Data assimilation over lakes

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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

Theoretical lake, d=10m
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
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

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: overview 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.
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 - discontinuities in the model
- fast variables and slow variables
- model biases?
EKF for FLake to assimilate LST

non-mixed regime

\[
\begin{bmatrix}
\bar{T} \\
T_b \\
h \\
C_T
\end{bmatrix}
\]

state vector

\[
x = \begin{bmatrix}
\bar{T} \\
T_b \\
h \\
C_T
\end{bmatrix}
\]

obs vector

\[
y = [T_s]
\]

obs operator \( H(X) \)

\[
T_s = \left( 1 - C_T \left( 1 - \frac{h}{D} \right) \right)^{-1} \left( \bar{T} - \left( 1 - \frac{h}{D} \right) T_b \right)
\]
EKF for FLake to assimilate LST

state vector
\[ \mathbf{x} = \begin{bmatrix} \overline{T} \end{bmatrix} \]

obs vector
\[ \mathbf{y} = \begin{bmatrix} T_s \end{bmatrix} \]

obs operator
\[ H(\mathbf{X}) \]

\[ T_s = \overline{T} \]
EKF for FLake to assimilate LST

non-mixed regime

Linearised obs operator:

\[
H = \begin{bmatrix}
1 & \frac{C_T (\bar{T} - T_b)}{(1 - C_T \eta)^2} & -\frac{C_T \eta}{1 - C_T \eta} & \frac{\eta (\bar{T} - T_b)}{1 - C_T \eta}
\end{bmatrix}
\]

mixed regime

Linearised obs operator:

\[
\eta = 1 - \frac{h}{D}
\]
EKF for FLake to assimilate LST

non-mixed regime, mixed regime

Jacobians matrix for FLake:

\[ M = \frac{\partial x_i^t}{\partial x_j^0} \]

No DA when jumping between regimes to handle discontinuities
EKF for FLake to assimilate LST

\[ x_B = M(x_A) \]

\[ B = MAM^T + Q \]

\[ K = BH^T(HBH^T + R)^{-1} \]

\[ x_A = x_B + K(y - H(x_B)) \]

\[ A = (I - KH)B \]
Assimilation of SYKE obs

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

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

Lake Ianri, 14m
Assimilation of SYKE obs
Lake Ianri, 14m
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
Assimilation of SYKE obs

Lake Saimaa,
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!