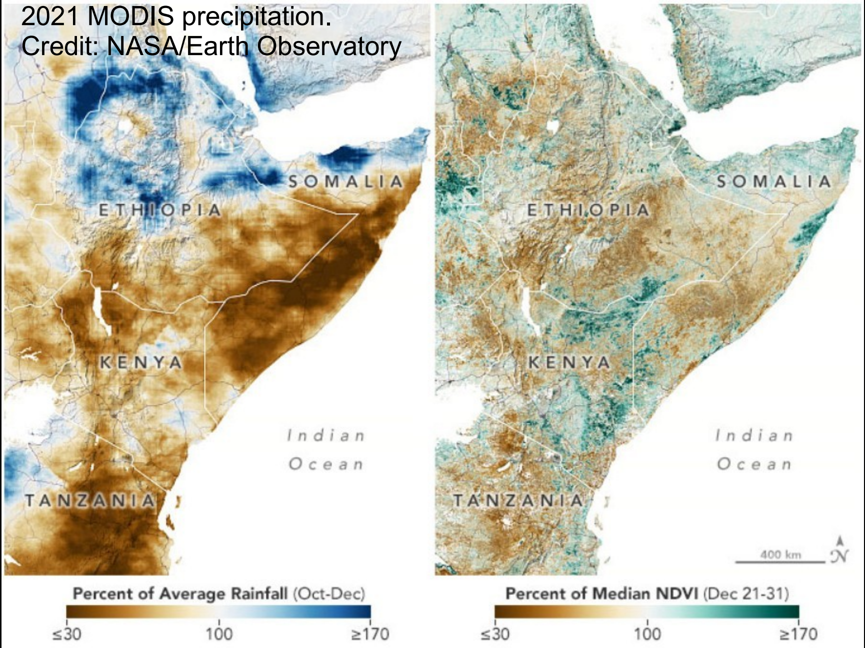
A new look at the closure of the water balance for large watersheds using satellite gravimetry, reanalysis, and river discharge

R. Rietbroek, M. Penning de Vries, Y. Zeng, Z. Su



Deceased giraffes in dried up mud pool, Northern Kenya, March 2022, nos.nl

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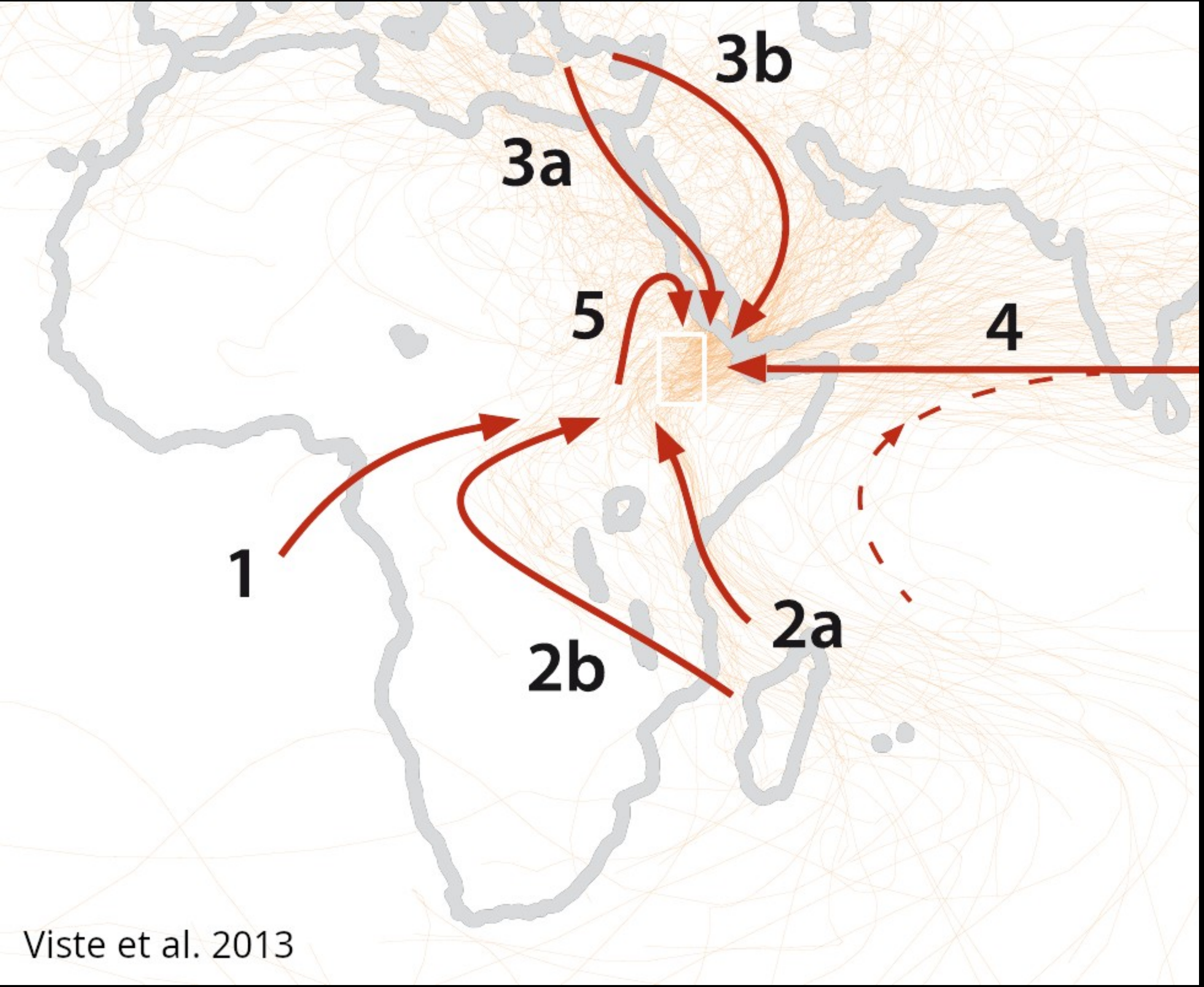
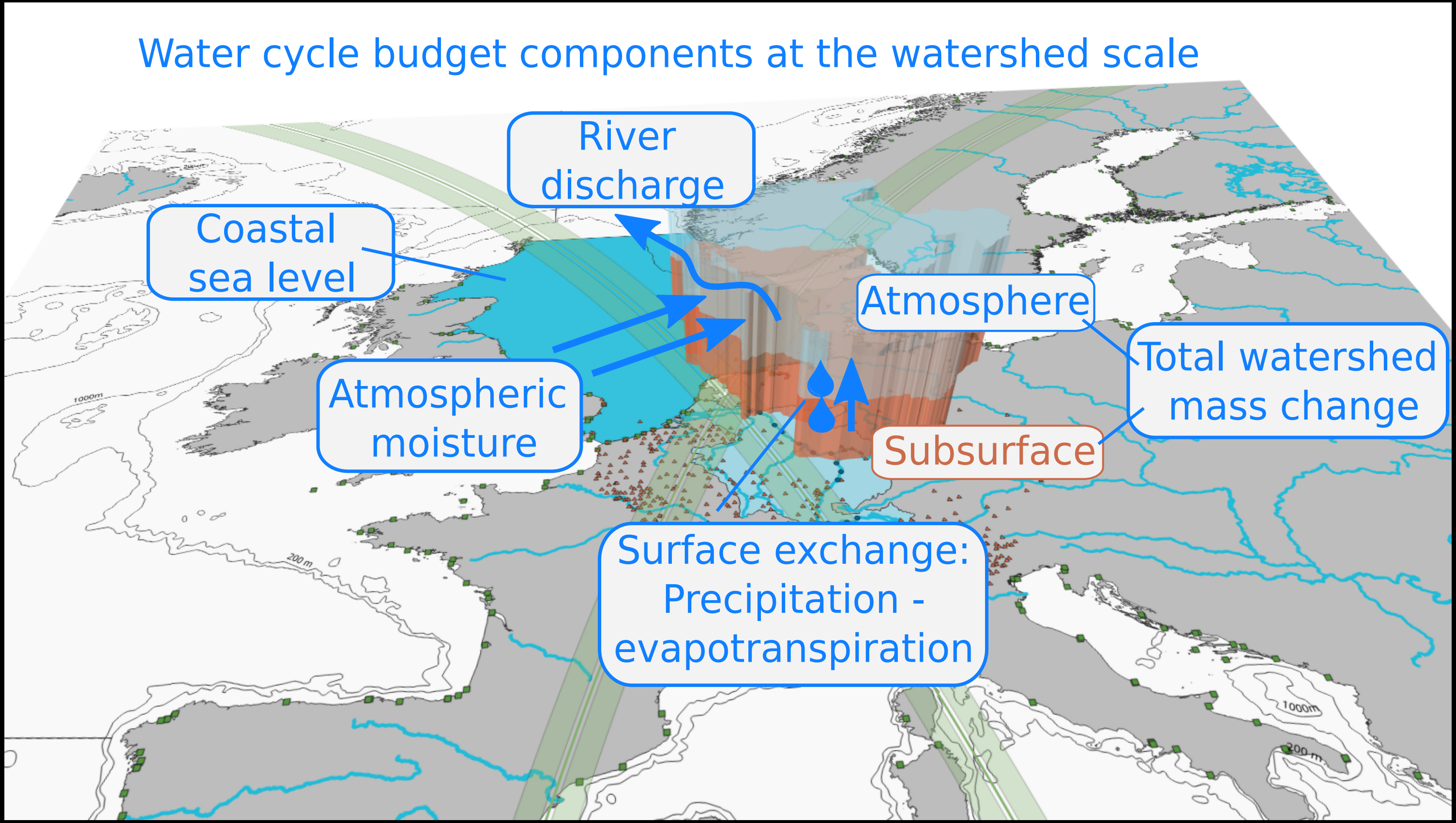
Example: the birthplace of Ethiopian rains

- Water enters a basin through several pathways
- Drought => too little water entering & 'sticking' in a basin
- Currently: transport from Indian Ocean is weak (2a, 2b)



Idea: Check mass balance consistency of watersheds



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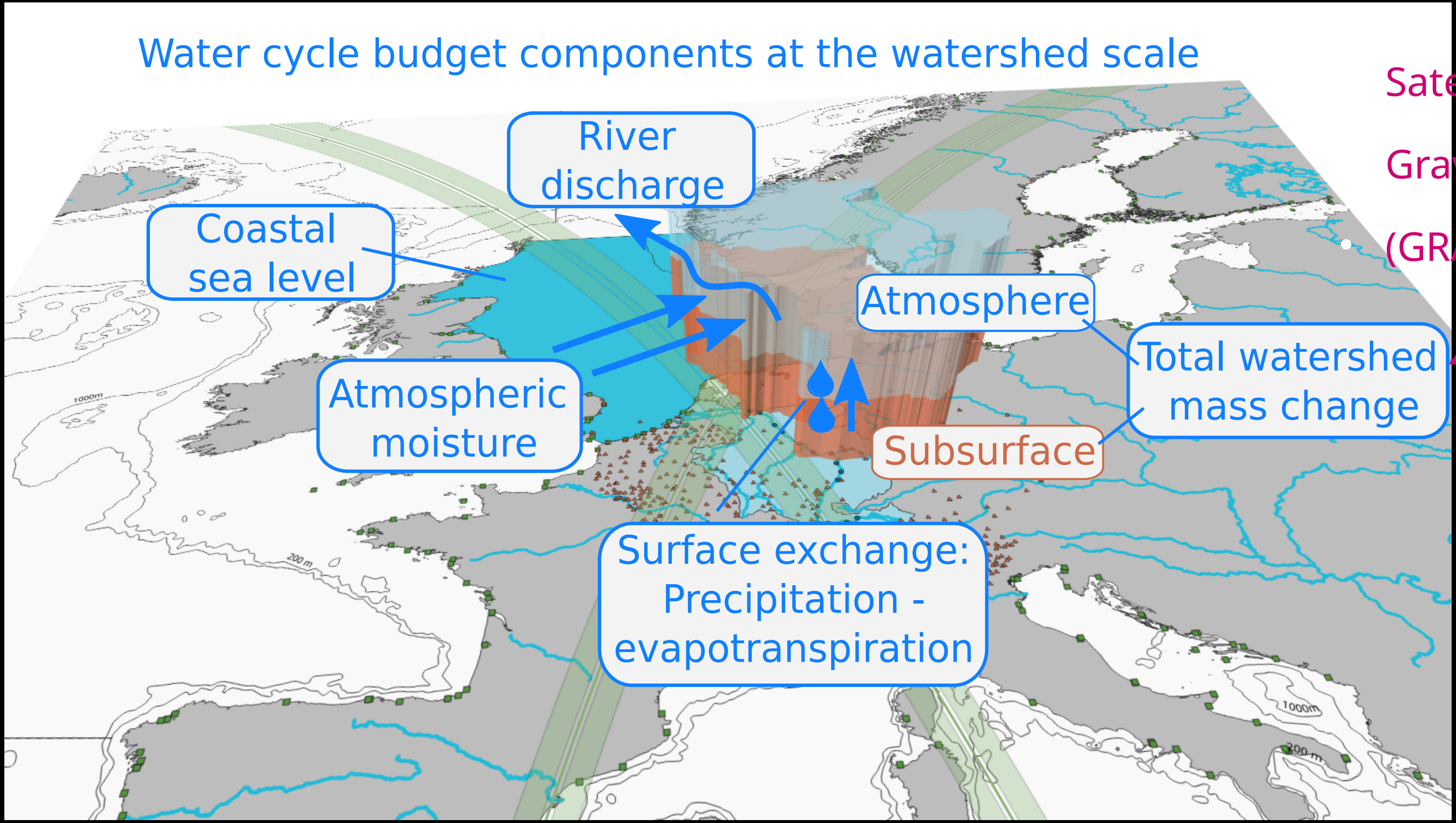

Satellite

Gravimetry

(GRACE/GRACE-FO)

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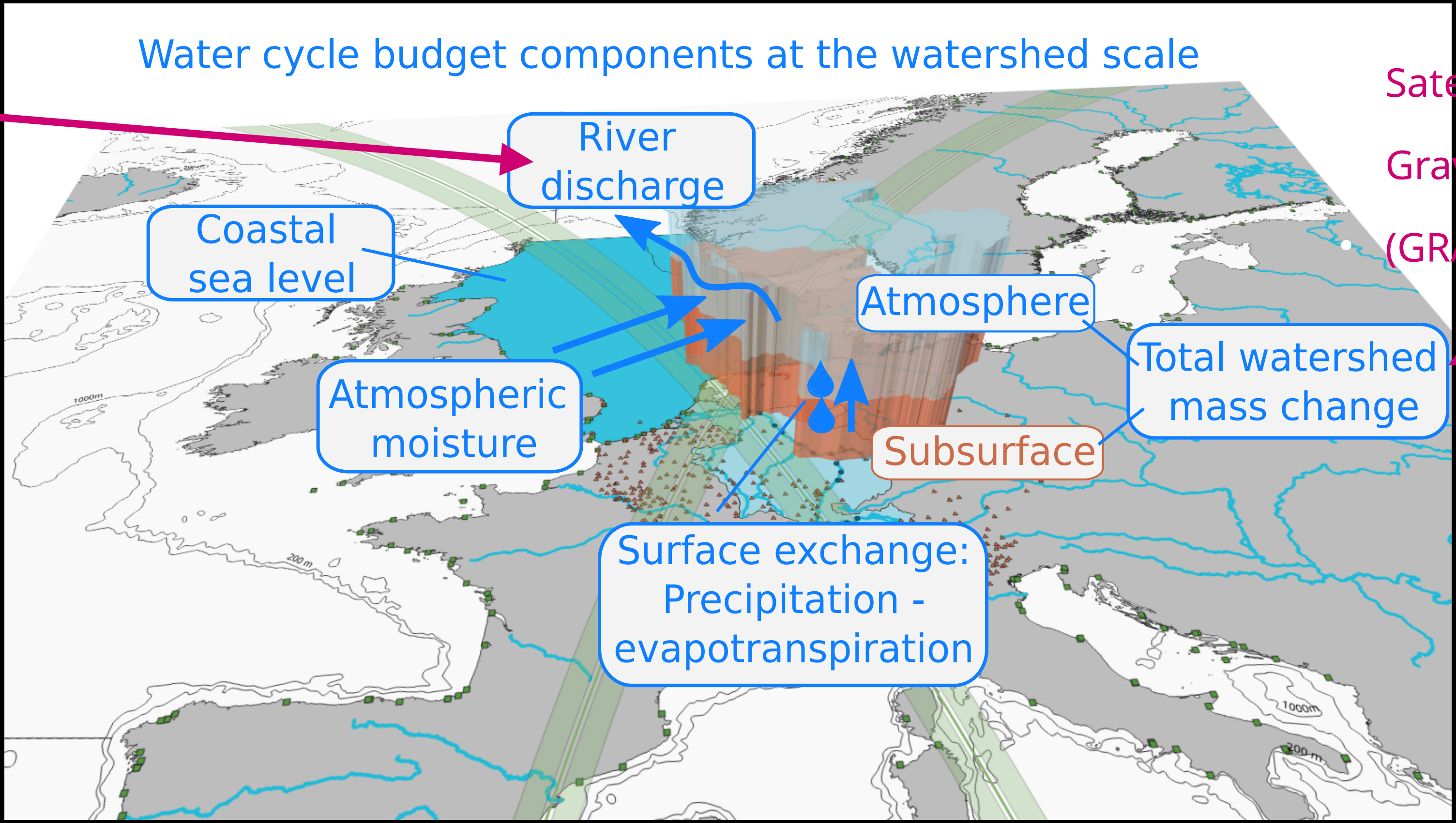
Glofas



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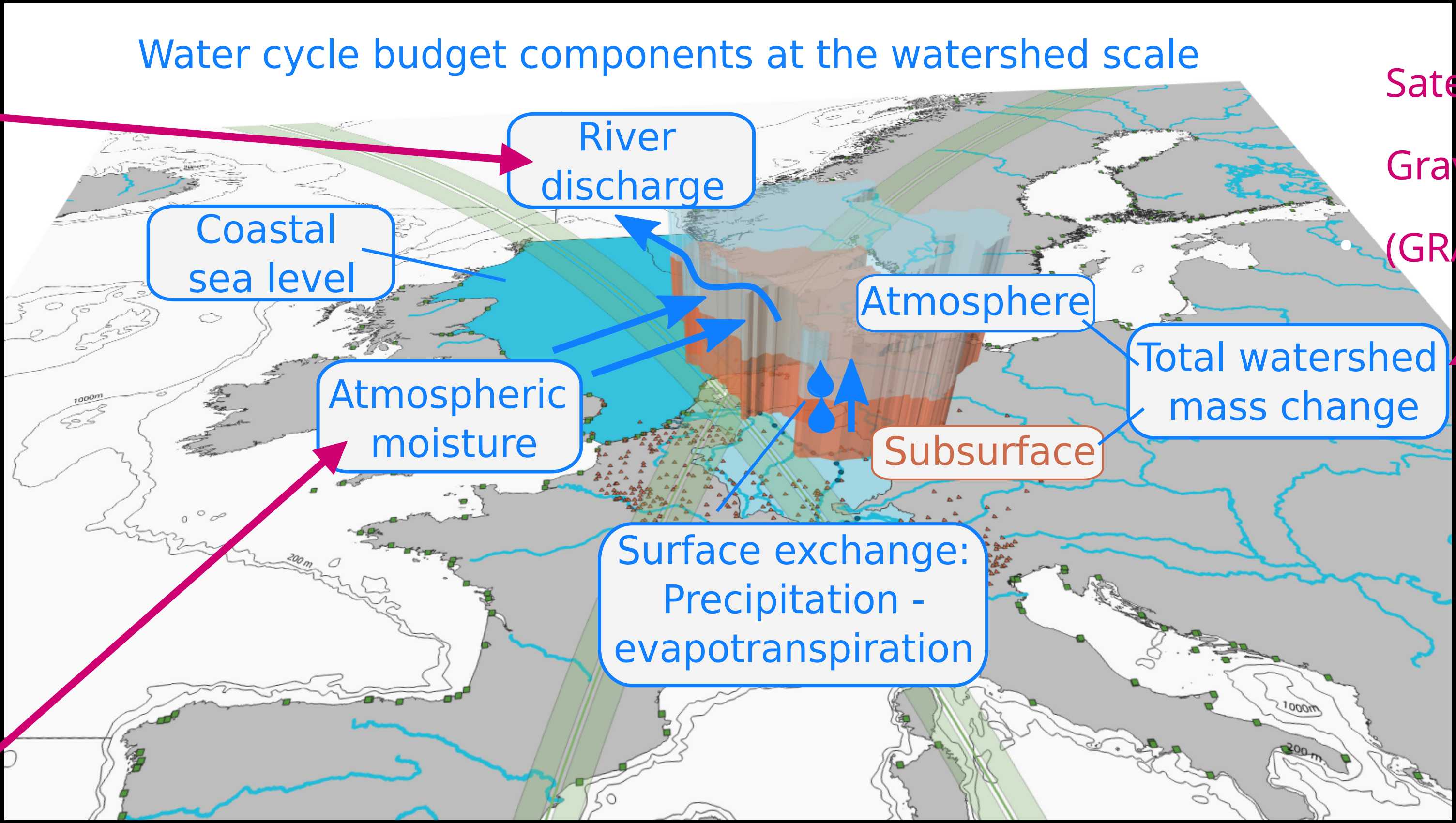

Satellite

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ERA5

Starting point: Water balance equation

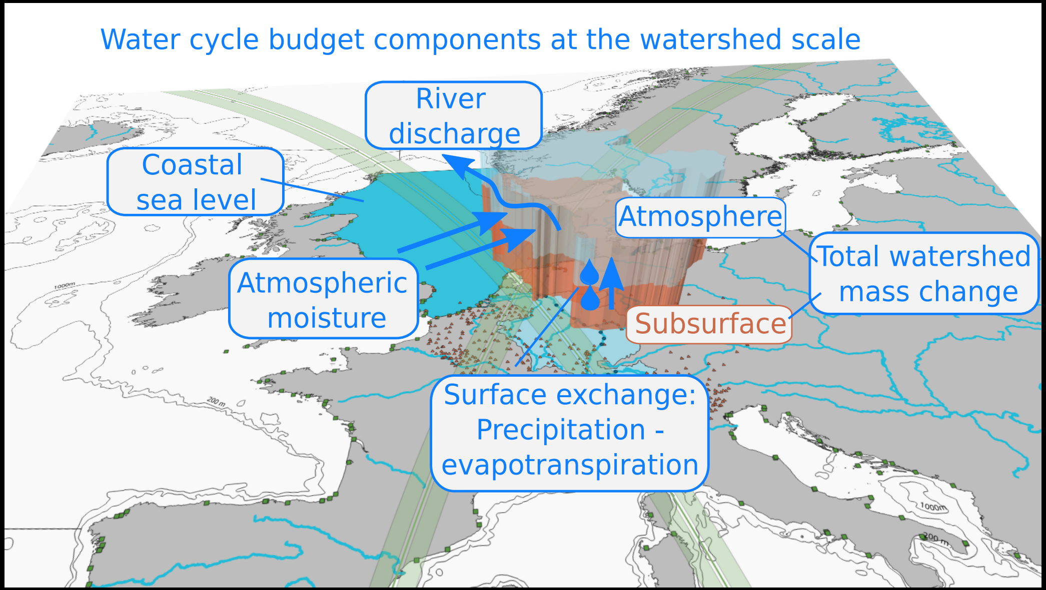
Moisture flux

Subsurface flows

$$\frac{dS}{dt} = Q - R - \cancel{F_{sub}}$$

Total water storage change rate

River discharge



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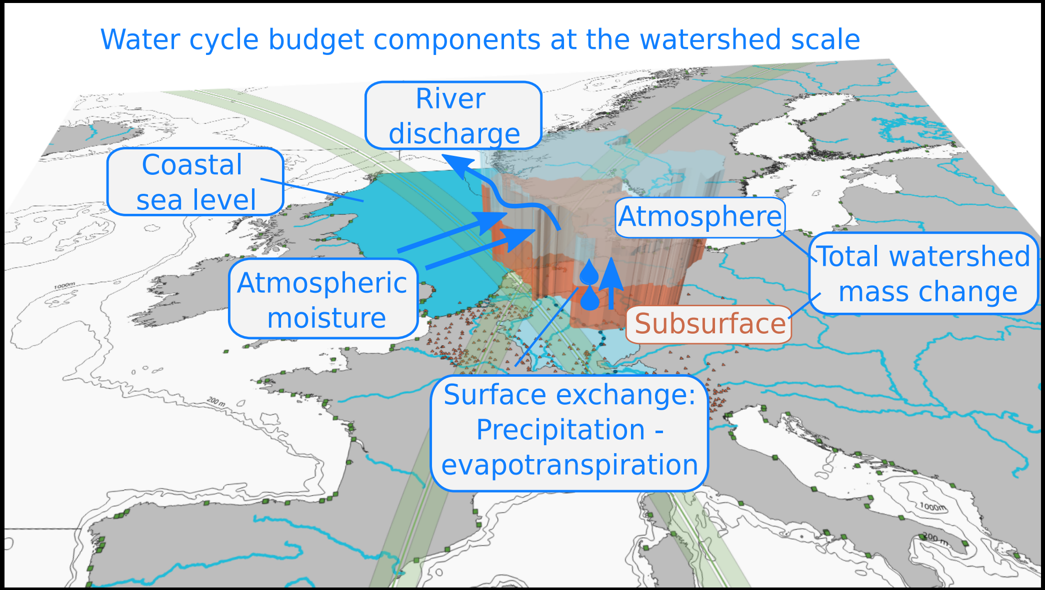
- Comparison with GRACE:
  - Differentiate or integrate:



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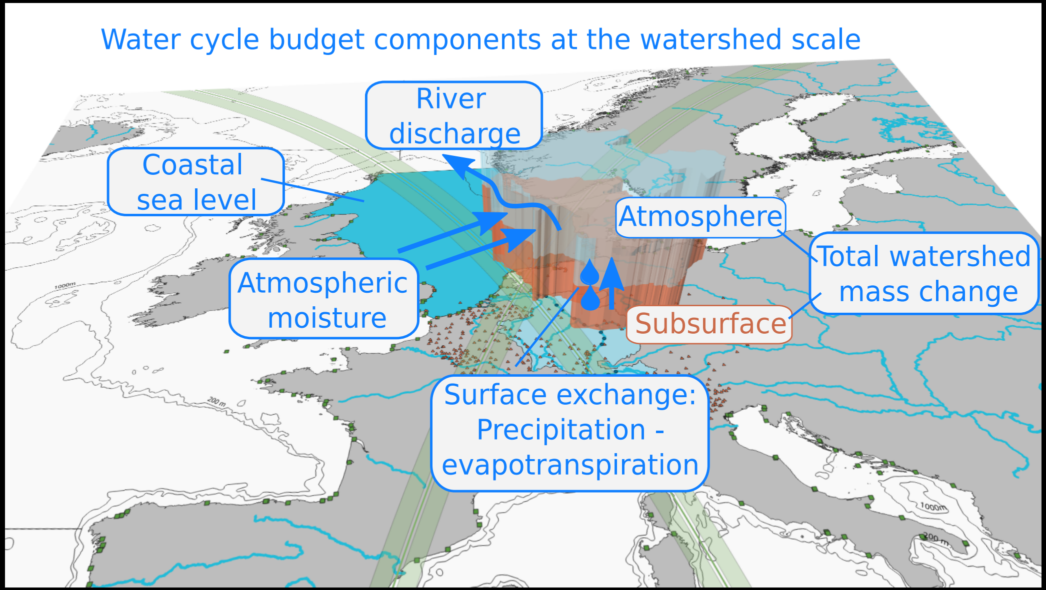
$$S(t) = \int_0^t (Q - R)\, dt'$$

GRACE ERA5 Glofas



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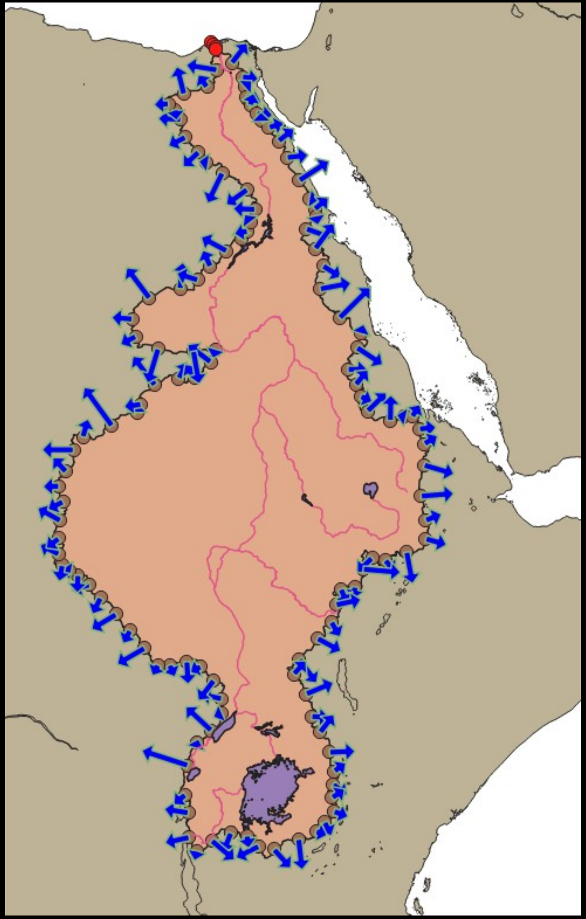
Integrate ERA5 moisture flux

- Get ERA5 monthly averages up to 300hPa (humidity, wind vectors, temperature,cloud water content)
- Compute basin normal vectors (123 basins)
- Compute total density (Using Magnus relation)
- Integrate over boundary and height to get flux (kg/s):

$$Q_W^{vapour} = \int_W \int_0^{300hPa} h_{spec}(z,s)\rho_{tot}(z,s)\boldsymbol{n}\cdot\boldsymbol{v}dzds$$

- Similar for liquid,ice (but that contribution is much smaller than vapour)



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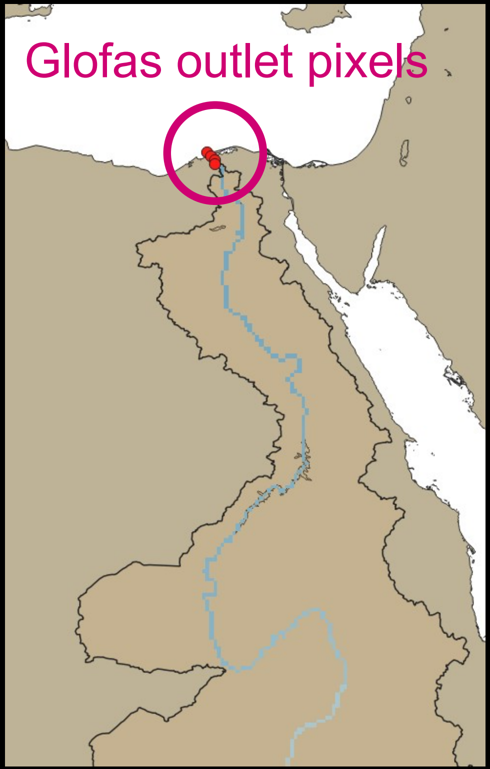
GLOFAS: Obtaining a consistent basin discharge estimate

- Glofas (Global Flood Awareness System) historical daily discharge
- Forced with ERA5 surface fluxes
- Query glofas pixels with largest upstream areas per basin
- Extract daily discharge, R (m3/s)



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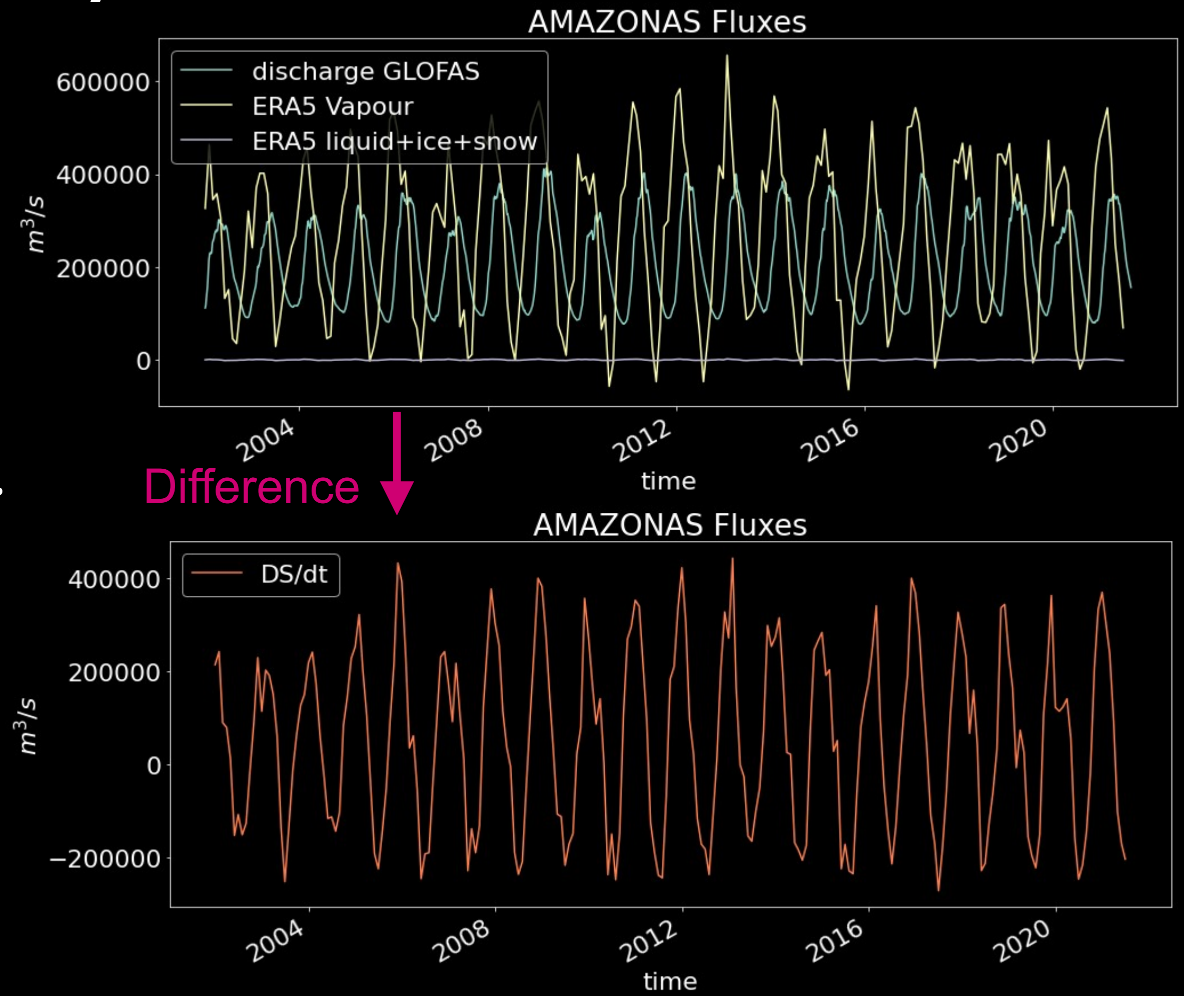
Sanity check

- Expected: Water vapour flux shows largest variations
- Expected: Discharge lags atmospheric influx
- But: no consistency in mean..
- Will accumulate when integrated over time
  - "solution": Adapt mean to match glofas



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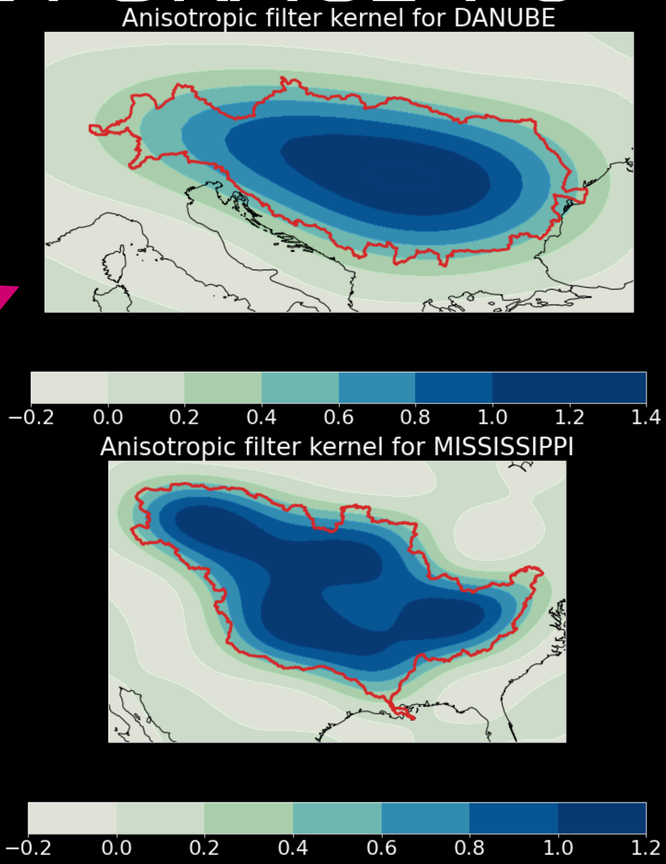
Basin averaged total water storage from GRACE /GRACE-FO

- JPL RL06, Stokes coefficients (max degree=96)
- Restore atmosphere component + degree 1 & 2 corrections
- Anisotropic filter (DDK5)
- Average per basin
- No rescaling for possible attenuation

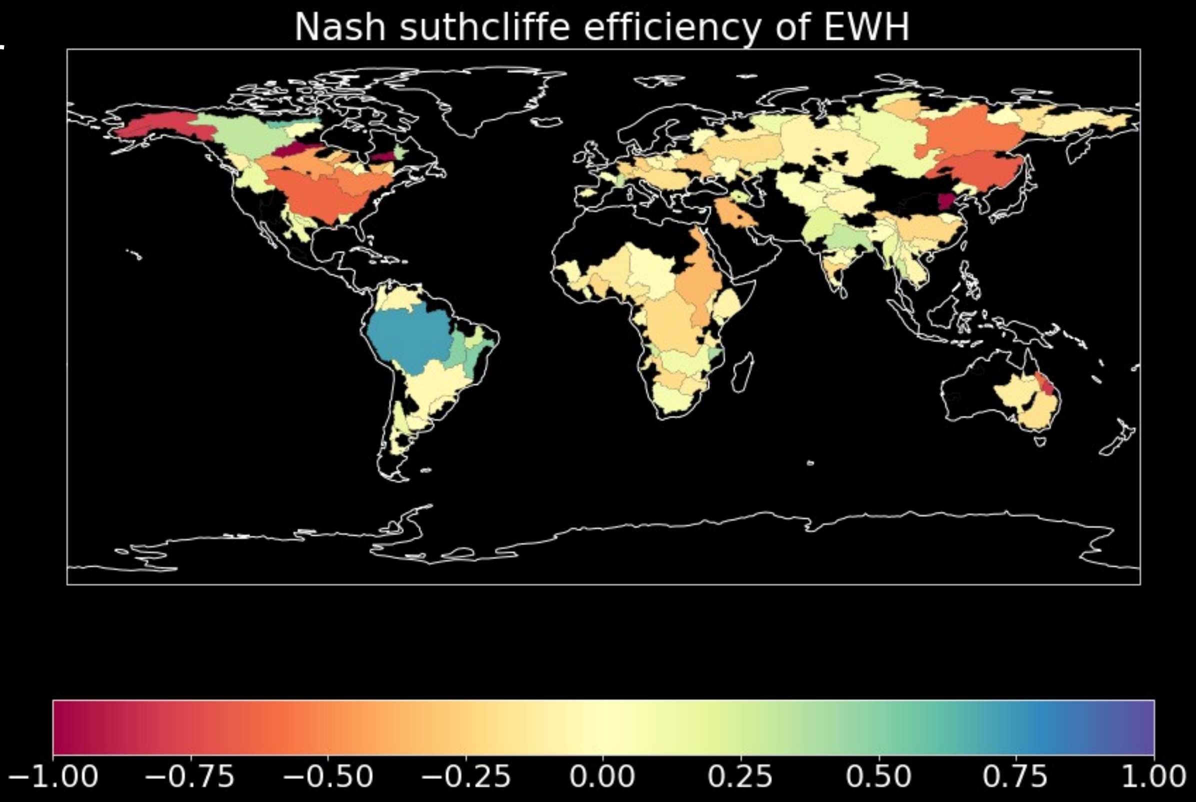


Can Era5-glofas produce GRACE-like time series?

- Integrate to obtain total water storage (normalize by basin area)
- Nash Suthcliffe efficiency:

$$NSE = 1 - \frac{\sum_t \left(h_{grace} - h_{era5}\right)^2}{\sum_t \left(h_{era5} - \bar{h}_{era5}\right)^2}$$

- Not performing well except for Amazon, why?



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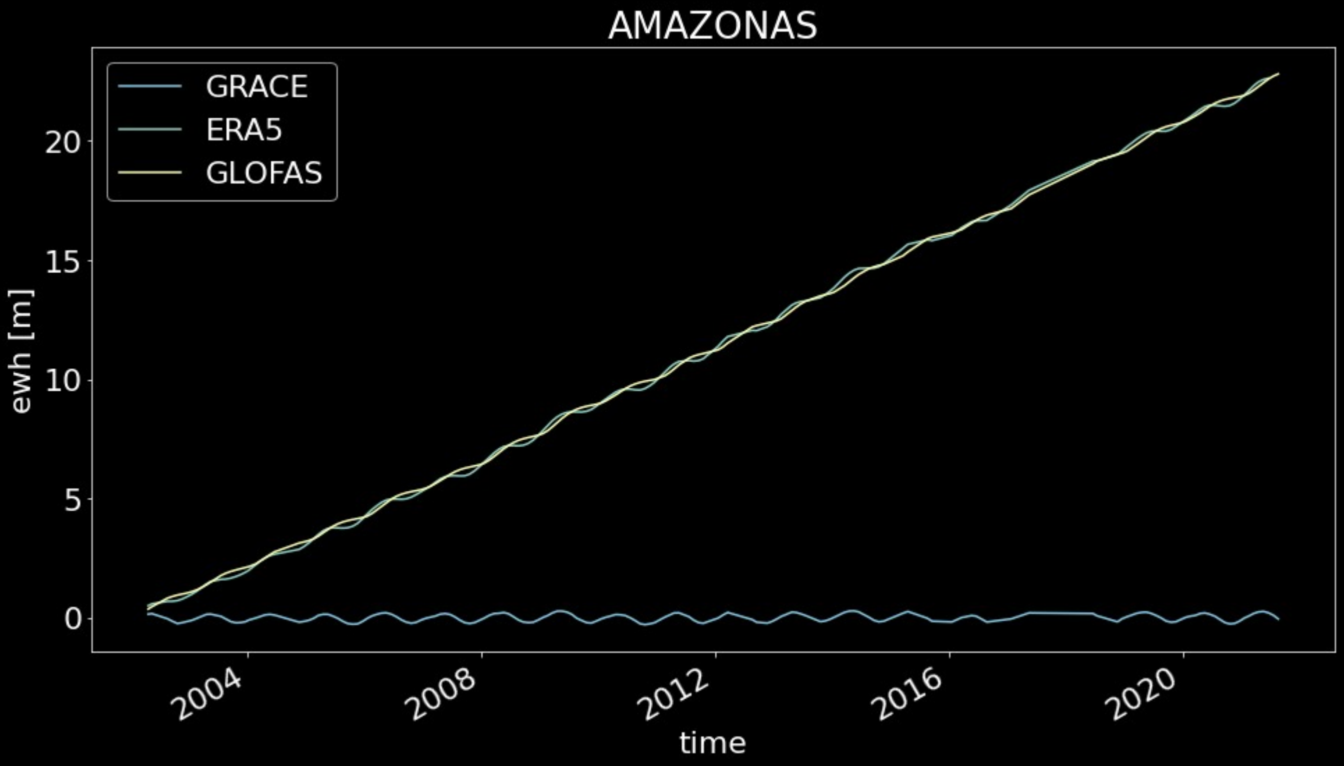
Amazon basin averages

- Intensification → partly invisible to GRACE
- Residual still exhibits large signals (short & long term)
- Currently not able to assess the residual trend (because Era5 trend is set to match GLOFAS)



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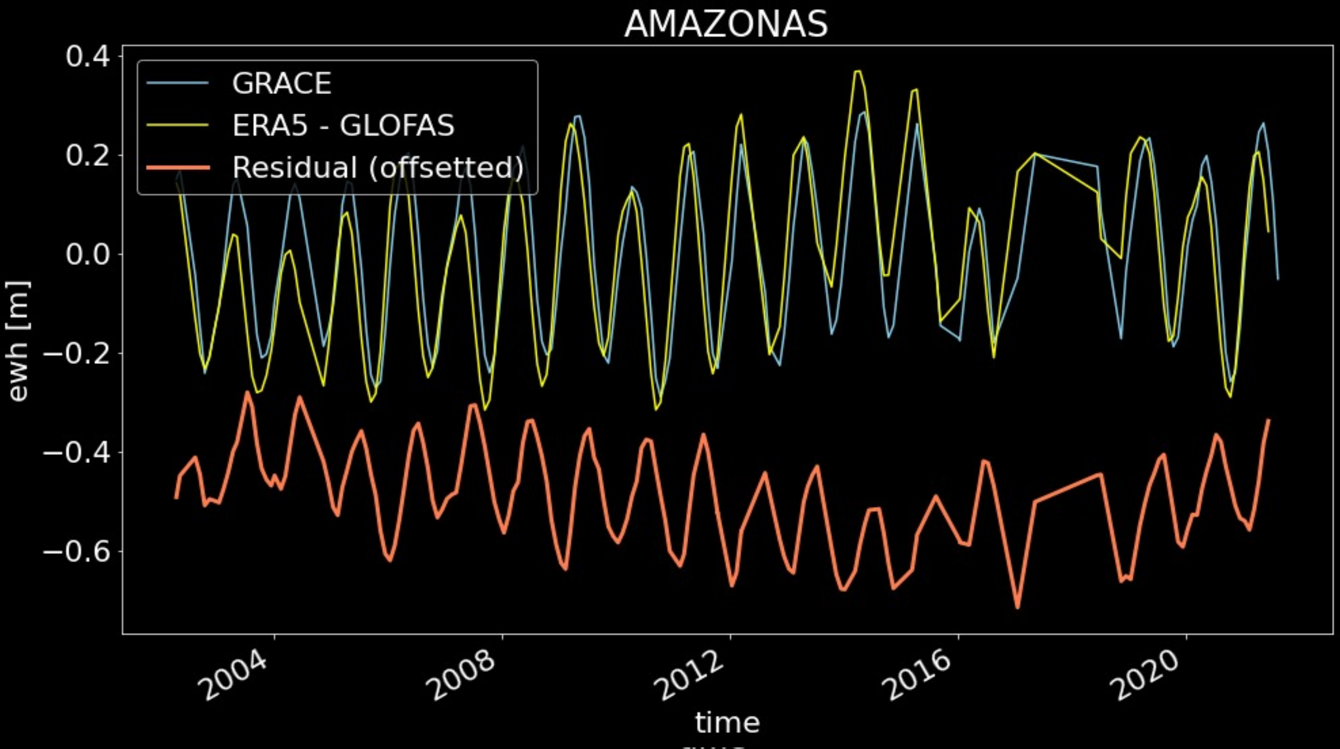
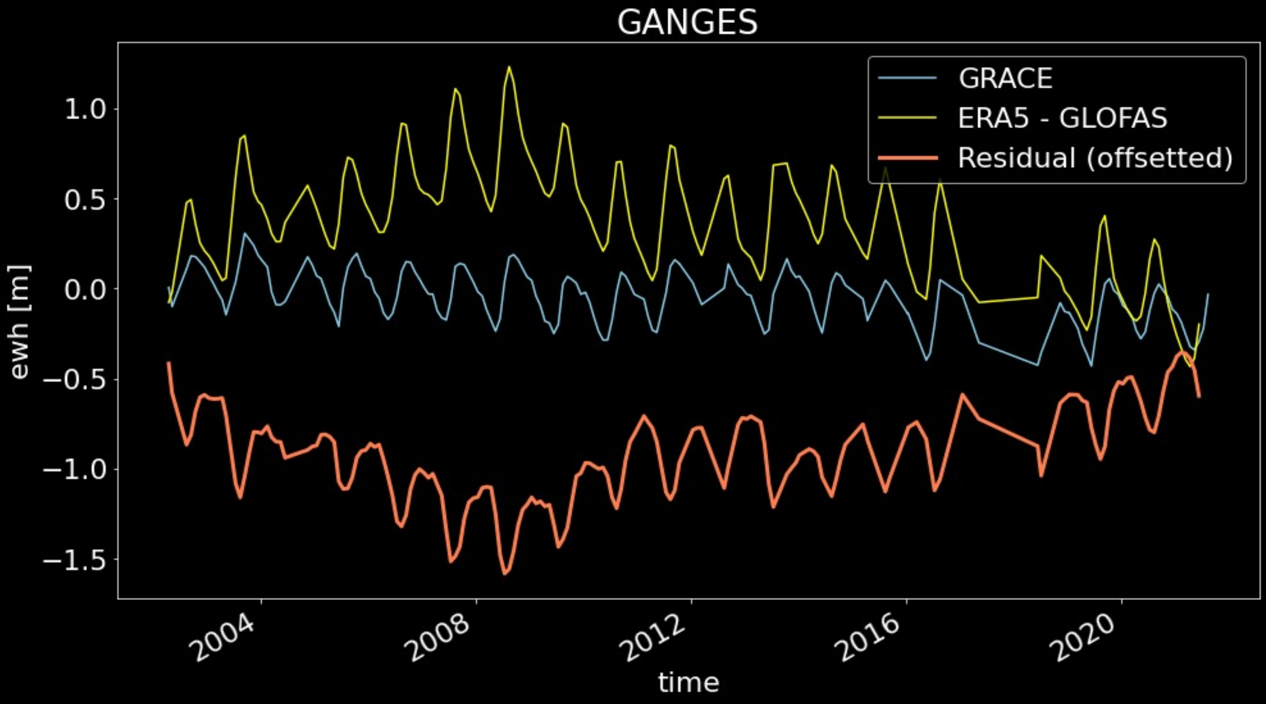


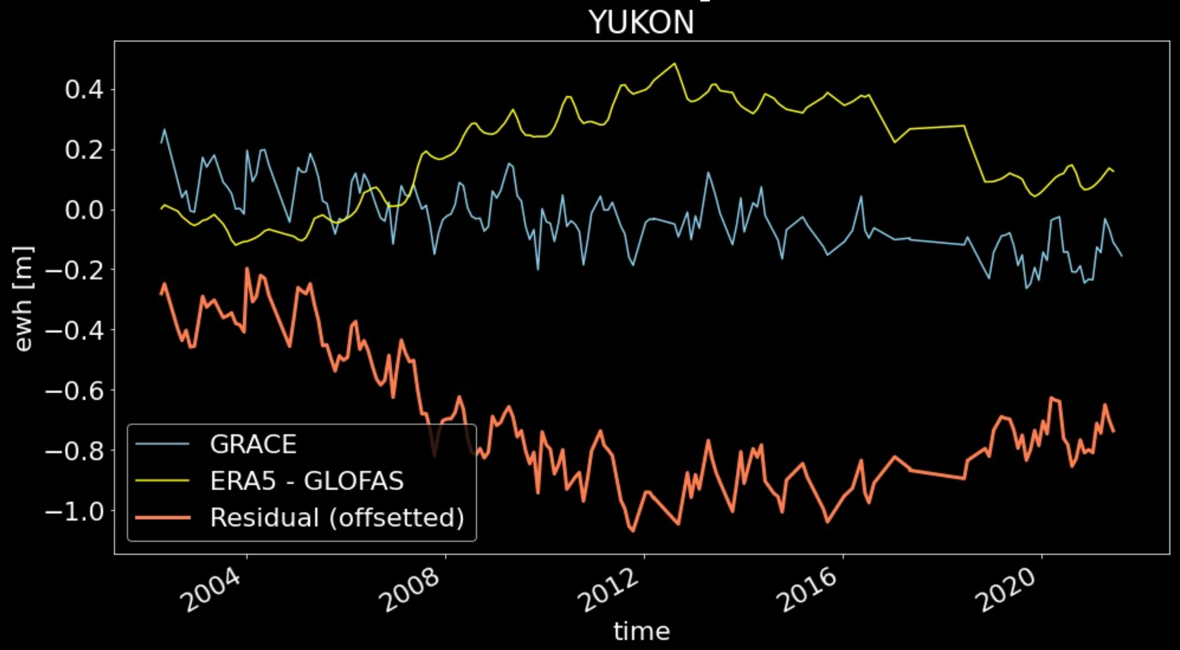
Ganges basin average

- Seasonal in phase but large residuals remain
- Era5 contribution (vapour) has strong interannual departures



Yukon Basin average

- No agreement in seasonal or internannual signals
- Accumulation in Equivalent water height is not obvious from fluxes



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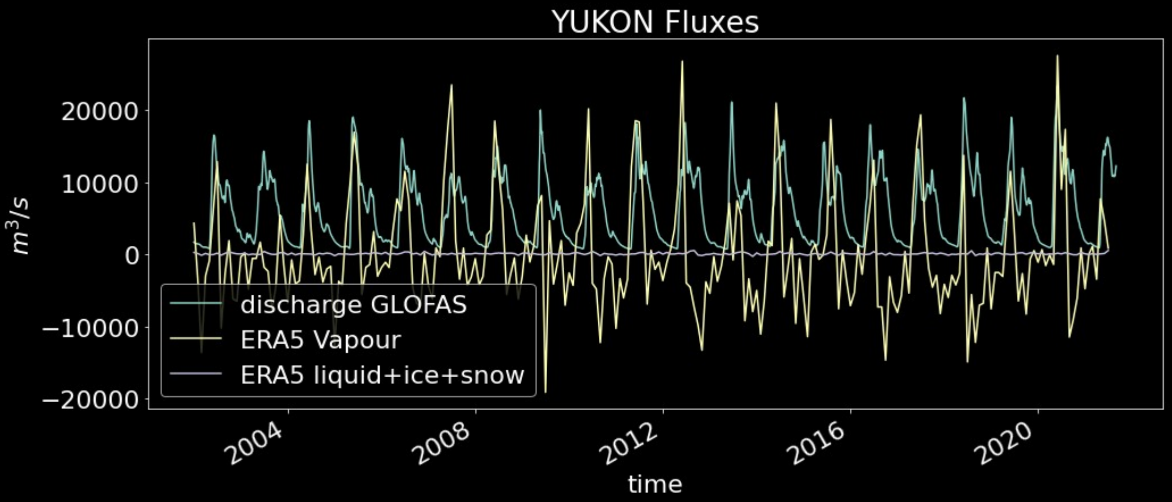
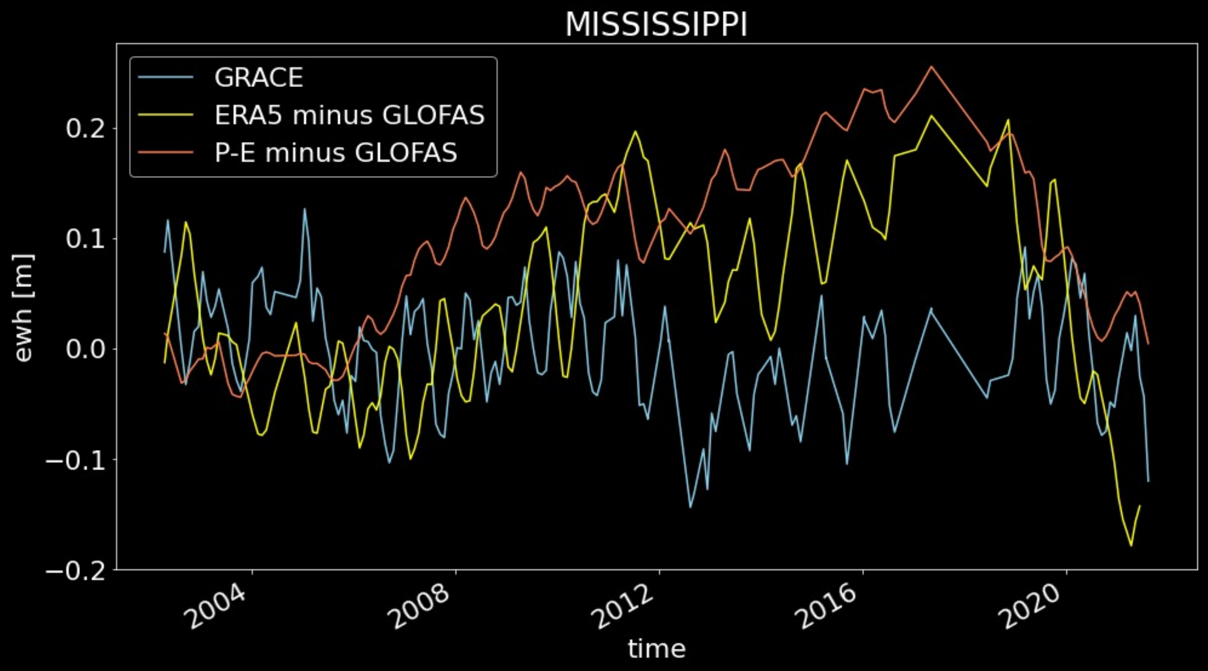


Conclusions ⚠ !

- Performed a water balance budget check at watershed scales
- Basin averages from Era5 (vapour) flux show multi-year departures → artefacts from accumulating anomalies in velocity/vapour at interpolated boundaries? Or signal from era5?
- GRACE/GRACE-FO is partly “blind” for water cycle intensification (can only see the ‘sticking’ part)
  - River discharge/flux estimates necessary to separate/understand
  - One size fits all filter may not work for all basins (signal attenuation and leaking)
- Outlook:
  - Check water balance with observed river discharge, other reanalysis products
  - Split up flux contributions at boundaries (e.g. ocean versus land boundary)

Epilogue:
P-E from ERA5 mvimd*

- P-E from integrating mvimd over basin
- But still shows spurious multi-year departures in ewh ..



* Mean vertically integrated moisture divergence kg/s/m2