**User’s guide to Hostetler and Bartlein Lake Model**

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1. **Description of model**

The Hostetler and Bartlein model is a 1-dimensional lake energy balance, water balance, and isotopic balance model. It was first developed in the late 1980’s as an energy balance model (Hostetler and Bartlein, 1990). The energy balance model was originally used in conjunction with water balance calculations on a coarser time step and applied to paleoclimate questions (Hostetler and Benson, 1990). Shortly afterwards, Hostetler (1991) incorporated the more sophisticated lake ice model of Patterson and Hamblin (1988) and Hostetler and Benson (1994) added the isotopic module. Later, Small et al. (1999) made modifications to improve the ice model and other components. These modifications include: new parameterizations for sensible and latent heat flux from the BATS land surface model, a Crank-Nicholson numerical solution for calculating eddy diffusion, inclusion of the effects of salinity on water properties and evaporation, and implementation of a partial ice cover scheme. Lastly, Morrill et al. (2001) added subroutines to allow sigma-level atmospheric model data as input.

1. **Input files**

As the model is currently configured for the Alaska Lakes project, one input file is needed. This file should be named <*met\_data.txt>* and contains the meteorological data that forces the model. The current configuration of the model expects hourly inputs, so each row in this file corresponds to a one hour time slice. Values in each row from left to right are:

1. Year
2. Day of year: ranges from 1 to 366
3. Hour of day: ranges from 0 to 23
4. Air temperature at 5 meters (degrees Celsius)
5. Relative humidity at 5 meters (%)
6. Wind speed at 5 meters (m/s)
7. Surface incident shortwave radiation (W/m2)
8. Downward longwave radiation (W/m2)
9. Surface pressure (mb)
10. Precipitation (mm)
11. Basin runoff (mm per unit area of the drainage basin)
12. delta 18O of precipitation (per mil VSMOW)
13. delta D of precipitation (per mil VSMOW)
14. delta 18O of basin runoff (per mil VSMOW)
15. delta D of basin runoff (per mil VSMOW)

Columns A through J are required. Column K is required to calculate the water balance, and columns K through O are necessary to model isotopes. If water balance and/or isotopes will not be modeled, these columns can either be left blank in the input file or filled with some sort of missing value.

1. **User-defined parameters and initial conditions**

A second file, *<lake.inc>*, includes parameter definitions, some of which are lake-specific. In this file, the user should specify the Earth’s obliquity (degrees), the lake’s latitude, longitude, local time relative to Greenwich Mean Time, maximum lake depth (i.e., the depth of the lake when it is at the sill elevation, in meters), the elevation of the basin bottom (meters), the area of the drainage basin when lake depth equals zero (hectares or 104 m2), the neutral drag coefficient (unitless), shortwave extinction coefficient (1/meters), the fraction of advected air in the air mass over the lake (ranges from 0 to 1), albedo of melting and non-melting snow, prescribed or initial lake depth (meters, typically represents mean lake depth), prescribed or initial lake salinity (parts per thousand), d18O and dD of air above the lake (per mil SMOW), functions used to calculate isotopic values from air temperatures, and the basin hypsometry (hectares or 104 m2; defined as the surface area the lake would attain at one meter depth increments from sill elevation to basin bottom).

The neutral drag coefficient is used to determine the vertical transfer of heat and water vapor between the lake and overlying atmosphere. To calculate this transfer, the model uses empirical “bulk formulae,” which rely on gradients of temperature and humidity between the lake and atmosphere along with exchange coefficients. These exchange coefficients depend on several parameters, including lake area and the height above the lake at which meteorological inputs were measured. The latter is set as z\_screen in <*lake.inc*>. For more information see the paper by Strub and Powell (1987).

The *<lake.inc>* file also contains a section of simulation specific parameters. These are used to turn on/off the following modules: water balance calculations, lake ice, variable salinity, lake water delta 18O and delta D, and explicit boundary layer computations for sigma-coordinate meteorological inputs from climate models.

Initial temperature, salinity, and isotopic profiles are specified within the lake model code itself, in the subroutine init\_lake. Other initial conditions including lake ice fraction and height, and height of snow present on top of lake ice are initialized at zero in this subroutine.

**4. Format of output file**

Currently, two output files are generated from the model and is called <*surface.dat*>. This file contains daily averaged values arranged in the following column sequence:

1. Julian day (from 1-365)
2. Lake surface temperature (degrees Celsius, averaged over top 1 meter)
3. Ice fraction (ranges from 0 to 1)
4. Lake evaporation (mm/day)
5. Average mixing depth (m)
6. Ice height (m)
7. Snow height (m)
8. Average lake delta 18O of upper 1 meter (per mil VSMOW)
9. Average lake delta D of upper 1 meter (per mil VSMOW)
10. Lake discharge (m per lake area)
11. Maximum mixed layer depth (m)
12. Lake depth (m)
13. Actual lake level above/below current 1-meter lake layer (fraction of meters).

**5. Project-specific coding**

The lake model is currently configured to specifications of the Toolik Lake project and modifications will be needed for other projects. Probable modifications for other project include enabling meteorological inputs other than hourly (program lakemodel), lake model outputs other than daily averages (subroutine shuffle), and meteorological inputs with different units (subroutine datain).

The Toolik Lake version of the Hostetler-Bartlein model was created by taking the original source code from Steve Hostetler, time-stamped July 21, 2006, and making the following modifications (many of which are general and would be useful for simulating other lakes):

1. Program lakemodel: Added call to tendency subroutine and other associated code in order to handle hourly inputs; removed hard-coding of runoff amount and of the isotopic compositions of precipitation and runoff, which are now read in via the meteorological input file; removed loop that allows for multiple lake columns, which lacked integration with water-balance calculation; added ability to spinup lake model by repeating first year of integration a user-specified number of times.
2. Subroutine lake\_main: Added if statements so that subroutine bndry\_flux is called only if inputs are sigma-level and so that water-balance and isotopes are tracked only if desired; deleted sections 6 and 12 for calculating initial energy balance since this was never used thereafter; changes to water balance calculations; added variable to track rain separate from snow, which is necessary to do isotopes and water balance correctly; allowed water and isotopic balance calculations to occur for all time steps and not just for ice-free conditions, which avoids the total loss of any rain, runoff, snow and ice evaporation, and snowmelt that occurs before ice off or during periods of fractional ice cover.
3. Subroutine bndry\_flux: Removed hard-coding of sigma level, which is now specified in lake.inc file; Removed hard-coding of surface pressure, which is now input through the meteorological inputs file; Moved gravity, gas constants, heat capacities to lake.inc file as these are used by other subroutines.
4. Subroutine datain: Changed conversions for Toolik-specific meteorological inputs.
5. Subroutines D2H and O18: Added accounting for melting snow on top of lake ice; in D2H only, fixed bug in calculation of lake outflow delta D by changing trace(2,1) to trace(1,2).
6. Subroutine eddy: Changed minimum allowed wind speed from 1 m/s to 0.5 m/s in line with RegCM lake model; Specified absolute value for sine of latitude to allow for negative (Southern Hemisphere) latitudes
7. Subroutine lake\_drag: Moved gravity, Von Karman constant, roughness length constants to lake.inc; Deleted calculation for neutral drag coefficient, which is now specified by user in lake.inc allowing for lake-specific tuning; Specified height of atmospheric values to be 2 m for simulations with bndry\_flag equals True.
8. Subroutine lake\_albedo: Added variable to distinguish the albedo of melting snow from non-melting snow.
9. Subroutine lake\_ice: Converted the evaporation of snow (evaps) from a length into a rate for consistency with other evaporation variables (evapw, evapi); incremented snowmelt by the amount of remaining snow when all lake ice has melted.
10. Subroutine latsens: Removed hard-coding of surface air density and now calculate it from temperature, humidity, surface pressure, and gas constants.
11. Subroutine salt\_init: Removed hard-coding of surface pressure, which is now provided in the meteorological inputs; Corrected last coefficient of the equation from -7.53e-3 to -7.53e-4.
12. Subroutine shuffle: Removed shuffling of time-invariant constants (i.e., latitude, eta) and of time-varying inputs (e.g., o18prec) for simplicity; Added shuffling of variables used to make time averages (e.g., mix\_ave).
13. Subroutine solar\_dec: Removed hard-coding of obliquity, which is now specified by user in lake.inc.
14. Subroutine tendency: Wrote this subroutine to handle linear interpolation for model time steps smaller than time between input reads.
15. Subroutine water-balance: Removed psum term from water balance calculation, which potentially double-counted snow and added snowmelt term instead.
16. Subroutine zenith: Removed hard-coding of time to be noon, allowing for time to evolve according to model time step; Added longitude and time zone to zenith angle calculation in order to get correct true solar time using equations from NOAA ESRL solar calculator.

**6. Possible future work (non-exhaustive list)**

* Simulation of the lake’s salt balance needs to be double-checked. Code exists in the model to simulate the salt balance, but it is currently turned off by setting s\_flag to false in <*lake.inc*>. Does isotopic fractionation during evaporation depend on lake salinity? Salinity of runoff is hard-coded in the subroutine water\_balance.
* It would be possible to re-implement looping through multiple lake columns. This could be useful for simulating either large lakes that span regions with different meteorological conditions, or lakes with significant areas of both shallow and deep depths. The trick will be to integrate all columns and then complete the water balance.
* Some enhancements could be made to the isotopic calculations. For example, evaporation of snow and ice are non-fractionating (though perhaps this would be a small effect?), and the delta 18O and delta D of air do not vary through time.

**7. References**

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