Twenty years of HIRLAM lake experience

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with contributions by
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Margarita Choulga, Homa Kheyrollah Pour, Elena Saltikoff

Waterloo Lake Workshop 11 April 2017
Improving weather forecasting models with satellite data
CONTENTS

Introduction
  Why to treat lakes in NWP
  HIRLAM lake history

Observed lake surface state
  Observations
  Method of optimal interpolation

Forecasting lake surface state
  Freshwater Lake Model Flake
  Lake depth and climatology

Coupling the analysis with the forecast
The first convective clouds in May around the cold lakes and Baltic Sea.
Why to account for the lake processes in NWP models?

Watch a radar animation in January 2016 over Finland composed by Elena Saltikoff from the Finnish Meteorological Institute
Twenty years ago the northern Finland Lake Inari never froze in HIRLAM because of the usage of the climatology extrapolated from the ocean.
## HIRLAM LAKE MILESTONES

<table>
<thead>
<tr>
<th>Year</th>
<th>Analysed LSWT</th>
<th>Forecast</th>
<th>Diagnosed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Extrapolated monthly SST climatology, no analysis</td>
<td>-</td>
<td>Ice fraction diagnosed from this SST</td>
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<tr>
<td></td>
<td><strong>FINLAKEx</strong> climatology as pseudo LSWT observations.</td>
<td></td>
<td>Ice fraction diagnosed from LWST analysis</td>
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<td></td>
<td>Previous analysis as background.</td>
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<td></td>
<td>Relaxation of to climatology.</td>
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<tr>
<td>1995</td>
<td><strong>ECMWF</strong> time-lagged $T_{2m}$ over big lakes as pseudo LSWT obs</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Baltic ice map →</strong> pseudo LSWT over Vänern, Vättern</td>
<td>LIT forecast treated as land by the ISBA surface scheme (?)</td>
<td></td>
</tr>
<tr>
<td>ca. 2000</td>
<td>SYKE lake water observations replace all pseudos</td>
<td>LIT forecast by renewed ISBA</td>
<td>OI²</td>
</tr>
<tr>
<td>ca. 2003</td>
<td>Analysis background from FLake. Relaxation to climatology stopped.</td>
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<tr>
<td></td>
<td>LSWT analysis does not influence the atmospheric forecast anymore!</td>
<td></td>
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<tr>
<td>2011</td>
<td>Analysis background from FLake. Relaxation to climatology stopped. LSWT analysis does not influence the atmospheric forecast anymore!</td>
<td>LSWT and LIT forecast by FLake independently of LSWT analysis</td>
<td>Ice fraction diagnosed independently from LSWT analysis and forecast</td>
</tr>
<tr>
<td>2012</td>
<td></td>
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</tbody>
</table>
This is how HIRLAM currently works!

Independent lake data assimilation in an integrated NWP + lake model

Observations LWST

Background LWST

Optimal interpolation of LWST

Analysed lake surface temperature and ice cover

Surface layer parametrizations

Screen level variables turbulent and radiation fluxes

Flake parametrizations with own prognostic lake variables

Surface forecast fields

Diagnostic lake surface temperature and ice cover
THIS IS WHERE WE WOULD LIKE TO GO IN HARMONIE!

FULL LAKE DATA ASSIMILATION IN AN INTEGRATED NWP + LAKE MODEL

SURFACE LAYER PARAMETRIZATIONS
- SCREEN LEVEL VARIABLES
- TURBULENT AND RADIATION FLUXES
  - FLAKE PARAMETRIZATIONS with own prognostic lake variables

SURFACE FORECAST FIELDS
- DIAGNOSTIC AND PROGNOSTIC LAKE VARIABLES

OPTIMAL INTERPOLATION OF LWST
- EKF ASSIMILATION WITH FLAKE PROGNOSTIC VARIABLES

OBSERVATIONS LWST et al.

BACKGROUND LWST et al.
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Coupling the analysis and the forecast
Daily lake water temperature measurements from Finnish Environment Centre (SYKE) for 27 lakes over Finland (turquoise) are used in operational HIRLAM NWP since 2011. MODIS LSWT observations (yellow) have been used for development and experimenting in HIRLAM.
HOW TO INTERPOLATE THE POINT OBSERVATIONS TO THE NWP MODEL GRID?

Method of optimal interpolation (Gandin, 1965)

Provides the NWP model with:

An analysed LSWT value in every gridpoint that contains a fraction of lake

Requires

Observations and estimated observation errors
Autocorrelation function for model-observation departures
Background field – short forecast / previous analysis

Kheyorollah Pour et al., 2017. Towards improved objective analysis of lake surface water temperature in a NWP model: preliminary assessment of statistical properties
LSWT observation statistics
summers 2010 - 2014

- Distances
- Depths

Structure and autocorrelation functions depending on distance

\[ \sigma = 0.9\text{K} \]

\[ \sigma = 1.2\text{K} \]
Autocorrelation functions depending on distance and lake depth difference

An exponential function has a natural physical interpretation as the scales which can be related to distances and differences. For the two-dimensional autocorrelation function, a two-dimensional exponential approximation may be suggested, for example:

$$\mu(\rho, \delta) = e^{-\left(\frac{\rho^2}{2L_H^2} + \frac{\delta^2}{2L_V^2}\right)}$$  \hspace{1cm} (A11)$$

where $\delta$ is the vertical distance (or difference in depth) and $L_V$ is the vertical length scale.

Scales $L_H = 800$ km and $L_V = 20$ m were tried in HIRLAM
WHERE TO TAKE THE LSWT BACKGROUND FIELD FOR THE OPTIMAL INTERPOLATION?

Climatology
(Possible stand-alone analysis)

Previous analysis
• HIRLAM before 2012
• Contemporary OSTIA
- requires relaxation to climate to prevent drifting in time

Short forecast by the model
HIRLAM since FLake, 2012
- ”peaceful coexistence”
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Freshwater lake model FLake is being used in the FMI operational HIRLAM since 2012

Flake has 11 prognostic variables:
(From presentation by Dmitri Mironov in Lake15)

- the mean temperature of the water column,
- **the surface temperature**, (=mixed layer water temperature $T_{ml}$)
- 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.

Flake official site: http://www.flake.igb-berlin.de
Gridded lake climatology is needed to initialize the prognostic lake variables in the very first cycle of an operational NWP model that is coupled with FLake.

**CliLake1:**
Model lake climatology from global off-line runs of FLake

- 20 year global runs with a resolution of 1°
- 12 different depths
- Annual cycle with a resolution of 10 days
- Serious errors in spring corrected in CliLake2, version to be released

Slide based on presentation by Yuri Batrak & Ekaterina Kourzeneva in Lake12
External parameters: lake depth database

Data on the mean depth for each lake individually, includes 14500 lakes

ECOCLIMAP map 1 km resolution

Estimates of depth from geological origin of lakes

Bathymetry for 36 large lakes

Data on the lake depth with 1 km resolution

From the presentation by Ekaterina Kourzeneva in HIRLAM-ALADIN ASW17:
VALIDATION OF FLAKE IN OPERATIONAL HIRLAM
(ongoing, planned)

Case studies – Ladoga, January 2012

Comparison of background, analysis to LSWT observations 2011-2016

Comparison of forecast and observed freezing and melting dates 2012-2016

Statistical validation of weather forecast by using SYNOP observations close to / far from lakes
VALIDATION OF FLAKE IN OPERATIONAL HIRLAM
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Freezing of Lake Ladoga January 2012

Example of freezing Ladoga from the presentation by Kalle Eerola in Lake workshop 2012, Eerola et al, 2014. DOI:10.3402/tellusa.v66.23929
The first experiences of Flake performance in HIRLAM: Ladoga, January 2012


25.1.2012 00UTC+30h: old MBE71 v.s. 7.4beta1 with FLake
FLake results are very sensitive to the lake depth: Ladoga was frozen two weeks earlier when it was assumed shallow!
Validation of HIRLAM Flake and LSWT analysis over selected lakes

Lake Ounasjärvi
Lake Inari
ICE PROBLEMS AT LAKE OUNASJÄRVI

Operative
April-May 2011
SYKE no FLake

Operative
Oct-Nov 2011
SYKE no FLake

Operative
April-May 2012
SYKE + FLake

Experiment
April-May 2011
SYKE + FLake

Experiment
Oct-Nov 2011
SYKE + FLake

Experiment
April-May 2012
SYKE + FLake

Observed: melting 15 May
freezing 19 Nov
melting 19 May
SUMMER 2011 AT LAKE OUNASJÄRVI

Operative 2011 SYKE no FLake

- When observations are regularly available, analysis follows them
- (Ocean-based LSWT climatology is used for relaxation at lakes where are no observations)
- (Beware of small errors in setup: cut-off time, keeping sea/lake separated, getting rid of all pseudos, etc.)

with Flake:
- Analysis follows background FLake more closely than observations
- Flake background is always available at all lakes
- Flake tends to warm the mixed layer more than observed in shallow lakes

no Flake:
- Analysis follows background FLake more closely than observations
- (Ocean-based LSWT climatology is used for relaxation at lakes where are no observations)
- (Beware of small errors in setup: cut-off time, keeping sea/lake separated, getting rid of all pseudos, etc.)
HIRLAM/FLAKE LSWT forecasts* v.s. SYKE observations*
2012-2016 (open water periods) Ounasjärvi

N = 3850
Mean $T_{\text{obs}} = 278.9$
Bias = 3.3 K
Stde = 1.8 K
MAE = 3.3 K
Corr = 0.96

*FC+6h at 00,06,12,18 UTC
*SYKE at 6 UTC
HIRLAM/FLAKE LSWT forecasts* v.s. SYKE observations*
2012-2016 (open water periods) over all 27 lakes

N = 88977
Mean $T_{\text{obs}} = 283.2$
Bias = 1.4 K
Stde = 2.4 K
MAE = 2.2 K

*FC+6h at 00,06,12,18 UTC
SYKE at 6 UTC
HIRLAM/FLAKE LSWT analyses* v.s. SYKE observations*
2012-2016 over all 27 lakes

N = 88977
Mean $T_{\text{obs}} = 283.2K$
Bias = 0.6 K
Stde = 1.7 K
MAE = 1.4 K

*AN+00h at 00,06,12,18 UTC
*SYKE at 6 UTC
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Coupling the analysis with the forecast
Development of data assimilation for lakes

Assimilation of lake observations into FLake integrated in NWP using extended Kalman filter or nudging
Observations LWST et al.

This is where we would like to go in Harmonie!

Background LWST et al.

Full lake data assimilation in an integrated NWP + lake model

Optimal interpolation of LWST

EKF assimilation with FLAKE prognostic variables

Surface layer parametrizations

Screen level variables

Turbulent and radiation fluxes

Flake parametrizations with own prognostic lake variables

Surface forecast fields

Diagnostic and prognostic lake variables
Lake model FLake from DA point of view

Prognostic equations:
- the mean water temperature: $\overline{T}$
- the bottom temperature
- the mixed layer depth
- the shape factor

Diagnostic equation:
- the mixed layer (surface) temperature

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

Mixed layer temperature at a location on Lake Inarinjärvi, mean depth 14 m

Stand-alone FLake updated with SYKE and MODIS observations using Extended Kalman Filter EKF

With EKF FLake, no assim Observations

FOR DISCUSSION *
- key tasks from the point of view of NWP

Improvement of FLake model used as a parametrisation scheme in NWP: snow on ice, three-layer structure, salinity?

Usage of remote sensing observations on lake water surface temperature and ice cover, ice thickness

Development and operational application of in-lake data assimilation in NWP models which apply prognostic lake parametrisations

Improvement of physiographic and climatological input data: lake depth, cover, extinction coefficient

*Based on Lake12 workshop summary


Kourzeneva, E., Martin, E., Batrak, Y. and Moigne, P. L. 2012. Climate data for parameterisation of lakes in numerical weather prediction models. Tellus A. 64, 17226. DOI:10.3402/tellusa.v64i0.17226.

Rontu, L., Eerola, K., Kourzeneva, E. and Vehviläinen, B. 2012. Data assimilation and parametrisation of lakes in HIRLAM. Tellus A. 64, 17611. DOI:10.3402/tellusa.v64i0.17611.

Semmler, T., Cheng, B., Yang, Y. and Rontu, L., 2012. Snow and ice on Bear Lake (Alaska) – sensitivity experiments with two lake ice models. Tellus A. 64, 17339. DOI:10.3402/tellusa.v64i0.17339
Important dates:
01 April 2017 - 2nd Announcement and Call for Abstracts
01 June 2017 - Registration Deadline
16-19 October 2017 - Workshop dates

Send your questions, inquiries, and suggestions for sessions/discussion panels to Georgiy Kirillin

Berlin
16-19 October 2017
THANK YOU FOR YOUR ATTENTION!
FUTURE
- key tasks from the point of view of NWP

Improvement of FLake model used as a parametrization scheme in NWP
- Improved handling of snow and ice, connection with related snow parametrizations which are applied in NWP framework
- Introduction of a three-layer structure?
- A possibility to handle saline lakes?
FUTURE
- key tasks from the point of view of NWP

Usage of remote sensing observations on lake water surface temperature and ice cover

- Evaluate the quality and possibilities of the different satellite observations available: temperature, ice cover (on/off), ice thickness, snow on ice

- Develop the methods of optimal interpolation in handling of lake observations

- Build the real-time operational analysis systems
FUTURE
- key tasks from the point of view of NWP

Development and operational application of integrated lake data assimilation in NWP models which use prognostic lake parametrizations

- Intercomparison of extended Kalman filter and nudging methods in stand-alone FLake framework

- Building operational NWP system where the optimally interpolated fields are used as input for the integrated data assimilation
FUTURE
- key tasks from the point of view of NWP

Improvement of physiographic and climatological input data: depth, cover, extinction coefficient

- Continue the ongoing improvement of lake depth data base

- Study the lake cover of GLOBCOVER, ECOCLIMAP and other global data sets applied in NWP

- Improve the lake climatology data bases for forecast and analysis of lake surface state in NWP models