FLake in SURFEX

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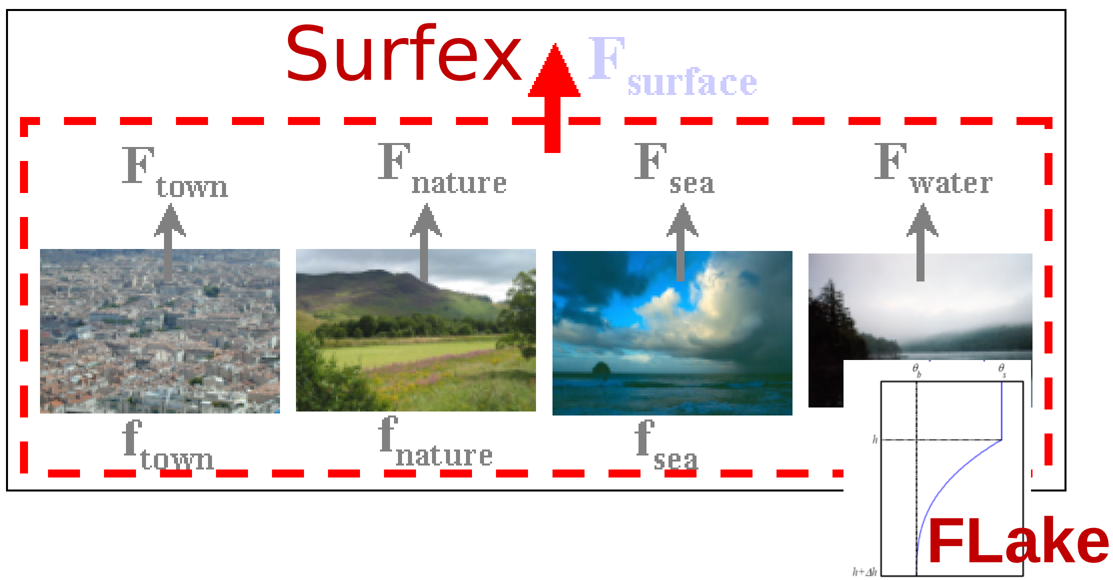

- FLake model:
  - Mironov D.V. 2008: Parameterization of lakes in numerical weather prediction. Description of a lake model. *COSMO Technical Report* 11, Deutscher Wetterdienst, Offenbach am Main, Germany, 41 pp.

- FLake implementation in SURFEX
  - Salgado, R. and Le Moigne, P., 2010: Coupling of the FLake model to the Surfex externalized surface model, Boreal Env. Res., 15, in press

- In this presentation some slides were adapted from:
  - Mironov,D., Heise, E., Kourzeneva, K., Ritter, B., Schneider, N. and Terzhevic, 2008: FLake – A Lake Parameterisation Scheme for Numerical Weather Prediction and Climate Models, presented at Lake08 workshop

Plan

- Why lake schemes in numerical weather prediction models?
- The lake model FLake
  - The Concept of Self-Similarity of the Temperature Profile in the Thermocline
  - FLake concept
  - FLake Equations
  - Prognostic variables and parameters
- Implementation of FLake in SURFEX
- How to use FLake in SURFEX
  - PREP_PGD
  - PREP_REAL
  - RUN
  - DIAG
- Future work

Why lake schemes in numerical weather prediction models?

- Lakes affect the structure of the atmospheric boundary layer and the weather on a variety of scales, depending on the dimensions and shapes of the lakes, and the prevailing synoptic situation
- The surface heat fluxes over lakes depend significantly on the water surface temperature.

- Global coverage of inland water does not exceed 2%
- The past generation of mesoscale and weather forecast models doesn't include an explicit representation of the evolution of lake temperature, which is most of the time maintained constant over the integration period.

Why lake schemes in numerical weather prediction models?

- Some regions can be highly influenced by the presence of lakes
  - The boreal zone (9.2% of the area of Sweden and 10% of the area of Finland are covered by lakes)
  - Eastern Africa and of the American Great Lakes region
  - In the Mediterranean region, dams and reservoirs have been constructed.

An accurate prescription of lake surface temperatures becomes more important as the horizontal resolution of the weather forecast models increases.

Lake Regions: Finland, Karelia

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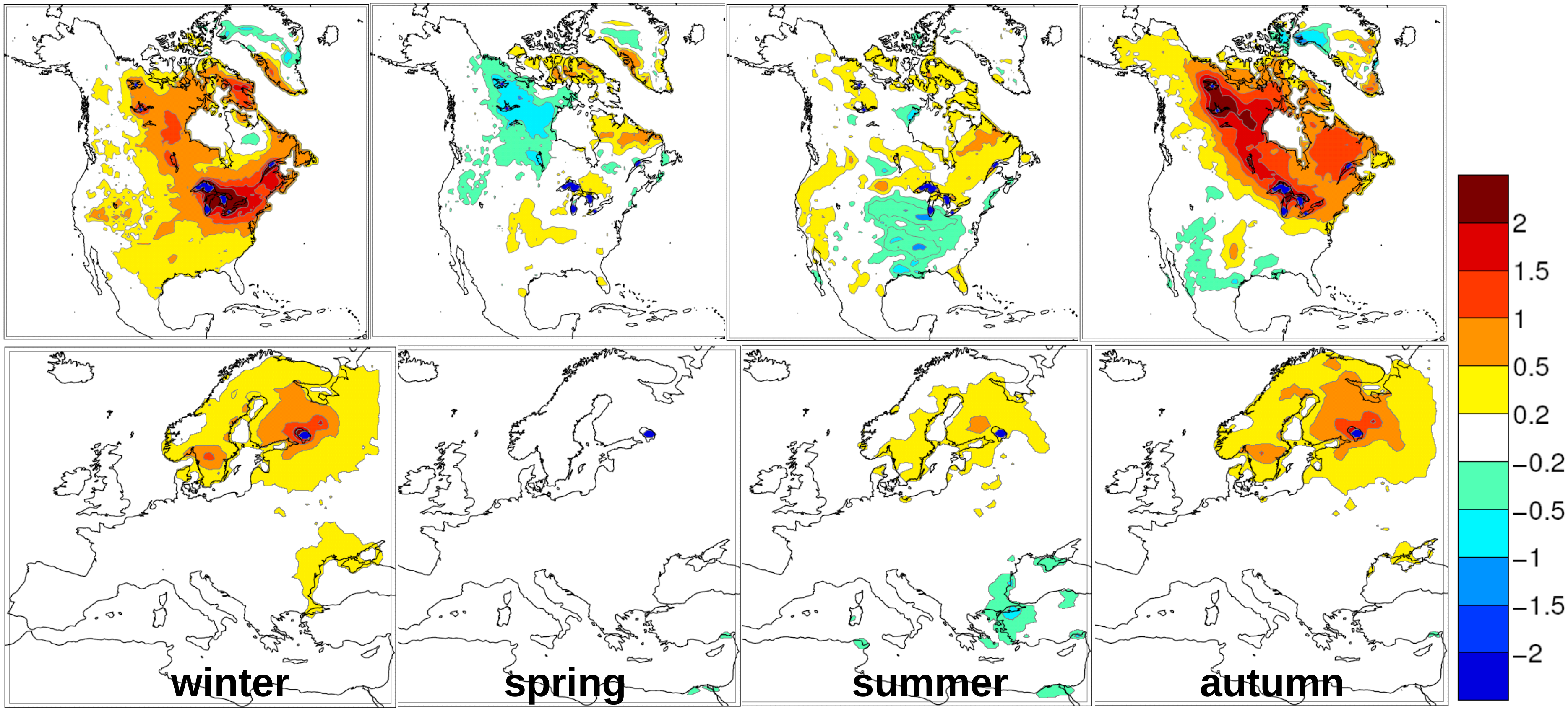
Toujours un temps d'avance

Why lake schemes in numerical weather prediction models?

2m-air-temperature for (lake version) – (no lake version):



Samuelsson et al. (2010): The impact of lakes on the European climate as simulated by a regional climate model, Boreal Env. Res., in press

Possible Lake Parameterisation Schemes

- Full 3D lake models, like ocean models. Very expensive computationally
- Multi-layer 1D models.
  - K-models with convective adjustment
  - TKE evolution - 1.5 turbulence closure models

  Also, too expensive
- One-layer models. Don’t account for stratification. Large errors

- A compromise between physical realism and computational economy
  - **A two layer-model with a parameterised vertical temperature structure**

↓

FLake

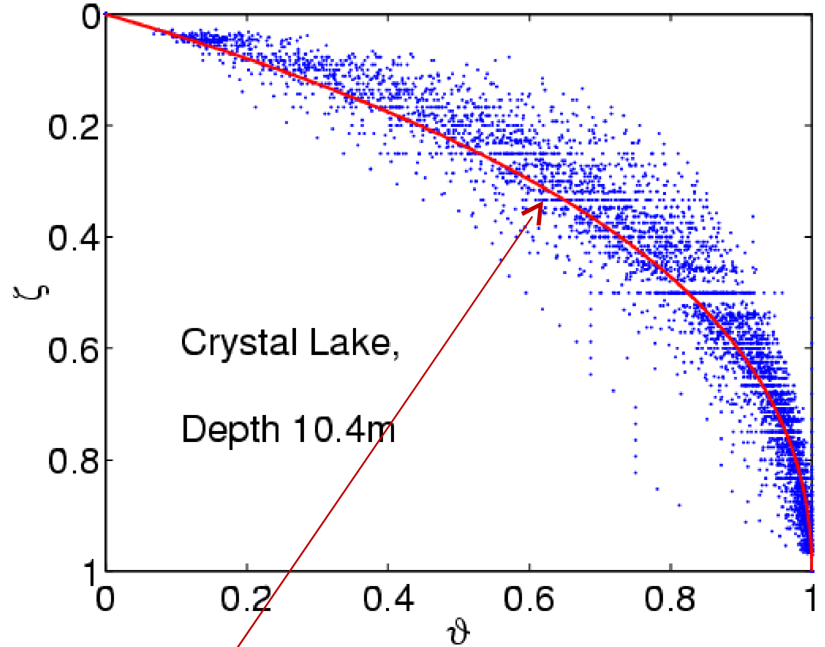
The Concept of Self-Similarity of the Temperature Profile

- 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:

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

$\Phi(\varsigma)$ is an "universal" dimensionless function

4th order polynomial approximation



Dimensionless temperature profile in a lake thermocline. An example from Kirillin (2002)

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The FLake model: Water temperature profile

- Water temperature profile:

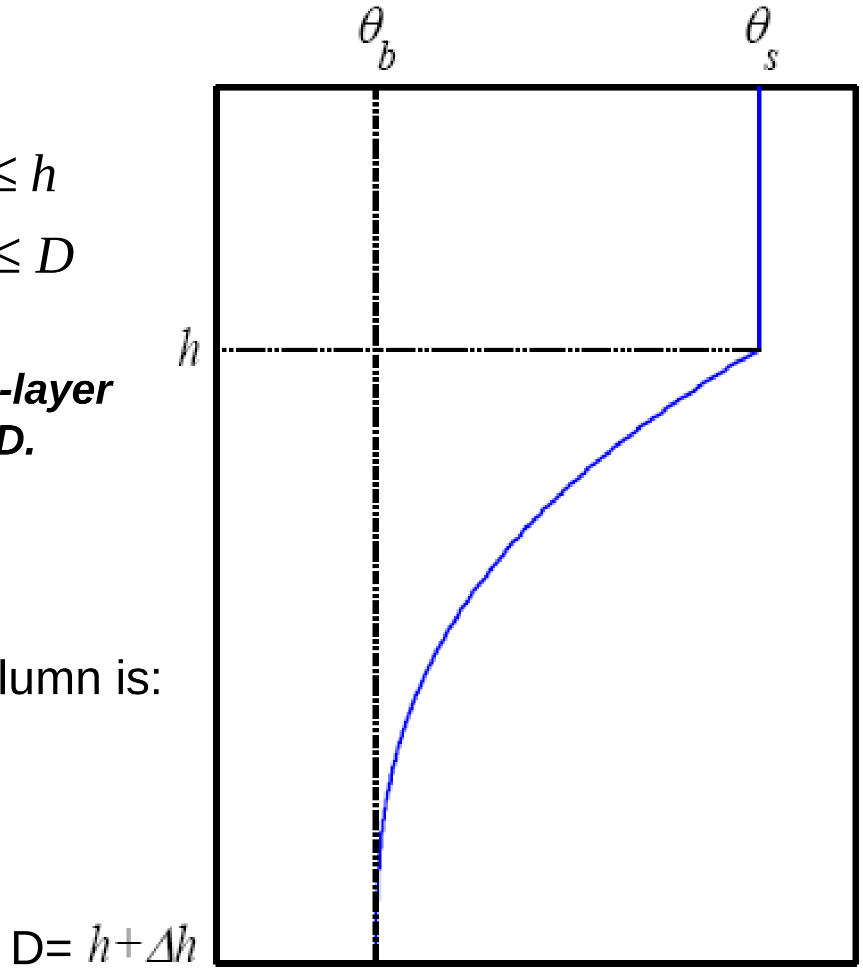
$$\theta(z,t)=\begin{cases}\theta_s & at\ 0\le z\le h\\ \theta_s-(\theta_s-\theta_b)\Phi(\varsigma) & at\ h\le z\le D\end{cases}$$

The thermocline extends from the mixed-layer outer edge z = h to the basin bottom z = D.

If we define: $C_T=\int_0^1\Phi(\varsigma)d\varsigma$

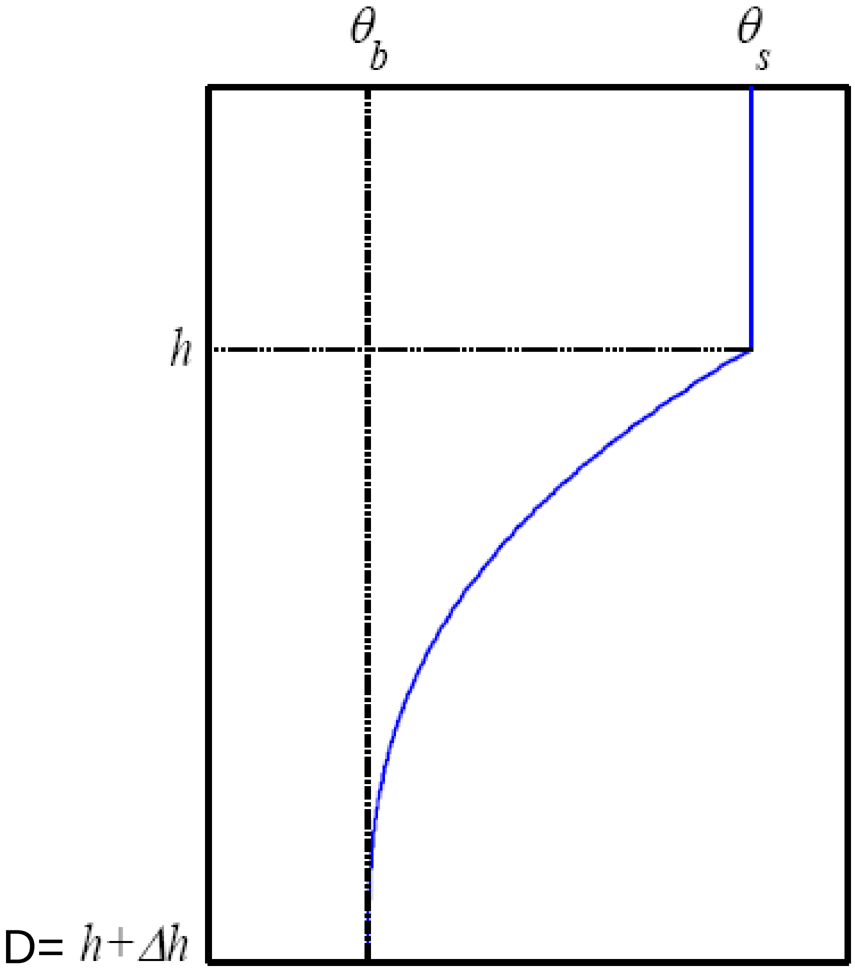
The mean temperature of the water column is:

$$\bar{\theta}=\theta_s-C_T(1-h/D)(\theta_s-\theta_b)$$



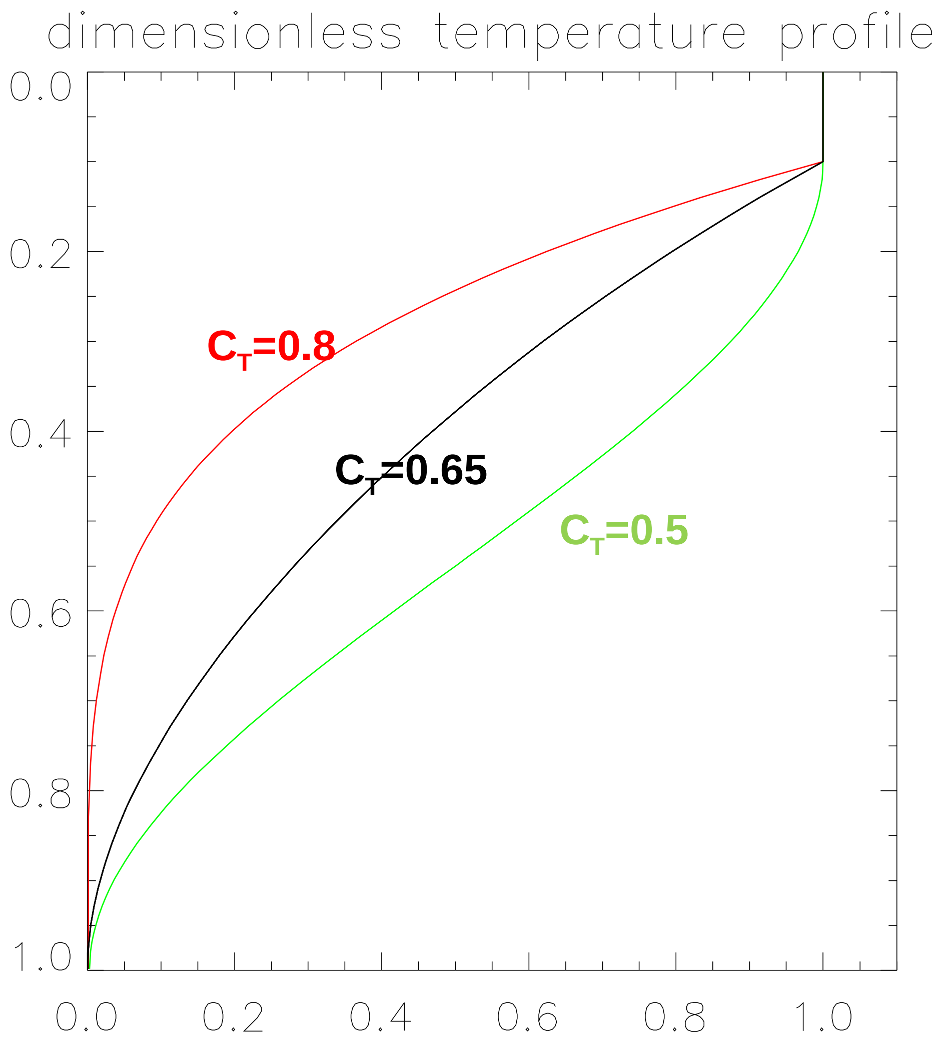
The FLake model: Water Variables

- Surface or mixed layer temperature, θ_s
- Bottom temperature, θ_b
- Mixed layer depth, h
- Shape factor, C_T
- Mean water temperature, $\overline{\theta}$
  - Only 4 independent



Comments on the shape factor

- The dimensionless temperature profiles lie in the area bounded by the green and the red curves.
- During the mixed-layer deepening, dh/dt > 0, the temperature profile evolves towards the limiting curve, where $C_T = C_{max} = 0.8$
- During the mixed-layer stationary state or retreat, dh/dt ≤0, the temperature profile evolves towards the green curve, where Cmin= 0.5
- Cmin = 0.5 is consistent with a linear temperature profile that is assumed to occur under the ice



FLake prognostic equations (1,2)

(1) ▪ Conservation of energy applied to the water column

– Prognostic equation for mean water temperature:

$$D\frac{d\overline{\theta}}{dt} = \frac{1}{\rho_w c_w}\left[Q_s + I_s - Q_b - I(D)\right]$$

(2) ▪ Conservation of energy applied to the mixed layer

– Prognostic equation for mixed layer temperature:

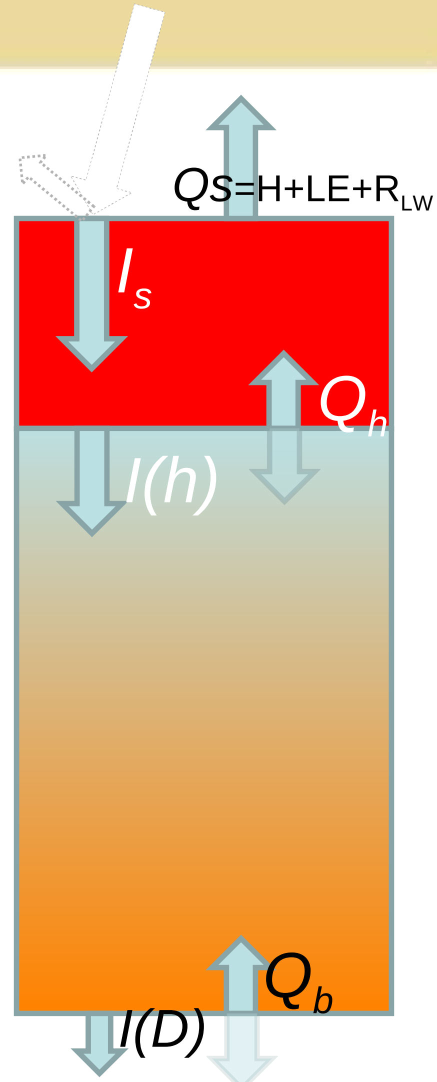
$$h\frac{d\theta_s}{dt} = \frac{1}{\rho_w c_w}\left[Q_s + I_s - Q_h - I(h)\right]$$

c_w is the specific heat of water

Q_s is the heat flux at air-water interface (latent + sensible + long-wave radiation)

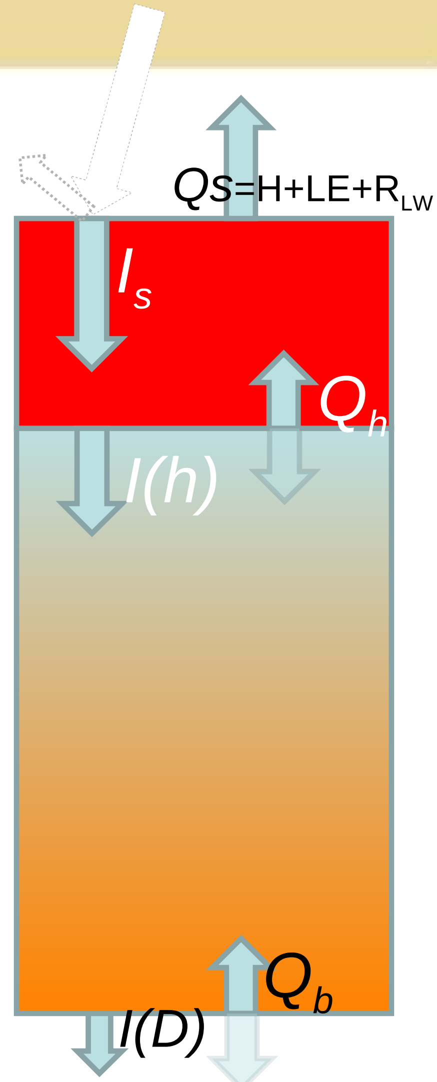
I_s , *I(D), I(h)* are the short-wave radiation flux, respectively at lake surface, lake bottom and at mixed layer depth

Q_b Q_h are the heat flux through, respectively at the lake bottom and at the bottom of the mixed layer



FLake prognostic equations (1,2)

- To compute the short-wave radiative flux I_s
  - Know the short wave radiative flux (observations or model)
  - The albedo of the water surface, α
- To compute *I(D), I(h):*
  - Use the exponential approximation of the decay law for the flux of short-wave radiation with an:
  - Extinction coefficient of solar radiation in the water
    - Depends on the turbidity of the water
    - Different wavelength bands may be considered
- Q_h is computed
  - Assuming that the profile of the vertical turbulent heat flux in the thermocline can also be represented in a self-similar form.
- To compute Q_s, FLake need:
  - Air temperature and moisture, wind, downward long-wave flux (or all the fluxes computed by an atmospheric model)



Surface layer parameterization

- To compute Q_S, FLake need:
  - Air temperature and moisture, wind, downward long-wave flux
  - or all the fluxes computed by an atmospheric model
- FLake stand-alone version includes the atmospheric surface-layer parameterization scheme SfcFlx that is used to compute fluxes of momentum and heat at the air-water interface.

⇩

- The SfcFlx scheme is included in the SURFEX distribution
  - May be used as an option to the SURFEX own water flux scheme

(some useful comments can be found directly in the source code of SfcFlx)

FLake prognostic equations (3,4)

(3) ▪ The evolution of h is computed using a sophisticated formulation, that treats both convective and stable regimes and accounts for the vertically distribution of the radiation heating.

- In convective case, the convective mixed-layer depth h is computed by an entrainment equation.
- Under stable and neutral stratification, the wind-mixed layer depth h is computed by a relaxation-type equation.

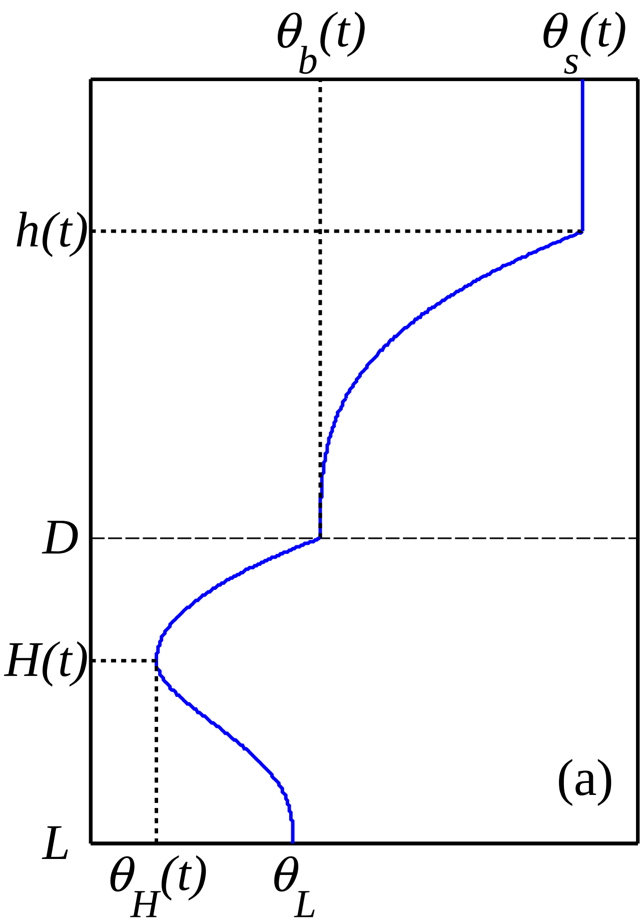
(4) ▪ The evolution of the shape factor C_T is computed using a relaxation type rate equation with a relaxation time, t_{rc} which is proportional to the square of the thermocline thickness $(D - h)^2$.

$$\frac{dC_T}{dt} = sign\left(\frac{dh}{dt}\right)\frac{C_{max} - C_{min}}{t_{rc}}$$

So, we have 4 equations for 4 prognostic variables

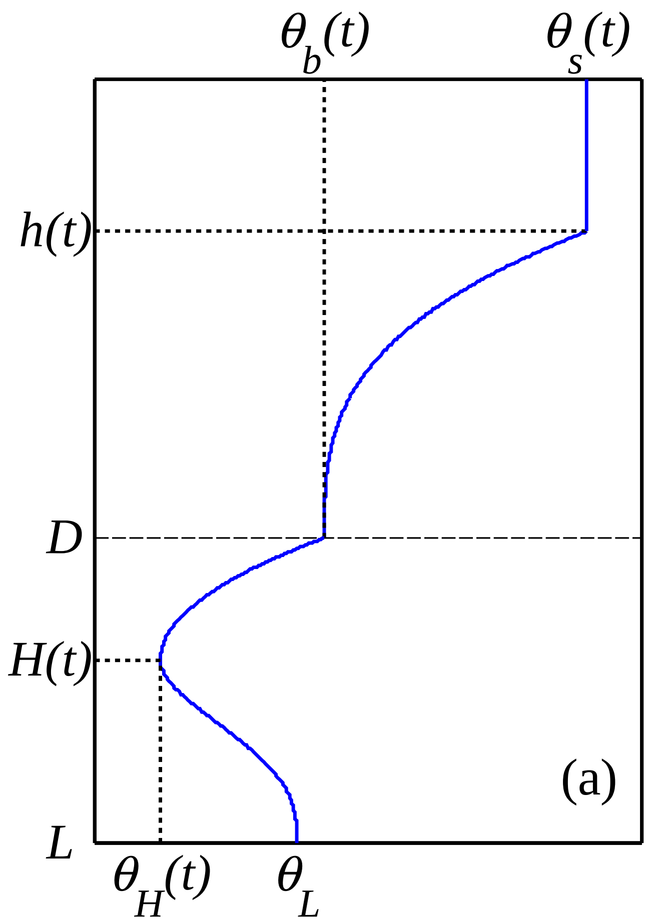
Bottom sediments

- In order to compute Q_b
- FLake includes also an optional module that describes the vertical temperature profile of the thermally active layer of bottom sediments.
- The approach is based on a two-layer self-similar parametric representation of the sediments thermal profile, conceptually similar to the representation of the temperature profile in the thermocline
- Important in shallow lakes, where it is a strong thermal interaction between the water body and the bottom sediments.



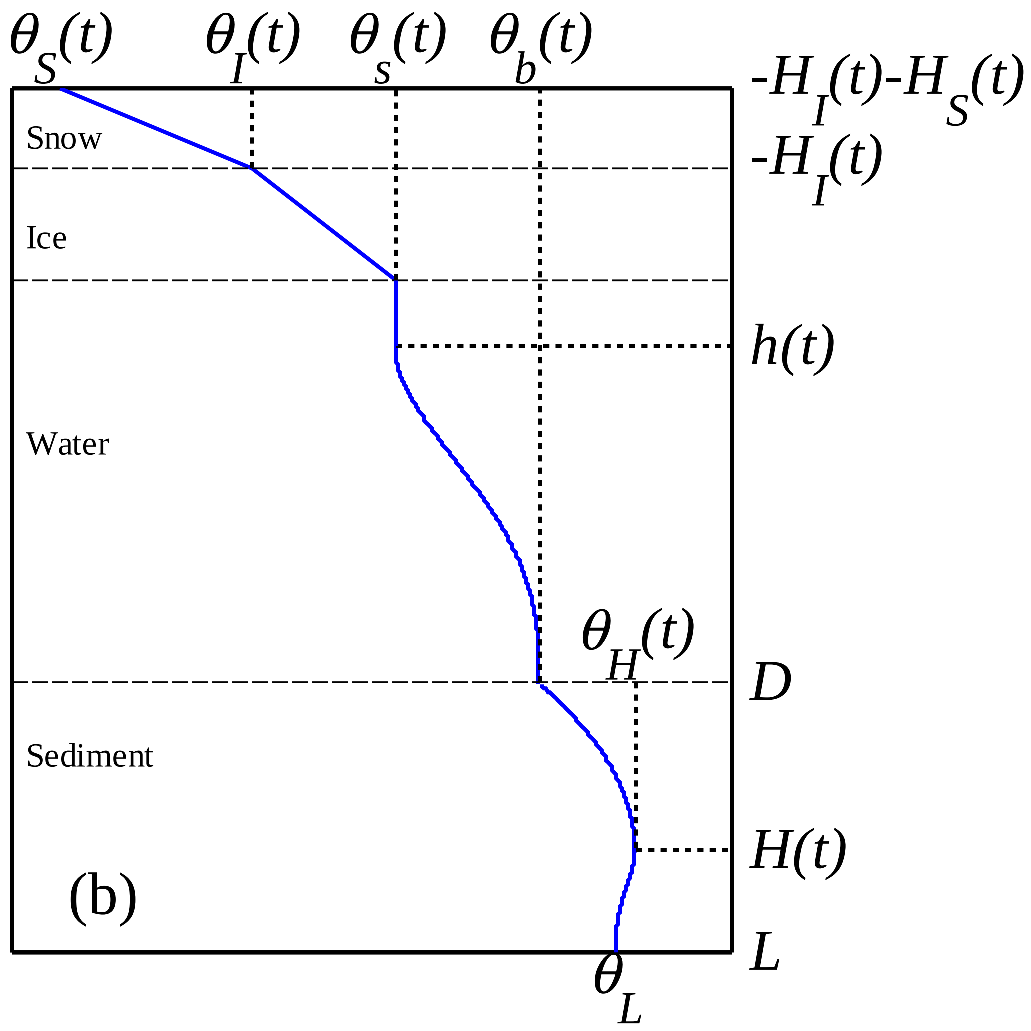
Bottom sediments

- Prognostic variables:
  - The depth within bottom sediments penetrated by the thermal wave *H*
  - The temperature at that depth θ_H
- Parameters:
  - The temperature at the outer edge of the thermally active layer of bottom sediments, θ_L
  - The depth of the thermally active layer of bottom sediments, *L*



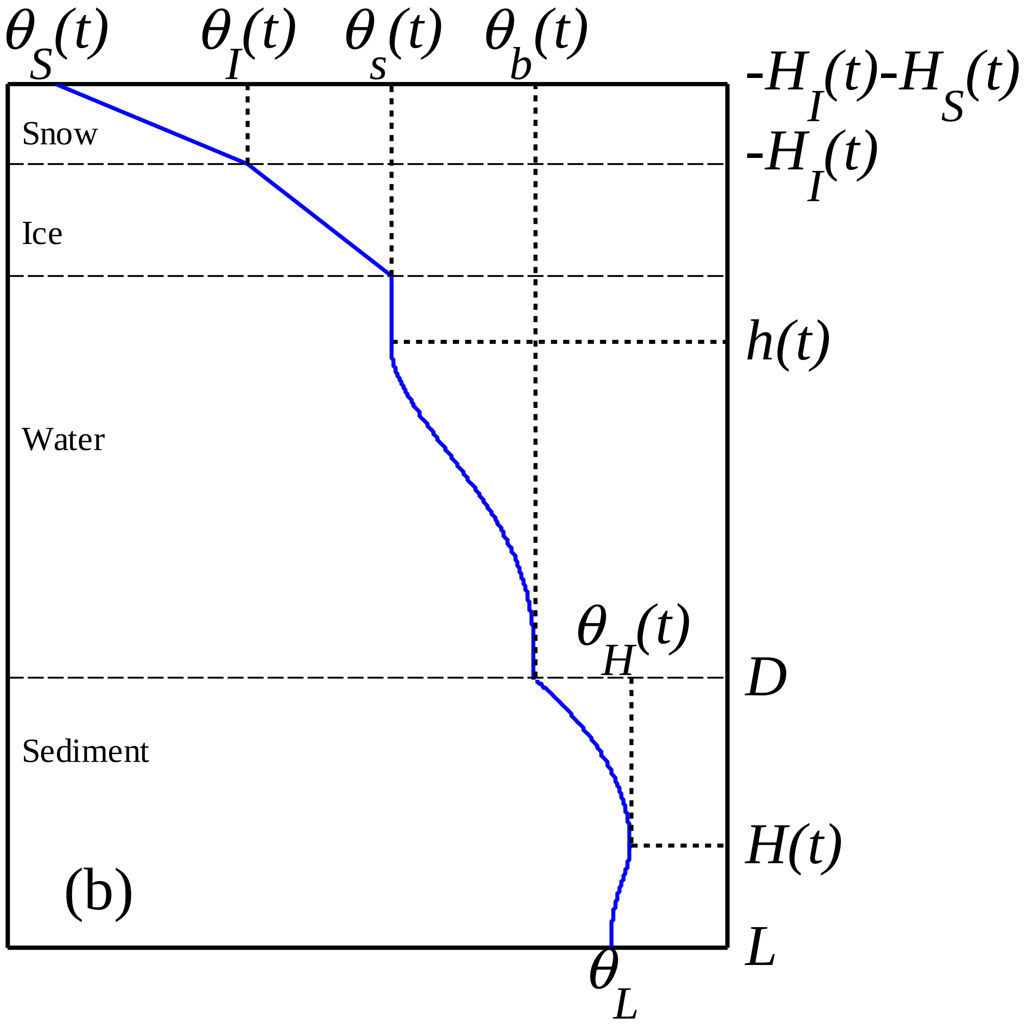
Ice and snow

- In Winter, in case of ice-covered lake, 4 additional prognostic variables are computed:
  - Ice depth,
  - Temperature at the ice upper surface,
  - snow depth
  - Temperature at the snow upper surface.
- Once more, it use a self-similar parametric representation of the temperature profile within ice
- According to the authors, the snow module of FLake has not been sufficiently tested and may be not used at the moment.



Ice and snow

- Note: The Ice and snow modules are included in SURFEX, but have not been tested.



Surfex implementation of FLake

- As possible, keep the FLake code as it is (http://lakemodel.net), to be able to introduce FLake upgrades . Note that the code is not in the SURFEX norms
- Minor changes made in the computation of the shape function in order to adapt the FLake model to warm lakes
- An interface (flake_interface.f90) to communicate with SURFEX was writen.
- FLake code is prepared for single-column applications. So, the flake_interface calls the flake routines inside a DO loop over the horizontal grid points where lakes are present.
- The coupling is explicit.
- The fluxes are computed before the advance of flake variables, namely of the Surface Temperature.
- The fluxes of momentum and of sensible and latent heat may be computed using the routines provided by FLake (SfcFlx routines) or by the SURFEX WATER_FLUX routine.
- All the routines for the pgd, prep and diag procedures have been modified in accordance.

Surfex implementation of FLake

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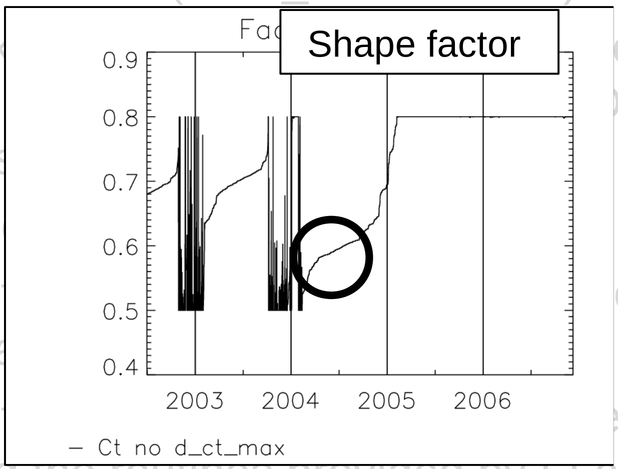
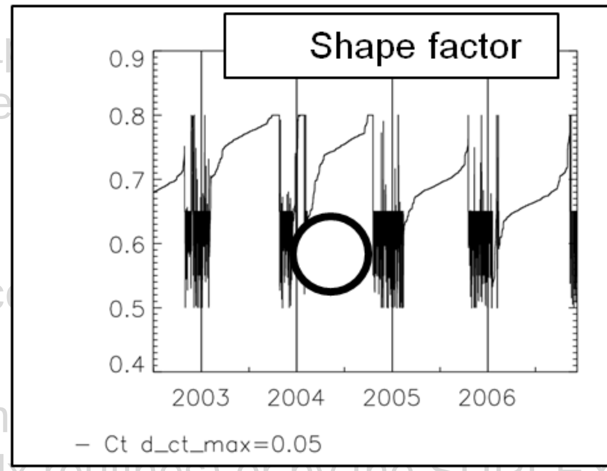




Not realist:
Force bottom temperature to decrease in spring, reaching the temperature of maximum density

Thermal evolution more realist

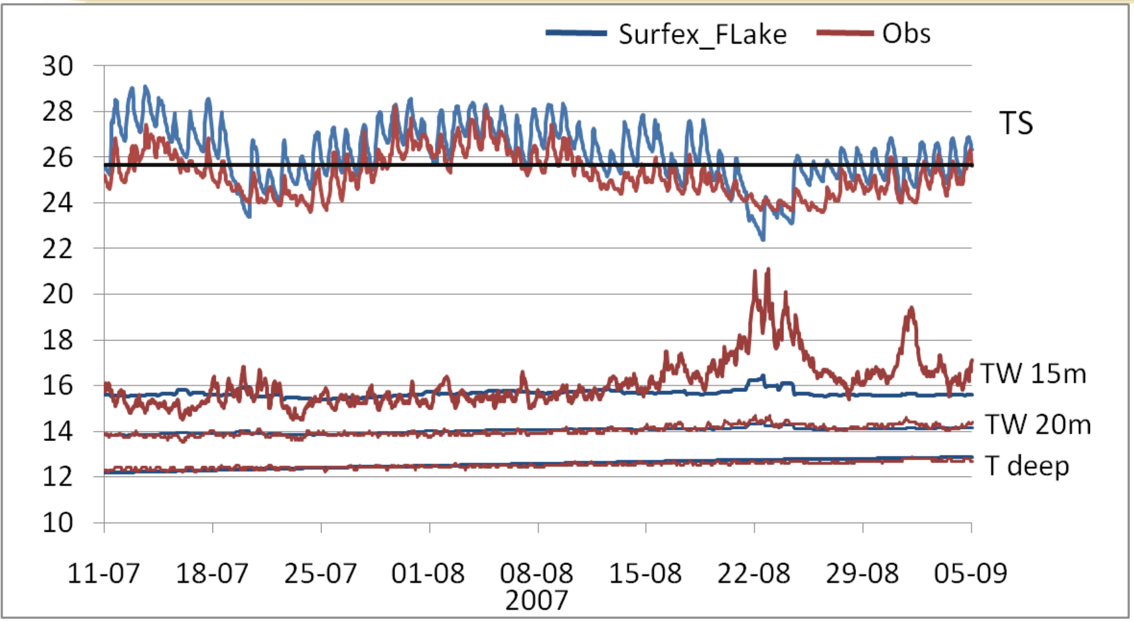
Validation of the coupled system Surfex-FLake

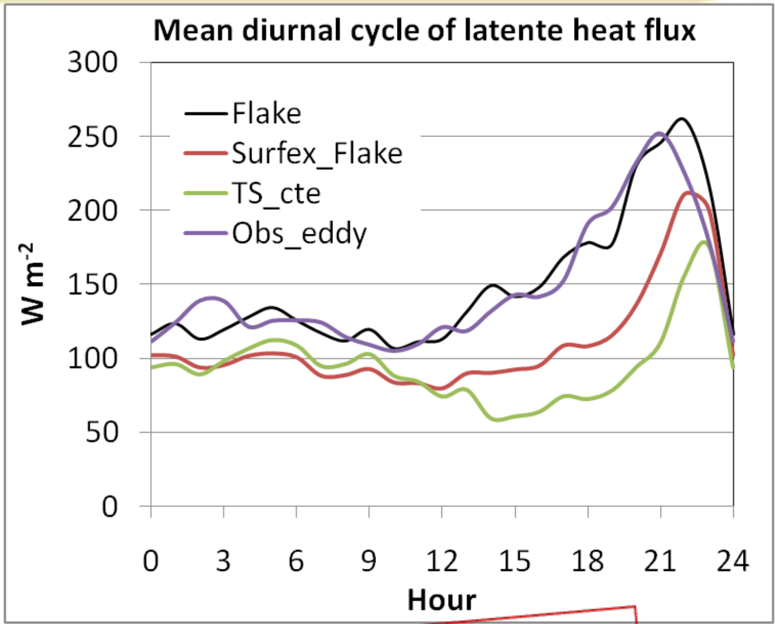
Data from Alqueva Field Experiment

- 10 July – 5 September 2007
- Sensible and latent heat fluxes with an eddy correlation system
  - Sonic Anemometer(metek)
  - Krypton Hygrometer (Campbell)
- Radiation:
  - Solar (up and down)
  - Long wave (up and down)

- Time series used in the tests:
  - Forcing (56 days):
    - T2m, q2m, v2m, Rs, Ratm
  - Data for validation
    - Tw_1m, Tw_15m, Tw_20m, Tw_deep
    - H (53 days)
    - LE (18 days)

Validation of the coupled system Surfex-FLake: 1D





3D simulations: on going

- TS: Good correlation; Bias -> TS_Mod > TS_Obs
- Good representation of deep temperature, bad representation of an late august episode of mixing layer deepening (3D process?)
- Impact of the lake model in LE Flux is visible and positive, in particular in late afternoon
  - *Flux Scheme of Flake accord better with the observations in this case*
- Salgado, R. and Le Moigne, P., 2010: Coupling of the FLake model to the Surfex externalized surface model, *Boreal Env. Res.*, **15**, *in press*

How to use FLake: prep_pgd step

- Namelis NAM_PGD_SCHEMES:

  CWATER = 'FLAKE ‘

  Initialization of constant parameters

- Namelist NAM_DATA_FLAKE

Fortran name	Default	Description	unit
XUNIF_WATER_DEPTH	20.	Lake Depth	(m)
YWATER_DEPTH	none	filename	
YWATER_DEPTHFILETYPE	none		
XUNIF_WATER_FETCH	1000	Typical Wind Fetch over Water	(m)
YWATER_FETCH	none	filename	
YWATER_FETCHFILETYPE	none		
XUNIF_T_BS	286	Temperature at the outer edge of the thermally active layer of the bottom sediments	(K)
YT_BS	none	filename	
YT_BSFILETYPE	none		
XUNIF_DEPTH_BS	1	Depth of the sediments layer	(m)
YDEPTH_BS	none	filename	
YDEPTH_BSFILETYPE	none		
XUNIF_EXTCOEF_WATER	3	Extinction coefficient of solar radiation in water	(m^{-1})
YEXTCOEF_WATER	none	filename	
YEXTCOEF_WATERFILETYPE	none		

How to use FLake: prep_real step

- namelist NAM_PREP_FLAKE

Fortran name	Default	Description	unit
XUNIF_TS_WATER	none	Lake surface (water, ice or snow) temperature	(K)
XUNIF_T_SNOW	273.15	Surface temperature of Snow	(K)
XUNIF_T_ICE	min(273.15,XTS_WATER)	Surface temperature at the ice-atmosphere or ice-snow interface	(K)
XUNIF_T_MNW	depends on XTS_WATER	Mean Water Column Temperature	(K)
XUNIF_T_BOT	depends on XTS_WATER	Water Temperature at the bottom of the lake	(K)
XUNIF_T_B1	depends on XTS_WATER	Temperature at the bottom of the upper layer of the sediments	(K)
XUNIF_H_SNOW	0.	Snow layer thickness	(m)
XUNIF_H_ICE	0. or 0.01(if XTS_WATER<273.15)	Ice layer Thickness	(m)
XUNIF_H_ML	3	Thickness of the water mixed layer	(m)
XUNIF_H_B1	0.3	Thickness of the upper level of the active	(m)
CFILE_FLAKE			
CTYPE			

How to use FLake: model run

- namelist NAM_FLAKEn

Fortran name	Values	Default	Description
LSEDIMENTS		.TRUE:	To use or not the bottom sediments scheme
CFLAKE_SNOW	“NON” FLAKE” “ISBA-ES”	“FLAKE”	Name of the snow scheme to use over lakes
LWATFLX		.FALSE.	Use WATER_FLUX to compute surface fluxes over water?

Not implemented

The default is to use ScfFlx routines

How to use FLake: diag step

- namelist NAM_DIAG_FLAKEn

Fortran name	Default	Description
LWATER_PROFILE	.FALSE:	flag used to compute and write the water temperature at given depths into the output file
XZWAT_PROFILE		depth of output levels (m)

Example:
LWATER_PROFILE = .TRUE.
XZWAT_PROFILE = 1. 5. 10. 10. /
Up to 20 depths are allowed

Future developments

- Tests, and more tests
- In particular, test momentum and heat fluxes at air-lake interface
  - Data series are needed
- **Lake database for use in mesoscale, NWP and Climate**
  - Depth (on going, Ekatherina Kourzenova)
  - Extinction coefficients
- Climatological data base for initial values
- Link with Surfex snow modules?
- Prognostic depth, for use in cases of man made lakes?
- 3th layer, below termocline, to improve the representation of deep lakes (proposed by D. Mironov)