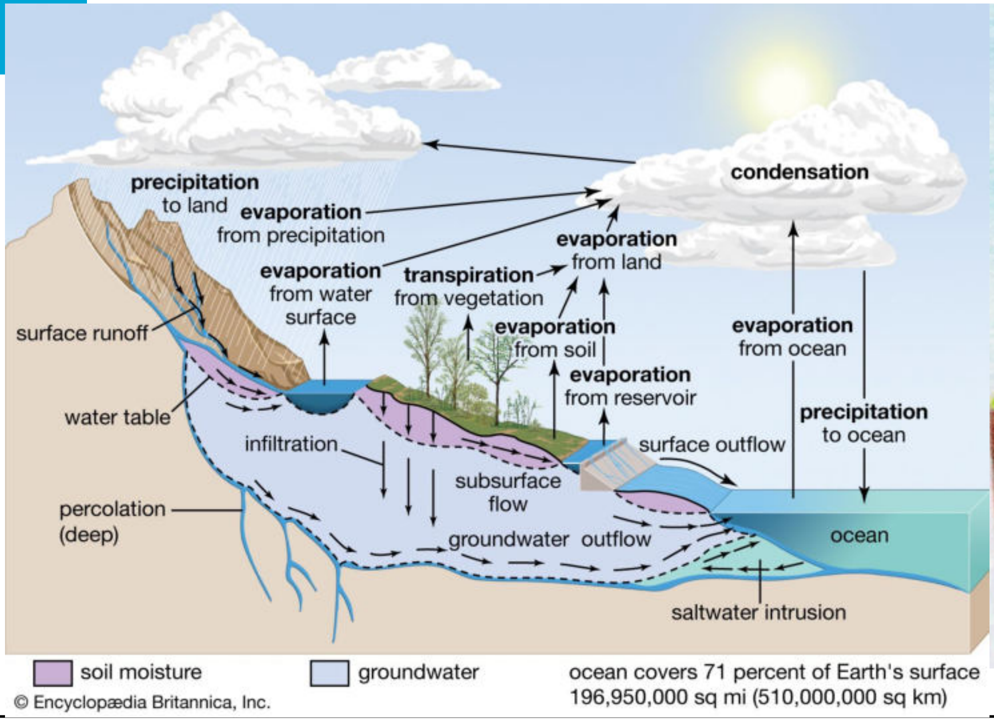
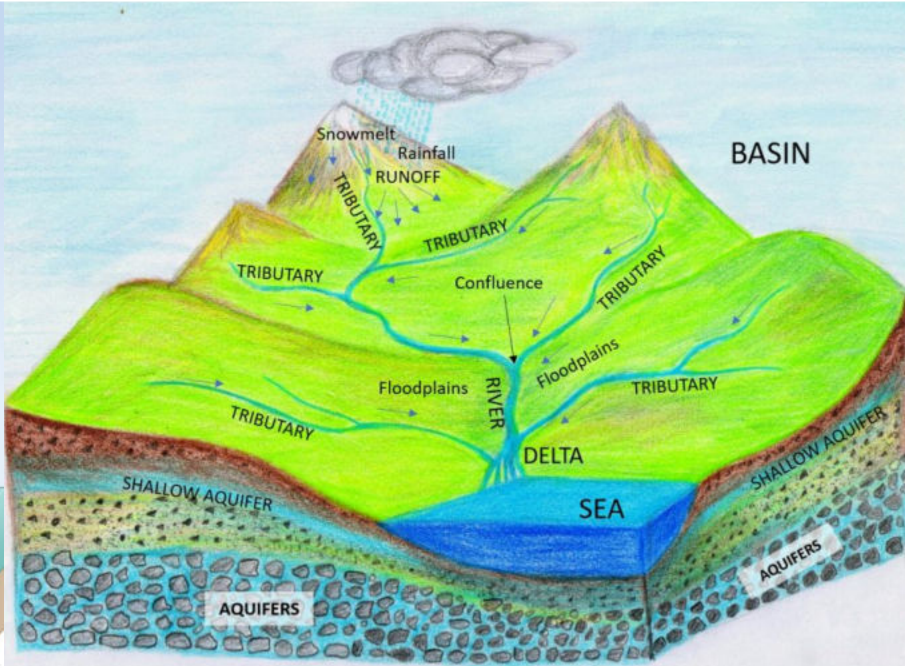
The River Basin as a Living Organism

Hubert H.G. Savenije
Emeritus professor of Hydrology

Hydrological Cycle and River Basin





Holistic View of the World

"The Whole is Greater than the Sum of the Parts"

Aristoteles (384-322 BCE)

"All forces of Nature are connected and mutually dependent"

Alexander von Humboldt (1769-1859)

"[…] Earth functions as a single organism"

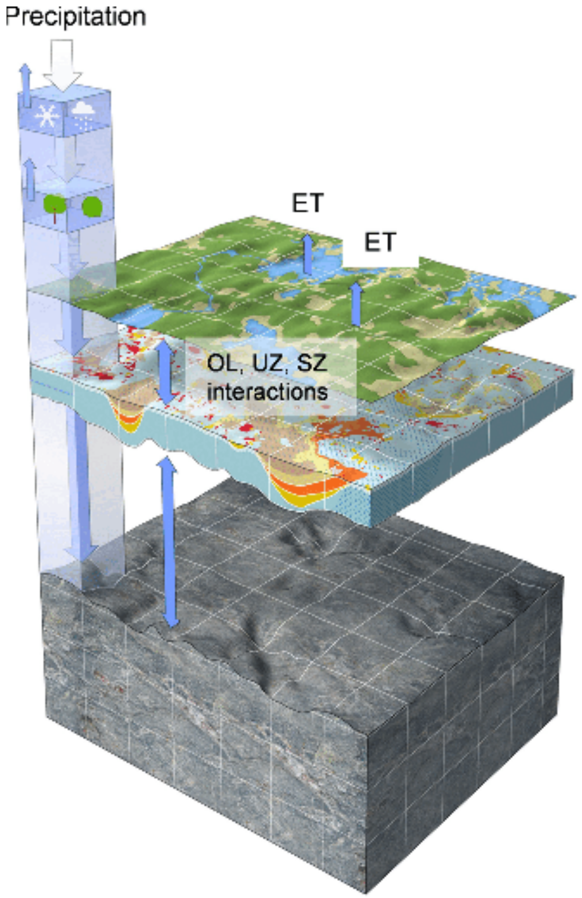
James Lovelock (1972)

The Earth is a "dissipative structure" that exchanges low entropy radiative influx for high entropy radiative outflux, just like a living organism exchanges food for waste

The Dominant Paradigm

so called: “Physically-Based”

- World split-up in cubes
- Interact by conservation laws
  - Mass
  - Momentum (parameterized)
- Highly complex
- Time consuming
- Expensive
- Destruction of patterns



A new Hydrological Theory

New Theory

- Holistic
- System thinking
- All physical Laws
- Fractal Patterns
- Self-organisation
- An active adapting agent
- Alive

Old Theory

- Reductionist
- Fragmented
- Only Newton's Laws
- Chess Board
- Imposed structure
- Static, no adaptation
- Dead

The Ecosystem is the water manager

Most hydrological models do not consider this fact!

Instead:

- They split-up the Ear
- That destroy pattern
- They consider the su
- They are dead and d which can adjust to c
- They are unnecessar
- They rely on calibrati

Hydrol. Earth Syst. Sci., 21, 1–10, 2017
www.hydrol-earth-syst-sci.net/21/1/2017/
doi:10.5194/hess-21-1-2017

Hydrology and Earth System Sciences
Open Access
EGU

The Catchment is Alive !

HESS Opinions "Catchments as meta-organisms – a new blueprint for hydrological modelling"

Hubert H. G. Savenije and Markus Hrachowitz

Department of Water Management, Delft University of Technology, Delft, the Netherlands

Correspondence to: Hubert H. G. Savenije (h.h.g.savenije@tudelft.nl)

Received: 22 August 2016 – Discussion started: 29 August 2016
Revised: 22 December 2016 – Accepted: 6 February 2017 – Published:

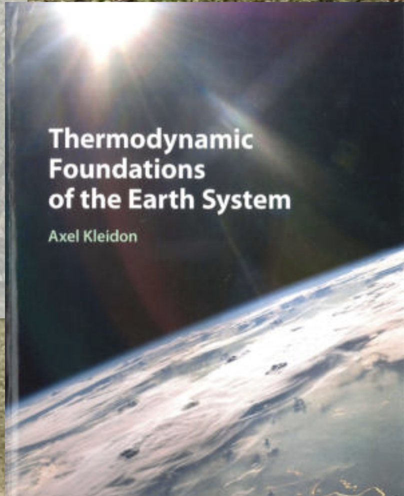
Abstract. Catchment-scale hydrological models frequently miss essential characteristics of what determines the func- towards a more robust understanding of spatial organization and its evolution. This will further permit the development of

Why are there Simple Laws in Hydrology ?

Thermodynamics

The Earth system functions at Maximum Power:

- The Earth is a "dissipative structure" that exchanges low entropy for high entropy
- It does so at Maximum Power, close to the "Carnot limit" of a dissipative engine
- Maximizing the Power of a natural process often leads to surprisingly 'Simple Laws'



Maximum Power in the water cycle

Is there an active agent?

- That operates the hydrological system near the Carnot limit?
- That partitions
- That stores and delays
- That creates pathways
- That drains and evacuates
- That optimizes its environmental conditions

Can conceptual models do this?

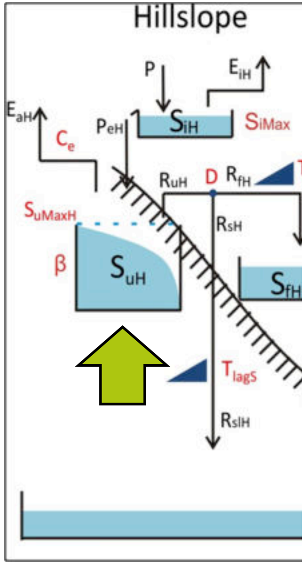
- can they account for patterns?
- can they account for evolution?
- can they represent a living, active and adjusting system?
- can they do with less calibration?
- And remain relatively simple?

Hydrology is the blood stream of the Ecosystem

- Maximum power implies ‘optimality’ in the ecosystem
- The hydrology functions near to the Carnot limit
- This holds the key to model structure and parameter values:
  - Infiltration capacity
  - Partitioning
  - Root zone storage
  - Dominant drainage and runoff characteristics

Landscape-based Modelling

Landscape reflects evolution and is key to dominant processes

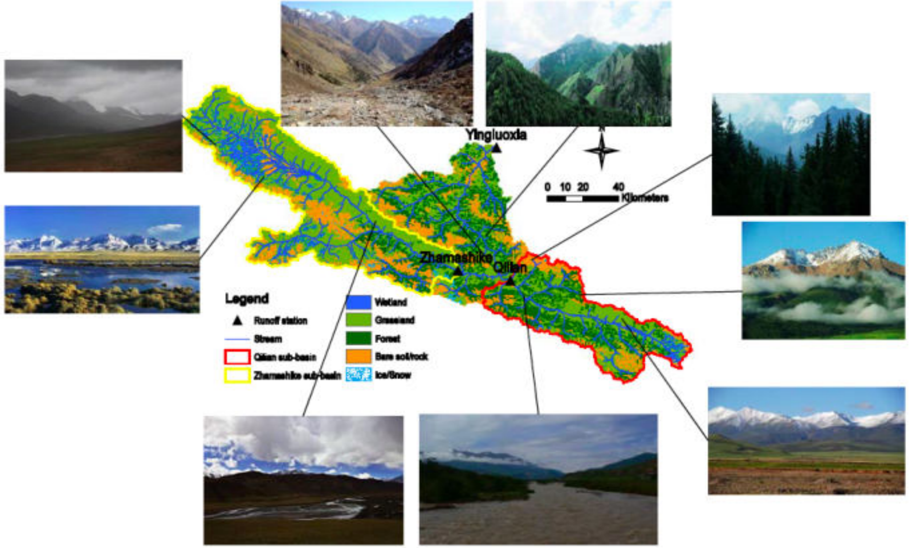


Hydrol. Earth Syst. Sci., 14, 2681-
www.hydrol-earth-syst-sci.net/14/2
doi:10.5194/hess-14-2681-2010

HESS Opinions
"Topography drive

H. H. G. Savenije
Delft University of Technology, W

Received: 3 July 2010 – Published
Revised: 3 December 2010 – Accepted: 20 December 2010 – Published: 23 December 2010



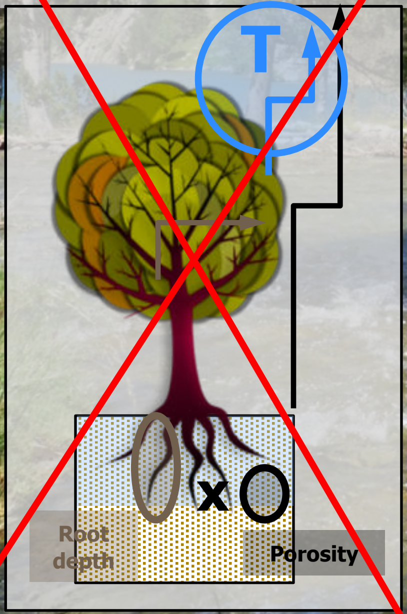
Gao, H., M. Hrachowitz, F. Fenicia, S. Gharari, and H. H. G. Savenije, 2014.

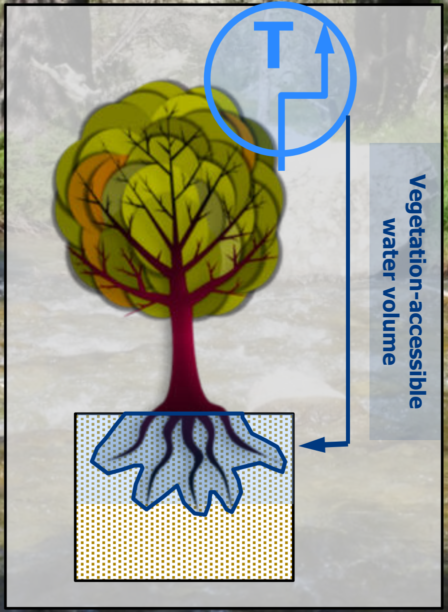
Vegetation-accessible water storage volume $S_{u,Max}$

~~Do not let soil observations control transpiration~~

instead

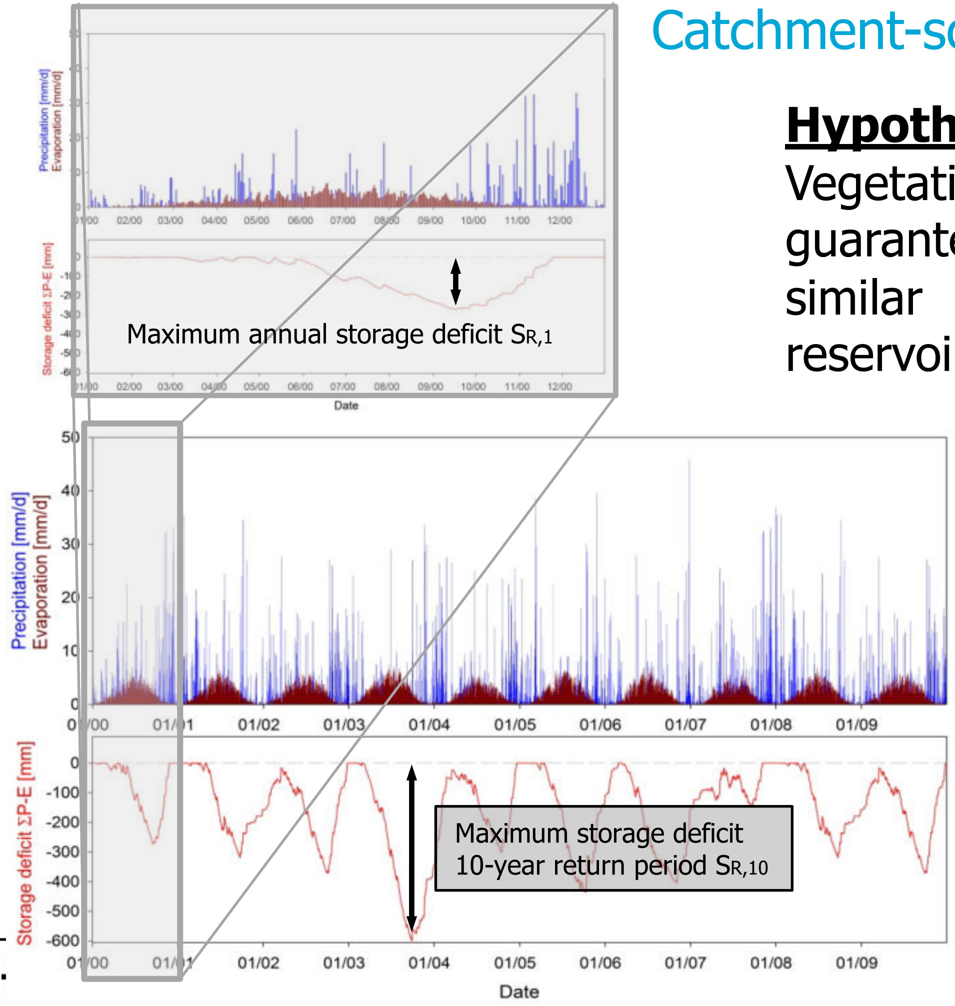
Transpiration demand controls root-systems





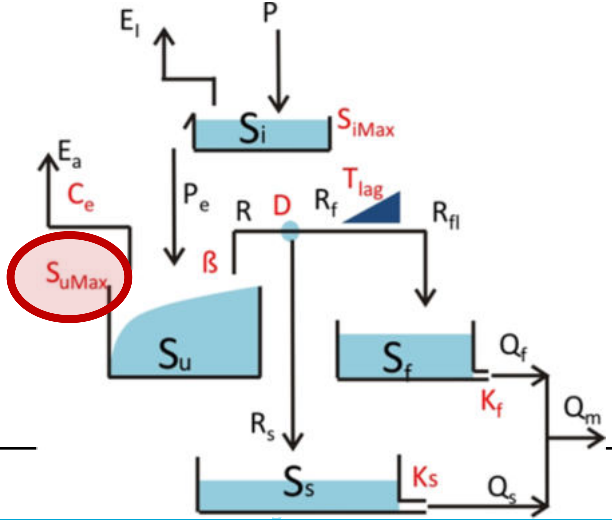
Vegetation is an **active agent** that adapted root-systems to meet water (and nutrient) requirements

Catchment-scale estimation of $S_{u,Max}$



Hypothesis:

Vegetation designs its root system to guarantee continuous access to water similar to how humans design water reservoirs, based on supply and demand



Hydrol. Earth Syst. Sci., 20, 1459–1481, 2016
www.hydrol-earth-syst-sci.net/20/1459/2016/
doi:10.5194/hess-20-1459-2016

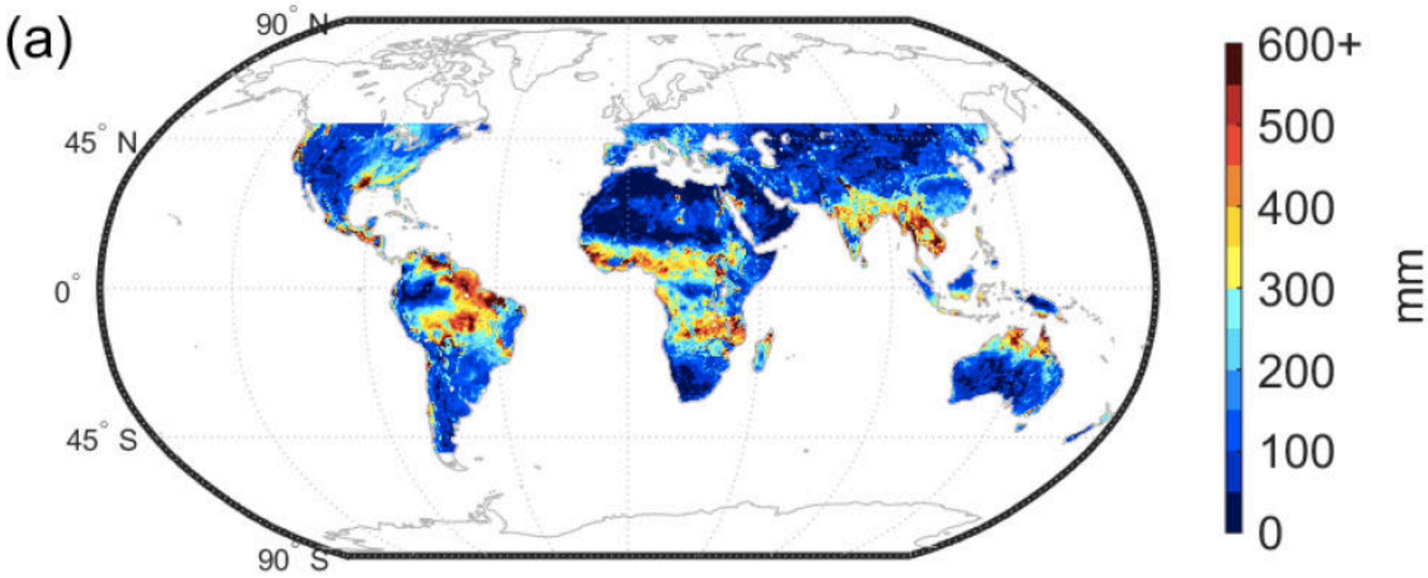
Hydrology and Earth System Sciences
Open Access

Global root zone storage capacity from satellite-based evaporation

Lan Wang-Erlandsson[1,2], Wim G. M. Bastiaanssen[2,3], Hongkai Gao[2,4], Jonas Jägermeyr[5], Gabriel B. Senay[6], Albert I. J. M. van Dijk[7,8], Juan P. Guerschman[8], Patrick W. Keys[1,9], Line J. Gordon[1], and Hubert H. G. Savenije[2]

[1]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden
[2]Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands
[3]UNESCO-IHE Institute for Water Education, Delft, the Netherlands
[4]Global Institute of Sustainability, Arizona State University, Tempe, AZ 85287, USA
[5]Research Domain Earth System Analysis, Potsdam Institute for Climate Impact Research, Potsdam, Germany
[6]US Geological Survey, Earth Resources Observation and Science Centre, North Central Climate Science Centre, Fort Collins, CO, USA
[7]Fenner School of Environment and Society, The Australian National University, Canberra, Australia
[8]CSIRO Land and Water, Canberra, Australia

Root zone storage capacity from space



Lan Wang-Erlandsson et al., 2016

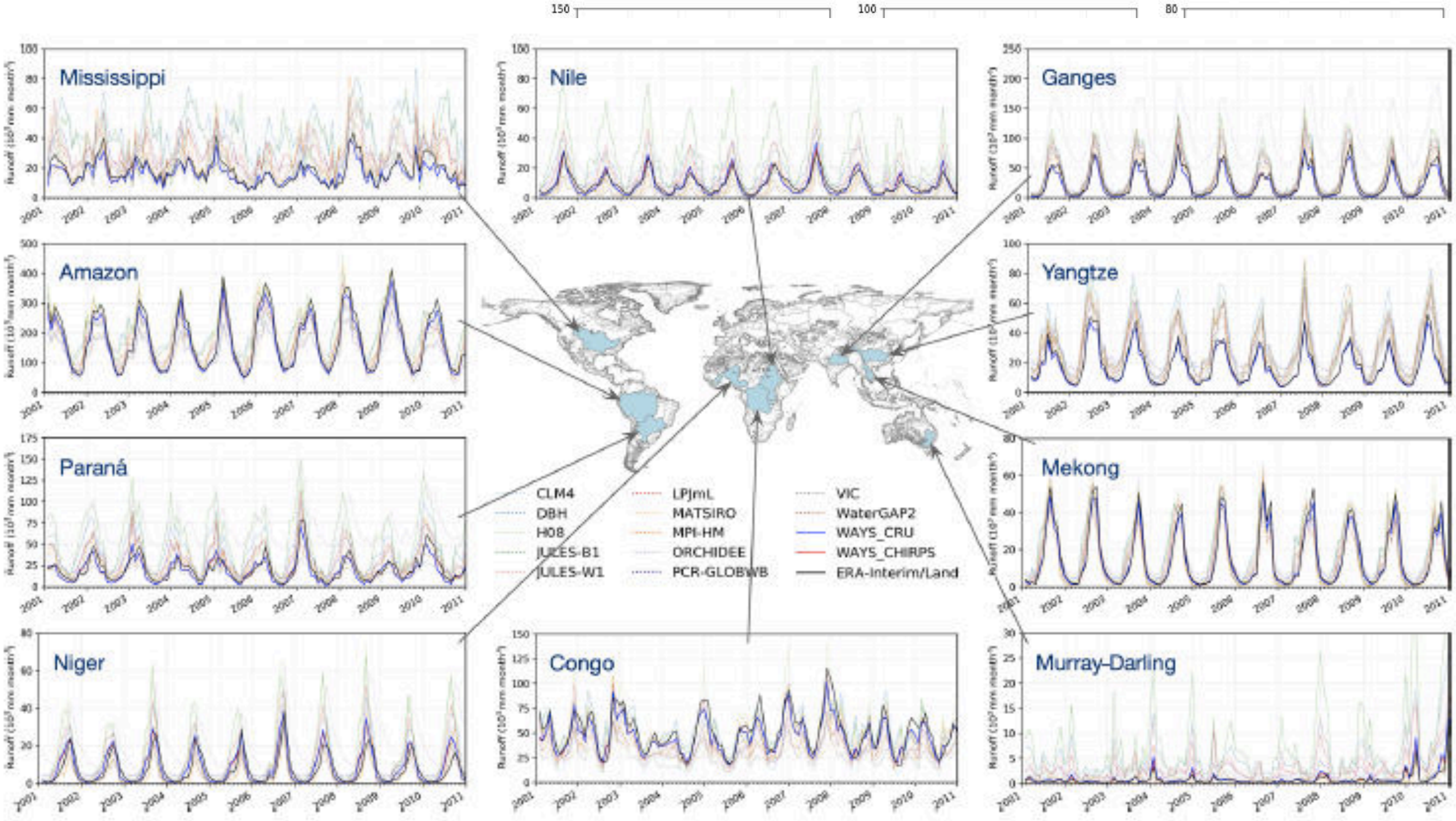
Geosc
https:/
© Aut
the Cr

WA
sim

Ganq
Schoo

Corre

Recei
Revise



IOP Publishing   *Environ. Res. Lett.* **15** (2020) 124021   https://doi.org/10.1088/1748-9326/abc377

Environmental Research Letters

CrossMark

OPEN ACCESS

RECEIVED
2 August 2020

REVISED
4 October 2020

ACCEPTED FOR PUBLICATION
21 October 2020

PUBLISHED
30 November 2020

LETTER

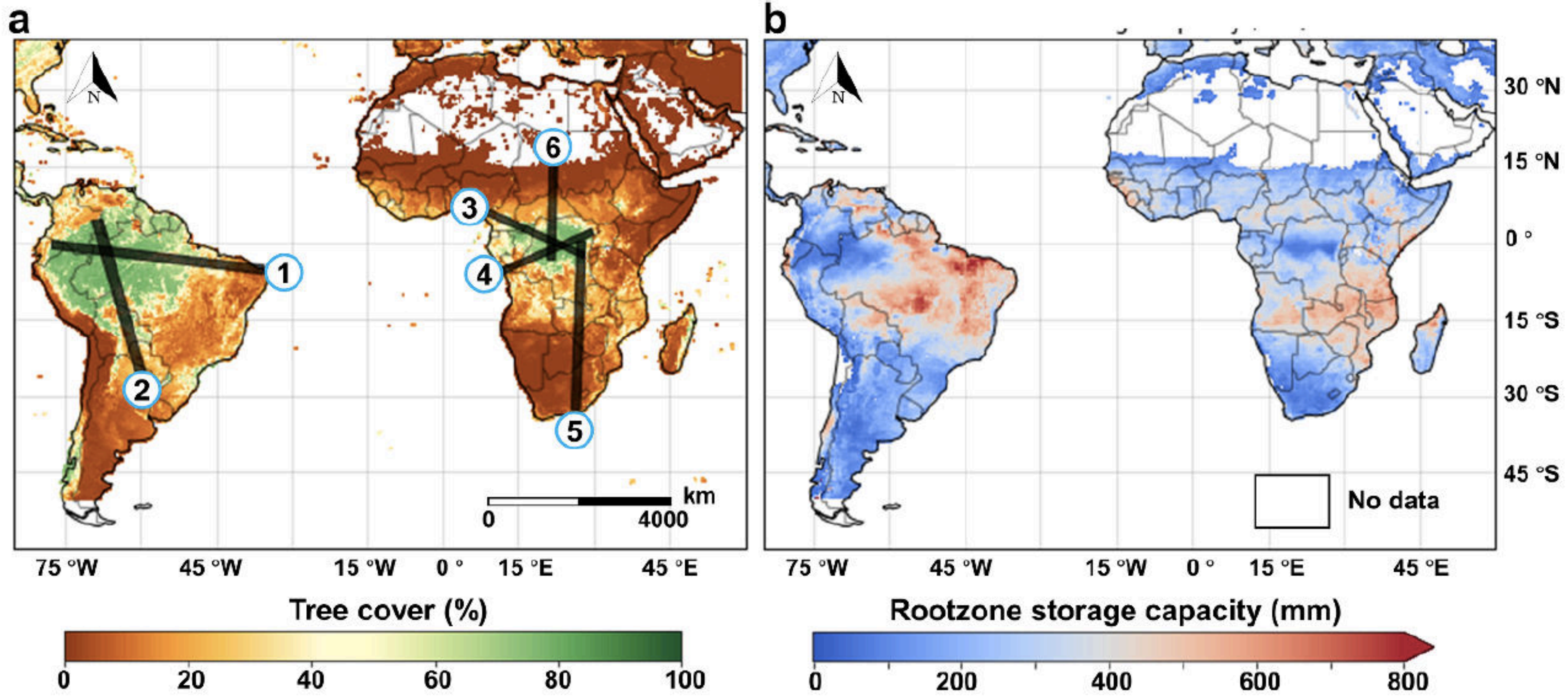
Rootzone storage capacity reveals drought coping strategies along rainforest-savanna transitions

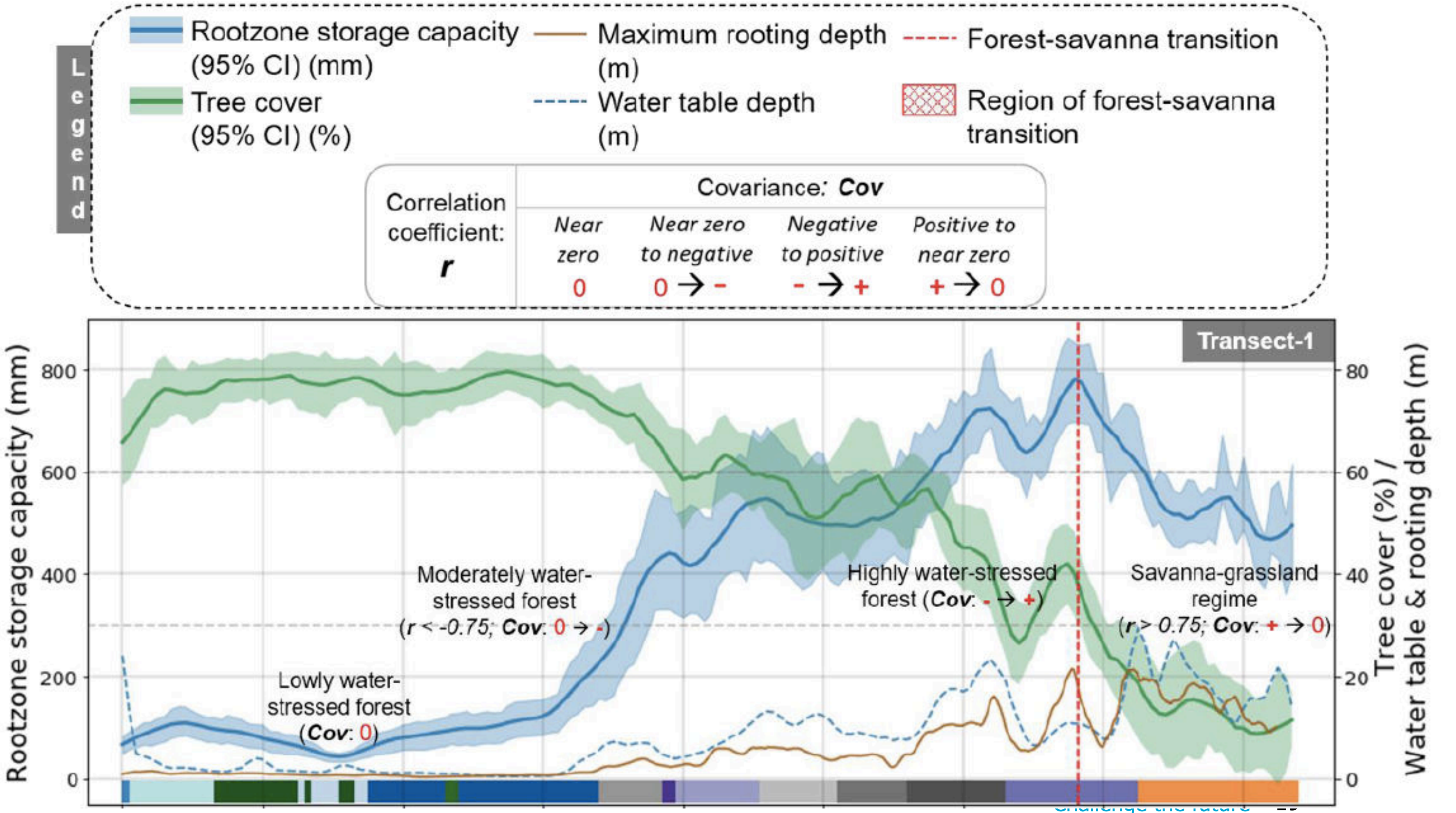
Chandrakant Singh[1,2,3,6], Lan Wang-Erlandsson[1,2], Ingo Fetzer[1,2], Johan Rockström[4] and Ruud van der Ent[3,5]

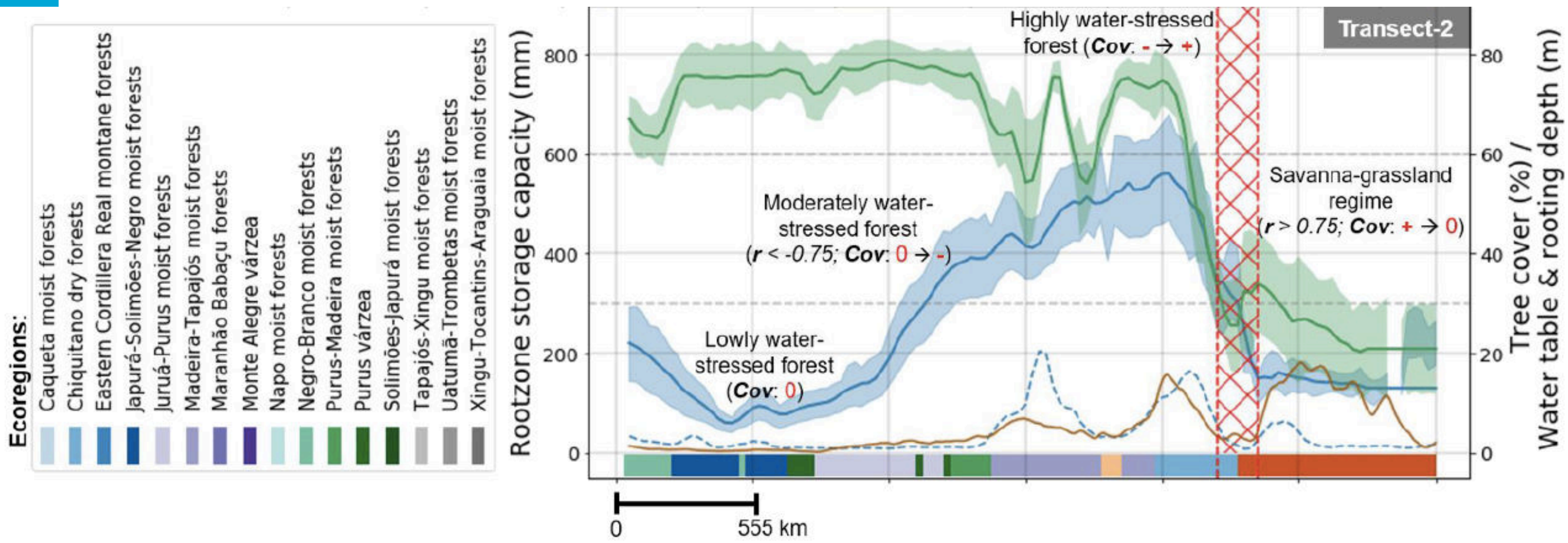
1 Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden
2 Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden
3 Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands
4 Potsdam Institute for Climate Impact Research, Potsdam, Germany
5 Department of Physical Geography, Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands
6 Author to whom any correspondence should be addressed

E-mail: chandrakant.singh@su.se

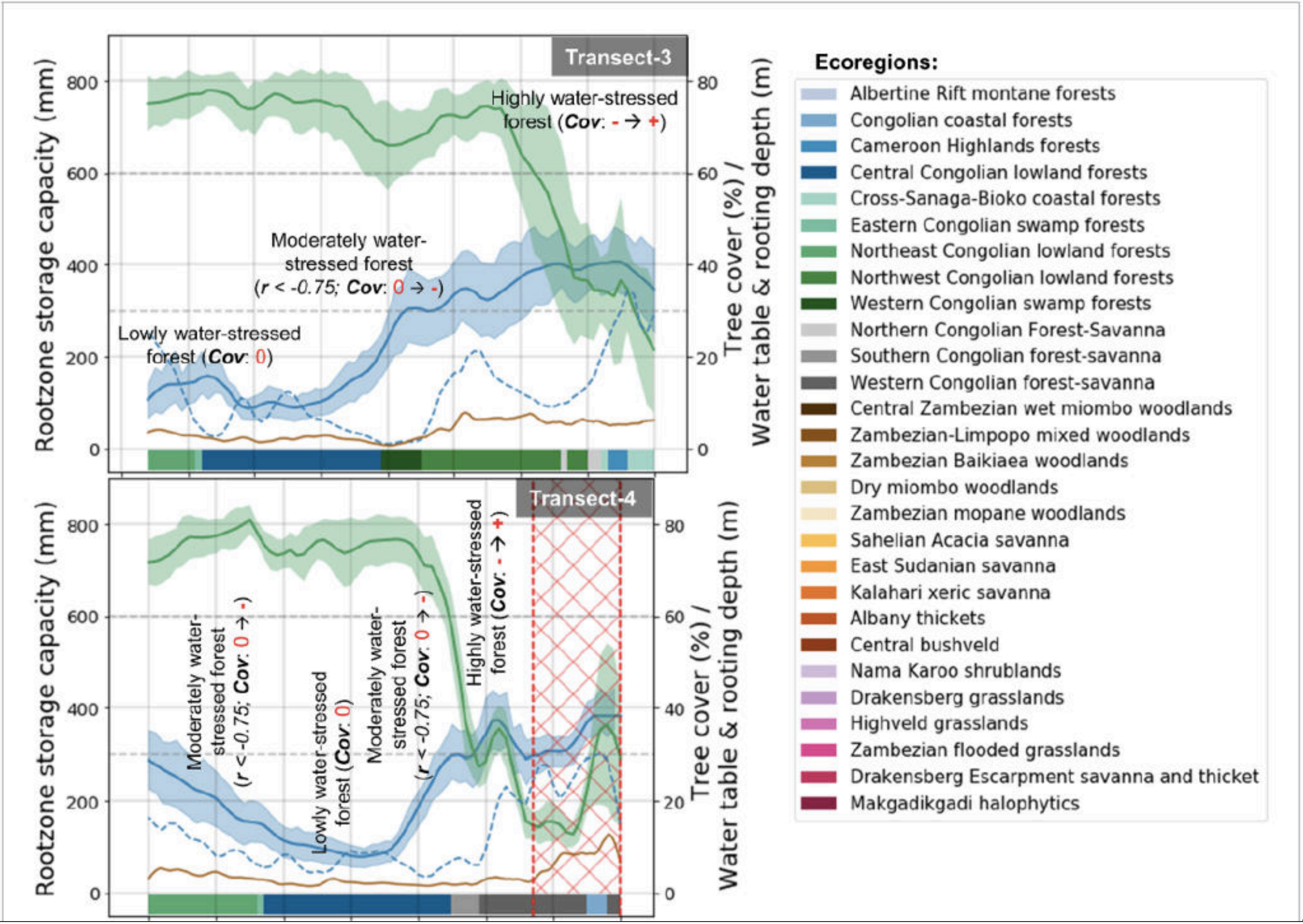
Keywords: Amazon, Congo, ecohydrology, ecosystem dynamics, remote sensing, transects, water-stress

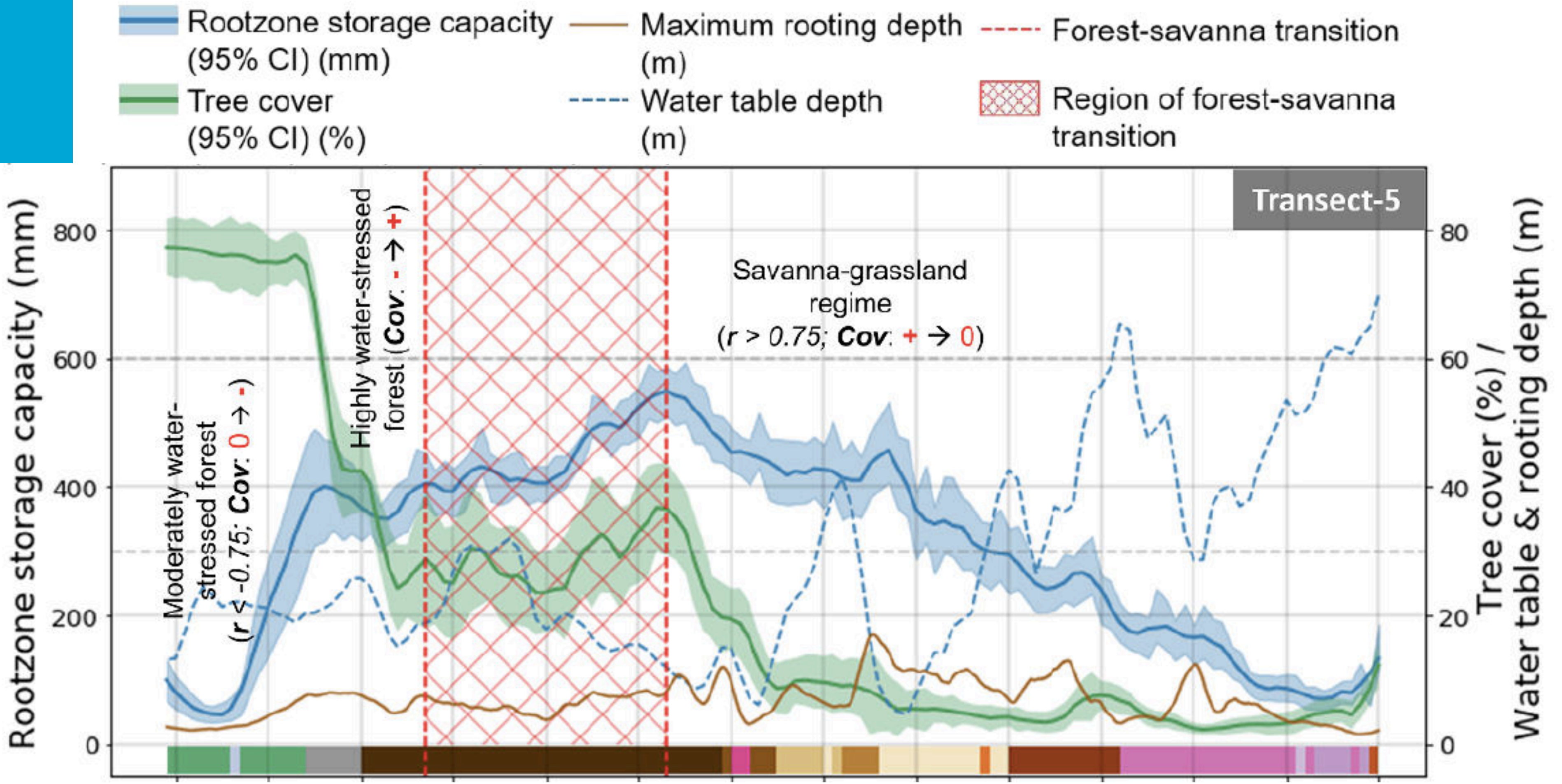

a
b
N
6
3
4
1
2
5
km
0
4000
75 °W
45 °W
15 °W
0 °
15 °E
45 °E
Tree cover (%)
0
20
40
60
80
100
30 °N
15 °N
0 °
15 °S
30 °S
45 °S
No data
Rootzone storage capacity (mm)
200
400
600
800


Legend
Rootzone storage capacity (95% CI) (mm)
Tree cover (95% CI) (%)
Maximum rooting depth (m)
Water table depth (m)
Forest-savanna transition
Region of forest-savanna transition
Correlation coefficient: r
Covariance: Cov
Near zero 0
Near zero to negative 0 → -
Negative to positive - → +
Positive to near zero + → 0
Transect-1
Rootzone storage capacity (mm)
Tree cover (%) / Water table & rooting depth (m)
800
600
400
200
0
80
60
40
20
0
Lowly water-stressed forest (Cov: 0)
Moderately water-stressed forest (r < -0.75; Cov: 0 → -)
Highly water-stressed forest (Cov: - → +)
Savanna-grassland regime (r > 0.75; Cov: + → 0)



Ecoregions:
Caqueta moist forests
Chiquitano dry forests
Eastern Cordillera Real montane forests
Japurá-Solimões-Negro moist forests
Juruá-Purus moist forests
Madeira-Tapajós moist forests
Maranhão Babaçu forests
Monte Alegre várzea
Napo moist forests
Negro-Branco moist forests
Purus-Madeira moist forests
Purus várzea
Solimões-Japurá moist forests
Tapajós-Xingu moist forests
Uatumã-Trombetas moist forests
Xingu-Tocantins-Araguaia moist forests
Rootzone storage capacity (mm)
Tree cover (%) / Water table & rooting depth (m)
Transect-2
Highly water-stressed forest (Cov: - → +)
Moderately water-stressed forest (r < -0.75; Cov: 0 → -)
Lowly water-stressed forest (Cov: 0)
Savanna-grassland regime (r > 0.75; Cov: + → 0)
0
555 km


Transect-3
Highly water-stressed forest (Cov: - → +)
Moderately water-stressed forest (r < -0.75; Cov: 0 → -)
Lowly water-stressed forest (Cov: 0)
Rootzone storage capacity (mm)
Tree cover (%) / Water table & rooting depth (m)
Transect-4
Moderately water-stressed forest (r < -0.75; Cov: 0 → -)
Lowly water-stressed forest (Cov: 0)
Moderately water-stressed forest (r < -0.75; Cov: 0 → -)
Highly water-stressed forest (Cov: - → +)
Ecoregions:
Albertine Rift montane forests
Congolian coastal forests
Cameroon Highlands forests
Central Congolian lowland forests
Cross-Sanaga-Bioko coastal forests
Eastern Congolian swamp forests
Northeast Congolian lowland forests
Northwest Congolian lowland forests
Western Congolian swamp forests
Northern Congolian Forest-Savanna
Southern Congolian forest-savanna
Western Congolian forest-savanna
Central Zambezian wet miombo woodlands
Zambezian-Limpopo mixed woodlands
Zambezian Baikiaea woodlands
Dry miombo woodlands
Zambezian mopane woodlands
Sahelian Acacia savanna
East Sudanian savanna
Kalahari xeric savanna
Albany thickets
Central bushveld
Nama Karoo shrublands
Drakensberg grasslands
Highveld grasslands
Zambezian flooded grasslands
Drakensberg Escarpment savanna and thicket
Makgadikgadi halophytics


Rootzone storage capacity (95% CI) (mm)
Tree cover (95% CI) (%)
Maximum rooting depth (m)
Water table depth (m)
Forest-savanna transition
Region of forest-savanna transition
Transect-5
Rootzone storage capacity (mm)
Tree cover (%) / Water table & rooting depth (m)
800
600
400
200
0
80
60
40
20
0
Moderately water-stressed forest (r < -0.75; Cov: 0 → -)
Highly water-stressed forest (Cov: - → +)
Savanna-grassland regime (r > 0.75; Cov: + → 0)

Conclusions

- Landscape and ecosystem hold the key to hydrology
- The ecosystem is the manager of the hydrological system
- The ecosystem adjusts to climate change
- Adjustment can be FAST
- Models should also evolve and adjust to climate change
- Hydrological models should be alive !
- Only then can we address Change in Hydrology


Thank you!

References:

Savenije, H. H. G. and Hrachowitz, M.: HESS Opinions "Catchments as meta-organisms – a new blueprint for hydrological modelling", *Hydrol. Earth Syst. Sci.*, 21, 1107-1116, 2017.

McDonnell, J. J., et al., 2007. Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology, Water Resour. Res., 43, W07301, doi:10.1029/2006WR005467, 2007

Sriwongsitanon, N., Gao, H., Savenije, H. H. G., Maekan, E., Saengsawang, S., and Thianpopirug, S., 2016. Comparing the Normalized Difference Infrared Index (NDII) with root zone storage in a lumped conceptual model, *Hydrol. Earth Syst. Sci.*, 20, 3361-3377, doi:10.5194/hess-20-3361-2016, 2016

Wang-Erlandsson, L., Bastiaanssen, W. G. M., Gao, H., Jägermeyr, J., Senay, G. B., van Dijk, A. I. J. M., Guerschman, J. P., Keys, P. W., Gordon, L. J., and Savenije, H. H. G.: Global root zone storage capacity from satellite-based evaporation. *Hydrol. Earth Syst. Sci.*, 20, 1459–1481, 2016.

Boer-Euser, T. ., H. K. McMillan, M. Hrachowitz, H. C. Winsemius, and H. H. G. Savenije, 2016. Influence of soil and climate on root zone storage capacity, *Water Resour. Res.*, 52, 2009–2024, 2016.

Gao, H., Hrachowitz, M., Schymanski, S. J., Fenicia, F., Sriwongsitanon, N. and Savenije, H. H. G.: Climate controls how ecosystems size the root zone storage capacity at catchment scale, *Geophysical Research Letters*, 41, 7916-7923, doi: 10.1002/2014GL061668, 2014.

Wang-Erlandsson, L., van der Ent, R. J., Gordon, L. J., and Savenije, H. H. G.: Contrasting roles of interception and transpiration in the hydrological cycle – Part 1: Temporal characteristics over land, *Earth Syst. Dynam.*, 5, 441-469, doi:10.5194/esd-5-441-2014, 2014

Montanari, A., Young, G., Savenije, H.H.G., et al., 2013. “Panta Rhei, Everything Flows”: Change in hydrology and society; The IAHS Scientific Decade 2013–2022. *Hydrological Sciences Journal*, 58 (6), 1256-1275, 2013.

Sivapalan, M., H.H.G. Savenije, and G. Bloeschl, 2012. Socio-hydrology: A new science of people and water, *Hydrological Processes*, 26, 1270-1276, 2012

References (cont.)

Gao, H., M. Hrachowitz, F. Fenicia, S. Gharari, and H. H. G. Savenije, 2014. Testing the realism of a topography driven model (FLEX-Topo) in the nested catchments of the Upper Heihe, China, Hydrol. Earth Syst. Sci., 18, 1895-1915

Gao, H., Birkel, C., Hrachowitz, M., Tetzlaff, D., Soulsby, C., and Savenije, H. H. G., 2019. A simple topography-driven and calibration-free runoff generation module, Hydrol. Earth Syst. Sci., 23, 787-809, https://doi.org/10.5194/hess-23-787-2019.

Gharari, S., M. Hrachowitz, F. Fenicia, and H. H. G. Savenije, 2011. Hydrological landscape classification: investigating the performance of HAND based landscape classifications in a central European meso-scale catchment, *Hydrol. Earth Syst. Sci.*, 15, 3275–3291, doi:10.5194/hess-15-3275-2011

Mao, G. and Liu, J.: WAYS v1: a hydrological model for root zone water storage simulation on a global scale, Geosci. Model Dev., 12, 5267–5289, https://doi.org/10.5194/gmd-12-5267-2019, 2019.

Nijzink, R., Hutton, C., Pechlivanidis, I., Capell, R., Arheimer, B., Freer, J., Han, D., Wagener, T., McGuire, K., Savenije, H., and Hrachowitz, M., 2016. The evolution of root-zone moisture capacities after deforestation: a step towards hydrological predictions under change?, Hydrol. Earth Syst. Sci., 20, 4775-4799, doi:10.5194/hess-20-4775-2016.

Bouaziz, L. J. E., Steele-Dunne, S. C., Schellekens, J., Weerts, A. H., Stam, J., Sprokkereef, E., Winsemius, H., Savenije, H., Hrachowitz, M., 2020. Improved understanding of the link between catchment-scale vegetation accessible storage and satellite-derived Soil Water Index. Water Resources Research, 56, e2019WR026365.

de Boer-Euser, T., J. Palalane, H. Savenije, D. Juízo, 2019. How climate variations are reflected in root zone storage capacities, Physics and Chemistry of the Earth, 112 (2019) 83–90.

Gao, H., Birkel, C., Hrachowitz, M., Tetzlaff, D., Soulsby, C., and Savenije, H. H. G., 2019. A simple topography-driven and calibration-free runoff generation module, Hydrol. Earth Syst. Sci., 23, 787-809, https://doi.org/10.5194/hess-23-787-2019.

Singh, C., Wang-Erlandsson, L., Fetzer, I., Rockström, J., and Van der Ent, R., 2020. Rootzone storage capacity reveals drought coping strategies along rainforest-savanna transitions, *Environ. Res. Lett.* 15 (2020) 124021

Relevant Opinion Papers

Savenije, H.H.G., 2001. Equifinality, a blessing in disguise?, HP Today Invited commentary, Hydrological Processes, 15, pp. 2835-2838.

Savenije, Hubert H.G., 2004. The importance of interception and why we should delete the term evapotranspiration from our vocabulary. Hydrological Processes, 18(8):1507-1511.

Savenije, H.H.G., 2009. The Art of Hydrology. Hydrology and Earth System Sciences, 13, 157–161.

Savenije, H.H.G., HESS Opinions "Topography driven conceptual modelling (FLEX-Topo)", Hydrol. Earth Syst. Sci., 14, 2681–2692, 2010. doi:10.5194/hess-14-2681-2010

Savenije, H. H. G. and Hrachowitz, M., 2017. HESS Opinions "Catchments as meta-organisms – a new blueprint for hydrological modelling",Hydrol. Earth Syst. Sci., 21, 1107-1116, doi:10.5194/hess-21-1107-2017.

Savenije, H. H. G. , 2018. HESS Opinions: Linking Darcy's equation to the linear reservoir. Hydrol. Earth Syst. Sci., 22, 1911-1916.