Water Surfaces in SURFEX

SURFEX training course

Outline

- Characteristics of water surfaces
- Surface fluxes
- A 1d Ocean Mixed Layer model for oceans
- The 1D Freshwater Lake model FLake

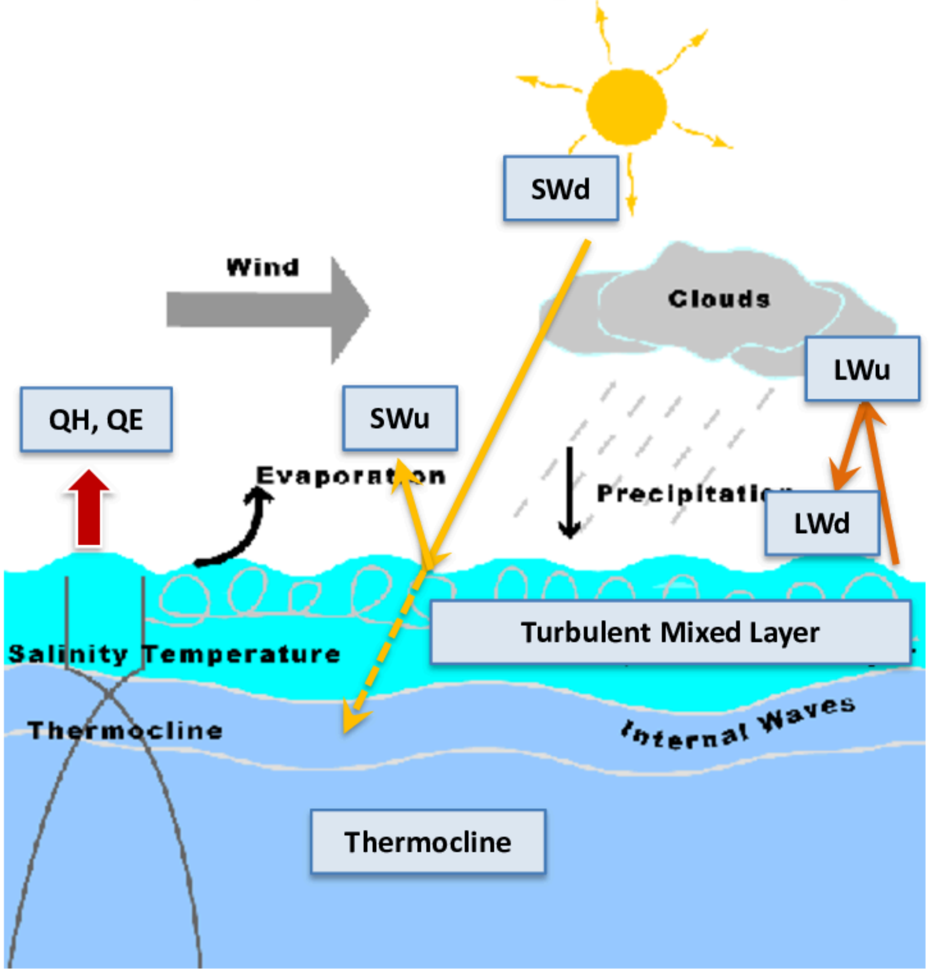
Characteristics of water surfaces

- 70% of the Earth is covered by sea and oceans
- Less than 5% of continental surfaces is covered by inland waters
- Water is available in the form of water, snow and ice
- The thermal inertia of the water is high and the diurnal amplitude is low:
  - Water can store a large amount of energy during the day and release it at night with almost no change in temperature
- The heat capacity of water:
  - In order to increase the water temperature by 1K, 4 times more energy is required than for air:

    C_{water} = 4185 J kg^{-1} K^{-1} ; C_{snow} = 2060 J kg^{-1} K^{-1}; C_{air} = 1005 J kg^{-1} K^{-1}
- Typical water surface parameters
  - Albedo: 0.07 ocean ; 0.8 fresh snow ; 0.6 ice
  - Emissivity: 0.96 open water
  - Roughness length: 0.0002 m for open ocean (0.1 m for low crops)

Characteristics of water surfaces

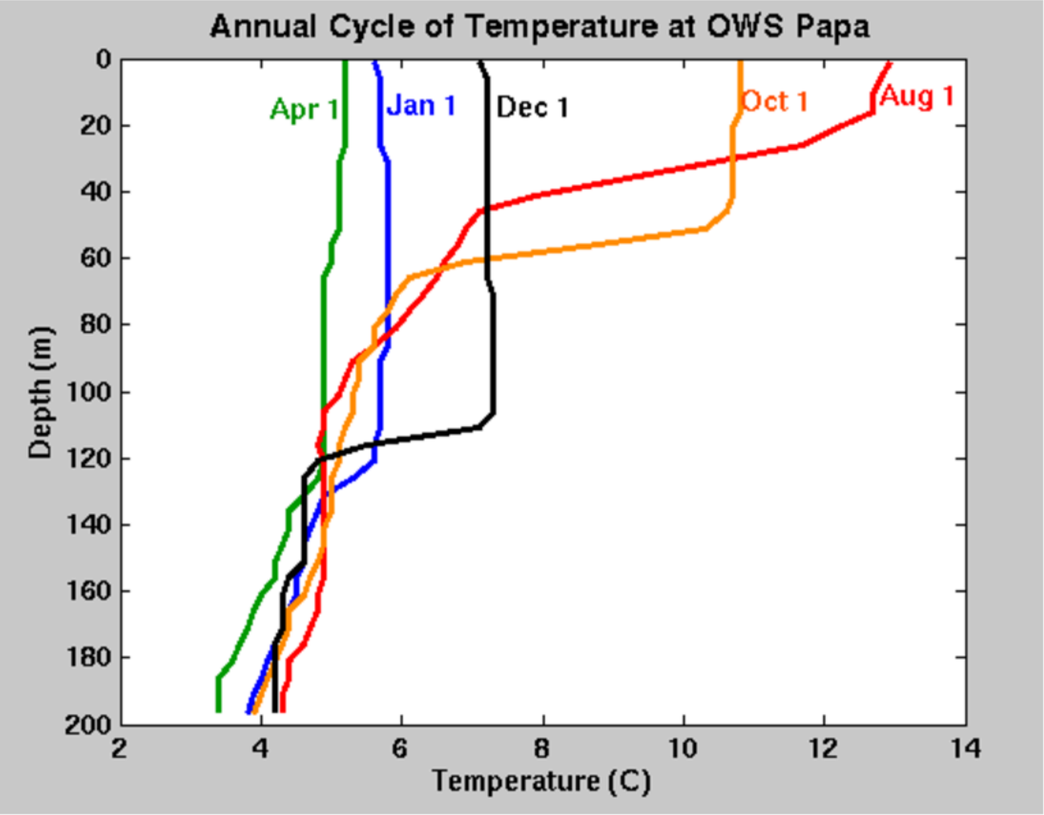
- Major processes acting on a mixed layer



- Thermocline is the depth at which the vertical temperature gradient is a maximum
- During the winter the surface is cold and winter storms deepen the mixed layer.
- In the summer the surface temperature rises, the water becomes more stable and a seasonal thermocline forms in the upper zone.

Characteristics of water surfaces

- ☐ Temperature profiles



- ☐ Between January and April, the temperature cools and the mixed layer deepens to about 120m.
- ☐ In the spring and summer, the water warms and the mixed layer becomes shallow, reaching its shallowest point by August. In the late summer and fall, the surface cools and the mixed layer deepens, and the cycle begins again.
- ☐ Heating during the day also causes the water column to stabilize and the mixed layer to shallow while heat loss at night and wind mixing cause it to deepen.

Surface fluxes

- ☐ Surface turbulent fluxes are then computed using a bulk formulation:
  - $Q_H \propto C_H(z0,Ri) * \Delta U * \Delta T$
  - $Q_E \propto C_E(z0,Ri) * \Delta U * \Delta q$
  - $Q_M \propto C_D(z0,Ri) * \Delta U * \Delta U$

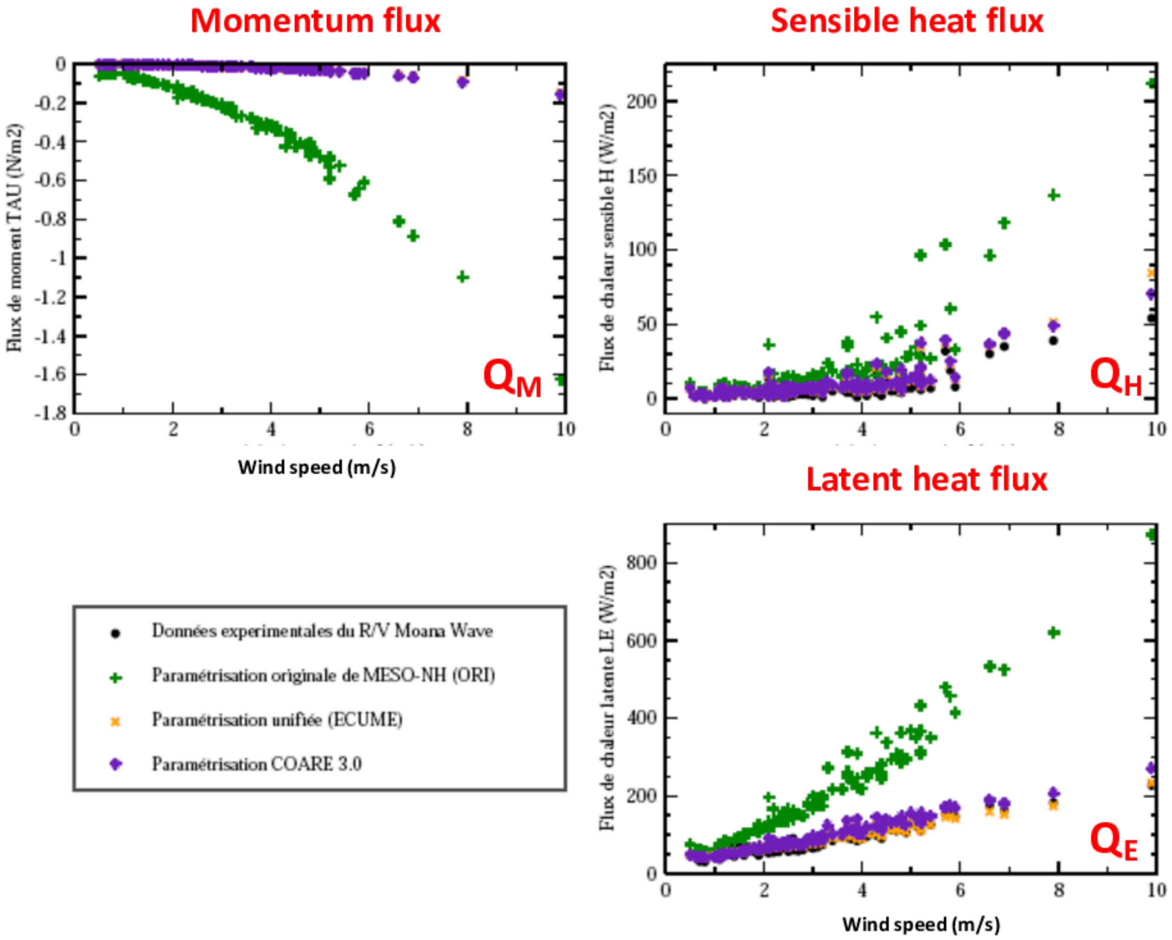
Where the unknown C_H, C_E, C_D are the turbulent exchange coefficients

ΔU, ΔT and Δq are the vertical gradients of wind, temperature and specific humidity

- ☐ Direct approach
  - Knowing the Richardson number Ri (stability of the atmosphere) and assuming a roughness length of 1mm, one can compute u_* the characteristic scale of turbulence for momentum, and Q_M
  - The Charnock formula gives the roughness length $z_0 = 0.015\ u_*^2 / g$
  - C_H and C_E are the computed as a function of Ri and Z0
  - Finally QH and QE are computed, assuming a constant surface temperature

Surface fluxes

- ☐ Iterative approach ECUME for oceans
  - Exchange coefficients in neutral condition are calibrated according to the 10m wind speed measured during field campaigns over oceans



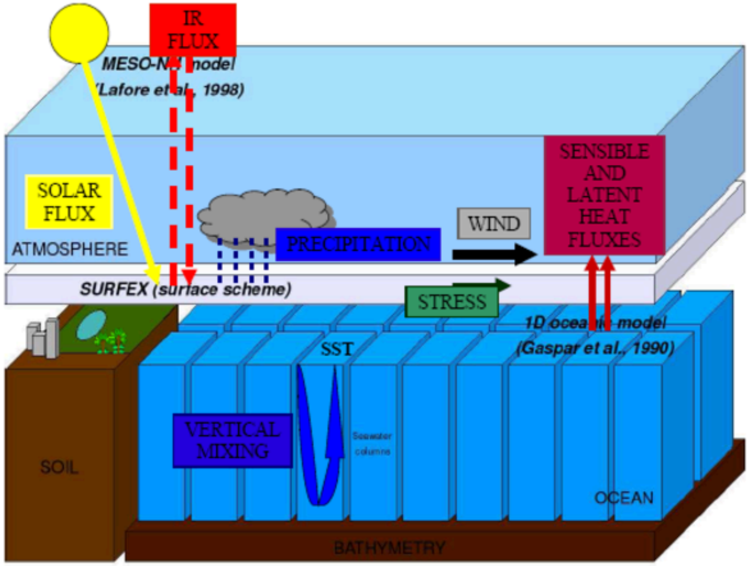
Momentum flux

Sensible heat flux

Latent heat flux

1D Ocean Model for oceans/seas

- Gaspar et al., 1990
- Temperature, salinity, current, TKE



equations

$$\frac{\partial T}{\partial t} = \frac{F_{sol}}{\rho_0 C_p}\frac{\partial I(z)}{\partial z} - \frac{\partial \overline{w'T'}}{\partial z}$$

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

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

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

system closure

$$\overline{w'T'} = -K \cdot \frac{\partial \overline{T}}{\partial z}$$

$$\overline{w'S'} = -K \cdot \frac{\partial \overline{S}}{\partial z}$$

$$\overline{w'u'} = -K \cdot \frac{\partial \overline{u}}{\partial z}$$

$$\overline{w'v'} = -K \cdot \frac{\partial \overline{v}}{\partial z}$$

diffusivity coefficient

$$K = c_k \cdot l_k \cdot \overline{e}^{1/2}$$

turbulent kinetic energy : $e = \frac{1}{2}(u'^2 + v'^2 + w'^2)$

$$\frac{\partial \overline{e}}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{w'e} + \frac{1}{\rho_0}\overline{w'p'}\right) - \left(\overline{w'u'}\frac{\partial \overline{u}}{\partial z} + \overline{w'v'}\frac{\partial \overline{v}}{\partial z}\right) + \overline{b'w'} - \epsilon$$

$$-\frac{\partial}{\partial z}\left(\overline{w'e} + \frac{1}{\rho_0}\overline{w'p'}\right) = -K_e \cdot \frac{\partial \overline{e}}{\partial z}$$

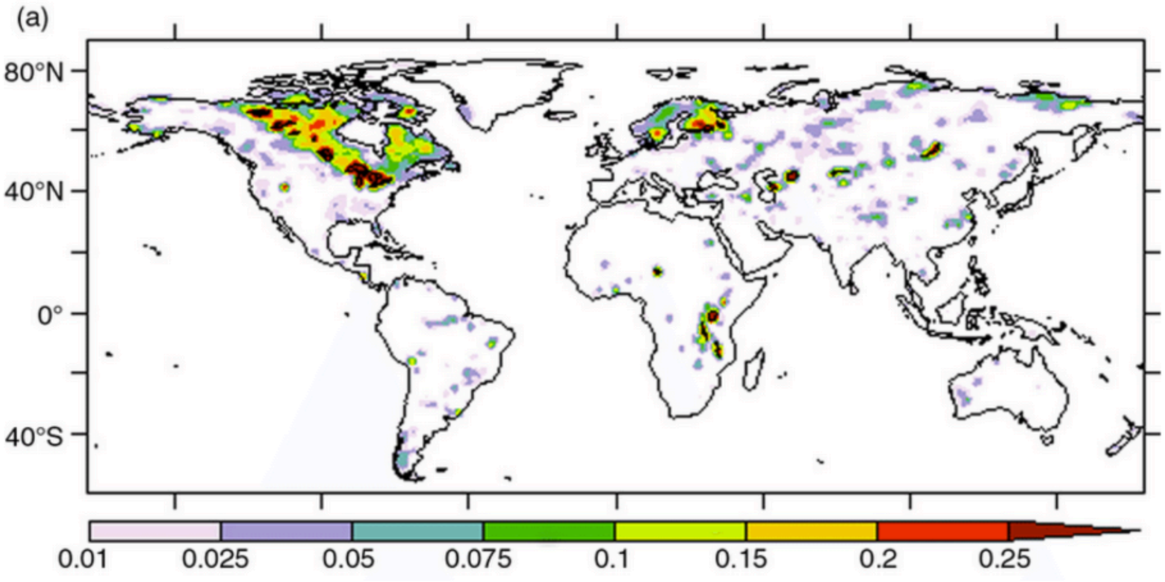
$$K_e = c_e \cdot l_e \cdot \overline{e}^{1/2}$$

$$b = \frac{g}{\rho_0}(\rho - \rho_0) \qquad \rho = \rho(T, S)$$

$$\epsilon = c_\epsilon \cdot l_\epsilon \cdot \overline{e}^{3/2}$$

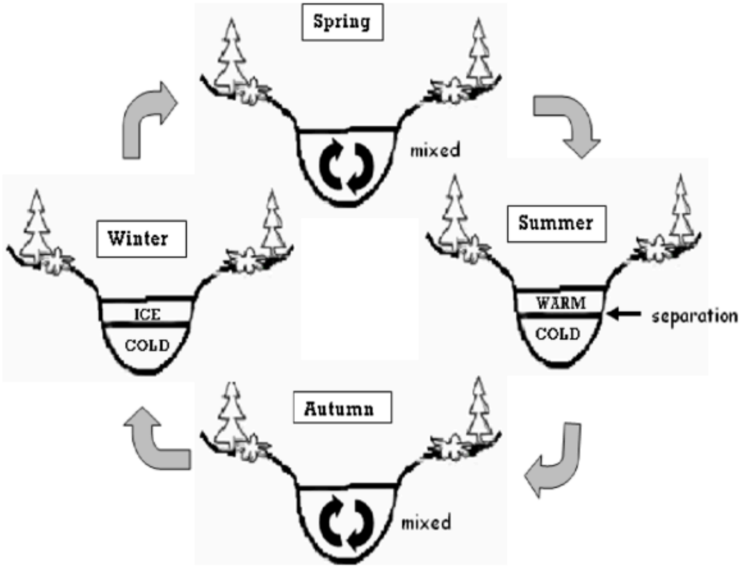
The lake model FLake

- ☐ Lakes represent about 3% of total continental water
- ☐ Lakes affect locally the boundary layer structure and the sensible weather
- ☐ The effects depend on the lakes morphology and on the meteorological situation
- ☐ The density of lakes varies spatially: North America, Canada, Scandinavia have a large density of lakes



The Dynamics of lakes

In spring, the ice melts and cooler surface water mix with the warmer water below.



During winter a layer of ice (and snow) insulates the water below.

The suns warms the surface in summer and a stratification appears (barrier) at the interface with colder layer below.

In autumn, colder weather cools down the surface of lakes until the layers mix.

The FLake model (Mironov, 2005)

- The interactions between surface and atmosphere is strongly dependent on the surface temperature and its time-rate-of-change. NWP models consider water surface temperature can be kept constant over the forecast period. This assumption is doubtful for small-to-medium size shallow lakes, where the diurnal variations of the surface temperature can reach several degrees.
- Lakes strongly modify the structure and the transport properties of the atmospheric surface layers.
- FLake is a two layer-model with a parameterized vertical temperature structure:
  - The temperature in the thermocline is parameterized by a universal function of depth

$$\Phi(\zeta) = \frac{\theta_s(t) - \theta(z,t)}{\Delta\theta(t)} \quad ; \quad \zeta = \frac{z - h(t)}{\Delta h(t)}$$

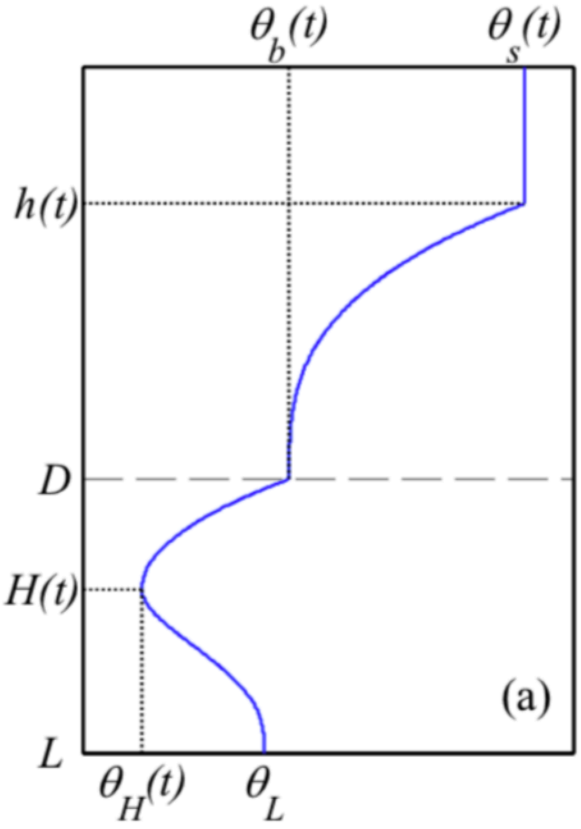
  - ϕ=0 from the surface to the bottom of the mixed layer,
  - ϕ=1 at the bottom of the lake

$$\theta(z,t) = \theta_s(t) - (\theta_s(t) - \theta_b(t))\Phi(\zeta)$$

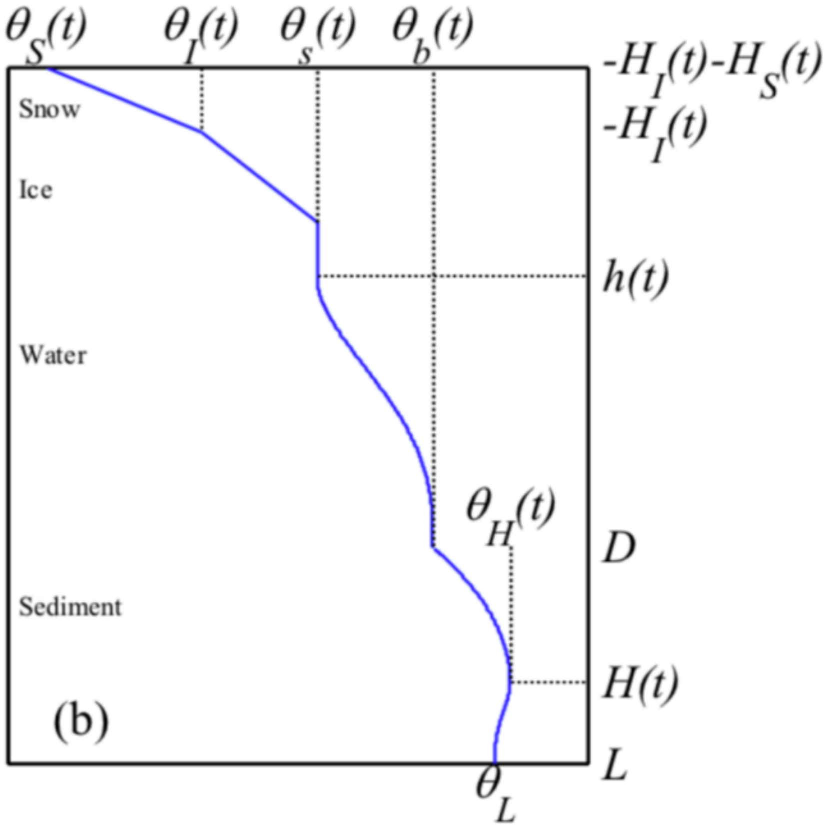
The FLake model

- The model is based on the idea of self-similarity (assumed shape) of the evolving temperature profile.
- That is, instead of solving partial differential equations (in z, t) for the temperature and turbulence quantities (e.g. TKE), the problems is reduced to solving ordinary differential equations for time-dependent parameters that specify the temperature profile. These are:
  - the surface temperature,
  - the bottom temperature,
  - the mixed-layer depth,
  - the depth within bottom sediments penetrated by the thermal wave, and
  - the temperature at that depth.
- In case of ice-covered lake, additional prognostic variables are
  - the ice depth,
  - the temperature at the ice upper surface,
  - the snow depth, and the temperature at the snow upper surface.

The FLake model Typical temperature profiles



Summer profile

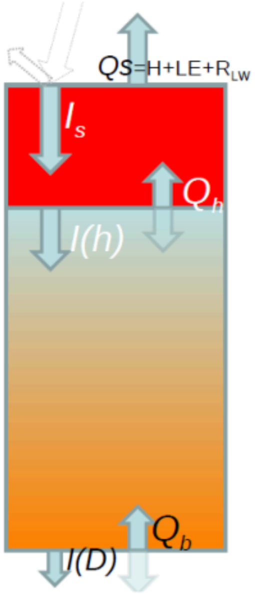


Winter profile

The FLake model parameters

- Lake fraction of the model grid-box:
  - Use of ECOCLIMAP in SURFEX
- Lake depth: not easy at all, e.g. for the lack of data
  - Use of the external database GLDB (Choulga et al., 2019)
- Typical wind fetch
- Optical characteristics of lake water (extinction coefficients with respect to solar radiation)
- Depth of the thermally active layer of bottom sediments, temperature at that depth
- Default values of the last three parameters can be used.

Lake energy budget

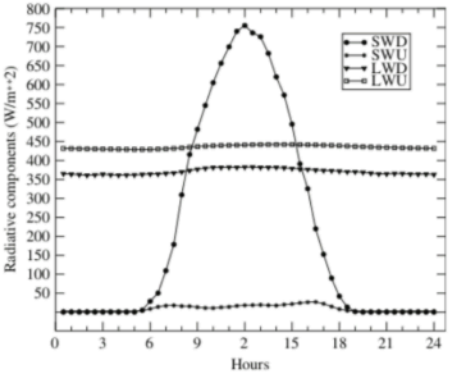


- Model properties
  - conservation of the total energy : $\rho_w c_w D \frac{d\bar{\theta}}{dt} = Q_s - Q_b + I_s - I(D)$
  - conservation of the mixed layer $\rho_w c_w h \frac{d\theta_s}{dt} = Q_s - Q_h + I_s - I(h)$
  - h evolution : computed by accounting for convective and stable regimes

- Heat storage

$$QW = \rho_w C_w D \frac{\partial < T >}{\partial t} = QN - (QH + QE) - QB - I(D)$$

$$I(D) = (1 - \alpha_w) \cdot SWD \cdot \exp\{-kD\}$$

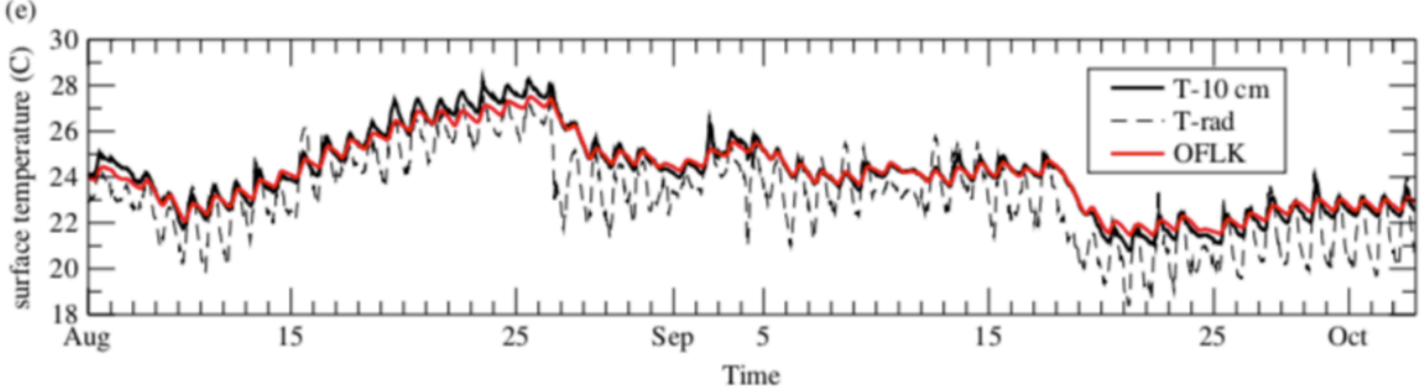


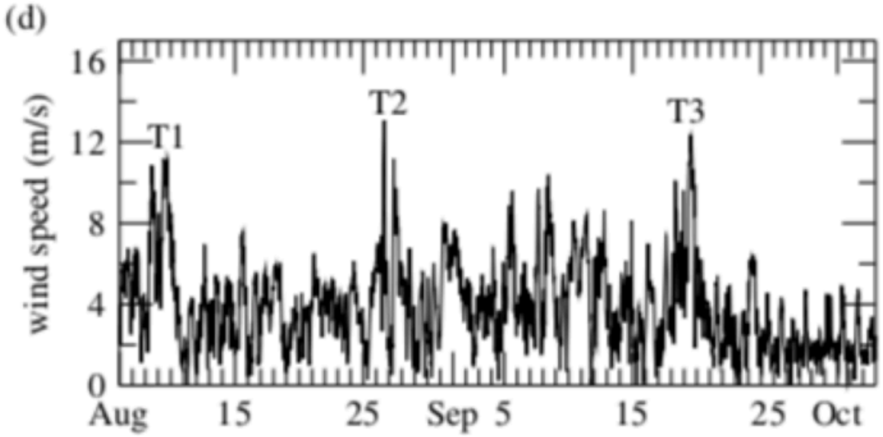
		QN	$I(D)$	QW	QE	QH	QB
Day	OBS	171	29	84	57	7	−6
	OFLK	167	29	70	63	3	0
	DIAG	171	29	84	58	2	−2
Night	OBS	−29	0	−84	23	7	25
	OFLK	−31	0	−80	42	7	0
	DIAG	−29	0	−84	33	3	19
Total	OBS	141	29	−4	82	13	21
	OFLK	135	29	−12	108	10	0
	DIAG	141	29	−4	93	5	18

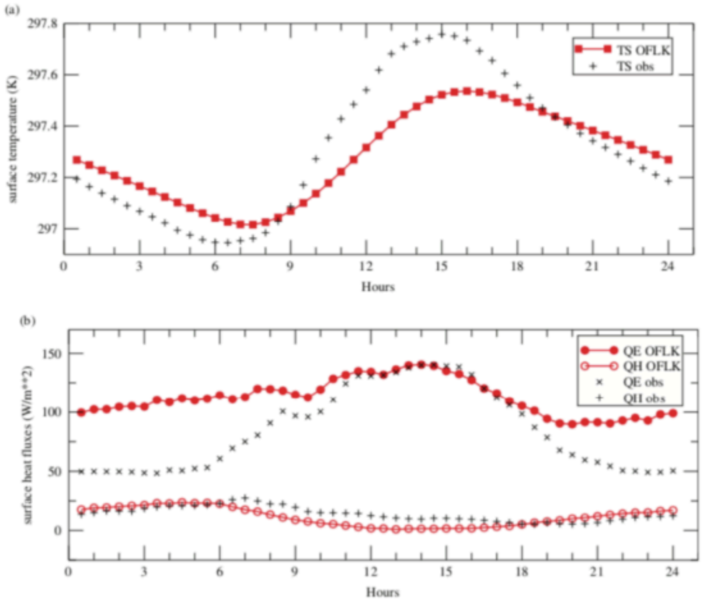
From THAUMEX campaign 2011

Coupling FLake to the Meso-NH mesoscale model

- ☐ Preliminary offline calibration of the extinction coefficient

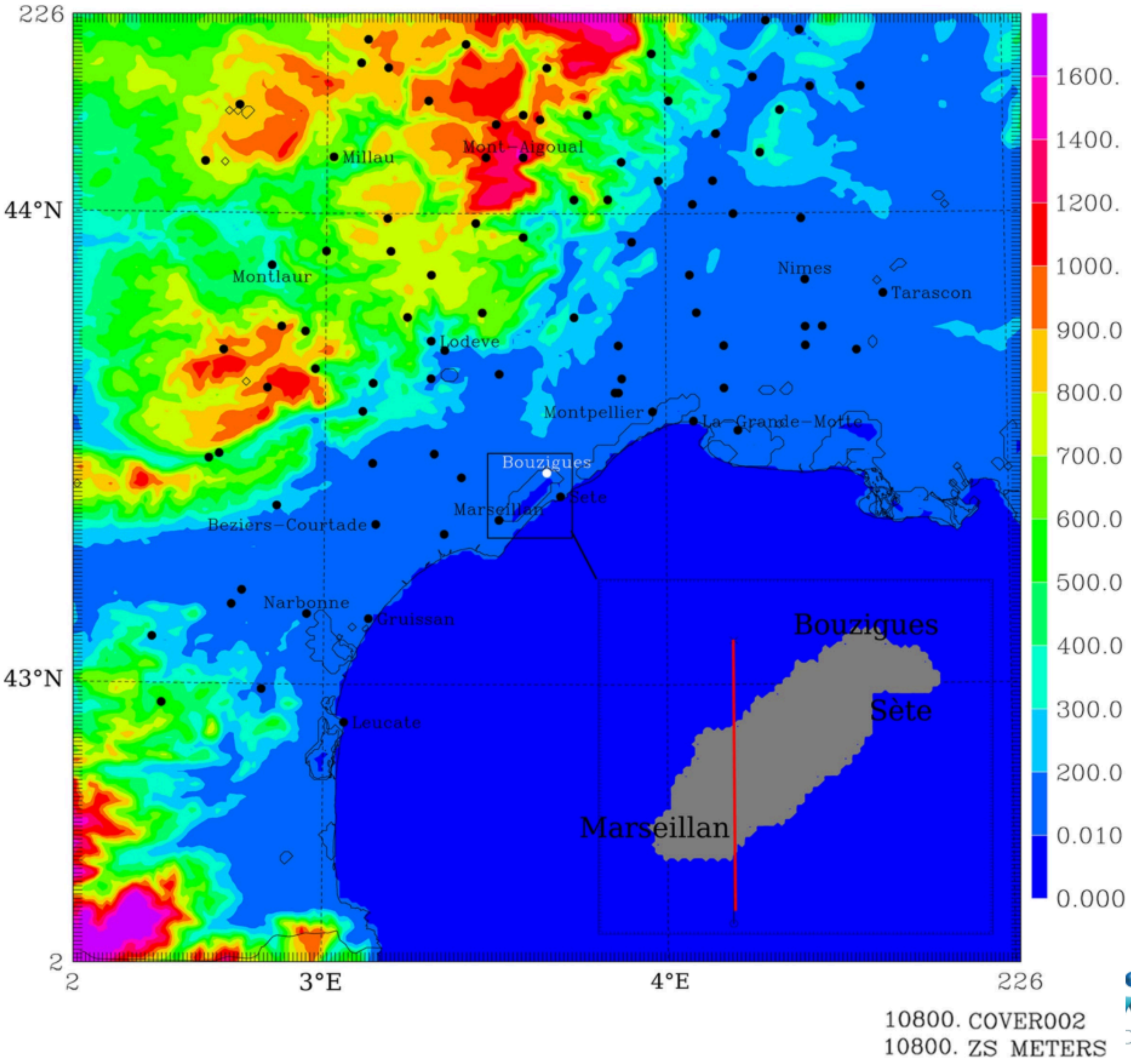




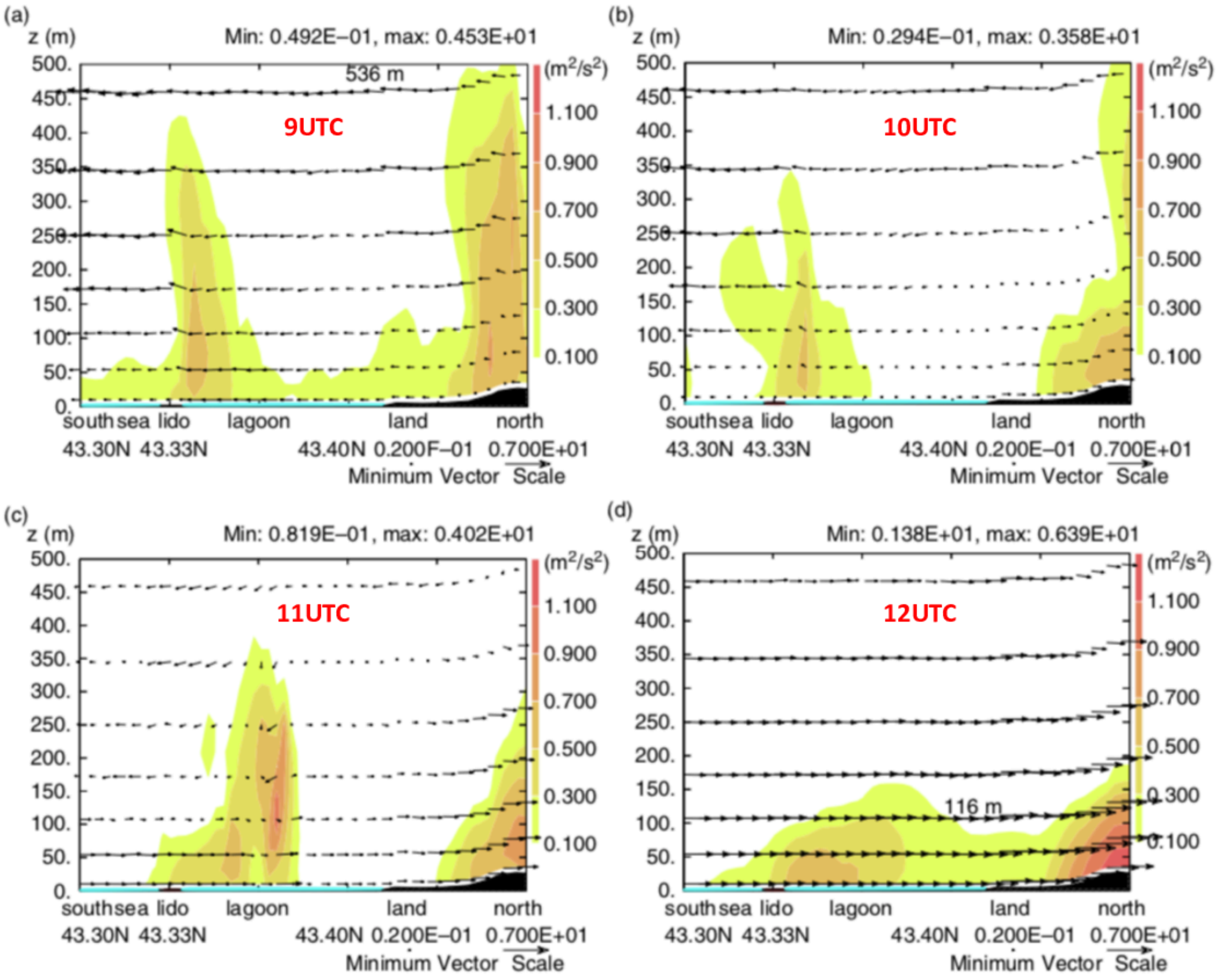


Coupling FLake to the Meso-NH mesoscale model

- 3h coupling using AROME model at 2.5km
- 2-way grid-nesting at 1km and 200m
- 20 layers in the BL below 1000m



Coupling FLake to the Meso-NH mesoscale model



Coupling FLake to the CNRM-CM5 climate model

- ☐ Offline calibration of:
  - Maximum lake depth
  - Ice albedo
  - Extinction coefficient
  - Skin temperature

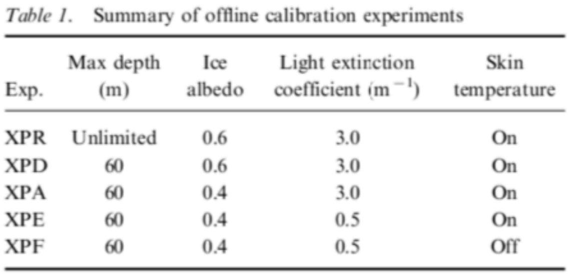
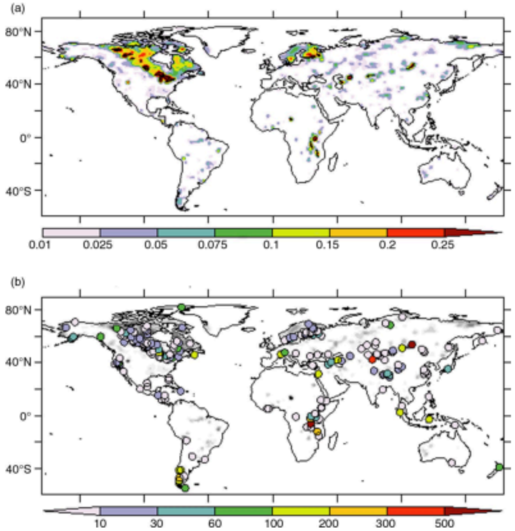
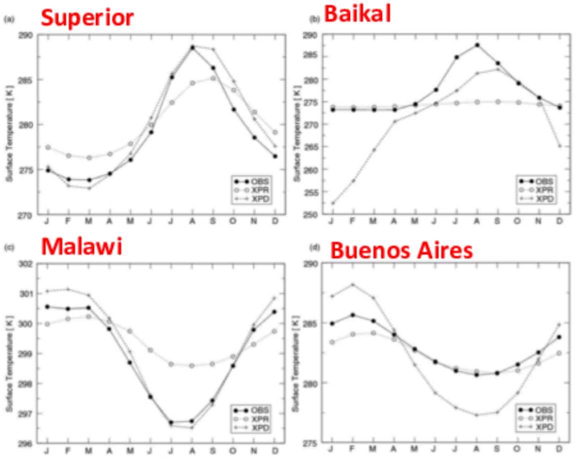


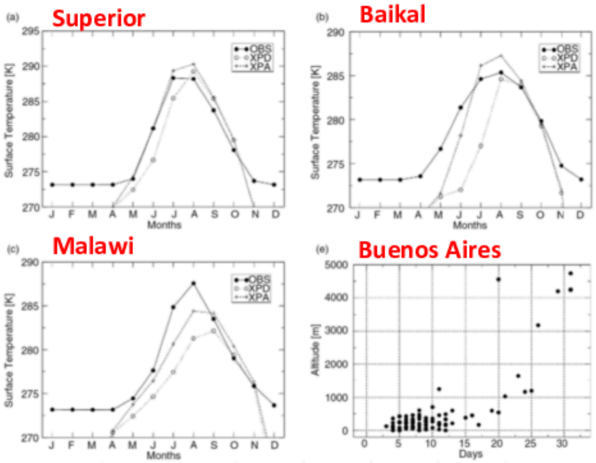
Table 1. Summary of offline calibration experiments

Exp.	Max depth (m)	Ice albedo	Light extinction coefficient (m^{-1})	Skin temperature
XPR	Unlimited	0.6	3.0	On
XPD	60	0.6	3.0	On
XPA	60	0.4	3.0	On
XPE	60	0.4	0.5	On
XPF	60	0.4	0.5	Off

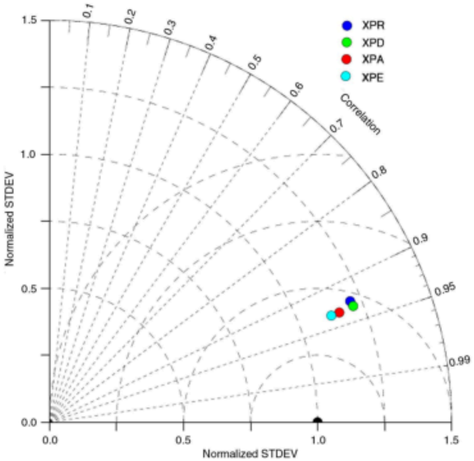




Depth limitation



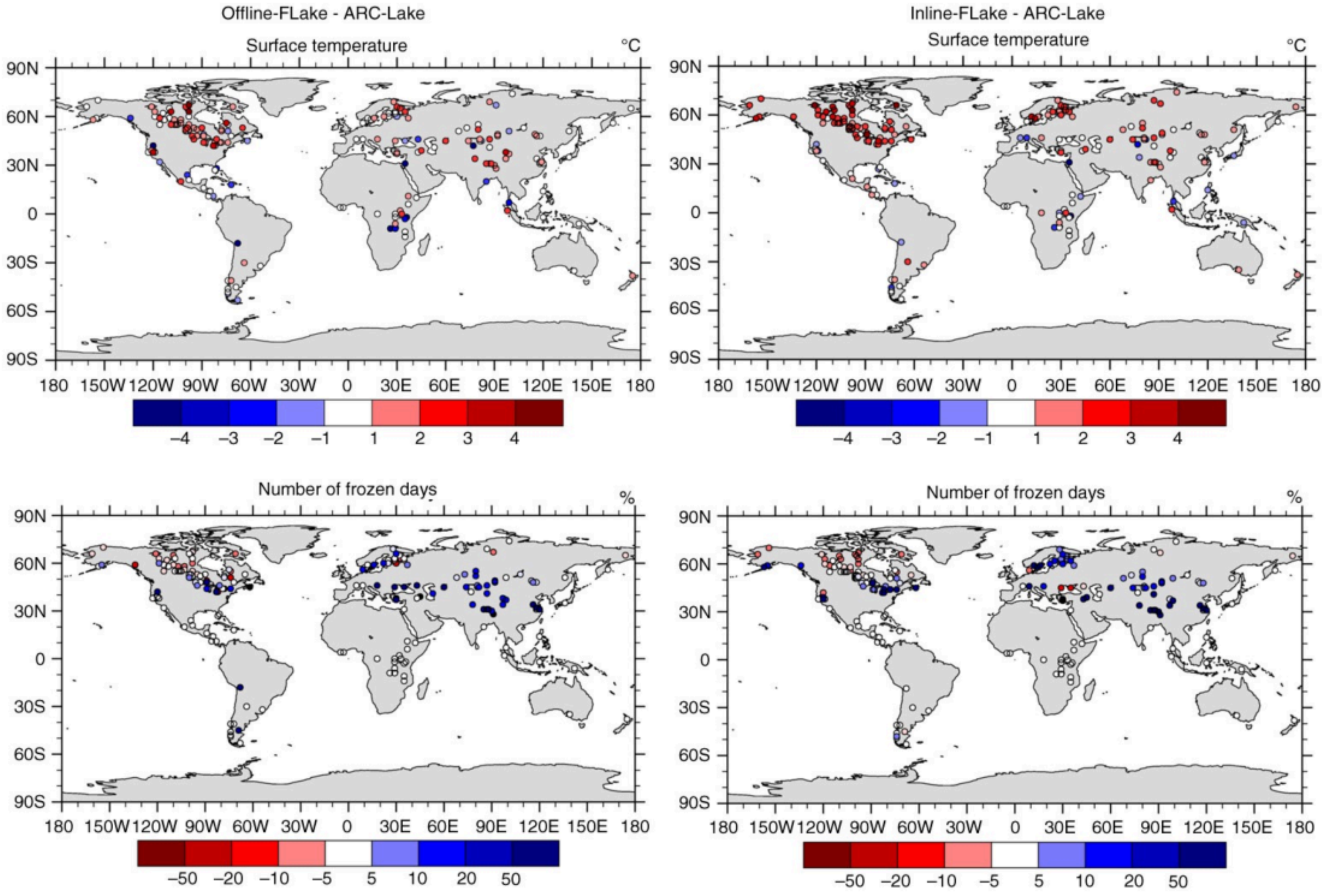
Ice albedo



Extinction coefficient

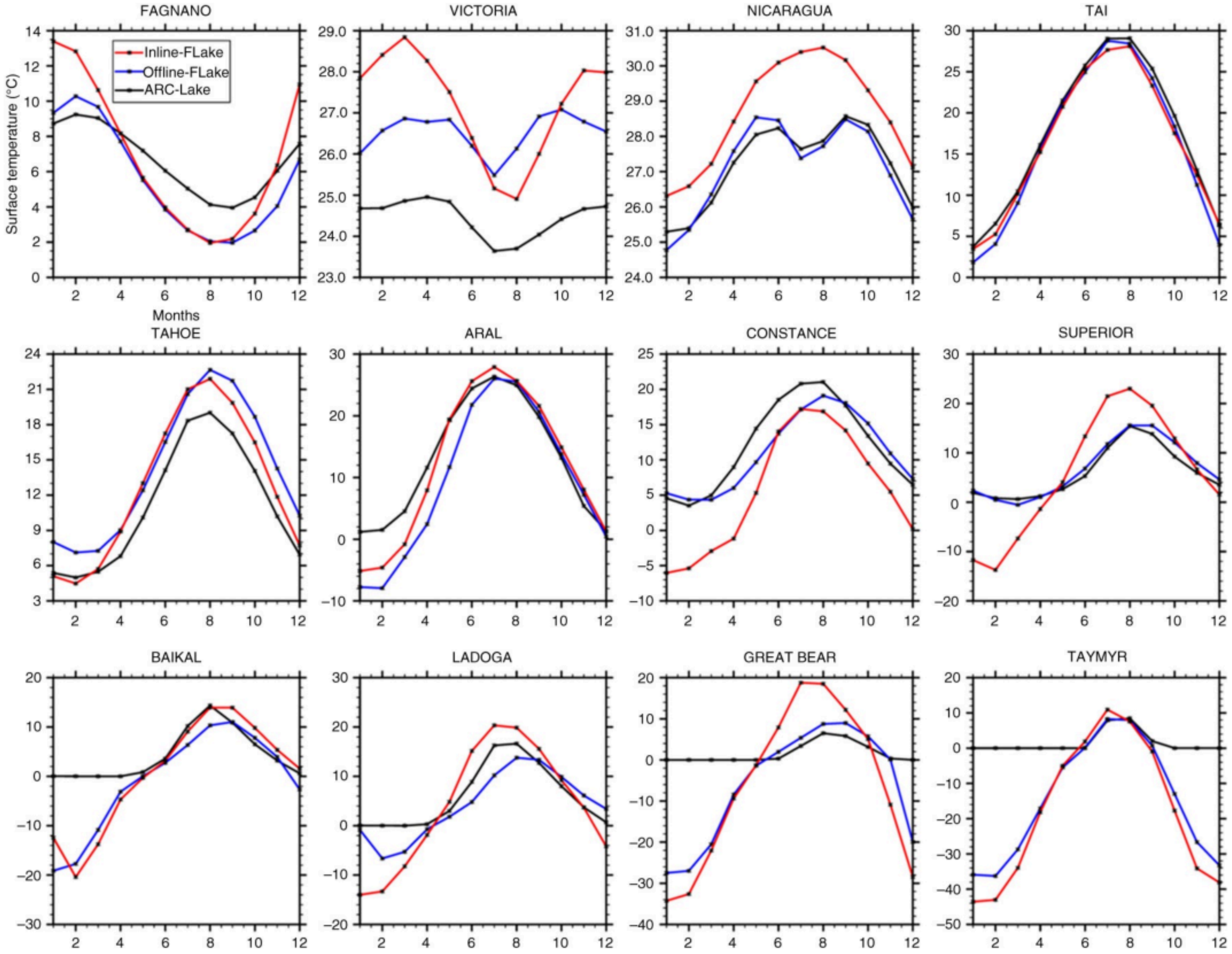
Coupling FLake to the CNRM-CM5 climate model

- Offline versus Inline simulations
  - Inline simulations: 32years with prescribed SST and sea-ice.



Coupling FLake to the CNRM-CM5 climate model

- Offline versus Inline simulations

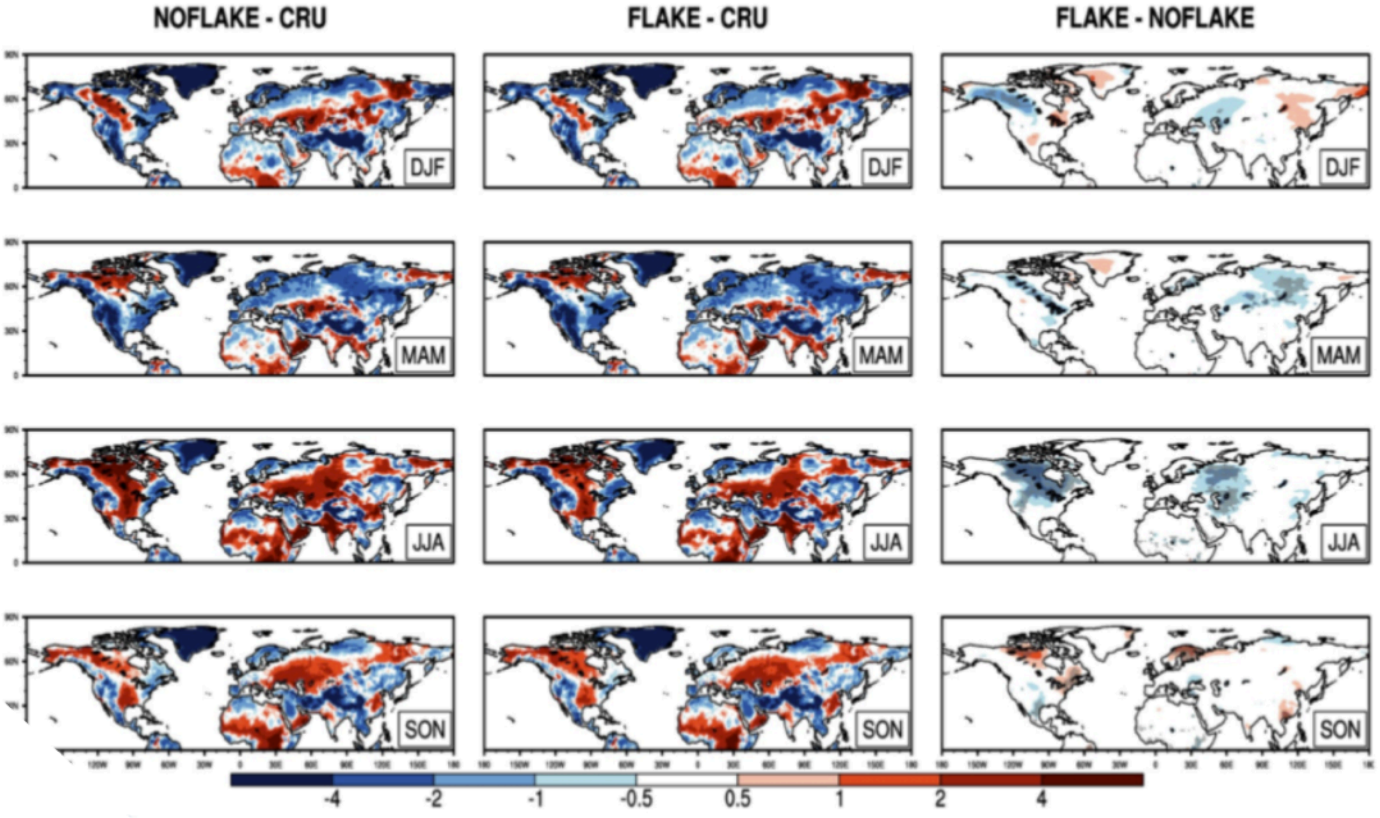


Sensitivity of the CNRM-CM5 climate model to FLake

- 2 configurations of CNRM-CM Global Model, T127, 1979-2010: **FLAKE,** and **NOFLAKE** where inland water is replaced by vegetation

Cooling effect

Maximum Temperature



Sensitivity of the CNRM-CM5 climate model to FLake

- **FLAKE - NOFLAKE**

Moistening effect

Specific Humidity | **Latent Heat Flux** | **Sensible Heat Flux**