

Reviewer 1

The manuscript “AQUA v1: The Application for QUality Assessment for the Climate Change Adaptation Digital Twin” by Nurisso et al. the first part of a new software package (AQUA) that facilitates monitoring and evaluation of simulations performed by the Climate Change Adaptation Digital Twin of the Destination Earth initiative. The manuscript focuses on the description of the underlying code philosophy, code structure and core functionalities of AQUA and provides some examples about AQUA's data handling performance.

The manuscript is very well written and well structured, and it provides the necessary information to understand the structure of the software without going too deep into technical details. The topic of the manuscript lays clearly within the scope of GMD, and the new software could potentially be of interest to a substantial part of the climate modeling and Digital Twin community. There are, however, a few things that I would like to see addressed/discussed to help the reader better understand the work that has been done and what the novel parts of the work are.

I recommend the publication of the manuscript after revisions.

We thank the reviewer for the kind words about the relevance of the manuscript for the climate modeling community. We appreciate in particular the comment about the level of technical details included in the paper, which required important planning while structuring the paper.

We've addressed the recommendations listed below, together with, where available, updates which are already part of the final code and presenting in the conclusions new implementations that will soon be part of the main code.

Comments/recommendations:

- I understand that the software was created with the monitoring and evaluation of simulations from ClimateDT with its specific requirements and needs in mind. The authors explain that AQUA could potentially also be used to evaluate simulations from CMIP or CORDEX. There are several other software packages around (some of them are mentioned in the introduction of the manuscript), however, that are used to do exactly that, and successfully doing so. If it is indeed a near-term goal of AQUA to be used for simulations from these projects then I would want to see a much more detailed discussion where AQUA would fit in the landscape of these already existing software packages, where the overlap between these packages and AQUA are, and where AQUA is unique. If this is not a near-term goal of AQUA to evaluate the simulations from these projects then I think the discussion of AQUA should be more clearly focused on the capabilities of AQUA with respect to evaluating simulations from ClimateDT.

Yes, the software was initially forged around the needs of the online monitoring for the ClimateDT. The possibility to open and analyse data from CMIP and CORDEX simulations is in the near-term motivated by the need of comparing the ClimateDT results with other communities (e.g. the HighResMIP experiments).

However, we envision the usage of AQUA as not limited to some comparison of ClimateDT data. The software can be highly beneficial to models which are in the development phase, for which the entire CMORization of data is not yet available but a monitoring framework is required. A recent example has been the EC-Earth4 model development, where AQUA has been used aside other tools to provide support during the tuning process. Additionally more projects dealing with km-scale models and complex workflows such the European Eddy-Rich ESMs (EERIE) and the DE_393 (Development and Implementation of Climate Emulator for Destination Earth) projects are currently undergoing and are starting to leverage AQUA for the model evaluation. Being focused on high resolution data, in this perspective AQUA greatly complements the capabilities of other diagnostic suites.

Finally different observational dataset start to have versions available on bucket as Zarr chunked data or ARCO dataset. We believe the capability and flexibility to open and work with those datasets is of general interest and not limited to the ClimateDT community.

- AQUA is software package that is added to a collection of already existing software packages that do similar things (although not specifically focused on the evaluation of data from ClimateDT). What are AQUA's plans to interact with the rest of the evaluation community? What priorities do the AQUA developers have with regards of sharing efforts with the rest of the community to avoid development duplications?

On the relevance of this point we completely agree with the reviewer: the interaction with other existing software packages is a priority for AQUA. The modularization of the code allows for having different possibilities to interact with other software packages: modules like the Fixer could be beneficial for other software as well, allowing a seamless metadata handling without duplicating the code. At the same time a module of AQUA could be substituted with features provided by other codes. AQUA can provide a layer of data access to run other diagnostics tools, and, despite not being part of this specific manuscript, the diagnostics suite is flexible and might be extended by incorporating external diagnostics to avoid reinventing the wheel.

A strong contribution to the software community could be to enhance the WMO GRIB to CMOR compatibility. It is of our interest to develop the possibility to open the ClimateDT data as CMOR-like data, so that the climate community could not only work with the usual software, but with the standard metadata format.

The focus of AQUA is intended to be on the high resolution data access, with the specialization of Zarr or cloud data access and the management of HEALpix grids. This setup is now the standard of the km-scale community, as shown in the recent km-Scale Hackathon 2025.

More ambitiously, the integration of the AQUA code with a selected list of diagnostics in the REF would be a great contribution to the software packages. This is envisioned by our team and development of new features takes into consideration this possibility and we hope to have the opportunity to proceed along this path with the support from the specific projects.

- The authors have stressed the fact that AQUA is based on the WMO GRIB standards. However, the example of the smmregrid code performance is based on netCDF files. Would it not make sense to base this performance test on GRIB data?

AQUA is based on the WMO GRIB2 when we refer to the metadata convention. This means that we refer to the GRIB2 tables and the WMO definitions to define a variable's metadata. However there is no assumption on the data format required by AQUA, since it can work with whatever data format is ingested by intake and opened as a xarray dataset. For this reason we didn't involve GRIB data on our smmregrid test, but only netCDF files. We've better explained the difference between the two concepts while introducing the WMO GRIB2 metadata convention in the manuscript.

More specific comments:

- Line 65: Spelling of "EsmValTool" should be "ESMValTool"

Thanks, this has been corrected in the revised version of the manuscript.

- Line 85: In the sentence "The Application for QUality Assessment (AQUA) is a Python3 package specifically tailored to address this challenge" it would be good to mention (again) that you refer to version 1 of AQUA (as stated in the manuscript title but not anywhere else)

We've added the specification of the version (1.0.0). We will also update the title to match the specific details of the version that will be released upon resubmission.

- Line 88: "Paper II" is mentioned here and in some other parts of the manuscript, but this paper is not mentioned in the literature or in more detail in the text. I guess this paper is planned, but not in a stage yet to be referenced with more details. But if this is the case, I would recommend to mention in the text ONCE that this paper is planned and what the content of the paper will be, and then remove the rest of the references to this paper since it is not clear when it will be available.

We removed as suggested the mentions to the Paper II in the text and left only a mention of a companion manuscript at the end of the introduction. The manuscript is very close to submission but indeed not mentioned in the literature yet.

- Line 176: "variables metadata" should be "variable metadata"?

Thanks, this has been corrected in the revised version of the manuscript.

- Line 202: "dataset" should be "datasets"?

Thanks, this has been corrected in the revised version of the manuscript.

- Line 291: "the coordinates nature" should be "the coordinates' nature"?

Thanks, this has been corrected in the revised version of the manuscript.

- Line 309: "and a metadata" should be "and metadata"?

Thanks, this has been corrected in the revised version of the manuscript.

- Line 343: “to generate in highly efficient and modular” should be “to generate in a highly efficient and modular”?

Thanks, this has been corrected in the revised version of the manuscript.

- Line 396: The sentence “The computations have been done 3 times and the results presented average the times” seems redundant since very similar text is present in the paragraph before.

The sentence has been removed from the final text.

- Line 416: What do the authors mean with the sentence “It should be noted that Polytope is also sensitive to bandwidth, as it is based on remote access”? Does it mean that accessing the data as soon as it is the Data Lake is harder and slower? But is that not the whole point of doing analyses on data that span several years and not just the most recent month?

In the new version of the manuscript we better specify the difference among local FDB and Polytope access. The FDB access happens on the same machine as the data and it is available only to the team part of the ClimateDT computational project. For this reason it is inevitably faster than any remote access. The Polytope access, on the other side, needs to query a remote machine, the Data Lake, and then download chunks of data as GRIB format on the local machine. For this reason we mentioned the bandwidth as a limiting factor and possible bottleneck depending on the machine in which the evaluation is performed.

- Line 512: “CORDE” should be “CORDEX”?

Thanks, this has been corrected in the revised version of the manuscript.

- Line 517 to 521: In my opinion this last paragraph is aiming too high. There are novelties to AQUA in comparison to other software packages, but claiming that AQUA can be seen as a blueprint for future software packages that are “grounded in solid engineering, adapted to the new data landscape, and committed to enabling scientific progress” implies that all other software packages cannot provide any of this. And that is not correct. I would strongly recommend to carefully rephrase this paragraph.

The last paragraph has been rephrased and the statement has been toned down as suggested. We stress the goal of interoperability and comparison among different modeling communities. Additionally we better explain our vision on the contribution of AQUA in the landscape of analysis tools, with a better perspective on collaboration among them (e.g. developing modular parts of the code which can be useful for other tools or integrating already developed solutions in order to avoid duplication of effort).

- Figure 4 figure heading: “the different dataset” should be “the different datasets”?

Thanks, this has been corrected in the revised version of the manuscript.

Reviewer 2

This manuscript introduces AQUA v1 (Application for QUality Assessment), a Python-based framework developed within the Climate Change Adaptation Digital Twin of the Destination Earth (DestinE) initiative. The tool is designed to support the automated evaluation of kilometer-scale, high-resolution global climate simulations.

The paper is well-written and represents an important contribution to the community by providing a useful tool for high-resolution climate model evaluation. The authors provide a good amount of detail, specifically focusing on the architecture and core functionalities of the AQUA core, which effectively handles data ingestion, standardization, and pre-processing.

A major strength of this work is the strategy presented in the package design. The manuscript demonstrates a reasonable degree of thought regarding the flexible and modular use of the package. By building on widely adopted Python libraries, AQUA successfully delivers a modular infrastructure that allows for scalable, out-of-core computations and handles data access across varying formats. Furthermore, its ability to integrate into automated workflows and user-defined pipelines makes it highly valuable for both operational and research-oriented applications. As an open-source, actively maintained framework, it is well-positioned to serve as a community tool that ensures interoperability, usability, and reproducible climate data analysis across different projects and institutions.

Overall, this manuscript provides a thorough and well-designed contribution to the climate modeling community. I have a few minor comments and technical suggestions detailed in the next section. Therefore, I recommend that the paper is acceptable for publication after the authors address the points raised in the specific comments below.

We thank the reviewer for finding our manuscript an important contribution to the community. We've addressed the comments listed below and answered them individually when more explanation was needed. Together with these comments, we've updated the text for features which are now part of the code or to an updated stage with respect to the original draft.

Specific comments:

Line 44: Please consider including the following reference for CMOR, which is the following one.

Mauzey, C., Doutriaux, C., Nadeau, D., Taylor, K. E., Durack, P. J., Betts, E., Cofino, A. S., Florek, P., Hogan, E., Rodriguez Gonzalez, J. M., Kettleborough, J., Nicholls, Z., Ogochi, K., Seddon, J., Wachsmann, F., & Weigel, T. (2026). The Climate Model Output Rewriter (CMOR) (3.14.3). Zenodo. <https://doi.org/10.5281/zenodo.19869925>

Line 66: Please use the representative reference paper for the PMP: Lee, J., Gleckler, P. J., Ahn, M.-S., Ordonez, A., Ullrich, P. A., Sperber, K. R., Taylor, K. E., Planton, Y. Y., Guilyardi, E., Durack, P., Bonfils, C., Zelinka, M. D., Chao, L.-W., Dong, B., Doutriaux, C., Zhang, C., Vo, T., Boutte, J., Wehner, M. F., Pendergrass, A. G., Kim, D., Xue, Z., Wittenberg, A. T., and Krasting, J.: Systematic and objective evaluation of Earth system models: PCMDI Metrics Package (PMP) version 3, *Geosci. Model Dev.*, 17, 3919–3948, <https://doi.org/10.5194/gmd-17-3919-2024>, 2024.

The two citations have been added to the final version of the manuscript.

Lines 65-73: Those two paragraphs are shorter than others, maybe they could be merged into one paragraph?

We have merged the two paragraphs as suggested by the reviewer.

Lines 162-165: The authors note that the analysis performed with the integrated diagnostic suite will be covered in a separate publication ("Paper II"). While it is understandable that the detailed analysis is reserved for a future paper, the manuscript would be significantly strengthened by providing a brief overview or a high-level summary of the specific diagnostics currently considered or implemented in AQUA. Even a concise description or a bulleted list of key metrics and diagnostic categories would give readers a clearer, more immediate understanding of the package's practical capabilities.

We included in this paragraph a brief sentence of the available diagnostics, without going into details or providing a full list. The explanation on how the diagnostics are designed will be one of the important points of the companion paper, so that a more detailed description of the available diagnostics will be available in that paper with adequate context about the design choices.

Lines 517–521: The authors set an excellent and ambitious vision for AQUA to serve as a "blueprint for next-generation climate data analysis software." To further strengthen this concluding point, it would be highly beneficial to explicitly contextualize AQUA within the existing landscape of open-source, community-driven climate analysis packages. Since several successful community tools already share a similar open philosophy, briefly acknowledging these established frameworks would provide valuable context. This would help clarify how AQUA builds upon or uniquely complements existing efforts, making the manuscript's conclusion even more impactful.

We have modified the last paragraph and toned down the statement according to this comment. As now explained in the new version of the manuscript, one goal of AQUA is to allow interoperability among different projects. At the same time the modular nature of the code allows to expand or adapt a specific part of the codebase in order to be useful for other tools as well as ingest other modules provided by other tools, enhancing the collaboration among different codes. Additionally, as it will be described in detail in the Paper II, is it a possibility of aqua-diagnostic to eventually use diagnostics already available in the analysis packages ecosystem, with the goal of synergizing with other tools rather than duplicating the effort.

Editor

Could you please have a look at the "code and data availability" section, considering the long-term availability of the data and code underpinning this publication?

In particular,

- Please clarify the difference of the AQUA DOI reference to the version used in the paper and the github repo containing the latest version.

We have clarified the distinction between the two references in the manuscript. The DOI refers to the immutable AQUA v1.0.0 release used for the analyses presented in this paper, while the GitHub repository contains the actively maintained and subsequently developed versions of the code.

- Can you store the code for Fig. 5 and 6 in Zenodo as well to ensure that the code remains accessible in this unchanged version on the long term? There seem to be a referenced spreadsheet containing results, please take care that this data is also preserved.

We have archived the code used to produce Figs. 5 and 6, together with the associated results/spreadsheet, in Zenodo. The manuscript has been updated accordingly. The original high-resolution Climate DT data used to produce these results are not redistributed in the repository, as their access is subject to the Climate DT data access policy. The manuscript now provides instructions for accessing these data through the Polytope service.

We want to report that we also changed:

- The order of the affiliation for the first author in order to represent the present institution in which the first author is currently working. The number has been changed for the other authors accordingly.*
- We moved part of the acknowledgements, mentioning the project supporting the software development to the financial support section and expanded the acknowledgements thanking the project and the anonymous referees.*
- We removed the disclaimer section since the text was a duplicate of what is now present in the financial support section.*