Universität Bremen

Institut für Umweltphysik

# Destabilization of carbon in tropical peatlands by enhanced rock weathering

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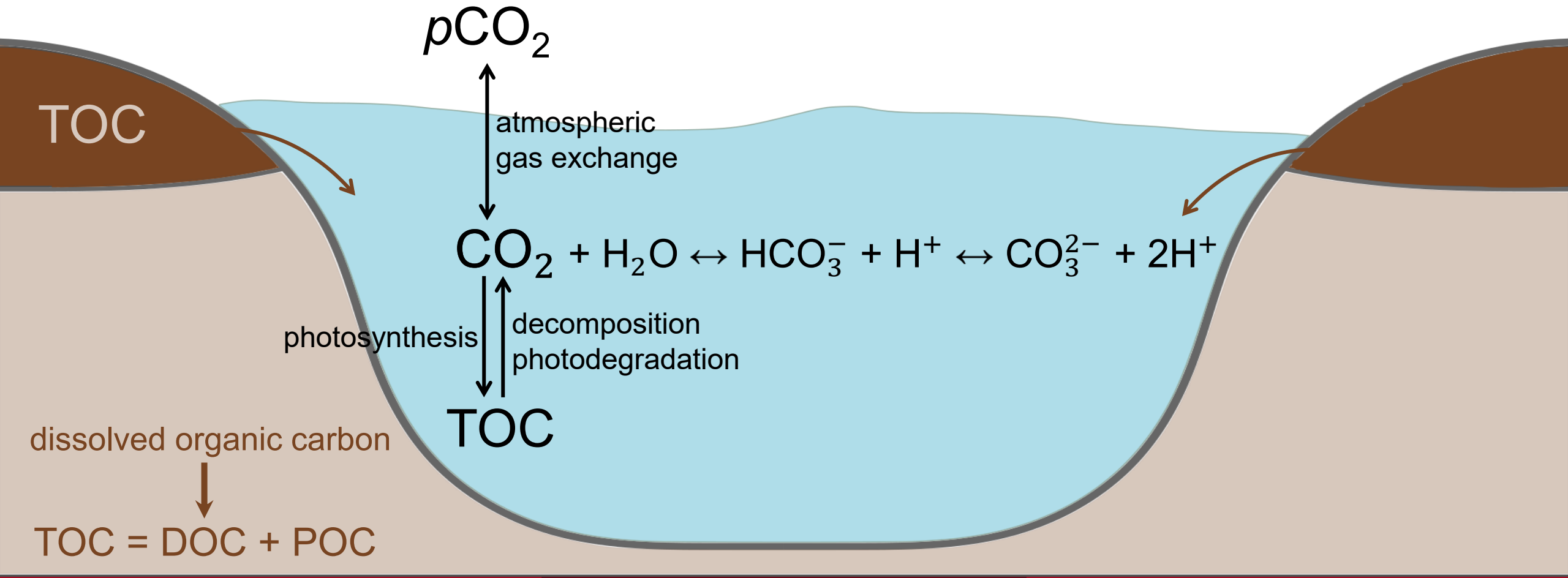
# Peatlands and peat draining rivers



Peatlands…

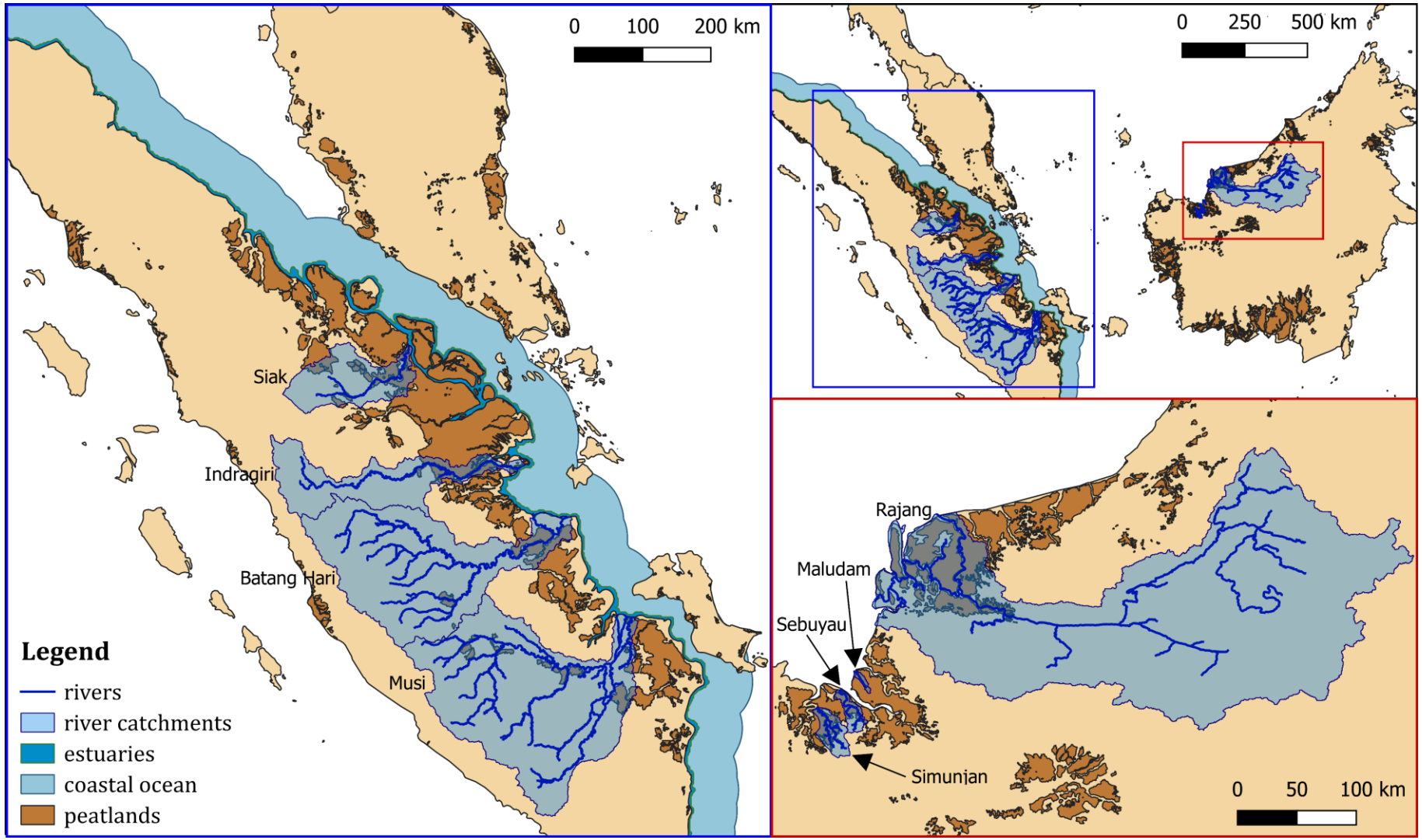
.. cover (3 – 4) % of global land area

.. store about one-third of terrestrial soil carbon



# Study area and river campaigns



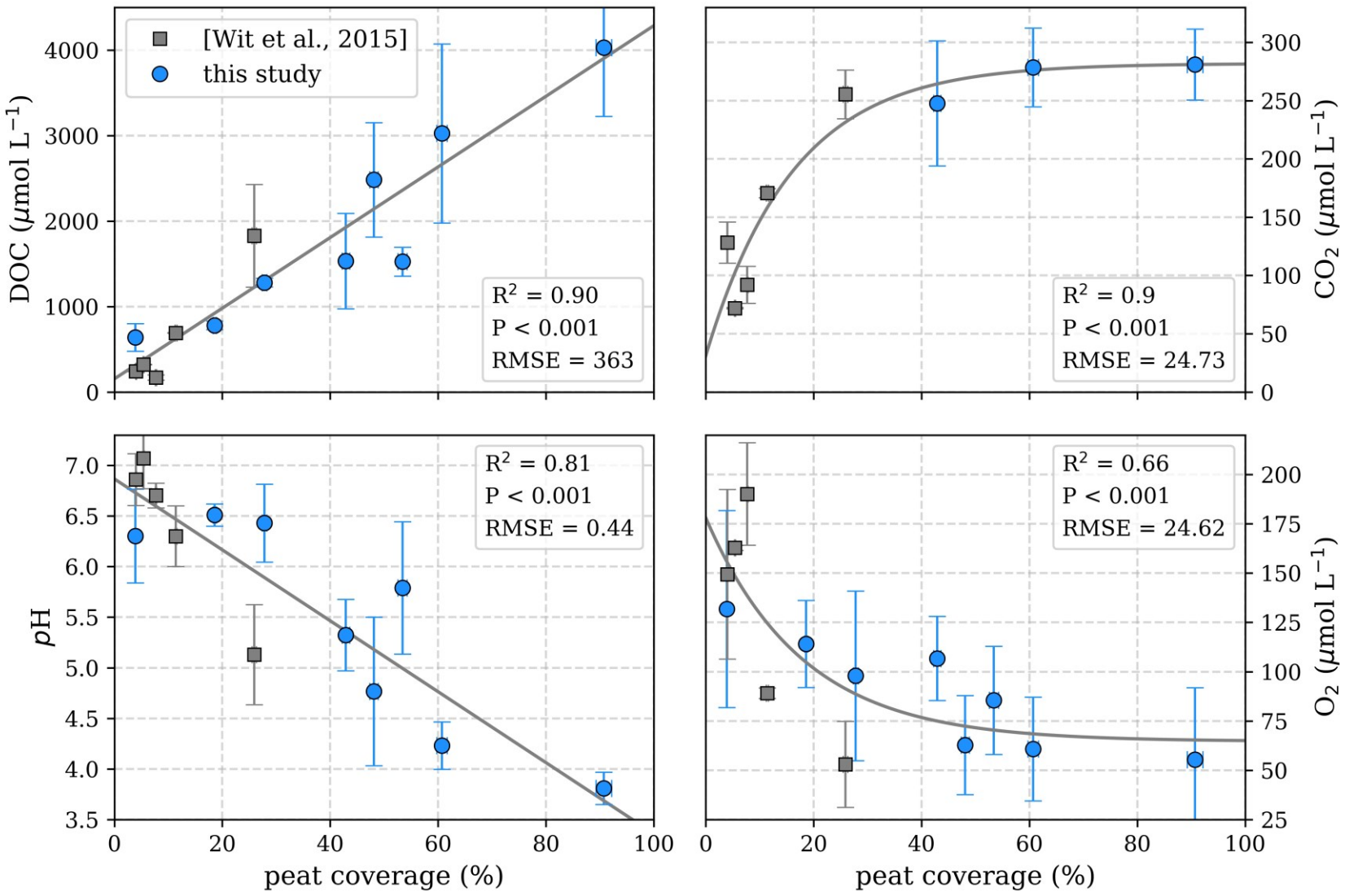


# River parameter dependencies on peat coverage (PC)



- Previous knowledge:
  - DOC & CO2 increase with PC
  - pH and O2 decrease with PC
- New findings:
  - CO2 increase and O2 decrease stagnate for high PC

→ There must be a limiting factor for $CO_2$ production and $O_2$ consumption in rivers of high peat coverage



# Limitation of DOC decomposition & EW implications



Decomposition: $DOC + O_2 \rightarrow CO_2 + H_2O + energy$

- Decomposition rates depend on ..
  - .. the availability of **DOC**
  - .. the availability of **$O_2$**
  - .. the activity of the enzyme **phenol oxidase**, which depends on **$O_2$** availability and **pH**

Least-squares approximation to measured data:

→ River $O_2$ limits decomposition by < 10 %

→ River pH limits decomposition by up to 85 %

- Enhanced rock weathering causes ..
  - .. atmospheric uptake of **$CO_2$**
  - .. an increase in soil and water **pH**

$CO_2$ uptake = (25 – 50) gC $m^{-2}$ $yr^{-1}$
pH increase = 0.2 – 1.3

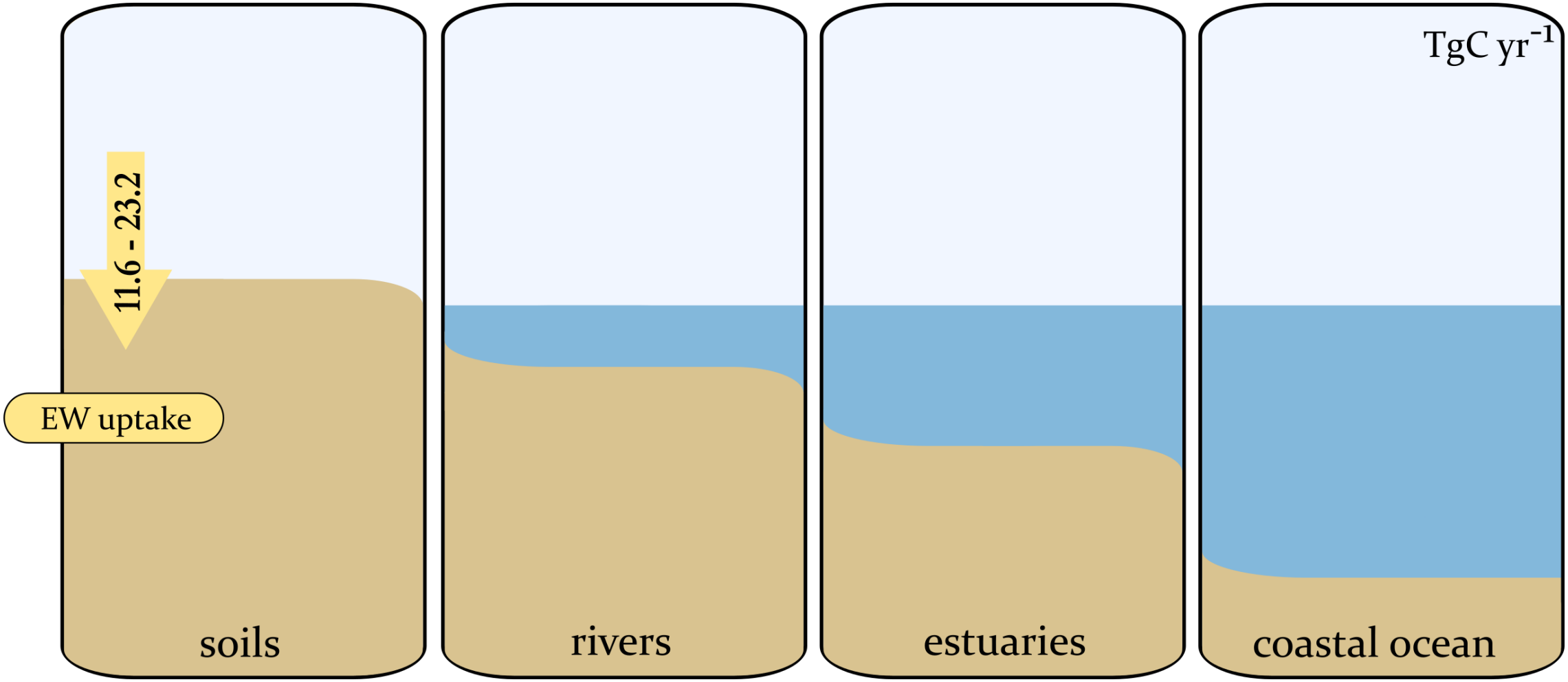
[Taylor et al., 2016; Beerling et al., 2020]

Question:

How do $CO_2$ emissions from tropical peat regions respond to this pH increase?

# Sumatra's response on enhanced weathering (EW)





# Sumatra's response on enhanced weathering (EW)



TgC yr$^{-1}$

11.6 - 23.2

EW uptake

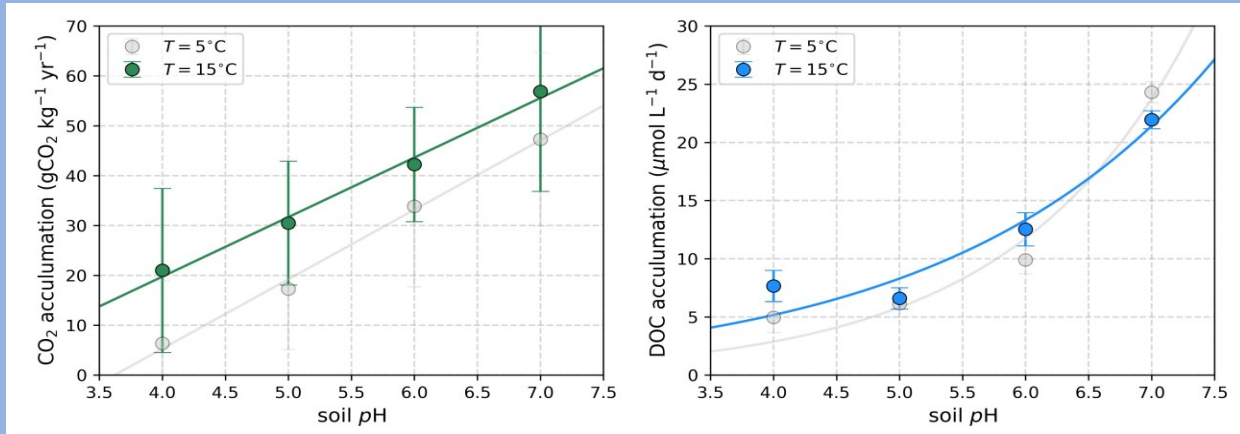
soils

rivers

estuaries

coastal ocean

## Soil carbon mobilization depends on pH

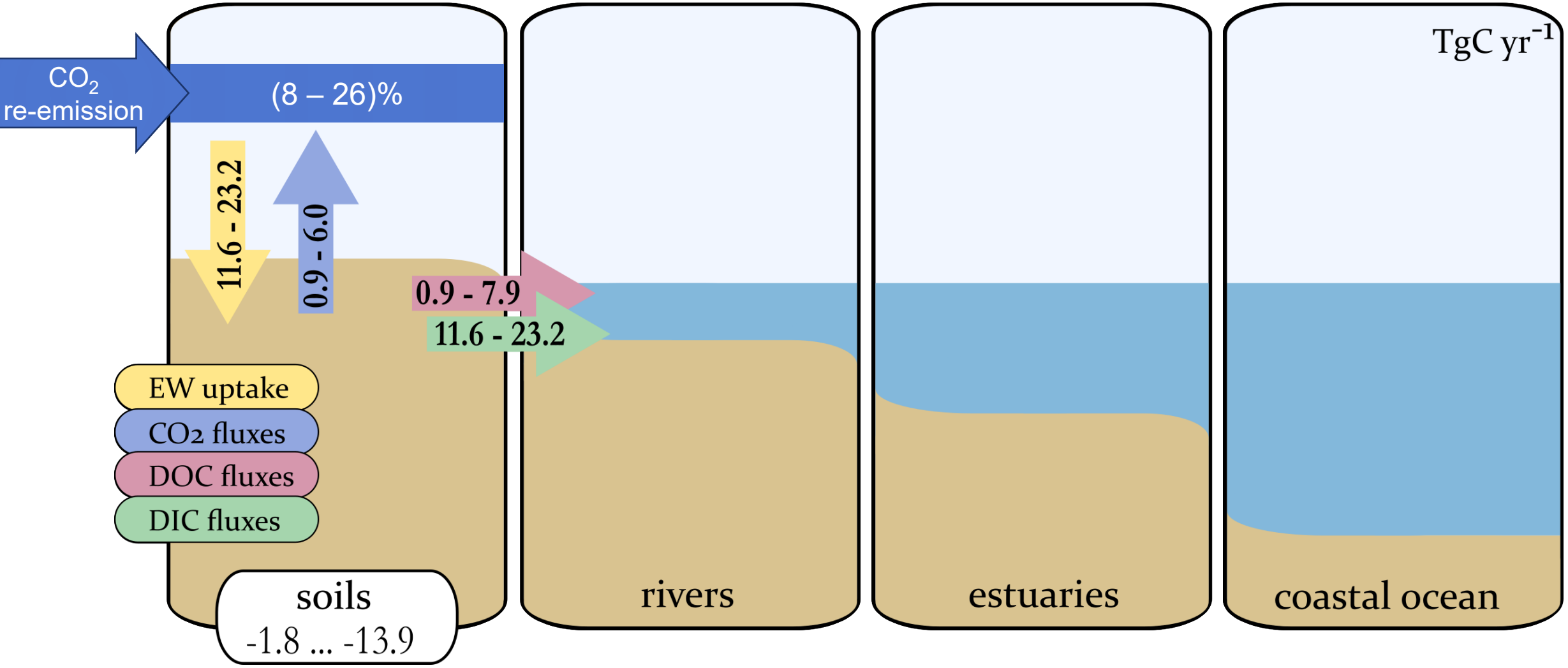



[Kang et al., 2018]

→ apply estimated pH increase to peat soils on Sumatra

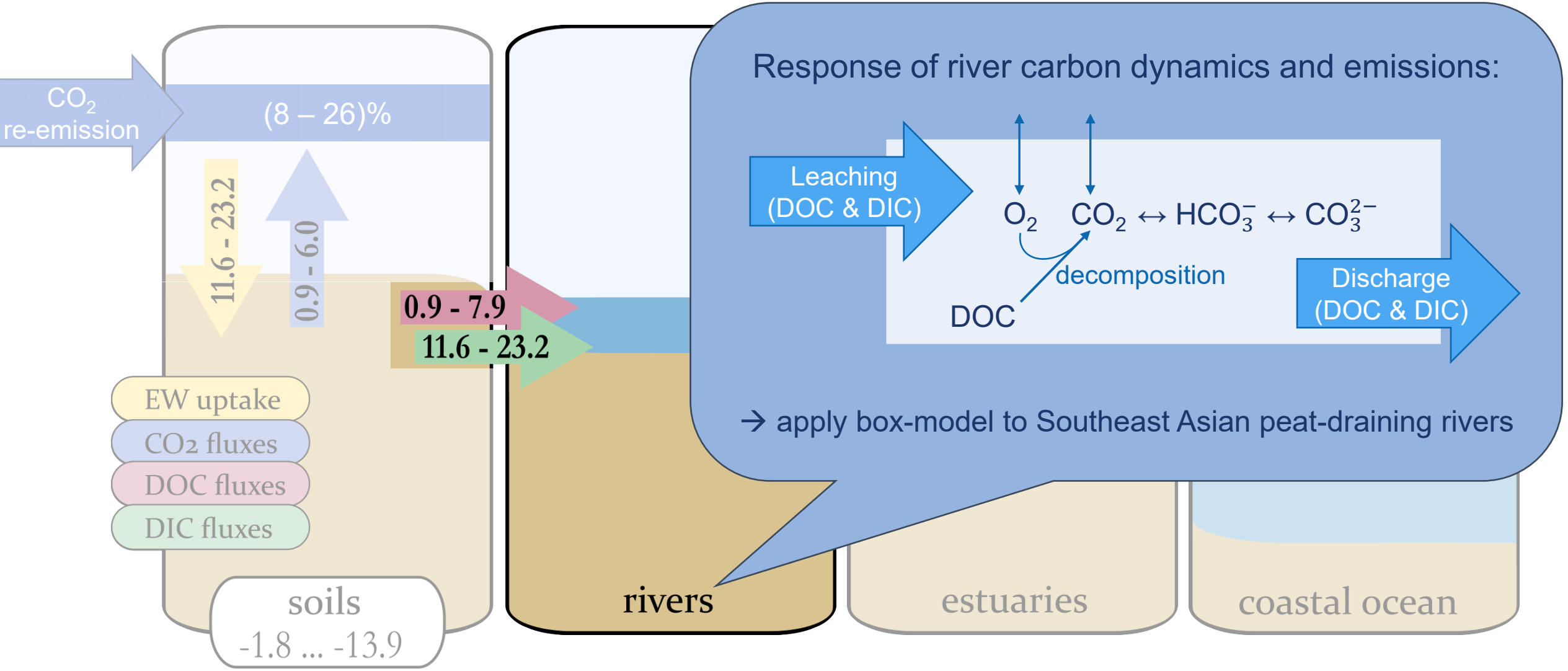
# Sumatra's response on enhanced weathering (EW)





# Sumatra's response on enhanced weathering (EW)





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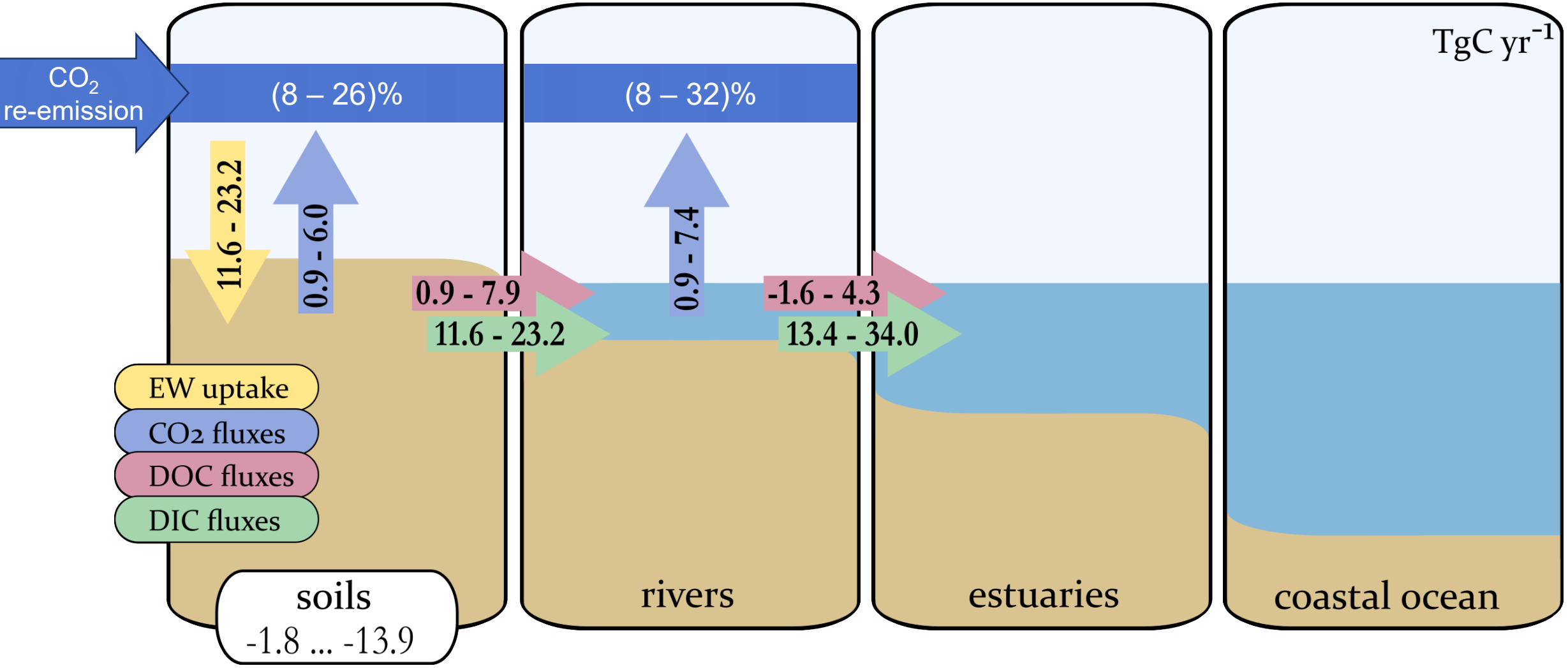
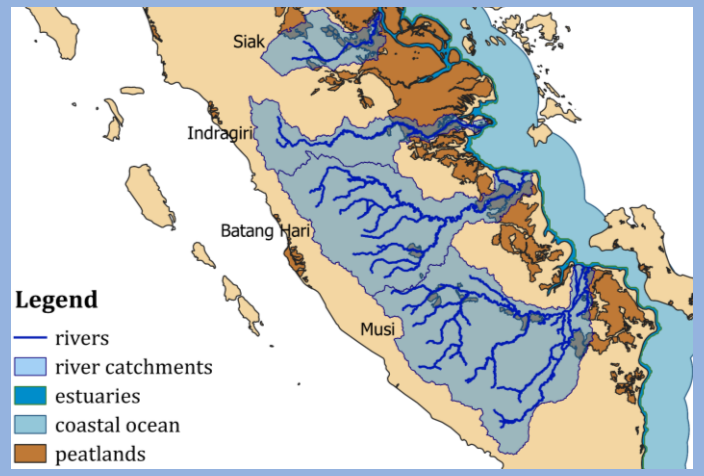


# Sumatra's response on enhanced weathering (EW)



## Response of coastal carbon emissions:

Separation between …
… estuaries:
(0 – 3) km from shore
… coastal ocean:
(3 – 27) km from shore

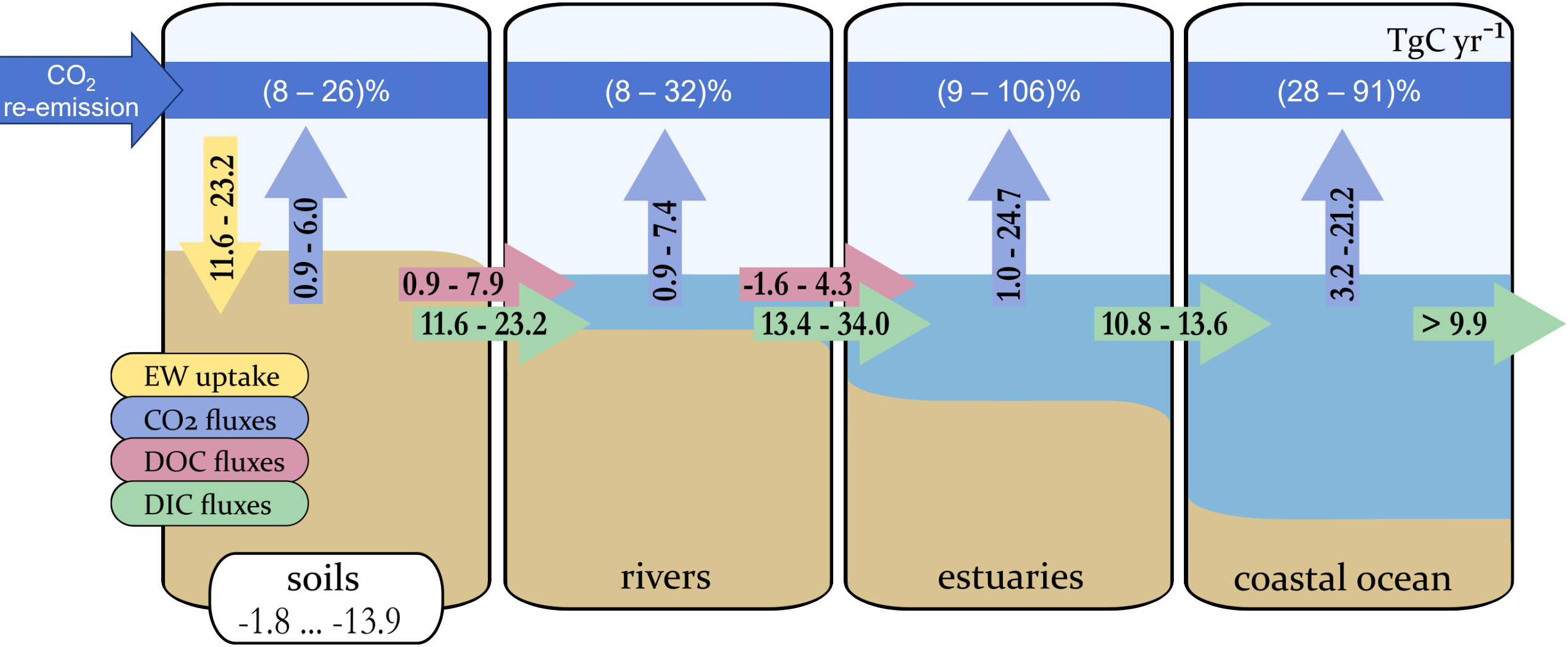



→ Derive response from mixing of river and ocean water

DOC fluxes
DIC fluxes
soils
-1.8 … -13.9
rivers
estuaries
coastal ocean
TgC $yr^{-1}$

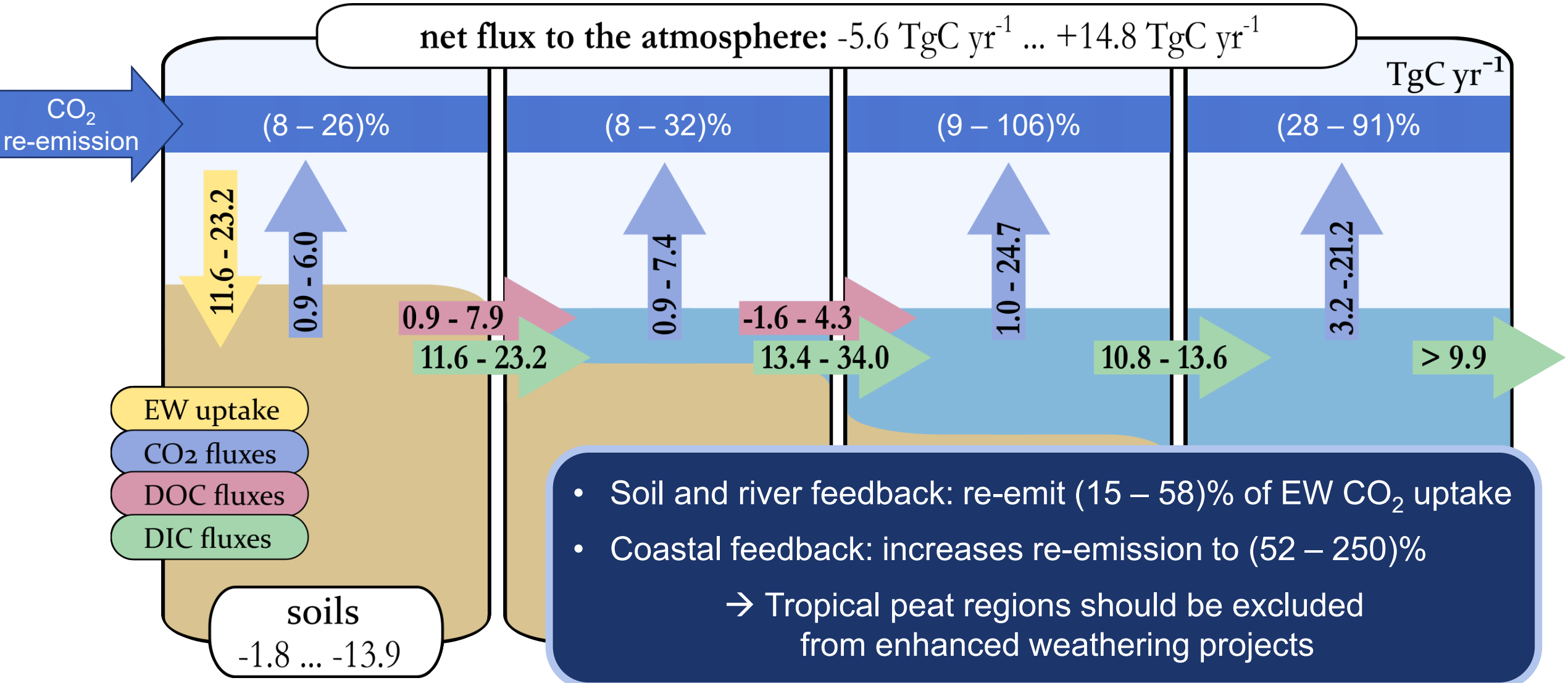
# Sumatra's response on enhanced weathering (EW)





# Sumatra's response on enhanced weathering (EW)





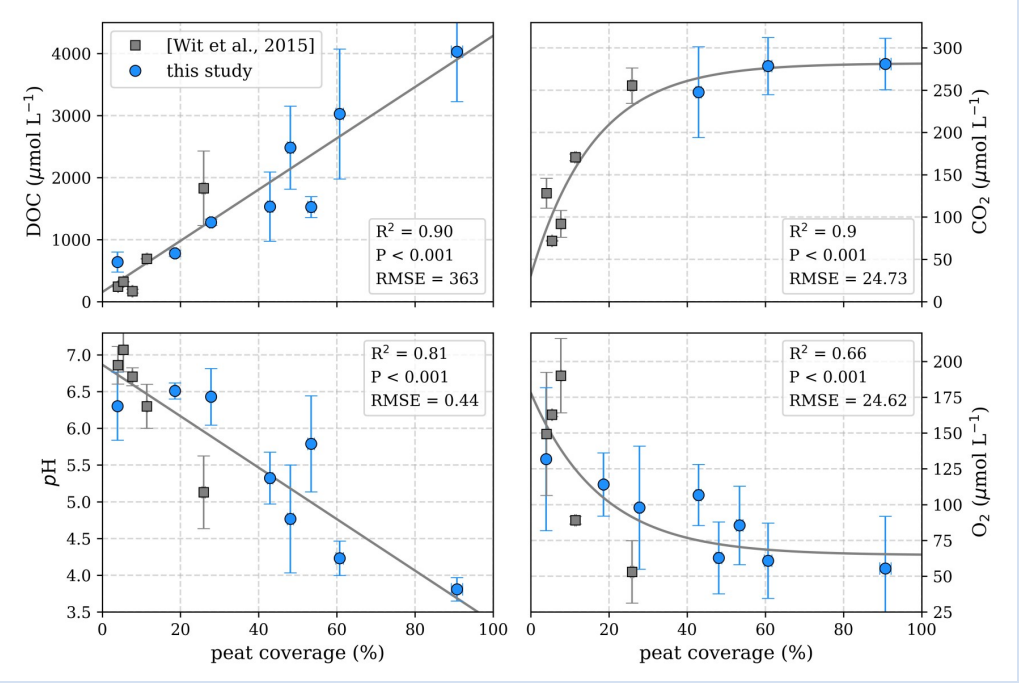

- Soil and river feedback: re-emit (15 – 58)% of EW $CO_2$ uptake
- Coastal feedback: increases re-emission to (52 – 250)%

→ Tropical peat regions should be excluded from enhanced weathering projects

# More information in related publications:

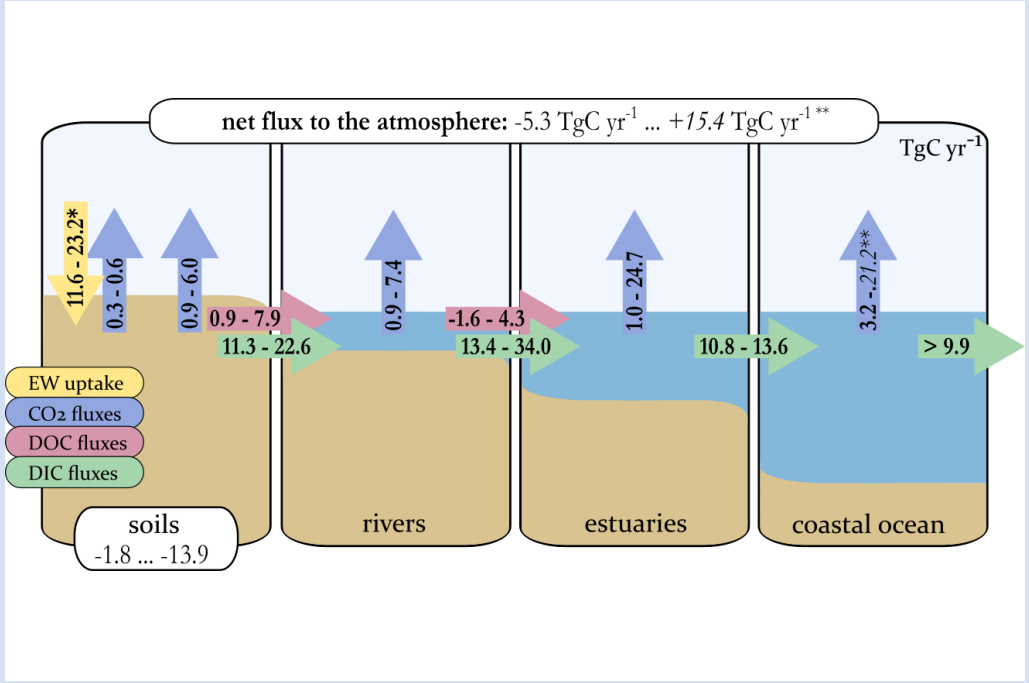


## $CO_2$ emissions from peat-draining rivers regulated by water pH




Klemme *et al.*
*Biogeosciences*, **19**, 2855–2880 (2022)
DOI: 10.5194/bg-19-2855-2022

## Destabilization of carbon in tropical peatlands by enhanced weathering




Klemme *et al.*
*Commun Earth Environ*, **3,** 212 (2022)
DOI: 10.1038/s43247-022-00544-0

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# Carbon emissions from wetlands



Wetlands…

.. cover (6 – 8) % of global surface area

.. store about one-third of terrestrial soil carbon

## Natural wetlands:

→ Water-logged soil conditions

→ Slow anaerobic decomposition

$C_6H_{12}O_6 + 3H_2O \rightarrow 3CH_4 + 3HCO_3 + 3H^+$

(glucose + water → methane + bicarbonate + hydrogen)

→ Largest natural $CH_4$ source

→ Net carbon sink

## Drained wetlands:

→ $O_2$ availability is increased

→ Fast aerobic decomposition

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

(glucose + oxygen → carbon dioxide + water)

→ $CO_2$ emissions

→ Net carbon source

# Limitation of DOC decomposition



Decomposition: $DOC + O_2 \rightarrow CO_2 + H_2O + energy$

- Decomposition rates depend on ..
  - .. the availability of **DOC**
  - .. the availability of **$O_2$**
  - .. the activity of the enzyme **phenol oxidase**, which depends on **$O_2$** availability and **pH**

$$\Delta CO_2 = \mathrm{DOC} \cdot R_{\max} \cdot L_{O_2} \cdot L_{\mathrm{pH}}$$

$L_{O_2}$ = $O_2$ limitation factor

$$L_{O_2} = \frac{O_2}{O_2 + K_m}$$

$L_{\mathrm{pH}}$ = pH limitation factor

$$L_{\mathrm{pH}} = e^{\lambda \cdot (\mathrm{pH} - \mathrm{pH}_0)}$$

$R_{\max}$ = maximum decomposotion rate

Least-squares approximation to measured data revealed that …

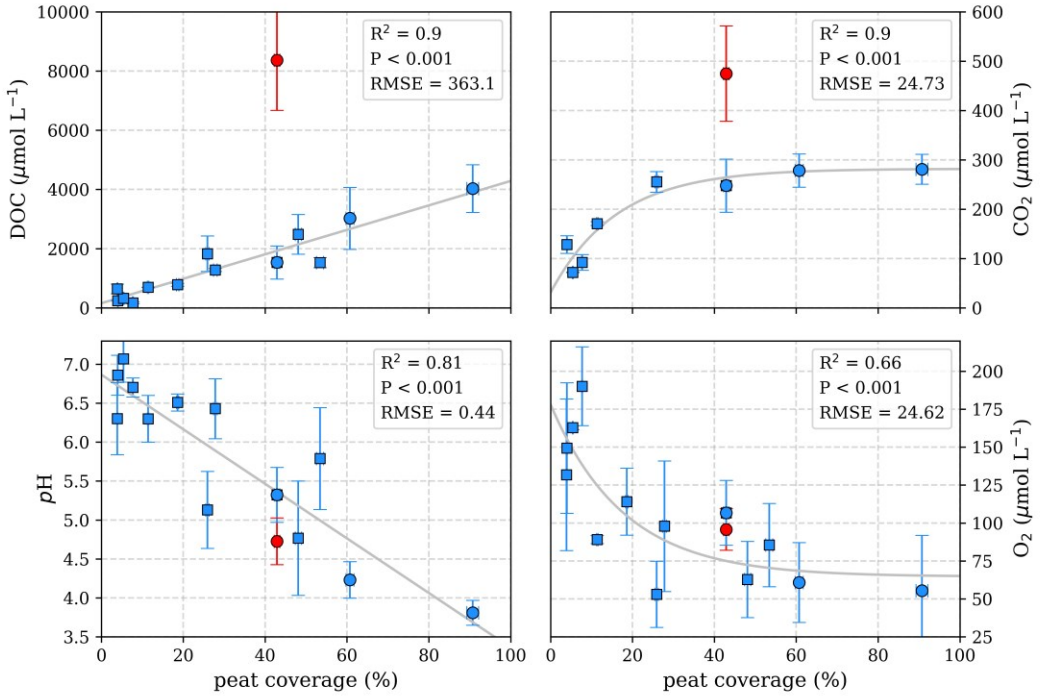
… $O_2$ concentrations in rivers limit decomposition by < 10 %

… low river *p*H limits decomposition in peat draining rivers by up to 85 %

# The impact of carbonate on river parameters



- 2 anomalous campaigns at the Simunjan river
- Extremely high carbon concentrations
- Co-occurrence of high $CaCO_3$ concentrations
  - → Indicate production of bicarbonate ions
  - → Bicarbonate ions could buffer a *p*H decrease caused by high $CO_2$ production




| Campaign | *p*H | DOC ($10^3$ µmol $L^{-1}$) | $CO_2$ (µmol $L^{-1}$) | $O_2$ (µmol $L^{-1}$) | $CaCO_3$ (mg $L^{-1}$) |
|---|---|---|---|---|---|
| March 2015 | 5.2 ± 0.3 | 1.7 ± 0.7 | 268 ± 71 | 99 ± 10 | n.d. |
| January 2016 | 4.5 ± 0.3 | 9.4 ± 1.2 | > 330 | 139 ± 9 | 0.52 ± 0.34 |
| March 2017 | 5.0 ± 0.3 | 7.4 ± 0.6 | 475 ± 97 | 52 ± 19 | 0.63 ± 0.64 |
| July 2017 | 5.4 ± 0.3 | 1.4 ± 0.3 | 227 ± 16 | 115 ± 14 | 0.07 ± 0.05 |

# Enhanced weathering (EW)



Natural weathering of silicate and carbonate rocks consumes ≈ 3 % of fossil fuel $CO_2$ emissions

$$CaSiO_3 + \mathbf{2CO_2} + H_2O \rightarrow Ca^{2+} + \mathbf{2HCO_3^-} + SiO_2$$

Weathering is promoted by ..

.. warm & humid climates

.. high primary production

→ Tropical peatlands are among target areas

**Enhanced weathering:**
Application of pulverized rocks over the land surface


[Strefler et al., 2018]

Estimates for basalt rock application in tropics

$CO_2$ uptake = (25 – 50) gC $m^{-2}$ $yr^{-1}$
*p*H increase = 0.2 – 1.3

[Taylor et al., 2016; Beerling et al., 2020]

How do $CO_2$ emissions from tropical peat regions respond to the EW induced *p*H increase?

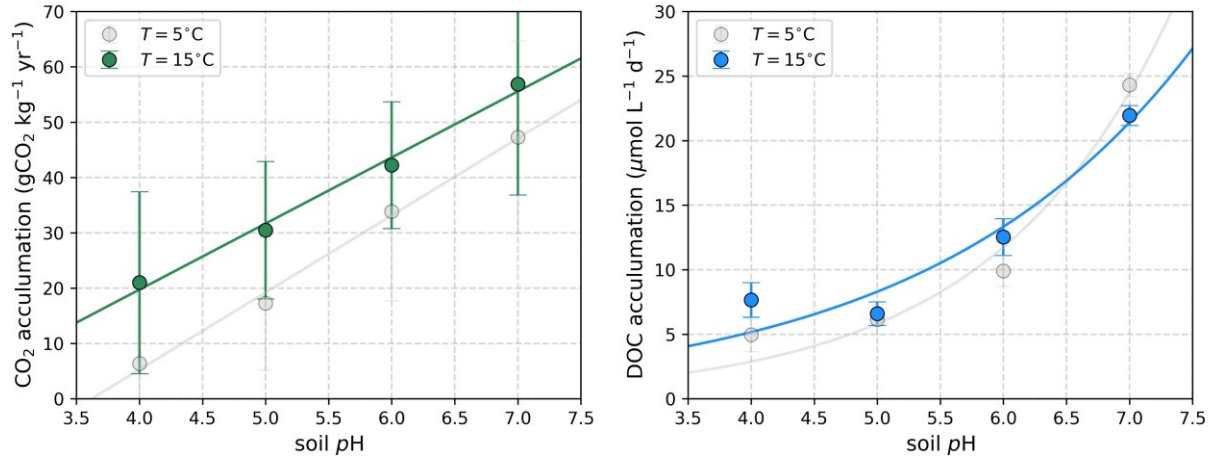
# Soil response on enhanced weathering (EW)

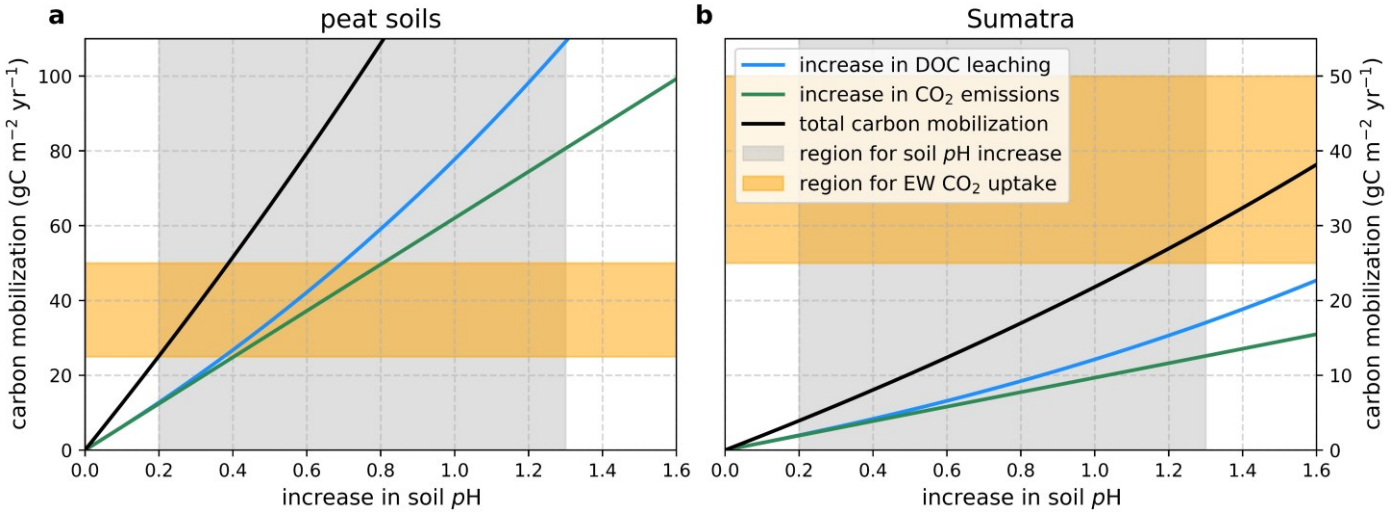


- Soil carbon mobilization depends on pH
- Data from Kang et al., 2018:
  - A pH increase of 1 value causes…

  … a $CO_2$ emission increase of 12 $gCO_2$ $yr^{-1}$

  … a DOC leaching increase of 60 %



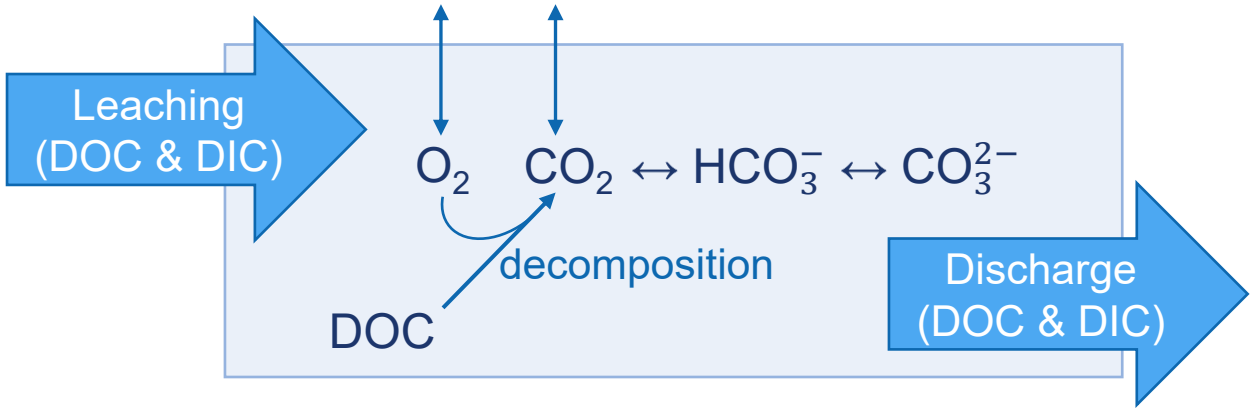




- EW on peat soils induces carbon mobilization representing 100 - 400 % of the EW carbon uptake on peat soils
- Sumatra has a peat coverage of 15.6 %
  - 2-13 gC $m^{-2}$ CO2 mobilization
  - 2-17 gC $m^{-2}$ DOC mobilization

# River response on enhanced weathering (EW)



- River box-model calculations including:
  - Carbon leaching from soils
  - pH dependent decomposition
  - pH dependent carbonate system dynamics
  - Atmospheric gas exchange fluxes
  - Oceanic carbon yields




➢ Enhanced DIC leaching strongly impacts rivers of high peat coverage …

… due to the pH increase

➢ Enhanced DOC leaching has a stronger impact on rivers of lower peat coverage …

… due to the $O_2$ limitation

Area weighed average:

➢ River $CO_2$ emissions increase by 20 – 75%

For case study of Sumatra:

➢ $CO_2$ emissions increase by 0.9 – 7.4 TgC $yr^{-1}$

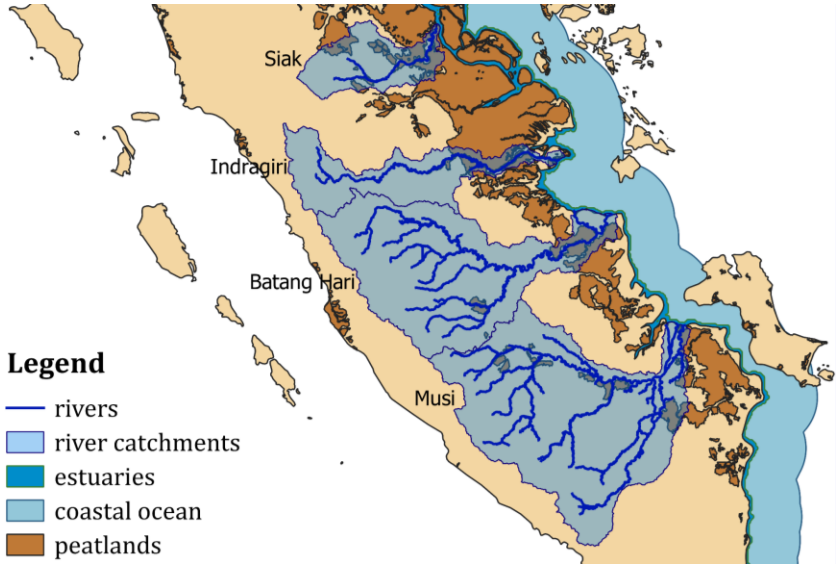
➢ DOC discharge increases by -1 – 4 TgC $yr^{-1}$

➢ DIC discharge increases by 11 – 33 TgC $yr^{-1}$

# Coastal response on enhanced weathering (EW)



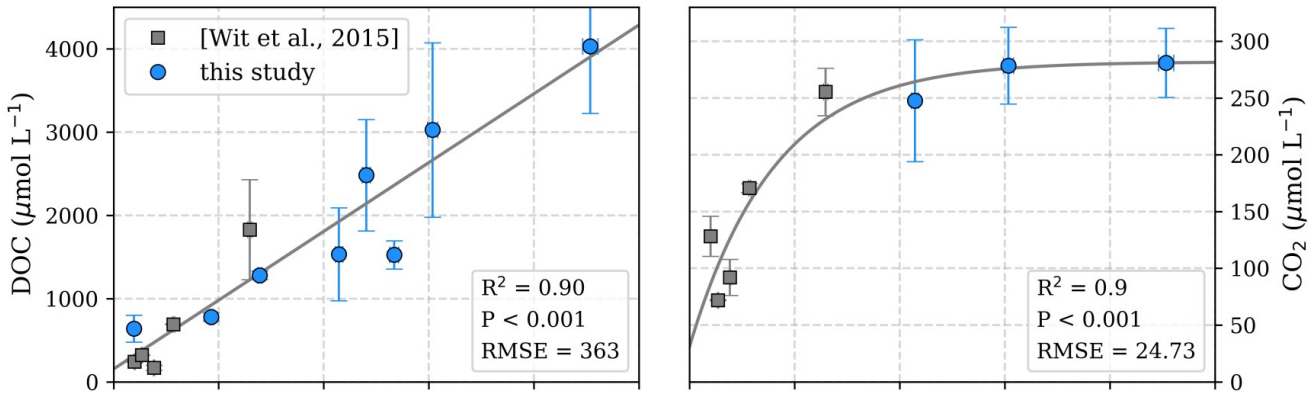
- Separation between …
  - … estuaries (0 – 3) km from shore
  - … coastal ocean (3 – 27) km from shore
- Water mixing between river and ocean water
  - → Fraction of river water in coastal regions is derived from water salinities




- Slightly increased DIC leaching reduces coastal $CO_2$ emissions …
  - … due to carbonate dissolution
- Stronger DIC leaching increases $CO_2$ emissions from coastal regions …
  - … due to high carbon input
- Enhanced DOC leaching massively increases $CO_2$ emissions from coastal regions
- EW increases $CO_2$ emissions from Sumatra's coast by 70 – 380 %
- High uncertainty due to…
  - … simplified mixing calculations
  - … neglection of estuary emissions in calculation of coastal ocean emissions

# Summary

- $CO_2$ concentrations in peat-draining rivers stagnate for high peat coverages
- This is caused by an exponential pH limitation of decomposition rates
- Enhanced weathering (EW) causes an increase in carbonate supply and pH that …
  - … mobilizes soil carbon in form of $CO_2$ and DOC
  - … induces $CO_2$ re-emission from soils and rivers equal to (15 – 58) % of Sumatra's EW uptake
  - … could create a $CO_2$ source in coastal areas of tropical peat regions




$$\Delta CO_2 = DOC \cdot R_{max} \cdot \frac{O_2}{O_2 + K_m} \cdot e^{\lambda \cdot (pH - pH_0)}$$