VRIJE UNIVERSITEIT BRUSSEL

Fonds Wetenschappelijk Onderzoek Vlaanderen
Opening new horizons

Global heat uptake by inland waters

Inne Vanderkelen

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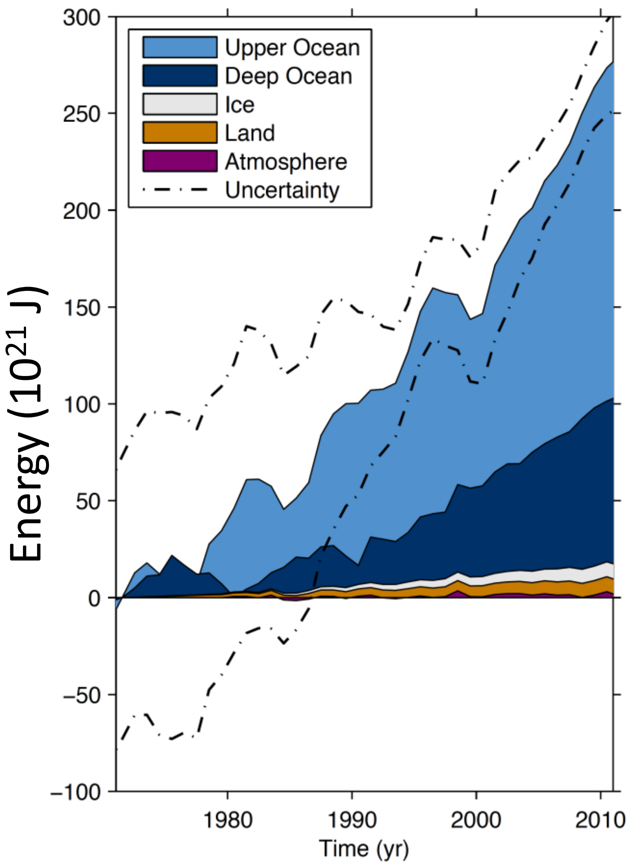
Excess heat is taken up by the Earth system

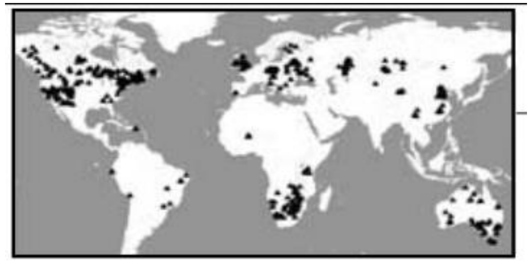


IPCC AR5, Box 3.1

Oceans	~93%
Ice	~4%
Land and atmosphere	~3%

Von Schuckmann et al., 2016

Continental uptake from borehole measurements



Beltrami et al., 2002

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

Inland waters include

Lakes

Reservoirs

Rivers

Wetlands and floodplains are not taken into the analysis, because of limited global data availability

Data and methods
River heat content

Simulations of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) 2b

1900 – 2017: historical and RCP 6.0, 0.5 x 0.5° resolution

ISIMIP Inter-Sectoral Impact Model Intercomparison Project

https://www.isimip.org/

River storage

2 global hydrological models

WaterGAP2 and MATSIRO

forced by

Climate forcing

4 Earth system models

GFDL-ESM-2M, MIROC5, HadGEM2-ES, IPSL-CM5A-LR

River heat calculation

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

Q_{river} [J] (annual river heat content per grid cell)

c_{liq} = 4188 J kg-1 K-1 (constant; specific heat capacity of liquid water)
m_{river} [m-2] (river storage; given by the global hydrological models)
ρ_{liq} = 1000 kg m-3 (constant; density of liquid water)
T_{river} [K] (river temperature based on regression approach)

River temperatures

using regression approach with T_{air} from GCMs

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

Regression of Punzet et al (2012)

Data and methods

Lake and reservoir heat content

Simulations of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) 2b

1900 – 2017: historical and RCP 6.0, 0.5 x 0.5° resolution

https://www.isimip.org/

Water temperatures

2 global lake models

CLM4.5, SIMSTRAT-UoG

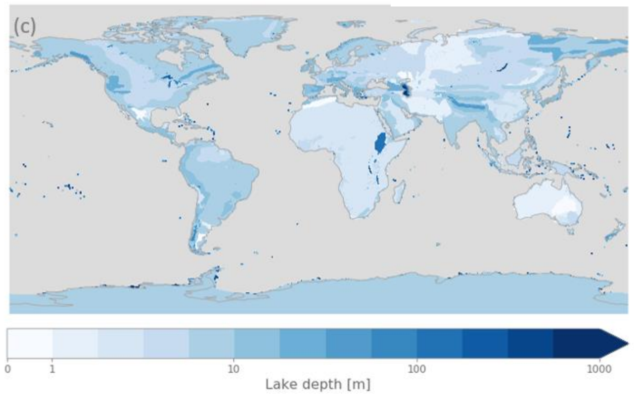
forced by

Climate forcing

4 Earth system models

GFDL-ESM-2M, MIROC5, HadGEM2-ES, IPSL-CM5A-LR

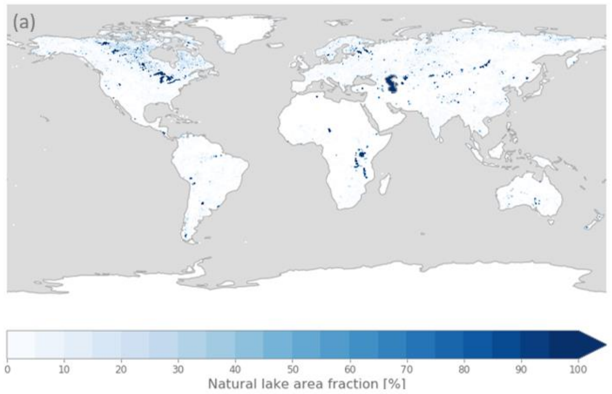
Lake depth



Global Lake Database

Choulga et al., 2019

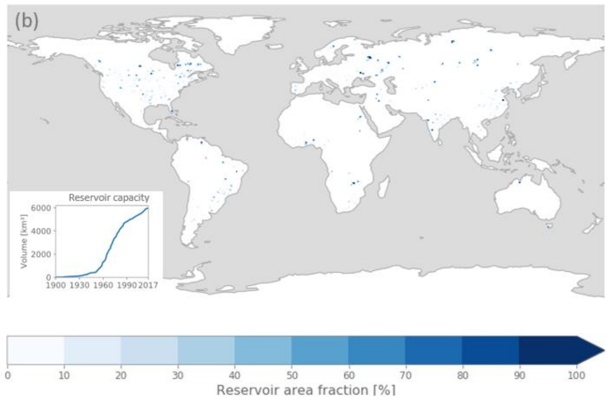
Natural lakes



HydroLAKES

Messager et al., 2016

Reservoirs



Global Reservoir and Dam database

Lehner et al., 2011

Data and methods
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)

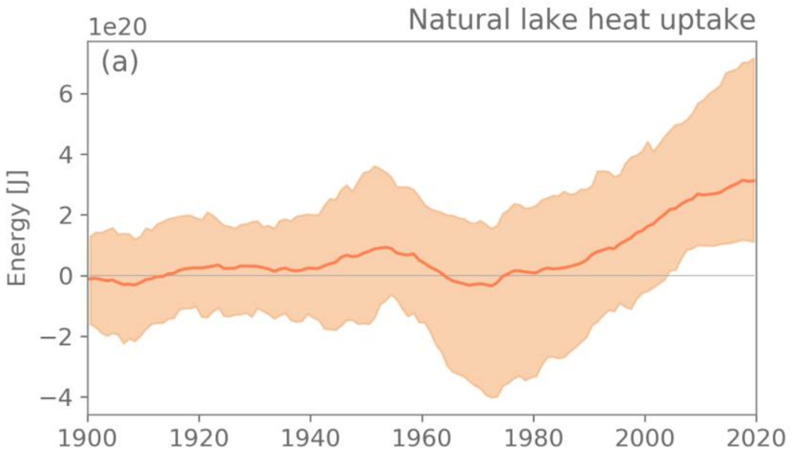
c_{liq} = 4188 J kg-1 K-1 (constant; specific heat capacity of liquid water)
A_{lake} [m-2] (lake area; given by HydroLAKES and GRanD*)
ρ_{liq} = 1000 kg m-3 (constant; density of liquid water)
T_n [K] (water temperature of the lake layer, given by the lake models)
d_n [m] (depth of the lake layer, scaled against lake depth of GLDB)

* Reservoirs are defined to appear in their year of construction (from GRanD).

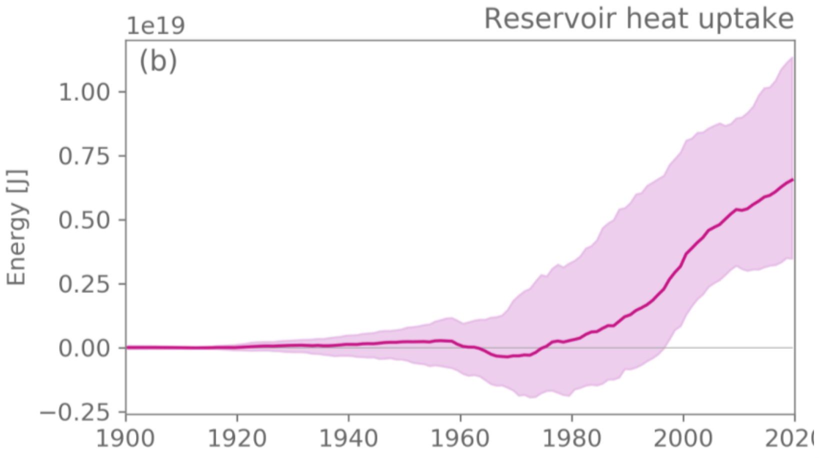
Global heat uptake by inland waters

Average heat uptake for 2011-2020, relative to 1900-1929

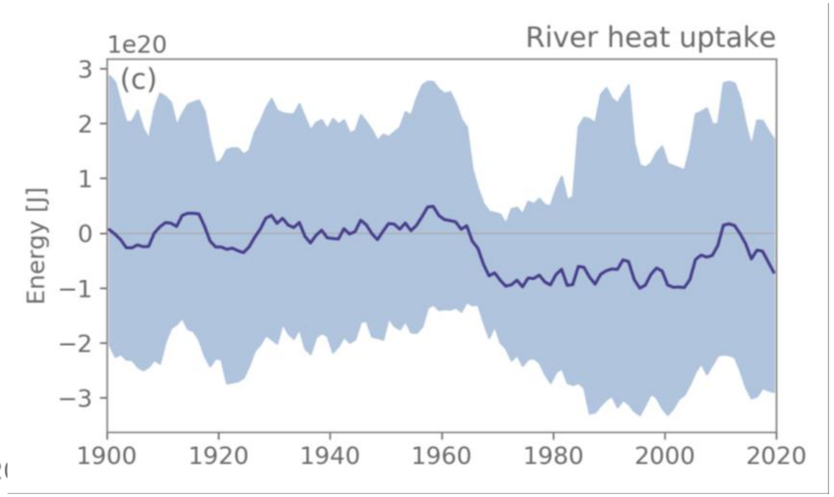
$2.9 \pm 2.0 \times 10^{20}$ J



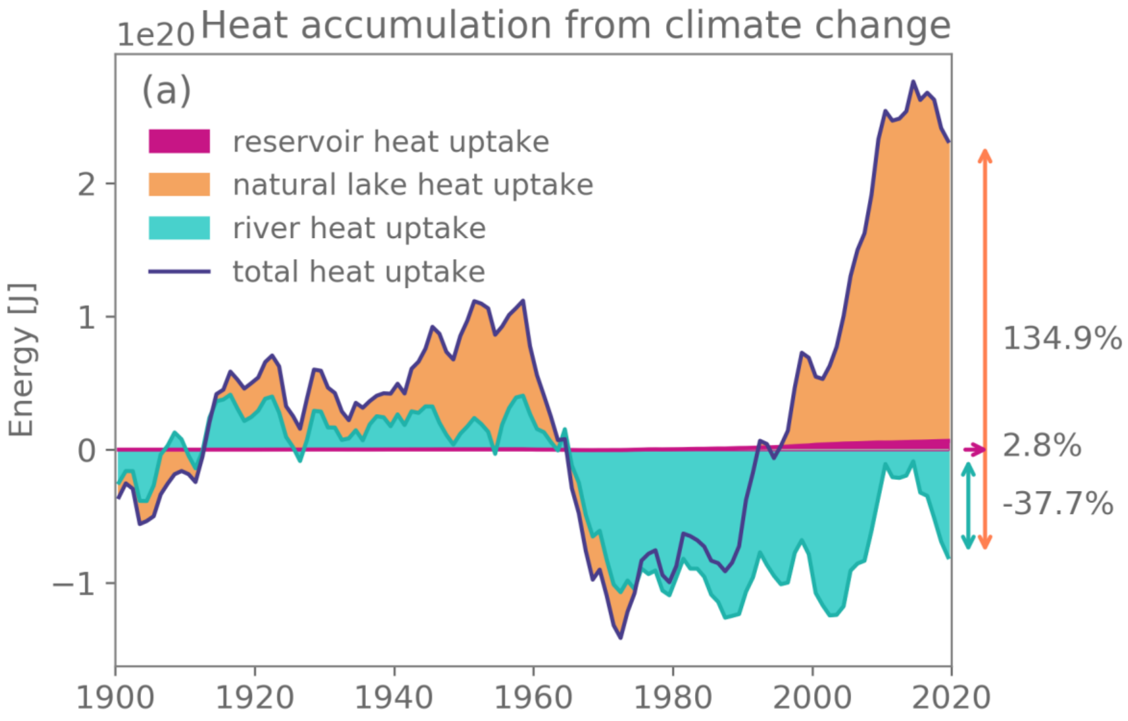
$5.9 \pm 2.7 \times 10^{18}$ J



$-0.15 \pm 2.3 \times 10^{20}$ J



Global heat uptake by inland waters



Total heat uptake by climate change:
2.8 +- 4.3 x 10^{20} J

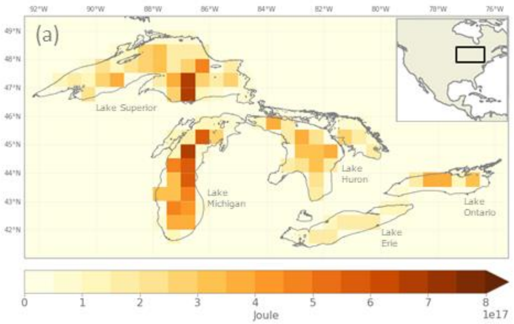
Inland water heat uptake is:
~ 0.08% of oceans
~ 3.1 % of land uptake *
inland waters cover 2.58% of land

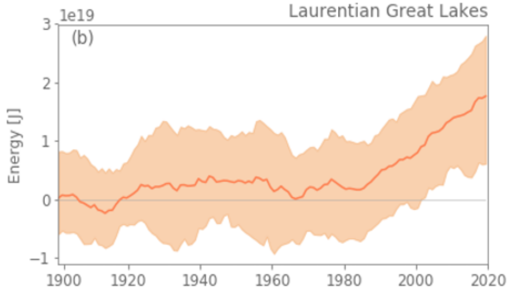
* Compared to estimations of land heat uptake for 1950-2000 of Beltrami, 2002

Regional studies confirm the global picture

Laurentian Great Lakes

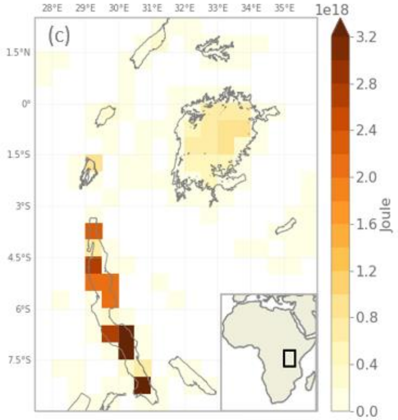
12.4% of global lake volume
5.2 % of global heat uptake

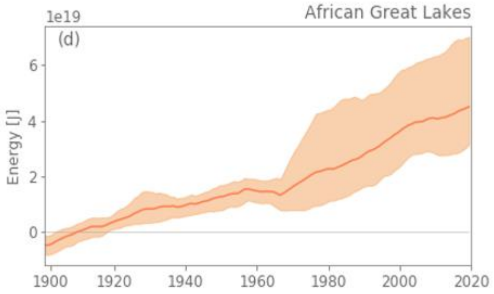




African Great Lakes

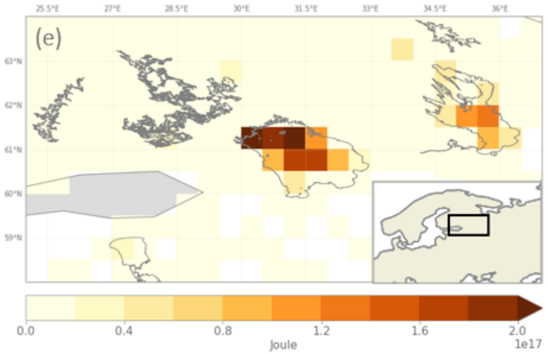
12.38% of global lake volume
15.1 % of global heat uptake

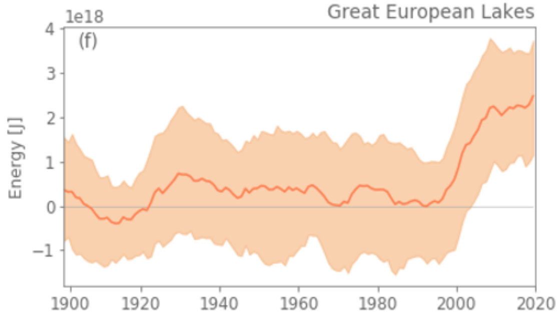




Great European Lakes

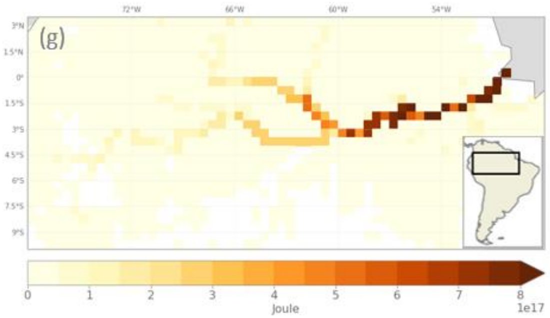
0.79% of global heat uptake

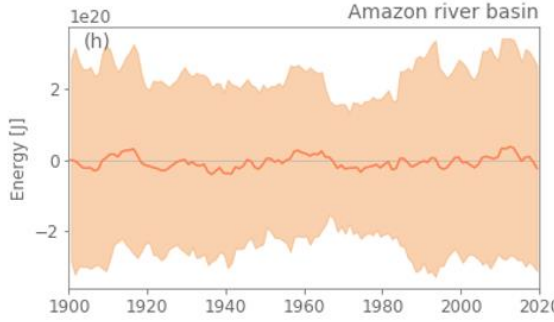




Amazon river:

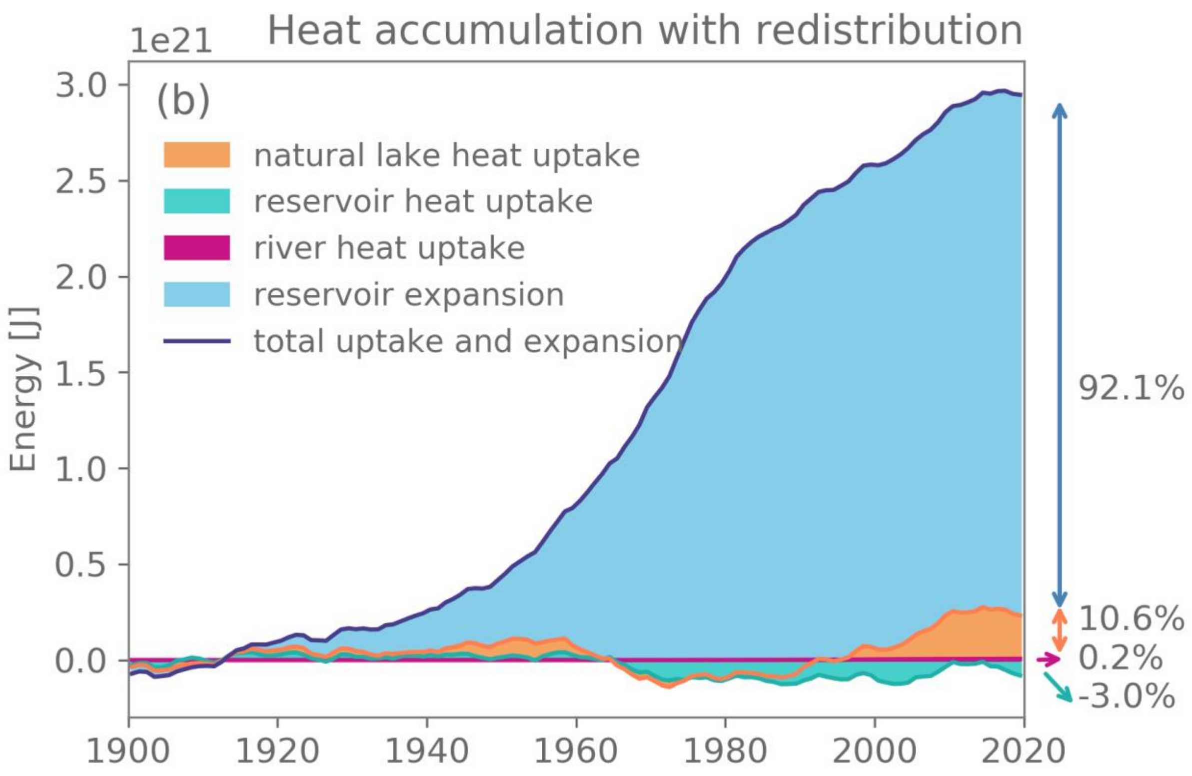
6.4% of global heat uptake





Reservoir expansion redistributes heat

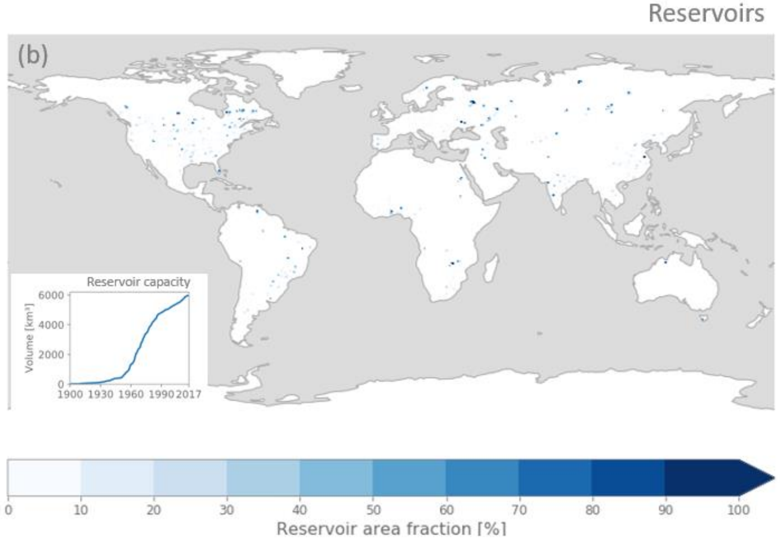
carried within the water which is stored on land by filling up reservoirs



Total heat redistributed by reservoir expansion:
$2.7 \pm 2.1 \times 10^{20}$ J

Follows increase in reservoir capacity

Almost **10 times larger** than heat uptake by climate change



Discussion

Negative heat uptake by rivers could be attributed to a decrease in water stored in rivers, but uncertainties are large (see back-up slides).

Heat redistribution by reservoirs:

→ increases potential of storing extra heat on land

→ could have important effects locally

Dampening temperatures, altering precipitation, …

Opportunities for refining the estimations

Lake hypsometry and variations in volume

Variations in specific heat capacity (ice)

Conclusions

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 2.8 +- 4.3 x 10^{20} J or 3.1 % of the continental heat uptake.

The thermal energy of the water trapped on land due to dam construction (2.7 +- 2.1 x 10^{20} J) is ~9.6 times larger than inland water heat uptake.

This study is under review in Geophysical Research Letters:

Vanderkelen I., van Lipzig N.P.M., Lawrence D. M., Bram Droppers B., Gosling S. N., Janssen A. B. G., Marcé R., Müller-Schmied H., Perroud M., Pierson D., Pokhrel Y., Satoh Y., Schewe J., Seneviratne S. I., Stepanenko V. M., Woolway R. I.,Thiery W. (2020) Global heat uptake by inland waters. Geographical Research Letters, in review.

Extra material

Overview of heat uptake and trends

	Heat uptake	Trend (1991-2020)
Natural lakes	$2.9 \pm 2.0\text{x}10^{20}$ J	$8.1\text{x}10^{18}$ J yr^{-1}
Reservoirs	$5.9 \pm 2.7\text{x}10^{18}$ J	$1.8\text{x}10^{17}$ J yr^{-1}
Rivers	$-0.15 \pm 2.3\text{x}10^{20}$ J	$-1.9\text{x}10^{17}$ J yr^{-1}
Uptake by climate change	$2.8 \pm 4.3\text{x}10^{20}$J	$8.1\text{x}10^{18}$ J yr^{-1}
Redistribution by reservoir expansion	$27 \pm 2.1\text{x}10^{20}$J	$1.0\text{x}10^{19}$ J yr^{-1}

* Average heat uptake in 2011-2020 relative to 1900-1929

Overview of ISIMIP2b impact models used in the study

Table 1. Overview of ISIMIP2b impact models used in this study.

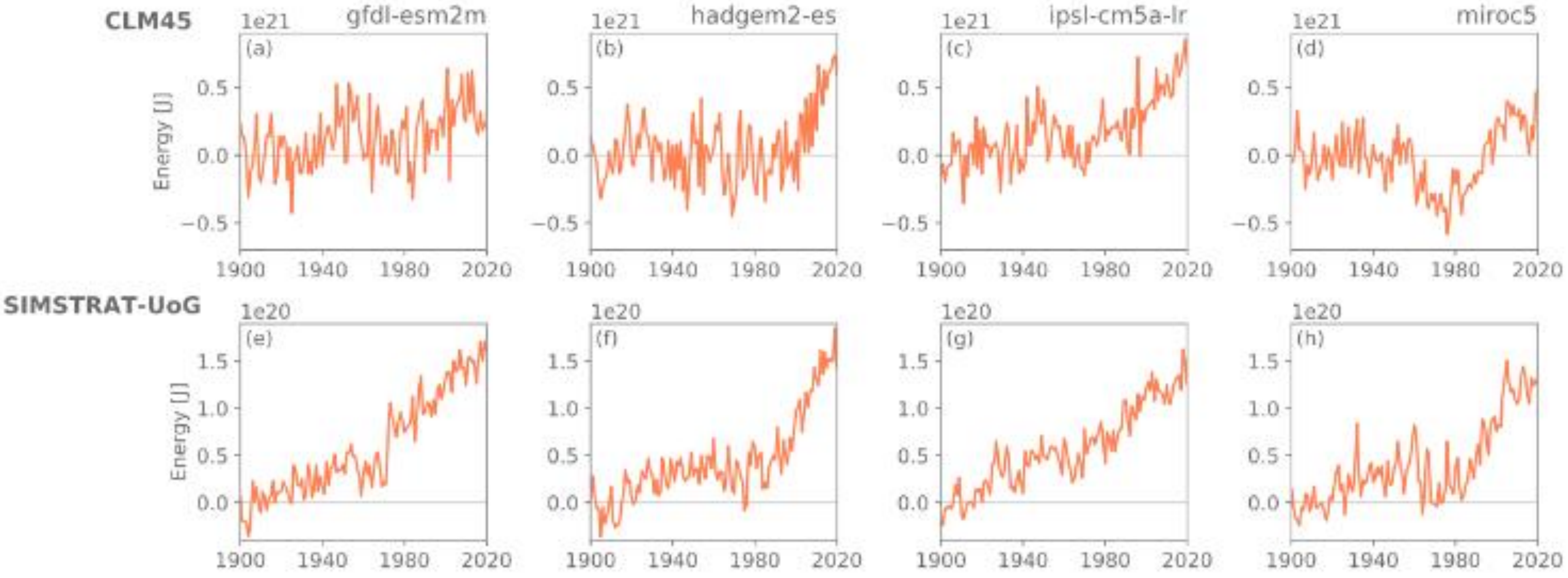
Lake models	# layers	Lake depth	Reference
CLM4.5	10	Constant at 50 m	Subin et al. (2012); Oleson et al. (2013)
SIMSTRAT-UoG	1 - 13	GLDB	Goudsmit et al. (2002)

Hydrological models	Human influences	Reference
MATSIRO	No human influences	N. Y. Pokhrel et al. (2015)
WaterGAP2	Historical human influences	Müller Schmied et al. (2016)

* More ISIMIP lake models will be added when simulations become available

Lake heat uptake per model and GCM forcing

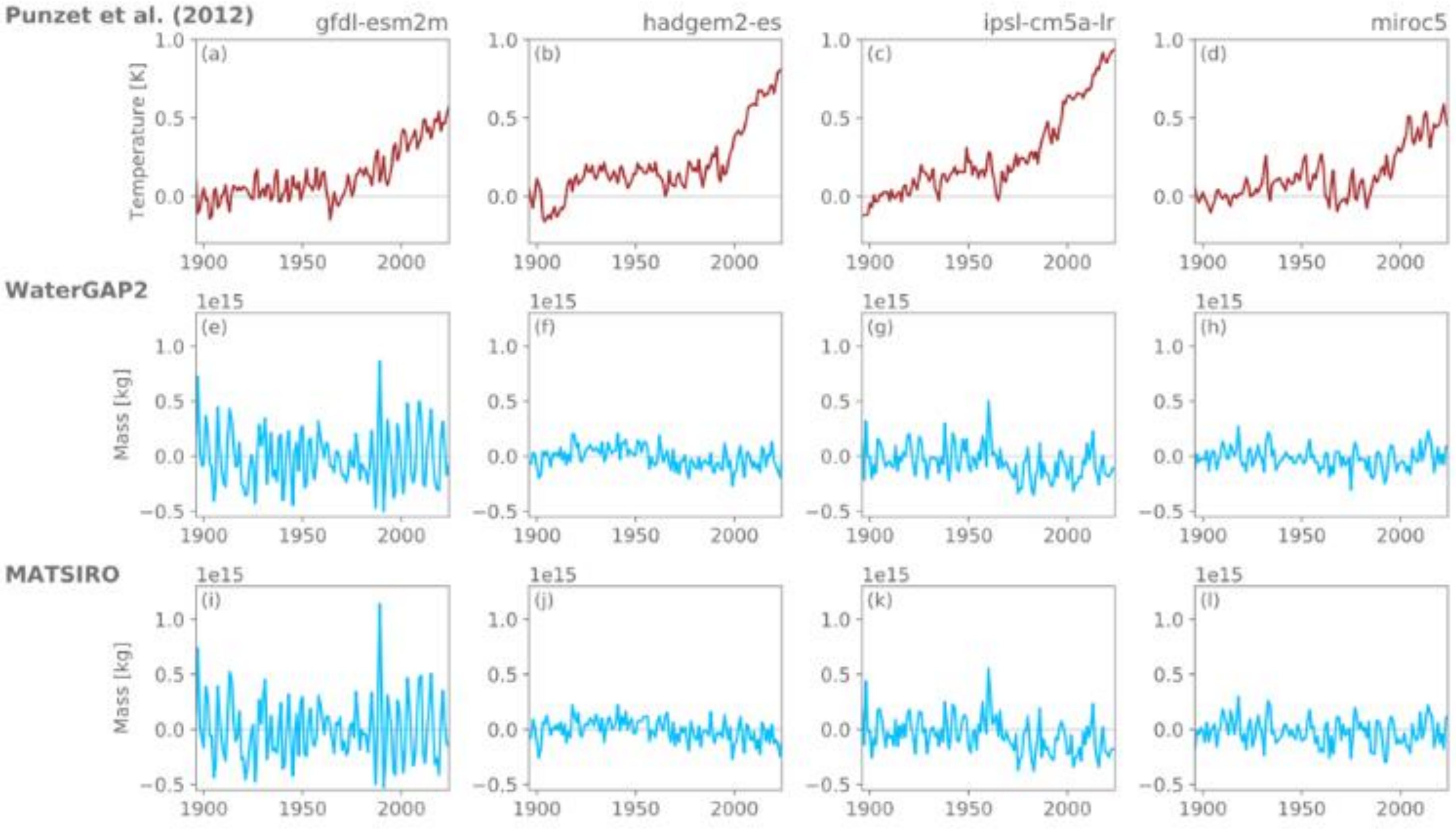
Lake heat uptake



Terms in the river heat calculation per model and forcing

River temperature

River storage



River heat uptake per model and GCM forcing

River heat uptake