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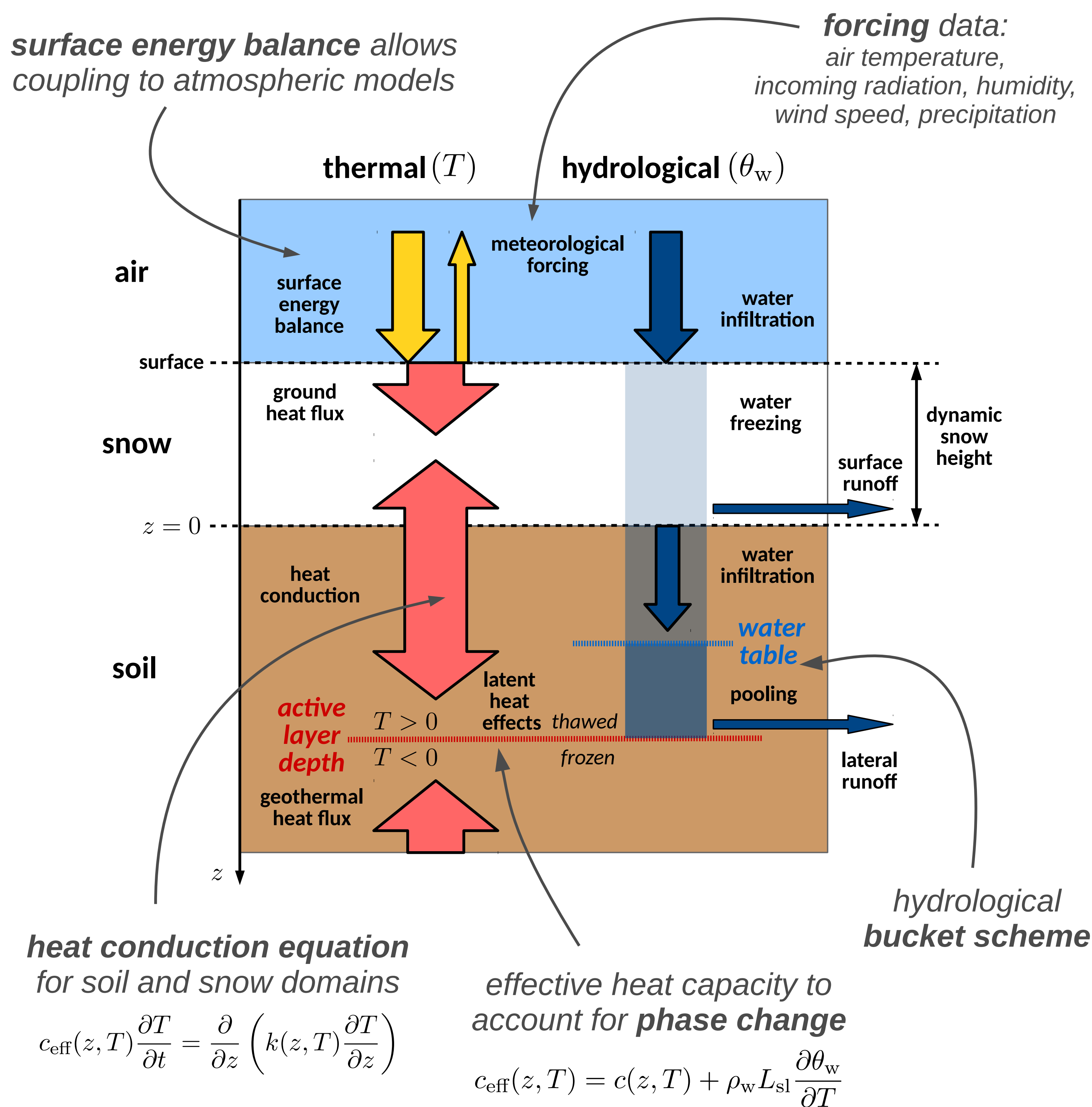UND MEERESFORSCHUNG

Towards representing thermokarst processes in land surface models

Motivation

- **Thermokarst landscapes** cover about 20% of the permafrost region and contain **up to 50% of the soil organic carbon** in this region.

- **Small-scale permafrost degradation** is not represented in large-scale models, but considerably **impacts energy, water and carbon budgets**.

- **Up-scaling techniques are required** for representing subgrid-scale processes in land surface models.

CryoGrid3 land surface model

surface energy balance allows coupling to atmospheric models

forcing data:
air temperature, incoming radiation, humidity, wind speed, precipitation

hydrological bucket scheme

heat conduction equation for soil and snow domains

$$c_{\text{eff}}(z,T)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(k(z,T)\frac{\partial T}{\partial z}\right)$$

effective heat capacity to account for **phase change**

$$c_{\text{eff}}(z,T) = c(z,T) + \rho_w L_{\text{sl}}\frac{\partial \theta_w}{\partial T}$$

Conceptual modeling of thermokarst and thermoerosion

- **Excess ground ice** and **subsidence** scheme *(Westermann et al. 2016)*

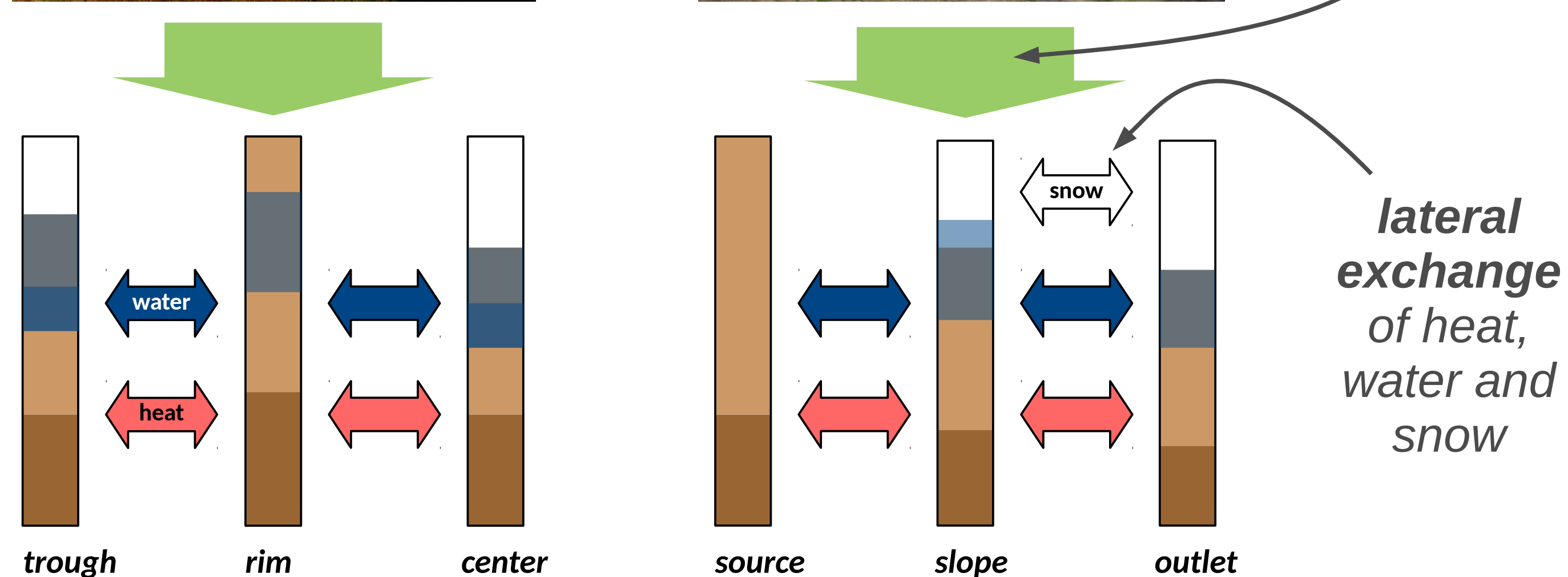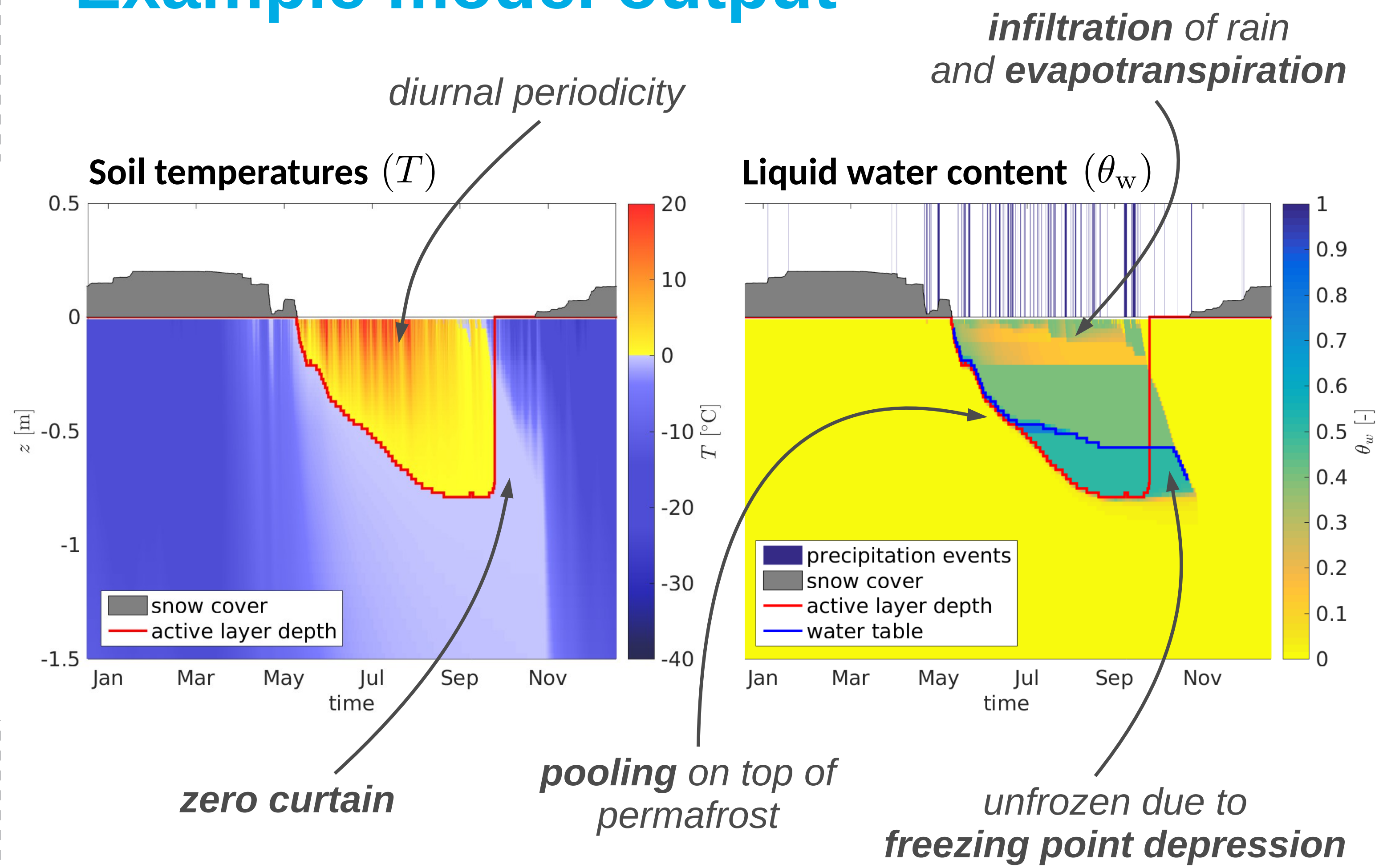- Coupling with *FLake* to include **water bodies** *(Langer et al. 2016)*

Polygonal tundra

Photo: S. Zubrzycki (imaggeo)

Thermo-erosional valley

Photo: G. Hugelius (Nat. Commun.)

generating **representative columns**

lateral exchange of heat, water and snow

Example model output

diurnal periodicity

infiltration of rain and **evapotranspiration**

Soil temperatures (T)

Liquid water content (θ_w)

zero curtain

pooling on top of permafrost

unfrozen due to **freezing point depression**
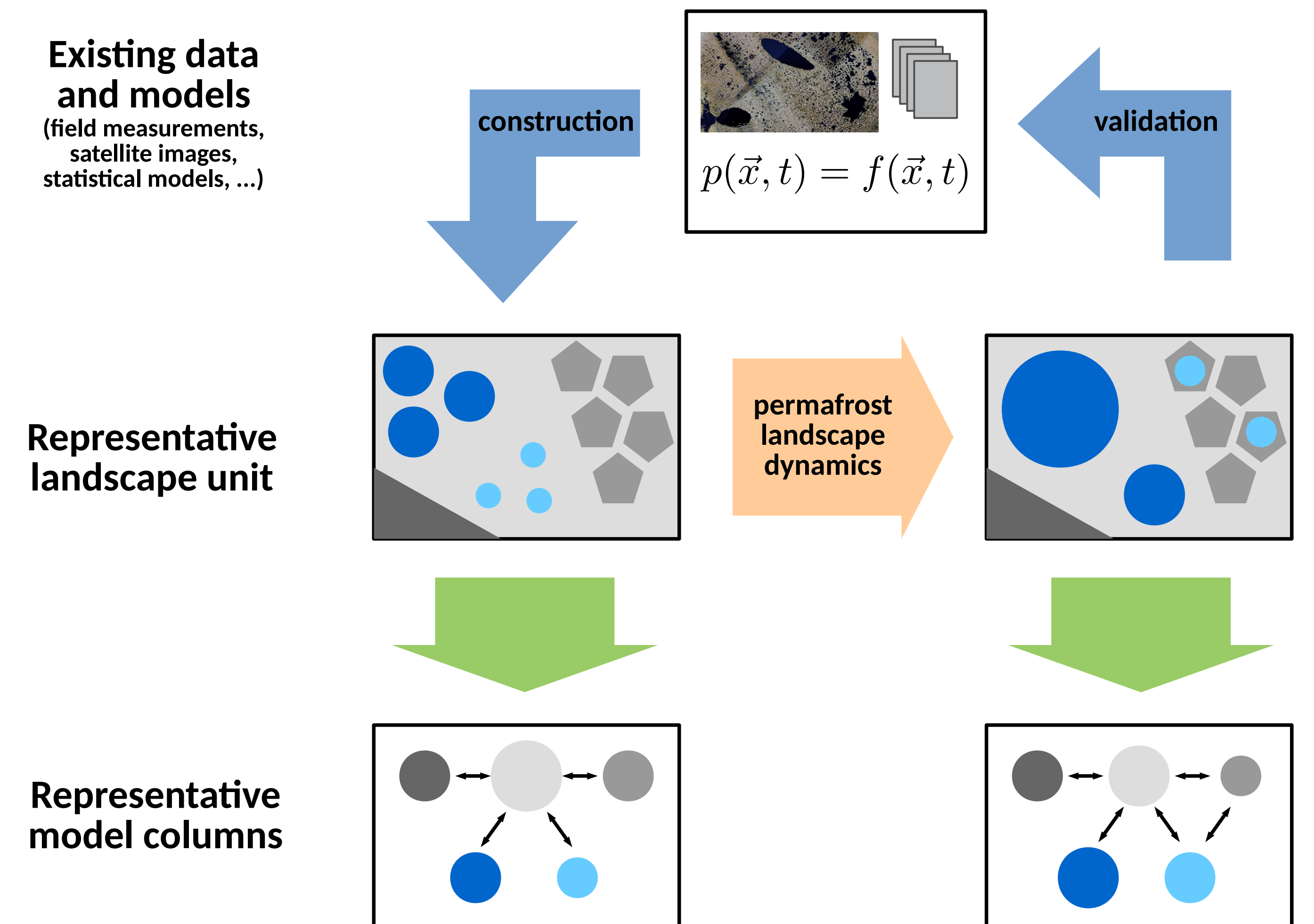
Meteorological Forcing: Samoylov Island, Lena River Delta (Northern Siberia) for the year 2012

From landforms to landscapes

Existing data and models
(field measurements, satellite images, statistical models, …)

construction

$$p(\vec{x},t) = f(\vec{x},t)$$

validation

Representative landscape unit

permafrost landscape dynamics

Representative model columns

Field measurements

- Long-term observatories in the **Lena Delta, Northern Siberia** *(Boike et al. 2013)*

- Meteorological **forcing data**

- Field measurement of **model input parameters** (stratigraphy, topography, surface properties)

- Data for **model validation** (soil temperature, soil moisture, active layer depth, water table)

Permafrost distribution in the northern hemisphere
Source:Brown et al. (1997); IPA
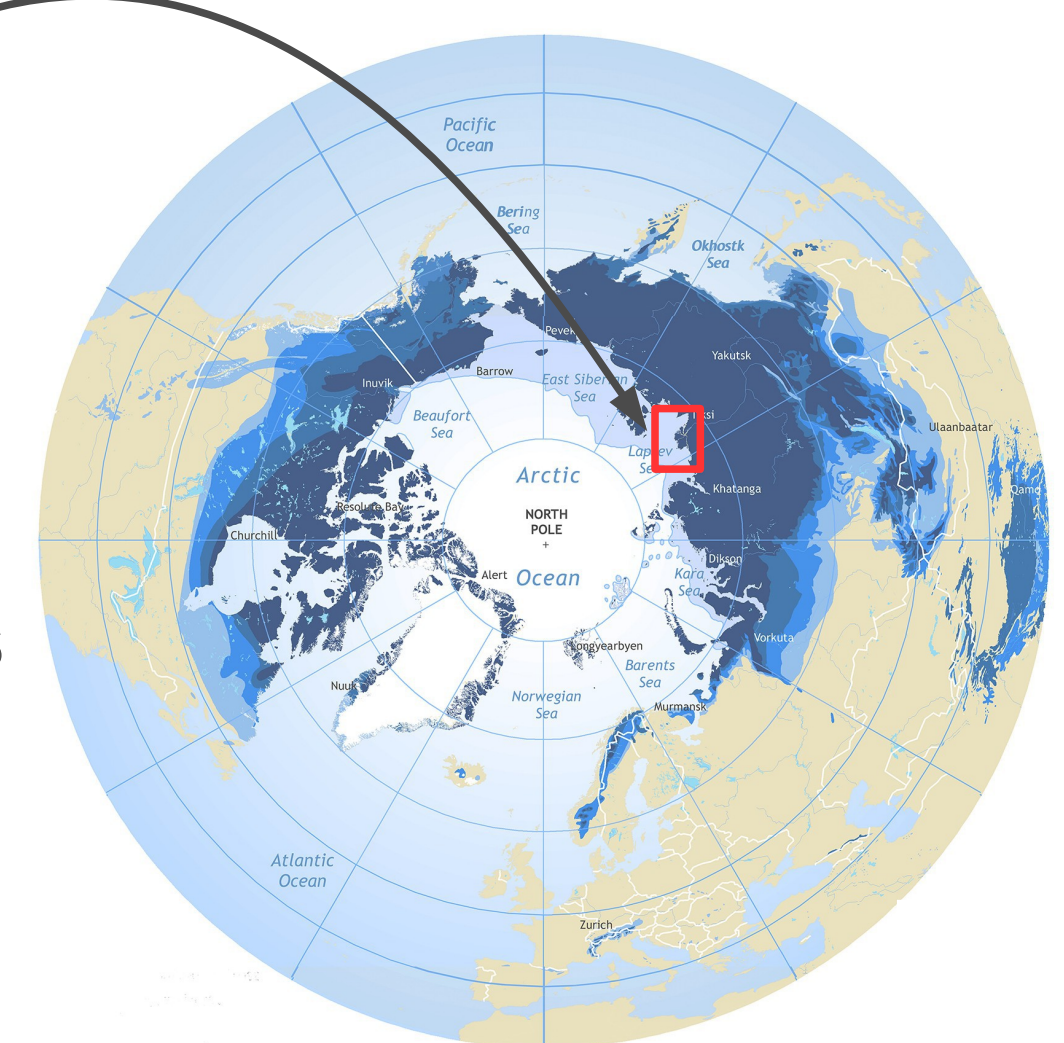
Outlook

- Evolution of permafrost landscapes in a **warming climate**

- Employing methods from complex systems and network theory

- Estimation of potential **carbon mobilization** from thermokarst landscapes

References

Westermann, S., Langer, M., Boike, J., Heikenfeld, M., Peter, M., Etzelmüller, B., & Krinner, G. (2016). Simulating the thermal regime and thaw processes of ice-rich permafrost ground with the land-surface model CryoGrid 3. *Geoscientific Model Development*, 9(2), 523–546.

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Boike, J., et al. (2013). Baseline characteristics of climate, permafrost and land cover from a new permafrost observatory in the Lena River Delta, Siberia (1998-2011). *Biogeosciences*, 10(3), 2105–2128.