Responses to Reviews of Egusphere-2025-2984: "Questioning the Endorheic Paradigm: Water Balance dynamics in the Salar del Huasco basin, Chile" By Francisca Aguirre-Correa et al.

We sincerely thank Howard Wheater for taking the time to review our manuscript and for the constructive comments. For clarity, we have grouped some related comments by theme and provided joint responses where appropriate. We answered the comments in blue font.

This paper addresses a critically important issue for arid land hydrology and water management and provides an important case study. It is generally very well written and clearly explained. However, I have two important reservations.

The conclusions depend on satellite-derived forcing data applied to a hydrological model. The interpretation of missing water is wholly dependent on the validity of the forcing data, but there is limited discussion of the use of local data to improve these products, and crucially no attempt to quantify the potential errors and their impact on the water balance conclusions. Some effort to quantify the effects of errors on the water balance conclusions is essential.

Line 151: 'first order approximation'. I note no discussion as yet of the likely error bounds on the satellite estimates of precip and evaporation, but this is crucial for the data interpretation! The use of local data to improve the products is summarized rather briefly in Appendix B. More information would be helpful here, e.g. the local data available. The plots in App B do indicate quite large residual scatter. Some efforts to quantify likely errors and incorporate them in the analysis are in my view essential to the credibility of the conclusions.

We thank the reviewer for highlighting this essential point, which overlaps with a comment raised by Reviewer #2. Accordingly, we have provided a consistent response to ensure clarity and alignment.

We agree that the validity of our conclusions depends on the reliability of the satellite-derived datasets. To better explain the corrections of the satellite-derived data and quantify their uncertainty on the basin-scale water balance conclusions, we will make the following revisions in the manuscript:

1. Expand description of local data and corrections: We will provide detailed metadata for the DGA precipitation and temperature stations used for bias correction, including their locations, elevations, record lengths, and error metrics of the corrected satellite-derived timeseries (PBIAS, RMSE, R^2). These will be presented in Tables B1 and B2 to complement Fig. B2 in Appendix B (see below), which will be referenced in the main text when introducing the satellite-derived datasets. In light of this comment, we would like to note that we identified a minor error in Fig. B2, specifically in the color legend. This will be corrected and updated in the revised manuscript (see Fig. R1).

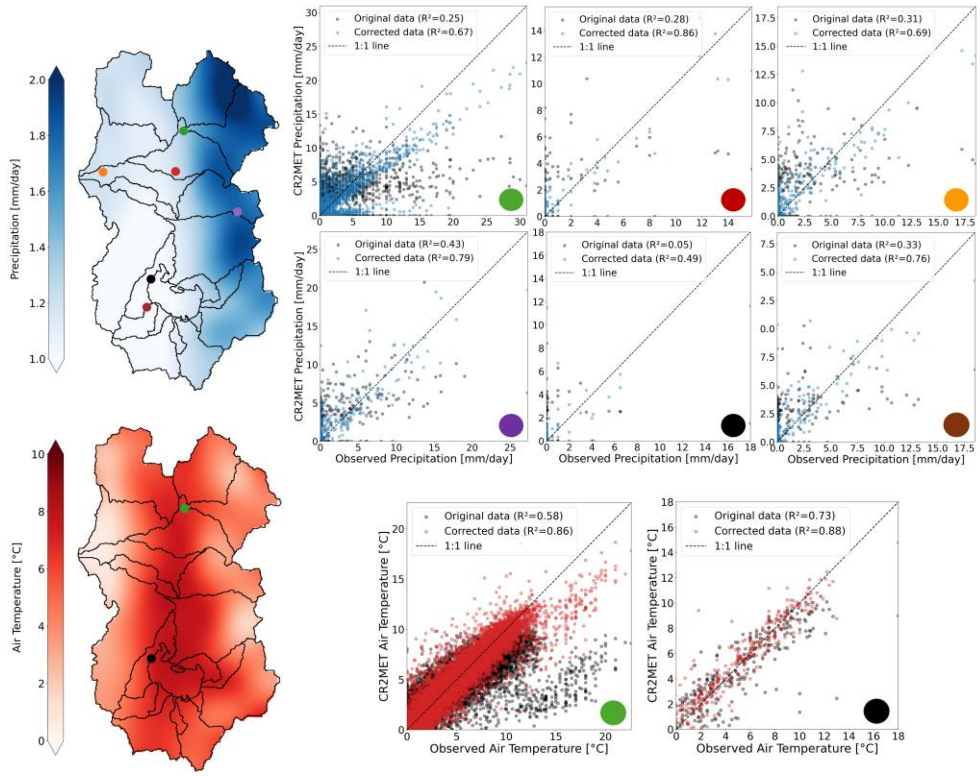

Figure R1: Original (black dots) and corrected CR2MET data (blue dots for precipitation and red dots for air temperature) for the Salar del Huasco basin. A machine learning bias correction approach was implemented (Fig. B1).

Table B1. Summary of validation metrics for daily precipitation at DGA meteorological stations used for CR2MET bias correction. The colors in parentheses correspond to station markers in Fig. B2. PBIAS represents the percent bias computed for all days with recorded precipitation > 1 mm, RMSE is the root mean square error, and R^2 is the coefficient of determination. The basin median signed bias is derived from aggregating all station records into a single time series.

Station	Lat/Lon	Elevation (m asl)	Record length	PBIAS (%)	RMSE (mm day^{-1})	R^2
Coyacagua (green)	-20.04°/-68.83°	4013	14326	22.4	1.05	0.67
Río Collacagua (red)	-20.10°/-68.84°	3853	612	11.4	0.56	0.86
Diablo Marca (orange)	-20.10°/-68.97°	4585	1397	0.7	0.93	0.69
Sillillica (purple)	-20.17°/-68.74°	3840	1427	-0.3	1.03	0.79
Salar Huasco (black)	-20.28°/-68.89°	3800	457	26.1	0.81	0.49
Altos del Huasco (brown)	-20.32°/-68.89°	4044	1449	2.6	0.62	0.76
Basin median signed bias (%)		-9.1				

Table B2. Summary of validation metrics for daily air temperature at DGA meteorological stations used for CR2MET bias correction. The colors in parentheses correspond to station markers in Fig. B2. PBIAS represents the percent bias, RMSE is the root mean square error, and R^2 is the coefficient of determination. The basin median signed bias is derived from aggregating all station records into a single time series.

Station	Lat/Lon	Elevation (m asl)	Record length	PBIAS (%)	RMSE (°C)	R^2
Coyacagua (green)	-20.04°/-68.83°	4013	11383	-0.2	1.52	0.86
Salar Huasco (black)	-20.28°/-68.89°	3800	300	3.9	1.24	0.88
Basin median signed bias (%)		-0.9				

2. Quantification of error ranges: We will quantify the uncertainties in the satellite-derived data and incorporate this analysis into the discussion, highlighting how these errors may influence our conclusions.
    - Precipitation (P): Nearly all individual DGA stations show positive percent bias (PBIAS) values, indicating that bias-corrected CR2MET precipitation mainly overestimates the measurements at the station level, with magnitudes ranging from -0.3% to +26% (Table B1). The largest errors occur at lower-elevation stations, where total precipitation is low and satellite products tend to overestimate the few convective events that do occur. To evaluate the implications for the water balance at the basin scale, we aggregated all station records into a combined time series. This yielded a basin median signed bias of ∼-10%, which we adopt as a representative error bound for precipitation (±10%). We chose the basin-wide median rather than the mean of station biases because the median provides a more robust estimate of central tendency, less influenced by extreme local values, and more consistent with the scale at which the water balance is assessed. However, note that our water balance results indicate evaporation exceeds precipitation, and since the precipitation product is more likely to be overestimated, as evidenced by the positive PBIAS (Table B1), the imbalance we report can be considered as conservative in terms of precipitation (true precipitation deficit is likely larger than our estimates suggest).

    - Temperature (T): For air temperature, the available stations showed very small biases (<4%), with a basin-wide median signed bias of -0.9%. This indicates that after correction CR2MET temperature fields are in close agreement with in-situ observations, supporting their reliability as inputs to the rainfall-runoff model. This outcome is also consistent with the general expectation that satellite and reanalysis products reproduce temperature more accurately than precipitation.

    - Evaporation (E): Direct local validation of evaporation was limited due to the absence of flux towers or lysimeter measurements in the basin. However, we will now compare EEFLUX-derived actual evaporation against daily evaporation estimated from pan measurements, adjusted using a pan coefficient of 0.7 as recommended by DGA (2009). These observations were collected at a representative site within the salt flat nucleus sub-basin (GP Consultores, 2008), the area with the highest evaporative fluxes in the study site. EEFLUX-derived actual evaporation underestimates the observed evaporation by approximately -18%, with a root mean square error (RMSE) of 1.41 mm day^{-1} (Fig. R2). EEFLUX effectively reproduces the temporal variability captured by the tank observations, and its magnitude remains within a plausible range (Fig. R2). Furthermore, since EEFLUX/METRIC retrievals are strongly constrained by temperature, and satellite-derived temperature fields closely align with ground observations, confidence in the accuracy of the evaporation estimates is further supported. Nonetheless, because this comparison is limited to a single site and relies on pan measurements rather than actual evaporation, and considering that published evaluations of METRIC/EEFLUX in arid and mountainous regions have reported uncertainties of ~5-20% (Nisa et al., 2021; Wasti, 2020; Lima et al., 2020; Madugundu et al., 2017), we will adopt a conservative ±20% error bound for evaporation in our basin-scale water balance analysis. It is important to note, however, that the reported imbalance may be also conservative with respect to evaporation, which could be underestimated in this high-evaporation environment, as observed in Fig. R1.

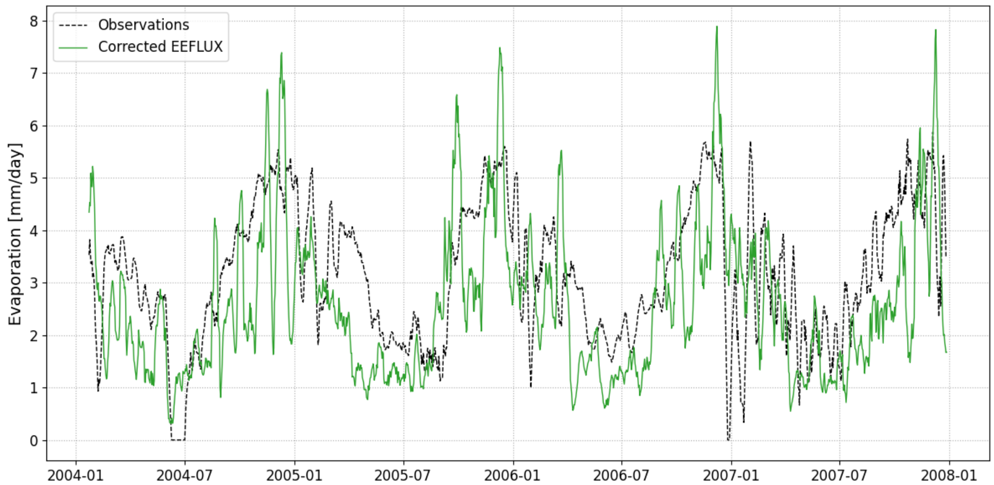

Figure R2: Comparison of EEFLUX-derived daily evaporation at the salt nucleus sub-basin (green) with ground-based observations of potential evaporation (black) at a representative location in the salt flat nucleus sub-basin (GP Consultores, 2008). Both time series have been smoothed using a 10-day rolling average to highlight temporal variability.

3. Analysis of implication of these errors into the basin water balance: Our baseline results indicate that basin-wide evaporation exceeds precipitation by a factor of ~1.5. To test whether plausible uncertainties could account for the imbalance, we will apply representative error bounds of ±10% for precipitation and ±20% for evaporation. Even under the most favorable scenario (increasing precipitation by 10% and decreasing evaporation by 20%), evaporation still exceeds precipitation and the imbalance persists. Based on our discussion, we hypothesize that the observed imbalance may reflect the influence of transboundary or interbasin groundwater flows not represented in the current hydrological model. We will now stress that future efforts should incorporate hydrogeological mapping and assessments of geological connectivity, particularly toward neighboring Bolivian basins, to evaluate whether Salar del Huasco receives groundwater inflows from adjacent regions. This could help reconcile the apparent precipitation-evaporation deficit. Nevertheless, we will also emphasize in the revised manuscript the need for further validation of satellite-derived inputs against additional local observations across the basin, particularly for evaporation and air temperature for which only limited ground data are available, to strengthen the robustness of the water balance assessment.

Despite these limitations, we would like to highlight that the use of satellite-derived data represents a significant improvement in capturing the spatiotemporal variability of precipitation and evaporation in the basin. In the Altiplano region, convective storms and strong spatial heterogeneity limit the reliability of traditional approaches based on topographic gradients, as originally used in the rainfall-runoff model. While uncertainties in satellite products remain, our approach therefore provides a more realistic representation of hydrological dynamics in the Salar del Huasco, particularly of the interplay between precipitation, evaporation, and recharge. With this uncertainty analysis we will add transparency and robustness to our analysis, and we believe it will strengthen the overall contribution of the manuscript by providing a valuable first-order assessment of basin-scale water availability under the current climatic and data constraints.

The discussion of the seasonal dynamics of groundwater recharge depends on modelling results, but the model was calibrated using only surface flows. It seems that the groundwater dynamics are largely unconstrained. Some validation with local groundwater data would be invaluable. If not, at least there should be appropriate caveats.

Fig 3 results. The model that was used to simulate groundwater recharge was calibrated on observed river flows. So this provides only very limited information to define the dynamics of groundwater recharge fluxes. Were there no groundwater observations available to calibrate/validate this important component?

We acknowledge that the recharge component is less constrained than precipitation and evaporation because calibration relies solely on surface flow records. Local groundwater observations do exist, but they are sparse and spatially discontinuous, making them unsuitable for direct quantitative calibration or validation of groundwater recharge estimates. For this reason, we opted not to compare model outputs with these heterogeneous datasets. However, although not validated here against groundwater levels, the same model has been applied in the Salar del Huasco and other basins, where its recharge estimates were incorporated into groundwater flow models that performed well (Blin et al., 2022; Blin & Suárez, 2023). For instance, the Uribe et al. (2015) model was used by Blin et al. (2022) to estimate aquifer recharge in the basin, which was then further employed to drive the groundwater model that represented well the water levels observed throughout the basin. Therefore, although this model is calibrated with river discharge, it does provide a plausible spatiotemporal distribution of recharge that is consistent with observations from groundwater wells in the Salar de Huasco aquifer (see simulated and observed well levels in Blin et al., 2022). This gives confidence that our recharge outputs are reasonable as first-order estimates.

To strengthen the manuscript, we will:

1. Clarify the role of the model: Section 2.2 now will explicitly state that the model provides inferred recharge fluxes based on surface-water calibration, rather than direct simulations of groundwater levels. We will also emphasize that the model is primarily used to represent the partitioning and timing of surface runoff and recharge.

2. Note previous successful applications: We will now highlight in the manuscript that the same model structure has been successfully used in the Salar del Huasco and other basins, where its recharge estimates were incorporated into groundwater models (e.g., MODFLOW in Blin et al., 2022), where observed water levels are well represented.

3. Added current limitations and future directions: We will now reinforce the ideas that (i) recharge estimates should be viewed as first-order approximations; and (ii) future work should integrate groundwater-level or tracer data where available to validate recharge dynamics.

Line 13: replace 'insinuate' by 'imply'

We will update the manuscript accordingly.

Line 37: composed of

We will update the manuscript accordingly.

Line 91 of the Uribe et al…

Line 112 the Uribe….

Line 131 the Uribe...

Line 156 the Uribe... please correct throughout – including Fig 3 caption

We will add "the" before "Uribe et al." throughout the manuscript, including Figure 3 caption.

Line 94: into

We will update the manuscript accordingly.

Section 2.2 para 2 specify the model and forcing data time steps. I assume daily??

We will clarify that model and forcing data time steps are daily.

Line 116: data … are used…

We will update the manuscript accordingly.

Line 118: please clarify what is meant by evaporation here. It isn't obvious until line 137.

We will clarify the definition in the manuscript: *"In this study, evaporation refers specifically to satellite-retrieved actual evaporation from EEFLUX/METRIC, rather than potential evaporation or model-estimated fluxes."*

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