Response to Reviewer #1

Dear Reviewer,

Thank you for the time and effort you have dedicated in providing valuable feedback on the manuscript. We have been able to incorporate most of the suggestions provided. The manuscript has clearly benefitted from the review process, and we hope you also find that the suggestions have made our manuscript suitable to publication. All authors agree with the modifications made to the manuscript. The comments by the referee are reported in italic font followed by our response. The line numbers reported in the answers referred to the location in the revised manuscript. The new supplementary figures are also provided at the end of this document.

Major Comments:

> *The definition of upwelling, non-upwelling, and oceanic locations is indeed interesting, but it does not look very statistically robust. Are these locations constant in time? If you calculate the correlations for different periods, are the locations the same? This a very important potential issue that should be addressed.*

We understand your concern about the statistical robustness of our location. In order to address this issue, we performed two analyses. The first analysis is similar to the one used in (Barton et al., 2013) to build confidence in the trend. The figure beneath shows how in sub-series shorter than 15 years (30 years) in the case of the norhern (southern) hemisphere's EBUS trends varied widely. However, we found that with sufficiently long time series, the upwelling cell trends stabilized and became independent of the period. The confidence intervals reveal statistical significance at 90% in all the major upwelling cells used in this study (exact values of the trend will be added in figure 4).

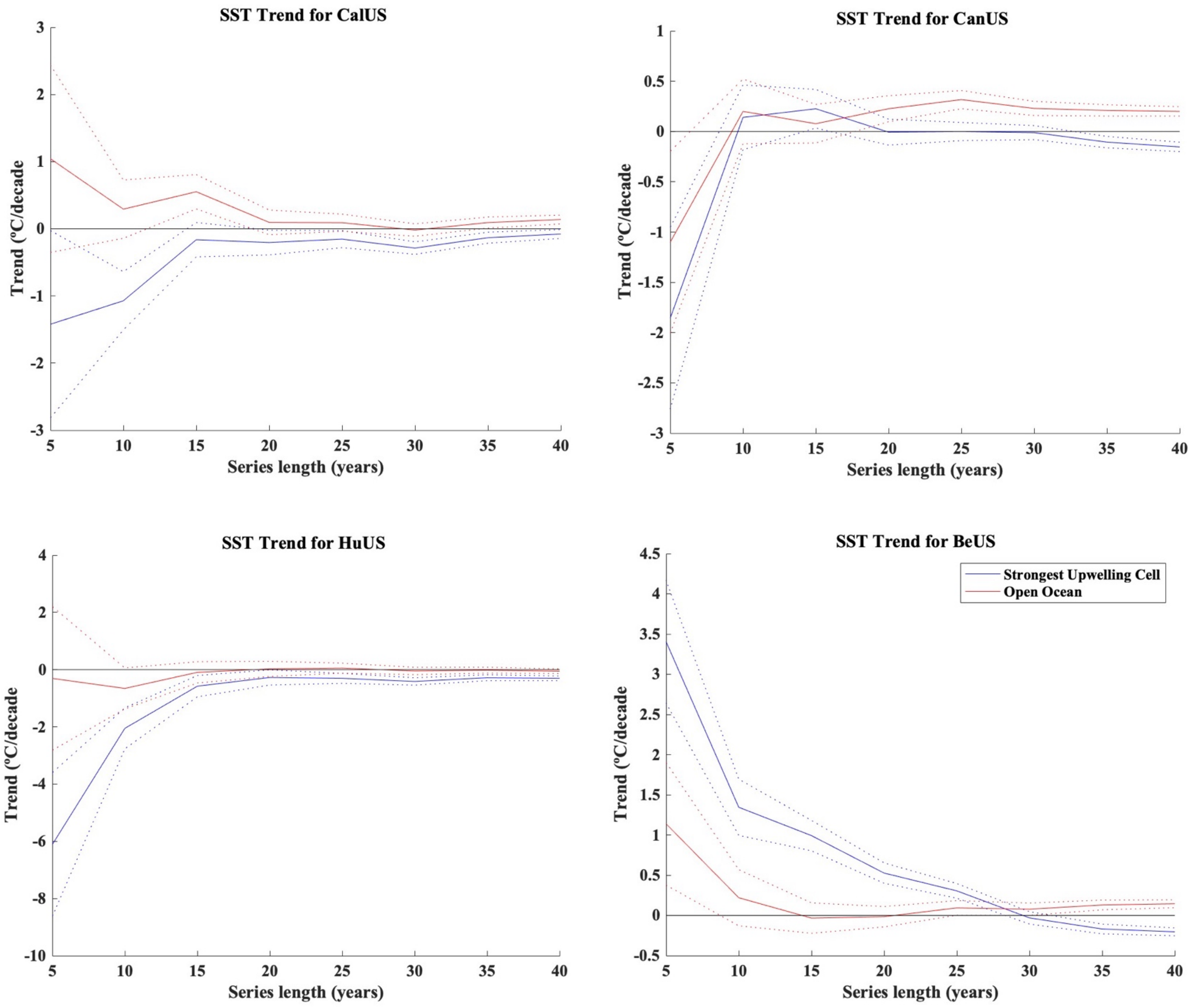
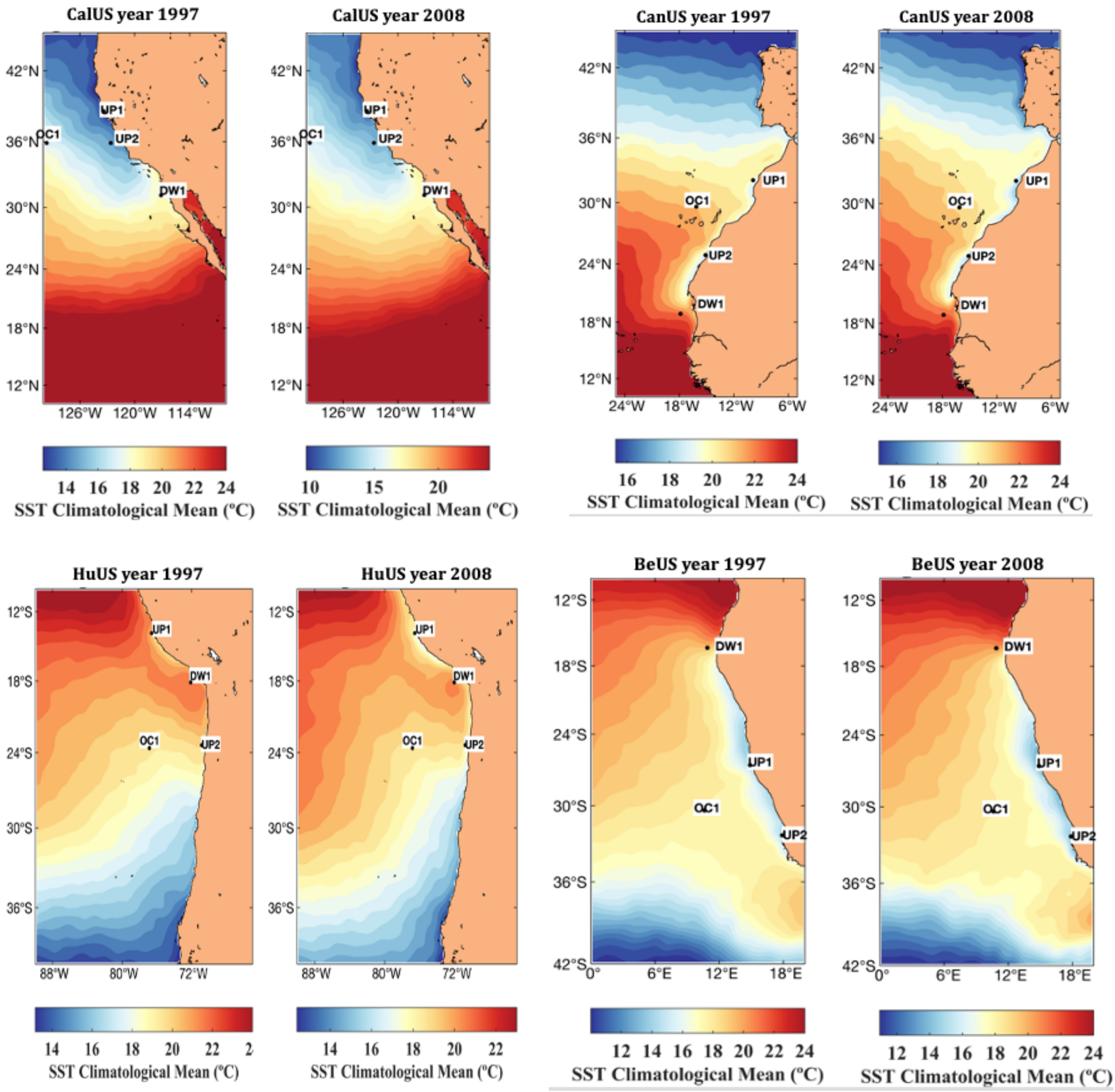


Fig S5: Trend values calculated as a function of series length for SST trends in the higher upwelling cell and open ocean areas. Trend values are shown as solid lines and 90% confidence limits as broken lines.

The second analysis performed consisted in analyzing the SST field to account for the spatial stability of the location. Thus, we examined the mean field in anomalous years, when the variability of the upwelling center should be maximum, like El Niño and La Niña years (1997 and 2008, respectively, see figure beneath). For both cases the locations of the upwelling centers are the same even in El Niño years, although the extension of the upwelling center may vary.



Mean SST fields comparison for El Niño (1997) and La Niña (2008) year in each EBUS.

In addition, and attending to a comment of reviewer #2 we analyzed the change in the angle due to changes in the latitude of the upwelling center,and it suggests that the points are representative of the permanent upwellings. Beneath the new Figure Fig 6 added on the manuscript.

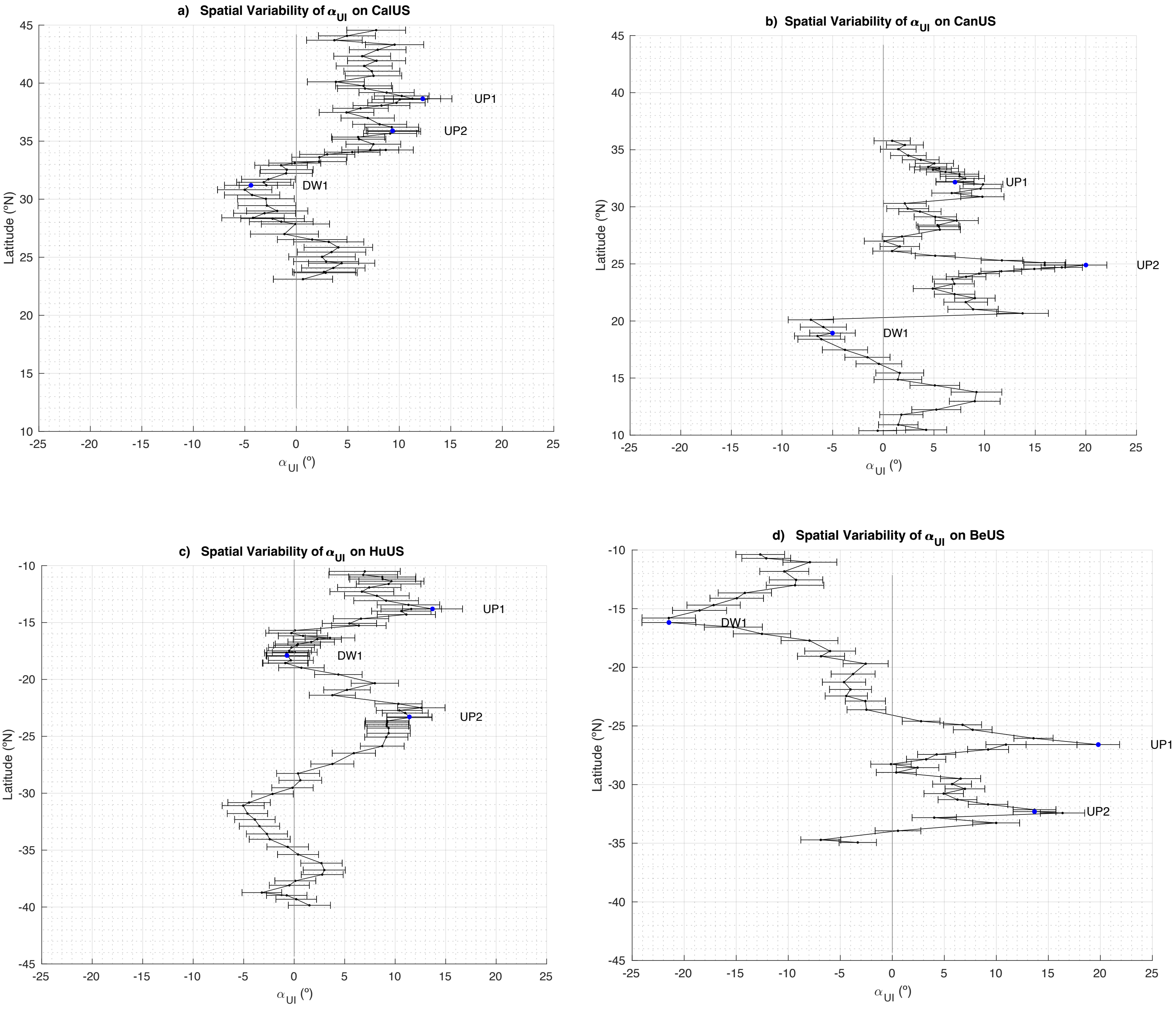


Fig 6: Spatial distribution of the α_{UI} (over the period of 1982-2021) along the coast for CalUS (a), CanUS (b), HuUS(c) and BeUS(c). The α_{UI} is calculated between grid points along the coast and OC1, with error bars representing the Monte Carlo error for each grid point. Key locations UP1, UP2, and DW1 are highlighted with blue markers.

You say that analyzing the upwelling locations is better that using spatially-averaged regions, you also discuss other papers, but what about your own results for averaged regions? You should contrast your current results to larger averaged regions. And *remember, one advantage (a very important indeed) is that the spatial average should reduce errors.*

Thank you for your suggestions. We agree with the reviewer on the importance of providing additional information regarding the effects of averaged regions on our results. While spatial averaging can reduce errors, it is crucial to focus on upwelling regions to fully capture the main dynamical processes. To address this issue, we used four different averaging zones in our study. Zone A, encompassed a large average of the whole coastal region. Zone B, covered an area just large enough to include the three main coastal upwelling areas (UP1, UP2 and DW1). Zone C, focused around the two main upwelling centers of each region, and Zone D, targeted only the strongest upwelling center. The results are summarized in the following table:

Zone	CalUS	CanUS	HuUS	BeUS
A	2º±2º	2º±2º	3º±2º	1º±2º
B	3º±2º	2º±2º	4º±2º	2º±2º
C	8º±3º	7º±2º	9º±2º	9º±2º
D	10º±3º	15º±2º	12º±3º	16º±2º
This Study	11º±3º	20º±2º	14º±3º	21º±2º

Table S1: α_{UI} estimation for different portions of the coastal region: the whole coastal area, Zone A, covered an area just large enough to include the three main coastal upwelling areas (UP1, UP2 and DW1), Zone B, focused around the two main upwelling centers of each region, and Zone C, and targeted only the strongest upwelling center, Zone D. Last Row show the results obtained in figure 5.

When we averaged over larger regions, ignoring the specific dynamics of the upwelling zones, our results remained consistent regardless of the area size. This suggests that larger spatial averaging does indeed reduce random errors. However, this approach tends to obscure the finer-scale dynamics and local variations that are critical for understanding upwelling processes.

In contrast, when we focused on specific upwelling zones, selecting the areas around upwelling centers (Zones C and D), our results were very similar to those obtained without averaging areas. This indicates that focusing on precise upwelling locations captures the essential features of the upwelling dynamics, providing results that are both accurate and representative of the localized processes. Based on these results, we have decided to add these results to the discussion in line 442 as follow:

'...Additionally, we tested the effects of averaging areas around the upwelling cells to build the index (see supplementary material, Fig S5). We compare the results obtains in this manuscript with the index recalculated for different average portions of the coastal regions in each EBUS. First, we computed the index for the entire coastal region, referred to as zone A in the supplementary material. The results in zone A remained positive although the mix of the different dynamical regions in each area resulted in non-significant values. Similarly, zone B is a large average region but covering only the three different dynamical areas in this study. Again, the results were positive but not significant when using large averaged portions of the coastal regions. In contrast, focusing on the surrounding of upwelling zones (zone C which includes both upwelling center, UP1 and UP2, and zone D, which includes only the surroundings of the main upwelling center), made the intensification more evident, especially in zone D where results are the closest values compare to the results in this manuscript. Moreover, we verified the stability of the trends both spatially and temporally by performing the analysis of Barton et al. (2013) across all EBUS (see supplementary material Fig S5)'.

> *What about the significance test for the trends? Some trend values seem to be too small their values should be shown to be significant.*

The 90% confidence is added to figure 4 for reliability.

> *Table 1: Plots of satellite-data comparisons should be included; Table 1 should be a complement for these plots.*

Thank you for your suggestion. We agree that the comparison is relevant for the study and that it is necessary to support the tables with plots of satellite data comparison. However, they will be added to supplementary information for the sake of text clarity.

> *The proposed index is potentially useful, but it does not provide a convincing argument to confirm the Bakun hypothesis. The analysis of an additional variable, for example sea-level pressure, could be useful to confirm such a hypothesis. Other explanations for the upwelling (e.g., Arellano and Rivas, 2019).*

This is a fair point. While SST is useful and reliable for inferring upwelling intensification, it does not provide enough information about its drivers. To address this, we analyzed the trends in pressure gradients from 1982 to 2023 using two well-known datasets: ERA5 and NCEP, to complement our findings on the α_{UI}.

For ERA5, we found positive and significant trends (see table beneath) for all EBUS. Although small, these trends are all significant. On the other hand, the NCEP dataset shows no significant trend for the BeUS but stronger trends than ERA5 for the other EBUS. However, due to its coarser resolution (2.5º) compared to ERA5 (1/4º), NCEP data is arguably less reliable. Nevertheless, these results support an intensification of the pressure gradient, aligning with Bakun's hypothesis of enhanced upwelling-favorable winds.

	CalUS (mb/decade)	CanUS (mb/decade)	HuUS (mb/decade)	BeUS (mb/decade)
ERA5	0.24 (0.039)	0.04 (0.017)	0.33 (0.038)	0.15 (0.051)
NCEP	0.37 (0.073)	0.17 (0.034)	0.54 (0.070)	-0.02 (0.072)

Table 3. Values of the trend, over the period 1982-2023, for the ERA5 (first row) and NCEP (second row) for all the EBUS. Parentheses enclose spatial standard deviation.

Additionally, as suggested by studies such as Rykaczewski et al. (2015) and Arellano and Rivas (2019), the migration of large-scale pressure systems offers an alternative explanation for upwelling intensification trends. Their research indicates that shifts in pressure systems can significantly impact upwelling regions, influencing wind patterns and subsequently upwelling processes. However, there are still open questions about the nature of the intensification, as a poleward migration of high-pressure systems could also contribute to these trends. Therefore, a new section will be included in line 386 to accommodate the new results:

"4.5. SLP Gradients

The coastal upwelling intensification postulated by Bakun (1990), would involve a stronger increase of near-surface temperature over land than over the ocean, which would lead to an intensification of the continental thermal low-pressure system relative to the ocean. To test this driver mechanism, we have calculated the trends

(Fig 7) of the pressure gradient between the continental thermal low and the oceanic high pressure.

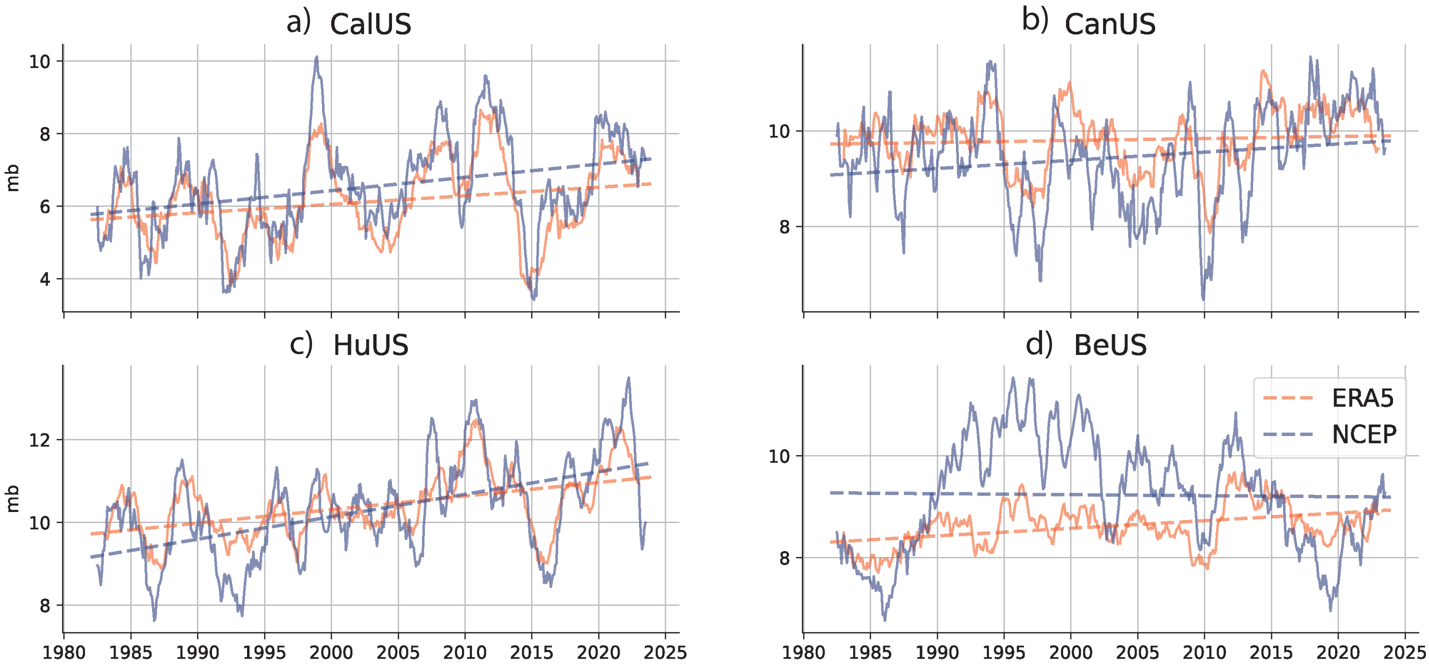


Fig 7: EBUS SLP gradients trends and temporal series for NCEP (blue lines) and ERA5 (red lines) datasets over the period 1982- 2023.

For ERA5, we found positive and significant trends (see Table 3) for all Eastern Boundary Upwelling Systems (EBUS). Specifically, the trends in SLP gradients are 0.24 mb/decade (with a spatial standard deviation of 0.039 mb/decade) for CalUS, 0.04 mb/decade (0.017 mb/decade) for CanUS, 0.33 mb/decade (0.038 mb/decade) for HuUS, and 0.015 mb/decade (0.051 mb/decade) for BeUS. On the other hand, the NCEP dataset shows no significant trend for the BeUS but stronger trends than ERA5 for the other EBUS, with 0.37 mb/decade (0.073 mb/decade) for CalUS, 0.17 mb/decade (0.034 mb/decade) for CanUS, 0.54 mb/decade (0.070 mb/decade) for HuUS, and -0.02 mb/decade (0.072 mb/decade) for BeUS. However, due to its coarser resolution (2.5º) compared to ERA5 (0.25º), NCEP data is arguably less reliable."

In Section 5 we have included the following discussion in line 543:

‘The SST changes in the EBUS respond mainly to changes in the upwelling processes which are ultimately driven by the pressure gradients. We analyzed the pressure gradients trends in all four EBUS. Our findings further support the intensification of the pressure gradients driven by climate change, as stated by (Bakun, 1990). However, there are probably other contributors to the intensification of the upwellings. Some researchers question whether the impacts of differential heating on the pressure gradient force drives intensification of coastal upwelling. Rather, a complementary hypothesis proposes that evidence of an intensifying pressure gradient force is limited to poleward migration of the Hadley Cell (Arellano & Rivas, 2019; Rykaczewski et al., 2015; Wang et al., 2015). Nevertheless, these projections are only supported by observational records in the Humboldt and Benguela Systems, (Sydeman et al., 2014). In contrast, we have tested this hypothesis on the historical record by computing the latitudinal distribution of αUI. The results shown in Fig 6 partially agree with Rykaczewski et al, (2015), as only CalUS and BeUS presented a poleward intensification of α_{UI}. To further understand the drivers of these changes, we examined the spatial stability of the trends in the SLP continental-oceanic gradient was also tested using Monte Carlo simulation. The discrepancy between the latitudinal distribution of α_{UI} and the small standard deviation of trends around the cores of the pressure systems suggests that the hypothesis of poleward displacement of the high-pressure systems remains inconclusive.’

Minor Comments:

> *Methods: You could include the historical hydrographic data available at NOAA – World Ocean Database (WOD).*

Thank you for your suggestion. The SST data set that we have used has been calibrated using in-situ observations (Reynolds et al., 2007), and additionally we have used in-situ observations to demonstrate that the data set is representative of the SST in-situ observations. Therefore, we have used all the historical hydrographic data in the area to validate the results.

> *93: Specify the period used to calculate the monthly climatology.*

The period will be added in line 158 as: “...NOAA SST analyses data (1982-2021) into…”

119: "unitary vector normal (n) to", unit vector (n) normal to…

Thank you for your suggestion, this change will be incorporated to the manuscript.

122: "atan2" is not a standard notation for the arc tan.

We thank the reviewer for pointing this out. The notation was made to clarify the lector that we are using the four-quadrant arc tangent which is a function of two arguments that allow identification of the angle sign. However, to respect standard notation we will include the clarification as a footnote as follow in line:

$$\text{“}\alpha_{UI} = arctan^{*}\left(\frac{((\overline{Up}\ x\ \overline{Oc})\cdot\bar{n}\ )}{\overline{Up}\cdot\overline{Oc}}\right) = \ arctan\left(\frac{|\overline{Up}||\overline{Oc}|\ \ sin(\alpha_{UI})}{|\overline{Up}||\overline{Oc}|\ cos(\alpha_{UI})}\,|\bar{n}|\cos(\beta)\right)$$

[*] We used the four-quadrants arc tangent in this analysis since it allows to determine the sign of the angle based on the signs of the arguments."

134: What about error propagation?

Thank you for your comment. We have carried out Monte Carlo simulation as described in section 3.3 which already accounts for the full variability of both temporal series. We will rephrase the text in line 197:

'…We also conducted a probabilistic assessment of uncertainties for α_{UI}, taking into account the uncertainties associated with upwelling and open ocean SST series. We performed error estimation using the Monte Carlo method: residual errors for individual data points were separately and randomly sampled 10,000 times within their respective $\overline{Up}$- and $\overline{Oc}$- uncertainty ranges. These sampled errors were then used to calculate αUI. The standard deviation of the 10,000 simulations represents the uncertainty of α_{UI}.'

137-138: "…shifts northward in summer", this is not accurate, especially in the southern portion of the upwelling system

Thank for you comment. The text will be modified as follow: "…CalUS. In summer the strongest winds occur…"

141: "…and Point Conception", south of it, the wind's seasonal variability is different.

Thank for you comment. The text will be modified accordingly

Caption of Figure 2: "…buoys", moorings.

Following the reviewer's comment, we have modified Figure 2 caption accordingly

> *210: "…this areas", these areas.*

The text will be modified accordingly

> *Section 4.2 (and rest of the text): Three decimals in the trend values is probably excessive, two should be enough or justify why you use three. Also, for example, a trend of -0.2 *C/decade should be -0.20 *C/decade or, if three decimals are used, -0.200*C/decade; remember, significant decimals.*

Following the reviewer's suggestion two decimals will be implemented (using truncation) when possible (e.g. 0.007 ºC/decade).

> *243: "Luderitz cell", include a reference.*

The following references will be included in section 3.4 and 4.2:

(Andrews & Hutchings, 1980; Lutjeharms & Meeuwis, 1987; Peard, 2007)

> *295: "spikes", peaks. "…Niño appeared…", …Niño that appeared…*

Thank for your suggestions. "spikes" will be replaced by "peaks"

> *364: Define IPO.*

Following reviewer suggestion the definition of IPO will be added in line 515: "the Interdecadal Pacific Oscillation (IPO)"

> *366-372: Specify the periods used for the trend calculations in those references.*

Period now are specified in the text

References:

Andrews, W. R. H., & Hutchings, L. (1980). Upwelling in the Southern Benguela Current. *Progress in Oceanography*, *9*(1), 1–81. https://doi.org/10.1016/0079-6611(80)90015-4

Arellano, B., & Rivas, D. (2019). Coastal upwelling will intensify along the Baja California coast under climate change by mid-21st century: Insights from a GCM-nested physical-NPZD coupled numerical ocean model. *Journal of Marine Systems*, *199*, 103207. https://doi.org/10.1016/J.JMARSYS.2019.103207

Bakun, A. (1990). Global climate change and intensification of coastal ocean upwelling. *Science*, *247*(4939), 198–201. https://doi.org/10.1126/science.247.4939.198

Barton, E. D., Field, D. B., & Roy, C. (2013). Canary current upwelling: More or less? *Progress in Oceanography*, *116*, 167–178. https://doi.org/10.1016/j.pocean.2013.07.007

Lutjeharms, J. R. E., & Meeuwis, J. M. (1987). The extent and variability of South-East Atlantic upwelling. *South African Journal of Marine Science*, *5*(1), 51–62. https://doi.org/10.2989/025776187784522621

Peard, K. R. (2007). *Seasonal and interannual variability of wind-driven upwelling at Lüderitz, Namibia*. http://hdl.handle.net/11427/6498

Reynolds, R. W., Smith, T. M., Liu, C., Chelton, D. B., Casey, K. S., & Schlax, M. G. (2007). Daily high-resolution-blended analyses for sea surface temperature. *Journal of Climate*, *20*(22), 5473–5496. https://doi.org/10.1175/2007JCLI1824.1

Rykaczewski, R. R., Dunne, J. P., Sydeman, W. J., García-Reyes, M., Black, B. A., & Bograd, S. J. (2015). Poleward displacement of coastal upwelling-favorable winds in the ocean’s eastern boundary currents through the 21st century. *Geophysical Research Letters*, *42*(15), 6424–6431. https://doi.org/10.1002/2015GL064694

Sydeman, W. J., García-Reyes, M., Schoeman, D. S., Rykaczewski, R. R., Thompson, S. A., Black, B. A., & Bograd, S. J. (2014). Climate change and wind intensification in coastal upwelling ecosystems. *Science*, *345*(6192), 77–80. https://doi.org/10.1126/science.1251635

Wang, D., Gouhier, T. C., Menge, B. A., & Ganguly, A. R. (2015). Intensification and spatial homogenization of coastal upwelling under climate change. *Nature*, *518*(7539), 390–394. https://doi.org/10.1038/nature14235

Response to Reviewer #2

Dear reviewer 2,

We would like to acknowledge the manuscript's careful reading and the constructive comments that substantially helped to improve and clarify the paper. Detailed answers to each of your comments can be found hereafter. All authors agree with the modifications made to the manuscript. The comments by the referee are reported in italic font followed by our response. The line numbers reported in the answers referred to the location in the revised manuscript. The new supplementary figures are also provided at the end of this document.

> *General Comments:*
>
> *The results and methods presented in this paper are interesting and valuable for understanding the evolution of EBUS under climate change. However, the manuscript should be accepted only after major revisions are addressed. Below are specific comments and suggestions for improvement:*

Thank you very much for your comment. We hope to address all your concerns and suggestions properly.

> *1. You have used only two points for each EBUS. While you have justified this decision, I recommend including a map of angles for each grid point along the EBUS coast versus one open ocean point (or versus an averaged time series in the open ocean). This could potentially prove your hypothesis in other regions as well, demonstrating the validity over the entire coastal area and possibly providing insight into the spatial distribution.*

We appreciate your thorough review and insightful recommendation. We agree that incorporating this suggestion would enhance our discussion, particularly regarding the hypothesis of the poleward migration of the atmospheric highs from Rykaczewski et al. (2015). Attending to this suggestion, we have calculated the latitudinal distribution of the α_{UI} (see figure below). As expected, the latitudinal distribution is not homogeneous, and the locations of the upwelling intensification (for example 35-45ºN on CalUS) match with our chosen locations based on historical publications on the area (E.g. UP1 and UP2 on the CalUS are at 38ºN and 36ºN, respectively). Our results assess the latitudinal distribution of the upwelling intensity proxy, based on historical records. As the figure and findings from this suggestion are quite interesting, we have decided to add to the manuscript with a new dedicated section in line 365:

"4.5. Latitudinal distribution of α_{UI}

Many authors have previously tested the Bakun hypothesis, providing little consensus on both historical and projected records (Barton et al., 2013; Belkin, 2009; McGregor et al., 2007; Sambe et al., 2016; Sydeman et al., 2014). Such controversy has yielded alternative hypotheses to explain changes observed in the magnitude and timing of upwelling processes. Rykaczewski et al. (2015), suggests an alternative mechanism to the intensification of the upwelling process. They suggest a poleward shift of the oceanic high-pressure system which would stimulate latitude-dependent changes in the upwelling winds. To address this, we have calculated the latitudinal distribution of the α_{UI} (see Fig 6) in each EBUS. The spatial variability of the upwelling intensity proxy, $\alpha_{UI,}$ reveals distinct patterns and regional differences. In the CalUS, upwelling intensification demonstrates consistent upwelling activity between 35°N to 45°N with α_{UI} values reaching up to approximately 10° (Fig 6a). Conversely, in the CanUS, significant upwelling intensification is observed between 20°N and 30°N, with α_{UI} values peaking at 20º and in locations consistent with our dynamical analysis based on literature review (Fig 2b, UP1 and UP2). Similarly, in the HuUS upwelling intensification is confined to low latitudes (10-20 ºS, Fig 6c), and the values are close to those of the CalUS, (index values around 10º), as seen in the previous section. In contrast with the other regions, the BeUS shows intensification at high latitudes with maximum values of α_{UI} (20º) in the upwelling center of this region – Lüderitz upwelling center at 25ºS and Cape Columbine (around 32ºS)-. While results of BenUS and CalUS appear consistent with the findings by Rykaczewski et al, (2015), there is no supportive evidence in the other regions. To elucidate the possible mechanism responsible for such differences we will attend to the driver of the favorable-upwelling wind, the sea level pressure gradient"

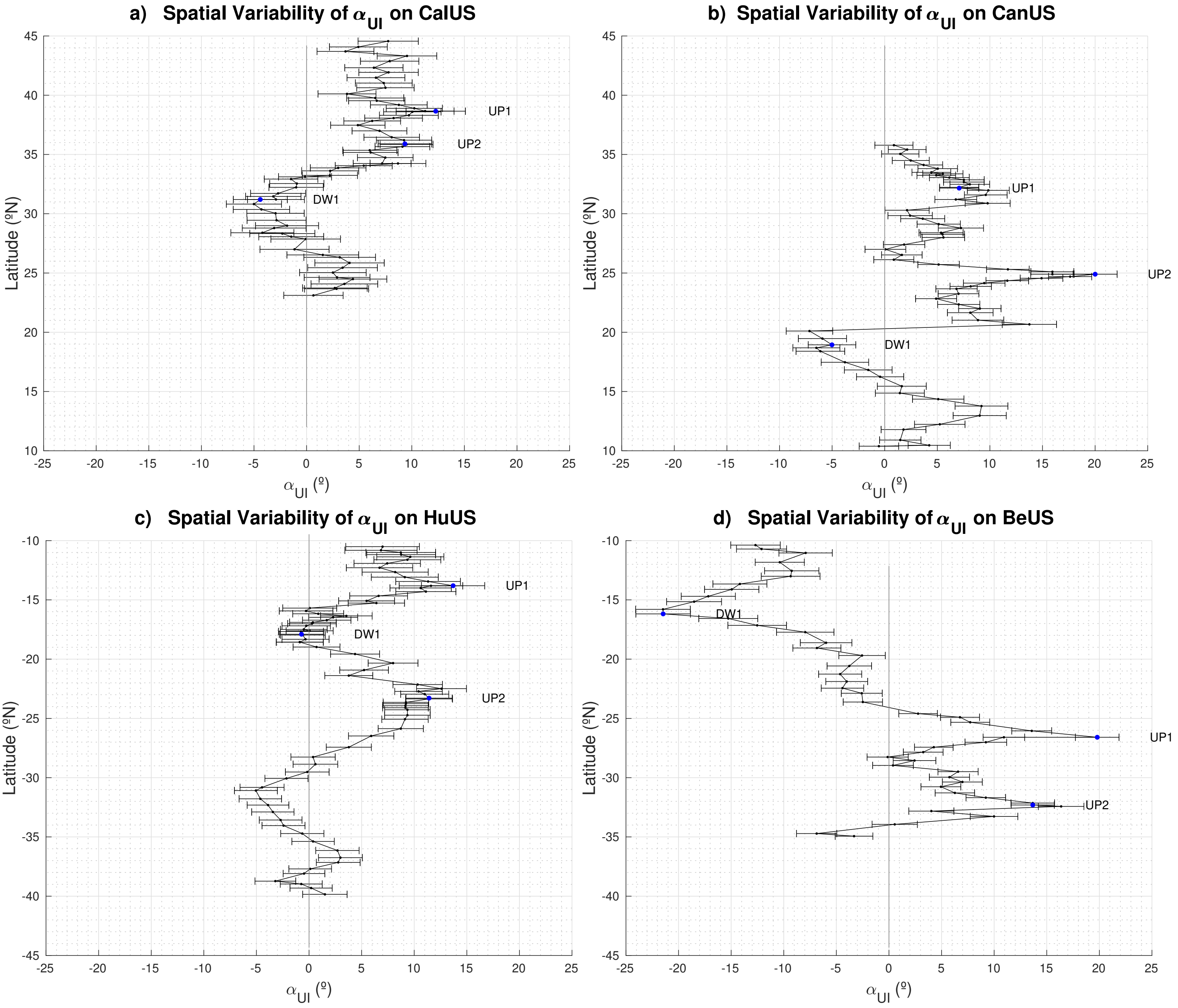


Fig 6: Spatial distribution of the α_{UI} (over the period of 1982-2021) along the coast for CalUS (a), CanUS (b), HuUS(c) and BeUS(c). The α_{UI} is calculated between grid points along the coast and OC1, with error bars representing the Monte Carlo error for each grid point. Key locations UP1, UP2, and DW1 are highlighted with blue markers.

2. As review 1 pointed out, provide an estimation of this new index using averaged time series for both the upwelling areas and the open ocean areas.

We kindly refer reviewer 2 to the answer given to reviewer 1 about the index recalculation using an average time series. Here we provide the response to reviewer 1:

'Thank you for your suggestions. We agree with the reviewer on the importance of providing additional information regarding the effects of averaged regions on our results. While spatial averaging can reduce errors, it is crucial to focus on upwelling regions to fully capture the dynamic processes at play. To address this, we used four different averaging zones in our study. Zone A, encompassed a large average of the whole coastal region. Zone B, covered an area just large enough to include the three main coastal upwelling areas (UP1, UP2 and DW1). Zone C, focused around the two main upwelling centers of each region, and Zone D, targeted only the strongest upwelling center.

When we averaged over larger regions, ignoring the specific dynamics of the upwelling zones, our results remained consistent regardless of the area size. This suggests that larger spatial averaging does indeed reduce random errors. However, this approach tends to obscure the finer-scale dynamics and local variations that are critical for understanding upwelling processes.

In contrast, when we focused on specific upwelling zones, selecting the areas around upwelling centers (Zones C and D), our results were very similar to those obtained without averaging areas. This indicates that focusing on precise upwelling locations captures the essential features of the upwelling dynamics, providing results that are both accurate and representative of the localized processes.’

Zone	CalUS	CanUS	HuUS	BeUS
A	2º±2º	2º±2º	3º±2º	1º±2º
B	2º±2º	3º±2º	4º±2º	2º±2º
C	8º±3º	7º±2º	9º±2º	9º±2º
D	11º±3º	16º±2º	10º±3º	17º±2º
This Study	11º±3º	20º±2º	14º±3º	21º±2º

Table S1: α_{UI} estimation for different portions of the coastal region: Zona A, for the whole coastal area; Zone B just covered an area just large enough to include the three main coastal upwelling areas (UP1, UP2 and DW1); Zone C, include an area around the two main upwelling centers of each region; and Zone D, only include the strongest upwelling center.

3. The figures in the manuscript are blurry. Ensure that all figures are of high resolution and clearly labeled for better readability.

We apologized for the inconvenience. We will provide with high resolution figures in the next update of the manuscript.

4. Explain the methodology used to assess the significance of your results. This is crucial for validating the findings and understanding their robustness.

We apologize for the misunderstanding and appreciate the opportunity to further clarify our methodology. We used two methodologies for uncertainty assessment. For the SST trend error estimation, we applied the 90% confidence interval. For the index, as explained at the end of section 3.3, we used a Monte Carlo simulation to estimate the error given that it is a function of two trends. The text will be modified to clarify the method used as follows in line 197:

'…We also conducted a probabilistic assessment of uncertainties for α_{UI}, taking into account the uncertainties associated with upwelling and open ocean SST series. We performed an error estimation using the Monte Carlo method: individual data points were separately and randomly sampled 10,000 times within their respective $\overline{Up}$- and $\overline{Oc}$-uncertainty ranges. These new sampled series were then used to calculate α_{UI}. The standard deviation of the 10,000 simulations represents the uncertainty of α_{UI}…'

Following reviewer 1 recommendation, we included a new section to the manuscript analyzing the SLP gradient to complement the proposed index and assess the possible drivers of the upwelling intensification. Since we also want to test the hypothesis of a poleward migration of the atmospheric centers (Rykaczewski et al., 2015), we tested the error of the SLP gradients trends computing the gradients within a 3° radius from the core of both continental and oceanic pressure systems, as a migration of the pressure systems should increase the standard deviation of the trends in the surroundings on its core. The following paragraph is added to clarify the methodology of SLP analysis in line 170:

'Additionally, to assess the drivers of change in upwelling intensity, we calculated the sea level pressure (SLP) gradients for each EBUS. The gradients were calculated between the cores of the high- and low-pressure systems (exact positions provided in supplementary material, Fig. S1). To corroborate the Rykaczewski hypothesis, we used the spatial standard deviation. A displacement of the pressure systems would increase the standard deviation of the trends around their cores.'

> *5. Expand the discussion on the implications of upwelling intensification. This will help in understanding the broader ecological and economic impacts.*

Thank you for your comments, many authors have addressed the implications of upwelling intensification since it holds a huge ecological and economic impacts, however, is difficult to obtain conclusive results since there is not yet an adequate amount of biogeochemical data to effectively investigate the effects of changes in climatic conditions on biogeochemistry in the EBUS. We highlighted the complexity of the ecological impacts and summarize the main possible impacts in line 425 as follow:
'…Their novel methodology holds significant importance in unraveling the connection between the physical upwelling phenomenon and its ecological impacts. However, predicting ecological impacts remains challenging. While intensified upwelling could mitigate habitat warming, it may also increase ocean acidification, hypoxic events and reduce suitable food for fish larvae (Abrahams et al., 2021; Bakun et al., 2015). Nonetheless, they successfully establish a link between decreased SST and changes in upwelling intensity…'

> *6. Expand the discussion on the differences between your results and the hypothesis of the poleward displacement of upwelling-favorable winds. This comparison is important for contextualizing your findings within existing literature.*

We extended the discussion taking into account both reviewers' comments. You will find the expanded discussion in line 543:
'The SST changes in the EBUS respond mainly to changes in the upwelling processes which are ultimately driven by the pressure gradients. We analyzed the pressure gradients trends in all four EBUS. Our findings further support the intensification of the pressure gradients driven by climate change, as stated by Bakun, (1990). However, there are probably other contributors to the intensification of the upwellings. Some researchers question whether the impacts of differential heating on the pressure gradient force drives intensification of coastal upwelling. Rather, a complementary hypothesis proposes that evidence of an intensifying pressure gradient force is limited to poleward migration of the Hadley Cell (Arellano & Rivas, 2019; Rykaczewski et al., 2015; Wang et al., 2015). Nevertheless, these projections are only supported by observational records in the

Humboldt and Benguela Systems, (Sydeman et al., 2014). In contrast, we have tested this hypothesis on the historical record by computing the latitudinal distribution of α_{UI}. The results shown in Fig 6 partially agree with Rykaczewski et al, (2015), as only CalUS and BeUS presented a poleward intensification of α_{UI}. To further understand the drivers of these changes, we examined the spatial stability of the trends in the SLP continental-oceanic gradient was also tested using Monte Carlo simulation. The discrepancy between the latitudinal distribution of α_{UI} and the small standard deviation of trends around the cores of the pressure systems suggests that the hypothesis of poleward displacement of the high-pressure systems remains inconclusive.'

> *7. The manuscript would benefit from more discussion or possibly a dedicated section on the relationship between climate modes and upwelling. Consider computing correlations between them to provide deeper insights (e.g., Bonino et al. 2019).*

Thank you for your suggestions. Indeed, the results of Bonino et al., (2019) are relevant for our paper since their results highlighted the difference of each EBUS driver and variability. We try to tackle this challenge with our index, α_{UI}. The α_{UI} is based on the SST trends and it normalized by the oceanic background that way we aim to reduce large scale variability. Nonetheless, the discussion about climate indices is still valuable and will be expanded as follow in lines 516:

'…On the other hand, Bonino et al. (2019) found that local drivers and trends favoring upwelling (e.g., equatorward wind stress, cyclonic wind stress curl, and thermocline depth variation) explain the low-frequency modulation of upwelling. Bonino et al. (2019) also explored the link between wind-based upwelling indices and climate modes. They found that Atlantic and Pacific upwelling variabilities are mainly independent, while intra-basin domain variabilities present some coherency, which is consistent with our results. This intra-basin covariability is especially marked in the Pacific Ocean, where the shared variability is majorly due to the El Niño Southern Oscillation (ENSO) mode. In contrast, in the Atlantic Ocean, coherent variability is associated with upwelling trends, whereas only in the CanUS is it linked to the AMO. These results suggest that long-term climate indices may influence coastal upwelling dynamics, which is especially important in the Pacific. However, our index, $\alpha_{UI,}$ by normalizing the trend for its oceanic background, our results should account for the effects of local climate indices.'

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