Influence of Soil Properties on Latent and Sensible Heat Transport in the Major Soil Types in Western Senegal

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BACKGROUND

- Land = a major element of the climate system
- Understanding **land-atmosphere interactions** essential for weather forecasting and climate modeling [1]
- **Sahel** presents prime setting for investigating interactions
- Central aspect to land-atmosphere interaction is evapotranspiration driven by latent and sensible heat fluxes
- **Partitioning of fluxes** influenced by heterogeneity of soil

soil = ∑ (physical soil properties, SHP, temperature, moisture)

- Current climate models lack key soil properties [2]
- Additionally soil hydraulic parameters (SHP) scarce for different soil types in Sahel region [3]
- Evaporation divided into **two stages**
  - (I) Liquid hydraulically connected network, high and constant evaporation rates, **latent heat dominates**
  - (II) Liquid network disrupted, drying front moves deeper into the soil, **sensible heat dominates** [4]
- Fluxes in vadose zone governed by gradients
  - Water fluxes described using Richard's equation
  - Soil permeability as a function of the fluid content can be described using **van Genuchten-Mualem model**
  - Heat fluxes by using Fourier's law of heat conduction

$$\theta(\psi) = \frac{\theta_s - \theta_r}{\left[1 + (\alpha * |\psi^n|)\right]^{1-\frac{1}{n}}}$$

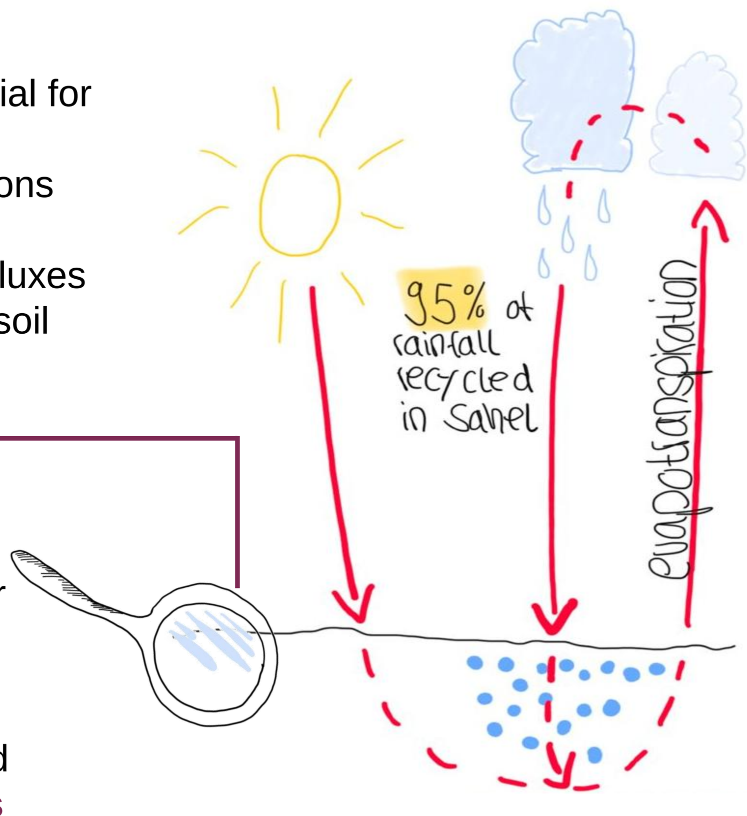
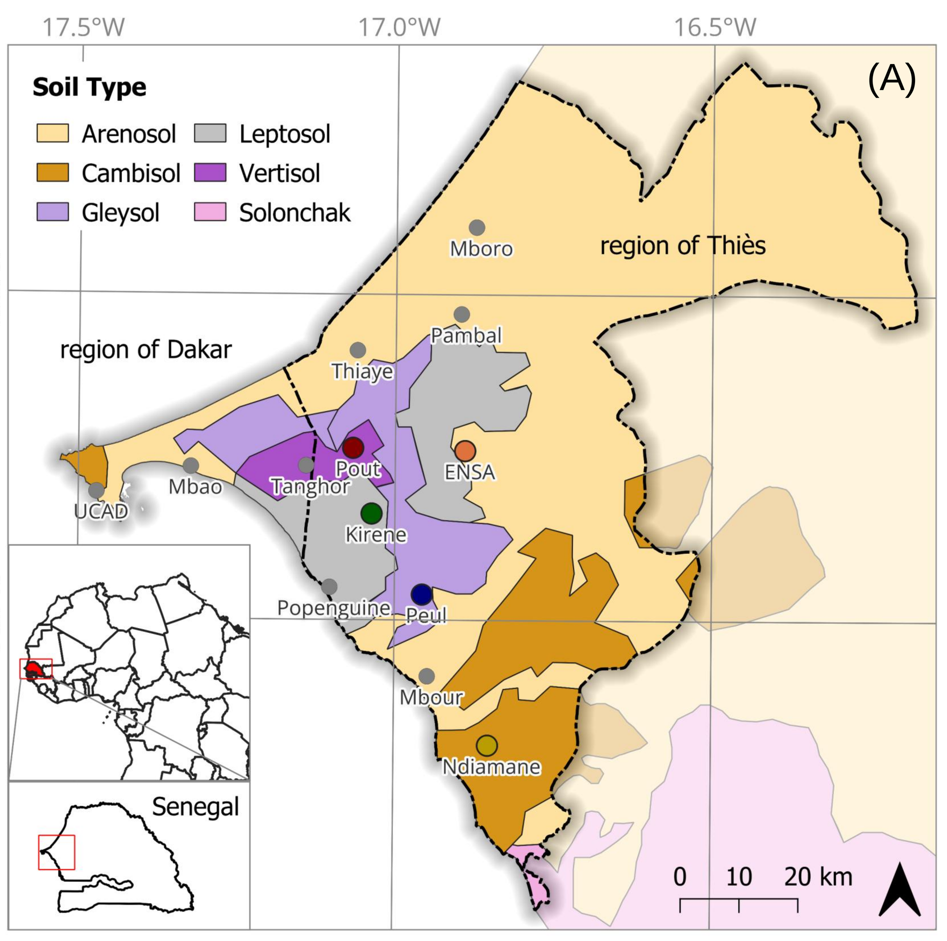


Fig. 1: Evapotranspiration – precipitation feedback loop in the Sahel (Own image)

AIM AND OBJECTIVES

Improve	Understanding of the influence of soil properties on latent and sensible heat transport in Western Senegal using field data and soil hydrological modeling
Characterise	SHP of the main soil types within the study area
Develop	Soil hydrological model using HYDRUS-1D to simulate heat and water transport
Calibrate	Model using observed soil moisture data

MATERIALS AND METHODS



- Study region: **Western Senegal**, as part of the Sahel region
- Rainy season with majority of rain between July and September
- Sandy loamy soils
- Study period: 6 months
- Focus on 5 locations of the DakE project which cover the five main soil types within the area (see Figure 2)

Fig. 2: Map of the region Dakar and Thies, Senegal showing the major soil types and sensor network of the DakE project. Colored dots indicate locations with TDR sensors and locations central to this study (A) and soil sensor setup in Pout (B)

- Estimate SHP using two different approaches
- (I) LABROS: using **observational data**, fitting van Genuchten-Mualem model to observational volumetric water content (see Figure 2B) and matric potential
- (II) HYDRUS: using **hydrological modeling**
- Model: coupled heat and water transport model (setup see Figure 3)
- Testing different model setups for two selected sites (ENSA, Kirene) (see Figure 4)

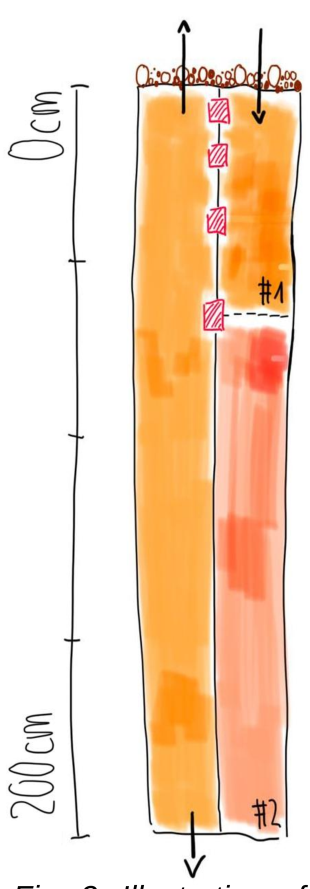


Fig. 3: Illustration of HYDRUS-1D model setup (Own image)

Tab. 1: Parameter boundaries for fitting van Genuchten-Mualem model. p corresponds to porosity. HYDRUS boundaries refer to VGM-HYD. α in cm^{-1} and K_s in cm d^{-1}

	LABROS		HYDRUS	
	lower	upper	lower	upper
α	10^{-5}	0.5	0.01	0.5
n	1.01	8	1.1	5
θ_r	0	0.25 x p	θ_{min}	θ_{min}
θ_s	0.2	p	0.2	0.4
K_s	10^{-2}	20	2.4	120
λ	0.5	0.5	0.5	0.5

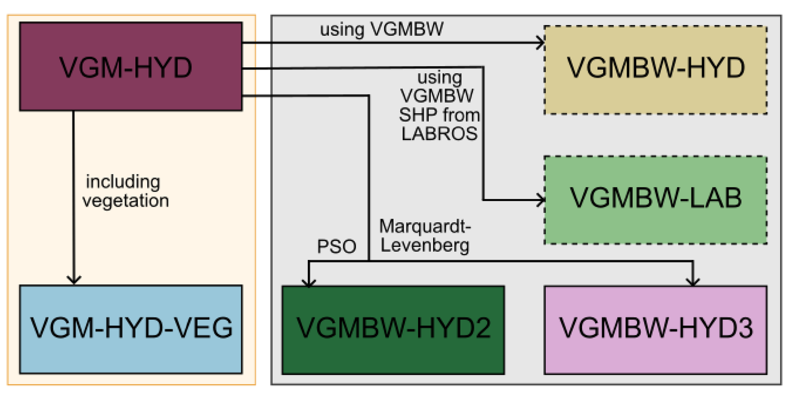


Fig. 4: Different model configurations with usage of van Genuchten-Mualem (VGM) model on the left side and usage of van Genuchten-Mualem Brunswick (VGMBW) model on the right side. PSO correpsonds to calibration algorithm Particle Swarm Optimization. Dashed border means uncalibrated model. HYD and LAB referr to origin of SHP beeing HYDRUS or LABROS respectively

RESULTS

- Predominant fraction across all sites **sand**
- **Bulk density high** (~ 1.8 g/cm^3)
- SHP estimates differ per approach, but overall comparable to literature values (see Figure 5)

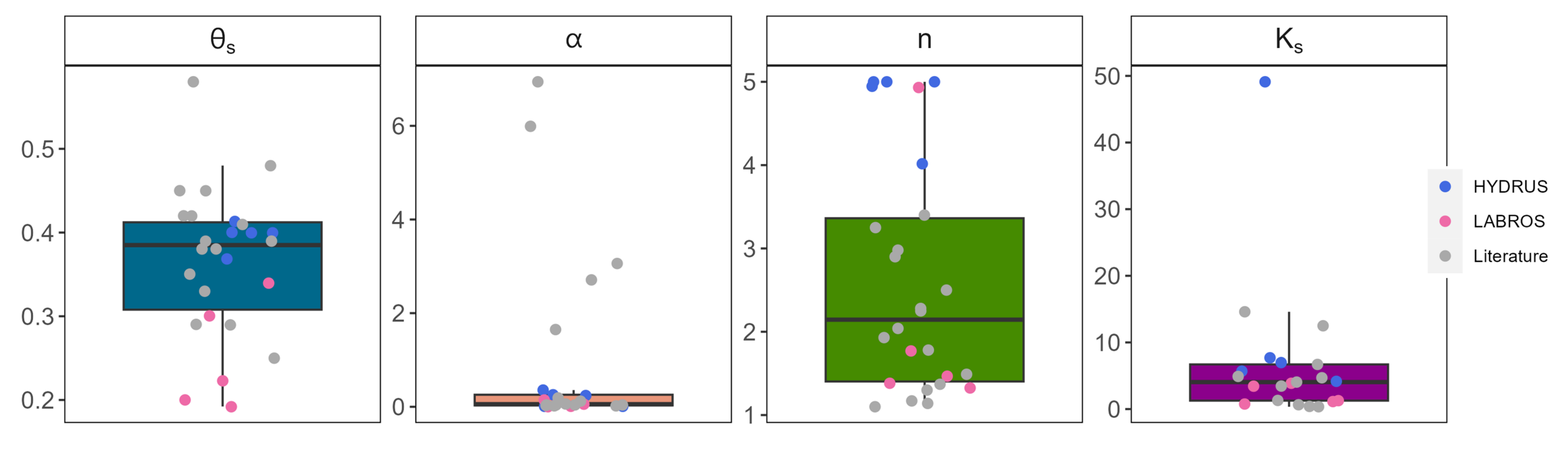


Fig. 5: Distribution of estimated SHP. Values from site specific estimation (I) LABROS and (II) HYDRUS (VGM-HYD model configuration) and literature values

- Simulated heat fluxes site specific and dependent on physical and hydrological soil properties
- **High positive correlation** between clay content, K_s (saturated hydraulic conductivity) and recovery time of soil moisture with latent heat flux (see Figure 6)

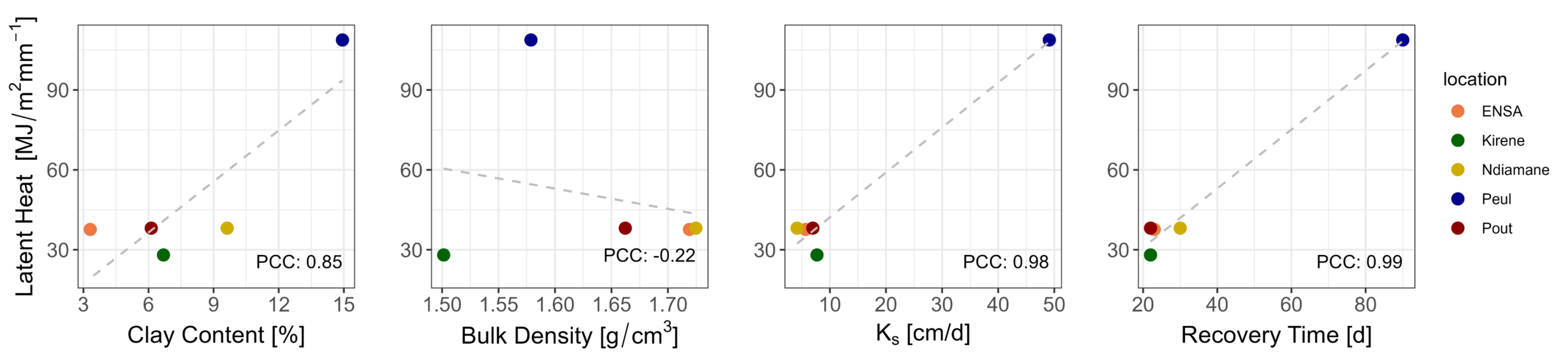


Fig. 6: Correlation of soil properties with simulated normalized cumulative latent heat (VGM-HYD configuration). PCC corresponds to Pearson's correlation coefficient. Grey dashed line indicate linear regression of data points

- Model **accuracy in need for improvement** (with Ø KGE_θ ~ 0.02 and Ø KGE_{temp} ~ 0.7) (Ø KGE referrs to mean of VGM-HYD model setups for all 5 locations)
- Various model runs (conducted for two selected sites) yield differing outcomes with contrasting levels of performance when evaluating the two sites (see Table 2, Figure 7)

Tab. 2: Kling-Gupta Efficiency (KGE) values for soil moisture simulations for two selected sites ENSA, Kirene. Abbreviations correspond to different model configurations (see Figure 4). Best and worst KGE values in bold font.

	VGM-HYD	VGM-HYD-VEG	VGMBW-HYD	VGMBW-LAB	VGMBW-HYD2	VGMBW-HYD3
ENSA	0.69	**-0.10**	0.47	0.59	0.70	**0.84**
Kirene	**0.05**	0.48	0.14	0.40	0.46	**0.68**

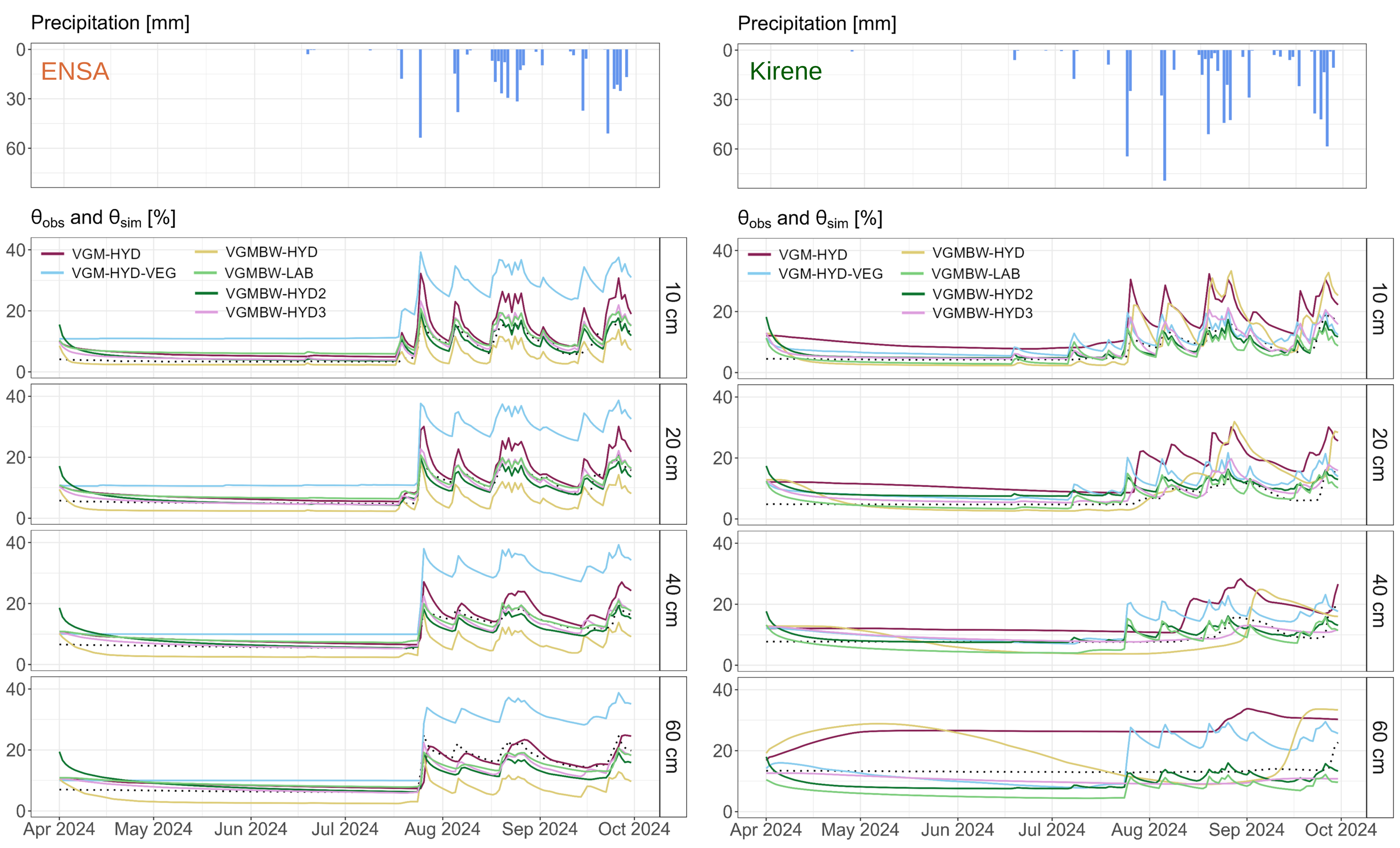


Fig. 7: Simulated and observed soil moisture (dashed black line) for two selected locations. Simulated timelines originate from different model setups. For KGE values see Table 2

CONCLUSION

- Pivotal role of clay content, bulk density, K_s, recovery time in partitioning and driving heat fluxes
- High heat flux rates creating **ideal conditions for convection** processes
- Contribution to **closing data gap** regarding SHP in Sahel

Present	Initial step in a larger effort linking soil properties with atmospheric processes
Future	Enhance accuracy in SHP estimation and modeling by broadening temporal and spatial extend of measurement network, work with **time dependent SHP**, exploring various model configurations (VGMBW appears to be best choice for semiarid conditions), consider macropores through usage of **dual-porosity** models, calibrate on **soil temperature** as it presents a more robust parameter Soil sampling during wet season and including **vegetation**

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ACKNOWLEDGEMENTS

Special thanks to the Université Cheikh Anta Diop, especially Dame Gueye, Aisha Seck, and Salif Diédhiou, to the staff and students of École Nationale Supérieure d'Agriculture and Edward Engelbrecht for helping with the field and laboratory work; to Dr. Lena Scheiffele for lending me an important piece of code; to Dr. Giuseppe Brunetti and Dr. Jirka Šimunek for the constructive discussions on the use of HYDRUS

For more information regarding the DakE project, please scan here or visit the website dake-senegal.com
You can also reach out: karoline.kny@freenet.de

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