Supplementary material

Exploring uncertainties in global crop yield projections in a large ensemble of crop models and CMIP5 and CMIP6 climate scenarios

Christoph Müller[1], James Franke[2,3], Jonas Jägermeyr[4,5,1], Alex C. Ruane[4], Joshua Elliott[3], Elisabeth Moyer[2,3], Jens Heinke[1], Pete D Falloon[6], Christian Folberth[7], Louis Francois[8], Tobias Hank[9], R. César Izaurralde[10], Ingrid Jacquemin[8], Wenfeng Liu[11], Stefan Olin[12], Thomas A. M. Pugh[12,13,14], Karina Williams[6,15], Florian Zabel[9]

[1]Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany
[2]Department of the Geophysical Sciences, University of Chicago, Chicago, IL, USA
[3]Center for Robust Decision-making on Climate and Energy Policy (RDCEP), University of Chicago, Chicago, IL, USA
[4]NASA Goddard Institute for Space Studies, New York, NY, United States
[5]Center for Climate Systems Research, Columbia University Earth Institute, New York, USA
[6]Met Office Hadley Centre, Exeter, UK
[7]Ecosystem Services and Management Program, International Institute for Applied Systems Analysis, Laxenburg, Austria
[8]Unité de Modélisation du Climat et des Cycles Biogéochimiques, UR SPHERES, Institut d'Astrophysique et de Géophysique, University of Liège, Liège, Belgium
[9]Ludwig-Maximilians-Universität München (LMU), Department of Geography, Munich, Germany
[10]Department of Geographical Sciences, University of Maryland, College Park, MD, USA
[11]College of Water Resources and Civil Engineering, China Agricultural University, Beijing, China
[12]Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden
[13]School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK
[14]Birmingham Institute of Forest Research, University of Birmingham, Birmingham, UK
[15]Global Systems Institute, University of Exeter, Exeter, UK

Appendix tables

Table 1: Climate models (GCMs) considered from the CMIP5 archive (n=45). Two models (GISS-E2-H and GISS-E2-R) have provided outputs for three different parameterization schemes (p) and were considered as separate climate projections

CLIMATE MODEL	ENSEMBLE MEMBER	RCP 2.6	RCP 4.5	RCP 8.5
ACCESS1-0	r1i1p1		X	X
ACCESS1-3	r1i1p1		X	X
BCC-CSM1-1	r1i1p1	X	X	X
BCC-CSM1-1-M	r1i1p1	X	X	X
BNU-ESM	r1i1p1	X	X	X
CanESM2	r1i1p1	X	X	X
CCSM4	r1i1p1	X	X	X
CESM1-BGC	r1i1p1		X	X
CESM1-CAM5	r1i1p1	X	X	X
CESM1-WACCM	r2i1p1	X	X	X
CMCC-CESM	r1i1p1			X
CMCC-CM	r1i1p1		X	X
CMCC-CMS	r1i1p1		X	X
CNRM-CM5	r1i1p1	X	X	X
CSIRO-Mk3-6-0	r1i1p1	X	X	X
EC-EARTH	r8i1p1	X	X	X
FGOALS-g2	r1i1p1	X	X	X
FIO-ESM	r1i1p1	X	X	X
GFDL-CM3	r1i1p1	X	X	X
GFDL-ESM2G	r1i1p1	X	X	X
GFDL-ESM2M	r1i1p1	X	X	X
GISS-E2-H	r1i1p1	X	X	X
GISS-E2-H	r1i1p2	X	X	X
GISS-E2-H	r1i1p3	X	X	X
GISS-E2-H-CC	r1i1p1		X	X
GISS-E2-R	r1i1p1	X	X	X
GISS-E2-R	r1i1p2	X	X	X
GISS-E2-R	r1i1p3	X	X	X
GISS-E2-R-CC	r1i1p1		X	X
HadGEM2-AO	r1i1p1	X	X	X
HadGEM2-CC	r1i1p1		X	X
HadGEM2-ES	r2i1p1	X	X	X
INMCM4	r1i1p1		X	X
IPSL-CM5A-LR	r1i1p1	X	X	X
IPSL-CM5A-MR	r1i1p1	X	X	X
IPSL-CM5B-LR	r1i1p1		X	X
MIROC-ESM	r1i1p1	X	X	X
MIROC-ESM-CHEM	r1i1p1	X	X	X
MIROC5	r1i1p1	X	X	X
MPI-ESM-LR	r1i1p1	X	X	X
MPI-ESM-MR	r1i1p1	X	X	X
MRI-CGCM3	r1i1p1	X	X	X
MRI-ESM1	r1i1p1			X
NorESM1-M	r1i1p1	X	X	X
NorESM1-ME	r1i1p1	X	X	X

Table 2: Climate model (GCM) projections considered from the CMIP6 archive (n=34). One model (CIESM) had to be excluded for discontinuities in the time series (strong decline in temperature in last 5 years of the 21st century). One other model (CanESM5) provided data for 2 different parameterizations and is thus included twice.

CLIMATE MODEL	ENSEMBLE MEMBER, VERSION AND REFEERENCES	SSP 126	SSP 245	SSP 585
ACCESS-CM2	r1i1p1f1 v20191108 (scenarios (Dix *et al.*, 2019b)) (historical (Dix *et al.*, 2019a))	X	X	X
ACCESS-ESM1-5	r1i1p1f1 v20191115 (scenarios (Ziehn *et al.*, 2019b)) (historical (Ziehn *et al.*, 2019a))	X	X	X
BCC-CSM2-MR	r1i1p1f1 v20190314 (scenarios (Xin *et al.*, 2019)) v20181126 (historical (Xin *et al.*, 2018))	X	X	X
CAMS-CSM1-0	r1i1p1f1 v20190708 (scenarios (Rong, 2019a)) (historical (Rong, 2019b))	X	X	X
CanESM5	r1i1p1f1 v20190429 (scenarios (Swart *et al.*, 2019d)) v20190306 (historical (Swart *et al.*, 2019c))	X	X	X
CanESM5	r1i1p2f1 v20190429 (scenarios (Swart *et al.*, 2019d)) v20190429 (historical (Swart *et al.*, 2019c))	X	X	X
CanESM5-CanOE	r1i1p2f1 v20190429 (scenarios (Swart *et al.*, 2019b)) (historical (Swart *et al.*, 2019a))	X	X	X
CESM2	r1i1p1f1 v20190730 (scenarios (Danabasoglu, 2019d, e, f)) (historical (Danabasoglu, 2019c))	X	X	X
CESM2-WACCM	r1i1p1f1 v20190815 (scenarios (Danabasoglu, 2019b)) (historical (Danabasoglu, 2019a))	X	X	X
CIESM	Excluded, implausible decline in T at end of 21st century			
CNRM-CM6-1	r1i1p1f2 v20190219 (scenarios (Voldoire, 2019)) v20180917 (historical (Voldoire, 2018))	X	X	X
CNRM-ESM2-1	r1i1p1f2 v20191021 (ssp585) v20190328 (ssp245 & ssp126) (scenarios (Seferian, 2019)) v20181206 (historical (Seferian, 2018))	X	X	X
EC-Earth3	r1i1p1f1 v20200310 (scenarios (EC-Earth Consortium, 2019d, e, f)) (historical (EC-Earth Consortium, 2019c))	X	X	X
EC-Earth3-Veg	r1i1p1f1 v20200225 (scenarios (EC-Earth Consortium, 2019b)) (historical (EC-Earth Consortium, 2019a))	X	X	X
FGOALS-f3-L	r1i1p1f1 v20191013 (scenarios (Yu, 2019)) v20190927 (historical (Yu, 2018))	X	X	X
FGOALS-g3	r1i1p1f1 v20190818 (scenarios (Li, 2019b)) (historical (Li, 2019a))	X	X	X
FIO-ESM-2-0	r1i1p1f1 v20191226 (ssp585 & ssp245) v20191227 (ssp126) (scenarios (Song *et al.*, 2019b)) v20191209 (historical (Song *et al.*, 2019a))	X	X	X
GFDL-CM4	r1i1p1f1 v20180701 (scenarios (Guo *et al.*, 2018b)) (historical (Guo *et al.*, 2018a))		X	X
GFDL-ESM4	r1i1p1f1 v20180701 (scenarios (John *et al.*, 2018)) (historical (Krasting *et al.*, 2018))	X	X	X
GISS-E2-1-G	r1i1p3f1 v20200115 (scenarios (Nasa Goddard Institute for Space Studies, 2020)) (historical (Nasa Goddard Institute for Space Studies, 2018))	X	X	X
HadGEM3-GC31-LL	r1i1p1f3 v20200114 (ssp585 & ssp126) v20190908 (ssp245) (scenarios (Good, 2019)) (historical (Ridley *et al.*, 2018))	X	X	X
INM-CM4-8	r1i1p1f1 v20190603 (scenarios (Volodin *et al.*, 2019b)) (historical (Volodin *et al.*, 2019a))	X	X	X
INM-CM5-0	r1i1p1f1 v20190724 (ssp585) v20190619 (ssp245 & ssp126) (scenarios (Volodin *et al.*, 2019d)) (historical (Volodin *et al.*, 2019c))	X	X	X
IPSL-CM6A-LR	r1i1p1f1 v20190903 (ssp585, ssp126) v20190119 (ssp245) (scenarios (Boucher *et al.*, 2019)) v20180803 (historical (Boucher *et al.*, 2018))	X	X	X
KACE-1-0-G	r1i1p1f1 v20190920 (ssp585), v20191125 (ssp245) v20191007 (ssp126) (all scenarios (Byun *et al.*, 2019a)) (historical (Byun *et al.*, 2019b))	X	X	X
MCM-UA-1-0	r1i1p1f2 v20190731 (scenarios (Stouffer, 2019b)) (historical (Stouffer, 2019a))	X	X	X
MIROC6	r1i1p1f1 v20190627 (scenarios (Shiogama *et al.*, 2019)) (historical (Tatebe and Watanabe, 2018))	X	X	X
MIROC-ES2L	r1i1p1f2 v20190823 (scenarios (Tachiiri *et al.*, 2019)) (historical (Hajima *et al.*, 2019))	X	X	X
MPI-ESM1-2-LR	r1i1p1f1 v20190710 (scenarios (Wieners *et al.*, 2019a)) (historical (Wieners *et al.*, 2019b))	X	X	X
MRI-ESM2-0	r1i1p1f1 v20191108 (ssp585 & ssp126) v20190222 (ssp245) scenarios (Yukimoto *et al.*, 2019b)) (historical (Yukimoto *et al.*, 2019a))	X	X	X
NESM3	r1i1p1f1 v20190728 (scenarios (Cao, 2019)) (historical (Cao and Wang, 2019))	X	X	X
NorESM2-LM	r1i1p1f1 v20191108 (scenarios (Seland *et al.*, 2019b)) v20190815 (historical (Seland *et al.*, 2019a))	X	X	X
NorESM2-MM	r1i1p1f1 v20191108 (scenarios (Bentsen *et al.*, 2019b)) (historical (Bentsen *et al.*, 2019a))	X	X	X
UKESM1-0-LL	r1i1p1f2 v20190507 (ssp585 & ssp245) v20190503 (ssp126) (scenarios (Good *et al.*, 2019)) (historical (Tang *et al.*, 2019))	X	X	X

Appendix figures

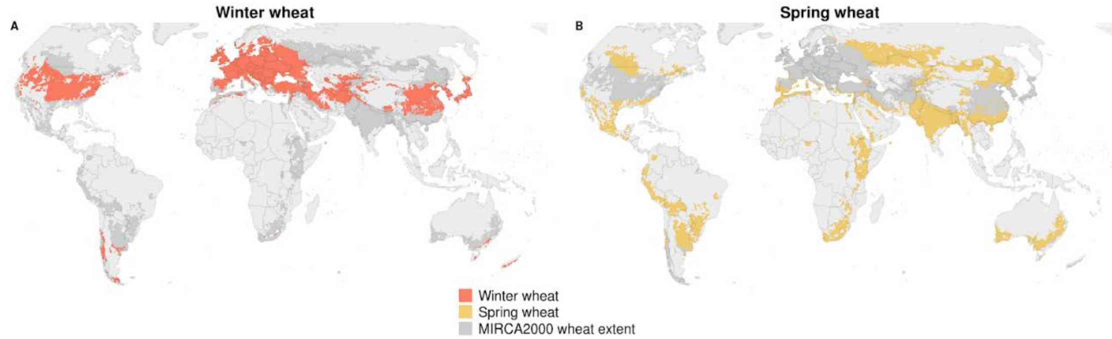


Figure S1: Assumptions on where winter and spring wheat is grown. This Boolean attribution is a simplification because winter and spring wheat can also be grown in parallel, depending on the crop rotations.

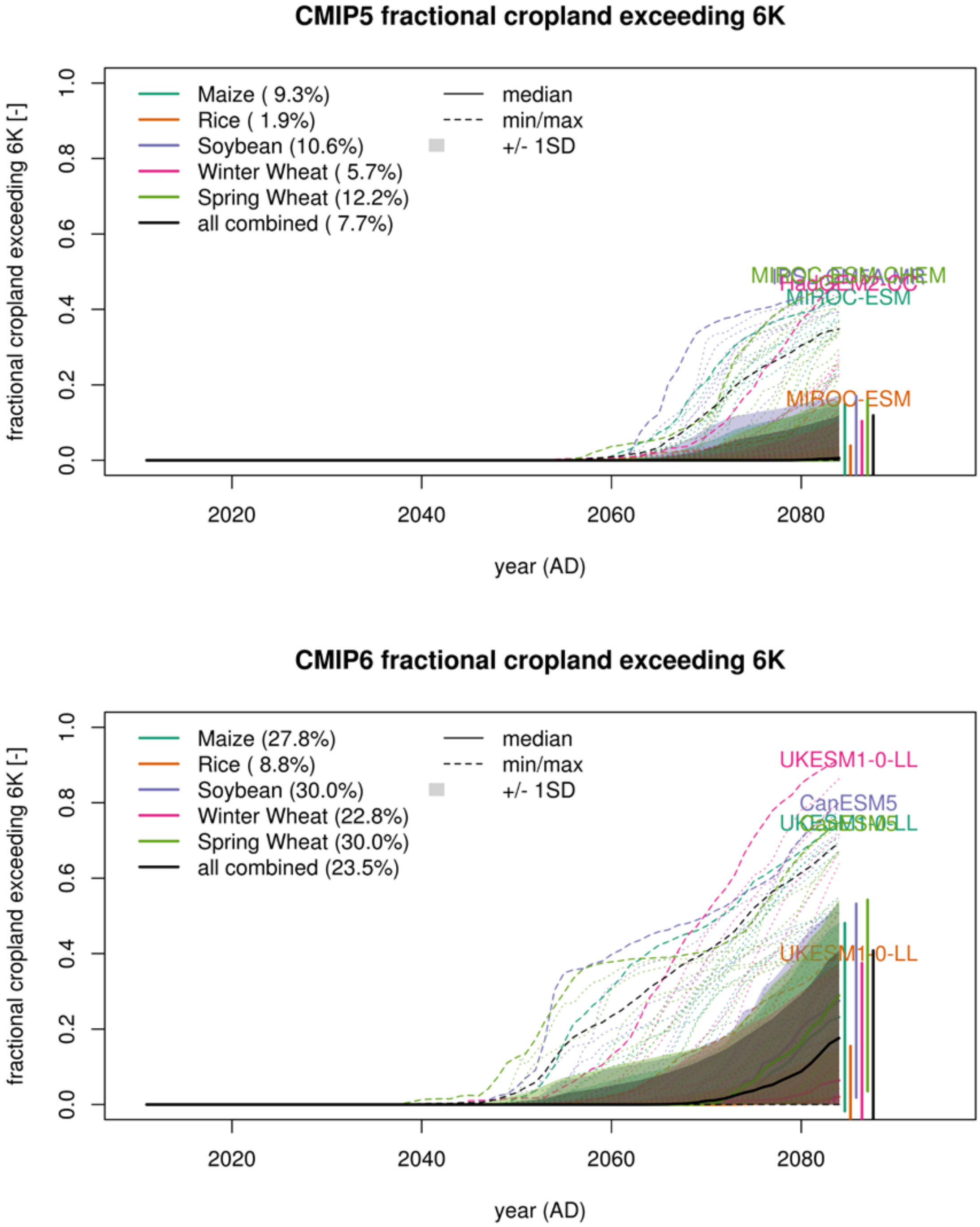


Figure S2: fractional cropland extent exceeding +6K for growing season warming (ΔT) for CMIP5 (top) and CMIP6 (bottom). Colors distinguish different crops, black is the combination of all cropland of the 5 crops considered here. Thick solid lines represent crop specific medians, shaded areas the +/- 1 standard deviation range (but not showing values lower 0). Dotted lines represent individual GCMs, dashed lines the maximum of all GCMs, which are also labeled in the color of the respective crops. Numbers in parenthesis show the mean cropland (in %) per crop that exceeds +6K averaged across all GCMs in the last time slice (2069-2099).

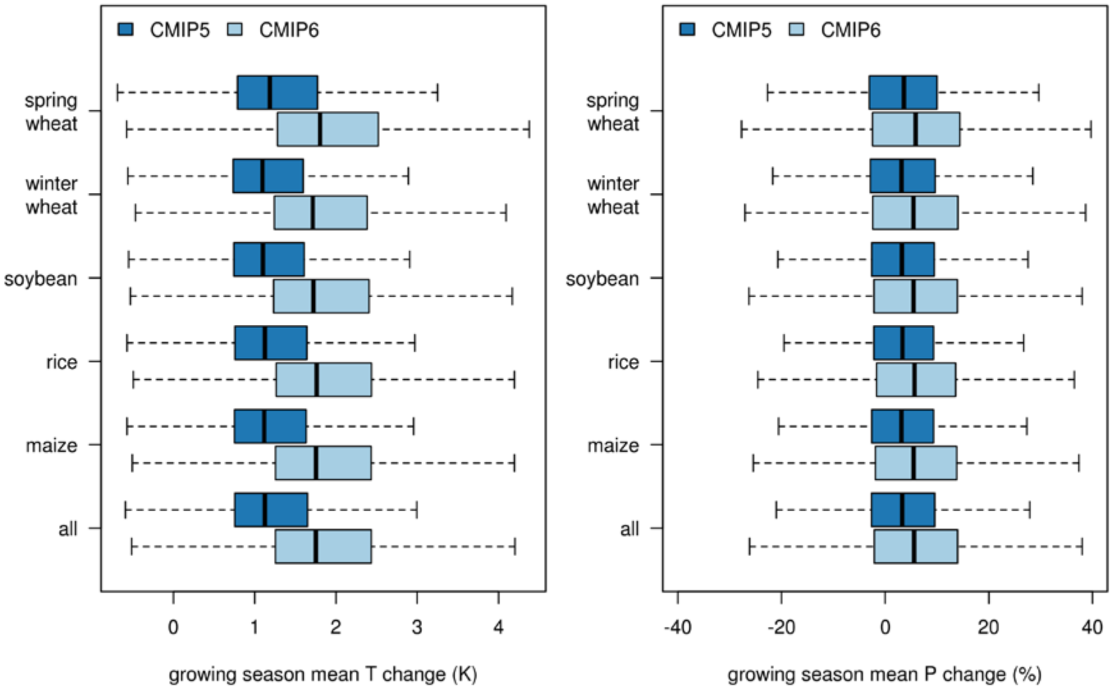


Figure S3: Same as figure 1 in the main text, but for RCP2.6.

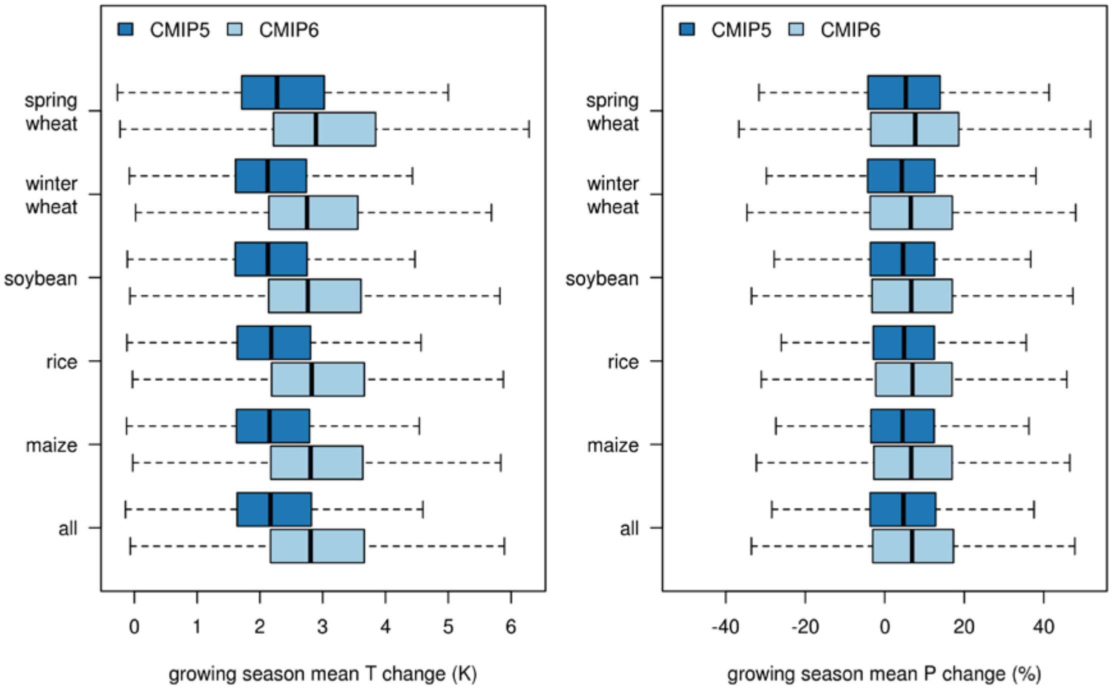


Figure S4: Same as figure 1 in the main text but for RCP4.5.

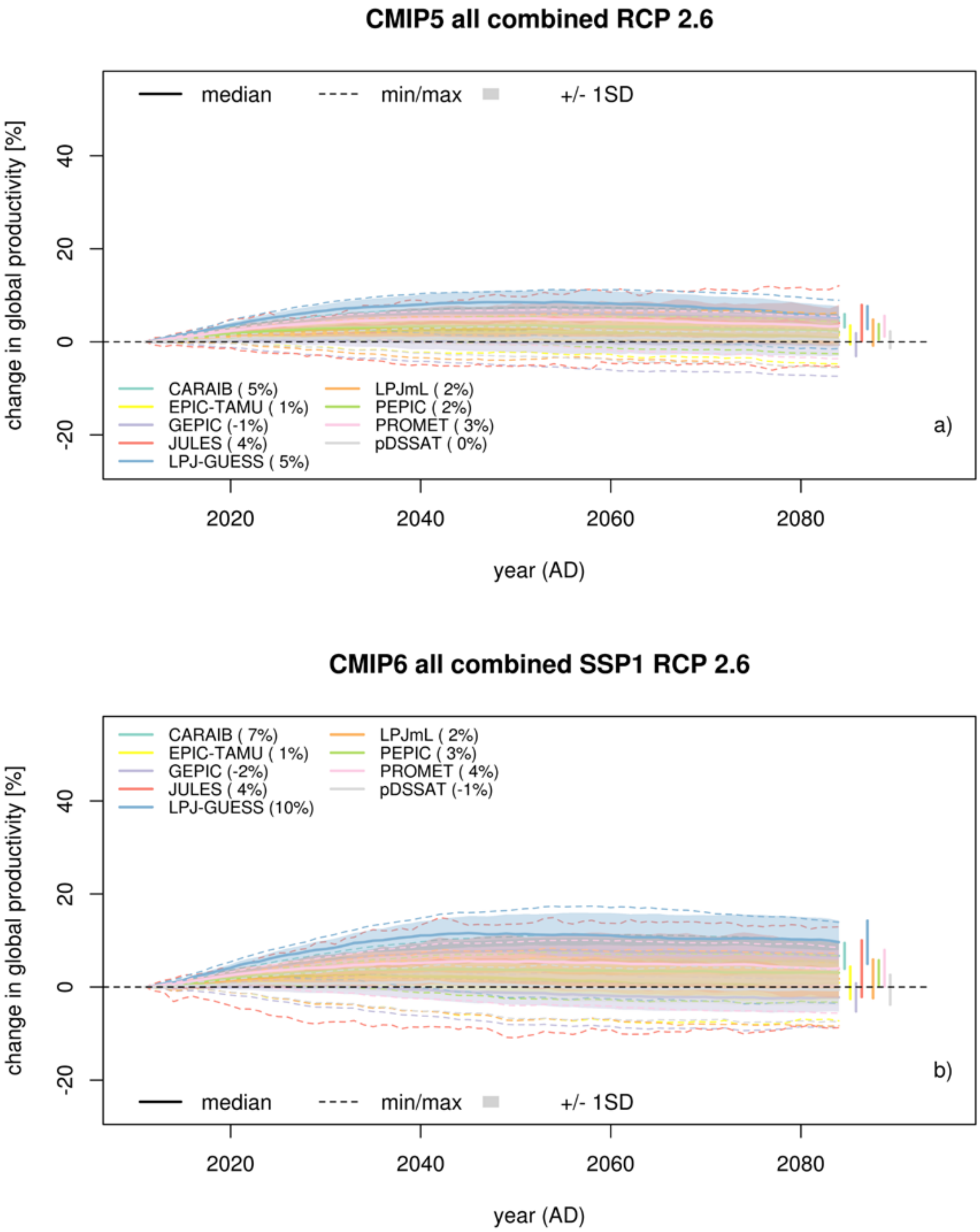


Figure S5: same as Figure 2 in the main text, but for RCP 2.6

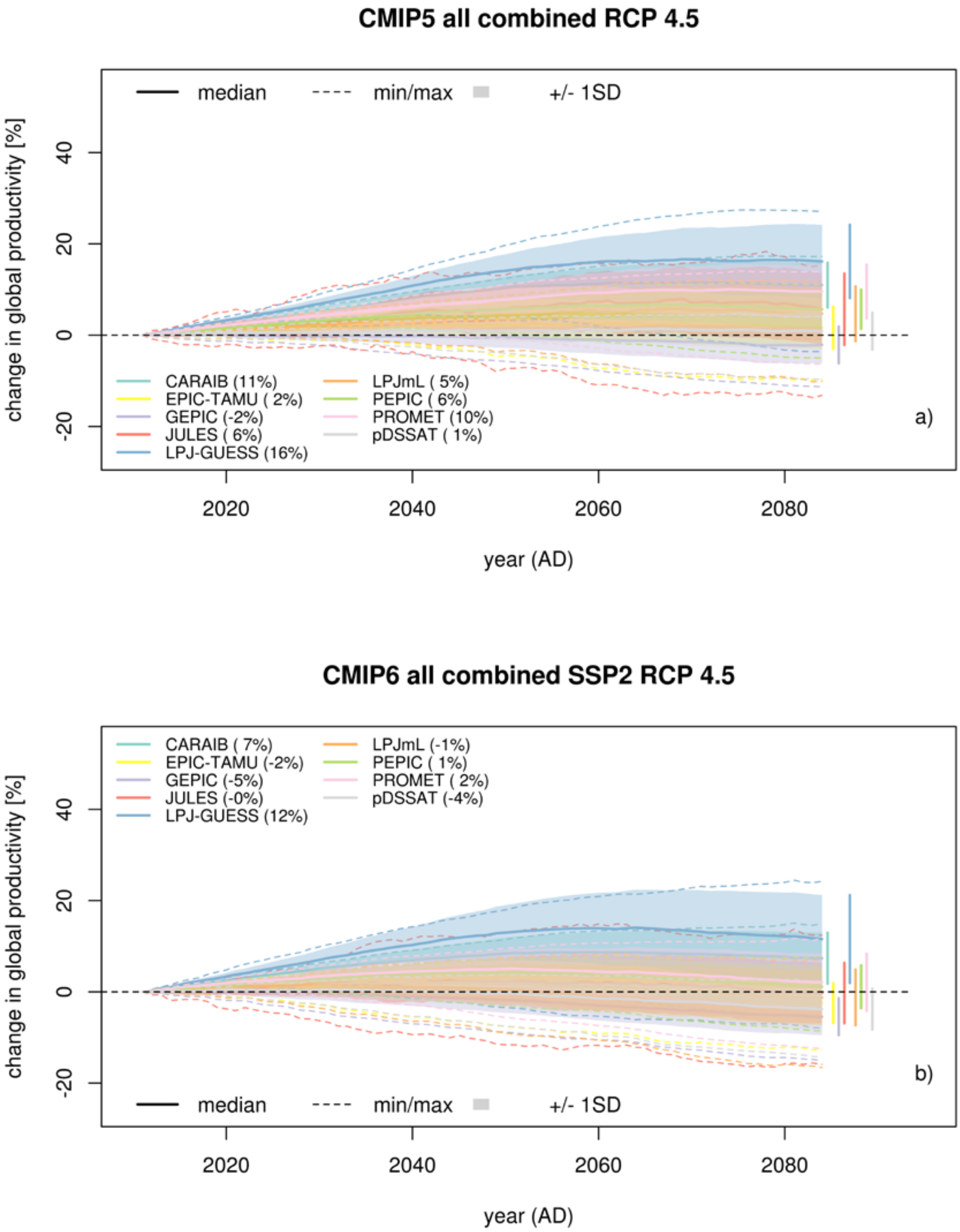


Figure S6: same as Figure 2 in the main text, but for RCP 4.5

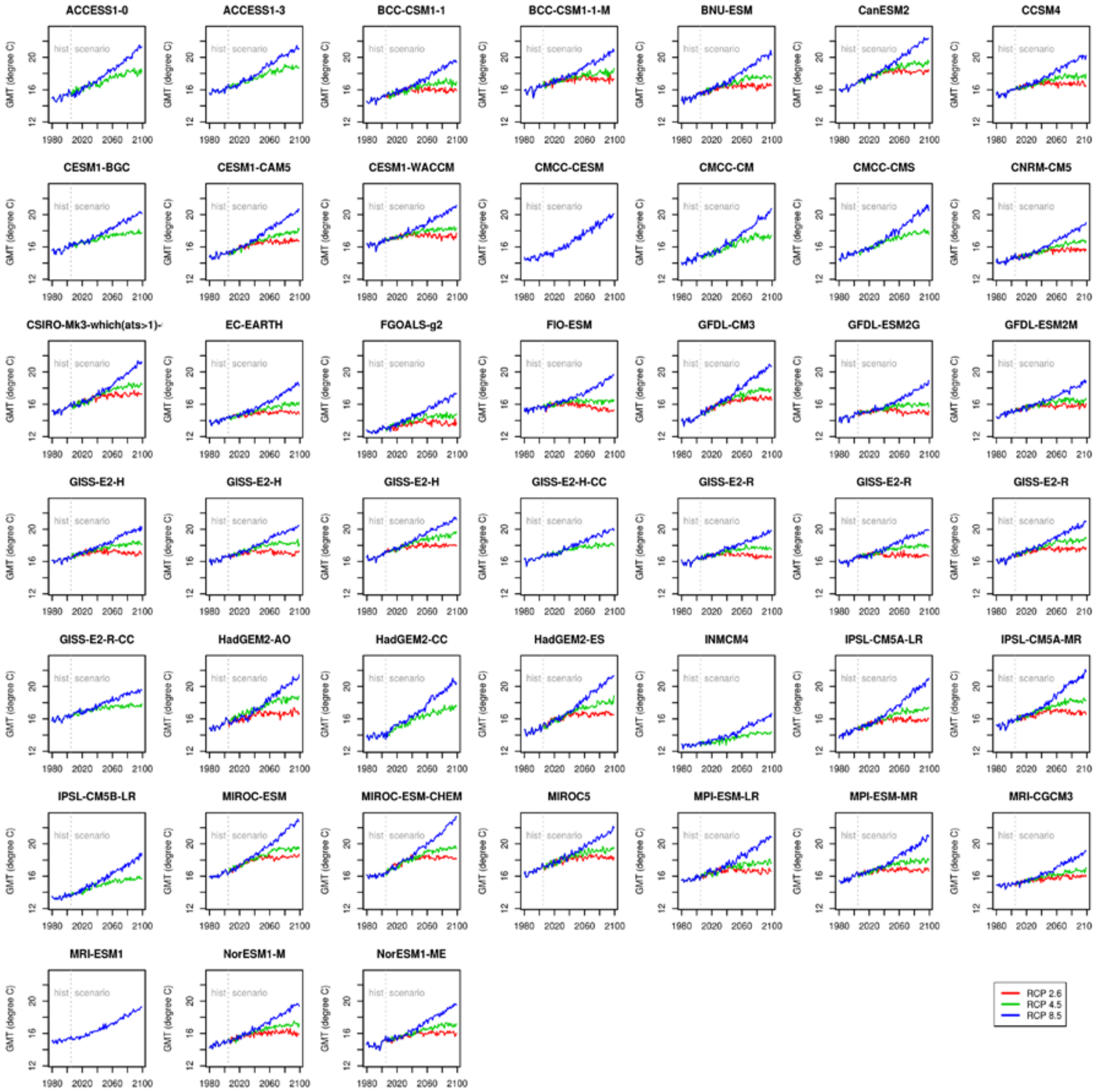
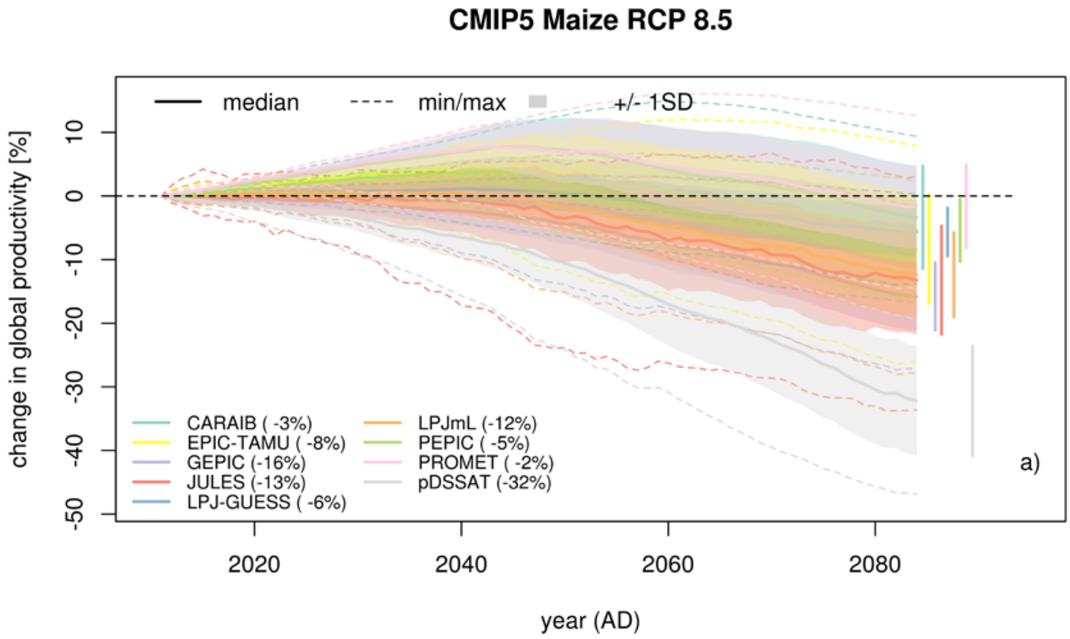


Figure S7: Global mean temperature increase on total cropland of the 5 crops considered here per GCM of the CMIP5 ensemble. Colors indicate the different RCPs.

Crop specific impact projections



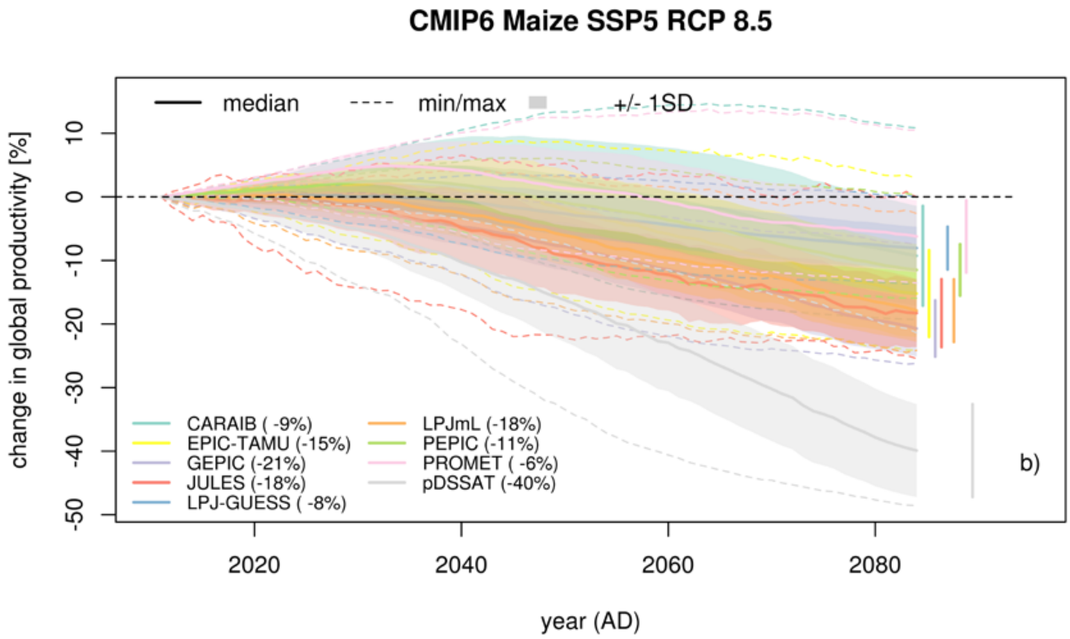
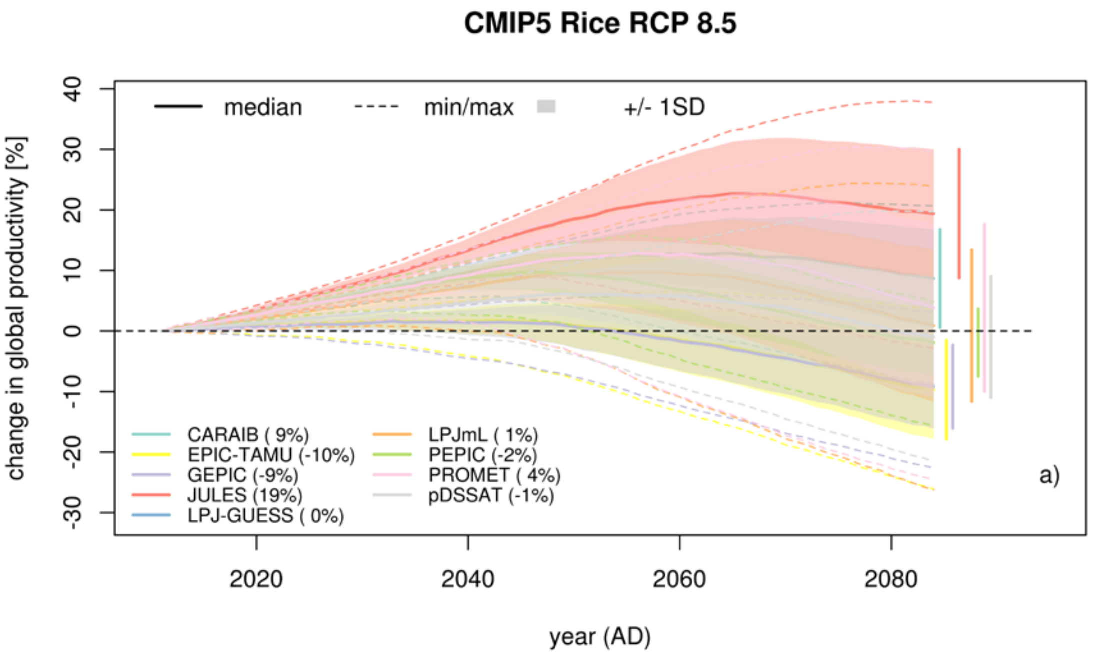


Figure S8: projections of global productivity for maize. pDSSAT is by far the most pessimistic model, explaining why excluding it from the ensemble would substantially reduce the GGCM-induced share in variance (Figure 7 in main text)



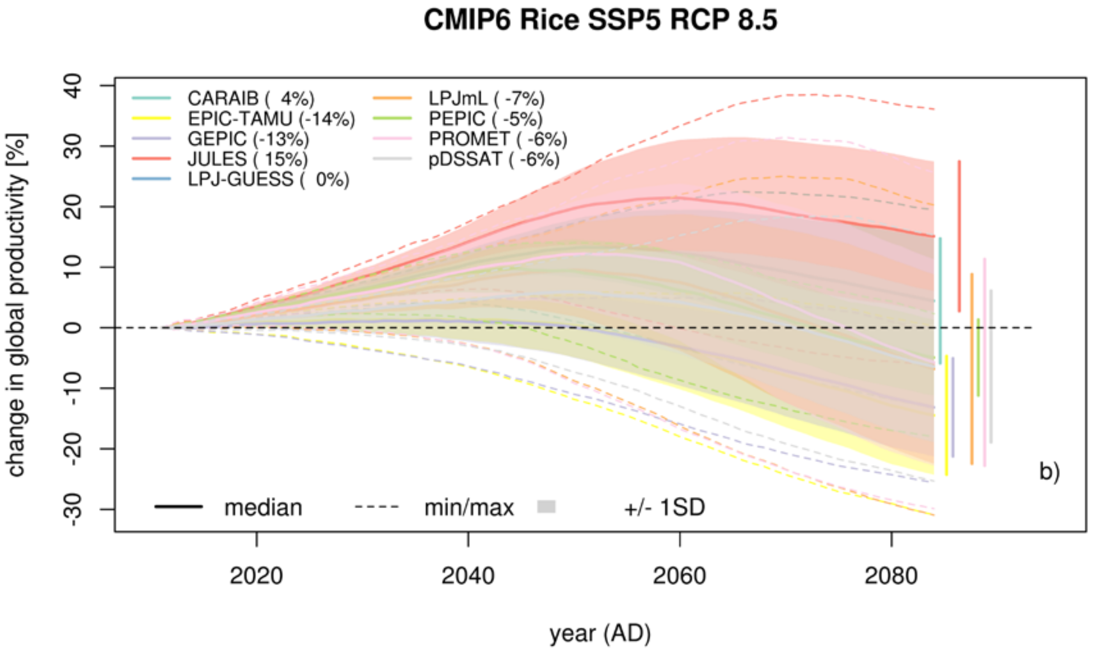


Figure S9: Same as figure S8, but for rice.

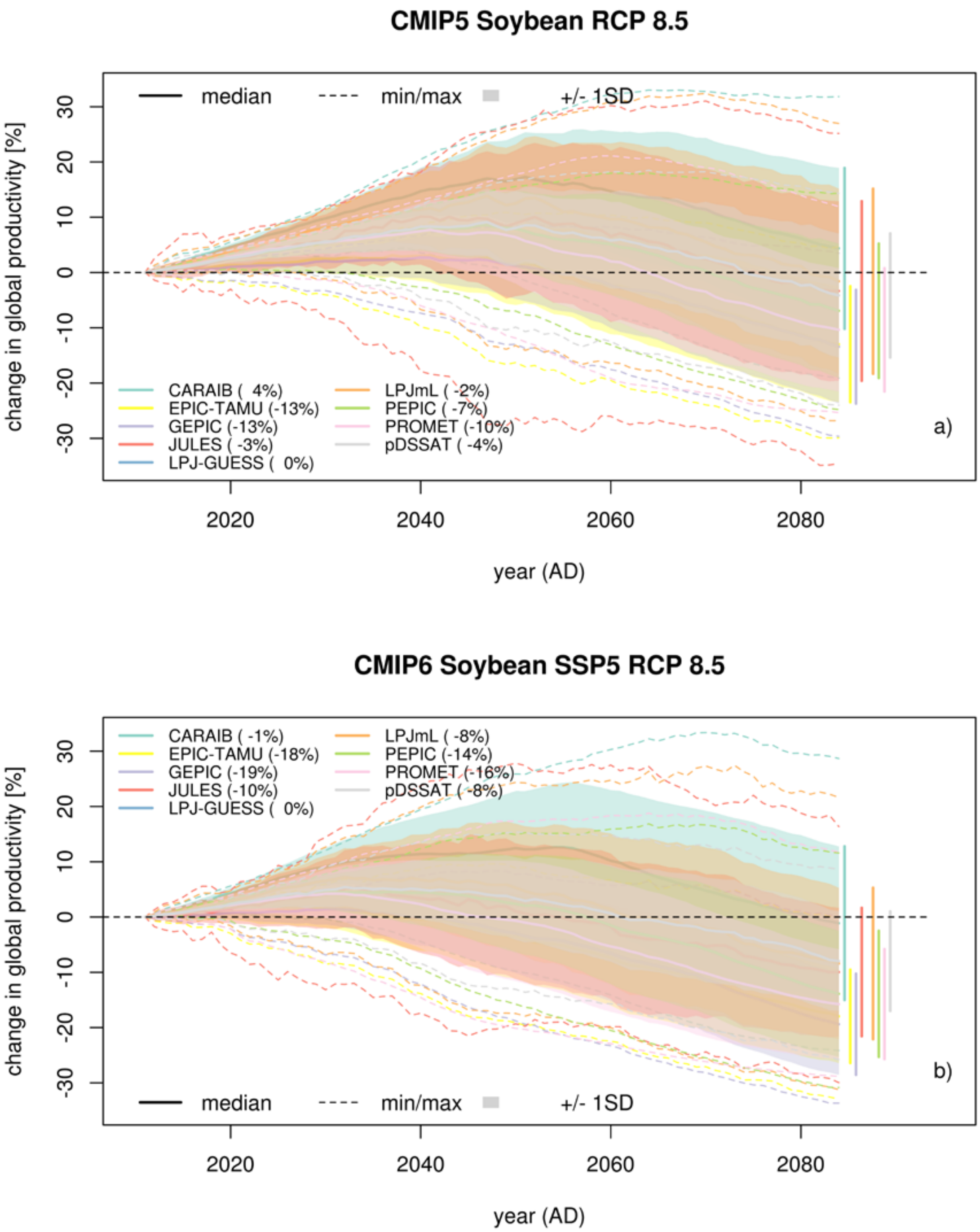


Figure S10: Same as figure S8, but for soybean.

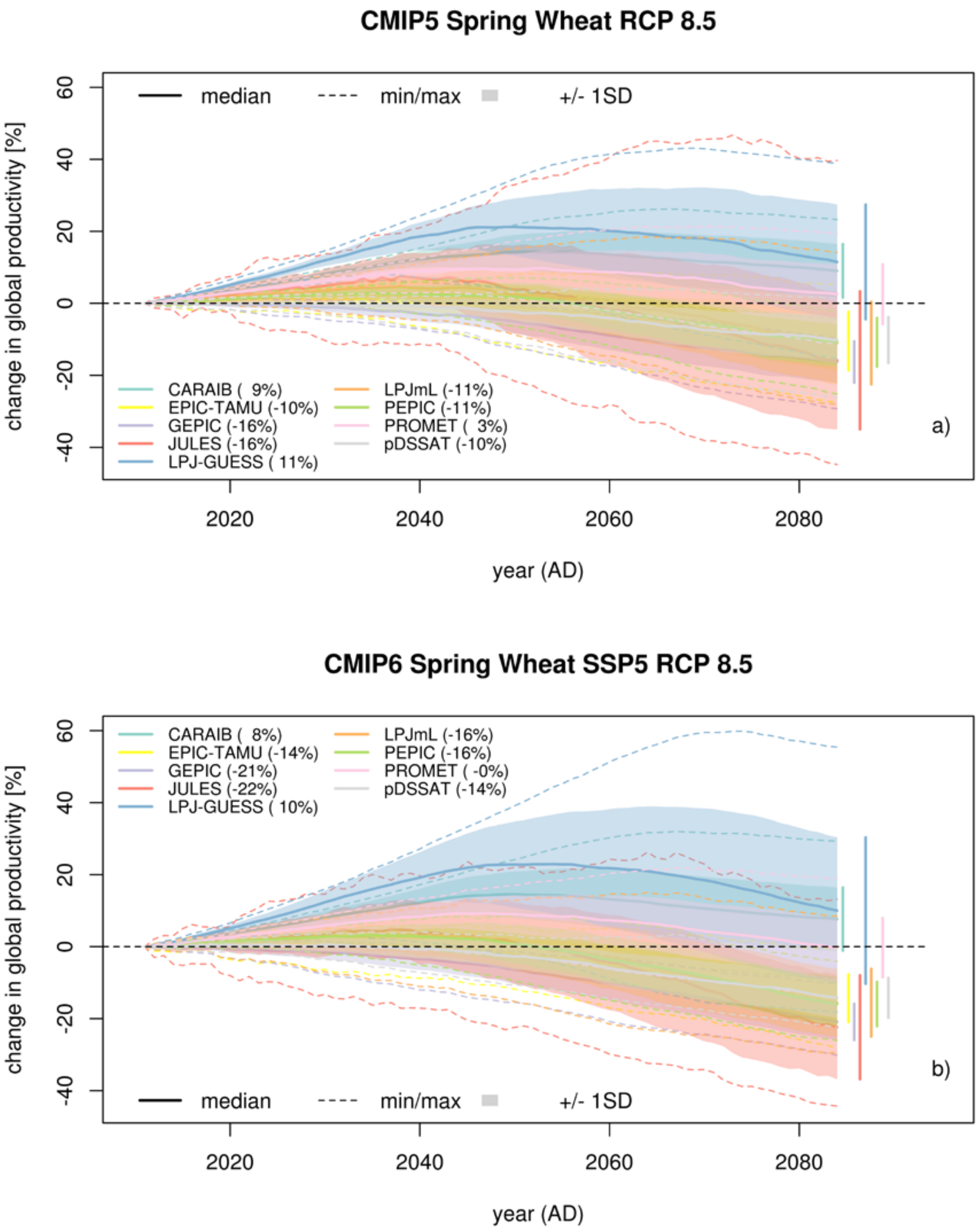


Figure S11: Same as figure S8, but for spring wheat.

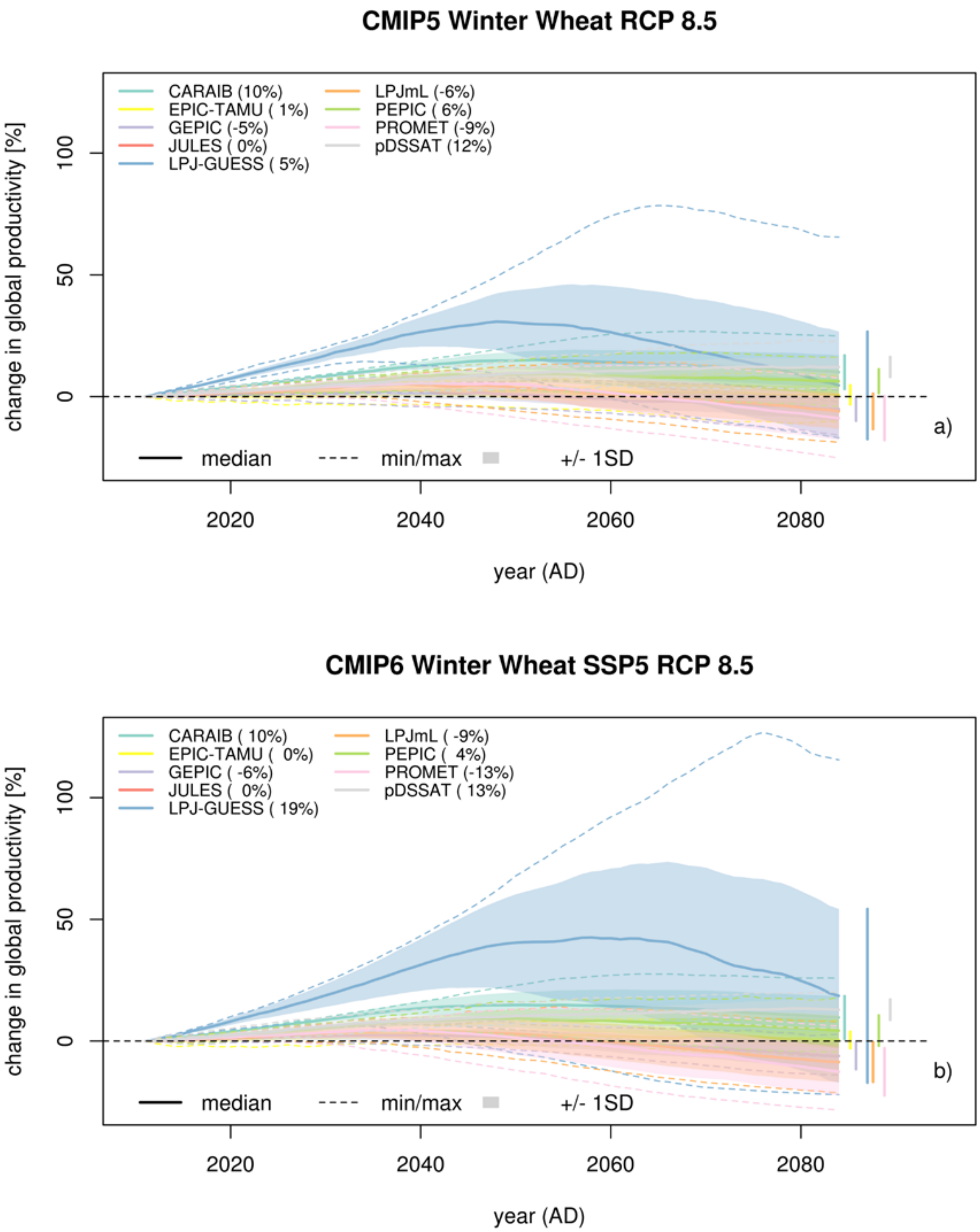


Figure S12: Same as figure S8, but for winter wheat.

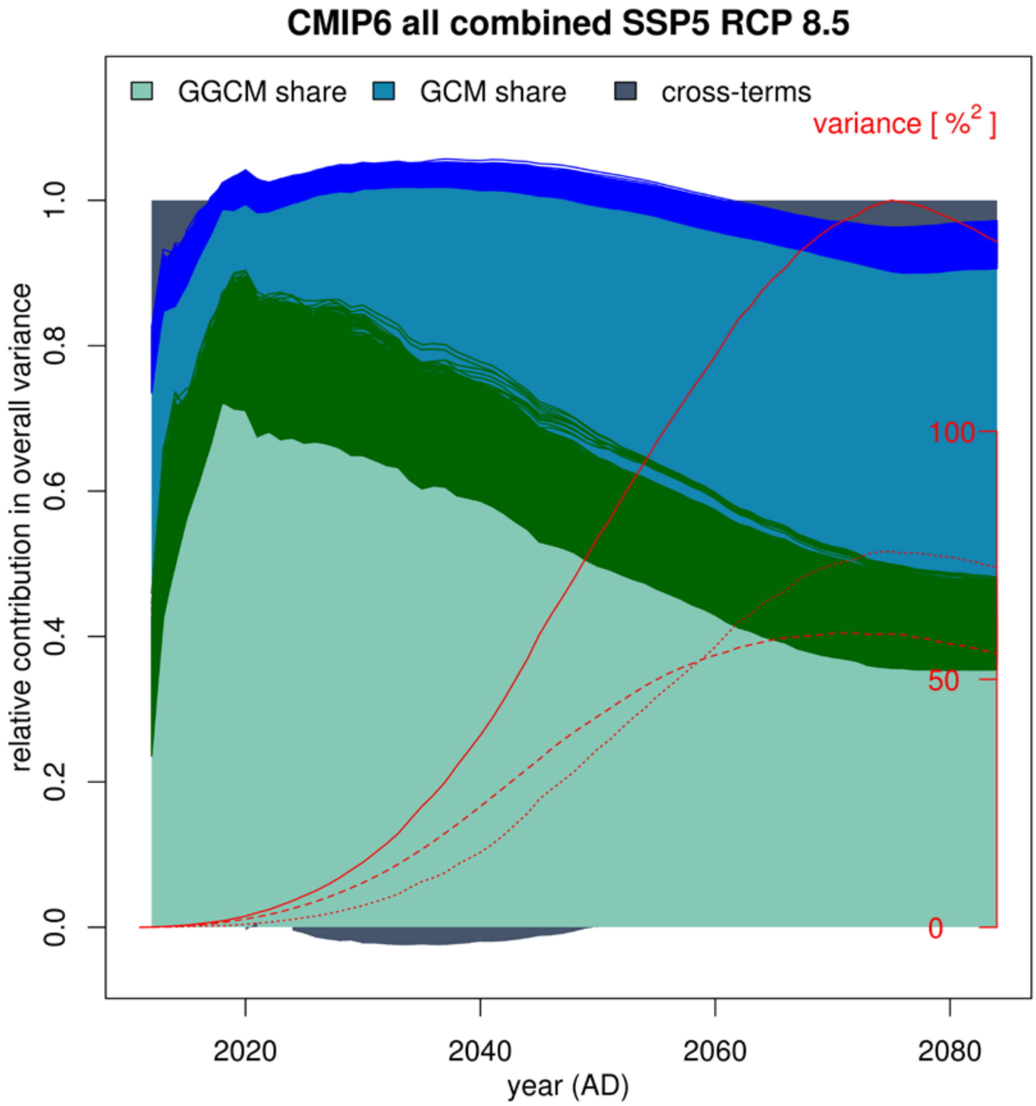


Figure S13: Same as figure 6b in the main text, but instead of excluding individual GGCMs, here 46376 unique 4-GCM combinations of the 34 total CMIP6 GCM ensemble have been excluded. The thin green and blue lines show how the GGCM- and GCM-induced variance shares change if random 4-GCMs are excluded from the ensemble.

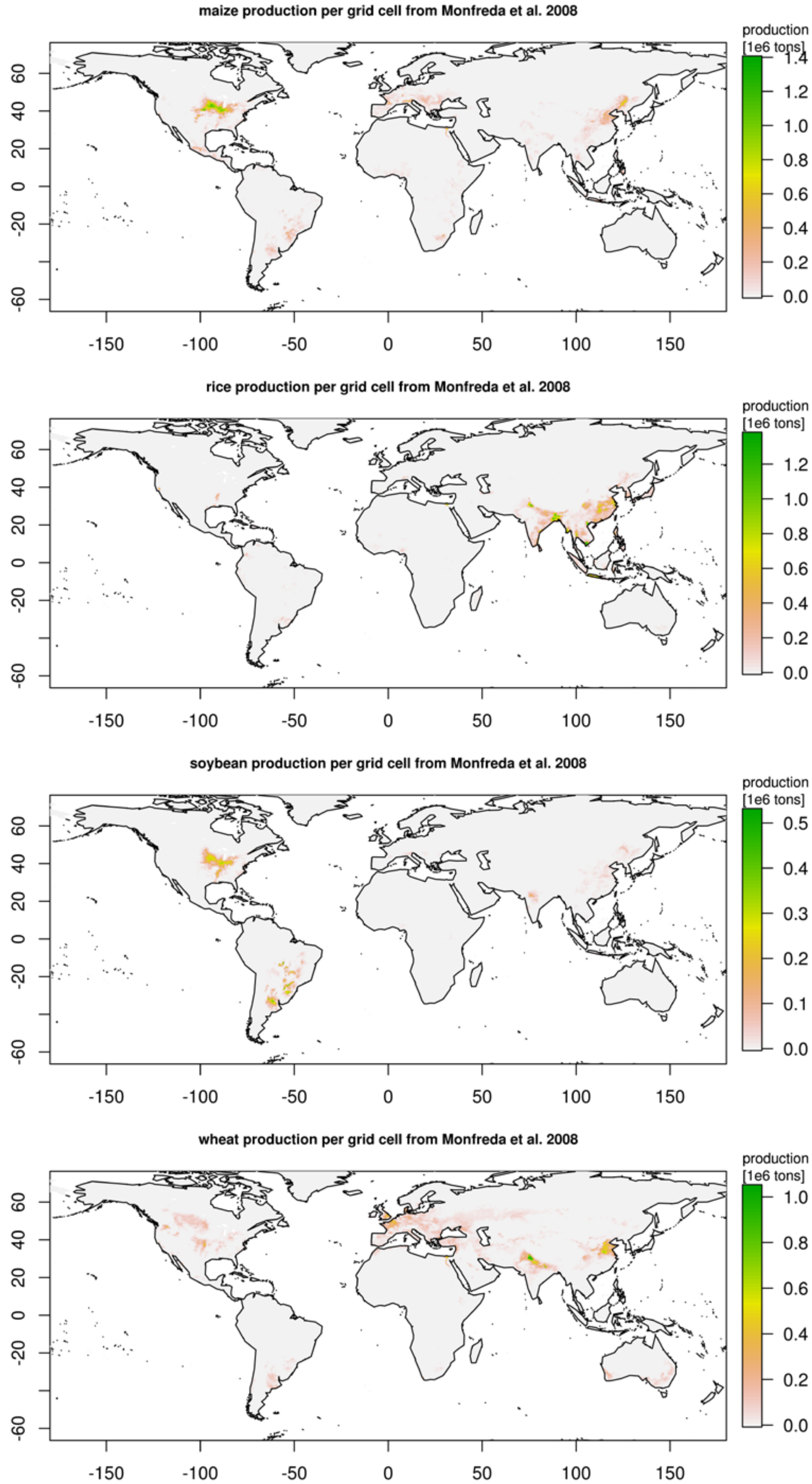


Figure S14: Production per grid cell in million tons. Data from Monfreda *et al.* (2008).

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