

# Bering Strait Ocean Heat Transport Drives Decadal Arctic Variability in a High-Resolution Climate Model

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## Key Points:

- Ocean heat transport variability through the Bering Strait has an outsized effect on Arctic sea ice cover and surface temperature
- Atlantic ocean heat transport anomalies into the Arctic are compensated by atmospheric heat transport anomalies on decadal timescales

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## Abstract

We investigate the role of ocean heat transport (OHT) in driving the decadal variability of the Arctic climate by analyzing the pre-industrial control simulation of a high-resolution climate model. While the OHT variability at 65°N is greater in the Atlantic, we find that the decadal variability of Arctic-wide surface temperature and sea ice area is much better correlated with Bering Strait OHT than Atlantic OHT. In particular, decadal Bering Strait OHT variability causes significant changes in local sea ice cover and air-sea heat fluxes, which are amplified by shortwave feedbacks. These heat flux anomalies are regionally balanced by longwave radiation at the top of the atmosphere, without compensation by atmospheric heat transport (Bjerknes compensation). The sensitivity of the Arctic to changes in OHT may thus rely on an accurate representation of the heat transport through the Bering Strait, which is difficult to resolve in coarse-resolution ocean models.

## Plain Language Summary

We studied how ocean heat transport (OHT) affects decade-timescale variability in the Arctic climate using a high-resolution climate model. Specifically, we compared the impacts of heat entering the Arctic Ocean through the Nordic Seas from the Atlantic and through the Bering Strait from the Pacific. Though more heat is transported from the Atlantic, Arctic surface temperature and sea ice respond more strongly to changes in OHT through the Bering Strait. Unlike Atlantic OHT, changes in Bering Strait OHT impact local air temperatures directly, without compensating changes in atmospheric heat transport. Proper representation of the Arctic’s sensitivity to future increased OHT may thus rely on correctly representing OHT through Bering Strait, which is challenging in coarse-resolution ocean models.

## 1 Introduction

The Arctic is warming faster than the rest of the world (Rantanen et al., 2022; Chylek et al., 2022). This amplification of Arctic climate change is caused by a coupling between local feedbacks and increased poleward heat transport from lower latitudes (Hwang et al., 2011; Nummelin et al., 2017; Previdi et al., 2021). However, the mechanisms of this coupling are complex and still poorly understood.

Decadal to multidecadal timescale variability in the Arctic—manifested by changes in sea ice extent, surface temperatures, etc.—has been previously shown to be closely related to ocean heat transport (Zhang, 2015; Jungclaus & Koenigk, 2010). Further, it has been suggested that variability in *total* heat transport into the Arctic is reduced by a phenomenon known as Bjerknes Compensation (BC), whereby anomalies in meridional ocean heat transport (OHT) tend to induce roughly equal and opposite anomalies in meridional atmospheric heat transport (AHT). Bjerknes (1964) proposed that this result follows from energy conservation on timescales where the top-of-atmosphere (TOA) fluxes and ocean heat content remain approximately constant. A recent study (Y. Liu et al., 2020) indeed found evidence of decadal-timescale BC in several reanalysis datasets and confirmed the importance of surface heat fluxes in communicating OHT variability to the atmosphere. However, as they note, the exact causal relationships of decadal-timescale heat transport variability are very difficult to parse out in such short observational time series.

Models have thus been indispensable to the study of BC due to the need for sufficiently long time series. In coupled global climate models, BC is typically strongest at the high northern latitudes (Shaffrey & Sutton, 2006; Swaluw et al., 2007; Outten & Esau, 2017; Jungclaus & Koenigk, 2010), due to the presence of strong regional climate feedbacks in the marginal ice zone (Z. Liu et al., 2016; Kurtakoti et al., 2023). Specifically,

64 Swaluw et al. (2007) and Outten and Esau (2017) argue that BC in high northern lat-  
65 itudes is due to the modulation of sea ice by decadal Atlantic OHT variability. The canon-  
66 ical mechanism is illustrated as follows: positive OHT anomalies melt back sea ice, en-  
67 hancing heat loss from the previously ice-covered ocean. The anomalous heat flux into  
68 the atmosphere may be amplified by local radiative feedbacks such as the ice-albedo feed-  
69 back, causing local atmospheric warming. This warming then reduces the meridional tem-  
70 perature gradient and thus baroclinity, reducing the northward heat transport by atmo-  
71 spheric eddies.

72 This canonical perspective does not take into account significant longitudinal vari-  
73 ations in the Earth’s geography and climate mean state. In particular, OHT from the  
74 sub-Arctic to the Arctic Ocean takes place primarily through two main gateways: flow  
75 across the Greenland-Scotland Ridge connects the Arctic Ocean to the subpolar North  
76 Atlantic Ocean, while flow through the Bering Strait connects the Arctic to the subpo-  
77 lar North Pacific. OHT through the Atlantic sector is an order of magnitude larger than  
78 that through the Bering Strait, both in mean value and in amplitude of variability. Con-  
79 sequently, most studies on the connection between decadal Arctic variability and Bjerke-  
80 nes Compensation have focused mainly on Atlantic OHT variability. An exception is the  
81 study by Li et al. (2018), who analyzed three Earth system models (ESM) and demon-  
82 strated that OHT through both gateways has an important impact on Arctic climate.  
83 In fact, they argue that OHT through Bering Strait is more efficient in causing low-frequency  
84 variability of Arctic sea ice than OHT through the Atlantic sector. A strong sensitiv-  
85 ity of Arctic sea ice on Bering Strait throughflow has also been found in observations (Woodgate  
86 et al., 2012; MacKinnon et al., 2021).

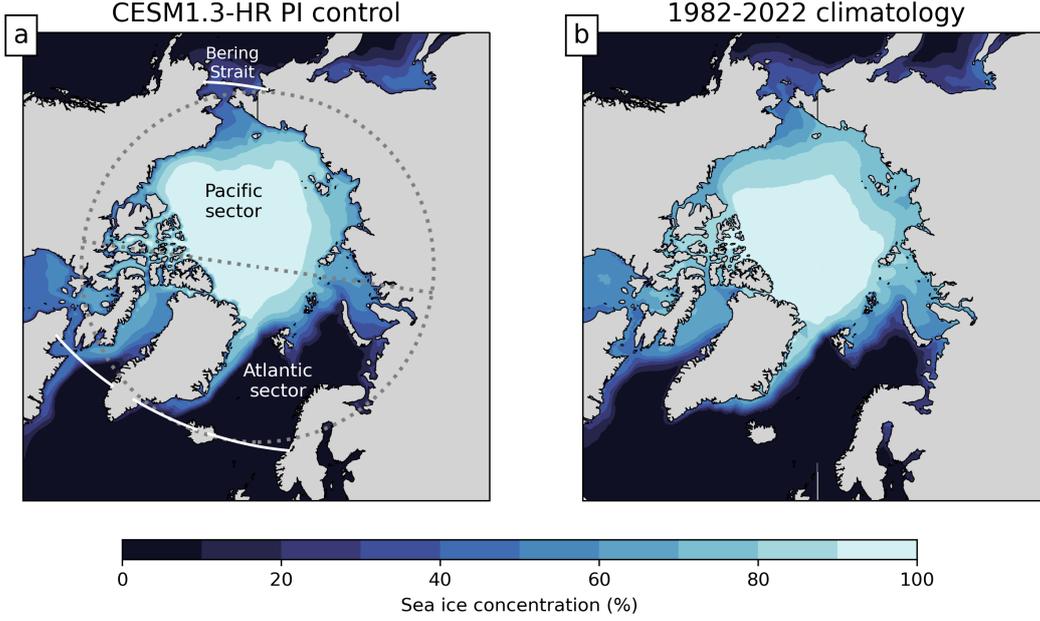
87 This raises the question: how does the atmosphere respond to OHT variability through  
88 the different gateways given the differences in sea ice sensitivity, and what are the con-  
89 sequences for the atmosphere’s ability to compensate for this OHT variability?

90 This question is important for several reasons. First, observations over the past few  
91 decades (Woodgate, 2018; Tsubouchi et al., 2021) as well as model projections of future  
92 climate change (Shu et al., 2022) show a robust increase of northward OHT going into  
93 the Arctic from both the subpolar North Atlantic and North Pacific Oceans. The extent  
94 to which AHT will compensate these changes is therefore of primary concern for con-  
95 straining uncertainty in Arctic climate change. Second, the current generation of climate  
96 models typically have a spatial resolution of  $\sim 1^\circ$  in their standard configuration ocean  
97 models. Such low resolution leaves narrow channels like the Bering Strait significantly  
98 underresolved (Chang et al., in review), while poorly resolved bathymetry also appears  
99 to weaken OHT across the Greenland-Scotland Ridge (Heuzé & Árrthun, 2019). Conse-  
100 quently, OHT in standard resolution climate models may be significantly biased, and their  
101 results should be treated with caution.

102 Recently, an unprecedented multi-century simulation of a high-resolution global cli-  
103 mate model was performed (Chang et al., 2020), which at the time of analysis was the  
104 longest pre-industrial control simulation run at high resolution (see Data and Methods).  
105 In this paper we use this unique data set to investigate the Arctic atmospheric response  
106 to OHT variability through the primary oceanic gateways. We find that Bering Strait  
107 OHT plays an outsized role in driving Arctic climate variability. By decomposing the  
108 meridional energy balance, we show that while the AHT partially compensates for anoma-  
109 lies in the zonally-integrated OHT, lateral atmospheric energy fluxes do not compensate  
110 for anomalies in OHT through Bering Strait.

## 111 2 Data and Methods

112 We use a portion of the 500-year pre-industrial (PI) control simulation of CESM1.3  
113 (Community Earth System Model version 1.3), configured with nominal horizontal res-



**Figure 1.** (a) Annual-mean climatology of Arctic sea ice concentration in the PI control simulation analyzed in this study. The dotted grey lines show  $65^\circ\text{N}$  and the boundary between the Pacific and Atlantic sectors defined in this paper. The white lines indicate the logical latitudes used for integration. (b) Observed 1982-2022 climatology of annual-mean Arctic sea ice concentration (NOAA OISST v2).

114 olutions of  $0.25^\circ$  in the atmosphere and land models and  $0.1^\circ$  in the ocean and sea-ice mod-  
 115 els (Chang et al., 2020). The PI control was forced with greenhouse gas conditions kept  
 116 constant at the 1850 levels throughout the simulation. We exclude the first 150 years from  
 117 our analysis due to model drift, so all time series are 350 years long (see Chang et al.,  
 118 2020, for context). The sea ice climatology of the PI control simulation is shown in Fig-  
 119 ure 1a and shows good agreement with the observed climatology during the satellite era  
 120 (Fig. 1b).

We estimate meridional OHT and AHT at  $65^\circ\text{N}$  from monthly-averaged fields. We choose  $65^\circ\text{N}$  as the boundary of the Arctic, however our results are not sensitive to the choice of latitude. The OHT time series is calculated by integrating the product of meridional velocity ( $v$ ) and potential temperature ( $\Theta$ ):

$$\text{OHT} = \int_{\varphi_E}^{\varphi_W} \int_{-H}^0 c_p v \Theta \cos \theta \, dz \, R_e d\varphi \quad (1)$$

121 where we use  $\theta$  and  $\varphi$  to denote latitude and longitude, respectively.  $\varphi_E$  and  $\varphi_W$  denote  
 122 the eastern and western boundaries of the basin and  $H$ ,  $c_p$ ,  $z$ , and  $R_e$  denote basin depth,  
 123 heat capacity of seawater at constant pressure, vertical depth, and the radius of the Earth,  
 124 respectively. This reconstruction, which ignores contributions by sub-monthly covariance  
 125 between velocity and temperature, is necessary because the model’s online diagnostic OHT  
 126 output was corrupted for the first 277 years and thus would have significantly shortened  
 127 the available timespan for our analysis. For ease of computation, we also choose to ap-  
 128 proximate OHT across  $65^\circ\text{N}$  by heat transport across a *logical* latitude line of the model’s  
 129 tripolar grid that tracks  $65^\circ\text{N}$  reasonably well. A comparison between our OHT time series,  
 130 the OHT time series from the model’s online diagnostic output across the same log-  
 131 ical latitude line (after the period of data corruption), and an estimate of the OHT across

132 the actual 65°N latitude line, shows that our OHT time series is an accurate represen-  
 133 tation of OHT across 65°N in the Atlantic (Supplementary Information).

The AHT time series is estimated by assuming a negligible atmospheric heat capacity and cumulatively integrating the energy flux divergence (e.g., Shaffrey & Sutton, 2006; Swaluw et al., 2007; Outten et al., 2018). We define AHT at the north pole ( $\theta = \pi/2$ ) to be zero and integrate the zonally-integrated flux divergence southward to find the AHT at each latitude  $\theta$ :

$$\text{AHT} = \int_{\theta}^{\pi/2} \int_0^{2\pi} (F_{\text{sfc}} - F_{\text{TOA}}) R_e^2 \cos \theta' d\varphi d\theta' \quad (2)$$

134 where  $F_{\text{TOA}}$  and  $F_{\text{sfc}}$  are the net downward heat flux at the top-of-atmosphere and sur-  
 135 face, respectively. By this formulation, northward AHT is positive.

Since we are concerned with variability on decadal timescales, all monthly time series are annually-averaged, detrended, and then smoothed using a 10-year moving average. Moreover, to account for inflated Pearson's  $r$  when regressing smoothed time series, we calculate an effective number of degrees of freedom for significance tests. We follow the formulation given in Jungclaus and Koenigk (2010) to estimate the effective number of samples:

$$n_{\text{eff}} = \frac{n}{1 + 2(\sum_{i=1}^n r_i r'_i)} \quad (3)$$

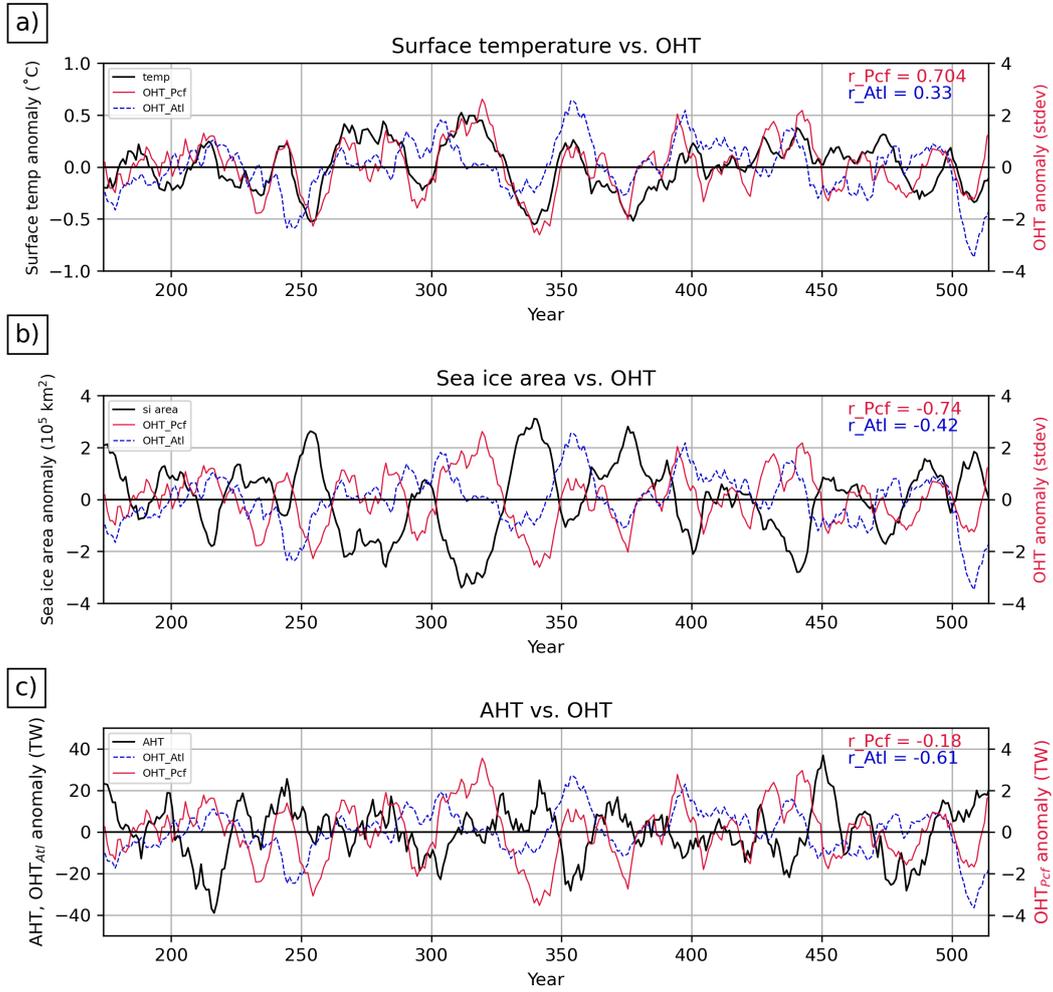
136 where  $n$  is the original length of the time series and  $r_i, r'_i$  are the autocorrelations of the  
 137 two time series at lag  $i$ . For smoothed time series originally with 341 samples,  $n_{\text{eff}}$  is on  
 138 the order of 30-50.

### 139 3 Results

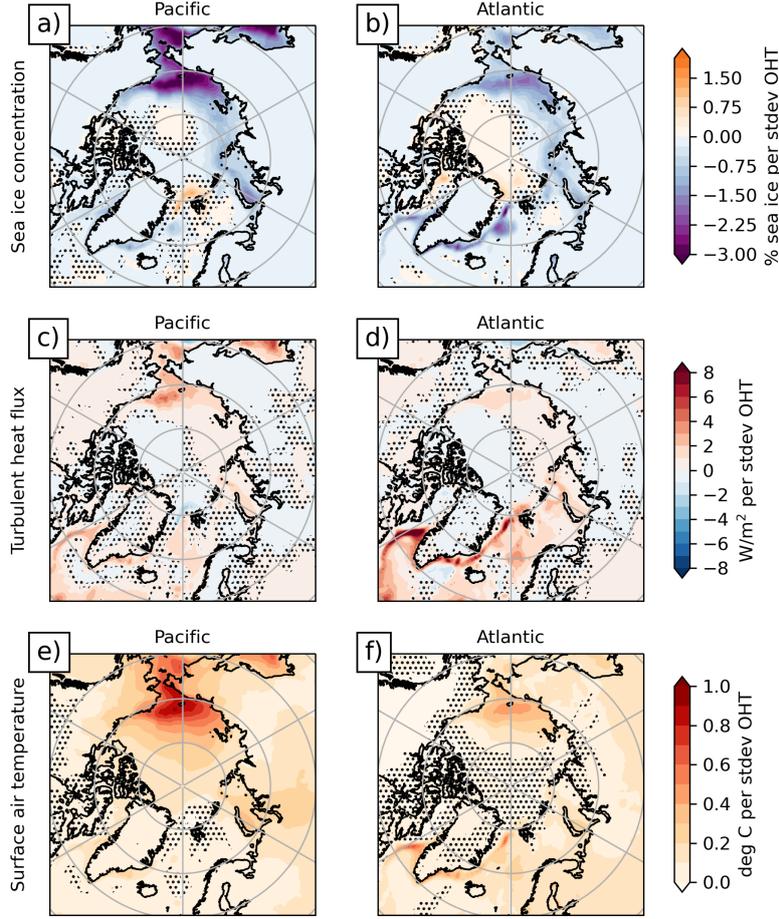
#### 140 3.1 Arctic response to Pacific and Atlantic OHT

141 The OHT through the Atlantic and Bering Strait (the blue and red lines in Fig-  
 142 ure 2, respectively) both display decadal to multidecadal variability. OHT anomalies are  
 143 positively correlated with Arctic-average surface air temperature anomalies and nega-  
 144 tively correlated with sea ice area anomalies (Figure 2a,b). Strikingly, Bering Strait OHT  
 145 (mean = 8.6 TW, standard deviation = 1.4 TW) has a stronger correlation with both  
 146 surface temperature and sea ice than Atlantic OHT (mean = 342 TW, standard devi-  
 147 ation = 10.5 TW), even though it is considerably smaller in magnitude. It is not pos-  
 148 sible to conclude from correlation alone whether 1) OHT variability is driving these changes  
 149 in temperature and sea ice, 2) OHT variability is driven by surface temperature changes,  
 150 or 3) OHT, temperature, and sea ice covary due to another driving mode of variability.  
 151 In later sections, however, we present evidence indicating that OHT plays the driving  
 152 role in modulating sea ice and air-sea heat flux, thus communicating ocean heat anom-  
 153 alies to the atmosphere.

154 At 65°N, anomalies in AHT and Atlantic OHT compensate each other on decadal  
 155 timescales, with an anticorrelation of  $r = -0.61$  (Figure 2c). The compensation is in-  
 156 consistent over time, with some periods displaying almost perfect compensation, while  
 157 others show undercompensation (where the magnitude of the AHT anomaly is less than  
 158 the magnitude of the OHT anomaly) or overcompensation (where the magnitude of the  
 159 AHT anomaly exceeds the magnitude of the OHT anomaly). Moreover, Bering Strait  
 160 OHT is not correlated with the AHT. In general, the *total* OHT (not shown here) and  
 161 AHT anomalies are opposite in sign, indicative of Bjerknes compensation on a decadal  
 162 timescale.



**Figure 2.** (a): Area-averaged surface air temperature anomaly over the Arctic domain (black) plotted with standardized Bering Strait (red) and Atlantic (blue, dotted) OHT anomalies. (b): same as (a), but sea ice area anomaly (black) is shown instead of temperature. (c): same as (a), but AHT anomaly (black) is shown instead of temperature. The time series are not standardized to emphasize their magnitudes. Note that in (c) the vertical scale for Bering Strait OHT has been magnified by a factor of 10 for better visibility. Pearson's  $r$  correlation coefficients are given in the top right.



**Figure 3.** (a): regression of 10-year moving mean sea ice concentration anomalies onto the standardized Bering Strait OHT anomalies at  $65^{\circ}\text{N}$ . Stippling indicates statistical insignificance with respect to a  $p = 0.05$  threshold. (b): as in (a), but regressed onto Atlantic OHT. (c): as in (a), but turbulent heat fluxes (defined as sensible plus latent surface heat flux with positive going from ocean to atmosphere). (d): as in (c), but regressed onto Atlantic OHT. (e): as in (a), but surface air temperature. (f): as in (e), but regressed onto Atlantic OHT.

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### 3.2 Bering Strait OHT Drives Variability in the Pacific Sector

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To better understand the atmosphere-ocean interaction that mediates these distinct OHT-AHT relationships, we regress the sea ice anomaly, surface turbulent heat flux (defined as the sum of latent and sensible heat fluxes) anomaly, and surface air temperature anomaly onto the standardized OHT anomaly across  $65^{\circ}\text{N}$ .

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Figure 3 shows the linear regressions of anomalous sea ice concentration, turbulent heat flux, and surface temperature onto the OHT anomaly through Bering Strait and the Atlantic separately. During periods of anomalously high OHT, ice is lost in the marginal ice zone and anomalous heat flux is transferred from the newly exposed ocean to the atmosphere. The greatest changes associated with Atlantic OHT variability occur along the East Greenland Current while the greatest changes associated with Bering Strait OHT variability occur in the Chukchi Sea. The greatest changes in surface heat flux are found at the marginal ice zone, similar to what was found in Outten and Esau (2017), Jungclaus and Koenigk (2010), and Kurtakoti et al. (2023). Regression of anoma-

177 lous sea surface temperatures (SST) onto OHT reveals a spatial pattern similar to the  
 178 heat flux regression (Figure S1). This positive correlation between SST and heat flux  
 179 indicates that anomalous turbulent heat fluxes are primarily driven by changes in SST,  
 180 rather than the other way around.

181 Even though Bering Strait OHT is much smaller compared to Atlantic OHT at 65°N,  
 182 it has an outsized impact on the local sea ice and heat flux variability. Heat fluxes as-  
 183 sociated with anomalous OHT in the Pacific sector are comparable in magnitude to those  
 184 in the Atlantic sector. Furthermore, loss of sea ice in the Pacific sector during periods  
 185 of high Bering Strait OHT generates a substantial heat dome centered on the same area  
 186 (Fig. 3e). Thus, we emphasize that the local influence of Bering Strait OHT on the at-  
 187 mosphere cannot be neglected.

### 188 3.3 Lateral flux decomposition

Next, we compare the effects of Atlantic versus Bering Strait OHT variability on  
 the Arctic atmosphere by decomposing the lateral heat balance. Because the AHT is com-  
 puted by assuming negligible atmospheric heat storage over decadal timescales, the fluxes  
 may be summed and area-integrated over the Arctic domain to recover the AHT like so:

$$\text{AHT}(\theta) = \int_{\theta}^{\pi/2} \int_0^{2\pi} (\text{LW}_{\text{sfc}} + \text{SW}_{\text{sfc}} + \text{LHF} + \text{SHF}) - (\text{LW}_{\text{TOA}} + \text{SW}_{\text{TOA}}) dA$$

where LHF and SHF refer to surface latent heat flux and sensible heat flux, and LW and  
 SW refer to longwave and shortwave radiation respectively. All flux terms above are pos-  
 itive downward to keep consistency with sign conventions in Equation 2. By linearity  
 of integration, we integrate each term separately and refer to each component as an area-  
 integrated flux, denoted as  $[F]$ :

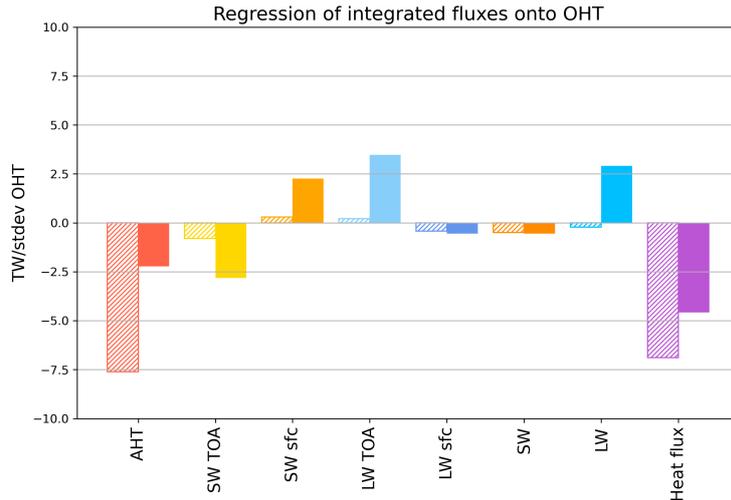
$$\text{AHT}(\theta) = ([\text{LW}_{\text{sfc}}] + [\text{SW}_{\text{sfc}}] + [\text{LHF}] + [\text{SHF}]) - ([\text{LW}_{\text{TOA}}] + [\text{SW}_{\text{TOA}}])$$

189 We linearly regress each timeseries  $[F]$  onto Bering Strait OHT and Atlantic OHT;  
 190 the linear slopes, with units [TW flux per standard deviation OHT] are shown in Fig-  
 191 ure 4. A positive slope indicates that positive (resp. negative) OHT anomalies are as-  
 192 sociated with anomalous flux out of (resp. into) the atmospheric sector through either  
 193 the surface or TOA, and vice versa for negative slopes.

194 This decomposition reveals distinct atmospheric responses to OHT through the At-  
 195 lantic and Bering Strait gateways. Similar to what is found in Figure 2c, there is a stronger  
 196 compensating AHT anomaly in response to an anomaly in Atlantic OHT than Bering  
 197 Strait OHT. For both Atlantic and Bering Strait OHT, turbulent heat fluxes are anti-  
 198 correlated with OHT, consistent with Figure 3c,d. A crucial difference in the atmospheric  
 199 response can be seen in the TOA longwave radiation. While there is essentially no sig-  
 200 nal in the Atlantic sector, the Pacific sector experiences strong changes in TOA long-  
 201 wave radiation covarying with anomalous OHT. This longwave flux at the TOA com-  
 202 pensates the anomalous turbulent heat fluxes driven by Bering Strait OHT variability.  
 203 Therefore, the primary mechanism for compensation of OHT anomalies in the Pacific  
 204 sector is through direct adjustment of the TOA energy balance rather than through changes  
 205 in AHT.

206 Furthermore, consistent with the fact that Bering Strait OHT is closely coupled  
 207 with sea ice in the Pacific sector (Fig. 3a), it is also positively correlated with downwelling  
 208 shortwave at both the surface and TOA (yellow and orange bars in Fig. 4). This response  
 209 magnifies the initial ocean-driven heat anomaly via changes in the summertime absorp-  
 210 tion of shortwave radiation by the ocean.

211 It remains unclear why atmospheric heat transport does not adjust to compensate  
 212 significant changes in air-sea heat fluxes in the Pacific sector. Following the mechanism



**Figure 4.** Linear regression slopes of area-integrated flux anomalies onto standardized ocean heat transport. Dashed bars are fluxes regressed onto Atlantic OHT, while solid bars are fluxes regressed onto Bering Strait OHT.

213 proposed by Swaluw et al. (2007), one would expect air temperature variability over the  
 214 Pacific sector to affect the local baroclinicity and thereby change the energy transported  
 215 by atmospheric eddies. One possible reason that this does not translate into compen-  
 216 sating AHT is that the mean position of the North Pacific storm track may not extend  
 217 far enough north for atmospheric eddy heat transport to adjust to changes in baroclin-  
 218 icity centered over the Pacific Arctic. A recent study (Wang et al., 2023) evaluated the  
 219 Northern Hemisphere storm track in the same simulation used by this study. The mean  
 220 position of the wintertime storm track (shown in their Figure S1d) indeed extends fur-  
 221 ther north over the Atlantic sector than the Pacific. Therefore, atmospheric eddies may  
 222 be more efficient at compensating changes in the air-sea heat flux over the Atlantic sec-  
 223 tor than the Pacific. However, the precise mechanisms that preclude AHT compensa-  
 224 tion in the Pacific sector are left for future study.

## 225 4 Summary and Conclusions

226 We have shown that decadal variability in Arctic surface air temperature is largely  
 227 driven by variability of OHT through the Bering Strait in a high-resolution coupled cli-  
 228 mate simulation. By decomposing the atmospheric response into sector-integrated flux  
 229 anomalies, we find that Bering Strait OHT anomalies are not damped by Bjerknes Com-  
 230 pensation and instead change the TOA longwave energy balance. Thus, Bering Strait  
 231 OHT, despite its low magnitude compared to Atlantic OHT, has an outsized impact on  
 232 driving the overall decadal variability in the Arctic.

233 The main implication of this work is that increases in Bering Strait OHT may be  
 234 an important driver of future Arctic climate change and, in particular, Arctic Amplifi-  
 235 cation. Our results suggest that even if the total zonally-integrated OHT into the Arct-  
 236 ic is compensated by opposing zonally-integrated AHT anomalies—that is, Bjerknes Com-  
 237 pensation holds—the comparatively small Bering Strait OHT may still exert significant  
 238 influence on Arctic climate despite not projecting onto the Bjerknes Compensation sig-  
 239 nal. In the PI control simulation analyzed here, this is manifested in the decadal vari-  
 240 ability of sea ice and air temperatures in the Pacific sector.

Our results are consistent with Li et al. (2018), who found that simulated multi-decadal variability of September Arctic sea ice extent was impacted to similar degree by both Atlantic OHT and Bering Strait OHT, despite the standard deviation of Bering Strait OHT being an order of magnitude smaller. Furthermore, there is observational evidence that accelerated sea ice loss in the Chukchi Sea is indeed linked to additional northward heat inflow through Bering Strait. Woodgate et al. (2010) found that record high Bering Strait OHT in 2007 contributed to anomalous sea ice loss by triggering earlier onset of seasonal sea ice melt and by providing additional subsurface heat during winter months. Furthermore, in-situ mooring data has revealed an increase in Bering Strait OHT over the past three decades (though data between 1991 to 1999 is missing; Woodgate, 2018). This increase has been attributed, about equally, both to increases in ocean temperatures and northward transport (Woodgate et al., 2012).

We will conclude by noting a few caveats of our work and by proposing some next steps. The robustness of these results depends both on the simulated sea ice climatology and the representation of OHT through the Atlantic and Bering Strait gateways. Therefore, a natural extension of this work is to analyze the relationship between Bering Strait OHT and the Arctic heat budget in other models of both comparable complexity (i.e., high-resolution Earth system models) and lower complexity (e.g., lower resolution models or idealized configurations). Another extension of this work would be to consider the mechanisms from a seasonal perspective. Effects of ocean heat transport on sea ice and the overlying atmosphere tend to be amplified in winter, when the ocean is the primary source of heat for the atmosphere while shortwave feedbacks are more prominent in summer (Previdi et al., 2021; Taylor et al., 2022). Finally, to what extent the current analysis of internal climate variability provides lessons for the future of the Arctic also remains to be explored. Chang et al. (in review) demonstrate how improved representation of Bering Strait heat transport in this high-resolution configuration of CESM1.3 increases Arctic warming under a scenario of future anthropogenic forcing compared to a low-resolution configuration of the same model, suggesting that our results have immediate relevance for a future that most likely will feature enhanced OHT through Bering Strait.

## 5 Open Research

The code used to produce the figures in this study is available upon request to the authors. The model output from the iHESP project is publicly available through the iHESP data archive: [https://ihesp.github.io/archive/products/ds\\_archive/Sunway\\_Runs.html](https://ihesp.github.io/archive/products/ds_archive/Sunway_Runs.html). The CESM1.3-HR simulation is documented in Chang et al. (2020). The NOAA OISST sea ice product is available at <https://www.ncei.noaa.gov/products/optimum-interpolation-sst>.

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