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Developing an emulator to calculate present temperature field in the Antarctic Ice Sheet

Catherine Ritz[1], Christophe Dumas[2], Marion Leduc-Leballeur[3], Giovanni Macelloni[3], Ghislain Picard[1], and Aurélien Quiquet[2]
[1]CNRS, IGE, Saint-Martin d'Heres, France (catherine.ritz@univ-grenoble-alpes.fr)
[2]Laboratoire des Sciences du Climat et de l'Environnement (LSCE), CEA/CNRS-INSU/UVSQ, Gif-sur-Yvette, France
[3]Institute of Applied Physics "Nello Carrara"—National Research Council—IFAC—CNR, Italy

Ice temperature within the ice is a crucial characteristic to understand the Antarctic ice sheet evolution because temperature is coupled to ice flow. Since temperature is only measured at few locations in deep boreholes, we only rely on numerical modelling to assess ice sheet-wide temperature. However, the design of such models leads to a number of challenges. One important difficulty is that the temperature field strongly depends on the geothermal flux which is still poorly known (see White paper by Burton-Johnson and others,2020). Another point is that up to now there is no fully suitable model, especially for inverse approaches: i) analytical solutions are only valid in slowly flowing regions; ii) models solving only the heat equation by prescribing geometry and ice flow do not take into account the past changes in ice thickness and ice flow and do not couple ice flow and temperature. Conversely, 3D thermomechanical models that simulate the evolution of the ice sheet take into account all the relevant processes but they are too computationally expensive to be used in inverse approaches. Moreover, they do not provide a perfect fit between observed and simulated geometry (ice thickness, surface elevation) for the present-day ice sheets and this affects the simulated temperature field.

GRISLI (Quiquet et al. 2018), belongs to this family of thermomechanically coupled ice sheet models An emulator, based on deep neural network (DNN), has been developed in order to speed-up the simulation of present-day ice temperature. We use GRISLI outputs that come from 4 simulations, each covers 900000 years (8 glacial-interglacial cycles) to get rid of the initial configuration influence. The simulations differ by the geothermal flux map used as boundary condition. Finally a database is built where each ice column for each simulation is a sample used to train the DNN. For each sample, the input layer (precursor) is a vector of the present-day characteristics: ice thickness, surface temperature, geothermal flux, accumulation rate, surface velocity and surface slope. The predicted output (output layer) is the vertical profile of temperature. In the training, the weights of the network are optimized by comparison with the GRISLI temperature.

The first results are very encouraging with a RMSE of ~ 0.6 °C (calculated from the difference between the emulated temperatures and GRISLI temperatures over all the samples and all the

depths). Once trained, the computational time of GRISLI-DNN for generating temperature field of whole Antarctica (16000 columns) is about 20 s.

The first application (in the framework of the ESA project 4D-Antarctica, see Leduc-Leballeur presentation in this session) will be to use this emulator associated with SMOS satellite observations to infer the 3D temperature field and improve our knowledge of geothermal flux. Indeed, it has been shown that SMOS data, coupled with glaciological and electromagnetic models, give an indication of temperature in the upper 1000 m of the ice sheet. Our emulator could also be used for initialization of computationally expensive ice sheet models.