MAP-BORealis: Ice Routing Optimization

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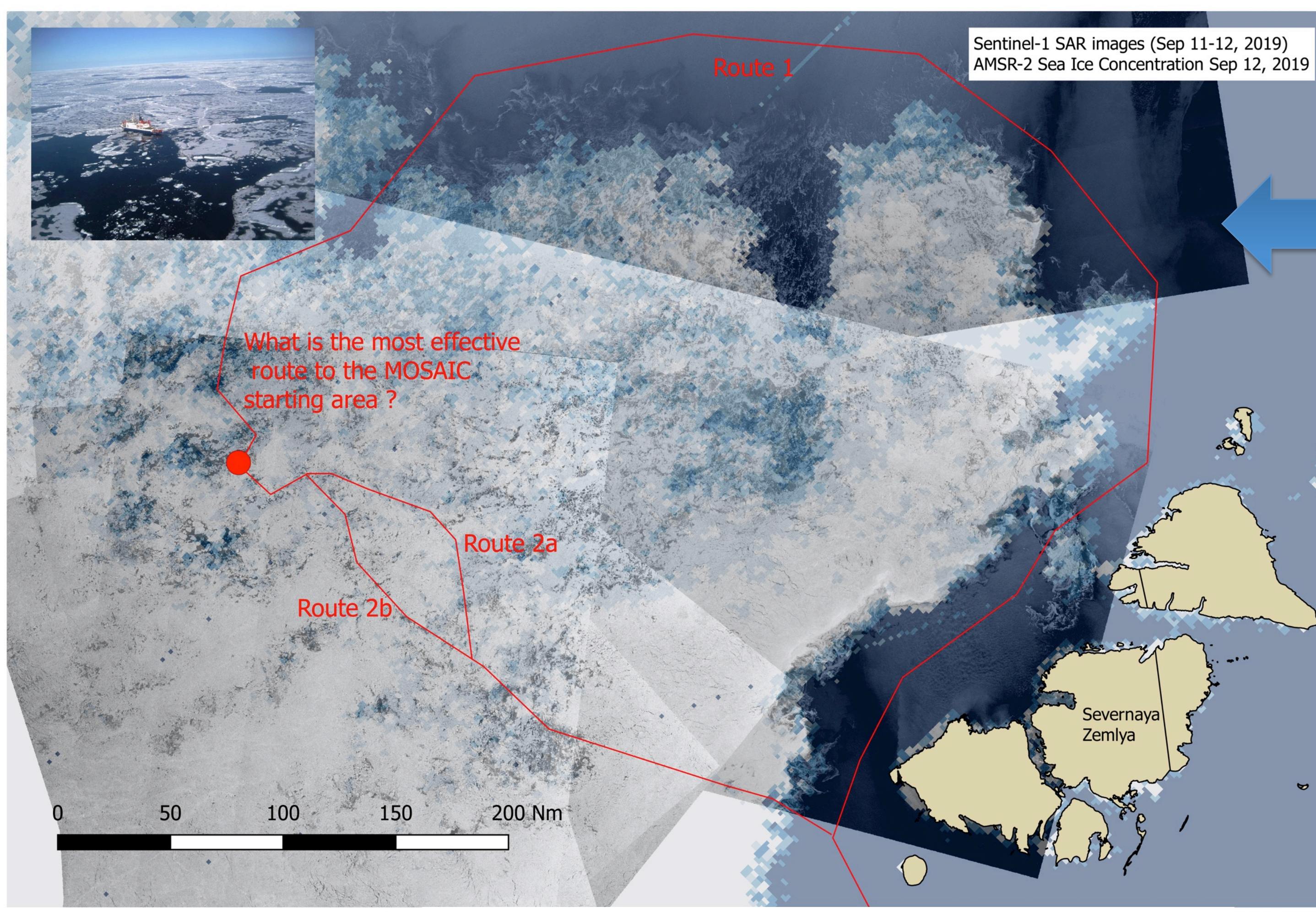
Project Idea

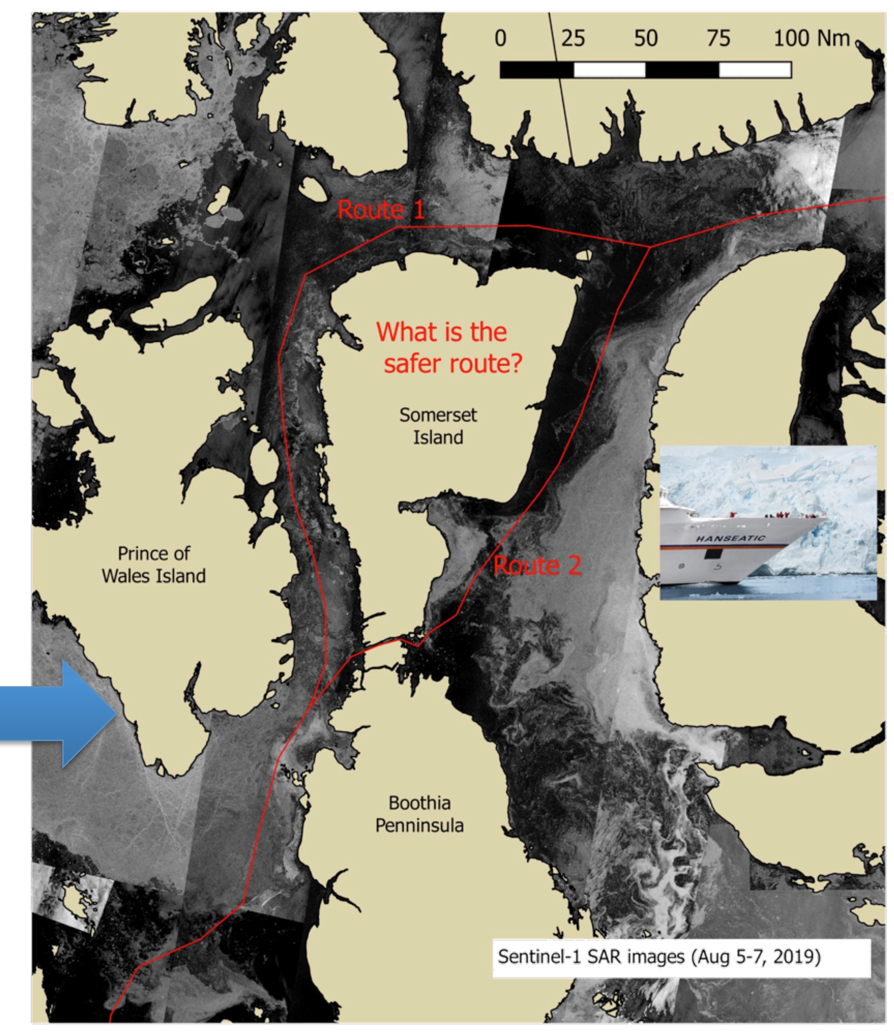
MAP-BORealis aims on the development and better understanding of ship route optimization in ice covered oceans. Compared to previous research projects with that objective, MAP-BORealis uses innovative techniques from the fields of remote sensing, applied mathematics, artificial intelligence, sea-ice modelling and system integration. In particular it combines a workflow which includes automated sea ice classification of satellite images, hourly predictions of the sea-ice evolution and multi dimensional optimization routines to eventually provide route suggestions which minimize risk, time and/or fuel consumption. The project works in close collaboration with test users from different application fields, such as the German research ice breaker RV Polarstern and the nautical crew on board Hapag Lloyd cruise ships.

Two Example Scenarios



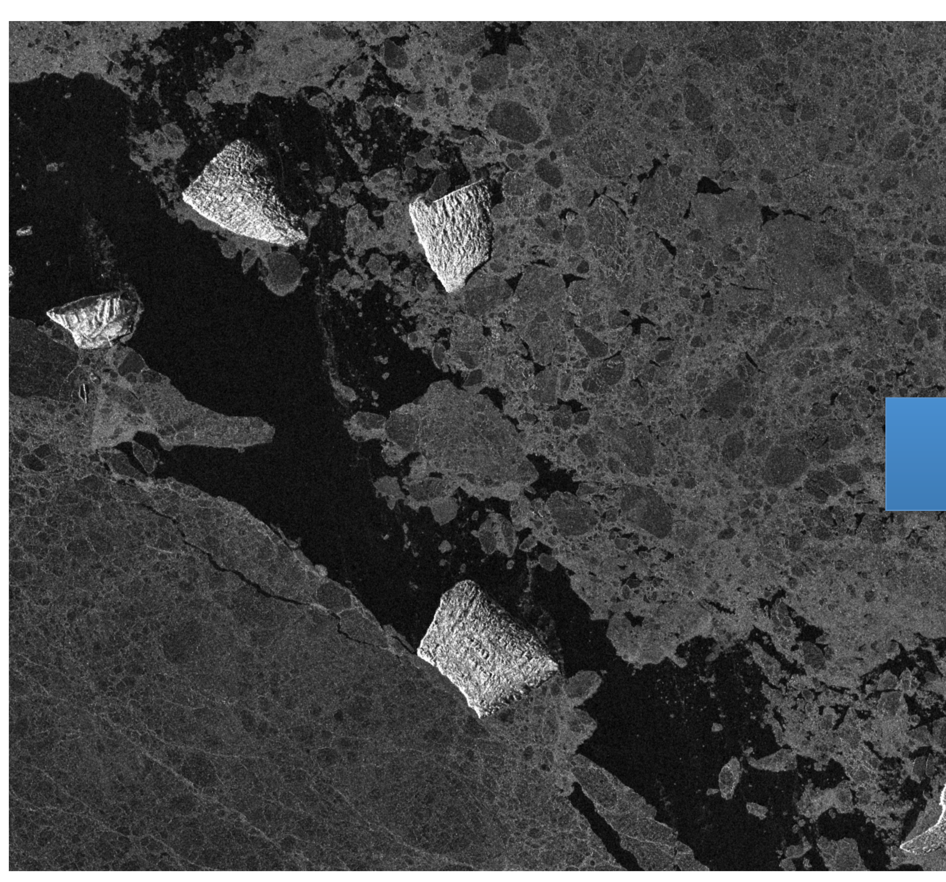
Example 1: RV Polarstern's MOSAiC expedition
RV Polarstern is heading towards a dedicated area within the ice cover, in this case the MOSAIC expedition starting area. The most effective route to the area in terms of travel time and fuel consumption is not obvious. The red marked tracks are possible intuitively chosen possibilities. Given ship operations costs of more than 70'000 EUR per day, a route suggestions based on quantitative measures would be of great benefit.

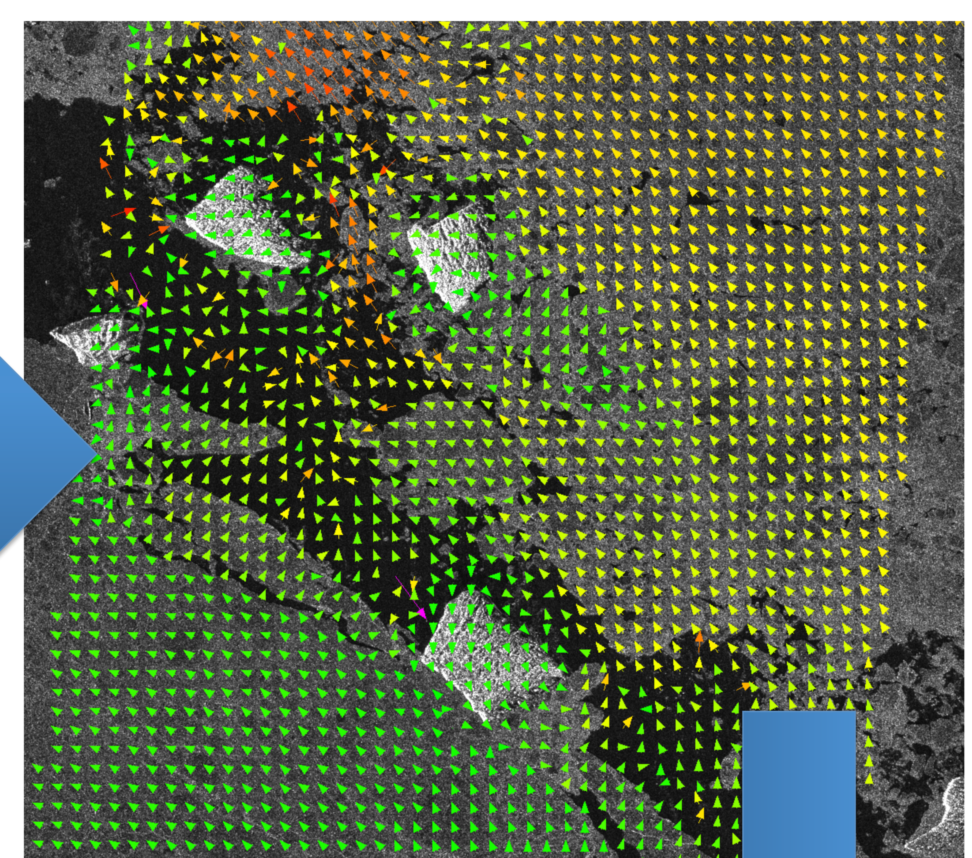
Example 2: Ice strengthened ships in the North West Passage
The central North West Passage gives the choice of two alternative routes. Route 1 through the Peel Sound or Route 2 through the narrow Bellot Strait between Somerset Island and the Boothia Penninsula. For typical cargo or expedition cruise vessels in the NWP, a risk minimized route is most important.



1. SAR images

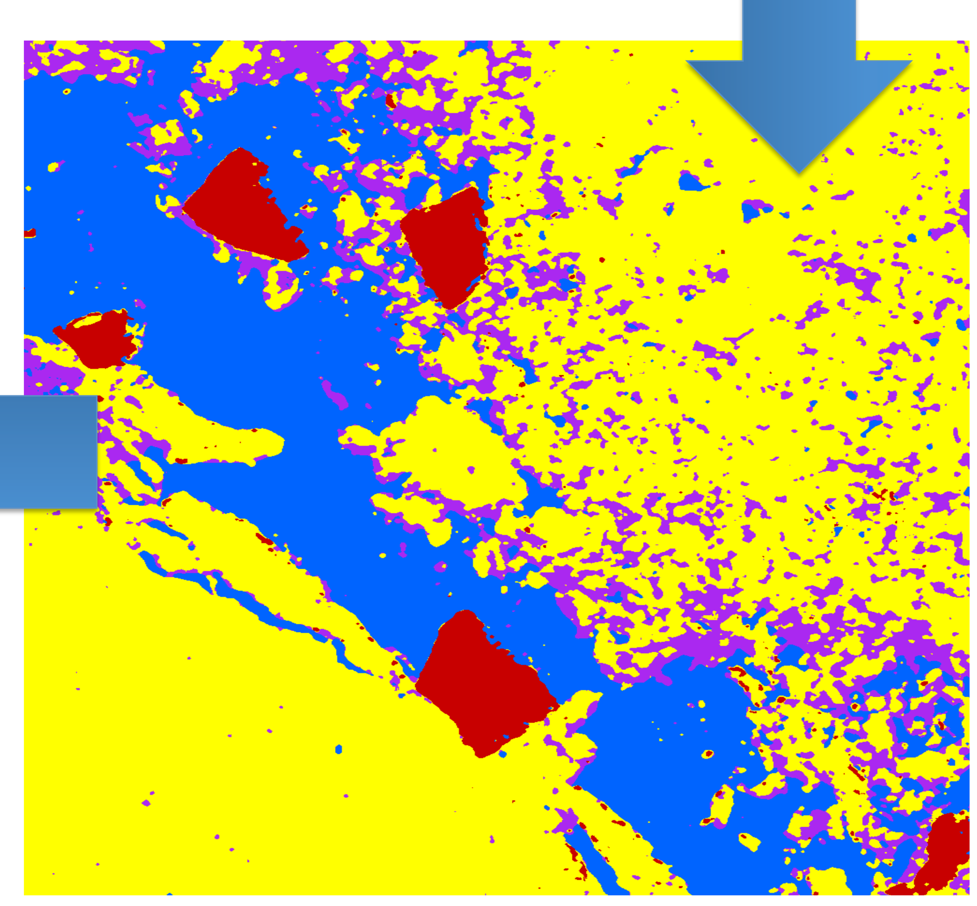
The high spatial resolution of SAR images is of enormous importance. Only in high resolution it is possible to see smaller ice patches or preferred pathways in a closed ice cover such as open cracks or trails from icebreakers previously navigated the area. The preferred image source will be ESA's Sentinel-1 satellite constellation, as these data are freely accessible. Additionally, observations from the TerraSAR-X satellite can be used.

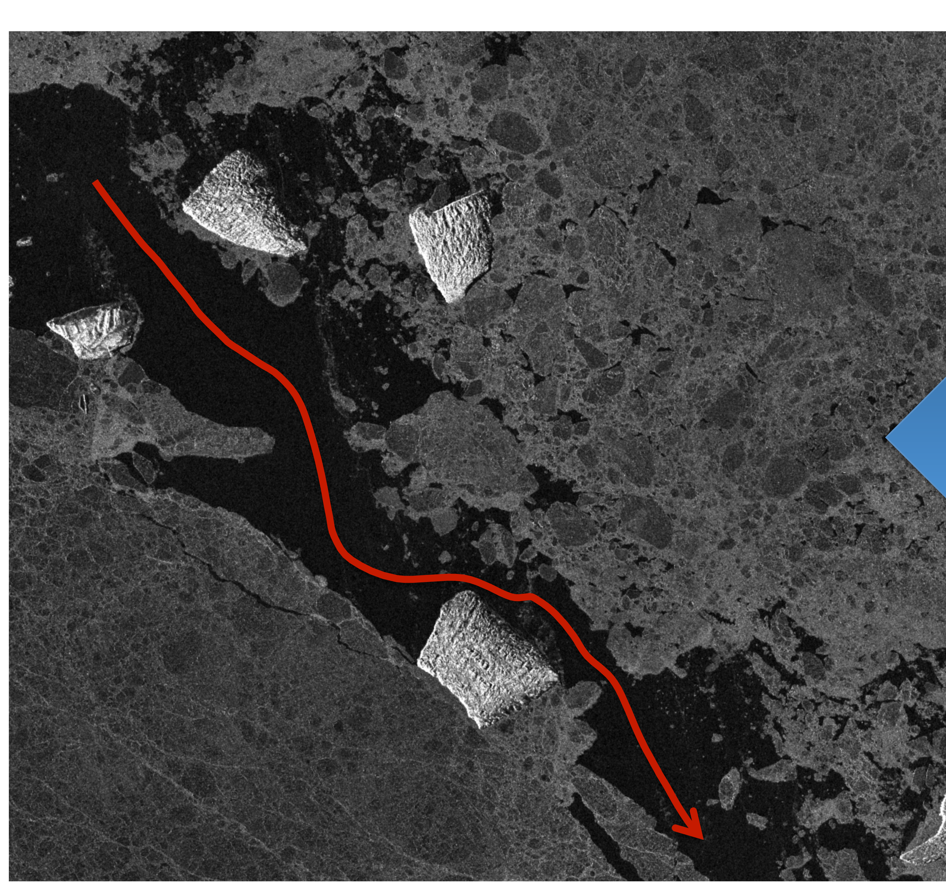




2. Sea Ice Dynamics

Remote sensing data in polar regions are strongly limited in their temporal resolution and it is difficult to determine the current and future ice dynamics. However, the current momentum of the ice cover can be derived with two subsequent satellite images of the same region and the future momentum for the next 48 hours by means of operational weather and sea-ice models. The prediction will be based on weather models (ECMWF, ICON) and the operational sea-ice model TOPAZ4 from the Copernicus Marine Service while the high resolution of a SAR image will be maintained by the newly developed image warping technique PRIIMA.





3. Sea Ice Classification

The time series of SAR images (observation and prediction) in grey scales has to be further processed before it can serve as input for the optimization. For the classification of sea ice types, like young ice, smooth first year ice or multi-year ice, we use machine learning algorithms. The result might be a risk or velocity map, which can be used for ship navigation. One goal of the project is the improvement of classification algorithms in order to achieve the WMO sea ice classification, which can then easily be translated to the Risk Index Outcome (RIO).

4. Optimal Route Planning

The problem of sea ice navigation is a problem of finding an optimal trajectory with moving boundary conditions. Reasonable objectives could be time, fuel consumption or risk minimization. A first estimate of the solution can be found using a customized A* search. For this purpose, the risk map is translated in a weighted graph. The cost function consists of two terms: the known costs to get from the start to a node and the estimated costs needed to get from this node to the goal. The resulting path can serve as starting solution for an optimal control problem, which can be solved by our optimization software WORPH.

Challenges of the Project:

(comments and feedback welcome):

- Classify satellite images (preferred Sentinel-1 images) following WMO ice classification standards
- Detection of ice ridges and open leads on satellite images
- Parameterize ice classes with respect to velocity, fuel consumption and risk (for the last point the POLARISK risk assessment can be used)
- Determination of sensitive input parameters, inter alia number of ice classes
- Calculation of uncertainties of route suggestions, depending e.g on the accuracy of drift forecasts
- Operationalization of on-the-fly route suggestions
- Validation of route suggestions in the field

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