Applied Machine Learning 2025 - Antarctic ice sheet ice thickness inversion - handbook

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1 Overview

The Antarctic ice sheet is the biggest ice body on Earth, equivalent to more than 58 meters of sea level rise, if melted completely. The ice lies on top of a continental bedrock, which topography is even at times below the mean sea level. This vast and desertic iced continent has been now monitored from space using satellites for over 4 decades. We know with fairly high accuracy the elevation of the surface of Antarctica, but the ice thickness (hence the topography of the underlying bedrock) is still known with significant uncertainty. So far, a map of the Antarctic ice thickness has been produced from glaciological models, e.g. BedMachine v3.7 [1, 3], which relies mostly on mass conservation. This model is the current state-of-the-art. It works well in certain regions, less well in other regions.

The goal of this project is to create an ice thickness map of Antarctica, using machine learning methods.

So far, just few attempts using machine learning have been explored, despite 80 million measurements of ice thickness exist. Those have been collected using ground penetrating radar devices carried on airplanes, allowing measurements of ice thickness along the flight tracks. In this quest of determining the ice thickness of Antarctica, you are provided with a training dataset of ice thickness measurements: Bedmap. Other variables are provided (alongside the BedMachine model), but you may get inspired and experiment with new ones or generate your own dataset.

- **Surface ice velocity** module v (units: m/yr). The ice velocity of Antarctica has been monitored from space, with Synthetic Aperture Radar sensors. Ice tends to flow from the interior of the ice sheet towards the boundaries of the continent, forming ice streams that end up in the Antarctic ocean.
- **Surface mass balance**, smb (units: mm w.e./yr). The surface mass balance is the difference between the amount of snowfall and the mass loss due to ice melt, iceberg formation (calving), or other mechanisms. If MB>0, the location is accumulating ice, if MB<0, the location is experiencing net loss of ice.
- **Surface elevation**, z (units: m a.s.l.). The elevation of ice surface, in meters above sea level. On a very crude first approximation, Antarctica elevation is high in the interior and slopes down to sea level towards its margins.
- **Surface slope**, s. The surface slope is defined as:

$$s = \sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2} \tag{1}$$

  where z(x,y) is the surface elevation in meters at location (x,y).

2 Data

I provide you with the maps (a.k.a. rasters) of elevation, mass balance, velocity, and a state-of-the-art model for ice thickness, called BedMachine v3.7, which you can compare your results with. I also provide a tabular dataset of such variables and the ice thickness measurements. The variables are obtained by linearly interpolating the corresponding maps at the location of the measurements. You may have 2 options: either train a model using the tabular dataset, or create your own dataset of "images" generated from the rasters, and train using the images as inputs. I also added the BedMachine v3.7 linearly interpolated ice thickness values as part of the tabular dataset.

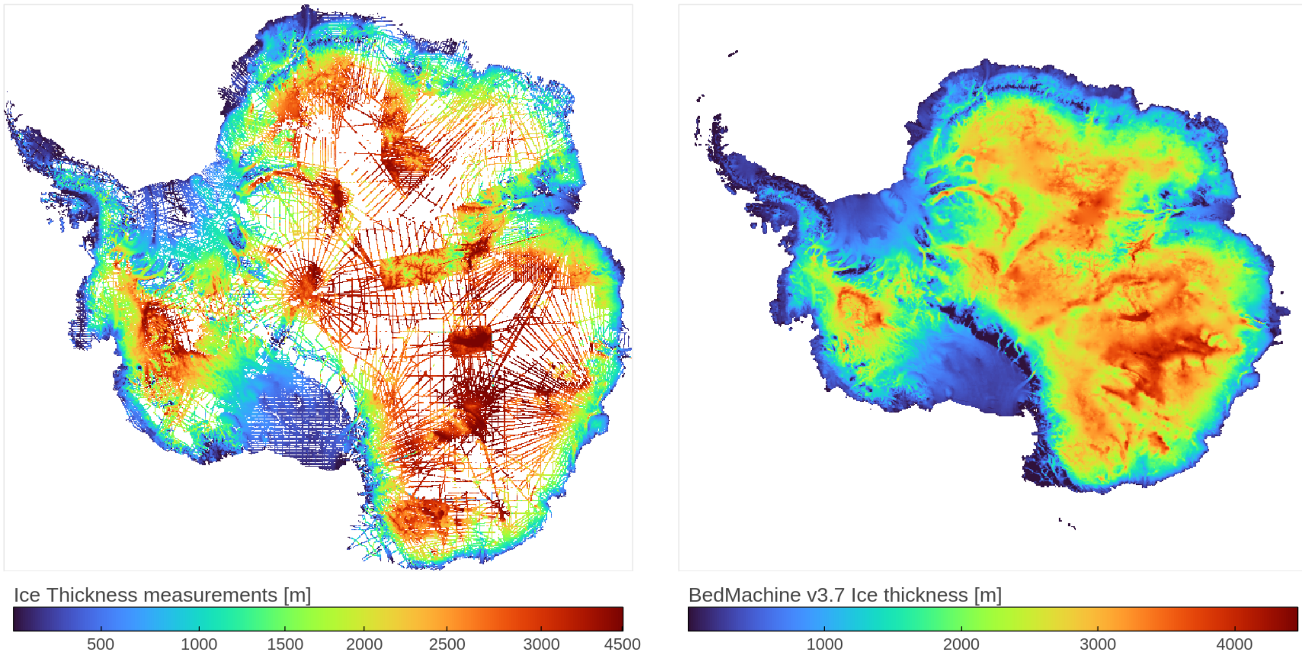

Figure 1: Left: Ice thickness (training) measurements from the combined BedMap datasets. The measurements are collected often in straight lines reflecting the flight survey tracks. Some tracks contain spurious measurements. Right: BedMachine v3.7 model of ice thickness.

3 Spatial resolution of the rasters and projection

The grid of the raster products (i.e. 1 pixel corresponds to):

- Mass balance: 2000 m
- Ice velocity: 450 m
- Surface elevation map: 500 m

All rasters are provided in the "3031" projection. This projection is the standard for Antarctica, as minimizes distortions. In this projection x and y are units of meters, therefore you can safely apply geospatial functions. e.g. the distance between two points will be simply $d(1,2) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$.

4 Physics

An approximation of the mass conservation equation is the following:

$$\nabla \cdot (H\vec{v}) \approx smb \tag{2}$$

where H is the ice thickness, $\vec{v}$ is the surface ice velocity and smb is the surface mass balance and $\nabla\cdot$ is the divergence operator. For a more detailed explanation of an (almost exact) mass-conservation based approach to this problem, see [2].

5 Useful packages

For plotting purposes and geospatial analyses, I'd recommend the following python packages:

- Geopandas, xarray, rasterio, rioxarray.
- datashader, holoviews (for plotting millions of points and big rasters)

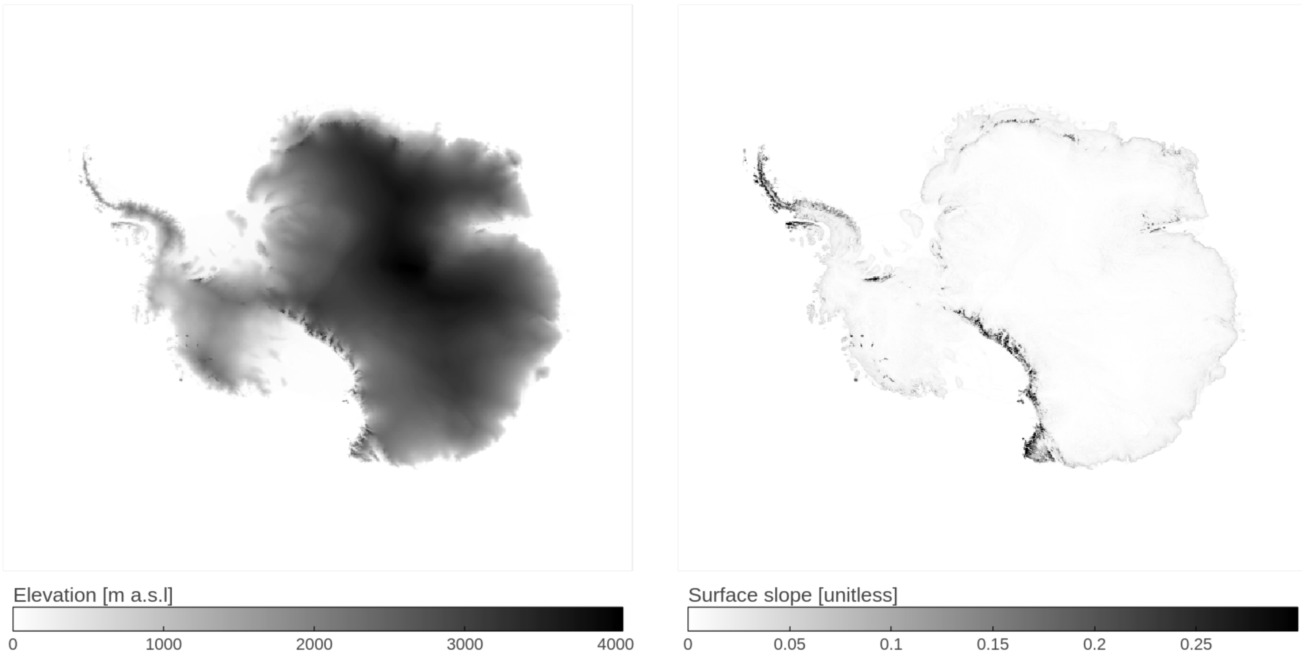

Figure 2: Surface elevation in meters above sea level (left) and surface slope (right).

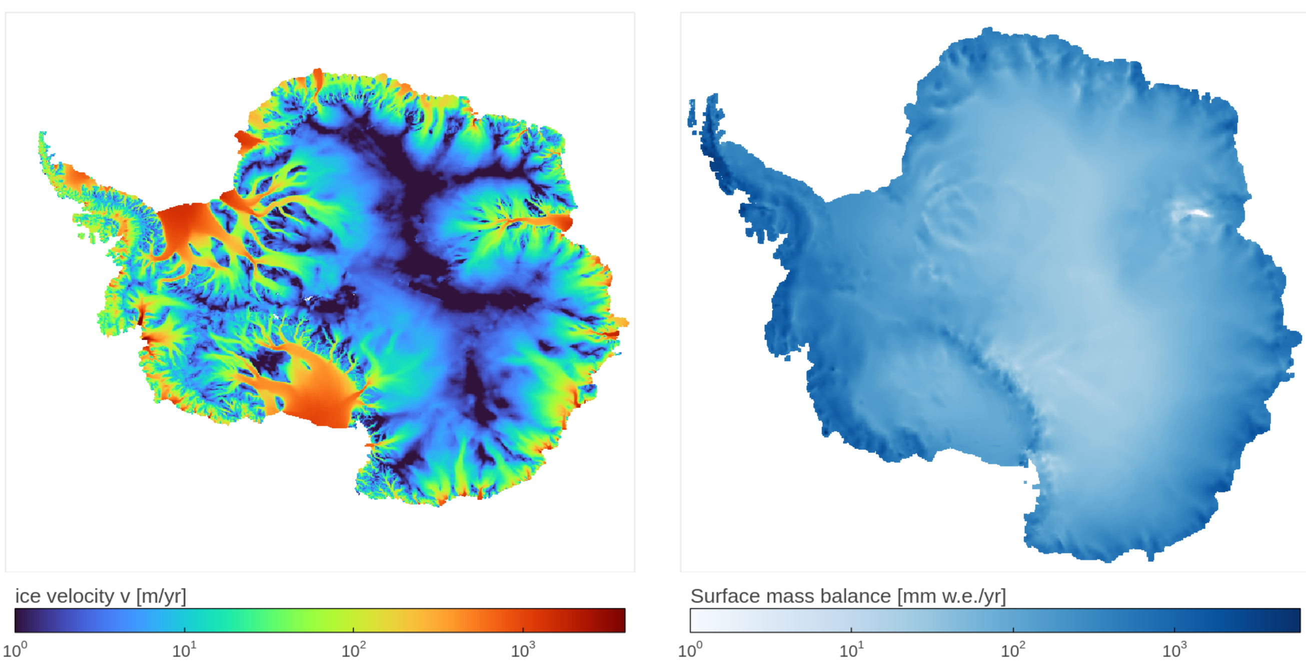

Figure 3: Surface ice velocity (left) and mass balance (right).

References

[1] Mathieu Morlighem. *MEaSUREs BedMachine Antarctica, Version 3*. 2022. DOI: 10.5067/FPSU0V1MWUB6. URL: http://nsidc.org/data/NSIDC-0756/versions/3.

[2] Mathieu Morlighem et al. “A mass conservation approach for mapping glacier ice thickness”. In: *Geophysical Research Letters* 38.19 (2011).

[3] Mathieu Morlighem et al. “Deep glacial troughs and stabilizing ridges unveiled beneath the margins of the Antarctic ice sheet”. In: *Nature geoscience* 13.2 (2020), pp. 132–137.