Supplementary material for "Multi–model evidence for an atmospheric circulation response to Arctic sea ice loss in the CMIP5 future projections"

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1 Abrupt4xCO2 and 1%yr^{-1}CO2 experiments

To test the robustness of the results displayed in Fig 4 of the main paper, the same analyses have been repeated using the abrupt4xCO2 and the 1%yr^{-1}CO2 CMIP5 experiments in place of the RCP8.5 scenario. Whilst the RCP8.5 scenario involves changes in different greenhouse gases and aerosols, both the abrupt4xCO2 and the 1%yr^{-1}CO2 CMIP5 experiments are only forced with changes in the CO2 concentrations, thus enabling a more direct comparison with the AMIP4xCO2 experiment. This enables us to test whether the results of the study are affected by the additional forcing agents included in RCP8.5.

The 1%yr^{-1}CO2 response is evaluated as the difference in climate between years 111–140 relative to years 1–30 from the time CO2 starts increasing. This experiment has the further benefit that the pattern in the CMIP5 mean SST response is the closest to the SST perturbation employed in the AMIPFuture experiment, which was also derived from the 1%yr^{-1}CO2 experiment but from the CMIP3 ensemble. The scaling factors to generate the AMIPsst+co2 response equivalent to the 1%yr^{-1}CO2 response, as for Eq. 1 of the main paper, are $k_{sst} = 0.62$ and $k_{co2} = 0.79$.

The abrupt4xCO2 response is evaluated as the difference between years 121- 150 from the time of CO2 quadrupling relative to a 100 years climatology from the pre–industrial control. abrupt4xCO2 has larger differences in the pattern of SST change relative to AMIP-Future than the RCP8.5 and 1%yr^{-1}CO2 scenarios, as the SSTs have had longer time to reach equilibrium following the abrupt CO2 increase. However, this scenario has the benefit of requiring the least amount of pattern scaling in order to combine the AMIPFuture and

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AMIP4xCO2 responses into the AMIPsst+co2 response. In particular, we obtain $k_{sst} = 0.88$ and $k_{co2} = 1$.

Both the abrupt4xCO2 and the 1%yr^{-1}CO2 experiments are analysed for the same subset of 10 models available for the AMIPFuture and AMIP4xCO2 experiments (see table S1). The results are presented in Fig. S2 (abrupt4xCO2) and Fig. S3 (1%yr^{-1}CO2), and both feature very similar patterns to those shown in the Fig 4 of the main paper. This suggests that the conclusions of the study are robust to the presence of non–CO2 radiative forcing, to the magnitude of the pattern scaling and to the presence of small differences in the pattern of SST change.

2 Internal variability on jet response

The uncertainty on the multi-model mean jet response due to internal variability in the CMIP5 ensemble is estimated as follows. For each model, the standard deviation in the 30-year mean jet latitude due to internal variability (σ_m) is obtained by bootstrapping the model year to year variability in the historical period. A standard error for the multi-model mean jet response is then obtained as $\frac{1}{M}\sqrt{\sum_{m=1}^{M}(2\,\sigma_m^2)}$ where M is the number of models. This assumes that the variability in the jet latitude is not affected by climate change, which is approximately satisfied.

	Basic Information		# Runs	
	Model Name	Institution	HIST/RCP	AMIP/Future/4xCO2
1	ACCESS10	CSIRO-BOM, *Australia*	1	-
2	ACCESS13		1	-
3	BCC-CSM1-1	BCC,*China*	1	1
4	BCC-CSM1-1m		1	-
5	CANESM2	CCCma, *Canada*	1	1 (CanAM4)
6	CCSM4	NCAR, *USA*	1	-
7	CESM1-BGC	NSF-DOE-NCAR, *USA*	1	-
8	CESM1-CAM5		1	-
9	CMCC-CESM	CMCC, *Italy*	1	-
10	CMCC-CM		1	-
11	CMCC-CMS		1	-
12	CNRM-CM5	CNRM, *France*	1	1
13	CSIRO-mk360	CSIRO, *Australia*	1	-
14	EC-EARTH	European Consortium, *Europe*	1	-
15	FIO-ESM	FIO, *China*	1	-
16	GFDL-CM3	GFDL, *USA*	1	-
17	GFDL-ESM2G		1	-
18	GFDL-ESM2M		1	-
19	GISS-E2H	NASA GISS, *USA*	1	-
20	GISS-E2H-CC		1	-
21	GISS-E2R		1	-
22	GISS-E2R-CC		1	-
23	HadGEM2-AO	MOHC, *UK*	1	1 (HadGEM2-A)
24	HadGEM2-CC		1	-
25	HadGEM2-ES		1	-
26	INMCM4	INM, *Russia*	1	-
27	IPSL-CM5A-LR	IPSL, *France*	1	1
28	IPSL-CM5A-MR		1	-
29	IPSL-CM5B-LR		1	1
30	MIROC-ESM	MIROC, *Japan*	1	-
31	MIROC-ESM-CHEM		1	-
32	MIROC5		1	1
33	MPI-ESM-LR	MPI–M, *Germany*	1	1
34	MPI-ESM-MR		1	1
35	MRI-CGCM3	MRI, *Japan*	1	1
36	NORESM1-M	NCC, *Norway*	1	-
37	NORESM1-ME		1	-

Table 1. CMIP5 models considered in the study. The column HIST/RCP provides the data availability for the Historical and RCP8.5 simulations, and the AMIP/Future/4xCO2 column for the AMIP, AMIPFuture and AMIP4xCO2 simulations. A one indicates that one ensemble member has been analysed, specifically r2i1p1 for EC-EARTH and r1i1p1 for all the others, while the dash indicates that no data is available. The last column also reports the name of the atmosphere–only model corresponding to the coupled model, if different.

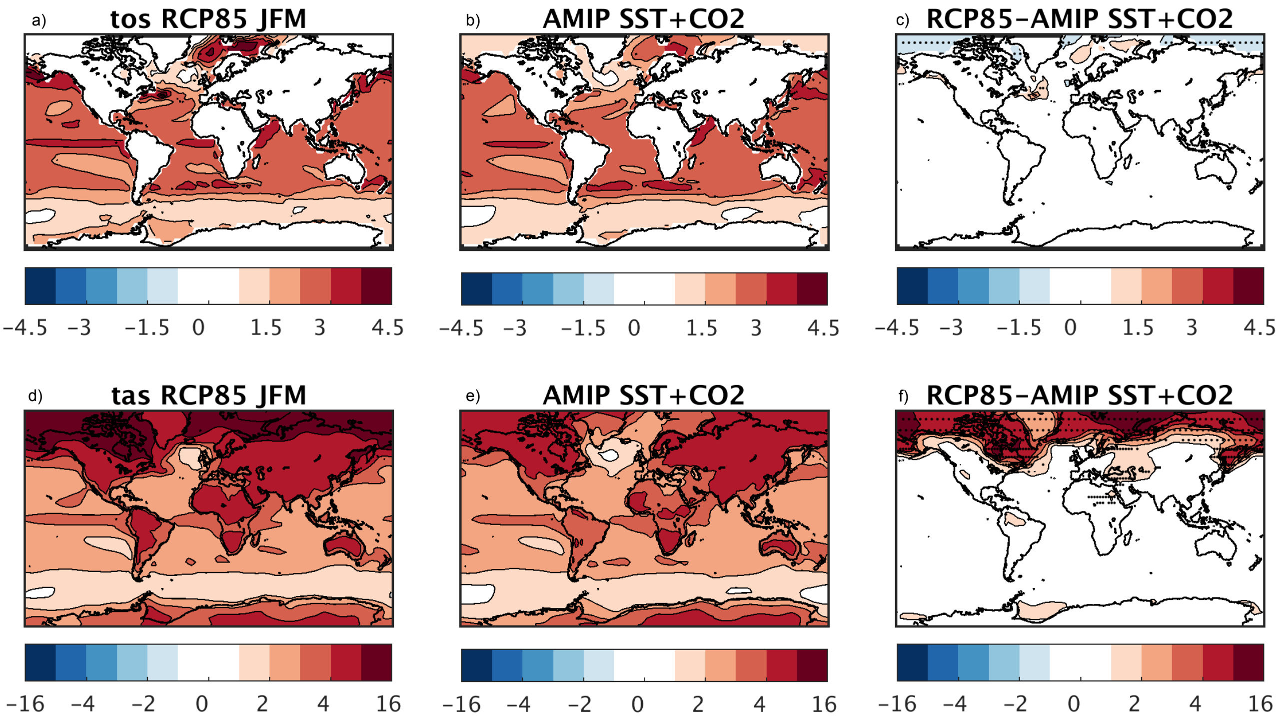

Figure 1. a-c) CMIP5 multi-model mean response in the ocean surface temperature (K) in a) the RCP8.5 scenario, b) in AMIPsst+co2 and c) the difference between the two. The responses are evaluated for the subset of 10 CMIP5 models available for the AMIP experiments. d-f) is as a-c) but of the near-surface atmospheric temperature response (K). In panels c) and f) the stippling indicates areas where the difference has the same sign in at least 90% of the models. Note that the contour intervals are non-linearly spaced in d-f).

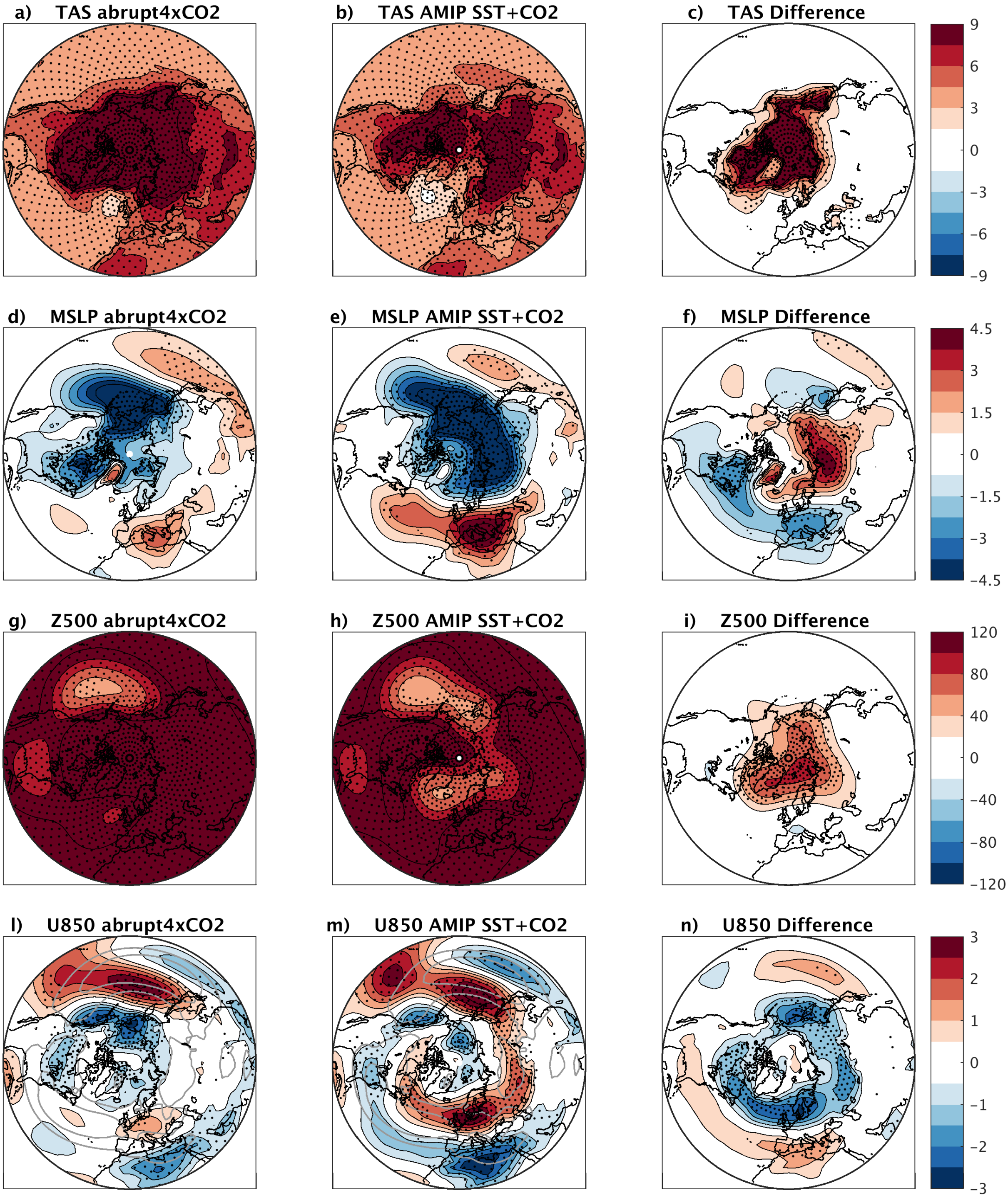

Figure 2. Same as Fig. 4 of the main paper but using the abrupt4xCO2 experiment to evaluate the future response instead of the RCP8.5 scenario.

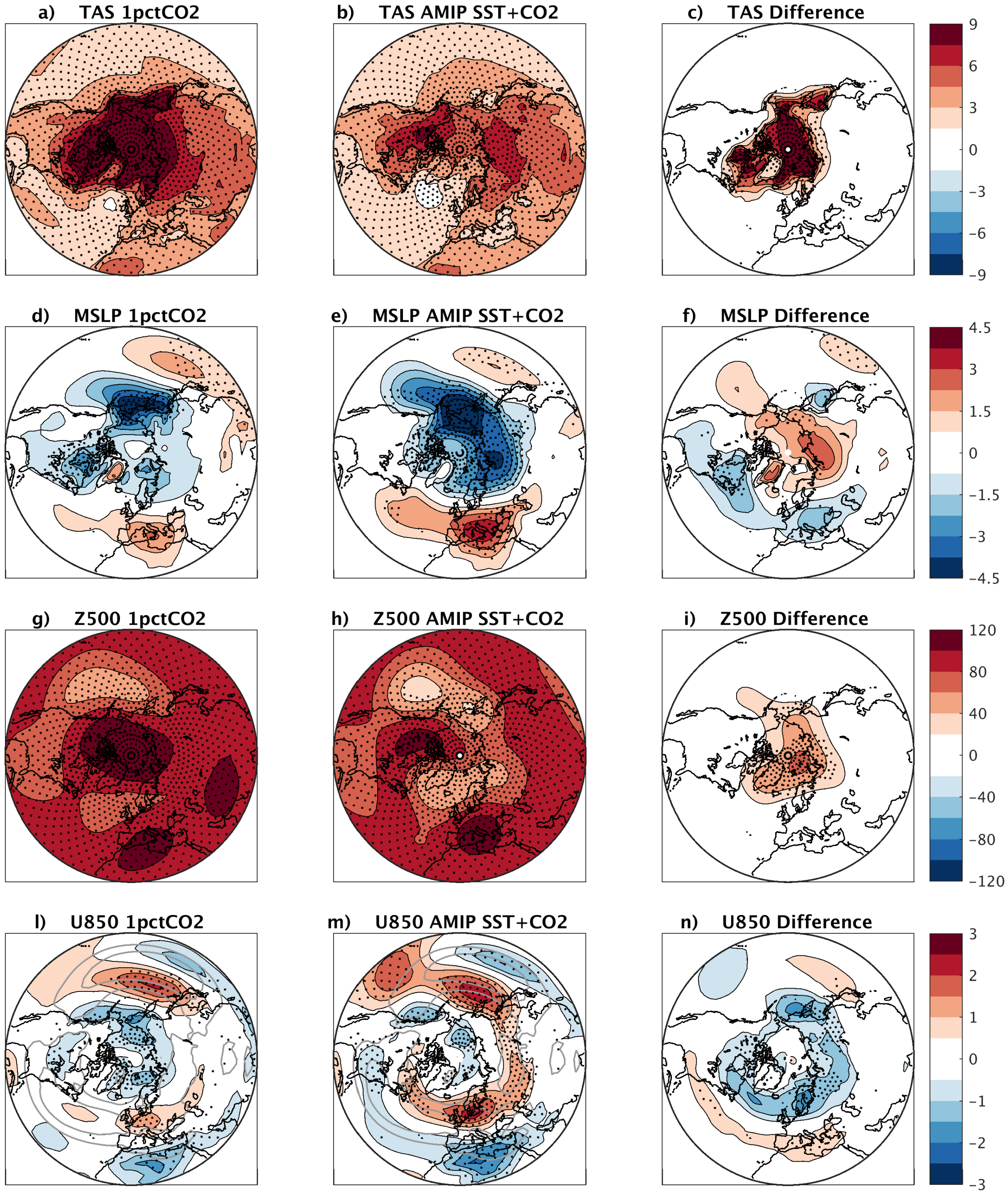

Figure 3. Same as Fig. 4 of the main paper but using the 1%yr^{-1}CO2 experiment to evaluate the future response instead of the RCP8.5 scenario.

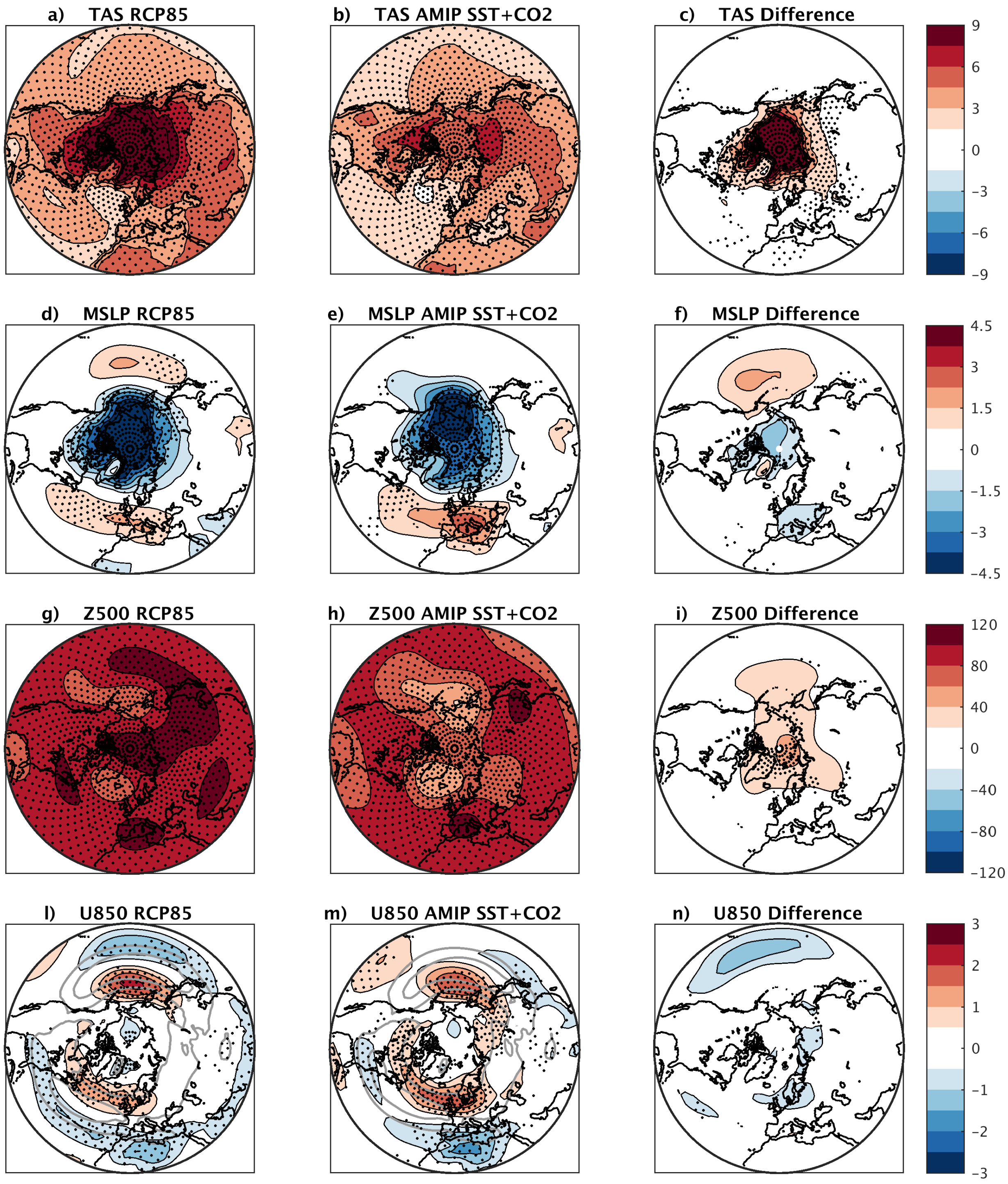

Figure 4. Same as Fig. 4 of the main paper but for the early winter response (OND).

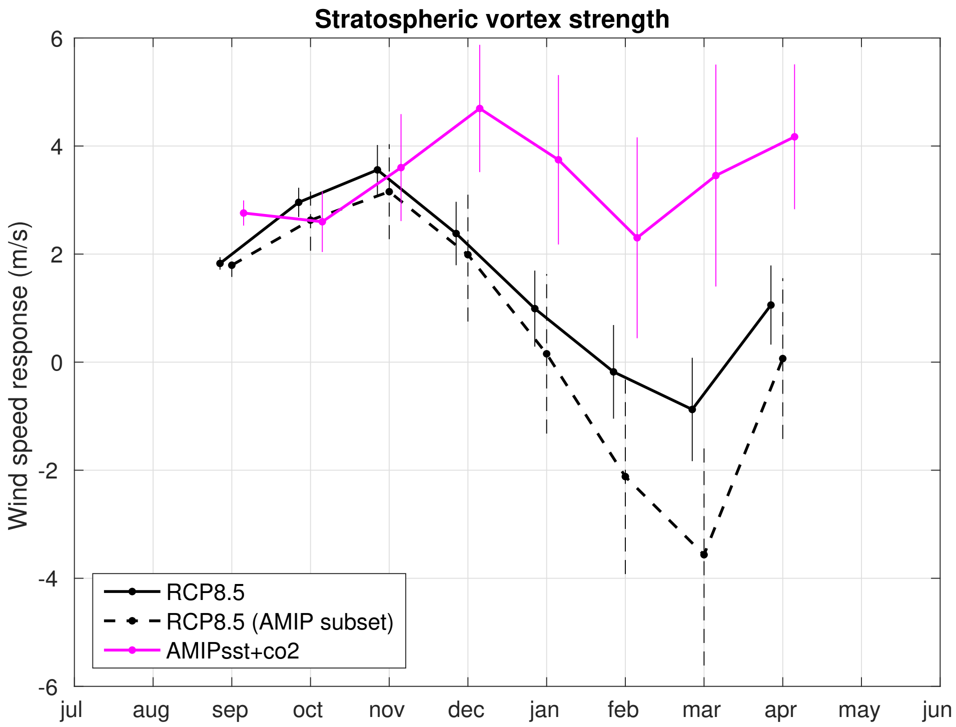

Figure 5. Multi-model mean response in the strength of the stratospheric vortex. The vortex strength is measured as the maximum in the NH zonal mean zonal wind at 20 hPa. The full black line refers to the mean of the CMIP5 models in the RCP8.5 scenario (37 models), the black dashed is the same but for the 10 models subset available in the AMIP simulations, and the magenta line refers to the AMIPsst+co2 response. Values are only presented for the months in which the vortex is formed, i.e. where the maximum in zonal mean zonal wind at 20 hPa is westerly.