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Data assimilation over lakes

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Contents

- Introduction
- Lake observations
- Lake data assimilation: overlook and methods
- Lake model FLake from DA point of view
- EKF for FLake to assimilate LST
- Assimilation of SYKE obs
- Plans, perspectives

Introduction

Why DA for lakes is needed?

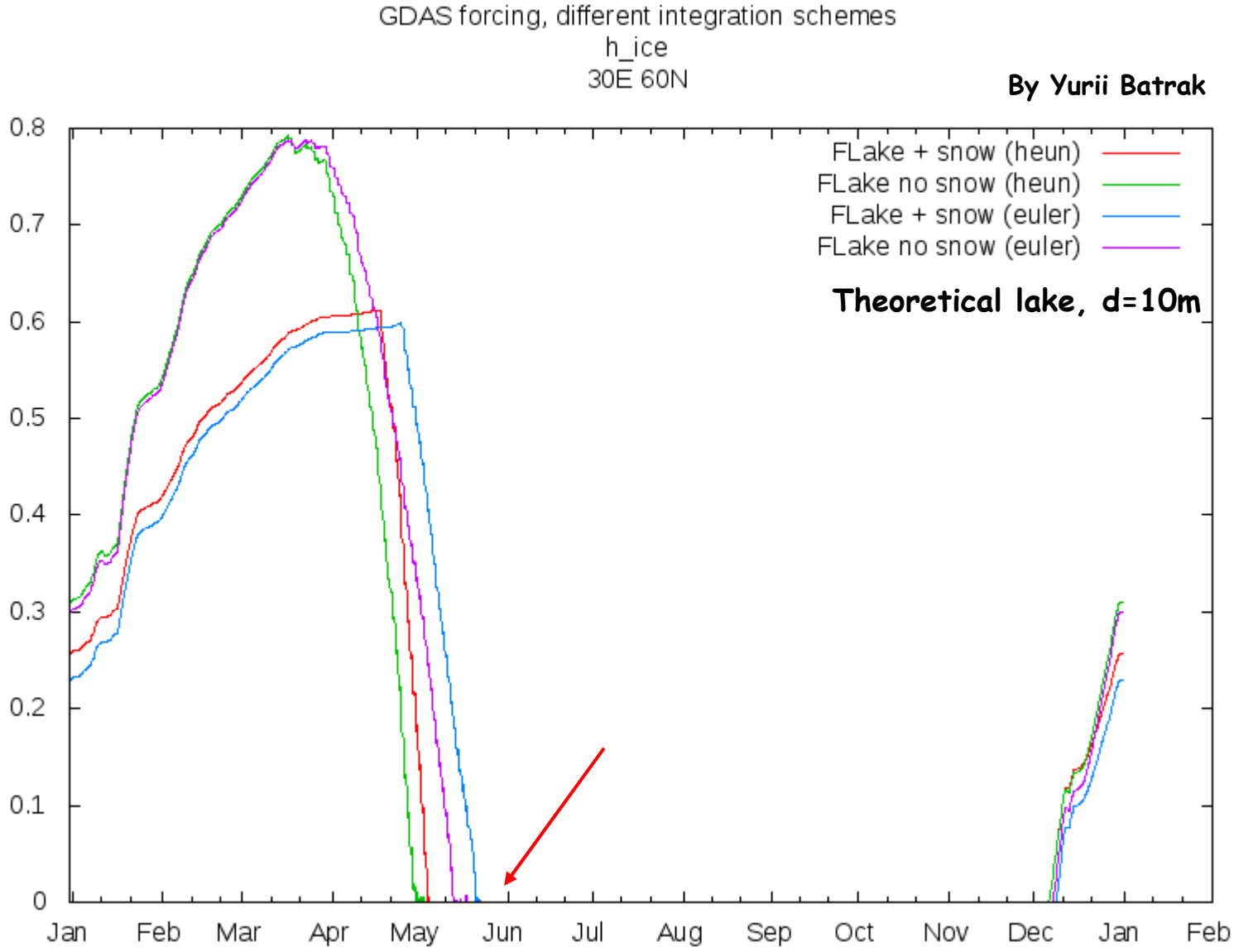
Model errors may be large.

Observations exist: in-situ, satellite – MODIS

New data are coming: ESA-funded projects

ArcLake – ATSR, coarse resolution, 500 large lakes

North Hydrology – ATSR, 1 km resolution, all lakes in Nordic domain


GDAS forcing, different integration schemes
h_ice
30E 60N
By Yurii Batrak
FLake + snow (heun)
FLake no snow (heun)
FLake + snow (euler)
FLake no snow (euler)
Theoretical lake, d=10m
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb

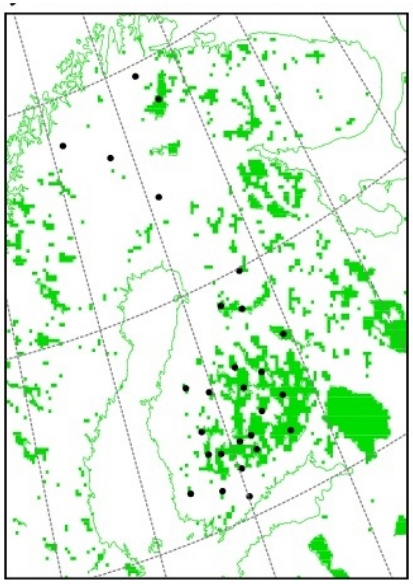
Lake observations

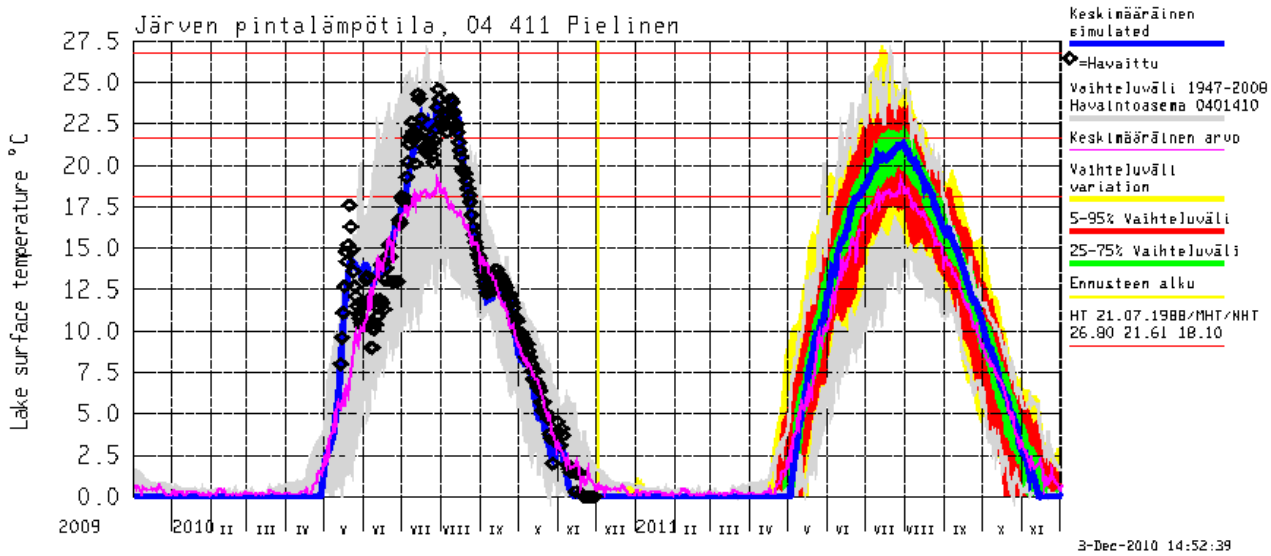
What we observe and can assimilate:

- Temperature - LST
- Ice cover
  - very important!
  - ice/no ice, ice fraction, ice thickness (?),
    snow on ice (?)

In general, both fields are discontinuous in space and time

Lake observations





Lake surface temperature
in-situ observations over 27 lakes in Finland

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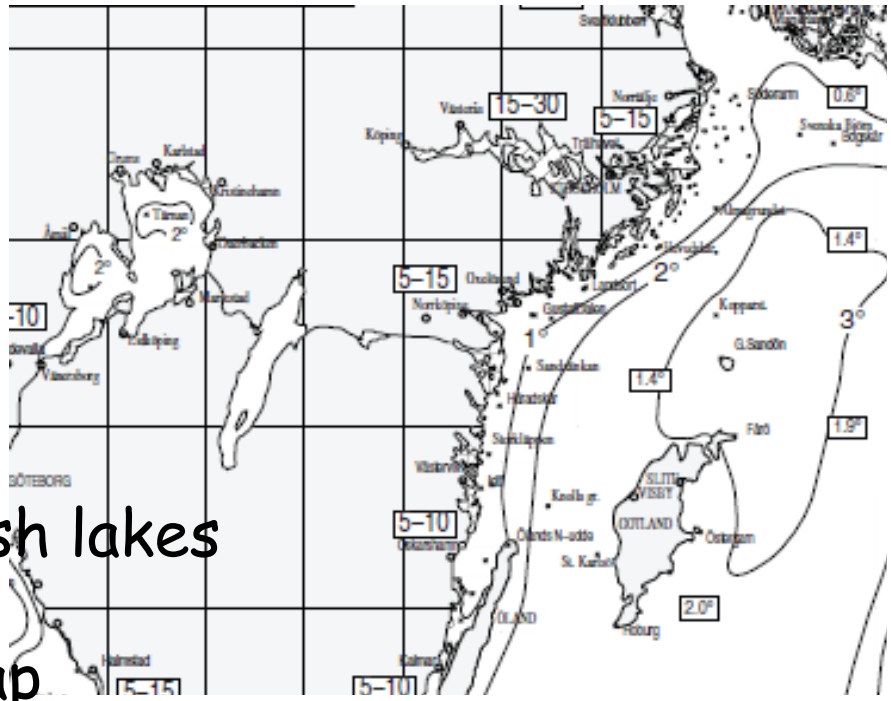
Lake observations

Satellite-based, gridded

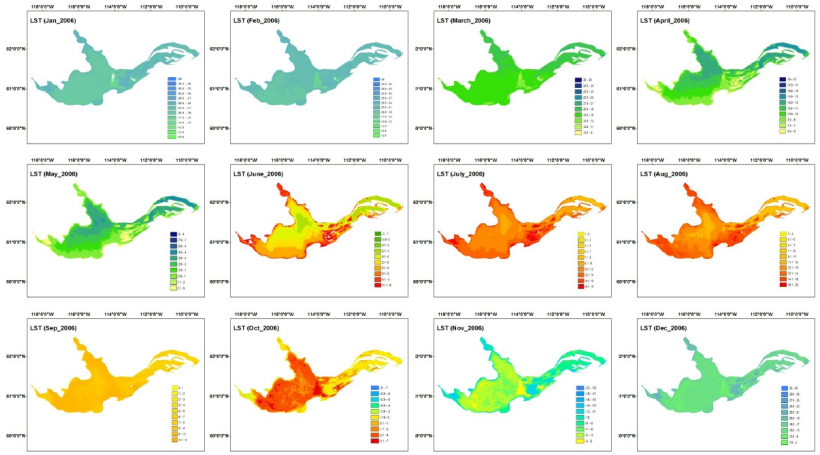


water temperature obs for
the Baltic Sea and large Swedish lakes
Lake Vänern and Lake Vettern,
based on the operational ice map
by FMI

http://www.itameriportaali.fi/en/itamerinyt/en_GB/jaatilanne/

Lake observations

LST, Great Slave Lake



remote sensing observations
- MODIS 1 km resolution, clear sky conditions.

Quality of remote sensing observations:
- Undetected clouds
- Skin temperature
- Lake mask
- Spring ice

Preprocessing and quality control is needed

Lake data assimilation: overlook and methods

More similar to Land surface than to oceanographic DA

For the coupled system lake/atmosphere (3D) we need:

- To spread information in vertical (inside FLake) (1D)

- To spread information in horizontal (2D)
  - from in-situ obs into the model grid
  - from the image grid to the model grid

Lake data assimilation: overlook and methods

To spread information in horizontal

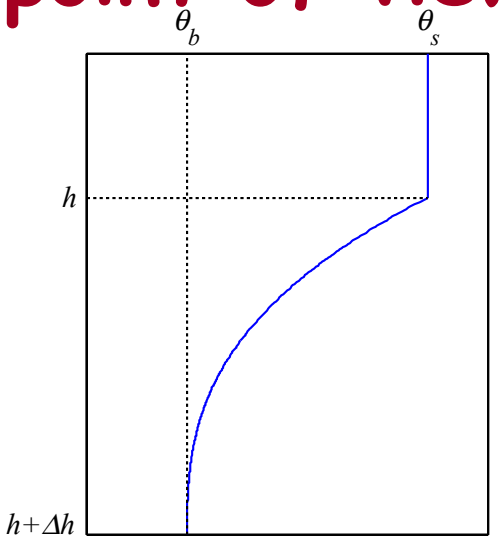
- for LST and fraction of ice, use OI as for SST, but with the dependency of structure functions on the difference in lake depth and elevation?

- for remote sensing data: thinning, super-observations by averaging, lake masks consistency problem

Lake model FLake from DA point of view

FLake – a bulk lake model 1D (0D)

based on two-layer parametric representation of the temperature profile and self-similarity concept

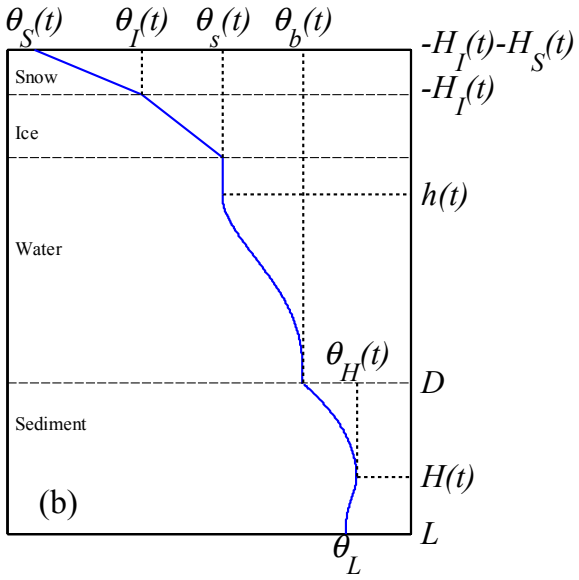


$\theta_s(t)$– mixed layer temperature

$h(t)$ – mixed layer depth

$\theta_b(t)$, –bottom temperature

$D=h+\Delta h$ – lake depth.



Lake model FLake from DA point of view

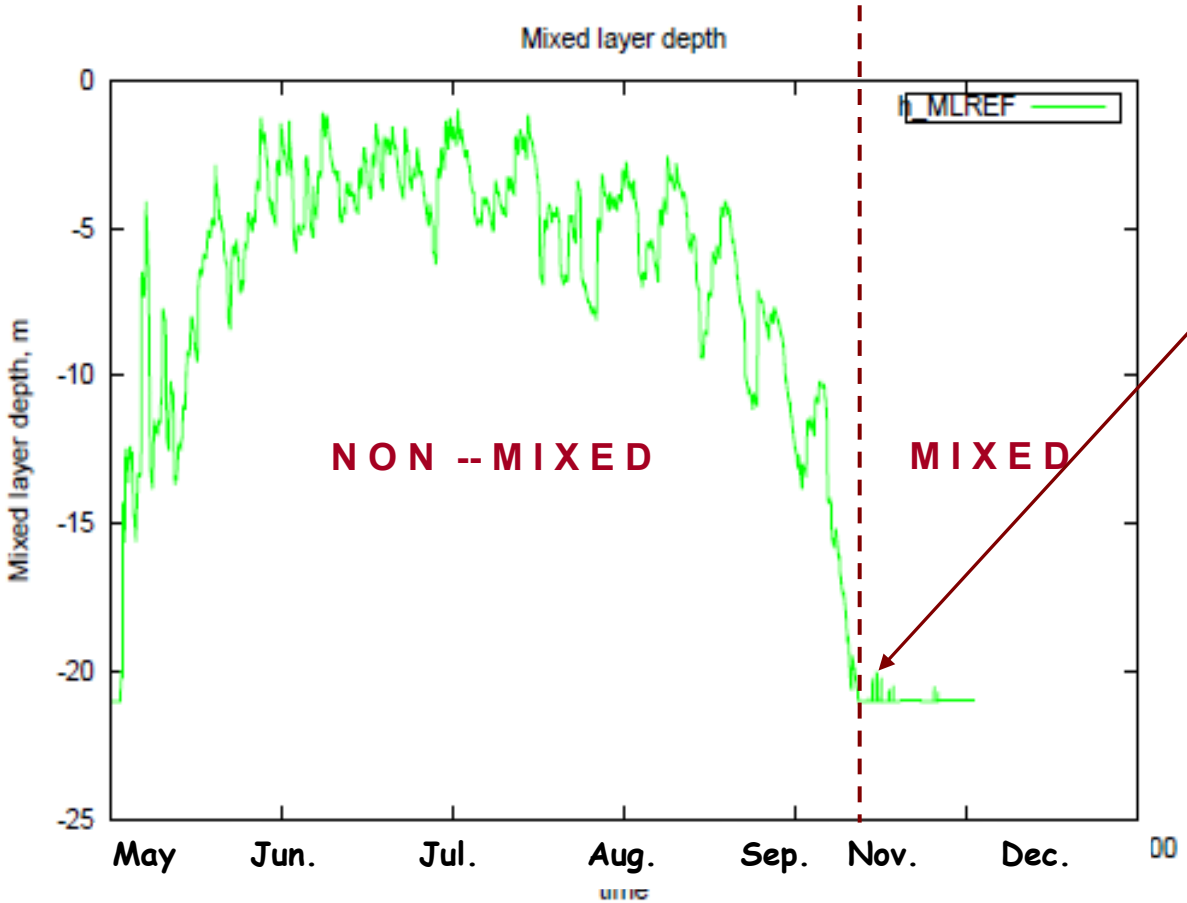
Prognostic equations

- for the mean water temperature
- for the bottom temperature
- for the mixed layer depth (in the cases of neutral stratification and convection)
- for the shape factor

Diagnostic equation

- for the mixed layer (surface) temperature

Lake model FLake from DA point of view



- jumps between regimes - discontinuouties in the model

- fast variables and slow variables

- model biases?

EKF for FLake to assimilate LST

non-mixed regime

$$\mathbf{x} = \begin{bmatrix} \overline{T} \\ T_b \\ h \\ C_T \end{bmatrix}$$

state vector

obs vector

$$\mathbf{y} = \left[T_s \right]$$

obs operator $H(\mathbf{X})$

$$T_s = \left(1 - C_T\left(1 - \frac{h}{D}\right)\right)^{-1}\left(\overline{T} - \left(1 - \frac{h}{D}\right)T_b\right)$$

EKF for FLake to assimilate LST

mixed regime

state vector

$$\mathbf{x} = \left[\overline{T}\right]$$

obs vector

$$\mathbf{y} = \left[T_s\right]$$

obs operator $H(\mathbf{X})$

$$T_s = \overline{T}$$

EKF for FLake to assimilate LST

non-mixed regime

Linearised obs operator:

$$\mathbf{H} = \left[\frac{1}{1 - C_T \eta} \quad \frac{C_T \left(\overline{T} - T_b \right)}{\left(1 - C_T \eta \right)^2} \quad \frac{-C_T \eta}{\left(1 - C_T \eta \right)} \quad \frac{\eta \left(\overline{T} - T_b \right)}{\left(1 - C_T \eta \right)} \right]$$

mixed regime

$$\eta = 1 - \frac{h}{D}$$

Linearised obs operator:

$$\mathbf{H} = 1$$

EKF for FLake to assimilate LST

non-mixed regime, mixed regime

Jacobians matrix for FLake:

$$\mathbf{M} = \frac{\partial x_i^t}{\partial x_j^0}$$

No DA when jumping between regimes to handle discountinuties

EKF for FLake to assimilate LST

$$\mathbf{x}_B = M(\mathbf{x}_A)$$

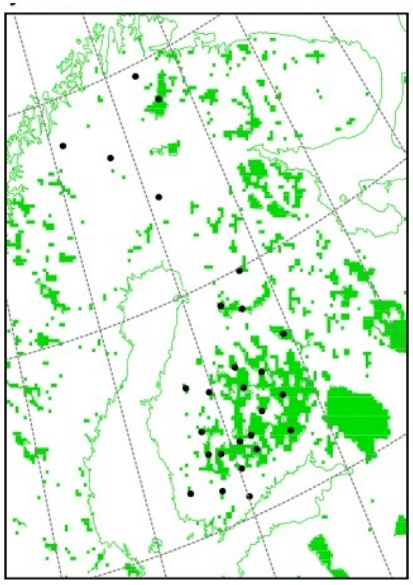
$$\mathbf{B} = \mathbf{M}\mathbf{A}\mathbf{M}^{\mathrm{T}} + \mathbf{Q}$$

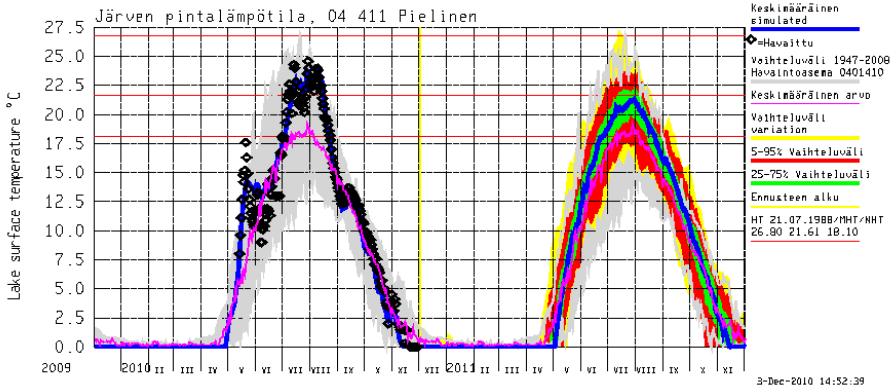
$$\mathbf{K} = \mathbf{B}\mathbf{H}^{\mathrm{T}}\left(\mathbf{H}\mathbf{B}\mathbf{H}^{\mathrm{T}} + \mathbf{R}\right)^{-1}$$

$$\mathbf{x}_{\mathrm{A}} = \mathbf{x}_{\mathrm{B}} + \mathbf{K}\left(\mathbf{y} - H(\mathbf{x}_{\mathrm{B}})\right)$$

$$\mathbf{A} = (\mathbf{I} - \mathbf{K}\mathbf{H})\mathbf{B}$$

Assimilation of SYKE obs





Lake surface temperature
operational in-situ obs
over 27 lakes in Finland

No LST obs during ice period:

if LST="no data" value,
it may be ice!

if LST = "no data", stop DA!
=> ice is considered indirectly

Assimilation of SYKE obs

- 27 lakes
- 3.11.2010-10.11.2011
- FLake offline
- Forcing from operational HIRLAM forecasts
- Obs at 8.00 UTC
- Analysis at 6.00 UTC
- Assimilation window - 2h
- Assimilation cycle - 24 hours

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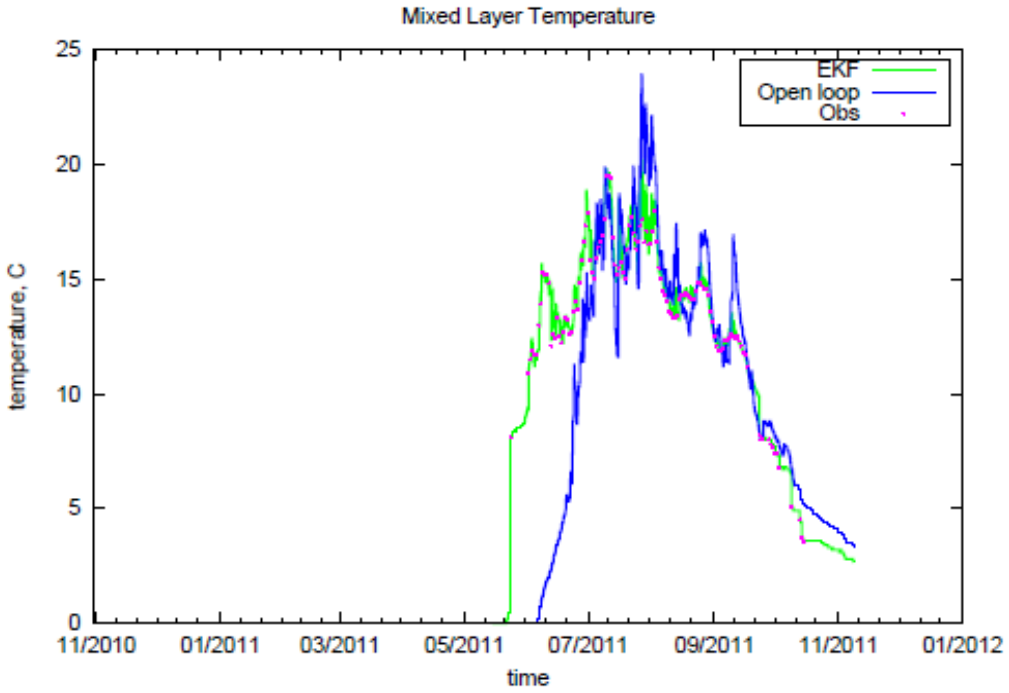
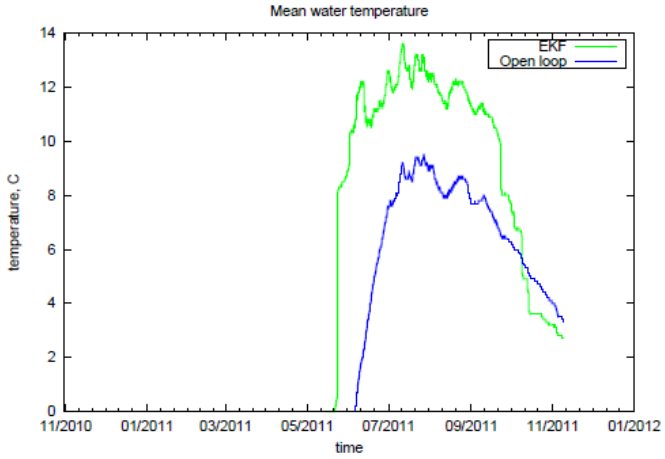
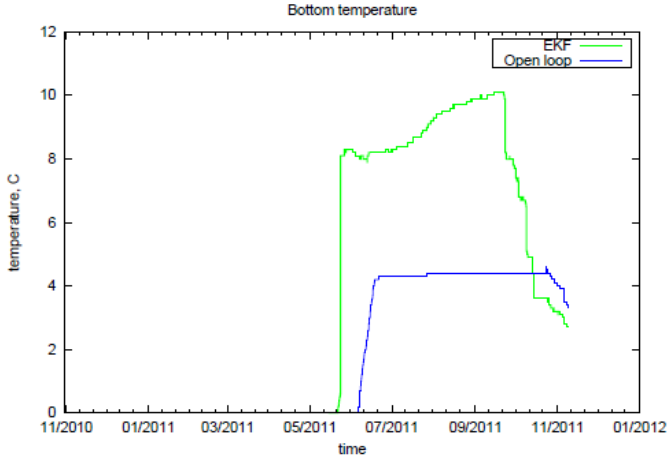
Assimilation of SYKE obs

Lake Ianri, 14m

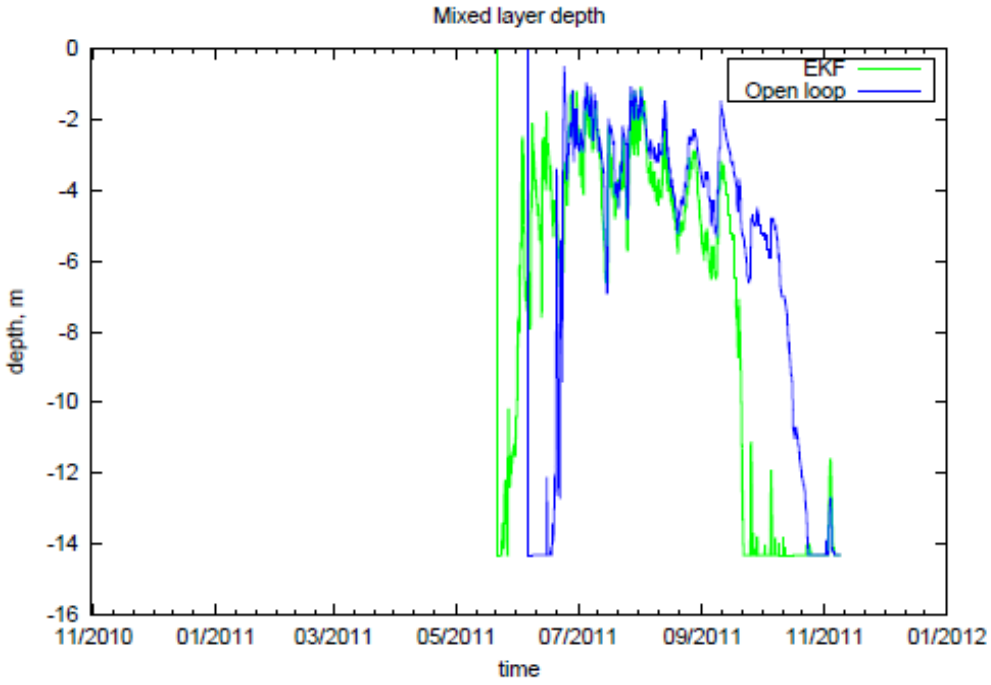


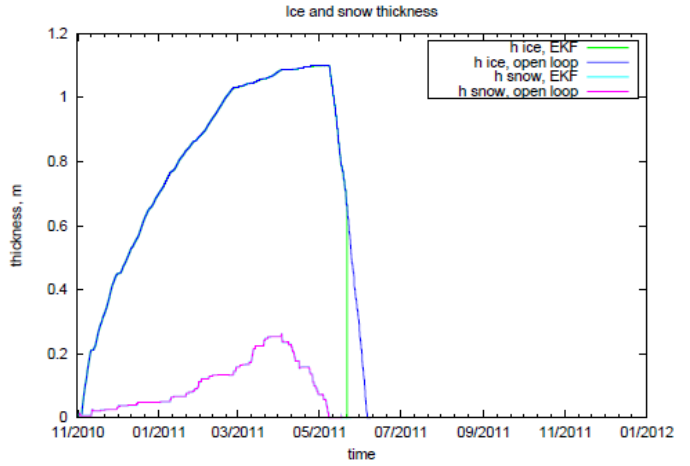


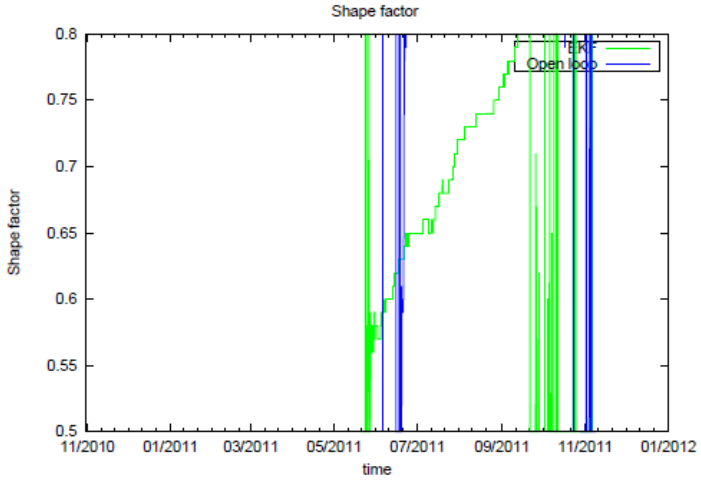


Assimilation of SYKE obs

Lake Ianri, 14m







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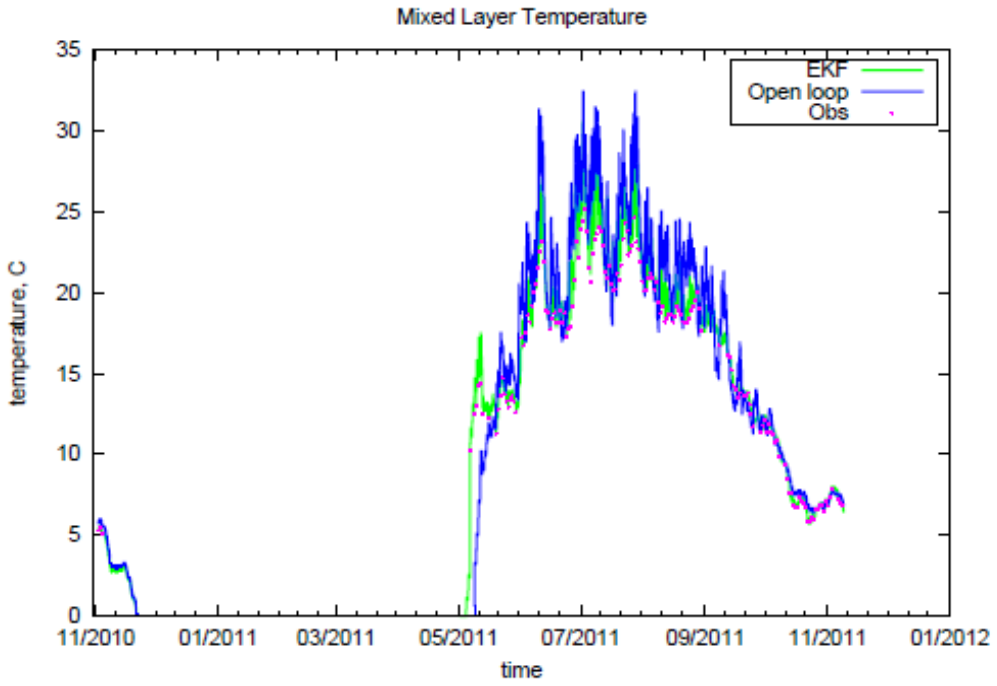
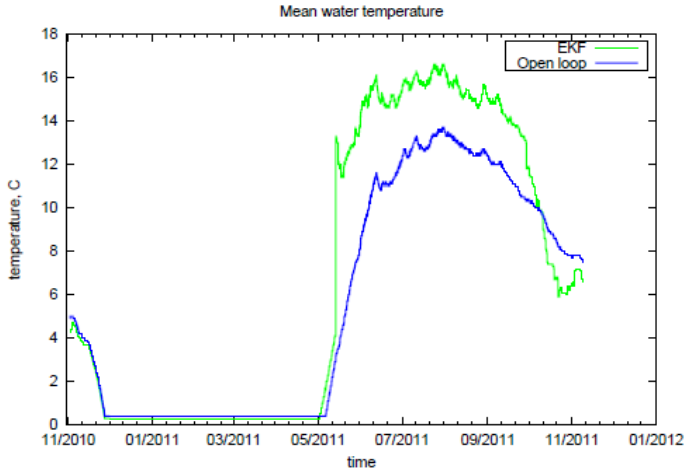
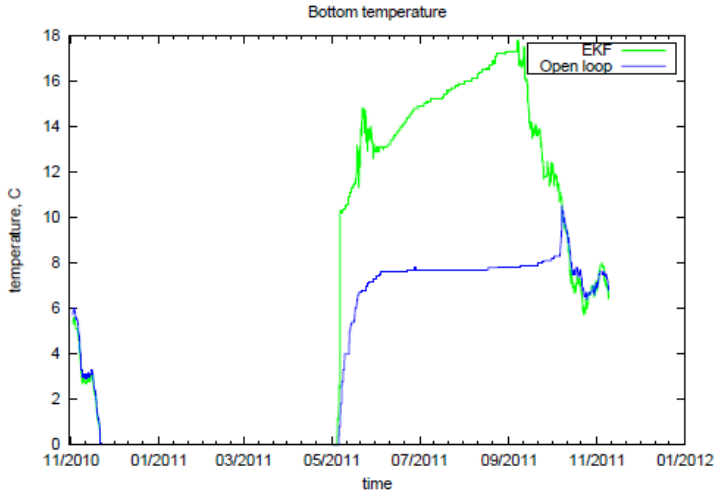
Assimilation of SYKE obs

Lake Tuusula, 3m

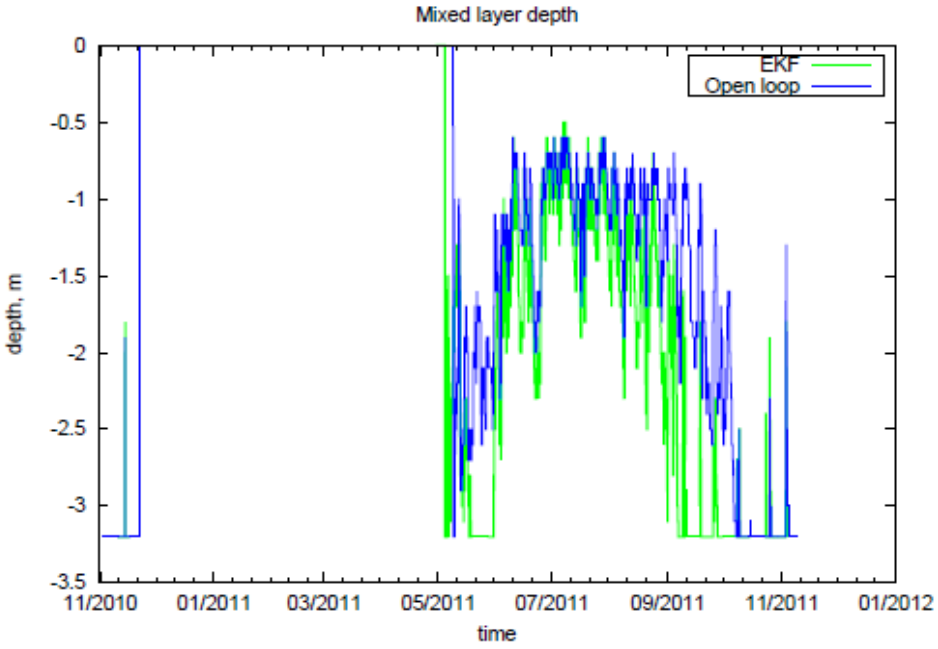


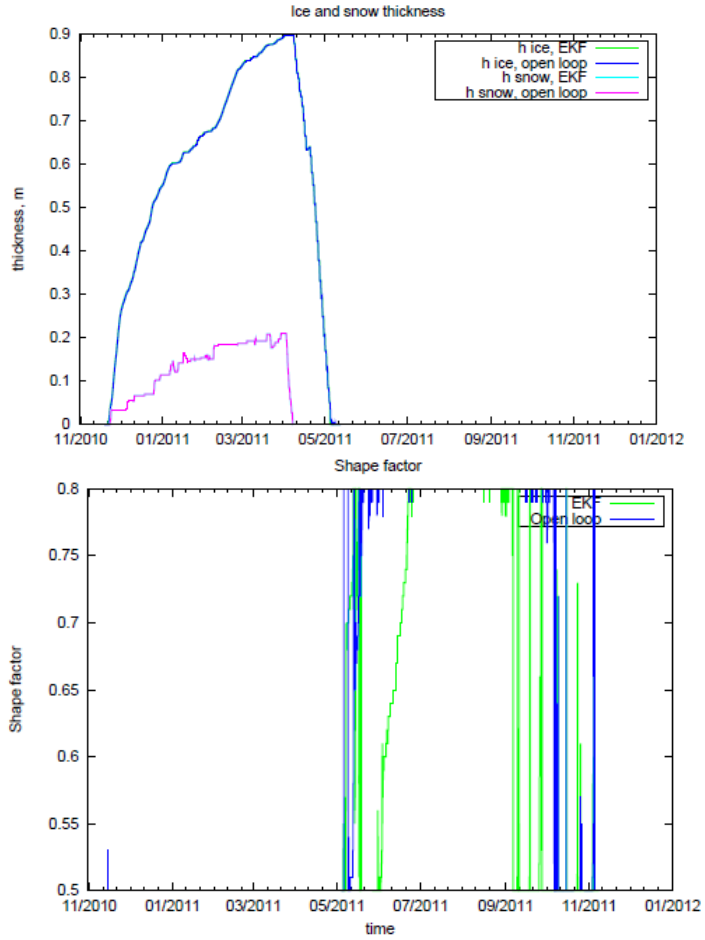




Assimilation of SYKE obs

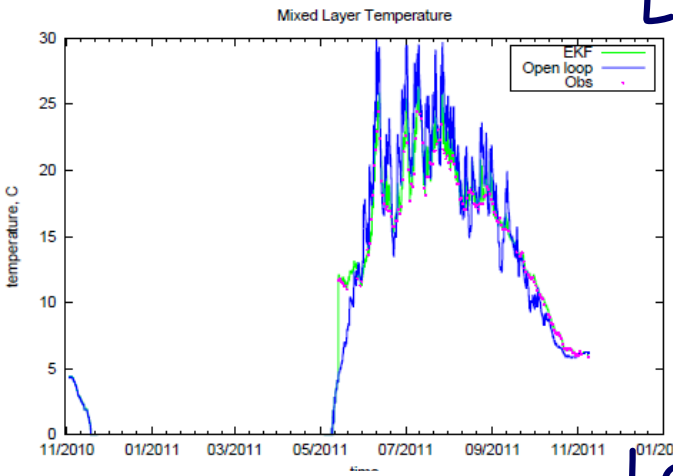
Lake Tuusula, 3m



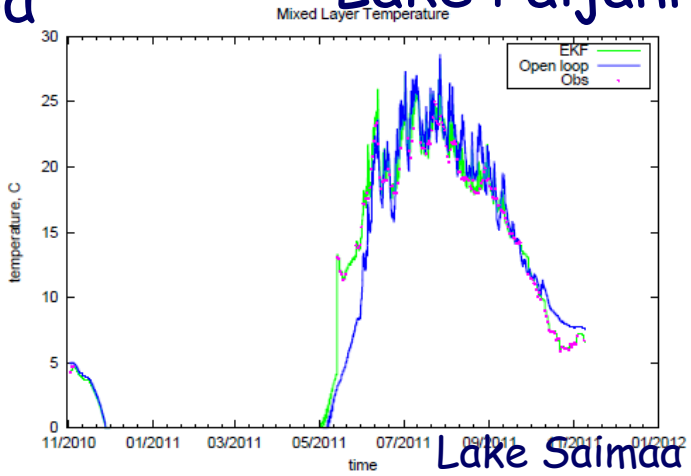


Assimilation of SYKE obs

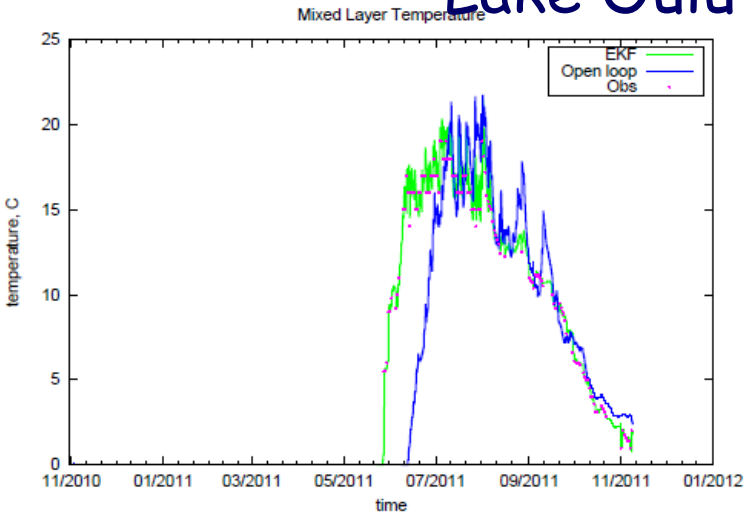
Lake Lappa



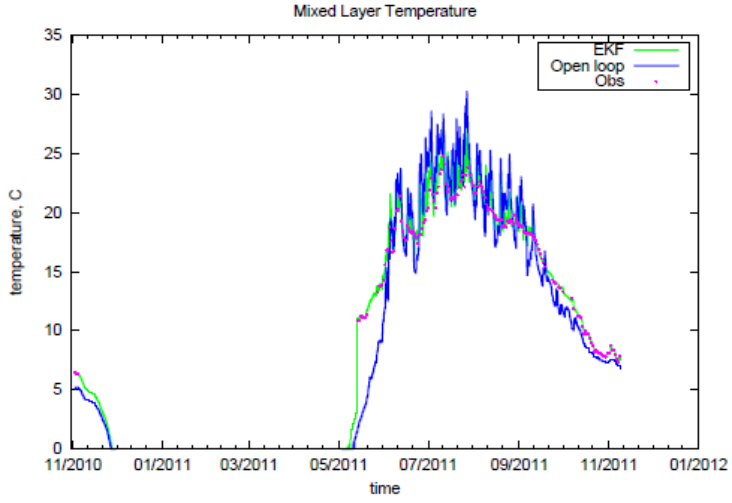
Lake Paijanne



Lake Oulu



Lake Saimaa



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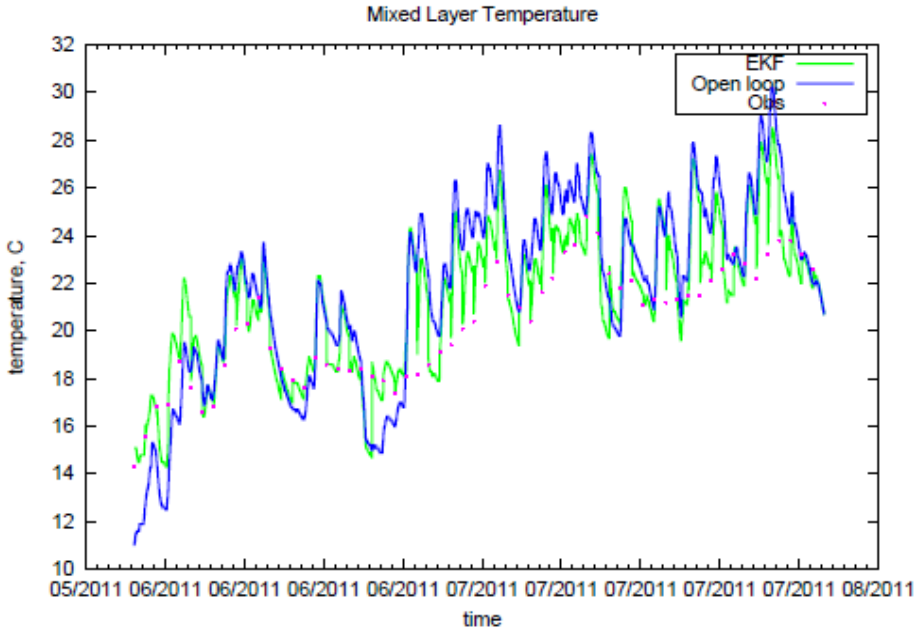
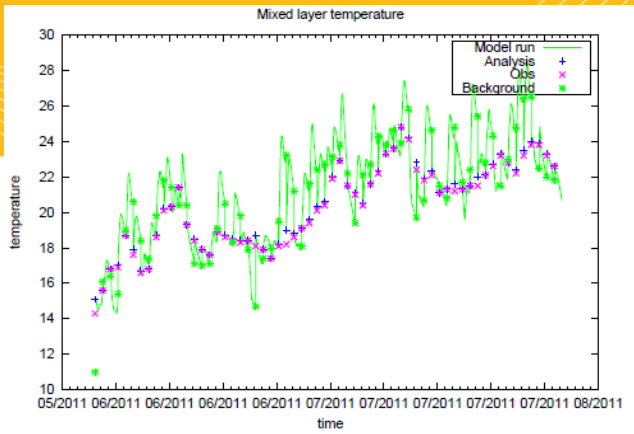
Assimilation of SYKE obs

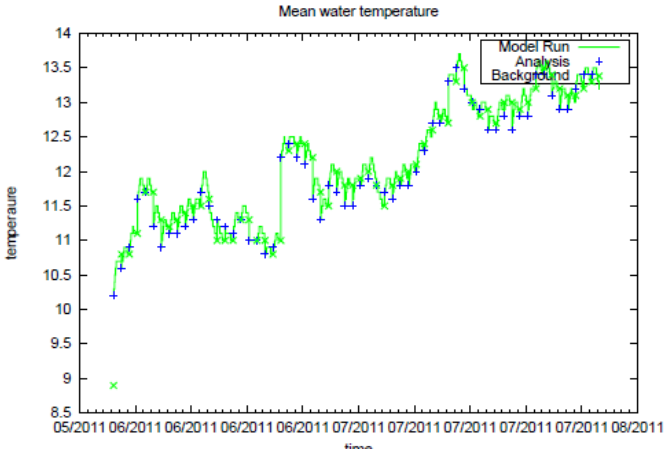
Lake Saimaa,

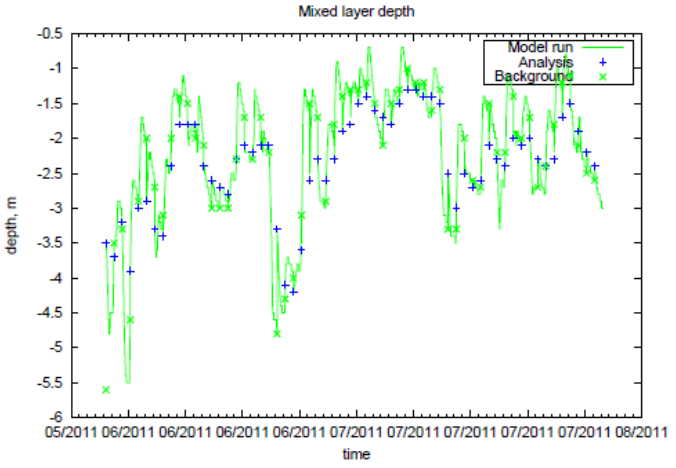
BUT … cold start at June, 1

… 2 months









Plans, perspectives:

- Verification with independent obs or cross - validation
- Study errors
- Model bias corrections … (mixed layer depth in stable regime) – if needed
- Testing with remote sensing obs
- OI with specific correlation functions
- Quality control for remote sensing obs
- Include into SURFEX/VARRASIM and HARMONIE


Thank you for attention!