



Tashkent, Uzbekistan, 18 – 20 May 2023

Role of soil water and heat transfer physics in portraying the ecosystem functioning

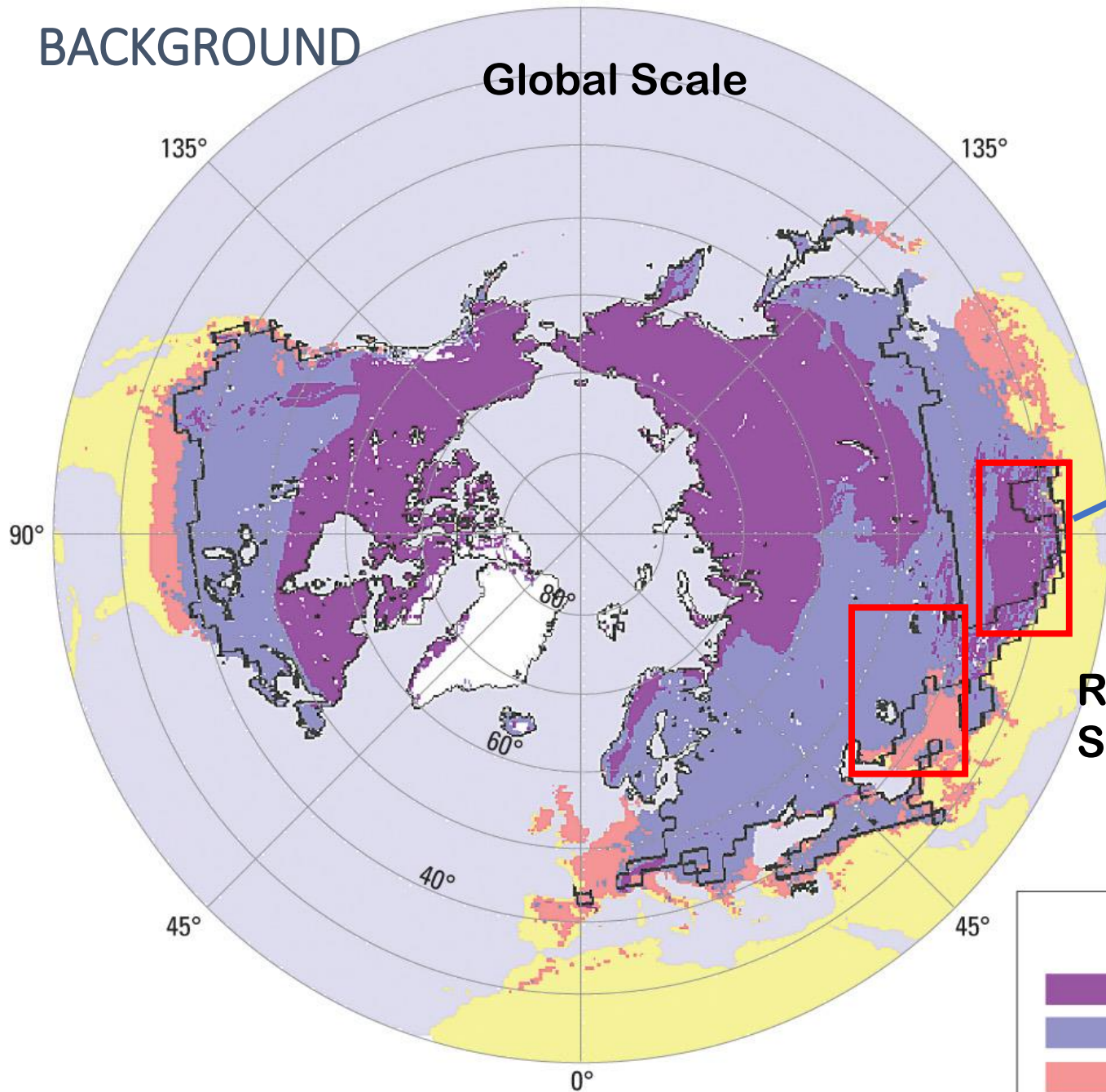
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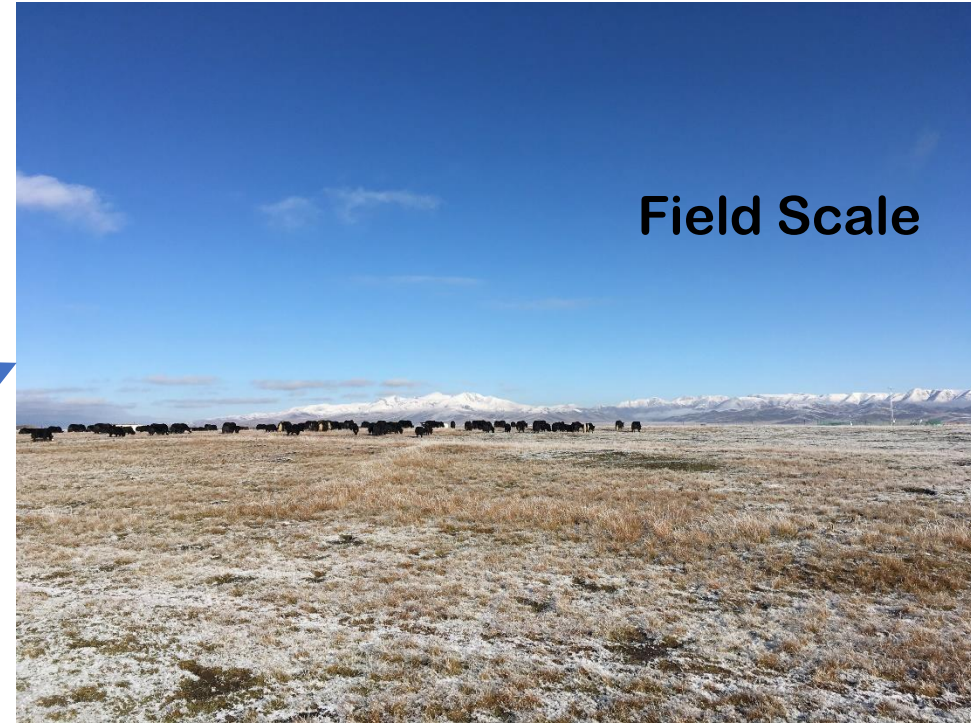
BACKGROUND

Global Scale



Frozen ground matters

Field Scale



Regional Scale

Tibetan Plateau largely involved in FT process, and the Central Asia

EXPLANATION

- Perennially frozen ground
- Seasonally frozen ground
- Intermittently frozen ground

Frozen soil constitution

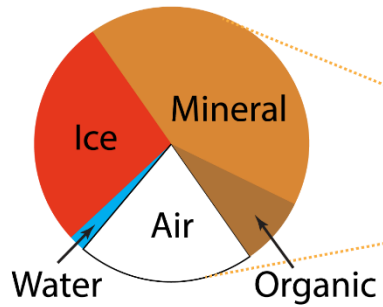
Soil Samples

Laboratory Scale

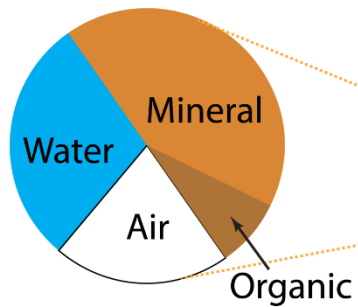
Field Scale

Soil Pore

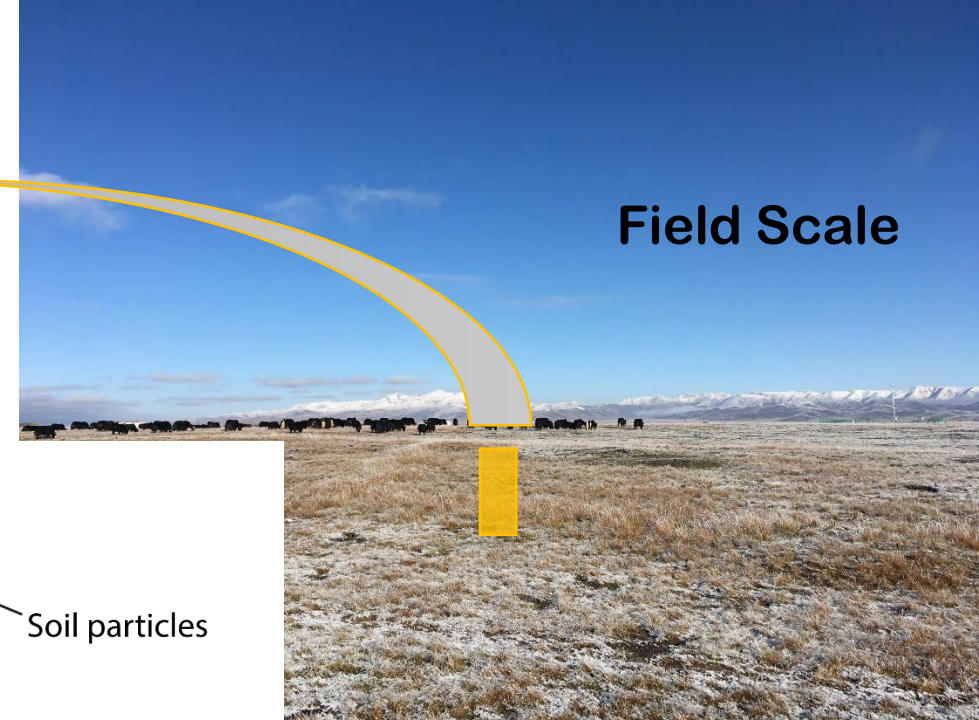
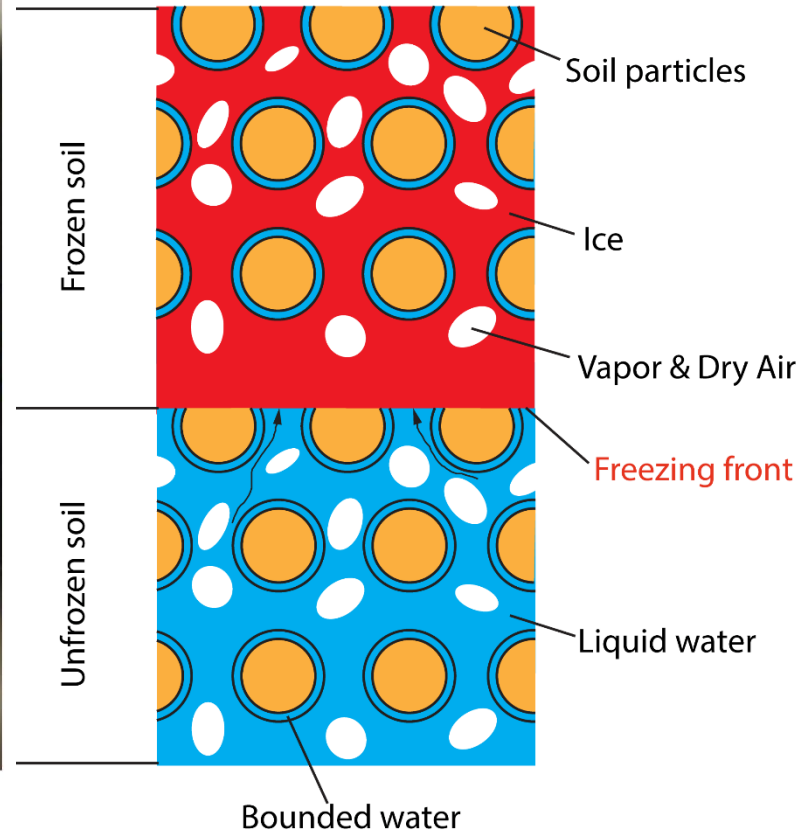
Frozen Soil



Unfrozen Soil



Frozen soil specimen
Figure from Lay (2005)



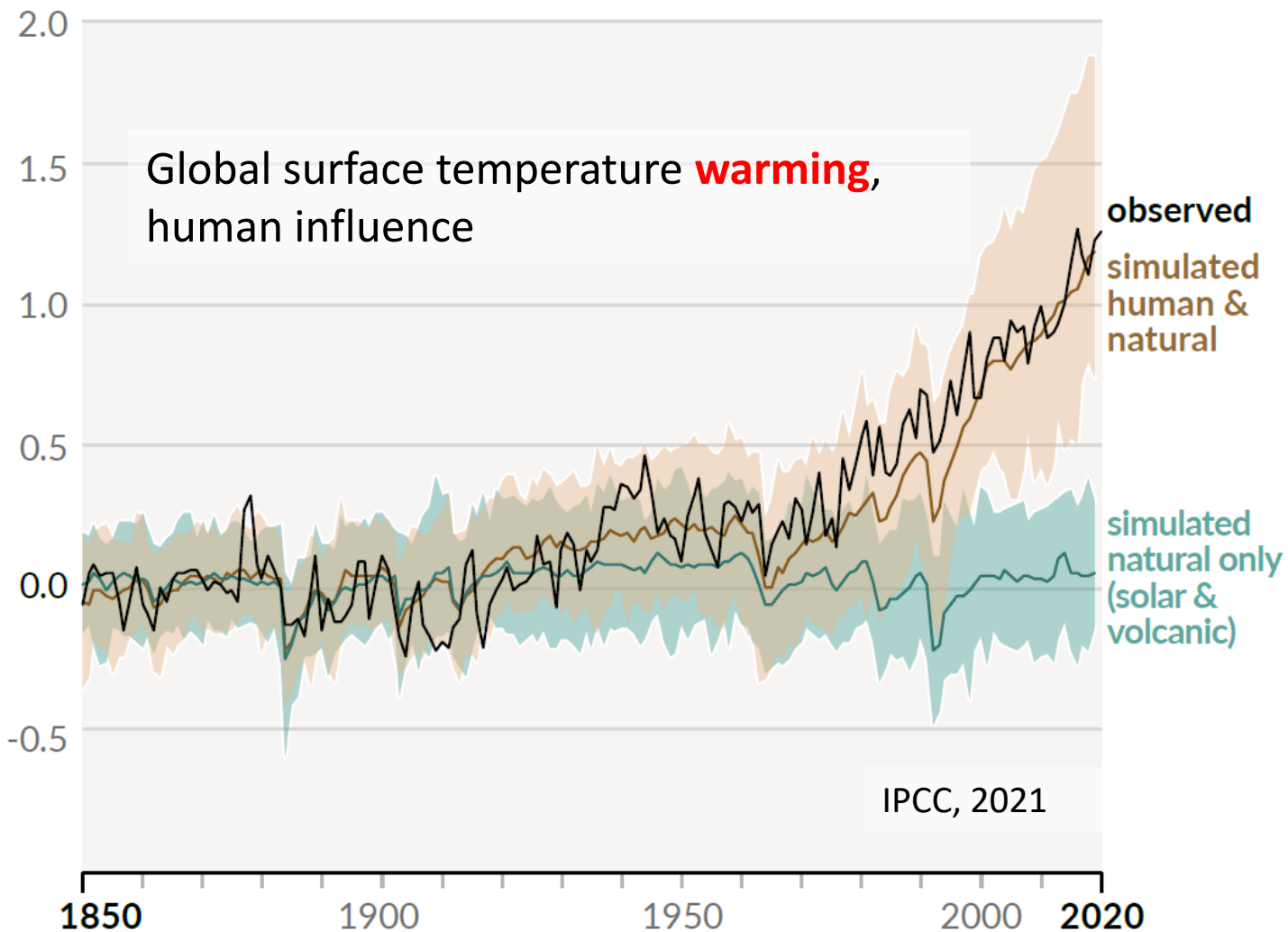
Soil particles:

- mineral,
- organic matter

Soil pores:

- water in three phases
(liquid, ice, and water vapor)
- dry air

WHY COLD REGIONS IMPORTANT?

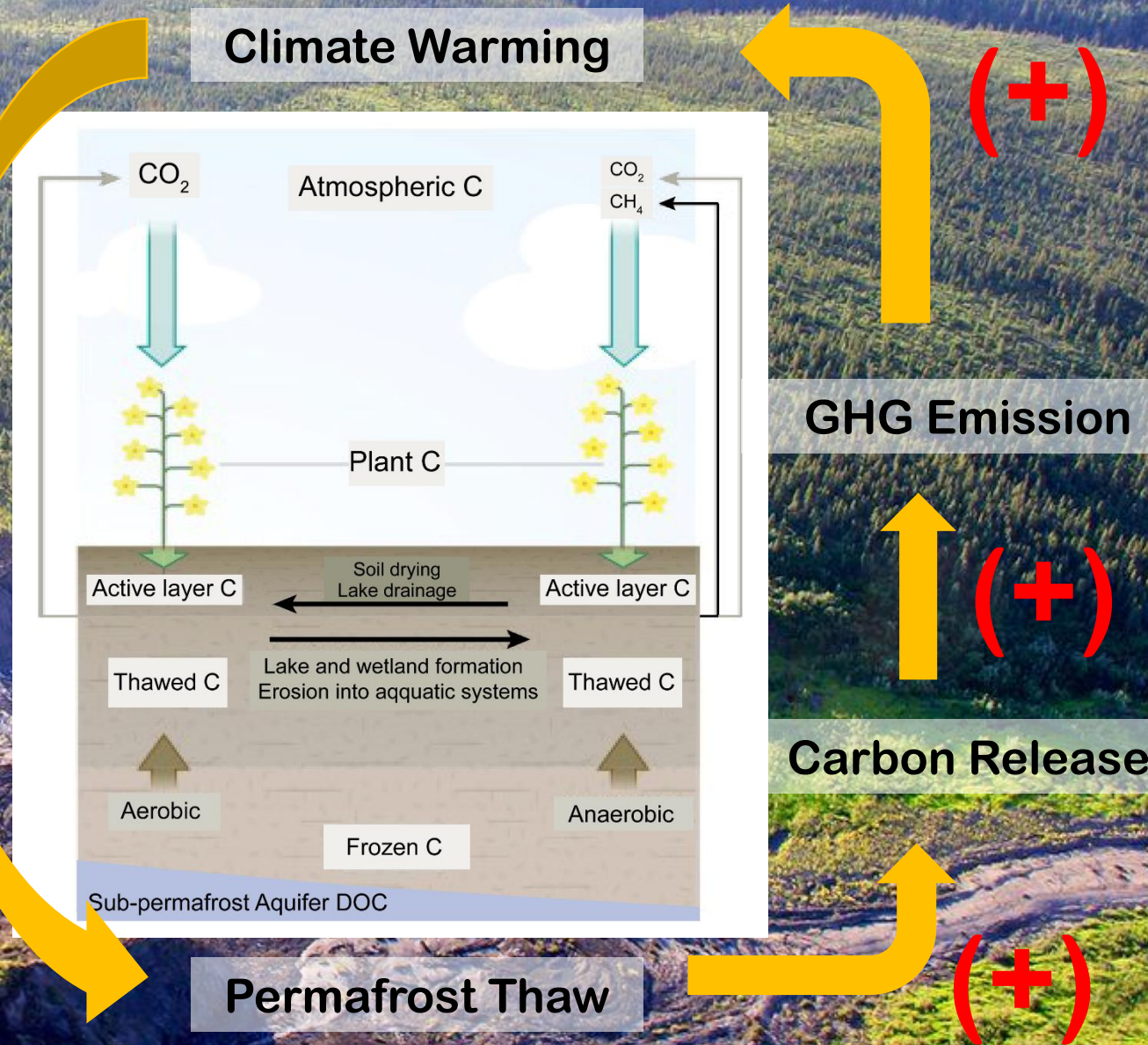


Plants suffering from the cold stress



Abrupt permafrost thaw, ground collapse, permafrost carbon emissions

Permafrost Carbon Feedback to climate change



(Image credit: Scott Zolkos)

(Schuur et al. 2015, Nature)

GHG: greenhouse gases, CO_2 , CH_4

MOTIVATION

- PCF, the magnitude and timing remain uncertain.
- ESMs, single phase flow assumption.
- unrealistic physical interpretations, two phase flow physics needed.

Questions:

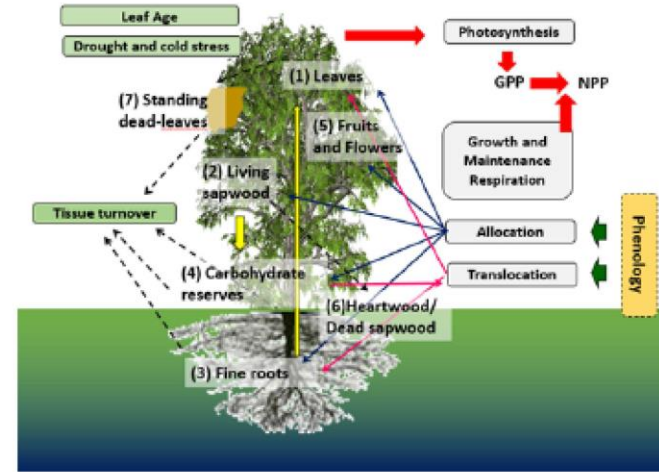
- How does different vadose zone physics affect our interpretation of soil hydrothermal regimes?
- Furthermore, how does such difference affect ecosystem functioning (carbon status)?



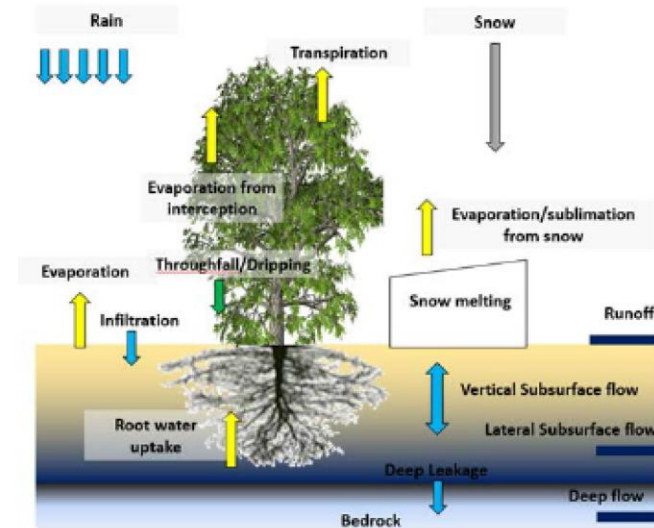
Tethys-Chloris (T&C)

(Fatichi, et al. 2012, ETH)

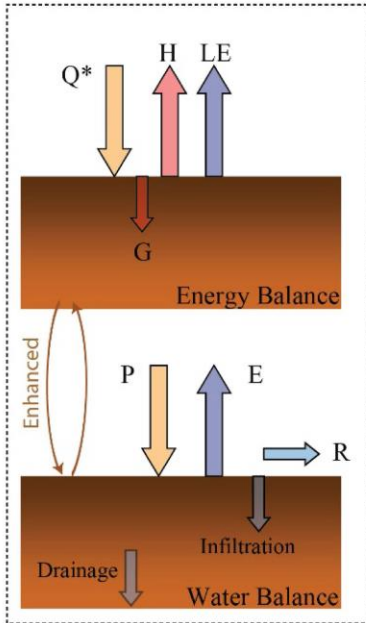
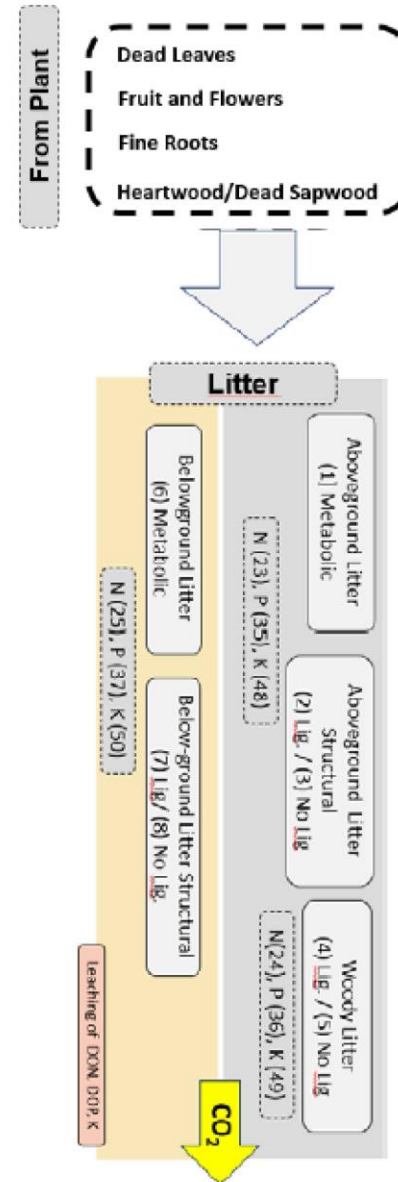
Vegetation Part



Hydrological Part



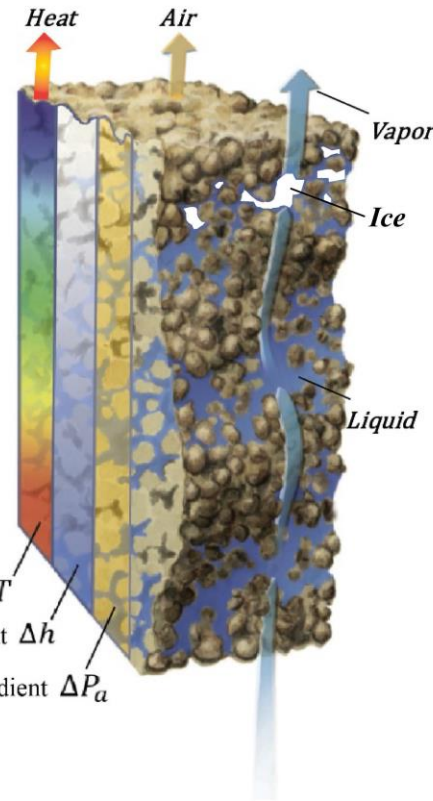
55 prognostic pools



(Zeng & Su, 2013;
Yu, Zeng, Wen, Su, 2018)

Q* – Downward Radia
H – Sensible Heat Flu
LE – Latent Heat Flux
G – Ground Heat Flux
P – Precipitation
E – Evaporation
R – Surface Runoff

Temperature Gradient ΔT
Matric Potential Gradient Δh
Air Pressure Gradient ΔP_a

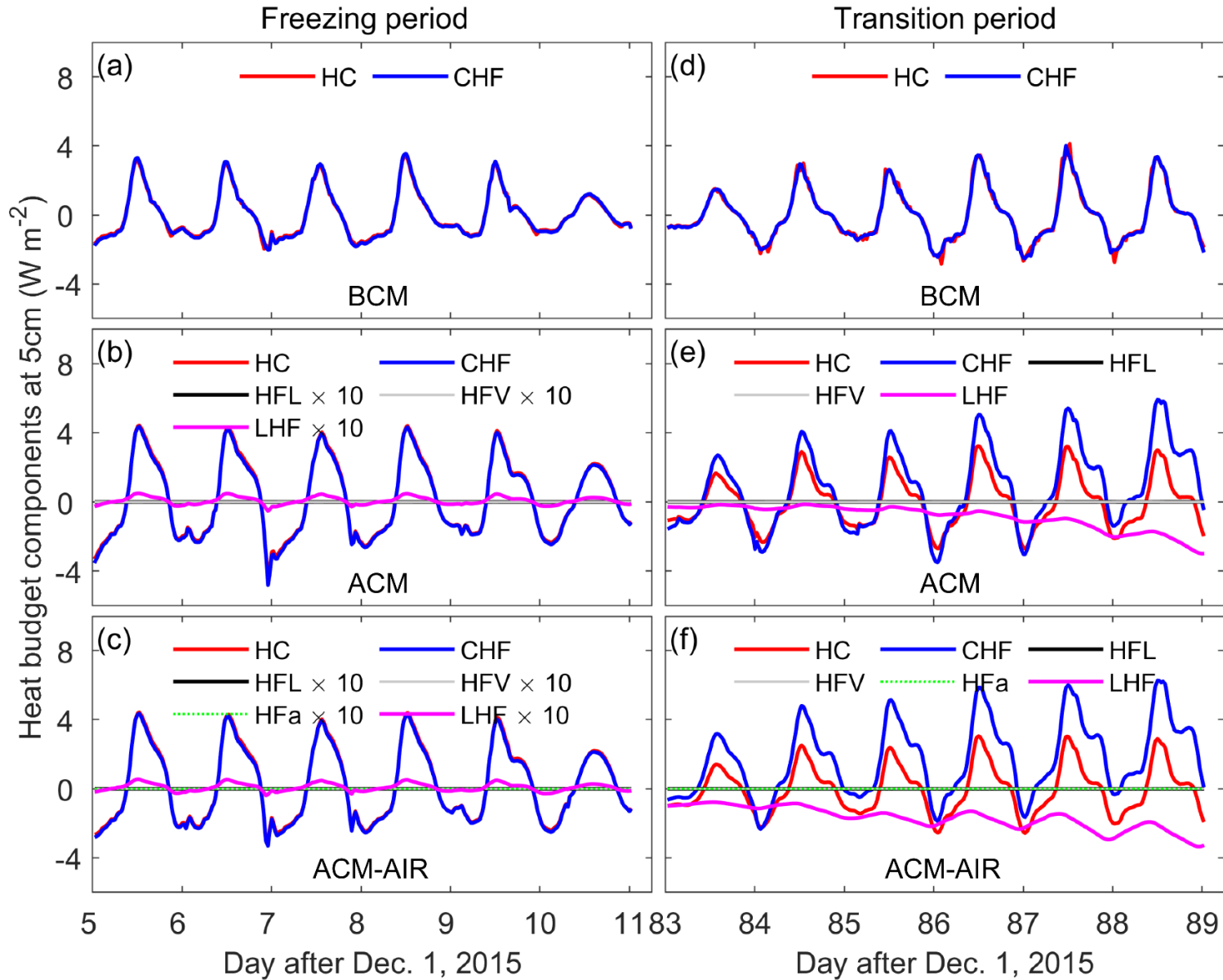


METHODOLOGY

Model Explanation		Soil Physical Processes	
Sing-Phase flow		unCPLD	Independent water and heat transfer;
			No ice effect on soil properties;
			No latent heat due to phase change;
Sing-Phase flow with Freeze-Thaw	BCM	unCPLD-FT	FT induced water and heat transfer coupling;
			Ice effect on soil properties;
			Latent heat due to phase change;
Two-Phase flow with Freeze-Thaw	ACM	CPLD	Tightly coupled water and heat transfer;
			Ice effect on soil properties;
			Latent heat due to phase change;
			Convective heat due to liquid/vapor flow.
Two-Phase flow with Freeze-Thaw and airflow	ACM-AIR		Tightly coupled water and heat transfer;
			Ice effect on soil properties;
			Latent heat due to phase change;
			Convective heat due to liquid/vapor flow.

LHF is important while neglected in BCM

RESULTS

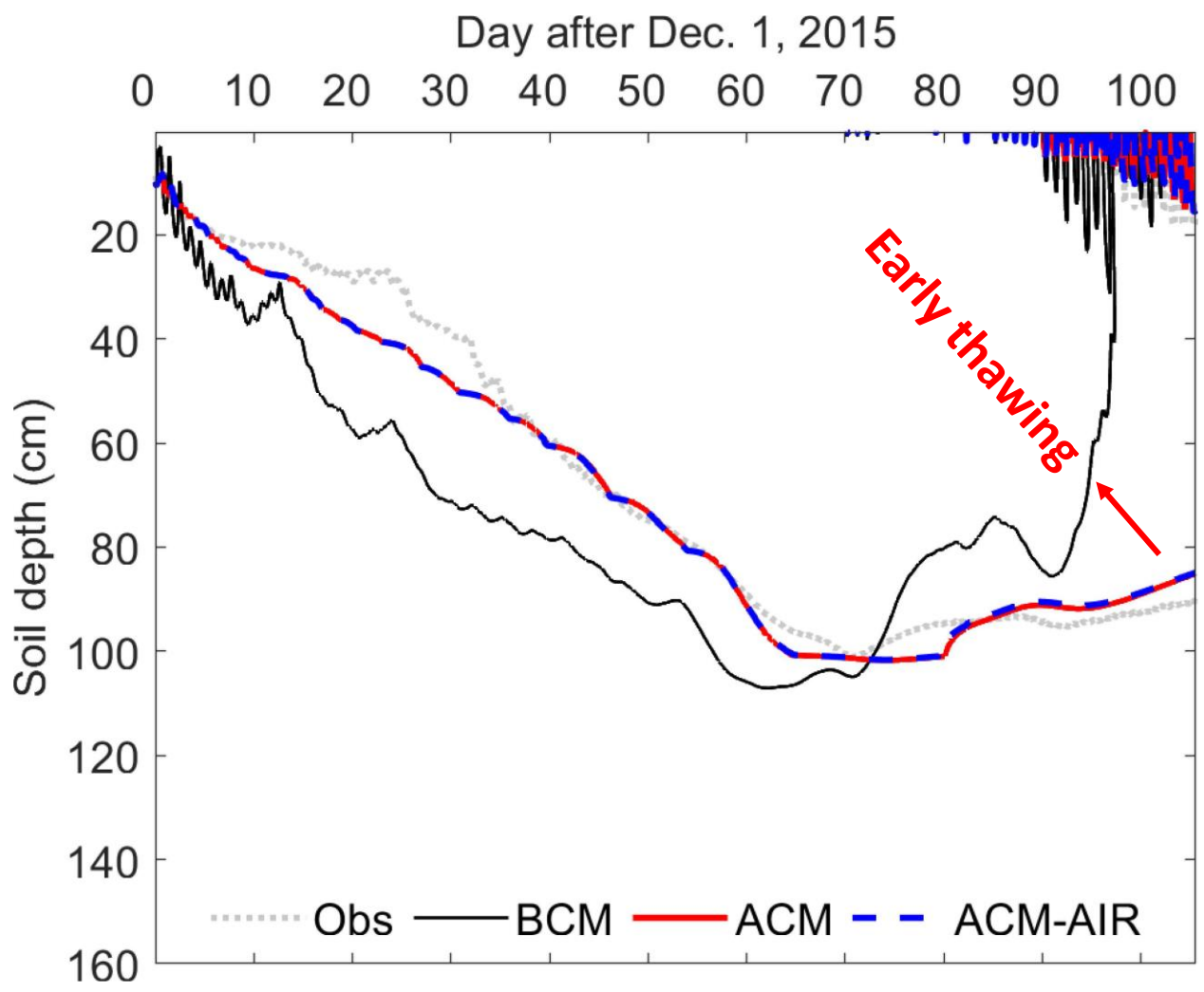


Time series of model simulated soil heat budget components.

HC, change rate of heat content,
 CHF, conductive heat flux divergence,
 HFL, convective heat flux divergence due to liquid water flow,
 HFV, convective heat flux divergence due to water vapor flow,
 HFa, convective heat flux divergence due to air flow,
 LHF, latent heat flux divergence.

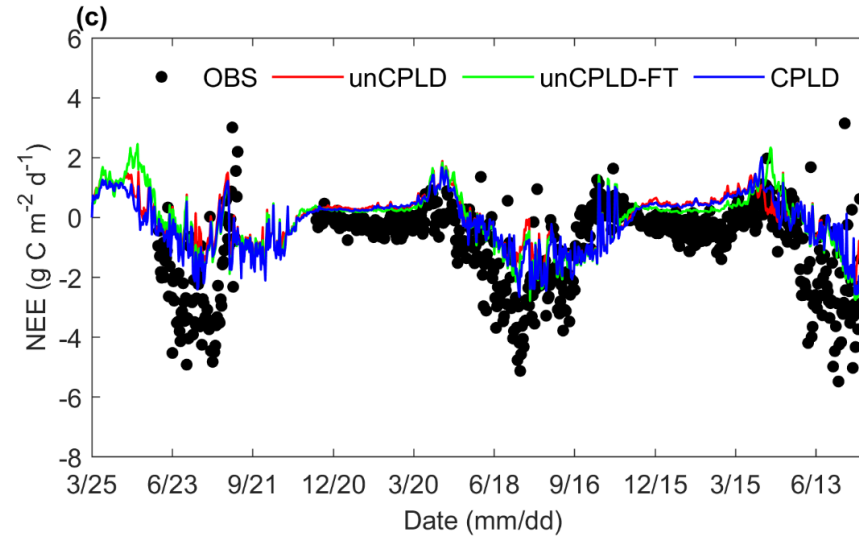
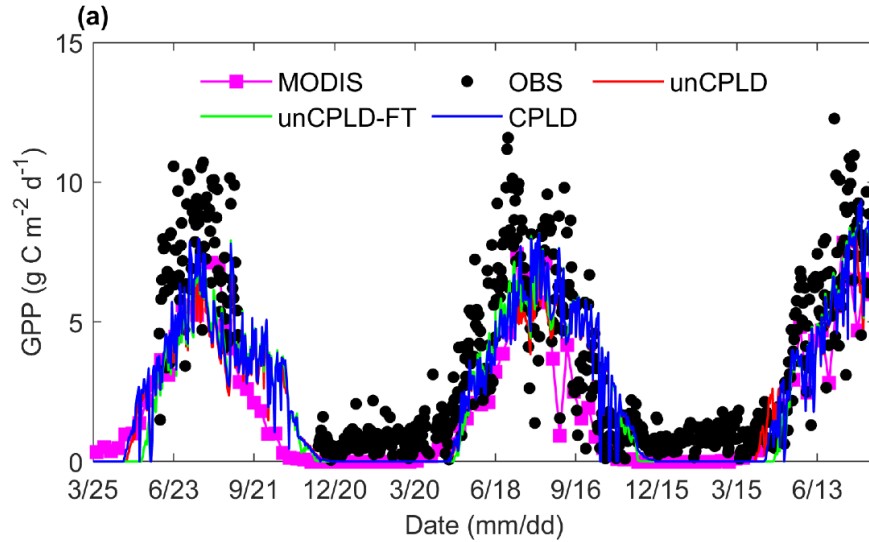
➤ How does different vadose zone physics affect our interpretation of soil hydrothermal regimes?

Early warming of frozen soil simulated by BCM

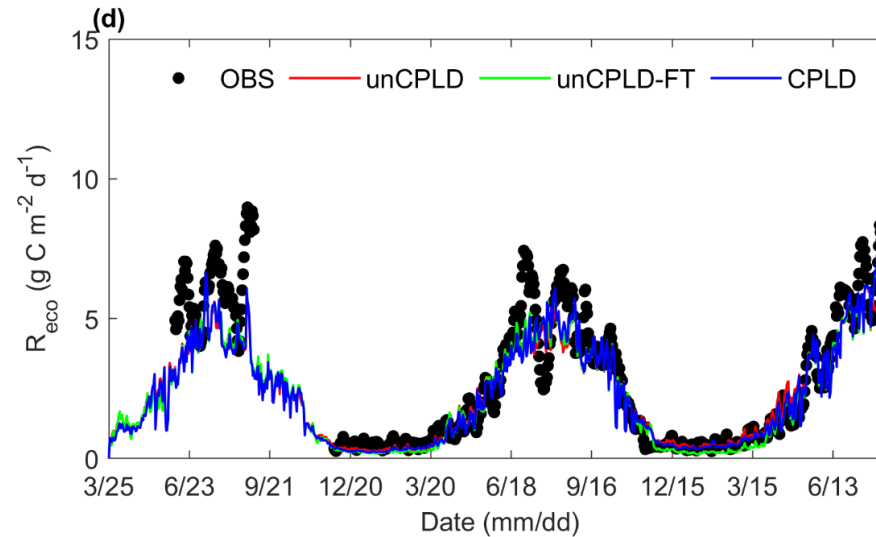
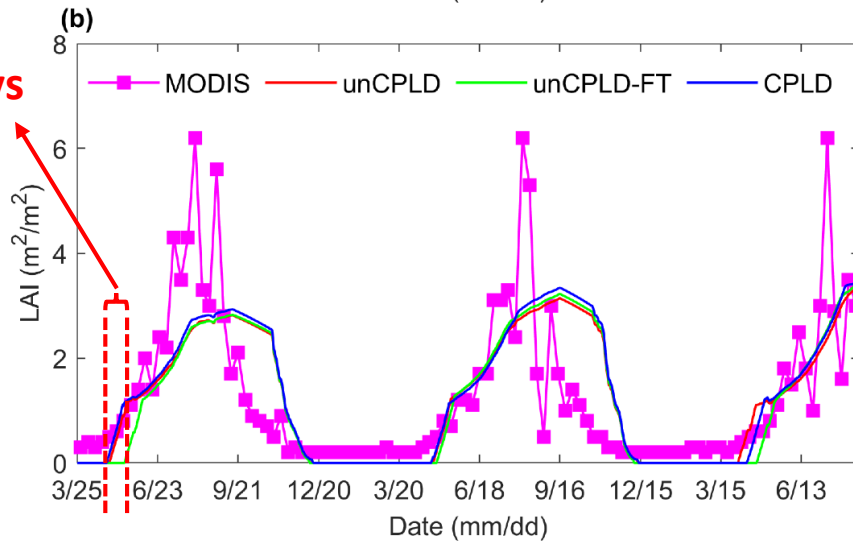


Comparison of measured (Obs) and model simulated soil freezing front propagation (FFP)

using Basic Coupled Model (BCM),
Advanced Coupled Model (ACM) and
Advanced Coupled Model with Airflow (ACM-AIR).



2-3 days



Temporal variations of ecosystem carbon budget components (25th Mar. 2016 – 12th Aug. 2018).

GPP, Gross Primary Production, LAI, Leaf Area Index, NEE, Net Ecosystem Exchange, R_{eco} , Ecosystem respiration.

➤ How does such soil hydrothermal difference affect the ecosystem functioning (carbon status)?

SUMMARY

- Models with single phase flow physics cannot produce the slowing effect due to phase change-induced heat exchange, result in the **early thawing of frozen soils**.
- The **vegetation greens earlier** in response to the early warming of subsurface soil, which affects the cold region ecosystem functioning (carbon status).
- The model uncertainty (from the single-phase flow assumption) should be further investigated in terms of better projection of future climate change.