PaleoAIce: AI-driven Paleo-ice sheet reconstructions

3 Years – Start 1st of October 2025. Application deadline : 30th of April 2025

1. Context and concepts

Subglacial bedforms: the basic ingredients for palaeoglaciology

Currently, less than 10% of Earth's land surface is covered by ice, primarily concentrated in the polar regions. However, during the peak of the Pleistocene ice ages, approximately 20,000 years ago, ice sheets covered 25-30% of the global landmass (Figure 1). The three main components of the glacial system then interacted to create unique landscapes whose topographic signal is recognisable at the continental scale (e.g. North America, Figure 2): (1) a mobile ice column hundreds to thousands of meters in thickness, (2) a pressurised subglacial hydrological system, and (3) a soft, mobile sedimentary bed. Parts of this topographic signal are gigantic fields (106 km^2) of individual and periodic sedimentary mounds of pluri-metre to pluri-kilometre scale called subglacial bedforms. They are reliable proxies for unravelling the characteristics of subglacial processes, which are poorly constrained in ice sheet models, and considered as the basic ingredients for the growing field of palaeoglaciology, at the crossroads of glaciology and geomorphology (Vérité et al., 2024).

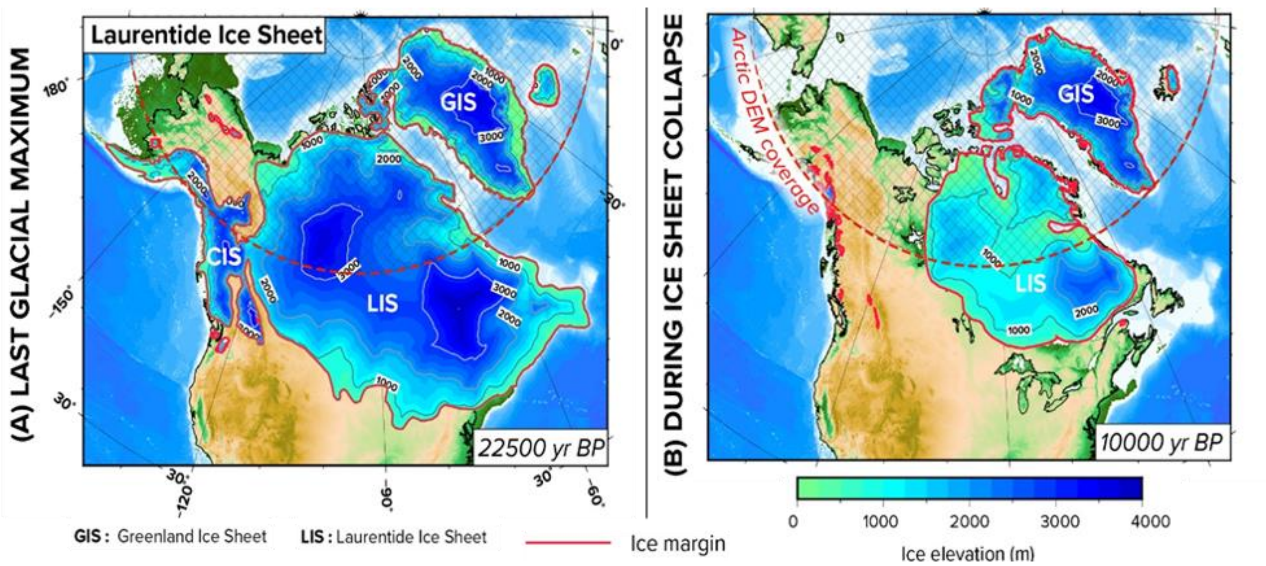

Figure 1: Reconstruction of North American ice sheets during (A) the Last Glacial Maximum and (B) a period of enhanced retreat in Late Pleistocene to Early Holocene (modified after Gowan et al., 2021).

...possibly unlocking the hidden dynamics of ice sheet collapse

The mechanisms driving the final demise of ice sheets (e.g. collapse) remain poorly understood. Since the events leading to collapse is connected to widespread changes in subglacial processes, analyzing the geomorphological records of past collapse events offers a robust, data-driven approach. The reorganisation of ice and meltwater flow dynamics under enhanced warming leads to the massive transfer and reshaping of subglacial sediments into bedforms that often remain pristine when the ice has quickly vanished. Considering the dimensions and shapes of bedforms are controlled by spatio-temporal variations in ice-meltwater-bed interactions (Ely et al., 2023; Vérité et al., 2024), their morphometric characteristics are now considered to be reliable indicators for palaeoglaciological reconstructions.

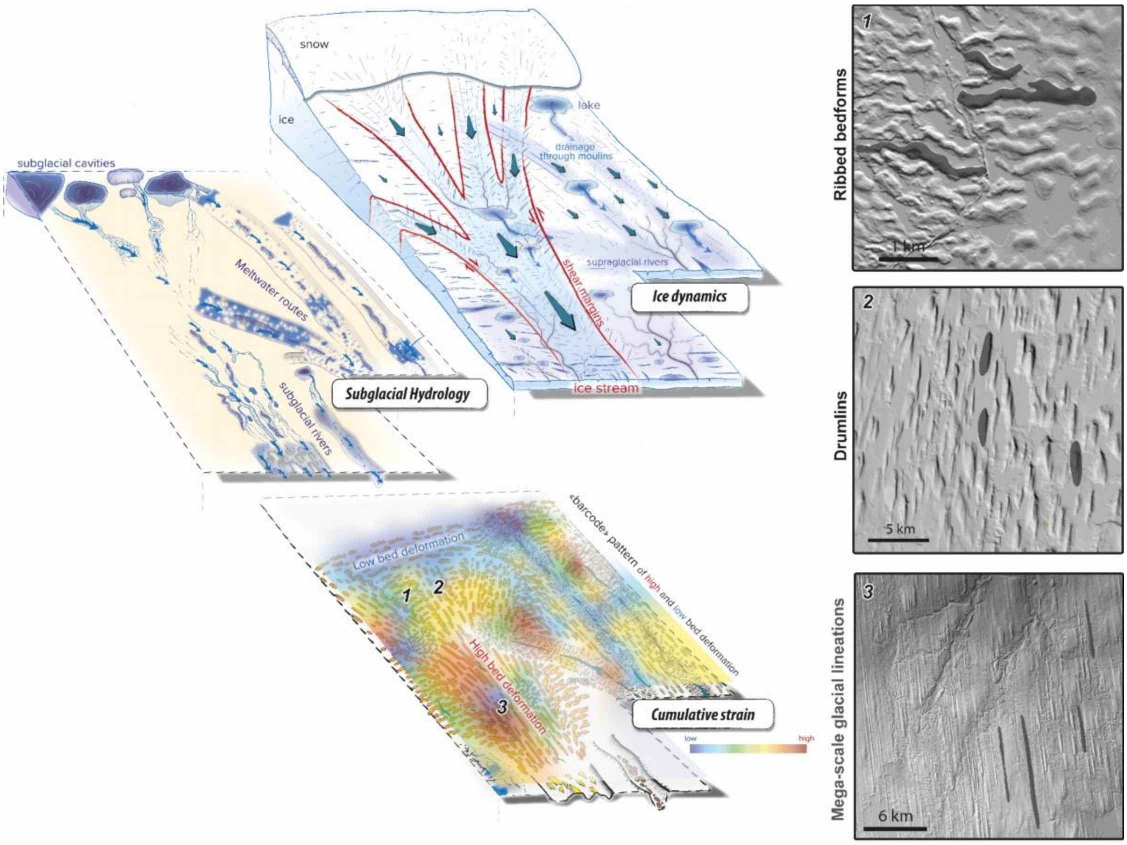

Figure 2*: Schematic assemblage of subglacial bedforms and associated cumulative strain related to subglacial hydrology and ice dynamics of an idealized ice sheet. According to positions and subglacial processes, bedform of different sizes and shapes spread at the subglacial bed interface and are illustrated on a hillshaded Digital Elevation Model (Right panel).*

2. AI-driven methods to reach a breakthrough in palaeoglaciology

Until now, deciphering the detailed geomorphological signature of ice sheet collapse produced from the analysis of big bedform databases is prevented by (i) the lack of a solid automated bedform mapping workflow, (ii) ambiguities in classical theories about bedforms and their paleoglaciological significance and (iii) the absence of an efficient ice sheet-scale palaeoglaciological reconstruction tool. Members of our team have already taken the first steps of this challenging task eluding the classification step of subglacial bedforms (Vérité et al., 2023, 2024a) and producing a semi-automated workflow relying on a threshold segmentation (Hesni et al., 2025). However, this method faces new challenges associated with its large-scale deployment with time consuming manual post-processing to remove non-subglacial features (e.g. bedrock, man-made infrastructures, postglacial weathering and permafrost degradation).

AI application to palaeoglaciology and ice sheet modeling is still in its early stages of development. Recent studies have showcased the potential of Convolutional Neural Networks (CNNs) for processing vast geomorphological datasets and automating feature extraction and mapping (Rocamora et al., 2023; Daynac et al., 2024). This will pave the way to the inversion of unknown parameters such as ice thickness and velocities, or meltwater pathways from palaeoglaciological databases and bridge the gap between big data and numerical models. This could be crucial for refining the reliability of projections of ice sheet response to climate change.

3. Objectives and tasks to achieve breakthrough

The PhD student will **develop a full AI-driven protocol for automated palaeoglaciological reconstructions at the scale of an ice sheet.** This objective will be achieved by carrying out the following tasks:

1) **Spectral and topographic data selection and pre-processing** from free satellite datasets (available at large scale and high resolution) to differentiate depositional subglacial bedforms (and landforms) from other features.

2) **Benchmarking** the efficiency and performance of different Deep Learning (DL) models which map subglacial bedforms and landforms with an accuracy above 90 % (U-Net, ResNet, Diffusion models and Vision-Transformers).

3) **Production of an annotated datasets** (> 3000 bedforms/landforms) from spectral (Sentinel-1 and 2, Landsat 8-9), topographic (ArcticDEM), manual (e.g. Vérité et al., 2022) and semi-automated (Hesni et al., 2025) digitizing for assessment of DL models performance.

4) **Produce the first database of subglacial bedform outlines at the scale of an ice sheet** from DL models.

5) **Complete the developed morphometric descriptors of bedforms** (Vérité et al., 222, 2024a, Hesni et al., 2025) with new spectral (e.g. Till indicator derived from Moisture and Vegetation indices) and spatial (e.g. Gridded FFT) ones.

6) **Identification of the main bedform descriptors, classification/continuum analysis and interpretation from 4 different multivariate (Principal Component Analysis (PCA) and Cluster Analysis) and spatial statistics (Spatial Autocorrelation).**

7) **Apply the full automated workflow for palaeoglaciological reconstructions at the ice sheet-scale**, and improve recent theoretical results (Ely et al., 2023; Vérité et al., 2024) on the relations between bedform shapes, till deformation, glacial flow and subglacial hydrology.

8) **Data-model comparisons** by integrating existing ice sheet simulations on the Laurentide (Stokes et al., 2016; Gowan et al., 2016, 2021) i) with the new palaeoglaciological reconstructions and ii) with the compilation of published geomorphological and geochronological data (e.g. till thickness, Ice flow field data, moraine ages) in a Laurentide Ice Sheet scale database.

4. Target, Data & Tools

- Target

The PhD student will focus on the Laurentide Ice Sheet covering a large part of the North American continent during the last glacial period (Figure 1).

- Data

- ***ArcticDEM*** (10m resolution), made available online free of charge by the Polar Geospatial Center (Porter et al., 2018; https://livingatlas2.arcgis.com/arcticdemexplorer/).

- ***Free Lidar-based DEMs*** for areas beneath the Arctic circle available for Scandinavia (https://www.lantmateriet.se/.; https://www.maanmittauslaitos.fi/)

- ***Sentinel 2*** (10-20 m resolution) multispectral data made available by ESA Copernicus and derived indices NDWI, NDVI, SWIR, NSMI, WI, CMR, albedo

- Compilation of published calibrated ages for ice sheet collapse chronology (radiocarbon, cosmogenic radionuclides, OSL, TL).

- Tools

- QGIS and Python (VisualStudio, Jupyter Notebook, PyTorch).
- Local Workstation.
- Regional Computing centre GLiCID (Groupement Ligérien pour le Calcul Intensif Distribué), made available at very low computing charge for researchers of its member laboratories.

5. Provisional calendar

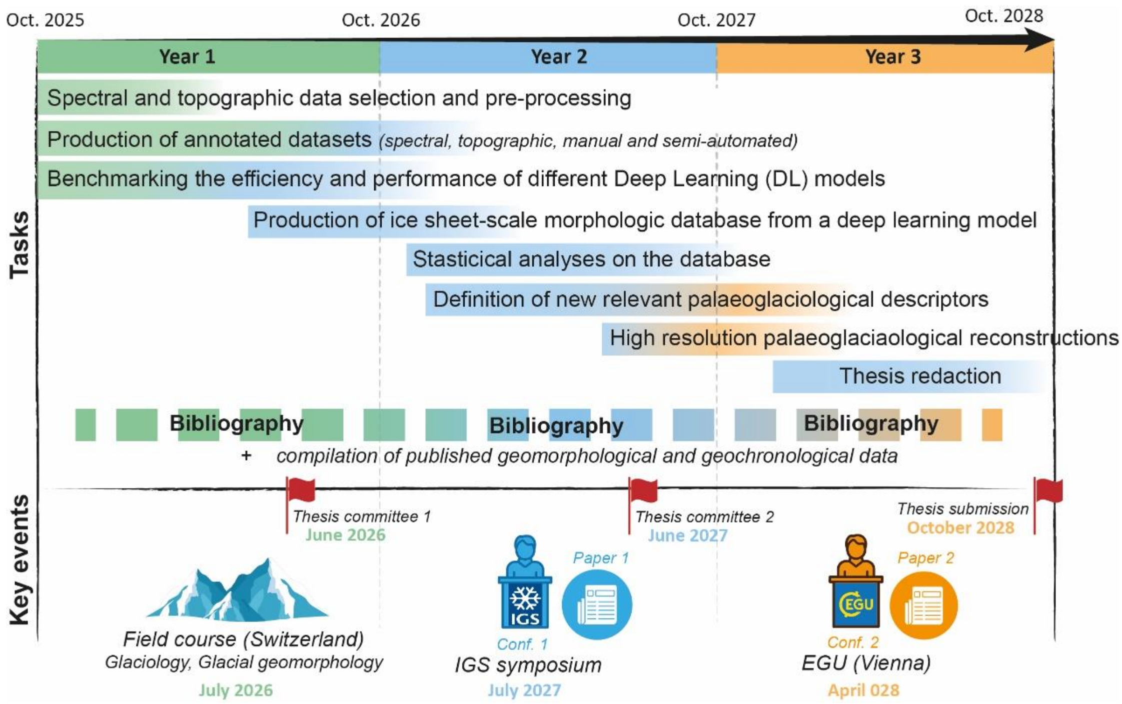

Figure 3. *Gantt chart of the provisional calendar of Tasks and Key Events during PhD.*

6. Lab context and the supervision team

Located at the **science faculties of Nantes, Angers** and **Le Mans universities**, the "**Laboratoire de Planétologie et Géosciences**" (LPG) is a multi-site Mixed Research Unit supported by the CNRS and the Universities of Nantes, Angers and Le Mans. Research activities are divided into three research themes: (1) **Coastal and Marine Systems, (2) Earth**, and **(3) Planets and Moons**. One of the main research axes inside the **Earth** theme deals with the geomorphological and structural transformation of geological materials caused by liquids. Within this research axis, our team focuses on subglacial environments, in which the circulation of pressurised interstitial liquids plays a fundamental role in erosion, sedimentary transfer and the creation of bedforms.

The **« Laboratoire d'Informatique de l'Université du Mans » (LIUM)** has been established as a pioneer in deep learning applications since 2007. Located in Le Mans and Laval, its research activities include technology-enhanced learning as well as language and speech processing but also active-learning and continual learning.

The supervision team

The main supervision team (**Edouard Ravier, Paul Bessin** and **Anthony Larcher**) has a strong and recognized experience in geomorphology, glaciology and **Deep Learning.** The team has also recognized skills in GIS combined with the use artificial intelligence, especially in some of their most recent publications (Daynac et al., 2024, Hesni et al., 2005). The PhD student will also benefit from **Olivier Bourgeois** and **Stéphane Pochat** (LPG – Nantes) expertise on geomorphology, glaciology and kinematics of subglacial bed deformation.

7. Candidate profile and prerequisites

- Master degree in Earth Sciences or Physical Geography.
- Proficiency in Python and GIS required.
- Strong interest in Artificial intelligence and big data.
- Solid knowledge in Geomorphology.
- Background knowledge in glacial sciences and fluid mechanics will be appreciated.
- Good level in oral and written scientific English.

8. Salary

2300 €/month (gross salary)

9. How to candidate ?

Go to website AMETHIS

https://amethis.doctorat.org/

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