CHARACTERIZING THE QUALITY OF RIVER WATER LEVEL TIME SERIES DERIVED FROM SATELLITE RADAR ALTIMETRY: EFFORTS TOWARD A STANDARDIZED METHODOLOGY

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ABSTRACT

The potential contribution of satellite radar altimetry to the monitoring of inland water levels (inner seas, lakes, floodplains and large rivers) has been demonstrated by numerous works during the last 15 years. Currently a significant number of satellites provide radar altimetry information and could ensure the continuity of operational monitoring of continental water levels. Still, hydrologists do not use these data for operational applications such as water resource quantification, flood forecast or water resource management. Among the reasons accounting for hydrologists reluctance to use water level data derived from satellite radar altimetry is the lack of a standardized method to characterize the quality of these data [Birkett1998]. This paper focuses on that subject and proposes a standardized methodology for two complemetary purposes (1) the quantification of the accuracy and uncertainty of individual satellite measurements, (2) the characterization of the quality of daily water level time series reconstructed from sampled satellite radar altimetry measurements.
This method will both (1) contribute to provide to hydrologists radar altimetry water level time series with associated uncertainty, thus allowing hydrologists to use qualified data, (2) allow the quantification of improvements generated by new processing chains (waveform retracking algorithms, filtering techniques, interpolation techniques,…).

1. BACKGROUND AND OBJECTIVES

Satellite radar altimetry was initially designed for the monitoring of ocean surface topography. Numerous works during the last fifteen years have shown its potential contribution to the monitoring of water levels of inland water bodies (inner seas, lakes, floodplains and large rivers) [Birkett1995b, Birkett1998, De Oliveira Campos 2001, Mercier2002]. Over this period, a significant number of satellites have provided radar altimetry information (Topex Poseidon, ERS, Envisat, Jason) and could ensure the continuity of operational monitoring of continental water levels [Mercier2001].

Recently, various research groups have dedicated large efforts in three complementary directions : (1) improving the algorithms for waveform retracking in order to increase the accuracy of radar altimetry measurement of inland water levels ; (2) building databases of rivers and lakes water levels derived from satellite radar altimeters ("Global reservoir and lake monitor" Project, "River and Lake" Project, "CASH" Project, MSSL Global Lakes Database [Birkett1995a]) ; (3) developing new measurement concepts for the monitoring of inland water levels from space (satellite radar interferometry, LiDAR altimetry).

However, hydrologists are still far from using these data for operational applications such as water resource quantification, flood forecast or water resource management. The main explanation for that is that hydrologists generally require daily sampled water levels with a few centimetres accuracy. Lower sampling frequency and lower accuracy can still be of interest for them, but their confidence in radar altimetry data will depend on a standardized method to characterize in a reliable way the quality of these data [Birkett1998]. Additionally such a standardized method, that still does not exist, would be of primary interest for research groups in order to quantify the improvements in accuracy generated by new waveform retracking algorithms.

The objective of the present paper is to contribute to the definition of such a standardized methodology for the characterization of the quality of inland water levels measured from satellite radar altimetry. It develops two complementary topics :

(1) the quantification of the accuracy and uncertainty of individual satellite measurements,

(2) the characterization of the accuracy and uncertainty of daily water level time series reconstructed from sampled satellite measurements.

2. BUILDING TIME SERIES OF INLAND WATER LEVELS FROM SATELLITE RADAR ALTIMETRY

Building water level time series from altimetry measurements is a five step process:

- The first step consists in localizing an intersection between a satellite track and a river.
- The second step consists in defining a geographic selection window around this intersection. Generally the selection window corresponds to the open water area.
- The third step consists in extracting the data from the GDRs[1] over the geographic selection window. Result will depend on the waveform retracking algorithm (or set of algorithms) that will translate waveform records into water levels. The size of the selection window will influence both the data temporal density and the data quality :

  (a) a "reduced" extraction window will provide few measurements for a given satellite overflight, which generally results in a reduced internal dispersion. In some cases however this could even lead to no measurement during a satellite overflight, resulting in a reduced measurement density and increased effective sampling period.

  (b) on the other hand, a "large" extraction window will result in a large number of simultaneaous measurements and introduce a greater internal dispersion.
- The fourth step consists in determining a unique water level value for each satellite overflight over the water body, from the multiple measurements made within the selection window. Various methods can be implemented, for instance applying a median operator (this method strongly reduces the sensitivity to measurement dispersion, particularly when erroneous measurements appear), or an average operator.
- The fifth and last step consists in filtering the resulting data set to remove aberrant values of water levels. For instance a filtering technique consists in applying a "3σ" filter on the overall time series, excluding any measurement whose value is outside the $\mu \pm 3\sigma$ interval around the serie's average μ. Intelligent filtering methods that would allow to identify erroneous measurements inside the $\mu \pm 3\sigma$ interval would be of high interest.

3. QUANTIFICATION OF THE ACCURACY AND UNCERTAINTY OF RIVER WATER LEVELS DERIVED FROM RADAR ALTIMETRY MEASUREMENTS

3.1. Definition of "dispersion", "measurement error", "accuracy", "uncertainty" and "effective sampling period" of radar altimetry water levels

A real confusion exists between these various terms and it is of primary importance to clarify these concepts :

"**Dispersion**" of the radar altimetry water level measurement is a quantification of the distribution of the measurement values during a given overflight within the selection window. Fig. A (b) illustrates this dispersion.

"**Measurement error**" is the difference between the radar altimetry water level at a given location for a given overflight and the "real" water level (measured in situ) at the same location and time

"**Accuracy**" is a quantification of the distribution of the measurement error between satellite derived time series and "real" water level values. It can be, for instance, the mean error and standard deviation at a given location for a given period of time. When measurement errors decrease, accuracy is qualified as increasing.

"**Uncertainty of radar altimetry water levels**" is a statistical characterization of the probability for the real value to be within a given interval around the water level value derived from radar altimetry.

[1] GDR : Geophysical Data Records

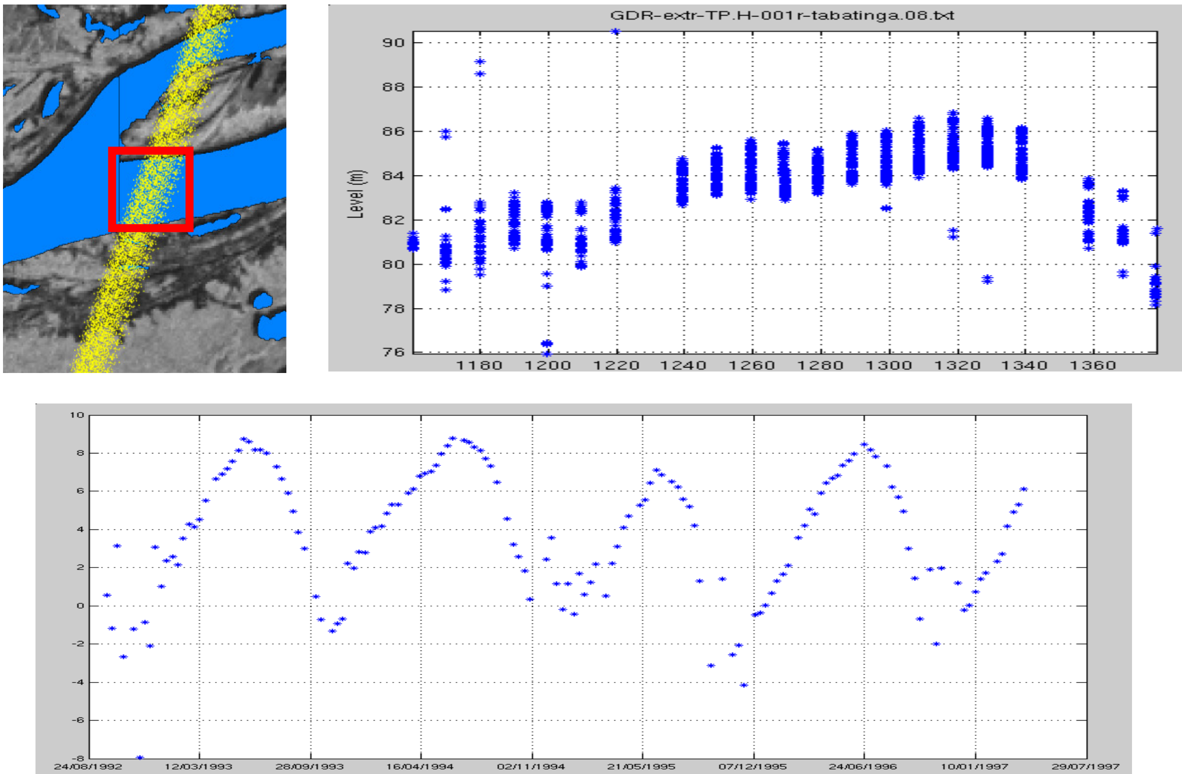


Figure A: Illustration of the generation of water level time series from radar altimetry measurements : (a) steps 1 & 2 : extraction window over a satellite track and river intersection, (b) step 3 : extraction of measurements over the selection window during successive satellite overflights (this shows the measurement dispersion within the selection wndow), (c) steps 4 & 5 : resulting sampled time serie after applying the sorted median operator and a 3σ filter.

"Dispersion" is clearly different from "accuracy" and a reduced dispersion is not a proof of "high accuracy". While quantification of dispersion is intrinsic to the radar altimetry data over the selection window, quantification of accuracy can only be realized through comparison between radar altimetry water levels and *in situ* water levels measured at gauging stations. Such a comparison can be difficult due to the fact that satellite tracks rarely pass over hydrometric stations, thus requiring to estimate (extrapolate) in situ water levels on the track from the closest hydrometric station.

Fig. B illustrates the quantification of measurement errors and their distribution at the intersection between Topex Poseidon track n°63 and Solimões river (Fig. A). Topex data used on this figure are 10 Hz data (~600m ground distance between two measurements), using the "ocean type" waveform retracking algorithm. Satellite measurements (black dots) are compared to in situ water level time series (blue line) derived from the closest gauging station, at Manaus (Fig. B upper left). These two data sets of water levels (namely radar altimetry and in situ) show high correlation at high river stage and lower correlation at low river stage (Fig. B upper right). Resulting measurement errors (red dots Fig. B. lower left) vary along time and appear to be higher at low river stage. Therefore, as illustrated later, a methodology for quantification of accuracy should take into account the error dynamics at various river stages: "low water", "medium water" and "high water".

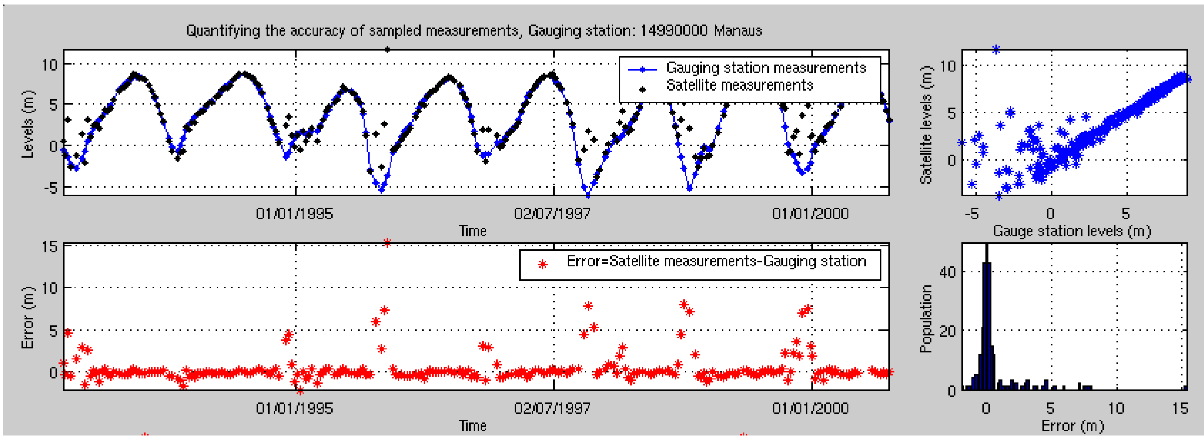


Figure B: Comparison between In situ & radar altimetry measurements : respective time series (upper left), correlation between the two datasets (upper right), resulting measurement error (bottom left) and measurement error distribution (bottom right).

Finally, the statistical analysis of the probability distribution of the measurement error (Fig. B lower right) will lead to the quantification of both "accuracy" and "uncertainty" : "accuracy" when related to in situ water level, "uncertainty" when related to satellite measurement. This will be developed further on in the text.

"**Effective sampling period**" is the mean duration between radar altimetry water level measurements on a given intersection between satellite track and river.

It can be different from the theoretical sampling period by the satellite when some satellite overflights do not provide interpretable measurements. For instance, a reduced selection window will allow reduced measurement dispersion and potentially increased accuracy but in some cases may induce blanks in the radar altimeter time series, increasing the effective sampling period. "Effective sampling period" is an additional parameter to assess the quality of radar altimetry water levels, as it has drastic impact on the ability to reconstruct oversampled (interpolated) time series (see point 4. below) for hydrological applications.

3.2. Method for quantification of the satellite measurements accuracy and uncertainty

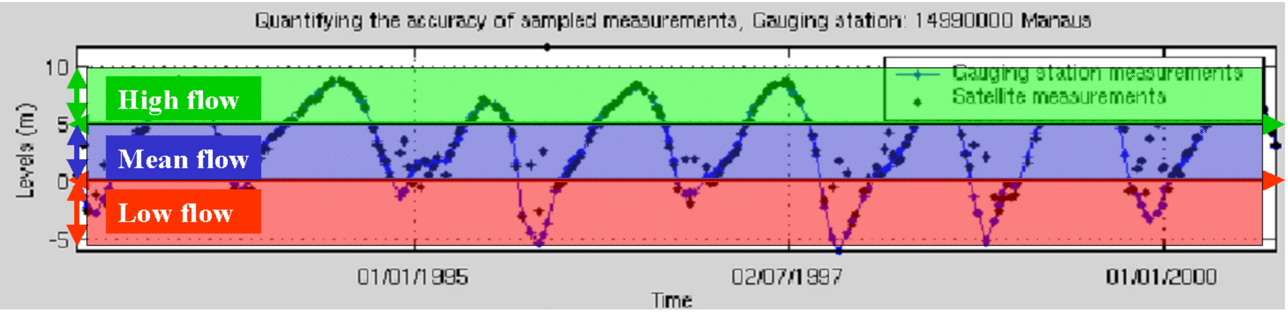
The main objective of the present work is to introduce standardized procedures to analyse the quality (i.e. accuracy, uncertainty and effective sampling period) of satellite measurements. Such a standardized methodology will allow the community of inland water satellite radar altimetry to compare different methods to derive water levels time series, including assessing the benefits from new altimeter technologies, new waveform retracking algorithms [Berry2003, Frappart2004, Frappart2006], new filtering techniques, etc.

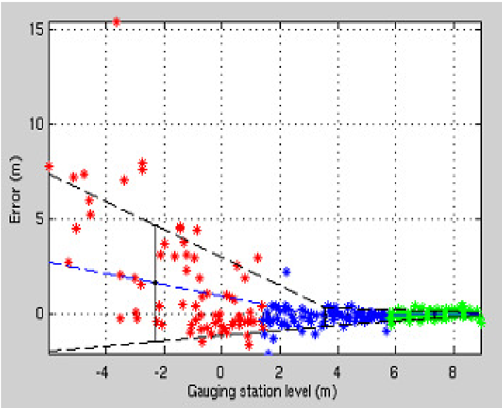
As mentioned above, in a lot of cases measurement errors appear to be correlated with the water level. Therefore it is relevant to analyse the error and accuracy for various intervals of water levels. Consequently, three stages are defined : low (red dots), medium (blue dots) and high (green dots) stages, for instance through splitting of the overall dataset of measured water levels in three equal size populations (Fig. C upper). This allows a stage by stage analysis of the quality of satellite measurements, instead of simply analysing it for the overall time series.

Fig. C shows the detailed analysis of measurement errors over the satellite track presented in Fig. A and Fig. B (Topex/Poseidon track 63 over the Solimoes river; Amazon basin; Brazil, related to the closest gauging station). Water level data set has been divided in three intervals (Fig. C top). Two different representations allow the statistical analysis and quantification of both data accuracy and data uncertainty:

(a) <u>Accuracy analysis (Fig. C center left) :</u> measurement errors are represented in relation to the in situ river level, derived from the closest gauging station. This representation helps, for a given in situ water level, to analyse the distribution of the measurement error and to quantify the accuracy of the radar altimetry measurement : mean error and corresponding standard deviation (Fig. C. Table lower left).

(b) <u>Uncertainty analysis (Fig. C center right):</u> measurement errors are represented in relation to the radar altimetry water level. This representation helps, for a given radar altimetry measurement, to analyse the distribution of the measurement error and quantify the uncertainty of this measurement : mean error and corresponding standard deviation. This type of representation will help to compute uncertainty estimation in a near-real time context (see below), provided that the error distribution has been quantified on this station during a past period (a few years) (Fig. C. Table lower right).

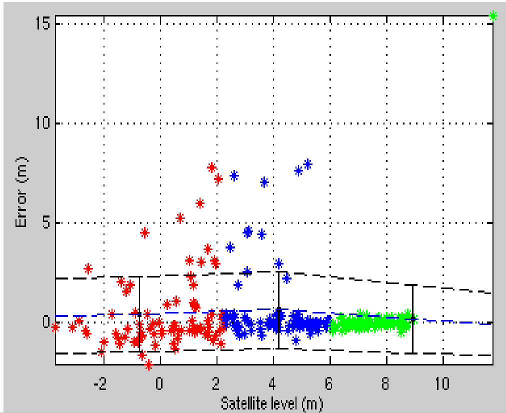




Accuracy of Topex Poseidon on Solimões river (track 63)

(m)	Zmin	Zmean	Zmax	RMS	Mean error		stand. dev.
Global	-6.00	1.47	8.93	**1.88**	0.44	+/-	1.83
High flow	5.76	7.35	8.93	**0.20**	0.00	+/-	0.20
Mean flow	1.43	3.59	5.76	**0.50**	-0.12	+/-	0.49
Low flow	-6.00	-2.30	1.43	**3.42**	1.63	+/-	3.03

(a) Accuracy



Uncertainty of Topex Poseidon on Solimões river (track 63)

(m)	Zmin	Zmean	Zmax	RMS	Mean error		stand. dev.
Global	-3.75	4.01	11.76	1.88	0.44		1.83
High flow	6.10	8.93	11.76	**1.70**	0.21		1.70
Mean flow	2.27	4.18	6.10	**2.00**	0.65		1.90
Low flow	-3.75	-0.74	2.27	**1.92**	0.46		1.88

(b) Uncertainty

Figure C: Analysis of the measurement error distribution for quantification of : (a) "accuracy" , error in relation with gauging station water levels ; (b) "uncertainty", error in relation with the satellite measured values.

Tables illustrate the detailed analysis considering 3 different water level intervals (stages).

Accuracy : the radar altimetry measurement accuracy[2] on this river section (fig. C.a) is high at high level stage (0 ± 0.20m), and declines as the river level decreases (-0.12 ± 0.49m at medium stage; +1.63m ± 3.03cm at low river stage). The global measurement accuracy, considering all water levels, is +0.44 ± 1.83m. As a result, stage by stage analysis allows to characterize the accuracy in a more precise way than when implementing a global analysis.

Uncertainty : the radar altimetry measurement uncertainty on this river section (fig. C.b) is high for all stages (standard deviations of 1.70m, 1.90m, 1.88m for high, medium and low stages) with a global uncertainty of (+0.44 ± 1.83m).

[2] in that case « radar altimetry measurement » refers to Topex Poseidon, using an ocean type waveform retracker, with a 3σ filtering technique. Results in terms of accuracy would be different for another configuration (other satellite, other retracker, other filtering method,…)

This underlines the fact that accuracy and uncertainty can have very different behaviours. A high in situ water level will lead to a high value of radar altimetry water level and reduced error. But in some cases radar altimetry will give high values when in situ water level is medium or low. Therefore a high value of radar altimetry water level is associated with high uncertainty, as the corresponding in situ value could be high, medium or low. Such cross stage class confusions that appear on Fig. C center left and right account for the fact that structured accuracy (left) can lead to averaged uncertainty.

Two main conclusions must be derived from the previous developments :

- Accuracy depends on the in situ water level and cannot be reliably synthesized with a single couple ($\mu \pm \sigma$), but should be quantified for different stages.
- Uncertainty on satellite radar altimetry data is different from accuracy when stage by stage analysis is performed. Particularly accuracy at high stage is not a reliable indicator of radar altimetry measurement accuracy (in the illustration case accuracy at high stage is 0.20 m when uncertainty is 1.83m)

Figures and numbers here are only meant to illustrate the methodology for characterization of the quality of radar altimetry measurement of water levels. Other river sections, other satellites and retracking methods would give different results but still the qualification methodology could be applied in a consistent way and allow to compare results.

3.3. Factors affecting the quality (accuracy and uncertainty) of satellite radar altimetry water levels

Various factors affect the quality of satellite sampled time series of inland water levels. This results from the type and morphology of the water body and surrounding land, but also from the satellite data processing chain (see chapter 2.).

The data processing chain brings sensitivity (1) to the size of the extraction window which affects the measurements dispersion, (2) to the waveform retracking algorithm, (3) to the filtering technique and (4) to the technique for selection of a unique representative measurement per satellite overflight. On the other hand, the hydrology (water level, open water area, water surface roughness) and morphology of the river (topography and land surface roughness) are physical parameters that affect the waveform and may degrade the final accuracy. Based on this standardized methodology for qualification of the radar altimetry data, future studies will focus on analysing the influence of such physical parameters and processing steps on the structure of the measurement error and resulting accuracy, uncertainty and effective sampling period.

3.4. Associating "uncertainty" information to sampled times series of radar altimetry water levels

A major challenge in delivering to hydrologists reliable time series of radar altimetry water levels is to associate uncertainty information to the radar altimetry water level values, as illustrated on Fig. D.

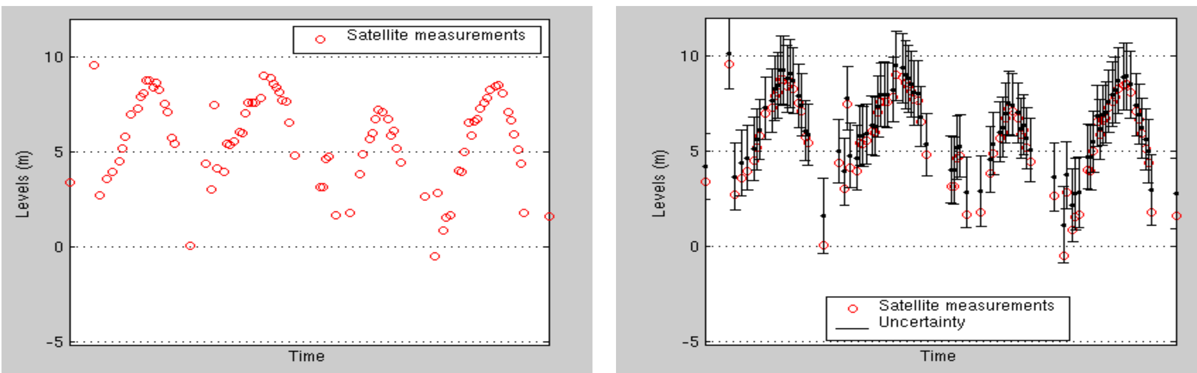


Figure D: Radar altimetry water level time series (left) and the same time series with corresponding uncertainties (right).

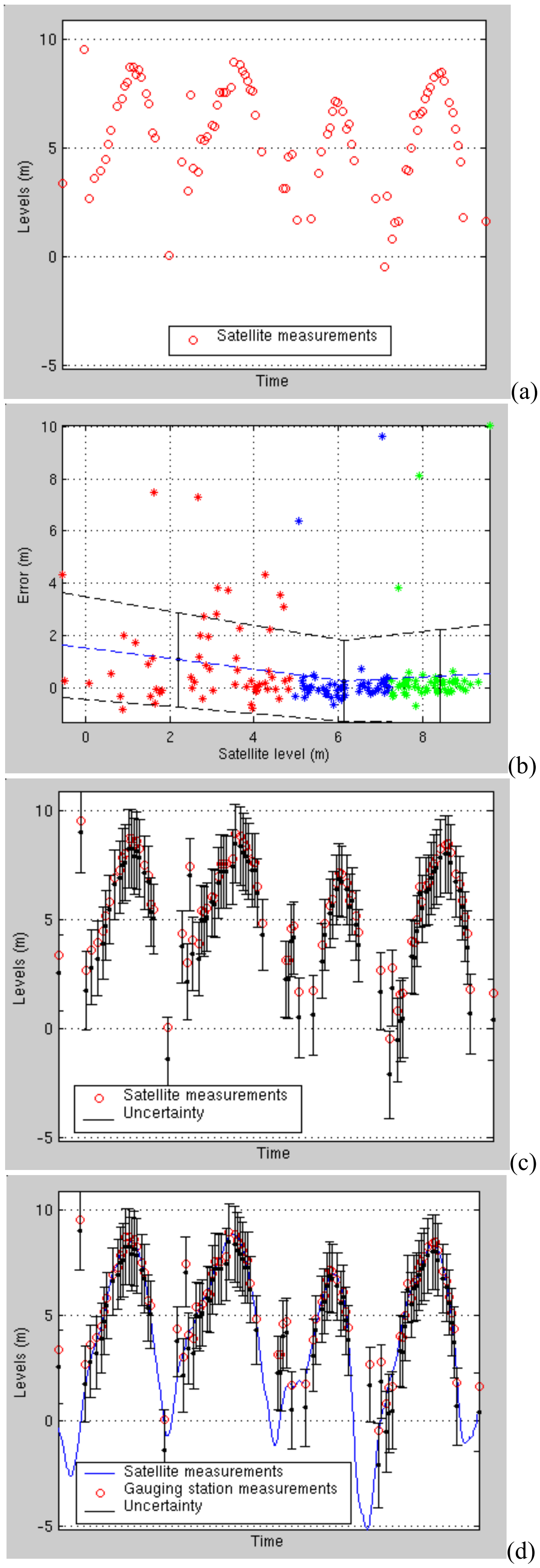


Figure E: Uncertainty of radar altimetry water level values from the statistical uncertainty model

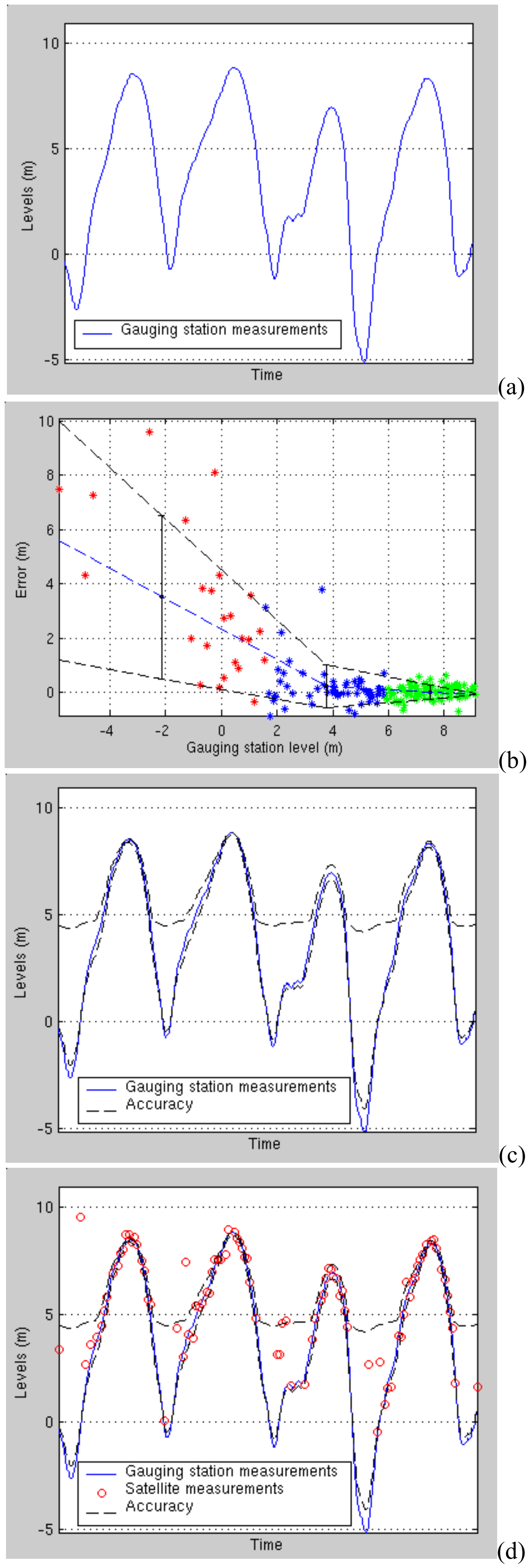


Figure F: Accuracy of radar altimetry water level values from the statistical accuracy model

Fig. E illustrates the methodology to achieve this objective. Given a time series of satellite radar altimetry water levels (Fig. E.a.) and a statistical uncertainty model (Fig. E.b.) each satellite measurement is processed through the **statistical uncertainty model** resulting in an uncertainty interval for the real value (Fig. E.c.). This is the product that should be delivered to hydrologists. Fig E.d. illustrates the fact that the real in situ time series of water levels passes through these uncertainty intervals.

Currently, the main difficulty to generalize this approach lays in the fact that in situ data are needed to establish the statistical uncertainty model (Fig. E second). Two situations can be considered :

- ***When in situ data are available from a gauging station close to the satellite track intersection*** : this method allows to establish the statistical uncertainty model, to quantify the uncertainty of past radar altimetry data and **to quantify the uncertainty of near-real time radar altimetry data**, even if in situ data are not known near-real time
- ***When no in situ data is available in the region :*** efforts will be dedicated to parameterizing statistical uncertainty models from data such as river width, which will allow an estimation of uncertainty.

Fig. F illustrates the accuracy approach, similar to the uncertainty approach. It allows, based on the in situ time series (Fig. A.a.) and the **statistical accuracy model** (Fig. A. b.), to calculate the accuracy interval at any time (Fig. A.c.). This indicate the temporal band in which radar altimetry measurement values are expected. Fig. A.d. illustrates the fact that the radar altimetry measurements are indeed within this temporal band.

4. QUANTIFICATION OF THE ACCURACY AND UNCERTAINTY OF RECONSTRUCTED (OVERSAMPLED) RIVER WATER LEVEL TIME SERIES DERIVED FROM SAMPLED RADAR ALTIMETRY MEASUREMENTS

Radar altimetry satellites have cycle periods of 10 days (Topex Poseidon, Jason) or 30 days (ERS, Envisat). They can only provide sampled time series of water levels, with temporal gaps between measurements. Practically, effective radar altimetry sampling periods are even longer than their theoretical values.

Hydrologists generally use daily information on water levels, except in some cases were hydrodynamic prosesses are faster (ocean tide, flash flood,…). In the case of water level time series derived from radar altimetry, they will interpolate between available measurements to reconstruct daily time series (or "oversampled" time series). Such interpolation, for instance linear or polynomial, will generate additional errors, that will for a large part depend on the effective sampling period : the shorter the satellite sampling period, the smaller the interpolation error. Additionnally, quality of the interpolation will depend on the hydrological dynamics of the water body : slowly changing water levels can be monitored with a long sampling period (for instance Amazon river) while rapidly changing water levels would require shorter sampling periods for reliable interpolation.

The following method is dedicated to the characterization of the quality of reconstructed (oversampled) time series of water levels derived from satellite radar altimetry.

What we call "quantification of the quality" is the quantification of the error of interpolated time series regarding to the gauging station time series. Because of the daily sampling period of gauging station measurements, we will oversample satellite time series to a daily period.

- **Oversampling : building a "continuous" time series from sampled satellite measurements**

Any temporal signal can be characterized by its frequency spectrum determined, for instance, by a Fourier transform analysis. The Shannon sampling theorem [Shannon1948] states that if the sampling frequency is twice greater than the maximum frequency of the real signal, then the sampled signal contains the same information as the continuous one. If not, only part of the natural signal can be reconstructed from the sampled signal : the sampled signal is said to have an aliased frequency spectrum. In signal processing, oversampling an aliased signal is still an open problem [Guichard1998, Moisan2001, Vandewalle2003]. As will be illustrated further on, the sampling period has an important impact on the overall quality of the reconstructed time series of water levels.

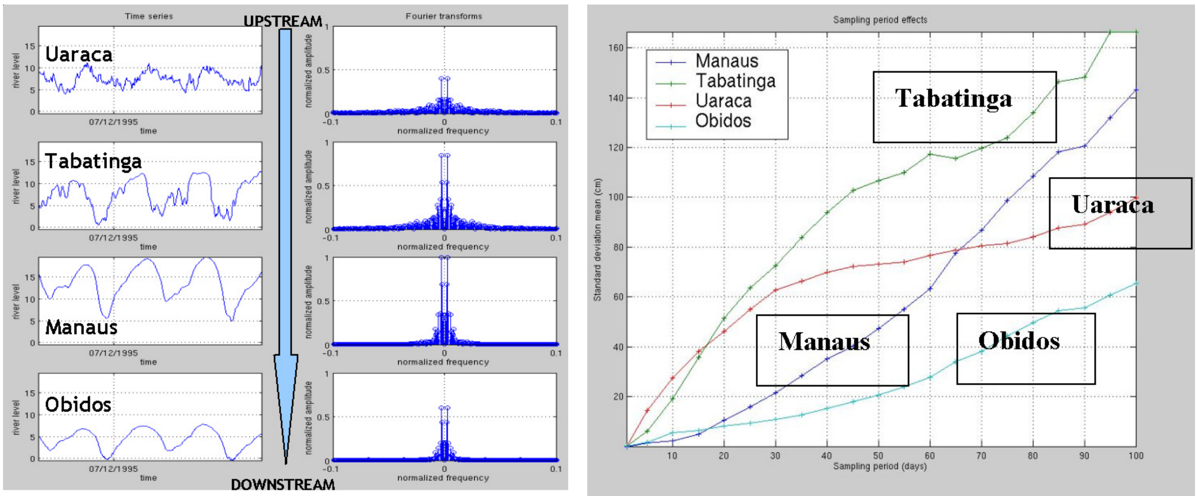
Future investigations will focus on testing various temporal interpolation techniques [Bellanger2002] and developing a method for select the most efficient one according to the river hydrology. For the current study a simple linear interpolation was used.

- **Influence of sampling period and river hydrology on the quality of reconstructed time series**

Fig. G (left column) presents the hydrological behaviour of water level time series from various hydrometric stations along the Amazon river and its tributaries. The larger the upstream watershed, the smoother the temporal signal of water level.

The second column presents the frequency spectrums of each of these stations : a relatively quiet station is characterized by a peaked spectrum while a perturbed one is characterized by a "smoothed and spread" spectrum, composed of high frequency harmonics of non-negligible amplitude that induce the aliasing phenomenon when sampled. Additionally, the energy at low frequency is proportional to the annual amplitude of the hydrological signal.

As a result, the mean error generated when reconstructing a daily time series from exact sampled measurements depends on both the sampling period value and the hydrology of the natural signal. This is illustrated by Fig. G (right column) : A 30 days sampling period with exact measurements will result in a mean error of the reconstructed signal of 10cm for Obidos station, 22 cm for Manaus station, 64cm for Uaraca station and 72 cm for Tabatinga station. On the opposite, in order to ensure a 20cm accuracy (mean error) of the reconstructed daily time series, a 50 days sampling period is acceptable at Obidos, while it should be reduced to 28 days at Manaus, 11 days at Tabatinga and 7 days at Uaraca.



(a) (b)

Figure G: Effect of the sampling period on the quality of reconstructed daily time series for four hydrometric stations along the Amazon river and tributaries: (a) from top to bottom: upstream to downstream gauging stations time series & associated Fourier transforms; (b) standard deviation of the reconstruction error according to the sampling period.

- **Coupled influence of measurement accuracy, effective sampling frequency and river hydrology on the quality of water level time series reconstructed from sampled radar altimetry measurements**

As explained above the quality of reconstructed daily time series of water levels derived from satellite radar altimetry depend on two main factors : (1) the quality of individual radar altimetry measurements of the water level (accuracy, uncertainty) that depends on the water body morpho-hydrology and on the satellite data processing chain, (2) the quality of the oversampling method to reconstruct daily time series from sampled radar altimetry data, that will depend on the effective mean sampling frequency, on the river hydrology and on the interpolation technique.

The following theoretical study analyses the evolution of the error on the reconstructed time series depending on the value of the sampling period and a Gaussian measurement noise. Fig. H illustrates these results for Manaus station.

This study has been applied on water level time series from various hydrometric stations in order to analyse the resulting error (Fig. I). Table 1 enlightens the fact that daily time series derived from measurements by an "accurate satellite" (exact measurement) with a poor sampling period can turn to be worse than daily time series derived from measurements by a "non-accurate satellite" with a shorter sampling period.

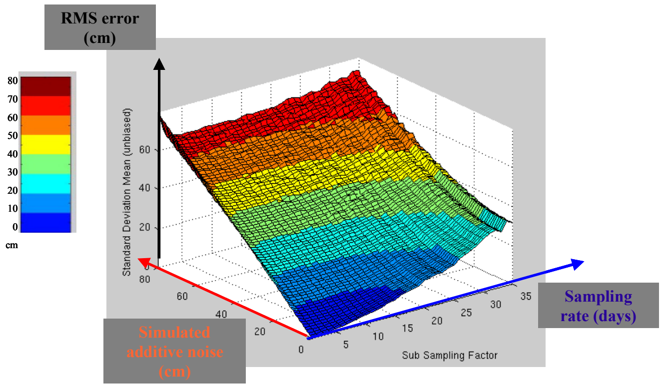


Figure H: Representation of the coupled impact of both measurement accuracy and sampling period on the mean error of the reconstructed daily time series of water levels.

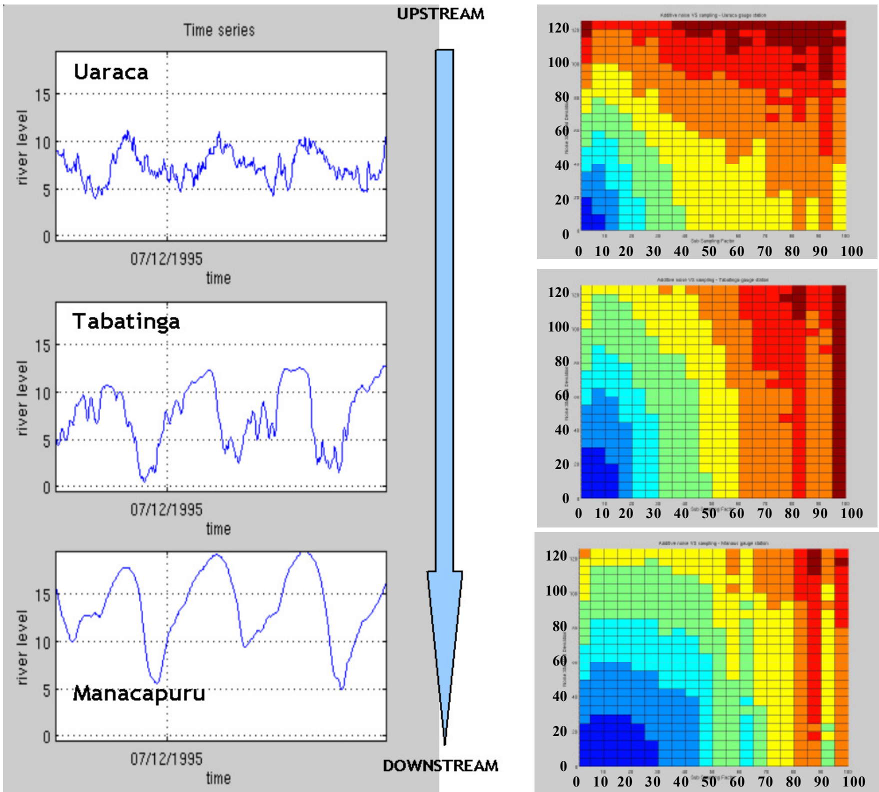


Figure I: Sensibility of the quality of river water derived from satellite altimetry to the coupled effect of both the sampling period and the measurements accuracy.

Sampling period	10 days	35 days
Measurement uncertainty (m)	0.60 m	0.00 m
	Error on reconstructed daily time series (m)	
Uaraca	0.5 m	0.6 m
Tabatinga	0.5 m	0.7 m
Manacapuru	0.5 m	0.2 m

Table 1 : Error on reconstructed daily time series at various hydrometric stations from two satellites with different sampling periods and measurement uncertainties.

- **Method for characterization of the quality of oversampled time series (reconstructed daily time series)**

In order to characterize the quality of oversampled time series of water levels derived from sampled radar altimetry measurements, it is possible to use the same methodology that was proposed in the previous chapter (3.2.).

Fig. J illustrates the results for Topex Poseidon 10 days sampling of Solimões river water level on track 63 using the "ocean type" waveform retracker, a 3.σ filtering technique and linear interpolation between the sampled measurements. Results appear to be poor, with a high uncertainty, as interpolation has generated additional errors, particularly in case of long periods without satellite measurement (low water stage).

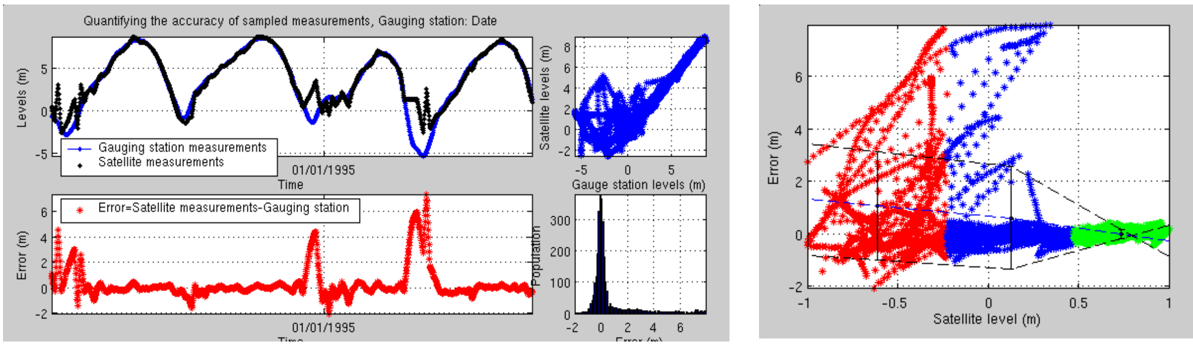


Figure J: Characterization of the quality of an oversampled (linear interpolation) daily time series of water levels derived from sampled radar altimetry measurements (Topex Poseidon, track 63 Solimões river).

Research efforts in numerous directions will allow drastic improvements in the quality of water levels time series derived from satellite radar altimetry : waveform retracking, filtering techniques, oversampling – interpolation techniques,… The quality assessment methodology that was presented here will help in quantifying these improvements and guiding the research efforts.

5. CONCLUSION & PERSPECTIVES

Recent research efforts have demonstrated the potential contribution of satellite radar altimetry for the monitoring of inland water levels. A key step for future research development consists in the characterization of the quality of radar altimetry water levels, as it will both guide researchers for the development of improved techniques (waveform retracking algorithms, filtering techniques,…) and help hydrologists to assess the added value they gain from these measurement. This paper has proposed a standardized methodology for quality characterization.

Characterizing the quality of radar altimetry water levels implies, as a first step, a clear **definition of data dispersion, data accuracy, data uncertainty and effective sampling frequency**. Such definitions were introduced and helped to emphasize the fact that dispersion of satellite measurements is in no way a measure their accuracy, and that data uncertainty can be significantly different from data accuracy when the measurement error is correlated with the water level.

Due to the fact that measurement error is not gaussian but structured in relation with the observed variable (water level) a global quantification of the measurement error (i.e. standard deviation) is not sufficient. A 3 stage approach (low water stage, medium water stage and high water stage) was designed that quantifies, for each stage, the mean error and standard deviation.

Hydrologist request daily time series of water levels that can be derived from radar altimetry measurements through interpolation (oversampling) techniques. The overall quality of reconstructed daily time series strongly depends on the value of the effective sampling period in relation with the river hydrology (frequency spectrum).

The methodology that was presented here to characterize the quality (accuracy, uncertainty, sampling frequency) of radar altimetry water level measurements and oversampled time series allows to provide time series of water levels with the corresponding uncertainty and to compare different satellite data sources or study cases (including various satellites, retracking algorithms, study sites, etc.). The next step will consist in applying this methodology to a large number of rivers and satellite data sets.

Further developments will address intelligent filtering methods (aiming at the detection of aberrant values), temporal interpolation methods (aiming at the construction of daily oversampled times series).

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