

# Local-scale secondary water resources modulate seasonal water limitation across Africa

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## 1 Introduction

2 Quantify Fractional Vegetation Cover (FVC) using geostationary satellite

3 Machine learning based attribution of land effects on FVC decay rate

# Understanding Vegetation Dynamics in Water Limited Systems via Remote Sensing

*Drylands:* Important for global biogeochemical cycles and IAV

*Secondary water resources:* Critical for water-limited systems

- Local scale processes, highly uncertain or ignored in large scale studies
- Strongly modulated by land properties

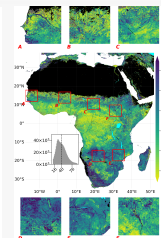
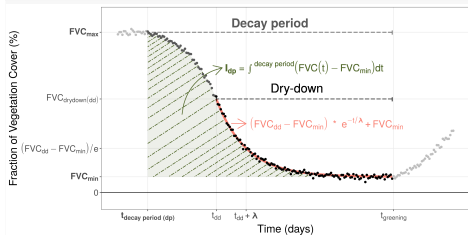
*Africa:* Predominantly water-limited

- High uncertainties in large scale studies
- Scarcity of ground measurements

*Data driven approach:*

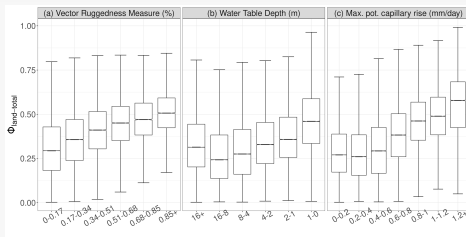
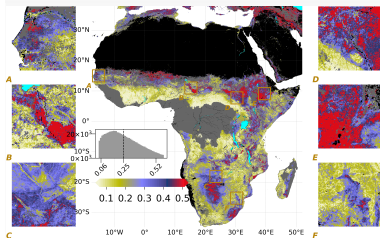
- High resolution remote sensing products
- Advances in machine learning

# Quantify Fractional Vegetation Cover (FVC) using geostationary satellite



- Set of metrics with diagnostic potential
- *Preprint*: Characterising the response of vegetation cover to water limitation in Africa using geostationary satellites. doi: 10.1002/essoar.10504964.1

## Machine learning based attribution of land effects on FVC decay rate



Stronger land effects:

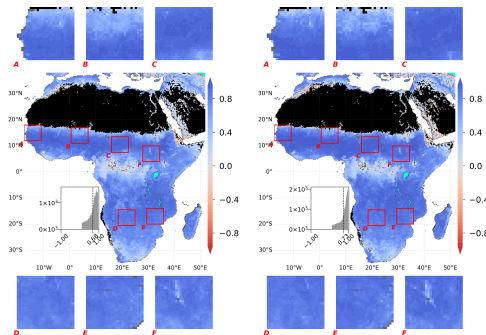
- Topographic complexity
- Shallow groundwater
- Capillary rise

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# Motivation

- Africa is predominantly water limited → FVC time series can be exploited to diagnose secondary water resources against water-limitation with a data-driven, Earth-observation perspective.
- Characteristics of FVC time series contain information on ecohydrological processes related to topography, groundwater, soil properties, vegetation traits, etc.

Temporal correlation of FVC and GLEAM root-zone soil moisture time series of 16 years for complete time series, and for periods where FVC decays, respectively. Pearson correlation is computed and grid cells only with significant correlation are mapped.



# Hypothesis

- Asymptotic values of FVC time series may be used to find “green islands”, groundwater dependent ecosystems at local scales
- Effect of complex topography at hillslope scales due to enhanced lateral moisture convergence and shading may be relevant for vegetation dynamics over large scales
- Integral of FVC during decay period may be used to diagnose plant accessible water storage capacity in soil
- FVC decay rate may mimic land evaporation decay rate if FVC and soil moisture have a linear relationship during dry-down

# Fractional Vegetation Cover (FVC) data & estimated diagnostic metrics

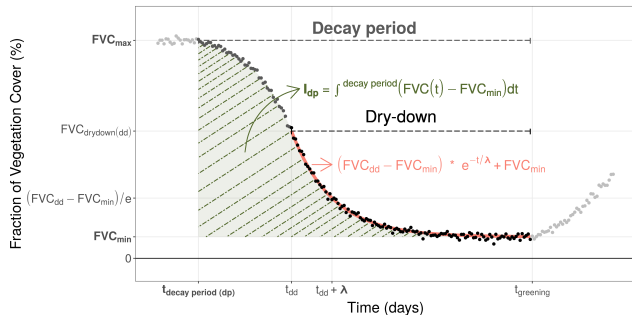
**Spatial Domain:** Africa; Res:  $0.0417^\circ (\sim 5km)$

**Temporal Domain:** 2004–2019; Res: Daily

**Source:** SEVIRI sensor, MSG satellite, LSA-SAF of EUMETSAT

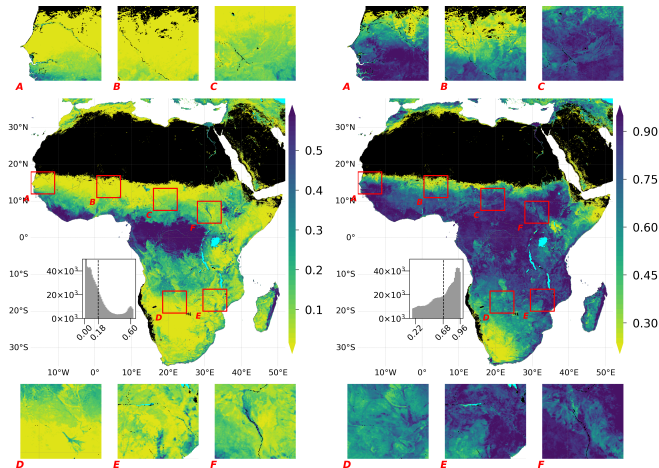
- (i) Robust asymptotic values for minimum and maximum FVC
- (ii) Integral of FVC during decay period ( $I_{dp}$ )
- (iii) Decay rate of FVC during dry-down ( $\lambda$ )

→ Decay period is detected by using only FVC data and its derivatives



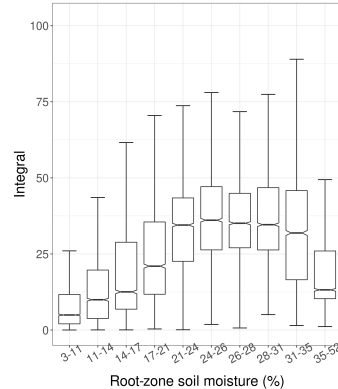
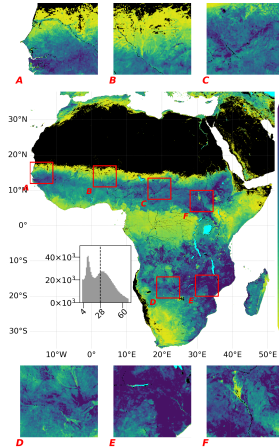
# Patterns of ecohydrological metrics - $FVC_{min}$ and $FVC_{max}$

- Maps of  $FVC_{min}$ ,  $FVC_{max}$ , respectively
- Larger  $FVC_{min}$  values with shallow groundwater, i.e. Sudd Swamp
- Larger  $FVC_{min}$  values with complex topography, i.e. Ethiopian Highlands



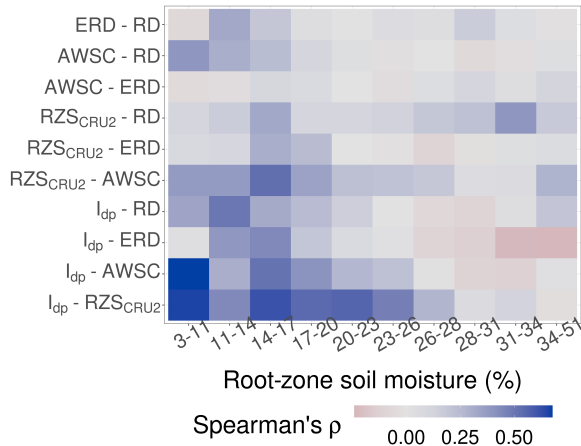
# Patterns of ecohydrological metrics - $I_{dp}$

- Map of  $I_{dp}$  and its variation over climatological aridity, respectively
- Largest values in semi-arid regions with strong seasonality but similar precipitation and land evaporation values annually
- Lowest values in arid regions as incapacity to develop deep roots
- Lower values in humid regions as no/weak water limitation



# Plant accessible water storage capacity and $I_{dp}$

- Spearman's correlation among different plant available water storage products
- Strong agreement among  $I_{dp}$  and other storage capacity products
- Highest correlation between  $I_{dp}$  and  $RZS_{CRU2}$  over continental scale
- Higher correlation with stronger aridity



ERD: Effective Rooting Depth (Yang et al. 2016)

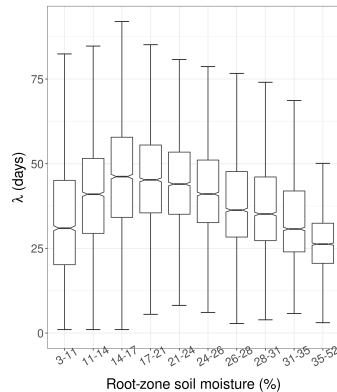
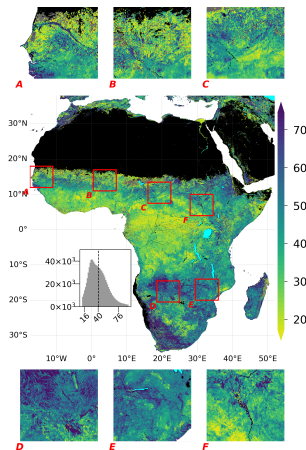
RD: Rooting Depth (Fan et al. 2017)

AWSC: Accessible Water Storage Capacity Tian et al. (2019)

$RZS_{CRU2}$ : Root Zone Storage Capacity (Wang-Erlandsson et al. 2016)

# Patterns of ecohydrological metrics - $\lambda$

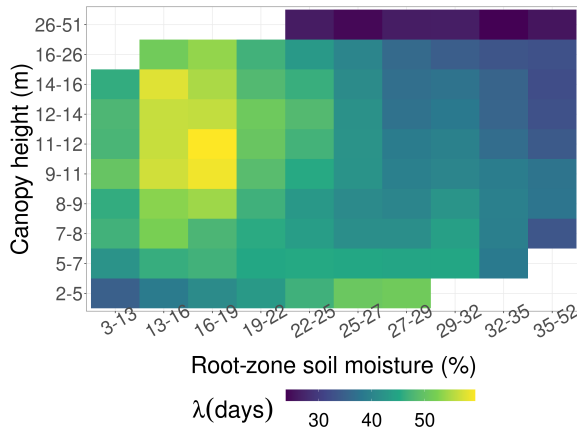
- Map of  $\lambda$  and its variation over climatological aridity, respectively
- Largest values in semi-arid regions and lowest in arid and humid regions
- Structured local scale variations suggesting importance of land effects



# Decay rate of $\lambda$ and land evaporation

- Slower decay in evapotranspiration with increasing aridity and taller canopy (Boese et al. 2019)

→ Consistent with the variations in  $\lambda$



- We provide observation based metrics from FVC time series over Africa, characterising the dynamics of vegetation during water limitation
- The metrics, derived from daily FVC data with  $0.0417^\circ$ , have strong diagnostic power to understand fine-scale vegetation–water interactions
- Focused on water-limited periods, the metrics can be used to test hypothesis and constrain models on highly uncertain processes

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- *Secondary water resources* (i.e.: groundwater, seasonally flooded areas, lateral convergence) may be of critical importance in water limited ecosystems
  - *Land properties* (i.e.: soil properties, topography) control accessibility of such resources and vary strongly over hillslope scales
  - *Question:* Effects of land properties on water limitation over large domains?
- *Hypothesis:* Any land property creating secondary water resource supports ecosystem and slows seasonal FVC decay

1. Filter seasonal FVC decay rate ( $\lambda$ ) for precipitation  $< 1500$  mm/year
2. Model  $\lambda$  with gradient boosted regression trees (XGBoost, Chen & Guestrin, 2016)
3. Analyse the model output for land parameters (SHAP, Lundberg et al. 2020))

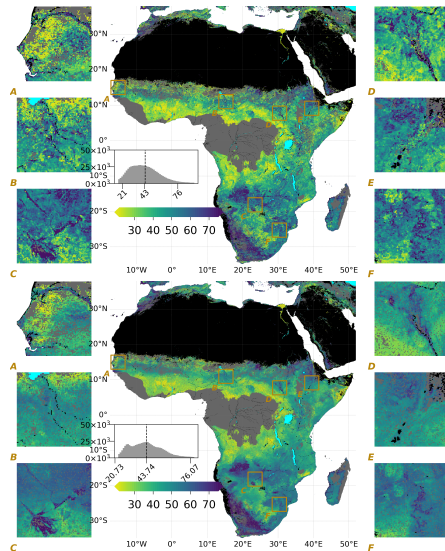
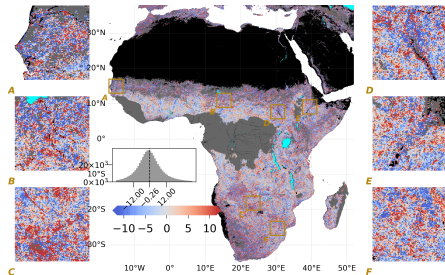
# Dataset

| Variable                                                                                                                         | Details                                             | Spat. Res.                     | Source                                                                                         |
|----------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|--------------------------------|------------------------------------------------------------------------------------------------|
| $\lambda$                                                                                                                        | Target variable                                     | 5 km                           | Küçük et al. (2020)                                                                            |
| Plant available water<br>Soil hydraulic conductivity<br>Max potential upwards capillary flux                                     | Estimated; using Hengl et al. (2017)                | 250 m                          | based on Saxton and Rawls (2006)<br>based on Richards (1931)                                   |
| Water Table Depth<br>Wetlands<br>Height Above Nearest Drainage<br>Topographic Wetness Index<br>Vectoral Ruggedness measure (VRM) |                                                     | 1 km<br>500 m<br>90 m<br>250 m | Fan et al. (2013)<br>Tootchi et al. (2019)<br>Yamazaki et al. (2019)<br>Amatulli et al. (2020) |
| Magnitude and scale of 3D roughness                                                                                              | derived from VRM                                    |                                |                                                                                                |
| Precipitation<br>Temperature<br>Radiation                                                                                        | Annual and seasonal scales                          | 5 km                           | Fick and Hijmans (2017)<br>Abatzoglou et al. (2018)                                            |
| Canopy height                                                                                                                    |                                                     |                                | 1 km                                                                                           |
| Vegetation cover<br>Plant Functional Type<br>Burned area                                                                         | Tree & non-tree veg. cov.<br>Major type & variation | 250 m                          | Dimicelli et al. (2015)<br>Friedl and Sulla-Menashe (2019)<br>Giglio et al. (2015)             |

- Land, climate, and vegetation parameters used to model  $\lambda$ . Note that 5 km  $\approx$  0.0417°

# Modelling $\lambda$

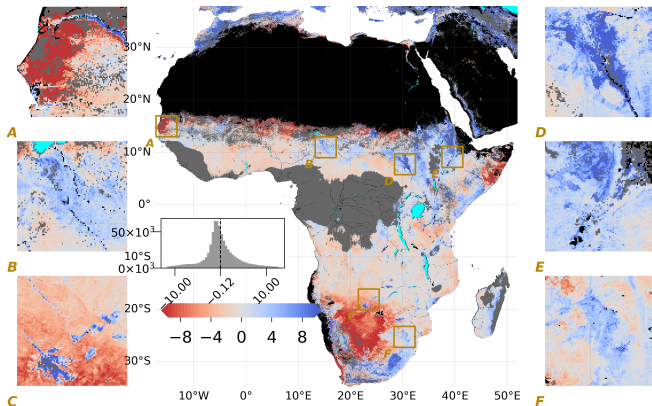
- $NSE = 0.55$
- Captures continental gradient and some of local variations
- Observed on top, model output on bottom



# Spatial variation of land effects

Map of total land effects:

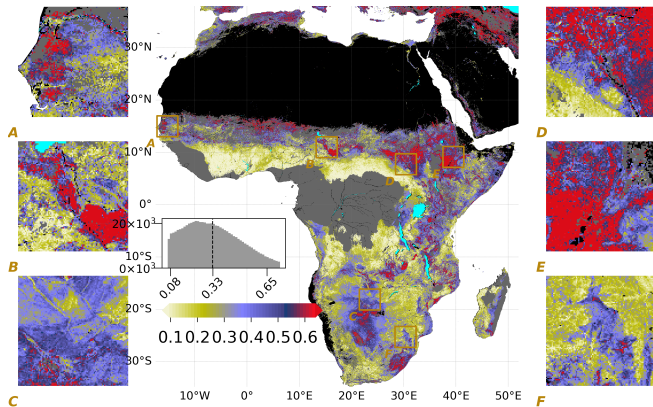
- Slower decay in shallow groundwater while faster decay where groundwater is disconnected from surface
- Slower decay in topographically complex regions



# Spatial variation of land effects

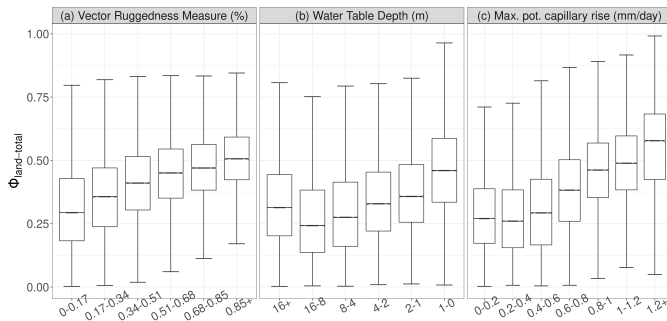
Map of relative mean absolute of land effects as the barplot:

- More than 60 % of control in decay rate in the hotspots,



# Driving factors of land effects

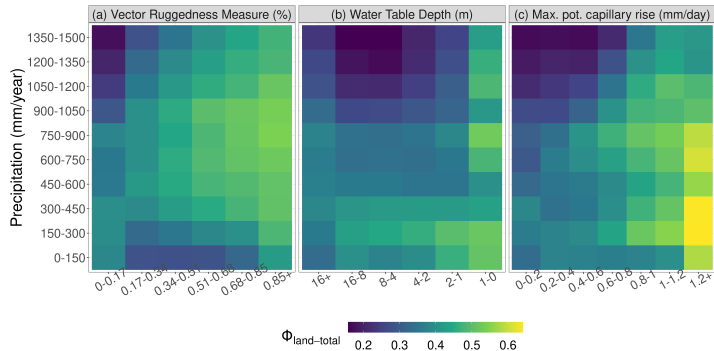
- (a) Positive correlation with topographic complexity:
  - Lateral convergence of soil moisture at hillslope scales
- (b) Positive correlation with shallow groundwater
  - Only if groundwater is connected to surface
- (c) Strongest correlation with capillary rise
  - $I_{cap}$  incorporates soil properties, topography and groundwater together



# Driving factors of land effects

Along climatological aridity gradient

- (a) Topographic complexity effects the most in semi-arid regions
- (b) Shallow WTD is important against water-limitation, regardless of climatological aridity
- (c) Capillary rise has the clearest gradient for climatological and actual aridity



# Conclusions II

1. Secondary water resources in local scales modulate water-limited vegetation decay over drylands
    - Also at large scales
  2.  $\sim 1/3$  of spat. var. of  $\lambda$  is controlled by land in African drylands
    - Can be more than 60 % in hotspots with combinations of shallow groundwater, complex topography, etc.
  3. Importance of land effects increases with increasing climatological aridity
- Importance of local scale ecohydrological processes in continental to global scales
- Processes across spatial scales should be considered in studies

- Thank you!
- Looking forward for discussions at “HS6.4: Remote sensing of interactions between vegetation and hydrology” Fri., 30 Apr. 15:30 - 17:00 or any other time via [ckucuk@bgc-jena.mpg.de](mailto:ckucuk@bgc-jena.mpg.de)