CONSORTIUM FOR SMALL SCALE MODELING

COSMO

Deutscher Wetterdienst

Wetter und Klima aus einer Hand

DWD

Treatment of Snow over Lake and Sea Ice within COSMO and ICON

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Outline

- Bulk models (parameterisation schemes): basic idea
- Lake ice vs. sea ice, interaction of ice thermodynamic model with data assimilation scheme
- Tests through numerical experiments
- Treatment of snow: perspective with bulk approach
- Possible alternatives

Bulk Ice Models – Basic Idea

Based on the idea of self-similarity (assumed shape) of the temperature-depth curve. Using ice surface temperature $\theta_i(t)$ and ice thickness $h_i(t)$ as appropriate scales of temperature and depth, the temperature profile within the ice layer is represented as

$$\theta(z,t) = \theta_f + [\theta_i(t) - \theta_f]\Phi(\varsigma), \quad \varsigma = z / h_i(t)$$

A "universal" function $\Phi(\zeta)$ satisfies the boundary condition is $\Phi(0)=0$ and $\Phi(1)=1$ (the z-axis is directed upward with the origin at the lower surface of the ice).

Analogy to the Mixed-Layer Concept

Using $\theta_s(t)$ and $h(t)$ as appropriate scales of temperature and depth, the temperature profile in the upper mixed layer is represented as

$$\frac{\theta(z,t)}{\theta_s(t)} = \Phi(\xi), \quad \xi = \frac{z}{h(t)}.$$

Since the layer is well mixed, the "universal" function $\Phi(\xi)$ is simply a constant equal to 1.

Then, integrating the heat transfer equation (partial differential equation in z, t)

$$\frac{\partial \overline{\theta}}{\partial t} = -\frac{\partial \overline{w'\theta'}}{\partial z}$$

over z from 0 to $h(t)$, reduces the problem to the solution of an ordinary differential equation for $\theta_s(t)$,

$$\frac{d\theta_s}{dt} = \frac{Q_s - Q(h)}{h}.$$

Analogy to the Concept of Self-Similarity of the Temperature Profile in the Thermocline

Put forward by Kitaigorodskii and Miropolsky (1970) to describe the temperature structure of the oceanic seasonal thermocline. The essence of the concept is that the temperature profile in the thermocline can be fairly accurately parameterised through a "universal" function of dimensionless depth, using the temperature difference across the thermocline, $\Delta\theta=\theta_s(t)-\theta_b(t)$, and its thickness, Δh, as appropriate scales of temperature and depth:

$$\frac{\theta_s(t)-\theta(z,t)}{\Delta\theta(t)}=\vartheta(\varsigma),\quad \varsigma=\frac{z-h(t)}{\Delta h(t)}$$

Bulk Lake/Sea Model – Summary

... Integrating the heat transfer equation (partial differential equation) with due regard for the self-similar representation of $\theta_s(z,t)$ and rearranging ... we get the system of ordinary differential equations for time-dependent ***parameters*** that specify the temperature profile, viz., $\theta_i(t)$ and $h_i(t)$, where **θ_i is a major concern**.

In the regime of ice growth (and/or melting from below for sea ice)

- equations for $h_i(t)$ and $\theta_i(t)$

In the regime of ice melting from above

- equation for $h_i(t)$, and θ_i is constant equal to the θ_{f0} (fresh-water freezing point)

NB: The model does not require re-tuning and

is computationally very inexpensive (vitally important for NWP!)

Bulk Lake/Sea Model – Summary (cont'd)

Ice growth and/or melting from below

$$C_* h_i \frac{d\theta_i}{dt} = -\frac{1}{\rho_i c_i}\left(Q_a + I_a\right) - \Phi_i'(0)\frac{\kappa_i}{\rho_i c_i}\frac{\theta_i - \theta_f}{h_i}\left[1 + \left(1 - C_*\right)R\right],$$

$$\frac{dh_i}{dt} = -\Phi_i'(0)\frac{\kappa_i}{\rho_i L_f}\frac{\theta_i - \theta_f}{h_i}, \quad C_* = \int_0^1 \Phi(\varsigma)d\varsigma, \quad R = \frac{c_i\left(\theta_i - \theta_f\right)}{L_f}$$

Temperature profile shape factor

Ice melting from above

$$\theta_i = \theta_{f0}, \quad \left[1 + \left(1 - C_*\right)R\right]\frac{dh_i}{dt} = \frac{1}{\rho_i L_f}\left(Q_a + I_a\right)$$

Lake Ice vs. Sea Ice
Interaction with Data Assimilation Scheme

Lake ice (ice module of the fresh-water lake model Flake)

- thermodynamic ice model carries equations for $h_i(t)$ and $\theta_i(t)$ and can produces new ice (lakes are allowed to freeze up themselves in response to atmospheric forcing)
- no observational data on the surface temperature are assimilated at present; data on ice (present/absent) are used to correct the forecast but for Laurentian Great Lakes only

Sea ice

- thermodynamic ice model carries equations for $h_i(t)$ and $\theta_i(t)$ but creates no new ice (ocean is not allowed to freeze up itself)
- horizontal distribution of sea ice is subordinate to data assimilation scheme that delivers ice fraction f_i for each atmospheric-model grid box
- no ice if f_i is small (remove leftover as needed), h_i and θ_i are initialised with ad hoc values if there was no ice but data indicate it is present

Diagnostic Ice Albedo Parameterization

Snow over sea/lake ice is not treated explicitly.

The effect of snow is accounted for implicitly (parametrically) through the changes in surface albedo with respect to solar radiation.

Lake ice (COSMO and ICON):

$$\alpha = \alpha_{\max} - (\alpha_{\max} - \alpha_{\min}) \exp[-C_\alpha (\theta_{f0} - \theta_i) / \theta_{f0}]$$

$$C_\alpha = 95.6, \quad \alpha_{\min} = 0.10, \quad \alpha_{\max} = 0.60$$

Prognostic Ice Albedo Parameterization (ICON sea ice ony)

Relaxation-type equation

$$\frac{d\alpha_i}{dt} = -\frac{\alpha_i - \alpha_{ie}}{\tau_{\alpha i}} - \frac{\alpha_i - \alpha_{sne}}{\tau_{\alpha sn}}$$

Relaxation towards equilibrium "snow-over-sea-ice" albedo only if $\alpha_i < \alpha_{sne}$ (albedo tends to increase) and $\theta_i < 272.95$ K (close to the freezing point, melt ponds do not re-freeze)

Relaxation time scales

$$\tau_{\alpha sn} = R_{sn}/R_*$$

$R_* = 5$ kg·m^{-2} is a disposable parameter (R_{sn} is a snowfall rate)

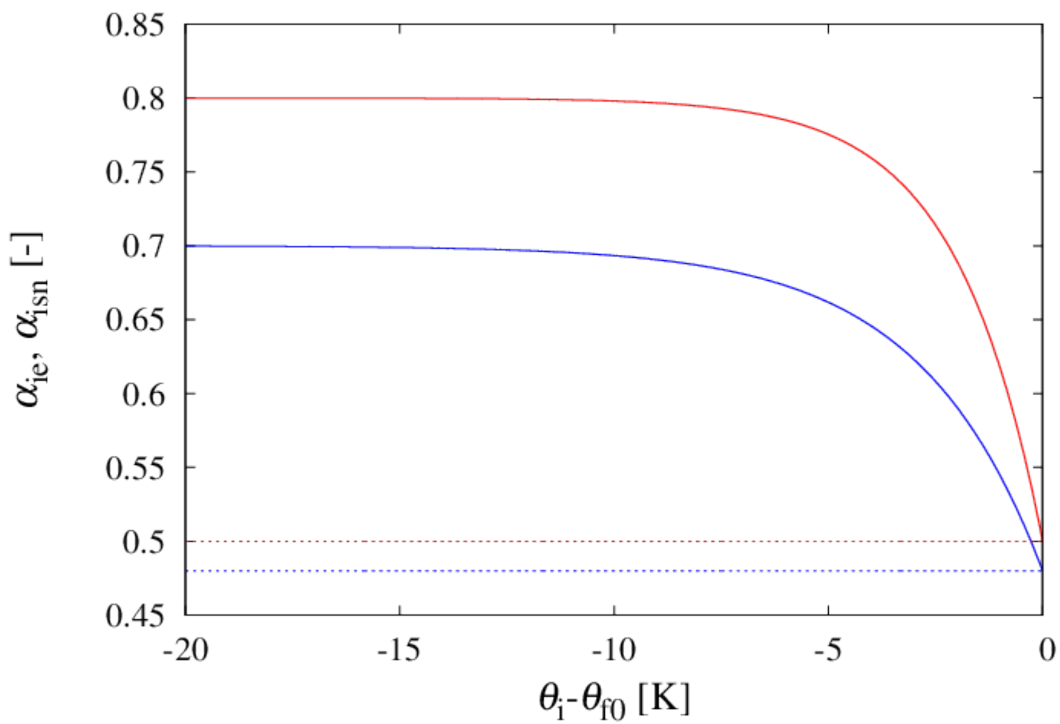
$\tau_{\alpha i} = 3$ days at (fresh-water) freezing point, and increases towards 21 days as θ_i approaches 268.15 K

Prognostic Ice Albedo Parameterization (cont'd)

Equilibrium "snow-over-sea-ice" albedo

$$\alpha_{sne} = \alpha_{sn}{}^{max} - \left(\alpha_{sn}{}^{max} - \alpha_{sn}{}^{min}\right)\exp\left[-C_{\alpha sn}\frac{\theta_{f0}-\theta_i}{\theta_{f0}}\right]$$

$$C_{\alpha sn}=136.6$$
$$\alpha_{sn}{}^{min}=0.50$$
$$\alpha_{sn}{}^{max} = 0.80$$



Red solid curve shows "snow-over-ice" equilibrium albedo

Explicit Treatment of Snow

Bulk approach is advantageous. In fact, the snow module exists within FLake but it is switched off within COSMO and ICON. Off-line numerical experiments (Mironov et al. 2012) show promising results.

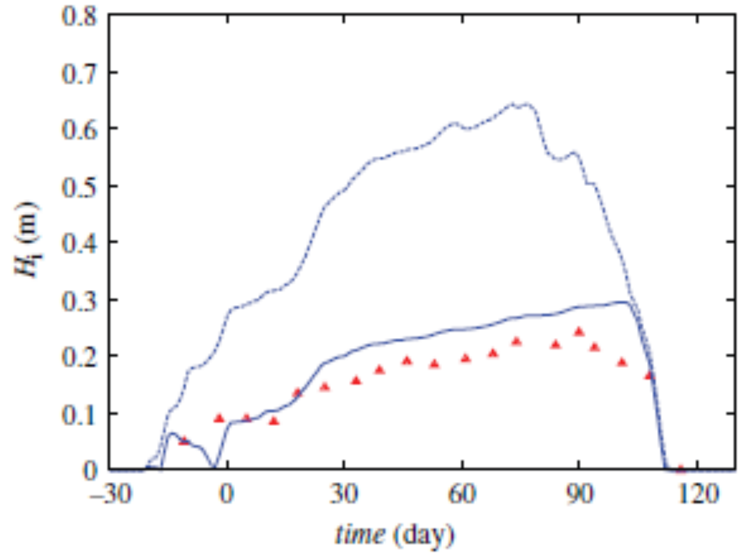


Fig. 9. Ice thickness in Lake Pääjärvi during winter 1999–2000, where day = 0 corresponds to 1 January 2000. Blue curves show results of simulations with FLake: solid curve – with a snow layer above the ice, and dashed curve – no snow above the ice. Red symbols show observational data.

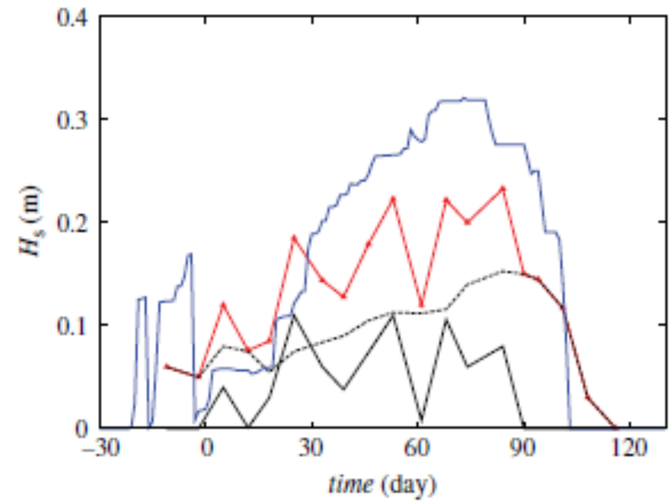


Fig. 10. Snow thickness in Lake Pääjärvi during winter 1999–2000, where day = 0 corresponds to 1 January 2000. Blue curve is computed with FLake. Black solid and dashes curves show observed values of the snow thickness and the snow ice thickness, respectively. Red curve with symbols shows the total thickness of the two layers.

Possible Alternatives

Bulk parameterization (as within Flake)

- Holds promise but improved formulations of snow density and snow heat conductivity are required
- Comprehensive testing is necessary

Finite-difference parameterization coupled with bulk ice parameterization

- Possible but there are issues, e.g. coupling of temperature and heat flux at the ice-snow interface is tricky

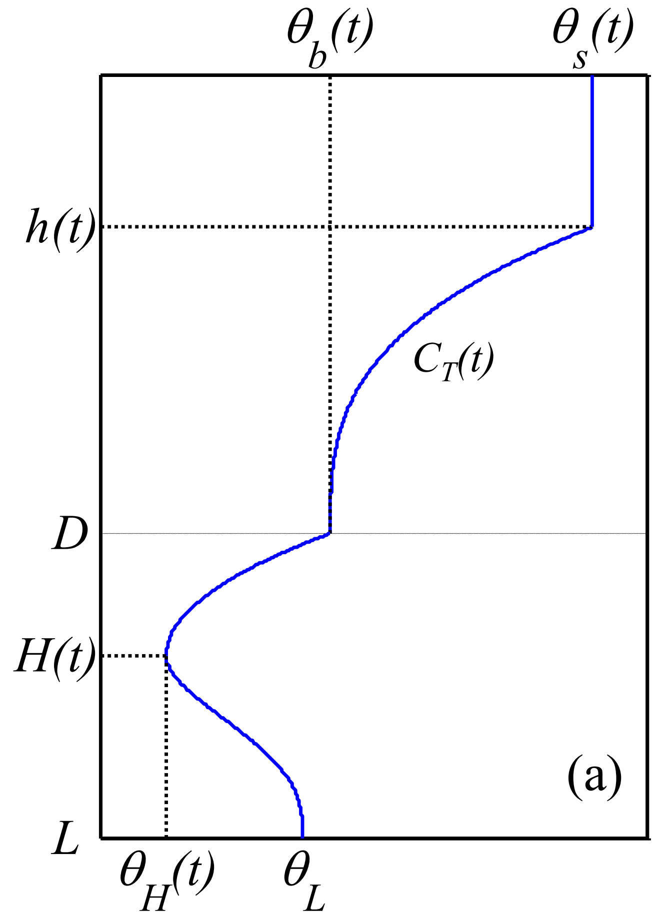
Thank you for your attention!

Mironov, D. V., 2008: Parameterization of lakes in numerical weather prediction. Description of a lake model. COSMO Technical Report, No. 11, 41 pp. (http://www.cosmo-model.org/content/model/documentation/techReports/)

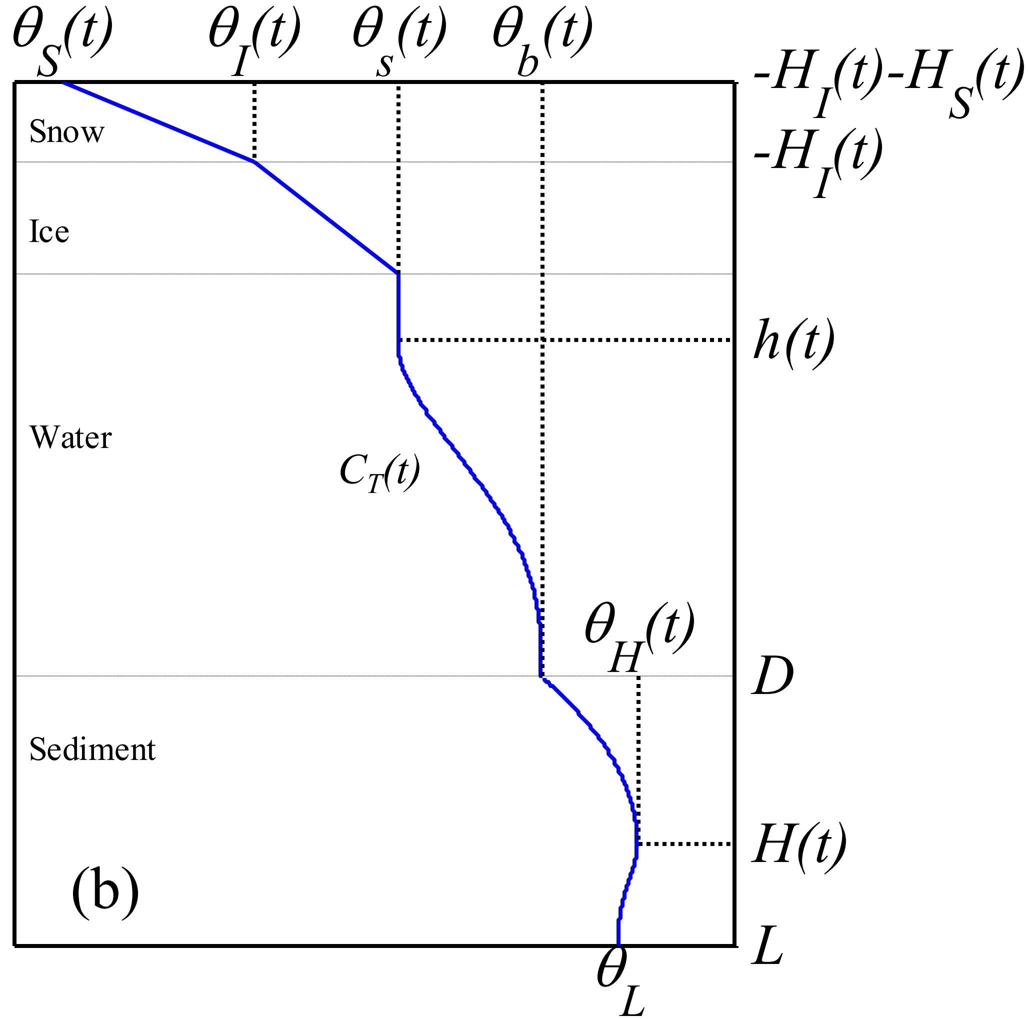
Mironov, D., B. Ritter, J.-P. Schulz, M. Buchhold, M. Lange, and E. Machulskaya, 2012: Parameterization of sea and lake ice in numerical weather prediction models!! of the German Weather Service. *Tellus A*, **64**, 17330. doi:10.3402/tellusa.v64i0.17330

Unused

Schematic Representation of the Temperature Profile



(a) The evolving temperature profile is characterised by a number of time-dependent parameters, namely, the temperature $\theta_s(t)$ and the depth $h(t)$ of the mixed layer, the bottom temperature $\theta_b(t)$, the shape factor $C_T(t)$ with respect to the temperature profile in the thermocline, the depth $H(t)$ within bottom sediments penetrated by the thermal wave, and the temperature $\theta_H(t)$ at that depth.



(b) For frozen lakes, four additional variables are computed, namely, the temperature $\theta_S(t)$ at the air-snow interface, the temperature $\theta_I(t)$ at the snow-ice interface, the snow thickness $H_S(t)$, and the ice thickness $H_I(t)$.