Efficient Algorithms for Monitoring Polar Areas Using Satellite Images

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When we want to classify different ice cover types in thematic maps based on satellite images, we can directly start with the publicly available image products of the European Sentinel-1 and Sentinel-2 missions and include some appropriate classification algorithm. In our case, we are mainly interested in cartographic ice maps generated from selected single images as well as time series of overlapping ice cover images of the Arctic region that can be derived either from polarized synthetic aperture radar images (in case of Sentinel-1) or from multispectral optical images (in case of Sentinel-2 that includes infrared bands).

Therefore, in the following, we will concentrate on the selection of appropriate classification algorithms, where the goal of our ice cover analysis is the routine generation of multi-class thematic maps that can be used for the analysis of snow and ice cover phenomena, and for the monitoring of shipping routes. In both cases, we have to interpret large-scale target areas with discernible brightness levels and neighborhood contrast for cold (fresh) or melting (old) ice, snow cover, seawater and local water leads, ships, coastlines, and icebergs.

In order to assess and compare the performance of various ice-type classification algorithms we selected a number of typical arctic Sentinel-1 and Sentinel-2 level-1B images, and cut them into easily manageable small patches (typically comprising 128×128 or 256×256 pixels for Sentinel-1 images, or 120×120 pixels for Sentinel-2 images). Then we applied and compared several selected algorithms to these patches and analyzed their ice classification performance:

1. Traditional image feature extraction followed by ice classification via a Support Vector Machine (SVM) and semantic content labeling by human ice image experts ("Active Learning"). This resulted in semantic ice category maps typically comprising up to 12 discernible categories. However, we have to be aware of the fact that the resulting single main category of each patch does not give any hint to additional sub-categories ("The winner takes all").
2. As an alternative, we also tested the use of Autoencoders or Deep Neural Networks (DNNs), where also several public-domain software packages are available. For training, we used the examples of the first algorithm. Quality monitoring was done by comparisons with the active learning results.

3. Another tested approach were bagging algorithms (“Bag of …”) that are interesting for straightforward ice classification, for instance, “Bags of Words” or “Bags of Topics” allow for rapid classifications without classification biases due to improperly selected training data. The bagging techniques represent a powerful alternative to the well-known *k*-means, random dictionaries, or SVM approaches.
4. Still better results can be reached when one applies Convolutional Neural Networks (CNNs), a very popular variant of deep learning for image classification; however, the final results depend on the actual selection of reference data during training. Therefore, we exploited the LDA approach (see below) for the optimal training of the CNN parameters.
5. Addition of Latent Dirichlet Allocation (LDA) to the bagging and CNN algorithms. Here, the image patches are cut into smaller sub-patches (typically comprising 4×4 pixels) that are routinely classified into 20 statistically (i.e. mathematically) defined types of clusters without any support by human ice type experts. These cluster types are then converted by LDA into 10 highly accurate ice type topics (then a semantic ice category is a combination of a number of topics).

As our main result, it turned out that LDA approaches should be an integral part of polar ice mapping algorithms.

As future work, we are planning to analyze the ice classification behavior of complex-valued Sentinel-1 radar images, the use of (multi-)hashing techniques instead of SVMs, the attainable image patch compression rates as a cluster discrimination criterion, as well as the semantic fusion of co-aligned Sentinel-1 and Sentinel-2 images.