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River Discharge Precursor
(RD_cci+)

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APPLICABLE DOCUMENTS

Presentations done during the workshop and available at: https://groupcls.sharepoint.com/:f:/r/sites/CCI_Discharge/Shared%20Documents/Meetings_ESA/2024_06_03-04_UserWorkshop?csf=1&web=1&e=IK4Iwa

1 Introduction

The first CCI River Discharge User Workshop was held 3-4 June 2024 in Toulouse, at the CIC (Météo-France International Convention Center, http://www.meteo.fr/cic/, 42 avenue Gaspard Coriolis, 31057 Toulouse Cedex 1). It lasted one day and half and aimed at presenting the CCI River Discharge products and their validation to potential users and collect their feedback. The purpose was to make sure the R&D work is aligned with user needs, updates the User Requirements Document and discuss the project roadmap to derive operationally and at global scale discharge from satellite data as ECV in the upcoming years.

2 Participants

The list of participants to this user workshop is provided below for:

- onsite attendance (12 people from the CCI precursor project and 5 users):

Name	Organisation
ANDRAL Alice	CLS
BENVENISTE Jérôme	Retired from ESA
BIANCAMARIA Sylvain	LEGOS
CALVET Jean-Christophe	CNRM
CERBELAUD Arnaud	Caltech/JPL
GAL Laetitia	Hydro Matters
KITAMBO Benjamin	LEGOS
MUNIER Simon	CNRM
NOUAL Gaëtan	CNRM
OUBANAS Hind	G-Eau
PARIS Adrien	Hydro Matters
SADKI Malak	Magellium
PEDINOTTI Vanessa	Magellium
TARPANELLI Angelica	CNR-IRPI
TOURIAN Mohammad	Universität Stuttgart
VAYRE Maxime	CLS
VERMA Kaushlendra	CNRM
ZAKHAROVA Elena	EOLA

- online attendance (6 people from the CCI precursor project and 7 users):

Name	Organisation
ALBERGEL Clément	ESA
BARBETTA Silvia	CNR-IRPI
BLAREL Fabien	LEGOS

BOUTIN Jacqueline	LOCEAN
DE ROSNAY Patricia	ECMWF
FILIPPUCCI Paolo	CNR-IRPI
GARRIC Gilles	Mercator Ocean
MATTHEWS Gwyneth	ECMWF
NIÑO Fernando	LEGOS
PRUDHOMME Christelle	ECMWF
SAHOO Debi Prasad	CNR-IRPI
SCHERER Daniel	DGFI-TUM
SIRERE Claire	Capgemini

3 Workshop agenda

Monday 03-Jun				
Start	**End**	**Duration**	**Title**	**Speaker**
9:00:00	**9:30:00**	**0:30:00**	**Welcome coffee**	
9:30:00	9:50:00	0:20:00	Science objectives and goals	A. Andral
9:50:00	10:10:00	0:20:00	Introduction from ESA	C. Albergel
10:10:00	10:20:00	0:10:00	CCI River Discharge User Requirements	S.Biancamaria
10:20:00	10:30:00	0:10:00	Selected basins and stations	L. Gal
10:30:00	11:00:00	0:30:00	Altimetry river Water Surface Elevation	S. Biancamaria
11:00:00	**11:30:00**	**0:30:00**	**Break**	
11:30:00	12:30:00	1:00:00	River discharge from altimeters and ancillary data	L. Gal
12:30:00	**14:00:00**	**1:30:00**	**Lunch**	
14:00:00	15:00:00	1:00:00	Multispectral images-based river discharge	P. Filippucci and D. P. Sahoo
15:00:00	15:45:00	0:45:00	Combined satellite-based river discharge	A. Tarpanelli
15:45:00	**16:00:00**	**0:15:00**	**Break**	
16:00:00	17:00:00	1:00:00	River discharge products validation	M. Vayre and L. Gal
17:00:00	17:30:00	0:30:00	ECV Assessment for use in climate tasks	E. Zakharova

Tuesday 04-Jun				
Start	**End**	**Duration**	**Title**	**Speaker**
9:00:00	**9:30:00**	**0:30:00**	**Welcome coffee**	
9:30:00	10:15:00	0:45:00	Use case: data assimilation into large-scale river routing systems	M. Sadki and G. Noual
10:15:00	11:00:00	0:45:00	Feedbacks from users on products and user requirements	All
11:00:00	**11:20:00**	**0:20:00**	**Break**	
11:20:00	12:40:00	1:20:00	Discussion on river discharge roadmap	All
12:40:00	12:50:00	0:10:00	Conclusion of the workshop	S. Biancamaria
12:50:00	**13:50:00**	**1:00:00**	**Lunch and end of the workshop**	

4 Main messages from formal presentations

4.1 Introduction and context

Alice ANDRAL, project manager, began the user workshop with few introductive words. She then introduced the precursor project objective: analyse the feasibility of providing long time series of river discharge on several river basins. The consortium is composed of: CLS, CNRS-LEGOS, CNRS-CNRM, CNR-IRPI, EOLA, Hydro Matters and Magellium. Finally, the products generation, validation and the use cases are briefly introduced. River discharge cannot be measured directly from satellite sensors. However, two types of remotely senses datatypes are correlated with river discharge proxy and have been used in this precursor project: radar nadir altimetry data and multispectral images.

Clément ALBERGEL, technical officer of the River Discharge CCI precursor project, presented the ESA CCI/Climate Space program and the 27 ECV projects funded by ESA. The ESA CCI outcomes are to: 1- link satellite observation and modelling communities, 2- advance climate science, and 3- develop satellite-derived climate data records and finally enhance knowledge. CCI datasets computed by each project are available on the CEDA platform.

4.2 User requirements and selected locations

User requirements have been defined in May 2023 and collected from 17 people interviewed (from CCI projects, Hydrology modelers, GRDC, GCOS, GEWEX, hydrologists, and a stakeholder). These requirements are available in the User Requirements Document (URD) in the RD_cci website: https://climate.esa.int/media/documents/D1_CCI-Discharge-0003-URD.pdf.

54 locations on 18 river basins have been defined to show the feasibility to derive long-term (at least over 2002-2022) discharge time series from satellite data and ancillary data. These locations have been selected to be representative of the global situation, following user requirements.

4.3 Altimetry-based water surface elevation and discharge products

The first type of earth observation (EO) data used to derive discharge in this precursor project and presented in this user workshop corresponds to radar nadir altimeters observations. These data can be used to derive an almost direct measurement of river Water Surface Elevations (WSE). Then, when combined with ancillary discharge data, a rating curve can be derived and applied to altimetry WSE to derive a long-term discharge product.

The methodology to compute long-term WSE time series from nadir altimetry missions is introduced, along with the WSE Climate Record Data Product (CRDP), available on the CEDA Data Catalogue: https://catalogue.ceda.ac.uk/uuid/c5f0aa806ec444b4a4209b49efc4bb65 . Limitations of the product have also been presented. To sum up long-term WSE could have been computed over 53 locations out of 54. Time series at 3 locations cover 7 years or slightly less, time series at 2 locations cover 15 years, time series at 28 locations cover 21 years, and time series at 20 locations cover nearly 30 years.

After the presentation, some questions have been asked by the users. It appears that a quality flag will have to be added in next version of the WSE product. Oldest missions provide noisier data and it could impact climate studies. Mohammad TOURIAN highlighted that the effort to remove intermission biases might not be needed, as the purpose is to derive river discharge. Sylvain BIANCAMARIA et al. acknowledge this point and it should be assessed in a next phase of the project the errors associated to each approach (derive discharge from a long-term WE time series, or to derive a rating curve for each altimetry WSE time series). But it is also highlighted that some users interviewed to define the user requirements (see URD) the need to also have long-term WSE (which is also a GCOS ECV) in addition to long-term river discharge. This WSE product is therefore not just an intermediate product to derive discharge, but is also valuable by itself.

Then, the long-term altimetry-based river discharge methodology, computed product, and definition of the calibration/validation periods are presented. There are 31 locations where there Is time overlap between ancillary in situ discharge and altimetry WSE, and 23 locations without time overlap. An uncertainty is also provided along with discharge, but some simplifications had to be done to compute them. Among the selected locations, there are 3 locations for which in situ data could not have been collected. Therefore, long-term altimetry-based river discharge could be computed for 50 locations out of 54. The perspectives discussed the limitations of the method that could impact its use at global scale.

The first question asked concerned flagging of data when water is frozen. The methodology used seem quite robust but some clarification was requested concerning removal of outliers in the rating curve. The audience also highlighted the need to improve associated uncertainties to the product. For one station without ancillary in situ discharge, outputs of hydrology model, a question has been asked on the need to use this alternative source of discharge to go to global scale. It is acknowledged that for some location it could be a good alternative, but caution will be required. Last questions concerned on which parameters have been estimated with the Bayesian approach and how to potentially use the Z_0 parameter.

4.4 Multispectral images-based discharge products

Multispectral images from multiple sensors have been used to extract long time series of reflectance indices that are useful to identify variations of river discharge over several environments. 6 algorithms (combination of signals regarding sites characteristics), combined with 2 kernels to aggregate pixels (large to small variation in width, defined to combined multimission images that have different resolutions from 10m to 300m) and two calibration methods have been tested to compute multispectral indices, that are proxies to river discharge. Therefore, 24 potentials approaches adapted to different environments have been investigated. Around 25,000 images after 2000 have been used for each selected location. Finally, two procedures to derived discharge are used (one calibrating the parametrization using overlapping river discharge and uncalibrated method that could be used even for ungagged locations). For the calibrated method, two products are provided (one based on an empirical approach, the second one based on a probabilistic approach). Some promising preliminary tests have been done to use machine learning approaches to derive discharge in addition to the calibrated and uncalibrated methods. The main limitation for space/time coverage is due to data loss because of cloud cover, cloud shadow, presence of snow and ice.

At the end of presentation, the first questions asked some clarifications on different aspects of the methodology. The audience highlighted the need to develop a methodology to provide uncertainties with the river discharge products. Then followed some questions concerning the impacts of sediment, vegetation, and wetness on the estimated discharge. From the discussion, it appears that further investigation to understand their impacts are needed, typically on tropical regions.

4.5 Combined discharge product

The methodology of merging previous products is based on several previous ESA-funded projects, especially the RIDESAT and STREAMRIDE projects. These approaches combined EO data (WSE and multispectral indices) to derive river discharge. If a multiple regression model is used, then the merging can be done only to common time steps between EO, which is very limiting. That's why these methods rely on multimission approaches to overcome this issue. A Copula-based approach converts multispectral indices to an equivalent WSE time series and then the rating curve computed for the altimetry-based river discharge is used to derive discharge. The first results show that the combined product can increase temporal sampling from altimetry (in average ~12 days) to 3 to 2 days. The uncertainties are a little bit decreased compared to altimetry-based discharge, but it is increased compared to multispectral images-based discharge product and are promising. Another approach has been developed to combine directly the previously developed river discharge products and the first results need to be more analysed.

The first question asked concerned the possibility to use passive microwave data in addition to optical/infrared images. It has been replied that the original formulation of the algorithm developed in the early 2000's was developed for microwave data (AMSRE), but given the crude resolution and the wavelength used, it is adapted for floods of big rivers, but not for river reaches studied here. Another question concerned the inclusion of river width estimation from optical images in addition or in replacement of multispectral indices. It has been acknowledged by Angelica TARPANELLI that it could be investigated, but as the multispectral indices contain more information on the river dynamic than only the river width, they are not similar. It has been recognized that including both methods in a round robin could be interesting. Another question was about the extension of time series before 2000, using for example AVHRR data. This data has not been used and it might be a potential alternative. However, the crude resolution of AVHRR data might prevent its use. The last question concerned the quantitative impact of the merging on temporal sampling improvement. It is true that it has not been shown, but it improved temporal sampling at mid-latitude, less on tropical basins.

4.6 Products validation

River discharge products presented previously have been validated first using in situ discharge used to calibrate the discharge/EO data relationship on the predefined validation period (the last 2/3 of the time series have been used for calibration, the first 1/3 of the time series corresponds to the validation period). Altimetry-based River discharge provides the best results. Multispectral indices calibrated products also have good evaluation metrics (NSE, KGE, and nRMSE). The multispectral indices uncalibrated product has the lower performance of all products. Results over the validation period are less impressive than over the calibration period, because it is done on the time period covered by the oldest missions. Nevertheless, the results are still very accurate and meet the GCOS requirement (nRMSE < 15%). A complementary validation has been performed with independent in situ data, that have not been used to calibrate the relationships. This complementary validation provides similar results and conclusion than with in situ discharge used for calibration over validation period. Uncertainty provided with altimetry-based river discharge has also been compared to the errors estimated with in situ measurements. These provided uncertainties are consistent with computed errors, but are quite higher and therefore are more pessimistic than what is obtained in this validation study. Validation of monthly average shows similar results for multispectral indices-based river discharge and slightly lower for altimetry-based river discharge, which still provides the best validation metrics of all CCI river discharge products. Some sensitivity studies were also presented. They showed that the quantile method used when there is no time overlap for altimetry-based product is, as expected, less precise than the overlap method, but it still has some good accuracy. The non-overlap method is sensitive to the distribution of extreme events in the in-situ discharge data and altimetry WSE used to calibrate the rating curve.

A recommendation has been provided by a user to compute uncertainty separately for high and low flows.

4.7 Use cases

4.7.1 Climate assessment

The purpose of this task is to assess the suitability of CCI River discharge products for climate studies. First, the analysis of the number of available measurements per month has been investigated and its impact on monthly and yearly averages. Altimetry-based discharge has lower time resolution, especially for oldest missions, impacting the average. However, errors on monthly average discharge are below 10% for 50% and 40% for altimetry-based discharge and calibrated on Copula method for multispectral indices method, respectively. For yearly average, error is below 10% for 70% and 55% of these two products, respectively. Then, representation of seasonal freshwater fluxes in these products has been estimated. Correlation of seasonal cycle between in situ and CCI products are higher than 0.75 for 84%, 34%, 69%, and 71% of altimetry-based, uncalibrated multispectral indices-based, best-fit calibrated multispectral indices-based, and Copula calibrated multispectral indices-based discharge product, respectively. Results also showed that all CCI products are very good for climate means and for climate variability assessment. Multispectral indices-based product seems better suited than altimetry-based product for regional flow reconstruction. These results are still being analysed by the team in charge of this work package. Trends in CCI products are similar to the in-situ ones, except for few locations.

Some questions to clarify the methodology have been asked. More analysis of these results is needed.

4.7.2 CCI products assimilation in large-scale river routing models

The last formal presentation from the user workshop was done on Tuesday June 4th at 9:30am. It corresponds to a use case of the CCI products in a context of a climate-related study. It presented the first and preliminary results of CCI altimetry-based WSE and discharge products assimilation in the ISBA-CTRIP (which is not calibrated with in situ data) and MGB (which is calibrated with in situ data) large-scale hydrology models, to get 20 years discharge reanalysis at basin scale. Two scientific questions are addressed:

- Does assimilating higher uncertain river discharge data perform better than assimilating lower uncertain water elevation data?
- Are the spatial coverage and temporal resolution of these products enough for the scale of hydrological processes being studied (depending on each model application)?

First, models' characteristics are presented. MGB model set up is available for the Niger and Congo basins, whereas ISBA-CTRIP covers all world river basins. Results are presented only on the Niger basins, and results on the Congo have not yet been analysed. Different types of observation errors have been tested. The first results tend to show, for both models, that assimilating WSE anomalies slightly better correct discharge than direct assimilation of CCI products. It also appeared that too few locations are provided in this CCI precursor project to correct river discharge along the full river network at basin scale, then spatially limiting the impact of the assimilation.

Many questions were asked by the audience for more than 30 minutes. The first ones corresponded to methodological questions, forcing used, and the obtained results. Assimilation of WSE in the MGB model leads to oscillations in the analysis (discharge after the assimilation), which is not realistic but quite common with assimilation outputs, as highlighted by a user. The best solution to cope with it is to assimilate more information with proposer knowledge of accuracy. Most biases in land surface model is due to precipitation. Would it be possible to somehow correct precipitation? For the CCI team, it might be difficult due to the high non-linearity between precipitation and river discharge. A user does not recommend tuning model parameters to correct discharge and oscillation, as it might lead to the correct answer for wrong reasons. Sensitivity to some parameters of the assimilation scheme could be investigated (number of elements in the ensemble, localization parameters, implement a smoother…). It has been highlighted by the CCI team, but also by some users, that models need to be fed by observed data (both in space and time) to correct model errors. Assimilating the combined discharge product might overcome this issue. A user asked if seasonal prediction is foreseen in the project. The team replied that the purpose was not to do forecast, but to estimate discharge over the last 20 years. A question delt with the calibration of MGB model with in-situ data. The same in situ data that has been used for calibration of the CCI river discharge products, which question the added value of assimilation. It might be interesting to calibrate the model with CCI discharge instead of in situ data. It has been recalled that there should be some benefits of using SWOT to densify observation, link WSE and width and propagate these relationships in time. A discussion on the different results obtained between assimilation of WSE and river discharge led to some recommendations:

- investigate the observation errors used,
- computing as much WSE time series as possible (even at locations where discharge cannot be computed) to densify time/space observations might help to better correct model outputs with assimilation.

5 Discussions and feedback with users

5.1 Feedback on user requirements

A user highlighted that seasonal prediction is important for climate activities and it might be considered to derive some requirements. River discharge may become important in the future to improve initial conditions of hydrology models to compute seasonal predictions. It might be interesting to have a requirement on NRT capabilities for discharge products, as timeliness might be an issue.

There was no other request to update or add some requirements from user(s).

5.2 Discussion on the river discharge roadmap

An interactive presentation on the river discharge roadmap has been done by the Science Lead (i.e., activities overseen by the team to derive river discharge operationally at global scale). The discussion lasted 1h30. Only the points which lead to most discussion are highlighted below, for other points, please refer to the presentation.

To overcome the time gap between some altimetry missions (especially, Envisat and Saral), the question to integrate other sensors has been discussed (GFO, HY series, missions not on nominal orbits…).

The need to densify in space and time WSE is important. It could be provided on virtual stations with valid data, even if no ancillary in situ discharge data is available. Besides, to combine multimissions data, slope information from Cryosat/ICESat-2/SWOT must be of interest. The methodology to combine EO (WSE and multispectral indices) might also be useful to densify WSE observations.

To tackle the intermission bias issue, it might be needed to use specific retracking methods.

Is the impact of subsidence corrected from WSE? No, but the magnitude of subsidence is an order of magnitude smaller than observed WSE amplitudes and trends.

The use of other missions to extend multispectral indices might be considered.

It must be needed to define a methodology to compute uncertainty with the multispectral indices-based discharge.

The question to derive river discharge combining multiple variables (WSE, width, slope, multispectral indices…) has been also discussed. It could be studied over some locations.

The need to integrate more observation (without modifying long term signal) for the use case and improve assimilation scheme is also an important task (see above).

The CCI river discharge workshop ended at 1pm Tuesday June 4th.