

Supplementary Materials for

**The Integration of nitrogen dynamics into a land surface model  
AVIM: 1. Model description and site-scale validation**

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## **Model description**

In the new version model AVIM\_CN (Figure S1), the incorporated nitrogen dynamic cycle is based on the following assumptions: (1) leaf, stem and root carbon to nitrogen ratios (C:N) for a specific type of plants is fixed, while 8 soil pools C:N ratios fluctuate with the income and loss of available nitrogen; (2) Nitrogen fluxes are combined closely with the carbon fluxes among the atmosphere-vegetation-soil system. That is to say, nitrogen flows among the 8 nitrogen pools exactly the same way as carbon moves in carbon pools; (3) Nitrogen maintains balance in the whole dynamics. The key parameters required in the nitrogen processes of AVIM-CN mostly were cited from reference papers which either had been tested in previous researches or calibrated by field experiments.

### ***1. Plant uptake of available nitrogen***

Nitrogen is absorbed by vegetation mainly from the inorganic nitrogen compartment in the form of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  through roots, while the fraction taken by leaf and stoma via  $\text{NO}_2$ ,  $\text{NH}_3$  and  $\text{HNO}_3$  is not taken into account. Nitrogen uptake ( $N_{\text{up}}$ ) by plants is driving by both Michaelis-Menten kinetics (Raich et al. 1991; Li 2013) and transpiration effects, as displayed in Equation (S1).  $N_{\text{upmax}}$ , Up to the litter production, is the maximum rate of nitrogen active uptake by plants.  $N_{\text{av}}$  represents the soil available nitrogen which can be used directly by plants, while  $N_{\text{amm}}$  and  $N_{\text{nit}}$  are the storage of ammonium and nitrate, respectively.  $k$  is a constant value of  $0.09 \text{ kg N m}^{-2}$  (Lin et al. 2000), which is used to denote the concentration of available nitrogen at which the rate of nitrogen uptake equals to half of its maximum rate. Soil relative moisture  $W_s$  and soil temperature  $T_s$

represent the influences of soil water content and temperature on nitrogen uptake.  $E_{tr}$  is the plant transpiration flux and  $\delta H$  is the thickness of water lifted.

$$N_{up} = \frac{N_{upmax}(W_s^3+0.1)N_{av}}{k+(0.9W_s^3+0.1)N_{av}} e^{0.0693T_s} + N_{av}E_{tr} \frac{1}{\delta H} \quad (S1)$$

$$N_{av} = N_{amm} + N_{nit} \quad (S2)$$

## 2. Nitrogen flows between atmosphere, litter and soil nitrogen pools

As plant litter goes into the soil structural and metabolic pools, organic nitrogen in detritus or humus is released by respiration and decomposition as inorganic nitrogen. This process can be regarded as part of the process of mineralization, symbolled as  $\delta_1$ ,  $\delta_2$ ,  $\delta_5$  and  $\delta_6$ , respectively (Equations (S3-S6)).

$$\delta_1 = (1 - f_m) \left[ L_l C_l \left( \frac{1}{r_l} - \frac{1}{CN_1} \right) + L_s C_s \left( \frac{1}{r_s} - \frac{1}{CN_1} \right) \right] - \sigma_1 C_1 \frac{1}{CN_1} \quad (S3)$$

$$\delta_2 = (1 - f_m) L_r C_r \left( \frac{1}{r_r} - \frac{1}{CN_2} \right) - \sigma_2 C_2 \frac{1}{CN_2} \quad (S4)$$

$$\delta_5 = f_m \left[ L_l C_l \left( \frac{1}{r_l} - \frac{1}{CN_5} \right) + L_s C_s \left( \frac{1}{r_s} - \frac{1}{CN_5} \right) \right] - \sigma_5 C_5 \frac{1}{CN_5} \quad (S5)$$

$$\delta_6 = f_m L_r C_r \left( \frac{1}{r_r} - \frac{1}{CN_6} \right) - \sigma_6 C_6 \frac{1}{CN_6} \quad (S6)$$

$$\delta_i = \begin{cases} k_i f(T_s) f(W_s) L_c & i = 1, 2 \\ k_i f(T_s) f(W_s) & i = 5, 6 \end{cases} \quad (S7)$$

$$L_c = e^{(-3L_{st})} \quad (S8)$$

$L_c$ , the fraction of carbon lost caused by organic leaching, stands for the impact of lignin content of structural materials ( $L_{st}$ ) on structural pools decomposition.  $F_m$  is the proportion of decomposable metabolic in vegetation residues.  $L_l$ ,  $L_s$ ,  $L_r$  are loss rates and  $r_l$ ,  $r_s$ ,  $r_r$  are C:N ratios of leaf, stem and root, respectively. Symbols  $C_l$ ,  $C_s$ ,  $C_r$  represent the biomass of leaf, stem and root, respectively.  $CN_i$  is the carbon to nitrogen ratio of the

ith soil pool, while  $k_i$  is the maximum decomposition rate parameter for the corresponding soil pool. Detailed description of the carbon soil module can be as given by (Huang et al. 2007).

Meanwhile, the nitrogen mineralized or immobilized ( $N_{min}^i$ ) in the course of nitrogen transferring among the 8 soil pools are calculated as Equation (S9). The first part of the right side of the equation represents the nitrogen amount released from soil organic matter decomposition in the ith soil nitrogen pool, while the second part is the nitrogen transferred to the jth pool, ie this part of nitrogen is immobilized. In other words, positive value of  $N_{min}^i$  symbols mineralization and negative indicates immobilization in the ith soil nitrogen pool. In addition,  $f_i$  is the proportion of decomposition, so that  $1-f_i$  stands for the efficiency of microorganisms. Summing up the above, the gross amount of nitrogen mineralization in the total nitrogen pool is aggregated as Equation (S10).

$$N_{min}^i = \frac{dC_i}{dt} \frac{1}{CN_i} - \frac{dC_i}{dt} (1 - f_i) \frac{1}{CN_j} \quad i, j = 1, 8 \quad (S9)$$

$$N_{min} = \sum_{i=1}^8 N_{min}^i + \delta_1 + \delta_2 + \delta_5 + \delta_6 \quad (S10)$$

The process of nitrification (denitrification) is simulated as a function of the content of ammonium (nitrite) in soil, soil temperature, and soil moisture. And ammonia volatilization is modeled as a function of soil pH and soil ammonium concentration. Furthermore, nitrogen leaching is considered to be related to soil texture, soil water content, and the quantity of available nitrite content (Li 2013).

### **3. Ecosystem nitrogen inputs**

Land ecosystem nitrogen inputs from the atmosphere ( $N_{dep}$ ) contains both wet and dry deposition of ammonium, nitrate, ammonia gas and a small amount of nitrogen

compounds via rain, snow or dust. Previous study shows that the rain fall ( $Pre$ ) typically consists one part nitrite and two parts ammonium (Brady 1998). Thus, in the new nitrogen model, wet deposition is linearly related with the precipitation in which the concentration of ammonium and nitrite has a specific value varying with different plant types, and dry deposition is assumed as a global average constant  $0.2 \text{ kg ha}^{-1} \text{ yr}^{-1}$  (Lin et al. 2000; Hudson et al. 1994). The deposition of ammonium ( $Ndep_{amm}$ ) and nitrate ( $Ndep_{nit}$ ) is modelled as Equations (S11-S13).

Another source of nitrogen input is biological N fixation by soil microorganisms, including symbiotic and nonsymbiotic fixation, during which soil temperature is the main control factor (Lin et al. 2000; Li 2013).

$$Ndep_{amm} = \frac{1}{3}r_{rain}Pre + N_{dep\_dry\_amm} \quad (S11)$$

$$Ndep_{nit} = \frac{2}{3}r_{rain}Pre + N_{dep\_dry\_nit} \quad (S12)$$

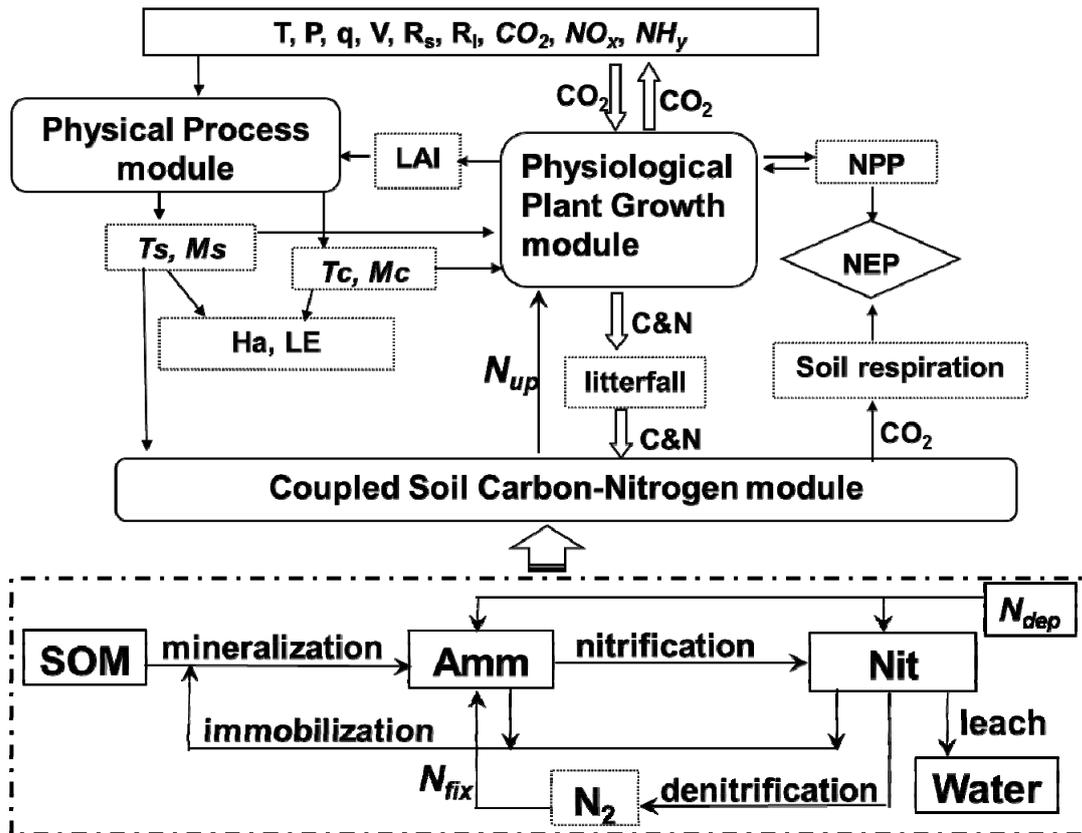
$$Ndep = Ndep_{amm} + Ndep_{nit} \quad (S13)$$

Summing up the above, AVIM-CN covers all the key nitrogen processes in real ecosystem, including interaction between nitrogen dynamics with plant photosynthesis, carbon allocation and soil respiration, vegetation uptake of nitrogen, biological and non-biological nitrogen fixation, decomposition and transformation of nitrogen-containing compounds, nitrogen deposition, etc.

## References

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**Figure S1.** Schematic structure of the nitrogen cycle in combination with the former AVIM model. The original structure of AVIM is displayed on the top versus the nitrogen dynamics showed on the bottom. Symbols  $T$ ,  $q$ ,  $P$ ,  $V$ ,  $CO_2$ ,  $R_l$ ,  $R_s$ ,  $NH_x$ ,  $NO_y$  denote air temperature, humidity, wind speed, rainfall, concentration of  $CO_2$ , short and long wave radiations, the deposition of ammonium and nitrate, respectively. Variables  $T_s$ ,  $M_s$ ,  $T_c$ ,  $M_c$  are soil temperature and water content, canopy temperature and moisture, respectively.  $H_a$  and  $LE$  are sensible and latent heat fluxes.  $LAI$  is leaf area index.  $NPP$  and  $NEP$  represent net primary productivity and net ecosystem productivity, respectively.  $Amm$  and  $Nit$  denote the ammonium and nitrate in soil nitrogen pool. Symbols  $N_{dep}$ ,  $N_{up}$ ,  $N_{fix}$  represent downward nitrogen deposition, the nitrogen uptaken by plants upward, and the nitrogen fixed by both symbiotic and nonsymbiotic nitrogen fixations, respectively.