Target journal: ESD

Estimating the lateral transfer of organic carbon through the European river 1 network using a land surface model

Table S1 Values of the key parameters used in the ORCHIDEE-$C_{lateral}$ to simulate the lateral transfer of sediment and carbon.

Parameter	Value	Unit	Description	Source
a	26.96	Unitless	Coefficient in Eq. 1	Calibrated
b	0.76	Unitless	Coefficient in Eq. 1	Calibrated
c	1.79	Unitless	Coefficient in Eq. 2	Calibrated
d	-0.065	Unitless	Coefficient in Eq. 2	Calibrated
c_{ebed}	0.5	Unitless (0-1)	The fraction of sediment deficit that can be complemented by erosion of river bed (Eq. 6)	Calibrated
c_{ebank}	0.5	Unitless (0-1)	The fraction of sediment deficit that can be complemented by erosion of river bank (Eq. 6)	Calibrated
c_{rivdep}	0.1, 0.2, 0.5[a]	Unitless (0-1)	Daily deposited fraction of the sediment surplus in stream reservoir (Eq. 5)	Calibrated
c_{flddep}	0.5, 1.0, 1.0[a]	Unitless (0-1)	Daily deposited fraction of the sediment surplus in flooding reservoir (Eq. 11)	Calibrated
$P_{flooding}$	0.1	year	Return period of daily bankfull flow	Calibrated
τ_{fast}	3.0	day	A factor which translates the topographic index into the water residence time of the 'fast' reservoir (Eqs. 5, 6)	Guimberteau et al., 2012
τ_{flood}	1.4	day	A factor which translates the topographic index into the water residence time of the flooding reservoir (Eq. 18)	Guimberteau et al., 2012
τ_{poc}	0.3, 1.12, 0.3[b]	year	A factor which translates the topographic index into the water residence time of the flooding reservoir (Eq. 25)	Lauerwald et al., 2017
ω	12.0, 5.0, 2.5[a]	$g\ s^{-1}$	Coefficient of proportionality for calculating sediment transport capacity (Eq. 8)	Calibrated

[a] For clay, silt and sand sediment, respectively. [b] For active, slow and passive POC, respectively.

Table S2 Abbreviation used in this study.

Abbreviation	Discription
A	Upstream drainage area (m^2)
c_{ebank}	Fraction of sediment deficit that can be complemented by erosion of river bank each day (0-1, unitless)
c_{ebed}	Fraction of sediment deficit that can be complemented by erosion of river bed each day (0-1, unitless)
c_{flddep}	Daily deposited fraction of the suspended sediment in flooding waters (0-1, unitless)
C_{iday}	Daily actual cover management factor (unitless, 0-1)
C_{ref}	Assumed reference cover management factor of MUSLE (unitless, 0-1)
c_{rivdep}	Daily deposited fraction of the sediment surplus (0-1, unitless)
DA_i	Drainage area of headwater basin i (m^2)
DOC	Dissolved organic carbon
E_{h2o}	Evaporation of flooding water (m3 day^{-1})
f_{A_fld}	Fraction of floodplain area in each grid cell (0-1, unitless)
f_{A_riv}	Fraction of river surface in each grid cell (0-1, unitless)
$F_{bed2fld\_k}$	Transformation of sediment (k=sed, g day^{-1}) and POC (k= POC g C day^{-1}) deposited in river channel to the floodplain soil
F_{bero_k}	Sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day^{-1}) entering the target river segment due to erosion of river bank
$F_{down2fld\_k}$	Water (k=*h2o*,m^3 day^{-1}), sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or *CO2*, g C day-1) flow from the target river segment to the neighbouring downstream floodplain
$F_{down2riv\_k}$	Water (k=*h2o*,m^3 day^{-1}), sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day-1) flow from the target river segment to the neighbouring downstream river
F_{DR_k}	Water (k=*h2o*,m^3 day^{-1}) or carbon (k= *DOC* or CO_2, g C day^{-1}) flow from upland to the slow water reservoir through drainage
F_{fd_k}	Water (k=*h2o*,m^3 day^{-1}), DOC (k= *DOC* g C day^{-1}) or CO2 (k= CO2 g C day^{-1}) infiltrated to floodplain soil, or sediment (k=*sed*, g day^{-1}) or POC (k= POC g C day^{-1}) deposition on floodplain
$F_{fld2riv\_k}$	Water (k=*h2o*,m^3 day^{-1}), sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day^{-1}) input from flooding water to the target river segment
F_{Fout_k}	Water (k=*h2o*,m^3 day^{-1}), sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day^{-1}) flow from fast reservoir to stream reservoir
F_{POC_i}	Daily decomposition rate of POC in water reservoir i (g C day^{-1}, i= fast, stream, flooding water)
F_{rd_k}	Sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day^{-1}) deposition in river channel
F_{rero_k}	Sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day^{-1}) entering the target river segment due to erosion of river bed
F_{RO_k}	Water (k=*h2o*,m^3 day^{-1}), sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day-1) flow from upland to the fast water reservoir through surface runoff
f_{topo}	Topographic index of each headwater basin (unitless)
F_{up2fld_k}	Water (k=*h2o*,m^3 day^{-1}), sediment (k=*sed*, g day^{-1}) or carbon (k= *POC*, *DOC* or CO_2, g C day-1) flow from upstream river segment to the neighbouring downstream floodplain
F_{up2riv_k}	Water (k=*h2o*,m^3 day^{-1}), sediment (k=*sed*, g day-1) or carbon (k= *POC*, *DOC* or CO_2, g C day-1) input from upstream river segments to the target river segment
I_{h2o}	Infiltration of flooding water (m^3 day^{-1})

K_i	Soil erodibility factor of MUSLE in headwater basin *i* (Mg MJ^{-1} mm^{-1})
LS_i	The combined dimensionless slope length and steepness factor MUSLE in headwater basin *i* *(unitless, 0-1)*
PFT	Plant functional type
POC	Particulate organic carbon
POC_a	Active POC pool
POC_p	Passive POC pool
POC_s	Slow POC pool
P_{ref}	Factor of erosion control practices (unitless, 0-1)
q_{ave}	Long-term average stream flow rate (m^3 s^{-1})
q_{i_ref}	Daily peak flow rate at the outlet of headwater basin *i* under the assumed reference runoff condition (m^3 s^{-1})
Q_{i_ref}	Total water discharge at the outlet of headwater basin *i* for the daily reference runoff condition (m^3 day^{-1})
q_{iday}	Stream flow rate on day *i*(m^3 s^{-1})
R_{30_k}	The maximum half-hour runoff in each day (mm 30-min^{-1})
R_{30_ref}	Assumed reference daily maximum 30-minutes runoff (mm 30-min^{-1})
R_{iday}	Daily total surface runoff (mm day^{-1})
R_{ref}	Assumed reference daily total runoff (= 10 mm day^{-1})
S_{deep}	Soil layer under 2 m depth
S_{fast_k}	Water (*k*=*h2o*,m^3), sediment (*k*=*sed*, g) or carbon (*k*= *POC*, *DOC* or CO_2, g C) storage in the fast water reservoir (i.e. the upland surface runoff)
S_{fld_k}	Water (*k*=*h2o*,m^3), sediment (*k*=*sed*, g) or carbon (*k*= *POC*, *DOC* or CO_2, g C) storage in the flooding water reservoir
S_{i_ref}	Daily sediment delivery from headwater basin *i* under a given set of reference runoff and vegetation cover conditions (Mg day^{-1} $basin^{-1}$)
S_{iday}	Actual daily sediment delivery from land to river a specific 0.5°×0.5° grid cell (g day^{-1} $grid^{-1}$)
SOC	Soil organic carbon
S_{POC_i}	Stock of POC in each water reservoir (g C day^{-1}, *i*= fast, stream, flooding water)
S_{ref}	Total sediment delivery from land to river in a specific 0.5°×0.5° grid cell under reference runoff and vegetation cover conditions (g day-1 grid-1)
S_{riv_k}	Water (*k*=*h2o*,m^3), sediment (*k*=*sed*, g) or carbon (*k*= *POC*, *DOC* or CO^2, g C) storage in the stream water reservoir
TC	Sediment transport capacity (g m^{-3})
TOC	Total organic carbon
T_{water}	Temperature of water reservoirs (°C)
τ_{fast}	Default water residence time of the fast reservoir (= 3 days)
τ_{flood}	Default water residence time of the flooding water reservoir (= 3 days)
τ_{POC_i}	the turnover time of the *i* (active, slow and passive) POC pool (year)
ω	Coefficient of proportionality for calculating sediement transport capacity (unitless)

Figures in Supplementary Information

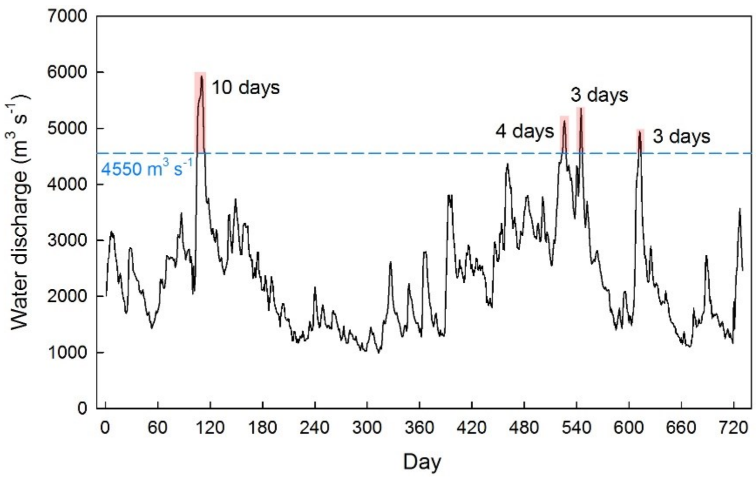

Figure S1 Comparison between the return period of daily bankfull flow ($P_{flooding}$) and the return period of flooding event. When the threshold of bankfull flow is set to 4550 m^3 s^{-1}, $P_{flooding}$ showed in this figure is 0.1 year as the bankfull flow occurred in 20 days during the investigated term of two years. But the return period of flooding event is 0.5 year as there are four flooding events.

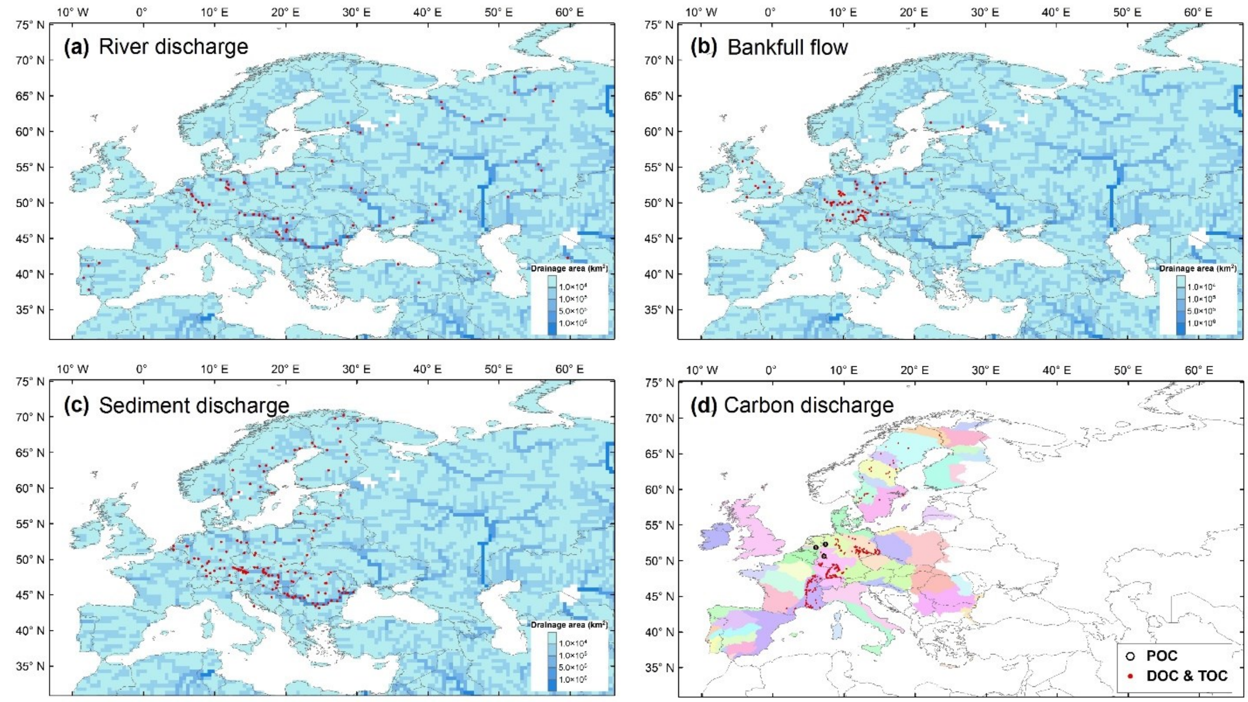

Figure S2 Geographical location of the gauging stations for river discharge (a), bankfull flow (b), sediment discharge (c) and riverine organic carbon discharge (d) used in this. Figure (d) also shows the spatial distribution of 57 catchments in Europe. The simulated average net soil loss rates (g m^{-2} yr^{-1}) at these 57 catchments were compared to the average net soil loss rates extracted from the sediment delivery data provided by the ESDAC (see section 2.3 of the main text).

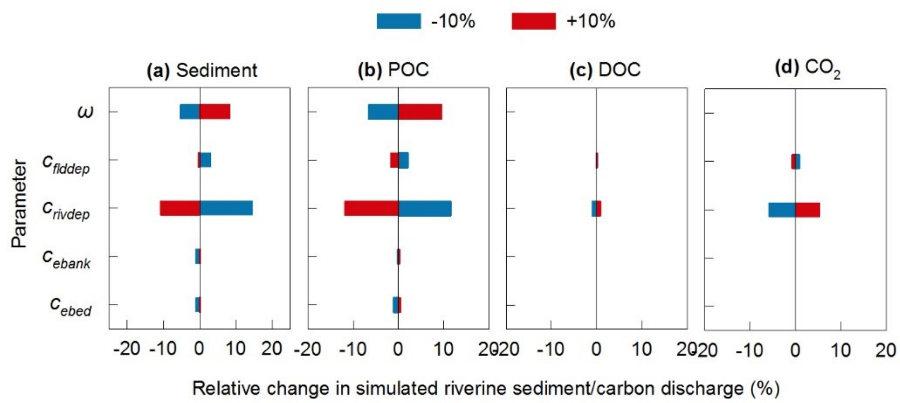

Figure S3 Relative changes in simulated riverine sediment and carbon discharges with 10% increase and decrease in parameters controlling sediment transport in river network. ω is the coefficient of proportionality for calculating sediment transport capacity (Eq. 8); c_{flddep} is the daily deposited fraction of the sediment surplus in flooding reservoir (Eq. 11); c_{rivdep} is the daily deposited fraction of the sediment surplus in stream reservoir (Eq. 5); c_{ebank} is the fraction of sediment deficit that can be complemented by erosion of river bank (Eq. 6); c_{ebed} is the fraction of sediment deficit that can be complemented by erosion of river bed (Eq. 6);

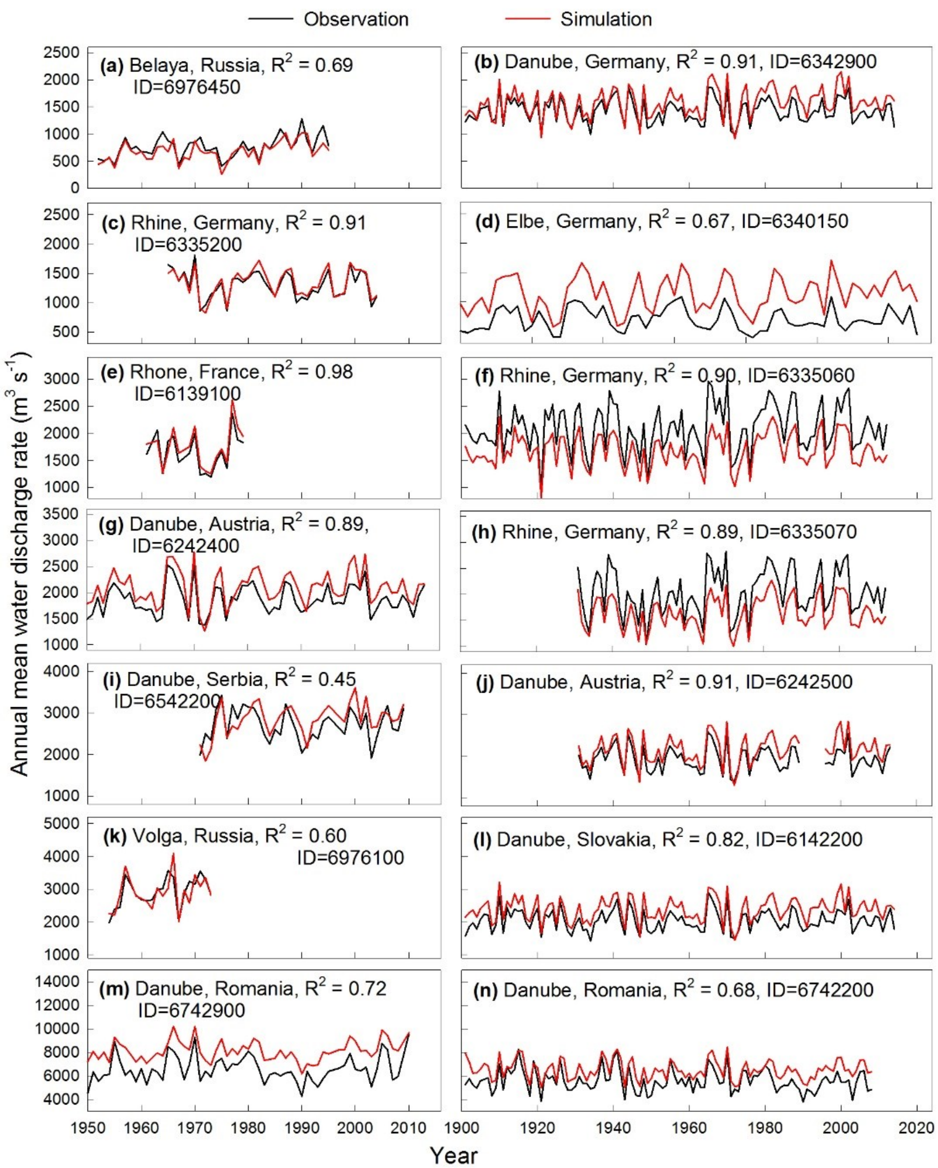

Figure S4 Comparison between the simulated and observed time series of mean annual water discharge rates at 14 gauging stations.

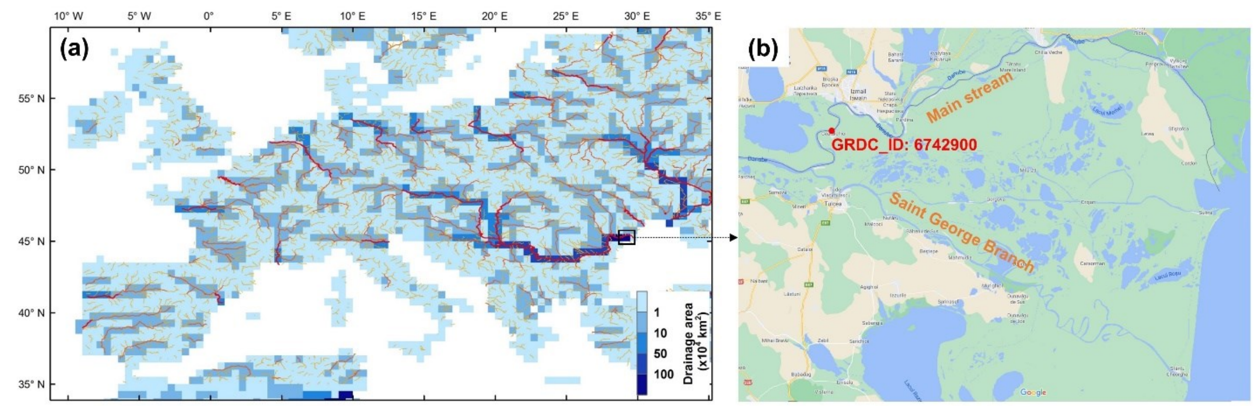

Figure S5 (a) Comparison between the river network extracted from the STN-30p database at 0.5° resolution (blue) (i.e. the forcing data of stream flow directions used in this study) and the river network derived from the HydroSHEDS DEM data at 3″ resolution (red); (b) the real river network in the estuary region of the Danube River (obtained from © Google Maps). GRDC_ID denotes the identify number of the gauging station in the GRDC database (Table 1).

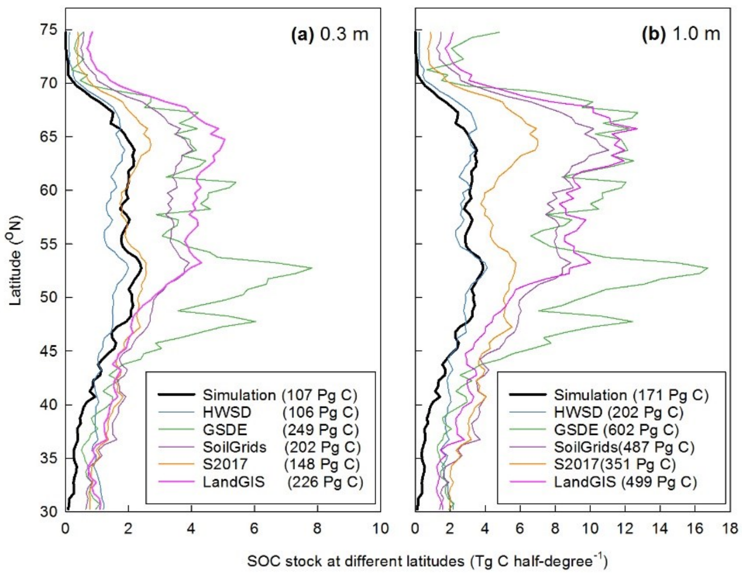

Figure S6 Comparison between the simulated SOC stock by ORCHIDEE-$C_{lateral}$ and those obtained from five soil databases. Figure (a) and (b) showed the SOC stocks in the 0-0.3 m and 0-1.0 m soil layer, respectively. Value in the legend following the name of each soil database is the total SOC stock in the whole Europe. Sources of the soil databases used in this figure can be found in Table 1.

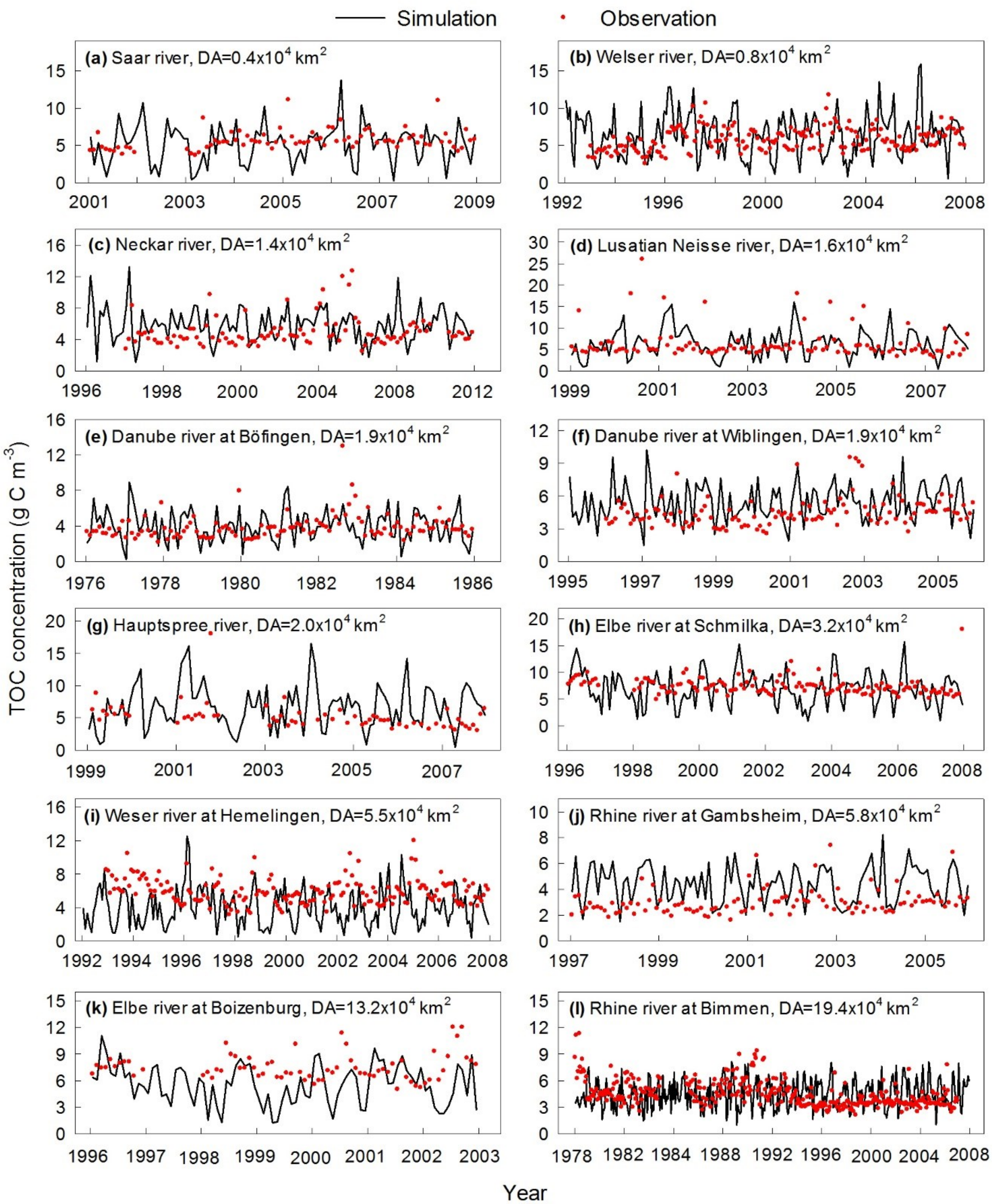

Figure S7 Comparison between the simulated and observed total organic carbon (TOC) concentrations in representative European rivers. DA is the drainage area of the corresponding gauging station.

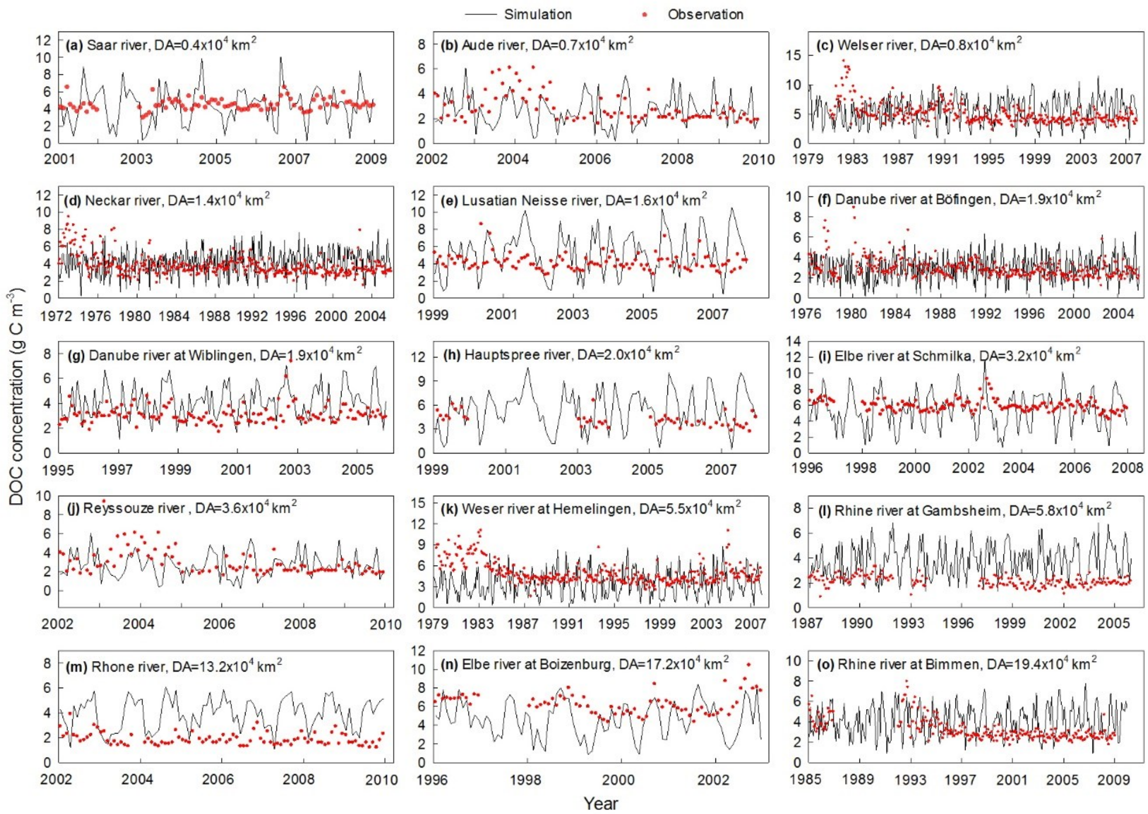

Figure S8 Comparison between the simulated and observed dissolved organic carbon (DOC) concentrations in representative European rivers. DA is the drainage area of the corresponding gauging station.

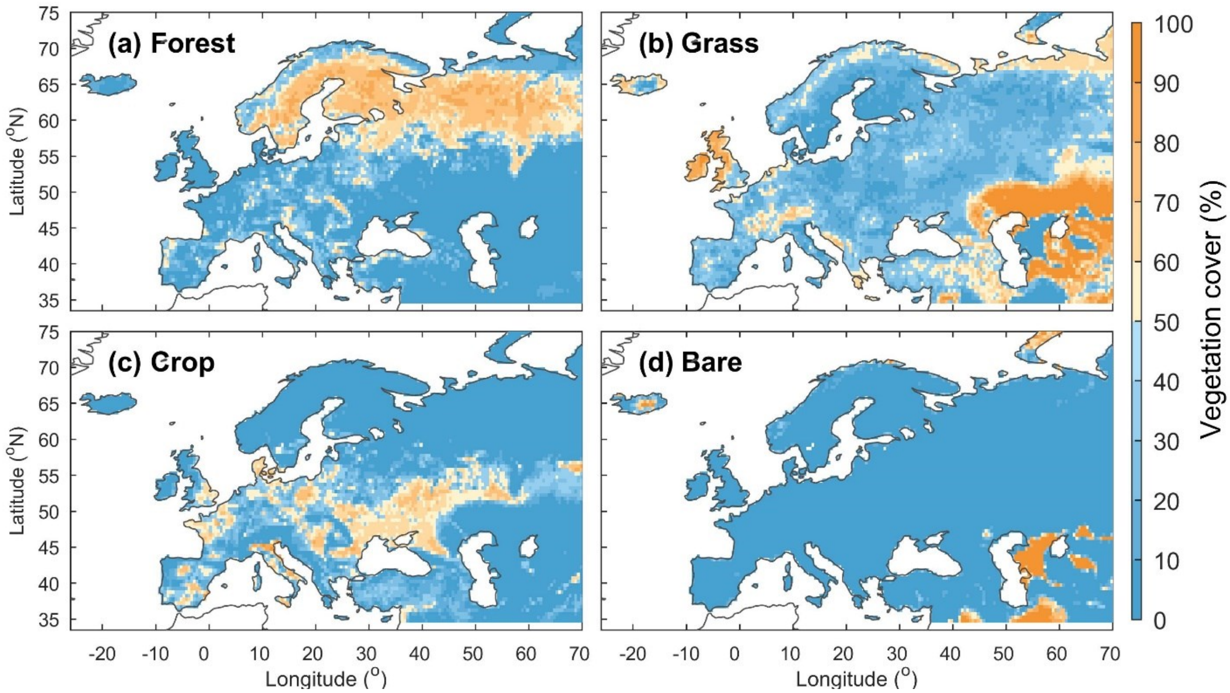

Figure S9 Land cover fraction of forest, grassland, cropland and bare soil (e.g. desert, waterbodies and bare rock) in each 0.5°×0.5° grid cell in Europe during the period 1901-2014. For the Europe, the land cover fraction of forest, grassland, cropland and bare soil are 30.0%, 41.1%, 21.1% and 7.8%, respectively.

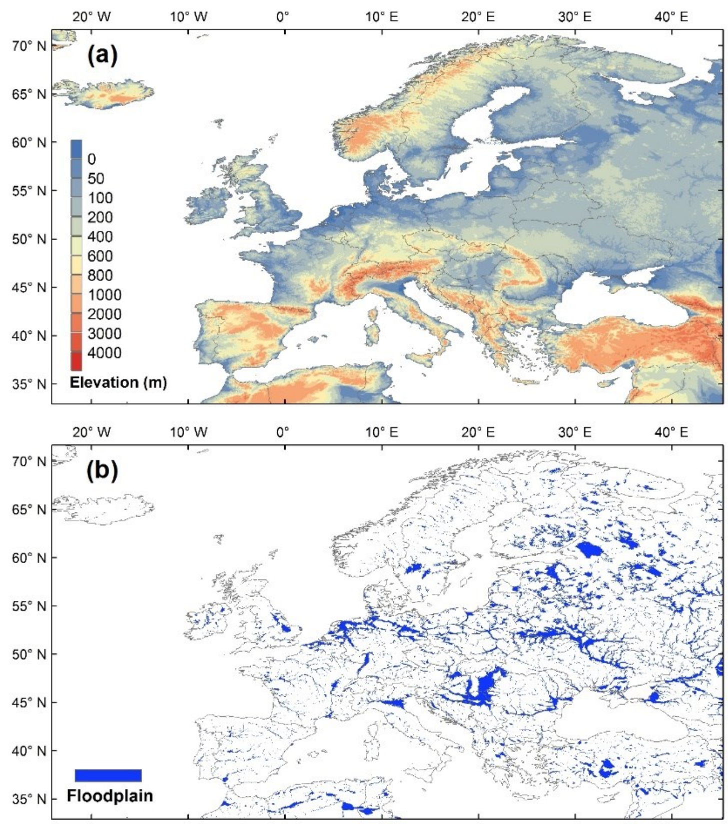

Figure S10 Spatial distribution of elevation (a) and floodplains (b) in Europe. Elevation and floodplain distribution data are obtained from the ASTER GDEM v3 (Abrams et al., 2020) and GFPLAIN250m (Nardi et al., 2019), respectively.

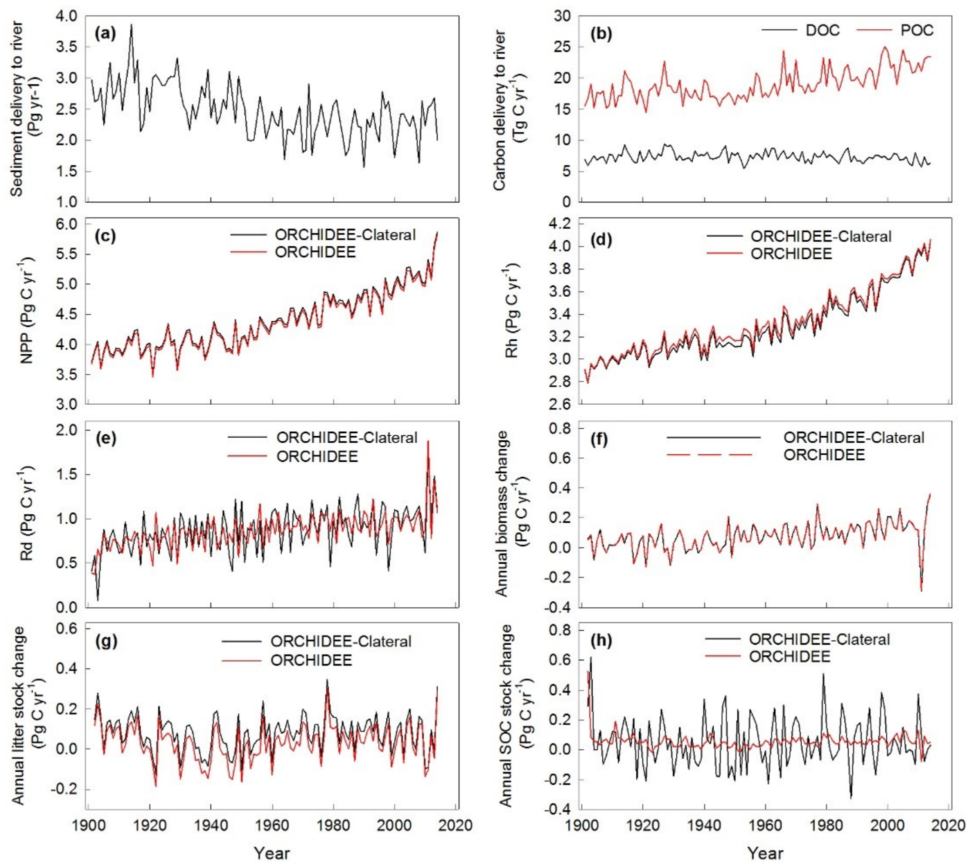

Figure S11 The simulated time series of annual total sediment delivery from upland to river network (a), DOC and POC delivery from land to river network (b), vegetation net primary production (NPP, c), heterotrophic respiration (Rh, d), respiration due to disturbances like harvest and land cover change (Rd, e), changes in living biomass (f), changes in litter carbon stock (g) and changes in SOC stock (h) in whole Europe from the year 1901 to 2014.

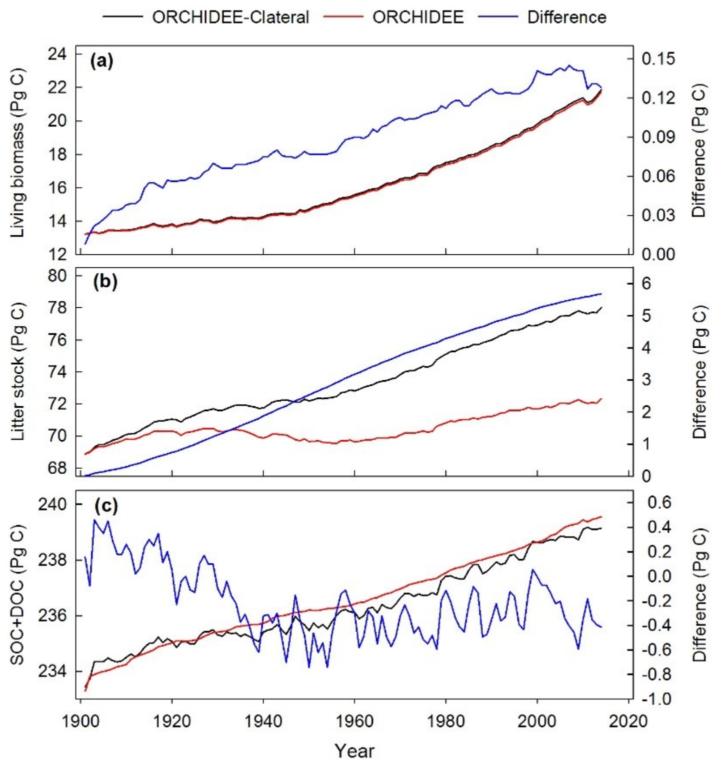

Figure S12 The simulated time series of living vegetation biomass (a), litter carbon pool (b) and total soil organic carbon pool (SOC+DOC, c) by ORCHIDEE-$C_{lateral}$ and ORCHIDEE (i.e. ORCHIDEE-$C_{lateral}$ with deactivated soil erosion and routing module) in whole Europe from the year 1901 to 2014. The blue line in each subplot is the difference between the simulated results from ORCHIDEE-$C_{lateral}$ and ORCHIDEE.

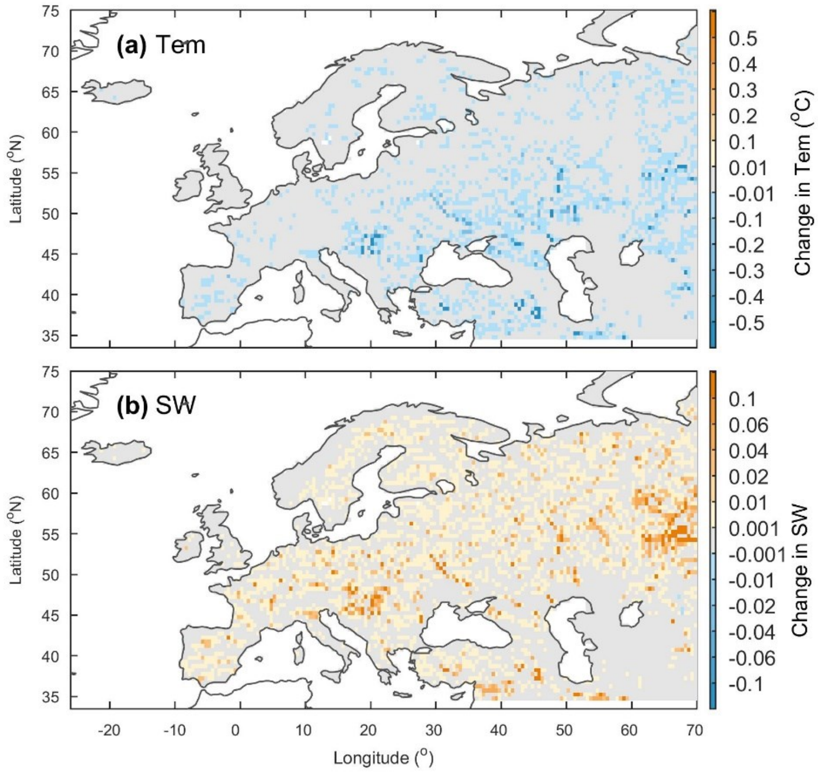

Figure S13 Changes in soil temperature (Tem, °C) and soil wetness (SW, unitless) above wilting point due to the lateral carbon transport. The change of Tem was calculated as Tem_{lat} - Tem_{nolat}, where Tem_{lat} and Tem_{nolat} are the soil temperatures when lateral carbon transport is considered and ignored, respectively. The change of SW was calculated in the same method as the Tem.