

Investigating SAR Altimetry over the Great Salt Lake

Comparing SAMOSA+ / ++ and ALES+ SAR

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Martina Wenzl, 19.-23.10.2020

OSTST2020,

then run the Slide Show mode

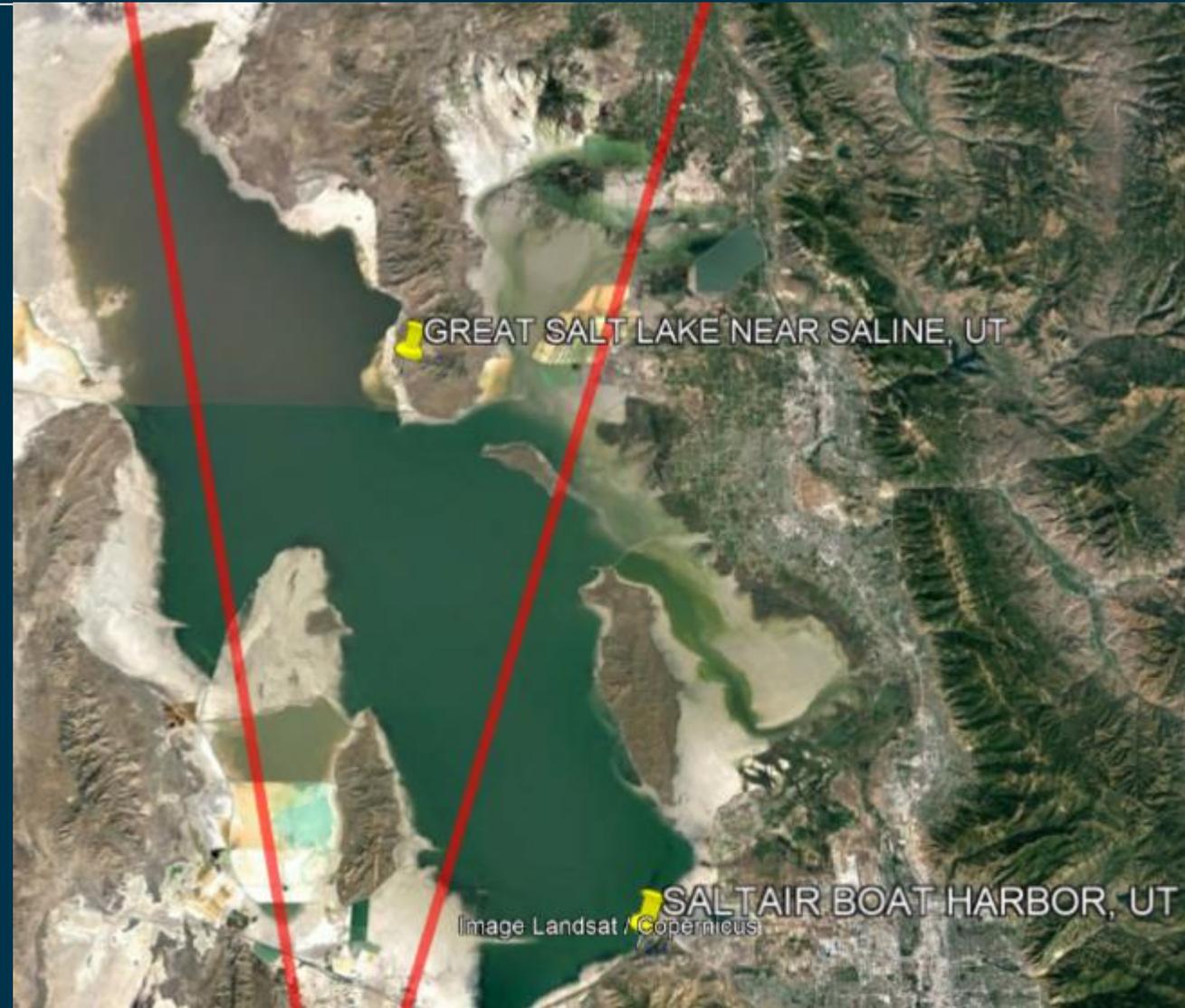
to see how it looks

- ❑ Study area – The Great Salt Lake
- ❑ GPOD/SARvatore and the SAMOSA+ /+++ retrackerers
- ❑ ALES+ SAR retracker
- ❑ Methodology
- ❑ Results
- ❑ Conclusion

- ❑ River water level is a key information for resource management, modelling and climate change investigations.
- ❑ Radar altimetry sensors on-board satellite missions have demonstrated their capability to provide valid water level measurements not only over the open ocean but also in the inland water domain.
- ❑ SAR processing enables the reduction of the along-track footprint which reduces noise contamination over smaller inland water targets like medium sized lakes and rivers or close to the coast.
- ❑ The Great Salt Lake is the 8th largest terminal lake worldwide and marks the transition between characteristics of the inland water domain and the coastal region.
- ❑ This study aims to investigate the performance of dedicated inland water retracers of the SAMOSA family with the newly adopted ALES+ SAR processor for Sentinel-3A/B, which is tailored to coastal regions and not specifically designed for the inland water domain

Study area - The Great Salt Lake

- ❑ Two Sentinel-3A tracks (track 275 and track 369) cross the Great Salt Lake.
- ❑ The Lake is split by a causeway in a north-western and north-eastern arm and a southern part. The southern and north-western arm are connected via a 55 m broad opening in the causeway.
- ❑ The gauge “Near Saline” is connected via a circa 4.3 km long and 10 m wide trench to the north-western arm. The gauge “Saltair Boat Harbour” is located at the southern arm.
- ❑ The water level measured at both gauges showed a large discrepancy before February 2017. This could be explained by the opening of the causeway in December 2016 which lead to an equalisation of the water level in the north-western arm.

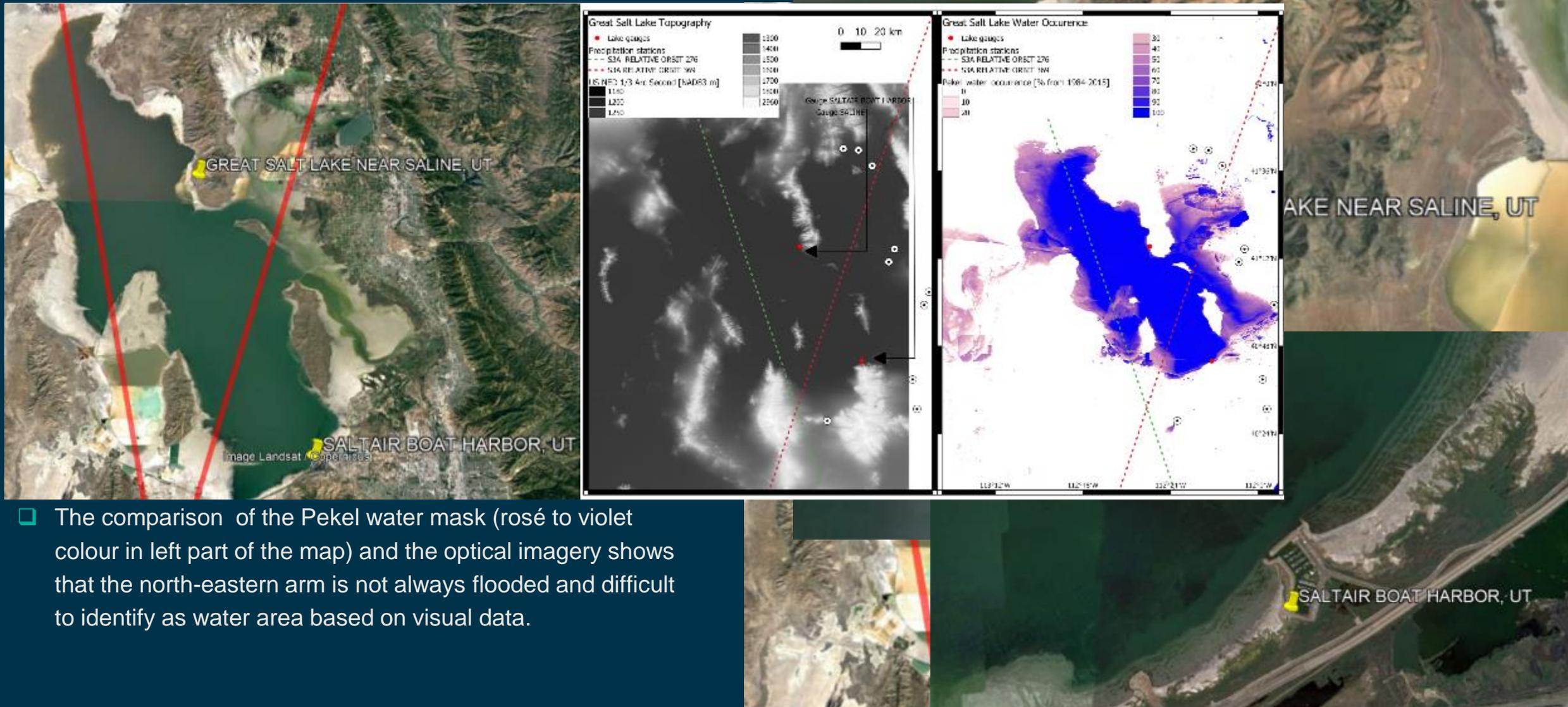


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Study area - The Great Salt Lake



❑ The comparison of the Pekel water mask (rosé to violet colour in left part of the map) and the optical imagery shows that the north-eastern arm is not always flooded and difficult to identify as water area based on visual data.

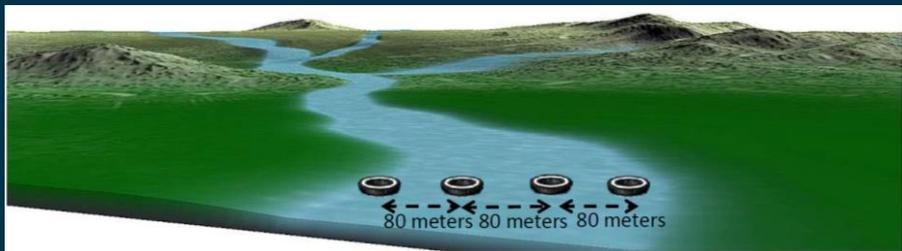
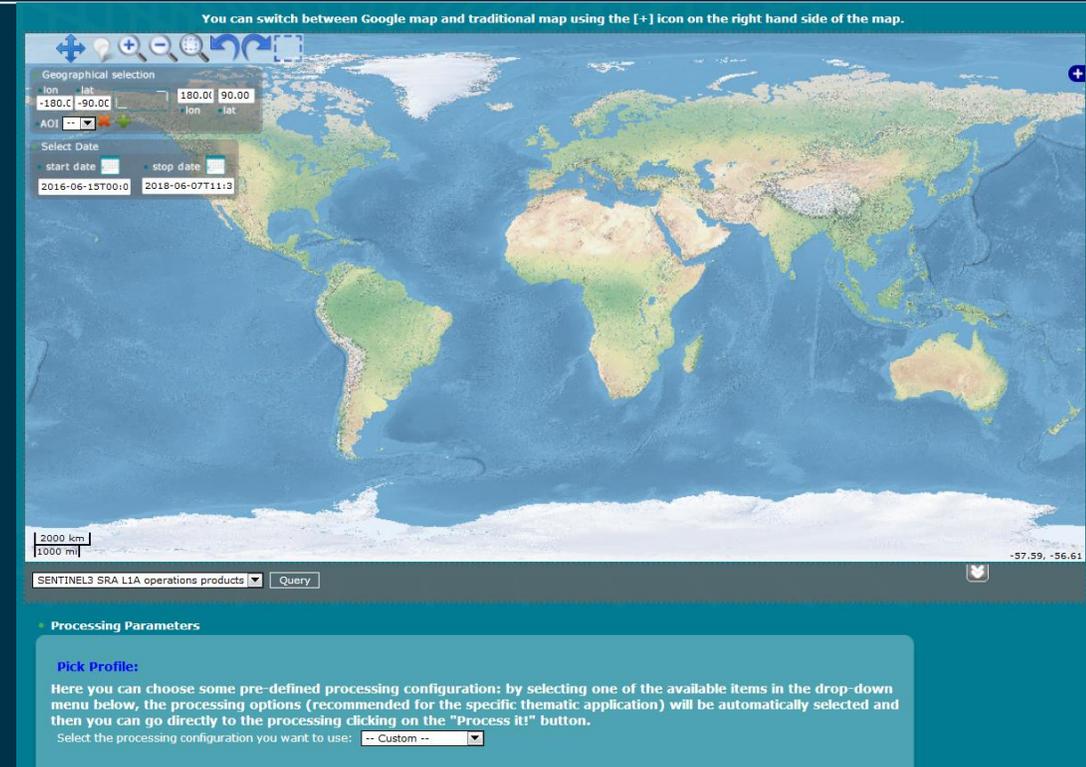
SRAL datasets:

GPOD/SARvatore for Sentinel-3 data

ALES+ SAR in GPOD/SARvatore

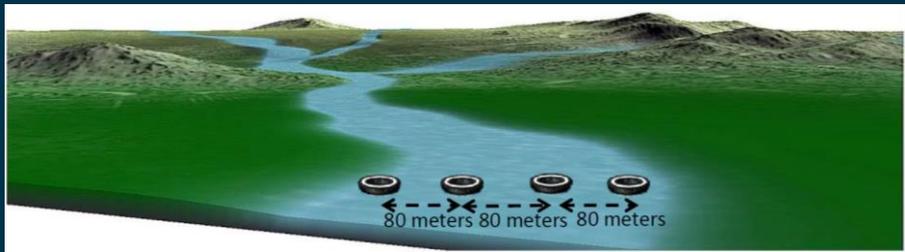
Dataset 1: GPOD/SARvatore for Sentinel-3 data

- ❑ The GPOD/SARvatore processor enables users to choose scenario-dependent L1b and L2 processing options
- ❑ The service is accessible at <http://gpod.eo.esa.int/> after registration.
- ❑ The L1b profile “Inland Water HPR” is designed to increase the number of estimates over the water body with a posting rate of 80 Hz, which corresponds to roughly one estimate every 80 meters.
- ❑ The analytical retrackerers SAMOSA+ and SAMOSA++ (tailored to the inland water domain) are applied in the L2 options.



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You can switch between Google map and traditional map using the [+] icon on the right hand side of the map.

Here you can choose some pre-defined processing configuration: by selecting one of the available items in the drop-down menu below, the processing options (recommended for the specific thematic application) will be automatically selected and then you can go directly to the processing clicking on the "Process it!" button. Please note that only the profiles " with data" will produce output netCDF data products including the Range Integrated Power (RIP) and the SAR Echo Waveforms.

Select the processing configuration you want to use:

Here you find a list of processing options that you can select according to the processing level
For a wiki user manual of the service, go here: [wiki](#)
For a hands-on presentation, go here: [slides](#)

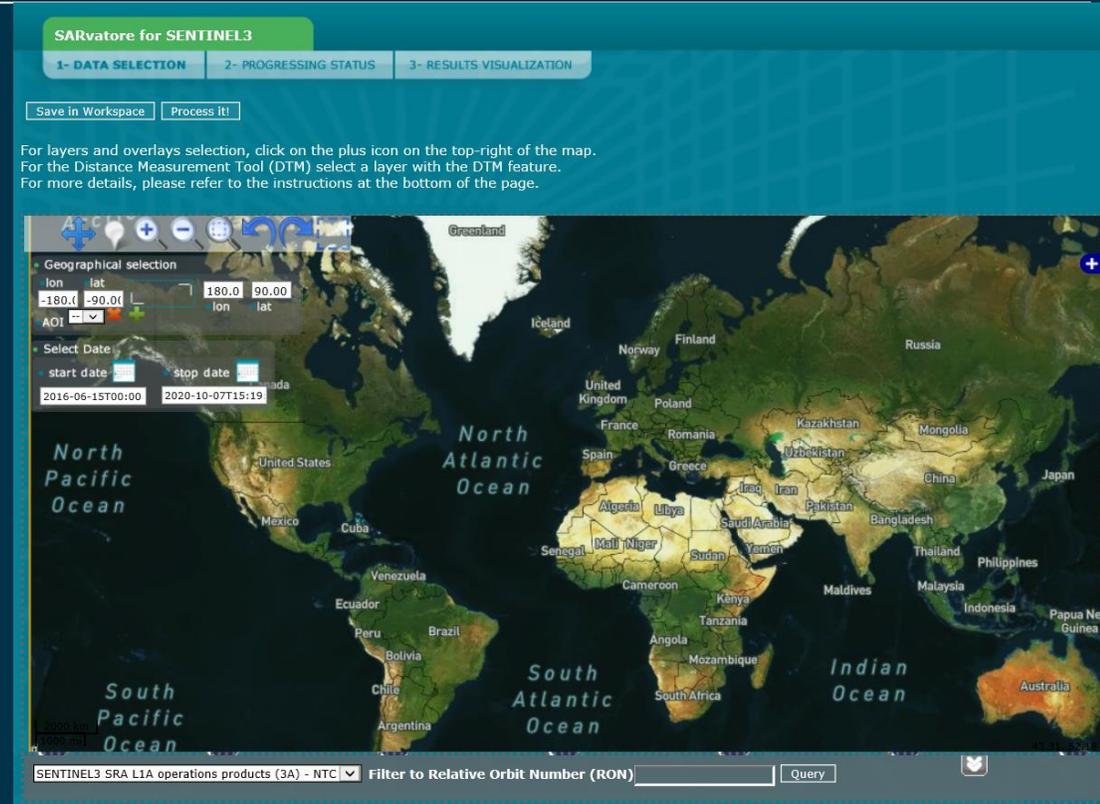
Pre-Processing and Debugging Filters:

- **Pass Direction**
Flag to select whether to process only ascending or descending passes
- **Publish Processing Summaries**
Flag to publish summary lists of non-processed inputs. In case of non-processed or skipped input files two lists are created: one with the filenames of such files, and one with the G-POD catalogue entries (in a format than can be passed to the service as input)

L1B Processor:

- **Data Posting Rate**
Flag to set the data posting rate: 20 Hz (canonic posting rate) or 80 Hz (finer posting rate)
- **Hamming Weighting Window**
Flag to set the application of the Hamming Weighting Window on the burst data (section 4.4 in REF1)
- **Exact Beam-Forming**
Flag to set the application of exact or approximated Doppler Beam Steering (section 4.4 in REF1)
- **FFT Zero-Padding**
Flag to operate the Zero-Padding prior to the range FFT (section 4.8 in REF1). Zero-Padding is indicated for coastal zone analysis
- **Radar Receiving Window Size**
Flag to select the size of the radar receiving window: 128 range bins (standard) or 128 x N range bins (extended N times). Extended window with N=2 is indicated for coastal zone and sea ice analysis. N>2 may be indicated only for inland water over very steep topographic regions.
- **Stack Subset**
Subset the Stack to Looks: [100, 120, 140, 160, 180, ALL]
- **Antenna Pattern Compensation**
Flag to activate the antenna pattern compensation on the Stack Data
- **Dump SAR Stack Data in output**
Flag to dump the SAR Stack Data in the output package. Be aware that SAR Stack Data are bulky data products (around 1 GB for single pass); do not process them massively but limit yourself at around 10/20 passes at the time

- ❑ In Passaro et. al 2018. the ALES+ SAR retracking strategy, based on a sub-waveform retracker that is able to adapt the fitting of the signal depending on the sea state and on the slope of its trailing edge, was presented. The algorithm modifies the existing Adaptive Leading Edge Subwaveform retracker originally designed for coastal waters (Passaro et. al, 2014), and was applied to ENVISAT and ERS-2 missions.
- ❑ In the frame of the current ESA Baltic+ SEAL project (<http://balticseal.eu/>), the ALES+ retracker has been further developed and extended to all the missions considered (ERS-2, ENVISAT, Jason-1/2/3, SARAL/AltiKa, Cryosat-2, Sentinel-3A/B).
- ❑ **ALES+ for SAR** adopts a simplified version of the Brown-Hayne functional form as an empirical retracker to track the leading edge of the waveform. This empirical application of the Brown-Hayne model implies that ALES+ cannot estimate a physical value of SWH and of σ_0 . Nevertheless, the retracker is fully able to track the mid-point of the leading edge.
- ❑ The ALES+ SAR dataset provides estimates every 300 meter, corresponding to the posting rate of 20 Hz.



Dataset 2: ALES+ SAR in GPOD/SARvatore

- ❑ In Passaro et. al 2018. the ALES+ SAR retracking strategy, based on a sub-waveform retracker that is able to adapt the fitting of the signal depending on the sea state and on the slope of its trailing edge, was presented. The algorithm modifies the existing Adaptive Leading Edge Subwaveform retracker originally designed for coastal waters (Passaro et. al, 2014), and was applied to ENVISAT and ERS-2 missions.
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SARvatore for SENTINEL3

1- DATA SELECTION | 2- PROGRESSING STATUS | 3- RESULTS VISUALIZATION

Save in Workspace | Process It!

L2 Processor:

- **Restrict the re-tracking on specific surfaces**
Flag to limit the processing on open sea or on water (open sea, coastal zone and inland water) or to process the full pass.
- **PTR width alphap parameter**
Use a LUT (Look-Up Table) or a constant for PTR (Point Target Response) alphap parameter.
- **SAMOSa Model Generation**
Flag to select the generation of the SAMOSa model to use in the re-tracking. SAMOSa3 is a truncated version (only zero order term) of SAMOSa2 (REF2), SAMOSa+ is the SAMOSa2 model tailored for inland water, sea ice and coastal zone domain.
- **Dump RIP in output**
Flag to append Range Integrated Power (RIP) in the output netCDF data product.
- **Dump SAR Echo Waveforms in output**
Flag to append the SAR Echo Waveforms in the output netCDF data product.
- **Single-look or Multi-look Model**
Flag to set the application of the Model Multilooking (Single-Look or Multi-Look). Single-Look option is indicated for quick look operations while Multi-Look is the most accurate.
- **Choose the default Tide Model**
Choose the default Tide model between FES2014b, TPX08-ATLAS and TPX09-ATLAS.
- **Choose the default Mean Sea Surface Model**
Choose the default Mean Sea Surface Model between DTU18, DTU15 and CLS-CNES15.

Post-processing:

- **Append the ALES+ SAR output to the output netcdf product**
Please, be aware that ALES+ SAR option is not selectable in case:
- "FFT Zero-Padding" is applied in the L1b processing options above.
- "Radar Receiving Window Size" exceeds 128 bins in the L1b processing options above.
- "Dump SAR Echo Waveforms in output" is set to "No" in the L2 processing options above.

- ❑ In Passaro et. al 2018. the ALES+ SAR retracking strategy, based on a sub-waveform retracker that is able to adapt the fitting of the signal depending on the sea state and on the slope of its trailing edge, was presented. The algorithm modifies the existing Adaptive Leading Edge Subwaveform retracker originally designed for coastal waters (Passaro et. al, 2014), and was applied to ENVISAT and ERS-2 missions.
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- ❑ **ALES+ for SAR** adopts a simplified version of the Brown-Hayne functional form as an empirical retracker to track the leading edge of the waveform. This empirical application of the Brown-Hayne model implies that ALES+ cannot estimate a physical value of SWH and of σ_0 . Nevertheless, the retracker is fully able to track the mid-point of the leading edge.
- ❑ The ALES+ SAR dataset provides estimates every 300 meter, corresponding to the posting rate of 20 Hz.

SARvatore for SENTINEL3

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L2 Processor:

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ALES+ SAR is a subwaveform retracker for open ocean and coastal zone SAR altimetry data*. ALES+ SAR adopts a simplified version of the Brown-Hayne functional form (which is the functional form for pulse-limited altimetry) as an empirical retracker to track the leading edge of the waveform.

ALES+ SAR L2 NetCDF products will be placed into a dedicated output folder and will include the fields indicated in the section below.

*ALES+ SAR is not conceived for the inland water domain.

The following fields are produced as output of ALES+ SAR:

- **[lat_20_ku]**: Latitude at 20 Hz in degrees north.
- **[lon_20_ku]**: Longitude at 20 Hz in degrees [-180° to +180°].
- **[range_ales_20_ku]**: This is the altimetric range in meters. It corresponds to the distance between the satellite the satellite-to-surface range (calculated by measuring the time taken for the signal to make the round trip).
- **[range_ales_qual_20_ku]**: This is a 1-0 quality flag based on the fitting quality of the leading edge of the signal. A value of 1 corresponds to a bad quality flag. Note that this flag does not exclude the presence of further wrong retrievals in the product. A careful outlier analysis is strongly suggested.
- **[ssb_ales_20_ku]**: This is the sea state bias correction to be applied to the [range_ales_20_ku] when computing the sea surface height. It is computed empirically based on the proportionality between the wave height and the rising time of the leading edge in the waveform.
- **[time_20_ku]**: time in seconds since 2000-01-01 00:00:00.0.

For further information on the ALES+ SAR retracker and on how Range and Sea State Bias are computed, please check the Algorithm Theoretical Baseline Document of the ESA Baltic SEAL Project, available from <http://balticseal.eu/outputs/>.

Methodology:
Deriving the water level
Filtering
Validation based on distance to gauges

❑ GPOD/SARvatore SAMOSA+/++:

The water level is estimated based on the uncorrected sea surface height parameter *SSH_Unc_20Hz*. (The variable names are not updated to match the posting rate of 80 Hz, however all variables are provided in 80 Hz.)

$$gpod_ssh = (SSH_Unc_20Hz - GEO_Corr_Land_20Hz - GEOID_EGM2008_20Hz)$$

❑ GPOD/SARvatore ALES+ SAR:

The water level is estimated based on the range parameter found in the appended Ales+ SAR L2 files. All variables are posted in 20 Hz and the correction terms are found in the original GPOD/SARvatore L2 files.

$$ales_ssh = (altitude_20Hz - range_ales_20_ku) - GEO_Corr_Land_20Hz - GEOID_EGM2008_20Hz)$$

- ❑ *The GPOD water flag was used to mask measurements over land*

- ❑ *A simple filtering approach was applied :*
 1. *No filter was applied as reference dataset*
 2. *GPOD/SARvatore : filtering data with Misfit > 3.5; ALES+ SAR: filtering data with quality flag*
 3. *Filtering data based on Pulse Peakiness ≥ 0.3 .*
 4. *Combination of Misfit/quality flag and Pulse Peakiness filter*

- ❑ *As a last step, measurements which were not within the median water level ± 3 x standard deviation were discarded*

- ❑ *The filtering results were then compared to the two gauges and based on the following intervals:
0-5 km, 5-10 km, 10-15 km, 15-20 km, 20-25 km, 25-30 km, 30-35 km, 35-40km, 40-45 km, above 50 km*

Results

Track 275

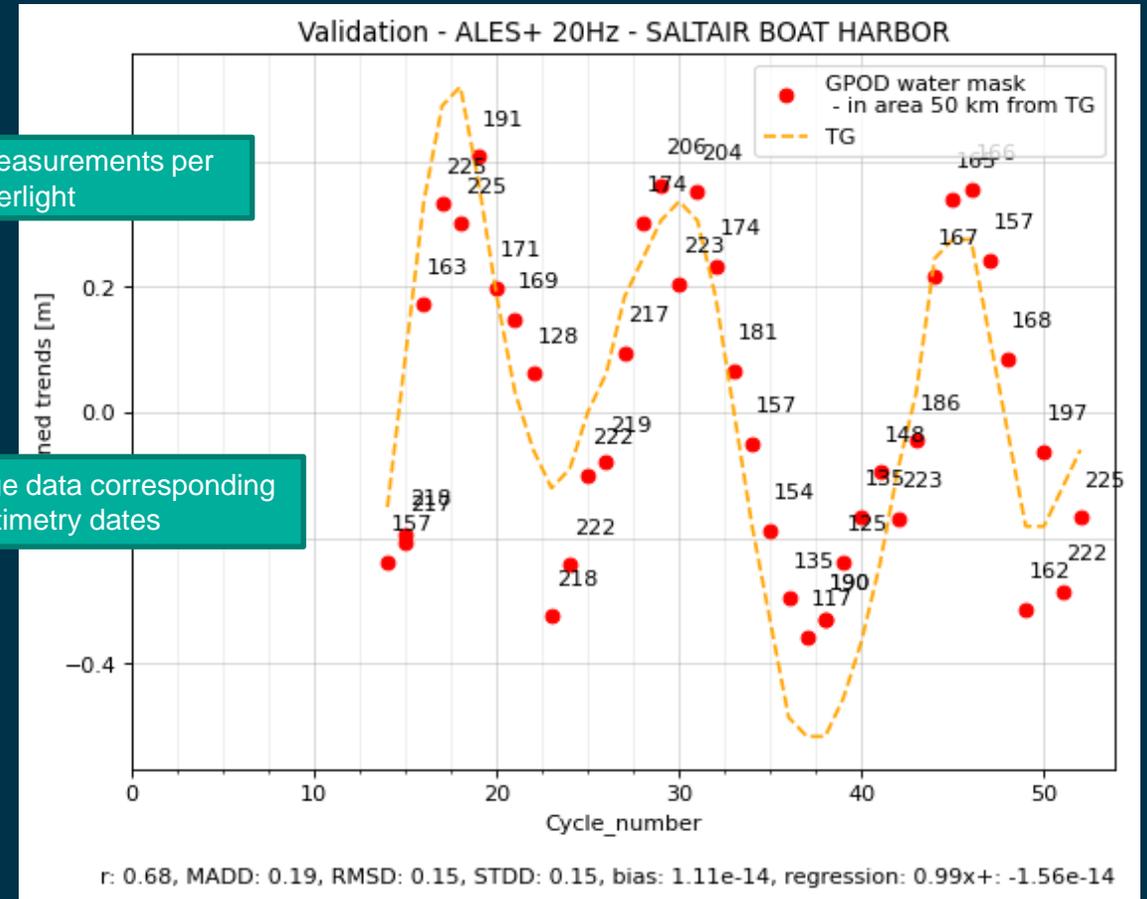
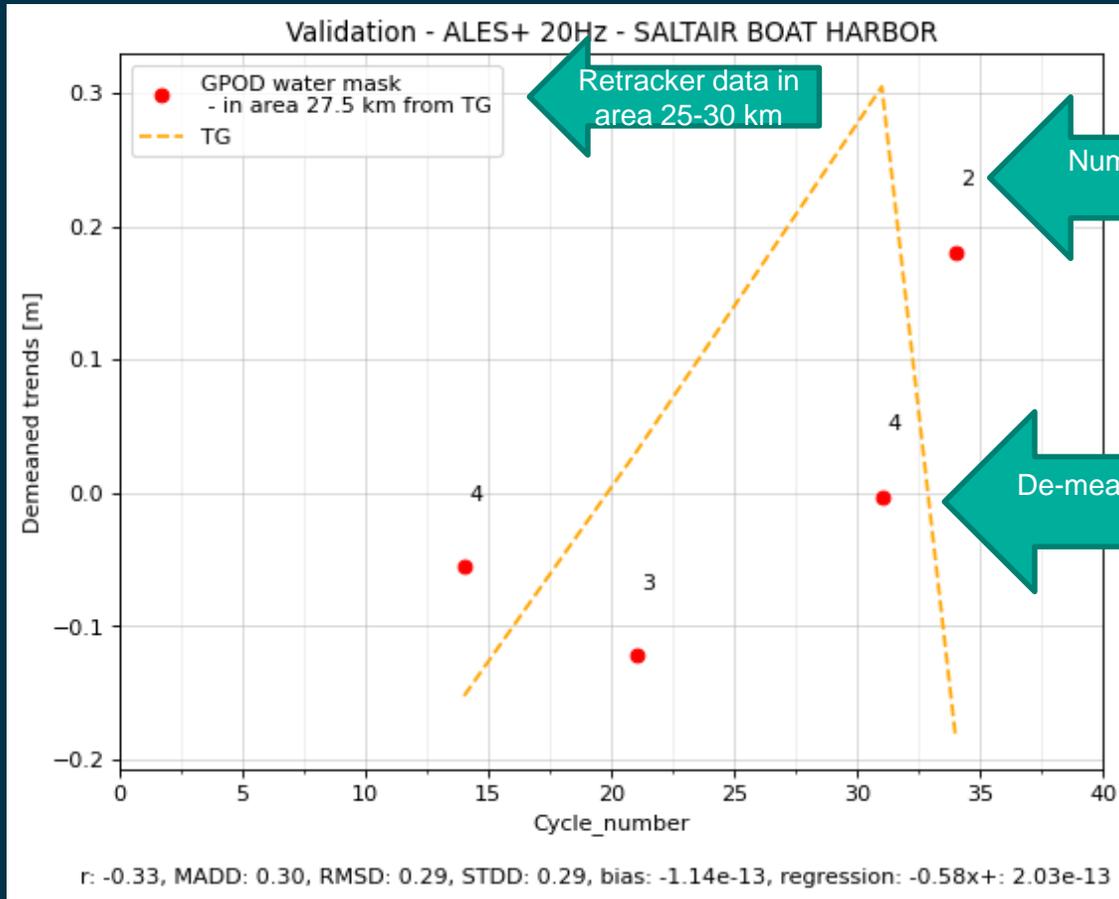


Track 275 – no filter, at gauge BOAT HARBOUR

Worst performance

ALES+ SAR

Best performance



Retracker data in area 25-30 km

Number of measurements per overlight

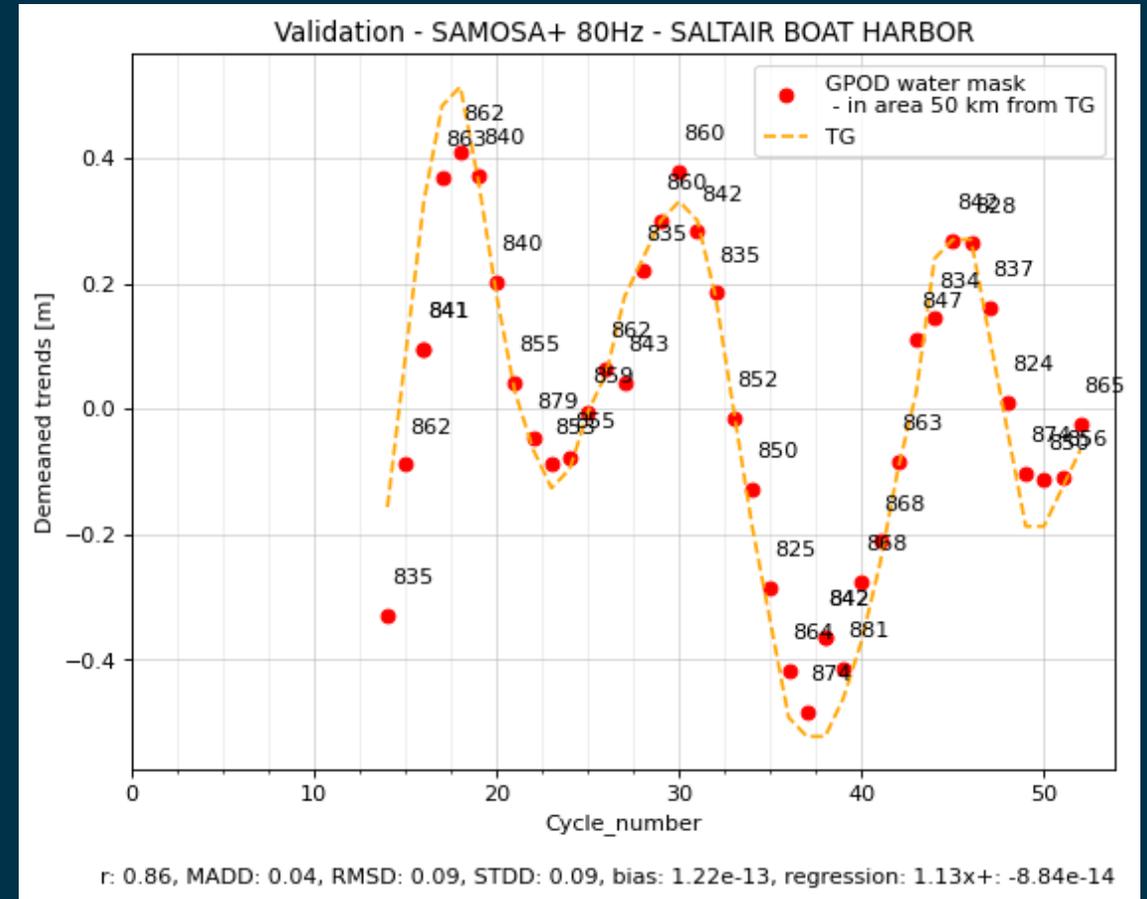
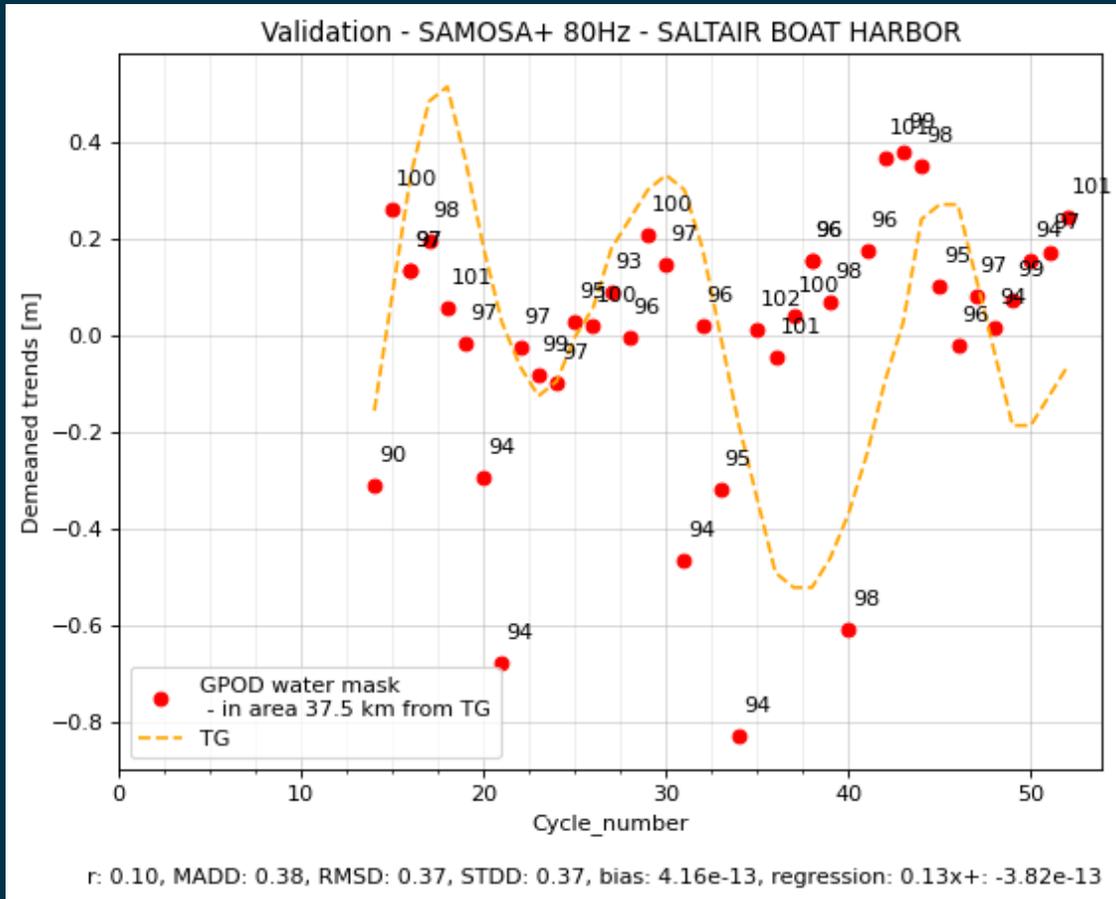
De-meaned gauge data corresponding to the altimetry dates

Track 275 – no filter, at gauge BOAT HARBOUR

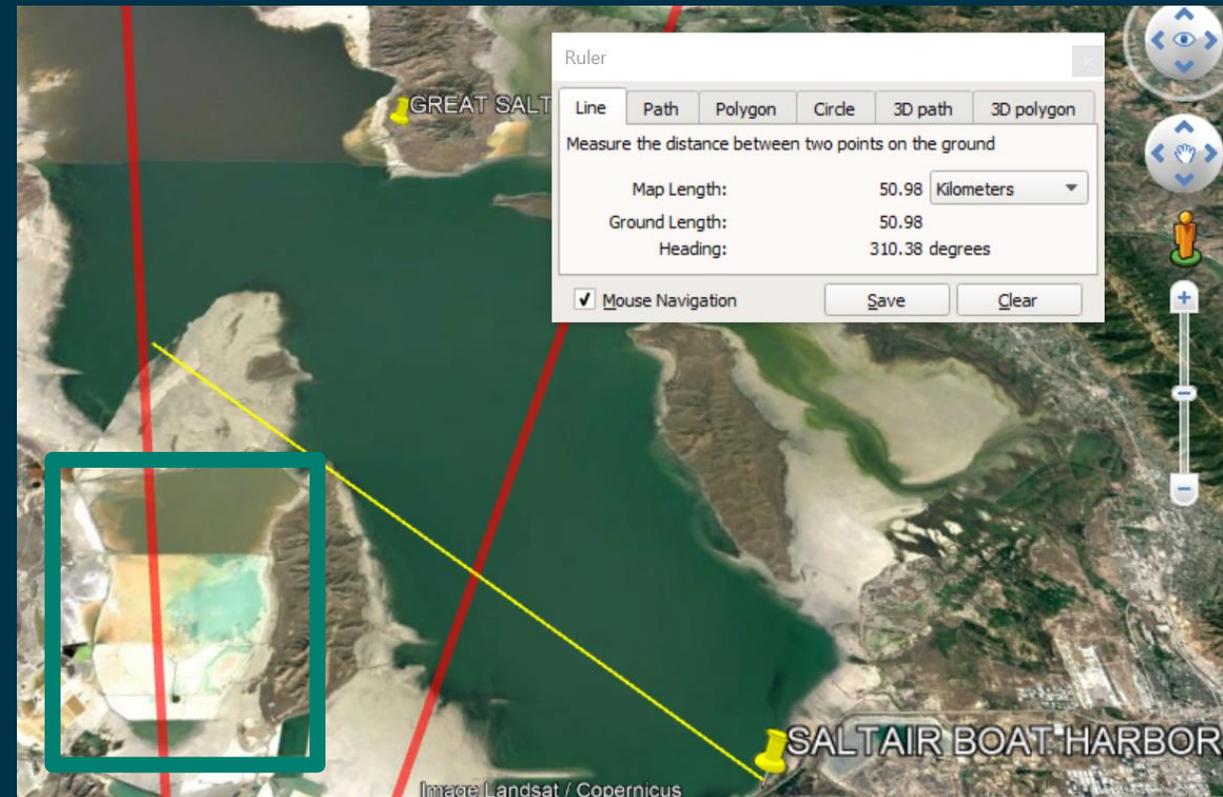
Worst performance

SAMOSA+

Best performance



- ❑ All retrackerers show the best performance with distance > 50 km. Although the area marked by the green box is indicated as water by the GPOD/SARvatore water flag, the optical imagery shows that this area is distinctly different from the main water body. The nearby shores could be the cause of noisy waveforms, leading to bad performances in all retrackerers.
- ❑ SAMOSA+ results show the best results, while ALES+ SAR captures the water level dynamic well.

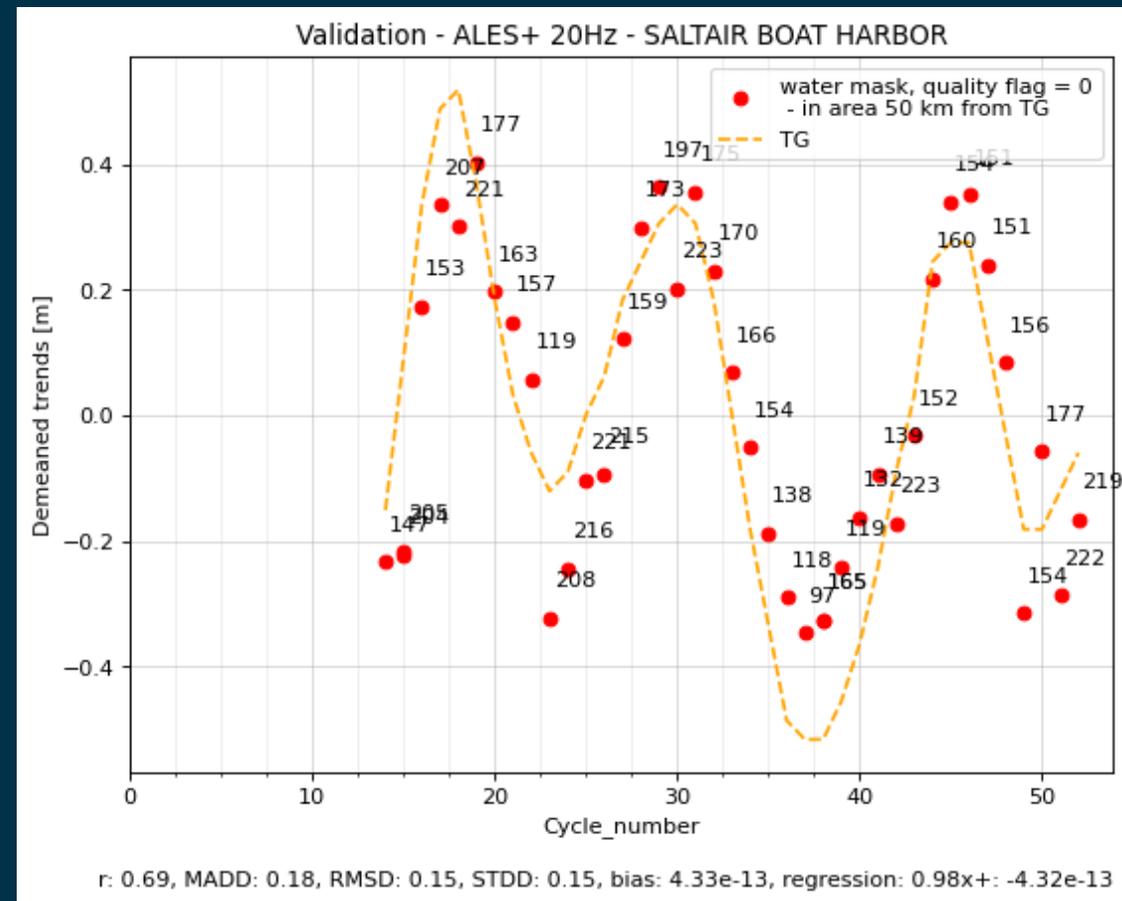
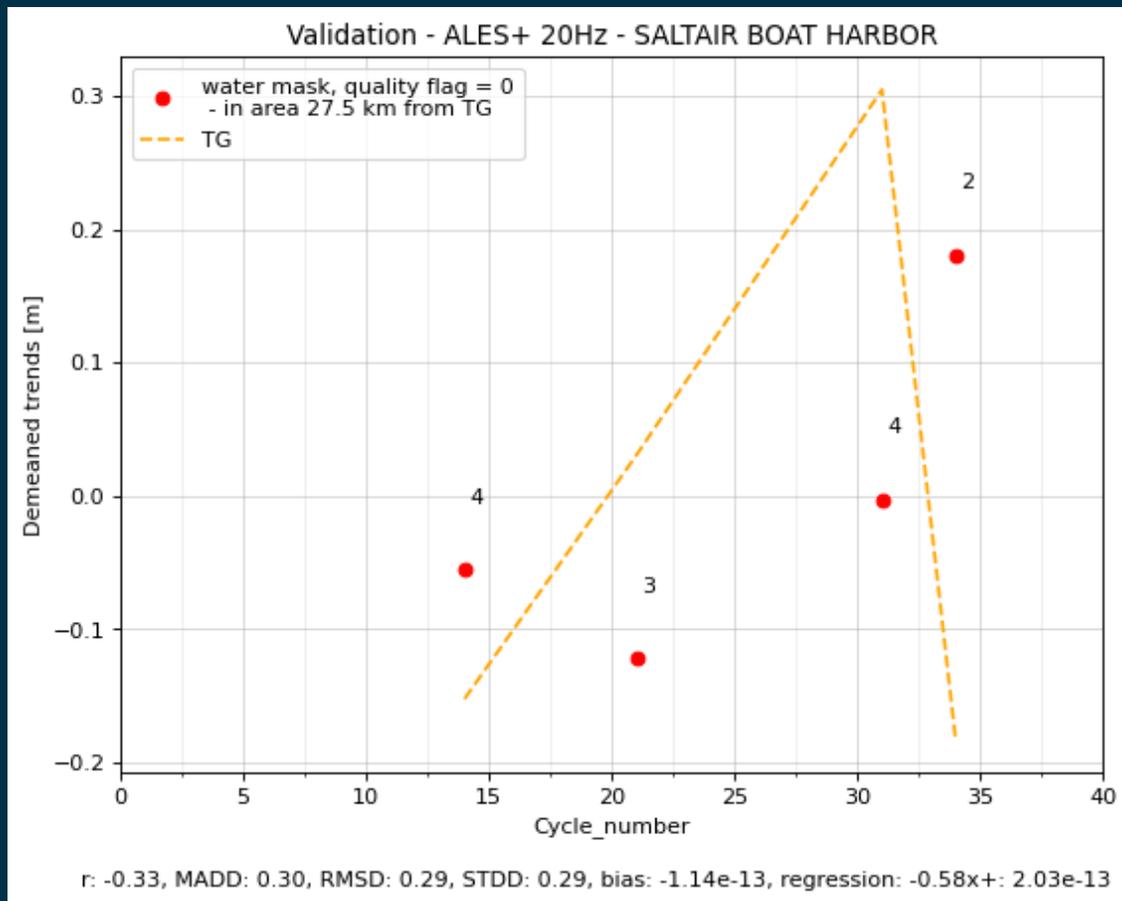


Track 275 – Misfit and quality flag filter, at gauge BOAT HARBOUR

Worst performance

ALES+ SAR

Best performance

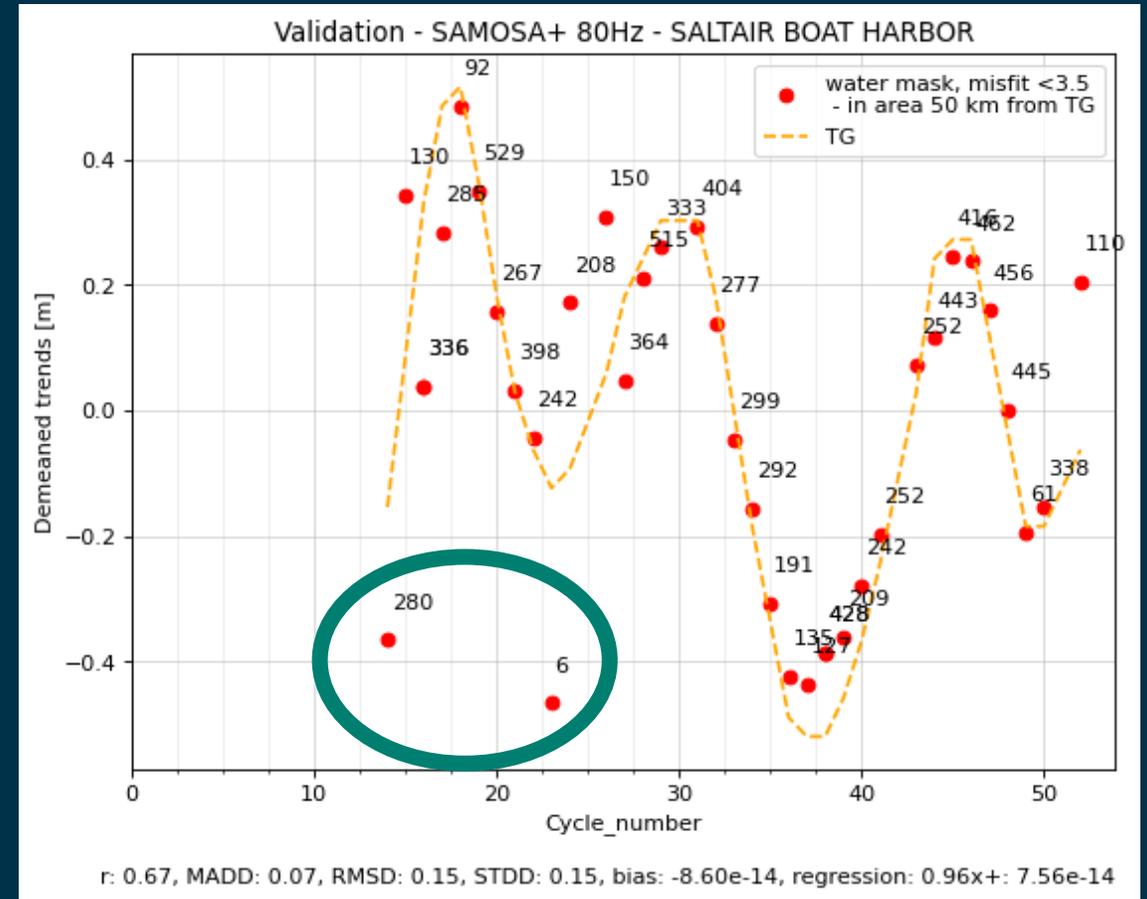
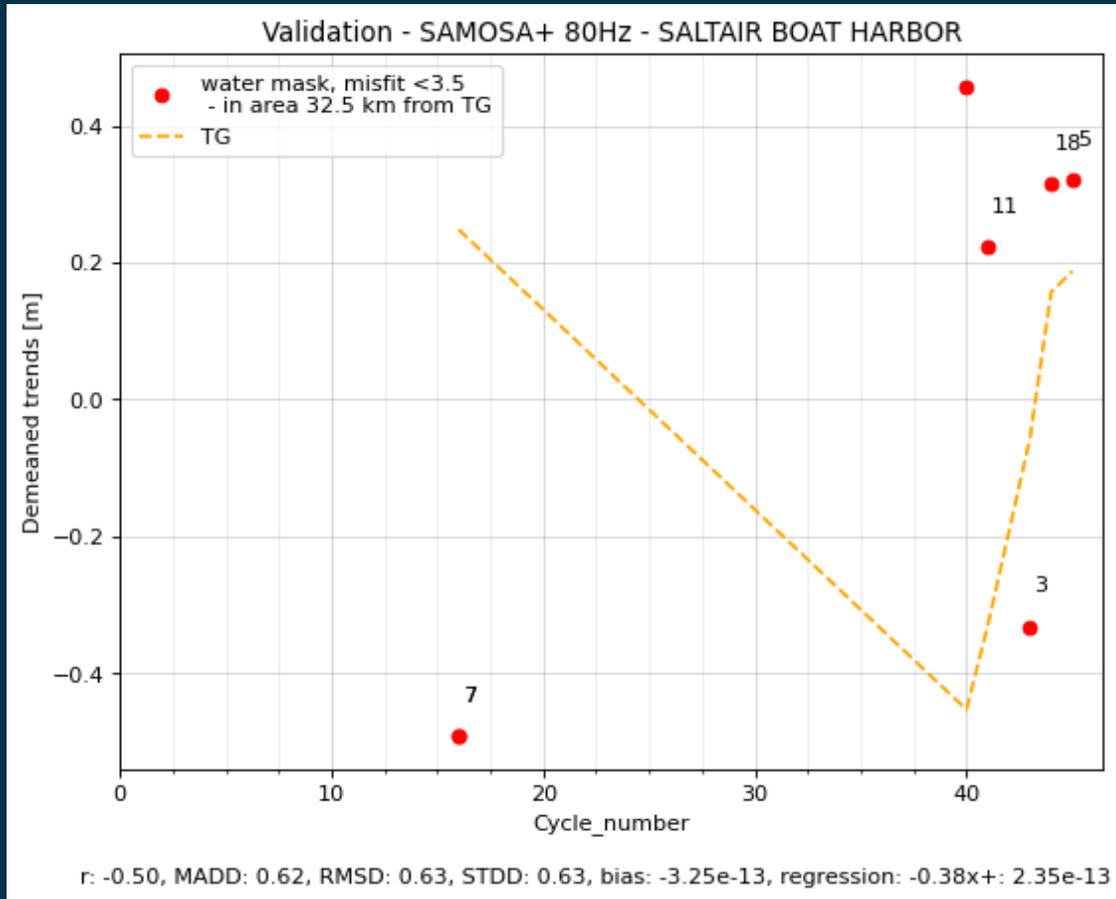


Track 275 – Misfit and quality flag filter, at gauge BOAT HARBOUR

Worst performance

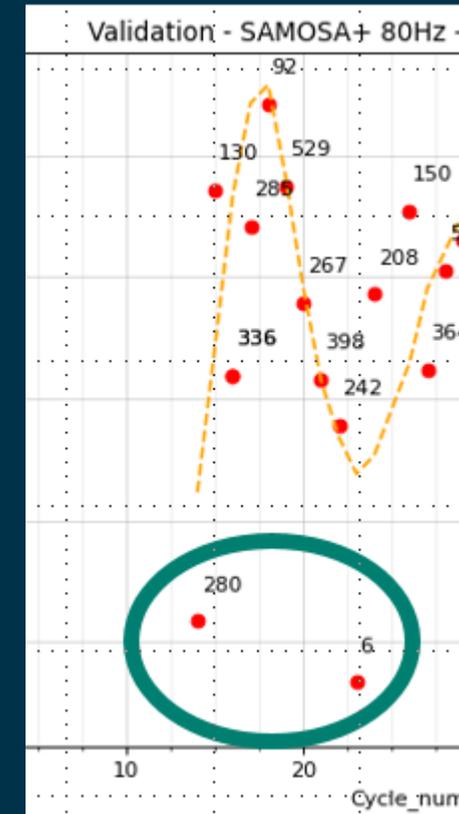
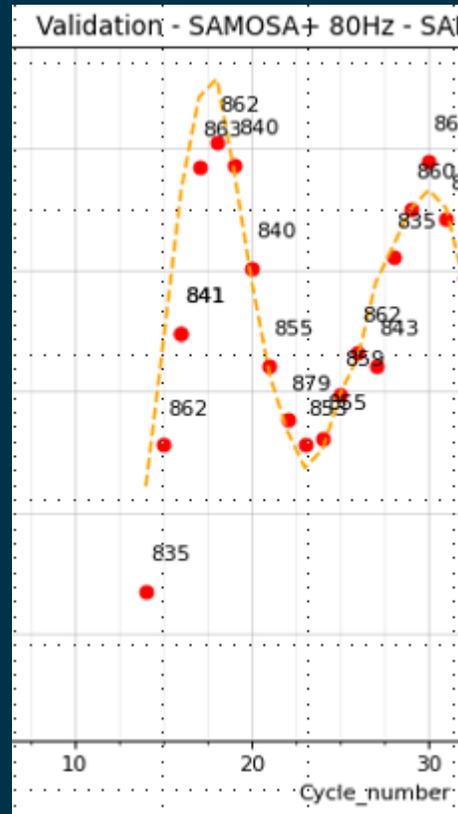
SAMOSA+

Best performance



Track 275 – Misfit and quality flag filter, at gauge BOAT HARBOUR

- ❑ Applying the quality flag to the ALES+ SAR data does not influence the results much.
- ❑ However, SAMOSA+ performs worse when applying the Misfit filter. The outliers which were present in the non-filter dataset are not removed. Only the number of measurements are reduced
- ❑ Additionally, the Misfit filter removes partly so many measurements that the median of the remaining measurements is further away from the gauge data (left image).

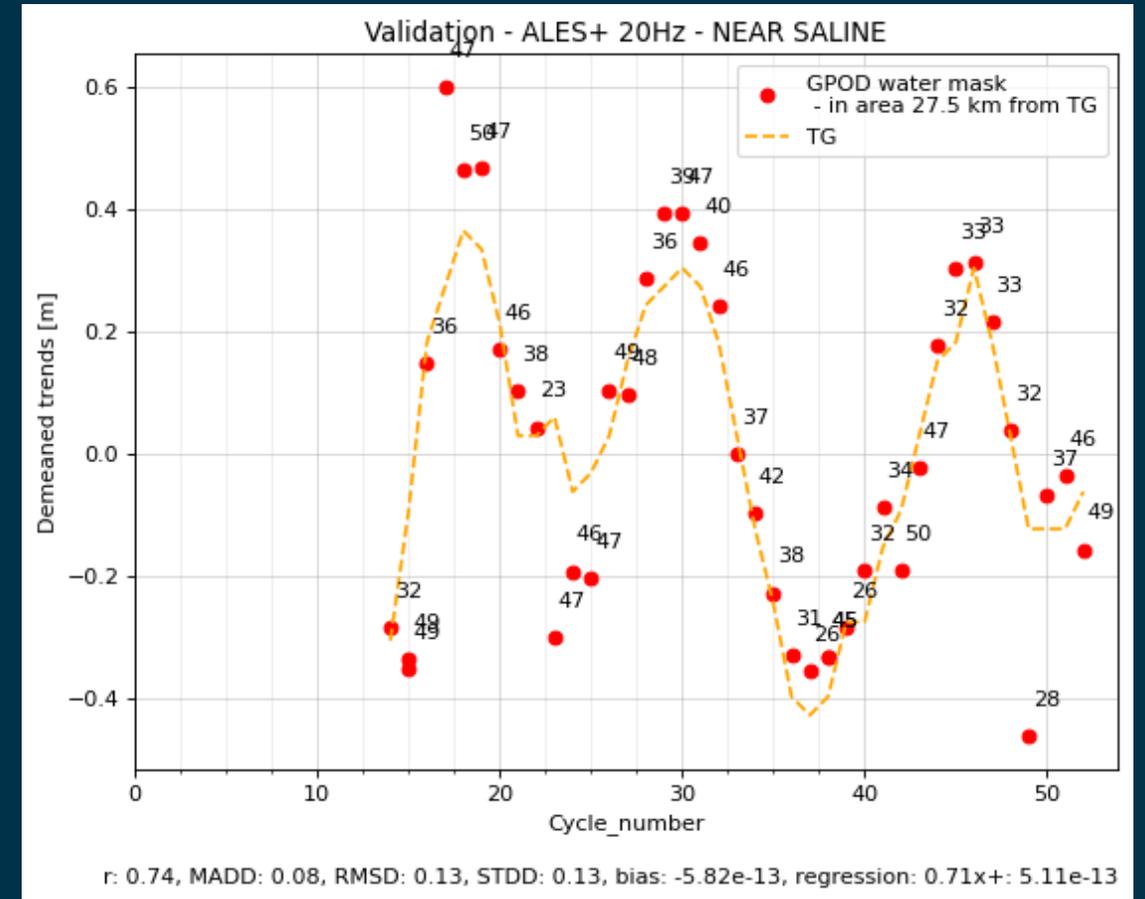
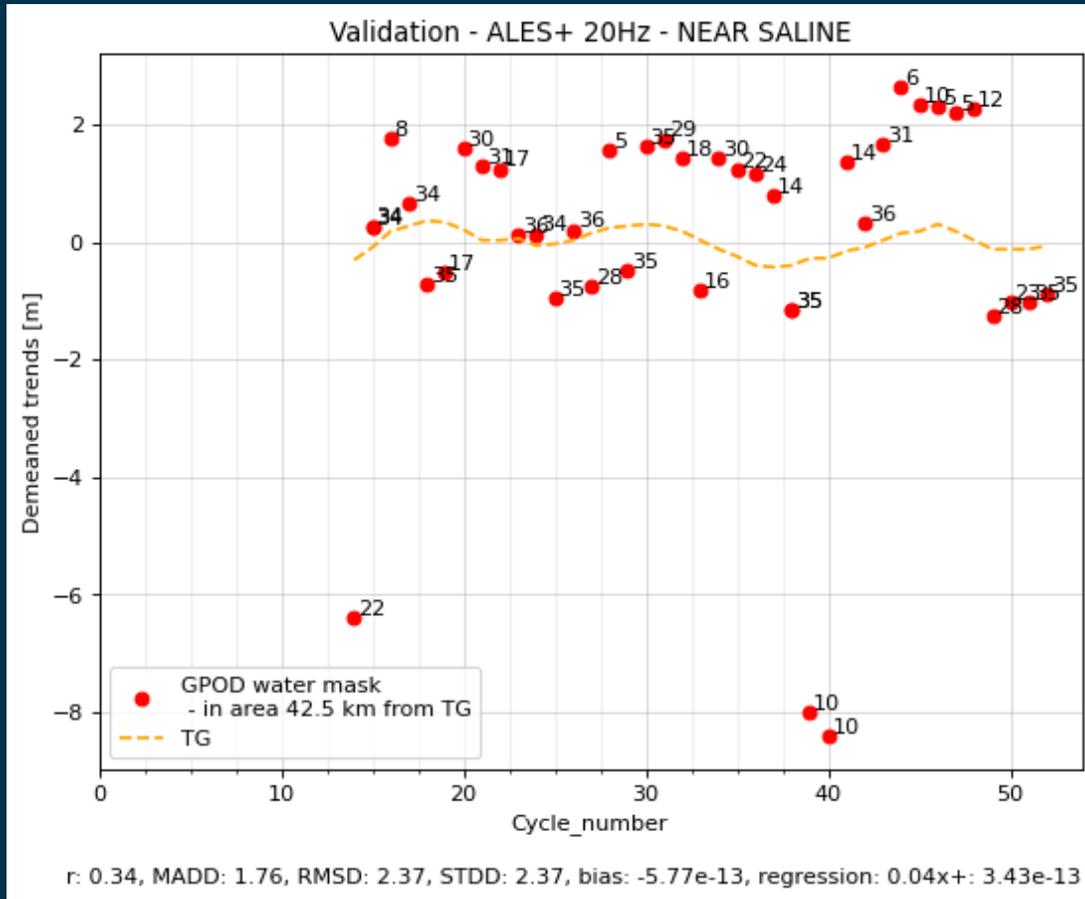


Track 275 – no filter, at gauge NEAR SALINE

Worst performance

ALES+ SAR

Best performance

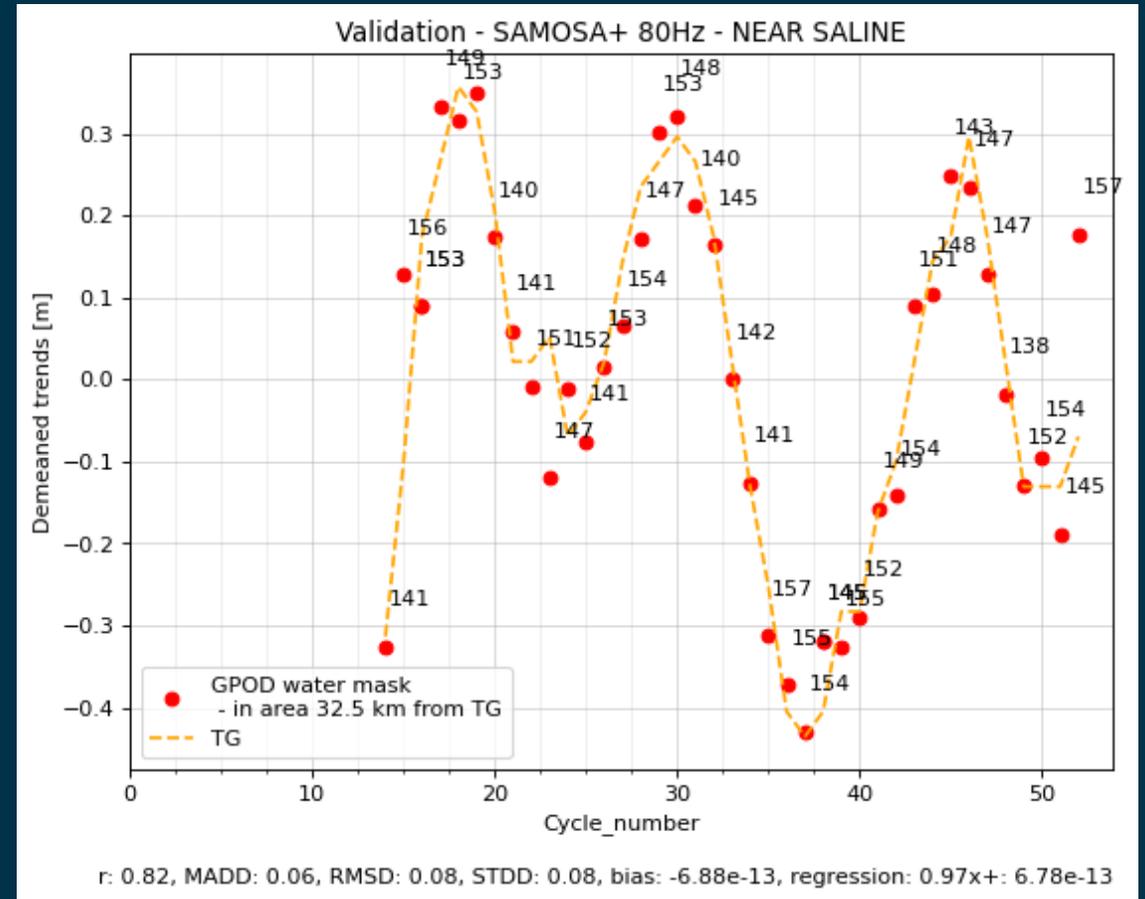
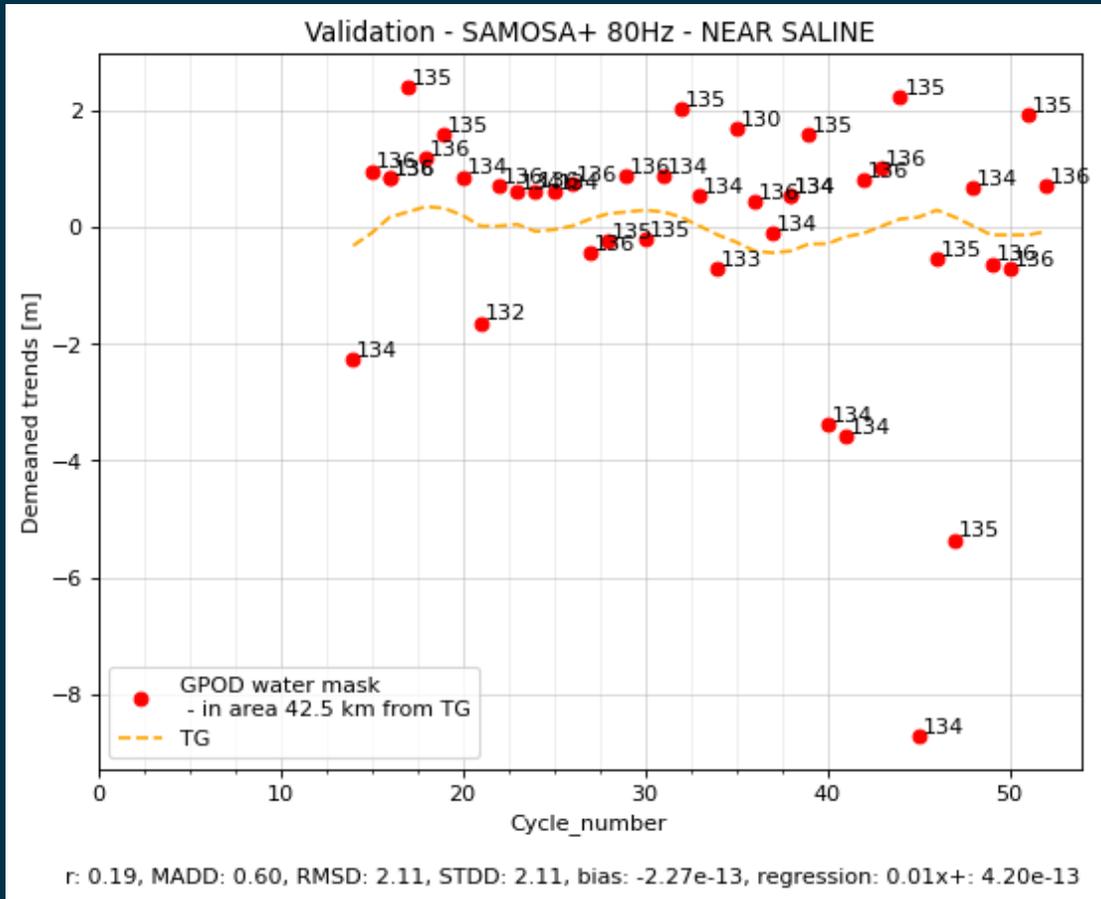


Track 275 – no filter, at gauge NEAR SALINE

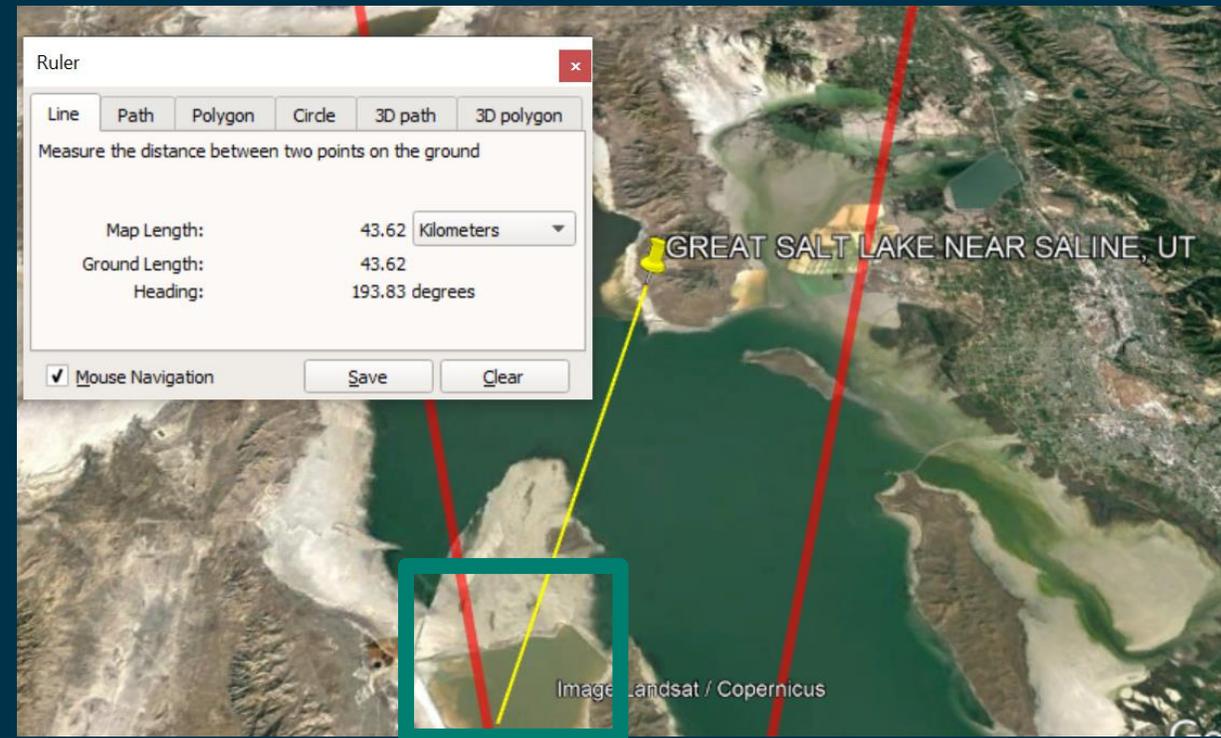
Worst performance

SAMOSA+

Best performance



- ❑ All retrackers perform worst in region 40-45 km away from the gauge. Again, this corresponds to the **same region** resulting in the worst performance when comparing with gauge NEAR SALINE.
- ❑ ALES+ SAR exhibits more outliers and therefore performs slightly worse than SAMOSA+. Since ALES+ SAR is processed with a posting rate of 20 Hz, significantly less estimates are acquired over the Lake area.

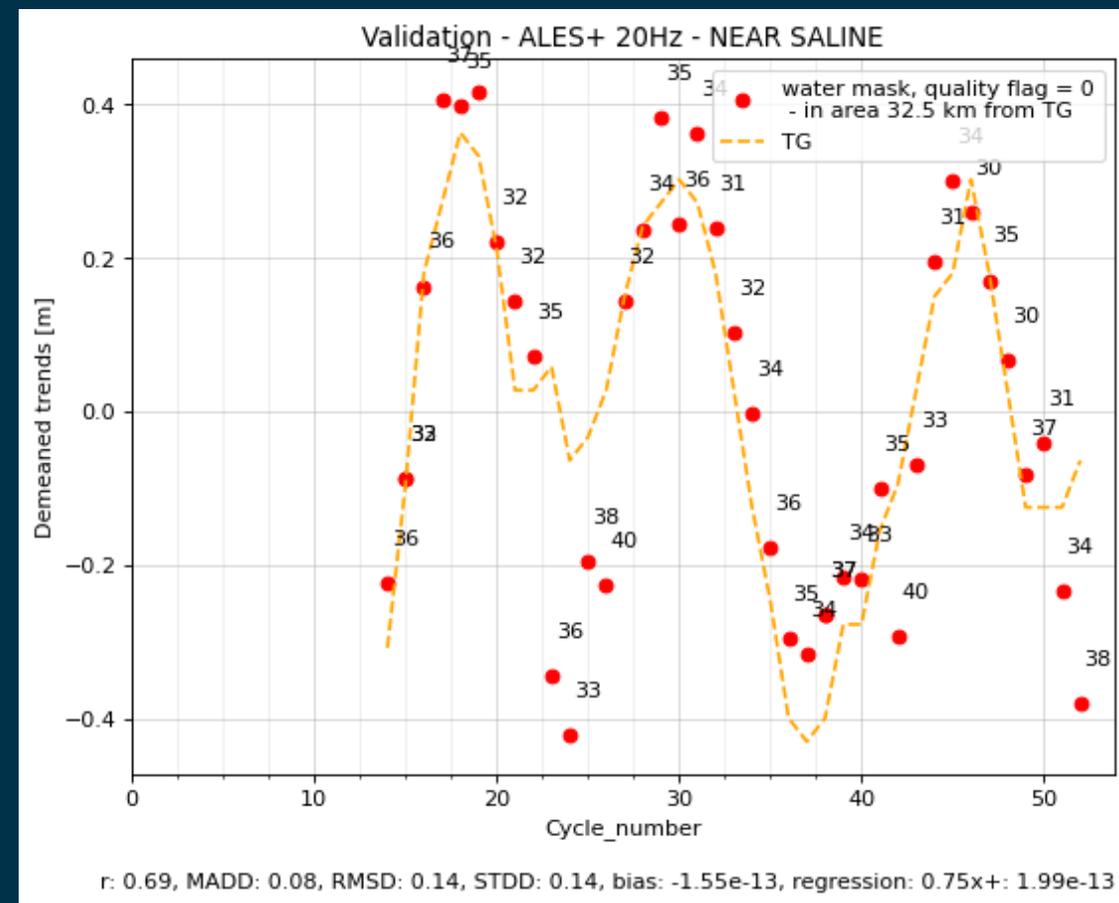
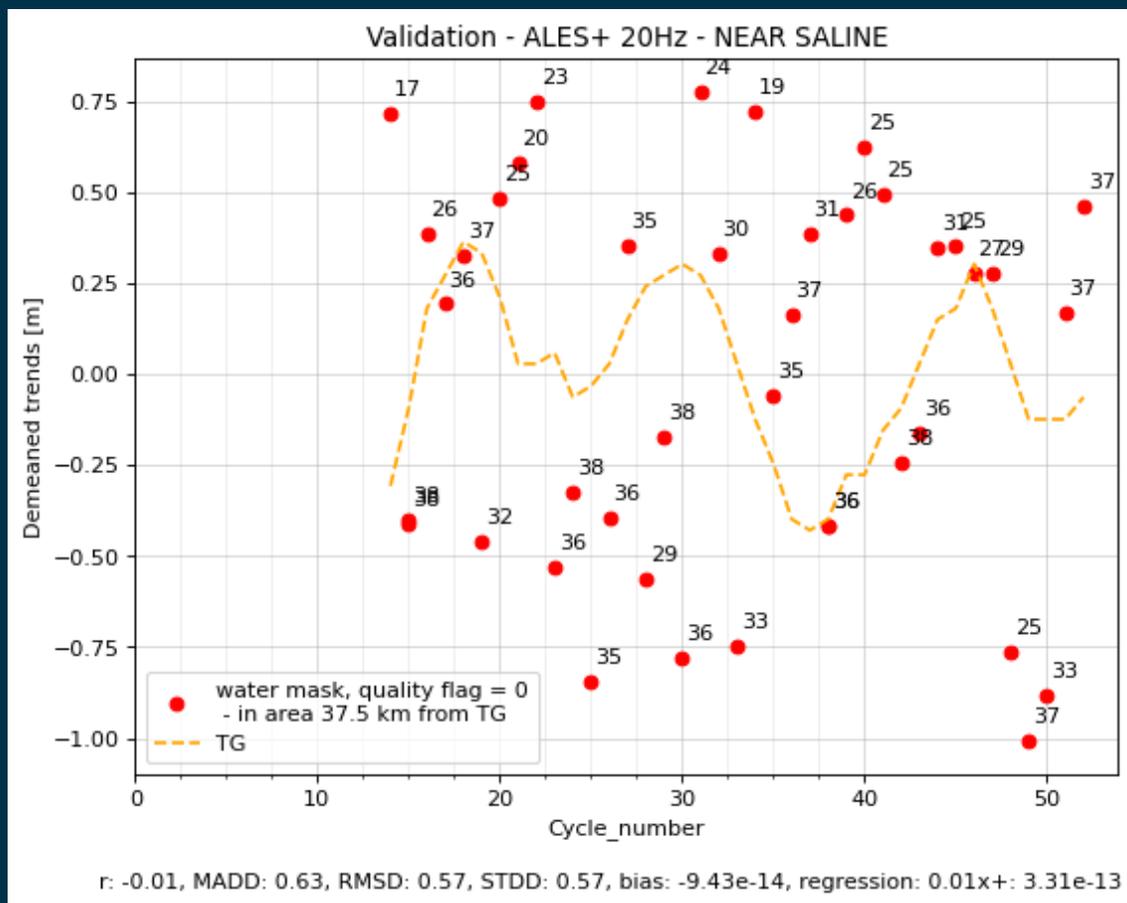


Track 275 – Misfit and quality flag filter, at gauge NEAR SALINE

Worst performance

ALES+ SAR

Best performance

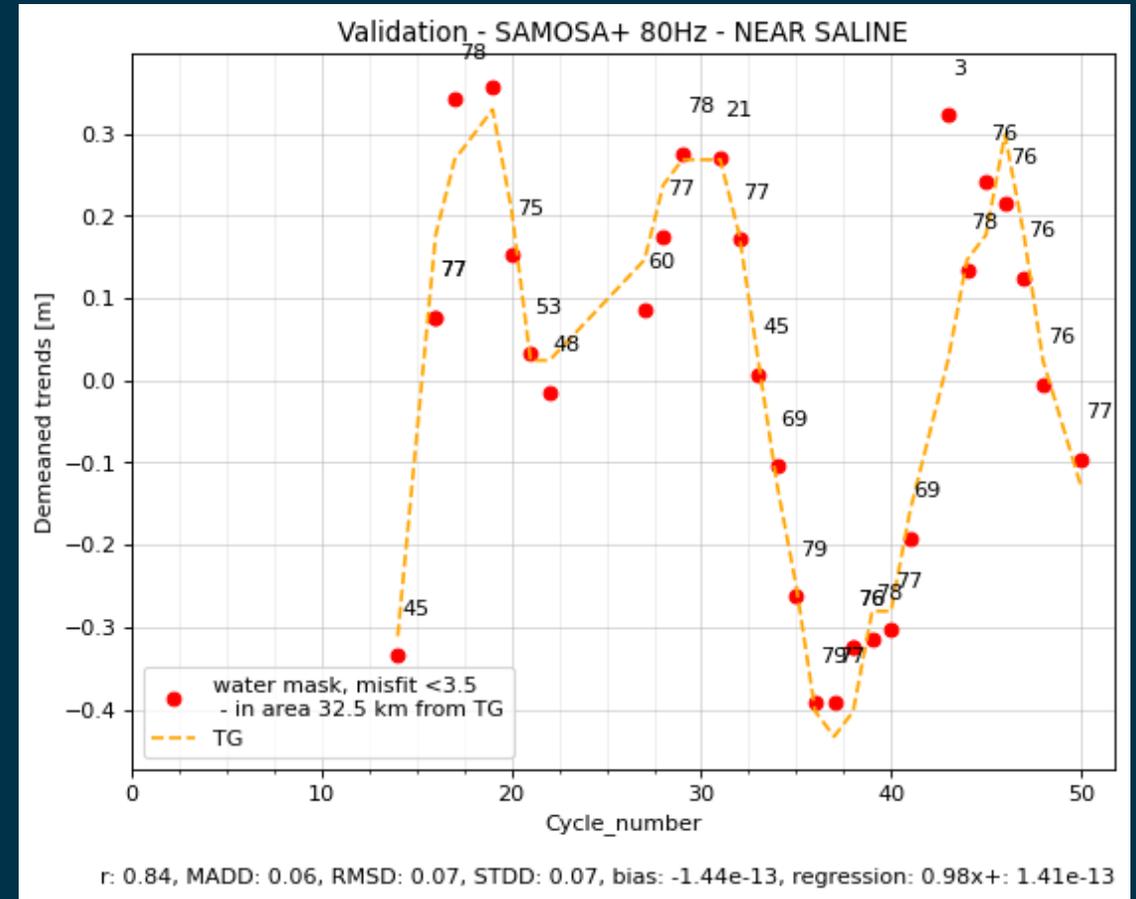
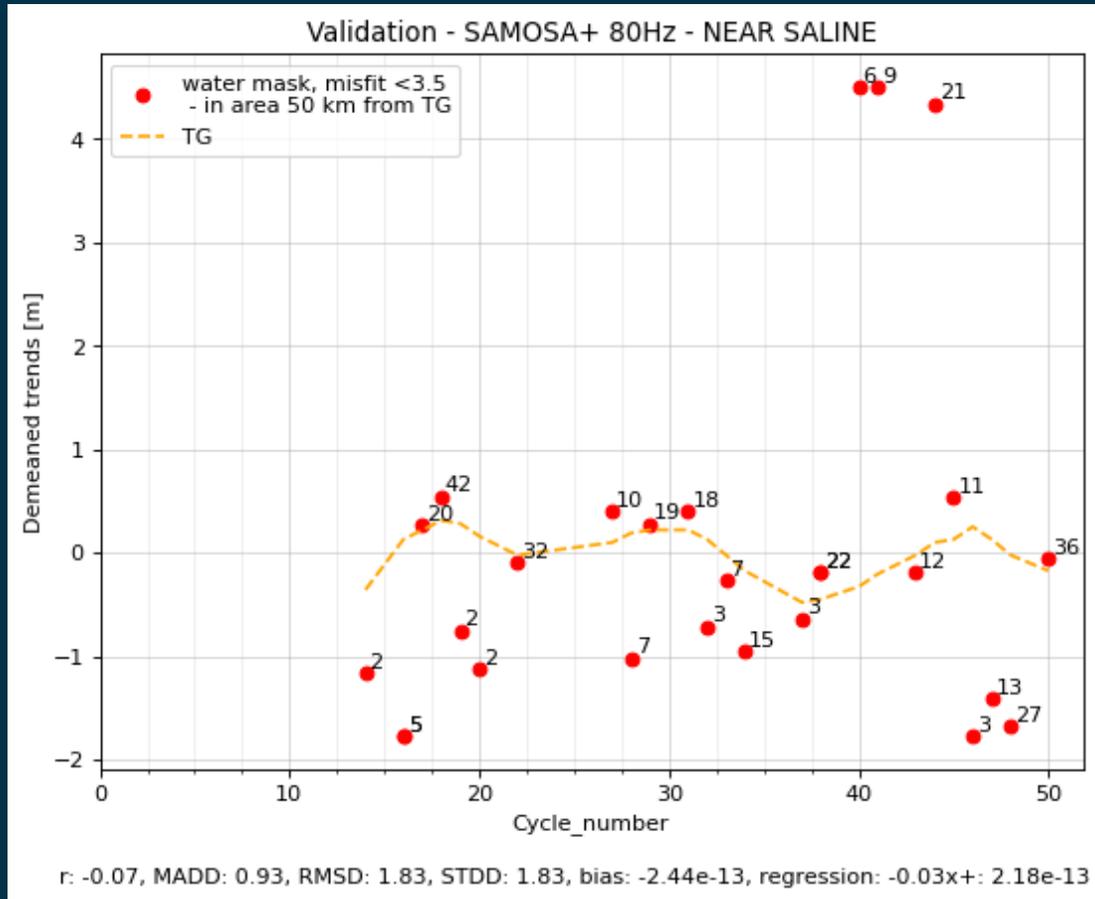


Track 275 – Misfit and quality flag filter, at gauge NEAR SALINE

Worst performance

SAMOSA+

Best performance



Track 275 – Misfit and quality flag filter, at gauge NEAR SALINE

- ❑ The Misfit filter improves the performance of SAMOSA+ in comparison to the no-filter dataset.
- ❑ The ALES+ SAR quality flag removes measurements from both outliers and accurate measurement. However, the performance decreases as outliers are not completely eliminated.

Results

Track 369

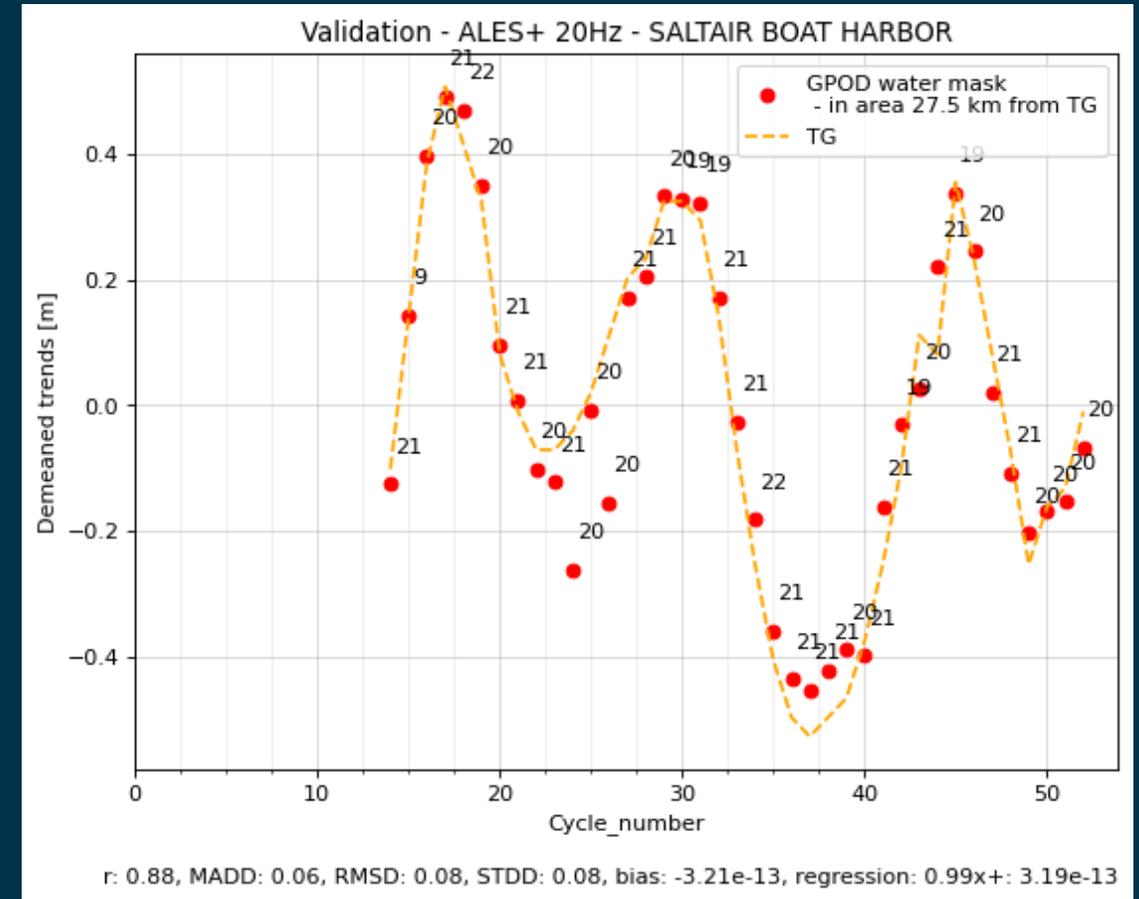
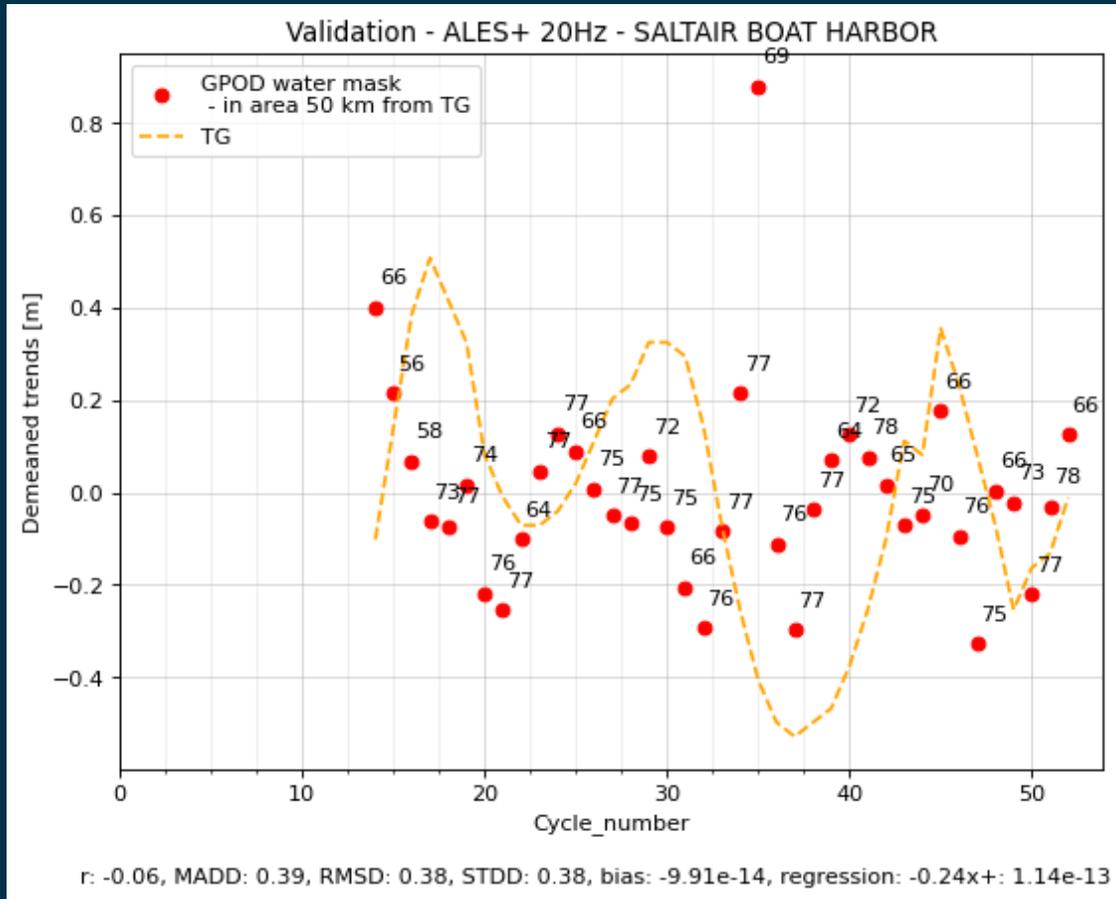


Track 369— no filter, at gauge BOAT HARBOUR

Worst performance

ALES+ SAR

Best performance

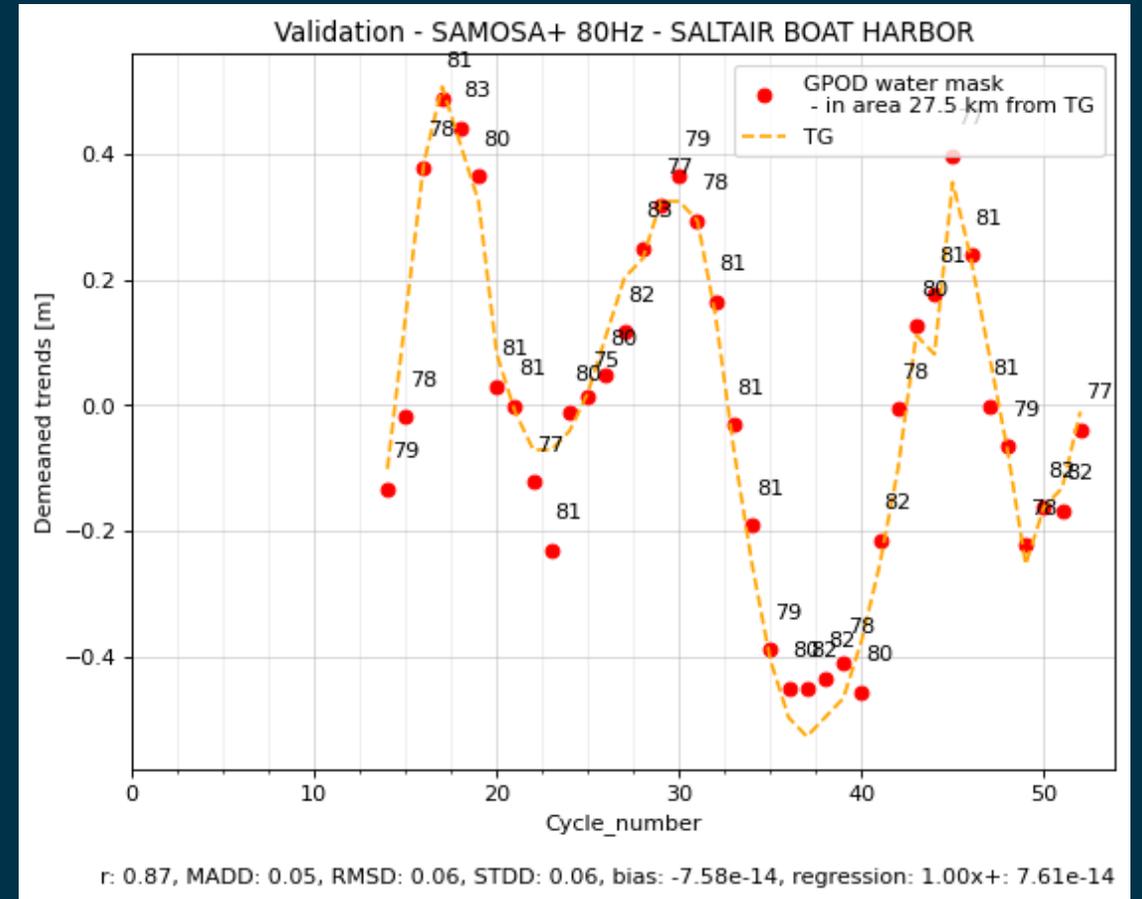
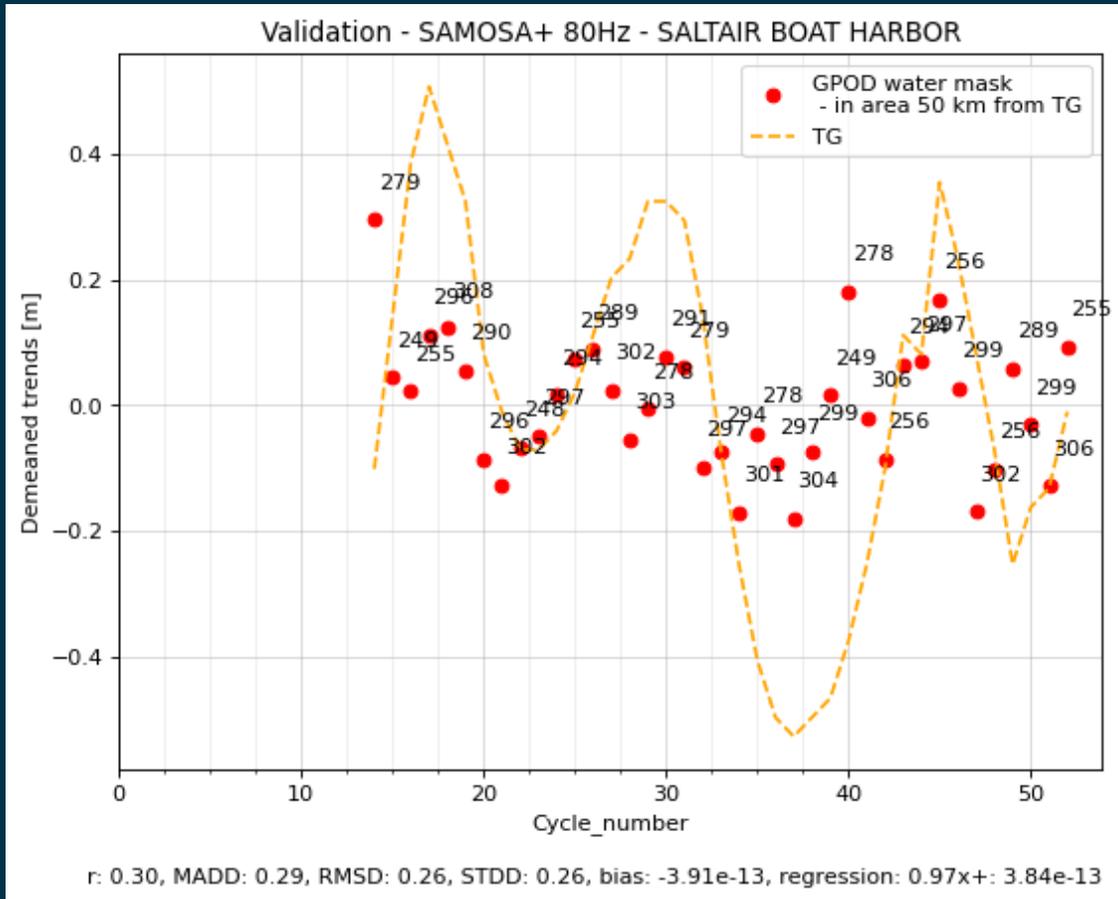


Track 369 – no filter, at gauge BOAT HARBOUR

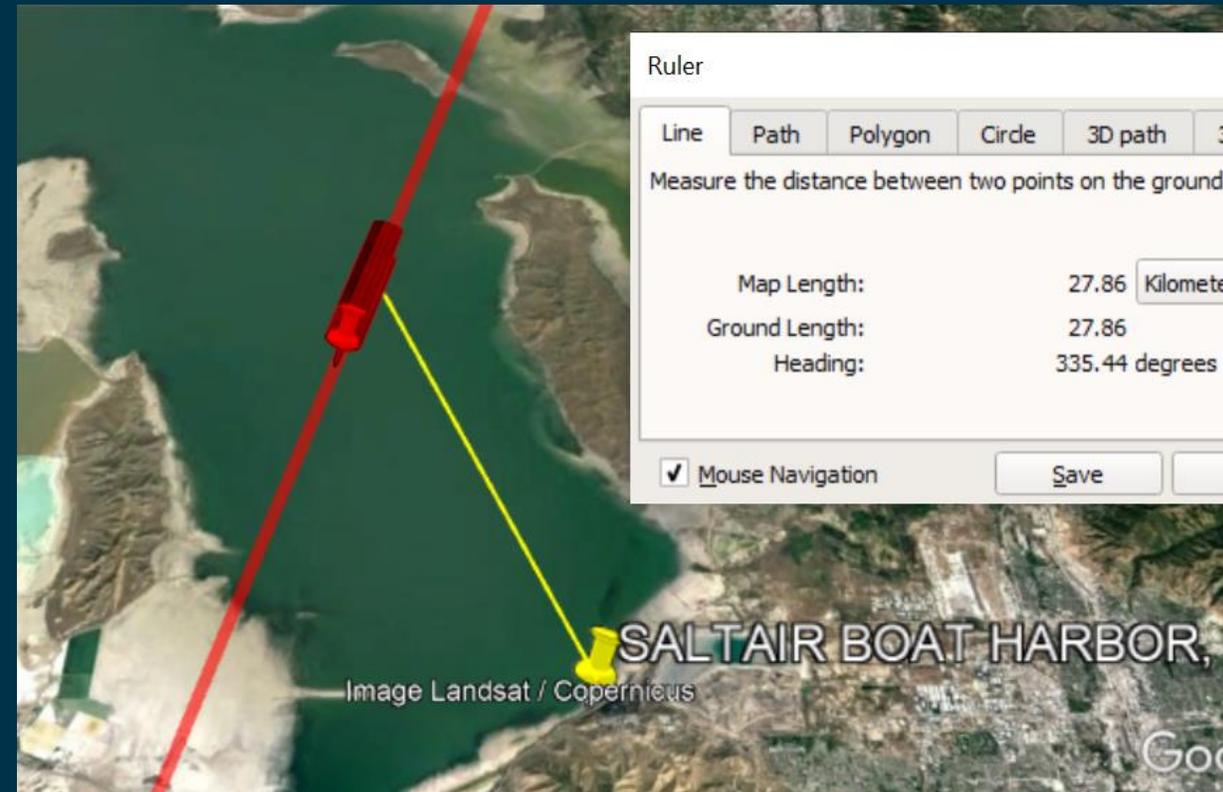
Worst performance

SAMOSA+

Best performance



- ❑ Both retrackerers perform well in the region 25-30 km (left images, red markers) and badly in the region > 50 km.
- ❑ The question arises why the measurements are not better closer to the gauge. A possible explanation could be that the closer areas might not always be flooded as indicated by the white colour (Pekels water mask indicates variable water occurrence as well). In addition, the track is relatively close to the island which might lead to a corruption of the waveforms.
- ❑ The metrics are similar for the best case, although the estimates of ALES+ SAR are based on a smaller number of measurements.

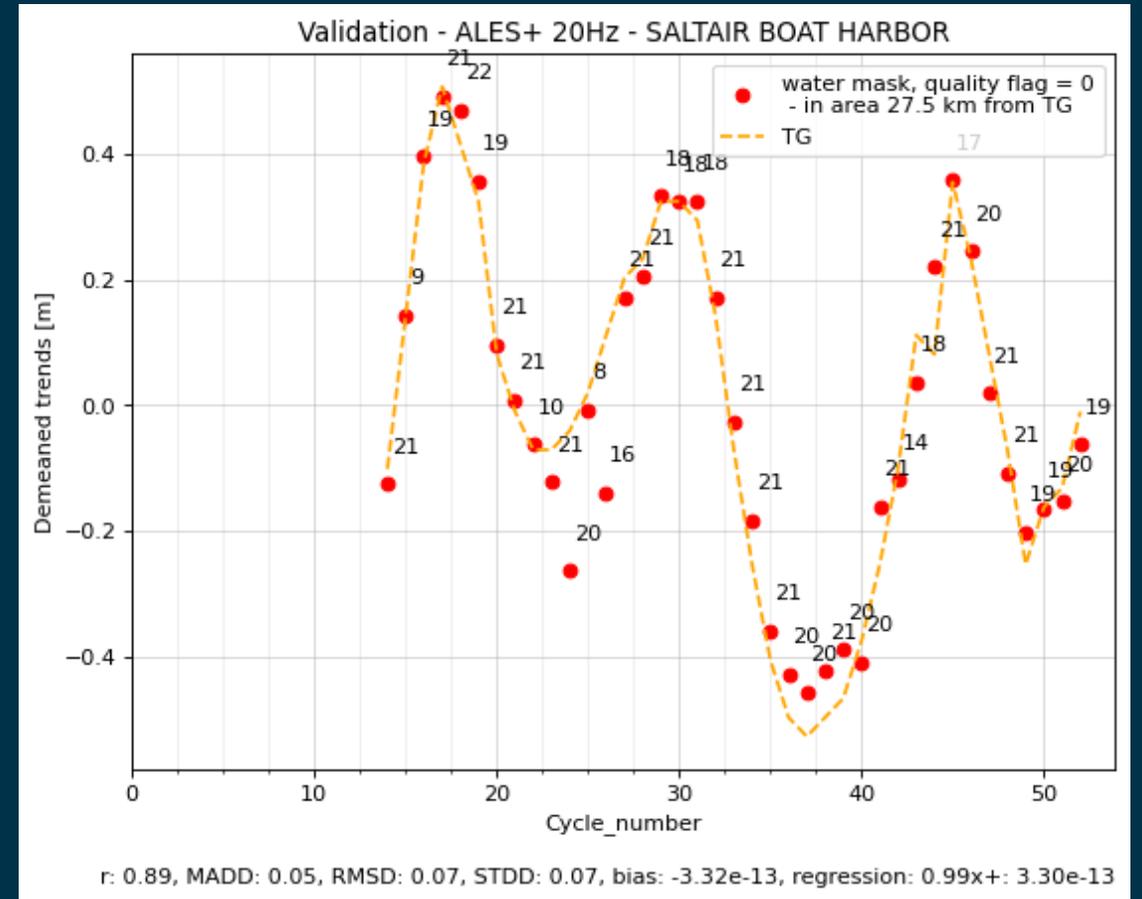
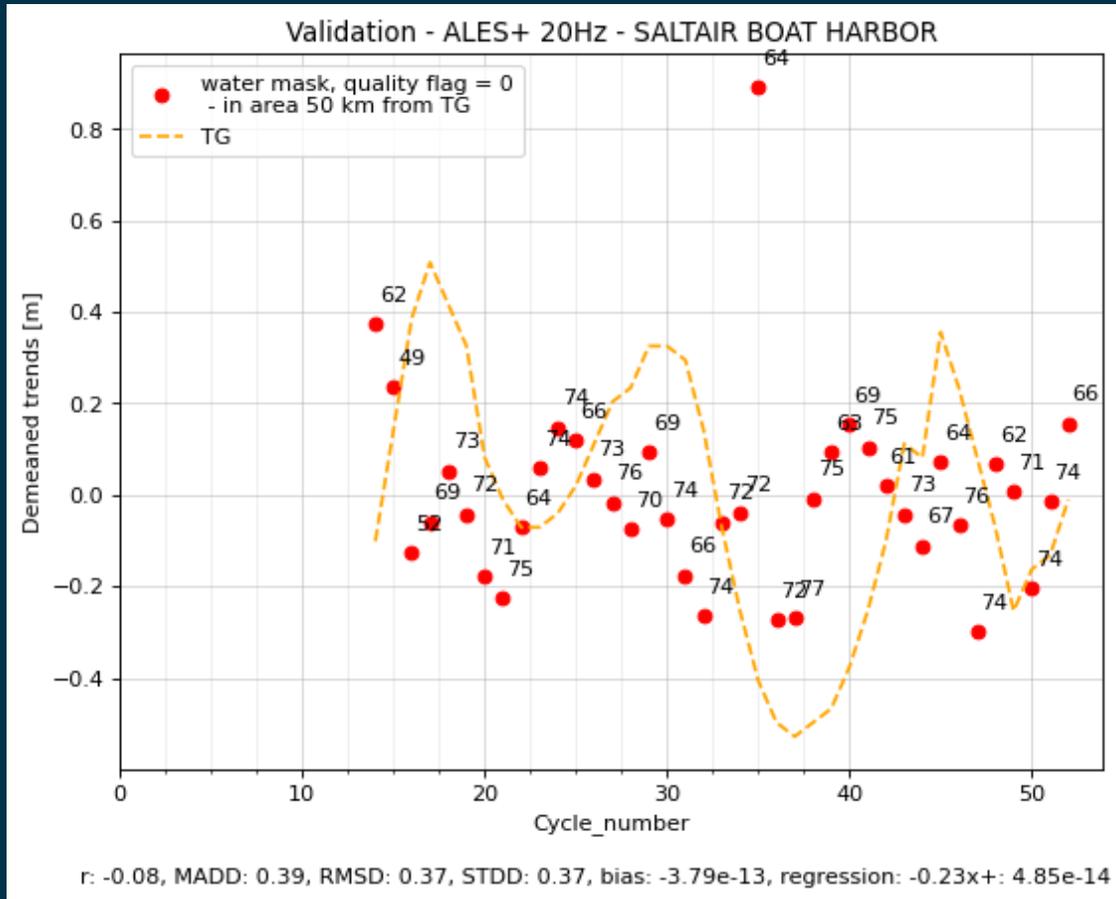


Track 369 – Misfit and quality flag filter, at gauge BOAT HARBOUR

Worst performance

ALES+ SAR

Best performance

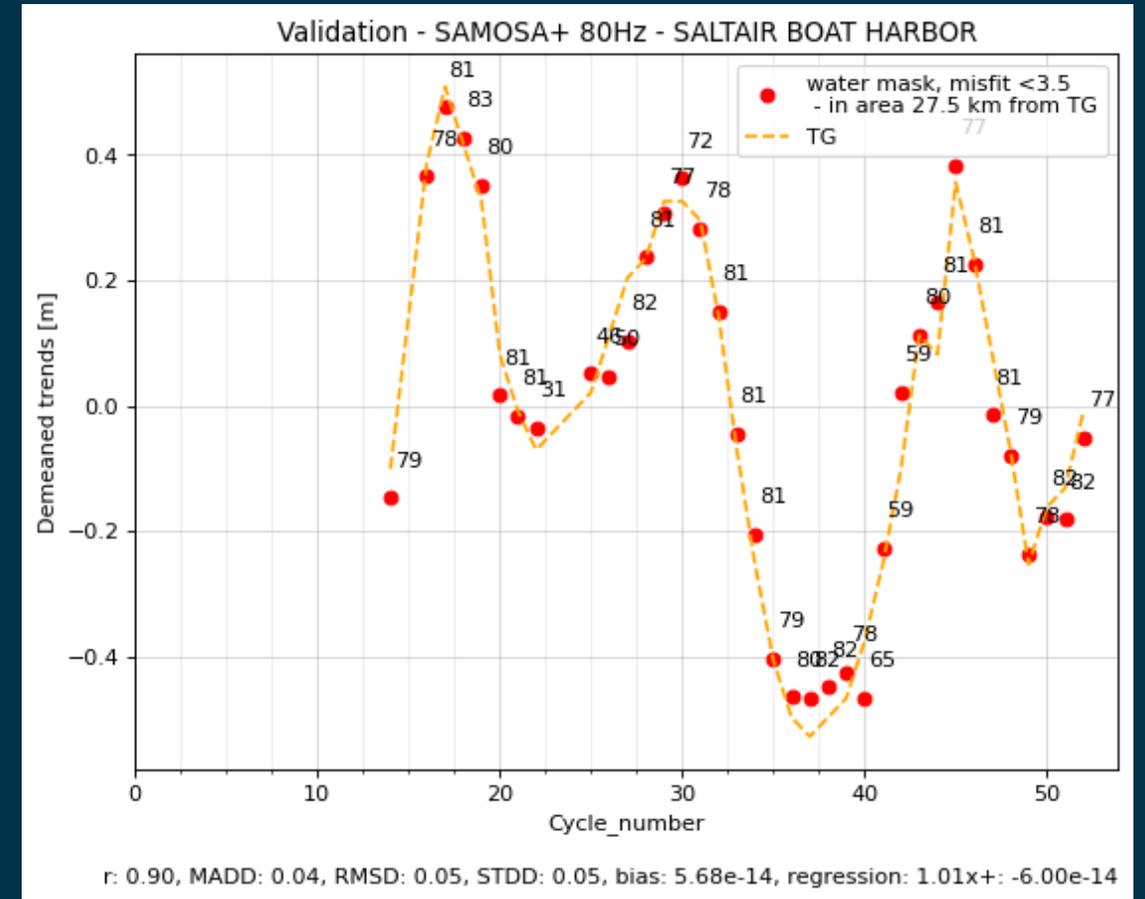
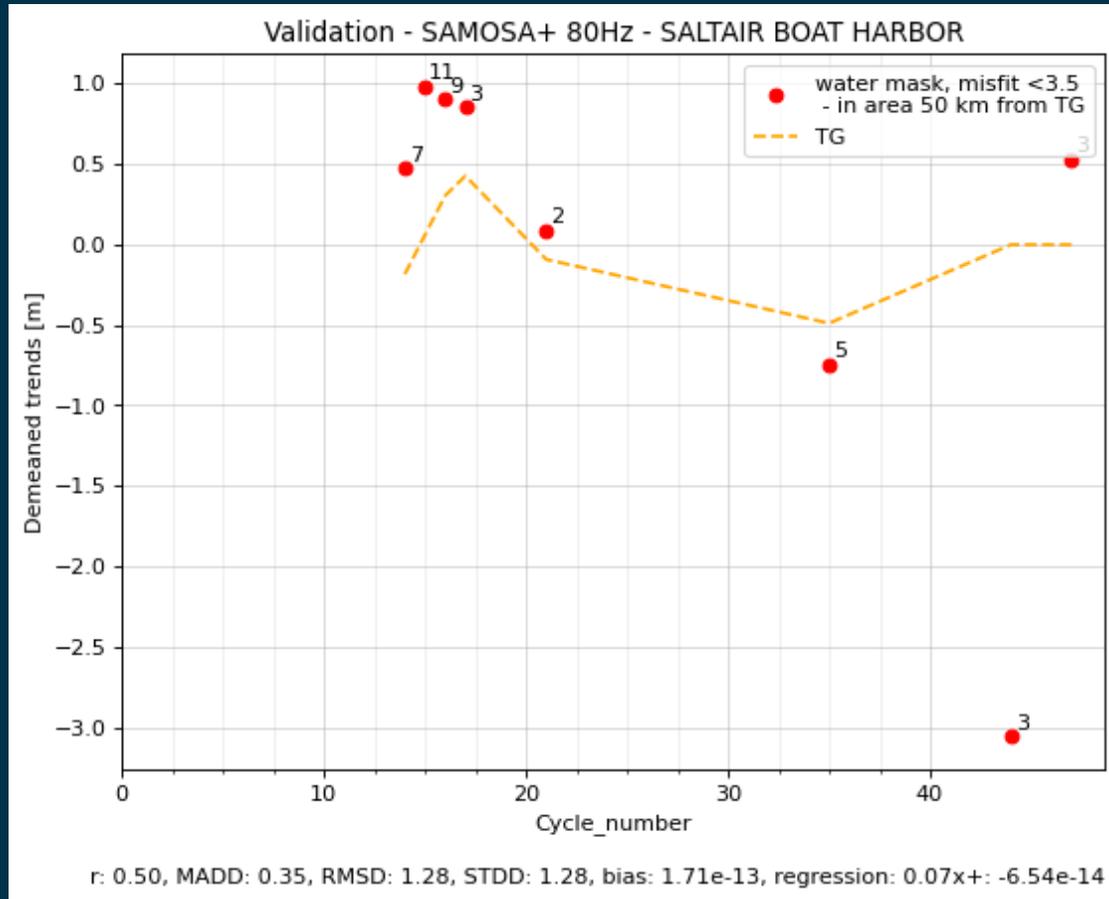


Track 369 – Misfit and quality flag filter, at gauge BOAT HARBOUR

Worst performance

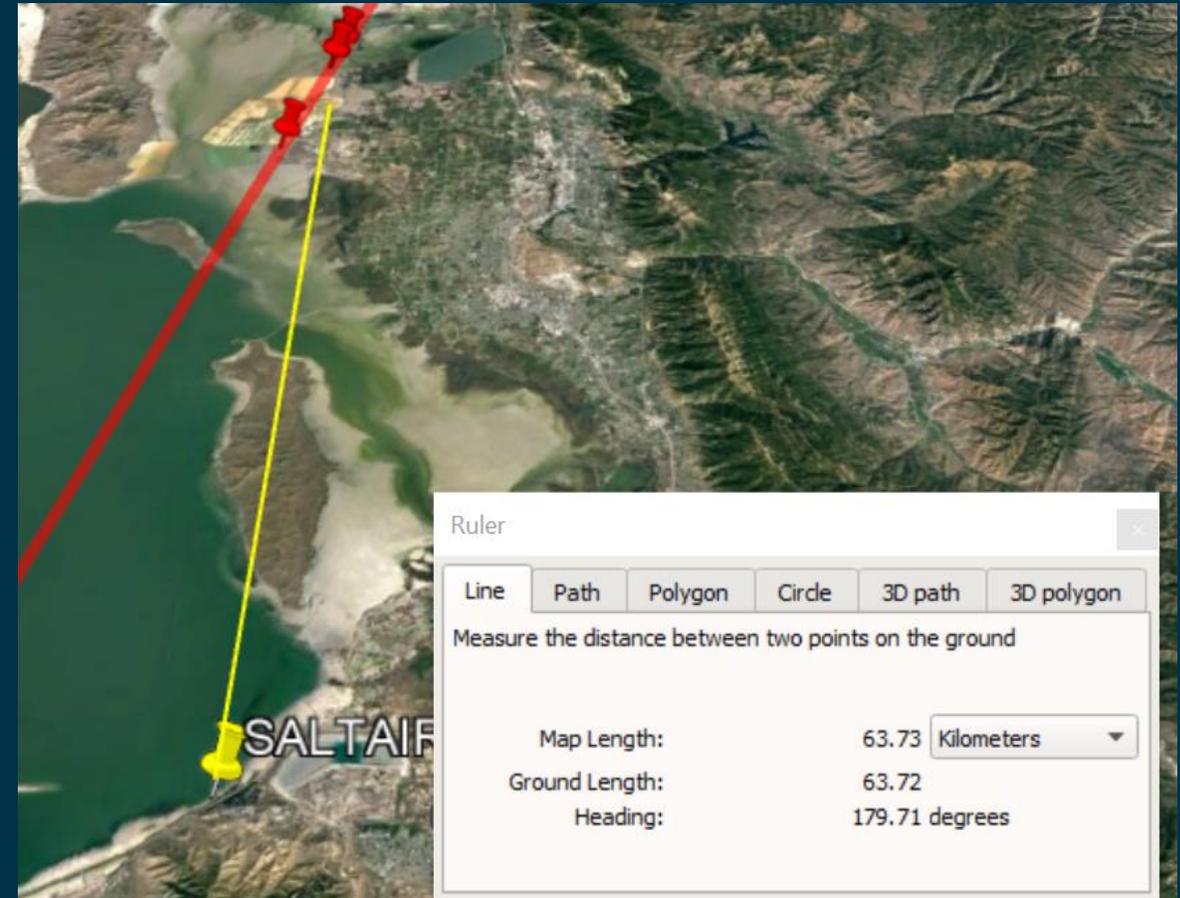
SAMOSA+

Best performance



Track 369 – Misfit and quality flag filter, at gauge BOAT HARBOUR

- ❑ The ALES+ SAR data improves slightly when applying the quality flag.
- ❑ SAMOSA+ shows very good metrics after the Misfit filtering.
- ❑ The best data is still found in region 25-30 km.
- ❑ The filtering cannot compensate for changing characteristics of salinity and water level in the north-eastern arm of the lake.

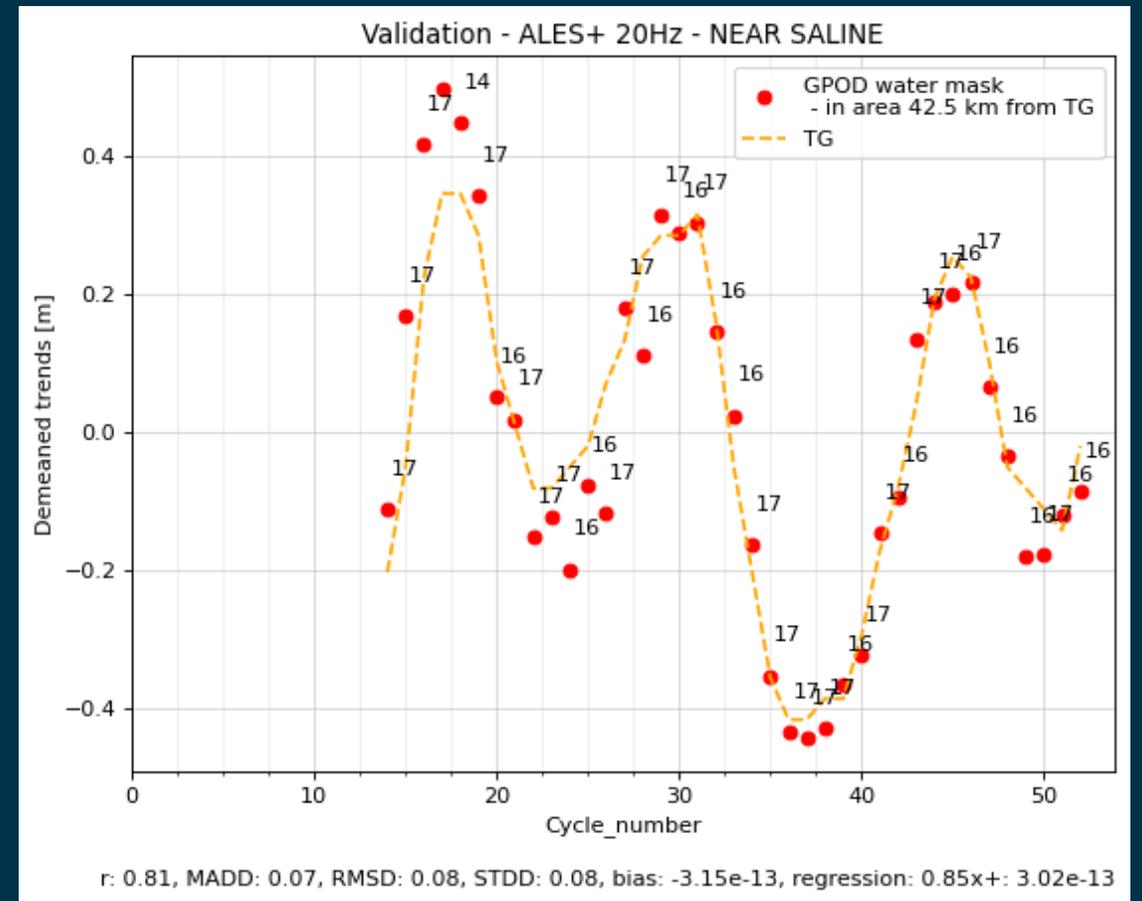
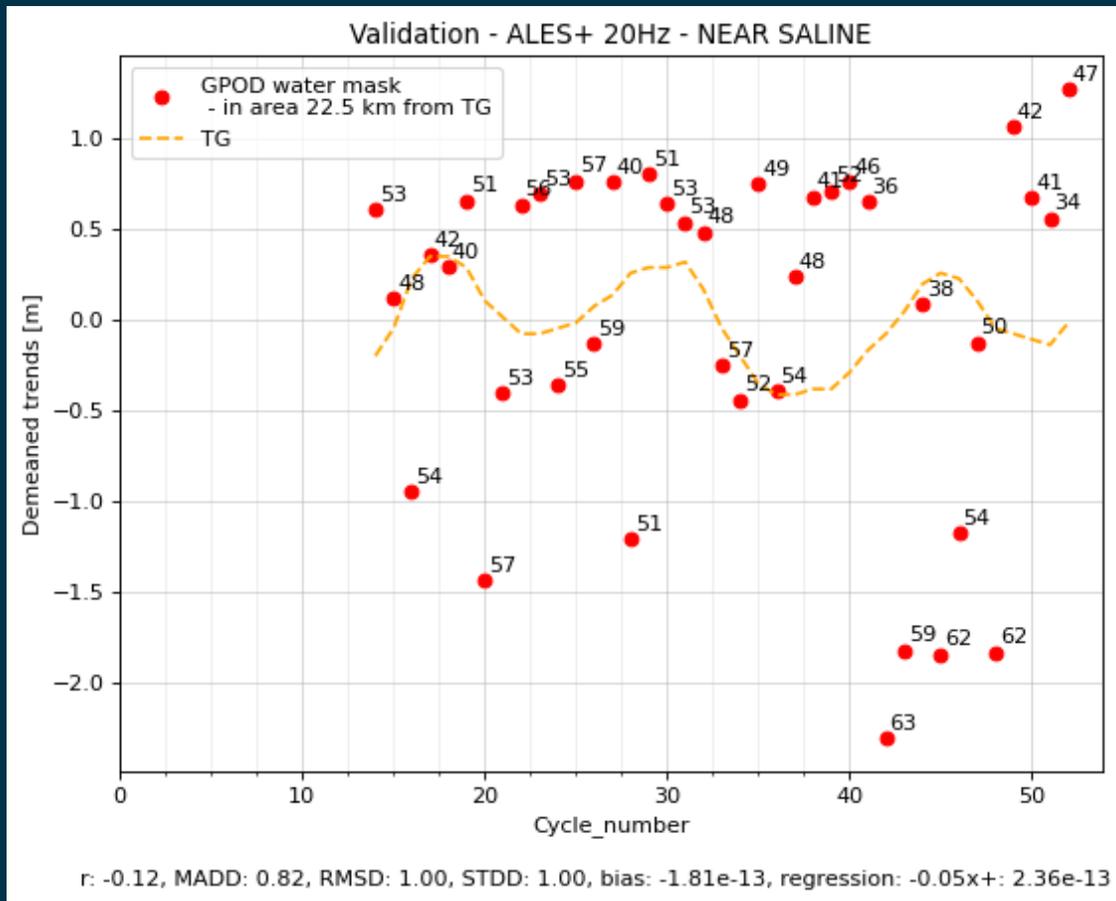


Track 369 – no filter, at gauge NEAR SALINE

Worst performance

ALES+ SAR

Best performance

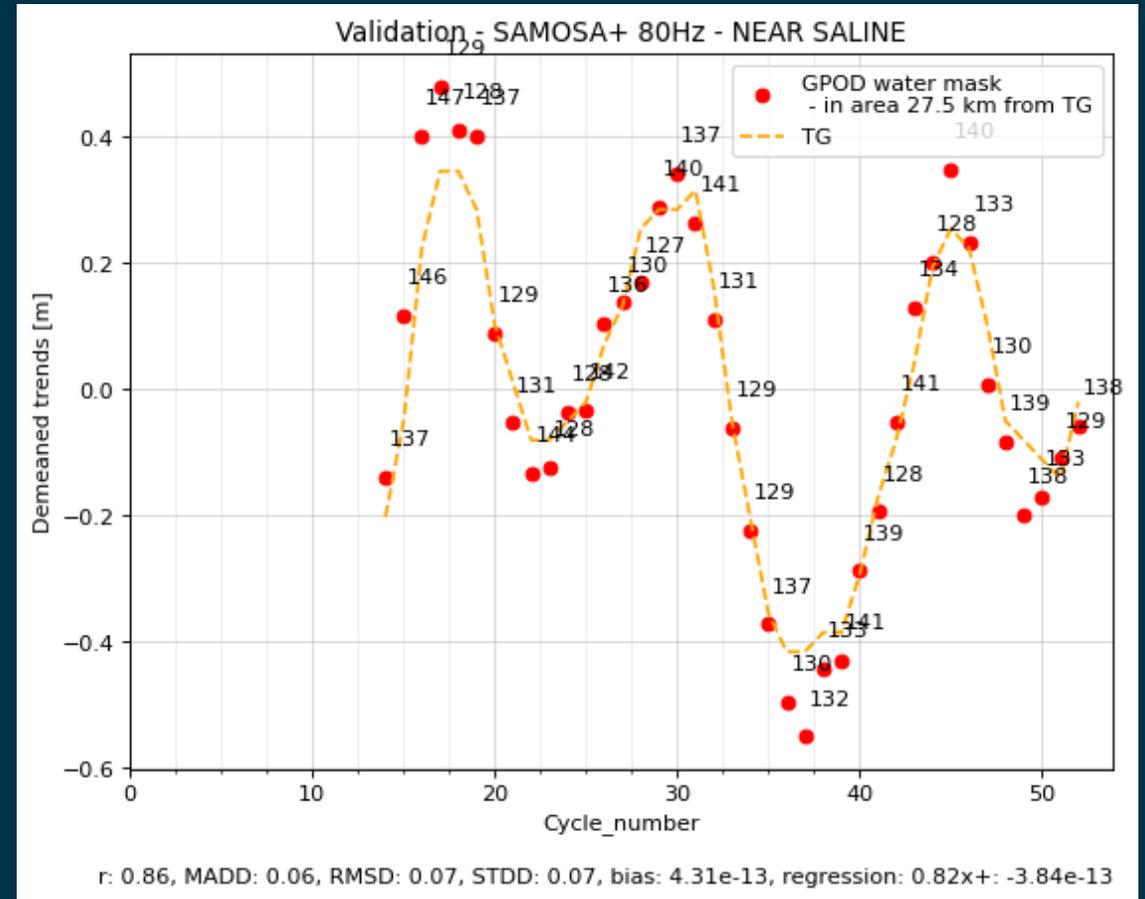
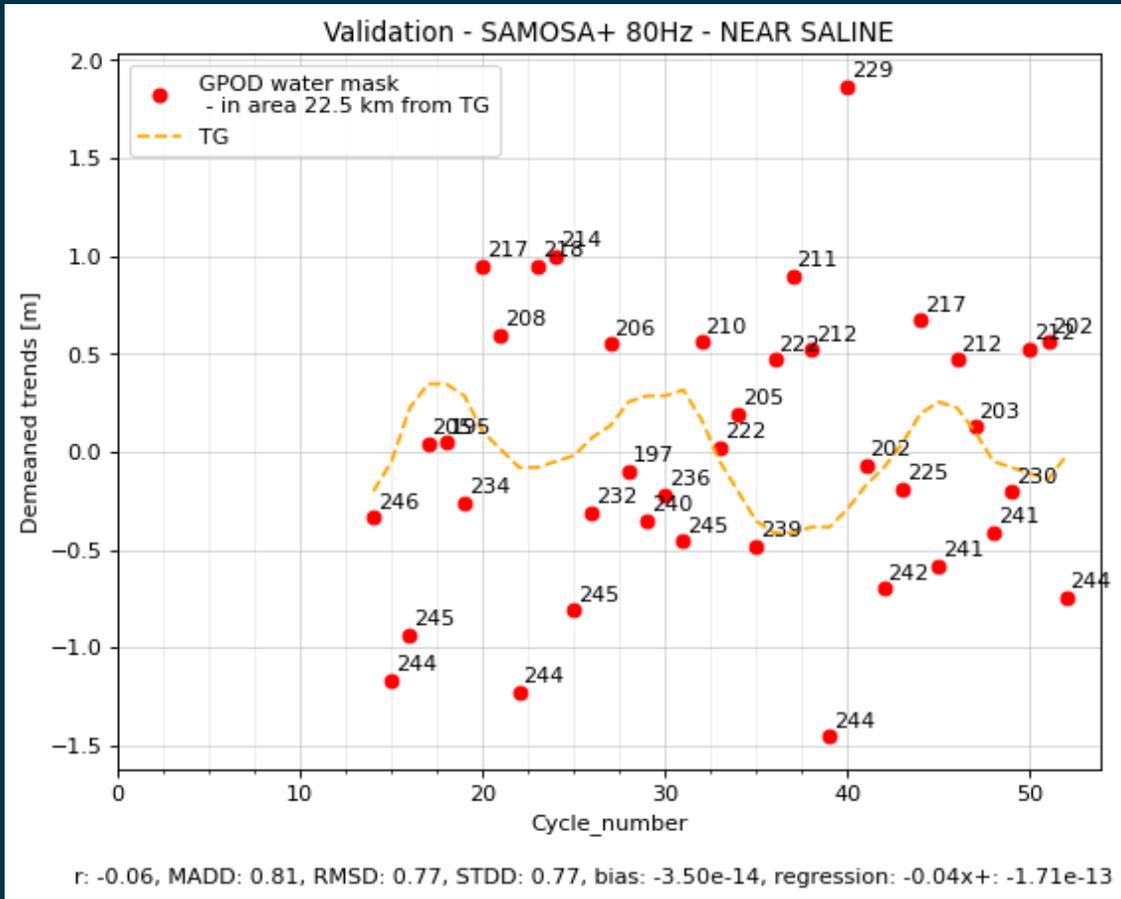


Track 369 – no filter, at gauge NEAR SALINE

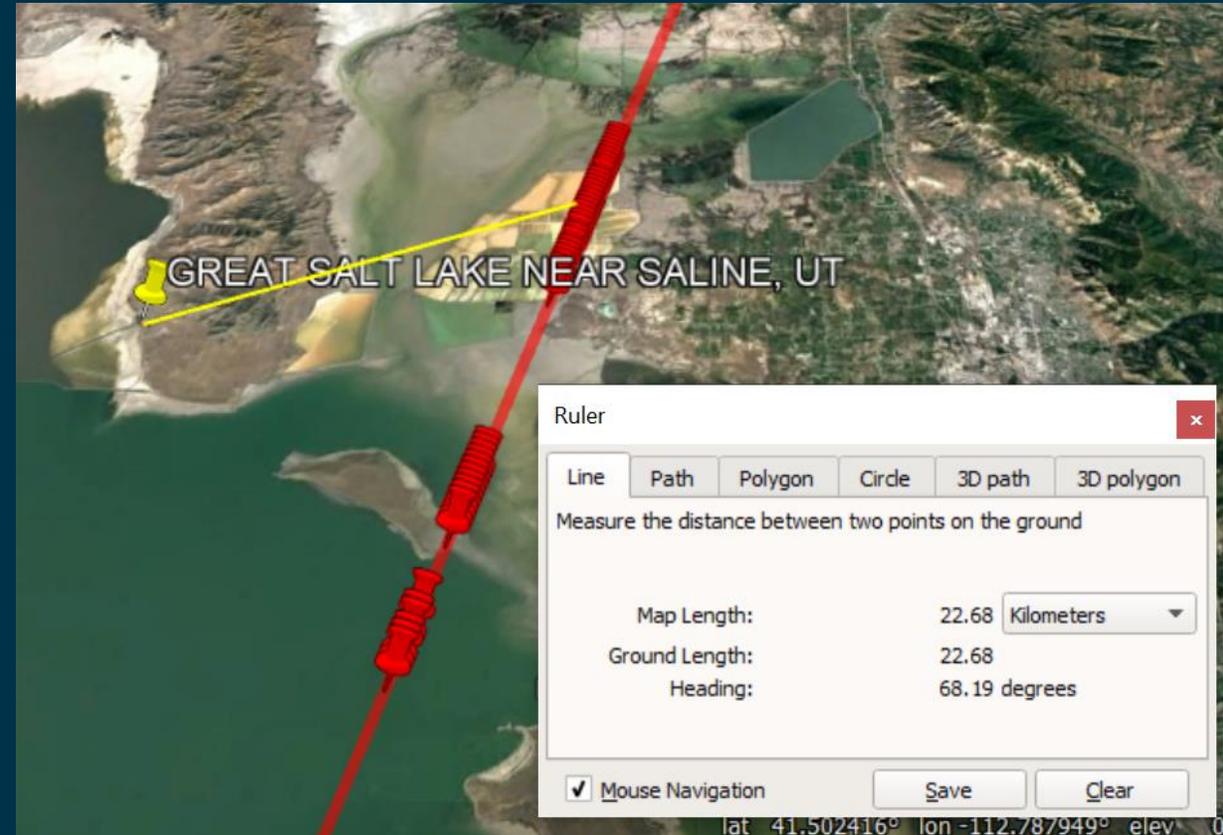
Worst performance

SAMOSA+

Best performance



- ❑ Both retrackerers perform worst in the region of 20-25 km away from the gauge. The north-east arm lies within this range and exhibits different characteristics in salinity and also water level than the main lake body. This is evident when looking at optical imagery. In addition, the track crosses an island and the gauge is located in the north-western arm of the lake.
- ❑ In the best case scenario, both retrackerers exhibit good metrics, however in different areas.

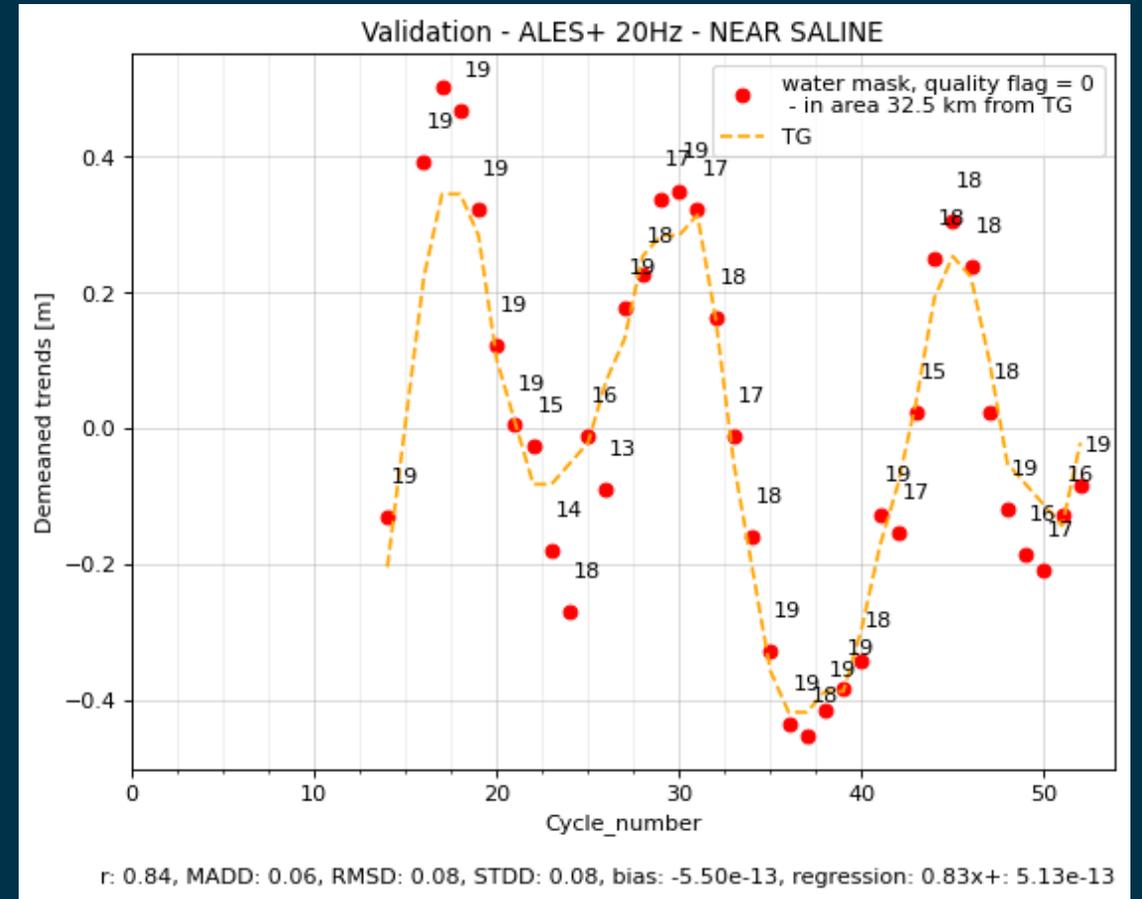
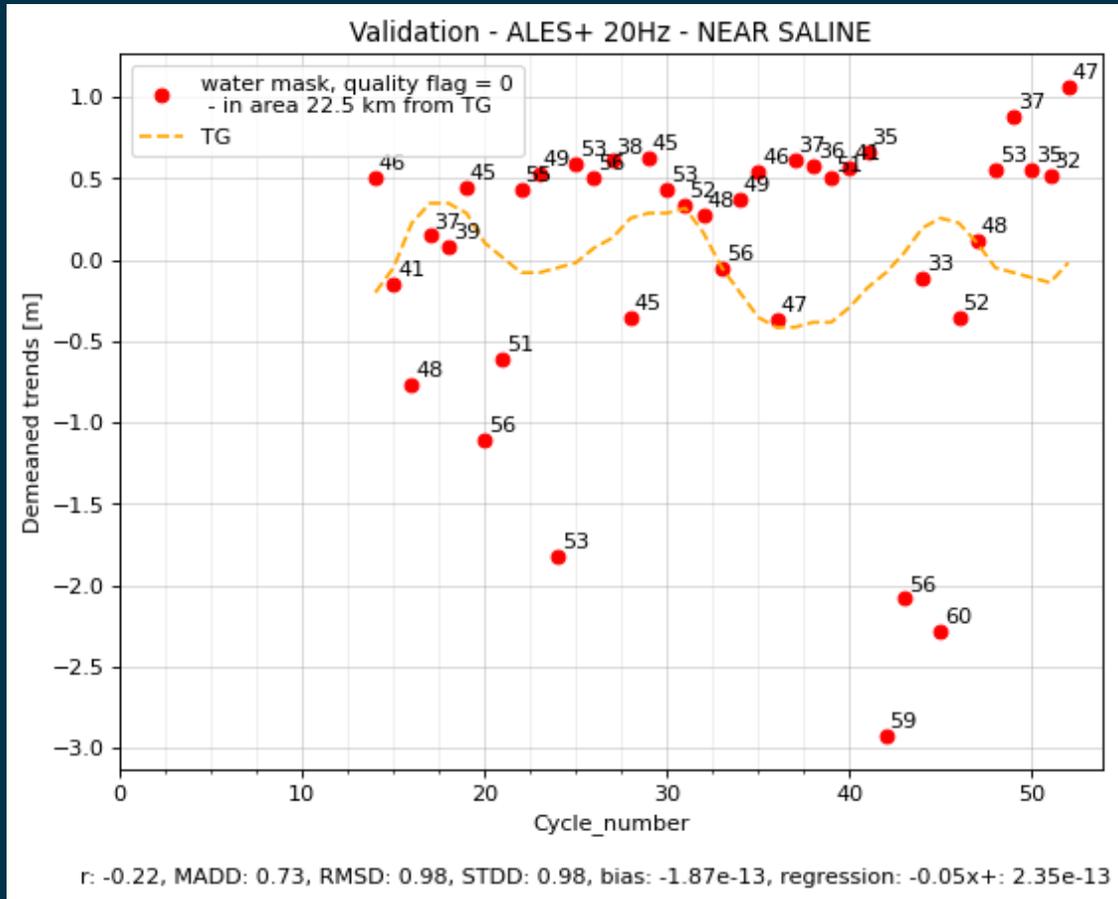


Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

Worst performance

ALES+ SAR

Best performance

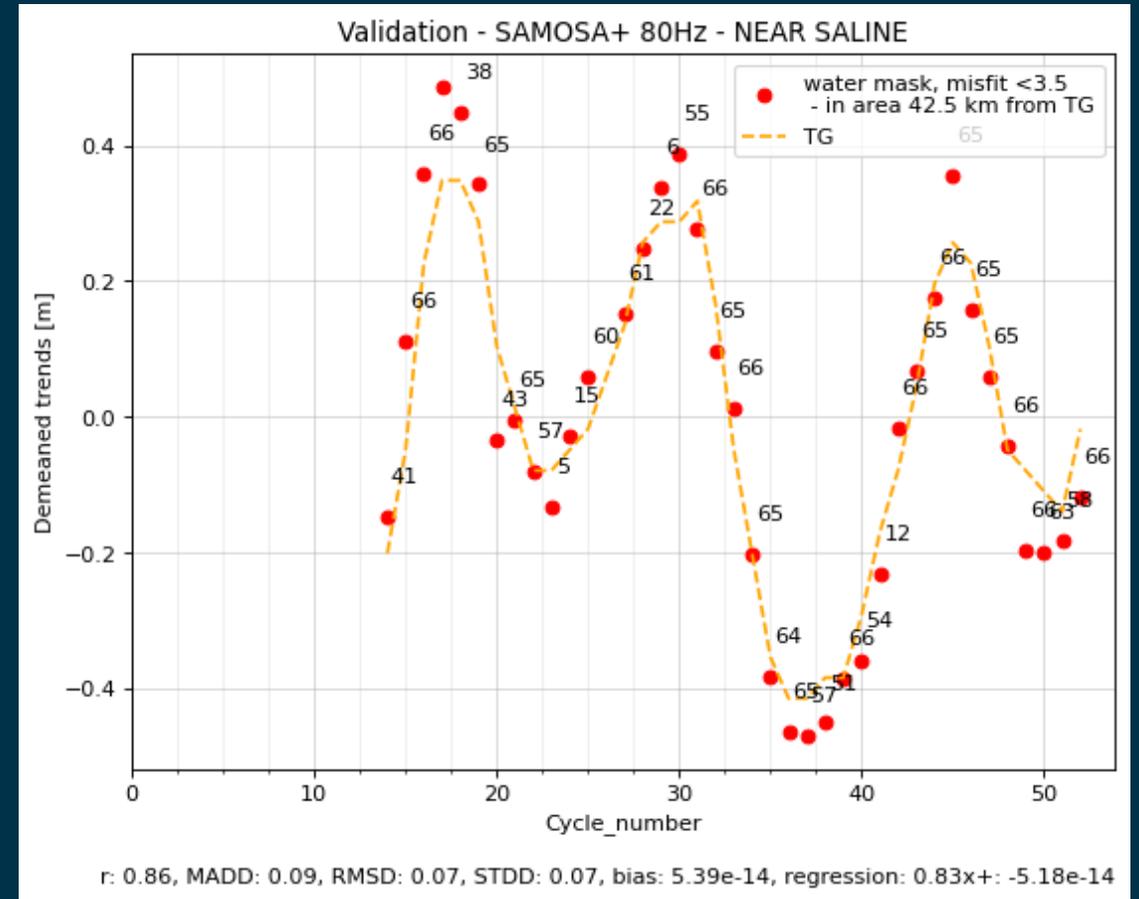
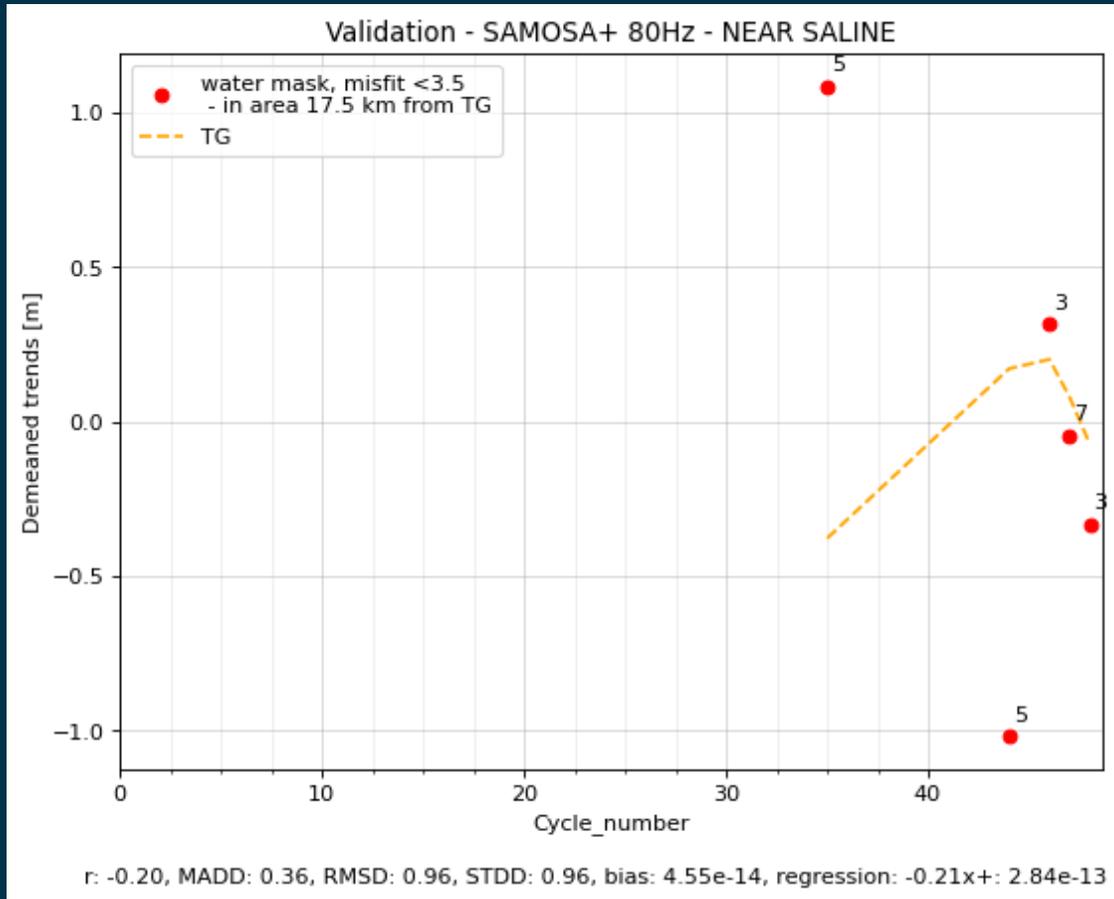


Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

Worst performance

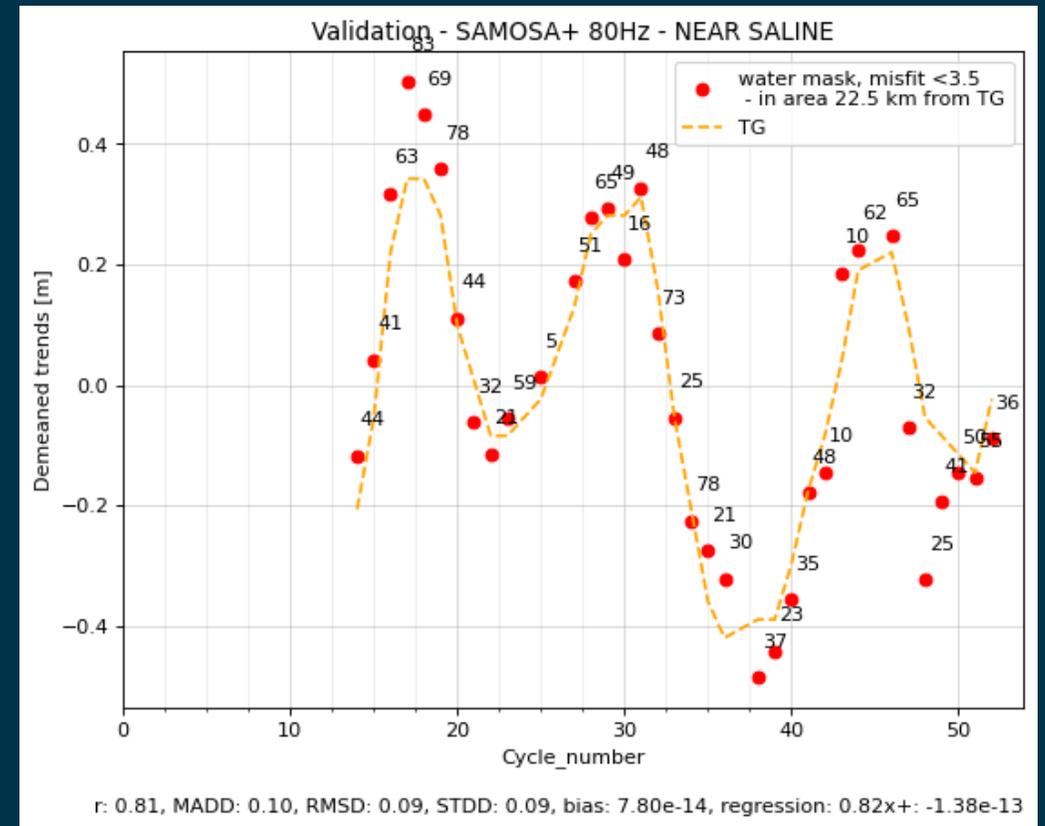
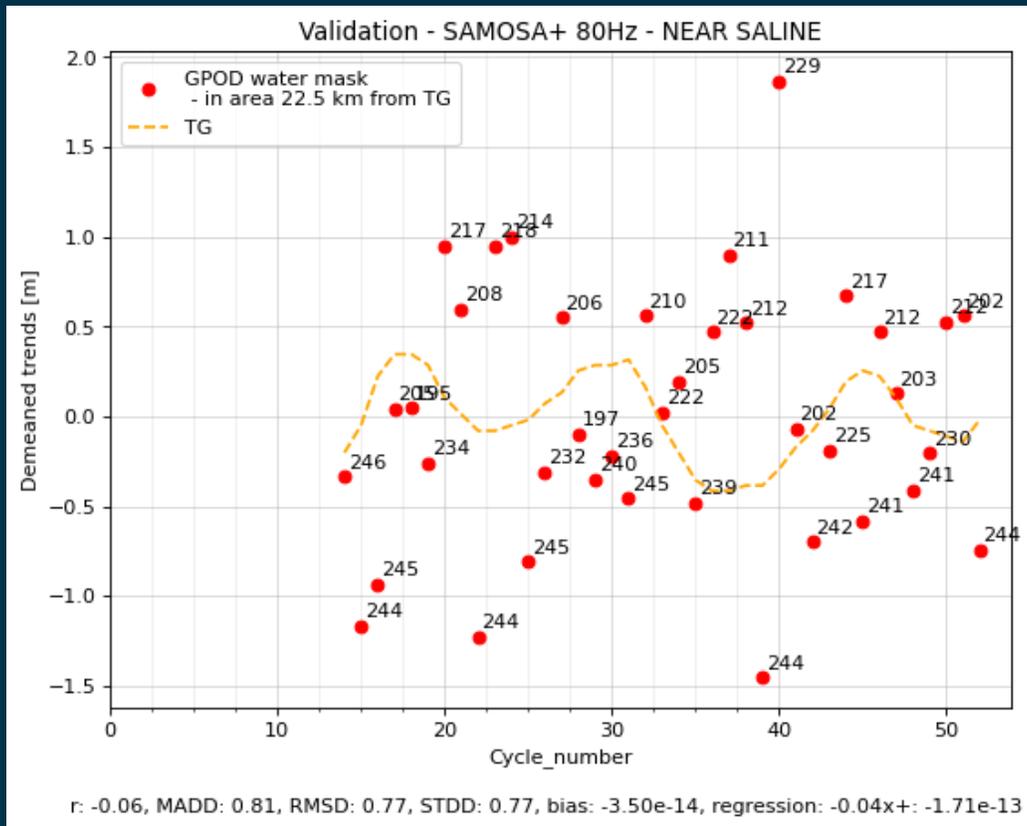
SAMOSA+

Best performance



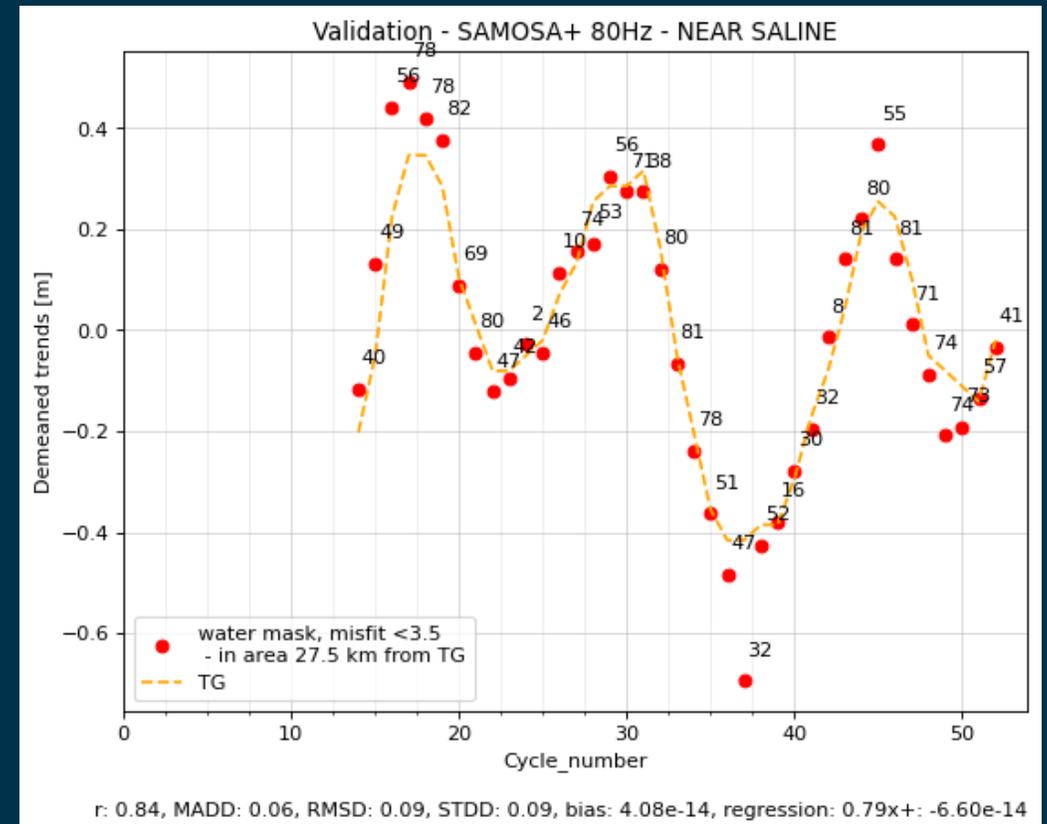
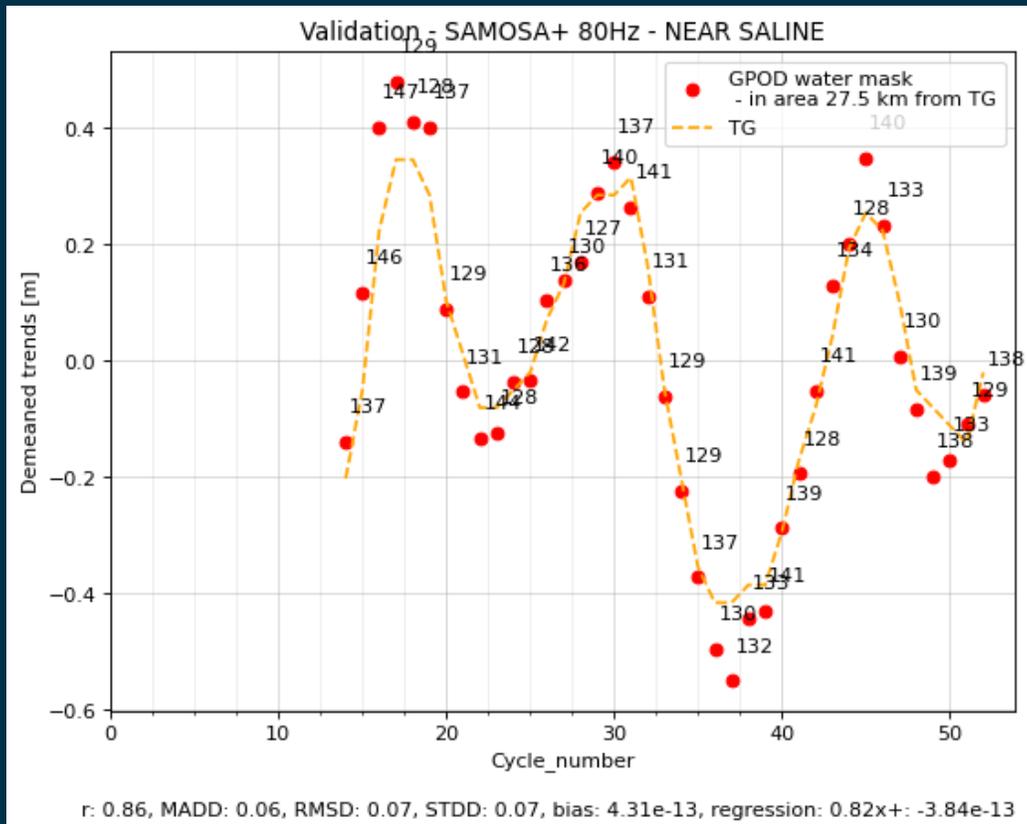
Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

- ❑ The quality filter improves the ALES+ SAR data.
- ❑ SAMOSA+ exhibit similar metrics after applying the Misfit filter.
- ❑ However when comparing the outputs of all regions for the non-filter data set and the Misfit-data set, it becomes evident that the Misfit filtering step leads to less outliers and provides good results for additional areas.



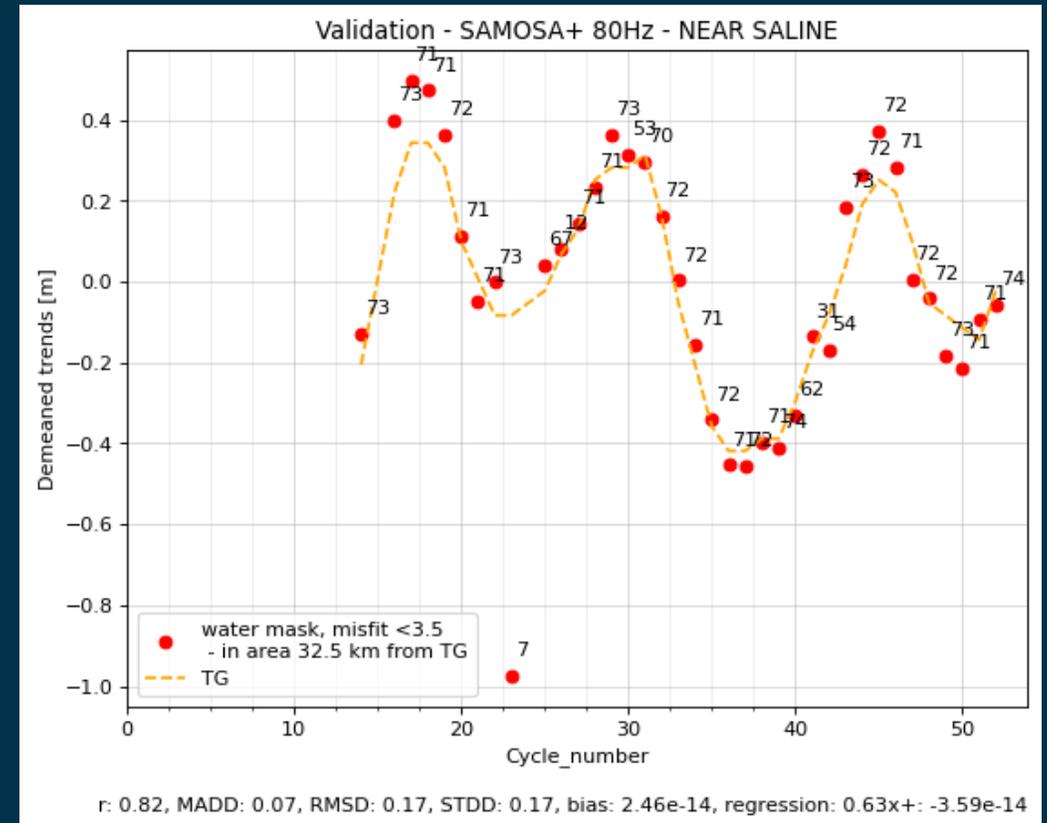
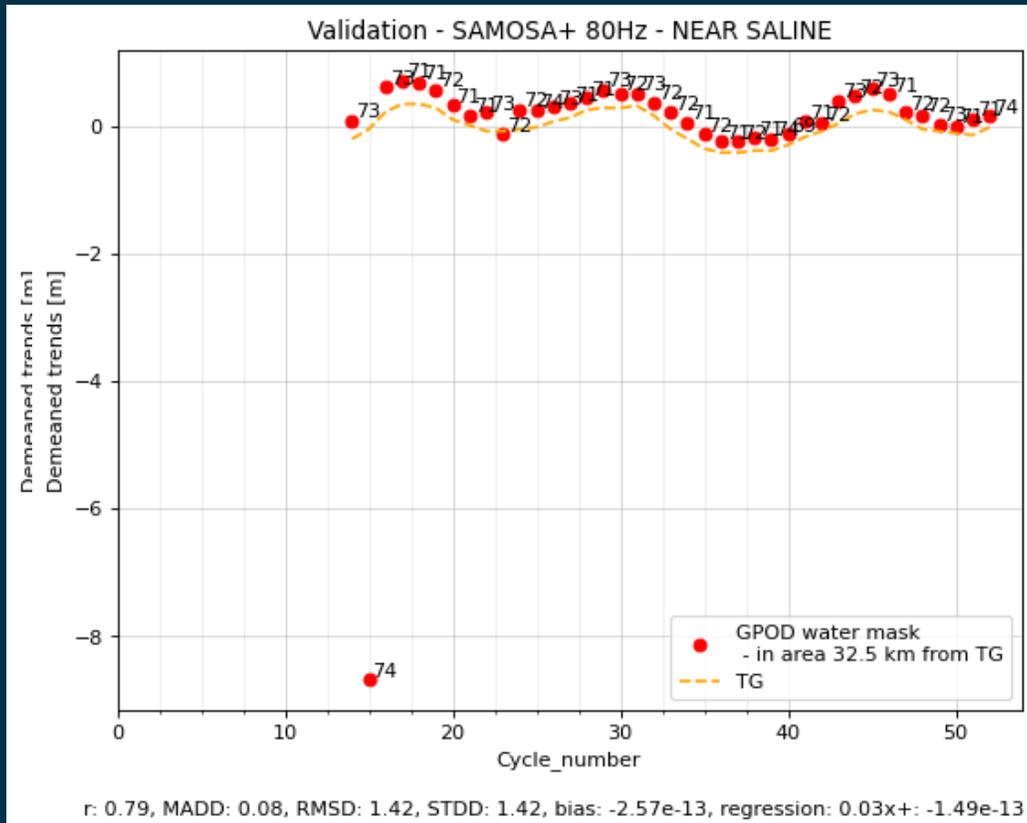
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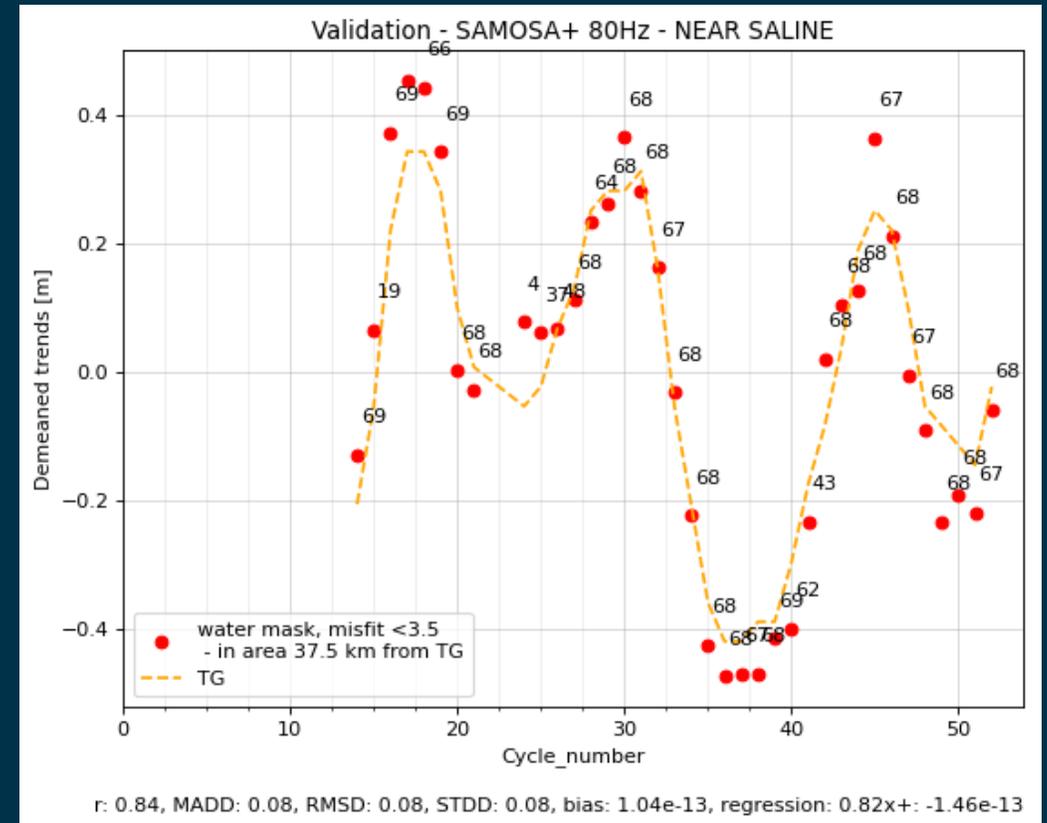
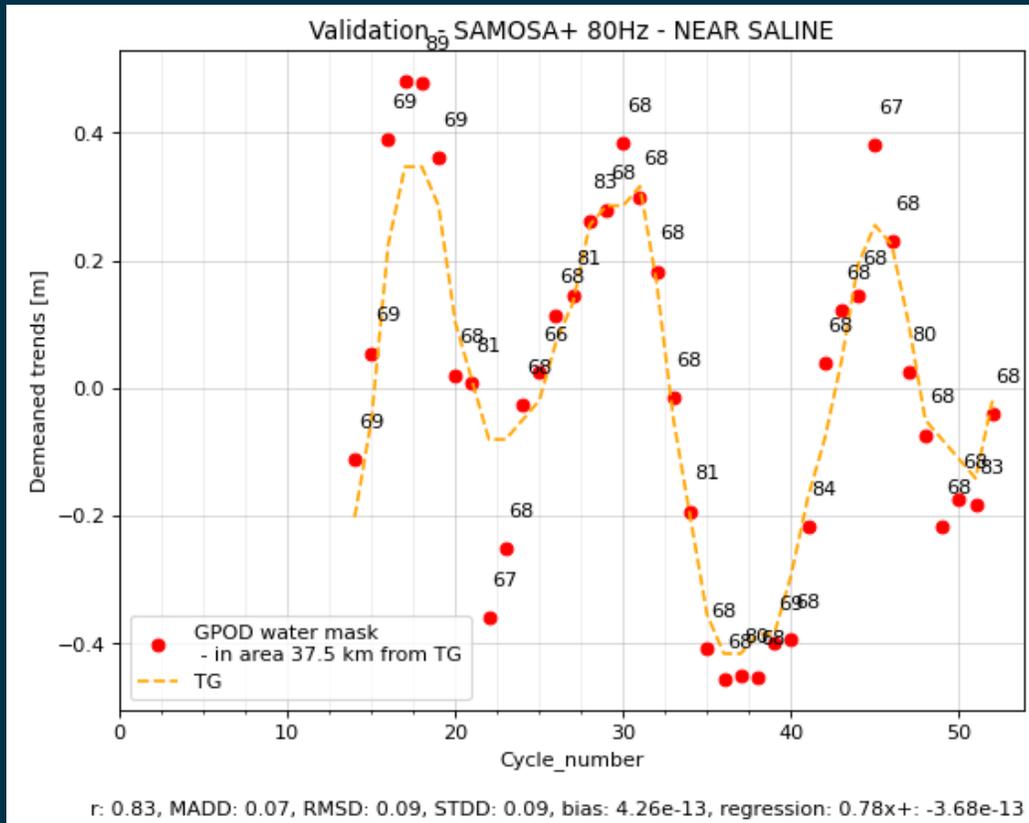
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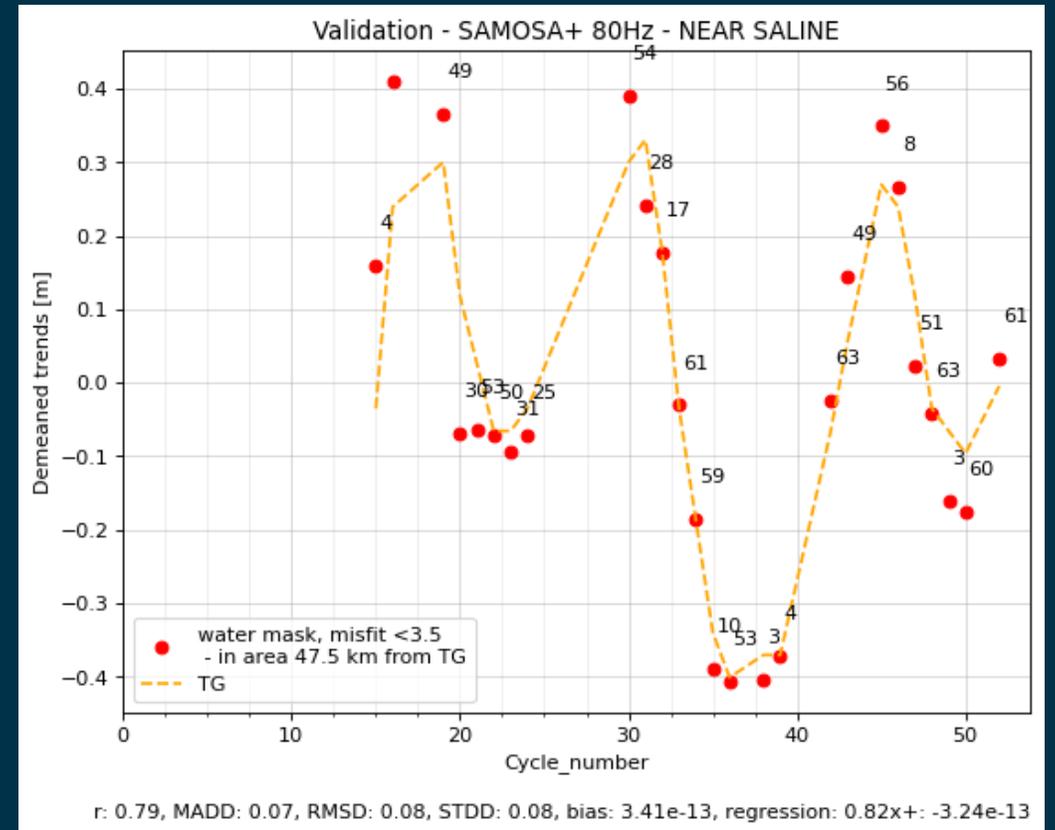
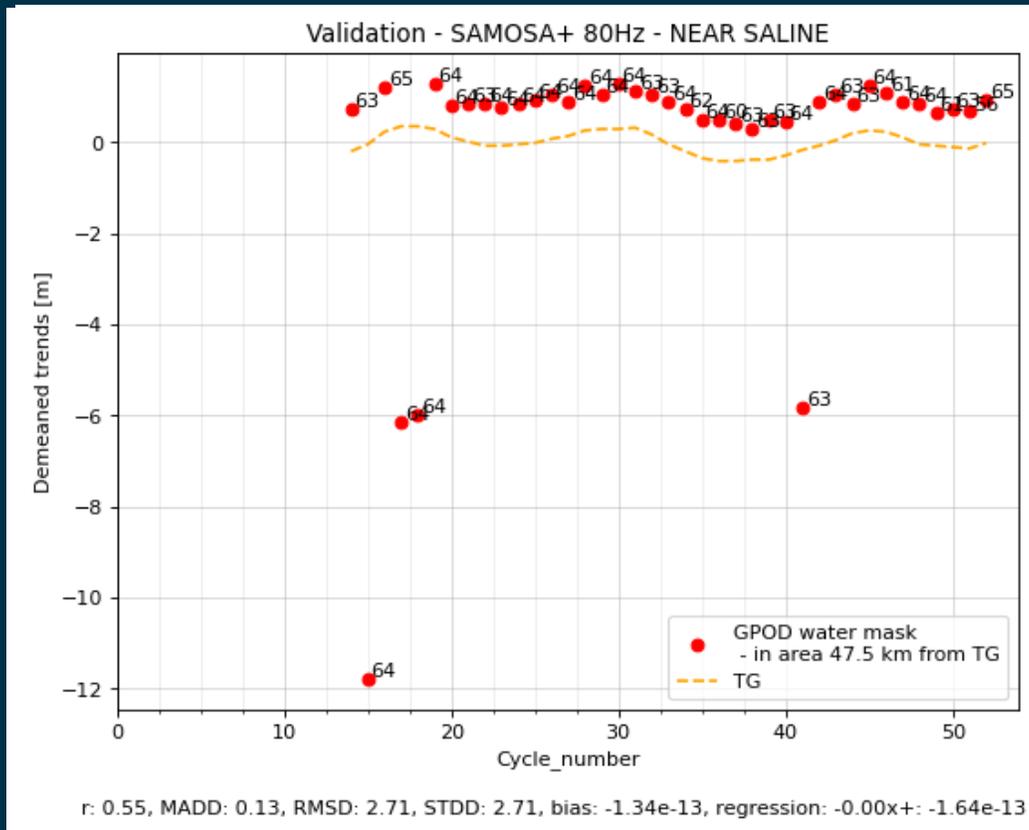
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Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

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- ❑ Both retrackerers ALES+ SAR and SAMOSA+ provide good metrics with high correlation coefficients over the Great Salt Lake.
- ❑ SAMOSA+ shows slightly better performance when compared to ALES+ SAR. However the results for ALES+ SAR are surprisingly good, considering that ALES+ SAR was conceived for the coastal area. The sub-waveform retracker seems to have a great potential for the inland water domain.
- ❑ Applying the validation based on the distance to the gauges is very important as it underlines the influence of topography and measurement geometry on the performance of the retrackerers.
- ❑ Applying the Misfit and quality flag parameter do improve the data in general, however this cannot be said for all datasets.

- ❑ Since the Great Salt Lake consist of three arms with varying salinity and inhibited exchange of water, it is important to identify the water areas which can be compared to each other. The GPOD/SARvatore water flag is therefore not sufficient.
- ❑ Introducing a user-defined water mask would allow for a more precise comparison, e.g. comparing only measurements derived over the north-western arm with the gauge NEAR SALINE and excluding measurements close to the shore.
- ❑ The comparison with the SAMOSA++ retracker, which is tailored for the inland water domain, is ongoing.

A detailed description of the GPOD service and processing options can be found in the training material presented at the 12th Coastal Altimetry Workshop.

The banner features a dark blue background with a satellite view of a coastline. At the top, a row of logos includes TUM, Observatoire de Paris SYRTE, FC PORTO, UCA Universidad de Chile, UNIVERSITY OF HAWAII MANOA, cnes, NOAA, EUMETSAT, University of New Hampshire, and ESA. Below the logos, the text '12th COASTAL ALTIMETRY WORKSHOP' is displayed in a white box, followed by 'Coastal Altimetry Training'. The central part of the banner shows several satellite icons in white and light blue, with the word 'PROGRAMME' in white text. At the bottom, the text '4-7 February 2020 | ESA-ESRIN | Frascati (Rome), Italy' is written in white.

The training material can be downloaded here: <https://www.coastalaltimetry.org/>