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A new blue ice area map of Antarctica

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Whereas most of the continent of Antarctica is covered by snow, in some areas, blue-colored ice emerges to the surface. In these blue ice areas (BIAs), mass is removed at the surface through ablative processes. This mass removal exposes deeper layers of ice that are normally located closer to the underlying bedrock. As a result, we can find old ice at the surface of BIAs, as well as the material contained within the ice, such as meteorites and terrestrial rocks. BIAs are unique locations for sampling old ice for palaeoclimatic purposes and collecting meteorites (about □ of all meteorites ever retrieved on Earth come from Antarctica BIAs). Hence, a high-quality BIA map is essential for meteorite searches, the quest for the oldest ice, and surface mass balance modeling.

Prior efforts to map BIAs across the Antarctic continent using remote sensing are single-sensor based, introducing biases related to temporary snow coverage of the exposed ice, and sensor-dependent conditions such as solar illumination angles, anisotropic reflectance, or cloud coverage. To overcome these challenges, we opt for using multi-sensor observations in a deep learning framework to create a new BIA map. The observations we use are (i) radar backscatter, (ii) surface morphology, (iii) elevation, and (iv) multi-spectral reflectance. The deep learning algorithm consists of the well-established convolutional neural network U-Net, which allows for an efficient training process and inclusion of spatial context. The algorithm outputs a pixel-level prediction of blue ice presence. Moreover, by training multiple, randomly initialized models and rotating and flipping data, we obtain multiple predictions for each pixel. Thanks to this data augmentation at test time, we estimate the variation in the predictions, which we then use as an indication of uncertainty.

We use an existing dataset of BIA outlines as reference for training the model. It is known that these existing labels are noisy due to i) large uncertainties related to the use of a single sensor, and ii) biases as a result of applying a threshold that is based on local observations over the entire continent. However, convolutional neural networks, combined with regularization methods like weight decay and batch normalization, can learn from underlying 'clean' patterns of noisy labels

during initial epochs of training (i.e., at the start of the training process). Here, we demonstrate this noise-eliminating property by assessing the algorithm's performance on noisy pixels that are used for training, where we see that over 80% of these noisy instances are attributed correctly. Furthermore, we optimize the performance of the neural network based on a reduced set of "noise-free", hand-labeled validation data. Last, we test the performance of our model on hand-labeled test data, therefore having a realistic estimate of the model performance on precise, so far unused data. These tests indicate that it is possible for the neural net to learn how to map blue ice from the noisy data, leading to an improved map of BIAs in Antarctica.