Investigating SAR Altimetry over the Great Salt Lake
–
Comparing SAMOSA+/++ and ALES+ SAR

Martina Wenzl [(1)], Marcello Passaro [(2)],Marco Restano [(3)], Jérôme Benveniste [(1)]

[(1)]ESA-ESRIN, Largo Galileo Galilei, 1, Frascati, Italy, Email: jerome.benveniste@esa.int
[(2)]Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM) , Arcisstraße 21, 80333 Munich, Germany
[(3)] SERCO, c/o ESA-ESRIN, Largo Galileo Galilei, 1, Frascati, Italy

Martina Wenzl, 19.-23.10.2020

OSTST2020,

then run the Slide Show mode

to see how it looks

Summary

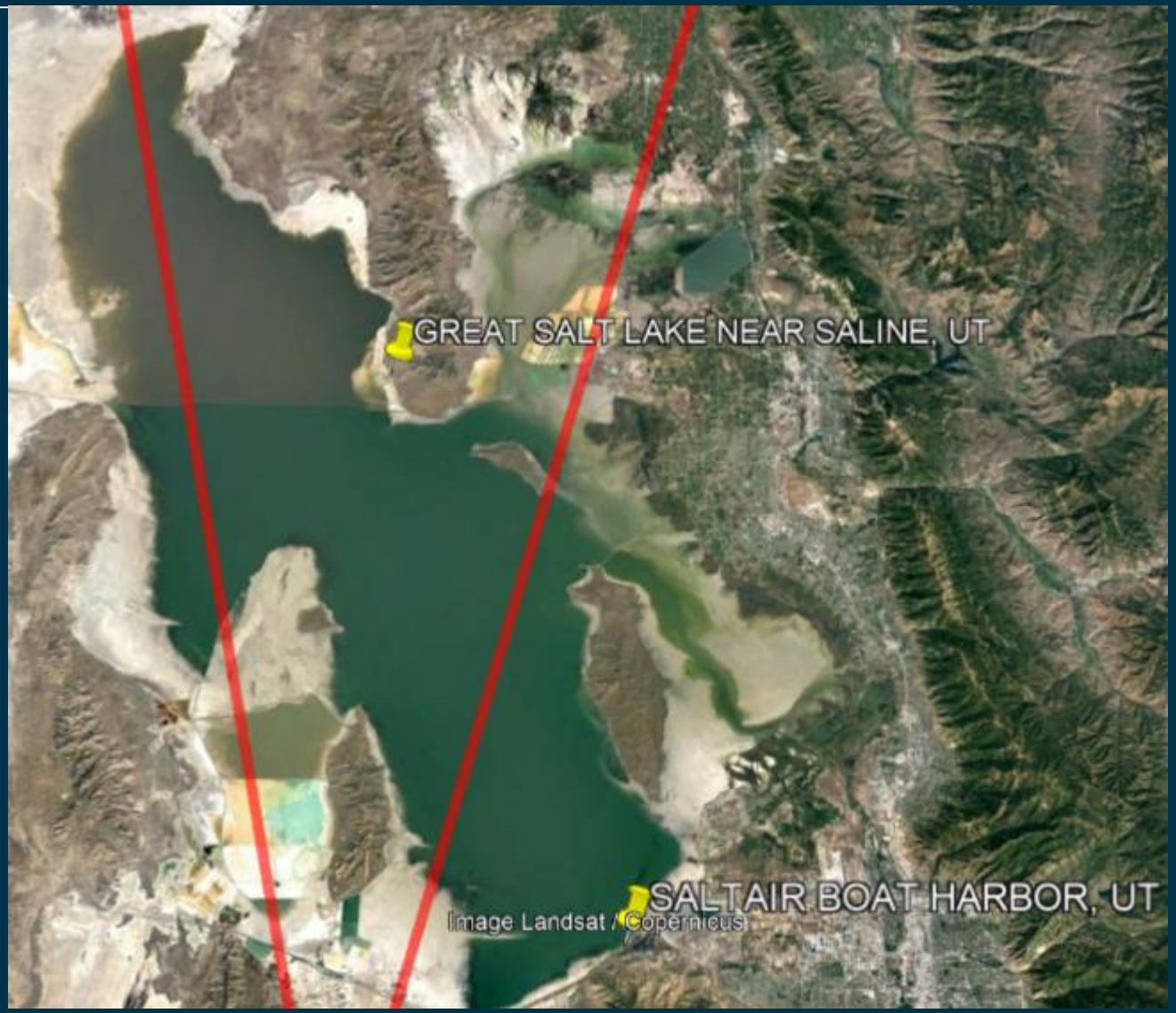
- Study area – The Great Salt Lake
- GPOD/SARvatore and the SAMOSA+/++ retrackers
- ALES+ SAR retracker
- Methodology
- Results
- Conclusion

Introduction

- 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 retrackers of the SAMOSA family with the newly adopted ALES+ SAR processer 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

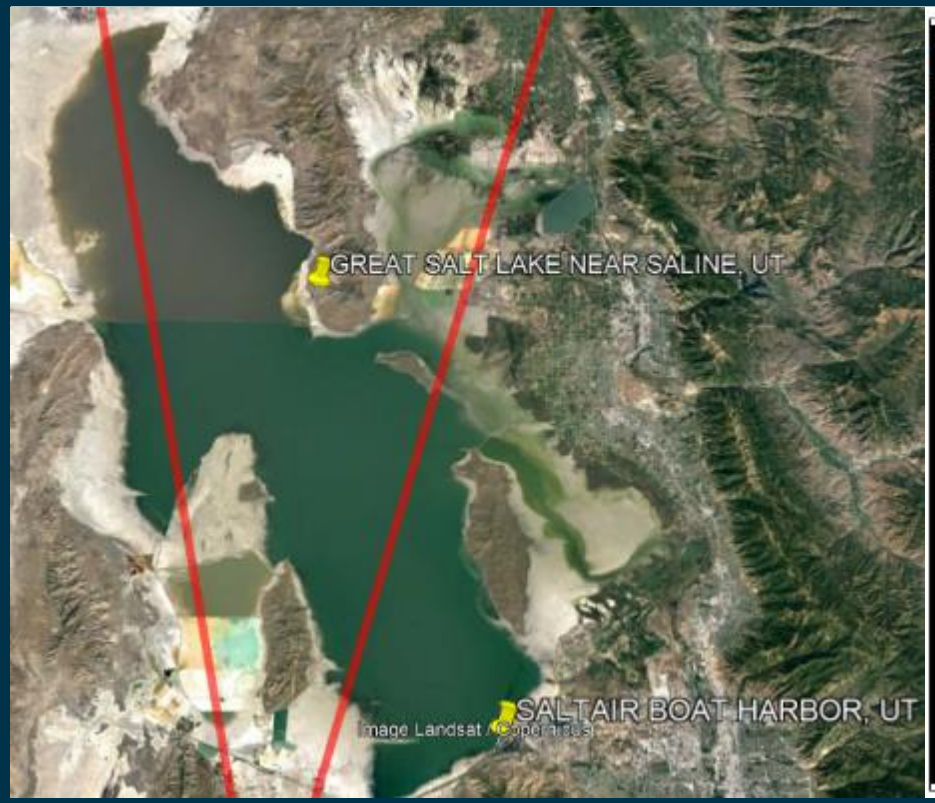
- Two Sentinel-3A tracks (track 275 and track 369) cross the Great Salt Lake.
- The Lake is split by a causeway in a north-western and north-eastern arm and a southern part. The southern and north-western arm are connected via a 55 m broad opening in the causeway.
- The gauge “Near Saline” is connected 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.

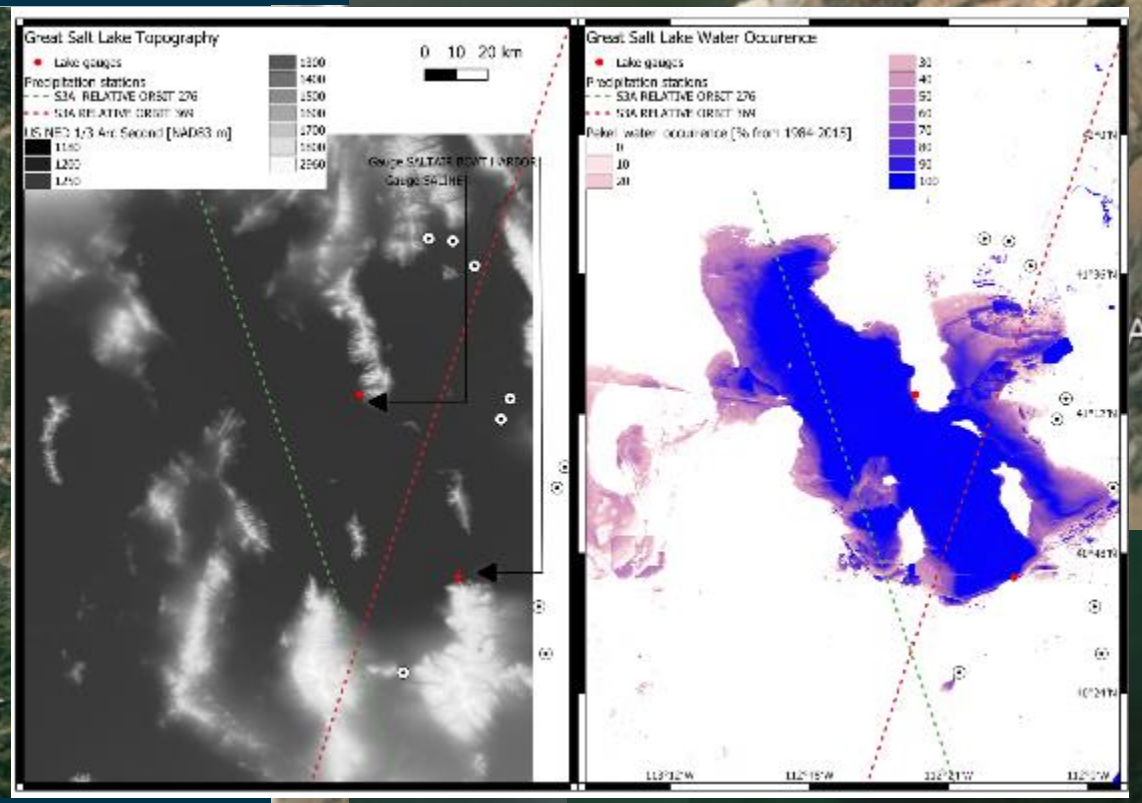


Study area - The Great Salt Lake

- 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.

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.

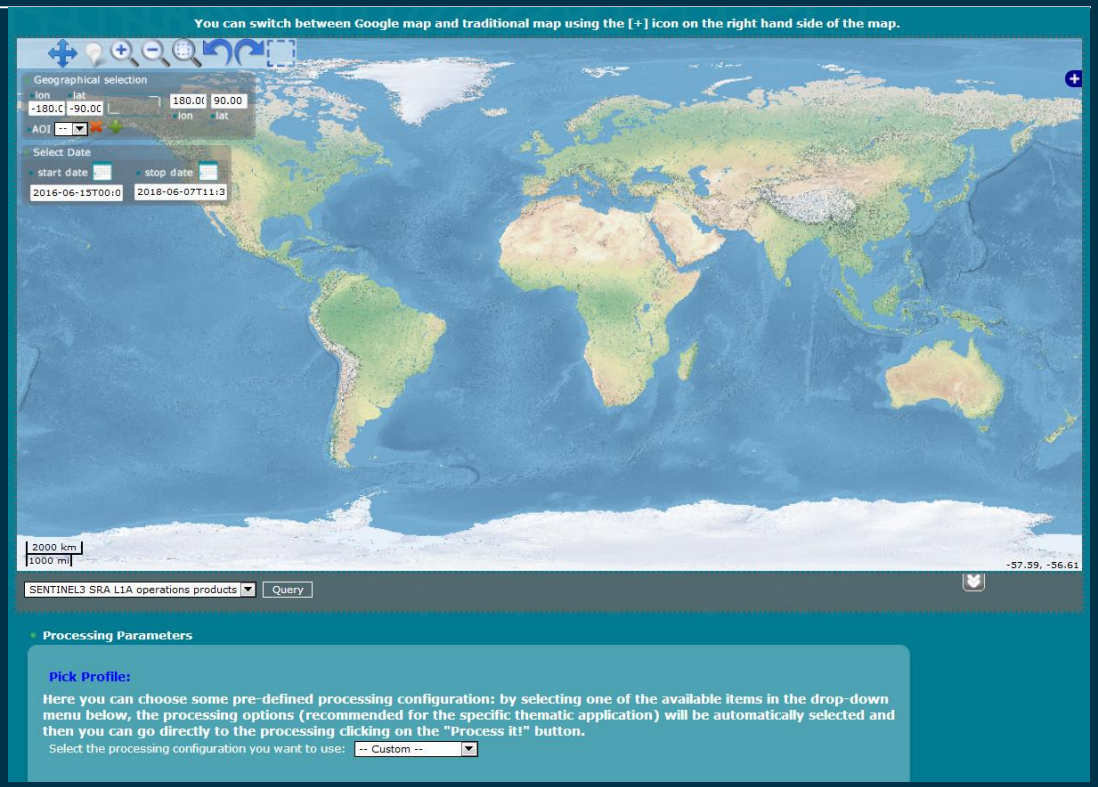
SRAL datasets:

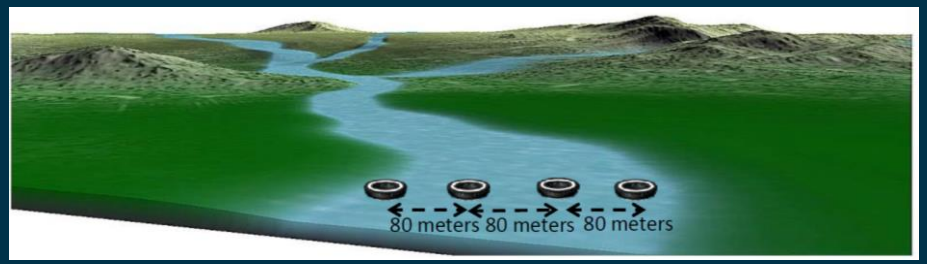
GPOD/SARvatore for Sentinel-3 data

ALES+ SAR in GPOD/SARvatore

Dataset 1: GPOD/SARvatore for Sentinel-3 data

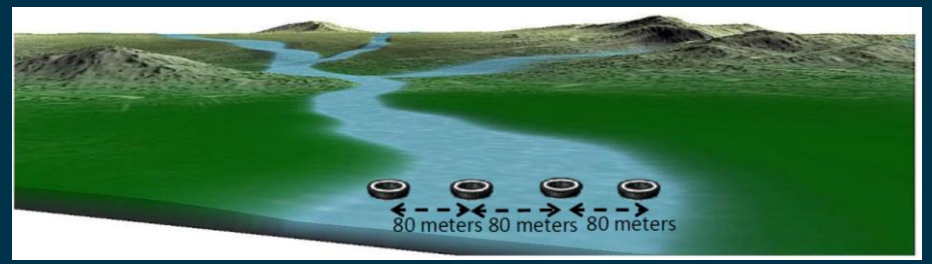
- The GPOD/SARvatore processor enables users to choose scenario-dependent L1b and L2 processing options
- The service is accessible at http://gpod.eo.esa.int/ after registration.
- The L1b profile “Inland Water HPR” is designed to increase the number of estimates over the water body with a posting rate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





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 retrackers SAMOSA+ and SAMOSA++ (tailored to the inland water domain) are applied in the L2 options.



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: Inland Water (HPR)

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: All

- **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): No

L1B Processor:

- **Data Posting Rate**

Flag to set the data posting rate: 20 Hz (canonic posting rate) or 80 Hz (finer posting rate): 80 Hz

- **Hamming Weighting Window**

Flag to set the application of the Hamming Weighting Window on the burst data (section 4.4 in REF1): Yes, apply it

- **Exact Beam-Forming**

Flag to set the application of exact or approximated Doppler Beam Steering (section 4.4 in REF1): Approximated

- **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: Yes, apply Zero-P

- **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.: 128x2 range bins

- **Stack Subset**

Subset the Stack to Looks: [100, 120, 140, 160, 180, ALL]: ALL

- **Antenna Pattern Compensation**

Flag to activate the antenna pattern compensation on the Stack Data: No

- **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: No

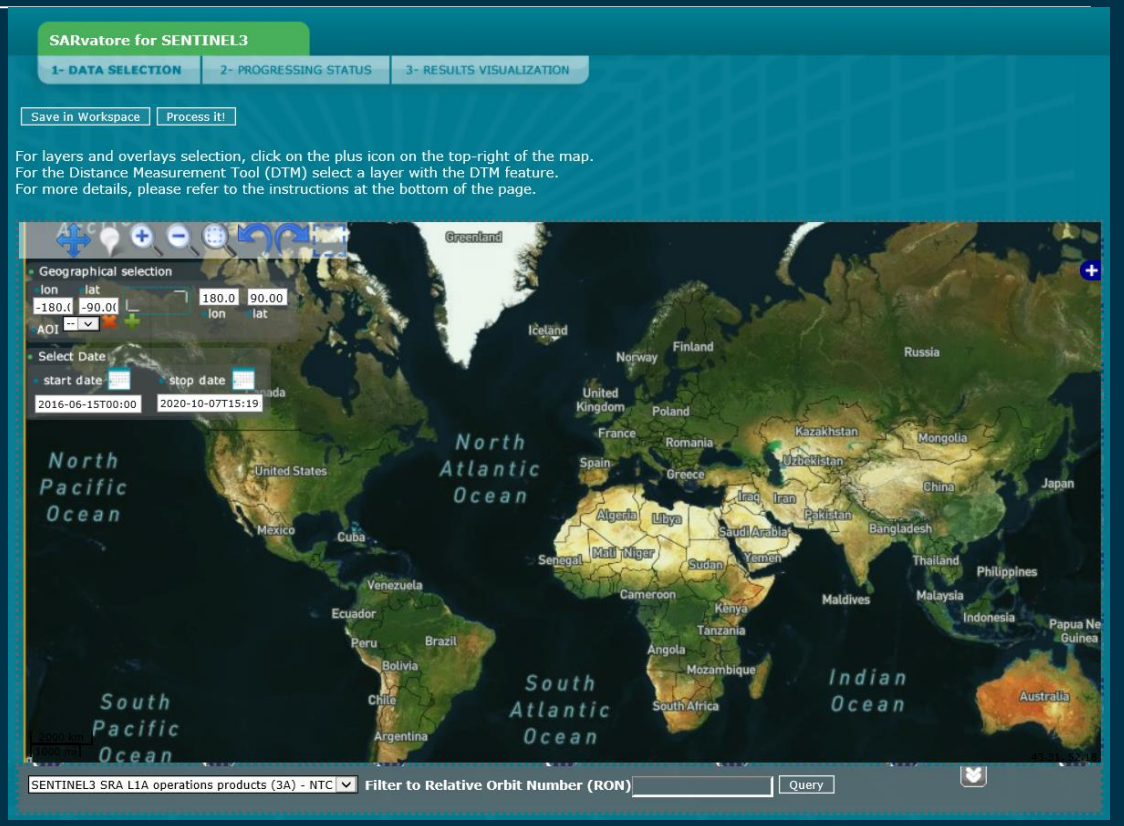
Dataset 2: ALES+ SAR in GPOD/SARvatore

- 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.

- 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 $\sigma 0$. 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.



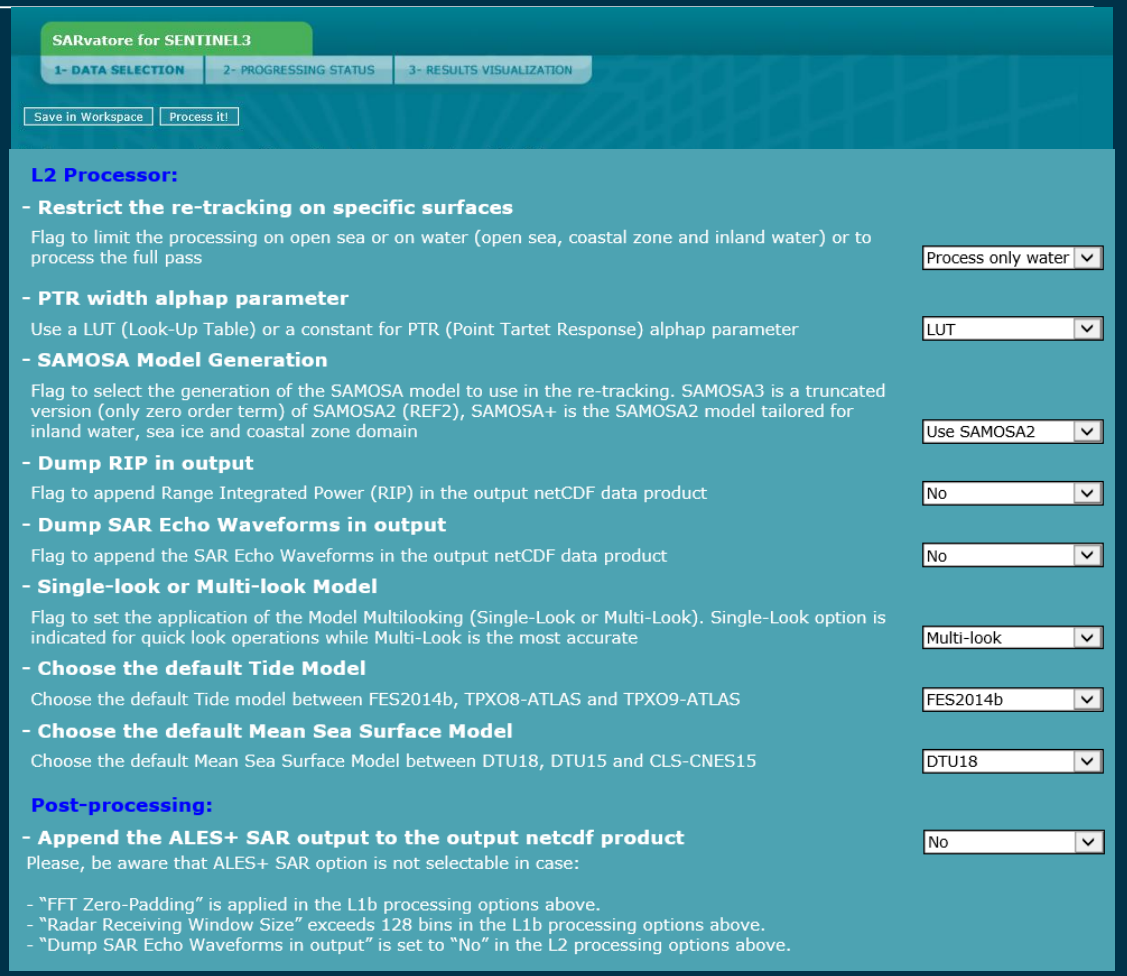
Dataset 2: ALES+ SAR in GPOD/SARvatore

- 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.

- 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 $\sigma 0$. 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.



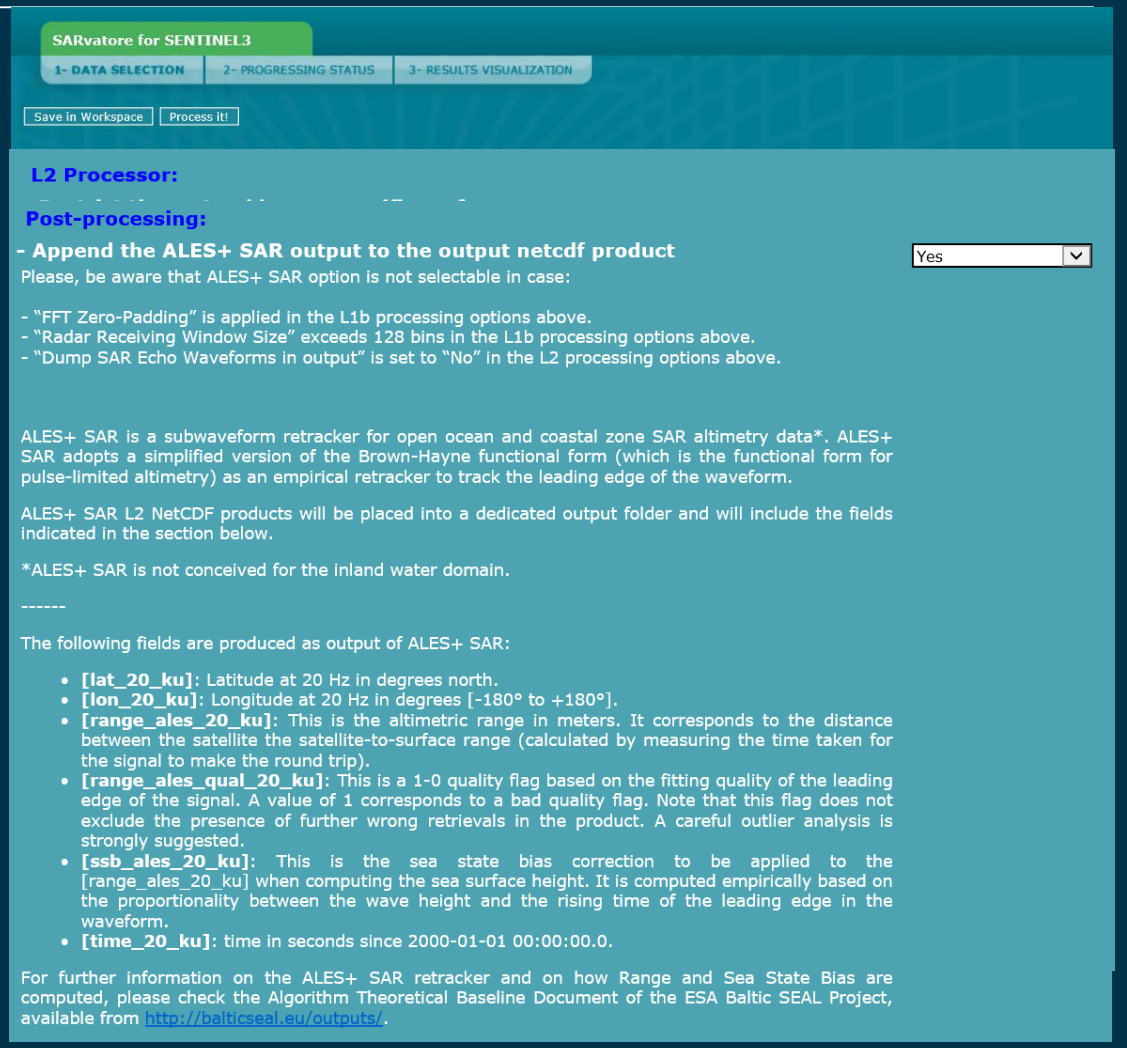
Dataset 2: ALES+ SAR in GPOD/SARvatore

- 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.

- 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 $\sigma 0$. 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.



Methodology:

Deriving the water level

Filtering

Validation based on distance to gauges

Methodology – deriving the water level

- 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)

Methodology – masking and filtering

- *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 where 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

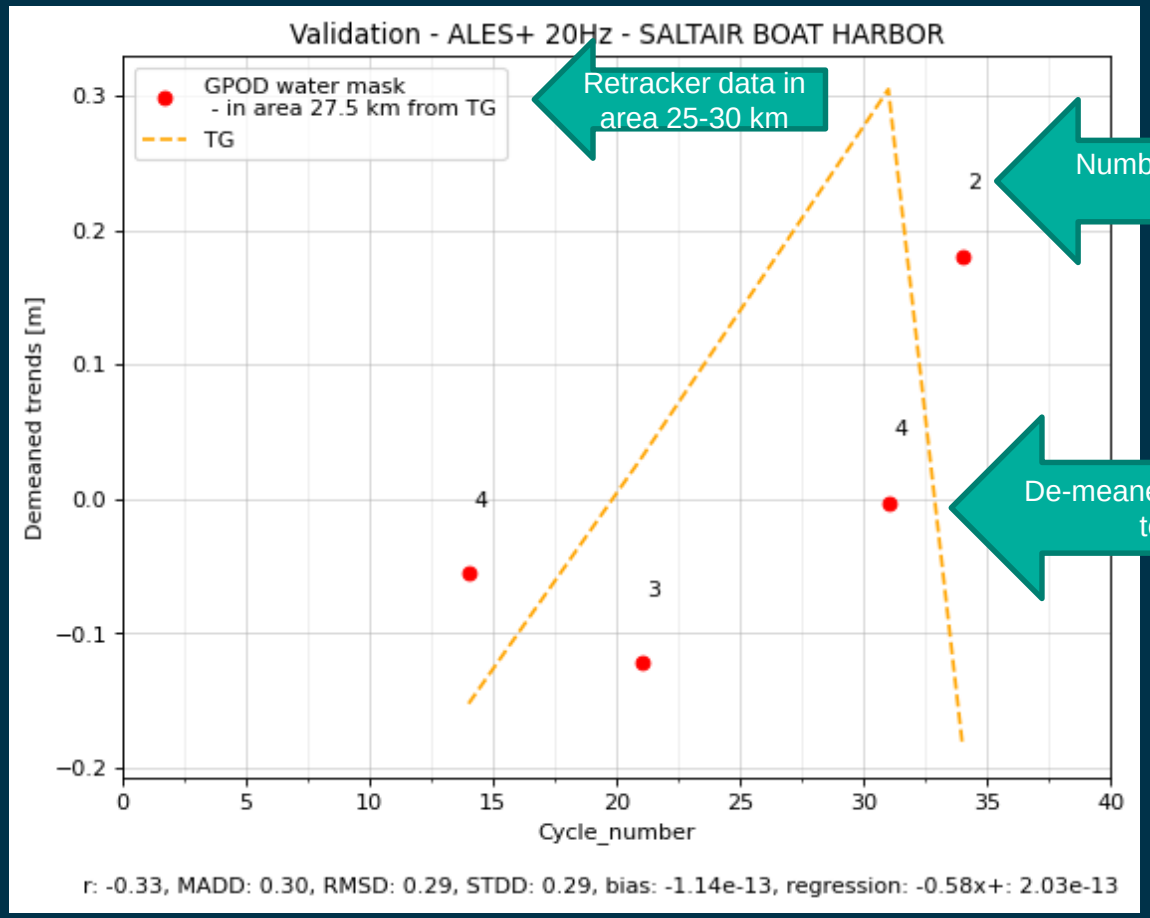
Track 275

Track 275 – no filter, at gauge BOAT HARBOUR

Worst performance

ALES+ SAR

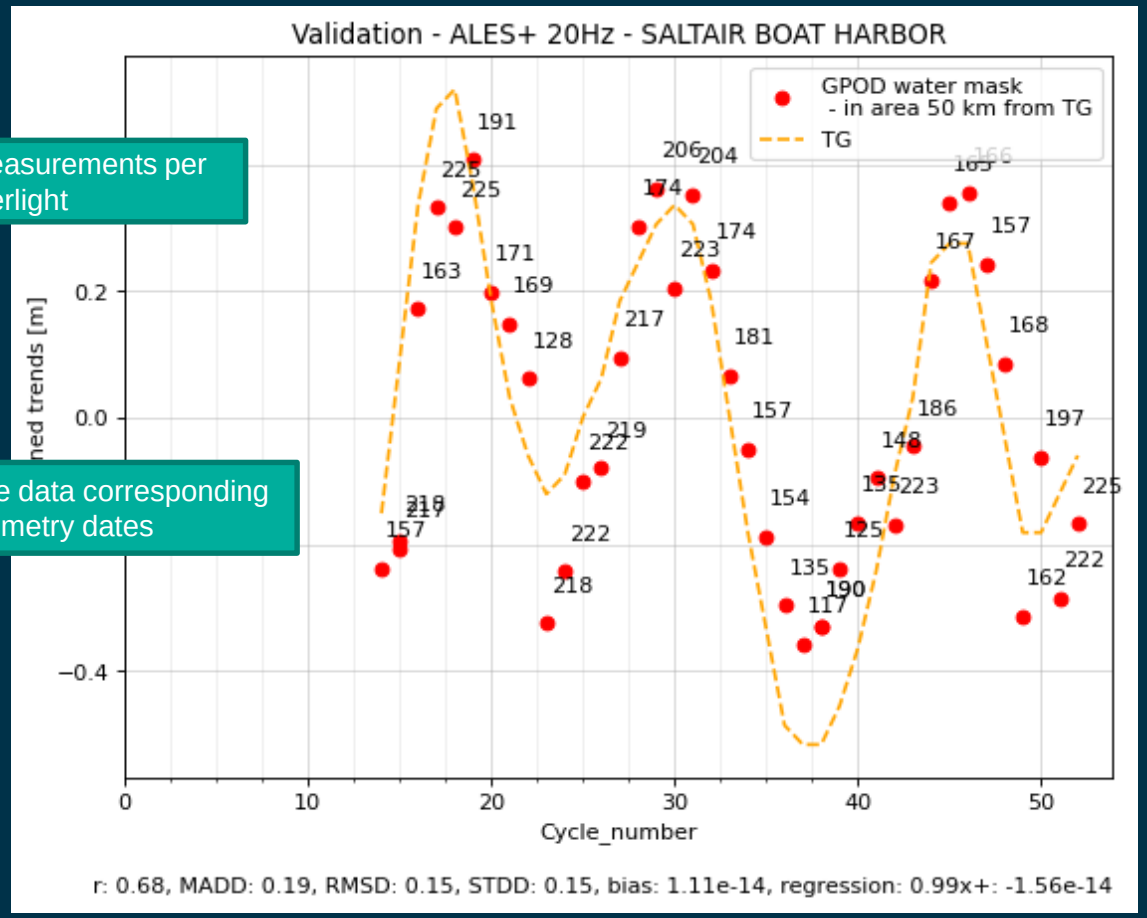
Best performance



Retracker data in area 25-30 km

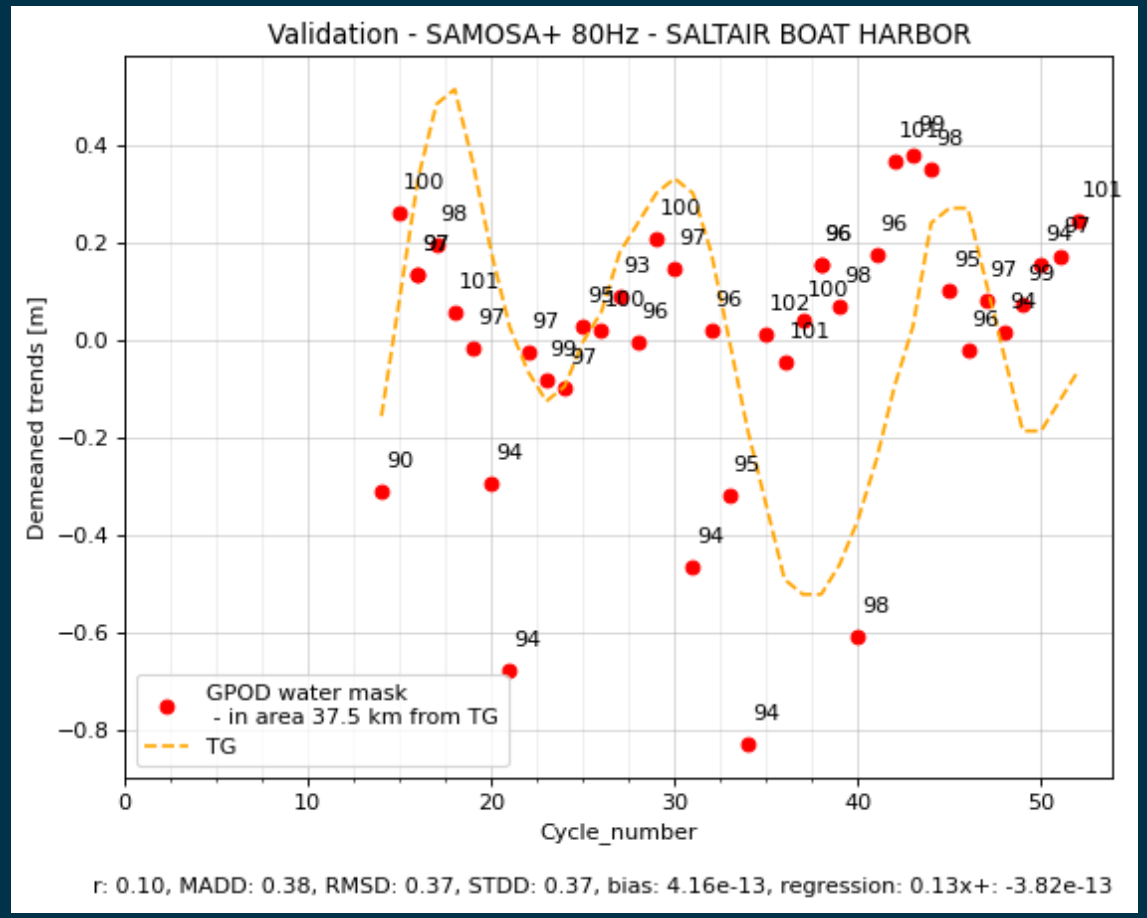
Number of measurements per overlight

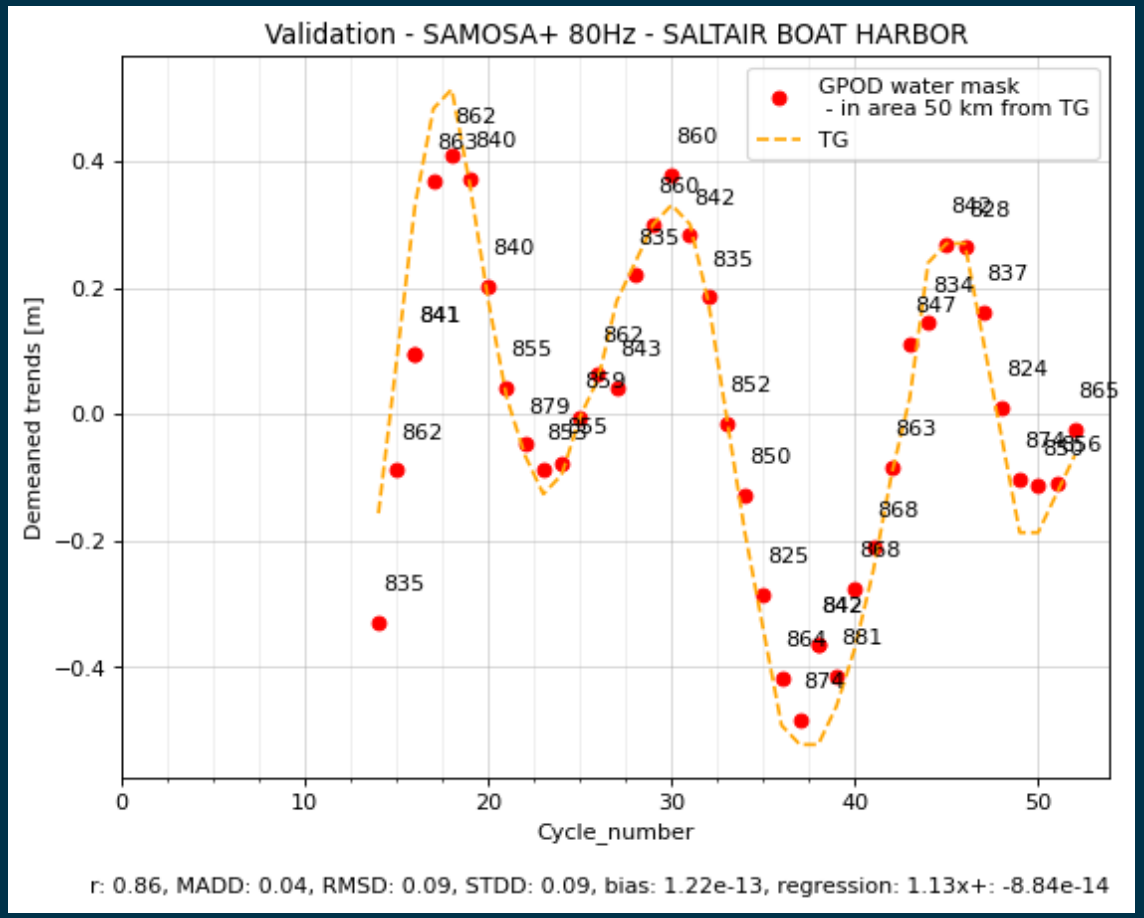
De-meaned gauge data corresponding to the altimetry dates



Track 275 – no filter, at gauge BOAT HARBOUR

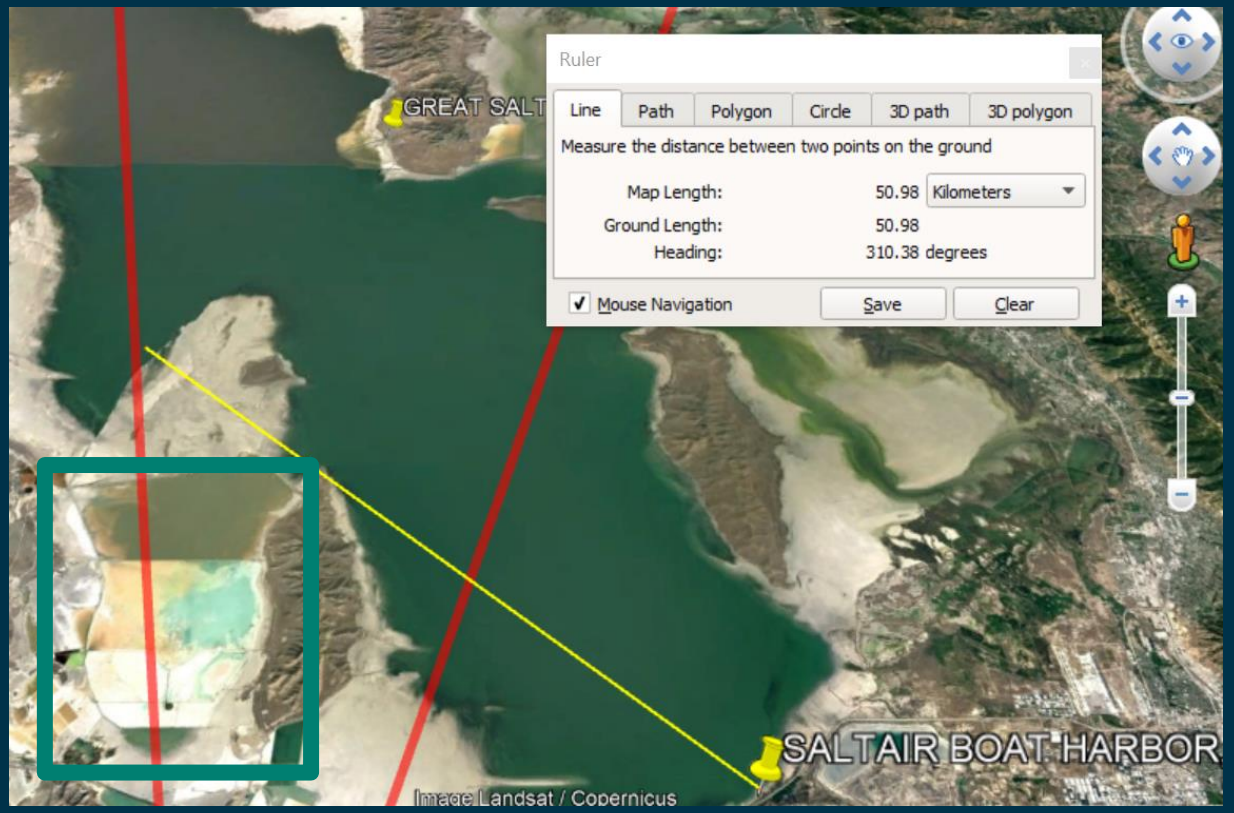
Worst performance SAMOSA+ Best performance





Track 275 – no filter, at gauge BOAT HARBOUR

- All retrackers 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 retrackers.
- SAMOSA+ results show the best results, while ALES+ SAR captures the water level dynamic well.

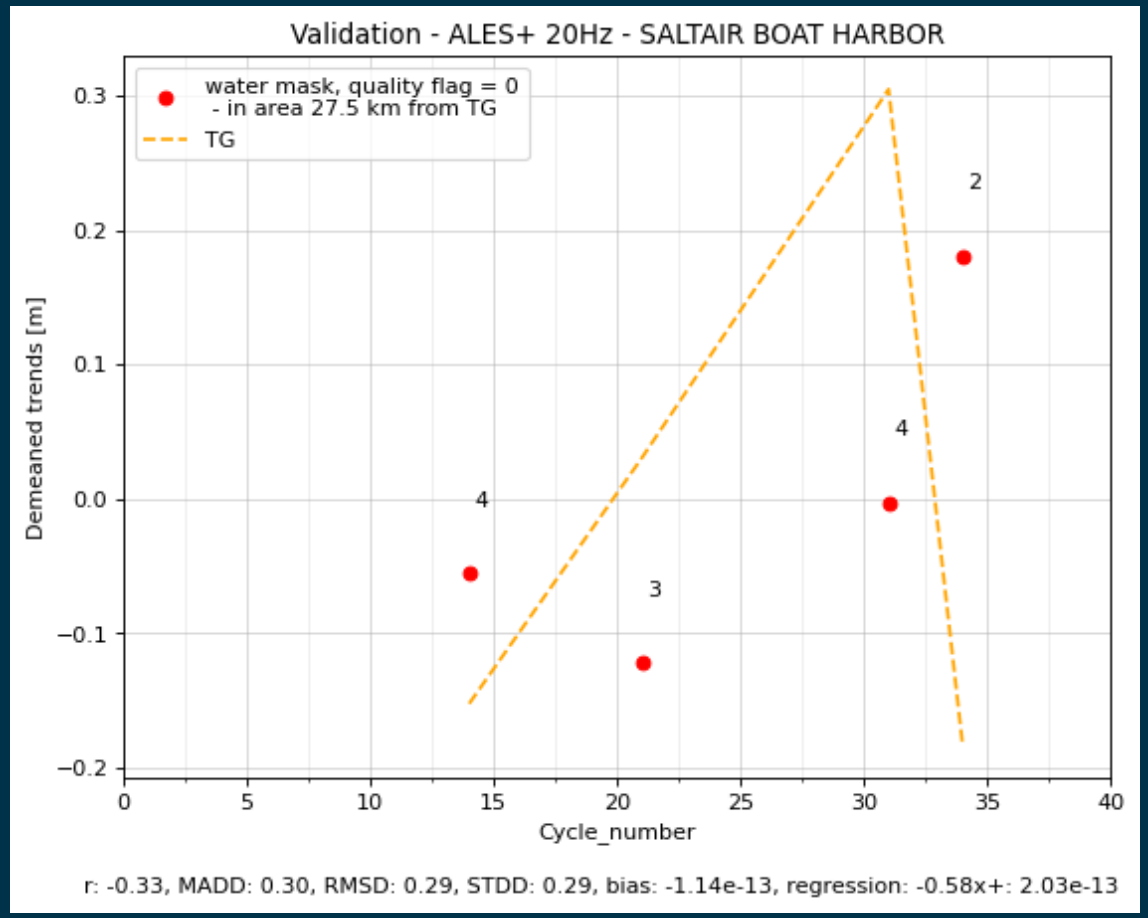


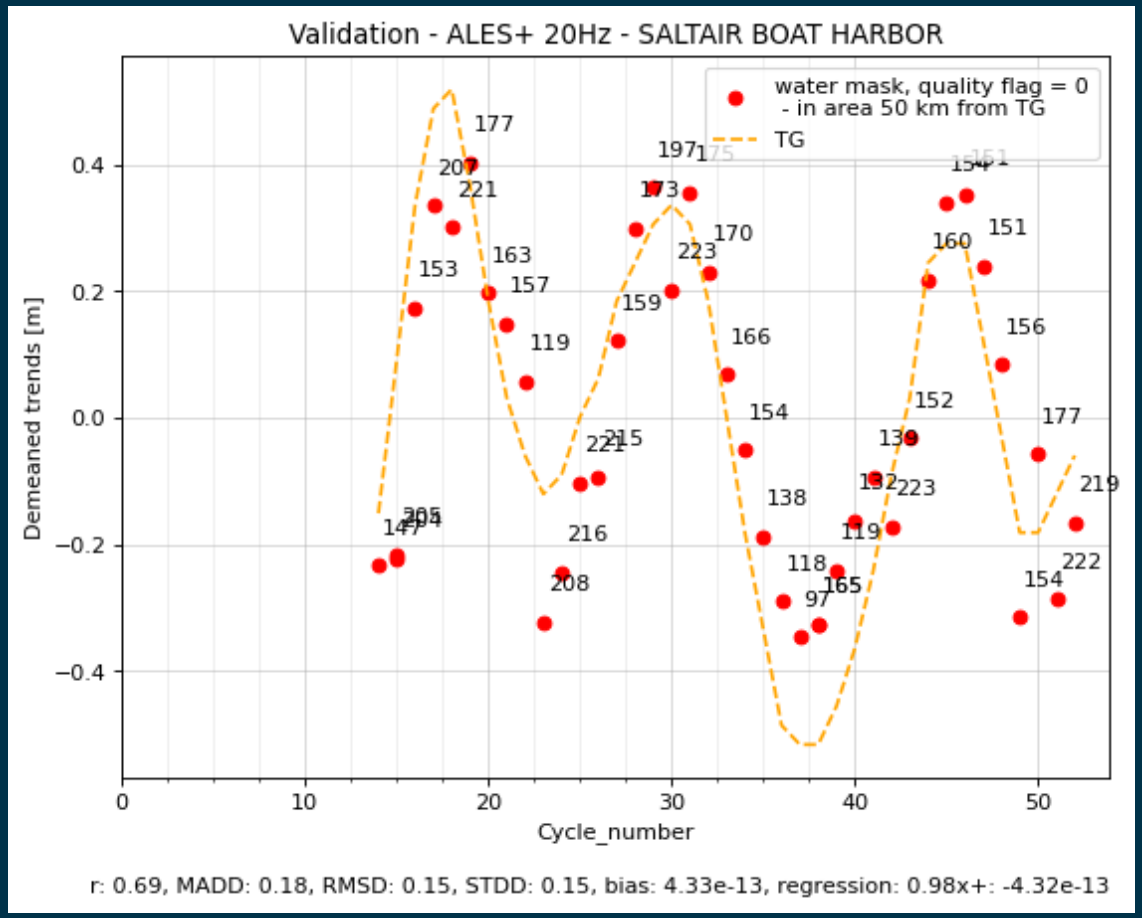
Track 275 – Misfit and quality flag filter, at gauge BOAT HARBOUR

Worst performance

ALES+ SAR

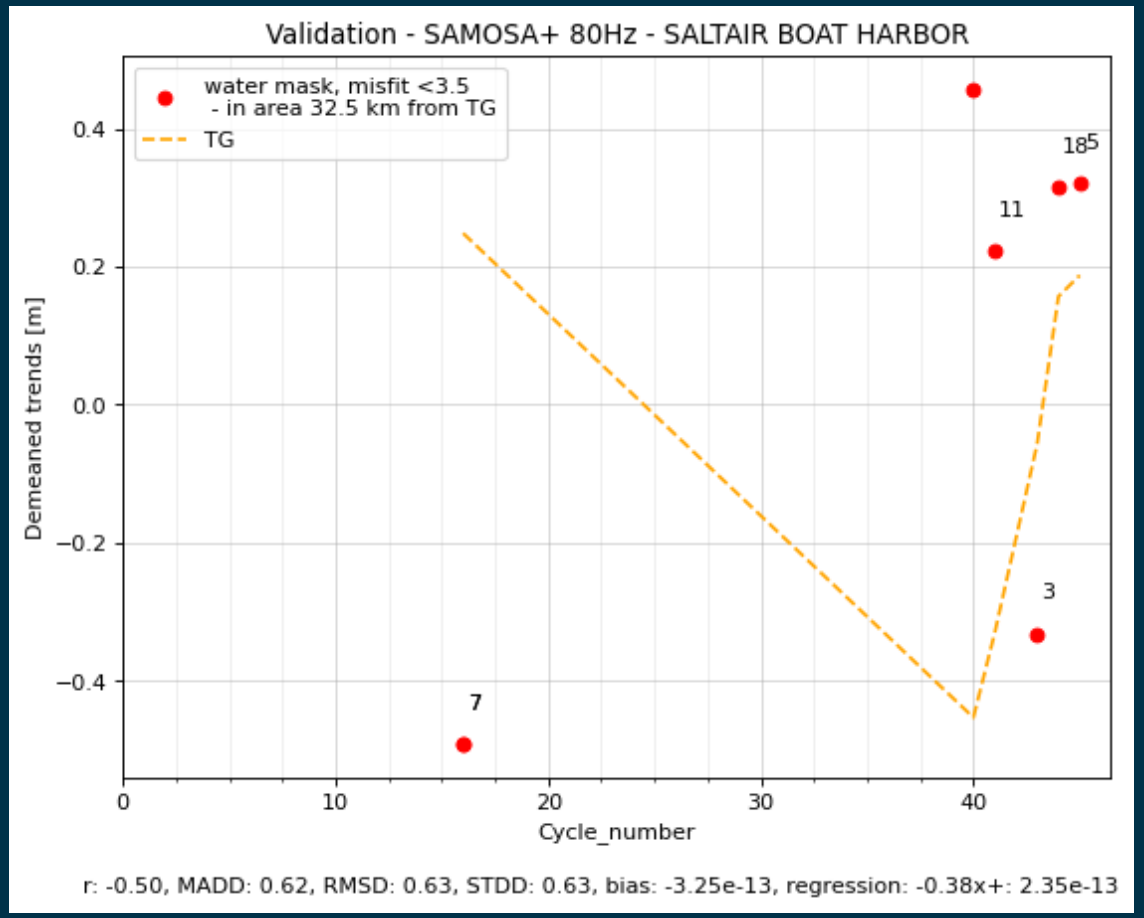
Best performance

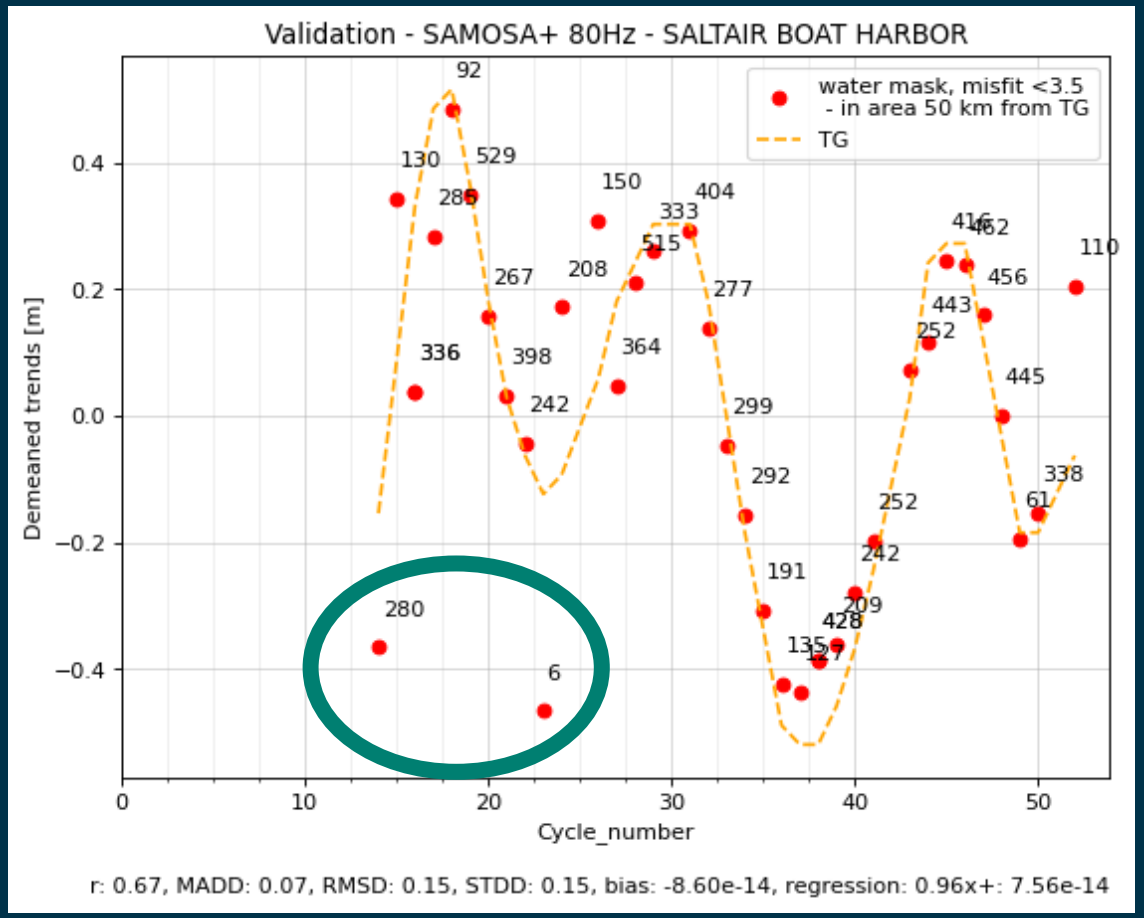




Track 275 – Misfit and quality flag filter, at gauge BOAT HARBOUR

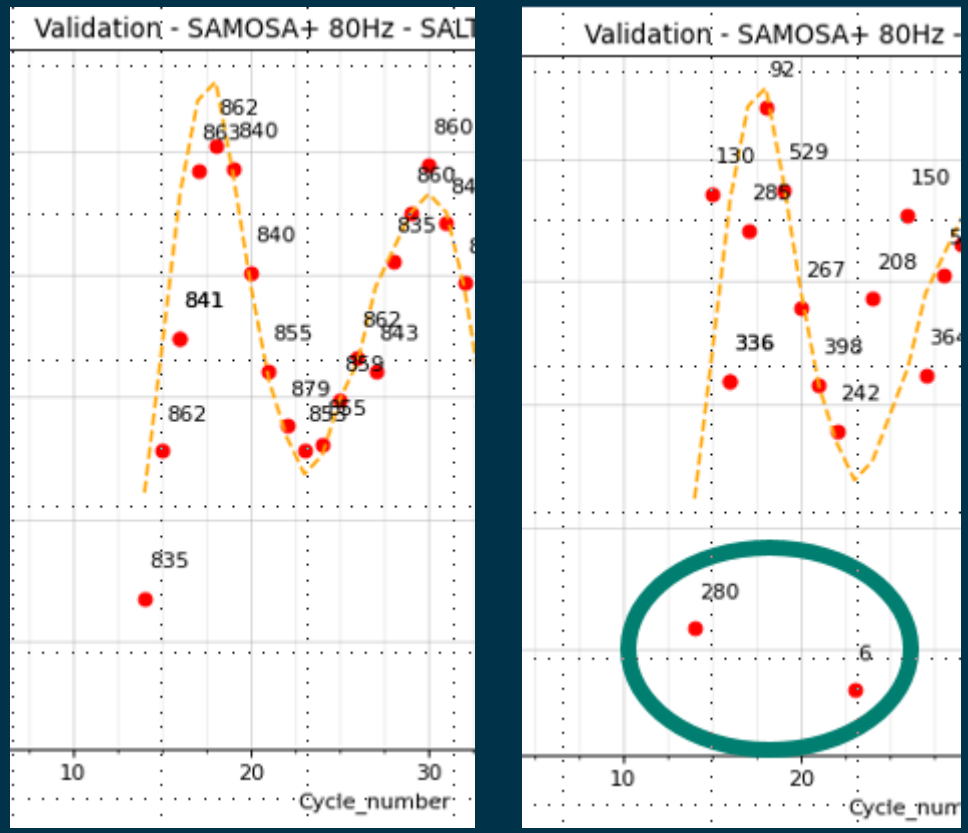
Worst performance SAMOSA+ Best performance





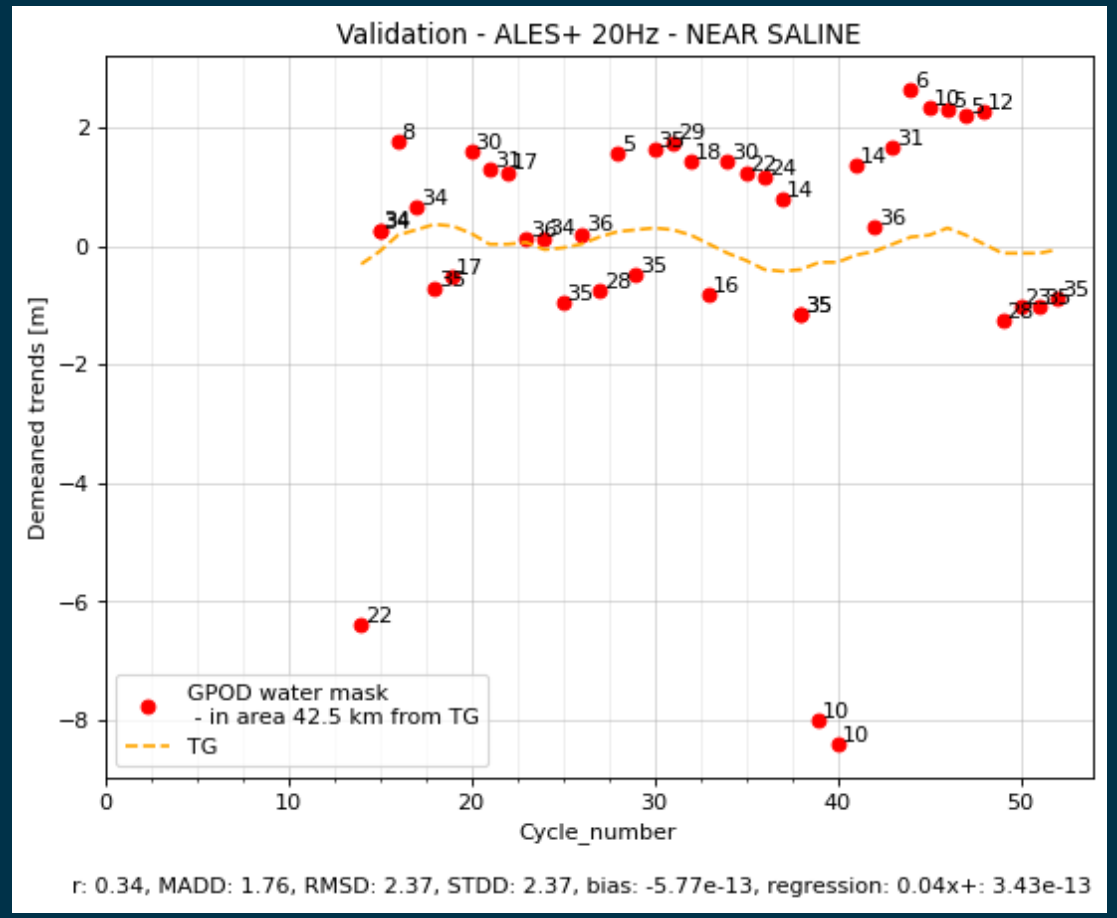
Track 275 – Misfit and quality flag filter, at gauge BOAT HARBOUR

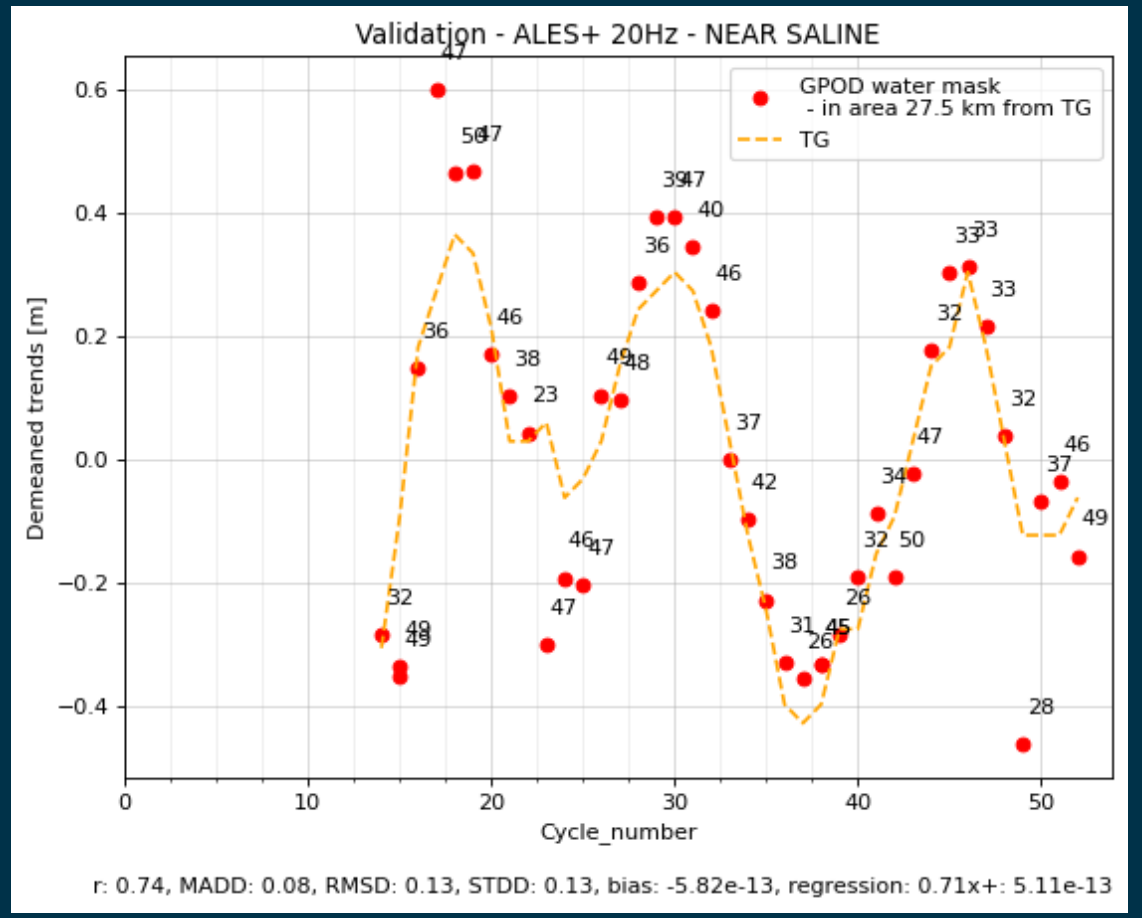
- Applying the quality flag to the ALES+ SAR data does not influence the results much.
- However, SAMOSA+ performs worse when applying the Misfit filter. The outliers which where present in the non-filter dataset are not removed. Only the number of measurements are reduced
- Additionally, the Misfit 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

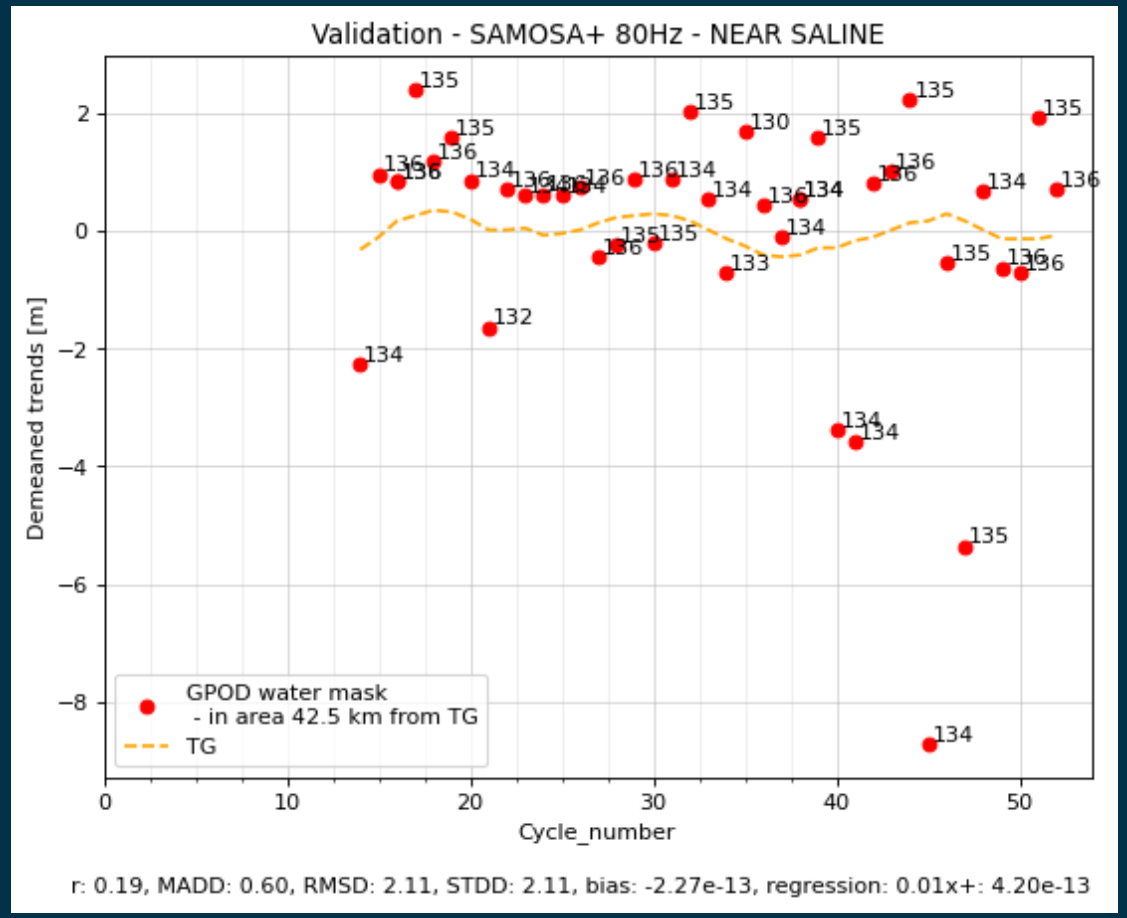
Worst performance ALES+ SAR Best performance

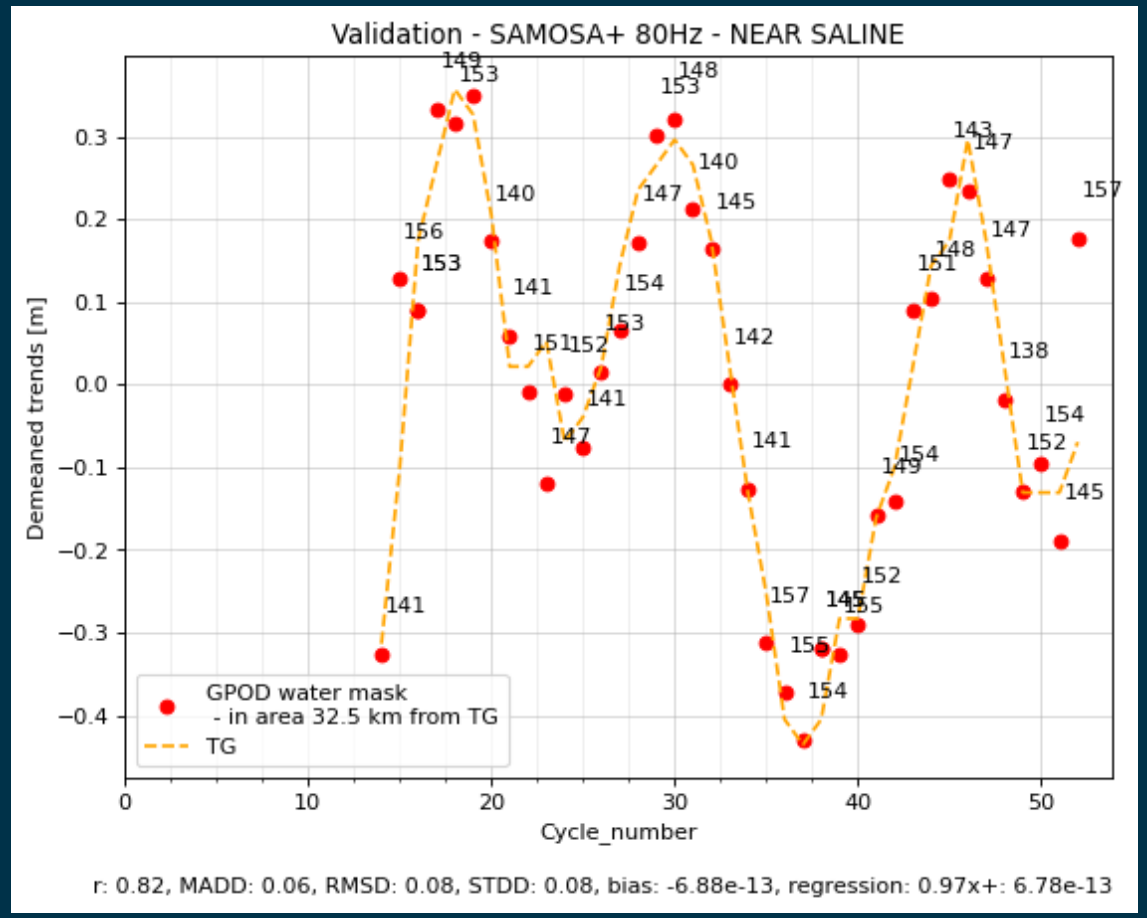




Track 275 – no filter, at gauge NEAR SALINE

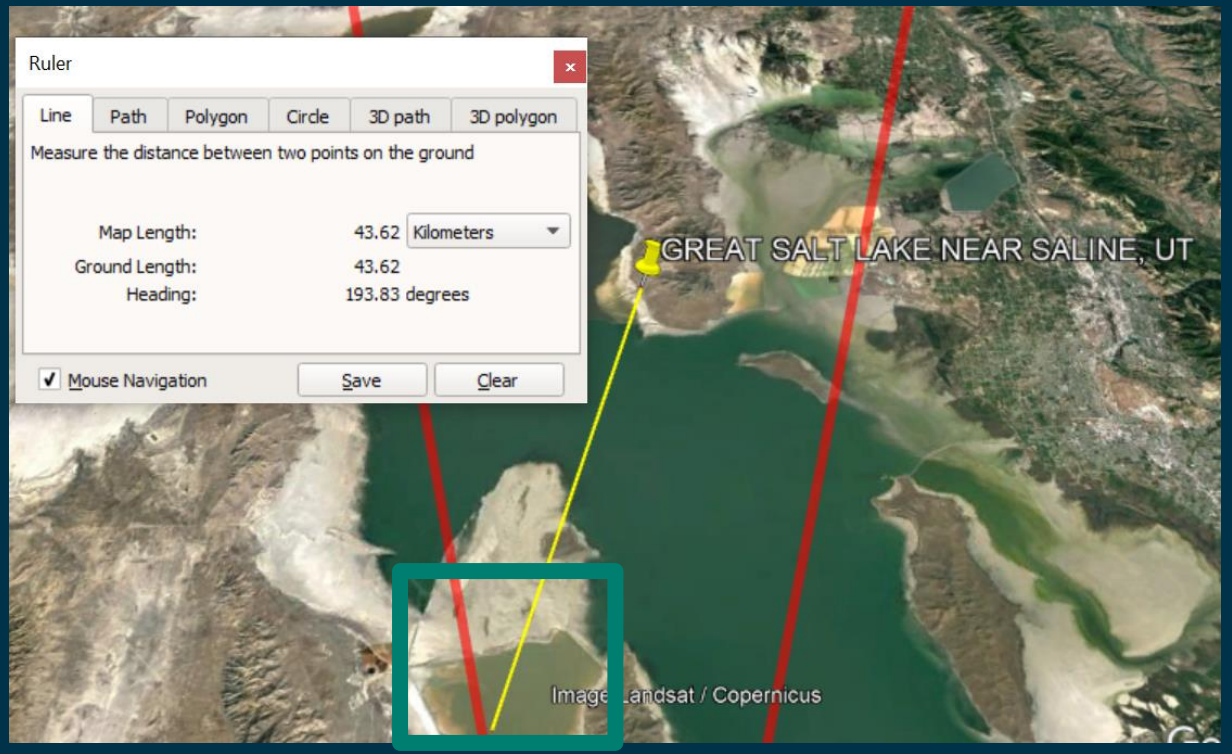
Worst performance SAMOSA+ Best performance





Track 275 – no filter, at gauge NEAR SALINE

- 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.

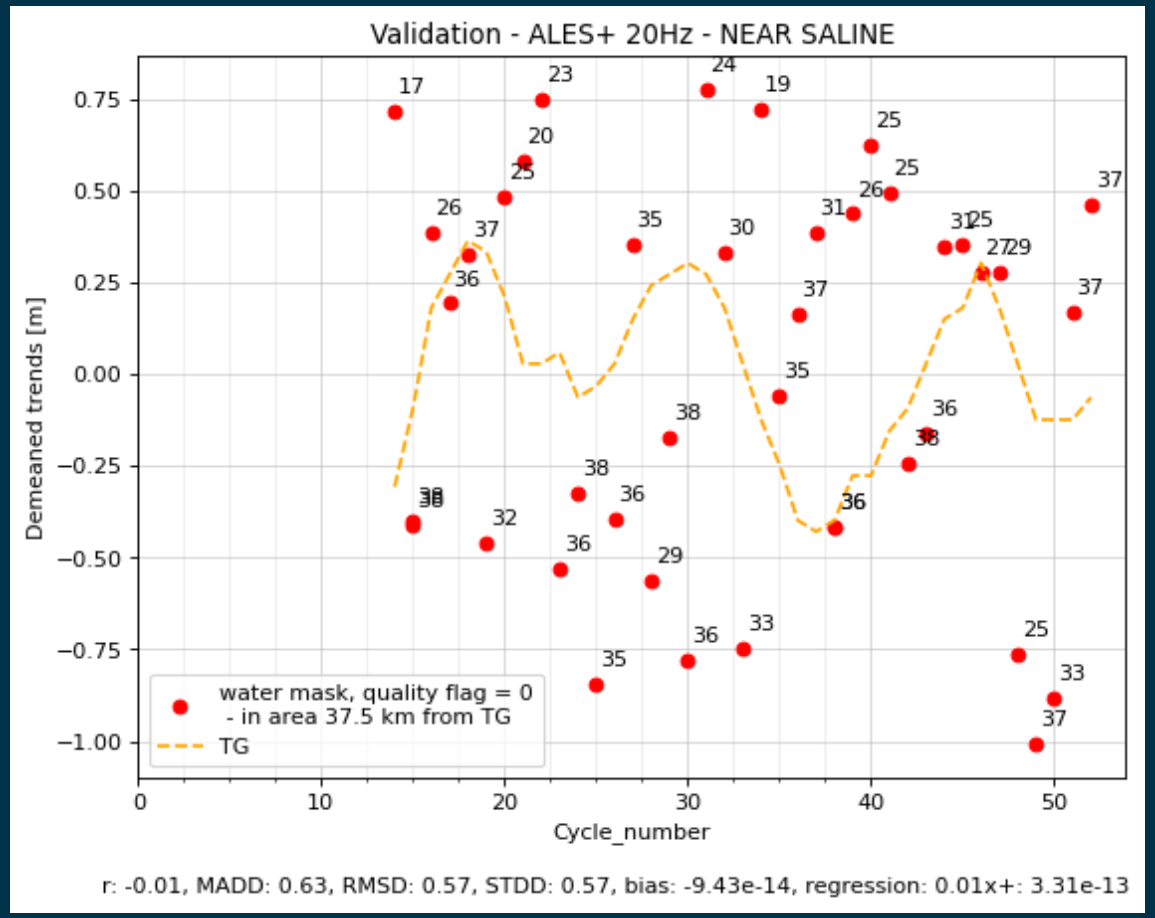


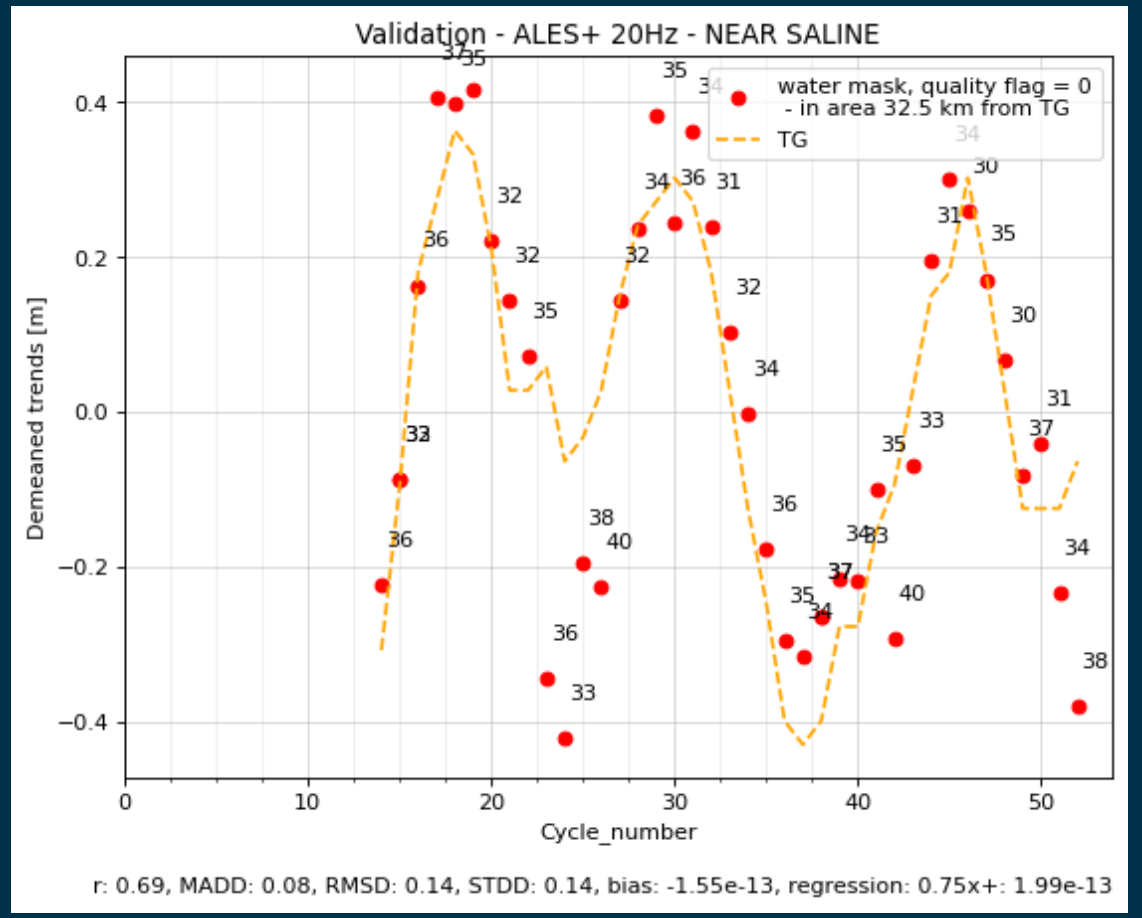
Track 275 – Misfit and quality flag filter, at gauge NEAR SALINE

Worst performance

ALES+ SAR

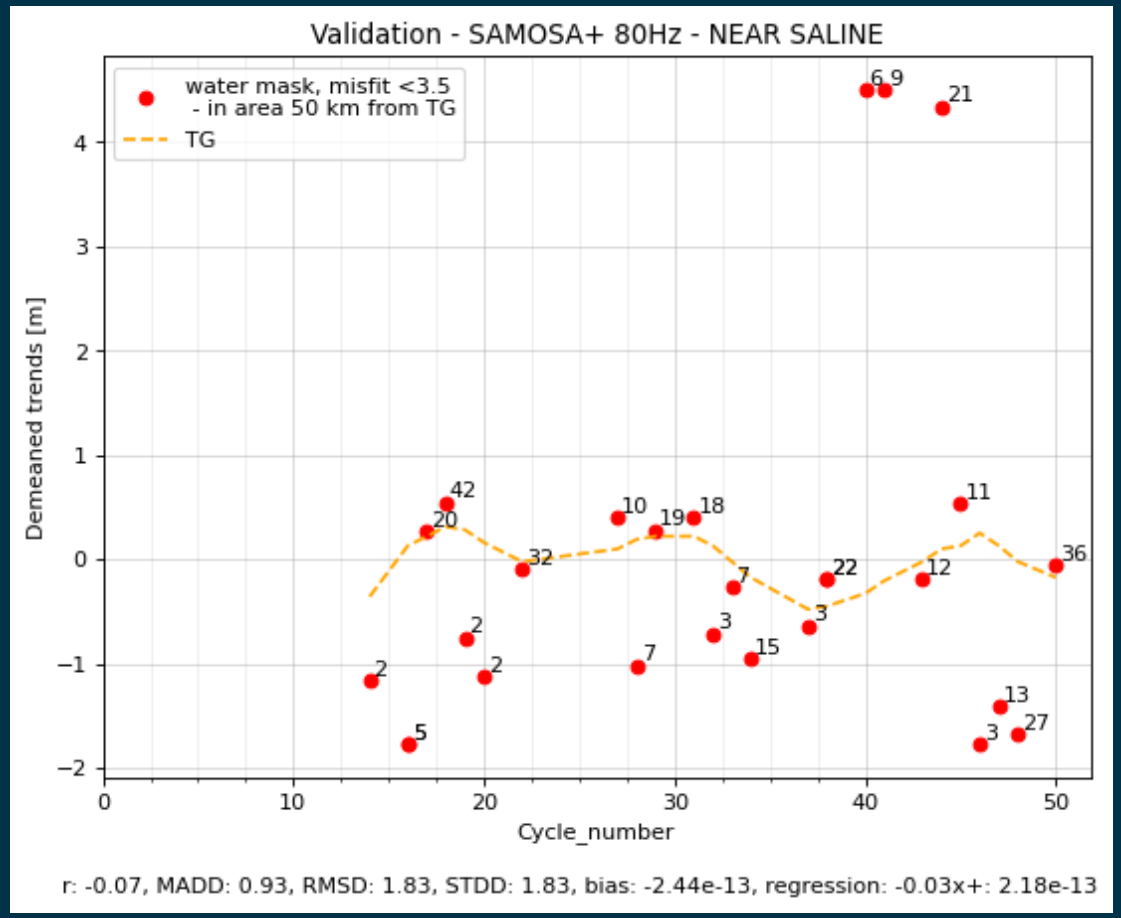
Best performance

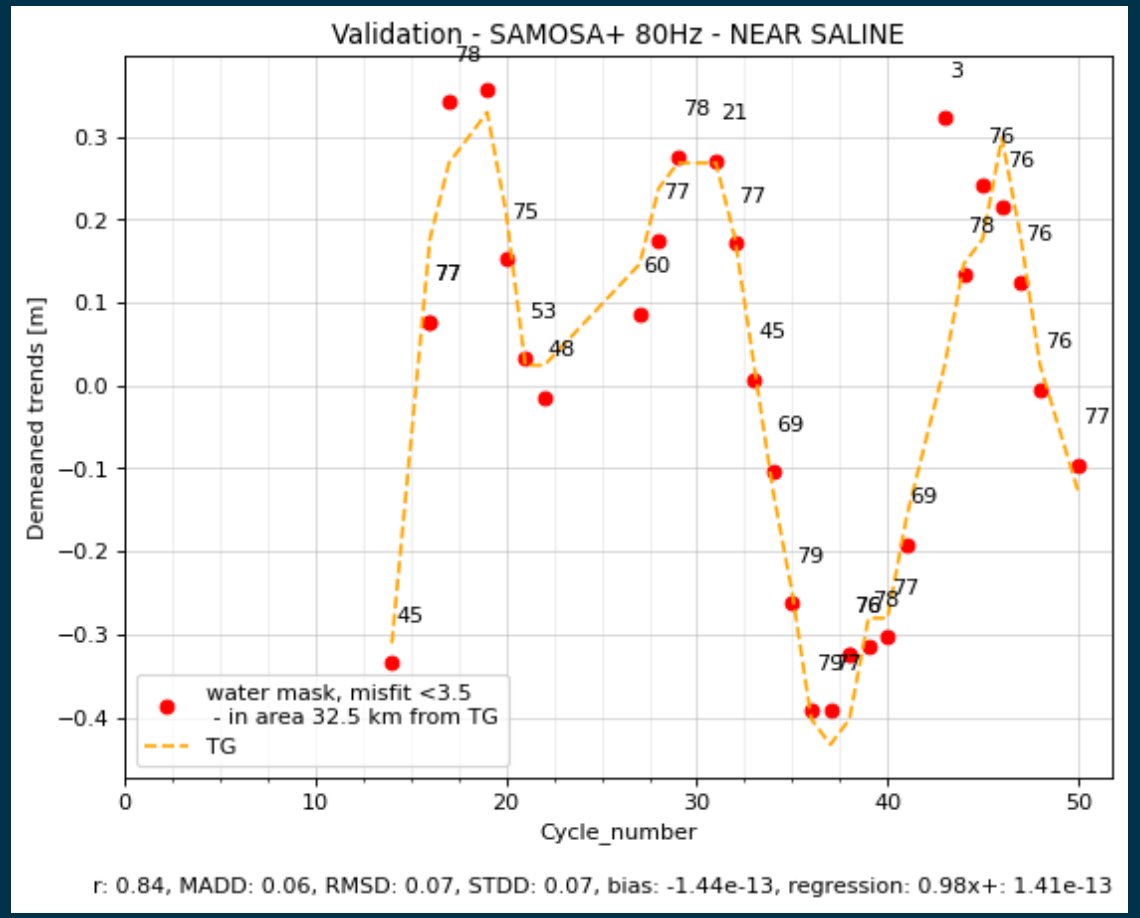




Track 275 – Misfit and quality flag filter, at gauge NEAR SALINE

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.

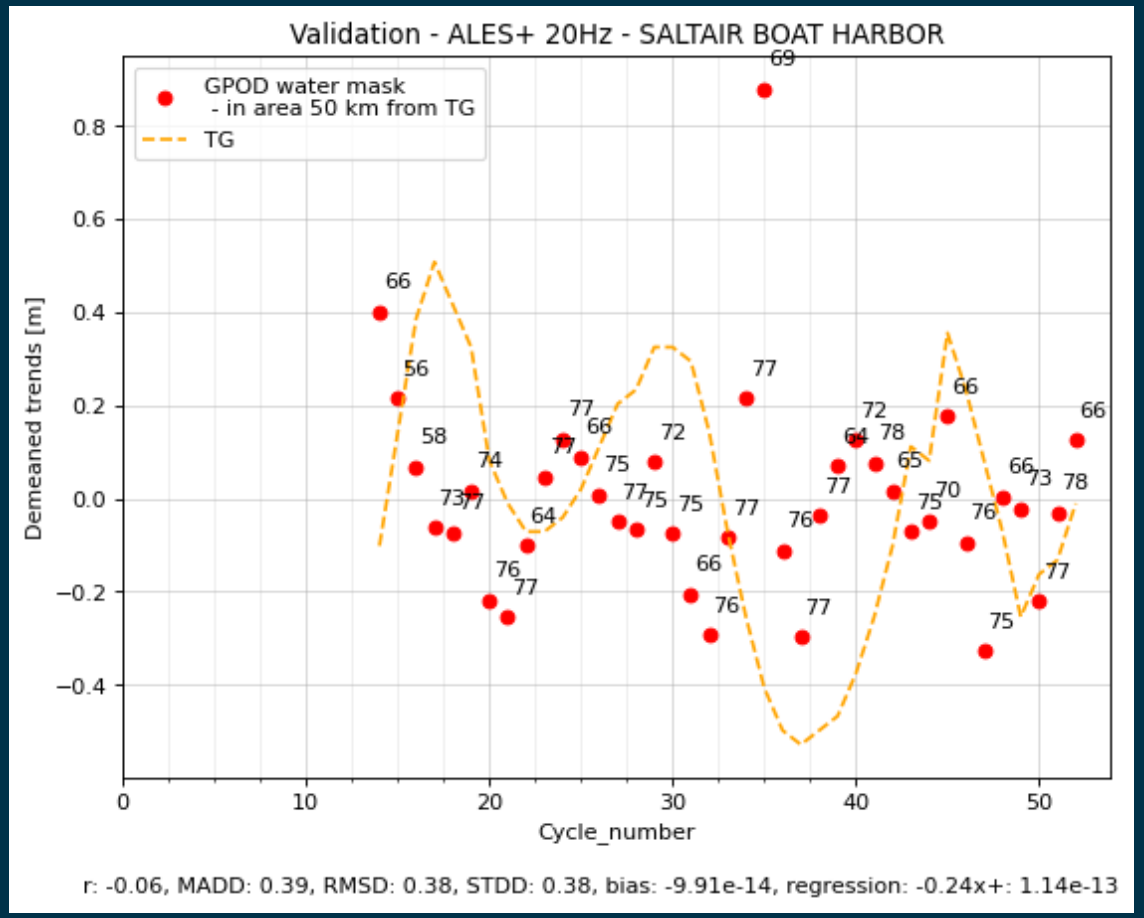
- The ALES+ SAR quality flag removes measurements from both outliers and accurate measurement. However, the performance decreases as outliers are not completely eliminated.

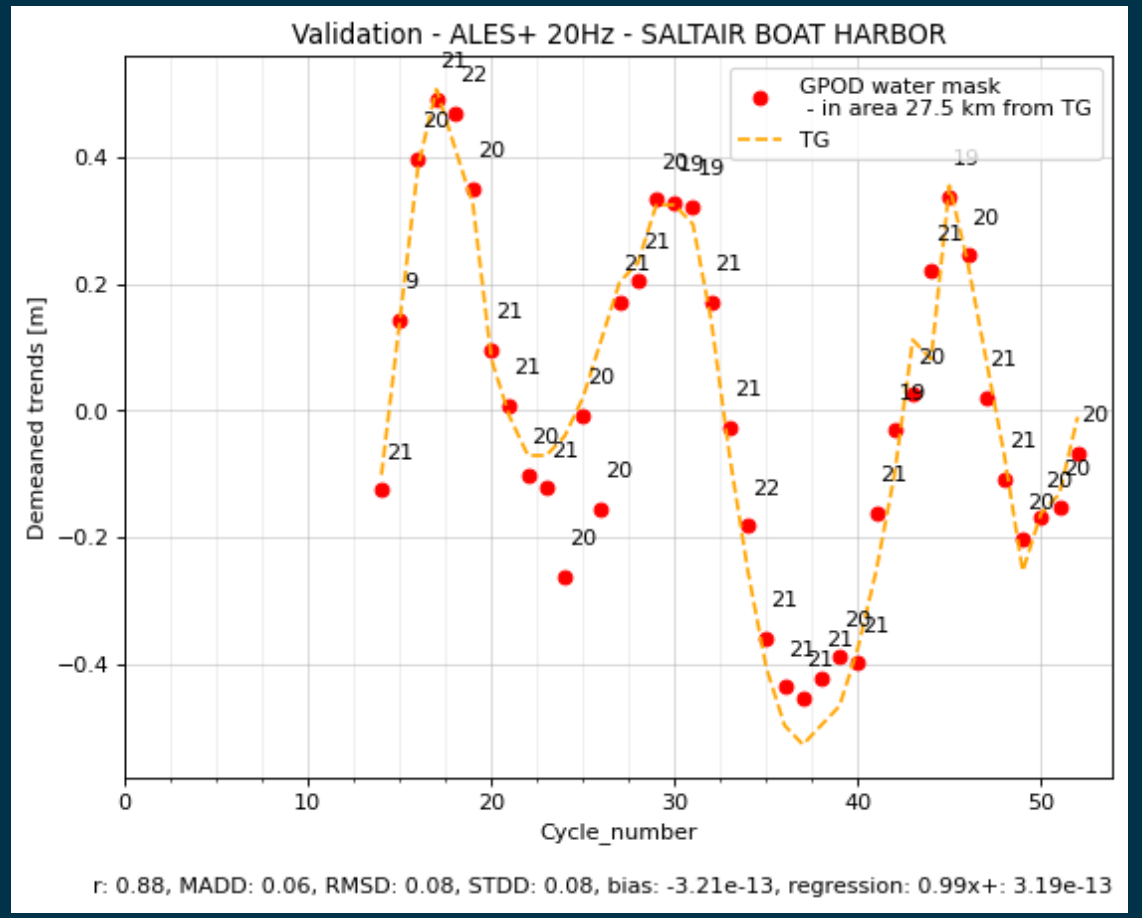
Results

Track 369

Track 369– no filter, at gauge BOAT HARBOUR

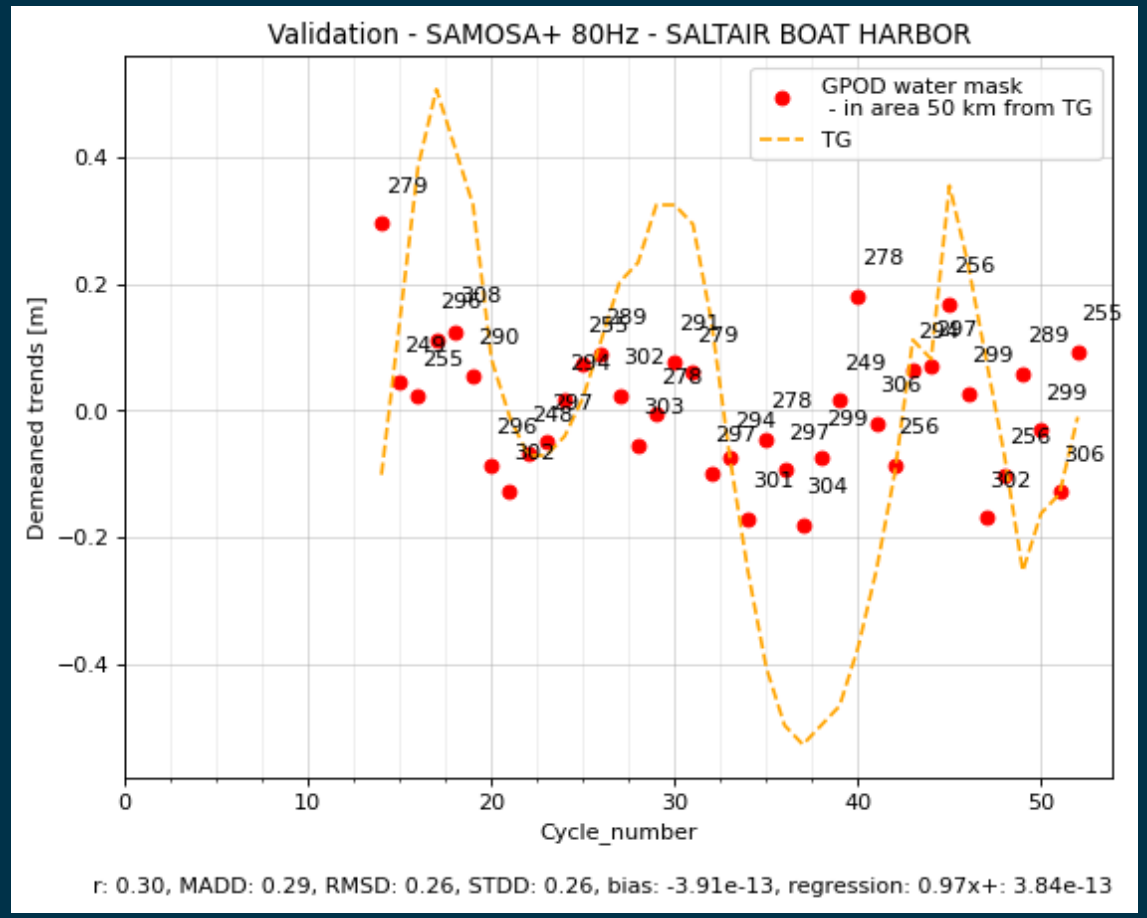
Worst performance ALES+ SAR Best performance

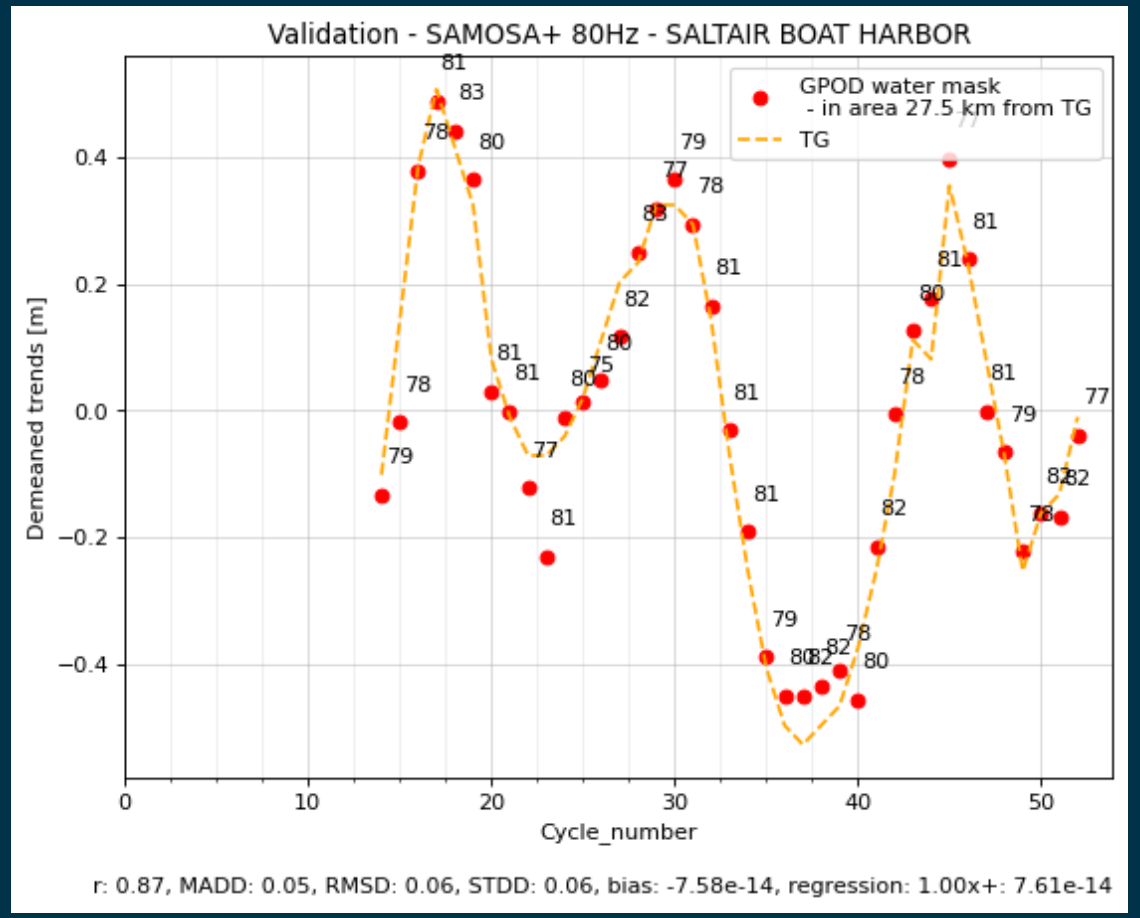




Track 369 – no filter, at gauge BOAT HARBOUR

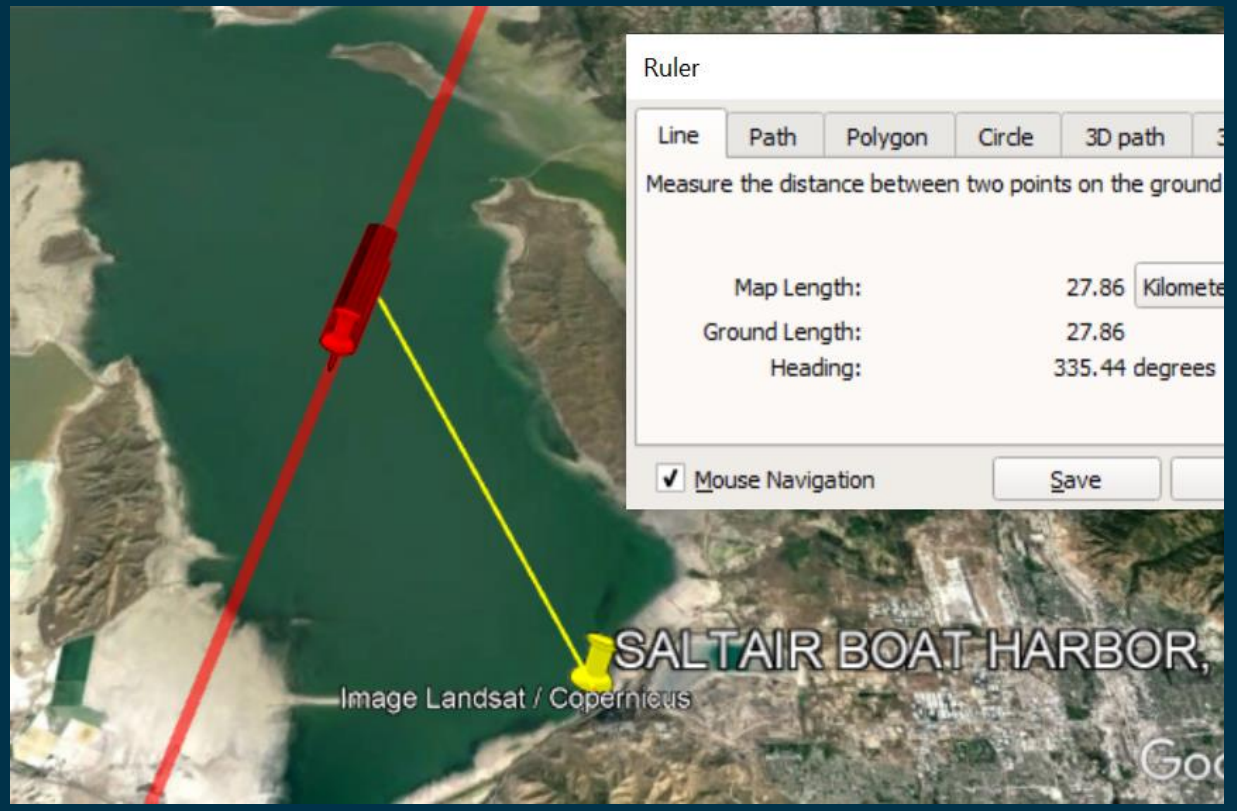
Worst performance SAMOSA+ Best performance





Track 369 – no filter, at gauge BOAT HARBOUR

- Both retrackers 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.

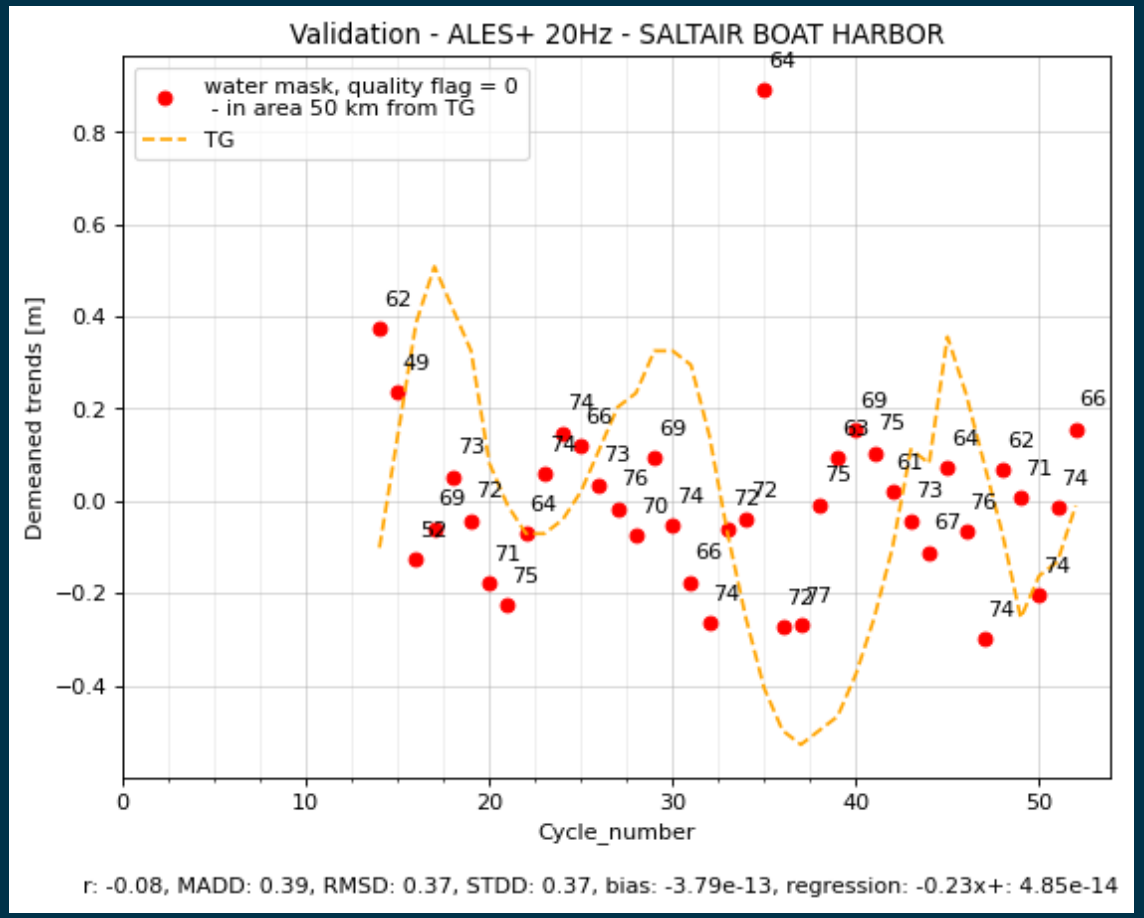


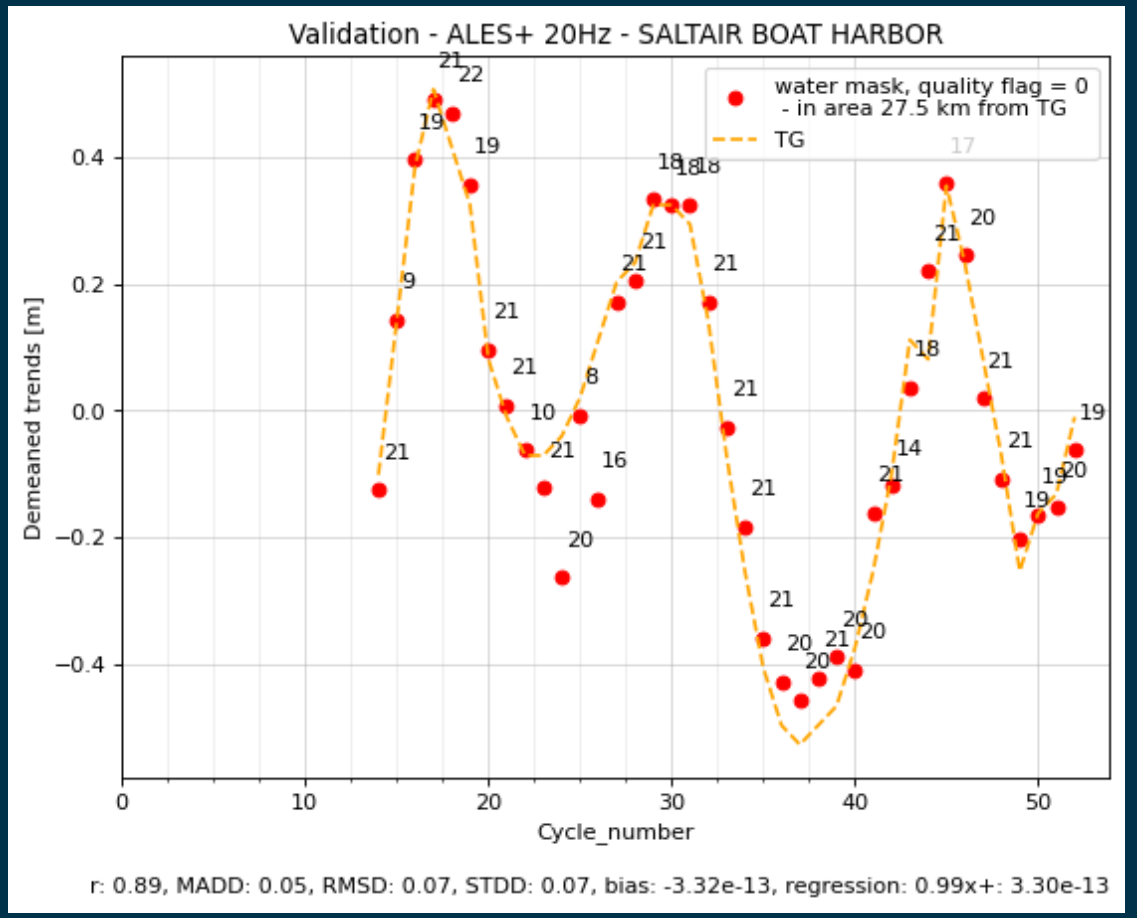
Track 369 – Misfit and quality flag filter, at gauge BOAT HARBOUR

Worst performance

ALES+ SAR

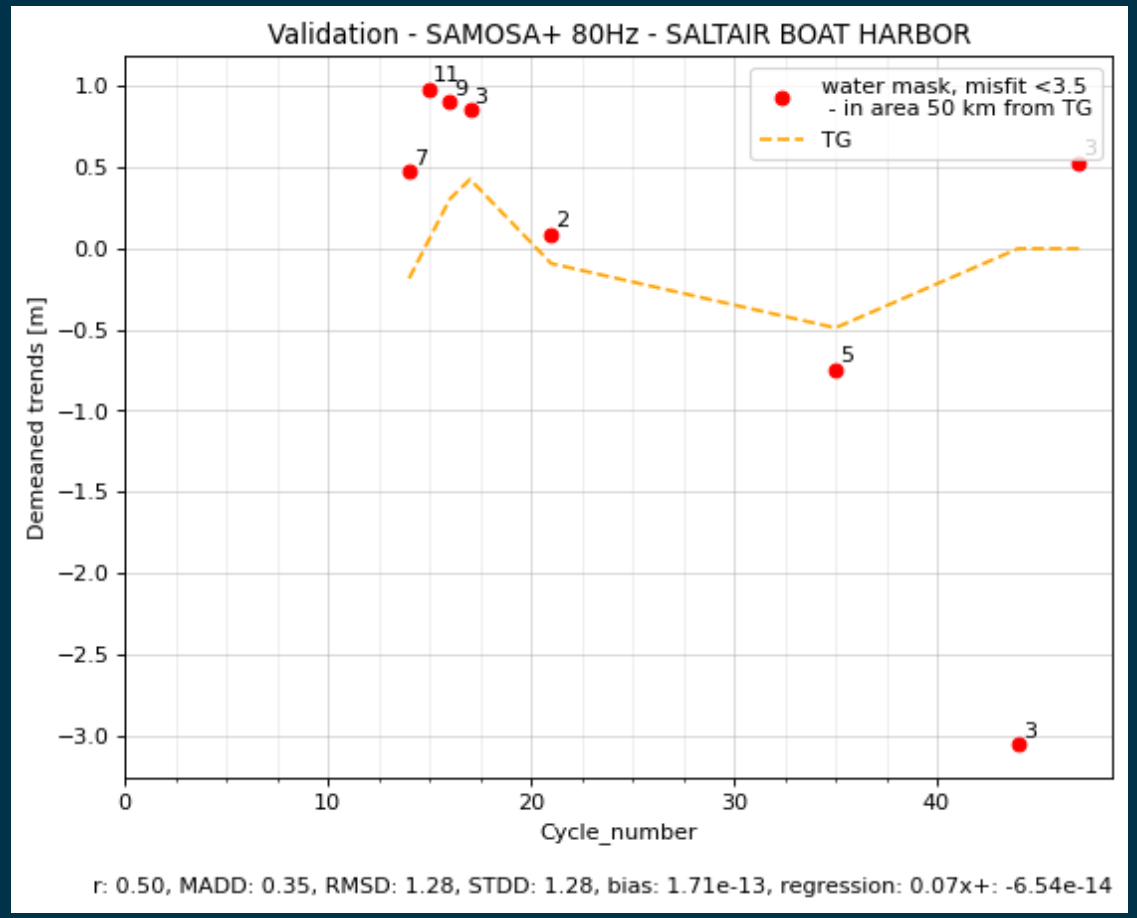
Best performance

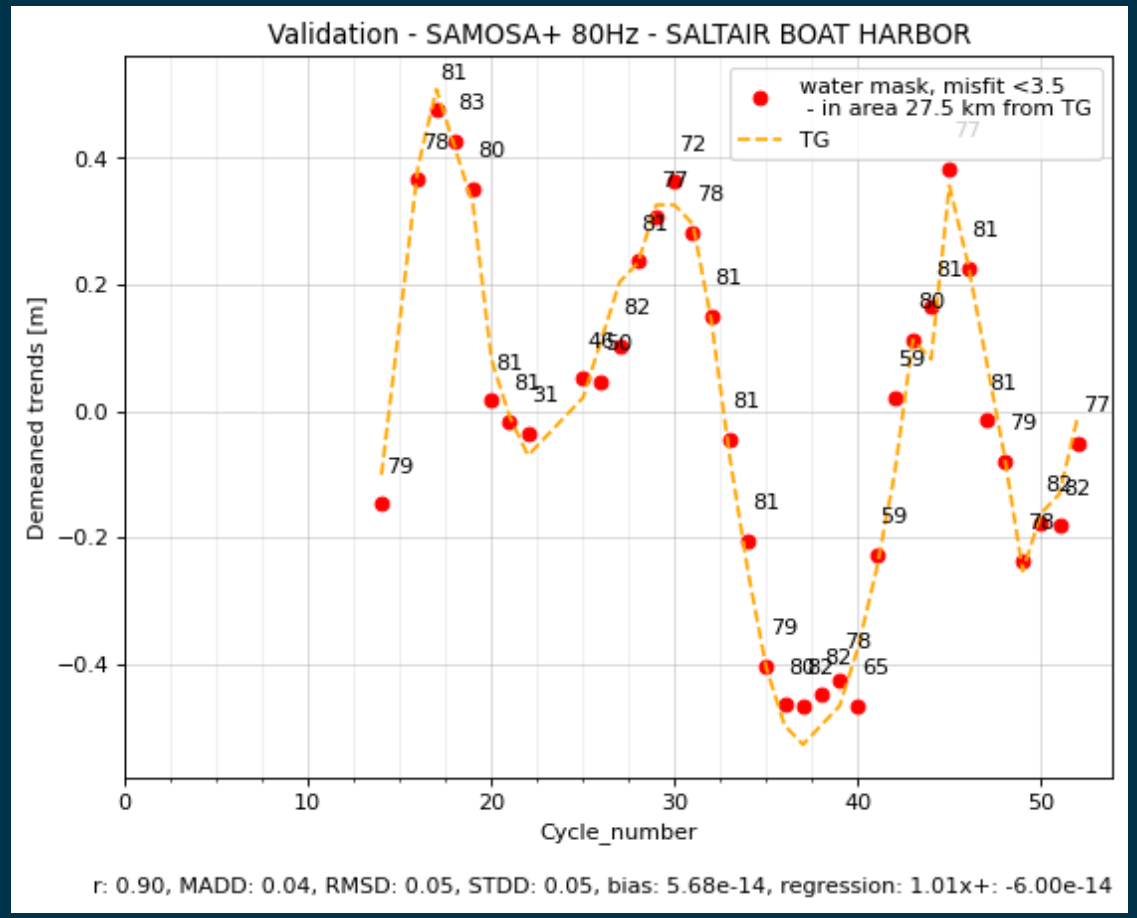




Track 369 – Misfit and quality flag filter, at gauge BOAT HARBOUR

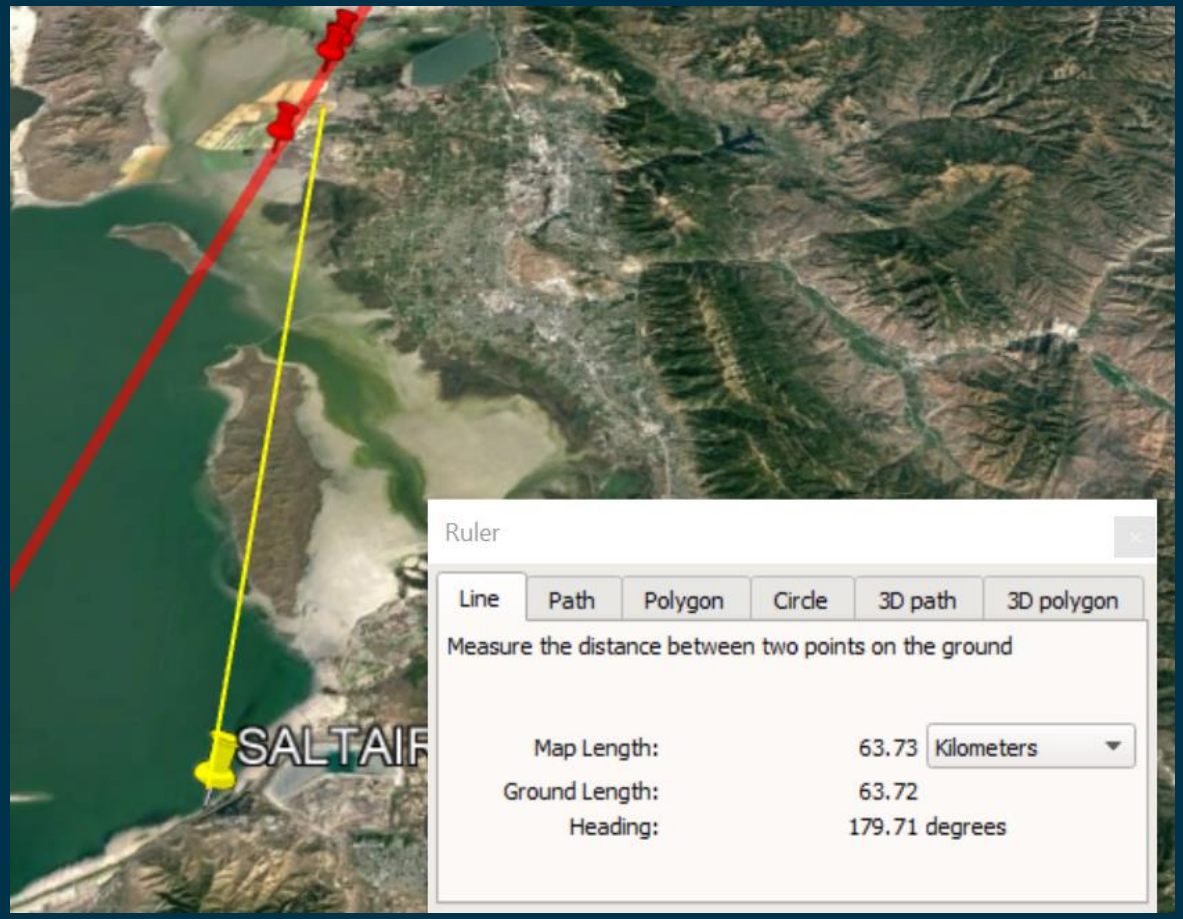
Worst performance SAMOSA+ Best performance





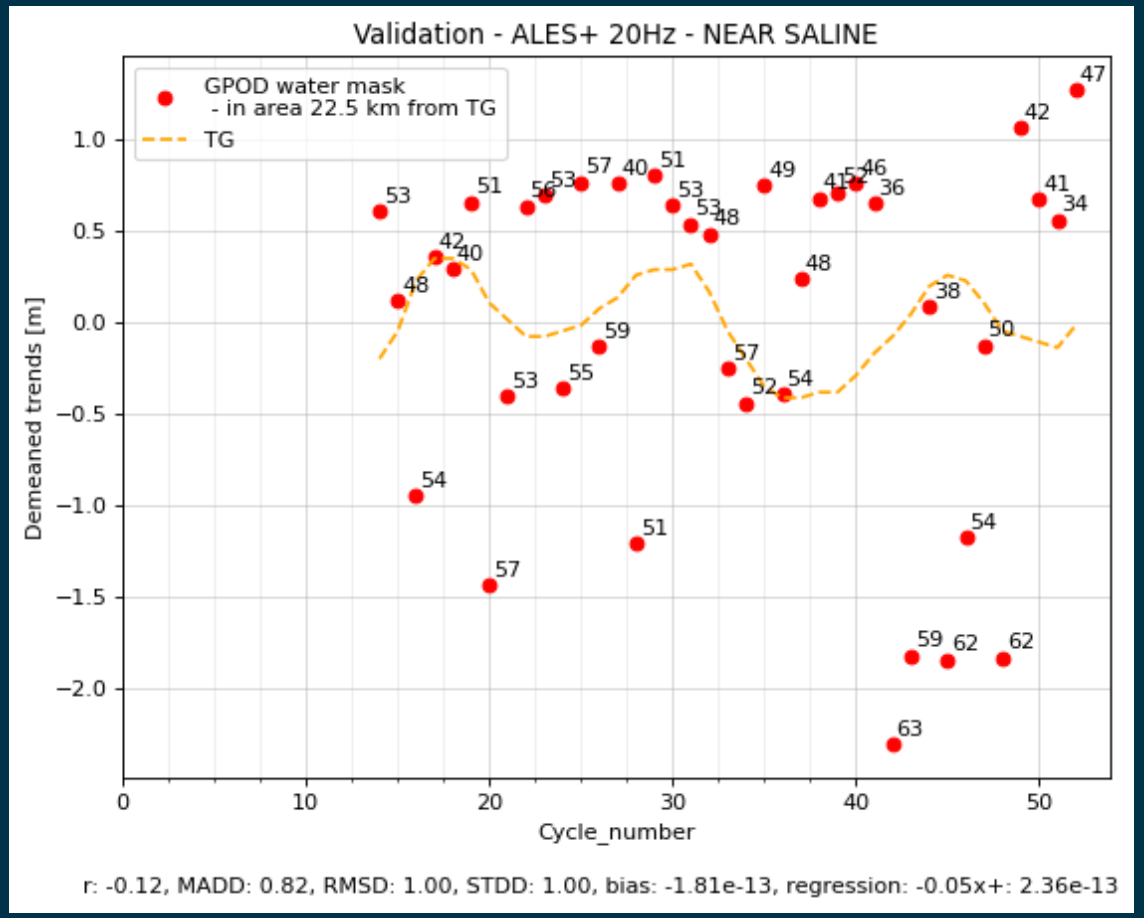
Track 369 – Misfit and quality flag filter, at gauge BOAT HARBOUR

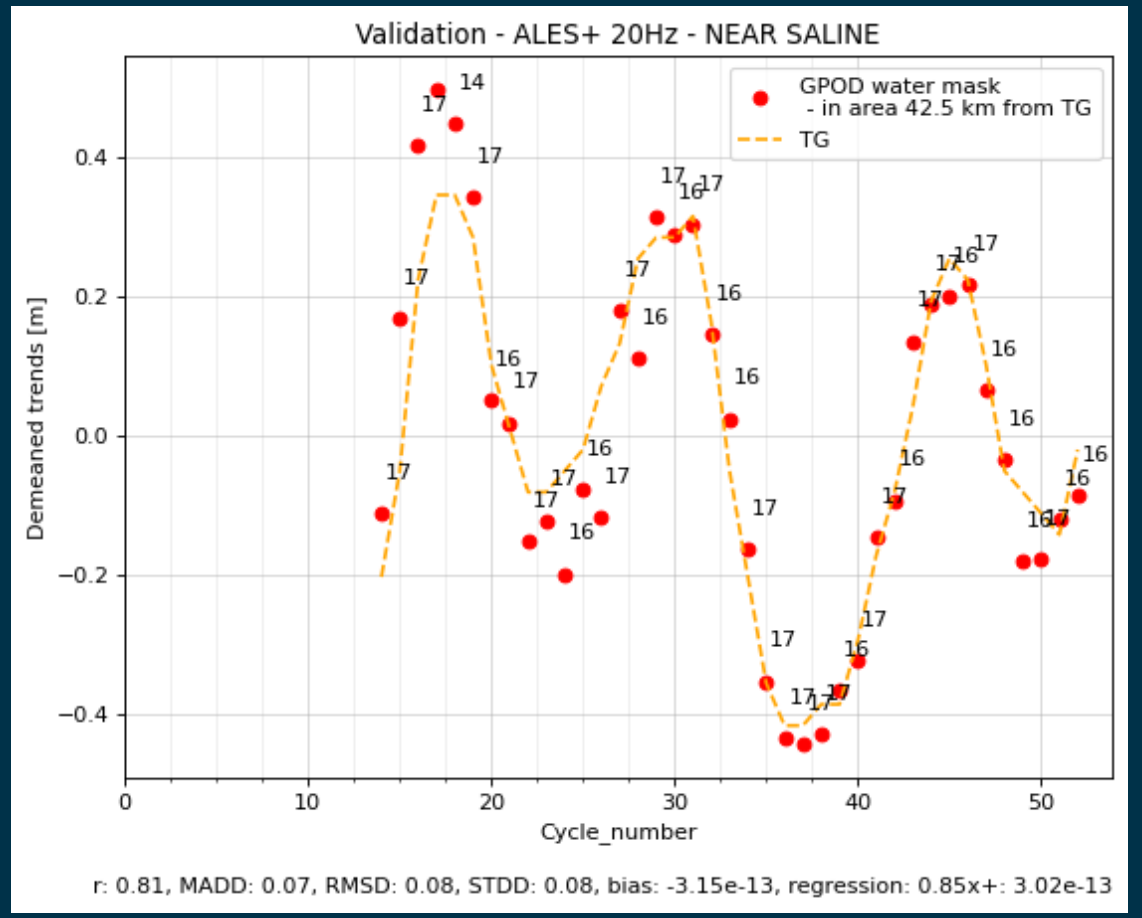
- The ALES+ SAR data improves slightly when applying the quality flag.
- SAMOSA+ shows very good metrics after the Misfit filtering.
- The best data is still found in region 25-30 km.
- The filtering cannot compensate for changing characteristics of salinity and water level in the north-eastern arm of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



Track 369 – no filter, at gauge NEAR SALINE

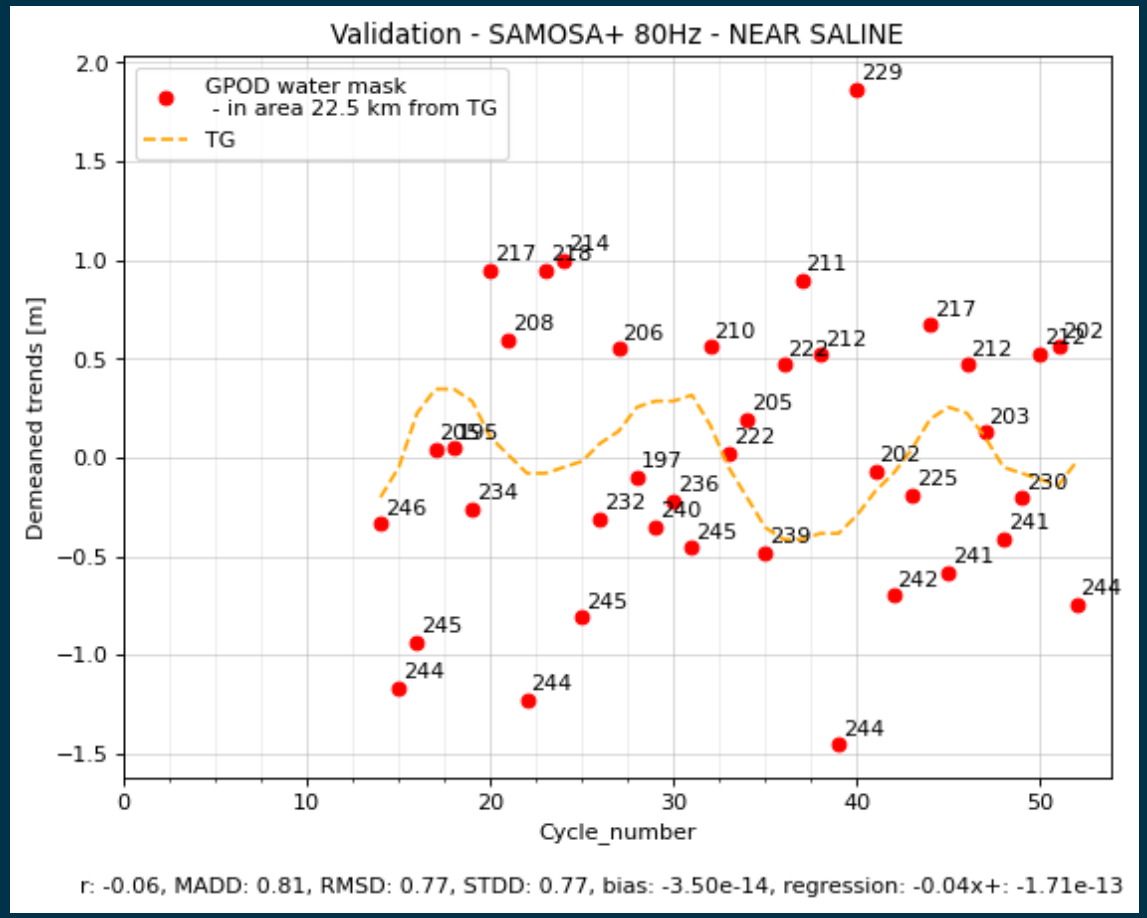
Worst performance ALES+ SAR Best performance

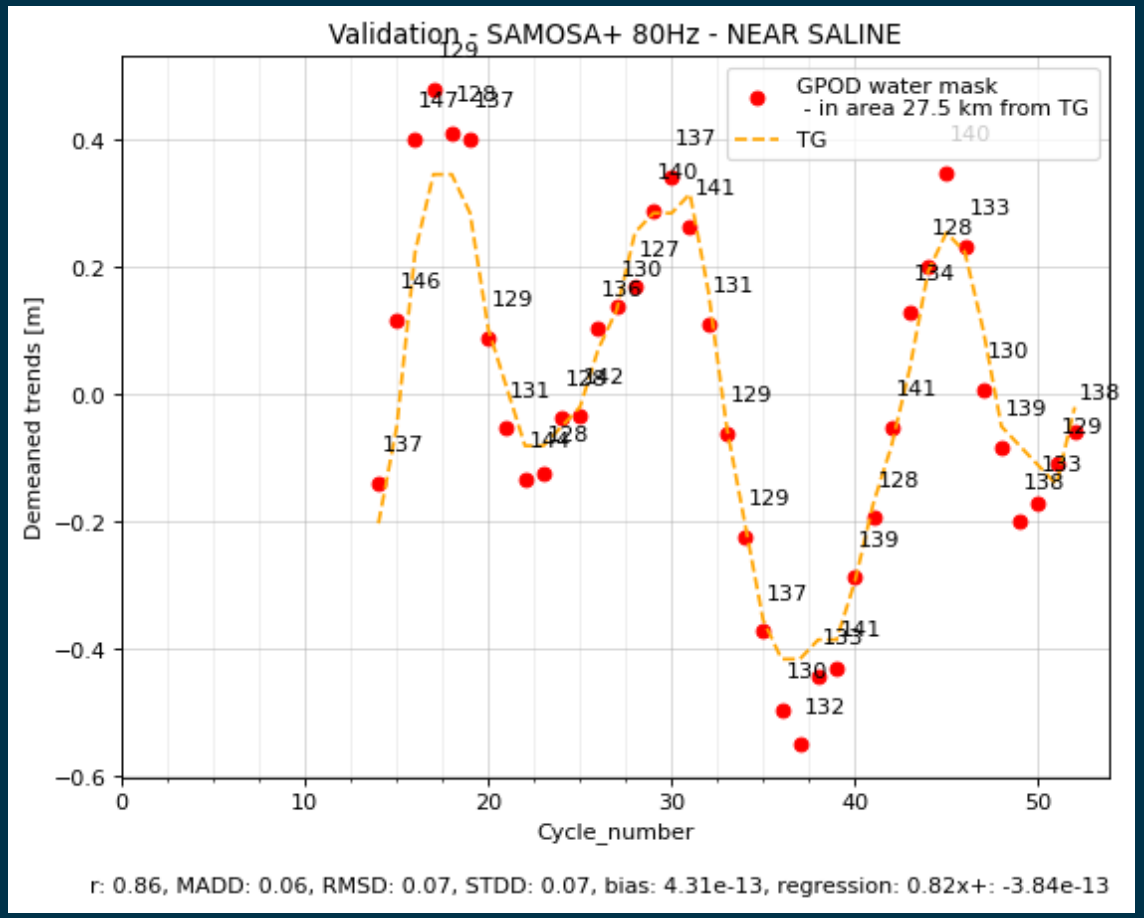




Track 369 – no filter, at gauge NEAR SALINE

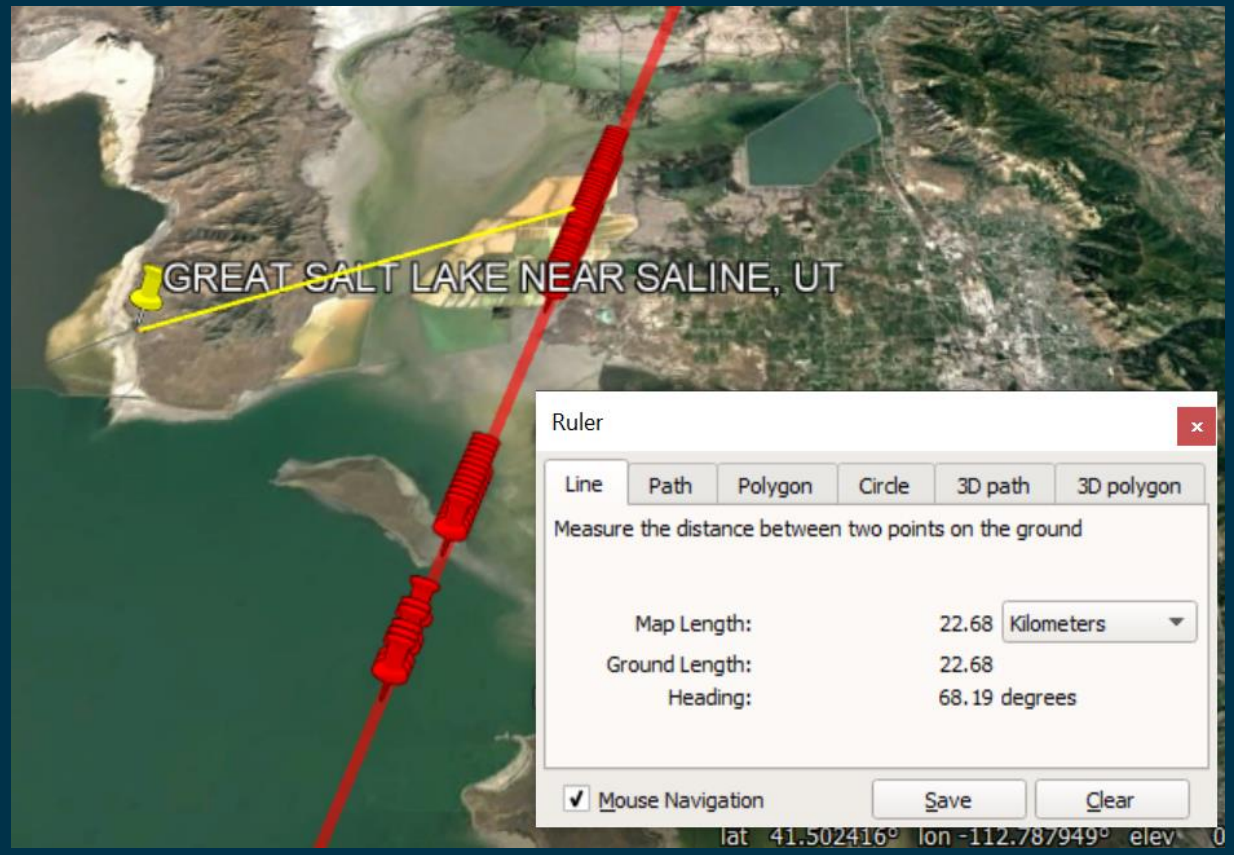
Worst performance SAMOSA+ Best performance





Track 369 – no filter, at gauge NEAR SALINE

- Both retrackers preform worst in the region of 20-25 km away from the gauge. The north-east arm lies within this range and is 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 retrackers exhibit good metrics, however in different areas.

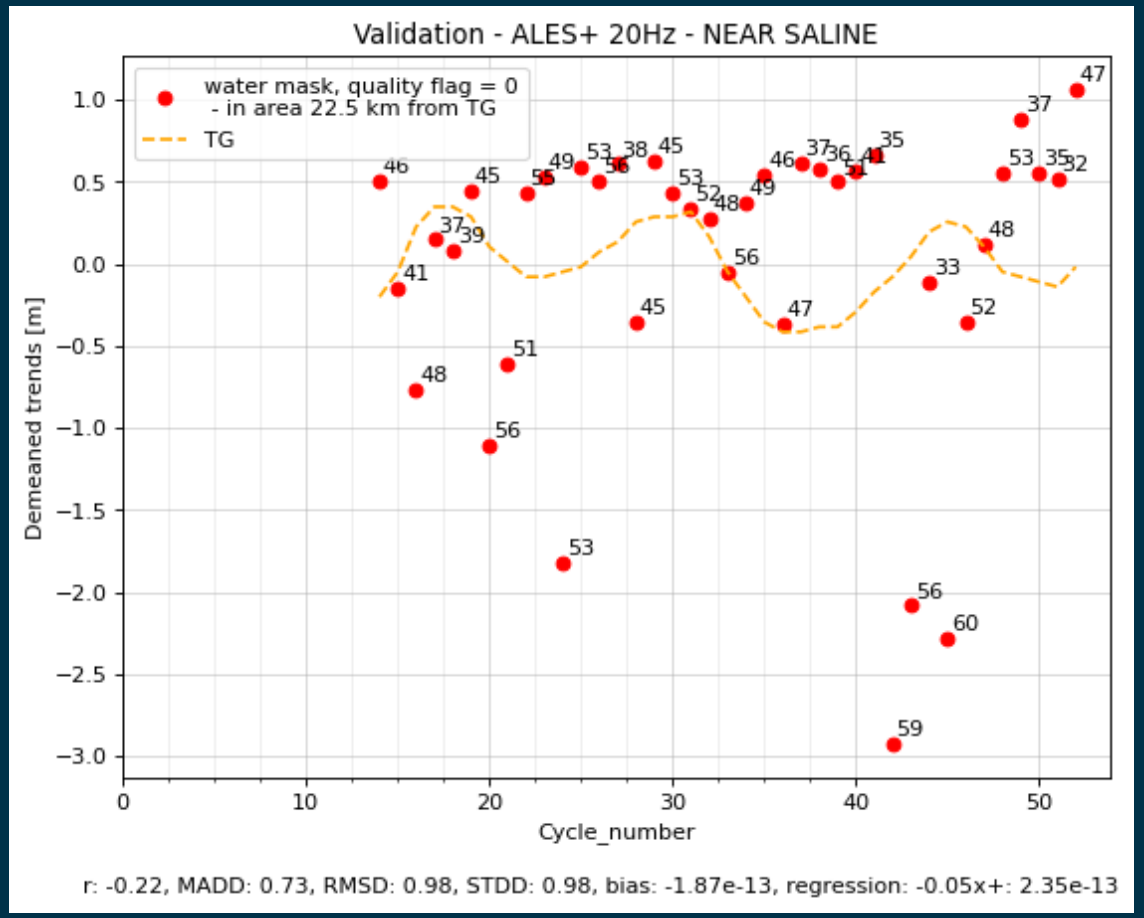


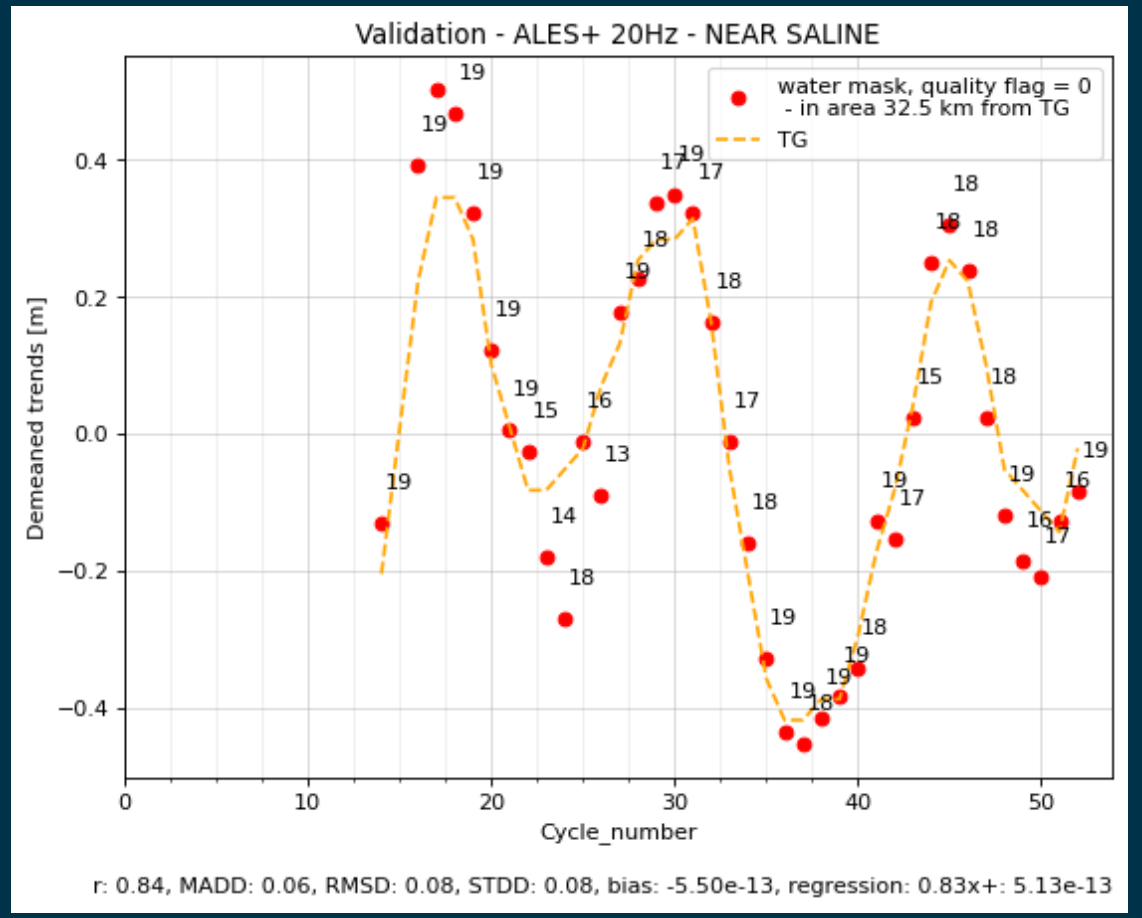
Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

Worst performance

ALES+ SAR

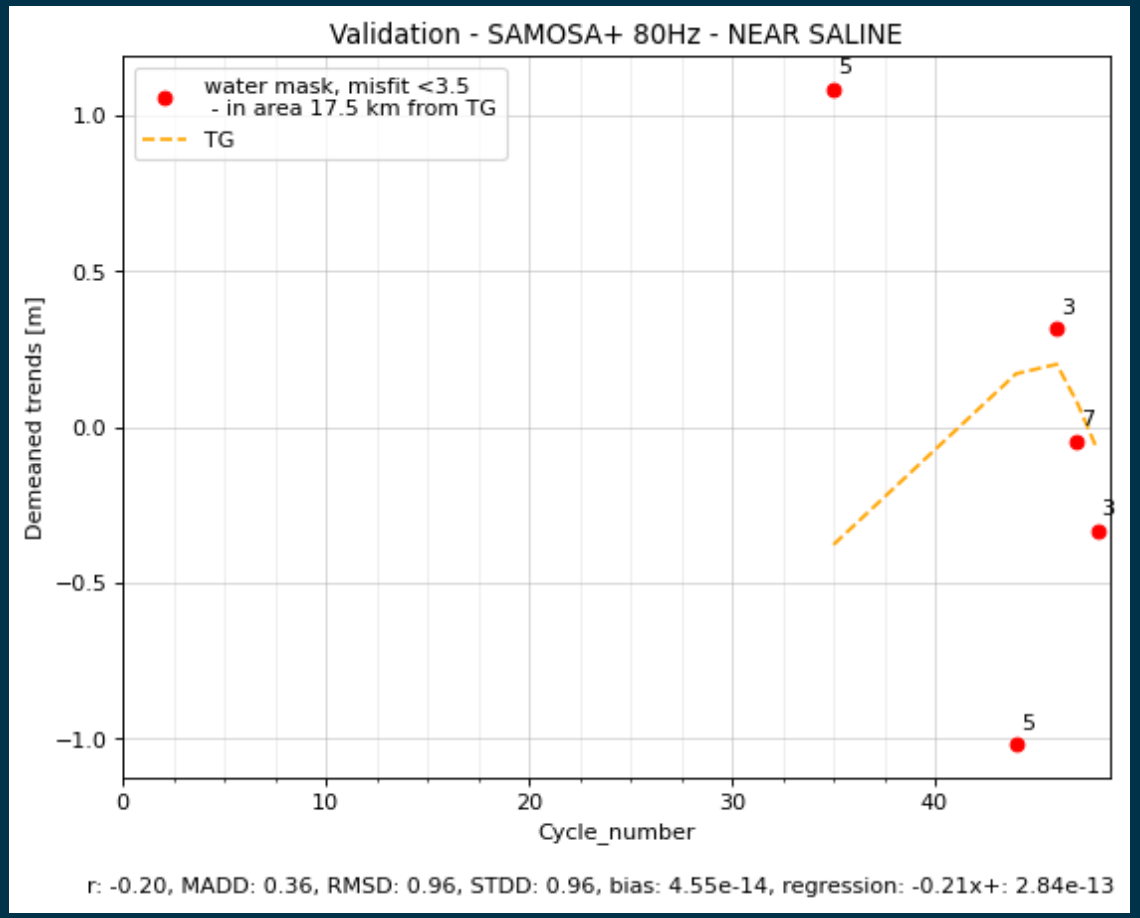
Best performance

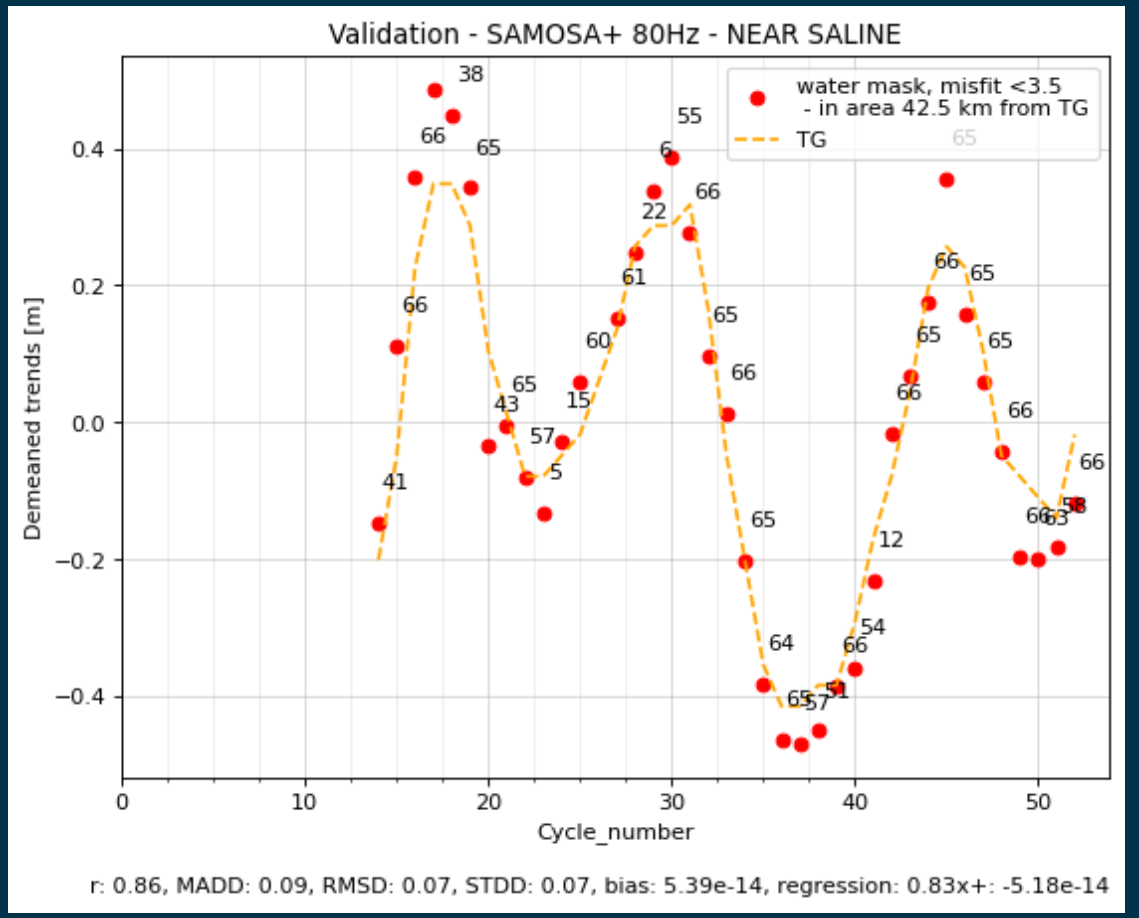




Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

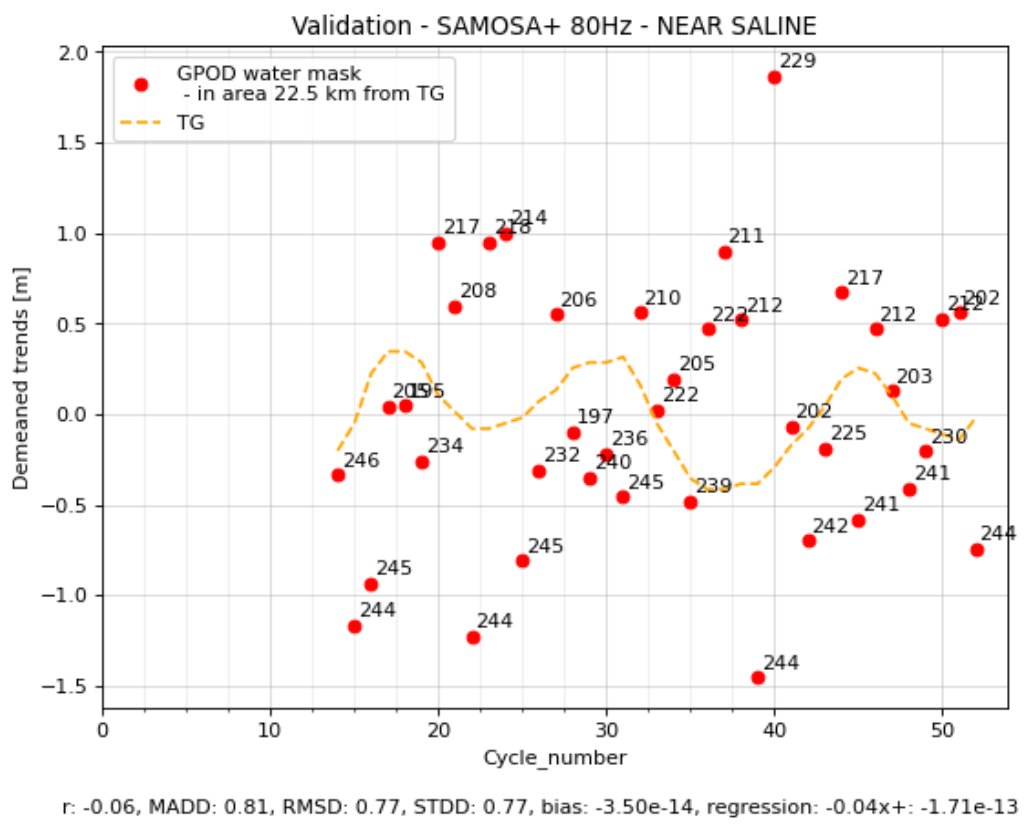
Worst performance SAMOSA+ Best performance

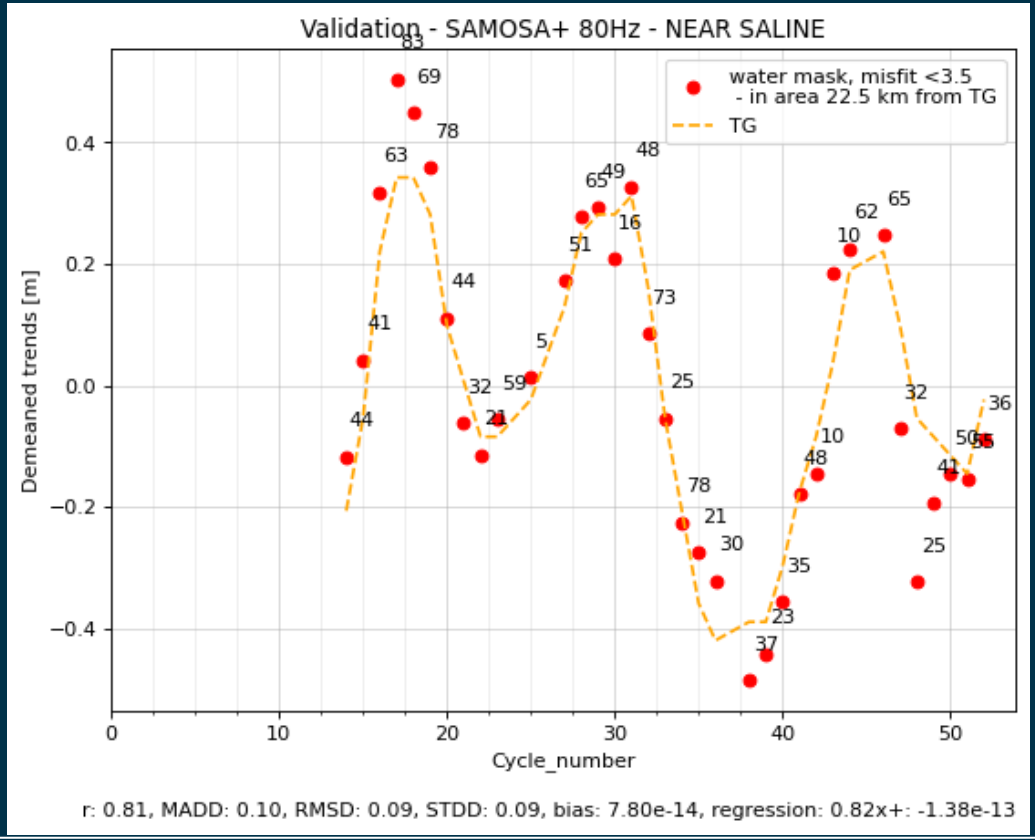




Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

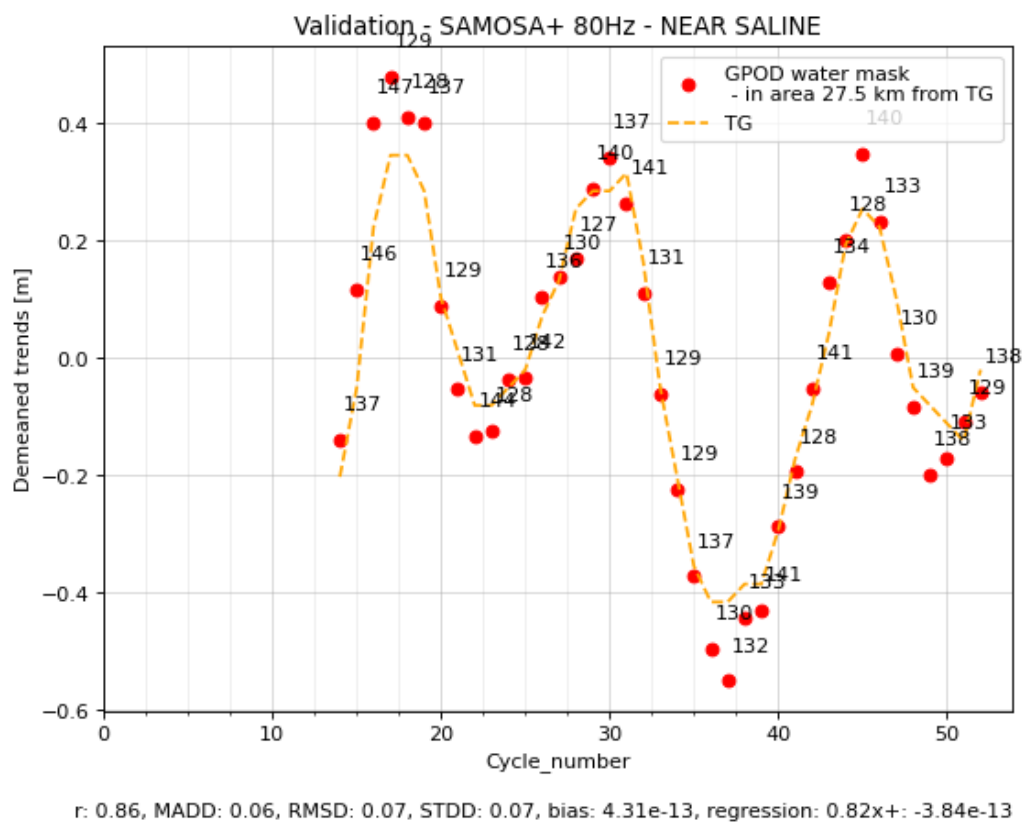
- The quality filter improves the ALES+ SAR data.
- SAMOSA+ exhibit similar metrics after applying the Misfit filter.
- However when comparing the outputs of all regions for the non-filter data set and the Misfit-data set, it becomes evident that the Misfit filtering step leads to less outliers and provides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

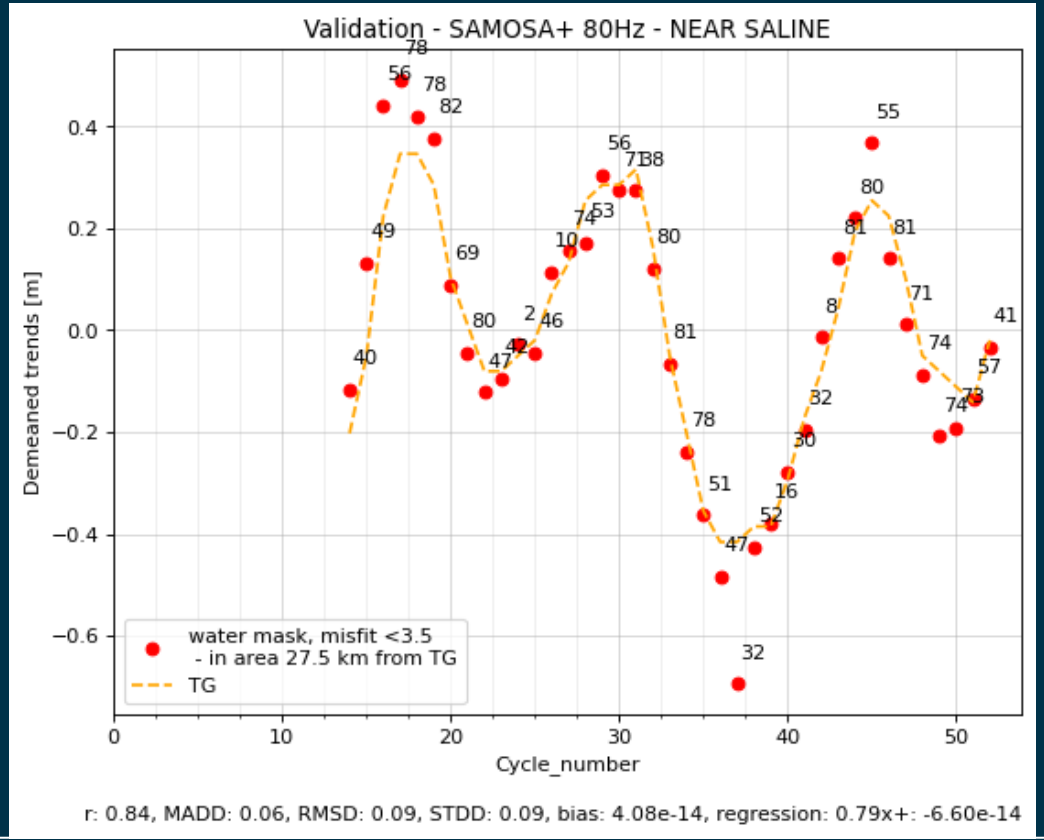




Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

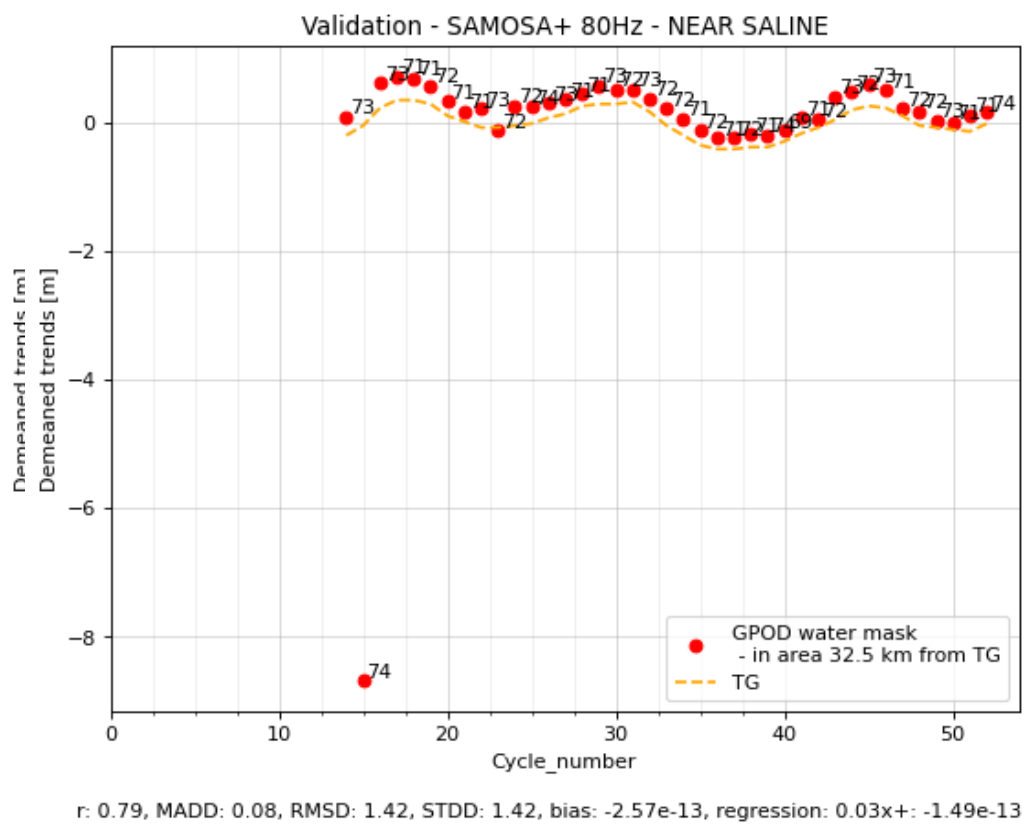
- The quality filter improves the ALES+ SAR data.
- SAMOSA+ exhibit similar metrics after applying the Misfit filter.
- However when comparing the outputs of all regions for the non-filter data set and the Misfit-data set, it becomes evident that the Misfit filtering step leads to less outliers and provides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

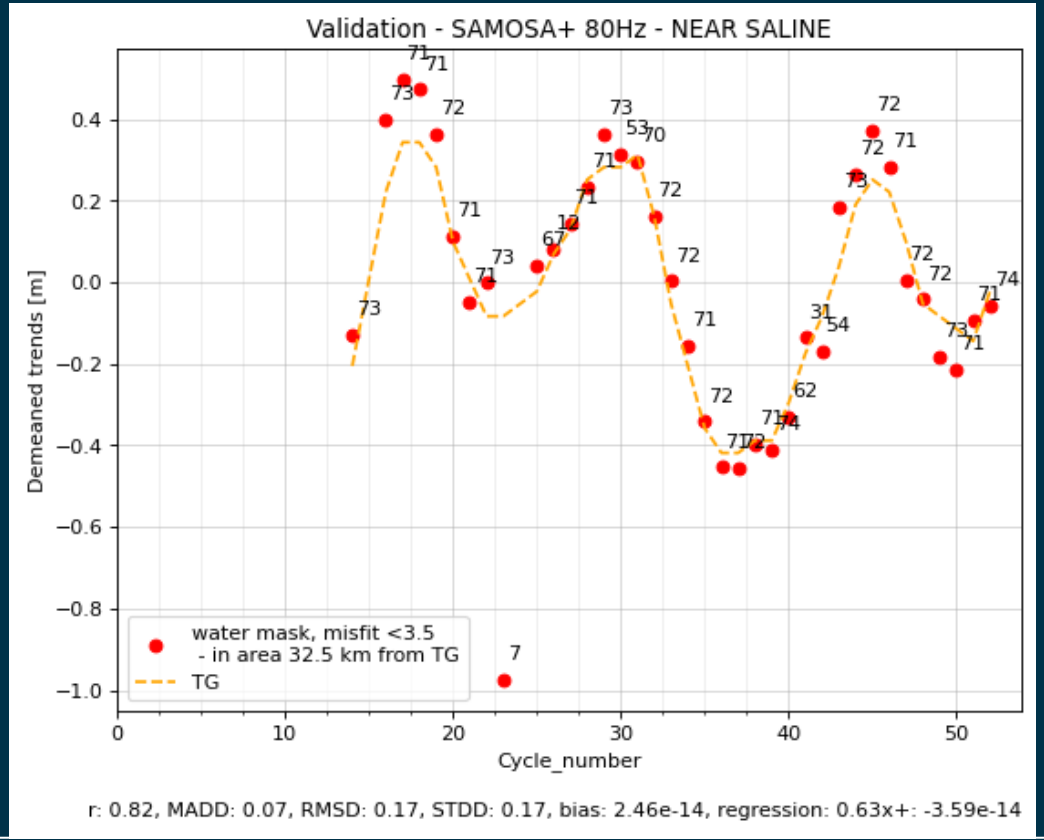




Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

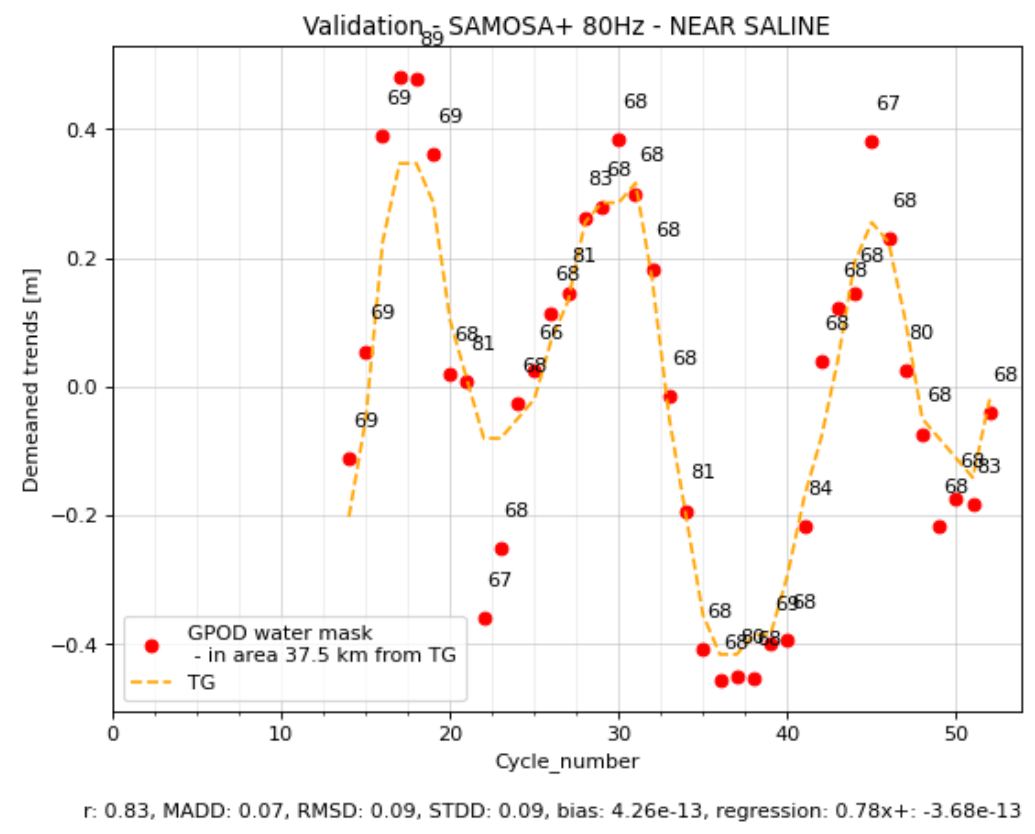
- The quality filter improves the ALES+ SAR data.
- SAMOSA+ exhibit similar metrics after applying the Misfit filter.
- However when comparing the outputs of all regions for the non-filter data set and the Misfit-data set, it becomes evident that the Misfit filtering step leads to less outliers and provides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

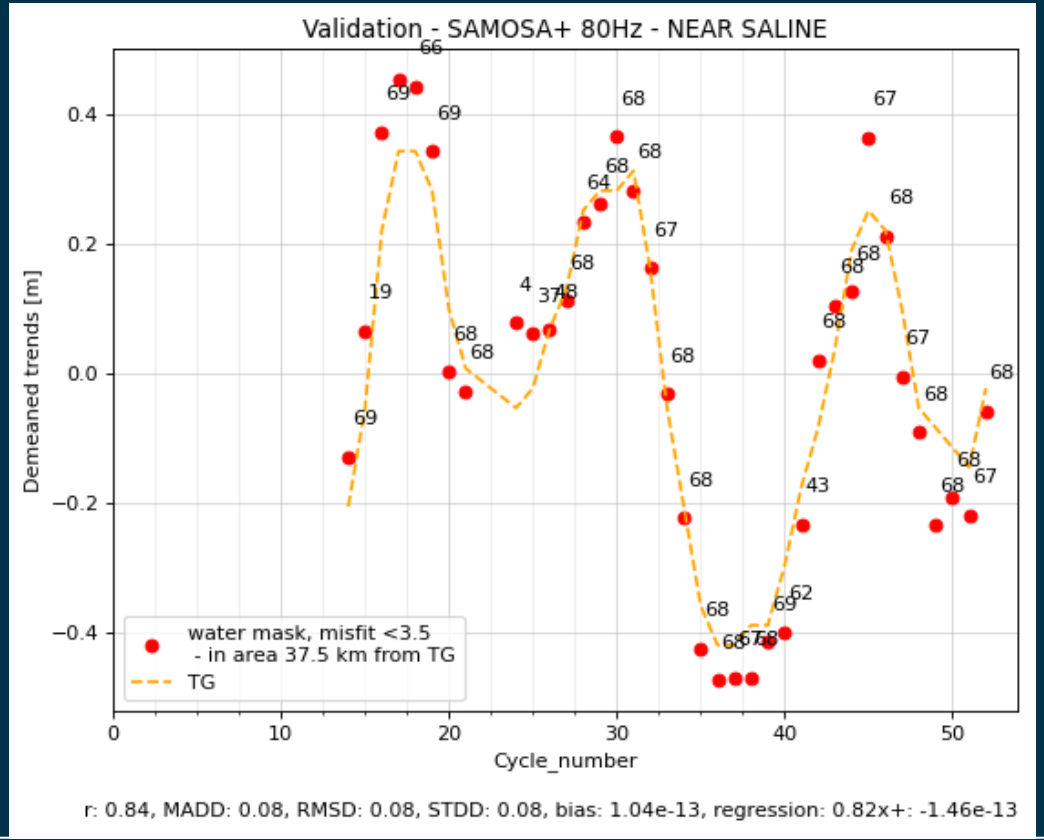




Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

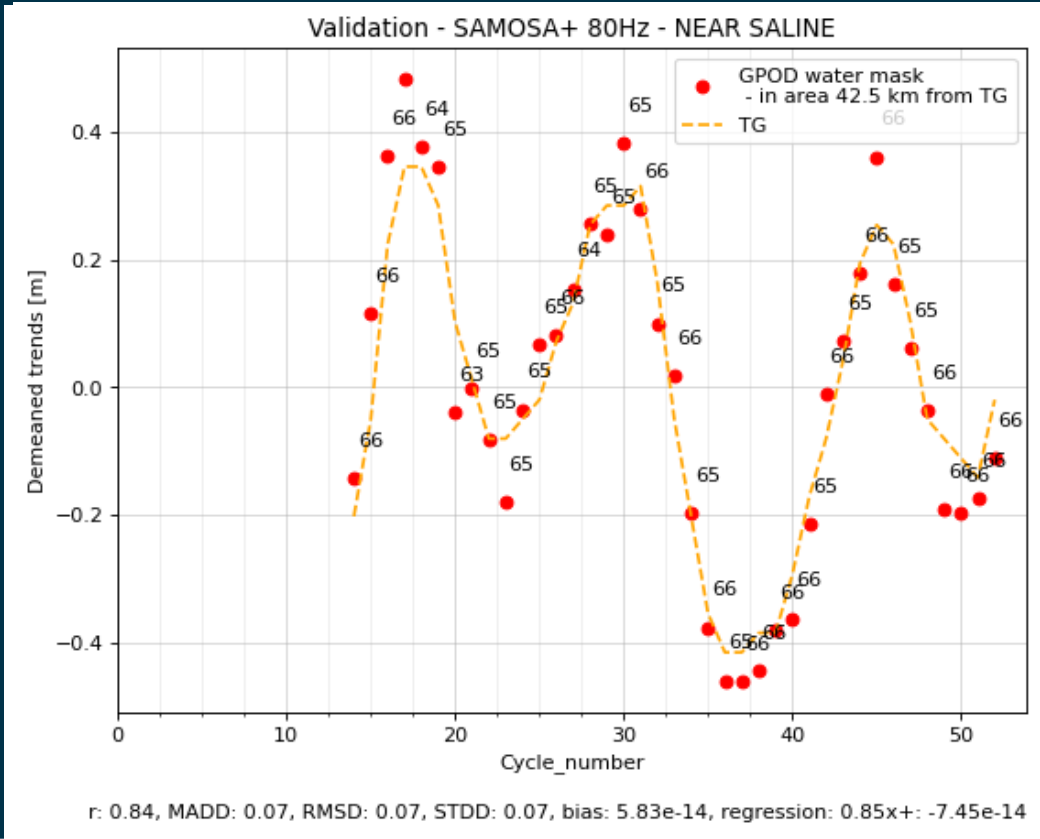
- The quality filter improves the ALES+ SAR data.
- SAMOSA+ exhibit similar metrics after applying the Misfit filter.
- However when comparing the outputs of all regions for the non-filter data set and the Misfit-data set, it becomes evident that the Misfit filtering step leads to less outliers and provides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

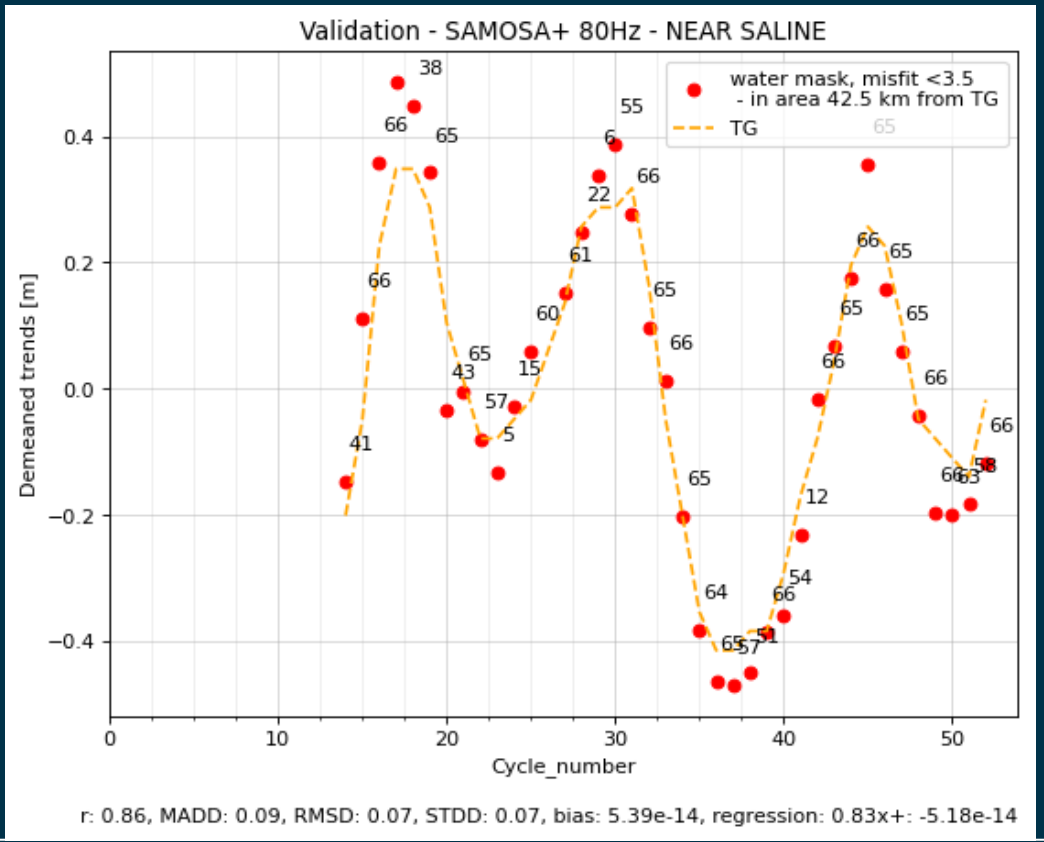




Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

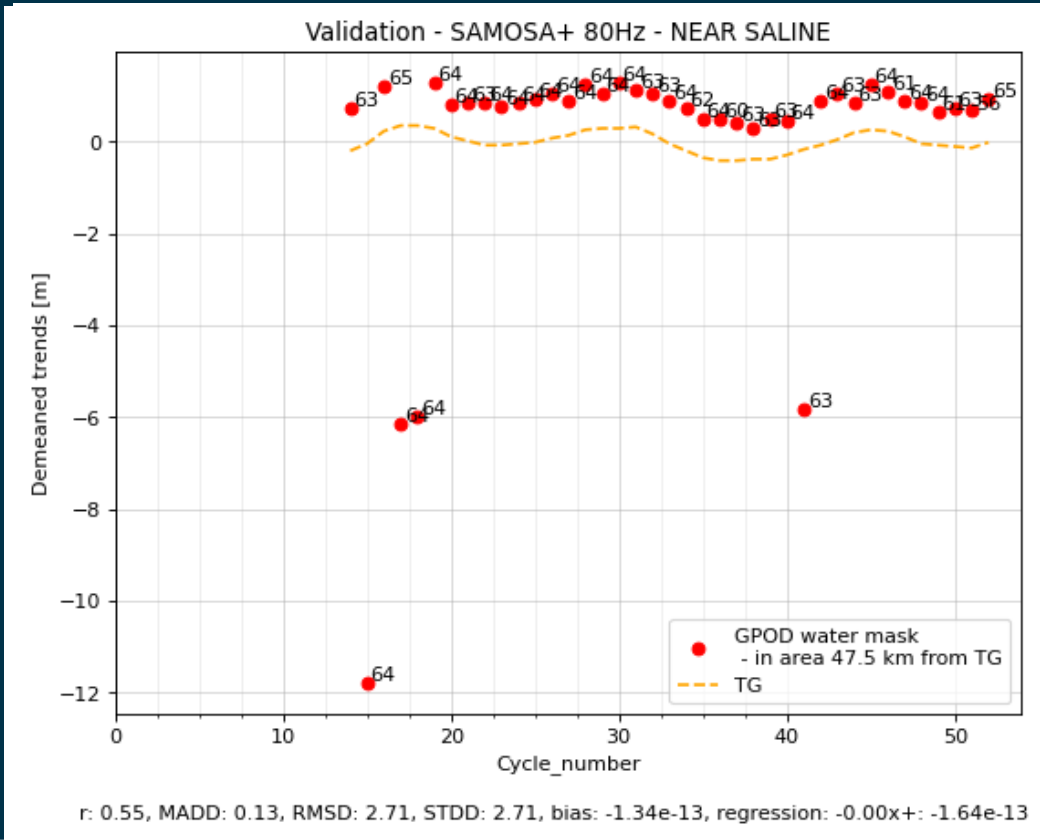
- The quality filter improves the ALES+ SAR data.
- SAMOSA+ exhibit similar metrics after applying the Misfit filter.
- However when comparing the outputs of all regions for the non-filter data set and the Misfit-data set, it becomes evident that the Misfit filtering step leads to less outliers and provides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

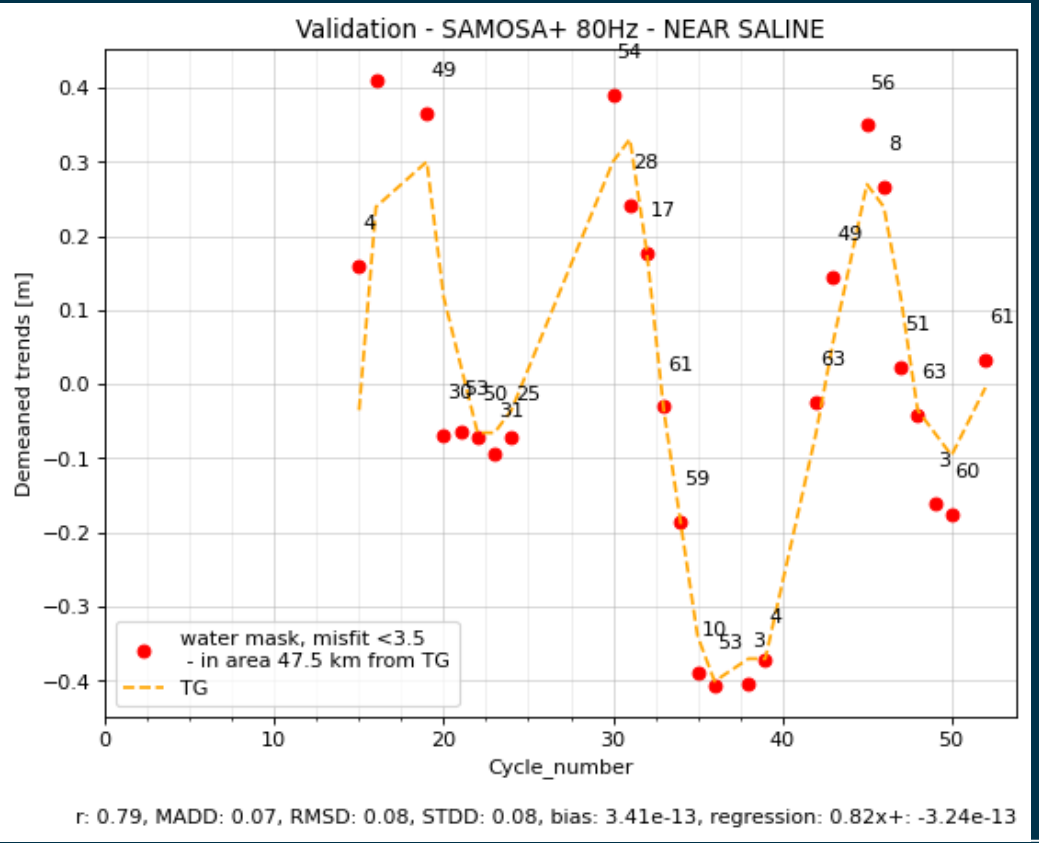




Track 369 – Misfit and quality flag filter, at gauge NEAR SALINE

- 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.





Conclusion

- Both retrackers 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 retrackers.
- Applying the Misfit and quality flag parameter do improve the data in general, however this cannot be said for all datasets.

Outlook

- 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.

Additional Material - GPOD

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