VOLUME CHANGES OF LAKE BRACCIANO DURING THE SENTINELS ACQUISITION PERIOD

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ABSTRACT

Lakes and reservoirs are considered sentinels of climate and anthropogenic changes. Lakes and reservoirs surface water storage is an essential hydrological variable but poorly known as this information is scarce. Earth Observation data are a reliable source of information to overcome this scarcity. Among these, the combined use of satellite images, to derive water extent, and radar altimetry, which enables to estimate water levels, provides valuable information on water storage changes. Here, we used Synthetic Aperture Radar images from Sentinel-1 and radar altimetry data from Sentinel-3 to monitor the water volume changes of Lake Bracciano from 2016 to 2021. This lake was affected by a water crisis in 2017 and the water supply to the city of Rome (Italy) was interrupted September 2017 to preserve its ecosystem. Hence, we demonstrate how Sentinel-1 and Sentinel-3 data can be useful to monitor water extent and level, which can be profoundly changed by the climate crisis.

Index Terms— Lake, water level, altimetry, SAR

1. INTRODUCTION

Lakes and reservoirs play an essential role in the global hydrological and biogeochemical cycles as well as for socio-economic activities such as water supply, irrigation, hydropower generation, aquaculture etc [1], [2]. Despite the importance of monitoring lakes and reservoirs water storage, these data are scarcely available either due to the cost of installation and maintenance of the gauges or due to dissemination issues [3].

Remote sensing techniques are unique tools providing reliable information on both water stages and lake extent, and hence water storage [4], [5]. Satellite altimetry provide accurate water levels (e.g., [6]) while satellite images allows a precise estimates of lake extent (e.g., [7]). Their combination gives access to temporal changes in water storage [8], even for small lakes [9].

In this study we apply these techniques for the monitoring of changes in water stages, extent, and storage of Lake Bracciano, which experienced a severe decrease in water storage in 2017 using Synthetic Aperture Radar (SAR) images from Sentinel-1 and radar altimetry data from Synthetic Aperture Radar Radar Altimeter (SRAL) onboard Sentinel-3

2. STUDY AREA AND DATASETS

2.1. Lake Bracciano

Lake Bracciano (42°07′16″N 12°13′55″E), located 32 km northwest of Roma, in the Latium area, Italy, is a sub-circular volcanic lake (Figure 1). Its mean area is 57.6 km² for a total volume of 5.13 km^3, a maximum depth of 165 m [10]. It has been subject to a severe water crisis in 2017 related to an excessive abstraction for human consumption and low precipitation coupled with high evaporation in the 2 preceding years [11].

2.2. Sentinel-1 SAR images

Sentinel-1A and B, developed by the European Space Agency (ESA) have been acquiring SAR images in C-band at VV and VH polarizations since 2016 and 2018, respectively. The images used in this study were acquired in Interferometric Wide-swath (IW) with a 10 m Ground Sampling Distance (GSD) in Ground Range Detected (GRD) format.

2.3. Sentinel-3 radar altimetry data

SAR altimetry data from Sentinel-3A, launched in April 2016, were used to estimate the water level of the lake. The altimeter ranges derived from the Offset Center of Gravity (OCOG) [12] were chosen for lake stage estimates as they provide accurate levels over inland water bodies [13]. These data were made available by Centre de Topographie des Océans et de l'Hydrosphère (CTOH): http://ctoh.legos.obs-mip.fr.

2.4. In-situ water levels

In-situ water levels from Lake Bracciano were provided by the Bracciano Smart Lake at: https://braccianosmartlake.com/rilevamento-quota-lago/.

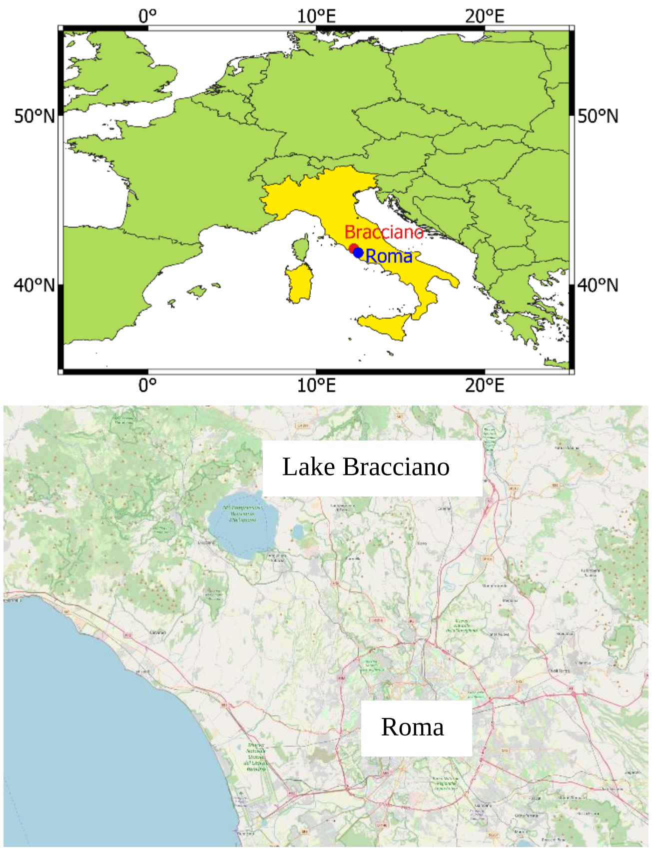

Figure 1: Lake Bracciano (red dot) is located northwest of Roma (blue dot) in Italy (yellow) (top panel). It is a quasi-circular volcanic lake (bottom panel – Open Street Map).

3. METHODS

3.1. SAR images preprocessing

The Sentinel-1 SAR images were pre-processed using VtWeb is an open platform developed by VisioTerra and accessible at https://visioterra.org/VtWeb/. The pre-processing is composed of the following steps: orbit correction, thermal noise removal, γ^0 calibration, terrain correction and speckle filtering. See [14] for more details.

3.2. Lake area estimate

The same approach as the one proposed by [15] to create a land water mask is applied here. A k-means unsupervised clustering technique [16] is applied to each SAR image. As open water surfaces are characterized by a low backscattering (Figure 2), the cluster with the lowest centroid is considered to correspond to the lake surface pixels, from which lake area is estimated. By isolating this cluster an initial water mask is obtained. An active contouring process is then applied to the water mask in order to improve its accuracy.

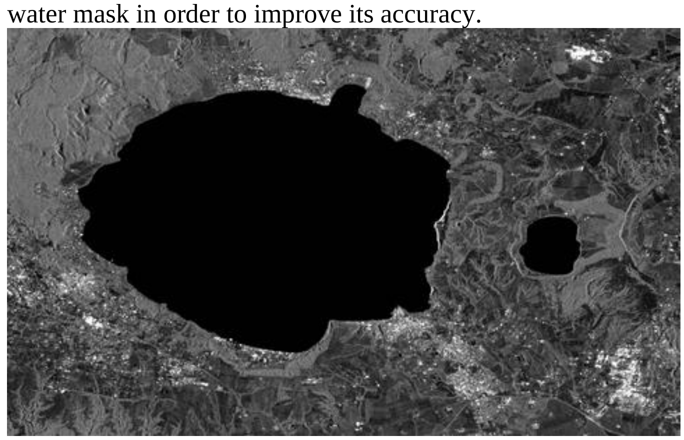
Figure 2: Average of 26 SAR images of Lake Bracciano from Sentinel-1 acquired from 01/01/2016 to 31/12/2018 at VV polarization.

3.3. Time-series of water level

The time-series of water level of Lake Bracciano was generated from the Altimetry Time-Series (AlTiS) software, which is dedicated to the processing of radar altimetry data over land surfaces [17]. It allows to select valid radar altimetry data over rivers and lakes and compute the time series of water levels using the median of the valid measurements of each cycle. This software is made available by CTOH.

3.4. Lake volume estimates

The water volume variations (ΔV) of Lake Bracciano are estimated assuming a regular morphology of the lake and a pyramidal shape as in [5], [18], [19]:

$$\Delta V = \frac{(h_t - h_{t-1})\left(S_t + S_{t-1} + \sqrt{S_t S_{t-1}}\right)}{3}$$

Where h and S are the lake level and its extent, respectively, at consecutive time steps t and t-1.

4. RESULTS

The altimetry-based time-series of water levels of Lake Bracciano was estimated using AlTiS from March 2016 to November 2021. It was compared to the in-situ gauge record from June 2017 to December 2018. Very good agreement was obtained over the 19 pairs of concomitant water level values (RMSE = 0.07 m and R = 0.92). These results are of similar quality as the ones obtained in other validation studies performed over lakes using Sentinel-3 data (e.g., [6], [17]).
The Sentinel-3A-derived time-series of water levels of Lake Bracciano exhibits a strong drop of ~1.6 m between May 2016 and November 2017. It is followed by an increase of the water levels of ~1.3 m with a maximum reached in May 2021. This positive trend is modulated by a strong seasonal signal characterized by maxima occurring between end-April and mid-June, in the second half of spring, and minima occurring at the end of the summer and the beginning of fall, between September and early November.

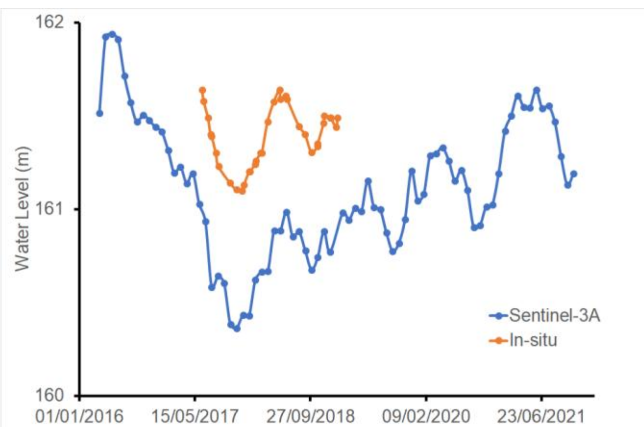

Figure 2: Time-series of water level of Lake Bracciano using Sentinel-3A data (blue) and in-situ gauge records (orange).

5. FUTURE WORK

The results presented here are only preliminary. The comparisons between the altimetry-based water levels and the in-situ gauge records will be updated for the IGARSS 2022. SAR images from one Sentinel-1 orbit were preprocessed from 2014 to the end of 2021. They are currently under processing for estimating surface water extent. Early results are very encouraging as the standard deviation (std) of the series of 26 Sentinel-1 SAR images at VV polarization from 01/01/2016 to 31/12/2018 exhibits high values over the lake and especially close to the shore. Over the lake, the high std values are due to changes in roughness during the observation period caused by variations in the wind intensity and direction. Close to the shore, the high variations of the std are related to change in water extent causing a change in the land cover in some areas where the pixels correspond sometimes to land and other times to open water (Figure 3).
Once this step performed, lake extent will be estimated as well as surface water volume changes. Using the bathymetry of the lake, we will be able to assess the accuracy of our estimates. Surface water volume changes will be compared to the lake water balance using in-situ rainfall data and a modeling of the evapotranspiration based on in-situ temperature. The two quantities will be compared and the difference attributed to abstraction.

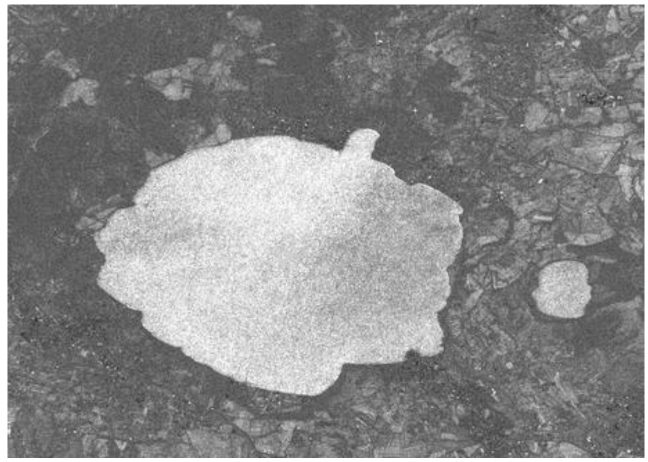

Figure 3: Std of 26 SAR images of Lake Bracciano from Sentinel-1 acquired from 01/01/2016 to 31/12/2018 at VV polarization.

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