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Nitrogen cycle module for INM RAS climate model

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Abstract: Nitrogen is one of the most abundant chemical elements on the Earth and plays an important role in global environmental change. Leading Earth system models include coupled carbon and nitrogen cycle modules of varying complexity, but the INM RAS climate model family has not yet included an explicit N-cycle description. This paper presents a parameterization of the terrestrial N-cycle based on a simplification of the JULES-CN model, adapted for coupled use with the INM-CM land C-cycle module. Numerical simulations were carried out with a standalone carbon cycle model with nitrogen feedback disabled and enabled versions for the period 1850–2100. The simulated global pools show good agreement with results of other models with an implemented N-cycle. Taking into account the N-limitation of the C-cycle, the modelled dynamics of total carbon storage in terrestrial ecosystems from 1850 to the mid-20th century is specified.

Keywords: Climate model, terrestrial model, nitrogen cycle, carbon cycle.

MSC 2010: 35Q86, 65Z05, 68U20, 86A10, 92F99

Nitrogen (N) is one of the most abundant chemical elements on the Earth. It exists in both organic and inorganic forms and makes up a biogeochemical cycle by moving between associations in numerous chemical species. In a statistically steady-state climate, external inputs to terrestrial ecosystems (which are mainly biological fixation of atmospheric N_2 to ammonium and deposition of nitrogen via precipitation) are balanced by losses (nitrogen leaching by groundwater and exsolution from soil water back to air). However, the climate change may disrupt this balance. Depending on the nutrient regime (including primarily nitrogen and phosphorus, [7]) of vegetation and soils within an ecosystem, the uptake and outflow of nitrogen can change, resulting in systematic changes of vegetation biomass and soil organic matter, as well as, on larger timescales, inorganic sediments accumulation.

The specific effects related to nitrogen in the Earth climate system in the context of the ongoing global environmental changes are as follows. First, as nitrogen is not accessible to plants directly from atmospheric N_2, the primary productivity is often limited by inorganic nitrogen accessibility in the root zone; plants assimilate ammonium (NH_3), nitrates (NO_3), and nitrites (NO_2). Thus, the potential growth of global primary production due to the ‘fertilisation’ effect under elevated atmospheric CO_2, which would accumulate a portion of the extra atmospheric carbon (C) to terrestrial C storage, will be partially impeded by nitrogen availability. Second, the activity of the soil microbiota in decomposition of plant residues, is also controlled by N abundance, as bacteria, archaea, and fungi need N for build-up of their own biomass. In terms of the C net ecosystem exchange, these two processes at least partially compensate each other in yet poorly constrained degree. Finally, the third, anthropogenic activity (primarily, fertilisation at agricultural lands) leads to additional N inputs into soils, intensifying both primary production and soil respiration, as well as N loads to water ecosystems due to soil runoff and erosion. The latter favour algal blooms with notorious consequences for water quality and potential enhancement of CH_4 emissions.

To include these effects into the Earth system model, an N-cycle compartment is needed. In addition to the processes of land-atmosphere exchanges of N mentioned above, it should represent the soil-vegetation inter-

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actions in the way similar to how they are simulated in C-cycle submodels. Organic nitrogen from vegetation is transferred to the soil through litter fall. The litter (fast pool) decomposes into the soil organic matter (slow pool), which is in turn mineralized to inorganic nitrogen (NH_3, NO_2, NO_3) and thus again becomes available for plant uptake. Organic nitrogen can also be taken up by plants, but its contribution is small and is usually neglected [19].

The leading Earth system models include coupled carbon and nitrogen cycles of varying complexity [1, 5, 10, 18, 20–22]. In the family of the INM RAS climate models (e.g., INM-CM48 [16]), there are modules that simulate the soil and vegetation carbon of terrestrial ecosystems, the evolution of carbon species in the ocean, and the flux of carbon dioxide at the atmosphere-ocean interface [15]. However, no explicit nitrogen cycle description has been incorporated so far.

The present paper proposes a parameterization of the coupled processes of carbon and nitrogen transformations in terrestrial ecosystems based on the INM RAS land C-cycle module [15] and the JULES-CN model [20]. The results of numerical experiments with an advanced standalone CN-cycle model are presented.

1 Model description

There is a family of the INM-CM versions with different spatial and temporal resolutions and different sets of physical parameterizations. The model version INMCM60 [17] is the basis for the perspective Earth system model of INM RAS. It consists of three main modules: atmospheric, ocean and aerosol dynamics. The spatial resolution of the INMCM60 global atmospheric circulation model ($2^\circ \times 1.5^\circ$ in longitude and latitude and 21 vertical σ levels) and its set of land parameterizations (e.g., heat and water soil transport [14], terrestrial carbon cycle [15]) are the same as in the INM-CM48 version [16]. The similar set of modules describing physical and biogeochemical processes in soil and vegetation is also included in the INM RAS–MSU land surface model TerM, which is a standalone version of the INM-CM land compartment; TerM is more flexible for land-focused studies and is used as a testbed for advanced parameterizations of the land surface processes.

In this study we use a separate model of the terrestrial carbon cycle. Its initial physics are fully consistent with the current version of the terrestrial carbon cycle module in INMCM60. Atmospheric forcings (temperature and humidity at 2 m, incoming shortwave radiation flux, total runoff, soil temperature and humidity) are used as input data for the model. These data are obtained from historical and scenario simulations with the global climate model INMCM60. In addition, data on atmospheric CO_2 concentrations and land use are used as forcings for the carbon cycle.

1.1 Initial version of INM-CM terrestrial carbon cycle model

The initial version of a carbon cycle model used in the INM RAS climate model [17] is described in detail in [15]. Land carbon storage is divided into two main pools: vegetation carbon (C_{veg}) and soil carbon (C_{soil}). Their dynamics are described by the following equations:

$$\frac{\partial C_{\mathrm{veg}}}{\partial t} = \underbrace{F_{\mathrm{GPP}} - F_{\mathrm{PLR}}}_{F_{\mathrm{NPP}}} - \frac{C_{\mathrm{veg}}}{\tau_{\mathrm{veg}}} - F_{\mathrm{DFR}} \cdot C_{\mathrm{veg}} \tag{1.1}$$

$$\frac{\partial C_{\mathrm{soil}}}{\partial t} = \frac{C_{\mathrm{veg}}}{\tau_{\mathrm{veg}}} - \frac{C_{\mathrm{soil}}}{\tau_{\mathrm{soil}}} - F_{\mathrm{SOR}} \cdot C_{\mathrm{soil}}. \tag{1.2}$$

Here, the fluxes F_{GPP} and F_{PLR} are the plant photosynthesis and respiration rates (calculated from the equations of the LSM-1.0 model [2]). F_{NPP} is the net primary production rate. The parameters τ_{veg} and τ_{soil} are the characteristic lifetimes of vegetation and soil organic matter decomposition. The fluxes F_{DFR} and F_{SOR} are the rates of deforestation and soil erosion due to human activities per unit of carbon mass.

The model uses a mosaic approach to describe the Earth's surface. It is assumed that several types of cover can exist within a cell. There are a total of 13 possible plant functional types (PFTs) and two additional non-vegetation types: bare soil and open water, similarly [6]:

1. tropical forest
2. broadleaf-deciduous trees
3. mixed forest
4. needleleaf-evergreen trees
5. needleleaf-deciduous trees
6. trees of savanna
7. groundcover only
8. broadleaf shrubs with perennial groundcover
9. broadleaf shrubs with bare soil
10. trees of tundra
11. grass of tundra
12. trees of cultivated areas
13. grass of cultivated areas
14. bare soil
15. open water

The spatial distribution of cover types for each year is according to the Land Use Harmonization 2 project dataset [9].

Equations (1.1) and (1.2) are solved for each of the 13 described PFTs and for each land grid cell. The numerical solution is obtained by the explicit Euler method. In the original version, e.g., implemented in the INMCM60 [17], a time step of 1 hour is used, that is due to the time scales of processes in the terrestrial layer, particularly heat and moisture transfer. The accumulation and decomposition of carbon pools in terrestrial ecosystems takes several months, so it is reasonable to use increased time step in the standalone C-cycle model to 1 month.

1.2 Coupled carbon and nitrogen cycle model

The proposed nitrogen cycle parametrization is based on a simplification of the coupled carbon and nitrogen cycle model JULES-CN [20], adapted to the INM-CM land carbon cycle module [15]. Firstly, the adaptation consists in the reduction of the vegetation types used in the JULES-CN model to 13 PFTs used in INM-CM. Secondly, soil carbon storage in the JULES model [3] has a complicated structure with four sub-pools: decomposable and resistant plant material, microbial biomass and long-lived humus. It is therefore necessary to aggregate them into a main pool as in the INM-CM carbon module. Thirdly, the JULES model includes a dynamic vegetation module, that simulates growth and spread of plants, as well as competition between different PFTs. For simplicity, all carbon production is assumed to be used for plant growth, and vegetation competition is also neglected due to prescribed land use.

Nitrogen storage in terrestrial ecosystems is divided into three main pools: plant nitrogen (N_{veg}), organic and inorganic soil nitrogen ($N_{\mathrm{soil}}^{\mathrm{org}}$ and $N_{\mathrm{soil}}^{\mathrm{in}}$, respectively). Programmatically, the nitrogen dynamics time step is calculated within the carbon cycle time step, using and adjusting its results. A flowchart of the nitrogen cycle model for terrestrial ecosystems is shown in Fig. 1.

1.2.1 Dynamics of vegetation pools

This section describes the dynamics of carbon and nitrogen stocks in vegetation. The carbon balance in plants is given by an equation similar to (1.1), but with adjusted net primary production $\hat{F}_{\mathrm{NPP}}$:

$$\frac{\partial C_{\mathrm{veg}}}{\partial t} = \hat{F}_{\mathrm{NPP}} - \frac{C_{\mathrm{veg}}}{\tau_{\mathrm{veg}}} - F_{\mathrm{DFR}} \cdot C_{\mathrm{veg}}. \tag{1.3}$$

Adjustment of production is necessary because it is in fact limited by the inorganic soil nitrogen that is available to plants.

The nitrogen balance in vegetation is described by the following law:

$$\frac{\partial N_{\mathrm{veg}}}{\partial t} = \Phi - \frac{N_{\mathrm{veg}}}{\tau_{\mathrm{veg}}} - F_{\mathrm{DFR}} \cdot N_{\mathrm{veg}}. \tag{1.4}$$

Here, Φ is the intensity of inorganic nitrogen uptake by plants from the soil. The adjusted NPP flux $\hat{F}_{\mathrm{NPP}}$ can be less than or equal to the initial production F_{NPP} from (1.1). It is limited by the inorganic soil nitrogen storage. The equations for calculating Φ and $\hat{F}_{\mathrm{NPP}}$ are described in Section 1.2.4.

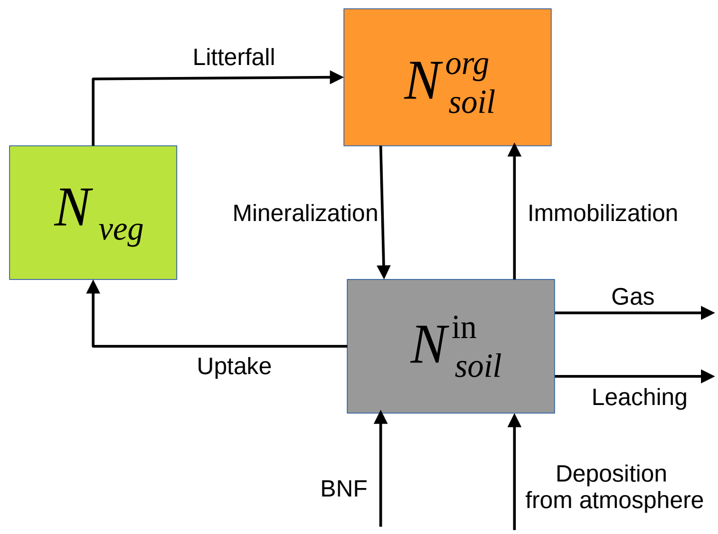


Fig. 1: Flowchart of the nitrogen cycle model (BNF – biological nitrogen fixation).

The carbon production F_{NPP} can be negative, while nitrogen uptake Φ is always non-negative (since the reverse transition is impossible by nature in this case). The case $F_{NPP} < 0$ describes the wilting of vegetation due to unfavourable external conditions, such as drought. If $F_{NPP} \leqslant 0$ or $F_{GPP} = 0$, then the flux Φ is considered to be zero.

1.2.2 Organic soil nitrogen

This section describes the dynamics of carbon and organic nitrogen stocks in the soil. Equation (1.2) for soil carbon from the original parameterization remains unchanged. The dynamics of soil organic nitrogen pool is described by the following equation:

$$\frac{\partial N^{org}_{soil}}{\partial t} = \frac{N_{veg}}{\tau_{veg}} - M_N + I_N - F_{SOR} \cdot N^{org}_{soil}. \tag{1.5}$$

Here M_N is the mineralization of organic nitrogen, I_N is the immobilization of inorganic nitrogen into organic nitrogen, which are defined similarly [20]:

$$M_N = \frac{1}{1-\beta} \cdot \frac{C_{soil}}{\tau_{soil}} \cdot \frac{1}{(C:N)_{soil}} \cdot F_N \tag{1.6}$$

$$I_N = \frac{\beta}{1-\beta} \cdot \frac{C_{soil}}{\tau_{soil}} \cdot \frac{1}{CN_{soil}}. \tag{1.7}$$

Here, $(C : N)_{soil}$ is the ratio of carbon pool to organic nitrogen pool in the soil at the current time step (is a predictive variable), CN_{soil} is the prescribed target ratio the ecosystem aims for (the chosen value for all types is $CN_{soil} = 10.0$). The parameter β depends on the clay content of the soil (δ_{clay} in percent) [20]:

$$\beta = \frac{1}{c_1 + c_2 \cdot e^{(-c_3 \cdot \delta_{clay})}}. \tag{1.8}$$

Here, $c_1 = 4.09$, $c_2 = 2.67$, $c_3 = 0.079$ are empirical coefficients. Depending on the granulometric composition of the soil in the cell, β takes values from 0.15 (complete absence of clay) to 0.25 (clay only). The parameter F_N is a modifier of the intensity of organic nitrogen decomposition, which depends on the inorganic nitrogen content of the soil; for simplicity, $F_N \equiv 1.0$ is considered.

Equation (1.5) can be rewritten as follows, introducing the concept of net mineralization $M_{\mathrm{net}} = M_{\mathrm{N}} - I_{\mathrm{N}}$:

$$\frac{\partial N_{\mathrm{soil}}^{\mathrm{org}}}{\partial t} = \frac{N_{\mathrm{veg}}}{\tau_{\mathrm{veg}}} - M_{\mathrm{net}} - F_{\mathrm{SOR}} \cdot N_{\mathrm{soil}}^{\mathrm{org}}. \tag{1.9}$$

1.2.3 Inorganic soil nitrogen

This section describes the dynamics of inorganic nitrogen pools in soils. In contrast to the previous pools, there is no equivalence with the carbon cycle. Inorganic N stocks vary as a result of atmospheric deposition (e.g., rainfall), biological fixation by soil microorganisms, mineralization of organic matter, as well as losses by immobilization, leaching and gaseous emissions, and are also taken up by plants during photosynthesis:

$$\frac{\partial N_{\mathrm{soil}}^{\mathrm{in}}}{\partial t} = N_{\mathrm{dep}} + N_{\mathrm{bnf}} + M_{\mathrm{net}} - N_{\mathrm{gas}} - N_{\mathrm{leach}} - N_{\mathrm{gasI}} - \Phi. \tag{1.10}$$

Here, N_{dep} is the flux of nitrogen from the atmosphere into ecosystems (considered as prescribed, integral 66 Gt N/year [20]). As a result of mineralization–immobilization processes, some of the resulting inorganic nitrogen (≈ 1%) is released into the atmosphere as a gas [13]:

$$N_{\mathrm{gas}} = f_{\mathrm{gas}} \cdot M_{\mathrm{net}}, \quad f_{\mathrm{gas}} = 0.01. \tag{1.11}$$

There are also additional nitrogen losses N_{gasI} as a result of the release of nitrogen-containing gaseous compounds into the atmosphere (accounting for about 90% of all gaseous nitrogen losses):

$$N_{\mathrm{gasI}} = \gamma_{\mathrm{N}} \cdot N_{\mathrm{soil}}^{\mathrm{in}}, \quad \gamma_{\mathrm{N}} = 3.215 \times 10^{-8}\ s^{-1}. \tag{1.12}$$

The flux N_{leach} is the leaching of inorganic nitrogen from the soil with runoff:

$$N_{\mathrm{leach}} = \alpha \cdot \left(\frac{N_{\mathrm{soil}}^{\mathrm{in}}}{\vartheta_{1\mathrm{m}}}\right) \cdot Q_{\mathrm{subs}}. \tag{1.13}$$

The value $\vartheta_{1\mathrm{m}}$ is the soil moisture in the upper 1 m layer, the flux Q_{subs} is the total subsurface runoff, $\alpha = 0.1$.

The flux N_{bnf} is the rate of biological fixation of inorganic nitrogen by microbes in the soil. A common way to specify this parameterization is a functional dependence on net primary production, for example, [4, 20]:

$$N_{\mathrm{bnf}} = \xi \cdot F_{\mathrm{NPP}} \tag{1.14}$$

where $\xi = 0.0016$ [kgN/kgC] (the value before adjustment is taken as F_{NPP}). This approach allows changes in the concentration of CO_2 in the atmosphere to be taken into account. There are other approaches, for example, in the CLASSIC land model [1] the dependence on temperature and humidity of the top 0.5 m of soil is used.

1.2.4 Effect of nitrogen storage on photosynthesis

This section describes the correction of net primary production and the calculation of the inorganic nitrogen uptake from soil to vegetation. The value $\Phi \cdot \Delta t$ is the inorganic nitrogen taken up by plants from the soil as a result of photosynthesis over a period of time Δt. The values of Φ and $\hat{F}_{\mathrm{NPP}}$ are calculated as follows:

1. The amount of carbon that could potentially be produced by photosynthesis (corresponds to NPP_{pot}) is calculated:

$$\Delta C_{\mathrm{veg}}^{\mathrm{PSN}} = F_{\mathrm{NPP}} \cdot \Delta t = (F_{\mathrm{GPP}} - F_{\mathrm{PLR}}) \cdot \Delta t. \tag{1.15}$$

2. The amount of inorganic nitrogen required to produce the potential amount of carbon is calculated:

$$\Delta N_{\mathrm{in}}^{\mathrm{PSN}} = \frac{\Delta C_{\mathrm{veg}}^{\mathrm{PSN}}}{CN_{\mathrm{veg}}^{\mathrm{opt}}} \tag{1.16}$$

where $CN_{\mathrm{veg}}^{\mathrm{opt}}$ is a set of prescribed optimal proportionality coefficients of carbon and nitrogen pools (C : N) in different PFTs to which the ecosystem tends (Tab. 1).

Vegetation type	CN_{veg}^{opt}
tropical forest	130.0
broadleaf-deciduous trees	160.0
mixed forest	175.0
needleleaf-evergreen trees	200.0
needleleaf-deciduous trees	190.0
trees of savanna	130.0
groundcover only	20.0
broadleaf shrubs with perennial groundcover	40.0
broadleaf shrubs with bare soil	40.0
trees of tundra	175.0
grass of tundra	35.0
trees of cultivated areas	120.0
grass of cultivated areas	20.0

Tab. 1: Prescribed optimal values of carbon-to-nitrogen ratio (C : N) per vegetation type.

3. The value ΔN_{in}^{PSN} is compared with the available inorganic nitrogen in the soil N_{soil}^{in} and adjusted if necessary:
$$\Delta \hat{N}_{in}^{PSN} = \min\{\Delta N_{in}^{PSN},\ N_{soil}^{in}\}. \tag{1.17}$$
4. Values ΔC_{veg}^{PSN} and F_{NPP} are adjusted according to (1.17):
$$\Delta \hat{C}_{veg}^{PSN} = \Delta \hat{N}_{in}^{PSN} \cdot CN_{veg}^{opt} \tag{1.18}$$
$$\hat{F}_{NPP} = F_{NPP} - \frac{\Delta C_{veg}^{PSN} - \Delta \hat{C}_{veg}^{PSN}}{\Delta t}. \tag{1.19}$$
Here, $\hat{F}_{NPP}$ corresponds to $NPP_{achieved}$. The ratio $NPP_{pot}/NPP_{achieved}$ shows the effect of the nitrogen demand of different PFTs on the carbon production.
5. The value of Φ is calculated:
$$\Phi = \frac{\Delta \hat{N}_{in}^{PSN}}{\Delta t}. \tag{1.20}$$

The parameter set CN_{veg}^{opt} (see Tab. 1) is initially based on the canopy height function according to [20]. It is adjusted during the model tuning so that regional patterns and global metrics of the nitrogen pools are consistent with data from other models.

2 Numerical experiments

Simulations were carried out with two versions of the standalone carbon cycle model: with nitrogen feedback disabled and enabled. The first version of the model is fully equivalent to the module used in the global model INMCM60. All model runs can be divided into two groups: spin up (necessary to initialise carbon and nitrogen pools in vegetation and soil) and baseline experiments. The time step in all experiments is 1 month.

During the initial runs, all input forcings are set to 1850 to prepare initial conditions corresponding to that year. These simulations need to continue for at least 3000 years for the version without nitrogen model and 9000 years for the coupled model of carbon and nitrogen cycles due to slow dynamics in the soil. Figure 2 shows the achievement of a steady state for simulated pools. The horizontal axis of the graph shows the model time and the vertical axis shows the dimensionless quantity which is the ratio of the current value to the steady state.

The main runs are performed from 1850 to 2100, with all forcings corresponding to the current year. Data from 1850 to 2014 correspond to the historical experiment [8] and from 2015 to 2100 to the scenario experiment (SSP3-7.0) [12]. The prescribed land use forcing (see Fig. 3) is prepared based on data from the Land Use Harmonization 2 project [9].

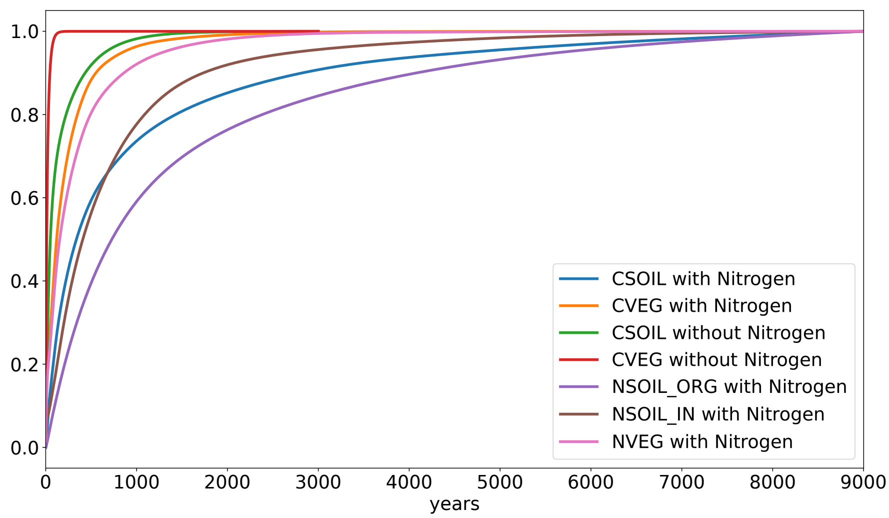


Fig. 2: Carbon and nitrogen pools reaching steady-state under constant climate forcing of 1850 year.

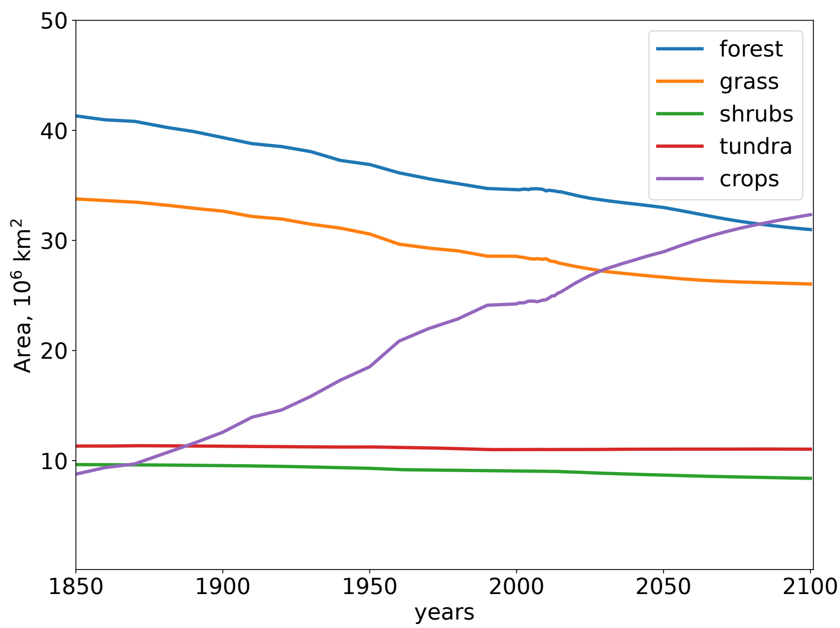


Fig. 3: Global land area covered by different types of vegetation according to the LUH2 project (HIST + SSP3-7.0).

3 Results

Global simulated nitrogen pools by the land carbon–nitrogen module of the INM-CM (see Figs. 4 and 5) show good agreement with results of other models with implemented N-cycle (see Tab. 2). Note the large scatter between all these models and the large difference between the absolute values of the vegetation and soil pools. There is also a lack of observational data on nitrogen pools, especially global ones. These facts make it very difficult to verify the simulated nitrogen stocks.

The dynamics of vegetation and soil organic nitrogen stocks is comparable to that of carbon pools, while soil inorganic nitrogen storage is more variable (see Fig. 4). This can be explained by the limiting function of available inorganic nitrogen, that controls the carbon–nitrogen balance (C : N) in plants.

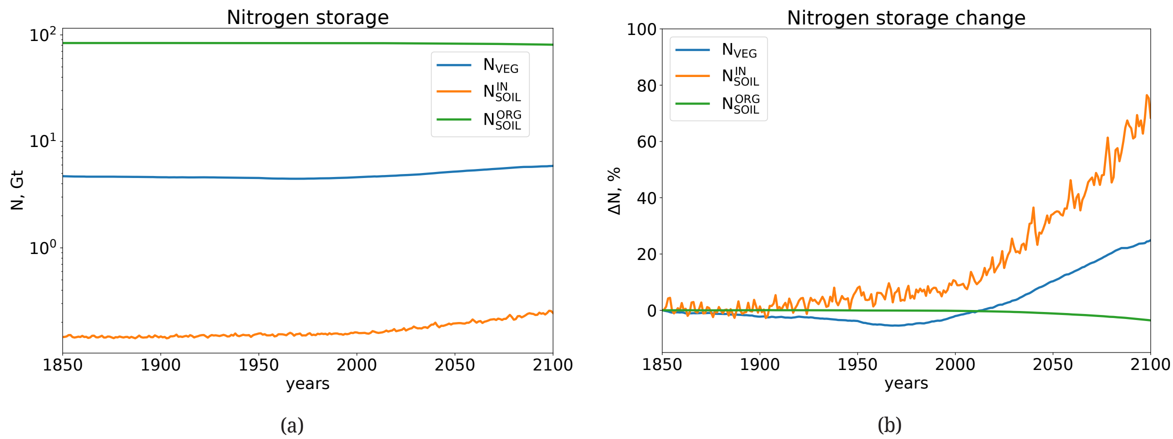


Fig. 4: Simulated global nitrogen pools by the land carbon–nitrogen module of the INM-CM (absolute value and variation during 1850–2100).

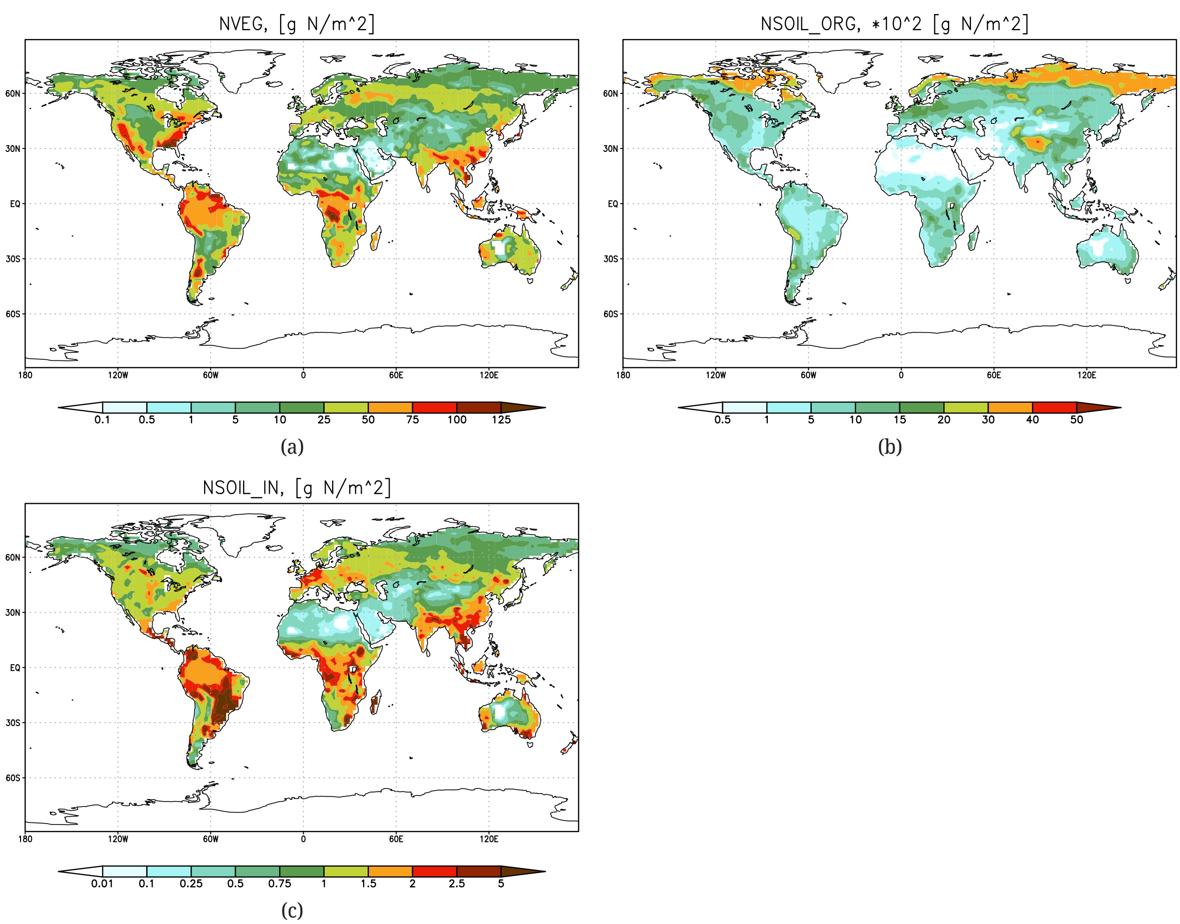
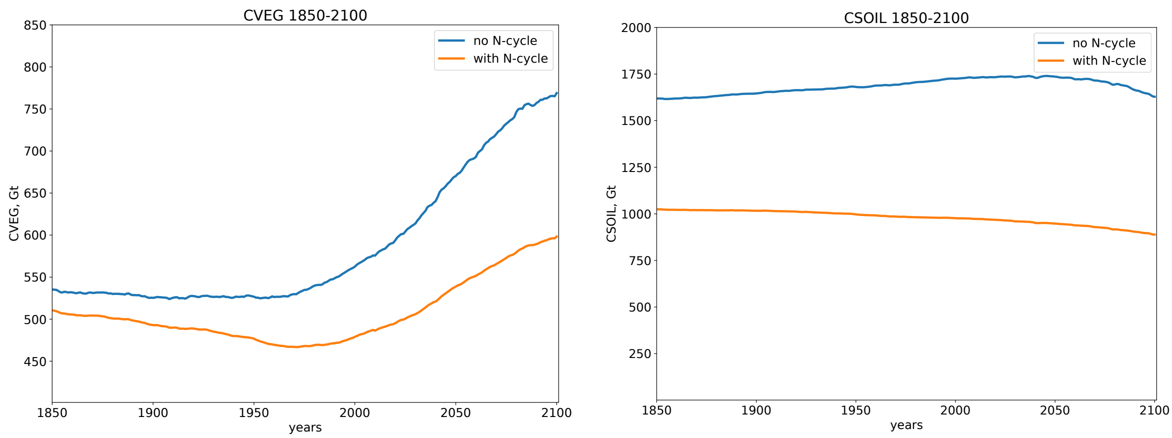


Fig. 5: Spatial distribution of simulated nitrogen pools by the land carbon–nitrogen module of the INM-CM (averaged over 1996–2015).

Enabling nitrogen feedback in a terrestrial carbon cycle model resulted in a reduction of carbon stocks in both vegetation and soil (see Fig. 6). Integral N-limitation gives the most significant effect for cultivated plants. It is related to the specific nitrogen uptake requirements of vegetation types (CN_{veg}^{opt}, see Table 1) and also their covered areas. According to the land use scenario exploited, the modelled period is characterised by deforestation and an increase in agricultural land (see Fig. 3). Farmland, in turn, has a significantly higher demand for



(a) (b)

Fig. 6: Vegetation and soil carbon stocks simulated by the INM-CM (blue – version with disabled nitrogen module, orange – version with enabled nitrogen module).

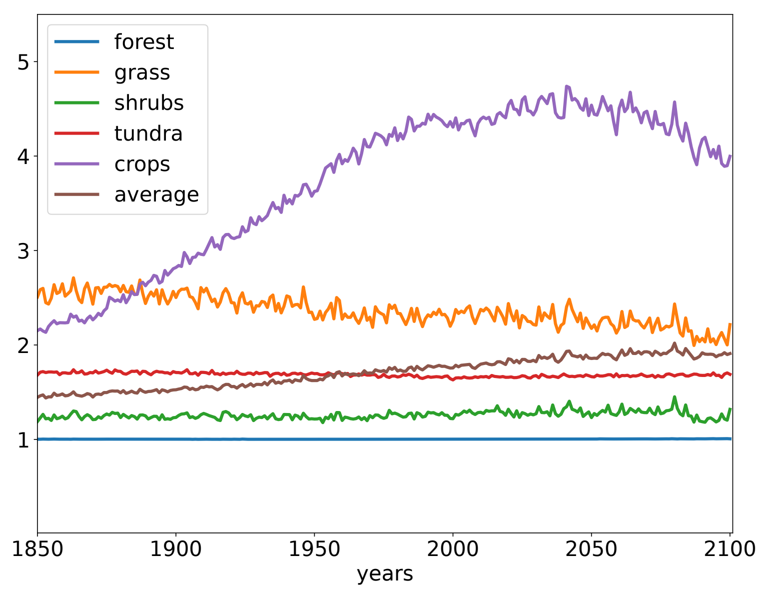


Fig. 7: NPP response ratio $NPP_{pot}/NPP_{achieved}$ for different types of vegetation.

Tab. 2: Simulated global nitrogen stocks for the period 1996–2015 by different models, [Gt N].

	INM-CM	JULES-CN [20]	CLASSIC [1]	O-CN [22]	LPJmL [18]	DGVM [21]
N_{veg}	4.7	3.0	3.0	3.8	1.8	5.3
N^{org}_{soil}	83.7	87.0	77.2	100.0	106.0	56.8
N^{in}_{soil}	0.2	0.2	4.0	—	2.9	0.9

available nitrogen (see Fig. 7), leading to N-limitation and consequently an increase in integral biomass reduction.

Figure 8 shows the change in global land carbon storage relative to the start of the experiment by the INM-CM. The effect is similar to that observed for the separated pools in Fig. 6. This value is important because there is observational data for it and most modern models simulate it consistently. The INM-CM version with enabled

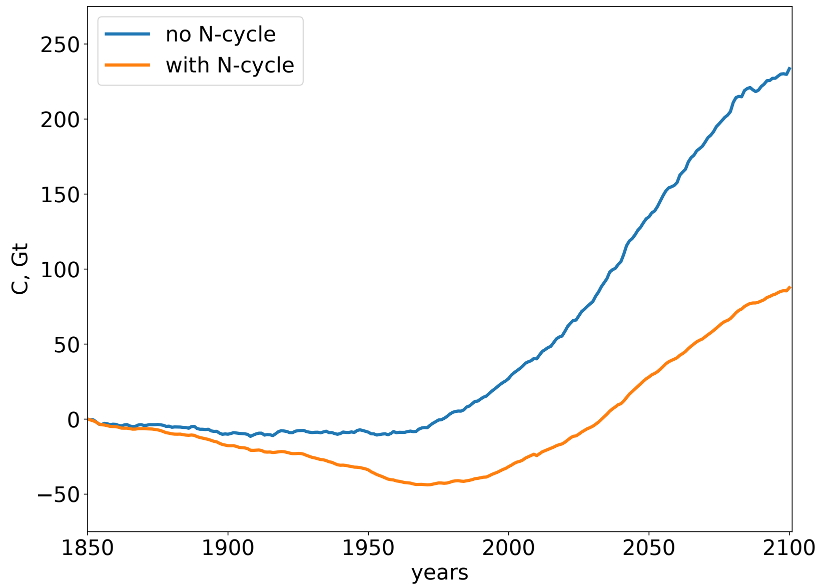


Fig. 8: Land carbon storage change simulated by the INM-CM for the period 1850–2100 (blue – version with disabled nitrogen module, orange – version with enabled nitrogen module).

nitrogen cycle shows a closer result for the period 1850–2014 to the results of the 6th Assessment Report of the IPCC (see [11, Fig. 5.23]).

4 Conclusions

In this paper, we present a parameterization of coupled processes in the terrestrial carbon and nitrogen cycles that is compatible with the INM RAS Earth system model. It fills the gap caused by the lack of an explicit land N-cycle description in the INM-CM. Numerical experiments were carried out with this parameterization in a standalone mode forced by the INMCM60 climate data. The global nitrogen stocks in vegetation and soil (for soil, in both organic and inorganic forms) reproduced by the model well correspond to published data of other ESMs. As a result of the enabled nitrogen limitation of the primary productivity, a decrease in the simulated 'fertilization' effect of enhanced atmospheric CO_2 on terrestrial ecosystems is observed. This allowed us to reproduce in the model the decrease of the global land carbon storage from 1850 to the mid-20th century. Thus, the proposed CN-cycle parameterization is recommended for implementation as a module in the INM-CM ESM family, as well as in the standalone INM RAS-MSU land surface model TerM (Terrestrial model).

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