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Retrieving climatic and temporal information from the last glacial maximum using an invert glacier model

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Understanding past natural climate variations during the Quaternary period is crucial for understanding the ongoing climate change. Glaciation events during the Quaternary have left visible footprints in today's landscape, such as moraines and trimlines, that could be used to reconstruct paleo glacier extent.

Reconstructed glacier extent offers great potential to retrieve paleo-climate information during the coldest episodes of the Quaternary by inverting a glacier evolution model. However, current inversion methods are computationally expensive and their forward model relies on simplified physics. Fundamentally, they all assume glaciers are in a stationary state, which is simplistic and fails to capture essential transient features linking climate to glacier response.

Here, we develop a new Machine-Learning (ML)-based inversion technique that overcomes the previously-mentioned limitations to reconstruct the glacier equilibrium line altitude (ELA), a proxy for temperature and precipitation, during a glacial maximum from reconstructed glacier extent. Our forward model consists of a deep-learning emulator that learns the physical processes of a glacier from climate forcing to the glacier response. This approach has the advantage of being computationally highly-efficient, as well as allowing for automatic (thanks to the automatic differentiation) inversion of reconstructed glacier extent to retrieve a realistic ELA field that informs us about paleoclimates.

When applying our method to the Last Glacial Maximum in the European Alps, our reconstructed ELA fields show a clear separation between the northern and southern Alps, with northern ELAs being considerably lower as shown in Fig 1. Our results are supported by the glacier footprints reconstructed from geomorphological observations in the northern Alps, which suggest the presence of large glacier lobes. In contrast, the glacial lobes in the southern Alps were noticeably smaller.

Our method is applicable in any formerly glaciated areas, and therefore has a high potential for paleoclimate reconstruction of the Earth's coldest episodes.

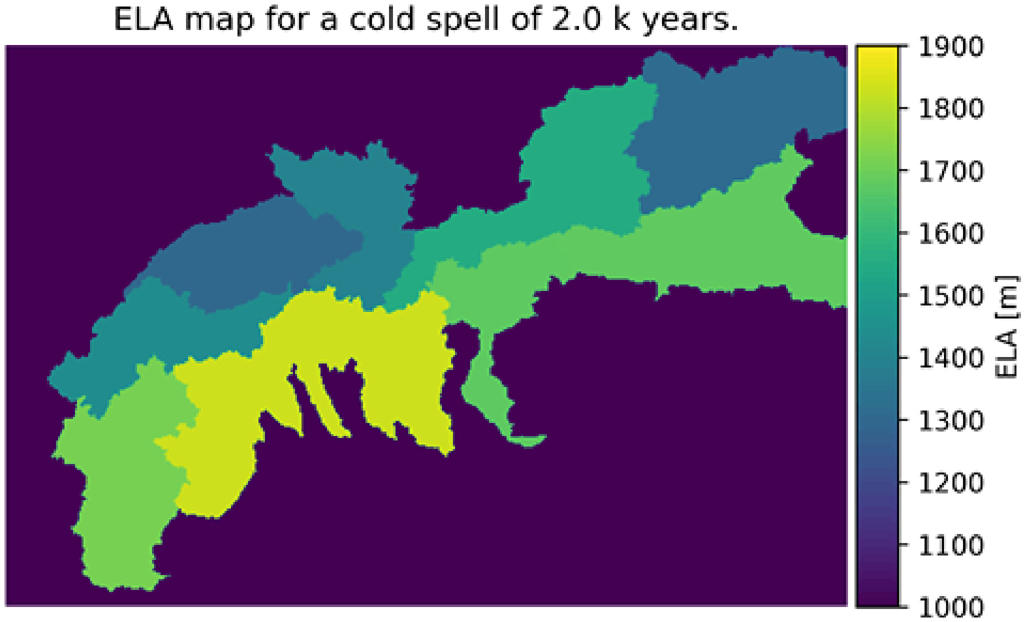

Figure1. The resulting ELA field from inverting the ‘observed’ glacier footprint. There is a visible difference in the climate between the north and the south.