Karlsruhe Institute of Technology

Estimating in-situ soil moisture dynamics from soil thermal dependencies

Svenja Hoffmeister, Sibylle K. Hassler, Mirko Mälicke and Erwin Zehe

Institute for Water and River Basin Management – Chair of Hydrology

Aim

Estimation of soil moisture dynamics from soil temperature time series.

- Water content impacts soil thermal properties:
  - Volumetric soil heat capacity
  - Effective soil heat conductance
  - Thermal diffusivity
- This influence can be observed in the amplitude attenuation and shift of a soil temperature signal
- Potential for estimating water fluxes or to investigate the water redistribution as a cost-efficient and robust alternative or supplement to existing soil moisture measurements

SPONSORED BY THE

Federal Ministry of Education and Research

DLR-PT

ASAP Background

In the near future southern Africa will have to face various challenges as a consequence of climate change, affecting sustainable development of economy, ecology and society as projected to current climate patterns suggest. The transdisciplinary research project '*Agroforestry in Southern Africa - new Pathways of innovative land use systems under a changing climate (ASAP)*' explores the suitability of agroforestry system to improve the bio-economy in rural areas, provide an adaptation strategy for human needs and preserve natural resources and biodiversity.

Soil moisture dependence of governing equations

- **Heat balance equation**

$$\frac{\partial T}{\partial t} = \frac{\lambda_{eff}(\theta)}{c_v(\theta)} \frac{\partial^2 T(z,t)}{\partial z^2}$$

where T = temperature [K], t = time [s], z = depth [m], θ = soil water content [m-3/m-3], for λ_{eff} & c_v see below

- **Volumetric heat capacity of soil [J m^{-3} K^{-1}]**

$$c_v = \theta(t) c_{water} + (\theta_s - \theta) c_{air} + (1 - \theta_s) c_{solid}$$

where θ_s = porosity and $c_{solid/water/air}$ = vol. heat capacity of constituent [J m^{-3} K^{-1}]

- **Effective soil heat conductance [W m^{-1} K^{-1}]**

λ_{eff} increases with θ and different parameterisations are available (e.g. Chung & Horton (1987))

Chung S.-O., and R. Horton, Soil heat and water flow with a partial surface mulch, Water Resour. Res., 23(12), 2175-2186, 1987.

Approach

- The heat balance equation was solved analytically for wet and dry sand to run simulations
- Soil moisture dependency (fig.1)
  - Assuming **a homogeneous soil, homogeneous soil moisture and a constant energy flux** at the surface: Increasing wetness leads to a decrease of the attenuation (and phase shift) of soil temperature amplitudes

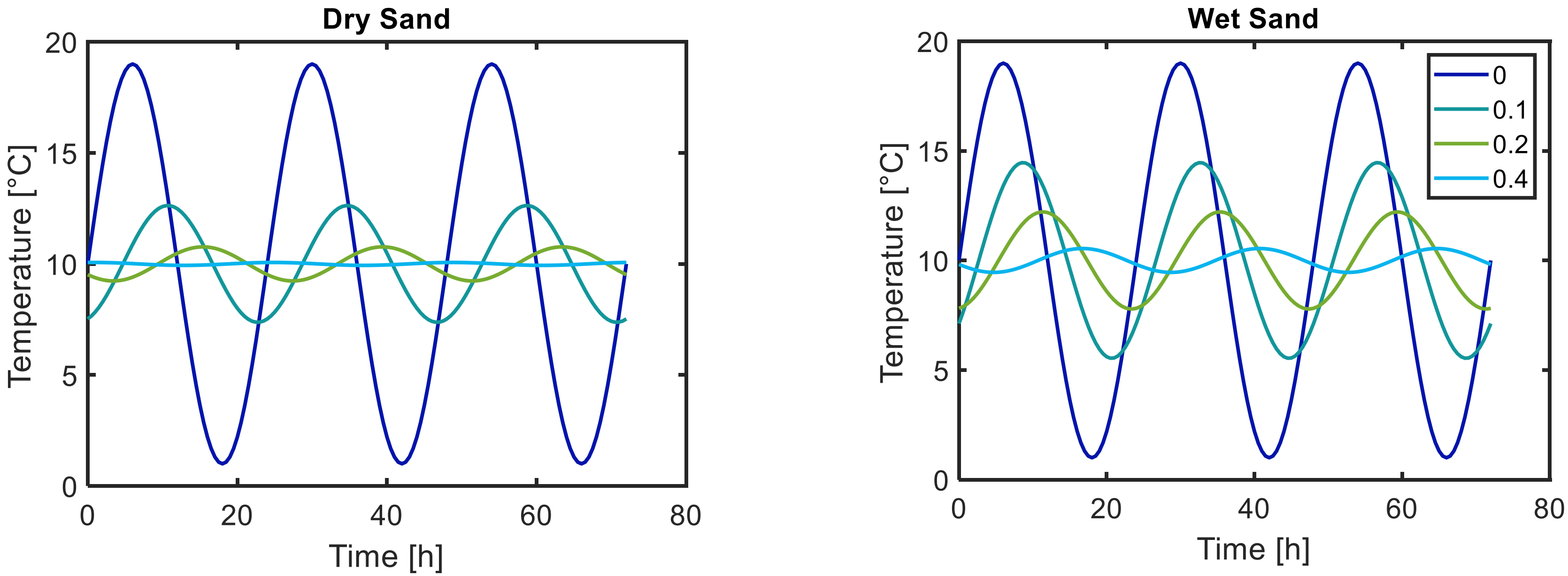

Fig. 1. Simulation of temperature signals at different depths (legend entries [m]) and soil moisture content. Thermal diffusivity was set to $\alpha = 0.24 \times 10^{-6}$ m^2 s^{-1} (dry) and to $\alpha = 0.74 \times 10^{-6}$ m^2 s^{-1} (wet).

Field site

- Berry farm close to Stellenbosch, South Africa
- Installation of TDR profile probes and soil temperature sensors (fig. 2) in September 2019

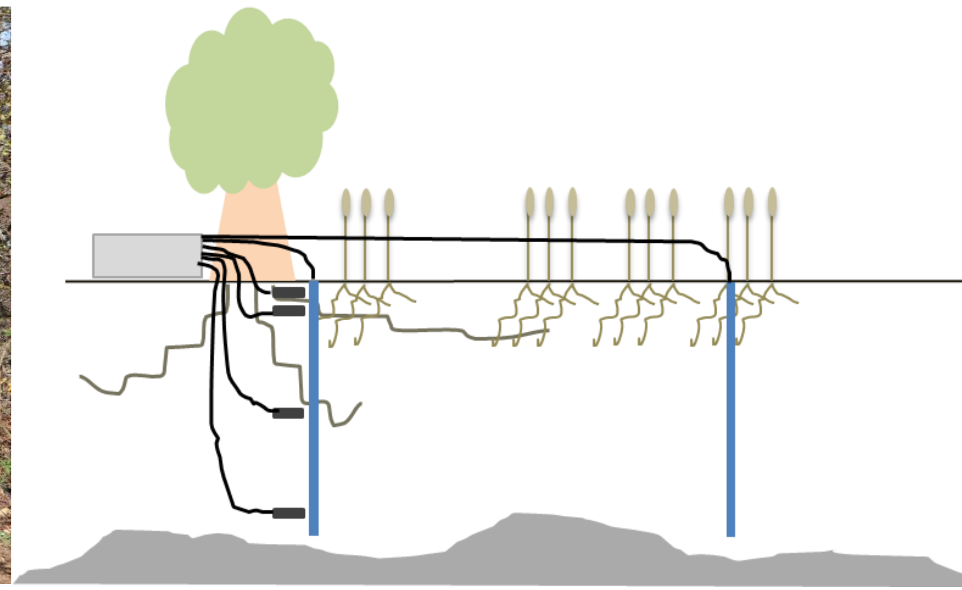

Fig. 2. Left: Photo blackberry plot where the sensors are installed. Right: Sketch of sensor setup in Stellenbosch, ZA. The blue tubes in this graph contain each four TDR profile sensors, black squares represent soil temperature sensors. In this study we only use data from sensors close to the tree row.

Temperature amplitude

- Calculation of the daily temperature amplitude from the daily minimum and the daily maximum temperature (fig. 3, left)
- The attenuation and phase shift are calculated (fig. 3, right) and correlated with soil moisture

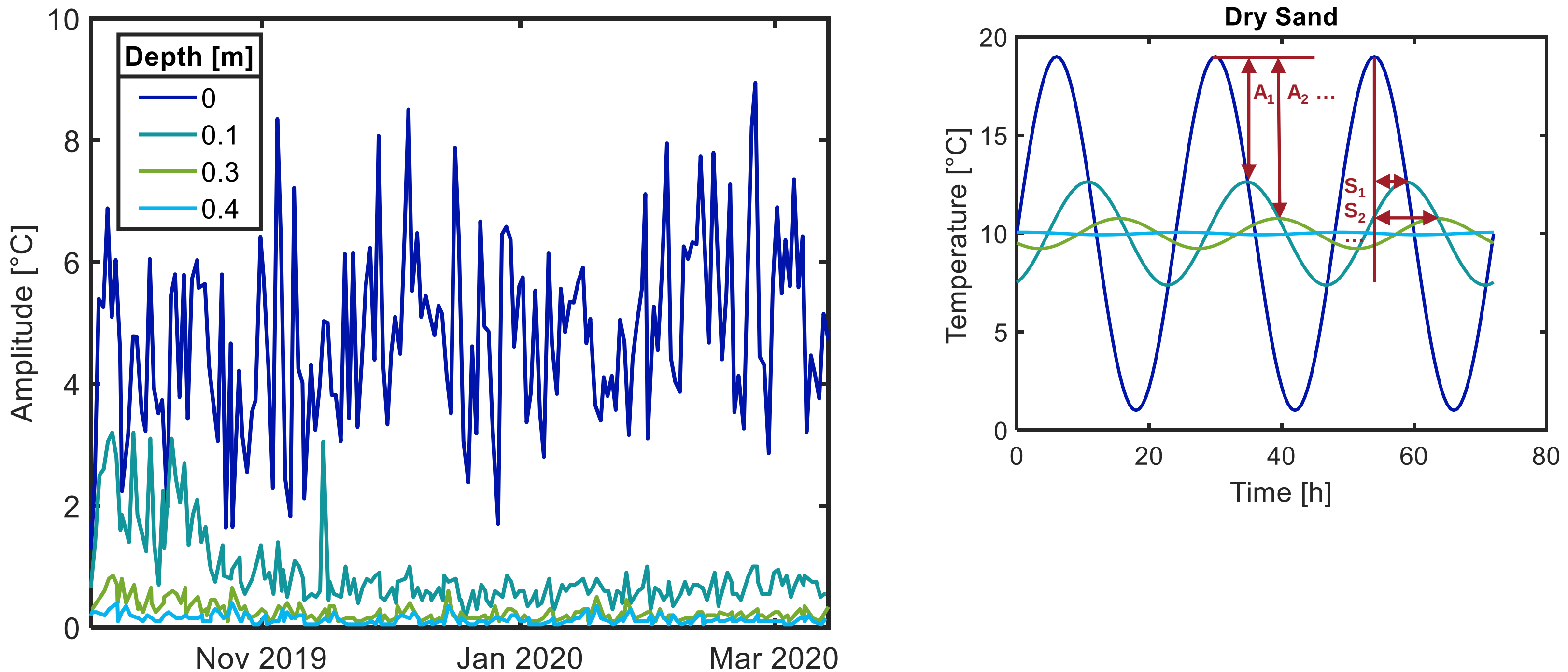

Fig. 3. Left: Amplitudes from soil temperature time series at different depths. Right: Schematic explaining attenuation (A) and phase shift (S) and its calculation from the daily temperature amplitude.

Karlsruhe Institute of Technology

ASAP

What can we already see?

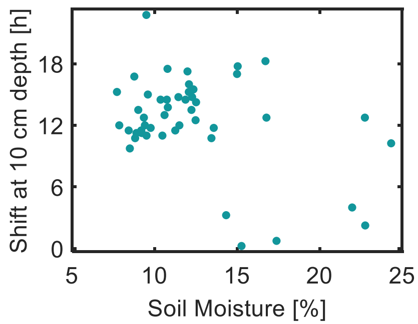

Fig. 4. Relationship between phase shift of the amplitude and soil moisture at 10 cm depth.

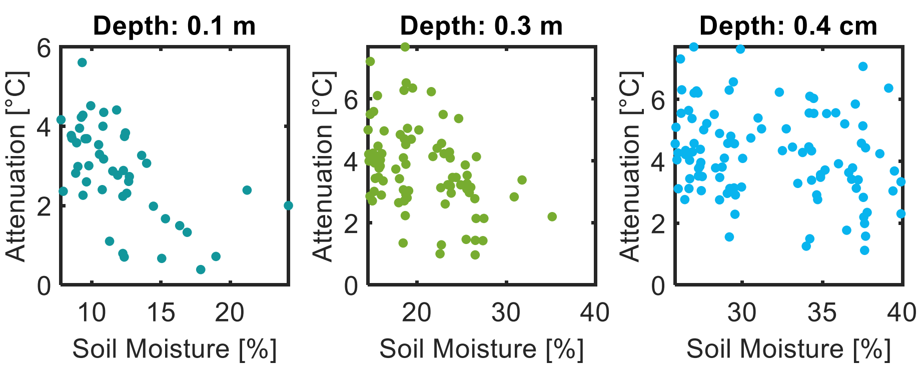

Fig. 5. Relationship between amplitude attenuation and soil moisture at different depths.

- Shift and attenuation indicate a correlation with soil moisture in the lower depths
- Attenuation is more dominant, indicating:
  - An important role of the storage term
  - That heat conductance seems less sensible (responsible for the phase shift)

- The correlation is not as clear as expected. Possible reasons:
  - Variation in daily temperatures
  - Variation in incoming radiation: Less energy input leads to weaker attenuation
  - Heterogeneity of soil thermal properties and material
  - Foliage cover (insulation effect by trapped air)

Outlook

- Further investigation of the soil temperature and soil moisture signal by better understanding the differences between theory and real world:
  - Dedicated experiments under laboratory conditions
  - Multivariate analysis to gain insights on how different factors (e.g. incoming radiation, measurement depth) affect the amplitude attenuation and phase shift
  - Sensitivity analysis to explore e.g. the impact of measurement errors
- Development of an experimental measurement system to track water movement from soil temperature signals

Thank you for your interest in my presentation!

For any comments and questions, you can contact me at:

svenja.hoffmeister@kit.edu