S1 Derivation of RUSLE factors

The regression equations to calculate the R-factor operate on one or more of the following parameters: total annual precipitation, mean elevation, and the simple precipitation intensity index, SDII. SDII is calculated based on the hourly precipitation data from ISIMIP2B (Frieler et al., 2016), by dividing the total yearly precipitation by the total number of wet days (> 1mm) in a year. Mean elevation is derived from the 5 arcmin-resolution ETOPO data (National Geophysical Data Center/NESDIS/NOAA, 1995).

After calculating the R-factor for the year 2005AD using the above-mentioned data, we compared it to the high-resolution global erosivity dataset from Panagos *et al.* (2017). We find that our global erosivity map shows a similar spatial variability in erosivity as that from Panagos *et al.* (2017). There are regions where the erosivity values from our study are at the low side, such as the west coast of North-America, Australia and parts of Asia, which can be explained by missing extreme events (Fig. S1A & B).

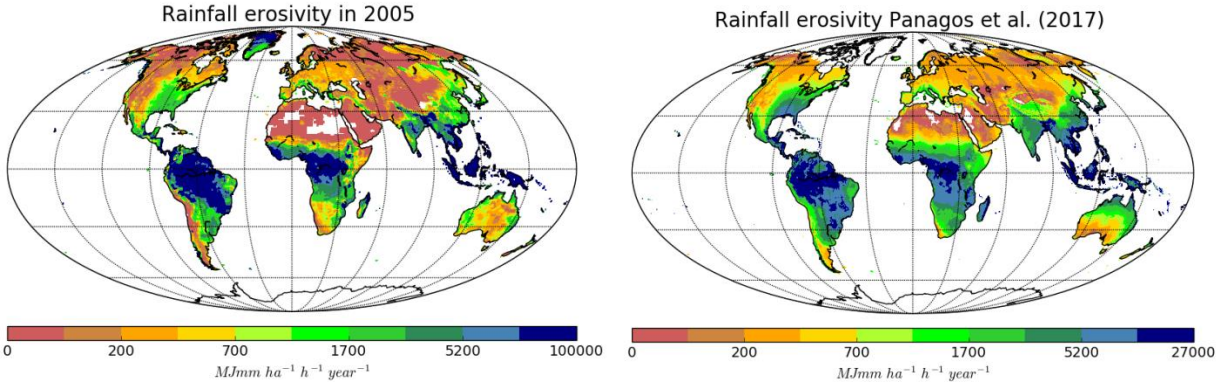

Figure S1: (A) Global rainfall erosivity from this study for the year 2005AD, and (B) global rainfall erosivity map derived from Panagos *et al.* (2017). Both maps have the resolution of 5 arcmin

Due to the lack of data on the normalized difference vegetation index (NDVI), the method presented in the study of Naipal *et al.* (2015) for estimation of the C factor of the Adj.RUSLE model could not be used in this study. Instead, the method from the study of Naipal *et al.* (2016)was used. This method is based on the C values provided by Panagos *et al.* (2015) for Europe for different land cover types, combined with the leaf area index (LAI) from the ORCHIDEE model. The LAI is used to estimate the percentage vegetation cover (cf), which has been shown to influence the overall value of the C factor for a specific land cover type (Walter & Wischmeier, 1972). cf (dimensionless) is estimated according to the Beer's Law approximation:

$$cf = 1 - e^{-0.5*LAI} \quad (1)$$

Five cf classes are distinguished: cf > 0.75, 0.6<cf<=0.75, 0.45<cf<=0.6, 0.2<cf<=0.45 and cf<= 0.2. The corresponding C-factors for the different land cover types used in this study is given in table S1. If cf was smaller than 0.2, all land cover types, except bare soil, were given a maximum value of 0.45. This value corresponds to the maximum C values found by United States Department of Agriculture (Walter & Wischmeier, 1972) and Panagos *et al.* (2015). For bare soil the maximum C value is 0.55, which is according to Panagos *et al.* (2015).

The K-factor (t ha h ha^{-1} MJ^{-1} mm^{-1}) of the Adj.RUSLE model is calculated using 30 arcsec soil data on sand, silt, clay fractions and percent organic matter (from Global Soil Data set for use in Earth System Models (GSCE) (Shangguan *et al.*, 2014), according to the method of Torri, *et al*. (1997):

$$K = 0.0293 * (0.65 - Dg + 0.24 * Dg^2) * e^{\{-0.0021*\frac{OM}{f_{clay}} - 0.00037*\left(\frac{OM}{f_{clay}}\right)^2 - 4.02*f_{clay} + 1.72*f_{clay}^2\}} \quad (2)$$

where Dg is defined as:

$$Dg = -3.5 * f_{sand} - 2 * f_{silt} - 0.5 * f_{clay} \quad (3)$$

where fsand, fsilt and fclay are the fractions of respectively sand (particle size of 0.05-2mm), silt (particle size of 0.002-0.05 mm) and clay (particle size of 0.00005-0.002 mm). OM is the percent organic matter. Volcanic soils are defined as Andosols according to the FAO 90 in the Harmonized World Soil Database (HWSD), and are given a K factor value of 0.08. To account for the effect of stoniness on soil erosion we reduced the total erosion by 30% for areas with a gravel percentage larger or equal to 30% for nonagricultural land (Cerdan et al., 2010). For agricultural and grassland areas we reduced soil erosion by 80% in areas where the gravel percentage exceeded 12% (Doetterl et al., 2012).

The S factor of the adjusted RUSLE model is computed by the continuous function of Nearing (1997):

$$S = 1.5 + \frac{17}{1+e^{(2.3-6.1*\sin\theta)}} \quad (4)$$

where θ is the percent slope that is derived from a 1 km digital elevation model (DEM) and scaled to a resolution of 150m according to the fractal method presented by Naipal *et al.* (2015).

S2 Variability in NPP, biomass and litter

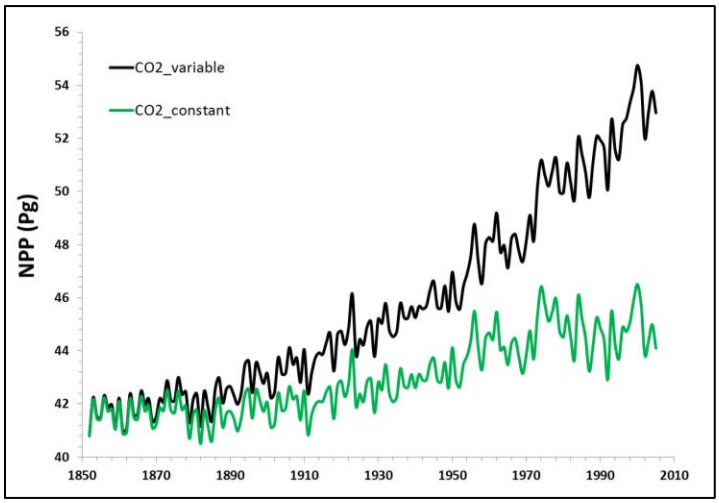

Figure S2: Global total NPP over the historical period from the "CO2_constant" simulation (green) and the "CO2_variable" simulations (black) using the full ORCHIDEE model

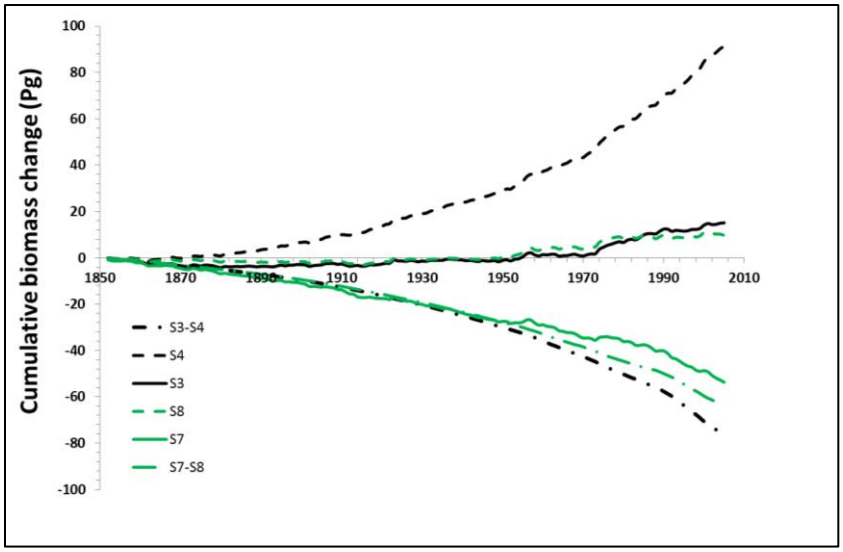

Figure S3: Cumulative historical changes in biomass from simulations with the emulator using variable atmospheric CO_2 (S3, S4, S3-S4), and using constant atmospheric CO_2 (S7, S8, S7-S8)

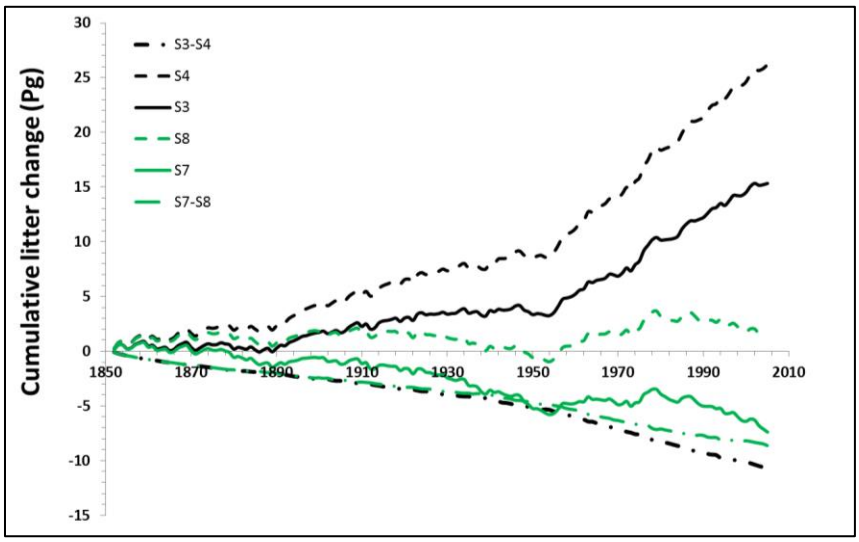

Figure S4: Cumulative historical changes in litter from simulations with the emulator using variable atmospheric CO_2 (S3, S4, S3-S4), and using constant atmospheric CO_2 (S7, S8, S7-S8)

cf	Forest	Grass	Crops	Bare
> 0.75	0.0001	0.01	0.03	0.1
0.6 - 0.75	0.00089	0.029	0.14	0.2
0.45 - 0.60	0.00168	0.048	0.26	0.29
0.20 - 0.45	0.003	0.08	0.45	0.45
< 0.20	0.45	0.45	0.45	0.55

Table S1: C values for different PFTs and cover fractions (cf)

PFT	r
Bare	5
Grass	4
Crop	4
Forest	1 or 0.8

Table S2: values of the r parameter (root profile ORCHIDEE)

Soil depth (m)	GSDE SOC total Crop (Pg)	GSDE SOC total Tree (Pg)	GSDE SOC total Grass (Pg)	S1 SOC total Crop (Pg)	S1 SOC total Tree (Pg)	S1 SOC total Grass (Pg)	S3 SOC total Crop (Pg)	S3 SOC total Tree (Pg)	S3 SOC total Grass (Pg)
0.3	76	274	242	59	420	264	103	516	439
1	145	556	490	84	779	384	139	908	629
2	189	718	632	105	1393	437	167	1706	716

Table S3: Statistics of the comparison of SOC stocks between GSDE soil database and simulations S1 (with erosion) and S3 (without erosion) per land cover type

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