Supplement of Geosci. Model Dev., 15, 8411–8437, 2022
https://doi.org/10.5194/gmd-15-8411-2022-supplement

Geoscientific Model Development
Open Access

Supplement of

Global biomass burning fuel consumption and emissions at 500 m spatial resolution based on the Global Fire Emissions Database (GFED)

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S1 Estimation of monthly MODIS-derived NPP

Net primary production (NPP) from our 500-m model was compared to monthly MODIS-derived NPP estimated using MODIS annual NPP from the MOD17A3HGF product (Running & Zhao, 2019b) in combination with MODIS monthly gross primary production (GPP) and net photosynthesis (PSNnet) from the MOD17A2HGF product (Running & Zhao, 2019a) (Fig. S3). The MODIS MOD17 algorithm calculates monthly GPP and PSNnet, after which NPP is calculated on an annual basis after summing of the respiration terms. However, monthly NPP at a global scale can be estimated by rewriting the MOD17 algorithm equations and linearly interpolating the annual live wood maintenance respiration over months (Maosheng Zhao, personal communication). From the MOD17 Collection 6 User Guide it follows that annual NPP can be expressed as (https://lpdaac.usgs.gov/documents/495/MOD17_User_Guide_V6.pdf):

$$NPP = 0.8 \cdot \left(GPP - MR_{Leaf} - MR_{Froot} - MR_{Livewood}\right) \tag{S1}$$

where MR_{Leaf}, MR_{Froot}, and $MR_{Livewood}$ are the leaf, fine roots and live wood maintenance respiration terms, respectively. The monthly sum of leaf and fine roots respiration can be calculated from monthly GPP and PSN provided by the MOD17A2HGF product:

$$MR_{Leaf} + MR_{Froot} = GPP - PSN_{net} \tag{S2}$$

In the MOD17 algorithm, live wood maintenance respiration is calculated annually and can be derived by rewriting Eq. S1:

$$MR_{Livewood} = GPP - 1.25 \cdot NPP - MR_{Leaf} - MR_{Froot} \tag{S3}$$

The monthly variation in maintenance respiration is dependent on the respiration term, $RESP$:

$$RESP = Q10\_mr^{(Tavg - 20.0/10.0)} \tag{S4}$$

where $Tavg$ is the daily or monthly average temperature. The MOD17 algorithm uses temperature data from GMAO/NASA meteorological reanalysis dataset. We used the ERA5-land air temperature data instead, since we use this dataset for other aspects of our 500-m model and because we expect little bias between temperature datasets at a global scale. Because the respiration term is the only factor introducing monthly variation, the monthly live wood maintenance respiration can be estimated by linear interpolation:

$$MR_{Livewood\_monthly} = MR_{Livewood\_annual} \cdot (RESP/\overline{RESP}) \tag{S5}$$

where $\overline{RESP}$ is the annual average respiration term. After deriving the monthly live wood maintenance respiration, Eq. S1 can be used to estimate monthly NPP. Although the result is a rough estimate of monthly NPP, it can be used at a global scale. We compare the resulting estimated monthly MODIS-derived NPP to the NPP from our 500-m model and GFED4(s) in Figure S3.

Table S1: Reclassification of MODIS MCD12Q1 land cover types (Methods 2.2). Boreal, temperate, and tropic zones are based on the FAO Global Ecological Zones 2010 update (FAO, 2012). The Subtropics are included in the temperate zone.

Biome	**Mask**	**MODIS IGBP class number**	**Description of reclassified MODIS classes**
Forest boreal	Boreal	1, 2, 3, 4, 5, 8	All forest classes + woody savannas
Sparse boreal forest	Boreal	6, 7, 9	Closed and open shrublands + open savannas
Tundra	Boreal + LCCS3 FAO Tundra	10, 51	Grasslands + Tundra based on LCCS3 classification (overrules other classes)
Forest tropical	Tropics	1, 2, 3, 4, 5	All forest classes
Forest temperate	Temperate	1, 2, 3, 4, 5	All forest classes
Temperate mosaic	Temperate	8, 9	Woody and open savannas
Shrublands tropical	Tropics	6, 7	Closed and open shrublands
Shrublands temperate	Temperate	6, 7	Closed and open shrublands
Grasslands temperate	Temperate	10	Grasslands
Grasslands tropical	Tropics	10	Grasslands
Savanna woody	Tropics	8	Woody savannas
Savanna open	Tropics	9	Open savannas
Croplands tropical	Tropics	12, 14	Croplands, Cropland/Natural Vegetation Mosaics
Croplands temperate	Temperate	12, 14	Croplands, Cropland/Natural Vegetation Mosaics
Croplands boreal	Boreal	12, 14	Croplands, Cropland/Natural Vegetation Mosaics
Wetlands	-	11	Permanent wetlands
Urban	-	13	Urban and built-up lands

Table S2: Model parameters per biome, including maximum light-use efficiency (ε_{max}) and annual effective light-use efficiency (ε_{eff}) in units of g C MJ^{-1}, and biomass and litter turnover rates (τ) in years for the stem, leaf, grass, fine litter, coarse woody debris (CWD), and root pools respectively. Stem turnover rates for the boreal region were determined separately for the North American (first value) and Eurasian continent (second value). Biomes are based on a reclassification of MODIS land cover types, as described in the Methods and shown in Table S1.

Biome	ε_{max}	ε_{eff}	τ_{stem}	τ_{leaf}	τ_{grass}	$\tau_{fine\ litter}$	τ_{CWD}	τ_{root}
Forest boreal	0.617	0.251	52 / 64	3.5	0.8	0.5	2.0	8.4
Sparse boreal forest	0.536	0.199	67 / 78	3.5	0.8	1.0	2.0	8.5
Tundra	0.520	0.189	58 / 82	3.5	1.0	1.0	2.0	9.7
Forest tropical	0.506	0.474	45	1.5	1.5	1.4	5.0	5.4
Forest temperate	0.641	0.378	44	2.5	1.0	0.4	2.5	6.4
Temperate mosaic	0.614	0.381	44	2.5	0.5	0.3	4.0	4.6
Shrublands tropical	0.341	0.185	61	0.7	1.0	0.4	5.0	7.6
Shrublands temperate	0.483	0.226	50	0.7	1.0	0.4	5.0	3.6
Grasslands temperate	0.547	0.259	50	0.7	0.5	0.3	5.0	3.7
Grasslands tropical	0.451	0.324	59	0.7	0.5	0.3	5.0	4.1
Savanna woody	0.484	0.435	42	0.7	0.5	0.3	5.0	3.7
Savanna open	0.482	0.406	45	0.7	0.5	0.3	5.0	3.8
Croplands tropical	0.421	0.315	45	2.0	1.2	1.0	4.0	1.2
Croplands temperate	0.599	0.316	42	2.0	1.2	1.0	4.0	1.0
Croplands boreal	0.587	0.251	53	2.0	1.2	1.0	4.0	1.8
Wetlands	0.455	0.401	45	1.0	0.5	0.5	4.0	6.5
Urban	0.606	0.321	32	1.0	0.5	0.5	4.0	2.3
Global	**0.512**	**0.285**	**48**	**1.1**	**0.7**	**0.5**	**3.6**	**3.7**

Table S3: Model combustion completeness (CC) ranges per biome and fuel pools, in percentage combusted. Leaf and root CC ranges are the same for all biomes. The actual CC is derived from the range by linear scaling based on the soil moisture scalar (see Methods 2.1.1). In case of fire-related forest loss in commodity-driven deforestation areas, the CC for the stem, CWD and roots pools were increased to 40–90%, 65–95% and 20–50% respectively, in order to simulate repeated slash burning and tree uprooting (see Methods 2.1.1).

Biome	Stem	CWD	Grass	Fine litter	Leaf	Root
Forest boreal	10 – 30	30 – 70	70 – 100	70 – 100	90 – 100	0 – 10
Sparse boreal forest	10 – 30	30 – 70	70 – 100	70 – 100	"	"
Tundra	10 – 30	30 – 70	70 – 100	70 – 100	"	"
Forest tropical	20 – 40	30 – 70	70 – 100	80 – 100	"	"
Forest temperate	30 – 50	20 – 60	50 – 100	70 – 100	"	"
Temperate mosaic	30 – 50	20 – 60	50 – 100	70 – 100	"	"
Shrublands tropical	40 – 60	30 – 70	80 – 100	80 – 100	"	"
Shrublands temperate	40 – 60	30 – 70	80 – 100	80 – 100	"	"
Grasslands temperate	30 – 50	20 – 60	60 – 100	70 – 100	"	"
Grasslands tropical	30 – 50	20 – 60	60 – 100	70 – 100	"	"
Savanna woody	30 – 50	20 – 60	60 – 100	70 – 100	"	"
Savanna open	30 – 50	20 – 60	60 – 100	70 – 100	"	"
Croplands tropical	40 – 60	30 – 70	40 – 100	80 – 100	"	"
Croplands temperate	40 – 60	30 – 70	40 – 100	80 – 100	"	"
Croplands boreal	40 – 60	30 – 70	40 – 100	80 – 100	"	"
Wetlands	20 – 40	40 – 60	70 – 100	80 – 100	"	"
Urban	20 – 40	40 – 60	70 – 100	80 – 100	"	"

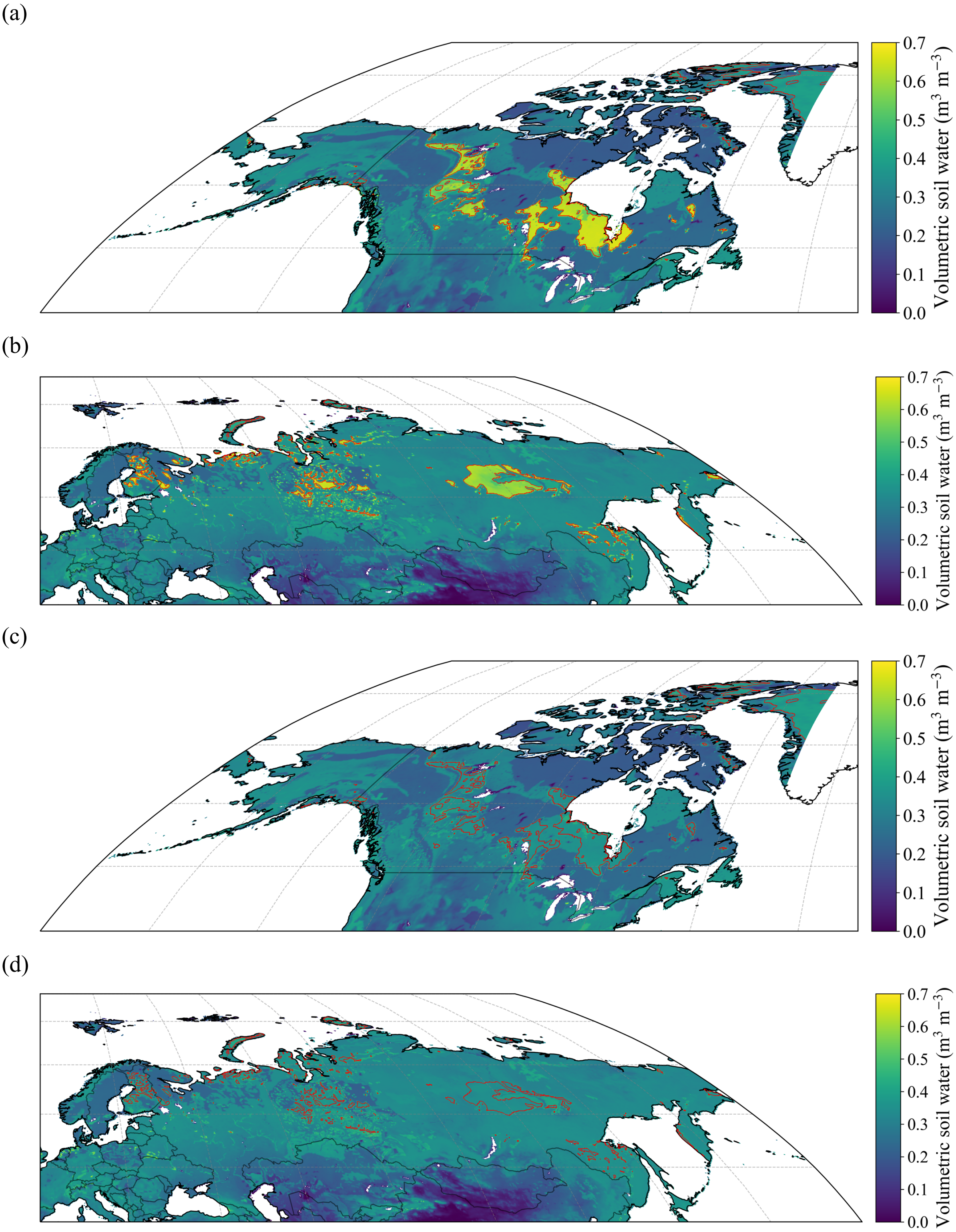


Figure S1: 2002–2020 average volumetric soil water content for **(a)** boreal North America and **(b)** boreal Eurasia. Red contours show the areas with a minimum water content that did not go lower than 0.35 m^3 m^{-3} over the full time period of 2002–2020, for which the values were adjusted to range from 0.25 to 0.45 m^3 m^{-3} based on a linear scaling function. The latter two panels show the average soil water content after the adjustment for **(c)** boreal North America and **(d)** boreal Eurasia.

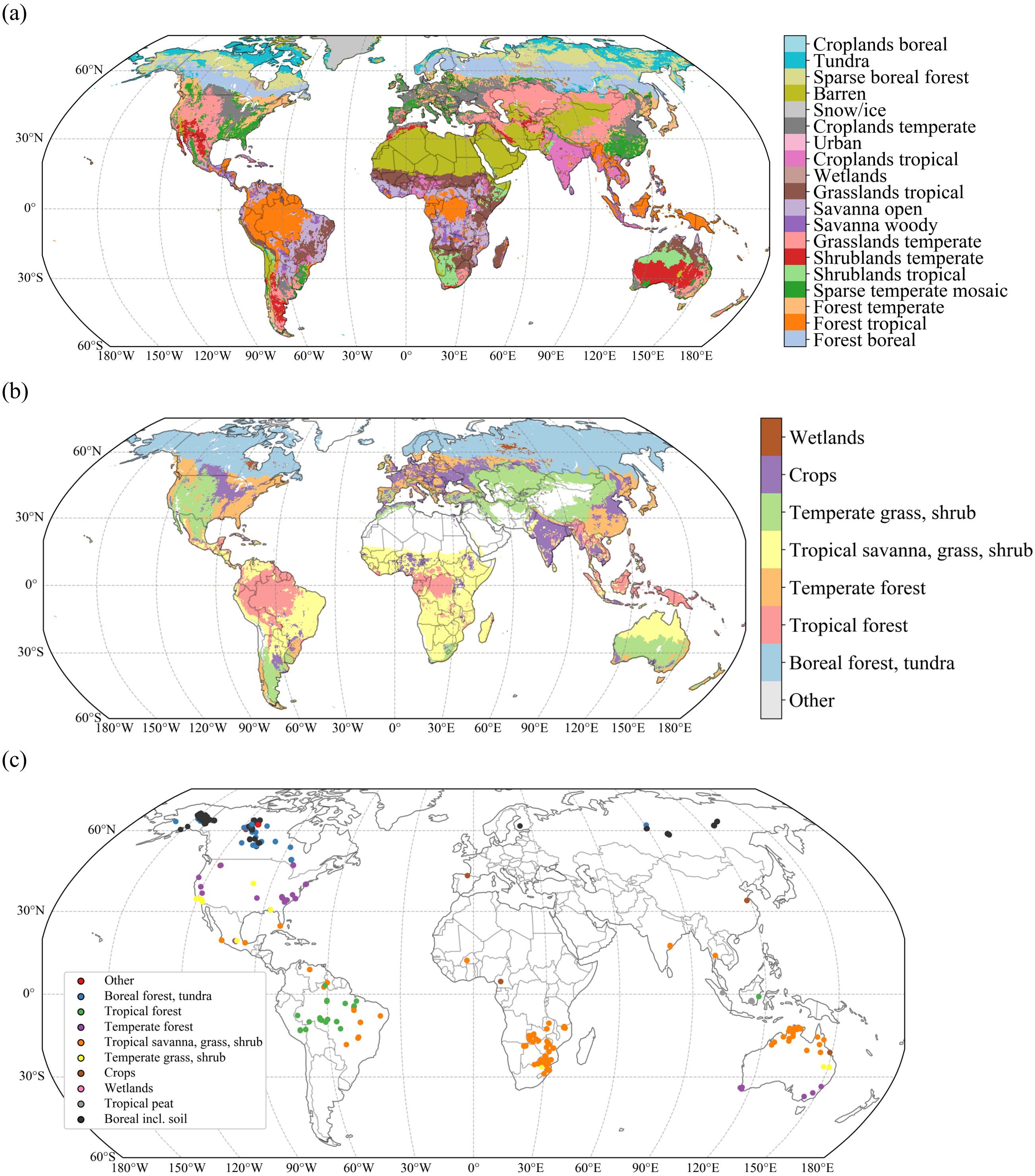


Figure S2: **(a)** Reclassified biome categories (as in Table S1). **(b)** Biome categories used for analysis of results. **(c)** Field plot locations grouped per biome class. Tropical, temperate and boreal regions are based on the FAO Global Ecological Zones 2010 update (FAO, 2012). Maps are aggregated to 0.25° for display.

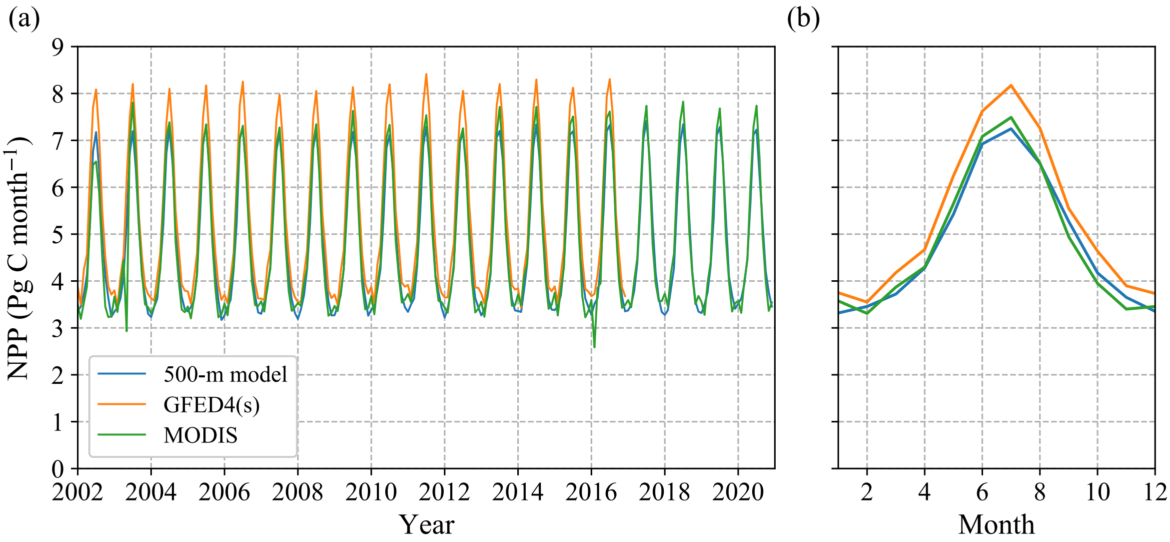
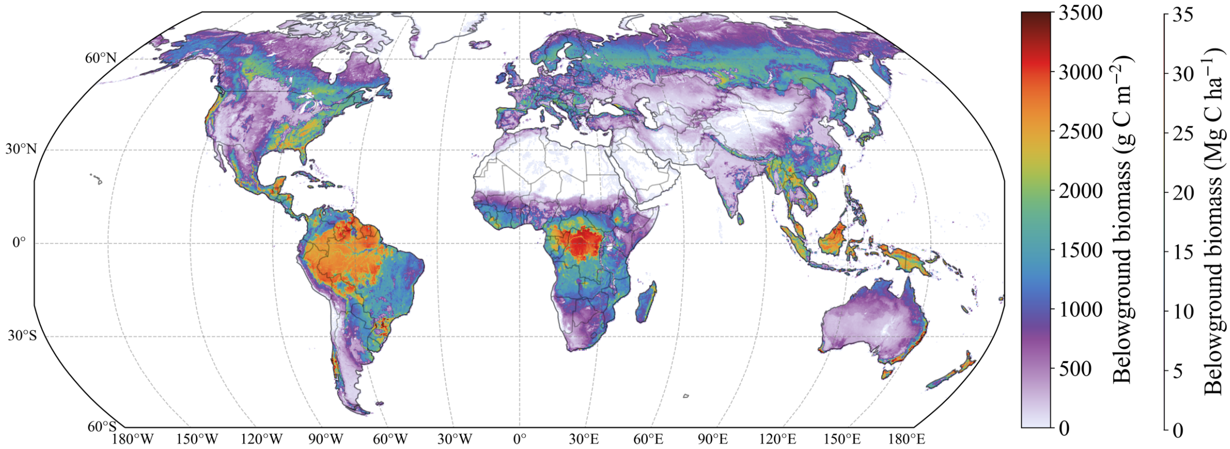


Figure S3: Modelled NPP for 2002–2020 as **(a)** monthly time series and the **(b)** monthly climatological seasonal cycle, as compared to NPP from GFED4(s) and MODIS. Monthly NPP from MODIS was estimated by using monthly gross primary productivity (GPP) and net photosynthesis (PSN) from MOD17A2H and annual NPP from MOD17A3H (See Methods 2.3.1 and S1).

(a)



(b)

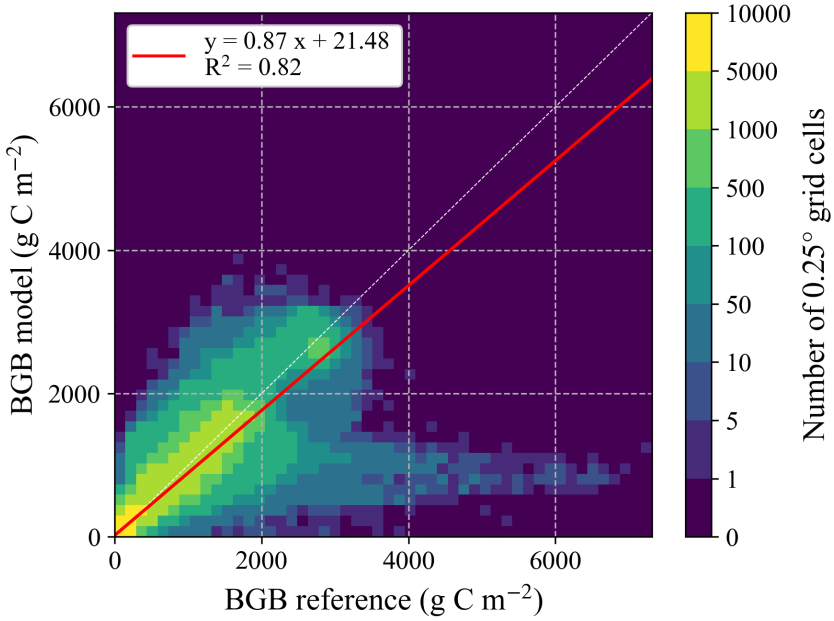


Figure S4: **(a)** Modelled belowground biomass (BGB) averaged over 2002–2020, **(b)** comparison of modelled versus reference belowground biomass at an aggregated 0.25° grid cell level. Model BGB comprises the roots model pool and does not include non-live pools of SOC. Panel **(a)** has been aggregated to 0.25° for display.

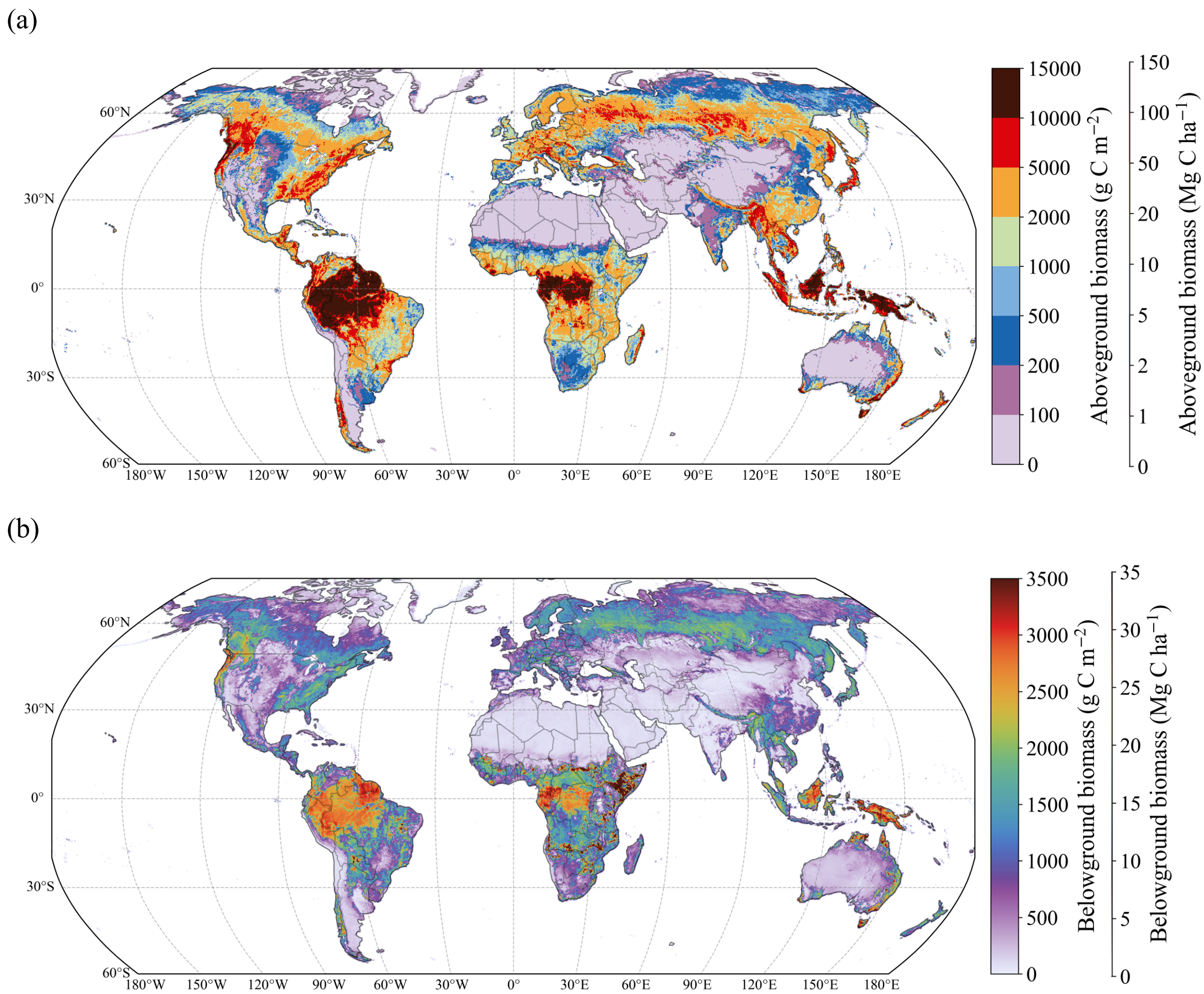


Figure S5: Reference (Spawn et al., 2020) **(a)** aboveground biomass (AGB) and **(b)** belowground biomass (BGB) for the year 2010. Aggregated to 0.25° for display.

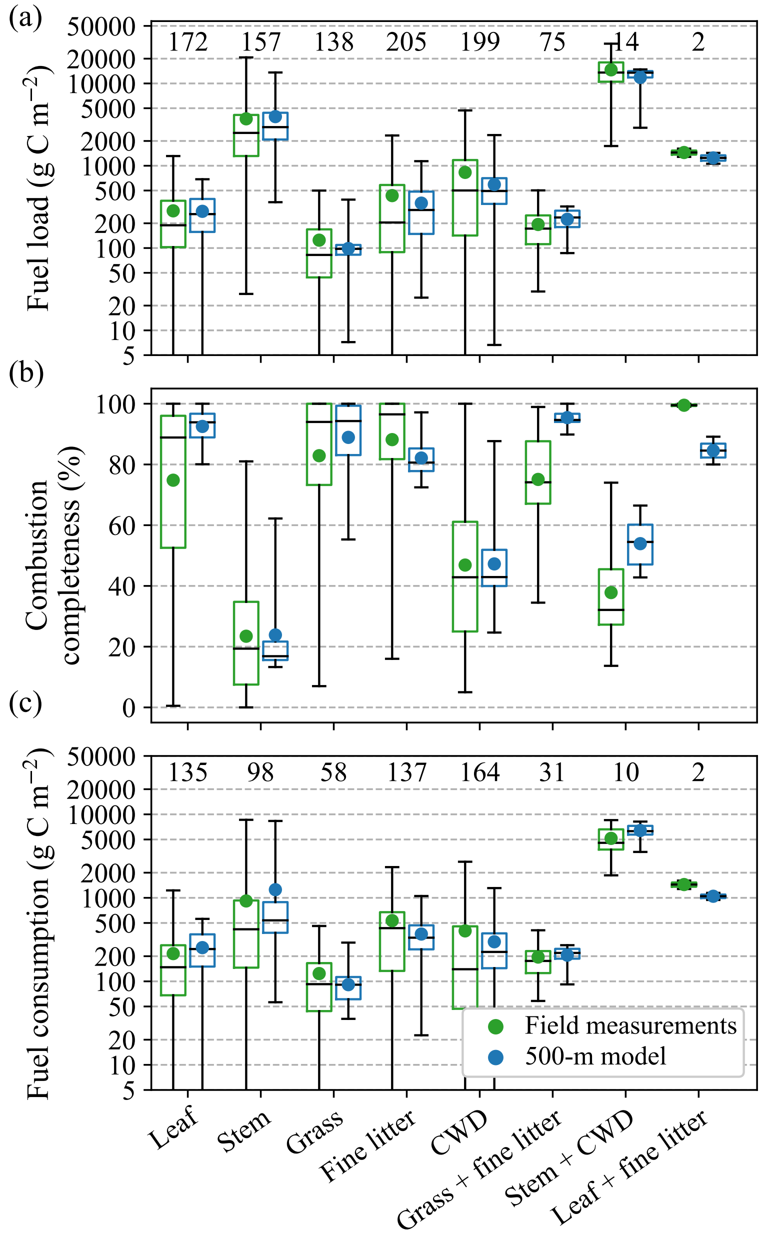


Figure S6: Comparison of field measurements of **(a)** fuel load, **(b)** combustion completeness (CC) and **(c)** consumption versus model estimates for all field data records reporting individual fuel classes (Table 2), grouped per fuel class. The number of measurement records included is given above each boxplot. Records are shown that report measurements of individual fuel classes, or report measurements of two combined fuel classes. The y-axis of panel **(a)** and **(c)** are logarithmic and the y-axis of panel **(b)** is linear. Boxplot whiskers give the range of data.

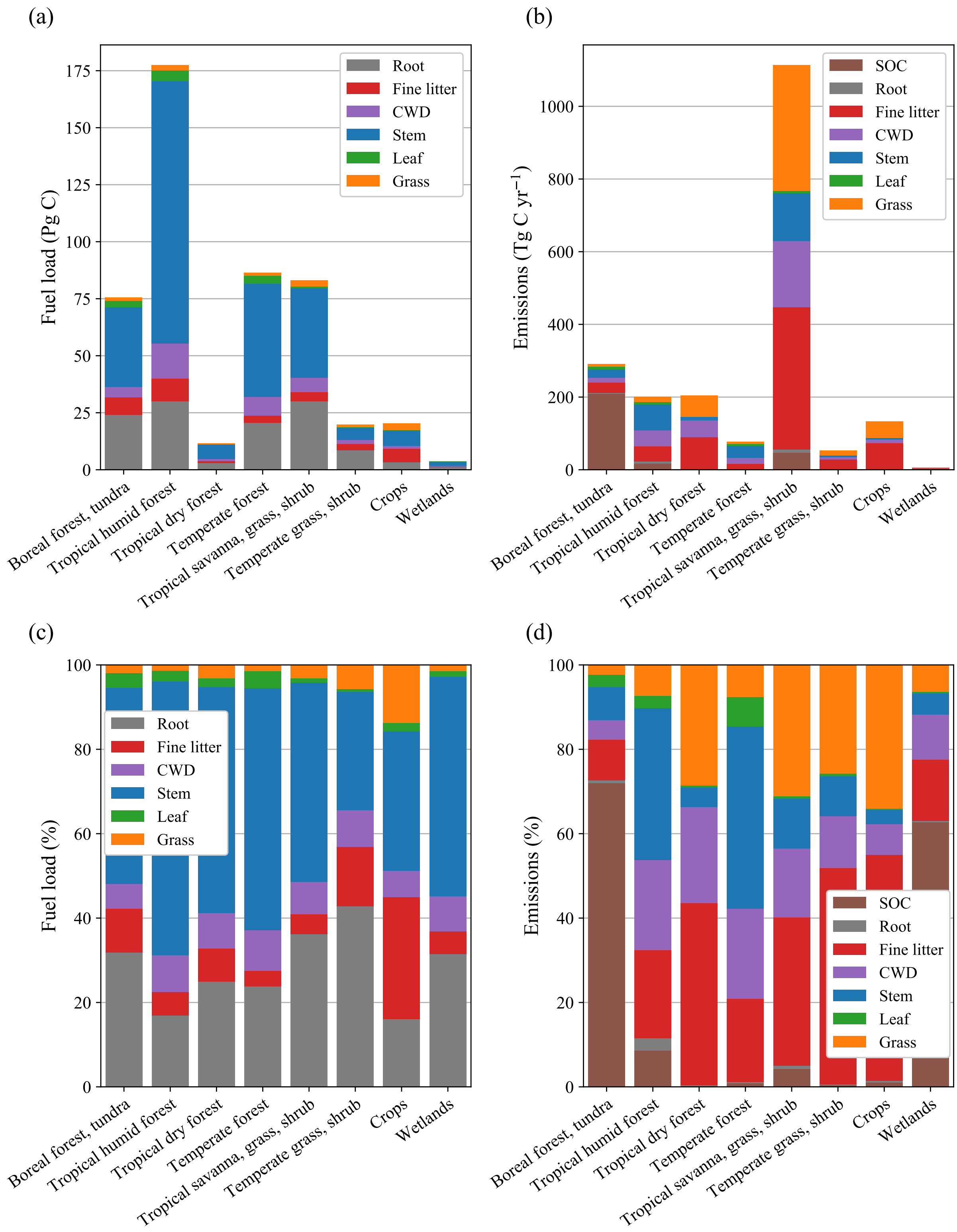


Figure S7: 2002–2020 average **(a)** total fuel load and **(b)** emissions per biome, and **(c)** and **(d)** relative to totals. Bars are subdivided in model biomass and litter pools. Because of the use of static SOC maps, fuel loads in panel **(a)** and **(c)** do not include soil organic carbon.

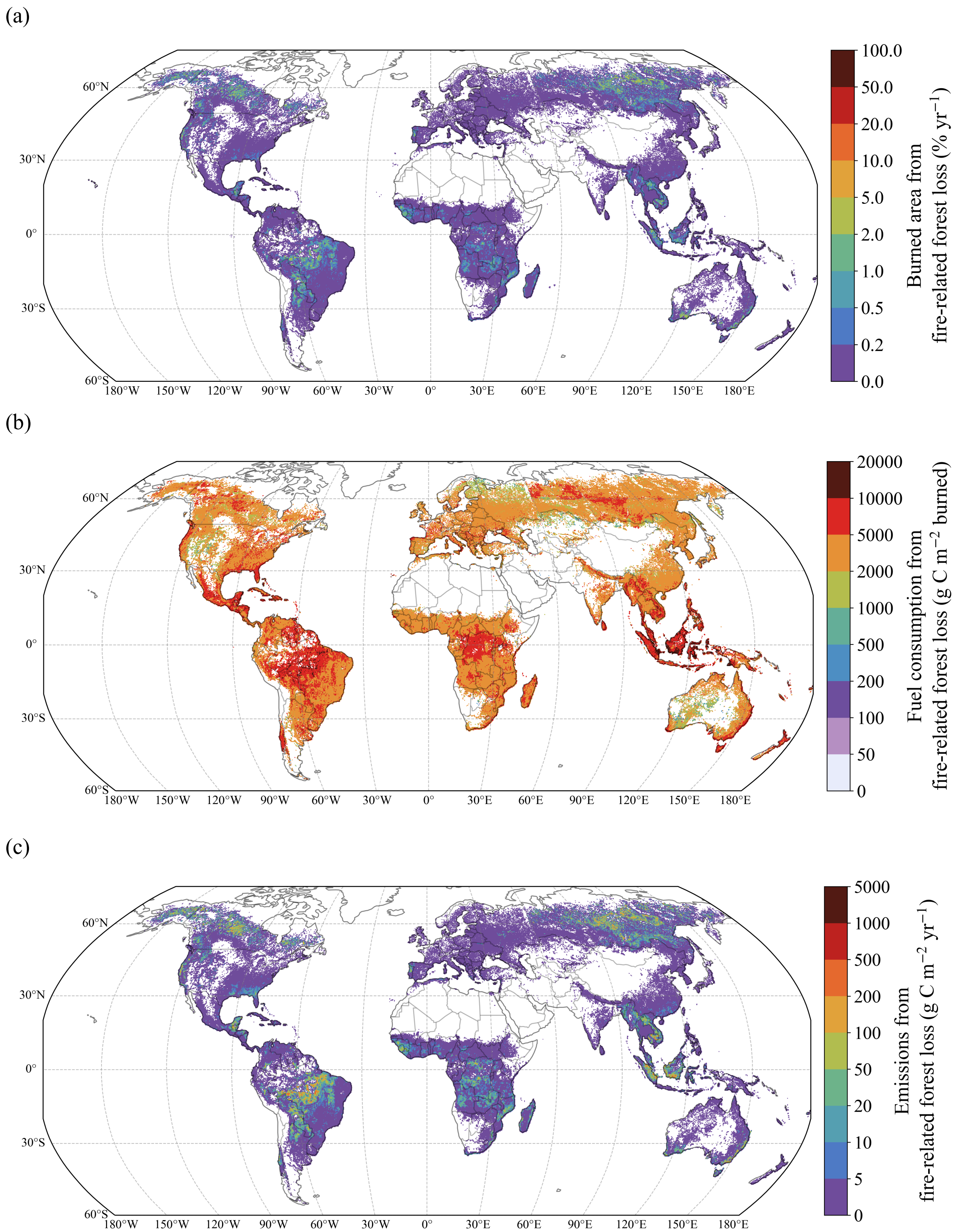


Figure S8: Global annual **(a)** burned area, **(b)** fuel consumption, and **(c)** emissions for fire-related forest loss, averaged over 2002–2020. Maps are aggregated to 0.25° for display.

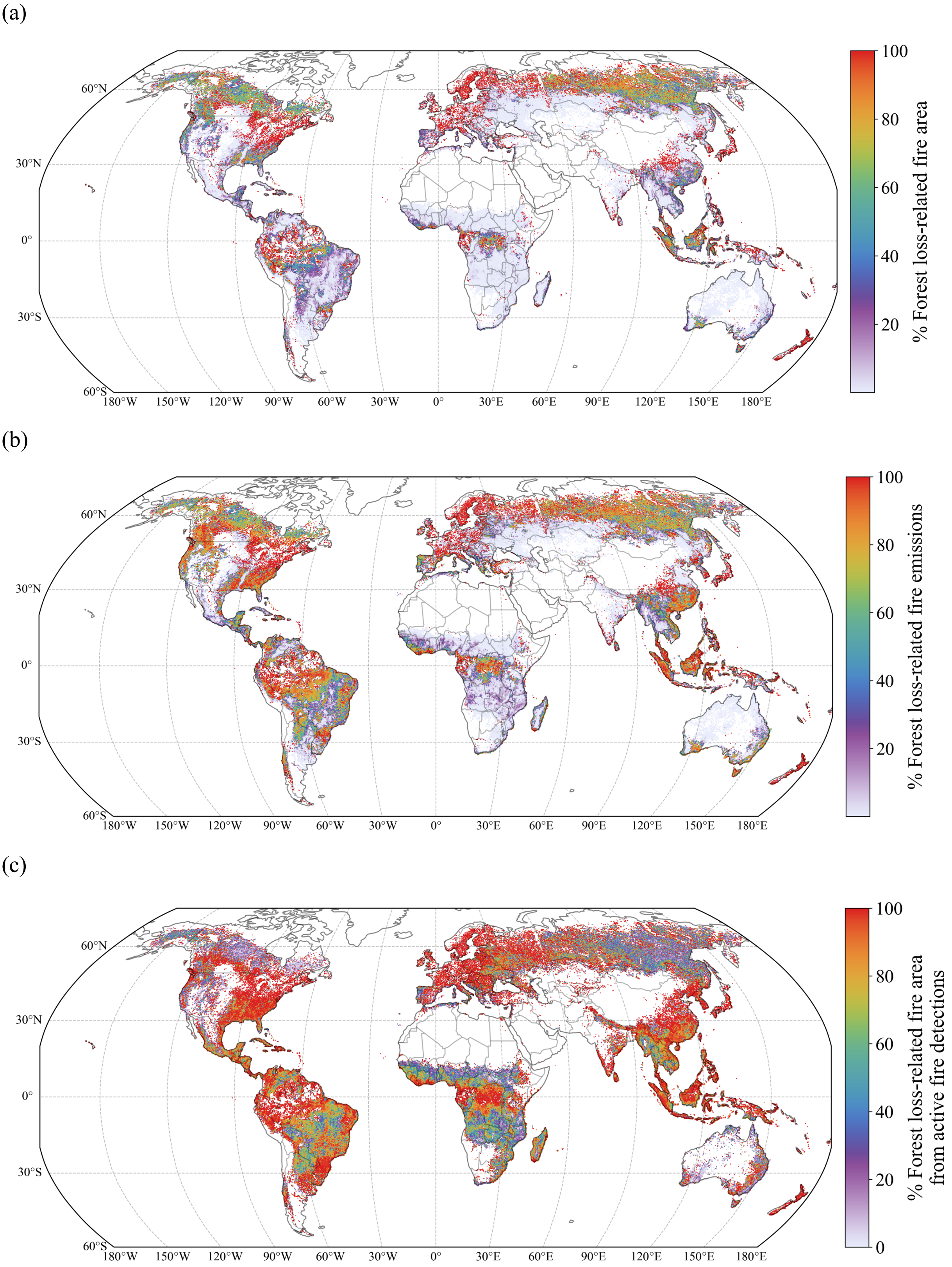


Figure S9: Percentage of total **(a)** burned area and **(b)** emissions due to fire-related forest loss for the period 2002–2020. **(c)** Fraction of forest loss-related fire area stemming from active fire detections. Maps are aggregated to 0.25° for display.

Figure S10: Monthly 2002–2020 emissions for the global total, global fire-related forest loss, and the 14 GFED regions, comparing the 500-m model to GFED4s. Global fire-related forest loss is only available for the 500-m model.

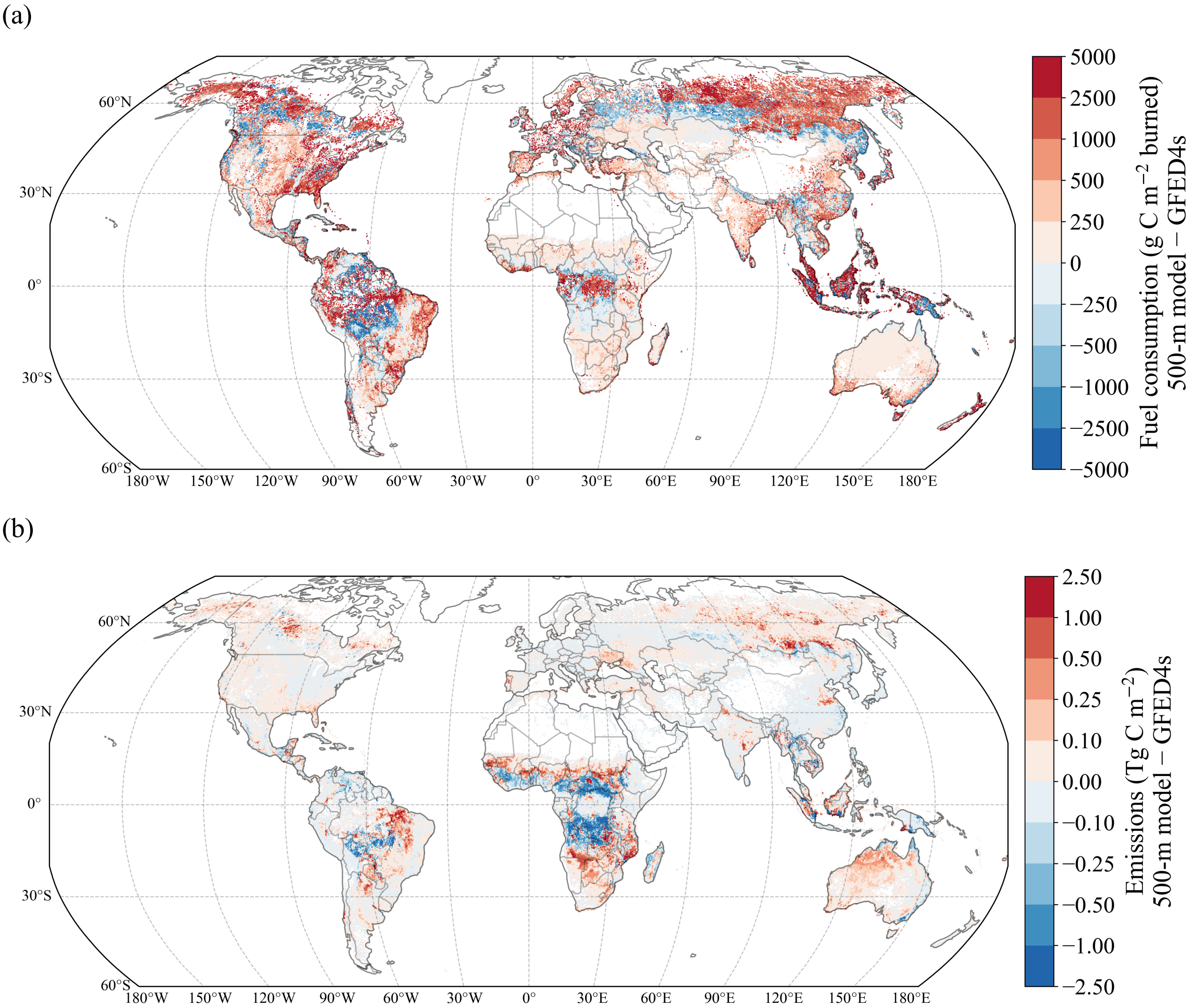


Figure S11: **(a)** Fuel consumption and **(b)** emissions difference between the 500-m model and GFED4s for 2002–2016. Red colors show higher values for the 500-m model compared to GFED4s, and blue colors show lower values. Maps are aggregated to 0.25° for display.