6 Water

6.1 Experiments

Table 10 provides an overview of all experiments to be run in the water sector in ISIMIP2a.

Table 10: Summary of experiments for water models.

Climate Data	Scenario	Human Impacts	Other settings (sens-scenario)	# runs
WATCH-WFDEI	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
GSWP3-W5E5	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
GSWP3-EWEMBI	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
GSWP3	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
PGMFD v2.1 (Princeton)	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
WATCH (WFD)	Hist	nosoc pressoc varsoc	historical CO2 (co2)	3
Additional sector-specific run: PGMFD v2.1 (Princeton)	Hist	varsoc	constant CO2 at 1971 levels (co2const)	1

6.2 Sector-specific input data

In ISIMIP2a, hydrological modelling teams are asked to take into account the historical evolution of irrigated areas, dams and reservoirs, in order to obtain a more realistic estimate of the historical evolution of runoff and discharge. The data sources to be used are listed in **Table** 11, along with a soil and vegetation dataset that may be used optionally.

Table 11: Input data to be used for the historical runs (ISIMIP2a), in addition to the common data listed in Section 4.

Dataset	Description	More info	Scale	Variables included, comments
Mandatory (if feasible)				
Dams/Reservoirs		See **Table** 5 (Other human influences) http://www.gwsp.org/products/grand-database.html		
DDM30 routing network, mapped to the CRU land mask	flow directions, slope, and basin numbers	Note: The routing network includes large lakes that are not included in the provided land mask. These cells should not be included when results are submitted and there should be no runoff added to the river network from these cells. I.e. these cells are included only for transportation purposes (streamflow).	global, 0.5°	**for global models only**[3]
Optional (does not have to be harmonized)				
HWSD, or GSWP3 (upscaled version of HWSD)	soil map	See http://hydro.iis.u-tokyo.ac.jp/~sujan/research/gswp3/soil-texture-map.html, upscaling method A. Each model does have the option to use their own soil datasets if they prefer.	global, 30 arc sec (HWSD) or 0.5° (GSWP3), fixed	soil type
GLIMS (Global Land Ice Measurements from Space)	Glacier distribution	See http://www.glims.org/About/		
HydroSHEDS	Topography/routing network	Hydrographically corrected SRTM data. Available in 3 resolutions, includes accumulated upstream area. Also, HydroSHEDS is not available north of 60 degrees, due		**for regional models only**[3]

[3] To allow a direct intercomparison of river flows between global and regional models on a gridded basis, the runoff produced by the global models could be collected and routed through the HydroSHEDS network as a post-processing step, using a single routing model. Volunteers for this task are welcome.

		to limitations in the SRTM data at high latitudes.		

6.3 Output data

Note that variable names are chosen to comply, where feasible, with the ALMA convention[4] and the names used in WATCH/WaterMIP. Although variable names are mixed-case here, make sure to use **only lower-case** letters in the output filenames (see Section 5.1.1).

All variables are to be reported as time-averages with the indicated resolution; do not report instantaneous values ('snapshots'). An exception is **maxdis**, which is the maximum daily-average discharge in a given month, to be reported on a monthly basis (see below).

Water balance equation in terms of requested output variables:

rainf + snowf = evap + qtot,

where **Evap** is the sum of interception, transpiration, sublimation, and evaporation from the surface. This equation only holds on timescales long enough for changes in water storage (e.g. in soil and groundwater) to average out.

IMPORTANT: Some output variables reported for the water sector are also appropriate for use in the permafrost sector described in Section 11*; these are marked with an *. If you plan to submit simulations for the permafrost sector, note that additional variables are also required for the permafrost sector (see* **Table** 28*).*

[4] http://www.lmd.jussieu.fr/~polcher/ALMA/convention_output_3.html

Table 12: Output variables to be reported by water sector models. Variables highlighted in orange are requested from both global and regional models, if computed; variables highlighted in purple are requested only from regional models; others only from global models.

Variable (long name)	Variable name	Unit (NetCDF format)	Resolution	Comments
Hydrological Variables				
*Runoff	**qtot**	kg m-2 s-1	daily* (0.5°x0.5°)	Total (surface + subsurface) runoff (qtot = qs + qsb). *if daily resolution not possible, please provide monthly[5]. Please also deliver for the permafrost sector.
Surface runoff	**qs**	kg m-2 s-1	monthly (0.5°x0.5°)	Water that leaves the surface layer (top soil layer) e.g. as overland flow / fast runoff.
Subsurface runoff	**qsb**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of water that flows out from subsurface layer(s) including the groundwater layer (if present). Equals qg in case of a groundwater layer below only one soil layer.
Groundwater recharge	**qr**	kg m-2 s-1	monthly (0.5°x0.5°)	Water that percolates through the soil layer(s) into the groundwater layer. In case seepage is simulated but no groundwater layer is present, report seepage as qr and qg.
Groundwater recharge	**qr**	kg m-2 s-1	monthly (average for basin until gauge location)	Water that percolates through the soil layer(s) into the groundwater layer. In case seepage is simulated but no groundwater layer is present, report seepage as qr and qg.
Groundwater runoff	**qg**	kg m-2 s-1	monthly (0.5°x0.5°)	Water that leaves the groundwater layer. In case seepage is simulated but no groundwater layer is present, report seepage as qr and qg.
Discharge (gridded)	**dis**	m3 s-1	daily* (0.5°x0.5°)	*if daily resolution not possible, please provide monthly.
Discharge (gauge level)	**dis**	m3 s-1	daily* (at gauge locations; see **Table** 13)	*if daily resolution not possible, please provide monthly.
Monthly maximum of daily discharge	**maxdis**	m3 s-1	monthly (0.5°x0.5°)	Optional variable – please report if daily discharge data is not reported.

[5] If storage issues keep you from reporting daily data, please contact the ISIMIP team to discuss potential solutions.

Monthly minimum of daily discharge	**mindis**	m3 s-1	monthly (0.5°x0.5°)	Optional variable – please report if daily discharge data is not reported.
Evapotranspiration	**evap**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of transpiration, evaporation, interception and sublimation.
Evapotranspiration	**evap**	kg m-2 s-1	monthly (average for basin until gauge location)	Sum of transpiration, evaporation, interception losses, and sublimation.
Potential Evapotranspiration	**potevap**	kg m-2 s-1	monthly (0.5°x0.5°)	As evap, but with all resistances set to zero, except the aerodynamic resistance.
Potential Evapotranspiration	**potevap**	kg m-2 s-1	monthly (average for basin until gauge location)	As evap, but with all resistances set to zero, except the aerodynamic resistance.
*Soil moisture	**soilmoist**	kg m-2	monthly (0.5°x0.5°)	Please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. If depth varies over time or space, see instructions in Section 5.1.5. Please also deliver for the permafrost sector.
Soil moisture	**soilmoist**	kg m-2	monthly (average for basin until gauge location)	Please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. If depth varies over time or space, see instructions in Section 5.1.5. Please also deliver for the permafrost sector.
Soil moisture, root zone	**rootmoist**	kg m-2	monthly (0.5°x0.5°)	Total simulated soil moisture available for evapotranspiration. If simulated by the model. Please indicate the depth of the root zone for each vegetation type in your model. If depth varies over time or space, see instructions in Section 5.1.5.
Frozen soil moisture for each layer	**soilmoistfroz**	kg m-2	monthly (0.5°x0.5°)	Soil_frozen_water_content This variable only for the purposes of the permafrost sector.

*Temperature of Soil	**tsl**	K	daily* (0.5°x0.5°)	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". **THIS IS THE MOST IMPORTANT VARIABLE FOR THE PERMAFROST SECTOR.** Also need depths in meters. Daily would be great, but otherwise monthly would work. If depth varies over time or space, see instructions in Section 5.1.5. This variable only for the purposes of the permafrost sector. *if daily resolution not possible, please provide monthly.
*Snow depth	**snd**	m	monthly (0.5°x0.5°)	Grid cell mean depth of snowpack. This variable only for the purposes of the permafrost sector.
*Snow water equivalent (= snow water storage)	**swe**	kg m-2	monthly (0.5°x0.5°)	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell. Please also deliver for the permafrost sector.
Total water storage	**tws**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in all compartments. Please indicate in the netcdf metadata which storage compartments are considered.
Canopy water storage	**canopystor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in the canopy.
Glacier storage	**glacierstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in glaciers.
Groundwater storage	**groundwstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in groundwater layer.
Lake storage	**lakestor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in lakes (except reservoirs).
Wetland storage	**wetlandstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in wetlands.

Reservoir storage	**reservoirstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in reservoirs.
River storage	**riverstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in rivers.
*Annual maximum thaw depth	**thawdepth**	m	monthly (0.5°x0.5°)	Calculated from daily thaw depths.
River temperature	**triver**	K	monthly (0.5°x0.5°)	Mean monthly water temperature in river (representative of the average temperature across the channel volume).
Rainfall	**rainf**	kg m-2 s-1	monthly (0.5°x0.5°)	These variables are required for test purposes only. If you need to reduce output data volumes, please provide these variables only once, with the first (test) data set you submit, e.g. for the first decade of each experiment. NOTE: rainf + snowf = total precipitation
Snowfall	**snowf**	kg m-2 s-1	monthly (0.5°x0.5°)	
Water management variables (for models that consider water management/human impacts)				
Irrigation water demand (=potential irrigation water withdrawal)	**pirrww**	kg m-2 s-1	monthly (0.5°x0.5°)	Irrigation water withdrawal, assuming unlimited water supply.
Actual irrigation water withdrawal	**airrww**	kg m-2 s-1	monthly (0.5°x0.5°)	Irrigation water withdrawal, taking water availability into account; please provide if computed.
Potential irrigation water consumption	**pirruse**	kg m-2 s-1	monthly (0.5°x0.5°)	Portion of withdrawal that is evapo-transpired, assuming unlimited water supply.
Actual irrigation water consumption	**airruse**	kg m-2 s-1	monthly (0.5°x0.5°)	Portion of withdrawal that is evapotranspired, taking water availability into account; if computed.
Actual green water consumption on irrigated cropland	**airrusegreen**	kg m-2 s-1	monthly (0.5°x0.5°)	Actual evapotranspiration from rainwater over irrigated cropland; if computed.
Potential green water consumption	**pirrusegreen**	kg m-2 s-1	monthly (0.5°x0.5°)	Potential evapotranspiration from rainwater over irrigated cropland; if computed and different from AIrrUseGreen.

on irrigated cropland				
Actual green water consumption on rainfed cropland	**arainfusegreen**	kg m-2 s-1	monthly (0.5°x0.5°)	Actual evapotranspiration from rainwater over rainfed cropland; if computed.
Actual domestic water withdrawal	**adomww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Actual domestic water consumption	**adomuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Actual manufacturing water withdrawal	**amanww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Actual Manufacturing water consumption	**amanuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Actual electricity water withdrawal	**aelecww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Actual electricity water consumption	**aelecuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Actual livestock water withdrawal	**aliveww**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Actual livestock water consumption	**aliveuse**	kg m-2 s-1	monthly (0.5°x0.5°)	If computed.
Total (all sectors) actual water consumption	**atotuse**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of actual water consumption from all sectors. Please indicate in metadata which sectors are included.
Total (all sectors) actual water withdrawal	**atotww**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of actual water withdrawal from all sectors. Please indicate in metadata which sectors are included.
Total (all sectors) potential water	**ptotww**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of potential (i.e. assuming unlimited water supply) water withdrawal from all sectors. Please indicate in

withdrawal				metadata which sectors are included.
Total (all sectors) potential water consumption	**ptotuse**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of potential (i.e. assuming unlimited water supply) water consumption from all sectors. Please indicate in metadata which sectors are included.
Static output (Note: data that cannot be submitted in NetCDF format may be submitted in another suitable format directly via email to Info@isimip.org)				
Natural vegetation types	**Names to be coordinated with biomes/ecosystem sector**	N/A	static (0.5°x0.5°)	Map of natural vegetation / land surface types as used by the model. Please include a description of the parameters and their values associated with these vegetation types (parameter values could be supplied as spatial fields where appropriate). In your description please also provide details of the evapotranspiration scheme used by your model.
Soil types	**soil**		static (0.5°x0.5°)	Soil types or texture classes as used by your model. Please include a description of each type or class, especially if these are different from the standard HSWD and GSWP3 soil types. Please also include a description of the parameters and values associated with these soil types (parameter values could be submitted as spatial fields where appropriate).
Leaf Area Index	**lai (to be coordinated with other sectors)**		static (0.5°x0.5°) or monthly (0.5°x0.5°) where appropriate	If used by or computed by the model.
Agricultural variables (optional output for all water models that also simulate crop yields)				
Crop yields (dry matter)	**yield-<crop>-<irrigation setting>**	dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	Irrigation setting = “cirr” for “constrained irrigation” or “noirr” for rainfed.
Actual planting dates	**plantday-<crop>-<irrigation setting>**	day of year	per growing season (0.5°x0.5°)	Julian dates.

Actual planting year	**plantyear-<crop>-<irrigation setting>**	year of planting	per growing season (0.5°x0.5°)	This allows for clear identification of planting that is also easy to follow for potential users from outside the project.
Anthesis dates	**anthday-<crop>-<irrigation setting>**	day of year of anthesis	per growing season (0.5°x0.5°)	Together with the year of anthesis added to the list of outputs (see below) it allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.
Year of anthesis	**anthyear-<crop>-<irrigation setting>**	year of anthesis	per growing season (0.5°x0.5°)	It allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.
Maturity dates	**matyday-<crop>-<irrigation setting>**	day of year of maturity	per growing season (0.5°x0.5°)	Together with the year of maturity added to the list of outputs (see below) it allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Year of maturity	**matyyear-<crop>-<irrigation setting>**	year of maturity	per growing season (0.5°x0.5°)	It allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Nitrogen application rate	**initr-<crop>-<irrigation setting>**	kg ha-1 per growing season	per growing season (0.5°x0.5°)	Total nitrogen application rate. If organic and inorganic amendments are applied, rate should be reported as inorganic nitrogen equivalent (ignoring residues).
Above-ground biomass (dry matter)	**biom-<crop>-<irrigation setting>**	Dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	The whole plant biomass above ground.
Soil carbon emissions	**sco2-<crop>-<irrigation setting>**	kg C ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	**sn2o-<crop>-<irrigation setting>**	kg N2O-N ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.

* If storage issues keep you from reporting daily data, please contact the ISIMIP team to discuss potential solutions.

Comments related to the optional agricultural outputs

The reporting of the crop yield-related outputs differs from the reporting of other variables in the water sector, as it is not done according to calendar years but according to **growing seasons** to resolve potential multiple harvests. See the agriculture section (section 10) for details.

Simulations should be provided for the four major **crops** (wheat, maize, soy, and rice) but output for other crops and also bioenergy crops are highly welcome, too; see Section 10 for crop naming.
Yields simulations provided in the water sector should account for **irrigation water constraints**. For each crop, yields should be reported separately for irrigated land (cirr for "constrained irrigation") and rainfed land (noirr). This complements the full irrigation (firr) pure crop runs requested in the agriculture part of the protocol (Section 10).
Those models that cannot simulate time varying management/human impacts/fertilizer input should keep these fixed at year 2000 levels throughout the simulations.

6.4 Additional information for regional hydrological models

CALIBRATION: Please use WATCH-WFDEI (from 1979 to 2016) for calibration, for all simulations.

Table 13**:** Catchment gauging stations for reporting regional hydrological model results.

River Basin (short name for filenames)	Station for calibration and validation (short name for filenames)	Coordinates Lat/Lon	GRDC Station Code	Data availability (monthly discharge)	Data availability (daily discharge)	Area upstream of gauge (km^2) according to GRDC or GIS
Amazon (amazon)	São Paulo de Olivenca (sao-paulo-de-olivenca)	-3.45/-68.75	3623100	1979-1993	1973-2010	990781
Blue Nile (blue-nile)	El-Deim, Sudan Border (el-diem) Khartoum (khartoum)	11/35 15.62/32.55	n.a.* 1663100	1961-2002 1900-1982	n.a. n.a.	160000 325000
Danube (danube)	Wien-Nußdorf (wien-nussdorf)	48.25/16.3	6242500	1828-1899	1900-to date	101700
Ganges (ganges)	Farakka (farakka)	25/87.92	2846800	1949-1973	n.a.	835000
Godavari (godavari)	Tekra (tekra)	19.068/79.9	n.a.	1964-2017	1964-2017	119781
Indus	Tarbela Reservoir (tarbela)	72.86/ 34.33	n.a.	2000-2016	2000-2016	173345

Lena (lena)	Krestovski (krestovski) Stolb (stolb)	59.73/113.17 72.37/126.8	2903427 2903430	1936-2002 1978-1994	1936-1999 1951-2002	440000 2460000
Mackenzie (mackenzie)	Artic Red River (artic-red-river)	67.4583/-133.745	4208025	1972-1996	1972-2015	1660000
Mississippi	Alton (alton)	38.885/-90.1809	4119800	1928-1984	1933-1987	444185
Murray Darling (darling)	Louth (louth)	-30.5318/ 145.1144	5204250	1954-2000	1954-2008	489300
Niger (niger)	Dire (dire) Koulikoro (koulikoro) Lokoja (lokoja) Tossaye (tossaye)	16.2667/-3.3833 12,8667/-7,55 7,8/6,7667 16.9416/ -0.579166	1134700 1134100 1834101 1134850	1924-2012 1907-2012 2007-2012 1954-1992	1924-2003 1907-2006 1970-2006 1954-1992	340000 120000 2074171 348000
Pajeú (pajeu)	Floresta (floresta)	-8,6089,-38,5767	n.a. (National system for information on water resources, Brasil)	n.a.	n.a.	12266
Rhine (rhine)	Lobith (lobith)	51.84/6.11	6435060	1901-1996	1901-2010	160800
Tagus (tagus)	Almourol (almourol) Trillo (trillo)	39.47/-8.37 40.7/-2.58	6113050 6213800	1973-1990 1977-1984	1982-1990 1977-1984	61490 3253
Yangtze	Cuntan (cuntan)	29,616667/106,6	n.a.	1987-2006	1987-2006	804859
Yellow, Huang He (yellow)	Tangnaihai (tangnaihai)	35.5/100.15	n.a.	1971-2002	1971-2002	121000

Note: If GRDC station is not available, the data availability is indicated for data from other sources; *GRDC data reported as poor

15 References

Arnell, N. (1999). A simple water balance model for the simulation of streamflow over a large geographic domain. *Journal of Hydrology*, *217*(3–4), 314–335.

Cescatti, A., & Piutti, E. (1998). Silvicultural alternatives, competition regime and sensitivity to climate in a European beech forest. *Forest Ecology and Management*, *102*(2), 213-223.

Choulga, M., Kourzeneva, E., Zakharova, E., & Doganovsky, A. (2014). Estimation of the mean depth of boreal lakes for use in numerical weather prediction and climate modelling, Tellus A. *Dyn. Meteorol. Oceanogr.*, *66*(1), 21295.

Cucchi, M., Weedon, G. P., Amici, A., Bellouin, N., Lange, S., Müller Schmied, H., Hersbach, H. and Buontempo, C. (2020) WFDE5: bias-adjusted ERA5 reanalysis data for impact studies. *Earth System Science Data*, 12, 2097–2120.

Davie, J. C., Falloon, P. D., Kahana, R., Dankers, R., Betts, R., Portmann, F. T., . . . Arnell, N. (2013). Comparing projections of future changes in runoff and water resources from hydrological and ecosystem models in ISI-MIP. *Earth System Dynamics Discussions*, *4*(1), 279–315.

De Lary, R. (October, 2015). *Massif des Landes de Gascogne. II – ETAT DES CONNAISSANCES TECHNIQUES.* Bordeaux: CRPF Aquitaine.

Dirmeyer, P. A., Gao, X., Zhao, M., Guo, Z., Oki, T. and Hanasaki, N. (2006) GSWP-2: Multimodel Analysis and Implications for Our Perception of the Land Surface. *Bulletin of the American Meteorological Society*, 87(10), 1381–98.

Dlugokencky, E., & Tans, P. (2019). *Trends in atmospheric carbon dioxide*. Retrieved November 2, 2019, from National Oceanic & Atmospheric Administration, Earth System Research Laboratory (NOAA/ESRL):

https://www.esrl.noaa.gov/gmd/ccgg/trends/gl_data.html

Döll, P., & Schmied, H. M. (2012). How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. *Environmental Research Letters*, *7*(1), 14037.

Döll, P., Kaspar, F., & Lehner, B. (2003). A global hydrological model for deriving water availability indicators: Model tuning and validation. *Journal of Hydrology*, *270*(1–2), 105–134.

Duncker, P. S., Barreiro, S. M., Hengeveld, G. M., Lind, T., Mason, W. L., Ambrozy, S., & Spiecker, H. (2012). Classification of Forest Management Approaches: A New Conceptual Framework and Its Applicability to European Forestry. *Ecology and Society*, *17*(4).

Elliott, J., Müller, C., Deryng, D., Chryssanthacopoulos, J., Boote, K. J., Büchner, M., . . . Ruane, A. C. (2015). The Global Gridded Crop Model Intercomparison: Data and modeling protocols for Phase 1 (v1.0). *Geosci. Model Dev.*, *8*, 261-277.

Fekete, B. M., Vörösmarty, C. J., & Grabs, W. (2000). Global Composite Runoff Fields on Observed River Discharge and Simulated Water Balances. *GRDC Reports*, *22*(115).

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., . . . Hill. (2011). Solutions for a cultivated planet. *Nature*, *478*(7369), 337-342.

Fürstenau, C., Badeck, F. W., Lasch, P., Lexer, M. J., Lindner, M., Mohr, P., & Suckow, F. (2007). Multiple-use forest management in consideration of climate change and the interests of stakeholder groups. *Eur J Forest Res*, *126*, 225-239.

González, J. R., & Palahí, M. (2005). Optimising the management of Pinus sylvestris L. stand under risk of fire in Catalonia (north-east of Spain). *Ann. For. Sci. 62*, *62*, 493-501.

Gosling, S. N., & Arnell, N. W. (2011). Simulating current global river runoff with a global hydrological model: Model revisions, validation, and sensitivity analysis. *Hydrological Processes*, *25*(7), 1129–1145.

Gosling, S. N., Warren, R., Arnell, N. W., Good, P., Caesar, J., Bernie, D., . . . Smith, S. M. (2011). A review of recent developments in climate change science. Part II: The global-scale impacts of climate change. *Progress in Physical Geography*, *35*(4), 443–464.

Gutsch, M., Lasch, P., Suckow, F., & Reyer, C. (2011). Management of mixed oak-pine forests under climate scenario uncertainty. *Forest Systems*, *20*(3), 453-463.

Haddeland, I. C. (2011). Multimodel estimate of the global terrestrial water balance: setup and first results. *Journal of Hydrometeorology*, *110531121709055*.

Haith, D. A., & Shoemaker., L. L. (1987). Generalized Watershed Loading Functions for stream flow nutrients. *Water Resour. Bull.*, *23*, 471-478.

Håkanson, L. (1995). Models to predict Secchi depth in small glacial lakes. *Aquatic Science*, *57*(1), 31–53.

Hanewinkela, M., & Pretzsch, H. (2000). Modelling the conversion from even-aged to uneven-aged stands of Norway spruce (Picea abies L. Karst.) with a distance-dependent growth simulator. *Forest Ecology and Management*, *134*, 55-70.

Hein, S., & Dhôte, J.-F. (2006). Effect of species composition, stand density and site index on the basal area increment of oak trees (Quercus sp.) in mixed stands with beech (Fagus sylvatica L.) in northern France. *Ann. For. Sci.*, *63*, 457-467.

Hijmans, R., Cameron, S., Parra, J., Jones, P., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*, 1965-1978.

Hurtt, G., Chini, L., Sahajpal, R., Frolking, S., & et al, .. (2020). Harmonization of global land-use change and management for the period 850-2100 (LUH2) for CMIP6. *Geoscientific Model Development*, *13*, 5425-5464.

Kerr, G. (1996). The effect of heavy or ‘free growth’ thinning on oak (Quercus petraea and Q. robur). *Forestry: An International Journal of Forest Research*, *69*(4), 303-317.

Kim, H. (. (n.d.). *Global Soil Wetness Project Phase 3*. Retrieved from Global Soil Wetness Project Phase 3: http://hydro.iis.u-tokyo.ac.jp/GSWP3/

Klein Goldewijk, D. i. (2016). *A historical land use data set for the Holocene; HYDE 3.2 (replaced)*. Utrecht University. DANS.

Koster, R. D., Fekete, B. M., Huffman, G. J., & Stackhouse, P. W. (2006). Revisiting a hydrological analysis framework with International Satellite Land Surface Climatology Project Initiative 2 rainfall, net radiation, and runoff fields. *Journal of Geophysical Research*, *111*(D22), D22S05.

Kourzeneva, E. (2010). External data for lake parameterization in Numerical Weather Prediction and climate modeling. *Boreal Environ. Res.*, *15*(2), 165–177.

Lähde, E., Laiho, O., & Lin, J. C. (2010). Silvicultural alternatives in an uneven-sized forest dominated by Picea abies. *Journal of Forest Research*, *15*(1), 14-20.

Lange, S. (2019a). WFDE5 over land merged with ERA5 over the ocean (W5E5). V. 1.0. doi:10.5880/pik.2019.023

Lange, S. (2019b). Earth2Observe, WFDEI and ERA-Interim data Merged and Bias-corrected for ISIMIP (EWEMBI) v1.1. *GFZ Data Services*. doi:10.5880/pik.2019.004

Lange, S. (2019c). Trend-preserving bias adjustment and statistical downscaling with ISIMIP3BASD (v1.0). *Geoscientific*

Model Development, 12, 3055–3070.

Lange, S. (2020). ISIMIP3BASD v2.4.1. *Zenodo*, doi:10.5281/zenodo.3898426.

Lascha, P., Badecka, F.-W., Suckowa, F., Lindnera, M., & Mohr, P. (2005). Model-based analysis of management alternatives at stand and regional level in Brandenburg. *Forest Ecology and Management*, *207*, 59-74.

Lehner, B., & Döll, P. (2004). Development and validation of a global database of lakes, reservoirs and wetlands. *J. Hydrol.*, *296*(1-4), 1-22.

Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A. J., & Yang, H. (2010). A high-resolution assessment on global nitrogen flows in cropland. *National Academy of Sciences*, *107*(17), 8035-8040.

Loustau, D., Bosc, A., Colin, A., Ogée, J., Davi, H., Francois, C., . . . Delage, F. (2005). Modeling climate change effects on the potential production of French plains forests at the sub-regional level. *Tree physiology*, *25*, 813-23.

Meinshausen, M., Raper, S. C., & Wigley, T. M. (2011). Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 – Part 1: Model description and calibration. *Atmospheric Chemistry and Physics*, *11*(4), 1417–1456.

Millero, F., & Poisson, A. (1981). International one-atmosphere equation of state of seawater. *Deep-Sea Research*, *28*, 625-629.

Monfreda, C., Ramankutty, N., & Foley, J. (2008). Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles*, *22*(GB1022).

Mueller, N., Gerber, J., Johnston, M., Ray, D., Ramankutty, N., & Foley, J. (2012). Closing yield gaps through nutrient and water management. *Nature*, *490*, 254-257.

Mund, M. (2004). *Carbon pools of European beech forests (Fagus sylvatica) under different silvicultural management*. Göttingen: Forschungszentrum Waldökosysteme.

Oleson, K. W., Niu, G.-Y., Yang, Z.-L., Lawrence, D. M., Thornton, P. E., Lawrence, P. J., . . . Qian, T. (2008). Improvements to the Community Land Model and their impact on the hydrological cycle. *Journal of Geophysical Research*, *113*(G1), G01021.

Pape, R. (1999). Effects of Thinning Regime on the Wood Properties and Stem Quality of Picea abies. *Scandinavian Journal of Forest Research*, *14*(1), 38-50.

Portmann, F., Siebert, S., & Döll, P. (2010). MIRCA2000 – global monthly irrigated and rainfed crop areas around the year 2000: a new high-resolution data set for agricultural and hydrological modeling. *Global Biogeochemical Cycles*, *24*(1).

Potter, P., Ramankutty, N., Bennett, E. M., & Donner, S. D. (2011). Global fertilizer and manure, version 1: nitrogen fertilizer application. *NASA Socioeconomic Data and Applications Center*.

Pukkala, T., Miina, J., Kurttila, M., & Kolström, T. (1998). A spatial yield model for optimizing the thinning regime of mixed stands of Pinus sylvestris and Picea abies. *Scandinavian Journal of Forest Research*, *13*(1-4), 31-42.

Sacks, W. J., Deryng, D., Foley, J. A., & Ramankutty, N. (2010). Crop planting dates: an analysis of global patterns. *Global Ecology and Biogeography*, *19*(5), 607-620.

Schneiderman, E. M., Pierson, D. C., Lounsbury, D. G., & Zion, M. S. (2002). Modeling the hydrochemistry of the Cannonsville watershed with Generalized Watershed Loading Functions (GWLF). *J. Am. Water Resour. Assoc.*, *38*, 1323-1347.

Schütz, J.-P., Götz, M., Schmid, W., & Mandallaz, D. (2006). Vulnerability of spruce (Picea abies) and beech (Fagus sylvatica) forest stands to storms and consequences for silviculture. *Eur J Forest Res*, *125*, 291-302.

Shatwell, T., Thiery, W., & Kirillin, G. (2019). Future projections of temperature and mixing regime of European temperate lakes. *Hydrology and Earth System Sciences*, *23*(3), 1533-1551.

Sheffield, J., Goteti, G., & Wood, E. F. (2006). Development of a 50-Year High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling. *Journal of Climate*, *19*(13), 3088–3111.

Štefančík, I. (2012). Growth characteristics of oak (Quercus petraea [Mattusch.] Liebl.) stand under different thinning regimes. *Journal of Forest Science*, *58*(2), 67-78.

Sterba, H. (1987). Estimating Potential Density from Thinning Experiments and Inventory Data. *Forest Science*, *33*(4), 1022-1034.

Stock, C. A., Dunne, J. P., & John, J. G. (2014). Global-scale carbon and energy flows through the marine planktonic food web: An analysis with a coupled physical-biological model. *Progress in Oceanography*, *120*, 1-28.

Subin, Z. M., Riley, W. J., & Mironov, D. (2012). An improved lake model for climate simulations: Model structure, evaluation, and sensitivity analyses in CESM1. *J. Adv. Model. Earth Syst.*, *4*(1), M02001.

Thivolle-Cazat, A. (2013). *Disponibilité en bois en Aquitaine de 2012 à 2025*. Bordeaux: FCBA, IGN, INRA, CRPF Aquitaine.

Tian, H., Yang, J., Lu, C., Xu, R., Canadell, J. G., Jackson, R., . . . Wini. (2018). The global N2O Model Intercomparison Project (NMIP): Objectives, Simu- lation Protocol and Expected Products. *B. Am. Meteorol. Soc.*

Weedon, G. P., Balsamo, G., Bellouin, N., Gomes, S., Best, M. J., & Viterbo, P. (2014). The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. *Water Resources Research*, *50*, 7505–7514.

Weedon, G. P., Gomes, S., Viterbo, P., Shuttleworth, W. J., Blyth, E., Österle, H., . . . Best, M. (2011). Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century. *Journal of Hydrometeorology*, *12*(5), 823–848.

Wu, B., Yu, B., Yue, W., Shu, S., Tan, W., Hu, C., . . . Liu, H. (2013). A Voxel-Based Method for Automated Identification and Morphological Parameters Estimation of Individual Street Trees from Mobile Laser Scanning Data. *Remote Sensing*, *5*(2), 584-611.

Yoshimura, K., & Kanamitsu, M. (2008). Dynamical Global Downscaling of Global Reanalysis. *Monthly Weather Review*, *136*(8), 2983–2998.

Yoshimura, K., & Kanamitsu, M. (2013). Incremental Correction for the Dynamical Downscaling of Ensemble Mean Atmospheric Fields. *Monthly Weather Review*, *141*(9), 3087–3101.