6.8 Sea Ice Model

6.8.1 Introduction

A numerical sea ice model is developed to support the sea ice forecast for the southern part of the Sea of Okhotsk which is operationally issued by JMA in the winter season. The sea ice model predicts the distribution and concentration of sea ice for the next 7 days based on dynamics and thermodynamics.

The outputs of the model have been operationally disseminated twice a week through JMH facsimile since Dec. 1990.

6.8.2 Model structure

6.8.2.1 Forecast area

Fig. 6.8.1 shows the forecast area with 71×71 square grids with intervals of 12.5km. The model calculates four physical elements (volume, concentration, velocity and thickness) of sea ice at each grid by using the initial sea ice distribution, sea surface temperature data, meteorological data and ocean current data.

6.8.2.2 Calculation of sea ice condition

The volume (M_i) and concentration (A_i) of the sea ice at each grid are governed by the following equations;

$$\begin{aligned} \frac{\partial M_\mathrm{i}}{\partial t} &= -\mathrm{div}(M_\mathrm{i} V_\mathrm{i}) + P_\mathrm{M} \\ \frac{\partial A_\mathrm{i}}{\partial t} &= -\mathrm{div}(A_\mathrm{i} V_\mathrm{i}) + P_\mathrm{A} + D_\mathrm{A} \end{aligned} \qquad (6.8.1)$$

where V_i is the sea ice velocity, which is determined in the dynamical process described in 6.8.2.3. P_M and P_A express the change of the volume and the concentration, respectively, due to the growth or melting of sea ice and the snowfall. They are determined in the thermodynamic process described in 6.8.2.4. D_A is a term related to the development of hummock due to the convergence of sea ice. D_A is given by calculating the convergence of V_i as follows; (Udin and Ullerstig, 1976)

$$D_\mathrm{A} = \begin{cases} \mathrm{div}(A_\mathrm{i} V_\mathrm{i}) & A_\mathrm{i} = 1 \quad \text{and} \quad \mathrm{div}(V_\mathrm{i}) < 0 \\ 0 & 0 < A_\mathrm{i} < 1 \quad \text{or} \quad \mathrm{div}(V_\mathrm{i}) \geq 0 \end{cases} \qquad (6.8.2)$$

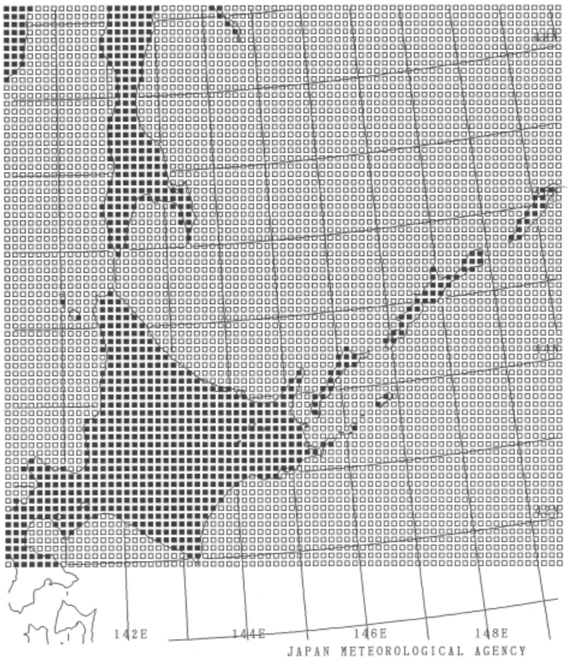

Fig. 6.8.1 Forecast area

■ : land □ : sea

6.8.2.3 Dynamical processes

The momentum equation of sea ice is described as follows; (Hibler, 1979)

$$\rho_i H_i \frac{\partial V_i}{\partial t} = \tau_a(V_a) + \tau_w(V_w, V_i) + C(V_i) + G(V_w) + F_i \qquad (6.8.3)$$

τ_a : wind stress,

τ_w : water stress,

C : Coriolis force,

G : pressure gradient force due to tilting sea surface,

F_i : internal ice stress.

Here V_a, V_w, and V_i denote the velocities of wind, ocean current and sea ice, respectively. ρ_i and H_i are sea ice density and thickness, respectively. Since the left-hand side term of eq. (6.8.3) is smaller than the other terms by more than one order of magnitude, V_i can be derived approximately on the assumption that the terms on the right-hand side of eq. (6.8.3) are in balance. V_a is given by GSM and V_w is given by climatology. Although F_i is actually a quite complex term, to save computational resources, the effect of F_i is included with a simplified method in which a provisional sea ice velocity calculated by the assumption that the first four terms of eq. (6.8.3) are balanced is modified by the non-slip condition at the coastal grid squares. We confirmed that the results are generally similar to those calculated by the viscous-plastic method used in Hibler (1979).

6.8.2.4 Thermodynamic processes

The thermodynamic processes included in the model are the development or melting of sea ice by the heat exchange among the atmosphere, ocean and sea ice. The change in the sea ice thickness is assumed to be caused by the heat exchange between the atmosphere and sea ice. The heat balance equation on the sea ice surface is as follows (Semtner, 1976);

$$R_{\mathrm{s}} + R_{\mathrm{a}} + SH(T_{\mathrm{i}}) + LH(T_{\mathrm{i}}) - FL(T_{\mathrm{i}}, H_{\mathrm{i}}) - R_{\mathrm{i}}(T_{\mathrm{i}}) = 0 \qquad (6.8.4)$$

here R_{s} : solar radiation,
R_{a} : atmospheric radiation,
SH : sensitive heat flux (positive downward),
LH : latent heat flux (positive downward),
FL : vertical heat flux in sea ice (positive downward),
R_{i} : radiation emitted from sea ice,
T_{i} : surface temperature of sea ice.

R_{s} and R_{a} are given by GSM. T_{i} can be calculated from eq. (6.8.4). If $T_{\mathrm{i}} < -1.8$°C, sea ice gains the thickness whose increment is estimated from FL. If $T_{\mathrm{i}} > 0$°C, sea ice loses the thickness whose negative increment is estimated from the sum of all the terms on the left-hand side of eq. (6.8.4) after T_{i} is set to 0°C. If $-1.8 < T_{\mathrm{i}} < 0$°C, sea ice remains unchanged.

The change in the sea ice area is assumed to be caused by the heat exchange between ocean and sea ice. The amount of the heat exchange between ocean and the atmosphere is described as follows;

$$Q_{\mathrm{w}} = R_{\mathrm{s}} + R_{\mathrm{a}} + SH(T_{\mathrm{s}}) + LH(T_{\mathrm{s}}) - R_{\mathrm{w}}(T_{\mathrm{s}}) \qquad (6.8.5)$$

Here R_{w} means the radiation emitted from the sea surface and T_{s} is the sea water temperature of the surface layer. It is assumed that ocean has a thin surface layer and a mixed layer below it, that the direct heat exchange between sea ice and sea water occurs only through the surface layer, and that the heat exchange between sea ice and the surface layer occurs to drive T_{s} to the melting point (0°C). Thus the change of sea ice area can be calculated.

We assume that the heat exchange between the sea surface layer and the mixed layer is calculated as follows;

$$T_s = \frac{(T_s - T_f)D_s + (T_m - T_f)D_m}{D_s + D_m} + T_f \qquad (6.8.6)$$

Here D_{s} and D_{m} denote the depth of the sea surface layer and that of the mixed layer, respectively. T_{m} is the sea water temperature of the mixed layer, and T_{f} is the freezing point of sea water. The same process is iterated in every time step.

6.8.3 Initial data of sea ice meteorological and ocean current data used in the model

6.8.3.1 Initial data of sea ice and sea surface temperature

The initial field of the sea ice concentration is subjectively estimated on the basis of the data from satellites (mainly MTSAT and NOAA), aircraft, ships, and coastal observations. The initial field of sea ice thickness is derived from the previous prediction. The Daily SST analysis data in the seas around Japan by JMA are used for the initial field of the sea surface temperature.

6.8.3.2 Meteorological data

Air pressure, air temperature, wind, dew point, solar radiation, atmospheric radiation, and precipitation on the sea surface at each grid are given by the interpolation of the predictions by the atmospheric numerical model (GSM).

6.8.3.3 Ocean current data

The distribution of the ocean currents used in the model is obtained from Japan Maritime Safety Agency (1983) and shown in Fig. 6.8.2. It is fixed throughout the sea ice season.

6.8.4 An example of the results of the Numerical Sea Ice Model

An example of the results of the 7-day prediction is shown in Fig. 6.8.3. The 7-day prediction by this model is better than the persistency in this particular case. Accuracy of this model, in general, worsens in the melting season and in the case of abrupt changes of atmospheric conditions. For better predictions, accurate information on external forcings, especially on ocean currents, is crucial as well as accurate initial fields, besides firm basis of model dynamics and thermodynamics.

References

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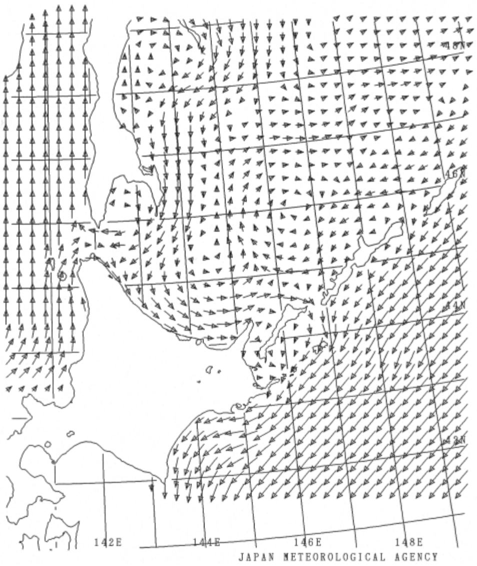

Fig. 6.8.2 Ocean current used in the model.

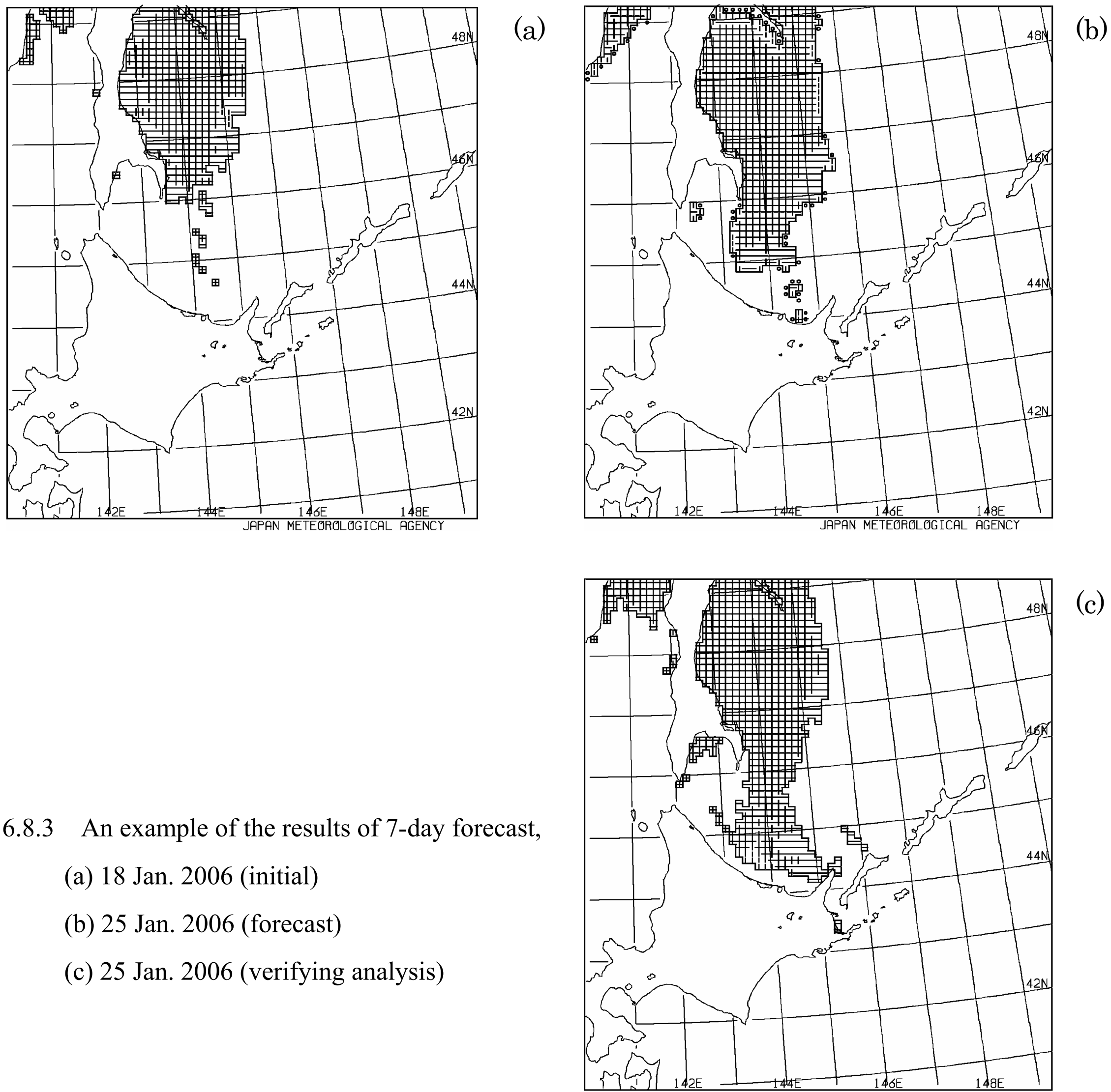

Fig. 6.8.3 An example of the results of 7-day forecast,

(a) 18 Jan. 2006 (initial)

(b) 25 Jan. 2006 (forecast)

(c) 25 Jan. 2006 (verifying analysis)