Global high-resolution water storage simulations from the OS LISFLOOD hydrological model

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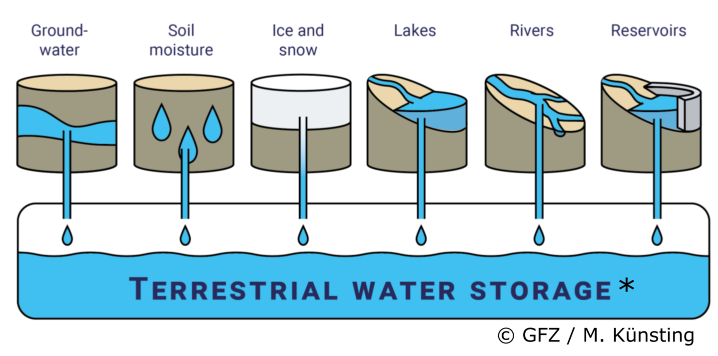
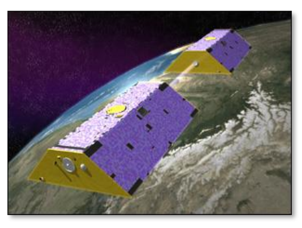
Overview

We globally evaluate terrestrial water storage (TWS) from the **hydrological model OS LISFLOOD**[1] with observations from **GRACE/-FO, GNSS** and **gauging stations**. We compare the results to older model data from the Land Surface Discharge Model (LSDM) and investigate the influence of the choice of the soil depth on TWS and discharge.





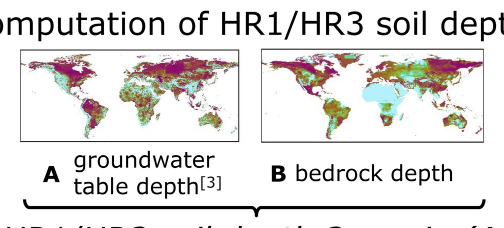
* expressed in equivalent water height (1m ≙ 1000 kg/m²)

Hydrological model OS LISFLOOD

- developed by the Joint Research Centre (JRC) of the European Commission, open-source software
- in operational use for the Global Flood Awareness System (GloFAS) of the Copernicus Emergency Management Service (CEMS)

Model setup:
- *Forcing: ERA5*
- *Resolution: 0.1°/0.05°/daily*
- *Pre-run: 23yrs (2000 – 2022)*
- *Initialization: 1990 – 1999*
- *Warm-run: 2000 - 2022*

Computation of HR1/HR3 soil depth:



HR1/HR3 soil depth 3 = min (A,B)

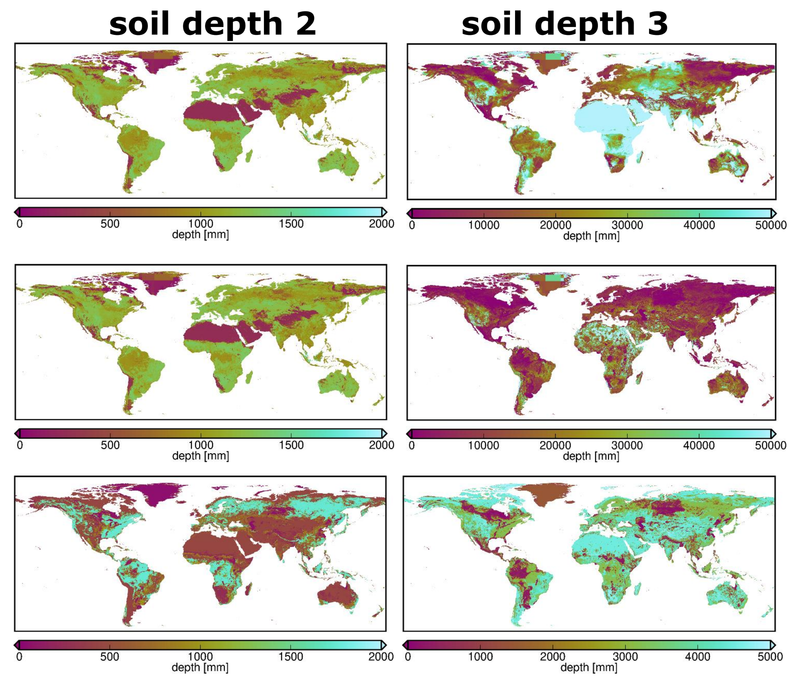
We perform **five OS LISFLOOD runs**, which differ in their model version (LR/HR), in the soil depth distribution (HR0/HR1/HR2), and in the initialization routine (HR3).

LR low resolution (1/10°) input fields from CEMS GloFAS v3.0 (deprecated)

HR0 high resolution (1/20°) with soil maps from v1.1.0 of LISFLOOD static and parameter maps for GloFAS[2]
max. soil 2: 3m
max. soil 3: 645m

HR1 with revised computation of the depth of the third soil layer[2,3]
max. soil 2: 3m
max. soil 3: 289m

HR2 with soil maps from low resolution (1/10°) OS LISFLOOD
max. soil 2: 1.7m
max. soil 3: 5m



HR3 same as HR1 but with optimized initialization routine (provided by JRC)

Influence of soil depth on modelled Terrestrial Water Storage (TWS)

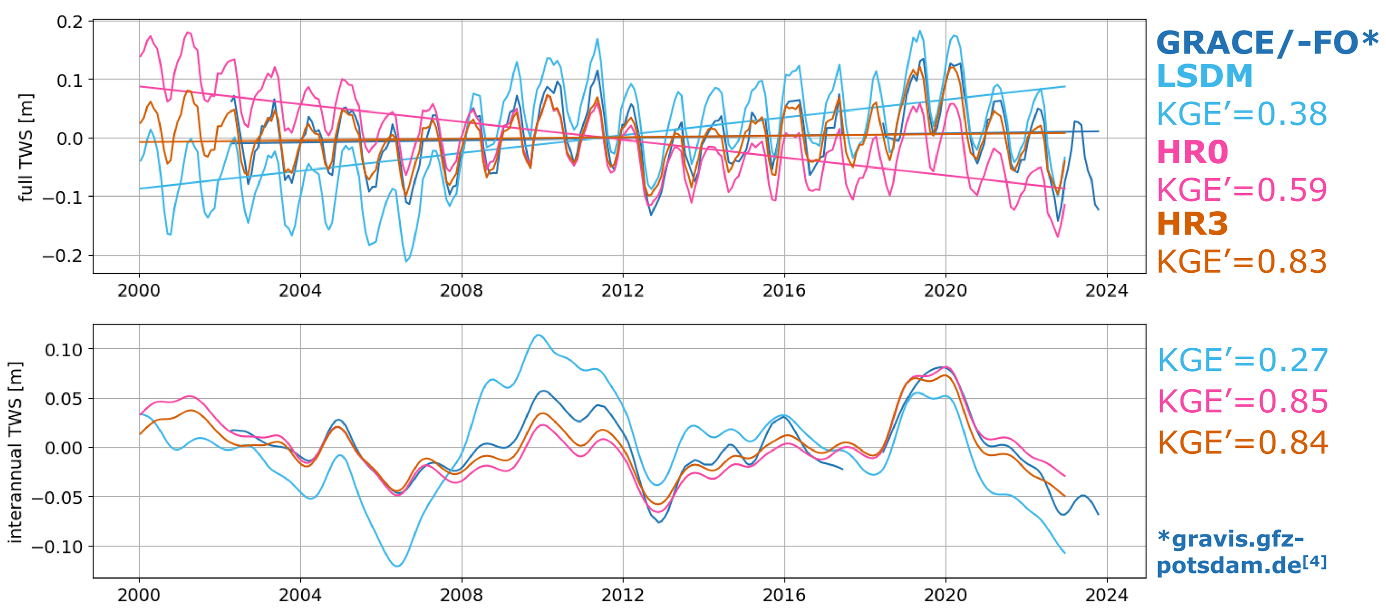


Fig.1: TWS time series for the Mississippi river basin; full and interannual signal

Modified Kling-Gupta efficiency (KGE')
combined difference to observations w.r.t. correlation, bias error and variability error; optimum value of 1.

$$KGE' = 1 - \sqrt{(\rho-1)^2 + (\beta-1)^2 + (\gamma-1)^2}$$

$$\beta = \mu_s/\mu_o \qquad \gamma = \frac{\sigma_s/\mu_s}{\sigma_o/\mu_o}$$

ρ = Pearson correlation coefficient, β = bias ratio, γ = variability ratio; s = simulation, o = observation, μ = mean, σ = std. dev.

Time series averaged over river basins (*Fig. 1*) show **spurious linear trends** for model TWS computed with OS LISFLOOD standard soil maps (HR0). The trend mainly stems from the third soil layer.

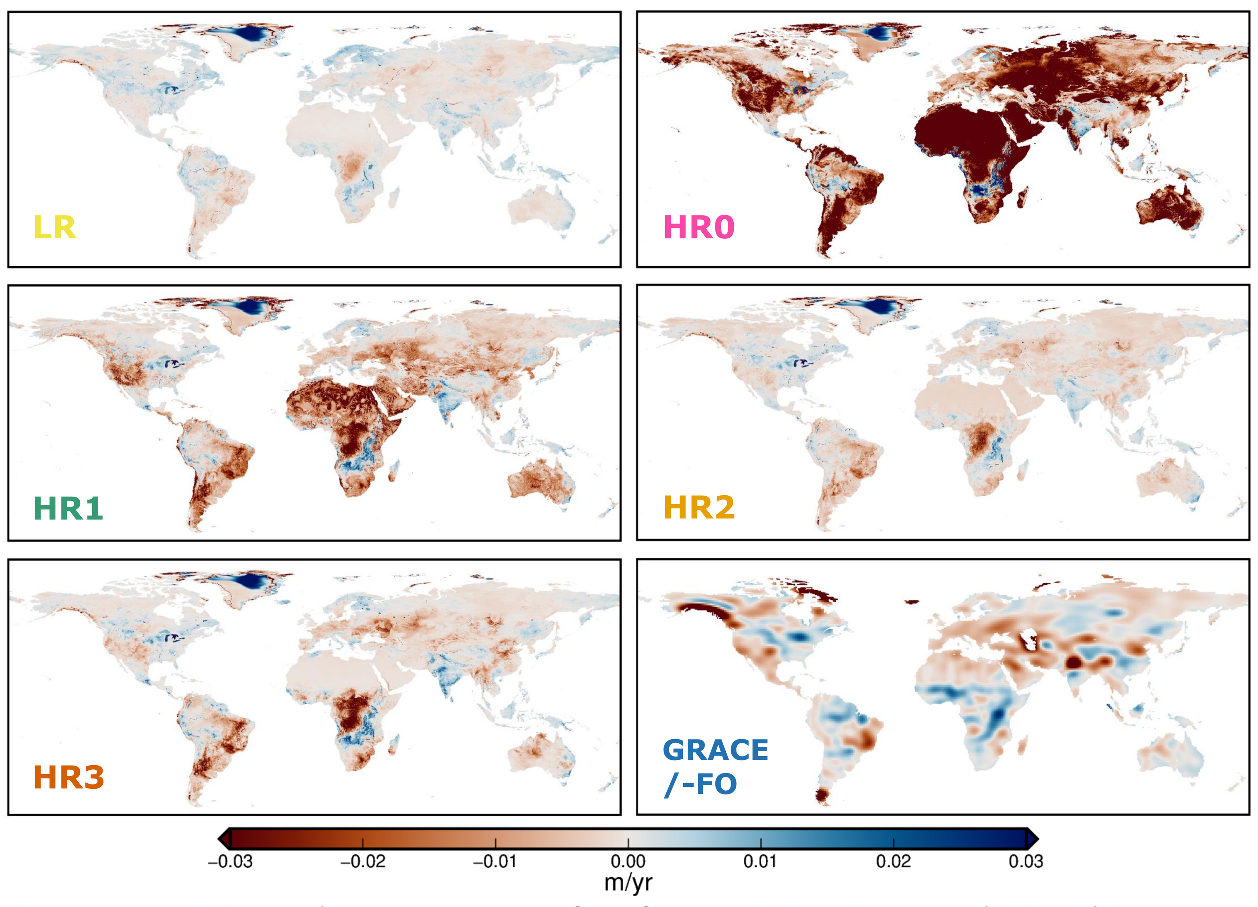


Fig. 2: Linear TWS trend over 2000 – 2022 from five OS LISFLOOD runs and GRACE/-FO.

Comparing modeled and observed discharge at 1538 gauging stations shows that using HR2 soil maps leads to significantly deteriorated results compared to using HR0 or HR1 soil maps (*Fig. 3*). Thus, HR2 is dismissed.

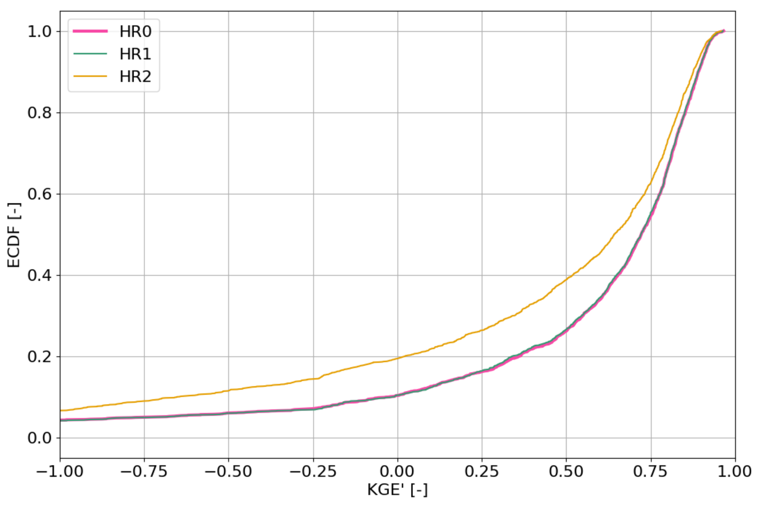
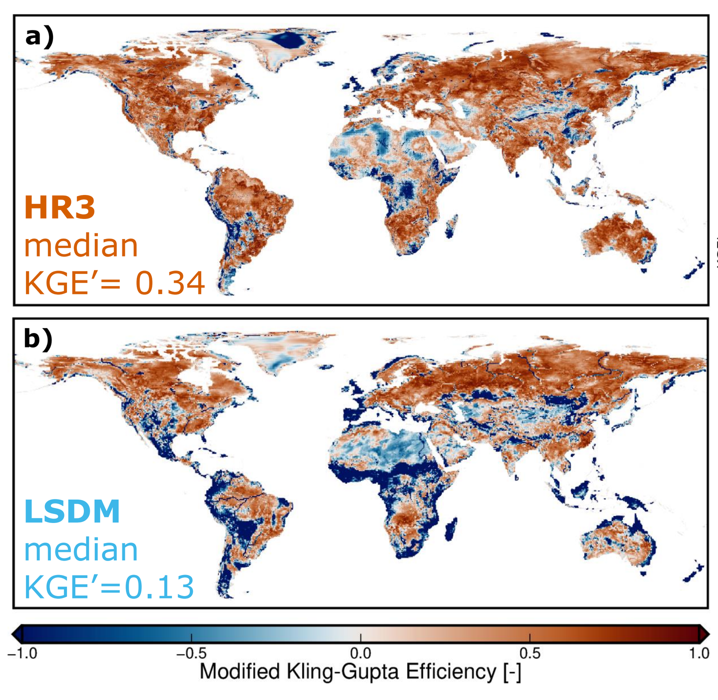


Fig. 3: Empirical cumulative density function for KGE' between observed discharge and OS LISFLOOD HR0, HR1, HR2 discharge.

Modifying the soil depth map has a strong impact on TWS trends (*Fig. 2*). Compared to HR0, the spurious TWS trends are reduced for HR1 and even more for HR2 and HR3. The impact of an improved initialization routine is demonstrated with HR3.

Evaluation with GRACE/-FO



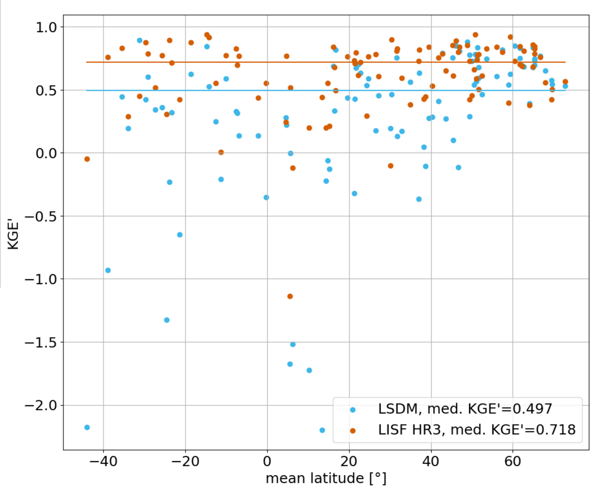


Fig. 4: KGE' for OS LISFLOOD HR3 and LSDM w.r.t. GRACE/-FO (interannual signal) for the 100 largest river basins

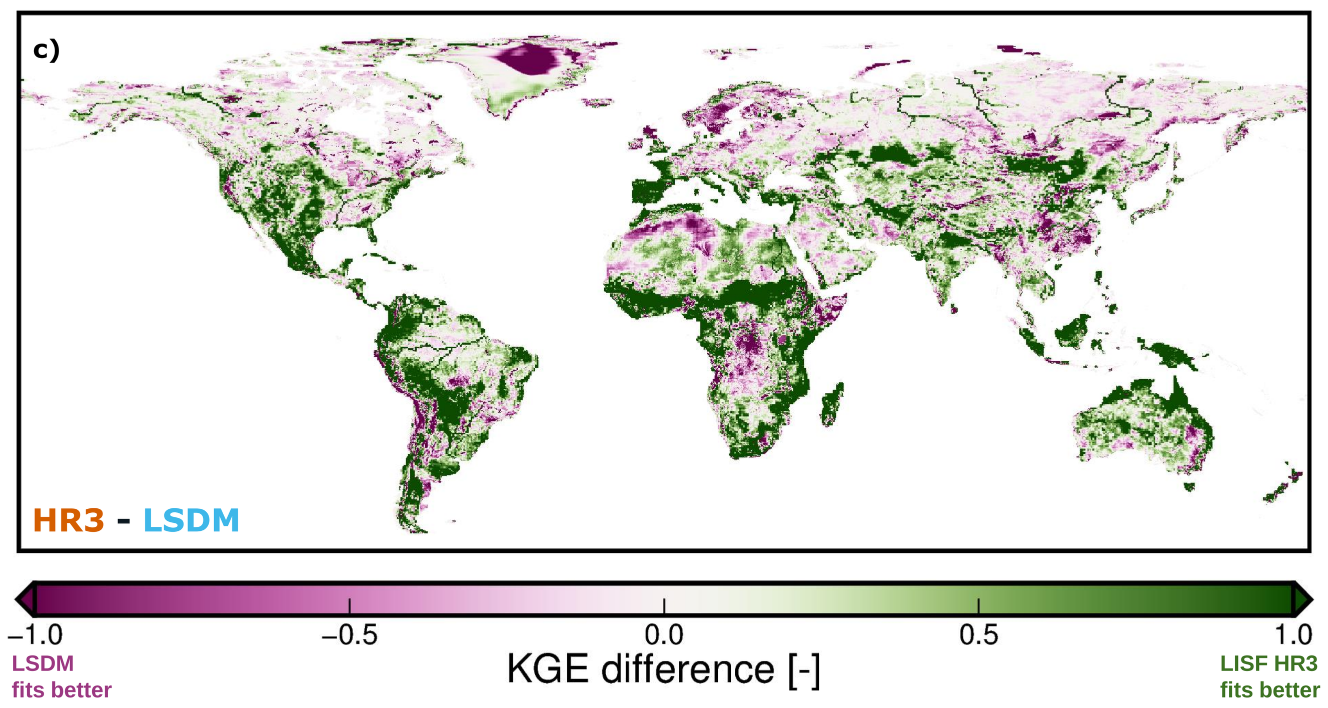


Fig. 5: Global maps of KGE' for the interannual signal of (a) OS LISFLOOD HR3 and (b) LSDM w.r.t. GRACE/-FO, and (c) KGE' difference between (a) and (b).

OS LISFLOOD HR3 outperforms LSDM in many regions on interannual time scales, especially south of 40°N (*Figs. 4 & 5*).

Evaluation with GNSS

To demonstrate the **advantage of the high resolution** we compute vertical displacements from model TWS and compare them to GNSS uplift data.

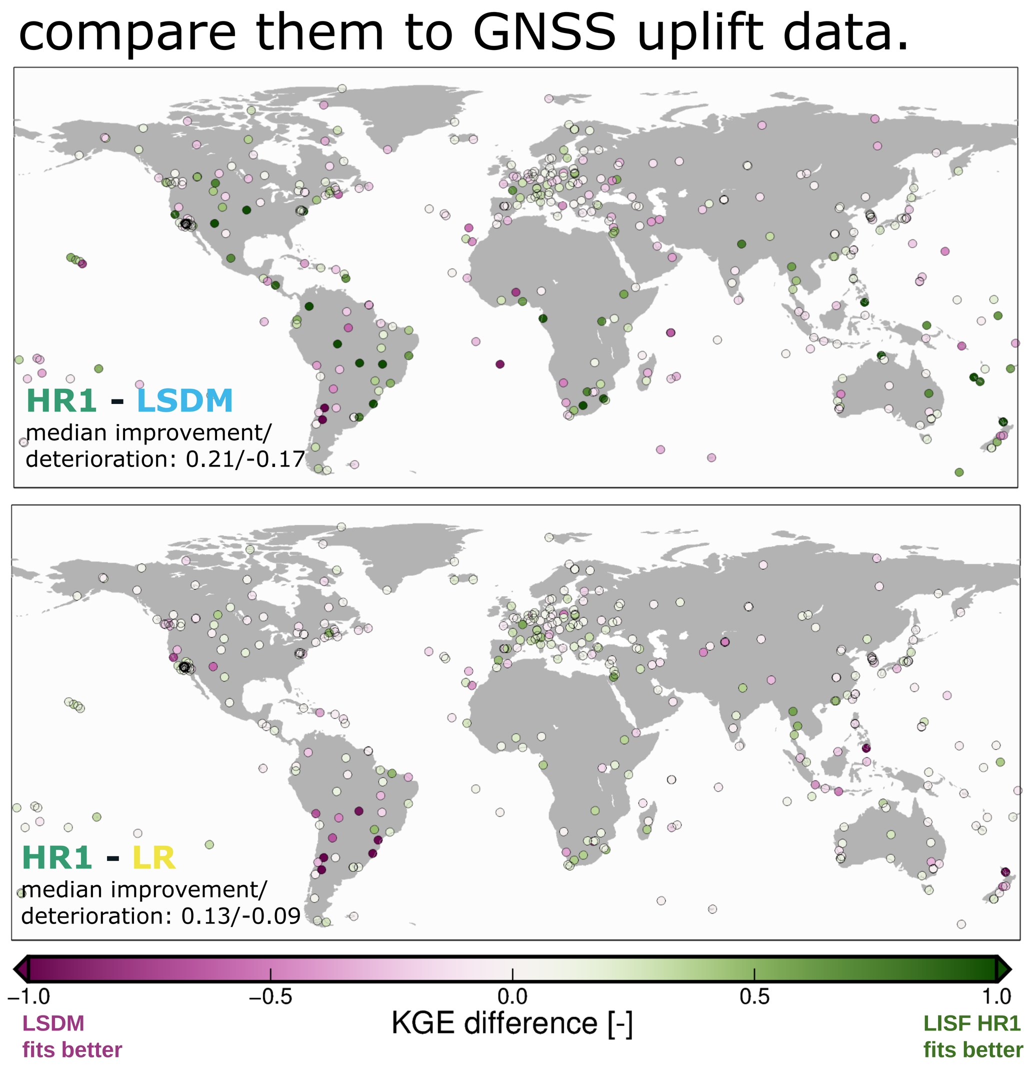


Fig. 6: KGE differences between vertical displacements from OS LISFLOOD HR1 and (top) LSDM and (bottom) OS LISFLOOD LR, w.r.t. GNSS observations; interannual frequency band

Vertical displacements
GNSS: from IGS repro 3 (input for ITRF2020), ~500 stations
OS LISFLOOD/LSDM: Load Greens functions using ak135 1D spherical Earth model

In 59% (55%) of the stations the interannual GNSS signal is better described by HR1 than by LR (LSDM, *Fig. 6*).

Conclusions

- High-resolution (1/20°) global daily TWS simulations for 2000 – 2022 are generated with open source model OS LISFLOOD
- Soil depth definition has significant impact on long-term trends in TWS
- Validation with independent observations (GRACE/-FO & GNSS) reveals that OS LISFLOOD outperforms LSDM in several regions
- Small advantage of HR over LR

Article submitted: Jensen, L., Dill, R., Balidakis, K., Grimaldi, S., Salamon, P. & Dobslaw, H. (under review). Global 0.05° Water Storage Simulations with the OS LISFLOOD Hydrological Model for Geodetic Applications.

Next steps:
- Long model run (from 1960)
- Include anthropogenic water use
- Investigate lakes & reservoirs
- Include endorheic lakes

References
[1] Van Der Knijff, J. M., Younis, J., & De Roo, A. P. J. (2010). LISFLOOD: a GIS-based distributed model for river basin scale water balance and flood simulation. International Journal of Geographical Information Science, 24(2), 189–212. doi: 10.1080/13658810802549154
[2] Choulga, M., Beck, H., Moschini, F., Mazzetti, C., Disperati, J., Grimaldi, S., Salamon, P., & Prudhomme, C. (2023). LISFLOOD static and parameter maps for GloFAS. European Commission, Joint Research Centre (JRC) [Dataset]
PID: http://data.europa.eu/89h/68050d73-9c06-499c-a441-dc5053cb0c86
[3] Fan, Y., Li, H., & Miguez-Macho, G. (2013). Global Patterns of Groundwater Table Depth. Science, 339(6122), 940–943. doi: 10.1126/science.1229881
[4] Boergens, E., Dobslaw, H., & Dill, R. (2019). GFZ GravIS RL06 Continental Water Storage Anomalies. GFZ Data Services. doi: 10.5880/GFZ.GRAVIS06L3TWSGravis

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