MONITORING RIVER WATER LEVELS FROM SPACE : QUALITY ASSESSMENT OF 20 YEARS OF SATELLITE ALTIMETRY DATA

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ABSTRACT

This paper presents the results of 20 years of validation of altimetry data for the monitoring of river water levels using a standardized method. The method was initially developed by Cemagref (2006-2011, [5, 6, 3]), now Irstéa, its implementation is now pursued at LEGOS.

Our initial statement was: "what if someone[1] wants to use satellite measurements of river water levels ?" The obvious question that comes to mind is **"what the quality of the data ?"**. Moreover, there's also a need - a demand from data producers, to monitor products quality in a standardized fashion.

We addressed such questions and have developped a method to assess the quality of, so called, "Alti-Hydro Products". The method was implemented for the following Alti-Hydro products (and automatically derived from a L2 product*) : **AVISO*** (Topex/Poseidon, Jason-2), **CASH** project (Topex/Poseidon), **HydroWeb** (Topex/Poseidon, ENVISAT), **River & Lake** Hydrology (ERS-2, ENVISAT) and **PISTACH*** (Jason-2).

Key words: satellite altimetry, river water level, quality, Amazon basin.

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1. METHOD

The first major validation campaigns of Alti-Hydro Products were implemented by and Koblinsky et al. [10] in 1993 and Birkett et al. [8] in 2002. Nevertheless, such studies never led to develop or adopt a standard methodology to quantify Alti-Hydro Products accuracy, neither they really discuss the sampling efficiency of the time series.

This section gives an overview of the standardized method we developed (see PhD thesis for full details [3]).

[1]Think of "an hydrologist with not any kind of expert knowledge in radar altimetry".

1.1. Input data

Basically speaking, the method takes two kinds of data as inputs:

- "Alti-Hydro Products" : they consist in a set of river water level "Alti-Hydro time series" derived from satellite altimetry, each time series is made of one unique representative measurement of the river water level for each satellite overflight over the river (that is, for each cycle-track combination).
- In situ gauge time series : they consist in a set of time series, usually delivered by water agencies. River water level time series are often made of a mean daily value of the river water level.

1.2. Building error time series

Alti-Hydro time series are processed from altimetry data extracted at virtual stations. For each virtual station, we build an error time series and derive synthetic quality indicators. This requires in situ river water level time series from in situ gauging stations. However, most of the virtual station configurations are too far from gauging stations to perform direct measurements comparison.

The solution we propose consist in a simple reconstitution method that estimates in situ time series from upstream and downstream gauging stations data. Basically, this reconstitution is based on the assumption of a **smoothed river profile**[2]. Hence, we are able to implement a river profile interpolation technique using a **smooth river profile model**[3] forced by upstream and downstream data. In situ values are estimated on a daily basis. Finally, reconsituted in situ time series are resampled to match satellite measurements timings (using UTC dates).

[2]We pay a particular attention to the upstream and downstream gauging stations we choose to perform the interpolation and avoid river sections that breaks the "smooth" assumption.

[3]A Nth order polynomials on which we minimize the integral of the square second derivative.

Alti-Hydro and in situ time series are paired together on their overlapping time interval. The error time series are computed as the difference “altimetry minus in situ” values.

1.3. Quality indicators

For each Alti-Hydro time series, we derive two kinds of quality indicators :

1. **Accuracy** indicators : Mean, Standard Deviation and RMS error derived from the error time series.
2. **Sampling efficiency** indicators : Mean Sampling Period and Sampling Loss Rate (SLR), derived from the Alti-Hydro time series. SLR is the ratio between the actual number of measurements of the time series versus the nominal number of measurements it should contain regarding the revisit period (and the possible multiple tracks that can cross the river at the same virtual station).

In order to give synthetic results for each Alti-Hydro Product, we focus on the RMS error and the SLR of its time series. Figure 1 gives a plot example where the quality indicators, RMS according SLR, are plotted for a large number of virtual stations as well as the mean quality indicators of the product.

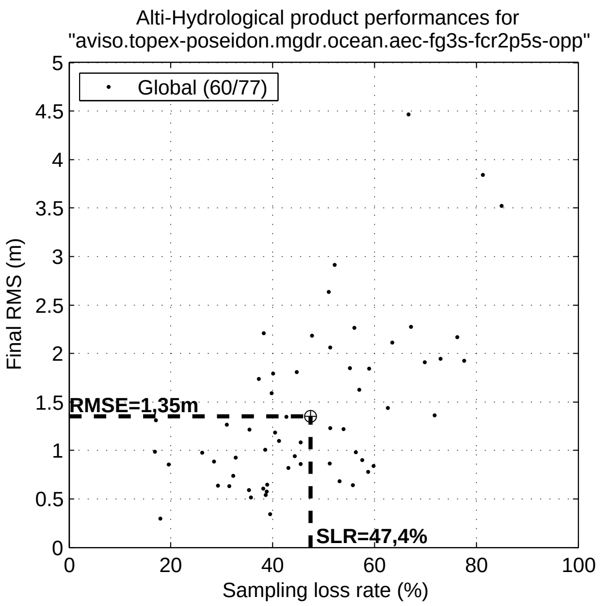

Figure 1. Plot example of the quality of an Alti-Hydro Product derived from AVISO Topex/Poseidon M-GDRs (1992-2002) on 60 virtual stations over the main rivers of the Amazon basin.

2. VALIDATION RESULTS

2.1. Validated products

Two kinds of products were validated :

(1) Publicly avalaible Alti-Hydro Products :

- CASH project (Topex/Poseidon) http://www.cls.fr/html/oceano/general/applications/cash_en.html
- HydroWeb (Topex/Poseidon, ENVISAT) http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/
- River & Lake Hydrology (ERS-2, ENVISAT) http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/shared/main

(2) “Homemade” Alti-Hydro Products are built on top of publicly available level 2 product (i.e., GDR), using **fully automated custom editing rules, routines and filters** :

- AVISO Topex/Poseidon http://www.aviso.oceanobs.com/index.php?id=1458
- AVISO Jason-2 (same URL)
- PISTACH Jason-2 (ice3) http://www.aviso.oceanobs.com/index.php?id=1527

2.2. Area : Amazon basin

We choose to implement the quality assessment of Alti-Hydro products over some of the main rivers of the Amazon basin. This basin has a large variety of river configurations and in situ data from nearly 400 gauging stations are available.

However, a major drawback is that the zeros of the limnimetric scales of the gauging stations are not leveled relative to any vertical reference To overcome this limitation, we used leveling from Kosuth et al. [11].

2.3. Product results

The method have been implemented on a limited number of rivers of the Amazon basin - namely the Amazon, Madeira and Negro rivers, where altimetry data are available for all of the validated Alti-Hydro products. Table 1 gives the mean values of RMS and SLR quality indicators for the Alti-Hydro products mentioned in section 2.1.

Alti-Hydro Product	Period (year)	VS	RMS (m)	SLR (%)
*AVISO T/P	1992-2002	17	1.36	46.1
CASH T/P	1993-2002	6	0.94	30.2
HW T/P	1993-2002	6	0.82	32.9
HW ENVISAT	2002-2008	41	0.66	8.9
R&L ERS-2	1995-2003	28	0.85	11.6
R&L ENVISAT	2002-2007	27	0.73	15.6
*AVISO J-2	2008-2012	16	0.91	5.6
*PISTACH J-2	2008-2012	16	0.74	5.5

*Table 1. Alti-Hydro products quality assessment results: mean RMS and SLR indicators for each product, time interval (period) and number of validated virtual stations (VS). (Alti-Hydro Products automatically processed built by ourselves are marked by a *)*

3. 20 YEARS OF PROGRESS IN ALTI-HYDROLOGY

Figure 2 shows the quality assessment results for the 20 past years, we can see an impressive improvement in terms of sampling loss rate (-90%) a global improvement trend in terms of vertical accuracy.

However, accuracy results for Jason-2 do not follow this trend. Jason-2 accuracy results are in contradiction with the results presented in the 2010 OST/ST edition [7] (Lisbon). This is discussed in the following section (§ 3.1).

3.1. Jason-2 unexpected results

Results for Jason-2, and notably the Alti-Hydro product derived from the PISTACH product are not as good as expected. Actually, the results of the 2010 validation campaign, presented at the 2010 OST/ST edition (Lisbon), gave an RMS error of 0.62 m for the Jason-2 PISTACH product, on the same rivers, but is now 0.74 m. Note that this is not the same for the Jason-2 AVISO product whose RMS error value is the same as of the 2010 campaign.

After investigations, we found out that we were facing several specific issues at the same time, during 2009-2011. We used Ice1 retracker from the AVISO product and Ice3 retracker from the PISTACH product, Ice3 being more accurate to monitor inland waters. Ice3 is also more sensible when it comes to estimate correct water levels in extreme situations, Ice1 being, anyhow, nearly always less accurate than Ice3. During 2009-2011, several rivers of the Amazon basin displayed unprecedented, really low, low flow stages. As an example, the gauging measurements for low flow at Manaus were 11 m in 2009, then 8 m in 2010 and 6 m in 2011. The low flow level of 2011 at Manaus is the lowest noted during the past 20 years.

Moreover, looking closely to virtual stations, we can observe that after flooding events, temporary lakes remain close to the riverbeds, while the river level has already started to decrease. In such situations, standard retrackers (e.g., Ice1 of the AVISO product) will often focus on the highest water surface (i.e., the first echoes in the waveforms) even if the power of the selected echo is lower than the power reflected by the river. This effect is combined with the rectangular shape of the geographical windows we use to extract the data at virtual stations. During 2009-2011, this kind of phenomenon occured a lot while the river level was expectionaly low, making it hard to aquire low water level measurements. Given the 2012 unfavorable hydrological contexts, compared to 2010, we see that the combination of rectangular geographical windows and the Ice3 retracker was pushed to its limit and that, **during the 2009-2011 low water stages, the Ice3 measurements accuracy is directly linked to the river water level**. Hence, the slight degradation of the PISTACH product results we see in figure 2.

It could be interesting to perform quality assessment for other missions, on the same period, and using the same automated routines to build the Alti-Hydro products.

3.2. State of the art

Despite the PISTACH Jason-2 unexpected mean results for the period 2008-2012, it is also the product that gave more accurate time series on the Amazon basin. Figure 3 illustrates such impressively accurate results over the Negro river where the accuracy (RMS) is 0.12 m only and the sampling loss rate (SLR) is only 2.4%. Not to mention that the SLR value is a direct consequence of the DIODE/DEM tracking mode (enabled during cycles 3, 5 and 7) of Poseidon-3, the Jason-2 altimeter, that was known to give “mitigated results” over inland waters [9]. Since then, It has been improved and uploaded to Poseidon-3.

Finally, figure 4 illustrates the improvement of satellite altimetry, and Alti-Hydrology in general, during the past 20 years. These results are limited to Negro river where low flow events were limited. The global trend is unambiguous : on this river the accuracy of products derived from satellite altimetry has been improved by a 4 factor over the 20 past years.

4. CONCLUSION

The validation of 18 years of Alti-Hydro products presented two years ago in Lisbon (OST/ST, 2010) exhibited a global improvement trend of the products quality[4]: -50% in terms of accuracy (RMS from 1.36 m to 0.73 m)

[4]Results presented at Lisbon 2010 OST/ST were based on the Amazon and Solimões rivers. But for the sake of a consistent comparison in this paper, and because of the 2009-2011 low flow events, quality results of the 2010 campaign were reprocessed on the same rivers than the 2012 campaign : the Amazon, Madeira and Negro rivers.

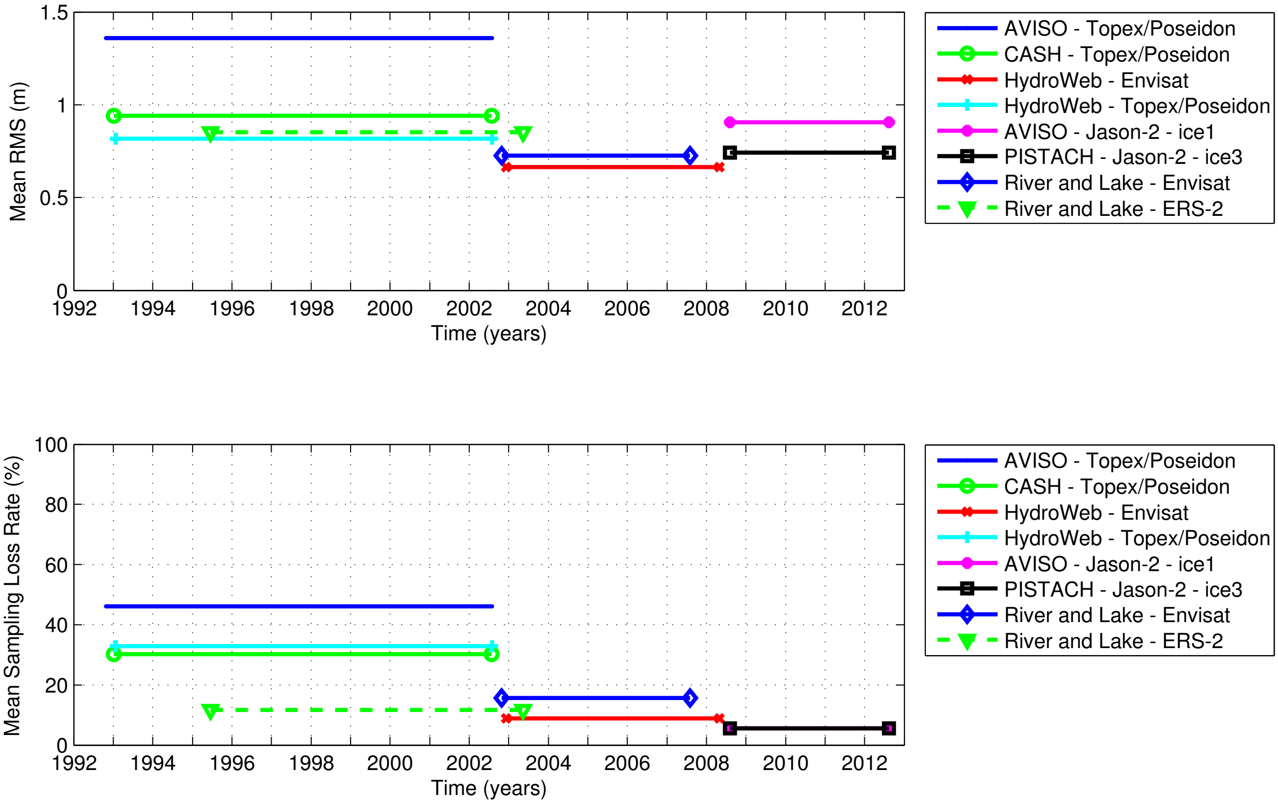

Figure 2. 20 year of progress in Alti-Hydrology over the Amazon, Madeira and Negro rivers (Amazon basin). Evolution of the mean RMS error [top] and the Sampling Loss Rate (SLR) [bottom] for the height assessed Alti-Hydro products (read section 3 for results discussion).

and -90% in terms of sampling loss rate (SLR from 45% to 5%).

The 2012 validation campaign is biased by unprecedented really low flow events, mainly on the Solimões river and its tributaries (but these events also have a significant impact on the Amazon river). Hence, products comparison have been performed on the Amazon, Madeira and Negro rivers (instead of Amazon and Solimões rivers in 2010) to mimize the low flow events impact. The SLR improvement trend follows the one of the 2010 results but the RMS error of Jason-2 products is not as good as expected due to the exceptional events of the last four years on the Amazon rivers. This highlights some kind of limitations inherent to the comparison of altimetry data to in situ data and to the rectangular extraction windows we use at virtual stations.

The method have been implemented in the frame of several contracts with space agencies and data producers (ESA, CNES, River & Lake, CLS) for the quality assessment of Alti-Hydro products (River & Lake Hydrology, PISTACH) as well as for more specific research studies to estimate the benefits of new retracking algorithms (CLS [1]).

It is a useful tool for both data producers (contracts) and end users (hydrologists, partnership in progress, [2]). It allows to monitor, in a very accurate way (same virtual stations) missions and products quality. We think such standardized method consitute an important step toward the operational use Alti-Hydrology data.

5. PERSPECTIVES

About the method - Quality assessment for future missions and products will be performed, notably for CryoSat-2 (cf. work in progress in [4]) and the forthcoming SARAL/AltiKa mission.

About the method - This method should be implemented in a data processing center such as AVISO or CTOH and used to routinely release quality assessment reports.

About the automatic processing of Alti-Hydro Products - Automatic processing of Alti-Hydro products is still an ongoing research field. For example, we have to improve geolocalized data extraction at virtual stations using static (SRTM Water Body Data) polygons of riverbed contours, or dynamic polygons based on instrument data (Sigma0 Ku/C, Waveforms and Waveforms inversion [13]).

About the Alti-Hydro Community - Just like the

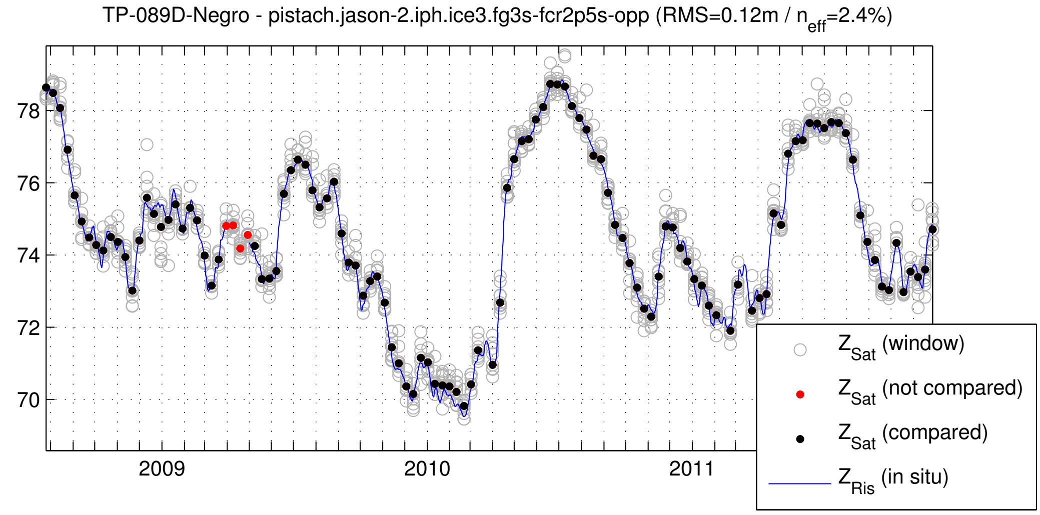

Figure 3. Illustration of the most accurate Alti-Hydro time series (back & red dots) of the 2012 quality assessment campaign, Negro river (Amazon basin). This time series was automatically built on top of the PISTACH Jason-2 product. Despite the complexity of the in situ water level signal (blue curve), it has a low RMS error (0.12 m, black dots only) and nearly no data loss can be noted (SLR=2.4%, due to the DIODE/DEM tracking mode, black & red dots). Grey circles depict altimetry data extracted at virtual station within a rectangular geographical window. For each satellite overflight, only one of them is kept to build the Alti-Hydro time series.

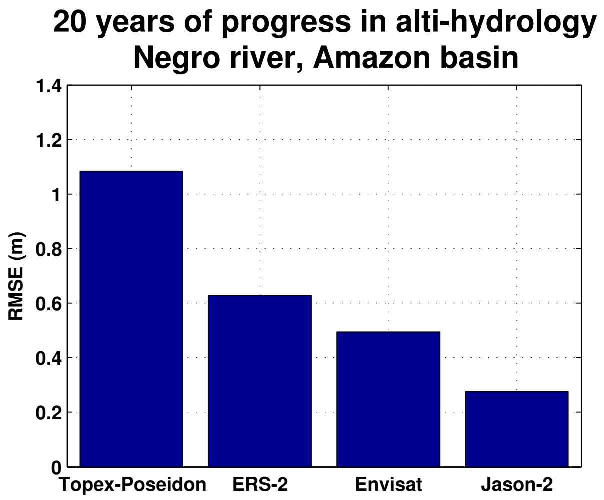

Figure 4. A synthetic view of 20 years of progress in Alti-Hydrology, results limited to the Negro river (Amazon basin). The accuracy of Alti-Hydro data has been improved by a 4 factor during the 20 past years.

OST/ST, we need a strong Alti-Hydro Community, and maybe a yearly dedicated symposium attached to the OST/ST events. For the moment, only a few Alti-Hydro data producers exist and the community is still fragile. There is no systematic assessment of the products quality.

All of this calls to think :
"Collective" : share data sources, document algorithms (including retrackers, geophysical corrections, etc.), give details about how the products are actually built,
"Open" : apply fully open data policies (upstream data, i.e., L1b/L2 products) in order to allow everyone to explore data in depth with no restrictions, share code when appropriate (BRAT [12] is a very good example),
"About the end users" : On demand internet-based services should be implemented in the forthcoming years (before Swot is launched !) : a web portal as an exhibition service for intermediate users (maybe through the *work in progress* new AVISO portal) and APIs for intermediate-expert users to get automated on-line access to the data, thus unlocking the way toward the operational use of Alti-Hydro data, in a near-real time fashion.

It remains an important amont of work to achieve in order to be able to produce homogeneous data products (GDRs that include the same retracker outputs, the same geophysical corrections, etc). This would constitute the basis of a full merged/multi-mission Altimetry Product to start produce Alti-Hydro products automatically (but still allow expert users to customize the products on their own). This could help a lot to address, for example, the problem of systematic bias that still exist between altimetry missions.

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