ICON-Land: Current development lines

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With contributions from

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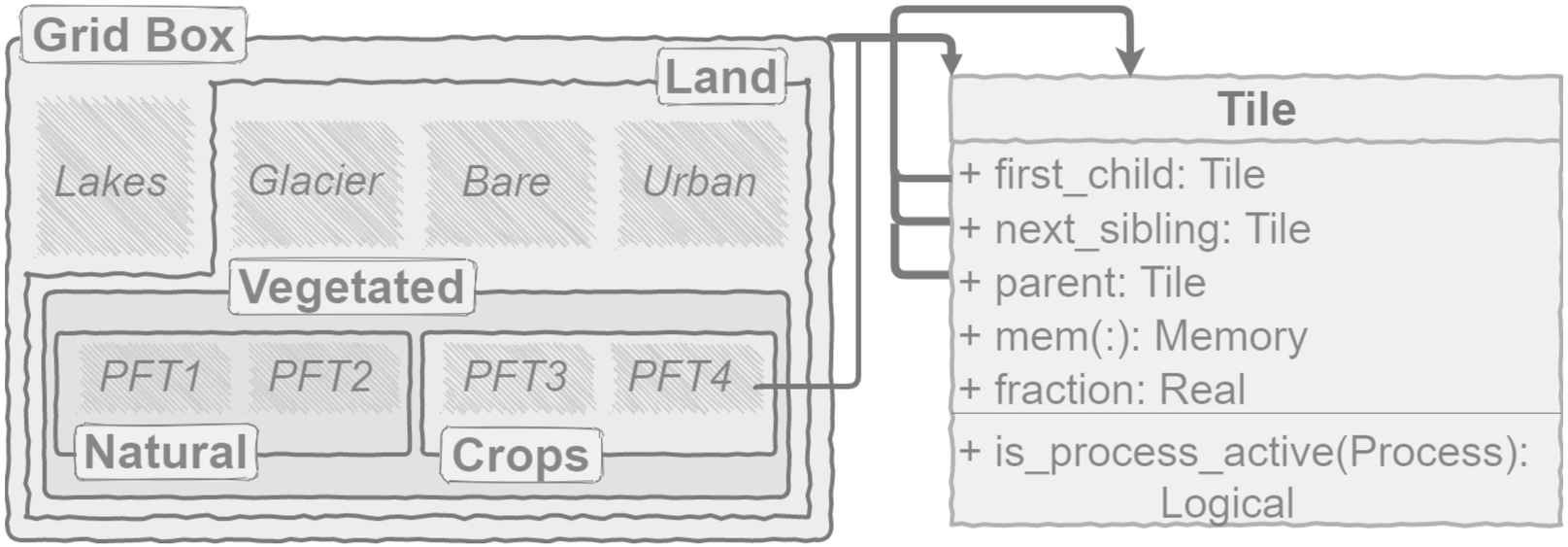
Julia Pongratz (LMU)



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ICON-Land Framework

- *ICON-Land is a framework for the modeling of land processes in ICON*

- **Goals**
  - Integration of concurrent process and surface descriptions in a flexible and easy-to-use way
  - Separate the infrastructure required to implement physical, bio-geophysical and bio-geochemical land processes from concrete process implementations accessed by abstract interfaces
  - Support various experimental configurations regarding scope and complexity, spatial and temporal extend, offline as well as coupled

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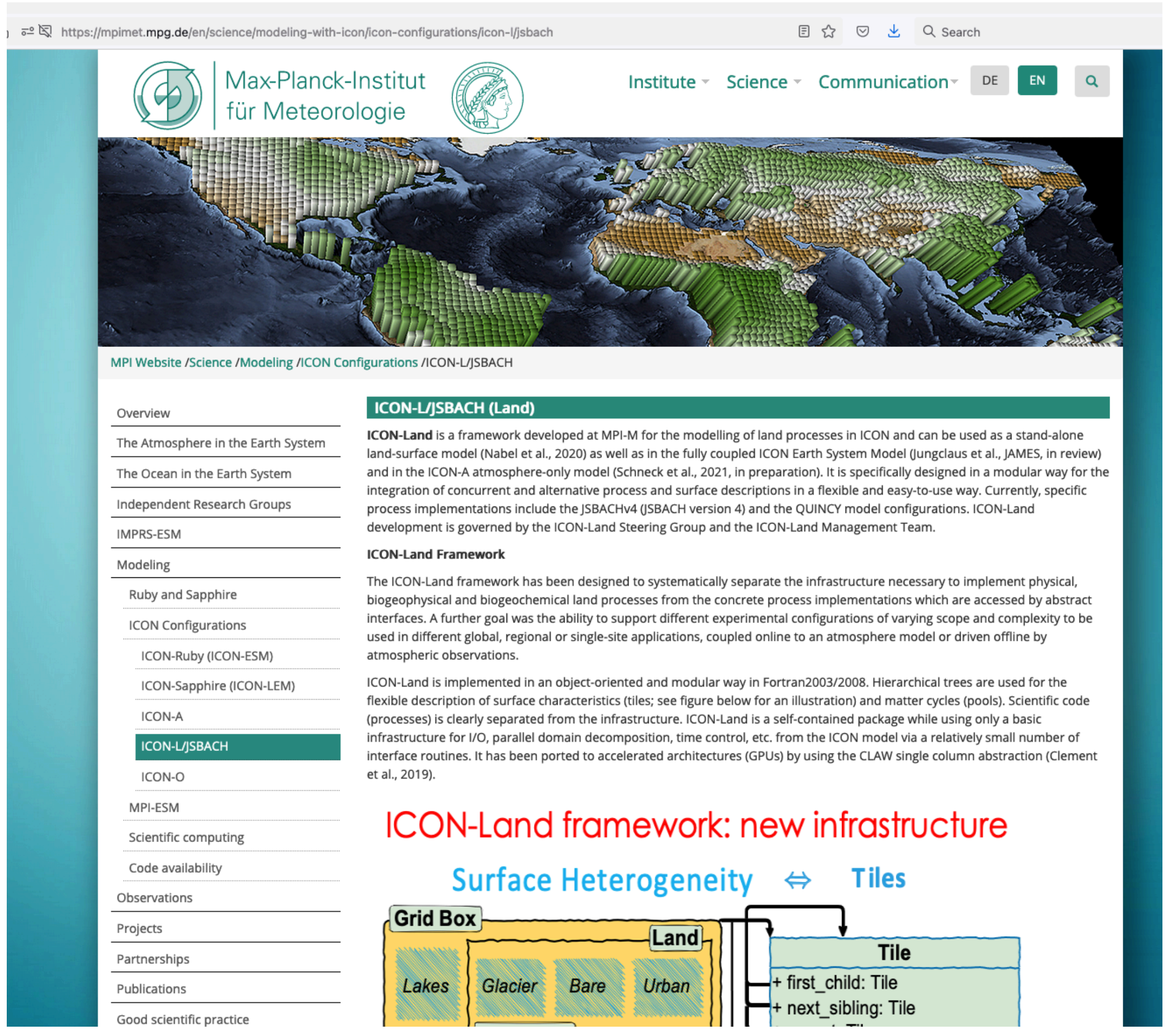
ICON-Land governance

ICON-Land is governed by the ICON-Land Steering Group.

- includes the representatives from several groups contributing to development of models of the land processes
  - key institutions: MPI-M, MPI-BGC, LMU
  - Also involved: DWD, MPI-C, UNI-HH, FMI Helsinki

- to coordinate and facilitate ICON-Land development across the different scientific institutions contributing to ICON-Land, and to decide on strategic developments.

https://mpimet.mpg.de/en/science/modeling-with-icon/icon-configurations/icon-land/jsbach



JSBACH4 within ICON-Land

Nabel et al. 2020, GMD,
Schneck et al. in review, GMD,
available under the MPI-M license

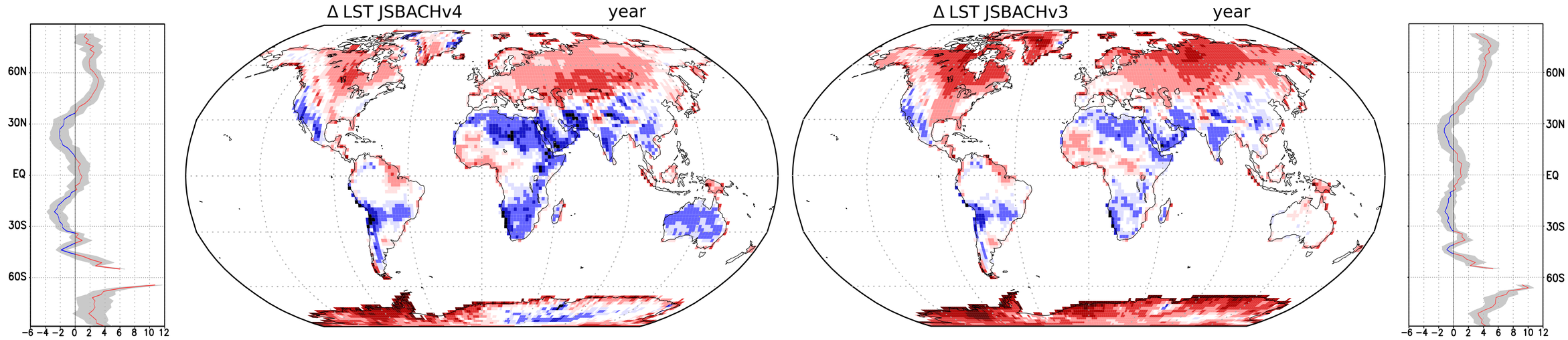
Version used within ICON-seamless

Processes included:

- Surface energy balance (implicitly coupled to atmosphere)
- Multi-layer soil model for temperature and moisture
- Multi-layer snow model
- Lakes: simple scheme for water temperature, ice thickness and temperature, and snow
- Hydrologic discharge (HD): freshwater flux from land into oceans, coupled via YAC
- Phenology (LAI): leaf growth and shedding rates under environmental conditions
- Photosynthesis: dynamics of plant carbon uptake by assimiliation and water loss via stomata
- Natural carbon cycle: transport of assimilated carbon through storage pools in vegetation and soil
- Natural disturbances of vegetation by fires and wind throw
- Land cover change (LCC)
  - Anthropogenic LCC by reading annual maps of cover fractions based on agricultural change
  - Natural LCC: dynamic vegetation based on bioclimatic limits
  - Relocation of quantities for which matter is to be conserved upon land cover change

ICON-Land / JSBACH4 evaluation

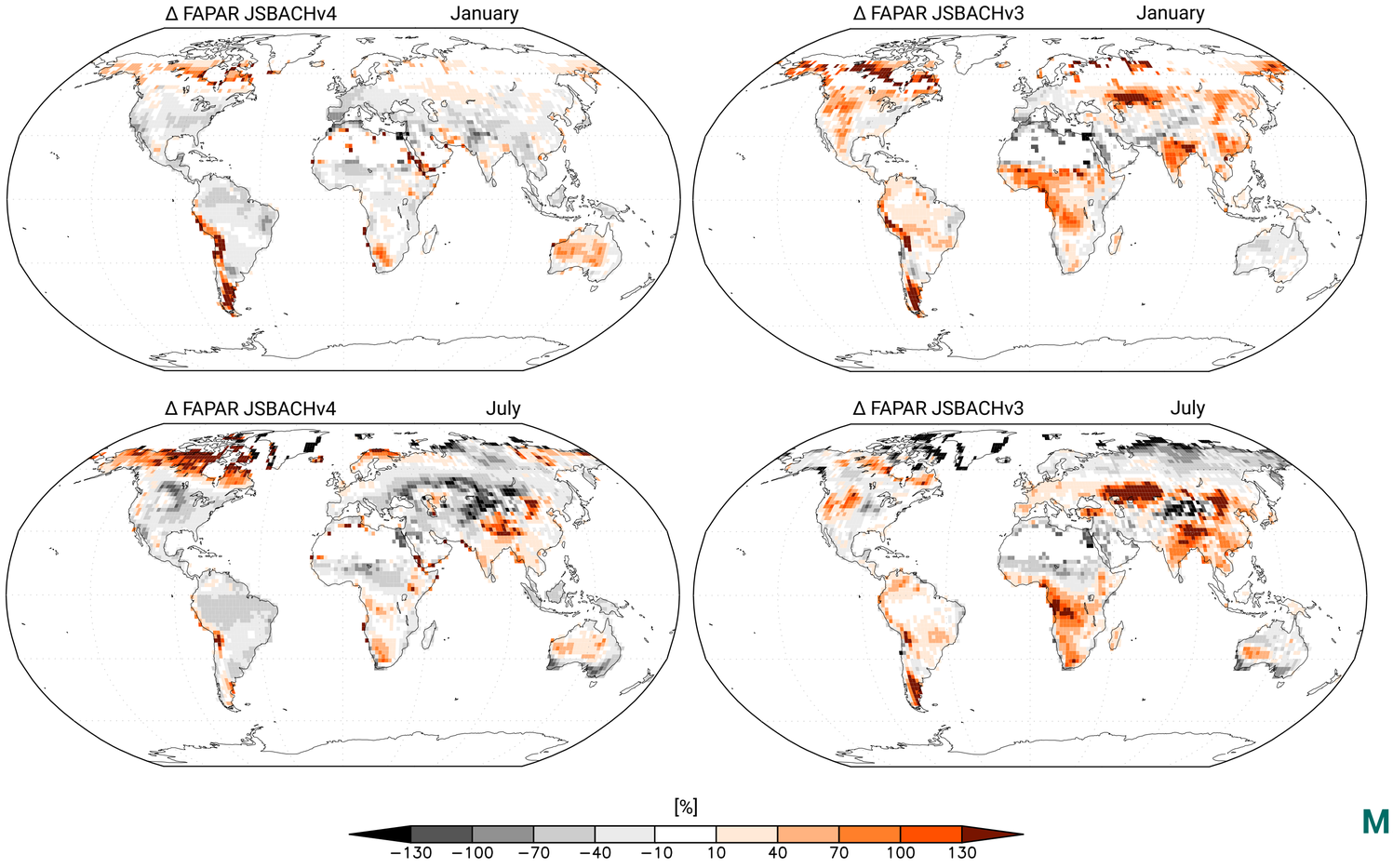
Bias in 2001-2014 Land Surface Temperature against MODIS observations



Schneck et al. in review, GMD

ICON-Land / JSBACH4 evaluation

Bias in 2001-2014 Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) against MODIS observations



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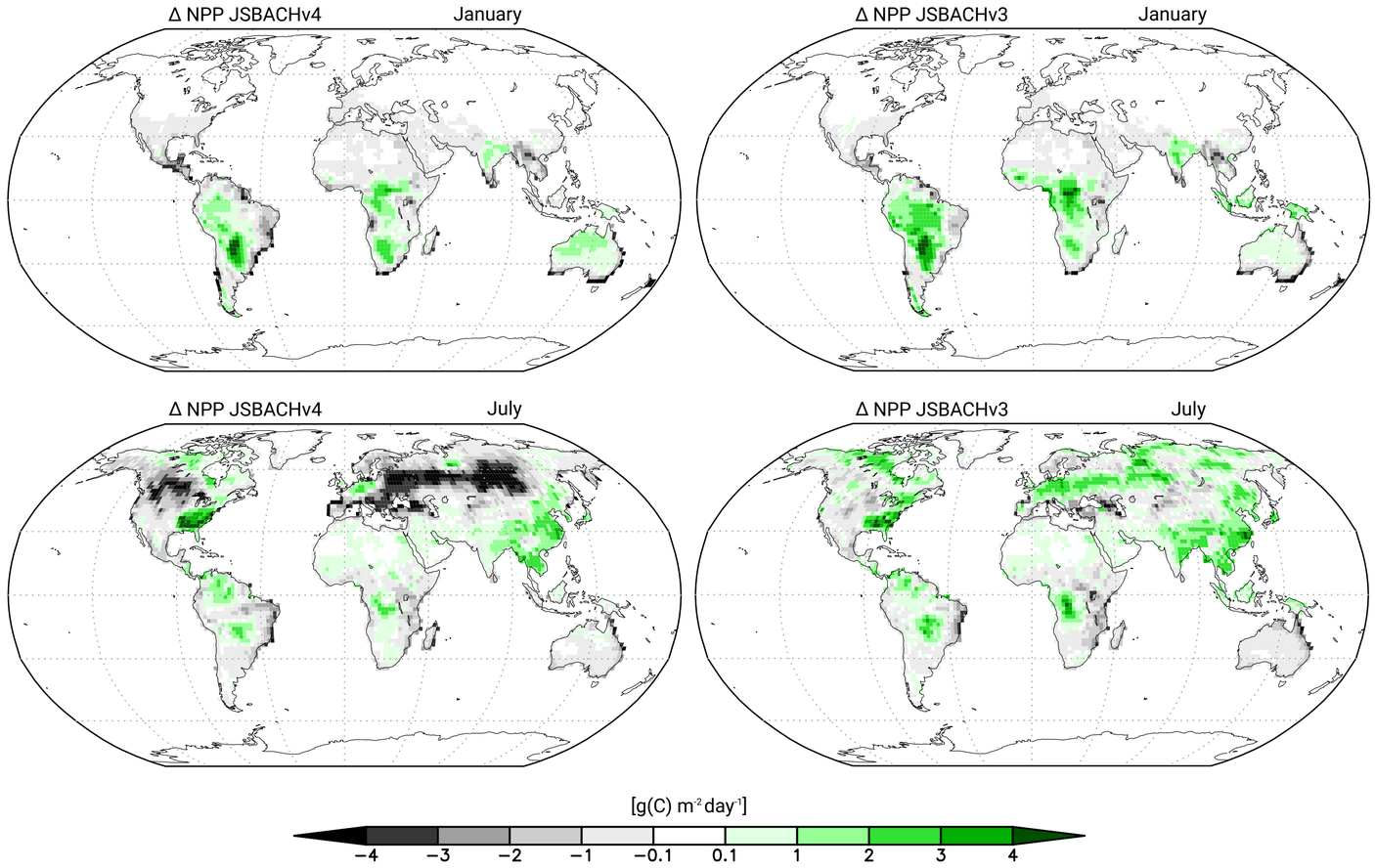
MAX-PLANCK-INSTITUT FÜR METEOROLOGIE

Schneck et al. in review, GMD

ICON-Land / JSBACH4 evaluation

Bias in 2001-2014 Net Primary production against MODIS estimates



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Schneck et al. in review, GMD

Focus: Boreal + Arctic environments (Victor Brovkin, MPI-M)

Rationale:

- the **permafrost** module performance in ICON-ESM1.0 (Ruby-0) was suboptimal in most of Siberia.

Too dry soils caused *too little ice in soils* and bias in surface energy budget, especially in summer, leading to *too dry atmosphere and potential boreal forest dieback*

Approach:

1. update hydrology and soil carbon processes in ICON/JSBACH-4 (ICON-Land) including recent permafrost developments in JSBACH (de Vrese et al., The Cryosphere, 2021)
2. run updated Ruby-0 model in AMIP and coupled experiments

Results:

- Pronounced warm-dry bias over continental areas in summer is reduced
- improved, more pronounced diurnal cycle in arid regions
- improved representation of the soil water and energy fluxes globally
- Distribution of ice in the soil layers in North America / Eurasia is improved

Cool Ruby: internal project at MPI-M

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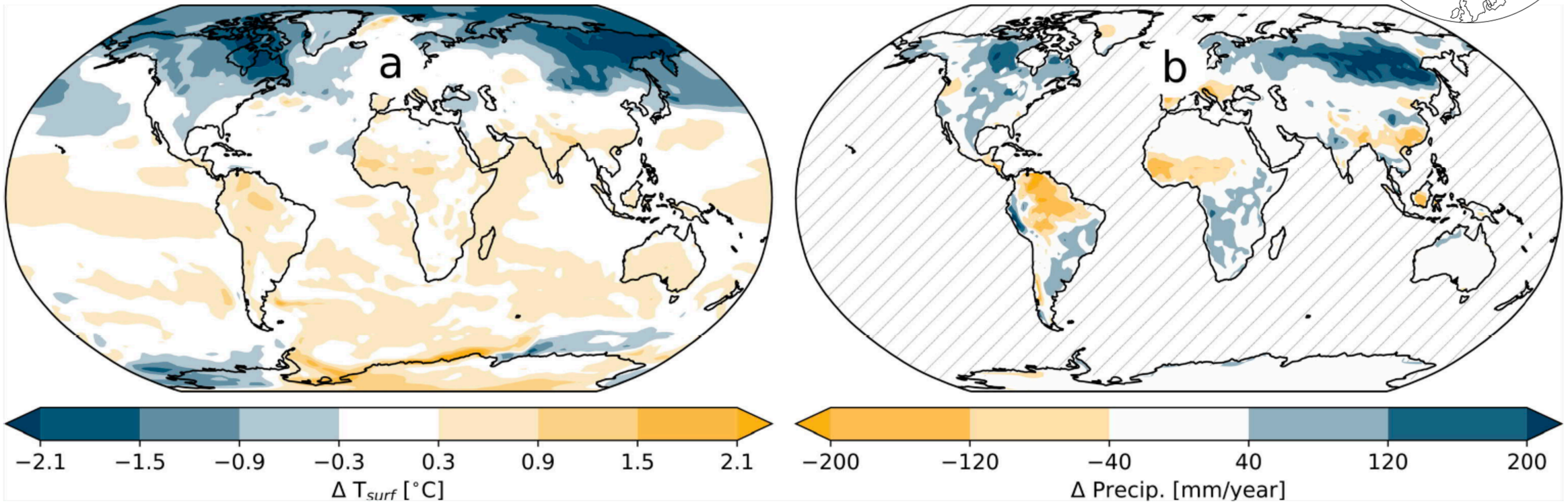
Wet vs Dry Arctic: changing permafrost hydrology in JSBACH

"Wet - Dry Arctic" impact on global climate at 1.5°C above pre-industrial levels



Changes in permafrost hydrology affect climate far beyond Arctic

- "Wet Arctic" setup leads to cooler North, warmer and drier tropics
- "Dry Arctic" setup results in warmer North, wetter tropics and North Africa

MPI-ESM results; to be repeated with the ICON-ESM

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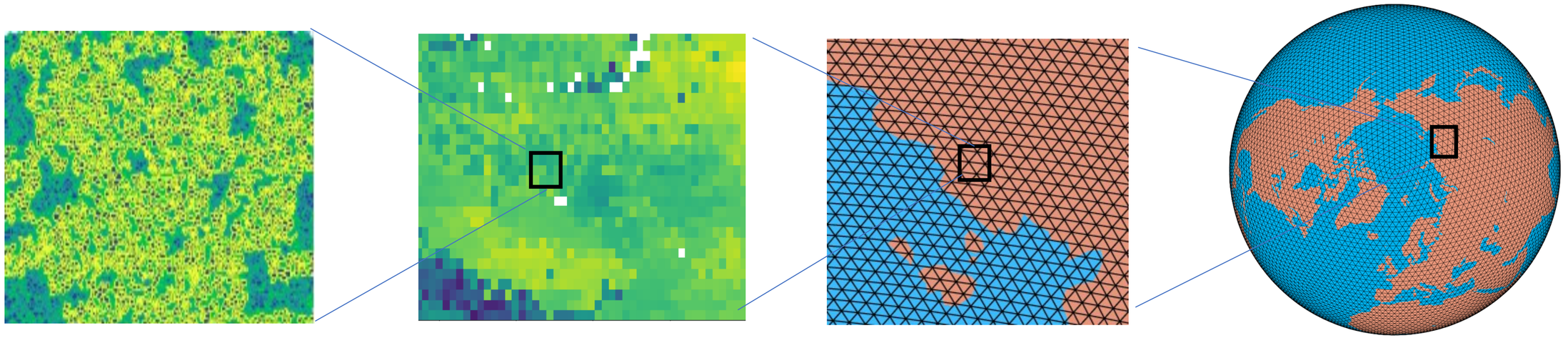
de Vrese et al., The Cryosphere, 2021

Q-ARCTIC: Multi-scale approach in the ICON framework

European Research Council

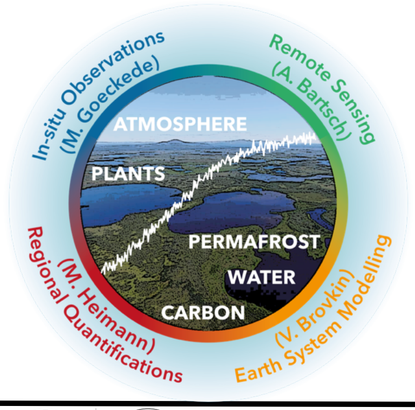
- lifetime: Oct 2021 – 2027

Micro scale | Meso scale | Macro scale



1-30 m | 1-5 km (JSBACH) | 40 km | 160 km (ICON-ESM 1.0)

- ESM resolution is too coarse to capture surface transformation after permafrost degradation
- Upscaling methods from *m* to *km* scale (Cresto-Aleina et al., 2013) and high-resolution pan-Arctic simulations of ICON-Land/JSBACH-4 within ICON-ESM
- JSBACH-4 is under restructuring: physical states & processes become tile-specific, new moisture classes (lake/pond, waterlogged, seasonally flooded, wet dry)
- *Pan-Arctic meso-scale simulations with updated JSBACH-4 are planned by the end of 2022*



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(modelling: Victor Brovkin, MPI-M)

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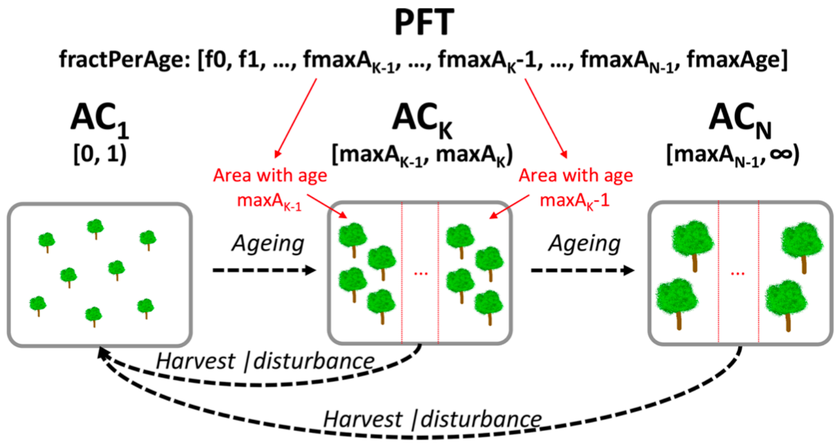
b·geos

Focus: Land-use change processes (Julia Pongratz, LMU)

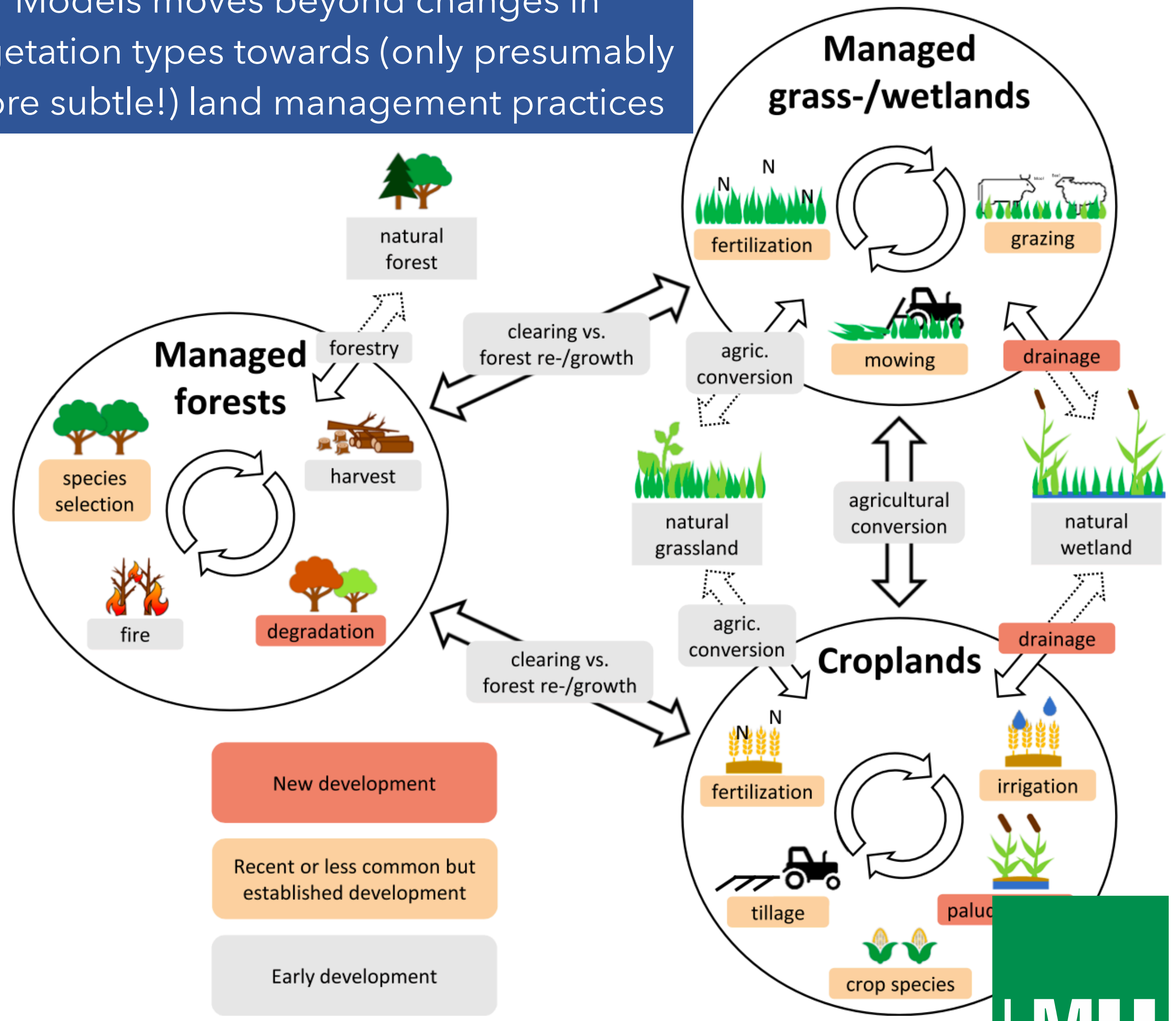
Ongoing developments in ICON-Land / JSBACH4:

- Implement (back- and forth) transitions between land-use types
- Integrate more land *management* practices (e.g., in ESM2025)

Forest age class implementation in JSBACH4



Land use representation in Earth System Models moves beyond changes in vegetation types towards (only presumably more subtle!) land management practices

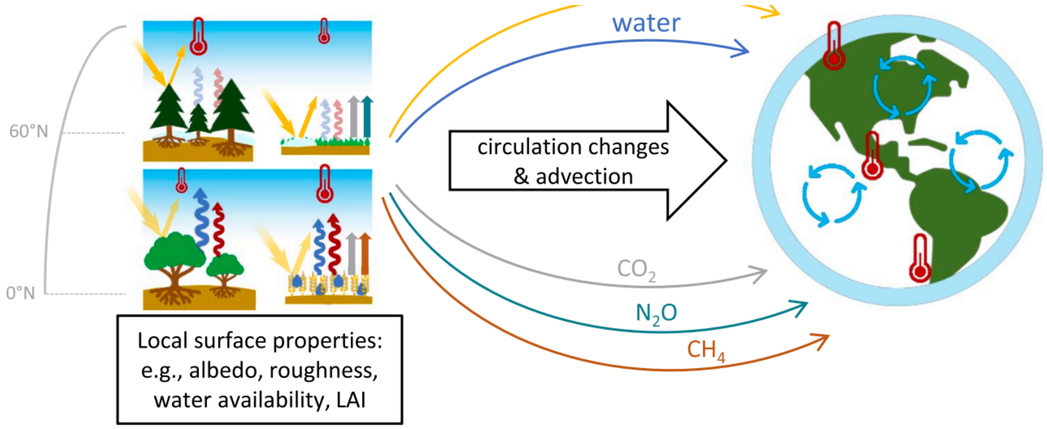


Nabel et al, *GMD,* 2020 Pongratz et al, *Current Clim. Change Reports,* 2021

Focus: Land-use change processes (Julia Pongratz, LMU)

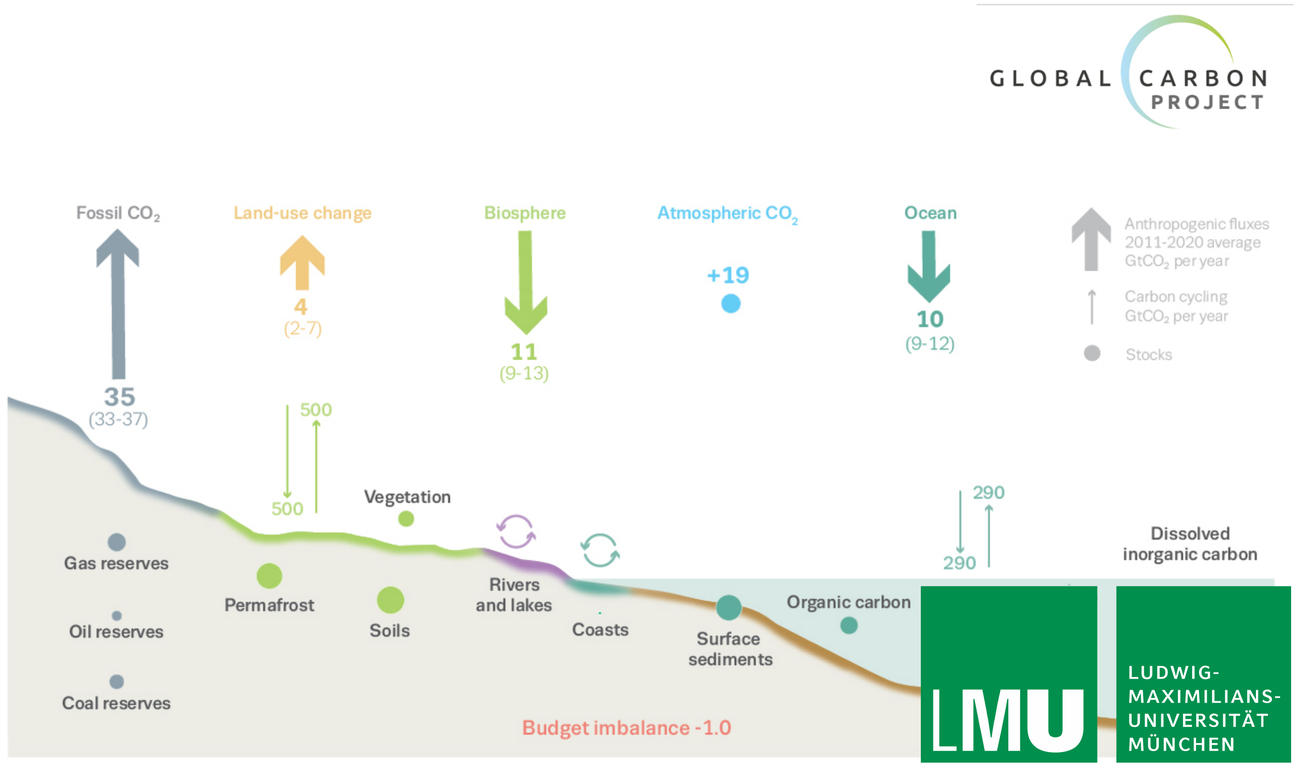
Focus: interactions of humans and climate via land use and land management

Assessing both carbon cycle and biogeophysical effects, from local to global scale



Example for application: Annual global carbon budgets.

? develop JSBACH further to better represent both the natural terrestrial CO_2 fluxes and the emissions and removals associated with land-use change.

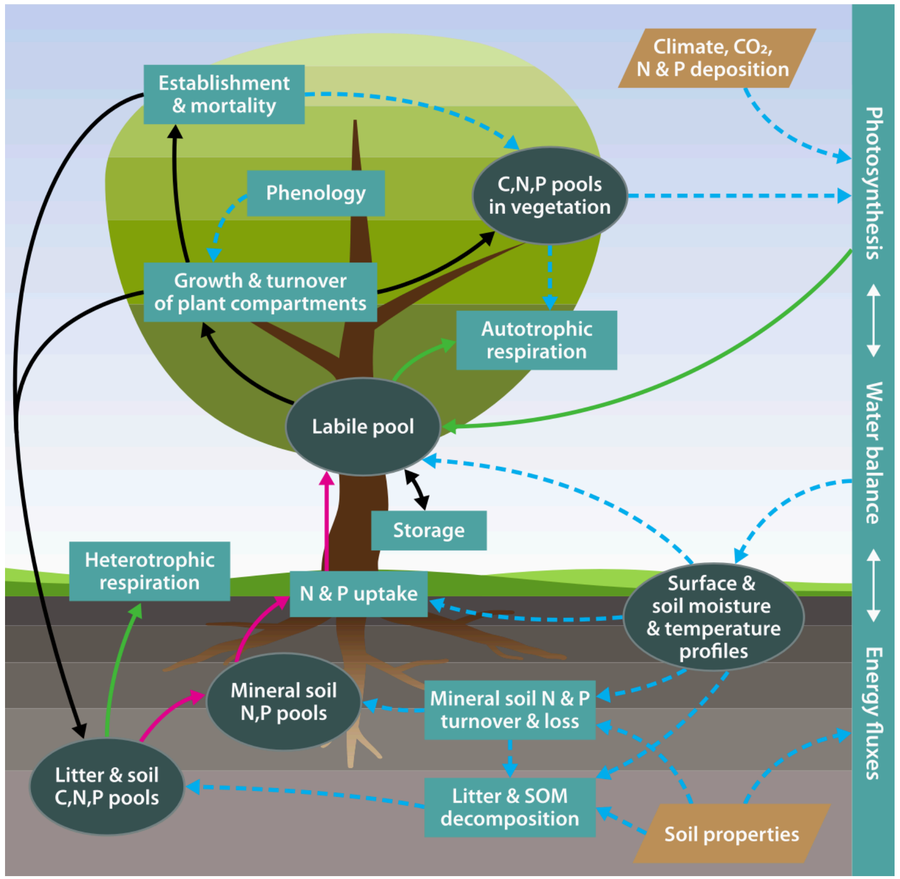


MPI-BGC Jena

Pongratz et al, *Current Clim. Change Reports,* 2021

Friedlingstein et al., *ESSD, in press*

QUINCY within ICON-Land
Processes Included



Thum et al. 2019, GMD, Yu et al. 2020, GMD, currently available under the GPL3 license, will move to BSD-license consistent with MPI-M

- *Surface energy balance, Multilayer soil physics, Lakes and HD. Land cover change (LCC) (similar to JSBACH4)*
- Multi-layer snow model + simple permafrost
- Phenology (LAI): dependent on plant physiology, stand properties and biogeochemistry, and trade-off between root and leaf growth
- Photosynthesis: coupled N-P limited assimiliation and water loss taking into account diffuse and direct radiation / sunlit and shaded leaves / plant buffering capacity
- Natural biogeochemical cycles: coupled carbon-nitrogen-phosphorus biogeochemistry affecting plant growth and allocation, soil and litter dynamics, including stable C and N isotopes
- Emission and deposition of N-trace gases (eg. NO_x, N_2O)
- Designed for ensemble studies/parameter sensitivity studies
- Natural disturbances of vegetation by fires and wind throw (through a new ERC grant)

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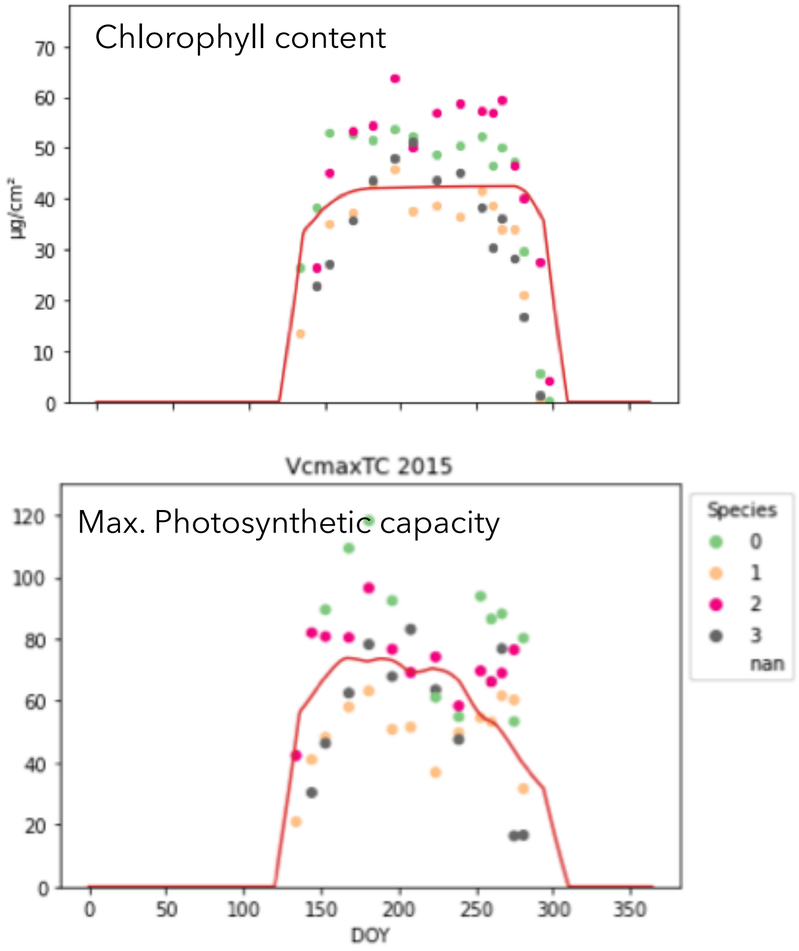
Focus: Integration of in-situ and remotely sensed data (ICON-Land/QUINCY)

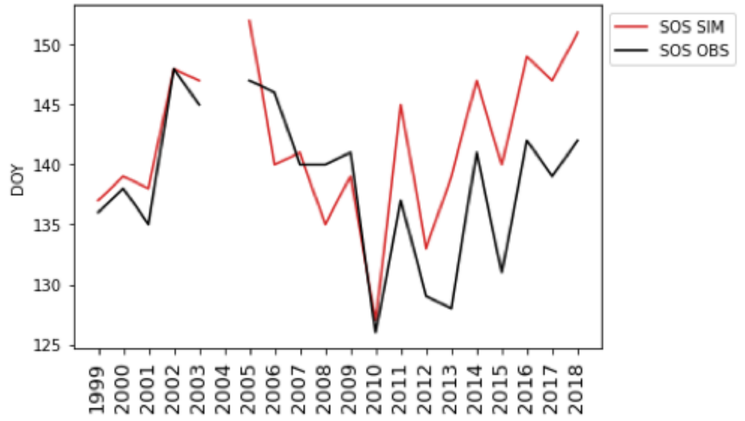
Observed and simulated variability of vegetation activity states
(start and end of growing season, based on LAI)



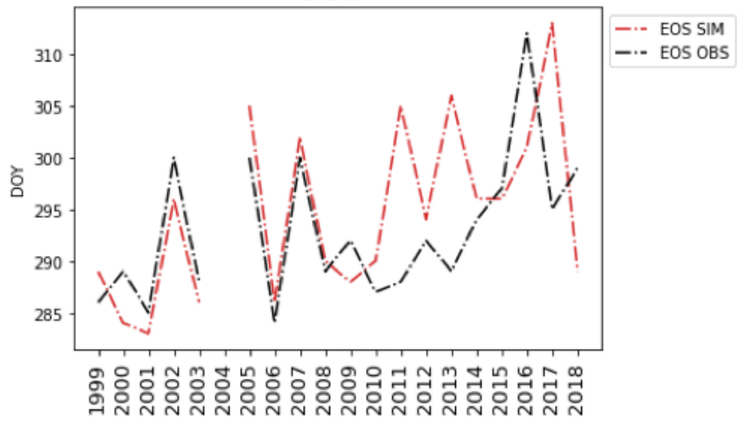
11 % Bigtooth aspen
73 % Red Maple
4 % Trembling aspen
12 % White ash

Observed and simulated variability of key phenological states
(start and end of growing season, based on LAI)

Start of growing season



End of growing season



Seppelä in prep

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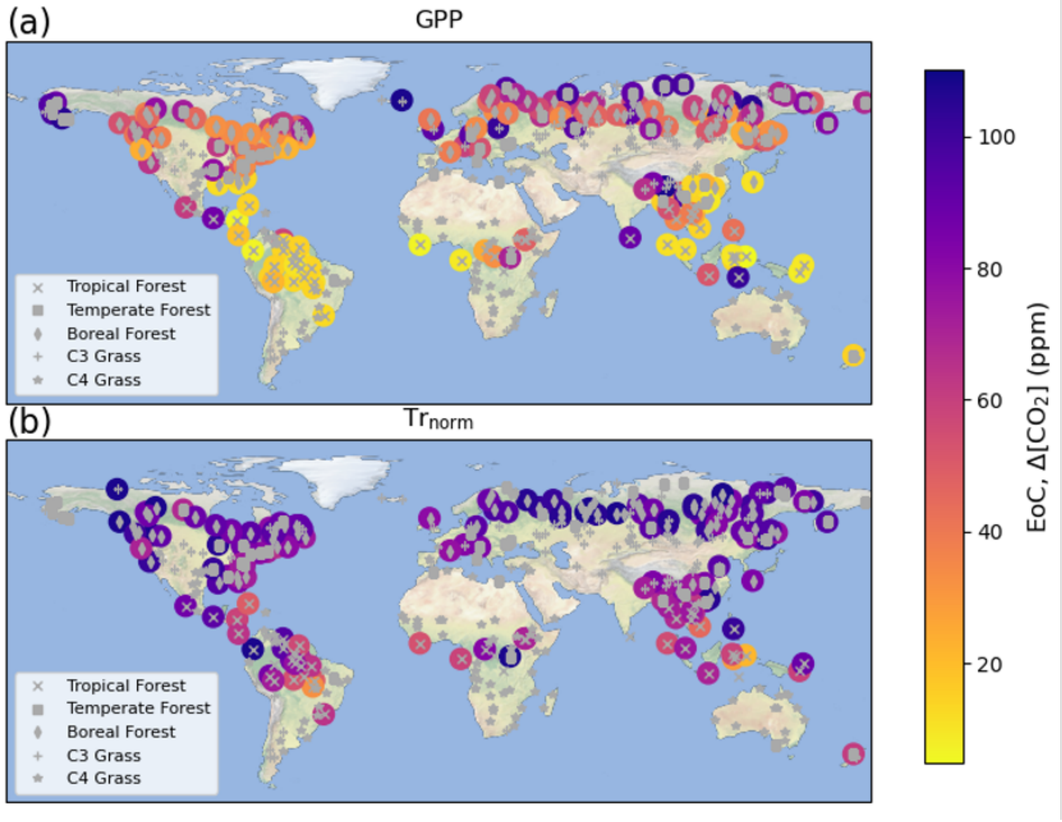
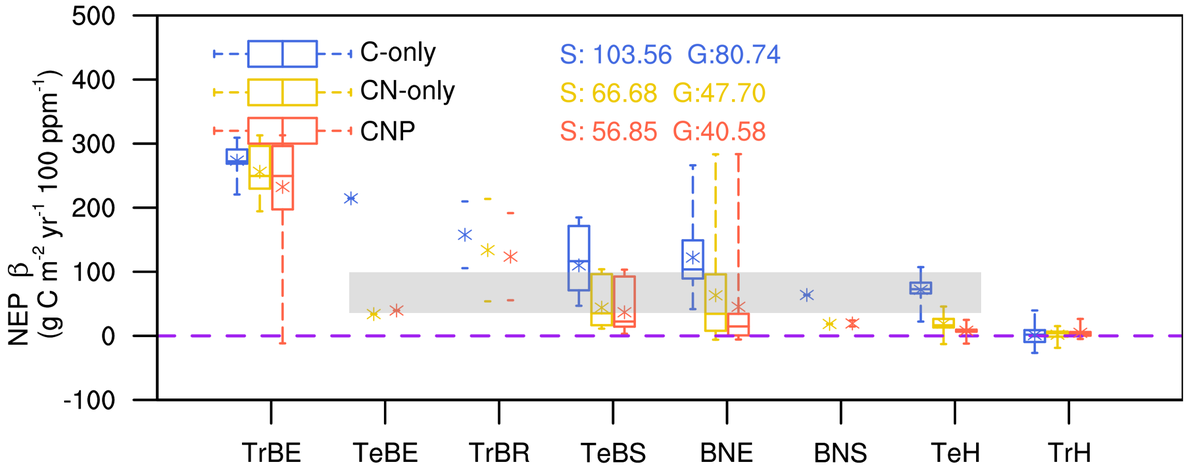
Focus: Biospheric responses to elevated CO_2 (ICON-Land/QUINCY)

When can we robustly detect trends in carbon and water cycle?



Nutrient constraints on the carbon storage response to rising CO_2



Observed range (outside tropics), Lui et al. 2019

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Zhang et al. in review, Gong et al., in prep.

European Research Council

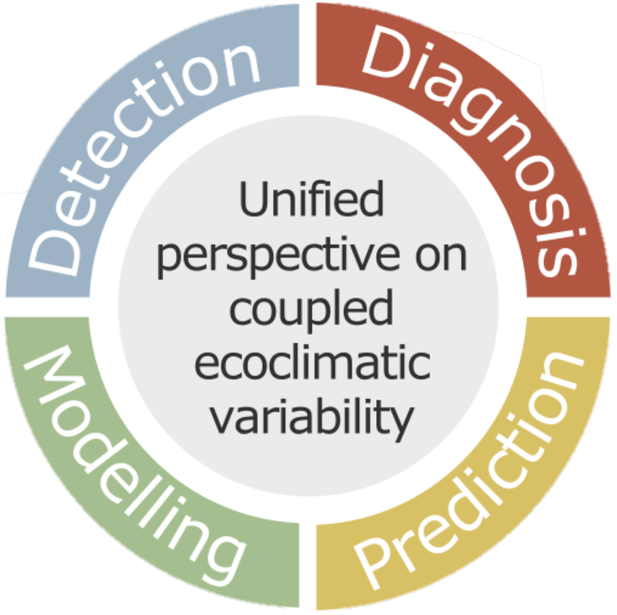
ForEXD

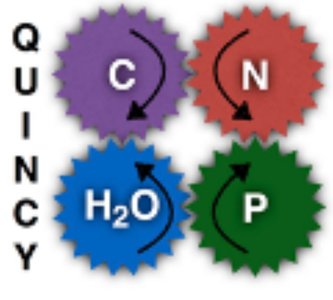
Forest vulnerability to compound extremes and disturbances in a changing climate

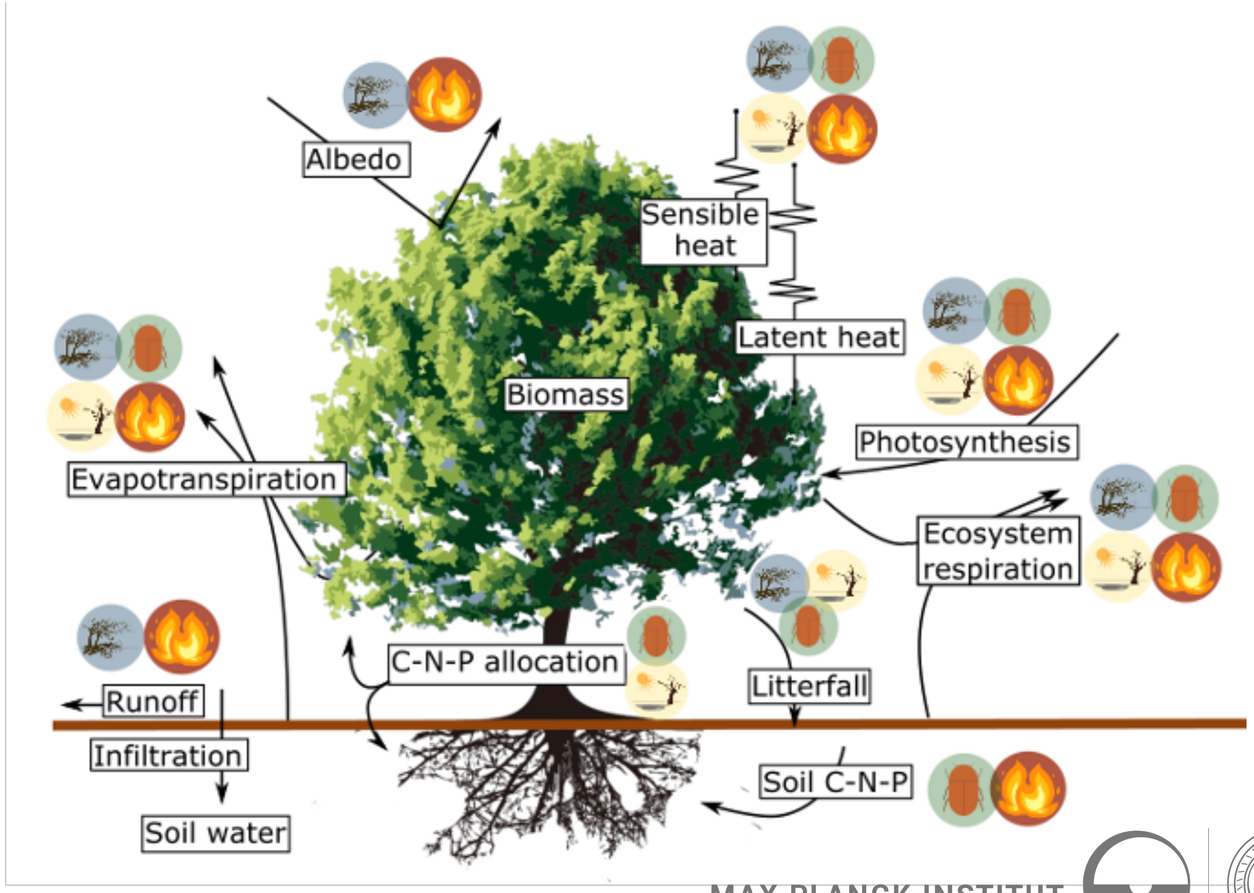
Improved representation of disturbance processes and feedbacks in ICON-Land QUINCY

+

Model-Data Synthesis and ML to better quantify disturbance dynamics







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ICON-Land in a nutshell

- ICON-Land: generic modelling framework for land processes
  - operational JSBACH4 implementation
    - current focus on high arctic and land-use processes
  - pre-operational QUINCY implementation
    - focus on „biology“ effects on land-surface processes and associated climate feedbacks, which should „seamlessly“ interact with relevant JSBACH4 processes
- parallel work planned on hydrology within Warm-World project

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Just for info: ICON-Land/QUINCY global simulation

Gross primary production (2001-2015 average)