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Applicable documents

AD 1 Sea level CCI project Management Plan
SLCCI+_PMP_003_ProjectManagementPlan

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1. D4 - Short Note: Roadmap

1.1. Executive Summary

Comprehensive knowledge of relative sea level change (RSLC) is essential for coastal adaptation, future planning and sea level research in general. The RSLC is comprised of absolute sea level changes and vertical land motion (VLM). While extensive efforts have been made to observe absolute sea level, in particular with the advent of satellite altimetry, there is still a relatively limited availability of direct VLM observations. While most of global VLM observations stem from the Global Positioning System (GPS), another source of VLM are differences of absolute (satellite altimetry) and relative sea level (tide gauge) measurements (SAT-TG) which can improve and densify VLM estimates along the coastlines (e.g., Cazenave et al., 1999). In this work dedicated coastal along track data was combined with TGs to improve accuracy and uncertainty of VLM estimates from the latter technique.

In the first task1.1. of the investigations different combination approaches of altimetry and TG data were applied. Different statistical criteria (e.g., correlation between TG and altimetry data) were utilized to select altimetry data which are in high agreement with the TG data, to reduce discrepancies between the measurements. In task1.2. the performances of the different VLM time series were analysed with respect to different statistical criteria (e.g. trend uncertainties, absolute correlations, trend deviations w.r.t. GNSS trends) and compared to alternative altimetry data sources. Task1.3 covers the production of the point-wise VLM data (and associated time series statistics) and a comparison with VLM based on Glacial Isostatic Adjustment. Task1.4 addresses the computation of a regularly spaced VLM profile, based on the VLM point estimates. The deliverables are summarized in Table 1:

Table 1: Deliverables

ID	Description	Deliverable
D1.1.	Application of different combination schemes of altimetry and tide gauge data: e.g., closest point, highest correlation, Zone of Influence	A **report** describing algorithms employed and validation results
D1.2	Comparison of combination schemes, trend validation against GNSS data, comparison against other datasets. VLM + uncertainty estimation based on XTRACK-ALES data.	A **dataset** consisting of Alt-TG VLM estimates on a set of tide gauges based on the ZOI approach
D3	Regional map 'densification': regularly-spaced coastline profile by spatial interpolation of sparse data; comparison against GIA-based VLM.	A dataset consisting of a regional regularly spaced VLM coastline profile
D4	Short Note - Roadmap	A roadmap for future studies based on the acq

1.2. Analyses and outputs

We generated a number of new insights and outputs through the range of our activities. The main objectives and advancements made are summarized in the following table.

Table 2: Objectives and advancements

Objective	Advancement made
To identify appropriate combination schemes of altimetry and TG data in order to decrease SATTG VLM uncertainties and increase their accuracy	We have investigated different approaches to combine SAT and TG data for VLM computation. We have shown that using multiple altimetry observations (averaged over different tracks), which are associated with a high correlation (or a low rms) w.r.t. TG, increases the VLM accuracy and reduces its uncertainty.
To evaluate the performance of the derived VLM estimates w.r.t external datasets (GNSS, GIA VLM)	We have compared different VLM datasets (based on different SAT-selection schemes), with several external VLM datasets. This includes direct GNSS VLM observations, GIA models, and effects of contemporary mass redistribution. We have studied how objective outlier-rejection criteria can be utilized to improve the comparability with external VLM data.
To compare the XTRACK-ALES VLM estimates with SATTG VLM estimates based on alternative altimetry data. This objective shall shed light on the improvements achieved as well as the remaining limitations.	The XTRACK-ALES based VLM was compared to a multi-mission ALES altimetry product as well as a gridded product (CMEMS). We have identified a trend bias (in the order of ~1 mm/year) between the datasets (when comparing the SATTG data to GNSS data). When the bias is neglected the XTRACK-ALES VLM have a similar accuracy as the CMEMS SATTG VLM data.
To examine and investigate the spatial interpolation of SATTG VLM trends.	We have generated a 2D interpolated VLM product, which represents continental scale observed VLM features.
To develop a Scientific Roadmap as a basis for further ESA activities with regards to future applications and improvements of the XTRACK-ALES dataset.	We recommend future activities to further improve the presented approach and highlight limitations of the current dataset.

1.3. Recommended scientific activities

Based on the analyses and outputs a number of scientific activities are recommended to be implemented.

Improving SATTG VLM point-estimates

- <u>Limitations of improving SAT trends in the coastal zone:</u>
  A central motivation of using dedicated coastal along track data is to improve the comparability and representation of the SL-signal close to the coast. Many previous studies have substantiated these improvements based on the rms or correlation of the data close to TGs. With our approach, however, we have shown that in order to improve the representation of sea level trends at tide gauges, it is beneficial to use a set of altimetry observations within a wider range in the coastal zone. Hence, these observations are not necessarily very close to the coast, because the higher correlated altimetry points are often located further offshore (due to a general degradation of the data very close to the coast). As a consequence, the selected altimetry data benefits less from the coastal improvements. In this context, we

have shown that the improvements w.r.t. to datasets, which do not incorporate dedicated coastal altimetry (e.g. CMEMS), are not substantial. In addition, we have also shown, that using an alternative approach, i.e. using the closest data to the coast, leads to a strong deterioration of the SATTG VLM estimates. Hence, we recommend further activities to develop appropriate frameworks in order to test to what extent the representation of coastal sea level trends is improved using dedicated coastal retracking. Such a framework would require:

- A validation basis for ASL trends: High quality TGs and information of VLM at the TG (based on high quality data from closely located GNSS stations). High quality refers here to the absence/correction of discontinuities in the data, the linearity of VLM as well as sufficiently long observational periods. The TG should also not be sheltered from open ocean (i.e. the zone) which is observed by altimetry and should present a reasonable minimum correlation with the altimetry data (0.5 – 0.6, based on de-seasoned data)
- Study of the altimetry-based sea level correlation length-scales
- Definition of coupling procedures: Zone-of-influence approach, average of altimetry data within different distances to the TG (e.g., 0-3 km, 3-5 km, 5-10 km)
- Use of cross-calibrated along-track data from missions outside the reference track, in order to increase the data frequency in the Zone of Influence
- Investigations on the noise behaviour in the SATTG time series, while focussing on the high and low frequency noise components.

➢ <u>Assessment of remaining Trend bias in the along-track data:</u>

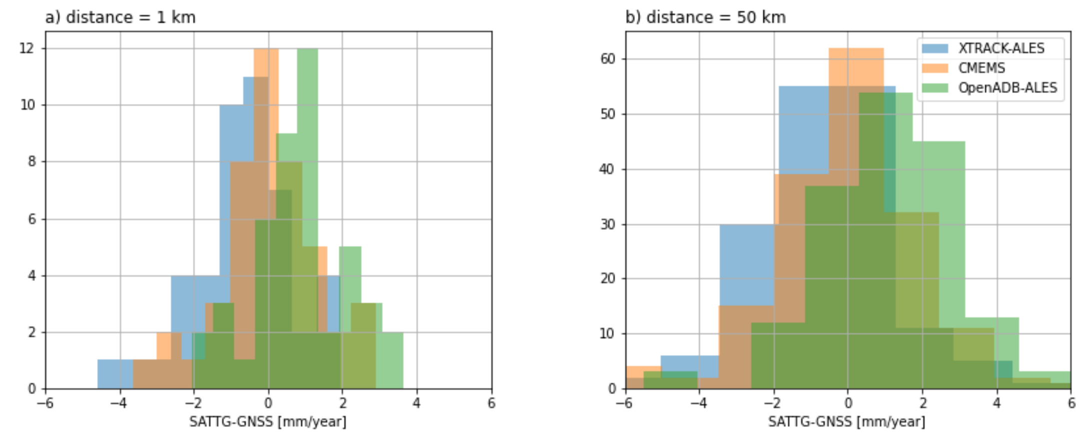

Figure 1: (Taken from the last technical report D1.1, D.1.2) Histograms of trend differences (SAT-TG minus GNSS VLM) of the different altimetry dataset for different maximum allowed distances between TG and GNSS station: a) 1 km b) 50 km

The analysis showed that the XTRACK-ALES trends are biased w.r.t. to GNSS data by about 0.6 mm/year. In contrast, the gridded product had a lower bias of 0.1 mm/year. Thus, a prerequisite of improving coastal sea level trend estimates (and thus the SATTG VLM estimates) is the identification and mitigation of the origin of the systematic bias. In the last technical note, several factors were mentioned which could contribute to this issue. We highlight the importance of the following analysis to solve this issue

- Mission dependency, multi-mission cross-calibration
- Impact of the Ionospheric correction

In particular, considering the last point, the GNSS-based GIM corrections, the corrections from climatological model NIC09 and the dual-frequency corrections shall be studied considering their impact on coastal trends (Dettmering and Schwatke, 2022).

Advancing the 2D interpolated VLM product

- The 2D interpolation, which is based on SATTG VLM estimates, yields relatively smooth VLM features, with a spatial resolution of several hundred km. The low resolution is mostly caused by the sparsity of the SATTG point estimates. Thus, together with the high VLM uncertainties of the SATTG approach, SATTG VLM estimates alone are relatively limited in representing smaller scale VLM features (< 100 km), when interpolating the data. To overcome the limitations of data quality and quantity. VLM data from GNSS stations could be incorporated in the interpolation as done by other studies (e.g., Hawkins et al., 2019). This would further increase the robustness of the 2D VLM estimates, as well as the spatial resolution of local VLM, depending on the availability of the data. We thus recommend to complement the SATTG VLM with GNSS VLM estimates.

2. References

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