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Predicting bare soil evaporation by numerical modeling - the role of hydraulic functions

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Zusammenfassung

Die Parametrisierung der bodenhydraulischen Eigenschaften (SHP) spielt eine große Rolle für die zuverlässige Vorhersage der Verdunstung. Insbesondere werden Unterschiede zwischen traditionellen Funktionen (hier: van Genuchten/Mualem, VGM), die nur den kapillaren Wasserfluss berücksichtigen, und Funktionen, die zusätzlich nicht-kapillare Prozesse berücksichtigen (hier: Peters-Durner-Iden, PDI), erwartet. Ziel dieser Studie war es, den Einfluss von (i) dem Modelltyp für hydraulische Funktionen und (ii) der Methode zur Bestimmung dieser Funktionen auf die Vorhersage der tatsächlichen Verdunstung zu untersuchen. Die Daten wurden von einem vegetationsfreien wägbaren Großlysimeter gewonnen. Alle Modellvorhersagen unterschätzten die tatsächliche Verdunstung. Die PDI-Modelle sagten jedoch systematisch höhere Verdunstungsraten als die VGM-Modelle voraus. Interessanterweise hatte die Wahl des Modelltyps einen wesentlich größeren Einfluss als die Methode zur Bestimmung der Funktionen.

Schlagwörter: Hydraulische Leitfähigkeit, Verdunstung, Filmfluss

Summary

The parametrization of the soil hydraulic properties (SHP) plays a crucial role in reliable prediction of evaporation. In particular, differences are expected between traditional functions (here: van Genuchten/Mualem, VGM) that consider capillary water flow and functions that additionally consider non-capillary processes (here: Peters-Durner-Iden, PDI). The purpose of this study was to investigate how the prediction of the actual evaporation under water-limited conditions depends on (i) the model type for soil hydraulic functions and (ii) the method for determining these functions. Data (lysimeter mass and outflow) were obtained from a bare-soil field lysimeter. All model predictions underestimated real evaporation under dry conditions. However, the PDI model predicted systematically higher evaporation rates than the VGM model. Interestingly, the choice of model type for the hydraulic functions had more influence than the method for determining these functions.

Keywords: Soil hydraulic conductivity, surface evaporation, film flow

Introduction

Evaporation from the soil surface is one of the key components of water and energy balance. The dynamics of evaporation is influenced by atmospheric conditions, such as radiation, humidity, temperature, and wind speed. In addition to that, hydraulic properties of soils are also decisive to control the evaporation, especially under limited water supply. Predicting evaporation from drying soils under these conditions is challenging. The parametrization of soil hydraulic properties (SHP) plays a crucial role in reliable predictions of evaporation.

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Basic parametrizations of different SHP functions differ in accounting for capillary and non-capillary processes, i.e., water storage and film flow on particle surfaces and in corners and channels of pores. Traditional models consider water flow only in capillaries (e.g. van Genuchten 1980), whereas more recent models account for both liquid flow components (e.g. Lebeau and Konrad 2010, Peters 2013). Neglecting the non-capillary flow may be a major source for the discrepancies in the predicted evaporation in the dry zone.

There exists a variety of methods to determine the parameters of the soil hydraulic functions. These range from usage of simple pedotransfer functions (Schaap et al. 2000) to time demanding measurements in the laboratory or in-situ with subsequent parameter estimation (Peters et al. 2015).

The objective of this study was to investigate how different soil hydraulic function types and different methods for determining function parameters lead to differences in predicting actual evaporation under water-limited conditions.

Material and methods

We used data from a large field lysimeter (2.5 m height; 1 m^2 surface area), located at the lysimeter station Grünewalde and operated by the Forschungsinstitut für Bergbaufolgelandschaften (FIB) e.V in Germany (*Figure 1*). The lysimeter had a bare soil surface and was exposed to natural atmospheric conditions with a rather dry climate. Pressure heads and water contents were measured at three depths. Lysimeter mass and outflow were measured in hourly time intervals with a precision of 0.1 mm for 5 years (2015-2019). Precipitation and actual evaporation, Ea, were calculated from the mass changes of the lysimeter, using a simplified version of the AWAT filter approach of Peters et al. (2017). Data gaps of precipitation were filled by the measured rainfall at the experimental site.

Meteorological parameters to calculate the potential evaporation were taken from 4 nearby weather stations of the national German Weather Service (DWD), depicted in *Figure 1*. Grass reference potential evaporation rates, ETp, were obtained by using the FAO-56 version of the Penman-Monteith equation (Allen et al. 1998). To calculate ETp at the lysimeter site, the average of the four stations was taken. Since the potential bare soil evaporation, Ep, will differ from the grass reference potential evapotranspiration we scaled the Ep by comparing measured evaporation with the calculated ETp (Synder et al. 2000). For this, the actual lysimeter evaporation, Ea, that was observed after heavy precipitation

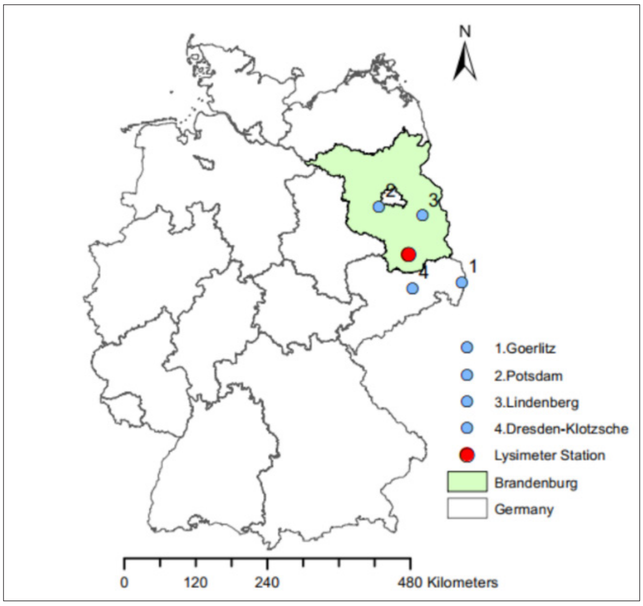

Figure 1. Location of the experimental site and national German Weather Service (DWD) stations.

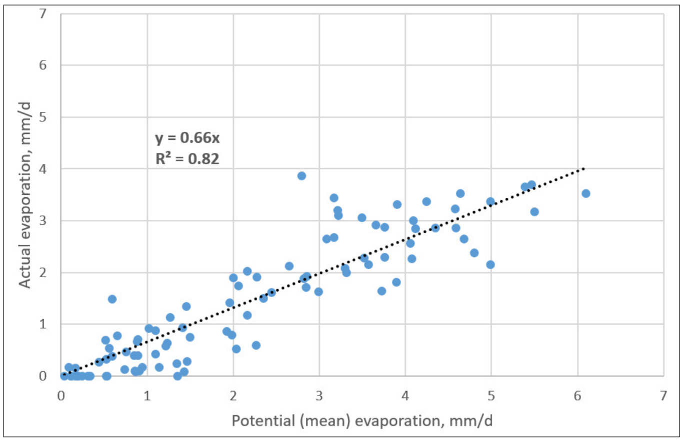

Figure 2. Correlation between mean potential evaporation rates observed form the DWD stations and actual evaporation measured with the lysimeters just after rainfall events for the experimental period.

events was related to calculated ETp. A linear relationship was found with a factor of Ea/ETp = 0.66, which was used to calculate the bare soil potential evaporation (*Figure 2*).

Modelling

Two different soil hydraulic model types (*Figure 3*) were used to predict the evaporation.

- van Genuchten/Mualem (VGM) model (Mualem 1976, van Genuchten 1980): only capillary storage and conductivity, and
- Peters-Durner-Iden (PDI) model (Peters 2013,2014; Iden and Durner 2014): additionally accounting for non-capillary storage and conductivity.

For each model type, three different methods were considered to estimate retention parameters:

- pedotransfer function using soil texture and bulk density (Schaap et al. 2000) (PTF)
- fitting lab measured data (lab)
- fitting in-situ measured data (field).

These variations make a total of 6 combinations of soil hydraulic functions. The Hydrus 1-D software (Šimůnek et al. 2008) was used to model the water dynamics in the soil. Isothermal water transport in the vapour phase was included in all models. Atmospheric conditions (measured precipitation and scaled potential evaporation) were used as upper boundary conditions. A seepage face was applied at the bottom. Measured pressure heads at different depths were used as the initial conditions.

Results and discussion

The measured Ep and the simulated cumulative evaporation for the six models and the whole 5-year period is depicted in *Figure 4*. The results show that evaporation predicted

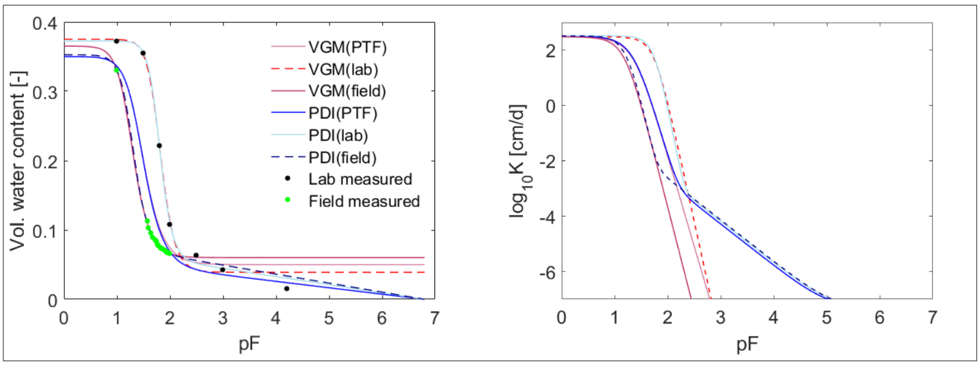

Figure 3. Soil hydraulic properties used for different modelling approaches. Left. Water retention function, right. Hydraulic conductivity function. Blue lines represent PDI parametrizations, red lines the classic VGM parametrizations.

Figure 4. Measured and simulated cumulative evaporation (cm) for the VGM and PDI models for years 2015-2019. Grey line shows the scaled potential evaporation.

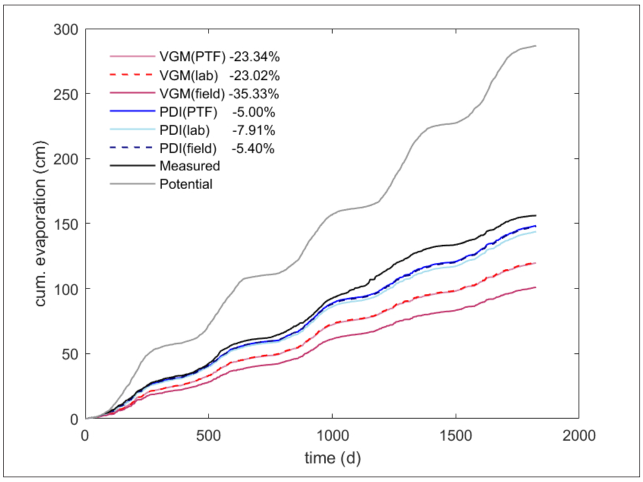

Table 1. Relative differences of measured and simulated evaporation for different years. Values are shown in percentage.

Model/ Year	2015	2016	2017	2018	2019
Measured E	00.00	0.00	0.00	0.00	0.00
VGM (PTF)	-23.10	-27.39	-21.12	-28.60	-16.43
VGM (lab)	-22.75	-26.87	-20.10	-27.76	-15.32
VGM (field)	-33.80	-39.25	-34.23	-42.51	-31.98
PDI (PTF)	-3.71	-7.62	-2.04	-4.92	8.96
PDI (lab)	-6.58	-10.69	-5.88	-8.43	5.03
PDI (field)	-3.75	-8.44	-5.33	-4.96	7.70

with any model underestimated the measured evaporation (black line). The PDI model predictions (blue lines) were closer to the measured evaporation for all three methods as compared to the VGM model predictions (red lines). The relative differences from the measured evaporation are quantified and shown in the legend insert of *Figure 4*. PDI predictions of Ea underestimated the observations by 5 % to 8 %, whereas using VGM functions lead to an underestimation of 23 % to 35 %. This underestimation builds up in periods where the soil dries out, because during wet periods the hydraulic functions have no influence on the simulated evaporation. *Table 1* shows the relative differences for each year in percentage. Negatives values represent an underestimation, whereas positive values indicate overestimation of evaporation.

For VGM model types, the lab-derived and the PTF derived functions led to practically identical simulations, whereas use of functions based on the in-situ measurements of the water retention curve lead to smaller Ea. The difference in Ea predictions due to the different model types is obviously systematic, with higher evaporation rates for the PDI model under dry conditions.

Figure 5 shows the cumulative evaporation for summer periods of the years 2016 to 2019. In each instance, predicted evaporation with the PDI models are close to the actual measured evaporation, indicating that inclusion of the non-capillary liquid water flow in the soil hydraulic model significantly improves the prediction of evaporation.

Summary and Conclusion

The bare soil evaporation of the sand was highly underestimated when non-capillary liquid water flow was neglected in the simulations, whereas a good match of model predicted and measured evaporation was found using the more comprehensive model. The choice of the method for determining the function parameters had only a small influence on the results.

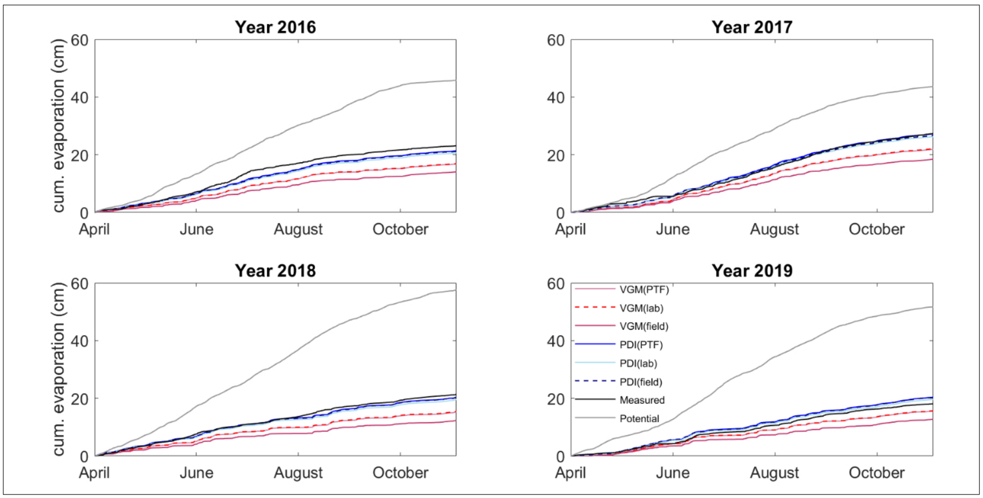

Figure 5. Measured and simulated cumulative evaporation (cm) for the VGM and PDI models for the year 2016-19.

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