Water Erosion Modelling Tools for the Use in Land Surface Models

V.Naipal[1], R.Lauerwald[2], P.Ciais[3], B.Guenet[3], Y.Wang[3]

[1]Ludwig-Maximilian University, Germany
[2]Université Libre de Bruxelles, Belgium
[3]Laboratoire des Sciences du Climat et de l'Environnement (LSCE)

Contact: victoria.naipal@lmu.de

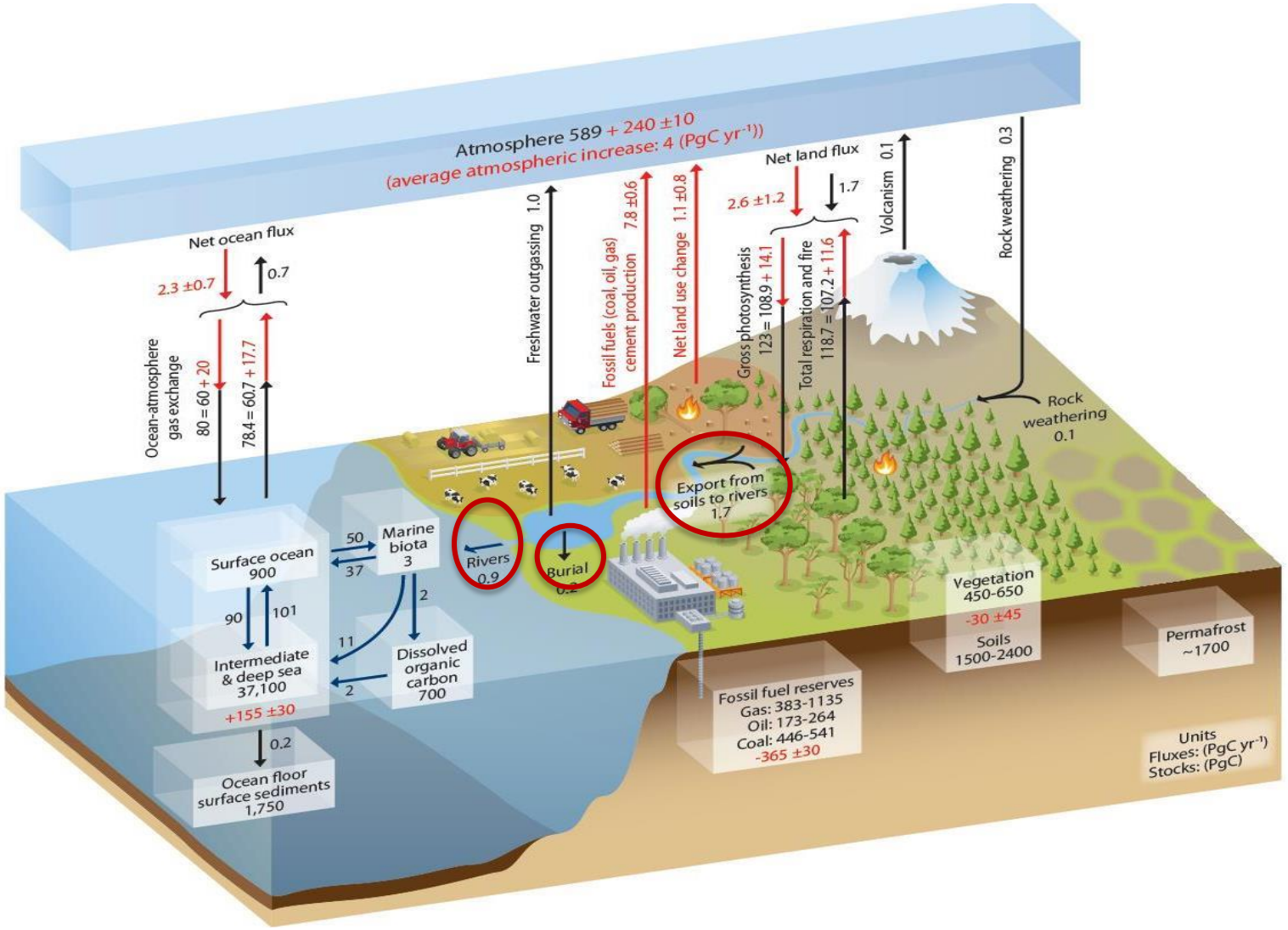
Schedule

- **14:00-14:45: General introduction on modelling water erosion and the carbon cycle at large spatial scales**
- 14:45-14:55: Short break
- 14:55-15:40: Practical session on soil erosion
- 15:40-15:50:Short break
- 15:50 – 16:45: Practical session – continuation
- Conclusion

https://www.researchgate.net/profile/Victoria_Naipal

https://www.researchgate.net/project/Interactions-between-sediment-and-carbon-dynamics-at-a-global-scale

The importance of lateral fluxes in the global carbon cycle



IPCC report Working group 1
Ciais et al., 2013

SOC sequestration and climate mitigation

8.9 giga tonne C

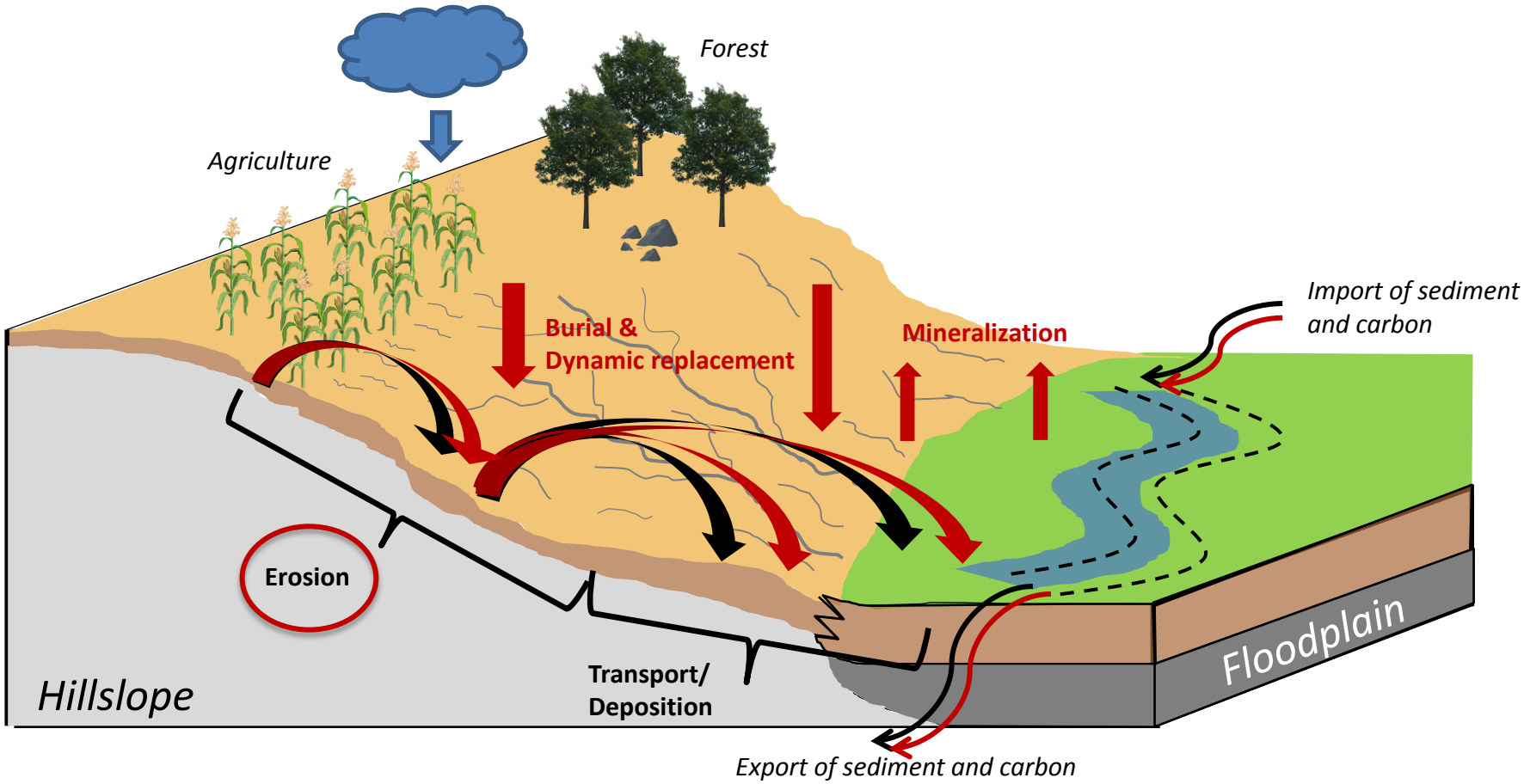
Annual Global CO_2 emissions from fossil fuels

$8.9 / 2400 = 4‰$

Amount of C stock increase needed to offset CO_2 emission

https://www.4p1000.org/

Soil redistribution and C dynamics

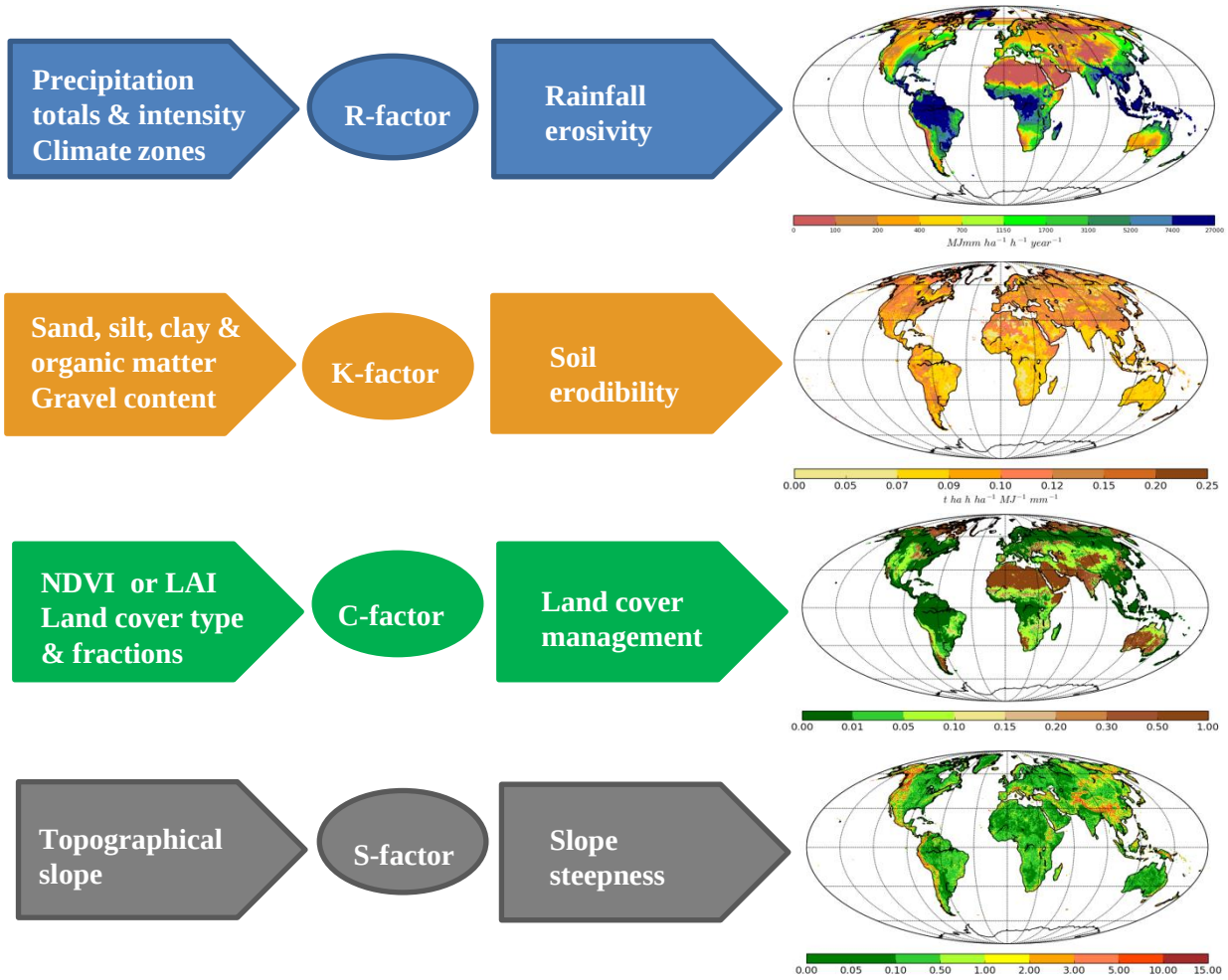


Sediment and C fluxes at landscape level. Black arrows are sediment fluxes while red arrows are C fluxes

The Adjusted RUSLE model

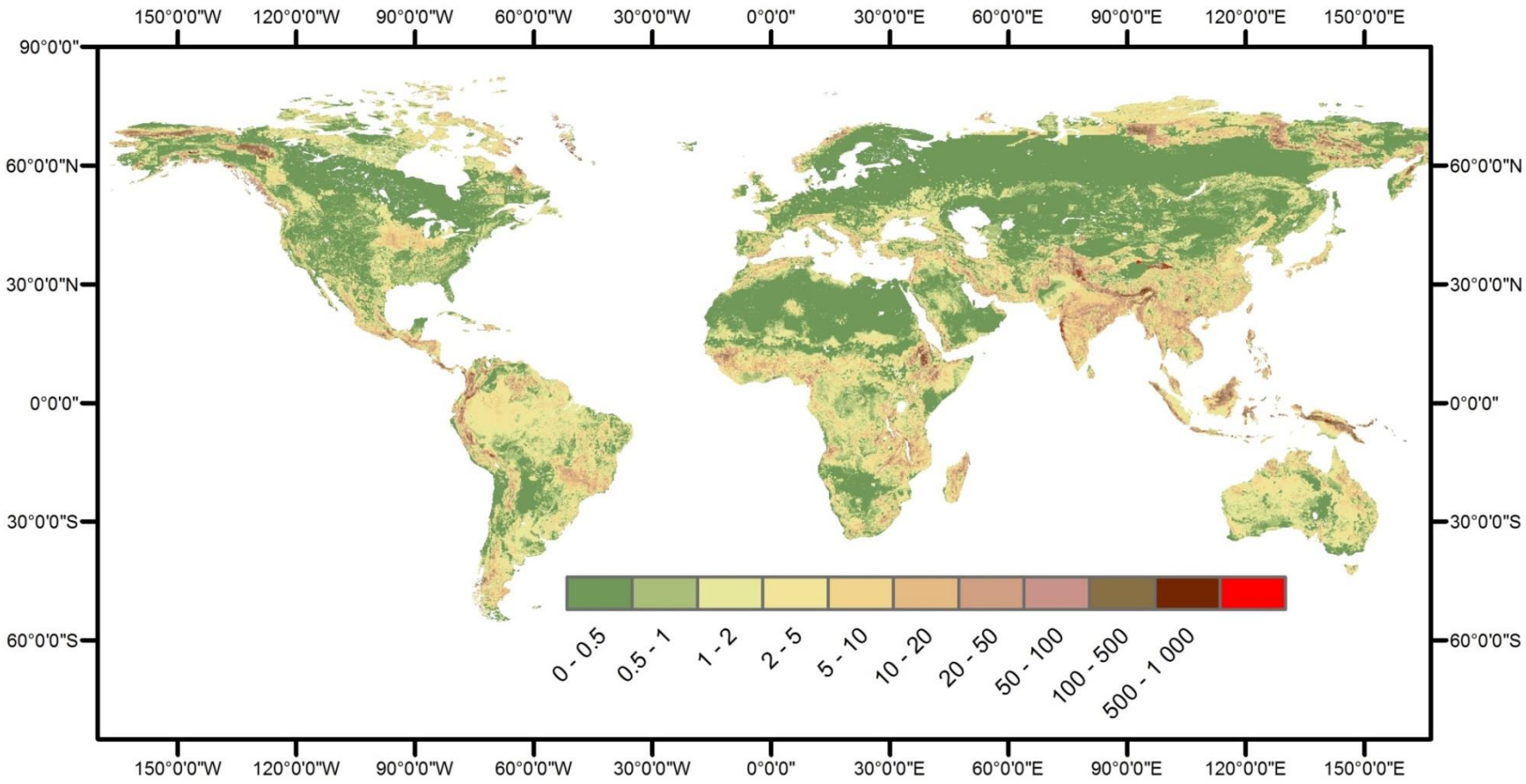
A globally applicable soil erosion model

Average annual soil erosion = R*K*C*S



Naipal et al., 2015, GMD

Present-day global soil erosion rates



Mean: 6.5 t ha^{-1} y^{-1}

Uncertainty mean: 5.3 -15 t ha^{-1} y^{-1}

Naipal et al., 2015, GMD

A novel global sediment budget model

- Soil removal by erosion is just one part of the story
- The destiny of the eroded soil plays an equal important role
- Using a mass-balance approach I added sediment deposition and transport to the adjusted RUSLE model, hereby, differentiating between hillslopes and floodplains
- The novelty of this modeling approach is the explicit representation of deposition and burial in floodplains
- This will be essential for a full representation of the linkages of soil erosion and the carbon cycle at regional scales

Naipal et al., 2016, ESD

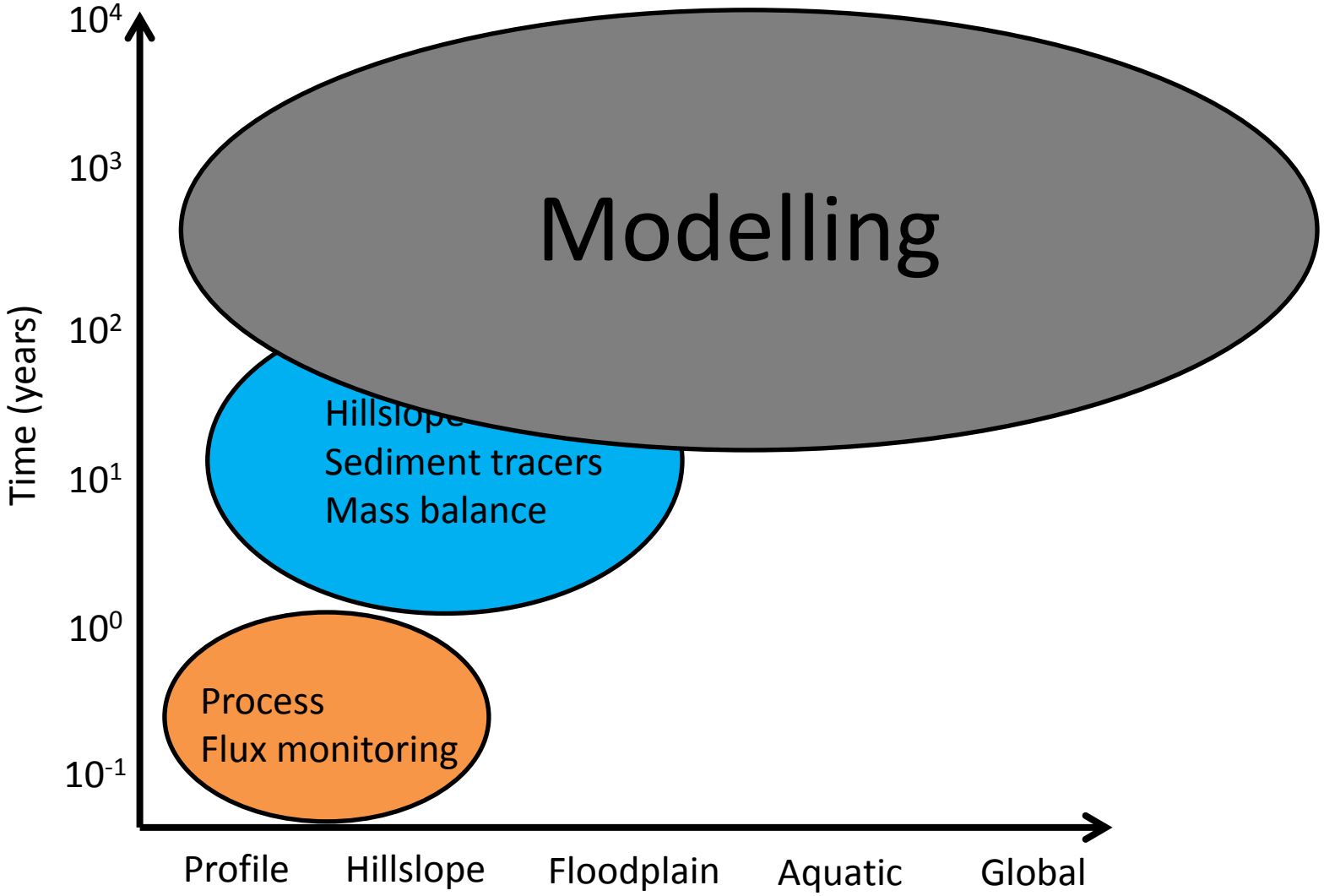
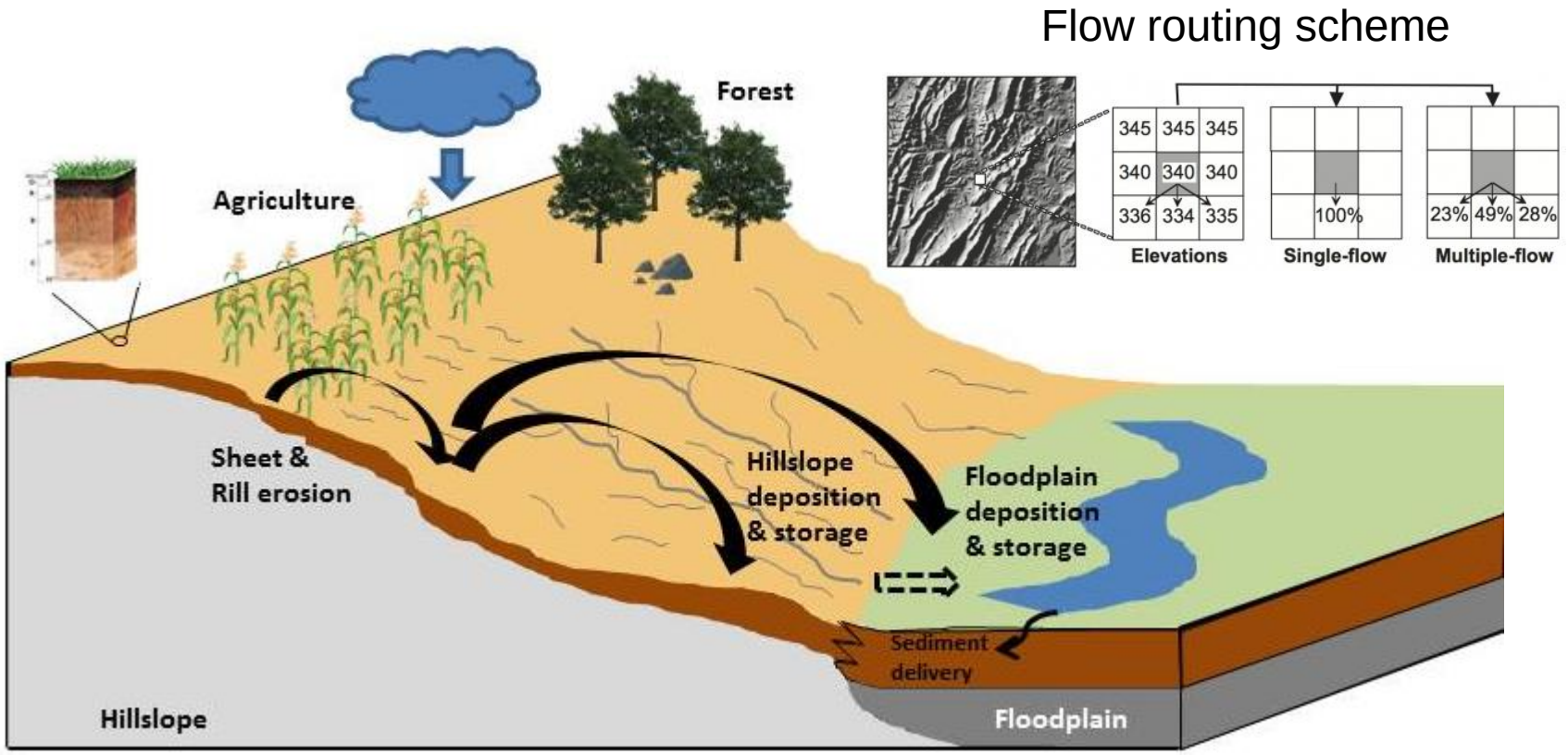


Figure taken from K. Van Oost

The global sediment budget model



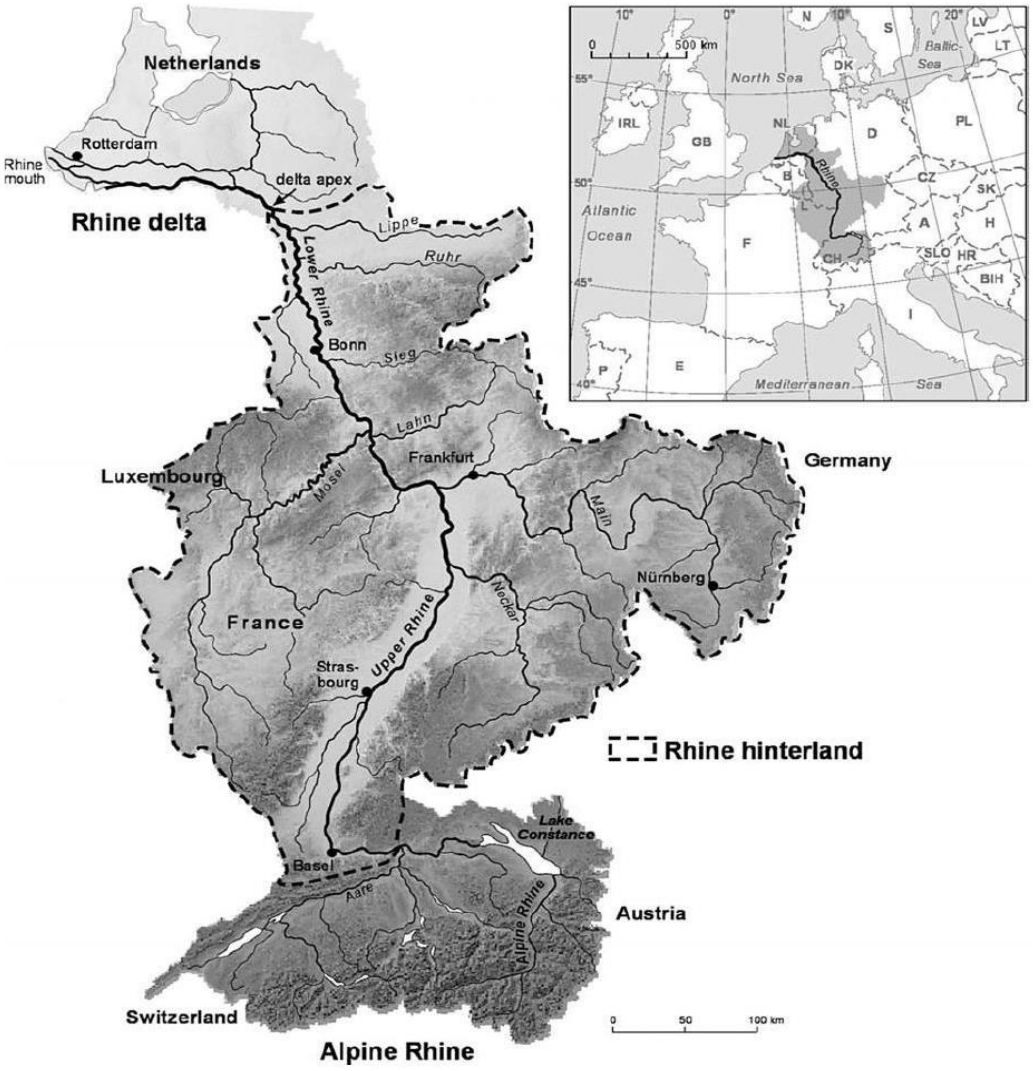
Erosion ($E_{(t)}$) = S * R * C * K $L_{(t)} = M_{a(t)}$ / residence time (τ)

$M_{a(t+1)} = M_{a(t)}$ + deposition fraction($f_{a(t+1)}$) * $E_{(t+1)}$ – Loss ($L_{(t)}$)

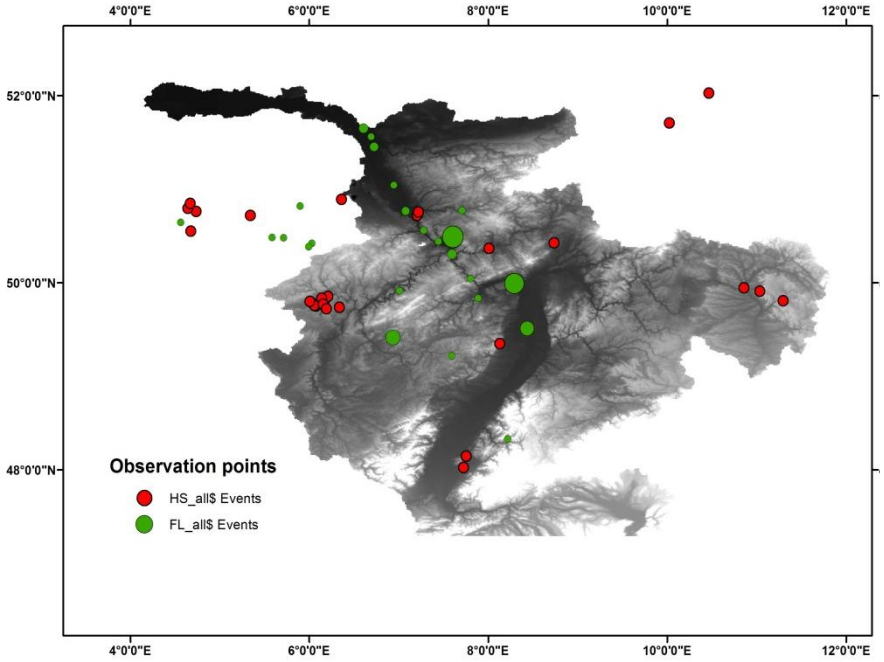
$M_{c(t+1)} = M_{c(t)}$ + deposition fraction($f_{c(t+1)}$) * $E_{(t+1)}$

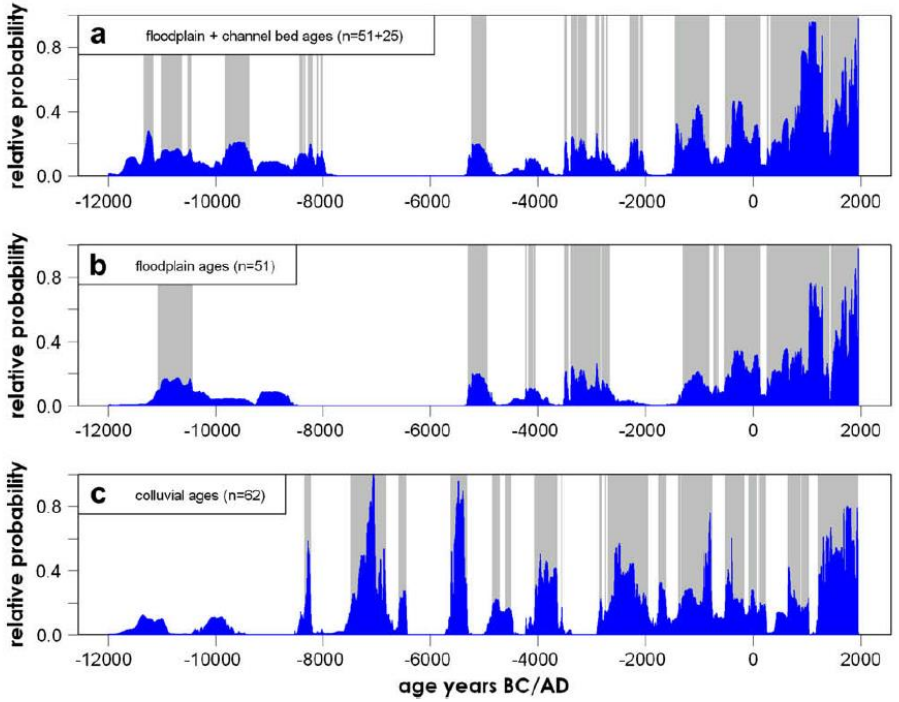
Naipal et al., 2016, ESD

Case-study: The Rhine catchment



Holocene sediment storage & age observations



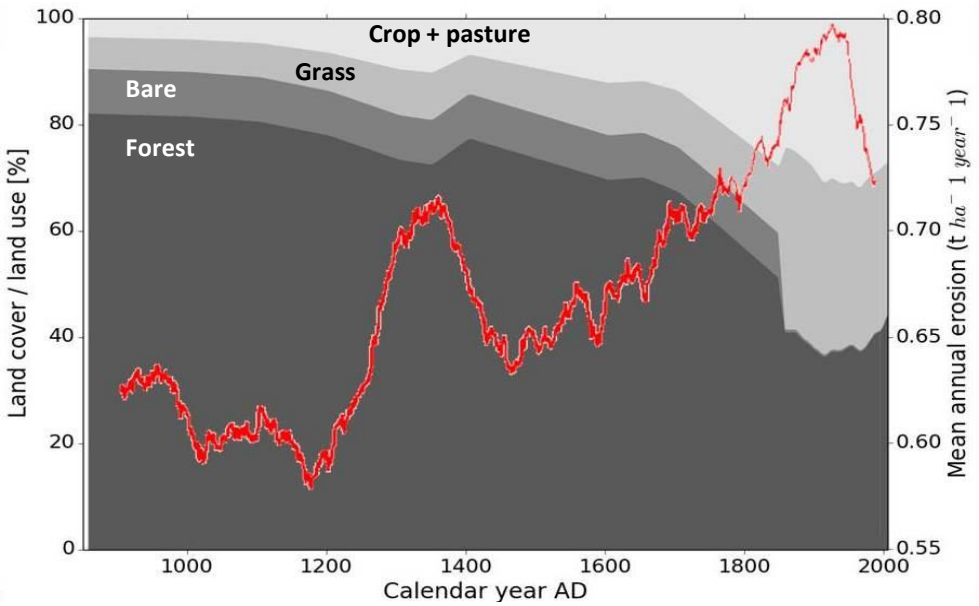


- **Holocene sediment storage** (past 7500 years)
- 41 hillslope and 36 floodplain sediment storage observations
- Source data: Borehole and geological maps

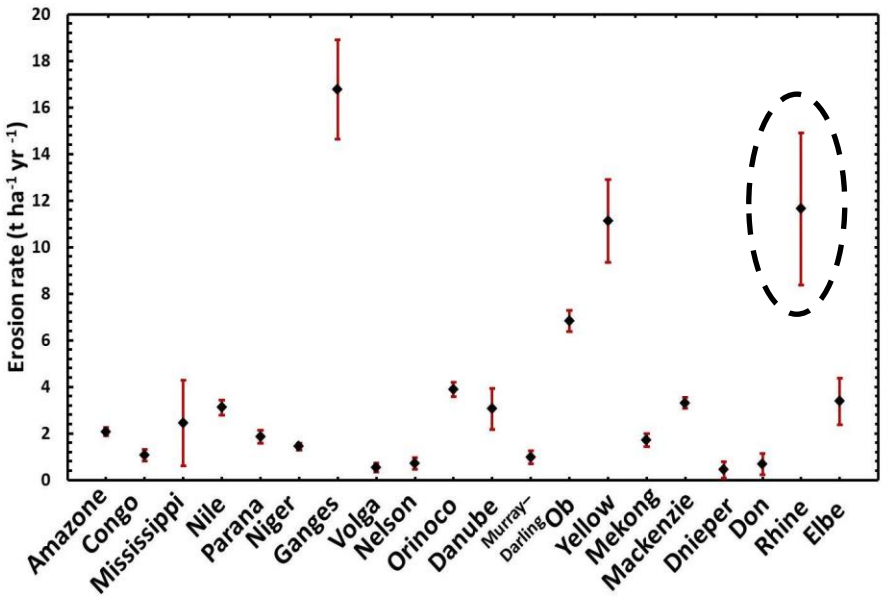
Floodplain versus colluvial sediment ages

Hoffmann et al., 2008
Hoffmann et al., 2013, GBC

Simulated soil erosion over the last millennium



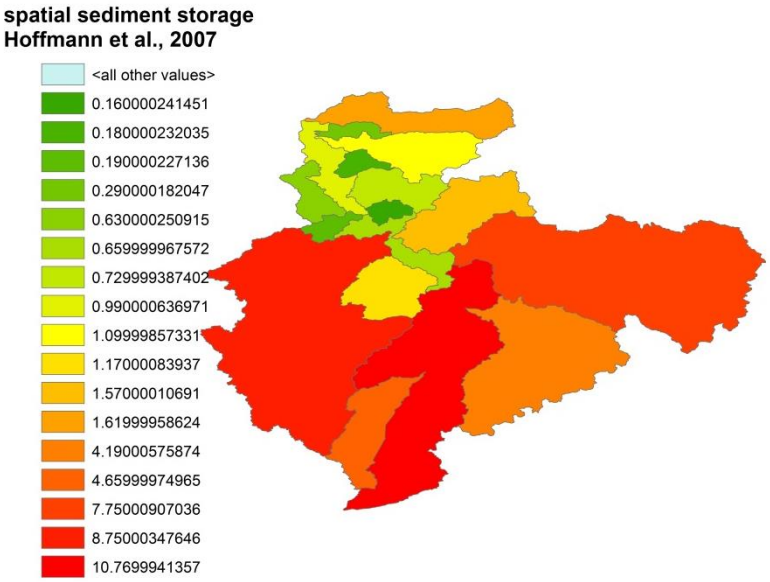
Soil erosion and land use change during the last millennium for the Rhine catchment

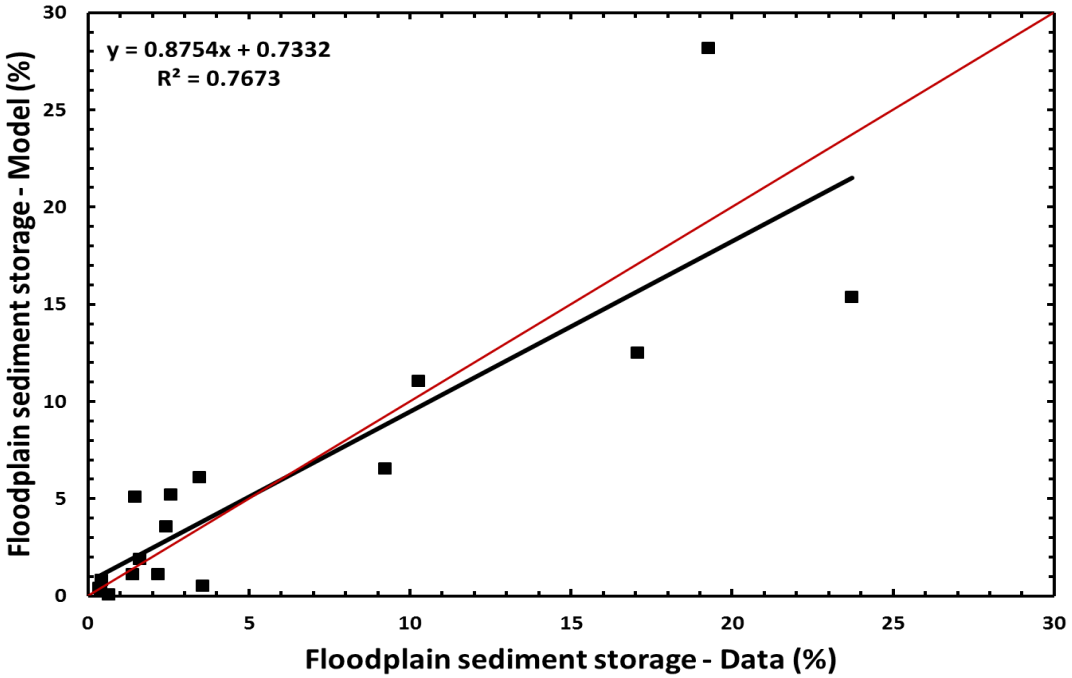


Average soil erosion rate of the last millennium for large river basins worldwide

Naipal et al., 2016, ESD
Naipal, 2016, PhD manuscript

Basin-scale model validation

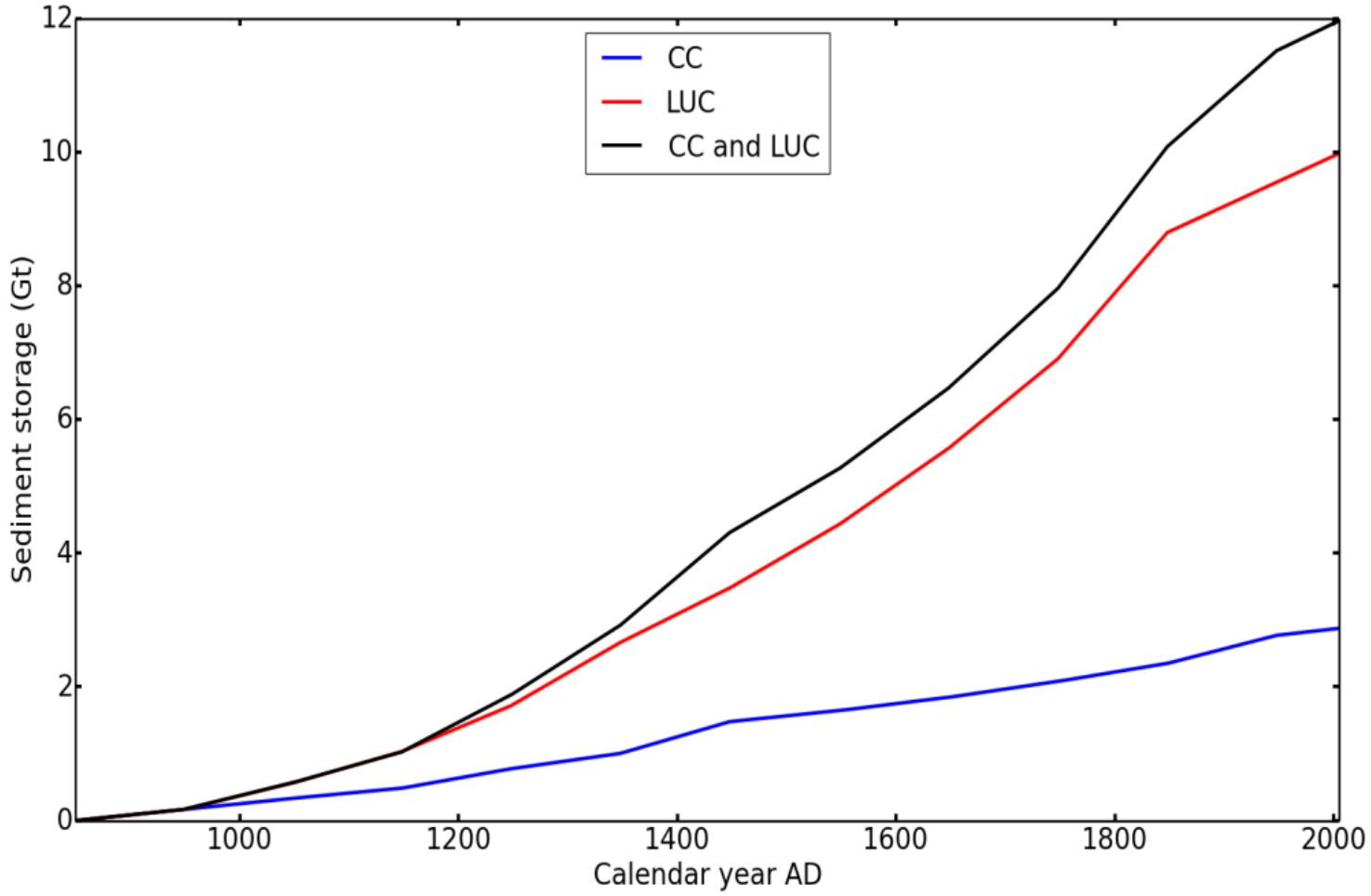




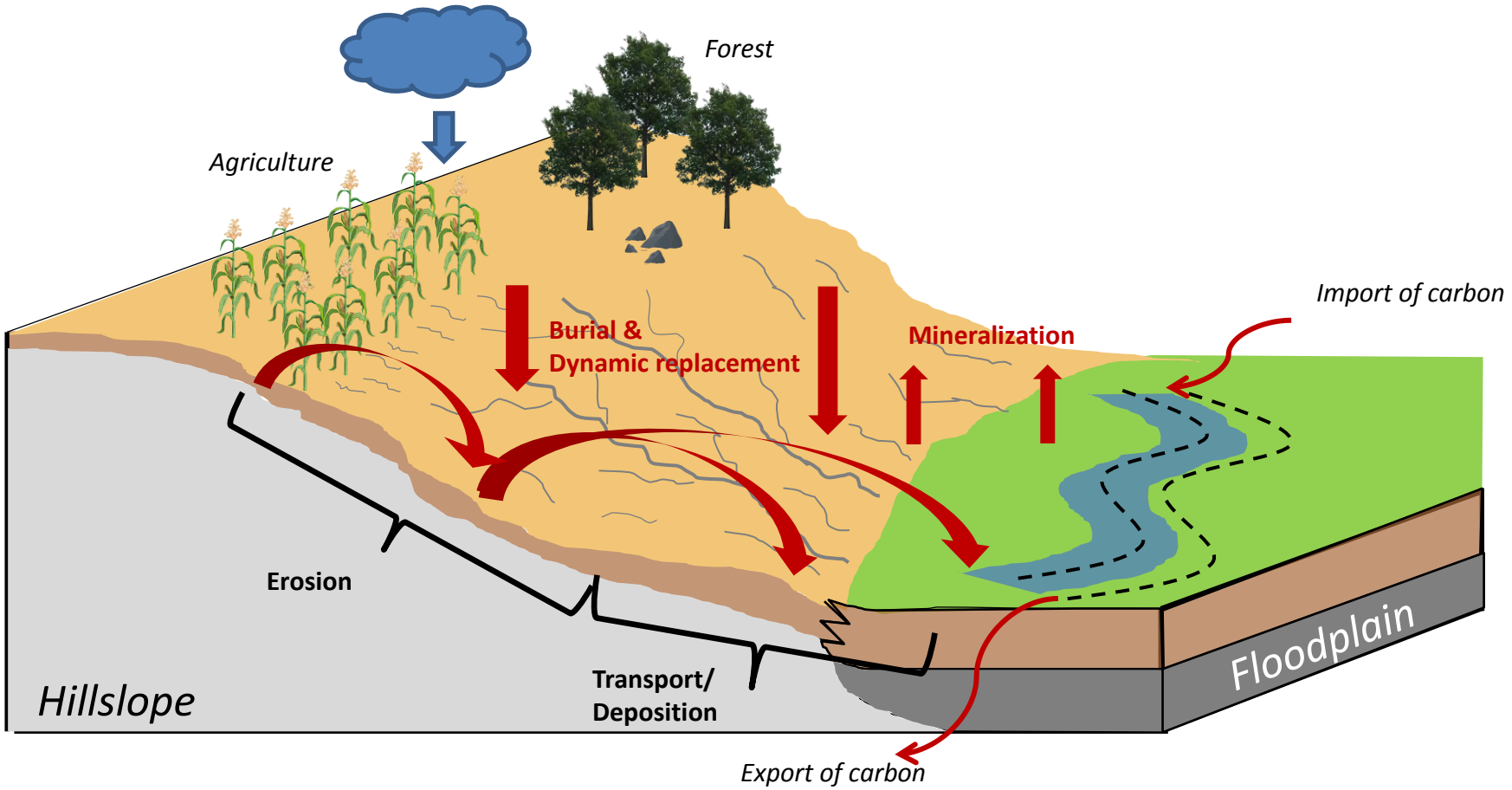
Naipal et al., 2016, ESD

Climate change versus land use change

Floodplain sediment storage changes for the Rhine during the last millennium



Soil redistribution and C dynamics



Sediment and C fluxes at landscape level as represented in the model. Black arrows are sediment fluxes while red arrows are C fluxes

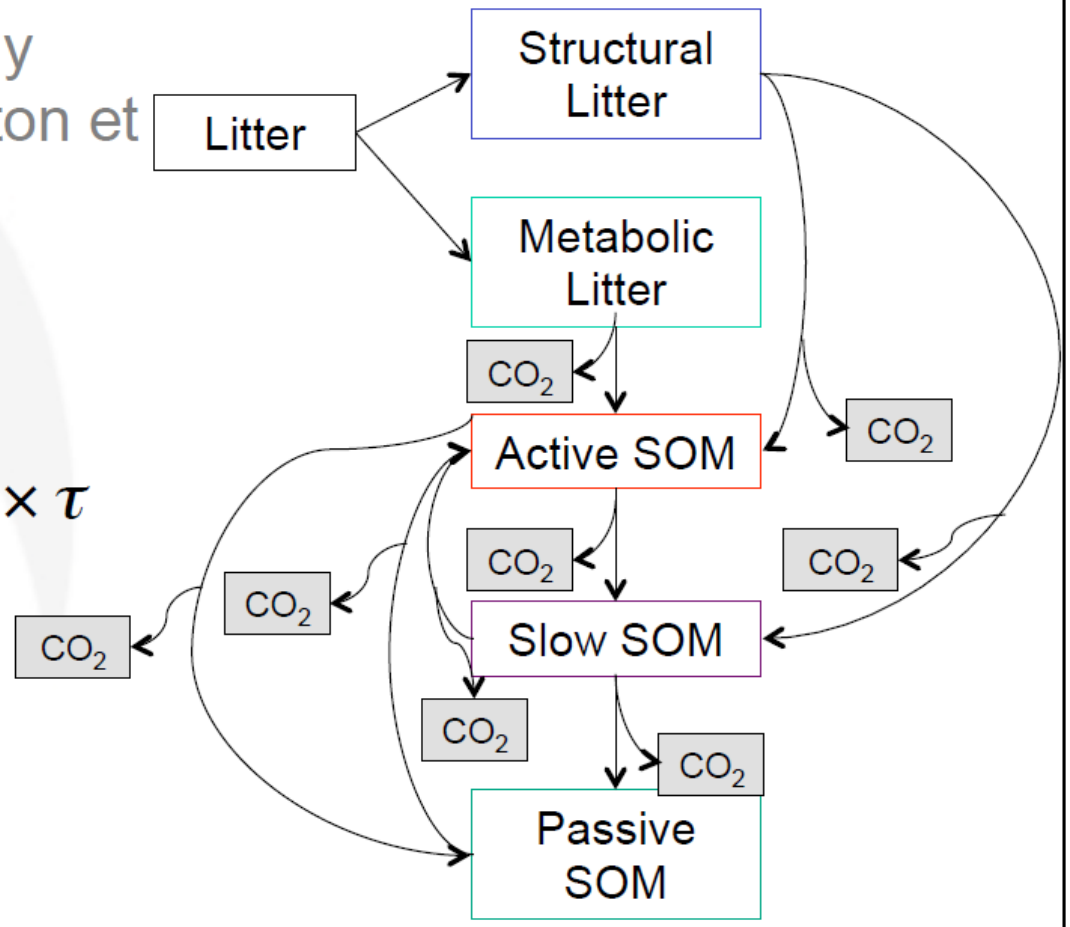
Naipal et al., 2018, BGS

Naipal et al., 2019, submitted GMD

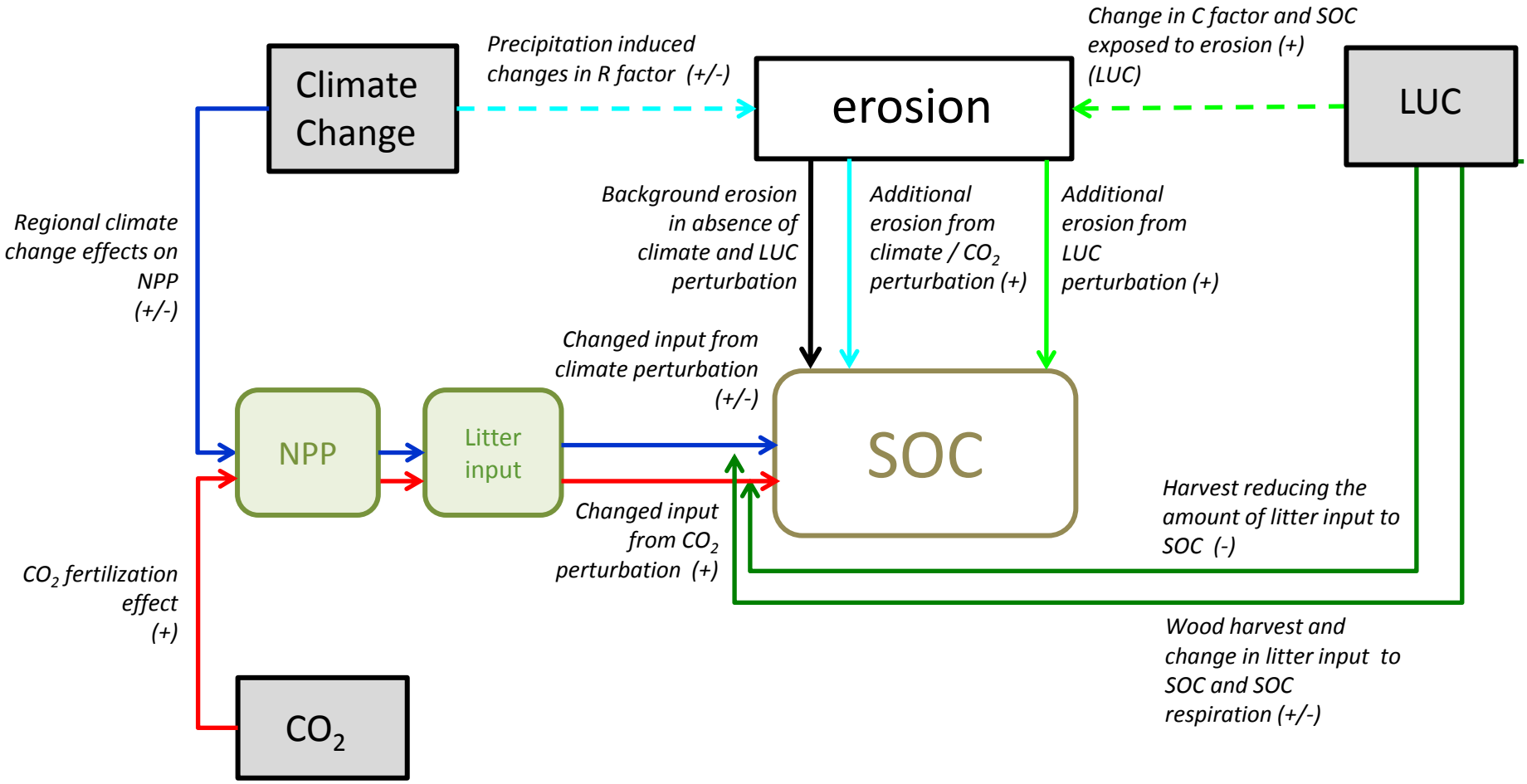
ORCHIDEE-SOM

- Soil representation mainly based on CENTURY (Parton et al., 1987).

$$\frac{\partial SOC}{\partial t} = I - k \times SOC \times \theta \times \tau$$



Taken from B. Guenet



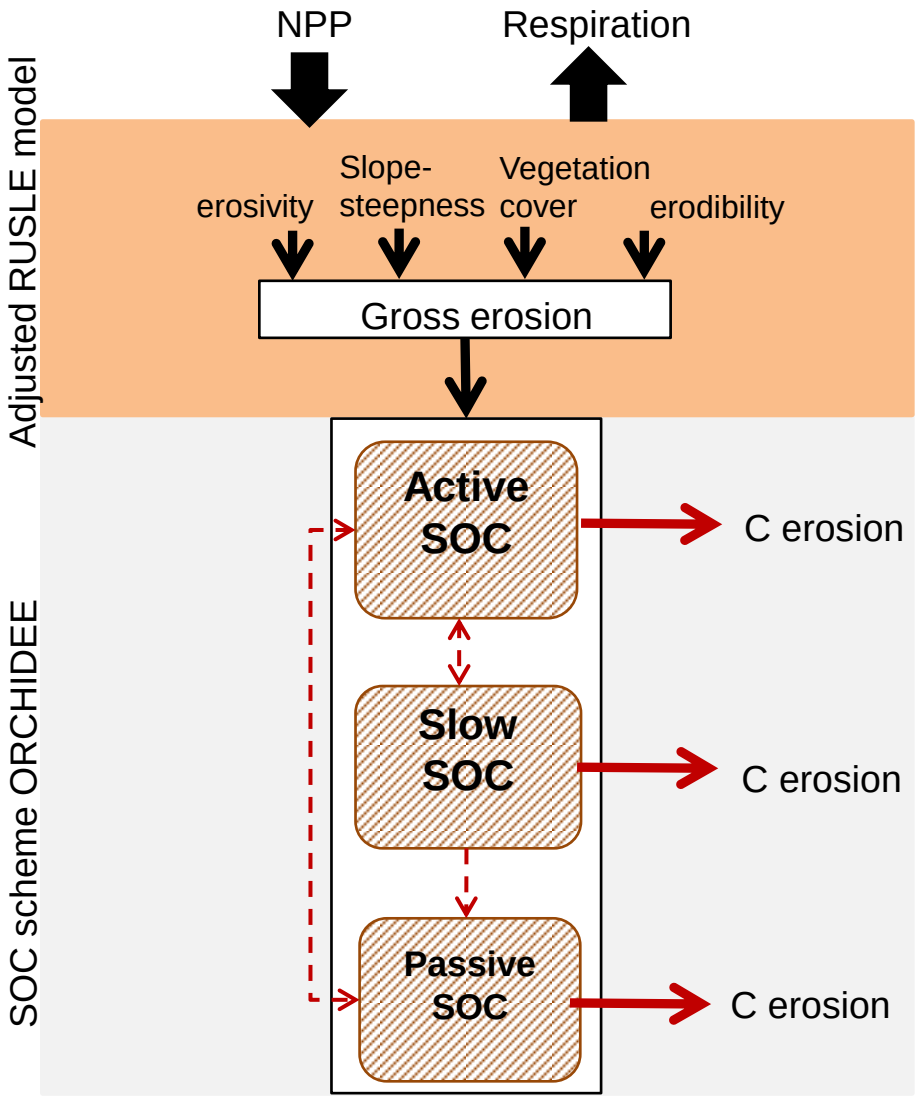
Naipal et al., 2018, BGS

A large-scale carbon erosion model CE-DYNAM

- A coupling between the sediment budget model and the carbon cycle of ORCHIDEE Land Surface Model
- Simulation of lateral soil and C transfers triggered by erosion across landscapes and the resulting changes in the land-atmosphere C fluxes at the regional scale
- Low number of parameters that allow running the model for large spatial scales and long timescales (C-emulator concept)
- Compatibility with land surface models

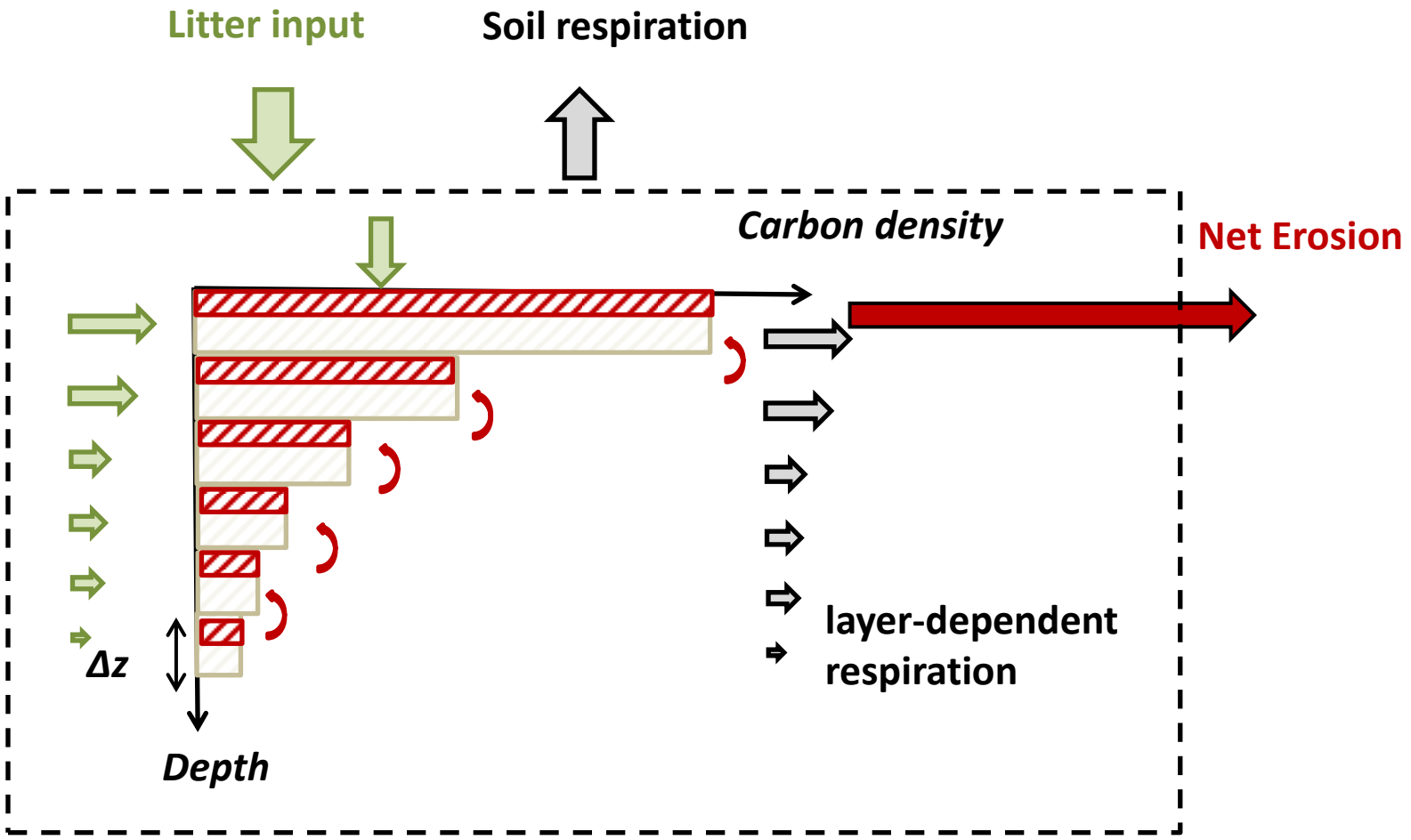
Naipal et al., 2018, BGS
Naipal et al., 2019, submitted GMD

CE-DYNAM : Soil removal only

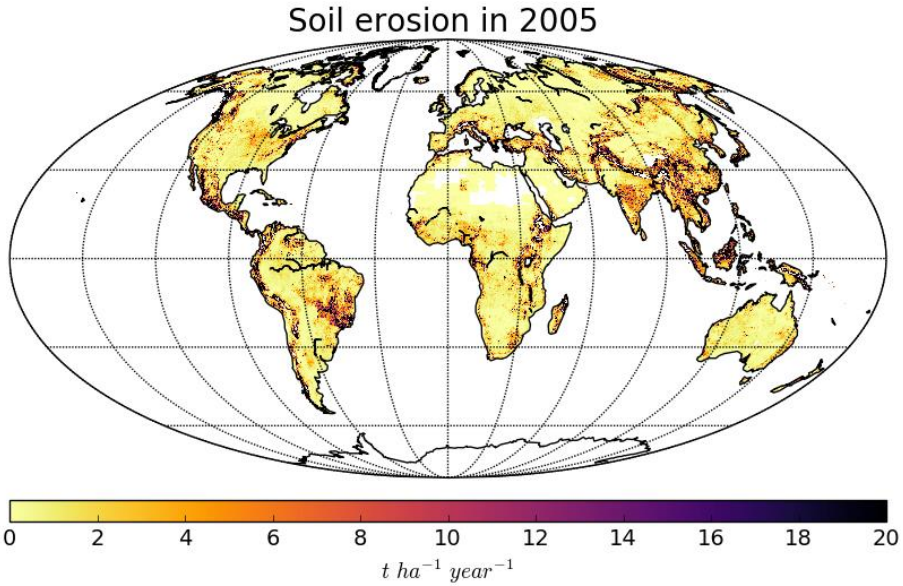


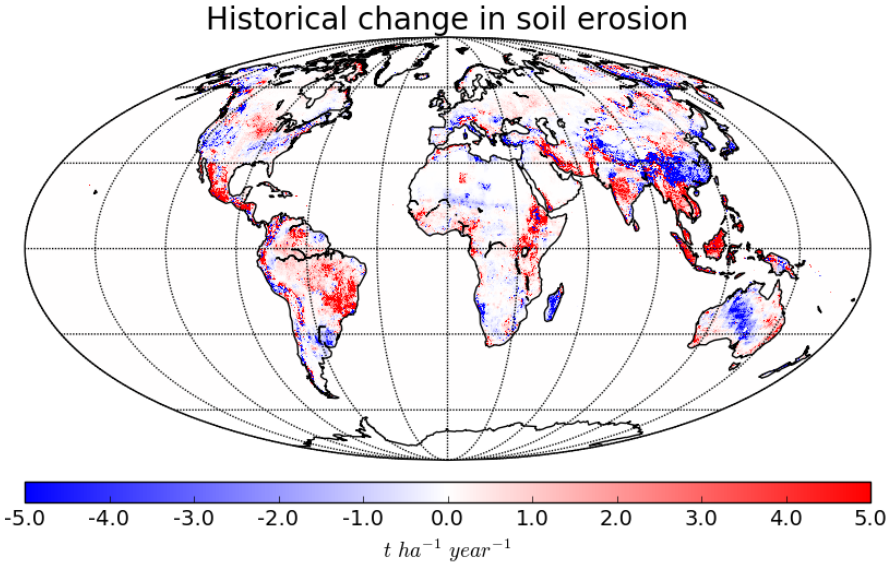
Naipal et al., 2018, BGS

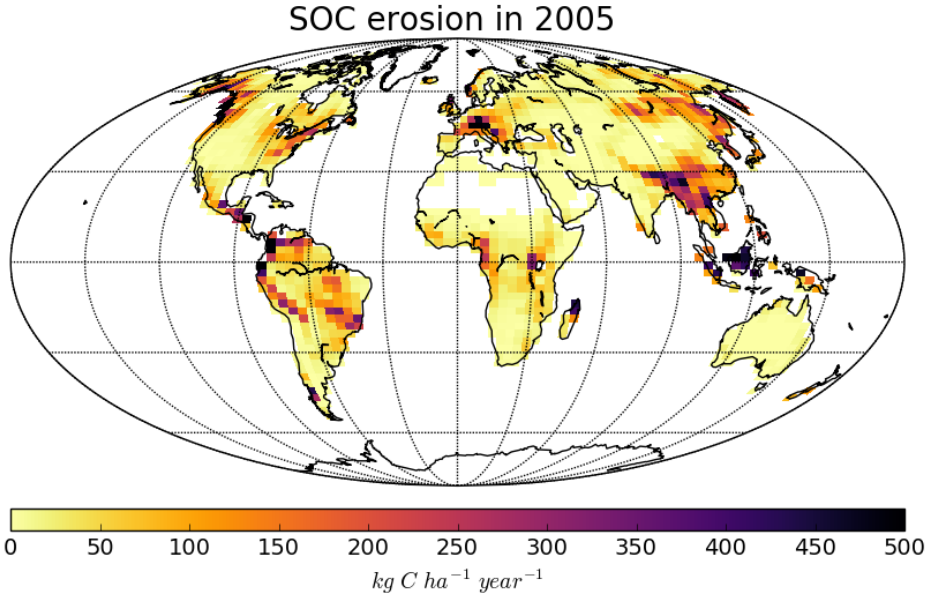
Vertical discretization scheme

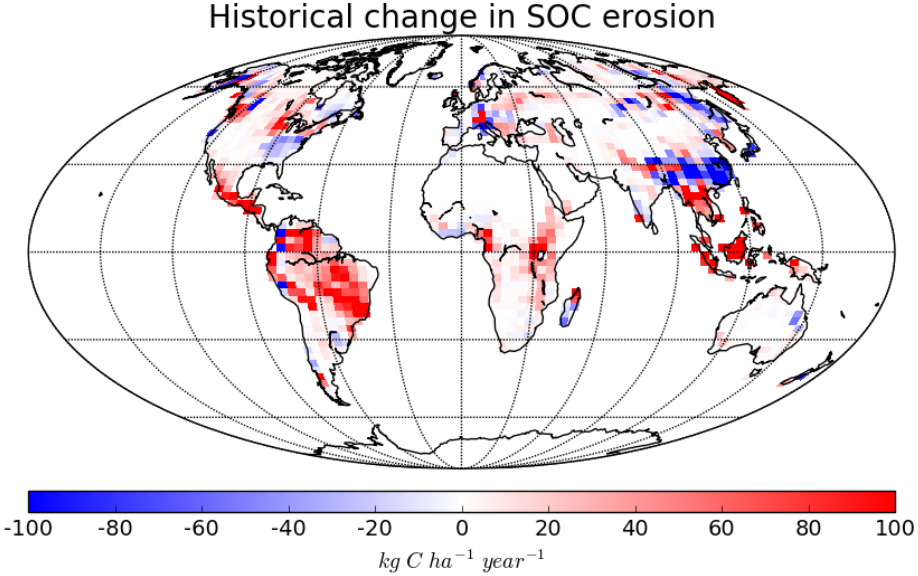


Naipal et al., 2018, BGS



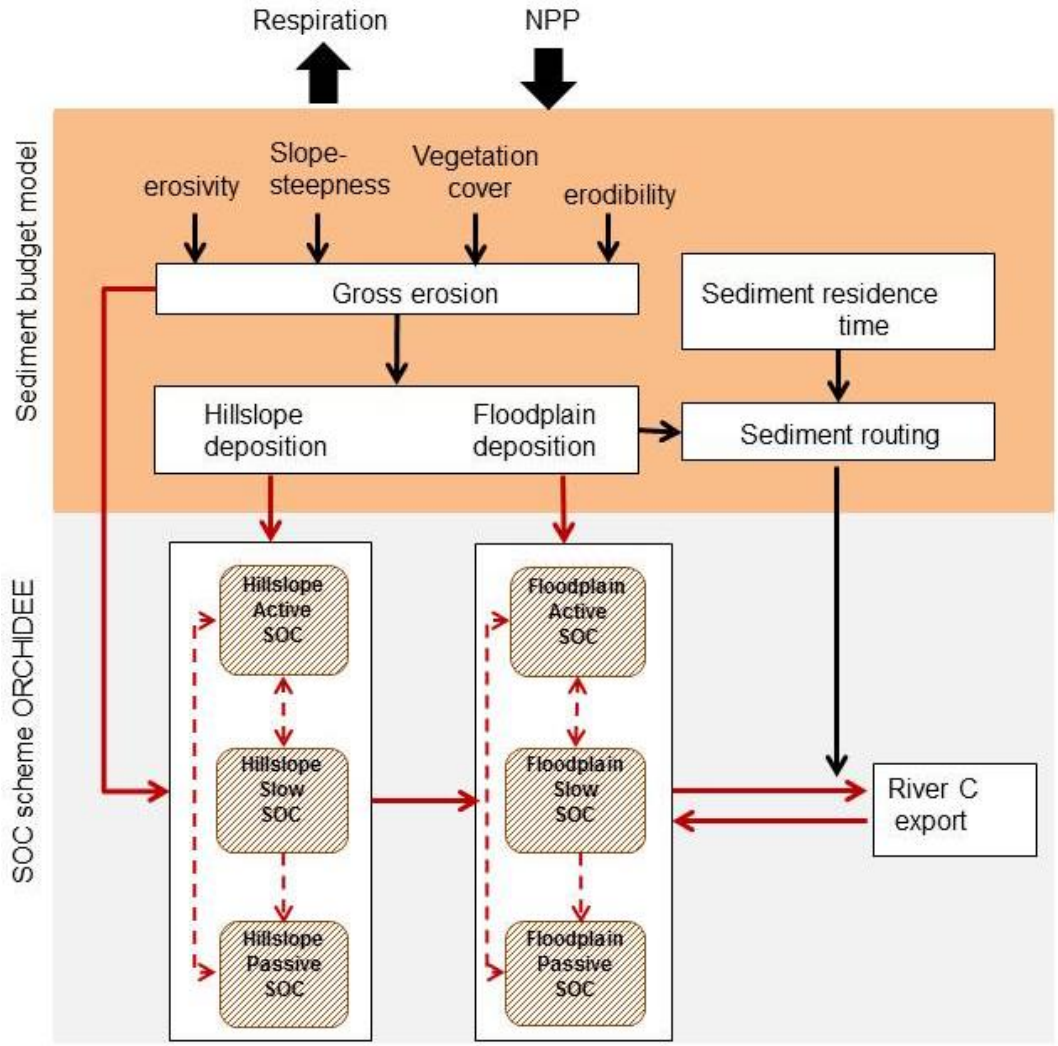






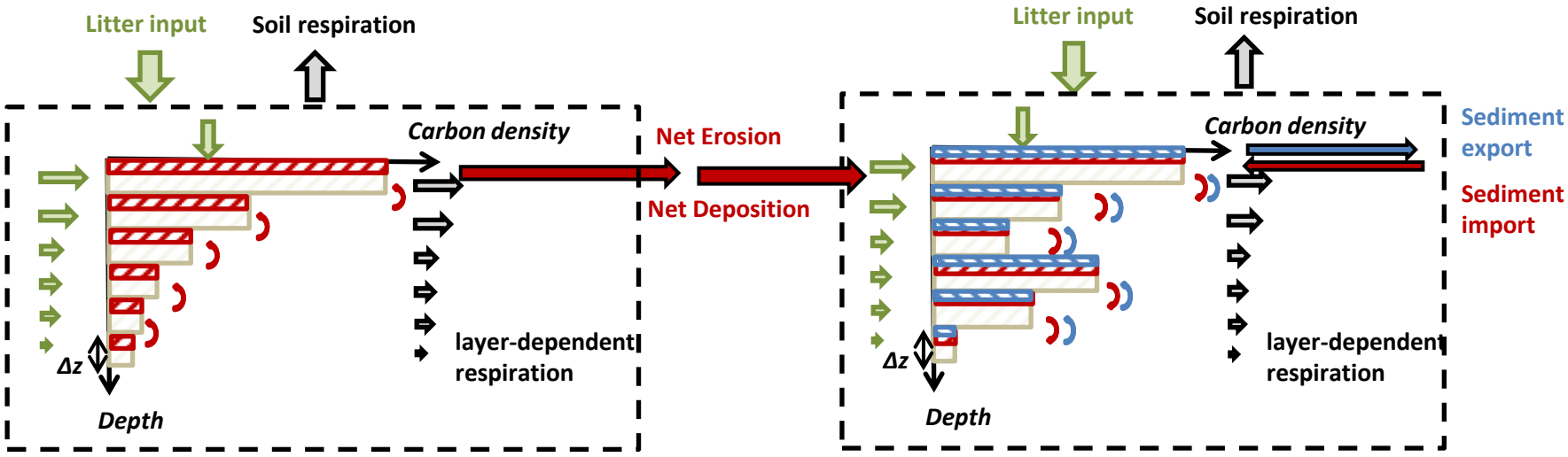
Naipal et al., 2018, BGS

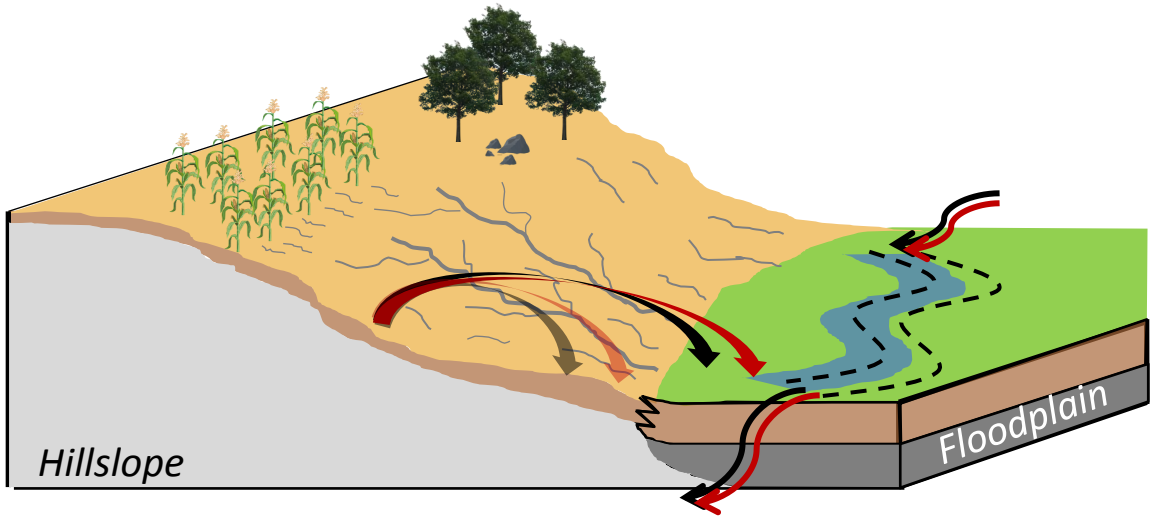
CE-DYNAM: Erosion, deposition and transport



Naipal et al., 2019, submitted to GMD

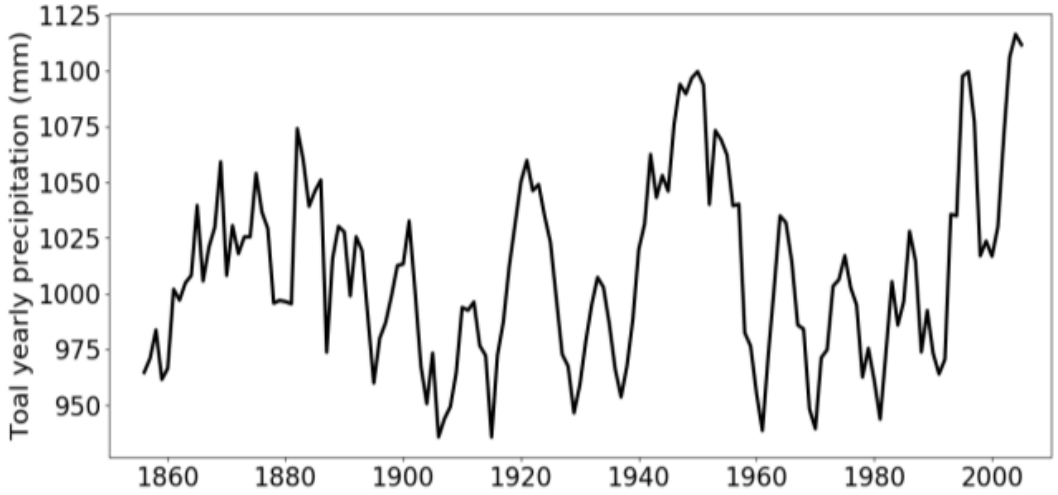
The vertical discretization scheme

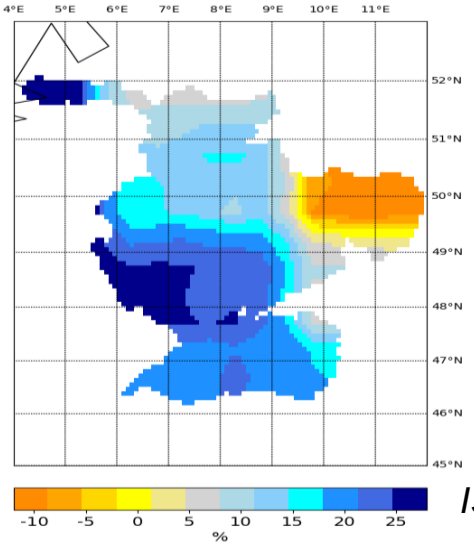




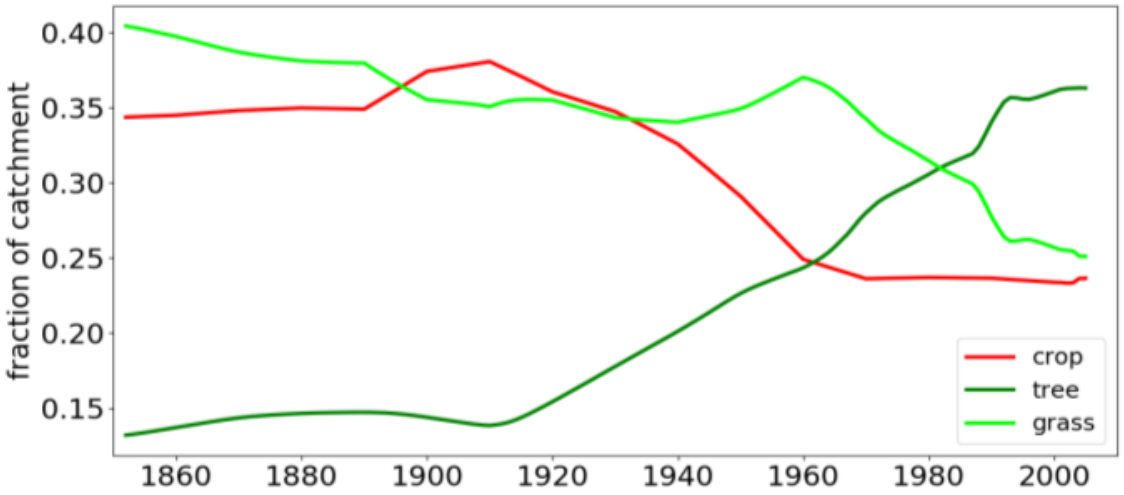
Naipal et al., 2019, submitted to GMD

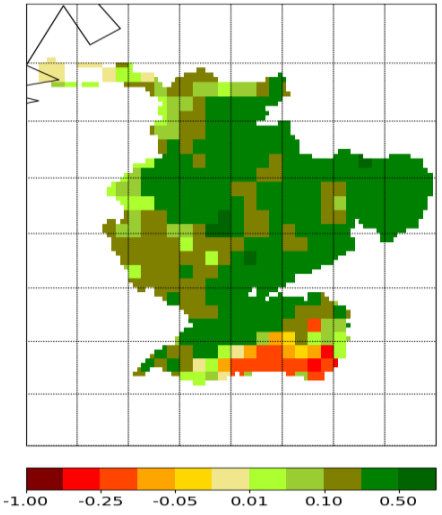
Land use and precipitation changes during 1850-2005





ISIMIP2b dataset

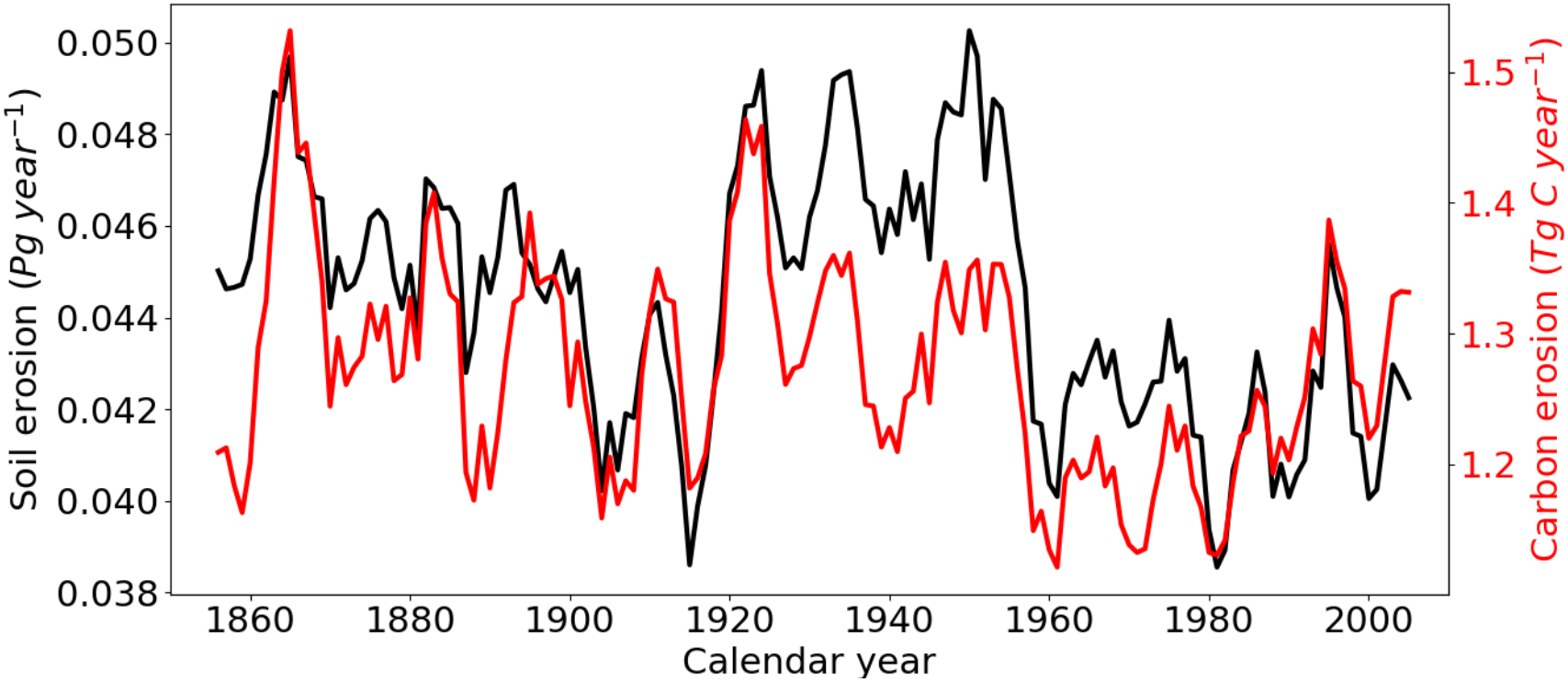




Peng et al. (2017)

Naipal et al., 2019, submitted to GMD

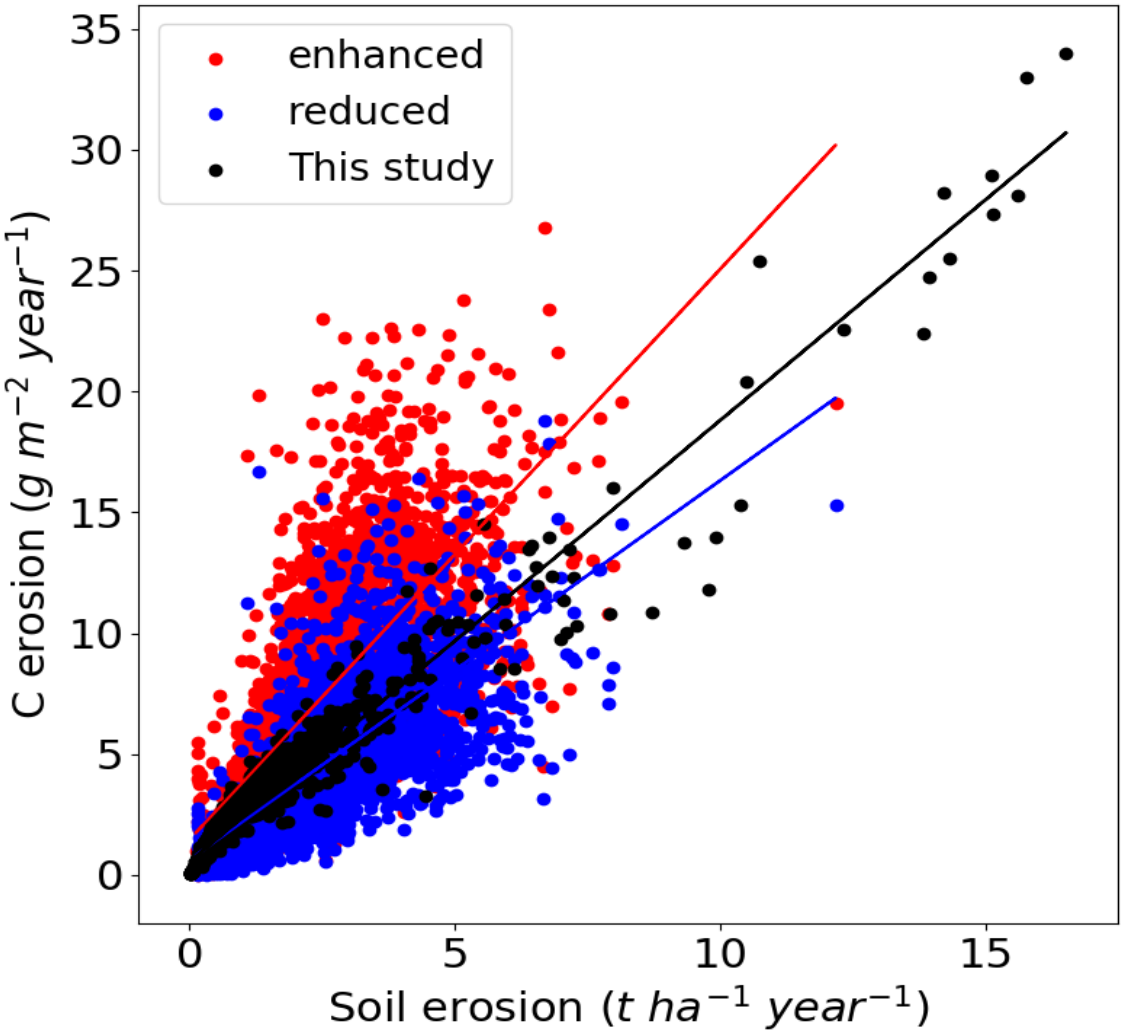
Erosion change during 1850-2005



Naipal et al., 2019, submitted to GMD

Model validation: relation between soil and C erosion

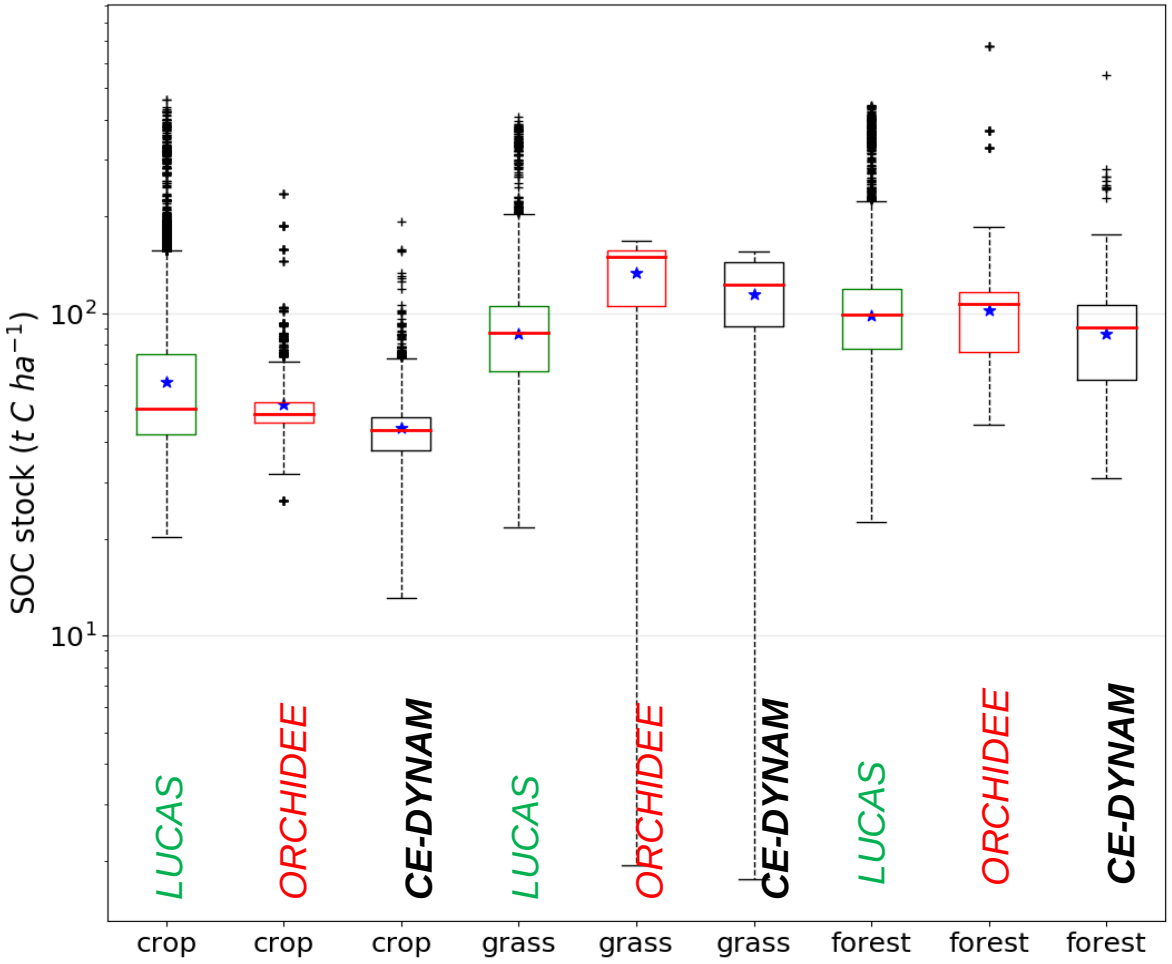
Comparison to Lugato et al. (2018)



Naipal et al., 2019, submitted to GMD

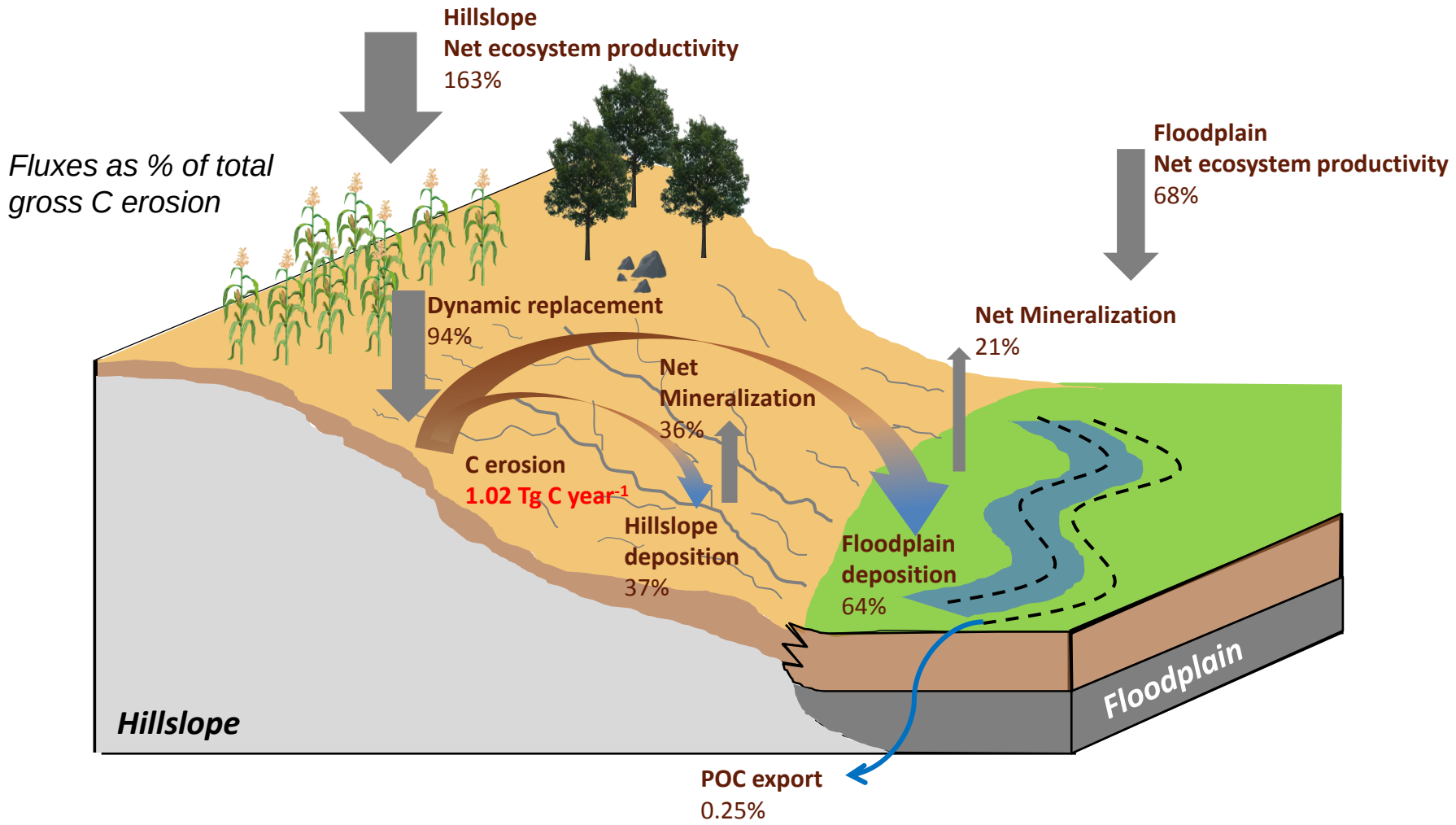
Model validation: SOC stocks

LUCAS: Land Use and Coverage Area frame Survey
https://esdac.jrc.ec.europa.eu/projects/lucas



Naipal et al., 2019, submitted to GMD

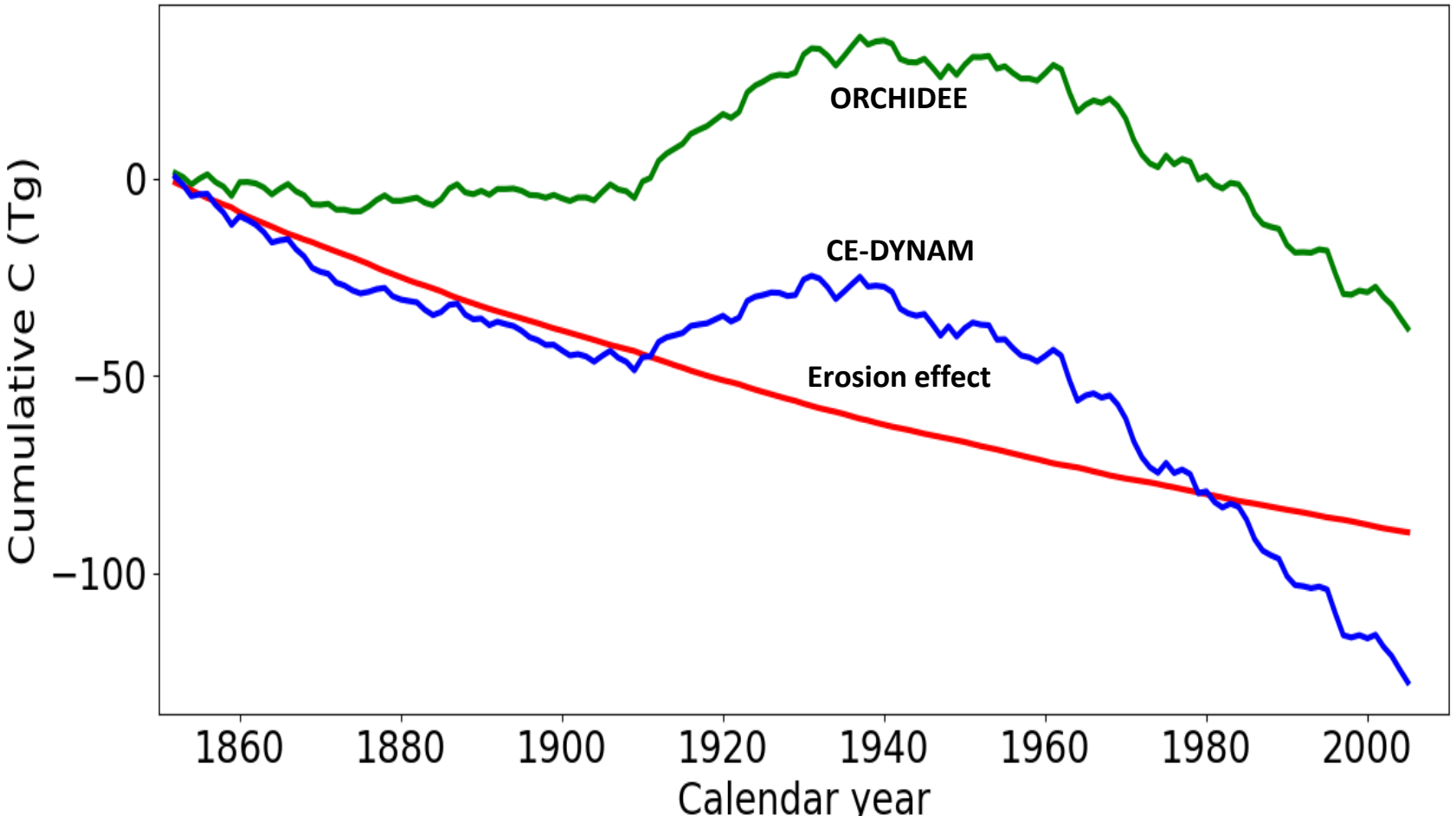
C budget of the Rhine for 1995-2005



Sink term =0.39 Tg C year^{-1} ~ 2.1 g m^{-2} year^{-1} ~ 38% of the total gross C erosion

Naipal et al., 2019, submitted to GMD

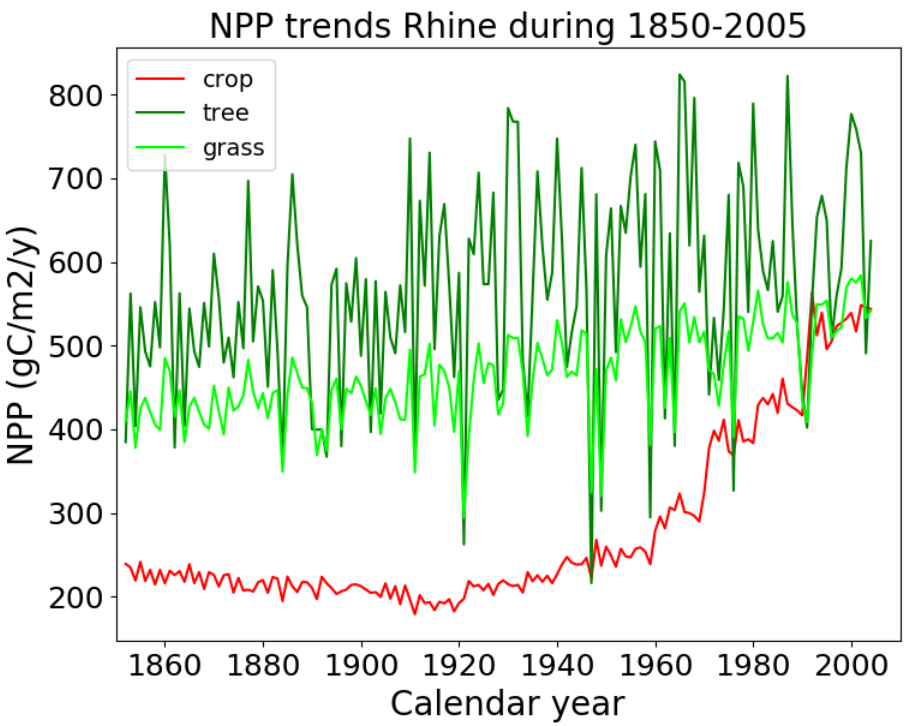
The erosion-induced C sink

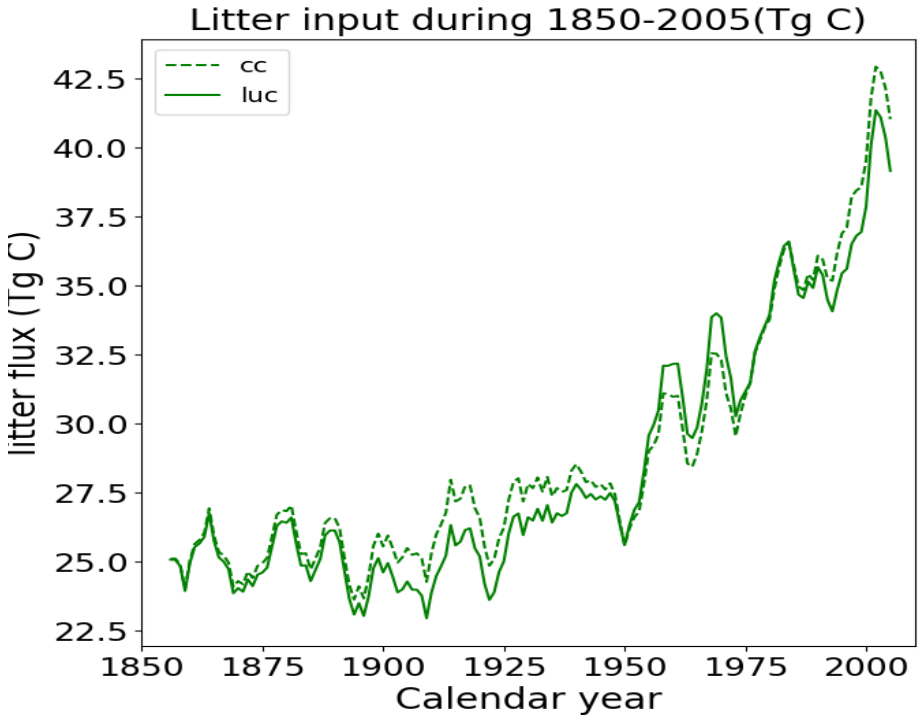


The erosion-induced cumulative C sink is **25% of the total land C sink without erosion** and about 1 % of the cumulative NPP of the Rhine

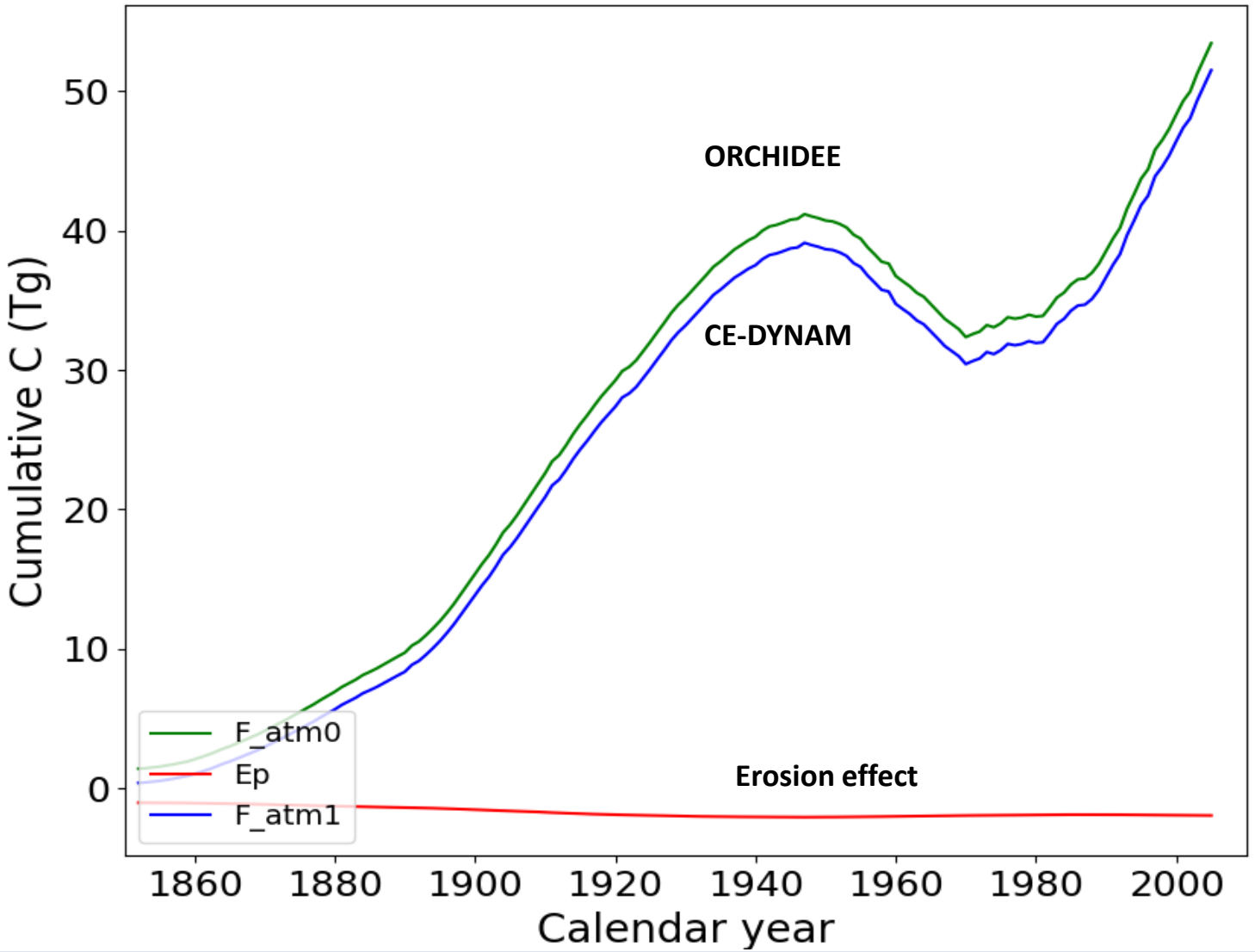
Naipal et al., 2019, submitted to GMD

Increasing NPP – CO_2 fertilization effect





The erosion-induced C sink – land use change only



Take-Home messages

- To quantify the overall net effect of soil erosion on the C cycle it is important to take global changes such as land use change, climate change, land management, into account
- Earth system models provide a unique framework to integrate soil erosion processes into the land surface and climate system
- Initial climate and land cover conditions (equilibrium state) and the transient period over which erosion under global changes takes place are essential for the determination if soil erosion is a net C sink or source and to what extent.

Schedule

- **Short break – 10 minutes**
- Introduction to the practical session and setup of computers, download data
- Start practical part 1:Calculate potential soil erosion rates using the Adusted RUSLE model
- Short break – 10 minutes
- Continue practical part 1
- Practical part 2: Analyze carbon erosion rates
- Conclusion

Schedule

- **Introduction to the practical session and setup of computers, download data**
- Start practical part 1:Calculate potential soil erosion rates using the Adjusted RUSLE
- Short break – 10 minutes
- Continue practical part 1
- Practical part 2: Analyze carbon erosion rates
- Conclusion

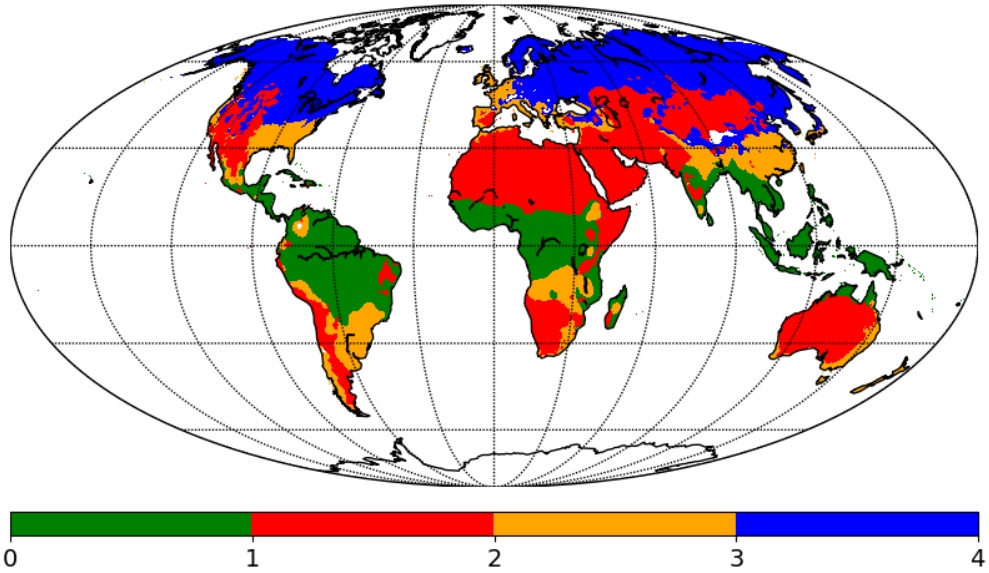
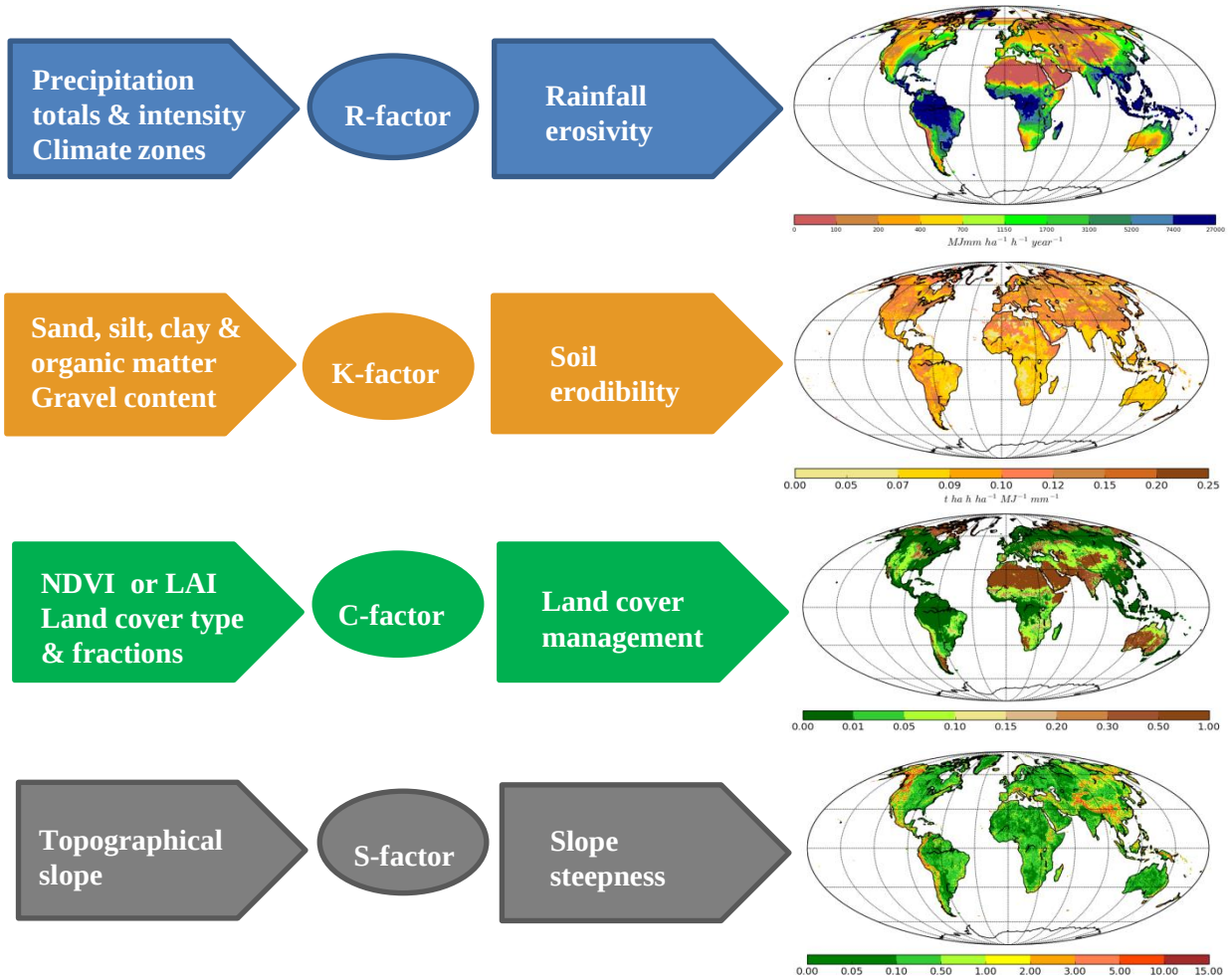


Fig 1: Major climate classification zones according the Koeppen-Geiger climate classification system. Zone A: Tropical; Zone B: Arid/Dry; Zone C: Temperate; Zone D: Cold

- Soil and carbon erosion on cropland in different climate zones
- Climate change versus land use change
- Groups of 1 or 2 people
- Presentation of results at the end

The Adjusted RUSLE model

Average annual soil erosion = R*K*C*S



Naipal et al., 2015, GMD

Schedule

- **Short break – 10 minutes**
- Continue practical part 1
- Practical part 2: Analyze carbon erosion rates
- Conclusion