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Lake data assimilation in SURFEX: ideas and first results

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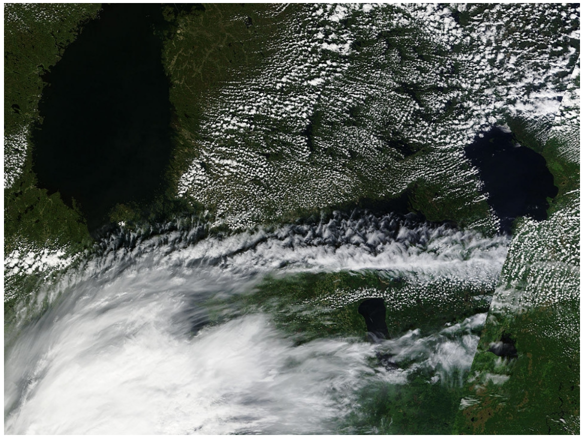
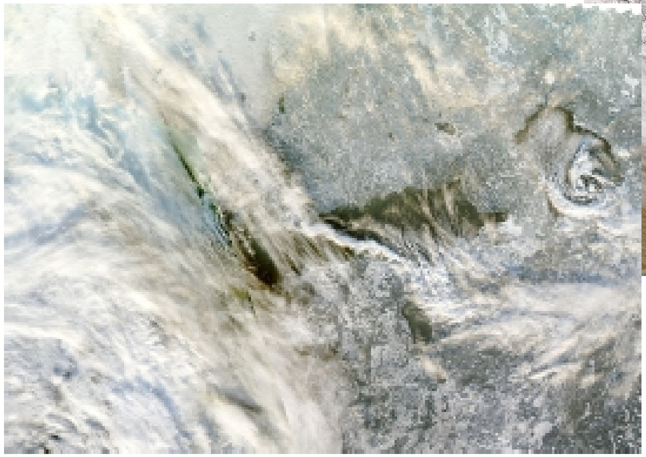
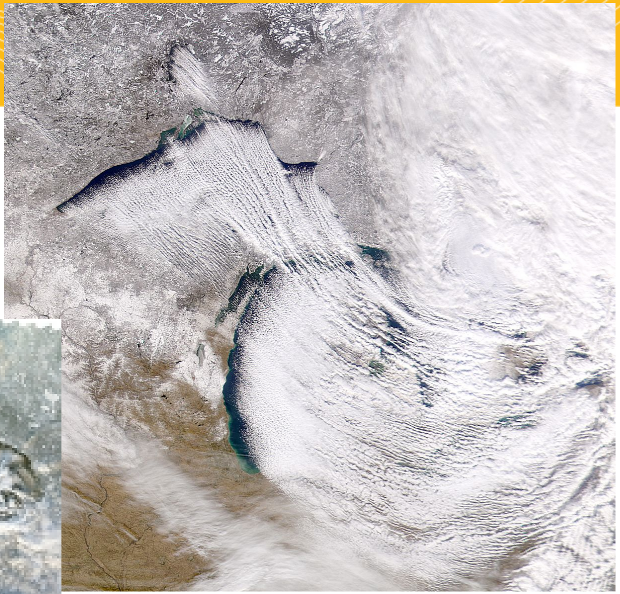
Introduction







MODIS, 2011

- hydrology, environmental studies, atmospheric applications
- in some regions lakes may cover the significant part of the territory
- lakes affect surface fluxes
- ice covered/ ice free surface – different physics
- lakes influence regional climate and local weather conditions

Introduction

Why DA 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

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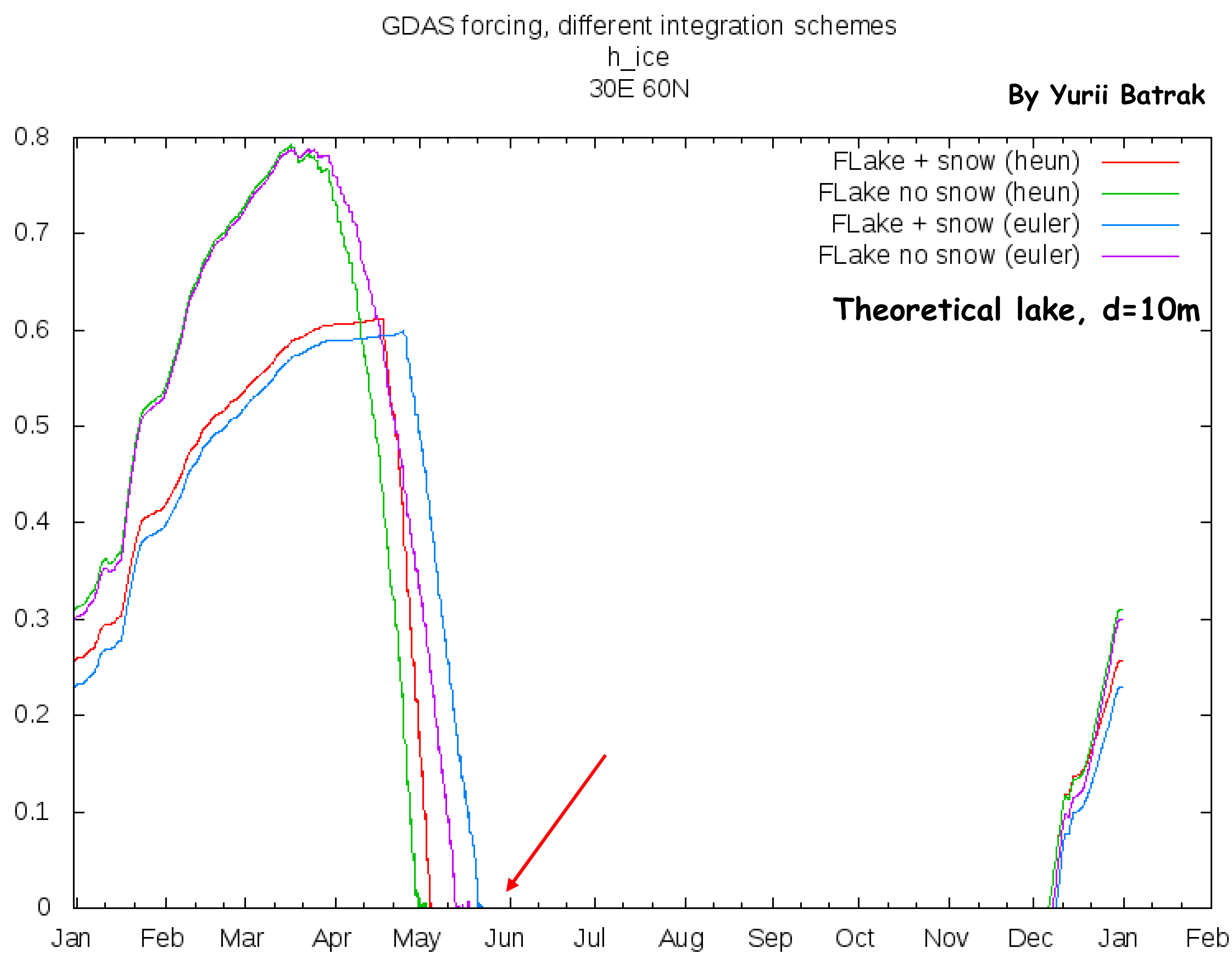
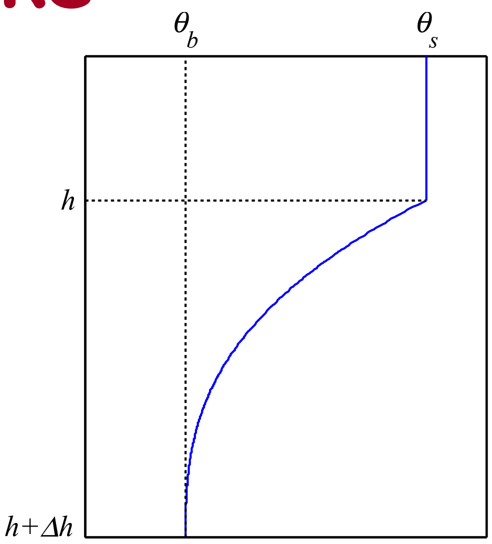


Lake model in SURFEX: FLake

FLake – a bulk lake model 1D (0D)

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

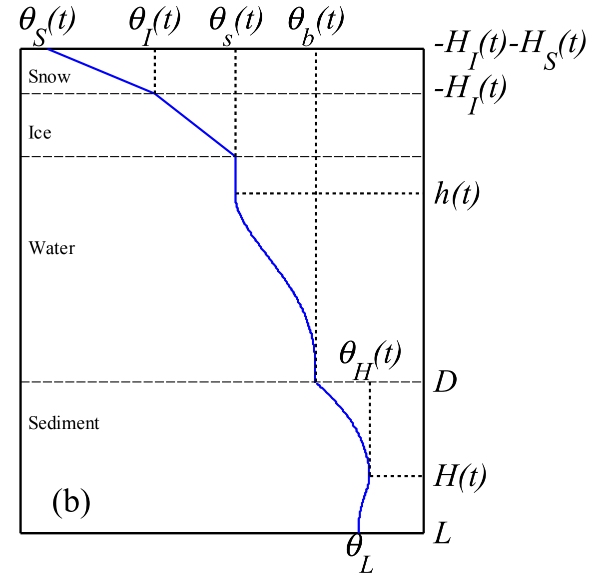


$\theta_s(t)$- mixed layer temperature

$h(t)$ - mixed layer depth

$\theta_b(t)$, -bottom temperature

$D=h+\Delta h$ - lake depth.



Lake model in SURFEX: FLake

- prediction of the mixed layer depth – convection, neutral and stable stratification
- short-wave radiation transfer
- ice and snow (needs testing)
- bottom sediments
- surface fluxes (if needed)

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Lake model in SURFEX: FLake

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 observations

What we observe and can assimilate:

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

In general, both fields are discontinuous in space and time – high non-linearity!

In time, different regimes: ice period, non-ice period, mixed lake, non-mixed lake, convective regime, stable stratification regime.

The most simple case: LST in summer, no ice

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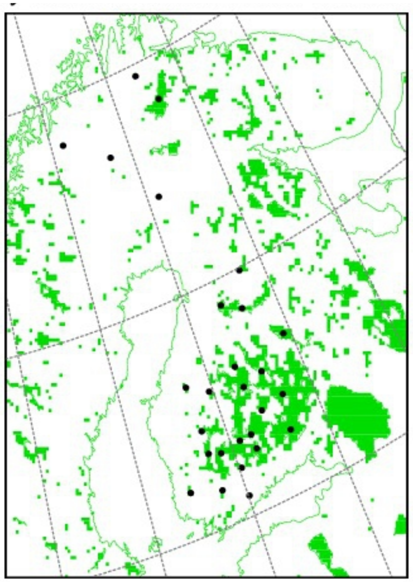
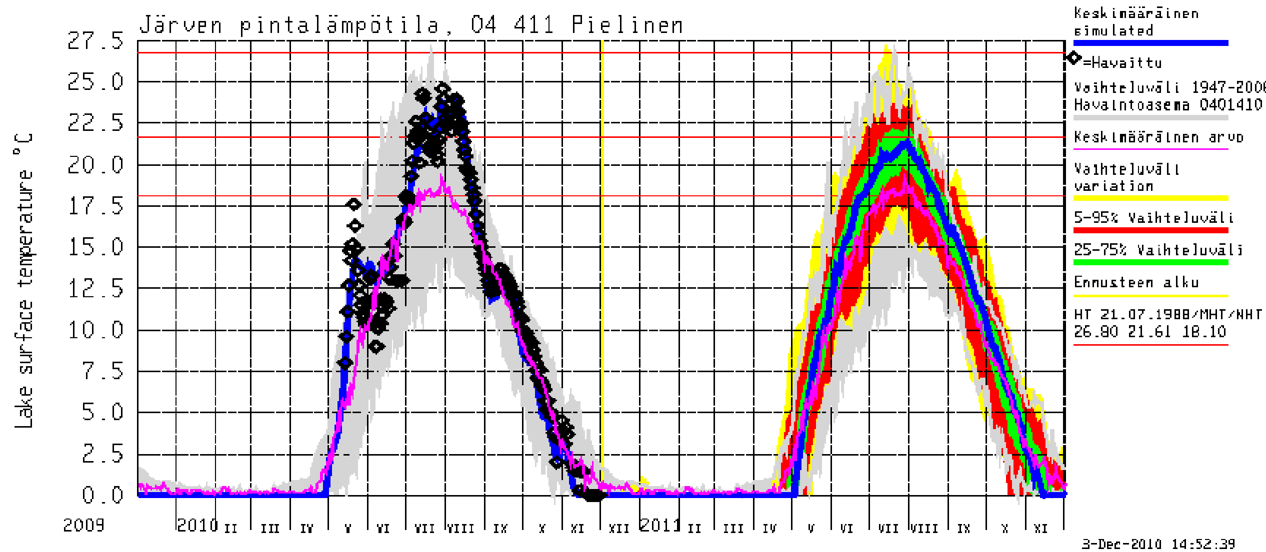
Lake observations



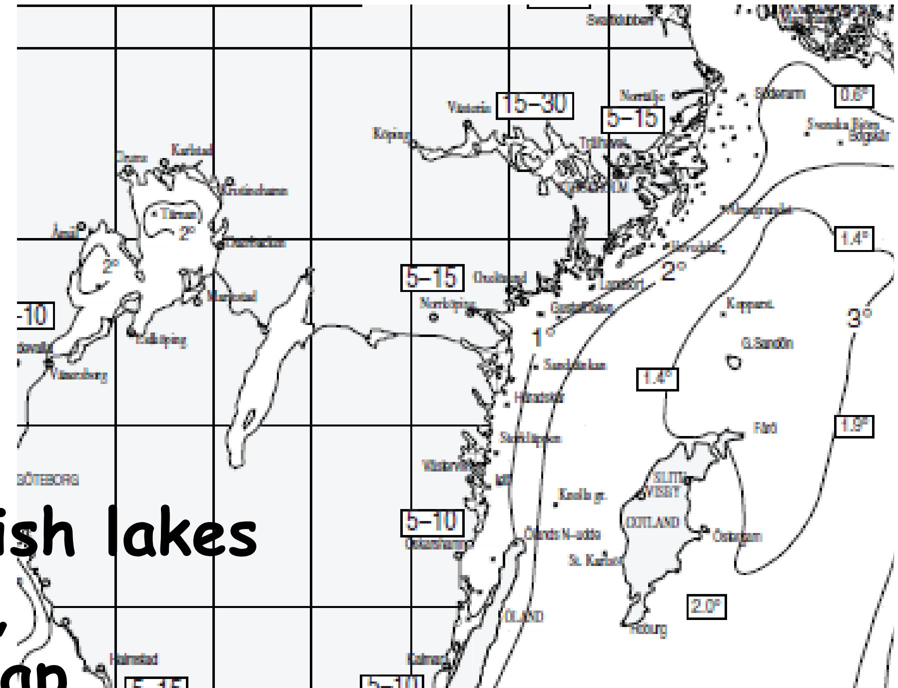


Lake surface temperature

in-situ **observations over 27 lakes in Finland**

Lake observations

Satellite-based, gridded

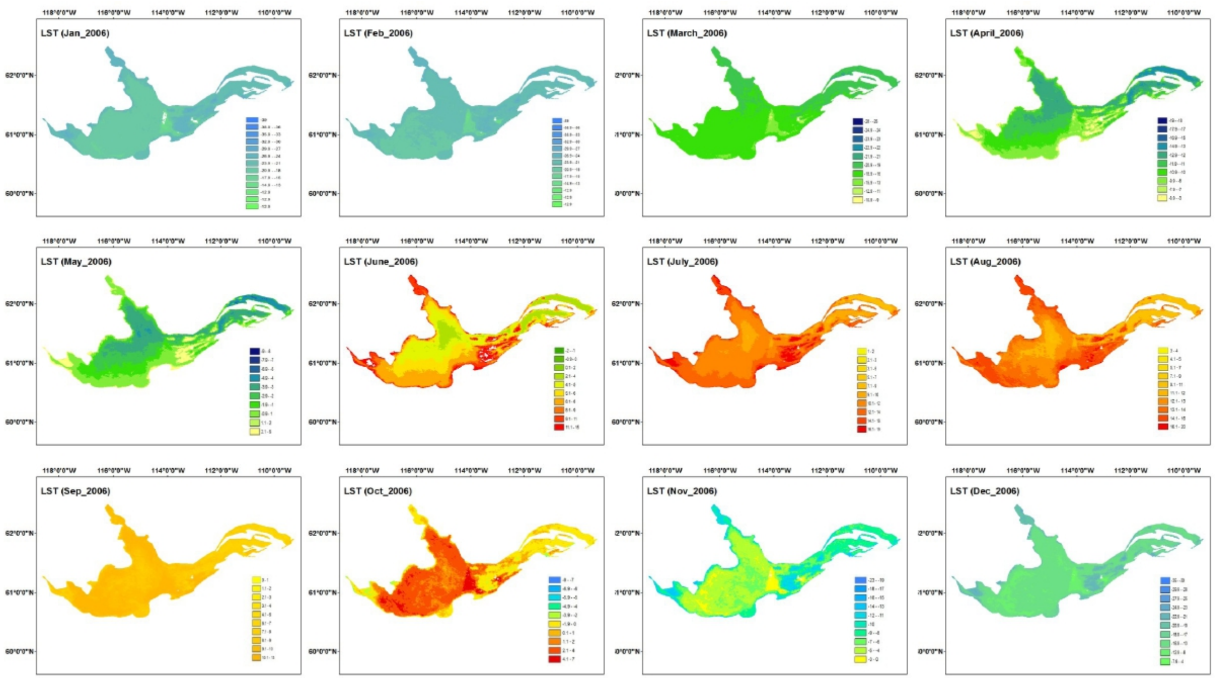


water temperature obs for
the Baltic Sea and large Swedish lakes
Lake Vänern and Lake Vettern,
based on the operational ice map
by FMI

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

Lake observations

LST, Great Slave Lake



remote sensing observations

- MODIS: Terra and Aqua, combined – 4 obs/day, 1 km resolution, clear sky conditions. Exapmle of NASA Level 2, monthly averaged

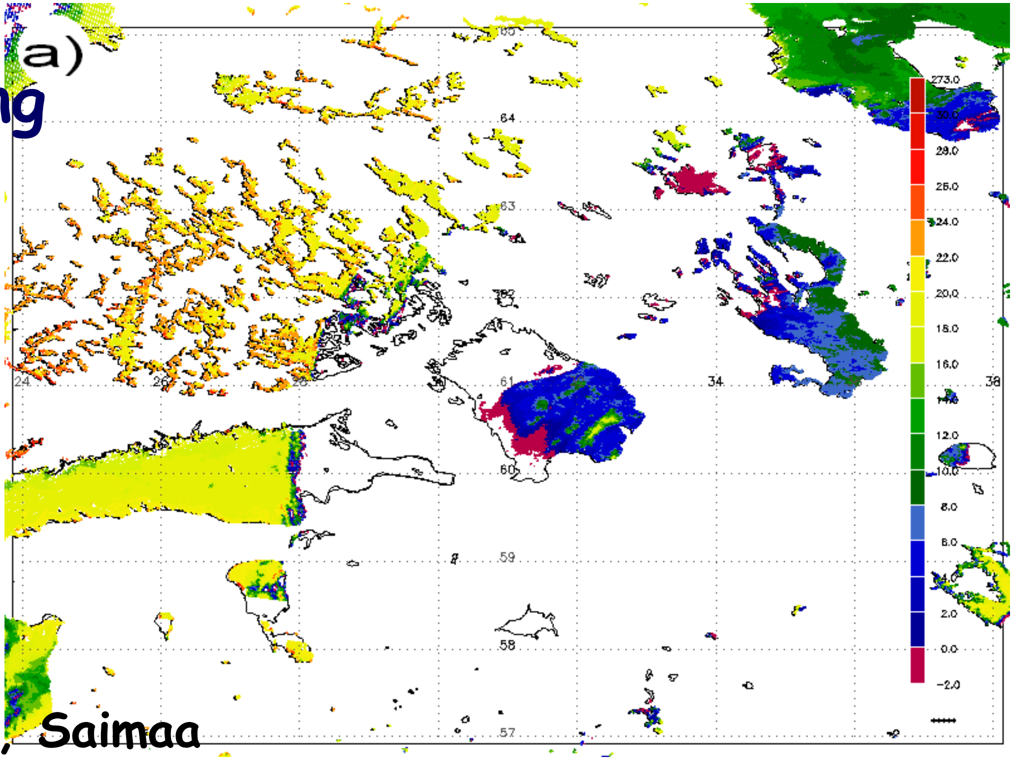
- coming ESA products

Lake observations

By Ekaterina Scherback, 2009

Quality of remote sensing observations:

- Undetected clouds
- Skin temperature
- Lake mask
- Spring ice



LST, Lake Ladoga, Lake Onego, Saimaa
June 2008
MODIS Terra, NASA Level 2, now less pressing

Preprocessing and quality control is needed

Lake data assimilation: ideas 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: ideas 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

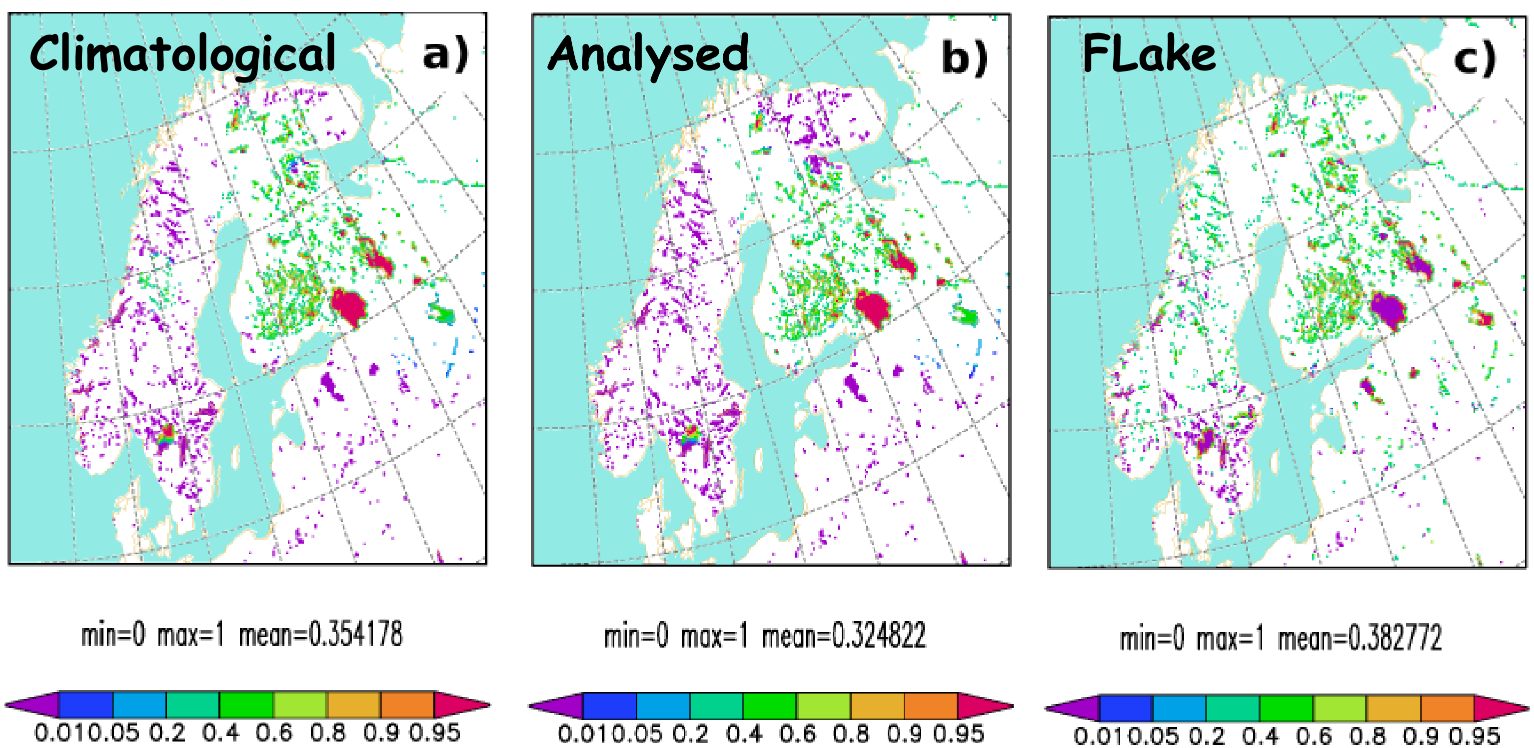
Lake data assimilation: impact of obs

Spreading information in horizontal, get started

OI the same as for SST,

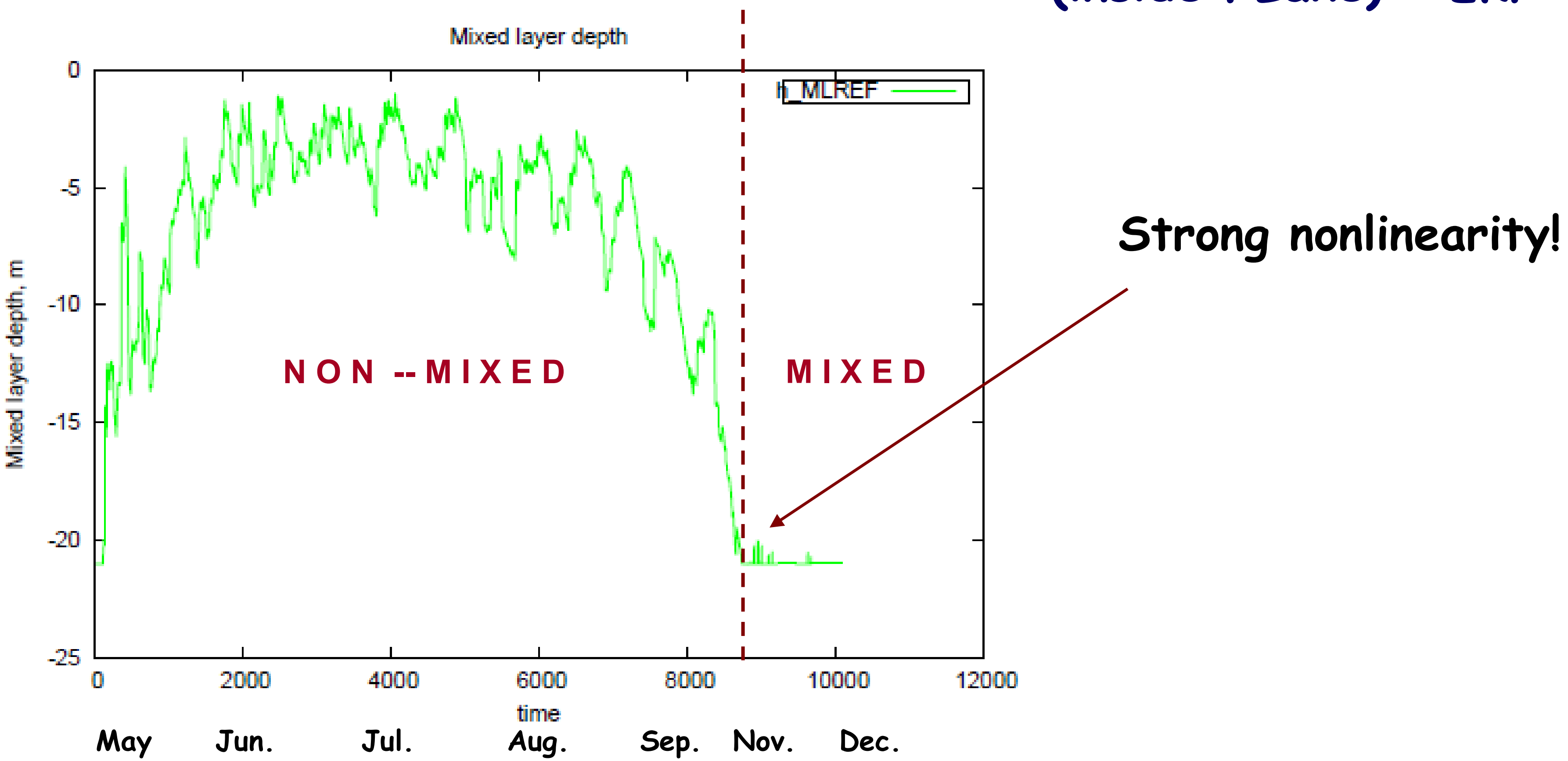
background from climatology or from FLake

Fraction of ice, Dec., 15, 2009



Lake data assimilation: ideas and methods

To spread information in vertical (inside FLake): EKF



Lake data assimilation: ideas and methods

To spread information in vertical (inside FLake): EKF

- different regimes (mixes or non-mixed, ice-no-ice)

- nonlinearity may be strong when jumping from one regime to another

- fast variables and slow variables

- model biases?

Lake data assimilation: EKF

non-mixed regime

state vector

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

obs vector

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

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

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

Lake data assimilation: EKF

mixed regime

state vector

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

obs vector

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

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

$$T_s = \overline{T}$$

Lake data assimilation: EKF

non-mixed regime

Linearised obs operator:

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

mixed regime

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

Linearised obs operator:

$$\mathbf{H} = 1$$

Lake data assimilation: EKF

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: nonlinearity may be too strong

Lake data assimilation: EKF

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

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

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

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

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

Lake data assimilation: EKF, first results

Measurements compaing over Lake Erken, Sweden (21m deep)

May, 1 – November, 15, 1989

LST measured every 1h, assimilated every 2 days

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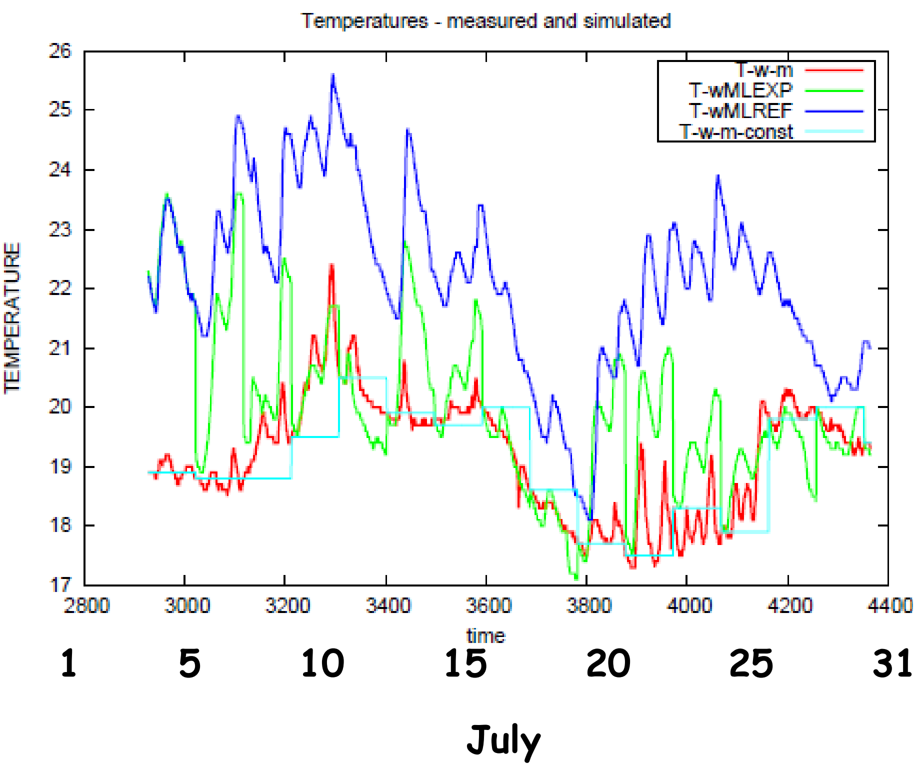
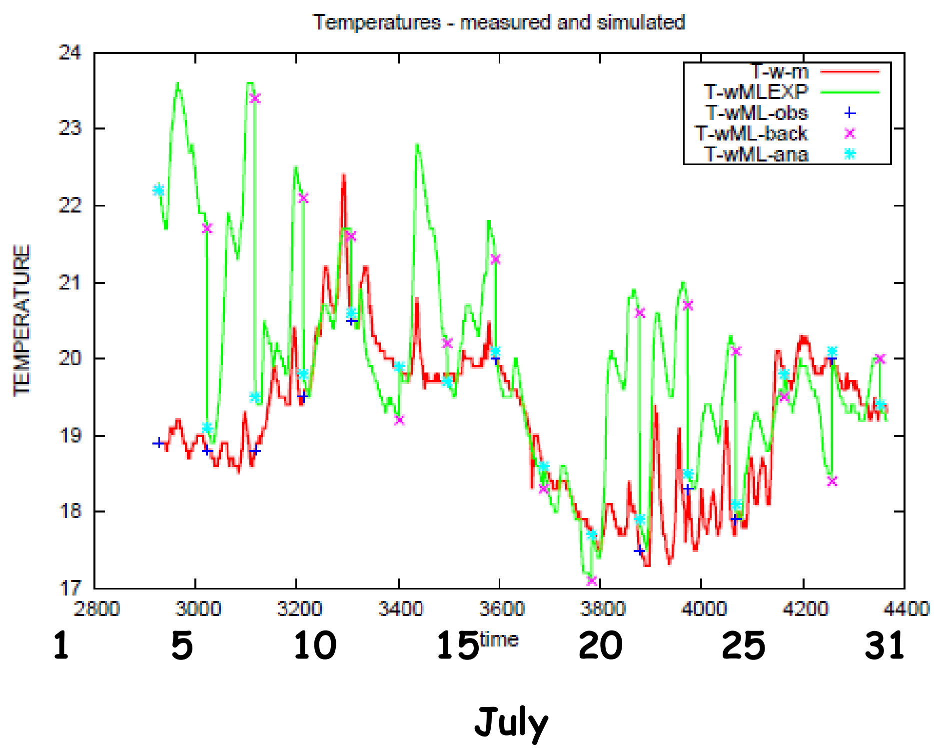
Lake data assimilation: EKF, first results





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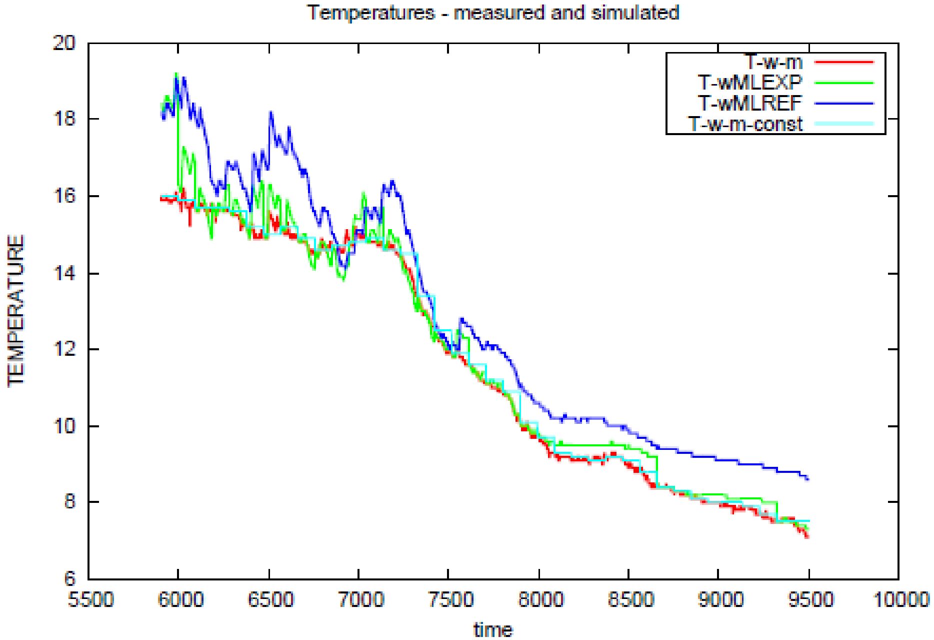
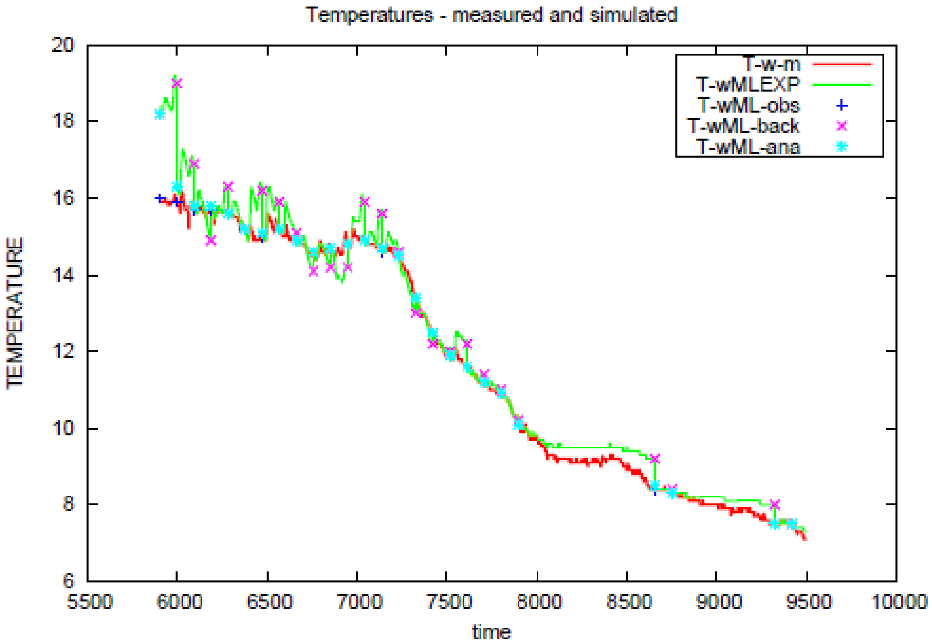


1 Sep. 15 Sep. 1 Oct. 15 Oct. 1 Nov. 15 Nov.



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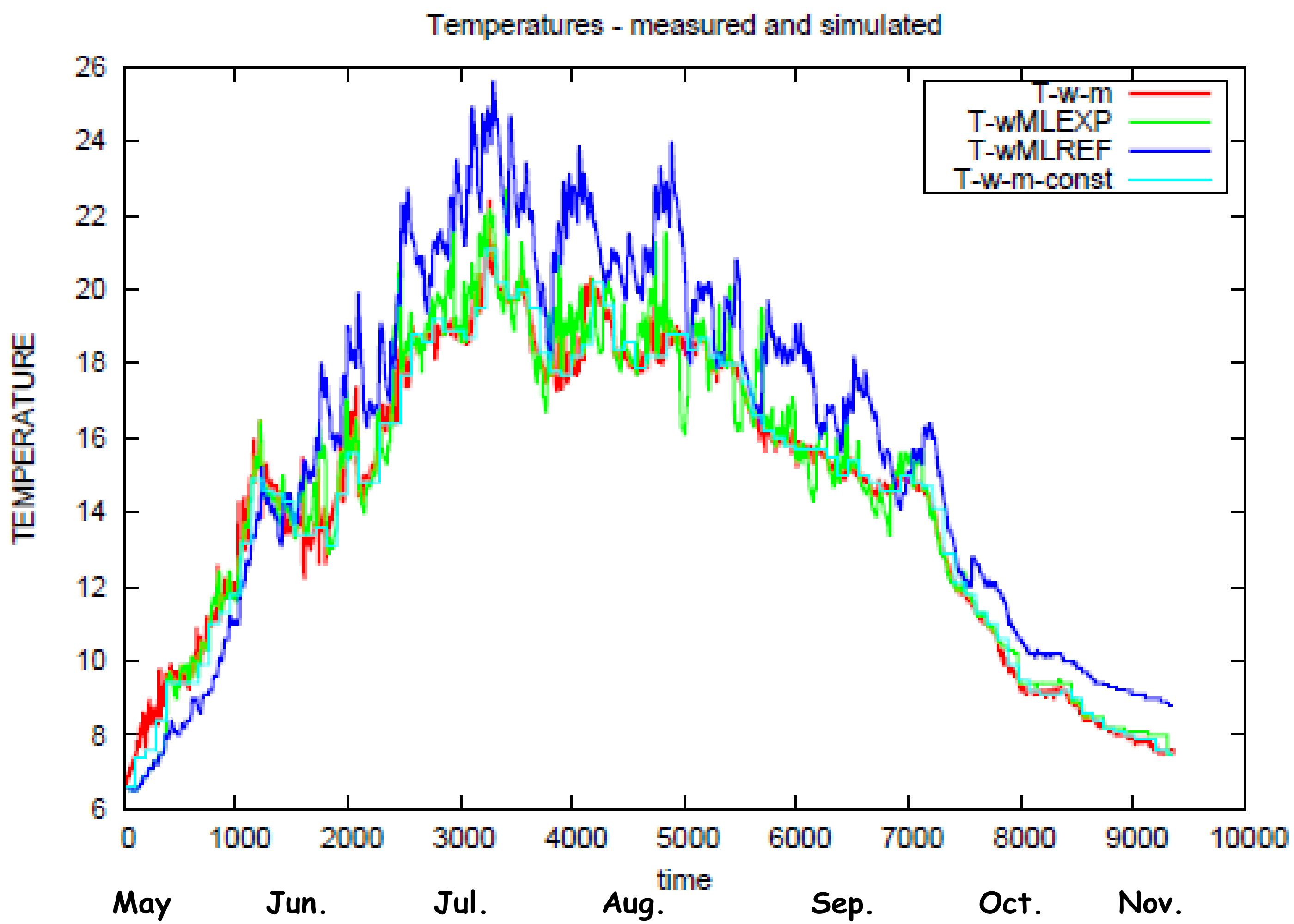

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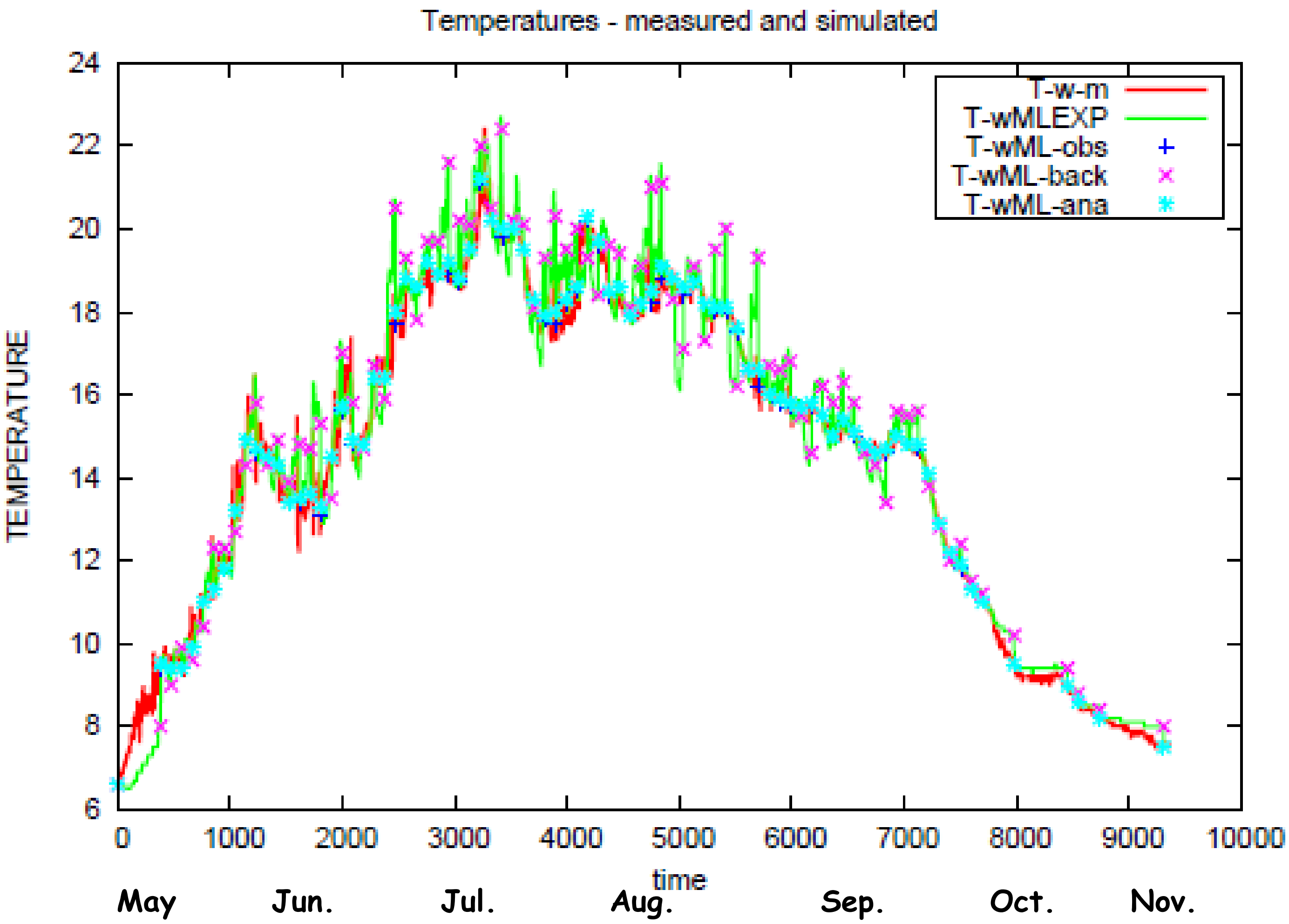

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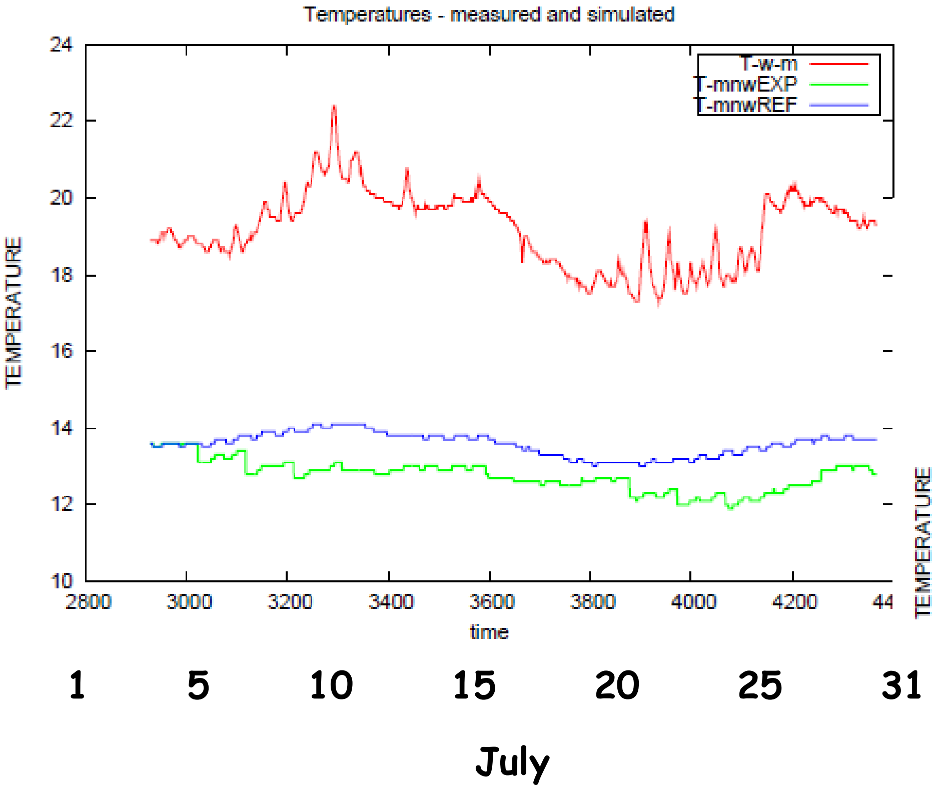

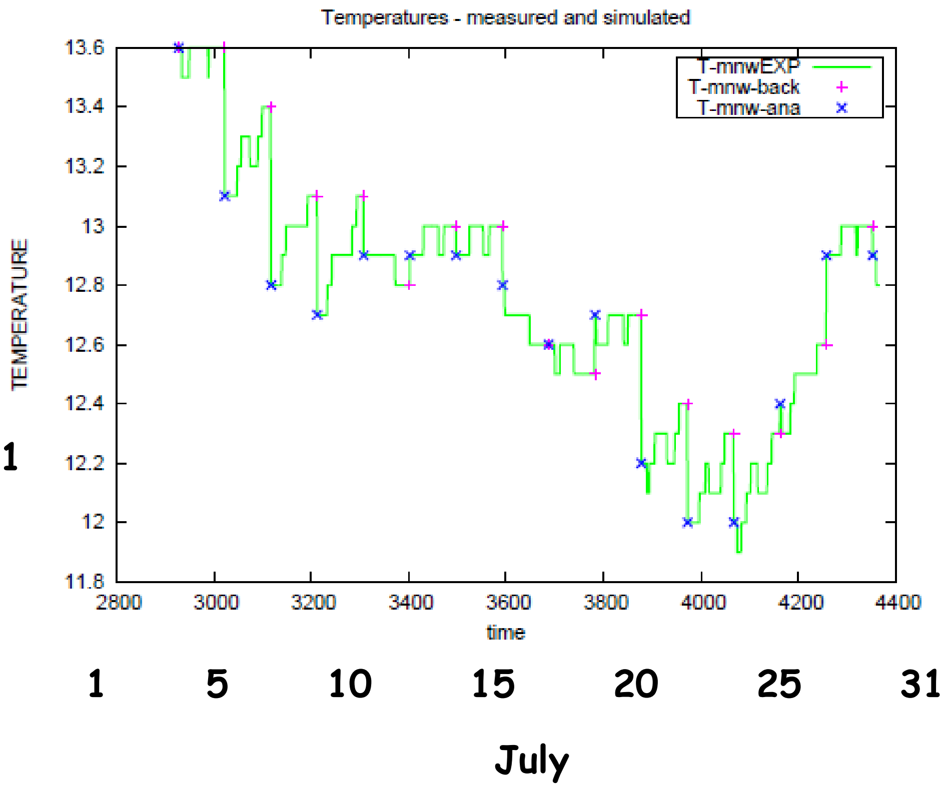

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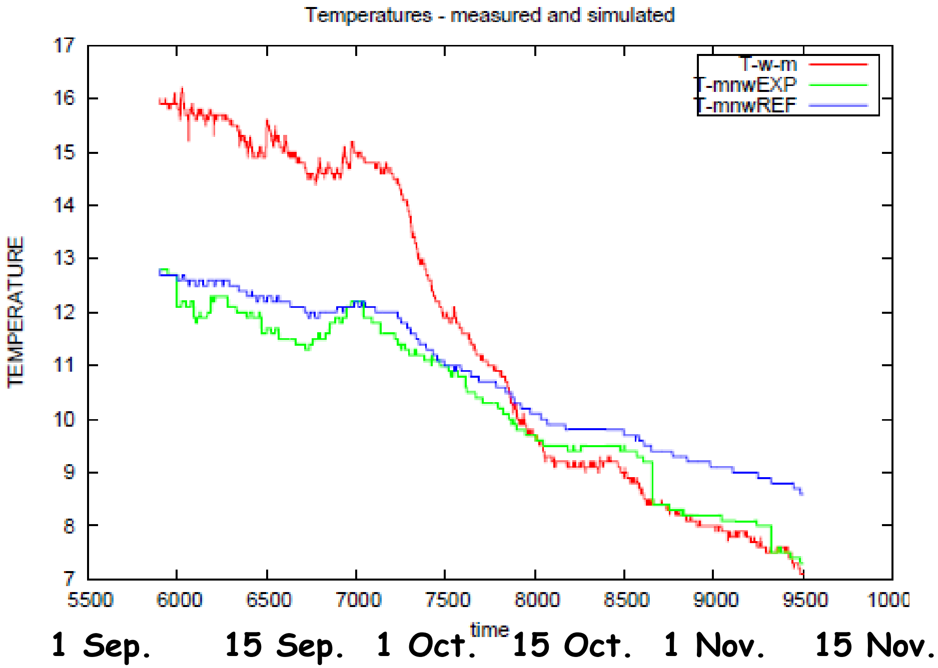

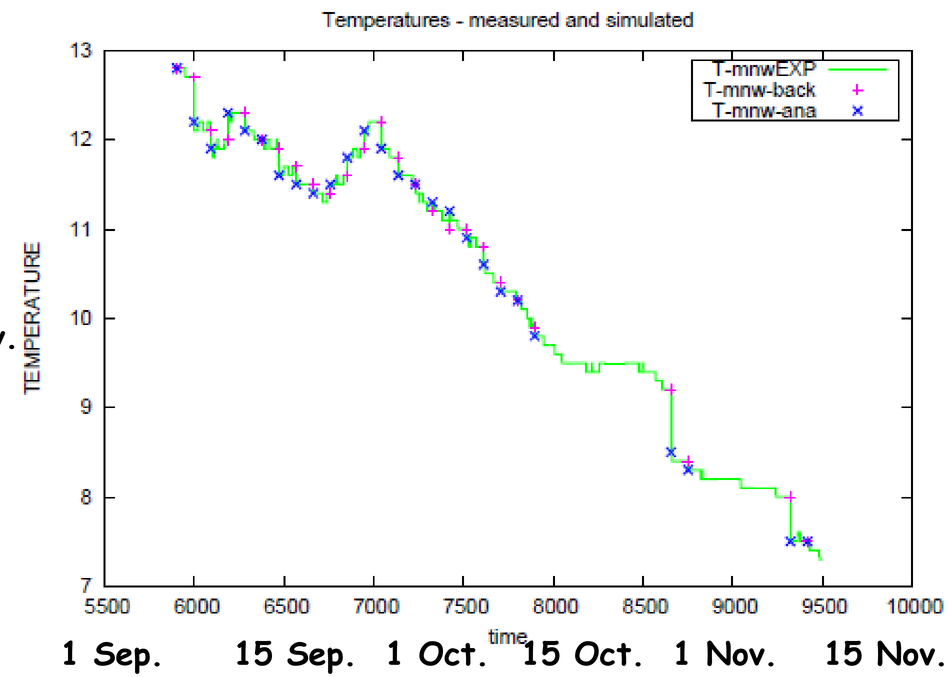

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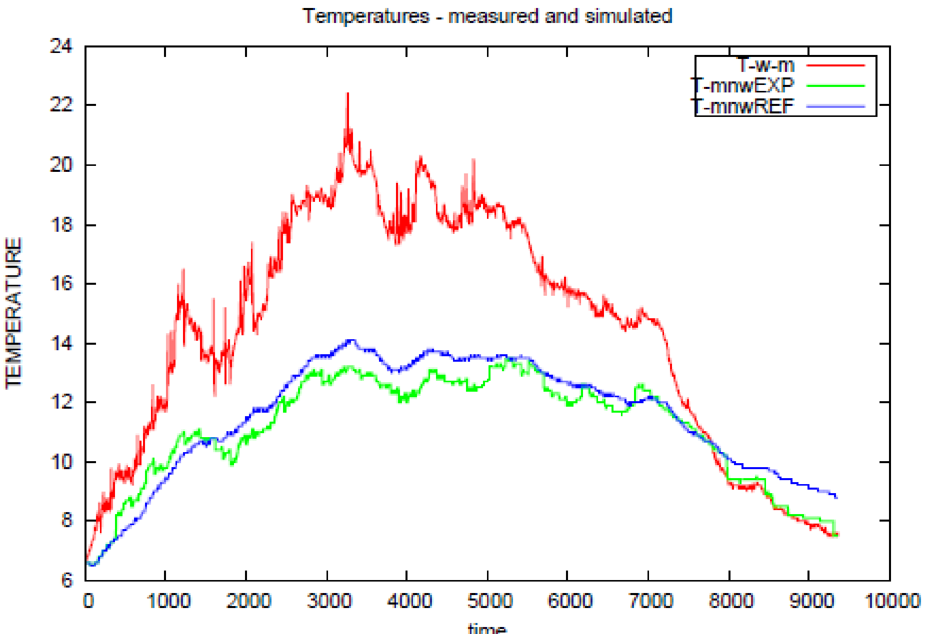
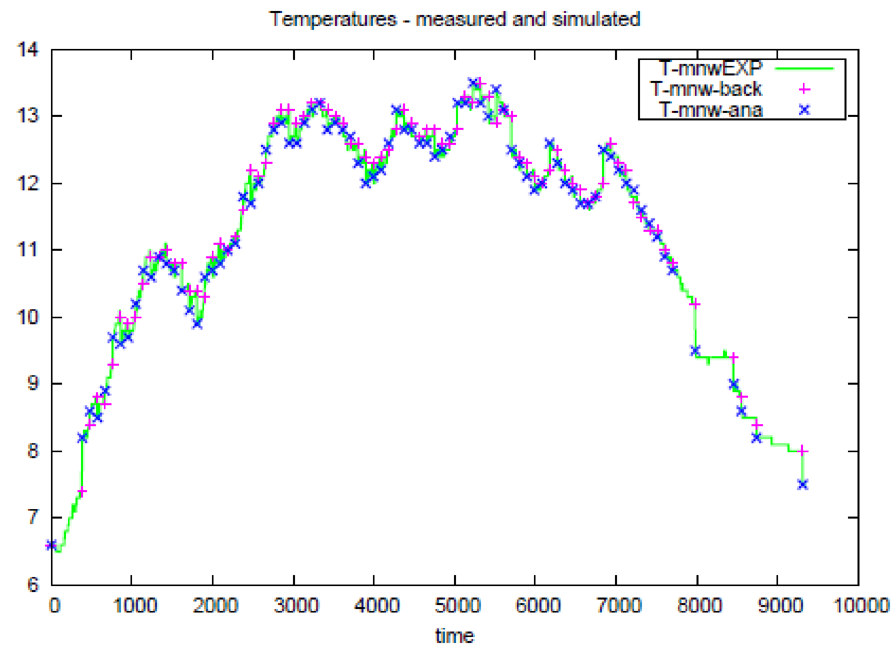


May Jul. Sep. Nov.



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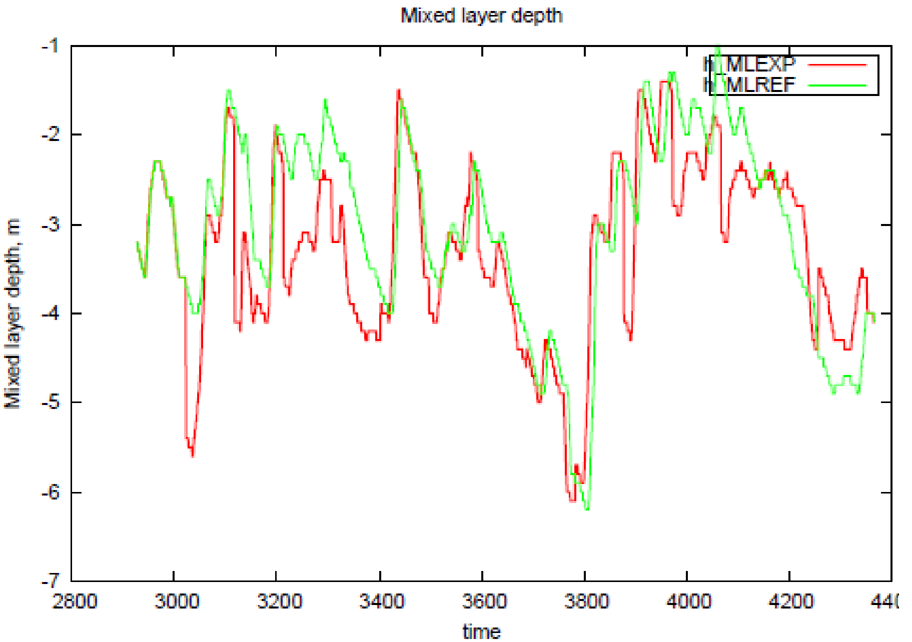
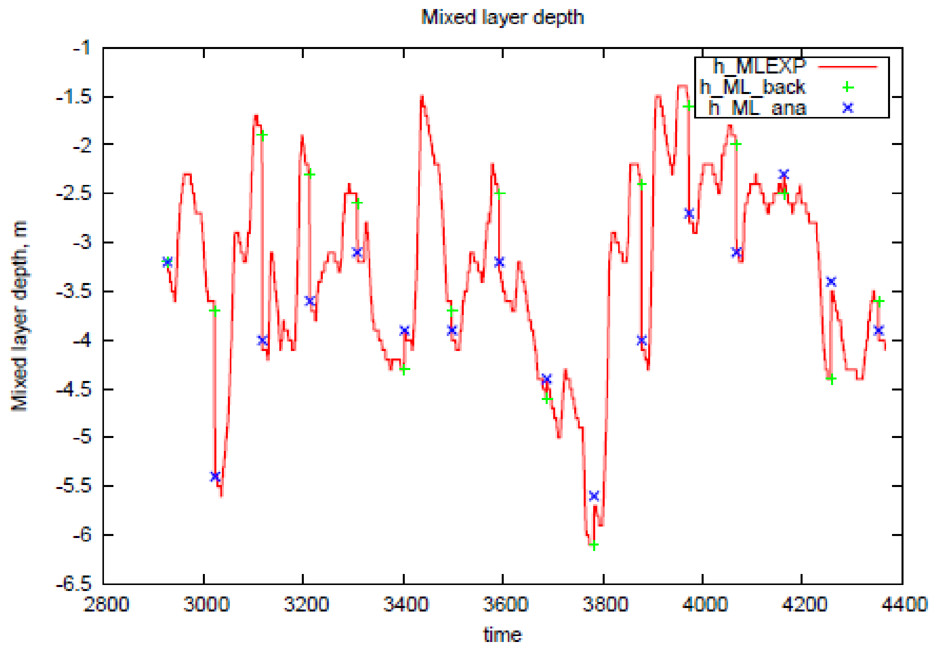


1 5 10 15 20 25 31

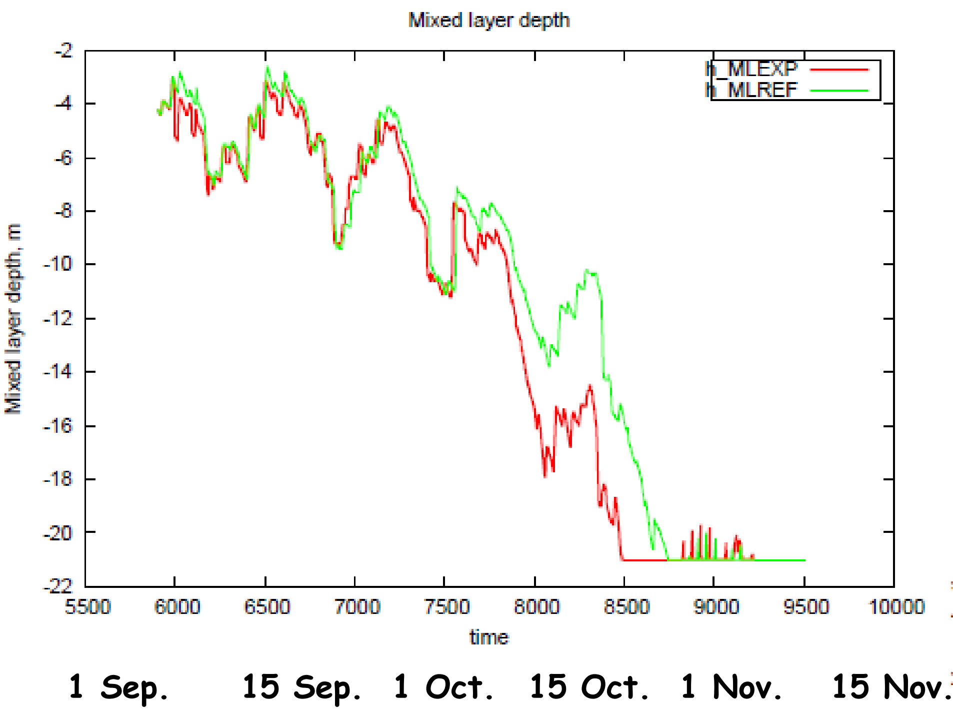
July

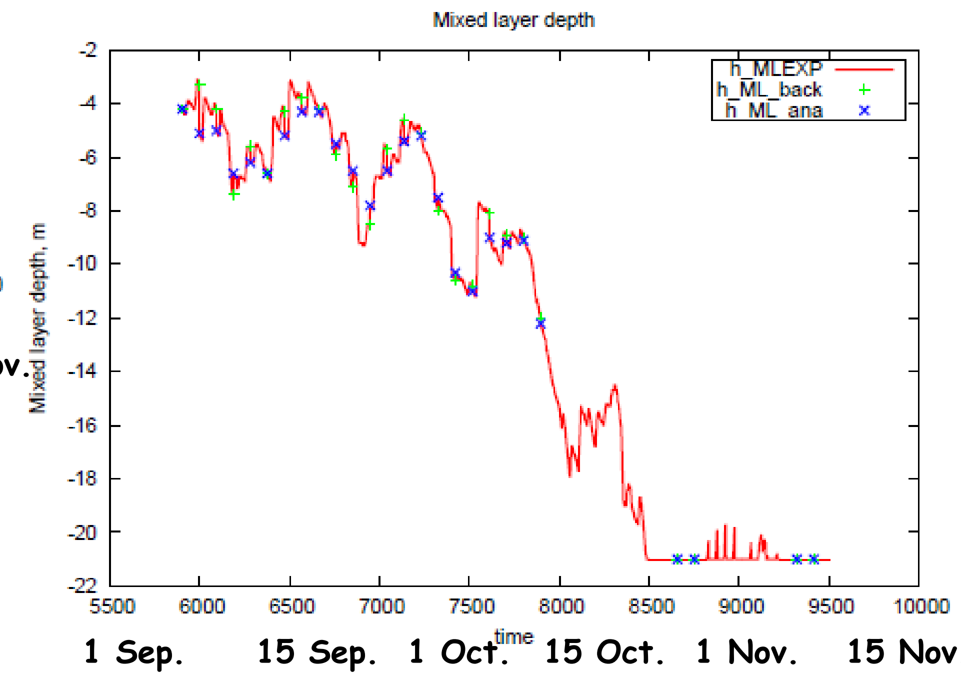


1 5 10 15 20 25 31

July

Lake data assimilation: EKF, first results





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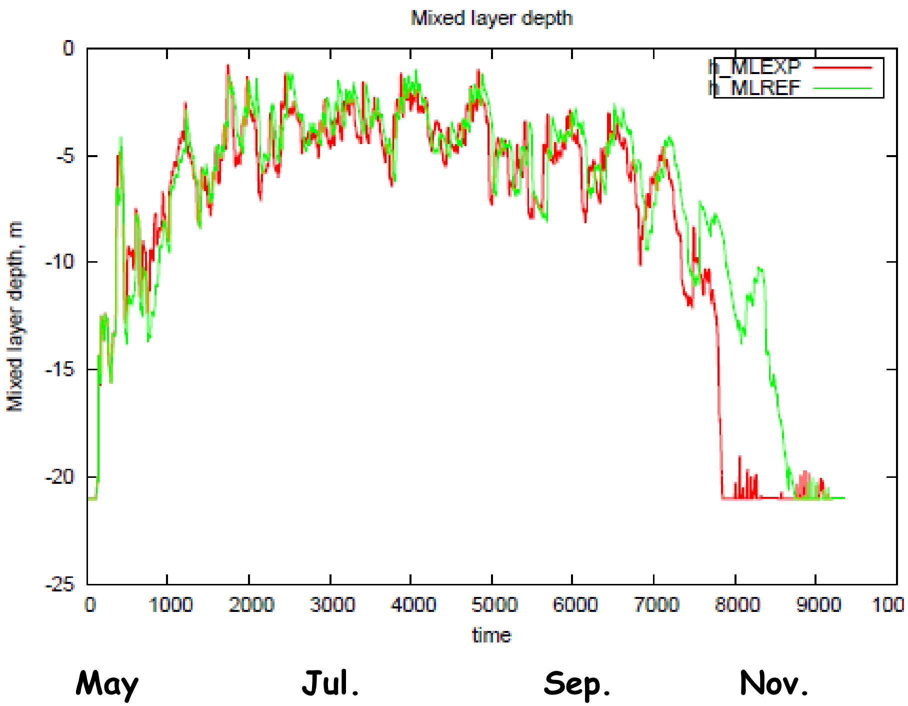

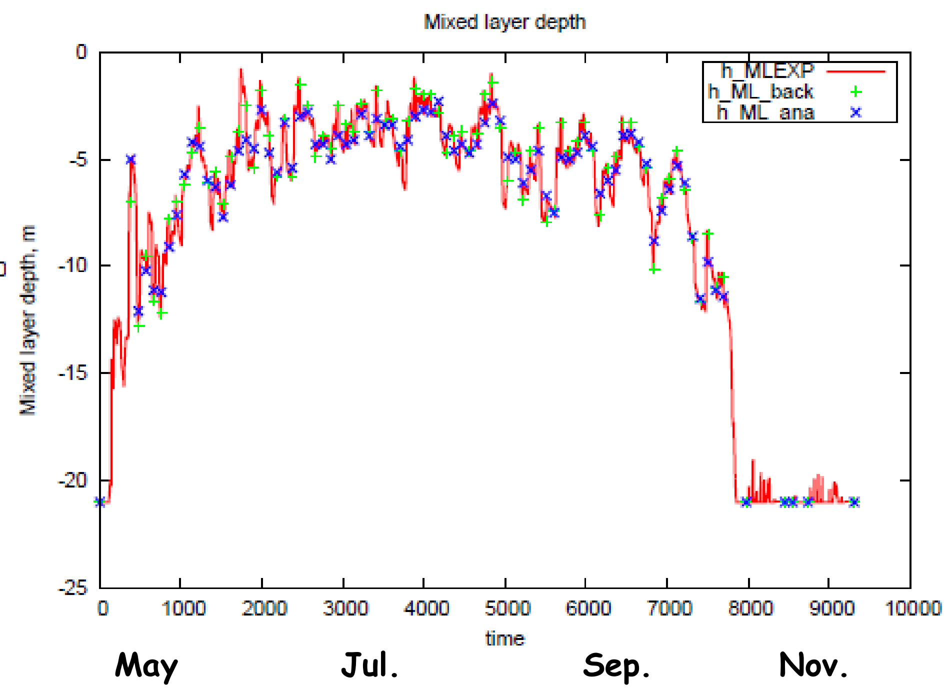

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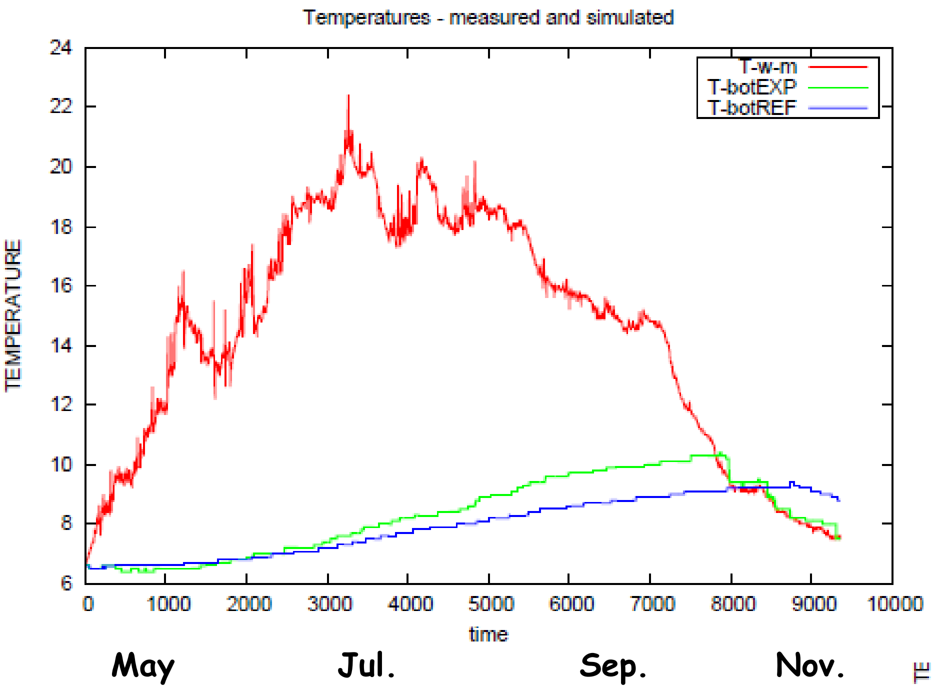

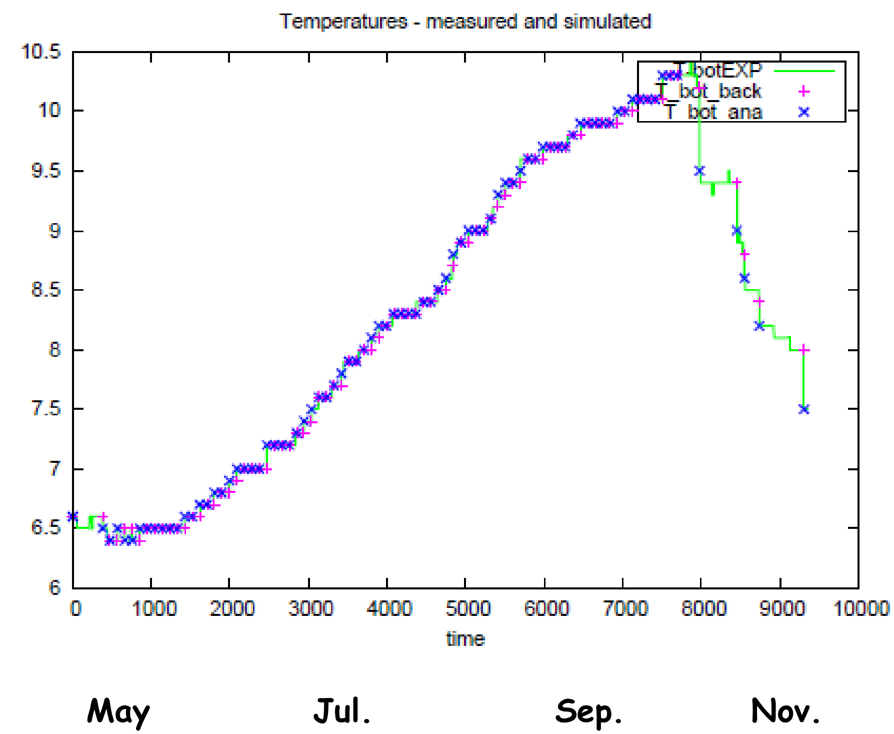

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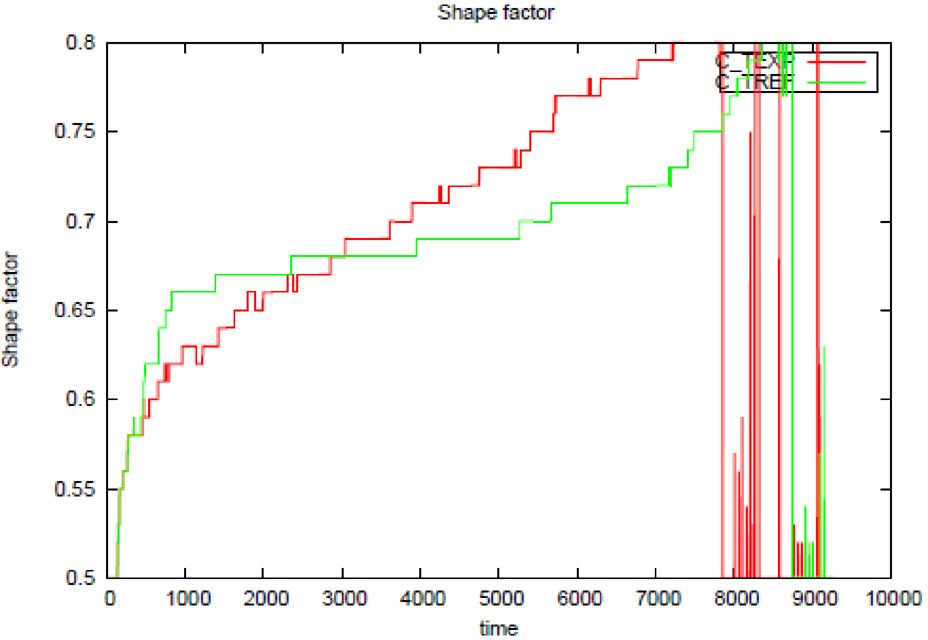

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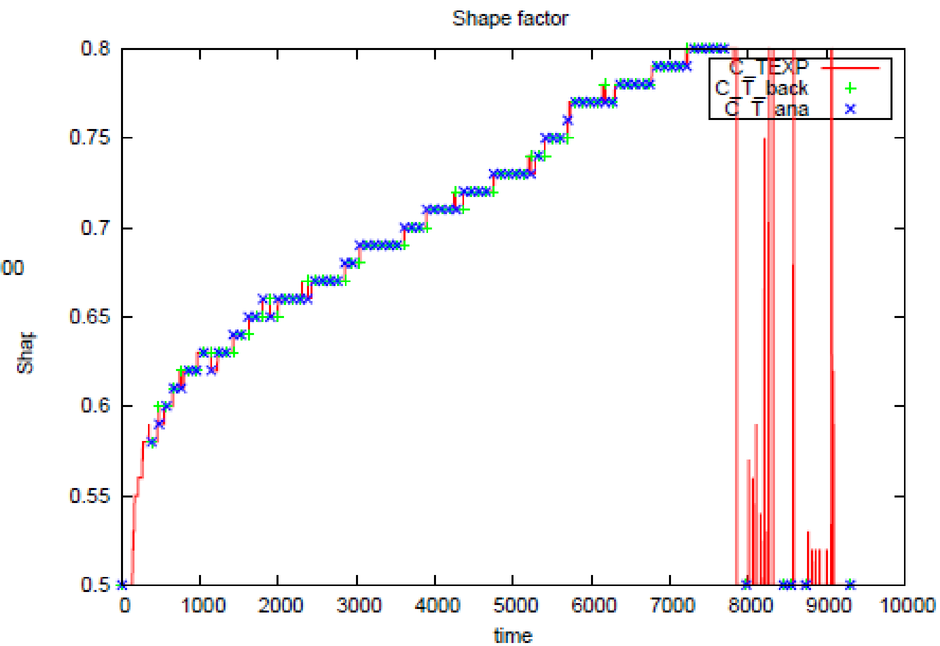

May Jul. Sep. Nov.

Plans, perspectives:

- EKF including ice period
- Extensive testing with different types of observations
- OI with specific correlation functions
- Quality control for remote sensing obs
- Model bias corrections … (mixed layer depth in stable regime)
- Include into SURFEX/VARRASIM and HARMONIE

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Thank you for attention!