NETLAKE toolbox for the analysis of high-frequency data from lakes

Factsheet #6

Lake stratification and ice phenology: Modelling with MyLake

Raoul-Marie Couture and Koji Tominaga

Objective

Lake modelling is a thriving field of research, and many modelling tools are now available to the researchers (see Janssen et al. 2015). Prospective users of a model will make a choice based, amongst others, on the desired level of complexity and their preferred scientific programming environment. Here we describe the MyLake lake model, a simple one-dimensional (1D) daily time-step model that can be used to simulate seasonal changes in ice coverage in lakes. This model is aimed at researchers who prefer to use Matlab/Octave language for scientific computing applications. This factsheet describes briefly how to set-up the MyLake lake model in order to simulate thermal stratification and ice phenology in a lake. Such modelling efforts will allow studying the effect of various forcing factors on the lake's thermal balance and predict the evolution of the ice coverage over time. Because the presence of ice influences exchanges between the atmosphere and the surface of the lake as well as the penetration of light in the water column, ice modelling is often a first step towards simulating other seasonal phenomenon, such as algal blooms and bottom-water anoxia.

The lake model MyLake v1.2 was written by Tuomo Saloranta and Tom Andersen (Saloranta and Andersen 2007). It has been used in several studies since then, focussing on boreal lakes experiencing seasonal ice cover. New functionalities and modules have been added during the course of these studies regarding biogeochemistry (e.g., Couture et al. 2015): here we focus on v1.2 which is described in the original publication. MyLake uses a stacked layer geometry consisting of mixed horizontal layers. Its hydrodynamic module (1) calculates day- and night-time surface heat fluxes and heat sources, turbulent kinetic energy from wind (in the absence of an ice cover), and heat-fluxes between water and sediment, (2) performs convective mixing, and (3) applies a routine to calculate the vertical turbulent diffusion coefficient and the settling of solid components. If the density of the water coming into the lake (i.e., inflow) is less than or equal to the density of the surface layer, the inflow is mixed with the surface layer. Otherwise, the inflow is added on top of the first layer which is heavier than the inflow, thus displacing an equal amount of outflowing water and conserving lake volume. The model then calculates congelation and ice growth.

Specific application

The MyLake lake model is best suited for applications having the following characteristics: (1) the geometry of the lake basin lends itself to the "1D assumption", which neglects lateral heterogeneity, or if you can accept the limitation of working with a single 1D profile (2) you favour short integration time over model complexity, (3) you do not need complex lake physics or ecological modelling (e.g., saline or groundwater intrusions, reservoir management, food-web, etc.), (4) you want access to the source code and would like to modify it yourself if necessary, and finally (5) the lake experiences seasonal ice cover. If you are satisfied with these constraints, the MyLake lake model is useful as it includes only the most significant physical (e.g., heat conservation equations for the temperature distribution in a horizontally homogenous, vertically stratified lake), chemical (e.g. P partitioning) and biological (phytoplankton growth) processes in a balanced way. From the computational point of view, the model is designed to facilitate sensitivity and uncertainty analysis and to simulate a large number of lakes over long periods of time (e.g., decades). Here, we will describe how to setup the MyLake model in a generic boreal lake with a simple bathymetry, launch a 40 year simulation, and visualize the results.

Background

The code is written in Matlab. Basic knowledge on how to retrieve code from the GitHub platform, and on using Matlab and associated computing skills (File I/O, scripting, plotting) is required.

Software requirements: MATLAB version > 2012 with Statistical toolbox, or Octave; a GitHub client (we recommend SourceTree). The model has been tested using Matlab in a Windows environment and using Octave in a Linux environment.

Type of data and requirements

Input files are tab-delimited text files, with one line per lake depth interval (initial condition file) or one line per simulation day (input file). They can be prepared in spreadsheet software and saved to tab-delimited text.

The MyLake initial condition file requires the following:

- Depth levels (in metres, positive from the surface).
- Horizontal areas of each depth layer (m^2).
- Initial temperature profiles (°C).
- Initial profiles of biogeochemical variables (set to zero for this exercise).
- Initial value of total ice thickness (m).
- Initial value of snow thickness (m).

The depth levels and horizontal areas are to be calculated from available bathymetric information. This will enable MyLake to calculate lake volume, which is then assumed to remain constant.

The Mylake input file comprises columns of the following daily values:

- Global radiation (MJ m^{-2} d^{-1}) (optional, can be estimated based on latitude/longitude)
- Cloud cover (0 - 1)
- Air temperature (°C) at 2 m
- Relative humidity (%) at 2 m
- Atmospheric pressure (hPa) at station level
- Wind speed (m s^{-1}) at 10 m height above ground
- Precipitation (mm d^{-1})
- Daily inflow (m^3 d^{-1})
- Daily inflow concentrations (mg m^{-3}) of suspended matter, total phosphorus, dissolved organic phosphorus, chlorophyll; dissolved organic carbon and other biogeochemical variables (can all be excluded if looking only at temperature and ice formation)

The MyLake v.1.2 parameter file (*lake_para.txt*) comprises two sets of parameters: the lake physical parameters and the lake biological parameters. Note that Mylake v.2, not described here, contains a new set for the biogeochemical processes in the water column and in the sediment column. These parameters can be edited manually via the text files, or written at run-time via either (1) the auto-calibration module or (2) a catchment model running before MyLake. The physical parameters relating to lake thermodynamics and ice formation are shown in Table 1.

Par	Detail	Units
Albedo	Input of fn heatflux_v12.m	
dz	Grid step size	m
Kz_K1	Open water diffusion parameter	
Kz_K1_ice	Under ice diffusion parameter	
Kz_N0	Min. stability frequency	s^{-2}
C_shelter	Wind shelter parameter	
lat	Latitude	decimal degrees
lon	Longitude	decimal degrees
alb_melt_ice	Albedo of melting ice, Input of fn heatflux_v12.m	
alb_melt_snow	Albedo of melting snow, Input of fn heatflux_v12.m	
lambda_i	PAR light attenuation coef. of ice	m^{-1}
lambda_s	PAR light attenuation coef. of snow	m^{-1}
F_sed_sld	Volume fraction of solid in sediment	1-phi
I_scV	Scaling factor for inflow volume (multiplicative)	
I_scT	Scaling coef. for inflow temperature (additive)	

Table 1. Name of the user-defined parameters affecting ice formation taken from the parameter file, along with short description and units.

In addition, additional parameters are found in the script file and not read from the parameter files (although they can be changed manually), as shown in Table 2.

Par	detail	default value	Units
dt	Time step	1	
e_par	Average energy of PAR photons	240800	J mol^{-1}
Kz_b1	Diffusion param. exponents	0.43	
Kz_b1_ice	Diffusion param. exponents	0.43	
rho_fw	Density of freshwater	1000	kg m^{-3}
rho_ice	Density of ice/snow-ice	910	kg m^{-3}
rho_new_snow	Density of new snow	250	kg m^{-3}
max_rho_snow	Maximum snow density	450	kg m^{-3}
L_ice	Latent heat of freezing	333500	J kg^{-1}
K_ice	Ice heat conduction	2.1	W m^{-1} K^{-1}
C1	Snow compaction coef. 1	7.0	
C2	Snow compaction coef. 2	21.0	
Tf	Water freezing point temperature	0	^{0}C
K_sed	Thermal diffusivity of seds	0.035	m^2 d^{-1}
rho_sed	Bulk density of inorg. solids in sed.	2500	kg m^{-3}
rho_org	Bulk density of org. solids in sed.	1000	kg m^{-3}
cp_sed	Heat capacity of sediment	1000	J kg^{-1} K^{-1}
Ksw	Sediment-p.w. mass transfer coef.	1×10^{-6}	
Frail2Ice_tresh	Threshold where frazil turns into ice	0.03	m
Cw	Volumetric heat capacity of water	4.18×10^6	J K^{-1} m^{-3}
G	Gravity acceleration	9.81	m s^{-2}

Table 2. Name of the model default parameters affecting ice formation fixed in the main code along with short description and units.

Basic procedures

The procedure to follow is detailed in the user manual available on the web-page (link below). Only a brief synopsis is given here:

1. Prepare your input and initial condition files.
2. Obtain the source code of MyLake v1.2 at the GitHub repository (see below).
3. Copy the folder v12 and all its contents to your computer.
4. Start MATLAB and modify all the path names for model code, observations, and forcing files in the example model application script (TSA_modelVAN_v12.m) so that they point to the right folders (search for string "H:\" in order to find these lines). Use relative file path names if preferred.
5. Run the application script. Some information, such as ice-on/off dates, is displayed on command window while the model is running. A default set of figures are plotted when the model run is finished, as shown on Figure 1 (upper panel).
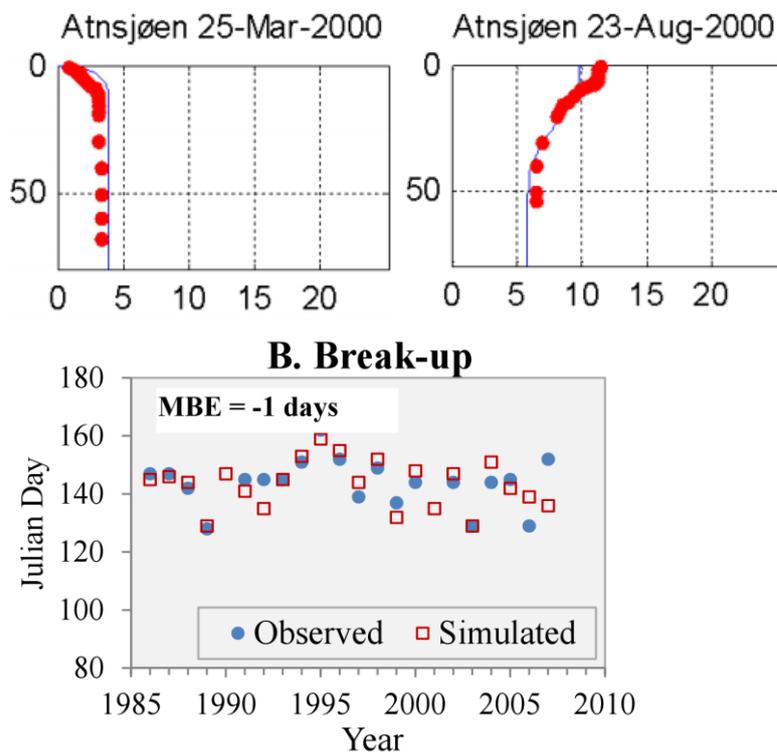
Figure 1. Upper panel: Vertical temperature profile measured (line) and simulated by the MyLake lake model (circles) in winter and spring in Lake Atnsjøen (Norway). Lower panel: Ice break-up dates observed (solid symbols) and predicted (open symbols) in the same lake based on observed meteorological forcing data; also shown are the mean bias error (MBE). Reproduced from Gebre et al. (2014).

Pitfalls and tips

- Input data that contain data gaps will be linearly interpolated by the model.

- The model is based on a daily time step (although surface heat balance is solved separately during day- and night time), therefore there might be numerical error if a process is much faster than a day. In particular, the surface layer can undergo significant temperature variations during a day. To alleviate this problem and avoid numerical instability in the temperature and ice simulations, the model grid size (dz, see Table 1) should be larger than the thickness of the surface layer.

- Model outputs are very sensitive to model daily inputs, such as inflow volumes, air temperature, and wind speed, especially so for smaller lakes.

- Changing default parameterisation for lake physics is rarely necessary outside of heat diffusion, wind mixing (sheltering) and ice albedo parameters.

Further reading

Key Reference:

Saloranta, T., Andersen, T. 2007. MyLake—A multi-year lake simulation model code suitable for uncertainty and sensitivity analysis simulations. *Ecological Modelling* 207: 45-60.

MyLake User Manual and code descriptions:

Saloranta, T., Andersen, T. 2004. MyLake (v.1.1) Technical model documentation and user's guide for version 1.1. http://brage.bibsys.no/xmlui/bitstream/handle/11250/212445/-1/4838_200dpi.pdf

For a Lake ice module physical description see supplement of Gebre et al (2014). http://www.the-cryosphere.net/8/1589/2014/tc-8-1589-2014-supplement.pdf

For the model's wiki pages on GitHub, see:
https://github.com/biogeochemistry/MyLake_public

Other useful references and recent applications of the model:

Gebre, S., T. Boissy, Alfredsen, K. 2014. Sensitivity of lake ice regimes to climate change in the nordic region. *The Cryosphere* 7: 1589-1605.

Janssen, A.G., Arhonditsis, G.B., Beusen, A., Bolding, K., Bruce, L., Bruggeman, J., Couture, R.-M., Downing, A.S., Alex Elliott, J., Frassl, M.A., Gal, G., Gerla, D.J., Hipsey, M.R., Hu, F., Ives, S.C., Janse, J.H., Jeppesen, E., Jöhnk, K.D., Kneis, D., Kong, X., Kuiper, J.J., Lehmann, M.K., Lemmen, C., Özkundakci, D., Petzoldt, T., Rinke, K., Robson, B.J., Sachse, R., Schep, S.A., Schmid, M., Scholten, H., Teurlincx, S., Trolle, D., Troost, T.A., Van Dam, A.A., Van Gerven, L.P.A., Weijerman, M., Wells, S.A., Mooij, W.M. 2015. Exploring, exploiting and evolving diversity of aquatic ecosystem models: a community perspective. *Aquatic Ecology* 4: 1-36.

Couture, R.M., Tominaga, K., Starrfelt, J., Moe, S.J., Kaste, O., Wright, R.F. 2014. Modelling phosphorus loading and algal blooms in a Nordic agricultural catchment-lake system under changing land-use and climate. *Environmental Science: Processes and Impacts* 16: 1588-1599.

Couture, R.M., DeWit, H., Tominaga, K., Kiuru, P., Markelov, I. 2015. Oxygen dynamics in a boreal lake responds to long-term changes in climate, ice phenology and DOC inputs. *Journal of Geophysical Research: Biogeosciences*. 120: 2441-2456.

Romarheim, A.T., Tominaga, K., Riise, G., Andersen, T. 2015. Natural stochasticity vs. management effort: use of year-to-year variance for disentangling significance of two mutually confounding factors affecting water quality of a Norwegian cold dimictic lake. *Hydrology and Earth System Sciences* 19: 2649-2662.

Holmberg, M., Futter, M., Kotamäki, N., Fronzek, S., Forsius, M., Kiuru, P., Pirttioja, N., Rasmus, K., Starr, M., Vuorenmaa, J. 2014. Effects of changing climate on the hydrology of a boreal catchment and lake DOC - probabilistic assessment of a dynamic model chain. *Boreal Environment Research* Suppl. A: 66-82.

Dibike, Y., Prowse, T., Bonsal, B., Rham, L.D., Saloranta, T. 2012. Simulation of North American lake-ice cover characteristics under contemporary and future climate conditions. *International Journal of Climatology* 32: 695-709.

Saloranta, T.M., Forsius, M., Jarvinen, M., Arvola, L. 2009. Impacts of projected climate change on the thermodynamics of a shallow and a deep lake in Finland: model simulations and Bayesian uncertainty analysis. *Hydrology Research* 40: 234-248.

Code

The code for this technique was written in the Matlab language, and is available at: https://github.com/biogeochemistry/MyLake_public

Contact details

Raoul-Marie Couture and Koji Tominaga. Norwegian Institute for Water Research, Norway. rmc@niva.no (*Twitter : @MyLake_model*)

Tuomo Saloranta. The Norwegian Water Resources and Energy Directorate, Norway.

Suggested citation

Couture, R.M. and Tominaga, K. 2016. Lake stratification and ice phenology: Modelling with MyLake. In Obrador, B., Jones, I.D. and Jennings, E. (Eds.) *NETLAKE toolbox for the analysis of high-frequency data from lakes* (Factsheet 6). Technical report. NETLAKE COST Action ES1201. pp. 28-34. http://eprints.dkit.ie/id/eprint/537.

Acknowledgement