Towards Short-Term Forecasts of Sea Ice Conditions for Ship Navigation in the Baltic Sea

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***Abstract*— Navigating in the seasonally ice-covered waters of the Baltic Sea is challenging and risky due to the constantly changing nature of sea ice. Winds can push floes together or pull them apart, forming dense pack ice in some areas and natural openings in others. To improve safety and efficiency, we present a new conceptual approach for generating high-resolution, predictive ice maps for the Baltic Sea. Using artificial intelligence, we derive critical ice properties from spaceborne Synthetic Aperture Radar data – in particular the stage of development. These properties are integrated into a newly developed sea ice drift forecast model to generate hourly forecasts of ice conditions. The resulting dataset provides a detailed, forward-looking view of ice, helping optimize ship routes through ice-covered waters.**

Keywords—Synthetic Aperture Radar, Maritime Situational Awareness, Ship Routing, Baltic Sea, Sea Ice Drift Forecast, Sea Ice Classification

I. Introduction

The navigation of ships in the seasonally ice-covered waters of the Baltic Sea places high demands on both humans and technology and is associated with significant risks. In this semi-enclosed sea, extreme wind events and wind-driven currents act on the ice cover, leading to rapid, dynamic changes in ice conditions. Within a few hours, converging forces can consolidate large masses of ice, forming pressure ridges where ice floes tilt upward or stack above and below one another. The resulting deformed ice can, in some cases, become impassable even for icebreakers [1]. Conversely, diverging forces in other areas can break apart continuous ice covers, creating leads and natural passages. For the safe and efficient navigation of ships in the Baltic, timely information regarding local ice drift and ice properties is therefore of critical importance.

Synthetic Aperture Radar (SAR) satellites, such as TerraSAR-X or Sentinel-1 provide a reliable basis for large-scale sea ice monitoring in the Baltic Sea. Due to their ability to provide image data of the oceans and frozen waters regardless of cloud cover or solar illumination, SAR observations have been an integral component for national ice services for decades. These data allow ice services to produce expert-level charts that distinguish between ice types, providing a vital safety framework for vessels navigating in ice-infested Baltic waters.

However, SAR images provide only a snapshot of the surroundings. By their very nature, they are static. Furthermore, data delivery is subject to latency; the process of downlinking, processing, and delivering data to the user often takes around three hours or longer (depending on the mission). During this interval, the highly dynamic ice conditions may have already shifted, meaning the derived insights may be outdated by the time they are applied.

In this study, we present a novel method for projecting SAR-based sea ice information, specifically classification by stage of development, into the future, involving sea ice drift forecast data. This approach allows the generation of spatio-temporal datasets with hourly resolution that show upcoming sea ice conditions, thereby forming the basis for automatic ship route calculation.

Chapter II briefly outlines the sea ice classification, and Chapter III the method for generating the spatio-temporal datasets.

II. SAR-Based Sea Ice Classification For The Baltic

Sea ice is traditionally classified according to its stage of development. This classification usually follows the international standard of the WMO (World Meteorological Organization), which ensures globally consistent ice charts. Consequently, there are numerous scientific publications describing various approaches to determine the stage of development from SAR data, which are comprehensively summarized in [2].

In [3], we demonstrated the effectiveness of UNET++ for sea ice mapping in terms of its stage of development. In this contribution, we present a significantly enhanced methodology specifically tailored to map sea ice in the Baltic Sea. Basically, the new method generates sea ice polygons to outline areas of similar ice conditions and employs artificial

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intelligence to classify these areas. The methodology has recently been integrated into the operational processing chain at the DLR ground segment in Neustrelitz, providing automated sea ice maps in near real-time directly to the German ice service of the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH).

III. Forecasting The Sea Ice Conditions

As mentioned before, the expected future sea ice conditions are of great interest to maritime navigation and are essential for automatic route planning. Therefore, a newly presented method utilizes specially developed sea ice drift forecasts for the Baltic Sea to project the derived SAR-based sea ice maps hourly into the near future. In detail, we use polygonised sea ice information to extract corner points, which are then advected using a Lagrangian tracking approach based on the drift forecast.

The resulting spatio-temporal dataset, termed the 'Dynamic Ice Map', overall maintains the high spatial resolution of the original SAR-derived sea ice maps. It compensates for the delay between data acquisition and delivery to the user, and also allows for a detailed look into the future.

IV. Outlook

By bridging the gap between static SAR-based observations and the dynamic requirements of modern navigation, the presented approach has the potential to improve situational awareness. The integration of high-resolution SAR data with predictive modeling not only improves operational safety but also provides a robust foundation for future autonomous maritime systems in the Baltic Sea.

References

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