Response to the Editor's Comments

General Comments: Thank you for your detailed revision and reply to the reviewers' comments, through which the quality of the manuscript has been substantially improved. In the second round of review, one referee suggests acceptance of the manuscript. The other referee who raised some major issues of the manuscript declined to review the revision, thus I did the review by myself. Based on the second round of review and my own evaluation, the manuscript is possible to be acceptable for publication after moderate revisions. The authors need to do more work to clarify or discuss the mechanism for the change of the near-surface wind speed, given the article scope of the WCD. Here are my suggestions on paper revision for consideration.

We are grateful for the Editor's constructive comments. We have revised carefully the manuscript following the comments and suggestions.

Comment 1: Mechanism for the non-monotonic change of the near-surface wind speed (NWSP)

In authors' response to Referee 2 and in the revised manuscript, the authors argue that the different relationship between the AMOC and the NWSP in Ramp-up and Ramp-down periods may attribute to the two somewhat competing influences: changes of AMOC and the change of GMST (global mean surface temperature). However, the variation of AMOC can also influence the planetary scale surface temperature, which can be an important part of the GMST. Though the authors have conducted bi-regression analysis to show their relative importance, these two effects are not independent. The authors at least need to point out this during the discussion.

As suggested, we added the following text to the second paragraph of Section 5 in the revised manuscript: "*Besides, the effects of AMOC and GMST are not completely independent due to the variation of AMOC also influencing large-scale surface temperature*. Essentially, it is the Arctic Amplification and AMOC's competing." (Lines 329–331)

Comment 2: The relationship between the North Atlantic jet speed and the surface wind speed

From Figure 3, in the ramp-up period, the relationship between the North Atlantic jet speed and the NWSP is different from other periods. Please note that in this period, the Northern Hemispheric (NH) and North Atlantic (NA) surface wind speed, SAT gradient and the AMOC all show decreasing trends, except for the NA jet speed. I suggest the authors check this result (e.g. check the change of jet speed in other vertical levels or whether the result depends on the definition of North Atlantic). If the surface wind and surface SAT gradient over North Atlantic all decrease, it is not clear to me why the jet speed increase. Is there any explanation for this?

Your observation is correct. Our previous analysis neglected to describe and discuss this detail. Because we wanted to consider the combined large-scale climate effects of the AMOC and CO_2, the current definition of the NA meridional temperature gradient uses 0–30° as low latitudes and 60–90° as high latitudes. However, the spatial distribution of surface air temperature trends during the CO_2 ramp-up period (Fig. S2a) reveals the presence of a cold blob in the NA, with a region of warming to its south. For the mid-latitudes of the NA, this regional surface temperature change would strengthen the north-south meridional temperature gradient. According to thermal wind relations, the NA westerly jet would strengthen (Fig. 3e). On a larger scale, the Arctic amplification caused by global warming due to CO_2 increases weakens the north-south meridional temperature gradient (both globally and in the NA). Therefore, the changes in the meridional temperature gradient caused by AMOC and CO_2 offset each other, and in the confrontation, AMOC has a stronger climate effect on the intensity of the NA westerly jet. Hence, the NA westerly jet is slightly strengthened, and NSWS over Europe is slightly strengthened (Fig. 2a). However, in the entire NH, the climate effect of CO_2 is stronger, so the NH meridional temperature gradient and the NH westerly jet are weakened synchronously (Figs. 3b–c).

We added the following discussions in Section 4 as follows:

"*However, a slight increase in the NA westerly jet is observed in Fig. 3e. This is due to an AMOC-associated cold blob and a warming center to its south (Fig. S2a), which enhances the regional meridional temperature gradient, and its effect on the NA westerly jet is stronger than that from the CO_2 increase. Hence, the NA westerly jet is slightly strengthened, and NSWS over Europe is slightly strengthened (Fig. 2a).*" (Lines 242–246)

In addition, the authors need to clarify the definition of NH and NA near-surface wind speed. According to the authors' statement in section 2.4 in Line 145, all the calculations of near-surface wind speed focus on land regions. Does this rule also apply to the authors' calculation of the NA near-surface wind speed? And do the authors' calculations of the global and regional mean surface temperature apply for both land the oceanic surface? Those key information need to be clarified.

Thanks for this suggestion. NA NSWS is calculated only over the ocean. Surface temperature is calculated over both ocean and land. We clarified these details in Section 2.4:

"*All calculations related to NSWS are focused on the land regions, except that North Atlantic NSWS focuses on oceanic NSWS. Calculations related to surface temperature include both ocean and land regions.*" (Lines 147–149)

Comment 3: Cause-effect issue for the role of AMOC

I agree that the AMOC can be an important player for the change of the near-surface wind. However, the authors' current argument seems to claim that the AMOC is a main reason for the decrease of the surface wind, especially in the Ramp-down period. But what's the reason for the change of AMOC? Does the change of the surface wind also affect the AMOC, especially in the Ramp-down and Stabilization periods in which the initial state of the AMOC may have little influence on the AMOC evolution (Is there any initialization of the ocean state before the Ramp-up run?). Is there any significant lead-lag correlation between AMOC, SAT gradient and surface wind?

We appreciate the reviewer's insightful question.

(i) The reason for the change of AMOC: The AMOC variation is a buoyancy-driven response with strong salt-advection feedback and stratification changes. During the ramp-up period, CO_2-forced surface heat/freshwater fluxes freshen and warm the subpolar North Atlantic, weakening deep convection and AMOC. During the early ramp-down period, due to the slow recovery of AMOC, it shows strong hysteresis. During the late ramp-down period, the subtropic–subpolar salinity gradient and reduced stratification favor enhanced dense-water formation and an AMOC "overshoot"/rapid recovery. This mechanism and timing have been diagnosed in detail for the same experimental design by An et al. (2021), who showed that subpolar North Atlantic temperature lags the AMOC by 10–20 years and that the AMOC overshoot arises from amplified salt-advection feedback under evolving stratification and surface freshwater fluxes.

(ii) Does the change of NSWS affect AMOC: In principle, wind stress and its curl can modulate gyre circulation and thus the overturning. However, in this particular CO_2-pathway experiment, the multi-decadal AMOC evolution is dominated by buoyancy forcing and salt-advection feedback rather than by wind-driven changes. An et al. (2021) explicitly traced the AMOC tendency to salinity advection and surface freshwater/heat flux anomalies. They showed AMOC leads the subpolar temperature by 10–20 years (AMOC → subpolar SST/stratification → atmosphere). In our analysis, when AMOC anomalies become large during the late ramp-down period, inter-ensemble correlations show that members with stronger AMOC are systematically associated with a weaker NA meridional SAT gradient, a reduced NA westerly jet, and lower European NSWS (Fig. 4), again consistent with AMOC forcing the atmosphere. In these simulations, Ramp-down and Stabilization are a seamless continuation of Ramp-up, so the AMOC trajectory in these periods reflects the thermohaline anomalies accumulated along the pathway rather than sensitivity to the present-day initial phase. Under these conditions, any feedback from NSWS onto the AMOC is secondary relative to buoyancy control.

(iii) Is there any initialization of the ocean state before the Ramp-up run: Yes. CESM1.2 was first integrated for 900 years at fixed 367 ppm, which is a present-day (PD) state, to generate an equilibrium ocean–atmosphere state. The 28 ramp-up members then branched from distinct PD-year ocean/atmosphere initial conditions that sample different phases of multidecadal variability (AMO/PDO). The ramp-down run continues directly from the end of ramp-up following the CDRMIP symmetry protocol. We revised the related description into "*and the model is integrated for 900 years to generate an equilibrium ocean–atmosphere state*" in Lines 116–117.

(iv) Is there any significant lead-lag correlation between AMOC, SAT gradient and surface wind: We agree that significant lead–lag relationships are expected: in the North Atlantic, AMOC tends to lead subpolar SST and the regional meridional SAT gradient by roughly 10–20 years, as well as atmospheric wind/jet responses. In our study, the three analysis periods span 140, 80, and 60 years, respectively; within such multi-decadal windows, a 10–20-year lead is effectively absorbed by the period-mean and year-by-year zero-lag cross-member diagnostics we use to isolate the forced, contemporaneous co-variability. Moreover, under a non-stationary CO_2 pathway, the lead is state-dependent rather than constant, so fixed-lag correlations can be less informative than contemporaneous relationships for attribution.

In the revised manuscript, we acknowledge the expected decadal lead–lag chain (AMOC → SAT gradient & westerly jet & NSWS), while noting that our conclusions are based on zero-lag cross-member covariation that remains robust to such decadal offsets. A full state-dependent lead–lag quantification is beyond our present scope. Specifically, we added "*Although AMOC is expected to lead subpolar NA SST and the regional meridional SAT gradient by 10–20 years (An et al., 2021), our analysis is based on zero-lag cross-member covariation over multi-decadal windows. Such decadal leads are small relative to these windows and do not alter the sign or interpretation of the contemporaneous relationships reported here. We therefore emphasize contemporaneous, forced covariation for attribution, while acknowledging the expected lead–lag behavior.*" in Lines 292–297.

References:

An, S.-I., J. Shin, S.-W. Yeh, S.-W. Son, J.-S. Kug, S.-K. Min, and H.-J. Kim (2021). Global cooling hiatus driven by an AMOC overshoot in a carbon dioxide removal scenario, Earth's Future, 9, e2021EF002165. https://doi.org/10.1029/2021EF002165

Comment 4: Figure 5

The schematic of Figure 5 does not accurately represent the results (i.e. Figures 3 and 4). For example, in Figure 4, in the Ramp-up and Stabilization periods, there is no significant correlation between AMOC index and the NA westerly jet. Though the figure mainly reflects the internal variability, the relationship between AMOC and the atmosphere is supposed to exist for decadal and longer time scales. Therefore, the change of the westerly jet in Figure 5a with the AMOC is not convincing to me. The correlation between the AMOC and the SAT gradient seems more robust and direct. Please note that the 500 hPa jet stream and the surface wind do not have to change in the same way. In the North Atlantic, the surface wind strength is usually more related to the eddy-driven jet, which is further related to the eddy activity and background baroclinicity.

We revised the anomalous warming center in Fig. 5a. Also, we replaced the westerly jet with a westerly jet trend in the schematic figure, with a solid line representing an enhanced jet and a dashed line representing a weakened jet, respectively.

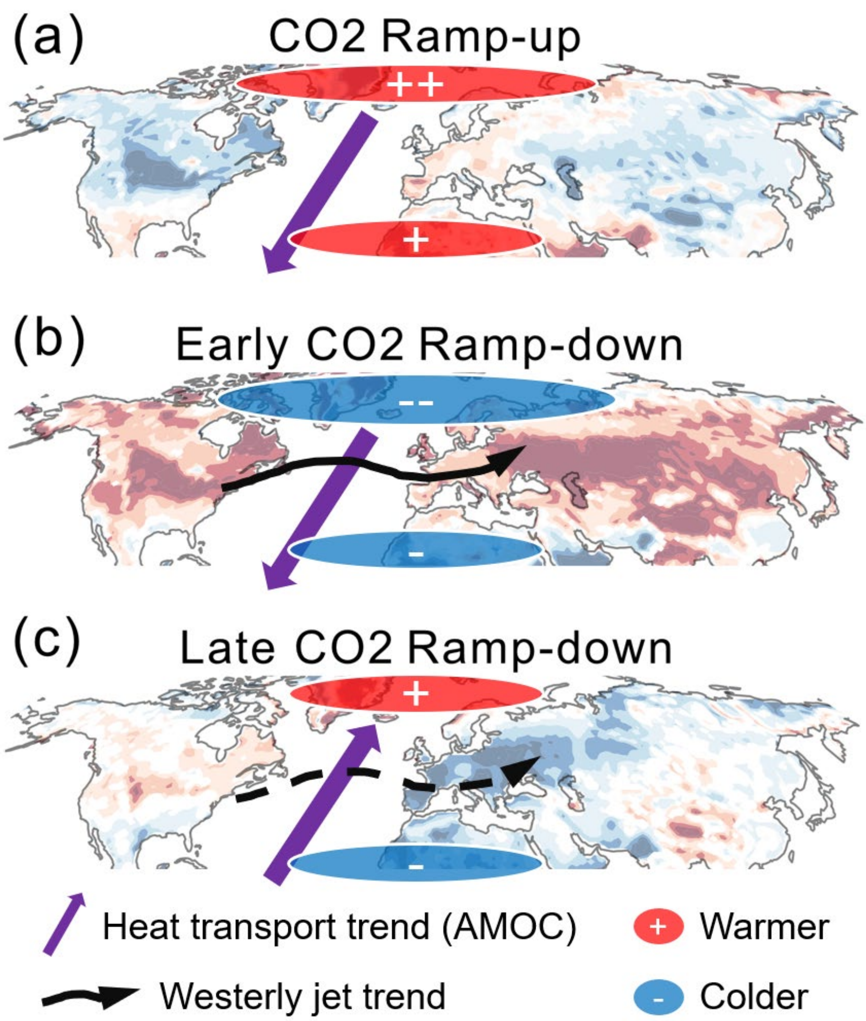

Fig. 5. The physical mechanisms by which CO2 and Atlantic Meridional Overturning Circulation modulate extratropical near-surface wind speed during three periods. The warmer and colder centers denote the combination effects of GMST and AMOC. The strengthened NA westerly jet is in solid line, while the weakened jet is in dashed line.

Comment 5: Abstract

The authors' argument on the role of AMOC in line 43-44 ("phase dependent role") as well as in the concluding part is not very clear and maybe misleading, as it is very easily to link to the phase of AMOC. The results actually suggest that the AMOC's effect is different in different periods of CO2 variation, with most dominant influence in the late Ramp-down period.

Agree. We deleted the descriptions about "phase dependent" in the Abstract and Section 5.