Data – Supplement S1 of

Process-oriented models of autumn leaf phenology: ways to sound calibration and implications of uncertain projections

Michael Meier, Christof Bigler
https://doi.org/10.5194/gmd-16-1-2023-supplement

Correspondence to: Michael Meier (michael.meier@cefe.cnrs.fr)

S1 Past climate – GLDAS

We derived daily minimum, mean, and maximum air temperature, net short- and longwave radiation, downwelling shortwave radiation, precipitation, and soil moisture from corresponding 3-hourly weather variables on a 0.25° × 0.25° grid from two NASA global land data assimilation system datasets (GLDAS-2.0 and GLDAS-2.1 for the years 1948–2000 and 2001–2018, respectively; Table S1; Rodell et al., 2004; Beaudoing and Rodell, 2019, 2020). Both applied datasets consist of modelled weather variables derived from the NOAH land surface model Noah-3.6 (Chen et al., 1996; Koren et al., 1999; Chen et al., 2001; Chen and Dudhia, 2001; Ek et al., 2003; Beaudoing and Rodell, 2019, 2020), which was forced with entirely observational (GLDAS-2.0; Sheffield et al., 2006; Carroll et al., 2009; Beaudoing and Rodell, 2019) and combined observational and modelled data (GLDAS-2.1; Derber et al., 1991; Huffman et al., 2001; Adler et al., 2003; Beaudoing and Rodell, 2020). The data was downloaded from Google Earth Engine (Gorelick et al., 2017) in October 2021 via the sampleRegions function for ee.Image objects, which was applied to the coordinates of each site. From the 3-hourly data, we calculated the mean and extracted the minimum or maximum values per day and per site. In these data, temperatures are given in Kelvin [K], which we converted to degree Celsius [°C], and precipitation is given as rate [kg m^{-2} s^{-1}], from the daily mean of which we calculated the daily sum [mm] (Table S2).

Table S1. The applied datasets, full data product name, and digital object identifier (DOI).

Dataset	**Data product name**	**DOI**
GLDAS-2.0	GLDAS Noah Land Surface Model L4 3 hourly 0.25 × 0.25 degree V2.0 (GLDAS_NOAH025_3H_2.0)	10.5067/342OHQM9AK6Q
GLDAS-2.1	GLDAS Noah Land Surface Model L4 3 hourly 0.25 × 0.25 degree V2.1 (GLDAS_NOAH025_3H_2.1)	10.5067/E7TYRXPJKWOQ

Table S2. Daily weather variables for the model drivers and calculations from the corresponding NASA GLDAS-2 variables.

Daily variables for model drivers		**Calculation**	**Base variables from NASA GLDAS-2 (short name*)**	
Variable	**Unit**		**Variable**	**Unit**
Daily minimum air temperature	°C	Daily min. - 273.15 K	Tair_f_inst	K
Daily mean air temperature	°C	Daily mean - 273.15 K	Tair_f_ inst	K
Daily maximum air temperature	°C	Daily max. - 273.15 K	Tair_f_ inst	K
Daily net shortwave radiation	W m^{-2}	Daily mean	Swnet_tavg	W m^{-2}
Daily net longwave radiation	W m^{-2}	Daily mean	Lwnet_tavg	W m^{-2}
Daily downwelling shortwave radiation	W m^{-2}	Daily mean	SWdown_f_tavg	W m^{-2}
Daily precipitation sum	mm	Daily mean × 86400 s	Rainf_tavg	kg m^{-2} s^{-1}
Daily soil moisture content in 0–10 cm	kg m^{-2}	Daily mean	SoilMoi0_10cm_inst	kg m^{-2}
Daily soil moisture content in 10–40 cm	kg m^{-2}	Daily mean	SoilMoi10_40cm_inst	kg m^{-2}
Daily soil moisture content in 40–100 cm	kg m^{-2}	Daily mean	SoilMoi40_100cm_inst	kg m^{-2}
Daily soil moisture content in 100–200 cm	kg m^{-2}	Daily mean	SoilMoi100_200cm_inst	kg m^{-2}
*) inst: Instantaneous values tavg: Backward 3-hour averages				

Note: The latter are 3-hourly data, either instantaneous values or backward 3-hour averages. From these data, the daily mean was calculated or the daily minimum (min.) or maximum (max.) was extracted.

S2 Climate projections – CORDEX

We excluded some climate model chains (CMC) of the CMIP5-based CORDEX-EUR-11 dataset (Jacob et al., 2014) based on entries in the respective errata table and on missing values, and transformed certain variables. After having obtained the entire dataset from the Institute for Atmospheric and Climate Science (IAC, ETH Zurich; August 2021), we consulted the errata table for the dataset (https://www.euro-cordex.net/078730/index.php.en, accessed on 17 February 2022) and excluded problematic CMC or runs. Thereafter, we inspected the remaining CMC for missing values. The omission of site-years with more than 10 missing values per year or more than 1 consecutive missing value led to the exclusion of further entire CMC as well as individual site-years (Table S3). Missing values in the remaining data were linearly interpolated between the previous and following day (Table S4). After controlling against the errata table and for missing values, we remained with 16 and 10 climate model chains for the representative concentration pathways 4.5 and 8.5 (RCP 4.5 and RCP 8.5; Table S5), respectively, with daily data for minimum, mean, and maximum air temperature, precipitation, soil moisture, down- and upwelling short- and longwave radiation. Finally, we converted temperatures from Kelvin [K] to degree Celsius [°C] and precipitation from a rate [kg m^{-2} s^{-1}] to a daily sum [mm]. In addition, we derived daily net short- and longwave radiation by subtracting the daily upwelling radiation from the daily downwelling radiation (Table S6).

Table S3. Number of sites with excluded site-years per species, representative concentration pathway (RCP; 4.5 = RCP45 and 8.5 = RCP85), and climate model chain (CMC).

Species	**RCP**	**CMC**	**NA values**	**Cont. NA values**	**No of site-years**	**Daily weather variables**
Beech	RCP45	CMC9	365	365	4	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP45	CMC14	365	365	4	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP45	CMC16	365	365	4	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC4	365	365	4	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC4	365	365	18	mrso
Beech	RCP85	CMC9	365	365	4	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC9	365	365	18	mrso
Beech	RCP85	CMC10	365	365	4	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC10	365	365	10	mrso
Larch	RCP85	CMC4	365	365	3	mrso
Larch	RCP85	CMC9	365	365	3	mrso
Larch	RCP85	CMC10	365	365	1	mrso
Oak	RCP45	CMC9	365	365	2	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP45	CMC14	365	365	2	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP45	CMC16	365	365	2	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC4	365	365	2	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC4	365	365	17	mrso
Oak	RCP85	CMC9	365	365	2	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC9	365	365	17	mrso
Oak	RCP85	CMC10	365	365	2	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC10	365	365	10	mrso

Note: The maximum number (no) of NA values and of continuous (cont.) NA values per site-year as well as the number of concerned site-years is listed for every combination of species, RCP, and CMC. Daily weather variables are mean, maximum, and minimum near-surface temperature (tas, tasmin, tasmax), precipitation (pr), downwelling and upwelling surface shortwave radiation (rsds and rsus), downwelling and upwelling surface longwave radiation (rlds and rlus), and total soil moisture content (mrso).

Table S4. Number of sites with interpolated data per species, representative concentration pathway (RCP; 4.5 = RCP45 and 8.5 = RCP85), and climate model chain (CMC).

Species	**RCP**	**CMC**	**NA values**	**Cont. NA values**	**No of site-years**	**Daily weather variables**
Beech	RCP45	CMC9	1	1	2389	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP45	CMC14	1	1	2389	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP45	CMC16	1	1	2389	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC4	1	1	2371	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC4	1	1	18	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Beech	RCP85	CMC9	1	1	2371	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC9	1	1	18	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Beech	RCP85	CMC10	1	1	2379	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Beech	RCP85	CMC10	1	1	10	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Larch	RCP45	CMC9	1	1	752	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Larch	RCP45	CMC14	1	1	752	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Larch	RCP45	CMC16	1	1	752	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Larch	RCP85	CMC4	1	1	749	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Larch	RCP85	CMC4	1	1	3	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Larch	RCP85	CMC9	1	1	749	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Larch	RCP85	CMC9	1	1	3	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Larch	RCP85	CMC10	1	1	751	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Larch	RCP85	CMC10	1	1	1	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Oak	RCP45	CMC9	1	1	2317	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP45	CMC14	1	1	2317	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP45	CMC16	1	1	2317	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC4	1	1	2300	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC4	1	1	17	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Oak	RCP85	CMC9	1	1	2300	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC9	1	1	17	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus
Oak	RCP85	CMC10	1	1	2307	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus, mrso
Oak	RCP85	CMC10	1	1	10	tas, tasmax, tasmin, pr, rsds, rsus, rlds, rlus

Note: The maximum number (no) of NA values and of continuous (cont.) NA values per site-year as well as the number of concerned site-years is listed for every combination of species, RCP, and CMC. Daily weather variables are mean, maximum, and minimum near-surface temperature (tas, tasmin, tasmax), precipitation (pr), downwelling and upwelling surface shortwave radiation (rsds, rsus), downwelling and upwelling surface longwave radiation (rlds, rlus), and total soil moisture content (mrso).

Table S5. Applied CORDEX-EUR-11 climate model chains (CMC) for the representative concentration pathways (RCP) 4.5 and 8.5 including modelling run and version (Vrs.).

RCP	**CMC**	**Institution**	**Global climate model**	**Regional climate model**	**Run**	**Vrs.**
RCP45	CMC1	CLMcom	CNRM-CERFACS-CNRM-CM5	CLMcom-CCLM4-8-17	r1i1p1	v1
RCP45	CMC2	CNRM	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN63	r1i1p1	v2
RCP45	CMC3	KNMI	CNRM-CERFACS-CNRM-CM5	KNMI-RACMO22E	r1i1p1	v2
RCP45	CMC4	SMHI	CNRM-CERFACS-CNRM-CM5	SMHI-RCA4	r1i1p1	v1
RCP45	CMC5	CLMcom	ICHEC-EC-EARTH	CLMcom-CCLM4-8-17	r12i1p1	v1
RCP45	CMC6	KNMI	ICHEC-EC-EARTH	KNMI-RACMO22E	r12i1p1	v1
RCP45	CMC7	KNMI	ICHEC-EC-EARTH	KNMI-RACMO22E	r1i1p1	v1
RCP45	CMC8	SMHI	ICHEC-EC-EARTH	SMHI-RCA4	r12i1p1	v1
RCP45	CMC9	SMHI	IPSL-IPSL-CM5A-MR	SMHI-RCA4	r1i1p1	v1
RCP45	CMC10	CLMcom	MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	r1i1p1	v1
RCP45	CMC11	MPI-CSC	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	r1i1p1	v1
RCP45	CMC12	MPI-CSC	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	r2i1p1	v1
RCP45	CMC13	SMHI	MPI-M-MPI-ESM-LR	SMHI-RCA4	r1i1p1	1a
RCP45	CMC14	DMI	NCC-NorESM1-M	DMI-HIRHAM5	r1i1p1	v3
RCP45	CMC15	GERICS	NCC-NorESM1-M	GERICS-REMO2015	r1i1p1	v1
RCP45	CMC16	SMHI	NCC-NorESM1-M	SMHI-RCA4	r1i1p1	v1
RCP85	CMC1	MOHC	CNRM-CERFACS-CNRM-CM5	MOHC-HadREM3-GA7-05	r1i1p1	v2
RCP85	CMC2	SMHI	CNRM-CERFACS-CNRM-CM5	SMHI-RCA4	r1i1p1	v1
RCP85	CMC3	SMHI	ICHEC-EC-EARTH	SMHI-RCA4	r12i1p1	v1
RCP85	CMC4	KNMI	IPSL-IPSL-CM5A-MR	KNMI-RACMO22E	r1i1p1	v1
RCP85	CMC5	KNMI	MPI-M-MPI-ESM-LR	KNMI-RACMO22E	r1i1p1	v1
RCP85	CMC6	MOHC	MPI-M-MPI-ESM-LR	MOHC-HadREM3-GA7-05	r1i1p1	v1
RCP85	CMC7	MPI-CSC	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	r1i1p1	v1
RCP85	CMC8	MPI-CSC	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	r2i1p1	v1
RCP85	CMC9	KNMI	NCC-NorESM1-M	KNMI-RACMO22E	r1i1p1	v1
RCP85	CMC10	MOHC	NCC-NorESM1-M	MOHC-HadREM3-GA7-05	r1i1p1	v1

Table S6. Daily weather variables for the model drivers and how they were calculated from the corresponding CORDEX-EUR-11 daily variables.

Daily variables for model drivers		**Calculation**	**Base variables from CORDEX-EUR-11**	
Variable long name	**Unit**		**Variable name**	**Unit**
Daily minimum air temperature	°C	tasmin. − 273.15 K	tasmin	K
Daily mean air temperature	°C	tas − 273.15 K	tas	K
Daily maximum air temperature	°C	tasmax − 273.15 K	tasmax	K
Daily net shortwave radiation	W m^{-2}	rsds − rsus	-	W m^{-2}
Daily net longwave radiation	W m^{-2}	rlds − rlus	-	W m^{-2}
Daily downwelling shortwave radiation	W m^{-2}		rsds	W m^{-2}
Daily downwelling longwave radiation	W m^{-2}		rlds	W m^{-2}
Daily upwelling shortwave radiation	W m^{-2}		rsus	W m^{-2}
Daily upwelling longwave radiation	W m^{-2}		rlus	
Daily precipitation sum	mm	pr × 86400 s	pr	kg m^{-2} s^{-1}
Daily soil moisture content in 0–10cm	kg m^{-2}		mrso	kg m^{-2}

Note: Daily variables are mean, maximum, and minimum near-surface temperature (tas, tasmin, tasmax), precipitation (pr), downwelling and upwelling surface shortwave radiation (rsds, rsus), downwelling and upwelling surface longwave radiation (rlds, rlus), and total soil moisture content (mrso).

S3 Past and projected atmospheric CO2 concentrations

Past CO_2 concentrations were obtained from the high-resolution CO_2 dataset of the synthesis historical greenhouse gas concentrations for climate modelling (CMIP6) data product for the years 1948–2014 (Meinshausen et al., 2017; downloaded from https://climate-energy-college.org/ghg-factsheets in October 2021) and completed with in situ observations at the Mauna Loa observatory for the year 2015 (Thoning et al., 2021; downloaded from https://gml.noaa.gov/ in October 2021). The former monthly data on a 0.5° latitudinal grid of was interpolated for each site, whereas the latter monthly averages were directly applied. Corresponding projected CO_2 concentrations for the years 2006–2099 were taken from CMIP5 datasets (Meinshausen et al., 2011; downloaded from http://www.pik-potsdam.de/~mmalte/rcps/ in June 2021) matching the RCP4.5 and RCP8.5 scenarios (Smith and Wigley, 2006; Clarke et al., 2007; Riahi et al., 2007; Wise et al., 2009). The yearly data was directly applied.

S4 Leaf area index

The leaf area index (LAI) can be approximated with earth system models, field measurements, or remote sensing methods (Fang et al., 2019; Park and Jeong, 2021). While Park and Jeong (2021) have shown that earth system models tend to overestimate annual mean LAI, the combined spatial and temporal range of field measurements is small if compared to products based on remote sensing (Fang et al., 2019). Fang et al. (2019) further mention NOAA AVHRR data as the only source for global LAI approximations extending back to the 1980s and estimated the lowest error for the LAI3g product (Zhu et al., 2013) if compared to MODIS LAI data. Hence, we derived the monthly LAI averaged over the years 1981–2015 on a 0.25° × 0.25° grid from the GIMMS-LAI3g dataset (version 2; Mao and Yan, 2019; retrieved from NASA Earth Data, https://earthdata.nasa.gov/ on October 8, 2021) and applied it to calculate the past and projected net photosynthesis. To derive the LAI for the coordinates of the phenological observations, we extracted the data with the function extract() from the R package raster (Hijmans, 2021), setting the method to “bilinear” and hence locally interpolating the LAI from the four nearest raster cells.

S5 Volumetric plant-available water capacity

Site-specific soil properties affect the volumetric plant-available water capacity (PAWC; [%]; i.e. the difference between the water holding capacity at field capacity and at wilting point expressed as a fraction of soil layer depth), which influences the effect of water limitation on the net photosynthesis and thus the water deprived net photosynthetic rate. We estimated PAWC for a soil layer depth of 2 m according to two different ISRIC SoilGrids250m datasets (versions 2017-03 and 2.0; Hengl et al., 2017, downloaded from https://data.isric.org/ and https://maps.isric.org/, respectively, in October 2021) with a 250 m × 250 m grid, depending on spatial data availability. On the one hand, we assumed PAWC to be equal to the volumetric available soil water capacity until wilting point at a soil layer depth of 1 m according to the SoilGrids250m 2017-03 dataset. On the other hand, we classified the soil according to the respective clay, sand, and silt fractions, applying the USDA Soil Texture Triangle (Davis and Bennett, 1927) and derived PAWC according to Haxeltine and Prentice (1996, Table 3); Sitch et al. (2000, Table 3); and Sitch et al. (2003, Table 4). The corresponding values for clay, sand, and silt were extracted from the SoilGrids250m 2.0 dataset and for a depth of 60–100 cm. From these two estimates for PAWC, we prioritized the directly extracted values according to SoilGrids250m 2017-03 over the derived values according to soil texture based on SoilGrids250m 2.0 data. We extracted all values from the grid cells where the sites were located. Overall, PAWC was assigned according to SoilGrids250m 2017-03 for 1231 sites and estimated from SoilGrids250m 2.0 data for 1 site.

S6 Utilized data sets – overview

Table S7. The data sets utilized for this research are as follows.

Short Name	Utilized data	Reference	DOI / URL
PEP725	Phenological observations	Templ, B., E. Koch, K. Bolmgren, M. Ungersbock, A. Paul, H. Scheifinger, T. Rutishauser, M. Busto, F. M. Chmielewski, L. Hajkova, S. Hodzic, F. Kaspar, B. Pietragalla, R. Romero-Fresneda, A. Tolvanen, V. Vucetic, K. Zimmermann, and A. Zust. 2018. Pan European Phenological database (PEP725): a single point of access for European data. Int J Biometeorol 62:1109-1113.	10.1007/s00484-018-1512-8 http://www.pep725.eu/ Query details: Main part: Sect. 2.1.1
GLDAS-2.0	Past weather variables	Beaudoing, H., and M. Rodell. 2019. GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree V2.0.in NASA/GSFC/HSL, editor. Goddard Earth Sciences Data and Information Services Center (GES DISC), Greenbelt, Maryland, USA.	10.5067/342OHQM9AK6Q Query details: Supplement S1: Sect. 1
GLDAS-2.1	Past weather variables	Beaudoing, H., and M. Rodell. 2020. GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree V2.1.in NASA/GSFC/HSL, editor. Goddard Earth Sciences Data and Information Services Center (GES DISC), Greenbelt, Maryland, USA.	10.5067/E7TYRXPJKWOQ Query details: Supplement S1: Sect. 1
CMIP6, CO_2	Past atmos-pheric CO_2 concentration	Meinshausen, M., E. Vogel, A. Nauels, K. Lorbacher, N. Meinshausen, D. M. Etheridge, P. J. Fraser, S. A. Montzka, P. J. Rayner, C. M. Trudinger, P. B. Krummel, U. Beyerle, J. G. Canadell, J. S. Daniel, I. G. Enting, R. M. Law, C. R. Lunder, S. O'Doherty, R. G. Prinn, S. Reimann, M. Rubino, G. J. M. Velders, M. K. Vollmer, R. H. J. Wang, and R. Weiss. 2017. Historical green-house gas concentrations for climate modelling (CMIP6). Geoscientific Model Development 10:2057-2116.	10.5194/gmd-10-2057-2017 Query details: Supplement S1: Sect. 3
Mauna Loa, CO_2	Past atmos-pheric CO_2 concentration	Thoning, K. W., A. M. Crotwell, and J. W. Mund. 2021. Atmospheric Carbon Dioxide Dry Air Mole Fractions from continuous measurements at Mauna Loa, Hawaii, Barrow, Alaska, American Samoa and South Pole. 1973-2020, Version 2021-08-09 in G. M. L. G. National Oceanic and At-mospheric Administration (NOAA), editor., Boulder, Colorado, USA.	https://doi.org/10.15138/yaf1-bk21 ftp://aftp.cmdl.noaa.gov/data/greenhouse_gases/co2/in-situ/surface/ Query details: Supplement S1: Sect. 3

Table S7. Continued.

CORDEX-EUR-11	Future weather variables	Jacob, D., J. Petersen, B. Eggert, A. Alias, O. B. Christensen, L. M. Bouwer, A. Braun, A. Colette, M. Deque, G. Georgievski, E. Georgopoulou, A. Gobiet, L. Menut, G. Nikulin, A. Haensler, N. Hempelmann, C. Jones, K. Keuler, S. Kovats, N. Kroner, S. Kotlarski, A. Kriegsmann, E. Martin, E. van Meijgaard, C. Moseley, S. Pfeifer, S. Preuschmann, C. Radermacher, K. Radtke, D. Rechid, M. Rounsevell, P. Samuelsson, S. Somot, J. F. Soussana, C. Teichmann, R. Valentini, R. Vautard, B. Weber, and P. Yiou. 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. Regional Environmental Change 14:563-578.	10.1007/s10113-013-0499-2 Query details: Supplement S1: Sect. 2
CMIP5, CO_2	Future atmospheric CO_2 concentration	Meinshausen, M., S. J. Smith, K. Calvin, J. S. Daniel, M. L. T. Kainuma, J. F. Lamarque, K. Matsumoto, S. A. Montzka, S. C. B. Raper, K. Riahi, A. Thomson, G. J. M. Velders, and D. P. P. van Vuuren. 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change 109:213-241.	10.1007/s10584-011-0156-z Query details: Supplement S1: Sect. 3
GIMMS-LAI3g Version 2	LAI observations	Mao, J., and B. Yan. 2019. Global Monthly Mean Leaf Area Index Climatology, 1981-2015. ORNL DAAC, Oak Ridge, Tennessee, USA.	https://doi.org/10.3334/ORNLDAAC/1653 Query details: Supplement S1: Sect. 4
ISRIC SoilGrids Versions 2017-03 & 2.0	Plant-available water capacity	Hengl, T., J. Mendes de Jesus, G. B. M. Heuvelink, M. Ruiperez Gonzalez, M. Kilibarda, A. Blagotić, W. Shangguan, M. N. Wright, X. Geng, B. Bauer-Marschallinger, M. A. Guevara, R. Vargas, R. A. MacMillan, N. H. Batjes, J. G. B. Leenaars, E. Ribeiro, I. Wheeler, S. Mantel, and B. Kempen. 2017. SoilGrids250m: Global gridded soil information based on machine learning. PLoS One 12:e0169748.	10.1371/journal.pone.0169748 Query details: Supplement S1: Sect. 5

References

Adler, R. F., Huffman, G. J., Chang, A., Ferraro, R., Xie, P.-P., Janowiak, J., Rudolf, B., Schneider, U., Curtis, S., and Bolvin, D.: The version-2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979–present), J. Hydrometeorol., 4, 1147-1167, 2003.

Beaudoing, H. and Rodell, M.: GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree V2.0, Goddard Earth Sciences Data and Information Services Center (GES DISC) [dataset], 10.5067/342OHQM9AK6Q, 2019.

Beaudoing, H. and Rodell, M.: GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree V2.1, Goddard Earth Sciences Data and Information Services Center (GES DISC) [dataset], 10.5067/E7TYRXPJKWOQ, 2020.

Carroll, M. L., Townshend, J. R., DiMiceli, C. M., Noojipady, P., and Sohlberg, R. A.: A new global raster water mask at 250 m resolution, International Journal of Digital Earth, 2, 291-308, 2009.

Chen, F. and Dudhia, J.: Coupling an Advanced Land Surface-Hydrology Model with the Penn State-NCAR MM5 Modeling System. Part I: Model Implementation and Sensitivity, Mon. Weather Rev., 129, 569-585, 10.1175/1520-0493(2001)129<0569:Caalsh>2.0.Co;2, 2001.

Chen, F., Pielke Sr., R., and Mitchell, K.: Development and application of land-surface models for mesoscale atmospheric models: Problems and promises, in: Land Surface Hydrology, Meteorology, and Climate. Observation and Modeling, edited by: Lakshmi, V., Albertson, J., and Schaake, J., Water Science and Application, 3, American Geophysical Union, Washington, DC, 107-135, 2001.

Chen, F., Mitchell, K., Schaake, J., Xue, Y., Pan, H.-L., Koren, V., Duan, Q. Y., Ek, M., and Betts, A.: Modeling of land surface evaporation by four schemes and comparison with FIFE observations, Journal of Geophysical Research: Atmospheres, 101, 7251-7268, https://doi.org/10.1029/95JD02165, 1996.

Clarke, L., Edmonds, J., Jacoby, H., Pitcher, H., Reilly, J., and Richels, R.: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-Report 2.1a of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Department of Energy, Office of Biological & Environmental Research, Washington DC, 2007.

Davis, R. O. E. and Bennett, H. H.: Grouping of soils on the basis of mechanical analysis, United States Department of Agriculture, Washington DC, 1927.

Derber, J. C., Parrish, D. F., and Lord, S. J.: The new global operational analysis system at the National Meteorological Center, Weather and Forecasting, 6, 538-547, 1991.

Ek, M. B., Mitchell, K. E., Lin, Y., Rogers, E., Grunmann, P., Koren, V., Gayno, G., and Tarpley, J. D.: Implementation of Noah land surface model advances in the National Centers for Environmental Prediction operational mesoscale Eta model, Journal of Geophysical Research: Atmospheres, 108, https://doi.org/10.1029/2002JD003296, 2003.

Fang, H., Baret, F., Plummer, S., and Schaepman-Strub, G.: An Overview of Global Leaf Area Index (LAI): Methods, Products, Validation, and Applications, Rev. Geophys., 57, 739-799, 10.1029/2018rg000608, 2019.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., and Moore, R.: Google Earth Engine: Planetary-scale geospatial analysis for everyone, Remote Sens. Environ., 202, 18-27, 10.1016/j.rse.2017.06.031, 2017.

Haxeltine, A. and Prentice, I. C.: BIOME3: An equilibrium terrestrial biosphere model based on ecophysiological constraints, resource availability, and competition among plant functional types, Glob. Biogeochem. Cycle, 10, 693-709, 10.1029/96gb02344, 1996.

Hengl, T., Mendes de Jesus, J., Heuvelink, G. B. M., Ruiperez Gonzalez, M., Kilibarda, M., Blagotić, A., Shangguan, W., Wright, M. N., Geng, X., Bauer-Marschallinger, B., Guevara, M. A., Vargas, R., MacMillan, R. A., Batjes, N. H., Leenaars, J. G. B., Ribeiro, E., Wheeler, I., Mantel, S., and Kempen, B.: SoilGrids250m: Global gridded soil information based on machine learning, PLOS ONE, 12, e0169748, 10.1371/journal.pone.0169748, 2017.

Hijmans, R. J.: raster: Geographic Data Analysis and Modeling. R package version 3.4-13. https://CRAN.R-project.org/package=raster, 2021.

Huffman, G. J., Adler, R. F., Morrissey, M. M., Bolvin, D. T., Curtis, S., Joyce, R., McGavock, B., and Susskind, J.: Global precipitation at one-degree daily resolution from multisatellite observations, J. Hydrometeorol., 2, 36-50, 10.1175/1525-7541(2001)002<0036:GPAODD>2.0.CO;2, 2001.

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L. M., Braun, A., Colette, A., Deque, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kroner, N., Kotlarski, S., Kriegsmann, A., Martin, E., van Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J. F., Teichmann, C., Valentini, R., Vautard, R., Weber, B., and Yiou, P.: EURO-CORDEX: new high-resolution climate change projections for European impact research, Reg. Envir. Chang., 14, 563-578, 10.1007/s10113-013-0499-2, 2014.

Koren, V., Schaake, J., Mitchell, K., Duan, Q.-Y., Chen, F., and Baker, J. M.: A parameterization of snowpack and frozen ground intended for NCEP weather and climate models, Journal of Geophysical Research: Atmospheres, 104, 19569-19585, https://doi.org/10.1029/1999JD900232, 1999.

Mao, J. and Yan, B.: Global Monthly Mean Leaf Area Index Climatology, 1981-2015 [dataset], https://doi.org/10.3334/ORNLDAAC/1653, 2019.

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L. T., Lamarque, J. F., Matsumoto, K., Montzka, S. A., Raper, S. C. B., Riahi, K., Thomson, A., Velders, G. J. M., and van Vuuren, D. P. P.: The RCP greenhouse gas concentrations and their extensions from 1765 to 2300, Climatic Change, 109, 213-241, 10.1007/s10584-011-0156-z, 2011.

Meinshausen, M., Vogel, E., Nauels, A., Lorbacher, K., Meinshausen, N., Etheridge, D. M., Fraser, P. J., Montzka, S. A., Rayner, P. J., Trudinger, C. M., Krummel, P. B., Beyerle, U., Canadell, J. G., Daniel, J. S., Enting, I. G., Law, R. M., Lunder, C. R., O'Doherty, S., Prinn, R. G., Reimann, S., Rubino, M., Velders, G. J. M., Vollmer, M. K., Wang,

R. H. J., and Weiss, R.: Historical greenhouse gas concentrations for climate modelling (CMIP6), Geosci. Model Dev., 10, 2057-2116, 10.5194/gmd-10-2057-2017, 2017.

Park, H. and Jeong, S.: Leaf area index in Earth system models: how the key variable of vegetation seasonality works in climate projections, Environ. Res. Lett., 16, 17, 10.1088/1748-9326/abe2cf, 2021.

Riahi, K., Grübler, A., and Nakicenovic, N.: Scenarios of long-term socio-economic and environmental development under climate stabilization, Technological Forecasting and Social Change, 74, 887-935, https://doi.org/10.1016/j.techfore.2006.05.026, 2007.

Rodell, M., Houser, P. R., Jambor, U., Gottschalck, J., Mitchell, K., Meng, C. J., Arsenault, K., Cosgrove, B., Radakovich, J., Bosilovich, M., Entin, J. K., Walker, J. P., Lohmann, D., and Toll, D.: The global land data assimilation system, Bull. Amer. Meteorol. Soc., 85, 381-394, 10.1175/bams-85-3-381, 2004.

Sheffield, J., Goteti, G., and Wood, E. F.: Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling, J. Clim., 19, 3088-3111, 10.1175/jcli3790.1, 2006.

Sitch, S., Prentice, I. C., Smith, B., Cramer, W., Kaplan, J. O., Lucht, W., Sykes, M. T., Thonicke, K., and Venevsky, S.: LPJ - A Coupled Model Of Vegetation Dynamics And The Terrestrial Carbon Cycle. https://www.researchgate.net/publication/37456884, 2000.

Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J. O., Levis, S., Lucht, W., Sykes, M. T., Thonicke, K., and Venevsky, S.: Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model, Global Change Biology, 9, 161-185, 10.1046/j.1365-2486.2003.00569.x, 2003.

Smith, S. J. and Wigley, T. M. L.: Multi-gas forcing stabilization with Minicam, The Energy Journal, 2006.

Thoning, K. W., Crotwell, A. M., and Mund, J. W.: Atmospheric Carbon Dioxide Dry Air Mole Fractions from continuous measurements at Mauna Loa, Hawaii, Barrow, Alaska, American Samoa and South Pole. 1973-2020, Version 2021-08-09 [dataset], https://doi.org/10.15138/yaf1-bk21, 2021.

Wise, M., Calvin, K., Thomson, A., Clarke, L., Bond-Lamberty, B., Sands, R., Smith, S. J., Janetos, A., and Edmonds, J.: Implications of Limiting CO2 Concentrations for Land Use and Energy, Science, 324, 1183-1186, doi:10.1126/science.1168475, 2009.

Zhu, Z. C., Bi, J., Pan, Y. Z., Ganguly, S., Anav, A., Xu, L., Samanta, A., Piao, S. L., Nemani, R. R., and Myneni, R. B.: Global Data Sets of Vegetation Leaf Area Index (LAI)3g and Fraction of Photosynthetically Active Radiation (FPAR)3g Derived from Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI3g) for the Period 1981 to 2011, Remote Sens., 5, 927-948, 10.3390/rs5020927, 2013.