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Nudging of the Water Surface Temperature and Ice Cover Observations into Lake Parameterization Scheme FLake

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Outline

- The problem
- Formulation of nudging terms
- Changes in FLake code (towards FLake version 2.0), decision tree
- Numerical experiments
- Conclusions and outlook

What is the Problem?

FLake variables are related through (http://lakemodel.net)

$$\theta_{av} = \theta_{ml} - C_T\left(1 - h/D\right)\left(\theta_{ml} - \theta_b\right) \qquad (1)$$

Within FLake, $\theta_{av}(t)$, $\theta_b(t)$, $h(t)$ and $C_T(t)$ are computed from prognostic equations, whereas the mixed-layer temperature $\theta_{ml}(t)$ is computed diagnostically from Eq. (1).

Given data from observations of the water surface temperature θ_s (in ice-free conditions, θ_s is assumed to be equal to θ_{ml}), how to determine the nudging terms in prognostic equations for $\theta_{av}(t)$, $\theta_b(t)$, $h(t)$ and $C_T(t)$ in terms of θ_s?

Formulation of Nudging Terms

From Eq. (1) we get

$$\left[1-C_T\left(1-h/D\right)\right]\frac{d\theta_{ml}}{dt}=\frac{d\theta_{av}}{dt}-C_T\left(1-h/D\right)\frac{d\theta_b}{dt}$$

$$+\left(1-h/D\right)\left(\theta_{ml}-\theta_b\right)\frac{dC_T}{dt}-\frac{C_T}{D}\left(\theta_{ml}-\theta_b\right)\frac{dh}{dt} \qquad (2)$$

It is easy to verify, that Eq. (2) (where $d\theta_{ml}/dt=d\theta_s/dt$) is satisfied if

$$\left(\frac{d\theta_{av}}{dt}\right)_{ndg}=\alpha_{av}\left[1-C_T\left(1-h/D\right)\right]\left(\frac{d\theta_s}{dt}\right)_{ndg},\quad \left(\frac{d\theta_b}{dt}\right)_{ndg}=-\alpha_b\frac{1-C_T\left(1-h/D\right)}{C_T\left(1-h/D\right)}\left(\frac{d\theta_s}{dt}\right)_{ndg},$$

$$\left(\frac{dC_T}{dt}\right)_{ndg}=\alpha_C\frac{1-C_T\left(1-h/D\right)}{\left(1-h/D\right)\left(\theta_{ml}-\theta_b\right)}\left(\frac{d\theta_s}{dt}\right)_{ndg},\quad \left(\frac{dh}{dt}\right)_{ndg}=-\alpha_h\frac{D}{C_T}\frac{1-C_T\left(1-h/D\right)}{\theta_{ml}-\theta_b}\left(\frac{d\theta_s}{dt}\right)_{ndg},$$

$$\alpha_{av}+\alpha_b+\alpha_C+\alpha_h=1$$

Relative weights

Relaxation (nudging) term for θ_s

Formulation of Nudging Terms (cont'd)

Relative weights

$$\{\alpha_b, \alpha_C, \alpha_h\} = \{\alpha_b^0, \alpha_C^0, \alpha_h^0\}(1 - h/D)^\gamma,$$
$$\alpha_{av} = 1 - (\alpha_b + \alpha_C + \alpha_h),$$
$$\alpha_b^0 + \alpha_C^0 + \alpha_h^0 \le 1, \quad \gamma \ge 1$$

$\alpha_{av} \to 1$ as $h \to D$. A reasonable estimate is γ=1.

An ad hoc constraint to avoid singularity

$$(\theta_{ml} - \theta_b) = \max\left[|\theta_{ml} - \theta_b|, \Delta\theta^*\right]\mathrm{sign}(\theta_{ml} - \theta_b), \quad \Delta\theta^* = 0.5\,\mathrm{K}$$

Formulation of Nudging Terms (cont'd)

Relaxation (nudging) term for the surface temperature θ_s

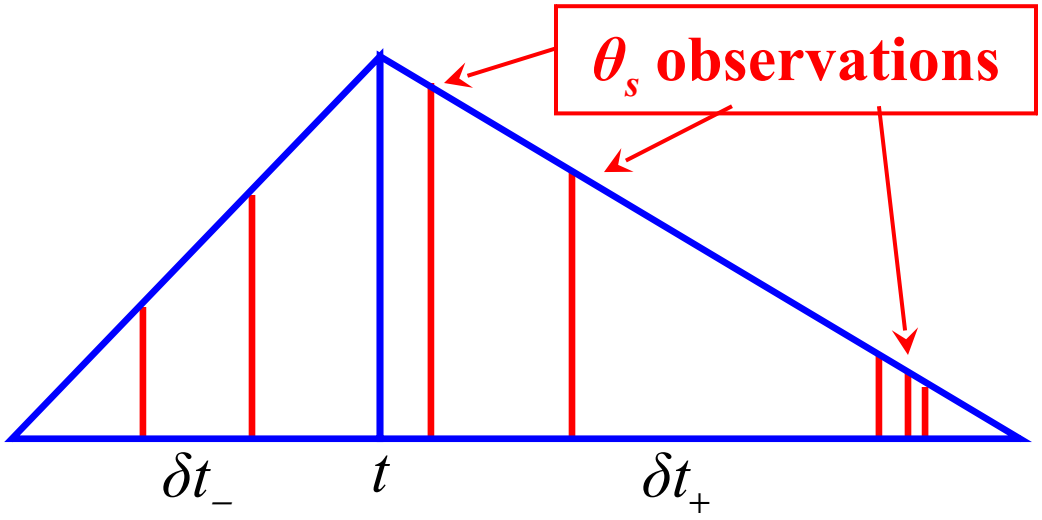
$$\left(\frac{d\theta_s}{dt}\right)_{ndg} = -\tau_r^{-1}\sum_{k=1}^{N_{obs}} W_k\left(\theta_s - \theta_k^{obs}\right),$$

τ_r is the relaxation (nudging) time scale.

Observation-dependent weights (Schraff and Hess 2003)

$$W_k = w_k \frac{w_k}{\sum_{i=1}^{N_{obs}} w_i}$$

Observation taken at time t has w_k=1



Changes in FLake Code

(towards FLake version 2.0)

Changes in existing FLake routines

- changes in MODULE flake (include 'flake_nudging.incf')
- new logical switch lflk_nudging in MODULE flake_configure
- changes in SUBROUTINE flake_interface (among other things, new additional optional arguments)

New routines

- new MODULE flake_param_nudging (disposable parameters of the nudging scheme)
- new MODULE mo_flake_interface (includes flake_interface.incf, simplifies handling of optional arguments)
- new SUBROUTINE flake_nudging (main routine of the nudging scheme, called by flake_interface)

Changes in FLake Code (cont'd)

If lflk_nudging=.TRUE., subroutine flake_interface should be called with three additional arguments, viz.,

- a character variable cice_obs, equal to 'ice', 'noice', or 'nodata', and
- two real variables $<W>$ and $<W\theta>$ defined as

$$\left(\frac{d\theta_s}{dt}\right)_{ndg} = -\tau_r^{-1}\sum_{k=1}^{N_{obs}} W_k\left(\theta_s - \theta_k^{obs}\right) = -\tau_r^{-1}\left(\langle W\rangle - \langle W\theta\rangle\right)$$

$$\langle W\rangle = \sum_{k=1}^{N_{obs}} W_k, \quad \langle W\theta\rangle = \sum_{k=1}^{N_{obs}}\left(W_k\theta_k^{obs}\right)$$

Additional flake_interface arguments are optional!

Decision Tree

cice_obs =

‘ice’	‘noice’	‘nodata’
There is ice in the forecast ⇒ do nothing No ice in the forecast ⇒ create new ice No observational data on θ_s are assimilated if ice is present	There is ice in the forecast ⇒ remove ice Nudge θ_s data if available ($<W>$ and $<W\theta>$ should be provided, a negative $<W\theta>$ indicates no data)	Nudge θ_s data if available ($<W>$ and $<W\theta>$ are provided) Do nothing if there are no θ_s data ($<W\theta>$ is negative)

Numerical Experiments

Lake Valkea-Kotinen, Finland (61 N, depth = 3 m)

Lake Pääjärvi, Finland (61 N, depth = 15 m)

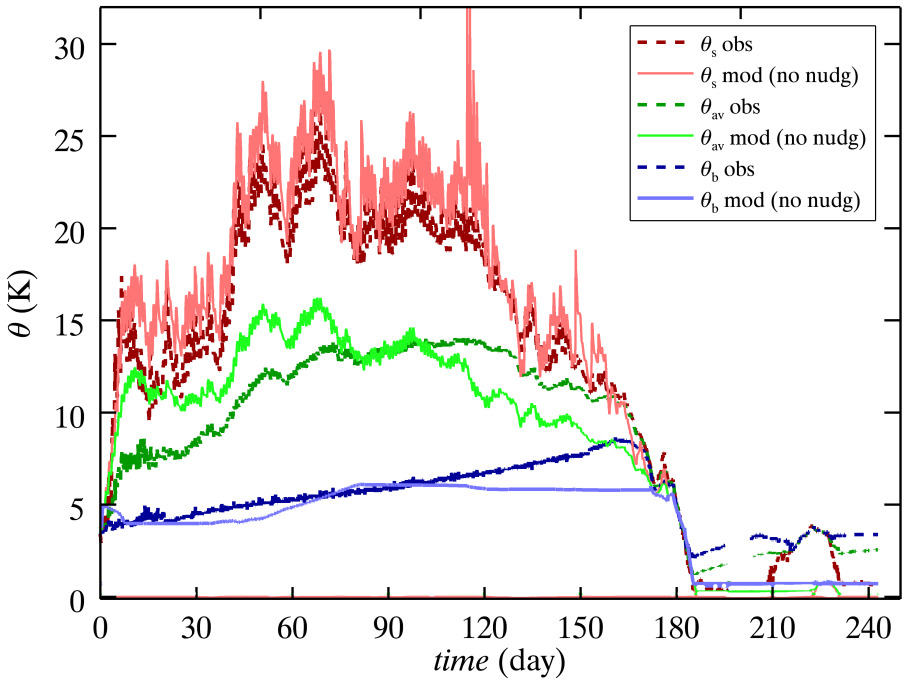
- Sensitivity experiments with γ=0 and one of the relative weights (α_{av}, α_b, α_C or α_h) set to 1 whereas the other weights are set to 0
- Runs with our "best choice" parameters

$$\alpha_C^0 = 0.05, \quad \alpha_b^0 = 0.10, \quad \alpha_h^0 = 0.45, \quad \gamma = 1$$

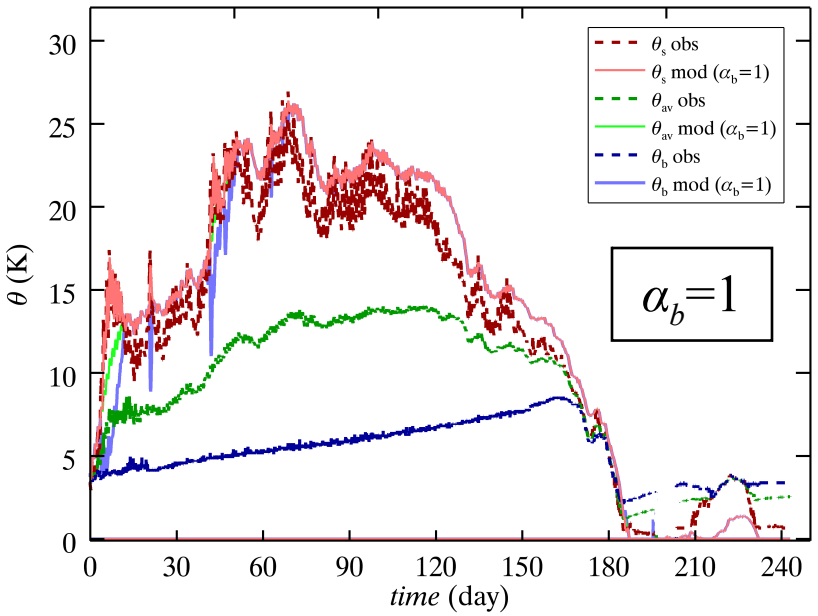
$$\alpha_{av} = 1 - \left(\alpha_C^0 + \alpha_b^0 + \alpha_h^0\right)\left(1 - h/D\right)^{\gamma}$$

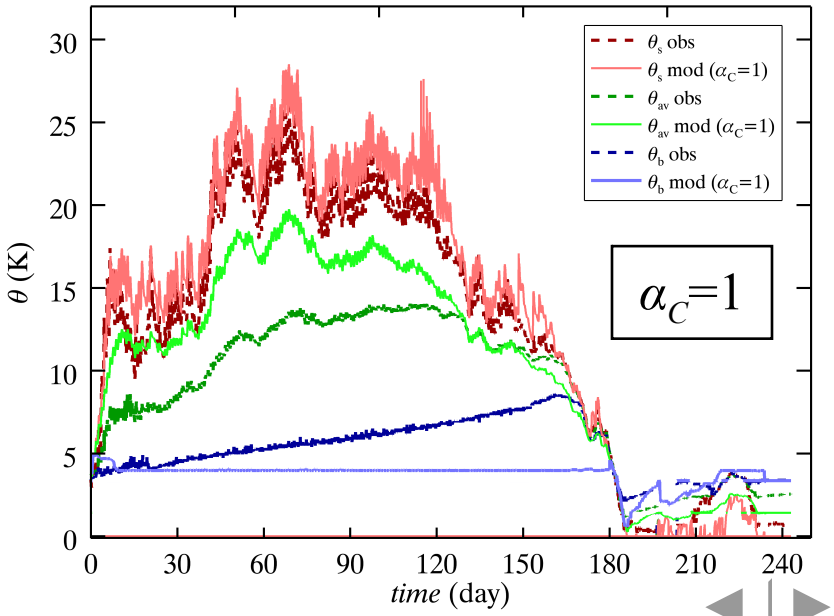
The relaxation (nudging) time scale τ_r=3 h.

Lake Valkea-Kotinen: sensitivity experiments



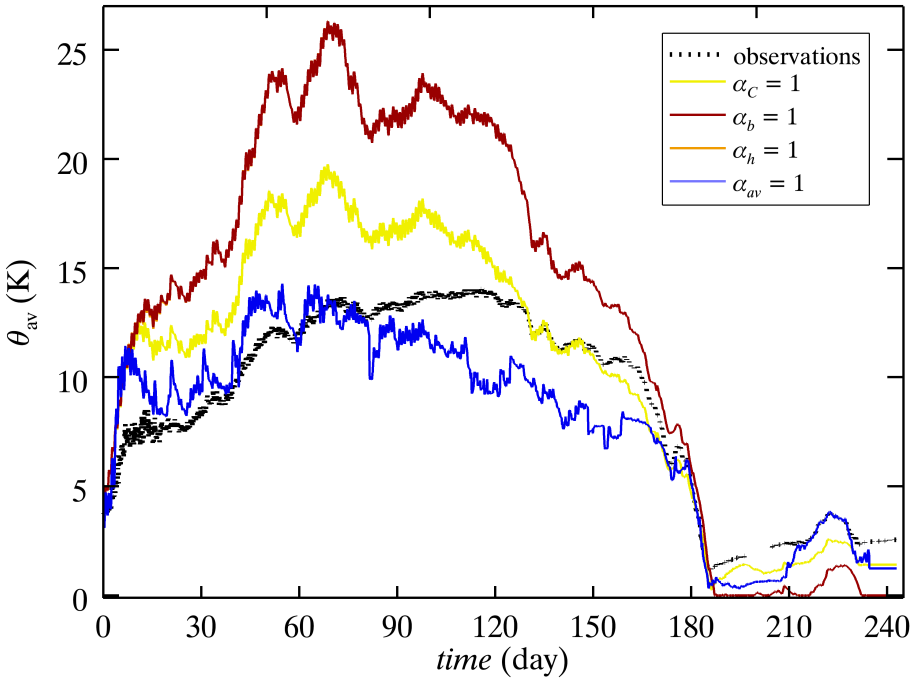
no nudging

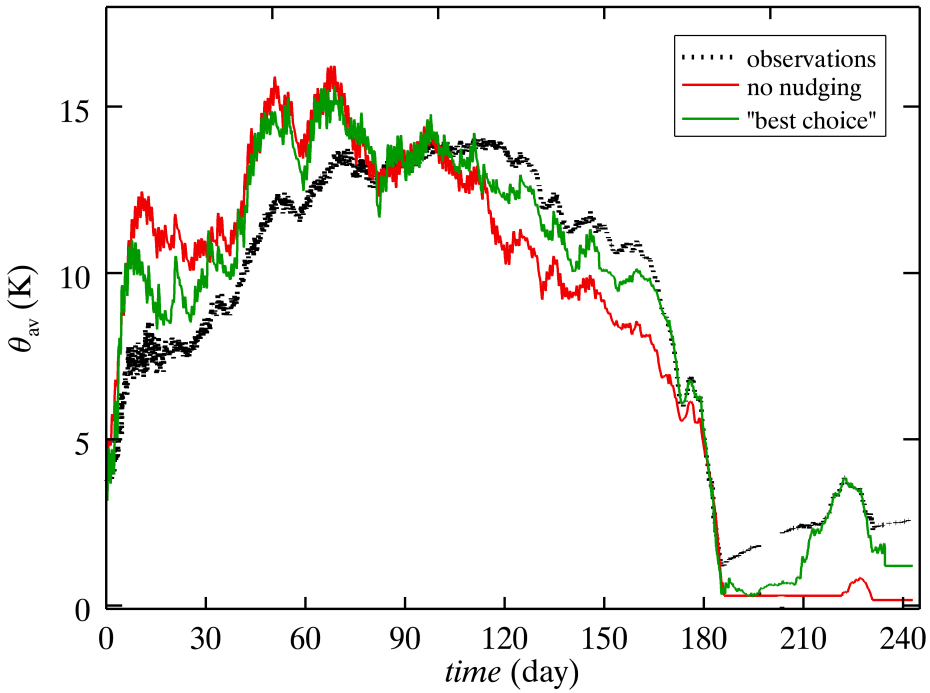




Mixed-layer temperature (red), mean temperature of the water column (green) and bottom temperature (blue) in Lake Valkea-Kotinen over the period from 2 May to 31 December 2006. Dotted curves show observational data. Solid curves are computed by FLake with different values of the relative weights α_{av}, α_b, α_C and α_h.

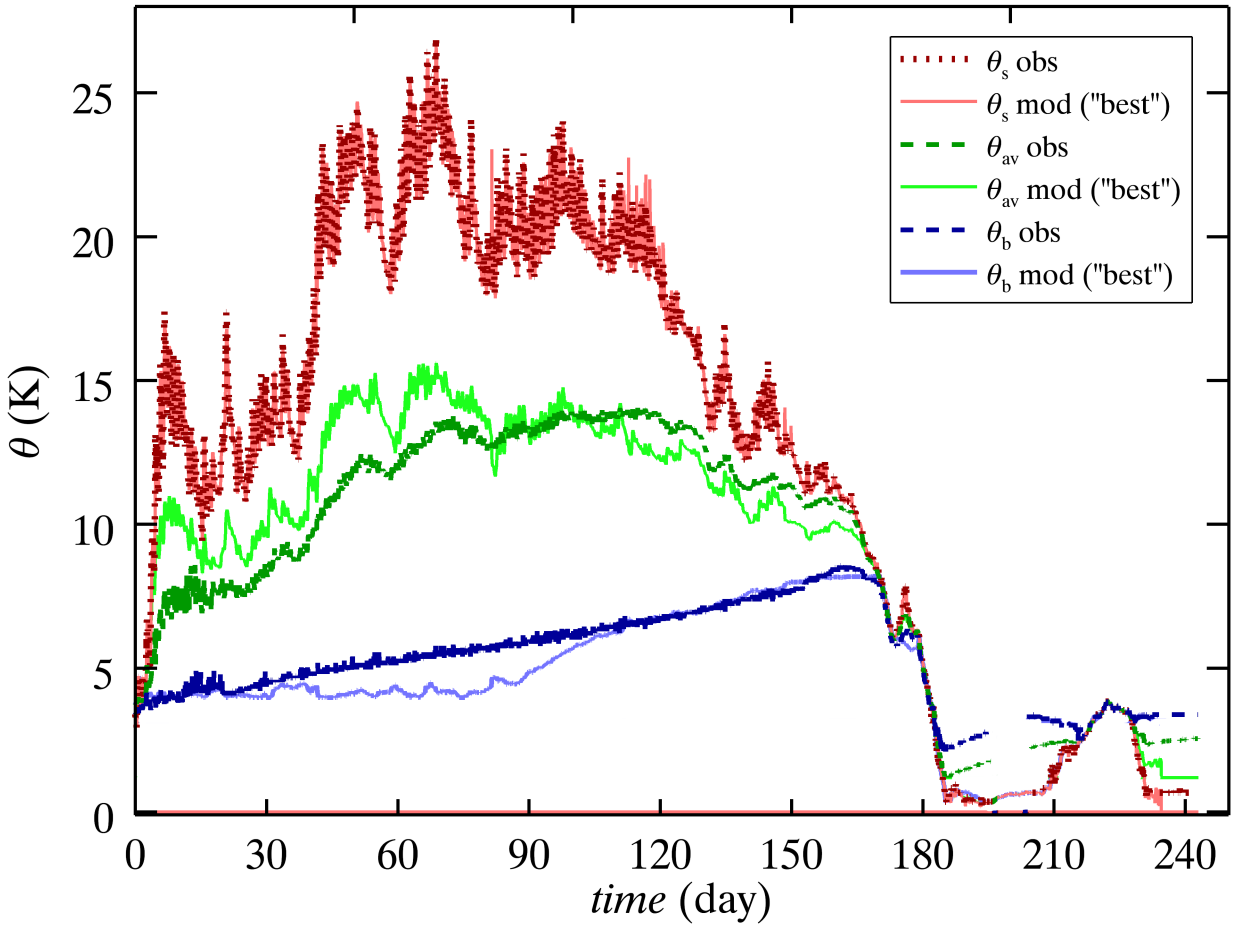
Lake Valkea-Kotinen: sensitivity experiments





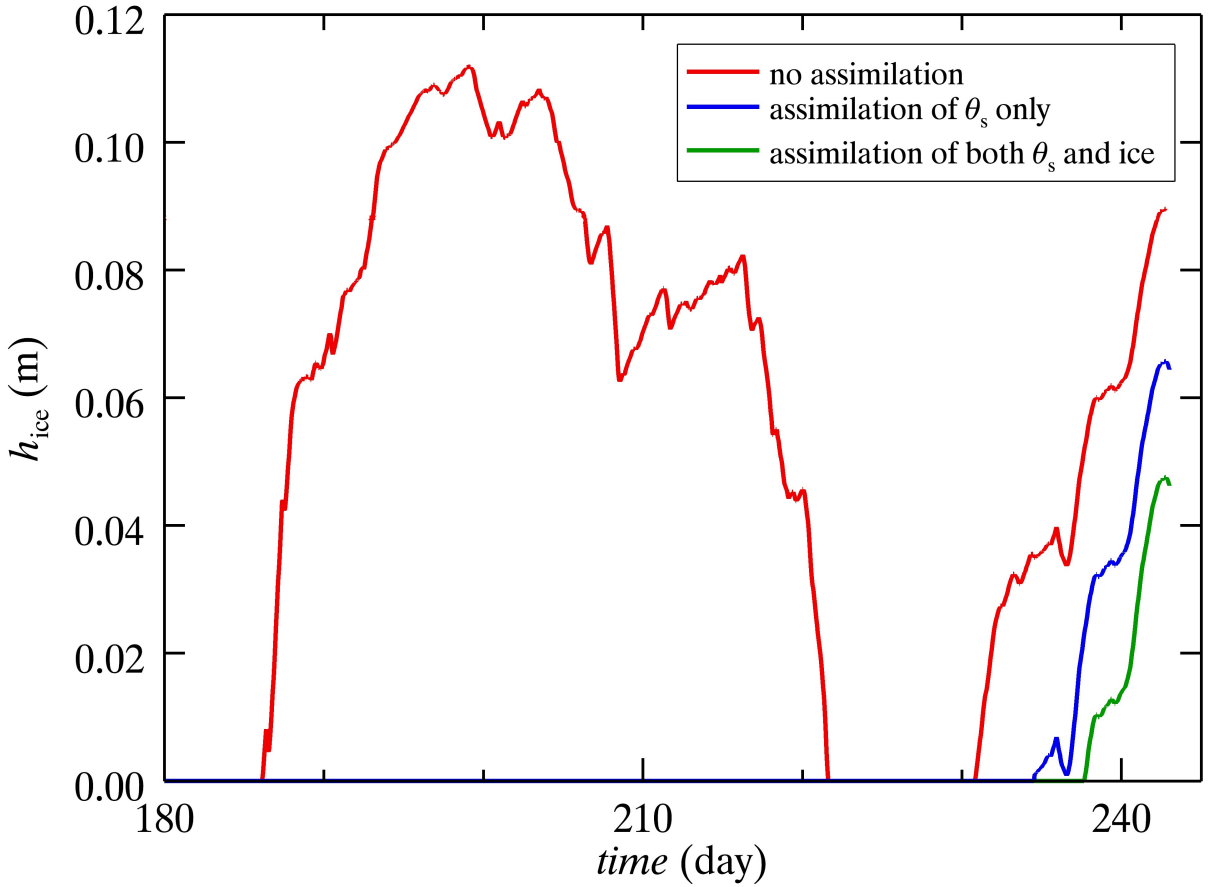
Mean temperature of the water column in Lake Valkea-Kotinen over the period from 2 May to 31 December 2006. Dotted curves show observational data. Solid curves are computed by FLake with different values of the relative weights α_{av}, α_b, α_C and α_h.

Lake Valkea-Kotinen: nudgecast



Mixed-layer temperature (red), mean temperature of the water column (green) and bottom temperature (blue) in Lake Valkea-Kotinen over the period from 2 May to 31 December 2006. Dotted curves show observational data. Solid curves are computed by FLake with "best choice" values of the relative weights α_{av}, α_b, α_C and α_h.

Lake Valkea-Kotinen: ice thickness



Ice thickness in Lake Valkea-Kotinen in November – December 2006 as computed by FLake: red – no nudging, blue – θ_s observation are nudged with the "best choice" estimates of the relative weights but ice cover observations are not used, i.e. `cice_obs`='nodata' throughout the simulation, and green – both θ_s and ice cover observations are used, where `cice_obs` is set equal to 'ice' over the period of ice cover and to 'noice' otherwise.

Lake Valkea-Kotinen: statistics

Summary table of the Lake Valkea-Kotinen test runs (Bias/RMSE).

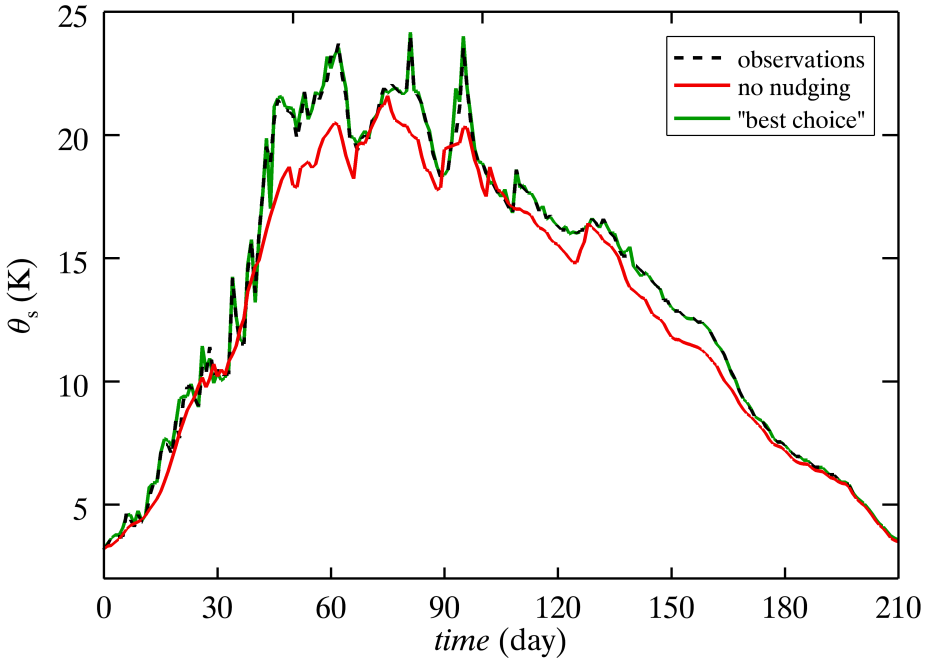
	θ_s (K)	θ_{av} (K)	θ_b (K)	u_* (m/s)	Q_{sen} (W/m²)	Q_{lat} (W/m²)
no nudging	1.29 / 2.13	0.20 / 2.25	-0.77 / 1.21	-0.12 / 0 .16	-2.94 / 12.42	-16.73 / 32.65
$\alpha_C = 1$	1.03 / 1.77	1.82 / 3.04	-1.54 / 2.13	-0.13 / 0.17	-4.81 / 11.49	-17.55 / 31.79
$\alpha_b = 1$	0.98 / 1.79	4.79 / 6.59	8.36 / 11.24	-0.13 / 0.17	-5.45 / 12.74	-17.63 / 36.97
$\alpha_h = 1$	0.98 / 1.79	4.79 / 6.59	8.28 / 11.24	-0.13 / 0.17	-5.45 / 12.75	-17.70 / 36.79
$\alpha_{av} = 1$	0.028 / 0.31	-0.81 / 2.03	-1.31 / 1.62	-0.13 / 0.17	-0.32 / 10.77	-4.13 / 24.81
"best choice"	0.037 / 0.28	0.32 / 1.34	-0.59 / 0.91	-0.13 / 0.17	-0.41 / 10.74	-4.28 / 24.91

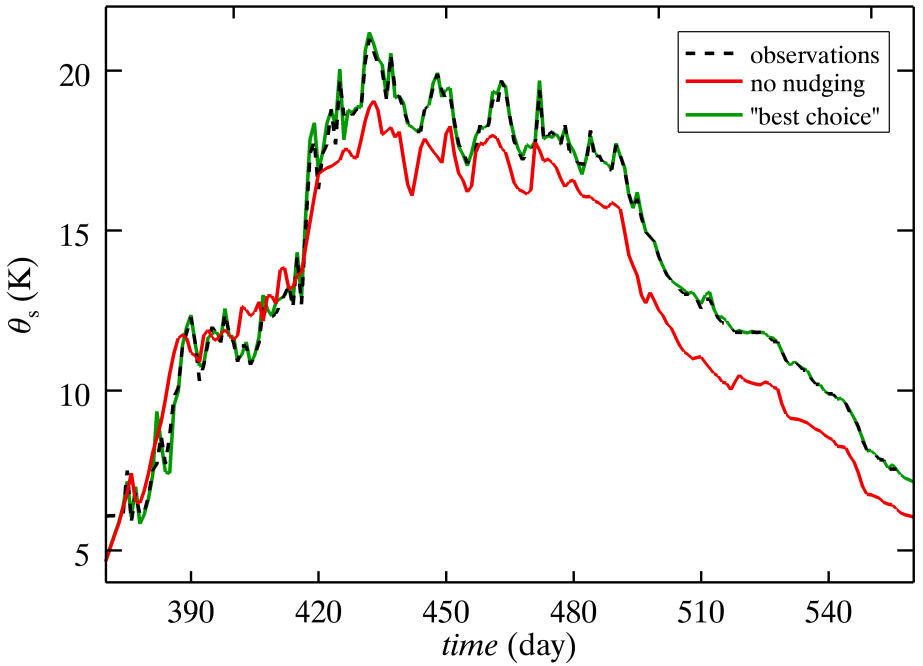
Lake Pääjärvi: statistics

Summary table of the Lake Pääjärvi test runs (Bias/RMSE).

	θ_s Bias (K)	θ_s RMSE (K)
no nudging	-0.91	1.34
$\alpha_C = 1$	-0.84	1.38
$\alpha_b = 1$	-0.96	1.25
$\alpha_h = 1$	-0.74	1.05
$\alpha_{av} = 1$	0.06	0.32
"best choice"	0.05	0.31

Lake Pääjärvi : nudgecast





Mixed-layer temperature in Lake Pääjärvi during summer 1998 (left panel) and summer 1999 (right panel). Dotted curve shows observational data. Solid curves are computed by FLake: red – no nudging, and green – with nudging using “best choice” values of the relative weights.

Conclusions and Outlook

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- A scheme to nudge the water surface temperature and ice cover (ice vs. no ice) observations into the lake model (parameterization scheme) FLake is developed
- The nudging scheme is favourably tested through single-column numerical experiments
- Comprehensive off-line testing of the FLake nudging scheme (different lakes, frequent vs. infrequent observations, width of nudging time window, relaxation time scale, etc.)
- Testing within an NWP model
- High-quality observational data with good spatial and temporal coverage is the key issue!

Thank you for your attention!

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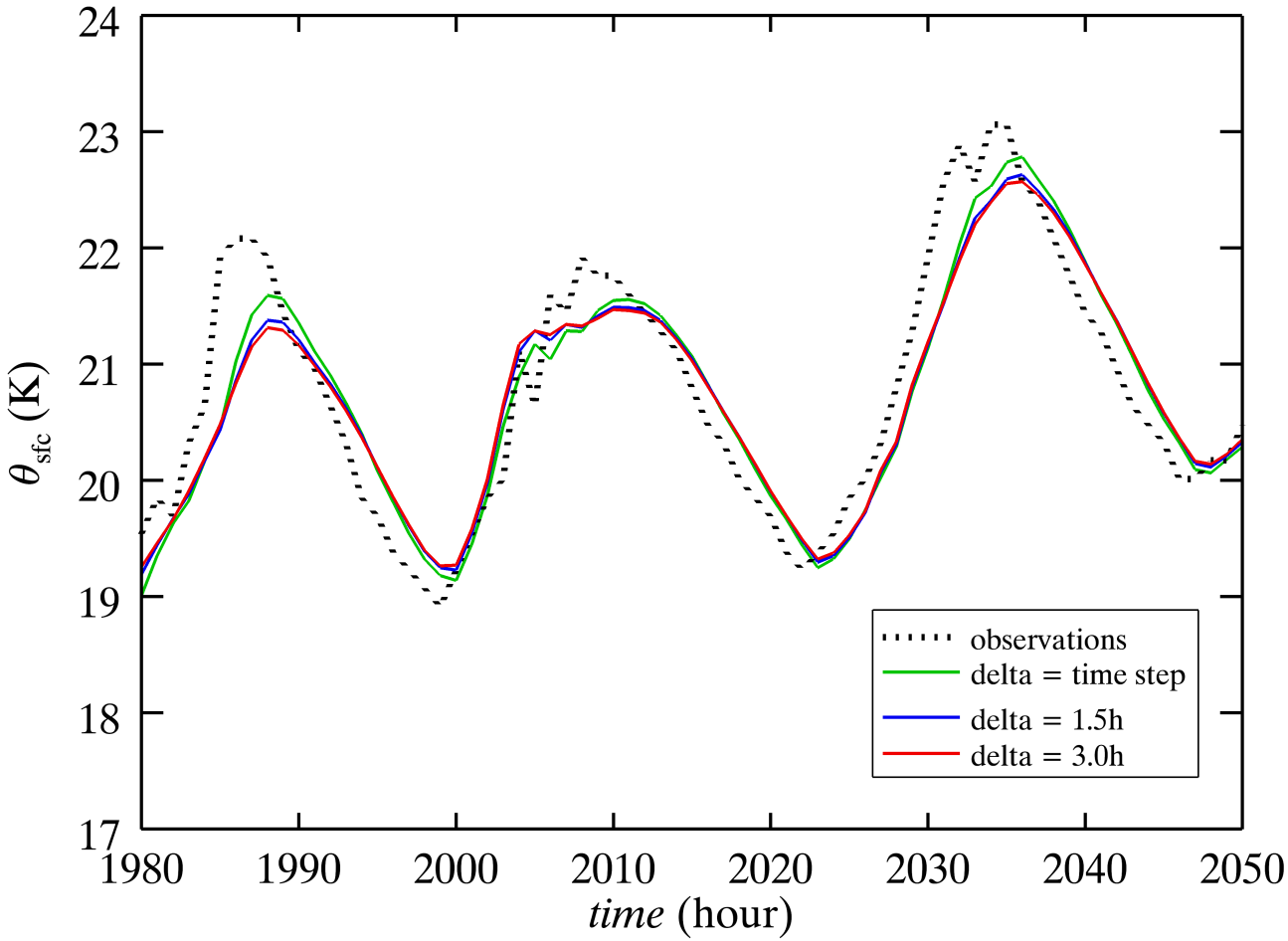
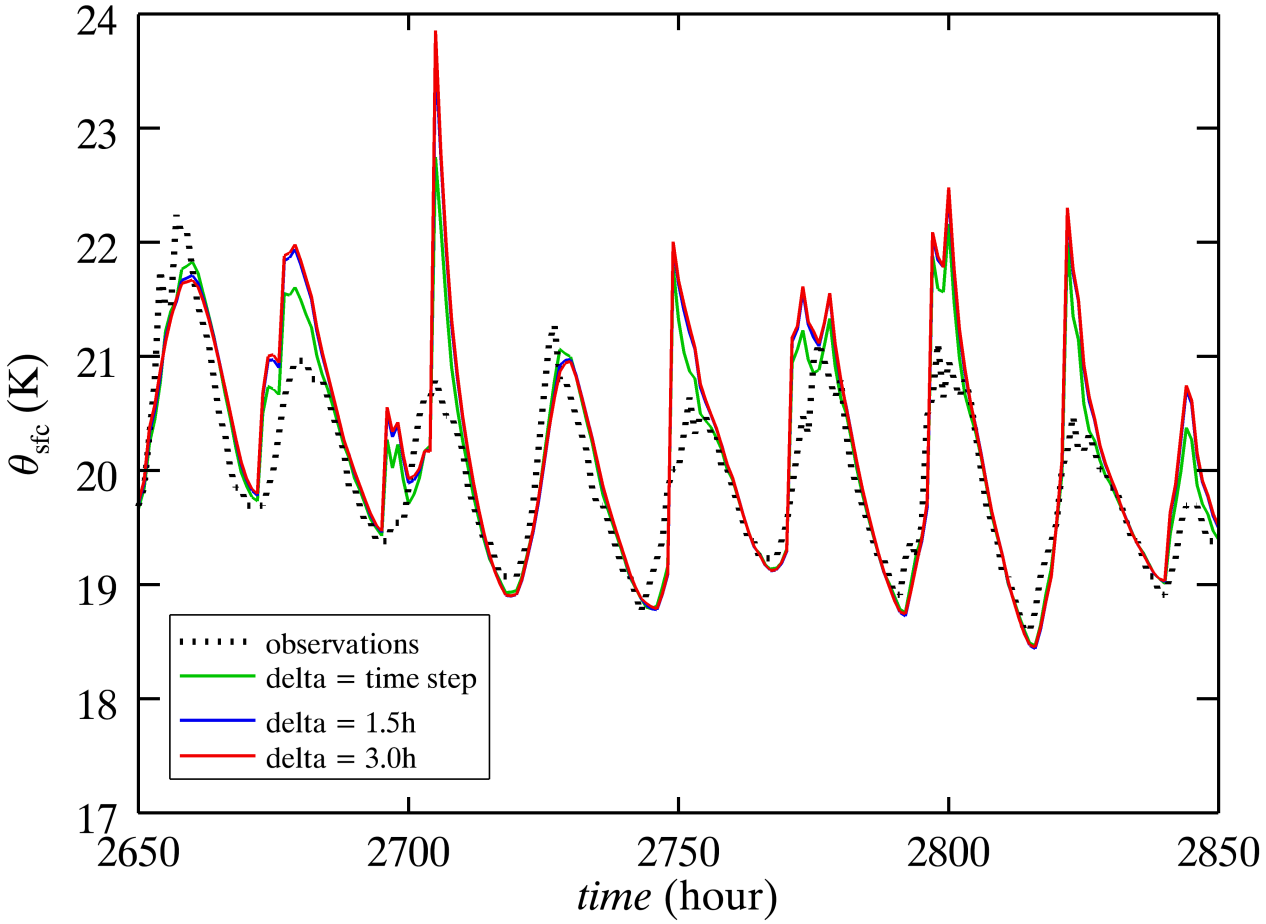
Lake Valkea-Kotinen: nudgecast (cont'd)



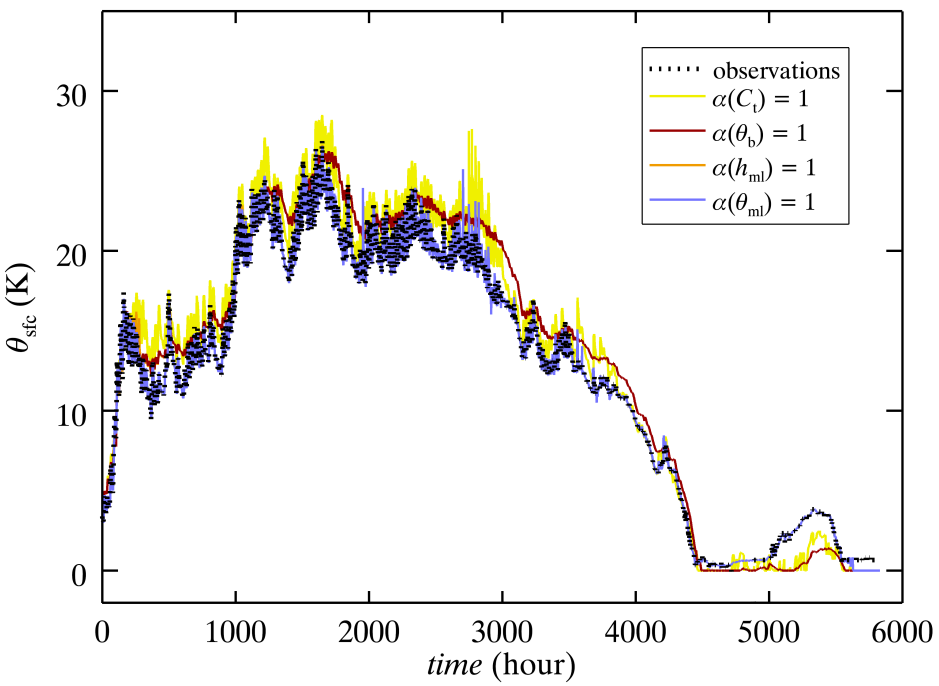
Mid summer 2006 mixed-layer temperature in Lake Valkea-Kotinen. Dotted curves show observational data. Solid curves are computed by FLake with different widths of nudging time window.

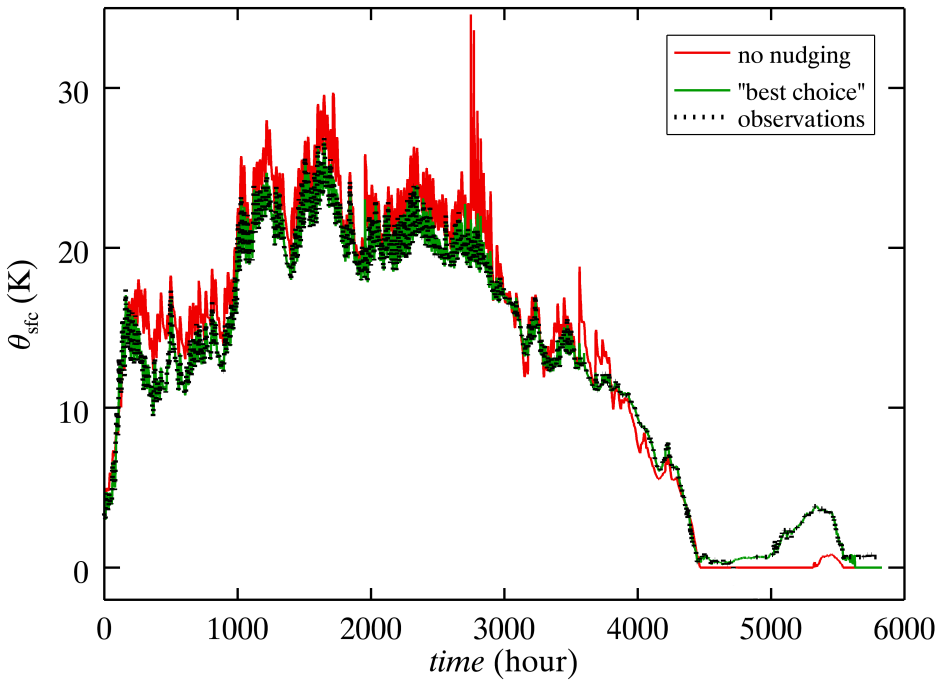
Lake Valkea-Kotinen: nudgecast (cont'd)



Autumn 2006 mixed-layer temperature in Lake Valkea-Kotinen. Dotted curves show observational data. Solid curves are computed by FLake with different widths of nudging time window.

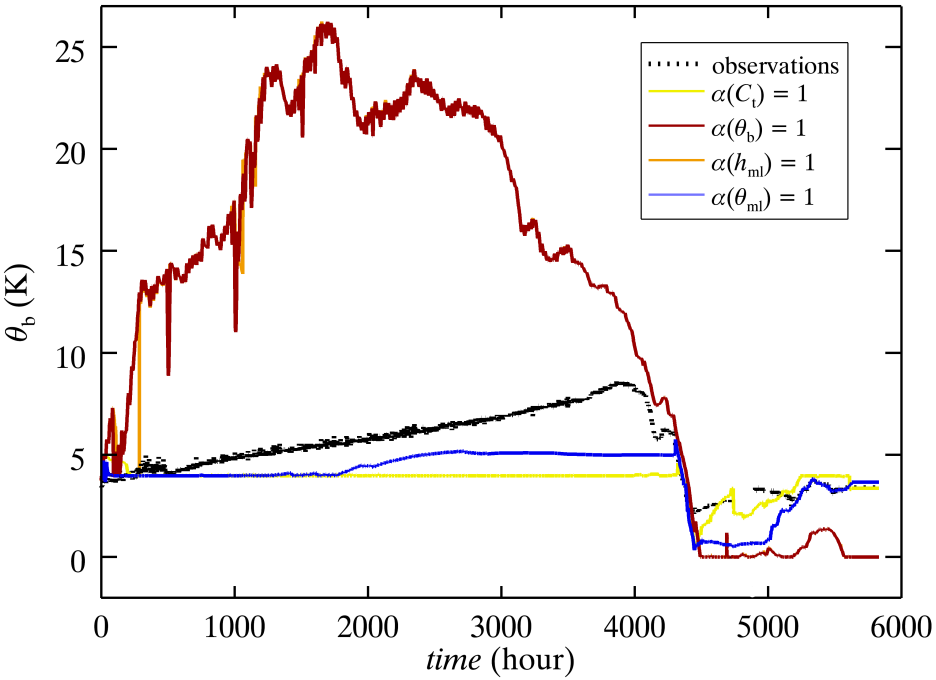
Lake Valkea-Kotinen: surface temperature

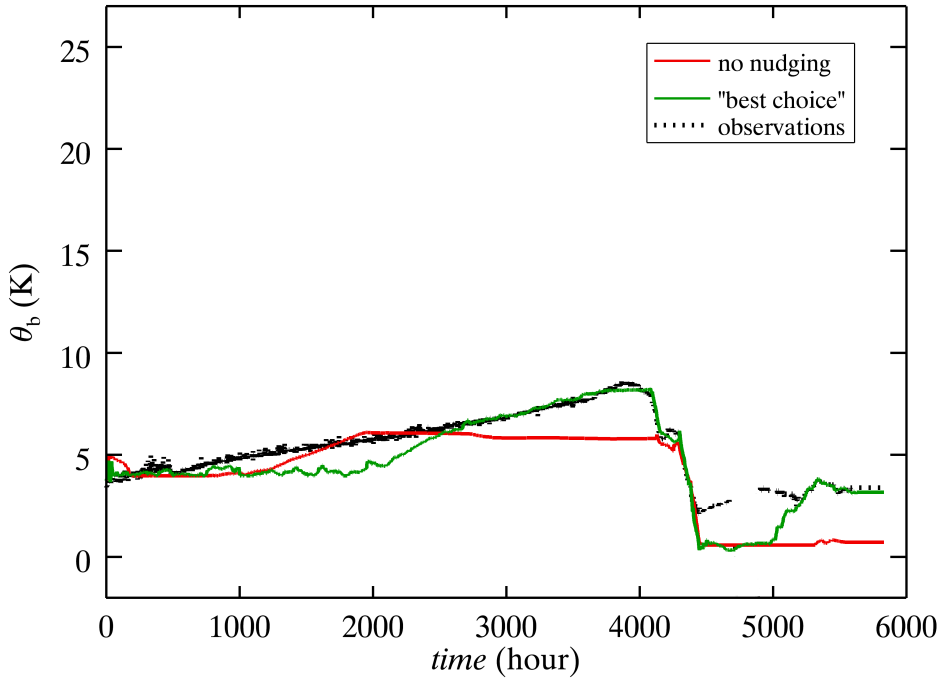




Mixed-layer temperature in Lake Valkea-Kotinen over the period from 2 May to 31 December 2006. Dotted curves show observational data. Solid curves are computed by FLake with different values of the relative weights.

Lake Valkea-Kotinen: bottom temperature





Bottom temperature in Lake Valkea-Kotinen over the period from 2 May to 31 December 2006. Dotted curves show observational data. Solid curves are computed by FLake with different values of the relative weights.