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Improved Flood Simulation through GRACE/GRACE-FO Data Assimilation in Noah-MP

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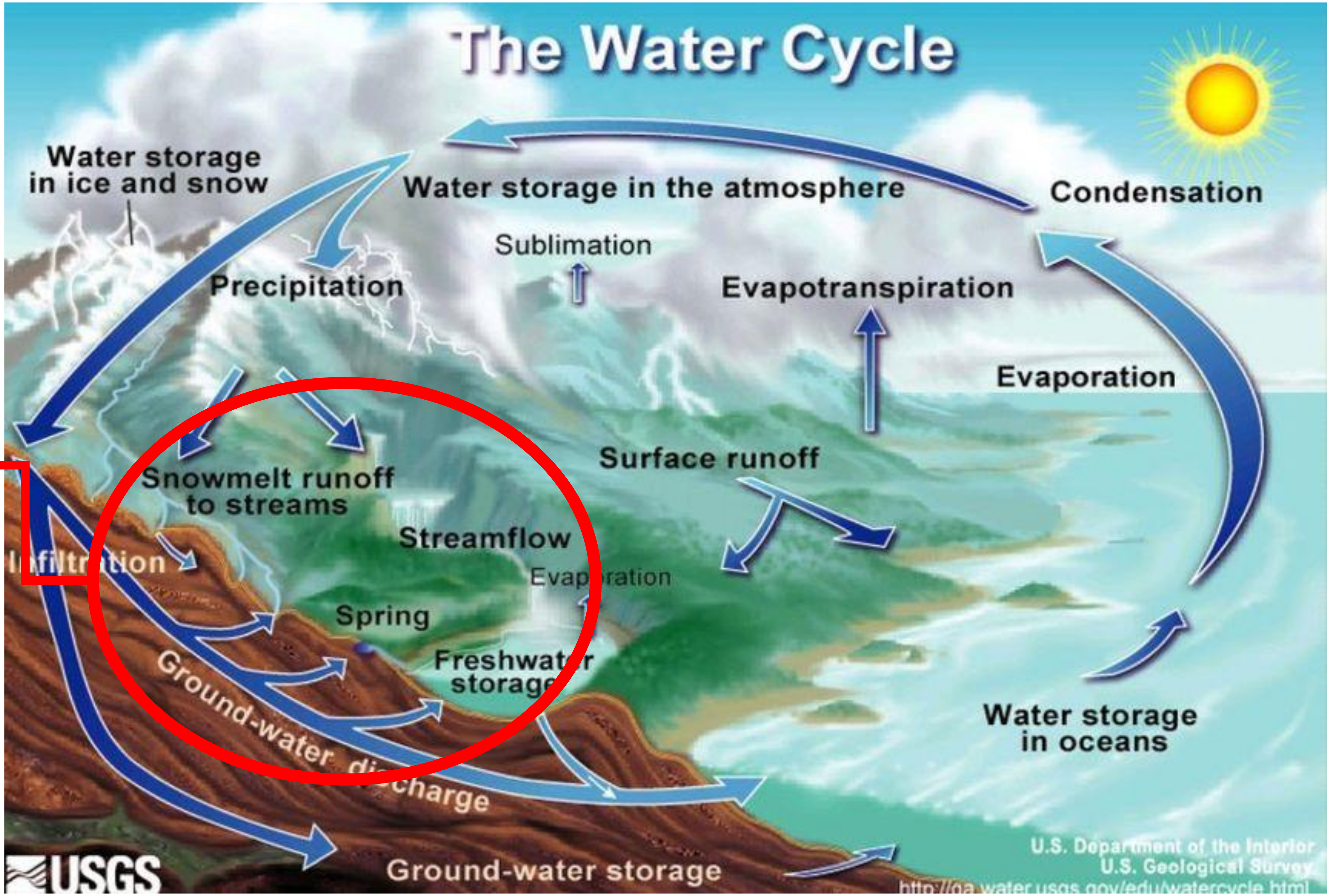
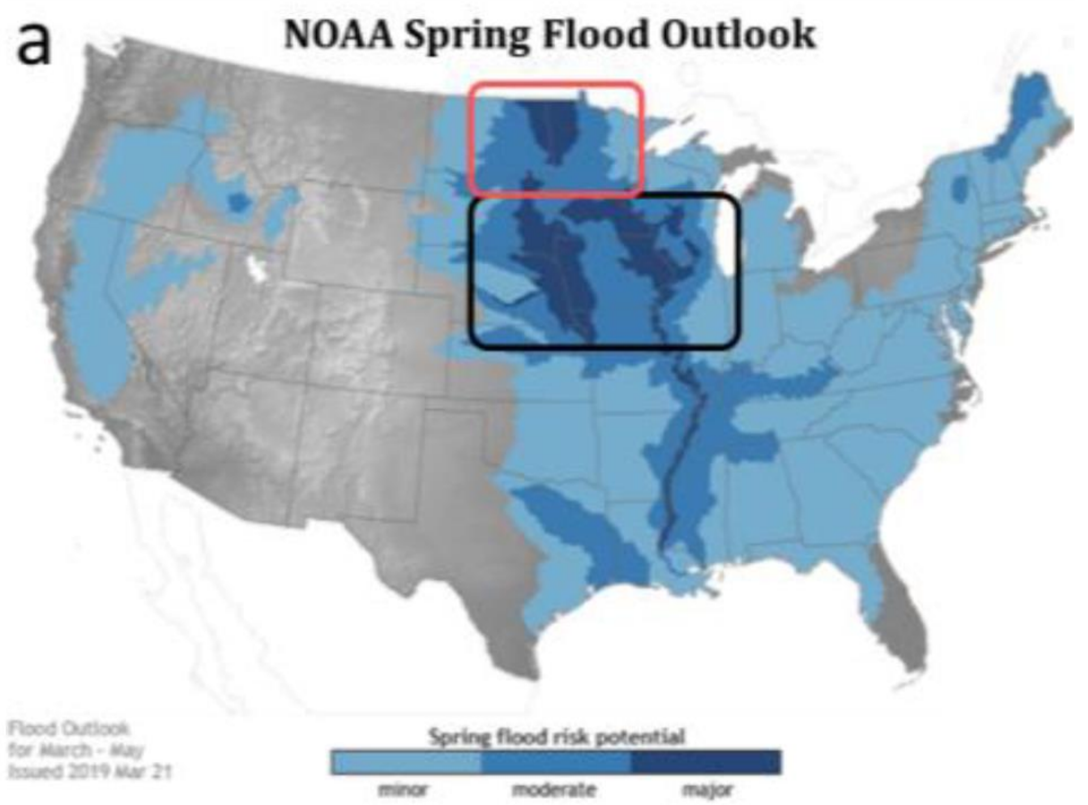
Introduction

- **Groundwater-runoff interactions are essential** to flood generation processes (Maxwell and Condon, 2016; Carroll et al., 2019; Brooks et al., 2025).
- **Groundwater depletion can reduce flood risk** by allowing greater infiltration before runoff generation.
- **Saturated groundwater conditions can increase flood risk** by limiting infiltration and percolation, resulting in rapid runoff generation.

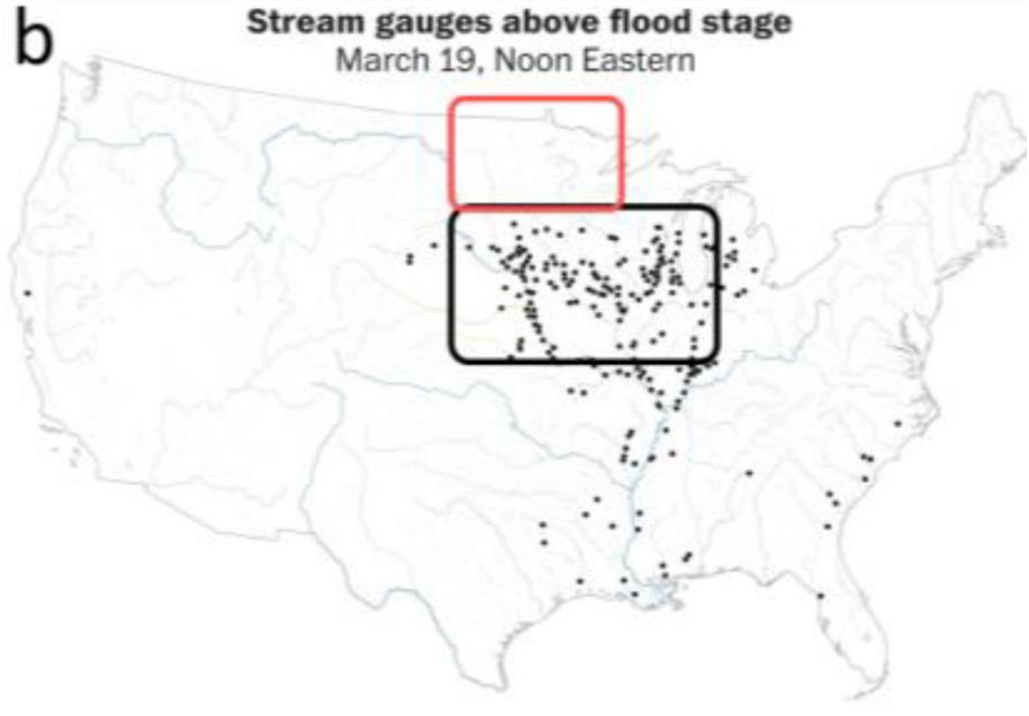


Credit: US Geological Service (2024)

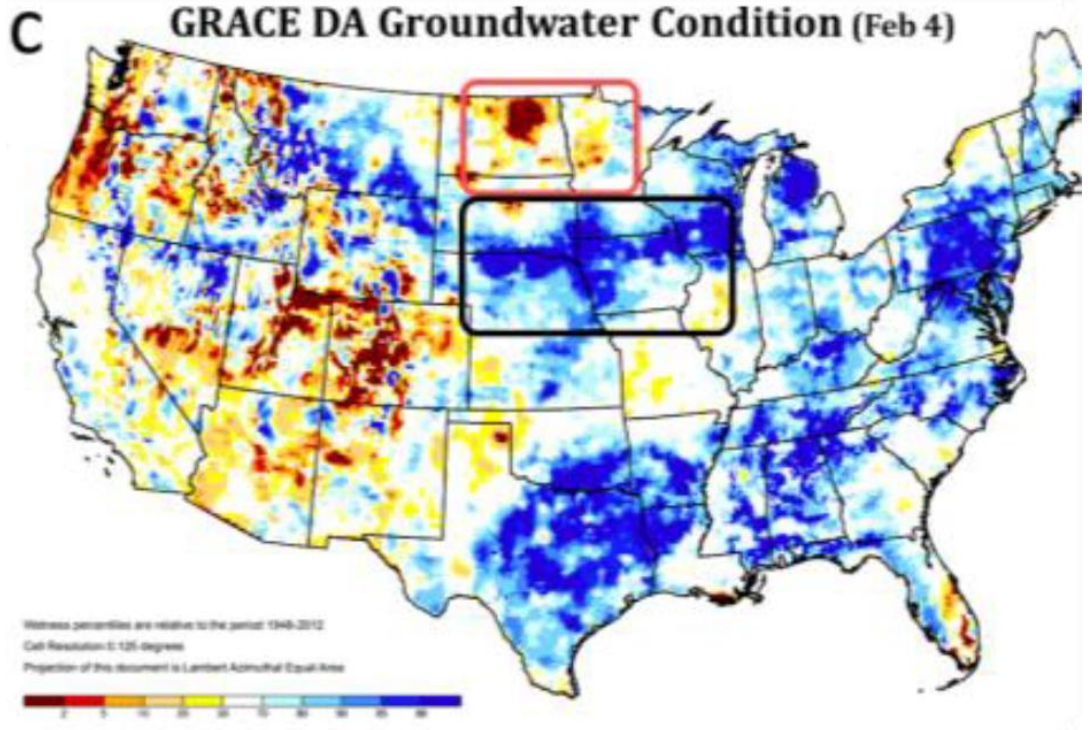
Introduction



(a) Flood forecasting



(b) Flood observation



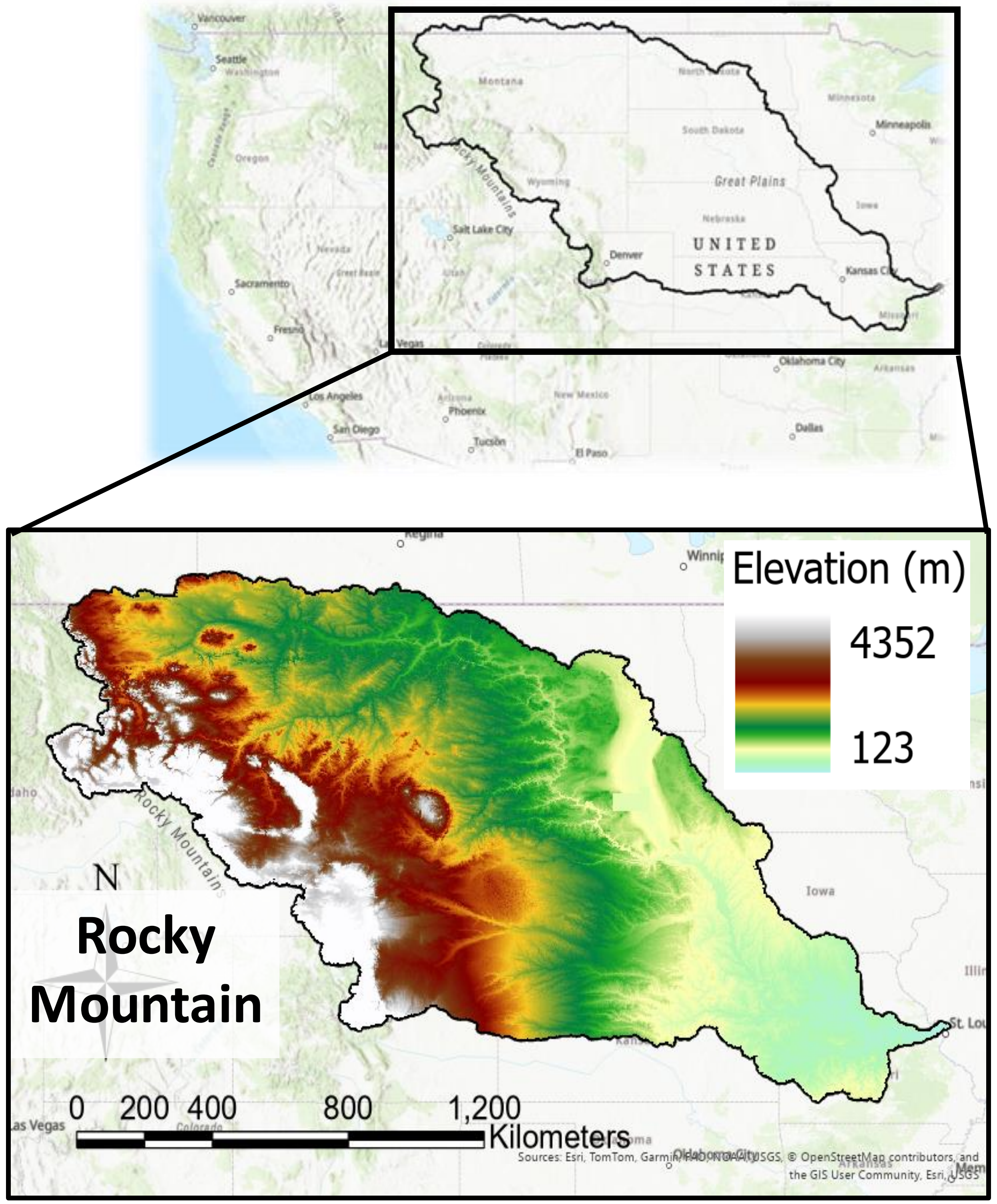
(c) GRACE observation

Clear *(Li et al., 2019; Getirana et al., 2020)*

Research Questions

Assimilating Satellite Data into Land Surface Model → **Better Groundwater Representation** → **Better Runoff and Streamflow Simulation?**

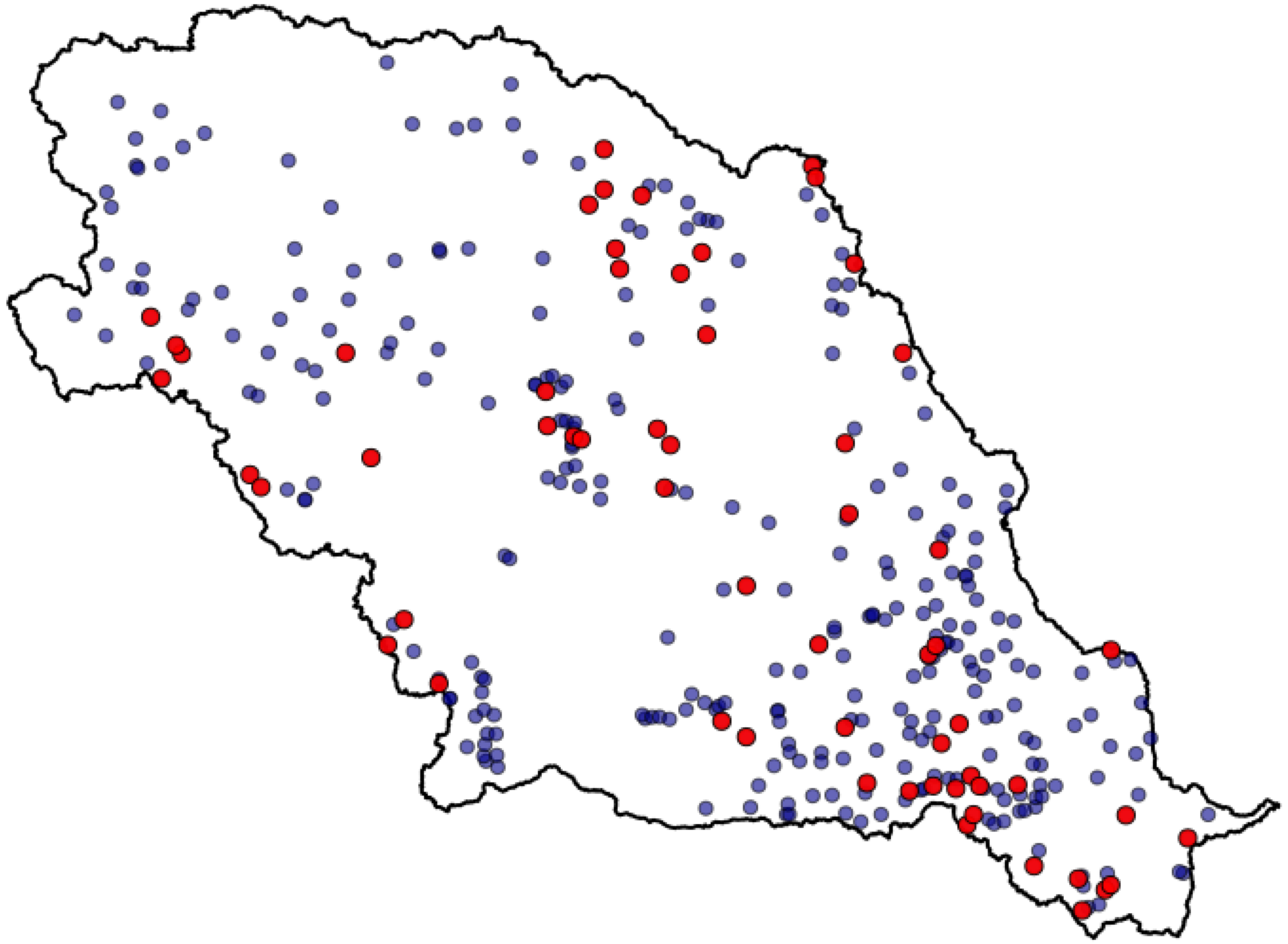
Study Area and Data



Missouri River Basin with Digital Elevation Model

Hydro-Climatic Data Network (HCDN)

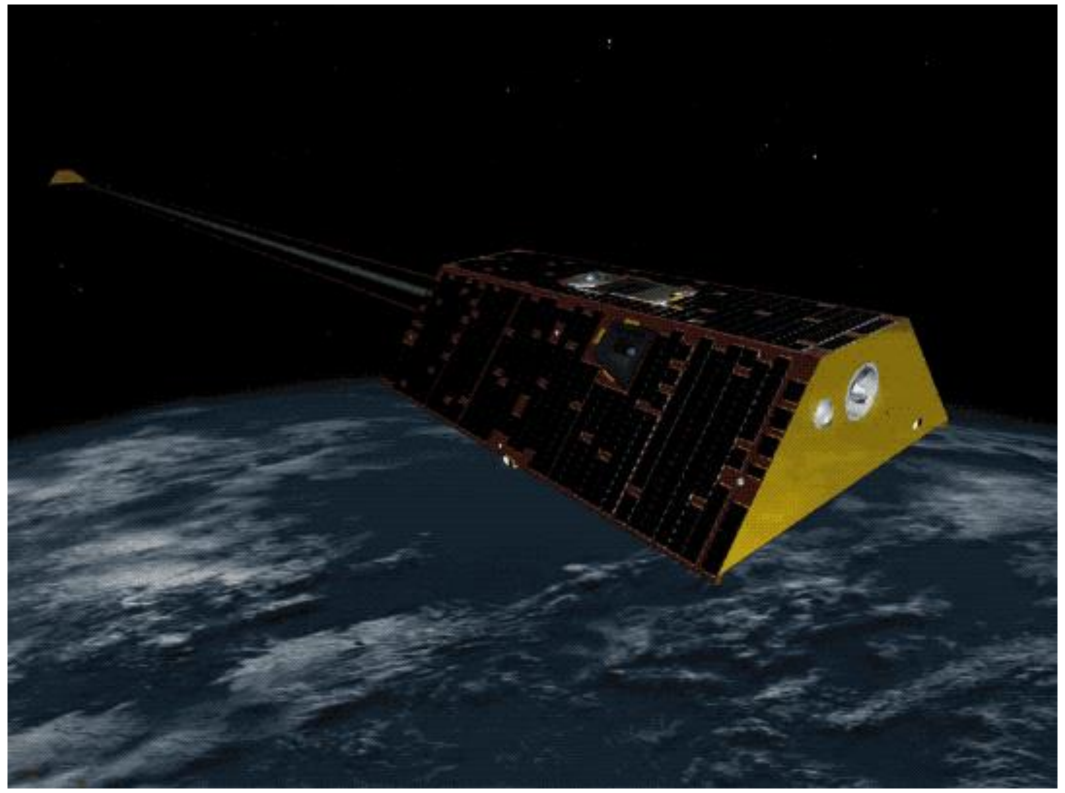
✓ USGS streamflow stations selected to be minimally affected by human activities



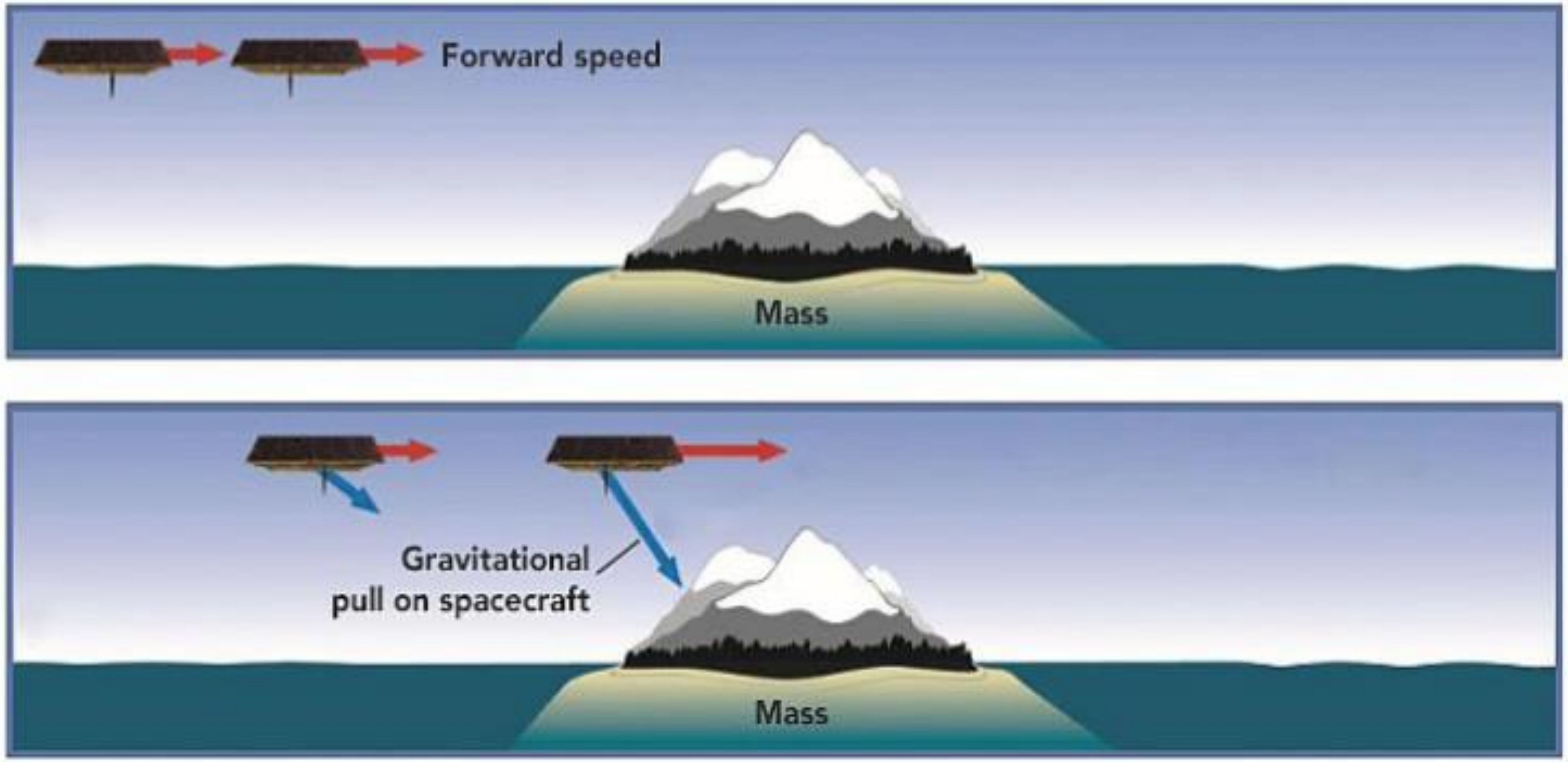
562 USGS (blue) 61 HCDNs (red) with more than 30 years of record

Gravity Recovery and Climate Experiment (GRACE)

✓ Twin satellites measuring gravity anomaly of the Earth

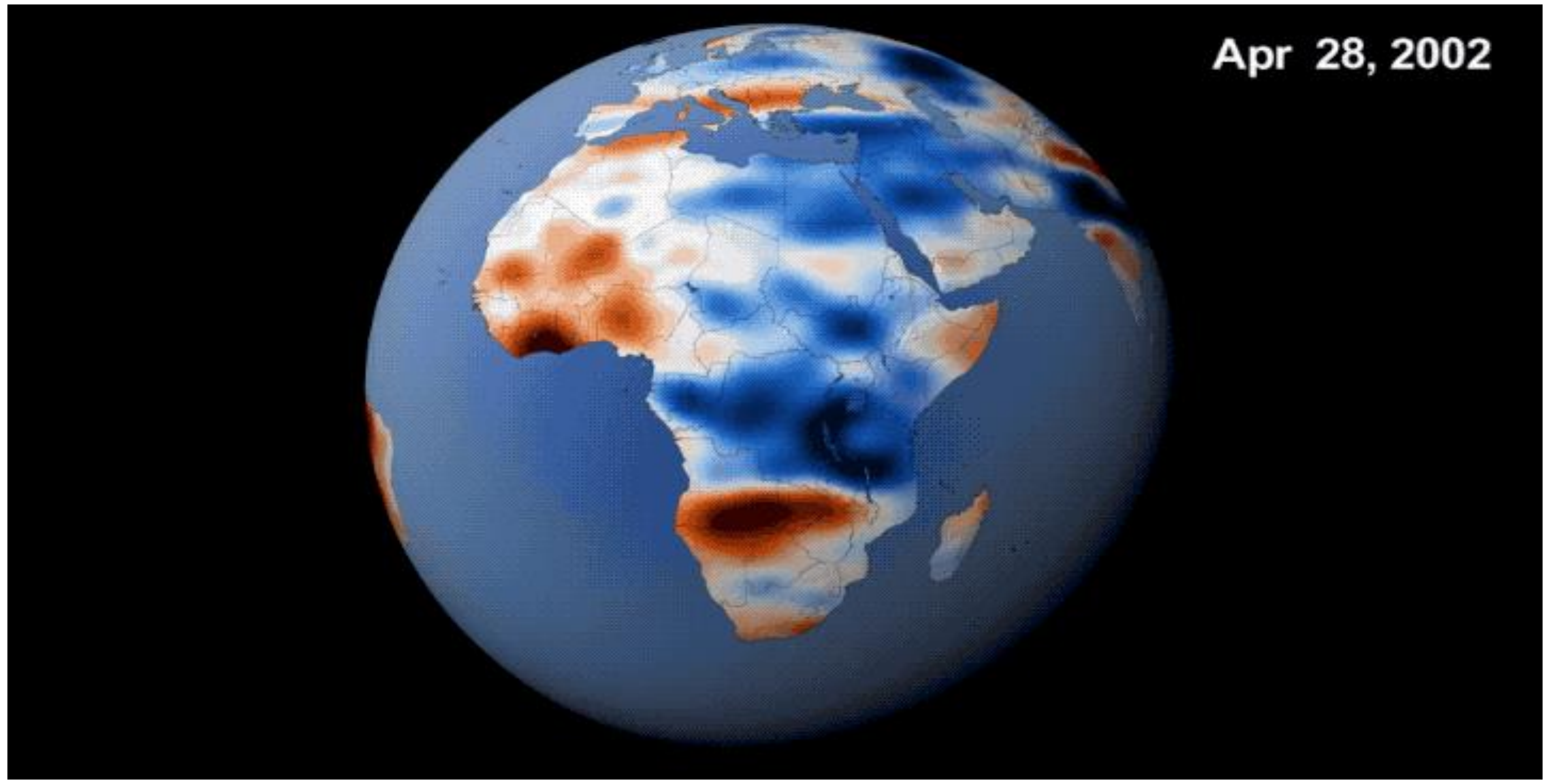


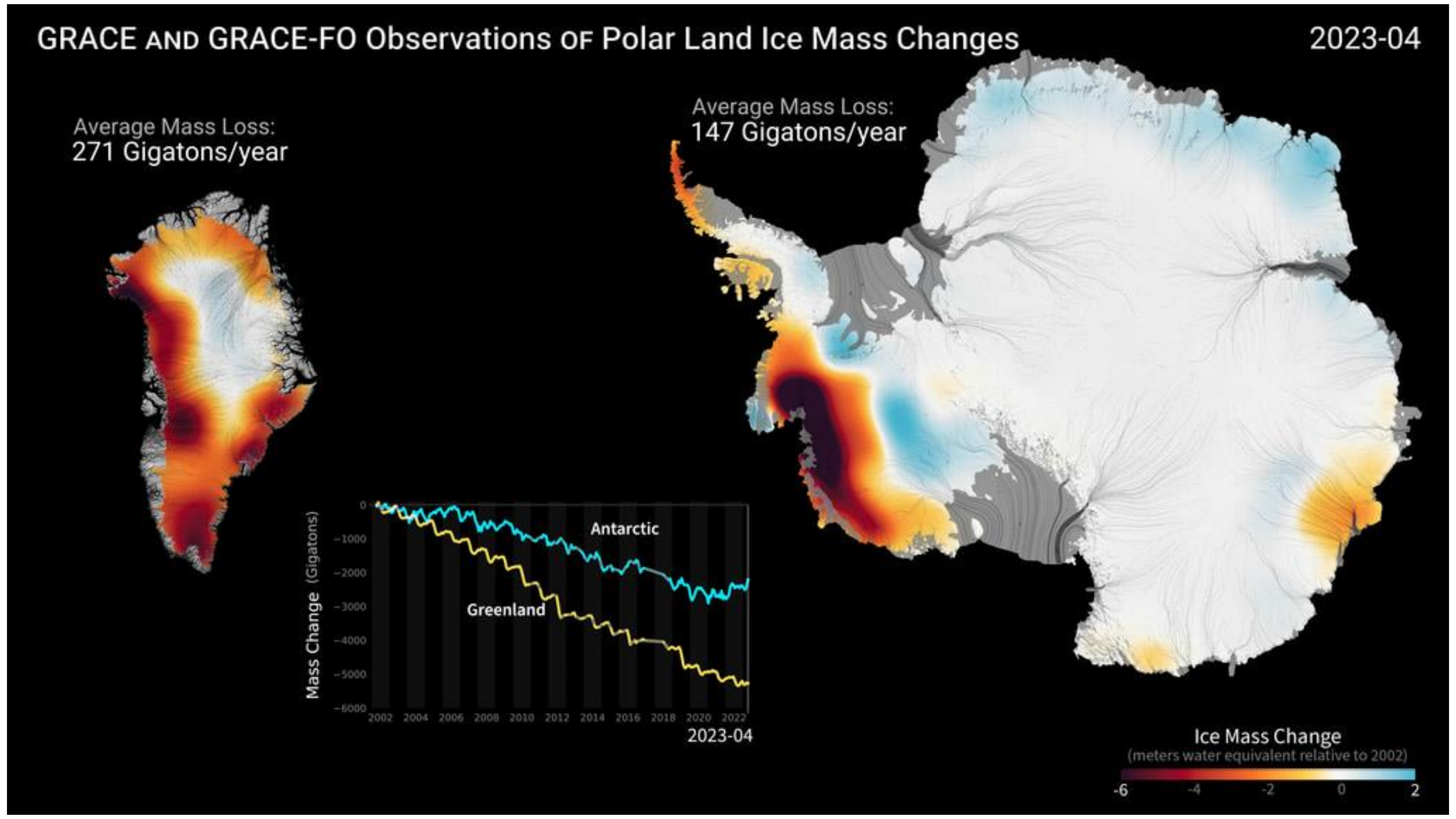
Credit: NASA Jet Propulsion Laboratory

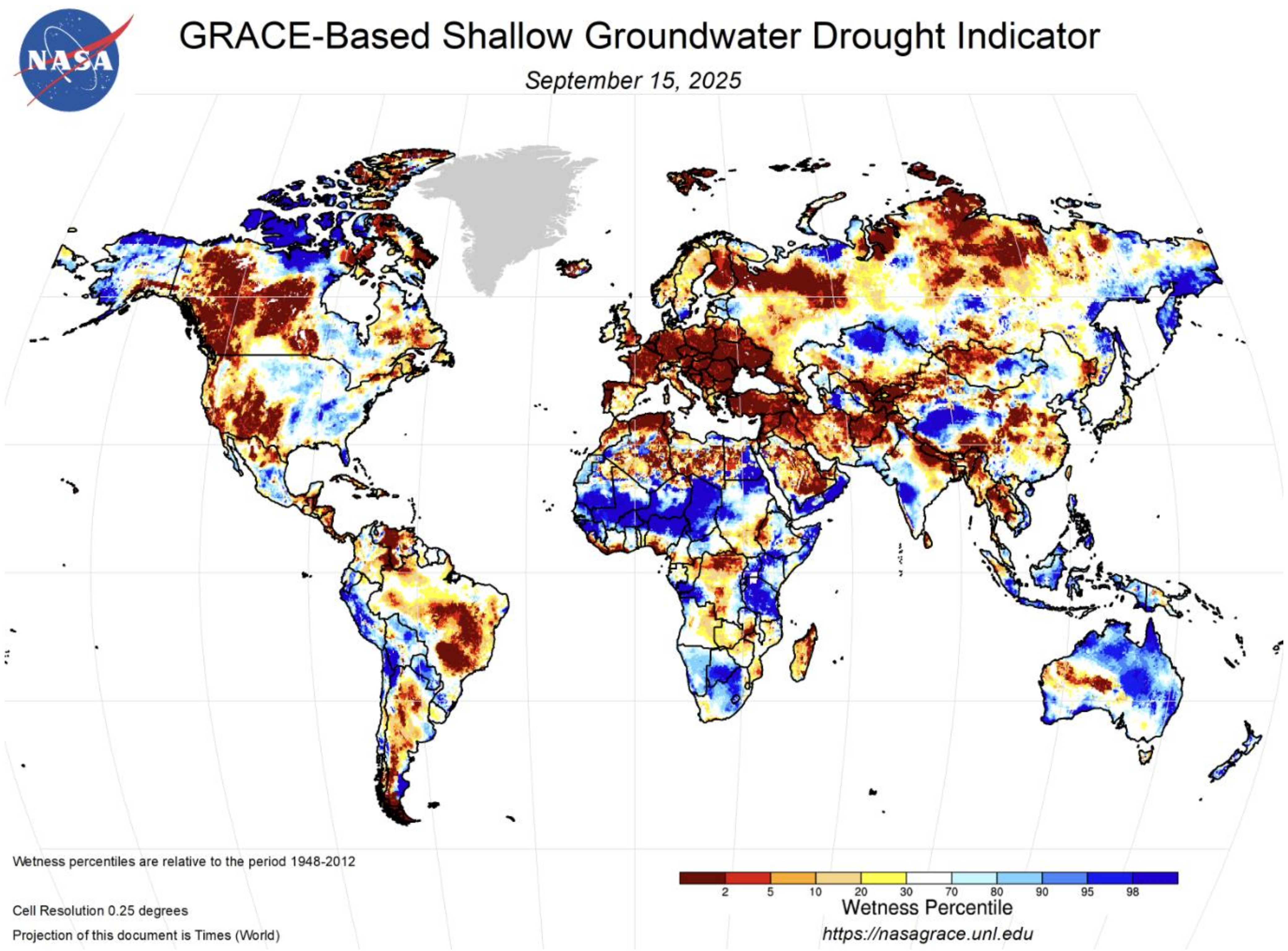


Credit: NASA Earth Observatory

Study Area and Data







Model Setting for Data Assimilation

NLDAS-2 Met Forcing

MODIS Land Cover

FAO + State Soil Geographic

SRTM Elevation data

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Noah-MP 4.0.1 from Land Information System

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Spin-up Run for Initial Condition (1980-2002)

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Open Loop Run (2003-2023)

GRACE Terrestrial Water Storage

- Spatial resolution: 0.125° × 0.125°
- Time step: Daily

Ensemble Kalman Smoother

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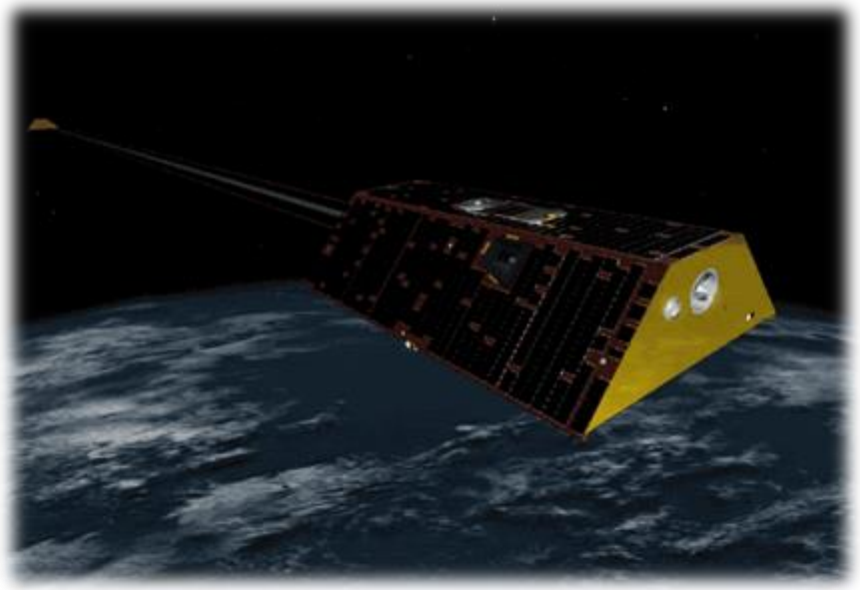
GRACE DA Run (2003-2023)

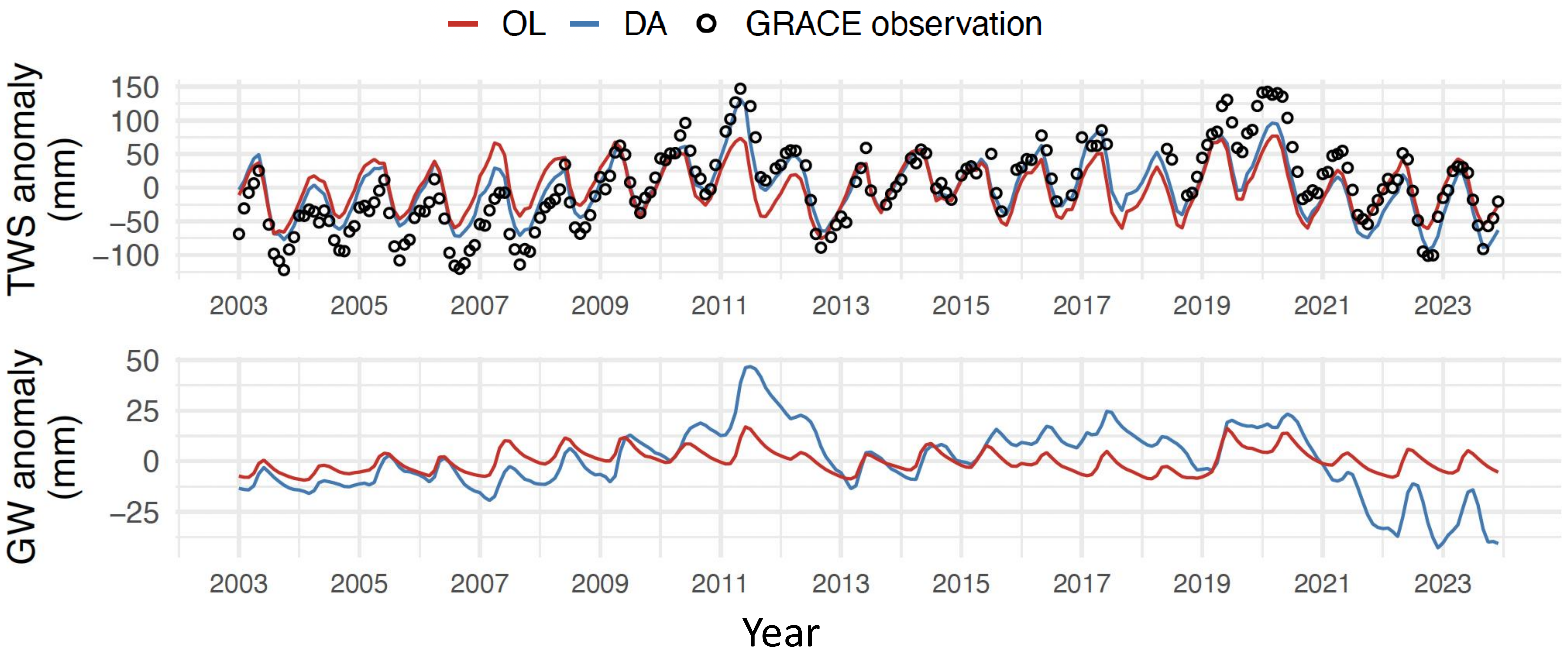
Gravity Recovery And Climate Experiment



Credit: NASA Jet Propulsion Laboratory

Terrestrial Water Storage from OL and DA

Terrestrial Water Storage = Groundwater + Soil Moisture + Ice and Snow + Lake + Rivers + Reservoirs



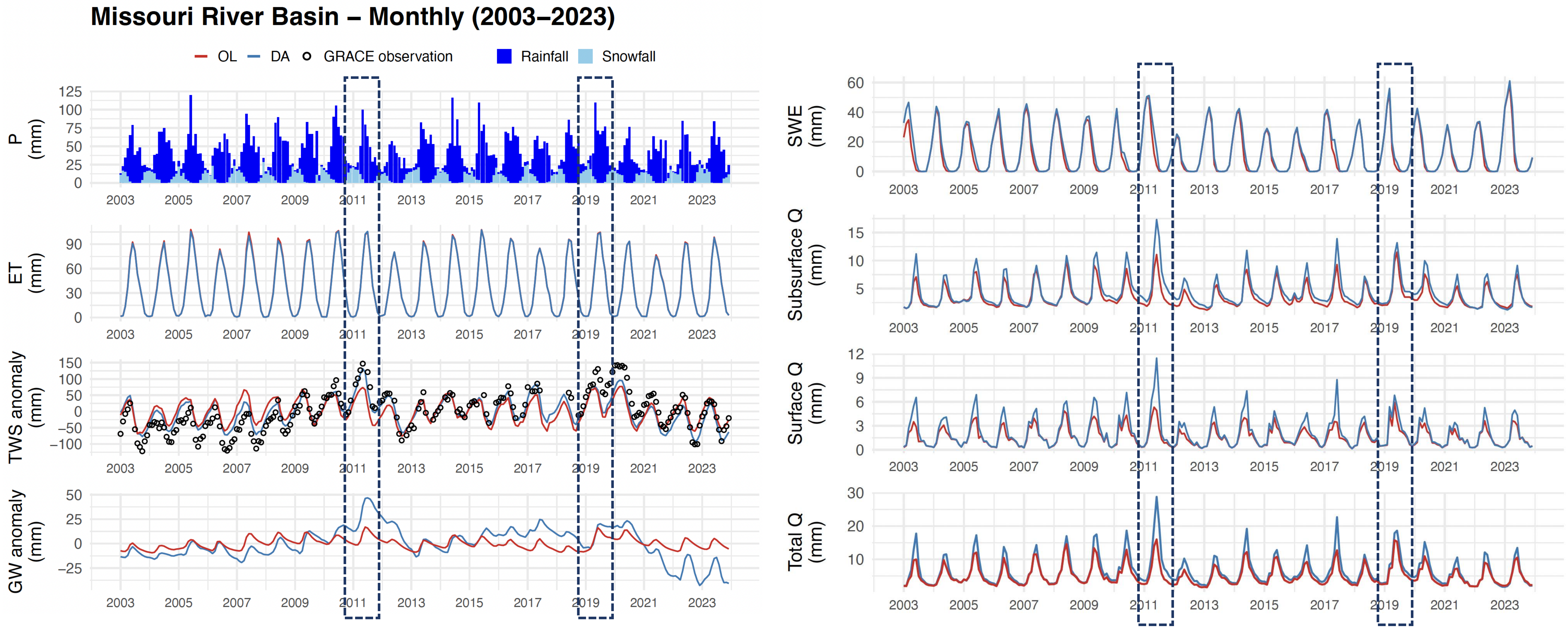
Results

1. Basin-average Time Series

2. Map-based Groundwater and Runoff Comparison

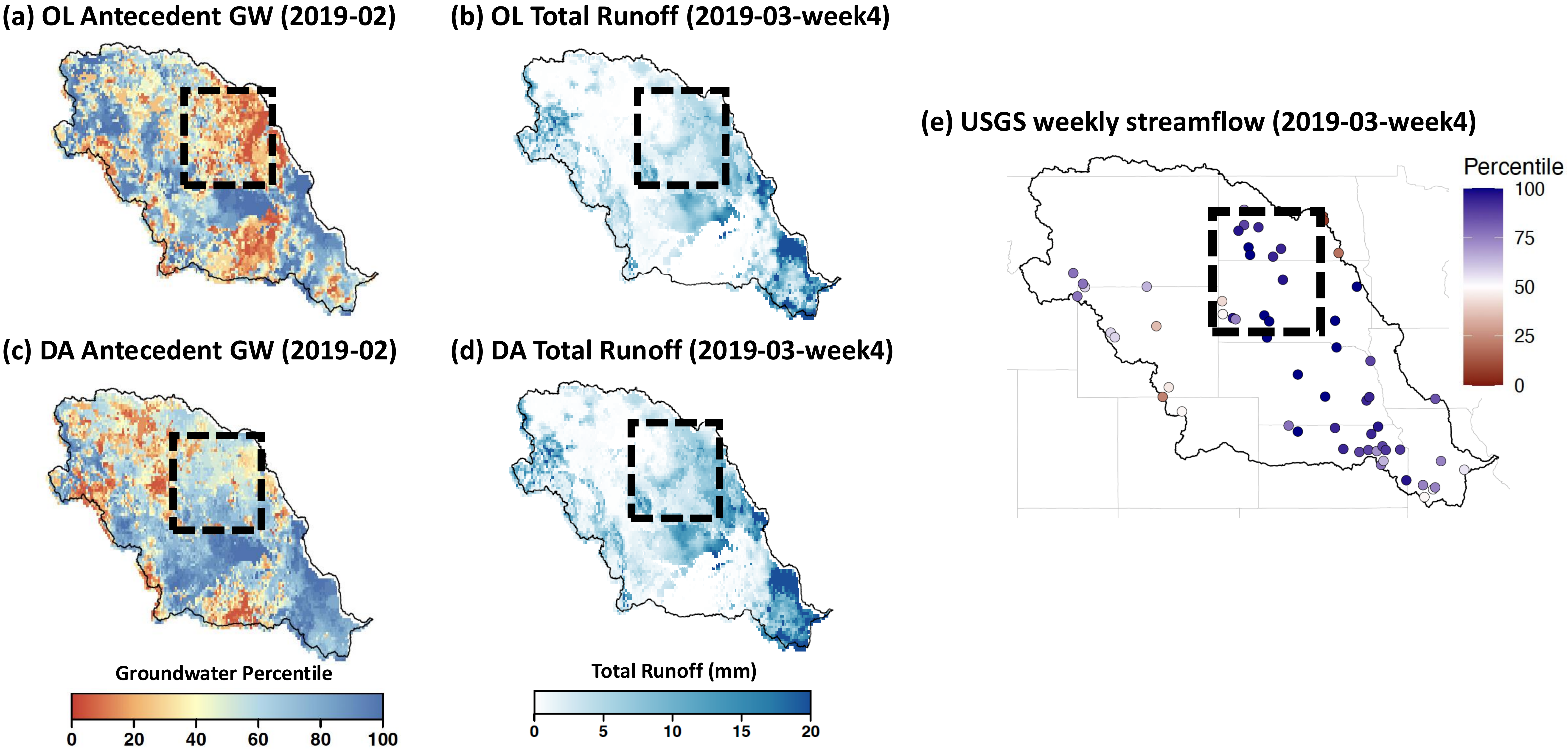
3. HCDN-scale Groundwater and Runoff Comparison

Time Series of Hydrological Variables across Missouri River Basin



2011 Missouri River Flood (Historic Flood); 2019 Midwest Flood (Snowmelt-driven Flood)

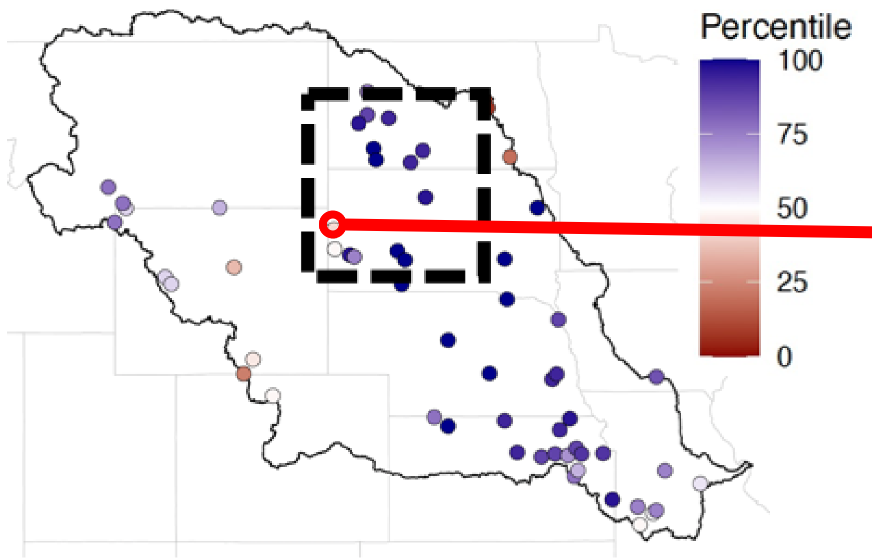
Impact of GRACE-DA on 2019 Midwest Flood

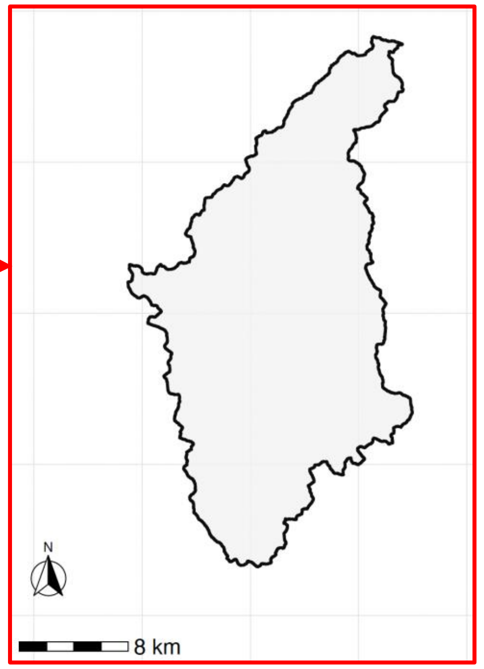


Groundwater in the OL simulation is lower than in DA across regions that experienced high spring streamflow.

Impact of GRACE-DA on 2019 Midwest Flood

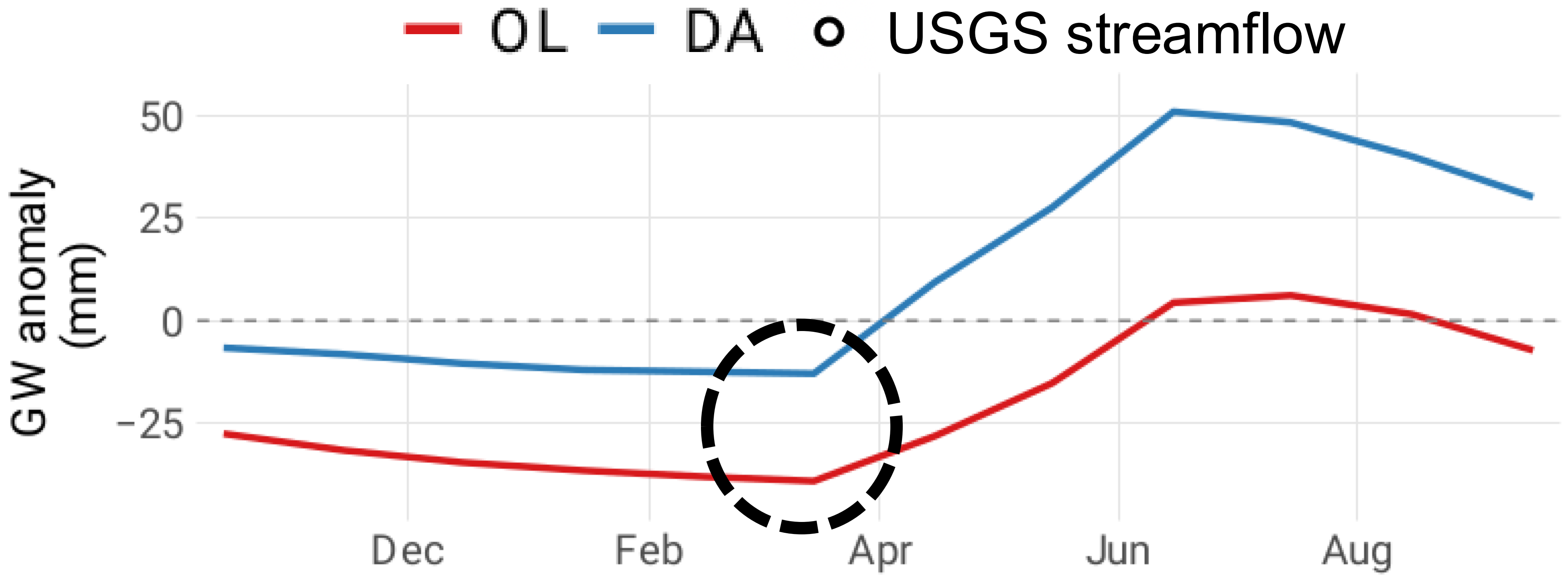
(e) USGS weekly streamflow (2019-03-week4)

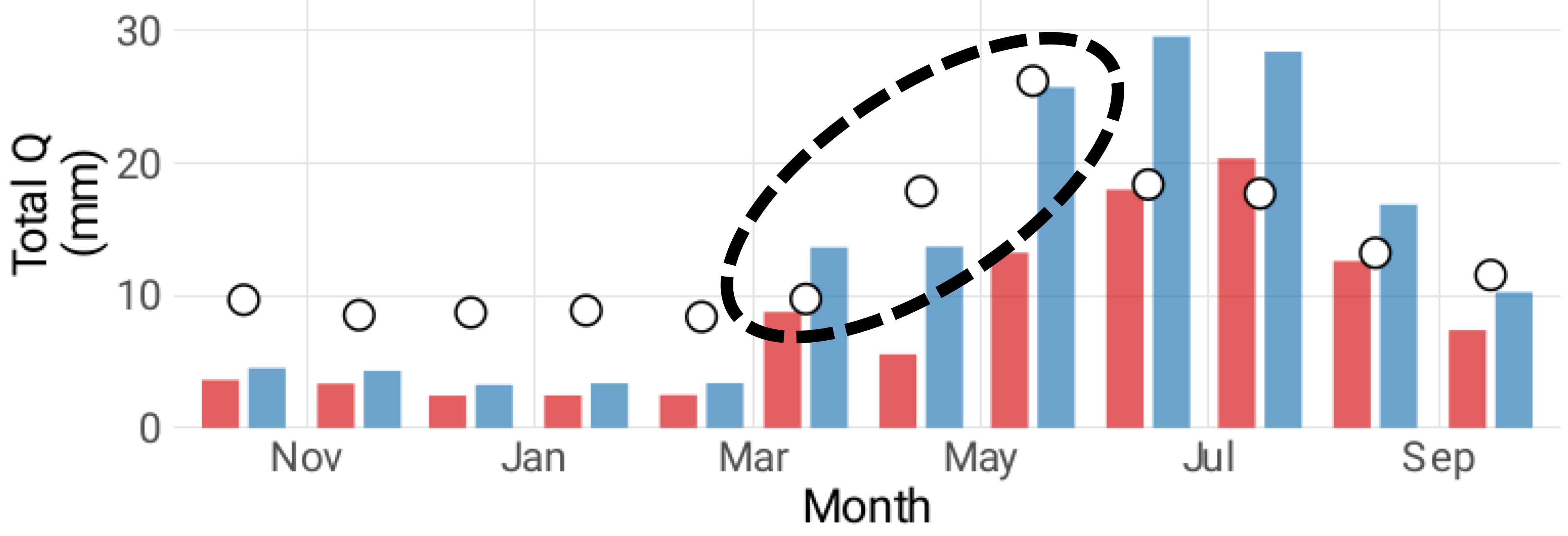




Spearfish Creek Basin (USGS 06431500)

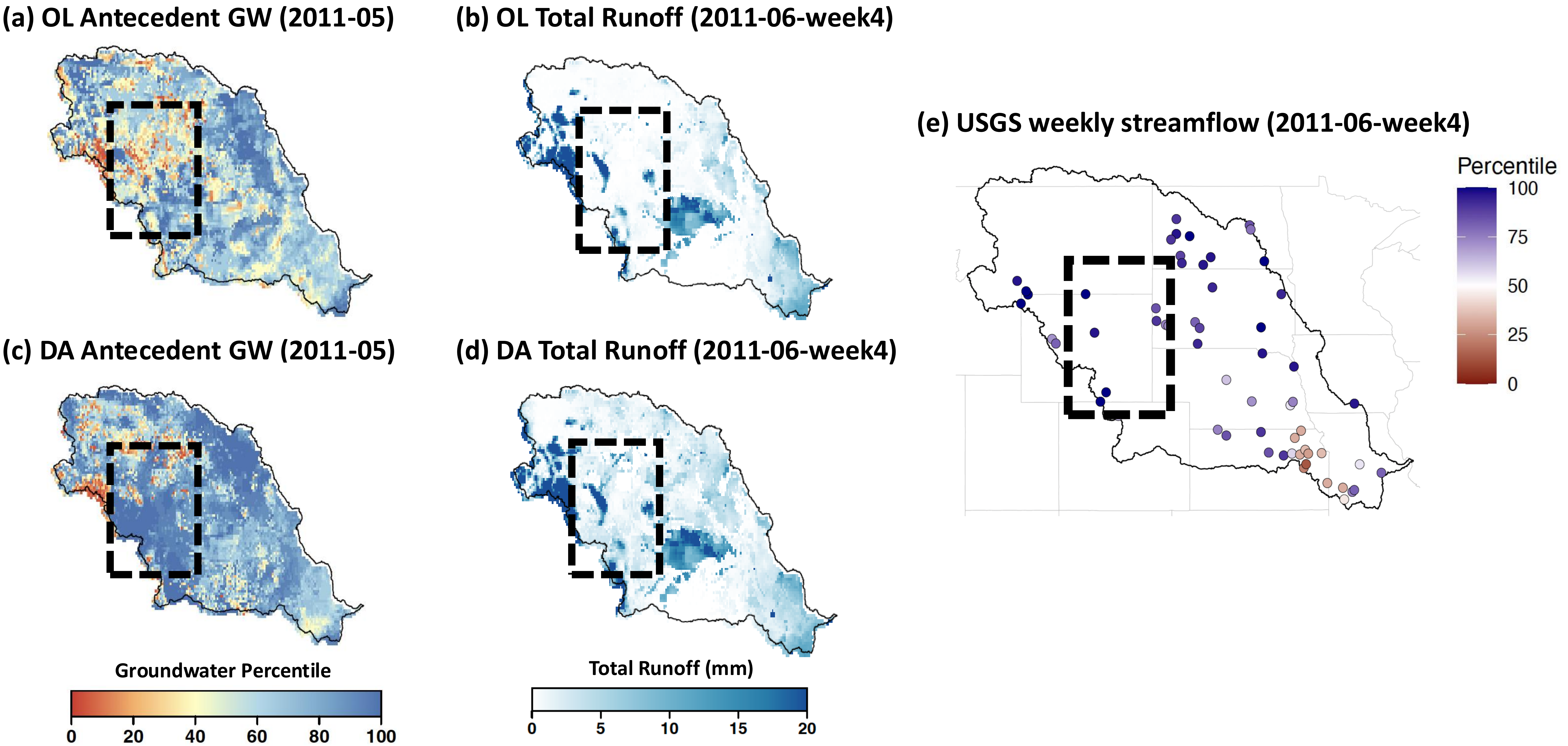
Variable	OL	DA
Antecedent GW (February)	-38.3 mm	-12.6 mm
Runoff Bias (March)	- 1.0 mm	3.9 mm
Runoff Bias (April)	- 12.3 mm	- 4.2mm
Runoff Bias (May)	**- 13.0 mm**	**- 0.5 mm**
Runoff Bias (March – May)	**- 8.8 mm**	**- 0.3 mm**





Water Year 2019

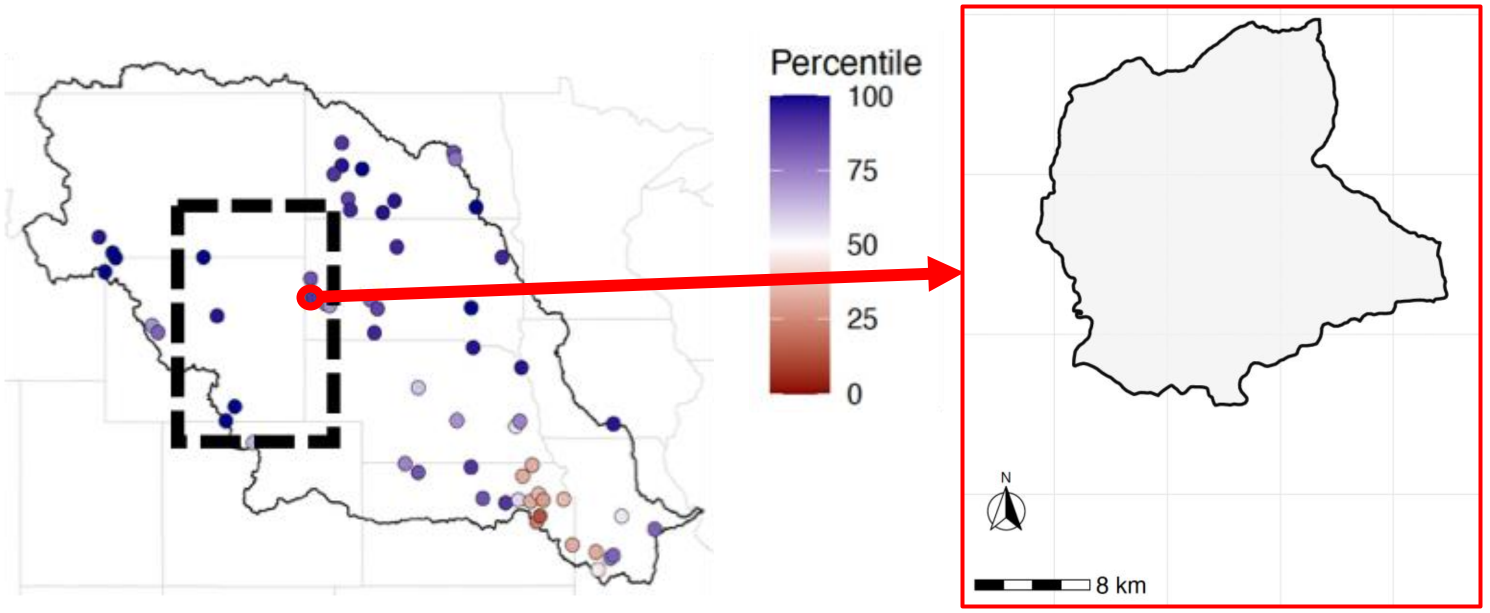
Impact of GRACE-DA on 2011 Missouri River Flood



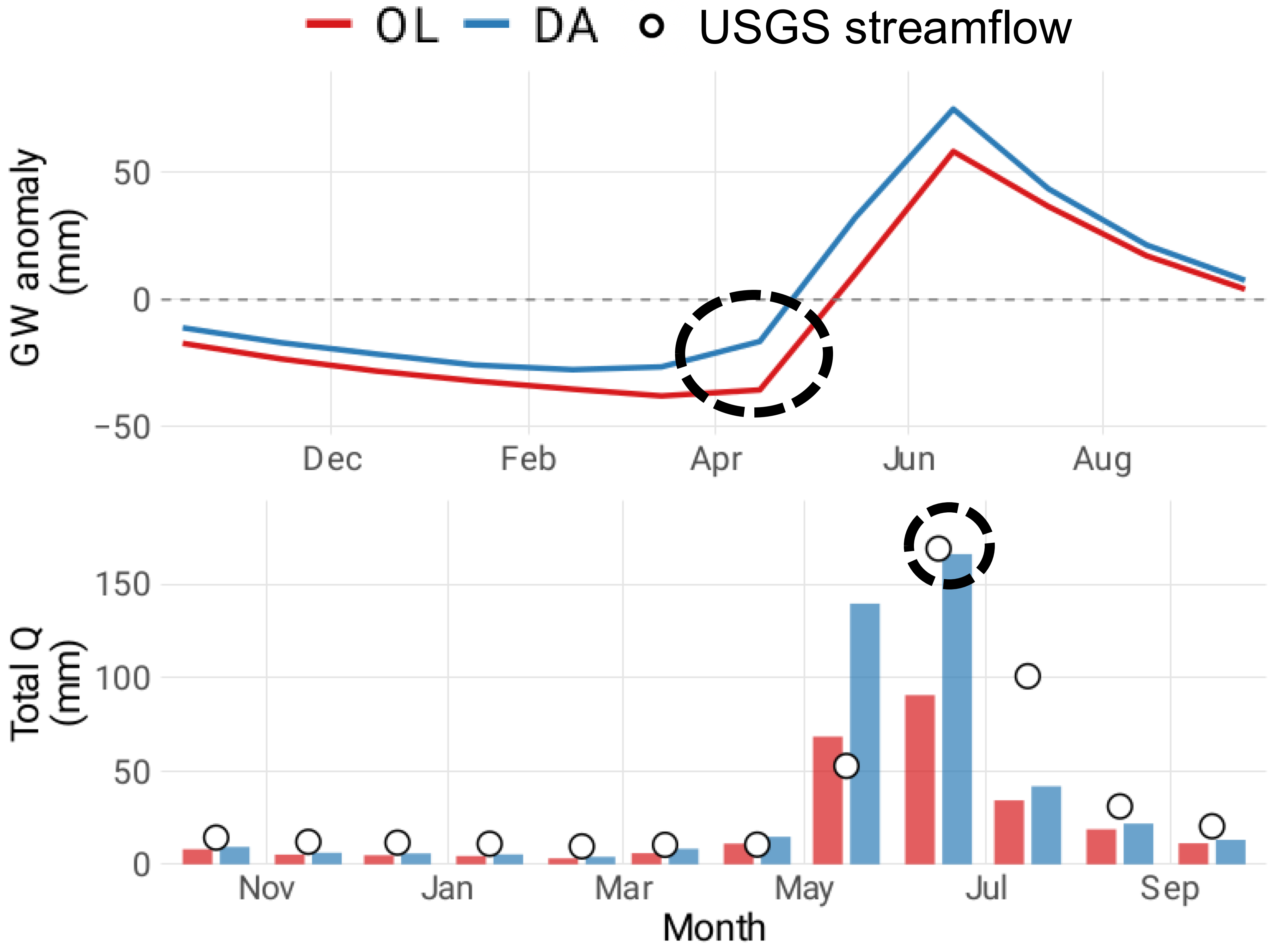
Higher groundwater levels in GRACE-DA improved the underestimated runoff in OL.

Impact of GRACE-DA on 2011 Missouri River Flood

(e) USGS weekly streamflow (2011-06-week4)



Little Bighorn River Basin (USGS 06289000)

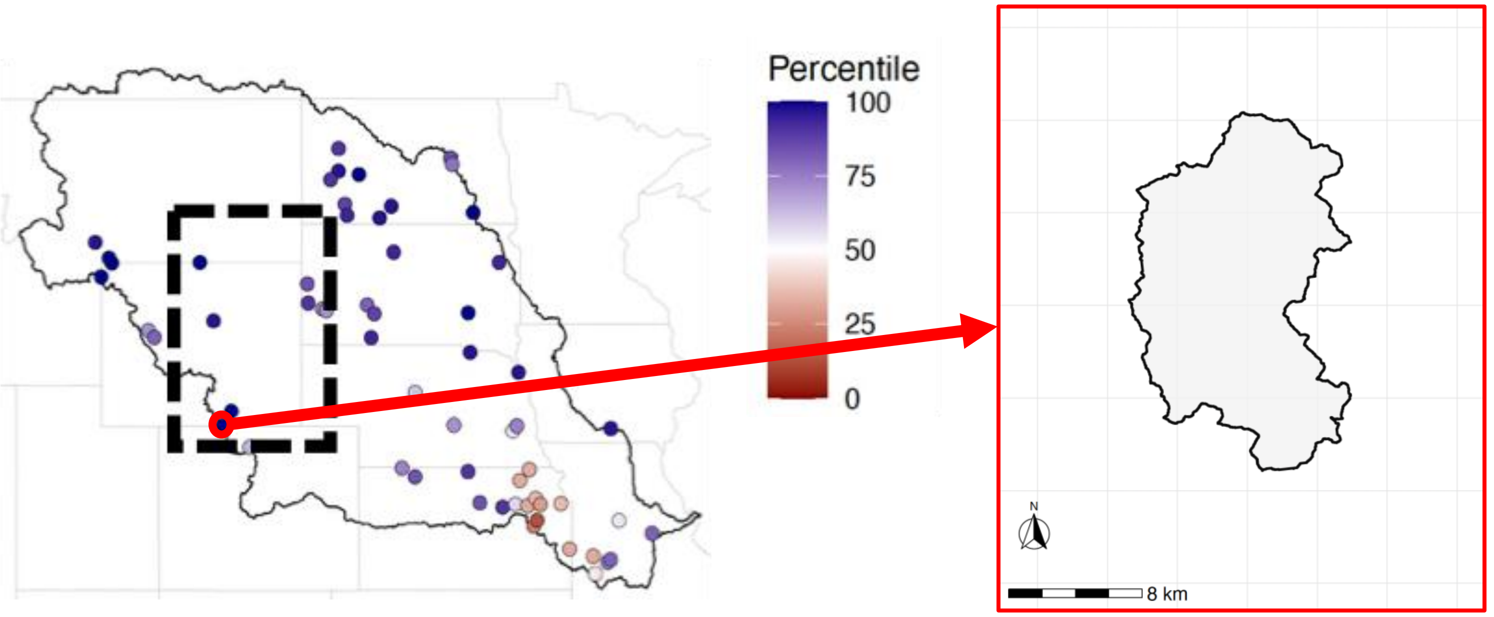


Water Year 2019

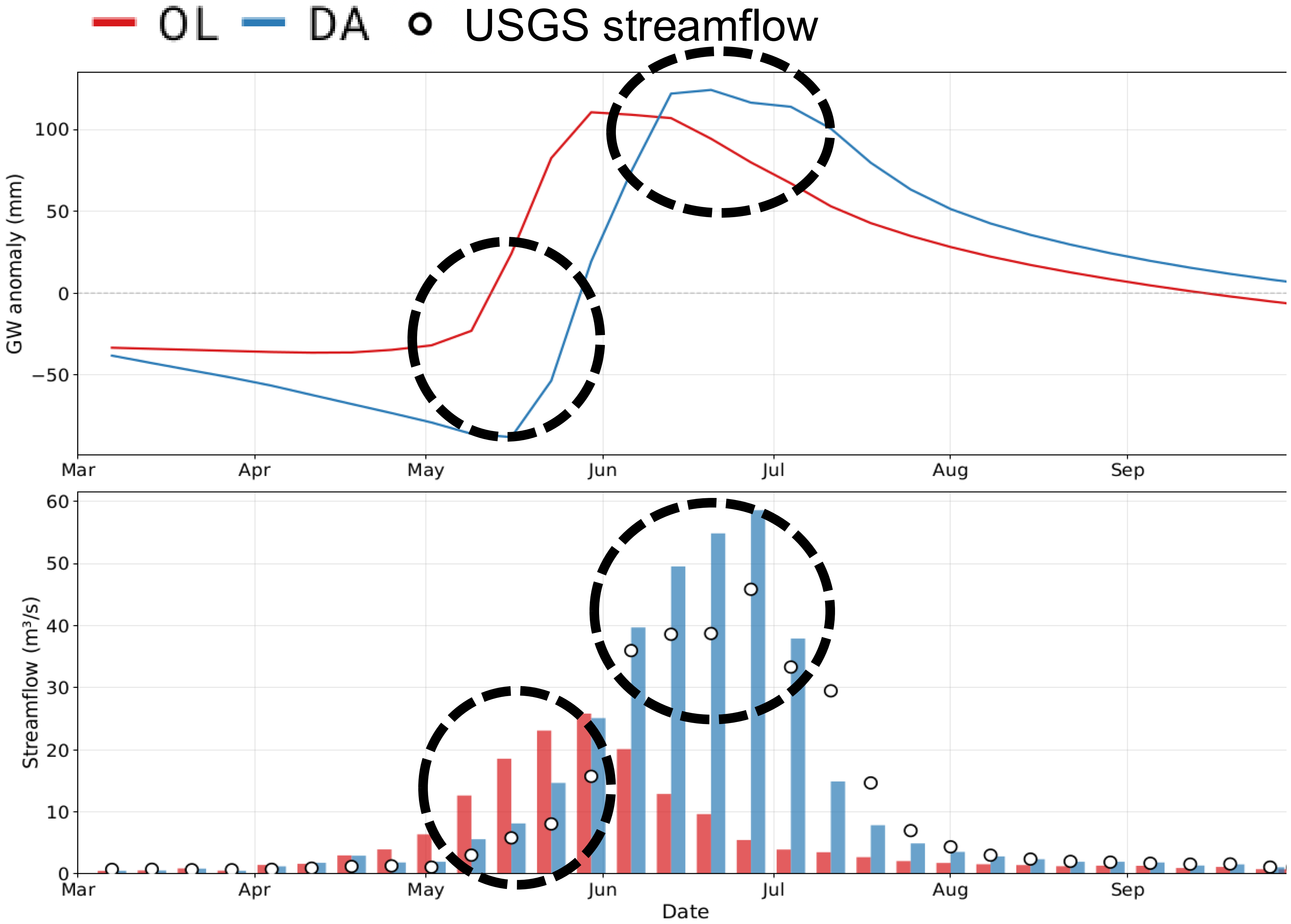
Variable	OL	DA
Antecedent GW (April)	-35.6 mm	-16.5 mm
Total Runoff Bias (May)	15.7 mm	86.9 mm
Total Runoff Bias (June)	**- 78.4 mm**	**- 2.9mm**
Total Runoff Bias (July)	- 66.5mm	- 59.0 mm
Total Runoff Bias (May – July)	**- 43.1 mm**	**8.4 mm**

Impact of GRACE-DA on 2011 Missouri River Flood

(e) USGS weekly streamflow (2011-06-week4)



Encampment River Basin (USGS 06623800)



Water Year 2011

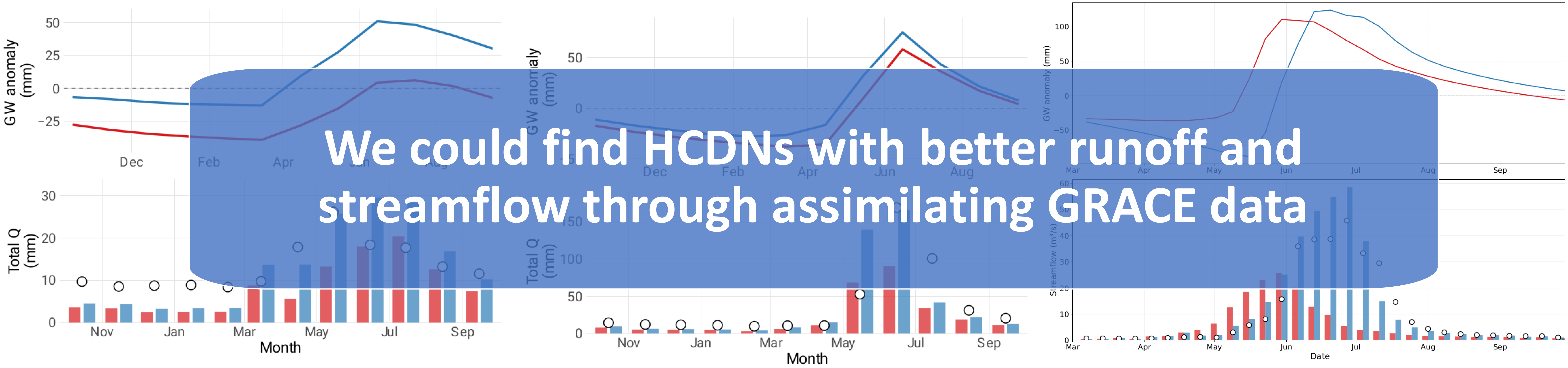
Hydrological Modeling and Analysis Platform version 3 (HyMAP-3)

- ✓ Direct comparison with USGS streamflow
- ✓ Weekly streamflow comparison

Take-home Message

Clear (Li et al., 2019; Getirana et al., 2020) | *Research Questions*

Assimilating Satellite Data into Land Surface Model → **Better Groundwater Representation** → **Better Runoff and Streamflow Simulation?**



We could find HCDNs with better runoff and streamflow through assimilating GRACE data

Future Research Directions

Expanding analysis to additional HCDN sites to better understand the impact of GRACE-DA on streamflow simulation.

Identifying historical flood events where antecedent groundwater depletion corresponded with lower streamflow.

Applying the same framework to the Red River Basin and other HUC-2 level basins across diverse hydroclimatic regimes.

Integrating USGS groundwater observations to evaluate groundwater simulation from open loop and GRACE-DA.

GODDARD EARTH SCIENCES

Question and Answer

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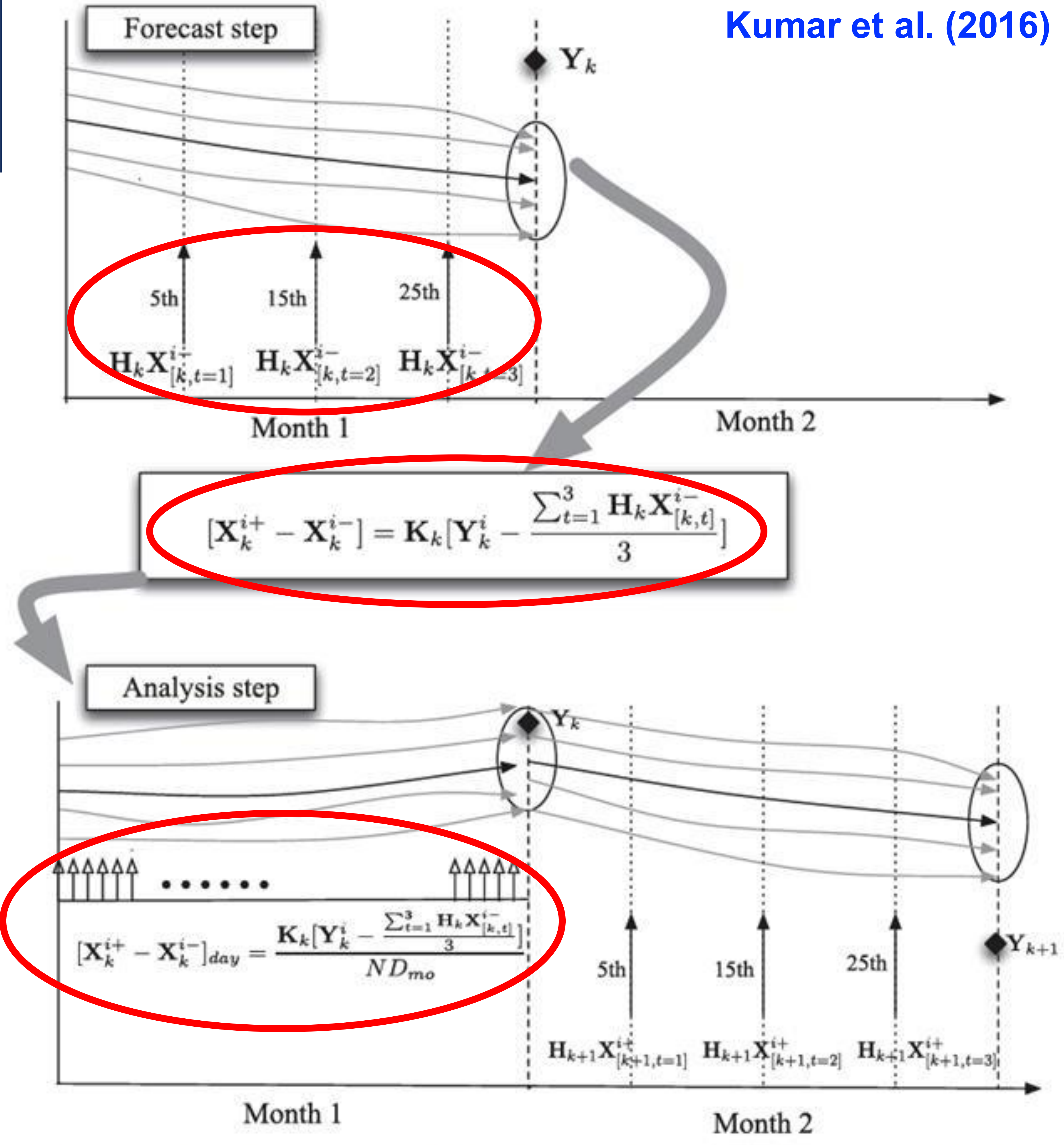
GRACE-DA Process: Ensemble Kalman Smoother

1) Each month, the model predicts TWS by averaging the simulated daily values from the 5th, 15th, and 25th days.
2) This prediction is then compared with GRACE observations, and increments are estimated based on Kalman Gain.
3) The increment is then applied to the model's daily TWS for the entire month (from day 1 through the last day).

Kumar et al. (2016)



Study Area: Missouri River Basin

Noah-MP Simulation Results

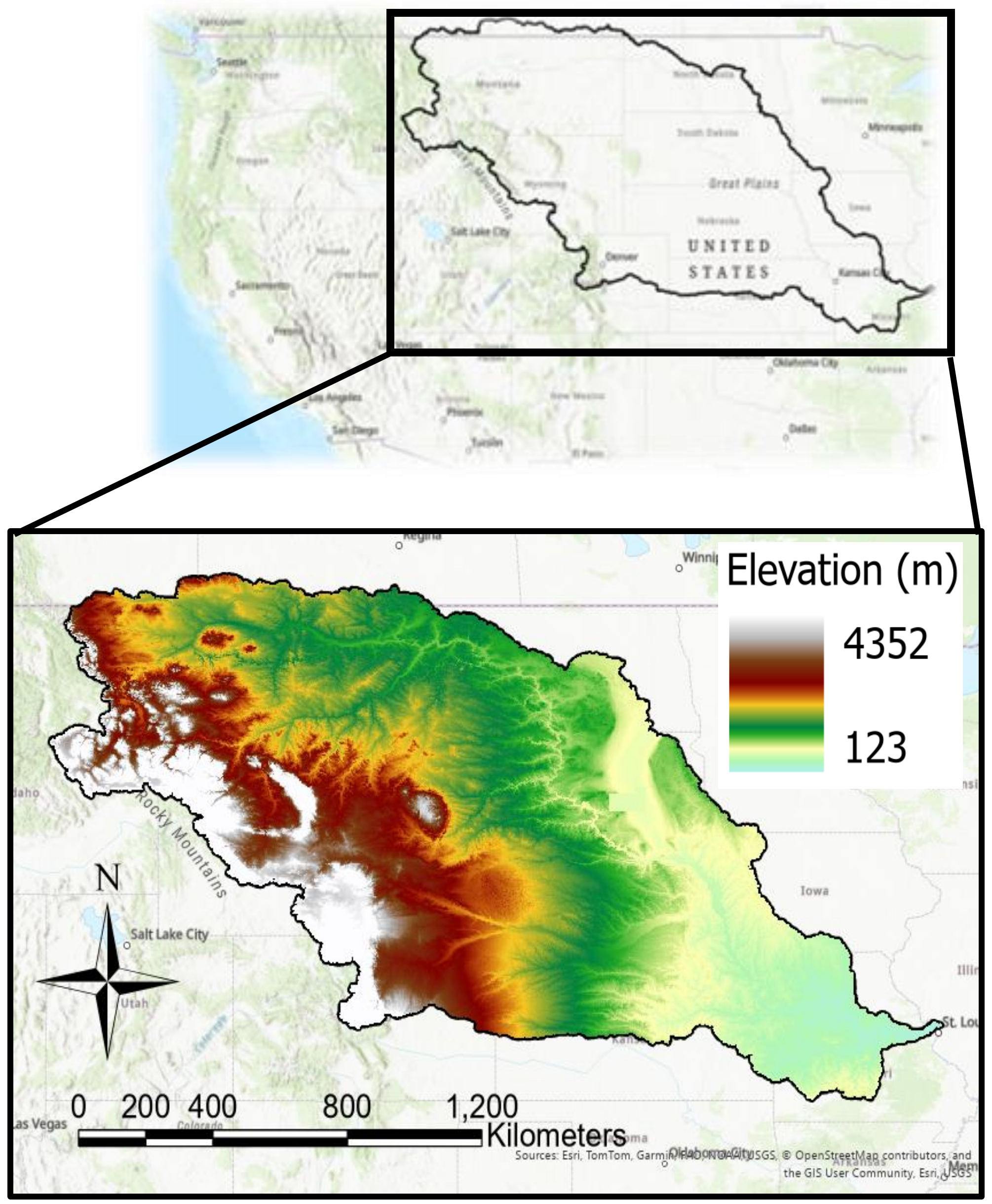
- Forcing Data: North American Land Data Assimilation System (NLDAS-2)
- Temporal Resolution: Daily
- Spatial Resolution: 0.125° × 0.125°
- Period: 2014-01-01 to 2023-12-31

USGS Streamflow Observation

- 50 Hydro-Climatic Data Network
- Temporal Resolution: Daily
- Period: 2014-01-01 to 2023-12-31

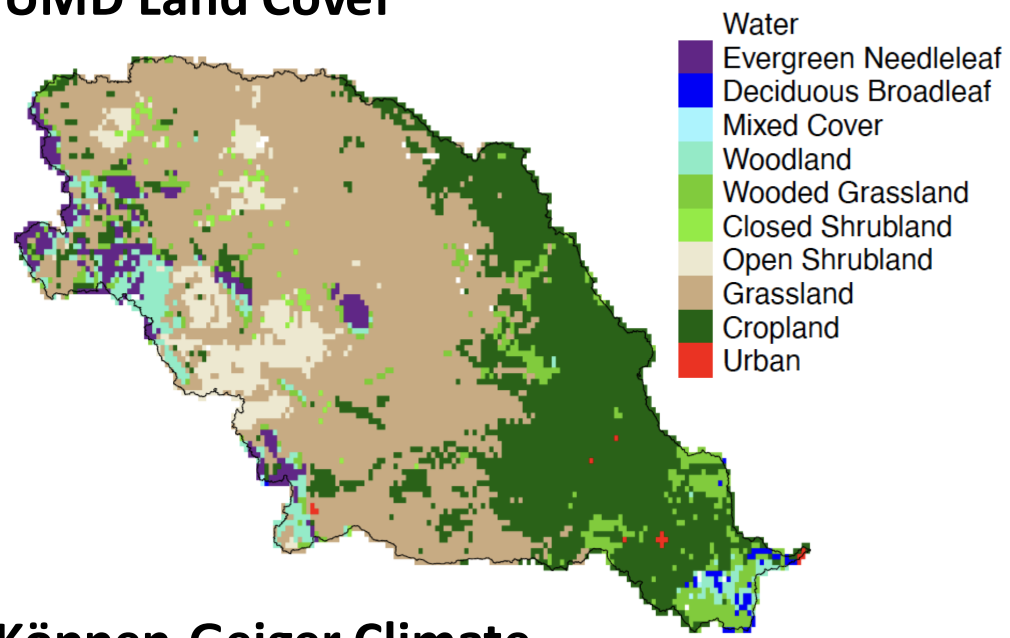
Snow Water Equivalent data

- University of Arizona SWE
- Temporal Resolution: Daily
- Spatial Resolution: 4 km × 4 km
- Period: 2014-01-01 to 2023-12-31

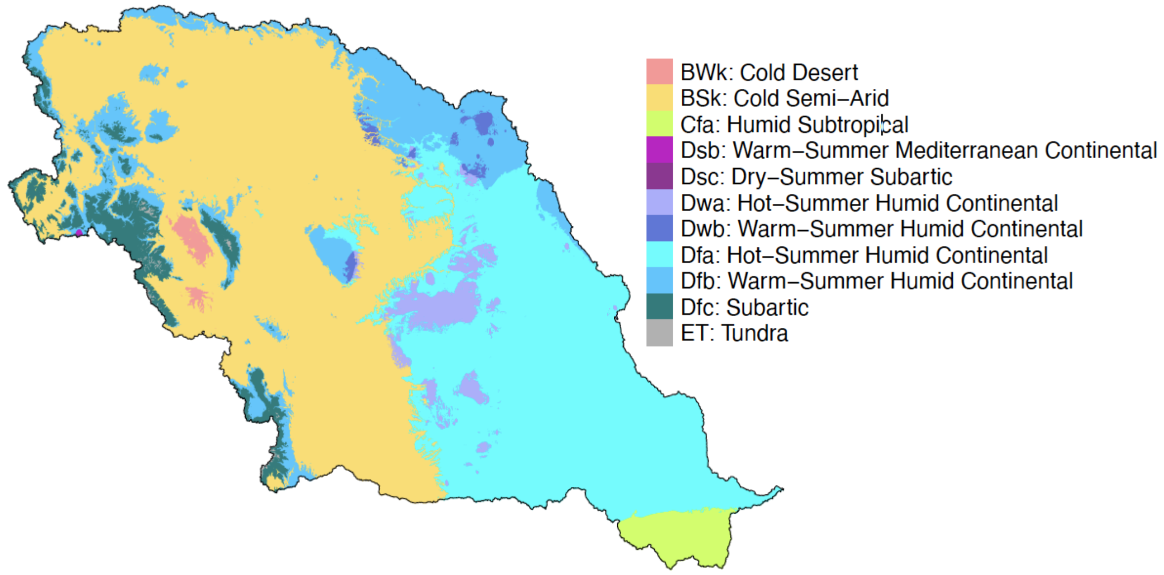


Missouri River Basin with Digital Elevation Model

UMD Land Cover



Köppen-Geiger Climate



Sturm Snow Classification