Hydrogeology of Arid Environments
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Combining field measurements and modeling of soil water dynamics to quantify groundwater recharge in Dryland Savanna, Namibia

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The actual problem of rangeland savannas: bush encroachment

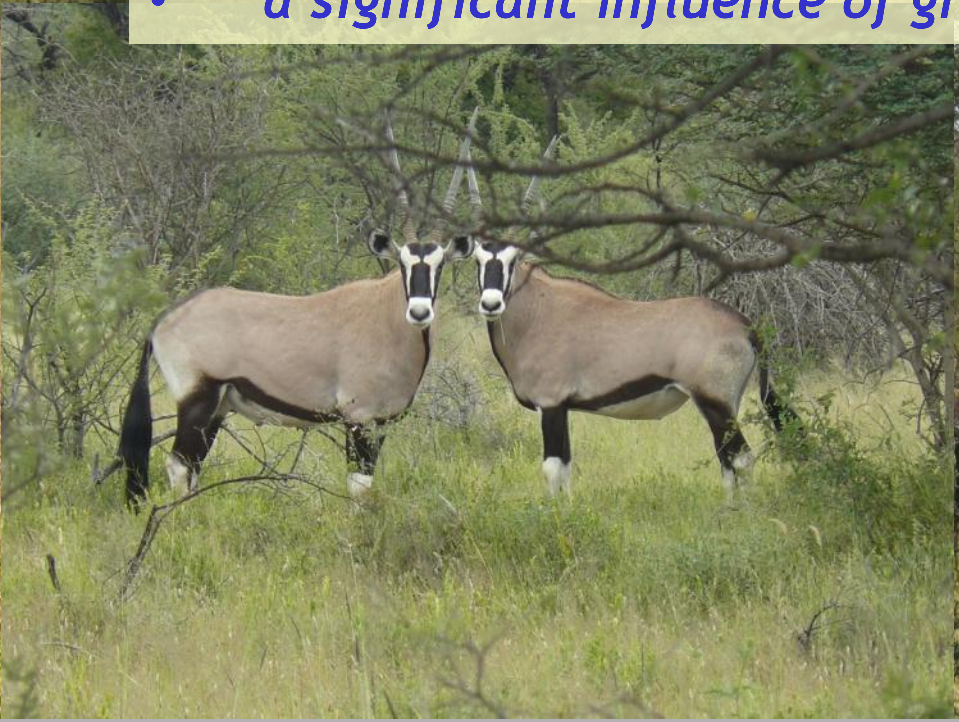
„With respect to the large amounts of water intercepted by invader bushes it is reasonable to conclude that the underground water table is being negativly affected by bush encroachment through increased evapotranspiration, water run-off and less infiltration to subsoils.“

(JN de Klerk 2004)

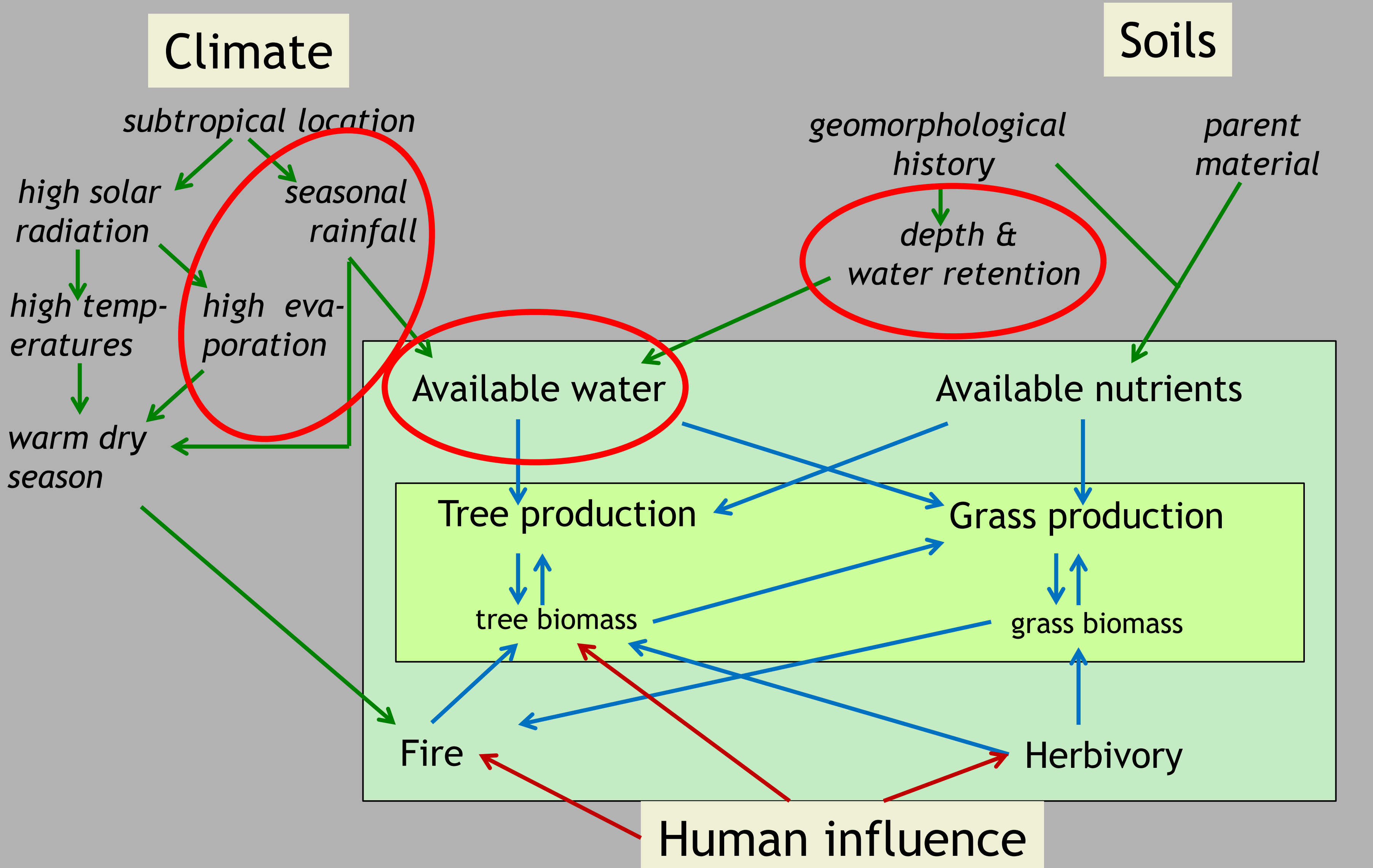
Savannas and water

Savannas are characterised by

- *a subtropical (warm, dry) climate situation*
- *a vegetation pattern consisting of a mixture of grasses with interspersed trees or shrubs*
- *a significant influence of grazing mammals.*



Factors controlling savanna ecosystems (Scholes & Walker 1993)



Hypothesis

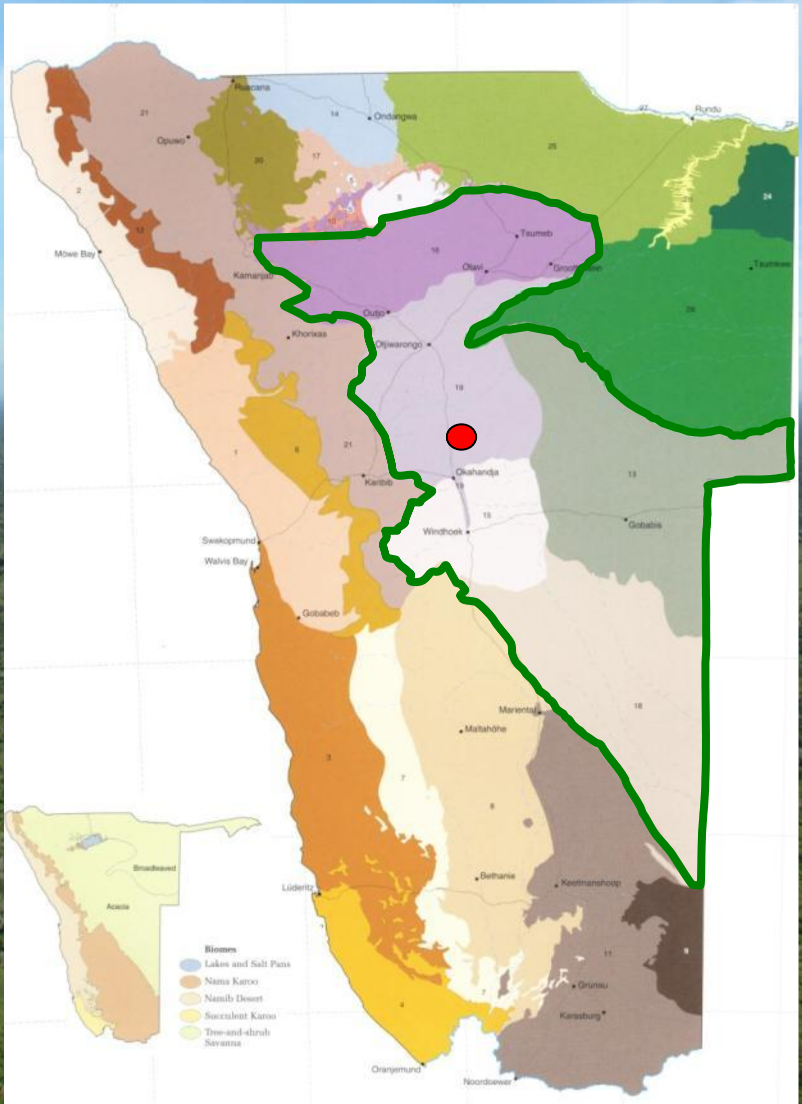
Shifts in controlling factors for the ecosystem lead to an increase in woody vegetation (bush encroachment)

→ *Soil water dynamics differ between sites with woody vegetation and grasses (depth distribution; water availability)*

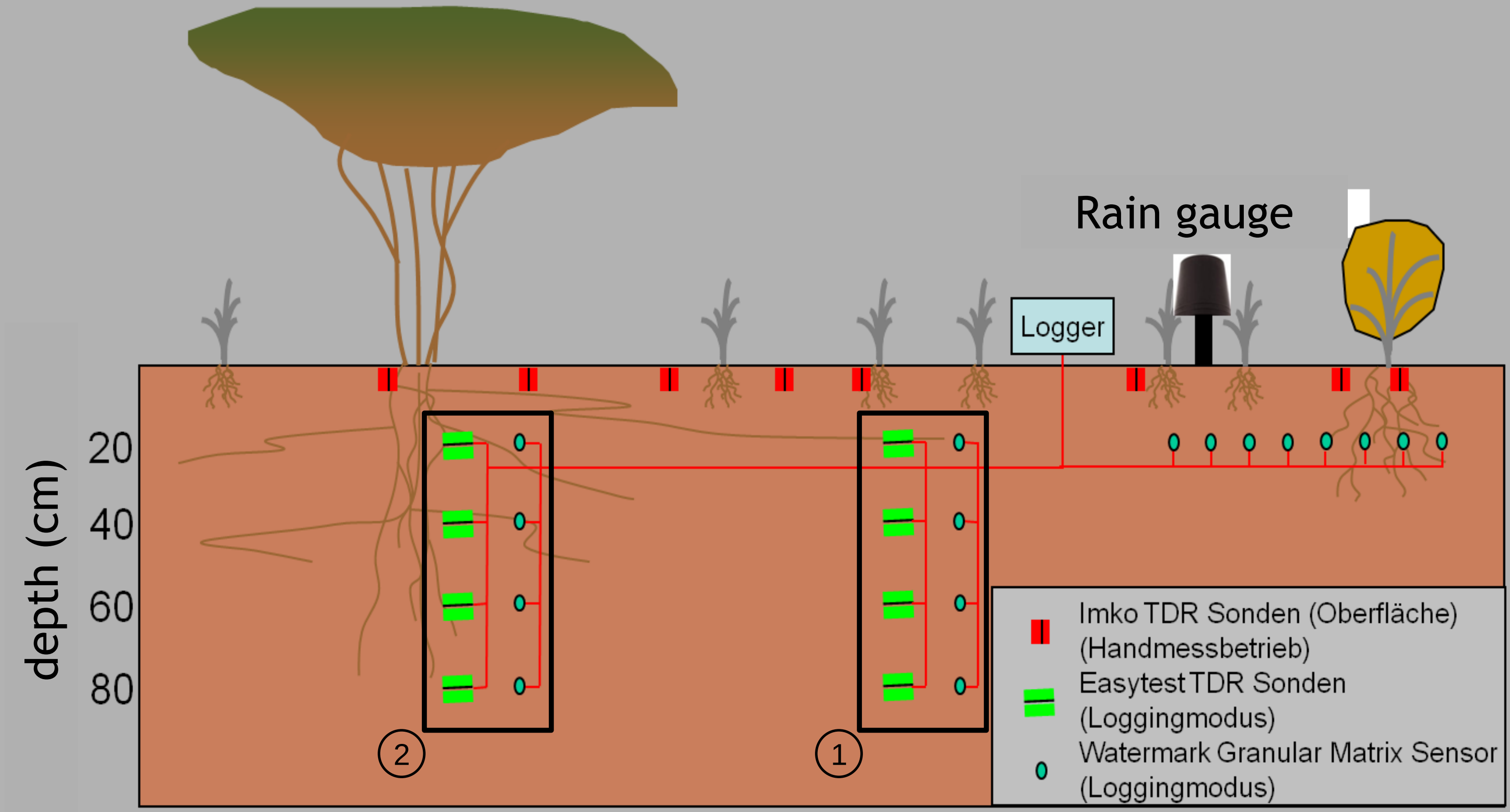
→ *Increase in woody vegetation reduces the groundwater recharge*

→ *Soil water balance is modified by processes which under ‘normal’ conditions are insignificant (e.g. tree uplift, thermal induced water transport)*

Thorn-bush savanna ecosystems in Namibia



Our methodological approach



Our methodological approach

In-situ soil hydrological measurements

• water content [Vol%]
•matrixpotential [hPa]

Weather data

• precipitation [mm]
• Temperature [C]
• humidity [%]
• wind [m/s]
• radiation [kJ m^{-2}]

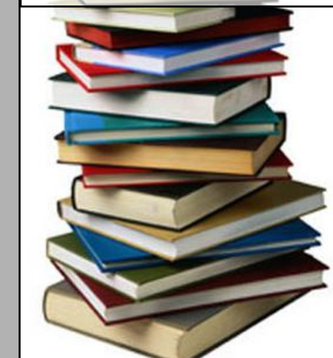
Vegetation characteristics

• LAI [m^2 m^{-2}]

Soil physical laboratory tests

• Hydrologic properties Θ(ψ), k(ψ)

Sedundary data

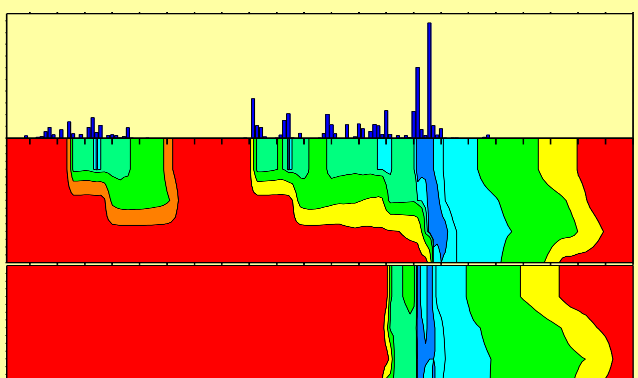


• Stomatärer Widerstand
• Bestandswiderstand
• Albedo

Validierung

INPUT

Modell SWAP 3.2



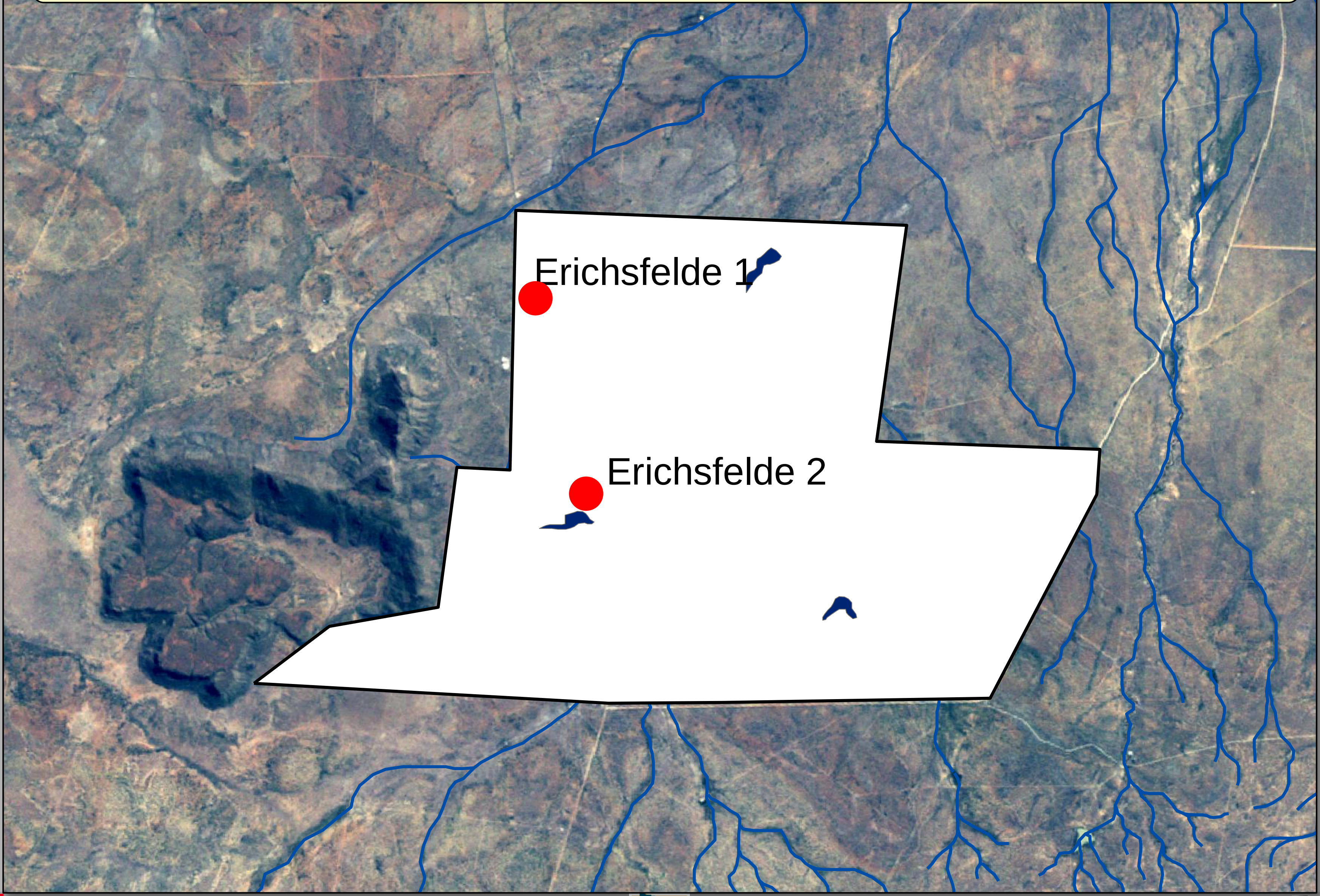
Output soil water dynamic

depth distribution of water content
&
matrix potentials

Output water balance:

• Interception
• Runoff
• Epot - Eact
• Tpot - Tact
• recharge

Study site characteristics



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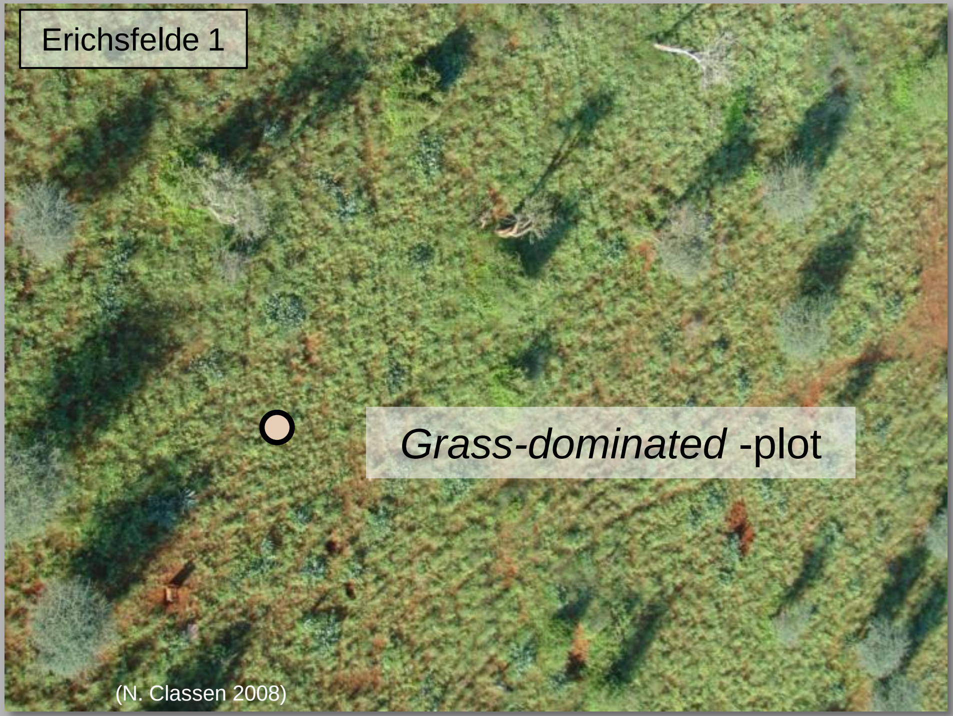
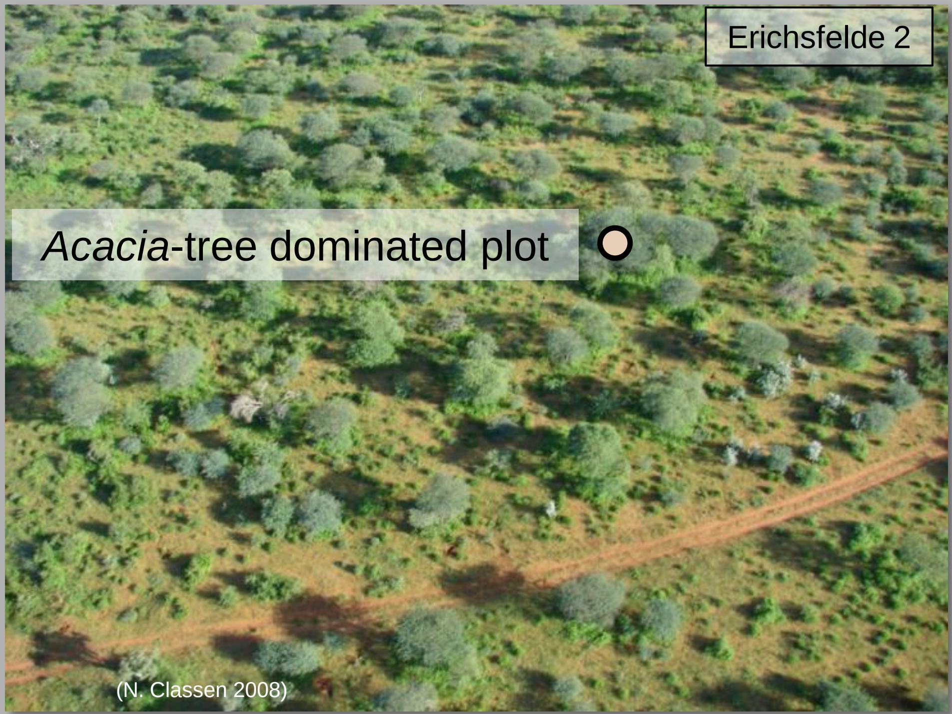
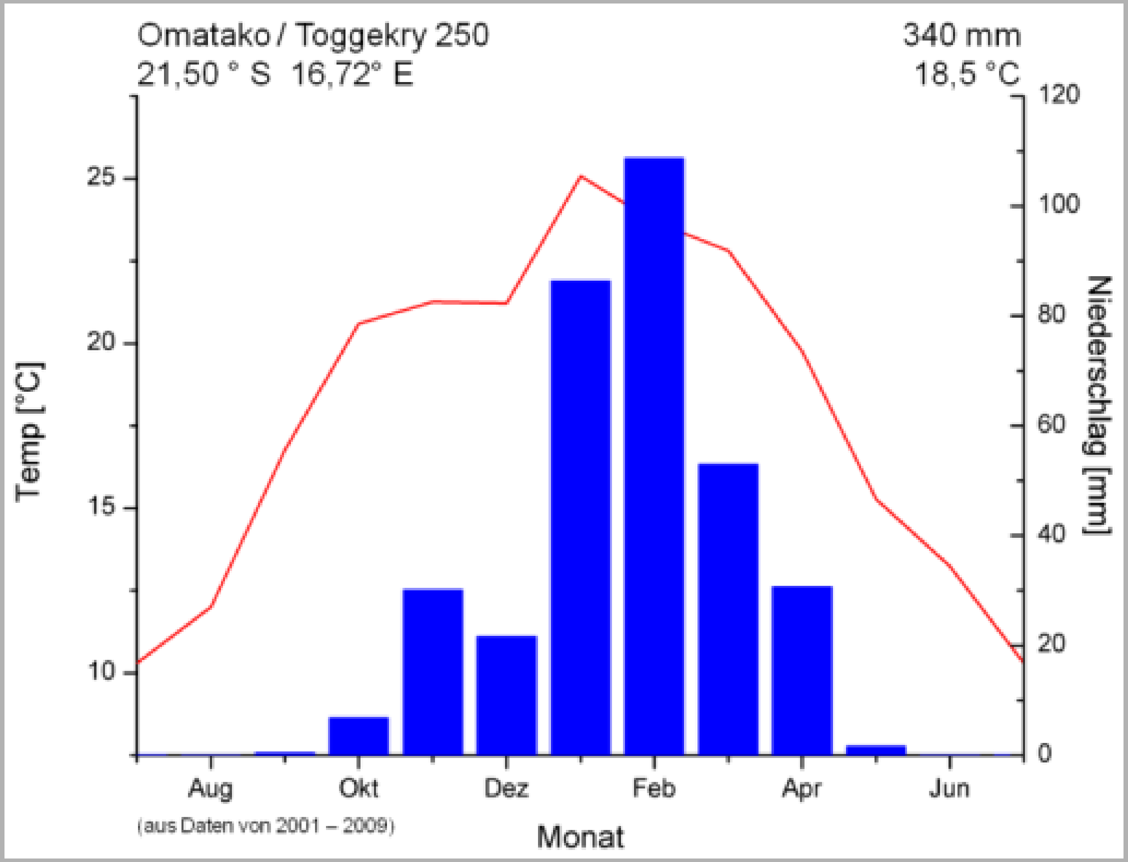




species	Coverage [%]	Type
Stipagrostis uniplumis	50	Perennial grass
Lycium oxycarpum	2	Perennial shrub
Acacia mellifera	1	Tree
Geigeria ornativa	1	Annual herb
others	7	
total	**61**	

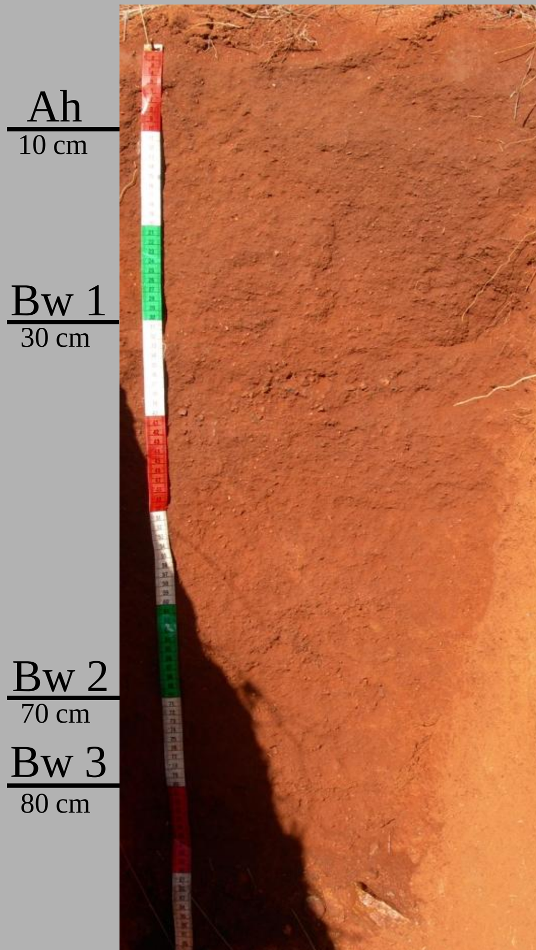
species	Coverage [%]	Type
Acacia mellifera	15	Tree
Monechma genistifolium	5	Perennial dwarf shrub
Acacia tortilis	5	Tree
Stipagrostis uniplumis	3	Perennial grass
Lycium oxycarpum	2	Perennial shrub
Eragrostis jeffreysii	1	Perennial grass
others	10	
total	**41**	

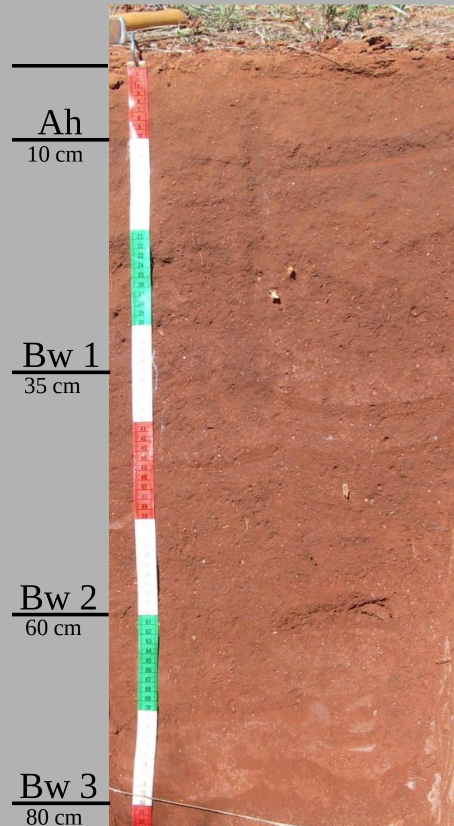
Study site characteristics



- Potential ET: 1800-2000 mm a^{-1}

Study site characteristics





Both sites:

Haplic Luvisol (Chromic)

≈ 0.85 m soil cover
Loamy Sand

↓

Sandy Clay Loam,

high bulk density

Low SOC

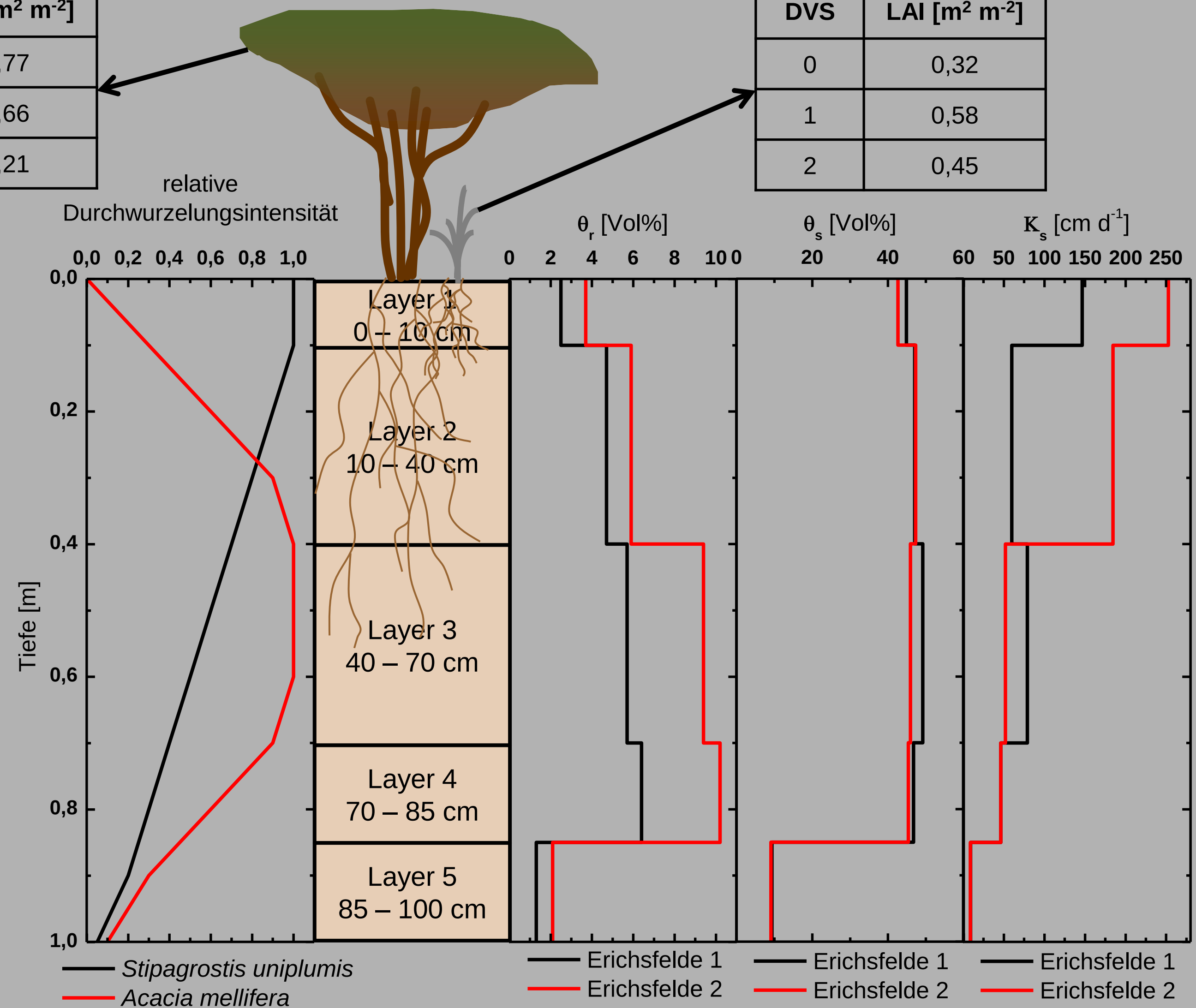
≈ 0.15 m saprolite
granites (fractured !)

≈ 70 m groundwater level

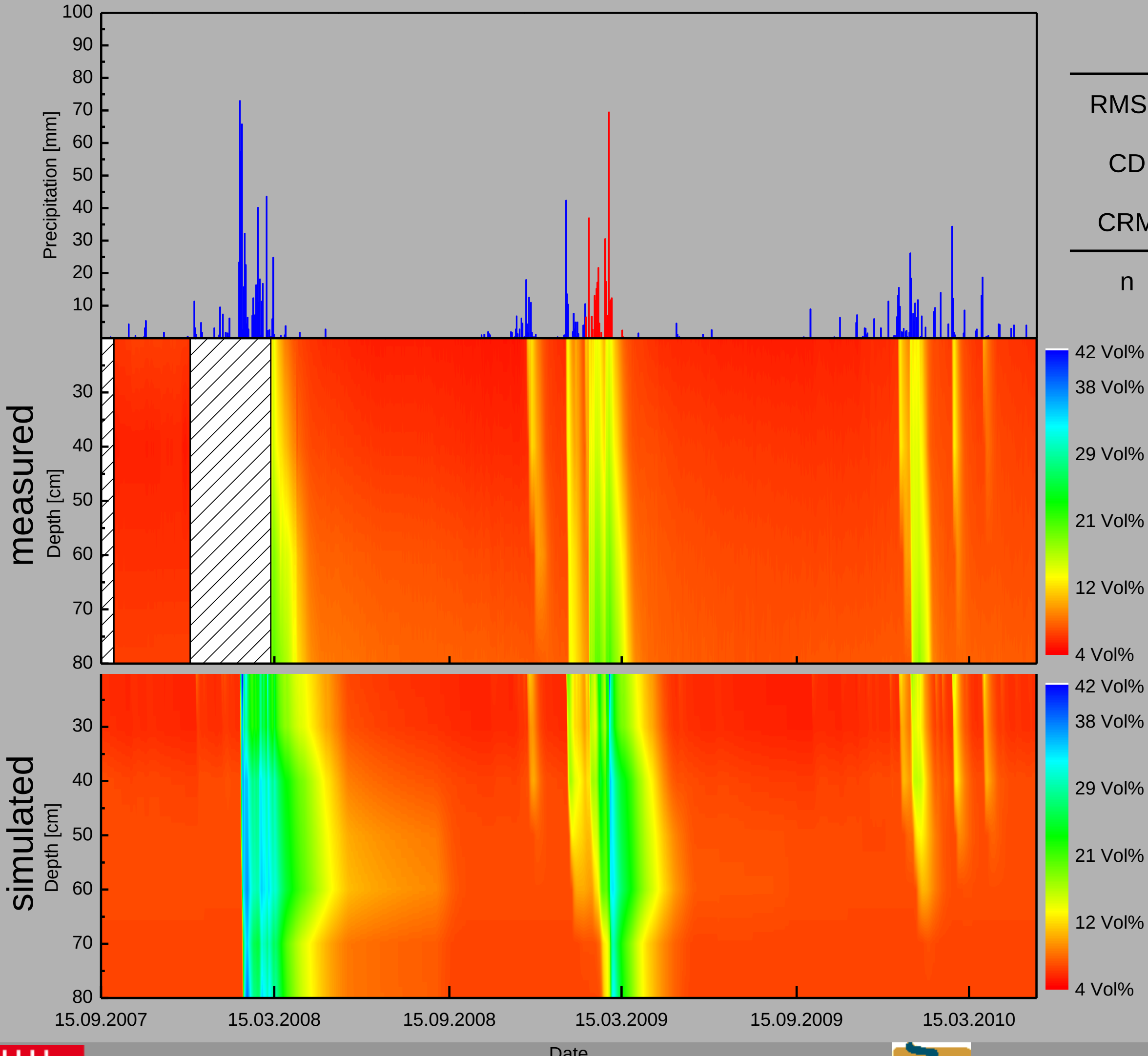
Parameterization of soil & vegetation

DVS	LAI [m² m⁻²]
0	0,77
1	1,66
2	1,21

DVS	LAI [m² m⁻²]
0	0,32
1	0,58
2	0,45



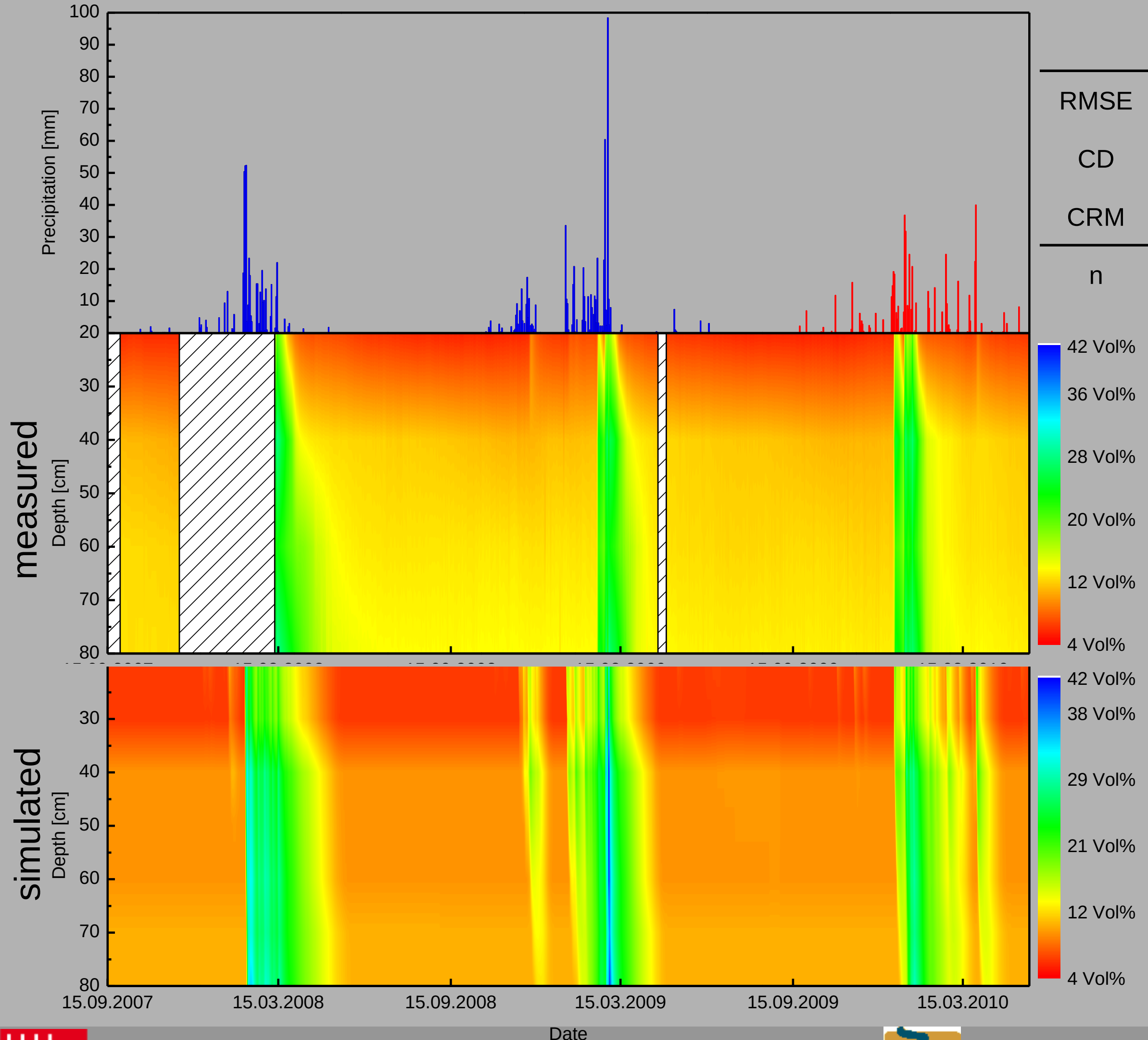
Model validation of site Erichsfelde 1 (grass-dominated)



	20 cm	40 cm	60 cm	80 cm	Range	Opt.
RMSE	3,24	4,46	4,41	3,28	≥ 0	0
CD	0,23	0,17	0,23	0,59	≥ 0	1
CRM	-0,44	-0,56	-0,45	-0,16	≤ 1	0
n	883	883	883	883		

time
15.09.2007 – 25.05.2010

Model validation of site Erichsfelde 2 (tree-dominated)

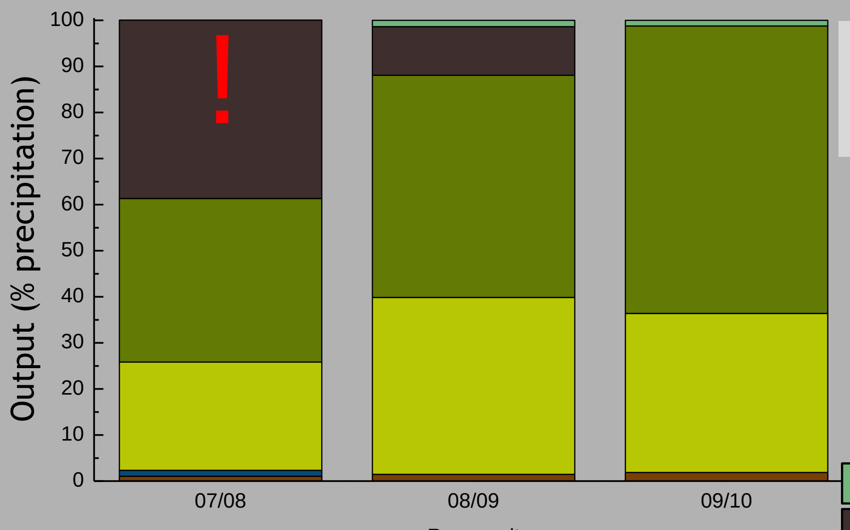


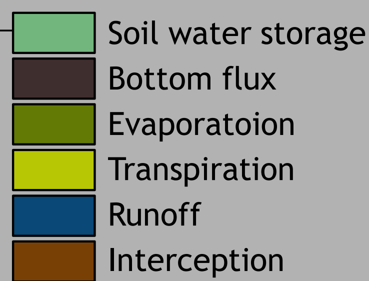
	20 cm	40 cm	60 cm	80 cm	Range	Opt.
RMSE	3,26	2,76	3,09	2,99	≥ 0	0
CD	0,29	0,87	1,00	1,19	≥ 0	1
CRM	-0,52	-0,13	-0,06	-0,04	≤ 1	0
n	859	859	859	859		

time
15.09.2007 – 25.05.2010

Three-years modelled water balance

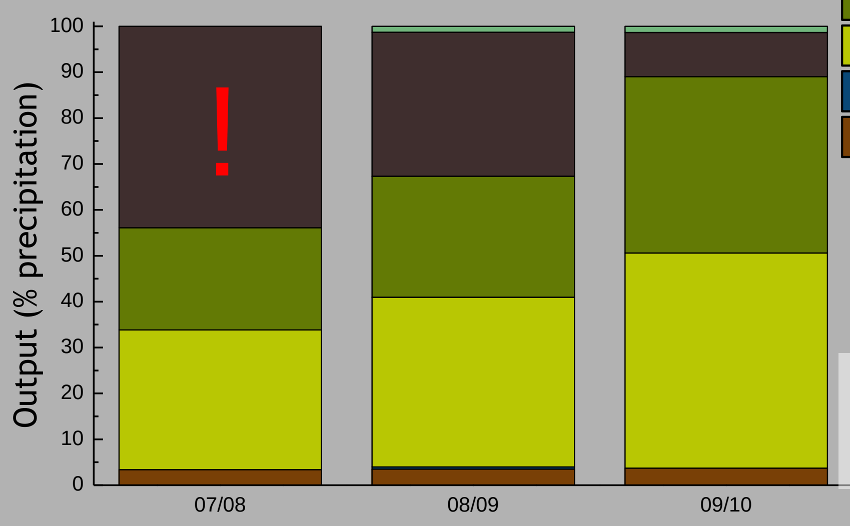
1) Grass-dominated





	07/08	08/09	09/10
Precipitation [mm]	612	529	364
Interception [mm]	6,4	7,7	7,0
Runoff [mm]	7,9	0	0
Transpiration [mm]	144	203	128
Evaporation [mm]	217	255	232
Bottom flux [mm]	237	56	0

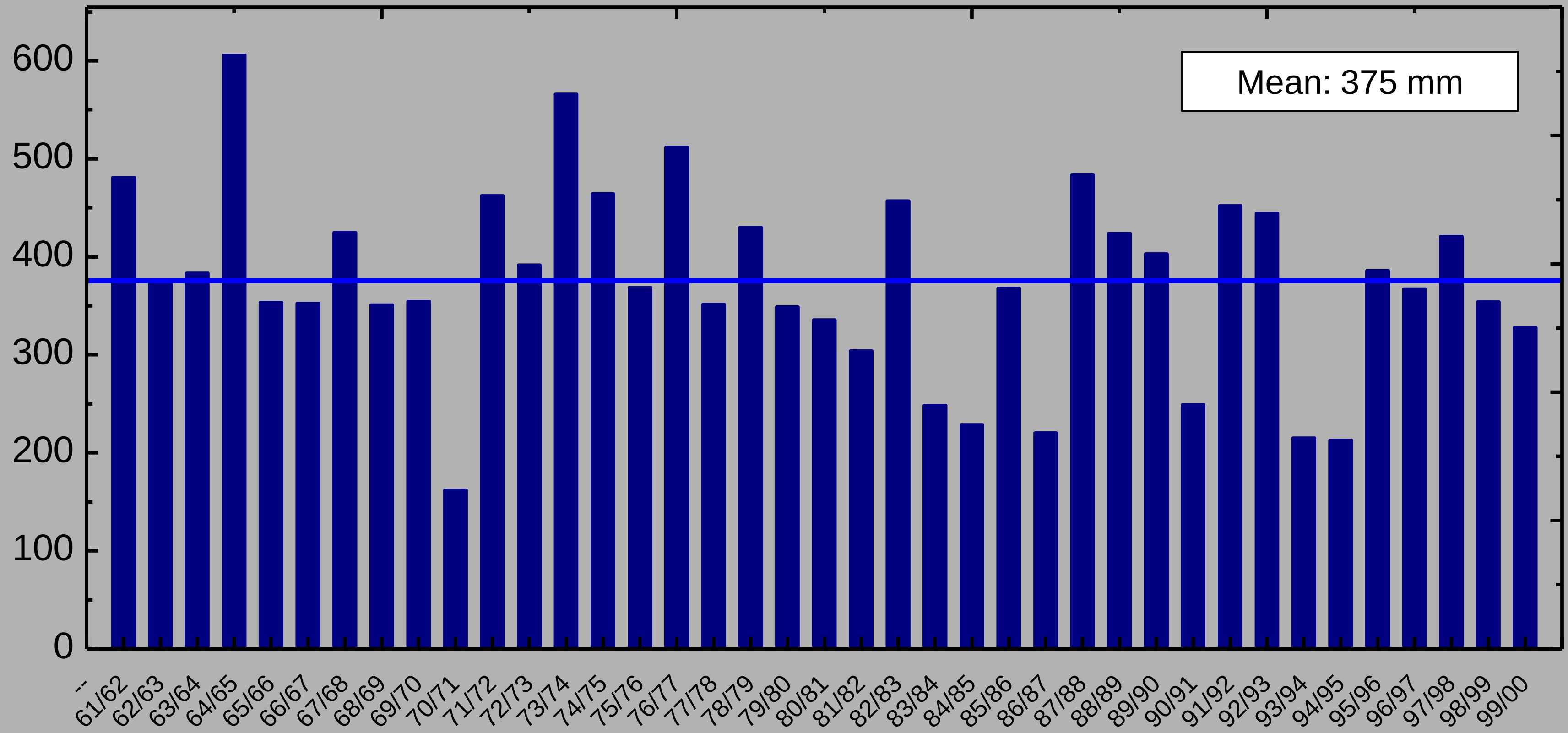
1) Tree-dominated



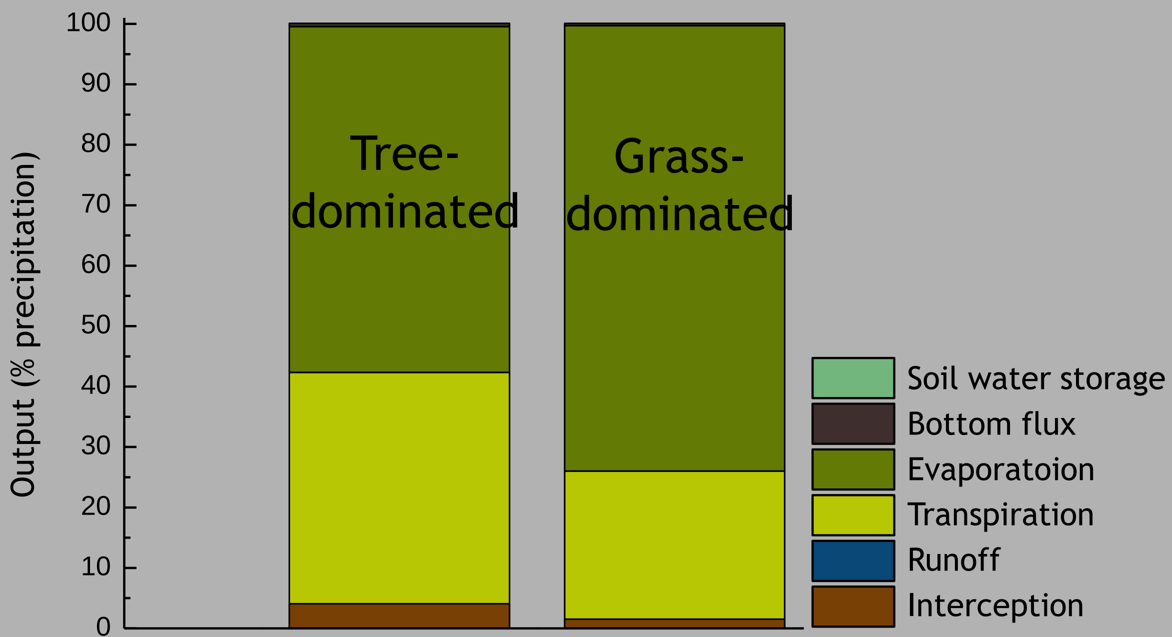
	07/08	08/09	09/10
Precipitation [mm]	465	597	505
Interception [mm]	15,8	21,1	19,1
Runoff [mm]	0	2,7	0
Transpiration [mm]	142	221	241
Evaporation [mm]	104	158	197
Bottom flux [mm]	204	188	49

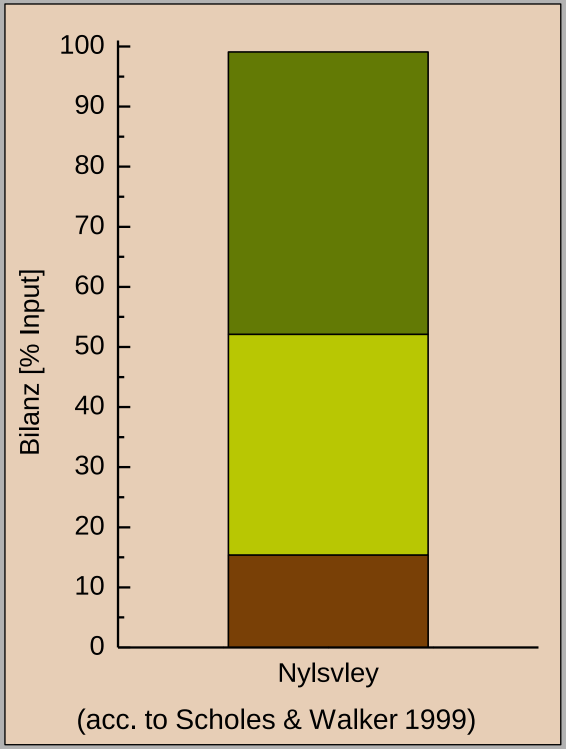
Long-term modeling of soil water balance

Basis: 30 years of stochastic weather data (daily values) based on observed data of station Windhoek.



Long-term modeling of soil water balance





	Precipitation [mm]	Interception [mm]	Transpiration [mm]	Evaporation [mm]	Bottom flux [mm]
Acacia mellifera	**375**	**15,3**	**144**	**215**	**2,1**
Stipagrostis uniplumis	**375**	**5,7**	**92**	**277**	**1,4**

Intermediate results of the on-going project

1. Compared to measured data and results from literature model runs seem to generate reliable output data.
2. The higher transpiration of *Acacia*-stands compared to grass sites is levelled by the higher evaporation of grassy areas.
3. Within 100 cm of soil material the rainwater input is turned over almost completely.
4. Bottom flux, which may lead to groundwater recharge, does occur only in 3 of 30 years (with exceptional high precipitation)
5. There is no indication of higher run-off on *Acacia* plots, as supposed by De Klerk (2004)

The water balance simulations give indication that the effect of bush encroachment on aridification is less severe (on these Luvisols !) as postulated by De Klerk

However,..

1. ..,due to the root distribution of savanna-trees it has to bee questioned if a one-dimensional modeling is appropriate.

2. ..,part of the water, which infiltrates into the granite fissures, may be extracted by deep-rooting trees.

3. .., concept of evaporation rate calculation in SWAP may not fit to open grounds between plants due to special microclimate

Outlook

1. Until now we know, that a transfer of results to differing soils in the same landscape (Calcisols, Vertisols) is not possible and that the transfer to the vast areas of Kalahari sands is unconfident.

2. To understand the water cycling of savanna ecosystems – which includes groundwater recharge - multi-disciplinary research approaches have to be conducted. At least we need
    - Meteorology
    - Plant physiology
    - Soil hydrology
    - Hydrogeology
    - Rangeland Agronomy

3. Only combination of on-the –ground studies with modeling approaches seem to be challenging.

4. Within the planned Southern African Science Service Centre for Climate Change and Adaptive Land Management (**SASSCAL**) the open questions may be solved in future


Thank you for your attention