Modeling in aquatic environment

Lecture 4

Temperature models

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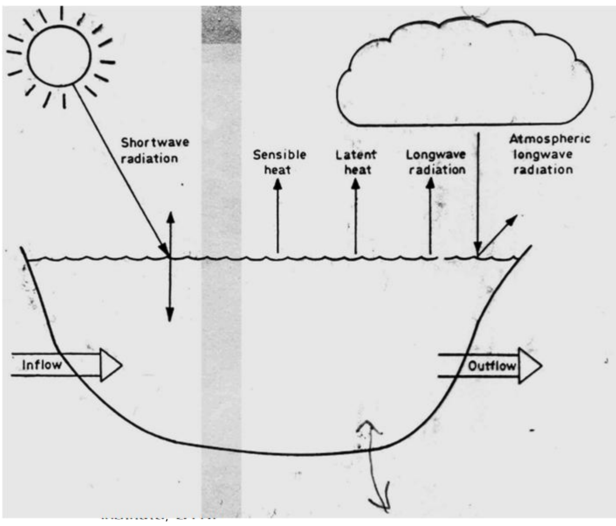
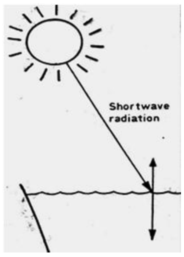
Heat balance components

Heat budget is calculated as water balance.

We need to know the components in the balance

In small role also heat from precipitation and sediment



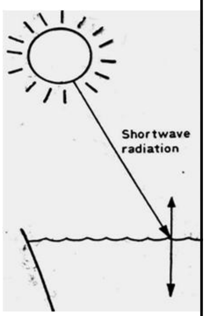


Short wave radiation, F_s

- Wave length below 2 mikrom (visible light: 0.39 mikrom…0.74 mikrom)
- Flux on earth surface is dependent zenith angle of sun and atmospheric conditions (humidity, dustiness, cloudiness)
- In Finland highest daily means are O(600) Wm^{-2}
- At Equator the flux is about double to our values

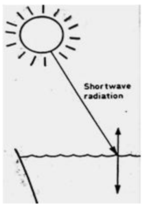
Short wave radiation on water surface

- Is partly reflected
- Reflection is dependent on incoming angle (between surface normal and incoming beam) and surface properties (turbidity, roughness)
- If angle is large the reflection is larger as in the case of small angle
- Albedo: (intensity of reflected short wave radiation)/(intensity of incoming short wave radiation)
- Examples of albedo values: Water surface: 0.03-0.40, Snow: 0.40-0.85, Dense forest: 0.10-0.15



Penetration of short wave radiation

$$F_{si} = F_{s0} e^{-zK_e}$$



- Decays exponentially with depth
- Decay is dependent on absorption and scattering from particles like plankton, suspended solids…
- Absorption is dependent on water colour
- Longer waves penetrate deeper
- Decays mostly during the first 10-20 m from the lake surface

In FINNECO-model:

$$K_e = \alpha_0 + \gamma_0 \frac{SS_t - SS_0}{n}$$

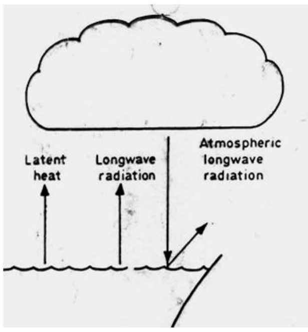
K_e=extinction coeff.

α_0=extinction coeff. when no suspended substances in water γ_0=shelf shading coeff. of suspended matter

$SS_{t,0}$= concentration of suspended matter at moment t and in the beginning of calculation (0)

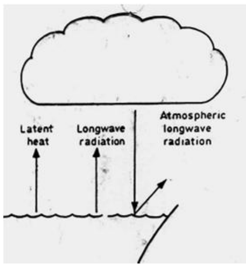
n=amount of water layers, where suspended matter is found

Incoming long wave radiation, F_1(down)



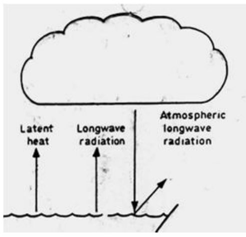
- Wave length 2 mikrom….20 mikrom
- Originally from sun, then absorbed by clouds, atmosphere and buildings …
- They are emitting according Stefan – Bolzman equation (eq. given later)
- Cloudiness correction
- Stable heat source around the year
- Max. daily means by us about 450 Wm^{-2}
- Is absorbed very near the water surface, within 10 cm.

Long wave back radiation from water F_1(up) and sensible heat flux, F_c



- F_1(up)
  - Reflected part and part emitted as black body
  - Reflected is only about 3 % from incoming and its daily values range to 5…15 Wm^{-2}
  - Emitted long wave back radiation is in maximum about 250…500 Wm^{-2} (daily average)
  - Important especially in late summer and also in autumn
- F_c
  - Can be directed +/-
  - Direct heat conduction between air and water masses
  - Depends on water temperature difference between air and water, wind velocity and transfer coefficient
  - By us daily values are –70…200 Wm^{-2}

Latent heat flux (F_l) and other components



- Latent heat flux (heat used in evaporation or released in condensation)
  - Dependent on difference between the prevailing water vapour pressure and saturation vapour pressure as well as wind velocity
  - By us the values range to –50…350 Wm^{-2}
- Other components
  - Heat from or to river waters. Important only in lakes with a short retention time
  - Heat from ground water. Important in small lakes within eskers
  - Sediment heat flux. Heat is absorbed in summer, released in winter. Important in shallow muddy lakes. Values range to 1…3 Wm^{-2}.

Potential energy vs. kinetic energy

- Heat is accumulated near the lake surface
- Vertical mixing is the process leading the heat down to water body
- Mixing can be caused by currents. Most important are wind induced and convective currents
- In warming up the thermal energy of the water parcel is increased
- Water stability is a measure to express the mixing resistance of certain water body
- Wind work is the amount of energy to mix the water body to certain depth

Stratification calculation options

- Adsoprtion models (Dake&Harleman), mixing only due to the convection
- Energy balance models. Potential energy of the water body is compared to the kinetic energy of the wind (Klaus&Turner)
- Models based on the turbulent eddy diffusivity (Spalding&Svensson, Baumert, …)
- Combinations of models of previously mentioned types

Solution principles of temperature models

- Calculate heat fluxes at the upper and lower boundaries
- Calculate the heat fluxes of the river water (in and out)
- Calculate the penetration of the short wave fluxes
- Solve the density (=state) equation (equation given later)
- Apply vertical mixing
- Calculate the ice formation or melt

Equations in PROBE-model, F_s

$$F_s = (1-a)S_0 \cos z (T_r - A_w)\prod_{i=1}^{3}(1-N_i(-T_i))$$

$$A_w = 0.077(u \sec z)^{0.3}$$

$$T_r = 1.041 - 0.16(\sec z)^{0.5}$$

$$T_{low} = 0.35 - 0.015 \sec z$$

$$T_{middle} = 0.45 - 0.01 \sec z$$

$$T_{high} = 0.9 - 0.04 \sec z$$

$$\sec z = (\cos z)^{-1}$$

a=albedo

A_w= absorption by the water vapor (low, middle, high).

S_0=solar constant, 1395 Wm^{-2}

T_r= scattering-transmission function= f(z)

u= amount water in the air mass

z=solar zenit angle

N_i= Ni is the amount of clouds of the different categories

T_i= cloud function

Equations in PROBE-model, Net long wave radiation F_1

$$F_1 = F_1 \uparrow - F_1 \downarrow$$

$$F_1 \uparrow = \varepsilon' \sigma T_s^4$$ == Stefan-Bolzman type equation

$$F_1 \downarrow = \sigma T_a^4 (c + b\sqrt{e_a})(1 + dN)$$

ε'= emissivity of the lake water =0.97

σ=Stefan-Bolzman constant=5.67*10^{-8} Wm^{-2} K^{-4}

T_s=lake water surface temperature (^{0}K)

T_a= air temperature (^{0}K)

e_a= water vapour pressure in air (mb) = f(temperature and humidity)

N= cloudiness

c,b ja d = constants

Equations in PROBE-model Sensitive heat flux, F_c

$$F_c \downarrow\uparrow = \rho_a C_p \overline{U}(C_{c1} - C_{c2}(T_s - T_a))$$

$$S_t = \overline{U}(T_s - T_a)$$

ρ=air temperature, kg $m^{-3,}$ Cp=specific heat of water =4200 J kg^{-1} ,U= wind velocity m s^{-1} S_t= air stability, C_{c1}, C_{c2} = are sensible heat transfer, which depend on air stability

In stable conditions (S_t<0) C_{c1} = 0.0026 and C_{c2} =0.86E^{-3}

In unstable conditions (0<S_t<25), C_{c1} = 0.002 and C_{c2} =0.97E^{-3}

Very unstable conditions (25<S_t), C_{c1} = 0.0 and C_{c2} =1.46E^{-3}

Equations in PROBE-model…

Latent heat flux, F_e

$$F_l \downarrow = LC_e\overline{U}(Q_w - Q_a)$$

Total heat flux

$$F_N = F_1 + F_c + F_e$$

L= the latent heat of evaporation,

Ce =the moisture transfer coefficient

Qw and Qa = the water vapor densities close to the water surface and in the atmosphere respectively.

PROBE: Heat equation and vertical mixing

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\frac{\nu_T}{\sigma_T}\frac{\partial T}{\partial z}\right) + S_T$$

$$\nu_T = \frac{C_\nu \rho k^2}{\varepsilon}$$

Boundary condition at the upper boundary

$$\frac{\nu_T \partial T}{\sigma_T \partial z} = \frac{F_N}{\rho C_p}$$

ν_T= eddy diffusivity (= > this is a turbulent model)

σ_T=turbulent Prandtl number= ν/γ

ν=kinematic viscosity

γ=heat conductivity

k=kinetic turbulent energy

ε=dissipation of turbulent energy

C_ν=empirical constant

Experiences about PROBE-model

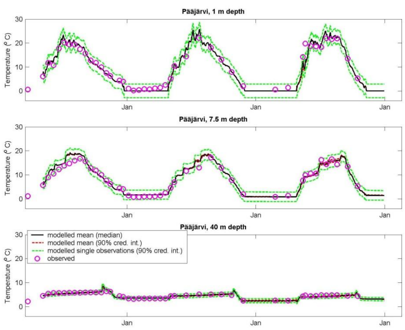
- Case study: Huttula ym. 1994 ..\..\..\..\TH_artikkeleja\Effects of Climate Change....pdf
- Good results in scales from days…to years
- Water balance well calculated
- Ice formation and decay well calculated
- Heat exchange coefficients need to be calibrated for some lakes
- Hypolimnetic temperatures too low sometimes 🡐 vertical mixing too small in model
- Sheltering effects, effects of sediment quality and penetration of short wave radiation (extinction coefficients) need special attention

MyLake

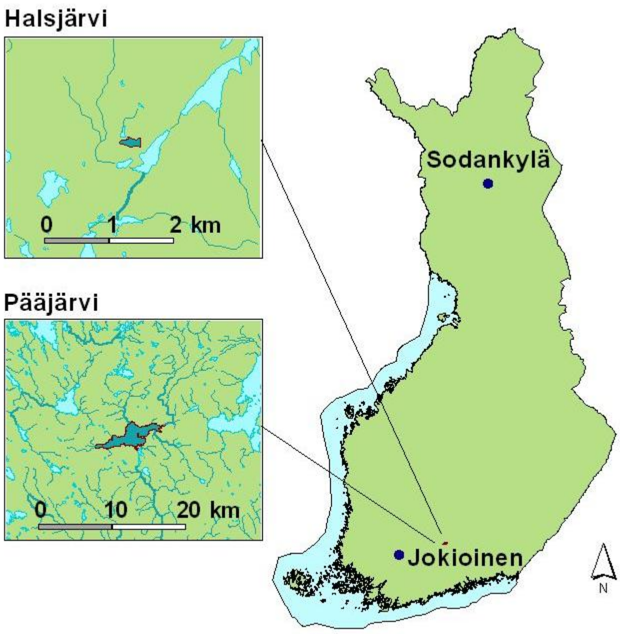
- One dimensional vertical lake model
- Andersson and Saloranta 2000
- Ice model by Leppäranta (1991) and Saloranta (2000)
- The vertical diffusion coefficient from the stability frequency N^2 (Hondzo and Stefan, 1993)
- Utilises the MATLAB *Air-Sea Toolbox* (http://sea-mat.whoi.edu/air_sea-html/) for calclulation of radiative and turbulent heat fluxes, surface wind stress and astronomical variables
- Vertical mixing is based on the energy calculation between kinetic energy from wind and potential energy of layer(s) to be mixed
- Recent MyLake applications:
  - Pulkkanen et al. 2010: Assessment of impacts and adaptation of fisheries production and wash off effects in Lake Päijänne
  - Pätynen, A., Elliott, J., Kiuru, P., Sarvala, J., Ventelä, A., & Jones, R. (2014). Modelling the impact of higher temperature on the phytoplankton of a boreal lake. *BOREAL ENVIRONMENT RESEARCH*, 19 (1), 66-78.
  - Holmberg, Maria, et al. "Effects of changing climate on the hydrology of a boreal catchment and lake DOC--probabilistic assessment of a dynamic model chain." Boreal Environment Research, vol. 19, 2014, p. 66+. Academic OneFile, Accessed 17 Nov. 2016.

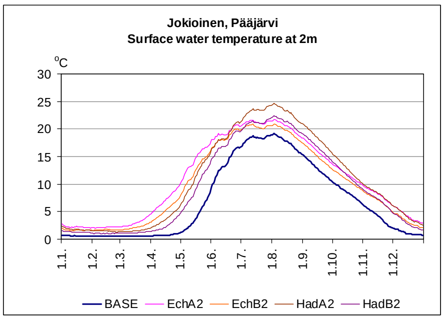
FINESSI-project

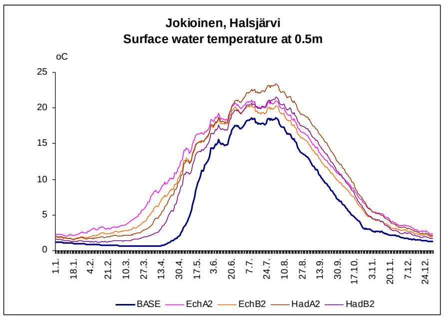
May 2000-Dec 2002

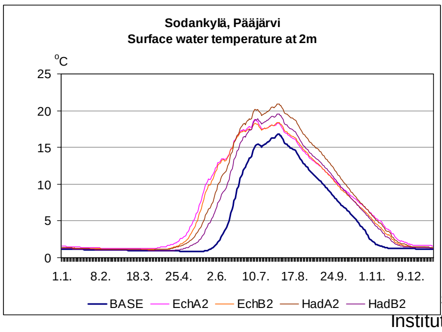


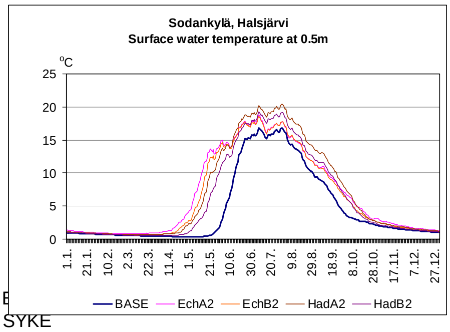
- Web tool for assessing the effects of global chage in Finland www.finessi.info/finessi
- Lake Pääjärvi (area= 13.5 km^2 , max depth= 87 m) and Halsjärvi (area= 0.5 km^2 , max depth= 6 m)
- Meteorological data from Jokioinen
- Calibration results for Pääjärvi were very good
- FINESSI uses 6 GCM-models Link
  - We Echam and Hadley Center



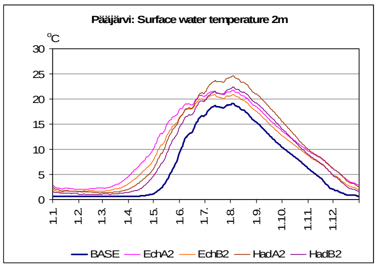

Jokioinen, Pääjärvi
Surface water temperature at 2m
°C
BASE EchA2 EchB2 HadA2 HadB2

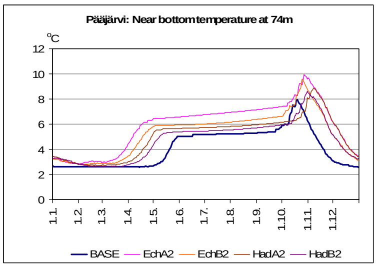

Jokioinen, Halsjärvi
Surface water temperature at 0.5m
oC
BASE EchA2 EchB2 HadA2 HadB2

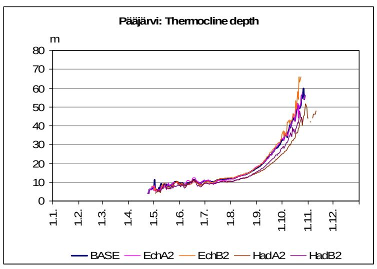

Sodankylä, Pääjärvi
Surface water temperature at 2m
°C
BASE EchA2 EchB2 HadA2 HadB2

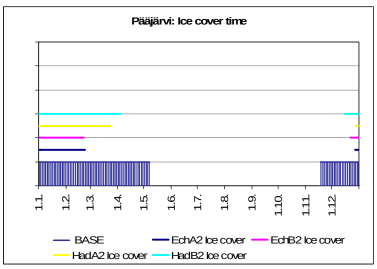

Sodankylä, Halsjärvi
Surface water temperature at 0.5m
°C
BASE EchA2 EchB2 HadA2 HadB2

Jokioinen

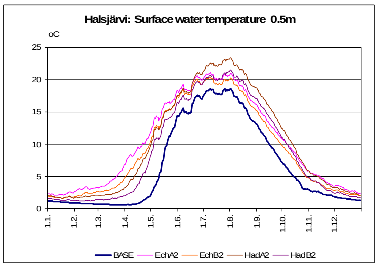

Pääjärvi: Surface water temperature 2m
°C
BASE EchA2 EchB2 HadA2 HadB2

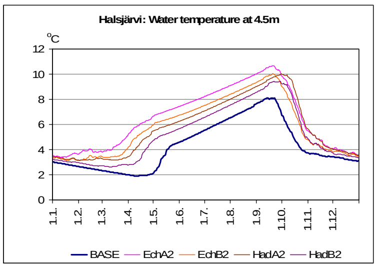

Pääjärvi: Near bottom temperature at 74m
°C
BASE EchA2 EchB2 HadA2 HadB2

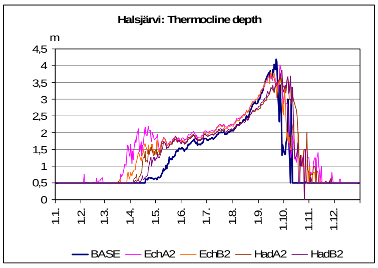

Pääjärvi: Thermocline depth
m
BASE EchA2 EchB2 HadA2 HadB2


Pääjärvi: Ice cover time
BASE EchA2 Ice cover EchB2 Ice cover
HadA2 Ice cover HadB2 Ice cover

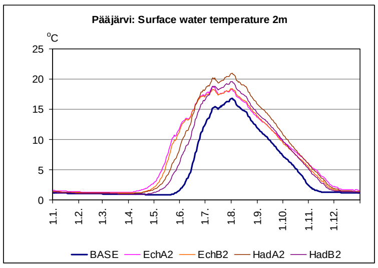
Jokioinen

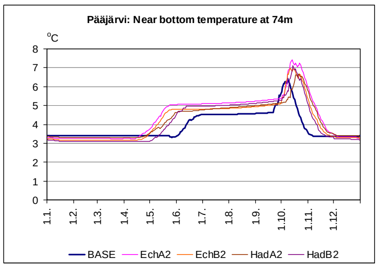


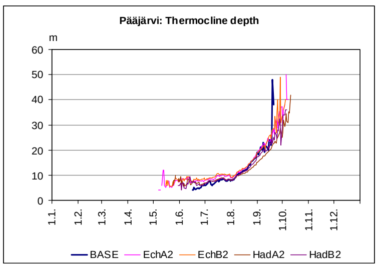


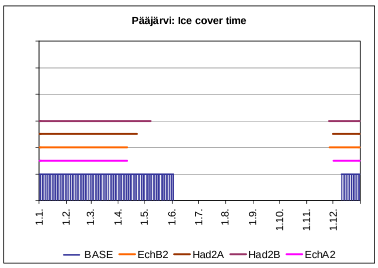


Sodankylä

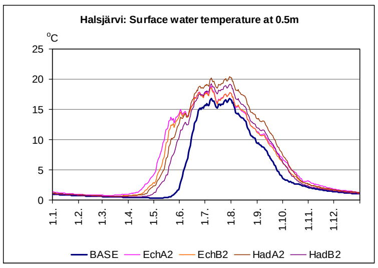




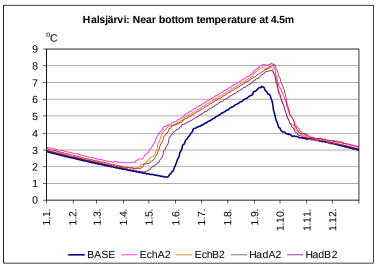




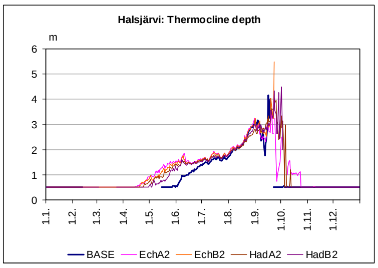
Sodankylä



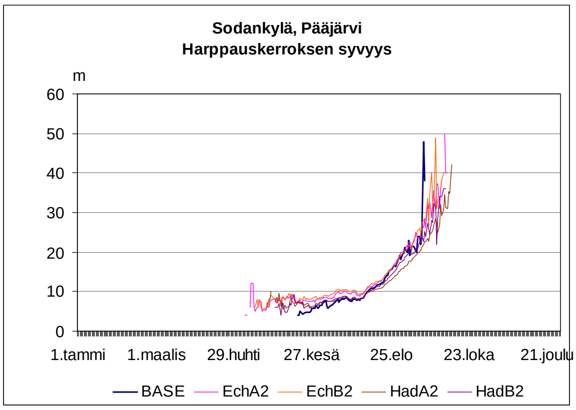
Halsjärvi: Surface water temperature at 0.5m
°C
BASE EchA2 EchB2 HadA2 HadB2



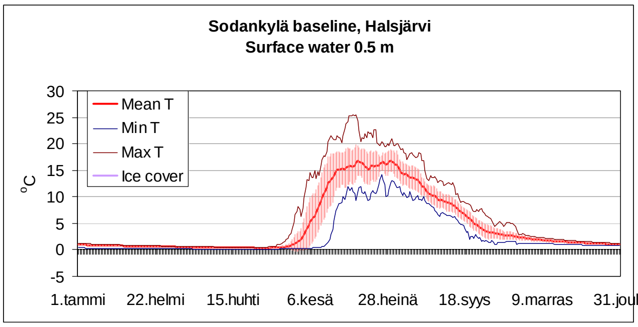
Halsjärvi: Near bottom temperature at 4.5m
°C
BASE EchA2 EchB2 HadA2 HadB2

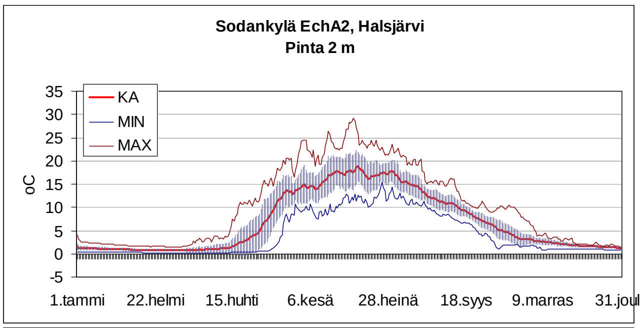


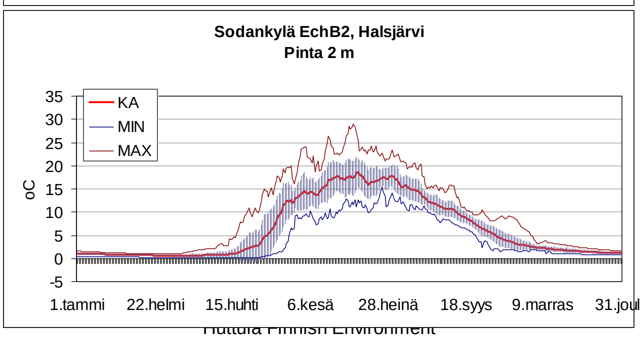
Halsjärvi: Thermocline depth
m
BASE EchA2 EchB2 HadA2 HadB2

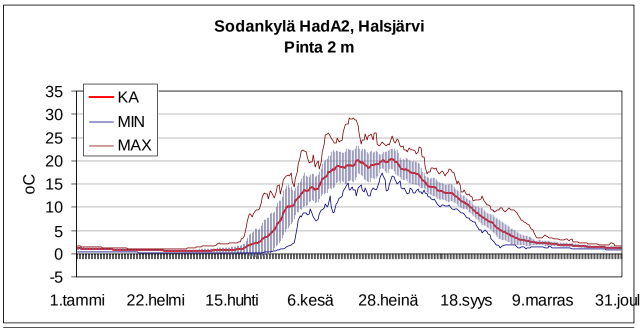


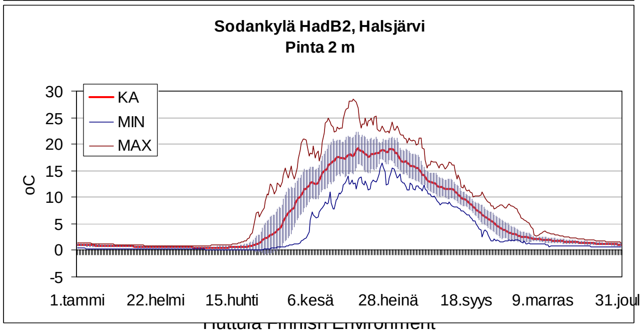
Sodankylä, Pääjärvi
Harppauskerroksen syvyys
m
1.tammi 1.maalis 29.huhti 27.kesä 25.elo 23.loka 21.joulu
BASE EchA2 EchB2 HadA2 HadB2

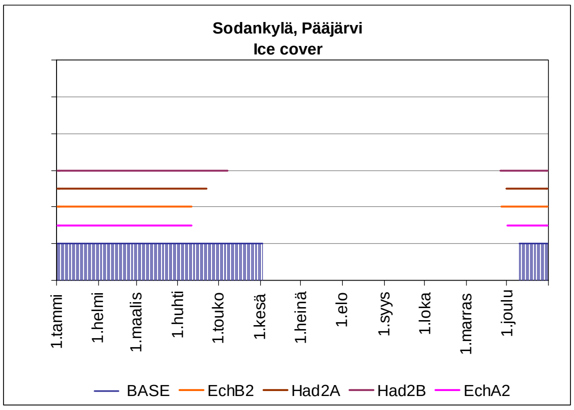

Sodankylä baseline, Halsjärvi
Surface water 0.5 m
°C
30
25
20
15
10
5
0
-5
Mean T
Min T
Max T
Ice cover
1.tammi
22.helmi
15.huhti
6.kesä
28.heinä
18.syys
9.marras
31.joul


Sodankylä EchA2, Halsjärvi
Pinta 2 m
oC
35
30
25
20
15
10
5
0
-5
KA
MIN
MAX
1.tammi
22.helmi
15.huhti
6.kesä
28.heinä
18.syys
9.marras
31.joul


Sodankylä EchB2, Halsjärvi
Pinta 2 m
oC
35
30
25
20
15
10
5
0
-5
KA
MIN
MAX
1.tammi
22.helmi
15.huhti
6.kesä
28.heinä
18.syys
9.marras
31.joul


Sodankylä HadA2, Halsjärvi
Pinta 2 m
KA
MIN
MAX
oC
35
30
25
20
15
10
5
0
-5
1.tammi
22.helmi
15.huhti
6.kesä
28.heinä
18.syys
9.marras
31.joul


Sodankylä HadB2, Halsjärvi
Pinta 2 m
KA
MIN
MAX
oC
30
25
20
15
10
5
0
-5
1.tammi
22.helmi
15.huhti
6.kesä
28.heinä
18.syys
9.marras
31.joul


Sodankylä, Pääjärvi
Ice cover
1.tammi
1.helmi
1.maalis
1.huhti
1.touko
1.kesä
1.heinä
1.elo
1.syys
1.loka
1.marras
1.joulu
BASE
EchB2
Had2A
Had2B
EchA2

Related literature

1. Huttula T., Peltonen A., Bilaletdin Ä., Saura M., 1992: The effects of climatic change on lake ice and water temperature. Aqua Fennica Vol. 22,2. Linkki