

A global assessment of mangrove soil organic carbon sources and implications for blue carbon credit

Corresponding Author: Dr Faming Wang

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

Overall:
Being able to distinguish between autochthonous and allochthonous contributions to mangrove soils carbon stocks is a significant challenge for completing mangrove carbon project development, particularly as these ecosystems and projects are dominantly in low-income countries with more limited science programs. Applying stable isotope analysis to carbon stocks within the top of intact mangroves provides a means to assess bulk contributions from various sources. Soils to this depth are routinely collected as part of carbon project (and wider mangrove) investigations and to which stable isotope analysis can readily done to scale up the dataset from this investigation.

Particular comments:

It is not clear from the analysis whether the isotope data are collected from the same samples as the carbon data. Even within a relatively small country the carbon stocks can be quite variable. I note that the SWAMP dataset is applied. Have the authors looked at the data archive in held by the Coastal Carbon Network, of which the SWAMP dataset is a subset. There may be opportunity to expand the analysis without too much additional effort (<https://serc.si.edu/coastalcarbon/data>).

The proximity of sampling locations to tidal / river channel margins may also influence the relative contribution of carbon sources. See for example this study of fringe and interior mangroves in a marine and estuarine setting. https://www.fs.usda.gov/psw/publications/mackenzie/psw_2016_mackenzie001.pdf

As monitoring programs, particularly in Rhizophora mangroves, are biased to fringing mangroves because of access challenges does this influence the interpretation of the authors dataset?

It is not clear to me how robust the analysis of environmental drivers is. Are there defined boundaries for estuarine and marine mangroves? There is reference to data being derived from the DIVA model, but my understanding is that this model is not a source of data in itself. The data source of Total Suspended Matter is particularly opaque and a parameter that in itself would be helpful to carbon projects as well as more broadly evaluating coastal system resilience to sea level rise. Similarly, there is reference to nearest tidal station for derivation of tidal parameters but this is there a cut off beyond which a tide station may not be appropriate. Commonly, when estimating elevations at a site an approach may be taken to interpolate between neighboring stations to capture longshore variation.

There is reference to elevations being derived from CoastalDEM, a proprietary dataset. Noting there are now public access datasets available (EDTM, DeltaDTM, Diluvium DEM). The authors may consider including an analysis of not only the absolute tidal and elevation parameters but the relationship of the site elevation within the tidal frame (Z").

https://d3o6w55j8uz1ro.cloudfront.net/s3-d0f68fa49c8cba12794bb586349f2341/o/ml-cumulus-prod-public.s3.us-west-2.amazonaws.com/cms/Coastal_US_Elevation_Data/comp/Coastal_US_Elevation_Data.pdf?A-userid=None&Expires=1718736037&Signature=FaBcDR2-wDTff1RCpNhNZuL~3Ne-05d19H0viRE5KVwCKXzcKMOOuxspigzIY~V42CVhjGKVCZNavrtYXpgaSrx5uASyRGAjoTYgec8717iJDTw6znW0oAqWxexbSjw2r75sm51zxcSYifwzlylQsw7dbcYB6730VXntkz5AB3e5Ja3KUpHJ87JAUUCw-tPqt9NyZdgE1YbVLLU8m5oLhNcQV7CkzxU-yb5oytY0o1vUUTJQdZioVSCCYfHWZbMkK4FTMErBoo-6bWlhqKtiZ-qrN3w__&Key-Pair-Id=K2N95OSU57UMPV

The authors provide global estimates of relative contributions of C sources for estuarine and marine mangroves. Given their dataset would the authors feel comfortable providing any higher resolution stratification (e.g. either geographically or climate zone based)?

Recognition of land use conversion for agriculture is noted as a potential impact on carbon sources. What of dam construction? <https://www.nature.com/articles/s43017-021-00253-w#Abs3>

Reference is provided for VM0033:

Emmer, I. M., B. A. Needelman, S. Emmett-Mattox, S. Crooks, J. P. Magonigal, D. Myers, M. P. J. Oreska, and K. J. McGlathery. 2023. Estimation of Baseline Carbon Stock Changes and Greenhouse Gas Emissions in Tidal Wetland Restoration and Conservation Project Activities (BL-TW). VCS Module, v 2.1. Verra (Verified Carbon Standard), Washington, D.C.

Check text: when stating greater accumulation rates is this in absolute values or relative proportion between sources.

Line 62: Consider replacing "environmental benefits: with "climate mitigation benefits".

line 171: facialized?

Reviewer #2

(Remarks to the Author)

The authors did a global assessment of soil organic carbon stocks in mangrove forests, and compared the results between two environmental settings according to mangrove distribution (i.e. marine mangroves vs estuarine mangroves). Although there are multiple global-scale analyses on mangrove soil carbon stocks, this study is unique that it quantified total carbon stocks by different sources (autochthonous vs allochthonous), and found significant differences in the sources and controlling variables of soil carbon stock between the two types of mangrove forests – which is a new finding, with clear practical implications to guide future mangrove restoration and coastal wetland management. While I find the study well-designed and the results quite interesting, I do believe that another round of edit and revision is needed before it can be accepted by Nature Communications.

General comments

1. Since the identification of soil carbon sources (Lines 267-269) is key to the main findings of this study, for improved reproducibility, more information in the data searching/selection (such as keywords, time period, and criteria) is needed in Section "Organic carbon source identification" (Materials & Methods, Line 266) to clarify how different soil sources are defined and recognized.
2. I have some concerns regarding the random forest models applied to identify major predictors for organic carbon sources (Line 287, Section "Primary regulators of organic carbon sources"). Although random forest model is relatively robust and has been widely used in ecology, its output is not always straightforward to interpret. While I have no problem with using random forest model in this study, I find the results presented in Figure S2 a little confusing, and it thus needs some clarification. First, there seems to be too many predictors retained in the model ($n > 20$), and some may be correlated (e.g. mean tidal range, mean high water spring, mean high water neap). I suggest to simplify the model a little by removing some highly-correlated variables step by step so as to improve model performance and also enhance the interpretability of model output. Second, shouldn't the relative importance of each independent variables sum up to 100%? A quick look at Figure S2 shows that the sum seems way beyond 100%. Maybe I read the figure wrong, but some clarification may be helpful in the figure legend to help the audience capture the main message of the figure, especially considering it is a key finding of this study.
3. Please be more specific regarding "Estuarine and marine mangroves mapping" (Line 330). The authors used "88 spectral covariates derived from the Landsat Archive data ... for machine learning to distinguish the misclassified pixels". Since the differentiation between marine/estuary mangrove is quite important for accurate quantification of overall mangrove soil carbon stock, I suggest adding two tables – one listing all the covariates and one assessing clarification accuracy – as supplementary for enhanced clarity.

Specific comments

1. Please define all abbreviations the first time they are mentioned in the study, such as VERRA (Line 57), N/C (Line 67), RSLR (Line 100), and OM (Line 107).
2. Line 73, how about carbon cycling rather than "carbon cycles"?
3. Line 84 & 178: avoid using "study's". How about replacing "the study's analysis" with "our analysis", "the study's exploration" with "our exploration"?
4. Lines 117-120: the meaning of this sentence is a little confusing, please clarify.

5. Line 164, please add "OC" after "autochthonous".
6. Line 171: would you please clarify what you mean by "facilized by the later C flux"?
7. Figure S2: please define variable abbreviations in the figure legend, such as MHWN, MTR.

Reviewer #3

(Remarks to the Author)

I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

Additional analysis in response to comments have been made and strengthened the manuscript. My comments reflect minor clarifications:

- 1) Lines 26-29: suggest recognizing the central role of stable isotope analysis to the authors work.
- 2) Line 57: for VCS standard the terminology is methodology rather than protocol. May refer to the VCS methodology (VM0033) or specifically to procedures within VCS Methodology (VM0033).
- 3) Lines 108-112: I do not understand these statements about marine sources. Is this a reference to dilution by mineral particles? please clarify.
- 4) Line 168: Remove the word 'landmark'.
- 5) Table: recommend including N (No. data points) and description of data variability for each region.

Reviewer #2

(Remarks to the Author)

We would like to thank the authors for carefully addressing each of our comments. With all our concerns resolved/clarified, we believe the work has been largely improved and it will be an importance addition to this field. Thus, we have no further concerns.

Reviewer #3

(Remarks to the Author)

I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

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*****NOTE*****

Response to comments:

Reviewer #1 (Remarks to the Author):

Overall:

Being able to distinguish between autochthonous and allochthonous contributions to mangrove soils carbon stocks is a significant challenge for completing mangrove carbon project development, particularly as these ecosystems and projects are dominantly in low-income countries with more limited science programs. Applying stable isotope analysis to carbon stocks within the top of intact mangroves provides a means to assess bulk contributions from various sources. Soils to this depth are routinely collected as part of carbon project (and wider mangrove) investigations and to which stable isotope analysis can readily be done to scale up the dataset from this investigation.

Particular comments:

It is not clear from the analysis whether the isotope data are collected from the same samples as the carbon data.

Response: Thanks for this comment. The initial intent of the data collection is to collect the SOC stock data of mangroves, and the isotope data were also collected as factors that might need to be analyzed later. When analyzing the data, we noticed that the isotope data is sufficient to conduct a global analysis to identify the mangrove C sources. We conducted the analyses and the result shows that there were differences between SOC stock and OC sources in estuarine and marine mangroves. There were some researches that only reported the isotope data without the SOC stock data. Therefore, there were actually two main datasets used in this study, the mangrove SOC stock dataset and the mangrove isotope dataset, with some of them are from the same publication. We have added how we collected the isotope data in methods in line 198-204: ‘We compiled published data on isotope ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) and N/C values of global mangrove sediments from the Web of Science using combinations of keywords “mangrove C* source”, “mangrove isotope”, “mangrove source”, utilizing 100 studies and 441 observations. The database should meet the following requirements: (1) parameters that used to calculate the OC sources should be reported (either $\delta^{13}\text{C}$ and N/C or $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$); (2) the work must have been published in peer-reviewed publications; (3) the study must have been a field study in natural conditions without artificial manipulation.’

Moreover, we have uploaded the full isotope datasets in the supporting materials in this revision, and we will also upload these data to the Coastal Carbon Network after the publication of this paper. We will share these data with other blue C researchers through the Coastal Carbon Network.

Even within a relatively small country the carbon stocks can be quite variable.

Response: Thanks for this comment. Yes, we also have noticed that. That's the reason why we use the mangrove SOC stock datasets combined with the Kriging interpolation to estimate the total SOC stock in estuarine and marine mangroves. If we only use the mangrove SOC stock derived from the isotope dataset, the estimation might be largely biased because of the limited observations (400 vs. 2000 in mangrove SOC stock datasets).

I note that the SWAMP dataset is applied. Have the authors looked at the data archive in held by the Coastal Carbon Network, of which the SWAMP dataset is a subset. There may be opportunity to expand the analysis without too much additional effort (<https://serc.si.edu/coastalcarbon/data>).

Response: Yes, we have looked into the Coastal Carbon Network, and cited the dataset by Holmquist et al., 2023 in GCB. This is absolutely an amazing dataset which provide a convenient access for researchers to the blue carbon dataset. We had used this dataset in another manuscript aimed to analyze the SOC stock changes during land use changed in coastal ecosystems. When we looked into the CCN datasets, we found that there were few data that were overlapped. On this basis, we improved our mangrove SOC datasets by adding those unique data collected by CCN datasets. We have added this part in line 312-316 : ‘We further fulfill our dataset with data from Coastal Carbon ATLAS ⁴⁰ (mostly published after 2020 or unpublished data). The final database has 2356 SOC observations, where 1682 observations were extracted from Ouyang and Lee ³⁹, 476 observations were additionally added and 198 observations are from Coastal Carbon ATLAS)’

We attached all these isotope data in the supporting materials, and will upload all our data of mangrove C stocks and C isotopes to the Coastal Carbon Network after the publication of this and the other paper.

The proximity of sampling locations to tidal / river channel margins may also influence the relative contribution of carbon sources. See for example this study of fringe and interior mangroves in a marine and estuarine setting. https://www.fs.usda.gov/psw/publications/mackenzie/psw_2016_mackenzie001.pdf As monitoring programs, particularly in *Rhizophora* mangroves, are biased to fringing mangroves because of access challenges does this influence the interpretation of the authors dataset?

Response: Thanks for comments. This publication was also included in our mangrove SOC datasets. We looked through all of the collected publications and we find that among 441 isotope data, 164 of them reported their locations to tidal/ river channel margins, and most of the sampling sites were fringe mangroves (n=129), while only 25 and 16 were located in interior and transition zones, respectively. This corresponds to your comment that most of the samples were fringe mangroves because of the easy access. Among the 129 fringe mangroves, only 11 were pure *Rhizophora* mangroves,

with most of them are mix of multiple species such as *Avicennia*, *Kandelia*, *Rhizophora*, *Sonneratia*, *Bruguiera* mangroves. For detailed information, please check the newly uploaded supporting Excel files. To address your concern, we did the general additive model (GAM) of those influencing factors that ranks the top 30% of the random forest model of mangrove OC contribution, marine OC contribution and terrestrial OC contribution to OC in mangrove sediments, respectively (Table S7-S9). The results showed that the sampling location had no significant influence on the OC contributions.

It is not clear to me how robust the analysis of environmental drivers is. Are there defined boundaries for estuarine and marine mangroves?

Response: For those studies that has clearly define their sampling site as estuarine or marine mangroves, we simply use their original definition. For studies that did not define their sampling sites but gives their sampling maps, we define estuarine mangroves according to the existence of rivers, lagoons or estuaries. For studies that only gives a location without any sampling maps, we use the global estuary mapping derived from Ander et al., 2003 and Watson, et al. 2004 in Google Earth Engine to define the estuarine mangroves, with the left being marine mangroves. We have added details of how to define estuarine and marine mangroves in line 234-241: ‘The 441 isotope observations were further separated into estuarine and marine mangroves according to the following conditions: (1) if the sampling site was clearly defined as estuarine or marine mangroves, we used its original classification; (2) when the sampling site did not meet condition 1, but the sampling map were provided in the literature, we classified estuarine or marine mangroves by the appearance of river or estuaries; (3) if the condition 1 and 2 were not meet, we used the global estuarine and marine mangrove maps generated in the following steps (Estuarine and marine mangrove mapping) to identify their environmental settings.’ and line 288-299: ‘The mapping of estuarine and marine mangroves contains two steps, the mapping of global mangroves and the mapping of estuarine regions. The Global Mangrove Watch datasets are the most commonly used mangrove datasets with public access. Therefore, we extracted the global mangrove distribution in 2020 from Global Mangrove Watch ³⁷. For the estuarine region mapping, we applied a mask of the global estuary distribution developed by Sea Around Us project to mangrove distribution ²⁴⁻²⁶. However, we noticed that the estuary distribution only covers the water, while mangroves around the estuary was overlooked. We therefore combine the estuary distribution with the sampling point in our collection which was clearly defined as estuarine mangroves to manually draw the boundaries between estuarine and marine mangroves (Fig. S7).’

To make readers easily understand the significance of impacts of the environmental drivers on different OC contributions, we further used ‘rfPermute’ package in R to add the significance of each influencing factors. We have added this in line 279-280: ‘Moreover, we used “rfPermute” package to assess the significance of each influencing factors ³⁶.’

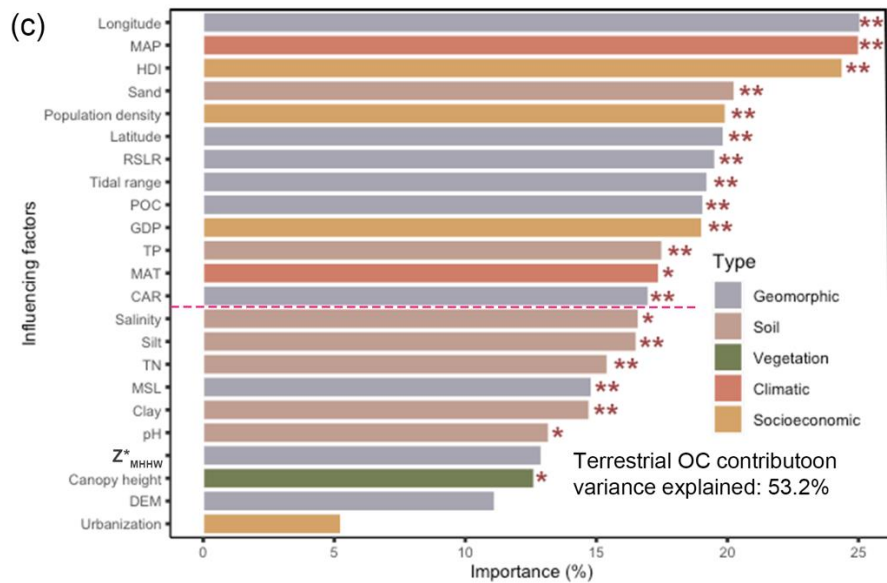
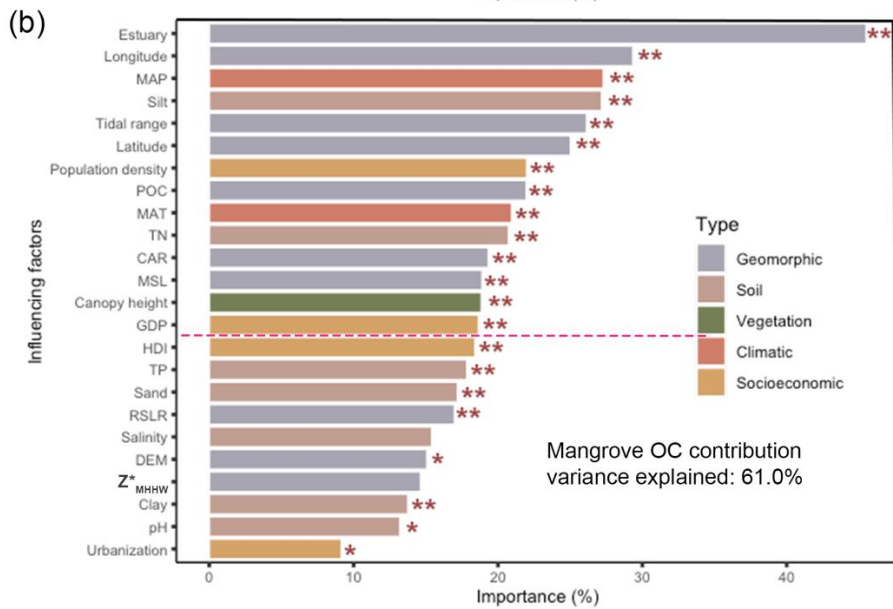
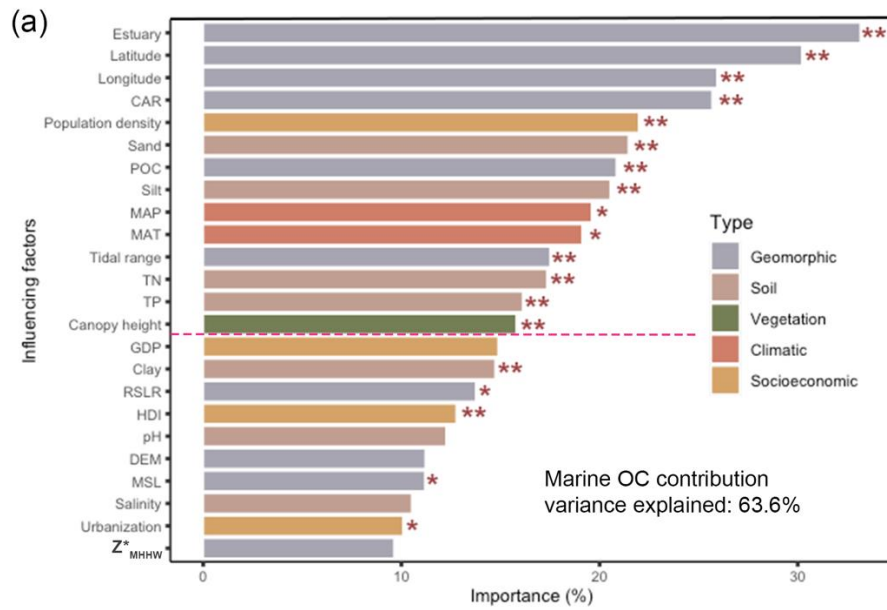
There is reference to data being derived from the DIVA model, but my understanding is that this model is not a source of data in itself. The data source of Total Suspended

Matter is particularly opaque and a parameter that in itself would be helpful to carbon projects as well as more broadly evaluating coastal system resilience to sea level rise.

Response: Thanks for this comment. To increase the robustness of this model and address this concern, we now use the POC concentration derived from ocean color datasets instead of TSM of DIVA dataset in this model. We have revised this in line 250-253: ‘The particulate organic matter (POC) data were extracted in GEE entitled with Ocean Color SMI: Standard Mapped Image MODIS Aqua data. (https://developers.google.com/earth-engine/datasets/catalog/NASA_OCEANDATA_MODIS-Aqua_L3SMI).’

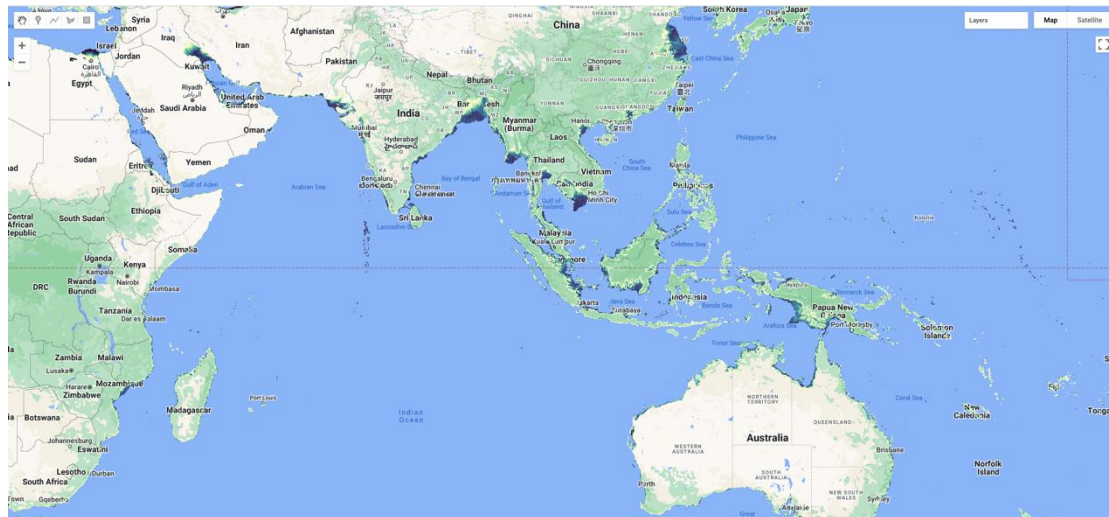
Similarly, there is reference to nearest tidal station for derivation of tidal parameters but this is there a cut off beyond which a tide station may not be appropriate. Commonly, when estimating elevations at a site an approach may be taken to interpolate between neighboring stations to capture longshore variation.

Response: Thanks for this comment. Using the nearest tidal station might introduce bias to our analyzes and using the interpolate is a good solution. However, when conducting interpolation, the buffered area is usually set to be 100 km (similar as our mangrove SOC stock interpolation), there are several sites that were still out of the buffered and interpolated areas. Therefore, we decided to use another set of data that has higher resolution and more coverage of our collected sampling site. Furthermore, Reviewer#2 suggested that we should reduce some of the correlated influencing factors such as mean high water spring, mean tidal range, mean high water neap. We decided putting the most commonly used parameters, mean sea level and tidal range to the model. We have revised this in line 248-250: ‘Tidal range and mean sea level were extracted from Muis, et al.²⁷ in Copernicus platform (<https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-water-level-change-indicators-cmip6?tab=overview>).’ Therefore, we updated the influencing factors put into the model and add the significance analysis of them. The final random forest results were shown as follow:

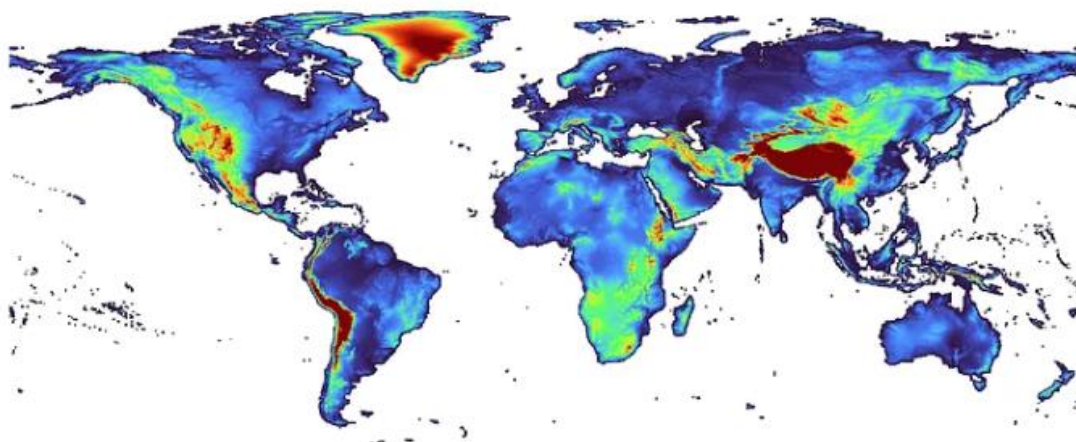


There is reference to elevations being derived from CoastalDEM, a proprietary dataset. Noting there are now public access datasets available (EDTM, DeltaDTM, Diluvium DEM).

Response: Thanks for this comment. The CoastalDEM is also a public access dataset under the resolution of 90*90 m, all we need to do is to register and download the data without any cost. We have checked the DeltaDTM and EDEM, we found that their coverage for coastal areas is not enough to extract the elevation for intertidal areas. We can see that the DeltaDTM and EDEM only covers the land while the coastal DEM covers more tidal areas. The coverage of Diluvium DEM is equivalent to the Coastal DEM, however, we found that some mangrove DEM was above 20 m, even 30 m, especially in Australia. This might because the satellite measures the elevation including the canopy height rather than the elevation of the bare land. The coverage and accuracy of CoastalDEM is enough for conducting mangrove analysis, therefore, we choose to use CoastalDEM in this study.

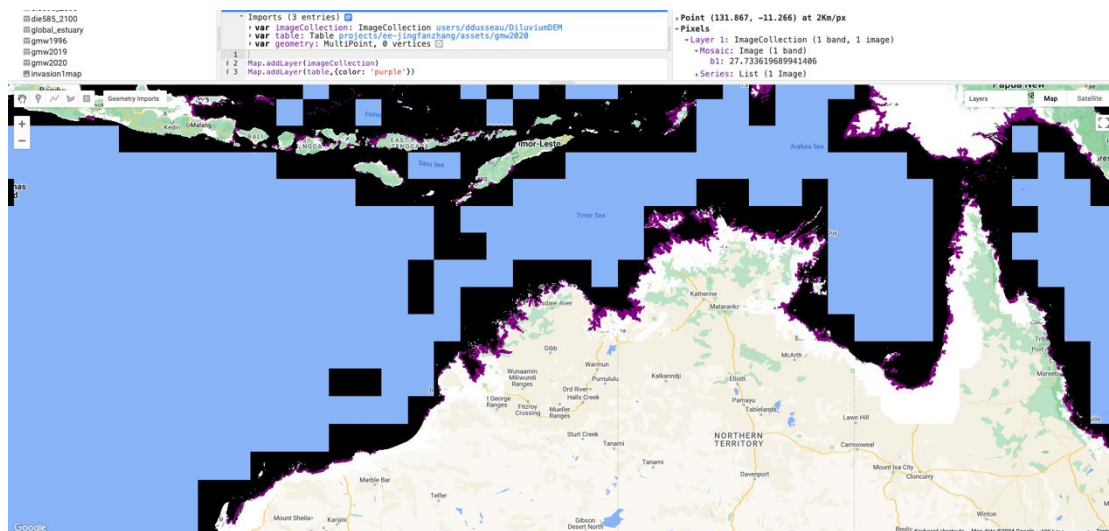


The coverage of DeltaDTM

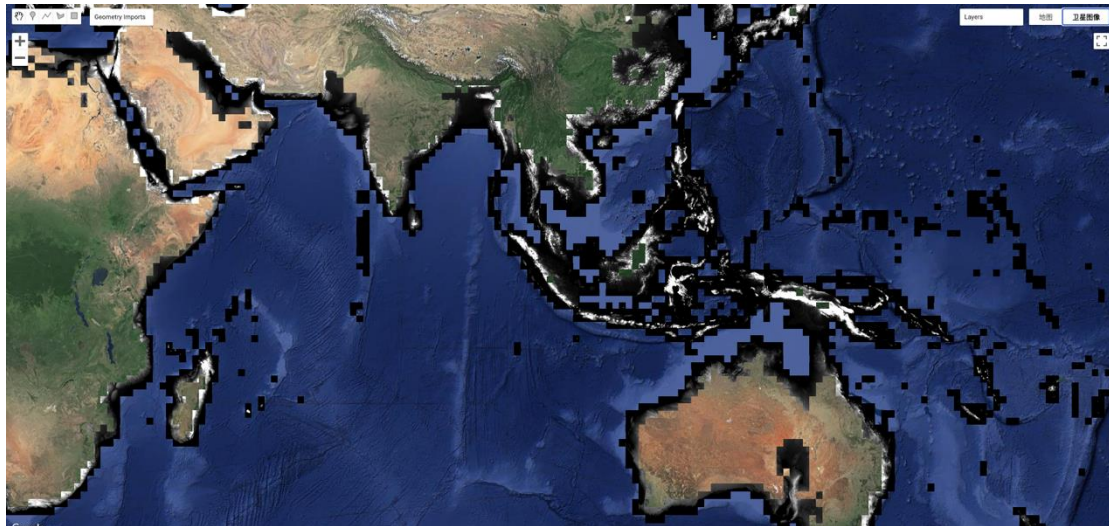


Ensemble DTM in 30m.

The coverage of EDEM



The coverage of Diluvium DEM is equivalent to the Coastal DEM.



The coverage and accuracy of CoastalDEM is enough for conducting mangrove analysis, therefore, we choose to use CoastalDEM in this study.

The authors may consider including an analysis of not only the absolute tidal and elevation parameters but the relationship of the site elevation within the tidal frame (Z^*).

https://d3o6w55j8uz1ro.cloudfront.net/s3-d0f68fa49c8cba12794bb586349f2341/ornl-cumulus-prod-public.s3.us-west-2.amazonaws.com/cms/Coastal_US_Elevation_Data/comp/Coastal_US_Elevation_Data.pdf?A-userid=None&Expires=1718736037&Signature=FaBcDR2-wDTff1RCpNhNZuL~3Ne-05d19H0viRE5KVwCKXzcKMOOuxspigzIY~V42CVhjGKVCZNavrtYXpgaSrx5uASyRGAjoTYgec87l7fJDTw6znW0oAqWxexbSjw2r75sm51zxcYifwzIylQsw7dbcYB6730VXntkz5AB3e5Ja3KUpHJ87JAUUq8~xBWcqDwHKxuxO1QFOiZEhDAJpMdeIDvp1w82R1Pr1tLe77DOyxeeJQN-w-tPqt9NyZdgE1YbVLLU8m5oLhNcQV7CkzxU-

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Response: Thanks for this comment. Sorry we cannot open this link, but we assumed it was Holmquist et al., 2022 entitled ‘A Conterminous USA-Scale Map of Relative Tidal Marsh Elevation’. We noticed that Z^*_{MHW} was used in that study, however, we cannot find any global MHW datasets. Therefore, we used Z^*_{MHHW} referenced by that study to refer the site elevation within the tidal frame. We have added this in line 253-260: ‘We additionally calculated the relationship of the site elevation within the tidal frame (Z^*_{MHHW}) using the following equation^{29,30}:

$$Z_{MHHW}^* = (Elevation - MSL) / (MHHW - MSL)$$

where the Elevation is the data extracted from the above-mentioned DEM datasets, MSL is mean sea level, MHHW is mean higher high water extracted from Muis, et al.²⁷,

The authors provide global estimates of relative contributions of C sources for estuarine and marine mangroves. Given their dataset would the authors feel comfortable providing any higher resolution stratification (e.g. either geographically or climate zone based)?

Response: Thanks for this comment. We now added the estimation of relative contributions of OC sources for different continents. We provide OC sources for estuarine and marine mangroves in East Asia, Southeast Asia, South Asia, West Asia, Oceania, East Africa, South Africa, North America, South America (Table 1). Furthermore, we also provided the relative contributions of OC sources in each country where the data were collected (Table S2 and S3).

Recognition of land use conversion for agriculture is noted as a potential impact on carbon sources. What of dam construction? <https://www.nature.com/articles/s43017-021-00253-w#Abs3>

Response: Thanks for this comment. Dam construction might have influence on the terrestrial OC retained in mangroves due to blocking the river and the terrestrial OC transported by the river. We added this to the discussion and cited this paper to provide readers with a broader view. We have added this in line 132-134: ‘Moreover, dam construction might have influence on the terrestrial OC retained in mangroves due to blocking the river and the terrestrial OC transported by the river¹⁹.’

Reference is provided for VM0033:

Emmer, I. M., B. A. Needelman, S. Emmett-Mattox, S. Crooks, J. P. Megonigal, D. Myers, M. P. J. Oreska, and K. J. McGlathery. 2023. Estimation of Baseline Carbon Stock Changes and Greenhouse Gas Emissions in Tidal Wetland Restoration and Conservation Project Activities (BL-TW). VCS Module, v 2.1. Verra (Verified Carbon Standard), Washington, D.C.

Response: Thanks, we have revised it throughout our manuscript.

Check text: when stating greater accumulation rates is this in absolute values or relative

proportion between sources.

Response: The accumulation rates referred here is the absolute values.

Line 62: Consider replacing "environmental benefits: with "climate mitigation benefits".

Response: Thanks for the suggestion, we have replaced 'environmental benefits' with 'climate mitigate benefits' in the revised manuscript.

line 171: facialized?

Response: Thanks for this comment, we have revised 'facialized' into 'facilitated'.

Reviewer #2 (Remarks to the Author):

The authors did a global assessment of soil organic carbon stocks in mangrove forests, and compared the results between two environmental settings according to mangrove distribution (i.e. marine mangroves vs estuarine mangroves). Although there are multiple global-scale analyses on mangrove soil carbon stocks, this study is unique that it quantified total carbon stocks by different sources (autochthonous vs allochthonous), and found significant differences in the sources and controlling variables of soil carbon stock between the two types of mangrove forests – which is a new finding, with clear practical implications to guide future mangrove restoration and coastal wetland management. While I find the study well-designed and the results quite interesting, I do believe that another round of edit and revision is needed before it can be accepted by Nature Communications.

General comments

1. Since the identification of soil carbon sources (Lines 267-269) is key to the main findings of this study, for improved reproducibility, more information in the data searching/selection (such as keywords, time period, and criteria) is needed in Section "Organic carbon source identification" (Materials & Methods, Line 266) to clarify how different soil sources are defined and recognized.

Response: Thanks for this comment. We now added a detailed description of our data collecting process in material and methods in line 197-204: 'We compiled published data on isotope ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) and N/C values of global mangrove sediments from the Web of Science using combinations of keywords "mangrove C* source", "mangrove isotope", "mangrove source", utilizing 100 studies and 441 observations. The database should meet the following requirements: (1) parameters that used to calculate the OC sources should be reported (either $\delta^{13}\text{C}$ and N/C or $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$); (2) the work must have been published in peer-reviewed publications; (3) the study must have been a field study in natural conditions without artificial manipulation.'. Moreover, we also provided a detailed Excel file containing all the data we have used in this study.

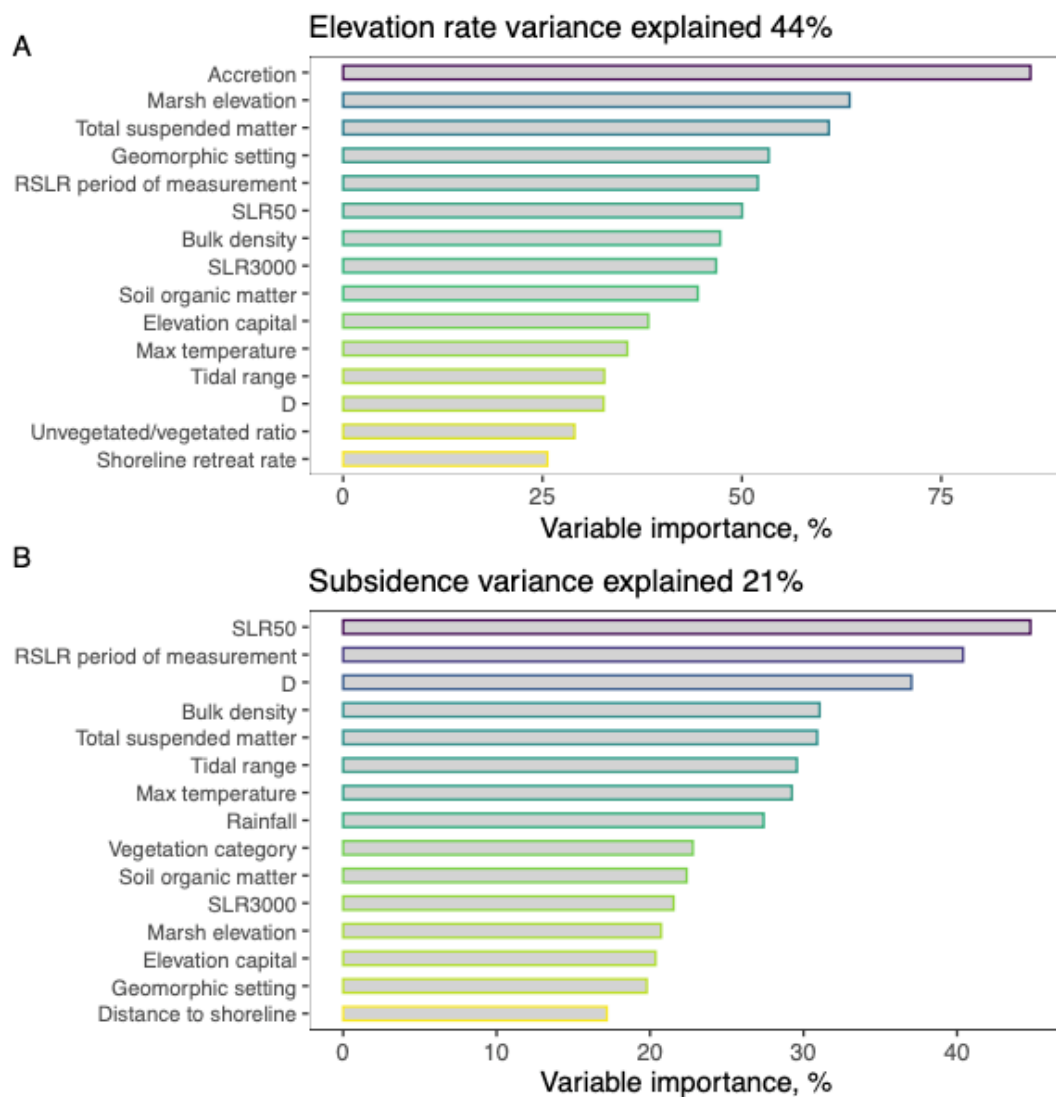
2. I have some concerns regarding the random forest models applied to identify major predictors for organic carbon sources (Line 287, Section “Primary regulators of organic carbon sources”). Although random forest model is relatively robust and has been widely used in ecology, its output is not always straightforward to interpret. While I have no problem with using random forest model in this study, I find the results presented in Figure S2 a little confusing, and it thus needs some clarification. First, there seems to be too many predictors retained in the model ($n > 20$), and some may be correlated (e.g. mean tidal range, mean high water spring, mean high water neap). I suggest to simplify the model a little by removing some highly-correlated variables step by step so as to improve model performance and also enhance the interpretability of model output.

Response: Thanks for this comment. Reviewer #1 also has the similar concern of the random forest model, especially the DIVA dataset (mean high water spring, tidal range and mean high water neap). In the revised manuscript, instead of using DIVA dataset, we decided to use a dataset that contain the most commonly used tidal parameter (tidal range and mean sea level) with a broader coverage and higher spatial resolution. And for vegetation properties, only canopy height was used instead of using aboveground biomass, belowground biomass and canopy height since the these three are highly collected and canopy height dataset was an open dataset which is easier for other researchers to get. We have revised this in line 254-250: ‘Mangrove canopy heights were extracted from public Google Earth Engine (GEE) datasets as vegetation properties in this study. Open-access global datasets were used to extract the geomorphic and climatic properties. Tidal range and mean sea level were extracted from Muis, et al.²⁸ in Copernicus platform (<https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-water-level-change-indicators-cmip6?tab=overview>).’

Second, shouldn't the relative importance of each independent variables sum up to 100%? A quick look at Figure S2 shows that the sum seems way beyond 100%. Maybe I read the figure wrong, but some clarification may be helpful in the figure legend to help the audience capture the main message of the figure, especially considering it is a key finding of this study.

Response: Thanks for this comment. In R's 'randomForest' package (we use this to conduct the random forest analyze in this study), the variable importance calculating returns to a measure called %IncMSE (the percentage increase of the mean squared error) for regression cases (random forest can also do classification). Therefore, in this case, it is usual that the importance did not add up to 100%. For example, there was also a random forest analysis in the supporting materials of Saintilan et al., 2022, which very similar as what we have done in this study, the importance also did not add up to 100%. For readers who has the same concern, we added more detailed information in the captions of Figure S2: ‘The relative importance of independent variables for marine OC contributions (a), mangrove OC contributions (b) and terrestrial OC contributions (c) to OC in mangrove sediments as identified by the percentage increase of the mean

squared error (MSE%) using random forests models, therefore, the ‘Importance (%)’ here might not added up 100.’ For detailed information of how the importance of random forest model was generated, please check <https://stats.stackexchange.com/questions/403310/per-cent-increase-in-mse-incmse-random-forests-importance-measure-why-is-measured>



3. Please be more specific regarding “Estuarine and marine mangroves mapping” (Line 330). The authors used “88 spectral covariates derived from the Landsat Archive data ... for machine learning to distinguish the misclassified pixels”. Since the differentiation between marine/estuary mangrove is quite important for accurate quantification of overall mangrove soil carbon stock, I suggest adding two tables – one listing all the covariates and one assessing clarification accuracy – as supplementary for enhanced clarity.

Response: Thanks for this comment. The mapping of estuarine and marine mangroves contains two steps, the mapping of global mangroves and the mapping of estuarine regions. The original method in this study used the global mangrove distribution developed by Liao et al., 2022. Although this global mangrove mapping has high resolution and wide time span, we found that the mangrove distribution of 2020 was underestimated because mangroves still exists in pixels that were defined as ‘mangrove loss’ when we looked it up in Google Earth. We therefore used the random forest classification adapting 88 spectral covariates derived from the Landsat Archive data to calibrate the mangrove mapping in 2020. However, in this revised manuscript, we realized it is better to use Global Mangrove Watch datasets than the calibrated one for the following reasons: (1) calibrating the mangrove mapping using a different data source than the original product might also introduce bias and errors; (2) The Global Mangrove Watch datasets are the most commonly used mangrove datasets with public access, which is easier for other researchers to perform our analysis process. For the estuarine region mapping, we masked the global estuary distribution developed by Sea Around Us project to mangrove distribution in the original manuscript. However, we noticed that the estuary distribution only covers the water, while mangroves around the estuary was overlooked. In the revised manuscript, we combine the estuary distribution with the sampling point in our collection which was clearly defined as estuarine mangroves to manually plot the estuarine mangroves, with the left being the marine mangroves, such as the following figures shows (The purple pixels were mangroves, red pixels were estuaries and the yellow regions were the manually drawn boundaries). Therefore, in the revised manuscript, instead of calibrating the mangrove distribution product using complicated method, the Global Mangrove Watch dataset were used for the mangrove distribution in 2020. Moreover, the process to differentiate the estuarine and marine mangroves were more convincing and reliable. We have revised the whole part of ‘Estuarine and marine mangroves mapping’ in line 288-299: ‘The mapping of estuarine and marine mangroves contains two steps, the mapping of global mangroves and the mapping of estuarine regions. The Global Mangrove Watch datasets are the most commonly used mangrove datasets with public access. Therefore, we extracted the global mangrove distribution in 2020 from Global Mangrove Watch³⁸. For the estuarine region mapping, we applied a mask of the global estuary distribution developed by Sea Around Us project to mangrove distribution²⁵⁻²⁷. However, we noticed that the estuary distribution only covers the water, while mangroves around the estuary was overlooked. We therefore combine the estuary distribution with the sampling point in our collection which was clearly defined as estuarine mangroves to manually draw the boundaries between estuarine and marine mangroves (Fig. S7).’

Response: Thanks for this comment, we have revised this in line 119-121 to make it clearer: ‘Anthropogenic nutrient fluxes can act as fertilizers for mangroves, enhancing their growth and consequently increasing the input of autochthonous OC^{14,15}.’

5. Line 164, please add “OC” after “autochthonous”.

Response: Thanks for this comment, we have added OC after autochthonous in line 166-168: ‘Generally, utilized by microbes and transformed into more recalcitrant C (like mineral-associated OC), allochthonous OC can be more stable than autochthonous OC when deposited in mangrove sediments²².’

6. Line 171: would you please clarify what you mean by “facilized by the later C flux”?

Response: Sorry for using the wrong word here, Reviewer#1 also pointed out this mistake, we now changed ‘facilized’ into ‘facilitated’.

7. Figure S2: please define variable abbreviations in the figure legend, such as MHWN, MTR.

Response: Thanks for this comment. We have added all the definitions of variable abbreviations in figure captions: ‘Figure S2. The relative importance of independent variables for marine OC contributions (a), mangrove OC contributions (b) and terrestrial OC contributions (c) to OC in mangrove sediments as identified by the percentage increase of the mean squared error (MSE%) using random forests models, therefore, the ‘Importance (%)’ here might not added up 100. Factors above the red dashed lines were put into the later general additive models. CAR is carbon accumulation rate; POC is the particulate organic carbon concentration; MAT is mean annul temperature; MAP is mean annual precipitation; TN is total nitrogen content; TP is total phosphorus content; GDP is gross domestic production; RSLR is relative sea level rise ; HDI is human development index; DEM is digital elevation model which refers to site elevation here; MSL is mean sea level; Z^*_{MHHW} is the relationship of the site elevation within the tidal frame.’

Reviewer #3 (Remarks to the Author):

I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

Response: Thanks for your comments. We hope the revised version can well address all your concerns.

Response to comments

Additional analysis in response to comments have been made and strengthened the manuscript. My comments reflect minor clarifications:

1) Lines 26-29: suggest recognizing the central role of stable isotope analysis to the authors work.

Response: Thanks for this comment. We have pointed out the central role of stable isotopes analysis in abstract in line 4-6: ‘Here, we conduct a global-scale analysis of sediments autochthonous and allochthonous OC contributions in estuarine and marine mangroves using stable isotopes.’

2) Line 57: for VCS standard the terminology is methodology rather than protocol. May refer to the VCS methodology (VM0033) or specifically to procedures within VCS Methodology (VM0033).

Response: Thanks for this comment, we have specifically referred VCS methodology (VM0033) in line 32-34: ‘Accurate quantification of these OC fractions is essential for the proper allocation of C credits under certification standards such as the Verified Carbon Standard (VCS) methodology (VM0033).’

3) Lines 108-112: I do not understand these statements about marine sources. Is this a reference to dilution by mineral particles? please clarify.

Response: Thanks for this comment, we have revised this statement to make it clearer in line 86-88: ‘Marine particles usually had low OC content, therefore higher sedimentation of marine particles would cause less particulate organic matter (OM) to be imported into estuarine mangroves¹².’

4) Line 168: Remove the word 'landmark'.

Response: Thanks for this comment. We have removed the ‘landmark’.

5) Table: recommend including N (No. data points) and description of data variability for each region.

Response: Thanks for this comment. We have including N and the data variability for each region in Table 1.