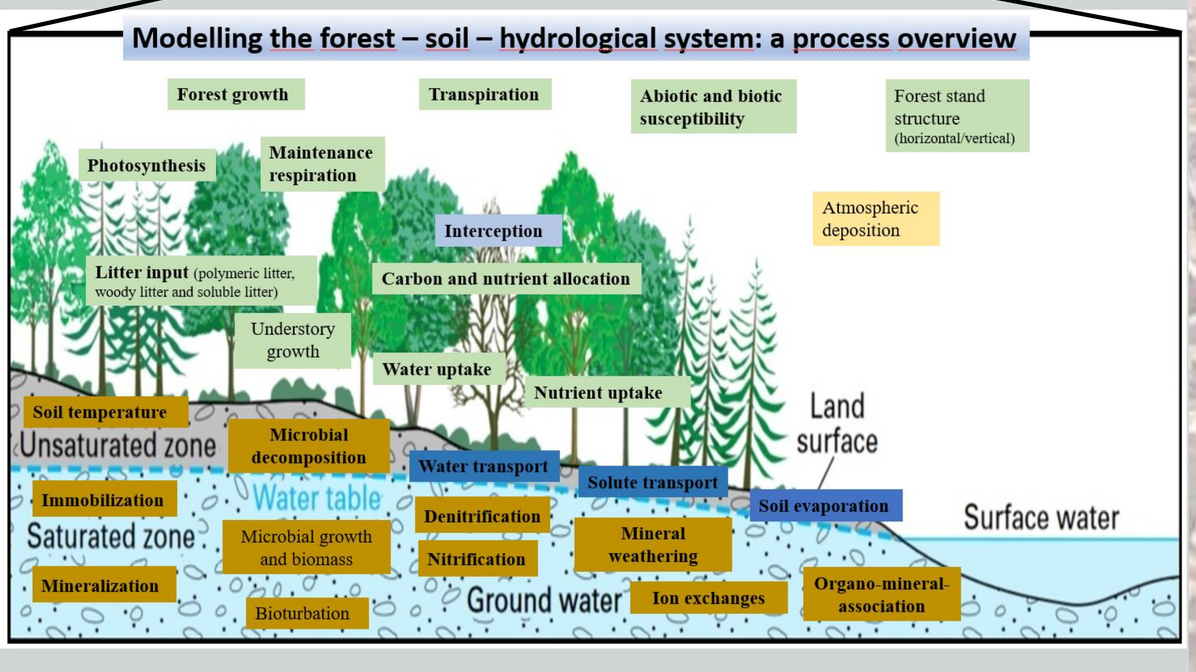
Looking for the Swiss Army Knife to simulate forest biogeochemistry

An overview on modelling coupled forest – soil interactions in a changing world

1. Introduction, challenges and approaches

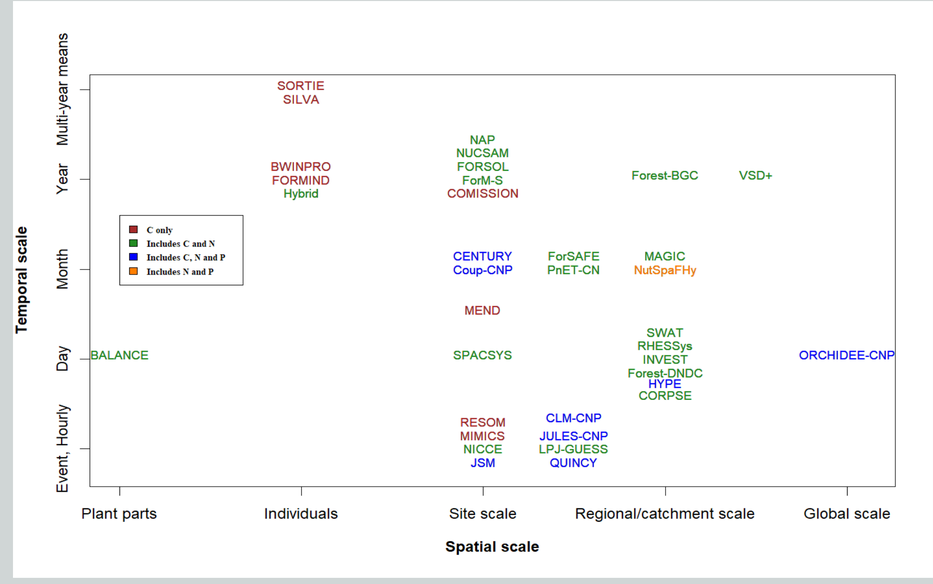
In the same extent as process-based forest models and soil models represent a powerful tool for understanding and predicting changes in forest ecosystems in times of rapid environmental shifts they are equally challenging to work with due to their many necessary simplifications of the complex forest – soil system.
During several decades of model development for investigating forest growth, soil hydrology, soil acidification, carbon turnover, and nutrient cycling a broad selection of independent and coupled forest models and soil models has emerged. Even though all of these models display certain overlaps in their general focus they also display large differences in regard to their specific research questions and process implementations.



2. Selection of available forest biogeohemical models

Acronym	Full name	Primary focus	Model scale	References
CLM-CNP	Community Land Model - CNP	Land use and fluxes of energy, water, carbon and nutrients	Site scale – area scale	Yang et al. (2014), Oleson et al. (2010)
Coup-CNP	Coupled CNP model	Land use and fluxes of energy, water, carbon and nutrients	Site scale	He et al. (2021), Janson (2004)
Forest-DNDC (also uses PnET-CN)	Forest DeNitrification-DeComposition	Soil-Vegetation-Atmosphere	Site scale – area scale – global scale	Kurbatova et al. (2008), Li et al. (2000), Zhang et al. (2002)
Hybrid v3.0	Hybrid model v3.0	Forest-Soil system	Site scale – area scale	Friend et al. (1997)
JULES-CNP	Joint UK Land Environmental Simulator	Land use and fluxes of energy, water, carbon and nutrients	Site scale – area scale – global scale	Kurbatova et al. (2008), Li et al. (2000), Zhang et al. (2002)
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator	Land use and fluxes of energy, water, carbon and nutrients	Site scale – area scale – global scale	Clark et al. (2011) Nakhavali et al. (2022) Wiltshire et al. (2021)
NutSpaFHy	NutSpaFHy model	N/P cycles in forest ecosystems	Catchment scale	Lauren et al. (2021)
ORCHIDEE-CNP	Observatoire Radar Coherent Helioporte d'Investigation des Elements Ennemis	Vegetation-Atmosphere	Global scale	Goll et al. (2017) Zaehle and Friend (2010)
PnET-CN	PnET-CN model	C/N cycles in forest ecosystems	Site scale – watershed scale	Aber et al. (1997)
QUINCY	Quantifying Interactions between terrestrial Nutrient CYcles and the climate system	Soil-Vegetation-Atmosphere	Site scale – area scale – global scale	Thum et al. (2019)
RHESSYS	Regional Hydro-Ecological Simulation System	Nutrrient cycles and ecohydrological assessment	Regional/catchment scale	Tague and Brand (2004)

3. Spatiotemporal scales of available forest biogeohemical models



4. Process inclusion in selected forest biogeohemical models

Acronym	Processes within the coupled forest – soil system: Forest growth/ Mortality	Carbon/ Nutrient allocation	Understory growth	Litter input	Decomposition	Immobilization/ Mineralization	Microbial growth	Water/ Solute transport
CLM-CNP	+	+	-	+	+	+	-	+
Coup-CNP	+	+	+	+	+	+	-	+
Forest-DNDC (also uses PnET-CN)	+	+	-	+	+	+	-	+
Hybrid v3.0	+	+	+	+	+	+	-	+
JULES-CNP	+	-	+	+	+	+	-	+
LPJ-GUESS	+	+	+	+	+	+	-	+
NutSpaFHy	-	-	+	+	+	+	-	+
ORCHIDEE-CNP	+	+	-	+	+	+	-	+
PnET-CN	+	+	-	+	+	+	-	+
QUINCY	+	+	-	+	+	+	-	+
RHESSYS	+	+	+	+	+	+	-	+

5. Choosing „the right" forest biogeochemical model for your own research purposes

Due to the complexity of the forest – soil system it is of great importance to choose a suitable model system based on

- The respective research focus of a study
- The area which is supposed to be investigated
- The available forcing and validation data.

One will quickly realize that the "Swiss Army Knife" of forest – soil models, meaning a model which simulates all desired processes at variable spatiotemporal scales and chemical elements does not exist in reality. However, it is possible to choose a model which is tailored to specific research interests and thus considers most of the desired processes.

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