Reply to Referee #2

General comments

The authors present the development of a Data Integration model with Satellite Embeddings (DISE), which reconstructs streamflow by combining existing discharge products with Google Satellite Embeddings via a machine learning approach. Overall, the manuscript provides valuable insights into generating streamflow data for ungauged river reaches—a critical component of water resource management—and I believe this timely research is well-suited for HESS."

However, I recommend a 'major revision' of the manuscript, primarily due to the following concerns: (1) a lack of detailed explanation regarding the methodology, (2) an incomplete review of relevant existing literature, and (3) a weak core argument demonstrating the necessity and novelty of this research.

Detailed comments are provided below.

We sincerely thank the reviewer for recognizing the value and timeliness of the study and for the constructive recommendation. We agree that the manuscript needs a clearer motivation, a stronger literature context, and a sharper statement of methodological contribution. In the revision, we will expand the introduction to better explain streamflow reconstruction needs, data fusion and data assimilation backgrounds, and previous residual-correction work. We will also clarify that our main novelty is the use of satellite embeddings as spatial context for river-network streamflow reconstruction.

Major comments

1. Abstract: Clearly stating the motivation behind streamflow reconstruction in the abstract would better engage readers and highlight the study's importance.

Response: Thank you and we agree that the motivation for streamflow reconstruction should be stated more clearly. We will revise the abstract and introduction to explain why streamflow reconstruction across river networks is important, particularly for ungauged reaches, water-resources assessment, consistent hydrological monitoring, and understanding changes in the water cycle. We will also clarify the broader hydrological implications of reliable streamflow reconstruction before introducing the proposed DISE framework. This revision will help readers better understand the practical and scientific need for the study.

2. Introduction: The Introduction would benefit from a more comprehensive literature review, particularly regarding the specific data fusion approaches employed in this study, emphasizing the novelty and strengths of the current approach compared to existing ones.

Response: We agree that the Introduction should include a more comprehensive review of existing data-fusion approaches relevant to this study. We will add a focused literature review on streamflow and hydrological data fusion. We will then clarify how the proposed DISE framework differs from existing approaches. In particular, we will emphasize that the central contribution of this study is to use Satellite Embeddings as spatial contextual information for streamflow reconstruction across river networks. This revision will better highlight the novelty and strengths of the proposed approach relative to previous data-fusion methods.

3. Introduction: I recommend providing more information on how the reconstructed streamflow data can be applied in scientific research, engineering practices, and decision-making processes (supported by relevant references). This would significantly strengthen the justification for why this work is necessary.

Response: We thank the reviewer for pointing this out. We will revise the Introduction to include the application contexts. Specifically, we will discuss the use of reconstructed streamflow for understanding changes in the water cycle, water-availability assessment, ecological and sediment-related studies and infrastructure planning. These revisions will strengthen the motivation of the study and more clearly justify why improving streamflow reconstruction across river networks is scientifically and practically important.

4. Line 49: While Satellite Embeddings (SE) are explained in the Data and Method section, providing more foundational context in the Introduction would significantly improve readability. Specifically, I recommend clarifying what type of satellite information is compressed within SE, as well as discussing how SE has been utilized in previous studies, supported by relevant references.

Response: We agree that the Introduction should provide more foundational context on Satellite Embeddings (SE) before they are introduced in the Data and Methods section. We will revise the Introduction to clarify what types of satellite-derived information are encoded in SE, and will expand the description of the relevant input imagery and datasets used by the AlphaEarth Foundation model. We will also summarize emerging uses of SE in the hydrological community.

It is important to note that, to the best of our knowledge, no hydrological study using SE had been published when we submitted this manuscript. During the peer-review process, a related study applying SE to streamflow simulation was published in GRL (Ou and Zheng, 2026). That study applied a different methodological framework (i.e., extracts information from SE using a convolutional network and uses it as basin attributes in an LSTM model) to digest the SE information for streamflow simulation in Australian catchments. Nevertheless, we both reached a

consistent conclusion that SE can provide spatial information that is difficult to fully represent using traditional attributes. Compared to that study, our work further examines the conditions and boundaries under which SE provides performance gains. We thank the reviewer for reminding us to cite that study to provide better contexts for the readers.

5. Lines 34 to 48: To ensure a complete and thorough literature review, a brief overview of data assimilation approaches should also be integrated into the Introduction.

Response: Although data assimilation is not directly relevant here, we agree that the Introduction would benefit from a brief overview of data assimilation approaches to provide a more complete literature context. This addition will help position our data-fusion framework relative to assimilation-based approaches. We will keep this review concise so that the Introduction remains focused, while still providing sufficient background for readers familiar with observation-constrained streamflow estimation.

6. Line 56: “fuses satellite embeddings”. The introduction would benefit from a brief discussion contrasting data fusion and data assimilation approaches. Clearly outlining their similarities, differences, strengths, and limitations will provide readers with a stronger conceptual foundation.

Response: We agree that the terms “data fusion” and “data assimilation” should be distinguished more clearly to avoid conceptual ambiguity. We will revise the Introduction to explain that data assimilation generally updates model states, parameters using observations within a dynamic modeling framework, whereas the data-fusion approach used in this study combines discharge products, meteorological forcings, and satellite-derived spatial-context features within a machine-learning residual-correction framework. We will also briefly discuss the strengths and limitations of this approach. This clarification will provide readers with a stronger conceptual foundation for understanding the role of “fusion” in the proposed DISE framework.

7. Line 204: “residual correction”. It is currently unclear whether this study proposes a completely novel method for residual error correction, or if it applies an existing approach with further enhancements. The authors should explicitly clarify their specific methodological contributions and ground them by introducing relevant previous studies in this domain.

Response: We need to clarify that residual correction itself is not claimed as a completely novel method. Instead, the main contribution of the proposed DISE framework is to incorporate satellite embeddings as spatial-context descriptors within a residual-correction setting for streamflow reconstruction across river networks. Nonetheless, we agree that our methodological contribution should be stated more precisely. We will also revise the manuscript to introduce relevant previous studies that have used residual correction for streamflow simulation.

8. Lines 361 to 364: To prevent potential misunderstanding, the authors should explicitly state that the spatial embeddings (SE) capture purely temporally static spatial characteristics—at least within a given year, given that the SE in this study are utilized on an annual basis. It should be made clear that these embeddings do not reflect highly dynamic hydrological variables such as soil moisture, vegetation canopy, snow cover, or water level variations.

Response: It is true that SE are used as annual spatial-context descriptors and therefore represent temporally static spatial characteristics within the study year. Therefore, they should not be interpreted as dynamic predictors of within-year hydrological conditions. We will clarify this in the Methods and Discussion sections. We will also revise any wording that may imply that SE capture dynamics in the current experimental design. This clarification will better define what information SE can and cannot provide in our study.

Editorial comments

1. Line 37: Please provide the full expansion for 'PCR-GLOBWB' when it is first introduced. More generally, many acronyms throughout the manuscript lack definitions upon first use; please ensure all abbreviations are spelled out when they first appear in the text.

Response: Thanks and we will check to ensure that all acronyms are spelled out when they first appear in the text, including PCR-GLOBWB.

2. Line 249: “embeddings”. I recommend using either 'SE' or 'embeddings' consistently throughout the manuscript to minimize confusion for readers who may not be familiar with this terminology.

Response: Thank you and we will define Satellite Embeddings (SE) at first use and then use “SE” consistently throughout the manuscript to avoid confusion. We will also check figure captions, tables, section headings, and supplementary materials to ensure that the same terminology is used consistently.

References

Ou, Z. and Zheng, Y.: Foundation-scale satellite embeddings reframe hydrological generalization as a representation problem, Geophys. Res. Lett., 53, e2025GL121604, https://doi.org/10.1029/2025GL121604, 2026.