NCAR LMWG Meeting

PROcess-guided deep learning and DAta driven modelling (PRODA)

From realistic representation to mechanistic understanding of global soil carbon

Feng Tao, Yuanyuan Huang, Bruce A. Hungate, Xingjie Lu, Toby D. Hocking, Umakant Mishra, Gustaf Hugelius, Xiaomeng Huang, and Yiqi Luo

Feng Tao

Department of Earth System Science, Tsinghua University

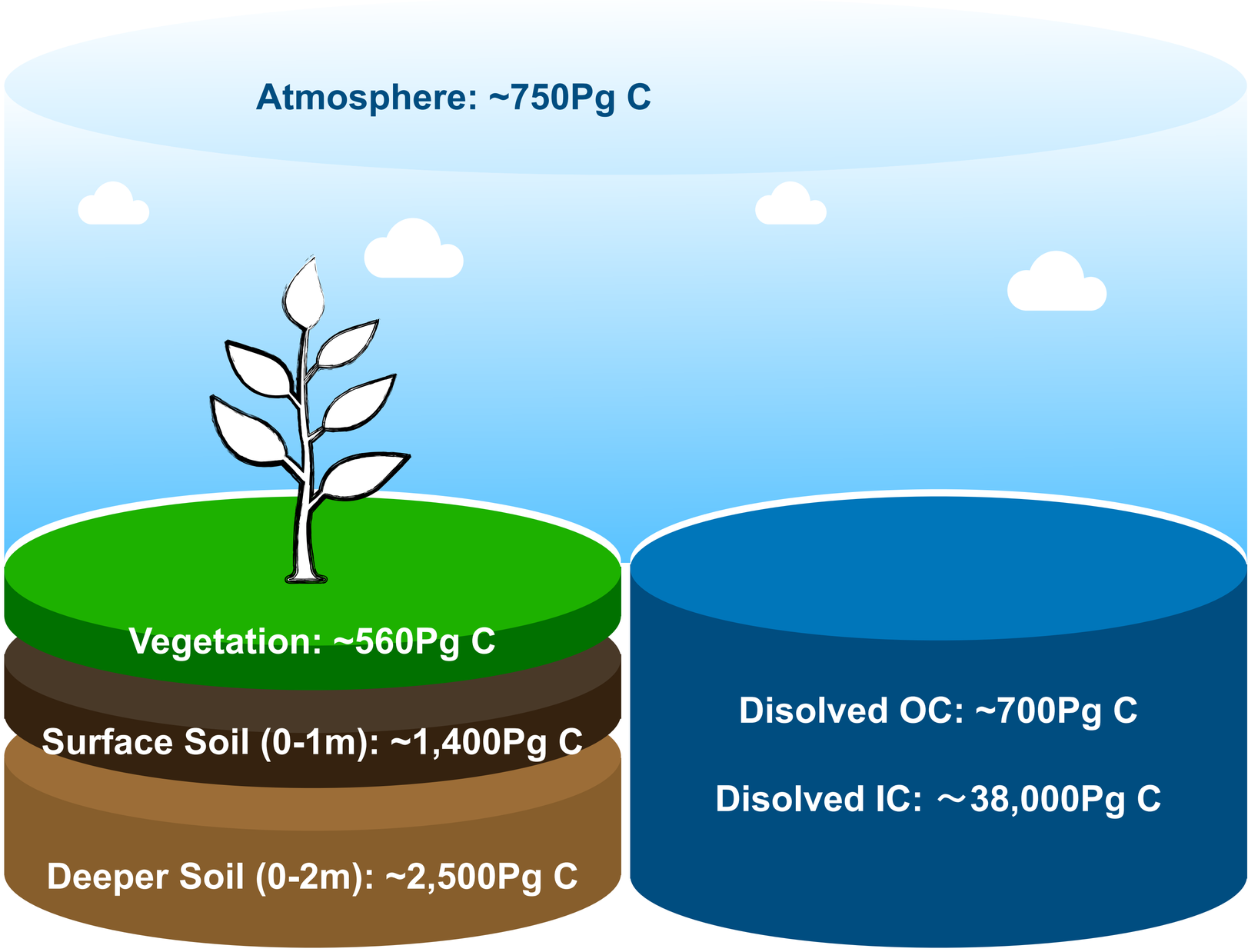
taof18@mails.tsinghua.edu.cn, @phxtao

Thursday, 25 February 2021

Background

SOC in the Earth System

- Biggest terrestrial C pool



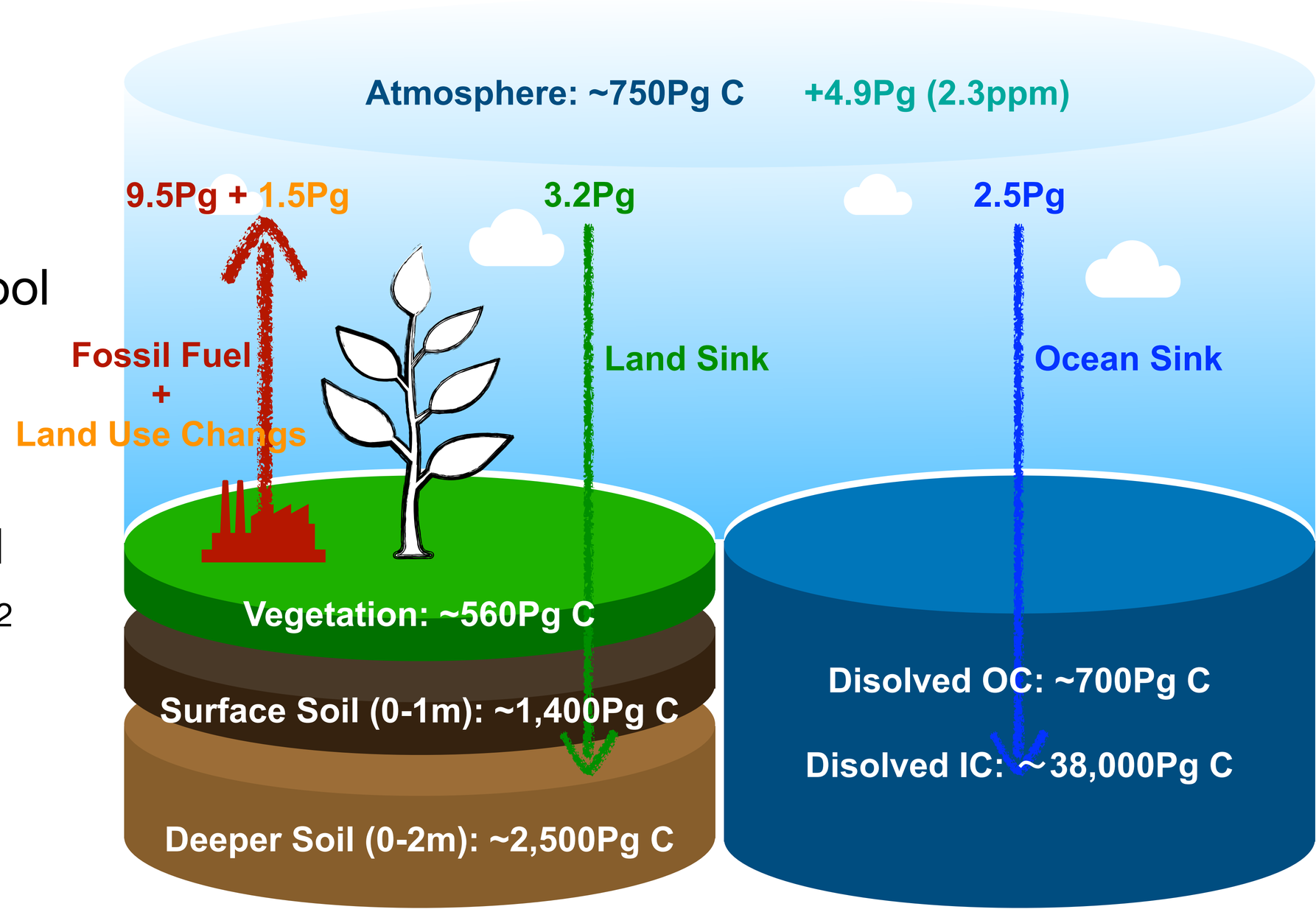
Time Period：2009 - 2018 **Imbalance：0.4Pg** (Data: Global Carbon Budget 2019)

清華大學 Tsinghua University

Background

SOC in the Earth System

- Biggest terrestrial C pool
- Potential nature-based resolution to rising CO_2

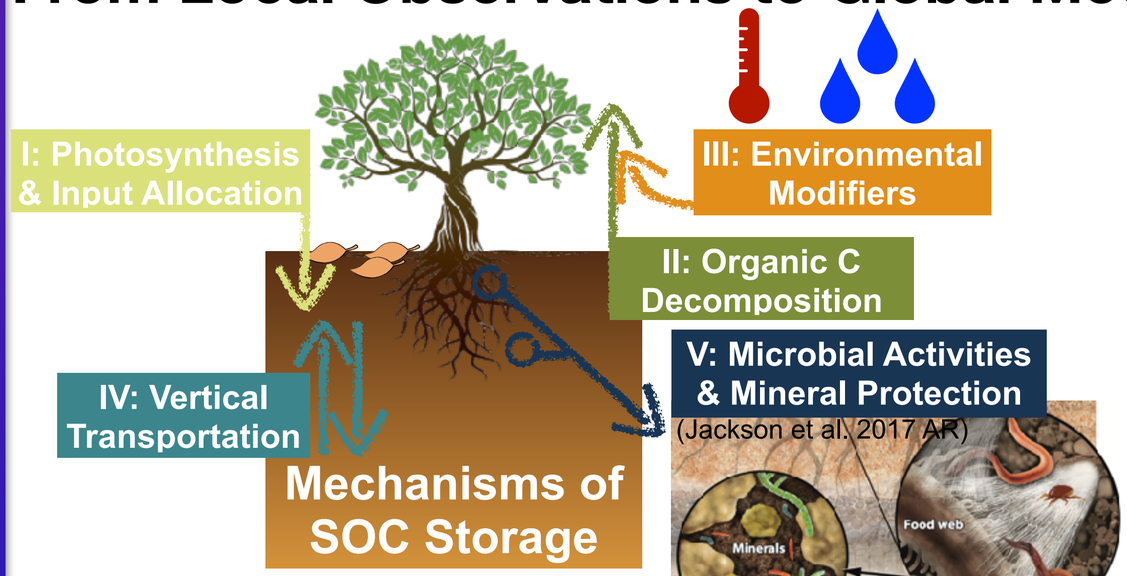


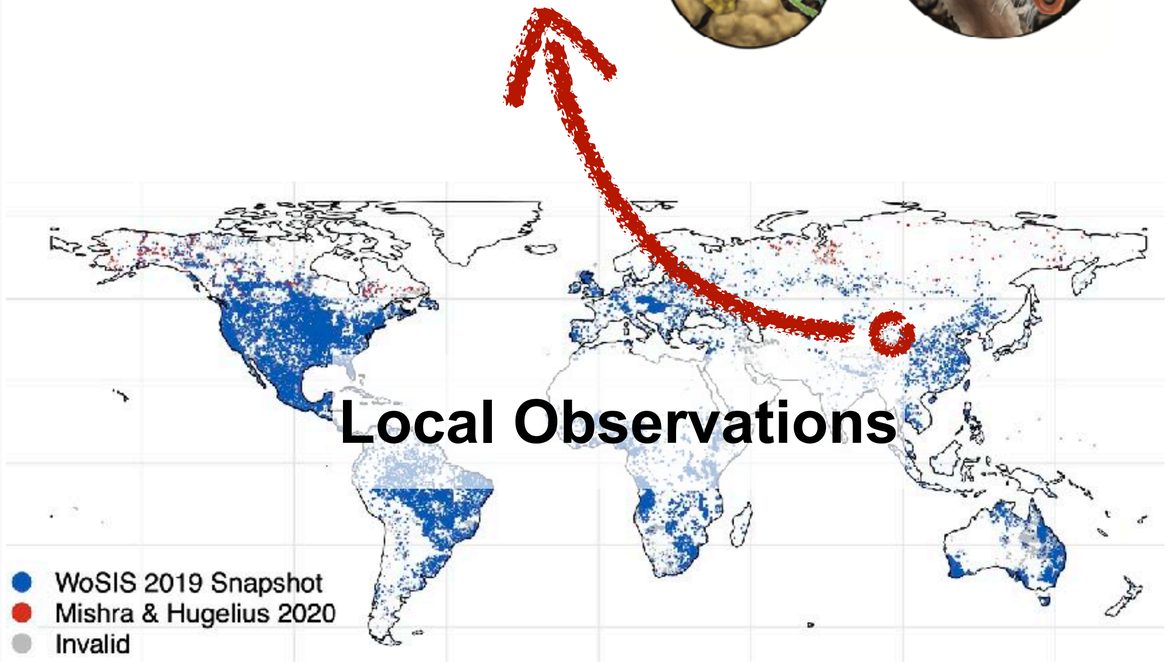
Time Period：2009 - 2018　　Imbalance：0.4Pg　　(Data: Global Carbon Budget 2019)

清華大學 Tsinghua University

Background

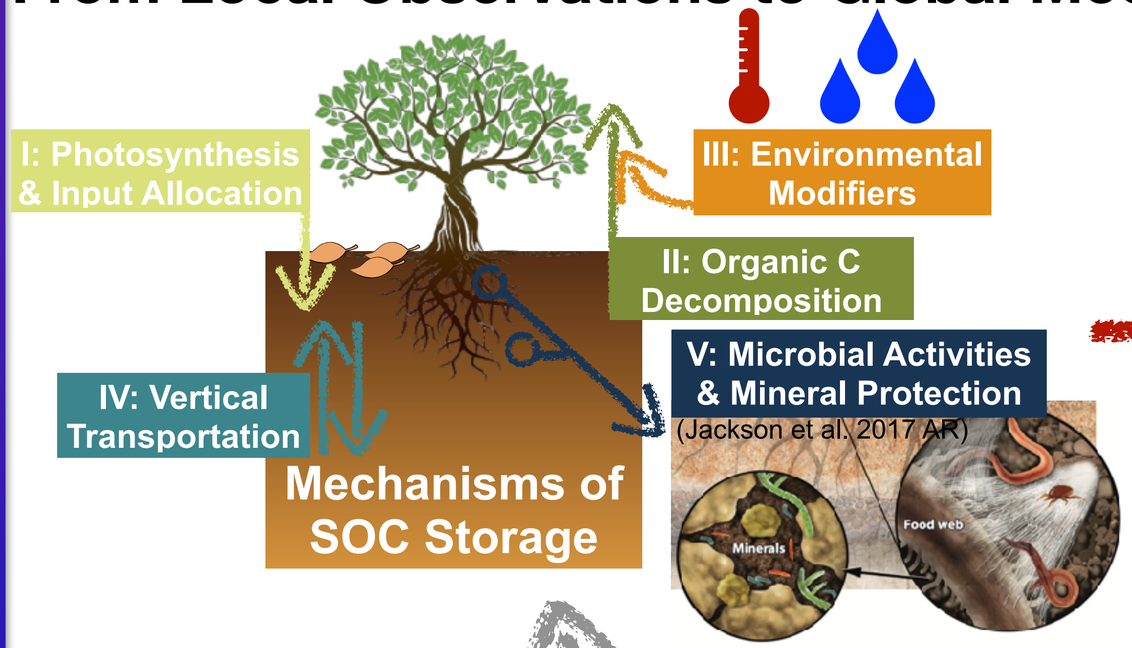
From Local Observations to Global Mechanistic Understanding

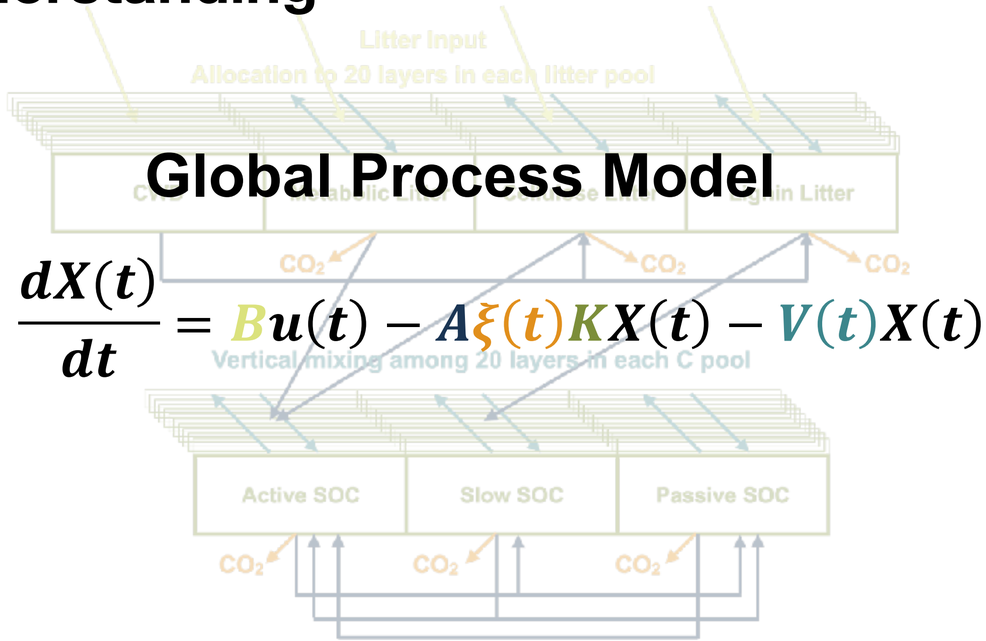




Background

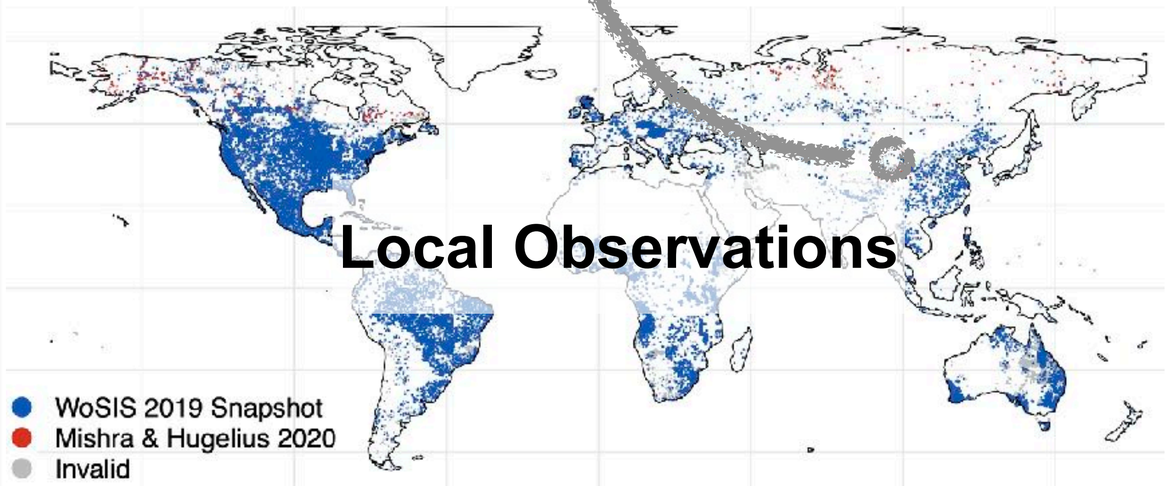
From Local Observations to Global Mechanistic Understanding





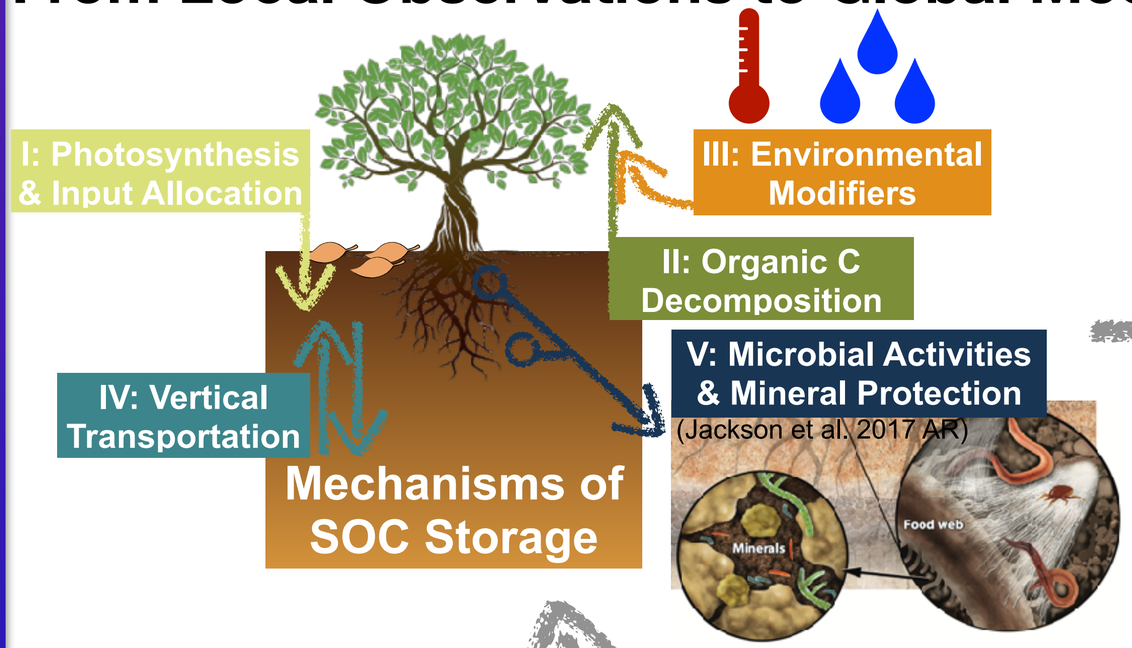
Global Process Model

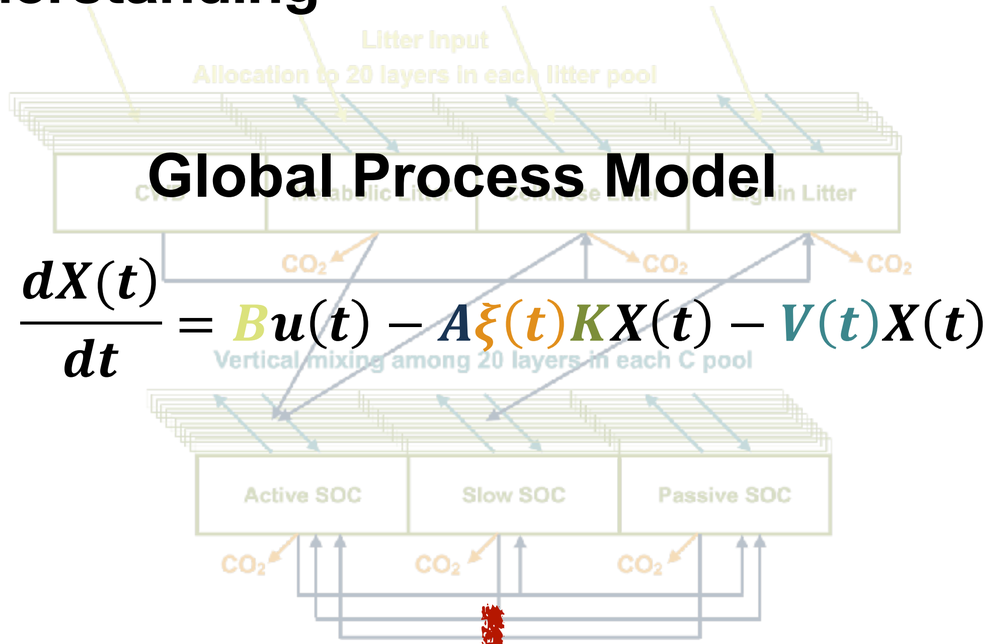
$$\frac{dX(t)}{dt} = Bu(t) - A\xi(t)KX(t) - V(t)X(t)$$



Background

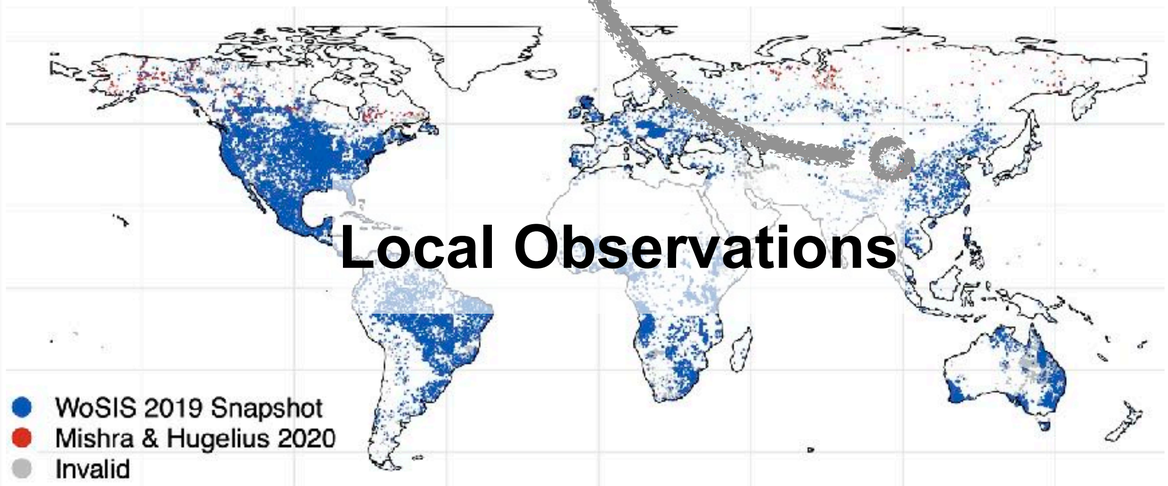
From Local Observations to Global Mechanistic Understanding



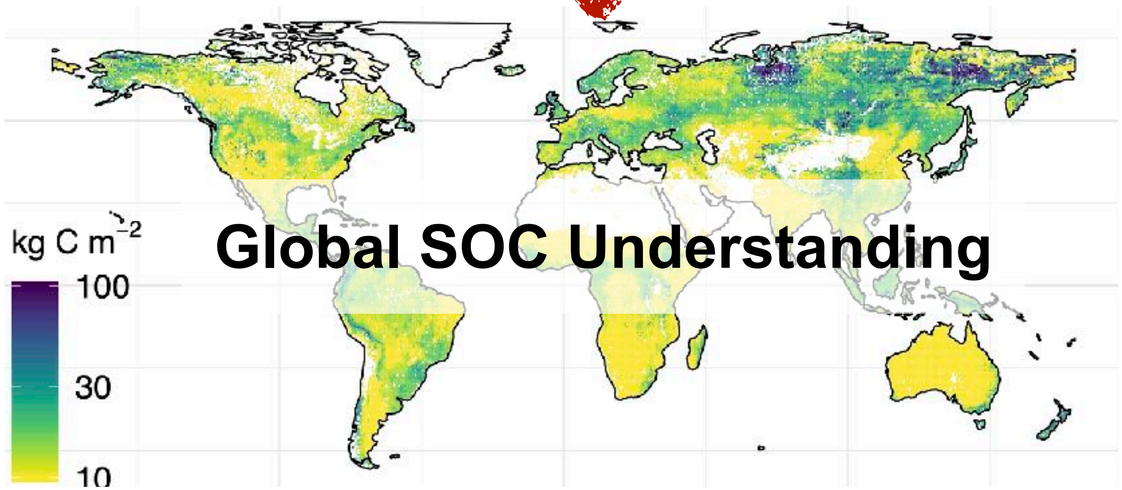


Global Process Model

$$\frac{dX(t)}{dt} = Bu(t) - A\xi(t)KX(t) - V(t)X(t)$$



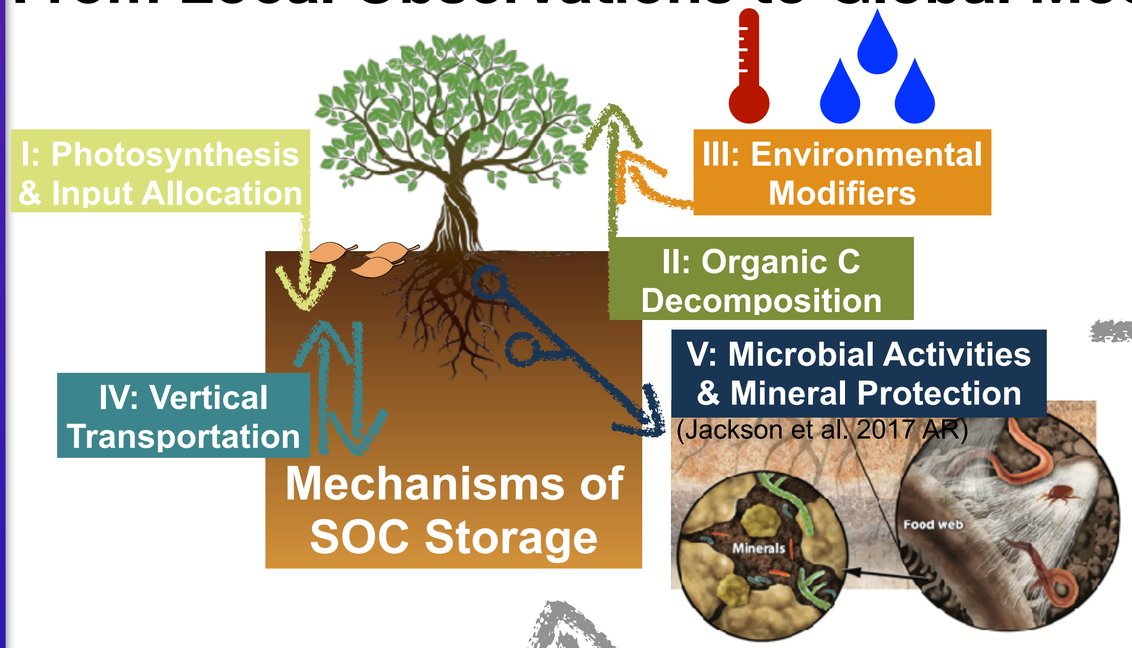
Local Observations

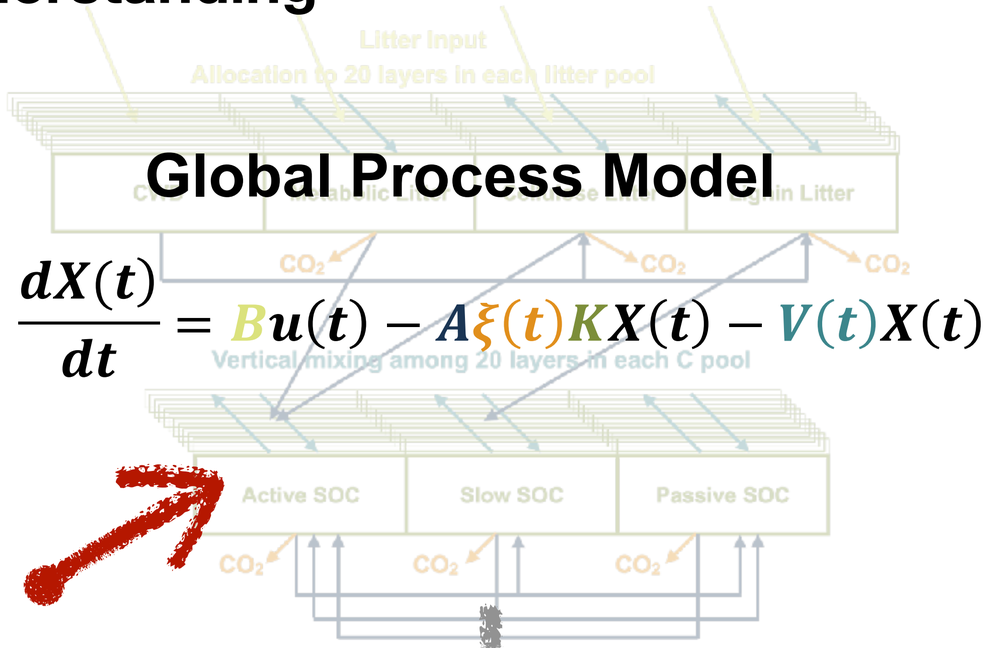


Global SOC Understanding

Background

From Local Observations to Global Mechanistic Understanding

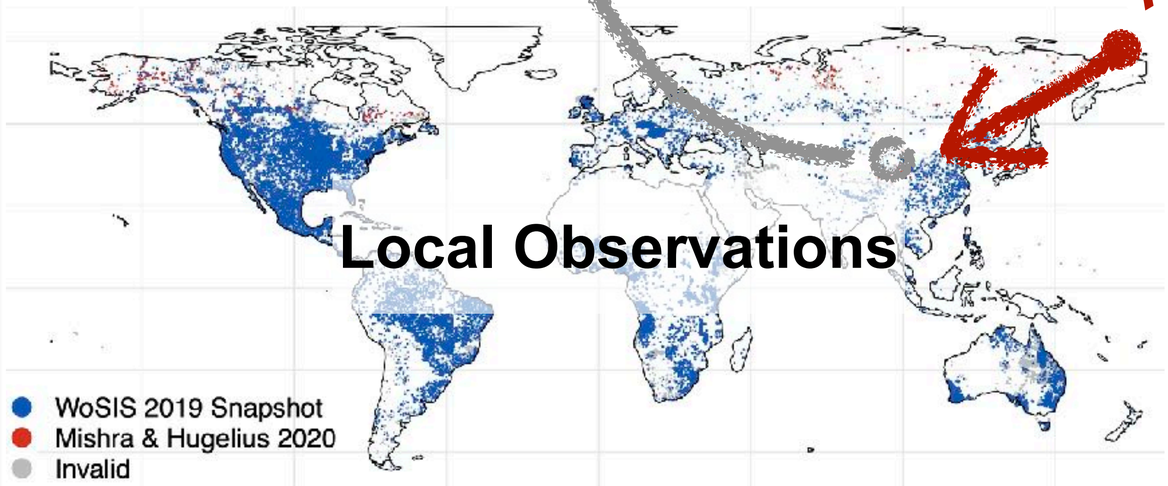




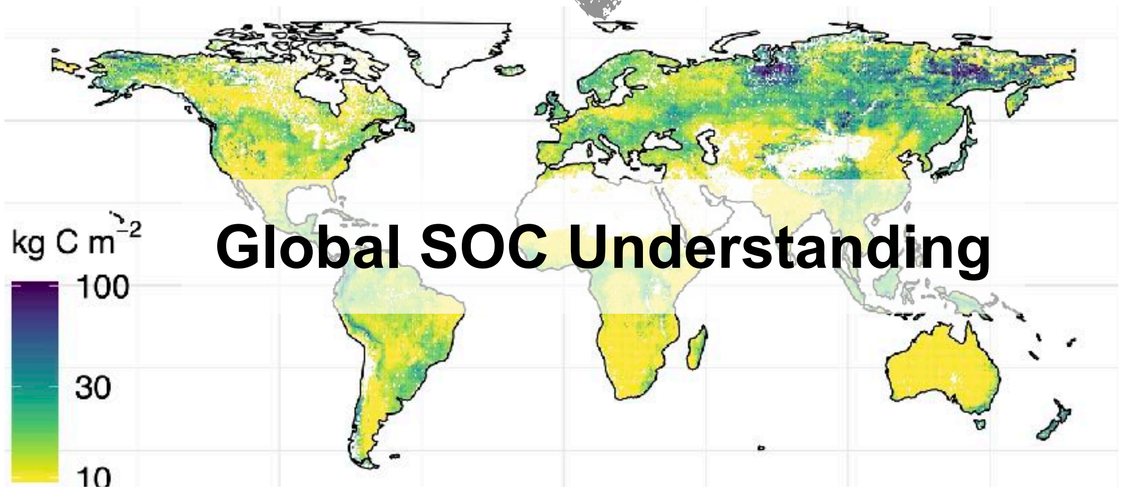
Global Process Model

$$\frac{dX(t)}{dt} = Bu(t) - A\xi(t)KX(t) - V(t)X(t)$$

Absent Direct Connection



Local Observations

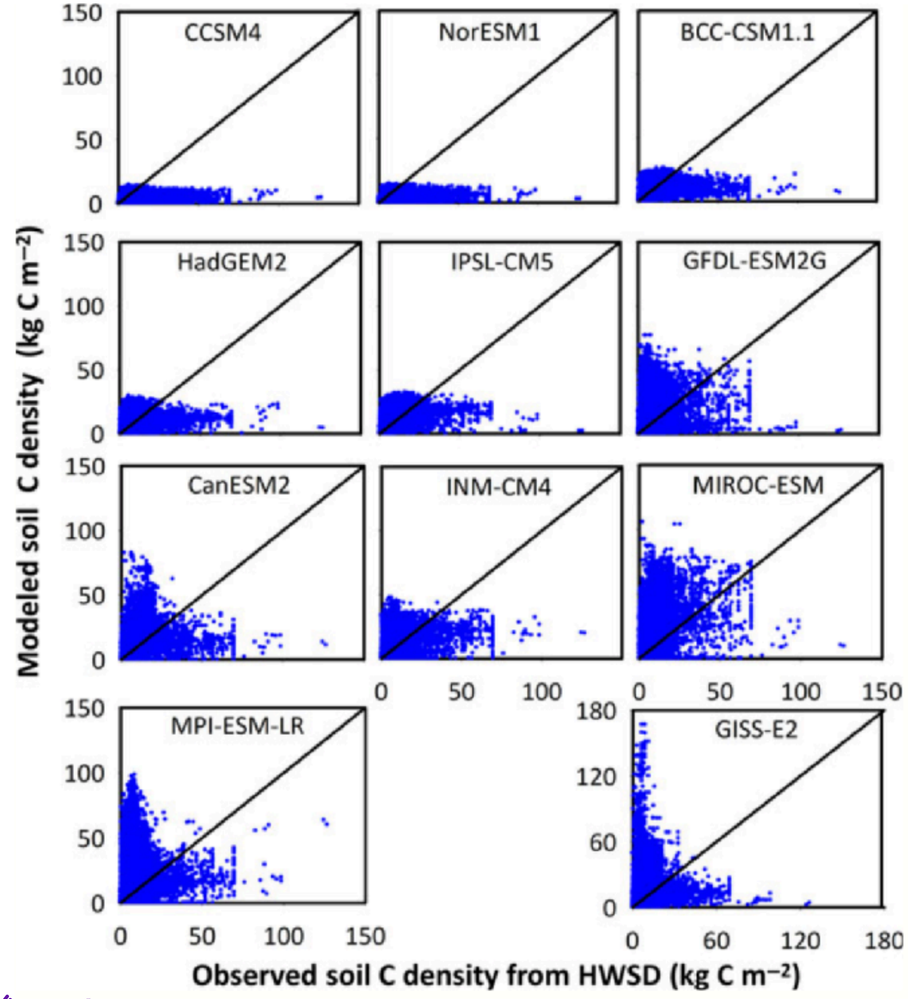


Global SOC Understanding

Background

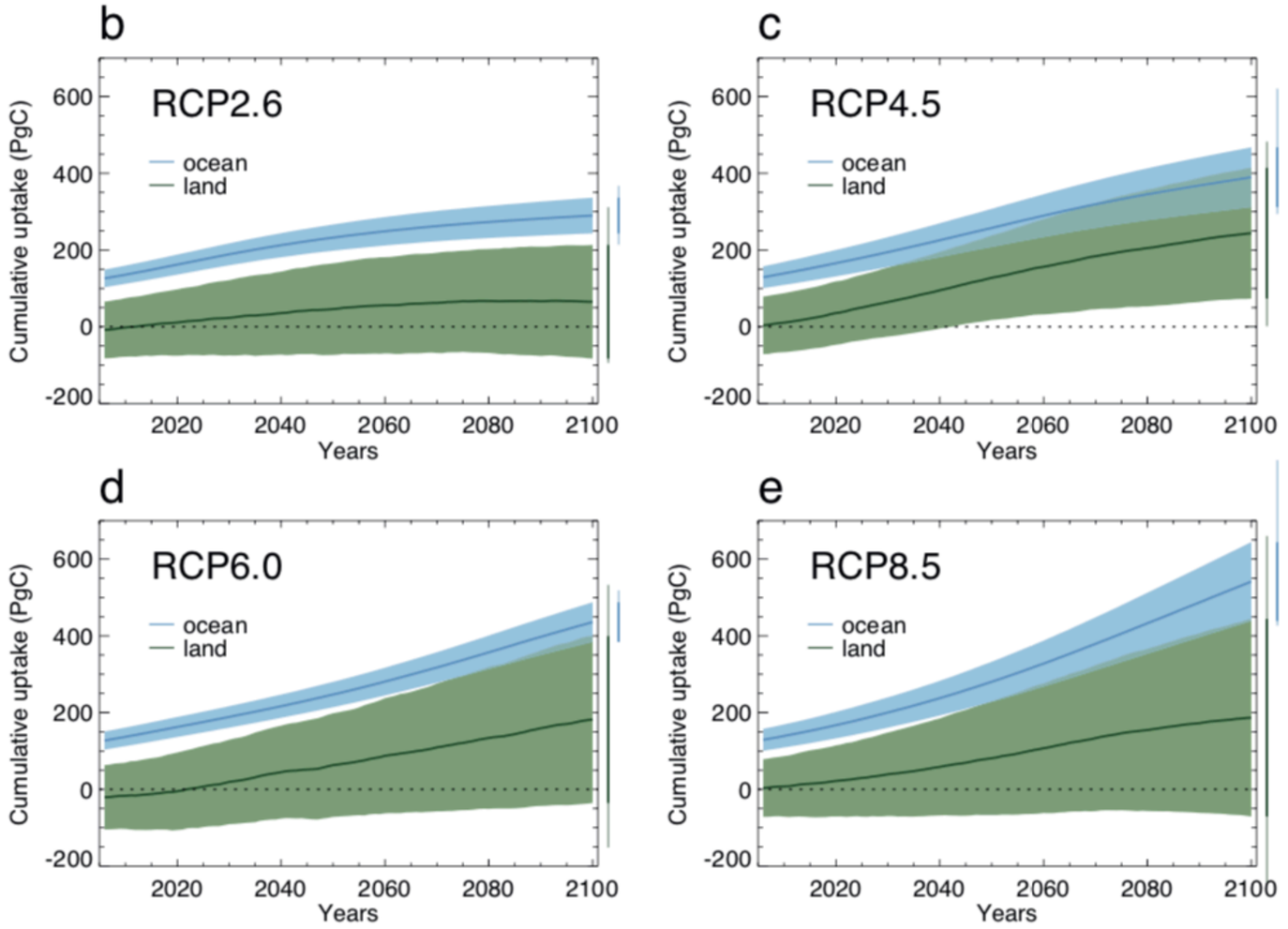
From Local Observations to Global Mechanistic Understanding

Current: highly biased representation



(Luo et al. GCB, 2015)

Future: highly uncertain projection



IPCC AR5, 2013

清華大學 Tsinghua University

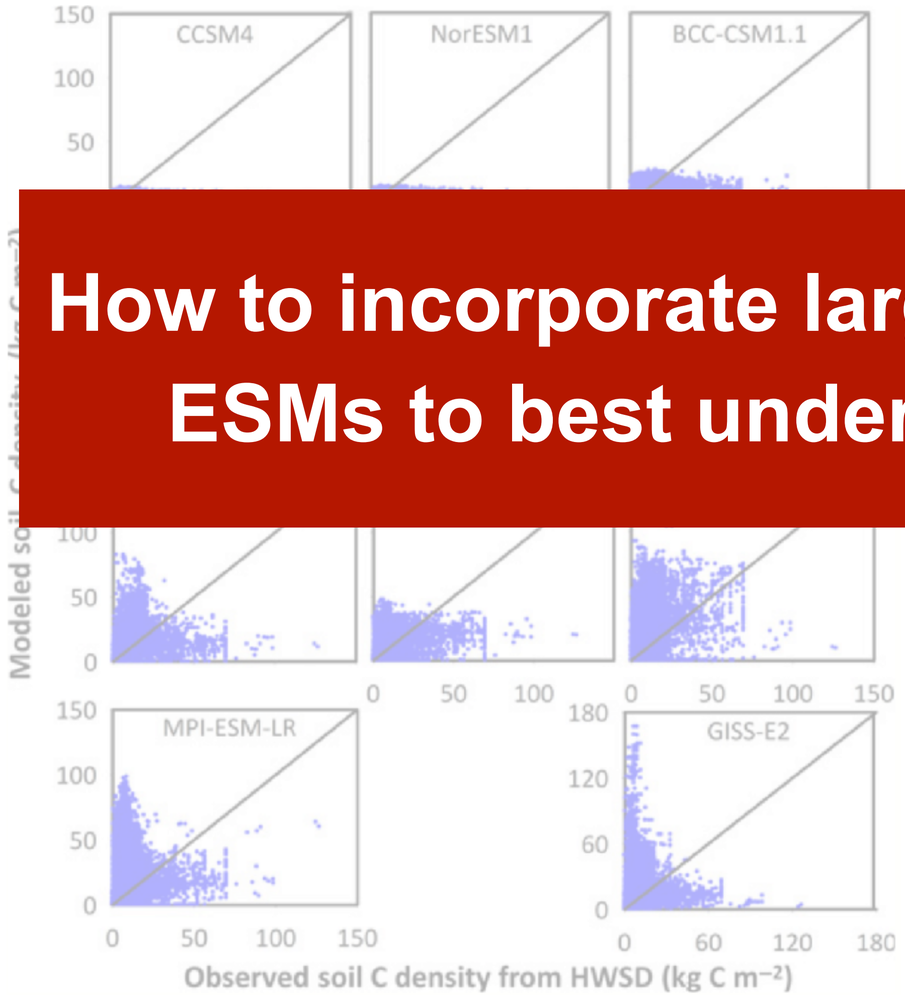
Background

From Local Observations to Global Mechanistic Understanding

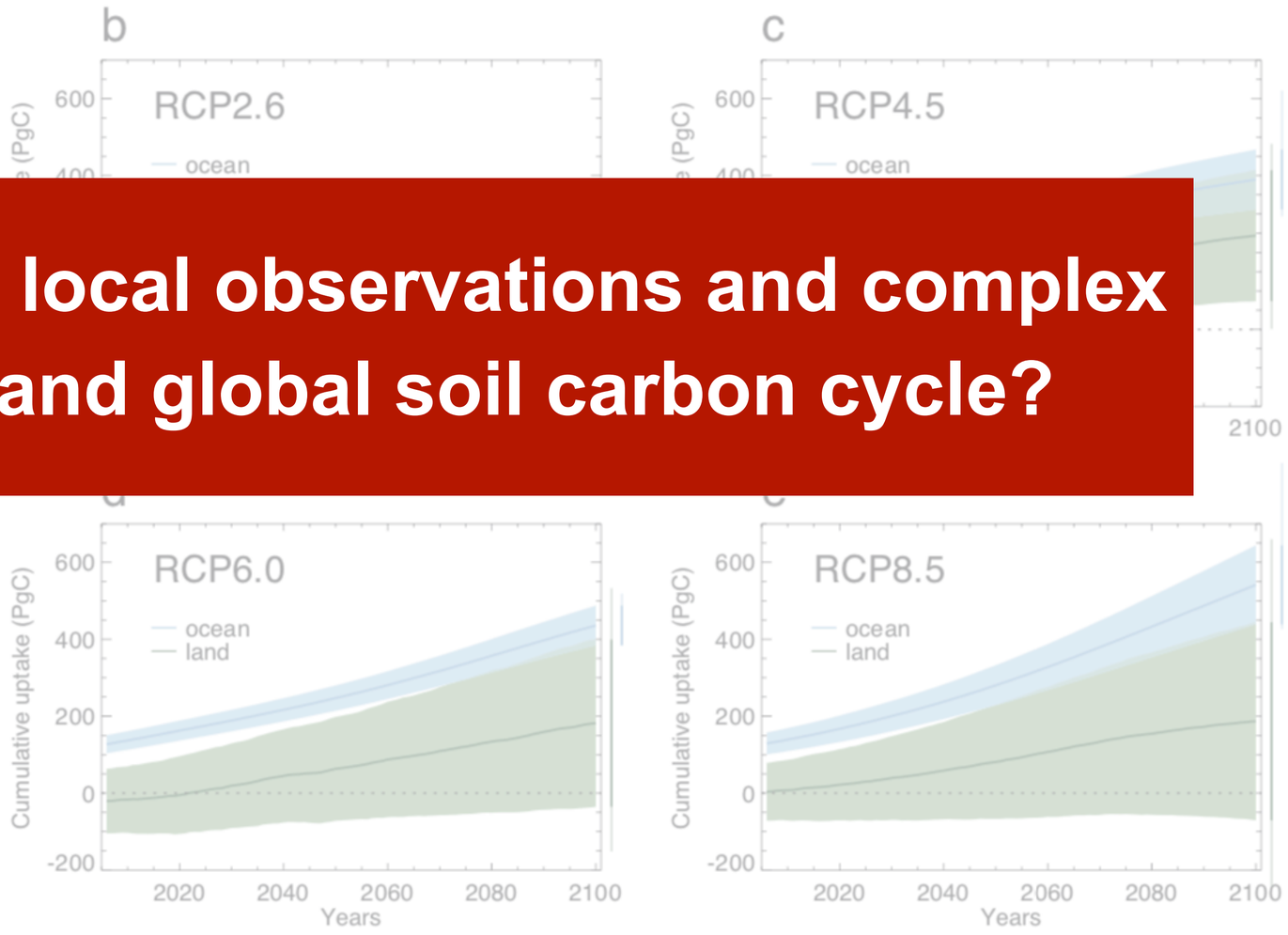
Current: highly biased representation

Future: highly uncertain projection

How to incorporate large local observations and complex ESMs to best understand global soil carbon cycle?

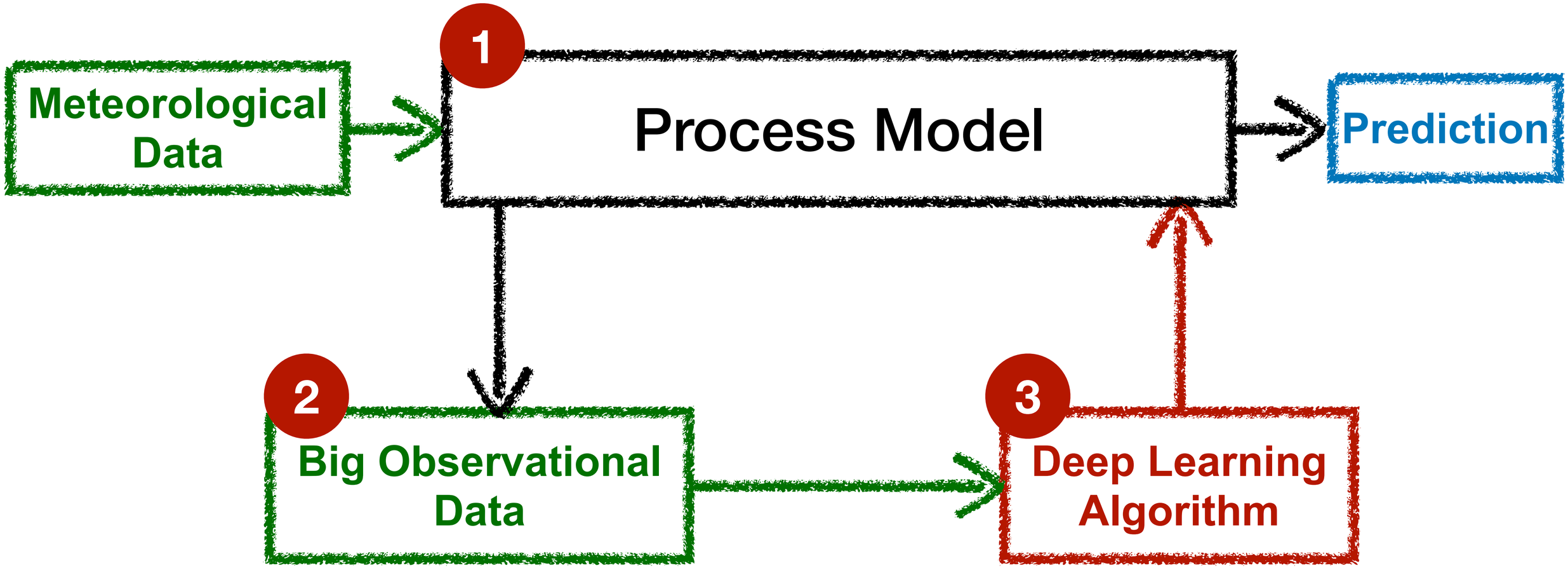


(Luo et al. GCB, 2015)



IPCC AR5, 2013

PRODA: PROcess-guided deep learning and DAta-driven modelling



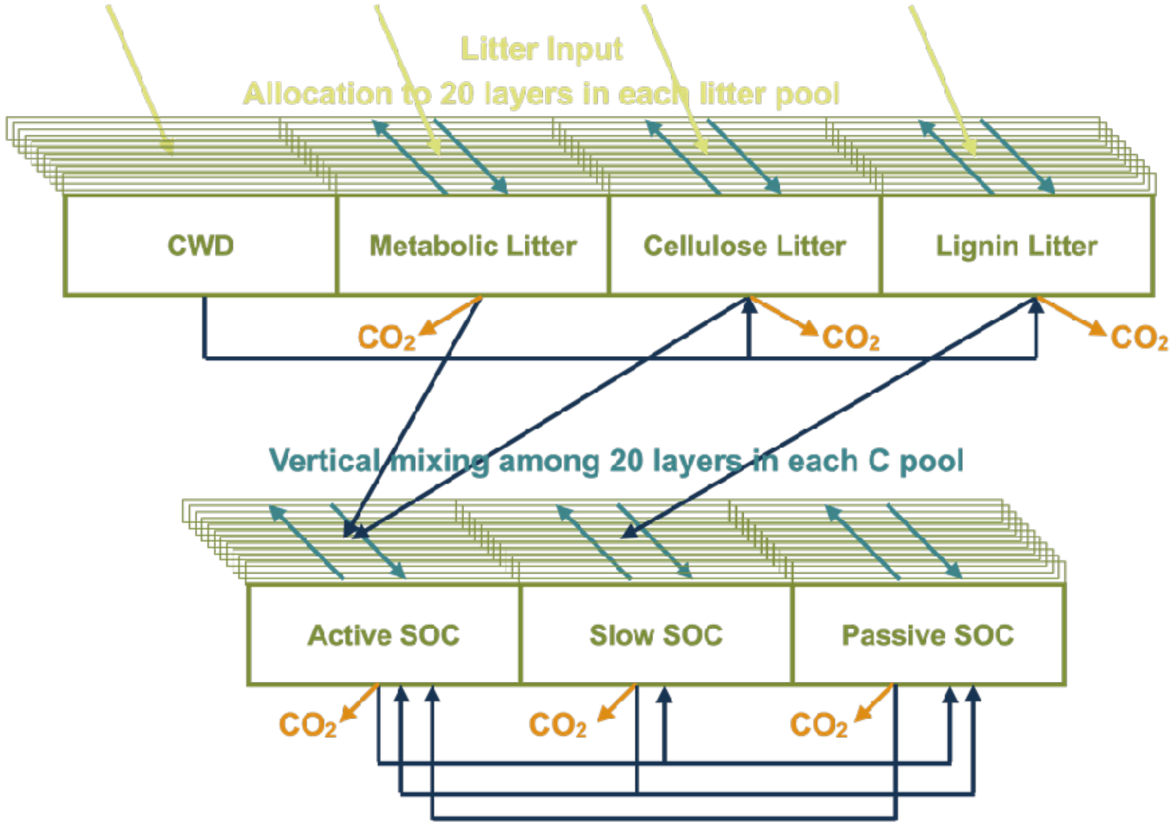
(Tao et al. 2020 Frontiers in Big Data)

PRODA: PROcess-guided deep learning and DAta-driven modelling

Process-guided Model: CLM5

Meteorological Data →

$$\frac{d\mathbf{X}(t)}{dt} = \mathbf{I}(t) - \mathbf{A}\xi(t)\mathbf{K}\mathbf{X}(t) - \mathbf{V}(t)\mathbf{X}(t)$$



Five categories of processes

- Input allocation
- Decomposition rate
- Microbial CUE
- Vertical transportation
- Environmental modifiers

(Huang et al. GCB, 2017)

(Tao et al. 2020 Frontiers in Big Data)

清華大學 Tsinghua University

PRODA: PROcess-guided deep learning and DAta-driven modelling

Big Observational Data

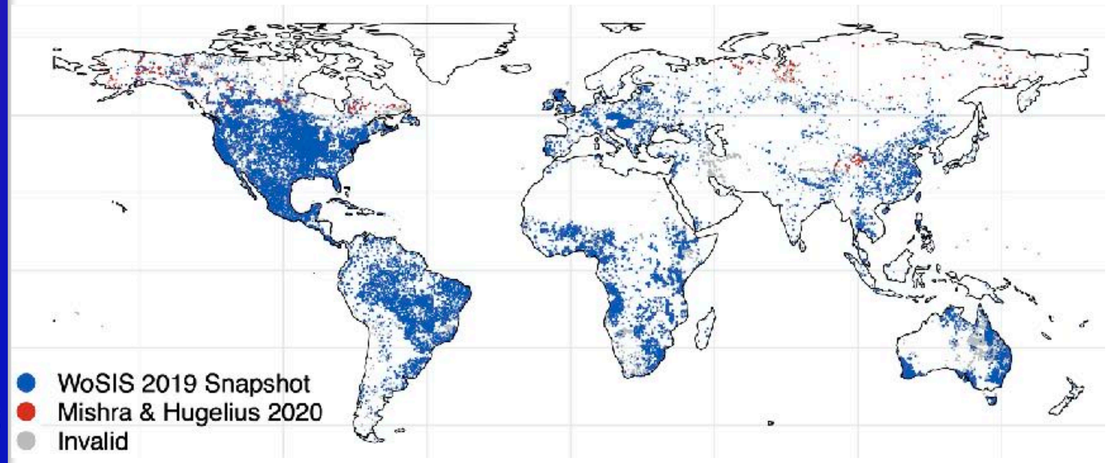
Meteorological Data

$$\frac{d\mathbf{X}(t)}{dt} = \mathbf{I}(t) - \mathbf{A}\xi(t)\mathbf{K}\mathbf{X}(t) - \mathbf{V}(t)\mathbf{X}(t)$$

> 50,000 Vertical Soil Profiles

Site level data assimilation

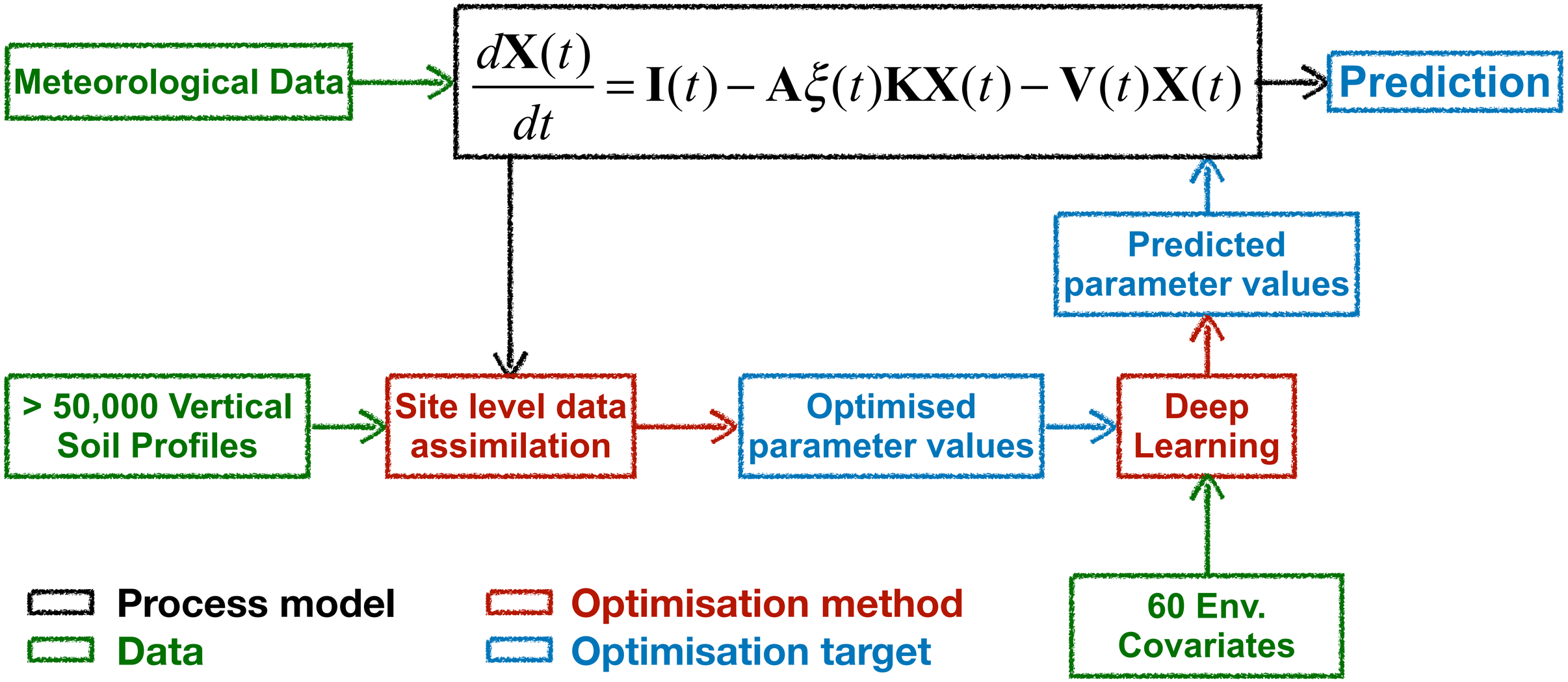
Optimised parameter values



(Tao et al. 2020 Frontiers in Big Data)

PRODA: PROcess-guided deep learning and DAta-driven modelling

Deep Learning Algorithm

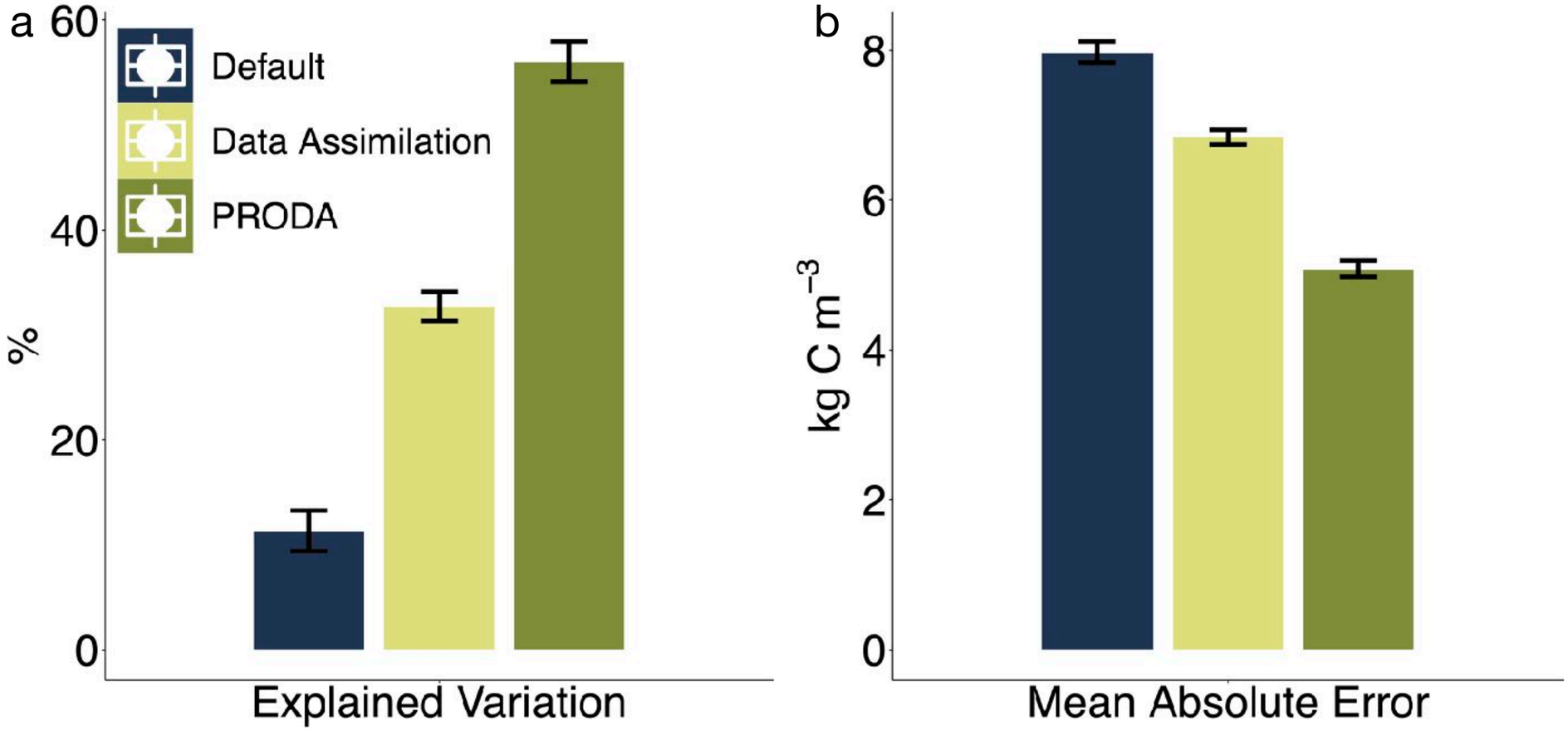


(Tao et al. 2020 Frontiers in Big Data)

清華大學 Tsinghua University

PRODA Performance

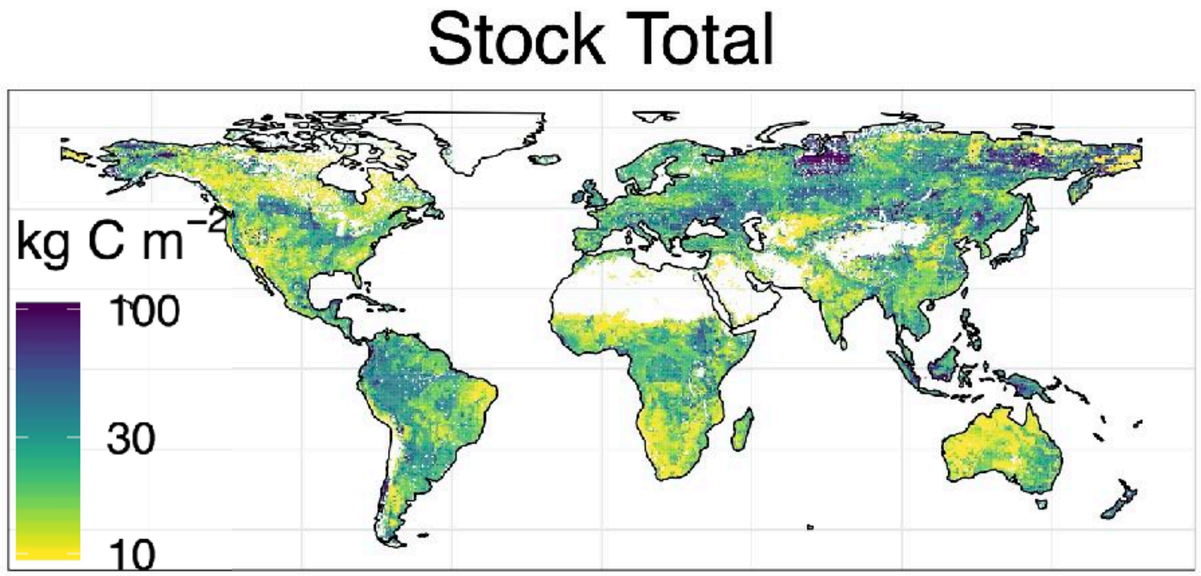
Improved SOC Representation

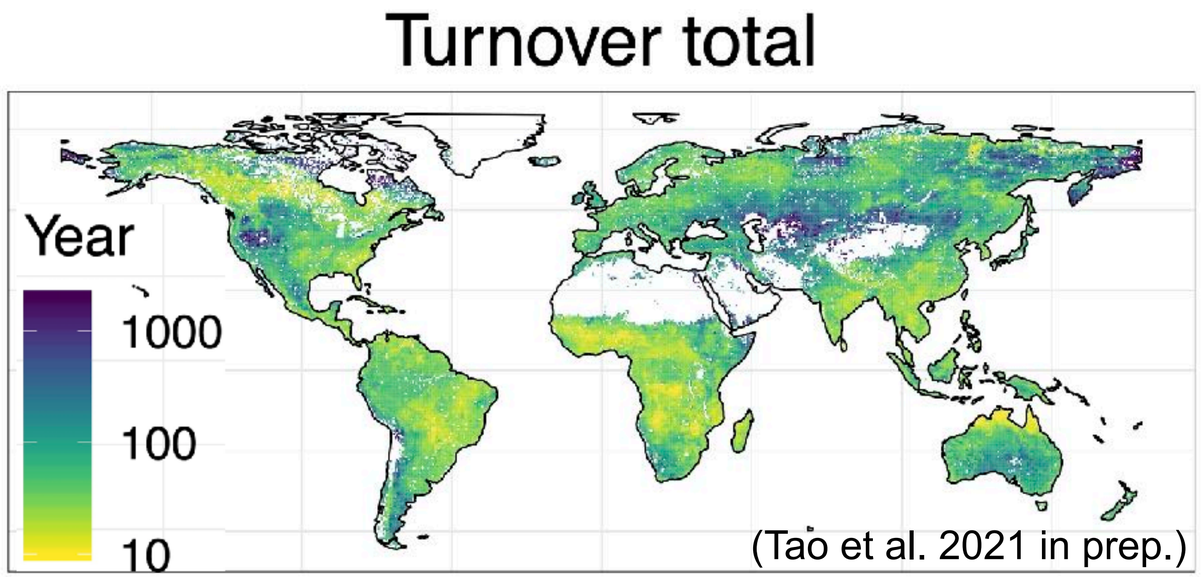


(Tao et al. 2021 in prep.)

Big Data Retrievals

SOC Stock, Distributions and Turnover





(Tao et al. 2021 in prep.)

Global SOC Stock and Distribution

- 56±2% spatial variation of observations (11% by default setting)
- Whole depth (0 - 840cm): 2404±105 Pg C
- 0 - 100cm: 1322±75 Pg C

Global SOC Turnover time:

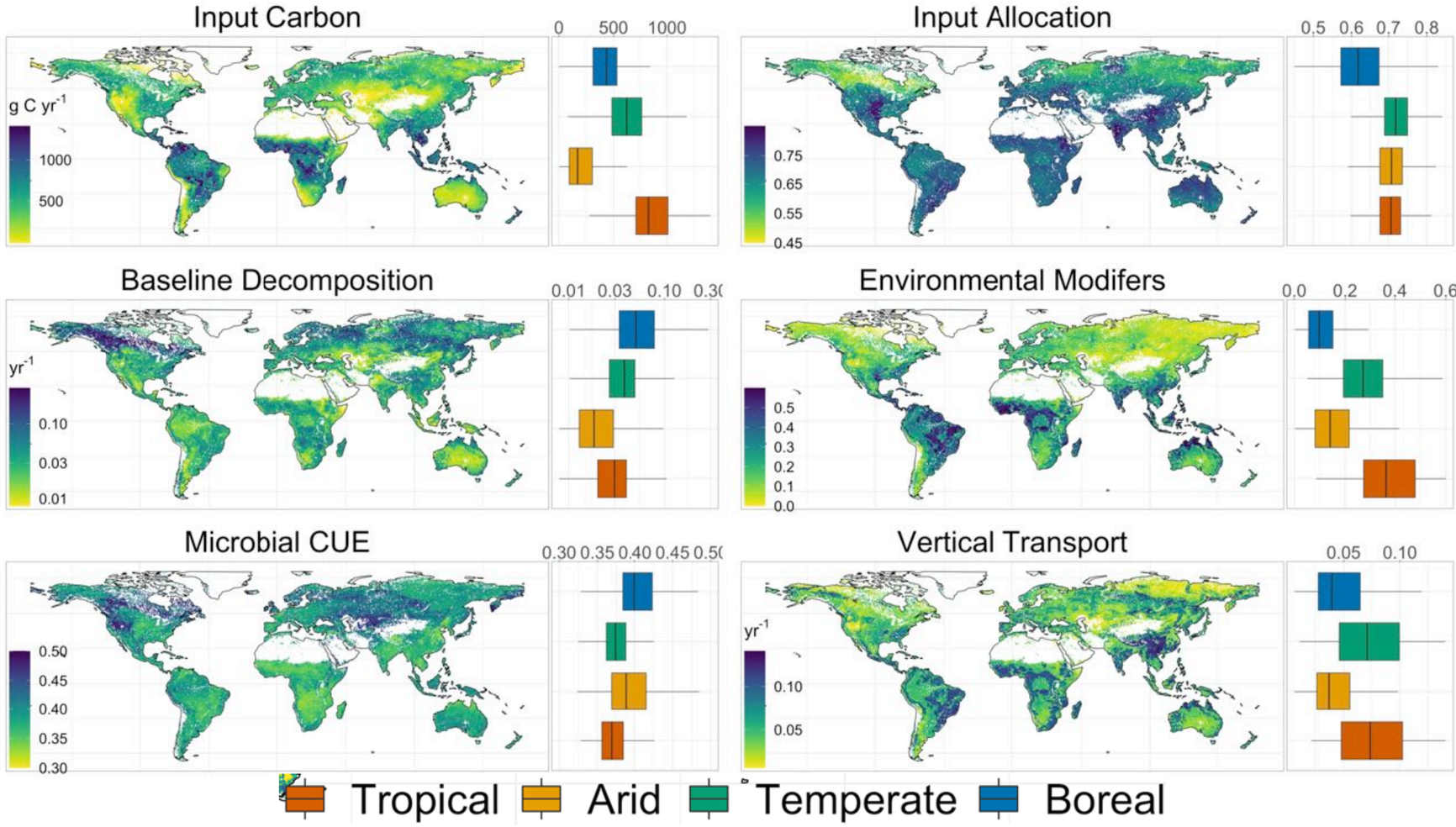
- Mean: 112±10 years
- Median: 44±2 years

Big Data Retrievals

Key Mechanisms underlying SOC

Pervasive spatial variation of mechanisms

- Roots reach deeper soil in tropics than in boreal regions
- Higher baseline decomposition in boreal regions than tropics
- Env. modifiers increases from boreal regions to tropics
- CUE in boreal regions is higher than tropics



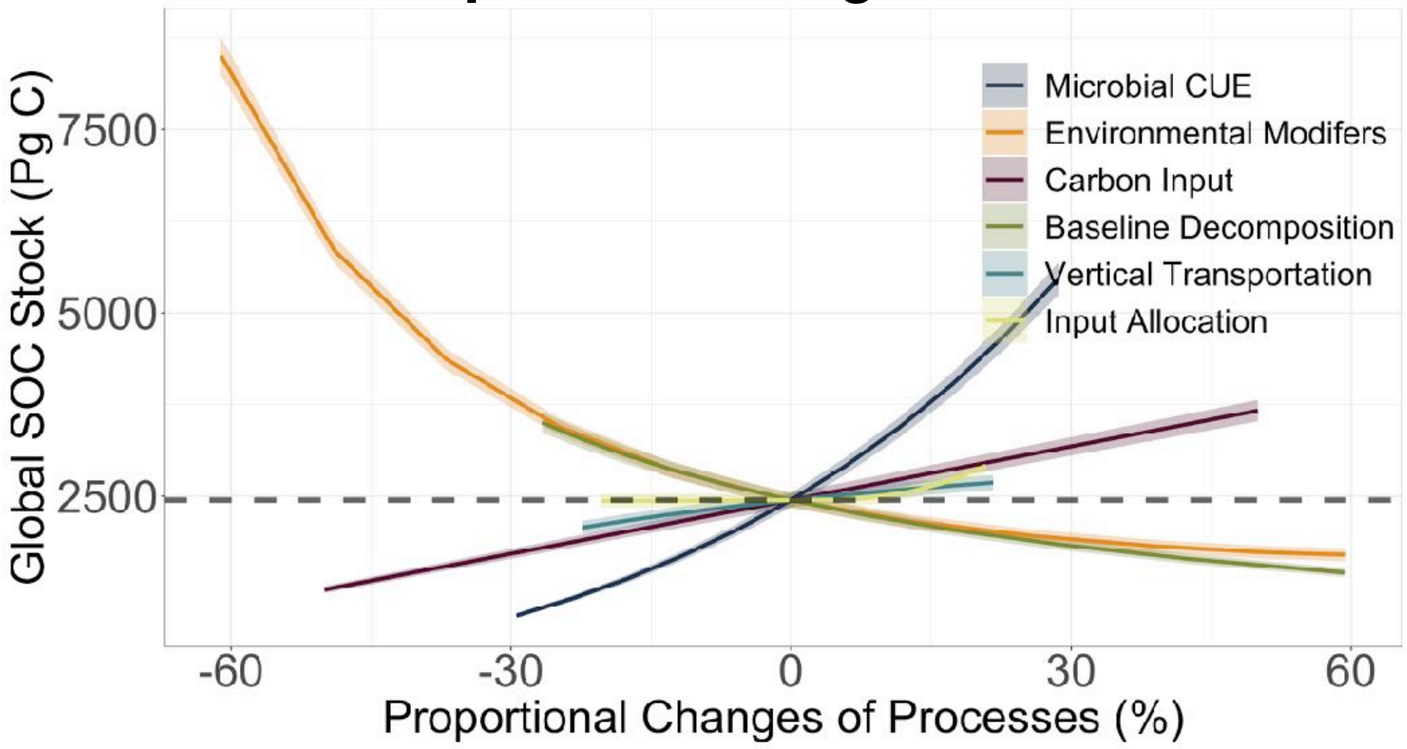
(Tao et al. 2021 in prep.)

Which Mechanism Determines SOC Storage?

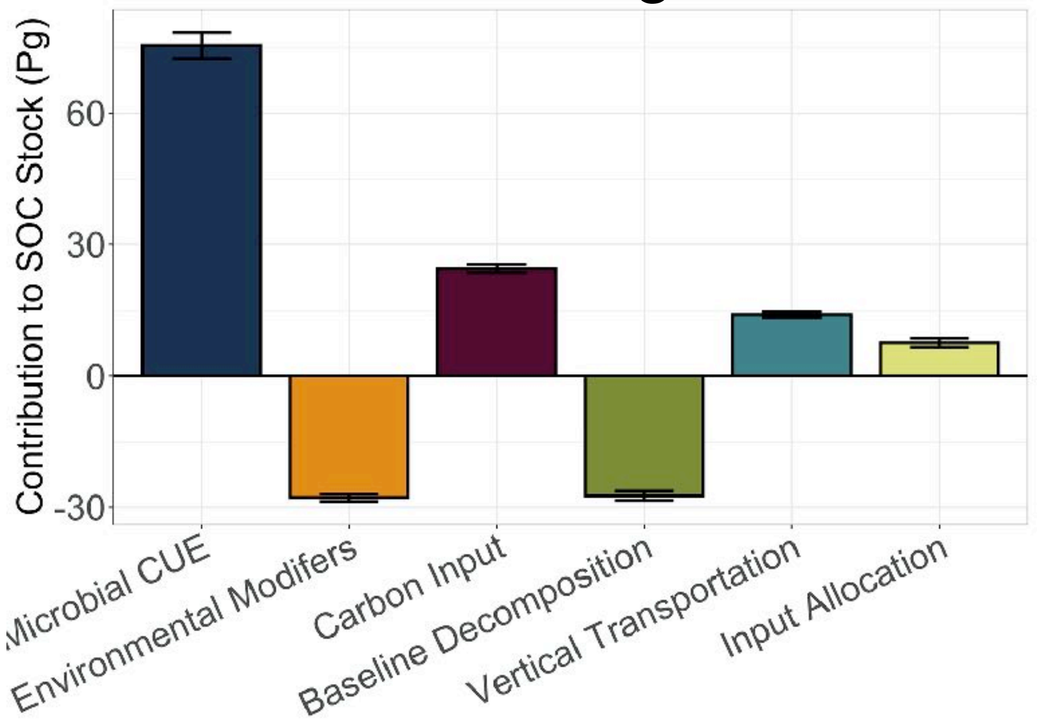
CUE as the Main Regulator

How will global SOC change with different mechanisms?

Proportion Change Gradient



+1% Change



Global SOC stock is most sensitive to CUE instead of carbon input or its allocation processes

(Tao et al. 2021 in prep.)

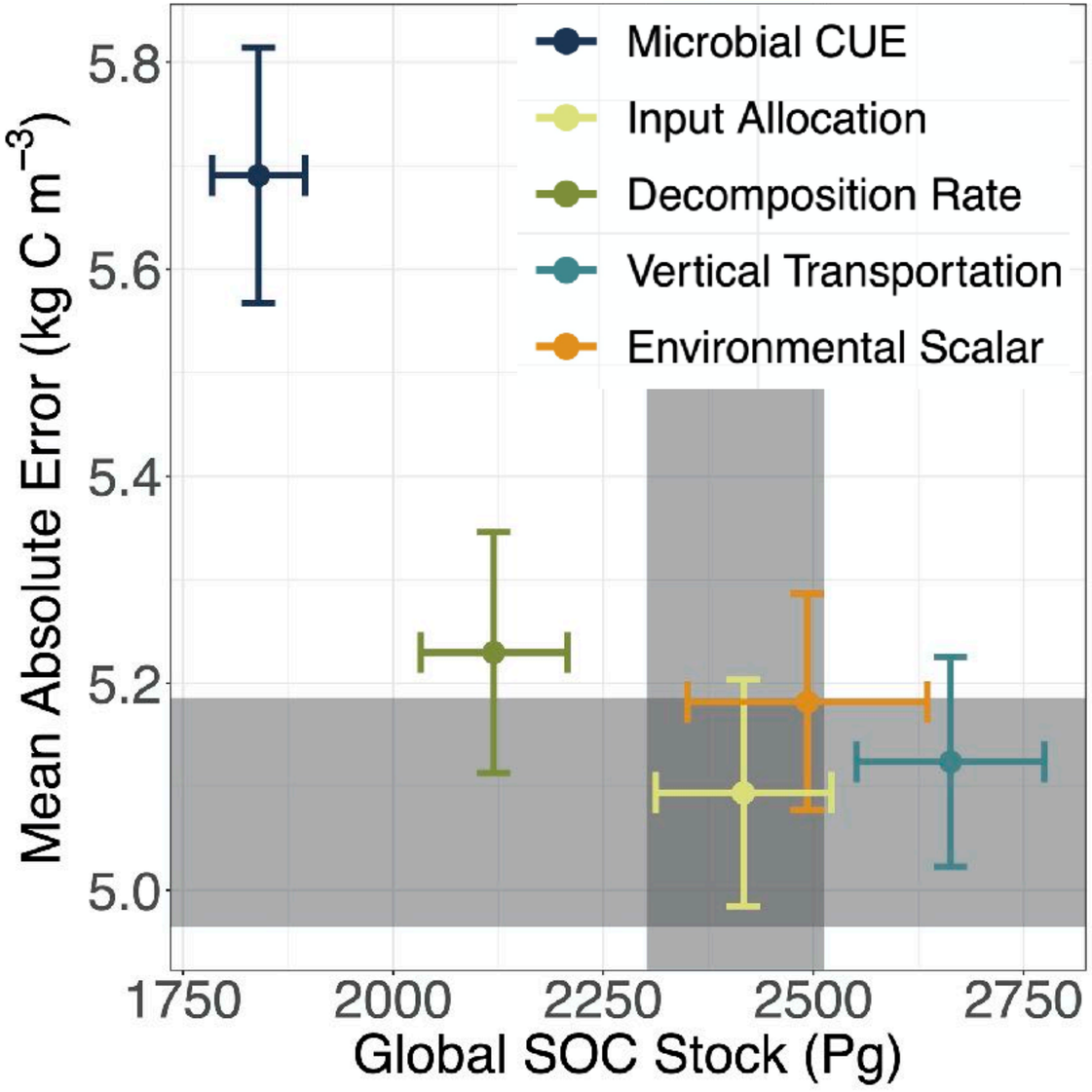
清華大學 Tsinghua University

Which Mechanism Determines SOC Storage?

CUE as the Main Regulator

How will global SOC deviates from reality when ignoring mechanism's spatial variability?

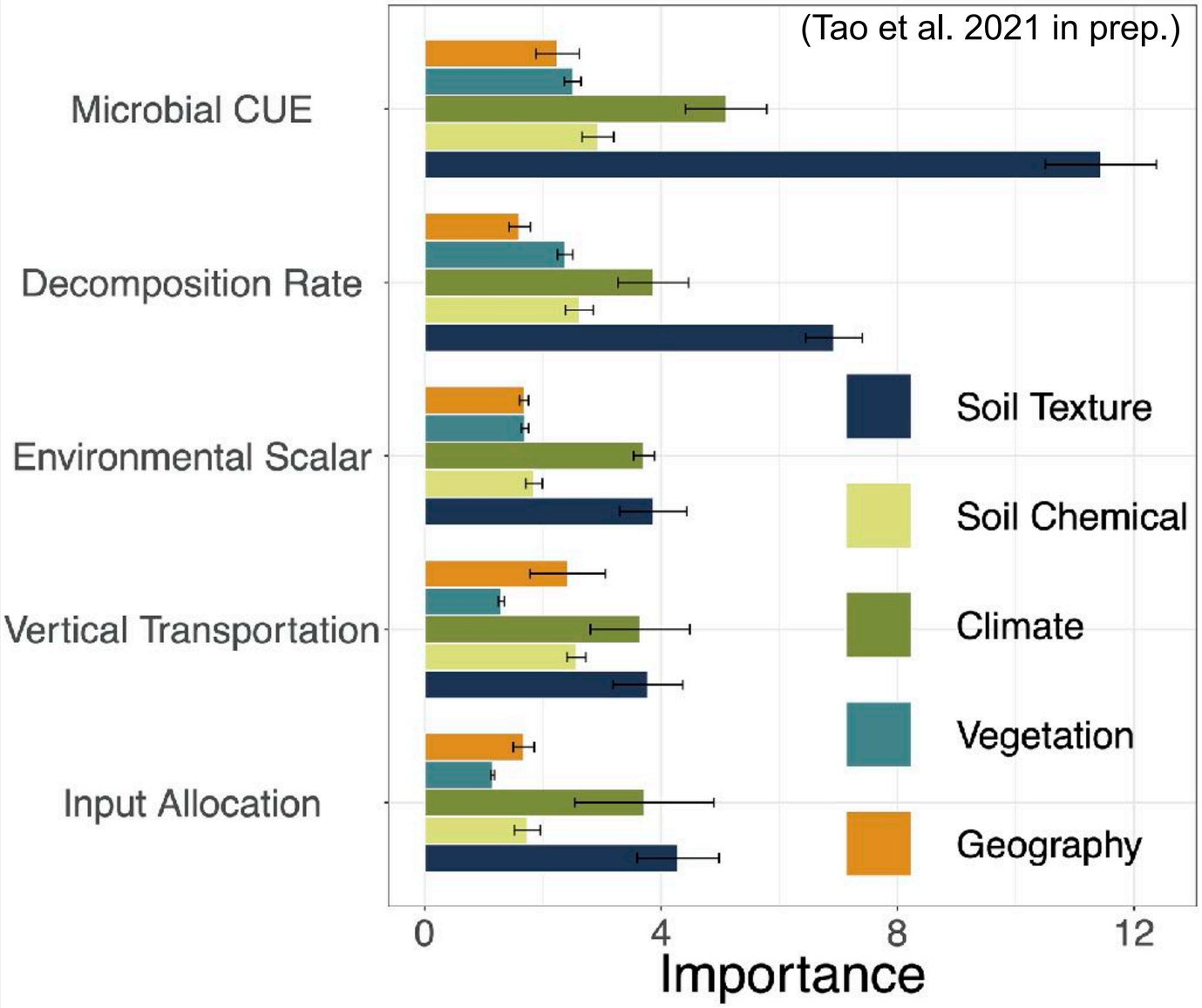
Model simulation deviates from observations most when ignoring CUE's spatial variability EVEN IF all others' spatial dependences are counted



(Tao et al. 2021 in prep.)

Environmental Depended Mechanisms

Importance of Environmental Variables

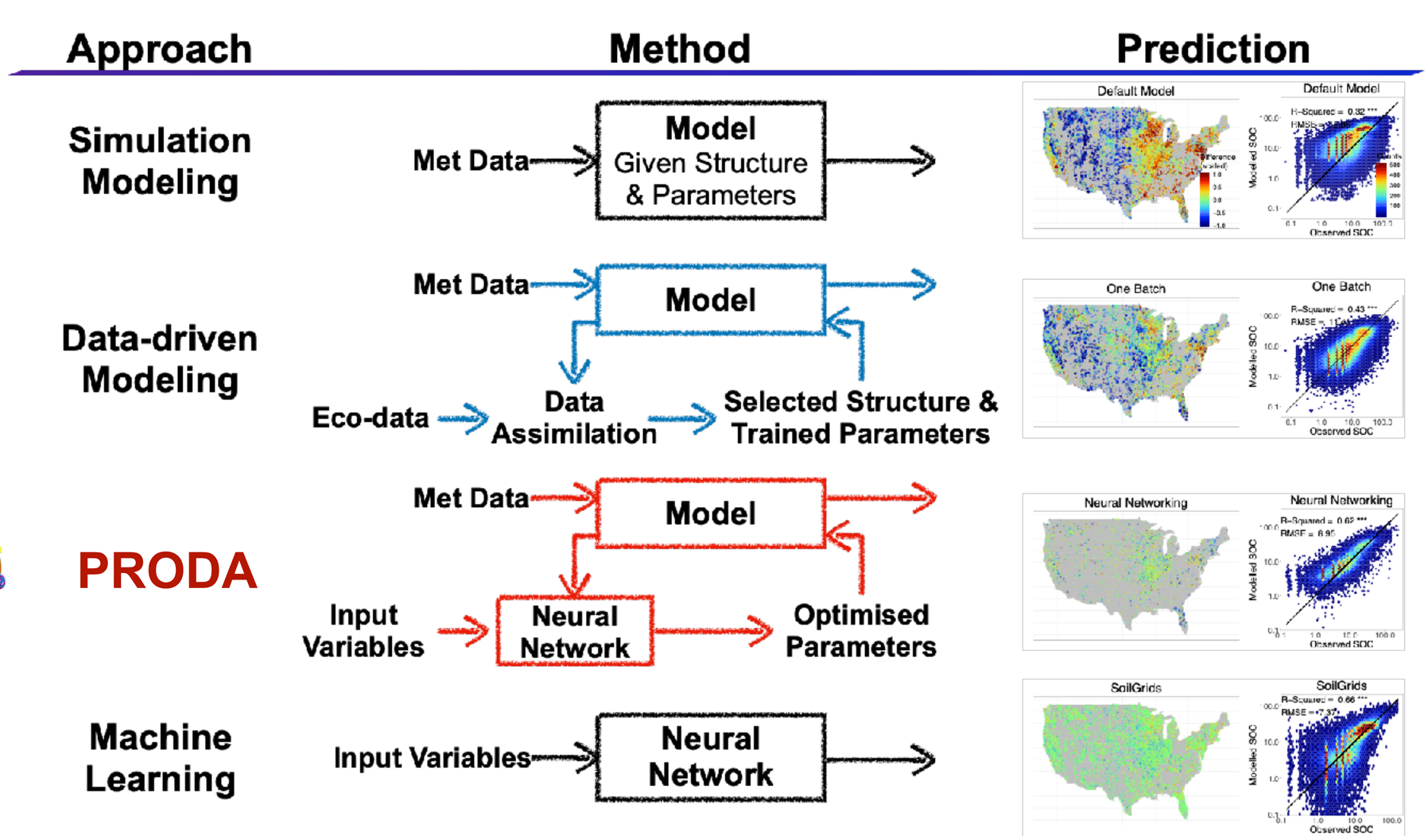


- **Soil texture** (i.e., clay, silt, sand content, etc.) is the most important feature in regulating processes

- **Climate variables** (i.e., temperature, precipitation) are equally important with texture for environmental scalars and vertical transportation

Take-Home Message

PRODA strikes a balance between process modelling & data mining to best represent AND understand global SOC



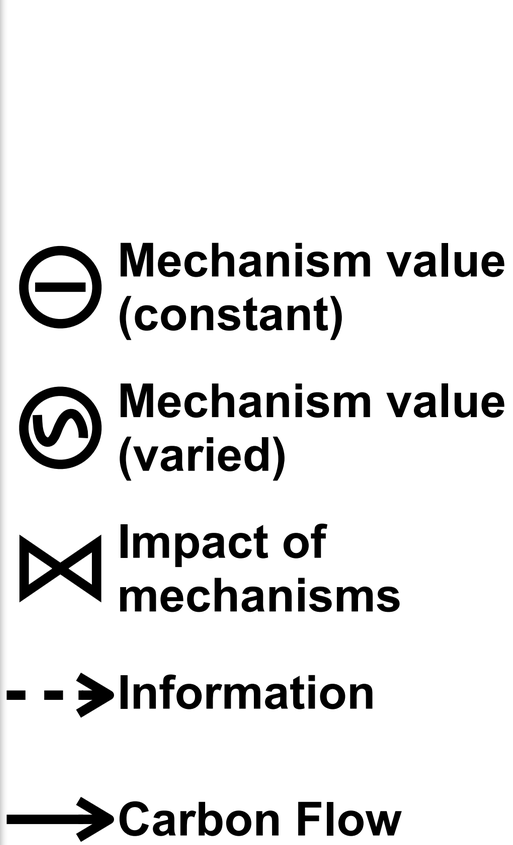
Processes Understanding

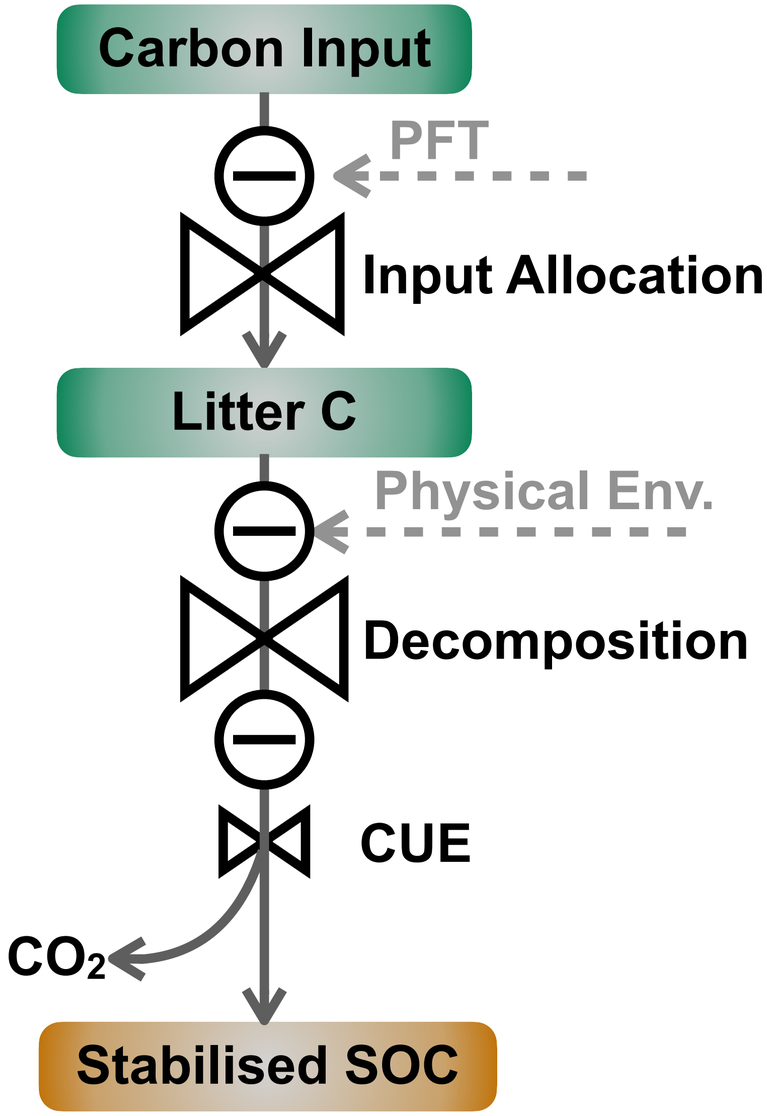
Data Mining

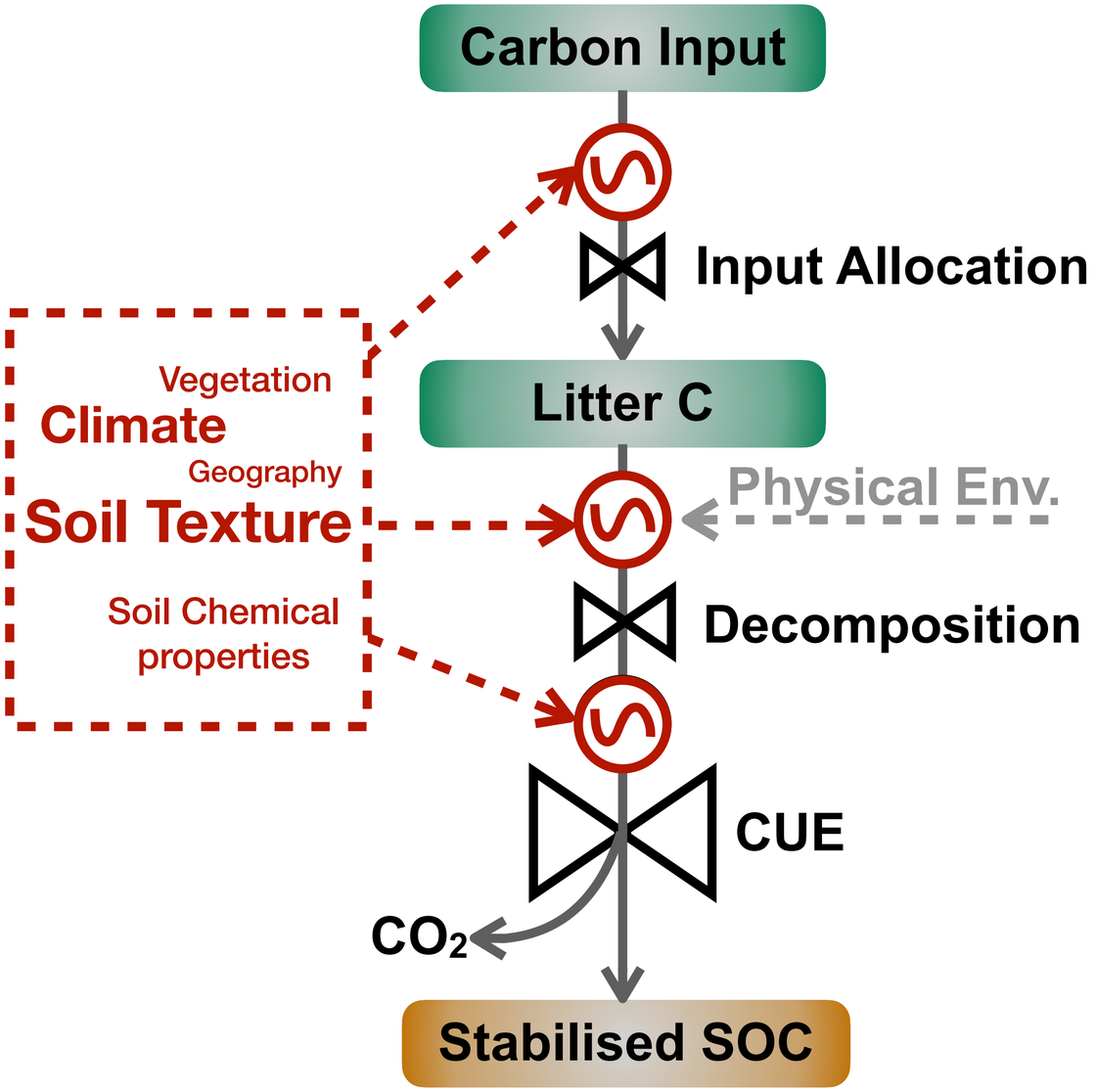
清華大學 Tsinghua University

Take-Home Message

Environment dependent mechanisms &
Microbial centred SOC stabilisation







清華大學 Tsinghua University

THANKS!

QUESTIONS TIME