VRIJE UNIVERSITEIT BRUSSEL

Fonds Wetenschappelijk Onderzoek Vlaanderen
Opening new horizons

Global heat uptake by inland waters

Inne Vanderkelen

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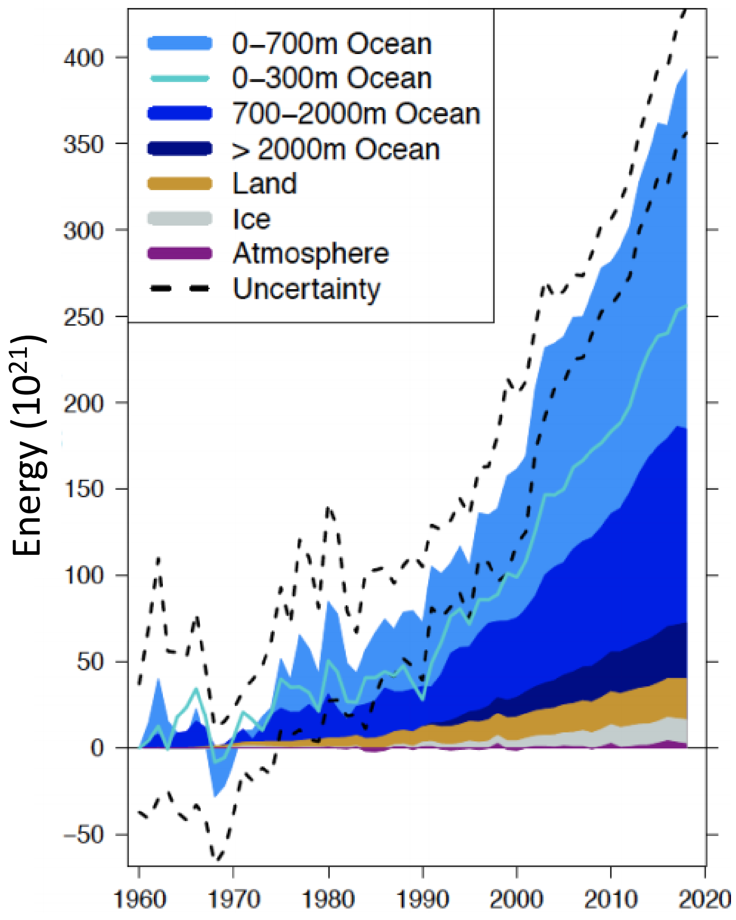
Excess heat is taken up by the Earth system



Von Schukmann et al., 2020 (ESSDD)

Heat gain 1960-2018

Oceans	~89%
Land	~6%
Ice	~4%
Atmosphere	~1%

Von Schuckmann et al., 2020 (ESSDD)

What is the share of inland waters?

Excess heat is taken up by the Earth system
but what is the share of inland waters?

Lakes

1.8 % of land surface

Reservoirs

0.2 % of land surface

Rivers

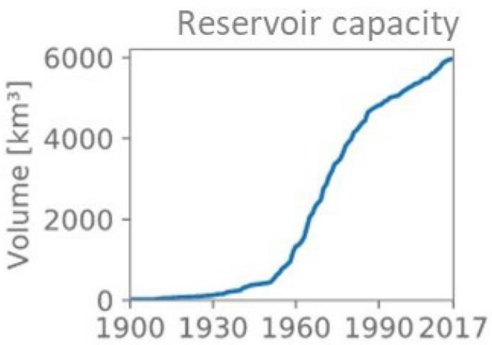
0.58 % of land surface

No wetlands and floodplains (limited data availability on global scale)

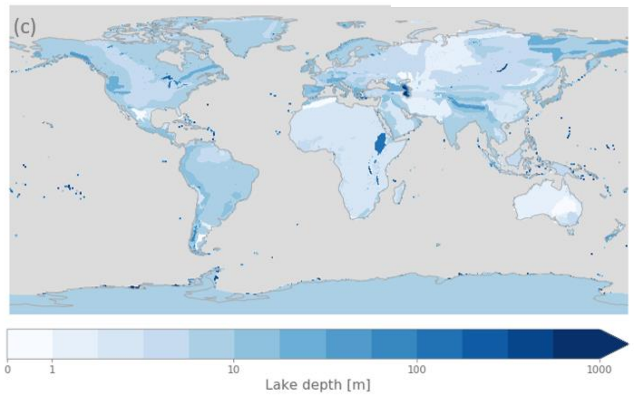
Lake and reservoir heat content

Simulations of ISIMIP 2b global lake sector
1900 – 2020: historical and RCP 6.0, 0.5 x 0.5° resolution

Water temperature profiles from 12 simulations:
3 lake models: CLM4.5, SIMSTRAT-UoG, ALBM
4 ESMs: GFDL-ESM-2M, MIROC5, HadGEM2-ES, IPSL-CM5A-LR



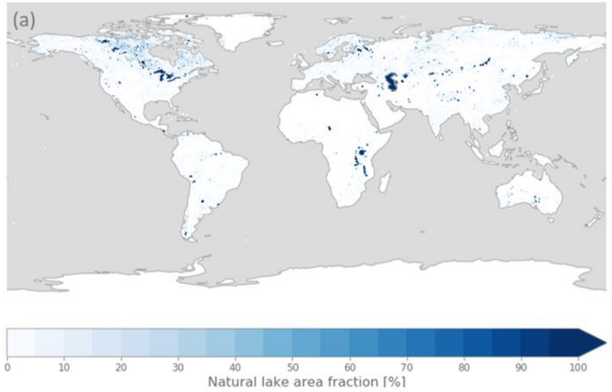
Lake depth



Global Lake Database

Choulga et al., 2019

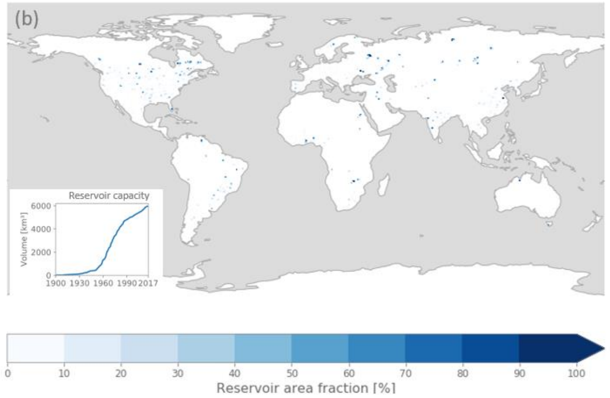
Natural lakes



HydroLAKES

Messager et al., 2016

Reservoirs



Global Reservoir and Dam database

Lehner et al., 2011

Lake and reservoir heat content

$$Q_{lake} = c_{liq} \, A_{lake} \, \rho_{liq} \sum_{n=1}^{n=nlayers} T_n \, d_n$$

Q_{lake} (J): Annual lake heat content per grid cell
A_{lake} (m^2): lake area; given by HydroLAKES and GRanD*
T_n (K): water temperature of the lake layer, given by the lake models
d_n (m): depth of the lake layer, scaled against lake depth of GLDB

c_{liq} = 4188 J kg^{-1} K^{-1} (constant; specific heat capacity of liquid water)
ρ_{liq} = 1000 kg m^{-3} (constant; density of liquid water)

Heat uptake (ΔQ_{lake}) calculated relative to 1900-1929
Apart from reservoir construction, no changes in lake storage

River heat content

Simulations of ISIMIP 2b global water sector
1900 – 2020: historical and RCP 6.0, 0.5 x 0.5° resolution

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project
https://www.isimip.org/

River storage from 8 simulations:
2 global hydrological models: WaterGAP2 and MATSIRO
4 ESMs: GFDL-ESM-2M, MIROC5, HadGEM2-ES, IPSL-CM5A-LR

River temperatures :
Regression approach based on air temperatures from the 4 ESMs

$$T_{\text{water}} = \frac{C_0}{[1 + e^{(C_1 T_{\text{air}} + C_2)}]},$$

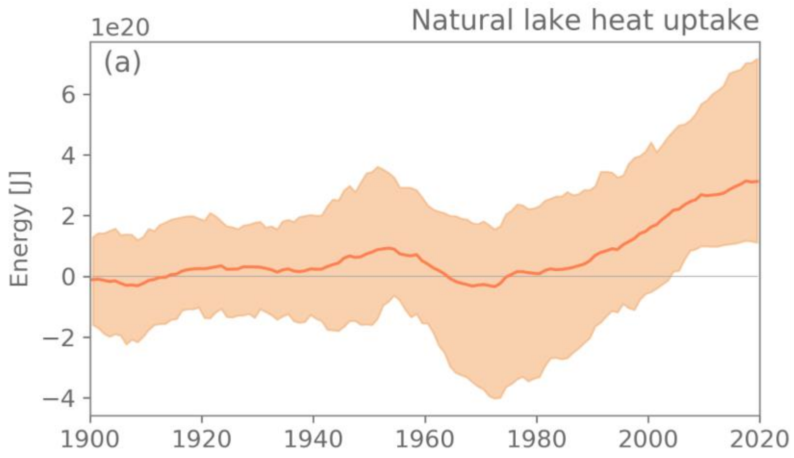
Punzet et al (2012)

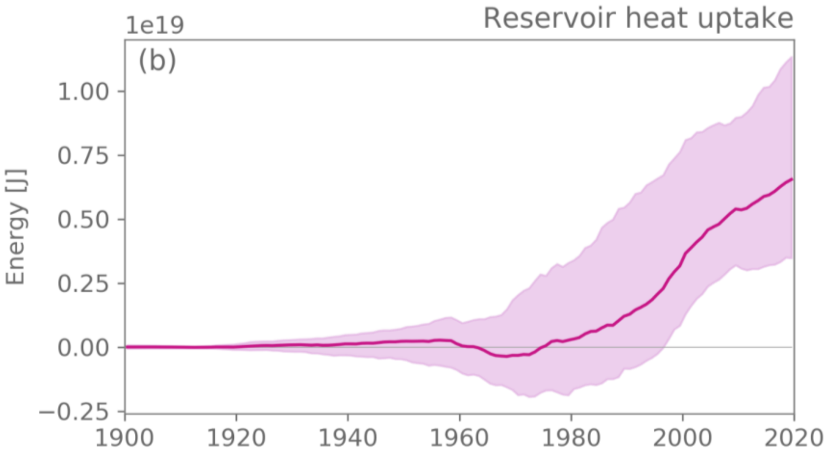
$$Q_{river} = c_{liq}\ m_{river}\ T_{river}$$

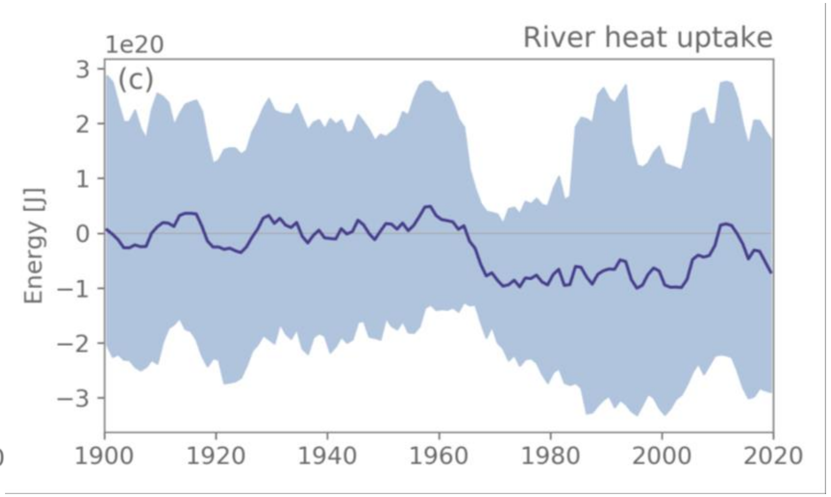
Q_{river} (J): annual river heat content per grid cell
m_{river} (kg): river storage
T_{river} (K): river temperature based on regression approach

c_{liq} = 4188 J kg^{-1} K^{-1} (specific heat capacity of liquid water)

Global heat uptake by inland waters





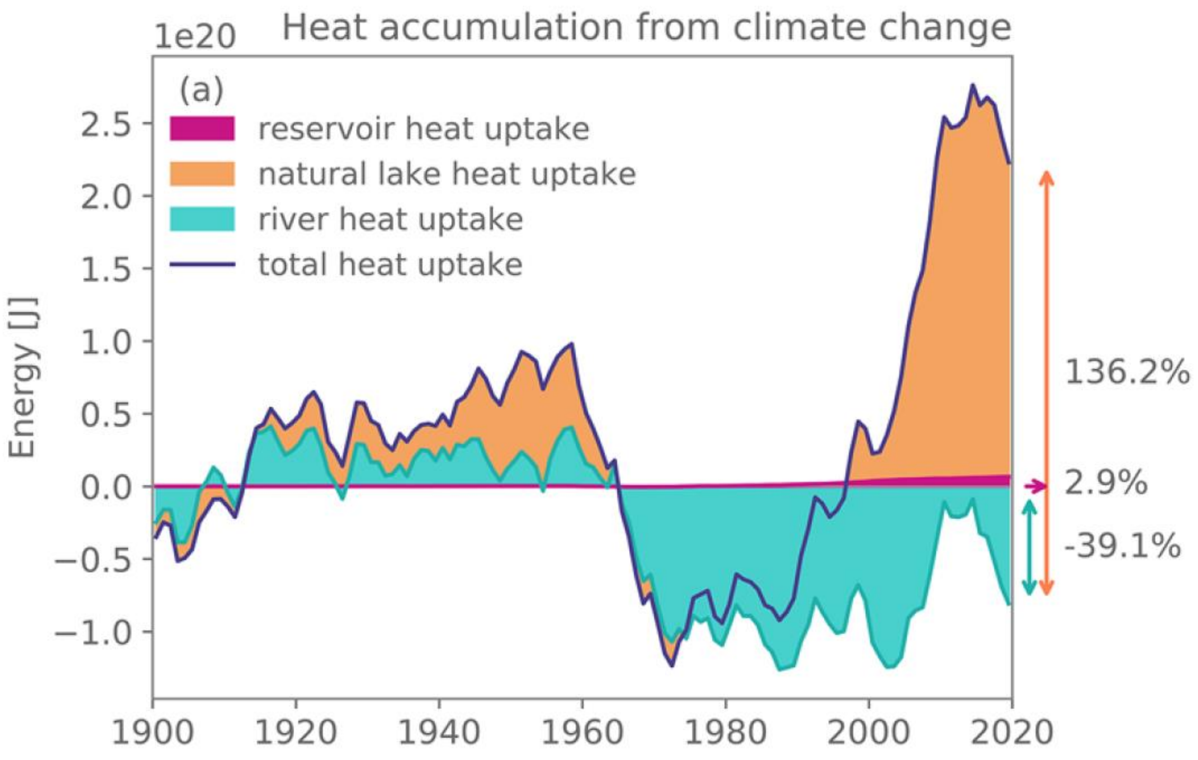


Heat uptake
averaged for 2011-2020,
relative to 1900-1929

	Natural lake	Reservoir	River
Heat uptake	$2.9 \pm 2.0 \times 10^{20}$ J	$5.9 \pm 2.7 \times 10^{18}$ J	$-0.15 \pm 2.3 \times 10^{20}$ J
Heat flux	0.1 ± 0.04 W m^{-2}	0.1 ± 0.04 W m^{-2}	0.05 ± 0.05 W m^{-2}

Heat flux
for 1991-2020

Global heat uptake by inland waters



Total heat uptake $2.57 \pm 3.23 \times 10^{20}$ J

averaged for 2011-2020, relative to 1900-1929

Heat flux 0.09 ± 0.04 W m^{-2}

for 1991-2020

Inland water heat uptake is:

~ 0.08% of oceans

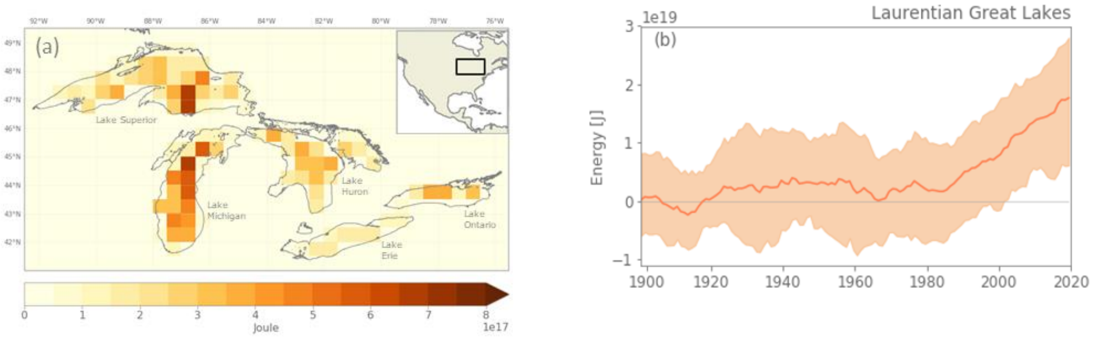
~ 3.1 % of land uptake

inland waters cover 2.58% of land

Regional studies confirm the global picture

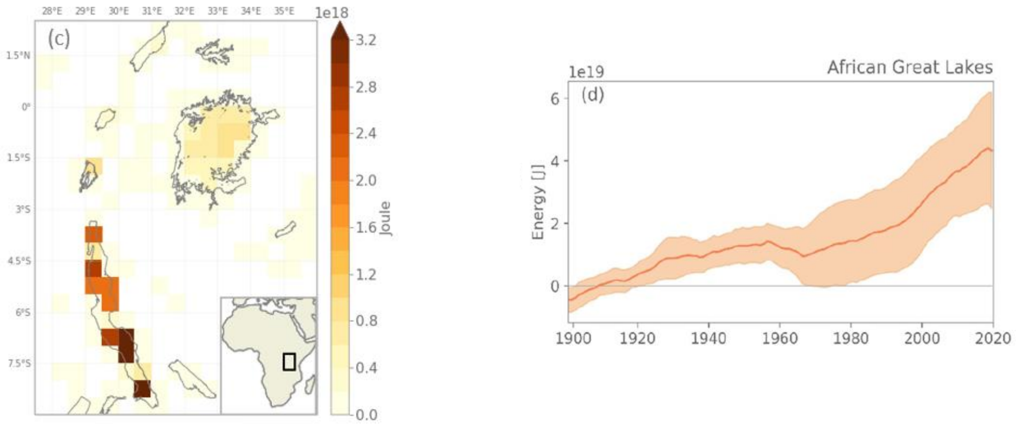
Laurentian Great Lakes

12.4% of global lake volume
5.2 % of global heat uptake



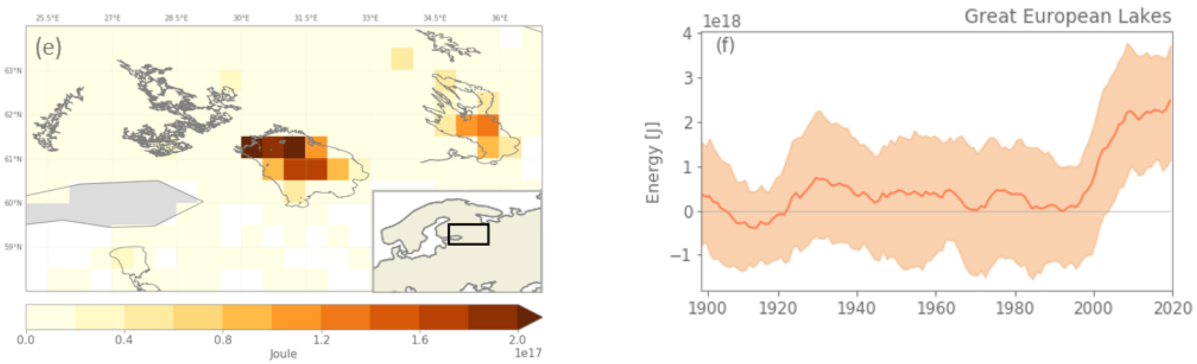
African Great Lakes

12.38% of global lake volume
15.1 % of global heat uptake



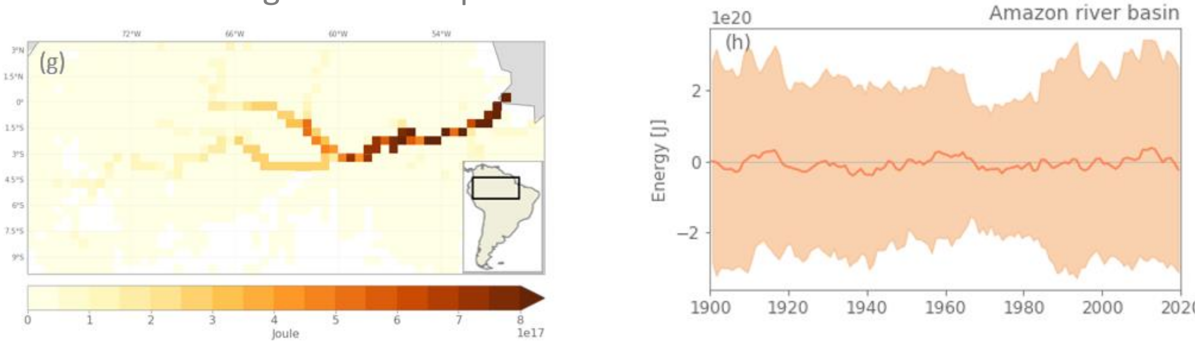
Great European Lakes

0.79% of global heat uptake



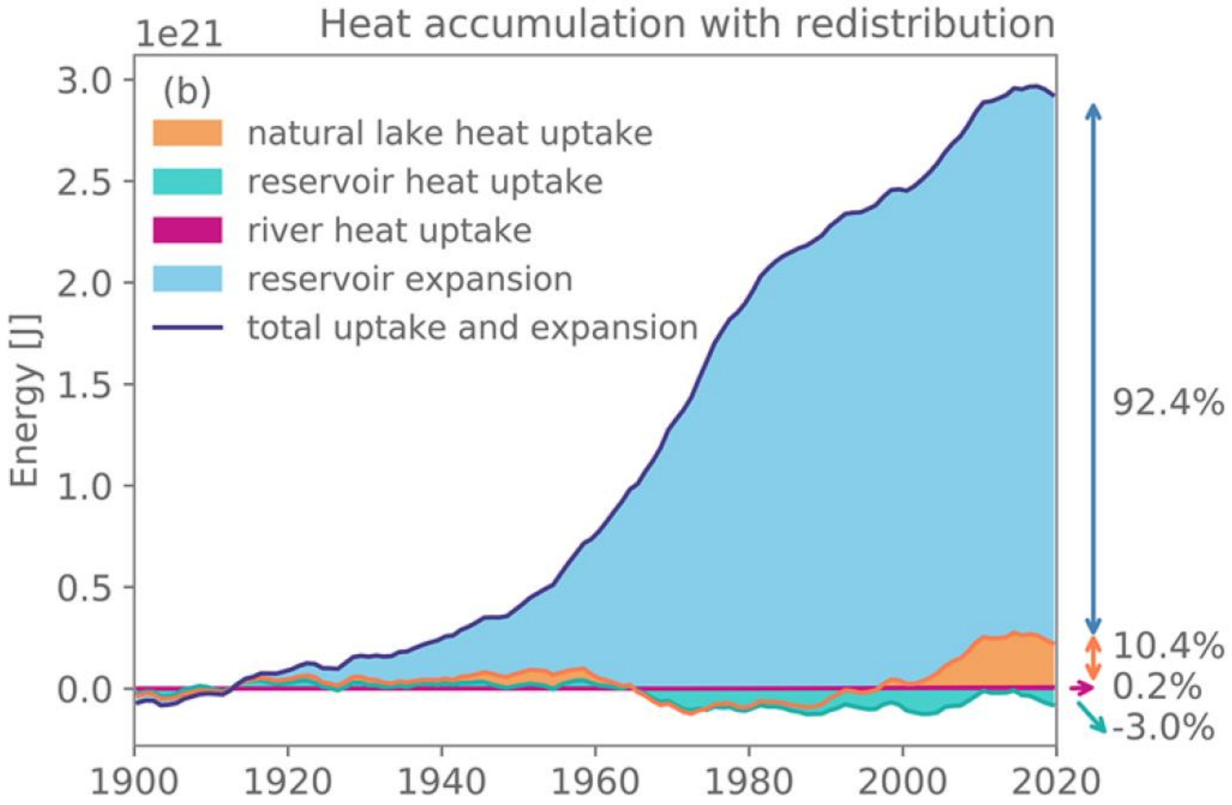
Amazon river:

6.4% of global heat uptake



Reservoir expansion redistributes heat

carried within the water which is stored on land by filling up reservoirs



Total heat redistributed by reservoir expansion:
2.7 +- 2.1 x 10^{20} J

Follows increase in reservoir capacity

Almost 10 times larger than heat uptake by climate change

→ increases potential of storing extra heat on land

Conclusions

Heat uptake by inland waters over the industrial period is 2.8 +- 4.3 x 10^{20} J or 3.1 % of the continental heat uptake.

Quantified for the first time, contribution to IPCC WG1 assessment

Relatively small, but importance of inland waters for buffering atmospheric warming, especially on regional scale.

ISIMIP intersectoral approach allows integration of lake models, hydrological models, and ESMs in the calculation.

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Geophysical Research Letters

RESEARCH LETTER

10.1029/2020GL087867

Global Heat Uptake by Inland Waters

I. Vanderkelen[1], N. P. M. van Lipzig[2], D. M. Lawrence[3], B. Droppers[4], M. Golub[5], S. N. Gosling[6], A. B. G. Janssen[4], R. Marcé[7,8], H. Müller Schmied[9,10], M. Perroud[11], D. Pierson[5], Y. Pokhrel[12], Y. Satoh[13], J. Schewe[14], S. I. Seneviratne[15], V. M. Stepanenko[16,17], Z. Tan[18], R. I. Woolway[19], and W. Thiery[1,15]

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Key Points:
- We use a unique combination of lake models, hydrological models, and Earth System models to quantify global heat uptake by inland waters
- Heat uptake by inland waters over the industrial period amounts up to 2.6×10^{20} J, or 3.6% of the continental heat uptake
- The thermal energy of the water trapped on land due to dam construction (26.8×10^{20} J) is 10.4 times larger than inland water heat uptake

Supporting Information:
- Supporting Information S1

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THANK YOU

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Picture: Glen Canyon Dam Adaptive Management Program

Additional slides

Total heat uptake and Trend for the different inland water components

	Heat uptake	Heat flux (1991–2020)	Trend (1991–2020)
Natural lakes	$2.87 \pm 2.01 \times 10^{20}$ J	0.1 ± 0.04 W m^{-1}	10.2×10^{18} J yr^{-1}
Reservoirs	$0.06 \pm 0.03 \times 10^{20}$ J	0.02 ± 0.001W m^{-1}	0.2×10^{18}J yr^{-1}
Rivers	$-0.36 \pm 1.20 \times 10^{20}$ J	0.05 ± 0.05W m^{-1}	2.7×10^{18}J yr^{-1}
Total heat uptake	$2.57 \pm 3.23 \times 10^{20}$ J	0.09 ± 0.04W m^{-1}	13.1×10^{18}J yr^{-1}
Redistribution by reservoir expansion	$26.76 \pm 2.13 \times 10^{20}$ J	0.52 ± 0.30W m^{-1}	15.2×10^{18}J yr^{-1}

Heat uptake is averaged for 2011-2020 relative to 1900-1929

Observed and modeled heat uptake per lake

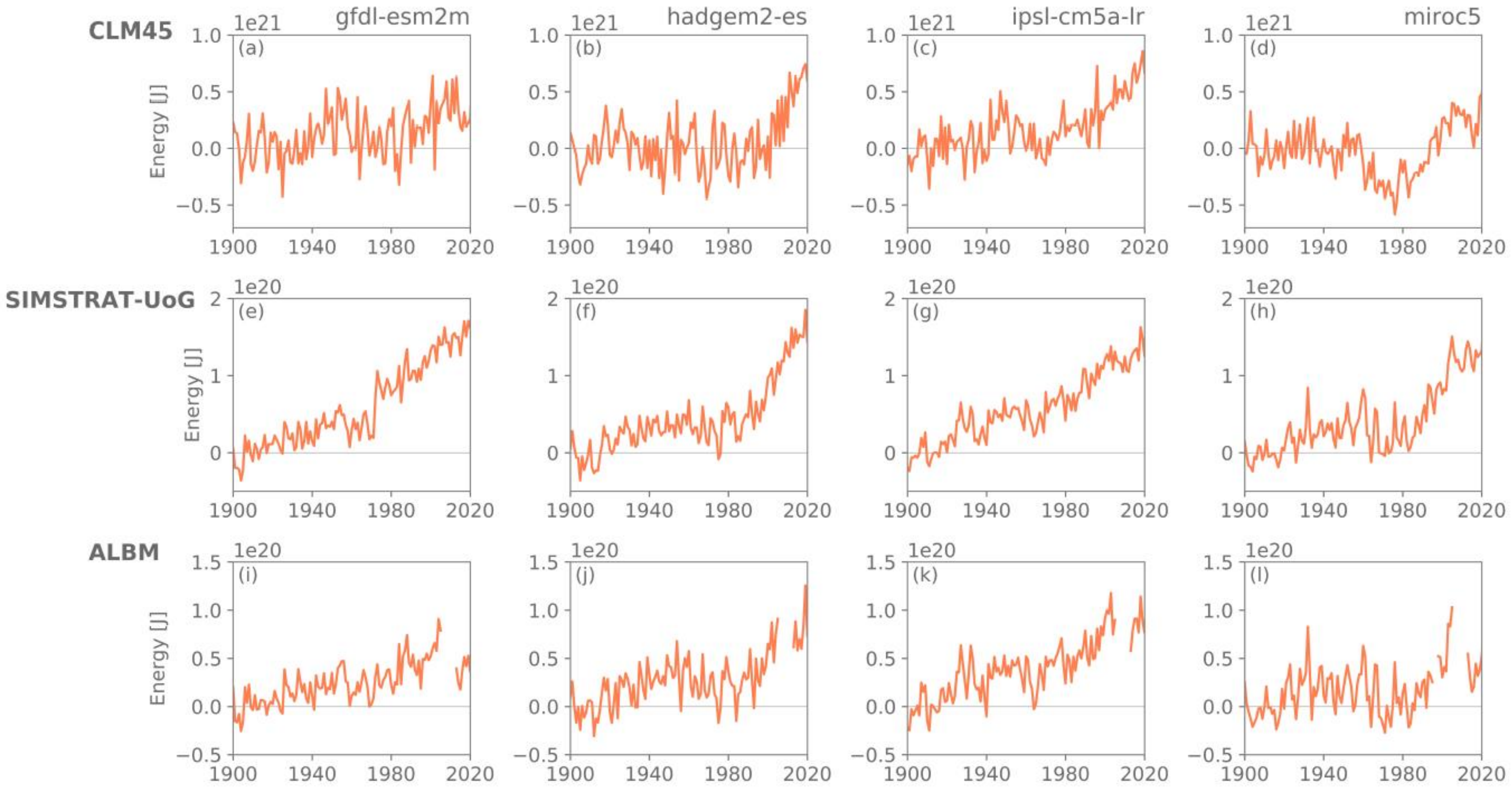
Lake name	Period	Observed $[Wm^{-2}]$	Modeled $[Wm^{-2}]$
Allequash Lake	1981-2014	0.003	0.003 ± 0.0002
Big Muskellunge Lake	1981-2008	0.039	0.001 ± 0.0002
Crystal Lake	1981-2007	-0.018	0.004 ± 0.0014
Lake Mendota	1995-2014	-0.096	0.001 ± 0.0007
Lake Monona	1995-2014	-0.156	0.001 ± 0.0007
Sparkling Lake	1981-2014	0.223	0.003 ± 0.0002
Toolik Lake	1998-2014	0.635	0.006 ± 0.0015
Trout Lake	1981-2014	0.136	0.003 ± 0.0002
Lake Wingra	2001-2014	-0.039	0.001 ± 0.0007

Differences could be attributed to:

- Uncalibrated global models
- Use of representative lakes
- ESM forcing provide climatology, not observed atm forcing
- Structural model deficiencies
- Vertical resolution of sampling profile (different for all lakes)

Observations from LTER Network, 9 lakes in Wisconsin, USA.

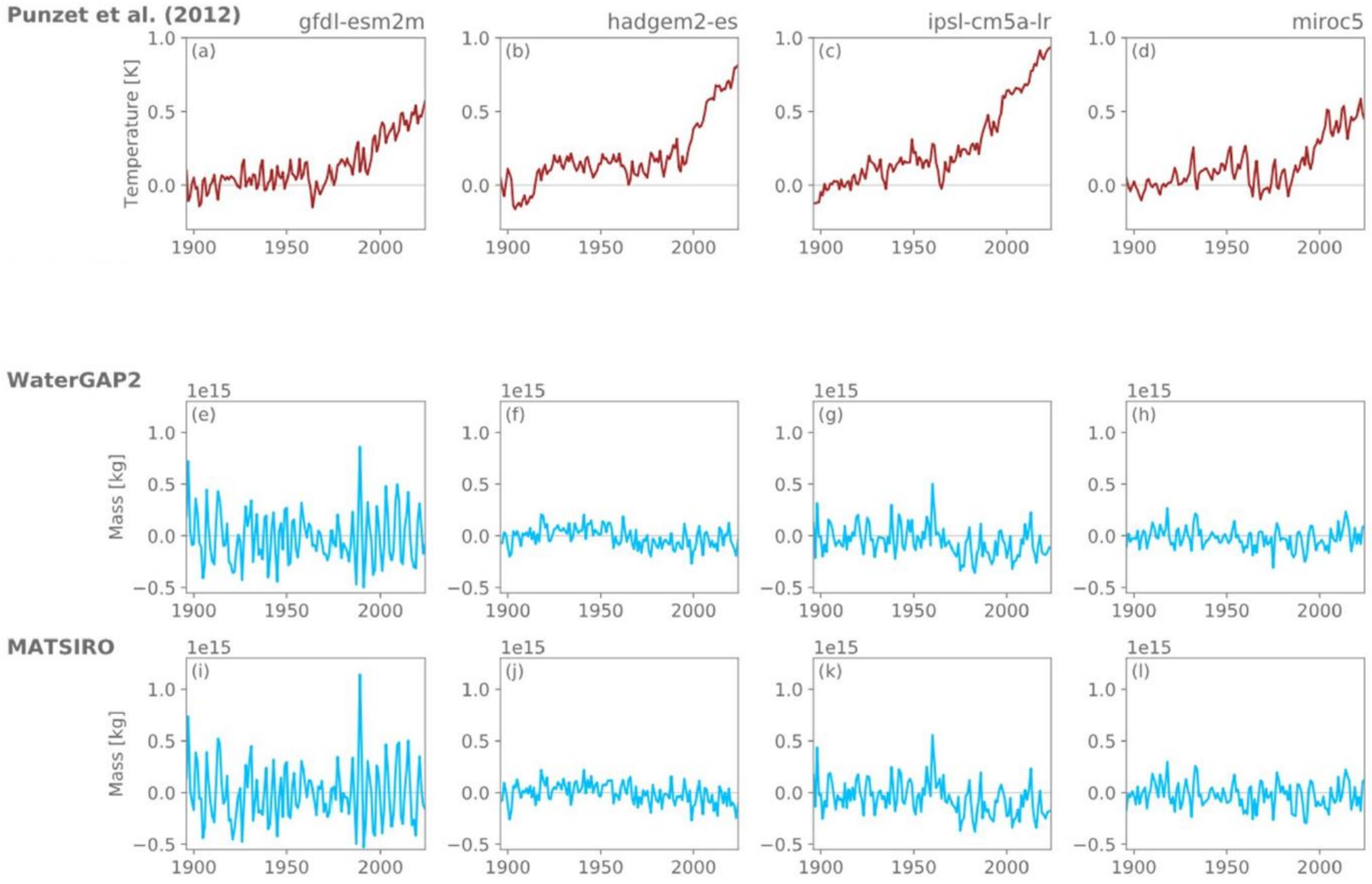
Lake heat uptake per model and ESM forcing



River temperature and storage per model and ESM forcing

River temperature

River storage



River heat uptake per model and GCM forcing

River heat uptake