Can GRACE observe the total drainable water storage of a river basin?
A first estimate over the Amazon basin

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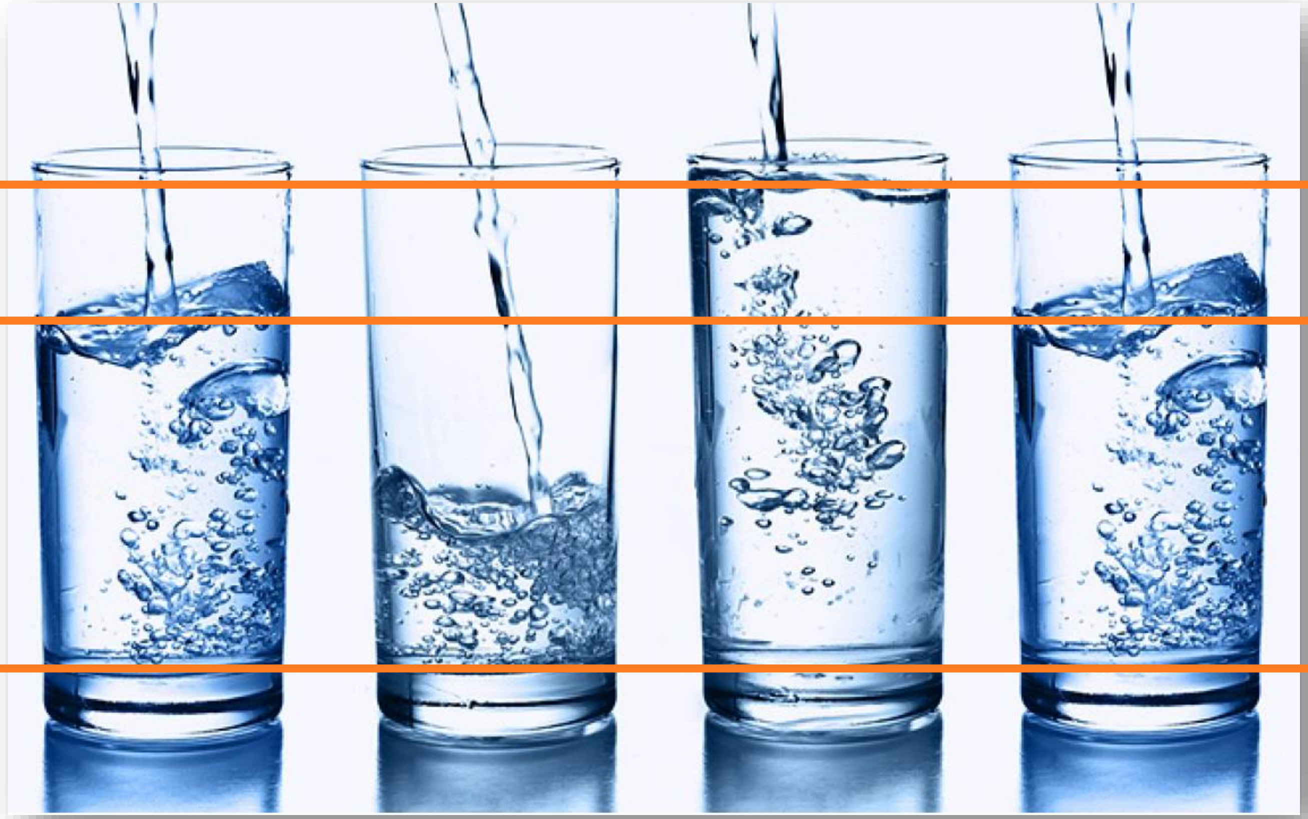
2nd Workshop of DAAD Thematic Network
Modern Geodetic Space Techniques for Global Change Monitoring
24–28 July 2018, University of Luxembourg

GRACE: time-variable gravity

1. How much water is stored in different compartments?
2. How does storage evolve over time?



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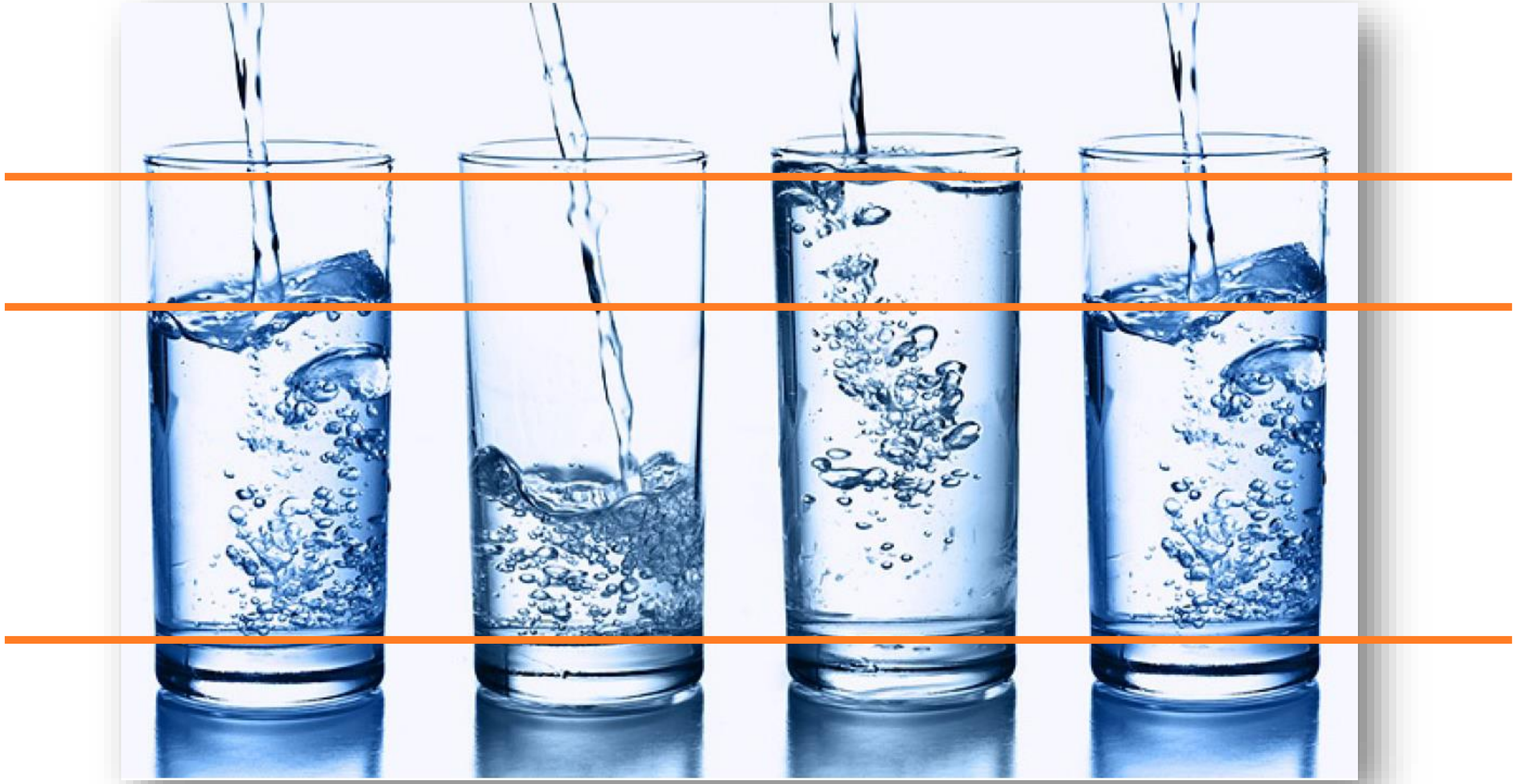
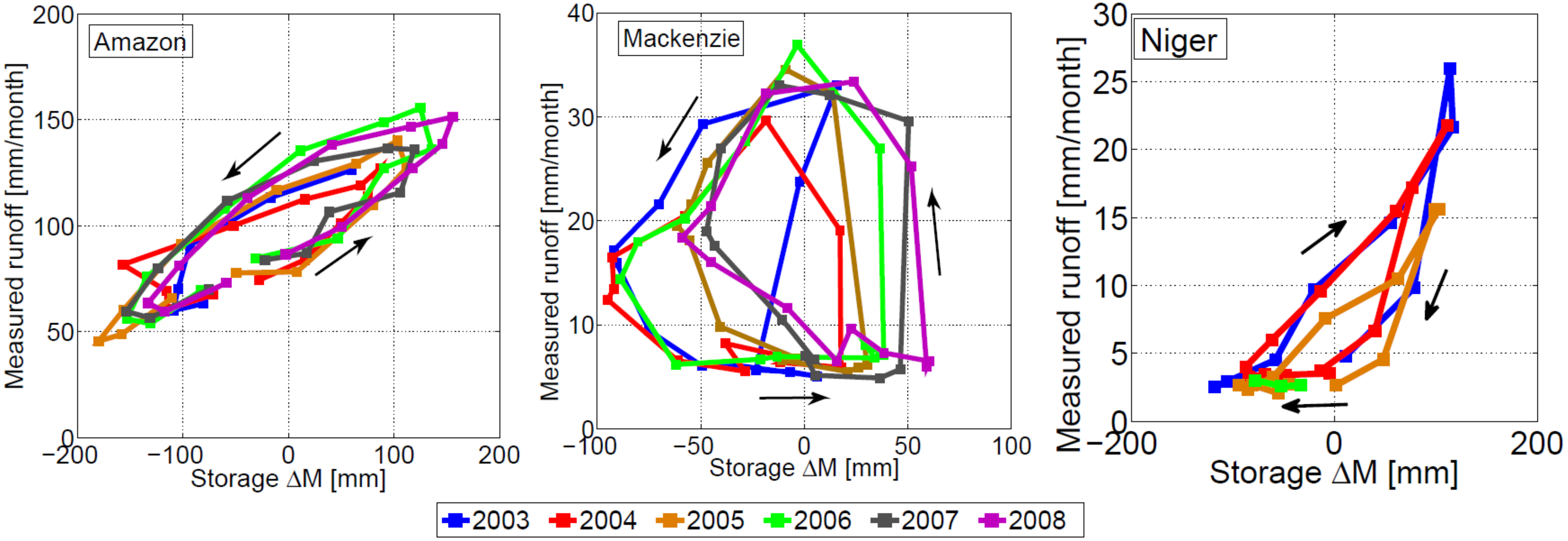


Amazon

ca. 900 km³
or 200 mm
(amplitude)

ca. 1800 km³
or 375 mm

runoff-storage relationship



fully humid tropical

boreal

seasonally dry tropical

Riegger J and MJ Tourian (2014),
Characterization of runoff-storage relationships by satellite gravimetry and remote sensing, Water Resour. Res. 50, 3444–3466, doi:10.1002/ 2013WR013847

storage driven discharge

baseflow vs. storage

$$R_{\mathrm{BS}}(t) = \frac{1}{\tau} S(t)$$

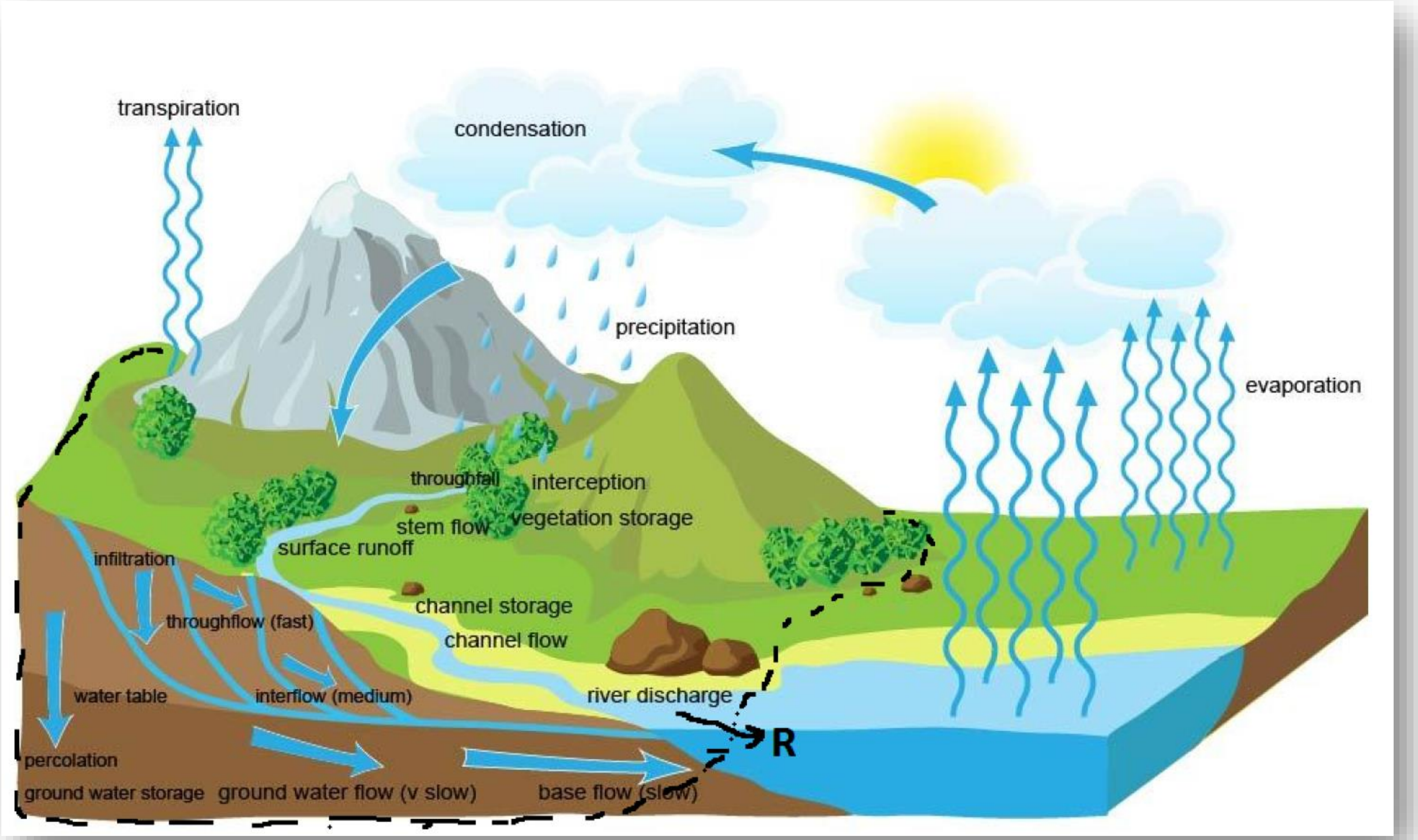
$$S(t) = S_0 + \Delta S(t + \Delta t)$$

$$\Leftrightarrow$$

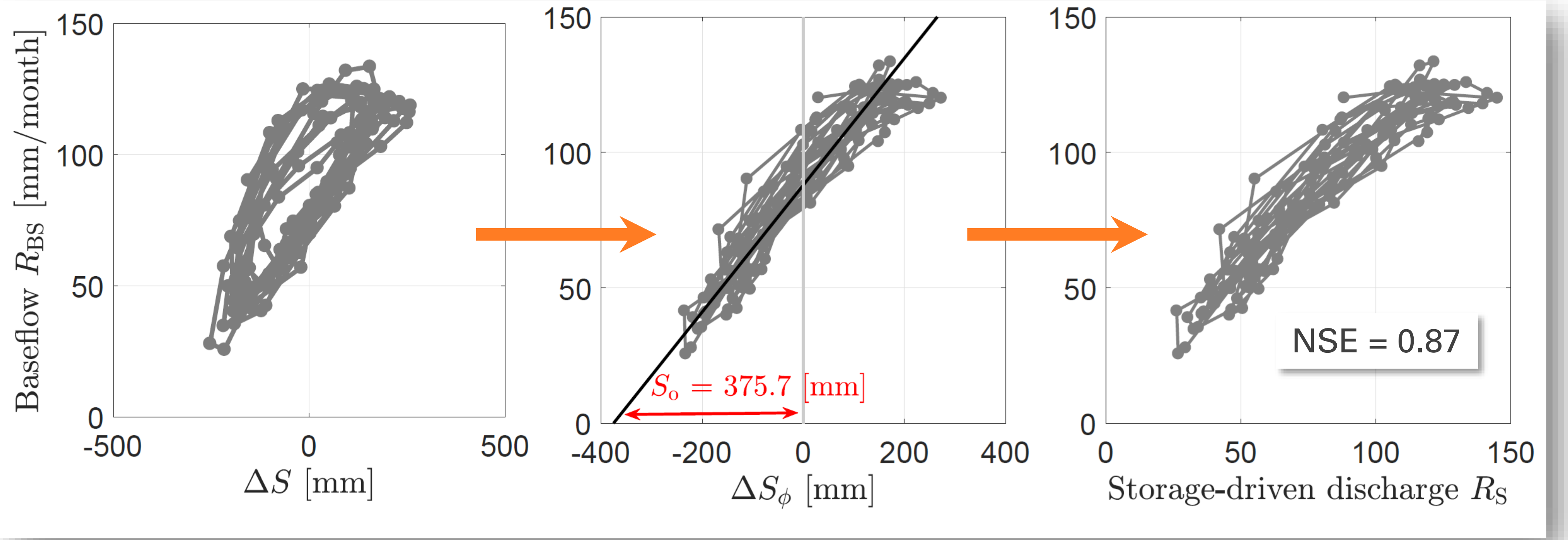
$$R_{\mathrm{BS}}(t) = \frac{1}{\tau}\left(S_0 + \Delta S(t + \Delta t)\right)$$

with

- τ basin's hydraulic time constant (resistance)
- S_0 storage offset
- Δt delay at basin outlet



Total Drainable Water Storage of Amazon



$\varphi \approx 0.52$ rad $\Rightarrow$ $\Delta t \approx 30$ d

$\tau \approx 4.3$ mo

$S_0 = 375.7$ mm $\rightarrow$ 1766 km^3

by Hilbert transform

by Gauss-Helmert LS estimation

how to validate TDWS?

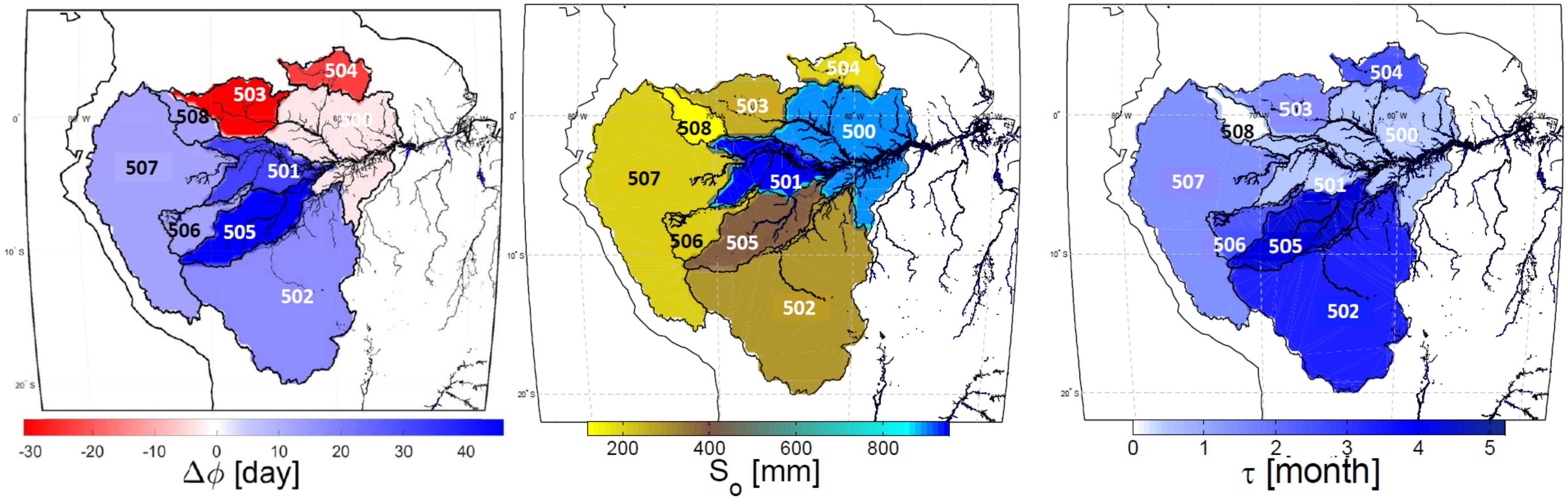
- in situ?
- models?
- plausibility (e.g. permeability, hydrogeology, …)
- residence time S_0/P_0
- isotopic tracer analysis (Mortatti et al., 1994)
  - Amazon sub-surface storage of 840 km^3
- sub-catchment analysis ←
- quantification of surface water storage ←

sub-catchment analysis

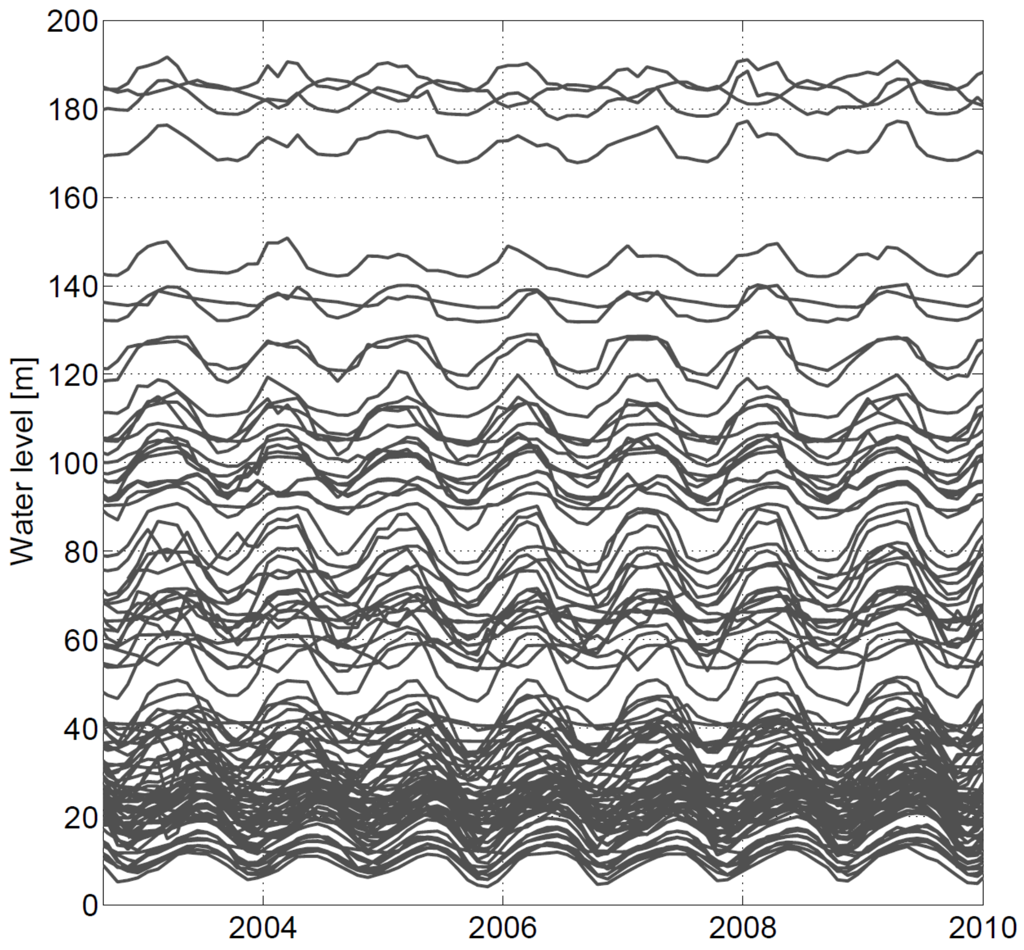
	performance		parameters			storage volume
Basin	corr	NSE	$\Delta\phi$ [day]	τ [month]	S_o [mm]	$S_o \times$Area [km^3]
508	0.85	0.70	10	0.43±0.02	128±1	15±1
507	0.92	0.83	11	1.82±0.04	222±6	272±7
506	0.92	0.84	10	3.02±0.09	223±8	36±1
503	0.81	0.60	−31	1.78±0.08	299±14	83±4
505	0.94	0.85	44	5.10±0.21	349±17	127±7
504	0.84	0.67	−25	2.9±0.10	163±6	28±1
501	0.96	0.92	29	1.16±0.01	929±7	297±3
502	0.96	0.91	18	4.43±0.12	274±7	360±10
500	0.94	0.87	−5	1.55±0.03	883±17	654±12
Weighted average					391±11	$\sum$ 1840 ± 21
Amazon	0.94	0.88	30	4.27±0.11	375±10	1766±47
difference					16	74

Observable	Source (agency)	temporal resolution	duration
Water storage anomaly ΔS	JPL RL05M	monthly	2002–2016
Discharge R	GRDC	daily	1970–2016
altimetric water level	DAHITI&HydroSat	10–35 days	2002–2010
surface water extent	GIEMS	monthly	1993–2007

sub-catchment analysis



surface storage 1: heights in river network



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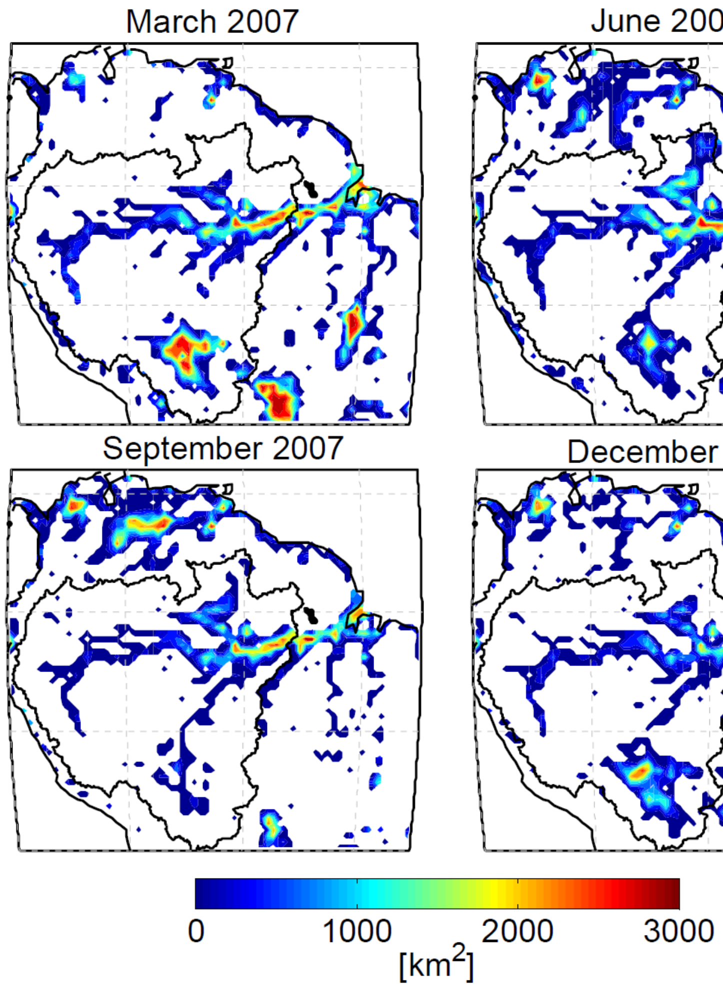
surface storage 2: surface water extent



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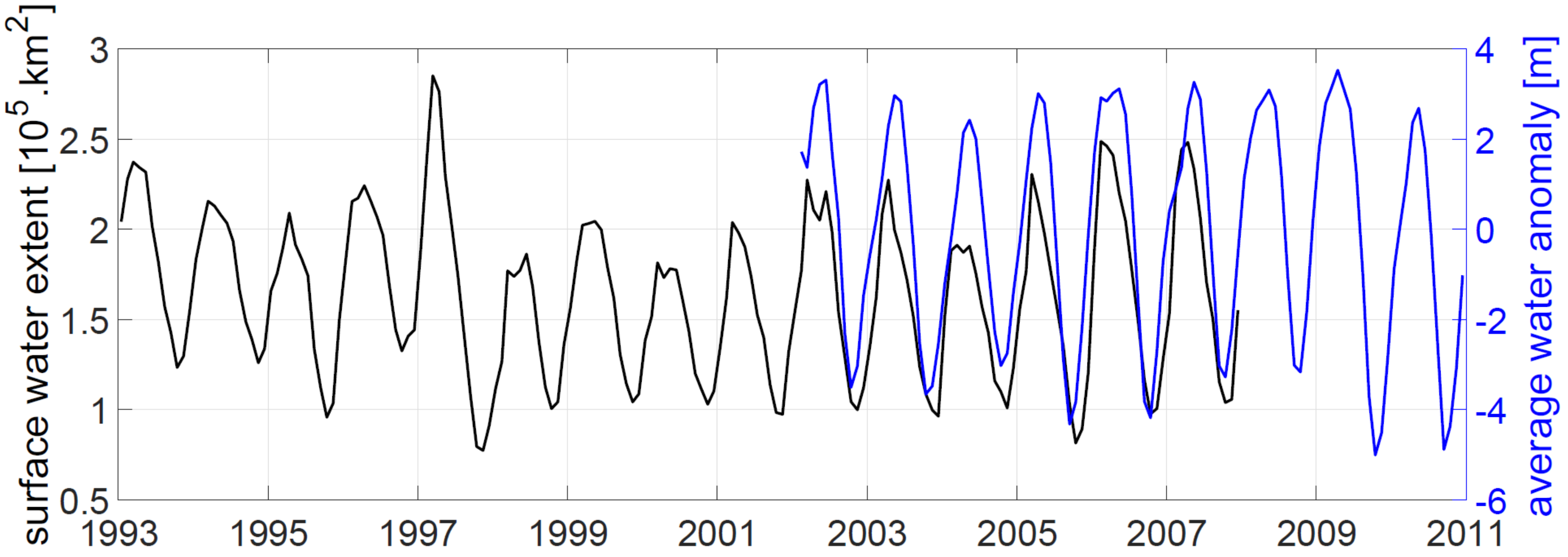
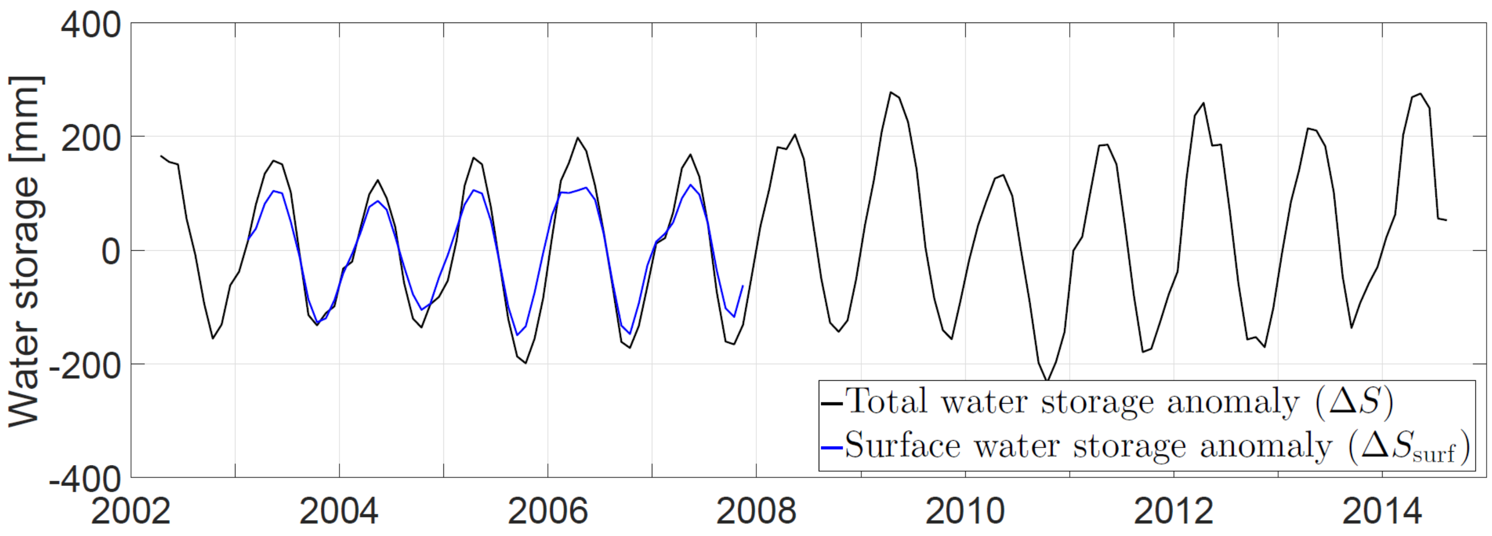
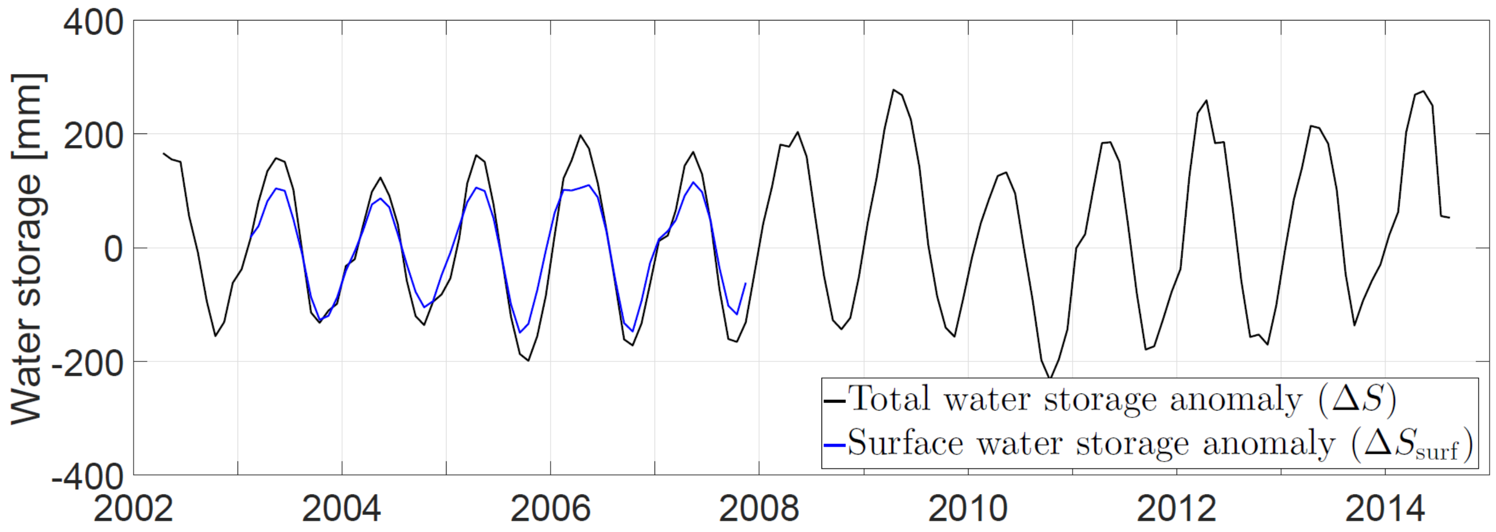
surface storage 3: volume = height × area





surface storage 4: $\Delta S_{\text{surf}} \rightarrow S_{0,\text{surf}}$

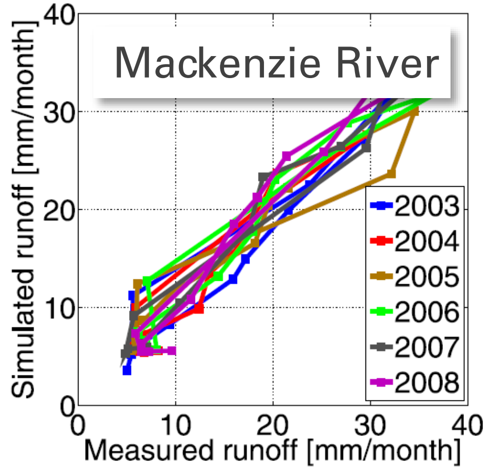


surface storage $S_{0,\text{surf}} = 247\ \text{mm} = 65\%$ of TDWS

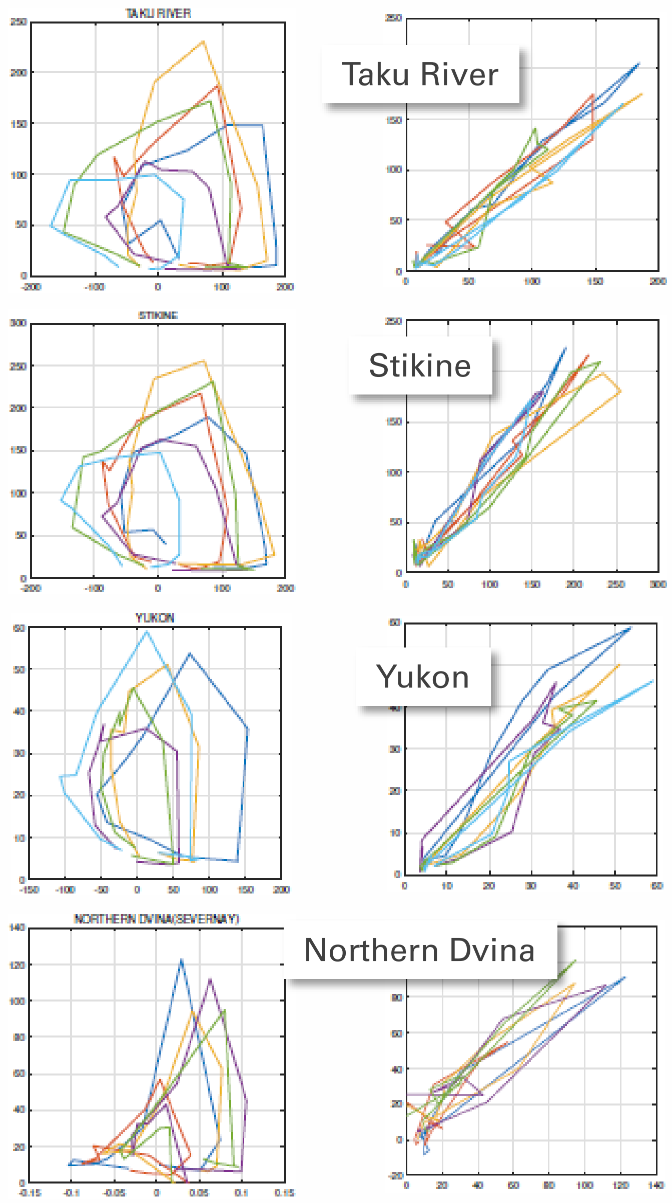
conclusions & outlook

- GRACE reveals more than time variations alone.
- total drainable water storage accessible by GRACE
- practically defined as storage level where baseflow becomes zero
- First estimate over Amazon basin:
  $$S_0 \approx 1800\ \mathrm{km}^3$$
- 65% of which available as surface storage
- Formalism also provides hydraulic time constant of (sub-)basins.

- TBD: a lot
- boreal and seasonally-dry catchments
- $R_{\mathrm{BS}} = \mathrm{LFF}\{R_{\mathrm{obs}}\}$
- surface storage estimation
  - area: e.g. DLR WaterPack
  - height: operational continental satellite altimetry
  - SWOT
- validation



boreal catchments



Name	time lag	τ	M_0	$RMS.R$	$Corr.R$	$NSE.R$
ANABAR	0.05	0.46	11.65	6.22	0.98	0.97
ANDERSON	1.01	1.22	28.00	10.60	0.79	0.21
BOLANYUY	1.01	1.11	56.28	6.58	0.94	0.87
CANIAPISCAU	1.13	0.72	56.71	8.87	0.91	0.78
CHURCHILL	0.94	34.00	226.00	2.29	0.63	0.36
COPPER	0.12	5.29	1300.00	30.00	0.92	0.84
FRASER	0.43	2.70	153.68	6.91	0.95	0.89
HAYES	3.36	2.05	86.00	5.70	0.80	0.60
KALIXAELVEN	0.07	0.20	15.71	10.83	0.97	0.92
KAZAN	0.36	1.33	72.75	10.96	0.91	0.81
KUSKOKWIM	4.20	2.95	229.00	15.76	0.82	0.67
LENA	0.67	1.21	56.30	9.46	0.93	0.84
MACKENZIE	0.32	4.64	140.42	3.40	0.96	0.88
MEZEN	3.13	0.35	58.02	15.05	0.92	0.85
MUONIO	4.03	0.13	38.24	8.39	0.98	0.94
NASS	2.10	0.64	195.00	51.00	0.85	0.70
NORTHERN DVINA	3.12	1.01	68.09	11.65	0.90	0.80
OB	0.95	5.73	117.80	3.05	0.95	0.88
OLENEK	0.02	1.00	43.83	8.69	0.94	0.89
PECHORA	2.07	0.68	84.00	20.00	0.91	0.82
PEEL	0.01	1.10	83.50	12.17	0.91	0.82
STIKINE	1.04	1.07	241.53	18.00	0.96	0.93
TAKU	2.05	1.41	231.77	17.00	0.95	0.90
THELON	0.19	5.85	247.60	6.00	0.86	0.62
WESTERN DVINA	2.01	1.28	34.00	9.70	0.89	0.76
YANA	0.13	2.45	108.82	5.40	0.97	0.94
YENISEI	0.83	1.16	54.40	9.25	0.87	0.76
YUKON	0.18	4.60	211.40	6.73	0.93	0.84

source: Ruiheng XIA (2018) MSc Thesis, University of Stuttgart

further information

Jet Propulsion Laboratory
California Institute of Technology

GIS

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Water Resources Research

RESEARCH ARTICLE

10.1029/2017WR021674

The Total Drainable Water Storage of the Amazon River Basin: A First Estimate Using GRACE

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Key Points:

- Amazon drainable water storage quantified observationally at 1,766 km^3
- Storage-driven flow and total Amazon River flow are partitioned and modeled
- On average, 65% of the total drainable water of the basin stored as surface water
- Basin waters demonstrate an average 2 month residence time

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Citation:
Tourian, M. J., Reager, J. T., & Sneeuw, N. (2018). The total drainable water storage of the Amazon river basin: A first estimate using GRACE. *Water Resources Research*, *54*. https://doi.org/10.1029/2017WR021674.

Received 8 AUG 2017
Accepted 10 APR 2018
Accepted article online 17 APR 2018

Abstract In the Amazon River basin, water stored for months to years in the soils and subsurface provide a persistent resource that regulates local and global climate via teleconnections and provides water to plants in times of little rain. While Gravity Recovery and Climate Experiment (GRACE) satellites have provided the hydrological community with large advances in the understanding of large river basin dynamics and for water resources monitoring applications, the relative storage measurements from GRACE satellites have not yet been utilized for the quantification of total available freshwater on landmasses. In this study, we quantify the total drainable water storage (TDWS) in the Amazon basin by characterizing the relationship between the water storage anomaly of a large catchment and its base flow. Previous studies have shown that these two hydrological parameters behave like a linear time-independent system over a catchment like the Amazon dominated by fully humid tropical climate. This linear relationship allows us to determine a zero water storage level, at which the storage-driven discharge becomes zero. We quantify the TDWS of the Amazon basin as 1,766 km^3 and estimate an average 2 month residence time for stored waters. An independent analysis over nine major subbasins confirms our estimate for the entire basin. We show that our estimated TDWS values for individual subbasins, varying between 15 and 654 km^3, follow two different linear relationships with their mean annual input. Through these relationships we also quantify the storage-driven portion of the streamflow and the total streamflow for Amazon and its subbasins. Furthermore, we estimate surface water storage variation of the Amazon River system by combining the water level time series from satellite altimetry and surface water extent time series from satellite imagery. Our results show that 61% of total basin water storage variation occurs in the surface water compartment. In addition, we find that 65% of the TDWS is available in its surface water system.