Response to comments from reviewer 4

Manuscript: Coastal upwelling and tropical warm water intrusions are key drivers of interannual fog variability along the southwestern African coast # EGUSPHERE-2026-1208

First of all, we would like to thank the reviewer for the positive comments and for providing very helpful and constructive feedback. We thank the four anonymous reviewers in the acknowledgments of the updated version of the manuscript. The comments and suggestions from reviewer 4 are incorporated in italics and addressed by the authors in blue.

1 General Comments

Ln25-28: This paragraph uses several terms that seem to describe similar phenomena (e.g., "advection fog", and "advected marine stratus clouds"). Clarifying the distinctions between these terms, if any, and using consistent terminology would improve readability.

We thank the reviewer for this comment. We distinguish coastal advection fog, which forms through near-surface cooling of moist marine air, from inland "high fog," associated with advected marine stratus clouds whose base intersects the surface further inland; both are generally regarded as marine and advective phenomena but differ in where saturation occurs and in the atmospheric processes producing surface fog. We clarify in the revised text that these two types are grouped together as FLC both because they are predominantly marine in origin and because our satellite-based product cannot reliably distinguish between them.

Ln65-67: Validation against surface observations is reported to demonstrate good performance of the FLC detection algorithm; however, the specific surface observation datasets used are not specified. Please clarify which observations were used.

The validation referred to here uses nighttime surface net radiation measurements from the FogNet station network (Kaspar et al., 2015), part of the SASSCAL initiative, in the central Namib (2015–2017), as described in Andersen and Cermak (2018). Nighttime net radiation accurately captures the presence of low cloud, which corresponds to what the satellite product detects. We have revised the sentence to specify this dataset explicitly, rather than referring to "surface observations" without naming the source.

Ln75-77: It is unclear what is meant by "spatially and temporally averaged" FLC cover. Please clarify whether this corresponds to a domain-averaged time series and specify the spatial domain used for each zone.

"Spatially and temporally averaged" refers to a single domain-averaged monthly time series per region, derived in two steps from the daily, cell-based FLC cover (itself already a temporal average of the native 15-min classification, over each 24-hour period from 12:00 UTC). First, the daily cell-based values are spatially averaged over all valid grid cells within each region's domain (AN: 15–17 °S; CN: 22–24 °S, both restricted to grid cells within 24 km of the coastline), yielding one daily value per region. These daily regional values are then temporally averaged over each calendar month to produce the monthly FLC cover time series used as the predictand. We have revised the text to state this explicitly and to specify the spatial domain for each region.

2 Section 2.2 Cloud controlling factors

Ln82-89: The section introduces five controlling factors supported by literature, but these are also referred to as predictor variables (e.g. EIS, relative humidity at 700 hPa). It would be helpful clarify the physical processes represented by each variable and their relationship to FLC variability, rather than only listing them as predictors. In particular, linking these variables to processes such as cloud-top radiative cooling and entrainment, and how these processes may influence EIS, would improve the physical interpretation.

We thank the reviewer for this suggestion. We agree that the original text focused primarily on the predictor variables themselves rather than the physical processes they represent. We have therefore expanded Sect. 2.2 to briefly describe the physical interpretation of each cloud-controlling factor, including the role of EIS in regulating boundary-layer mixing and cloud persistence, the influence of free-tropospheric humidity on cloud-top radiative cooling and entrainment, the thermodynamic role of SST, and the representation of fog and low-cloud advection through the wind components, which additionally carry information on marine boundary layer dynamics.

Ln86-87: Subsidence is excluded from the final set of predictors because it does not improve model skill. However, this factor has been used in previous studies cited in the manuscript (e.g., Klein et al., 2018; Scott et al, 2020; Ceppi&Nowack,2021; Andersen et al., 2022). It is very important to provide an explanation for its exclusion beyond the model skill since subsidence is one of the main physical processes controlling marine low stratus formation in tropical oceans.

We agree that subsidence is an important component of the large-scale circulation. Our intention was therefore not to imply that subsidence is physically unimportant, and we have clarified this point in the revised manuscript. Rather, we tested whether the reanalysis-derived W700 field available to us provides additional predictive information for FLC cover anomalies beyond the five predictors already included.

In our experiments, it did not. We tested model skill both with and without W700 in the predictor set, and additionally trained a model using W700 alone. Adding W700 to the five-predictor model did not improve skill, and the W700-only model did not provide predictive skill. The ridge coefficient fields from the six-predictor model (Fig. 1 in this document), shown on the ERA5 grid, provide some insight into this result: EIS, R700, SST, U10, and V10 exhibit coherent coastal structures, whereas W700 coefficients are comparatively patchy and lack a clear physical interpretation. The reason for this is not established, though the patchiness of the W700 coefficients suggests the field may be less well constrained at the spatial scale considered here. A further possibility is that some aspects associated with subsidence are already represented indirectly by the other predictors, given their covariability.

We emphasize that the statistical model is an imperfect representation of the processes controlling FLC cover anomalies. W700 was excluded because the available reanalysis product did not provide useful information at the spatial and temporal scales investigated here, not because we conclude that subsidence is unimportant for FLCs.

-Added in 2.2: "Subsidence was tested as an additional predictor but was excluded from the final set, as it did not provide additional predictive information within our modelling framework. This does not imply that subsidence is physically unimportant for FLCs, but rather that it did not provide additional usable information for predicting FLC cover anomalies at the spatial and temporal scales considered here."

Ln101: The use of the 1991-2020 period as the reference climatology for SST anomalies is not fully justified. Could you

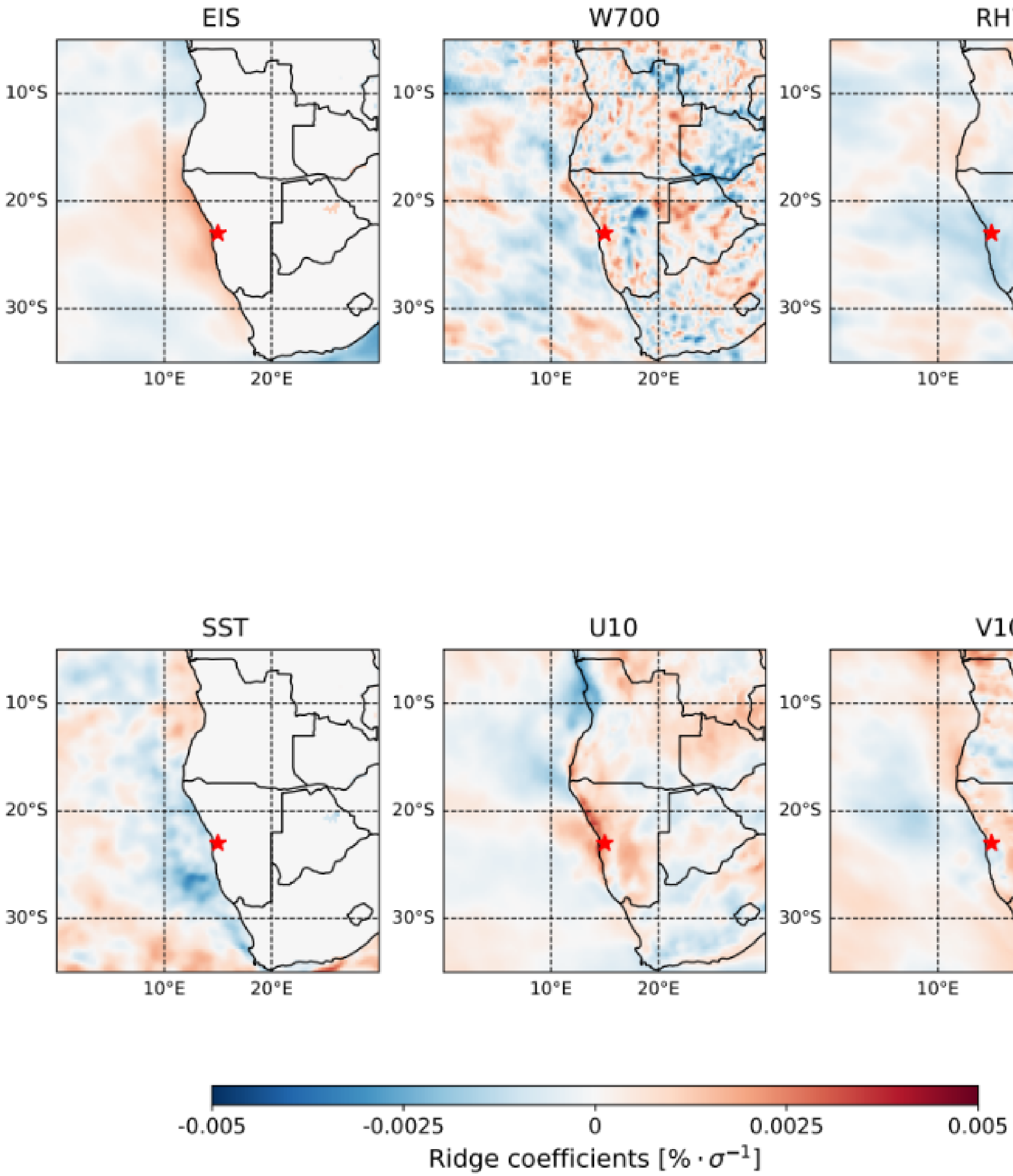

Figure 1: Ridge coefficients [% $\cdot\sigma^{-1}$] for the six-predictor model, including W700, for the CN region on the ERA5 grid. EIS, R700, SST, U10, and V10 show spatially coherent structures concentrated near the coast, whereas the W700 coefficients are comparatively patchy and lack a clear physical interpretation at this spatial scale. The red star marks the Central Namib (CN) region.

clarify whether this choice affects the results and why it was preferred over the 1982-2019 period?

The 1991–2020 period was chosen to follow the BNI definition of McPhaden et al. (2024), which we adopt here, and because it corresponds to the base period used by NOAA for the ONI, so that the BNI, LUCI, and ONI indices are all defined relative to a common climatology and remain directly comparable. The choice of base period shifts the monthly anomalies by a near-constant offset and therefore has little effect on interannual variability. Recomputing both indices relative to a 1982–2019 climatology yields time series that are almost identical to the original ones ($r = 0.998$ for BNI, $r = 0.997$ for LUCI), and leaves their correlations with the reconstructed FLC anomalies essentially unchanged (BNI–AN: $r = -0.68$ in both cases; LUCI–CN: $r = -0.47$ vs. $r = -0.46$). The choice of reference period therefore does not affect our conclusions.

Ln149: In relation to the comment on Ln101, why is the 2004-2019 period used as the reference for calculating the anomalies? It would be preferable to use a consistent reference period throughout the analysis to ensure comparability.

The two reference periods serve different purposes. The 2004–2019 period is set by the availability of the satellite FLC record: as the statistical model is trained on this period, both the predictand and the predictors are deseasonalized over the same window to ensure they are defined consistently. The 1991–2020 period applies only to the SST-based indices (ONI, BNI, LUCI), which are not model predictors but are used to interpret the reconstructed variability; here we follow the definitions used in the literature (McPhaden et al. (2024) for the BNI, and the NOAA base period for the ONI) so that our indices remain comparable to published values. A single period could not be used for both, as no FLC observations exist before 2004, while defining the SST indices over 2004–2019 would depart from their standard definitions.
-Added in 2.3: "This reference period is set by the availability of the satellite FLC record, and applying it to both predictand and predictors ensures they are defined consistently over the training period."

Ln232-233: Li et al. (2025) is cited multiple times. Could the authors clarify the reason for the difference in the reported decline in fog amount after 1996? In particular, is this related to differences between low clouds and fog, or could it be attributed to methodological choices or other factors?

The two studies measure different quantities over different domains, which we think largely accounts for the apparent discrepancy. Li et al. (2025) report the annual amount of fog water collected at a single station (Gobabeb, some 60 km inland), whereas our reconstruction describes FLC cover anomalies, averaged over the coastal strip within 24 km of the coastline. A decline in collected fog water can result from fewer, shorter, or less productive fog events without a corresponding change in the frequency with which low cloud is present, and, as noted in Sect. 2, our satellite-based product cannot distinguish fog from low stratus that does not reach the surface. Gobabeb is furthermore located well beyond our study domain, at the inland margin of the fog gradient, where occurrence is lower and the marine layer only intermittently reaches the surface, making it particularly sensitive to changes in inland penetration that a coastal-strip average would not resolve. Finally, Li et al. (2025) attribute much of their post-1996 decline to air temperature and to local hydrological and vegetation processes (groundwater availability, plant transpiration), which are not represented in our cloud-controlling-factor framework. We have added a sentence to the manuscript noting these differences. It should also be noted that the record used by Li et al. (2025) is not homogeneous: it combines measurements from three different fog collectors, with the pre-1996 data subject to two successive conversions to make them comparable to the later instruments. The 1996 breakpoint coincides with a transition between measurement devices, which suggests the timing of the breakpoint would warrant further analysis before

being interpreted as a purely climatic signal.
-Added in 3.2: "However, this contrasts with Li et al. (2025), where in-situ fog water measurements show a decline in fog amount after 1996. These measurements are from Gobabeb, which, although within the latitudinal band of the CN region, lies some 60 km inland and therefore outside the study domain, which is restricted to the coastal strip within 24 km of the coastline. No corresponding break point is found in the reconstructed FLC cover time series, though the reconstruction carries substantial uncertainty. A change observed at Gobabeb, an inland site outside the study domain, would not necessarily be expected to emerge in this regional-average coastal reconstruction. Their record is also not a single continuous measurement, but a series assembled from successive fog collectors operating on different measurement principles. The 1996 step coincides with one of these instrument transitions, which calls for care in interpreting the break point."

Ln236 - Fig 4.: I would question whether Fig. 4 is needed, as it is only mentioned twice in the text. If retained, it should be used more effectively to summarize the contribution of each cloud-controlling factor and their general behavior.

Figure 4 is central to the study, as the decomposition of the reconstructed trends into individual predictor contributions is what allows the underlying processes to be identified; in particular, it shows that the near-zero total trends result from opposing contributions of increased stability and SST warming, which is one of the main conclusions of this work. We agree, however, that this was not adequately reflected in the text: while the entire discussion of the individual predictor trend contributions (EIS, R700, SST, U10, V10) is based on this figure, it was explicitly referenced only in a few places. We have added references to Fig. 4 throughout the corresponding paragraphs, and a sentence when the figure is introduced stating what the decomposition is intended to show.

Fig.6c. Ln.287. Please provide a clearer description of how the Pearson correlation coefficients are calculated as a function of monthly time lag, including how the lag is applied. If it is necessary, this information should be included in the Methods section.

The lagged correlations are computed by shifting the index series relative to the FLC anomaly series in one-month increments: for a lag of k months, the FLC anomalies are correlated with the index values from k months earlier, so that positive lags indicate the index leading the FLC anomalies. The correlation is evaluated over the overlapping portion of the two series at each lag. We have added a description of this procedure to the Methods section.
-Added in 2.2: "The relationship between the SST-based indices and the reconstructed FLC anomalies at different time lags is quantified using lagged Pearson correlations. Prior to this analysis, all series are smoothed with a 3-month centred running mean, consistent with the definition of the ONI. For a lag of k months, the FLC anomaly series is correlated with the index series shifted k months earlier, such that positive lags correspond to the index leading the FLC cover anomalies."

Fig 6 and 7. The correlation between FCL and ONI es low and scattered and the correlation between FLC and BNI is stronger. Even though anomalies time series are a nice way to represent these findings, adding a inset or small scatter plot between those variables highlighting cool and warm phases might improve the visualization.

We have added scatter plots of the monthly FLC anomalies against the respective index alongside each time series (panels b and d in Figs. 6 and 7), with points coloured by warm, cool, and neutral phase. These make the contrast between the two relationships directly visible: the ONI scatter is diffuse, with warm and cool phases overlapping substantially in FLC anomaly and only a weak slope, whereas the BNI and LUCI scatters show a clearer relationship with less overlap between phases. The corresponding figures for the MERRA-2 configuration in the Appendix have been updated in the same way.

Ln12, 49-50, 292-294 and 295-296: Please clarify which ENSO phase is associated with the enhancement of FLC. ENSO is typically characterized by warm (El Nino) and cold (La Nina) phases, and it would be helpful to specify the phase-dependent behavior in this context.

The relationship is positive: El Niño conditions are associated with enhanced FLC cover and La Niña conditions with reduced FLC cover, as is now visible in the scatter plots added to Figs. 6 and 7. We have revised the text at the locations noted to refer explicitly to El Niño conditions rather than to ENSO events or years, and have stated the phase-dependent behaviour explicitly in Sect. 3.3 and in the Conclusions.

3 Specific comments

Ln12-14: The statement on interannual FLC variability would benefit from clarification of whether the SST-FLC relationship, i.e., whether SST anomalies are positively or negatively associated with FLC occurrence.

The relationship is negative: warmer SST anomalies are associated with reduced FLC cover. We have made this explicit in the sentence in question.
-Modified in the abstract: "Benguela Niño events, associated with tropical water intrusion and SST warming, explain up to half of the interannual FLC variability in the Angolan Namib, with warmer SSTs reducing FLC cover."

Ln18: The word "harsh" may be perceived as subjective. A more specific or objective term would improve clarity.

We have replaced the subjective term with a more specific one.
-Modified in the introduction: "Despite these hyper-arid conditions, it is home to a large number of plant and animal species, several of which are endemic."

Ln29: The term "these clouds" is ambiguous. Please clarify whether it refers to advection fog, advected marine stratus clouds, fog, or high fog.

The sentence refers to the advected marine stratus clouds described in the preceding sentence. We have made this explicit.
-Modified in the introduction: "High fog is most frequent between September and March and extends up to 100 km inland."

Ln38-48: The paragraph initially introduces the fog hotspots, but the description subsequently shifts to upwelling and the intrusion of warm tropical waters. Explaining the relationship between these processes and fog occurrence would improve the coherence of the paragraph.

We agree that the connection between the upwelling regime and fog occurrence was left implicit. We have added a sentence introducing this link before the description of the two upwelling cells.

-Added in the introduction: ”Upwelling is a key component of fog formation in the Namib Desert, as marine air advected over cold upwelled water cools towards saturation (Olivier and Stockton, 1989).”

Ln53: The term “non-local effects” is somewhat vague. Please clarify which processes are included under this definition and provide representative examples.

By ”non-local effects” we mean the influence on FLC cover of conditions occurring outside the AN and CN regions themselves, which the use of spatial predictor fields allows us to capture. Examples include SST anomalies associated with upwelling cells located upwind of these regions, such as the Lüderitz cell relative to the CN, and large-scale circulation patterns extending across the domain. We have clarified this in the text.
-Modified in the introduction: ”We extend the traditional CCF framework to account for advection patterns and non-local effects, i.e. the influence of conditions occurring outside the AN and CN regions themselves, such as SST anomalies associated with upwelling cells located upwind of them, by using spatial predictor fields (Andersen et al., 2020; Ceppi and Nowack, 2021; Ceppi et al., 2026).”

Ln56: This further highlights the need for consistent terminology as mentioned in the comment on Ln38-48. Please ensure that “marine low clouds” is either clearly defined or aligned with the previously used terminology, and adjust accordingly throughout the manuscript.

We use ”marine low clouds” when referring to the broader class of low clouds over the ocean addressed by the cloud-controlling factor literature, and FLC for the fog and low clouds analysed in this study, as defined in Sect. 1. The distinction is intentional here: the hypothesis being tested is precisely whether the sensitivities we derive for FLC match those established for marine low clouds, which would support a marine, advective origin for the FLC observed in the Namib. We have checked the manuscript and confirm that ”marine low clouds” is used only in reference to the broader literature, and FLC throughout when referring to our own analysis.

Ln69-71: The reference to Malik et al. (2026) appears somewhat out of context in this paragraph. It introduces an alternative approach for estimating cloud base height, but this method is not used in the present study and is immediately followed by its exclusion. Clarifying the purpose of this citation or better integrating it into the argument would improve the flow of the paragraph.

The citation was intended to acknowledge that separating fog from low stratus is possible in principle, so that grouping them is a deliberate choice rather than an unavoidable limitation of the retrieval. We agree the sentence interrupted the flow and have shortened it.
-Modified in 2.1: ”It should be noted, however, that this satellite-based method cannot on its own distinguish between fog and low stratus clouds, as it is not straightforward from a satellite perspective to determine whether the cloud base is in contact with the surface. Cloud base height can be estimated by combining the satellite product with additional near-surface relative humidity data (Malik et al., 2026), but such an estimate is not required for our analysis, and fog and low clouds are therefore grouped together throughout.”

Fig 1. In relation to the general comment on Ln75-77, please add boxes indicating the spatial domains used for the domain-averaged calculations.

The red outlines in Fig. 1 now show the domains used for the regional averaging, i.e. the grid cells within 24 km of the coastline between 15–17 °S (AN) and 22–24 °S (CN).

Ln189-191: The reference to a weakened South Atlantic High is not fully supported by the analyses presented, as pressure systems and subsidence are not explicitly examined. If this interpretation is based on previous literature, please include relevant references to support this statement.

We agree that the reference to a weakened South Atlantic High is not supported by the analyses presented, as pressure systems are not examined in this study, and we have removed it. We have revised the paragraph to describe the V10 structure as it appears in the coefficient fields, noting that it consists of negative values over the region and a positive band upwind to the south, and that it is consistent across all four configurations. We suggest a possible link between the upwind positive band and upwelling, and relate the negative values over the region to Andersen et al. (2020), who found less pronounced coast-parallel winds on fog days in the CN, associated with synoptic-scale disturbances producing a northerly wind anomaly ahead of the trough that favours stratus formation and onshore advection.
-Modified in 3.1: "Finally, for V10 (Fig. 2e), the sensitivities are weaker than those for U10, with negative values over the region itself and a broader band of positive values farther south. This structure appears in all four configurations and shifts northward in the AN region (See Appendix A), like the other sensitivity patterns. The positive area lies upwind of the region, where stronger southerly winds favour coastal upwelling and cooler SSTs, which in turn favour FLCs. The negative values over the region itself are consistent with Andersen et al. (2020), who found less pronounced coast-parallel winds on fog days in the CN, associated with synoptic-scale disturbances producing a northerly wind anomaly ahead of the trough that favours stratus formation and onshore advection."

Ln197: Please clarify which features are referred to as "the features discussed above", as this is not clearly specified.

The phrase referred to the sensitivity patterns described in the preceding paragraphs for each predictor. We have named them explicitly.
-Modified in 3.1: "Compared with CN, the AN sensitivity patterns are systematically shifted northward, toward the AN region: this applies to the EIS, R700, SST and wind sensitivities described above."

Fig. 3. It would be useful to include observed fog occurrence anomalies in order to better evaluate which configuration performs best.

As noted in the manuscript, the final reconstruction (Fig. 3) uses fold-averaged sensitivities, in which each month from 2004–2019 contributes to the training data in all but one of the six cross-validation folds, making the resulting reconstruction non-independent. A fully out-of-sample reconstruction can instead be obtained by combining the predictions from all test folds, yielding correlations with the observations of $r = 0.64$ for AN-ERA5, $r = 0.62$ for AN-MERRA-2, $r = 0.61$ for CN-ERA5, and $r = 0.63$ for CN-MERRA-2. Using fold-averaged sensitivities ensures a continuous time series from 1982 to 2019, which allows the analysis of interannual variability and long-term trends, but as these fold-averaged values are not

fully independent, we consider it potentially misleading to overlay the observations directly on Fig. 3.
To address the reviewer's request while keeping this distinction clear, we have added Fig. B1 (Appendix), showing the observations against both the fully out-of-sample prediction ($\hat{y}$) and the fold-averaged reconstruction, at annual resolution, for both regions and reanalyses. As expected, the fold-averaged reconstruction correlates much more closely with the observations ($r = 0.88$–0.94) than the genuinely out-of-sample prediction does ($r = 0.61$–0.64).
-Added Figure B1

Line 256-257: Please clarify the sign of the U10 and V10 trend contributions (i.e., which is positive and which is negative), as this is currently not specified despite stating that they compensate each other.

This paragraph has been revised and now states the signs explicitly: U10 contributions are negative or near-zero while V10 contributions are positive in three of the four configurations (AN-MERRA-2, CN-MERRA-2 and AN-ERA5), whereas CN-ERA5 shows the opposite pattern, with a positive U10 and a negative V10 contribution. The individual values are given for each configuration.

Ln323-325: This final statement reads more like a conclusion than a discussion point. Please consider moving it to the Conclusions section or remove/rephrase it.

We agree and have removed this closing statement, as the point is already made in the Conclusions.
-Removed: "Overall, these two indices highlight the importance of regional SST pattern variability on FLCs and, more specifically, emphasize the roles of both tropical warm water intrusions and local upwelling cells in partially explaining the interannual variability of FLCs in the region."

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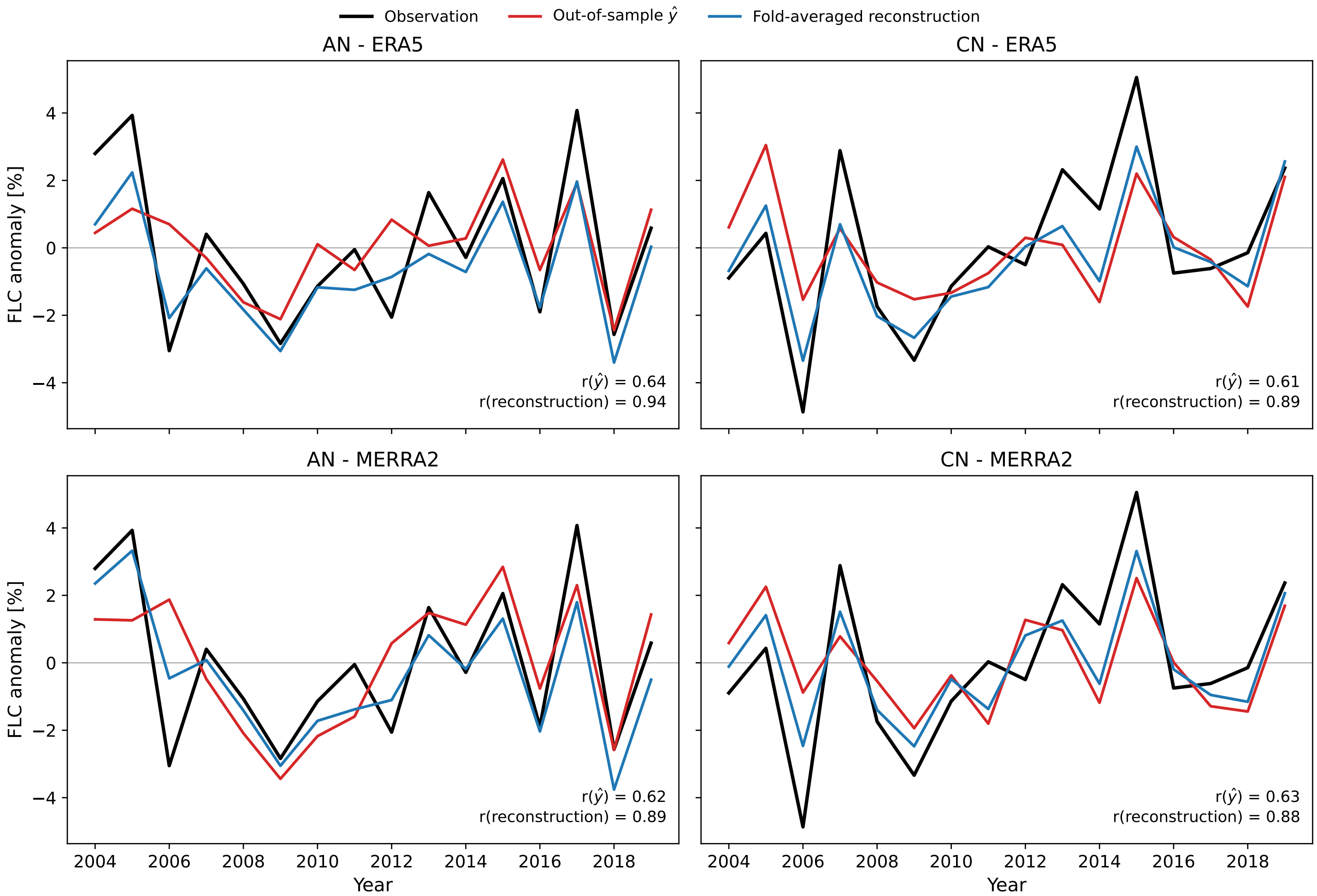

Figure 2: Comparison of observed annual FLC anomalies against the fully out-of-sample prediction ($\hat{y}$, red) and the fold-averaged reconstruction used in Fig. 3 (blue), for each region and reanalysis. The fold-averaged reconstruction is not independent of the observations and correlates more closely with them than the genuinely out-of-sample prediction, illustrating why Fig. 3 does not overlay observations directly.

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