Response to the Reviewers' Comments

Dear editor and reviewer,

We appreciate the reviewers' constructive comments very much. Our responses to the reviewers' comments are given as follows. All reviewers' comments are in black, while the authors' responses are in blue.

Response to Reviewer #1's Comments

The authors present an interesting study on changes in near surface wind speed over South Asia with a focus on links to internal modes of variability such as IPO and AMO. Most of the results are based on a MPI-ESM large ensemble. In the current state, an evaluation of how well MPI-ESM reproduces crucial physical mechanisms related to NSWS in South Asia is missing. The manuscript is well written and structured and after some revision would be a valuable contribution to the field.

Response: We sincerely appreciate your time to review our manuscript and provide valuable feedback. We have carefully revised the manuscript in accordance with your comments and suggestions. Specifically, we have added relevant content on MPI-ESM's performance in reproducing the physical mechanisms related to NSWS over South Asia. We believe that all issues have been adequately addressed in this revised version of the manuscript. Please note, all line numbers referenced in this response letter correspond to those in the clean version of the revised manuscript. Additionally, we have acknowledged your contribution to the Acknowledgements section of the revised manuscript.

Reviewer #1 Comment 1: The authors do not sufficiently evaluate how well MPI-ESM reproduces the physical mechanisms related to NSWS (and it's changes). While the NSWS of reanalysis datasets lies well within the MPI-ESM ensemble spread, this might be due to multiple compensating misrepresentations in the model. I would suggest to compare the 850mbar wind climatology as shown in fig 4c to reanalysis datasets. If possible, please also show figures comparable to 4a,b for reanalysis data. If available, it would also be helpful to refer to the literature to evaluate the representation of IPO dynamics in MPI-ESM and projected trends in the Pacific and the Indian Ocean in comparison to reanalysis and other climate models.

Response: Your points are well taken. Following your advice, we have included a comparison between the 850 hPa wind climatology from reanalysis datasets and that simulated by the MPI-ESM ensemble (now provided in Figure S3, as shown below). The

relevant analysis of Figure S3 has also been added to section 3.1 to provide evidence that MPI-ESM can adequately represent the physical mechanisms associated with NSWS (See ***Lines 159–161 in the revised manuscript***). Additionally, we have expanded the discussion on MPI-ESM's capability to represent IPO dynamics and projected SST trends over the Pacific and Indian Oceans (See ***Lines 265-274 in the revised manuscript***).

However, we cannot generate figures comparable to Fig. 4a–b from reanalysis data due to the nature of reanalysis. These figures rely on correlation analyses across a large ensemble of MPI-ESM simulations to robustly identify spatial patterns and internal variability relationships. Since reanalysis datasets represent only a single realization of the climate system, they do not allow a similar robust statistical characterization of internal variability.

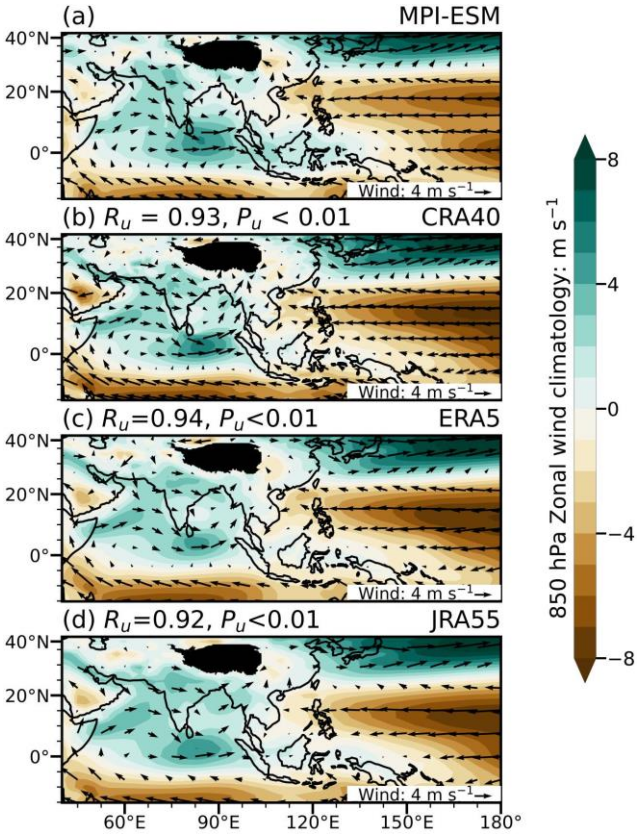

Figure S3. Climatological 850 hPa circulations during the historical period. Climatological zonal wind (shading) and horizontal wind vectors at 850 hPa for (a) the multi-member mean of MPI-ESM, (b) CRA40, (c) ERA5, and (d) JRA55. The climatology is computed over 1970–2005, except for CRA40, which covers the period 1979–2005. For (b)-(d), R_u denotes the spatial correlation of the climatological zonal wind between panel (a) and panels (b)–(d), respectively. Values of P_u < 0.01 indicate that the correlation is statistically significant at the 99% confidence level.

Reviewer #1 Comment 2: Concerning the regression between IPO and NSWS: Is NSWS averaged over the region of interest? I do not understand why you perform the regression over the period 1974-2095. I thought that with this analysis you wanted to estimate how

much IPO can influence trends over periods of roughly 30 years. The regression slope between IPO and NSWS over 1974-2095 should be quite weak and does not really represent the influence of IPO on NSWS you are interested (at least in Figure 5 a). Why don't you use a similar timescale for this regression?

Response:

Answer to the comment: "*Concerning the regression between IPO and NSWS: Is NSWS averaged over the region of interest?*": Yes, the NSWS is averaged over the land region of interest (the black-boxed region in Figure 1).

Answer to the comment: "*I do not understand why you perform the regression over the period 1974-2095. I thought that with this analysis you wanted to estimate how much IPO can influence trends over periods of roughly 30 years. The regression slope between IPO and NSWS over 1974-2095 should be quite weak and does not really represent the influence of IPO on NSWS you are interested (at least in Figure 5 a). Why don't you use a similar timescale for this regression?*": We appreciate this insightful comment. Indeed, our primary aim is to evaluate the IPO's influence on NSWS trends over approximately 30-year periods. However, to robustly quantify the relationship between IPO and NSWS, we first tried to isolate the IPO-related component from the full NSWS time series (1974–2095) to ensure statistical stability by capturing multiple IPO cycles. This approach allows us to clearly identify and extract the long-term persistent influence of IPO, thereby minimizing sampling uncertainty. Similar methodology has been adopted successfully in previous studies (e.g., Huang et al., 2020). To clarify, we have added one sentence in the revised manuscript to provide more details for it (See ***Lines 127-129 in the revised manuscript***).

References:

Huang, X., Zhou, T., Dai, A., Li, H., Li, C., Chen, X., Lu, J., Von Storch, J.-S., and Wu, B.: South Asian summer monsoon projections constrained by the interdecadal Pacific oscillation, Science Advances, 6, eaay6546, 10.1126/sciadv.aay6546, 2020.

Reviewer #1 Comment 3: Related to the precious comment, I'm wondering whether analyzing the RCP85 scenario is the right choice for studying the link between dominant modes of variability and NSWS. In RCP85 there should are strong forced changes in NSWS as well as SSTs and SST patterns. Therefore both NSWS and IPO (or AMO) are very likely changing over the time frame of a century. I assume that the detrended (part of the signal that is not forced) IPO and NSWS is used for the analysis. Is that the case? Please clarify in the methods section.

Response: Yes, your assumption is correct. We confirm that the analysis is conducted on the detrended components to isolate internal variability from externally forced signals.

We have clarified this in the revised methods section (See ***Lines 119-120 in the revised manuscript***).

Reviewer #1 Comment 4: L79: Are the periods for all reanalysis datasets and CRA-40 the same?

Response: No, the time periods differ slightly among the datasets. ERA and JRA cover the period from 1970 to 2020, while CRA-40 spans from 1979 to 2020. We have clarified these ranges in the revised manuscript (See ***Lines 81-82 in the revised manuscript***).

Reviewer #1 Comment 5: L86: Are you sure about 2006 as start date for the projections? In Figure 1 you write about 2015.

Response: We see your point. The MPI-ESM large ensemble follows the CMIP5 protocol, where the historical experiment ends in 2005, and the RCP projection experiment begins in 2006. While data from 2006 to 2020 are technically part of the RCP experiment, they no longer represent the future from today's perspective. To keep the analysis relevant, we **subjectively** treat 2021 as the beginning of the future period, and designate 1970–2020 and 2021–2099 as the present and future periods, respectively. We have revised the incorrect statement in the manuscript and clarified this point (See ***Lines 91-94 and Lines 153-155 in the revised manuscript***).

Reviewer #1 Comment 6: L128-129: Why do you frame it as a hiatus? I find the term "hiatus" misleading here, as the MMM should not contain any influence of internal variability, right?

Response: We apologize for the confusion caused by the unsuitable use of the term "hiatus." We have revised it to "a relatively stable phase" to avoid misunderstanding (See ***Lines 167 in the revised manuscript***).

Reviewer #1 Comment 7: L150: Please explain the "inter-member EOF analysis" in more detail. Is the EOF analysis performed on a combination of NSWS patterns and SST fields? Is it performed on NSWS fields only?

Response: The inter-member EOF analysis is performed on NSWS fields only, not on SST fields or a combination of NSWS and SST. We have added a detailed description of this inter-member EOF procedure and its rationale to the Methods section (See ***Lines 98-106 in the revised manuscript***).

Response to Reviewer #2's Comments

The topic—understanding the role of internal variability, particularly the IPO, in shaping near-surface wind speed (NSWS) projections over South Asia—is highly relevant and novel. Given the importance of NSWS for energy planning, air quality, and hydrology in this region, I believe the paper will be of broad interest to the climate modeling and regional impacts communities. The authors make good use of a large ensemble and apply a clear methodology to isolate the IPO's contribution. The finding that IPO-related variability explains a meaningful share of NSWS projection uncertainty is an important result that will help guide future work and practical assessments. Overall, I think this is a solid and useful contribution that merits publication in EGUsphere after addressing a few minor points that would help strengthen the clarity and robustness of the paper.

Response: Thank you for your encouraging feedback and valuable suggestions. We have carefully revised the manuscript in accordance with your comments and suggestions. We believe that all concerns have been adequately addressed in this revised version. Please note that all line numbers mentioned in this response letter refer to the clean version of the revised manuscript.

Reviewer #2 Comment 1: Model dependency: The authors are transparent about their reliance on the MPI-ESM ensemble, which is commendable. However, I think this limitation could be discussed in a bit more depth. It would be helpful to comment on whether MPI-ESM is known to have biases in its IPO representation, or in Pacific SST teleconnections to South Asia. This would provide useful context for interpreting the robustness of the results.

Response: Good suggestion. Previous studies (Maher et al., 2017; Bellenger et al., 2013) show that MPI-ESM captures the IPO's spatial pattern reasonably well. We have added a concise discussion of these biases and their implications for our study (See ***Lines 265-274 in the revised manuscript***).

References:

1. Bellenger, H., Guilyardi, E., Leloup, J., Lengaigne, M., and Vialard, J.: ENSO representation in climate models: from CMIP3 to CMIP5, Climate Dynamics, 42, 1999-2018, 10.1007/s00382-013-1783-z, 2013.
2. Maher, N., England, M. H., Gupta, A. S., and Spence, P.: Role of Pacific trade winds in driving ocean temperatures during the recent slowdown and projections under a wind trend reversal, Climate Dynamics, 51, 321-336, 10.1007/s00382-017-3923-3, 2017.

Reviewer #2 Comment 2: Observational evaluation: The brief comparison with reanalysis datasets (Fig. 1e) is a good start, but I feel this could be expanded. A spatial evaluation (e.g. maps of historical trends compared between model and reanalyses) would give more confidence that MPI-ESM is capturing relevant regional patterns of NSWS variability.

Response: Point taken. We have added a spatial comparison between the historical NSWS trends in the MPI-ESM and reanalysis datasets. (see Figure S2, attached below).

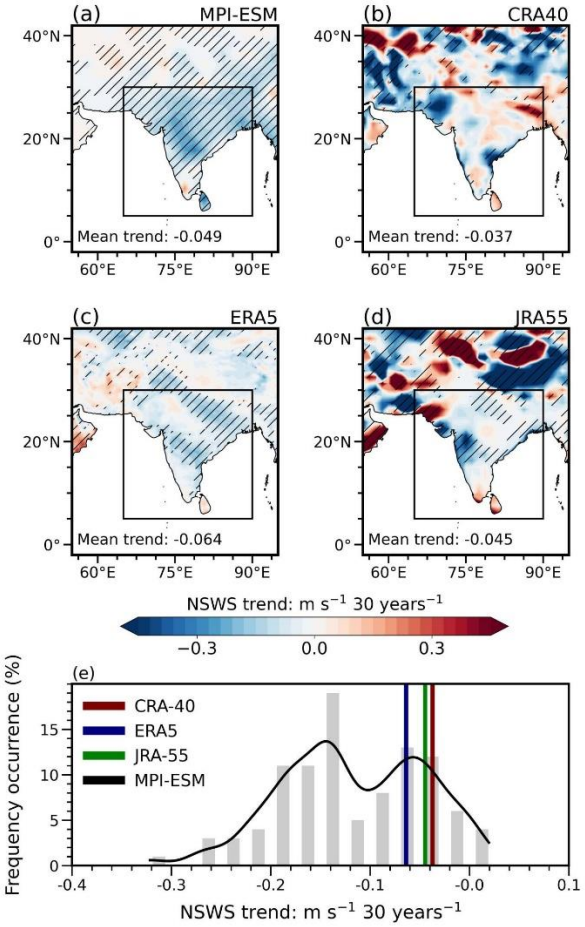

Figure S2. Evaluation of MPI-ESM in reproducing historical NSWS over South Asia. (a–d) Spatial patterns of historical NSWS trends from (a) the multi-member mean of MPI-ESM, (b) CRA40, (c) ERA5, and (d) JRA55. Trends are calculated over 1970–2005, except for CRA40, which spans 1979–2005. The text in the bottom-right corner indicates the area-averaged NSWS trend over South Asia (units: m s^{-1} 30 years^{-1}). (e) Histograms and fitted distribution lines of the area-averaged South Asian NSWS trend derived from the 100 MPI-ESM ensemble members from 1970 to 2005. Vertical solid lines indicate the corresponding regional trend estimates from CRA40 (purple), ERA5 (dark-blue), and JRA55 (green).

Reviewer #2 Comment 3: Other sources of uncertainty: The authors note that model uncertainty dominates total projection uncertainty (citing Zhang & Wang, 2024), while IPO accounts for ~8–15% of variability. It would help readers if the paper clarified, at least

qualitatively, how internal variability and model spread compare in this study's own results—are the two sources of uncertainty of similar order in South Asia?

Response: We see your point. The comparison made by Zhang & Wang (2024) is based on an ensemble of different CMIP6 models, so their "model spread" supposedly reflects structural differences among models. Our study, in contrast, is built on a single-model large ensemble (MPI-ESM), where spread arises only from internal variability. Thus, we cannot quantify inter-model uncertainty within the present framework. To acknowledge this limitation, we have added a clarifying sentence to the discussion (See ***Lines 289-291 in the revised manuscript***): "Additionally, because our analysis uses a single-model ensemble, the projection spread reported here represents internal variability alone. The inter-model uncertainty, shown elsewhere to be larger than any single mode of internal variability, remains to be quantified in future multi-model work."

Reviewer #2 Comment 4: IPO prediction prospects: The paper suggests that improved IPO prediction could help reduce NSWS projection uncertainty. This is a valid point, but I would suggest adding a brief caution about the current limits of decadal prediction skill for IPO. This would provide a balanced perspective on the practical implications.

Response: We agree with you, and we have added a relevant discussion in the revised manuscript to highlight this point (See ***Lines 285-288 in the revised manuscript***)

Reviewer #2 Comment 5: AMO result: The result that AMO plays a negligible role is interesting but not discussed in much detail. I think the paper would benefit from adding a short paragraph offering a physical interpretation—why does tropical Pacific variability dominate NSWS trends in South Asia, compared to Atlantic modes?

Response: To addressee this, we have added a brief discussion relevant to this point in the manuscript (See ***Lines 256-259 in the revised manuscript***).

Response to Reviewer #3's Comments

This manuscript presents a comprehensive analysis of near-surface wind speed (NSWS) projections over South Asia, with a particular emphasis on understanding the role of internal variability using a large-ensemble approach from the Max Planck Institute Earth System Model (MPI-ESM). The authors identify the Interdecadal Pacific Oscillation (IPO) as a leading mode influencing regional NSWS variability and quantify its contribution to projection uncertainties. The findings highlight the significance of the IPO in modulating regional wind speed projections, which has valuable implications for regional climate adaptation, particularly in wind-sensitive sectors such as energy production and agriculture. Overall, the manuscript is well-written and clearly structured, with robust methodologies. To be suitable for publication, the manuscript requires a minor revision before acceptance:

Response: Thanks for your positive comment! We have carefully revised the manuscript in accordance with your comments and suggestions. We believe that all issues have been adequately addressed in this revised version of the manuscript. Please note, all line numbers referenced in this response letter correspond to those in the clean version of the revised manuscript.

Reviewer #3 Comment 1: The manuscript would benefit from a clearer explanation of the rationale for selecting MPI-ESM specifically. A brief justification or evaluation highlighting the selection of MPI-ESM for this study is needed.

Response: Thank you for this suggestion. To address this, we have included a comparison between MPI-ESM's simulation and reanalysis datasets, focusing on MPI-ESM's representation of 850 hPa winds climatology, and historical trends for both multi-members mean and each member over South Asia. These analyses demonstrate that MPI-ESM can reasonably reproduce observed regional wind patterns, confirming its suitability for our study (See ***Lines 148-163 and Figure S2-3 in the revised manuscript***).

Reviewer #3 Comment 2: Some figures could be improved for readability and clarity. Specifically, Figure 4 would benefit from clearer vector scaling or additional annotations to help readers easily interpret the patterns described in the text.

Response: We have carefully revised relevant figures by adjusting the vector scaling and adding additional annotations to enhance readability and clarity.

Reviewer #3 Comment 3: On page 3, line 91, the term "member discrepancies" might be unclear; consider replacing it with "differences among ensemble members" for clarity.

Response: Point taken. We have revised the term following your advice.

Reviewer #3 Comment 4: On page 7, line 151, the phrase "internal climate variability stems" could be made clearer by briefly specifying the primary mechanisms involved.

Response: We see your point. We have clarified the text by briefly specifying that internal climate variability primarily arises from several important mechanisms (See ***Lines 189-191 in the revised manuscript***).

Reviewer #1 Comment 5: The captions for Figures 2 and 3 could include brief additional details on how the EOF analysis was specifically implemented to aid readers' comprehension.

Response: We have revised the captions of Figures 2 and 3 to briefly summarize how the EOF analysis was implemented, and also provided a more detailed description in the methods section for clarity.