Author Response to Referees

Manuscript: *Mesoscale modulation of marine boundary layer water vapor isotopologues during EUREC4A*
Authors: Galewsky & Los

The reviewer comments substantially improved the clarity, rigor, and physical interpretation of the manuscript, and we appreciate their feedback. Below we reproduce the referee comments (italicized) and respond point-by-point. Line numbers refer to the revised manuscript unless otherwise noted.

Response to Referee #1

1. Apparent AI hallucination / citation error

"…The Galewsky et al. (2022) study cited multiple times has an incorrect full reference… This appears to be a hallucination…"

Response:
The referee is correct. The reference was incorrect and has been fully corrected. The correct citation is now:

Galewsky, J., Jensen, M. P., & Delp, J. (2022), *Marine boundary layer decoupling and the stable isotopic composition of water vapor*, JGR-Atmospheres, 127, e2021JD035470.

All references were re-checked manually to ensure no further errors remain.

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2. Measurement uncertainty and data inclusion (L110)

"…What exactly does this mean for the statistics shown? Were only circles with δD values outside the 1.24‰ range considered?"

Response:
No filtering was applied based on δD uncertainty. The value 1.24‰ represents the **1σ absolute accuracy of a 2-hour mean δD measurement** from the shipboard Picarro system, expressed in per mil (‰), not percent. All HALO and P-3 circle-matched observations are included in the analysis.

The purpose of stating this uncertainty is to quantify the **noise floor** relative to the observed campaign variability (σ δD ≈ 1.94‰). Measurement uncertainty therefore contributes scatter but does not alter which points are included. We now clarify this explicitly in the text and emphasize that we focus interpretation on gradients and contrasts that exceed this noise level.

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3. Figure 3 timing and sampling consistency

"…Were ship-derived properties averaged over the HALO circle time? Ideally circle-time should be obtained through Konow et al. (2021) segmentation…"

Response:
All timing is keyed to the **JOANNE Level-4 circle definitions**, which use the Konow et al. (2021) flight-segmentation framework. Shipboard δD and H_2O values are averaged within ±2 hours of each JOANNE circle time and spatially matched to the circle footprint. Vertical velocity profiles come from the same JOANNE dataset and the same circle identifiers. We have clarified this explicitly in the Methods.

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4. Figure 4 discrepancies (number of circles, Feb 1)

"…0209 shows 7 points… 0210 shows a point despite no HALO flight…"

Response:
These points correspond to **P-3 circles**, not HALO. The original text incorrectly implied HALO-only usage. We now explicitly state that both **HALO and P-3** dropsonde circles are used throughout and label this clearly in the text and figure captions.

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5. Averaging methodology (6-hour vs ±2-hour)

"…The choice of a 6-hour average is confusing…"

Response:
The referee is correct. This was legacy wording from an earlier analysis. All averaging is ±2 hours around each circle time. The incorrect "6-hour" language has been removed everywhere.

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6. Diagonal structure in Figure 5

"…The 'clear diagonal pattern' is unconvincing without quantification…"

Response:
We agree and removed the word "clear." We now quantify the relationship explicitly. Using all 56 circle means, the fitted relationship is:

$$E = -0.25(\pm 0.24)\, W + 18.6, \quad p = 0.044,$$

demonstrating a modest but statistically significant negative tilt. This quantification is now reported.

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7. Multilinear regression performance (Figure 6)

"...Please provide coefficients and residual errors..."

Response:
Done. We now report full regression coefficients, p-values, MAE, RMSE, and R^2 for both δD and H_2O. The spread in the figures is consistent with the reported R^2 values and is discussed explicitly.

- δD ~ E + W: coefficients [const −68.74, E −0.071, W +0.100]; R^2 = 0.357. Coefficient p-values: E p≈0.013, W p≈0.00027 (both significant at 5%). Residual MAE = 1.15‰; RMSE = 1.33‰.

- H_2O ~ E + W: coefficients [const 16.72, E −0.083, W +0.019]; R^2 = 0.633. Coefficient p-values: E p≈2.5×10^{-11}, W p≈0.040. Residual MAE = 0.365 g/kg; RMSE = 0.472 g/kg.

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8. Counteraction efficiency and residual analysis

"...Residual analysis assumes E and W are uncorrelated..."

Response:
We agree this needed clarification. We now define counteraction efficiency **exclusively from standardized coefficients of the joint E–W regression**, which yields the **partial effects accounting for E–W covariance (r ≈ −0.27)**. The residual plot is retained only as a visualization of the partial relationship and is explicitly described as such.

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9. Normalization and unit bias

"...1 mm s^{-1} of E is not comparable to 1 mm s^{-1} of W..."

Response:
Agreed. We revised the definition of counteraction efficiency to use **standardized regression coefficients** (|βW/βE|), which is unitless and scale-free. Physical cancellation in mm s^{-1} is now discussed separately using unstandardized slopes, and the distinction is made explicit throughout.

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10. Precipitation and cold pools

"…The effect of precipitation and cold pools is missing from the discussion…"

Response:
We added a dedicated paragraph addressing cold pools and precipitation, citing Touzé-Peiffer et al. (2022) and Radtke et al. (2022, 2023). We note that the strongest isotopic–W correlations occur above the shallowest cold-pool-affected layers, suggesting that the signal primarily reflects deeper mesoscale overturning rather than near-surface cold-pool dynamics.

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11. Minor comments and line edits

All suggested minor edits, terminology corrections, figure clarifications, and reference additions (Konow et al., LES studies, etc.) have been implemented. We thank the referee for the detailed attention.

Response to Referee #2

Major comment: analytical model failure

"…The analytical model fails to capture the core observed behavior…"

Response:
This critique was pivotal and correct. The original model formulation could not reproduce the observed separation between δD and q sensitivities. We therefore **revised the model** to include **hydrometeor–vapor isotopic exchange**, motivated directly by the referee's suggestion. With this addition, the model reproduces the observed E–W contour structure and the stronger isotopic sensitivity. The model description and Appendix were rewritten accordingly.

Normalization critique

"…The 7.5× sensitivity is an artifact of normalization…"

Response:
We agree and removed the problematic normalized sensitivity plot. The model is now evaluated by comparing **E–W contour structures directly**, consistent with Figure 6.

Steady-state assumption

"…The steady-state assumption is crude…"

Response:
We now explicitly state that the mixed-layer model is **diagnostic**, not predictive, and intended to clarify relative sensitivities rather than capture transient evolution. This limitation is now acknowledged in both the Methods and Discussion.

Minor comments

All minor text edits, figure label changes, terminology corrections, and reference additions have been incorporated. We also clarified the definition of "bottom-heavy variance" following George et al. (2023).

Closing statement

We again thank both referees for their careful and constructive reviews. The manuscript is substantially improved as a result, particularly in the interpretation of counteraction efficiency, the analytical model formulation, and the discussion of mesoscale–isotope coupling.
