11 Permafrost

11.1 Experiments

The permafrost sector in ISIMIP2a will not require any additional runs. The runs developed for the biomes sector and the water sector can also be assessed by the permafrost sector (see Section 4.7 Scenario design for the scenario setup). Finnland (region 12) and the Lena catchment (region 11) are the two regions affected by permafrost. Therefore, any runs over these regions can be assessed for permafrost. Permafrost will require additional output data. Models which do not include a carbon cycle should still submit the requested hydrological variables as these can be used to assess permafrost extent and thaw.

11.2 Sector-specific input

None

11.3 Output data

Table 28 below is very similar to **Table** 18 in the Biomes sector, but with some hydrological variables added. **Soil temperature at each model level is the most important variable – if that is all you can deliver then please do so, it will be useful.**

Table 28: Variables to be reported for the permafrost sector.

Variable (long name)	Variable name	Unit (NetCDF format)		Resolution	Comment
Essential outputs					
Temperature of Soil	**tsl**	K	per gridcell	Day (mon)	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". **THIS IS THE MOST IMPORTANT VARIABLE.** Also need depths in meters. Daily would be great, but otherwise monthly would work.

Pools (as Biomes output Table)					
Carbon Mass in Vegetation	**cveg-<pft>**	kg m-2	per pft and gridcell total	year	Gridcell total cveg is essential. Per PFT information is desirable.
*Carbon Mass in aboveground vegetation biomass	**cvegag-<pft>**	kg m-2	per pft and gridcell total	year	Gridcell total cvegag is essential. Per PFT information is desirable.
*Carbon Mass in belowground vegetation biomass	**cvegbg-<pft>**	kg m-2	per pft and gridcell total	year	Gridcell total cvegbg is essential. Per PFT information is desirable.
Carbon Mass in Litter Pool	**clitter**	kg m-2	per gridcell	year	Total of all pools. Info for each individual pool is desirable.
Carbon Mass in Soil Pool	**csoil**	kg m-2	per gridcell	year	Total of all pools. Info for each individual pool is desirable.
Fluxes (as Biomes output Table)					
Carbon Mass Flux out of Atmosphere due to Gross Primary Production on Land	**gpp**	kg m-2 s-1	per gridcell	mon (day)	
Carbon Mass Flux into Atmosphere due to Autotrophic (Plant) Respiration on Land	**ra**	kg m-2 s-1	per gridcell	mon (day)	
Carbon Mass Flux out of Atmosphere due to Net Primary Production on Land	**npp**	kg m-2 s-1	per gridcell	mon (day)	
Carbon Mass Flux into Atmosphere due to Heterotrophic Respiration on Land	**rh**	kg m-2 s-1	per gridcell	mon (day)	
Carbon Mass Flux into Atmosphere due to	**fireint**	kg m-2 s-1	per gridcell	mon (day)	

CO2 Emission from Fire					
Fraction of cell burnt by fire	**firefrac**	Fractional	per gridcell		Burnt area fraction: single value for each scenario corresponding to year 2100
Carbon Mass Flux out of Atmosphere due to Net Biospheric Production on Land	**ecoatmfluxc**	kg m-2 s-1	per gridcell	mon (day)	This is the net mass flux of carbon between land and atmosphere calculated as photosynthesis MINUS the sum of plant and soil respiration, carbonfluxes from fire, harvest, grazing and land use change. Positive flux is into the land.
Structure (as Biomes output Table)					
Fraction of absorbed photosynthetically active radiation	**fapar-<pft>**	%	per pft and gridcell average	mon (day)	
Leaf Area Index	**lai-<pft>**	1	per pft and gridcell average	mon (day)	
Plant Functional Type Grid Fraction	**pft-<pft>**	%	per gridcell	year (or once if static)	The categories may differ from model to model, depending on their PFT definitions. This may include natural PFTs, anthropogenic PFTs, bare soil, lakes, urban areas, etc. Sum of all should equal the fraction of the grid-cell that is land.
Soil moisture for each layer	**soilmoist**	kg m-2	per gridcell	mon	Please provide soil moisture for all depth levels and indicate depth in m. (As for Water sector)
Frozen soil moisture for each layer	**soilmoistfroz**	kg m-2	per gridcell	mon	Please provide soil moisture for all depth levels and indicate depth in m. **This is a new variable.**
Snow depth	**snd**	m	per gridcell	Day	Grid cell mean depth of snowpack. **This is a new variable.**
Annual maximum thaw depth	**thawdepth**	m	per gridcell	year	Calculated from daily thaw depths
Snow water equivalent	**swe**	kg m-2	per gridcell	mon	Total water mass of the snowpack (liquid or frozen) averaged over grid cell (As for Water sector)
Runoff	**qtot**	kg m-2 s-1	per gridcell	mon (day)	Total runoff leaving the land portion of the grid cell (this

					is in both Biomes and Water Tables)
Optional outputs					
Burnt Area Fraction	**burntarea**	%	per gridcell	mon (day)	fraction of entire grid cell that is covered by burnt vegetation

Note: If you cannot provide the data at the temporal or spatial resolution specified, please provide 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.

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.