## Anonymous Referee #1

### General Comments

1. Overall, I find that the dataset is of general interest to the community and should be published. The first four sections are of the highest priority, whereas the section on "Further Analysis" more describes applications for future users of the dataset. Therefore, my attention is focused on the first sections to have a clear and understandable description in order to increase the possibility of many users of (and citations to) the dataset.

**Response**: We are sincerely grateful for your thorough review and constructive comments. Our point-by-point responses to each comment are provided below.

2. I have a small problem with the title because it gave me the impression that all 5085 stations have 22-year long time series. In fact, the majority of the stations have time series that are significantly shorter. What about something like: "A global GPS climate data record for 5085 stations covering up to 22 years"?

**Response**: We totally agree with your constructive suggestion, and the original title could indeed lead to unnecessary misleading and misunderstanding regarding the length of the dataset. To avoid this ambiguity while remaining faithful to the scope of the manuscript, we revise the title to:

***"A global GNSS climate data record from 5085 stations spanning up to 22 years".***

It is worth noting that we also note your subsequent comment regarding the utilisation of "GNSS" vs. "GPS": (1) regarding the revised title, we intentionally use GNSS to make it a general term, to support future applications of GNSS meteorology and climatology, and to align with the ongoing deployment of multi-constellation, multi-frequency GNSS (which is also our current work); (2) in the main text, we have standardised terminology, using 'GNSS' for multi-constellation content and reserving "GPS" only for GPS-specific contexts (see the responses below).

In addition, we have reviewed the whole manuscript to remove wording that might imply uniform 22-year coverage (like in the Abstract, Introduction, and Section 2.1), and we consistently state that the record lengths vary, using the phrase "***spanning up to a 22-year period***" throughout.

3. Early in the manuscript you make clear that only GPS data are used. Later it is however very often you refer to GNSS data. I think it is okey only when you refer to GNSS data in general terms, not when you discuss your dataset. Furthermore, in the summary section you may have some ideas to discuss the future use of GNSS (rather than just GPS), pros, and cons?

**Response**: We highly value this suggestion. In the revised manuscript,

(1) we have clearly separated contexts where GNSS is appropriate from those where GPS must be used. Specifically, as suggested, when discussing the generated dataset, detailed processing, results, and other GPS-specific contexts, we now use "GPS" consistently. We reserve the use of "GNSS" for those general statements about the field and future directions, primarily in the Introduction and Summary.

(2) In addition, since the dataset was generated using only GPS data, we have also added a few sentences to Section 7, outlining the limitations of the work and our planned new reprocessing campaign, which will incorporate multi-GNSS observations and expand the network through collaboration with regional data centres. We also briefly summarise some potential benefits

(improved satellite visibility and geometry, better temporal availability and robustness) and trade-offs (management of inter-system/inter-frequency biases, harmonisation of antenna calibrations and metadata, and ensuring cross-system consistency):

**Lines 690-697:**

"*Despite these advancements, several key challenges and opportunities for improvement remain.* ***First, while this study mainly employed GPS observations, integrating multi-GNSS systems such as Galileo, GLONASS, and BeiDou could improve satellite visibility and geometry, and may enhance spatiotemporal availability and robustness, particularly in under-represented regions like polar areas and oceans. However, as noted in Section 2.2, introducing additional constellations can impose inter-system biases and calibration complexities that may induce shifts in the time series. In other words, the net benefit is context-dependent and not yet settled. Given this, our ongoing research is conducting a new reprocessing campaign that will incorporate multi-GNSS observations using the latest Bernese V5.4 and updated tropospheric models like VMF3, while managing inter-system and inter-frequency biases, harmonising antenna calibrations and metadata, and ensuring cross-system consistency.***"

## Specific Comments

1. line 79: You state that a shortcoming of previous studies is that the length of the time series is only around 10 years. This is certainly true and climate scientists often use 30 year averages which means that the time series in your dataset suffer from the same shortcoming. In fact, many of the sites in the dataset have time series of about 10 years or less. I think it is fair to state this. The decision to use 30-year averaging periods was taken by IMO (now WMO) at a congress in 1935. Also, at line 106 you give the false impression that all time series are 22 years.

**Response**: Many thanks for your suggestion, we have made some modifications accordingly:

(1) In Section 1, we have added some sentences and two references to further elaborate on this:

**Lines 77-82:**

"*However, despite recent advances, the potential of GNSS atmospheric monitoring remains largely under-utilised in the climate community.* ***This is primarily due to the lack of robust long-term GNSS climate datasets, whereas climate applications typically require the use of datasets spanning several decades (e.g., 30-year climatological normal; WMO, 2007; Arguez and Vose, 2011). In this context, many datasets used in the aforementioned studies span only around 10 years, even if this is partly because the limited record length at many sites, such durations is still insufficient for uncovering the climate change signals embedded in these parameters.***"

(2) Please note that, as these statements are used to provide a review of previous work, so we do not refer to our dataset. Instead, we have also added several sentences in Section 7 to state the same objective limitation for our dataset:

**Lines 697-701:**

"*Second, although the generated dataset covers up to 22 years and can support climate applications,* ***it does not yet meet the "30-year" timescale typically required for climatology****, largely because most GNSS stations lack sufficiently long historical observations as stated earlier.* ***Accordingly, we aim to continuously process new data*** *streams to extend the record beyond 30 years and provide a more complete dataset*."

(3) As indicated in our response to the General Comment#2, we have revised wording that could suggest a uniform 22-year coverage, changing "covering a 22-year period 2000–2021" to "spanning up to a 22-year period 2000–2021".

***References used here:***


*[1] Arguez, A., and Vose, R. S.: The definition of the standard WMO climate normal: The key to deriving alternative climate normals. Bulletin of the American Meteorological Society, 92(6), 699-704, doi:10.2307/26218540, 2011.*

*[2] WMO: The role of climatological normals in a changing climate (WMO/TD-No. 1377, WCDMP-No. 61), World Meteorological Organization, Geneva, Switzerland, 2007.*


2. line 89: later in the manuscript you also mention changes of hardware, such as antennas and radomes. It can be meaningful to mention these also here.

**Response**: This issue has been amended in the revised manuscript:

**Lines 92-94:**

"*However, the determined ZTD time series may still exhibit inhomogeneities due to updates to reference frames and models, variations in mapping function implementations, adjustments to elevation cut-off angles, modifications to processing strategies**, and changes in hardware (such as antennas and radomes)**.*"

3. line 127: "Following a rigorous data screening process, 95 sites were excluded due to identified issues with the atmospheric results, leading to a final dataset comprising 5085 GNSS stations." It will be helpful to list these 95 sites, not in the manuscript but in the data archive, together with the reason for excluding the site. I searched for a specific IGS site, with a long time series, but could not find it among the 5085 sites included. Perhaps it is among the 95 sites? In any case it will be helpful for future users of GNSS PWV to be aware of problem sites.

**Response**: We are sincerely grateful for this insightful suggestion. Documenting the excluded sites (and the reasons) will indeed improve the utility of the archive. We are not certain which IGS site you searched, but my gut feeling is that it may be among the 95 excluded sites.

As noted in the manuscript, the dataset is hosted in two places: (1) the PANGAEA repository and (2) our online portal. As per your suggestion, we will first compile a concise list of the excluded sites (including site code, coordinates, and a brief reason for exclusion). Then, for the PANGAEA repository, we will reach out to the Editor and add the list to the archive; for our online portal, we will directly add a specific subsection for easy reference.

4. line 162: Please motivate why you chose such a low cutoff angle. For example, when searching for trends varying systematic errors are very important and should be reduced. Multipath is an effect which get worse closer to the horizon, and this is especially true if the horizon mask change over long time.

**Response**: Many thanks for raising this concern. First, we fully acknowledge that observations at low elevation angles are generally more susceptible to multipath and increased noise, particularly if the horizon mask changes over a longer period. **Our choice of a 3° cut-off elevation angle was made cautiously and is supported by multiple previous literature showing that, when appropriately weighted and modelled, including low-elevation data reduces the correlation**

**between tropospheric parameters and station height and improves the accuracy and stability of long-term ZTD estimates.** More specific justifications are summarised as follows:

(1) In GNSS data analysis, the ZTD, station height, and receiver clock parameters are proven to be strongly correlated, which can introduce significant errors into coordinate and atmospheric estimates (Rothacher et al., 1998). **Including low-elevation observations improves satellite geometry and reduces this parameter coupling**. The Bernese Software manual (Dach et al., 2015, Section 12.4) recommends using a cut-off angle **not larger than 10°** for tropospheric parameter estimation. In addition, Dousa et al. (2017) further showed that, within the second European GNSS reprocessing campaign (1996-2014) aimed at identifying the optimal strategy for estimating tropospheric parameters, **lowering the elevation cut-off angle from 10°/7° to 3° reduces parameter correlations, improves station height repeatability, and enhances accuracy, thus supporting the inclusion of low-elevation observations in long-term GNSS reprocessing**.

**(2)** Minimising the coupling between height and tropospheric parameters is particularly important for climate applications, as height variations can otherwise propagate into ZTD estimates and introduce spurious trends or seasonal signals. This explains why **recent studies report better agreement of long-term GNSS-ZTD trends with independent references when lower cut-offs are used (Bai et al., 2023)**. While Ning and Elgered (2012) noted that GNSS-ZTD trends yield better agreement with radiosonde trends at a higher cut-off angle (~25°), Bai et al. (2023) indicated that this largely stemmed from the use of unhomogenised radiosonde data. **When homogenised radiosonde trends developed by (Dai et al., 2011) or ERA5-derived trends are used, lower cut-off angles (3°–7°) yield improved consistency.**

(3) Another reason for adopting a cutoff of 3° is to **ensure consistency with the reprocessing strategy of CODE in the IGS Repro3 campaign (Dach et al., 2021), whose reprocessed orbits, clocks, ERPs, and ionosphere products are key inputs to our processing campaign**. Although low-elevation data are more susceptible to multipath and have higher noise as illustrated, their impact can be mitigated using elevation-dependent weighting, latest tropospheric models (e.g., VMF1), and strict pre-/post-processing quality-control procedures in Bernese.

To further explain the rationale behind this choice, the following statement has been added:

**Lines 166-171:**

> "***Please note that the use of a low cut-off elevation angle of 3° is based on findings from previous literature, which indicated that including low-elevation observations reduces the correlation between tropospheric parameters and station height, thereby improving the accuracy of ZTD estimates and the reliability of long-term trends (Dach et al., 2015; Dousa et al., 2017; Bai et al., 2023). Moreover, this choice also ensures consistency with strategy adopted by CODE in the IGS Repro-3, whose orbit, clock, and ERP products are used in our study as illustrated earlier (Dach et al., 2021).***"

***References used here:***

*[1] Bai, J., Lou, Y., Zhang, W., Zhou, Y., Zhang, Z., Shi, C., and Liu, J.: Impact analysis of processing strategies for long-term GPS zenith tropospheric delay (ZTD). Atmospheric Measurement Techniques, 16(21), 5249-5259, doi:10.5194/amt-16-5249-2023, 2023.*

*[2] Dach, R., Lutz, S., Walser, P., and Fridez, P.: Bernese GNSS software version 5.2. Astronomical*

*Institute, University of Bern, 858, 2015.*

*[3] Dach, R., Selmke, I., Villiger, A., Arnold, D., Prange, L., Schaer, S., Sidorov, D., Stebler, P., Jäggi, A., and Hugentobler, U.: Review of recent GNSS modelling improvements based on CODEs Repro3 contribution. Advances in space research, 68(3), 1263-1280, doi:10.1016/j.asr.2021.04.046, 2021.*

*[4] Dai, A., Wang, J., Thorne, P. W., Parker, D. E., Haimberger, L., and Wang, X. L.: A new approach to homogenize daily radiosonde humidity data. Journal of Climate, 24(4), 965-991, doi: 10.1175/2010JCLI3816.1, 2011.*

*[4] Dousa, J., Vaclavovic, P., and Elias, M.: Tropospheric products of the second GOP European GNSS reprocessing (1996–2014). Atmospheric Measurement Techniques, 10(9), 3589-3607, doi: 10.5194/amt-10-3589-2017, 2017.*

*[6] Ning, T., and Elgered, G.: Trends in the atmospheric water vapor content from ground-based GPS: The impact of the elevation cutoff angle. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 5(3), 744-751, doi: 10.1109/JSTARS.2012.2191392, 2012.*

*[7] Rothacher, M., Springer, T. A., Schaer, S., and Beutler, G.: Processing strategies for regional GPS networks. In Advances in Positioning and Reference Frames: IAG Scientific Assembly Rio de Janeiro, Brazil, September 3–9, 1997 (pp. 93-100). Berlin, Heidelberg: Springer Berlin Heidelberg, 1998.*

5. line 165: "a 27-hour time window was adopted," How was these 27 hours defined? In the paper by Dousa et al. (which you refer to) I do not find this specific value, only that three days were combined and thereafter the atmospheric estimates from the day in the middle were selected.

**Response**: Many thanks for pointing this out. We have further clarified in the revised manuscript how the 27-hour window is defined and add a new reference here. Specifically, we state that this definition follows the strategy of the United States Naval Observatory (USNO) used in generating the IGS Final Product, which generates daily normal equations with an overlapping window to improve the stability of estimates near day boundaries (Byram, 2017). It effectively reduces edge effects around day boundaries and improves the continuity of the ZTD time series. We have also adjusted the surrounding text to avoid suggesting that this originates from (Dousa et al. 2017).

**Lines 174-179:**

> "***To address this, we adopted a 27-hour time window, that comprises 24 hours from the current day and an additional 3 hours from the subsequent day. This is consistent with the strategy of the United States Naval Observatory (USNO) for the IGS Final Troposphere Product, which forms daily normal equations and improves the stability of tropospheric estimates near day boundaries (Byram, 2017).*** *These equations were subsequently combined across three consecutive days to produce a 3-day solution (Dousa et al., 2017), from which ZTD estimates for the central date were extracted, thereby enhancing the continuity and accuracy of the dataset*"

***References used here:***

*[1] Byram, S.: IGS Final Troposphere Product Update. United States Naval Observatory, Washington DC, USA. https://files.igs.org/pub/resource/pubs/workshop/2017/W2017-PS04-03%20-%20Byram.pdf, 2017*

6. line 175+: Why did you choose this rather complicated procedure to derive the ZHD. Other studies I have seen use the Saastamoinen model for the gravity with the ground pressure and the site position as input parameters which I have assumed is sufficiently accurate for the ZWD retrieval. Did you examine if there were any differences that motivate your choice?

**Response**: Thanks for your comment, here are our further explanations:

The Saastamoinen model for ZHD is based on the assumption of hydrostatic equilibrium and has long been widely used because of its simplicity and reliability. When accurate surface pressure is available, it can reach sub-millimetre uncertainty in ZHD and is indeed often adequate for many meteorological or real-time applications. However, recent studies have identified some limitations. For example, Feng et al. (2020) showed that the Saastamoinen model tends to overestimate ZHD in dry regions such as the Antarctic coast and exhibits seasonal biases over continental areas, particularly at high elevations, with typical errors of 2–5 mm (corresponding to about 0.3–0.8 mm in PWV) and a mean RMS error of ~1.7 mm when compared against radiosonde ZHD estimates.

Given that the main aim of this study is to generate a high-quality dataset suitable for long-term climate monitoring, which demands the highest possible accuracy, we then chose a more rigorous method using ERA5 pressure level fields to derive ZHD estimates. It reduces potential systematic biases that could otherwise propagate into the PWV values. This is particularly important where PWV values per se can be only a few millimetres, so a sub-millimetre error may represent a significant fraction, affecting trend analysis and the detection of climatic anomalies. Our choice is therefore informed by previous studies and the underlying theory.

***References used here:***

*[1] Feng, P., Li, F., Yan, J., Zhang, F., and Barriot, J. P.: Assessment of the accuracy of the Saastamoinen model and VMF1/VMF3 mapping functions with respect to ray-tracing from radiosonde data in the framework of GNSS meteorology. Remote Sensing, 12(20), 3337, doi:10.3390/rs12203337, 2020*

7. Section 3.3: Why do you wait until this stage by removing unrealistic negative values of the PWV. You do not need reference data for this action.

**Response**: In this processing campaign, our quality control mainly comprised three stages:

(1) daily-solution screening based on coordinate repeatability (Section 3.1)

(2) ZTD outlier detection using temporal variability and formal errors (Section 3.2)

(3) PWV screening (i.e., **Section 3.3**)

It can be found from the consecutive stages that, only those ZTDs that passed both Stages 1 and 2 were converted to PWV, after which any negative PWV values were flagged and removed in Stage 3. This is to ensure that the removal of negative PWVs was applied to a reliable ZTD time series (after ZTD screening), avoiding spurious removals caused by transient ZTD outliers or coordinate instabilities upstream. In other words, the removal of unrealistic negative PWVs, in fact, does not rely on ERA5 and was performed before the ERA5 comparison in Stage 3. This also explains why this part is described at the beginning, i.e., the first paragraph of Section 3.3.

To make this sequence explicit, we have added a clarifying sentence at the beginning of Section 3.3 noting that negative PWVs are excluded after Stages 1/2 but prior to the ERA5 comparison:

**Lines 293-295:**

> "*In the final phase, the screened ZTD estimates were converted to PWV values and further validated using ERA5-derived PWVs as a reference.* ***Before comparing with ERA5 dataset, we first performed an initial range check to remove unrealistic negative PWV values. The initial check excluded 0.16 % of the estimates.***"

8. When you remove outliers by comparing with reference data you assume that the reference data are correct. I think that needs to be discussed. From my point of view, one application of

GPS/GNSS PWV is to use it as an independent dataset in order to identify problems in other datasets, such as the ERA5.

**Response**: Thanks for putting forward this valuable comment. First, we fully acknowledge that although ERA5-PWV is often used as a reference for quality control in previous studies, doing so implicitly assumes that ERA5 is sufficiently accurate, which may not always hold, particularly in regions with sparse observational coverage, complex topography, or rapidly varying atmospheric conditions. Second, we agree that GNSS-PWV should also be taken as an independent dataset for assessing reanalyses such as ERA5.

To address this and accommodate other use cases, we now provide two versions of the final PWV dataset (supplied to PANGAEA and uploaded to our online portal. *Note that the new datasets will become publicly available after the completion of the curation/review process, which may take a short while depending on the queue*):

(1) an "unfiltered" dataset containing all GNSS-PWV estimates after internal quality control only, without any ERA5-based outlier exclusion

(2) an ERA5-screened/filtered dataset in which ERA5 is used to remove outliers as described in Section 3.3.

Providing both datasets allows users to select the version most appropriate for their applications. For example, for studies that aim to use GNSS-PWV as an independent dataset benchmark against ERA5, we recommend the unfiltered version.

A corresponding clarification has been added to Section 3.3 of the revised version as follows:

**Lines 325-331:**

> "***Additionally, it is crucial to note that although ERA5-derived PWV has been widely used as a reference in ZTD/PWV quality control, this practice implicitly assumes that the ERA5 dataset is sufficiently accurate, which may not always hold in all regions, especially where observational constraints are limited or atmospheric variability is high. To accommodate various use cases, we provide two versions of the PWV dataset: an unfiltered product that contains all GNSS-derived PWV estimates after internal quality control, and an ERA5-screened product in which ERA5 is used only to flag and optionally remove gross outliers.***"

9. Table 2: The observing periods of the VLBI stations are much longer. I understand that you do not pick up data before the start of the GPS time series but there should be data after 2018? Please explain.

**Response**: In this study, we used the IVS-combined tropospheric products generated by the GFZ Potsdam Troposphere Combination Centre, which combine tropospheric delay estimates from multiple IVS Analysis Centres. However, the publicly available products currently extend only to the end of 2018 (see the archive at CDDIS: https://cddis.nasa.gov/archive/vlbi/ivsproducts/trop/). Accordingly, our comparison between GNSS and VLBI was only limited to the period up to 2018, consistent with the temporal availability of the IVS-combined data.

As indicated above, we are still working on processing GNSS atmospheric parameters using the latest version of Bernese and to incorporate multi-GNSS observations. Once combined products beyond 2018 become available, we will revisit and extend the comparison and include the results into our future work.

10. line 420: How do you define a robust agreement? For which value of the STD is it no longer robust?

**Response**: Thanks for raising this issue. We agree that the term "robust agreement" is a bit vague without a detailed explanation. We have therefore refined the statement from two aspects:

(1) We added a new reference to justify the "3 mm" criterion, which aligns with a commonly used PWV accuracy threshold for climate applications (Offiler et al., 2010).

(2) We also replaced "robust" with "close" to be more moderate and avoid ambiguity.

Accordingly, the statement now reads:

**Lines 454-456:**

> "*Notably, 88.06 % of the sites exhibit mean differences within the range of [-1, 1] mm, and 90.80 % have STD below 3 mm,* ***with 3 mm being a commonly used threshold for PWV accuracy in climate applications (Offiler et al., 2010), demonstrating close agreement between the two sets of PWV.***"

***References used here:***

*[1] Offiler, D., Jones, J., Bennit, G., and Vedel, H.: EIG EUMETNET GNSS Water Vapour Programme (E-GVAP-II). Product Requirements Document, MetOffice, http://egvap.dmi.dk/support/formats/egvap_prd_v10.pdf, 2010*

11. Section 4.3. Is not clear to me what was the action taken after finding these changepoints. Did you modify the PWV time series in the data archive, or not? Also in this case, are you sure that some detections of changepoints are not due to problems with ERA5? A related question is if you searched for changepoints in the ZHD. If such exist, they will indirectly cause a corresponding jump/offset in the PWV.

**Response**: In this study, changepoints in the PWV series were identified and reported as metadata flags, and no adjustments were applied to the archived PWV time series. We chose not to modify the series for two reasons: First, to preserve traceability and avoid introducing model dependence, given this is a data description paper. Second, attributing a detected break to a specific source such as data processing, hardware, local environment, or the reference dataset, is non-trivial in a global product, given the currently available information.

Using a reanalysis, such as ERA5, as a reference for changepoint detection is a common practice, typically applied to difference series to reduce natural variability and improve break detectability (Ning et al., 2016; Van Malderen et al., 2020). Benchmarking/sensitivity studies further highlight method dependence and practical caveats, including tests on synthetic or reprocessed GNSS-PWV and dedicated segmentation tools (Nguyen et al., 2021; Quarello et al., 2022). Moreover, documented biases and representativeness differences in reanalyses and GNSS indicate that detections should be interpreted with caution, rather than taken as proof of an ERA5/GNSS error (Bock and Parracho, 2019; Zhang et al., 2019; Van Malderen et al., 2020; Yuan et al., 2025).

In addition, in this study, we did not run a separate changepoint search on ZHD values. However, we mention this explicitly in the revised version and keep the detected breaks as flags for users to apply their homogenisation strategies if needed. To make our intent clear, we add this in the paper:

**Lines 515-520:**

> "***For clarity, the detected changepoints are provided as flags alongside the PWV series,***

***and the archived PWV time series are not modified based on these detections. Although ERA5 is used as a reference to aid detection, it is not the actual "truth", as previous studies suggest that both reanalysis and GNSS data may contain inhomogeneities (Bock and Parracho, 2019; Zhang et al., 2019; Yuan et al., 2025). Moreover, in this study, we did not perform a separate changepoint search on ZTD, ZHD or Tm. Since PWV is derived from these parameters, any discontinuity in them can induce a corresponding offset in PWV, and we will further examine these in detail in future updates.***"

Finally, in this work, we hope to provide a transparent baseline dataset processed with a standard and widely used method. We encourage the community to apply new/advanced homogenisation and changepoint-detection methods and to share derived products tailored to specific applications; where appropriate, we will incorporating well-documented improvements in future updates/work.

***References used here:***

*[1] Bock, O., and Parracho, A. C.: Consistency and representativeness of integrated water vapour from ground-based GPS observations and ERA-Interim reanalysis. Atmospheric Chemistry and Physics, 19(14), 9453-9468, doi:10.5194/acp-19-9453-2019, 2019.*

*[2] Ning, T., Wickert, J., Deng, Z., Heise, S., Dick, G., Vey, S., and Schöne, T.: Homogenized time series of the atmospheric water vapor content obtained from the GNSS reprocessed data. Journal of Climate, 29(7), 2443-2456, doi:10.1175/JCLI-D-15-0158.1, 2016*

*[3] Van Malderen, R., Pottiaux, E., Klos, A., et al.: Homogenizing GPS integrated water vapor time series: Benchmarking break detection methods on synthetic data sets. Earth and Space Science, 7(5), e2020EA001121, doi:10.1029/2020EA001121, 2020.*

*[4] Nguyen, K. N., Quarello, A., Bock, O., and Lebarbier, E.: Sensitivity of change-point detection and trend estimates to GNSS IWV time series properties. Atmosphere, 12(9), 1102, doi:10.3390/atmos12091102, 2021.*

*[5] Quarello, A., Bock, O., and Lebarbier, E.: GNSSseg, a statistical method for the segmentation of daily GNSS IWV time series. Remote Sensing, 14(14), 3379, doi:10.3390/rs14143379, 2022.*

*[6] Zhang, Y., Cai, C., Chen, B., and Dai, W.: Consistency evaluation of precipitable water vapor derived from ERA5, ERA-Interim, GNSS, and radiosondes over China. Radio Science, 54(7), 561-571, doi:10.1029/2018RS006789, 2019.*

*[7] Yuan, P., Blewitt, G., Kreemer, C., et al.: A global assessment of diurnal discontinuities in ERA5 tropospheric Zenith Total Delays using 10 Years of GNSS data. Geophysical Research Letters, 52(5), e2024GL113140, doi:10.1029/2024GL113140, 2025.*

## Technical Corrections

1. I find that the font size in all figures is unnecessarily small. The size could in general be say 50-100 % larger in order to improve the readability.

**Response:** Thanks for your suggestions. Almost all the figures have been replotted/further refined in the revised version. Please see the uploaded manuscript.

2. line 11: GPAC is not explained

**Response:** Many thanks for pointing this out. GPAC actually refers to our joint research centre. In the revised version, we spell out and define the acronym at first mention in the main text:

**Lines 112-113:**

"*This reprocessing campaign, **led by the GNSS data processing for Positioning, Atmosphere, and Climate research centre (GPAC) and hereinafter referred to as "GPAC-Repro"**, adopted precise satellite orbit, xxxxxx.*"

Regarding the Abstract, to avoid misleading, we have also refined the sentence in line 11:

**Lines 10-12:**

> "*This work presents a comprehensive global GNSS climate data record derived from 5085 stations, spanning up to a 22-year period 2000–2021. The dataset was generated using the state-of-the-art processing methodologies and precise products from the International GNSS Service (IGS) Repro-3 initiative.*"

3. line 34: please explain "data gaps". Are the gaps temporal or spatial or both?

**Response:** Thank you for raising the comment. We now clarify that the data gaps are both spatial (sparse coverage) and temporal (short or interrupted records). The sentence has been revised to:

**Lines 33-34:**

> "*Despite global efforts spanning several decades, considerable **spatial and temporal data gaps** remain in the existing climate observing networks.*"

4. line 53: changes in signals --> changes in the arrival time of the signals.

**Response:** Amended in the revised version.

5. line 57: With used together --> When used together

**Response:** Amended in the revised version.

6. Figure 2: use more different colours of the different symbols, both in the a and in the b graph. The present version is useless to see the differences, only the distribution of sites on the globe is clear. Also, I wonder if "data integrity" is identical to "data completeness" in the summary file downloaded from the archive? If so, use the the same expression at both places.

**Response:** Many thanks for your advice.

First, we have replotted Fig.2 using a higher-contrast and clearer symbol styling, hence differences between categories are easier to discern. It is noted that because data length and data completeness are continuous fields, we still maintain a single-hue gradient (with increased contrast and refined breaks) rather than entirely disparate colours, which is common practice for conveying monotonic variation. The revised figure also improves legibility for regional analyses for future users (longer records and higher completeness are now more apparent at a glance).

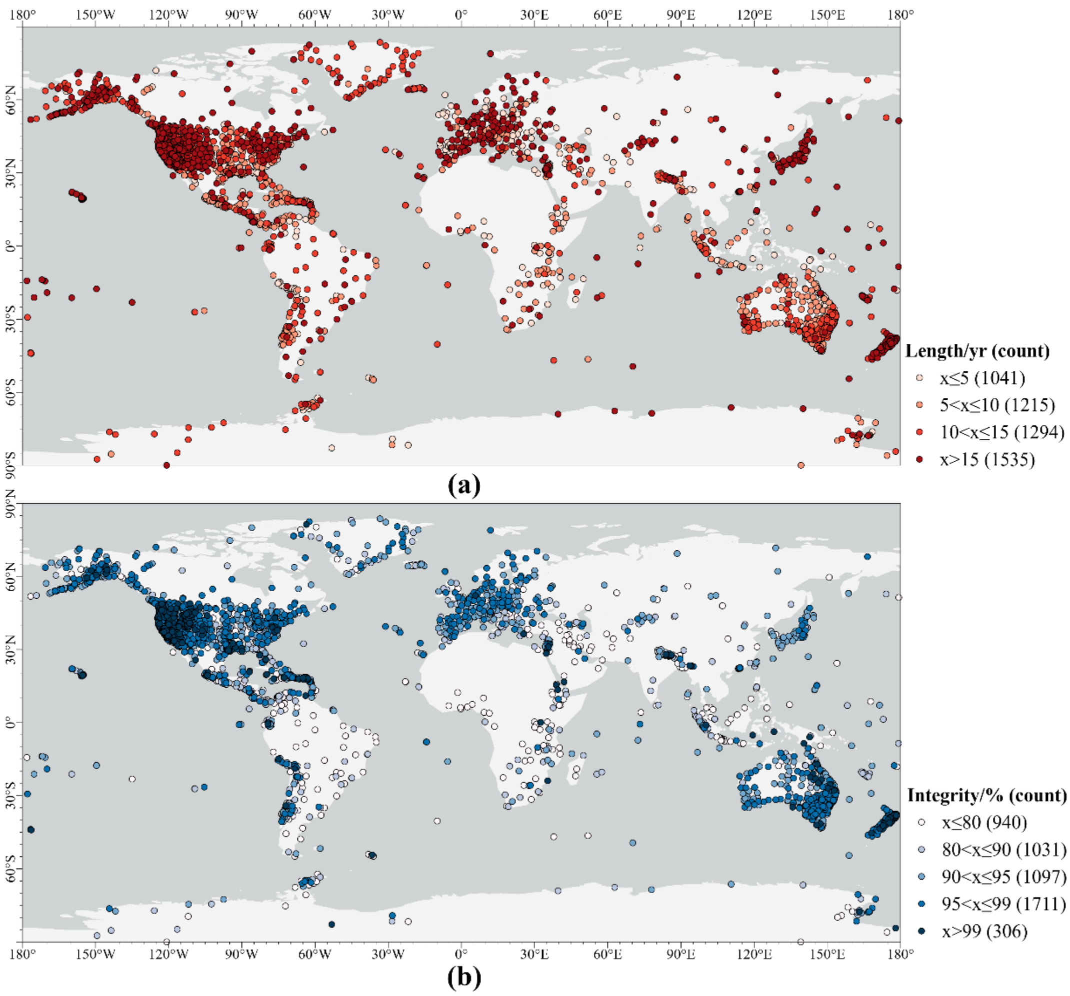



Figure 2. Recorded length (a) and data integrity (b) of the generated GNSS climate dataset across the 5085 stations

Second, data integrity was indeed intended to represent data completeness. We now harmonise the terminology across the manuscript (in Sections 2.1, 4.2, and 5.2) to data integrity for consistency.

7. lines 137, 141: Because you use British English spelling for "vapour" it will be consistent to write "colour".

**Response:** Many thanks for your meticulous review. We have gone through the whole manuscript and standardised spellings to British English throughout.

8. lines 139, 303, 309, 406, 420, 427, 468, 492, 499, 607: there shall be a space between value and unit according to SI standards.

**Response:** Thanks for your reminder. We have corrected the spacing between values and units in all instances. In addition, other similar issues in the paper have also been refined accordingly.

9. Table 1: If you include the citations in the strategy column you can shorten the running text significantly.

**Response:** Thanks for your suggestion. We have refined Table 1 to include the citations directly in the column and polished the following text accordingly.

**Table 1. Modelling features and corrections adopted in the GPAC-Repro campaign**

| Item | Strategy |
|---|---|
| Observations | GPS L1 and L2 observations with a 300 s sampling rate |
| Orbit/Clock/ERP | Products from CODE Repro-3 campaign (Dach et al., 2021) |
| Sub-daily EOP model | High frequency pole model (Desai and Sibois, 2016) |
| Gravity field model | EGM2008 up to degree and order 12 (Pavlis et al., 2012) |
| Solid Earth Tides, Solid and Ocean Pole Tides | IERS Conventions 2010 (Petit and Luzum, 2010) |
| Ocean Tide loading | FES2014b ocean tide loading model (Lyard et al., 2006) |
| Atmospheric tides | Not applied |
| Nontidal loadings | Not applied |
| Ionosphere | First-order effect was eliminated by forming the ionosphere-free linear combination, high order ionosphere (HOI) effect was corrected using CODE global ionosphere model |
| Cut-off elevation angle | 3° |
| Antenna model | igsR3_2077 mode for receiver and satellite phase centre offsets and variations |
| Mapping function | VMF1 (Boehm et al., 2006) |
| Priori hydrostatic delay | VMF1 (Boehm et al., 2006) |
| Troposphere gradient models | The Chen-Herring gradient model (Chen and Herring, 1997) |
| Troposphere-estimated parameters | ZTD (1 hour) and horizontal parameters (24 hours) |
| Solution type | Precise Point Positioning (PPP) |
| Data Span | Long-arc solutions include the data from three days, combined on normal equation level, ZTD and gradient parameters are extracted from the middle day |

10. lines 176, 190, 328: Units shall not be in italics.

**Response:** Amended in the revised version.

11. Eq. (4): will be more clear if it is split into two equations. Furthermore, the cosine function shall not be written in italic font.

**Response:** Many thanks for your valuable suggestion, these issues have been amended. Given the renumbering, we have also updated all subsequent equation references throughout the manuscript.

$$g_s \approx 9.80620 \cdot \left(1 - 0.0026442 \cdot \cos(2\varphi) + 5.8 \cdot 10^{-6} \cdot \cos^2(2\varphi)\right) \quad (4)$$

$$R_s = 6378.137/(1.006803 - 0.006706 \cdot \sin^2(\varphi)) \quad (5)$$

12. line 205: improve the contrast between font and background colour.

**Response:** Thanks for your suggestion. This figure has been replotted in the revised version:

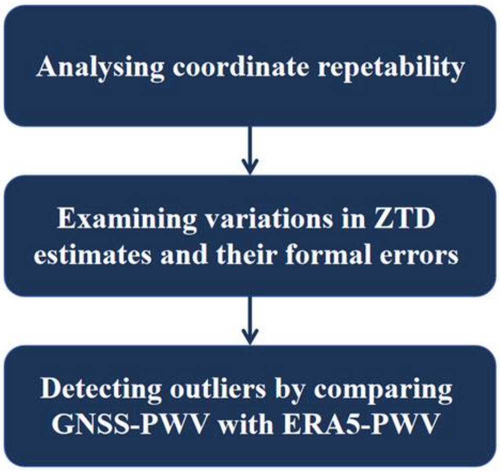



Figure 3. Flowchart of the multi-step data screening approach

13. Figure 4: Also, in this figure it is difficult to see the different colours.

**Response:** Thanks for your reminder. This figure has been replotted:

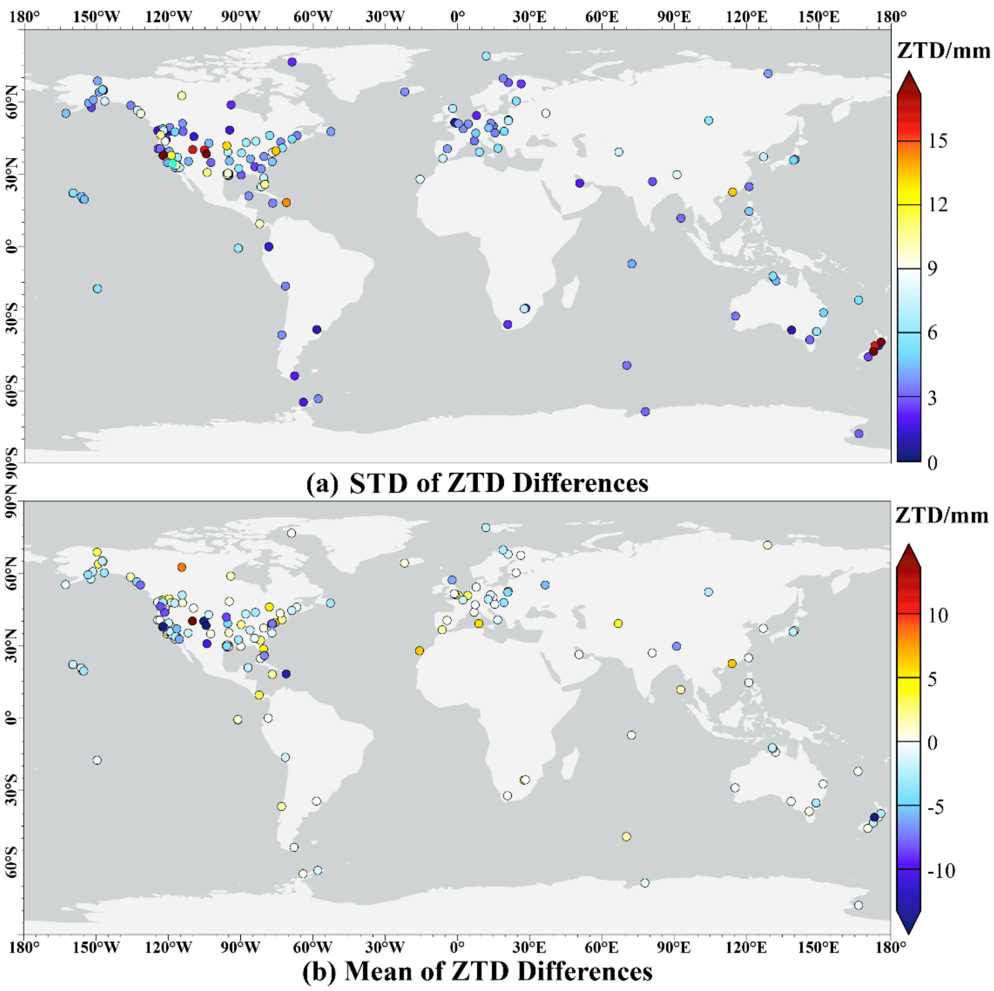



Figure 4. STD and bias in ZTD at 390 pairs of co-located GNSS stations

14. line 239: These stations are referred to as MDO1, MDO2, and MDO3 in Figure 5 (not MGxx).

Furthermore, when you show examples in the manuscript, I think it will be informative if you added where the stations are located. It will save the work of going into the data archive.

**Response:** Thanks for pointing this out, and we truly apologise for making this careless mistake. We have made the following corrections:

(1) After a careful double-check, we found that the station codes in the main text are correct (i.e., MDO1, MGO2, MGO3). However, the labels shown in Figure 5 were incorrect (i.e., MGxx). Given this, we have re-plotted Figure 5 with the correct station codes to ensure its accuracy

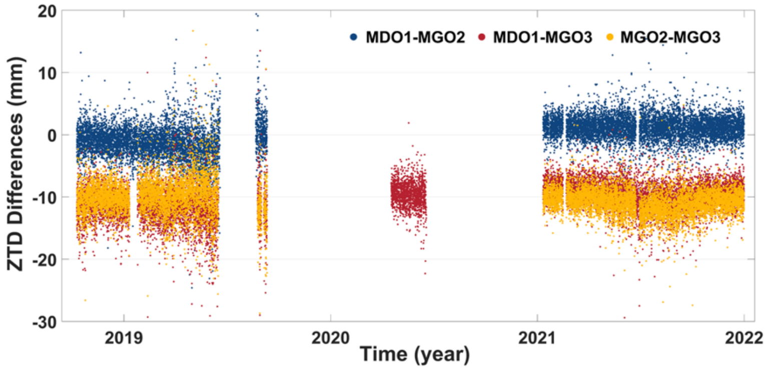



Fig. 5 ZTD differences among three pairs of co-location stations in Texas, USA: MDO1–MGO2 (blue), MDO1–MGO3 (red), and MGO2–MGO3 (yellow)

(2) We now state where these stations are located in the main text and the captions. We indicate the region (Texas and Colorado, USA) and provide representative coordinates:

**Lines 262-269:**

*"**As illustrated by three co-located GNSS stations in Texas, USA (30.68° N, 104.01° W) in Fig. 5**, xxxxxx. Another common source of discrepancies, as mentioned before, is errors in recording receiver or antenna types, often due to human errors. **As illustrated by two pairs of co-located GNSS stations, i.e., PUB1 vs. PUB2 and PUB5 vs. PUB6, in Colorado, USA (38.29° N, 104.35° W) in Fig. 6**, xxxxxx."*

15. line 292: "with 95 problematic sites" indicates that these are included among the 5085 sites. Please rewrite.

**Response:** We have rephrased this sentence in the revised manuscript:

**Lines 322-324:**

"*After completing the rigorous multi-step data screening process, the final dataset comprises 435.65M hourly PWV samples from 5085 sites, **i.e., with 95 sites excluded as problematic and 1.09M hourly samples removed as outliers from the initial set of 5180 stations.***"

16. Figure 11: Also, this Figure is difficult to get any useful information from Are all these radiosonde stations used? I mean is there a GPS site close enough. Perhaps increase the size of the graph and make the VLBI symbols larger? Or delete the figure?

**Response:** Many thanks for your feedback. This figure has been removed from the manuscript, as the essential information is conveyed in the accompanying text and subsequent figures. In addition, the figure numbering has been updated throughout accordingly.

17. Figure 14: the quality should be improved so that it is clear where the GPS sites are located. Perhaps these graphs are not needed as well? Everyone interested for sure knows the topography of Hawaii and the Andes.

**Response:** Thank you for the suggestion. After careful consideration, we have removed this figure from the manuscript. We have also updated the figure numbering throughout to reflect this change.

18. lines 406-407: Is this true solar time, local time, or UT?

**Response:** Thank you for pointing this out. The daytime/night-time windows refer to local time. We have revised this statement to:

**Lines 437-438:**

"*each date must include at least one observation during both daytime (08:00–18:00, local time) and nighttime (18:00–20:00, local time).*"

19. line 464: You can add "radomes" here.

**Response:** This sentence has been revised to:

**Lines 499-501:**

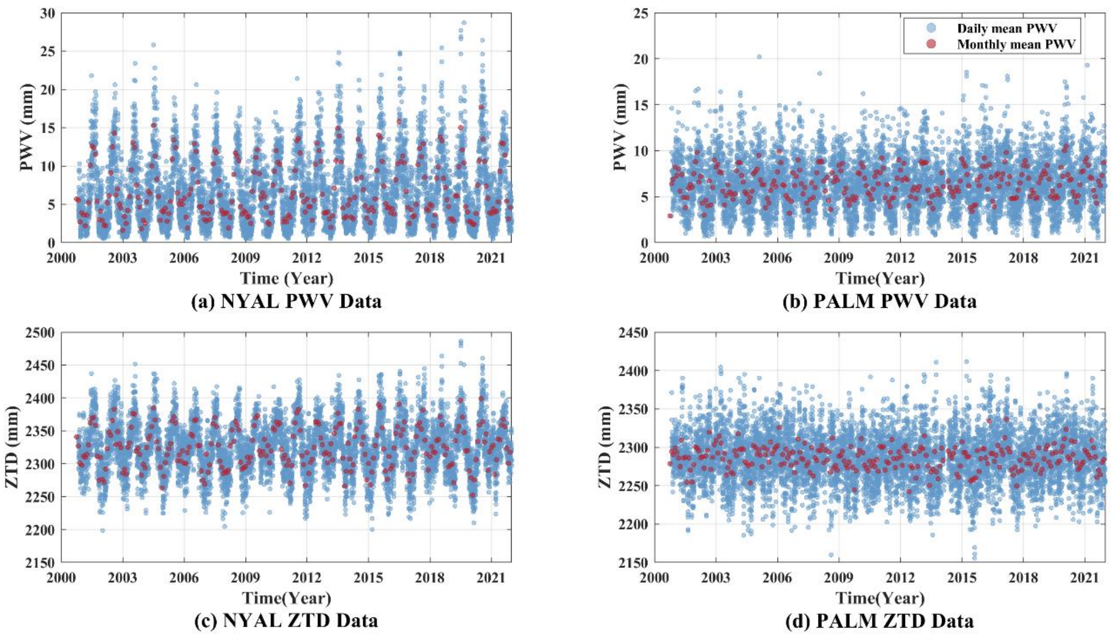
"*Despite the fact that GNSS reprocessing eliminates changepoints caused by inconsistencies in data processing strategies, **the determined PWV time series may still include offsets introduced by receiver, antenna or radome replacements, and observation environment changes.***"

20. line 491: Equator --> equator.

**Response:** Amended in the revised version.

21. Figure 18: Improve the contrast between the symbols, e.g., light green for daily values and black for monthly values.

**Response:** Thanks for your suggestion. The figure has been replotted in the revised version



(a) NYAL PWV Data (b) PALM PWV Data (c) NYAL ZTD Data (d) PALM ZTD Data

Figure 18. Time series of daily and monthly mean PWV and ZTD values at the NYAL and PALM sites over the study period

22. Figures 20 and 21: Colour only areas around the GPS sites, say with a radius of 10-20 km?

**Response:** Many thanks for your advice.

First, we do agree that the PWV over a GNSS station is often representative of conditions within a limited footprint, say a radius of 10–20 km as suggested. We also fully recognise that the current maps convey a broad, qualitative picture rather than fine-scale structure. In practice, however, site coverage over the study region (west coast of the US) is uneven and relatively sparse, after testing buffers from 10 km up to 50 km, colouring only the immediate surroundings of stations produced highly fragmented speckled maps that were difficult to interpret at the regional scale. Second, we note that some previous studies, such as (doi:10.5194/essd-15-723-2023, Fig. A1), have also used similar region-scale renderings even when site numbers are limited and their spatial distribution is uneven. For these reasons, we have retained the present rendering to preserve readability at map scale.

To address your concern, we have also made two concrete changes: (1) We now mask ocean areas (as per the other reviewer's suggestion), and (2) add a few sentences in the text to explicitly state the limitations and recommend that fine-scale analyses be carried out over smaller domains with denser networks.

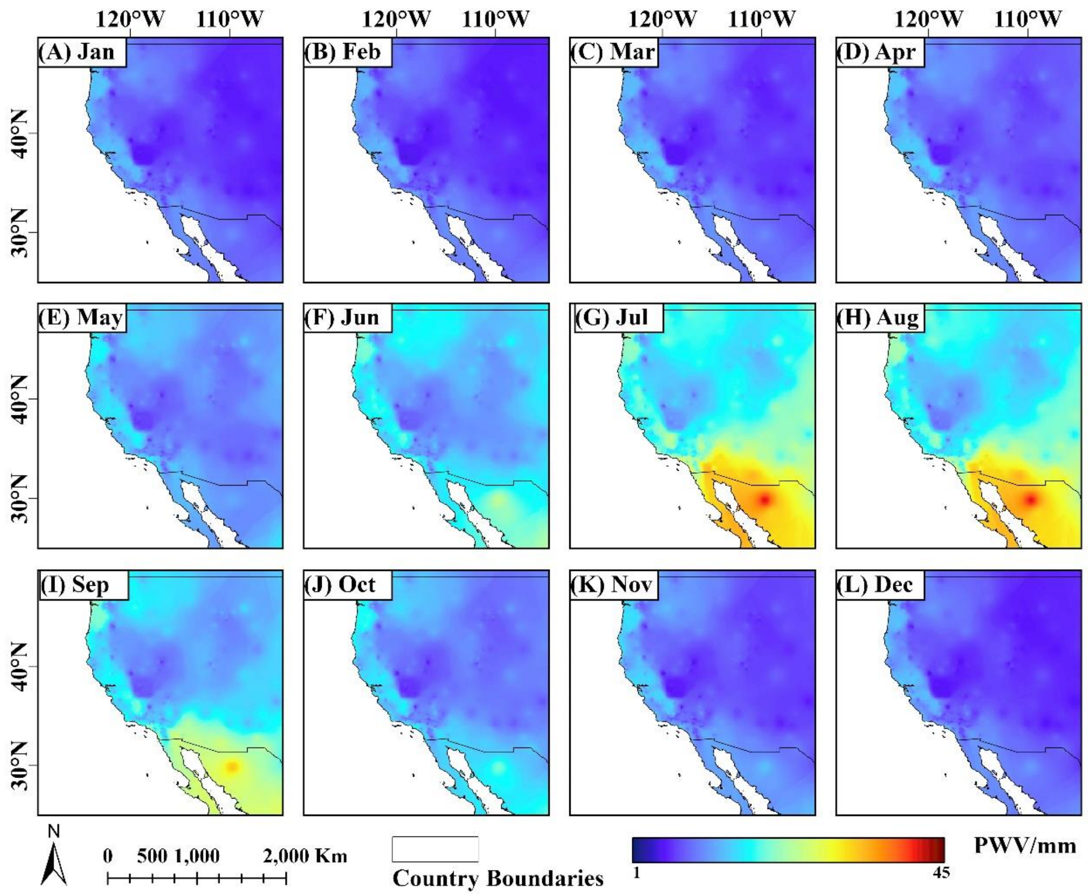



Figure 20. Rendered images of the 16-year climatological monthly mean PWV values for each month, derived from 590 GNSS sites located on the West Coast of the United States.

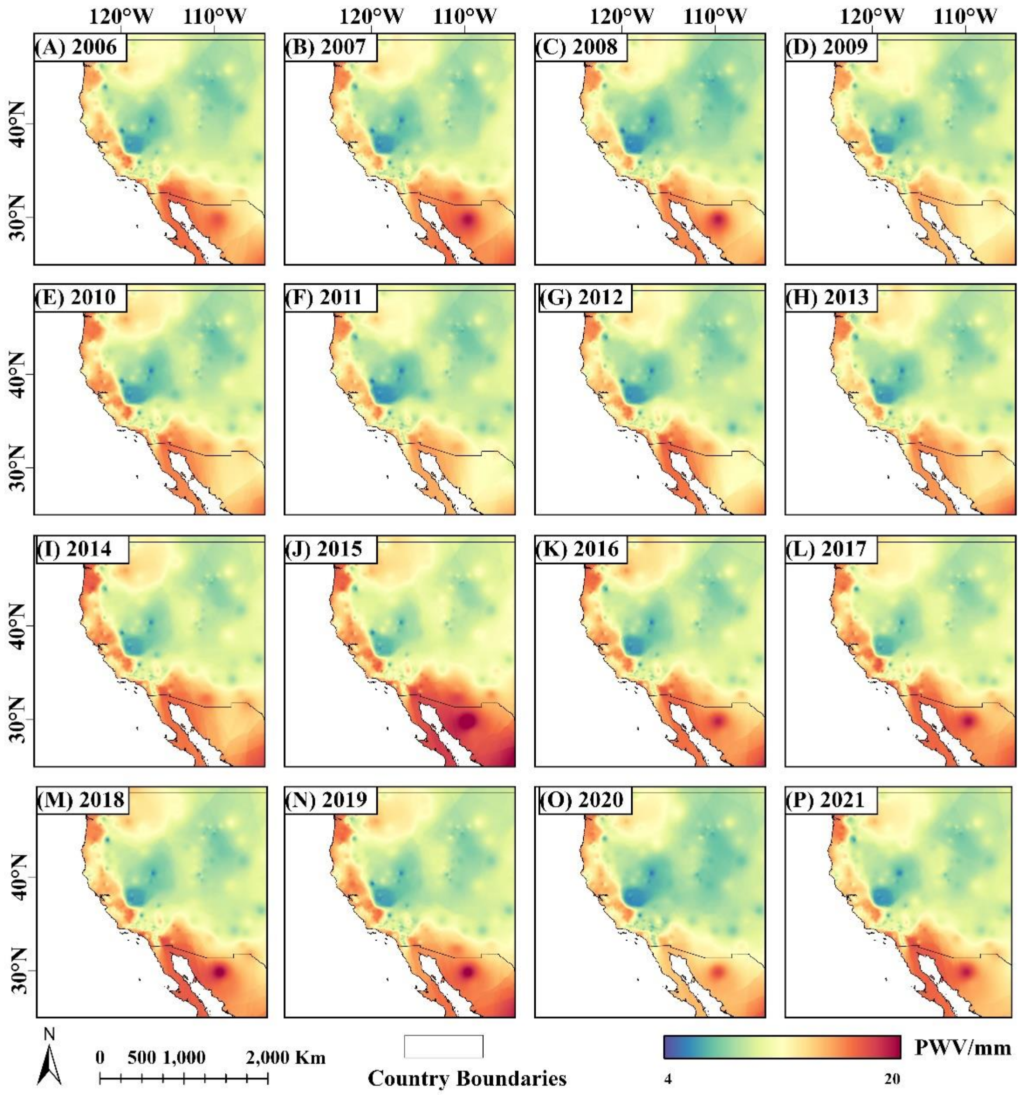



Figure 21. Rendered images of the annual mean PWV values for each year over the 16-year period 2006–2021, calculated from 590 GNSS sites located on the West Coast of the United States.

**Lines 613-615:**

"***Notwithstanding, this figure is mainly intended for regional-scale visualisation and qualitative analysis, given the uneven station spacing, they should not be interpreted at fine spatial scales.***"

**Lines 635-636:**

"***As with the monthly fields, the rendering is also qualitative at sub-regional scales. Users seeking local detail in future applications should restrict analyses to smaller areas with denser network coverage.***"

23. line 571: Northern Hemisphere --> northern hemisphere.

**Response:** Amended in the revised version.