The integration of the lake model into the general circulation model INMCM4

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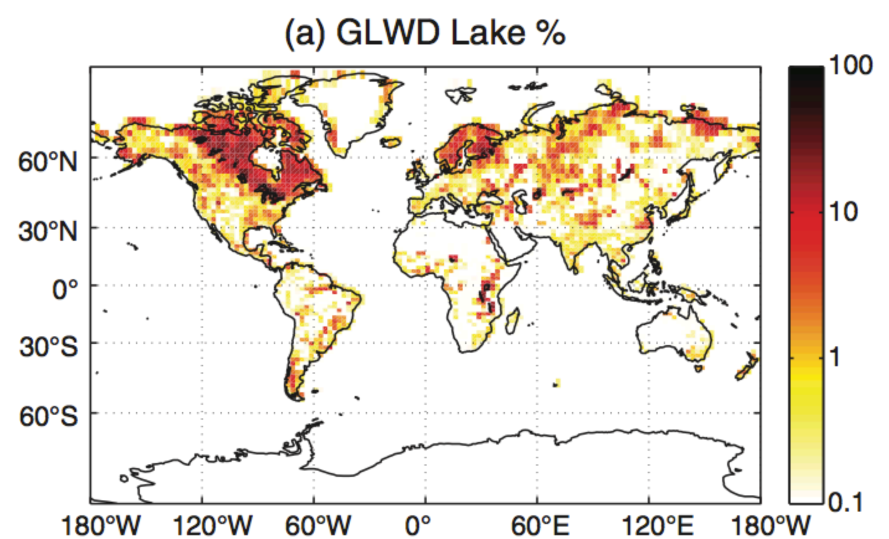
Distribution of lakes on the land surface

(*Downing et al., 2006; Zubin et al., 2012*)

- Total area 2-2.8*10^6 km^2 or 1.3-1.8%
- By number is dominated by small lakes
- Heterogeneity of distribution

(Meybeck 1995; Kalff 2001; Shiklomanov and Rodda 2003)



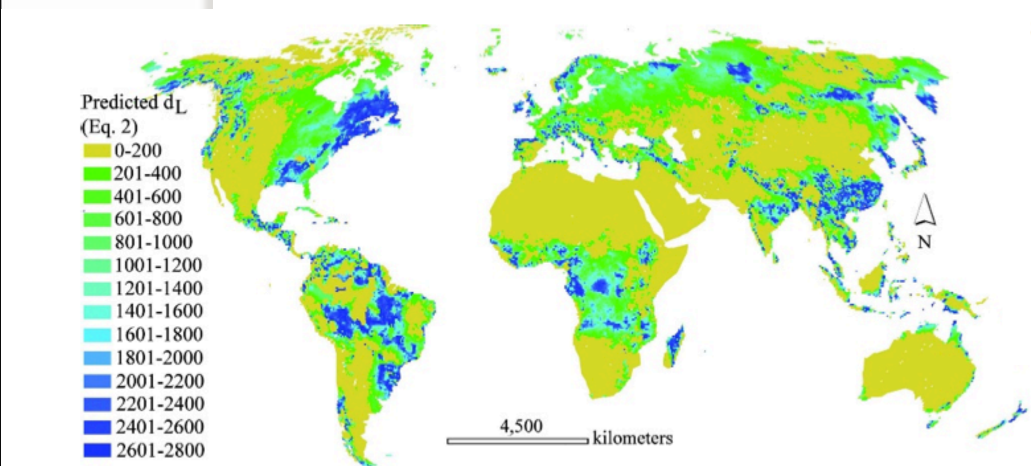


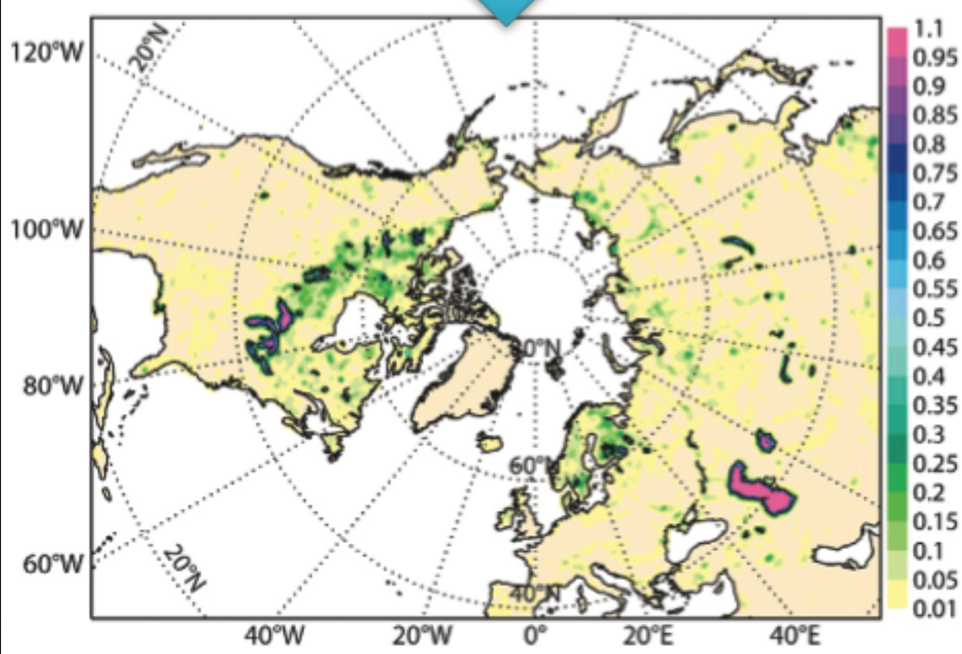
Fig. 3. Geographical analysis of the predicted world distribution of densities (d_L; Eq. 2) of lakes between 1 km^2 and 10 km^2 surface area. Predictions follow a world GIS model of annual run-off (Fekete et al. 2005) with a geographical resolution of 0.5° of latitude and longitude. Lake densities are shown in lakes per 10^6 km^2.

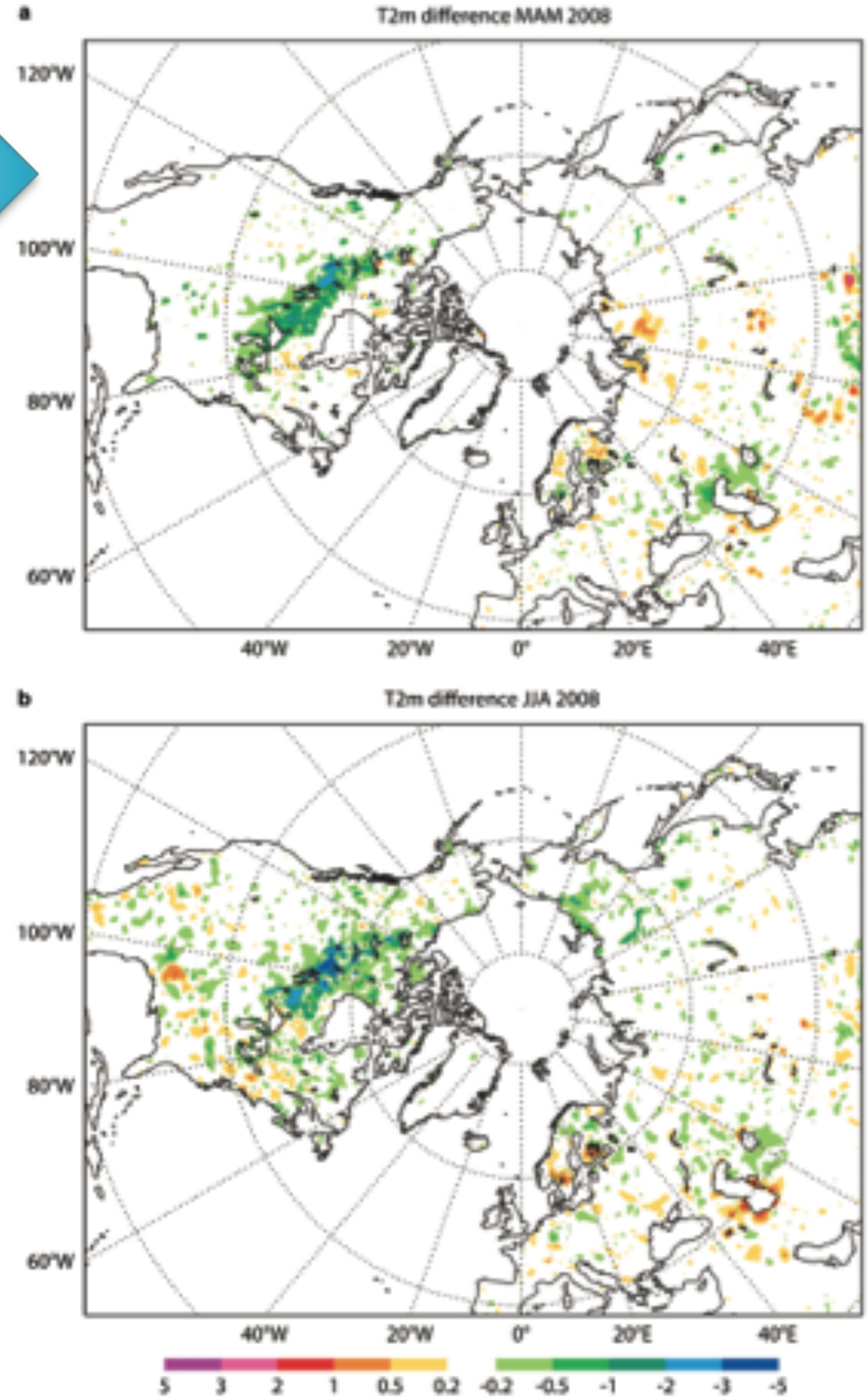
Lake models in climate models and weather forecasting systems

Climate/NWP model	Lake model
IFS (ECMWF)	FLake
UKMO (MetOffice)	FLake
COSMO (European Consortium)	FLake
HIRLAM (European Consortium)	FLake
CESM (US consortium)	CLM-LISSS4
CRCM (Canada)	Flake/Hostetler
WRF (Penn SU)	FLake
…	…

Effect of lakes on T_{2M} in IFS model *(Balsamo et al. 2012)*

The fraction of area occupied by lakes in IFS





Effect of lakes on the near surface temperature in the CESM model (Subin et al. 2012)

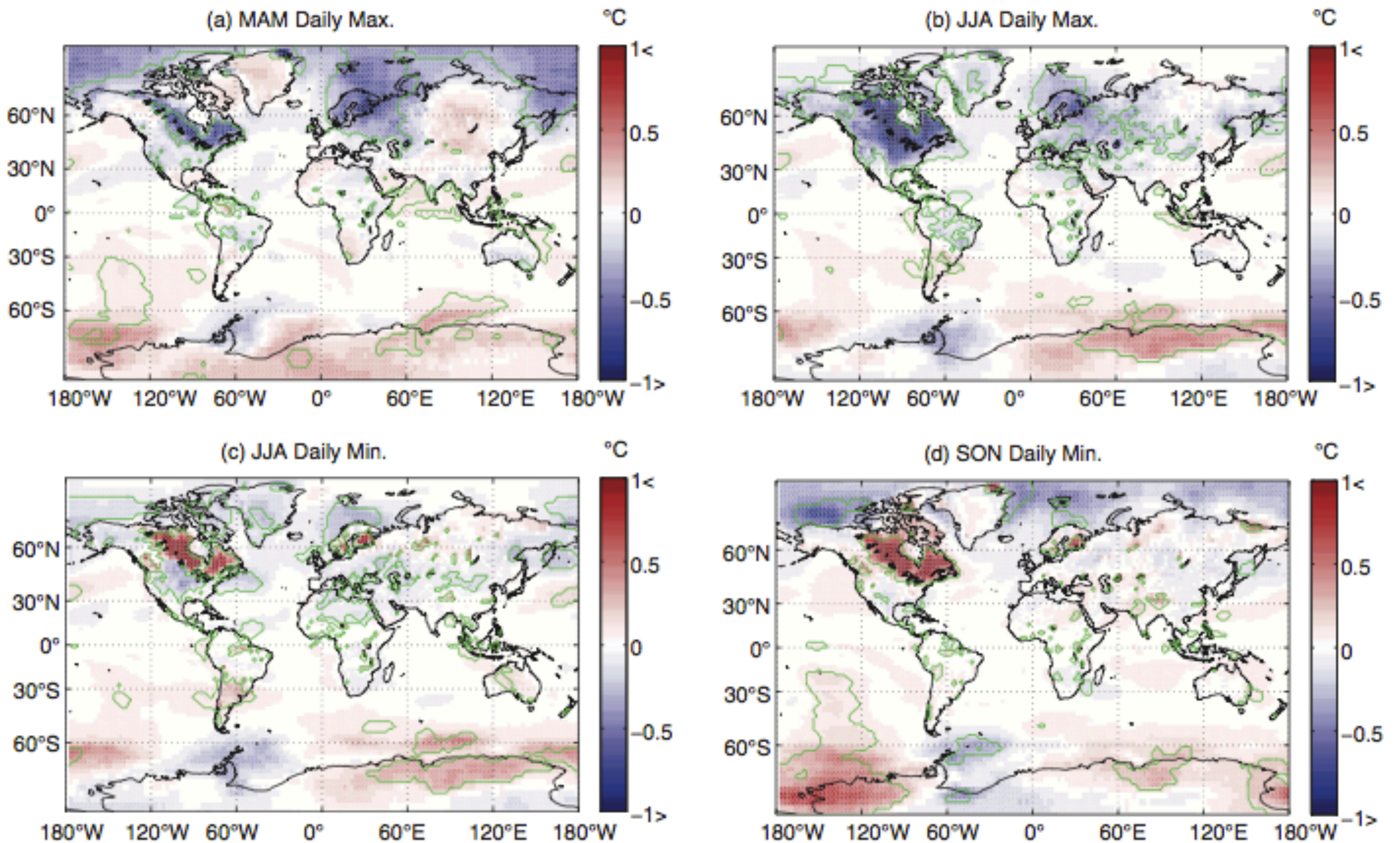
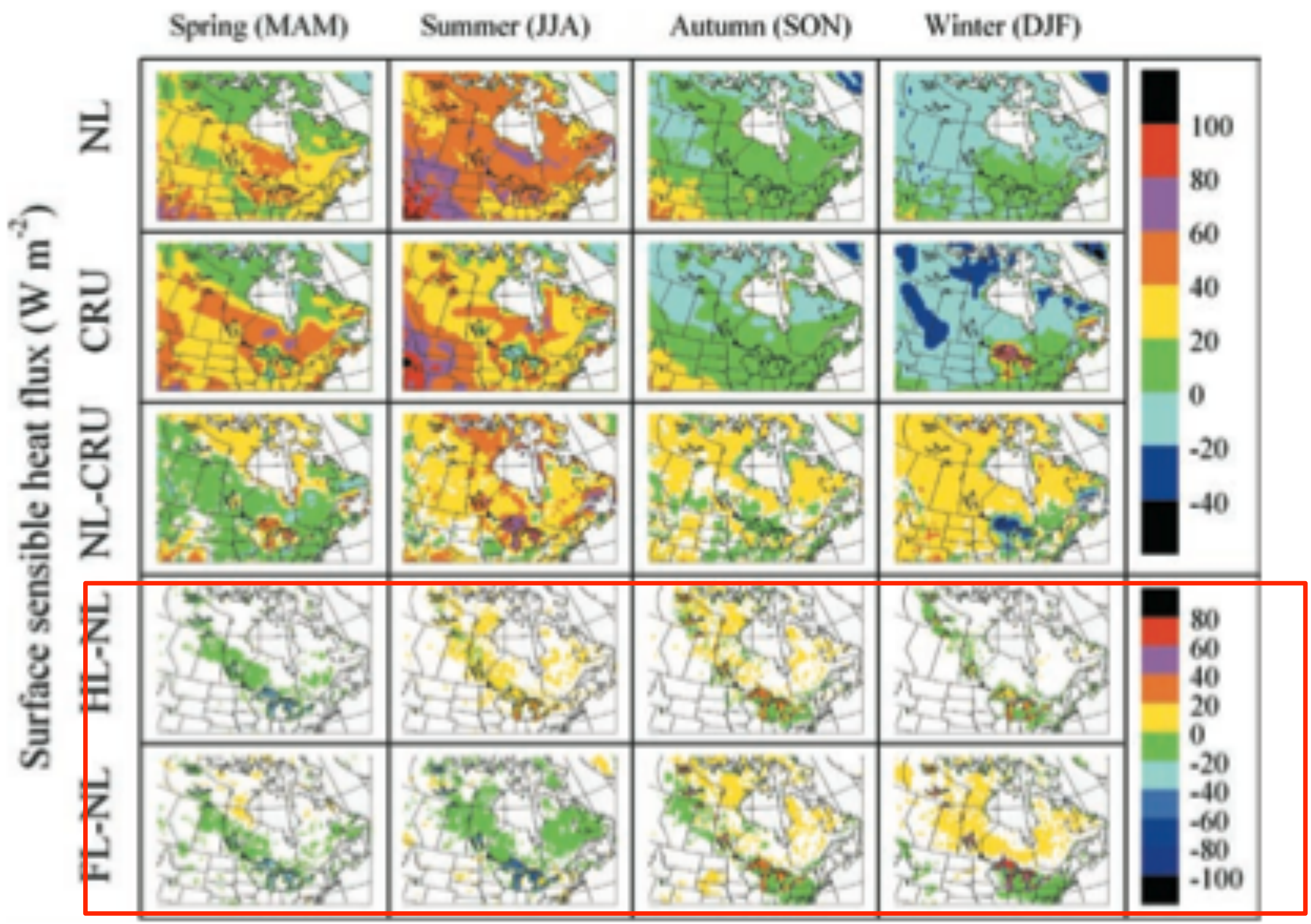
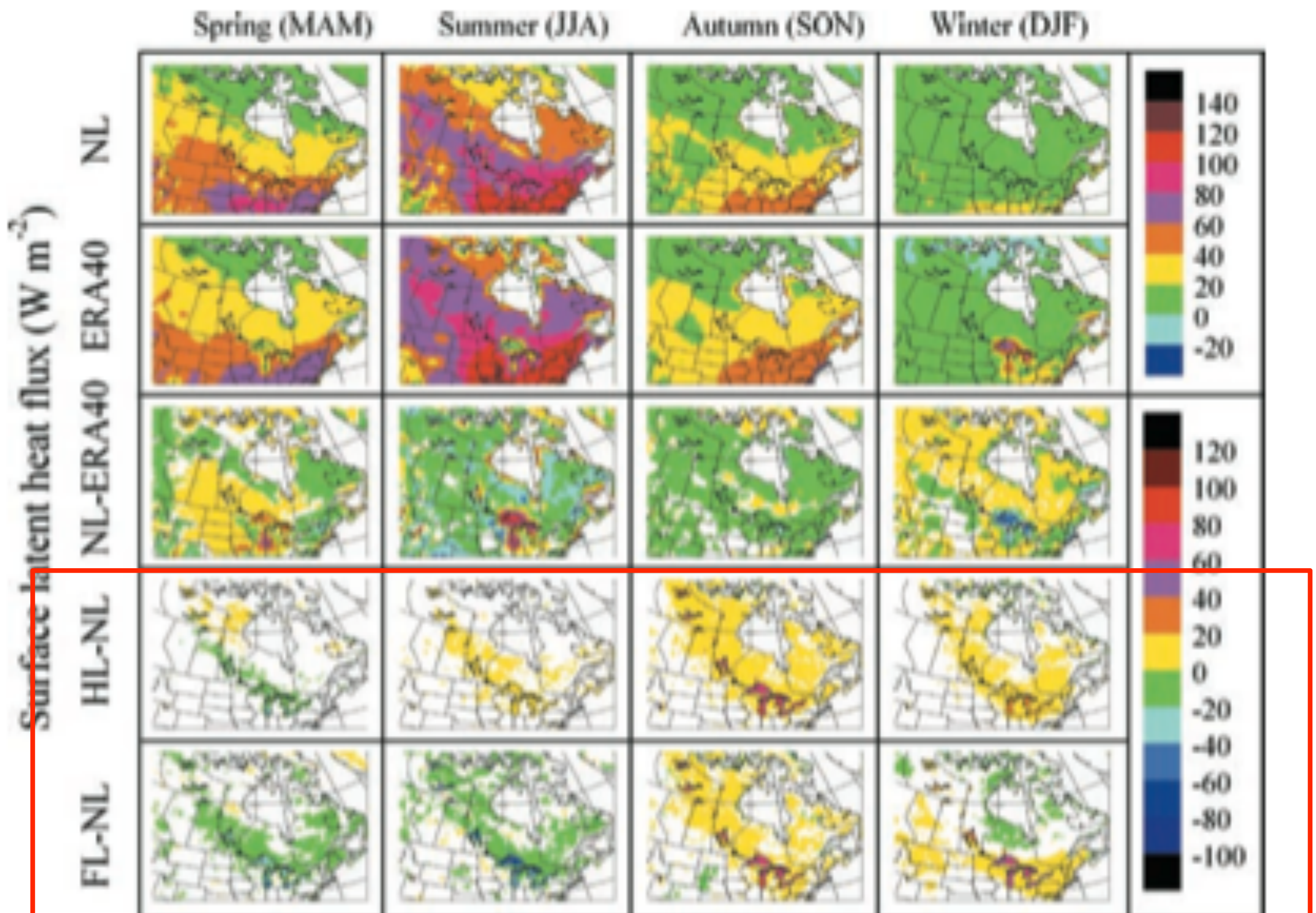


Fig. 3. Hi (GLWD lake area)–Lo (default CLM4 lake area) coupled seasonal average 2 m temperature anomalies under year 2000 conditions: (a) MAM daily maximum; (b) JJA daily maximum; (c) JJA daily minimum; and (d) SON daily minimum. Green contours encircle grid cells experiencing statistically significant changes. GLWD, Global Lake and Wetland Database.

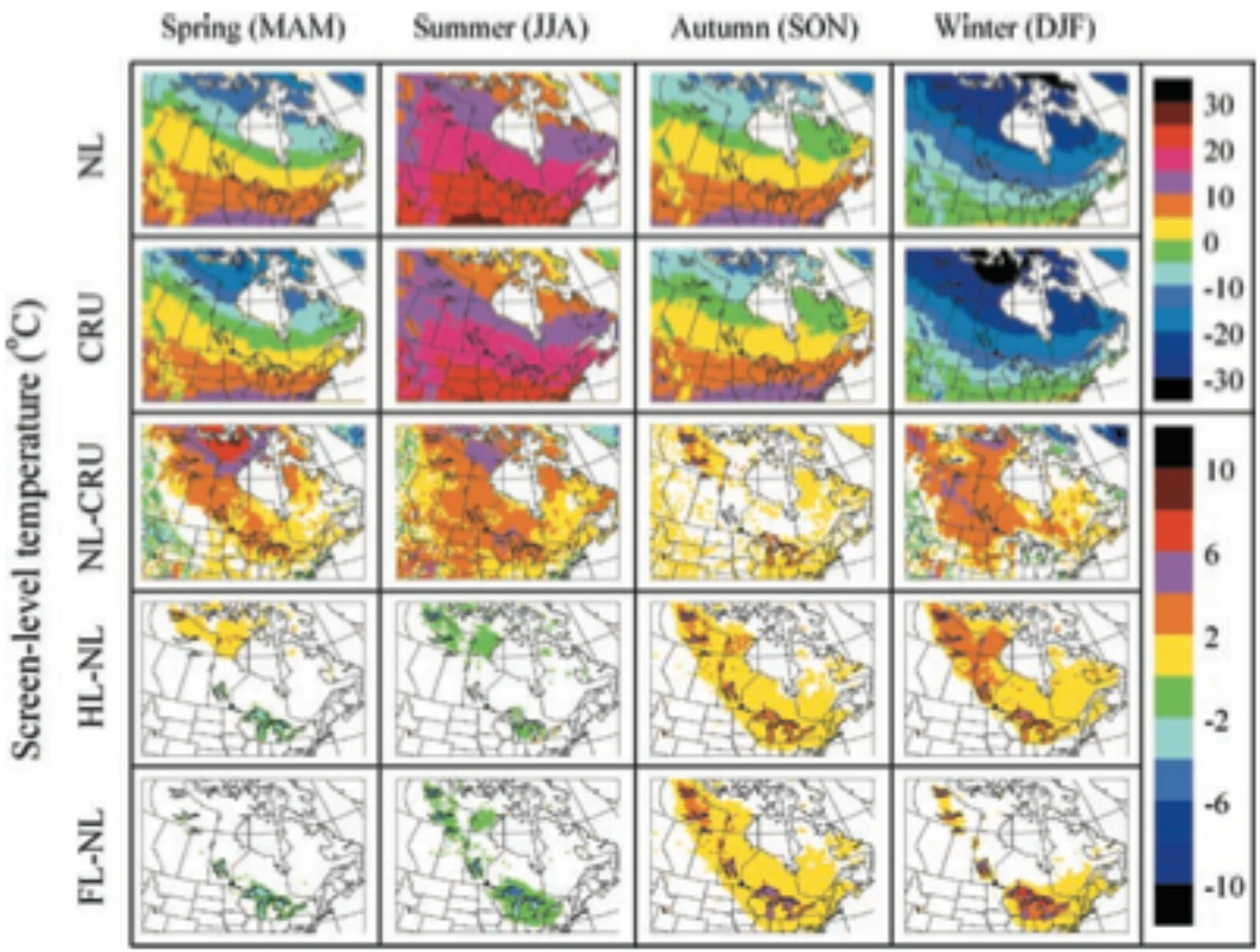
Influence of lakes on the sensible heat flux in the CRCM model (Martynov et al., 2012)



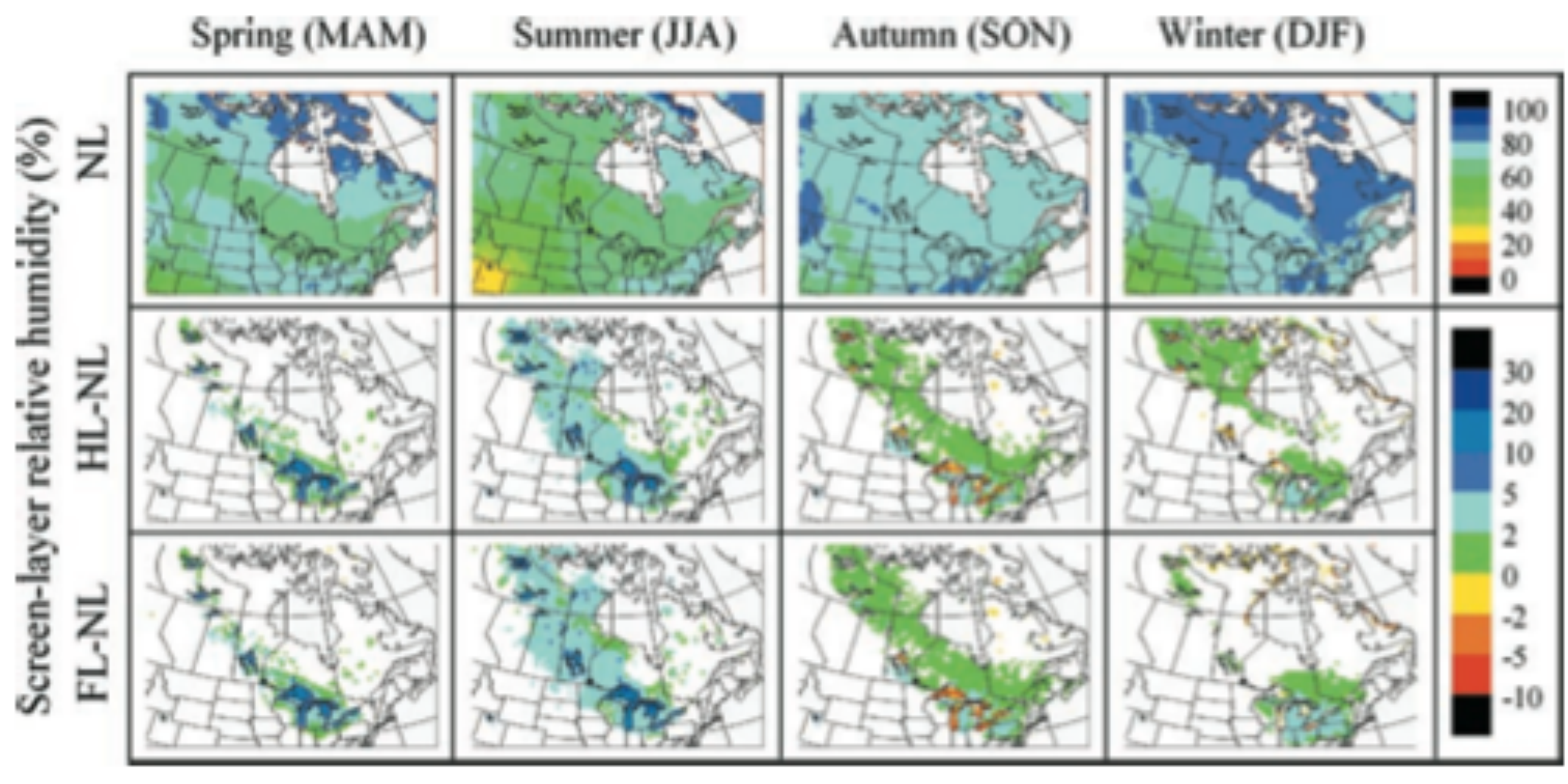
Influence of lakes on the latent heat flux in the CRCM (Martynov et al., 2012)



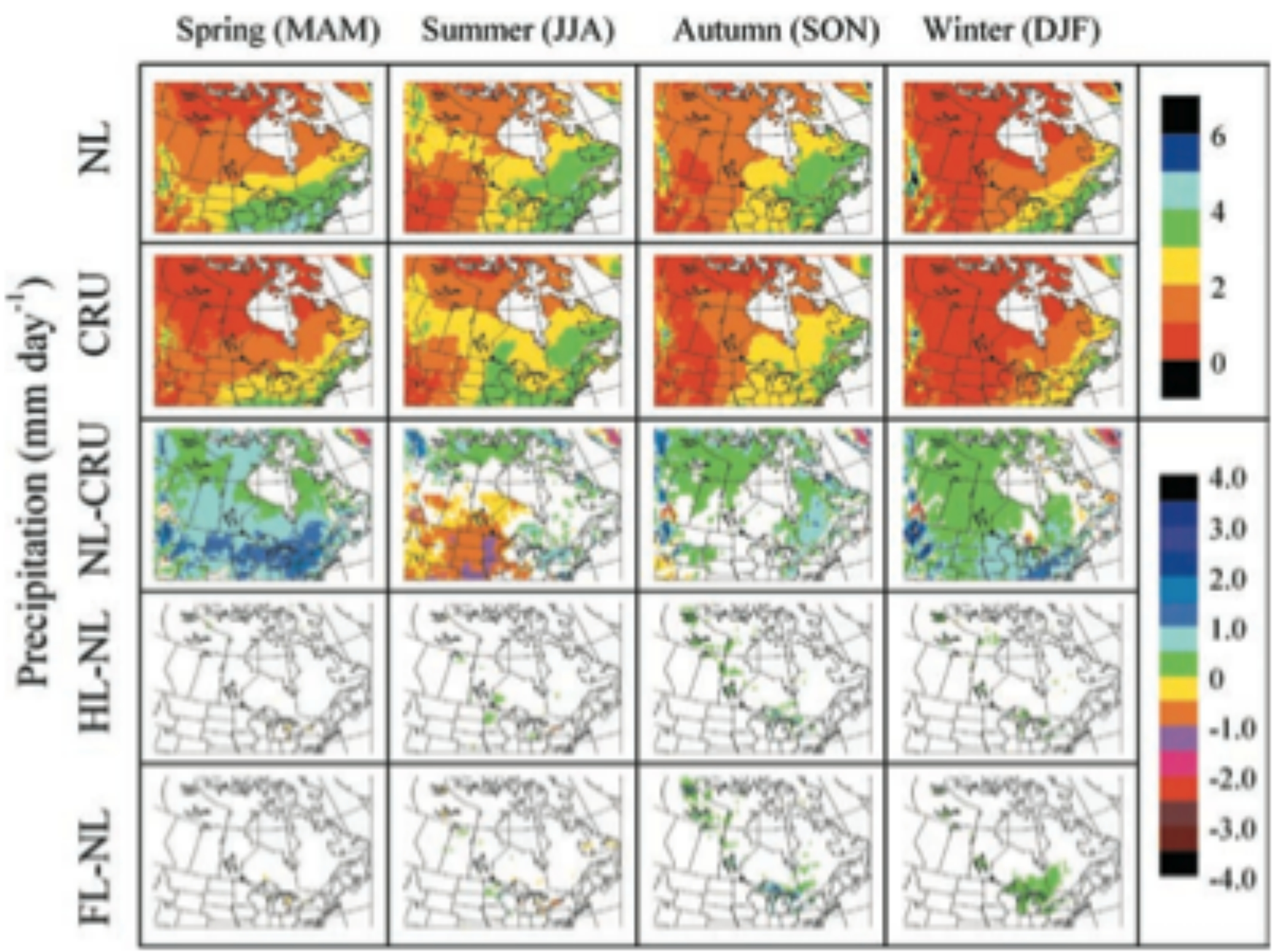
Influence of lakes on temperature in CRCM model (Martynov et al., 2012)



Influence of lakes on the near surface humidity in CRCM (Martynov et al., 2012)



Influence of precipitation by lakes on the CRCM (Martynov et al., 2012)



Lakes in INMCM4

- Climate model participates in CMIP 5 (http://cmip-pcmdi.llnl.gov/cmip5/)
- Resolution of atmospheric block: 2˚ x1.5˚ (lat., lon.), 21 vertical levels.
- The cell of land surface contains 4 types: vegetation, snow, bare ground, inland waters
- The share of snowless surface occupied with vegetation, inland waters and the bare ground is defined according to the (Wilson and Henderson-Sellers, 1985). Resolution of data: 1˚ x 1˚
- Humidity of air above the inland water surface is equal to the saturated, but water does not have its own additional heat content
- Soil located under different types of surfaces within the model grid cell has the same vertical profiles of temperature, humidity, ice concentration.

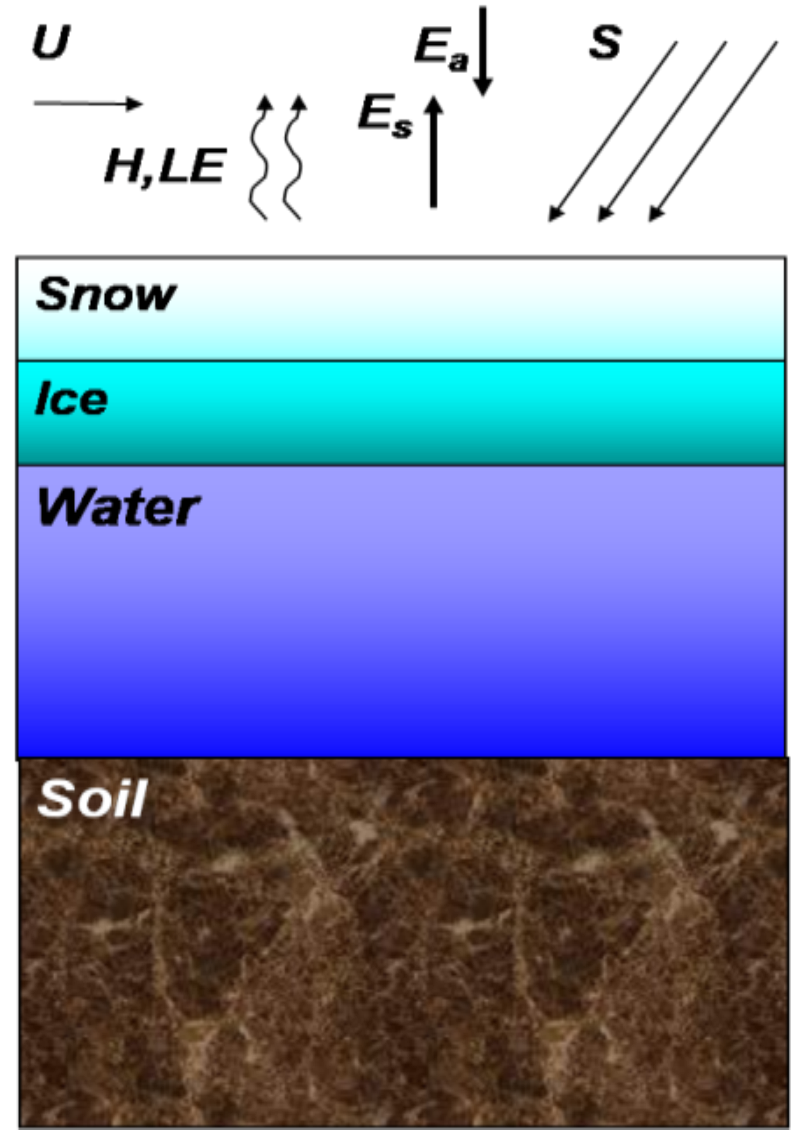
The components of lake parameterization in climate models

- Lake model
- Global lake depth and lake distribution maps
- Surface layer scheme (turbulent fluxes over the lake, the aggregation of fluxes in the land cell)

LAKE model

(Stepanenko & Lykossov 2005,
Stepanenko et al. 2011)

- Multilayer (~10) snow model with liquid moisture treatment
- Multilayer ice model (~10)
- Thermo- and hydrodynamics in water column (k-epsilon)
- Heat and moisture transfer in soil including permafrost
- Methane, carbon dioxide and oxygen production, diffusion and ebullition



K-ε turbulence closure in LAKE model

$$\overline{w'\phi'} = -k_\phi \frac{\partial \overline{\phi}}{\partial z}$$

- counter-gradient effects missing

Kolmogorov formula (1942)

$$k_M = C_e \frac{E^2}{\varepsilon}, \qquad C_e = C_e(M,N)$$

$$k_T = k_S = C_{eT} \frac{E^2}{\varepsilon}, \quad C_{eT} = C_{eT}(M,N)$$

M – friction frequency,
N – Brunt-Vaisala frequency

stability functions

k-ε parameterization

$$\frac{\partial E}{\partial t} = \frac{\partial}{\partial z}\left(\nu + \frac{k_M}{\sigma_E}\right)\frac{\partial E}{\partial z} + P + B - \varepsilon$$

$$\frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial z}\left(\nu + \frac{k_M}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial z} + \frac{\varepsilon}{E}\left(c_{1\varepsilon}P + c_{3\varepsilon}B - c_{2\varepsilon}\varepsilon\right)$$

Boundary conditions

$$-\frac{k_M}{\sigma_E}\frac{\partial E}{\partial z} = c_{we}\left(\frac{\tau_s}{\rho_w}\right)^{3/2}, \quad c_{we} \approx 100$$

$$-\frac{k_M}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial z} = \left(C_e^0\right)^{3/4}\frac{k_M}{\sigma_\varepsilon}\frac{E^{3/2}}{\kappa\left(z' + z_0\right)^2}$$

Ri-based diffusivity

- Parameterized velocity profile in the lake leads to *(Hendersson-Sellers, 1985)*

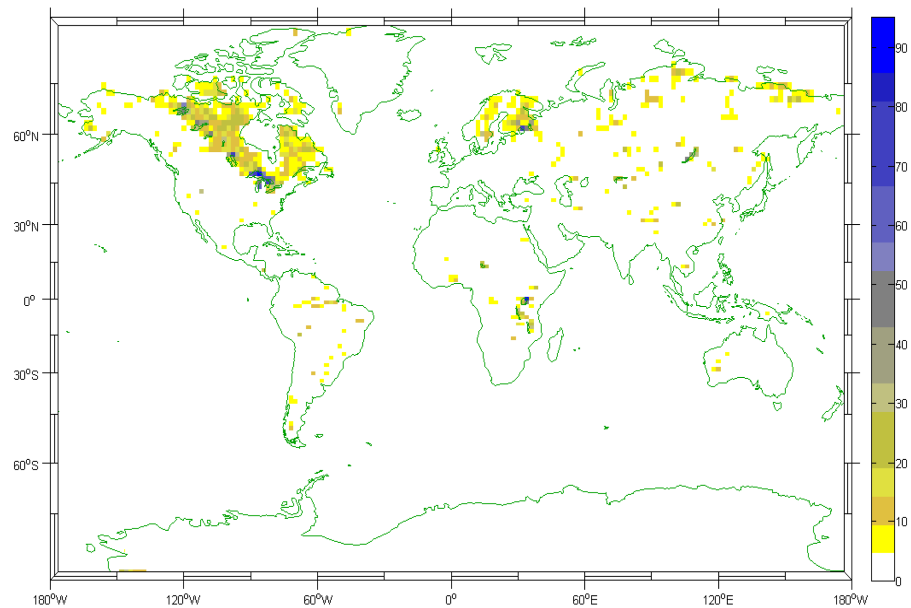
$$k_T = \frac{k w_s^* z}{Pr_0} \exp(-k^* z)(1 + Ri^2)^{-1}$$

$$Ri = \frac{-1 + \left[1 + 40 N^2 k^2 z^2 / (w_s^{*2} \exp(-2k^* z))\right]}{20}$$

- Good correspondence to many measurements in lakes
- No need for velocity profile calculation
- Allows for large time steps

Lake depth, lake map (global data)

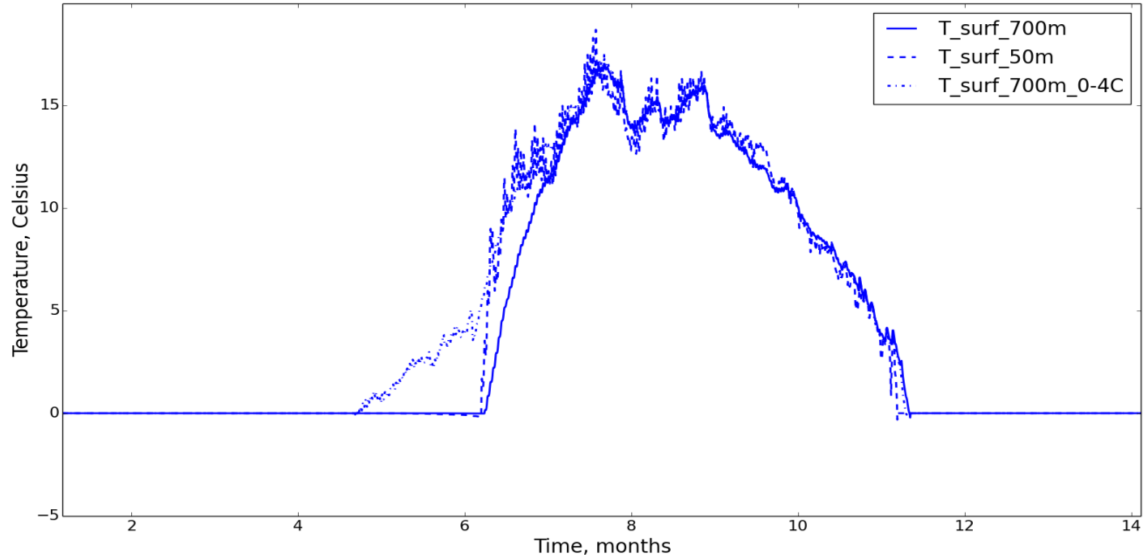
- A digital map of lakes is created: fraction of cells occupied by lakes and the average depth of the lakes in the cell.
- Map is based on the database, consisting of order 14000 freshwater lakes (Kourzeneva, et al. 2012).
- Old mask INMCM4 contains 13 types (1018 cells with lakes)
- New mask 14 types (2422 cells with lakes)



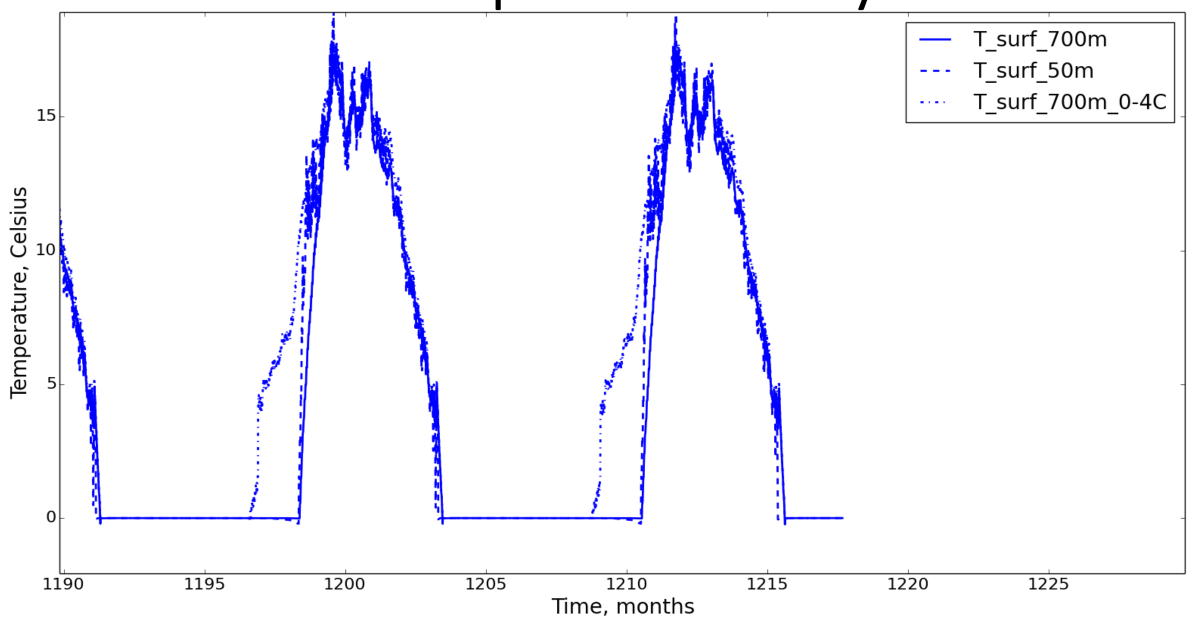
The problem of «deep lakes»

- Are 1D turbulence models capable to simulate large lakes?
- What is the minimum depth in a lake model sufficient to reproduce large lakes?
- Initial profiles?

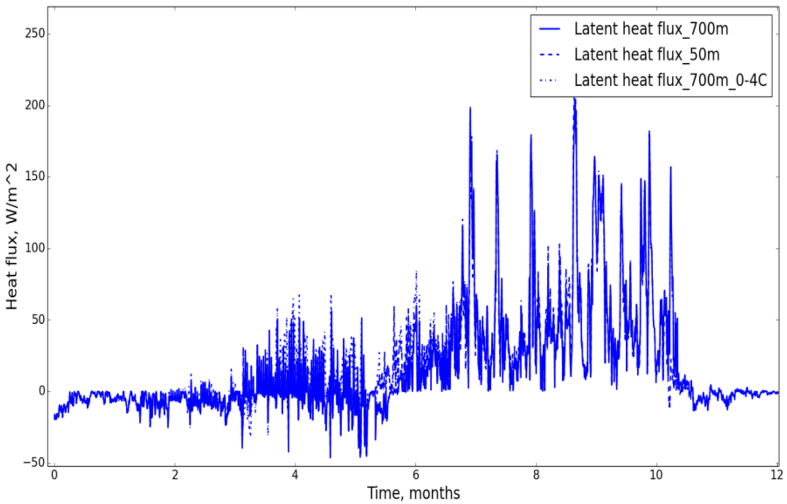
- Test for the lake with an average depth of 700 meters, 50 meters, for 100 years with periodical meteorological forcing



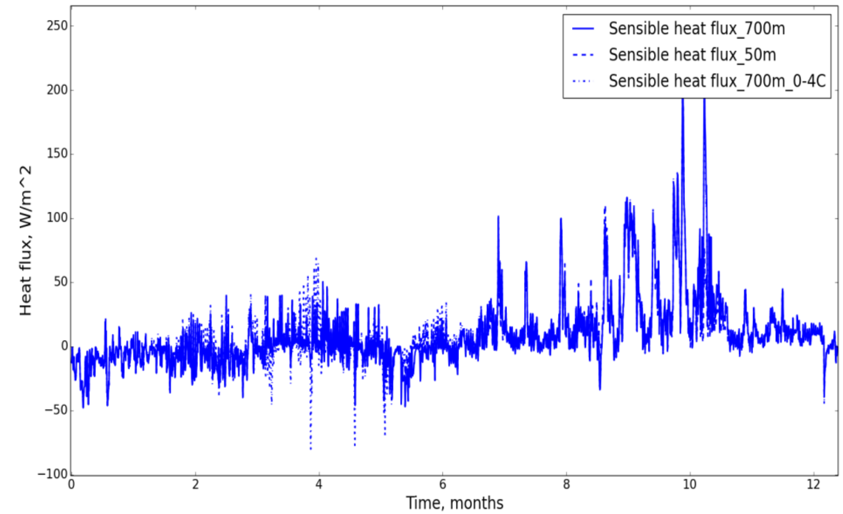
surface temperature first year



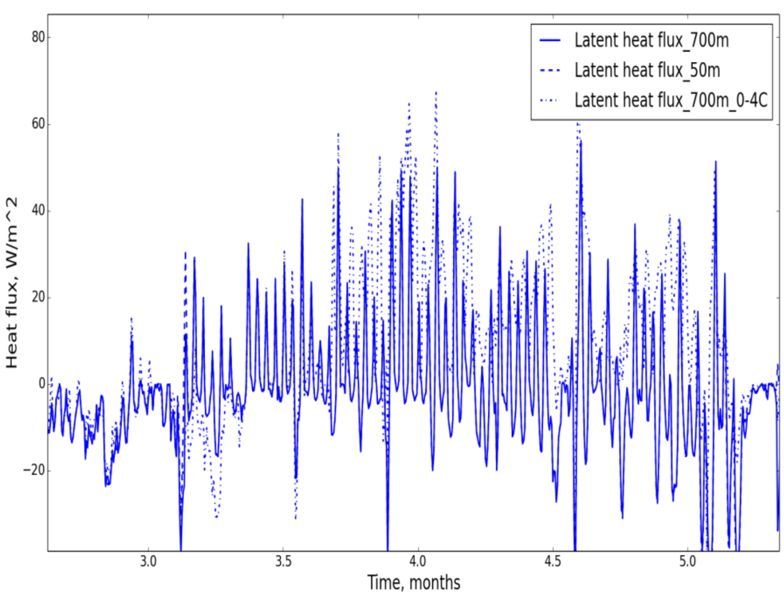
surface temperature last year



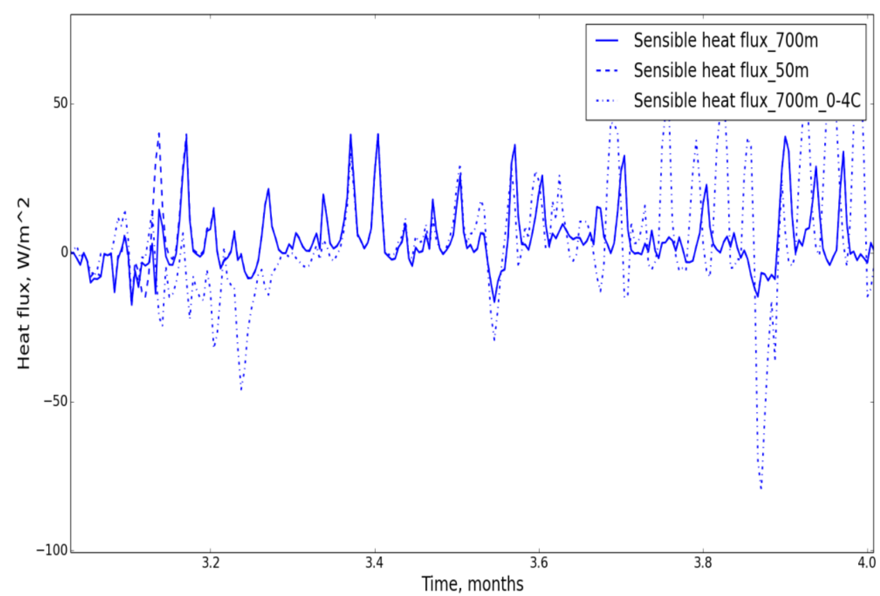
Latent heat flux for 1 year



Sensible heat flux for 1 year



Latent heat flux for 1 month



Sensible heat flux for 1 month

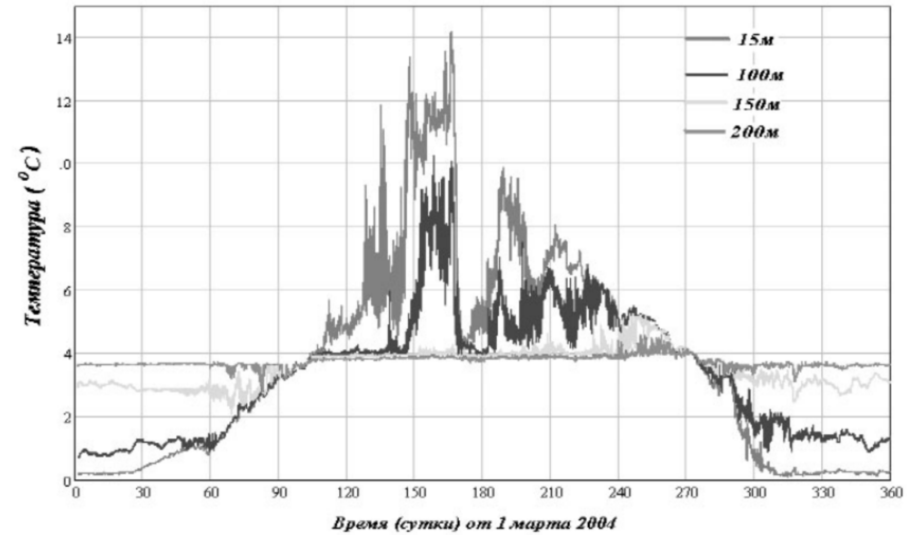
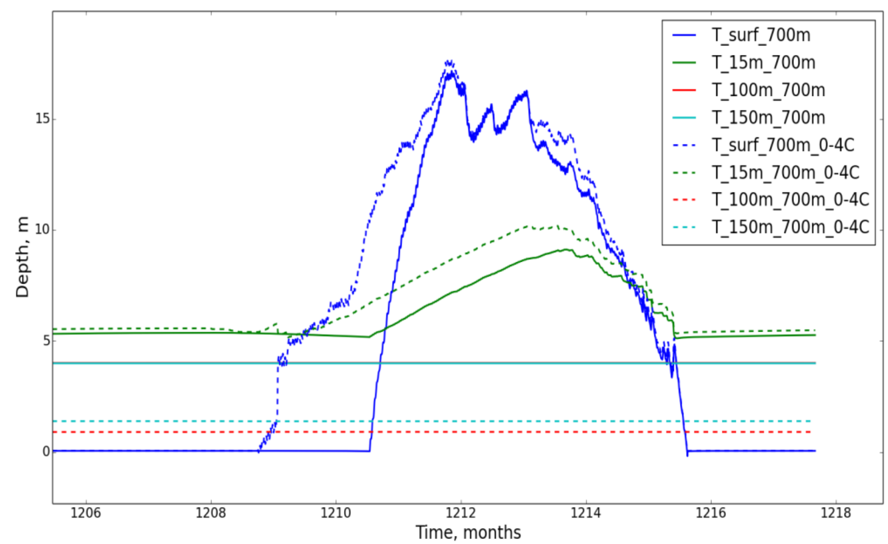


Рис. 4. *Зависимость температуры от времени на горизонтах 15–200 м*

Measurements: water temperature on levels 15-200 m.



Model: water temperature on levels 15-200 m.

Outlook

- Online implementation of thermodynamic lake model into INMCM 4
- Verification of the lake model in terms of methane and carbon dioxide concentration on concrete lakes (site level).
- Introduction of greenhouse lake model into INMCM4 climate model and verification of global CO_2 and CH_4 fluxes versus existent global freshwater flux estimates.

Thank!

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