Response to Reviewers

Manuscript No.: **hess-2023-299-R1**

Title: **Long-term monthly prediction of precipitation isotopes over Southeast Asia using various machine-learning techniques**

Type of the Manuscript: Article

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Dear Editor-in-chief of the Hydrology and Earth System Sciences journal

Thank you so much for the first round of review of our manuscript. Here **the** manuscript has been revised completely based on the comments of the communities and reviewers. Please find the comments in red **italics**, and **the** written response to the comments in black. (Please consider that important items are shown in **bold**).

Reviewer#2

The manuscript (hess-2023-299) compares the performance of a bunch of machine learning models in simulating the variation of precipitation stable isotope composition using monthly precipitation stable isotope records from six GNIP stations from SE Asia. The application of machine learning methods in hydrological modelling is a rapidly developing research direction. This is also true for the modelling of precipitation stable isotope compositions. Thus the work is timely and of interest. However, the manuscript still needs considerable revision to reach publication. One of my main problems with the manuscript is the lack of a scientific discussion. Section 4 in the current stage hardly goes beyond the description of the results. The other critical issue is the illustration material. Most of the figures and tables needs additional careful editing.

Response: Firstly, We (authors) appreciate the time and effort you have invested in reviewing our work and providing constructive comments. We understand the importance of a robust scientific discussion and the clarity of illustration material in enhancing the quality of our manuscript. Please find below a point-by-point response to your comments:

1. Scientific Discussion:

We acknowledge the need for a more substantive scientific discussion in Section 4. In the revised manuscript, we addressed this by:

• Contextualizing Results: We presented our findings within the broader context of hydrological modeling, discussing how our results contribute to the current understanding of precipitation stable isotope variations.

• Methodological Justification: A deeper explanation of the choice of machine learning models has been provided, including their strengths and limitations in the context of our study objectives.

• Inter-model Comparisons: We included a nuanced discussion comparing the performance of different machine learning models, supported by statistical analyses.

• Implications for Hydrology: The implications of our findings for the field of hydrology, particularly in Southeast Asia, has been elaborated upon, discussing potential impacts on future research and practice.

2. Illustration Material:

We take the comments on our figures and tables seriously and have made the following enhancements:

• Figure Revisions: Each figure has been critically assessed for its ability to convey the necessary information effectively. We have improve the visual quality and ensure that each figure is accompanied by a comprehensive legend.

• Table Improvements: Tables have been reformatted for better readability and consistency. We have ensured that the data presented is accurate and that the tables are well-integrated with the manuscript's narrative.

• Supplementary Material: Where necessary, we added supplementary material to provide additional clarity on the methodologies used and the results obtained.

We addressed these issues thoroughly and revised the manuscript accordingly. We hope that these changes significantly improve the manuscript and hope that it meets the journal's standards for publication.

General comments

source of the meteorological data: The manuscript vaguely refers to NOAA web site as the source for evaporation and wind speed data in line 139. It is not acceptable since the reader is completely blind which database was used. The actual source should be cited not the web server via the data were accessed. In the next sentence (lines 140-141) it is written that vapor pressure, precipitation amount and air temperature were used from the GNIP. It should be advised to retrieve all meteorological variables from the same source, for instance to avoid resolution problems. In addition, I strongly suggest not using meteo data from the GNIP. Please keep in mind that GNIP is an archive of precipitation isotope data and not for meteorological data. If meteorological data are corrected for measurement inhomogeneity by the national meteo services or agencies it is not transferred to the GNIP. I have my own experience of this.

Response: Thank you for your constructive feedback. We also agree that the specificity of data sources and consistency across datasets are crucial for the integrity of our research.

In your comment, you pointed out the need for a precise citation of the NOAA dataset used for evaporation and wind speed data, rather than a general reference to the NOAA website. **We have provided a complete and accurate reference in our revised manuscript.**

Furthermore, we concur with your recommendation to use a single source for all meteorological variables to avoid issues of resolution and measurement discrepancies. As such, we have revised our methodology to ensure that all meteorological data, including vapor pressure, precipitation amount, and air temperature, are obtained from the same source. This change brings uniformity to our data and strengthens the validity of our analysis.

Regarding the use of GNIP data for meteorological variables, we appreciate your advice and have decided to refrain from using it, given that GNIP is primarily an archive of precipitation isotope data. We understand that any corrections made by national meteorological services are not transferred to GNIP, which could lead to inaccuracies in our study. Therefore, we have modified our study and now rely solely on the **NOAA datasets** for our meteorological data needs in the revised manuscript.

We are confident that these revisions address your concerns and significantly improve the manuscript.

Structural problems:

- *The methodological description from line 218 to 232 should be moved to Section 3.*

Response: In response to your comment, we have carefully reviewed the structure of our manuscript and agree that the section in question would be better placed within the methodology section. This relocation provides a more logical sequence, allowing readers to understand the methods before delving into the results and discussion.

We have made the necessary adjustments in the revised manuscript, ensuring that the transition is smooth and the content in Section 3 is coherent and comprehensive. Please check the revised manuscript.

- *If I understand well, Authors consider VAR as the "gold standard" in the forecasting exercise and rank the ML predictions according to their accuracy compared to the VAR forecasts. However, it is not clear from the text why the VAR forecast can serve as a reference. Instead a year commonly covered each of the six station records could be retained from the ML training and could be used as a reference to compare the performance of the models.*

Response: Regarding your comment lets clarify our methodology and the rationale behind our choices step by step.

Regarding the Use of VAR as a Reference:

We acknowledge your suggestion to use a year of data from each station as a reference for model comparison. However, we would like to clarify the design of our study, which encompasses two distinct parts: simulation and forecasting.

Simulation Phase:

In the simulation phase, we employed machine learning (ML) techniques to simulate the stable isotope content in precipitation across six GNIP stations in Southeast Asia. For this phase, we used the entire

dataset available for each station, except for the last year, which was reserved for (forecasting section). We evaluated the performance of various ML models using established evaluation metrics to determine the most accurate models for each station.

Forecasting Phase:

In the forecasting phase, we aimed to forecast the stable isotope content of precipitation using the most accurate ML models identified during the simulation phase, as well as using the Vector Autoregression (VAR) method. The accuracy of these forecasting models was then evaluated using the last year of measured isotope data, which had been set aside from the initial dataset.

Difference Between Simulating and Forecasting:

Simulating and forecasting are two distinct tasks with different objectives and methodologies. Simulating involves generating synthetic data based on existing patterns and relationships within the dataset. This is typically done to understand the system's behavior under various scenarios. Forecasting, on the other hand, aims to predict future values based on historical data. In the context of our study, forecasting using ML models involves training the models on historical data (excluding the last year used for the forecasting part) to capture underlying patterns and then using these trained models to forecast the stable isotope content for the reserved future period.

Why We Kept the Last Year of Sampling:

We kept the last year of sampling in each station separate because we needed to use the rest of the dataset, from the first year until the year before the last year, for training and testing the simulation ML models. The last year was reserved for evaluating our forecasting models. When developing forecasting models, it is essential to evaluate them with actual measured data to determine their accuracy. By using the last year of sampling data, which was excluded from our dataset for the simulation phase, we were able to compare the forecasted values with the measured values to evaluate the performance of both the ML and VAR models. This approach allowed us to determine which model, ML or VAR, was better for forecasting.

Why VAR is Used as a Benchmark:

We chose VAR as a benchmark for several reasons. VAR is a widely recognized and accepted method for time series forecasting, known for its robust performance in various applications. By using VAR, we

intended to provide a standard reference point to evaluate the forecasting capabilities of ML models. This comparison allowed us to determine whether ML models could match or surpass the accuracy of a traditional, well-established forecasting method.

Importance of Our Approach:

Our study is pioneering in that it simultaneously investigates the simulation and forecasting capabilities of ML models for stable isotope content in precipitation. To our knowledge, no previous study has undertaken this dual approach. By doing so, we aimed to provide a comprehensive analysis of ML techniques, assessing their accuracy in both simulating historical data and forecasting future data. This dual assessment fills a significant gap in the literature and offers valuable insights into the broader applicability of ML models in environmental sciences.

Conclusion:

To summarize, we used VAR as a reference because it is a common and accepted model for forecasting time series. Our approach aimed to explore the effectiveness of ML models not only in simulation but also in forecasting, providing a holistic view of their capabilities. We believe this approach enhances the robustness and relevance of our findings.

The annotations are unreadable in Figs 4, 5, 6, and 7. I suggest changing the layout from the current 2×3 to 3×2 in Figs 4, 5 and 6. It will allow the authors to increase the panels. In addition, I strongly suggest increasing the font size in each panels. In addition, in the legend of Fig 1 "Bangkog" should be corrected to "Bangkok" and "Kota Bahura" should be corrected to "Kota Bharu"

Response: Comment is accepted. We apologize for the oversight and appreciate your suggestions for improving their readability. We made the following changes to address your concerns:

- Figures 4, 5, and 6: The layout has been adjusted from the current 2×3 to a 3×2 format. This change allows for an increase in the size of the panels, making the annotations more legible.

- Font Size: we increased the font size in the annotations of Figs 4, 5, 6, and 7 to ensure that they are easily readable.

• Figure 1 Legend Corrections: The misspellings in the legend of Fig 1 has been corrected to "Bangkok" and "Kota Bharu" to accurately reflect the names of the locations.

These changes have been implemented in the revised version of the manuscript to enhance clarity and accuracy. Please check the revised manuscript.

Specific comments:

line 26: insert a space after the full stop.

Response: Comment is accepted. The formatting error on line 26 has been corrected.

line 27: No need to introduce the abbreviation "(VAR)" here since it is not used elsewhere in the abstract.

Response: The reviewer's comment has been acknowledged and the abbreviation "(VAR)" has been removed from line 27 of the abstract. Please check the revised manuscript.

line 39: Beside (or instead of) the classic Clark & Fritz book, a more recent review should be cited e.g. Bowen et al., 2019 (https://doi.org/10.1146/annurev-earth-053018-060220)

Response: Comment is accepted. We have revised the manuscript to include the reference to Bowen et al. (2019) alongside the classic Clark & Fritz reference, as well as several additional recent references. This provides a more comprehensive and up-to-date overview of the topic. Please check the revised manuscript.

lines 42 and 44 I suggest moving the citations "IAEA/GNIP 2018" from kine 44 to the end of the sentence in line 42 and citing the most recent review from the IAEA Hydrology group in line 44: Vystavyna et al., 2021 (https://doi.org/10.1038/s41598-021-98094-6)

Response: Comment is accepted. We have moved the citations "IAEA/GNIP 2018" from line 44 to the end of the sentence in line 42. Additionally, we have included the most recent review from the IAEA Hydrology group as recommended in line 44. Please check the revised manuscript.

line 79: I suggest replacing "Am" with "monsoon climate"

Response: The reviewer's suggestion has been implemented. The term "Am" has been replaced with "monsoon climate" on line 79 to provide clearer context within the manuscript. Please check the revised manuscript.

line 128: Please correct the superscript formats in the equation. In addition, 1 should be deleted from the exponent.

Response: The reviewer's comment regarding the equation on line 128 has been addressed. The superscript formatting has been corrected, and the extraneous '1' in the exponent has been removed to accurately reflect the intended mathematical expression. Please check the revised manuscript.

line 131: The sentence needs revision. The mentioned analytical uncertainties surely refers to the delta values rather than the heavy isotopes.

Response: We have revised the sentence on line 131 to accurately reflect that the uncertainties pertain to the delta values of the isotopes, not the isotopes themselves. Please check the revised manuscript.

line 135 (and also elsewhere): "potential air evaporation" sounds strange. Probably "air" should be omitted?

Response: Comment is accepted, and the term "air" has been removed from "potential air evaporation" for clarity. We also checked and corrected this term in other parts of the manuscript.

line 149: "M.H." seems to be a mistake in the citation.

Response: Upon review, we found that "M.H." was a mistake. We have corrected it in the revised manuscript.

line 158: "spilited" should be changed to "splitted"

Response: Comment is accepted. We have corrected this typo and other similar errors in the revised manuscript. Please review the revised version.

line 210: It is unclear from the current text which results are referred at the beginning of the sentence.

Response: We clarified in the manuscript that the results referred to at the beginning of the sentence on line 210 **are those obtained by Pearson correlation coefficient in the previous paragraph.** This modification aims to prevent further misunderstanding and vagueness. Please review the revised version of the manuscript for enhanced clarity and coherence.

line 251: Please check the text. Is it possible that you meant to write "fairly weak" instead of "fairly strong"?

Response: We also agree that "fairly weak" is indeed the correct term to describe the relationship being discussed. The initial use of "fairly strong" was a misrepresentation of the observed correlation between the variables in our study.

To provide further clarification, our intention was to highlight the nuanced influence of temperature on stable isotope composition in tropical regions, as compared to non-tropical regions. In tropical regions, such as those examined in our study, the amount of precipitation plays a significant role due to the influence of seasonal monsoon patterns. This factor often supersedes the impact of air temperature on stable isotope composition. On the other hand, in non-tropical regions, where temperature fluctuations are more pronounced and consistent throughout the year, temperature stands out as a dominant factor in determining $\delta^{18}O$ values, alongside the amount of precipitation.

We have carefully amended the manuscript to reflect this distinction and ensure that our findings are presented with accuracy. Please check the revised manuscript.

Suggestions on Table 1 and Table 2

The layout of both tables could be improved.

Table 1: If you introduce the abbreviation LR for Lasso regression in the table title than you can use it in the table which will help the readability of the table. In addition, "$\delta^{18}O$ (VSMOW‰)" and $\delta^{2}H$ (VSMOW‰)" should go to the header of the first and second part of the table, respectively, to eliminate the current "Isotope" column, which again could help to make this table more compact and readable.

Response: We accept your suggestions regarding the formatting of Table 1. We have introduced the abbreviation LR for Lasso Regression in the table title and have used this abbreviation consistently within the table to improve readability. Additionally, we have moved $\delta^{18}O$ (VSMOW‰) and $\delta^{2}H$ (VSMOW‰) to the headers of the respective parts of the table, eliminating the need for a separate "Isotope" column. These changes have made the table more compact and easier to read.

Table 2: Similar suggestion as above. "$\delta^{18}O$" and $\delta^{2}H$" should go to the header above the methods to eliminate the current "Isotope" columns, to make this table more compact and readable.

Response: Comment is accepted. We also agree that moving the "$\delta^{18}O$" and "$\delta^{2}H$" to the header above the methods and removing the current "Isotope" columns would streamline the table, making it more compact and easier to read. We have conducted all these changes to enhance the clarity of the data presented. Please check the revised manuscript.