Changing Storage: Towards dams and reservoirs in Earth System Models

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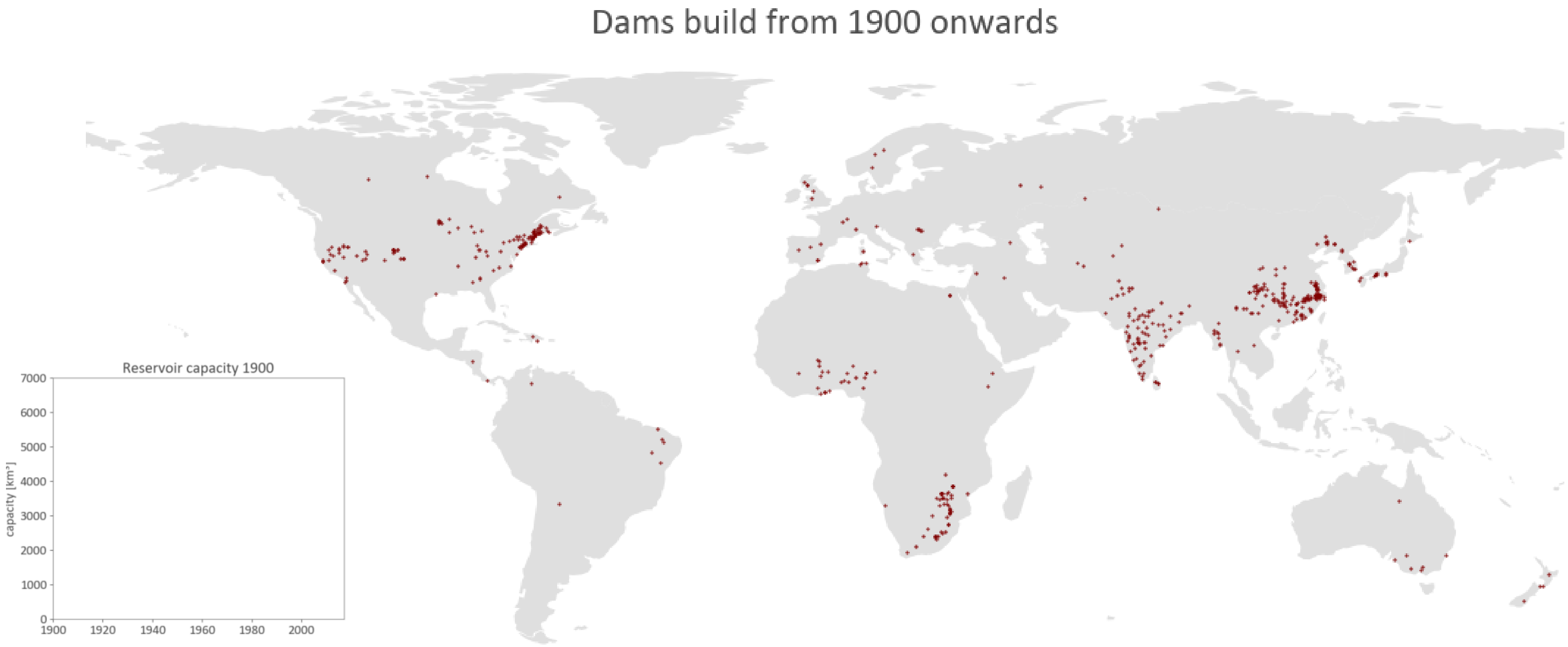
Collaborators:
Wim Thiery, Nicole van Lipzig, Ann van Griensven, Dave Lawrence, Bill Sacks, Martyn Clark, Shervan Gharari, Yadu Pokhrel, Naoki Mizukami, Sean Swenson, Naota Hanasaki, and many more!

Dam construction lead to the creation of a new open-water body, a reservoir

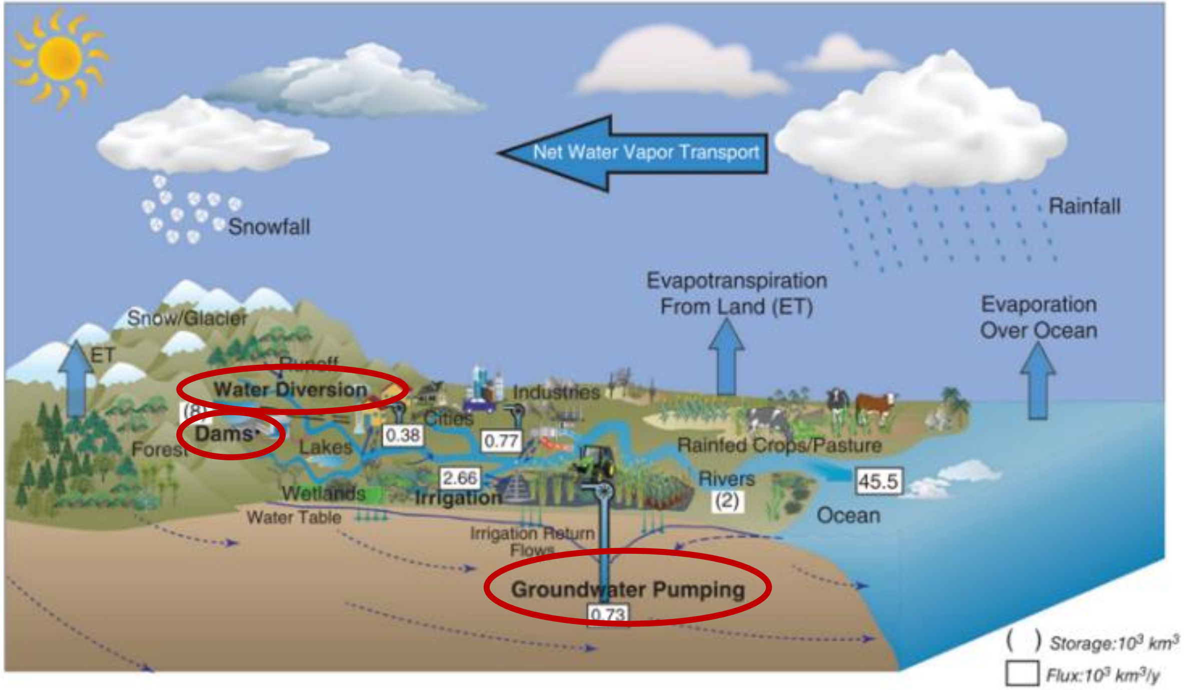
Since the 20th century, humans build 50 000 large dams worldwide

Representing 0.2 % of global land area, and 7% of total lake area



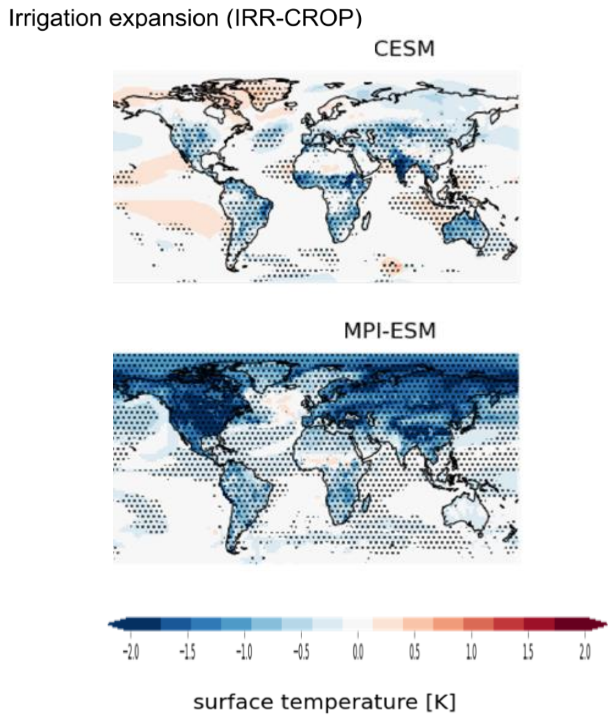
Humans directly interfere with the terrestrial water cycle

But Earth System models barely account for this…

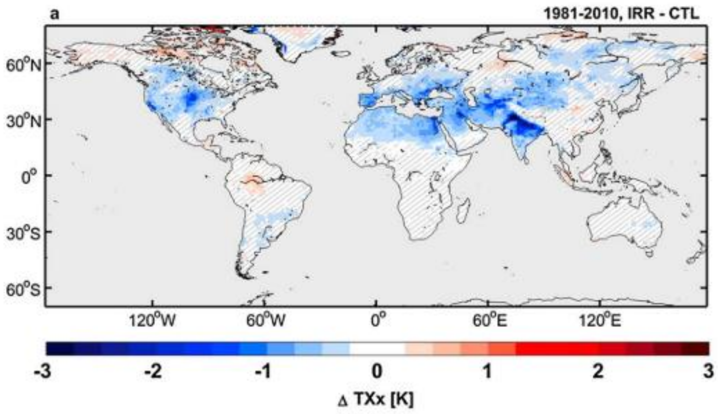


Pokhrel et al. 2016

Water management and land-atmosphere interactions: irrigation



De Hertog et al., in review, Earth System Dynamics Discussions



Thiery et al., 2017, JGR

What is the impact of reservoirs on the climate?
How can we represent reservoirs in CESM?

Representing reservoirs in Earth system models

Look at dam parametrizations in global hydrological models

Impact models

Detailed, specialized and process-based

Water management and catchment models

Observation-based storage and release policies

Global hydrological models

Generic dam parametrisations

Earth System Models

Holistic, coupled framework

Community Earth System Model (CESM)

Solving processes and feedbacks of atmosphere, ocean, land, ice and biosphere

Community Terrestrial Systems Model (CTSM)

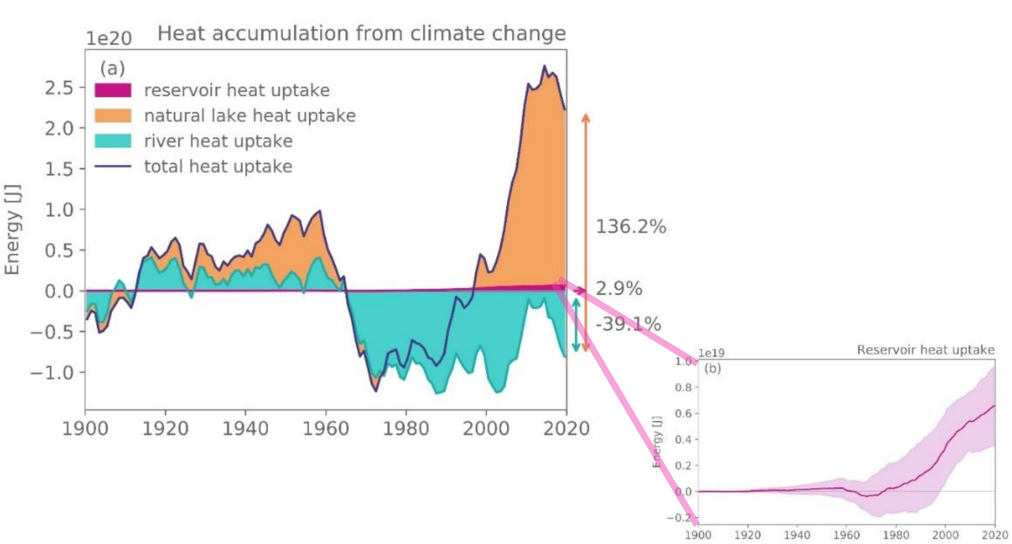
Land component, processes on terrestrial ecosystems and hydrology

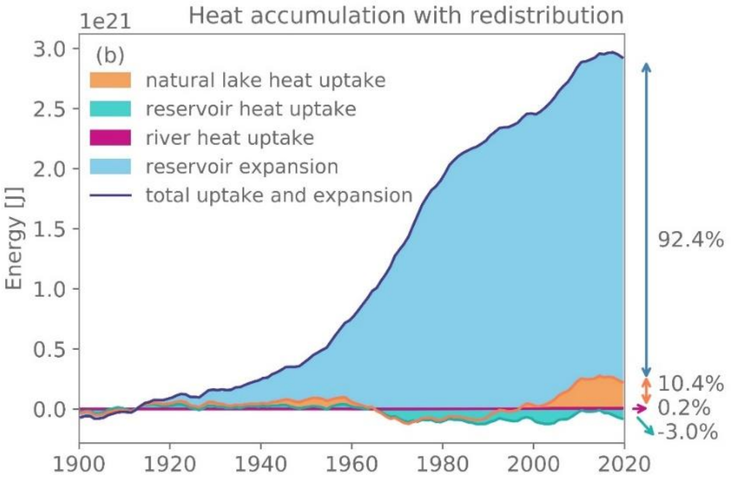
MizuRoute

Global routing model, transports water to the ocean through rivers and lakes

Heat uptake by inland waters: lakes, rivers and reservoirs

In addition, heat is redistributed through reservoir construction





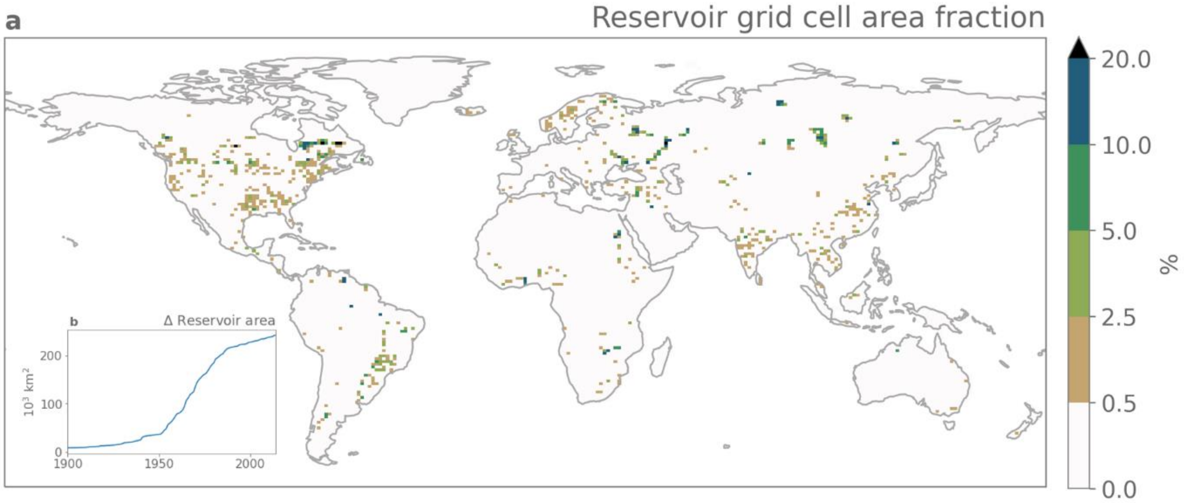
Total inland water heat uptake is **2.57 ± 3.23 x 10^{20} J**:
~ 3.6 % of land uptake

Heat redistribution by reservoir expansion: **26.8 ± 2.1 x 10^{20} J**
Exceeding heat uptake by climate change by factor ~10.4

Vanderkelen et al. 2020, GRL

An updated lake mask for CTSM

Based on HydroLAKES and GRanD

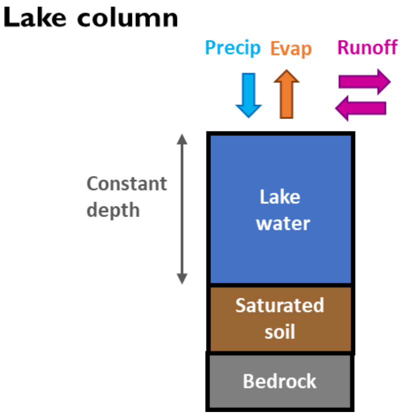


Developments implemented in source code, dataset will be available in CTSM5.2 tag

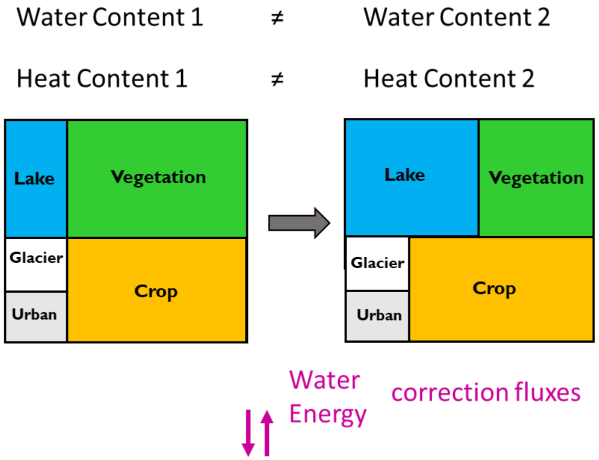
Vanderkelen et al. 2021, JGR

Implementation of reservoir expansion in CTSM
Dynamically growing lake fraction in the grid cell

In CTSM lakes are simulated with a constant depth



Reservoir expansion as growing lake fraction in the grid cell

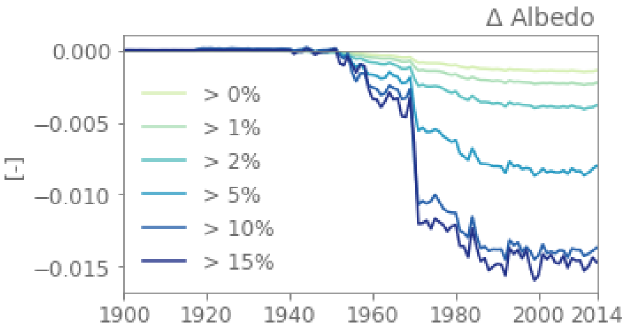


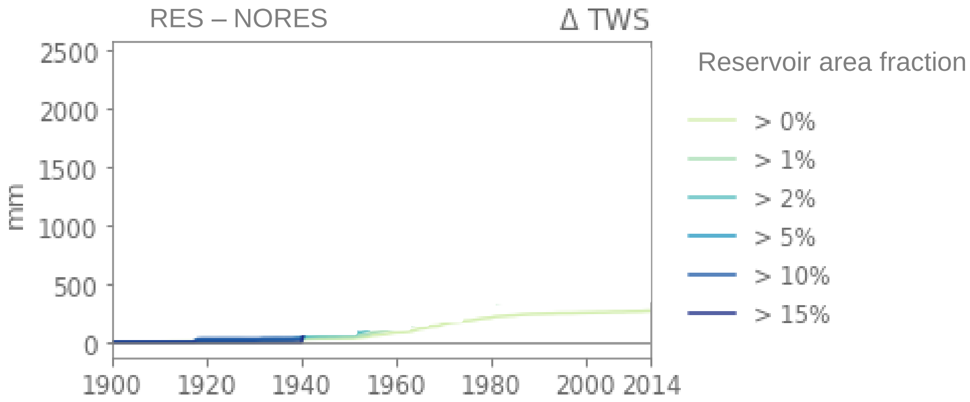
Correction fluxes are minimized with a baseline approach

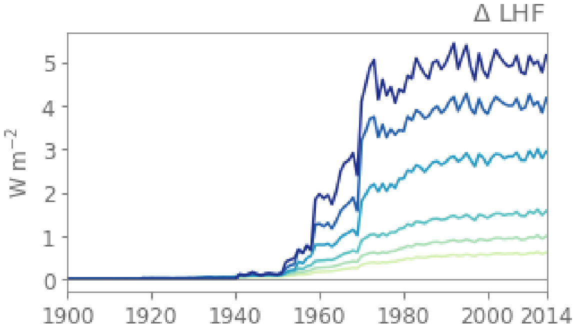
Vanderkelen et al. 2021, JGR

Land only experiments: impact of transient reservoir expansion

Land only
-1900-2014, 0.9° by 1.25°
- CLM5SP driven by GSWP3
- RES: transient reservoirs
- NORES: no reservoirs





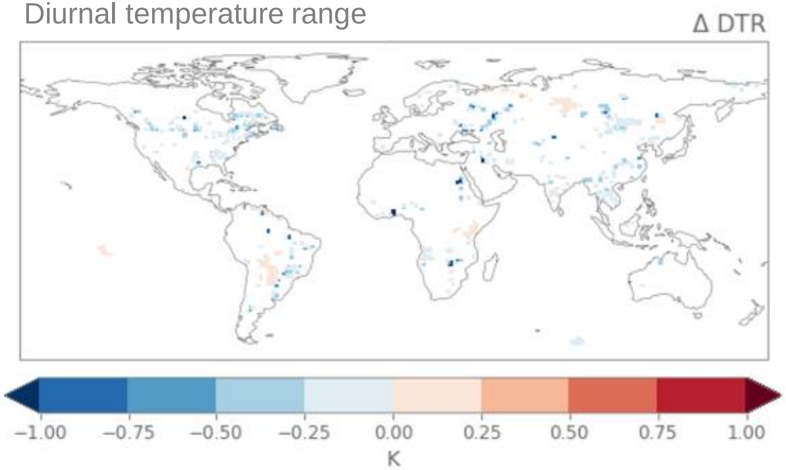


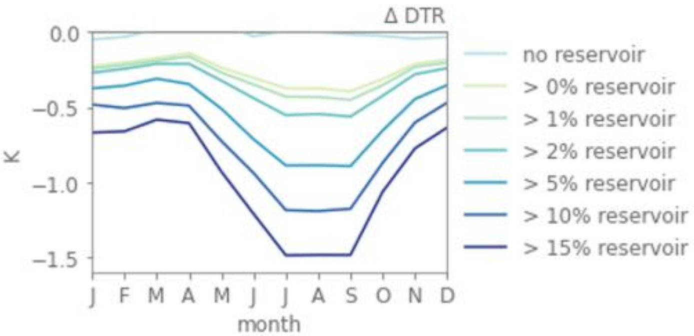
Vanderkelen et al. 2021, JGR

Coupled experiments: influence of reservoirs on climate

AMIP-style simulations
- 1980-2014, 0.9° by 1.25°
- 5 ens members RES and NORES

Diurnal temperature range

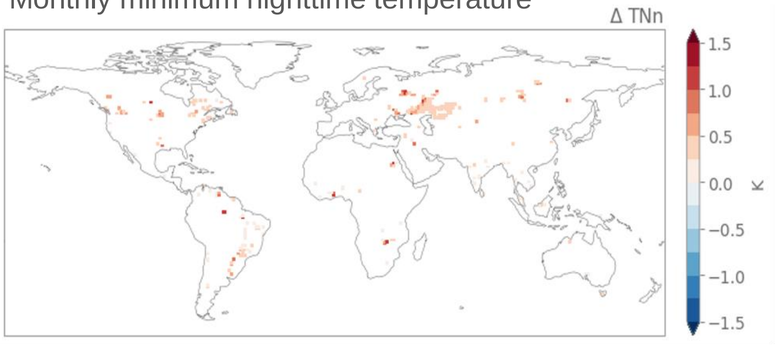


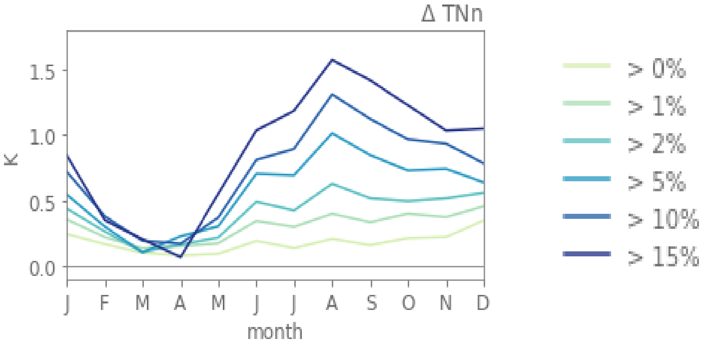


Vanderkelen et al. 2021, JGR

Reservoirs dampen temperature extremes

Monthly minimum nighttime temperature



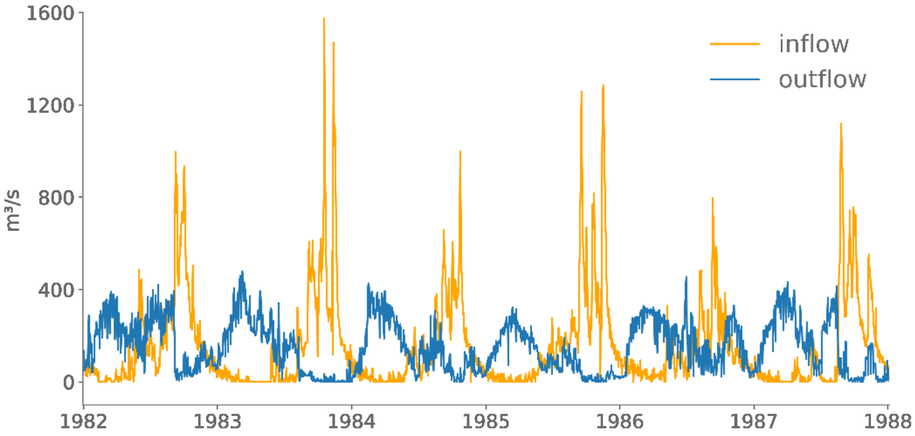


- Reservoirs dampen the daily and seasonal T cycle and T extremes
- Responses localized to reservoir grid cells
- Substantial where reservoirs make up a large fraction

Vanderkelen et al. 2021, JGR

Streamflow regulation through dam management

Bhumibol dam, Thailand



Implement dam management in the ESM

Irrigation demand per reservoir based on new **irrigation topology**

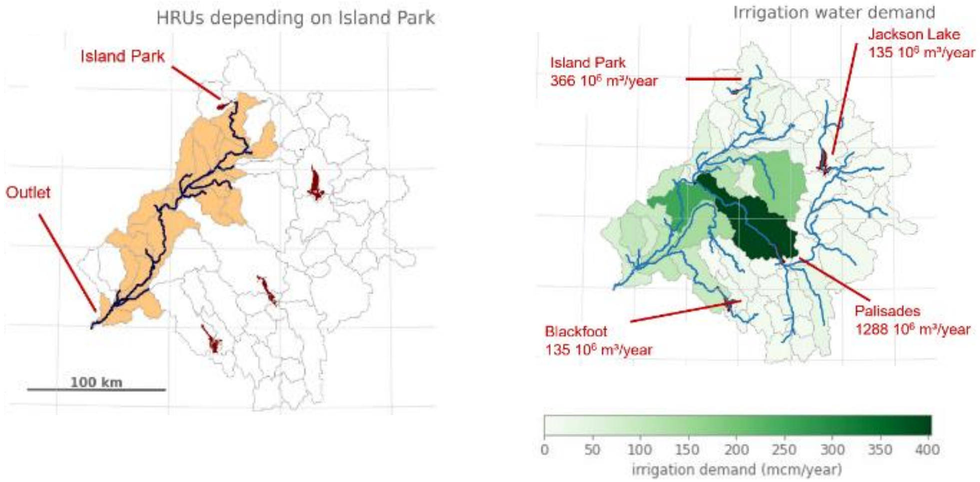
mizuRoute: vector-based river routing model

- Lakes and reservoirs part of river network

Mizukami et al. 2016, GMD
Mizukami et al. 2021, JAMES
Gharari et al., in review

Hanasaki et al. (2006) global dam parametrization

- Irrigation vs non-irrigation reservoirs
- “within-a-year” vs “muti-year” reservoirs
- Input: purpose, mean inflow and irrigation seasonality



Vanderkelen et al. 2022, GMD

MizuRoute simulations

NOLAKES	Run-of-river as outflow
NAT	Natural lake param. of Döll et al, 2003
DAM	Dam param. of Hanasaki, 2006
DAM NOIRR	Dam param. of Hanasaki, 2006; all reservoirs non-irrig

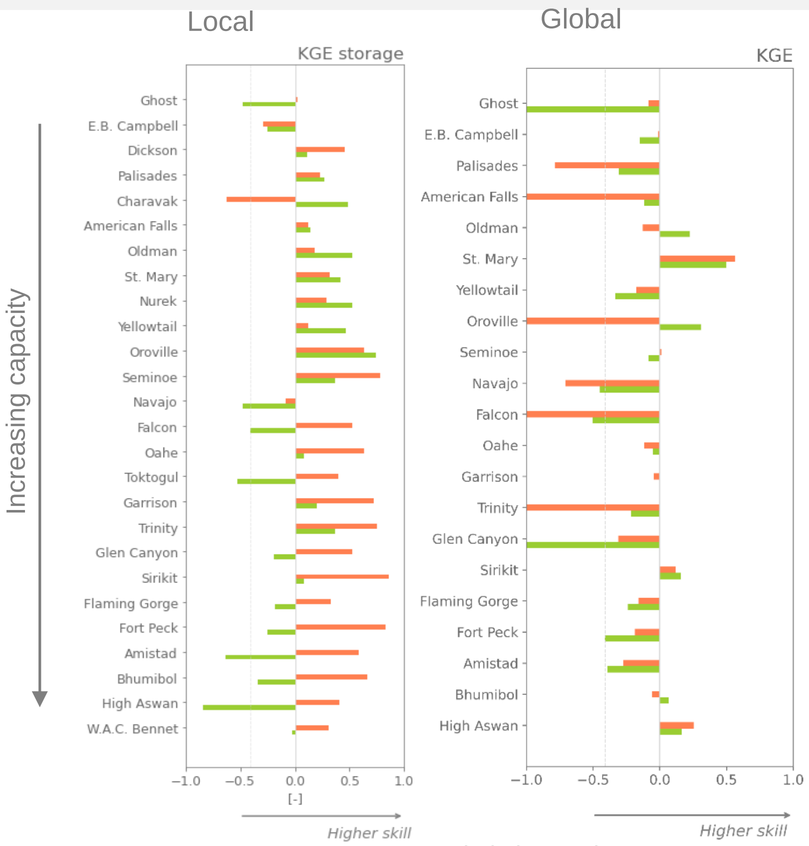
Local simulations

- 26 Individual reservoirs
- Observed reservoir inflows
- Irrigation water demands from CLM and irrigation topology

Global simulations

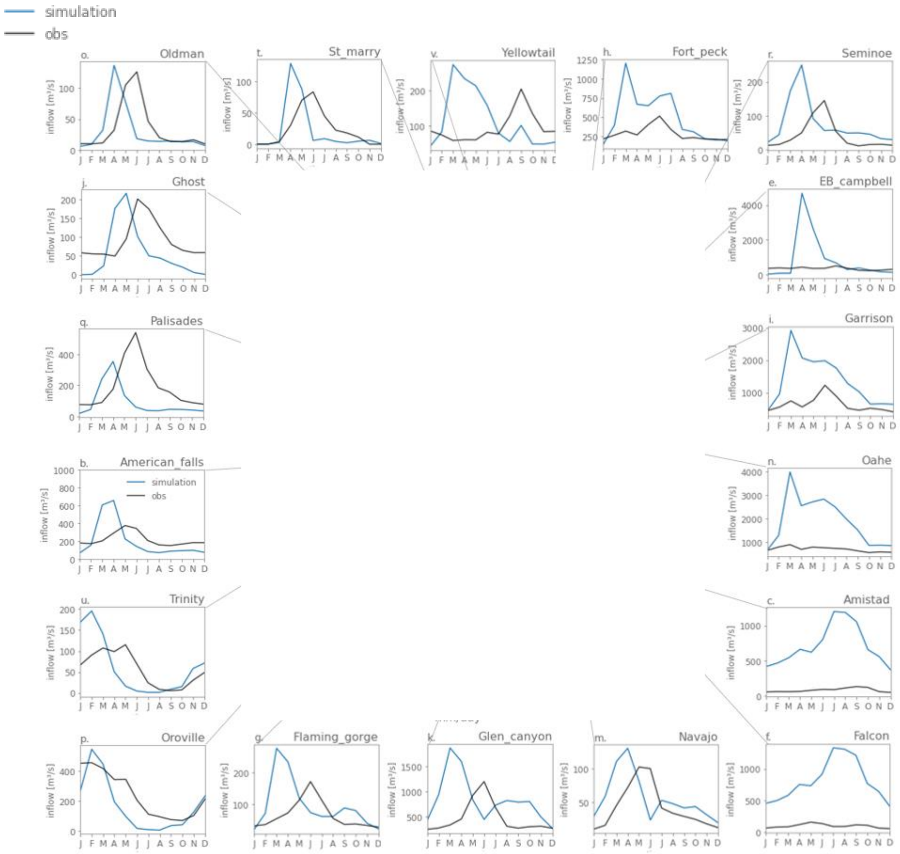
- HDMA river network with lakes
- 1773 reservoirs, of which 484 irrigation
- Runoff from CTSM

Why is there an inconsistency between local and global simulations?



Vanderkelen et al. 2022, GMD

Inflow and runoff biases in CONUS



- Unresolved dams upstream of river network
- Biases in catchment runoff
    - Water abstraction is not included in CTSM
    - Underestimation of irrigation water use upstream
    - Structural biases in snowmelt dynamics

Potential solutions

- CTSM parameter calibration for runoff *(Cheng et al., in review)*
- Domestic and indust. water abstraction *(Taranu et al., in prep)*
- Improve irrigation: different techniques *(Yao et al., in review)*
- Representative hillslope model (Sean Swenson)
- Use of higher resolution river network (e.g. MERIT-Hydro)

Vanderkelen et al. 2022, GMD

Conclusions
Towards reservoirs and dams in CESM

Representation of dams and reservoirs in CESM
- Reservoir expansion in CTSM as dynamical lakes
- Dam regulation in river routing model mizuRoute

Future work
- Improvements on biases in CTSM runoff
- Coupling of mizuRoute with CTSM and CESM (ongoing)

Opening new research avenues
- Improvement the terrestrial water cycle by including human water management
- Studies on water availability, role of human water management and climate change for adaptation and mitigation strategies.

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Bhumibol reservoir, Thailand

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Vanderkelen, I., Gharari, S., Mizukami, N., Clark, M. P., Lawrence, D. M., Swenson, S., Pokhrel, Y., Hanasaki, N., Van Griensven, A., & Thiery, W. (2022). Evaluating a reservoir parametrisation in the vector-based global routing model mizuRoute (v2.0.1) for Earth System Model coupling. *Geoscientific Model Development*, *15*(10), 4163–4192. https://doi.org/10.5194/gmd-2022-16

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