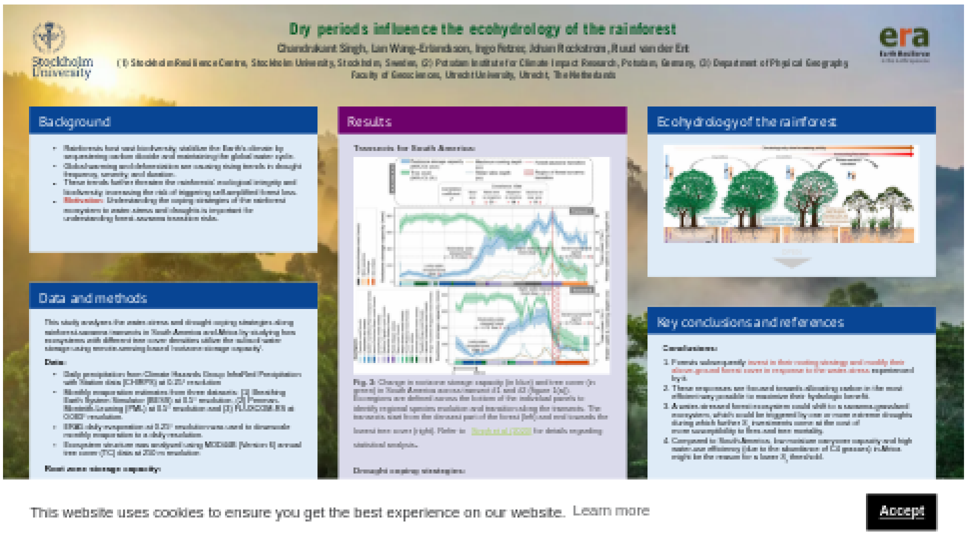
Dry periods influence the ecohydrology of the rainforest



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Earth Resilience in the Anthropocene

PRESENTED AT:

BACKGROUND

- Rainforests host vast biodiversity, stabilize the Earth's climate by sequestering carbon dioxide and maintaining the global water cycle.
- Global warming and deforestation are causing rising trends in drought frequency, severity, and duration.
- These trends further threaten the rainforests' ecological integrity and biodiversity, increasing the risk of triggering self-amplified forest loss.
- **Motivation**: Understanding the coping strategies of the rainforest ecosystem to water-stress and droughts is important for understanding forest-savanna transition risks.

DATA AND METHODS

This study analyzes the water-stress and drought coping strategies along rainforest-savanna transects in South America and Africa by studying how ecosystems with different tree cover densities utilize the subsoil water storage using remote-sensing based 'rootzone storage capacity'.

Data:

- Daily precipitation from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) at 0.25° resolution
- Monthly evaporation estimates from three datasets: (1) Breathing Earth System Simulator (BESS) at 0.5° resolution, (2) Penman-Monteith-Leuning (PML) at 0.5° resolution and (3) FLUXCOM-RS at 0.083° resolution.
- ERA5 daily evaporation at 0.25° resolution was used to downscale monthly evaporation to a daily resolution.
- Ecosystem structure was analysed using MOD44B (Version 6) annual tree cover (TC) data at 250 m resolution

Root zone storage capacity:

- Rootzone storage capacity (Sr) is the maximum amount of soil moisture that can be accessed by vegetation for transpiration. Plants can increase Sr by expanding their roots in the soil laterally as well as vertically.
- We adapted the mass-balance methodology in Wang-Erlandsson et al (2016) to estimate Sr from the maximum annual accumulated water deficit, which was calculated using daily estimates of rainfall and evaporation.

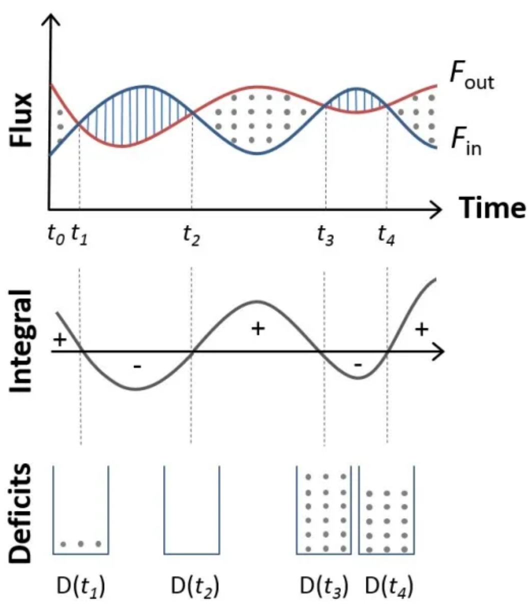


Fig. 1: Conceptual illustration of the algorithm for calculating the root zone storage capacity Sr (refer to Wang-Erlandsson et al (2016) (https://hess.copernicus.org/articles/20/1459/2016/hess-20-1459-2016.pdf) for more information).

- A 20-year drought return period based on the Gumbel extreme value distribution was used to calculate Sr
- Furthermore, maximum rooting depth data will be used to validate the findings and provide insights into dynamic rooting response and subsoil hydraulic structure.

Transect analysis:

We chose six representative transects following the longest possible transition line from the densest part of the rainforests all the way into the savannas and grasslands.

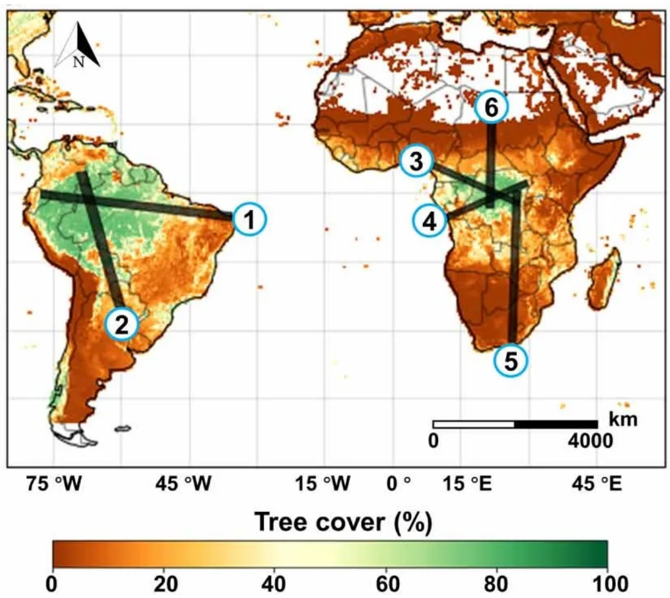


Fig. 2: South American and African spatial distribution of mean tree cover (2001–2012). The black straight lines depict the forest-savanna-grassland transects analyzed in this study.

Here, we only show the results for transect-1 and 2. For the rest of the transects, refer to Singh et al (2020) (https://iopscience.iop.org/article/10.1088/1748-9326/abc377#artAbst).

RESULTS

Evaluating transects for South America:

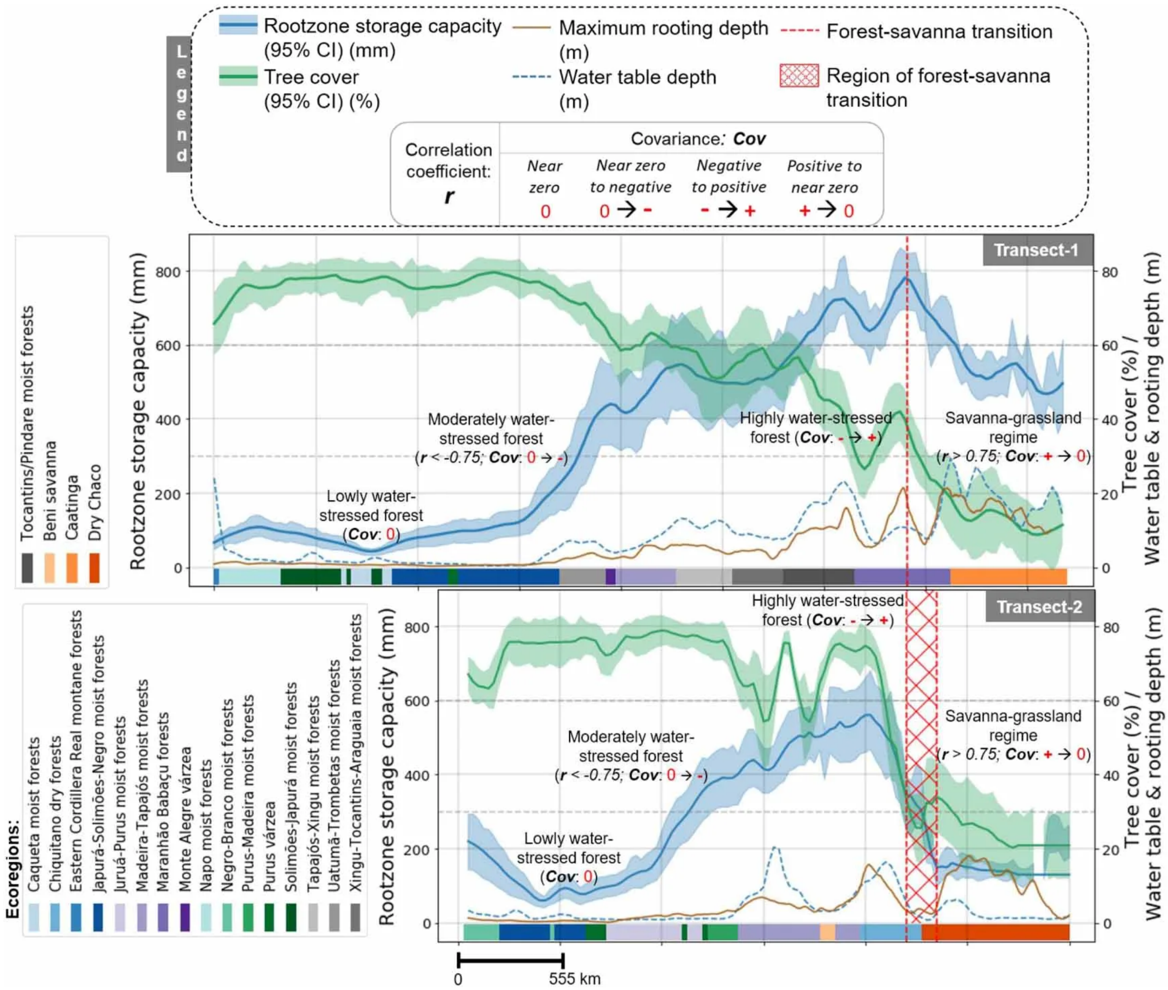


Fig. 3: Change in rootzone storage capacity (in blue) and tree cover (in green) in South America across transect #1 and #2 (figure 1(a)). Ecoregions are defined across the bottom of the individual panels to identify regional species evolution and transition along the transects. The transects start from the densest part of the forest (left) and end towards the lowest tree cover (right). Refer to Singh et al (2020) (https://iopscience.iop.org/article/10.1088/1748-9326/abc377#artAbst) for details regarding statistical analysis.

Drought coping strategies:

Based on the tree cover and Sr relationship, we categorize the drought coping strategies into four classes:

1. Lowly water-stressed forest (shallow roots, high TC)
2. Moderately water-stressed forest (investing in Sr, high TC)
3. Highly water-stressed forest (trade-off between investments in Sr and TC)
4. Savanna- grassland regime (competitive rooting strategy, low TC)

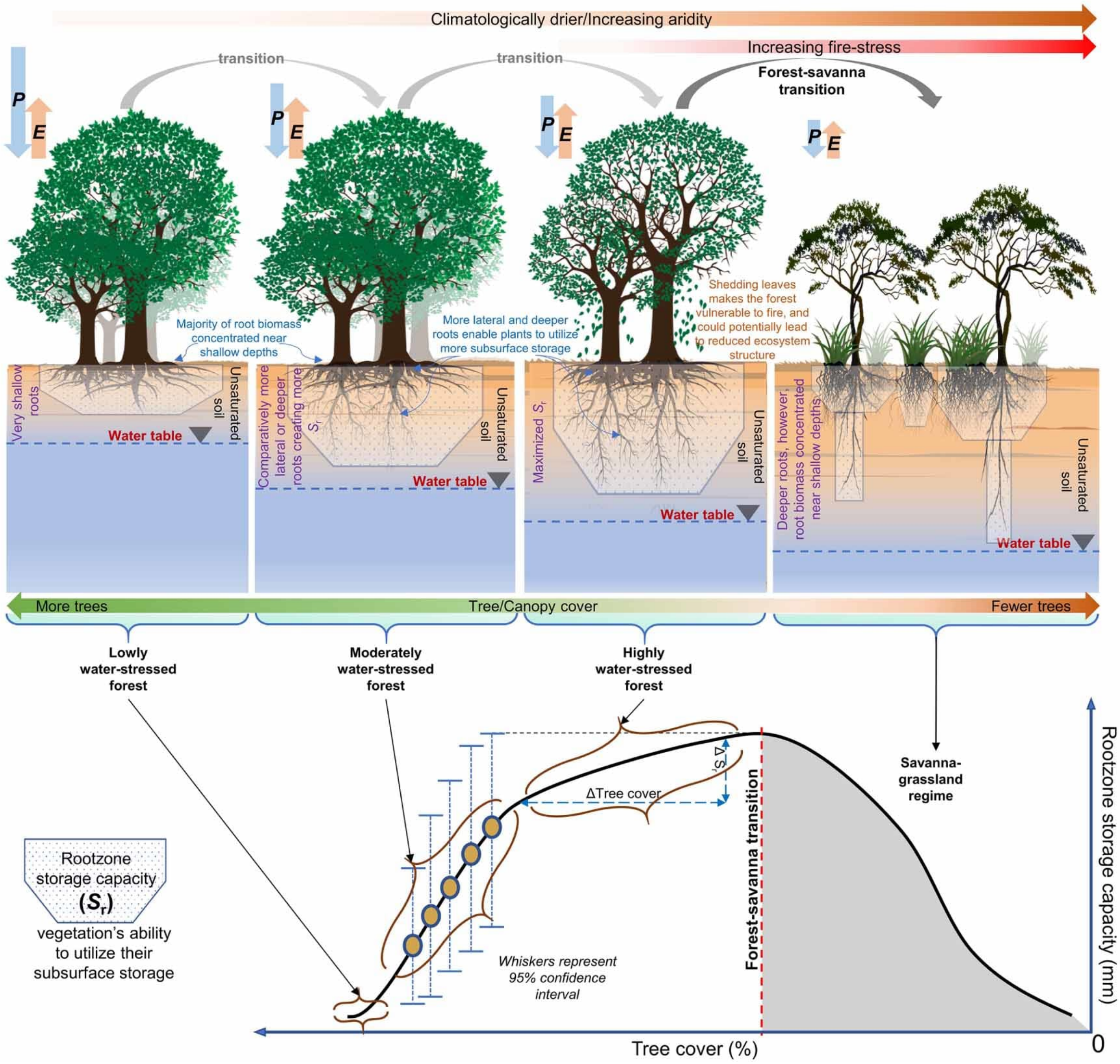


Fig. 4: The transition of vegetation from the 'lowly water-stressed forest' with high tree cover to a 'savanna-grassland regime' with low tree cover and the utilization of rootzone storage capacity to cope with the spatial change to a drier climate. Precipitation (i.e. rainfall; *P*) and evaporation (*E*) arrows describe the relative magnitude of these moisture fluxes for each forest class. The line plot below describes the physical state of change in rootzone storage capacity and tree cover.

KEY CONCLUSIONS AND REFERENCES

Conclusions:

1. Forests subsequently invest in their rooting strategy and modify their above-ground forest cover in response to the water-stress experienced by it.
2. These responses are focused towards allocating carbon in the most efficient way possible to maximize their hydrologic benefit.
3. The currently lowly water-stressed forest areas with low Sr may need to start investing in their root system if a changing hydroclimate brings more frequent droughts, less rainfall, or larger rainfall variability, eventually changing into a moderately water-stressed forest.
4. A water-stressed forest ecosystem could shift to a savanna-grassland ecosystem, which could be triggered by one or more extreme droughts during which further S_r investments come at the cost of more susceptibility to fires and tree mortality.
5. Compared to South America, low moisture carryover capacity and high water-use efficiency (due to the abundance of C4 grasses) in Africa might be the reason for a lower S_r threshold.

We conclude that the TC-Sr relationship is analytically robust because of its detailed and spatially consistent representation of ecosystem dynamics. This concept can be further explored to improve our understanding of forest resilience and to predict future regime shifts in the tropics.

References:

Singh, C., Wang-Erlandsson, L., Fetzer, I., Rockström, J., & Van Der Ent, R. (2020). Rootzone storage capacity reveals drought coping strategies along rainforest-savanna transitions. Environmental Research Letters, 15(12), 124021. [**This study** (https://iopscience.iop.org/article/10.1088/1748-9326/abc377)**]**

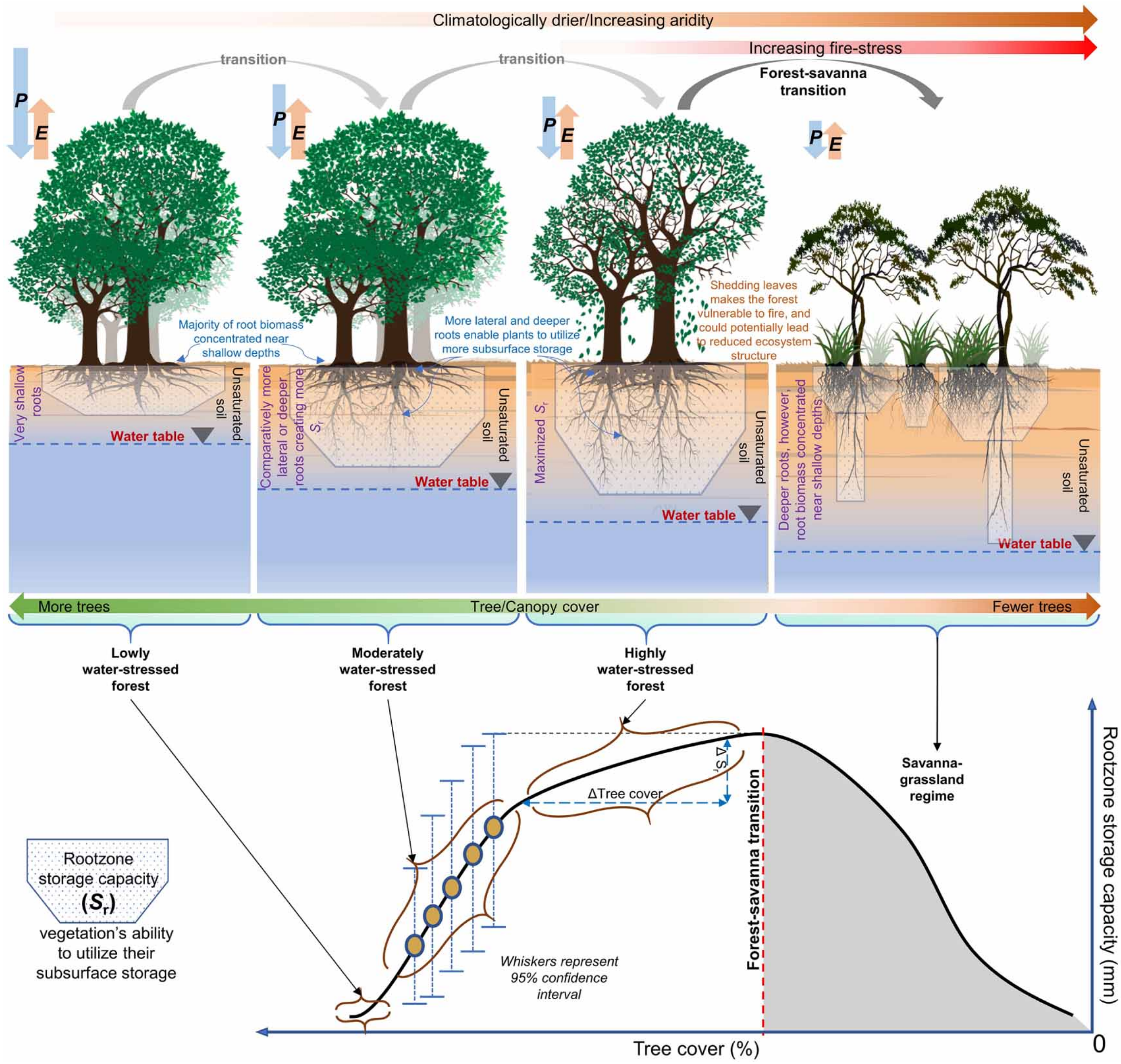
Wang-Erlandsson, L., Bastiaanssen, W. G., Gao, H., Jägermeyr, J., Senay, G. B., Van Dijk, A. I., ... & Savenije, H. H. (2016). Global root zone storage capacity from satellite-based evaporation. Hydrology and Earth System Sciences, 20(4), 1459-1481.

Acknowledgements:

This project acknowledges funding from the European Research Council (ERC) project on Earth Resilience in the Anthropocene (ERA), project number ERC-2016-ADG 743080.

ABSTRACT

Climate change and deforestation influence the rainfall patterns in the tropics, thereby increasing the risk of drought-induced forest-to-savanna transitions. Forest ecosystems respond to these changing environmental conditions by adapting various drought coping strategies driven by different magnitudes of water-stress (i.e., defined here as a deficit in soil water availability inhibiting plant growth due to change in rainfall patterns). A better understanding of forest dynamics in response to the water-stress conditions is, therefore, crucial to determine the rainforest's present ecohydrological conditions, as well as project a possible rainforest-savanna transition scenario. However, our present understanding of such transitions is entirely based on rainfall, which does not consider the adaptability of vegetation to droughts by utilizing subsoil moisture in a quantifiable metric. Using remote-sensing derived root zone storage capacity (*S*r) and tree cover, we analyze the water-stress and drought coping strategies of the rainforest-savanna ecosystems in South America and Africa. The results from our empirical and statistical analysis allows us to classify the ecosystem's adaptability to droughts into four key classes of drought coping strategies: lowly water-stressed forest (shallow roots, high tree cover), moderately water-stressed forest (investing in *S*r, high tree cover), highly water-stressed forest (trade-off between investments in *S*r and tree cover) and savanna-grassland regime (competitive rooting strategy, low tree cover). This study concludes that the ecosystems' responses are primarily focused on allocating carbon in the most efficient way possible to maximize their hydrological benefits. The insights from this study suggest remote sensing-based *S*r as an important indicator revealing important subsoil forest dynamics and opens new paths for understanding the ecohydrological state, resilience, and adaptation dynamics of the tropical ecosystems under a rapidly changing climate.



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