Dear Dr. Stenni,

Thank you for the opportunity to revise our manuscript, "Trends in South Pole Particle Concentration Imply Holocene Westerly Wind Strengthening." Your comments as well as the two reviewers provide thoughtful guidance for revising the paper, and we gratefully acknowledge yours and the reviewers' time, effort, and feedback. The following responses address each comment and/or question based on the previous submission.

Our responses are given below with the Editor/Reviewers' comments in italics. Our responses as the authors are given in regular font, and revised text from the paper is provided in blue font.

Please note that our Line Numbers listed below are based on the track changes document.

Editor Comments

In particular, the logical flow of the manuscript is not always clear. Significant restructuring is needed, especially (though not exclusively) in the second part of the Introduction.

Several sections of the text should be moved to more appropriate chapters, including parts that currently appear in the Conclusions. At present, there is virtually no description of the study region, apart from a single sentence (lines 65–67). This sentence, which refers to relatively high snow accumulation (without quantification), should be relocated and expanded, in line with the referee's comments. The proposed restructuring is clearly outlined in Referee 1's report.

We restructure the introduction, following comments from Reviewer 2, include a state-of-the-art understanding of Southern Hemisphere Westerly Wind (SHWW) dynamics, a clearer description of our hypothesis, and expand the initial site description to a paragraph. We include our new introduction section below.

Line 53: "The Southern Hemisphere Westerly Winds (SHWW) represent the strongest persistent surface wind system on Earth. Variations in the SHWW influence global carbon cycling and heat distribution, and are believed to play a critical role in Earth's climate and ice sheet stability across wide-ranging timescales (Hillenbrand et al., 2017; Russell et al., 2006). Variations of the strength and latitudinal position of the SHWW during the past several centuries are related to changes in the equator-to-pole temperature gradient (i.e., Perren et al., 2020). During warm periods, SHWW migrate southward and increase in strength and during cooler periods migrate northward and weaken. Increases in SHWW strength intensify the ocean-to-atmosphere transfer of CO_2 via upwelling and impact ice sheet stability and mid-latitude vegetation/precipitation dynamics (Anderson et al., 2009; Hillenbrand et al., 2017; Moreno et al., 2010; Toggweiler and Russell, 2008). ~~However, while the SHWW are an important climatic feature, Holocene SHWW dynamics are poorly constrained, with previous work disagreeing between zonally symmetric or asymmetric change in the strength and/or intensity as well as the mean latitudinal position of the winds (Hillenbrand et al., 2017; Moreno et al., 2010; Perren et al., 2020; Saunders et al., 2018; van der Bilt et al., 2022; Varma et al., 2012; Zwier et al., 2022).~~ However, while the SHWW are an important climatic feature, complete Holocene SHWW dynamics are poorly constrained. Previous research has focused on three possibilities for the style of change; 1) strong southward SHWW displacement at the start of the Holocene and northward displacement with cooling and/or stable temperatures beginning ~9 – 7.5 ka (Hillenbrand et al., 2017; Kaplan et al., 2016; Mulvaney et al., 2012), 2) progressive strengthening and southward displacement of the SHWW between ~8 – 7 ka (Moreno et al., 2010; Saunders et al., 2018; Zwier et al., 2022), and 3) strengthening of the SHWW wind belt core with latitudinal contraction of the northern margin of the winds throughout the past 12 ka (Lamy et al., 2010). Furthermore, the early Holocene is hypothesized to be a climatically similar period to the present day, facilitating comparison to ongoing climate dynamics (Kaufman et al., 2020; Marcott et al., 2013). However, Osman et al. (2021) provides an alternative scenario, with global average temperature steadily increasing throughout the Holocene, which suggests that the Early Holocene would not be a comparable period for comparison to modern climate dynamics. The current ambiguity of Holocene and in particular early Holocene SHWW dynamics is critical for understanding West Antarctic Ice Sheet (WAIS) stability and future climate projections (i.e., Bronselaer et al., 2020).

Microparticle records Records of microparticle concentration and relative particle size (i.e., coarse particle percentage; CPP) from Antarctic ice cores offer a unique perspective on SHWW strength and/or position dynamics because they have been interpreted to reflect source-to-sink conditions and atmospheric variability, specifically distillation (Markle et al., 2018), geomorphology of the source regions (Sugden et al., 2009), wind strength (Koffman et al., 2014), vegetation cover, precipitation (Tegen and Schepanski, 2018), and atmospheric transport patterns (Aarons et al., 2017; Aarons et al., 2016; Aarons et al., 2019; Albani et al., 2018; Delmonte et al., 2013; Delmonte et al., 2002; Delmonte et al., 2020; Koffman et al., 2023). Holocene dust records differ among Antarctica ice cores, with East Antarctic Plateau data reflecting atmospheric subsidence and peripheral cores reflecting regional variability (Albani et al., 2012; Delmonte et al., 2020). The relative few complete and available Holocene dust records from Antarctica prevent a full interpretation of past SHWW behavior. Nevertheless, we have developed and present here records of dust concentration and CPP from the South Pole Ice Core (SPC14) to better constrain Holocene SHWW dynamics within the context of early Holocene to modern climate dynamics. However, there are few complete Holocene dust records from Antarctica, limiting a full interpretation of past SHWW behavior.Here we measure and develop records of dust concentration and CPP in the South Pole Ice Core (SPC14) to better constrain Holocene SHWW dynamics. The South Pole is well-situated because of its geographic position, which facilitates hemispheric-scale interpretations, the relatively high snow accumulation rate that adds precision to the time record, and the 60 years of aerosol and meteorological studies in the region (Casey et al., 2014; Clem et al., 2020; Lazzara et al., 2012; Sheridan et al., 2016).

The South Pole is well-situated because 1) the symmetric position with respect to the annular SHWW belt favors interpretation of the hemispheric, rather than regional, SHWW system, 2) the relatively high snow accumulation rate (8 cm w.e.q. a^{-1}) relative to other sites in East Antarctica provides strong constraints on the ice core chronology and high temporal resolution and 3) aerosol and meteorological studies have been conducted at this location over the past 60 years, which provides context for paleo-interpretations (Casey et al., 2014; Clem et al., 2020; Lazzara et al., 2012; Sheridan et al., 2016). The South Pole primarily receives aerosols during the austral summer (DJF) via air masses moving into the East Antarctic plateau, most prominently via the Weddell Sea and the Amundsen-Bellingshausen Sea embayment (Clem et al., 2020; Lazzara et al., 2012; Nicolas and Bromwich, 2011; Tuncel et al., 1989). South Pole aerosols and particulates (i.e., cloud condensation nuclei and dust particles) are sensitive to seasonal and synoptic variability over the past 40 years, demonstrating that trends in ice-core particle records likely reflect long-term climate variability (Ardon-Dryer et al., 2011; Hogan et al., 1984; Parungo et al., 1981; Sheridan et al., 2016). We build upon instrumental-era South Pole particle research to investigate Holocene particle variability on centennial to millennial scales throughout the Holocene using microparticle data from the new SPC14 intermediate-depth ice core."

I find that all major and minor comments raised by the referees must be carefully addressed in order to improve both the scientific quality and the readability of the manuscript.

In addition, a figure showing the $\delta^{18}O$ record must be included. This is an important point that I already raised in my previous editorial comments, but it has not yet been addressed. You may consider moving Figure 2a to the Supplementary Material and introducing a new figure presenting the isotopic record in the main text.

Line 256: We add the South Pole (SPC14) $\delta^{18}O$ to Figure 2b. We keep Figure 2a because we feel it is important to show the SPC14 median particle flux relative to other records. We add the following description to the Figure 2 caption to highlight the importance of Figure 2a and the addition of the $\delta^{18}O$ record.

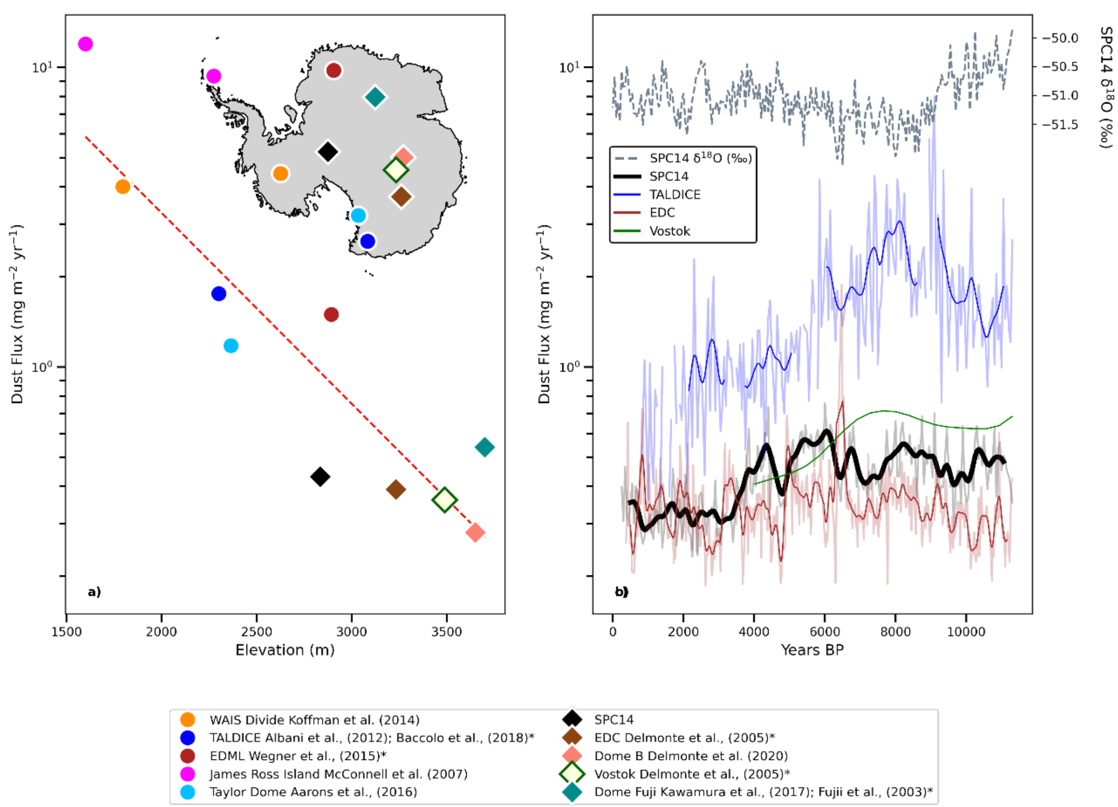


Figure 2a and b: Comparison of SPC14 dust metrics with other Antarctic Holocene records. In 2a, SPC14 dust flux is similar to other cores based on drill site elevation (following Koffman and Kreutz, 2014). Plateau sites are depicted with diamonds while non-plateau (i.e., WAIS and coastal locations) are depicted with circles. Labels containing * symbol at the end were reported in (Delmonte et al., 2020). 2b shows the South Pole (SPC14) $\delta^{18}O$ (Steig et al., 2021) resolved to 50-year resolution shows available Holocene flux records from Talos Dome fine (0.6 – 5 µm mg m^{-2} yr^{-1}) particle flux (Albani et al., 2012), Vostok (Petit et al., 1990), EPICA Dome C (EDC; Lambert et al., 2012). SPC14 dust flux is similar to other East Antarctic sites (Vostok and EDC) and is on average ~67% lower compared to TALDICE. TALDICE, SPC14, and EDC were resampled to 50-year median values (background variability), and the darkened lines are the 11-point rolling gaussian mean for TALDICE, SPC14, and EDC. WAIS Divide (Koffman et al., 2014), James Ross Island (McConnell et al., 2007), and SPC14 dust fluxes (this study) were calculated using a laser particle counter and Dome Fuji (Fujii et al., 2003; Members: et al., 2017) was calculated using both light scattering techniques and a laser particle counter. All other records were measured using a Coulter Counter providing volume accurate measurements (Aarons et al., 2016; Albani et al., 2012; Baccolo et al., 2018; Delmonte et al., 2013; Delmonte et al., 2005; Delmonte et al., 2020).

Finally, there are several instances in which figures are incorrectly cited in the manuscript. I have not listed them here, but I ask you to carry out a thorough and careful check of all figure references before resubmission.

All Figure references are now correct.

By the way, something not noticed by referees is reported below …

Line 72: uncertainty of what? Age I suppose, please modify. Here you can add a reference to the supplementary material where something is reported about the age model.

Line 110: We add, "…in the South Pole age model…" to the sentence so that it now reads, "Uncertainty in the SPC14 age model during the Holocene is ± 18 years while between 1800 – 3100 years BP and the uncertainty increases to ± 25 years (Winski et al., 2019)."

Line 88: 2.1 is a title of a paragraph? Please adjust.

Line 138: We adjust so that it is now a title of a new paragraph. We edit the title to also include the PMIP4 models. The title now reads, "2.1 HYSPLIT and CMIP6-PMIP4 models"

Table 1: what does mean "Amon" in the column Time resolution? Monthly? Please add in the caption.

Line 156: We add in the caption that Amon refers to atmospheric monthly data. We add a sentence to the end of Table 1 caption, "All data was downloaded using the atmospheric monthly data (Amon) time resolution.". We remove the column of data since all data have the same resolution. The adjust table is below.

Model	Institute	Grid Size		Model Run Time		Variables
		Latitude (°)	Longitude (°)	mid-Holocene	piControl	
ACCESS-ESM 1-5	Commonwealth Scientific and Industrial Research Organization, Australia	1.25	1.88	501 - 800	101 - 0600	pr, tas
AWI-ESM-1-1-LR	Alfred Wegner Institute, Germany	1.85	1.88	3106 - 3205	1850 - 1954	pr, sfcWind, tas
FGOALS-f3-L	Chinese Academy of Sciences, China	1	1.25	720 - 1219	600 - 1160	pr, sfcWind, tas
GISS-E2-1-G	Goddard Institute for Space Studies, USA	2	2.5	2900 - 3199	4150 - 5000	pr, sfcWind, tas
INM-CM4-8	Institute for Numerical Mathematics, Russian Academy of Science, Russia	1.5	2	1880 - 2079	1850 - 2380	pr, sfcWind, tas
IPSL-CM6A-LR	L'Institut Pierre-Simon Laplace, France	1.27	2.5	1850 - 2399	1850 - 2349	pr, sfcWind, tas
MPI-ESM1-2-LR	Max Planck Institute for Meteorology, Germany	1.85	1.88	1001 - 1500	1850 - 2849	sfcWind
MRI-ESM2-0	Meteorlogical Research Institute, Japan	1.11	1.13	1951 -2150	1850-2550	pr, sfcWind, tas
NCAR - CESM2	National Center for Atmospheric Research, USA	0.94	1.25	0 - 700	1 - 1200	pr, sfcWind, tas
NUIST - NESM3	Nanjing University of Information Science and Technology, China	1.875	1.875	1798 - 1897	500 - 0999	pr, tas
NorESM2-LM	Norwegian Climate Centre	1.875	2.5	2101 - 2200	1600 - 2100	pr, tas

<u>**Reviewer 1 *Minor Changes***</u>

Line 43. “core” here may be misleading and interpreted as “ice core”. Please clarify/rephrase.

Line 44: We remove the sentence and update our abstract per Reviewer 2.

Line 73. “There while …” is not clear. Please rephrase.

Line 111: “There…” has been removed from the text and the sentence now starts with “While…”

Line 80-83. As I previously stated, assuming spherical particles for better comparability with previous work only applies to previous work assuming spherical particles when interpreting the output of laser particle counters. On the other hand, this assumption does not improve the situation when comparing against Coulter counter data (roughly half of the datasets in Figure 1). I would recommend making this aspect more explicit, rather than talking about “volume assumption” which frankly has a rather undecipherable meaning, at least for me.

Line 263: We add to the end of Figure 2 caption the following sentences, "WAIS Divide (Koffman et al., 2014), James Ross Island (McConnell et al., 2007), and SPC14 dust fluxes (this study) were calculated using a laser particle counter and Dome Fuji (Fujii et al., 2003; Members: et al., 2017) was calculated using both light scattering techniques and a laser particle counter. All other records were measured using a Coulter Counter providing volume accurate measurements (Baccolo et al., 2018; Albani et al., 2012; Delmonte et al., 2020; Delmonte et al., 2013; Aarons et al., 2016; Delmonte et al., 2005)."

Reviewer 2 *Major Changes*

The introduction needs some improvements:

Line 53 – 56: This one line should be expanded to a paragraph explaining the research question. Which studies suggest what hypothesis? This way, this manuscript can then support a specific existing hypothesis.

Line 61: We revise and expand upon our previous sentences with the following, "~~However, while the SHWW are an important climatic feature, Holocene SHWW dynamics are poorly constrained, with previous work disagreeing between zonally symmetric or asymmetric change in the strength and/or intensity as well as the mean latitudinal position of the winds (Hillenbrand et al., 2017; Moreno et al., 2010; Perren et al., 2020; Saunders et al., 2018; van der Bilt et al., 2022; Varma et al., 2012; Zwier et al., 2022).~~ However, while the SHWW are an important climatic feature, complete Holocene SHWW dynamics are poorly constrained. Previous research has focused on three possibilities for the style of change; 1) strong southward SHWW displacement at the start of the Holocene and northward displacement with cooling and/or stable temperatures beginning ~9 – 7.5 ka (Hillenbrand et al., 2017; Kaplan et al., 2016; Mulvaney et al., 2012), 2) progressive strengthening and southward displacement of the SHWW between ~8 – 7 ka (Moreno et al., 2010; Saunders et al., 2018; Zwier et al., 2022), and 3) strengthening of the SHWW wind belt core with latitudinal contraction of the northern margin of the winds throughout the past 12 ka (Lamy et al., 2010). Furthermore, the early Holocene is hypothesized to be a climatically similar period to the present day, facilitating comparison to ongoing climate dynamics (Kaufman et al., 2020; Marcott et al., 2013). However, Osman et al. (2021) provides an alternative scenario, with global average temperature steadily increasing throughout the Holocene, which suggests that the Early Holocene would not be a comparable period for comparison to modern climate dynamics. The current ambiguity of Holocene and in particular early Holocene SHWW dynamics is critical for understanding West Antarctic Ice Sheet (WAIS) stability and future climate projections (i.e., Bronselaer et al., 2020).

Line 62 – 63: Expand this to a state-of-the-art paragraph. Which dust records do exist and what to they show in the context of SHWW Holocene dynamics? Then, start a new paragraph with Here, we…

Line 76: We expand our current paragraph to include more detailed information regarding existing dust records. "~~Microparticle records~~ Records of microparticle concentration and relative particle size (i.e., coarse particle percentage; CPP) from Antarctic ice cores offer a unique perspective on SHWW strength and/or position dynamics because they have been interpreted to reflect source-to-sink conditions and atmospheric variability, specifically distillation (Markle et al., 2018), geomorphology of the source regions (Sugden et al., 2009), wind strength (Koffman et al., 2014), vegetation cover, precipitation (Tegen and Schepanski, 2018), and atmospheric transport patterns (Aarons et al., 2017; Aarons et al., 2016; Aarons et al., 2019; Albani et al., 2018; Delmonte et al., 2013; Delmonte et al., 2002; Delmonte et al., 2020; Koffman et al., 2023). Holocene dust records differ among Antarctica ice cores, with East Antarctic Plateau data reflecting atmospheric subsidence and peripheral cores reflecting regional variability (Albani et al., 2012; Delmonte et al., 2020). The relative few complete and available Holocene dust records from Antarctica prevent a full interpretation of past SHWW behavior. Nevertheless, we have developed and present here records of dust concentration and CPP from the South Pole Ice Core (SPC14) to better constrain Holocene SHWW dynamics within the context of early Holocene to modern climate dynamics. ~~However, there are few complete Holocene dust records from Antarctica, limiting a full interpretation of past SHWW behavior.Here we measure and develop records of dust concentration and CPP in the South Pole Ice Core (SPC14) to better constrain Holocene SHWW dynamics. The South Pole is well-situated because of its geographic position, which facilitates hemispheric-scale interpretations, the relatively high snow accumulation rate that adds precision to the time record, and the 60 years of aerosol and meteorological studies in the region (Casey et al., 2014; Clem et al., 2020; Lazzara et al., 2012; Sheridan et al., 2016).~~

Line 65 – 67: This sentence has nothing to do with the "Here, we" paragraph. It should be moved up and expanded into paragraph on the study region.

Line 93: We added a paragraph at the end of the Introduction describing the study site and why it is a beneficial location. "The South Pole is well-situated because 1) the symmetric position with respect to the annular SHWW belt favors interpretation of the hemispheric, rather than regional, SHWW system, 2) the relatively high snow accumulation rate relative to other sites in East Antarctica provides strong constraints on the ice core chronology and high temporal resolution and 3) aerosol and meteorological studies have been conducted at this location over the past 60 years, which provides context for paleo-interpretations (Casey et al., 2014; Clem et al., 2020; Lazzara et al., 2012; Sheridan et al., 2016). The South Pole primarily receives aerosols during the austral summer (DJF) via air masses moving into the East Antarctic plateau, most prominently via the Weddell Sea and the Amundsen-Bellingshausen Sea embayment (Clem et al., 2020; Lazzara et al., 2012; Nicolas and Bromwich, 2011; Tuncel et al., 1989). South Pole aerosols and particulates (i.e., cloud condensation nuclei and dust particles) are sensitive to seasonal and synoptic variability over the past 40 years, demonstrating that trends in ice-core particle records likely reflect long-term climate variability (Ardon-Dryer et al., 2011; Hogan et al., 1984; Parungo et al., 1981; Sheridan et al., 2016). We build upon instrumental-era South Pole particle research to investigate Holocene particle variability on centennial to millennial scales throughout the Holocene using microparticle data from the new SPC14 intermediate-depth ice core."

Line 155 – 156: You may want to check if both the early and late Holocene are stable and the reduction occurs only during the mid-Holocene. To test this, I think it would be helpful to extend the dotted separation between the three periods to all panels a) b) and c) that share the same x-axis. If that hypothesis were correct, you may want to recalculate the slope only for the period *when the reduction in concentration occurs (i.e. mid-Holocene). If not, please describe this in the text.*

Line 197: We now include each time periods slope value and update the text to state, "During the early Holocene, dust concentration ~~remained relatively stable~~ decreased by ~24 particles mL^{-1} kyr^{-1} followed by a nearly two-fold decrease (~50 particles mL^{-1} kyr^{-1}) until the Late Holocene where particle concentrations are relatively stable until 250 years ago (~1.7 particles mL^{-1} kyr^{-1}~~)~~ ~~to the modern era (~~Table S1)."

Lines 169 to 171 and on the discussion of CPP: CPP is calculated relative to total dust concentrations, the two are therefore not independent from each other. This violates the assumption of independence for correlations and creates a well-known effect called "spurious correlation of ratios" which induces artificial correlations, as appears to be the case here. You therefore shouldn't (in most circumstances, and this does not seem to be one of the exceptions. Incidentally, EDC and Vostok are one of the exceptions because the strong positive correlation over glacial-interglacial timescales overrides the negative correlation bias) correlate a percentage with any of the two variables that were used to calculate it. One way around this could be to analyze the coarse and fine absolute fluxes separately. Instead of comparing CPP and total dust you could compare 1-3 (fine fluxes) and 3-5 (coarse fluxes) and make the same scientific conclusions with independent variables. Choose a way to do address this and adjust the discussion accordingly, in particular the discussion on the ice sheet (chapter 4.4).

Line 134: We add, "To avoid spurious correlation of ratios between our analyses, we also compare the coarse particle fraction (3.2 – 5.1 µm # mL^{-1}) to our fine particle fraction (1.1 – 3.2 µm # mL^{-1}), which we refer to as our coarse:fine ratio (CFR). Our CPP and CFR have a significantly strong relationship ($r = 0.95$, p-value = <0.01), suggesting similar forcings behind these particle size metrics.

Line 218: After original Lines 169 – 171, we add, "Because total dust concentration was used in the creation of the CPP metric, we test this relationship with CFR and identify a statistically weaker relationship ($r = -0.15$, $p < 0.05$). The statistically weaker relationship further supports the above interpretation of independent factors driving their variability."

Line 93 – 99: I understand now what the authors aim for, but I don't think this works as it is described right now, as you lump together models that show minimal changes with models that show statistically significant changes. First, you should separate the models that show a statistically significant difference, for example using the full timeseries of the simulation, and assign a 1 only to those that show a statistically significant increase.

We do use the full time series of data from CMIP6-PMIP4 model outputs, listed in Table 1. All model duration runs are different, so we averaged the data to compare between the different outputs. For every use of a model output, we averaged all the years together but preserved seasonal variability by averaging over months for each grid cell.

Line 376: We update Figure 4 to show both the model agreement (4a – c) and statistically significant regions (4d – f). We keep the model agreement because we use a two-sided test to test regions of significant change. By keeping the model agreement, we feel that it is easier to identify the sign of the change (i.e., increase or decrease) and the agreement of the models as to the significance of that change. We include the updated figure below, figure caption, and the updated section to the paper.

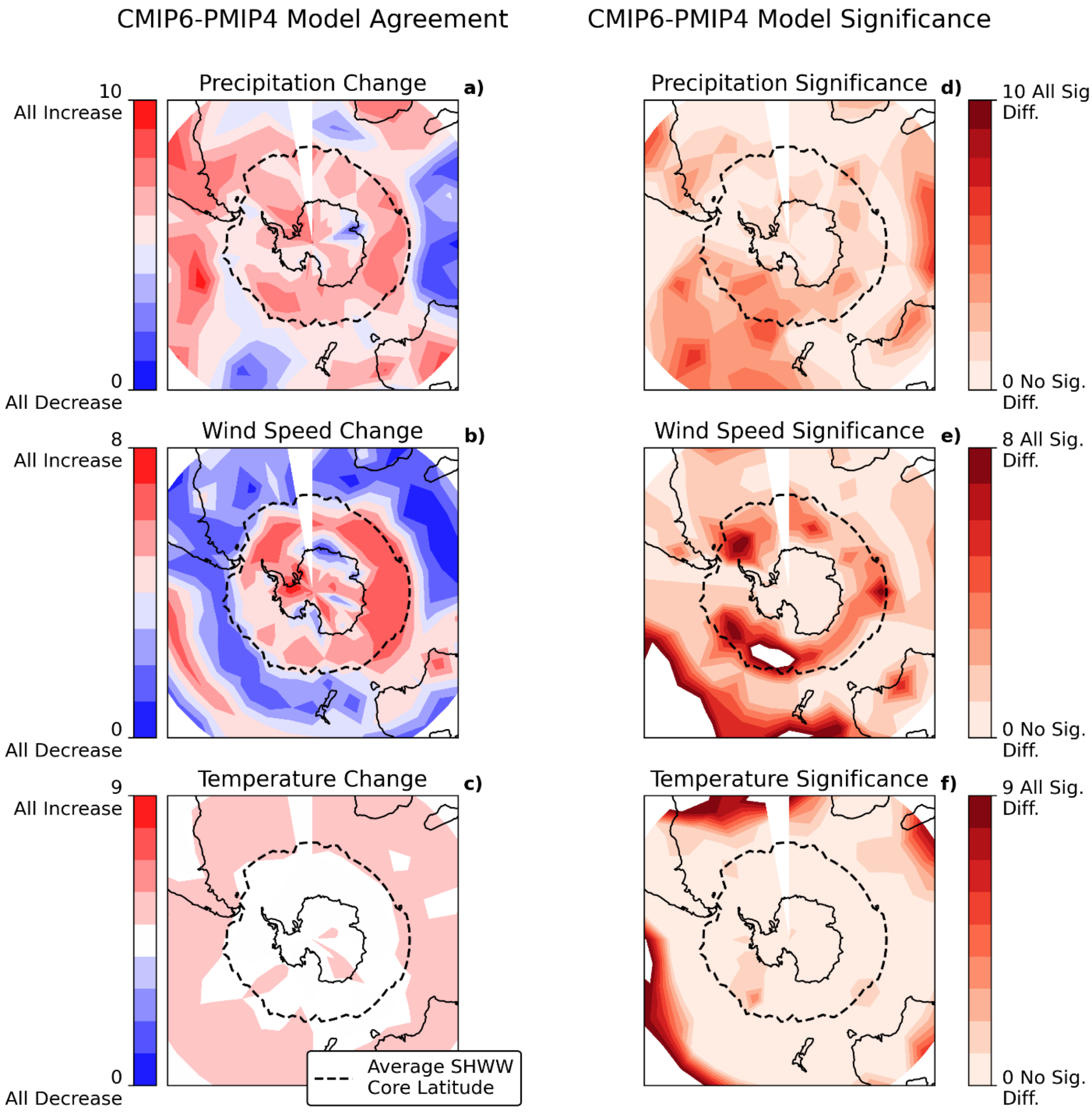


Figure 4a – f: CMIP6-PMIP4 models agreement displaying difference between mid-Holocene and piControl precipitation (4a), wind speed(4b), and temperature (4c; Brierley et al., 2020; Otto-Bliesner et al., 2017). Figure 4d – f highlights statistically significant difference (p-value < 0.05) between mid-Holocene and piControl using a two-sided t-test. Data are from a 10 x 10° grid to account for original model grid resolution (Table 1). Figure 4a – c color bars indicate the number of models that infer a positive or no/negative change in each variable between 6000 years BP and during the Pre-Industrial. Red regions indicate a stronger model consensus towards an increase and blue indicates a consensus towards a decrease in the respective variable. Values in the middle represent a lack of consensus. Figures 4d – f color bars highlight the number of models showing a significant change in the specific region, where darker red indicates all models used show a significant change. The black dotted line represents the average position of peak surface wind speed for both time periods.

Line 149: We add, "We test statistical significance by selecting data in the mid-Holocene and piControl runs using a 10x10° grid. We use a t-test to identify significant difference between the two periods for each model run (p-value <0.05). If the two periods are significantly different, then replace the values with a 1 and sum the totals between models, similar to our model agreement analysis."

Line 135 – 136: The SPC14 dust flux and d18O need to be shown together in one of the figures. It could for example replace panel a) of Figure 2, which is not discussed at all in the text at this moment…

Line 225: We add the SPC14 $\delta^{18}O$ to Figure 2 (Figure 2b) and update the figure caption. We keep Figure 2a because it highlights that the South Pole microparticle record and site itself is similar to other Antarctic records and sites, facilitating a comparison and analysis of the record. We add references to Figure 2a in the text (Line 130, 166, and 233).

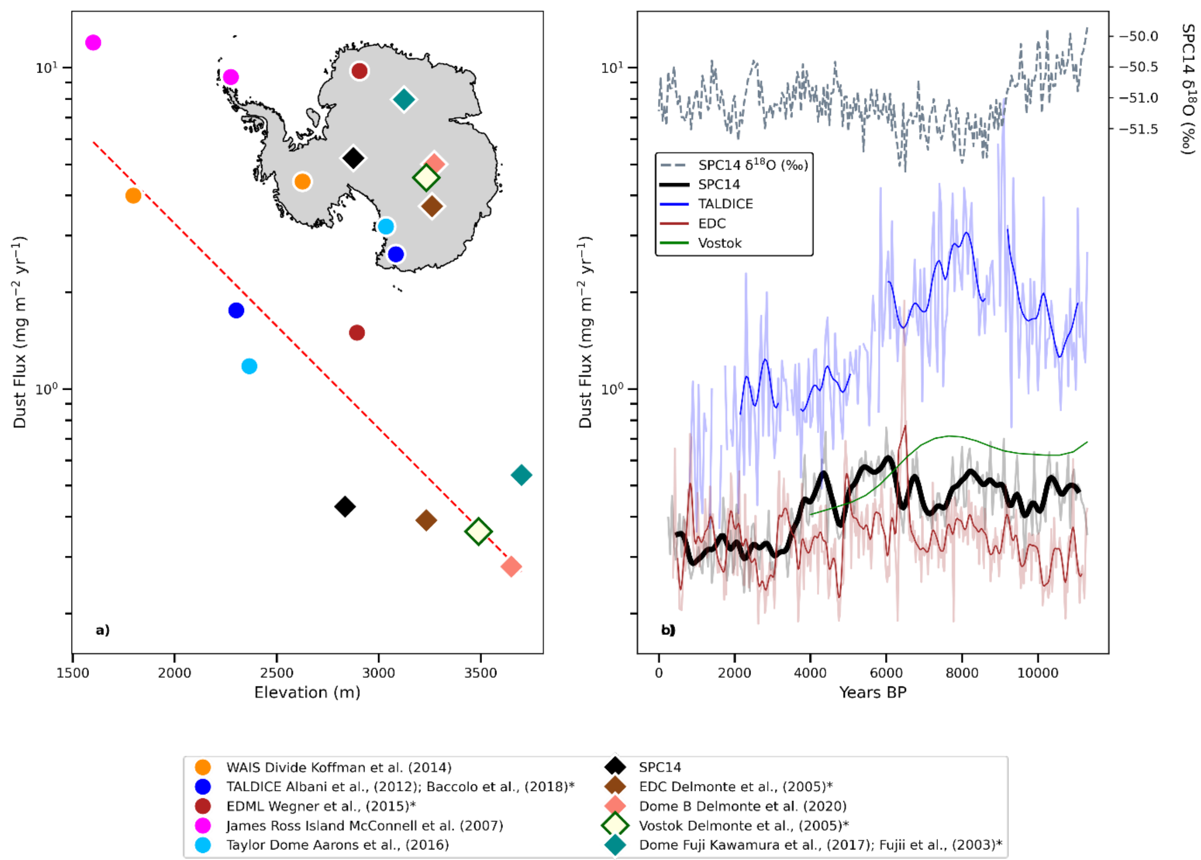


Figure 2a and b: Comparison of SPC14 dust metrics with other Antarctic Holocene records. In 2a, SPC14 dust flux is similar to other cores based on drill site elevation (following Koffman and Kreutz, 2014). Plateau sites are depicted with diamonds while non-plateau (i.e., WAIS and coastal locations) are depicted with circles. Labels containing * symbol at the

end were reported in (Delmonte et al., 2020). 2b shows the South Pole (SPC14) δ^{18}O (Steig et al., 2021) resolved to 50-year resolution shows available Holocene flux records from Talos Dome fine (0.6 – 5 µm mg m^{-2} yr^{-1}) particle flux (Albani et al., 2012), Vostok (Petit et al., 1990), EPICA Dome C (EDC; Lambert et al., 2012). SPC14 dust flux is similar to other East Antarctic sites (Vostok and EDC) and is on average ~67% lower compared to TALDICE. TALDICE, SPC14, and EDC were resampled to 50-year median values (background variability), and the darkened lines are the 11-point rolling gaussian mean for TALDICE, SPC14, and EDC. WAIS Divide (Koffman et al., 2014), James Ross Island (McConnell et al., 2007), and SPC14 dust fluxes (this study) were calculated using a laser particle counter and Dome Fuji (Fujii et al., 2003; Members: et al., 2017) was calculated using both light scattering techniques and a laser particle counter. All other records were measured using a Coulter Counter providing volume accurate measurements (Aarons et al., 2016; Albani et al., 2012; Baccolo et al., 2018; Delmonte et al., 2013; Delmonte et al., 2005; Delmonte et al., 2020).

The link between the SPC14 record and CO2 is weak right now. It can be mentioned "en passent" in a sentence, but without a modeling analysis supporting the claims, it is written too strongly right now. Maybe consider merging chapters 4.5 and 4.2.

We thank the reviewer for their comment and understand why they argue for merging Chapters 4.5 with 4.2. However, we believe that to interpret wind dynamics, our analyses in Chapters 4.3 and 4.4 are important since dust particles concentration and size metrics alone are not indicative enough to make inferences about wind strength. Therefore, we expand our analysis in 4.2 to state why we do not make inferences about wind change solely from the perspective of dust concentration.

Line 347: We add to the end Chapter 4.2, "Our interpretation of SHWW southward shift during the Holocene should correspond with changes in precipitation. Koffman et al. (2014) used Patagonian and Southern South American precipitation records in conjunction with WAIS Divide dust particle records to infer wind changes. Although the South Pole dust records are consistent with a southward shift in the SHWW, a corresponding increase in precipitation would further suggest such a change throughout the Holocene, rather than a possible decrease in glacial activity and/or vegetation change. Therefore, we assess our inferred dynamics of the SHWW within the context of precipitation variability over the Southern Hemisphere."

Line 431: We refocus our discussion and use of CO_2 as supporting evidence of wind dynamics rather than focusing on CO_2 outgassing. The sentences now state, "A southward migration of the SHWW can simultaneously explain the decrease in South Pole dust concentration and the increase in CPP, which is supported by our CMIP6-PMIP4 model trends and Southern Hemisphere proxy analysis. Southward migration of the SHWW is linked to Southern Ocean CO_2 outgassing (i.e., Anderson et al., 2009; Moreno et al., 2010; Toggweiler et al., 2006). The South Pole dust concentrations and CPP have significant relationships ($r = -0.76$ and 0.52, respectively, $p < 0.01$) with the composite Antarctic CO_2 record throughout the SPC14 Holocene record (Figure 5j; Bereiter et al., 2015). However, based on our data, this outside the scope of this paper."

Line 437: We remove Chapter 4.5 entirely. We move our discussion of insolation to the end of Chapter 4.4. The last paragraph of 4.4 now reads, "We suggest that the southward migration of the SHWW was in-part driven by increases in Southern Hemisphere temperatures related to increasing insolation (Figure 5b and i; Das and Alley, 2008; Laskar et al., 2004). Our SHWW model and proxy-based latitudinal reconstructions suggest that the latitudinal position and/or strength can reflect changes in regional temperature variability over millennial to centennial timescales consistent with previous studies (i.e., Jiang and Yan, 2020; Thompson and

Solomon, 2002; Toggweiler et al., 2006). High-latitude zonally averaged Holocene temperature reconstructions (60 – 90°S latitude) differ, where Kaufman et al. (2020) identify a relatively stable Holocene temperature of 0.04 ± 0.22 Δ°C (slope = < 0.01 Δ°C kyr^{-1}; relative to pre-industrial temperature) and Osman et al. (2021) suggest a more insolation-like increase (slope = 0.11 Δ°C kyr^{-1}; relative to last two millennia). The insolation-like structure in the South Pole dust record seems most consistent with the reconstruction of Osman et al. (2021), suggesting progressive, insolation-style, Southern Hemisphere warming and corresponding southward shift in the SHWW."

Minor comments:

Line 37: commas after change and weakening to make the sentence clearer

Line 36: We change the sentence to read, "Conflicting evidence suggests SHWW latitudinal change, weakening and/or strengthening, throughout the Holocene."

Line 38: Replace the vague "valuable" with a description of what makes it valuable, for example something related to the sensitivity of particle size to wind speed

Line 42: We remove the use of vague and change the sentence to now read, "We present South Pole Ice Core (SPC14) dust records spanning the Holocene. Dust concentrations (1.1 – 5.1 µm) decrease through the Holocene, while the coarse particle percentage (CPP) increase due to a relatively larger decrease in finer (1.1 – 3.2 µm) dust, highlighting an opposing trend."

Please rephrase the last 4 sentences of the abstract to clarify the message.

Line 47: We change the last four sentences of the abstract to now read, "The South Pole dust trends, consistent with CMIP6-PMIP4 model trends, southern mid-latitude insolation, and mid- to high latitude Southern Hemisphere proxy records, reflect SHWW southward migration and strengthening of wind speed south of 51°S during the mid-Holocene (~7000 – 3000 years ago). Our findings suggest orbitally-driven warming throughout the Holocene led to strengthening and southward migration of the SHWW beginning ~7000 years BP.

Line 73: While the CFA can produce nominal sub-annual resolution,…

Line 111: We change the sentence to now state, "While the CFA can produce data with nominal sub-annual resolution, we resample the dust data yielding the median value in 50-year intervals."

Line 78: Fix sentence

Line 117: We edit the sentence and add the following sentences and it now reads, "South Pole particle shape metrics (i.e., mass and flux) are unconstrained for the Holocene because of limited data (i.e., Chesler et al., 2023). In previously published ice core dust records using solely laser particle measurement techniques, the particle shape has been assumed to be spherical (Chesler et al., 2023; Simonsen et al., 2018; Potenza et al., 2016). Studies concerned with the absolute magnitude of dust flux at the South Pole should use prolate particle shapes to calculate flux

(Chesler et al., 2023; data at USAP-DC, DOI: 10.15784/601553). However, the spherical particle mass flux is used in this work to compare with other available Antarctic microparticle records."

Line 74 – 88: The sentences on fluxes and numbers are currently randomly mixed. Please separate the two.

Line 113: We change original Lines 74 – 88 so that it now reads, "To facilitate a comparison with other ice core records, we assume a spherical particle shape, rather than the measured prolate particle shapes (Chesler et al., 2023), and use a density of 2.6 g cm^{-3} (following Koffman et al., 2014) to estimate particle mass flux. ~~While we recognize that South Pole particle shape metrics (i.e., mass and flux) are unconstrained for the Holocene (i.e., Chesler et al., 2023) because of limited available data, we use South Pole flux as a comparison tool to assess similarities between other available microparticle Antarctic Holocene.~~ South Pole particle shape metrics (i.e., mass and flux) are unconstrained for the Holocene because of limited data (i.e., Chesler et al., 2023). In previously published ice core dust records using solely laser particle measurement techniques, the particle shape has been assumed to be spherical (Chesler et al., 2023; Potenza et al., 2016; Simonsen et al., 2018). Studies concerned with the absolute magnitude of dust flux at the South Pole should use prolate particle shapes to calculate flux (Chesler et al., 2023; data at USAP-DC, DOI: 10.15784/601553). However, the spherical particle mass flux is used in this work to compare with other available Antarctic microparticle records. We restrict particle metrics to number concentration and CPP because the particle shape assumption (i.e., particle flux and mass concentration), can artificially increase particle metric concentrations by 25 – 44%. We use a spherical particle shape assumption to facilitate comparison to other Antarctica ice core particle records that include a volume assumption (i.e., flux) using particles that range between 1.1 – 5.1 µm due to the particle number concentration distribution (Figure 1e). While this produces higher-than-realistic particle flux values, it mitigates discrepancies from comparing records with dissimilar metrics. We use particle number concentration measured between 1.1 – 5.1 µm and CPP (defined as number of particles mL^{-1} [3.2 – 5.1] /[1.1–5.1] µm diameter x 100) following other East Antarctic studies due to the similarity of the South Pole particle flux to other East Antarctic core records (Figure 2a and b; i.e., Delmonte et al., 2020). ~~While this produces higher-than-realistic particle flux values, it mitigates discrepancies from comparing dissimilar metrics, whereas in the past particle shape has been assumed to be spherical (Chesler et al., 2023; Potenza et al., 2016; Simonsen et al., 2018). Studies concerned with the absolute magnitude of dust flux at the South Pole should use prolate particle shapes to calculate flux (Chesler et al., 2023; data at USAP-DC, DOI: 10.15784/601553).~~ To avoid spurious correlation of ratios between our analyses, we also compare the coarse particle fraction (3.2 – 5.1 µm # mL^{-1}) to our fine particle fraction (1.1 – 3.2 µm # mL^{-1}), which we refer to as our coarse:fine ratio (CFR). Our CPP and CFR have a significantly strong relationship ($r = 0.95$, p-value = <0.01), suggesting similar forcings behind these particle size metrics."

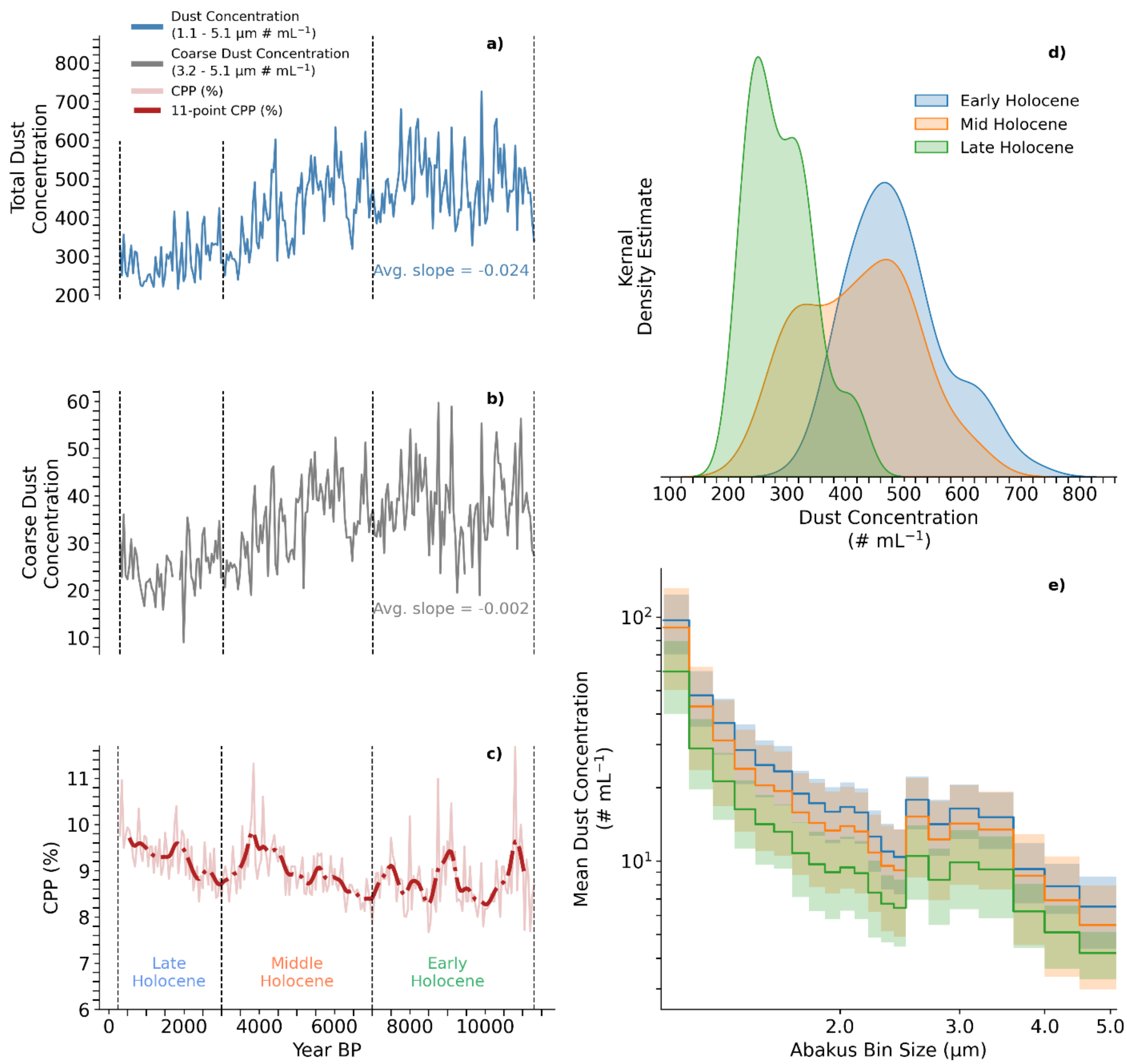
Line 89 – 99: Separate Hysplit section from CMIP section, these should be different paragraphs.

Line 138: We separate Chapter 2.1 into two different paragraphs instead of one, so the section now reads, "We obtain HYSPLIT NCEP trajectories for December, January, February (austral summer; DJF) and June, July, August (austral winter; JJA) from 1980 – 2022 (inclusive) hourly for 10 days over a 90-day period. We run the model at an altitude of 1000 m following Schwanck et al. (2017) and use the default vertical motion for the model. We then calculate air mass origin percentage using a 2 x 2° grid to identify where air masses originate 10 days prior to reaching the South Pole.

We also explore changes in atmospheric temperature, wind speed, and precipitation using CMIP6 – PIMP4 model outputs. We use 11 different models (Table 1) to assess model agreement between mid-Holocene runs (6,000 years ago) relative to pre-industrial control (piControl). We calculate model difference by subtracting the mid-Holocene from pre-industrial to assess change in each climate variable from the mid-Holocene to the pre-Industrial. We replace all positive values with a value of 1, which signifies an increase with time, and replace all negative values with a 0 and sum all model runs. Our method allows us to assess if the models agree to an increase/decrease in each climate variable rather than assessing the magnitude of change between each model. We test statistical significance by selecting data in the mid-Holocene and piControl runs using a 10x10° grid. We use a t-test to identify significant difference between the two periods for each model run (p-value <0.05). If the two periods are significantly different, then replace the values with a 1 and sum the totals between models, similar to our model agreement analysis."

Line 107 – 108: If this is indeed shown in the new Figure 1e, could you please indicate the 1.1um and 5.1um cutoffs? Right now it looks like only the 1.1-5.1um range is shown in Figure 1e.

Line 222: We adjust the figure so that the demarcation of the minimum bin value maximum bin value is shown more clearly. Below is the updated figure.



Lines 107-110: You can include an introductory paragraph immediately before a list of subchapters; it is called a "chapeau". It sets the overall scope and context of the following subchapters. The sentences in this section should be moved to the description of Figure 1.

Line 160: We move Lines 107 – 110 down to the start of our new Chapter 3.1 (Holocene trends in dust deposited at the South Pole). We also start Chapter 3 (Results) with the following based on the comment, "South Pole dust concentrations begin to decrease significantly from ~7000 years BP (the mid-Holocene), coinciding with an increase in the CFR and CPP. South Pole particle flux and NOAA HYSPLIT analysis suggests that trends in the South Pole particle flux are similar to those in other Antarctic records (Figure 2a and b) and broadly reflects synoptic scale Antarctic climate (Figure 3a and b)."

Line 191: Chapter 3.1 now reads, "The number concentrations of particles in the size range 1.1 – 5.1 µm comprise on average ~85 – 96% of all particles measured (median ± 1σ; Figure 1a and b). The total dust number concentration and CPP (Figure 1a – c) abundance have opposing trends, yet the timing of change in both trends begins about ~7000 years BP. This inverse relationship is most apparent during the mid-Holocene (~7000 – 3000 years BP). Because trend changes occur around the mid-Holocene, we divide the Holocene into early (11,300-7,000 years BP), middle (7,000-3,000 years BP) and late (3,000 - 250 years BP) periods. During the early Holocene, dust concentration remained relatively stable decreased by ~24 particles mL^{-1} kyr^{-1} followed by a nearly two-fold decrease (~50 particles mL^{-1} kyr^{-1}) until the Late Holocene where particle concentrations are relatively stable until 250 years ago (~1.7 particles mL^{-1} kyr^{-1}) to the modern era (Table S1). Dust concentration distributions in all three time periods are statistically different (Figure 1d; p-value < 0.01; Table S2a), further indicating a significant reduction in Holocene dust deposition.

Coarse particle concentrations have a similar decrease compared to the fine particles, however, at an order of magnitude smaller (total dust concentration slope = ~ -20 # particles mL^{-1} kyr^{-1} compared to coarse particle decrease ~ -2 # particles mL^{-1} kyr^{-1}. The number concentration of coarse particles has a decrease similar to the total particle concentration, but the coarse particle decrease is an order of magnitude smaller (total dust concentration slope = ~ -20 # particles mL^{-1} kyr^{-1} compared to coarse particle decrease ~ -2 # particles mL^{-1} kyr^{-1}. The total and coarse particle fractions have similar albeit slightly different changes throughout the Holocene, whereas there is a ~ -40% difference between the Early Holocene and Late Holocene for total dust concentration and a ~ -35% difference between the Early Holocene and Late Holocene for coarse dust concentration. The decrease in total dust concentration from the Early Holocene to Late Holocene is about 40% and about 35% for coarse dust concentration. This 5% difference results in an increase in the CPP starting at ~7000 years BP, where over the Holocene, CPP significantly increases from 8.6% to 9.4% (two-sided t-test; p-value < 0.01; Table S2b). In contrast, CPP increases over the Holocene from 8.6% to 9.4%. The CPP during the early and late Holocene are distinct, with significantly different distributions (two-sided t-test; p-value < 0.01; Table S2b). Although the coarse dust concentration also decreases slightly throughout the Holocene, the decrease is much less than that of the total dust concentration slope such that the proportion of coarse particles rises, especially during the middle Holocene. CPP has a weak statistical relationship with dust concentration during the Holocene (Spearman r = -0.28; p < 0.01), suggesting that their variability may be driven by different and/or independent factors. During the late Holocene, both the dust concentration and CPP have the lowest variability compared to the middle or early Holocene (Figure 1, Table S1). Because total dust concentration was used in the creation of the CPP metric, we test this relationship with CFR and identify a statistically weaker relationship (r = -0.15, p < 0.05). The statistically weaker relationship further supports the above interpretation of independent factors driving their variability."

Line 121: Why is there a chapter here on dust fluxes and Hysplit when you just introduced Figure 1 with no description? Please switch chapter 3.1 with chapter 3.2 and describe Figure 1 first. Then move on to Figure 2.

Line 191: We switch the positions of the original Chapters 3.1 and 3.2 so that now the dust concentration and CPP trends are described first, followed by the South Pole dust flux, and then our HYSPLIT analysis. We move the new Chapter 3.1 (dust particle trends) above Figure 1.

Line 158: Inset has become now Figure 1d. Please also fix the Figure 1 caption.

Line 227: Caption has been fixed. The use of inset has been removed and replaced with "1d…"

Line 159: Not fine particles. Compared to total concentrations.

Line 202: Removed sentence.

Line 161: "similar albeit slightly different changes" does not help the reader. Please describe what is similar and what is different.

Line 209: We remove and rephrase the sentence so that it now reads, "The decrease in total dust concentration from the Early Holocene to Late Holocene is about 40% and about 35% for coarse dust concentration."

Line 164: Don't use "in contrast" when the subject of the contrast is several phrases ago in another paragraph.

Line 210: We rephrase and combine sentences so that now the sentence before focuses on the reduction of fine vs coarse particles and the sentence now reads, "This 5% difference results in an increase in the CPP starting at ~7000 years BP, where over the Holocene, CPP significantly increases from 8.6% to 9.4% (two-sided t-test; p-value < 0.01; Table S2b)."

Line 123: I think you mean Figure 2.

Line 233: We correctly now identify Figure 2a.

Line 126 – 130: Move the description of Hysplit results to chapter 3.3 and description of Figure 3.

Line 269: We move all descriptions of our HYSPLIT analyses to section 3.3. Section 3.3 now reads, "Our NOAA HYSPLIT results from austral summer (DJF) and winter (JJA; 1980 – 2022) both highlight a dominant Atlantic sector signal (Figure 3; Rolph et al., 2017; Stein et al., 2015). Austral summer air masses at their 10-day origin are from the Weddell Sea, Dronning Maud Land, Enderby and Kemp Land (i.e., Atlantic Sector; Figure 3a), while austral winter air masses origins are more latitudinally and longitudinally diverse, with a greater percentage of air mass originates from the Atlantic and Pacific sectors of the Southern Ocean (Figure 3b). While both the longitude and latitude seasonal origins differ, the change is most pronounced in the latitudinal variability (Figure 3c and 3d). A primary austral summer peak was observed in previous South Pole dust and meteorological records (Bodhaine et al., 1986; Carrasco et al., 2003; Hogan et al., 1984; Lazzara et al., 2012; Parungo et al., 1981). Our HYSPLIT analysis identifies DJF 10-day air mass origin locations with an average coordinate of 70.9 (± 9.4)° S, -1.4 (± 80.03)° W, indicating a primarily Weddell Sea/Atlantic Sector modern signal. The similarity results from other East Antarctica sites (i.e., Dome C and Vostok; Figure 2b), the modern back-trajectory modelling (Figure 3), and the dust-water isotopes relationships all suggest that South Pole represents a site typical of Antarctic plateau locations, with the majority of dust likely sourced from remote regions rather than mixed remote-local dust sources, facilitating comparisons (Figure 2)."

Line 173: Figure 3, not Figure 2. Also flesh out this subchapters (e.g. description of panels a) and b)) with the hysplit text found in the dust flux subchapter above.

Line 269: The figure reference has been corrected. We also move text that was originally above to Chapter 3.3 so that it is more consistent. The text now reads, "Our NOAA HYSPLIT results from austral summer (DJF) and winter (JJA; 1980 – 2022) both highlight a dominant Atlantic sector signal (Figure 3; Rolph et al., 2017; Stein et al., 2015). Austral summer air masses at their 10-day origin are from the Weddell Sea, Dronning Maud Land, Enderby and Kemp Land (i.e., Atlantic Sector; Figure 3a), while austral winter air masses origins are more latitudinally and longitudinally diverse, with a greater percentage of air mass originates from the Atlantic and Pacific sectors of the Southern Ocean (Figure 3b). While both the longitude and latitude seasonal origins differ, the change is most pronounced in the latitudinal variability (Figure 3c and 3d). A primary austral summer peak was observed in previous South Pole dust and meteorological records (Bodhaine et al., 1986; Carrasco et al., 2003; Hogan et al., 1984; Lazzara et al., 2012; Parungo et al., 1981). Our HYSPLIT analysis identifies DJF 10-day air mass origin locations with an average coordinate of 70.9 (± 9.4)° S, -1.4 (± 80.03)° W, indicating a primarily Weddell Sea/Atlantic Sector modern signal. The similarity results from other East Antarctica sites (i.e., Dome C and Vostok; Figure 2b), the modern back-trajectory modelling (Figure 3), and the dust-water isotopes relationships all suggest that South Pole represents a site typical of Antarctic plateau locations, with the majority of dust likely sourced from remote regions rather than mixed remote-local dust sources, facilitating comparisons (Figure 2)."

Line 187 – 189: How does this sentence relate to this subchapter? It would fit better in 4.2.

Line 300: We removed the sentence.

Line 217 – 219: Do not ask the reader to read another paper to understand your reasoning. Write down the relevant conclusions from Denton et al., 2021.

Line 324: We change the sentence to now state, "We interpret this relationship to reflect changes in the Westerly Winds shifts and warm water circulation into the south Pacific gyre, which was also hypothesized by as described in Denton et al. (2021) to explain the onset of mountain glacier retreat during Termination I. Similar atmospheric dynamics may also occur during the Holocene."

Line 234 – 236: Sentence needs citation.

Line 344: We add the necessary citation to the end of the sentence, "Whereas in South America, the changes located at Lago Condorito and Lago Guanaco suggest southward migration starting at the earliest at 7800 years ago (Moreno et al., 2010)."

Lines 338 – 343: move to conclusions

Line 382: We move the entire paragraph to the last paragraph of the conclusions.

Line 475: The conclusions now read, "Mid-to-high latitude Southern Hemisphere Holocene proxy records provide ample evidence for an orbitally-driven, progressive, southward shift of Holocene thermal gradients resulting in the strengthening of the SHWW beginning at the start of the Holocene with the most dynamic change occurring between 7000 – 3000 years BP. Together, the data suggest that high-southern latitude wind dynamics and resulting precipitation changes are driven by high-latitude hemispheric temperature change on orbital timescales. While there is broad agreement among many proxy records, the Pine Island Bay upwelling record shows a different pattern, with reduced wind-driven upwelling near West Antarctica after ~8 ka (Figure 5g; Hillenbrand et al., 2017). Zonal differences in wind strength may account for these apparently conflicting observations (Kaplan et al., 2016).

Opportunities for future research include describing the asymmetry in the timing of SHWW wind shifts between Western and Eastern Antarctica, which could influence the output of ocean derived CO_2 to the atmosphere. Our results further suggest the early Holocene may be a poor analogue for modern climate change. The SHWW southward shift and CO_2 transfer from the ocean to the atmosphere increased throughout the Holocene and has continued to increase today (Menviel et al., 2023). Identifying and examining WAIS stability within the context of Holocene changes therefore becomes critical if the early Holocene can no longer be used as an analogue to modern temperature change.

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