From static to dynamic soil properties in JULES: implications for high-latitude simulations

Rémi Gaillard, Eleanor Burke, Stephen Sitch and Pierre Friedlingstein

r.gaillard@exeter.ac.uk

University of Exeter

JULES
Joint UK Land Environment Simulator

Outline

Part 1

Implementation physically consistent soil properties in JULES, including organic soils.
Manuscript in review in JAMES.

Part 2

Dynamic soil properties in JULES: coupling soil physics and carbon cycle.
Ongoing work.

Soil thermal and hydraulic properties in JULES (and most land surface models)

Option 1 : fixed properties

Dataset of soil texture, carbon and density + pedotransfer functions

↓ *Mineral soil or mineral + organic soil*

Fixed map of soil properties

Porosity
Hydraulic conductivity
Thermal conductivity
Heat capacity...

↓

JULES physics and carbon cycle

Used in most land surface models

Soil thermal and hydraulic properties in JULES (and most land surface models)

Option 1 : fixed properties

Dataset of soil texture, carbon and density + pedotransfer functions

↓ *Mineral soil or mineral + organic soil*

Fixed map of soil properties

↓

JULES physics and carbon cycle

Used in most land surface models

Limitations

→ Only 5/18 CMIP6 ESMs evaluated in Burke et al. (2020) include organic soils.

→ Organic soil representations rely on empirical parameterisations that lack physical consistency.

→ Generally no distinction between soil organic carbon (SOC) and total soil organic matter (SOM).

Soil thermal and hydraulic properties in JULES (and most land surface models)

Option 1 : fixed properties

Dataset of soil texture, carbon and density + pedotransfer functions

Mineral soil or mineral + organic soil

↓

Fixed map of soil properties

↓

JULES physics and carbon cycle

Used in most land surface models

Limitations

→ Only 5/18 CMIP6 ESMs evaluated in Burke et al. (2020) include organic soils.

→ Organic soil representations rely on empirical parameterisations that lack physical consistency.

→ Generally no distinction between soil organic carbon (SOC) and total soil organic matter (SOM).

→ New physically-consistent framework based on soil mixture theory (Decharme, 2025; Decharme et al. 2026)

Geosci. Model Dev., 18, 9349–9384, 2025
https://doi.org/10.5194/gmd-18-9349-2025

Geoscientific Model Development
Open Access
EGU

A process-based modeling of soil organic matter physical properties for land surface models – Part 1: Soil mixture theory

Bertrand Decharme
Météo-France, CNRS, Univ. Toulouse, CNRM, Toulouse, France

Geoscientific Model Development
Open Access
EGU

A process-based modeling of soil organic matter physical properties for land surface models – Part 2: Global land surface simulations and mineral soil compactness adjustment

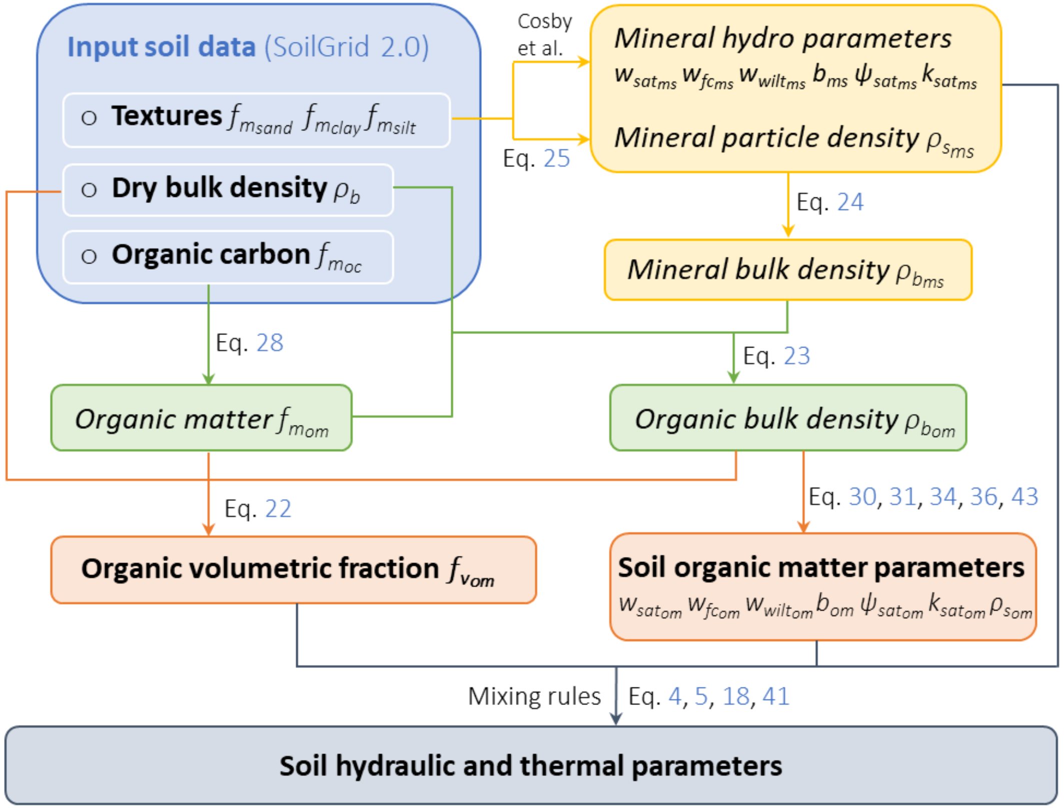
Bertrand Decharme[1], Diane Tzanos[1], Lucas Hardouin[1], Aaron Boone[1], Marie Minvielle[1], Patrick Le Moigne[1], and Rémi Gaillard[2]
[1]Météo-France, CNRS, Univ. Toulouse, CNRM, Toulouse, France
[2]Faculty of Environment, Science and Economy, University of Exeter, Exeter, UK

Framework from Decharme (2025)

→ Based on global gridded input soil data.

→ Mineral and organic soil properties calculated separately, then mixed based on their volumetric fractions.

→ Soil bulk density becomes a critical input.



Decharme et al. (2026)

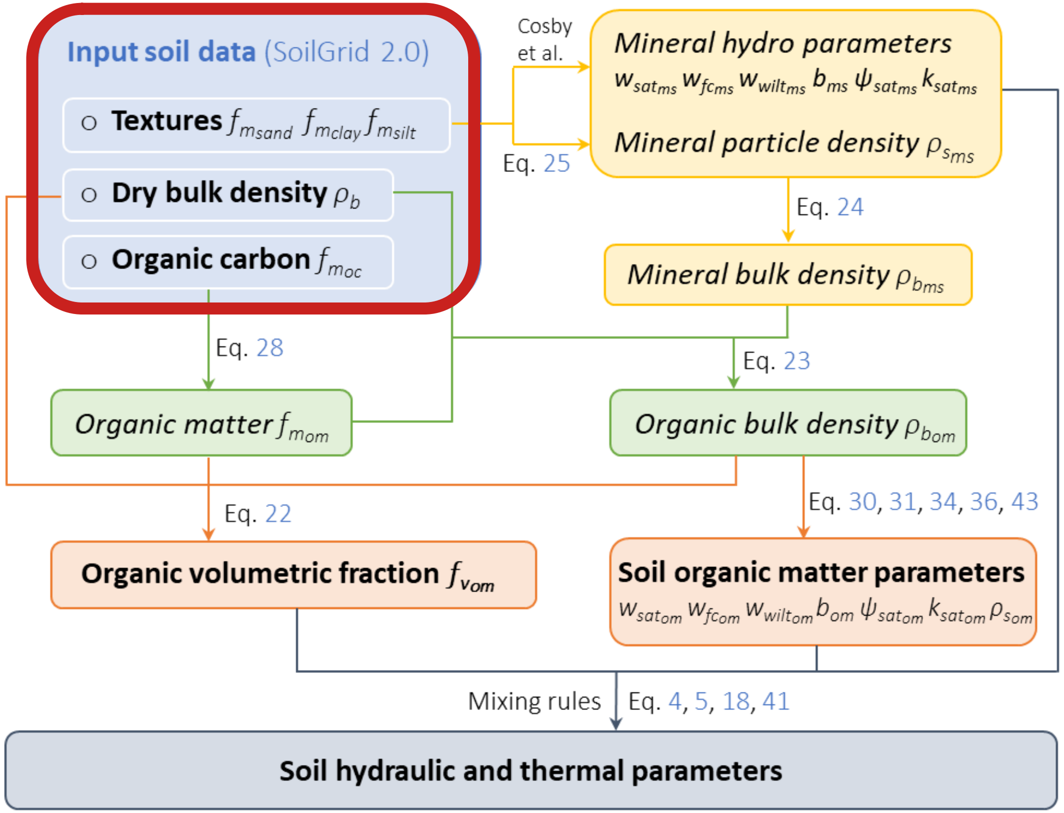
Framework from Decharme (2025)

This approach depends on the quality of input data.

→ Based on global gridded input soil data.

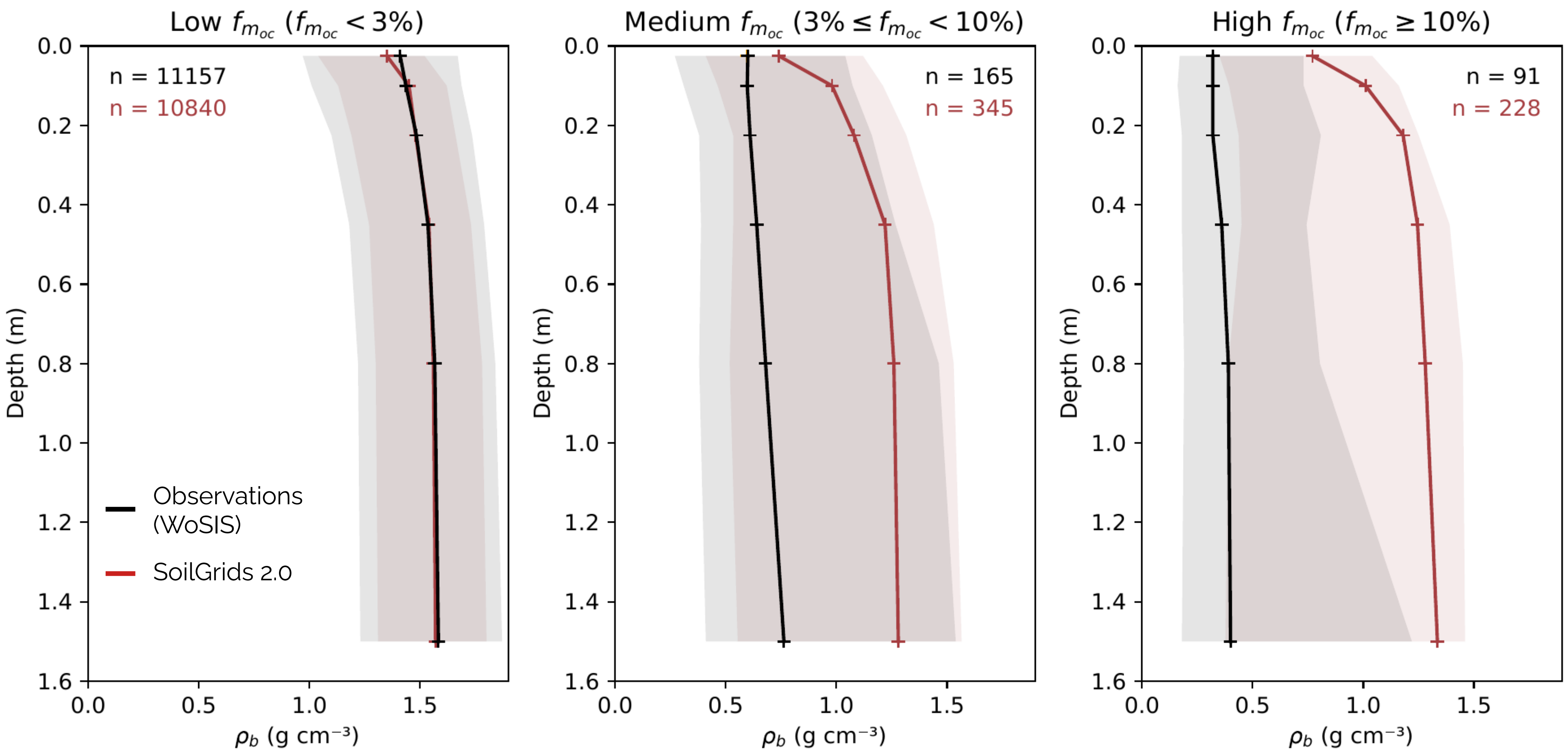
→ Mineral and organic soil properties calculated separately, then mixed based on their volumetric fractions.

→ Soil bulk density becomes a critical input.



Decharme et al. (2026)

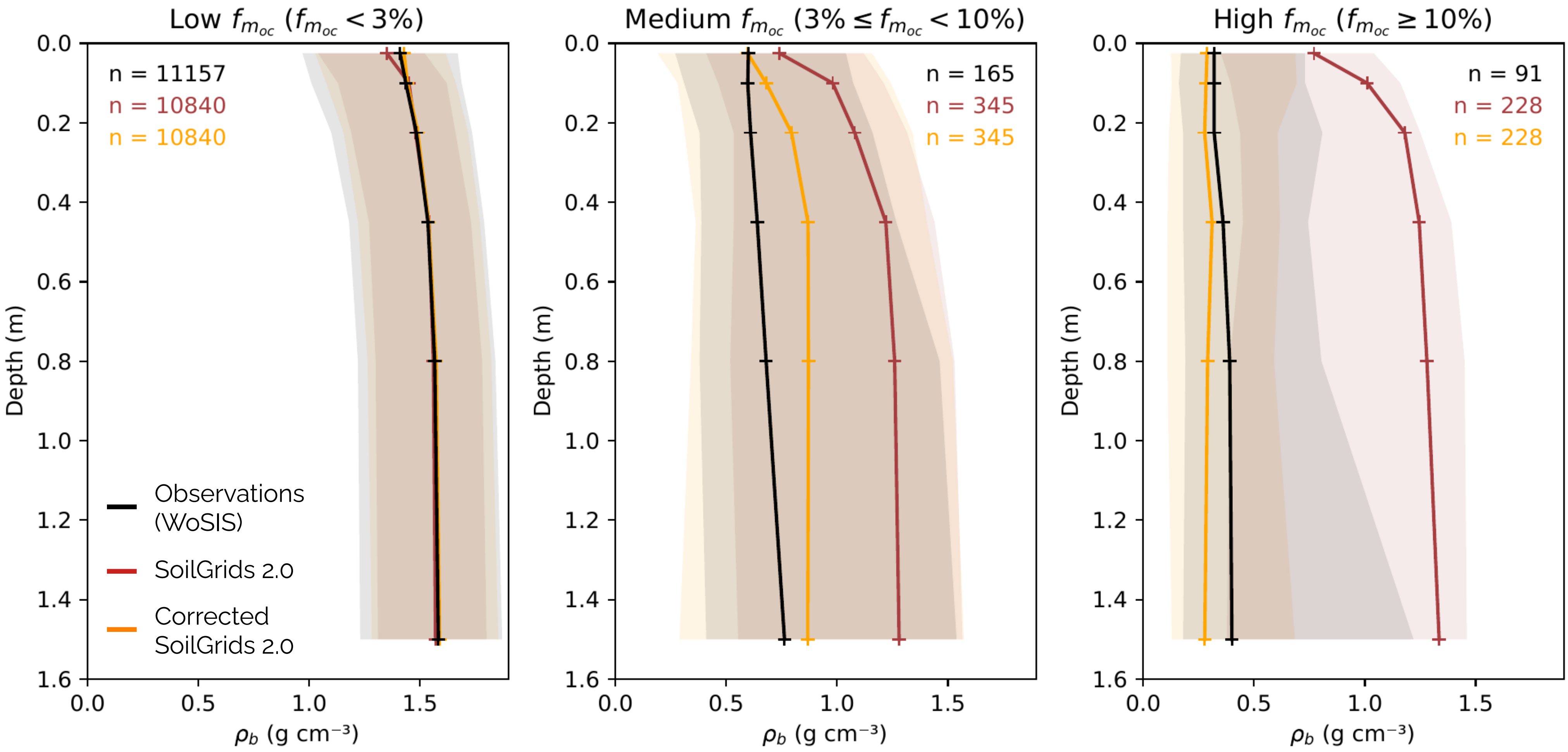
Bulk density is overestimated in carbon-rich regions in global soil datasets



f_{moc} = organic carbon mass fraction

Gaillard et al. (in review)

Machine-learning correction of bulk density provides better agreement with observations



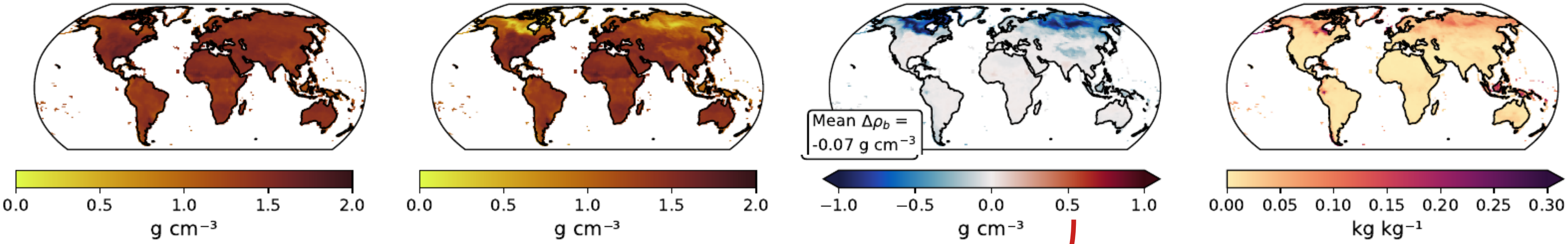
f_{moc} = organic carbon mass fraction

Gaillard et al. (in review)

Machine-learning correction of bulk density provides better agreement with observations

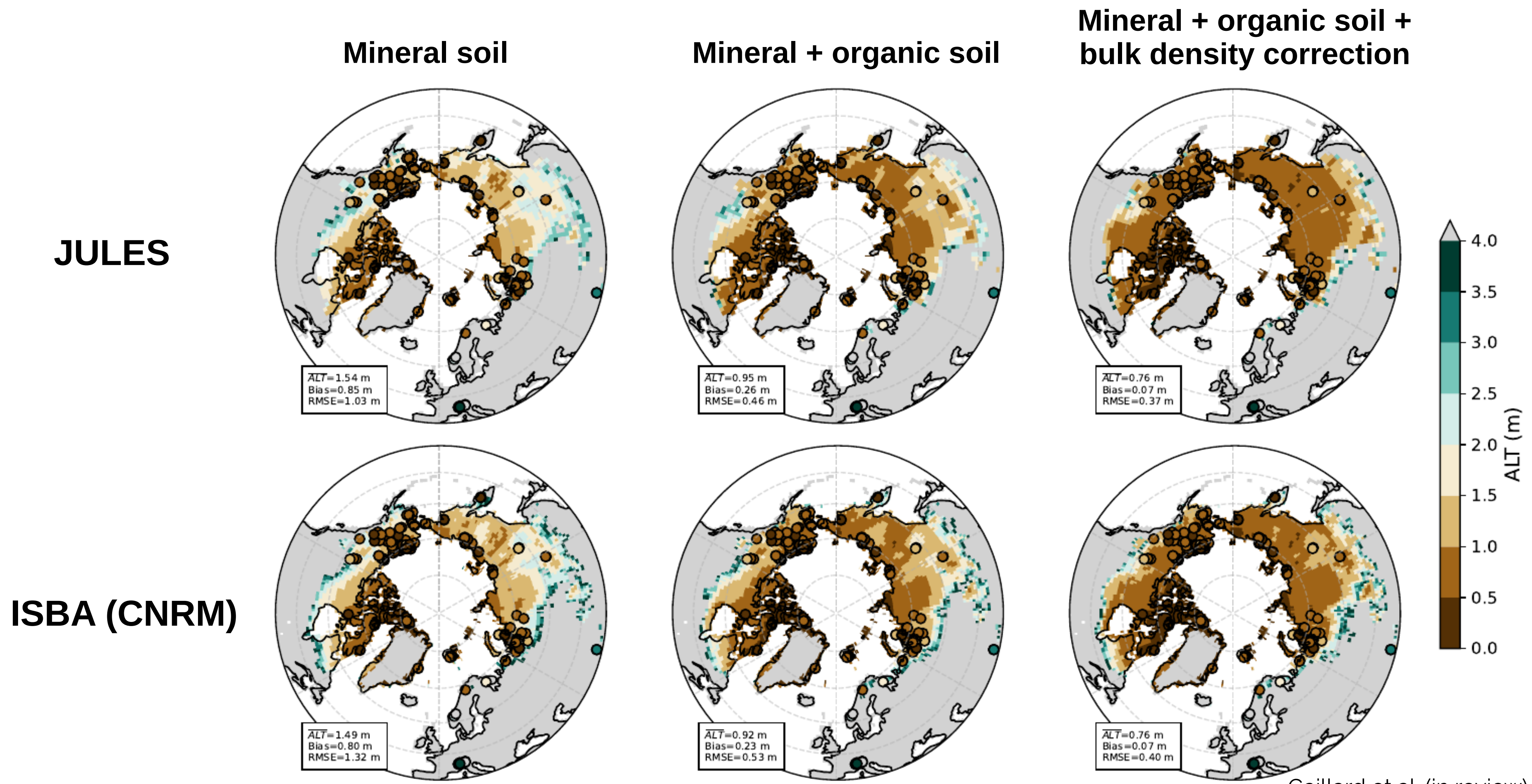
Example at a depth of 0.5 m

Original bulk density | Corrected bulk density | Corrected - Original | Soil carbon mass fraction



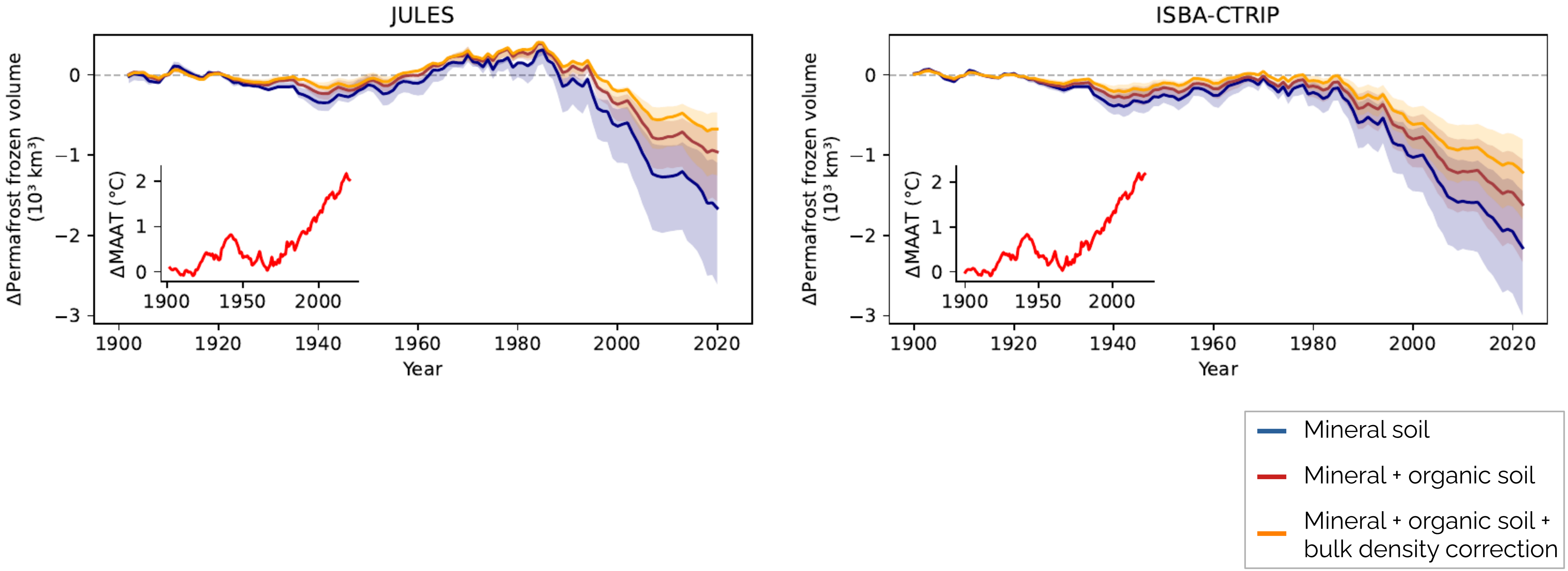
Correction decreases soil densities at northern high latitudes

Simulated active layer thickness is improved in two LSMs



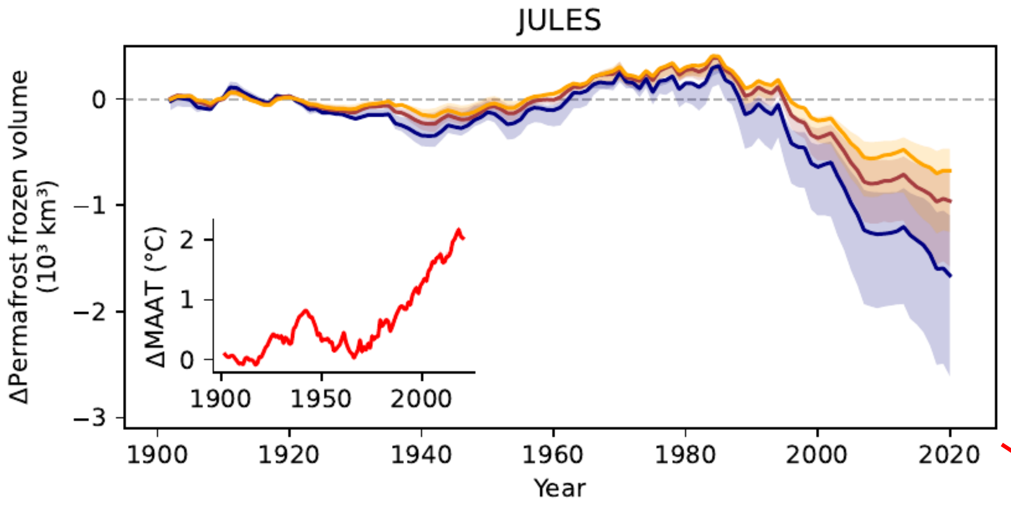
Gaillard et al. (in review)

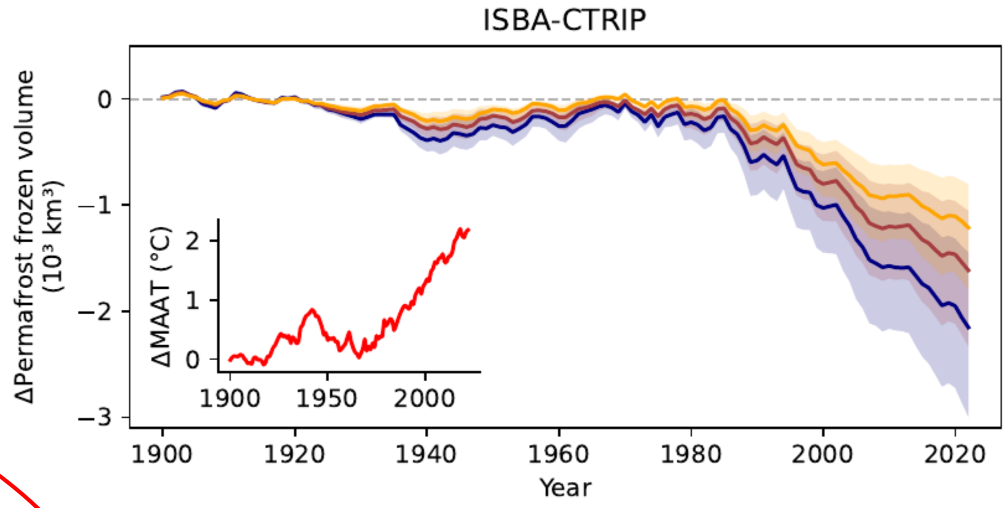
The correction reduces permafrost sensitivity to warming

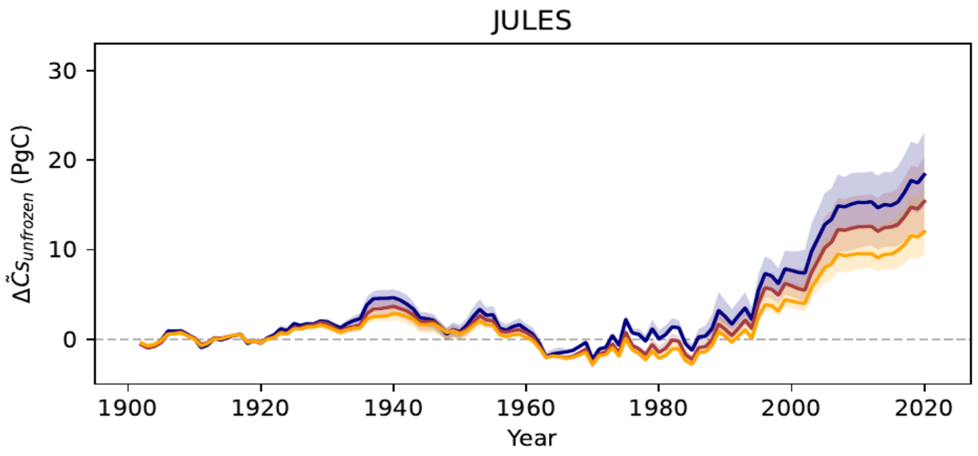


Gaillard et al. (in review)

The correction reduces permafrost sensitivity to warming







Reduced exposure of soil carbon to decomposition with the correction

Mineral soil

Mineral + organic soil

Mineral + organic soil + bulk density correction

Gaillard et al. (in review)

Thank you !

r.gaillard@exeter.ac.uk

University of Exeter

JULES
Joint UK Land Environment Simulator