Automatic Monitoring of Water Level in Small Lakes Using Planetscope

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AUTOMATIC MONITORING OF WATER LEVEL IN SMALL LAKES USING PLANETSCOPE

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ABSTRACT

Global water storage monitoring is often done using remote sensing to solve the problem of missing gauge station. Moreover, this information is very often not available to the public even when a measure station is available. The methods usually used are however often unpractical for small lakes, often require images that are costly or difficult to acquire (for example SAR images of sufficient resolution) or with a bad revisit time. In this paper we propose an automatic method for visible satellite images based on a precise tracking of shoreline. It uses bathymetry information of the lake when available but we also present different alternatives that still produce precise estimations. The method is applied to accurately track the water volume of lake of La Bultière in 2019 using only PlanetScope images.

***Index Terms*—** reservoir, lake, PlanetScope, water level

1. INTRODUCTION

Water storage is becoming very important to fight more and more frequent droughts. Monitoring of these water resources is very important to know how much water is available at any time and to be able to allocate the optimal amount to each need such as consumption, industrial or farming, without risking a shortage. Keeping track of the amount of water stored is very difficult. While the differential of water simply corresponds to the difference between the inflow and the outflow, both of them are particularly difficult to estimate due to the many parameters that need to be taken into account and their wide variety (*e.g.* precipitation, river inflow, evaporation, withdrawals, infiltration, river outflow *etc.*). This is why direct measurements of water volume are prioritized in practice.

Traditionally, gauge measurements have been used for onsite measurements. However, these measurements are becoming more and more scarce [1, 2], either because there is no measure station available (especially in developing countries) or because the information is not publicly available. This is why space agencies have started programs to encourage the development of remote sensing technologies for a global monitoring of water surface (NASA in 1999 with the "Terrestrial Hydrology Program" and CNES in 2003 with the "Hydrology from Space" workshop [3]).

In this paper, we propose a water volume estimation for small lakes using PlanetScope images (and requiring only the R, G, B bands since NIR is not always available). The water level is estimated by tracking the shoreline and the water volume is derived from this information. The method is automatic in the sense that it only requires a calibration step (which might require manual information based on the setup, this will be detailed in the methodology Section) before being completely automatic.

We discuss previous work on lake volume estimation in Section 2 and present the method in Sections 3 and 4. In Section 5, we apply the method on the lake of La Bultière where recent ground truth data is publicly available. We conclude in Section 6.

2. RELATED WORK

Both [4] and [5] present water level estimation methods based on radar altimetry. The water surface is estimated by thresholding the MNDWI index with a manually chosen threshold. Cretaux *et al.* [2] made a review of different altimetry based methods, comparing the accuracy of the different methods as well as using data from different satellites.

In [6], Ogilvie *et al.* presented a semi-automated method for very small lakes (1 to 10ha). They provided a detailed analysis of different water indexes with fixed or variable thresholds and compared them to GPS contours. They showed that while the error is larger on very small lakes, MNDWI seems to perform well when there are no clouds.

Alsdorf *et al.* [7] suggest an alternative method to altimetry. It requires two SAR images with subpixel registration. The phases are then substracted to produce interferometric data. It uses the property that radar pulses scatter over water so the coherence is very poor therefore water can be detected in the interferograms. More recently, Alexakis *et al.* [8] showed that a similar approach can be used to measure the volume of small lakes in Greece.

Melack and Hess [9] suggest to track water level changes by classifying pixels based on the different radar response us-

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ing all four polarizations HH, VV, VH and HV.

Feng *et al*. [10] proposed a gradient method to separate land from water using the FAI, floating algae index, after atmospheric corrections. They applied their method with MODIS to estimate the filling of the lake of Poyang. The water/land boundary is used as a bathymetric isobath to derive the volume since the bathymetry is known.

We can see that these methods are either not suited for smaller lakes (altimetry based methods) or require radar information which is costly to acquire. That is why we propose a method based on PlanetScope images. PlanetScope has a good enough image GSD (3m$\times$3m) to be able to work on smaller lakes and has a daily revisit. Since the NIR band is often not available with these images, the proposed method does not require this specific information. Moreover some of these methods require user input for the estimation, making them unsuitable for automatic monitoring. For that reason, the proposed method does not require any user input for the estimation thus making it completely automatic.

3. METHODOLOGY

In this section, we assume that the bathymetry information is known in the form of a digital elevation model (referred as DEM in the following). We discuss alternatives in Section 4 when this rare information is not available.

Preprocessing. The first step consists in removing cloudy images. Indeed, clouds block the visibility in R, G, B bands making it impossible to do accurate estimations. It has also been shown that PlanetScope images have uneven quality [11] so a good preprocessing can consist in removing low quality images as proposed in [11]. We then align the images with the DEM. For that we co-register all the images using [12] before aligning the DEM. We resample the DEM at the resolution of the PlanetScope images if necessary.

Shoreline detection. We propose to use a line segment detector to detect the shoreline. These methods are now very precise with subpixel detection and are robust to degradation (*e.g*. noise). Our shoreline detection step is based on the unsupervised subpixel contour detection method from Grompone and Randall presented in [13]. First the high frequencies of the image are extracted by difference of Gaussians. Then, using an arc operator, the region of the image where the values of the pixel on one side are much larger than the ones on the other side are found. A contour is defined as such a region. Once such a contour has been estimated, the probability of appearance of this contour in noise is computed. When the probability is low enough, the contour is said to be detected. The probability is selected so that the number of false alarms is 1. We refer to [13] for more details about the method, and especially how a practical implementation can be made. One of the main advantages is that the method is completely automatic (without any parameter) and robust.

Since the original method is very generic, we modified

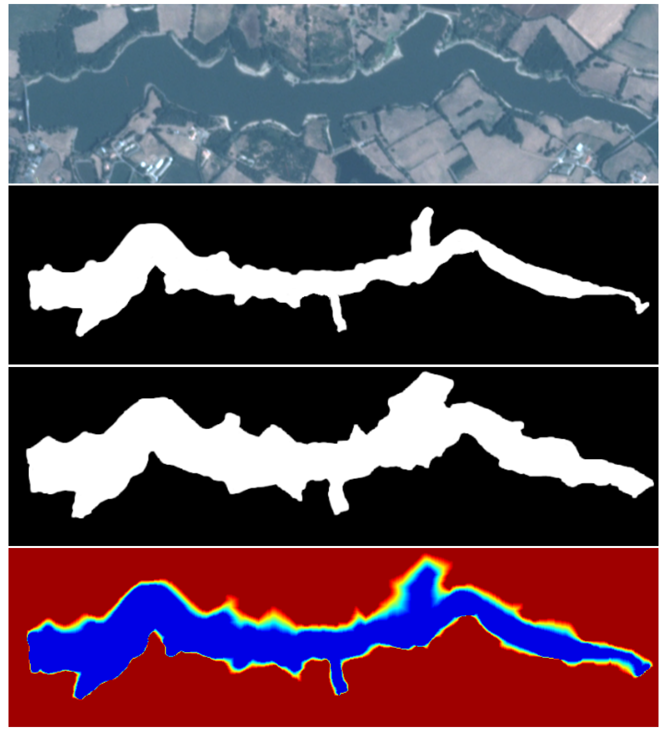

Fig. 1. From top to bottom: An example of a PlanetScope image of the lake of La Bultière, the mask corresponding to the empty lake surface, the mask of the surface of the filled lake, the DEM estimated using the two masks and the method presented in Section 4.

it to get only one single contour, corresponding to the most probable shoreline, at the end of the estimation process. In order to do so, we modified the criterion that considers a contour valid by adding a condition on the length of the boundary. Indeed, we expect the shoreline to be long, ideally the size of the entire region. However, we have seen in practice that these contours can be detected multiple times in a single region. This is because the water might leave temporary marks after a change of volume. In that case both the previous and the current shorelines are detected. Therefore we only keep the shoreline that is the lowest according to the DEM. Indeed, these wrong detections are only possible above the current water level. Therefore, the accurate shoreline is the one at the lowest height.

Volume estimation. Once the shorelines have been estimated for each region independently, we can compute the volume of water inside the lake. Given that the DEM is already aligned with the image and at the same spatial resolution, we have a height for each point of the shoreline. For each shoreline, we compute the median height. This is then used to discard unreliable measurements. For example the cloud detector is not perfect and can miss clouds that would still disturb the measurement. The final estimated height is then computed using the combined information of all valid shorelines.

4. ACQUISITION OF THE BATHYMETRY INFORMATION

As seen in Section 3, the bathymetry information is very important to derive a volume estimation from the shoreline position. In this section we present different alternatives when the bathymetry information is not available. All these alternatives are either based on remote sensing or simple mathematical modeling.

Remote sensing. The most simple way to acquire an accurate DEM is to use lidar acquisitions. Creating the DEM from the lidar 3D point cloud simply requires projecting, and, if necessary, resampling and interpolating the lidar information into a 2D map at the corresponding spatial resolution. Another option consists in performing a 3D reconstruction of the lake using a stereo acquisition. Some satellites, like SkySat, can be tasked to perform acquisitions of such stereo pairs. The 3D reconstruction is then performed using a specific tool such as S2P [14]. Similarly to lidar, the reconstruction yields a 3D point cloud that then needs to be projected using the camera model. The main limitation of the two previous methods is that the acquisitions must be done when the lake is empty. An acquisition done while the lake is not empty will only provide information on the regions that were not submerged at that time. This information can still be sufficient if the lake was empty enough.

Relative model. When both lidar and 3D reconstruction are unavailable, we can still estimate a relative model thanks to manual annotation. In that case, absolute volume estimations will only be possible using external information such as the maximum volume of the lake. In order to make such a relative model, we require a mask of the minimum area of the lake (corresponding to the minimum height of the water) and a mask of the maximum area (corresponding to the maximum height). We can then assume that the lake has the shape of a truncated cone, so we can generate automatically a DEM spanned by the two annotated areas. The relative volume V associated to the lake is then

$$V = \frac{\mathcal{A}_1 + \mathcal{A}_2 + \sqrt{\mathcal{A}_1 \mathcal{A}_2}}{3} h \tag{1}$$

with $\mathcal{A}_1$ and $\mathcal{A}_2$ the minimum area and the maximum area respectively and h the relative parameter. Since $\mathcal{A}_1$ and $\mathcal{A}_2$ are given by the manual annotation, h can be derived from external information such as the maximum volume of the lake. When no external data is available, h is set to 1 and relative height and volumes are computed.

5. RESULTS

We apply the proposed method to monitor the lake of La Bultière. The lake of La Bultière is a fresh water reservoir in France regulated by a dam. Its purpose is to supply fresh water to nearby towns. It is thus important to monitor the amount of water stored in it, in case of drought. We compare the estimation of the volume computed with our method with the ground truth data provided publicly by the organization managing the reservoir *Vendee eau*[1]. This organization provides publicly a weekly measure of the volume of water inside the lake. Since bathymetry information, lidar, or a 3D model were not available, we decided on using the relative model presented in Section 4 that we calibrated using publicly available information of the lake.

Fig. 2. The three regions of interest (in red) where the volume estimation is done. Measurements are estimated independently from these three regions and only then combined for the final estimation.

Figure 1 shows an example of a good PlanetScope image used for the estimation. We also show in that Figure the two masks used for the synthetic DEM estimation as well as the synthetic DEM generated for this lake. Based on this DEM, we selected three regions of interest where we think the method will be the most precise. Figure 2 shows the three regions of interest.

We plot in Figure 3 the evolution of the water volume of the lake. The proposed method, in purple, is compared to the ground truth, in green. As it can be seen, the estimation is very close to the ground truth. We can also see the effect of seasonality on this plot. Indeed, during winter, the images have a worse quality on average than during summer and thus yield less precise estimations. We can also see that the method suffers from lack of good images during some extended periods. In our case there were no images available for the periods from mid April to the end of June and from mid October to mid November. This is mainly due to either a poor image quality (very blurry) or to clouds covering the entire lake even though PlanetScope provides a daily revisit frequency. For this reason, we suggest coupling this method, which potentially has a daily revisit frequency, with another method that does not suffer from the presence of clouds, with a lower revisit frequency.

6. CONCLUSION

We presented an automatic water volume estimation for lakes and reservoirs, based on an accurate and robust shoreline

[1] https://www.vendee-eau.fr/index.html

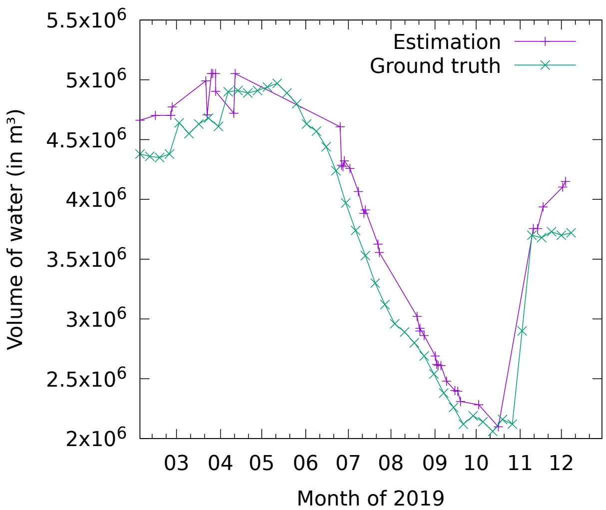

Fig. 3. Evolution of the volume of water inside the lake of La Bultière during the year 2019. Our estimation is very close to the ground truth and uses only R, G, B bands from PlanetScope imagery.

detection. It is able to produce accurate estimations, even on lakes that are too small (namely smaller than 1km²) for altimetry-based methods, and only requires visible information. It is thus particularly adapted to the PlanetScope constellation (it can however be used with any satellite with visible bands). We argue that this method can be combined with others (*e.g.* SAR-based methods or multispectral methods using NDWI) that usually have a longer revisit time: this allows to avoid long periods without any estimation, as well as to improve the estimation quality by combining different independent methods.

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