# Regional cal/val at multi-locations

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## Motivation

Innovative remote sensing information merged with in-situ data provide a two-dimensional surface water level which is denser and more accurate than previously. This is possible with the new generation of satellite altimetry since 2016 that includes Delay Doppler, laser and bistatic altimeter techniques.
Starting from a study at the Onsala Space Observatory we show examples where in-situ and space observations are merged in calibration/validation and scientific studies.
SWOT is the first satellite able to connect water level from lakes to the sea through rivers, estuary and coast. In view in the increasing risks of flood and inundation due to climate change and sea level rise, these observations are useful to coastal and inland communities for mitigation projects.

## Methods and Data

Fully-focused SAR (FFSAR) altimetry with Omega-kappa (WK) algorithm and SAMOSA+ waveform retracking (Guccione et al., 2018, Dinardo et al. 2020), posting rate of 80/140 Hz enhance resolution of SAR altimetry to monitor coast and small water bodies. We use Raster in coast and lakes, PICX in rivers.

## Monitoring coastal water level

SWOT has an accuracy vrs in-situ higher than nadir-altimetry at 2 km from coast and observes the water surface in two dimensions. At the Onsala Space Observatory (OSO) a geodetical network of GNSS-R and tide gauge instrumentats connect land and coastal WSE.

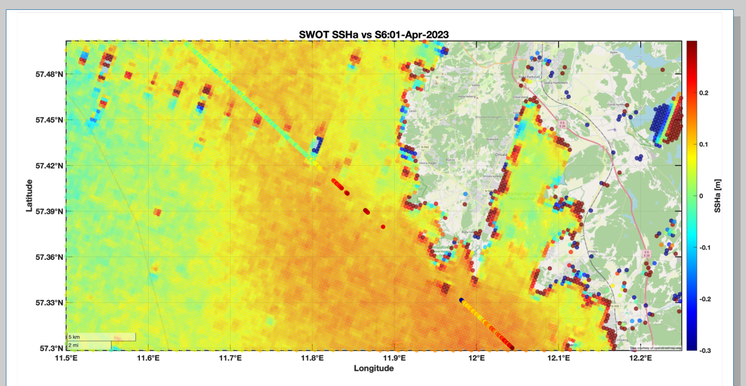


Fig. 1 SWOT L2 HR and Sentineel-6 A water level

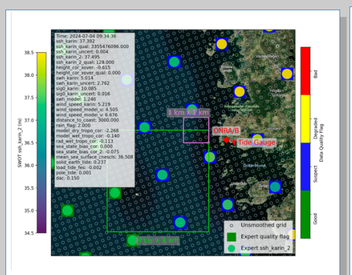


Fig. 2 SWOT SSH L2

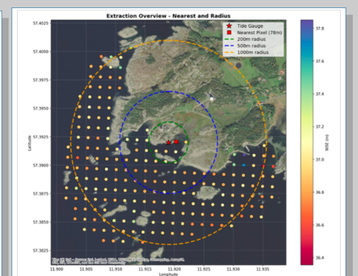


Fig. 3 SWOT raster

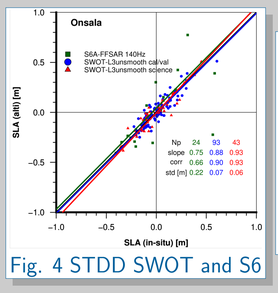


Fig. 4 STDD SWOT and S6


Fig. 5 SWOT SSH LR L2

## Bibliography

Andreadis K. et al., included L.Fenoglio, A first look at river discharge from SWOT satellite observations, GRL, accepted
Chen, J., Fenoglio, L. and Kusche, J. (2025). Measuring off-nadir river water levels and slopes from altimeter fully-focused SAR mode. Journal of Hydrology, 10.1016/j.jhydrol.2024.132553
Guccione, P.; Scagliola, M.; Giudici, D. (2018) 2D Frequency Domain Fully Focused SAR Processing for High PRF Radar Altimeters. Remote Sens. 10, 1943. https://doi.org/10.3390/rs10121943

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## Monitoring lake water level

1. Evaluated is WSE at 60 natural lakes and reservoirs in Switzerland with area between 4 and 0.25 km**2
2. 1/10 of lakes visited by both SWOT and S3/S6. At the intersection, SWOT higher accuracy and smaller bias is found, mean of STDD is 5 cm and 10 cm.
3. the water storage regulated hydropower reservoirs has minimum in early summer, the yearly storage changes of a 0.5 km**2 reservoir and of the Lake of Constance are comparable


Fig. 6 WSE in natural and man made lakes in Switzerland from SWOT Raster

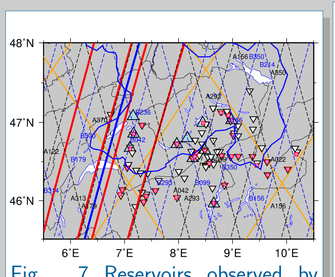

Fig. 7 Reservoirs observed by SWOT (pink) and S3,6 (blue)

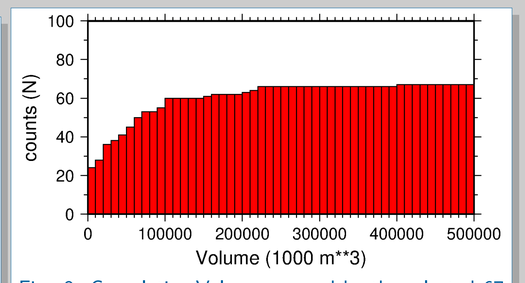


Fig. 8 Cumulative Volume covered by the selected 67 Reservoirs (white) in CH

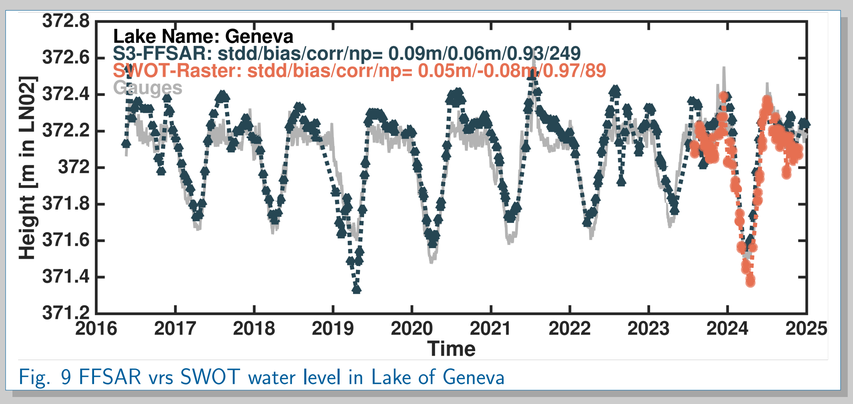


Fig. 9 FFSAR vrs SWOT water level in Lake of Geneva

## Lake validation with in-situ

WSE from swath- and SAR nadir-altimetry are cross-validated and validated against in-situ for lakes of area larger than 0.5 km**2 in 2016-2024. A sub-set of 14 lakes is selected, for the in-situ, Sentinel-3 and SWOT simultaneous measurements.

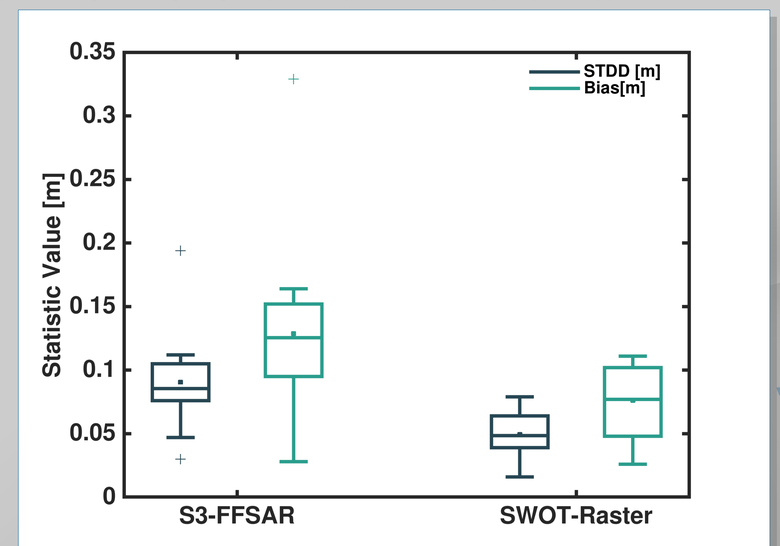


Fig. 10 Validation of SWOT and FFSAR water level in a subset of 14 lakes covered by both Sentinel and SWOT

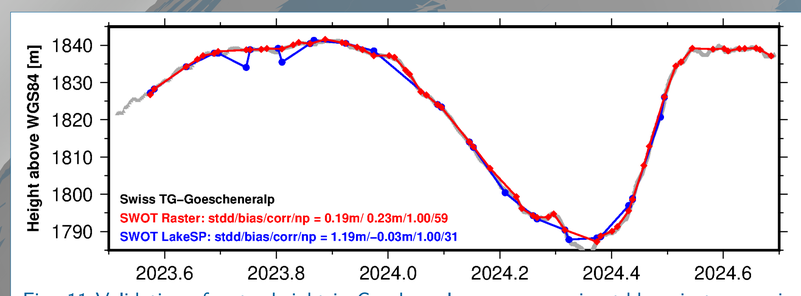


Fig. 11 Validation of watre height in Goeshneralpensee reservoir, stdd against gauge is 0.21 meters

## Monitoring lake water level (cont.)

We evaluate water surface elevation (WSE) from SWOT in water bodies in Sweden with area larger than 5 km*2.

1. data noisier than in Switzerland
2. smaller amplitude of variability, 2 meters for natural lakes, 4 meters for reservoirs
3. water storage in regulated hydropower reservoirs has minimum in early summer

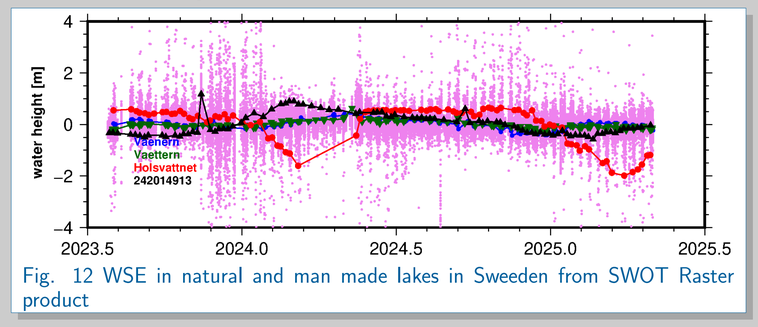


Fig. 12 WSE in natural and man made lakes in Sweeden from SWOT Raster product

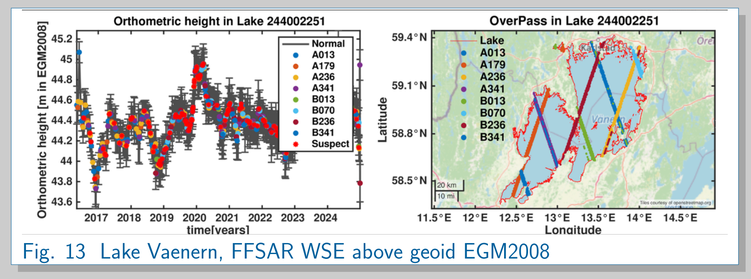


Fig. 13 Lake Vaenern, FFSAR WSE above geoid EGM2008

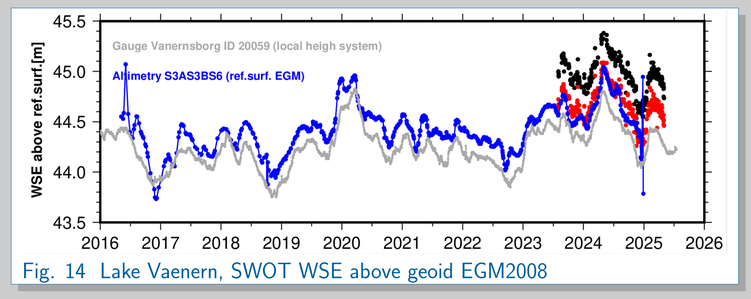


Fig. 14 Lake Vaenern, SWOT WSE above geoid EGM2008

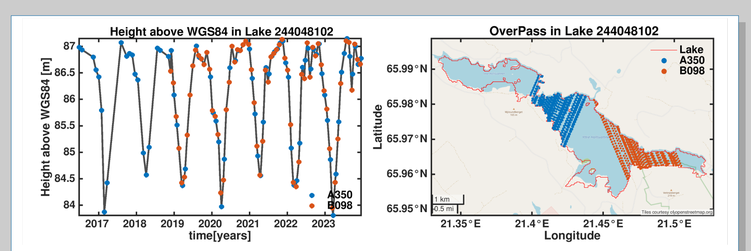


Fig. 15 Lake Holsvattnet, FFSAR WSE above geoid EGM2008

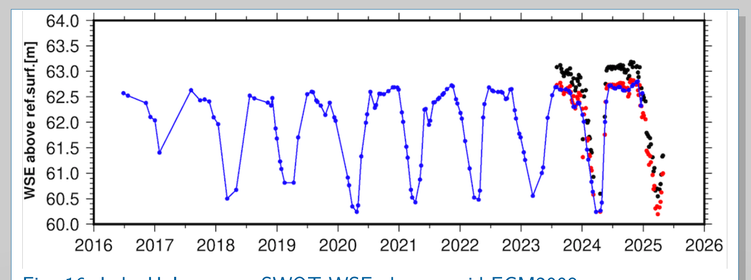


Fig. 16 Lake Holsvattnet, SWOT WSE above geoid EGM2008

## Conclusions

- For small water bodies and rivers below 100 m, a frequency higher than 20 Hz is required
- FFSAR WSE has higher quality and resolution than standard nadir-altimetry products
- FFSAR at 80 Hz allows to monitor water bodies smaller than 1 km**2 and width smaller than 80 m
- SWOT gives the unique chance to monitor all reservoirs and an higher accuracy respect to FFSAR nadir.
- WSE from altimetry agrees with in-situ on seasonal long-term change: in upper-middle Rhine the annual discharge has first maximum in early Spring, before 2010 the maximum was in Summer.
- DETECT B01 database with HR water level, discharge and storage change from SWOT and FFSAR is accessible at $https://detect-z03.geoinformation.net/map$
- challenging amount and data quality in SWEDISH lakes using SWOT raster data

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