# Parameterization of Lakes and Sea Ice in ICON (NWP)


***Dmitrii Mironov***

German Weather Service, Offenbach am Main, Germany

(dmitrii.mironov@dwd.de)


# Outline

- Parameterization of lakes in NWP and climate models: the problem
- The lake parameterization scheme "FLake", the sea-ice scheme: basic ideas, single-column tests
- FLake and sea-ice scheme within ICON (NWP)
- Interaction with data assimilation
- Some useful hints
- Conclusions and outlook
- (If time permits) Monitoring of FLake and sea-ice scheme performance

# Parameterization of Lakes in NWP and Climate Models: the Problem

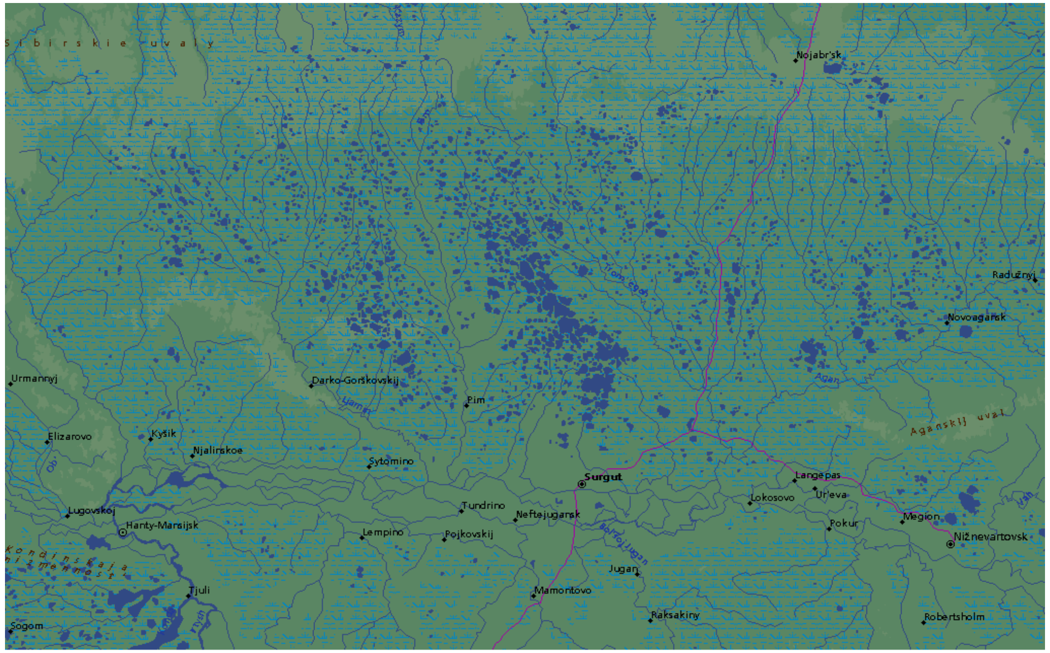
(1a) The interaction of the atmosphere with the underlying surface strongly depends on the surface temperature and its time-rate-of-change. In small-to-medium size relatively shallow lakes, the diurnal variations of the surface temperature reach several degrees (often more than 10 degrees). The effect of lakes (both grid scale and sub-grid scale lakes) on the grid-box mean temperature and humidity and on the grid-box mean fluxes should be accounted for.

(1b) Apart from forecasting the lake surface temperature, its initialization is also an issue.

(2) Lakes strongly modify the structure and the transport properties of the atmospheric surface layer. An outstanding question is the parameterization of the water-surface roughness for wind (e.g., limited fetch) and scalar quantities.

# Lake Regions: Finland, Karelia


Copyright © Rand McNally & Company or its licensors. All rights reserved. http://www.randmcnally.com




Copyright © Rand McNally & Company or its licensors. All rights reserved. http://www.randmcnally.com


Copyright © Rand McNally & Company or its licensors. All rights reserved. http://www.randmcnally.com

# Lake Regions: Khanty-Mansiisk region (middle Ob’ river)

# Lake Regions: Canada

# Lake Parameterization Schemes for NWP and Climate Models

(e.g. Croley 1989, 1992, Croley and Assel 1994, Hostetler and Bartlein 1990, Hostetler 1991, Hostetler et al. 1993, 1994, Barrette and Laprise 2005, Bates et al. 1993, 1995, Ljungemir et al. 1996, Goyette et al. 2000, Tsuang et al. 2001, Song et al. 2004, León et al. 2005, 2007, Long et al. 2007, Mackay 2005, Mackay et al. 2009, Stepanenko and Lykosov 2005, Stepanenko 2007, Stepanenko et al. 2010, Subin et al. 2012)

- One-layer schemes, complete mixing down to the bottom
  Neglect stratification ⇒ large errors in the surface temperature

- Turbulence closure schemes, multi-layer (finite-difference)
  Describe the lake thermocline better ⇒ computationally expensive

A compromise between *physical realism* and *computational economy* is required

**A two-layer scheme with**
**a *parameterized* vertical temperature structure**

# The Concept

Put forward by Kitaigorodskii and Miropolsky (1970) to describe the temperature structure of the oceanic seasonal thermocline. The essence of the concept is that the temperature profile in the thermocline can be fairly accurately parameterized through a “universal” function of dimensionless depth, using the temperature difference across the thermocline, $\Delta\theta=\theta_s-\theta_b$, and its thickness, $\Delta h$, as appropriate scales of temperature and depth:

$$\frac{\theta_s(t)-\theta(z,t)}{\Delta\theta(t)}=\vartheta(\varsigma), \quad \varsigma=\frac{z-h(t)}{\Delta h(t)}.$$

# Analogy with the Mixed-Layer Concept

Using $\theta_s(t)$ and $h(t)$ as appropriate scales of temperature and depth, the temperature profile in the upper mixed layer is represented as

$$\frac{\theta(z,t)}{\theta_s(t)} = \Phi(\xi), \quad \xi = \frac{z}{h(t)}.$$

Since the layer is well mixed, the "universal" function $\Phi(\xi)$ is simply a constant equal to 1.

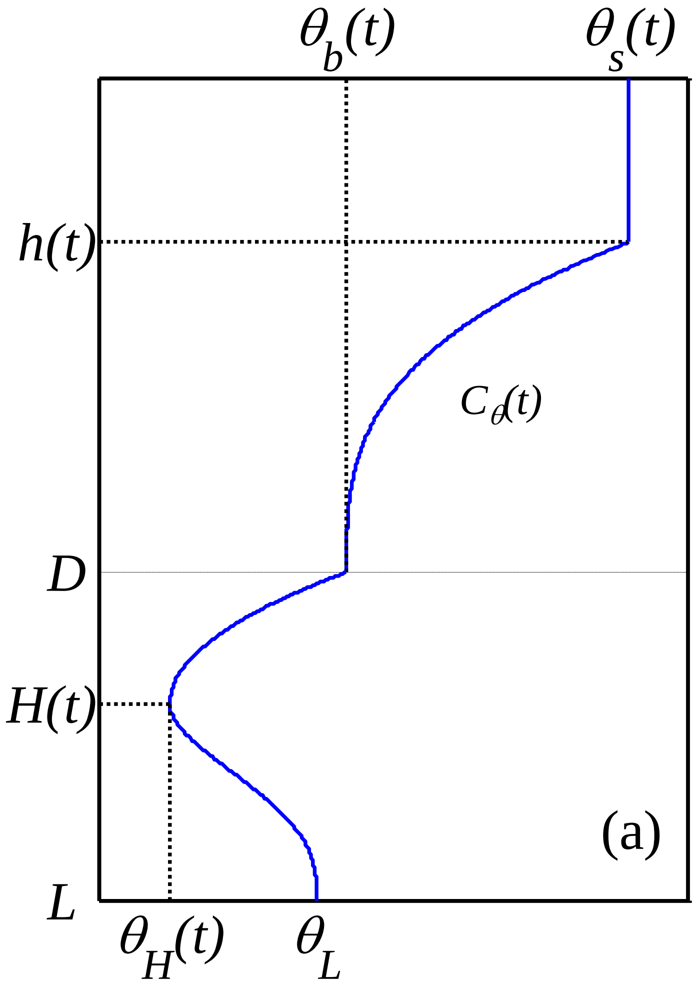
Then, integrating the heat transfer equation (partial differential equation in $z$, $t$)

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

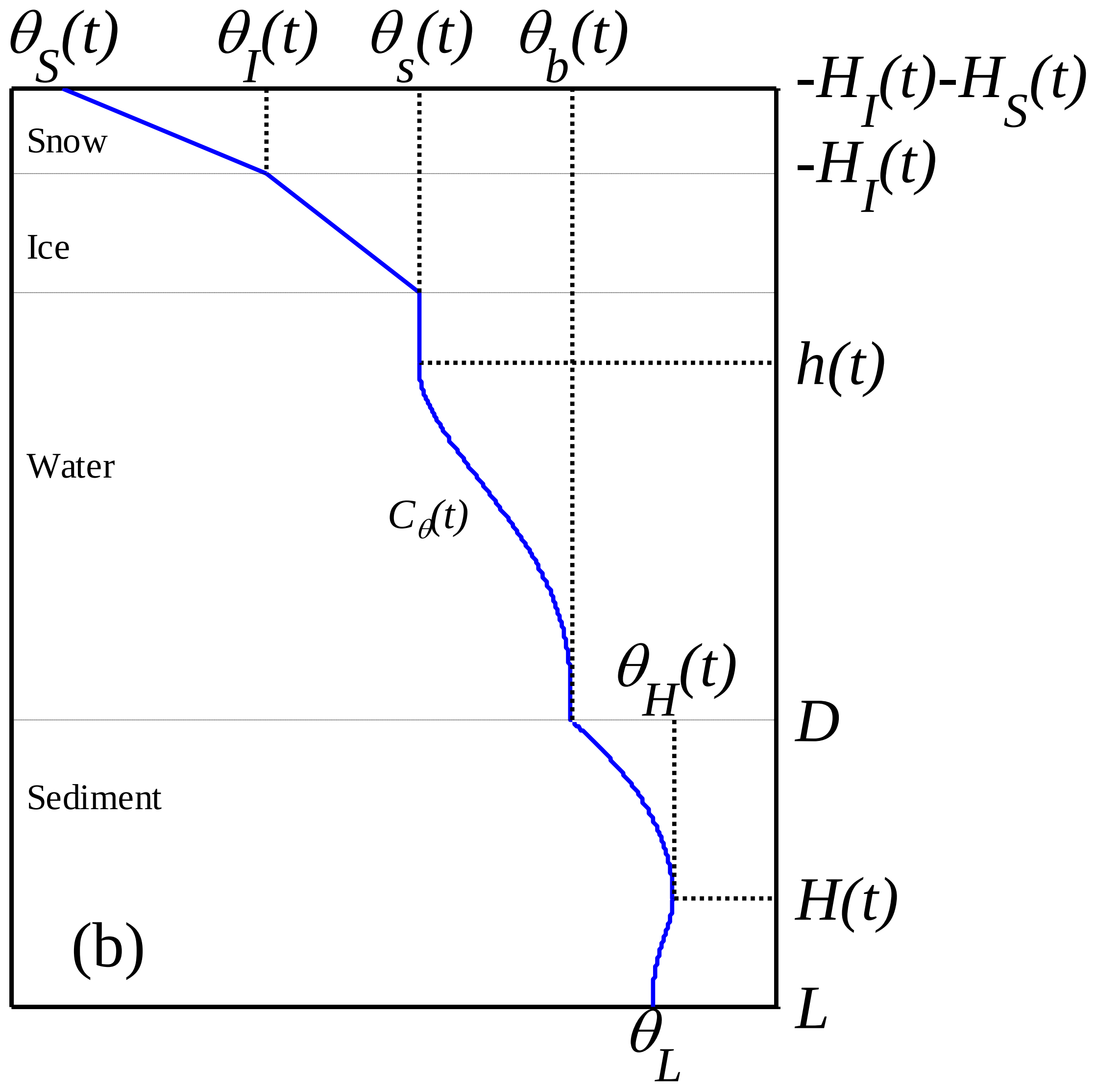
over $z$ from 0 to $h(t)$, reduces the problem to an ordinary differential equation for $\theta_s(t)$,

$$\boxed{\frac{d\theta_s}{dt} = \frac{Q_s - Q(h)}{h}}$$

# 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 $H_S(t)$.

# Lake Parameterization Scheme "FLake"

The scheme 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*** (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.**

# Bulk Ice Parameterization Schemes: Basic Idea

Bulk schemes are based on the idea of self-similarity (assumed shape) of the temperature-depth curve. Using the temperature difference across the ice $\theta_i(t)-\theta_f$ and the ice thickness $h_i(t)$ as appropriate scales of temperature and depth, the temperature profile within the ice layer is represented as

$$\theta(z,t)=\theta_f+[\theta_i(t)-\theta_f]\Phi(\varsigma), \quad \varsigma=z/h_i(t)$$

A "universal" function $\Phi(\zeta)$ satisfies the boundary condition is $\Phi(0)=0$ and $\Phi(1)=1$ (the $z$-axis is directed upward with the origin at the ice lower surface).

# Bulk Sea-Ice Scheme: Summary

... Integrating the heat transfer equation (partial differential equation) with due regard for the self-similar representation of $\theta_s(z,t)$ and rearranging ... we get the system of ordinary differential equations for time-dependent ***parameters*** that specify the temperature profile, viz., $\theta_i(t)$ and $h_i(t)$, where $\boldsymbol{\theta_i}$ **is a major concern**.

In the regime of ice growth (and/or melting from below for sea ice)

- equations for $h_i(t)$ and $\theta_i(t)$

In the regime of ice melting from above

- equation for $h_i(t)$, and $\theta_i$ is equal to the $\theta_{f0}$ (fresh-water freezing point)

**NB: The scheme does not require re-tuning and**

**is computationally very inexpensive (vitally important for NWP!)**

# Bulk Sea-Ice Scheme: Summary (cont'd)

## Ice growth and/or melting from below

$$C_* h_i \frac{d\theta_i}{dt} = \frac{1}{\rho_i c_i}\left[Q_a + I_a - I(0)\right] + \Phi'_i(0)\frac{\kappa_i}{\rho_i c_i}\frac{\theta_f - \theta_i}{h_i}\left[1 + \left(\frac{3}{2} - 2C_*\right)R\right] + \left(\frac{3}{2} - 2C_*\right)R\frac{Q_w}{\rho_i c_i},$$

$$\frac{dh_i}{dt} = \Phi'_i(0)\frac{\kappa_i}{\rho_i L_f}\frac{\theta_f - \theta_i}{h_i} + \frac{Q_w}{\rho_i L_f}, \quad C_* = \int_0^1 \Phi(\varsigma)d\varsigma, \quad R = \frac{c_i(\theta_i - \theta_f)}{L_f}$$

Temperature profile shape factor

## Ice melting from above

$$\theta_i = \theta_{f0}, \quad \left[1 + \left(\frac{3}{2} - 2C_*\right)R\right]\frac{dh_i}{dt} = -\frac{1}{\rho_i L_f}\left[Q_a + I_a - I(0)\right] + \frac{Q_w}{\rho_i L_f}$$

# Heat Flux from Water to Ice, Shape Function Parameters

- Coupled atmosphere-ocean runs (*is_coupled_to_ocean*=.TRUE.): heat flux from water to ice, $Q_w$, should be provided by the ocean model.

- Uncoupled runs: ad hoc parameterization of $Q_w$ (ensures $dh/dt \rightarrow 0$ as $h_i \rightarrow h_i^{max}$).

- Interaction with data assimilation in NWP runs (adaptive parameter tuning, (PRESENT(*fac_bottom_hflx*)=.TRUE.): $Q_w$ and $\Phi_i'(0)$ are adjusted, using assimilation increment of near-surface temperature.

- See ICON scientific documentation for details.

# Single-Column Tests
## (using FLake ice module)

- Lake Pääjärvi, Finland (61 N, depth = 15 m)
- Ryan Lake, USA (45 N, depth = 9 m)

**Forcing in single-column mode**

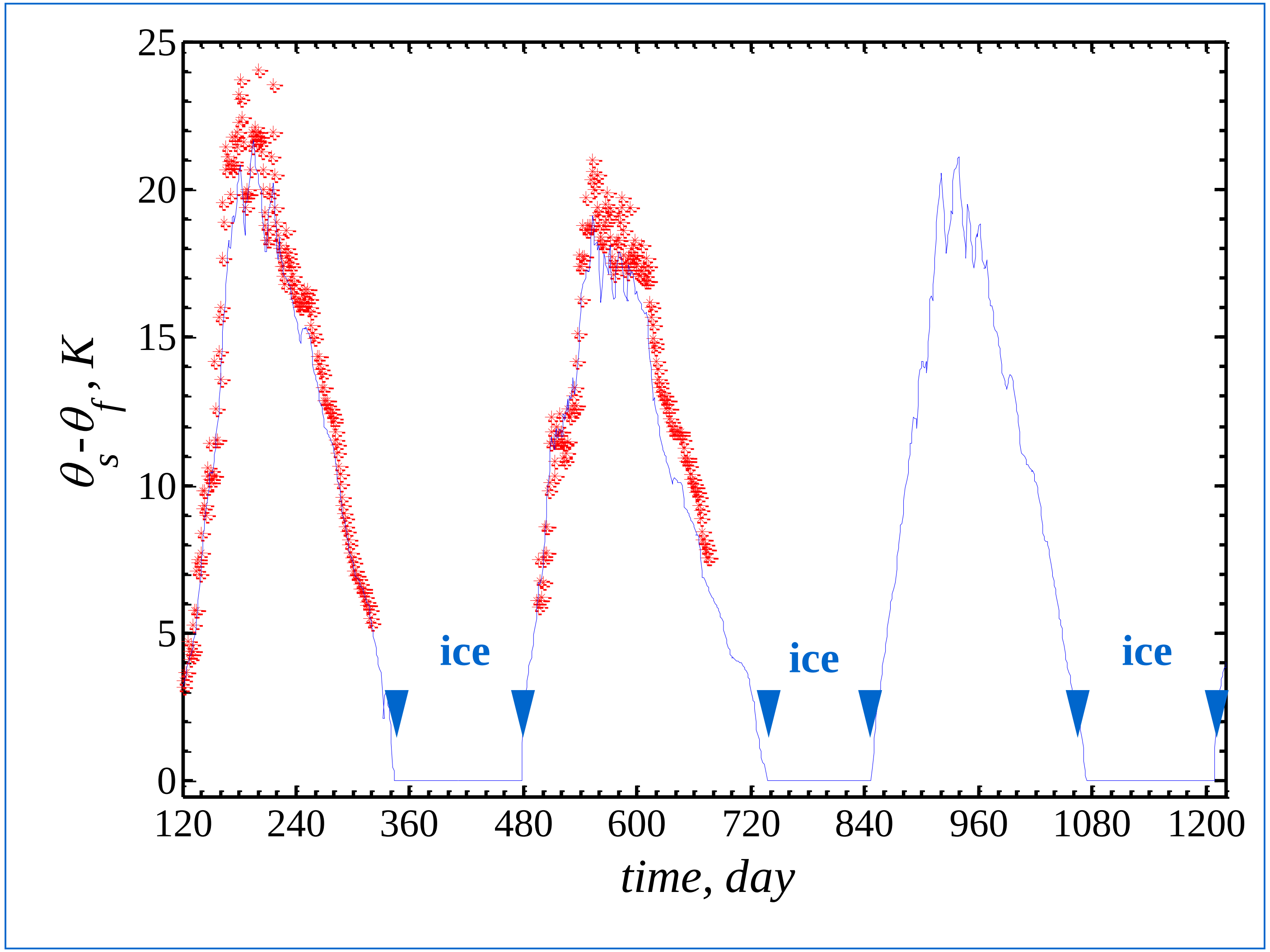
Known from observations:

- short-wave radiation flux,
- long-wave radiation flux from the atmosphere.

Computed as part of the solution (depend on lake surface temperature):

- long-wave downward radiation flux from the surface,
- fluxes of momentum and of sensible and latent heat,
- for ice-covered lakes, surface albedo.

# Lake Pääjärvi, 1 May 1999 - 31 August 2002




Water surface temperature $\theta_s$ ($\theta_f$ is the fresh-water freezing point)

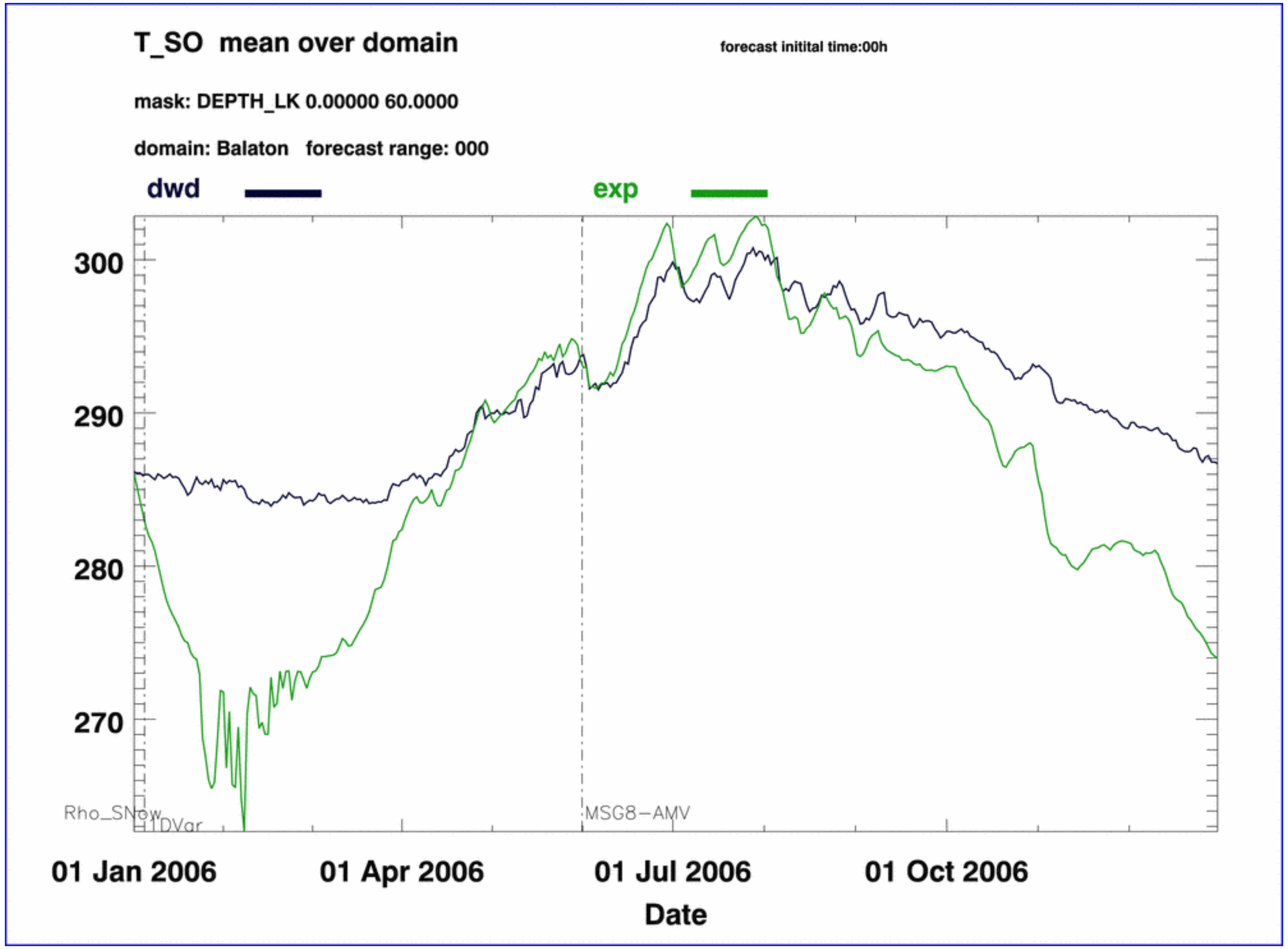
Dots – measured, line - computed

# FLake in COSMO: Testing through Parallel Experiment

- COSMO-model parallel experiment over one year, **1 January through 31 December 2006**, using the LM1 numerical domain of DWD
- The entire COSMO-model data assimilation cycle except that the lake surface temperature is not re-initialized through the SST analysis but is predicted by FLake
- Initial conditions at the cold start: the lake surface temperature is set equal to the COSMO-model SST from the analysis

# FLake in COSMO: Results from Parallel Experiment 5632

## 1 January – 31 December 2006

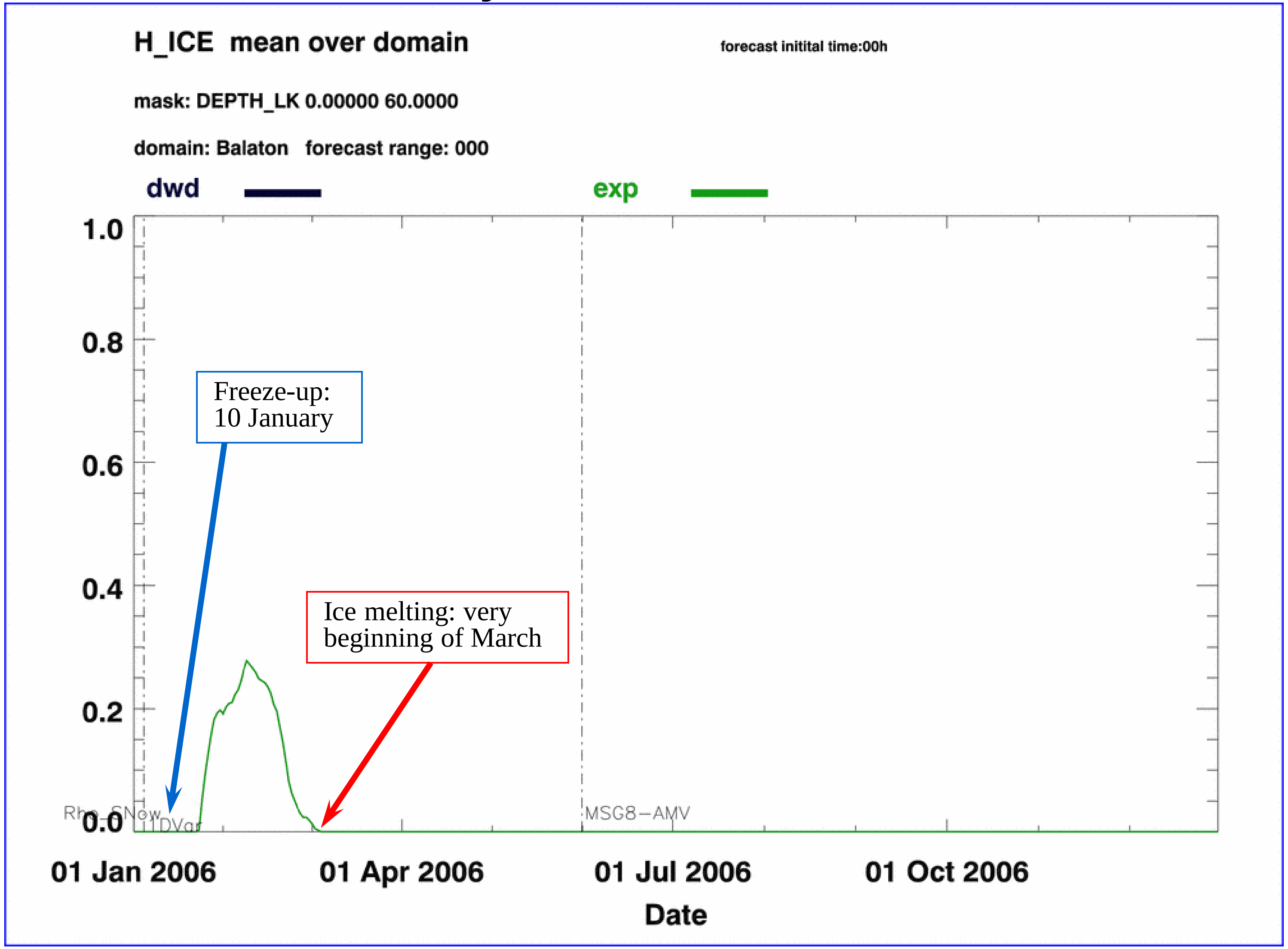



Lake Balaton, Hungary (mean depth = 3.3 m)

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

# FLake in COSMO: Results from Parallel Experiment 5632

# 1 January – 31 December 2006



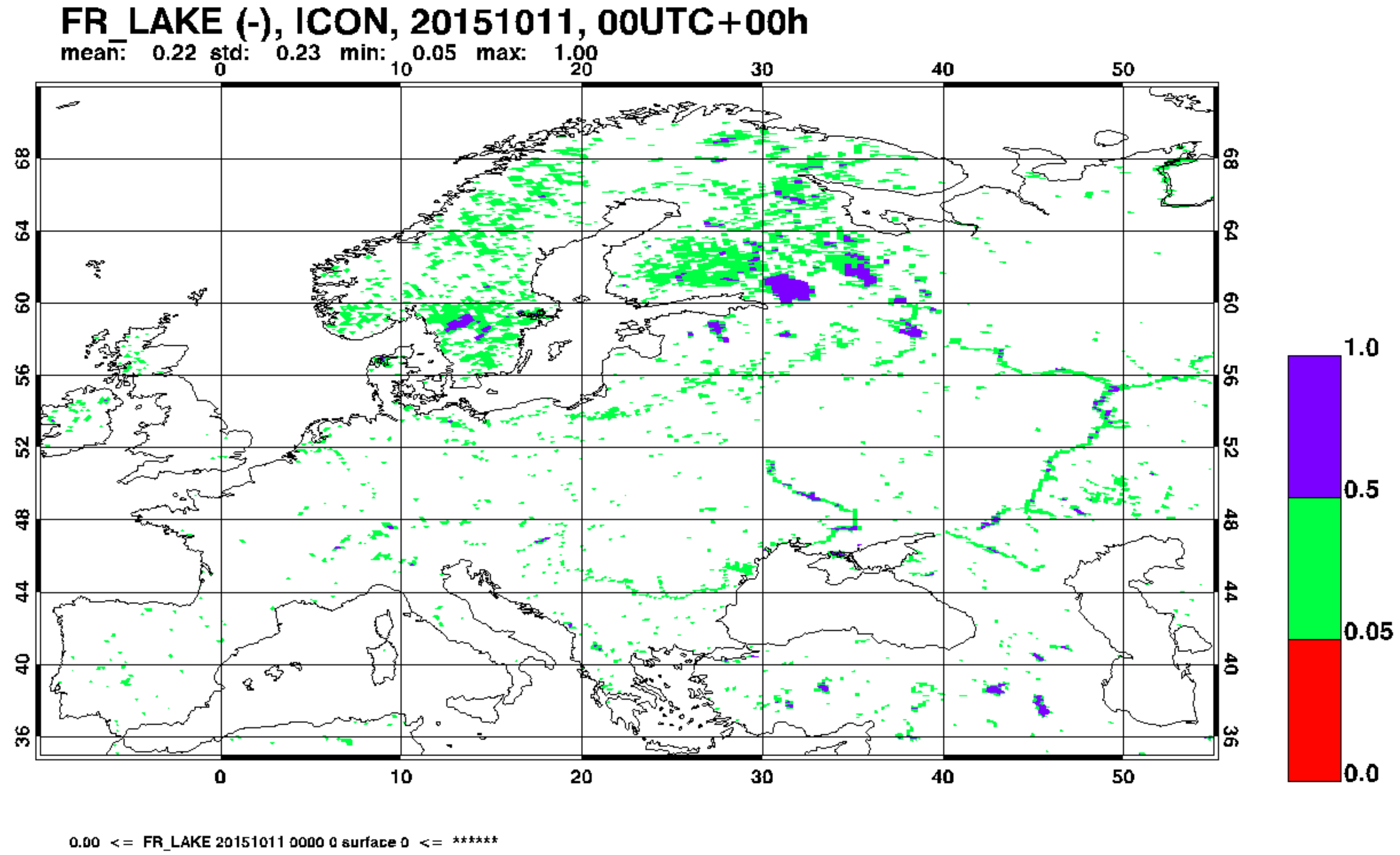

Lake Balaton, Hungary (mean depth = 3.3 m). Ice thickness computed with COSMO-FLake.

# FLake in NWP and Climate Models: External Parameters

- geographical latitude
- lake fraction of the NWP model grid-box (not so easy)
- lake depth (not easy at all, e.g., for lack of in situ data)
- 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 (cf. soil model parameters)

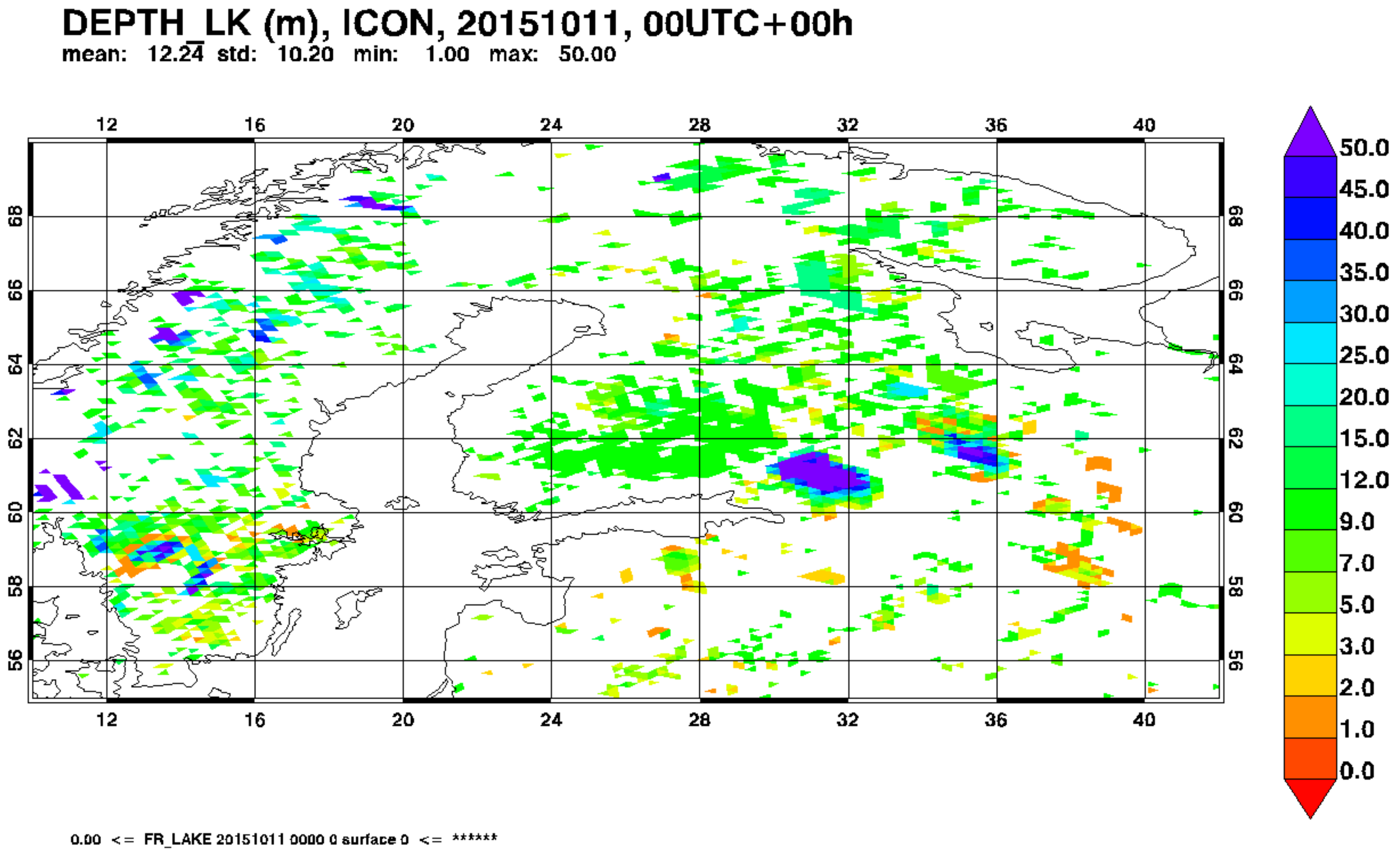
Default values are used.

# Lake Fraction (ICON global)



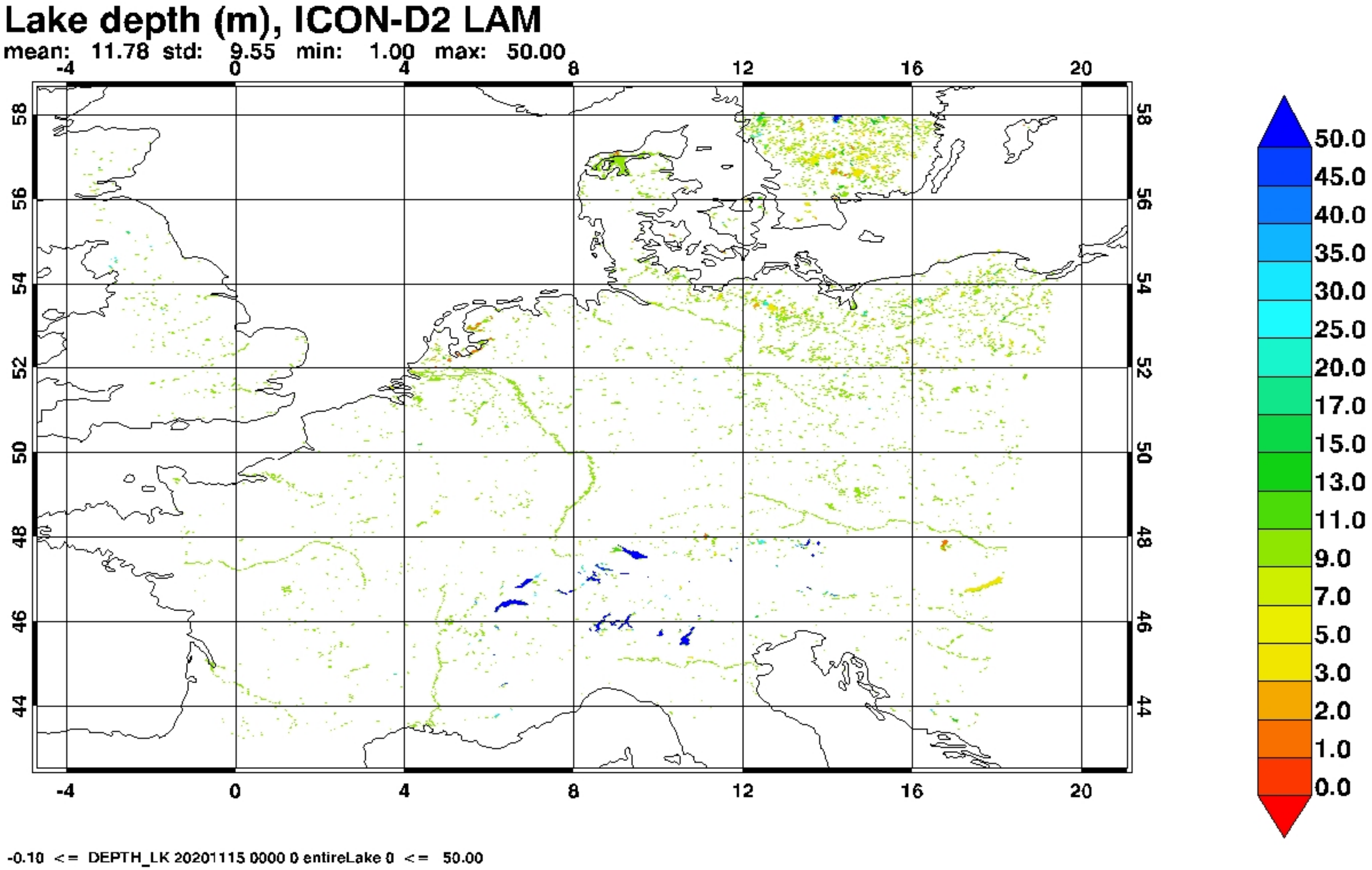

Lake fraction external-parameter field for ICON with ca. 13 km horizontal mesh size (**Global Lake Database**, Kourzeneva 2009, 2010, Kourzeneva et al. 2012, and Choulga et al. 2014).

# Lake Depth (ICON global)




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

# Lake Depth (ICON-D2)




Lake depth external-parameter field for ICON-LAM with ca. 2.2 km horizontal mesh size.

# Lake Ice Albedo

Snow over lake ice is not treated explicitly. The effect of snow is accounted for implicitly (parametrically) through the changes in the ice albedo with respect to solar radiation.

$$\alpha = \alpha_{\max} - (\alpha_{\max} - \alpha_{\min}) \exp[-C_\alpha (\theta_{f0} - \theta_i)/\theta_{f0}]$$

$$C_\alpha = 95.6, \quad \alpha_{\min} = 0.10, \quad \alpha_{\max} = 0.60$$

# Diagnostic Sea-Ice Albedo Parameterization

**Snow over sea ice is not treated explicitly.**

The effect of snow is accounted for implicitly (parametrically) through the ice-surface temperature dependence of the ice albedo with respect to solar radiation.

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

$$C_{\alpha i}=95.6, \quad \alpha_i^{min}=0.48, \quad \alpha_i^{max} = 0.70$$

# Prognostic Sea-Ice Albedo Parameterization

## Relaxation-type equation

$$\frac{d\alpha_i}{dt} = -\frac{\alpha_i - \alpha_{ie}}{\tau_{\alpha i}} - \frac{\alpha_i - \alpha_{sne}}{\tau_{\alpha sn}}$$

## Relaxation time scales

$$\tau_{\alpha sn} = R_{sn}/R_*$$

$R_* = 5$ kg·m$^{-2}$ is a disposable parameter ($R_{sn}$ is a snowfall rate)

Relaxation towards equilibrium "snow-over-sea-ice" albedo only if $\alpha_i < \alpha_{sne}$ (albedo tends to increase) and
$\theta_i < 272.95$ K (close to the freezing point, melt ponds do not re-freeze)

$\tau_{\alpha i} = 7$ days at (fresh-water) freezing point, and increases towards 21 days as $\theta_i$ approaches 268.15 K

# Prognostic Sea-Ice Albedo Parameterization (cont'd)

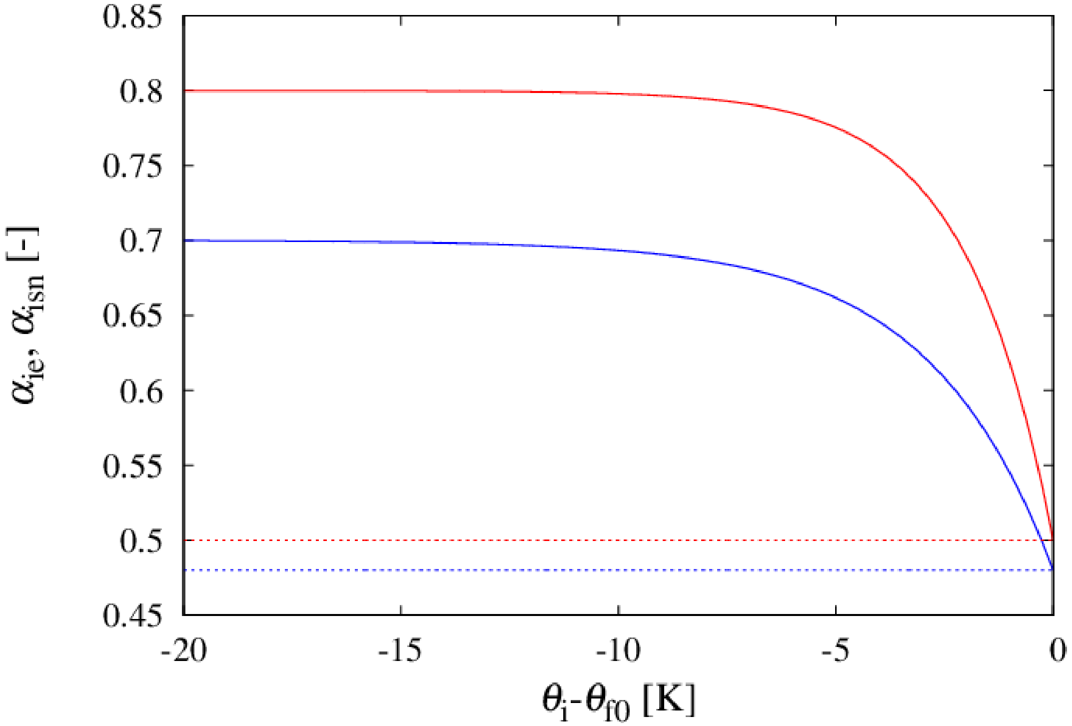
Equilibrium "snow-over-sea-ice" albedo

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

$C_{\alpha sn}$=136.6

$\alpha_{sn}{}^{min}$=0.50

$\alpha_{sn}{}^{max} = 0.80$




Red solid curve shows "snow-over-ice" equilibrium albedo

# FLake in ICON: Configuration

- Bottom sediment module is switched off (heat flux through the water-bottom sediment interface 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 and Ritter 2003, 2004, Mironov et al. 2012)
- Turbulent fluxes at the surface are computed with the current ICON surface-layer scheme (Raschendorfer 2001)
- 2D fields of lake fraction and lake depth based on Global Lake Database (Kourzeneva 2009, 2010, Kourzeneva et al. 2012, Choulga et al. 2014), default values of other lake-specific parameters
- Tile approach is used within ICON, all lakes with FR_LAKE≥0.05 are accounted for (no tile approach in COSMO, FR_LAKE>0.5)
- No data on lake water surface temperature are assimilated into FLake (but see below re. lake freeze-up and break-up of ice)

# Assimilation of Lake-Ice Fraction Data (G. Zängl)

(based on Mironov and Machulskaya, 2012, Lake 12 workshop, Helsinki)

Data on ice fraction are used to correct ice thickness and 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
- **0.03<FR_ICE<0.75**: there is ice in the first guess, then 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

# Interaction of Sea-Ice Scheme with Data Assimilation

- Thermodynamic sea ice scheme carries equations for $h_i(t)$ and $\theta_i(t)$ but creates no new ice (ocean is not allowed to freeze up itself, but ice can melt during the forecast); prognostic sea ice thickness is limited from below and from above by $h_{imin}$=0.05 m and $h_{imax}$=3.0 m, respectively
- Horizontal distribution of sea ice is subordinate to data assimilation scheme that delivers ice fraction $f_i$ for each ICON grid box (cf. climate runs)
- No ice if $f_i$ is small (remove leftover as needed)
- $h_i$ and $\theta_i$ are initialized with ad hoc values if there was no ice but data indicate it is present

# Sea-Ice Scheme Initialization – Decision Tree

**Sea ice fraction less than a threshold value (*frsi*<*frsi_min*)**

- No ice in the grid box ⇒ do nothing
- There is ice in the grid box (from previous ICON run) ⇒ remove ice: set the ice thickness to zero, the ice surface temperature to the fresh-water freezing point, and the ice fraction to zero

**Sea ice fraction exceeds a threshold value (*frsi*≥*frsi_min*)**

- No ice in the grid box ⇒ create new ice: set the ice thickness to a value between *hice_ini_min* and *hice_ini_max* as dependent on the ice fraction, and the ice surface temperature to the salt-water freezing point
- There is ice in the grid box ⇒ set the ice thickness and the ice surface temperature to their values at the end of previous ICON run

**Current ICON setting:**

- *frsi_min*=0.015 (tile approach is used), *hice_ini_min*=0.1 m and *hice_ini_max*=0.5 m

# Some Useful Hints: FLake

**ICON operational setting: *llake*=.TRUE. and *frlake_thrhld*=0.05 (tile approach)**

**To run without FLake, set *llake*=.FALSE. But be careful!**

**If *llake*=.FALSE. and tile approach is not used (*frlake_thrhld*=0.5)**

- Lakes are not considered. Inland water is treated in the same way as the ocean water. The water surface temperature (both inland water and ocean water) is initialized with the SST from the analysis. ICON should work, but an SST field of reasonable quality is required.

**If *llake*=.FALSE. and tile approach is used (*frlake_thrhld*<0.5)**

- This configuration has never been tested (no plan at DWD to run with tile approach but without FLake). **Using this configuration is at your own risk!**

# Some Useful Hints: Sea-Ice Scheme

**ICON operational setting: *lseaice*=.TRUE. and *frsi_min*=0.015 (tile approach)**

**To run without sea ice scheme, set *lseaice*=.FALSE. But be careful!**

**If *lseaice*=.FALSE. and tile approach is not used (*frsi_min*=0.5)**

- No sea ice is considered explicitly. A decision as to the open water or ice in a given grid box (e.g., required to compute the surface roughness) is taken on the basis of sea surface temperature from the SST analysis. ICON should work, but an SST field of reasonable quality is required, including the surface temperature of “ice-covered” grid boxes.

**If *lseaice*=.FALSE. and tile approach is used (*frsi_min*<0.5)**

- This configuration has never been tested (no plan to run with tile approach but without sea ice scheme). **Using this configuration is at your own risk!**

# Conclusions and Outlook

- Lake parameterization scheme FLake is implemented into ICON, since 20.01.2015 operational at DWD  (15.12.2010 FLake went operational within COSMO)
- FLake is used within the ICON tiled surface scheme (SGS water is important!)
- Operational results are monitored, no serious complaints so far

- Update external-parameter fields
- Explicit treatment of snow over lake ice (a bulk snow scheme is advantageous for NWP)

# Conclusions and Outlook (cont’d)

- A bulk sea ice parameterization scheme is implemented into ICON (description in Mironov et al. 2012, and in the ICON Documentation)
- The scheme is used within the framework of ICON tile approach (grid-box mean surface fluxes are computed as a weighted means over ice and over open water, ice/water fraction greater than **0.015** is accounted for)
- Prognostic parameterization of sea-ice albedo
- Ad hoc parameterization of heat flux $Q_w$ from ocean water to ice, adaptive tuning of $Q_w$ and based on the assimilation increments of the atmospheric surface layer quantities
- ICON results are monitored (no big problems so far)

- Snow over ice, a bulk snow scheme would be advantageous

# Info



**FLake Web Page** http://lakemodel.net, c/o Georgiy Kirillin

**Online FLake version** at http://lakemodel.net (take a look and have fun!)

**References**

Kirillin, G., J. Hochschild, D. Mironov, A. Terzhevik, S. Golosov, and G. Nützmann, 2011: FLake-Global: Online lake model with worldwide coverage. *Environ. Modell. Softw.*, **26**, 683-684.

Kourzeneva, E., 2010: External data for lake parameterization in Numerical Weather Prediction and climate modeling. *Boreal Env. Res.*, **15**, 165-177.

Kourzeneva, E., H. Asensio, E. Martin, and S. Faroux, 2012: Global gridded dataset of lake coverage and lake depth for use in numerical weather prediction and climate modelling. *Tellus A*, **64**, 15640. doi:10.3402/tellusa.v64i0.15640

Mironov, D. V., 2008: Parameterization of lakes in numerical weather prediction. Description of a lake model. *COSMO Technical Report*, No. 11, Deutscher Wetterdienst, Offenbach am Main, Germany, 41 pp.

Mironov, D., E. Heise, E. Kourzeneva, B. Ritter, N. Schneider, and A. Terzhevik, 2010: Implementation of the lake parameterisation scheme FLake into the numerical weather prediction model COSMO. *Boreal Env. Res.*, **15**, 218-230.

Mironov, D., B. Ritter, J.-P. Schulz, M. Buchhold, M. Lange, and E. Machulskaya, 2012: Parameterization of sea and lake ice in numerical weather prediction models of the German Weather Service. *Tellus A*, **64**, 17330. doi:10.3402/tellusa.v64i0.17330

Further references at http://lakemodel.net

# Thank you for your kind attention!

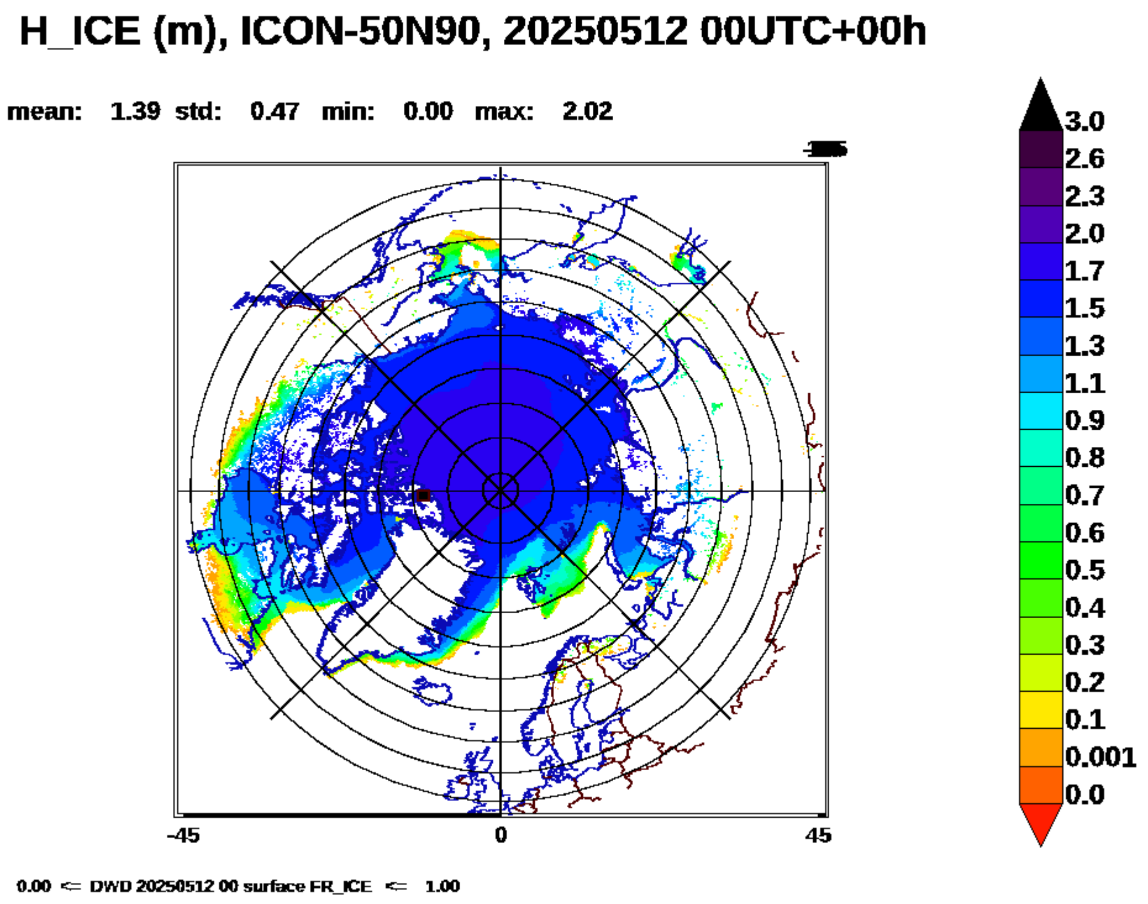
Acknowledgements: Hermann Asensio, Frank Beyrich, Michael Buchhold, Ulrich Damrath, Günther Doms, Jochen Förstner, Helmut Frank, Sergey Golosov, Thomas Hanisch, Erdmann Heise, Jürgen Helmert, Georgy Kirillin, Ekaterina Kourzeneva, Martin Lange, Ekaterina Machulskaya, Andrey Martynov, Peter Meyring, Aurelia Müller, Van Tan Nguyen, Daniel Reinert, Bodo Ritter, Burkhardt Rockel, Laura Rontu, Patrick Samuelsson, Ulrich Schättler, Jan-Peter Schulz, Christoph Schraff, Zachary Subin, Arkady Terzhevik, Günther Zängl, and many FLake users (http://lakemodel.net).

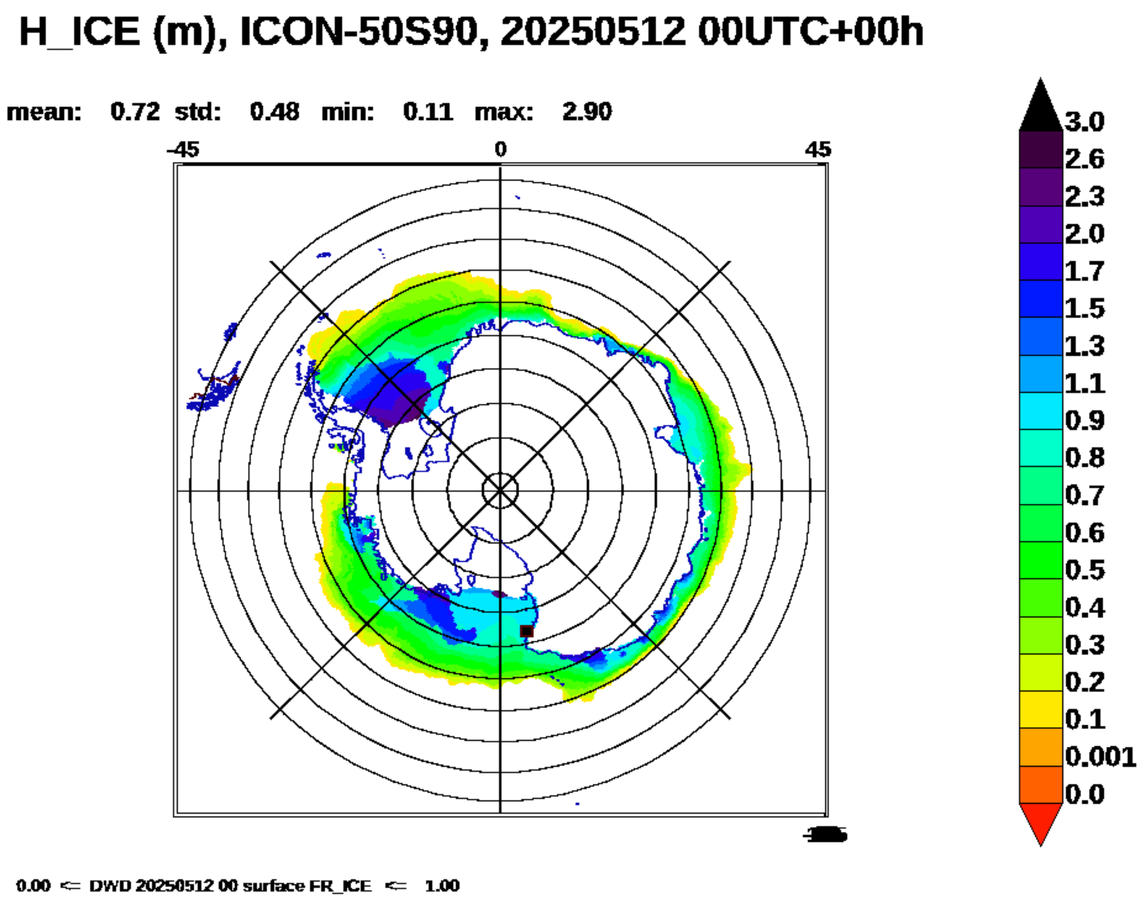
EU Commissions, Projects INTAS-01-2132 and INTAS-05-1000007-431; Nordic Research Board through the Nordic Networks NetFAM (Fine-Scale Atmospheric Modelling) and MUSCATEN (Towards Multi-Scale Modelling of the Atmospheric Environment).

Empirical data from Lake Pääjärvi are made available through the collaboration with the Division of Geophysics of the University of Helsinki that is supported by the Academy of Finland (project “Ice Cover in Lakes and Coastal Seas”) and by the Vilho, Yrjö and Kalle Väisälä Foundation of the Academy of Sciences and Letters, Finland (project “Modelling of Boreal Lakes”). Thanks are due to Christopher Ellis (University of Minnesota, USA) for providing data from measurements in Lake Ryan.

# Monitoring of
# Sea-Ice and FLake Schemes Performance at DWD

# Sea Ice Scheme within ICON

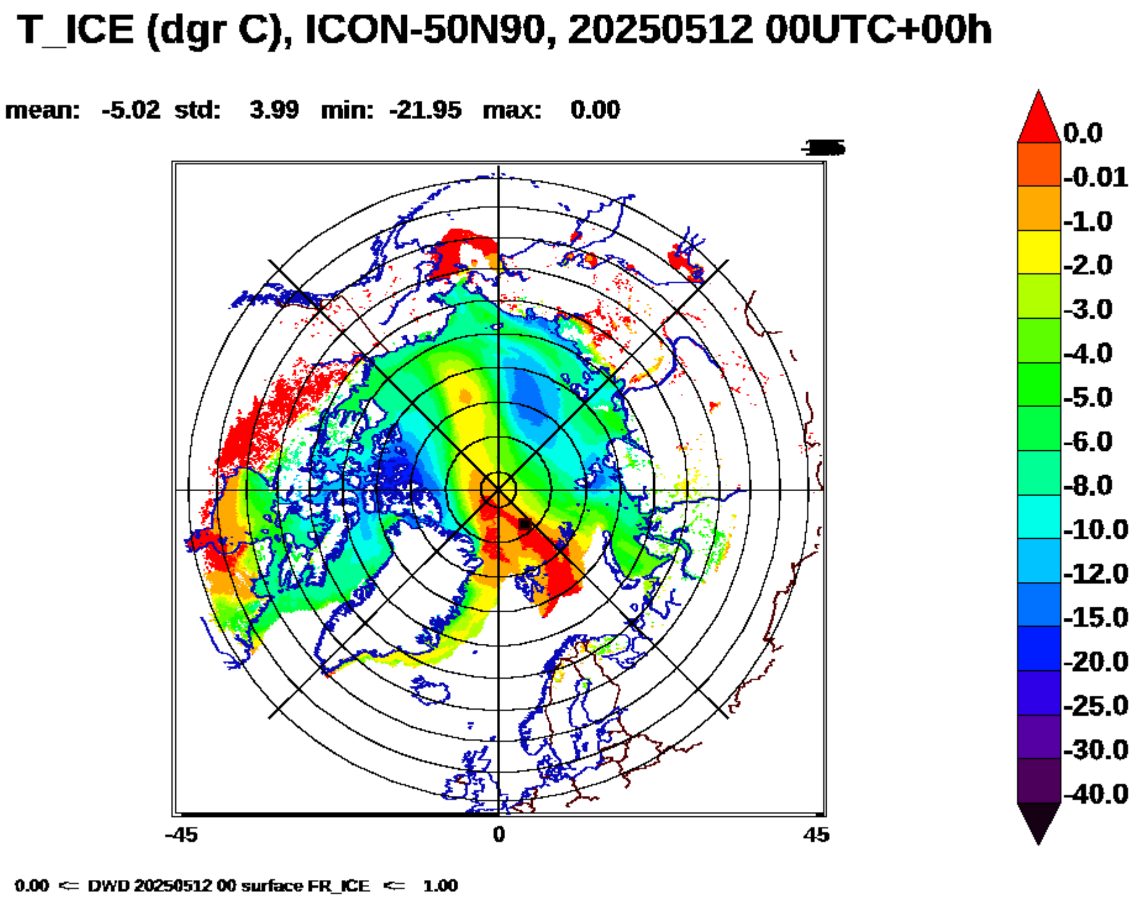


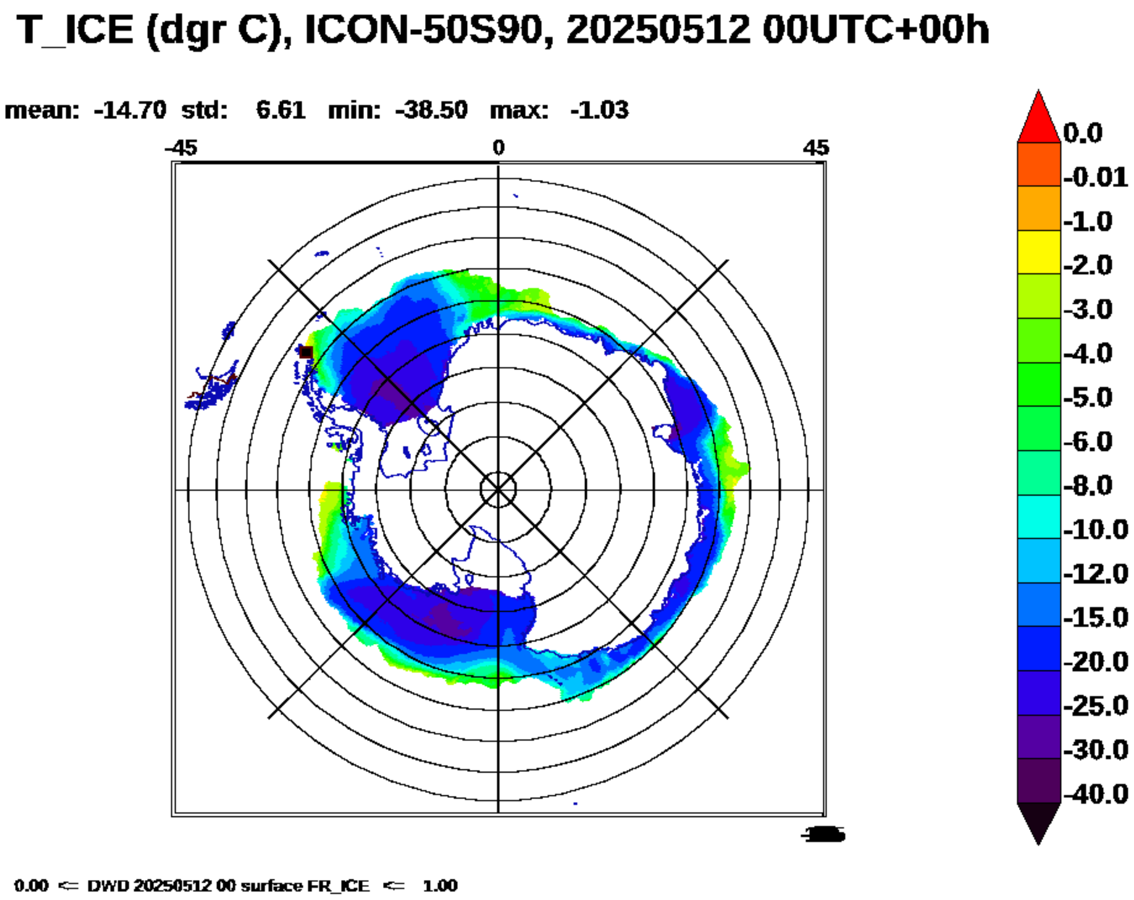




Ice thickness (m) from ICON, 12 May 2025, 00 UTC.

Left panel – Arctic, right panel – Antarctic.

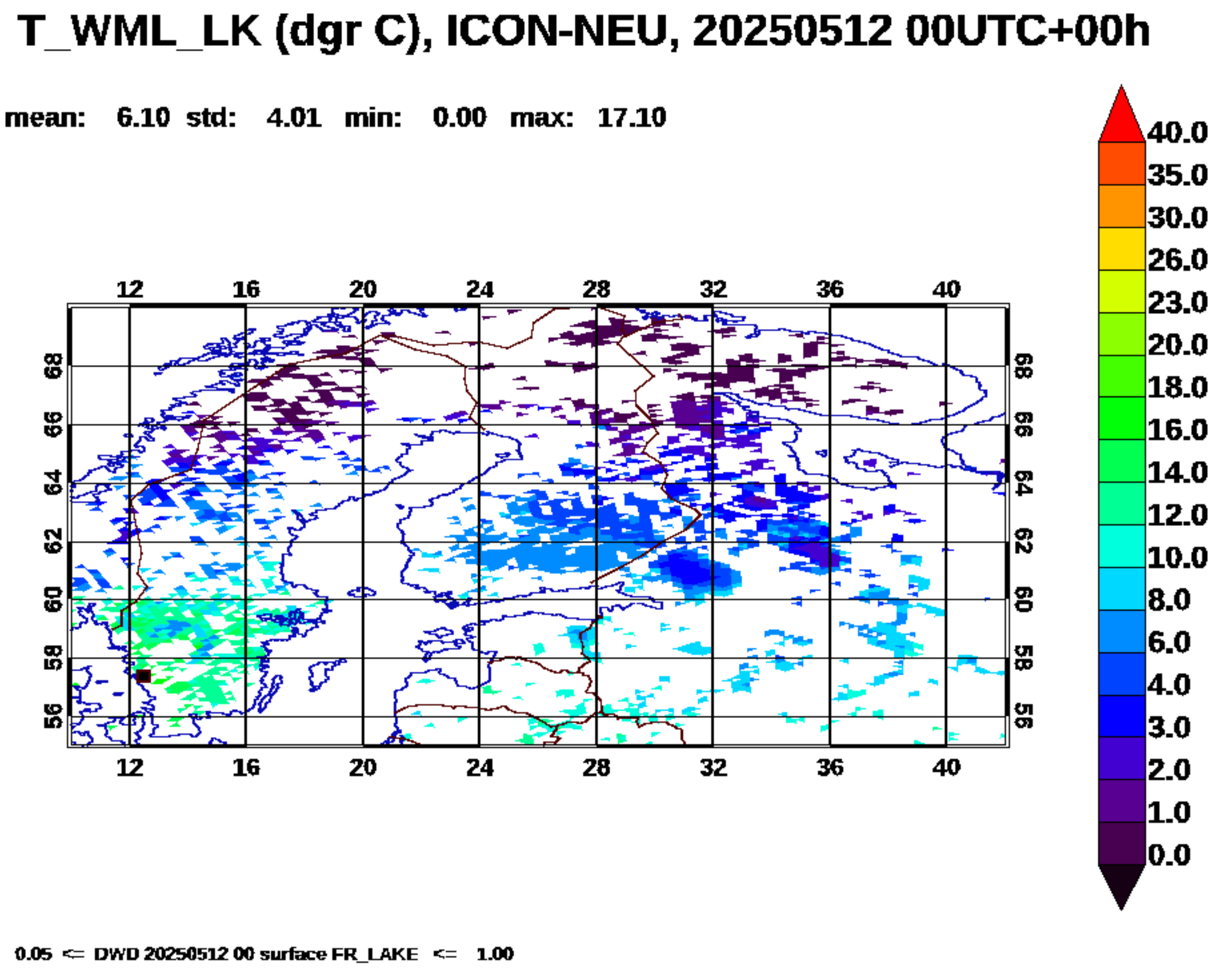
# Sea Ice Scheme within ICON (cont'd)

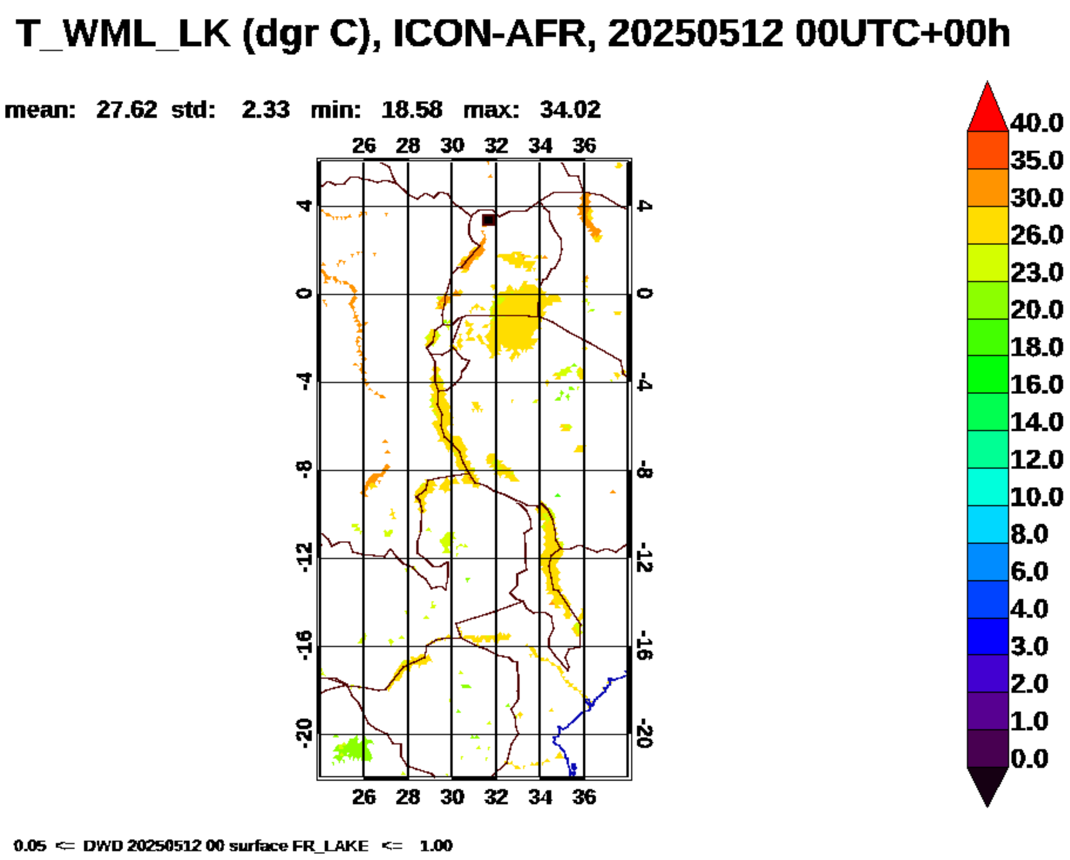



Ice surface temperature (dgr C) from ICON, 12 May 2025, 00 UTC.
Left panel – Arctic, right panel – Antarctic.

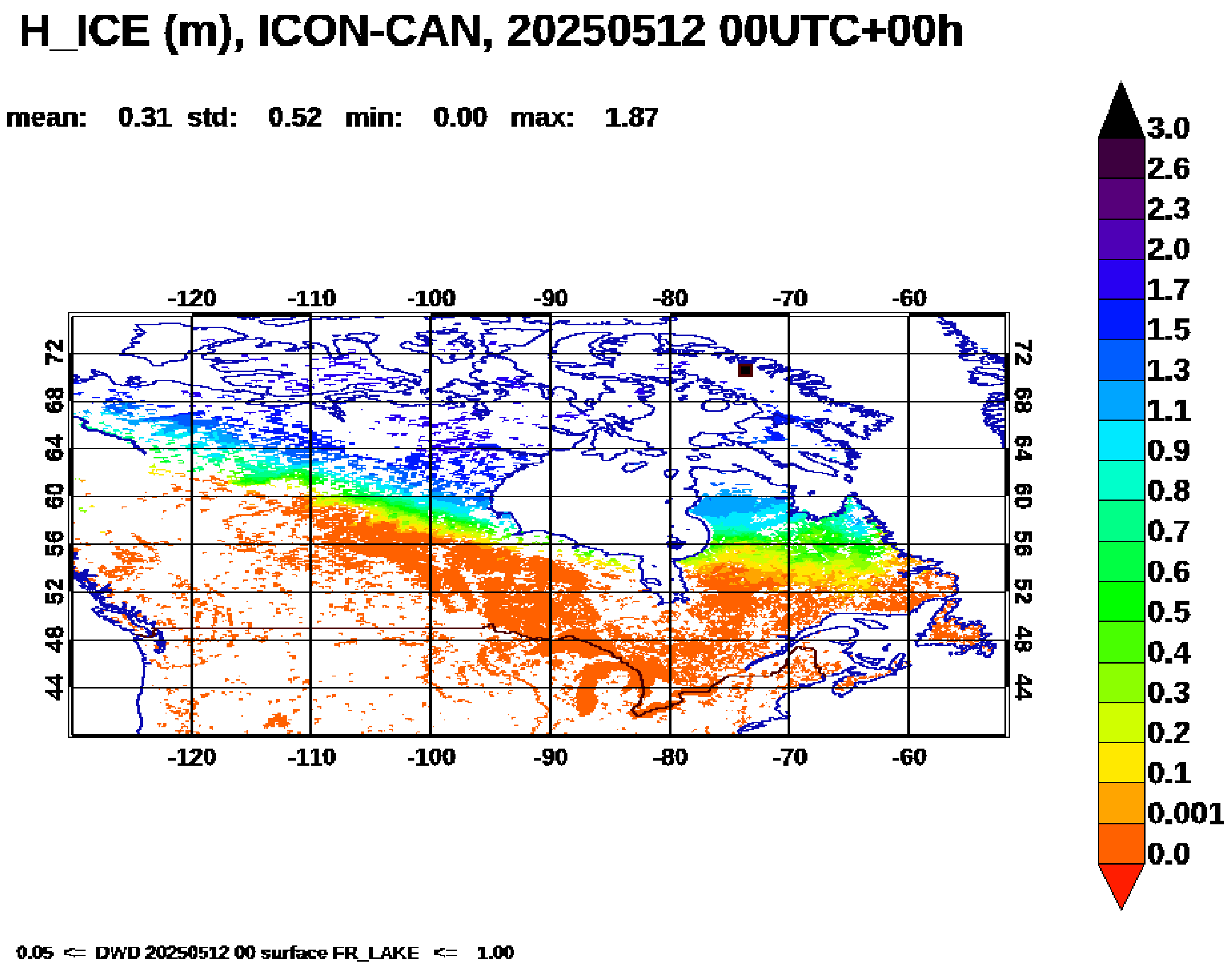
# FLake within ICON



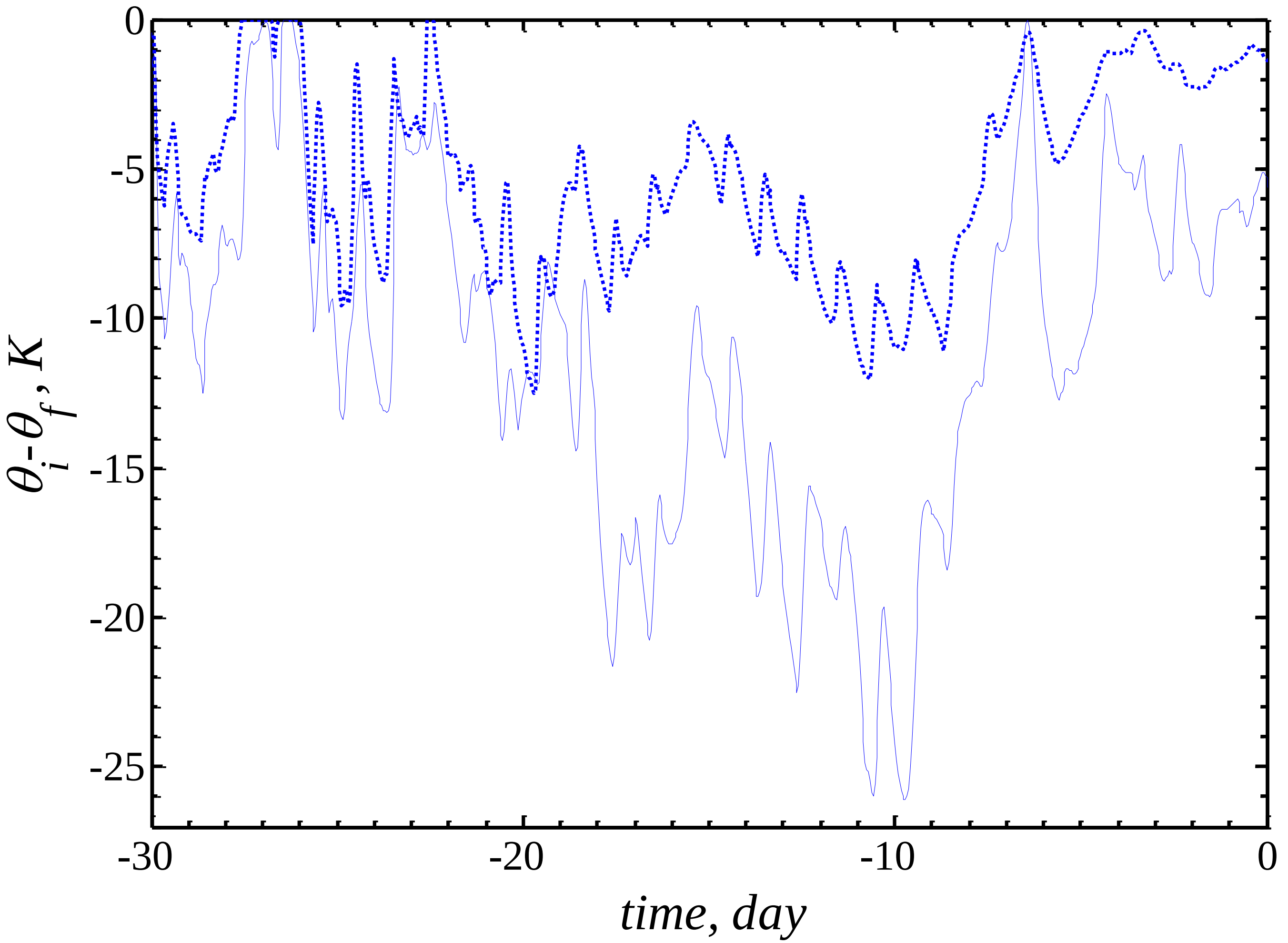

Mixed-layer temperature (dgr C) from ICON, 12 May 2025, 00 UTC.
Left panel – Northern Europe, right panel – Central Africa.

# FLake within ICON (cont'd)




Ice thickness (m) from ICON, 12 May 2025, 00 UTC. North America.

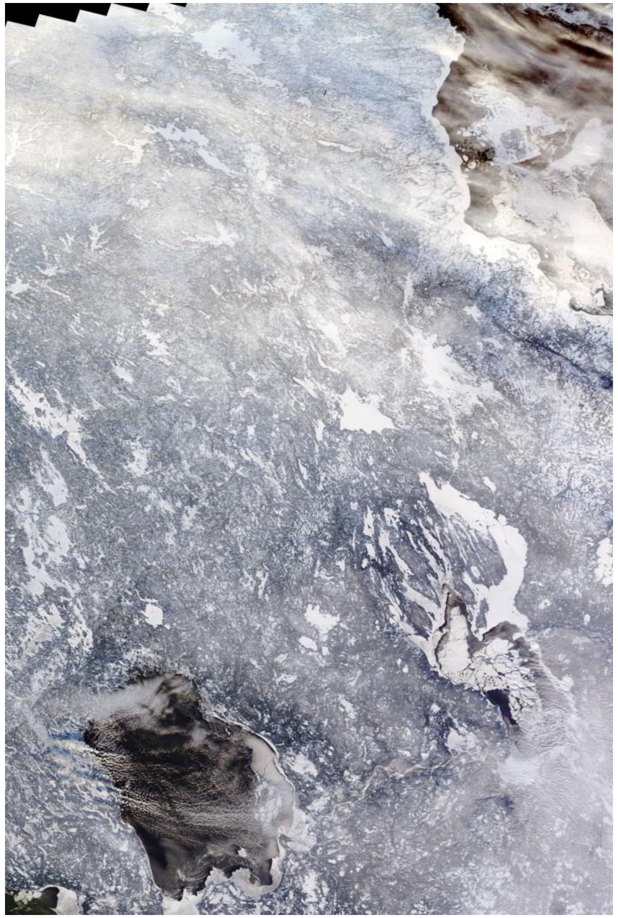
# Lake Ryan, December 1989

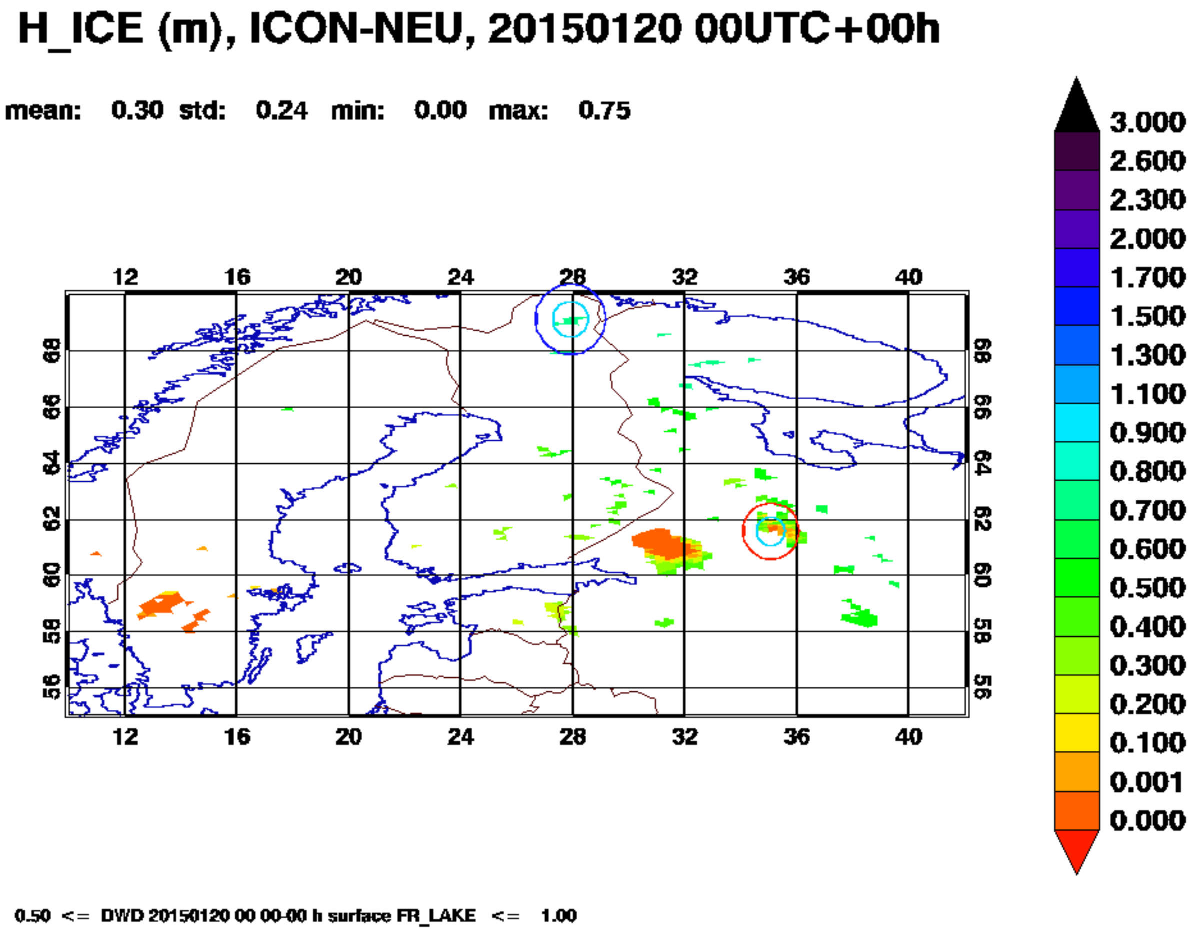



- Solid - modelled ice surface temperature
- Dotted - temperature measured with the uppermost sensor

...

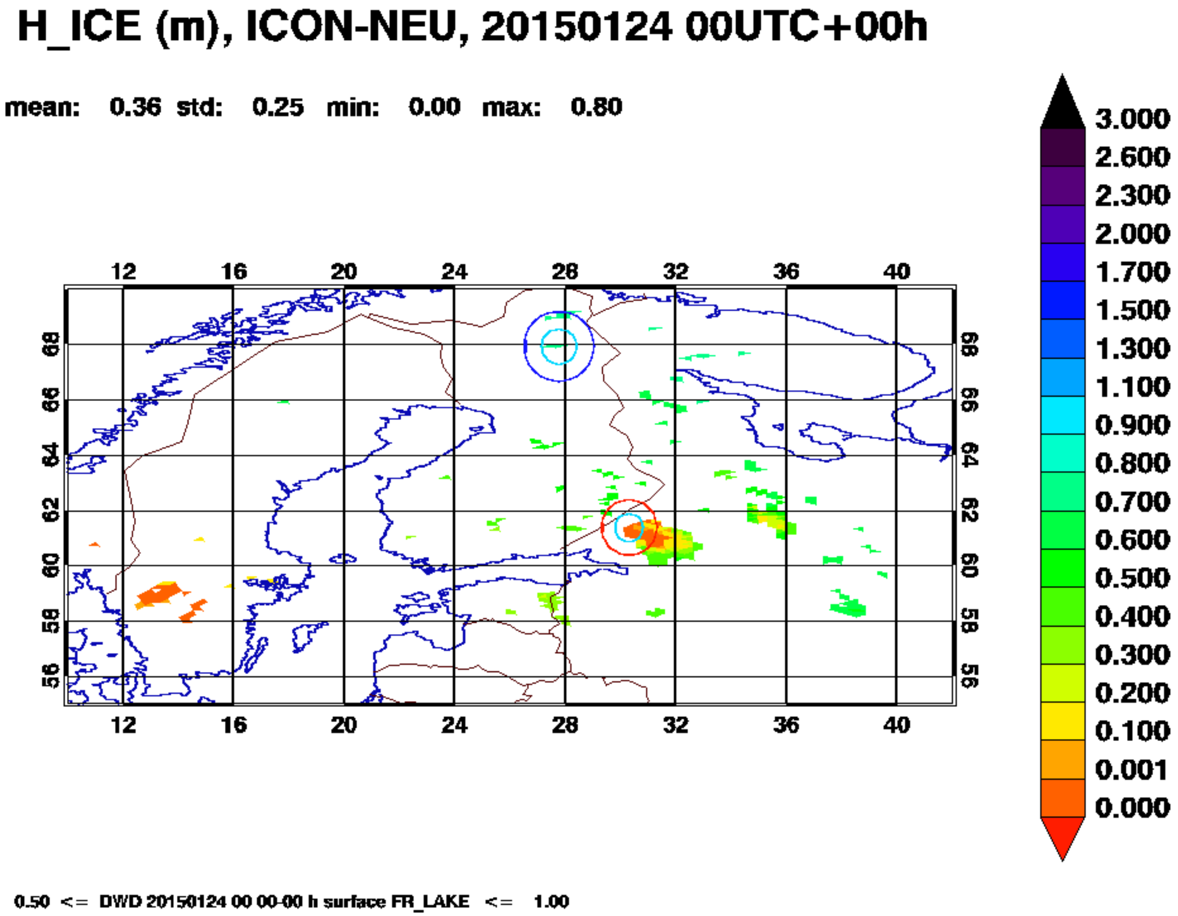
# ICON-NWP Results vs. Observations





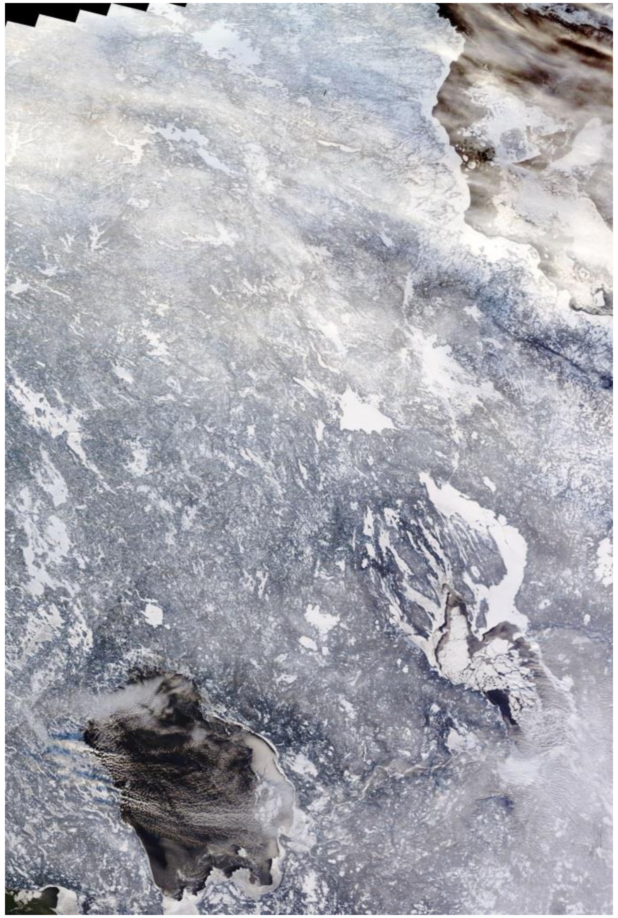

Lake Ladoga and Lake Onega ice cover, 20 January 2015. Satellite data (http://lance-modis.eosdis.nasa.gov/imagery/subsets/?subset=Karelia.2015020.terra.250m.jpg) vs. ICON forecast.

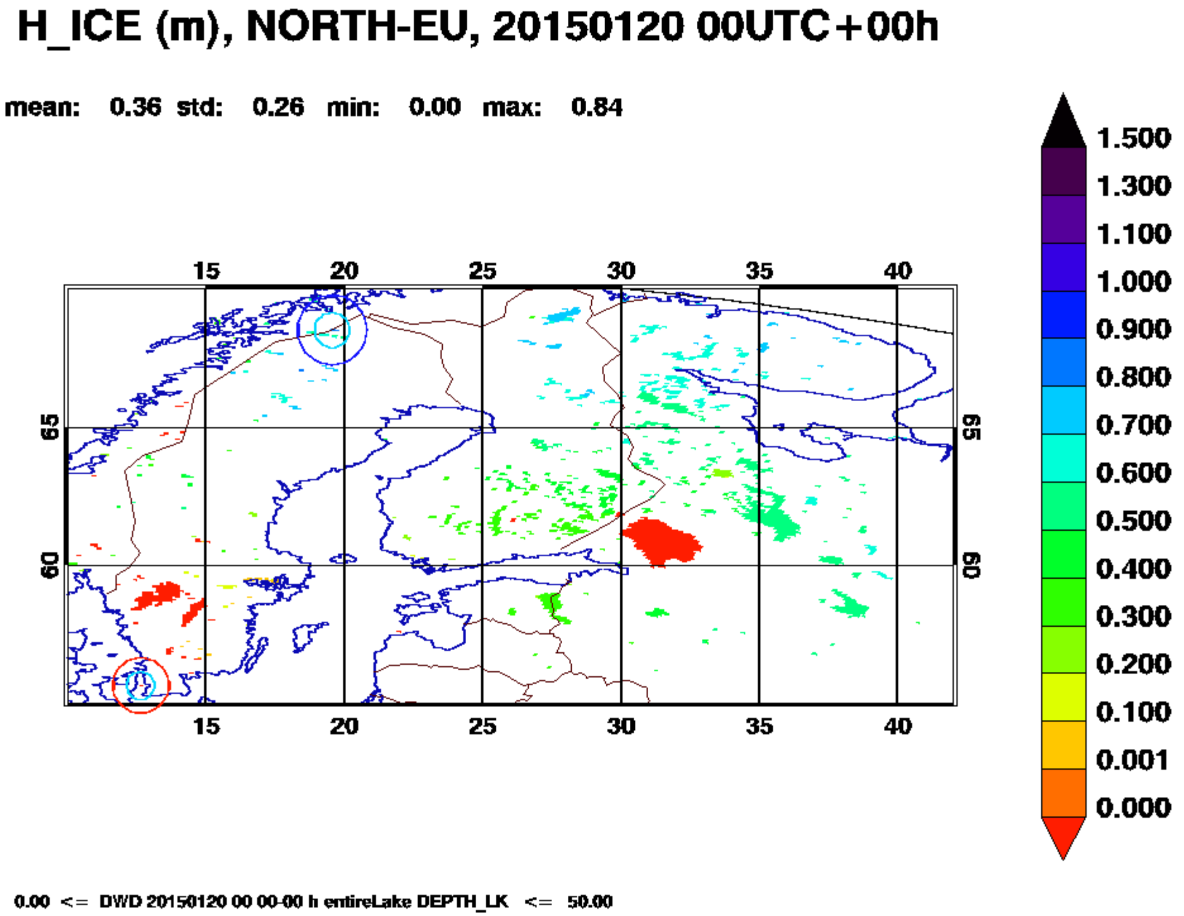
# ICON-NWP Results vs. Observations




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.

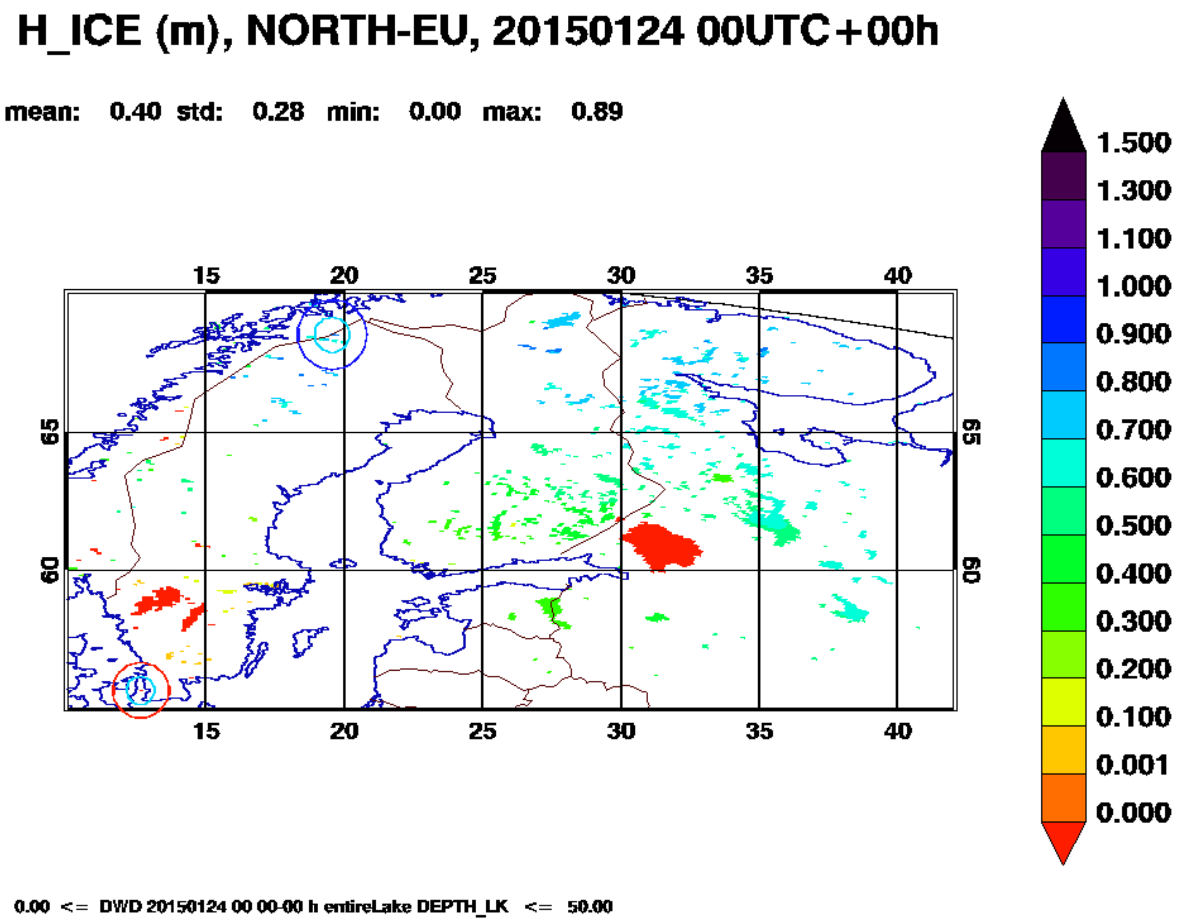
# Importance of External Parameters





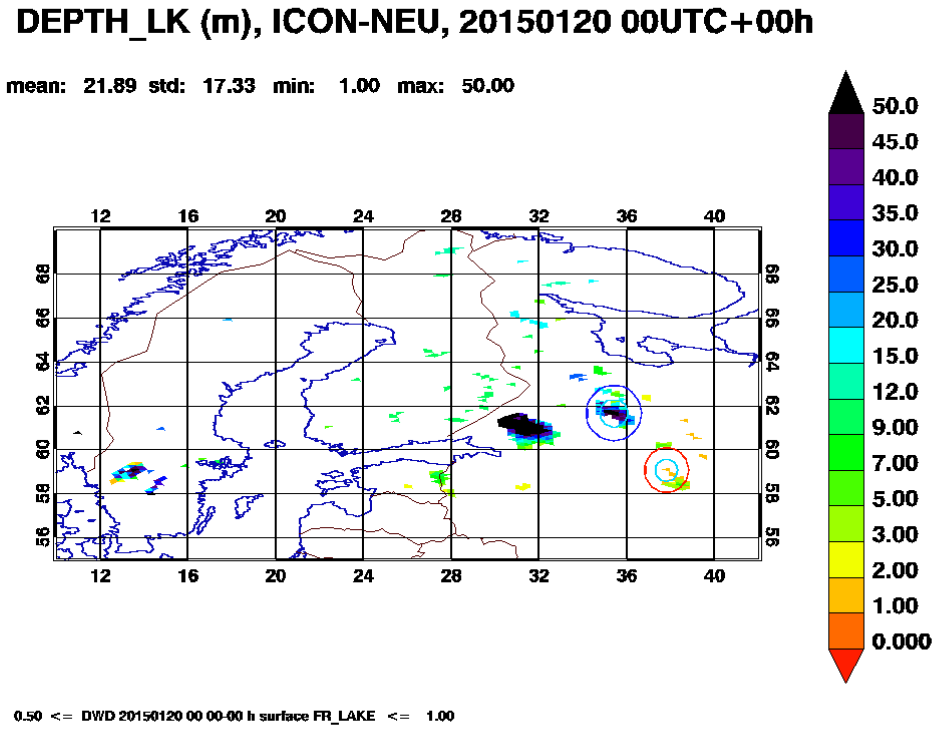

Lake Ladoga and Lake Onega ice cover, 20 January 2015. Satellite data (http://lance-modis.eosdis.nasa.gov/imagery/subsets/?subset=Karelia.2015020.terra.250m.jpg) vs. COSMO-EU forecast.

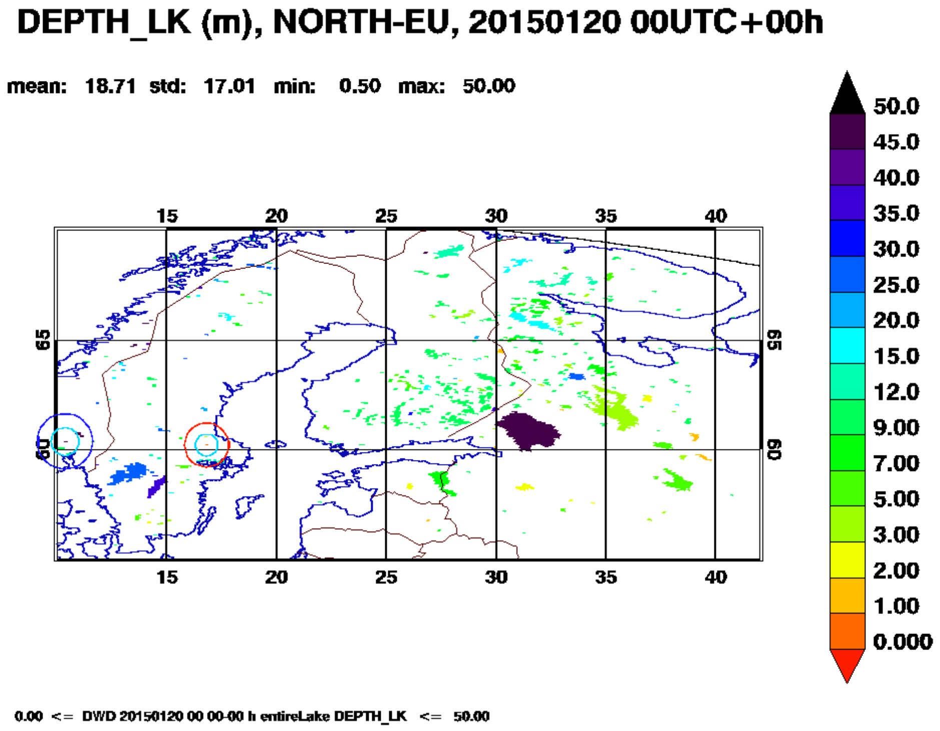
# Importance of External Parameters (cont’d)




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).