Conventional Mechanics and Self-Organizing Processes in the Arctic Pack

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ABSTRACT

Mechanical processes in the Arctic ice pack result in fragmented sea ice cover, the regular geometry of which could be described in main features in terms of the conventional mechanics. However the size distribution of sea ice floes does not exhibit the random (poissonian-like) statistics and follows the power law typical for self-similar (fractal) structures. The experimental data collected at the Russian ice-research camp “North Pole 35” established on the Arctic ice pack in 2008 evidence that the driving force of this scale-invariant patterning is the self-organized drift dynamics, which exhibits scaling properties both in the energy exchange with the environment and in the time distribution of mechanical events.

KEY WORDS: Arctic ice pack, crack-and lead pattern, drift dynamic, time series.

INTRODUCTION

The Arctic sea ice cover (ASIC) is a complicated mechanical system, whose components could spontaneously decrease or increase their dimensions in cycles of fragmentation and freezing. In addition, in dependence of mechanical perturbations, the ice floe geometry, as well as the floe size distribution, maintain permanently the same relations, some of which could be explained in the framework of conventional mechanics of solids, while some other ones represent the non-linear nature of the pack dynamics. The mechanical state of sea ice cover is of importance for navigation and marine engineering in cold regions, as well as for climate response through the albedo variation, therefore, the adequate description of the pack behavior is necessary for estimating and forecasting important changes in the state of sea ice cover.

We present a brief overview of state of the art in assessment of main trends in the mechanical and physical behavior of the ASIC with drawing one’s attention to the interplay between mechanical and thermodynamic features in the dynamics of sea ice. The main source of the experimental data was the database collected at the Russian ice research camp “North Pole 35” (NP 35) in 2008.

GEOMETRY AN SIZE DISTRIBUTION

The large-scale visualization of the ASIC, which became available from satellite systems in early seventies, revealed a rectilinear lead pattern ranging from 1 to 10² km. The most impressive finding was the parallelogram-like structure of the pattern with the constant angle ~ 30° between directions of intersecting leads. However, it was found later that this regular structure is not a unique feature inherent in the ASIC; fracturing of this kind have a direct analogy in the rock mechanics where three-dimensional strike slip faults occur in the semibrittle failure of horizontally stressed rock formations. Marco and Thompson (1977) explained the ~30° difference in orientation of leads on the base of the Mohr theory of failure, which suggests that the applied shear stress at failure, \( \tau \), and the normal stress, \( \sigma_n \), on the failure plane (or line in 2D-case) are related by

\[
\tau = C + \sigma_n \tan \phi 
\]

where \( C \) is the material cohesion strength, and \( \phi \) is the angle of internal friction, \( \phi = \frac{\pi}{2}(\alpha - 45°) \); here \( \alpha \) is the intersection angle. The resolution of Eq. (1) relatively the intersection angle with parameters characteristic for sea ice gives one \( \alpha \approx 30° \), that is the value observed in many satellite images.

Marco and Thompson (1977) pointed out also that the parallelogram-like pattern appears only at sufficiently rapid strain rates when the semibrittle failure prevails. At relatively slow strain rates, the ductile behavior takes place, which results in formation of polygonal (diamond-like) or fully disordered structures due to cohesion flow at low yield stress.

Erlingsson (1988) drew attention to the fact that the Mohr theory of constant friction between sliding surfaces has not any characteristic length, that is it is scale invariant. Therefore, the angular relationship is valid over the whole area where the conditions of semibrittle failure are satisfied. Thus, the self-similarity of the uniaxial geometry of ice floes is the direct consequence of the Mohr theory.

However, further investigations elucidated some features in the lead pattern, which cannot be explained in the framework of conventional mechanics. Rothrock and Thorndike (1984) and Matushita (1985)