HydroSat: a repository of global water cycle products from spaceborne geodetic sensors
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1. Licence

2. Citation

When using the data please cite:

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Tourian, M. J., Schwatke, C., & Sneeuw, N. (2017). River discharge estimation at daily resolution from satellite altimetry over an entire river basin. Journal of Hydrology, 546, 230-247. https://doi.org/10.1016/j.jhydrol.2017.01.009

Elmi, O., Tourian, M. J., & Sneeuw, N. (2016). Dynamic river masks from multi-temporal satellite imagery: An automatic algorithm using graph cuts optimization. Remote Sensing, 8(12), 1005. https://doi.org/10.3390/rs8121005

Tourian, M. J., Tarpanelli, A., Elmi, O., Qin, T., Brocca, L., Moramarco, T., & Sneeuw, N. (2016). Spatiotemporal densification of river water level time series by multimission satellite altimetry. Water Resources Research, 52(2), 1140-1159. https://doi.org/10.1002/2015WR017654

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3. Data Description

Against the backdrop of global change, both in terms of climate and demography, there is a pressing need for monitoring global water cycle. The publicly available global database is very limited in its spatial and temporal coverage worldwide. Moreover, the acquisition of in situ data and their delivery to the database are in decline since the late 1970s be it for economic or political reasons. Given the insufficient monitoring from in situ gauge networks, and with no outlook for improvement, spaceborne approaches are currently being investigated. Satellite-based Earth observation with its global coverage and homogeneous accuracy has been demonstrated to be a potential alternative to in situ measurements.

The Institute of Geodesy (GIS), within the Faculty of Aerospace Engineering and Geodesy at University of Stuttgart has a long-standing expertise, both theoretically and practically, in dynamic satellite geodesy. In recent years, GIS initiated and participated in studies and projects on application of spaceborne geodetic sensors for hydrological studies. HydroSat provides the results of these studies and projects. HydroSat, as a repository of global water cycle products from spaceborne geodetic sensors, provides estimates and their uncertainty of: water level from satellite altimetry, surface water extent from satellite imagery, terrestrial water storage anomaly from satellite gravimetry, lake and reservoir water storage anomaly from a combination of satellite altimetry and imagery, and river discharge from either satellite altimetry or imagery. These results can contribute to understanding of the global water cycle within the Earth system by being inputs to hydrological models, playing complementary role to current and future spaceborne observations, and defining the indicators of the past and future state of the global freshwater system. The repository is publicly available through http://hydrosat.gis.uni-stuttgart.de.

3.1. Data Sources

In order to obtain water level, surface water extent, terrestrial water storage anomaly for basins, lake and reservoir water storage anomaly and river discharge, spaceborne data of different satellite missions from following sources are used:

Satellite	Data download link	Product	Citation
Envisat	ftp://ra2-ftp-ds.eo.esa.int	GDR-v3	RA-2 Geophysical Data Record. (2018)
Saral	ftp://ftp-access.aviso.altimetry.fr/geophysical-data-record/	GDR T	Verron et al. (2015)
ICESat2	https://nsidc.org/data/atl13	ATLAS/ICESat-2 L3A Inland Water Suface Height, Version 3	Jasinski et al. (2020)
CryoSat-2	ftp://science-pds.cryosat.esa.int/	SIR GDR	
Jason-1	ftp://ftp-access.aviso.altimetry.fr/geophysical-data-record/	GDR	
Jason-2 (PISTACH)	ftp://ftpsedr.cls.fr/pub/oceano/pistach/J2/IGDR/hydro/	GDR	
Jason-2	ftp://ftp-access.aviso.altimetry.fr/geophysical-data-record/	GDR	
Jason-3	ftp://ftp-access.aviso.altimetry.fr/geophysical-data-record/	GDR	
Sentinel-3A	https://scihub.copernicus.eu/dhus/#/home	NT	
Sentinel-3B	https://scihub.copernicus.eu/dhus/#/home	NT	
GRACE	https://doi.org/10.5880/ICGEM.2018.003	Monthly data ITSG-Grace2018	Mayer-Gürr et al., 2018
GRACE-FO	https://doi.org/10.5880/ICGEM.2018.003	Monthly data ITSG-Grace2018	Mayer-Gürr et al., 2018
MODIS	https://ladsweb.modaps.eosdis.nasa.gov/	MODIS MOD09Q1	
Landsat based water masks	https://global-surface-water.appspot.com/	Full data set	Pekel et al. (2016)

3.2. Analytical procedure

3.2.1. Surface water extent of lakes and rivers

HydroSat provides surface water extent time series of both lakes and rivers from optical satellite images. For generating dynamic water masks, region-based classification is employed, for which we benefited from spatio-temporal behaviour of pixel-intensity. This allows us to deal with the complexities in extracting dynamic river masks. Moreover, such an algorithm setup allows obtaining a probabilistic water masks leading to an estimate for surface water extent uncertainty. For a quality assessment, time series of surface water extent over lakes are compared with available in situ and or altimetric water level time series. Over rivers, such a quality assessment is predominantly done through comparing the time series against in situ river discharge.

3.2.2. Water level time series of lakes and river

HydroSat provides water level time series of rivers, lakes and reservoirs in two modes of Standard-Rate (SR) and High-Rate (HR) with their uncertainty estimates. For water level time series HydroSat uses an automated, data-driven outlier rejection methodology designed within an iterative, non-parametric adjustment scheme. The outlier-free measurements form the final time series without any further smoothing. For the HR products over the lakes, inter-satellite biases are removed through a hybrid approach by incorporating lake surface area information. The quality of water level time series is assessed through a validation against in situ water level or proxy data like river discharge, river width or lake surface area.

3.2.3. Terrestrial water storage anomaly

HydroSat provides Terrestrial Water Storage Anomaly (TWSA) time series and its uncertainty over global major river basins using GRACE and GRACE-FO observations (Meyer-Gürr et al., 2018). To estimate TWSA time series from level-2 data (shperical harmonics up to degree/order 96), the C_{20} and C_{30} are replaced and degree-1 is added from the corresponding SLR estimates. Moreover, ellipsoidal and GIA correction are followed together with a smoothing Gaussian filter with a radius of 400 km. The final TWSA in HydroSat are corrected for tidal aliasing error and leaked signals. For the field product, the Gaussian filtering is applied together with a de-striping filter and leakage is corrected using forward modeling approach. The quality of TWSA time series are assessed through a comparison with two mascons products, CSR RL06 version 02 and JPL RL06 version 02.

3.2.4. Water storage anomaly of lakes and reservoirs

HydroSat provides time series surface water storage anomaly for lakes and reservoirs using the time series of water level and surface area measurements. For developing the surface water level-area-volume model, the scatterplot of simultaneous water level and area measurements is obtained. HydroSat performs an iterative data snooping procedure to obtain a reliable empirical relationship between surface water level and area. In this way, the quality of the obtained time series of water storage anomaly is ensured, since the non-representative measurements are eliminated.

3.2.5. River discharge estimates for large and small rivers

HydroSat provides SR and HR river discharge estimates together with their uncertainties. To obtain the SR products, HydroSat relies on a non-parametric quantile mapping approach that salvages gauging stations that are no longer updated with in situ measurements. Since no model assumptions are required under the non-parametric approach, the HydroSat discharge time series are less contaminated by a mis-modeling error. For the uncertainty estimation HydroSat applies a stochastic quantile mapping function algorithm supported by a Monte Carlo simulation. The availability of enough SR time series over a river network allows approximating the spatio-temporal dynamics of a river system by a linear dynamical system. The HR products are the solutions of such a dynamic system by Kalman filters obtained with up to daily temporal resolution at potentially any location along the river. For the quality assessment, SR and HR discharge time series are compared with in situ and spatial river discharges, water levels, and river widths.

3.3. Data processing

For each data type a flowchart is provided to describe the data processing (below). More info can be found in Tourian et al. (2021, ESSD in review).

3.3.1. Surface water extent of lakes and rivers

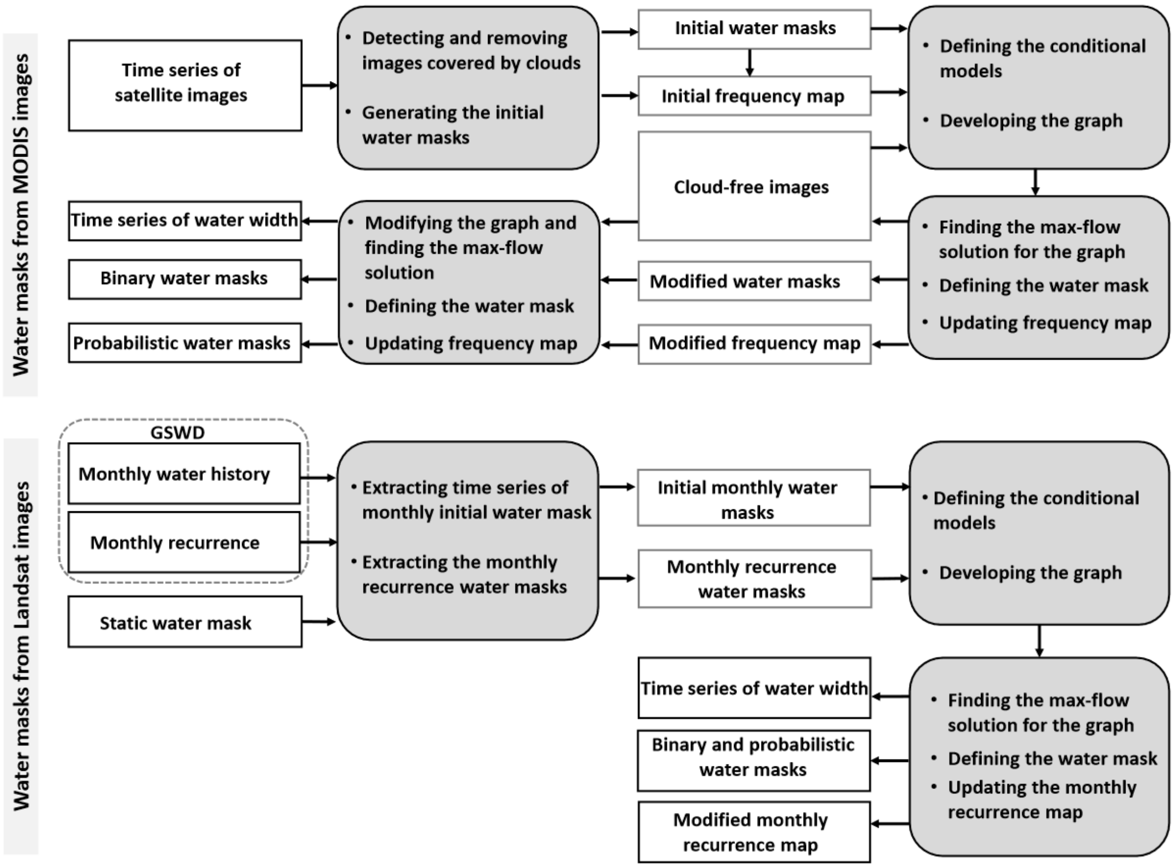


Figure 1: Flowchart of the proposed method for generating time series of average river width from MODIS images (top panel). Flowchart of the proposed algorithm for generating time series of river masks from Landsat-based GSWD product (bottom panel)

3.3.2. Water level time series of lakes and river

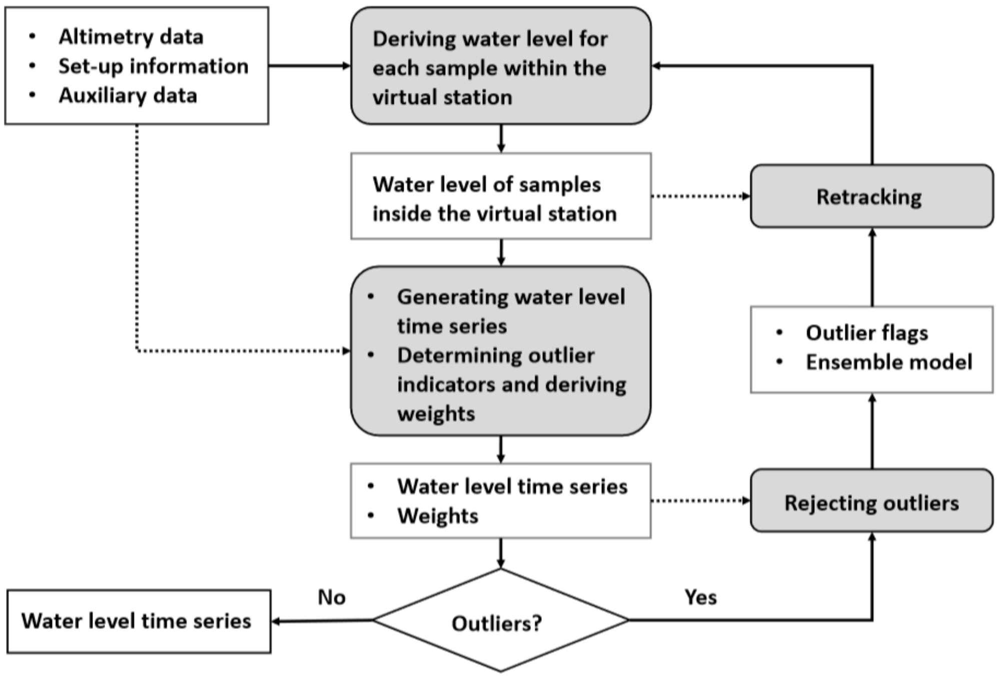


Figure 2: Flowchart of obtaining SR altimetric water level time series for a single virtual station

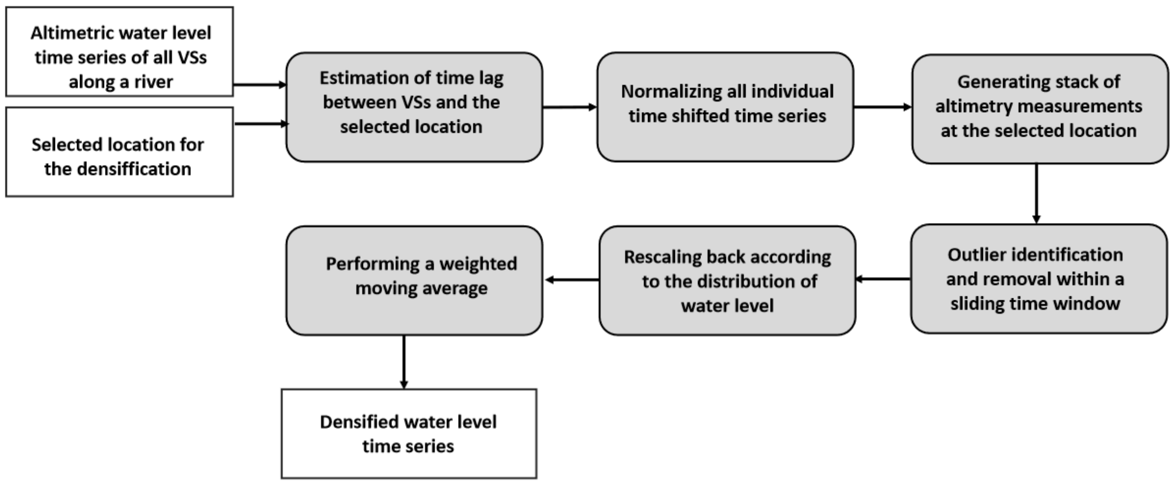


Figure 3: Flowchart of obtaining HR product over rivers through densification of individual altimetric water level time series along a rive

3.3.3. Terrestrial water storage anomaly

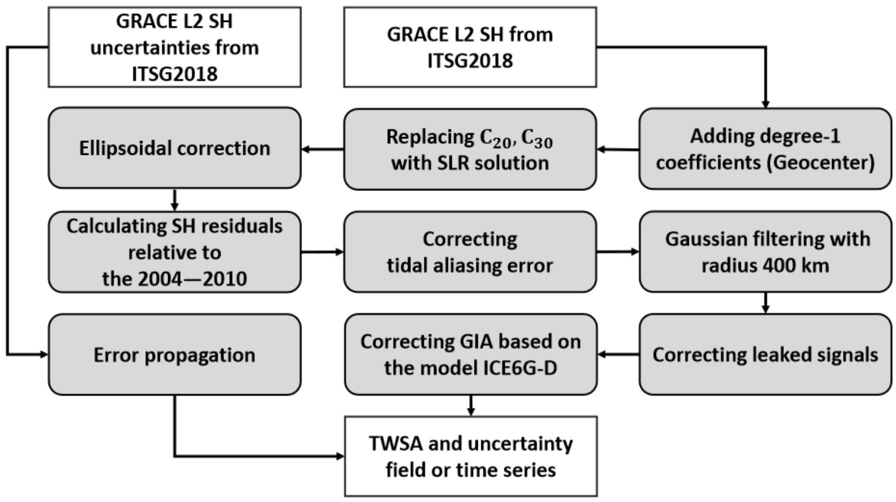


Figure 4: Flowchart of obtaining Total Water Storage Anomaly (TWSA) in HydroSat

3.3.4. Water storage anomaly of lakes and reservoirs

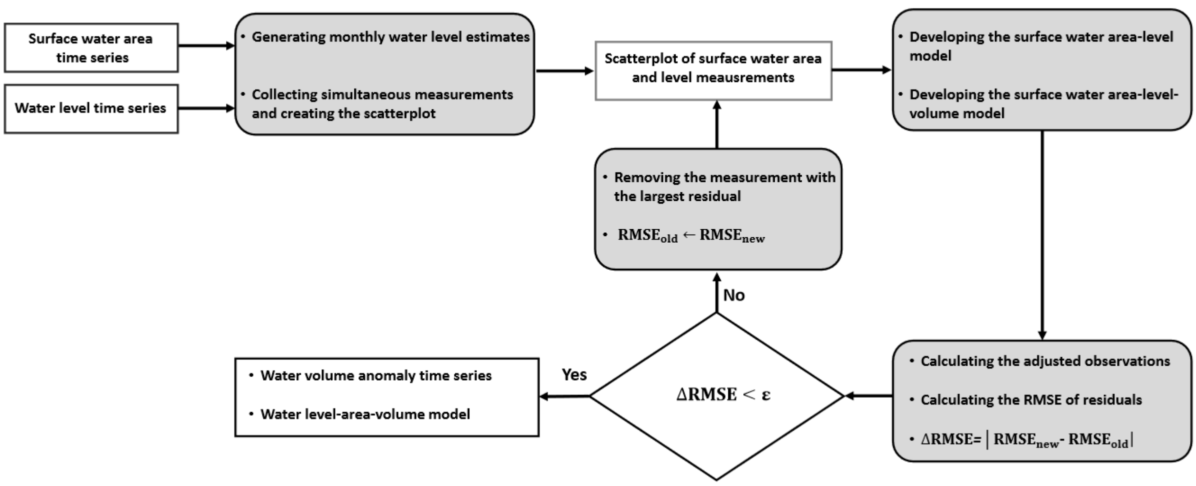


Figure 5: Flowchart of obtaining water volume anomaly using surface water area from satellite imagery and water level time series fromsatellite altimetry

3.3.5. River discharge estimates for large and small rivers

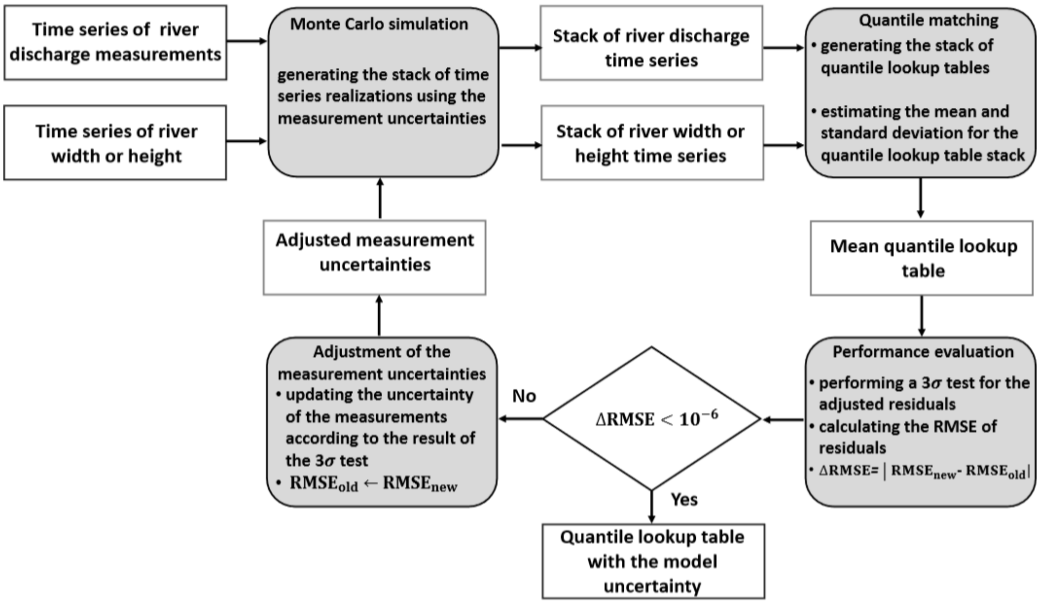


Figure 6: Flowchart of discharge estimation algorithm for generating the quantile mapping function

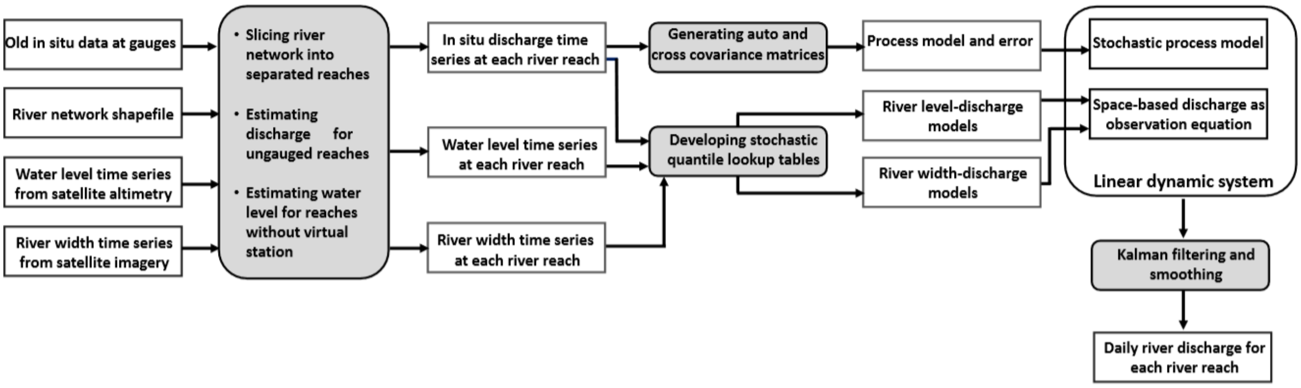


Figure 7: Flowchart of estimation of High-Rate river discharge using a Kalman filter approach

4. File description

The data collection included in HydroSat is archived as “format” versions according to the structure described in 4.1The main access to the data, however, is through the HydroSat website at http://hydrosat.gis.uni-stuttgart.de

4.1. File inventory

The data are stored in four different folders

- 1_Surface_water_extent
- 2_Water_level
- 3_River_discharge
- 4_Water_Storage_Anomaly

In each folder ASCII files are available including time series with uncertainty with a header representing the meta data.

In each folder, an overview text file is available which lists all available objects in the folder. The overview list contains the HydroSat ID (see 4.2), latitude, longitude and the object name. Moreover, a readme file is provided in the main folder describing the HydroSat ID. In addition, a text file is available, which contains the basins' name, number and location.

4.2. File naming convention

Each time series is provided in a separate text file named with a unique id, the HydroSat ID. The HydroSat ID is a 14-digit number defined as below

1st digit: data set content

1 - Surface water extent from satellite imagery - unit [km²]

2 - Water level from satellite altimetry - unit [m]

3 - River discharge from satellite altimetry, imagery or gravimetry - unit [m] or [km³]

4 - Water Storage Anomaly from satellite gravimetry - unit [m³/s]

2nd digit: source of data

1 - Satellite

2 - In Situ

3rd digit: water body

1 - Lake

2 - River

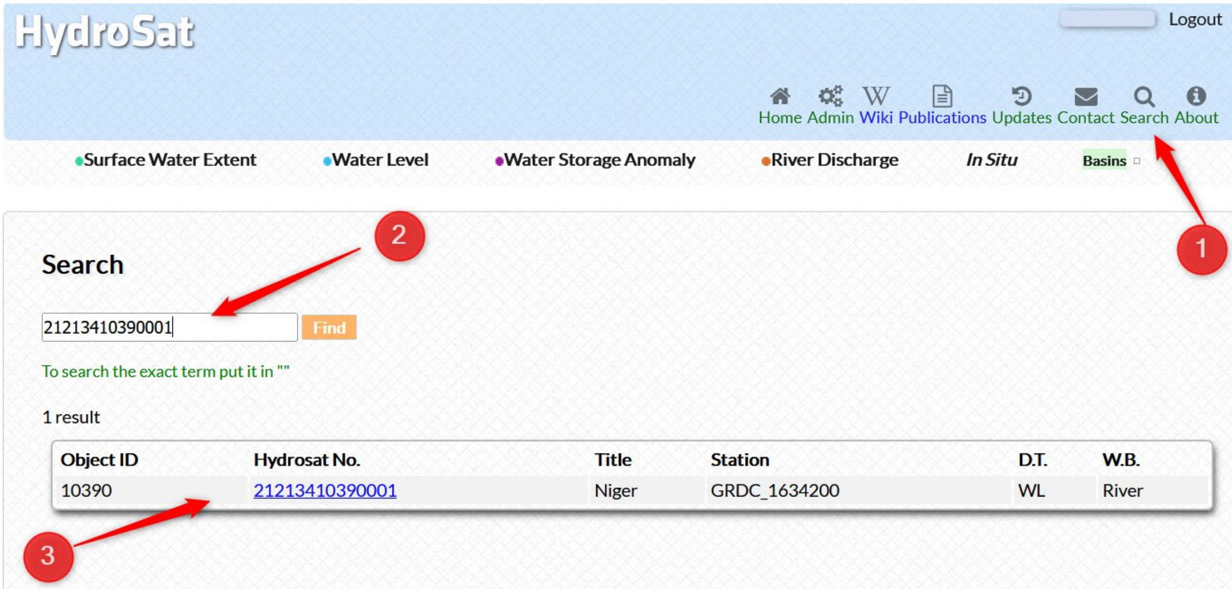
3 - Basin

4-6th digit: basin number (see basins_numbering text file)

7-11th digit: object-ID

12-14th digit: version of dataset (starting with 001)

Each time series is provided in a separate text file named with the HydroSat ID. The HydroSat ID can be found in the website through the search module http://hydrosat.gis.uni-stuttgart.de/php/search.php



4.3. Description of time series files

4.3.1. Header

The time series provided by HydroSat are provided with the following header items.

header	**Description**
Object	Object name
Data set content	Could be following options: 1 Surface water extent 2 Water level from satellite altimetry 3 River discharge 4 Water Storage Anomaly
Unit	Depending on the data content following units could appear 1 - Surface water extent from satellite imagery - unit [km²] 2 - Water level from satellite altimetry - unit [m] 3 - River discharge from satellite altimetry, imagery or gravimetry - unit [m] or [km³] 4 - Water Storage Anomaly from satellite gravimetry - unit [m³/s]
Date format	Describing the date format: YYYY,MM,DD,
Field delimiter	the delimiter is always ","
Hydrosat No.	hydroSat ID
Water body	Could be following options: 1 - Lake 2 - River 3 - Basin
Station	name or number of the station
Country	the country where the time series belongs to
Latitude (°)	Geocentric latitude in decimal degree
Longitude (°)	Geocentric longitude in degree
Altitude (m)	Mean orthometric height of the time series (valid for water level time series)
Datum	Height datum
Height system	Height system: orthometric, normal,...
Source	Always satellite
Mission	Name of the mission
Product	Product name or title
Track	Track number of the satellite (valid in case of altimetry missions)
Processing method	processing method's identifier
Basin No.	Number of basin (see basin numbering text file)
Last update	Last update of the time series
File generation date	File generation date in yyyy-mm-dd
How to cite	provides information on how to cite the used data

4.3.2. Time series

The time series are provided in the following format with 5 columns

YYYY,MM,DD,Data,Error

Column	Description
YYYY	Year
MM	Month
DD	Day
Data	Data
Error	Uncertainty of provided value

5. References

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