# Authors' response to the Interactive comment on "A coastally improved global dataset of wet tropospheric corrections for satellite altimetry" by Clara Lazaro et al.

**Anonymous Referee #1**
**Received and published: 18 November 2019**

We would like to start by thanking Reviewer#1 for his/her valuable contribution, for the many useful suggestions and corrections, and for his/her constructive comments that led to the improvement of the quality of the manuscript.

The main changes introduced in the manuscript following the comments and suggestions of the two Reviewers can be summarised as:

- Sections containing the Abstract and the Conclusions have been updated to accommodate the new results presented in the revised version of the manuscript.
- Some parts of the text have been moved to new sections or were rewritten/completed to be clearer and more informative.
- Figures 1 as well as figures 11, 12 and 13 have been updated, the latter to include the results for the comparison of the GPD+ WTC with the MWR-derived WTC, instead of that for the Comp WTC, following the concerns raised by Reviewer#2.
- Previous Figure 5 has been divided into Figures 7 and 8 and the geographic location of the Envisat tracks have been added, following the recommendation of Reviewer#1.
- New figures have been added to the revised version (Figures 2, 3 and 14).
- Tables 1 and 4 have been updated, the former to include more information, the latter in the sequence of the last update of the GPD+ database (performed to include more data for the recent missions).
- A new table (Table 2) has been added in the revised version.
- All figures and tables have been renumbered.
- Section 3.2 has been divided into sections 3.2.1 and 3.2.2 describing the global and the regional (coastal) results, respectively, and the text has been extended.
- Reference Vieira et al. (2019c) has been updated, since at the time of this revision it has already been published.
- Reference AVISO (2017) has been removed.
- Five new references (Bevis et al. (1994), Rudenko et al., (2017), Valladeau et al. (2015), Dinardo et al. (2020) and Escudier et al. (2017)) have been inserted in the revised version.

Our point-by-point responses to Reviewer#1 are presented below.

MAJOR COMMENTS

In this paper, the authors present a novel dataset of Wet Troposphere Correction (WTC) to correct the sea level anomaly (SLA) derived from satellite radar altimetry. The dataset is particularly important for coastal altimetry being well known that this correction is the most critical in the coastal zone. The new correction (known as GPD+) computes the Water Path Delay (WPD) for all along-track altimeter points where the default correction (from onboard radiometer) is unusable The method adopts an objective analysis approach to estimate WPD from a number of sources (coastal and island GNSS stations, satellites carrying microwave radiometers, valid on-board MWR measurements). The method is applied to all conventional missions and CryoSat-2. The validation of the dataset is made through statistical analysis of SLA and the metric used is the reduction of variance.

The author provide a clear description of the datasets apart details specified below in the minor comments. However, the validation of the dataset (that is the part of interest to users) is really poor in showing the improvements, in particular with reference to the coastal zone. The authors titled this paper "A coastally improved global dataset. . .", unfortunately the reader does not see any zooming in the coastal zone.

R.: The paper's aim was to present and describe the GPD+ WTC dataset/database. The authors' intention was to show the improvement in the SLA description in the coastal zone when using the correction in global terms, therefore with no focus on a particular region. The authors refer two papers that show in detail the improvement in the SLA signal description in the coastal region (German Bight and the Indonesia Archipelago) when the GPD+ WTC is used. However, in response to the Reviewer's comment, results for three coastal regions, selected on the one hand, due to the large number of available GNSS stations (North American and European coasts) and, on the other hand, due to the fact of being a challenging region for coastal satellite altimetry (Indonesia region), have been added to the revised version of the manuscript, as an attempt to show the potential of the GPD+ dataset along the coastal waters. Section 3.2.2 has been added in the manuscript to present these results.

The metric used is certainly appropriate for open ocean but not for the coastal zone. The results do not provide a clear measure of confidence of the dataset in these challenges area.

R.: The assessment of the performance of the GPD+ WTC dataset is made using statistical analyses of sea level anomaly variability. The reduction of SLA variance is a metric commonly used to assess the performance of a correction against its counterparts available in the altimetry products accessible to the user. The larger the SLA variance reduction, the better the correction, since its application will lead to an SLA whose variability is more likely to be due to oceanic conditions than to the error in the correction(s). The metric is used to assess the performance of the dataset and not to validate it. Observations adequate to validate the GPD+ WTC dataset over coastal regions are not of sufficient quantity and quality. The vertical distribution of water vapour in the troposphere can be obtained using data from a network of radiosondes. However, datasets from radiosondes possess undesirable inhomogeneities (e.g., vertical range, vertical resolution, temporal regularity, poor continuity), have poor spatial coverage, particularly over coastal zones, and are not collocated with altimeter measurements. Therefore, completeness of observations lacks in these regions.

For these reasons, the authors also performed an assessment of the GPD+ WTC performance using GNSS observations, as explained in Section 3.1 of the manuscript. Former Figure 7 (now Figure 10) illustrates the results, showing that the RMS of the differences GNSS-MWR increases when approaching the coast. On the contrary, the RMS of the differences GNSS-GPD+ decreases and this result is thought to be a clear indicator of the performance of the GPD+ correction.

All plots are global and some plots globally averaged when quantities are showed as a function of distance. Instead, the reader expects to see a selection of relevant coastal regions in the world, based e.g. on bibliography (i.e. areas where users already applied coastal altimetry) or peculiar characteristics (e.g. authors mentioned Indonesia).

R.: The main objective of this paper is to present the GPD+ WTC database to users of the Geophysical or Level 2 altimetry products, i.e., users mainly interested in ocean applications yet wishing to extend their analysis to the coastal regions. Therefore, the authors had opted to show the results for the latest Envisat reprocessing (which have not been published yet), summarised globally and to refer previous published results that have used GPD+ and focused on particular regions (Handoko et al., 2017; Dinardo et al., 2018). However, in response to the reviewer's comments, we have extended the Results section and provided some results for the three coastal regions already referred. Section 3.2.2 has been included in the revised manuscript.

Moreover, the testing in the coastal zone has to be at 20Hz being the available re-tracked products at this rate. The RADS product is fine for open ocean studies but not in the coastal zone.

R.: The rate of the altimetry measurements is not a limitation to the GPD+ methodology. In the scope of a current research project in which the University of Porto (UPorto) is involved, the GPD+ methodology will be used to estimate the WTC for the coastal (and inland water) zone for CryoSat-2 and Sentinel-3 missions. The outcome of this project will be a GPD+ WTC product at high rate (20 Hz), intended to be used for applications over the coastal zone (i.e., no ocean values included for distances larger than ~100 km off the coast) and over inland waters. However, the GPD+ WTCs presented in this manuscript have been computed to be incorporated in altimetry products providing observations at 1 Hz, the rate still most used by the altimetry community databases. They are intended for users who want to have a consistent and continuous WTC correction, from open ocean to coasts (and polar regions as well). The correction can be extended to the coast since a valid WTC value is provided for the first along-track measurement over land. Users can therefore use this measurement to interpolate the valid GPD+ WTC up to the coast, for the location and time instant of the 20 Hz data. Moreover, as the onboard radiometer data are not available at a higher than 7 Hz rate, neither these data nor the third-party data have enough resolution to be provided at 20 Hz. Therefore, and for the time being, the strategy for those users who want to focus on coastal zones, would be to interpolate these 1-Hz data to the location and time instant of the 20 Hz data.

For high-frequency MWR, expected in the future, high-rate WTC are definitely advisable, and the authors intend to exploit this possibility. A sentence has been added to the "Conclusions".

Also the metrics has to be different, as in the coastal zone we can use tide gauges as an independent measure of SLA. Therefore, by chaning the wet troposphere (default vs GPD+) in the altimetry formula, absolute differences of SLA along the track would show the distance of the coast at which noise increases in the specific region. Comparisons with TGs would show the improvements in terms of statistical indicators ( correlation and rms error).

R.: Some analyses previously performed by the authors seem to indicate that comparison with tide gauges is not the best way to validate the WTC, because the differences between

altimetry and tide gauges are large when compared to the SLA variability due to different WTC. For this reason, in this paper, the analysis suggested by the reviewer has been performed using GNSS data. Former Figure 7 (Figure 10 in the revised version) shows an independent comparison between GNSS-derived and MWR-derived WTC, function of distance from coast, for the newly reprocessed Envisat data. This result yields the distance from coast at which this contamination appears. This distance depends on the altimetric mission, due to their different footprint sizes and different MWR retrieval algorithms, varying from 10 to 30 km. For Envisat, this distance is 30 km. This assessment provided us the distance from coast at which an MWR measurement is expected to be contaminated by land. This means that the GPD+ methodology does not use MWR-derived WTC in the last 30 km to the coast, even if they are not flagged as invalid by other rejection criteria, to prevent land contamination in the GPD+ estimates.
We believe that the assessment with GNSS, together with the SLA variance analysis, are clear and sufficient indicators of the GPD+ performance.

Having said that there are other important remarks that I would like to highlight.
First, the authors are discussing a product at 1 Hz, when users need a product at 20 Hz in the coastal zone. So this product after publishing would not be usable for the typical non expert coastal users.
R.: As previously said, these products contain a consistent and continuous WTC correction at 1 Hz rate. Improved criteria have been established in the GPD+ methodology for each mission (e.g. criteria derived from statistical analyses to detect measurements contaminated by ice, land, rain and outliers, based not only on the information available on the points for which a GPD+ estimation is being computed, but also on the information available for neighbouring points) and applied to detect valid/invalid MWR measurements, besides the criteria based on the flags provided in the GDR/RADS/PEACHI products. Moreover, the correction has been calibrated against the SSM/SSMI radiometers, ensuring the long-term stability of the GPD+ WTCs.
As previously mentioned, the correction has been provided continuously over ocean and coastal regions, precisely to be used by non-expert users, working over ocean but wanting to extend their analysis to the coastal regions, without discarding altimeter measurements in the coastal zone as would happen when relying on MWR-derived measurements to compute SLA. As already explained, the correction provided at 1 Hz can be interpolated to 20 Hz data by expert users with enough accuracy. As explained before, this is due to the characteristics of current on-board radiometers.
Typical non expert coastal users who are not able to perform this interpolation procedure and in the absence of MWR data in the coastal strip can rely on a Numerical Weather Model (NWM) derived WTC. However, anomalies in the NWM-derived WTCs have been found in the Envisat FMR V3.0, which are corrected in the GPD+ processing. A sentence clarifying this has been added do the text: “Anomalies in this field have been found, with the field out of limits in a set of points, most of them concentrated on certain passes. This is due to the fact that this correction has been computed from 3D model fields at the altimeter measurement altitude. Therefore, whenever the altimeter-derived surface height is not set (NaN value), the corresponding Model WTC will also be NaN. As our goal is to be able to provide continuous WTC, without data gaps, this field is unsuitable for use in the GPD+ estimations.”. Moreover,

as described in this manuscript, NWM-derived WTC are not able to describe the small-scale variability of this field yet.

Second, I also see insufficient the strategy of showing results related to only one missions. As multi-mission approach is essential in the coastal zone to have more coverage in space and time, the reader expects to see the validation extended to all missions.
R.: The primary scope of this paper is the dissemination of the GPD+ database fostering its use among as many people as possible, since in the authors' opinion the GPD+ database is of sufficient quality for both expert and non-expert users. Therefore, the paper focuses mainly on the data description and their usage, and for this reason the Earth System Science Data (ESSD) journal has been chosen. The authors have tried to show the added value of the correction using the results for the newly recomputed Envisat FMR V3.0 data, not yet published before. Results for other missions have been already published by the authors in papers of more scientific nature (cf. references e.g. Fernandes et al. (2015) for results regarding reference and ESA missions, Fernandes and Lázaro (2016) for results for CryoSat-2 and GFO, Fernandes and Lázaro (2018) for Sentinel-3). These works are cited in the manuscript leading the readers to the reference list. The GPD+ WTC are available for all altimetry missions in the UPorto database, except for Sentinel-3A/B as their development is still on course and can therefore be chosen for a multi-mission approach.

Third, one important input for the estimation of an improved WTC in the coastal zone is the presence of GNSS station. The authors provide poor information about distribution in space and time. There is just one figure related to Envisat showing the number of GNSS stations over mission time. The authors have to add same figures for the other missions. Moreover, a map has to add concerning the geographical distribution (areas well covered and areas where no GNSS stations are available. These figures are important for the users that after zooming in their coastal regions of interest can perceive the space and time coverage.
R.: Figure 1 shows the number of GNSS stations used as input in the GPD+ algorithm, function of time. This information does not depend on the mission and therefore one single figure suffices to illustrate that the later the period of the mission, the larger the number of available GNSS stations. Figure 1 has been remade to include information for the whole satellite altimetry era, so the reader can more easily understand this and the Envisat period (2002-2012) is shaded in the figure.
However, the reviewer is right in indicating that the geographical location of the GNSS stations could be of interest to the reader and a new figure (Figure 2) has been added to the revised version of the manuscript.

In summary, the paper in the actual version fails to convince the reader that in the coastal zone the new correction cannot be immediately exploited by users (because not at 20 Hz) and that misses a thorough validation in selected coastal areas of investigation (i.e. zooming locally where the user would use SLAs). Therefore, the paper calls for significant revision in order to fill the gaps in term of exploitability of the product and validation of the correction in the coastal zone.
R.: The authors consider that the Reviewer's comments have undoubtedly improved the paper and therefore are thankful for his/her contribution. The authors expect to have satisfactorily responded to the critiques and/or suggestions raised by the Reviewer.

MINOR COMMENTS

Pg 1, abstract: "The results are presented with vague sentences (e.g. GPD+ WTC is the most effective. . ...). The reader expects here to see quantitative results that show the improvement with reference to the state-of-the-art and discussion of these results. In the present version, the abstract is substantially an introduction to the dataset that should be the core with more details, e.g., distance from the coast, etc..

R.: The ESSD journal encourages the submission of manuscripts describing original research datasets that use can be considered beneficial to Earth system sciences. Therefore, the authors focused on the description of the GPD+ dataset. However, the abstract has been rewritten according to the reviewer's suggestion and quantitative results have been added.

Pg. 1, rows 13-14, "SLA dataset over open ocean accurate to the centimetre-level": The authors in the previous sentences refer to sea level rise (which means mm/yr error level). The reader might be confused with cm level accuracy that is generally a target for oceanography. Moreover, accuracy is not enough for trends, there is also a need of "stability", and here it is the case of wet tropo not drifting over time. Please rephrase properly

R.: Lines 8 to 14 of the abstract have been rephrased and moved to Section 2.1.4 (Radiometer Calibration), to simplify the Abstract (since new information has been added to describe quantitative results, following the Reviewer's suggestion) and because this information is relevant to understand the need for performing the inter-calibration of the radiometers.

Pg. 2, row 44, "with a centimetre-level radial error": Please provide reference where it is demonstrated.

R.: The following reference has been added:

S. Rudenko, K. Neumayer, D. Dettmering, S. Esselborn, T. Schöne and J. Raimondo, "Improvements in Precise Orbits of Altimetry Satellites and Their Impact on Mean Sea Level Monitoring," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 55, no. 6, pp. 3382-3395, June 2017, doi: 10.1109/TGRS.2017.2670061.

Pg. 2, row 44, "precise SSH": You used "accurate" before. It depends on what you refer, e.g., global mean sea level requires accuracy; fronts requires precision, etc.)

R.: The suggestion has been accepted and the word "precise" has been replaced by "accurate".

Pg. 2, row 55, "Chelton et al. (2001).": please refer to recent bibliography (Satellite altimetry over oceans and land surfaces (Detlef Stammer & Anny Cazenave Editors), Earth observation of global changes book series, CRC Press Taylor & Francis, London, UK, 670 pp, doi:10.1201/9781315151779, 2017).

R: Chelton et al. (2001) is still an important reference. The following reference has been added:

Escudier, P., Ablain, M., Amarouche, L., Carrère, L., Couhert, A., Dibarboure, G., Dorandeu, J., Dubois, P., Mallet, A., Mercier, F., Picard, B., Richard, J., Steunou, N., Thibaut, P., Rio, M.-H., and Tran, N.: Satellite radar altimetry: principle, accuracy & precision, in: Satellite Altimetry Over Oceans and Land Surfaces, edited by: Stammer, D. and Cazenave, A., CRC Press Taylor & Francis, London, UK, 670 pp, doi:10.1201/9781315151779, 2017

Pg. 3, row 67, "as large as 2.3±0.2 m", is this cited in Fernandes et al. 2014? If not, please provide reference.

R.: Yes, these values are given in Fernandes et al. (2014).

Pg. 3, row 67-68, "calculated with millimetre-accuracy, provided the surface atmospheric pressure is known at each location": as we are talking about coastal zone, the authors have here to specify that pressure has to be know at surface level. This pressure is generally retrieved from coarse models that can fail in steep coastal regions.

R.: For oceanic coastal points, the DTC must be computed at sea level from sea level pressure data. If the DTC is provided in the altimetric products at the level of the model orography, as is usually the case, which can depart significantly from sea level at coastal zones, then the value of the dry tropospheric correction should be corrected as described in Fernandes et al. (2013a) (cited in this manuscript). In the same paper, it is also shown that current models are accurate enough to compute the DTC with this accuracy, including the coastal zones, provided adequate procedures are adopted.

The sentence "calculated with millimetre-accuracy, provided the surface atmospheric pressure is known at each location" has been changed to "over the ocean it can be calculated with millimetre-accuracy, provided the sea level atmospheric pressure is known at each location".

Pg. 3, row 69, "dry and wet tropospheric corrections (negative values)": why negative ? please explain.

R.: The measured distance between the satellite and the sea surface, or altimeter range $R_{obs}$, is computed from the following equation, neglecting atmospheric refraction:

$$R_{obs} = c\frac{\Delta t}{2}$$

where $c$ represents the velocity of light in vacuum and $\Delta t$ is the two-way travel time of a radar pulse between the satellite antenna and the sea surface. The velocity of the altimeter pulses is reduced in a refractive medium as the atmosphere. Therefore, when the signal passes through the troposphere, the propagation velocity of the altimeter pulses is smaller than $c$. This means that the $R_{obs}$ computed from equation above will be longer than the true range. To correct for this overestimation in the measured range, both the DTC and the WTC are negative.

Pg. 3, row 70, "DPD and WPD to the corresponding absolute values": What do you mean with "absolute"? what is the difference between DTC and DPD, WTC and WPD?

R.: Following the previous answer, we can define the effect of the troposphere on the altimeter signals, which appears as an extra delay in the measurement of the signal traveling from the satellite to receiver, as the tropospheric path delay, which can be divided into the dry and wet components, called the dry path delay (DPD) and the wet path delay (WPD), respectively. Each delay component contributes to an error (path length) in the measured distance that must be corrected for. The corrections needed to consider these delays – the dry tropospheric correction (DTC) and the wet tropospheric correction (WTC) – have therefore the same magnitude as the DPD/WPD and the opposite (negative) sign, and must be subtracted from the range estimated assuming the free-space value for the speed of light.

Hereupon, the term "absolute" is used to refer to the modulus of the DTC and WTC.

Pg. 3, row 73-74, “possessing an absolute value less than 0.50 m.”: Please specify how 0,50 is estimated. Please also specify the meaningful of “absolute” vs “relative”.

R.: As explained in the previous response, the term “absolute” is used to refer to the modulus of the corrections, which are negative.

In the computation of the water vapour range correction, passive microwave estimates of columnar water vapour from satellite radiometers are used. The maximum value of 50 cm for the wet path delay is known from decades of observations from satellite passive microwaves (e.g., Special Sensor Microwave/Imager (SSM/I) on board the United States Air Force Defense Meteorological Satellite Program (DMSP) satellites). Considering the global dynamic range of columnar water vapor, 0.5–7 g $cm^{-2}$, the wet tropospheric path delay varies from 3 to 45 cm, with standard deviations covering the range from 3 to 6 cm. A very thorough description of the underlying theory and principles of the wet tropospheric correction estimation can be found in:

Chelton, D. B., Ries, J. C., Haines, B. J., Fu, L. L., Callahan, P. S.: Satellite Altimetry. In Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications; Fu, L.L., Cazenave, A., Eds.; Academic: San Diego, CA, USA; Volume 69, 1–131, 2001.

Pg. 3, row 73, “Contrasting”: Maybe you mean “in opposite”

R.: Accepted and changed.

Pg. 3, row 79-86, “Radiometers .. 12 km”: please explain the different impact of the three radiometers on the retrieved measurements, e.g. with reference with data quality.y Are there differences in the coastal zone in retrieving data ?

R.: According to the literature, and as mentioned in the paper, radiometer footprints depend on instrument and frequency. So, footprint size is the key factor in the coastal zone. In addition to the known footprint of each radiometer and according to several analyses performed by the authors (e.g., Fernandes et al., 2015, Fernandes and Lázaro, 2016) land contamination for these missions occurs at distances from coast less than 15 km, while for ESA’s missions, T/P and GFO, this value is around 30 km. All this information is given in the paper.

Pg. 3, row 88, “precise modelling”: I think the word “modelling” is confusing. WTC can be derived from models too. However, here we are talking about “observations”.

R.: The suggestion has been accepted. The word “modelling” has been replaced by “estimation”.

Pg. 3, row 91, “flagged as invalid, being therefore discarded, or non-existent due to several reasons.”: The sentence is vague. Why data are flagged invalid? What is the criteria used ? What re the reasons for missing data ? please explain

R.: The reasons why the microwave measurements are flagged as invalid in the coastal zones are given in the sentences that follow the referred one. In the coastal region, the measurements of the MWR are in general contaminated by land, due to the large diameter of the footprint of the instrument. The WTC retrieval algorithms are based on sea surface emissivity conditions, which is valid only for open-ocean conditions since surface emissivity can be highly variable when the coastal land contribute to the returning signal. This cause a failure of the algorithms that retrieve the WTCs from the onboard microwave radiometer measurements, resulting in their absence. Also, the algorithms can retrieve the WTCs but their values are considered invalid and are, therefore, flagged by the retrieval algorithms. The invalid WTC values are exemplified in red in Figures 7 and 8 (former Figure 5). If used, invalid SLA values would consequently be obtained. For those altimeter points for which the MWR-derived WTC values are missing, no SLA values can be computed unless the user decides to use WTC values from the model. The estimation of the WTC in these points that has been made possible by GPD+, therefore allowing the computation of SLA, is one of the advantages of the methodology.

Pg.4, row 96, “surface emissivity”: Coastal zone has also non homogeneous scattering due to variable waves, winds, surfactant streaks, etc. Are they influencing the retrieval of a valid measurement?
R.: The microwave radiation measured by an on-board MWR, expressed as brightness temperature, corresponds to the sum of three contributions: atmosphere, surface and the cosmic background. Regarding the surface contribution, it depends on the surface temperature and emissivity properties. All WTC retrieval algorithms are based on sea surface emissivity models, so they do not consider the very strong (emissivity higher than 0.9) and variable non-ocean radiation. The problem of the non-homogeneous scattering as mentioned by the reviewer appears in the altimeter (active sensor) measurements. Any surface (different from calm waters) induces a non-homogeneous scattering, influencing the retrieval of altimeter measurements.

Pg. 4, row 105, “is to describe and grant access”: The access to a dataset cannot be an aiming of a paper. I think the authors have to reformulate clearly the main goal of this paper that is presenting and validating a dataset and then elucidate specific single objectives
R.: The sentence has been rewritten.

Pg. 4, rows 111-115, “The main objective”: Objectives have to be stated in the introduction. Also description of sections has to be moved in the introduction.
R.: The authors are here stating the main objective of the methodology and not of the study itself. To avoid any confusion to the reader, this sentence has been rewritten. The description of the sections has been moved to the Introduction, as suggested by the Reviewer.

Pg. 4, row 118, “GNSS network of stations”, please provide a map of GNSS stations used so the reader can appreciate the global coverage
R.: Figure 2 has been added to the manuscript as suggested.

Pg. 4, row 123, “This way”, please add “In”
R.: Accepted and changed.

Pg. 5, row 118, “this way are given at station height”. The GPS stations are over land. So you measure the column at land point. It is not clear to me (and probably to most of not expert people) how this value is extrapolated to the ocean
R.: The handling of the GNSS observations is described in Section 2.1.1. After the computation of the GNSS-derived WTC, at the level of the station height, the WTC are reduced to sea level, the quantity of interest for satellite altimetry, using the height reduction procedure

(exponential decay with height) proposed by Kouba (2008), cited in this paper. This height reduction is fully described in e.g. Fernandes et al. (2013a, 2015).

Pg. 6, row 156, “In fact, GPD+ is an upgrade from the GPD methodology”: Please better clarify differences between GPD and GPD+. Apparently you say that GPD+ was for coastal zone but now global. Is the reason related to CryoSat-2 ? as it has no radiometer onboard.
R.: The GPD methodology was developed to compute the WTC only for coastal points, where WTCs derived from the on-board MWR are usually invalid. In its former version, the GPD methodology used as input GNSS-derived WTCs and valid MWR measurements only. Later, the methodology was updated to estimate the WTC for CryoSat-2. Since this mission does not possess an on-board MWR, it was necessary to estimate the WTC not only for coastal regions, but also for open ocean. To do this, the GPD methodology was improved to use data from the scanning imaging radiometers, which are available over coastal regions as well as open ocean, as another input data source. This later version was called GPD Plus (GPD+).
The sentence has been rephrased for clarity:
“In fact, GPD+ is an upgrade from the GPD methodology, which was developed to compute the WTC only for coastal points, relying only on GNSS and valid on-board MWR measurements. Motivated by the need to compute an improved correction for CS-2, the SI-MWR data set was included and the focus of the correction extended to open ocean.”.

Pg. 5, row 158-164: as you provide a table it is redundant here to report names of the mission. It is important to add space and time resolution of single MWR sensors in the table. A matrix has to be added showing the MWR sensors available for each altimetry mission. Again, this is an important figure for the reader. Some comments about substantial differences between sensors should be recalled here from cited references
R.: We believe the information concerning the data providers for the different SI-MWR missions should be kept in the paper, however the spatial and time resolutions of the SI-MWR missions have been added to Table 1 as requested. Since the number of SI-MWR sensors varies with time, a figure showing their availability along time for each satellite altimetry mission has been added (current Figure 3). Also, a sentence summarizing the main differences between the data types has been added to the manuscript:
“Two types of TCWV products have been used: Level-2 swath products in HDF-EOS2 format (near real time products, 14-15 orbital swaths per day available for each instrument) from all data sources except RSS, and Level-2 gridded products (two grids per day, each containing the ascending/descending passes) in binary format from RSS.”.

Pg. 5, row 173-176, “It is known that, in addition to TCWV, WPD also depends on temperature. Expressions such as Eq. (3) account for an implicit modelling of this dependence. Fernandes et al. (2013b) have shown that this expression leads to similar results as those obtained by adopting formulae that make use of explicit values of atmospheric temperature given e.g. by an NWM.” The reader might not understand what you mean here with “Implicit” and “explicit” values. Please show examples of comparisons with WTC derived from NWPs in open ocean and in coastal zone.
R.: The WTC can be calculated from using the expression given in Bevis et al. (1994), given below:

$$WTC = -\left(0.101995 + \frac{1725.55}{T_m}\right)\frac{TCWV}{1000}$$

where $T_m$ is the weighted mean temperature of the atmosphere. This expression shows that the WTC explicitly depends on the temperature. Equation (3) given in the manuscript does not depend explicitly on temperature as the former. The results requested by the Reviewer are given in Fernandes et al. (2013b), which show that, after sensor inter-calibration, crucial to guarantee datasets consistency, the WTC derived from both methods are equivalent, with differences within ± 2 mm. This result has been added to the manuscript and the following sentence has been included in the revised manuscript:
"The authors show that after sensor inter-calibration, a crucial step to guarantee datasets consistency, the WTC derived from both methods are equivalent, with differences within ± 2 mm.".
Also, the reference Bevis et al. (1994) has been added to the manuscript to direct the reader to the appropriate literature, in case of interest:
Bevis, M., Businger, S., Chiswell, S., Herring, T.A., Anthes, R.A., Rocken, C., Ware, R.H. (1994), GPS Meteorology – Mapping Zenith Wet delays onto precipitable water. Journal of Applied Meteorology, 33, 379-386.

Pg. 6, row 179-180, "We recall that the WTC is the symmetric of the wet path delay and the quantity of interest in satellite altimetry" Please rephrase and specify what you mean with "symmetric"
R.: The term "symmetric" has been replaced by "absolute value" and the sentence referred by the Reviewer has been rewritten as: "It is recalled that the WPD is the absolute value of the WTC, the quantity of interest in satellite altimetry.".

Pg. 6, row 180, "RA data necessary to compute", Please specify the sources you used for corrections, orbit, MSS, etc.
R.: The models and corrections used to derive the SLA datasets are provided in the altimetric products (RADS and Envisat FRM V3.0). To derive these datasets, used to analyse the SLA variance reduction, the same corrections and models are kept unchanged except the WTC. In other words, an SLA dataset is computed using a set of selected models and corrections and the WTC from ERA, then another SLA dataset is computed using the same models and corrections and the MWR-derived WTC, and so on. We do not consider necessary to enumerate all the models and corrections used to generate the SLA datasets, since these SLA datasets have been generated only to perform the statistical assessment, i.e., have been used only as a mathematical tool.
Following the Reviewer's comment, however, the following sentence has been introduced in the revised version of the manuscript:
"The criteria to select valid SLA are those recommended in the literature and adopted in the standard RADS processing (Scharroo et al., 2012, cited in this manuscript) and include: application of thresholds for all involved fields (satellite orbit above reference ellipsoid, altimeter range, all range and geophysical corrections), altimeter ice and rain flag (whenever set) and SLA within ±2m.".

Pg. 7, row 191, "Threshold values used in this criterion depend on the RA mission": Please specify thresholds

R.: The threshold values are specified in the text that follows the referred sentence (lines 193-196). Values of 30 and 15 km have been set for ESA missions, GFO and T/P, and for the Jason series of satellites and SARAL, respectively.

Pg. 7, row 194, “at distances from coast”: The authors use some editing criteria. I am curious to know what happens when tracks are parallel to the coast , but also some situations, e.g., Indonesia where the altimeter crosses successive land segments due to presence of closest islands.
R.: The distance that is inspected by the algorithm is the distance from the point to the closest land point. If a track is parallel to the coast and the distance from its point to the coast is less than the threshold value, all points will be flagged as invalid by the methodology, even if they are not flagged as invalid in the original products. This guarantees that non-flagged invalid MWR-derived WTCs contribute to the estimations.

Pg. 7, row 203, “number of 18 Hz measurements to compute the 1 Hz”: is the global product at 1 Hz (i.e. around 7 km spaced for all missions)? While in open ocean it makes sense, I am bit skeptical the coastal zone might benefit from this product if not provided at 18/20 hz. It has been demonstrated that we need high resolution data in the coastal zone (and in fact waveforms are retracked at that rate and SLAs computed at that rate). Otherwise, the user will not be able to exploit the product.
R.: As already explained, the GPD+ WTC database has been computed for GDR products, which are used by most non-expert users. Over open ocean regions, the MWR-derived WTC is the best choice to account for the wet path delay in the altimeter measurements, and this correction is usually available in these regions. Users that want to extend the use of these products in the coastal zone must rely on model-derived WTC since the former is usually invalid or absent in the coastal zone. Discontinuities may therefore occur between both corrections. The GPD+ WTC, which preserves the valid MWR-derived WTC over open ocean and improves the WTC estimation in the coastal region, has the advantage of being a continuous correction in the transition open ocean/coastal zone. As already explained, expert users can interpolate the GPD+ WTC for the location and epoch of the high-rate altimeter measurements, benefiting this way of an improved WTC in coastal zones. To prevent the loss of points when interpolating to 20 Hz points, in addition to ocean points, the WTC for the closest land point, computed at sea level, is included as explained in the manuscript. Provided the necessary funding is allocated, the GPD+ WTC can be computed for high-rate altimetry products.
In the revised version of the paper, results highlighting the improvement in the Envisat SLA datasets when the GPD+ WTC is used in coastal regions have been added. A summary of the results for the other missions have been included in the revised manuscript. The readers are advised to refer to the cited references from the authors.

Pg. 7, row 203-204, “For approximately 10% of all oceanic points”: What do you mean with “oceanic domain ? Does it include coastal zone ? at which distance ? The value seems for Envisat only. What about the other missions?
R.: This percentage is computed using all points over ocean with valid SLA values (i.e., along-track points with all available corrections but the MWR-derived WTC, which is computed using GPD+), including coastal regions.

The values given in the manuscript are typical for ESA's missions. Results for other missions have been added in the conclusions section:

"The percentage of recovered points when GPD+ is applied in place of the baseline MWR-derived WTC, depends on instrument type, band of latitudes covered by the mission (which determines the extent of ice contamination) and instrument performance. For all ESA missions (ERS-1, ERS-2, Envisat, Sentinel-3) and SARAL, possessing 2-band radiometers and measuring up to latitudes ±81.2º, the percentage of recover data is similar to that of Envisat, in the range of 7% - 15% of the SLA valid points of each cycle. For the reference missions, measuring only up to ±66.7º and already possessing an improved WTC near the coast (all except T/P), this percentage is smaller, from 2 to 4%. For T/P, these values are from 4% to 7%, larger in the second half of the mission. For GFO, measuring up to ±72.0º, the percentage is similar to that of TP. Exceptions occur for various missions over periods of instrument malfunction, when the percentage of recovered points can be considerably larger, up to 100%, as it happens for Envisat and GFO.".

Pg. 8, row 220, "parameters have been obtained for Envisat": Please provide parameters for all missions

R.: The calibration parameters for all satellite altimetry missions possessing an MWR are now provided in Table 2. Subsequent tables have been renumbered.

Pg. 8, row 240, "For all satellite missions but CryoSat-2 and for each along-track point deemed as invalid": The sentence is unclear, please rephrase

R.: The sentence has been rewritten to: "For the altimetry missions carrying an on-board MWR (all but CryoSat-2), a GPD+ WTC estimate is calculated for all along-track points with an MWR-derived WTC deemed as invalid, using valid WTC observations from different sources at the nearby location and within a time interval, defined by the spatial and temporal radiuses of influence used in the computation.".

Pg. 9, row 275, "50 km from the ocean": The setting of this value has to ne justified

R.: The justification has been included: "To prevent the loss of points when interpolating to 20 Hz points, in addition to ocean points, the closest point over land is included, provided it is within a distance less than 50 km from the ocean. This guarantees that observations over ocean necessary to compute the WTC for this location are still available within the radiuses of influence centred on the point. The WTC estimated for the closest points over land are also estimated at sea level.".

Pg. 9, row 278, "Figure 4 gives an example of the GPD+ WTC for Envisat's cycle 12". I don't understand the message of this figure. The upper map is substantially unreadable. The lower map is not providing information as the reader would like. Moreover, one cycle per one mission would be only for visual purposes. There is no comments in the paper. The reader expects quantitative results about the improvement.

R.: Figure 4 is presented to show, as an example, the availability of the GPD+ WTC globally (Panel (a)). Panel (b) shows the correction over ocean only, to be used in satellite altimetry. The idea is to show the global coverage, and therefore one of the advantages, of the GPD+ WTC. This explanation is given in lines 278-279 of the original manuscript.

Pg. 10, row 289, “respectively, are provided at 1 Hz.”. Previously, the authors mentioned 20 Hz. People using the product in the coastal zone need 20 hz data. I don’t understand the utility of publishing a product that then in practice it is not usable from coastal zone users (who are not experts in altimetry). The authors refer to RADS that cannot be considered a “coastal altimetry product”. In my opinion, the authors have to satisfy the user requirements if they want to publish this dataset.
R.: We believe that the GPD+ WTC satisfies the requirements of the users who want to base their analyses on the GDR/RADS products. In what concerns the availability of the GPD+ WTC for coastal purposes only, please refer to previous answers.

Pg. 11, row 315-318: “For results concerning algorithm.”: The reader is confused here and reminded to previous paper. Indeed, the reader wants to see statistics of all missions here with the application of the algorithm described here. The authors have to add relevant statistics of all missions.
R.: We would like to emphasise that the purpose of this paper is not to describe in detail the results for all missions as that has already partly been done in previous papers. Moreover, a paper with an exhaustive description of the results for all missions would necessarily be very long and tedious. Here, we believe the focus should be on the benefits of using these products. Therefore, we detail the results for Envisat, not presented before, and provide a summary of the results for all other missions in the conclusions.

Pg. 11, row 320, “The GPD+ WTC is here compared to the ECMWF Reanalysis WTC”: This kind of comparison make sense in open ocean but not in the coastal zone. The authors provide a title “A coastally improved global dataset. . ...”. They clearly state previously that models fail in the coastal zone and now they use for validation.
R.: Actually, the authors assessed the performance of the GPD+ WTC by comparing it with those WTC available to the users in the altimetry products, to show the improvement attained when the GPD+ WTC is used in the SLA datasets generation, instead of using the MWR- or NWM-derived WTCs. The word “validation” has therefore been changed to “assessment” throughout the text whenever it was used incorrectly.

Pg. 11, row 335, “Figure 5 shows the GPD+ WTC for some Envisat tracks”: The reader expects to see the map showing where the passes are located and identification of the segments where the new corrections improves. The discussion of Figure 5 is not provided. The plots have to be commented in relation to the places touched over ground.
R.: Figure 5 has been divided into Figures 7 and 8 and now includes the geographical coverage of the selected tracks, as we agree with the Reviewer that this information is necessary. The discussion of these figures has been included.

Pg. 11, row 340, “interesting results”: please remove being subjective
R.: The sentence has been rewritten.

Pg. 11, row 346, “most of these points are located at high latitudes and in coastal regions”: This statement is not demonstrated in the figure. The authors expects to see zooming in coastal regions to see improvements.

R.: Results for three different coastal regions have been added in the revised version of the manuscript.

Pg. 11, row 361, “for the whole Envisat mission”: the authors have to provide th same figure for the other missions too

R.: We have already explained that it is not possible to present detailed results for all missions, neither it would be relevant to repeat results already published before.

Similar figures for most missions (T/P, Jason-1, Jason-2, ERS-1, ERS-2, Envisat, GFO and SARAL) are provided in Vieira et al. (2019) and in Fernandes and Lazaro (2018) for Sentinel-3 (both cited in the paper). The following sentences have been introduced in the paper:

“For other missions, results have been presented in Vieira at al. (2019) and in Fernandes and Lázaro (2018) and are summarised here. For the 2-band radiometers, land contamination on the MWR observations occurs for points at distances from coast smaller than 25-30 km (ERS-1 and ERS-2), 20-25 km (Sentinel-3) and 15-20 km (GFO and SARAL), the latter in agreement with the smaller radiometer footprint of the SARAL MWR. Similar analysis shows that land contamination is observed up to 25-30 km from the coast for T/P and Jason-1 and up to 20-25 km for Jason-2 and Jason-3. These numbers are function both of the instrument footprint size and of the efficiency of the criteria used to detect valid/invalid MWR observations, since in these plots only MWR values that passed all validation criteria, except for the distance from coast, have been used. In summary, for each mission, these analyses show the distances from coast up to which the MWR observations are contaminated by land and must be discarded. Moreover, they also show that GPD+ is efficient in removing this effect.“.

Pg. 12, row 369, “The results are shown in Fig. 7”. The authors state the product is at 1 Hz (7 km) and in the plot show values at less than 5 km

R.: Figure 7 (now Figure 10) shows the RMS of WTC differences in bins of distance from coast. While along-track points are separated by 7 km, the points closest to land can be at any distance from the coast, even at distances less than 5 km.

Pg. 13, row 393-395, “Therefore, three SLA datasets of collocated along-track points were derived using the same standard corrections (Sect. 1) but the WTC, which can be the Composite correction present in AVISO CorSSH L2P products (Comp), the GPD+ or the ERA Interim WTCs.”. This comparison makes sense only in the open ocean and not in the coastal zone (0-50 km)

R.: The GPD+ WTC has been compared with the other WTCs available in the altimeter products provided by RADS, GDR, PEACHI and AVISO for use in both open-ocean and coastal regions. The Comp WTC is the result of the methodology developed by AVISO, to improve the WTC in the coastal region, therefore we consider that the comparisons shown are reasonable. However, following the concerns of Reviewer#2, who were right pointing out that the Composite WTC available at the time of our analysis in AVISO products has not been computed using this new Envisat FMR V3.0, we decided to show in the revised version of the manuscript the assessment of the GPD+ WTC by comparing it with the ERA- and MWR-derived WTCs, which are the actual corrections provided in these products. Therefore, Section 3 has been rewritten accordingly.

Pg. 13, row 406, “Fig.8a”: Fig. 8c si not commented in the text. Moreoer, there is a strange behavior around cycle 95

R.: Figure 11 has been changed to include a new panel (b) the number of points used in the MWR and GPD+ WTCs, since it is different from the number of points used in the comparison with ERA (shown in panel (d) of the same figure). This is explained in the manuscript. Reference to both panels (b) and (d) of Figure 11 (previous Figure 8) have been added in the text.

In October 2010, a new orbit configuration (30-day repeat cycle) for Envisat was implemented, corresponding to a change from Envisat Phase b to Phase c. As a consequence, a large amount of data was lost in the period corresponding to cycles 94 and 95. This information has been added in the revised paper.