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Synoptic-scale variability of satellite-derived sea-ice deformation rates in the Arctic

A. Herman and O. Głowacki
Institute of Oceanography, University of Gdansk, Gdynia, Poland (oceagah@univ.gda.pl)

Observational data show that deformation of the compact sea ice covering the central Arctic takes place within elongated, narrow zones separating semi-rigid floes. Localization of deformation, and a related intermittent character of internal stress in the ice, cannot be satisfactorily reproduced with present state-of-the-art numerical models, especially those based on various versions of viscous-plastic rheology. Similarly, sea-ice models do not reproduce properly the observed power-law tails of deformation-rate probability distributions (pdfs), with a slope depending on the scale of the observation. In order to be able to improve the models, one needs: (i) relevant quantitative measures of ice deformation rates that the models should aim to reproduce; (ii) a better understanding of the time variability of those measures (existing studies are usually limited to the analysis of single events) and their dependence on changes of the external forcing and of the properties of the ice itself.

In this study, we use gridded sea-ice total deformation rates from the RGPS data provided by the RADARSAT-1 satellite, available for 11 winter seasons with a time resolution of 3 days and a spatial resolution of 12.55 km. The analysis is based on deformation-rate pdfs obtained by means of a rank-order analysis of the data for each snapshot in the dataset. We analyze the time variability of: (i) the slope of the power-law tails of the pdfs, estimated with a maximum-likelihood method; and (ii) the moments of the pdfs for a range of exponents q and spatial scales L from the original mesh size to approximately 1000 km. In all analyzed cases, the slope of the moments as a function of the length scale L increases (faster than linearly) with increasing power q. However, the tempo of this increase can be very different. Generally, there are two distinct, dominating patterns of variability, with the first pattern describing the overall level of deformation, and the second one being generally small, but peaking a number of times during a typical winter, during short periods of intense deformation.

Further, we demonstrate that the moments of sea-ice deformation pdfs are highly correlated (with correlation coefficients in the order of 0.6–0.7) with a very simple quantity characterizing the strength of the atmospheric forcing on the ice, namely with the area-averaged 10-m wind speed over the Arctic Ocean.

Finally, we sketch a theoretical explanation for the observed relationships between the sea-ice deformation rates and the wind forcing, based on simplified momentum equations and a very general rheology model of sea ice.