason-2, Saral/AltiKa). It is now possible to get water level times series for hundreds of lakes and river virtual stations. Moreover, for some selected lakes, Hydroweb also proposes water volume time series based on the combination of water level and surface water area fluctuations. Hydroweb also distributes water equivalent heights time series over most of the large river basins based on gravimetry measurements from GRACE mission.

Scientific references as well as description of the Hydroweb processing is accessible here: http://www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/index.html

In 2015, Hydroweb became a fully operational service via its implementation on the CNES/THEIA Platform and its operation by CLS. The new Hydroweb interface will soon be fully accessible via the URL: http://hydroweb.theia-land.fr/?lang=en&

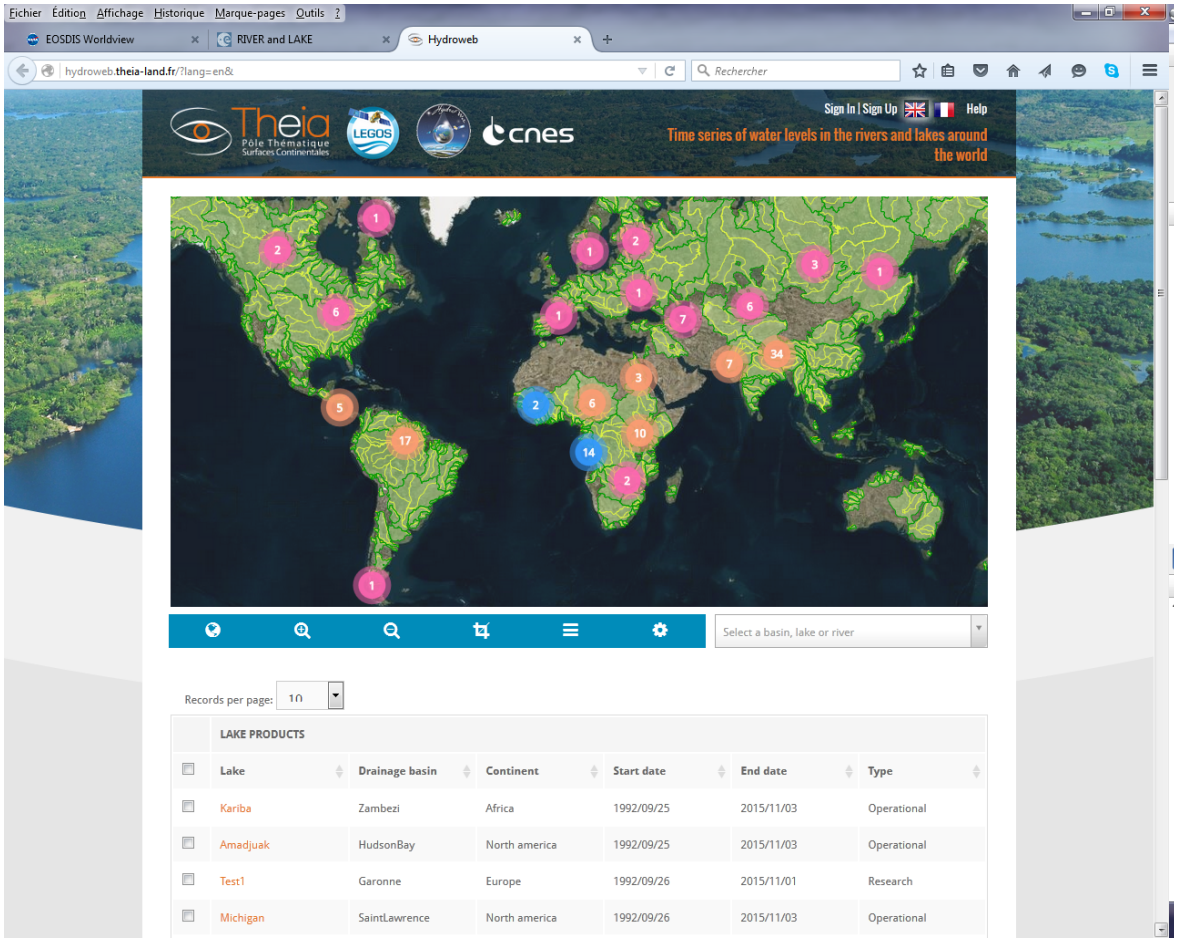


Figure 2: Home page of the new version of HydroWeb

3.2. River&Lake

In 2003, ESA started the **River&Lake** project with the aim of providing information on water levels of major lakes and rivers across the Earth's surface, derived from Envisat and ERS radar altimeter measurements. The development effort was headed by Professor Philippa Berry of the UK's De Montfort University, who previously developed an “expert system” for the retracking of the highly shape-variable inland radar altimetry echoes for the improvement of global DEM (cf ACE and ACE2 products web page http://tethys.eaprs.cse.dmu.ac.uk/ACE2/shared/overview). Taking advantage of that expert system, a new processing algorithm has been developed to extract rivers and lakes level findings from raw radar altimeter data. The River&Lake project has been continuously funded by ESA and its scope enlarged to other, non-ESA, altimetry missions such as Jason-1 and Jason-2. Further information and data sets, as well as products and processing description, can be found at the following URL: http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/shared/main

The principle of the River&Lake project if very similar to the one of HydroWeb: freely provide users with as many worldwide inland water level time series as possible.

The main difference consists in the reprocessing of the waveforms, which is not performed in the computing scheme of HydroWeb. However, no significant comparison between HydroWeb and River&Lake results has been published. At the time of writing (November 2015), it seems that the latest update on the River and Lake web page has been published in September 2014.

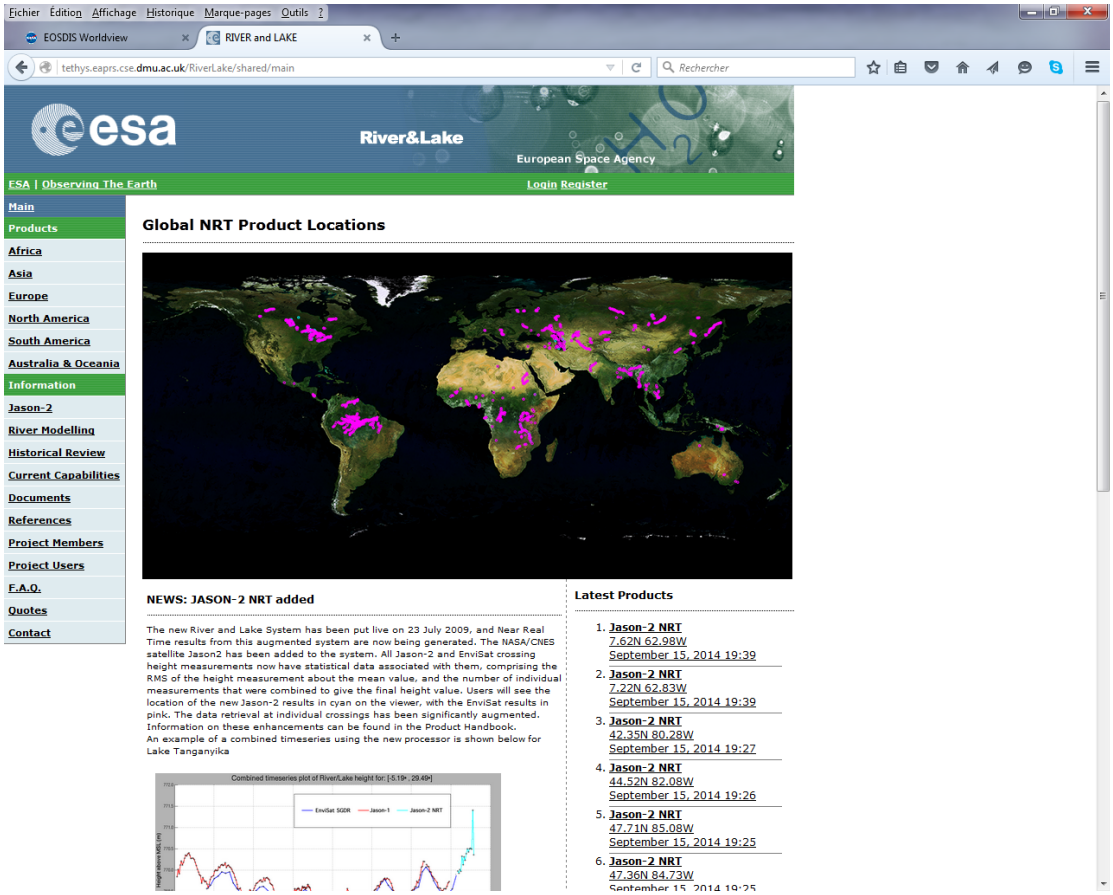


Figure 3 Home page of the River&Lake project

3.3. Global Reservoir and Lake Monitor

Dr Charon Birkett (Univ. of Maryland) is among the very first researchers who published worldwide lakes and rivers water level time series from Topex/Poseidon data in the mid and late 1990's. Together

with these time series, she also provided a detailed analysis of the behaviour of the radar altimeters over continental waters as well as a comprehensive description of her processing scheme and errors estimates. This work is legitimately considered as a reference by most of the subsequent studies published on the subject and it led to the setup of the operational service dedicated to the monitoring of lakes and reservoirs described below.

Since the early 2000's, the U.S. Department of Agriculture's Foreign Agricultural Service (USDA-FAS), in co-operation with the National Aeronautics and Space Administration, and the University of Maryland, are routinely monitoring lake and reservoir height variations for many large lakes around the world. The program utilizes NASA/CNES/ESA/ISRO radar altimeter data over inland water bodies in an operational manner. The surface elevation products are produced via a semi-automated process and placed at this web site for USDA and public viewing. Monitoring height variations greatly assists the USDA/FAS Office of Global Analysis to quickly locate regional droughts, as well as improve crop production estimates for irrigated regions located downstream from lakes and reservoirs. All targeted lakes and reservoirs are located within major agricultural regions. Reservoir and Lake height variations may be viewed in graphical and text format by placing the cursor on and clicking the continent and lake of interest on the following web page: http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

This service utilizes near-real time radar altimeter data from the Poseidon-3 instrument on-board the Jason-2 (or OSTM) satellite which was launched in June, 2008. In addition, data from the Jason-1 mission (2002-2008) and an historical data archive from the TOPEX/POSEIDON mission (1992-2002) are also used, together with historical data from GFO and EnviSat. When fully operational, updated products are delivered within 7-10 days after satellite overpass. The resulting time series of height variations are expected to be accurate to better than 10cm rms for the largest (and more open) bodies of water such as The Great Lakes, USA, Lakes Victoria and Tanganyika in Africa etc. Smaller lakes or those that experience more sheltered (from wind) conditions can expect to have accuracy's better than 20cm rms (e.g. Lake Chad, Africa). Satellite passes that cross over narrow reservoir extents in severe terrain will push the limits of the instruments with resulting rms values of many tens of centimeters. Full details and references can be found on the web page mentioned above and also on that URL: http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/reference.htm.

Note that **this service is restricted to lakes and reservoirs and does not provide river level time series**. However, its level of operationality is remarkably high with respect to HydroWeb (historical web site) and River&Lake.

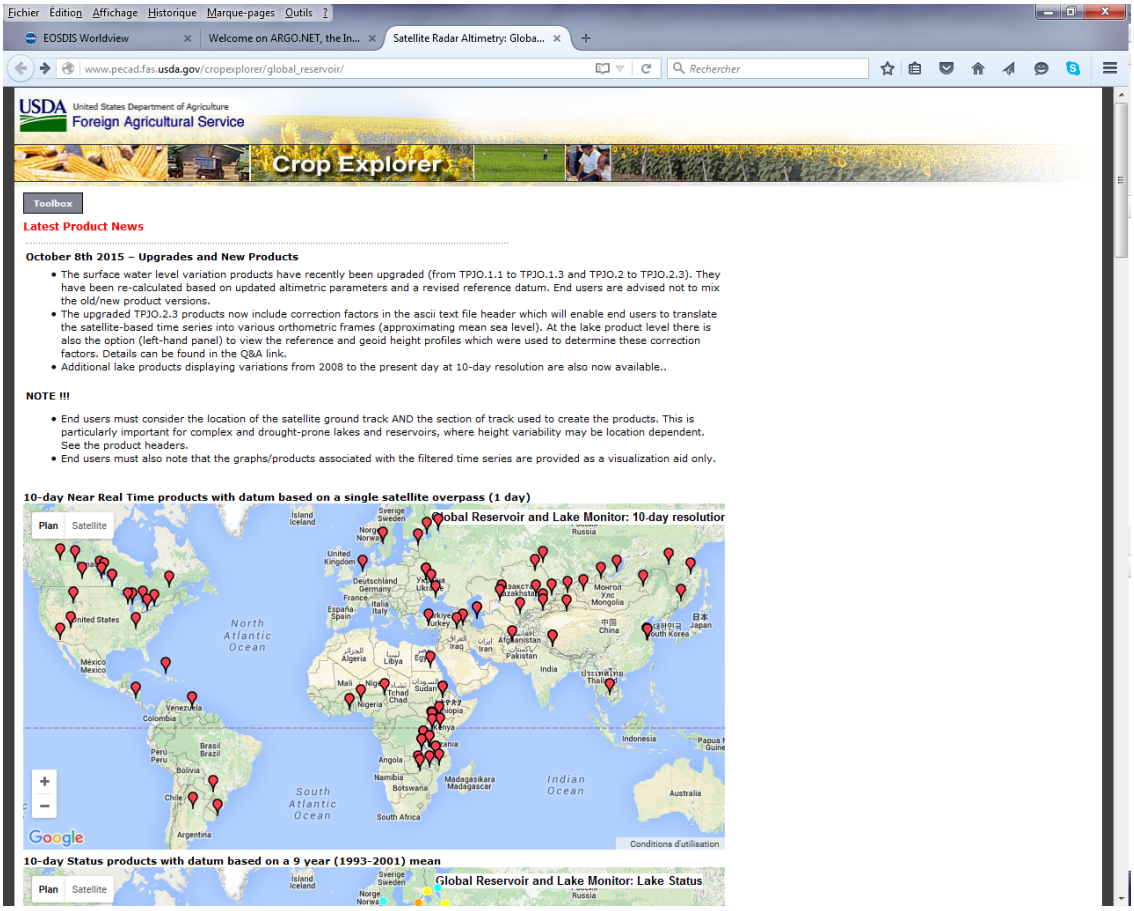


Figure 4: Home page of the Global Reservoir and Lake Monitor project

3.4. DAHITI

DAHITI (Database for Hydrological Time Series of Inland Waters) is a database (freely accessible) of water level time series derived from space radar altimetry missions is based on the same principle as HydroWeb, River&Lake and Global Reservoir and Lakes Monitor projects. It has been created in 2013 by the Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM) and is maintained by C. Schwatke. At the time of writing (November 2015) 354 water level time series are available on DAHITI (195 time series are located in South America) via the following URL: http://dahiti.dgfi.tum.de/en/.

DAHITI uses all the available altimetry missions, including archives dating up to 1992 with Topex/Poseidon, with a processing strategy based on an extended outlier detection and a Kalman filtering (see references on DAHITI web site).

Being more recent than the other services and projects described in this document, the Web interface of DAHITI takes advantage of most recent web mapping interfaces and thus may appear more friendly. Note also that users can express requests for the processing of data over their areas of interest.

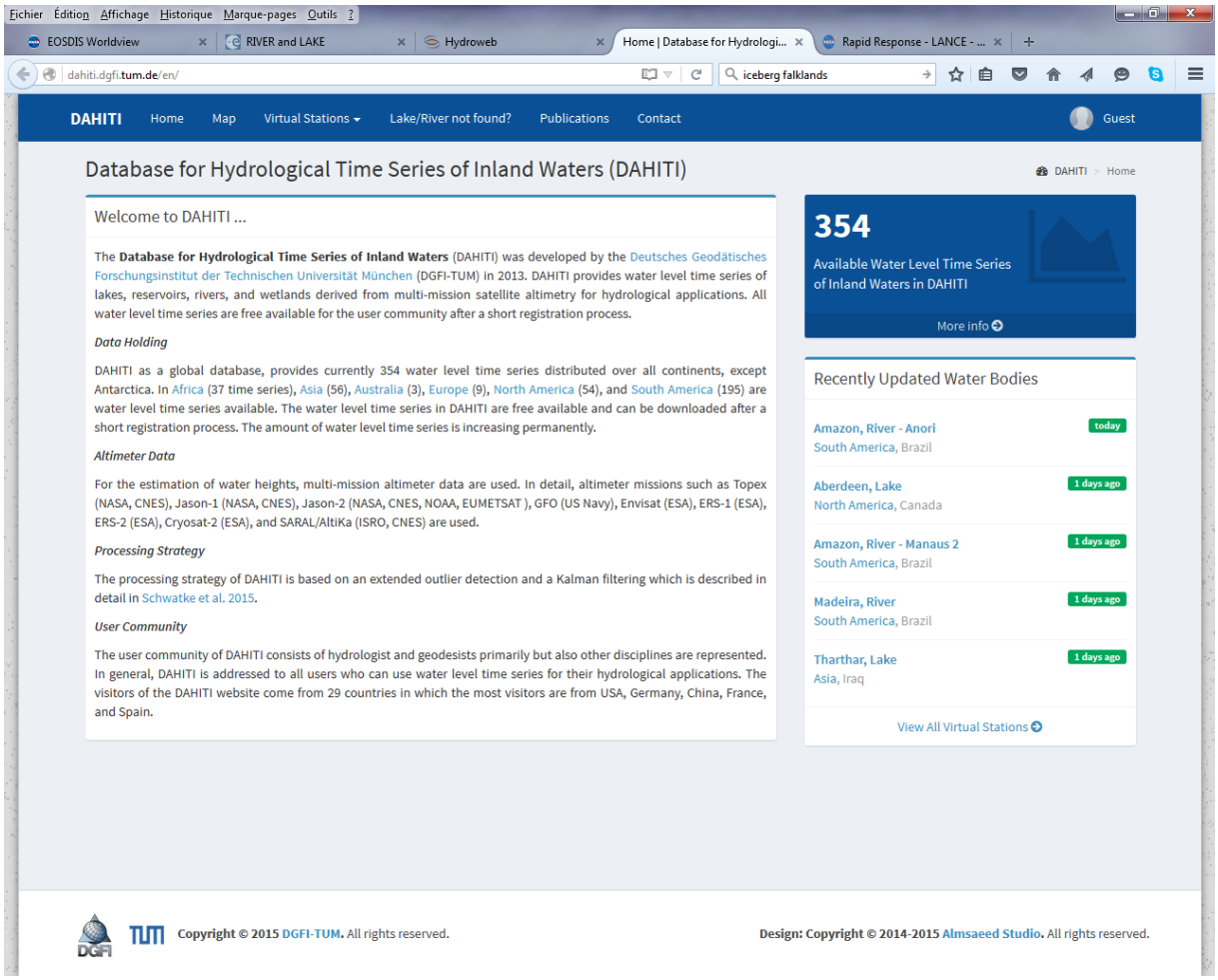


Figure 5: Home page of DAHITI project

3.5. PISTACH

With PISTACH products, the approach is completely different from the data bases described above. In fact, the inland water level time series computed by HydroWeb, River&Lake, …etc, are constructed with standard altimetry so-called “Level2 products” aka Geophysical Data Records or GDR, with several variants, such as Sensor GDR (GDR including waveforms) or Interim GDR (produced within 2 days, with some non-optimal parameters and corrections). But these standard products are primarily conceived and optimized for open ocean studies.

Therefore, the **PISTACH Project** (Innovative Prototype of Treatment System for Coastal Altimetry and Hydrology, in collaboration with CNES, CNRS, IRD and IRSTEA) was funded by CNES as part of Jason-2 project in order to **improve satellite radar altimetry products over coastal areas and continental waters**.

PISTACH products are described and are accessible via the AVISO web site: http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/coastal-and-hydrological-products.html

PISTACH mainly consisted in the development of new state-of-the-art dedicated processing algorithms: retracking of the waveforms, wet and dry tropospheric corrections, local models or high resolution global models for topography, geoid, land cover classification, land water mask, data editing. The PISTACH products adopt the same format and structure as Jason-2 standard GDR products to facilitate their appropriation and assessment by expert users, but with additional fields. These products are still presently disseminated on a operational near-real-time basis.

However, the PISTACH products are more dedicated to users already familiar with altimetry data. It is up to the users to download the PISTACH products, to extract the data over their areas of interest and to construct by their selves the water surface heights with the combination of parameters and corrections that appear the most appropriate to their application and/or study area.

3.6. Global land Component of the COPERNICUS Land Service

The Copernicus European Earth observation and monitoring program (formerly known as GMES, Global Monitoring for Environment and Security) has already entered operational phase.
The objective of Copernicus should be to provide accurate and reliable information in the field of the environment and security, tailored to the needs of users and supporting other Union policies, in particular relating to the internal market, transport, environment, energy, civil protection and civil security, cooperation with third countries and humanitarian aid.
Users will be provided with information through services dedicated to a systematic monitoring and forecasting of the state of the Earth's subsystems. Six thematic areas are developed: marine, land, atmosphere, emergency, security and climate change.

The Global Land component, known in short as “Global Land” (C-GL) was already earmarked as a component of the Land Monitoring Service, one of the two services identified for operational implementation in the initial phase of GMES (2011-2013). The Global Land Service has been operational since January 2013 and further information can be found at the following URL: http://land.copernicus.eu/global/

During summer 2015, the JRC, on behalf of the European Commission, launched an ITT which purpose was to operate, evaluate and evolve the Global Land Component. Two thematic domains are concerned: “Vegetation and Energy” on one hand and “Cryosphere and Water” on the other hand.

The scope of this tender for the C-GL service is:

- the timely production, re-processing, archival, and distribution of a variable number of biogeophysical parameters derived from low and medium resolution satellite data acquired at global scale so as to ensure the above-mentioned continuity and consistency requirements; and
- ensuring that produced bio-geophysical parameters and related services meet both user needsand technical requirements that may evolve with time.

Within the “Cryosphere and Water” thematic domain, several variables will have to be produced on an operational basis:

- snow area extent and snow water equivalent
- Lake ice coverage and lake surface water temperature
- Areas of water bodies
- **Water level (lakes and rivers)**
- Lake surface reflectance, lake turbidity and trophic state

Consequently, there should soon be online a data distribution portal that will provide users, under the COPERNICUS banner, with inland water level times series computed from Earth Observation Data and especially radar altimetry, notably with the inclusion of the future Sentinel-3A and Sentinel-3B missions.

At the time of writing the present document, it is highly probable that this portal will rely on one of the already existing service mentioned in the previous paragraphs.

4. Service requirements and specifications

Specific service requirements have been listed above from which the service will be based.

4.1.Requirements convention and acronyms

- "SHALL" is used to indicate a mandatory requirement
- "SHOULD" indicates a preferred solution but is not mandatory
- "MAY" indicates an option
- "WILL" indicates a statement of fact or intention.
- "N.A. " for Non Applicable.

The trace code will be compiled as follow:

R-XXX-NNN,

where XXX is a two/three letter acronym for the service section (see Table xxx), and NNN is the requirement number in this category.

Table 1: This table provides the service section trace codes.

Targeted Service Sections Trace Codes	Label
IN	Service inputs
DP	Data processing
OUT	Output product
QA	Quality assessment
DEL	Delivery platform

4.2.Service inputs

Table 2: Service input requirements

Trace Code	Service requirement
R-IN-001	CryoSat-2 L1b SAR products shall contain time indexed data
R-IN-002	CryoSat-2 L1b SAR products shall contain geolocated data (latitude, longitude)

R-IN-003	CryoSat-2 L1b SAR products shall contain stack of waveforms acquired for a single location

4.3.Data processing

Table 3: Data processing requirements

Trace Code	Service requirement
R-DP-001	The data processing unit shall run on a server
R-DP-002	The data processing unit shall have a Matlab/IDL license.

4.4.Output product

Table 4: Output product requirements

Trace Code	Service requirement
R-OUT-001	The output products should be delivered in a user-friendly format
R-OUT-002	The output products should be delivered in the input format of the existing services

4.5.Quality assessment

Table 5: Quality assessment requirements

Trace Code	Service requirement
R-QA-001	The quality assessment processing shall check the readability of the data
R-QA-002	The quality assessment processing shall check the format
R-QA-003	The quality assessment processing shall check the scientific quality of the data

4.6.Delivery platform

Table 6: Delivery platform requirements

Trace Code	Service requirement
R-DEL-001	The delivery platform should be free of charge access

5. Service description

5.1. Products definition

Two different products have been defined: the **time series river and lake products** for the AltWater and Hydroweb services, and the **along-track products** for the PISTACH service.

The **time series products** have been defined to correspond to the available product in the Hydroweb service. The product defined would be delivered in a text file format, including a small header, specifying the location of the water body and its name. Then, each water level estimation is stored together with its corresponding timestamp.

Table 7: Time series product definition

Product	River and lakes level for each specific water body
Type of information	Water level of each specific river and lake
Delivery format	Text file
Inputs needed to elaborate the product	CryoSat-2 – SIR_SAR_1B – 20 Hz Ku band SAR mode
Geographical coverage	Limited to the targeted water bodies
Time coverage	Monthly products
Geographic projection - Coordinate reference system	Single position - Latitude/Longitude coordinates

The **along track products** have been defined same as the PISTACH products. The PISTACH products have the same organization (and format) as the standard official Jason-2 Level Products (GDR): one file per track and per cycle. However, Cryosat-2 does not have a repeat pass, (or a very long cycle), the product would follow this approach: one file per track located in time between its start time and stop time.

The product is formatted in (Network Common Data Format) NetCDF format and convention. The NetCDF is commonly used in climatology, meteorology, oceanography and GIS applications. Several conventions to write and present data into the NetCDF format have been defined. The convention used for the river and lake levels product is the Climate and Forecast (CF) Metadata Convention. The metadata defined by the CF convention is included in the same file as the data, making the file "self-describing". The convention provides a definitive description of what the data values found in each NetCDF variable represents, and of the spatial and temporal properties of the data. Such convention produces a common format easily opened and read by software applications such viewers.

The product contains water level estimation located on satellite tracks. The data is time indexed, and located with latitude and longitude coordinates on a daily basis.

Table 8: Along track product definition

Product	River and lakes level along track
Type of information	Water level of river and lake along satellite track
Delivery format	Network Common Data Format – Climate and Forecast metadata conventions (NetCDF CF 1.6)
Inputs needed to elaborate the product	CryoSat-2 – SIR_SAR_1B – 20 Hz Ku band SAR mode
Geographical coverage	Global coverage, -88N – 88N
Time coverage	Daily products
Geographic projection - Coordinate reference system	Along-track product - Latitude/Longitude coordinates

5.2.Processing chain

For each waveform a subwaveform is extracted based on start and stop thresholds. These thresholds are found from the standard deviation of the power differences in consecutive bins (Jain et al., 2015). Once the subwaveform is extracted, the retracking bin is found by applying a threshold retracker on the subwaveform. The retracker employed is the Narrow primary peak threshold retracker (NPPTR).

In a post-processing procedure the MODIS mask is used to identify measurements over a given in-land water body. For each track that contains more than 5 measurements a robust mean water level is estimated in addition to the retracked water levels. The algorithm flow charts are presented in Figure 6.

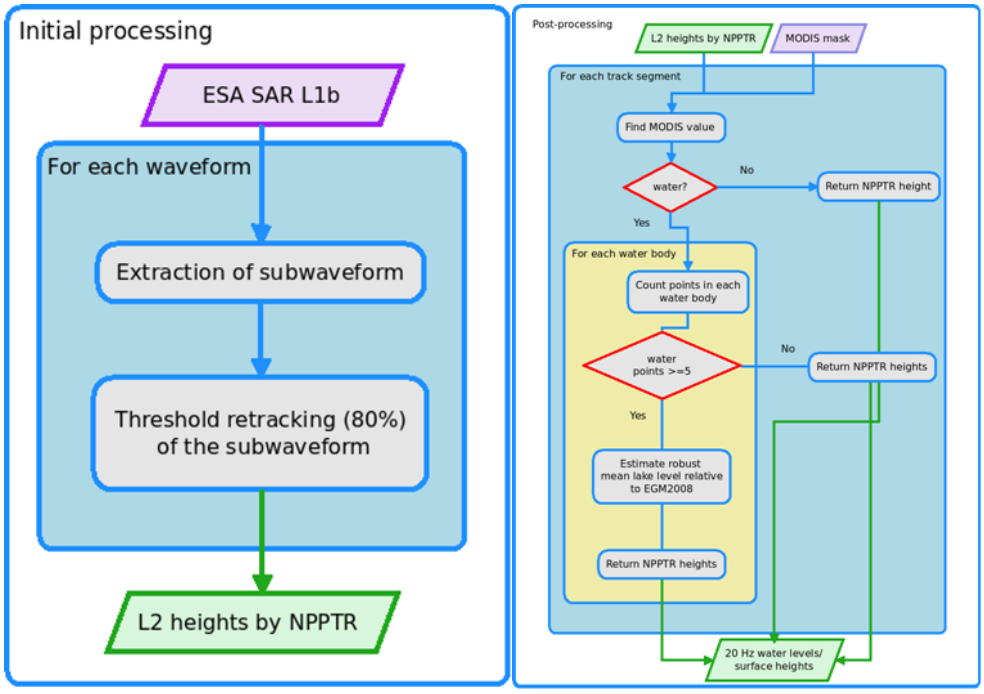


Figure 6: (Left) Flow chart describing the steps in SAR retracking procedure. (Right) Flow chart describing the steps in the post-processing

5.3.Global architecture of the service

In order to deliver the river and lake levels prototype datasets developed in the scope of the LOTUS project, we proposed two complementary approaches. First, a dedicated platform **AltWater** has been developed, showing the time series of the monitored rivers and lakes levels at specific locations. Second, the prototype stream flows products have been customized to be delivered to existing river and lake services such as **Hydroweb and PISTACH**. In the following section, details about the three services will be given.

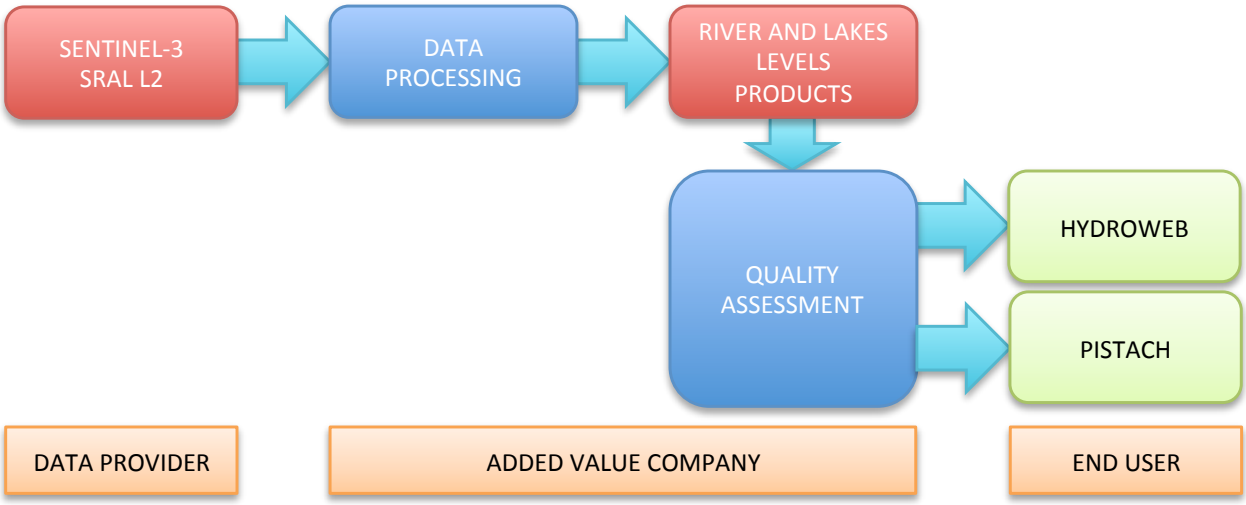


Figure 7: Service architecture

5.4.Main service - Altimetry for inland Water - AltWater

Altimetry for inland water (AltWater) is a new open service that provides altimetry based time series for inland water. Currently, the service only contains data from cryoSat-2, but other missions are planned to be included in future versions.

The service is available at http://altwater.dtu.space. The web page contains a Google map with the available inland water bodies and the user can access the data by clicking on the specific target of interest (see **¡Error! No se encuentra el origen de la referencia.**). For each target the following files can be downloaded:

- `lakename_levels_mode.dat`
- `lakename_ts_mode.dat`
- `lakename_mode.pdf`
- `README.txt`

Here the mode indicates the measuring mode of CryoSat-2 (SAR, SARIn, and LRM), `lakename_levels_mode.dat` contains along-track water levels and

`lakename_ts_mode.dat` contains the estimated mean water levels. The `README.txt` contains further information regarding the files.

Figure 8: Screenshot displaying the currently available targets.

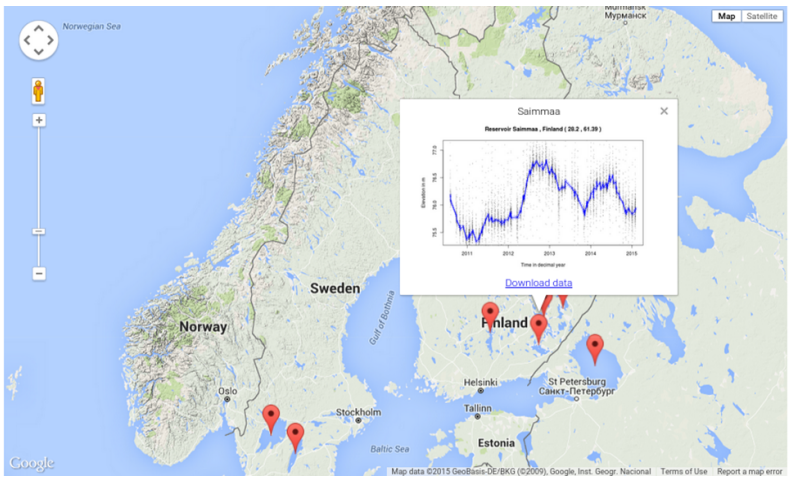


Figure 9: Zoom in on a specific target. The download link is displayed at the pop up window

The time series that are provided by AltWater are constructed by setting up a state space mode, which consists of a process and an observation models. The process model describes how we expect that the unobserved true water level evolve over time. In this case the true water level follow a random walk, which simply states that measurement taken within a short time span will tend to be more alike. The observation model states that a given observation is modelled by the unobserved true water level plus an error, which follow the described mixture distribution. A detailed description of the model is given in Nielsen et al, (2015).

5.5. Additional service provision

5.5.1. Hydroweb

Currently, the Hydroweb service has not been designed to receive or display additional data flows from third data providers. However, LOTUS data is a one-shot river and lake level dataset. After formatting the data with the same format as used in the Hydroweb service for their own internal products, the LOTUS dataset could be sent to it through an ftp. The Hydroweb service would have then to adapt their visualization systems to allow external datasets to be displayed.

5.5.2. PISTACH

PISTACH service also has not been designed to receive additional data flows from third data providers. The same procedure designed for Hydroweb could be used to use LOTUS data. As PISTACH is based on data availability through a file delivery system, the LOTUS datasets could be made available in the same server within another folder structure.

5.6.Service inputs

The inputs to the processing chains of the inland water level estimation are the CryoSat-2 SAR mode ESA L1b products: SIR_SAR_1B (FBR SAR MDS). They contain the complete waveform stacks at the specific 20Hz locations.

The products are composed of two files: a XML header, and a binary product file. The XML header file is an auxiliary ASCI file that users can easily access for identifying the product without looking inside the Product file. The Product file is the real product containing meaningful instrument's data.

5.7.Quality assessment

Based on service requirements, establishing an efficient quality assessment concept will guarantee the overall quality of the service implementation and of the final deliverables.

Table 9: Key element of a QA concept

QA concept element	Additional details	Responsibility
Data format verification	Detect inconsistencies in the format	Value adding specialist
Data content verification	Detect missing values, wrong values	Value adding specialist
Statistical and scientific evaluation	Evaluate datasets to record outliers	Value adding specialist

6. Summary

In this document, the river and lake levels service getting benefits from LOTUS development has been described. Existing services already provides end users with river and lakes levels services based on conventional altimetry. The algorithms developed are establishing a first step forward to the full exploitation of SAR altimetry to retrieve basins levels. The service AltWater has been developed in the scope of the LOTUS project to show to the potential of altimetry products to provide relvant information about river and lakes levels. Additionally, we proposed to supply existing services such as HydroWeb and PISTACH with LOTUS prototype products.

Finally, a Copernicus Global Land service will start in 2016 to provide the European Community with operational services for various parameters including river and lakes levels. Since, the planned products will be based on conventional altimetry, such future operational service could take advantage of LOTUS progresses using SAR altimeter instruments to estimate river and lake levels.

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