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Expanding cross-site synthesis of lake energy budgets through a global lake modelling collaboration

Bruce, L.*, Frassl, M., Read, J***. and Hipsey, M.***
* The University of Western Australia, Perth, Western Australia, Australia
** USGS Center for Integrated Data Analytics, Madison, Wisconsin, USA
*** Helmholtz-Centre for Environmental Research, Magdeburg, Germany

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Summary of key findings

In this study we have undertaken an analysis of the results of a multi-lake modelling project in an attempt to explore how lake energy budget response to global warming are affected by local climate and physical lake characteristics. For the initial study, 31 lakes taken from the Global Lake Ecological Observatory Network (GLEON) with a variety of morphometries, climatic, hydrological and trophic characteristics were simulated for a period of two years using the General Lake Model (GLM), a simple 1-D hydrodynamic model. By applying the model within a Bayesian Hierarchical Framework, using a Markov Chain Monte Carlo (MCMC) approach, we demonstrated key model parameter "learning" from the combined GLEON data set. A global comparison of thermodynamic properties using generated model output enabled us to search for systematic patterns in temperature response based on lake properties in context with local climatic conditions. It was found that deep lakes tended to buffer change more where lakes in warmer climates were more sensitive to temperature increases. The analysis demonstrates that integration of numerical models with data from a global sensor network can be an effective way to improve understanding of the complex relationships between limnological characteristics and energy budgets.

Background and relevance

Lakes and reservoirs support a number of ecosystem services and in many cases are considered "*sentinels of change*", due to their sensitivity to changes in climate and catchment hydrology (Adrian et. al 2009). Given the diversity of lake environments, regional pressures and management approaches, the Global Lake Ecological Observatory Network (GLEON: gleon.org) was initiated in 2004 as a grass-roots science community with a vision to observe, understand and predict freshwater systems at a global scale (Weathers et. al 2013). GLEON brings together environmental sensor networks, numerical models, and information technology to explore ecosystem dynamics across a vast range of scales - from an individual lake or reservoir to regional, and even global trends. Environmental modelling forms a critical component of these observing systems, to make sense of the data deluge and allowing users to build "virtual domains" to support knowledge discovery at the system-scale.

As energy partitioning is the driving factor behind physical and biogeochemical cycles in lakes and reservoirs (Juday 1940), a greater understanding of energy budgets is of paramount importance to effective lake management. Quantifying the response of lake thermo structure in terms of mixing and stratification dynamics to changes in energy input is crucial on scales from years (seasonal variation) to decades (patterns of climate change) and this is where numerical models can play a part. This study has taken advantage of using a computationally efficient 1-D model (GLM) and a network of lakes with high resolution temperature observation data (GLEON) with advanced methods of parameter estimation (Bayesian approach) to add to knowledge of climatic response of inland waters.

Results

As expected the surface temperature of most lakes increased with the warming scenario (Fig. 1.1) with the exception of the coldest lakes that simulated a slight decrease in surface temperature. Lakes in warm climates and those with highest incident short wave radiation recorded the greatest increase in surface temperature (Fig. 1.1). The response in difference between epilimnion and hypolimnion temperatures to the warming scenario was most pronounced in deep lakes with almost all lakes showing an increase in temperature difference (Fig. 1.2).

Discussion

It was found that large lakes tended to buffer response to stratification gradients and magnify response to absolute temperature differences where lakes in warmer climates were more sensitive overall to temperature increases. The analysis demonstrates how simple models can be an effective way to explore how complex relationships between limnological characteristics can effectively buffer or magnify climate change response.

Table 1.1 Summary of lakes in the Multi-Lake Comparison Project

	Lake Name	Volume (m^3)	Depth (m)	Inflow (m^3/s)	Air Temp (°C)	Wind Speed (m^3/s)	Kw	Latitude
AL	Alexandrina	1.11E+09	6.10	1.12E+07	14.88	3.81	0.30	-35.00
AM	Ammersee	1.78E+09	84.72	1.73E+06	8.79	1.59	0.35	48.00
BL	Blelham	5.39E+05	14.80	2.05E+04	9.41	1.46	0.67	54.35
BO	Bourget	3.53E+09	146.00	1.38E+07	11.48	1.76	0.40	45.44
CA	Cannonsville	1.14E+08	49.29	2.87E+06	7.36	2.11	0.40	42.09
CO	Como	2.21E+10	440.00	8.42E+06	13.96	2.14	0.46	46.00
CN	Constance	4.74E+10	256.00	3.26E+07	10.26	2.26	0.23	47.37
EG	ElGergal	3.05E+07	55.00	7.40E+04	18.14	1.67	0.80	37.00
EM	Emaiksoun	2.43E+06	2.40	0.00E+00	-9.06	4.21	0.65	71.24
ES	Esthwaite	6.25E+06	15.00	9.79E+04	9.50	2.09	1.07	54.35
FE	Feeagh	5.48E+07	43.00	6.02E+05	10.11	4.89	0.30	53.35
G3	Geneva03	9.06E+10	309.00	1.16E+07	10.95	1.90	0.10	46.43
G5	Geneva05	9.06E+10	309.00	1.05E+07	10.44	1.93	0.10	46.43
GD	GrosseDhunn	6.62E+07	48.50	1.64E+05	10.34	2.17	0.40	51.07
HA	Harp	9.26E+06	37.50	7.96E+03	3.73	5.39	0.77	45.38
IS	Iseo	7.07E+09	260.00	5.33E+06	13.17	2.45	0.26	46.00
K3	Kinneret03	4.26E+09	44.00	2.93E+06	22.01	2.74	0.59	32.00
K7	Kinneret97	4.13E+09	44.00	1.62E+06	22.37	2.41	0.57	32.00
ME	Mendota	4.86E+08	24.99	4.96E+05	8.23	4.15	0.69	43.00
MB	MtBold	2.68E+07	57.20	2.21E+05	13.60	5.11	0.98	-35.10
MG	Muggelsee	2.71E+07	9.00	3.65E+05	10.20	3.91	1.05	52.00
ON	Oneida	2.85E+08	17.00	5.68E+06	10.96	4.07	0.60	43.00
PU	Pusiano	7.60E+07	30.90	2.48E+05	13.91	1.95	0.66	45.80
RP	Rappbode	7.81E+07	85.60	1.93E+05	7.44	3.40	0.40	51.73
RS	Rassnitzersee	6.89E+07	40.00	7.78E+05	9.61	5.23	0.44	51.30
RV	Ravn	2.51E+07	35.00	3.57E+04	8.37	5.21	0.50	56.00
RO	Rotorua	7.27E+08	22.00	1.23E+06	12.64	3.07	0.80	-38.00
ST	Stechlin	9.84E+07	71.00	4.00E+03	9.32	4.67	0.25	53.17
TA	Tarawera	2.15E+09	90.00	6.17E+05	13.27	5.10	0.21	-38.20
TO	Toolik	5.68E+06	26.00	1.29E+04	-7.62	3.05	0.65	68.60
WI	Windermere	4.99E+08	66.76	1.58E+06	9.14	3.21	0.60	54.38
ZU	Zurich	3.37E+09	136.00	6.20E+06	10.06	1.57	0.34	47.25

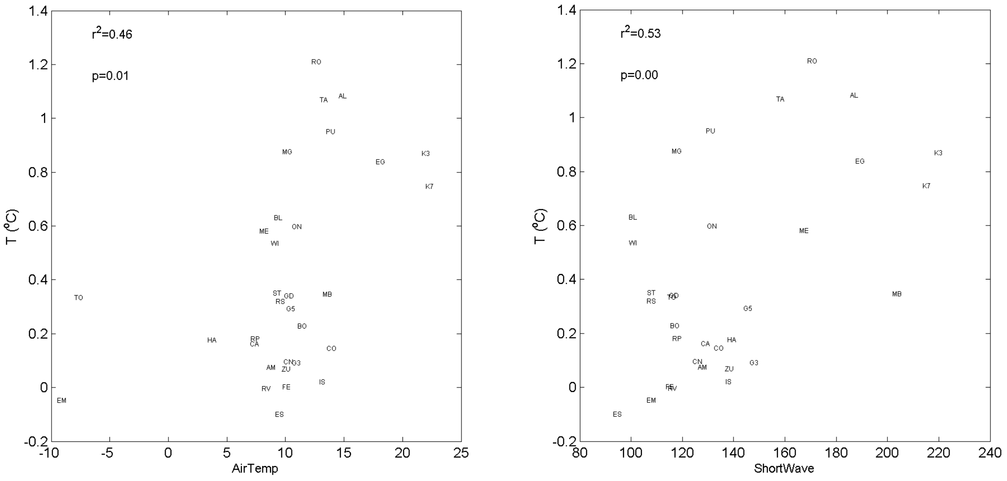

Figure 1.1 Change in mean lake surface temperature in response to a 2°C warming scenario correlated to ambient air temperature (left) and short wave radiation (right).

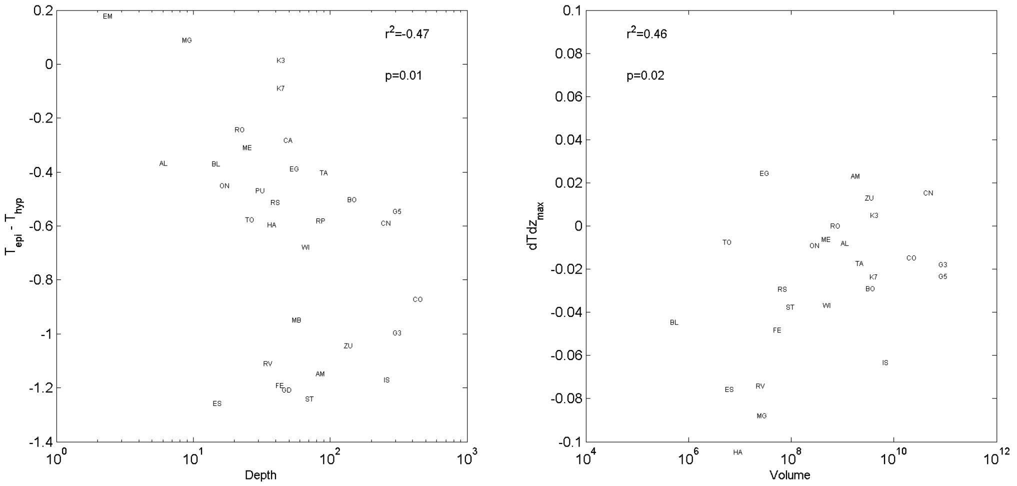

Figure 1.2 Change in mean epilimnion to hypolimnion temperature difference in response to a 2°C warming scenario correlated to lake depth (left) and change in maximum temperature gradient in response to a 2°C warming scenario correlated to lake volume (right).

References

Adrian, R., O'Reilly, C. M., Zagarese, H., Baines, S. B., Hessen, D. O., Keller, W., ... and Winder, M. (2009) Lakes as sentinels of climate change, *Limnology and Oceanography*, 54(6part2), 2283-2297

Juday, C. (1940) The annual energy budget of an inland lake, *Ecology*, 21(4), 438-450

Weathers, K., Hanson, P. C., Arzberger, P., Brentrup, J., Brookes, J., Carey, C. C., ... and Zhu, G. (2013) The Global Lake Ecological Observatory Network (GLEON): the evolution of grassroots network science, *Bulletin of Limnology and Oceanography,* 22(3), 71-73