Towards modelling global soil erosion and its importance for the terrestrial carbon cycle

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Overview

1. **Soils in Earth System Models**

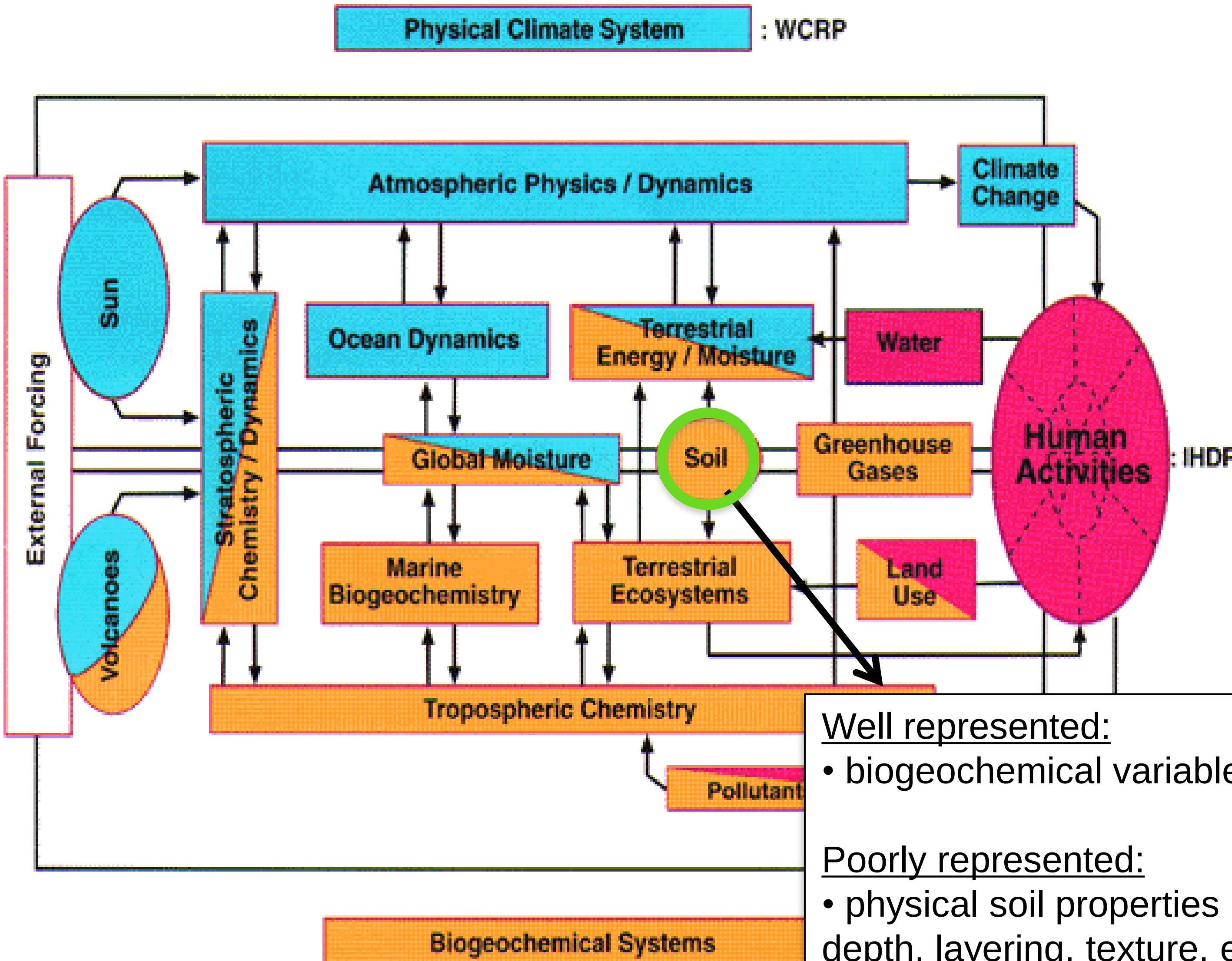
2. **Importance of soil erosion for the carbon cycle**

3. **Holocene soil erosion and modelling soil/carbon erosion**

4. **Scaling topographical properties for global-scale soil erosion modelling**

5. **Conclusions and future perspectives: towards constraining the effect of global-scale soil erosion on the carbon cycle**

Soils in Earth System Models



<u>Well represented:</u>

• biogeochemical variables/cycling

<u>Poorly represented:</u>

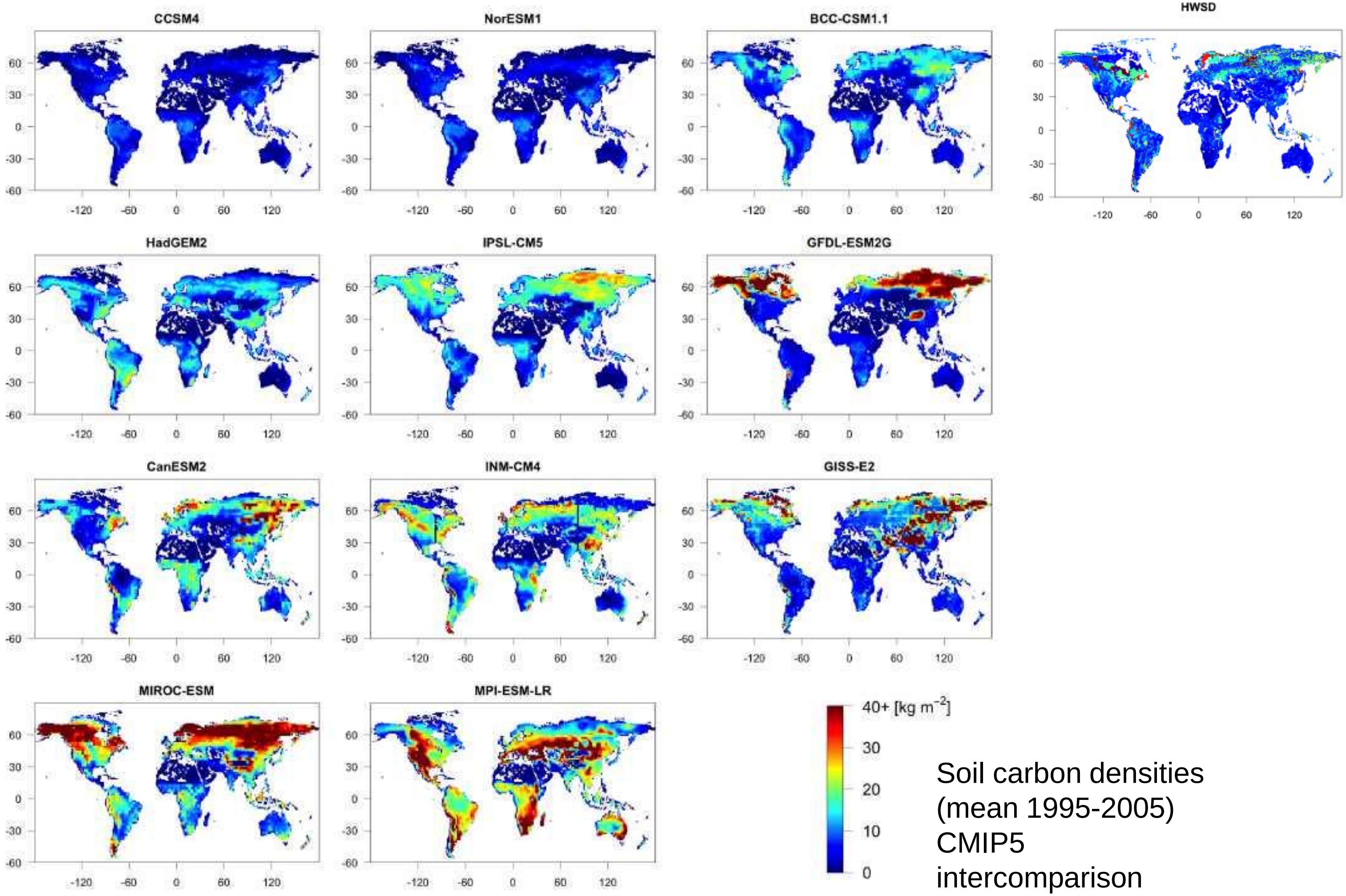
• physical soil properties (soil depth, layering, texture, etc.)

• **evolution → static**

Modified Bretherton Diagram (Guy Brasseur, NCAR Atmospheric Chemistry Division)

Soils in Earth System Models

How much do we know about soils on a global scale?



Soil carbon densities (mean 1995-2005) CMIP5 intercomparison

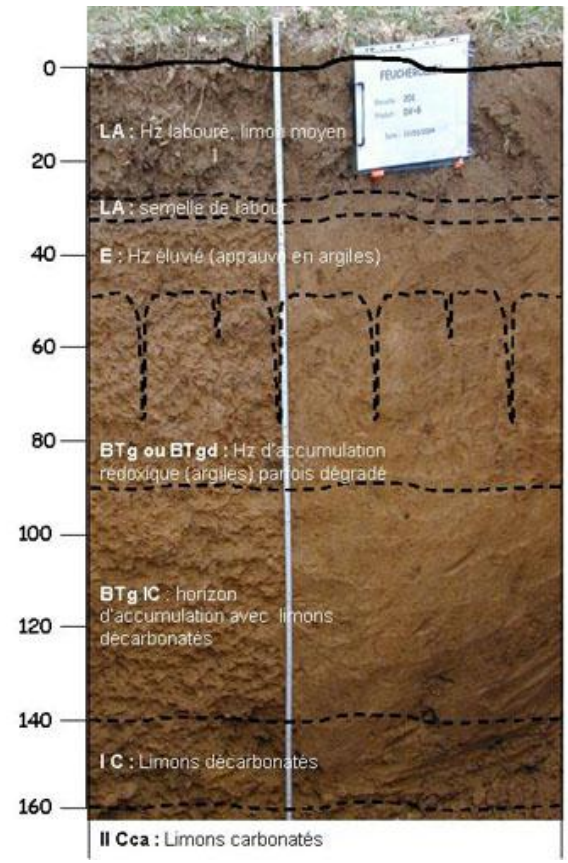
Todd-Brown et al. 2013. *Biogeosciences*

Soils in Earth System Models

How much do we know about soils on a <u>global scale</u> and a <u>Holocene timescale</u>?

Static or dynamic soils?

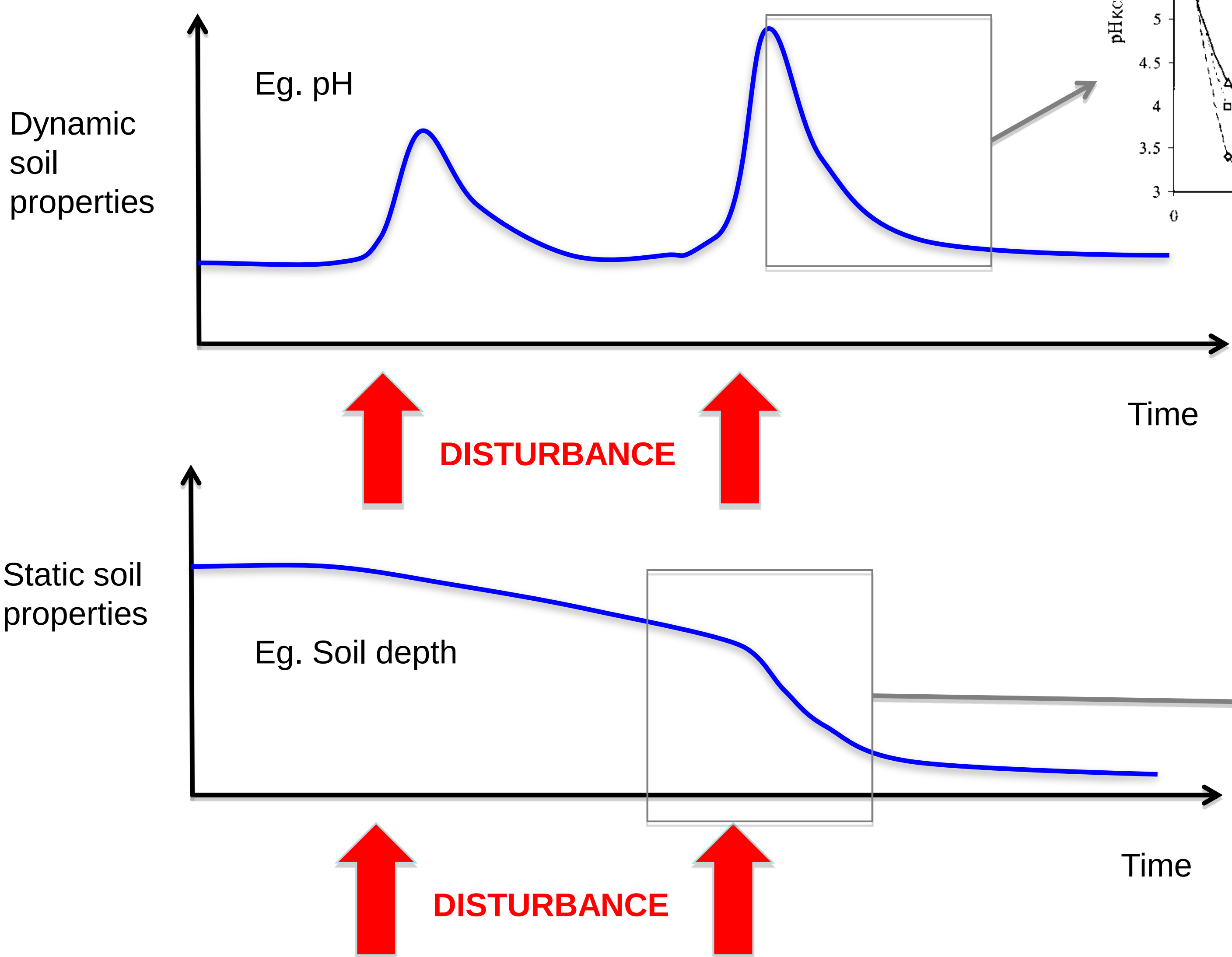
Shallow marls, S Spain

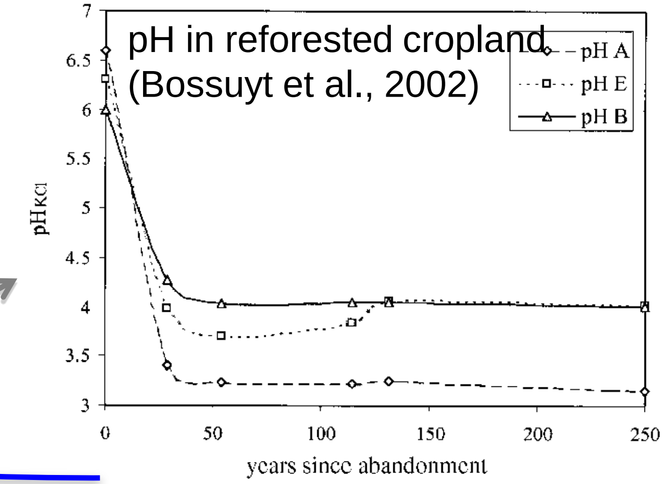


Loess soil profile (INRA, France)

Relating soil profiles and erosion

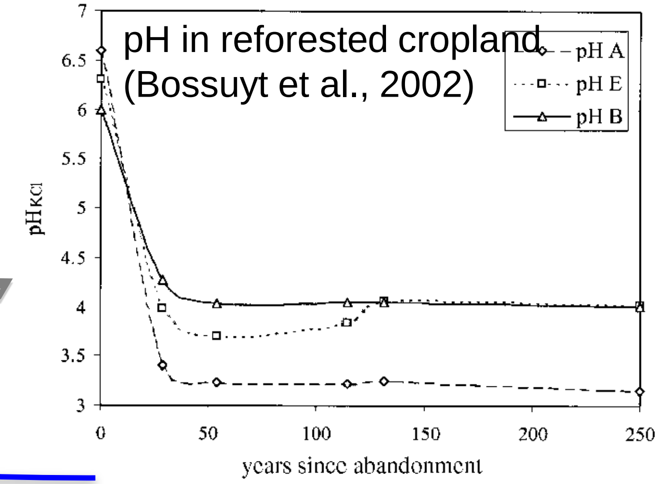
- **Static versus Dynamic soil properties**

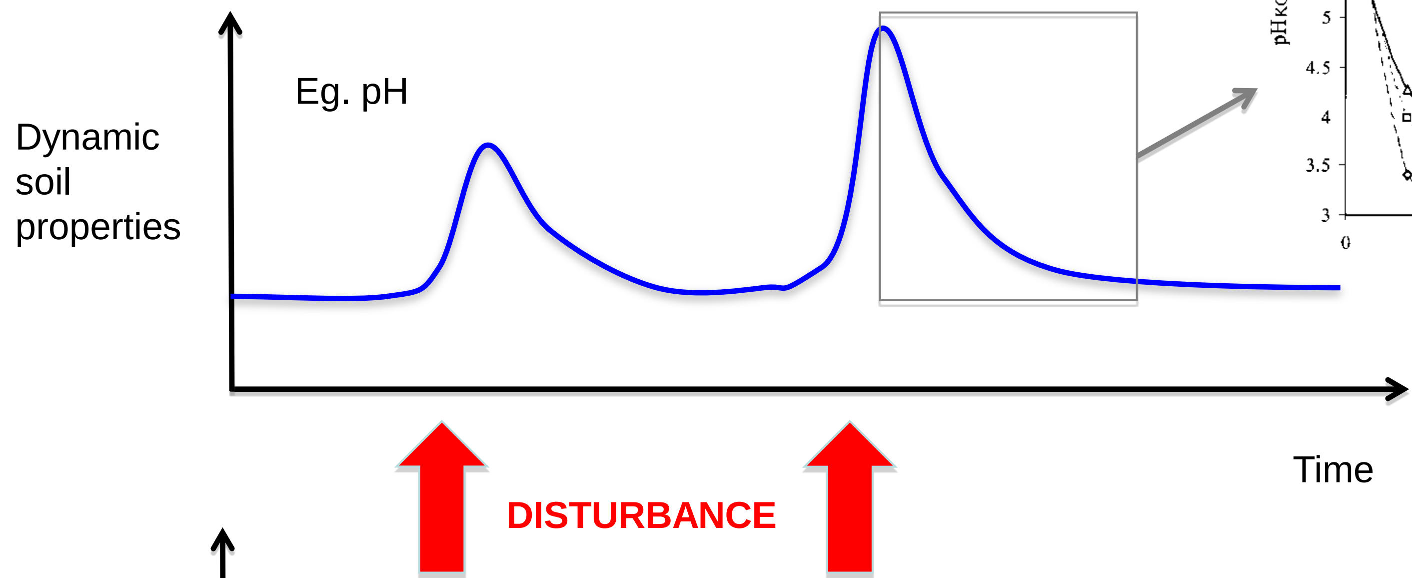


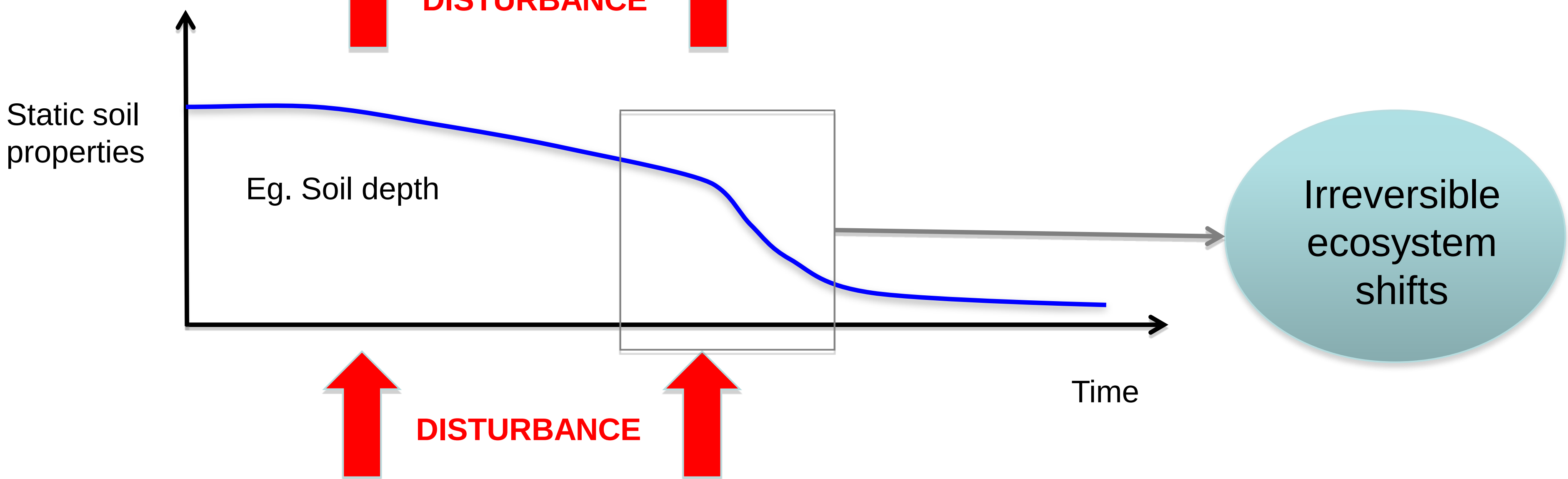


Relating soil profiles and erosion

- **<u>Static</u> versus <u>Dynamic</u> soil properties**

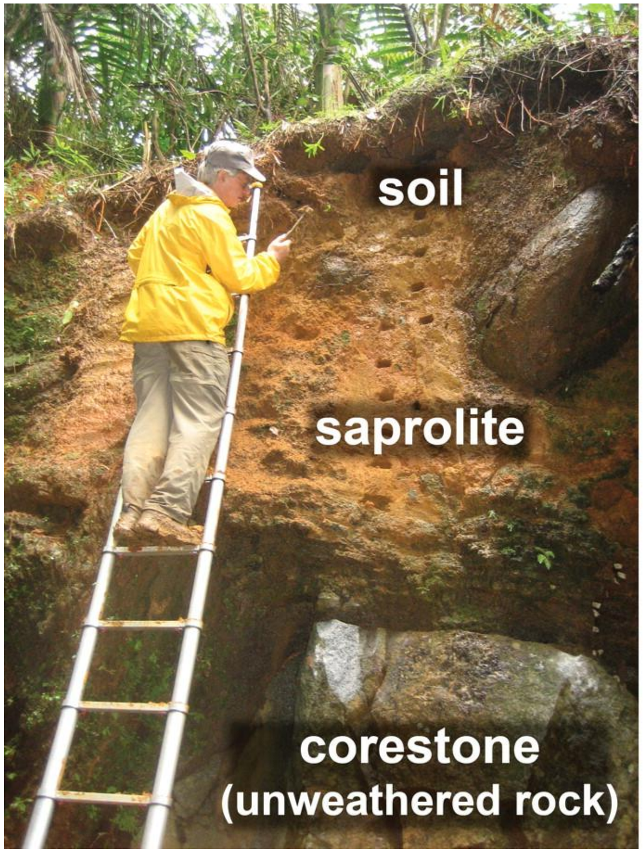


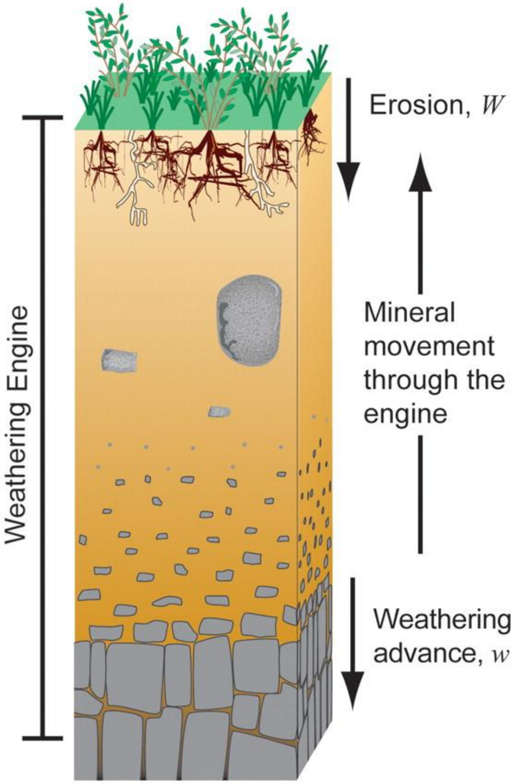




Dynamic soils: modelling

Evolution of soils

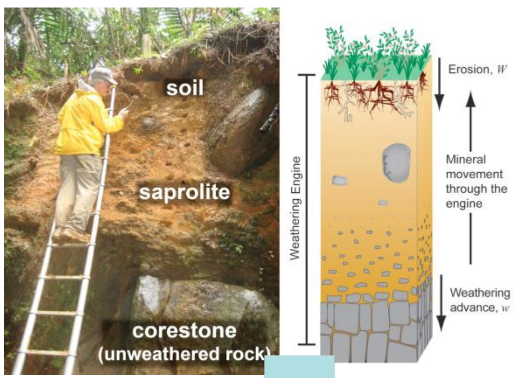




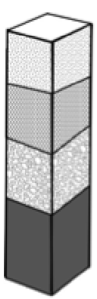
Brantley et al. 2007. *Elements*

Dynamic soils: modelling

Recent advances in modelling coupled soil-landscape evolution:



MODEL FOR INTEGRATED SOIL DEVELOPMENT



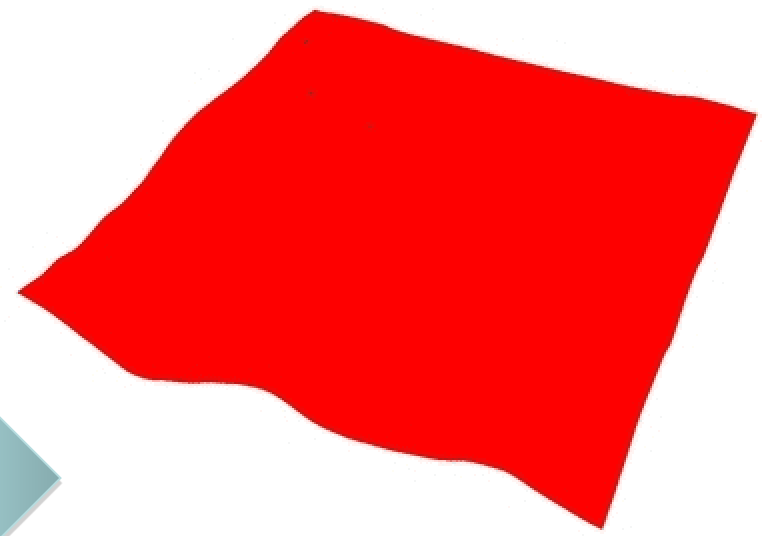
LAYER 1 (A)
LAYER 2 (B)
LAYER 3 (BC)
BEDROCK (C)

SOIL FORMATION

SOIL EROSION & DEPOSITION

4-layer model
5 particle size classes
Different soil formation and erosion processes

Total soil thickness (m)

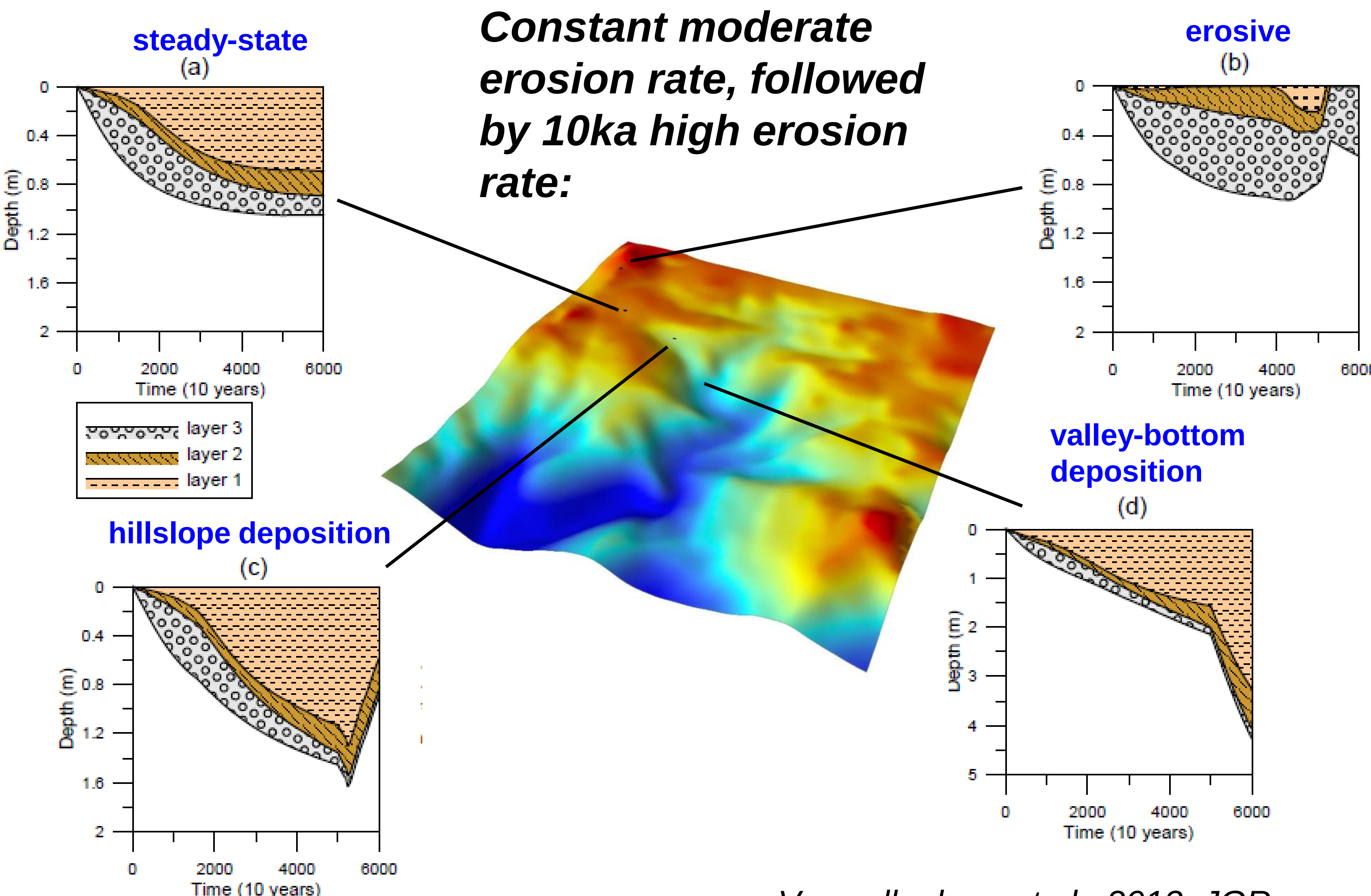


t = 0 ky

Vanwalleghem et al. 2013. *JGR-ES*

Model for Integrating Landscape and Soil Development

- **Soil thickness, integrating soil formation and soil erosion**

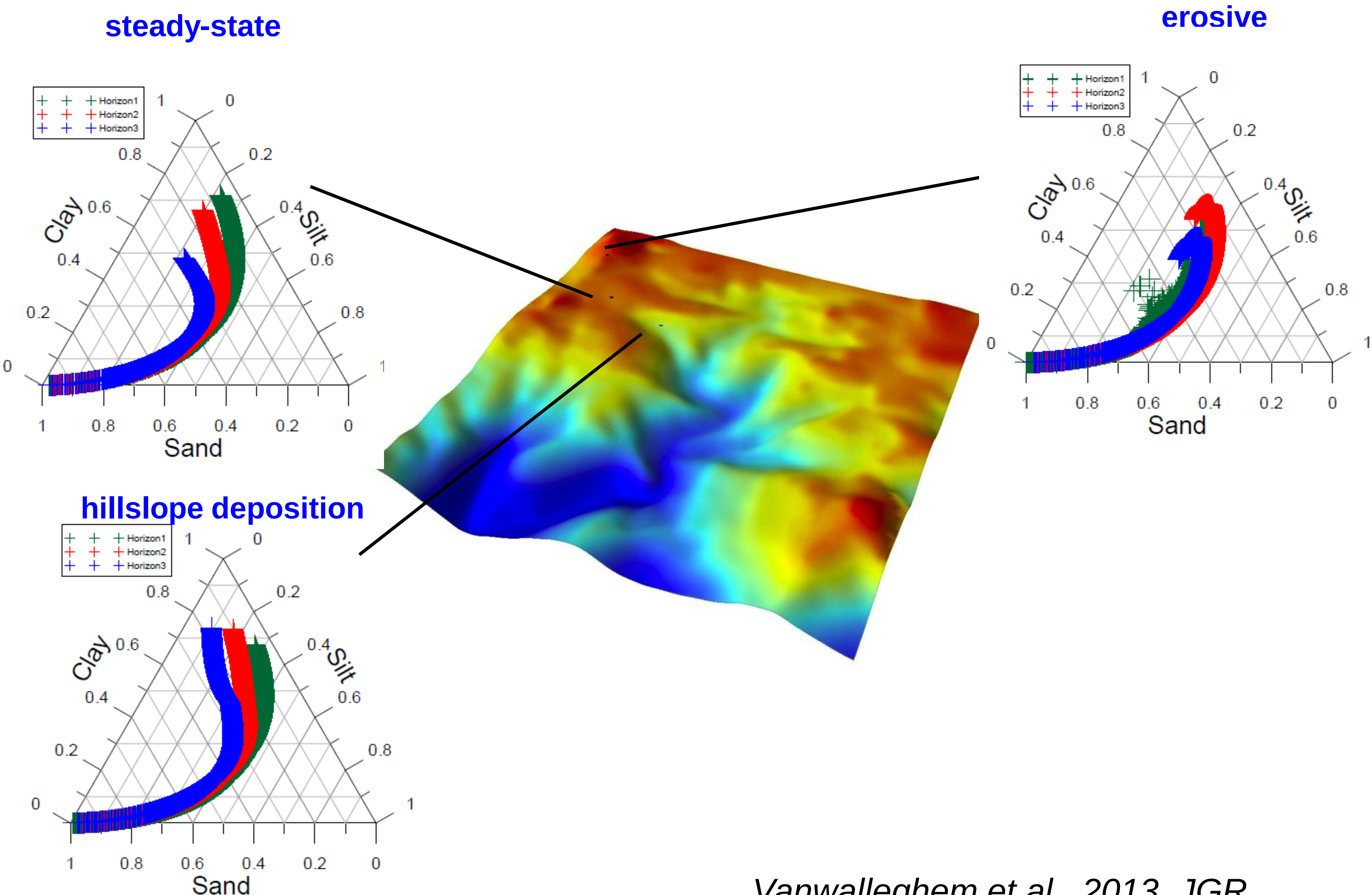


Vanwalleghem et al., 2013. JGR

Model for Integrating Landscape and Soil Development

- **Erosion effect on texture**

Scenario with constant moderate erosion rate:

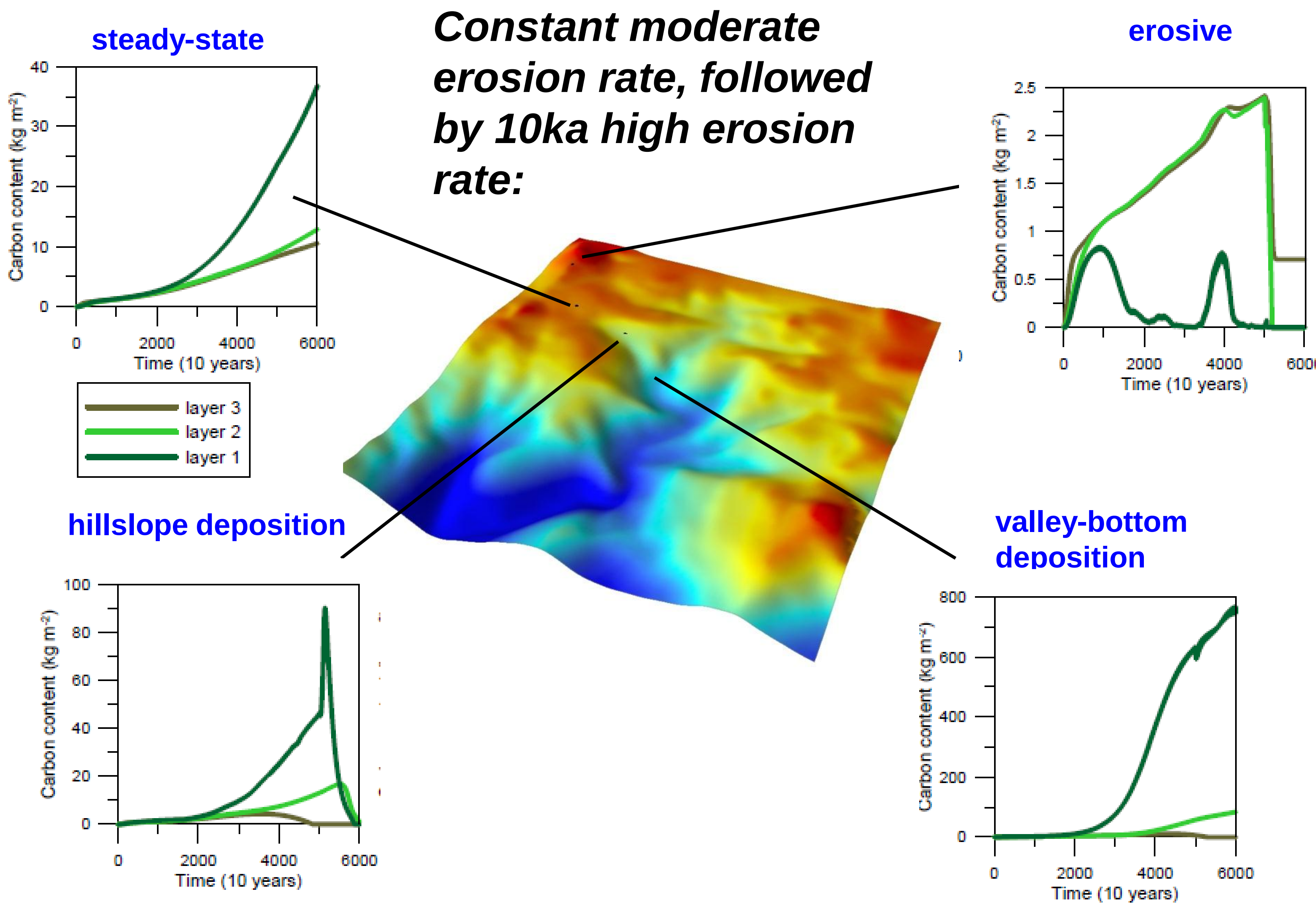


Vanwalleghem et al., 2013. JGR

Model for Integrating Landscape and Soil Development

- Soil organic carbon, integrating soil formation and soil erosion

Constant moderate erosion rate, followed by 10ka high erosion rate:

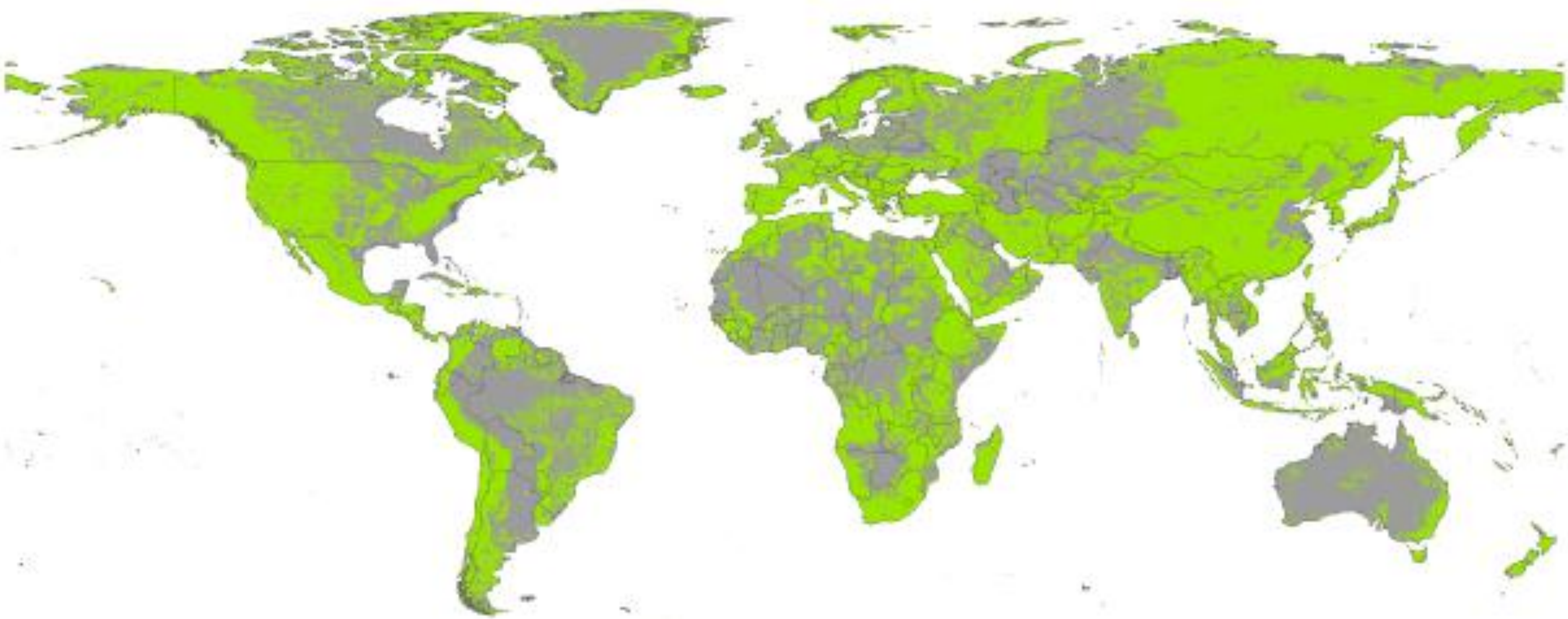


Importance of erosion for soil profiles

- **Soil erosion has been shaping our land and soils since historic times:**

Importance of erosion for soil profiles

- > 70% is sloping land



Relating soil profiles and erosion

- **Soils are not static!**
- **Impact on vegetation**
- **Soil loss rates in Mediterranean**

Table 5

Scale document down sion rates (weighted mean and standard deviation) for different land u

	Other regions			
Land use	Database entries*	Plot-months	Mean (t ha^{-1} $year^{-1}$)	Std. D
Bare	62	7599	17.12	30.23
Arable	73	6635	6.33	13.46
Forest	2	60	0.003	0.00
Grassland	7	1535	0.29	1.15
Shrub	3	90	0.13	0.19
Vineyard	4	144	23.64	26.0
Orchard	2	408	20.6	19.4

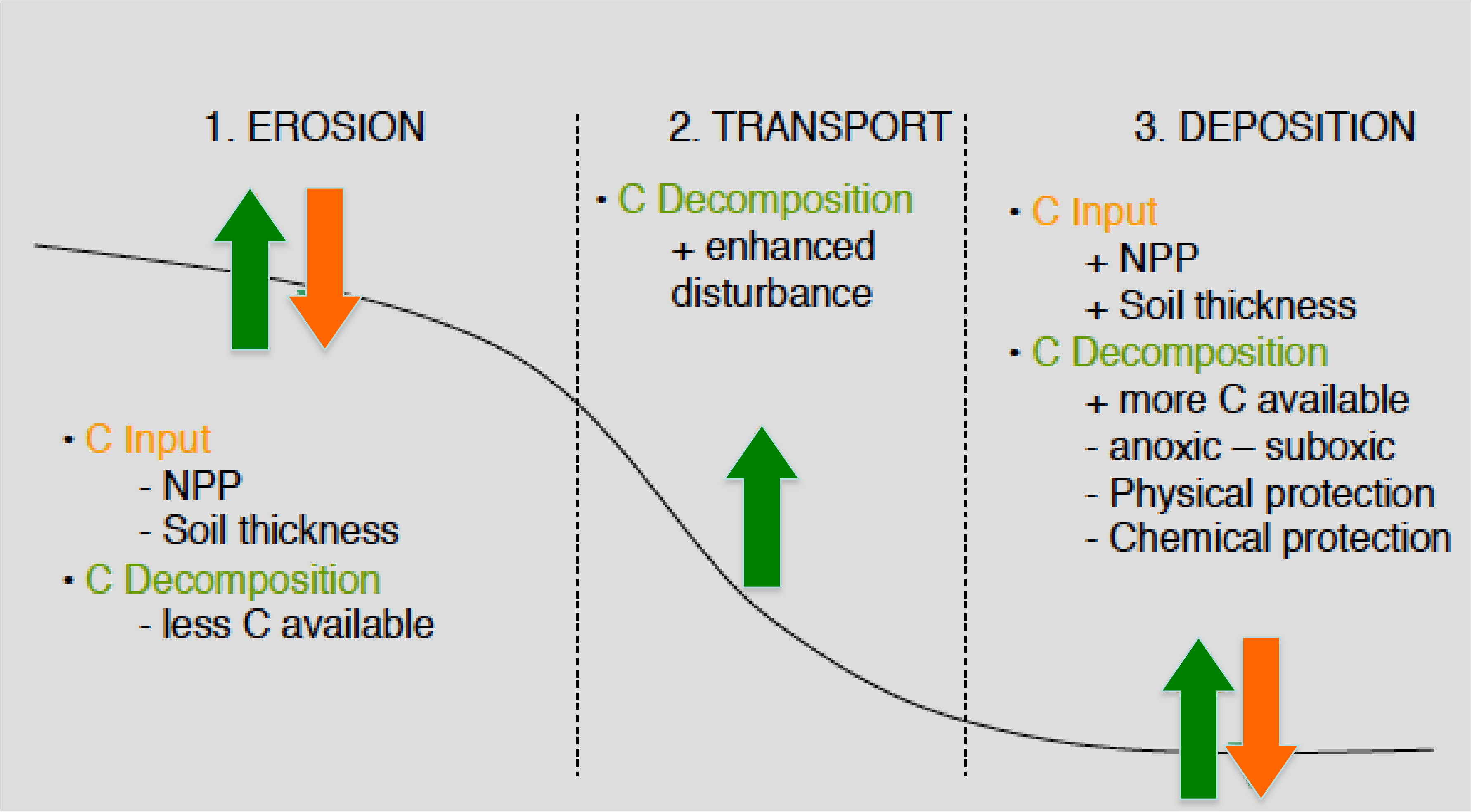
*One entry is the combination of one land use, slope, etc. for one experimental site.

Cerdan y col., 2010. Geomorphology

Fig. 1. Spatial distribution of soils with a high rock fragment content in Europe. Areas with soils having a rock fragment cover >30% are shown in dark brown. Data derived from the Soil Geographical Database of Europe (European Commission, 2004).

Importance of erosion for the carbon cycle

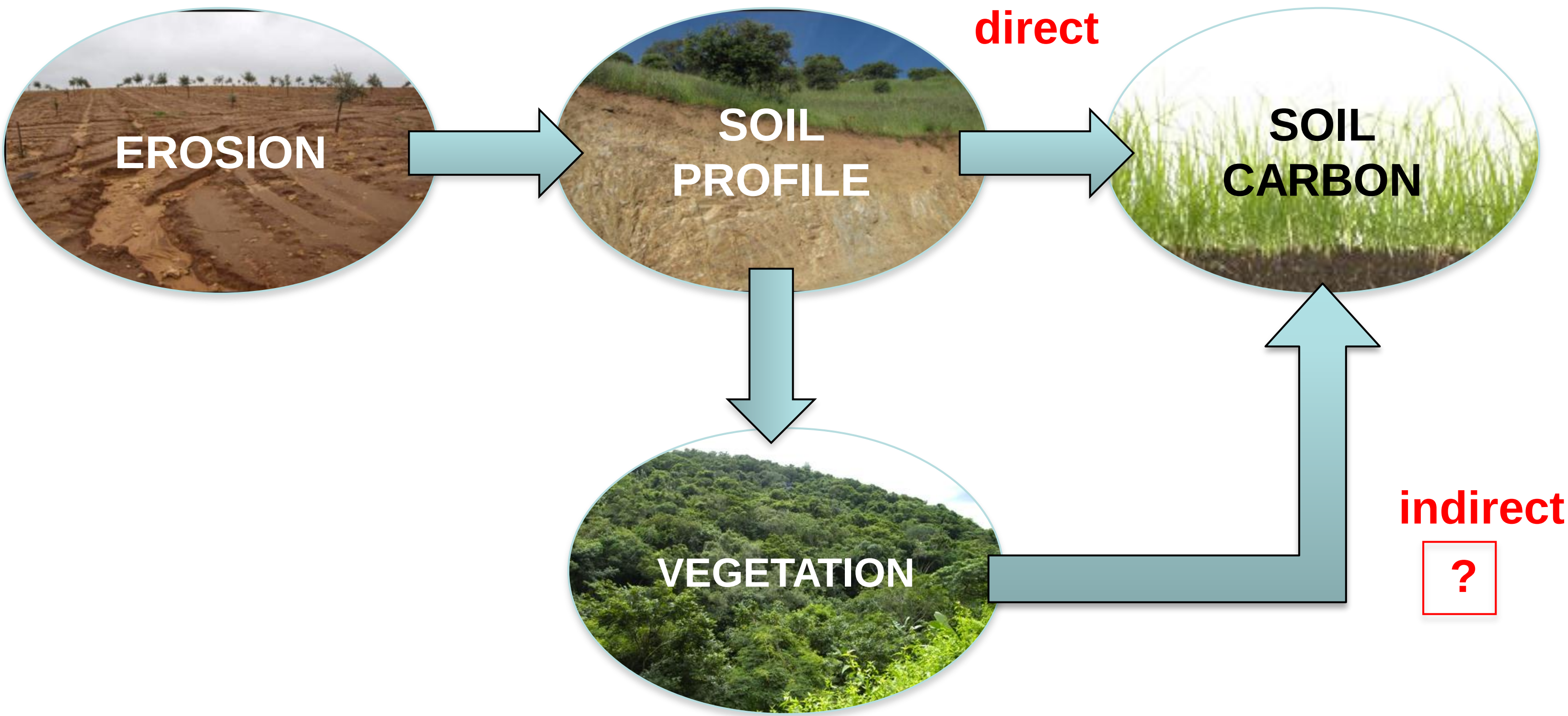
- **General framework**



Adapted from Van Oost, 2007

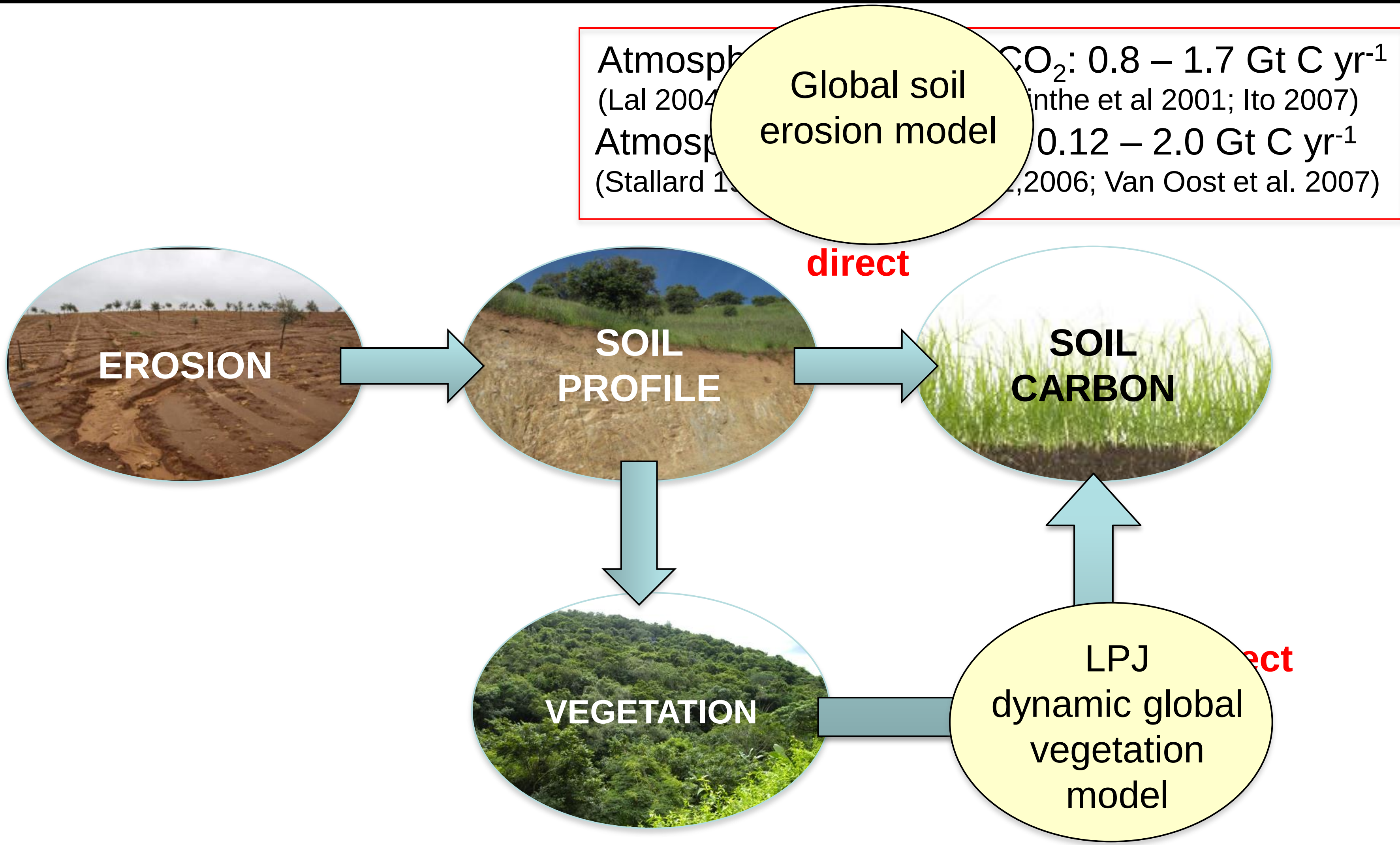
Importance of erosion for the carbon cycle

Atmospheric ***source*** of CO_2: 0.8 – 1.7 Gt C yr^{-1}
(Lal 2004; Schlesinger 1995, Jacinthe et al 2001; Ito 2007)
Atmospheric ***sink*** of CO_2: 0.12 – 2.0 Gt C yr^{-1}
(Stallard 1998; Smith et al. 2001,2006; Van Oost et al. 2007)



- **Unsufficient understanding of interaction erosion-carbon cycling at process level and challenge of upscaling local data to global level**
- **Uncertainty associated with estimate of global soil erosion**

Importance of erosion for the carbon cycle



- **Unsufficient understanding of interaction erosion-carbon cycling at process level and challenge of upscaling local data to global level**
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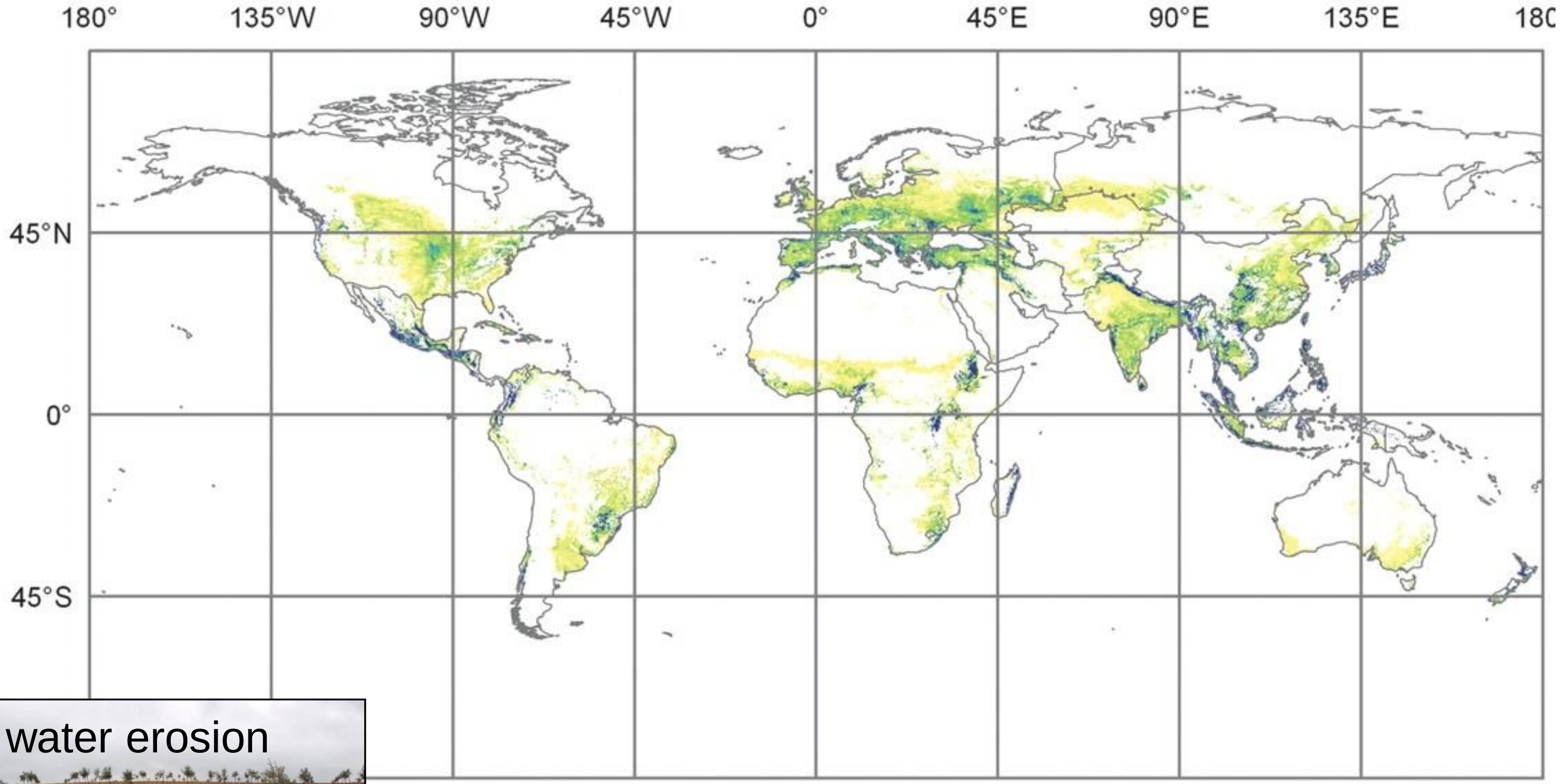
Soil erosion and carbon cycle

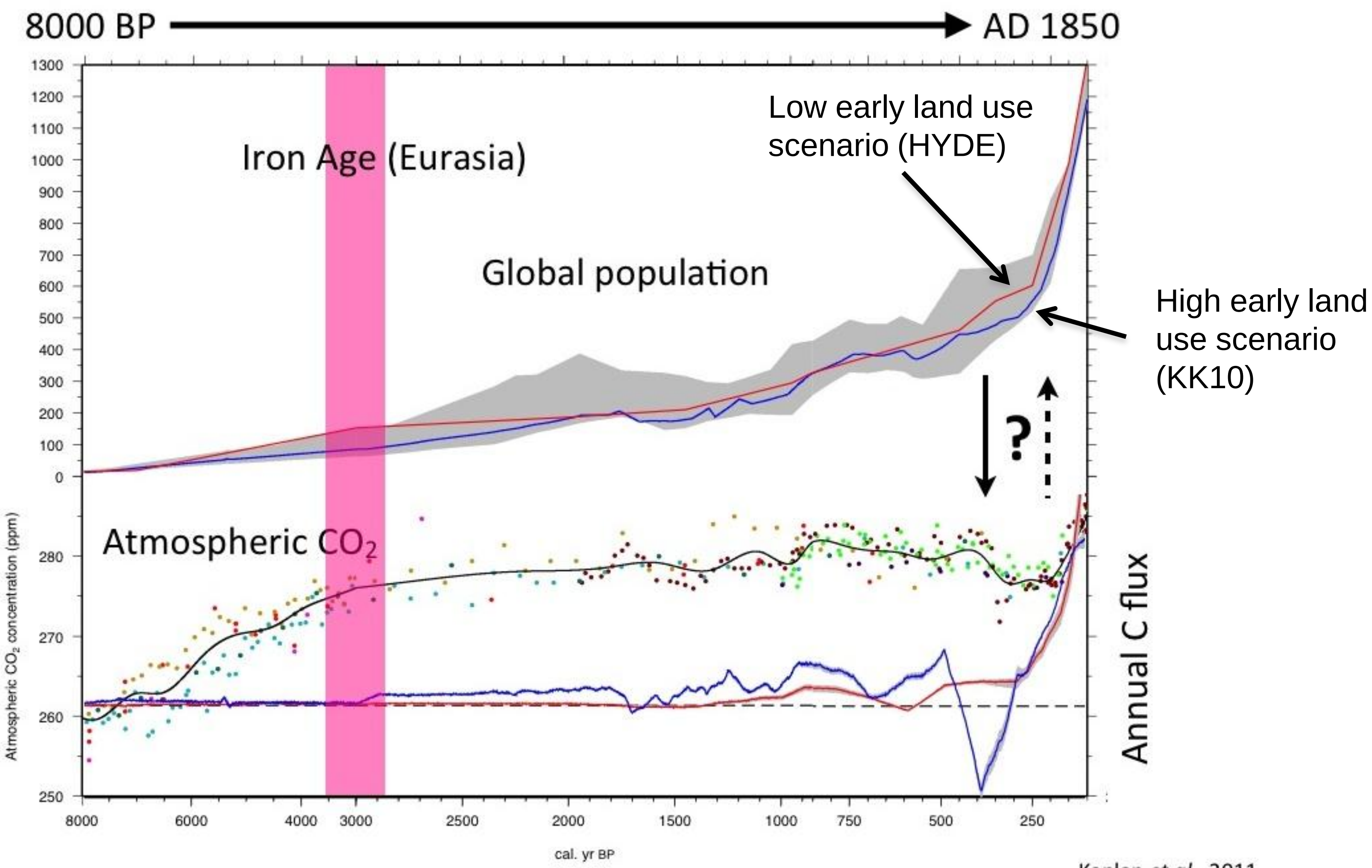
Importance of *current* soil erosion for the global C cycle



Holocene soil erosion and carbon cycle

What do we know? What are key model needs?

Holocene population and atmospheric CO2

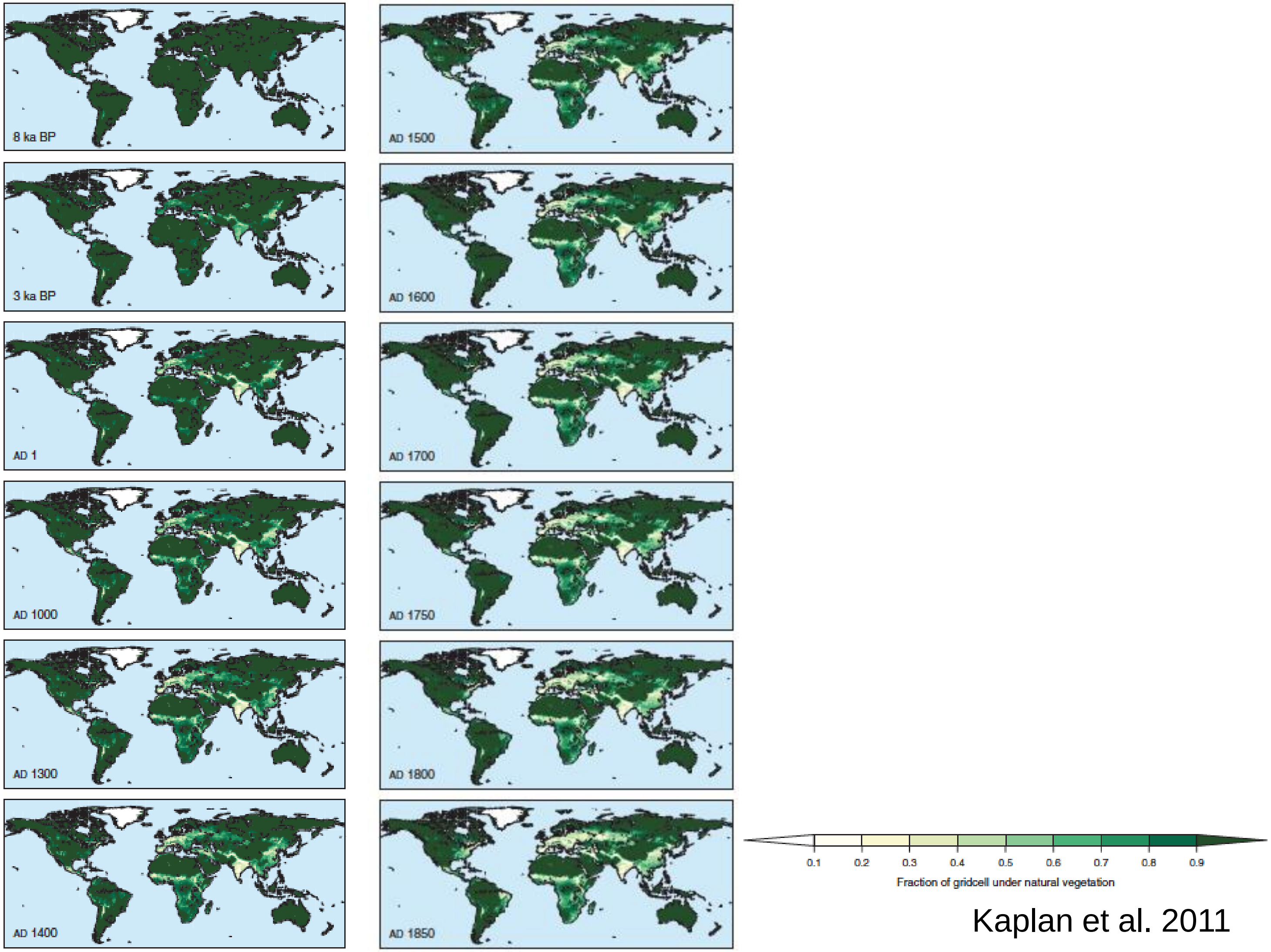


Kaplan *et al.*, 2011

Holocene soil erosion and carbon cycle

What do we know? What are key model needs?

KK10 Scenario of human-induced land use change

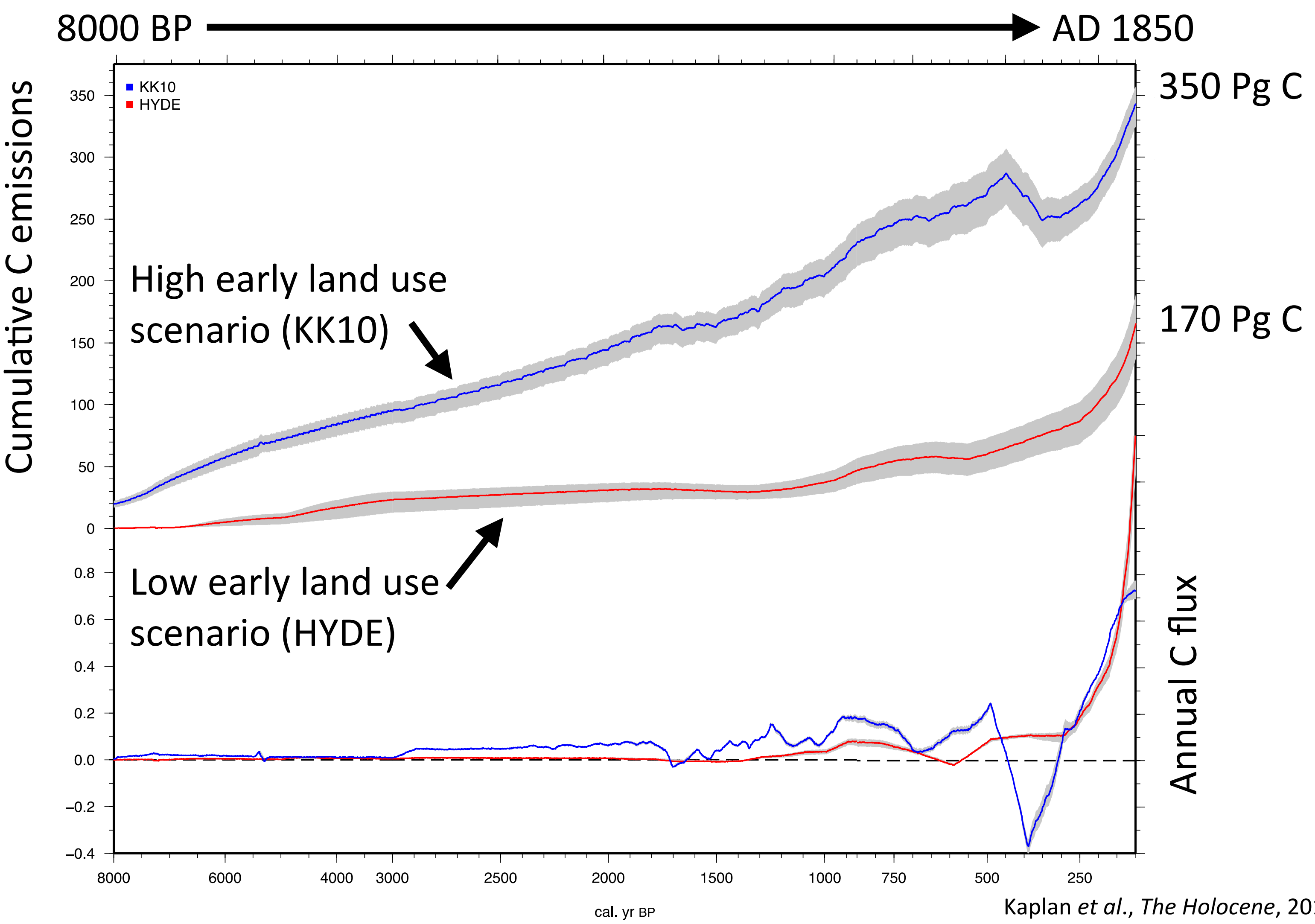


Kaplan et al. 2011

Holocene soil erosion and carbon cycle

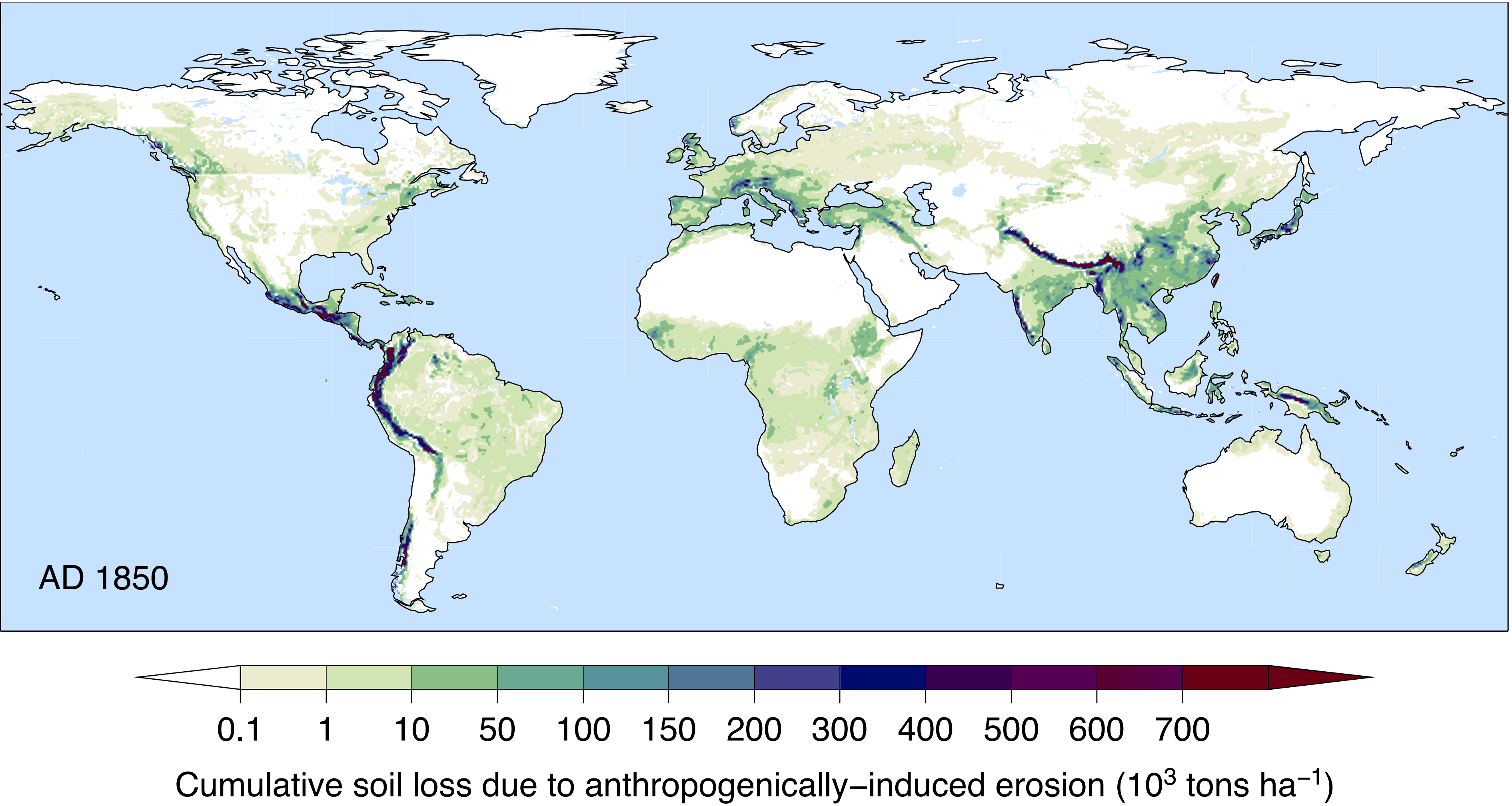
What do we know? What are key model needs?

Carbon emission from land cover change



Kaplan *et al.*, *The Holocene*, 2011

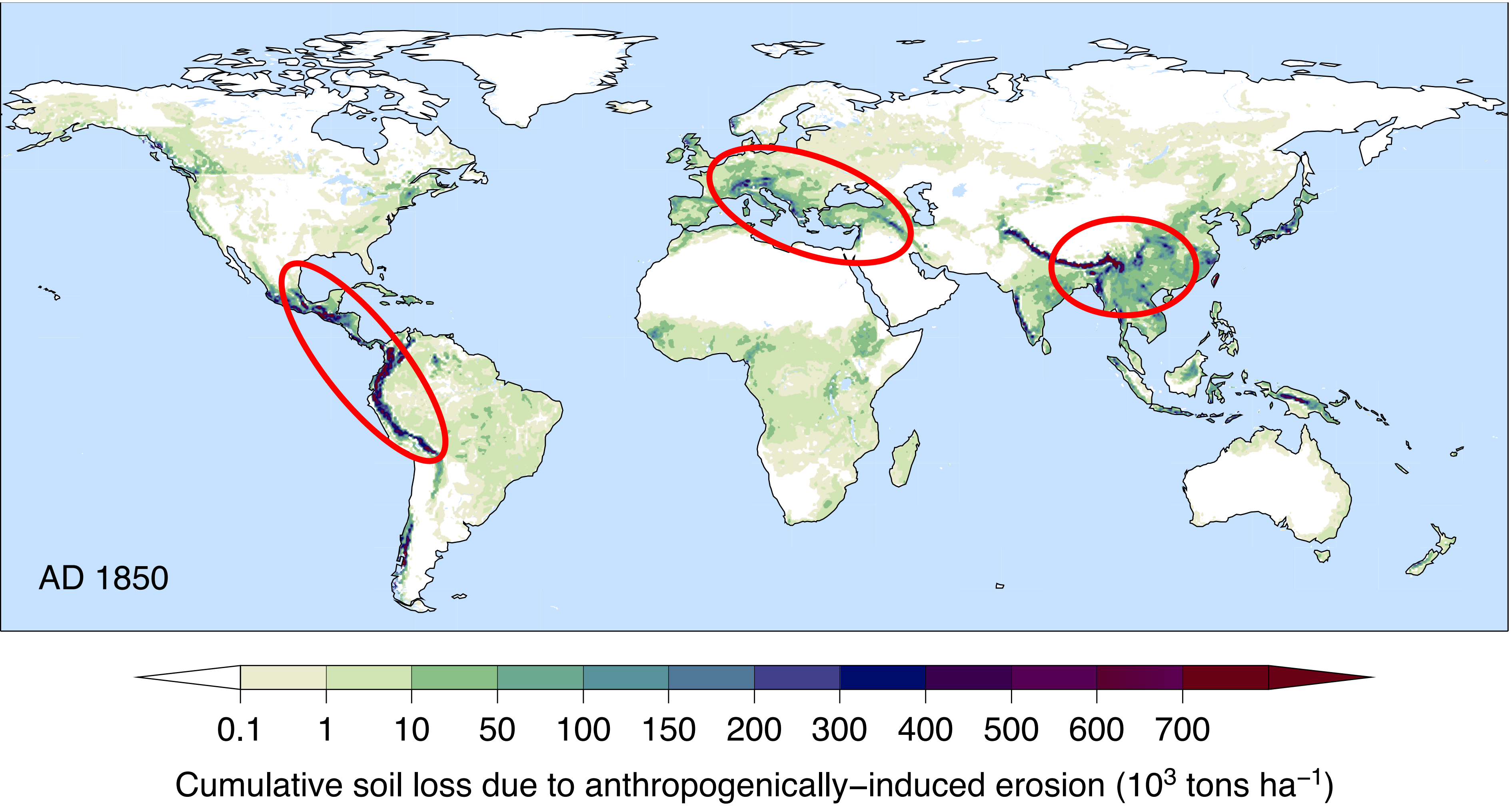
Cumulative soil erosion at AD 1850



Modelling soil erosion with RUSLE

Kaplan *et al.*, in prep.

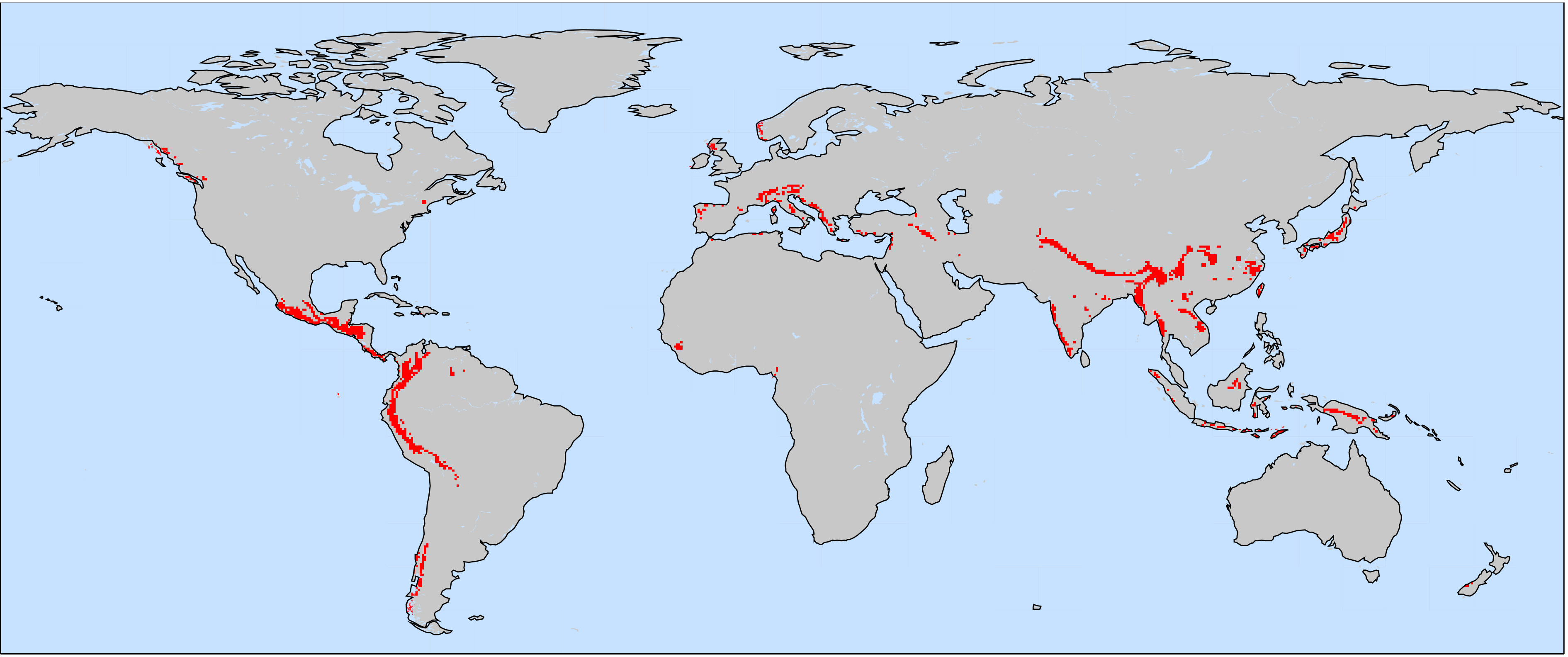
Cumulative soil erosion at AD 1850



Areas with very long human impact show significant soil degradation

Kaplan *et al.*, in prep.

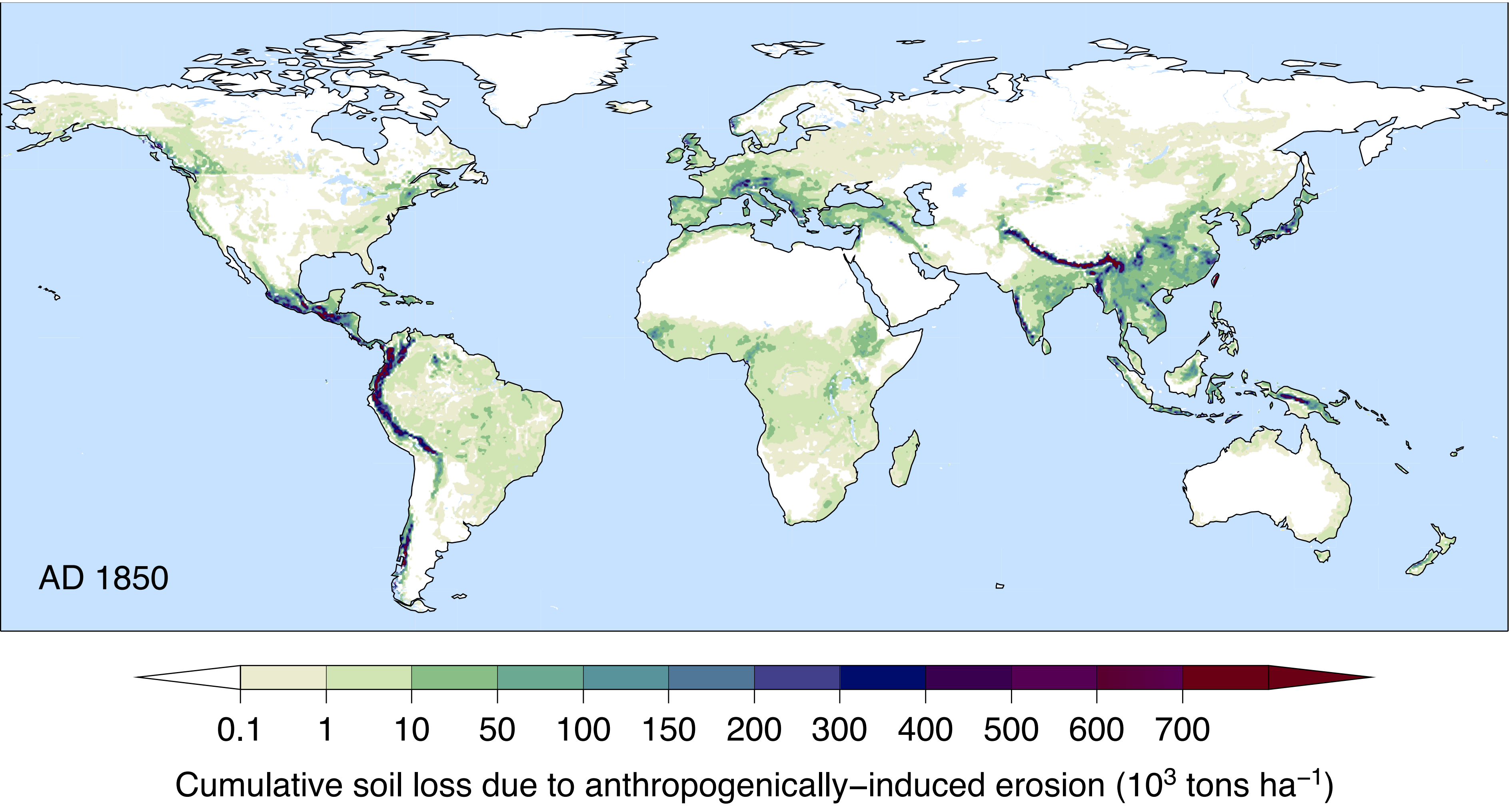
Irreversibly degraded ecosystems?



Areas with consolidated bedrock and high cumulative erosion (>100kt)

Kaplan *et al.*, in prep.

Cumulative soil erosion at AD 1850



However…no limit on erosion → overestimation

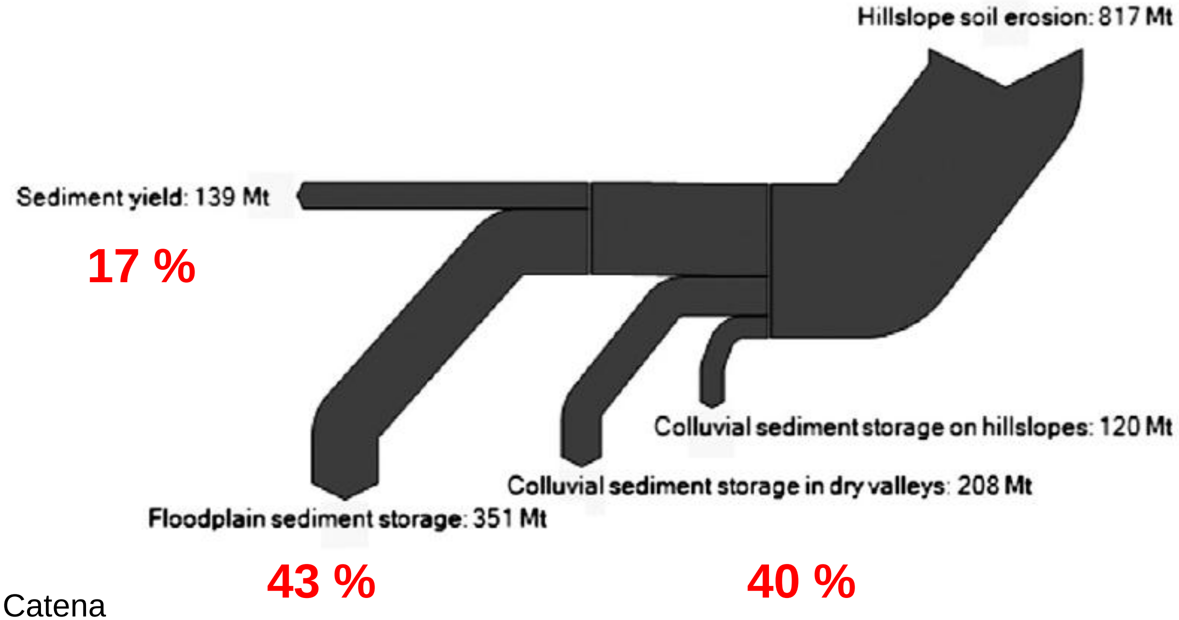
→ how to improve model?

Kaplan *et al.*, in prep.

Holocene soil erosion

- **Many case studies - regional scale**
- **2 key driving processes:** **1) erosion** **2) deposition**

Holocene sediment budget

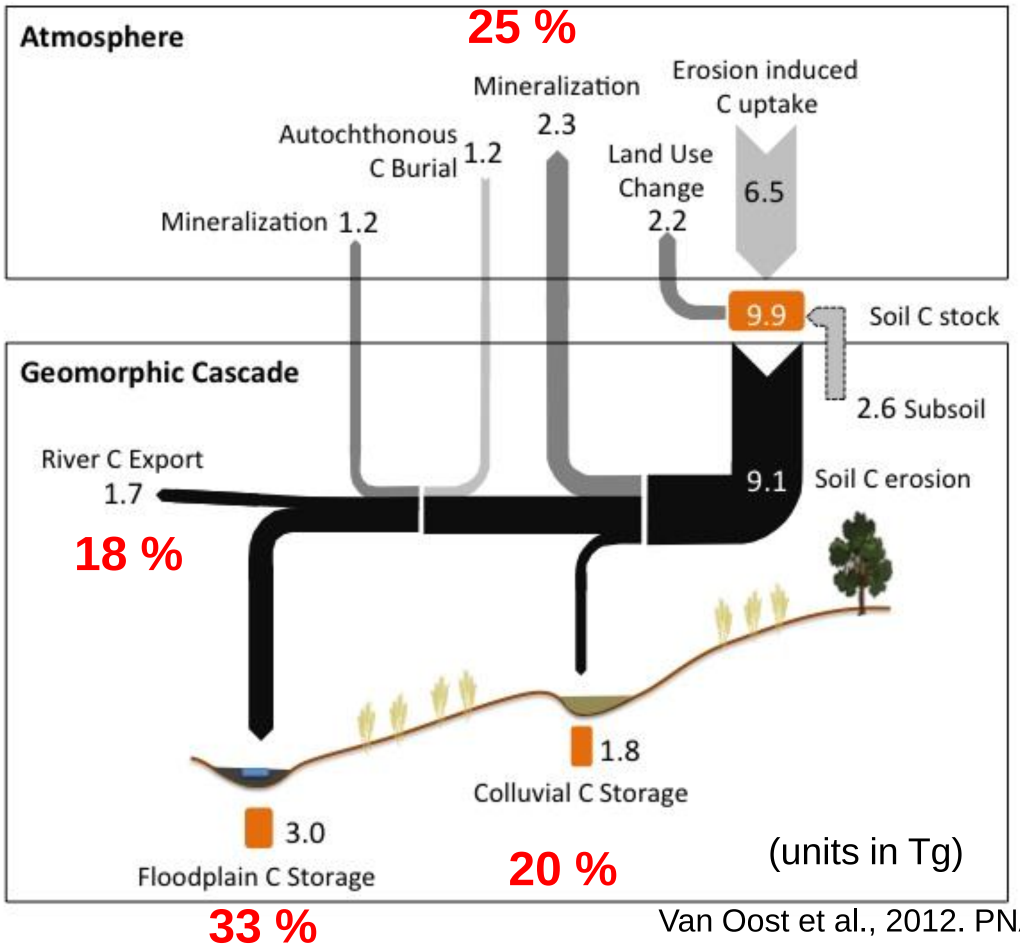


Notebaert et al., 2009. Catena

Holocene carbon budget

- **Many case studies - regional scale**
- **2 key driving processes: 1) erosion 2) deposition**

photo: Tom Rommens



Van Oost et al., 2012. PNAS

Modelling Holocene soil erosion

- **Universal soil loss equation (R)USLE → only part of the story**

USLE = R K LS C P

Rainfall
Soil erodibility
Topography
Land cover
Management practices

- **Deposition: transport capacity**

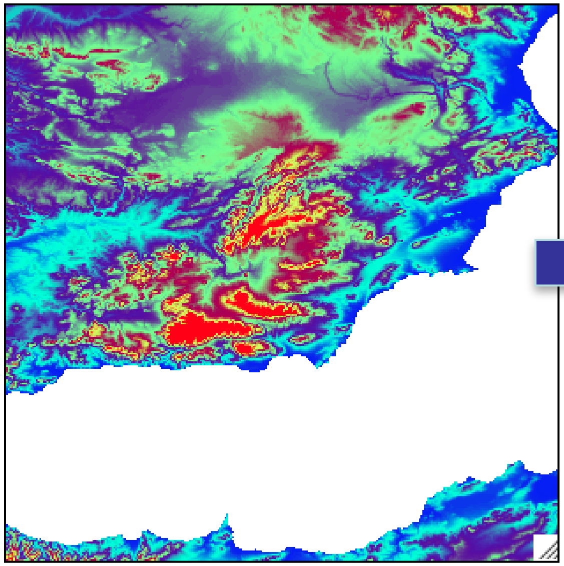
$$\mathrm{TC} = \mathrm{ktc}\ R\ K\left(\mathrm{LS}_{2\mathrm{D}} - 4.1 s^{0.8}\right)$$

- **WaTEM/SEDEM model** (Van Oost et al., 2000; Van Rompaey et al., 2001; Verstraeten et al., 2002)

Scaling topographical parameters: methodology

- **Subgrid representation of erosion/deposition processes**

SRTM 5º tile

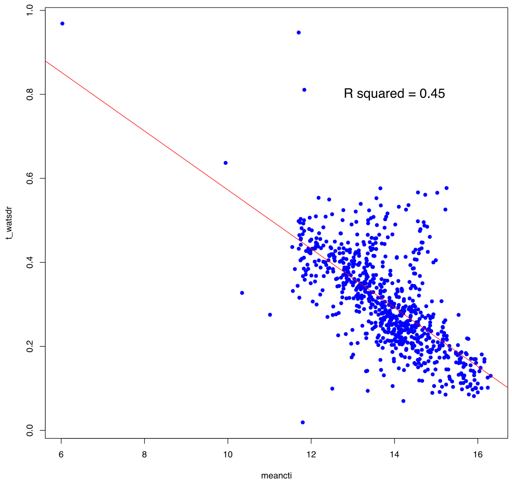


Detailed subgrid model

WaTEM/ SEDEM model

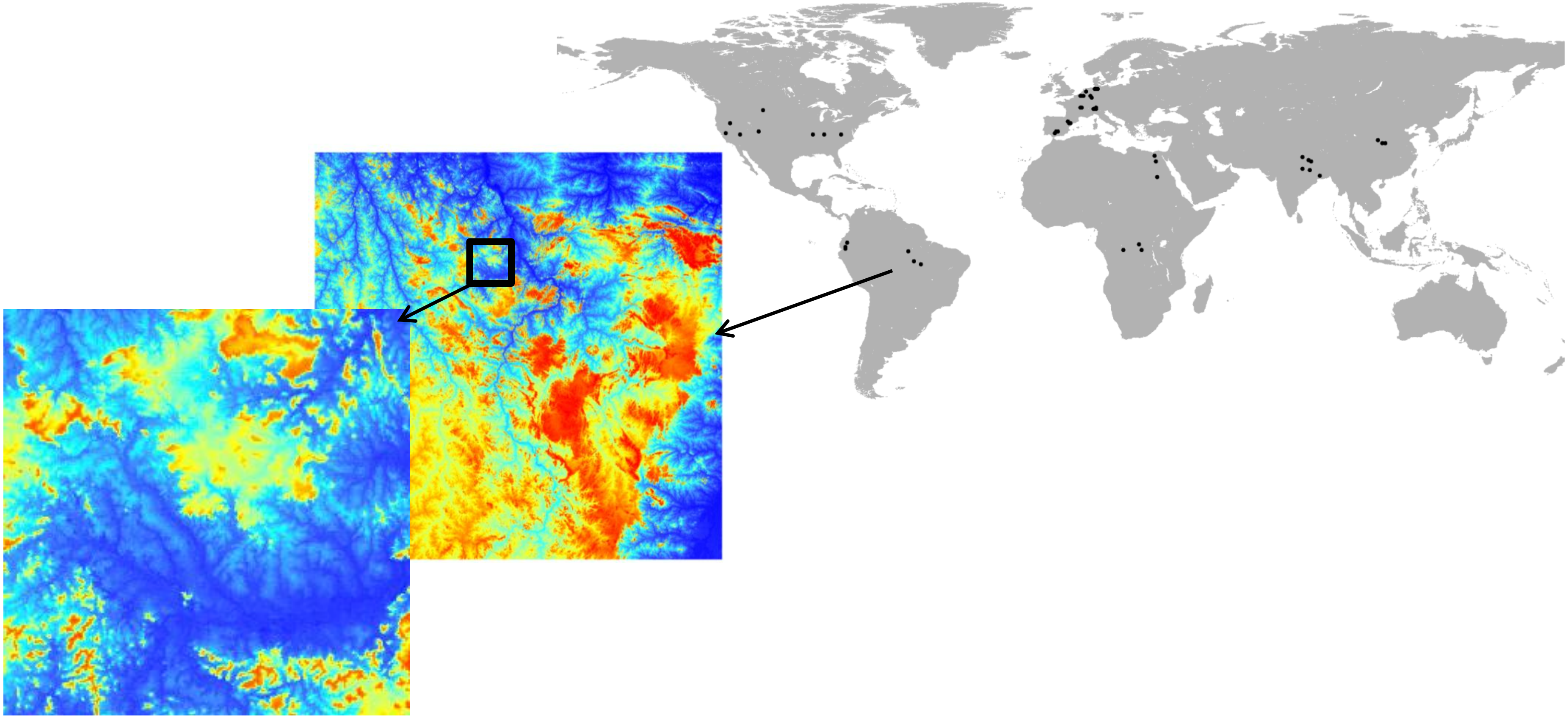
Generalized model

Scaling relationships with topographic variables



Scaling topographical parameters: methodology

- WaTEM/SEDEM: USLE + transport capacity
- 5 land use scenarios: 0 - 25 - 50 - 75 - 100 % cropland (random spatial allocation)
- SRTM: 50 subtiles of 0.5º (3" resolution)



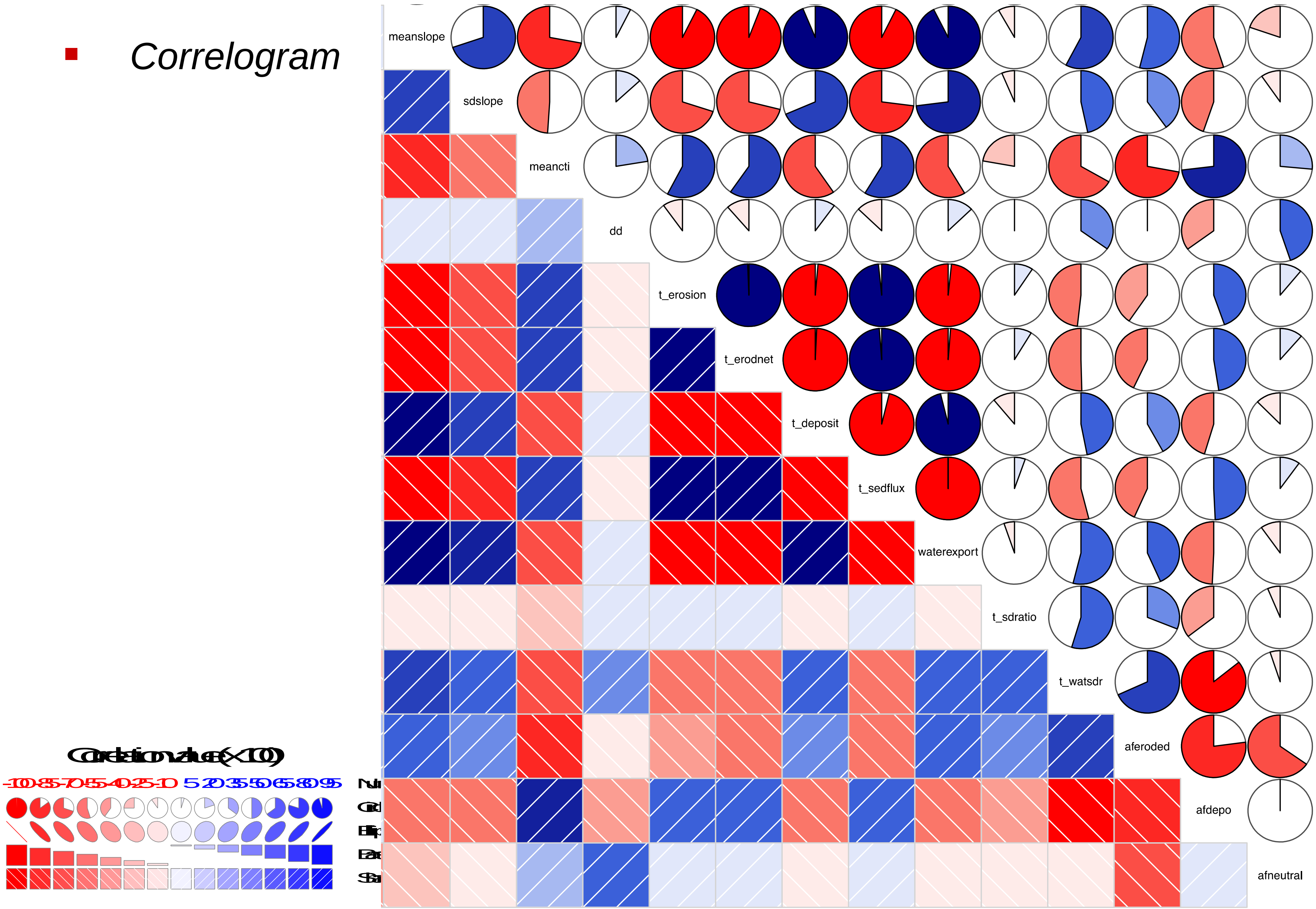
Scaling topographical parameters

- **Variables of interest:**
  - **Total erosion produced**
  - **Sediment delivery ratio (SDR)**
  - **Area affected by erosion/deposition**

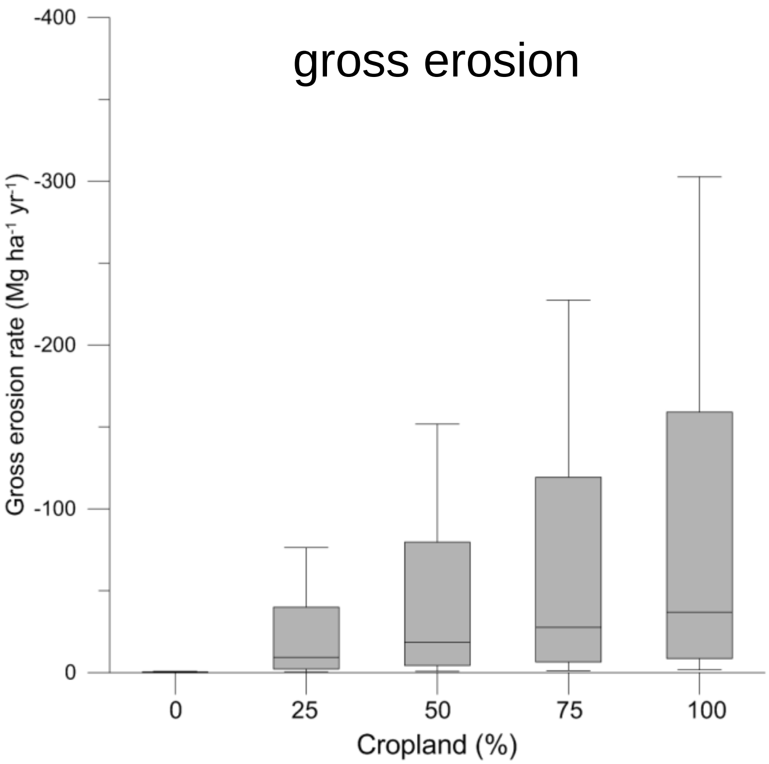
- **Predictor topographic variables:**
  - **Mean elevation**
  - **Standard deviation of elevation**
  - **Mean slope**
  - **Standard deviation of slope**
  - **Mean Compound topographic index (CTI)**
  - **Standard deviation of CTI**
  - **Drainage density**

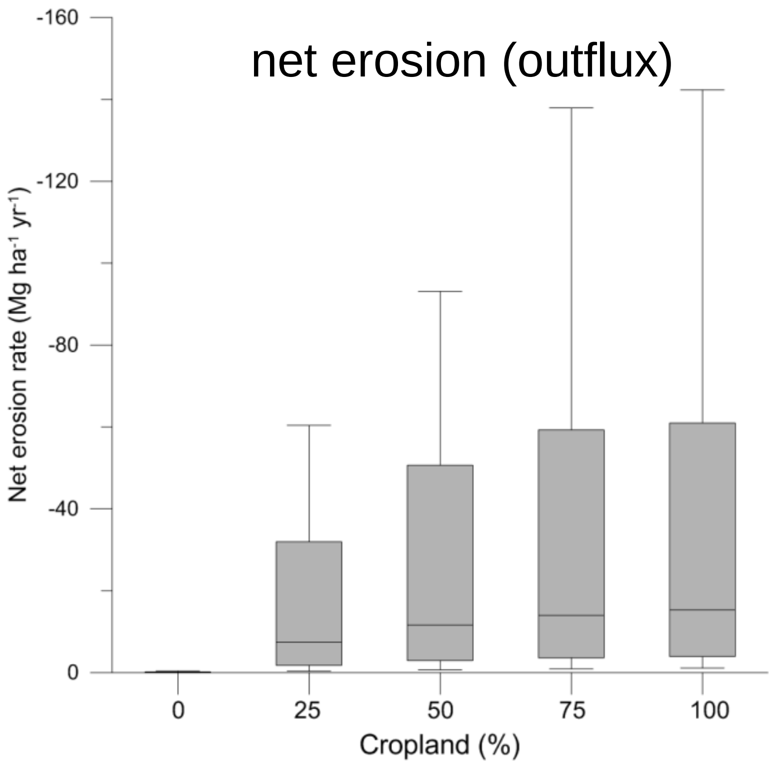
Results: scaling overview

- *Correlogram*



Results: scaling erosion rates





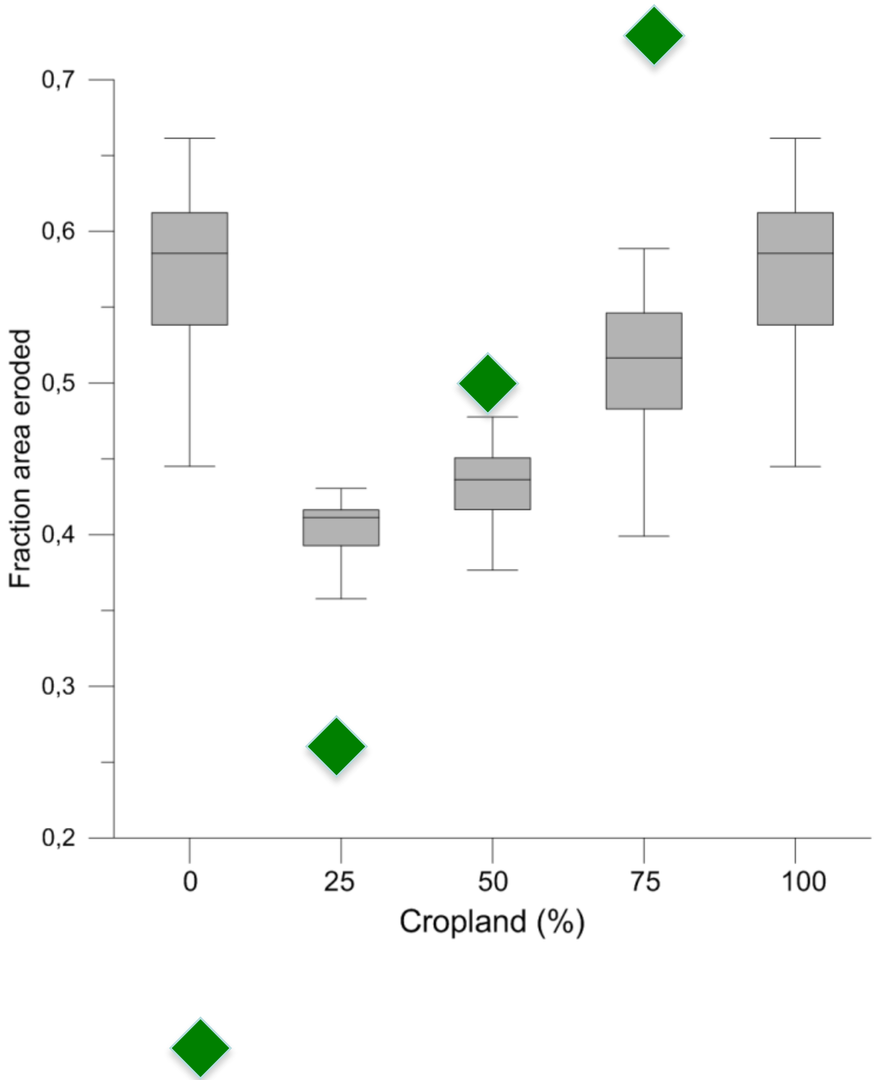
increasing cropland

increasing cropland

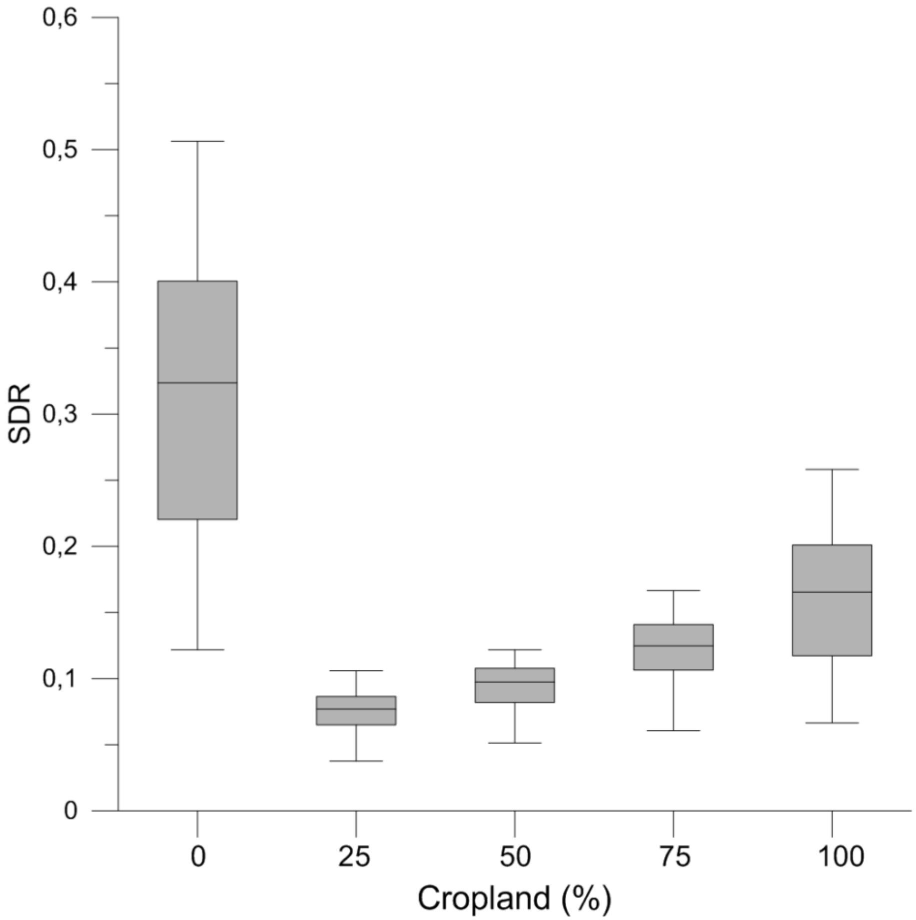
- Indication of levelling off after 75%

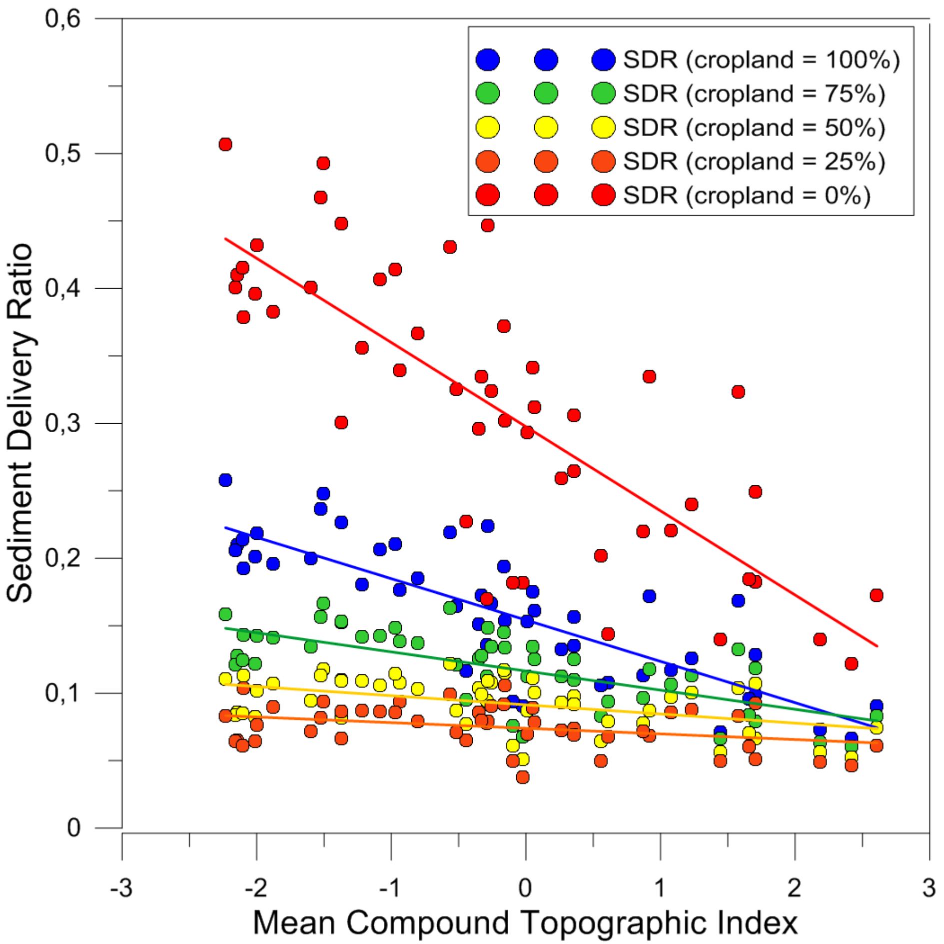
Results: scaling area fraction eroded

- **Area fraction eroded ≠ cropland fraction**



Results: scaling sediment delivery

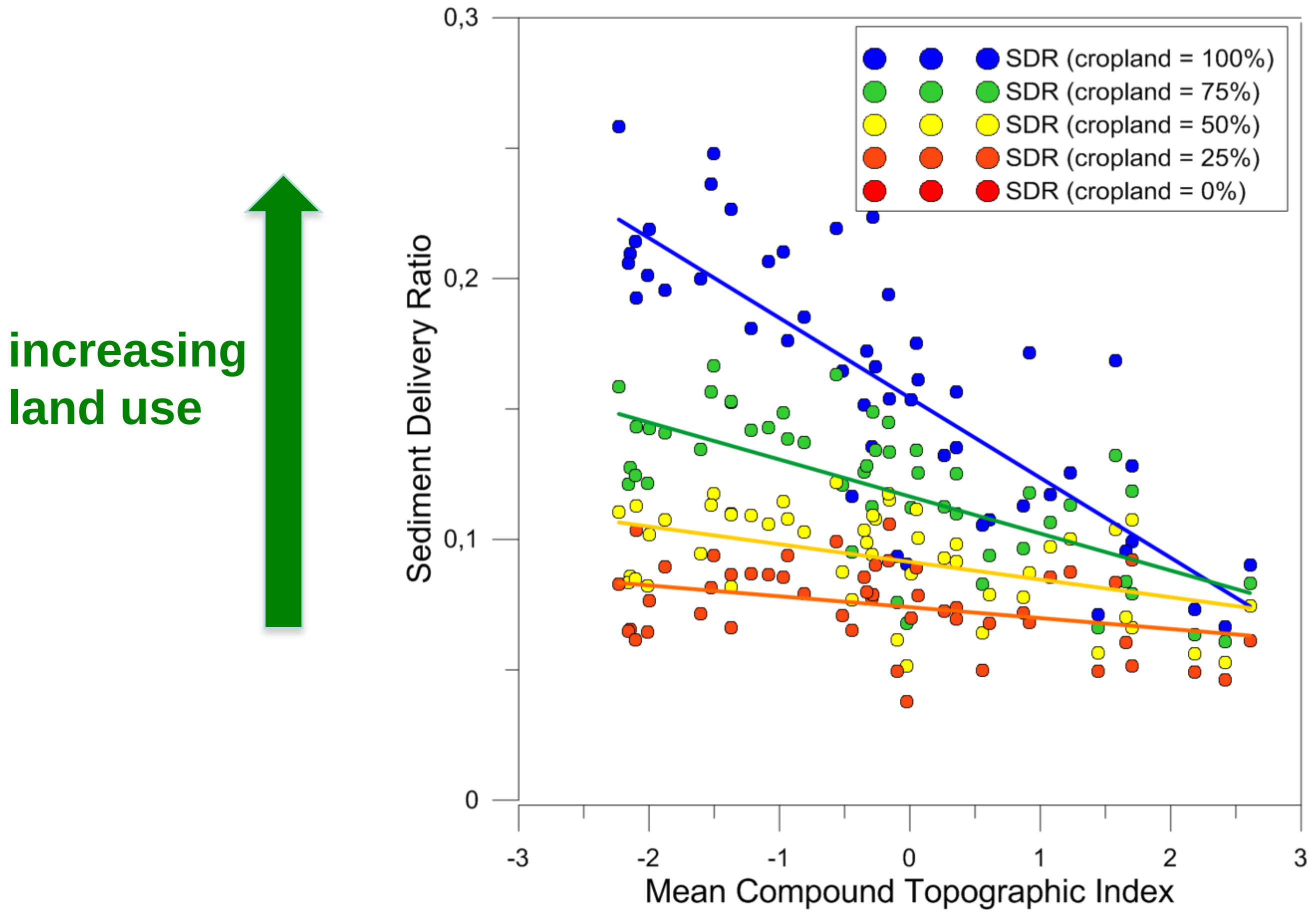




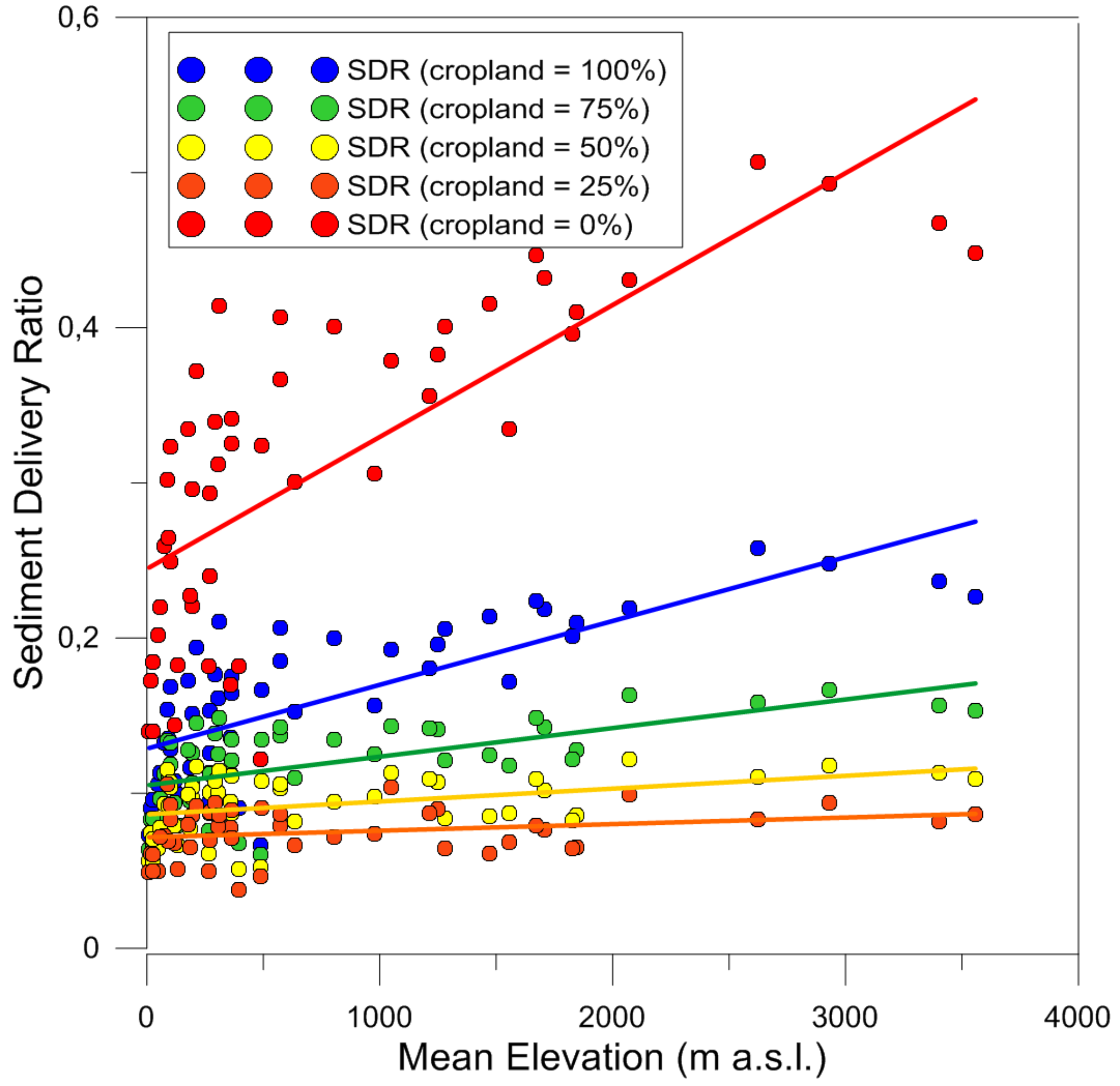
increasing cropland

Results: scaling sediment delivery

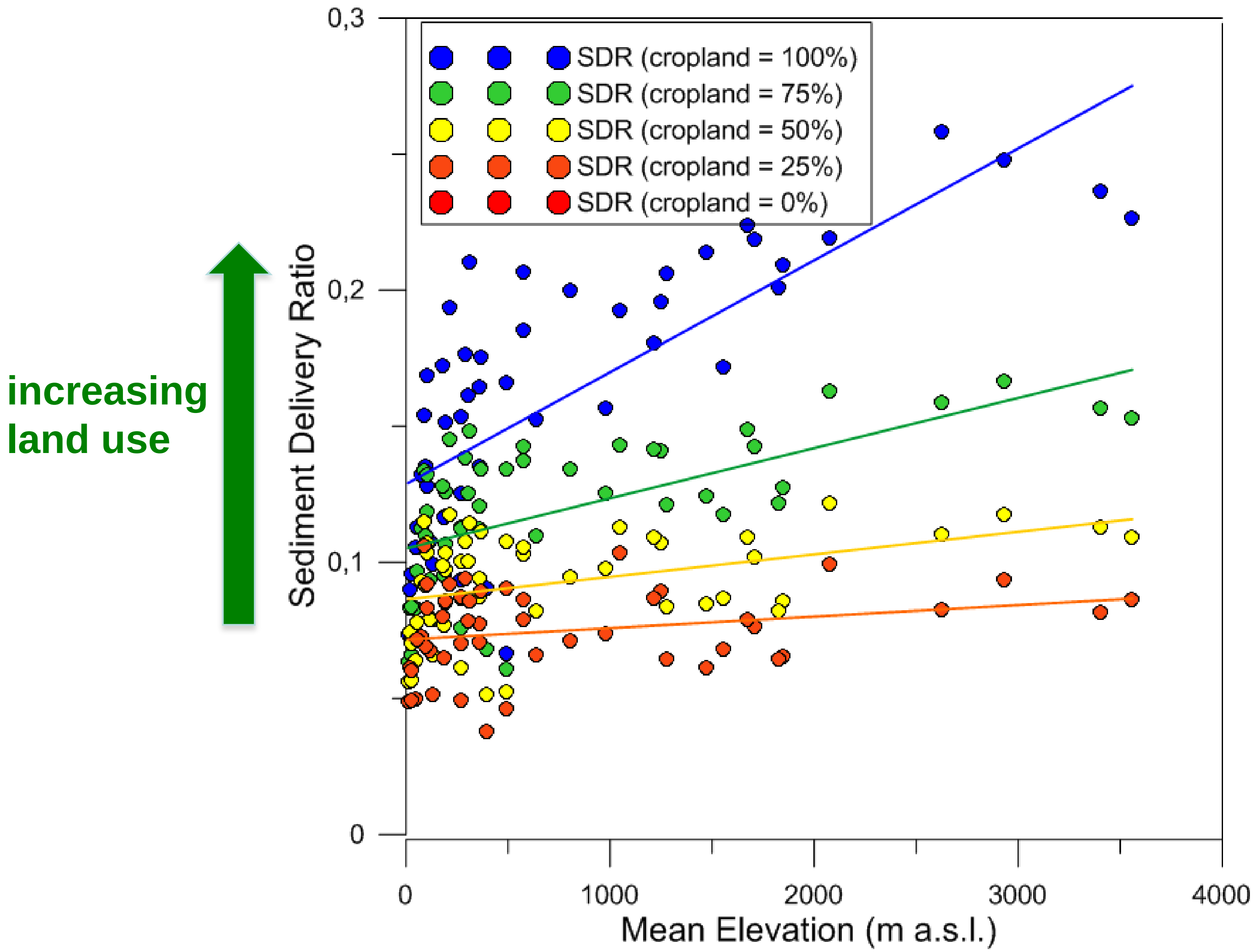
- **Excluding natural areas, where application of USLE is problematic**



Results: scaling sediment delivery

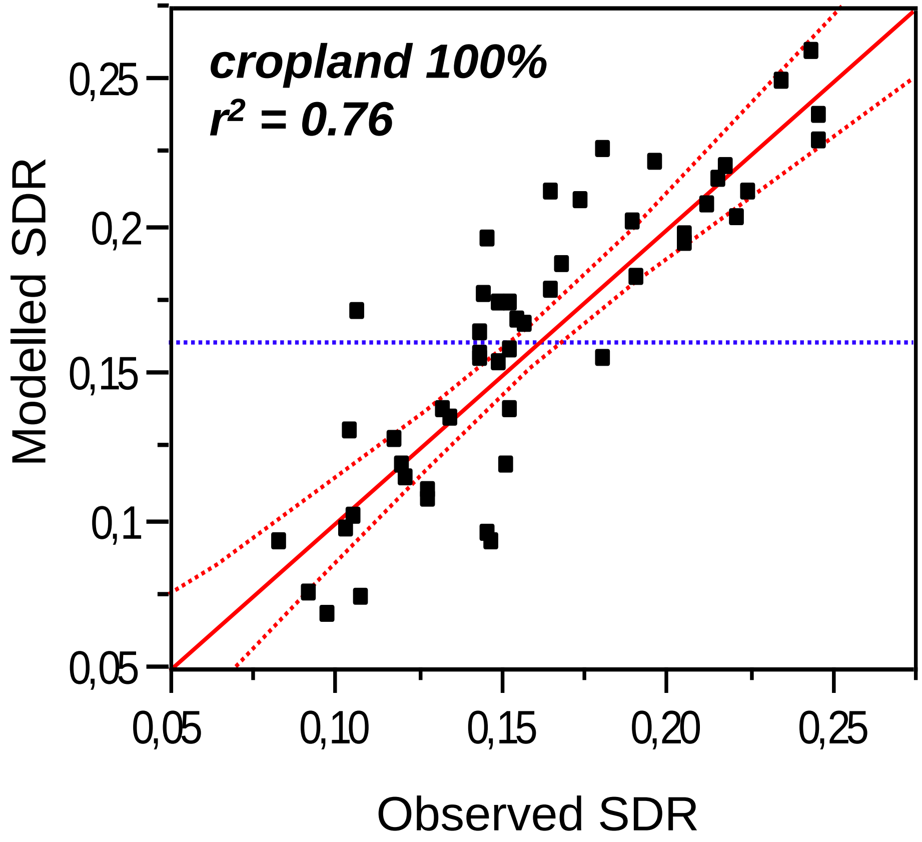


Results: scaling sediment delivery



Results: scaling sediment delivery

- **multiple linear regression model**
- **relations are universal, i.e. valid for all land use scenarios, although form and strength of correlation changes slightly**



Term	Estimate	Std Error	Prob>|t|
Intercept	0.14	0.005	<.0001
Mean Elv	2.21E-5	4.96E-6	<.0001
Mean CTI	-0.02	0.003	<.0001

Future perspectives and conclusions

- Erosion and deposition processes can be scaled from easily measurable topographic parameters
- Scaling relations appear universal
- Erosion and carbon cycle dynamics at the subgrid scale can be adequately represented at the coarse grid scale
- Most of the eroded sediment/carbon (>75 %) is redeposited before it reaches the river channels (SDR < 0.25)
- Include soil formation model important: feedbacks (e.g. stoniness), properties of sediment

Guadalquivir estuary, S Spain
NASA. November 12th 2012.

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