HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

June 2, 2019

Promotion Committee
St. Petersburg State University
St. Petersburg, Russia

Dissertation of Denis M. Demchev

Dear Sir/Madame,

I am pleased to write this review of the dissertation of Denis M. Demchev for the PhD degree in physical and mathematical sciences. The PhD thesis is in the field of oceanology, titled *Retrieval, analysis and monitoring methods for sea ice and iceberg drift in the Arctic using radar data.* The thesis consists of new results on two major research questions. Firstly, an algorithm for automated retrieval of sea ice drift from consequent sequential satellite synthetic aperture radar (SAR) data has been developed and applied for sea ice drift in the Arctic; and, secondly, identification of icebergs from SAR imagery has been investigated and the method has been employed in an iceberg forecasting system. The results of this work are most useful for basic research, for data assimilation in numerical modelling, and for the development of monitoring methods for sea ice and icebergs in Arctic seas.

The results of this research by Denis Demchev have been presented in many Russian and international conferences in 2012–2017. Eight papers have been published in peer reviewed journals, and four of them are also listed in the web of science core collection. According to the author's statement, he has formulated the research problem and scopes, developed research plan, and analyzed the obtained results. The task of the thesis has been well-defined, lies in the forefront of ice research in polar seas, and is wide enough for a PhD study.

Overview of the content of the thesis

The thesis consists of four main chapters and conclusions. The first chapter gives an introduction into geophysics of Arctic sea ice and icebergs and principles of remote sensing of sea ice using radars. Denis Demchev presents a very good overview on these topics. Since 1990s SAR has been one of the main tools in sea ice research and monitoring. It has limitations in that the mathematical mapping from sea ice to radar signal is surjective and cannot be fully inverted back, i.e. different types of surfaces may have similar SAR signature. However, many features repeat themselves in sequential imagery and can be identified, and thus these features serve as a perfect basis to observe the movement of sea ice. Icebergs, as well, form an observable group for SAR due their very strong backscatter. Specific sea ice types, in particular stamukhas, cause difficulties to identification of icebergs, and in open ocean small bergy bits may be hidden by the noise due to wind-generated surface waves. One critical question is how small icebergs can be found using SAR images.

The second chapter provides an excellent review of sea ice drift retrieval from SAR image time series and then leads in a logical way to the development of the new method derived by the candidate in this thesis. The first efforts were to examine local cross-correlations in sequential

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imagery or identify 'features' and track them in different ways from one image to the next one. The new method developed by Denis Demchev contains several steps: SAR data preprocessing, keypoint detection, keypoint description, and feature matching. It is shown that SAR image filtering using anisotropic diffusion enables detection and tracking of a higher number of points compared with the previously developed methods, resulting in more accurate sea ice drift estimates with statistically higher level of significance. Based on comparisons in different parts of the Western Arctic, the new method is shown to outperforms earlier ones. Also, comparisons were made with manually picked drift vectors, and the result showed good fit. The development of the method is an important, novel step in sea ice remote sensing and opens wide possibilities to mathematical modelling and real-time ice monitoring.

The third chapter derives a vector-algebraic method (VAM) to analyze the variability of sea ice drift obtained from SAR imagery. Sea ice drift vectors are taken as random vectors, and their first- and second-order moments are examined for interannual variability and trends. Distributions of ice drift speed and direction are also plotted and discussed. The VAM produced statistics are very good for comparisons between model outcome and observations. Data compressed in the statistical characteristics can guide in particular understanding the role of rheology in sea ice dynamics that still is a largely open question. Models have assumed deterministic semi-empirical plastic flow regimes or fracture mechanics theories but stochastic dynamics approach may become preferable, particularly considering downscaling and risk analyses. Statistical characteristics of sea ice deformation reveal the long-term impact of convergence and divergence of sea ice drift that is known to form a major component in redistribution of sea ice thickness, very difficult to observe directly. This also provides delicate tools to validate the approach mechanical processes are described in mathematical models.

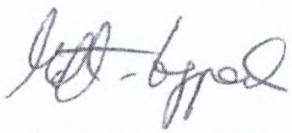
The fourth chapter presents an application of the sea ice and iceberg mapping to monitoring in the Kara Sea. Ice kinematics is retrieved from SAR data in the northern part of the Ob Bay and analyzed for sea ice drift and deformation. The sea ice drift monitoring case studies focused on safe navigation and other marine operations support Continuum approach is taken for the deformation with strain-rate tensor derived from the velocity data. Monthly drift speed statistics illustrate the mobility of ice and monthly divergences show the opening and accumulation region which bring much light to the understanding of the evolution of ice cover in the Ob Bay. In the iceberg study, a drift model accounting for the main forces to drive the translational movement are included. To obtain the forcing by ocean currents and sea ice on icebergs, AARI Ice and Ocean Circulation Model output was employed. Icebergs were identified using SAR data, and it was estimated that icebergs down to the size of the resolution cell of the instrument could be detected. Iceberg observing–forecasting system was developed and tested for the Kara Sea. Numerical forecasts were operatively used for the hydrometeorological support of exploration drilling at Universitetskaya-1 geologic structure in 2014. The application demonstrated the efficiency of the model technology developed.

Conclusion

The thesis manuscript *Retrieval, analysis and monitoring methods for sea ice and iceberg drift in the Arctic using radar data* by Denis Demchev presents an excellent work on the use of satellite SAR in research and monitoring of sea ice and icebergs in Arctic seas. I would especially point two novel achievements: development of the method for high accuracy retrieval of sea ice kinematics from sequential SAR data, and the combination of iceberg detection by SAR and mathematical iceberg drift model. The kinematics method has an improved accuracy as compared with earlier methods and can provide a large set of velocity vectors that is most useful for construction of sea ice drift models based on stochastic dynamics. Also, a vector-algebraic statistical method is employed to analyze sea ice drift and deformation in real cases. The iceberg monitoring part of the works develops a new tool for iceberg management in combining SAR observations of icebergs

with a model for iceberg drift. This is a crucial element in ice management in Arctic sea where icebergs form a significant risk, especially in areas with high recurrence of icebergs such as the Shtokman gas field.

In all, the work by Denis Demchev is by no doubt well worth for the PhD degree in physical and mathematical sciences in the Sankt Petersburg State University.



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