Water Extent Measurements with Sentinel-6 Fully-Focussed SAR data

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This study explores the capability of Fully-Focussed SAR (FF-SAR) processing in mapping inland water targets. FF-SAR processed Sentinel-6 data have been analyzed with the aim of monitoring the water coverage of the designated areas of interest, for off-nadir targets located within certain observation limitations.

The Sentinel-6 mission, launched in November 2020, carries a radar altimeter operating in open burst with a PRF high enough (~9kHz) to perform the focussing of targets in a fully coherent way, improving the along-track resolution down to the theoretical limit of around 0.5 m when processing the data with a Fully-Focussed SAR (FF-SAR) algorithm [1], far greater with respect to the ~300 m along-track resolution provided by operational processors based on Unfocussed SAR algorithms, commonly used in radar altimeters with a closed burst chronogram, such as CryoSat-2 and Sentinel-3.

A FF-SAR Ground Prototype Processor (GPP), developed by isardSAT and based on the backprojection algorithm, has been used to generate altimetry data FF-SAR radargrams of off-nadir inland targets, such as reservoirs or lakes, located within certain observation constraints. As a main outcome, we present a methodology to geo-reference and estimate the extent of water bodies located on unambiguous across-track targets and that present strong seasonal extension variability. Validation has been performed by comparing the FF-SAR water extent against optical and in-situ observations.

Targets

The dataset covers two case studies with targets of different water extent variability and distance from the Sentinel-6 ground tracks (tracks 035 and 248 respectively).

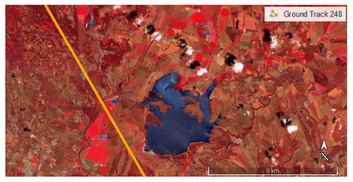

Fig. 1: *Tormos reservoir - observed from the 248 track, Sentinel-2 false colour layer from 02/06/2021. Source: Copernicus Sentinel data 2021 and Google Earth.*

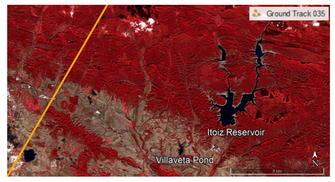

Fig. 2*: Itoiz reservoir - observed from the 035 track, Sentinel-2 false colour layer from 10/11/2021. Source: Copernicus Sentinel data 2021 and Google Earth.*

TORMOS

Located in Huesca, Aragon, Spain, is a complex inland water system, composed of size-variable lakes, small ponds and rivers, almost all of which are situated on the same track side, approximately one kilometre from nadir.

The water extent size changes considerably over the course of the year, reducing to approximately 40% of its maximum, making it an excellent case study to track water extent variability.

ITOIZ

Located in Navarra, Spain. Including the Itoiz, Nagore reservoirs and the Irati river. The Irati and Nagore back scattered power do not lay within the limits of the system range window and, consequently, cannot be captured.

Itoiz reservoir is approximately 10 km away from nadir.

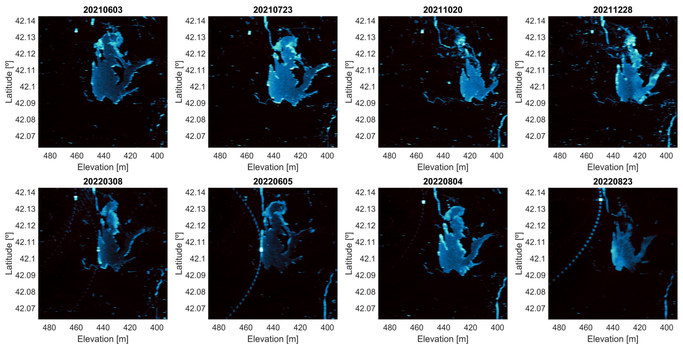

Fig. 5a: *Tormos FF-SAR processed radargrams from 03/06/2021 to 23/08/2022.*

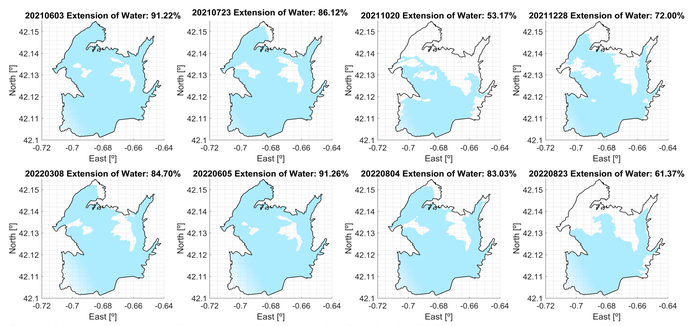

Fig. 6a: *Estimated Tormos Water Extension from 03/06/2021 to 23/08/2022, using FF-SAR data processed with the isardSAT processor.*

Methodology

FF-SAR processing produces a radargram with dimensions in slant range and azimuth directions (Fig. 5a and 5b). Across track samples are aligned and projected to ground range dimensions with respect to the associated in-situ water level measurement, achieving a geometrically realistic image, with coarser ground range resolution closer to nadir. Radargram pixels are georeferenced with the corresponding azimuth position and ground range distance from the subsatellite track, producing an image in geographic coordinates (Fig. 3).

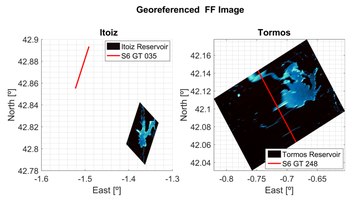

Fig. 3: *Itoiz and Tormos reservoirs, georeferenced in geographic coordinates.*

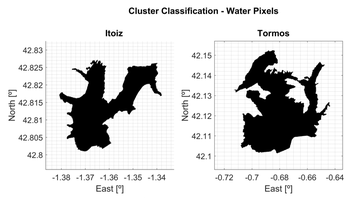

Fig. 4: *Binary mask of Itoiz and Tormos Reservoirs, classified using K-means clustering.*

Post-processing techniques have been implemented to enhance the water and land contrast before classification. Unsupervised K-means clustering is applied to partition the image, classifying pixels based on similarities in shape or intensity, to identify water pixels and land pixels (Fig. 4). Due to the degradation of the ground range resolution near nadir, a mask from the OpenStreetMap geographic database is applied. This mask describes the extension of the target, limiting waveform distortion and outliers.

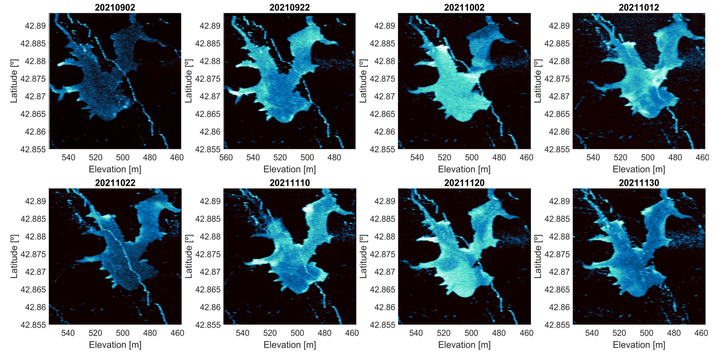

Fig. 5b: *Itoiz FF-SAR processed radargrams from 02/09/2021 to 30/11/2021.*

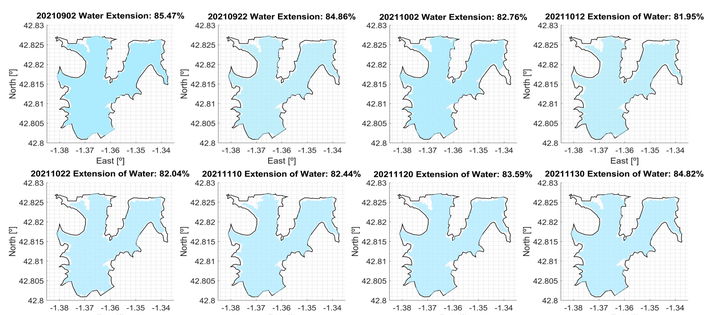

Fig. 6b : *Estimated Itoiz Water Extension from 02/09/2021 to 30/11/2021, using FF-SAR data processed with the isardSAT processor.*

Results

In **Tormos,** the FF-SAR water extent results match the in-situ and optic data quite accurately, with an error of about +/- 9% (Fig. 6a). This error is likely due to the larger proportion of the pixels that will be closer to nadir and therefore have a coarser resolution, reducing the precision of the data, and to the presence of wetlands that are classified as water (false positives). The apparent discrepancies between the in-situ and optical data when the reservoir is full are due to certain areas of flooded vegetation being misclassified as non water in the NDWI products.

Itoiz is a fairly stable basin with no significant changes in water extent throughout the whole monitored period. The resolution degradation is much lower in the FF-SAR products because of the distance of the reservoir from nadir. Consequently, the estimation of the water surface is more accurate, yielding measurements that coincide with the optical products with an error of just +/- 3% (Fig. 6b). As only a partial area of the reservoir is being estimated, in-situ data can not be considered.

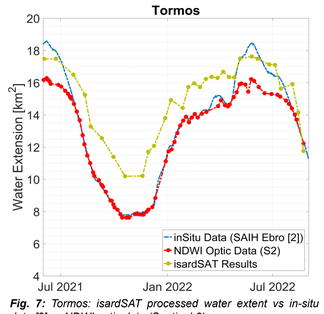

Fig. 7: *Tormos: isardSAT processed water extent vs in-situ data [2] vs NDWI optic data (Sentinel-2).*

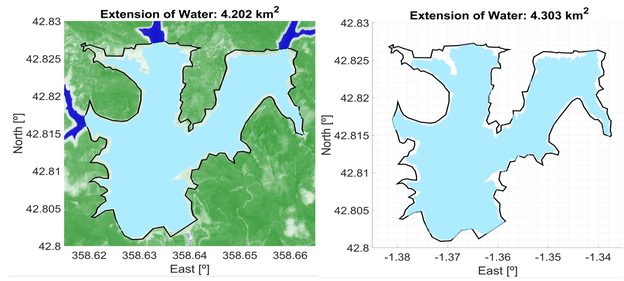

Fig. 9 : *Itoiz comparison between optical (31/08/2021) and FF-SAR (02/09/2021) products.*

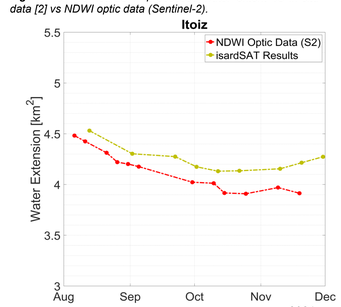

Fig. 8: Itoiz*: isardSAT processed water extent vs NDWI optic data (Sentinel-2).*

Conclusions

- Like all SAR methods cloud coverage is not an issue, meaning consistent, continuous measurements can be taken.
- The vastly improved resolution of the FF-SAR method allows good accuracy when measuring the water extent. Accuracy for lakes further off track will be even better considering that the ground range resolution will allow for computation of the water extent with more precision.
- Results are promising, already achieving precision within 3% in off track targets not affected by vegetation areas or wetlands.
- As long as the signal from the water body is within the receiving window, we can either measure the water surface elevation of nadir targets or provide the off-nadir targets water extent.
- The difficulty of identifying off-nadir spots within the limits of the system range window, even in areas with any nadir targets of interest, considerably restricts the number of observable targets. Adjusting the window to include off-nadir targets in certain regions would increase the number of water areas that can be tracked and improve the trade-off between off-track distance and resolution.
- Even when not the entire body of water is captured, partial regions can still be tracked.

References

[1] Egido, Alejandro and Walter H. F. Smith. “Fully Focused SAR Altimetry: Theory and Applications.” IEEE Transactions on Geoscience and Remote Sensing 55 (2017): 392-406

[2] Confederación Hidrográfica del Ebro. http://www.saihebro.com

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