# PhD Research Proposal Form
# China Scholarship Council (CSC)
# 2025

*A remplir en français ou en anglais en fonction de la langue qui sera utilisée pour la thèse*

**FIELD**

-------------Géosciences------------
(eg: Mathematics, Physics, Sociology, ….)

Thesis subject title:
Impact of soil moisture on global soil carbon dynamics

**Name of the French doctoral school/Ecole doctorale:**

**Name of the Research team/Equipe de recherche: Surface et Reservoir, Laboratoire de Géologie de l'ENS, Département de Géosciences**
Website: https://www.geologie.ens.fr/en/geology-laboratory/

**Name of the Supervisor/Directeur de thèse: Bertrand Guenet**
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**Lab Language/ Langue de travail: Anglais**

**Research Proposal Abstract/Présentation du sujet:**

**THE CURRENT RESEARCH CONDITION AND LEVEL OF THE RESEARCH PROJECT AT HOME AND ABROAD:**

Soil organic carbon (C) is the largest terrestrial C reservoir (IPCC, 2007). Accurately predicting SOC decomposition in response to environmental changes is critical for projecting carbon-climate feedbacks (Yan et al., 2018). Soil moisture is one of the most important environmental factors controlling microbial heterotrophic respiration (Cook and Orchard, 2008; Moyano et al., 2012), the process by which SOC is mineralized by microbes into carbon dioxide (Bond-Lamberty et al., 2004; Davidson and Janssens, 2006; Moyano et al., 2012). It is anticipated that global-scale shift in soil moisture levels will occur in the coming decades because of climate change (IPCC, 2007), thus potentially causing substantial alterations in soil carbon stocks across various regions (Falloon et al., 2011; Moyano et al., 2012).

Modeling is an effective way to investigate the response of soil carbon stocks to climate change due to the absence of global monitoring of soil organic carbon changes (Guenet et al., 2018). Most biogeochemical models use soil moisture response function to control rates of decomposition with varying functional forms (Table 1).

**Table 1. Functions used in common biogeochemical models to represent the effects of moisture on decomposition rates.**

| $f(W)$ | Model names | Sources |
|---|---|---|
| $\frac{1}{1+30exp(-8.5W_i)}$ | Century | Adair et al. (2008) |
| $(\frac{W_i-b}{a-b})^{d(\frac{b-a}{a-c})}(\frac{W_i-c}{a-c})^d$ | Daycent | Kelly et al. (2000) |
| $1-\exp(-\frac{3}{W_{min}}(W_i+a))^b exp(-(\frac{W_i}{M_{max}+c})^b)$ | Standcarb | Harmon and Domingo (2001) |
| $\begin{cases} 4W_i(1-W_i), & if\ W_i \le 0.5; \\ 1, & if\ W_i > 0.5 \end{cases}$ | Candy | Bauer et al. (2008) |
| $\exp(-\exp(a-bW_i))$ | Gompertz | Janssens et al. (2003) |
| $\max\left(0.25, \min\left(1, aW_i^2+bW_i+c\right)\right)$ | ORCHIDEE | Krinner et al. (2005) |
| $\begin{cases} 0, & if\ \psi_i < \psi_{min}; \\ \frac{log(\psi_{min}/\psi_i)}{log(\psi_{min}/\psi_{max})}, & if\ \psi_{min} \le \psi_i \le \psi_{max}; \\ 1, & if\ \psi_i > \psi_{max} \end{cases}$ | CLM | Andren and Paustian (1987) |
| Decomposed by oxidative enzymes:<br>$\begin{cases} 0, & \psi \le -10^{2.5} \\ 0.625-0.25\times\log_{10}(-\psi), & -10^{2.5} < \psi \le -10^{1.5} \\ 1, & -10^{1.5} < \psi \le -10^{-2.5} \\ [2.5+0.4\times\log_{10}(-\psi)]/1.5, & -10^{-2.5} < \psi \le -10^{-4} \\ 0.6, & \psi > -10^{-4} \end{cases}$<br>Decomposed by hydrolytic enzymes:<br>$\begin{cases} 0, & \psi \le \psi_{min} \\ 1-\left[\frac{\ln(\psi/\psi_{FC})}{\ln(\psi_{min}/\psi_{FC})}\right]^b, & \psi_{min} < \psi \le \psi_{FC} \\ 1, & \psi > \psi_{FC} \end{cases}$ | MEND | Wang et al. (2022) |
| $\begin{cases} -0.2+1.44W_i, & W_i \le 0.556 \\ 1, & W_i > 0.556 \end{cases}$ | Rothc | Bauer et al. (2008) |
| $3.11W_i-2.42W_i^2$ | Moyano | Moyano et al. (2013) |
| $W_i^3(1-W_i)^{2.5}$ | CORPSE | Sulman et al. (2014) |

$W_i$ is relative water content in a range from 0 to 1; $\psi$ is soil water potential (MPa); $\psi_{FC}$ is the $\psi$ at field capacity.

These functions are generally developed and validated using soils from specific field sites and, as a consequence, are not suitable for a wider range of soil types, resulting in significant uncertainty when they are expanded to global scales (Moyano et al., 2012; Yan et al., 2018). Thus, it is important to consider the variability in the relationships between soil heterotrophic respiration and soil moisture through soil properties in the soil carbon models (Moyano et al., 2012). This comprehensive sight enhances our understanding of the impact of soil moisture on soil carbon stocks across diverse soil types and geographic regions, and reduces uncertainty in climate-carbon cycle feedbacks (Falloon et al., 2011).

## THE AIM AND EXPECTATION OF THE RESEARCH:

**Aim**:

(1) Investigate the impact of incorporating diverse soil properties-dependent moisture response functions into the ORCHIDEE model, a land surface model;

(2) Examine the role of soil moisture in global soil carbon dynamics;

(3) Examine the interactions between soil moisture and priming effect and their role in global soil carbon dynamics.

**Expectation**:

Combining the improved soil moisture response function of soil organic carbon decomposition in the global land surface model, Organising Carbon and Hydrology In Dynamic Ecosystems (ORCHIDEE), will provide a more comprehensive understanding of the impact of soil moisture on global soil carbon stocks. The original moisture response function was simply in a parabolic form and did not explicitly consider variations in soil properties. We anticipate that compared to ORCHIDEE and the version incorporated with priming (ORCHIDEE-PRIM), the simulation results of the improved versions of ORCHIDEE (ORCHIDEE-SMR and ORCHIDEE-PRIM-SMR) will reflect significant regional differences in soil carbon stocks, and simulations of ORCHIDEE-PRIM-SMR will be closer to soil carbon stocks observations. Besides, we speculate that the reduction in soil carbon stocks attributed to the presence of the priming effect may also be offset by the limiting effect of soil moisture on SOC decomposition.

## THE EXPERIMENTAL METHODS, DATA ANALYSIS METHODS, AND TIME ARRANGEMENT(*where required*):

The proposed research involves integrating the soil moisture response functions of soil organic carbon decomposition rate from Moyano et al. (2012) into the global land surface model ORCHIDEE, considering both versions of the model: one with the priming effect (ORCHIDEE-PRIM) and one without (ORCHIDEE), as described by Guenet et al. (2018).

(1) ORCHIDEE

ORCHIDEE is a process-based terrestrial ecosystem model that calculates the fluxes of $CO_2$, $H_2O$, and heat exchange between the land surface and the atmosphere on a half-hourly basis, and the variations of carbon pools on a daily basis (Guenet et al., 2018; Guenet et al., 2016). The dynamics of soil organic carbon (SOC) for each pool with and without priming effect (ORCHIDEE-PRIM and ORCHIDEE, respectively) (Guenet et al., 2018) is represented as Eq (1) and Eq (2):

$$\frac{dSOC}{dt} = \mathrm{I} - \mathrm{k} \times (1 - e^{-c \times FOC}) \times \mathrm{SOC} \times f(\theta) \times f(T) \times f(\gamma) \quad (1)$$

$$\frac{dSOC}{dt} = \mathrm{I} - \mathrm{k} \times \mathrm{SOC} \times f(\theta) \times f(T) \times f(\gamma) \quad (2)$$

where *I* is the input of C into each pool and *k* is the soil organic carbon decomposition rate. *c* is a parameter controlling the interaction of the fresh organic carbon (FOC) pool with the soil organic carbon mineralization. $f(\theta)$, $f(T)$ and $f(\gamma)$ are the soil moisture function, the temperature function, and the texture function modulating decomposition, respectively. Where $f(\theta)$ is represented as Eq

(3):

$$f(\theta) = \max\big(0.25, \min(1, -1.1 \times \theta^2 + 2.4 \times \theta + 0.29)\big) \quad (3)$$

where $\theta$ denotes the soil moisture in $m^3\ H_2O\ m^{-3}$.

(2) Soil moisture response function considering soil properties

In ORCHIDEE-PRIM and ORCHIDEE, we aim to refine Eqs (1) and (2) by integrating the soil-dependent moisture-respiration functions developed by Moyano et al. (2012). The functions predicting Proportional Response of Soil Respiration ($PR_{SR}$) are as follows:

$$\mathrm{PR}_{SR} = -0.48\theta + 1.8\theta^2 - 1.6\theta^3 + 0.1BD - 0.3\theta \cdot \mathrm{BD} + 0.18clay \\ -0.31\theta \cdot clay + 1.4SOC + 0.98 \quad (4)$$

$$\mathrm{PR}_{SR} = -0.83M + 1.5\theta^2 - \theta^3 + 0.08clay + \beta_5\theta \cdot \mathrm{clay} + 1.28SOC + 1.11 \quad (5)$$

$$\mathrm{PR}_{SR} = -1.12\theta + 2.22\theta^2 - 1.40\theta^3 + 1.178 \quad (6)$$

where clay denotes the clay fraction (%), SOC denotes soil organic carbon (mg $g^{-1}$), and BD is bulk density (g $cm^{-3}$). The soil properties-dependent moisture response functions are obtained in a two-step calculation (take Eq (4) for example):

1) Using Eq. (4) to predict $PR_{SR}$ values for each 0.01 moisture interval at given BD, clay, and SOC;

2) Using Eq. (7) to calculate the soil-dependent moisture response function that including soil properties:

$$f(\theta)_{sp} = \prod_{k=M_0}^{M} PR_{SR_k} \quad (7)$$

where, $f(\theta)_{sp}$ is the soil moisture response function considering soil properties. *k* is 0.01 moisture intervals from the initial moisture ($M_0$) to M (for $M_0 < M$). Therefore, in ORCHIDEE-PRIM-SMR and ORCHIDEE-SMR, we intend to modify Eq (1) and Eq (2) to Eq (7) to improve the accurate predictions of the response of soil carbon to future climate scenarios.

(3) Global-scale simulation

After incorporating the soil-dependent moisture response functions into the ORCHIDEE-PRIM and ORCHIDEE, four versions of the ORCHIDEE models (i.e., ORCHIDEE, ORCHIDEE-PRIM, ORCHIDEE-SMR, and ORCHIDEE-PRIM-SMR) will be run globally with historical and future climate. Simulations spanned from the historical period (1901–2020) to projections for the 21st century (1951-2100) under different climate scenarios. The historical dataset comes from the Climate Research Unit (CRU) (Mitchell et al., 2004) and the National Centers for Environmental Prediction (NCEP) (Kalnay et al., 1996). The future climate forcings of SSP1 and SSP5 from CMIP6 will be obtained from models such as HadGEM, IPSL-CM5A, and MIROC-ESM-CH.

(4) Timeline of research project

| Activity | Month | | | | | | |
|---|---|---|---|---|---|---|---|
| | 9 | 10~11 | 12~1 | 2~3 | 4~5 | 6~7 | 8 |
| Literature Review | X | | | | | | |
| Data Collection and Model Modification | X | X | | | | | |
| Model Calibration and Validation | | X | X | X | X | | |
| Model Simulation | | X | X | X | X | | |
| Results analysis | | | | X | X | X | X |

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**Type of PhD :**

1.Full PhD

- Joint PhD/cotutelle (leading to a double diploma) : NO
- Regular PhD (leading to a single French diploma) : NO

2. Visiting PhD (students enrolled at a Chinese institution who come to ENS for mobility period) : NO

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