Global Biogeochemical Cycles

Supporting Information for

A combined tree-ring and vegetation model assessment of European forest growth sensitivity to inter-annual climate variability

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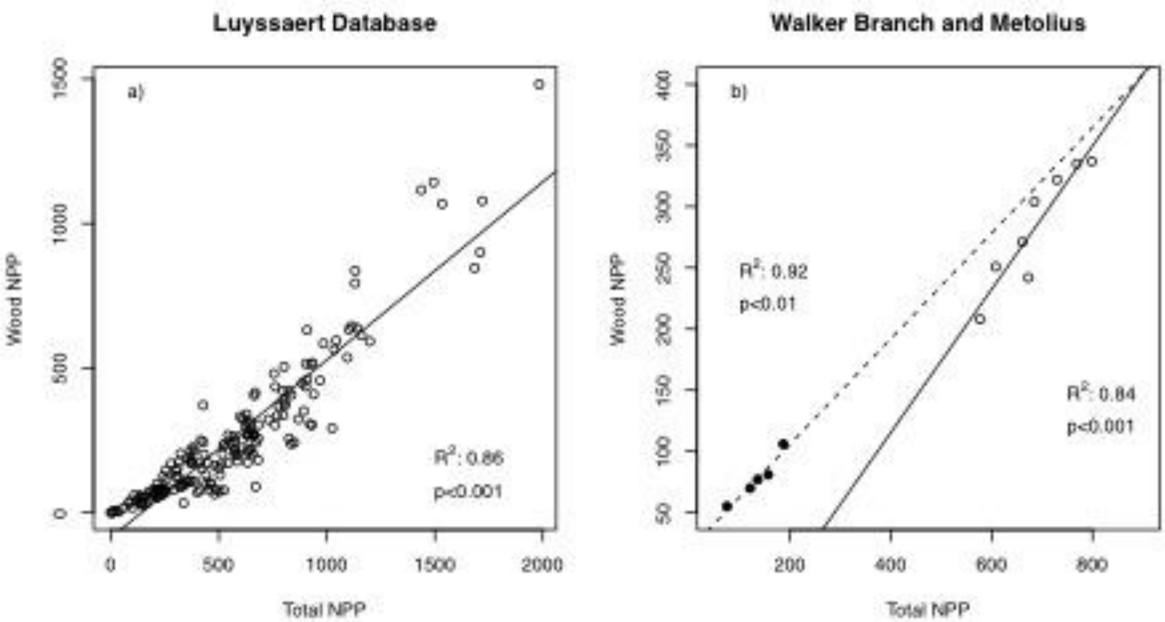

Fig. S1: a) Wood NPP (equal to the ABI metric used in the manuscript) plotted against Total NPP (belowground + wood + foliage) from a global database (Luyssaert et al. 2007). All plots are extratropical >35°N. b) Wood NPP against Total NPP from eight consecutive years of the Walker Branch site (open circles) and Metolius site (closed circles).

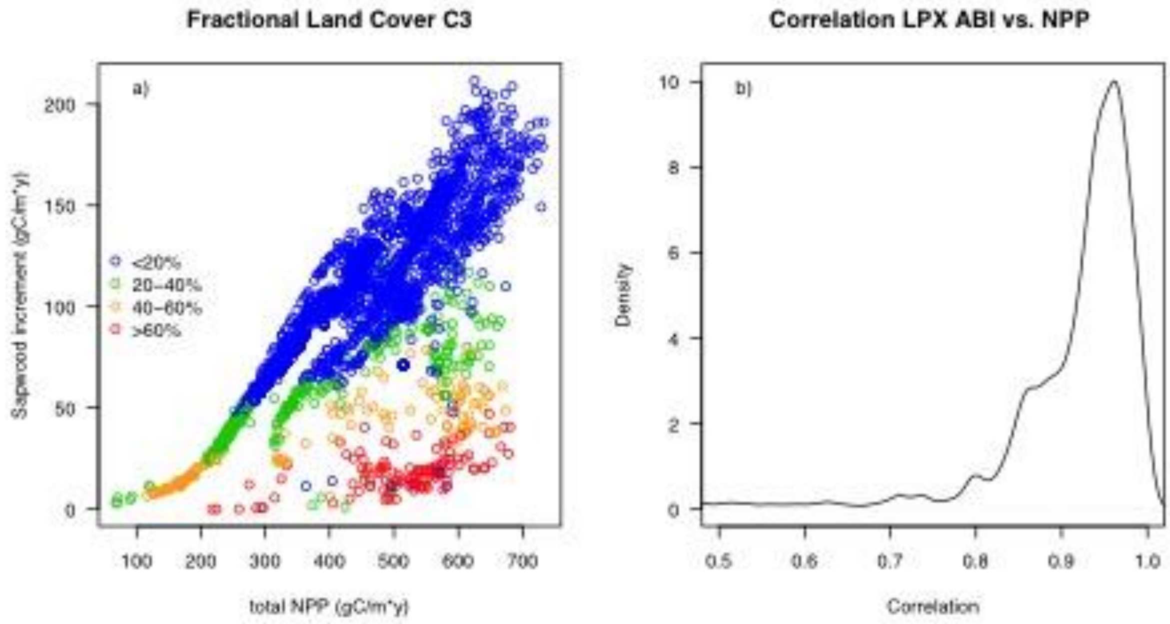

Fig. S2: a) Sapwood increment against total NPP as modeled by LPX. The different colors represent different fractional land cover of C3 grass, with forest dominated grid cells plotted in green and blue. b) Density distribution of correlation between 10-year high-pass filtered sapwood increment and total NPP output of the LPX model at each grid cell.

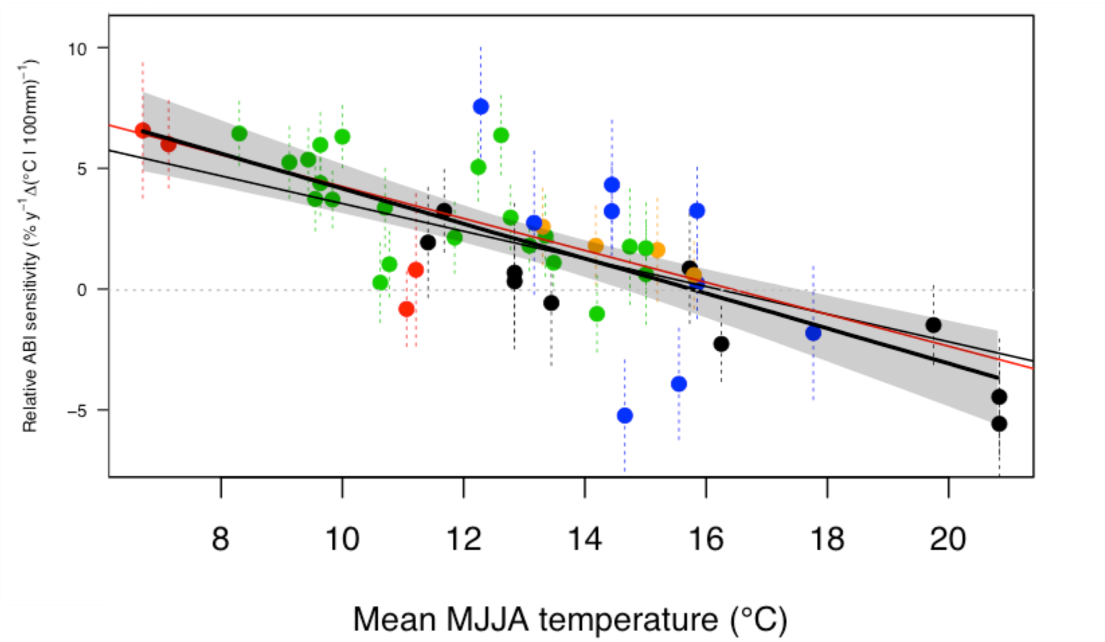

Fig. S3: Sensitivities of ABI to a change of 1°C in MJJA temperature as shown in Figure 2. Colors refer to different dominant species as in Fig. 1. Vertical dotted lines show the standard error of each sensitivity estimate. The thick black line represents the regression line based on robust linear regression. Grey shading indicates the 95% confidence interval after 1000 simulations accounting for uncertainties in the sensitivity values. The thin red and black lines show the regression slopes for the early (1910-1959) and late (1960-2009) period using only data from the 36 plots that span the entire 1910-2009 with more than 5 samples.

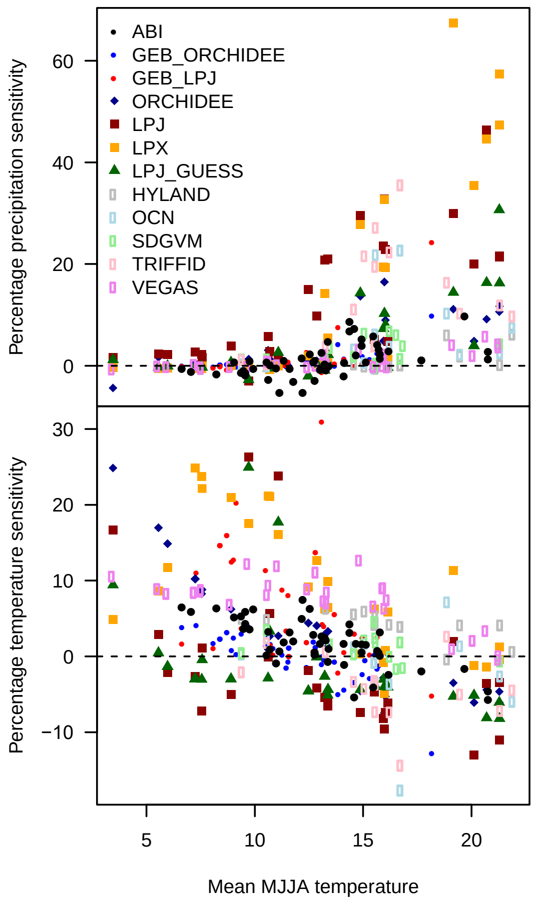

Fig. S4: Climate sensitivities of the ABI chronologies and the subset at tree ring site locations of 11 DGVMs against the mean growing season temperature. DGVM model grid cells were chosen according to the smallest distance between actual tree ring site and grid cell center. The GEB-model cells with the smallest difference in elevation within a 150 km radius around the actual tree ring site coordinates were taken from Babst et al. 2013.

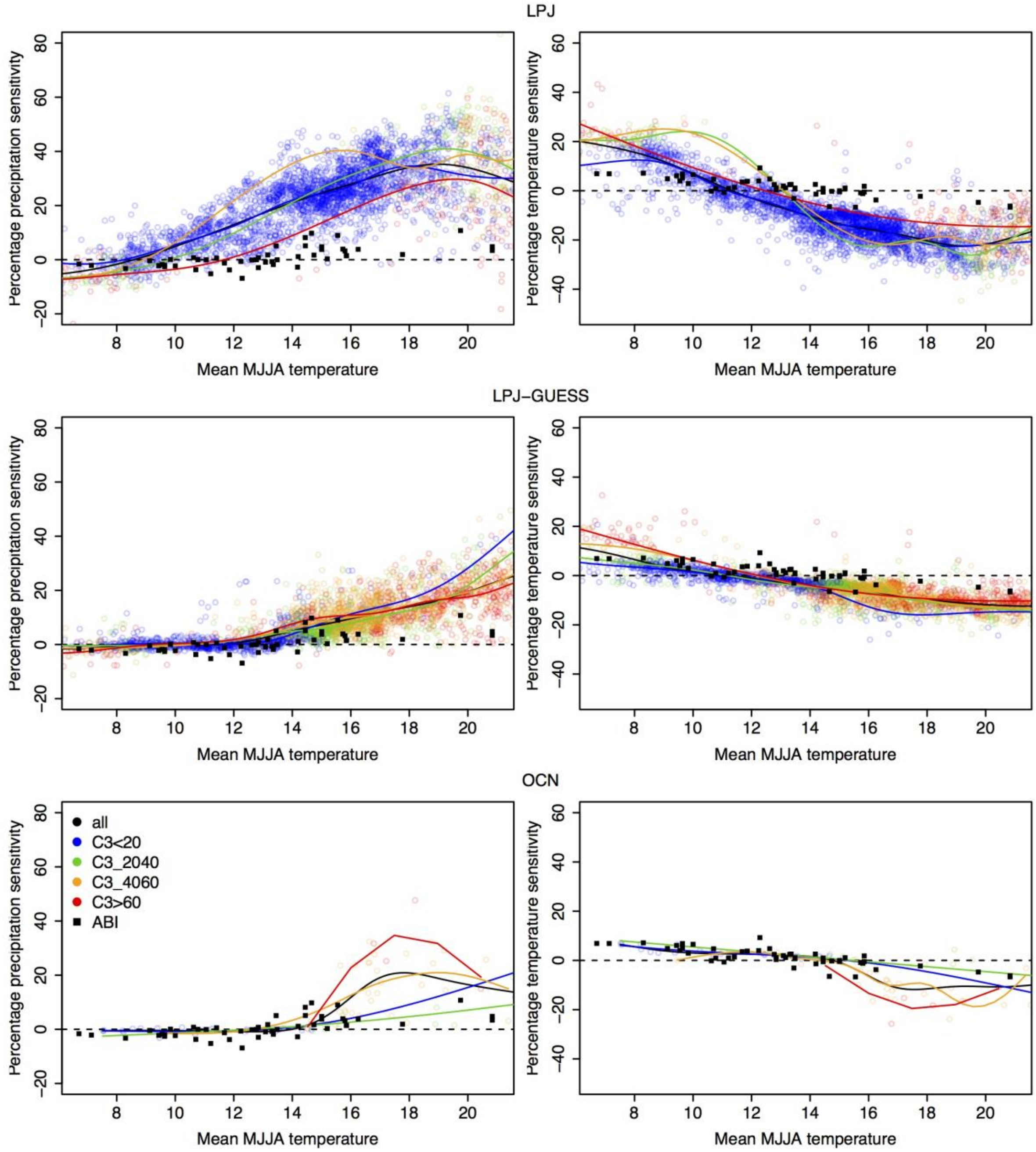

Fig. S5: Percentage precipitation (left) and temperature (right) sensitivities of three DGVMs. Different colors refer to different fractional land cover (FLC) of C3 grass. In the case of OCN the FLC of natural and agricultural C3 grass were summed. Smoothing curves are GAM-splines. The black line refers the mean response of all cells, disregarding FLC of C3. The black squares show the climate sensitivities of the 49 ABI chronologies. Removing cells with FLC_{C3} >20% from the analysis would not change the conclusion for the excessive spread in climate sensitivity of the DGVMs.

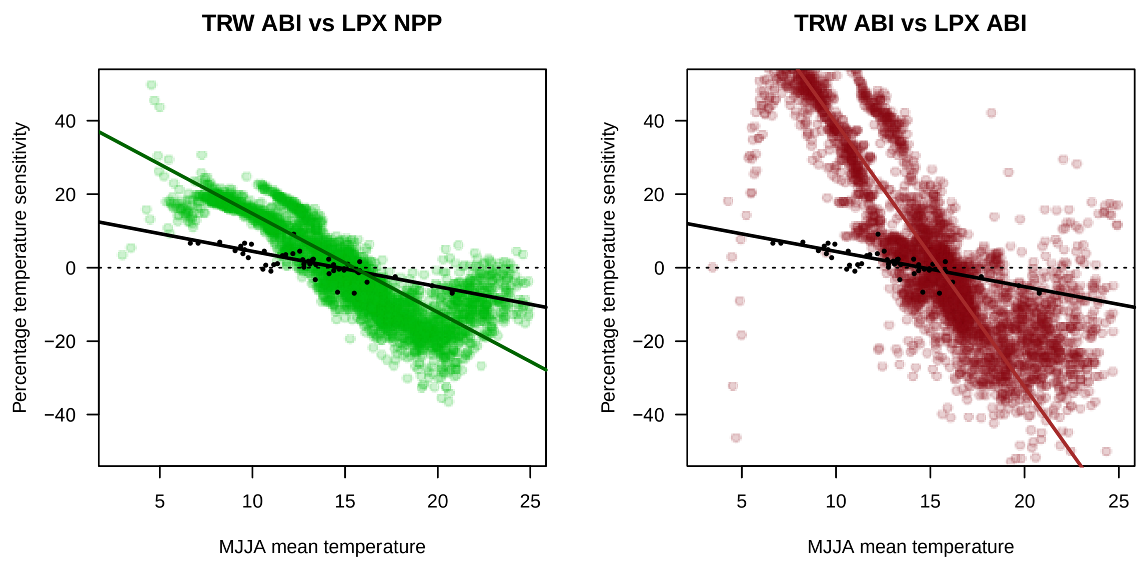

Fig. S6: TRW ABI derived sensitivity estimates (full black circles) and LPX NPP sensitivity estimates (green) against MJJA mean temperature (left panel), TRW ABI and LPX ABI (equivalent to sapwood increment, brown, right panel).

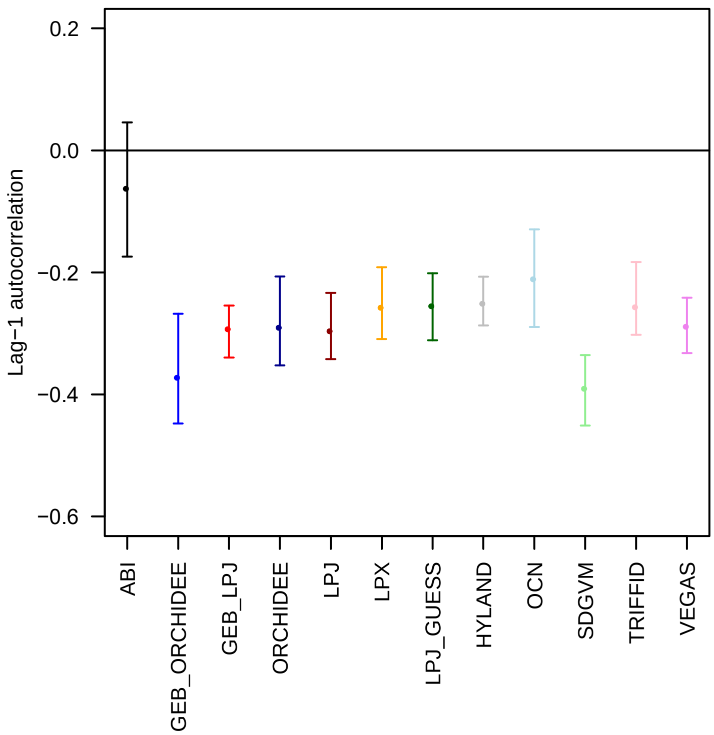

Fig. S7: Lag-1 autocorrelation of ABI chronologies and modeled NPP series. All series were detrended with a cubic smoothing spline with a 50% frequency cut-off at 10 years. Vertical lines denote the interquartile range.

Table S1: Overview of the 49 site and some characteristics (see attached file, due to formatting issues).

Table S2: Biomass equations used for the different tree species to convert tree-ring based diameter information into ABI. See Babst et al. 2014 for a detailed description. For allometric equations requiring tree height, we modeled height based upon the diameter-height relationship at sampling date. Depending on the shape of the observed relationship, the best fit followed either a logarithmic, inverse logarithmic or polynomial shape.

Tree species	**Aboveground biomass (AGB) equations** (unit: kg)	**Reference**
ABAL	$AGB = -2.1386 + 0.018125 * DBH^2 * Height + 1.1089 * DBH$	Tabacchi et al 2011
	$AGB = 0.123691 * DBH^{2.41766}$	Montero et al. 2005
ACPS	$AGB = exp(-2.7606 + 2.5189 * log(DBH))$	Bunce 1968
BEPU	$AGB = exp(-2.4166 + 2.4227 * log(DBH))$	Bunce 1968
CASA	$AGB = 0.1236 * DBH^{2.939}$	Patricio et al. 2005
FASY	$AGB = 0.453 * DBH^{2.139}$	Cienciala et al. 2004
	$AGB = 0.0798 * DBH^{2.601}$	Bartelink 1997
	$AGB = 10^{2.85102+2.0666 * log10(DBH)}/1000$	Duvigneaud & Timperman 1977
	$AGB = 0.1143 * DBH^{2.503}$	Pretzsch 2000
	$AGB = 0.0523 * DBH^{2.12} * Height^{0.655}$	Wutzler et al. 2008
FREX	$AGB = exp(-2.4598 + 2.4882 * log(DBH))$	Bunce 1968
LADE	$AGB = (0.248313 * DBH^{2.111} + 0.000553 * DBH^{3.423} + 0.001770 * DBH^{2.850} + 0.000492 * DBH^{2.912})$	Gower et al. 1993
QUPE	$AGB = -1.56 + 2.44 * log10(DBH)$	Drexhage et al. 2001
PCAB	$AGB = (0.57669 * DBH^{1.964})$	Cerny 2000
	$AGB = (10^{1.81298+2.51353*\log10(DBH)}/1000$	Duvigneaud & Timperman 1977
	$AGB = -43.13 + 2.25 * DBH + 0.452 * DBH^2$	Fiedler 1986
	$AGB = -60.55702 + 5.46558 * DBH + 0.27567 * DBH^2$	Pöppel 1989
PISY	$AGB = (0.1227 * DBH^{2.3272}) + (0.0022 * DBH^{2.913})$	Yuste et al. 2005
	$AGB = (10^{0.981+2.289*log10(\pi*DBH)}/1000$	Brakke 1996
	$AGB = exp(-3.2807 + 2.6931 * log(DBH))$	Mäkelä & Vanninnen 1998
	$AGB = 18.779 - 4.328 * DBH + 0.506 * (DBH^2)$	Briggs & Cunia 1982
	$AGB = exp(-3.215 + 9.764 * ((2 + 1.25 * DBH)/(2 + 1.25 * DBH + 12)) + 2.889 * ((2 + 1.25 * (-2.26 + 4.558 * log(DBH)))/(2 + 1.25 * (-2.26 + 4.558 * log(DBH)) + 12)))$	Repola et al. 2007
PINI & PIBR	$AGB = 0.062873 * DBH^{2.51564}$	Montero et al. 2005
PIPI	$AGB = -0.45885 + 0.025276 * DBH^2 * Height$	Tabacchi et al. 2011
PIPS	$AGB = 1.9539 + 0.020810 * DBH^2 * Height$	Tabacchi et al. 2011
TICO	$AGB = exp(-2.6788 + 2.4542 * log(DBH))$	Bunce 1968
ULGL	$AGB = 0.13 * DBH^{2.49}$	Alberti et al. 2005

Table S4: The set of 11 DGVM used in the present study

DGVM	Resolution	Dataset from	Model description
GEB-ORCHIDEE	Specific coordinates	Babst et al. 2013	Krinner et al. 2005
GEB-LPJ	Specific coordinates	Babst et al. 2013	Sitch et al. 2003
ORCHIDEE	0.5° * 0.5°	Sitch et al. 2015, TRENDY	Krinner et al. 2005
LPJ	0.5° * 0.5°	Sitch et al. 2015, TRENDY	Sitch et al. 2003
LPX	0.5° * 0.5°	This study	Spahni et al. 2013, Stocker et al. 2013
LPJ_GUESS	0.5° * 0.5°	Sitch et al. 2015, TRENDY	Smith et al. 2001
VEGAS	0.5° * 0.5°	Sitch et al. 2015, TRENDY	Zeng et al. 2004
OCN	3.75° * 2.5°	Sitch et al. 2015, TRENDY	Zaehle & Friend 2010
TRIFFID	3.75° * 2.5°	Sitch et al. 2015, TRENDY	Cox 2001
HYLAND	3.75° * 2.5°	Sitch et al. 2015, TRENDY	Levy et al. 2004
SDGVM	3.75° * 2.5°	Sitch et al. 2015, TRENDY	Woodward et al. 1995

Table S4: Median sensitivity differences (in %) and median average deviation (MAD) of the 11 DGVM across Europe (all modeled cells) in comparison to interpolated ABI derived from regression in Fig. 2. These statistics summarize the model minus observed (extrapolated) deviations across the whole of Europe. GEB_ORCHIDEE and GEB_LPJ are Tree-PFT-only models, whereas the other models simulate all PFTs.

Model	Precipitation		Temperature	
	Median difference	MAD	Median difference	MAD
GEB_ORCHIDEE	0.5	±2.37	-2.1	±2.37
GEB_LPJ	-1.3	±2.97	2.5	±4.96
VEGAS	-0.3	±2.07	7.5	±2.67
SDGVM	0.4	±2.37	1.2	±1.78
TRIFFID	8.0	±10.2	-3.4	±5.34
HYLAND	-2.1	±2.67	4.8	±1.48
ORCHIDEE	4.0	±5.04	-1.2	±3.85
OCN	1.3	±4.59	-1.1	±3.26
LPJ_GUESS	2.6	±6.98	-3.6	±2.22
LPJ	17.4	±10.67	-6.1	±4.89
LPX v1.2	17.2	±17.49	3.3	±5.63