

## Chapter VII. Parametrization of the radiation processes in the ice cover model

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The problem of heat and solar radiation redistribution in the snow-ice cover is of interest due to the complicated influence of this flow on the nonlinearity temperature profile in snow and ice cover within the spring-summer and autumn-winter periods.

As nonlinearity of temperature profile in sea ice cover depends on some reasons, it is necessary to account all parameters making influence on ice temperature to perform the calculations more accurately. That is why the actual models become more complicated. A question regarding the practicability of such complications appears.

The processes, which bring to essential nonlinearity of temperature profile, were investigated using one-dimensional nonstationary thermodynamical model of snow-ice cover. The equation system describing the sea ice growing with snow presence on ice is the following:

$$\left. \begin{aligned} c_s \rho_s \frac{\partial T_s}{\partial t} &= \lambda_s \frac{\partial^2 T_s}{\partial z_1^2} + k_s I_0 \exp(-k_s z_1); & 0 \leq z_1 \leq h(t) \\ c\rho \frac{\partial T}{\partial t} &= \lambda \frac{\partial^2 T}{\partial z^2}; & 0 \leq z \leq H(t) \end{aligned} \right\},$$

(1)

The boundary conditions are the following:

$$z_1 = 0 \quad \lambda_s \frac{\partial T_s}{\partial z_1} \Big|_{z_1=0} = \Phi,$$

(2)

$$z = 0 \quad \lambda_s \frac{\partial T_s}{\partial z_1} \Big|_{z_1=h} = \lambda \frac{\partial T}{\partial z} \Big|_{z=0},$$

(3)

$$z = 0 \quad T_s(t, h) = T(t, 0),$$

(4)

$$z = H \quad T(t, H) = \Theta,$$

(5)

$$L_z \rho_z \frac{\partial H}{\partial t} = \lambda_z \frac{\partial T}{\partial z} \Big|_{z=H} - \Phi_w, \quad (6)$$

where:  $t$ - time;  $z$ - vertical coordinate;  $L$ - efficient heat of sea ice fusion;  $H$ - ice thickness;  $h$ - snow depth;  $I_0$ - solar radiation penetrating into ice;  $\Phi_w$ - heat flow from water;  $\Phi$ - total heat flow on the snow (ice)-atmosphere interface;  $\Theta$ - freezing temperature of sea water.

When the snow starts to melt on the surface, the boundary condition (2) has the following form:

$$z_1 = 0 \quad T_s = 0, \quad (7)$$

and the equation describing the snow cover melting is introduced:

$$\frac{\partial h}{\partial t} = \frac{1}{L_s \rho_s} \left( \lambda_s \frac{\partial T_s}{\partial z_1} \Big|_{z_1=0} - \Phi \right), \quad (8)$$

where  $L_s$ - efficiency heat of snow fusion.

When ice begins to melt (snow completely melted), the equation system is the following:

$$c\rho \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial z^2} + k_I I_0 \exp(-k_I z); \quad 0 \leq z \leq H, \quad (9)$$

$$z = 0 \quad T_0 \approx 0 \quad (10)$$

$$z = H \quad T(t, H) = \Theta, \quad (11)$$

$$\frac{\partial H}{\partial t} = \frac{1}{L_z \rho_z} \left( \lambda_z \frac{\partial T}{\partial z} \Big|_{z=H} - \Phi_w \right) + \frac{1}{L_0 \rho_0} \left( \lambda_0 \frac{\partial T}{\partial z} \Big|_{z=0} - \Phi \right), \quad (12)$$

where  $k_I, k_s$ - extinction coefficients of short-wave solar radiation in ice and snow accordingly.

These equations include the thermophysical parameters of snow and sea ice (heat conductivity  $\lambda$ , heat capacity  $c$ , density  $\rho$ ) as the coefficients.

To calculate the heat capacity, heat conductivity and density of sea ice, the parameterizations proposed in publications (Nazintsev Yu.L., et.al., 1988; Doronin Yu.P. & D.E. Heisin, 1975; Ebert E., Curry I., 1993; Maykut G. A., Untersteiner N., 1971) were used.

To calculate heat conductivity and heat capacity of snow, the expressions proposed in publication of Ebert E. & Curry I. (1993) were used.

To define the vertical turbulence flows of heat and moisture, the integral aerodynamic formulas with heat exchange coefficients depending on atmosphere stratification in ice surface layer (Ebert E., Curry I., 1993) were used.

Long-wave net radiation was defined by the method of König-Landlo & Augstein (Makshtas A.P. et. al., 1999). The flux of incoming short-wave radiation ( $F_0$ ) was calculated by Zillman's formula (Makshtas A.P. & V.F. Timachev, 1992; Shine K. P., 1984). Short-wave surface net radiation has the following form:

$$F = F_0(1 - A)(1 - i_0), \quad (13)$$

where  $F_0$ - total short-wave radiation;  $A$ - surface albedo,  $i_0$ - coefficient of transmission, which characterizes a rate of short-wave radiation penetrated through the surface (or a thin layer, which is identified with the surface). The values of coefficient were selected according to the publications (Maykut G. A., Untersteiner N., 1971; Semptner A. J., 1976).

Before melting (dry snow) the snow surface albedo was accepted to be equal to 0.85, albedo of melting snow 0.70, albedo of ice surface (melting ice without snow on the surface) were calculated in dependence on its thickness by formula (Maykut G. A., 1986).

$$A = 0.44H^{0.28} + 0.08, \quad (14)$$

where  $H$ - ice thickness.

Extinction coefficient of solar radiation for ice ( $k_I$ ) was assumed to be equal to  $1.5 \text{ m}^{-1}$  (Maykut G. A., Untersteiner N., 1971; Doronin Yu.P., 1969), that for snow ( $k_s$ ) was selected in a range from  $7 \text{ m}^{-1}$  up to  $20 \text{ m}^{-1}$  (J-G. Winter, et.al., 1999; S. Gerland et.al., 1999).

The calculations in the model were performed on an example of ground-truth data obtained at NP-13 drifting station and in Kandalakshskiy Bay in the White Sea. In the model the meteorological data obtained by routine meteorological observations were used as the input parameters. Actual snow depths (i.e. the snow melting was not calculated, but the measured snow depths during melting period were used) were used for the calculations at NP-13.

To control the model operation and the adequacy of model calculations, temperature profiles in ice cover at NP-13 were calculated. Figure 1 represents the calculation results of ice temperature profiles at NP-13 carried out for the concrete days. Actual ice temperature profiles measured during the same days at one of the measurement sites at NP-13 are represented as well for the comparison. A conclusion can be made that the model profiles coincide rather accurately with the observed ones. Some differences in surface temperature can be explained by the errors in description of heat conducting features of snow, the differences inside ice can be explained by linear approximation of sea ice salinity profile.

Figure 2 represents the same calculation results of temperature profiles at NP-13 for the spring-summer period. It is clear that the model quantitatively correctly describes the temperature profile evolution. Significant differences of ice surface temperature are observed

due to spatial differences in snow depths at NP-13. It is true because the snow depth measured at the specific site is a local parameter, and the significant spatial changes of depth, especially within the melting period, can be observed at relative small area within the concrete ice floe.

Three situations were simulated in order to clear the role of short-wave solar radiation absorbed by snow and ice. In the first situation  $i_0$  was assumed to be equal to 0.3 (Semptner A. J. 1976), i.e. 70 % of incoming short-wave radiation is absorbed on the surface, 30 % is absorbed inside snow (ice) in accordance with the extinction coefficients mentioned above. In the second situation 70% of incoming short-wave radiation is absorbed by the surface, a radiation rate absorbed in snow and ice is not accounted. In the third situation total incoming short-wave radiation is absorbed by surface, i.e.  $i_0 = 0$  (Doronin Yu.P., 1969).

Figure 3 represents the calculation results of ice thickness at NP-13 for named methods of accounting the influence of solar radiation heat. In 2 and 3 situations the calculated thickness has the maximum difference and can reach 15 % of ice thickness. Analysis of temperature profiles for these situations did not show up the obvious differences.

Figure 4 represents the calculation results for ice cover in Kandalakshsky Bay, therewith, snow cover melting was calculated by equation (8). The maximum difference in calculated ice thickness also was observed for situations 2 and 3 as for NP-13. At the same time the analysis of temperature profiles in snow showed up small differences of absolute value (not more than some tenths of a degree) for considered situations. These differences are explained by changes of extinction coefficient for snow in the mentioned above range. But the coefficient changes do not make influence on melting speed.

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Distribution of temperature in the ice cover on NP-13, calculated by model (solid line) and measured (dashed line) at autumn-winter period.

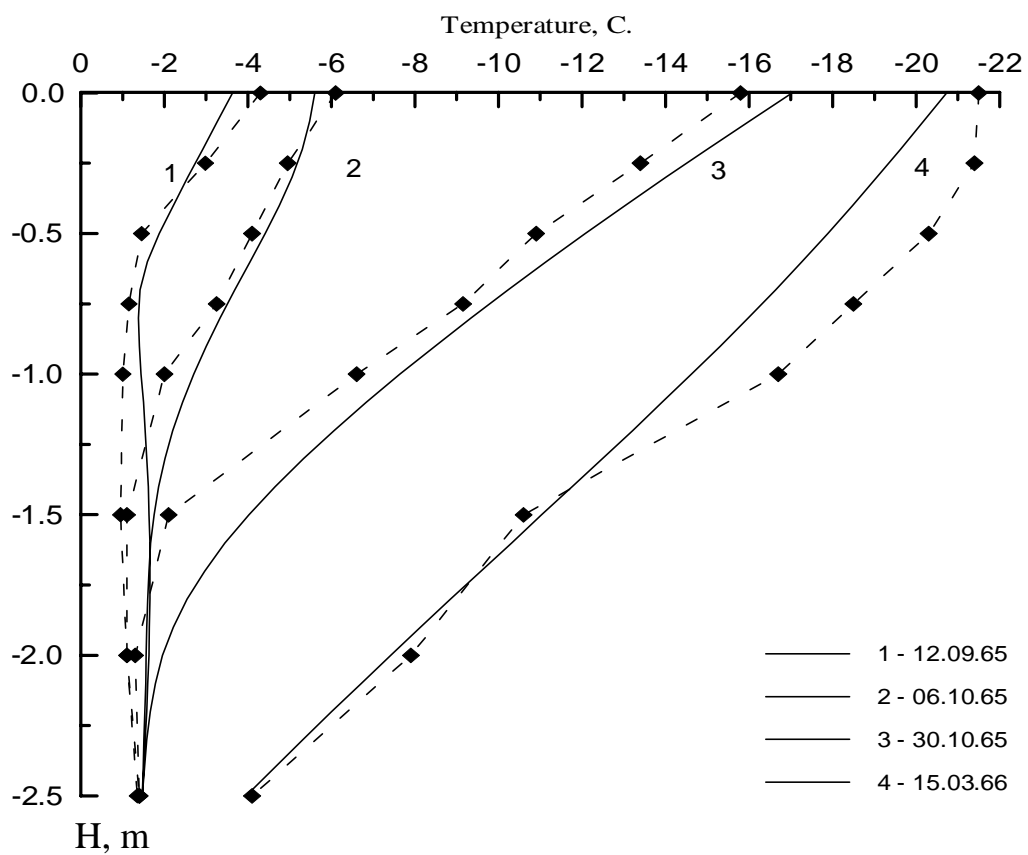


Figure 1.

Distribution of temperature in the ice cover on NP-13, calculated by model (solid line) and measured (dashed line) at spring-summer period.

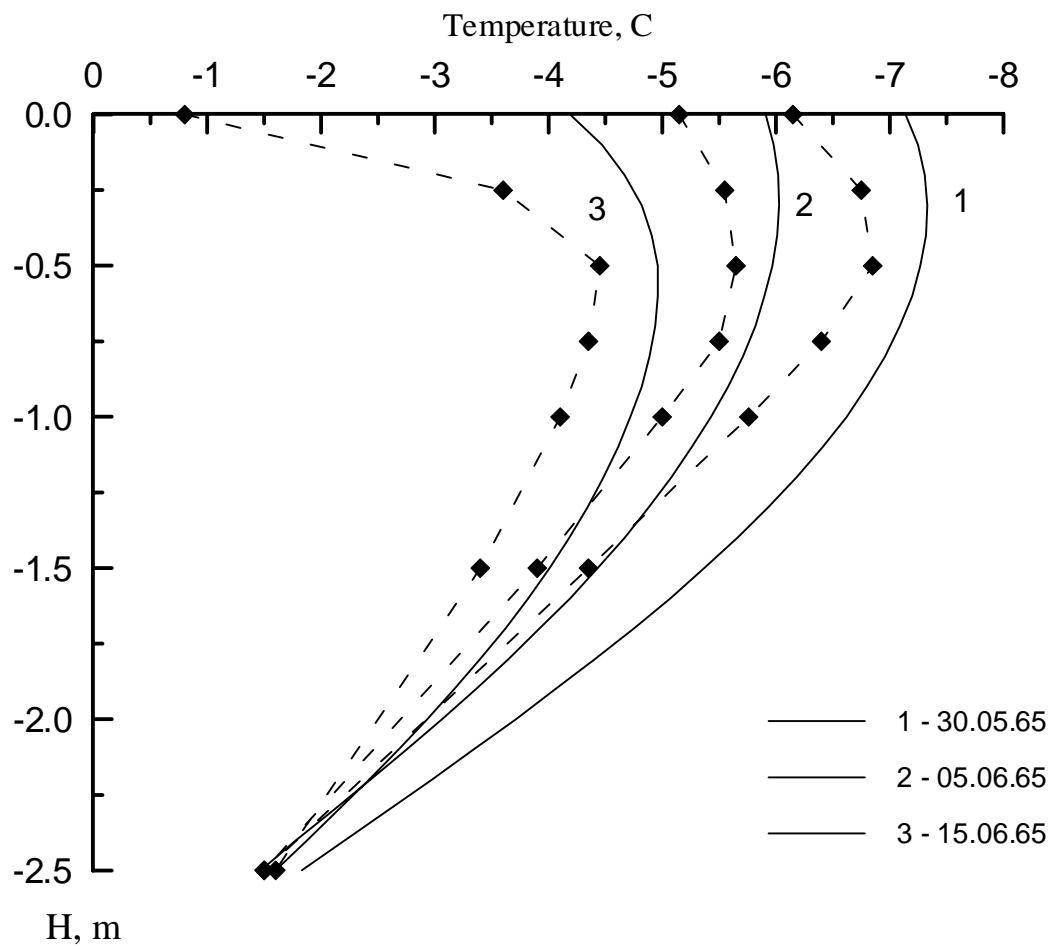
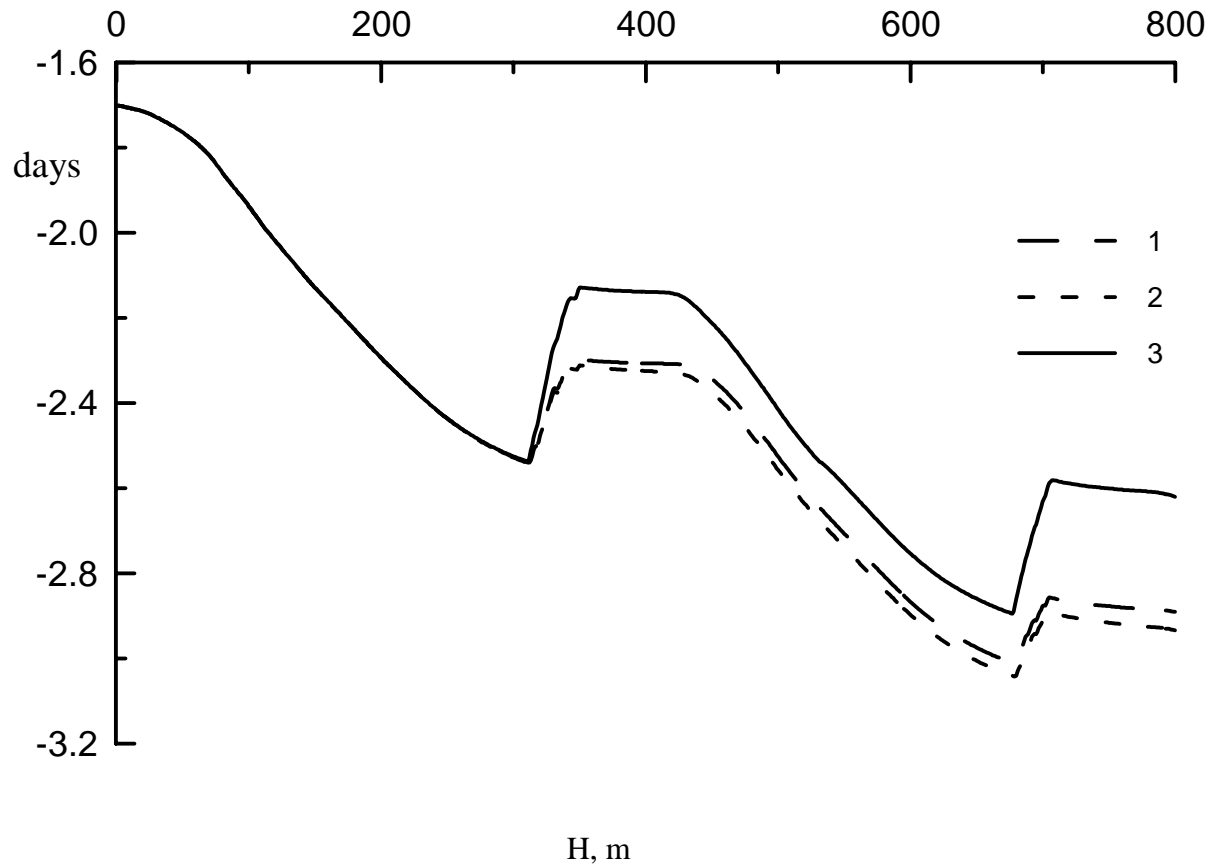


Figure 2.

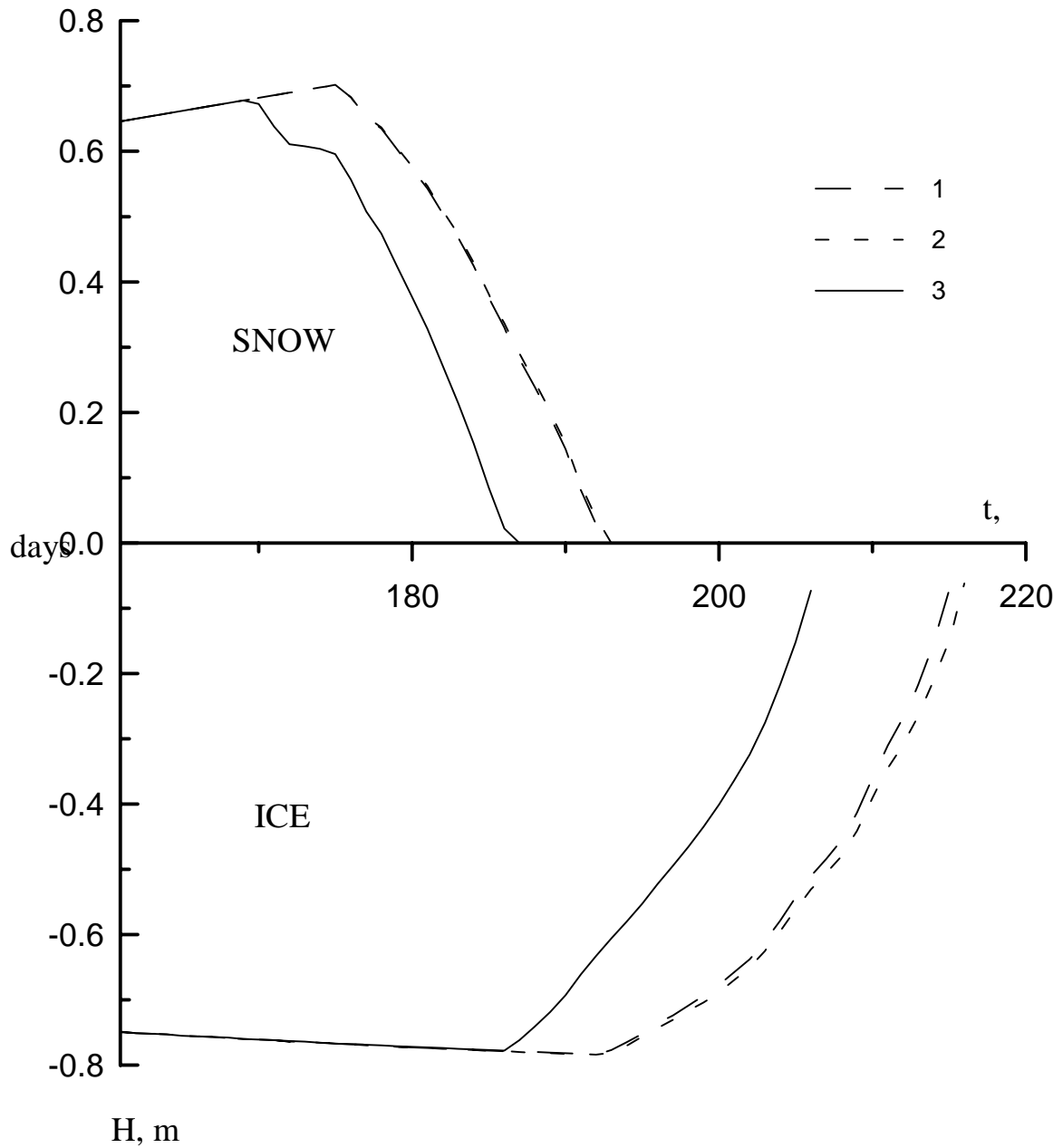
Model variations of ice cover thickness on NP-13.



- 1- Digestion of incoming solar radiation by surface (70%) and penetration into the ice interior (30%).
- 2- Digestion of 70% incoming solar radiation by surface.
- 3- Digestion of 100% incoming solar radiation by surface.

Figure 3.

The process of snow and ice cover melting in Kandalaksha Bay.  
 (Executed by model simulation with different variants of descriptions of  
 solar radiation influence.)



- 1- Digestion of incoming solar radiation by surface (70%) and penetration into the ice (snow) interior (30%).
- 2- Digestion of 70% incoming solar radiation by surface.
- 3- Digestion of 100% incoming solar radiation by surface.

t- conditional time from the moment of the beginning of ice forming.

Figure 4.