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Monte Carlo drift correction – quantifying the drift uncertainty of global climate models

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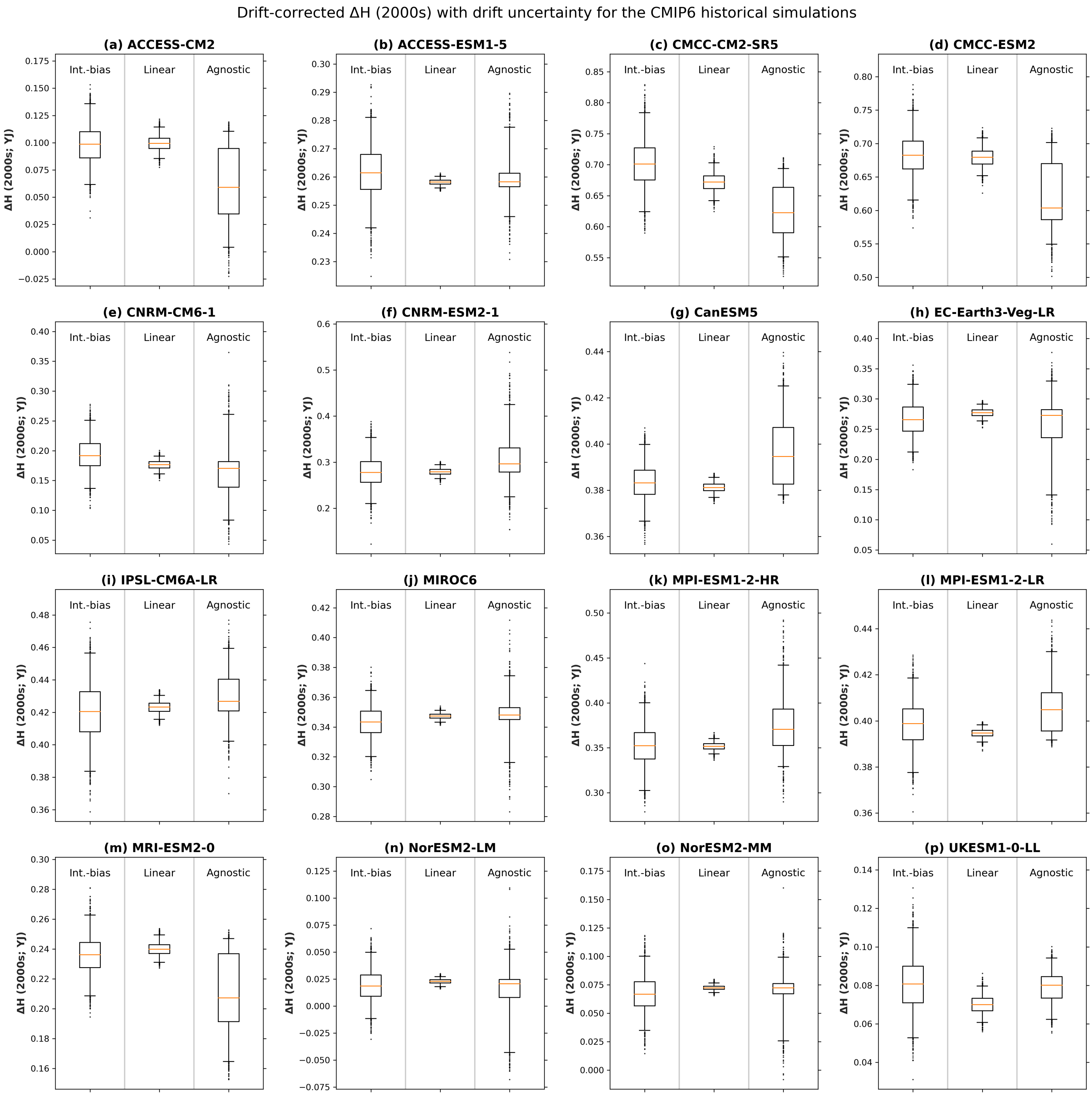

Figure S1: Drift-corrected excess ocean heat (ΔH) during the historical period and the corresponding drift uncertainty. We calculate ΔH as the decadal mean for the 2000s relative to the 1850s. Each panel shows results for one CMIP6 model. Within each panel, each box plot shows results for one MCDC method. The central line shows the median, the box shows the inter-quartile range, the whiskers show the 2nd–98th inter-percentile range, and the dots show outliers beyond the range of the whiskers.

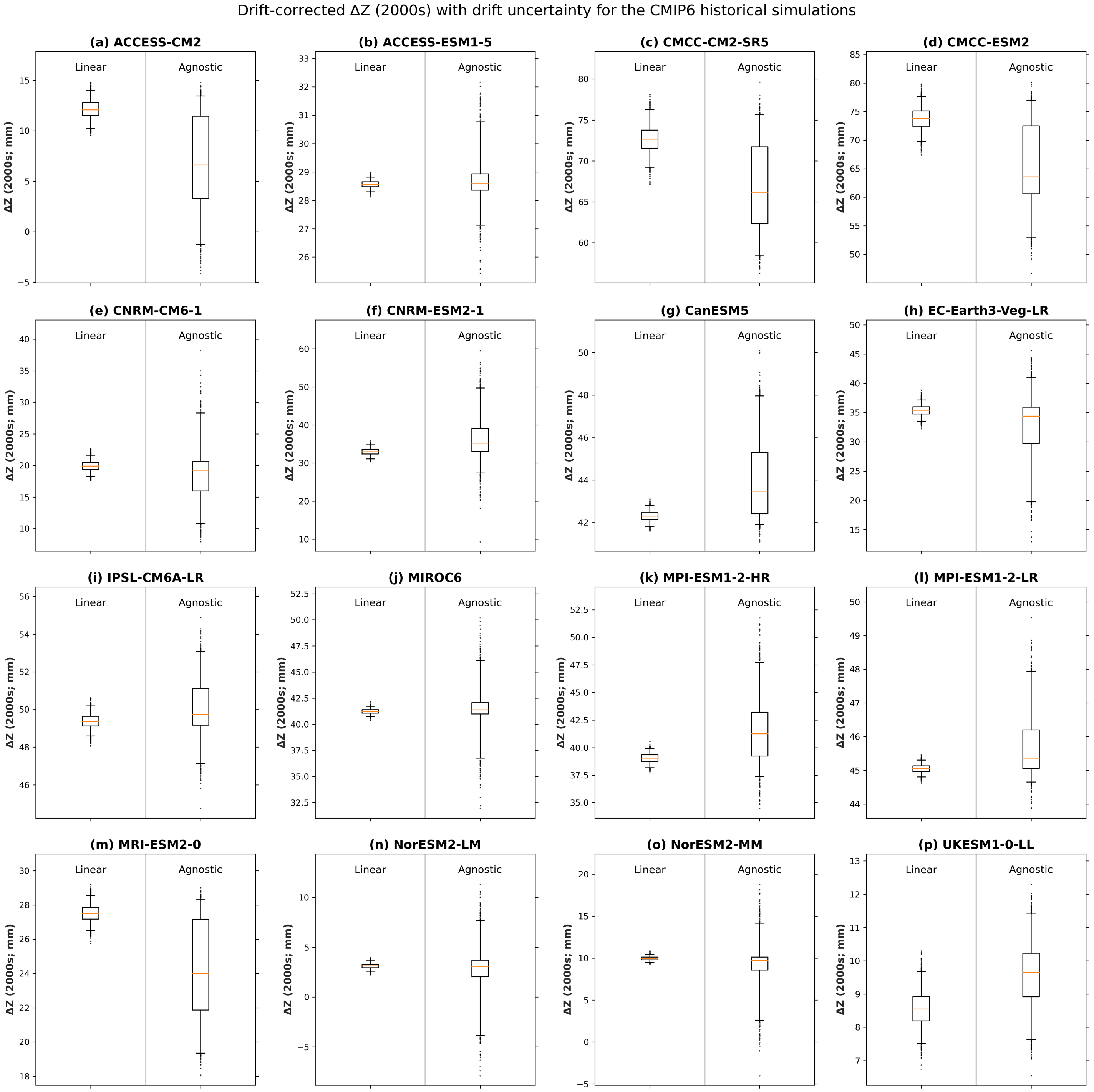

Figure S2: Drift-corrected thermosteric sea-level rise (ΔZ) during the historical period and the corresponding drift uncertainty. We calculate ΔZ as the decadal mean for the 2000s relative to the 1850s. Each panel shows results for one CMIP6 model. Within each panel, each box plot shows results for one MCDC method. The central line shows the median, the box shows the inter-quartile range, the whiskers show the 2nd–98th inter-percentile range, and the dots show outliers beyond the range of the whiskers.

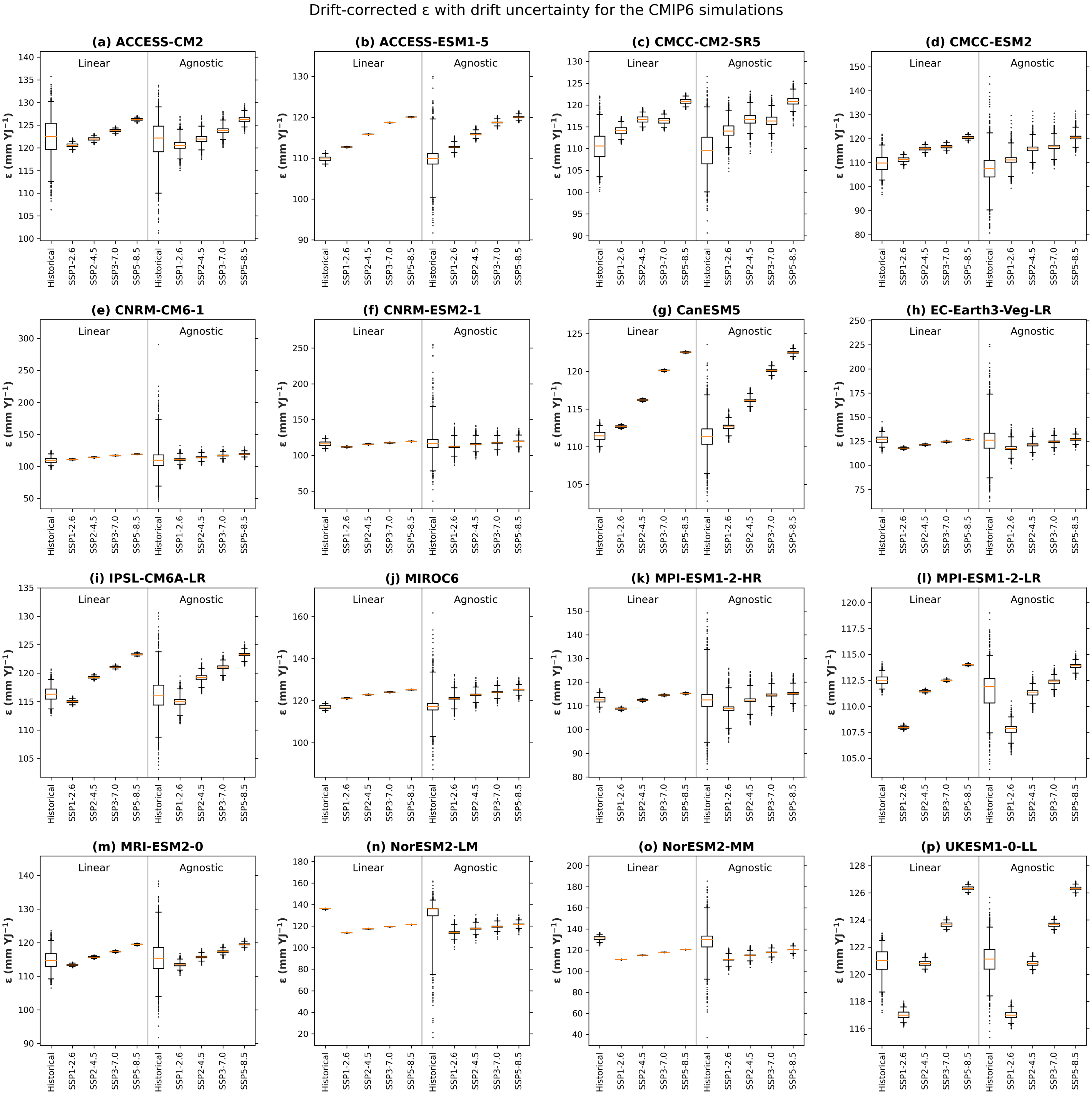

Figure S3: Drift-corrected estimates of the expansion efficiency of heat (ϵ) and the corresponding drift uncertainty. Each panel shows results for one CMIP6 model. Within each panel, each box plot shows results for one combination of MCDC method and projection scenario. The central line shows the median, the box shows the inter-quartile range, the whiskers show the 2nd–98th inter-percentile range, and the dots show outliers beyond the range of the whiskers.

Table S1: Coupled Model Intercomparison Project Phase 6 (CMIP6) models analysed in this study. "Control length" refers to the time series length of the pre-industrial control time series. The further information URLs also correspond to the control simulations.

Model	Variant	Control length (yr)	Calendar	Further information URL
ACCESS-CM2	r1i1p1f1	500	proleptic gregorian	https://furtherinfo.es-doc.org/CMIP6.CSIRO-ARCCSS.ACCESS-CM2.piControl.none.r1i1p1f1
ACCESS-ESM1-5	r1i1p1f1	1000	proleptic gregorian	https://furtherinfo.es-doc.org/CMIP6.CSIRO.ACCESS-ESM1-5.piControl.none.r1i1p1f1
CMCC-CM2-SR5	r1i1p1f1	500	365 day	https://furtherinfo.es-doc.org/CMIP6.CMCC.CMCC-CM2-SR5.piControl.none.r1i1p1f1
CMCC-ESM2	r1i1p1f1	500	365 day	https://furtherinfo.es-doc.org/CMIP6.CMCC.CMCC-ESM2.piControl.none.r1i1p1f1
CNRM-CM6-1	r1i1p1f2	500	gregorian	https://furtherinfo.es-doc.org/CMIP6.CNRM-CERFACS.CNRM-CM6-1.piControl.none.r1i1p1f2
CNRM-ESM2-1	r1i1p1f2	500	gregorian	https://furtherinfo.es-doc.org/CMIP6.CNRM-CERFACS.CNRM-ESM2-1.piControl.none.r1i1p1f2
CanESM5	r1i1p1f1	1000	365 day	https://furtherinfo.es-doc.org/CMIP6.CCCma.CanESM5.piControl.none.r1i1p1f1
EC-Earth3-Veg-LR	r1i1p1f1	501	proleptic gregorian	https://furtherinfo.es-doc.org/CMIP6.EC-Earth-Consortium.EC-Earth3-Veg-LR.piControl.none.r1i1p1f1
IPSL-CM6A-LR	r1i1p1f1	1000	gregorian	https://furtherinfo.es-doc.org/CMIP6.IPSL.IPSL-CM6A-LR.piControl.none.r1i1p1f1
MIROC6	r1i1p1f1	500	gregorian	https://furtherinfo.es-doc.org/CMIP6.MIROC.MIROC6.piControl.none.r1i1p1f1
MPI-ESM1-2-HR	r1i1p1f1	500	proleptic gregorian	https://furtherinfo.es-doc.org/CMIP6.MPI-M.MPI-ESM1-2-HR.piControl.none.r1i1p1f1
MPI-ESM1-2-LR	r1i1p1f1	1000	proleptic gregorian	https://furtherinfo.es-doc.org/CMIP6.MPI-M.MPI-ESM1-2-LR.piControl.none.r1i1p1f1
MRI-ESM2-0	r1i1p1f1	701	proleptic gregorian	https://furtherinfo.es-doc.org/CMIP6.MRI.MRI-ESM2-0.piControl.none.r1i1p1f1
NorESM2-LM	r1i1p1f1	501	365 day	https://furtherinfo.es-doc.org/CMIP6.NCC.NorESM2-LM.piControl.none.r1i1p1f1
NorESM2-MM	r1i1p1f1	500	365 day	https://furtherinfo.es-doc.org/CMIP6.NCC.NorESM2-MM.piControl.none.r1i1p1f1
UKESM1-0-LL	r1i1p1f2	1100	360 day	https://furtherinfo.es-doc.org/CMIP6.MOHC.UKESM1-0-LL.piControl.none.r1i1p1f2

Table S2: Sources of uncertainty in ΔE. We calculate ΔE as the decadal mean for the 2000s relative to the 1850s. For each drift-correction method and model, *drift uncertainty* corresponds to the 2nd–98th inter-percentile range. *Model uncertainty* corresponds to the inter-model range: (i) for each model, calculate the mean of the agnostic-method drift-corrected data, then (ii) calculate the inter-model range. The final three rows contain summary statistics: the minimum, median, and maximum of each column.

Sources of uncertainty in ΔE (2000s; YJ)				
Model or scenario	Drift uncertainty			Other uncertainty
	Int.-bias	Linear	Agnostic	Model
ACCESS-CM2	0.08	0.03	0.11	
ACCESS-ESM1-5	0.04	0.00	0.03	
CMCC-CM2-SR5	0.15	0.06	0.14	
CMCC-ESM2	0.13	0.06	0.15	
CNRM-CM6-1	0.10	0.02	0.15	
CNRM-ESM2-1	0.12	0.02	0.15	
CanESM5	0.03	0.01	0.05	
EC-Earth3-Veg-LR	0.11	0.03	0.17	
IPSL-CM6A-LR	0.08	0.02	0.06	
MIROC6	0.04	0.01	0.06	
MPI-ESM1-2-HR	0.10	0.02	0.11	
MPI-ESM1-2-LR	0.04	0.01	0.03	
MRI-ESM2-0	0.06	0.02	0.09	
NorESM2-LM	0.06	0.01	0.10	
NorESM2-MM	0.07	0.01	0.07	
UKESM1-0-LL	0.06	0.02	0.03	
Historical				0.56
Min	0.03	0.00	0.03	0.56
Median	0.07	0.02	0.09	0.56
Max	0.15	0.06	0.17	0.56

Table S3: Sources of uncertainty in ΔH. We calculate ΔH as the decadal mean for the 2000s relative to the 1850s. For each drift-correction method and model, *drift uncertainty* corresponds to the 2nd–98th inter-percentile range. *Model uncertainty* corresponds to the inter-model range: (i) for each model, calculate the mean of the agnostic-method drift-corrected data, then (ii) calculate the inter-model range. The final three rows contain summary statistics: the minimum, median, and maximum of each column.

Sources of uncertainty in ΔH (2000s; YJ)				
Model or scenario	Drift uncertainty			Other uncertainty
	Int.-bias	Linear	Agnostic	Model
ACCESS-CM2	0.07	0.03	0.11	
ACCESS-ESM1-5	0.04	0.00	0.03	
CMCC-CM2-SR5	0.16	0.06	0.14	
CMCC-ESM2	0.13	0.06	0.15	
CNRM-CM6-1	0.11	0.03	0.18	
CNRM-ESM2-1	0.14	0.03	0.20	
CanESM5	0.03	0.01	0.05	
EC-Earth3-Veg-LR	0.11	0.03	0.19	
IPSL-CM6A-LR	0.07	0.01	0.06	
MIROC6	0.04	0.01	0.06	
MPI-ESM1-2-HR	0.10	0.02	0.11	
MPI-ESM1-2-LR	0.04	0.01	0.04	
MRI-ESM2-0	0.05	0.02	0.08	
NorESM2-LM	0.06	0.01	0.10	
NorESM2-MM	0.07	0.01	0.07	
UKESM1-0-LL	0.06	0.02	0.03	
Historical				0.61
Min	0.03	0.00	0.03	0.61
Median	0.07	0.02	0.08	0.61
Max	0.16	0.06	0.20	0.61

Table S4: Sources of uncertainty in ΔZ. We calculate ΔZ as the decadal mean for the 2000s relative to the 1850s. For each drift-correction method and model, *drift uncertainty* corresponds to the 2nd–98th inter-percentile range. *Model uncertainty* corresponds to the inter-model range: (i) for each model, calculate the mean of the agnostic-method drift-corrected data, then (ii) calculate the inter-model range. The final three rows contain summary statistics: the minimum, median, and maximum of each column.

Sources of uncertainty in ΔZ (2000s; mm)			
Model or scenario	Drift uncertainty		Other uncertainty
	Linear	Agnostic	Model
ACCESS-CM2	4	15	
ACCESS-ESM1-5	1	4	
CMCC-CM2-SR5	7	17	
CMCC-ESM2	8	24	
CNRM-CM6-1	3	18	
CNRM-ESM2-1	4	22	
CanESM5	1	6	
EC-Earth3-Veg-LR	4	21	
IPSL-CM6A-LR	2	6	
MIROC6	1	9	
MPI-ESM1-2-HR	2	10	
MPI-ESM1-2-LR	0	3	
MRI-ESM2-0	2	9	
NorESM2-LM	1	12	
NorESM2-MM	1	12	
UKESM1-0-LL	2	4	
Historical			64
Min	0	3	64
Median	2	10	64
Max	8	24	64

Table S5: Sources of uncertainty in η. We calculate η for the period 2015 to 2100. For each drift-correction method and model, *drift uncertainty* corresponds to the 2nd–98th inter-percentile range: (i) for each projection scenario, calculate the 2nd–98th inter-percentile range of the drift-corrected data, then (ii) calculate the mean of this inter-percentile range by averaging across the projection scenarios. For each projection scenario, *model uncertainty* corresponds to the inter-model range: (i) for each model, calculate the mean of the agnostic-method drift-corrected data, then (ii) calculate the inter-model range. For each model, *scenario uncertainty* corresponds to the inter-scenario range: (i) for each projection scenario, calculate the mean of the agnostic-method drift-corrected data, then (ii) calculate the inter-scenario range. The final three rows contain summary statistics: the minimum, median, and maximum of each column.

Sources of uncertainty in η (unitless)					
Model or scenario	Drift uncertainty			Other uncertainty	
	Int.-bias	Linear	Agnostic	Model	Scenario
ACCESS-CM2	0.03	0.01	0.04		0.01
ACCESS-ESM1-5	0.01	0.00	0.02		0.01
CMCC-CM2-SR5	0.07	0.03	0.06		0.08
CMCC-ESM2	0.06	0.02	0.08		0.07
CNRM-CM6-1	0.04	0.01	0.10		0.01
CNRM-ESM2-1	0.05	0.01	0.14		0.01
CanESM5	0.01	0.00	0.01		0.01
EC-Earth3-Veg-LR	0.06	0.01	0.14		0.01
IPSL-CM6A-LR	0.03	0.01	0.03		0.02
MIROC6	0.02	0.00	0.06		0.01
MPI-ESM1-2-HR	0.05	0.01	0.12		0.03
MPI-ESM1-2-LR	0.02	0.00	0.02		0.01
MRI-ESM2-0	0.02	0.01	0.02		0.01
NorESM2-LM	0.03	0.00	0.08		0.03
NorESM2-MM	0.03	0.00	0.07		0.02
UKESM1-0-LL	0.02	0.01	0.01		0.01
SSP1-2.6				0.18	
SSP2-4.5				0.17	
SSP3-7.0				0.16	
SSP5-8.5				0.18	
Min	0.01	0.00	0.01	0.16	0.01
Median	0.03	0.01	0.06	0.17	0.01
Max	0.07	0.03	0.14	0.18	0.08

Table S6: Sources of uncertainty in ϵ. We calculate ϵ for the period 2015 to 2100. For each drift-correction method and model, *drift uncertainty* corresponds to the 2nd–98th inter-percentile range: (i) for each projection scenario, calculate the 2nd–98th inter-percentile range of the drift-corrected data, then (ii) calculate the mean of this inter-percentile range by averaging across the projection scenarios. For each projection scenario, *model uncertainty* corresponds to the inter-model range: (i) for each model, calculate the mean of the agnostic-method drift-corrected data, then (ii) calculate the inter-model range. For each model, *scenario uncertainty* corresponds to the inter-scenario range: (i) for each projection scenario, calculate the mean of the agnostic-method drift-corrected data, then (ii) calculate the inter-scenario range. The final three rows contain summary statistics: the minimum, median, and maximum of each column.

Sources of uncertainty in ϵ (mm YJ^{-1})				
Model or scenario	Drift uncertainty		Other uncertainty	
	Linear	Agnostic	Model	Scenario
ACCESS-CM2	1	5		6
ACCESS-ESM1-5	0	2		7
CMCC-CM2-SR5	3	7		7
CMCC-ESM2	3	11		9
CNRM-CM6-1	2	13		8
CNRM-ESM2-1	2	22		7
CanESM5	0	2		10
EC-Earth3-Veg-LR	2	16		9
IPSL-CM6A-LR	1	3		8
MIROC6	0	7		4
MPI-ESM1-2-HR	1	12		6
MPI-ESM1-2-LR	0	2		6
MRI-ESM2-0	1	2		6
NorESM2-LM	1	10		7
NorESM2-MM	0	9		10
UKESM1-0-LL	1	1		9
SSP1-2.6			13	
SSP2-4.5			11	
SSP3-7.0			12	
SSP5-8.5			13	
Min	0	1	11	4
Median	1	7	12	7
Max	3	22	13	10