



Supplement of

Current status of ocean observation, ensemble reanalysis and CMIP6 models in describing Antarctic Bottom Water

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This supplement provides additional sensitivity analyses, vertical-level diagnostics, and complete spatial comparisons supporting the main manuscript. Figures S1 and S2 document the neutral-density-only distribution and the potential-temperature sensitivity analysis, respectively. Figures S3 and S4 present the complete original (uncorrected) CMIP6 results at the 4000 m and near-bottom layers. Figures S5 and S6 show the practical-salinity structure and identified Antarctic Bottom Water (AABW) subtypes at 3500 and 4500 m, respectively. Figures S7 and S8 present the complete regional-mean-state-corrected CMIP6 results at the 4000 m and near-bottom layers. Figure S9 shows the interannual variations in the identified areas of the three AABW subtypes.

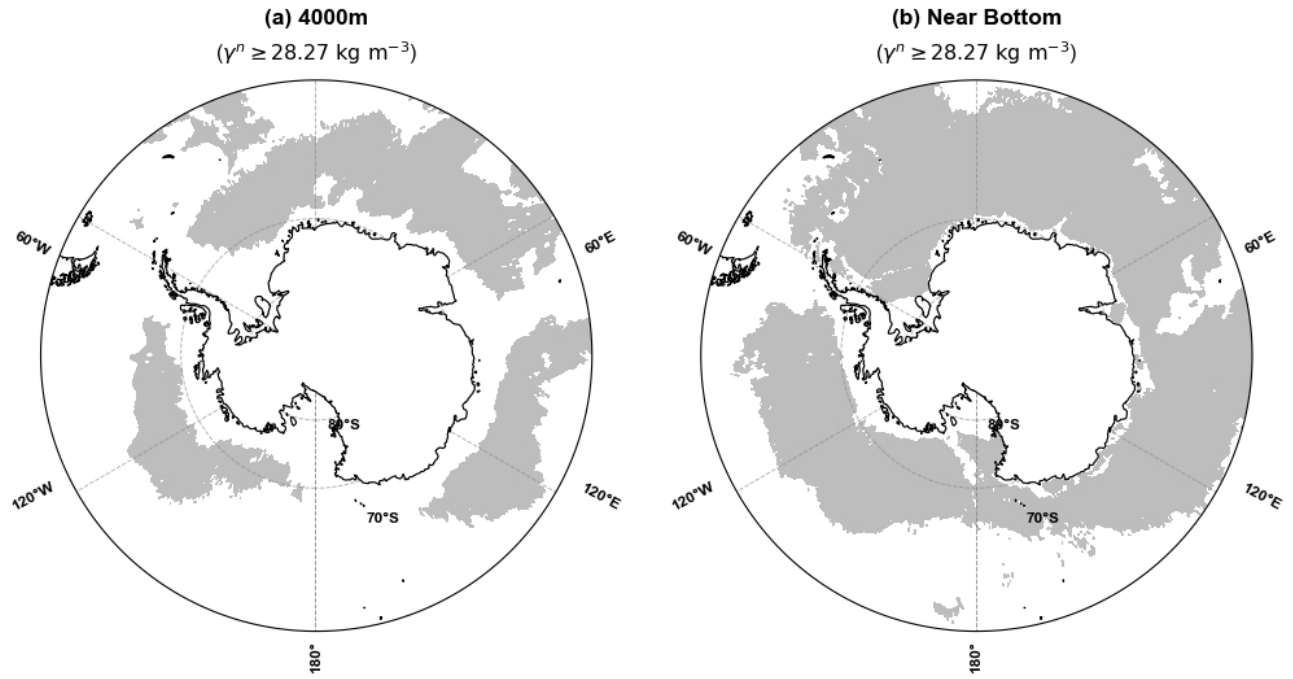


Figure S1. Spatial distributions of AABW in WOA23 identified using only the classical neutral-density criterion $\gamma^n \geq 28.27 \text{ kg m}^{-3}$. Panels (a) and (b) show the 4000 m and near-bottom layers, respectively. Gray shading denotes waters satisfying the neutral-density criterion. These distributions provide the density-only reference used in Sect. 2.3 of the main text.

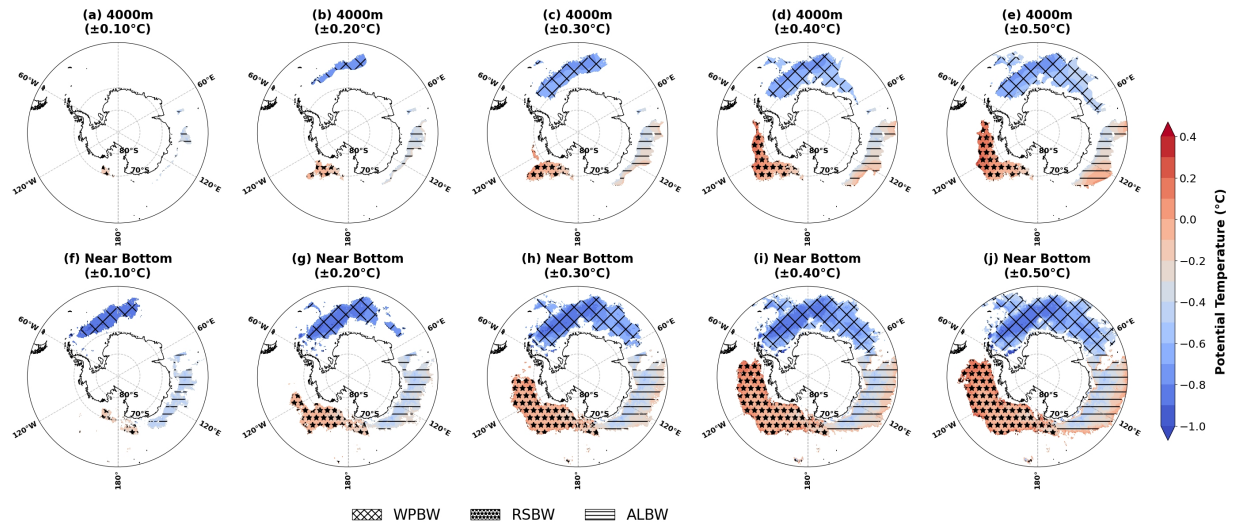


Figure S2. Spatial distributions of the identified AABW subtypes under different potential-temperature ranges (ΔT). The upper row (a–e) and lower row (f–j) show the 4000 m and near-bottom layers, respectively. Columns from left to right correspond to $\Delta T = \pm 0.10, \pm 0.20, \pm 0.30, \pm 0.40$, and $\pm 0.50^\circ\text{C}$ around the central potential temperatures specified in Sect. 2.3 of the main text (WPBW: -0.90°C ; RSBW: -0.25°C ; ALBW: -0.47°C). Background shading represents potential temperature. The respective AABW subtypes are distinguished by distinct hatching patterns, as detailed in the figure legend.

Table S1. Identified areas (10^6 km²) of WPBW, RSBW, and ALBW under progressively widened potential-temperature ranges at the 4000 m and near-bottom layers.

Layer	Subtype	±0.10 °C	±0.20 °C	±0.30 °C	±0.40 °C	±0.50 °C
4000 m	WPBW	0.00	0.95	2.74	4.71	6.23
	RSBW	0.15	0.73	1.31	2.38	2.92
	ALBW	0.41	1.16	2.03	2.58	3.11
Near-bottom	WPBW	2.19	4.05	6.93	8.90	10.47
	RSBW	0.63	3.08	5.34	6.92	7.42
	ALBW	2.23	3.95	5.03	5.78	6.35

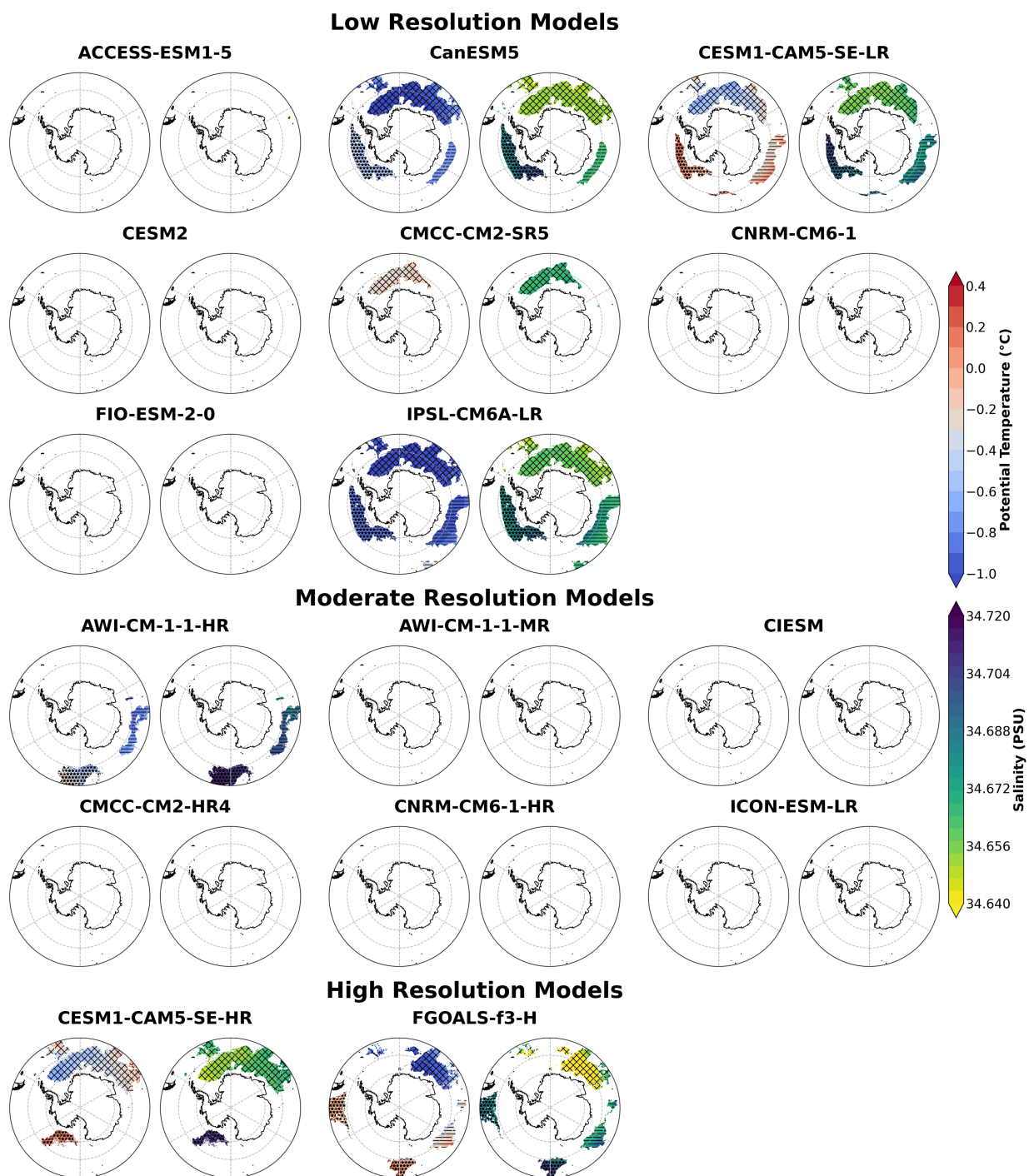


Figure S3. Spatial distributions of potential temperature and practical salinity within the identified AABW subtype regions in the original (uncorrected) simulations at 4000 m for the 16 CMIP6 models. Models are grouped according to the nominal horizontal resolution of their ocean components. For each model, the left and right panels show potential temperature and practical salinity, respectively. The respective AABW subtypes are distinguished by distinct hatching patterns, as detailed in the figure legend.

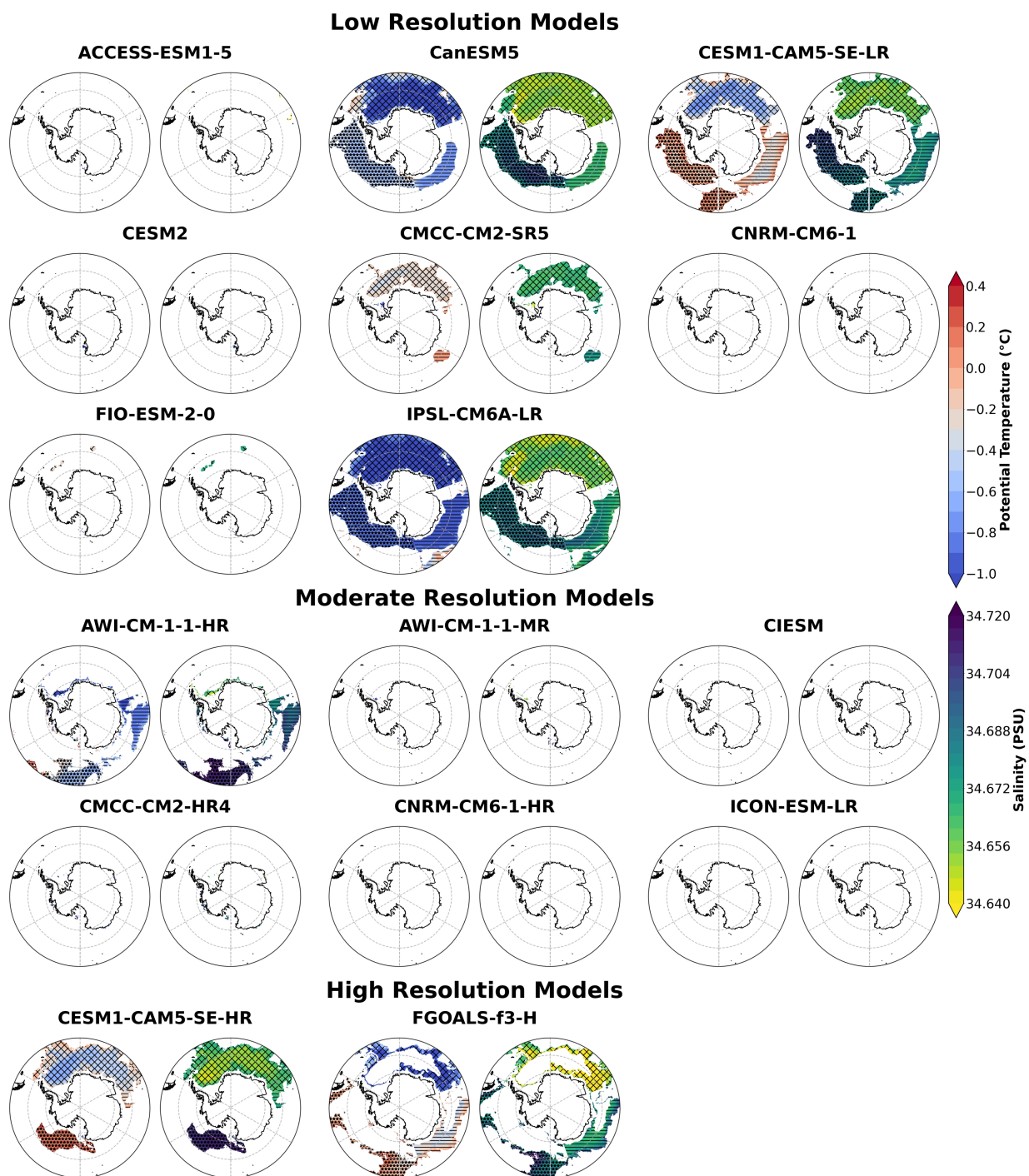


Figure S4. Same as Figure S3, but for the near-bottom layer.

Table S2. Quantitative metrics of the simulated Antarctic Bottom Water (AABW) subtypes at the near-bottom layer across the Southern Ocean (south of 50°S). The variables, evaluated datasets, and spatial averaging criteria are identical to those detailed in Table 4 of the main text. A value of 0 in the area column indicates that no grid cells satisfy the prescribed criteria for the corresponding subtype.

Dataset	WPBW Area	WPBW Mean PT	WPBW Mean S	RSBW Area	RSBW Mean PT	RSBW Mean S	ALBW Area	ALBW Mean PT	ALBW Mean S
[Observational and Reanalysis References]									
WOA23 (Reference)	12.19	-0.62	34.654	7.27	-0.04	34.700	5.59	-0.26	34.678
Ensemble Reanalysis	10.57	-0.56	34.658	6.33	0.04	34.704	6.01	-0.18	34.682
[Low-Resolution CMIP6 Models]									
ACCESS- ESM1-5	0.16	-0.25	34.635	0.02	-1.75	34.694	0	-	-
CanESM5	14.55	-0.87	34.653	8.09	-0.48	34.690	2.95	-0.70	34.665
CESM1- CAM5-SE-LR	10.07	-0.53	34.657	7.82	-0.02	34.691	4.81	-0.15	34.679
CESM2	0	-	-	0.05	-1.93	34.697	0	-	-
CMCC-CM2- SR5	6.75	-0.28	34.665	0.08	-0.81	34.692	0.72	0.01	34.678
CNRM-CM6-1	0	-	-	0	-	-	0	-	-
FIO-ESM-2-0	0.26	-0.26	34.669	0.03	-1.11	34.693	0	-	-
IPSL-CM6A- LR	14.95	-1.10	34.656	8.68	-0.85	34.685	6.51	-0.85	34.675
[Moderate-Resolution CMIP6 Models]									
AWI-CM-1-1- HR	0.56	-1.09	34.658	3.63	-0.44	34.708	3.13	-0.78	34.692
AWI-CM-1-1- MR	0.08	-1.24	34.650	0.08	-0.88	34.698	0.04	-0.48	34.687
CIESM	0	-	-	0	-	-	0	-	-
CMCC-CM2- HR4	0.07	-1.15	34.652	0.16	-0.54	34.695	0.05	-0.51	34.684
CNRM-CM6- 1-HR	0	-	-	0	-	-	0	-	-
ICON-ESM- LR	0.01	-0.31	34.658	0.01	-0.24	34.698	0.004	-0.13	34.683
[High-Resolution CMIP6 Models]									

Dataset	WPBW Area	WPBW Mean PT	WPBW Mean S	RSBW Area	RSBW Mean PT	RSBW Mean S	ALBW Area	ALBW Mean PT	ALBW Mean S
CESM1- CAM5-SE-HR	11.61	-0.41	34.657	3.20	0.14	34.709	0.44	-0.15	34.668
FGOALS-f3-H	5.71	-0.91	34.643	4.35	-0.07	34.689	3.89	-0.26	34.676

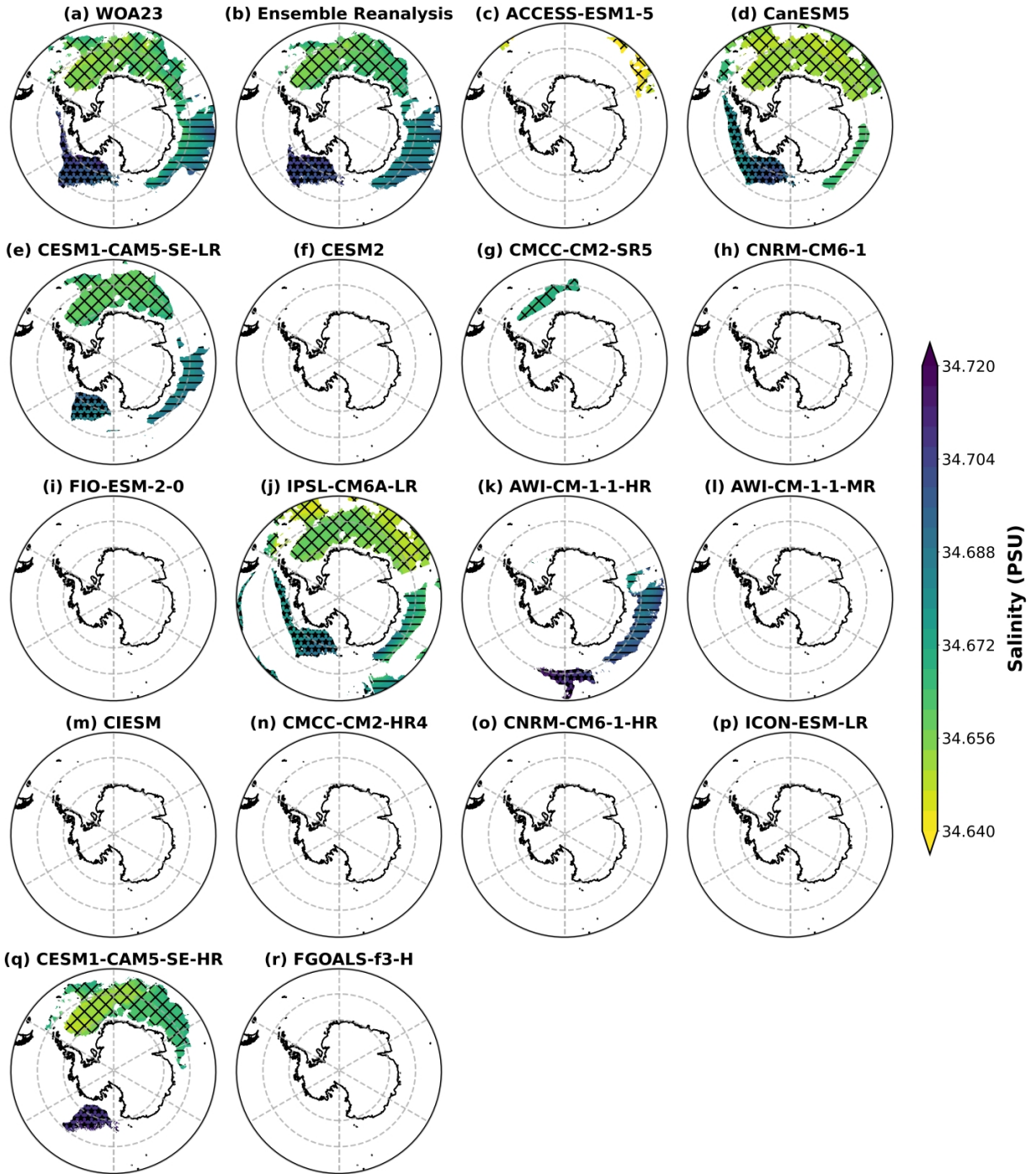


Figure S5. Spatial distributions of practical salinity and the identified Antarctic Bottom Water (AABW) subtypes at 3500 m in WOA23, the Ensemble Reanalysis, and the 16 CMIP6 models. The AABW subtypes are identified using the criteria described in Sects. 2.2 and 2.3 of the main text. Background shading represents practical salinity. The respective AABW subtypes are distinguished by distinct hatching patterns, as detailed in the figure legend.

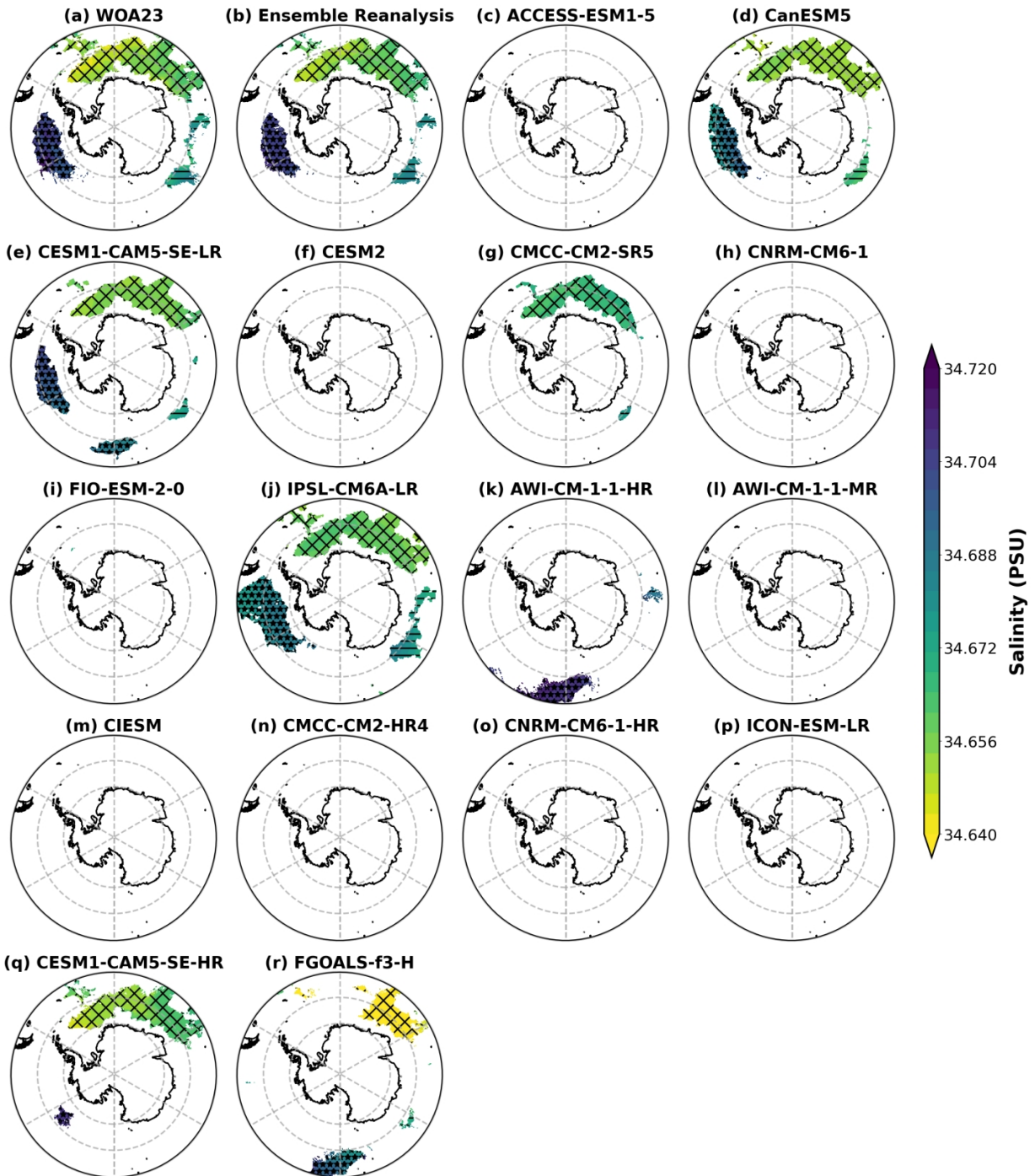


Figure S6. Same as Figure S5, but for the 4500 m depth layer.

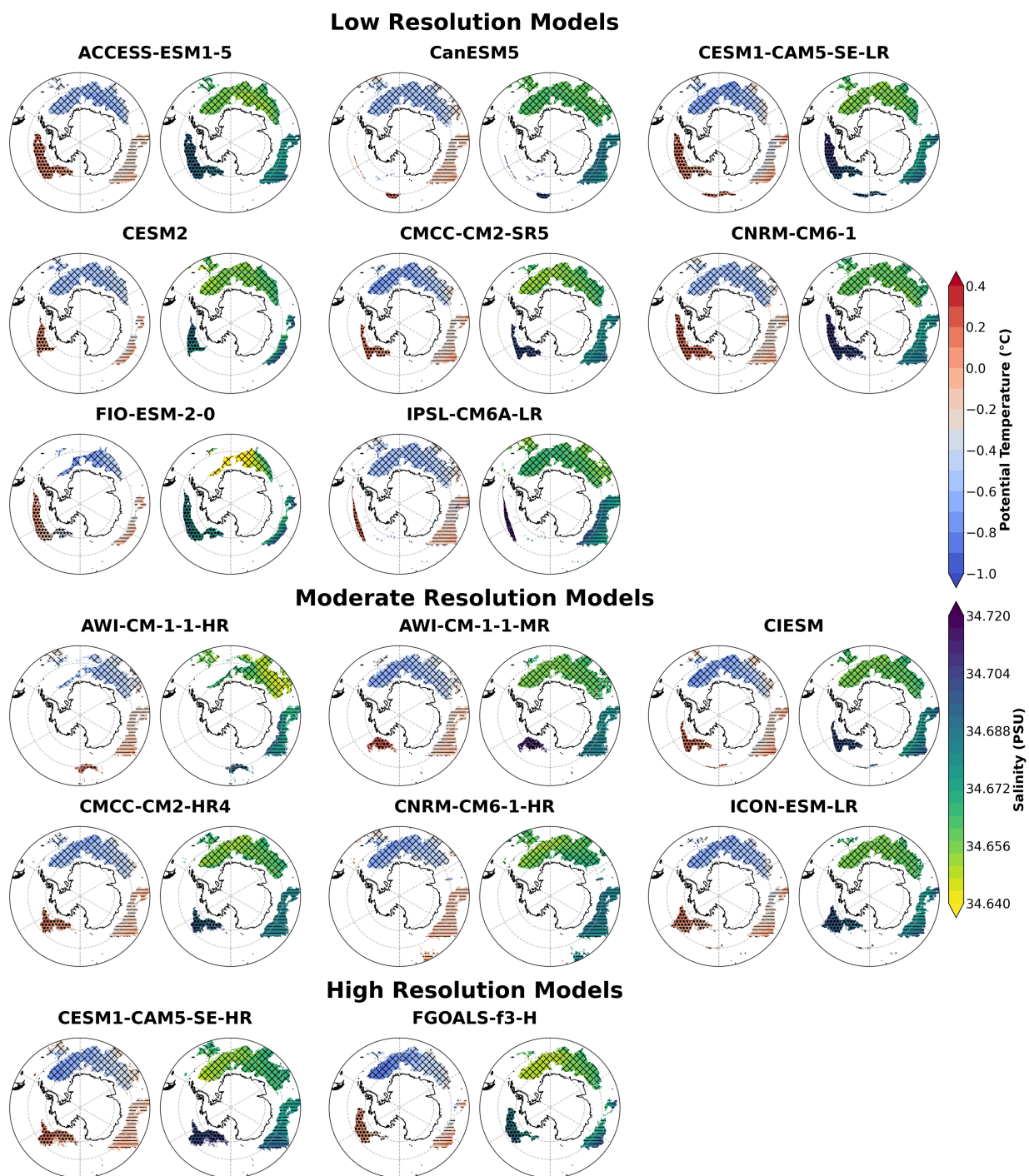


Figure S7. Spatial distributions of the bias-corrected potential temperature and practical salinity within the identified AABW subtype regions at 4000 m for the 16 CMIP6 models. Models are grouped according to the nominal horizontal resolution of their ocean components. For each model, the left and right panels show potential temperature and practical salinity, respectively. The correction removes the regional mean thermohaline offsets relative to the Ensemble Reanalysis while retaining each model's internal spatial anomaly pattern. The same neutral-density, practical-salinity, and geographical criteria used for the original simulations are reapplied after correction. The respective AABW subtypes are distinguished by distinct hatching patterns, as detailed in the figure legend.

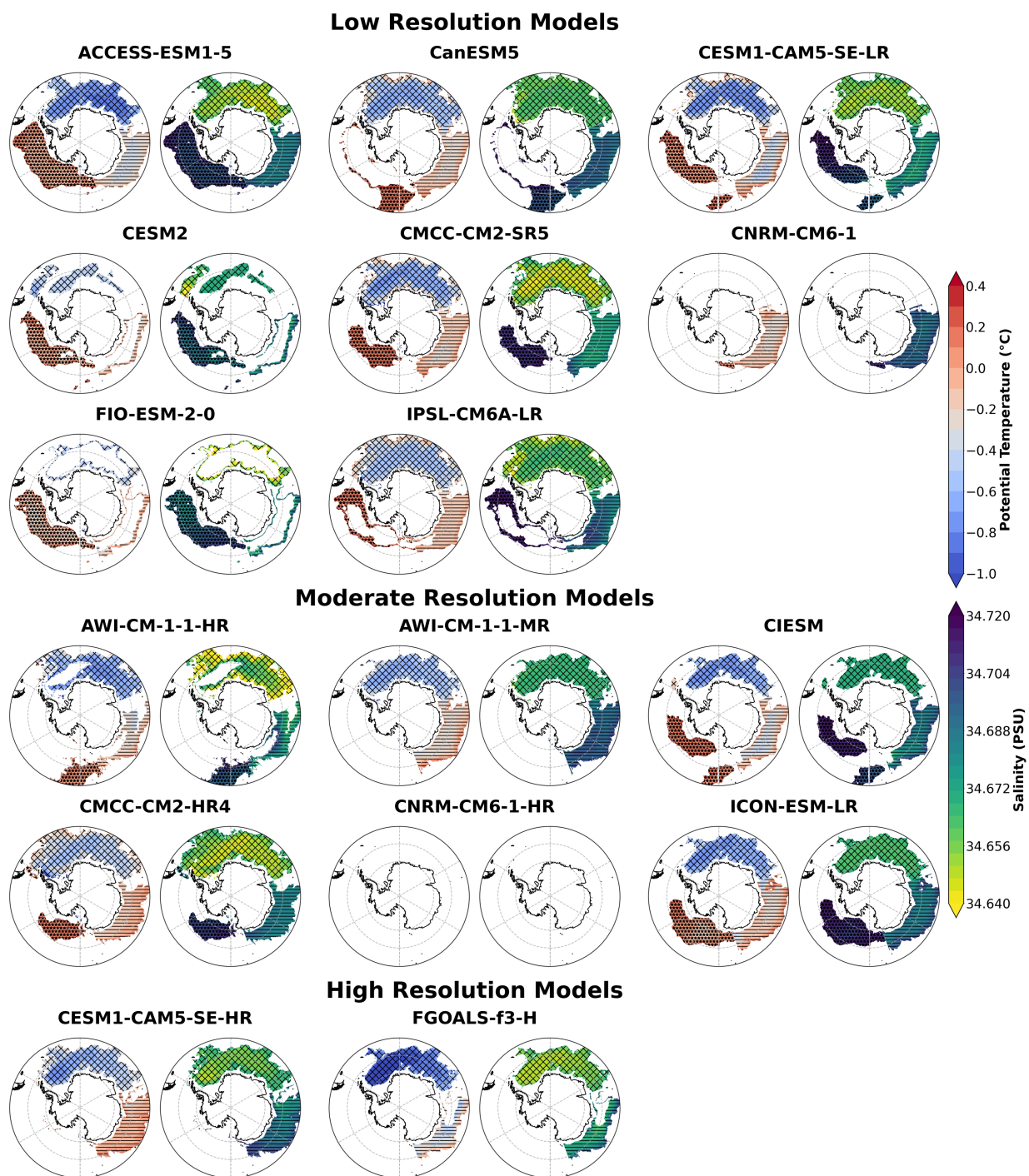


Figure S8. Same as Figure S7, but for the near-bottom layer. The corrected fields are used only as a diagnostic of the sensitivity of subtype identification to regional mean-state biases and are not interpreted as independent model simulations.

Table S3. Same as Table 5 of the main text, but for the near-bottom layer.

Dataset	WPBW Area	WPBW Mean PT	WPBW Mean S	RSBW Area	RSBW Mean PT	RSBW Mean S	ALBW Area	ALBW Mean PT	ALBW Mean S
[Low-Resolution CMIP6 Models]									
ACCESS-ESM1-5	9.71	-0.69	34.653	8.53	0	34.701	5.50	-0.26	34.686
CanESM5	12.55	-0.51	34.661	3.53	0.16	34.703	6.35	-0.17	34.692
CESM1-CAM5-SE-LR	10.58	-0.57	34.655	5.56	0.09	34.703	5.70	-0.22	34.677
CESM2	4.17	-0.43	34.666	5.17	0.01	34.691	1.70	-0.14	34.681
CMCC-CM2-SR5	11.80	-0.54	34.651	4.04	0.15	34.708	5.93	-0.14	34.675
CNRM-CM6-1	0	-	-	0.30	0.13	34.710	5.64	-0.15	34.694
FIO-ESM-2-0	2.79	-0.45	34.648	6.51	-0.10	34.692	1.77	-0.10	34.679
IPSL-CM6A-LR	13.53	-0.43	34.659	3.43	0.17	34.712	5.64	-0.13	34.688
[Moderate-Resolution CMIP6 Models]									
AWI-CM-1-1-HR	9.47	-0.61	34.650	2.52	0.07	34.697	3.90	-0.20	34.678
AWI-CM-1-1-MR	9.34	-0.54	34.665	0.07	-0.48	34.699	6.61	-0.17	34.694
CIESM	7.19	-0.64	34.668	4.95	0.17	34.709	5.29	-0.23	34.686
CMCC-CM2-HR4	12.68	-0.43	34.653	3.20	0.10	34.703	5.41	-0.09	34.685
CNRM-CM6-1-HR	0	-	-	0	-	-	0.01	0.19	34.702
ICON-ESM-LR	8.39	-0.63	34.664	5.71	0.03	34.710	6.49	-0.14	34.688
[High-Resolution CMIP6 Models]									
CESM1-CAM5-SE-HR	10.01	-0.52	34.660	0.14	-0.24	34.706	6.27	-0.03	34.689
FGOALS-f3-H	8.69	-0.88	34.654	0.03	-0.54	34.699	4.06	-0.29	34.677

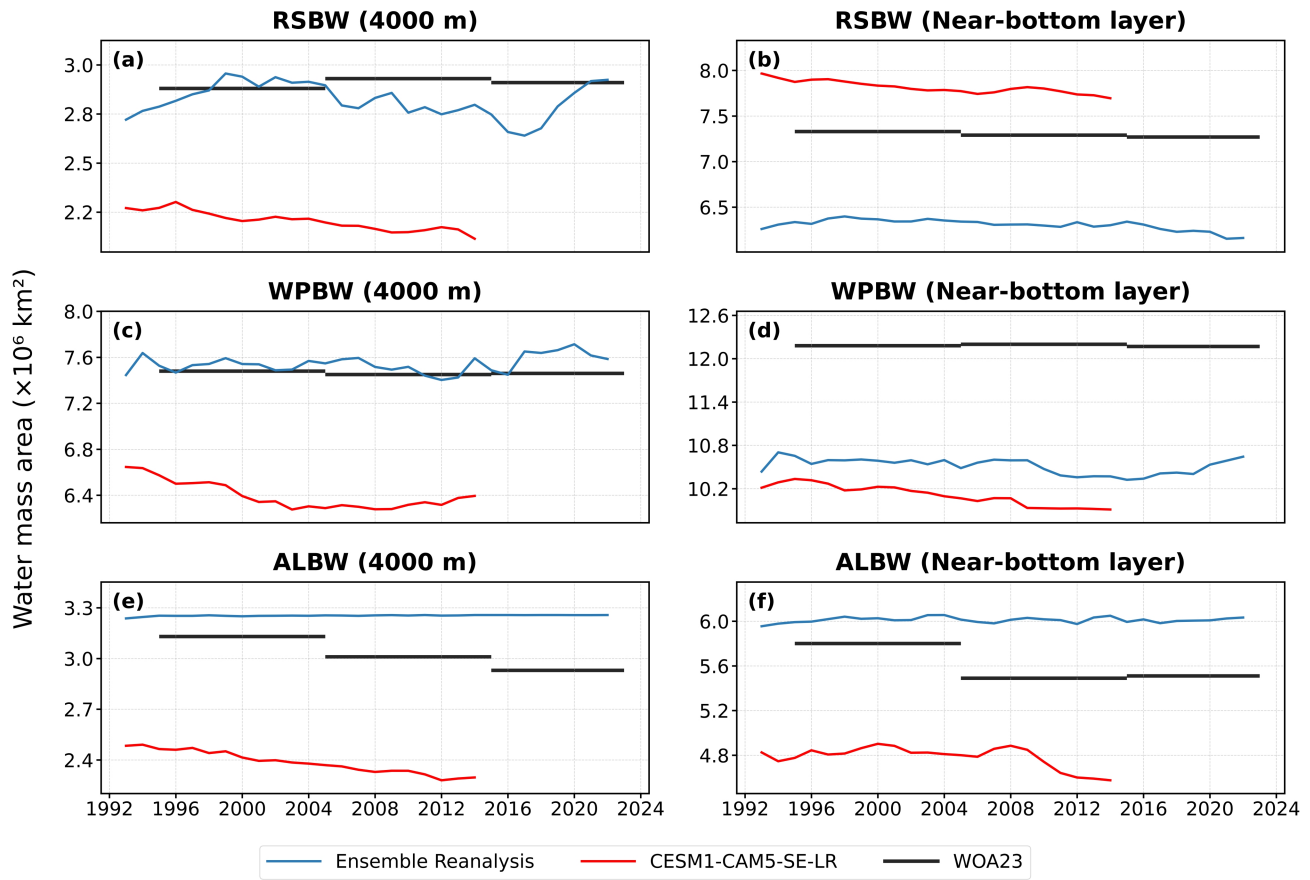


Figure S9. Interannual variations in the identified areas of the three AABW subtypes from the Ensemble Reanalysis and CESM1-CAM5-SE-LR, compared with WOA23 period-mean estimates. Panels (a, b) show RSBW, panels (c, d) show WPBW, and panels (e, f) show ALBW. The left column shows the results at 4000 m, and the right column shows the results in the near-bottom layer. Blue and red lines denote annual areas from the Ensemble Reanalysis and CESM1-CAM5-SE-LR, respectively; black horizontal segments denote WOA23 period-mean areas for 1995–2004, 2005–2014, and 2015–2022.