Neural Networks can Automate Monitoring the German Wadden Sea

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We introduce a two-stage neural network for the automated detection of water lines from Sentinel-1A/B VV-polarization SAR data in intertidal regions. The network provides a binary mask of intertidal flats and open water whose occurrence depends on the tidal phase and morphological processes. The selection of training data allows the network to make reliable projections about the extent of intertidal flats in the German Wadden Sea under different weather conditions. However, so far, the precision is limited due to numerical errors and a wide variation in recording quality.

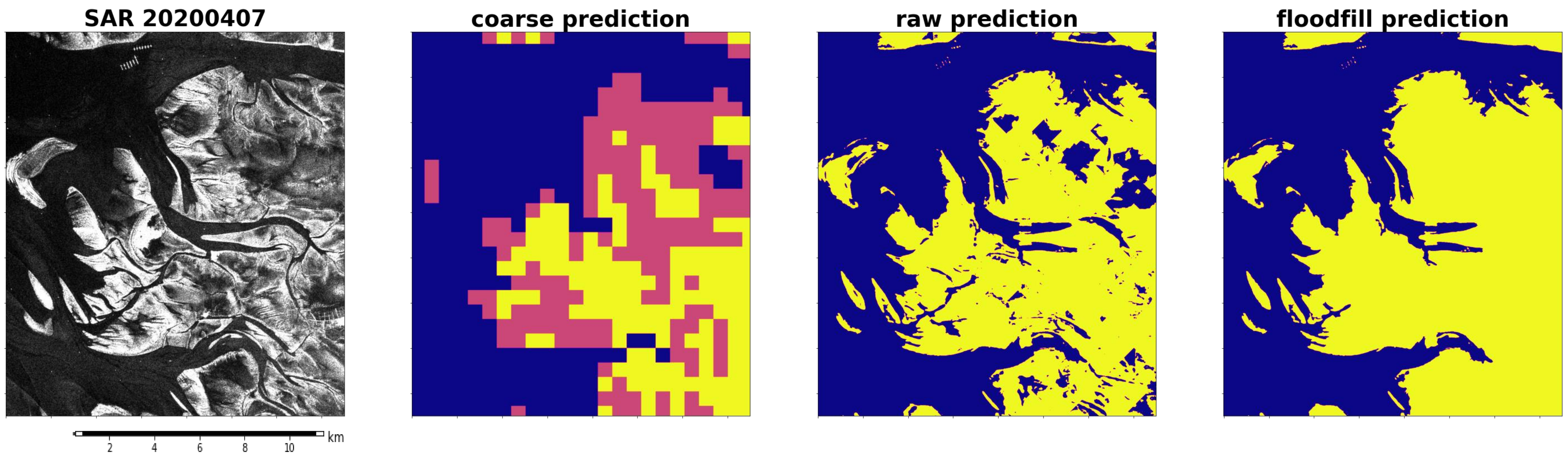

Figure 1: **(a)** Excerpt of a SAR image (Sentinel 1A, 7 April 2020, 17:17 UTC) showing the island of Trischen on the German North Sea coast, along with surrounding dry-fallen flats. **(b)** Coarse prediction (first stage) with a first guess between land and water. Magenta fields include equal shares of land and water. **(c)** detailed mask predicted by the network based upon (a), (b) and a general land-water mask (not shown). **(d)** floodfilled prediction based on (c).

Background

Intertidal flats are constantly exposed to strong tidal currents, causing displacement and erosion. These morphological changes influence shipping routes, fishery and coastal protection, hence a monitoring the intertidal region via digital elevation maps (DEMs) is also of economic interest. To capture the extent of intertidal flats at a certain point in time, SAR sensors are particularly advantageous, as they are independent of daylight and cloud conditions, and they may provide sub-weekly data.

However, the SAR image contrast between exposed flats and open water depends, among others, on local weather conditions, and hence, it challenges existing algorithms for the detection of water lines [1]. Further, both the SAR data's preprocessing and sensible fine tuning state problems of existing algorithms regarding flexibility and computation [2].

In contrast, the human mind, connected with basic knowledge about the region, could directly segregate between exposed flats and open water, when given a SAR acquisition. For this reason, we complement the physical algorithms with a deep learning network. Once trained on a suitable dataset, this neural network consumes few computational resources and is applicable to a wide range of SAR images.

Method

The proposed neural network consists of two stages, both of which are structured as an image-to-image network. The first stage of the network produces a low resolution (640 m × 640 m) classification of whether the area of interest is predominantly water or land, using VV polarization SAR data and a generic land-water mask as input.

The second stage uses the low-resolution allocation, along with the initial input, to accurately segregate water from intertidal flats at the full resolution of the radar image (10 m × 10 m). Like in the first stage, the resolution of the input image is reduced, and the number of information layers is increased. Then, the prediction is progressively built up with increasing resolution, so that the final result has the same resolution as the input.

To merge the individual details, the prediction is repeated with shifted image sections, and the results are combined. During post-processing, a floodfill routine is applied to ensure a reasonable distribution of land and water.

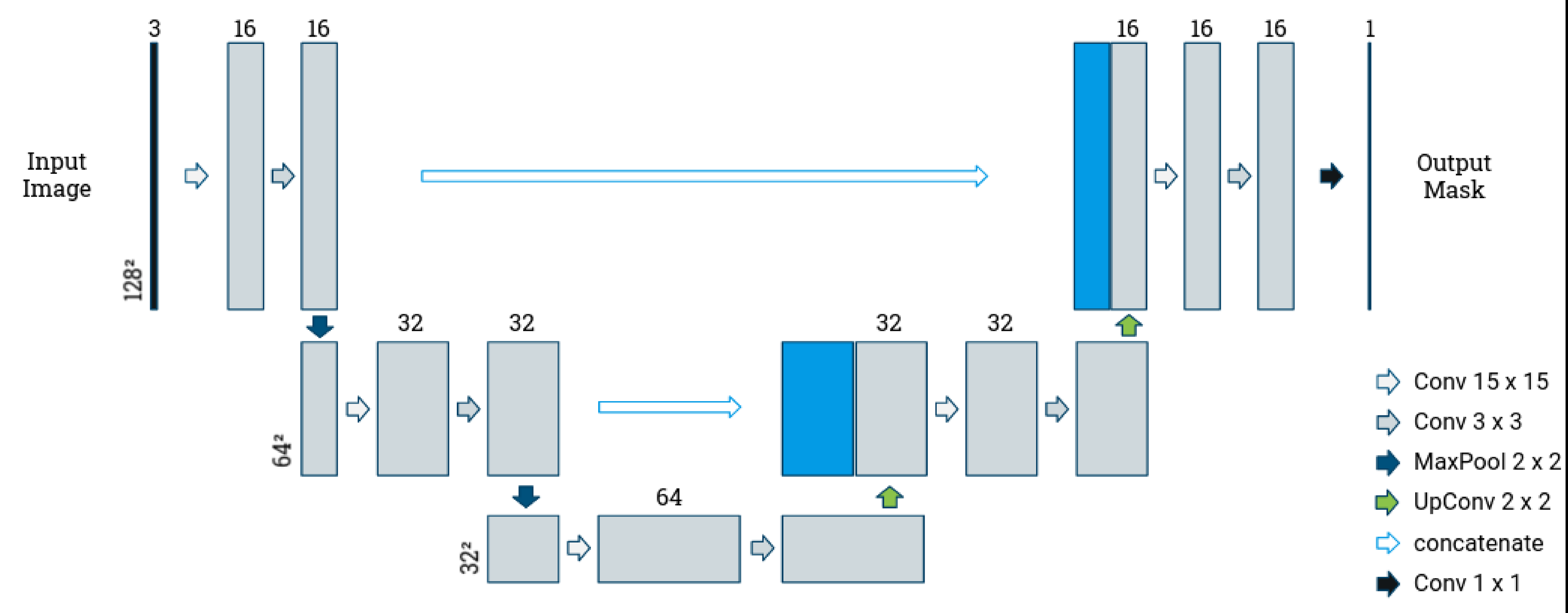

Figure 2: Architecture of the second stage of the neural network. The given structure is called U-Net, due to the encoding and reconstruction of the input image. Numbers above the blocks display the channel depth, numbers on the sides display the (virtual) image resolution. Convolutional layers are used to allocate image parts and shapes to either land or water. Tne number of total free parameters is 37441.

Results

The neural network produces a forecast that reliably predicts the rough structures of the intertidal flats. At this stage, it already detects tidal channels up to 50 metres in width.

At a finer scale, the network encounters challenges in terms of reliability. Although it successfully identifies smaller tidal channels, the floodfilling algorithm often removes them again. Conversely, large puddles of remnant water pose obstacles for the model in its unfilled predictions.

Notably, our observations reveal that the neural network excels in identifying sharp contrasts at higher precision, as opposed to flats where waterlines exhibit greater ambiguity.

Discussion & Outlook

Adverse weather conditions impact the reflective properties of water in SAR images. Under such conditions, a neural network trained exclusively using calm weather data, as exemplified above, is reaching its limits.

Broadening the training dataset by including SAR data acquired under a wider range of weather conditions enhances the network's versatility, but also compromises the accuracy of the depicted predictions. Therefore, achieving the right equilibrium between specificity and applicability becomes a crucial part of the optimization process.

While our neural network shows promising results, it also tends to miss smaller, narrow tidal creeks, and it still lacks in the desired breadth of applicability. To address these limitations, we consider extending the training dataset by a comprehensive range of data, or by including information on weather conditions. We hope that, by training the network to distinguish between different weather conditions, we can enhance its adaptability to a wider set of SAR data.

References

[1] S. Wiehle und S. Lehner. "Automated Waterline Detection in the Wadden Sea Using High-Resolution TerraSAR-X Images". Journal of Sensors (2015). DOI: 10.1155/2015/450857

[2] S. Peters, "Bestimmung morphodynamischer Veränderungen an der deutschen Nordseeküste mithilfe von Synthetik Apertur Radar Daten". BSc thesis, Univ. Hamburg, FB Erdsystemwissenschaften, 26 pp., 2022