

Imminent rapid decline of the Indonesian Throughflow after reaching a turning point of CO₂ concentration

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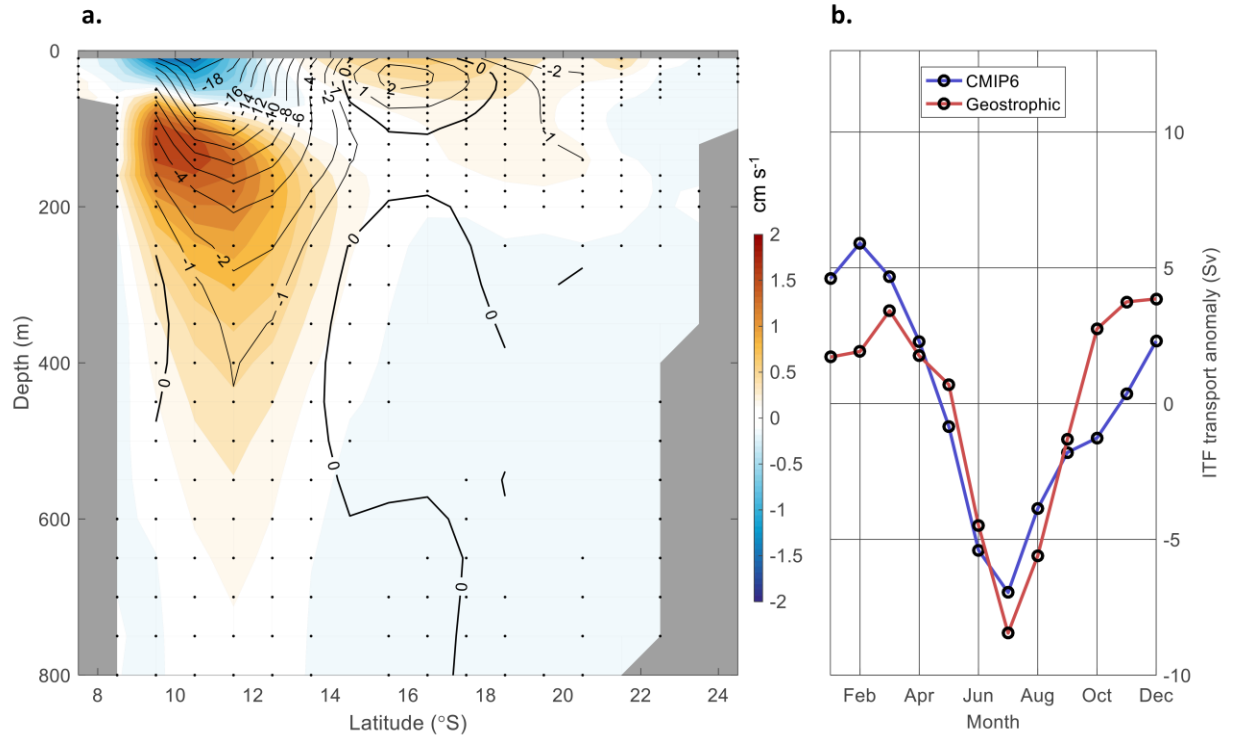
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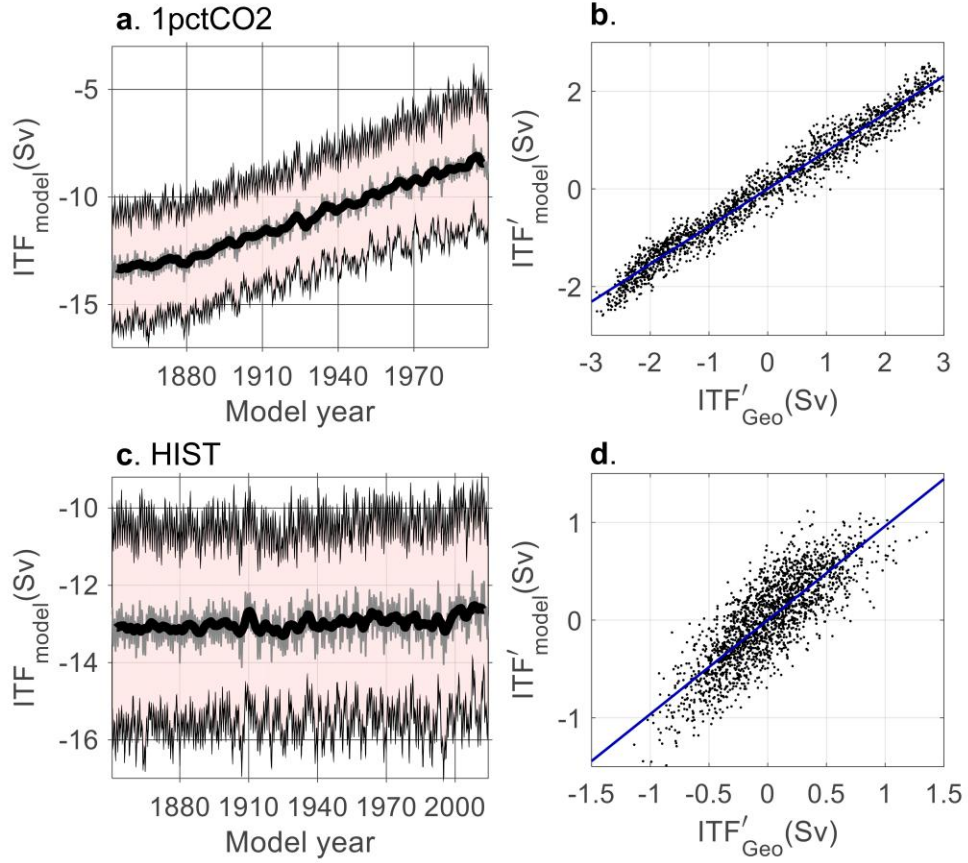
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Annotation: This supplementary file contains eight figures.



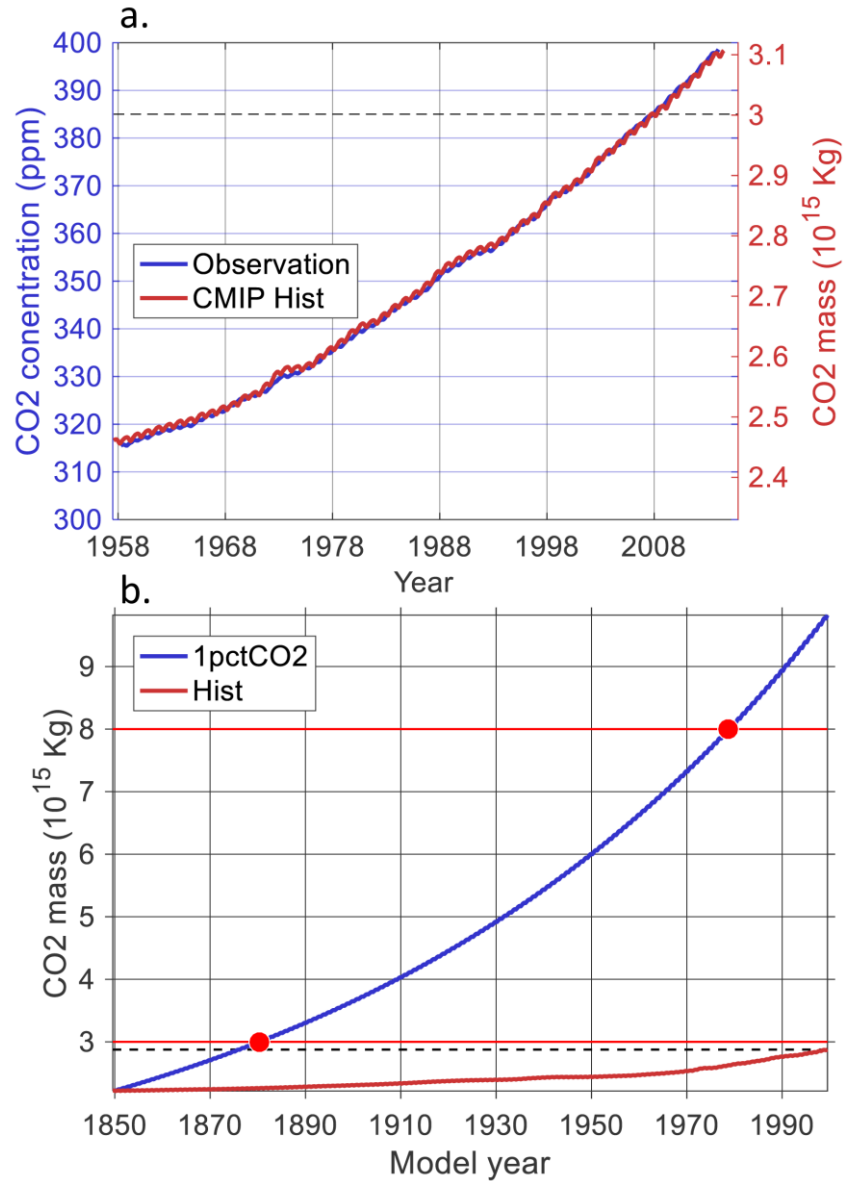
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20 **Supplementary Fig. S1.** (a) Climatological mean zonal velocity in the Hist runs at the 114°E
 21 section (contour lines, cm s⁻¹, positive for eastward) and its change (mean in 1pctCO2 runs minus
 22 mean in historical runs; shading color). (b) The seasonal cycle of ITF transports (Sv) from the
 23 historical runs of CMIP6 models (multi-model ensemble mean; blue line) and geostrophic
 24 calculations with observational datasets from Lu et al. (2024) (red line). Black dots in the left
 25 panel indicate positions where change is greater than standard deviation.

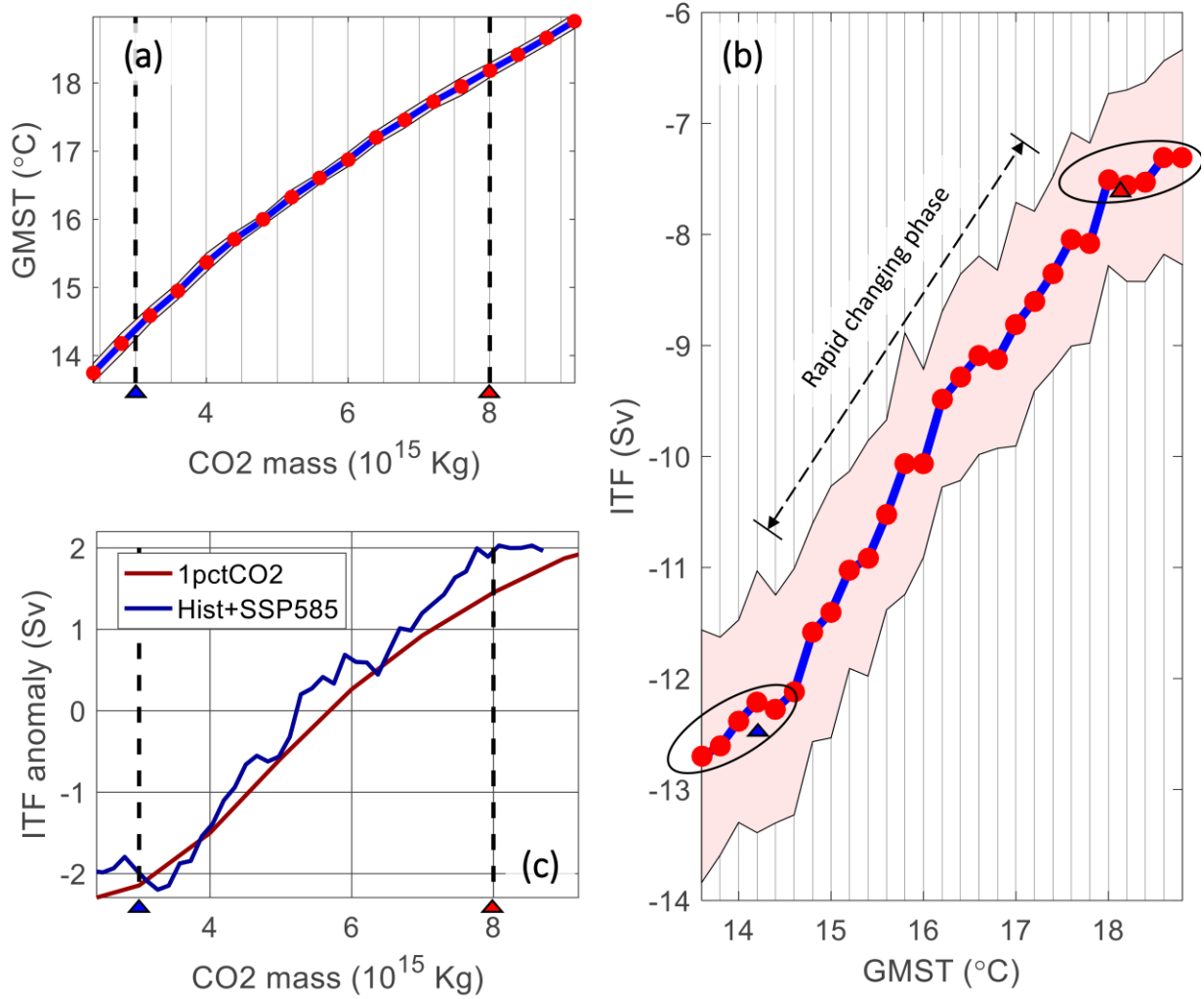


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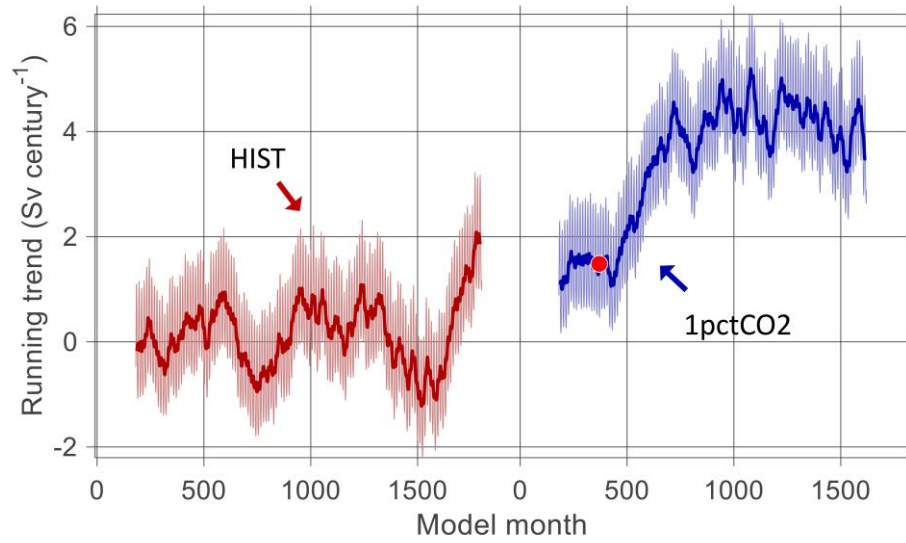
27 **Supplementary Fig. S2.** Panels (a) and (c) present the ITF transports (Sv, positive for eastward)
 28 at the 114°E section from the 1pctCO2 runs (a) and historical runs (c) of CMIP6 models, where
 29 heavy lines show ensemble model means. panels b and d compares total ITF transport anomaly
 30 (ITF'_{model}) and geostrophic transport anomaly (ITF'_{Geo}) in the 1pctCO2 runs (b) and historical
 31 runs (d), where blue lines show the regression relationship between ITF'_{model} and ITF'_{Geo} .



Supplementary Fig. S3. (a) Comparison between observed atmospheric CO2 concentration (red) and atmospheric CO2 mass in the Hist runs of CMIP6 (blue). (b) CO2 forcing in the 1pctCO2 experiments (blue) and Hist (red) runs. Monthly in-situ CO2 data sets provided by the Scripps CO2 program were taken at Mauna Loa, Observatory, Hawaii (19.5°N, 155.6°W, elevation 3397m; Keeling et al., 2001).

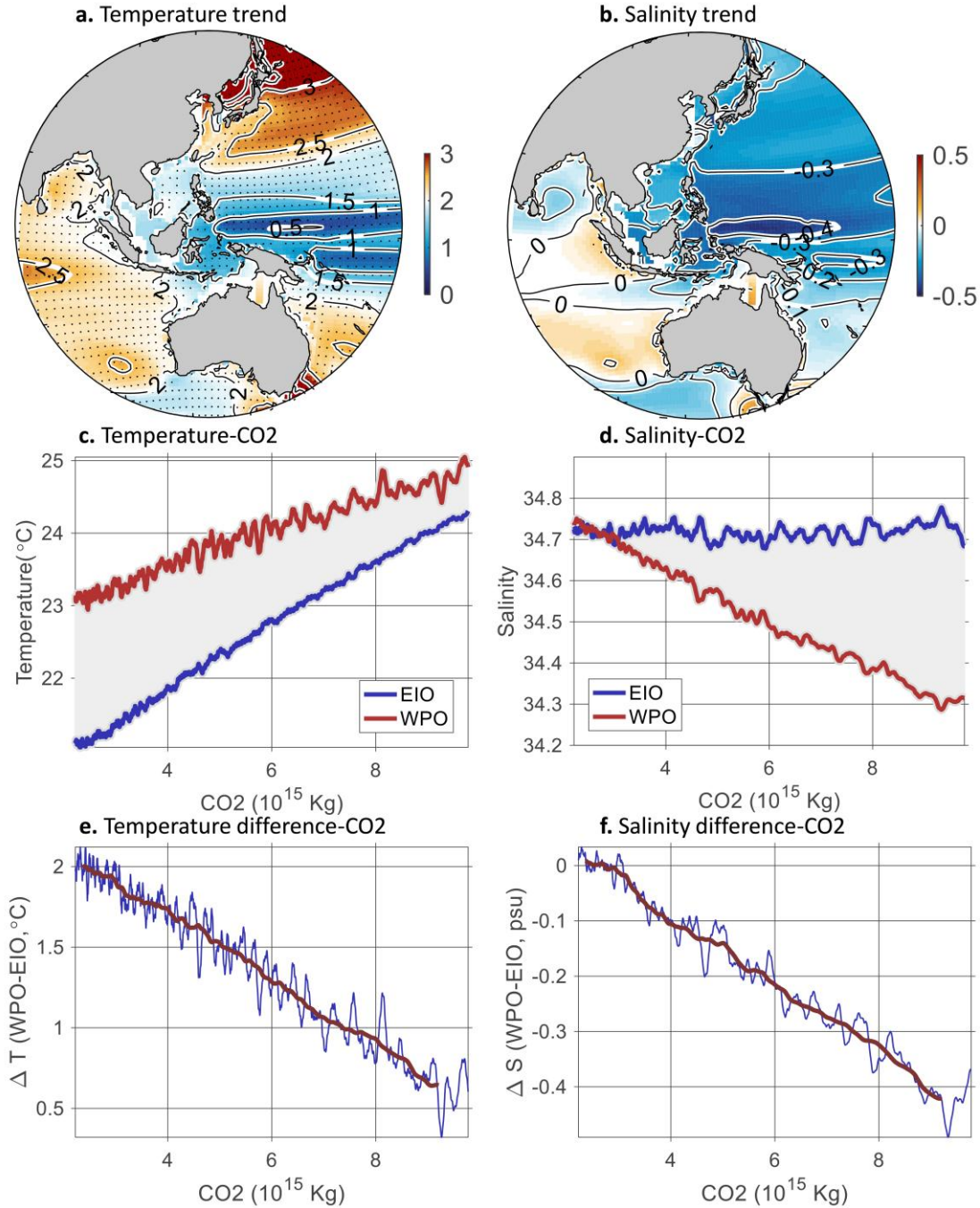


Supplementary Fig. S4. Relationships of: (a) global mean surface temperature (GMST) and CO2 mass, and (b) GMST and ITF. Panel (a) presents the GMST averaged over bins of CO2 mass with a bin width of $0.5 (10^{15} \text{ Kg})$. Panel (b) presents the ITF transport averaged over bins of GMST with a bin width of 0.2°C . Panel (c) plots the ITF anomaly (minus their corresponding mean values) in the three CO2 scenarios (1pctCO2, SSP585 and Hist) together. The ITF, GMST and CO2 mass are ensemble mean of the 1pctCO2 and/or SSP585, Hist experiments of CMIP6. The triangles represent the rough position of the two turning points and the circled areas represent the phases outside the two points. Seasonality is removed. The shaded color with thin black lines denotes the standard deviations among the models.



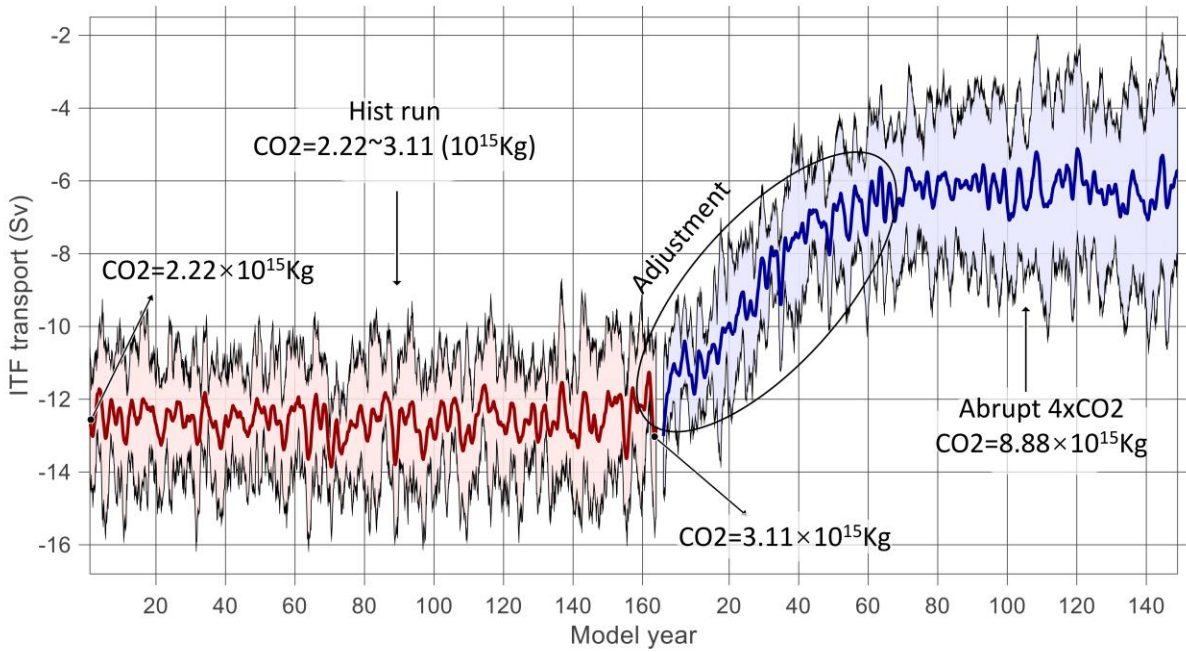
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49 **Supplementary Fig. S5.** The running trend of ITF in a 30-yr window in the 1pctCO2 runs and
 50 historical runs. The red dot denotes the first turning point as detected in the change in ITF
 51 transport over change in CO2, as shown in Figure 2b.

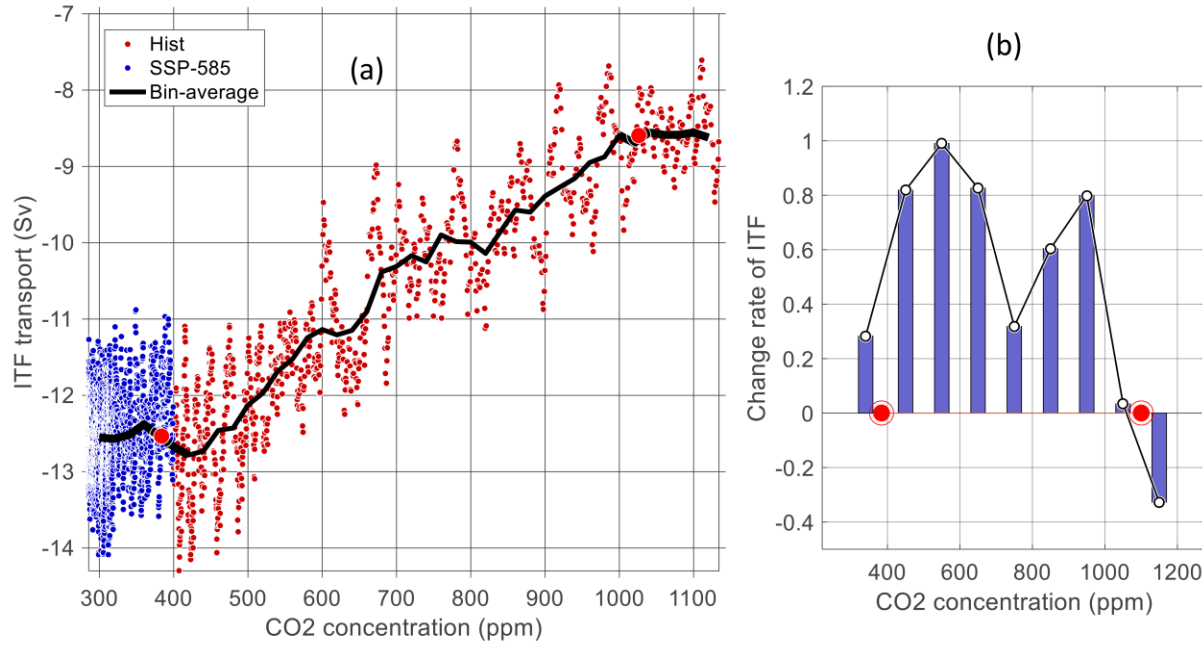


Supplementary Fig. S6. Upper panels: Ensemble mean trends of temperature (a) and salinity (b) in the 1pctCO2 experiments spanning from 1850 to 1999. Temperature and salinity are vertically averaged over the upper 200 m layer. The unit of the temperature trend is °C/century and the unit of the salinity trend is psu/century. Middle panels: time series of (c) temperature and (d) salinity averaged over the western Pacific Ocean (WPO, 120–180°E, 15°S–15°N) and the eastern Indian Ocean (EIO, 80–114°E, 22°S–8°S) regions with increasing CO2 emissions. The gray color

shading between the red (WPO) and blue (EIO) lines indicates the difference in temperature and salinity between the WPO and EIO with increasing CO₂ emissions. Bottom panels present the difference in temperature (e) and salinity (f) between the WPO and EIO as well. Panels (a) and (b) were generated using Matlab with a base map from the M_Map toolbox.



Supplementary Fig. S7. ITF in the Hist Runs (red lines, bold line for 13-month running mean) and abrupt 4xCO₂ experiments (blue lines, bold line for 13-month running mean). Note that the CO₂ in the 4xCO₂ experiments is constant. The shaded color with thin black lines denotes the standard deviations among the models.



Supplementary Fig. S8. ITF transports in the Hist runs and SSP585 runs (a). The right panel presents the change rate of ITF transport as a function of CO2 concentration ($\partial \text{ITF} / \partial \text{CO}_2$, unit in Sv per 100 ppm). The red circles denote the two turning points, between which the ITF change rate is significantly positive (i.e., the ITF is decreasing). Note that the time series here has been subjected to a 3-point moving average to focus on the low-frequency response.

References

Keeling CD, *et al.* Exchanges of atmospheric CO2 and 13CO2 with the terrestrial biosphere and oceans from 1978 to 2000. I. Global aspects. In: *SIO Reference Series* (2001).