Dear Prof. Carlson,

Thank you for handling our manuscript and for your patience with us. We have had several delays in revising the paper 1) because of the current situation with everybody being at home etc. and 2) because we found one error in the tree dataset for the stand Soro. It took us quite some time to get this fixed and we had to add more expertise on reconstructing data from tree rings. This is why we have added a new co-author, Flurin Babst. Other than that, we have made all changes requested by the reviewers and replied to their comments. We have also fixed a few minor issues, spelling mistakes etc. in the database and the paper which are documented in a change log available on the DOI landing page.

Thank you for giving us the opportunity to resubmit our work to ESSD!

On behalf of all co-authors

Christopher Reyer

Reviewer 1:

Current topic, meeting the need for having comprehensive modelling data sets within structured database (PROFOUND DB) and R-package (ProfoundData), providing opportunity for more simple reproduction of modelling results. Database is particularly valuable in the sense that provide excellent bases for implementation of different modelling approaches using range of environmental variables (soil, climate, forest stand and remote sensing data). R-package is allowing exploration, ploting, extraction of the data, calibration and evaluation of modelling results, which can be useful. Provided long climate time-series together all relevant modelling data are general advantage.
Manuscript is written quite precisely. It includes large amount of relevant information regarding modelling forest pilot plots. It fully satisfies the form of technical data paper. It is acceptable to remain published in current form.
Reply: Thanks for your constructive attitude and for seeing the value of our paper.

Page 18 Line 16,17 – “NO3” and “NH4”, numbers should be in subscript, as it is in other text.

Reply: Thanks for spotting, changed.

Page 20 Line 3,4 - “20th”, “21st”, st in superscript.

Reply: Thanks for spotting, changed.

Table 4. - adjust cell values in uniform way

Reply: Thanks for spotting, changed.

Reviewer 2:

This database is very well presented and I have only three smallish comments, although the first and second ones are important.

Reply: Thanks for your constructive attitude and for seeing the value of our paper.

There is no mention either in the manuscript title neither in the abstract that this is a database for Europe forests only. I strongly suggest that this comes indicated in the manuscript title and abstract.

Reply: Thanks, very good point: We have changed the title into: "The PROFOUND database for evaluating vegetation models and simulating climate impacts on European forests"

And also adjusted the third sentence of the abstract to include a mentioning of Europe: "The PROFOUND Database (PROFOUND DB) provides a wide range of empirical data on European forests to calibrate and evaluate vegetation models that simulate climate impacts at the forest stand scale."

How does this dataset differentiate from other datasets of its kind for DGVM evaluation, such as ILAMB (Collier et al. 2018 JAMES)?

Reply: This is an interesting point. Actually, in terms of the scope - providing data for thorough model evaluation ready to be used by modellers alongside a software packet etc - it is very similar. However, the crucial difference is that our dataset is focussing on the forest stand scale and hence aims at presenting most data at that scale while ILAMB and related databases and tools are global in scope. Additionally, we provide long-term and detailed measurements of forest stand structure which is not available in global datasets.

P5L6: hydrological cycle is also a biogeochemical cycle, so why the differentiation?

Reply: Good point, we removed "hydrological and"

Apart from that this is a high quality and useful database.

Reply: Thanks again for your constructive attitude!

The PROFOUND database for evaluating vegetation models and simulating climate impacts on European forests

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Abstract

Process-based vegetation models are widely used to predict local and global ecosystem dynamics and climate change impacts. Due to their complexity, they require careful parameterization and evaluation to ensure that projections are accurate and reliable. The PROFOUND Database (PROFOUND DB) provides a wide range of empirical data on European forests to calibrate and evaluate vegetation models that simulate climate impacts at the forest stand scale. A particular advantage of this database is its wide coverage of multiple data sources at different hierarchical and temporal scales, together with environmental driving data as well as the latest climate scenarios. Specifically, the PROFOUND DB provides general site descriptions, soil, climate, CO_2, nitrogen deposition, tree and forest stand-level, as well as remote sensing data for nine contrasting forest stands distributed across Europe. Moreover, for a subset of five sites, time series of carbon fluxes, atmospheric heat conduction, and soil water are also available. The climate and nitrogen deposition data contain several datasets for the historic period and a wide range of future climate change scenarios following the Representative Concentration Pathways (RCP2.6, RCP4.5, RCP6.0, RCP8.5). We also provide pre-industrial climate simulations that allow for model runs aimed at disentangling the contribution of climate change to observed forest productivity changes. The PROFOUND DB is available freely as a 'SQLite' relational database or 'ASCII' flat file version (at http://doi.org/10.5880/PIK.2020.006/, Reyer et al., 2020). The data policies of the individual, contributing datasets are provided in the metadata of each data file. The PROFOUND DB can also be accessed via the ProfoundData R-package (https://CRAN.R-project.org/package=ProfoundData, Silveyra Gonzalez et al., 2020), which provides basic functions to explore, plot, and extract the data for model set-up, calibration and evaluation.

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Keywords:

climate change, forest models, model validation, multiple constraints, process-based models, benchmarking, calibration

1. Copyright statement

To be included by Copernicus

2. Introduction

Process-based models are key tools for understanding systems and forecasting climate change impacts in ecology and Earth system science (Schellnhuber, 1999). Vegetation is a crucial component of the Earth system, and forests are particularly relevant through their influence on hydrological and biogeochemical cycles, biodiversity and ecosystem services. Process-based vegetation models are used as diagnostic tools to disentangle the influence of different environmental and human drivers on biogeochemical cycling as well as vegetation structure from local, plot-level (Eastaugh et al., 2011; Fontes et al., 2010; Pretzsch et al., 2015; Tiktak and van Grinsven, 1995) to global scales (Chang et al., 2017; Ito et al., 2017). At the same time these models are also the main tools to project climate change impacts on vegetation under changing environmental conditions, again from local (Reyer 2015; Rötzer et al., 2013) to global levels (Zhu et al., 2016).

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With increasing model complexity, the inclusion of more and more processes and models being increasingly used to as tools for making quantitative projections for policy and management, there is a strong need to install some quality control on their performance. A basic requirement would be that models are actually able to match observed data. Moreover, while informal methods for calibration and model comparisons were often used in the past, the community has shifted in recent years towards more formal statistical methods for such tasks (Dietze et al., 2013; Hartig et al., 2012), which creates a need for systematic benchmarking data. For all these tasks, the availability of a wide range of data types crossing different spatial-temporal scales is generally viewed as beneficial (Grimm and Railsback, 2012).

The process of formal calibration, comparison and evaluation of complex vegetation models is often hindered by the availability and the harmonization of suitable data. The data necessary to drive a vegetation model is often complex, and needs to be compiled from different data sources (e.g. Bagnara et al., 2019). In particular for model comparisons, besides data for the evaluation of individual models, common input and driving data for process-based vegetation models are needed to ensure fair comparisons between the participating models. Although model comparisons have a long tradition in vegetation modeling (Cramer et al., 1999, 2001; Bugmann et al., 1996, Morales et al., 2005), they have often been limited by overall data availability and comparability. Common databases that are ready-to-use for thorough model evaluation would allow the community to gain a better appreciation of model differences, explore structural uncertainties, and provide a basis for more systematic ensemble projections of climate impacts.

Recently, several initiatives have started compiling model evaluation, input or driving data for a wide range of applications of process-based vegetation models (Huntzinger et al., 2013; Kelley et al., 2013; Warszawski et al., 2014; Sitch et al., 2015). Although these initiatives have leveraged important scientific progress, many of them have focussed on the global scale, mostly providing input and driving data from global products. Such global products generally lack the breadth and depth of process-level detail required to rigorously assess model performance. The database for the project "Towards robust PROjections of european FOrests UNDer climate change" (hereafter PROFOUND DB) described here, aims to bring together data from a wide range of data sources to evaluate vegetation models and simulate climate impacts at the forest stand scale. It has been designed to fulfil two objectives:

- To allow for a thorough evaluation of complex, process-based vegetation models using multiple data streams covering a range of processes at different temporal scales
- To allow for climate impact assessments by providing the latest climate scenario data.

The PROFOUND DB only provides data for individual forest stands but contains a number of elements that are designed to foster comparison of both global/regional models and local models. The climate data, for example, are provided locally (or bias-corrected using local data) in the same way that stand-scale vegetation models would need them and also extracted from global gridded datasets that global vegetation models would use. The PROFOUND DB is also designed to allow for disentangling of uncertainties that affect quantitative model predictions in ecology (cf. Lindner et al., 2014; Dietze, 2017 for an explanation of different uncertainty types), for example by facilitating standardized evaluations of structural or process uncertainties via model comparisons. Model input and driver uncertainty are addressed through a wide range of climate data from different sources, covering the full range of Representative Concentration Pathways (RCPs). Collalti et al. (2018, 2019) for example, have used the PROFOUND DB to study the effects of thinning on carbon use efficiency across a combination of all four RCPs and five Global Climate Models. Finally, parametric uncertainty can be assessed through the wide range of data that can be used for inverse calibration. In the following we describe the main components of the PROFOUND DB (Reyer et al., 2020) and an R-Package (Silveyra Gonzalez et al., 2020) developed to explore the database and allow rapid and easy access for modellers.

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3. The PROFOUND database

3.1. Forest Site Selection and Concept

The forest sites featured in the PROFOUND DB were selected to provide a wide array of data sources across a European gradient. We focussed in particular on providing long time series of tree- and stand-level growth and yield as well as carbon cycle data available from eddy-flux measurements because these variables are most commonly in calibrating and evaluating process-based vegetation models. The selected sites spread along a wide climatic gradient across Europe (Figure 1, Table 3) and cover some of the most common European forest types, as well as the main central European forest management history of favouring mono-specific, even-aged forests or mixtures of two tree species.

We compiled the data from existing data sources and collected the definitions of variables, their units and information about the main measurement methods from the site principal investigators (PIs) and from official descriptions of the data to harmonize the variables as much as possible. The overall guiding principle for the compilation of the data was to provide data that can be easily used by modellers for setting up and evaluating their models. In order to allow for data uncertainty to be reflected in model calibration studies, we also included uncertainty estimates for the measured data, such as those available for carbon flux measurements (cf. Sect.3.2.9), wherever possible.

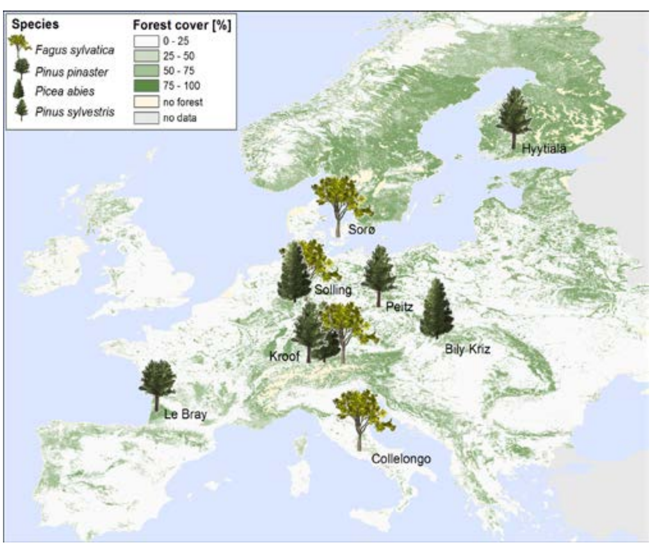

Figure 1: Location of forest sites and main tree species. Background shows the European forest cover after Brus et al. (2012).

3.2. Data sources

The PROFOUND DB provides information on the site, soil, and forest stand as well as data for climate, atmospheric CO_2 concentration, nitrogen deposition, carbon fluxes, atmospheric heat conduction, and remote sensing at a range of different temporal resolutions (i.e., from 30 minutes to decadal measurements). Table 1 provides an overview of the different data types and their temporal resolution available in the PROFOUND DB. All variables available are listed in the SOM tables 1-13. In the following we describe how the individual subdatasets of the PROFOUND DB have been brought together and describe the key variables and characteristics of each dataset.

Table 1: Overview of the data available in the PROFOUND DB. The years indicate the first and the last year for which data is available except for once-off measurements. The superscript letters indicate the temporal resolution of the data: O = one-off measurement(s), M = 30-min measurements; D = daily measurements; C = 8-day or 16-day composite, A = annual measurements.

	Bily Kriz	Collelongo	Hyytiälä	KROOF	Le Bray	Peitz	Solling	Sorø
Soil	2011^{O}	1995/2008^{O}	1995/1996^{O}	2003/2004^{O}	1995/2003/ 2004/2005^{O}	2011^{O}	2010^{O}	1997/2004/ 2006^{O}
Local climate	2000-2008^{D}	1996-2014^{D}	1996-2014^{D}	1998-2010^{D}	1996-2008^{D}	1901-2010^{D}	1960-2013^{D}	1996-2012^{D}
Reanalysis climate	1901-2012^{D}	1901-2012^{D}	1901-2012^{D}	1901-2012^{D}	1901-2012^{D}	1901-2012^{D}	1901-2012^{D}	1901-2012^{D}
Climate scenarios (ISIMIP2b)	1661-2299^{D}	1661-2299^{D}	1661-2299^{D}	1661-2299^{D}	1661-2299^{D}	1661-2299^{D}	1661-2299^{D}	1661-2299^{D}
Climate scenarios (ISIMIPFT)	1950-2099^{D}	1950-2099^{D}	1950-2099^{D}	1950-2099^{D}	1950-2099^{D}	1950-2099^{D}	1950-2099^{D}	1950-2099^{D}
Atmospheric CO_2	1765-2500^{A}	1765-2500^{A}	1765-2500^{A}	1765-2500^{A}	1765-2500^{A}	1765-2500^{A}	1765-2500^{A}	1765-2500^{A}
Nitrogen deposition (ISIMIP2b)	1861-2100^{A}	1861-2100^{A}	1861-2100^{A}	1861-2100^{A}	1861-2100^{A}	1861-2100^{A}	1861-2100^{A}	1861-2100^{A}
Nitrogen deposition (EMEP)	1980-2014^{A}	1980-2014^{A}	1980-2014^{A}	1980-2014^{A}	1980-2014^{A}	1980-2014^{A}	1980-2014^{A}	1980-2014^{A}
Forest tree data	1997-2015^{A}	1992-2012^{A}	2001-2008^{A}	1997-2010^{A}	-	1948-2011^{A}	1967-2014^{A}	1994-2017^{A}
Forest stand data	1997-2015^{A}	1992-2012^{A}	1995-2011^{A}	1997-2010^{A}	1986-2009^{A}	1937-2011^{A}	1967-2014^{A}	1994-2017^{A}
MODIS	2000-2014^{C}	2000-2014^{C}	2000-2014^{C}	2000-2014^{C}	2000-2014^{C}	2000-2014^{C}	2000-2014^{C}	2000-2014^{C}
Flux	2000-2008^{M}	1996-2014^{M}	1996-2014^{M}	-	1996-2008^{M}	-	-	1996-2012^{M}
Meteorological	2000-2008^{M}	1996-2014^{M}	1996-2014^{M}	-	1996-2008^{M}	-	-	1996-2012^{M}
Atmospheric heat conduction	2000-2008^{M}	1996-2014^{M}	1996-2014^{M}	-	1996-2008^{M}	-	-	1996-2012^{M}
Soil flux series	2000-2008^{M}	1996-2014^{M}	1996-2014^{M}	-	1996-2008^{M}	-	-	1996-2012^{M}

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3.2.1. Site information

For each forest site, the PROFOUND DB contains information on general site characteristics such as coordinates, elevation and forest type (Table 2). There is also information on the potential natural vegetation and main tree species belonging to the regional flora (not shown).

Table 2: Overview of the main site characteristics provided for each forest site in the PROFOUND DB.

Name	Lat	Lon	Country	Aspect (°)	Elevation (m.a.s.l.)	Slope (%)	FAO Soil type*	Main tree species
Bily Kriz	49.30	18.32	CZ	180	875	12.5	Haplic Podzol	*Picea abies*
Collelongo	41.85	13.59	IT	252	1560	10	Dystric Luvisol	*Fagus sylvatica*
Hyytiälä	61.85	24.29	FI	180	185	2	Haplic Podzol	*Pinus sylvestris, Picea abies*
KROOF	48.25	11.40	DE	1.8	502	2.1	Luvisol	*Picea abies, Fagus sylvatica*
Le Bray	44.72	-0.77	FR		61	0	Arenosol	*Pinus pinaster*
Peitz	51.92	14.35	DE		50	0	Dystric Cambisol	*Pinus sylvestris*
Solling (beech)	51.77	9.57	DE	225	504	1	Haplic Cambisol	*Fagus sylvatica*
Solling (spruce)	51.76	9.58	DE	90	508	1	Haplic Cambisol (dystric, densic)	*Picea abies*
Sorø	55.49	11.64	DK		40	0	Alfisols/Molisols**	*Fagus sylvatica*

*according to ISSS-ISRIC-FAO (1998).

**depending on base saturation under or over 50% with a 10-40 cm deep organic layer (cf. Pilegaard et al. 2003)

3.2.2. Soil data

The description of the soil profiles contains information about physical and chemical properties of each soil horizon including the organic layer. Unfortunately the soil data are very heterogeneous for the sites and considerable amounts of data are missing. In order not to lose the data that is available for only a subset of sites, we did not harmonize the individual variables but for each site provide the soil data in a consistent format. Despite these limitations, for most sites important soil data such as the depth of horizons, soil texture, bulk density, field capacity, wilting point, carbon and nitrogen content and pH of the soil solution are available (cf. SOM Table 2).

3.2.3. Local climate

For every site we compiled the locally observed daily meteorological data, either from measurement towers or from nearby meteorological stations. These time series cover the main climatic variables required by vegetation models and different time periods for each site (Table 3). They represent the best possible climate information for each site and are most suitable for model simulations comparing simulation output to observations.

3.2.4. Reanalysis products

In order to cover longer historical time periods and to assess uncertainties due to the choice of different climate inputs, the PROFOUND DB also provides long historical daily climate time series for each of the sites extracted from four different global reanalysis/observational products:

- Princeton's Global Meteorological Forcing Dataset (PGMFD v.2, hereafter Princeton) from 1901-2012 by Sheffield et al. (2006)
- Global Soil Wetness Project Phase 3 (GSWP3) from 1901-2010 by Kim (Personal Communication, http://hydro.iis.u-tokyo.ac.jp/GSWP3/)
- Water and Global Change programme (WATCH) from 1901-2001 by Weedon et al. (2011)
- WATCH-Forcing-Data-ERA-Interim (WFDEI) from 1901-2010 by Weedon et al. (2014)

Climate variables for the forest stands were extracted from the 0.5° x 0.5° grid cell of the global reanalysis/observational product in which the forest stand is located. The data is then kept at the original 0.5° x 0.5° resolution to allow for comparing the effects of choosing climate inputs for a vegetation model from a global reanalysis product as opposed to the local data presented in Sect. 3.2.3. The difference between the local data and the reanalysis data is most obvious for those sites located in complex, hilly terrain such as Collelongo or KROOF (Table 2). In these hilly locations the grid box average heights of the reanalysis products differ substantially from the heights of the site measurements.

Table 3. Averages of the daily maximum temperature (Tmax), daily minimum temperature (Tmin), daily mean temperature (Tmean), annual precipitation sum (P), daily mean relative humidity (RH), daily mean air pressure (AP), annual sum of global radiation (R, direct + diffuse shortwave radiation), and daily mean wind speed (W) for each of the sites in the PROFOUND DB from 5 different sources: a locally observed climate and four different global reanalysis/observational products (GSWP3, Princeton, WATCH, WFDEI). The column "Year" indicates the years for which the mean climates have been calculated for the different sources. Please note that the two Solling sites have the same climate.

Site	Source	Years	Tmax [°C]	Tmean [°C]	Tmin [°C]	P [mm]	RH [%]	AP [hPa]	R [J cm^{-2}]	W [m s^{-1}]
	local	2000-2008	11.50	7.36	3.80	1434.56	81.99	913.19	378774.86	2.19
	GSWP3	2000-2008	12.65	7.66	3.03	1034.22	76.77	957.64	395464.73	3.71
	Princeton	2000-2008	12.47	7.67	2.85	914.89	78.77	960.22	402658.93	3.12
Bily Kriz	WATCH	2000-2001	12.72	8.25	3.43	1124.52	75.08	948.34	322865.69	2.05
	WFDEI	2000-2008	12.43	7.66	2.81	1034.40	76.22	950.08	438978.13	3.25
	local	1996-2014	11.46	7.24	3.46	1178.62	74.03	849.59	541888.38	1.73
	GSWP3	1996-2010	20.64	15.12	10.46	977.40	68.42	903.78	530247.74	3.83
	Princeton	1996-2012	20.28	15.17	10.09	757.99	73.76	944.66	539045.09	4.55
	WATCH	1996-2001	20.57	15.21	9.99	962.33	69.66	897.07	465115.41	2.11
Collelongo	WFDEI	1996-2010	20.40	15.12	10.22	972.10	75.02	903.20	549826.57	2.40
	local	1996-2014	7.40	4.36	1.13	604.01	77.95	991.08	309628.86	3.42
	GSWP3	1996-2010	8.03	4.00	-0.20	689.08	83.96	998.01	350511.52	3.42
	Princeton	1996-2012	7.88	4.06	-0.37	574.87	83.41	1007.97	330041.85	3.52
	WATCH	1996-2001	7.93	3.88	-0.17	690.02	81.29	993.85	280668.38	2.44
Hyytiälä	WFDEI	1996-2010	7.97	4.00	-0.26	668.75	79.23	993.60	328551.11	2.12
	local	1998-2010	12.99	8.15	3.91	849.46	80.73	NA	391563.62	1.08
	GSWP3	1998-2010	14.43	9.65	5.23	1014.37	80.55	954.55	423260.65	3.04
	Princeton	1998-2010	14.15	9.66	4.95	772.08	82.05	935.11	433277.37	3.18
	WATCH	1998-2001	14.48	9.83	5.39	1061.27	76.35	959.58	337605.56	2.78
KROOF	WFDEI	1998-2010	14.41	9.65	5.22	976.78	76.67	954.13	431629.74	2.58
	local	1996-2008	17.76	13.37	9.39	920.18	76.11	1005.81	472940.36	3.02
	GSWP3	1996-2008	19.06	14.23	9.63	918.76	73.90	1014.64	490253.28	4.90
Le Bray	Princeton	1996-2008	18.62	14.24	9.19	951.01	80.41	989.70	484739.73	4.01

Site	Source	Years	Tmax [°C]	Tmean [°C]	Tmin [°C]	P [mm]	RH [%]	AP [hPa]	R [J cm^{-2}]	W [m s^{-1}]
	WATCH	1996-2001	18.60	13.98	9.34	1095.65	74.66	1021.76	398738.50	4.28
	WFDEI	1996-2008	19.20	14.23	9.78	988.57	74.37	1011.63	512514.20	2.77
	local	1901-2010	13.50	9.02	4.93	533.10	76.37	1008.29	369794.74	2.35
	GSWP3	1901-2010	13.48	9.22	5.34	654.19	75.73	1007.39	365709.48	3.74
	Princeton	1901-2010	13.20	9.23	5.07	557.89	85.43	999.16	374370.83	3.51
	WATCH	1901-2001	13.36	9.06	5.20	601.44	76.93	1007.07	309797.89	2.79
Peitz	WFDEI	1901-2010	13.47	9.18	5.23	607.58	76.54	1006.45	335821.69	3.02
	local	1960-2013	10.54	6.75	3.39	1113.06	85.56	NA	285026.90	1.01
	GSWP3	1960-2010	11.99	8.15	4.67	933.37	79.82	988.95	355905.60	3.95
	Princeton	1960-2012	11.76	8.20	4.42	734.76	85.55	995.05	364950.89	3.75
	WATCH	1960-2001	11.65	7.79	4.38	962.00	79.38	985.97	300414.77	2.74
Solling	WFDEI	1960-2010	11.89	8.14	4.58	963.98	79.21	985.95	353096.37	3.36
	local	1996-2012	10.66	8.26	5.91	760.52	82.95	1007.71	360687.83	5.13
	GSWP3	1996-2010	11.56	9.00	6.58	773.57	78.73	1012.59	376613.02	5.86
	Princeton	1996-2012	11.45	9.03	6.44	584.58	81.19	1005.25	363852.90	4.98
	WATCH	1996-2001	11.08	8.46	6.26	560.00	82.54	1009.39	343133.71	5.66
Sorø	WFDEI	1996-2010	11.52	9.01	6.55	640.02	83.06	1009.50	408098.02	4.81

3.2.5. Climate scenarios

The PROFOUND DB provides climate scenarios based on simulations performed for CMIP5 (https://cmip.llnl.gov/cmip5/) that were bias-corrected and interpolated to a common grid resolution of 0.5° x 0.5° according to Hempel et al. (2013). The climate variables for each site available were extracted from the grid cell of the downscaled climate forcing dataset in which the forest plot is located. The data can be used in very different ways by the vegetation modelling community:

- The 'ISIMIP Fast Track' scenarios (ISIMIPFT) consist of daily climate data available from five different Global Climate Models (GCMs) (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M and NorESM1-M.) for all four RCPs (Warszawski et al. 2014). The historical period lasts from 1950-2005 and then splits up into the four RCPs from 2006-2099 for each model. The RCPs cover future warming ranges of about 0-9°C in the late 21st century compared to the 1980-2005 average (Figure 2). These ISIMIPFT data are best suited for scenario studies that require a large ensemble of GCMs and RCPs.
- The 'ISIMIP2b' scenarios (ISIMIP2b) consist of daily climate data available from four different GCMs (IPSL-CM5A-LR, GFDL-ESM2M, MIROC5, HadGEM2-ES) for the RCP2.6 and RCP6.0 (Frieler et al. 2017, Lange 2018) as well as RCP4.5 and RCP8.5. The historical period lasts from 1861-2005 and then splits up into the four RCPs for each GCM from 2006-2099. The RCPs cover future warming ranges of about 1-9°C in the late 21st century compared to the 1980-2005 average (Figure SOM 1). For RCP2.6, RCP4.5 and RCP8.5 from IPSL-CM5A-LR, HadGEM2-ES and MIROC5, additional data are also available for the period 2100-2299. These long-term climatic pathways stabilise at around 1-2°C in the end of the 23rd century compared to 1980-2005 for RCP2.6, around 3-5°C for RCP4.5 and rise up to 16°C for RCP8.5. For all four GCMs, there are also time series of pre-industrial climatic conditions available from 1661-2299 (or 1661-2099 for GFDL-ESM2M), the so-called pre-industrial control run. The pre-industrial climates from each GCM for the time period 1661-1860 can be combined with the historical climates from 1861-2005 and any future time periods from the corresponding GCM to create a long-term time series of climate data from 1661-2299 (or 2099 depending on the GCM/RCP combinations) without almost any resampling (Frieler et al. 2017). The ISIMIP2b data are best suited to test the implications of long-term stabilization pathways and different degrees of warming relative to pre-industrial conditions in vegetation models.
- The 'ISIMIP2b locally bias-corrected' scenarios (ISIMIP2bLBC) have the same structure as the ISIMIP2b data but have been bias-corrected using an improvement of the method of Hempel et al. (2013) as described in Frieler et al. (2017) and Lange (2017) and the local observed climatologies presented in Sect. 3.2.3. The ISIMIP2bLBC data are hence best suited for scenario studies that require climatic data to be as consistent as possible with the observational data (Figure 3).

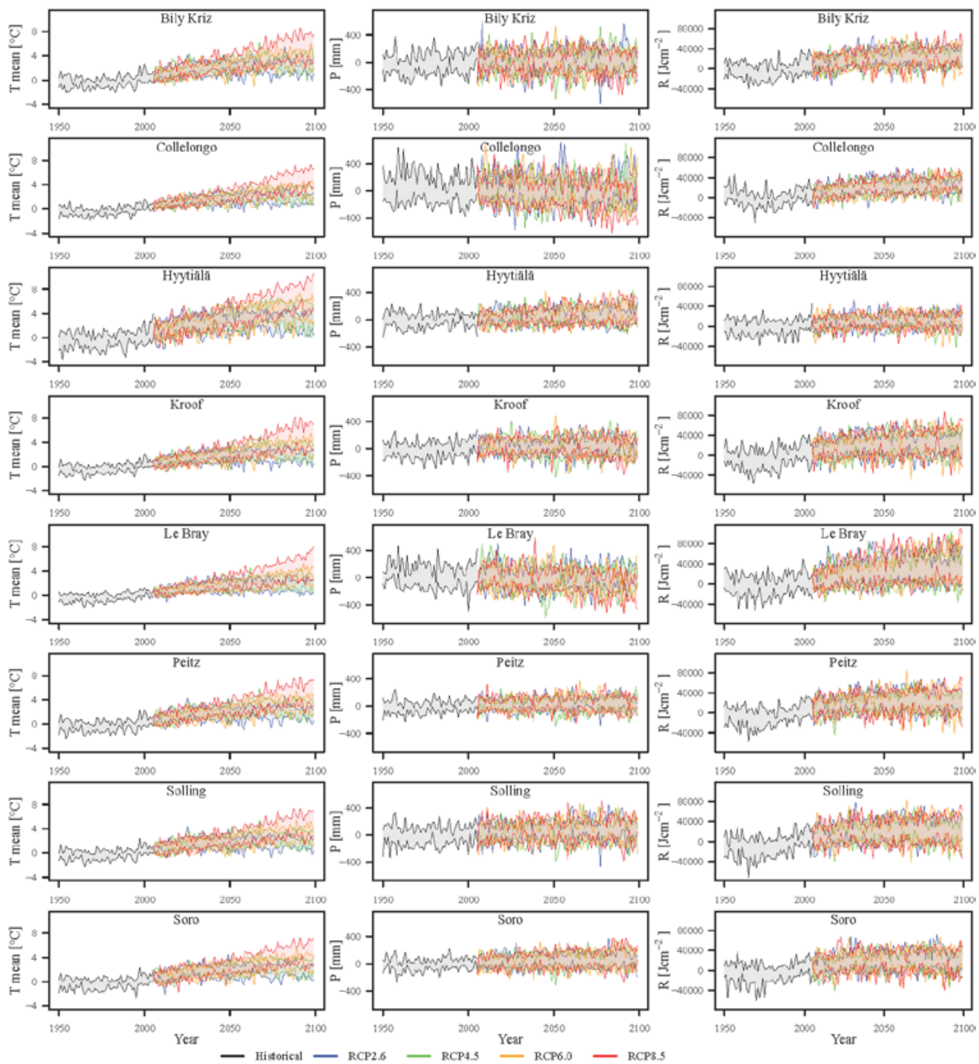

Figure 2. Change in mean annual temperature (T mean), annual precipitation sum (P) and annual sum of global radiation (R) over the time period 1950-2099 relative to the 1980-2005 average for the ISIMIPFT scenarios. Please note that the two Solling sites have the same climate.

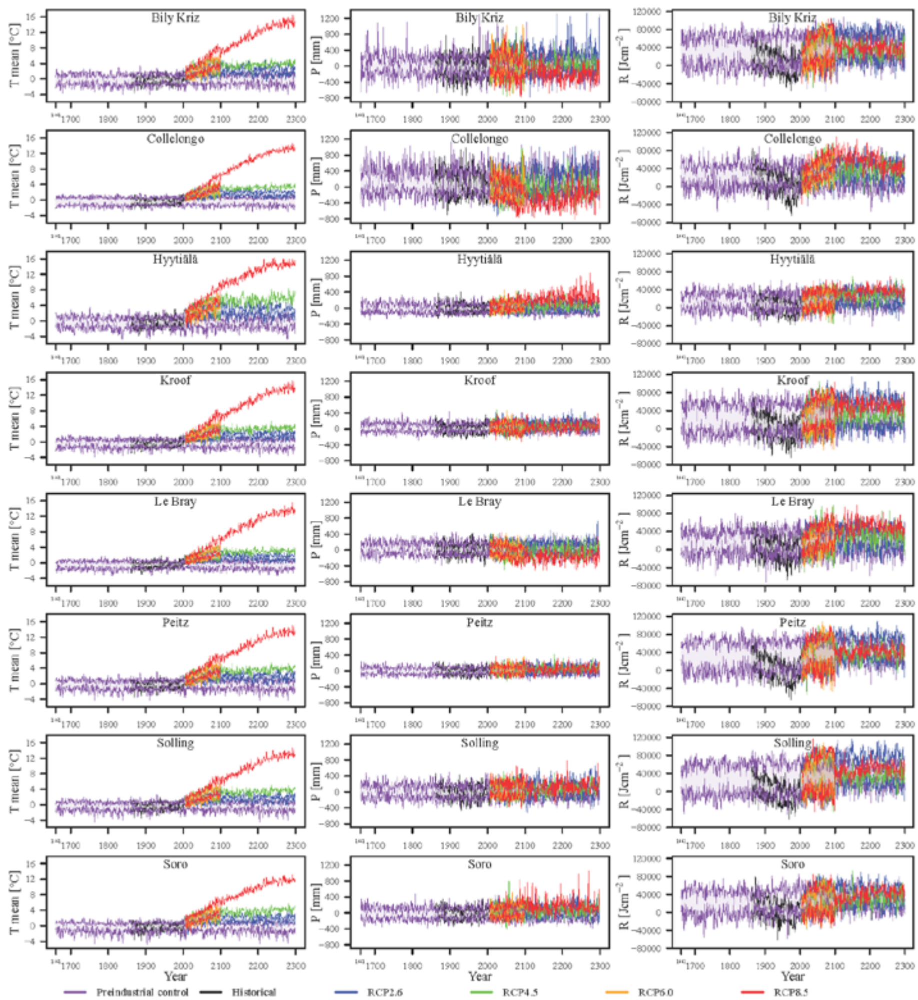

Figure 3. Change in mean annual temperature (T mean), annual precipitation sum (P) and annual sum of global radiation (R) over the time period 1661-2299 relative to the 1980-2005 average for the ISIMIP2b locally bias-corrected (ISIMIP2bLBC) scenarios. Please note that the two Solling sites have the same climate.

3.2.6. Atmospheric CO_2 concentrations

Time series of atmospheric CO_2 concentrations are provided as annual, global data, hence as one time series for all sites of the PROFOUND DB assuming a well-mixed atmosphere. The historical time series of atmospheric CO_2 are based on global atmospheric CO_2 concentrations from Meinshausen et al. (2011) from 1765-2005 and have been extended for the period 2006-2015 with data from Dlugokencky & Tan (2014). The future annual atmospheric CO_2 concentrations follow the four different Representative Concentration Pathways (RCPs, RCP2.6, RCP4.5, RCP6.0 and RCP8.5) from 2016-2500 from Meinshausen et al. (2011). Figure 4 shows the historical increase in CO_2 concentrations since 1765 and the projected future emissions according to the different RCPs. From RCP2.6 till RCP8.5 the total level of CO_2 increases strongly and also the date of stabilizing emissions is reached much later in RCP8.5. RCP2.6 is the only RCP that projects declining CO_2 levels in the long run.

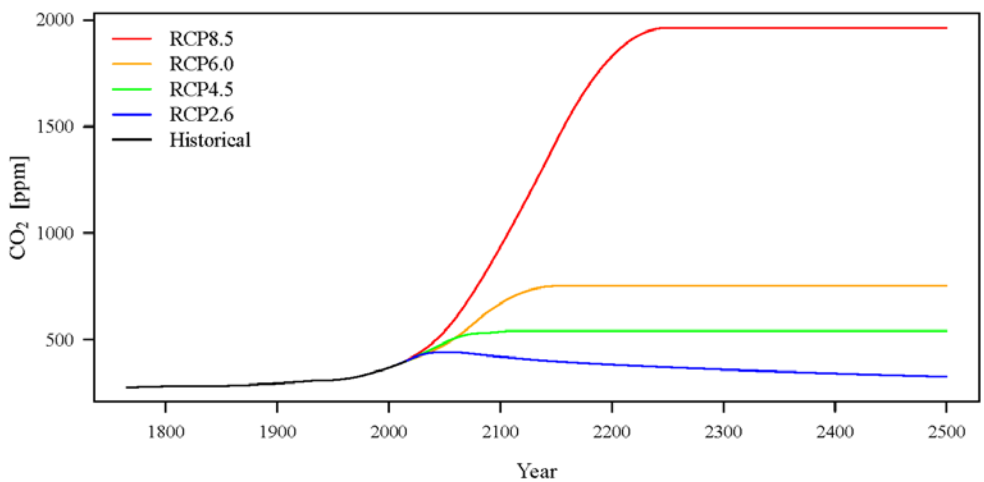

Figure 4: Global atmospheric CO_2 concentrations provided for all sites in the PROFOUND DB. The historical time period extends from 1765-2015 and the scenarios from 2005-2500 for each RCP.

3.2.7. Nitrogen deposition

The nitrogen deposition data, reported as total deposition of reduced and oxidized wet and dry nitrogen deposition, respectively, have been extracted for each site of the PROFOUND DB from two different datasets which serve different purposes.

- EMEP data: For detailed model evaluation studies that require the best possible estimates of local nitrogen deposition, we extracted data from the 'Co-operative programme for monitoring and evaluation of long-range transmission of air

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pollutants in Europe' (EMEP) for the time period 1980-2014 (EMEP/CEIP 2014). Sea-salt corrected data are available from 1980-1995 in five years steps and from 1986-2014 at annual time step and are derived by atmospheric transport modelling (Simpson et al., 2012).

- ISIMIP data: For model simulation studies, we also provide nitrogen deposition estimates based on atmospheric chemistry modelling for a historical time period (1861-2005) and four future scenarios, where nitrogen deposition follow the four RCPs respectively. The data are further described in Lamarque et al. (2013a, 2013b), sea-salt corrected and consistent with the global nitrogen deposition data provided within ISIMIP (Frieler et al. 2017). The data are taken from the global dataset without further corrections and hence are not intended to represent realistic, local forecasts but rather rough estimates of future nitrogen projections.

For the 1980-2014 time period, the ISIMIP data are typically lower and less dynamic than the EMEP estimates (Figure 5). However, while they do not seem suitable for historical model evaluations, they cover a much longer time period and are clearly interesting for scenario studies because they feature different nitrogen deposition pathways consistent with RCP climates and CO_2 pathways. It is also important to note that measured throughfall of NO_3 and NH_4 is on average lower than modelled total deposition, due to canopy uptake (Marchetto et al in prep.). Moreover, for the two Solling sites the data presented here are identical while in reality total N deposition rates in the spruce stand should be higher because of higher dry depositions. Actually, the ratio between Solling spruce and Solling beech is 1.4 for NH_4 throughfall fluxes, 1.6 for NO_3 throughfall fluxes, 1.4 for NH_4 total deposition, and 1.4 for NO_3 total deposition, both using a canopy budget model (Ulrich 1994) for the period 1980-2014. However, these ratios are not constant and are showing an increasing trend over time.

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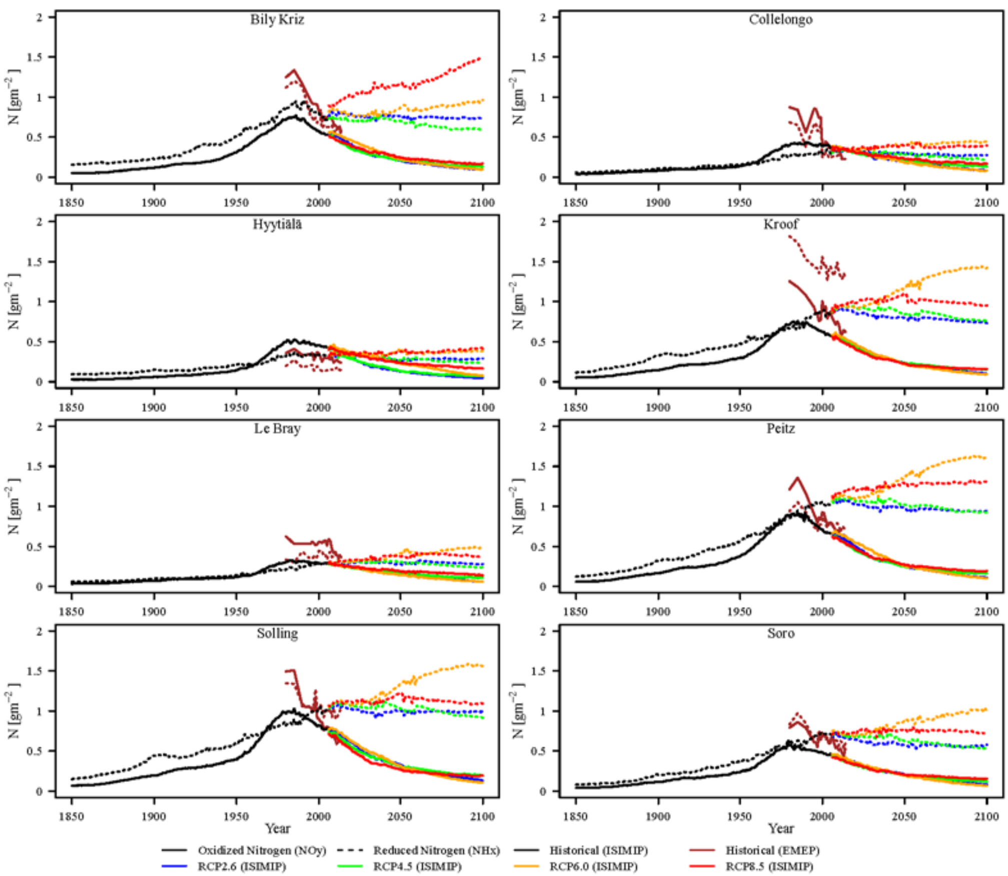

Figure 5: Total deposition of reduced (NHx) and oxidized (NOy) nitrogen (N) at each of the sites of the PROFOUND DB. The historical period for the EMEP data extends from 1980-2014 and for the historical ISIMIP data from 1861-2005. The future scenarios are available from 2006-2100 and follow the RCP2.6 and RCP6.0 scenarios. Please note that the two Solling sites have the same N depositions (see text for further explanations).

3.2.8. Forest inventory data

For each site, the PROFOUND DB provides information about the forest stand at tree and stand level. The data are available for different time periods and have different measurement intervals, but generally cover mostly the second half of the 20th century and the first decade of the 21st century (Table 1). The data also cover a wide array of height-age and DBH-age relationships (Figure 6-7). For 7 out of 9 sites individual tree diameter at breast height (DBH) and height measurements are available. The time series length ranges between 15 and 65 years within the time period 1948-2015. For the Sorø site, the DBH and heights have been reconstructed from tree-ring data (Babst et al., 2014) and the full stand reconstruction is available from 1996-2010 at annual resolution (cf Text SOM 1). Individual tree data allow analysis and comparison of model simulations with data on single tree growth. From the tree data, we calculated a range of widely used stand variables (cf SOM8). Additional stand-level data are available for some of the sites, such as leaf litter production or leaf area index, and have been included (cf SOM8).

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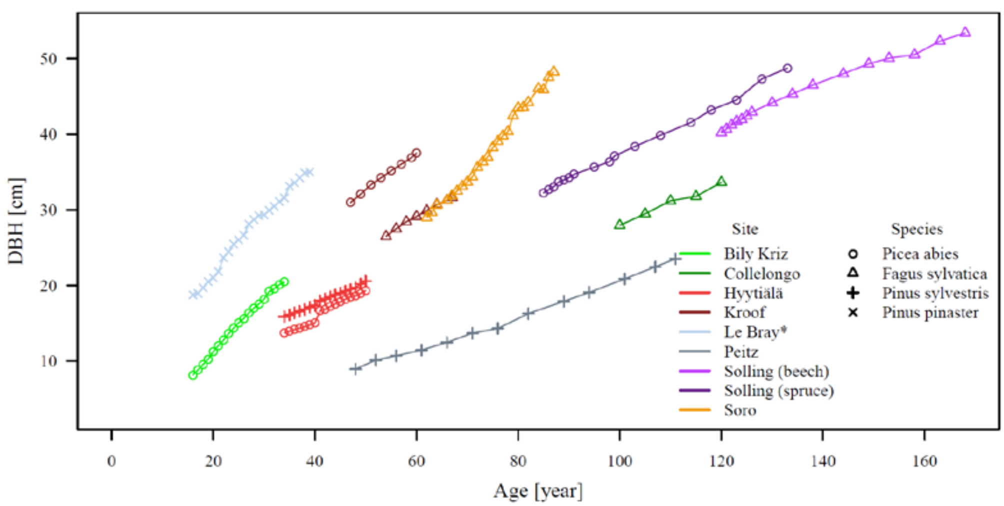

Figure 6: Time series of tree diameter at breast height (DBH) versus age of the forest stands in the PROFOUND DB. The basal area-weighted mean DBH is shown for all stands with the exception of Le Bray for which the arithmetic mean DBH is shown (marked by *). For Sorø, the DBHs have been reconstructed (see text in Sect. 4.9 and Text SOM 1).

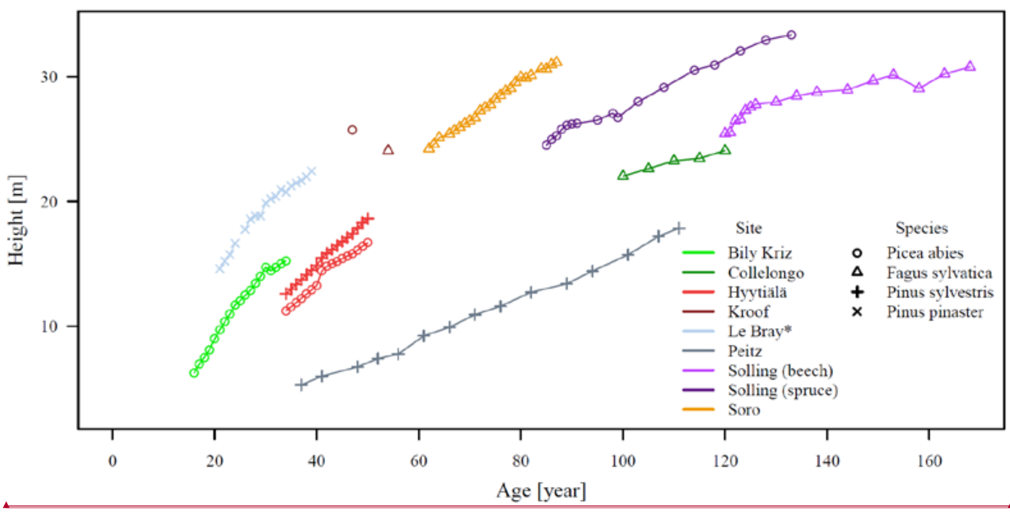

Figure 7: Time series of tree height versus age of the forest stands in the PROFOUND DB. The basal area-weighted mean height is shown for all stands with the exception of Le Bray for which the arithmetic mean height is shown (marked by *). For Sorø, the heights have been reconstructed (see text in Sect. 4.9 and Text SOM 1).

Table 4. Summary of the main stand variables for the forest stands in the PROFOUND DB. The first number in each cell indicates the value at the first measurement and the second number at the last measurement. The basal area-weighted mean height and DBH are shown for all stands with the exception of Le Bray for which the arithmetic mean height and DBH are shown (marked by *). The numbers in brackets indicate different data availability for height than for the other variables.

Name	Main species	# Obs	Year	DBH [cm]	Height [m]	BA [m^2*ha^{-1}]	Age [year]	Stem density [ha^{-1}]
Bily Kriz	*Picea abies*	19	1997-2015	8.16-20.47	6.26-15.26	10.33-36.96	16-34	2408-1252
Collelongo	*Fagus sylvatica*	5	1992-2012	27.95-33.65	22.03-24.08	32.25-43.76	100-120	905-740
Hyytiälä	*Picea abies*	17	1995-2011	13.74-19.32	11.24-16.7	2.96-3.8	34-50	965-770
Hyytiälä	*Pinus sylvestris*	17	1995-2011	15.89-20.58	12.61-18.62	12.64-18.33	34-50	870-684
KROOF	*Picea abies*	8 (1)	1997–2010 (1997)	30.96-37.49	(25.73)	30.26-39.66	47-60	512-434
KROOF	*Fagus sylvatica*	8 (1)	1997–2010 (1997)	26.5-31.64	(24.07)	12.44-13.2	54-67	324-220
Le Bray*	*Pinus pinaster*	24 (18)	1986-2009 (1991-2009)	18.76-35.01	(14.61- 22.44)	23.3-19.19	16-39	819-195
Peitz	*Pinus sylvestris*	13	1948-2011	8.96-23.54	6.75-17.86	20.66-36.36	48-111	4150-886
Solling (beech)	*Fagus sylvatica*	16	1967-2014	40.19-53.4	25.45-30.78	26.99-25.52	120-168	245-130
Solling (spruce)	*Picea abies*	17	1967-2014	32.25-48.74	24.51-33.36	44-49.46	85-133	595-290
Sorø	*Fagus sylvatica*	24	1994-2017	28.99-48.25	24.23-31.15	18.50-29.76	62-87	407-199

3.2.9. Flux data

The carbon fluxes, i.e. net ecosystem exchange (NEE), ecosystem respiration (RECO) and gross primary production (GPP) are taken from the Tier One Fluxnet2015 dataset (http://fluxnet.fluxdata.org/). We provide estimates of fluxes calculated using different estimates for gap-filled/partitioned fluxes to give a rough estimate of the uncertainty added to the long-term budgets in the process. NEE data are filtered using two different methods to calculate UStar thresholds (Barr et al. 2013, and a modified version of Papale et al. 2006, see also Fluxnet2015 (2017)). Daytime (i.e. Lasslop et al. 2012) and nighttime (i.e. Reichstein et al. 2005) refer to whether ecosystem respiration parameters were estimated from only nighttime fluxes or using also daytime

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data (zero intercept of GPP light response curve). In many cases the number of accepted nighttime fluxes is low and the temperature range is narrow, which leads to high uncertainty in the estimated respiration. This can be improved by using also daytime fluxes. On the other hand in the daytime method the uncertainties of photosynthetic light, temperature, and possible VPD responses may be attributed to respiration parameters. Further information about the daytime and nighttime methods is available in Lasslop et al. (2010) and Reichstein et al. (2005) and also Fluxnet2015 (2017). We also extracted different uncertainty estimates for each variable. Additionally, we provide time series of the sensible and latent heat flux, soil (soil water and soil temperature) and meteorological variables at a 30-min time resolution from the Fluxnet2015 database including measurement uncertainty estimates. Table 5 provides an overview of the main carbon fluxes at each of the sites featured in the PROFOUND DB. Table SOM9 and Table SOM11-13 provides the full list of available variables.

Table 5: Summary of the observed carbon fluxes at the sites in the PROFOUND DB. Shown is the range (min & max) and the average (in brackets) of the annual sums in the observational period. All data are estimates based on the CUTRef method with daytime data included for RECO and GPP. GPP is expressed with negative values because it is considered a downward flux from the atmosphere. Likewise negative NEE values indicate a carbon sink and positive a carbon source.

Name	Years	NEE [t C ha^{-1}]	RECO [t C ha^{-1}]	GPP [t C ha^{-1}]
Bily Kriz	2000 - 2008	-9.117 - -3.277 (-6.52)	5.478 – 10.295 (7.918)	-20.477 - -11.071 (-16.577)
Collelongo	1996 - 2014	-25.129 - -3.36 (-8.152)	4.495 – 15.936 (8.079)	-26.675 - -5.259 (-16.546)
Hyytiälä	1996 - 2014	-8.167 - -1.22 (-2.49)	1.668 – 11.511 (8.943)	-14.984 - -10.0 (-11.709)*
Le Bray	1996 - 2008	-7.396 – 0.104 (-3.915)	8.236 – 21.609 (14.569)	-23.651 - -12.648 (-19.455)*
Sorø	1996 - 2012	-8.245 – 0.892 (-1.92)	15.147 – 22.345 (17.335)	-23.832 - -15.873 (-19.163)

*year 2007 is without data for Hyytiälä and year 2002 for Le Bray

3.2.10. Remote sensing data

The PROFOUND DB includes remote sensing information at different spatial scales and temporal frequencies, specific for each product. We included five MODIS products (ORNL DAAC 2008a-e) and several vegetation indices calculated from the surface reflectance data for each of the forest sites. The original MODIS scenes are available at the NASA Land Processes Distributed Archive Center (LP DAAC) (https://lpdaac.usgs.gov/). The specific time series included in the PROFOUND DB were downloaded from the Land Product Subset Web Service of the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) (https://daac.ornl.gov/MODIS/). The ORNL DAAC MODIS subsetting Web service is implemented to allow users access to massive amounts of remote sensing data (Santhana-Vannan et al., 2011). In addition, a second set of vegetation indexes were calculated from the reflectance values. A summary of this information is shown in table 6. The full list of variables and how they were aggregated is provided in table SOM10.

Table 6. Summary of the remote sensing data included in the PROFOUND DB. VIS, NIR and SWIR are the visible, near infrared and shortwave infrared regions of the electromagnetic spectrum. NDVI: Normalized Difference

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Vegetation Index, EVI: Enhanced Vegetation Index; FPAR: Fraction of Photosynthetically Absorbed Radiation; LAI: Leaf Area Index; GPP: Gross Primary productivity; NDWI: Normalized Difference Water Index; AR: Angle at Red; ANIR; Angle at NIR; AS1: Angle at Shortwave Infrared 1; AS2: Angle at Shortwave Infrared 2; SANI: Shortwave Angle Slope Index; SASI: Shortwave Angle Slope Index

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Variable	**MODIS Source**	**Spatial Resolution [km]**	**Temporal Frequency [d]**	**Time period**
Reflectance (%) at 7 spectral bands in the optical domain VIS-NIR-SWIR	MOD09A1	0.5	8	2000-2015
Land surface temperature (night & day, Kelvin)	MOD11A2	1	8	2000-2015
NDVI, EVI	MOD13Q1	0.25	16	2000-2015
FPAR, LAI (Dimensionless -1,1)	MOD15A2	1	8	2000-2015
GPP & Net Photosynthesis (gC m^{-2} day^{-1})	MOD17A2	1	8	2000-2014
EVI, NDVI, NDWI (Dimensionless -1,1)	Ratio Indexes calculated from MOD09A1	0.5	8	2000-2015
AR, ANIR, AS1, AS2 (radians, 0-3.14)	Angular indexes calculated from MOD09A1	0.5	8	2000-2015
SANI (-3.14 – 3.14) SASI (-314-314))	Angular normalized indexes calculated from MOD09A1	0.5	8	2000-2015

The main difference among the forest sites is the data quality, which is highly dependent on the presence of clouds. When possible, low quality observations have been substituted by interpolated values, otherwise the cell was left blank. In any case the alteration of the original data was minimal. It is also important to note that the size of the pixel is large compared to the plot size of the forest stands, which means the pixel data also contain other vegetation than the ones present at the sites.

Three general types of data are included: (1) geophysical variables as measured from the MODIS sensor, i.e. reflectance and temperature, (2) spectral indexes derived directly from reflectance values at different wavelengths, and (3) vegetation properties (i.e. FPAR, LAI, GPP, and Net photosynthesis) as estimated from physical variables through a range of models.

Although the MODIS sensor acquires daily information, the PROFOUND DB includes only composite data, that is, for each pixel the best value during a period of time (8 or 16 days) is selected as being representative of that specific period. Spatial resolution is also specific for each product and is dependent on the physical and technical limitations in the acquisition process of the variables involved in the product computation.

The NDVI and EVI at 250 m spatial resolution coming from the MOD13Q1 product were calculated from the visible and near infrared spectral regions. A temporal frequency (16-day composite) was chosen to minimize the effect of clouds. The EVI Index was developed to correct for atmospheric and background effects so that it shows a larger dynamic range in areas with high vegetation density (Didan et al., 2015).

The spectral profiles in the whole optical domain (i.e. 459-2155 nm) for each 8-day composite are represented by the surface spectral reflectance at seven wavelengths coming from the MOD09A1 product at 500 m spatial resolution. The criteria for the compositing process are low cloudiness, cloud shadows and low solar zenith angle; when several of these criteria are fulfilled the selection is based on the minimum value in the blue band (Vermote et al., 2015).

The second set of spectral indexes was computed from the MOD09A1 product. The indices based on the spectral shape have the advantage of combining information on three bands instead of two, also when the bands used are located in the SWIR region relevant information related to water is captured (Palacios-Orueta et al., 2005; Khanna et al., 2007; Palacios-Orueta et al., 2012).

LAI is defined as the one−sided green leaf area per unit ground area in broadleaf canopies and as one−half the total needle surface area per unit ground area in coniferous canopies. The FPAR is the fraction of photosynthetically active radiation (400-700 nm) that is absorbed by the canopy (Myneni, 2015). Gross primary productivity and net photosynthesis estimations are based on the light use efficiency (LUE) concept (Monteith, 1972) using satellite-derived FPAR (from MOD15) and independent estimates of PAR, besides other types of ancillary data. These are highly aggregated variables that have gone through several modelling steps already. Detailed information on the model and information sources used can be found in Running and Zhao (2015).

4. Description of the forest sites

The most northern site is Hyytiälä in Finland with a boreal climate, while the most southern sites are Le Bray in France and Collelongo in Italy with an oceanic and Mediterranean montane climate, respectively. All other sites represent temperate climatic conditions ranging however, from oceanic (Belgium, Denmark), temperate (France, Germany) to sub-continental (Czech Republic). Unfortunately, sites representing more continental and (east)-Mediterranean forests from southern and south-eastern Europe are missing.

4.1. Bily Kriz (CZ)

The Bily Kriz site belongs to the ICP Forests Level II network and is a Fluxnet site located in the Moravian-Silesian Beskydy Mts, Czech Republic, at an altitude of 875 m.a.s.l. The climate is temperate with an annual mean temperature of 7.4°C and an annual precipitation sum of 1434 mm over the 2000-2008 period. The soil is classified as a Haplic Podzol. The site is typical for mountain regions of temperate Europe such as the Black Forest, Bohemian Forest Sumava and forested Carpathians (Hercynian (spruce-)fir-beech forests) but also the higher mountain belts in the (sub-)Mediterranean. Stand forming tree species for such sites are *Fagus sylvatica*, *Abies alba,* and *Picea abies*. Currently, a large part of mixed mountain forests are strongly managed for timber production. The main tree species occurring in Bily Kriz are *Picea abies* rarely with small proportion of *Fagus sylvatica*. The stand data represent an (even-aged) *Picea abies* monoculture with a mean DBH of 19 cm (year 2015). The potential vegetation belongs to the Geobiocoene type groups: Abieti-fageta (5AB3) - Abies alba Mill. + *Fagus sylvatica* L. with understory: *Calamagrostis arundinacea* (L.) Roth, *Oxalis acetosella* L., *Vaccinium myrtillus* L., *Deschampsia flexuosa* (L.) Trin. More information about the site can be found in Kratochvílová et al. (1989) and Meteorological yearbook (2012).

4.2. Collelongo (IT)

The experimental site of Collelongo is located in Selva Piana, a pure *Fagus sylvatica* forest in Collelongo (AQ, central Italy) at 1560 m.a.s.l. Located 100 km from Rome, it is one of the first Italian sites of the ICP network and also part of the ILTER international network. The climate is Mediterranean montane, with a mean annual temperature of 7.2°C and a mean annual precipitation of 1179 mm in the period 1996-2014. Bedrock consists of cretaceous limestone. Soil depth exhibits high spatial variability ranging from 40 to 100 cm and is classified as a Humic Alisol (Chiti et al. 2010) or Dystric Luvisol according to the FAO classification. The stand is a typical Apennine beech forests dominated by *Fagus sylvatica* with sporadic trees of *Taxus baccata*. The phytosociological association is Polysticho – Fagetum (Feoli & Lagonegro 1982). Currently, Collelongo constitutes a managed *Fagus sylvatica* stand with mean DBH of 25 cm in 2012. In the area around the eddy-flux tower there are only *Fagus sylvatica* trees. Moreover the footprint of the tower is totally included in the *Fagus sylvatica* forest. More information about the site can be found in Chiti et al. (2010), Collalti et al. (2016) and D’Andrea et al. (2019).

4.3. Hyytiälä (FI)

The most northern site included in the PROFOUND DB is the ICP Forests Level II site Hyytiälä, Finland. It is also a Fluxnet site and the coldest site with an annual temperature of 4.4°C and 604 mm annual precipitation during the 1996-2014 period and lies at 185 m.a.s.l. The soil is classified as a Haplic Podzol. *Picea abies* is the naturally dominant tree species building Fennoscandian moss-rich spruce forests with *Pinus sylvestris*. A *Pinus sylvestris* stand was sown in 1962, today with admixtures of *Picea abies* and hardwood species (*Betula pendula*, *Betula pubescens* and *Populus tremula*). Mean DBH were 17 cm for *P. sylvestris*, 5 cm for *P. abies* and 7 cm for hardwood species in the year 2008. More information about the site can be found in Haataja & Vesala (1997), Rannik et al. (2004), Vesala et al. (2005), Ilvesniemi et al. (2009), Mammarella et al. (2009) and Ilvesniemi et al. (2010).

4.4. KROOF (DE)

The KROOF forest belongs to the "Kranzberg Forest Roof Experiment" of the Technical University Munich (TUM) and the Helmholtz-Zentrum Munich. The site is located close to Freising, Germany, in the Kranzberger Forst in 502 m.a.s.l (wc-alt.). Mean annual temperature is around 8.2°C, annual rainfall around 849 mm during the period 1998-2010. The soil type, Luvisol, is typical for the region. The potential natural vegetation is (sessile oak-) beech forest (*Fagus sylvatica, Quercus petraea, Quercus robur*). The establishment of the research plot dates back to 1992. The mixed stand comprises large groups of *Fagus sylvatica* surrounded by *Picea abies* with mean DBH of 26 cm and 33 cm in 2010, respectively. Other occurring species are *Acer platanoides* (20 cm), *Pinus sylvestris* (31 cm), *Larix decidua* (26 cm) and *Quercus robur* (29 cm). More information about the site can be found in Pretzsch et al. (1998; 2014) and Matyssek et al. (2014).

4.5. Le Bray (FR)

The ICP Forests site Le Bray is located 20 km south-west of Bordeaux, France, at an altitude of 61 m.a.s.l. Mean annual temperature is about 13.4°C and precipitation 920 mm during the 1996-2008 period, constituting a moderate oceanic climate. The soil type is Arenosol (sandy and hydromorphic podzol), which is one of the most common soils in the region. The natural vegetation is formed by deciduous broadleaf forests such as pedunculate oak forests (*Quercus robur*), partly with *Quercus pyrenaica*, *Quercus suber* and *Pinus pinaster*. First measurements were made in 1986 in the monospecific planted *Pinus pinaster* stand. The site experienced a storm in 1999 and lost a large amount of trees. In 2009, the mean DBH was 35 cm. The final clear cut of the site occurred at the beginning of 2009. More information about the site can be found in Porté & Loustau (1998), Bosc et al. (2003) and Berbigier et al. (2001).

4.6. Peitz (DE)

Peitz is a long term research plot in eastern Brandenburg, Germany. The site lies at about 50 m.a.s.l. The annual rainfall amounts to more than 608 mm and annual mean temperature is around 9.2°C during the 1901-2010 period. The soil type is a Dystric Cambisol. The potential natural vegetation is a South Scandinavian-east Central European dwarf shrub- and lichen-rich pine forests (*Pinus sylvestris*), partly with *Quercus robur* in the understorey, with *Vaccinium vitis-idaea*, *Calluna vulgaris*, *Cladina spp.*, *Dicranum polysetum* on sandy soils and siliceous rocks. The forest is a pine forest (*Pinus sylvestris*) with a mean DBH of around 23 cm and a stand height of 17 m in 2011. The understorey consists partly of *Quercus robur*. Measurements were started in 1948. More information about this site can be found in Riek & Stähr (2004), Noack (2011; 2012) and about the climate data in Gerstengarbe et al. (2015).

4.7. Solling beech (DE)

Solling 304 is a long-term intensive forest monitoring plot (Level II) of the ICP Forests network in central Germany. The plot is also part of the LTER (site LTER_EU_DE_009) and of the permanent soil monitoring programme of the state of Lower Saxony. The site is situated in the center of the Solling plateau at an elevation of about 500 m a.s.l. The mean temperature was around 6.8°C and the mean annual rainfall amounted to 1113 mm during the period 1960-2013. The bedrock consist of Triassic sandstone covered with a 60 to 80 cm deep solifluction layer of loess material from which the soil, classified as an Haplic Cambisol, has developed. The humus type is a typical Moder. The tree layer consists only of European beech (*Fagus sylvatica* L.). *Oxalis acetosella* and *Luzula luzuloides* are the major species of the sparse ground vegetation. Actual vegetation was assigned to the Luzulo-Fagetum typicum and is close to the potential natural vegetation. The forest is a 168-year old stand with a mean DBH of 50 cm and a mean height of 30.7 m in 2016. More information about the site can be found in Meiwes et al. (2009), Meesenburg et al. (2009), Panferov et al. (2009), Le Mellec et al. (2010), Meesenburg et al. (2016) and Fleck et al. (2016).

4.8. Solling spruce (DE)

Solling 305 is also a long-term intensive forest monitoring plot of the ICP Forests Level II network in central Germany. As the Solling beech site it belongs to the LTER (site LTER_EU_DE_009) and is a permanent soil monitoring plot of the state of Lower Saxony. It is situated close to the Solling beech site at an elevation of about 508 m a.s.l and has similar site conditions as the Solling beech stand. Potential natural vegetation is a *Luzulo luzuloido Fagetum*. Dominant species of the actual ground vegetation are *Vaccinium myrtillus*, *Polytrichum formosum* and *Dechampsia flexuosa* (Bolte et al. 2004). The forest is a 133-year old Norway spruce (*Picea abies*) stand with a mean DBH of 46.6 cm and a mean height of 33.1 m in 2016. More information about the site can be found in Le Mellec et al. (2010), Bonten et al. (2011), Meesenburg et al. (2016), Fleck et al. (2016) and Wegehenkel et al. (2017).

4.9. Sorø (DK)

The ICOS site Sorø (DK-Sor in the FLUXNET and ICOS data bases) is located in Denmark at an elevation of 40 m.a.s.l.. The climate is warm temperate and fully humid with a mean annual temperature of 9°C and annual precipitation sum of 774 mm during the period 1996-2010. The soil has been classified as an Alfisols/Molisols. Potential natural vegetation is deciduous broad-leaved forest dominated by *Fagus sylvatica*. Other species occurring in the area are *Fraxinus excelsior*, *Larix decidua*, *Picea abies*, *Quercus spp*., *Acer spp*. However, the region is mostly used as cropland. Data on tree DBH are reconstructed from tree ring measurement (Babst et al. 2014) and historical management information for the time period from 1994 to 2017. Stand data is derived from this data for the time period from 1994 to 2017 (see Text SOM1). The mean DBH of this *Fagus sylvatica* stand was 41 cm in the year 2017. More information about the site can be found in Ladekarl (2001), Pilegaard et al. (2003, 2011), and Wu et al. (2013). More information about the site can be found in Ladekarl (2001), Pilegaard et al. (2003, 2011), and Wu et al. (2013).

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5. Forest management of the sites

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The sites available in the PROFOUND DB are managed forests and the historic management can be derived from the tree and stand level data (in terms of reduction of stem numbers). However, for future scenario studies generic, simple management and planting guidelines are available (Table 7-8). This future management corresponds best to “intensive even-aged forestry” as defined by Duncker et al. 2012.

Table 7 Generic future management scenarios for the main tree species featured in the PROFOUND DB.

Species	Thinning regime	Intensity [% of basal area]	Interval [yr]	Stand age for final harvest	References
Pinus sylvestris	below	20	15	140	Pukkala et al. 1998; Fürstenau et al. 2007; González et al. 2005; Lasch et al. 2005
Picea abies	below	30	15	120	Pape 1999; Pukkala et al. 1998; Hanewinkel and Pretzsch 2000; Sterba 1987; Lähde et al. 2010
Fagus sylvatica	above	30	15	140	Schütz 2006; Mund 2004; Hein and Dhôte 2006; Cescatti and Piutti 1998
Quercus robur/ petraea	above	15	15	200	Hein and Dhôte 2006; Fürstenau et al. 2007; Štefančík 2012; Kerr 1996; Gutsch et al. 2011
Pinus pinaster	below	20	10	45	Loustau et al. 2005, De Lary 2015, Banos et al. 2016

Table 8 Planting information for the sites included in the PROFOUND DB. The numbers in brackets indicate plausible ranges (na = not available).

Name	Density [ha^{-1}]	Age [years]	Height [m]	age when DBH is reached [years]	Remarks
Bily Kriz	4500	4	0.5	9	Historical planting density was 5000/ha but current practices are 4500/ha only
Collelongo	10000	4	1.3	4	Only a rough approximation, usually natural regeneration is the regeneration method. DBH = 0.1 cm at height 1.3m
Hyytiälä	2250 (2000-2500)	2	0.25 (0.2-0.3)	6 (5-7)	Regenerate as pure pine stand
KROOF (beech)	6000 (5000-7000)	2	0.6 (0.5-0.7)	5	The planting density is for single-species stands, hence when regenerating the 2-species-stand KROOF, the planting density of each species should be halved
KROOF (spruce)	2250 (2000-2500)	2	0.35 (0.3-0.4)	7	The planting density is for single-species stands, hence when regenerating the 2-species-stand KROOF, the planting density of each species should be halved
Le Bray	1250 (1000-14000)	1	0.2 (0.1-0.25)	3 (2-5)	These are the current practices (*De Lary*, *2015*) and should be used for future regeneration. Historically, the site was seeded with 3000-5000 seedlings per ha and then cleared once or twice to reach a density of 1250 ha-1 at 7-year old when seedlings reach the size for DBH recruitment.
Peitz	9000 (8000-10000)	2	0.175 (0.1-0.25)	5	The “age when DBH is reached = 5” is an estimate
Solling (beech)	6000 (5000-7000)	2	0.6 (0.5-0.7)	5	The actual stand was established in 1847 from natural regeneration. Until begin of measurements in 1966, the stand was regularly thinned. All figures in table are estimates. Natural regeneration is the recommended regeneration method of stand establishment; stem count in 2014: 130
Solling (spruce)	2250 (2000-2500)	2	0.35 (0.3-0.4)	7	The actual stand was planted in 1891 on a former meadow. Until begin of measurements in 1966, the stand was regularly thinned. All figures in table are estimates.; stem count in 2014: 290
Sorø	6000	4	0.82	6	Planted in 1921, stem count in 288 ha^{-1} in 2010, (Wu et al. 2013)

6. The PROFOUND R-package (ProfoundData)

The ProfoundData R-package provides functions to access the PROFOUND DB (Figure SOM2 and SOM3). The ProfoundData package plus a detailed vignette explaining the functionalities are available on CRAN (https://CRAN.R-project.org/package=ProfoundData). The ProfoundData package serves as interface for users that want to access the PROFOUND DB as a relational database via the R statistical software (R Core Team 2016). The following main functions are included to achieve this goal:

- “getData” to download data (data can be downloaded for one forest site and one underlying dataset at a time)
- “browseData” to check the available forest sites, datasets, variables for a dataset, datasets for a forest site as well as the database version, metadata, data policy, original data source
- “plotData” to quickly inspect any variable of the datasets visually.
- “summarizeData” to summarize data from the database.
- “queryDB” to pass self-defined queries
- “writeSim2netCDF” to write netCDF-files, can be used to convert data (and other files such as model simulation output) into netCDF-files.

While the ProfoundData R-package is meant to provide easy-access to the PROFOUND DB, the database is also fully functional without the R-package.

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7. Data availability

The PROFOUND Database (http://doi.org/10.5880/PIK.2020.006/, Reyer et al. 2020) is available under the Creative Commons Attribution-NonCommercial 4.0 International license (CC BY-NC 4.0). The PROFOUND R-Package (ProfoundData, https://CRAN.R-project.org/package=ProfoundData, Silveyra Gonzalez et al., 2020) is available via a GLP3 license. An earlier version of the database, including an outdated reconstruction of the Soro tree data has been published as Reyer et al. (2019).

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8. Conclusions

A wide range of data are needed to properly evaluate complex process-based vegetation models. The PROFOUND database compiles data from soil, climate, stand and flux measurements with data from remote sensing, atmospheric nitrogen modelling and climate modelling. Moreover, by providing data at 0.5° x 0.5° grid level plus locally bias-corrected climate data, the datasets can be used to compare local forest models to global vegetation models. The PROFOUND database thus facilitates model evaluation, calibration, uncertainty analysis and model intercomparisons, highlighting the immense value of long-term environmental monitoring data for robust inferences about causal processes and future dynamics of forests.

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9. Appendix: List of Fluxnet sites

Table A1: List of Fluxnet sites used in PROFOUND DB.

Flux sites	FLUXNET-ID	Data-years	Publication	Funding
Bily Kriz	CZ-BK1	2000-2008	Kratochvílová et al. (1989), Meteorological yearbook (2012)	Ministry of Education, Youth and Sports of CR within the CzeCOS program, grant number LM2015061
Collelongo	IT-Col	1996-2014	Chiti et al. 2010	EUROFLUX, CARBOEUROFLUX, CARBO EUROPE, CARBO AGE, CARBO EXTREME
Hyytiälä	FI-Hyy	1996-2014	Haataja & Vesala (1997), Rannik et al. (2004), Vesala et al. (2005), Ilvesniemi et al. (2009), Mammarella et al. (2009) and Ilvesniemi et al. (2010)	ICOS, EUROFLUX, CARBOEUROFLUX, CARBOEUROPE, CARBOEXTREME and by the Academy of Finland Centre of Excellence programme, projects 118615, 141135 and 272041
Le Bray	FR-LBr	1996-2008	Porté & Loustau (1998), Bosc et al. (2003) and Berbigier et al. (2001)	INRA, EUROFLUX, CARBOEUROFLUX, CARBO EUROPE, CARBO AGE, CARBO EXTREME
Sorø	DK-Sor	1996-2012	Ladekarl (2001), Pilegaard et al. (2003, 2011), and Wu et al. (2013)	EUROFLUX, CARBO-EUROPE, CARBO-EUROPE-IP, NITRO-EUROPE, CARBO-EXTREME and Risø-National Laboratory (DK) and technical University of Denmark (DTU)

10. Supplement Link

To be added by Copernicus

11. Author Contributions

CPOR and RSG contributed equally to the paper. CPOR & FH initiated the research. CPOR RSG, KD, FH designed the PROFOUND database. CPOR, RSG, YH, KD harmonized and prepared data for the PROFOUND database. RSG programmed the PROFOUND database and R package together with FH, FB and JS. LK and JK provided data for Bily Kriz. AC, GM, CT, EA provided data for Collelongo. PK, AM, TV, IM, JP provided data for Hyyitälä. TR, HP provided data for KROOF. DL, LMB, PB, DP, SL provided data for Le Bray. MN, PLB provided data for Peitz. HM, SF, MW provided data for the Solling sites. AI, KP, FB provided data for Sorø. DC, MV prepared the EMEP Nitrogen data. HT, MB prepared the ISIMIP Nitrogen data. AP, VC, RSG prepared the MODIS data. MB, JV, SL, HK prepared the climate data. SL bias-corrected the climate data. MM and MG checked the data and R-Package. All other authors provided expertise on individual datasets and how to prepare them. CPOR wrote the manuscript with the support of all authors.

12. Competing Interests

The authors declare that they have no conflict of interest.

13. Acknowledgements

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Supporting Online Material for **The PROFOUND database for evaluating vegetation models and simulating climate impacts on European forests**

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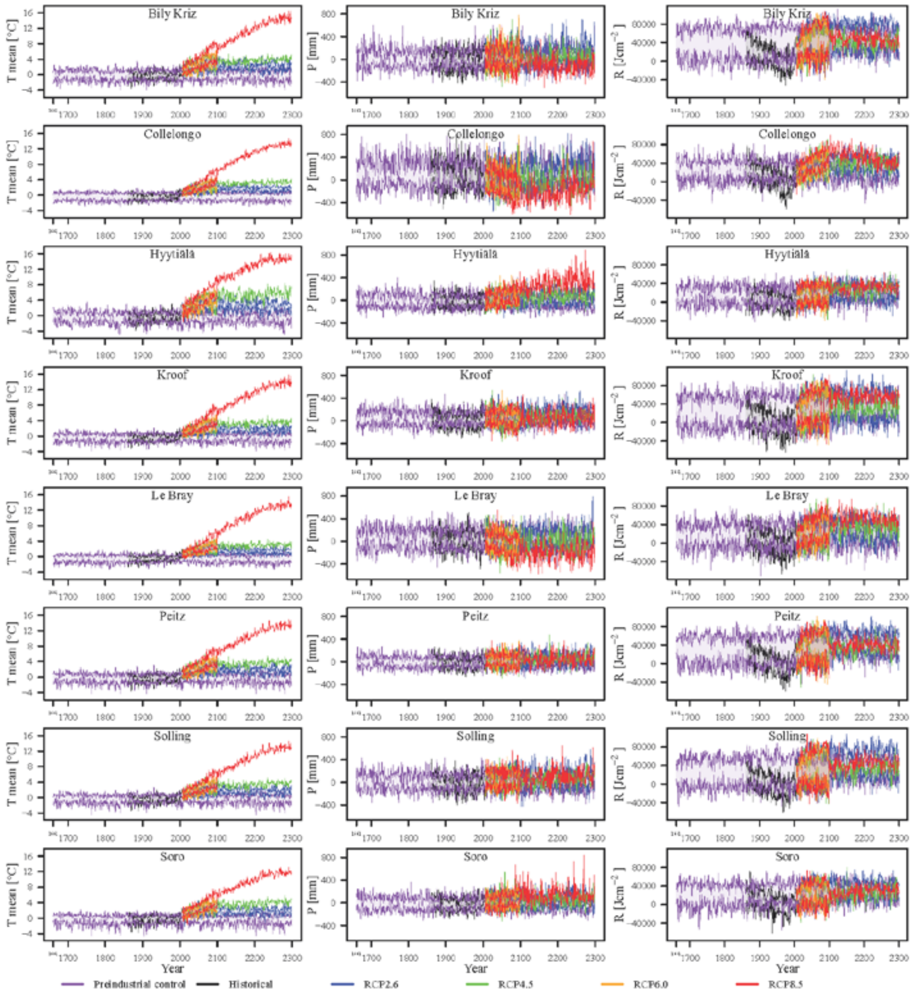

Figure SOM1: Change in mean annual temperature (T mean), annual precipitation sum (P) and annual sum of global radiation (R) over the time period 1661-2299 relative to the 1980-2005 average for the ISIMIP2b scenarios. Please note that the two Solling sites have the same climate.

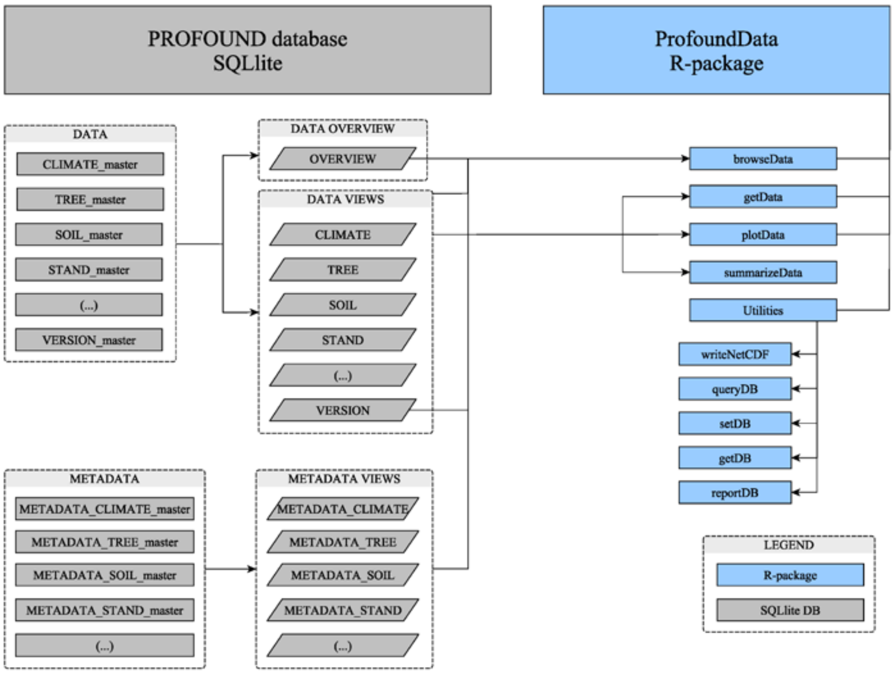

Figure SOM2: The main structure and links between the PROFOUND DB (grey) and the PROFOUNDData R-package (blue).

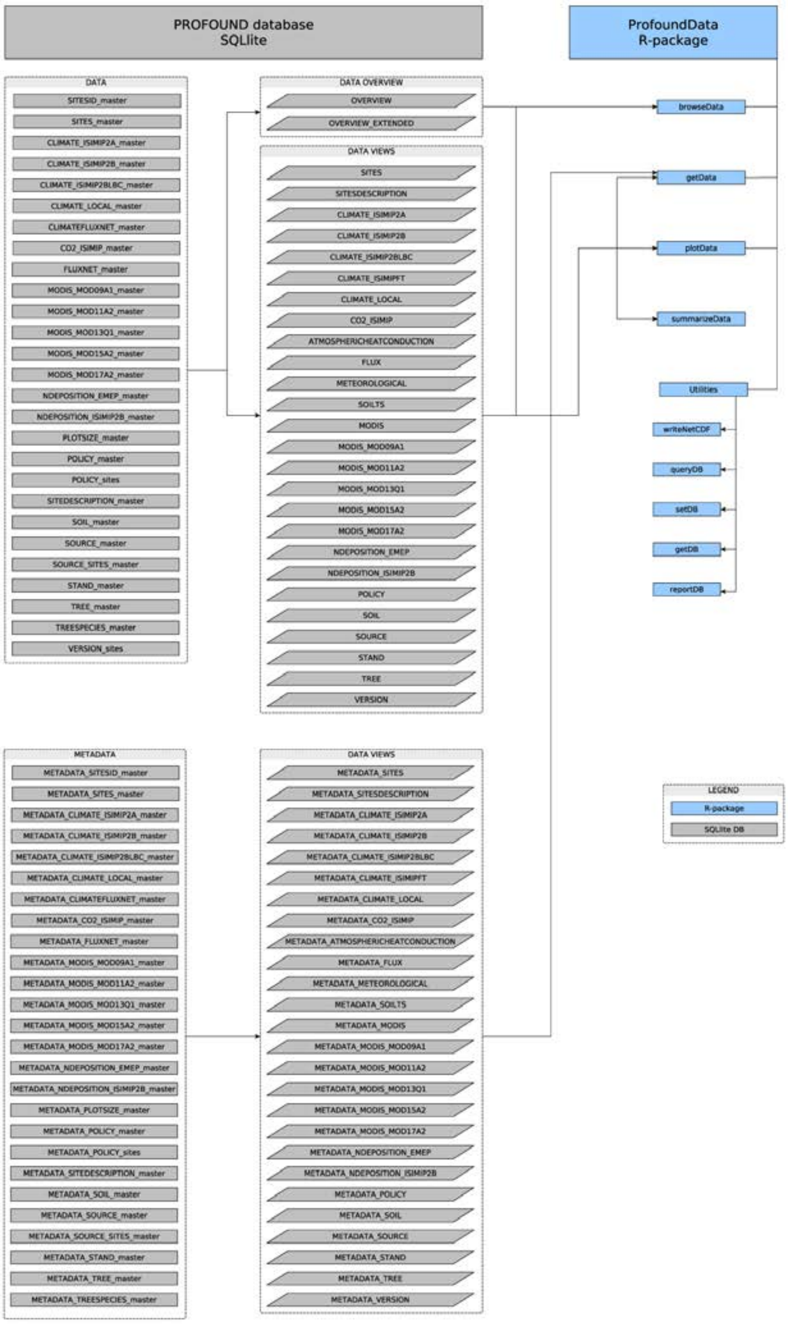

Figure SOM3: The full structure and links between the PROFOUND DB (grey) and the PROFOUNDData R-package (blue).

Table SOM1: Description of SITES variables included in the database.

variable	type	units	description
site	TEXT	adimensional	Site name
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
aspect_deg	REAL	degree	Direction of slope inclination. Degrees against North. No Value indicates no exposition.
country	TEXT	adimensional	Country
elevation_masl	REAL	m	Elevation above sea level as recorded by PI
epsg	INTEGER	adimensional	EPSG Coordinate System
lat	REAL	degree decimal	Latitude
lon	REAL	degree decimal	Longitude
natVegetation_code1	TEXT	adimensional	Code of the vegetation mapping unit group in the\"Map of the Natural Vegetation of Europe". BOHN, U.; GOLLUB, G. & HETTWER, C. (2000) Karte der natuerlichen Vegetation Europas. Massstab 1:2.500.000 Karten und Legende. Teil 1-3.. Bundesamt fuer Naturschutz, Bonn, Germany.
natVegetation_code2	TEXT	adimensional	Code of the vegetation mapping unit in the "Map of the Natural Vegetation of Europe". BOHN, U.; GOLLUB, G. & HETTWER, C. (2000) Karte der natuerlichen Vegetation Europas. Massstab 1:2.500.000 Karten und Legende. Teil 1-3.. Bundesamt fuer Naturschutz, Bonn, Germany.
natVegetation_description	TEXT	adimensional	Description of natVegetation_code2. BOHN, U.; GOLLUB, G. & HETTWER, C. (2000) Karte der natuerlichen Vegetation Europas. Massstab 1:2.500.000 Karten und Legende. Teil 1-3.. Bundesamt fuer Naturschutz, Bonn, Germany.
slope_percent	REAL	percent	Mean slope within the plot

Table SOM2: Description of SOIL variables included in the database.

variable	type	units	description
record_id	INTEGER	adimensional	Record ID as decimal number
site	TEXT	adimensional	Site name
site_id	INTEGER	adimensional	Site code as decimal number (1-99)
date	TEXT	adimensional	Unformatted date of inventory as provided for the inventory. See site specific metadata for further information on date.
bs_percent	REAL	percent	Percentage of alkaline and earth alkaline metals at CEC
cMax_percent	REAL	percent	Maximum soil carbon content
cMin_percent	REAL	percent	Minimum soil carbon content
cOrgSigma_percent	REAL	percent	Soil organic carbon content error estimate as standard deviation
cOrg_gcm3	REAL	g cm-3	Soil organic carbon content
cOrg_percent	REAL	percent	Soil organic carbon content
cSigma_kgm2	REAL	kg m-2	Soil carbon content error estimate as standard deviation
c_kgm2	REAL	kg m-2	Soil carbon content
c_percent	REAL	percent	Soil carbon content
cec_µeqg	REAL	µeq g-1	Soil cation exchange capacity
claySigma_percent	REAL	percent	Soil clay particle content error estimate as standard deviation
clay_percent	REAL	percent	Soil clay particle content
cn	REAL	adimensional	Soil C:N ratio
densitySigma_gcm3	REAL	g cm-3	Soil bulk density content error estimate as standard deviation

density_gcm3	REAL	g cm-3	Soil bulk density
fcapv_percent	REAL	percent	Soil field capacity
fineRoot_percent	REAL	percent	Distribution of fine roots accross soil horizons
gravel_percent	REAL	percent	Soil gravel particle content
horizon	TEXT	adimensional	Name of soil horizon
humus_tCha	REAL	tC ha-1	Humus carbon content
hydCondSat_cmd1	REAL	cm d-1	Soil hydraulic conductivity at saturation
layer_id	INTEGE R	adimensional	Layer code as decimal number (1-99)
lowerDepth_cm	REAL	cm	Lower soil horizon limit
mbCSigma_mgg	REAL	mg C g-1 dry soil	Soil microbial biomass carbon error estimate as standard deviation
mbC_mgg	REAL	mg C g-1 dry soil	Soil microbial biomass carbon
mbNSigma_mgNg	REAL	mg N g-1 dry soil	Soil microbial biomass nitrogen error estimate as standard deviation
mbN_mgNg	REAL	mg N g-1 dry soil	Soil microbial biomass nitrogen
minRSigma_mgkgh	REAL	mg N kg-1 h-1	Soil mineralisation rate error estimate as standard deviation
minR_mgkgh	REAL	mg N kg-1 h-1	Soil mineralisation rate
nMax_percent	REAL	percent	Maximum soil nitrogen content
nMin_percent	REAL	percent	Minimum soil nitrogen content
nOrgSigma_percent	REAL	percent	Soil organic nitrogen content error estimate as standard deviation
nOrg_percent	REAL	percent	Soil organic nitrogen content

n_kgm2	REAL	kg m-2	Soil nitrogen content
n_percent	REAL	percent	Soil nitrogen content
ofhC_percent	REAL	percent	The organic fermentative-humic (Ofh) subhorizon consists of forest litter (leaves, bark, twigs etc) showing considerable decay.
ofhN_percent	REAL	percent	Carbon content in a gram of OFH sample
ofh_gDWm2	REAL	g DW m-2	Litter layer (leaves not decomposed)
ol_gDWm2	REAL	g DW m-2	Nitrogen content in a gram of OFH sample
phSigma_h2o	REAL	adimensional	Soil pH determined with H2O error estimate as standard deviation
phSigma_kcl	REAL	adimensional	Soil pH determined by KCl error estimate as standard deviation
ph_cacl2	REAL	adimensional	Soil pH determined with CaCl2
ph_h2o	REAL	adimensional	Soil pH determined with H2O
ph_kcl	REAL	adimensional	Soil pH deterimed with KCl
porosity_percent	REAL	percent	Soil water content at saturation in the bulk soil
rainGroundWater	REAL	adimensional	Whether the soil is mostly influenced by rain or ground water
sandSigma_percent	REAL	percent	Soil sand particle content error estimate as standard deviation
sand_percent	REAL	percent	Soil sand particle content
siltSigma_percent	REAL	percent	Soil silt particle content error estimate as standard deviation
silt_percent	REAL	percent	Soil silt particle content
table_id	INTEGER	adimensional	Table code as decimal number (1-99)
texture	TEXT	adimensional	Soil texture
thicknesSigma_cm	REAL	cm	Soil thickness error estimate
thickness_cm	REAL	cm	Soil thickness

type_fao	TEXT	adimensional	Soil type after ISSS-ISRIC-FAO (1998) World reference basis for soil resources. World Soil Resources Reports 84. FAO, Rome. 92 p.
type_ka5	TEXT	adimensional	Soil type after AG Boden (2005) Bodenkundliche Kartieranleitung. Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover
upperDepth_cm	REAL	cm	Upper soil horizon limit
whcSigma_mm	REAL	mm	Soil water holding capacity error estimate
whc_mm	REAL	mm	Soil water holding capacity
whcp_percent	REAL	percent	Water holding capacity for plant available water
wiltp_percent	REAL	percent	Soil wilting point

Table SOM3: Description of CLIMATE variables included in the database.

variable	type	units	description
record_id	INTEGER	adimensional	Record ID as decimal number
site	TEXT	adimensional	Site name
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
date	TEXT	adimensional	Date in format YYYY-MM-DD
year	INTEGER	YYYY	Year with century as decimal number (0000-9999)
mo	INTEGER	MM	Month as decimal number (01-12)
day	INTEGER	DD	Day of the month as decimal number (01-31)
airpress_hPa	REAL	hPa	Mean daily air pressure
p_mm	REAL	mm	Total daily precipitation
rad_Jcm2	REAL	J cm-2	Total daily global radiation
relhum_percent	REAL	percent	Mean daily relative humidity
tmax_degC	REAL	degree Celsius	Maximum daily temperature
tmean_degC	REAL	degree Celsius	Mean daily temperature
tmin_degC	REAL	degree Celsius	Minimum daily temperature
wind_ms	REAL	m s-1	Mean daily wind speed

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Table SOM4: Description of CLIMATE_ISIMIP additional variables included in the database.

variable	type	units	description
site	TEXT	adimensional	Site name
forcingConditions	TEXT	adimensional	This category refers to the conditions underlying the climatic forcing, e.g. following historical CO2 time series, preindustrial picontrol runs or representative concentration pathways (rcp).
forcingDataset	TEXT	adimensional	This category refers to data taken from bias-corrected general circulation models (e.g. hadgem) or historical global meteorological forcing data based on bias-corrected reanalysis data (e.g. watch)

Table SOM5: Description of CO2_ISIMIP variables included in the database.

variable	**type**	**units**	**description**
record_id	INTEGER	adimensional	Record ID as decimal number
site	TEXT	adimensional	Site name
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
forcingConditions	TEXT	adimensional	This category refers to the conditions underlying the climatic forcing, e.g. following historical CO2 time series or representative concentration pathways (rcp).
year	INTEGER	YYYY	Year with century as decimal number (0000-9999)
co2_ppm	REAL	ppm	CO2 mean global concentrations for the different different forcing conditions: RCP and historical values (1975-2013)

Table SOM6: Description of NDEPOSITION and NDEPOSITION_ISIMIP2B variables included in the database.

variable	type	units	description
record_id	INTEGER	adimensional	Record ID as decimal number
site	TEXT	adimensional	Name of the site
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
year	INTEGER	YYYY	Year with century as decimal number (0000-9999)
nhx_gm2	REAL	g m-2	Total deposition of reduced nitrogen (Dry+Wet RdN)
noy_gm2	REAL	g m-2	Total deposition of oxidized nitrogen (Dry+Wet oxN)
forcingConditions	TEXT	adimensional	This category refers to the conditions underlying the climatic forcing, e.g. following historical CO2 time series, preindustrial picontrol runs or representative concentration pathways (rcp).

Table SOM7: Description of TREE variables included in the database.

variable	type	units	description
record_id	INTEGER	adimensional	Record ID as decimal number
site	TEXT	adimensional	Site name
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
species	TEXT	adimensional	Species name
species_id	TEXT	adimensional	Species text code
year	INTEGER	YYYY	Year with century as decimal number (0000-9999)
dbh1_cm	REAL	cm	Diameter at breast height
height1_m	REAL	m	Tree height
size_m2	REAL	m2	Plot size

Table SOM8: Description of STAND variables included in the database.

variable	type	units	description
record_id	INTEGER	adimensional	Record ID as decimal number
site	TEXT	adimensional	Site name
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
species	TEXT	adimensional	Species name
species_id	TEXT	adimensional	Species text code
year	INTEGER	YYYY	Year with century as decimal number (0000-9999)
aboveGroundBiomass_kgha	REAL	kg ha-1	Above ground biomass
age	INTEGER	years	Mean stand age
ba_m2ha	REAL	m2 ha-1	Basal area per hectare
branchesBiomass_kgha	REAL	kg ha-1	Branches biomass
dbhArith_cm	REAL	cm	Arithmetic mean diameter
dbhBA_cm	REAL	cm	Average diameter weighted by basal area calculated as dbhBA = (ba1*dbh1 + ba2*dbh2 + ... + bak*dbhk) / (ba1 + ba2+ ... + bak), where bai and dbhi are the basal area and dbh, respectively, of the tree i, and i = 1, 2, . . . , k
dbhDQ_cm	REAL	cm	Mean squared diameter or quadratic mean diameter calculated as dbhDQ = sqrt((dbh1^2 + dbh2^2+ ... + dbhk^2) / N), where dbhi is the diameter at breat height of tree i, i = 1, 2, . . . , k, N is the total number of trees, and sqrt is the square root
density_treeha	REAL	tree ha-1	Number of tree per ha
foliageBiomass_kgha	REAL	kg ha-1	Foliage biomass

heightArith_m	REAL	m	Arithmetic mean height
heightBA_m	REAL	m	Average height weighted by basal area or Loreys height calculated as heightBA = (ba1*h1 + ba2*h2 + ... + bak*hk) / (ba1 + ba2+ ... + bak), where bai and hi are the basal area and height, respectively, of the tree i, and i = 1, 2, . . . , k
lai	REAL	adimensional	Leaf Area Index
rootBiomass_kgha	REAL	kg ha-1	Root biomass
stemBiomass_kgha	REAL	kg ha-1	Stem biomass
stumpCoarseRootBiomass_kgha	REAL	kg ha-1	Stump and coarse roots biomass

Table SOM9: Description of FLUX variables included in the database.

variable	type	units	description
record_id	INTEGER	adimensional	Record ID as decimal number
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
date	TEXT	adimensional	Date in format YYYY-MM-DD hh:mm:ss. Derived from TIMESTAMP_START
year	INTEGER	YYYY	Year with century as decimal number (0000-9999). Derived from TIMESTAMP_START
mo	INTEGER	MM	Month as decimal number (01-12). Derived from TIMESTAMP_START
day	INTEGER	DD	Day of the month as decimal number (01-31). Derived from TIMESTAMP_START
gppDtCutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Gross Primary Production, from Daytime partitioning method, reference selected from GPP versions using a model efficiency approach. Based on corresponding NEE_CUT_XX version
gppDtCutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Gross Primary Production, calculated as stdev(gppDtCut_XX) / sqrt(40). SE from 40 half-hourly gppDtCut_XX
gppDtVutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Gross Primary Production, from Daytime partitioning method, reference version selected from GPP versions using a model efficiency approach. Based on corresponding neeVut_XX version
gppDtVutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Gross Primary Production, calculated as stdev(gppDtVut_XX) / sqrt(40. SE from 40 half-hourly gppDtVut_XX
gppNtCutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Gross Primary Production, from Nighttime partitioning method, reference selected from GPP versions using a model efficiency approach. Based on corresponding NEE_CUT_XX version
gppNtCutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Gross Primary Production, calculated as stdev(gppNtCut_XX) / sqrt(40). SE from 40 half-hourly gppNtCut_XX
gppNtVutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Gross Primary Production, from Nighttime partitioning method, reference version selected from GPP versions using a model efficiency approach. Based on corresponding neeVut_XX version

gppNtVutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Gross Primary Production, calculated as (stdev(gppNtVut_XX) / sqrt(40)). SE from 40 half-hourly gppNtVut_XX
neeCutRefJointunc_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Joint uncertainty estimation for neeCutRef, including random uncertainty and USTAR filtering uncertainty [sqrt(neeCutRef_RANDUNC^2 + ((NEE_CUT_84 - NEE_CUT_16) / 2)^2)] for each half-hour
neeCutRef_qc	INTEGER	adimensional	Quality flag for neeCutRef. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
neeCutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Net Ecosystem Exchange, using Constant Ustar Threshold (CUT) across years, reference selected on the basis of the model efficiency
neeVutRefJointunc_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Joint uncertainty estimation for neeVutRef, including random uncertainty and USTAR filtering uncertainty [sqrt(neeVutRef_RANDUNC^2 + ((neeVut_84 - neeVut_16) / 2)^2)] for each half-hour
neeVutRef_qc	INTEGER	adimensional	Quality flag for neeVutRef. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
neeVutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Net Ecosystem Exchange, using Variable Ustar Threshold (VUT) for each year, reference selected on the basis of the model efficiency
recoDtCutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Ecosystem Respiration, from Daytime partitioning method, reference selected from RECO versions using a model efficiency approach. Based on corresponding NEE_CUT_XX version
recoDtCutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Ecosystem Respiration, calculated as stdev(recoDtCut_XX) / sqrt(40). SE from 40 half-hourly recoDtCut_XX
recoDtVutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Ecosystem Respiration, from Daytime partitioning method, reference selected from RECO versions using a model efficiency approach. Based on corresponding neeVut_XX version
recoDtVutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Ecosystem Respiration, calculated as stdev(recoDtVut_XX) / sqrt(40). SE from 40 half-hourly recoDtCut_XX
recoNtCutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Ecosystem Respiration, from Nighttime partitioning method, reference selected from RECO versions using a model efficiency approach. Based on corresponding NEE_CUT_XX version
recoNtCutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Ecosystem Respiration, calculated as stdev(recoNtCut_XX) / sqrt(40. SE from 40 half-hourly recoNtCut_XX

recoNtVutRef_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Ecosystem Respiration, from Nighttime partitioning method, reference selected from RECO versions using a model efficiency approach. Based on corresponding neeVut_XX version
recoNtVutSe_umolCO2m2s1	REAL	umolCO2 m-2 s-1	Standard Error for Ecosystem Respiration, calculated as stdev(recoNtVut_XX) / sqrt(40. SE from 40 half-hourly recoNtCut_XX
timestampEnd	TEXT	YYYYMMDDHHMM	ISO timestamp end of averaging period - short format
timestampStart	TEXT	YYYYMMDDHHMM	ISO timestamp start of averaging period - short format

Table SOM10: Description of MODIS variables included in the database.

variable	type	units	description	comments	source
record_id	INTEGER	adimensional	Record ID as decimal number		
site	TEXT	adimensional	Site name		
site_id	INTEGER	adimensional	Site code as decimal number (01-99)		
date	TEXT	adimensional	Date in format YYYY-MM-DD		
year	INTEGER	YYYY	Year with century as decimal number (0000-9999)		
mo	INTEGER	MM	Month as decimal number (01-12)		
day	INTEGER	DD	Day of the month as decimal number (01-31)		
aB01_rad	REAL	radian	Angle in red. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.	Calculated from MOD09A1 after Khanna, S., A. Palacios-Orueta, M. L. Whiting, S. L. Ustin, D. R. no, and J. Litago, 2007. Development of angle indexes for soil moisture estimation, dry matter detection and land-cover discrimination. Remote Sensing of Environment 109:154 – 165. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation) in a window size of 5 observations have been filtered and substituted with the average value of the window.	MOD09A1
aB02_rad	REAL	radian	Angle in near infrared. Calculated with MOD09A1. Spatial resolution 0.5 km	Calculated from MOD09A1 after Palacios-Orueta, A., M. Huesca, M. L. Whiting, J. Litago, S. Khanna, M. Garcia, and S. L. Ustin, 2012. Derivation of phenological metrics by function fitting to time-series of spectral shape indexes AS1 and AS2: Mapping cotton phenological stages using modis time series.	MOD09A1

				Remote Sensing of Environment 12:148–159. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation) in a window size of 5 observations have been filtered and substituted with the average value of the window.	
aB05_rad	REAL	radian	Angle in SWIR 1.Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.	Calculated from MOD09A1 after Palacios-Orueta, A., M. Huesca, M. L. Whiting, J. Litago, S. Khanna, M. Garcia, and S. L. Ustin, 2012. Derivation of phenological metrics by function fitting to time-series of spectral shape indexes AS1 and AS2: Mapping cotton phenological stages using modis time series. Remote Sensing of Environment 12:148–159. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation) in a window size of 5 observations have been filtered and substituted with the average value of the window.	MOD09A1
aB06_rad	REAL	radian	Angle in SWIR 2. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.	Calculated from MOD09A1 after Palacios-Orueta, A., M. Huesca, M. L. Whiting, J. Litago, S. Khanna, M. Garcia, and S. L. Ustin, 2012. Derivation of phenological metrics by function fitting to time-series of spectral shape indexes AS1 and AS2: Mapping cotton phenological stages using modis time series. Remote Sensing of Environment 12:148–159. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation)	MOD09A1

				in a window size of 5 observations have been filtered and substituted with the average value of the window.	
evi16	REAL	adimensional	Enhanced Vegetation Index. Valid range: -0.2 - 1. Fill value: NA. Spatial resolution: 250 meters. Temporal resolution: 16-day composite.	Data are provided every 16 days at 250-meter spatial resolution. Each value corresponds to the best observation during a 16 day period.	MOD13Q1
evi16_qc	REAL	adimensional	Indicates the level of the product quality that is classified as follows: 0 = good quality, index produced; 2 = other quality, index produced, but check other qc and index produced, but most probably cloudy; 3 = index not produced due to other reasons than cloud, thus fill values were substituted by an interpolated values when the previous and the following values were available index = (indext-1 + indext+1)/2.		MOD13Q1
evi8	REAL	adimensional	Enhance Vegetation Index. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite		MOD09A1
fpar	REAL	adimensional	Proportion of available radiation in the photosynthetically active wavelengths. Valid range: 0 - 1. Fill value: NA. Spatial resolution: 1 km. Temporal resolution: 8-day composite.		MOD15A2
fpar_qc	INTEGER	adimensional	Indicates the level of the product quality that is classified as follows: 0 = Good quality (main algorithm with or without saturation); 2 = Other quality (back-up algorithm or fill values)		MOD15A2
gpp_gCm2d	REAL	gC m-2 d-1	Gross Primary Production. Valid range: -375 – 375. Fill value: NA. Spatial resolution 1 km. Temporal resolution: 8-day accumulation.	This has been calculated by dividing each 8-day values by 8 for the first 45 values/year and by 5 or 6 for the final period.	MOD17A2
gpp_qc	INTEGER	adimensional	Indicates the level of the product quality that is classified as follows: 0 = good quality, the estimates were done using the main algorithm		MOD17A2

			with or without saturation; 2 = other quality, the estimates were done using back-up algorithm.		
lai	REAL	adimensional	Leaf area index. Valid range: 0 - 10. Fill value: NA. Spatial resolution: 1 km. Temporal resolution: 8-day composite.		MOD15A2
lai_qc	INTEGER	adimensional	Indicates the level of the product quality that is classified as follows: 0 = Good quality (main algorithm with or without saturation); 2 = Other quality (back-up algorithm or fill values)		MOD15A2
lstDay_degK	REAL	degree Kelvin	Daytime land surface temperature. Valid range: 150 – 1310.7. Fill value: NA. Spatial resolution: 1 km. Temporal resolution: 8-day composite.	The level-3 MODIS global Land Surface Temperature (LST) and Emissivity 8-day data are composed from the daily 1-kilometer LST product (MOD11A1) the average values of clear-sky LSTs during an 8-day period. In this data set the daytime and nighttime LSTs, are provided. Products are validated to Stage 2, which means that their accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts.	MOD11A2
lstDay_qc	INTEGER	adimensional	Indicates the level of quality of the product that is classified as follows: 0 = good quality; 2 = other quality; 3 = interpolated, 4 = pixel not produced (NA)		MOD11A2
lstNight_degK	REAL	degree Kelvin	Nighttime land surface temperature. Valid range: 150 – 1310.7. Fill value: NA. Spatial resolution: 1 km. Temporal resolution: 8-day composite.	The level-3 MODIS global Land Surface Temperature (LST) and Emissivity 8-day data are composed from the daily 1-kilometer LST product (MOD11A1) the average values of clear-sky LSTs during an 8-day period. In this data set the daytime and nighttime LSTs, are provided. Products are validated to Stage 2,	MOD11A2

				which means that their accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts.	
lstNight_qc	INTEGER	adimensional	Indicates the level of quality of the product that is classified as follows: 0 = good quality; 2 = other quality; 3 = interpolated, 4 = pixel not produced (NA)		MOD11A2
ndvi16	REAL	adimensional	Normalized Difference Vegetation Index. Valid range: -0.2 - 1. Fill value: NA. Spatial resolution: 250 meters. Temporal resolution: 16-day composite.	Data are provided every 16 days at 250-meter spatial resolution. Each value corresponds to the best observation during a 16 day period.	MOD13Q1
ndvi16_qc	REAL	adimensional	Indicates the level of the product quality that is classified as follows: 0 = good quality, index produced; 2 = other quality, index produced, but check other qc and index produced, but most probably cloudy; 3 = index not produced due to other reasons than cloud, thus fill values were substituted by an interpolated values when the previous and the following values were available index = (indext-1 + indext+1)/2.		MOD13Q1
ndvi8	REAL	adimensional	Normalized Difference Vegetation Index. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite	Calculated from MOD09A1 after Tucker, C.J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment. 8, 127–150. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation) in a window size of 5 observations have been filtered and substituted with the average value of the window.	MOD09A1

ndwi	REAL	adimensional	Normalized Difference Water Index. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite	Calculated from MOD09A1 after Gao, B., 1996. NDWI—a normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment. 58, 257–266. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation) in a window size of 5 observations have been filtered and substituted with the average value of the window.	MOD09A1
psNet_gCm2d	REAL	gC m-2 d-1	Net Photosynthesis (GPP – maintenance respiration). Valid range: -375 – 375. Fill value: NA. Spatial resolution 1 km. Temporal resolution: 8-day accumulation.	This has been calculated by dividing each 8-day values by 8 for the first 45 values/year and by 5 or 6 for the final period.	MOD17A2
psNet_qc	INTEGER	adimensional	Indicates the level of the product quality that is classified as follows: 0 = good quality, the estimates were done using the main algorithm with or without saturation; 2 = other quality, the estimates were done using back-up algorithm.		MOD17A2
refl_qc	INTEGER	adimensional	Indicates the level of quality correction of the product (the seven bands) that is classified as follows: 0 = Highest quality, corrected product produced at ideal quality all bands; 2 = corrected product produced at less than ideal quality some or all bands, some bands could not be completely correct; 3 = interpolated, when corrected product has not been produced in one or some bands and they have been interpolated with the value Rt = (Rt-1 + Rt+1)/2; 4 = corrected product not produced, when product has not been completely corrected in one or some bands		MOD09A1

			and could not be interpolated. Data may be wrong or filled with NA; 5 = Missing data, indicates that the product was not available for that date. Some of them correspond to specific continuous periods. All the columns filled with NA.		
reflB01_percent	REAL	percent reflectance	Surface Reflectance Band 1 (620–670 nm) Red. Fill value: NA. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.		MOD09A1
reflB02_percent	REAL	percent reflectance	Surface Reflectance Band 2 (841–876 nm) NIR. Fill value: NA. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.		MOD09A1
reflB03_percent	REAL	percent reflectance	Surface Reflectance Band 3 (459–479 nm) Blue. Fill value: NA. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.		MOD09A1
reflB04_percent	REAL	percent reflectance	Surface Reflectance Band 4 (545–565 nm) Green. Fill value: NA. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.		MOD09A1
reflB05_percent	REAL	percent reflectance	Surface Reflectance Band 5 (1230–1250 nm) SWIR1. Fill value: NA. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.		MOD09A1
reflB06_percent	REAL	percent reflectance	Surface Reflectance Band 6 (1628–1652 nm) SWIR2. Fill value: NA. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.		MOD09A1
reflB07_percent	REAL	percent reflectance	Surface Reflectance Band 7 (2105–2155 nm) SWIR3. Fill value: NA. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.		MOD09A1
sani_rad	REAL	radian	Shortwave Angle Normalized Index. Valid range: -3.14 - 3.14. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite.	Calculated from MOD09A1 after Palacios-Orueta, A., Khanna, S., Litago, J., Whiting, M.L., Ustin, S.L., 2006. Assessment of NDVI	MOD09A1

				and NDWI spectral indices using MODIS time series analysis and development of a new spectral index based on MODIS shortwave infrared bands. 1st International Conference on Remote Sensing and Geoinformation Processing in the Assessment and Monitoring of Land Degradation and Desertification, Trier, Germany, pp. 207–209. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation) in a window size of 5 observations have been filtered and substituted with the average value of the window.	
sasi_rad	REAL	radian	Shortwave Angle Slope Index. Spatial resolution: 0.5 km. Temporal resolution: 8-day composite	Calculated from MOD09A1 after Khanna, S., A. Palacios-Orueta, M. L. Whiting, S. L. Ustin, D. R. no, and J. Litago, 2007. Development of angle indexes for soil moisture estimation, dry matter detection and land-cover discrimination. Remote Sensing of Environment 109:154 – 165. Note: The observations with values larger than (average + 1standard deviation) or smaller than (average – 1standard deviation) in a window size of 5 observations have been filtered and substituted with the average value of the window.	MOD09A1

Table SOM11: Description of CLIMATE_LOCAL quality variables from FLUXNET included in the database.

variable	type	units	description
site	TEXT	adimensional	Site name
airpress_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value
p_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value
rad_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value
relhum_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value
tmax_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value
tmean_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value
tmin_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value
wind_qc	REAL	adimensional	fraction between 0-1; indicating percentage of measured and good quality gapfill half-hourly data used to create the daily value

Table SOM12: Description of ATMOSPHERIC_HEAT_CONDUCTANCE variables included in the database.

variable	**type**	**units**	**description**
record_id	INTEGER	adimensional	Record ID as decimal number
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
date	TEXT	adimensional	Date in format YYYY-MM-DD hh:mm:ss. Derived from TIMESTAMP_START
year	INTEGER	YYYY	Year with century as decimal number (0000-9999). Derived from TIMESTAMP_START
mo	INTEGER	MM	Month as decimal number (01-12). Derived from TIMESTAMP_START
day	INTEGER	DD	Day of the month as decimal number (01-31). Derived from TIMESTAMP_START
hCORRJOINTUNC_Wm2	REAL	W m-2	Joint uncertainty estimation for h as sqrt(hRANDUNC^2 + ((hCORR75 - hCORR25) / 1.349)^2)
hCORR_Wm2	REAL	W m-2	Sensible heat flux, corrected hFMDS by energy balance closure correction factor
hFMDS_Wm2	REAL	W m-2	Sensible heat flux, gapfilled using MDS method
hFMDS_qc	INTEGER	adimensional	Quality flag for hCORR. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
leCORRJOINTUNC_Wm2	REAL	W m-2	Joint uncertainty estimation for le
leCORR_Wm2	REAL	W m-2	Latent heat flux, corrected le_FMDS by energy balance closure correction factor
leFMDS_Wm2	REAL	W m-2	Latent heat flux, gapfilled using MDS method
leFMDS_qc	INTEGER	adimensional	Quality flag for leCORR. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
timestampEnd	TEXT	YYYYMMDDHHMM	ISO timestamp end of averaging period - short format

timestampStart	TEXT	YYYYMMDDHHMM	ISO timestamp start of averaging period - short format

Table SOM13: Description of SOILTS variables included in the database.

variable	type	units	description
record_id	INTEGER	adimensional	Record ID as decimal number
site_id	INTEGER	adimensional	Site code as decimal number (01-99)
date	TEXT	adimensional	Date in format YYYY-MM-DD hh:mm:ss. Derived from TIMESTAMP_START
year	INTEGER	YYYY	Year with century as decimal number (0000-9999). Derived from TIMESTAMP_START
mo	INTEGER	MM	Month as decimal number (01-12). Derived from TIMESTAMP_START
day	INTEGER	DD	Day of the month as decimal number (01-31). Derived from TIMESTAMP_START
timestampEnd	TEXT	YYYYMMDDHHMM	ISO timestamp end of averaging period - short format
timestampStart	TEXT	YYYYMMDDHHMM	ISO timestamp start of averaging period - short format
swcFMDS1_degC	REAL	percent	Soil water content, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
swcFMDS1_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
swcFMDS2_degC	REAL	percent	Soil water content, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
swcFMDS2_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
swcFMDS3_degC	REAL	percent	Soil water content, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
swcFMDS3_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
swcFMDS4_degC	REAL	percent	Soil water content, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
swcFMDS4_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
swcFMDS5_degC	REAL	percent	Soil water content, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)

swcFMDS5_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
tsFMDS1_degC	REAL	degree Celsius	Soil temperature, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
tsFMDS1_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
tsFMDS2_degC	REAL	degree Celsius	Soil temperature, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
tsFMDS2_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
tsFMDS3_degC	REAL	degree Celsius	Soil temperature, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
tsFMDS3_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
tsFMDS4_degC	REAL	degree Celsius	Soil temperature, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
tsFMDS4_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.
tsFMDS5_degC	REAL	degree Celsius	Soil temperature, gapfilled with MDS (numeric index \"#\" increases with the depth, 1 is shallowest)
tsFMDS5_qc	INTEGER	adimensional	Quality flag for tsFMDS#. 0 = measured; 1 = good quality gapfill; 2 = medium; 3 = poor.

Text SOM 1 Reconstruction of the stand development at Sorø (SOR-DK)

Commented [r1]: Update: either reduce to 1996 or add data starting in 1958 to database?

The objective of this section is to describe how we reconstructed the stand development from the available data (Table SOM14), where exact data on thinning were not available. Therefore, we used the yield table to fill the missing information assuming that management at the site was following the general recommendations for this site (Møller 1933). Because of considerable differences in tree densities, we needed to scale the management cycle of Møller (1933) to the empirical data from our stand. We used mainly Møller's thinning schedule, i.e. at which age the stand was usually thinned. For this we reconstructed the stand backward, i.e. starting at 288 trees ha^{-1} at age 90 yr in 2010 until 1921. This tree density (*r*), i.e. numbers of trees per ha, was increased in years when the schedule (*S*) is one, i.e. forcing a thinning event. The degree of thinning is described by the two right hand side terms as a root function depending on the tree density itself. This procedure forced the fitting procedure to stay closely to the measured data at the end of the stand development. The fitted values for the empirical parameters *a* and *c* were 0.047 ± 0.012 (p=0.0045 **) and -1.26 ±0.107 (p=2.44E-6 ***), respectively. The results are displayed in Figure SOM2. Comparison with data after Møller's yield table shows that the reduction of tree density started earlier at Sorø than in the normal stand development. One probable reason for this is that the beech forest at Sorø might have been initiated underneath a canopy of a few remaining old beech trees. This could have fostered more intensive self-thinning than under normal conditions. On the other hand, the assumed initial number of beech trees of 6000 per ha, might be an overestimation given the numbers in 1933, that have been meticulously measured. The tree density values in the first 20 years are very uncertain. On the other hand, we are confident that the thinning scheme of Møller has been adopted by the Danish forestry management at least over a large part of the stand lifetime.

Table SOM14: New version on Management Information available

Year/Periods	**Tree density [ha^{-1}]**	**Source**	**Method**
1921-1930	6000	Møller (1933) + Th Kaspersens notes (assumed)	from yield table + notes from forester
1933	3550	from Munds Målebog	assumed measured in 468 m^2
1944	968	Taksationsbog	From volume and average DBH and height
1977	384	Estimated by Sorø Akademi	from yield table

1992	369	Estimated by Sorø Akademi	from yield table
1995	361	Estimated by Sorø Akademi	from yield table
2005 (03. 2006)	326.3	DTU measurements (P87)	measured
2007	288	DTU measurements (P87)	Measured
2014	199	DTU measurements (P87)	Measured
2017	199	DTU measurements (P87)	Measured

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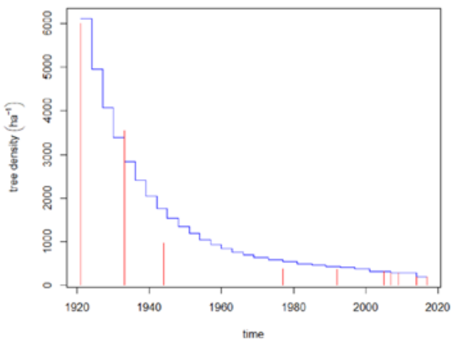

Figure SOM2. Reconstruction of the tree density at Sorø, division 335. During the years from 1921 to, at least, 1944 there was a canopy of old trees. The blue step function is the reconstructed series using the thinning intervals as in Møller (1933) and thinning intensities that match the observations best (red bars, see Table SOM14).

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Thinning

Unfortunately thinning of the trees is not anymore documented. Anders Grube, the current forest manager, explained the rule for thinning, which will be applied from now (= 2007 +) on, is thinning interval = tree age / 10 in years. This rule of thumb indicates a slight change from Møller's suggestion, i.e. thinning every 5 years at this stand age. Only a very few examples on how much wood volume was actually thinned can be found. In one example, 2007, thinning was performed in division 336 (planted in 1941, i.e. 66 years) the standing stock was 999 m^3 and he removed 40 m^3, which is 999/4.11 = 243 m^3 ha^{-1} and 40/4.11 = 10 m^3 ha^{-1} for standing stock and harvested wood, respectively. This means for this particular site, a relative extraction of 4 %. This is smaller than Møller's suggestion (ca. 11 %, for this age, Møller (1933)). Measurements of tree growth as part of contemporary forest planning (by Klaus Wunsch (KW-plan, c/o) are only performed on some divisions, none of them in the footprint of the tower. For this reason, we decided to use the available data from the forest owner, Sorø Akademi (Table SOM14), and use yield table information and tree rings to reconstruct thinning events and the stand development. We concentrate on division 335 where the inventory, ecological and meteorological measurements have been taken. With this approach it is not possible to reconstruct the exact thinning activity in a certain year, but instead the general forest development is being reconstructed. The thinning events are only accurate within a 3-5 years period.

Tree-ring data

In addition to estimating tree density through time, we collected tree-ring data from within the flux-tower footprint in Sorø to reconstruct the growth of individual trees and the stand at annual resolution. This was done in two separate sampling campaigns conducted in 2009 and 2017, which were subsequently merged into one homogeneous dataset. Our sampling targeted two fixed plots, a larger one close to the tower (European beech; 58 trees) and a smaller one at a distance of approximately 100 m (European beech and European ash; 12 trees). For each tree within the two plots, we measured the diameter at breast height, as well as tree and crown base heights using a Vertex IV device (Haglöfs, Sweden). In addition, we recorded the position (distance and azimuth) of each tree relative to the plot center. We then collected two increment cores to the pith of each tree, perpendicular to each other to capture circumferential growth variations. These core samples were brought to the lab and prepared according to standard dendrochronological procedures. We measured annual radial growth increment to a precision of 0.01 mm using a Lintab 5 device and the connected TSAP-Win software. The raw ring-width measurements from each sample were visually and statistically cross-dated to assure that the correct calendar year was assigned to each ring. In addition, we estimated the number of missing rings to the pith of the tree ("pith-offset"), which is required in case these data will be used to calculate tree basal area or biomass increment.

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Stand-scale data from reconstructed single tree data

After deriving the single tree diameter-at-breast-height (DBH) from the tree-ring data, the individual tree age was calculated. This was done by deriving the tree age at coring from the age of the tree ring and adding 4 years which is assumed to be the time an individual needs to reach breast height (1.3 m) and back projecting the age in time. The individual total tree height was estimated using the site-specific age-dependent height model of Nord-Larsen et al. (2009). In order to derive stand-scale data the reconstructed single tree traits (DBH, height and age) are averaged for seven DBH classes of 10 cm class width. The class assignment of single trees is based on the single tree data in 2009 and kept constant over time. The frequency distribution per DBH class is derived for the period 1994-2017 by interpolation and extrapolation of field measurements in 2005, 2009 and 2017 (table SOM15). This frequency distribution is used to weight the averaged DBH class values in order to calculate stand-scale data of DBH, height and age. Stand-scale tree density is derived as described above.

The full set of reconstructed individual tree data from 1925 to 2017 as well as derived DBH class data and stand data for 1994-2017 can be found in *Soroe_DBH_H_AGE_20200428.RData* (http://doi.org/10.5880/PIK.2020.006/). A description of the data found in this file can be displayed with *cat(Soroe_DBH_H_AGE.l.des)* using the statistical computing software R after loading the data file.

Table SOM15: DBH class frequency distribution per year. Note from 2005 to 2017 this is a per annual assessment (n=87) and before that the diameters were extrapolated from 2005/2009 to 1994. DBH classes have 10 cm width.

year	**class 1**	**class 2**	**class 3**	**class 4**	**class 5**	**class 6**	**class 7**
1994	0.069	0.241	0.115	0.322	0.195	0.057	NA
1995	0.069	0.241	0.092	0.322	0.218	0.057	NA
1996	0.046	0.264	0.069	0.299	0.264	0.057	NA
1997	0.034	0.264	0.08	0.276	0.287	0.057	NA
1998	0.034	0.264	0.08	0.264	0.299	0.057	NA
1999	0.034	0.253	0.092	0.253	0.31	0.057	NA
2000	0.034	0.241	0.092	0.264	0.31	0.057	NA
2001	0.034	0.241	0.08	0.276	0.31	0.057	NA
2002	0.023	0.253	0.092	0.253	0.322	0.057	NA
2003	0.023	0.253	0.092	0.207	0.368	0.046	0.011
2004	0.023	0.253	0.08	0.195	0.391	0.046	0.011
2005	0.023	0.253	0.069	0.207	0.379	0.057	0.011

2006	0.026	0.218	0.051	0.179	0.436	0.077	0.013
2007	0.026	0.205	0.064	0.167	0.436	0.09	0.013
2008	0.026	0.205	0.064	0.154	0.449	0.077	0.026
2009	0.026	0.205	0.064	0.141	0.462	0.077	0.026
2010	0.026	0.184	0.053	0.158	0.434	0.105	0.039
2011	0.03	0.136	0.045	0.152	0.455	0.136	0.045
2012	0.031	0.138	0.046	0.138	0.492	0.123	0.031
2013	0.031	0.138	0.046	0.138	0.462	0.154	0.031
2014	0.019	0.151	0.057	0.094	0.358	0.283	0.038
2015	0.019	0.151	0.057	0.094	0.453	0.189	0.038
2016	NA	0.17	0.057	0.038	0.396	0.302	0.038
2017	0.019	0.151	0.038	0.057	0.377	0.321	0.038

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