REFECCT-DETECT - Analysis or surface water level and water extent, GNSS-IR and Sentinel-1

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Motivation

In the DETECT-B01 project, by applying new spaceborne technologies, we build a multi-sensor database of water level and water extent of high accuracy and resolution. The database will be used for model validation and assimilation into the Integrated Monitoring System (IMS). Here we first evaluate water level elevation (WSE) from in-situ GNSS-interferometric reflectometry (GNSS-IR) (Larson, 2023) against river gauge measurements. We then derive water extension from Sentinel-1 data and use WSE from nadir-altimetry to compute storage water change in lakes.

Method and data

Water surface elevation (WSE) above WGS84 ellipsoid are derived at eight locations (red diamond, Fig. 1) from low cost instrumentation using GNSS-IR and from geodetic GNSS. First, reflector height above water is evaluated from GNSS-IR with software "gnssref" (Larson 2023) computing individual retrieval and daily means. Second, the antenna ellipsoidal height above WGS84 ellipsoid is estimated by the Laica Infinity geospatial software and in-house. Ellipsoidal WSE time-series at each location are found by summation of the two parts and cross-compared with real gauges (RG) and Vortex micro stations (vortex.io) WSE. The skill metrics parameters are bias, standard deviation of differences (stdd) and correlation.
To derive water storage change in lakes, the volume change is derived from area and water height changes measured by Sentinel-1 and satellite altimetry. Figs. 1 and 2 show Sentinel-3A and -3B (black and blue), Sentinel-6 (orange) and SWOT nadir (blue), gauge (triangle), GNSS-IR (diamond) and Vortex (square) available.

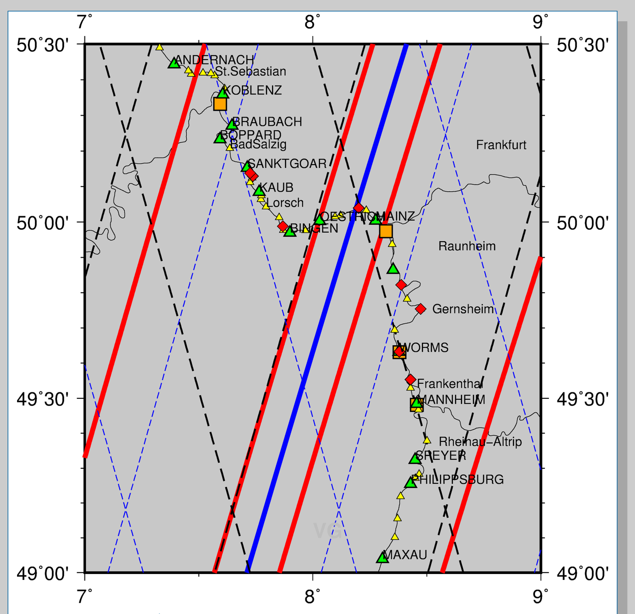
Fig. 1 Cal/Val in River Rhine

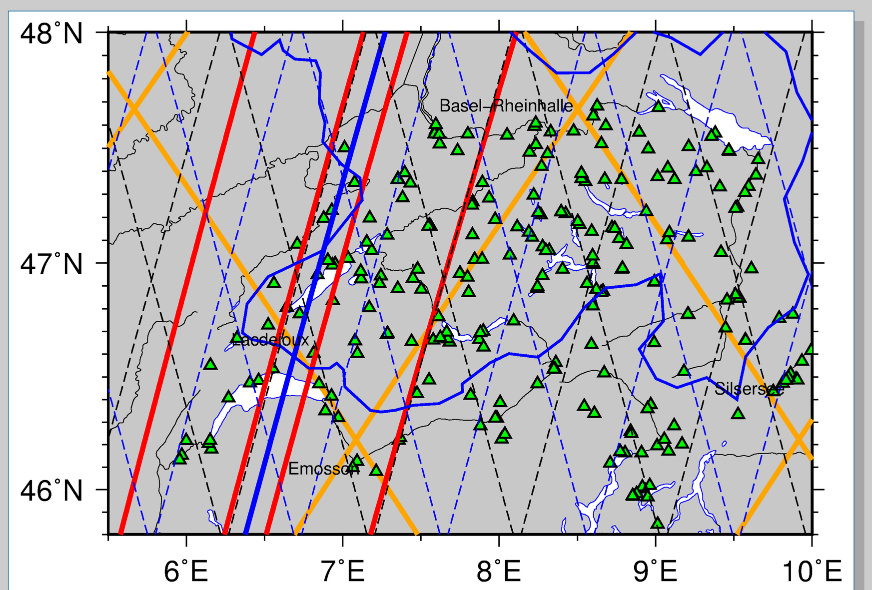
Fig. 2 Switzerland Lakes gauge network

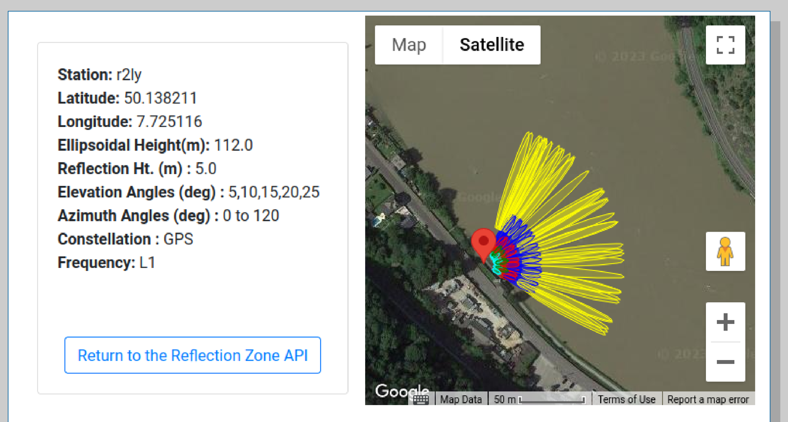
Fig. 3 GNSS-R in Loreley

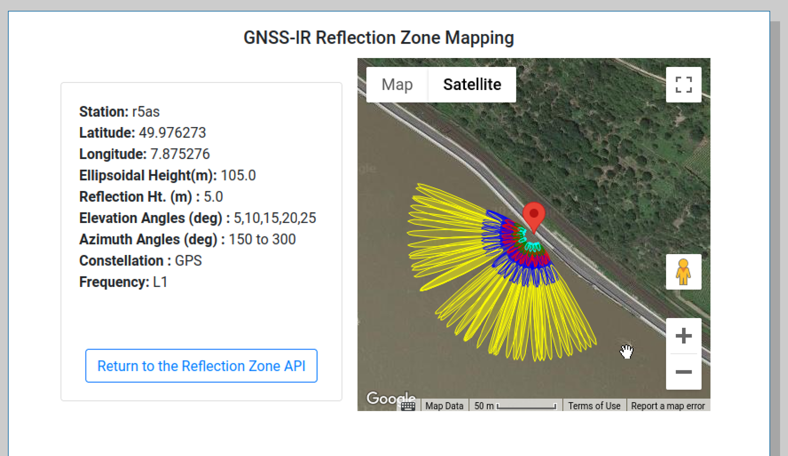
Fig. 4 GNSS-R in Assmannshausen

Water Storage Change

Volume change of Lungernsee lake in Switzerland is computed from area change from Sentinel-1 and from WSE change from Sentinel-3 (Liu C., 2022). Fig. 5.

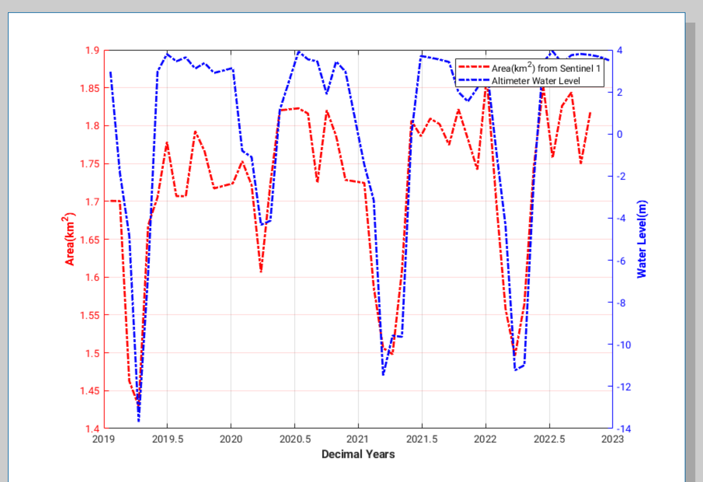
Fig. 5 Area from Sentinel-1

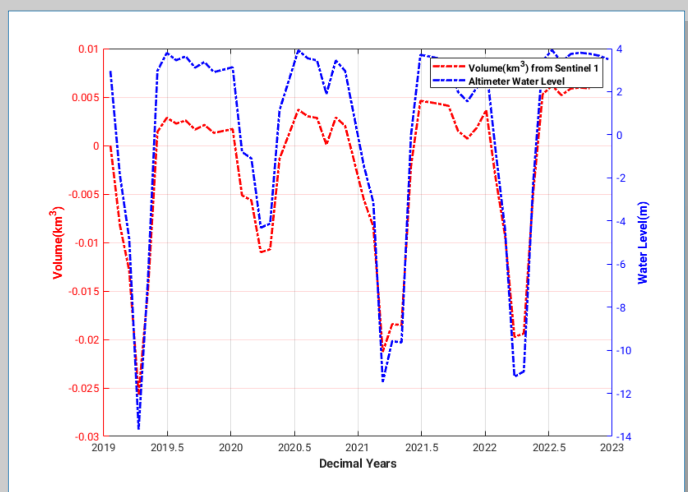
Fig. 6 Lake of Geneva

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WSE from GNSS-IR

At the Assmannshausen location, GNSS-IR and RG are colocated. See their WSE above WGS84 ellipsoid in Figs. 11 and 8. The subdaily stdd between GNSS-IR and RG is 0.08 m. From the regular WSA campain performed with GPS onboard a ship, a bias of 0.12m is detected at this location (Tab. 1). In Loreley, absolute height difference of GNSS-IR and RG are expected, due to the 1.5 km distance between RG and GNSS-IR locations. Stdd of GNSS-IR and RG is 0.05 m for subdaily retrievals and 0.08 m for daily retrievals. Bias between fixierung and R2LY is 0.03 m (Tab. 2). Fig. 9 shows in Gernsheim (R7GH) good retrievals (blue) and strong retrievals at NE and SE from the Lomb-Scarge Periodogram (Fig. 10). Absolute height of Vortex receiver evaluated by Vortex Firm at installation are to be checked, due to a difference of 54 cm in Mainz between WSE from RPR and WSE from GPS ships (Tab. 2).

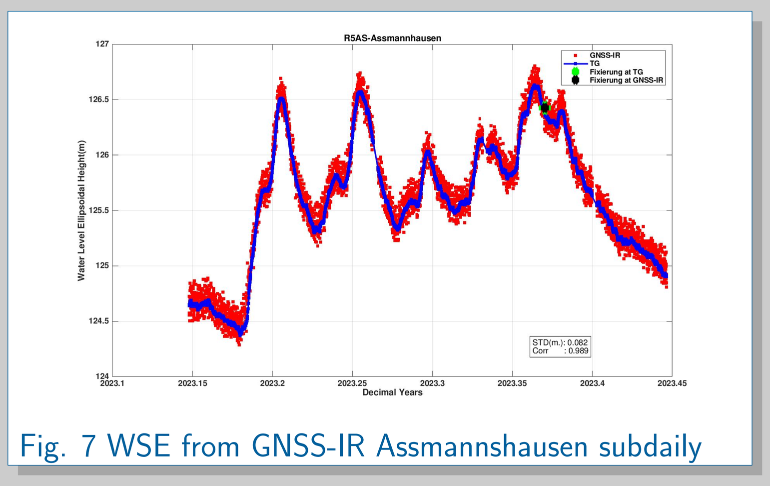
Fig. 7 WSE from GNSS-IR Assmannshausen subdaily

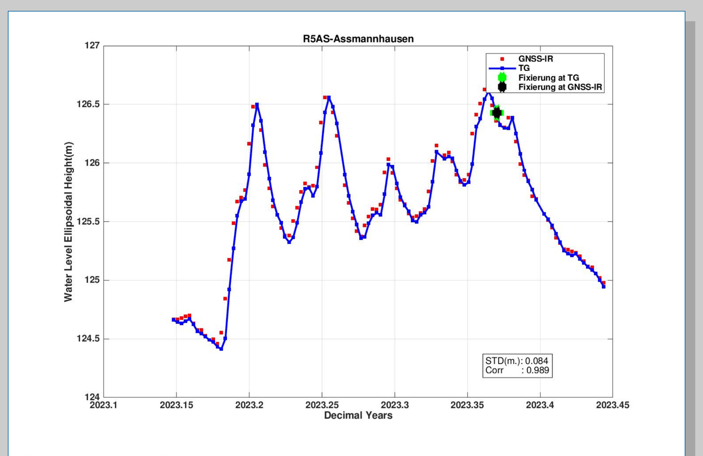
Fig. 8 WSE from GNSS-IR Assmannshausen daily

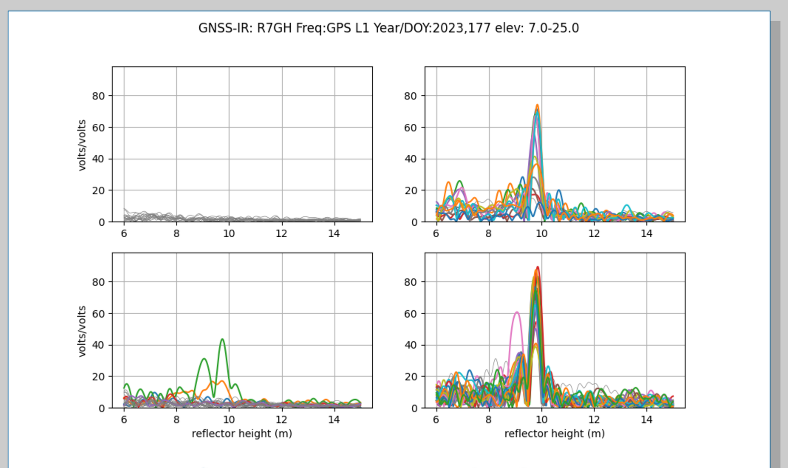
Fig. 9 Lomb–Scargle periodogram for Gernsheim

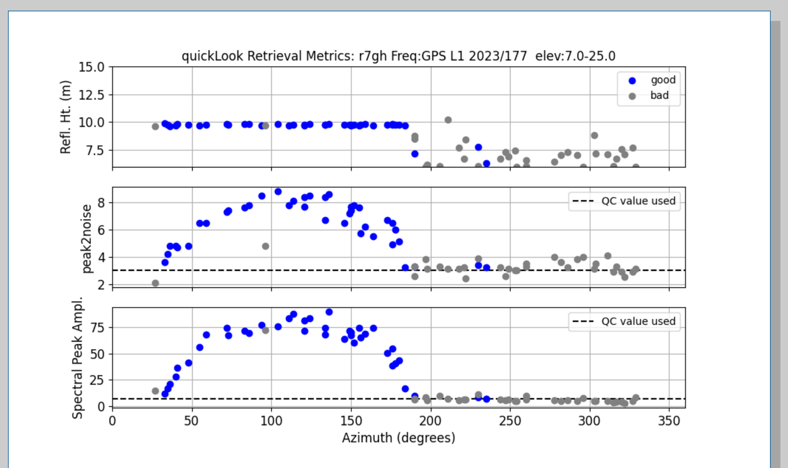
Fig. 10 Reflector height, peak2noise

Statistics of comparison of GNSS-IR, Vortex and nearest RG in Tables 1 and 2. Distance between GNSS-IR and RG is lower than 3.5 km for the all stations. In Worms Vortex and GNSS-IR are co-located within 100 m and within 400 m with RG. For daily GNSS-IR and RG values, stdd is lower than 9 cm. In Worms stdd are 2 cm and 3 cm between GNSS-IR and Vortex and between GNSS-IR and RG. GNSS-IR heights are validated using BfG Fixierung campains (Fix) as ground truth. Bias of daily between GNSS-IR and Fix is lower than 3 cm at Loreley and Kammerech and larger than 10 cm at Wiesbaden and Assmannshausen (Tab. 1). Absolute bias between Vortex and Fix lower than 5 cm in Mannheim and larger than 30 cm in Worms and Mainz (Tab. 2). For the RG stations the absolute bias is below 5 cm.

Table 1: STDD and distance of GNSS-IR and RG, bias and distance of GNSS-IR and Fix for four GNSS-IR, bias and distance of GNSS-IR and Vortex in Worms. Units are meters.

	R1WO	R2LY	R3WB	R4KM	R5AS	R6GB	R7GH	R8FT	R1WO-Vio
AllRH stdd	0.066	0.055	0.119	0.067	0.082	0.076	0.032	0.057	0.064
daily stdd	0.032	0.087	0.080	0.083	0.084	0.094	0.034	0.052	0.019
distance GNSS IR-RG	400	1500	2700	500	3	3200	670	3.12	0.1
bias GNSS IR-Fix	-	0.027	0.25	0.03	0.12	-	-	-	
distance GNSS IR-Fix	-	100	140	170	80	-	-	-	-
bias RG-Fix	-	0.011	0.034	0.08	0.065				
distance RG-Fix	-	145	146	213	78				

Table 2: Bias and distance between vortex and fixierung. Units are meters.

Parameters	Mannheim	Worms	Mainz
Distance vortex-Fix.(km)	0.07	0.12	0.11
Difference vortex-Fix.(m)	0.045	0.3	0.54

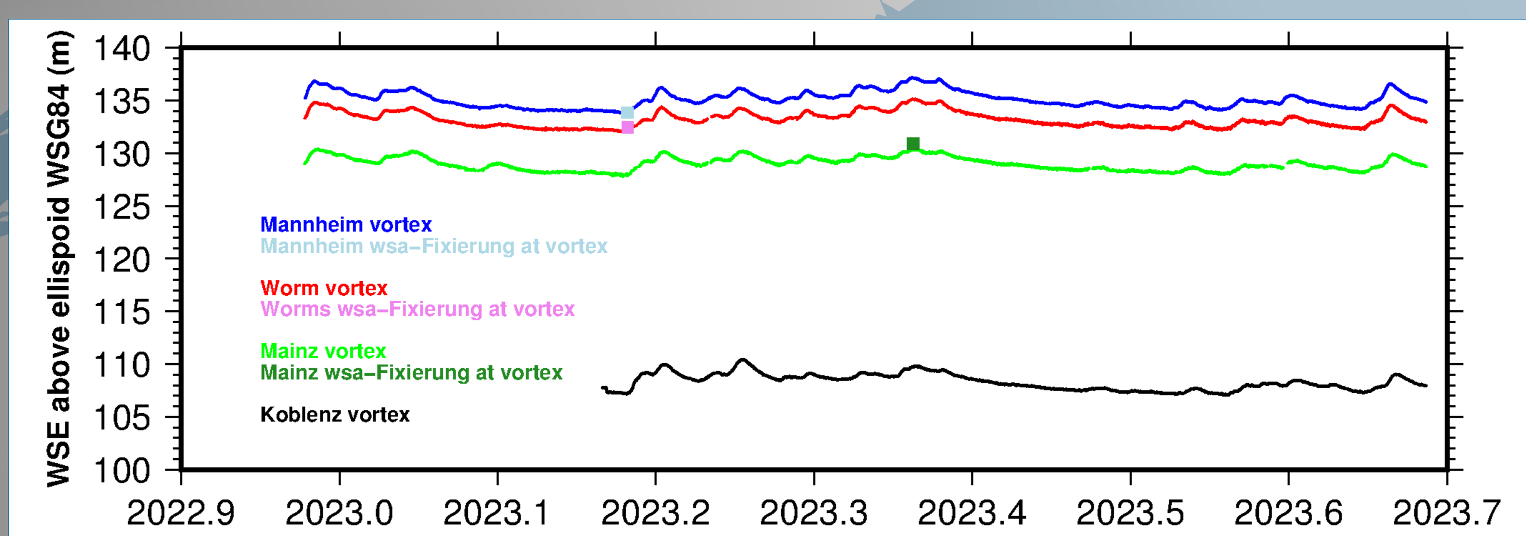

Fig. 11 WSE above WGS84 at Vortex locations

Conclusions

- Average accuracy of the eight GNSS-IR station WSE measurements wrt RG (stdd) is 0.069 m for all GNSS-IR retrievals and 0.066 m for daily retrievals.
- Bias FIX AND GNSS-IR lower than 5 cm for most stations, max. 55 cm Vortex and Fix in Mainz
- The stdd between GNSS-IR and RG reduces with co-location, 2 cm in Worms with Vortex
- The bias between Fix and RG is 5 cm, minimum in 1 cm.

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