Simulation protocol for the Harp Lake experiment
Version 10/11/2015

Harp Lake (Canada), 2010-2015

Latitude*:	45º22'34.2'' N
Longitude*:	79º07'34.9" W
Altitude (benchmark):	327.0 m above sea level
Area:	71.38 ha
Lake volume:	95.07 x 105 m3
Mean depth:	13.32 m
Maximum depth:	37.5 m
Average Secchi depth:	4.21 m
Starting date:	0:00 (UTC) 14 July 2010
Terminal date:	23:00 (UTC) 19 October 2015

1. The lake optics

The optical parameter	variable	Units	Water	Ice	Snow
Extinction coefficient	k	m^{-1}	0.40	/[1]	/
Shortwave albedo	α	n/d	0.07	/	/
Longwave albedo	α_{LW}	n/d	0.03	0.02	0.02
Longwave emissivity	ε	n/d	0.97	0.98	0.98
Shortwave fractioning coefficient into VIS & NIR	β	n/d	0.35	0.35	0.35

The light extinction coefficient of water, k, for the reference experiment, has been computed from the mean Secchi disk (SD) for Harp Lake z_{SD} = 4.21 m (n = 106, April 2010 – July 2015), by the classical Poole & Atkins formula:

$$k = 1.7/ z_{SD},$$

this leads to an extinction coefficient of 0.40 m^{-1}. The maximal and minimal values of k, computed in the same way for the whole SD time series are 0.68 m^{-1} and 0.28 m^{-1}, respectively.
Setting the VIS/NIR shortwave fractioning coefficient, β, to 0.35 implies that 35% of the total (!) shortwave radiation is expected to be the near-infrared part (700-2500 nm in EM-spectrum), while the remaining 65% is the visible part (300-700 nm) (ASTM, 2012; Thiery et al., 2014).
Of this visible fraction, a small portion, named shortwave albedo, α, is reflected, while the rest penetrates into the lake water according to:

$$SW_{net,VIS}(z) = SW_{in}\ (1-\beta)\ (1-\alpha)\ e^{-kz}$$

[1] Parameters marked by «/» are not unified between models due to their complex temporal behavior.

The NIR fraction is completely absorbed at the surface (a good approximation to reality, Natalia Chubarova, pers. comm.).
For ice and snow surfaces, radiation is recommended to be treated in the same way.

In models where the distinction within S_{Wnet} between VIS and NIR is originally not made (e.g. FLake), it is still recommended to introduce fractioning coefficient β. Otherwise, if β=0, participants are asked to let the coordinators know of this model peculiarity.

2. The snowpack parameterization

The snowpack and ice parameterization, i.e. heat transfer, ice growth, snow compaction and other processes are left on decision of participants. It is recommended to keep the native scheme in baseline experiment. Models lacking ice module are encouraged to implement simple ice model (Yao et al., 2014), while the others may run additional experiment with this model instead of the native one.

3. The surface flux scheme (computing sensible, latent heat and momentum fluxes)

Baseline experiment: native surface schemes should be used.
It is recommended but not mandatory to run an additional experiment with FLake's surface flux scheme.

4. The equation of state

Equations of state are kept as they are in lake models. Participants are asked to provide details on water density calculation.

5. The lake depth and morphometry

Baseline experiment. The lake depth in the model is the maximal Harp Lake depth, 37.5 m. No morphometry, sediments off.

Additional experiments.
(sediments on/off used only by models which include a sediment compartment, otherwise only scenario (ii) should be implemented)
(i) maximal depth, morphometry included (hypsometric curve, see below), sediments on;
(ii) average depth, no morphometry, sediments off;
(iii) average depth, no morphometry, sediments on.

Depth-area-volume relations:

Contour depth	contour area	stratum volume
(m)	(ha)	(10^5 m^3)
0	71.38	
2	66.10	13.75
4	58.64	12.43
6	51.73	11.06
8	44.77	9.64

10	38.13	8.29
12	32.47	7.02
14	27.85	6.02
16	23.93	5.16
18	20.61	4.45
20	17.69	3.82
22	15.20	3.28
24	12.43	2.79
26	9.69	2.19
28	7.42	1.71
30	5.62	1.29
32	3.99	0.97
34	2.64	0.65
36	1.48	0.42
37.5	0.00	0.14

6. The initial conditions

Initial profiles are given for temperature, DO, carbon dioxide for 14 July UTC 2010. The following table provides initial profiles for *baseline experiment*.

Depth (m)	Temp (°C)	Oxygen (mg l^{-1})	CO_2, ppm	CH_4 (mol l^{-1})
0.1	25.51	7.97	622[2]	0[3]
1.1	25.39	7.52	622	0
2.1	25.22	8.49	622	0
3.1	23.03	8.75	622	0
4.1	19.27	8.97	622	0
5.1	14.55	10.23	622	0
6.1	11.5	9.36	622	0
7.1	9.46	8.25	622	0

[2] Measured mean at 0.39 m for 00:00 UTC 14 July 2012-2015

[3] Not measured, 0 chosen due to high oxygen content.

8.1	7.86	8.61	622	0
9.1	6.91	8.25	622	0
10.1	6.4	8.20	622	0
11.1	6.05	8.04	622	0
12.1	5.72	8.20	622	0
13.1	5.52	8.28	622	0
14.1	5.4	8.00	622	0
15.1	5.26	8.03	622	0
16.1	5.15	8.19	622	0
17.1	5.06	8.04	622	0
18.1	4.93	7.81	622	0
19.1	4.95	7.83	622	0
20.1	4.8	7.59	622	0
21.1	4.8	7.42	622	0
22.1	4.8	7.46	622	0
23.1	4.7	7.10	622	0
24.1	4.7	6.92	622	0
25.1	4.7	7.00	622	0
26.1	4.7	7.03	622	0
27.1	4.7	6.87	622	0
28	4.7	6.75	622	0
29	4.7	6.98	622	0
30	4.6	6.88	622	0
31	4.6	6.91	622	0
32	4.6	6.58	622	0
33	4.6	6.56	622	0
34	4.6	6.55	622	0
35	4.6	6.55	622	0

7. The atmospheric forcing

The atmospheric forcing data is collected in Harp_forcing.dat
The file format is described in Harp_forcing_notes.dat

8. The geothermal heat flux and the heat flux at water-bottom interface

Lake models lacking sediments should impose zero heat flux at the lake bottom. Those including sediments are asked to perform at least two experiments:

(i) *baseline experiment*: sediments switched off with zero heat flux at lake's bottom (i.e. the same as models not including sediments);
(ii) sediments switched on with zero heat flux at the bottom of sediments layer.

9. Inflow and outflow

The daily stream discharge data are included in Harp_stream_discharge_daily.dat. The models introducing contribution of inlets and outlets to heat and gases' budget in a lake are welcome to run an experiment with this option on. In the baseline experiment it should be off.

10. The summary of experiments

Experiment name (suffix for output file name)	Variable/model component to be perturbed	Units	Value/ value in the baseline experiment	Remarks
baseline*[4]	Water extinction coefficient, k	m^{-1}	0.40	-
	Initial CO_2 and CH_4 concentration		Provided in Section 6	
	Inflow and outflow of heat and O_2	-	OFF	
	Surface flux scheme	-	native	
	Heat transfer in sediments	-	OFF	
	Lake depth	-	maximal depth	
	Bottom morphometry	-	OFF	
	Biochecmical constants	-	Native or from unified gas transfer module	
extmax*	Water extinction coefficient, k	m^{-1}	0.68 / 0.40	
extmin*	Water extinction coefficient, k	m^{-1}	0.28 / 0.40	
ext	Water extinction coefficient, k	m^{-1}	Measured series / 0.40	
gasmax*	Initial CO_2 and CH_4 concentration		Homogeneous CO_2 = 830 ppm[5] / baseline profile	
gasmin*	Initial CO_2 and CH_4 concentration		Homogeneous CO_2 = 0 ppm / baseline profile	
inflow	Inflow and outflow of temperature and O_2	-	ON / OFF	

4 Obligatory experiments are marked by asterisk, *

5 Maximum at 0.39 m for 00:00 UTC 14 July 2012-2015

sfc	Surface flux scheme	-	Surface flux scheme from FLake / native	
sed	Heat transfer in sediments	-	ON / OFF	No morphometry, maximal depth
mdepth*	Lake depth	-	Mean depth / maximal depth	No sediments
mdepthsed	Lake depth	-	Mean depth with sediments ON / maximal depth, sediments OFF	
morph	Bottom morphometry	-	ON, sediments ON / OFF, sediments OFF	To be performed with sediments ON[6]
ice	Ice scheme	-	Yao et al. 2014 / native scheme	For models, containing an ice compartment
Biochemical constants				Will be performed only with unified gas transfer module

11. The lake model output

For intercomparison of model results, the unified set of output items from each model is required. They have to be written in three ASCII files, described in sections 11.1 — 11.3. It is asked to represent the output data in exponential format (e.g. 1.71 E1), not as decimals (e.g. 17.1).

An example of doing this in FORTRAN is:

```
WRITE(filenumber,'(19(1pe12.3))') var1,var2,...,var19
```

11.1. File 1. The first file contains time series of the lake state variables with 1 hour timestep. The first 5 columns represent the time counted from the initial moment (corresponding to 0:00 (UTC) 14 July 2010), and the subsequent columns are the model output variables:

[6] Including morphometry without heat exchange with sediments leads to overwarming of the water column (Stepanenko et al., 2014).

No. of column	Variable	Units	Comments
1	year	year	
2	Month	month	
3	Day	day	
4	Hour	hour	
5	Min	min	0
6	surface temperature	Celsius	
7	mean temperature of the water column	Celsius	
8	bottom temperature	Celsius	
9	mixed-layer depth	m	the definition of mixed-layer depth should be indicated by a participant of the experiment. Common definitions are: (i) the depth of maximal Brunt-Vaisala frequency and (ii) the depth of minimal heat/buoyancy flux
10	the ice thickness	m	
11	the snow thickness	m	-999, if a model does not calculate this variable explicitly
12	the temperature at the ice upper surface	Celsius	
13	the temperature at the snow upper surface	Celsius	
14	sensible heat flux at the lake-atmosphere interface, positive if upwards	W/m^2	i.e. at the surface of snow, ice or water depending on the layer in contact with the atmosphere, **average value for the last 1h**
15	latent heat flux at the lake-atmosphere interface, positive if upwards	W/m^2	See the comment to 14-th column
16	momentum flux at the lake-atmosphere interface, positive if upwards	N/m^2	See the comment to 14-th column
17	upward long-wave radiation flux at the lake-atmosphere interface, positive if upwards	W/m^2	Not to be confused with net longwave radiation! See the comment to 14-th column
18	downward heat flux at the lake-atmosphere interface, positive if upwards	W/m^2	**"= (1-α_{LW})*LWin + β*SWin – LWout – SHF – LHF"**, please report if your data differs ["= (1-α_{LW})*LWin – LWout – SHF – LHF" in case your model does not differentiate between VIS and NIR for the SWin component], See the comment to 14-th column
19	surface albedo	fraction	This is the albedo of the surface interacting with the atmosphere (water, ice or snow)

For lake models with time steps much shorter than 60 min (e.g. K-ε models), it is asked to provide 60 min averages for the variables 14 to 18 (energy fluxes), as this will allow to compute total heat exchange between lake and the atmosphere for the 60 min time interval. In other models with explicit time stepping and time steps of 60 min or longer (e.g. MINLAKE, Hosteler, FLake), the energy fluxes are already assumed representative for the whole time step, so averaging is not needed.

11.2. File 2. The second ASCII file should contain the vertical water temperature (Celsius), density (kg/m^3) and eddy diffusivity (m^2/s) profiles, calculated by the model. It has to include the following columns:

year month day hour min Depth1 Temp1 Dens1 Diff1 Depth2 Temp2 Dens2 Diff2… DepthN TempN DensN DiffN

where the depths *Depth1, …, DepthN* are

0.1, 1.1, 2.1, …, 13.1, 15.1, … ,27.1, 29, 31, 33, 35 m

or, in format start:step:end,

0.1:1:13.1, 15.1:2:27.1, 29:2:35 m

for simulations with maximal lake depth and:

0.1, 1.1, 2.1, …, 13.1 m

or

0.1:1:13.1 m

for simulation with mean depth.

11.3. File 3. The File 3 should have the same format, with the same set of depths, as in File 2 but containing data on gas concentrations:

year month day hour min Depth1 O2_1 CO2_1 CH4_1 Depth2 O2_2 CO2_2 CH4_2 … DepthN O2_N CO2_N CH4_N.

11.4. Output overview.

In total, there are 6 mandatory experiments (1 reference (baseline) and 5 sensitivity runs – *gasmin, gasmax, extmin, extmax, mdepth*, see table in Section 10), plus 7 auxiliary ones, plus a series of experiments perturbing biochemical constants, that will be performed by Guseva Sofya and Victor Stepanenko with unified gas transfer module. Three output files are expected from each experiment.

File naming convention:
<lake model name>_<experiment suffix>.dat

e.g. FLake_sed.dat or FLake_baseline.dat. For suffixes see table in section 10.

The time interval in all output files is 60 min for models capable of that and the multiple of 60 min for other models.

Along with the variables above, the intercomparison participants are asked to provide the CPU time for a single run of the model with the processor type used.

13. Models currently engaged in the experiment

- LAKE
- LAKEoneD
- FLake
- Zeli Tan's model (ALBM)
- MTCR-1

14. Problems and questions

If you have any questions, problems or suggestions, please contact

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References

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Yao, H. et al., 2014. Comparing ice and temperature simulations by four dynamic lake models in Harp Lake: past performance and future predictions. Hydrological Processes, 28(16), pp.4587–4601. Available at: http://doi.wiley.com/10.1002/hyp.10180.