

Assessment of Mechanical Behavior of Sea-Ice Cover as Hierarchic, Self-Similar System

Alexandre Chmel, Victor S. Kuksenko, Nikita G. Tomilin and Olga I. Andreeva
Ioffe Physico-Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia

Victor N. Smirnov
Arctic and Antarctic Research Institute, St. Petersburg, Russia

ABSTRACT

The analysis of the AVHRR (advanced very high resolution radiometer) images demonstrates both the hierarchic and fractal properties of the sea-ice cover in the Central Arctic. The determined fractal dimension is the same for the entire collection of ice-floe fragments available for analysis, that is, it includes ice blocks 5 to 5×10^2 km in size. The processes that lead to compacting, shearing or diverging of ice fields affect the geometry of fragments with a corresponding response of the fractal dimension.

INTRODUCTION

The physical processes leading to the failure and fragmentation of sea-ice fields are specified by a wide spatial dimension (from tens of m to hundreds of km) and temporal intervals (from s to days). The cracking and aggregation yield a dynamic mosaic pattern with certain features of self-similarity. A vast number of satellite images obtained during the last 2 decades gives evidence that the sea-ice cover is composed of repeated rhomboid floe fragments with linear dimensions from 10^1 to 10^5 m (Marco and Thomson, 1977; Smirnov and Korostelev, 1995; Overland, Walter, Curtin and Turet, 1995; Chmel, Smirnov and Panov, 2003) as well as prevailing breaking angles of $\sim 30^\circ$ (Erlingsson, 1988). This spatial uniformity follows the fractal geometry law (Rothrock and Thorndike, 1984; Matsushita, 1985; Erlingsson, 1988; Chmel, Smirnov and Panov, 2003).

This work goes to demonstrate the informational significance of the data available from the fractal analysis of the fragmented ice fields that aims at the search for a new potential for the prediction of the mechanical behavior of ice. The fractal geometry is considered in close relation with the hierarchic properties of the sea-ice cover.

POSITIONING

In this study we analyzed the advanced, very high resolution, radiometer (AVHRR) images received from the NOAA satellite from 7 to 14 April, 1999. All images exhibited a clearly pronounced rectilinear pattern (Fig. 1a), such as that reported by Marco and Thomson (1977) and Smirnov and Korostelev (1995). In the image of 14 April, there appeared an advancing lead that gave proof of the intensive process of the ice fragmentation (Fig. 1b).

In order to discover current changes in the period preceding the appearance of the newly formed lead, we carried out the positioning of some easily recognizable features in the images. We

selected 12 most-contrast objects (thin ice or open water) as standard targets for monitoring the ice drift with reference to their initially recorded positions. The positions of these leads' central points were determined by using a local grid coordinate system bound to the coastline. The changes in coordinates during the observation period allowed us to trace the drift of the ice-field fragments and to detect a relative shift along the shearing break of 500 km in length. It was found that the general trend that manifested itself in a southeastern drift from 7 to 11 April was disturbed on April 12 by a strong rotational component. The distances between the selected points decreased, thus indicating the effect of ice compression. On April 14, a divergence of the previously compacted fragments was detected.

The obtained data were compared with the geometric characterization of the ice floes performed with the help of the fractal analysis.

FRACTALITY

Rothrock and Thorndike (1984) and then Matsushita (1985) analyzed the size distribution of the sea-ice floes and deduced a power-law dependence between the cumulative number of drift-ice pieces and their size. In accordance with the basic equation of the fractal geometry (Mandelbrot, 1982):

$$N = 1/R^D \quad (1)$$

(Here N is the number of repeated elements, R is the coefficient of similarity, and D is the fractal dimension.) The dependences they found were interpreted as due to the fractal nature of these discrete collections.

In general, the relation (Eq. 1) represents a law that allows one to reproduce a given shape by means of the increase of the number of constituent features when passing from a particular structural unit to any similar structural unit with a magnification R . The diverse forms of the law (Eq. 1) are used in dependence of the problem under consideration.

In particular, differently from the procedure used by Rothrock and Thorndike (1984) and Matsushita (1985)—where the fractality was concluded from the size distribution (i. e. by ignoring the shape of fragments)—in a more recent publication (Chmel,