Changing Storage:
Towards dams and reservoirs in Earth System Models

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Collaborators:
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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

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

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

**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 $2.57 \pm 3.23 \times 10^{20}$ J:
~ 3.6 % of land uptake

Heat redistribution by reservoir expansion: $26.8 \pm 2.1 \times 10^{20}$ 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
Implementation of reservoir expansion in CTSM
Dynamically growing lake fraction in the grid cell

In CTSM lakes are simulated with a constant depth.

Correction fluxes are minimized with a baseline approach.

Reservoir expansion as growing lake fraction in the grid cell.
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

Reservoir area fraction

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

Vanderkelen et al. 2021, JGR
Reservoirs dampen temperature extremes

- 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
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
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?
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)
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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