Global heat uptake by inland waters

Inne Vanderkelen

Excess heat is taken up by the Earth system

- 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

River storage
2 global hydrological models
WaterGAP2 and MATSIRO

Climate forcing
4 Earth system models
GFDL-ESM-2M, MIROC5, HadGEM2-ES, IPSL-CM5A-LR

River heat calculation

\[ Q_{\text{river}} = c_{\text{liq}} \cdot m_{\text{river}} \cdot \rho_{\text{liq}} \cdot T_{\text{river}} \]

- \( Q_{\text{river}} \) [J] (annual river heat content per grid cell)
- \( c_{\text{liq}} = 4188 \) J kg\(^{-1}\) K\(^{-1}\) (constant; specific heat capacity of liquid water)
- \( m_{\text{river}} \) [m\(^{-2}\)] (river storage; given by the global hydrological models)
- \( \rho_{\text{liq}} = 1000 \) kg m\(^{-3}\) (constant; density of liquid water)
- \( T_{\text{river}} \) [K] (river temperature based on regression approach)

River temperatures
using regression approach with \( T_{\text{air}} \) from GCMs

\[ T_{\text{water}} = C_0 \left[ 1 + e^{(C_1 T_{\text{air}} + C_2)} \right] \]

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

Water temperatures
2 global lake models
CLM4.5, SIMSTRAT-UoG

Climate forcing
4 Earth system models
GFDL-ESM-2M, MIROC5, HadGEM2-ES, IPSL-CM5A-LR

Water temperatures
Climate forcing

Lake and reservoir heat content

Global Lake Database
Choulga et al., 2019

HydroLAKES
Messager et al., 2016

Global Reservoir and Dam database
Lehner et al., 2011
Data and methods
Lake and reservoir heat content

\[
Q_{\text{lake}} = c_{\text{liq}} A_{\text{lake}} \rho_{\text{liq}} \sum_{n=1}^{n=\text{nlayers}} T_n d_n
\]

\(Q_{\text{lake}}\) [J] (Annual lake heat content per grid cell)

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

\(A_{\text{lake}}\) [m\(^{-2}\)] (lake area; given by HydroLAKES and GRanD*)

\(\rho_{\text{liq}} = 1000\) 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 x $10^{20}$ J

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

-0.15 $\pm$ 2.3 x $10^{20}$ J
Global heat uptake by inland waters

Total heat uptake by climate change:
\[ 2.8 \pm 4.3 \times 10^{20} \text{ J} \]

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 $2.8 \pm 4.3 \times 10^{20}$ J or 3.1 % of the continental heat uptake.

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

This study is under review in Geophysical Research Letters:
Extra material
Overview of heat uptake and trends

<table>
<thead>
<tr>
<th></th>
<th>Heat uptake</th>
<th>Trend (1991-2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural lakes</td>
<td>$2.9 \pm 2.0 \times 10^{20}$ J</td>
<td>$8.1 \times 10^{18}$ J yr$^{-1}$</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>$5.9 \pm 2.7 \times 10^{18}$ J</td>
<td>$1.8 \times 10^{17}$ J yr$^{-1}$</td>
</tr>
<tr>
<td>Rivers</td>
<td>$-0.15 \pm 2.3 \times 10^{20}$ J</td>
<td>$-1.9 \times 10^{17}$ J yr$^{-1}$</td>
</tr>
<tr>
<td>Uptake by climate change</td>
<td>$2.8 \pm 4.3 \times 10^{20}$ J</td>
<td>$8.1 \times 10^{18}$ J yr$^{-1}$</td>
</tr>
<tr>
<td>Redistribution by reservoir expansion</td>
<td>$27 \pm 2.1 \times 10^{20}$ J</td>
<td>$1.0 \times 10^{19}$ J yr$^{-1}$</td>
</tr>
</tbody>
</table>

* 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.

<table>
<thead>
<tr>
<th>Lake models</th>
<th># layers</th>
<th>Lake depth</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>CLM4.5</td>
<td>10</td>
<td>Constant at 50 m</td>
<td>Subin et al. (2012); Oleson et al. (2013)</td>
</tr>
<tr>
<td>SIMSTRAT-UoG</td>
<td>1 - 13</td>
<td>GLDB</td>
<td>Goudsmit et al. (2002)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrological models</th>
<th>Human influences</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATSIRO</td>
<td>No human influences</td>
<td>N. Y. Pokhrel et al. (2015)</td>
</tr>
<tr>
<td>WaterGAP2</td>
<td>Historical human influences</td>
<td>Müller Schmied et al. (2016)</td>
</tr>
</tbody>
</table>

* More ISIMIP lake models will be added when simulations become available
Lake heat uptake per model and GCM forcing
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