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Dynamics of Ice Cover Interacting with Ocean and Atmosphere

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ABSTRACT

Problems associated with mathematical modeling of the dynamics of ice cover as an interface between the ocean and the atmosphere are discussed. Particularities of deformation processes in ice cover are taken into consideration when estimating the internal forces in the ice. The external forces are specified using multilayered models in calculating the vertical exchange within the ice boundary layers of the ocean and the atmosphere. Practical applications of ice drift models are discussed.

INTRODUCTION

Methods of mathematical modeling of sea ice cover and variability of its state and dynamics are among those branches of polar oceanography being developed most actively. The practical and theoretical significance of these studies is obvious. The most advanced results have been published by Russian, American and Canadian researchers.

An idealization of ice cover as a two-dimensional, thin homogeneous and isotropic layer situated at the ocean-atmosphere interface is commonly accepted in oceanological models. Under actions of external factors, the ice cover is displaced over the water surface and its state and structure change. There occur, for example, ice thawing, ridging, splitting, rafting, etc. All these processes are interrelated and should be taken into consideration in mathematical modeling of the sea ice dynamics and evolution. The modeling can be either purely mechanical when the ice mass does not change, or mechanical-thermodynamical when either thawing of old ice or formation of new ice takes place in addition to the displacements.

Consequently, a study of ice cover should include a study of its structure, external actions and internal processes, aimed finally at the development of a complex model of ice cover-environment interaction. Clearly, it is also of equal importance to solve particular problems, such as development of a model of ice ridging or methods for calculating ice edge displacements.

PARAMETERS OF ICE COVER

Ice structures, their variations and age features have been the subjects of many studies for a long period. However, only a limited number of parameters characterizing ice structure is used in mathematical models. They include ice thickness, $\boldsymbol{h}$, concentration, $\boldsymbol{N}$, area of an ice floe, $\boldsymbol{A}$, as well as degree of ridging and decay of ice expressed in points. Due to a great variability of ice, all these parameters are considered to be random quantities which can be described statistically. For example, integral distribution function, $\boldsymbol{G(h)}$ and its density function, $\boldsymbol{g(h)}$ are defined for the ice thickness. Having grouped ice floes by their thicknesses, function G(h) can, as a rule, be assumed to be discrete. Partial concentration, $\boldsymbol{N_i}$, which characterizes the relative portion of ice floes of the given thickness $\boldsymbol{h_i}$ in the total assembly, can then be determined for each group. Obviously:

$$G(h_i)=\sum_{k=1}^{i} N_k\ ; \quad i=1,2,\ldots,M \tag{1}$$

where M is the number of groups.

When practically determining the characteristics of an ice cover, which is a discrete assembly, one should use a standard procedure of spatial averaging. The Monte Carlo technique, scanning, or other procedures are used within the selected representative areas.

In mathematical models, the evolution of ice structures is reduced to changing the ice thicknesses and concentrations. These changes occur due to advective transfer and thermal processes. The equation of conservation with regard to ice thickness can be written as follows:

$$\partial h / \partial t = -\nabla_h(\vec{u},h) + S_h(h,N) \tag{2}$$

where $\vec{u}$ is a velocity of ice drift; ∇_h is a horizontal gradient; S_h is a term accounting for thermal processes of ice growing and melting. It is clear that S_h depends on ice thickness h and total ice concentration $N = \Sigma N_i$. The following extrapolation formula is used for S_h (Hibler, 1979, 1987):

$$S_h = f(h/N)N + f(0)(1-N) \tag{3}$$

where function $f(h)$ is equal to the rate of growth of the ice h meters thick.

An equation similar to Eq. 2 is used for ice concentration (Hibler, 1979):

$$\partial N / \partial t = -\nabla_h(\vec{u},N) + S_N \tag{4}$$

and extrapolation formulae are used for determining S_N. For numerical realization, minor diffusion terms are added to Eqs. 2 ~ 4 to improve computational stability. Eqs. 2 and 4 are used in general models of ice drift. When analyzing short-term processes, the thermal changes (and sometimes, advection) are usually ignored. In this case, one can assume $h = const$.

SIMPLIFIED EQUATIONS

The equation of motion based on the balance of momentum is the main equation which describes the dynamics of ice cover. In a differential form and in the coordinate system which rotates

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