Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Representation of Lakes in NWP Models ICON and COSMO: What We Have and What is Still Missing

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Outline

- Lake parameterization scheme FLake
- FLake within NWP models ICON and COSMO: configuration, operational performance, monitoring
- Is anything still missing?
- Conclusions and outlook

The Lake Parameterization Scheme "FLake"

The scheme (Mironov 2008, Mironov et al. 2010, Kirillin et al. 2011, http://lakemodel.net) is based on the idea of self-similarity (assumed shape) of the evolving temperature profile. 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*** (variables) that specify the temperature profile. These are (optional modules)

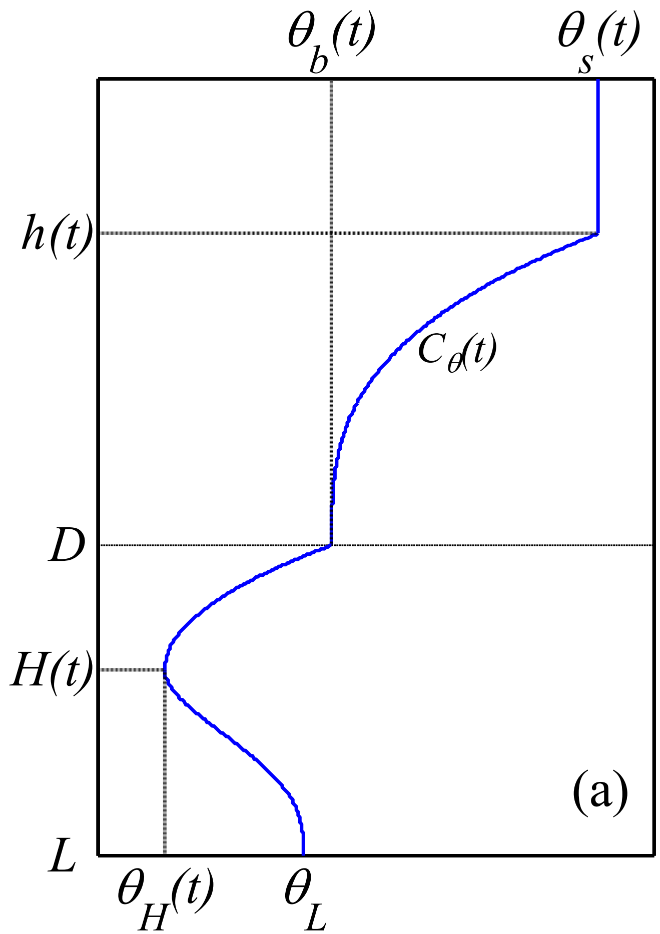
- the mean temperature of the water column,
- the surface temperature,
- the bottom temperature,
- the mixed-layer depth,
- the shape factor with respect to the temperature profile in the thermocline,
- the depth within bottom sediments penetrated by the thermal wave, and
- the temperature at that depth.

In case of ice-covered lake, additional prognostic variables are

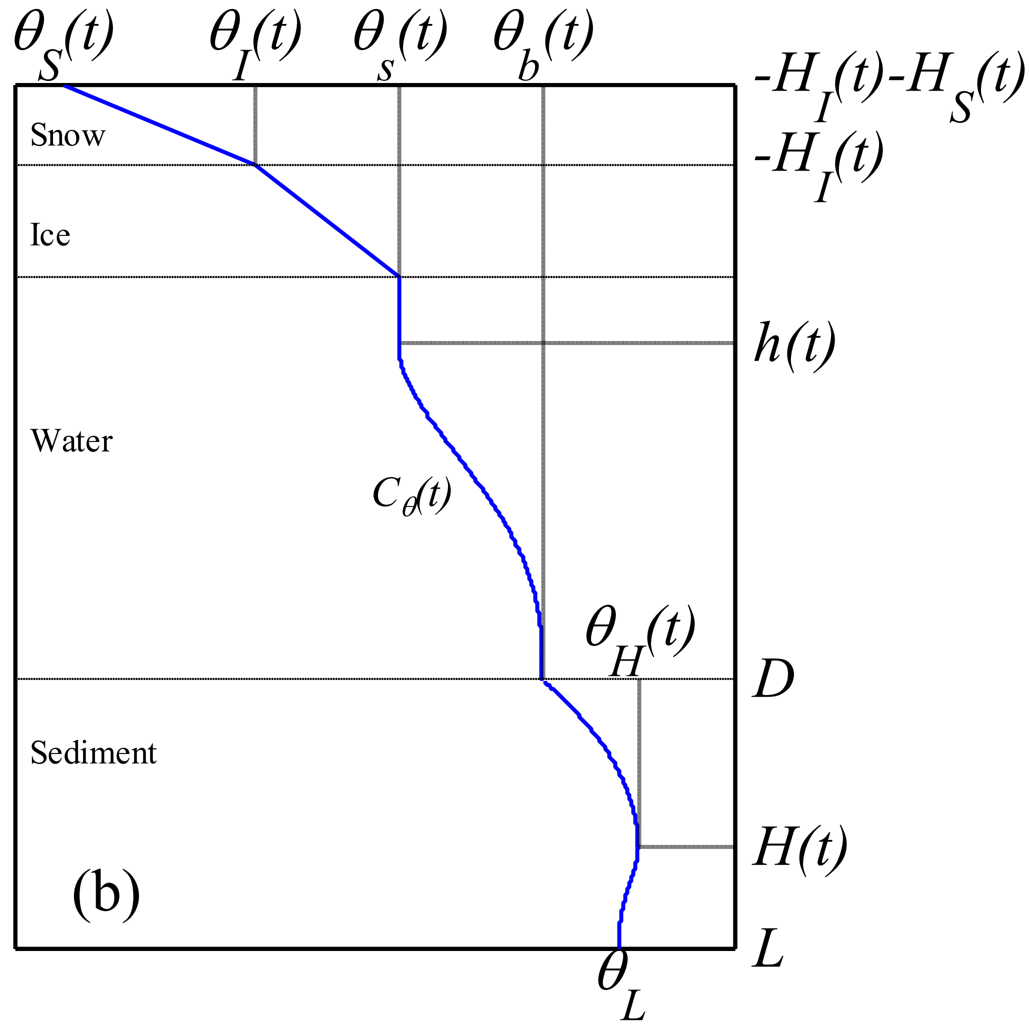
- the ice depth,
- the temperature at the ice upper surface,
- the snow depth, and the temperature at the snow upper surface.

Important! The scheme does not require (re-)tuning.

Schematic representation of the evolving temperature profile



(a) The evolving temperature profile is characterised by several time-dependent variables, namely, the temperature $\theta_s(t)$ of the mixed layer, its depth $h(t)$, the bottom temperature $\theta_b(t)$, and the temperature-profile shape factor $C_\theta(t)$. Optionally, the depth $H(t)$ within bottom sediments penetrated by the thermal wave and the temperature $\theta_H(t)$ at that depth can be computed.



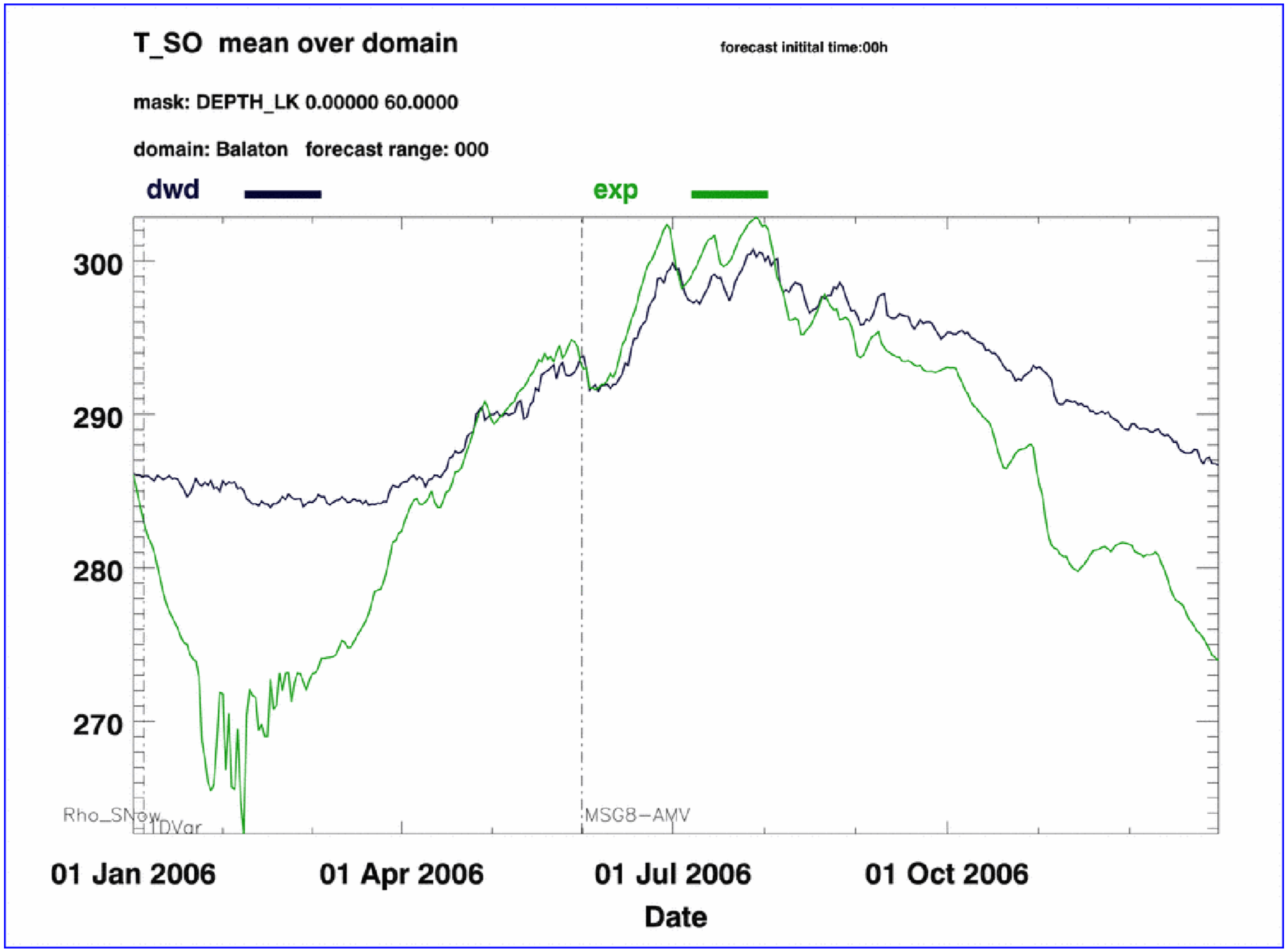
(b) For ice-covered lakes, additional variables are the temperature $\theta_I(t)$ at the ice upper surface and the ice thickness $H_I(t)$, and (optionally) the temperature $\theta_S(t)$ at the snow upper surface and the snow thickness $H_S(t)$.

FLake within COSMO-EU/DE (DWD)

Flake is used operationally at DWD since 15 December 2010 within COSMO-EU (ca. 7 km horizontal mesh size, no longer used), and since 18 April 2012 within COSMO-DE (ca. 2.8 km mesh size).

- Results of testing of COSMO-FLake are neutral to slightly positive.
- Verification against observational data indicate an improvement of some scores such as 2m-temperature in regions where many lakes are present (e.g. Scandinavia).
- The use of FLake allows to avoid some unwanted situations, e.g. an artificial cold air outbreak. This may occur in winter when a lake that is frozen in reality (low surface temperature) is treated as open water (high surface temperature) within COSMO due to the shortcomings of water surface temperature analysis scheme.

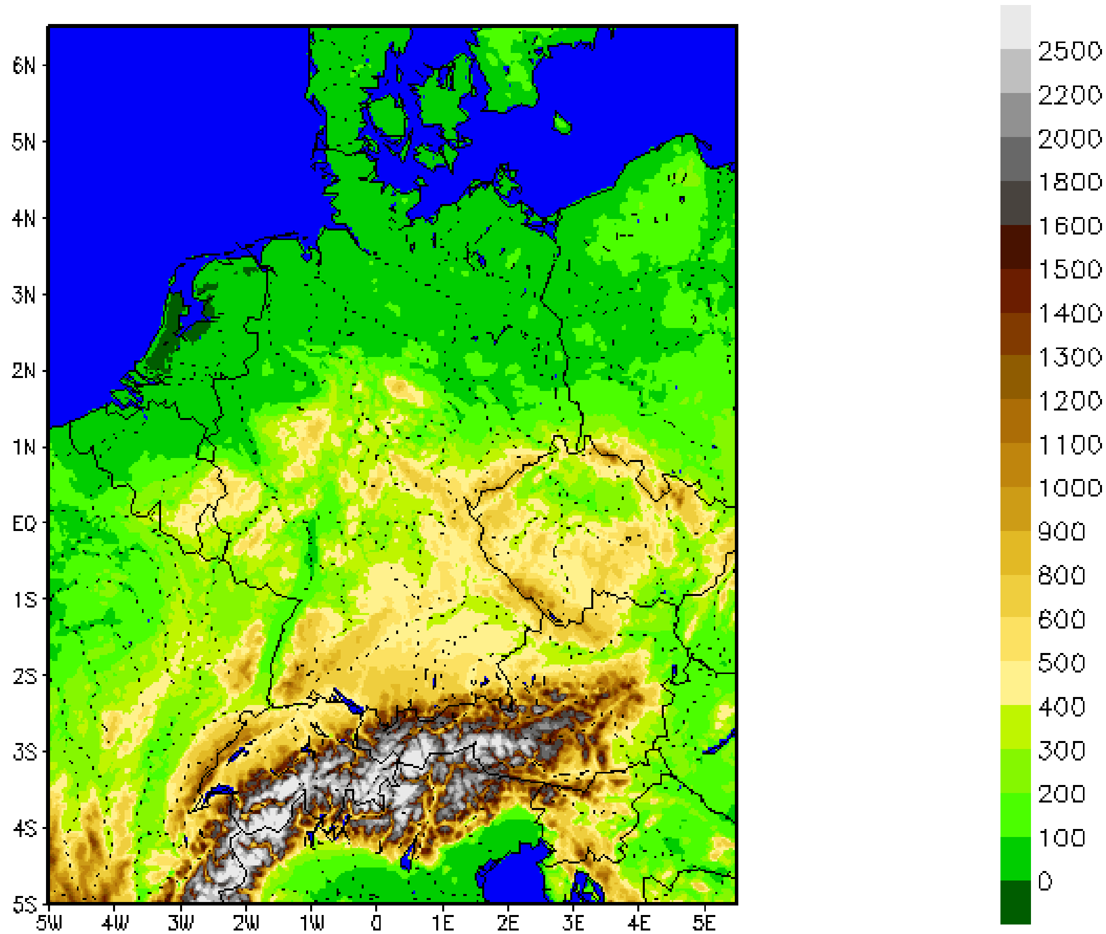
Results from Test Runs



FLake in COSMO, results from parallel experiment, 1 January - 31 December 2006.
Lake Balaton, Hungary (mean depth = 3.3 m)

- Black – lake surface temperature from the COSMO SST analysis
- Green – lake surface temperature computed with FLake

COSMO-DE Model Domain



Orography (height in m) of the operational domain of the COSMO-DE at DWD (horizontal mesh size ca. 2.8 km).

FLake within ICON-NWP (DWD)

<u>Flake is used operationally</u> at DWD since 20 January 2010 within ICON-NWP (ca. 13 km horizontal mesh size globally, ca. 7 km mesh size in ICON-EU Nest)

- Tiled surface scheme is currently used, effect of SGS lakes with FR_LAKE>0.05 is accounted for
- The performance of FLake within ICON is satisfactory

ICON Global and ICON-EU Nest

Horizontal mesh size is ca. 13 km in ICON- NWP global, and ca. 7 km in ICON-EU Nest.

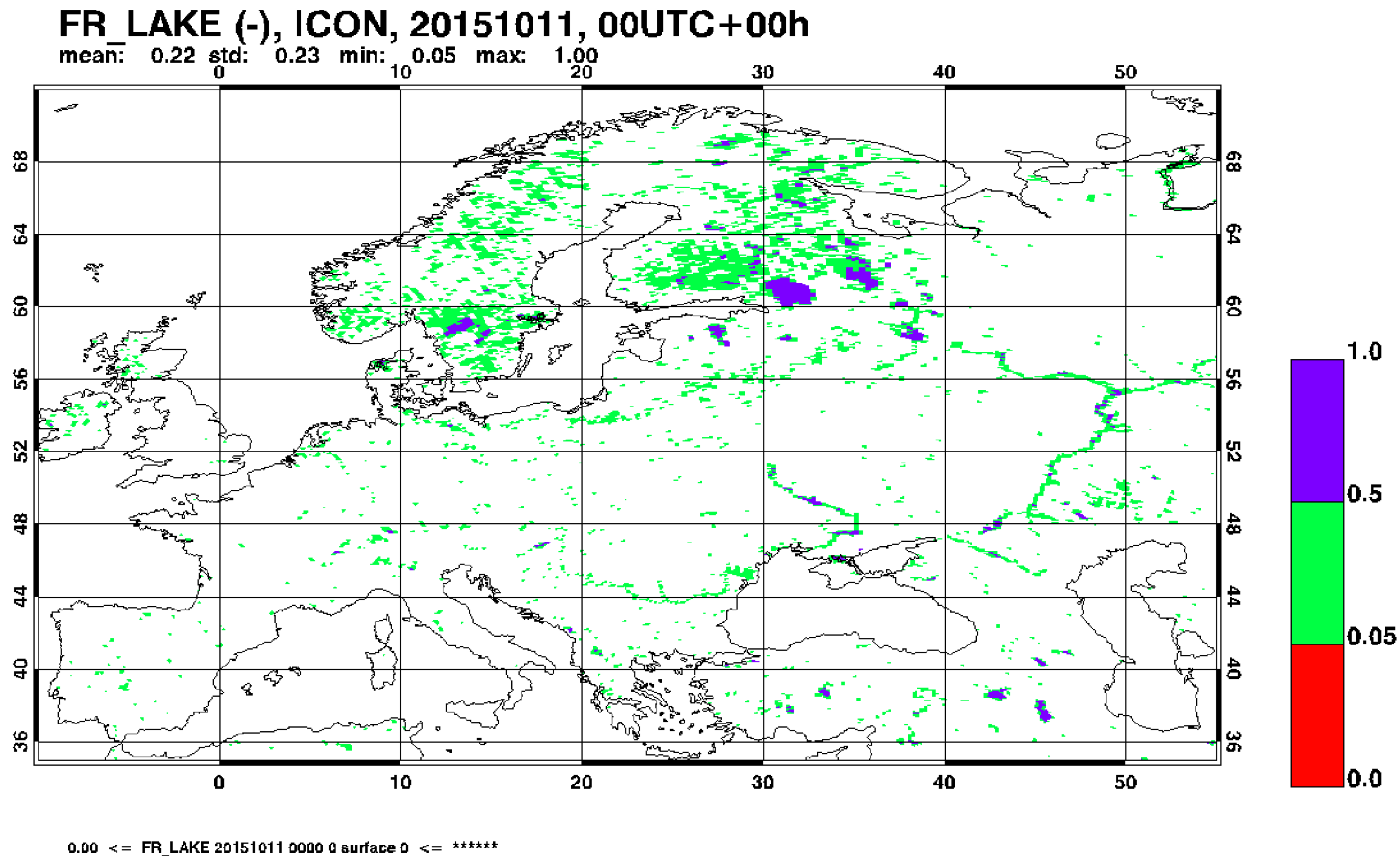
External Parameters

- **lake fraction** (area fraction of an atmospheric model grid box covered by lake water)
- **lake depth**

Data set is developed by Kourzeneva (2010), Kourzeneva et al. (2012), and Choulga et al. (2014).

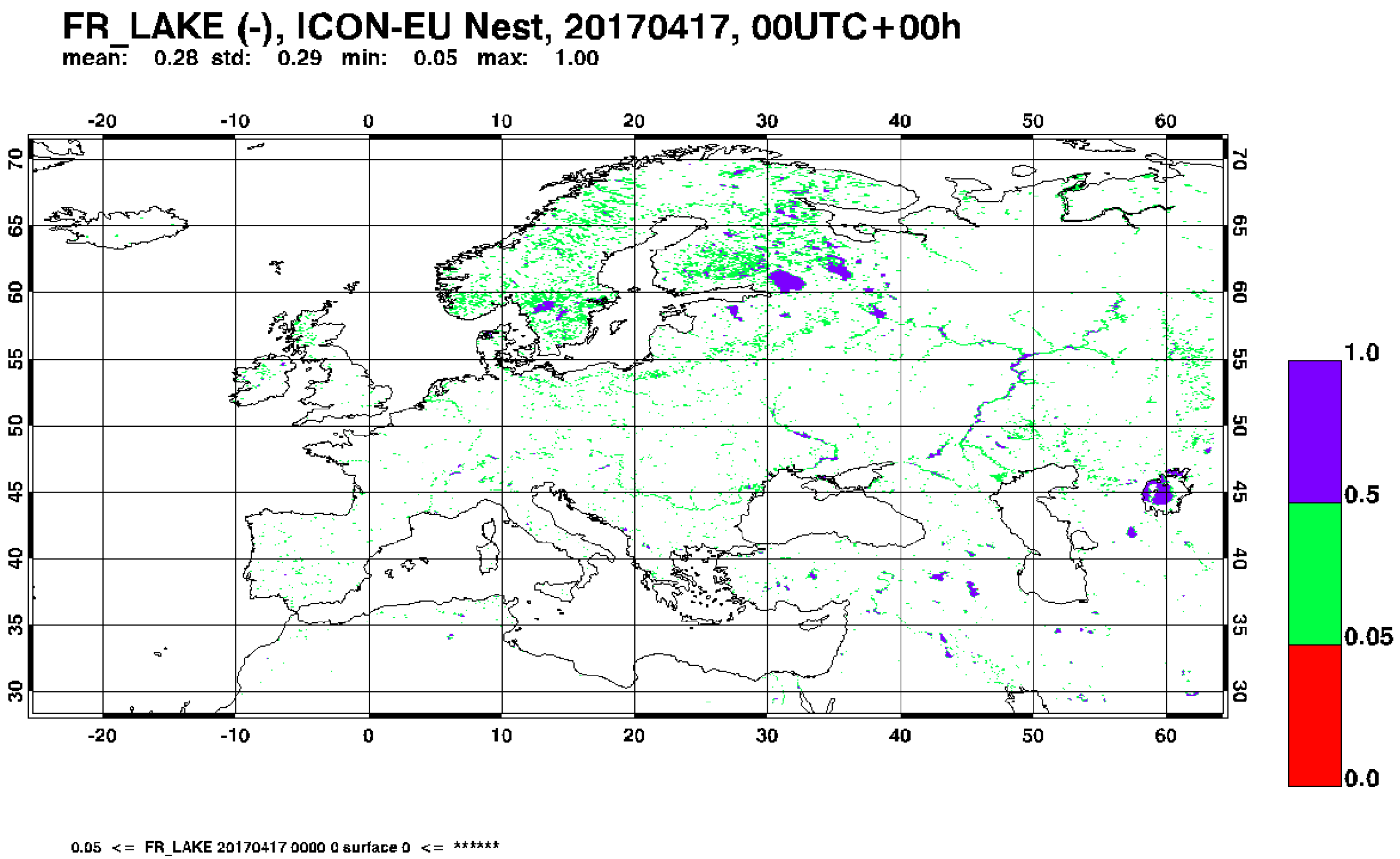
- Default values of wind fetch, optical characteristics of lake water (extinction coefficients with respect to solar radiation), depth of the thermally active layer of bottom sediments and temperature at that depth (not needed if bottoms sediment module is switched off)

Lake Fraction (ICON)



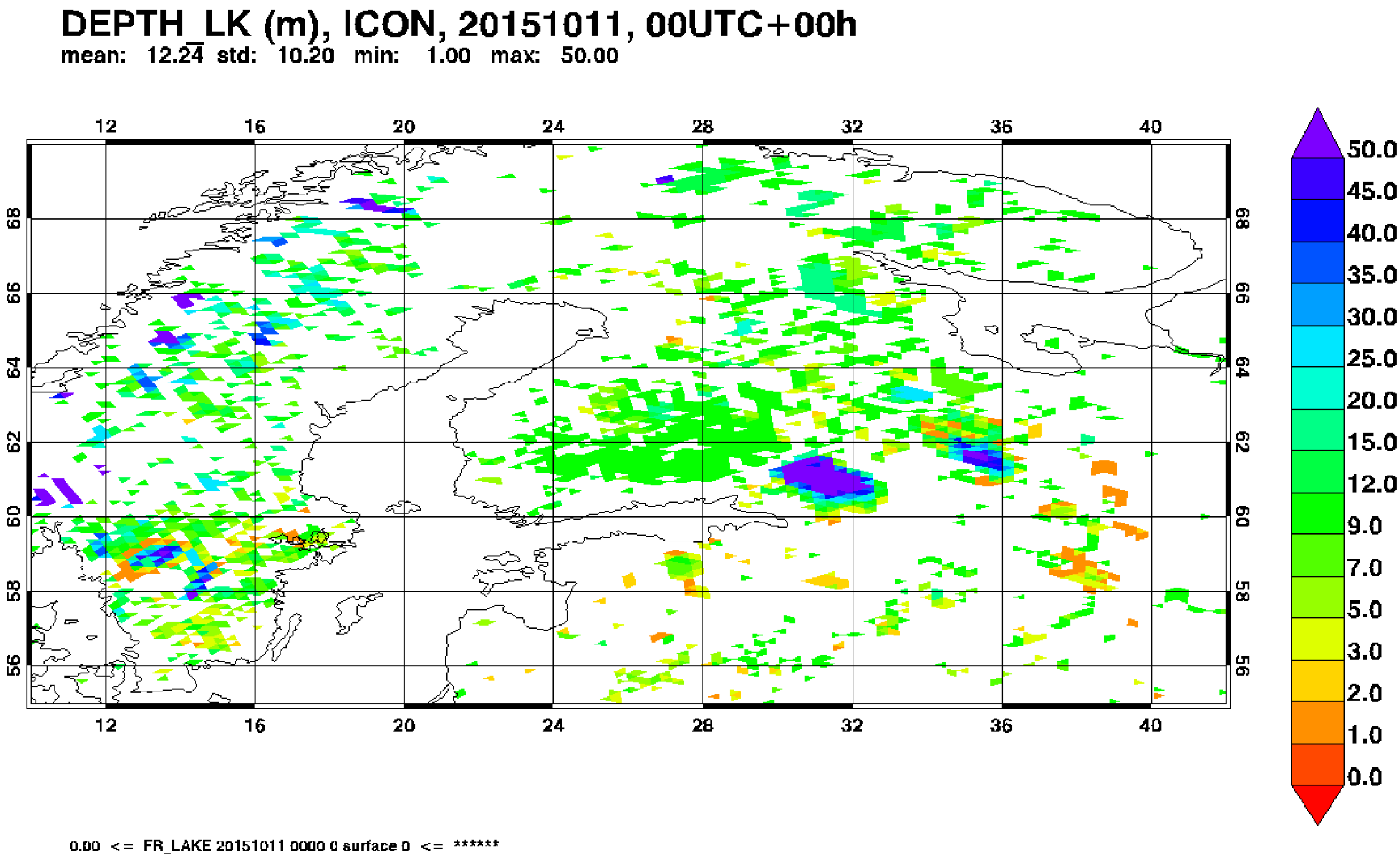
Lake fraction external-parameter field for ICON global with ca. 13 km horizontal mesh size.

Lake Fraction (ICON-EU)



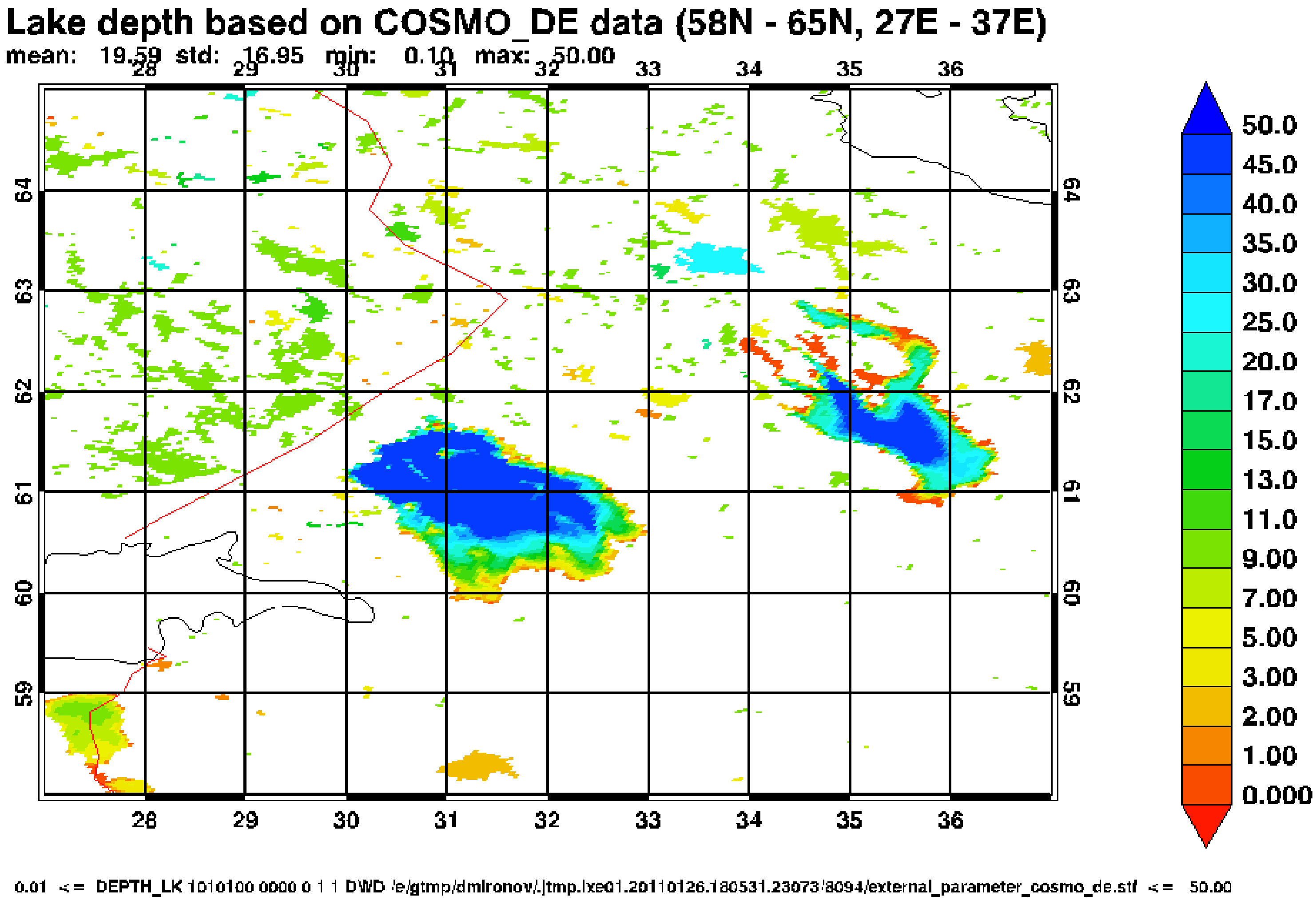
Lake fraction external-parameter field for ICON-EU Nest with ca. 7 km horizontal mesh size.

Lake Depth (ICON)



Lake depth external-parameter field for ICON global with ca. 13 km horizontal mesh size.

Lake Depth (COSMO)



Lake depth external-parameter field for COSMO with ca. 2.8 km horizontal mesh size.

FLake within COSMO and ICON: Configuration

- Bottom sediment module is switched off (bottom heat flux is zero), maximum lake depth of 50 m
- Snow above the lake ice is not considered explicitly, the effect of snow is accounted for implicitly through the temperature dependence of the ice surface albedo (Mironov et al. 2012)
- Turbulent fluxes at the surface are computed with the current COSMO/ICON surface-layer scheme (Raschendorfer 2001)
- No tile approach in COSMO: lakes are the COSMO-model grid-boxes with FR_LAKE>0.5, otherwise land or sea water
- Tile approach in ICON: all lakes with FR_LAKE>0.05 are considered

Lake Ice Albedo Parameterization

Lake ice albedo is a function of the ice surface temperature.

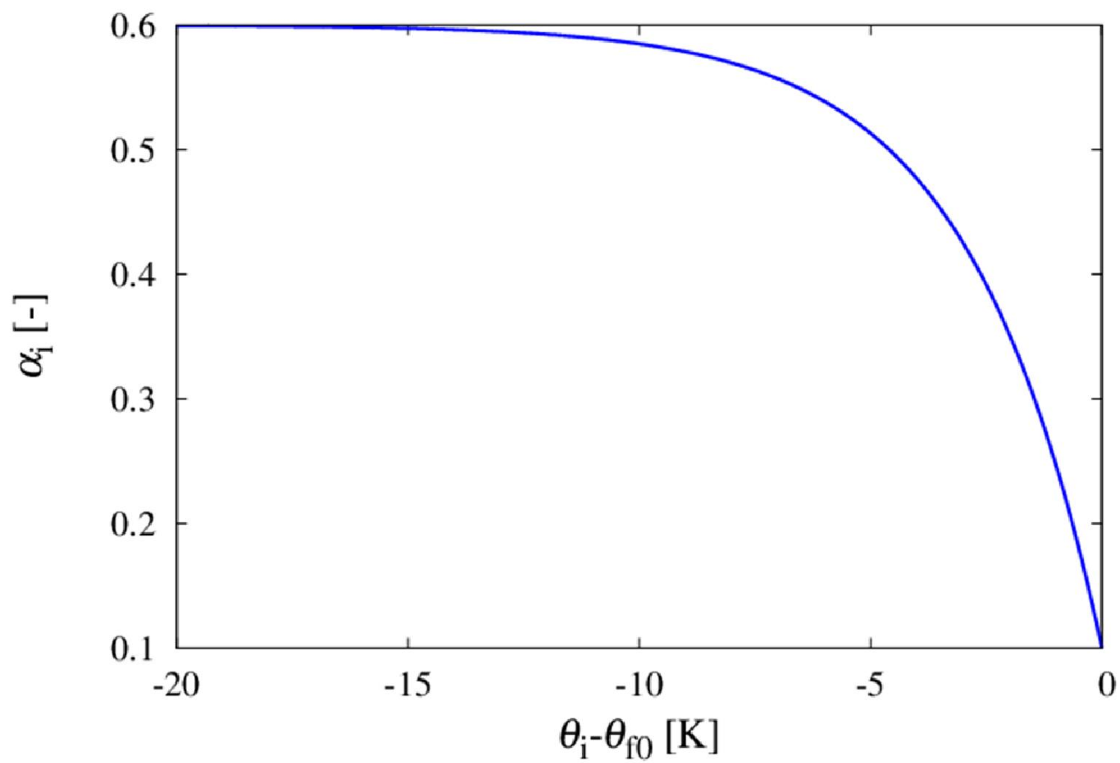
$$\alpha_i = \alpha_i^{max} - \left(\alpha_i^{max} - \alpha_i^{min}\right)\exp\left[-C_\alpha \frac{\theta_{f0}-\theta_i}{\theta_{f0}}\right],$$

θ_{f0}=273.15 K

C_α=95.6

α_i^{min}=0.1

$\alpha_i^{max} = 0.6$



Assimilation of Ice-Fraction Data (Günther Zängl)

(see also talk of Mironov and Machulskaya at Lake 12 workshop, Helsinki)

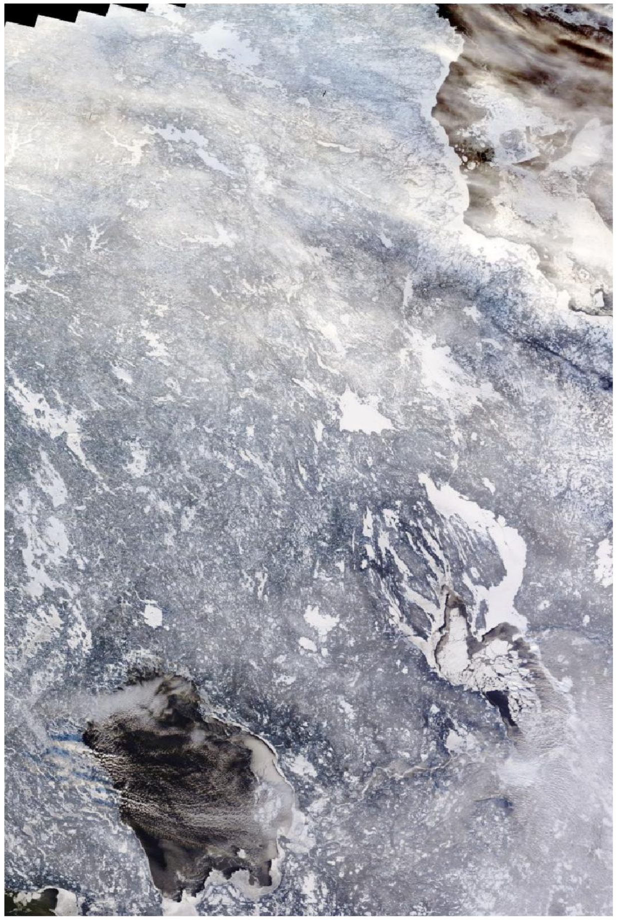
Within ICON, data on ice fraction are used to correct the ice thickness and the ice temperature (currently for the Laurentian Great Lakes only)

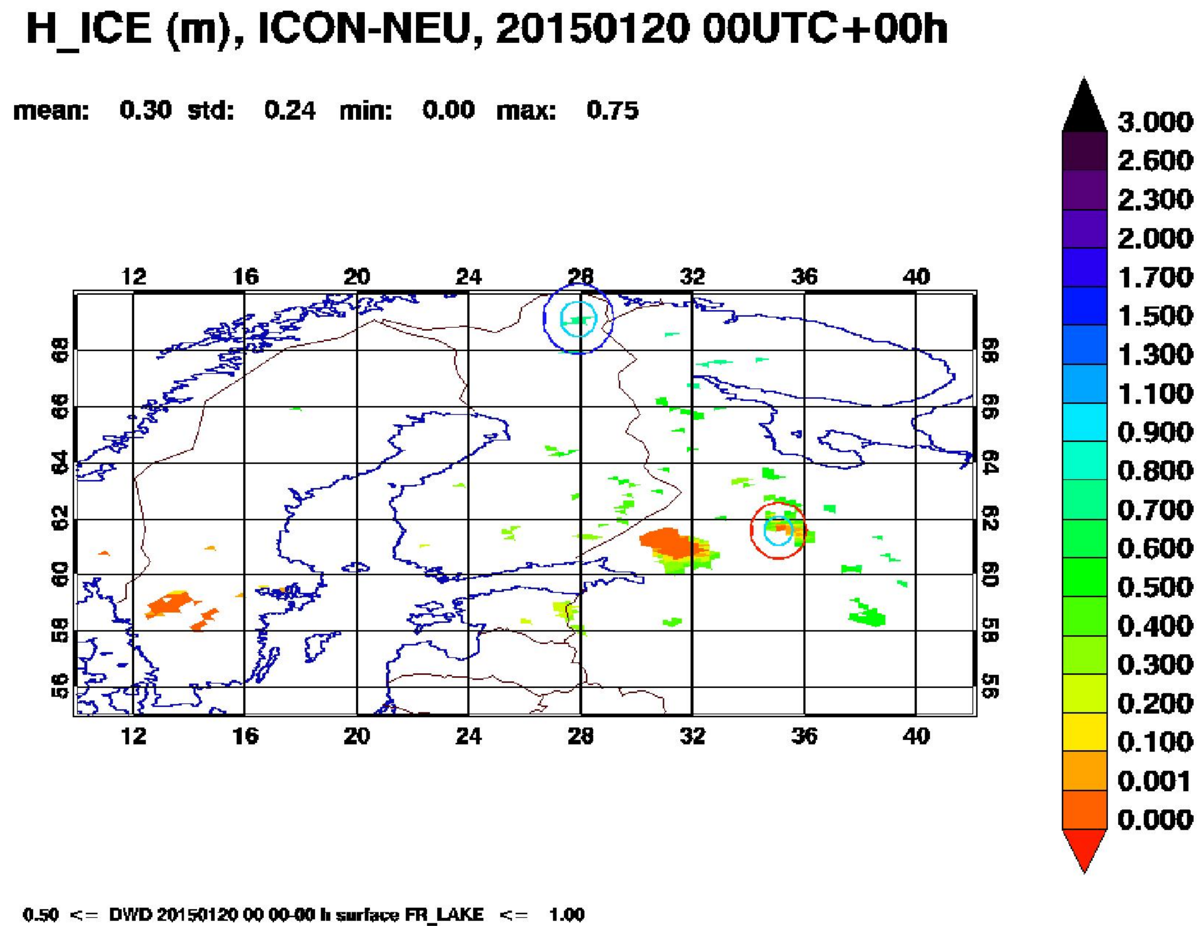
During the initialization of the ICON run, H_ICE (m) and T_ICE (K) are adjusted on the basis of observed ice fraction FR_ICE :

- **FR_ICE<0.03**: if there is ice in the first guess, remove it, i.e. set H_ICE=0 and the ice surface temperature to the freezing point, T_ICE=273.15
- **0.05<FR_ICE**: if there is no ice in the first guess, create new ice (H_ICE=0.025* FR_ICE) and set T_ICE=273.15
- **0.05<FR_ICE<0.75**: reduce H_ICE as needed (H_ICE=<0.1*FR_ICE), set T_ICE=273.15 for thin ice (H_ICE<0.01)
- N.B. The water temperature beneath the ice is adjusted accordingly

Within COSMO, no data are assimilated into FLake (e.g. freeze-up and break-up of lakes occurs freely)

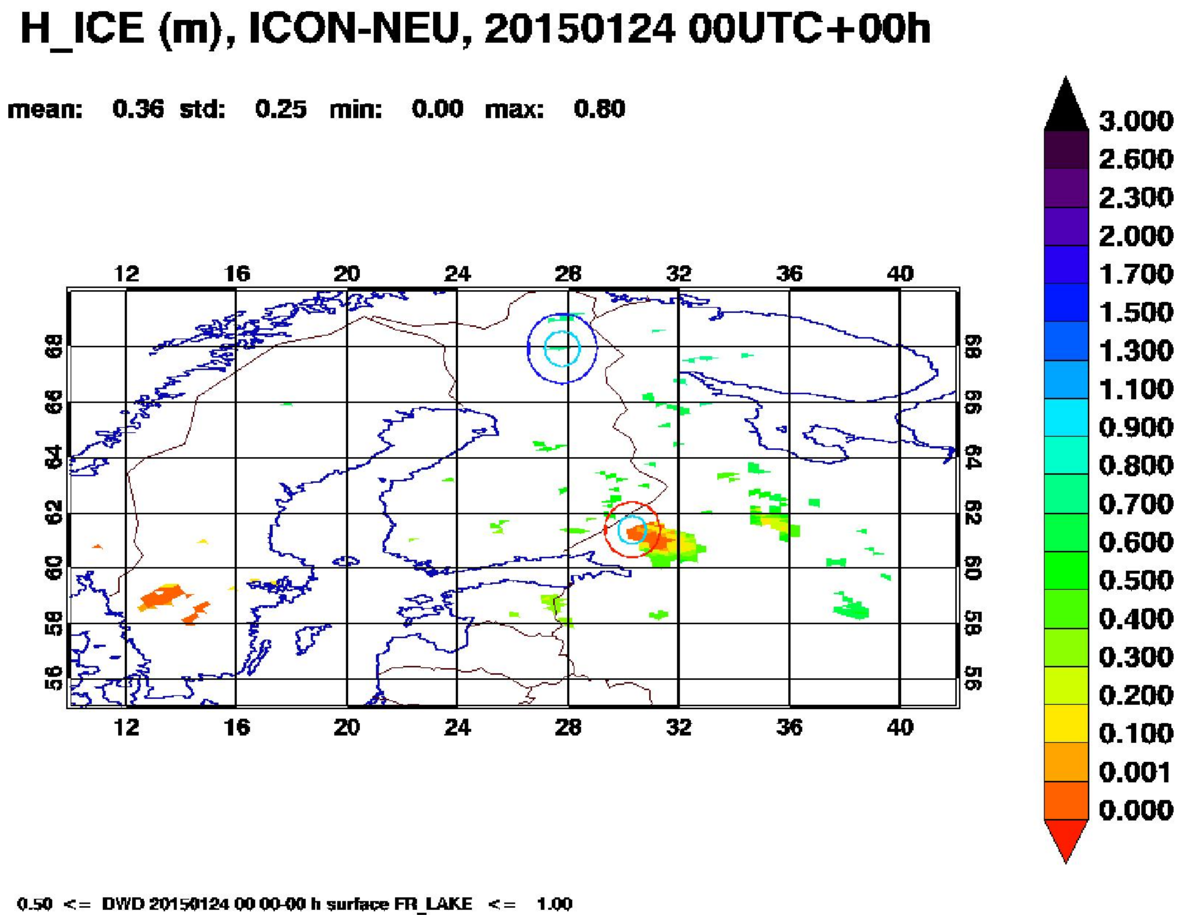
ICON Results vs. Observations





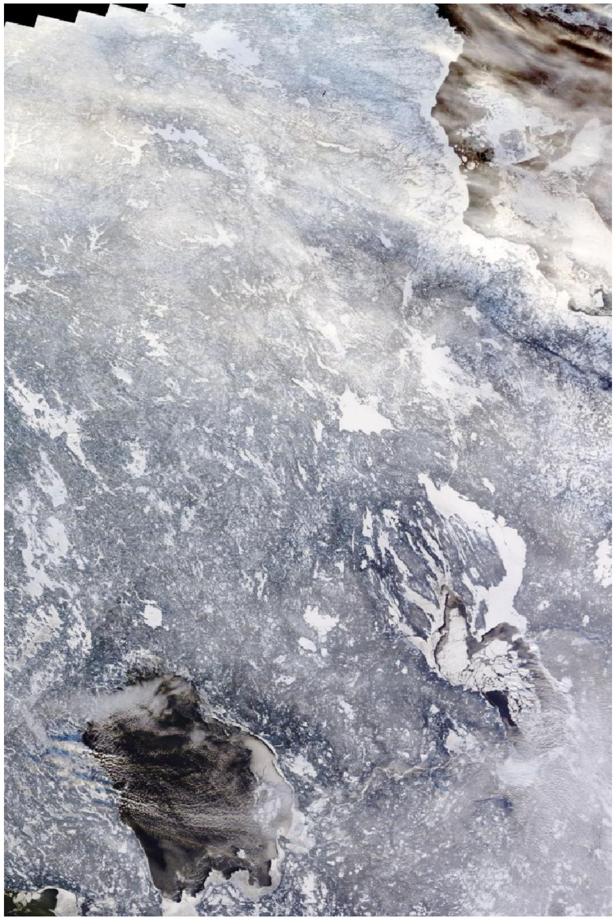
Lake Ladoga and Lake Onega ice cover, 20 January 2015. Satellite data (http://lance-modis.eosdis.nasa.gov/imagery/subsets/?subset=Karelia.2015020.terra.250m.jpg) vs. ICON forecast.

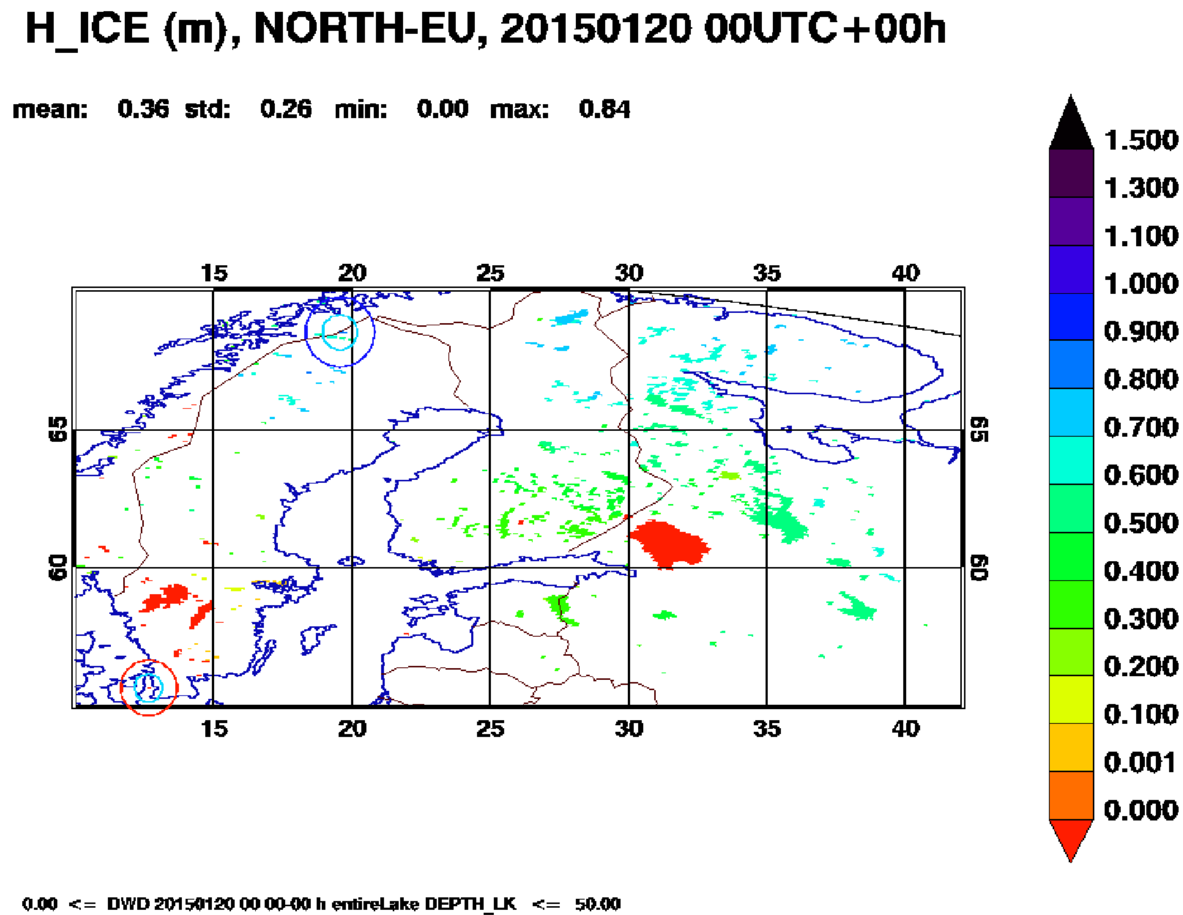
ICON Results vs. Observations



Lake Ladoga and Lake Onega ice cover, 24 January 2015. Satellite data (http://lance-modis.eosdis.nasa.gov/imagery/subsets/?subset=Karelia.2015024.terra.250m.jpg) vs. ICON forecast.

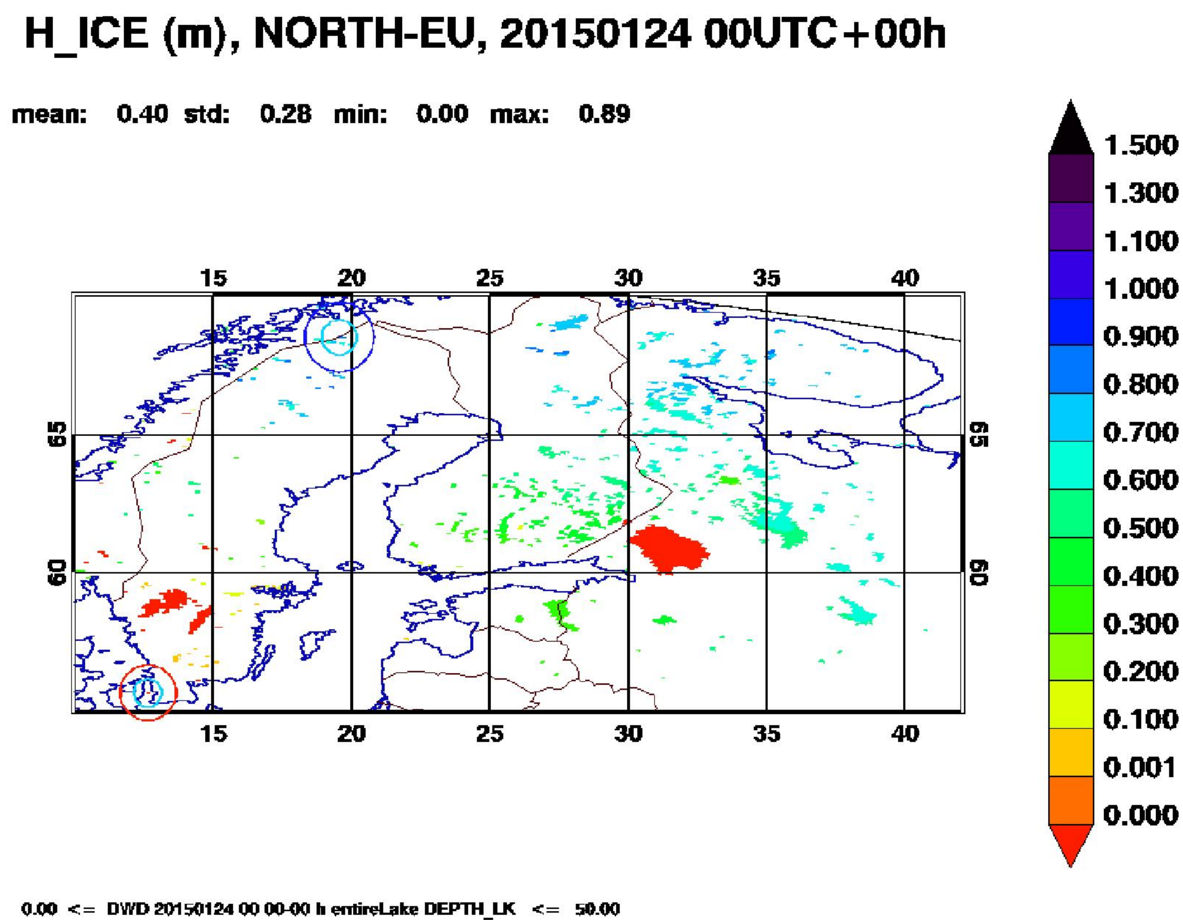
Importance of External Parameters





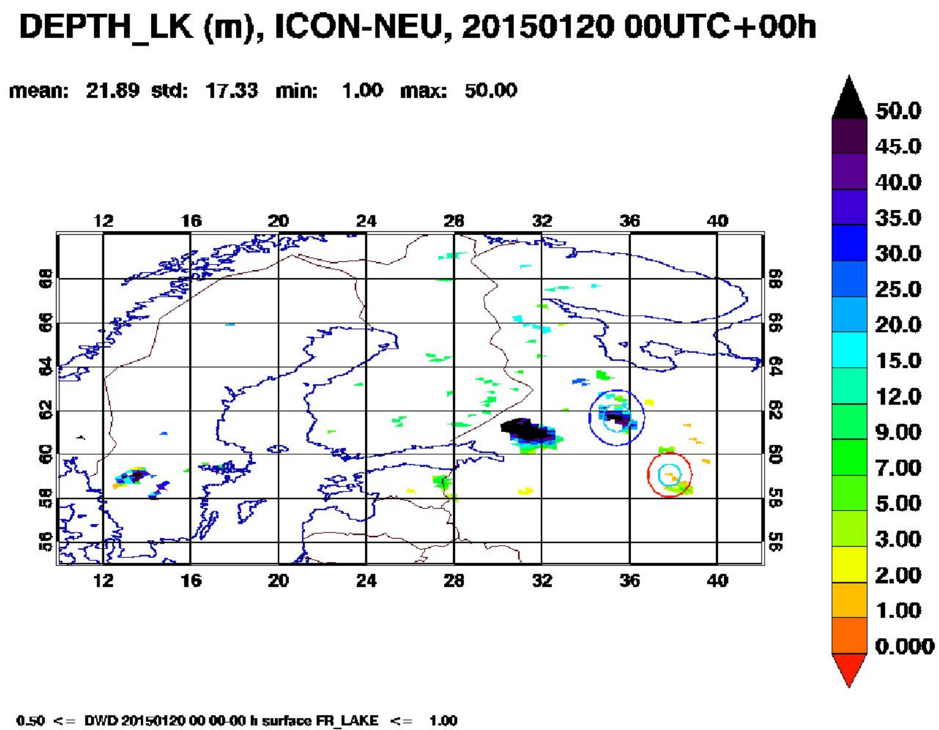
Lake Ladoga and Lake Onega ice cover, 20 January 2015. Satellite data (http://lance-modis.eosdis.nasa.gov/imagery/subsets/?subset=Karelia.2015020.terra.250m.jpg) vs. COSMO-EU forecast.

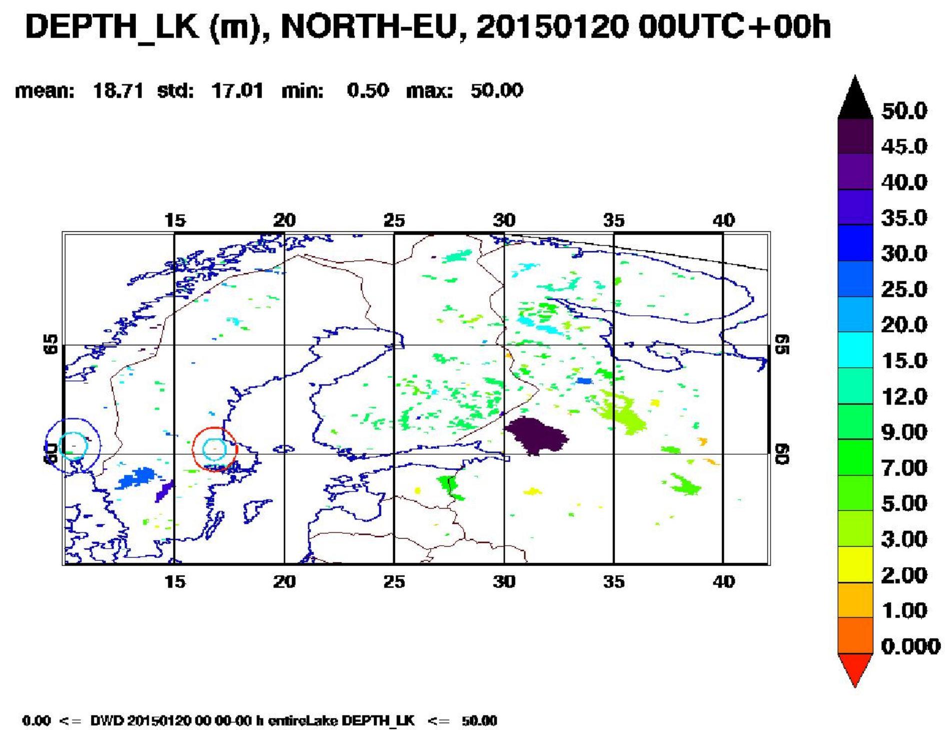
Importance of External Parameters (cont'd)



Lake Ladoga and Lake Onega ice cover, 24 January 2015. Satellite data (http://lance-modis.eosdis.nasa.gov/imagery/subsets/?subset=Karelia.2015024.terra.250m.jpg) vs. COSMO-EU forecast.

Importance of External Parameters (cont’d)





Lake-depth external-parameter field

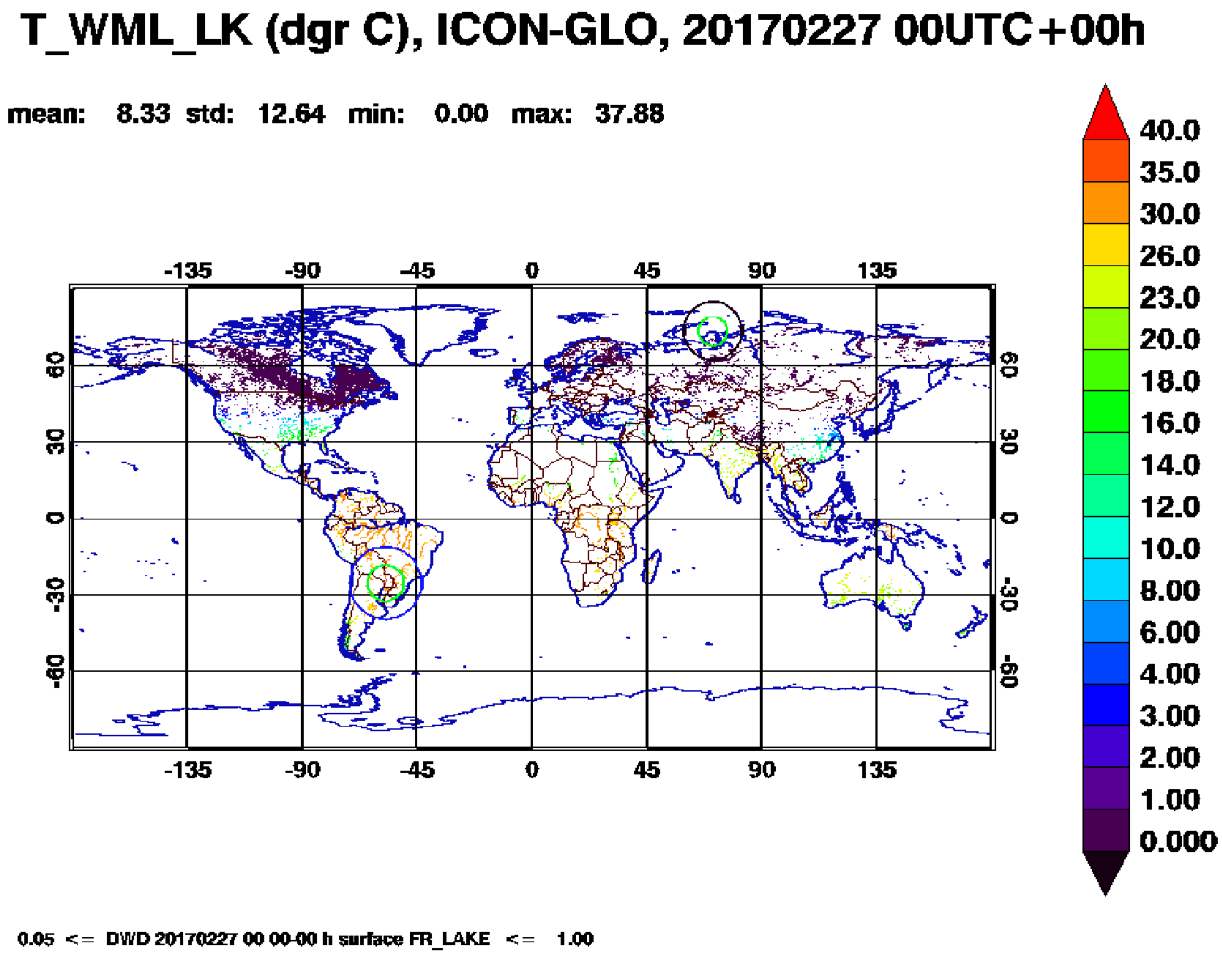
in ICON – left left and COSMO-EU – right

(Kourzeneva 2010, Kourzeneva et al. 2012, Choulga et al. 2014).

Monitoring of FLake Performance

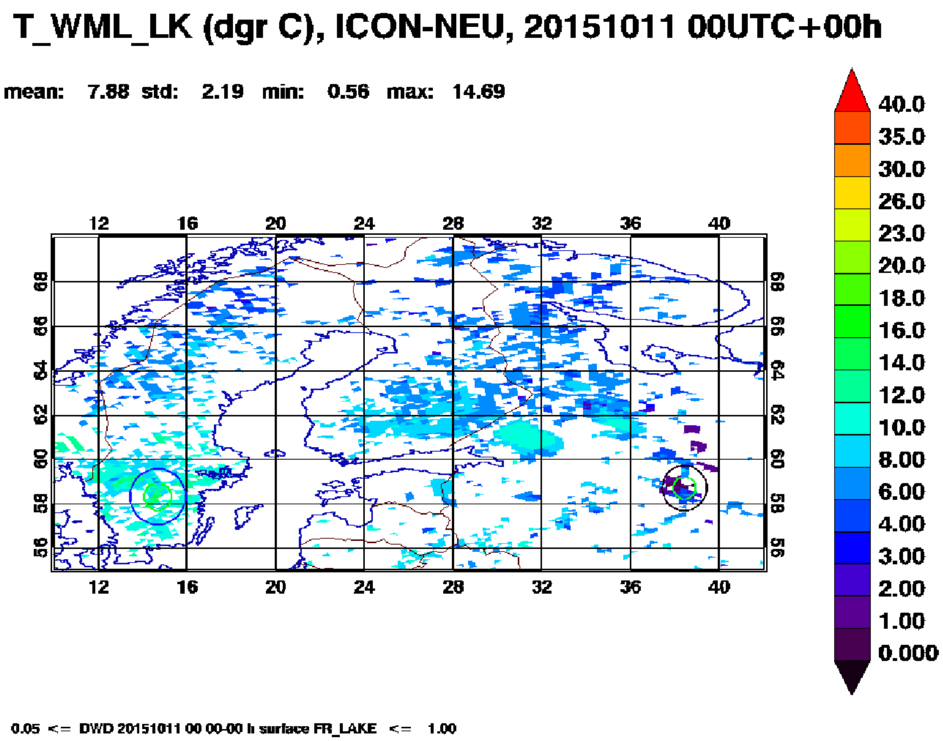
- FLake prognostic variables (+ surface fluxes) are retrieved from the DWD data bank (initial values form 00 UTC) and plotted
- Sanity check is performed and a warning e-mail message is sent if things go wrong (OK is sent if things look good)
- Monitoring results from the last week are available via DWD Intranet, results from the last months are stored in the archive

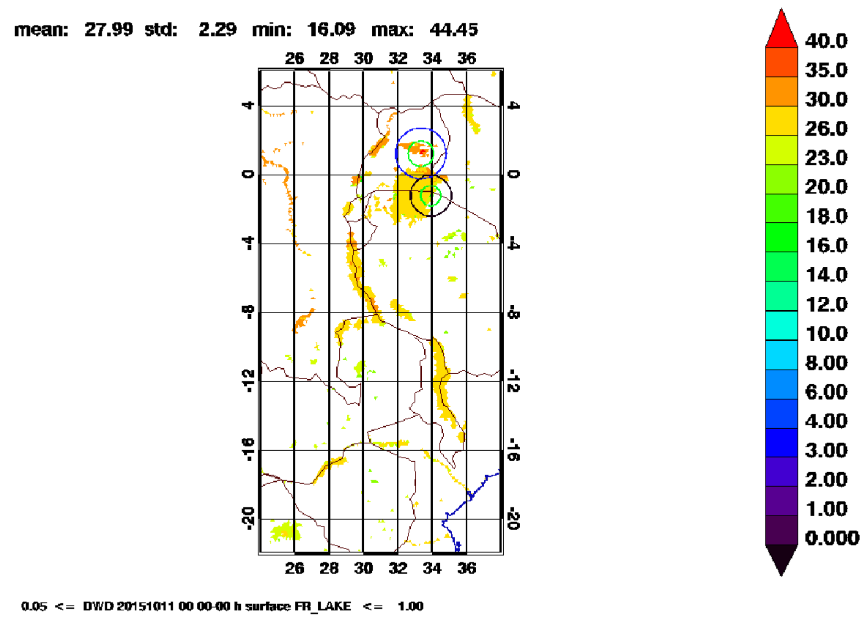
FLake within ICON



Mixed-layer temperature (dgr C) from ICON Global, 27 February 2017, 00UTC.

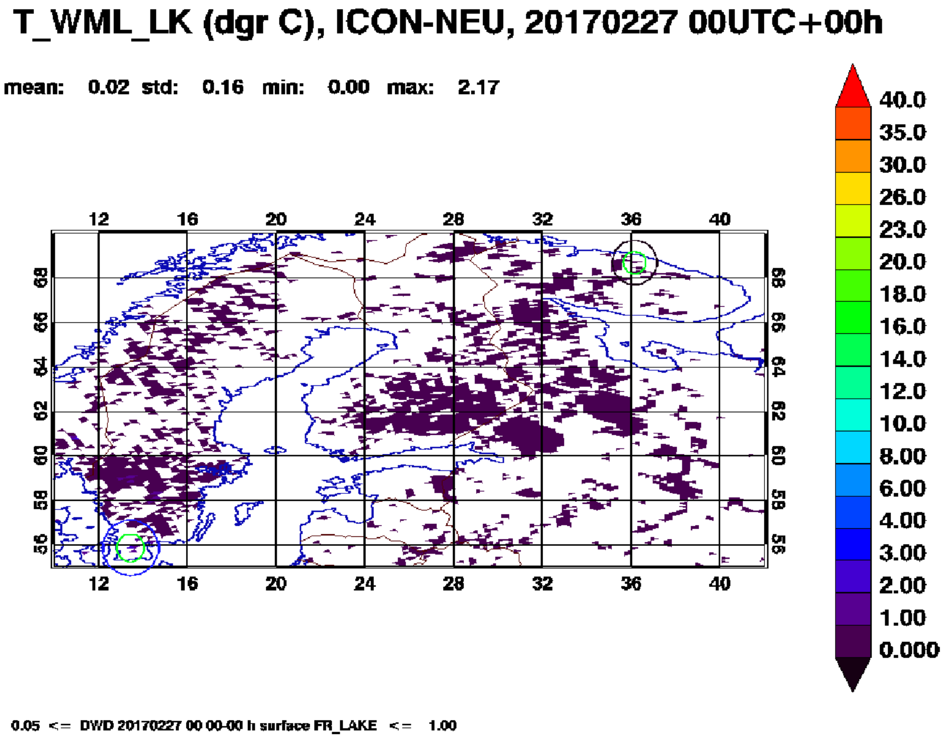
FLake within ICON

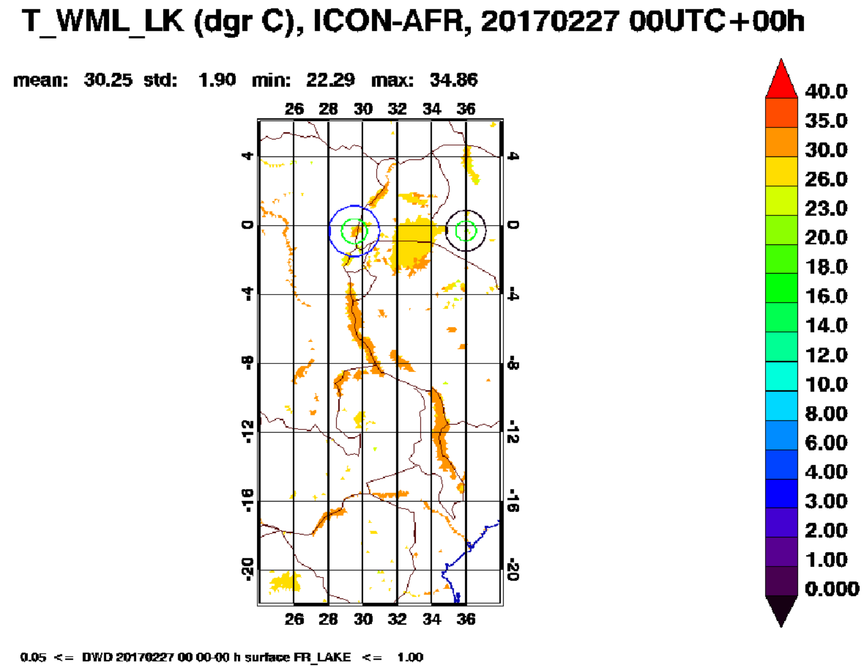




Mixed-layer temperature (dgr C) from ICON, 11 October 2015, 00UTC. Left panel – Norther Europe, right panel – Central Africa.

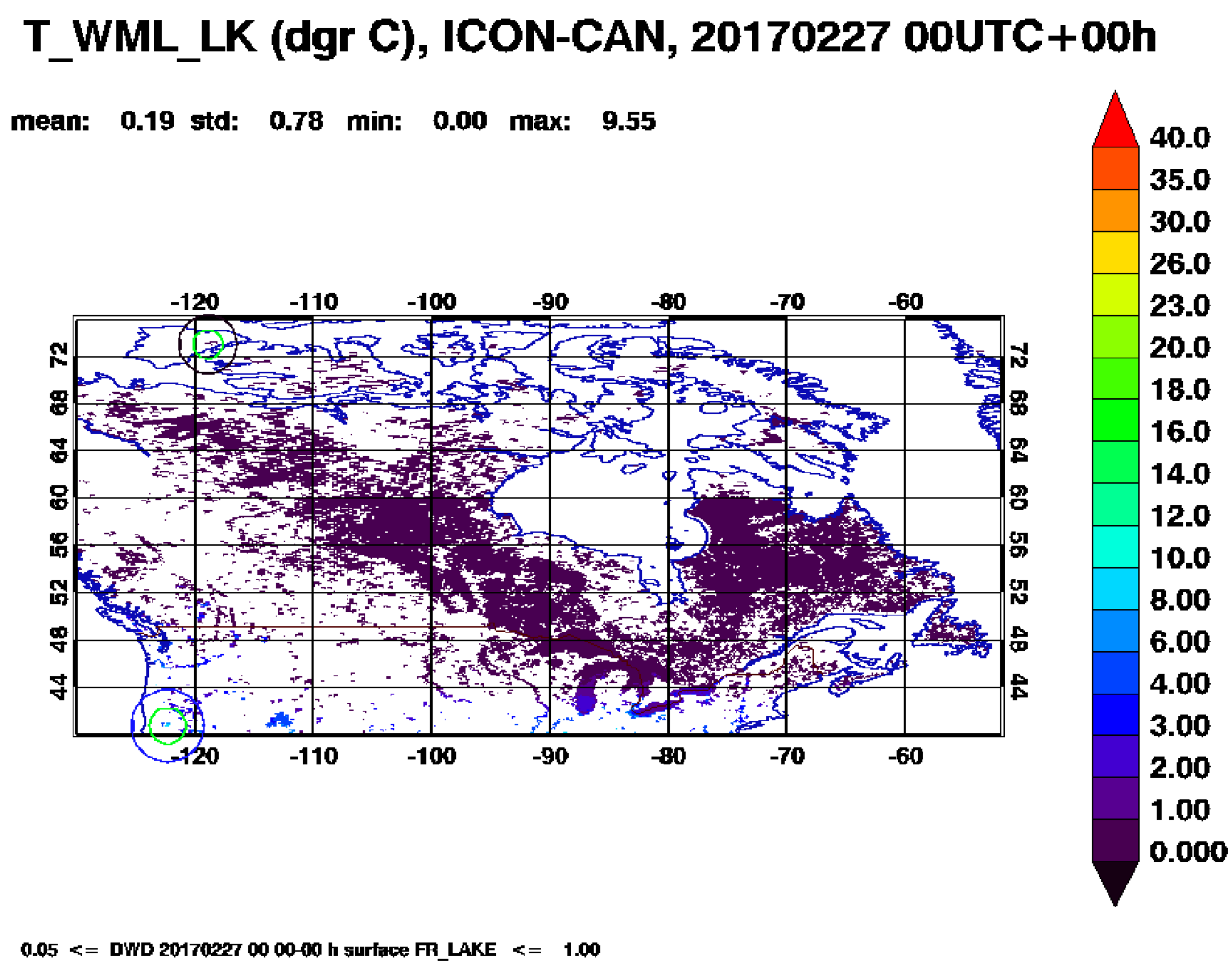
FLake within ICON





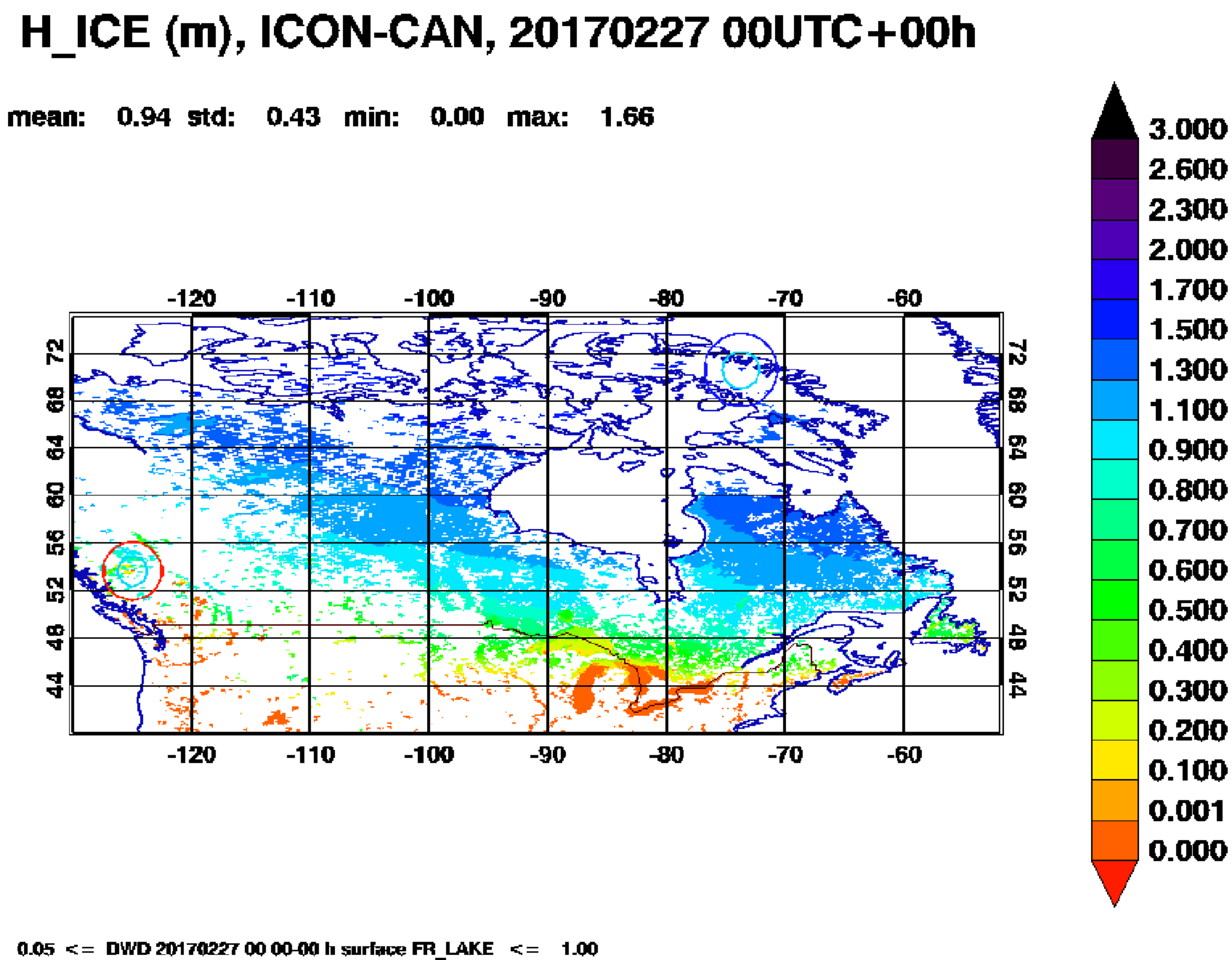
Mixed-layer temperature (dgr C) from ICON, 27 February 2017, 00UTC. Left panel – Norther Europe, right panel – Central Africa.

FLake within ICON (cont'd)



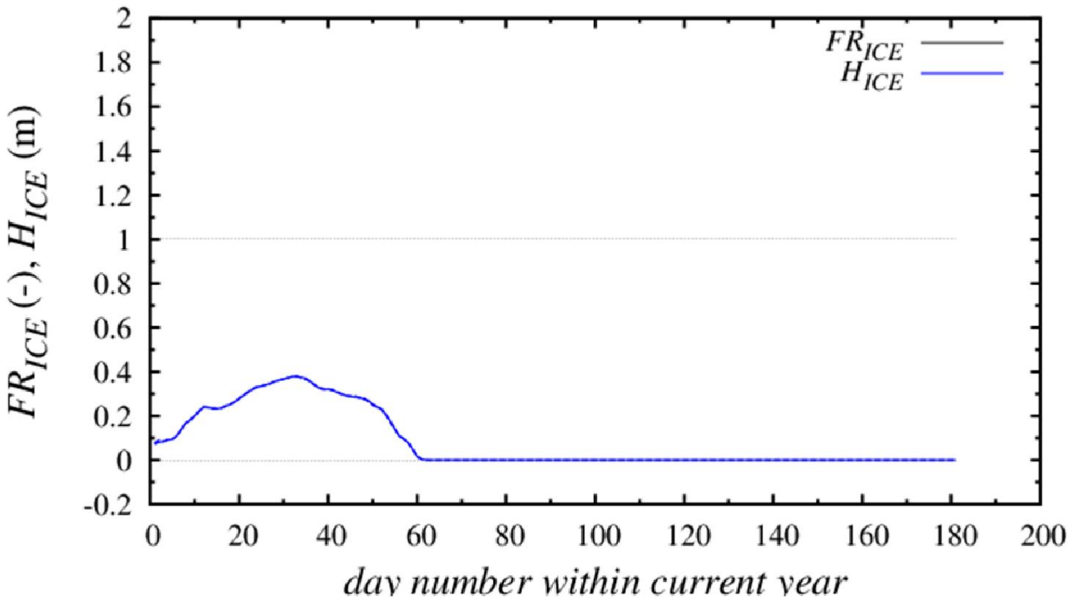
Mixed-layer temperature (dgr C) from ICON, North America, 27 February 2017, 00UTC.

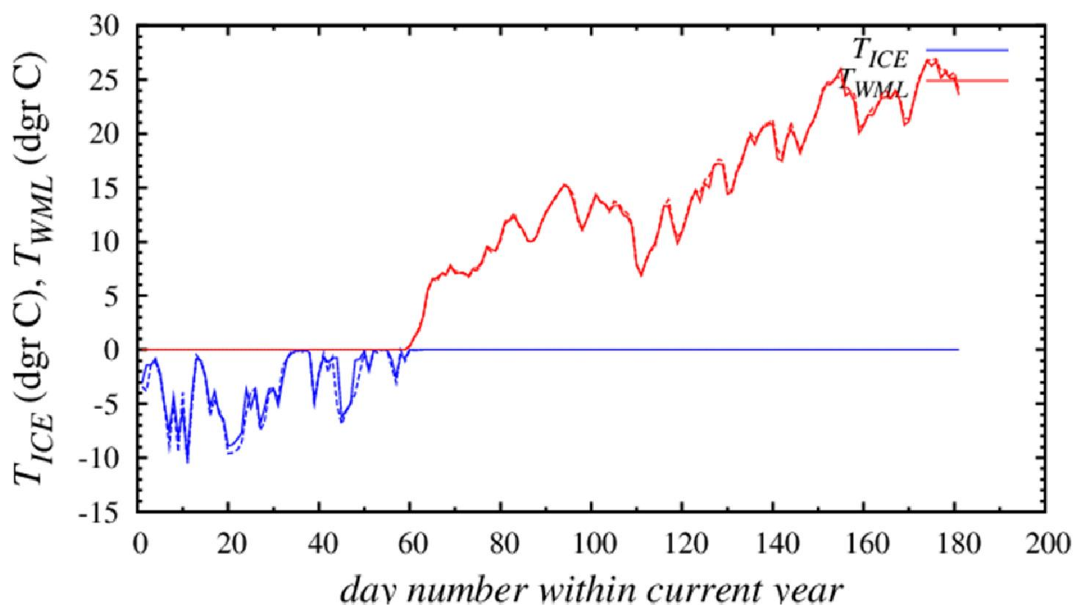
FLake within ICON (cont'd)



Ice thickness (m) from ICON, North America, 27 February 2017, 00UTC.

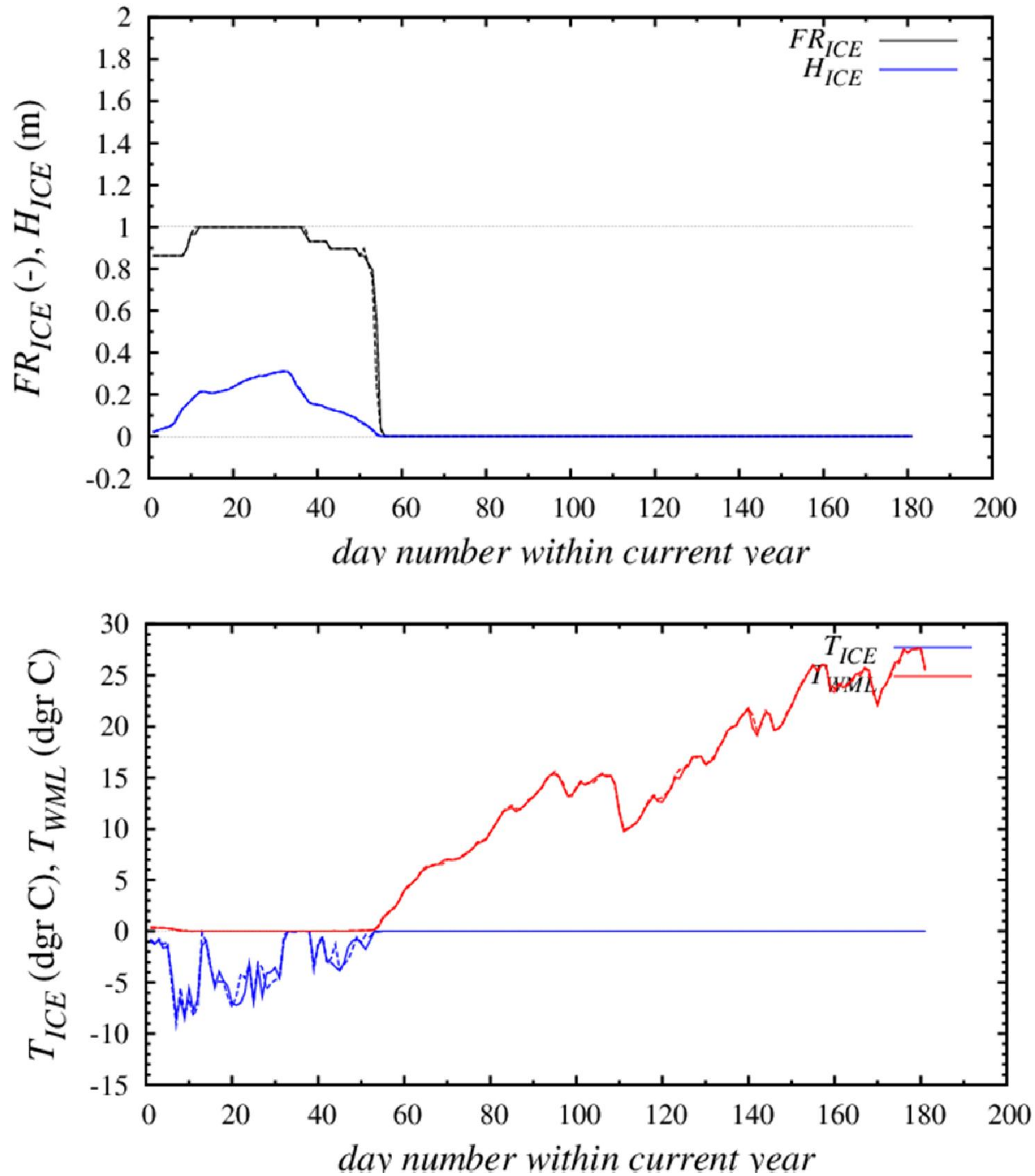
FLake Operational Performance: Time Series





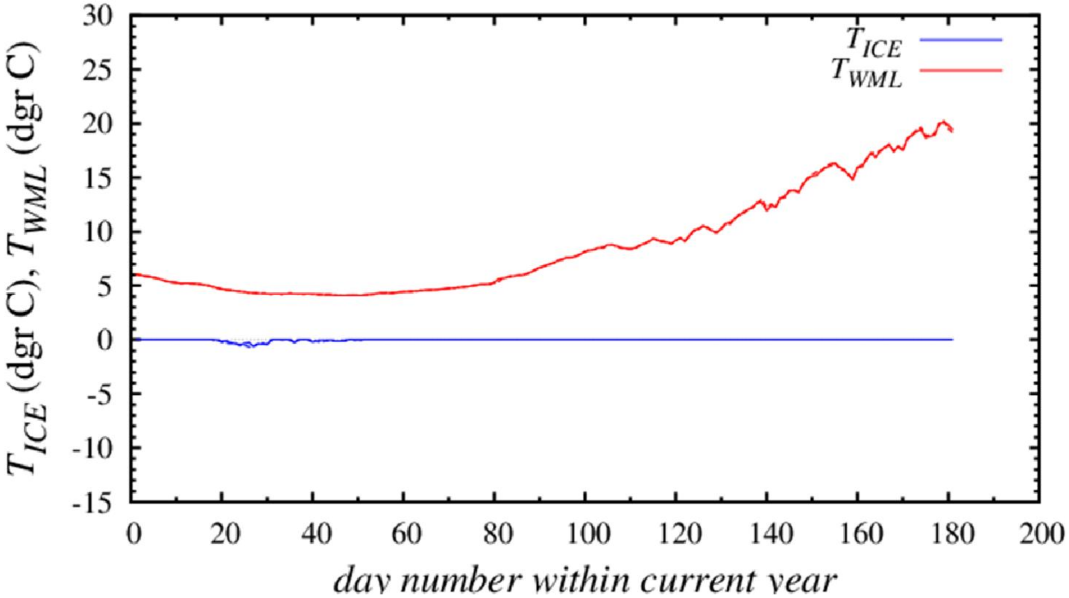
Ice fraction FR_{ICE} and ice thickness H_{ICE} (upper panel), and ice surface temperature T_{ICE} and mixed-layer temperature T_{WML} (lower panel) in **Lake Neusiedl** (Neusiedler See) in January – June 2017. Curves are computed with **COSMO-DE** using the lake parameterization scheme FLake (no tile approach). Solid curves show the 00 UTC analysis, and long-dashed curves show the 24h forecast for the same target date and time.

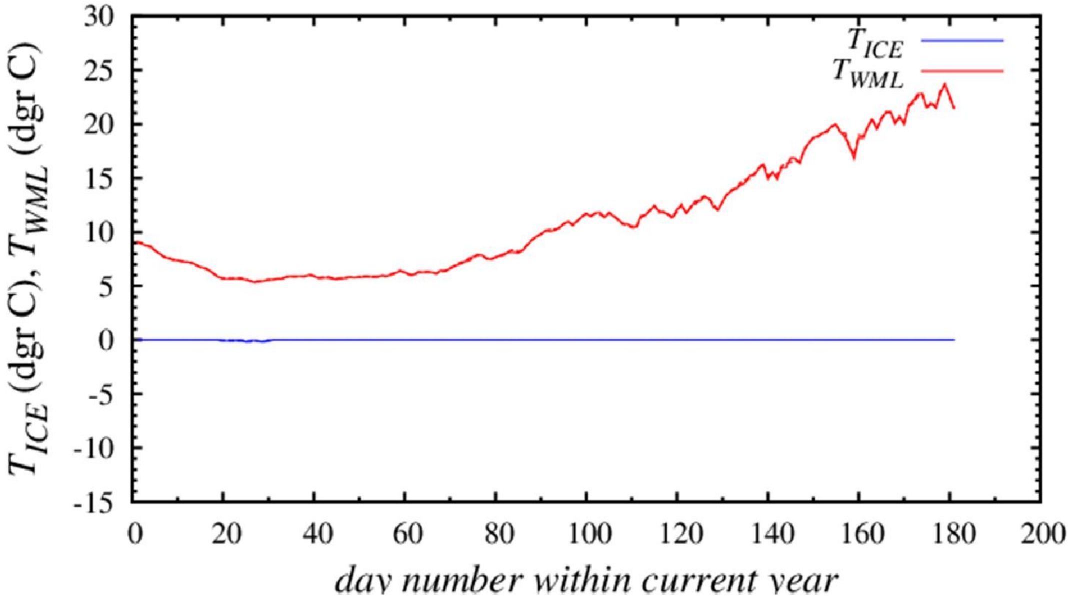
FLake Operational Performance: Time Series



Ice fraction FR_{ICE} and ice thickness H_{ICE} (upper panel), and ice surface temperature T_{ICE} and mixed-layer temperature T_{WML} (lower panel) in **Lake Neusiedl** (Neusiedler See) in January – June 2017. Curves are computed with **ICON-EU Nest** using the lake parameterization scheme FLake within a tiled surface scheme. Solid curves show the 00 UTC analysis, and long-dashed curves show the 48h forecast for the same target date and time.

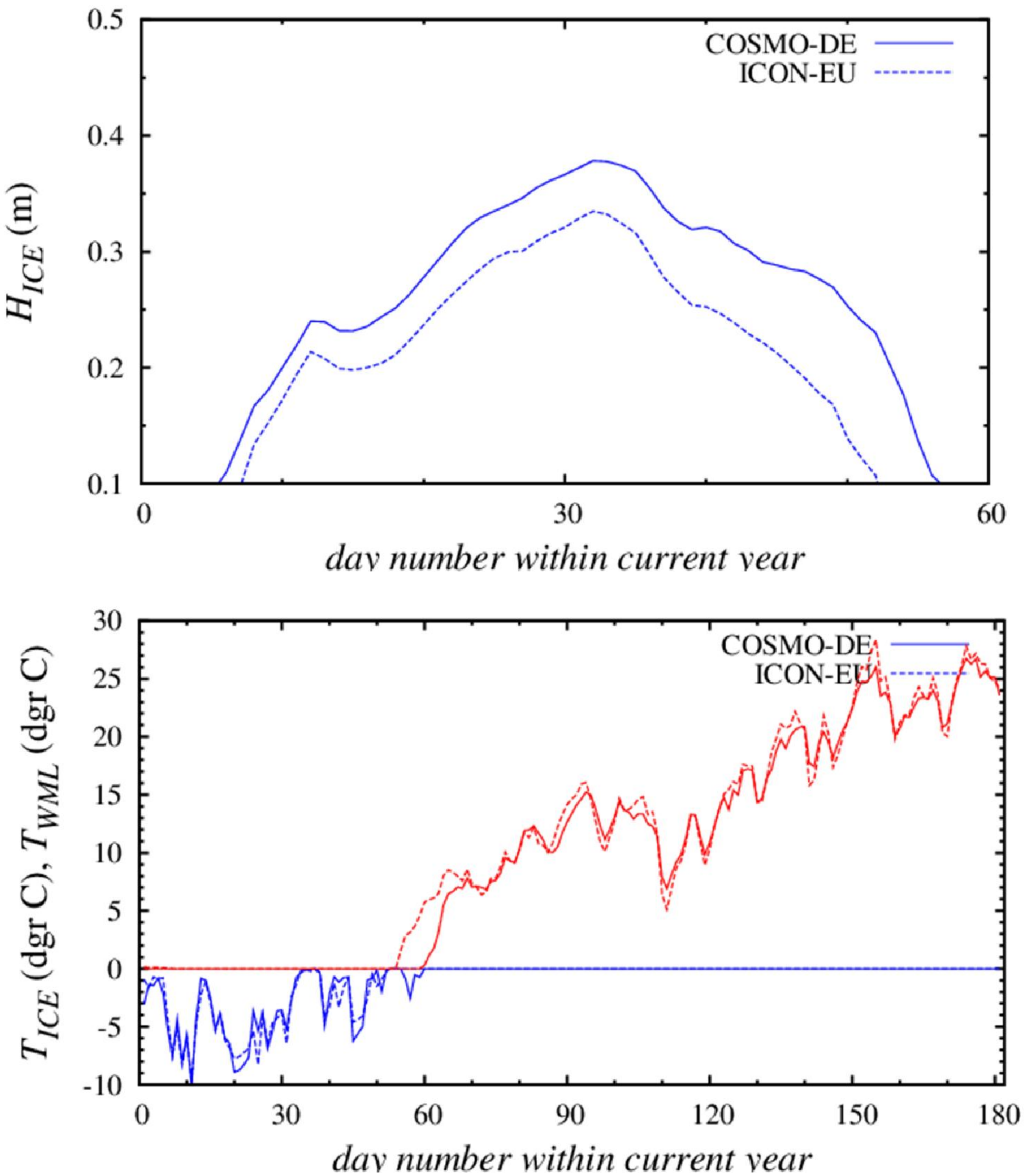
FLake Operational Performance: Time Series





Ice surface temperature T_{ICE} and mixed-layer temperature T_{WML} in **Lake Constance** in January – June 2017. Curves show the 00 UTC analysis from **COSMO** (upper panel) and **ICON-EU Nest** (lower panel).

FLake Operational Performance: Time Series



Upper panel – ice thickness H_{ICE}, lower panel – ice surface temperature T_{ICE} (blue curves) and mixed-layer temperature T_{WML} (red curves) in **Lake Neusiedl** (Neusiedler See) in January – June 2017. Curves show the 00 UTC analysis from **COSMO-DE**, (solid) and **ICON-EU Nest** (dashed).

Can we show results from several NWP models vs. data from observations, at least for some lakes?

Explicit Treatment of Snow

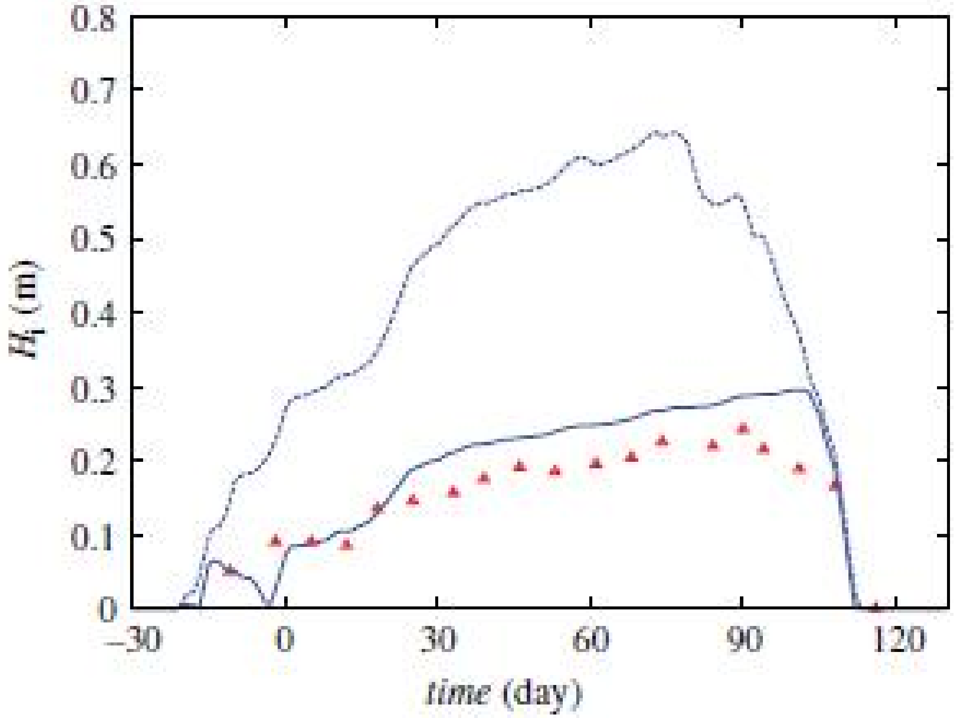


Fig. 9. Ice thickness in Lake Pääjärvi during winter 1999–2000, where day = 0 corresponds to 1 January 2000. Blue curves show results of simulations with FLake: solid curve – with a snow layer above the ice, and dashed curve – no snow above the ice. Red symbols show observational data.

Results of simulations with tuned snow density and snow heat conductivity (Mironov et al. 2012).

Extension to Salt Water

There are issues that require research efforts

- Equation of state (cf. salinity in the ocean)
- Bottom boundary condition for salt concentration
- Initial conditions (e.g. total amount of salt in lake)
- Lake water budget

Conclusions and Outlook

- Lake parameterization scheme FLake is used operationally within the NWP models COSMO and ICON (within tiled surface scheme, SGS water is important)
- Results are monitored (results have been satisfying so far)

Would be useful to

- Plot (monitor) results from various NWP centres for a number of lakes (COST Action?)
- Compare model output with observational data

Conclusions and Outlook (cont'd)

Permanent task

- Update external-parameter fields

In the medium-term prospects

- use prognostic ice albedo with respect to solar radiation (cf. the ICON sea-ice scheme with prognostic albedo parameterization)
- explicit treatment of snow over sea and lake ice (a bulk snow model is advantageous for NWP)

Would be nice to have (but not really crucial for NWP)

- extension of FLake to salt water

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Thank you for your kind attention!

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