COMBINED USE OF HIGH RESOLUTION SATELLITE IMAGES AND ALTIMETRY TO ESTIMATE VOLUME OF SMALL LAKES

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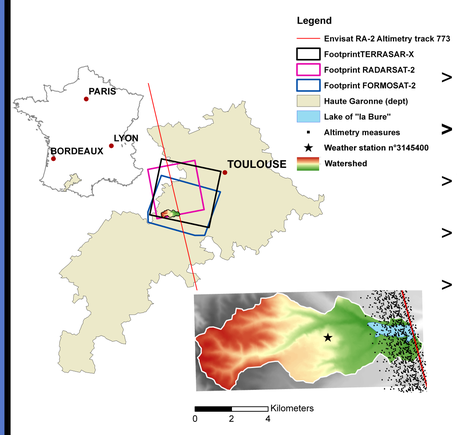
OBJECTIFS - CONTEXT

Global and systematic monitoring of water reserves, which are mostly used for irrigated agriculture (70% of world water consummation) are considered as a top prirority by international community (United Nations). With the increase of earth monitoring missions during the last decade and improvement of satellite sensors, monitoring and management of land particulary for agricultural purpose has become one of the most important research and application field in remote sensing.

The aim of this work, wich is in the **framework of the missions Sentinel 1-2-3 and SWOT** is to develop an approach to **estimate water volume of small lake (<100 ha) by combining satellite altimetry and high resolution imagery.**



STUDY AREA

> South West of France (43°24'54" N; 1°09'07" E)

> **Temperate climate** with a mean anual rainfall of approximatively 600mm.

> **Watershed of the lake (20.70km²)** : Not well marked relief (mean slope=2.8%)

> **Land use : Crops (41%)**, forest (24%) grassland (33%) and water bodies (2%)

> Study lake : - Theorical maximum extend of the lake : **52 Ha (4 million of m^3)**
- The charge of the lake is only due to rainfall events (no pumping in rivers).
- The discharge of the lake is mainly due to irrigation pumping (july-october).

(Baup et al., 2012a; Fieuzal et al., 2013)

DATA SET

> **Altimetry satellite data (65)** are provided by the **RA-2 sensor** onboard of Envisat (**one each 35 days since 2003**)
> **HR images** (**45** only during the year 2010 with R_{SPA} **<10m**) come from one optical satelitte (Formosat-2) and two Synthetic Aperture Radar (SAR) antennas (Terrasar-X and Radarsat-2)
> **In-situ data** (water volume) are provided by the lake manager **since 2003 (SIAH)**

HIGH RESOLUTION IMAGES *(Water surface)*

SAR Images (33)

SAR images are acquired by **TERRASAR-X (18) and RADARSAT-2 (15)** and characterized by pixel spacing of approximatively 3 and 5 m,respectively. All images are geo-referenced by using IGN ortho-photos (with a spatial resolution of 50 cm). The geo localisation accuracy is lower than 2 pixel (Fieuzal et al.,2013)

Optical Images (12)

Optical images **(12)** are provided by **FORMOSAT-2**. All the images are ortho-rectified using CNES ortho rectification tools. The cloud detection and atmospheric correction are also applied.

Satellite	Frequency/wavelength	Mode	Polarisations states	Range of incidence angle
RADARSAT-2	C-band (*f*=5,405 GHz)	FQ	HH,VV,VH,HV	23° to 41°
TERRASAR-X	X-band (*f*=9,65 GHz)	SM / SL	HH	27° to 53°
FORMOSAT-2	: 0,44-0,90 µm	Multi-spectral	-	± 45°

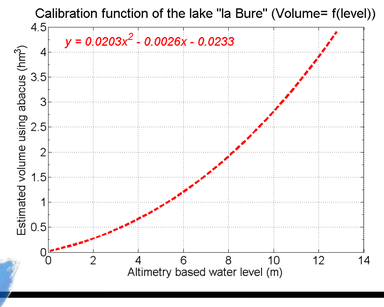
LAKE AREA EXTEND FROM SATELLITE IMAGERY

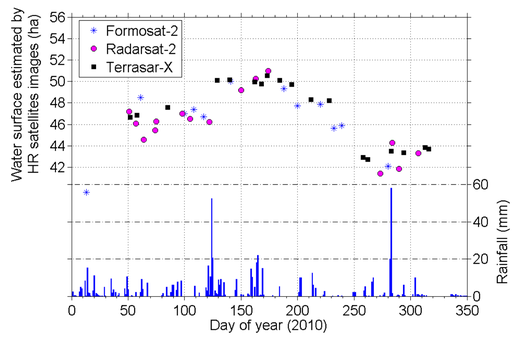
LAke area extend come from an **automatic parallelepiped classification (using ENVI software)**. Water surfaces are then vectorized and transformed to shape file. At the end, values of water surface are determined by using a **GIS software (ArcGIS)** for each acquisition date.

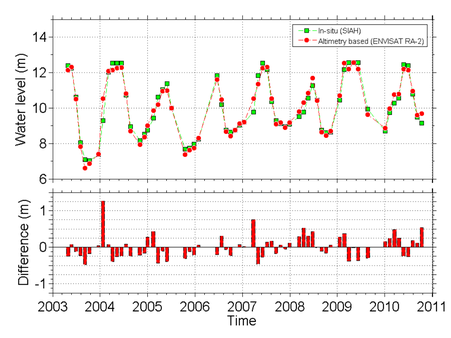
(Baup et al., 2012b)

IN SITU-DATA *(Water volume)*

Ground data	Dates	Sampling frequency
Lake calibration function (abacus)	1987	-
Bathymetric draw	2010	-
Water level	since 2003	Weekly
Rainfall	since 2006	Daily







ALITIMETRY DATA SELECTION *(Water level)*

The principle of radar alimetry is the following : the **altimeter emits a radar pulse and measures the two way traval time from satellite two the surface.**

$$h = H - R - C$$

h : the height of reflecting surface (water level here)
H : the satellite altitude referred to an ellipsoide
R : the distance between the satellite and the Earth surface
C : the sum of several corrections for delayed propagation through the atmosphere and solid or solar tides

An **altimetry station**, wich is the **equivalent** of an in situ **water level gauge** can be defined at each intersection between a lake, a river or a foodplain and the satellite ground track. In this study The Virtual ALtimetry Sation (VALS software is used to derive time serie of water level over the lake from Envisat RA-2 data from February 2002 to October 2010. **The processing of altimetry data using VALS is composed of three main steps :**

(i) A **coarse selection of the altimetry data** over the water body contained in a polyline using Google Earth is achieved,

(ii) **A refined selection of the valid based** on the visualization tool from VALS is performed to remove outliners and eventually to correct from hooking effects,

(iii) The **time-series of water levels is computed** using the median value of all valid altimetry based water levels for each cycle.

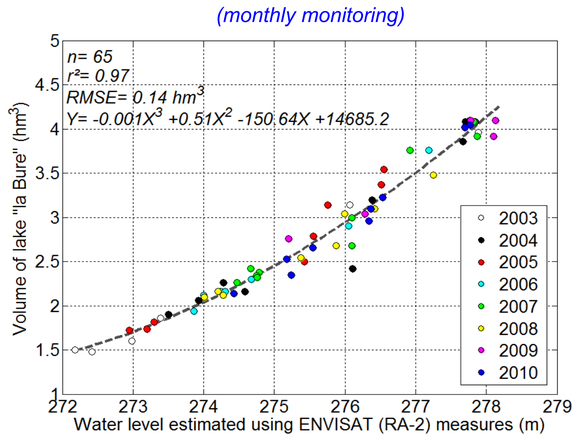
(Frappart et al., 2006; Santos da Silva et al., 2010)

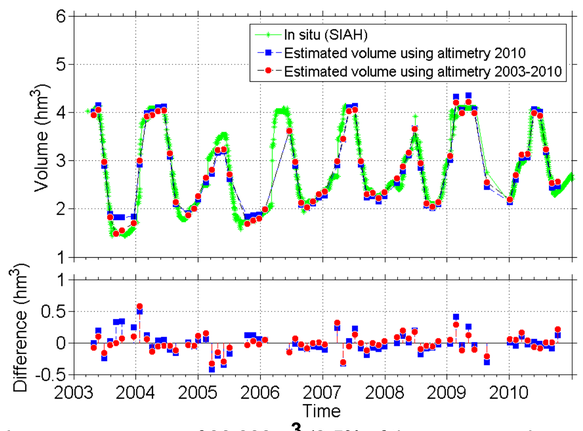
METHODOLOGY AND RESULTS

Three independent approaches are considered to **estimate the volume of the lake and its temporal variability**. The first two are empirical and involve **using synchronous ground measurement of volume and satelite products**. The third consist in **combining only synchronous satellite products** (altimetry for level of the lake and HR images for surface of the lake) to estimate a change of volume during time-lag between two couples of satellite'measures.

SATELLITE AND IN SITU DATA *(water volume stored)*

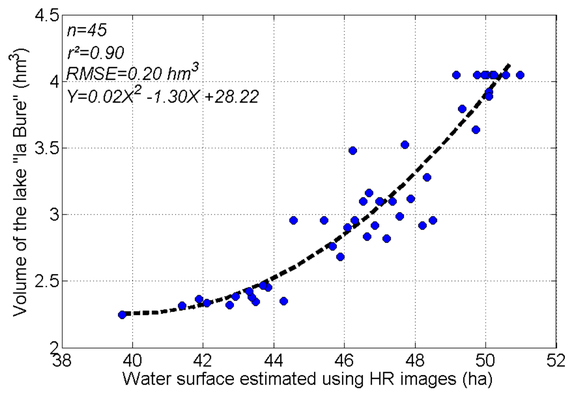
ESTIMATION OF LAKE'S VOLUME FROM ALTIMETRY *(monthly monitoring)*

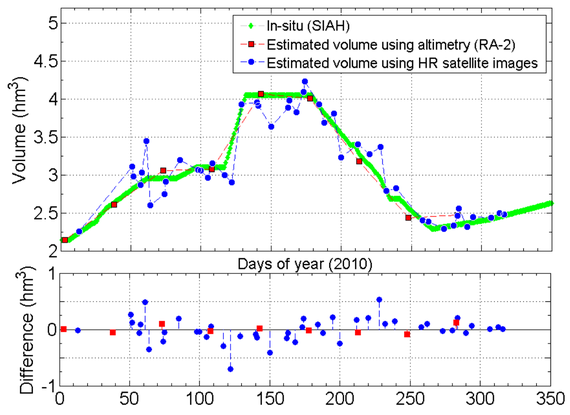




> Average accurancy of **90 000m³** (**3.5%** of the average volume of the lake)
> Higher accurancy is higher than **300 000m³ (11%)** in 90% of the measures between 2003 and 2010

ESTIMATION OF LAKE'S VOLUME FROM HR IMAGES *(weekly monitoring)*



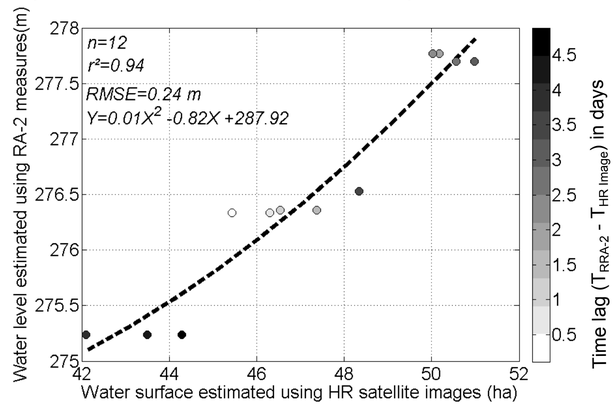


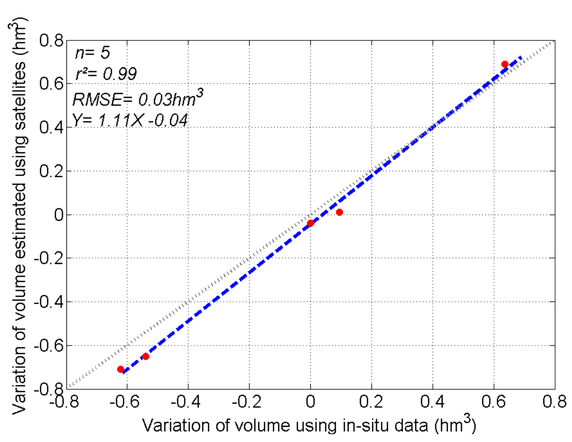
> Average accurancy of **200 000m³** (**7.4%** of the average volume of the lake)
> Accuracy is higher than **500 000m³ (16.6%)** in 96% of the measures in 2010

SATELLITES DATA ONLY *(variation of the available water volume)*

COMBINED USE OF HR IMAGES AND ALTIMETER DATA

> Time delay between combined acquisitions < 5 days





> **High average accuray of 30 000 m3** (i.e. **8%**) of the average water volume variation beween two dates of measurement during the year 2010

CONCLUSION

This study demonstrates the potential of monitoring the water volume variation over **small lakes** (< 100 ha) in strongly anthropised area, by using **satellite data**. Three different approaches combining **synchronous multi-satellite data and/or in situ measurement** were proposed. According to the results, they all provide reliable estimates of water volume changes, with an average accuracy **better than 7.4%**.

Thus, this study which is in preparation of mission Sentinel 1-2-3 and SWOT shows the potential of HR images and Altimetry products to well reproduce water variations of small lakes. It is real opportunity to extend the use of satellite data to manage small water bodies during the future dedades, according to the characteristics of future satellite sensors (high spatial and temporal resolutions...).

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