10 **Forest Models (Regional, Forest stand-level models)**

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10.1 Introduction to multi-model simulations in ISIMIP2a and PROFOUND

This is a protocol to support multi-model simulations of forest stands for both model evaluation with observed data but also for model projections under climate change. In addition to the general ISIMIP input data to be used for these simulations (mostly climate data), a number of sites has been selected for which a wide range of forest models can be rather easily initialized and observational data is available for model evaluation. The most important experiments are listed in **Table 23**. The priority for carrying out the experiments is: 1a, 2a, 1b, 2b. A few important particularities for the simulations are listed below.

1) The modeling experiments mostly encompass managed forests. The standard management is a business-as-usual (BAU) management and mimics the observed stand development described by simple, standard management routines that all models can implement. The BAU management corresponds best to the forest management approach “intensive even-aged forestry” as defined by Duncker et al. 2012. The management is defined by the data available for each site (e.g. stem numbers) and after the observations end, missing information is to be substituted with data from **Table 24** - **Table 27**. The management for the future runs should be designed according to the same tables. A “natural reference run (nat)” without any management has also been included in the experiments. The “nat”-run will help assessing the influence of forest management. Dynamic (adaptive) management or more complicated management practices such as coppicing are to be kept for future simulations.
2) Some of the models may require some kind of calibration or model development before they can contribute to ISIMIP. Such alterations of the model can influence the results of a model comparison and “model calibration” is understood differently by different modelers. All alterations to the model in the framework of this exercise should be reported in the model experiment documentation in order to support the understanding of model results. Whenever the model calibration or development is driven by an improvement of the model after a comparison to data that were originally made available in ISIMIP for model evaluation, a part of those data should be kept aside for model evaluation and not used for calibration.

a. Model development needed to run a model at specific sites is welcomed and needs to be transparent/ properly documented (e.g. adjustment of phenology model to include chilling effects). This is also applicable for more general calibration (i.e. fixing parameters once but not changing afterwards) for example to include a new tree species in a model.
b. Manual or automatic site-specific “tuning” of species-specific and process-specific parameters should be avoided. The same “model” (i.e. also with the same parameter values) should be used in all simulations. If needed, any tuning needs to be documented in a transparent way and should be backed up by existing data (e.g. from TRY-database). If your model contains genetic processes where the change in parameters is part of the model processes, this is naturally part of “your model approach” and should be clearly spelled out as part of the documentation of your model. In this specific case, please contact the sectoral coordinators to discuss if it makes sense to include a “genetic adaptation” and a “parameter-fixed, control” run.

3) The focus topic of ISIMIP2a is “extreme events”. In forest this covers both impacts of extreme climatic events but also of disturbances. A general test of the models representing the impacts of extreme climate events could be a comparison with the effects of the 2003 heatwave at flux sites (Ciais et al. 2005, Table 1) done in postprocessing. If models simulate specific disturbances such as bark beetle outbreaks or storm damage (so called “dist” runs) that can be switched on and off in the model they can take part in the experiments that have been designed to tease out the influence of disturbances. Together with the standard runs of experiments 1a and 2a (“nodist” runs), the “dist” runs can be used to isolate the effect of disturbances. The disturbances for this experiment are listed in **Table 29**. If you are in doubt if it qualifies as a disturbance, please get in touch with reyer@ik-potsdam.de.

4) Future runs will simulate a continuation of forest stand development from past runs to account for (natural) regeneration and mortality which are crucial features of forest dynamics. For some of the stands, running simulations until 2100 will result in very old forests. If you have to harvest the stands because of a maximum age or so (c.f. **Table 25** and **Table 26**), please proceed after harvest as your model usually does, e.g. plant the same tree species again or allow for regeneration of the same species. This should happen according to the regeneration guidelines outlined in

5) **Table 27**.

6) Important amendments to the overall ISIMIP protocol: The standard reporting period is 1971-2000 but since we have sometimes data for model initialization and validation going back even further in time, you should always start your reporting period for the first time step for which stand data is available (e.g. 1948 for the Peitz stand) and run your model until the last point in time where climate data is available. Similarly, if the model runs only start later than 1971, the reporting period is shorter. If the data for model initialization is only available very late (e.g. KROOF starts in 1998 only, you do not need to run your model for those climatic datasets which end early (e.g. Watch ending in 2001 already). Likewise, for the future runs using GCM data, the sites have to be initialized after 1950 because the GCM historical data is only available from 1950 onwards. This pertains to the sites Peitz and Soro (see

7) **Table 26**).

8) Important amendments to the spin-up as defined in the overall ISIMIP protocol: For those forest models requiring a spin-up, please use the spin-up data as explained in Chapter 5. For the runs using “observations from local meteorological stations or likewise”, Louis Francois will provide time series based on Princeton data but so that it matches the average of the data at the meteorological station during the period where meteorological measurements have been taken.

10.2 Experiments

Table 23 provides an overview of all experiments to be run with regional forest models in ISIMIPa. This table is for your reference only; please read chapters 1-6 of the general ISIMIP protocol and this whole section carefully before beginning with the experiments. The future simulations here are meant to be catch-up runs with the ISIMIP Fast track data. In case of any questions please contact info@isimip.org. Please note that aside from harmonized climate, stand, management and soil input, the default settings of your model should be used. Also note that for output data files the **file name is all lower case**! Models should run all four RCPs for each model before moving on to the next GCM.

Table 23 Experiment summary for regional forest models. Each experiment is to be carried out for each site named in **Table 24.** For management scenarios see **Table 25** - **Table 27**.

	Climate Data	Scenario	Management	Other settings (sens-scenario)	# runs
Historical runs without disturbances (Experiment 1a)	Observations from local meteorological station or likewise	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2nodist)	2
	PGMFD v.2 (Princeton)	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2nodist)	2
	GSWP3	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2nodist)	2
	WATCH (WFD)	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2nodist)	2
	WATCH+WFDEI.GPC	hist	1. Observed management (man)	historical CO_2 without disturbances	2

	C		2. Natural reference run (nat)	(co2nodist)	
Future runs without disturbances (Experiment 2a)	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat) without management	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2nodist)	8
	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, without disturbances (noco2nodist)	8
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2nodist)	8
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, without disturbances (noco2nodist)	8
	GCM3 (MIROC-ESM-CHEM)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2nodist)	8
	GCM3 (MIROC-ESM-CHEM)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, without disturbances (noco2nodist)	8
	GCM4 (GFDL-ESM2M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2nodist)	8
	GCM4 (GFDL-ESM2M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0),	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, without disturbances (noco2nodist)	8

		8.5 (rcp8p5)			
	GCM5 (NorESM1-M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2nodist)	8
	GCM5 (NorESM1-M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, without disturbances (noco2nodist)	8
Historical runs with disturbances (Experiment 1b)	Observations from local meteorological station or similar data	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 with disturbances (co2dist)	2
	PGMFD v.2 (Princeton)	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 with disturbances (co2dist)	2
	GSWP3	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 with disturbances (co2dist)	2
	WATCH	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 with disturbances (co2dist)	2
	WATCH+WFDEI.GPCC	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 with disturbances (co2dist)	2
Future runs with disturbances (Experiment 2b)	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 (co2) with disturbances (co2dist)	8
	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, with disturbances (noco2dist)	8
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6), 4.5	1. Observed management (man) +BAU after observation stops	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 with disturbances (co2dist)	8

		(rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	2. Natural reference run (nat)		
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, with disturbances (noco2dist)	8
	GCM3 (MIROC-ESM-CHEM)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 with disturbances (co2dist)	8
	GCM3 (MIROC-ESM-CHEM)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, with disturbances (noco2dist)	8
	GCM4 (GFDL-ESM2M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 with disturbances (co2dist)	8
	GCM4 (GFDL-ESM2M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops with disturbances (dist) 2. Natural reference run (nat) with disturbances (dist)	historical CO_2 + fixed CO_2 from 2000 onwards, with disturbances (noco2dist)	8
	GCM5 (NorESM1-M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 with disturbances (co2dist)	8
	GCM5 (NorESM1-M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) +BAU after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards, with disturbances (noco2dist)	8
					180

10.3 Sector-specific input

The input and evaluation data is provided through the PROFOUND database including a R-package to explore the database. Until the database is officially released, please get in touch with Christopher Reyer (reyer@pik-potsdam.de) to access the database.

Table 24 Overview of the forest stands to be simulated in ISIMIP/PROFOUND.

Site name	Lat	Lon	Country	Forest type	Species	Management	Period / years with data available (either as input or for evaluation)
hyytiala	61.8475	24.295	FI	Even-aged Conifer	pisy, piab with some deciduous mix	Thinning, data available about BA removed, nr of trees removed & individual data	Flux data: 1997-2014 Stand data: 1997-2014 Climate Data: 1997-2014 Soil Data: in principle the same as above, including water content, soil properties, etc Note that an experimental plot of pine contains a lot of data while footprint of flux tower is larger Please note that the deciduous admixtures only appear in the data at a later stage and hence do not need to be simulated.
peitz	51.9166	14.35	DE	Even-aged Conifer	pisy	Yes, weak thinning from below, plantation density should be 10000/ha	Stand data: 1948 – 2011 (13 observations) Climate Data: 1901-2010 (climate station DWD Lieberose) Soil Data: available (Source: LFE)
solling_beech	51.77	9.57	DE	Even-aged Deciduous	fasy	Yes	Stand data: 1967-2010 Climate Data: 1999-2009 Soil Data: yes
solling_spruce	51.77	9.57	DE	Even-aged Conifer	piab	Yes	Stand data: 1967-2010 Climate Data: 1999-2009 Soil Data: yes

soro	55.4858 44	11.644 616	DK	Even-aged Deciduous	fasy	Yes?	Flux data: 1996-2008 Stand data: Climate Data: Soil Data:
kroof	48.25	11.4	DE	Mixed deciduous and conifers		unmanaged/ thinning from below in past 20 years,	
le_bray	44.7171 1	-0.7693	FR	Even-aged Conifer	pipi	Yes, plantation density should be 1250/ha	Flux data: 1996-2008 Stand data: Climate Data: Soil Data:
collelongo	41.8494	13.588 1	IT	Even-aged Deciduous	fasy	?	Flux data: 1996-2008 (evtl.-2012) Stand data: partly Climate Data: 1996-2008 Soil Data: partly (Source: Euroflux, Level2, CarboEurope)
bily_kriz	49.3	18.32	CZ	Even-aged Conifer	piab	?	Data from FLuxnet2015 and Lenka Krupkova (pers. Comm.)
hesse	48.6742	7.0656	FR	Even-aged Deciduous	fasy	?	Flux data: 1996-2008 Stand data: published (Granier) Climate Data: like flux data Soil Data: published (Granier)
brasschaat	51.3092	4.5205	BE	Mixed deciduous and conifers	pisy	?	Flux data: 1996-2008 Stand data: BL15, Cermak 1998 Climate Data: 1997-2007 Soil Data: FutMon project S(source: Level II, Euroflux)

espirra	38.6394	-8.6018	PT	Even-aged Deciduous	eugl		Flux data: 2002-2008 Stand data: ? Climate Data: 2002-2008 Soil Data:
puechabon	43.74139	3.595833	FR	Evergreen			

Table 25 Business-as-usual management scenarios for the different tree species. If there is no information about management of the stands available in Table 29, please apply the following generic management guidelines. For past simulations and depending on the model, modellers should use the observed stem numbers from the time series of stand and tree level data to mimick stand management. Future management should then be added according to the generic management guidelines outlined below. E.g., The last management for the Peitz site can be infered from the tree data is taking place in 2011, hence the next management would then happen in 2026 according to **Table 26**.

Species	Thinning regime	Intensity [% of basal area]	Interval [yr]	Stand age for final harvest	Remarks
pisy	below	20	15	140	Pukkala et al. 1998; Fuerstenau et al. 2007; Gonzales et al-2005; Lasch et al. 2005
piab	below	30	15	120	Pape 2008; Pukkala et al. 1998; Hanewinkel and Pretzsch-2000; Sterba 1986; Laehde et al. 2010
fasy	above	30	15	140	Schuetz 2006; Mund et al. 2004; Hein and Dhote 2006; Cescatti and Piutti 1998
quro/qupe	above	15	15	200	Hein and Dhote 2006; Fuerstenau et al. 2007; Štefančík 2012; Kerr 1996; Gutsch et al. 2011
pipi	below	20	10	45	Management after Loustau et al. 2005 & Thivolle-Cazat et al. 2013
eugl	below	30?	10	40?	preliminary

Table 26 Management schedules for the sites included in the simulation experiments. The first available data point is used for model initialization (Ini). Following data points are used to mimick historic management (HM). When no more data is available, the generic management rules from **Table 25** are being used (FM). For a better overview, harvest and planting are marked in bold.

Name	Ini	HM	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11	Remarks
Bily Kriz	1997	1998-2015^{T}	2030^{T}	2045^{T}	2060^{T}	2075^{T}	2090^{T}							
Collelongo	1992	1997-2012^{T}	2027^{T}	**2032**^{H}	**2033**^{P}	2048^{T}	2063^{T}	2078^{T}	2093^{T}					
Hyytälä*	1995	1996-2011^{T}	2026^{T}	2041^{T}	2056^{T}	2071^{T}	2086^{T}							Only include pine and spruce not hardwoods in simulation
KROOF*	1997	1999-2010^{T}	2025^{T}	2040^{T}	2055^{T}	2070^{T}	2085^{T}	2100^{T}						
LeBray	1986	1987-2009^{T}	**2015**^{H}	**2016**^{P}	2026^{T}	2036^{T}	2046^{T}	2056^{T}	**2061**^{H}	**2062**^{P}	2072^{T}	2082^{T}	2092^{T}	
Peitz	1948**	1952-2011^{T}	2026^{T}	**2040**^{H}	**2041**^{P}	2055^{T}	2070^{T}	2085^{T}	2100^{T}					
Solling_beech*	1980	1985-2000^{T}	**2015**^{H}	**2016**^{P}	2031^{T}	2046^{T}	2061^{T}	2076^{T}	2091^{T}					
Solling_spruce*	1967	1968-2009^{T}	**2024**^{H}	**2025**^{P}	2040^{T}	2055^{T}	2070^{T}	2085^{T}	2100^{T}					
Soro	1944**	1945-2005^{T}	2020^{T}	2035^{T}	2050^{T}	**2061**^{H}	**2062**^{P}	2077^{T}	2092^{T}					

Ini = Initialization data, HM = Historic Management, FM = Future Management, T=Thinning, H= Harvest, P=Planting, *=maximum age extended a bit to match local management during observed period or avoid harvesting just before the end of the simulation, **= the GCM data only starts in 1950, hence for future runs (Experiment 2a), you have to initialize these forests at the first time step after 1949 (i.e. 1952 for Peitz and 1950 for Soro). For the historical validation runs (Experiment 1a) you can start with the first available stand initialization.

Table 27 Planting information for the sites included in the simulation experiments. DBH is defined as diameter at breast height of 1.30m. Thenumbers in brackest indicate plausible ranges.

Name	Density ha^{-1}	Age years	Height m	DBH cm	age when DBH is reached years	Remarks
Bily Kriz	4500	4	0.5	na	9	Historical planting density was 5000/ha but current practices are 4500/ha only
Collelongo	10000	4	1.3	0.1	**4**	Only a rough approximation, usually natural regeneration is the regeneration method.
Hyytälä	2250 (2000-2500)	2	0.25 (0.2-0.3)	na	6 (5-7)	
KROOF (beech)	6000 (5000-7000)	2	0.6 (0.5-0.7)	0.5	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)	0.5	7	See above
LeBray	1250 (1000-14000)	1	0.2 (0.1-0.25)	na	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 at 7-year old when seedlings reach the size for DBH recruitment. ➔ modelers could mimic this by "planting" trees with DBH of 7.5cm and 6m height in 1978 with a density of 1250 trees/ha
Peitz	9000 (8000-10000)	2	0.175 (0.1-0.25)	**0.1**	**5**	The “age when DBH is reached = 5” is an estimate
Solling_beech	6000 (5000-7000)	2	0.6 (0.5-0.7)	0.5	5	
Solling_spruce	2250 (2000-2500)	2	0.35 (0.3-0.4)	0.5	7	
Soro	6000	4	0.82	na	6	

10.4 Output data

Table 28 Variables to be reported by forest models. Abbreviations are provided in **Table 29**. Variables should be reported as documented in section 6.

Long name	units		output variable name	frequency	comment
Essential (mandatory) outputs					
Mean DBH	cm	per species and stand total	**dbh_<species/total>**	year	
Mean DBH of 100 highest trees	cm	stand total	**Dbh_domhei**	year	
Stand Height	m	per species and stand total	**height_<species/total>**	year	For models including natural regeneration this variable may not make sense, please report dom_height
Dominant Height	m	stand total	**dom_height**	year	Mean height of the 100 highest trees
Stand Density	Trees/ha	per species and stand total	**density_<species/total>**	year	
Basal Area	$m^2 ha^{-1}$	per species and stand total	**ba_<species/total>**	year	
Volume of Dead Trees	$m^3 ha^{-1}$	per species and stand total	**mort_<species/total>**	year	
Harvest by dbh-class	$m^3 ha^{-1}$	per species and stand total and dbh-class	**harv_<species/total>_<dbhclass>**	year	
Remaining stem number after disturbance and management by dbh class	Trees/ha	per species and stand total	**stemno_<species/total>_<dbhclass>**	year	
Stand Volume	$m^3\ ha^{-1}$	per species and stand total	**vol_<species/total>**	year	
Carbon Mass in Vegetation biomass (incl. Soil veg.?)	$kg\ C\ m^{-2}$	per species and stand total	**cveg_<species/total>**	year	
Carbon Mass in Litter Pool	$kg\ C\ m^{-2}$	per species and stand total	**clitter_<species/total>**	year	Info for each individual pool.
Carbon Mass in Soil Pool	$kg\ C\ m^{-2}$	per species and stand total	**csoil_<species/total>**	year	Info for each individual

					soil layer
Tree age by dbh class	yr	per species and stand total	**age_<species/total>_<dbhclass>**	year	
Gross Primary Production	kg m^{-2} s^{-1}	per species and stand total	**gpp_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production	kg m^{-2} s^{-1}	per species and stand total	**npp_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Autotrophic (Plant) Respiration	kg m^{-2} s^{-1}	per species and stand total	**ra_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Heterotrophic Respiration	kg m^{-2} s^{-1}	stand total	**rh_<total>**	day	As kg carbon*m^{-2}*s^{-1}
Net Ecosystem Exchange	kg m^{-2} s^{-1}	per stand	**nee_<total>**	day	As kg carbon*m^{-2}*s^{-1}
Mean Annual Increment	m^3 ha^{-1}	per species and stand total	**mai_<species/total>**	year	
Fraction of absorbed photosynthetically active radiation	%	per species and stand total	**fapar_<species/total>**	day	
Leaf Area Index	m^2 m^{-2}	per species and stand total	**lai_<species/total>**	mon	
Species composition	% of basal area	per ha	**species_<species>**	year (or once if static)	The categories may differ from model to model, depending on their species and stand definitions.
Total Evapotranspiration	kg m-2 s-1	stand total	**evap_<total>**	day	sum of transpiration, evaporation, interception and sublimation. (=intercept+esoil+trans)
Evaporation from Canopy (interception)	kg m-2 s-1	per species and stand total	**intercept_<species/total>**	day	the canopy evaporation+sublimatio n (if present in model).
Water Evaporation from Soil	kg m-2 s-1	per stand	**esoil**	day	includes sublimation.
Transpiration	kg m-2 s-1	per species and stand total	**trans_<species/total>**	day	
Soil Moisture	kg m-2	per stand	**soilmoist**	day	If possible, please provide soil moisture for all depth layers (i.e. 3D-

					field), and indicate depth in m. Otherwise, provide soil moisture of entire column.
Optional outputs					
Removed stem numbers by size class by natural mortality	Trees ha^{-1}	per species and stand total	**mortstemno_<species/total>_<dbhclass>**	year	
Removed stem numbers by size class by management	Trees/ha	per species and stand total	**harvstemno_<species/total>_<dbhclass>**	year	
Volume of disturbance damage	$m^3 ha^{-1}$	per species and stand total	**dist_<dist_name>**	year	
Nitrogen of annual Litter	g N $m^{-2} a^{-1}$	per species and stand total	**nlit_<species/total>**	year	
Nitrogen in Soil	g N $m^{-2} a^{-1}$	stand total	**nsoil_<total>**	year	
Net Primary Production allocated to leaf biomass	kg m-2 s-1	per species and stand total	**npp_landleaf__<species>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production allocated to fine root biomass	kg m-2 s-1	per species and stand total	**npp_landroot_<species>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production allocated to above ground wood biomass	kg m-2 s-1	per species and stand total	**npp_abovegroundwood_<species>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production allocated to below ground wood biomass	kg m-2 s-1	per species and stand total	**npp_belowgroundwood_<species>**	day	As kg carbon*m^{-2}*s^{-1}
Root autotrophic respiration	kg m-2 s-1	per species and stand total	**rr_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Carbon Mass in Leaves	kg m-2	per species and stand total	**cleaf_<species>**	year	
Carbon Mass in Wood	kg m-2	per species and stand total	**cwood_<species>**	year	including sapwood and hardwood
Carbon Mass in Roots	kg m-2	per species and stand total	**croot_<species>**	year	including fine and coarse roots

Temperature of Soil	K	per stand	**tsl**	day	Temperature of each soil layer

Note: If you cannot provide the data at the temporal or spatial resolution specified, please provide it the highest possible resolution of your model. Please contact the coordination team (info@isimip.org) to for any further clarification, or to discuss the equivalent variable in your model.

Table 29: Codes for species, disturbance names and dbh classes as used in protocol (species, dist_name, dbhclass).

long name	Short name
Fagus sylvatica	fasy
Quercus robur	quro
Quercus petraea	qupe
Pinus sylvestris	pisy
Picea abies	piab
Pinus pinaster	pipi
Larix decidua	lade
Acer platanoides	acpl
Eucalyptus globulus	eugl
Betula pendula	bepe
Betula pubescens	bepu
Robinia pseudoacacia	rops
Fraxinus excelsior	frex
Populus nigra	poni
Sorbus aucuparia	soau
hard woods	hawo
fire	fi
wind	wi
Insects	ins
Drought	dr
Grazing	graz
Diseases	dis
DBH_class_0-5*	dbh_c0
DBH_class_5-10*	dbh_c5
DBH_class_10-15*	dbh_c10
DBH_class_15-20*	dbh_c15

DBH_class_20-25*	dbh_c20
DBH_class_25-30*	dbh_c25
DBH_class_30-35*	dbh_c30
DBH_class_35-40*	dbh_c35
DBH_class_40-45*	dbh_c40
DBH_class_45-50*	dbh_c45
DBH_class_50-55*	dbh_c50
DBH_class_55-60*	dbh_c55
DBH_class_60-65*	dbh_c60
DBH_class_65-70*	dbh_c65
DBH_class_70-75*	dbh_c70
DBH_class_75-80*	dbh_c75
DBH_class_80-85*	dbh_c80
DBH_class_85-90*	dbh_c85
DBH_class_90-95*	dbh_c90
DBH_class_95-100*	dbh_c95
DBH_class_100-105*	dbh_c100
DBH_class_105-110*	dbh_c105
DBH_class_110-115*	dbh_c110
DBH_class_115-120*	dbh_c115
DBH_class_120-125*	dbh_c120
DBH_class_125-130*	dbh_c125
DBH_class_130-135*	dbh_c130
DBH_class_135-140*	dbh_c135
DBH_class_>140*	dbh_c140

*the boundaries of the dbh classes should interpreted as follows: dbh_class_0-5 = 0 to<5 cm; dbh_class_5-10 =5 to<10 cm, etc…. the dbh class dbh_c140 includes all trees of 140cm dbh and larger.

10.5 Experiments and possible analyses

10.5.1 Historic runs and validation exercise – Experiments 1a

These are the core simulations for ISIMIP2a. For the sites mentioned in **Table 24**, a detailed comparison of model-data-(mis)match is envisaged, especially with a focus on past extreme events (e.g. 2003) and variability. These data may also be interesting for some additional validation tasks that can be carried out during postprocessing. The simulations of Experiment 1a listed in **Table 23** are needed for this experiment.

10.5.2 ISIMIP Fast-track catch-up runs – Experiments 2a

These are simulations for the sites mentioned in **Table 24** using ISIMIP Fast track climate scenarios to project forest development under climate change in the future. These are interesting for cross-scale comparisons with DGVMs, cross-sectoral analysis of climate impacts and multi-model climate change impact projections. The simulations of Experiment 2a listed in **Table 23** are needed for this experiment.

10.5.3 Influence of disturbances – Experiments 1b and 2b

These are historic and future simulations as described in sections 7.3.5.1 and 7.3.5.2 but with dynamic disturbances switched on for those models that actually simulate such dynamics. These simulations can be used to isolate the effects of disturbances vs. climate or to consider the joint impact of climate change and disturbances on forest products and services. The simulations of Experiment 1b and 2b listed in **Table 23** are needed for this experiment.

10.5.4 Isolation of climate effects (optional, future experiment)

Simulate time slices (i.e. same stand as growing in past simulations is repeatedly simulated for different time slices of maybe 20-30 years) to isolate the effects of climate change from the effects of forest dynamics. Some stands are already very old and would reach 200 years or more of age in 2100.

10.5.5 Climate input uncertainty (optional, future experiments)

What is the influence of the climate data to be used? Currently, we focus on observed time series from stands for model evaluation and GCM-data from the grid-cell in which a forest stand is located for future runs. Further downscaling of GCM data is at the moment not envisaged for consistency with ISIMIP in general. However in the future it could be interesting to design additional runs with downscaled climate data, e.g., using CORDEX runs or data from other sources.

10.5.6 Influence of forest structure (optional, future experiments)

Given the societal and environmental changes affecting forest economics and ecology, forest management systems and practices must be adapted and improved in order to maintain the socio-economic and environmental functions of the European forests. The structurally complex stands such as uneven-aged mixed-species stands are promising to ensure a sustainable wood production while improving forest stand resilience and ecosystem service provision. However, the process-based eco-physiological and biogeochemical models designed to analyze forest ecosystem response to environmental changes generally accounts for the effects of stand structure in very simplified way.

Our objective is to simulate the effects of forest structure in terms of vertical structure and/or species composition and/or cohorts on the main carbon cycle and stand growth variables (e.g. GPP, NPP, Autotrophic Respiration, Mean Annual Volume Increment, Current Annual Volume Increment) and tree attributes (heights, DBHs) .

A first experiment could compare even-aged *vs* uneven-aged stands or pure *vs* mixed stands making sure everything is comparable except stand structure (using eventually virtual stands created based on existing ones but adapted to be more comparable).

A second experiment could be conducted to compare simulations of models with different levels of spatial description (stand, cohort, tree) and identify which approach is most appropriate depending on the stand structure complexity.

A third experiment would consist in simulating the evolution of existing stands with contrasted structure according to different silvicoltural and climate scenarios.