JULES-CNP: Towards Improved Nutrient Limitation Representation for Mature Temperate Deciduous Forests

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JULES annual meeting, Leicester

15.09.25

UK Centre for Ecology & Hydrology

Credit: University of Birmingham, BIFoR FACE

Motivation: Why nutrients matter

- **Mature temperate forests = critical carbon sinks**
- **Nutrient availability (N & P)** regulates carbon uptake
- **Uncertainty in nutrient limitation → uncertainty in climate projections & policy decisions**

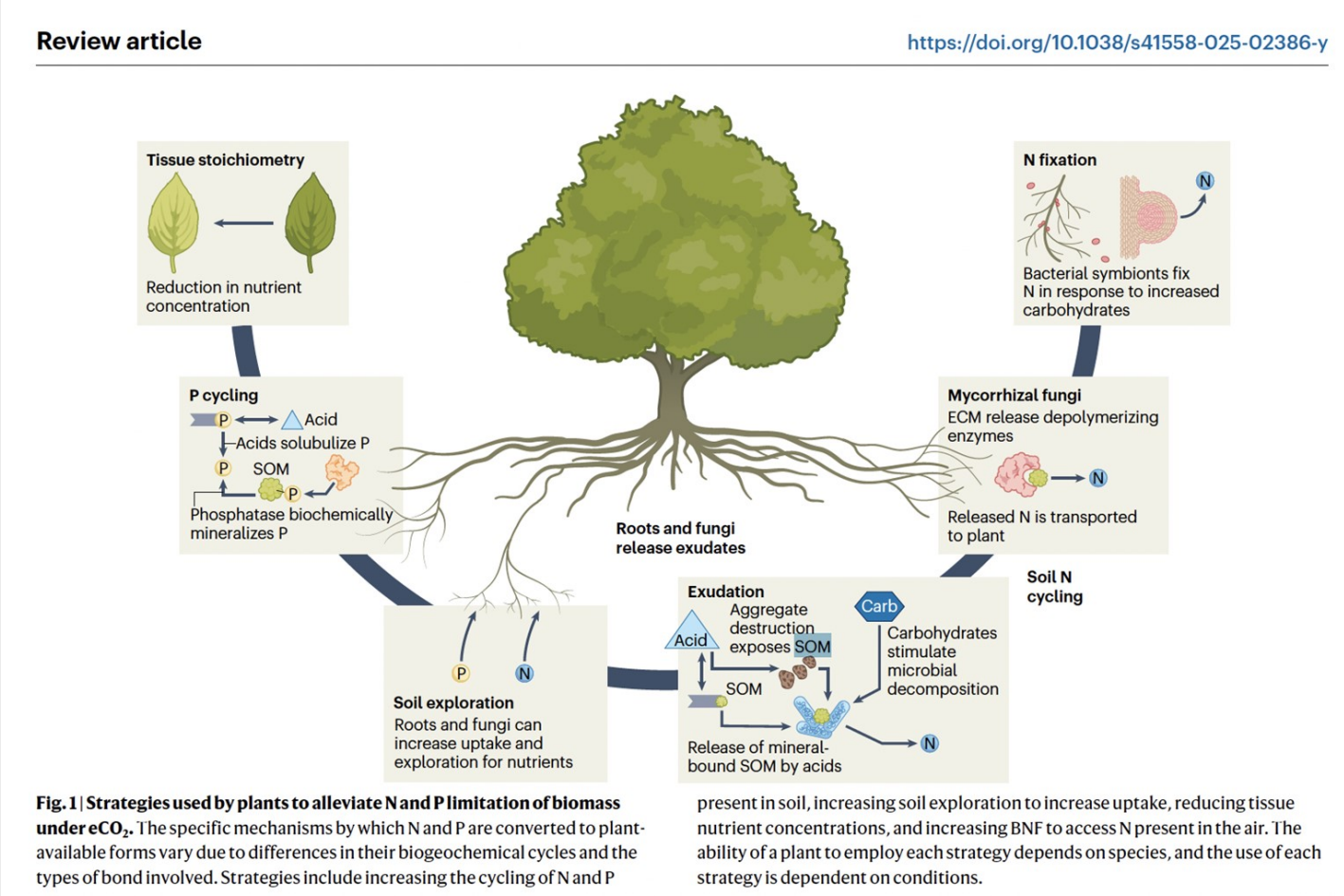


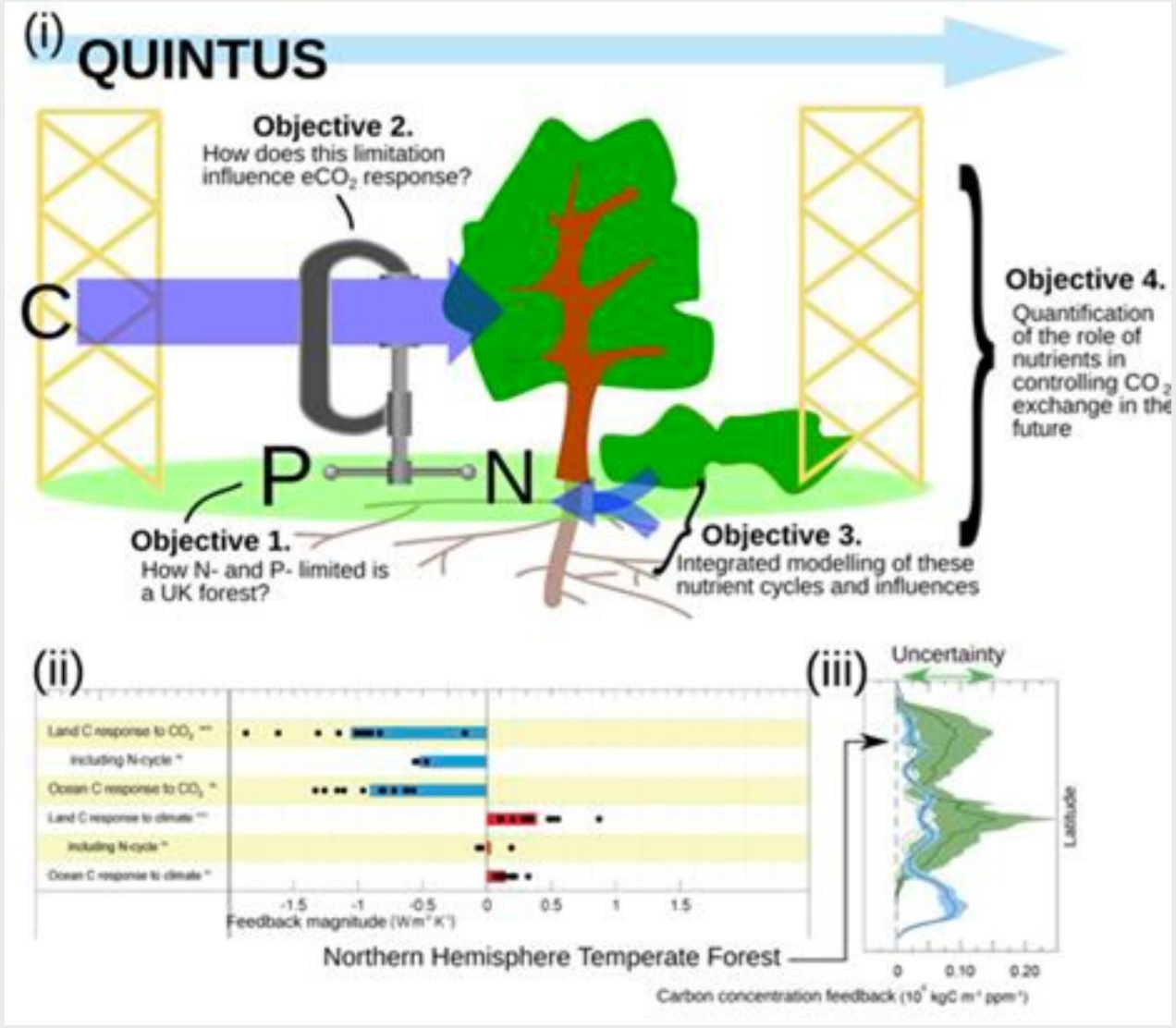
Fig. 1 | Strategies used by plants to alleviate N and P limitation of biomass under eCO_2. The specific mechanisms by which N and P are converted to plant-available forms vary due to differences in their biogeochemical cycles and the types of bond involved. Strategies include increasing the cycling of N and P present in soil, increasing soil exploration to increase uptake, reducing tissue nutrient concentrations, and increasing BNF to access N present in the air. The ability of a plant to employ each strategy depends on species, and the use of each strategy is dependent on conditions.

Source: Cambron et al., 2025, *Nature Climate Change*

QUINTUS* Project

*Quinquennial Carbon and Nutrient Dynamics in Temperate Forests

- **Aim:** **reduce uncertainty** in carbon–climate feedbacks
- **Approach:** combine **Free-Air CO_2 Enrichment (FACE)** experiment at **BIFoR (Birmingham Institute of Forest Research, UK)** with model development
- **JULES** as the central modelling tool



Source: QUINTUS Project Proposal

JULES and nutrient limitation

- **JULES**: UK land surface model (Clark et al., 2011)
- Previous developments:
  - **CN** scheme (Wiltshire et al., 2021)
  - **CNP** scheme (Nakhavali et al., 2022)
- Our work: **porting CNP** to **JULES v7.8** → aligned with current developments

Geosci. Model Dev., 14, 2161–2186, 2021
https://doi.org/10.5194/gmd-14-2161-2021

Geoscientific Model Development

JULES-CN: a coupled terrestrial carbon–nitrogen scheme (JULES vn5.1)

Andrew J. Wiltshire[1,2], Eleanor J. Burke[1], Sarah E. Chadburn[3], Chris D. Jones[1], Peter M. Cox[3], Taraka Davies-Barnard[3], Pierre Friedlingstein[3], Anna B. Harper[3], Spencer Liddicoat[1], Stephen Sitch[2], and Sönke Zaehle[4]

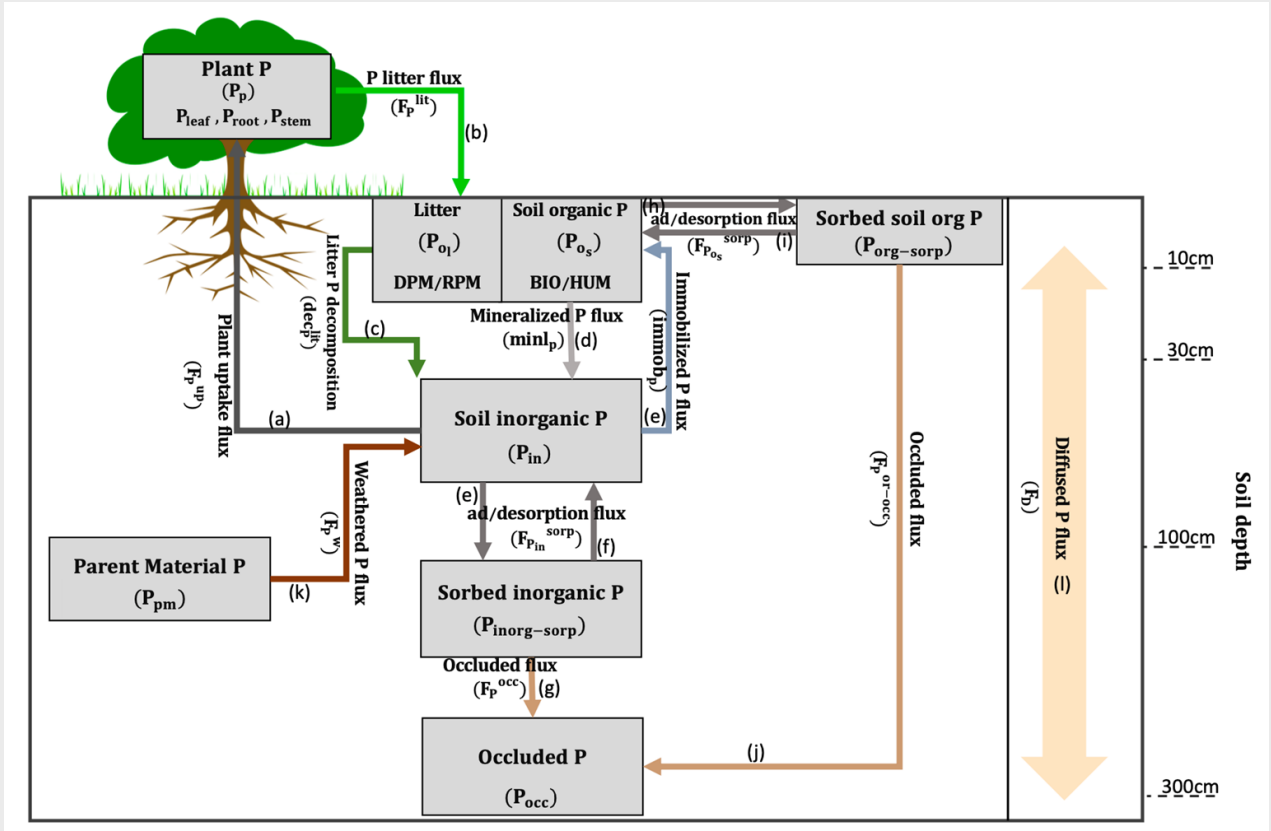
Geosci. Model Dev., 15, 5241–5269, 2022
https://doi.org/10.5194/gmd-15-5241-2022

Geoscientific Model Development

Model description paper

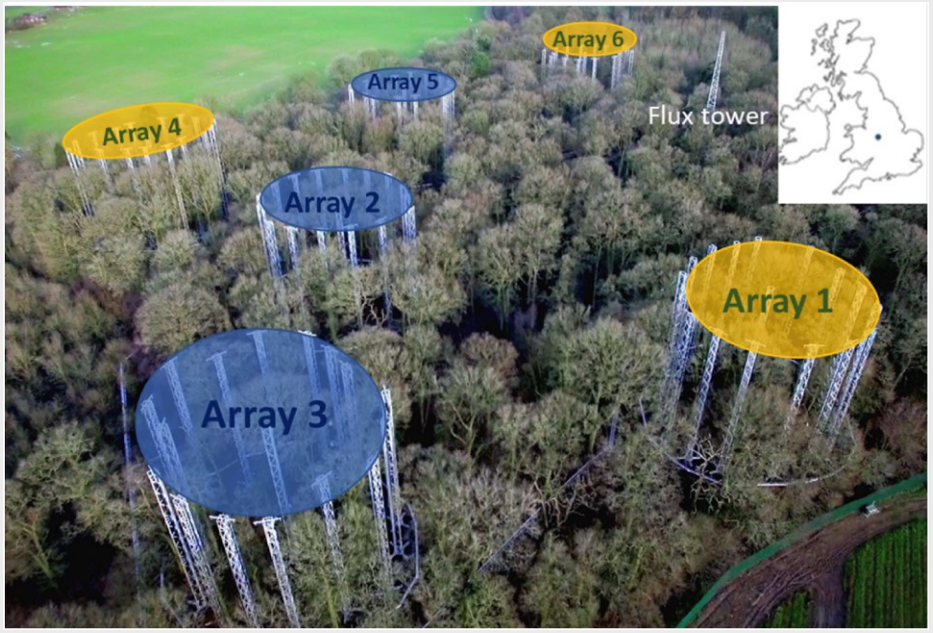
Representation of the phosphorus cycle in the Joint UK Land Environment Simulator (vn5.5_JULES-CNP)

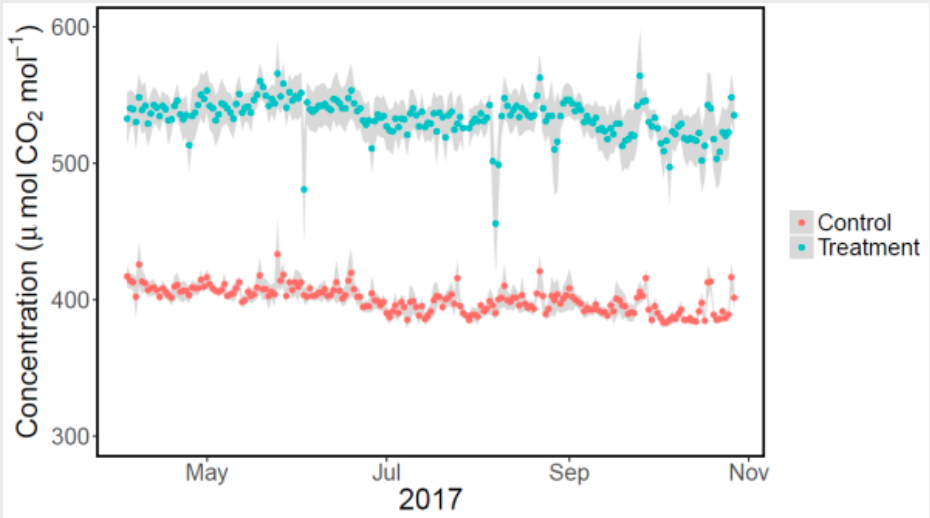
Mahdi André Nakhavali[1], Lina M. Mercado[1,2], Iain P. Hartley[1], Stephen Sitch[1], Fernanda V. Cunha[3], Raffaello di Ponzio[3], Laynara F. Lugli[3], Carlos A. Quesada[3], Kelly M. Andersen[1,4,5], Sarah E. Chadburn[6], Andy J. Wiltshire[1,7], Douglas B. Clark[2], Gyovanni Ribeiro[3], Lara Siebert[3], Anna C. M. Moraes[3], Jéssica Schmeisk Rosa[3], Rafael Assis[3], and José L. Camargo[3]



Study site: BIFoR FACE (Mill Haft, Staffordshire, UK)

- **First whole-ecosystem FACE experiment** in a mature temperate forest (**since 2017**).
- **20 ha deciduous woodland**, dominated by 160-year-old oak with mixed understory.
- Six experimental arrays: three ambient (**aCO_2**, **Array 2, 3, 5**) and three fumigated with **+150 ppm CO_2** (**eCO_2**, **Array 1, 4, 6**).
- **eCO_2 delivered continuously** into 25 m diameter plots; monitored with dense sensor network.
- **Unique long-term experiment** (planned 2017–2026) testing CO_2 impacts on an unmanaged, mature forest.
- Provides both ambient and elevated CO_2 time series and **ecosystem response** data to benchmark JULES.



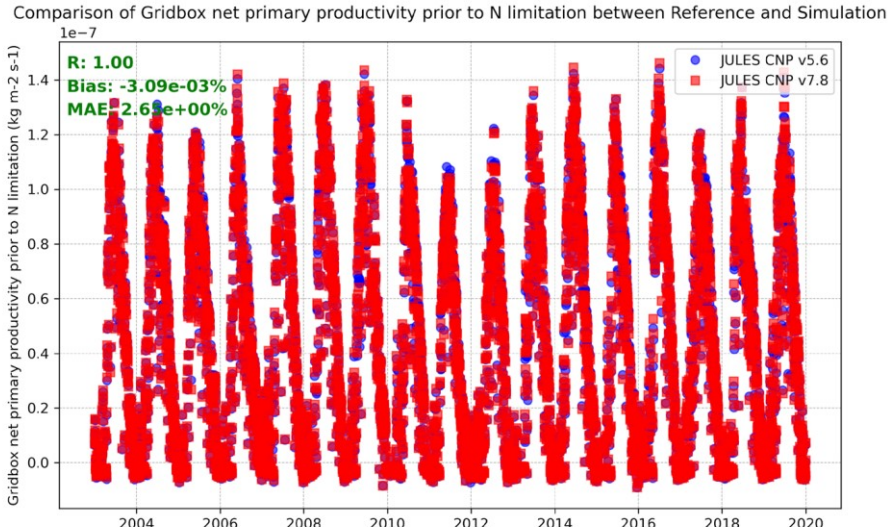


Figures: Rumeau et al., 2024 & QUINTUS project proposal

JULES: Model setup & experiments

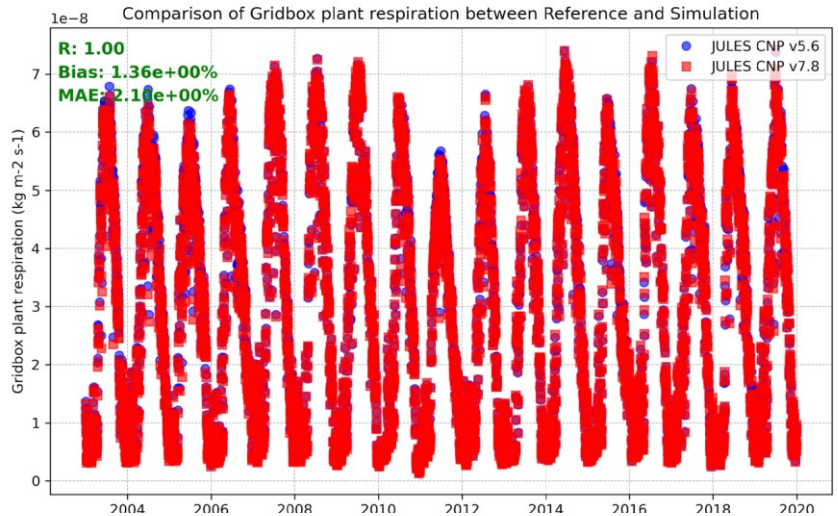
- **Single-point JULES runs for the BIFoR FACE site**
- **Period:** 2002–2019
- **Forcing:** Hourly meteo obs **Shawbury, Shropshire** (~6 km from BIFoR)
- **CO_2 treatments:**
  - **Fixed ambient:** ~403 ppm
  - **Fixed elevated:** 553 ppm (+150 ppm above ambient)
  - **Time-dependent CO_2:** CAMS-EGG4 3-hourly series, with +150 ppm for eCO_2
- **Experiments:**
  - **Ported JULES-CNP scheme** to v7.8 and compared with v5.5(6)
  - **CN, and CNP configurations** to quantify nutrient limitations
  - Assessed **model response** to ambient vs elevated CO_2 (fixed and CAMS-EGG4 time-dependent)

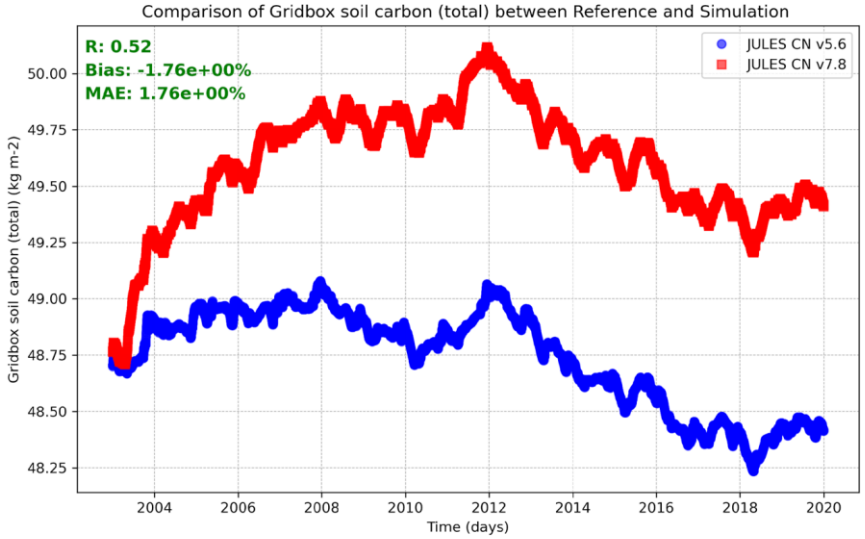
Results: JULES version sensitivity vn5.5(6) vs. vn7.8



<- NPP

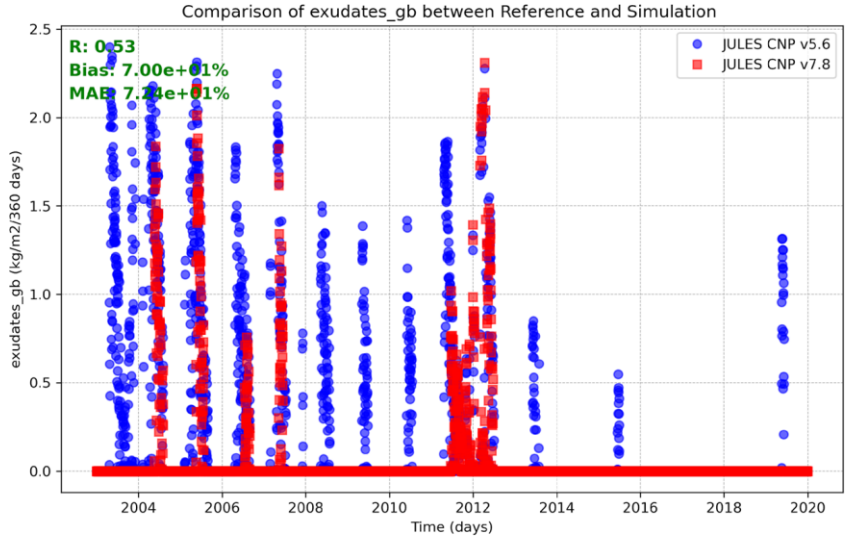
Plant respiration ->





<- Soil Carbon

Exudates ->



Understanding version differences

CN update v6.3 - possible cause of higher N

#1213 closed enhancement (fixed)

Opened 4 years ago
Closed 3 years ago
Last modified 3 years ago

update layered CN model

Reported by:	eleanorburke	Owned by:	eleanorburke
Priority:	normal	Milestone:	~~JULES v6.3 (Feb-22)~~
Keywords:	kgo CR:roddysharp	Cc:	

Description (last modified by eleanorburke) Δ

↳ Reply

This is ONLY for l_layeredc=TRUE

fn_gb is now applied so that the carbon going into the bio/hum pools is still multiplied by fn_gb (as before), but the amount of carbon going out of the dpm/rpm isn't limited and goes to the atmosphere. fn_gb is modified to reflect this change. This means the fraction of RESP_S (soil respiration) the fraction that is NOT released to the atmosphere now depends on the soil carbon pool (resp_frac_cspool(land_pts,dim_cslayer,dim_cs1))
Info on the rationale behind the fn_gb change can be found in Section 2.2 of this preprint
https://doi.org/10.5194/gmd-2021-263

The burnt litter needs to be removed before decay is called in soilcarb_layers for when the peat model is added. Note this only changes the order of calculations, not the results.

An extra turnover term is added to the inorganic nitrogen pool - this stops a huge ongoing build up in this pool in frozen soils. The additional turnover of inorganic nitrogen in frozen soils was used for the IMOGEN simulations carried out for this paper:
Thawing permafrost as a nitrogen fertiliser: implications for climate feedbacks (in preparation). The model produces realistic values of nitrogen stocks and fluxes.

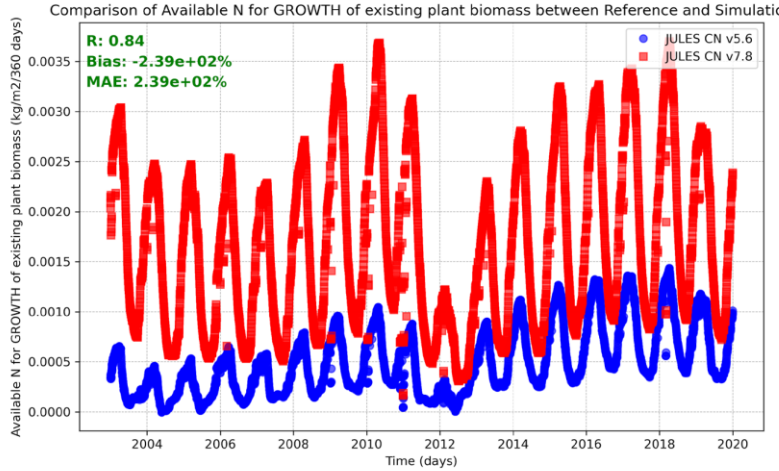
The figures for Samoylov show one year of simulation with and without these changes. The impacts are small except for nloss which, as expected increases because the inorganic nitrogen in frozen soils is allowed to turnover to stop it building up too much.

vn6.2_cnlayered_update

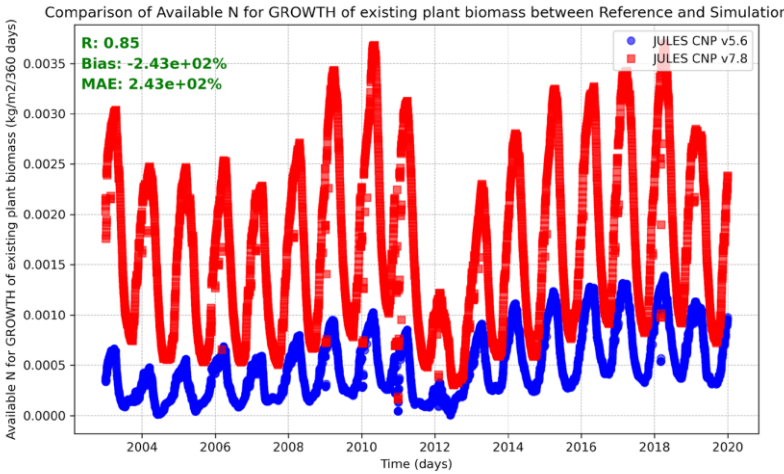
TicketSummary
SciTechReview
CodeSystemReview

Update to how soil carbon turnover and nitrogen availability are represented.
Less immobilisation → more N available for growth?

N growth, JULES-CN

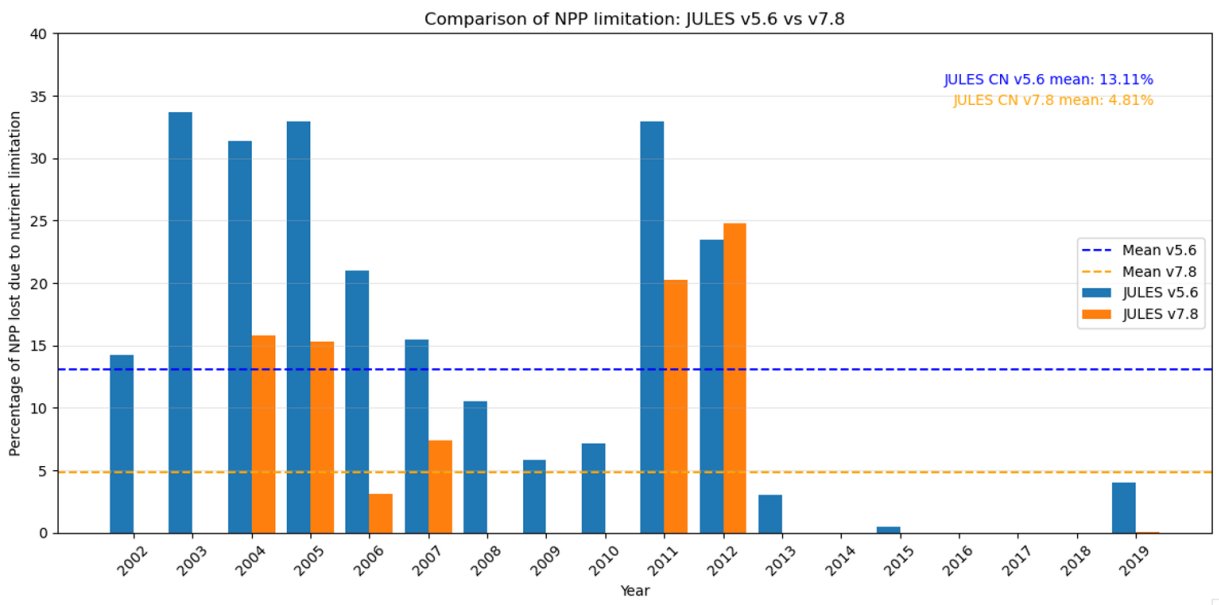


N growth, JULES-CNP

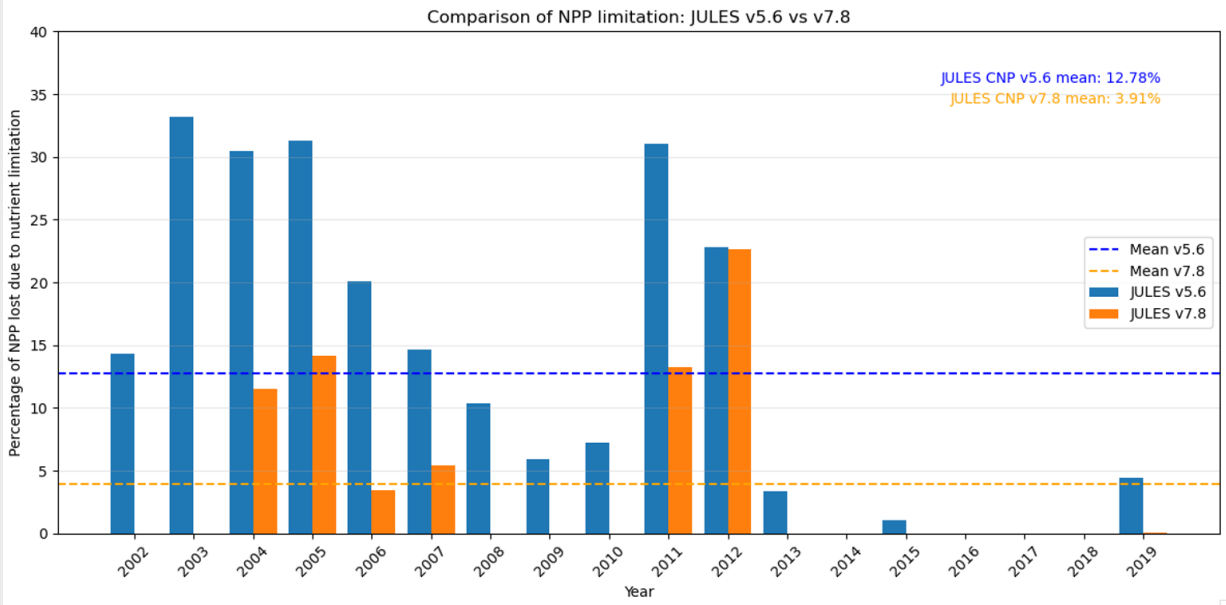


Nutrient limitation in JULES: v5.5(6) vs 7.8

JULES-CN

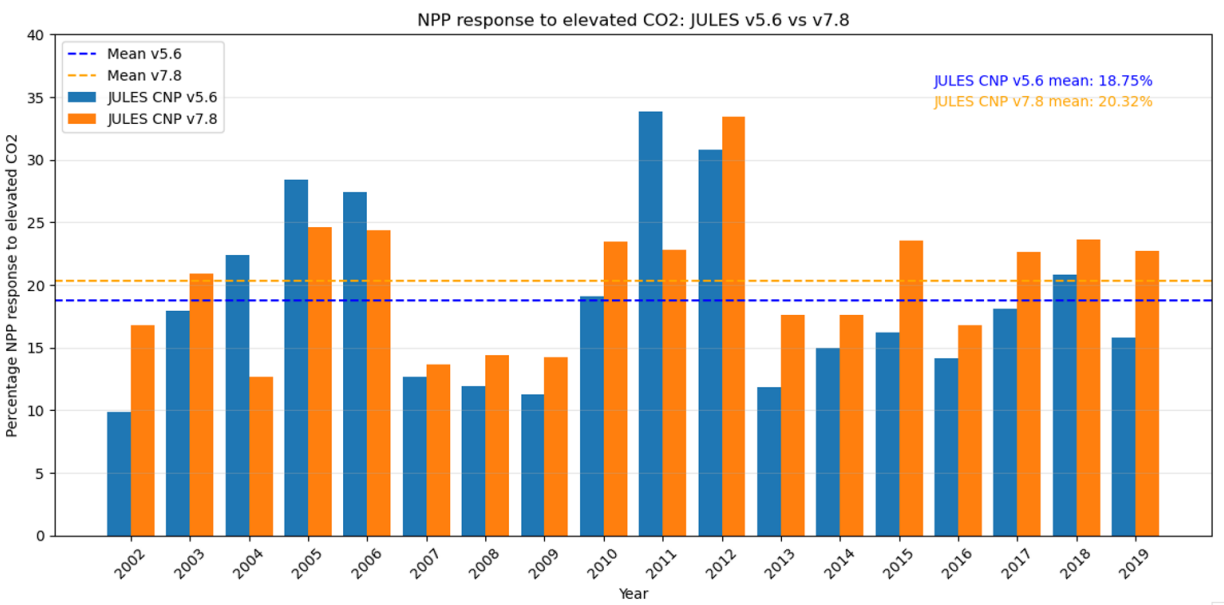


JULES-CNP

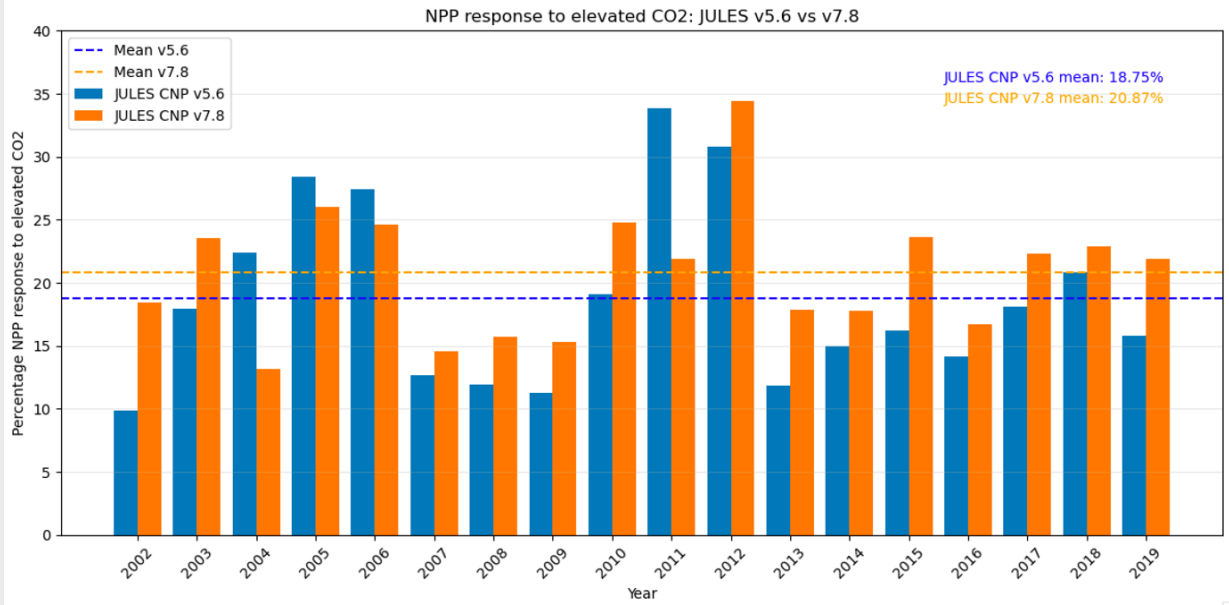


JULES model response to elevated CO_2

Fixed CO_2 levels



CAMS-EGG4 CO_2



Observed NPP response at BIFoR:
10% for 31% enrichment (21.8% for 41% enrichment at all FACE sites)
Norby 2025.

Summary & next steps

- **JULES-CNP successfully ported to v7.8 and compared with v5.5(6)**
- **N and P limitation:**
  - ~10% lower in v7.8; adding P decreases limitation by ~1% in both versions
- **Model response to elevated CO_2:**
  - v5.5(6) → 18.8%, v7.8 → 20.3%
  - using **CAMS-EGG4** time series instead of fixed CO_2 increases response by ~0.5%

Next Steps:

- Code revision/improvements: (**p_switch**, co-limitation, exudates interactions)
- Use more **BIFoR observations** to quantify stocks and fluxes, and assess whether CNP processes reproduce the right responses for the right reasons
- Apply model at **biome scale** beyond single-point BIFoR run

Thank you!

For more information please contact:

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UK Centre for Ecology & Hydrology

Credit: University of Birmingham, BIFoR FACE