Deriving Soil Moisture from Matric Potential in the WegenerNet Climate Station Network

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1 Introduction

Soil moisture is an important variable for weather and climate prediction and plays a key role in hydrological processes. It has recently been classified as an Essential Climate Variable by the Global Climate Observing System (GCOS) Programme [Albergel et al. 2012].

In the WegenerNet soil moisture is not measured directly but only indirectly by so called pF-Meters [GeoPrecision 2013]. Therefore we decided to derive soil moisture from the pF-Meter data and include this new parameter, together with estimates of its uncertainty, to the set of available soil parameters. This document gives an overview on the method used for these calculations.

2 Input parameters: pF-Value and matric potential

The pF-Meter's measurement parameter (and our function's input parameter) is the pF-value. It is defined as logarithm of the absolute value of soil matric potential [Lal and Shukla 2004]:

$$pF = \log |\psi_m|, \tag{1}$$

where ψ_m is the Matric potential in [cm]. Note that here Matric potential is expressed as energy per unit weight in terms of height of water in [cm]. It may also be expressed as energy per unit volume in [hPa] (1 cm = 0.981 hPa).

[Lal and Shukla 2004] define matric potential as:

> "...the work required to transfer reversibly and isothermally an infinitesimal amount of soil solution from a reservoir in soil to the point of interest in the soil."

In other words, according to the definition of [Pott and Hüppe 2007], matric potential is:

> "...the energy required to absorb water from the soil pores."

3 The relationship between soil water content and matric potential: Soil water retention curve

The amount of water in a given soil probe at a given matric potential depends on pore volume and pore size distribution. Therefore, for each soil type a characteristic transfer function between soil water content (soil moisture) and matric potential exists. This

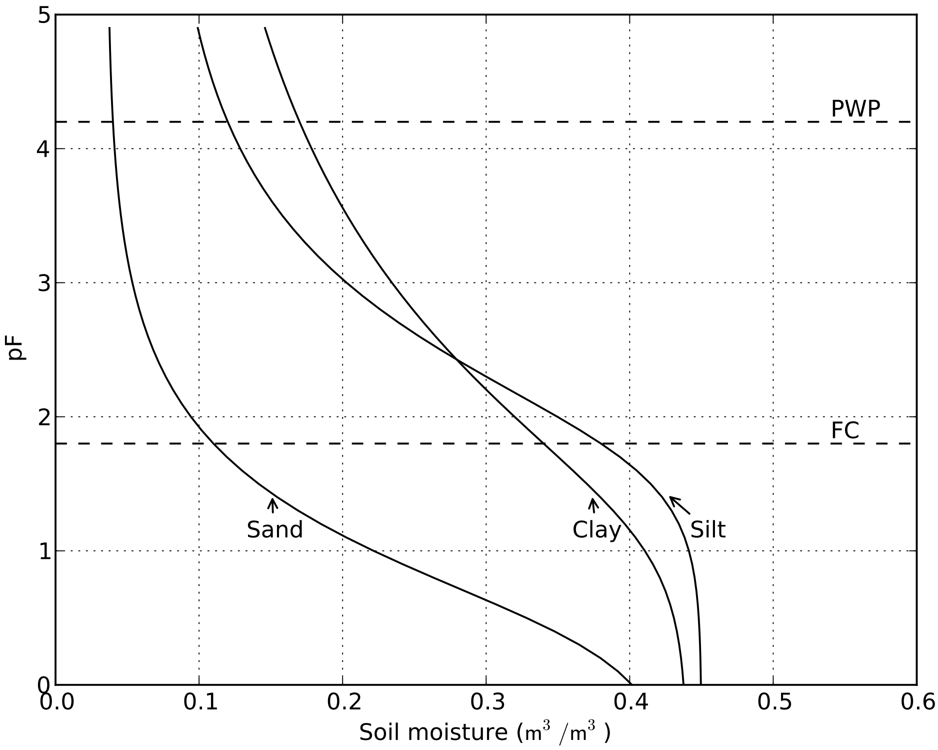

Figure 1: Soil water retention curves for three different soil types. Dashed lines mark Field Capacity (FC) and Permanent Wilting Point (PWP).

function is called soil water (or soil moisture) retention curve. [Scheffer and Schachtschabel 1998], [White 2009]. Figure 1 shows, as an example, the soil water retention curves for three different soil types.

[Van Genuchten 1980] and [Mualem 1976] developed a parametrized function, the Mualem-Van Genuchten (MvG) equation, which allows to describe the soil moisture retention curves analytically:

$$\theta(\psi) = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha|\psi|)^n]^{1-1/n}}, \quad (2)$$

where
$\theta(\psi)$ is the water retention curve expressing the soil moisture ($[L^3 L^{-3}]$, or vol. %);
ψ is the matric potential ($[L]$, or cm of water);
θ_s is the saturated water content $[L^3 L^{-3}]$;
θ_r is the residual water content $[L^3 L^{-3}]$;
α is related to the inverse of the air entry suction, $\alpha > 0$ ($[L^{-1}]$, or cm^{-1}); and,
n is a measure of the pore-size distribution, $n > 1$ (dimensionless).

4 Available soil sensors

Twelve of our 151 stations, the so-called special base stations, are equipped with soil sensors (pF-meters, measuring pF-value and soil temperature, located at a depth of 30 cm). Figure 2 gives an overview on the location of the stations and Table 1 shows a list of the soil stations together with available parameters.

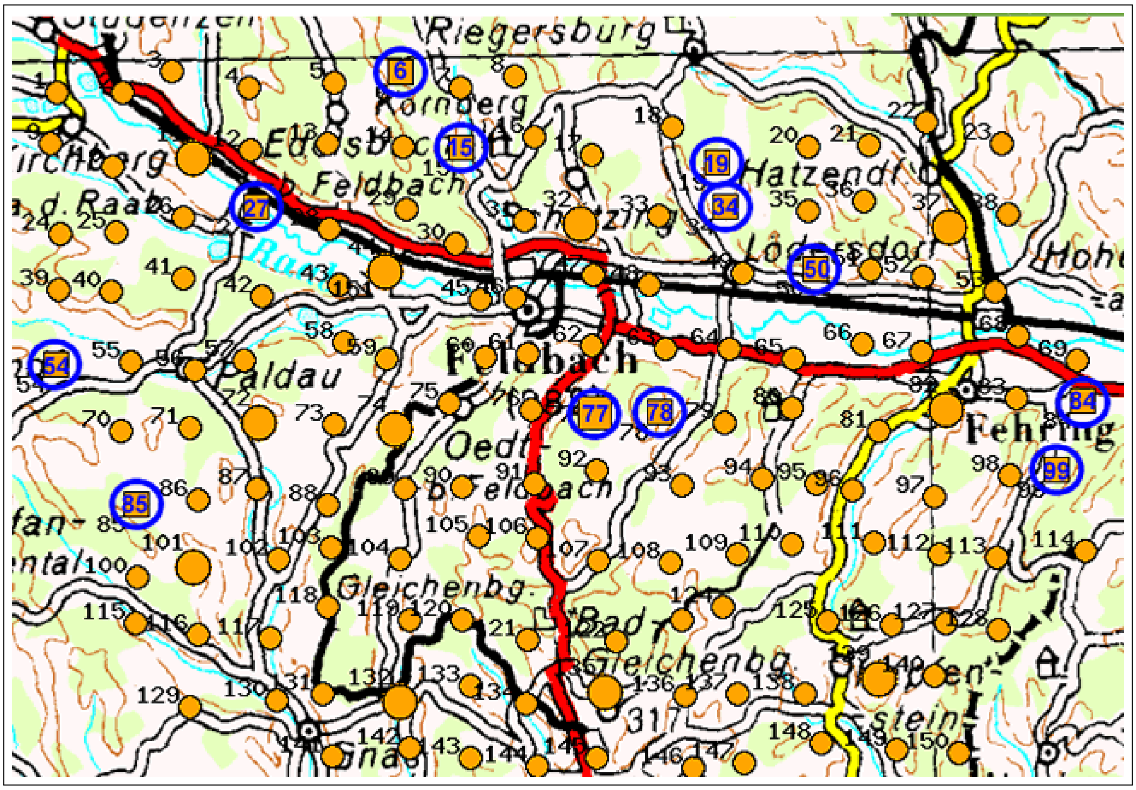

Figure 2: Map of WegenerNet stations, soil stations are marked by blue circles. (Map source BEV ÖK500 and WEGC, modified by [Brandl 2011].)

Station number	Horizon	Soil texture	Humus content	Soil classification
27	A	Ls	h3	Fluvisols in the Raab valley
15	A	Ls	h3	Gleysols in side valleys
99	Av	Ls	h4	
77	AB	Ls	h2-h3	Cambisols on tertiary loose sediment
50	A	Ls	h3	
34	A	Ls	h3	
85	A	Ls	h3	Soil complexes
54	A	Ls	h3	
19	AB	Lu	h2-h3	
84	B	Ls	h0	Planosols and stagnosols on quaternary loose sediment
6	Bpv	Ls	h0	
78	A	Ls	h2-h3	Volcanic soils

Table 1: List of soil stations and available parameters: Horizon, soil texture and soil classification were probed in 2006 by Prof. R. Lazar, University of Graz. Humus content taken from digital soil map eBod [BFW 2006]. Classification of soil texture and humus content according to [AG Boden 2005]; more details per station can be found in Appendix A of [Kabas 2012].

5 Deriving soil moisture retention curves

In order to calculate soil moisture from pF we need the moisture retention curves for each soil location.

For deriving the curves, we adapted a method used by [Reszler and Fank 2011]: They use soil parameters like grain size distribution, humus content and coarse grain proportion to get the water content values for Field Capacity (FC), Total Pore Volume (TPV) and Permanent Wilting Point (PWP) from the tables in chapter 1.2 of [AG Boden 2005]. Using $FC =$ pF 1.8, $TPV = \theta_s$ and $PWP \approx \theta_r$ they calculate the MvG parameters.

We use a similar approach: Having information on soil texture (Table 1) we can get a range of values for FC, TPV and PWP from [AG Boden 2005]. We use the values for station 15 as an example below (Table 2).

Since we do not have information on the exact soil texture class and dry bulk density, we define an uncertainty range using three possible values for each parameter: Maximum, minimum and mean. Where mean is simply $\frac{max.+min.}{2}$. Note that the parameters are only provided for the drying cycle and thus hysteresis effects can not be taken into account here. For the wetting cycle, intermediate pF-values will generally lie near the low values of the uncertainty range. The measurement uncertainty of the pF-values themselves (from the limited accuracy of the pF-Meter) is considered included in the uncertainty range, since the pF-Meter is stated to have an accuracy of ±0.05 [log hPa]. [GeoPrecision 2013]

Soil texture class	Dry bulk density	Resulting curve	FC	TPV	PWP
Ls2	ρt1+2	max	0.4	0.53	0.19
		mean	0.34	0.44	0.17
Ls4	ρt4+5	min	0.28	0.35	0.15

Table 2: Parameters FC, TPV and PWP for soil texture and dry bulk densities at Station 15. All values are in m^3/m^3.

With information on the soil's humus content we get further offsets for the parameters, shown in Table 3. Finally, Table 4 shows the resulting values for station 15.

Soil texture class	Humus content	Offset FK	Offset TPV	Offset PWP
Ls2	h3	0.06	0.09	0.03
Ls4	h3	0.06	0.08	0.02

Table 3: Offsets for FC, TPV and PWP for a given humus content and soil texture (station 15) taken from [AG Boden 2005]. All values are in m^3/m^3.

Soil texture class	Dry bulk density	Resulting curve	FC	TPV	PWP
Ls2	ρt1+2	max	0.46	0.62	0.22
		mean	0.4	0.525	0.195
Ls4	ρt4+5	min	0.34	0.43	0.17

Table 4: Parameters FC, TPV and PWP for soil texture and dry bulk densities at Station 15, using offsets from Table 3 together with parameters from Table 2. All values are in m^3/m^3.

Using FC = pF 1.8, PWP = pF 4.2 (according to [AG Boden 2005]) and $TPV = \theta_s$ we get three points of the soil moisture retention curves. With them we do a curve-fit of the MvG function (Equation 2) to get the parameters α, n and θ_r for each station, which are summarized in Table 5. Figure 3 shows the resulting curves for example station 15, together with the three points for the minimum curve.

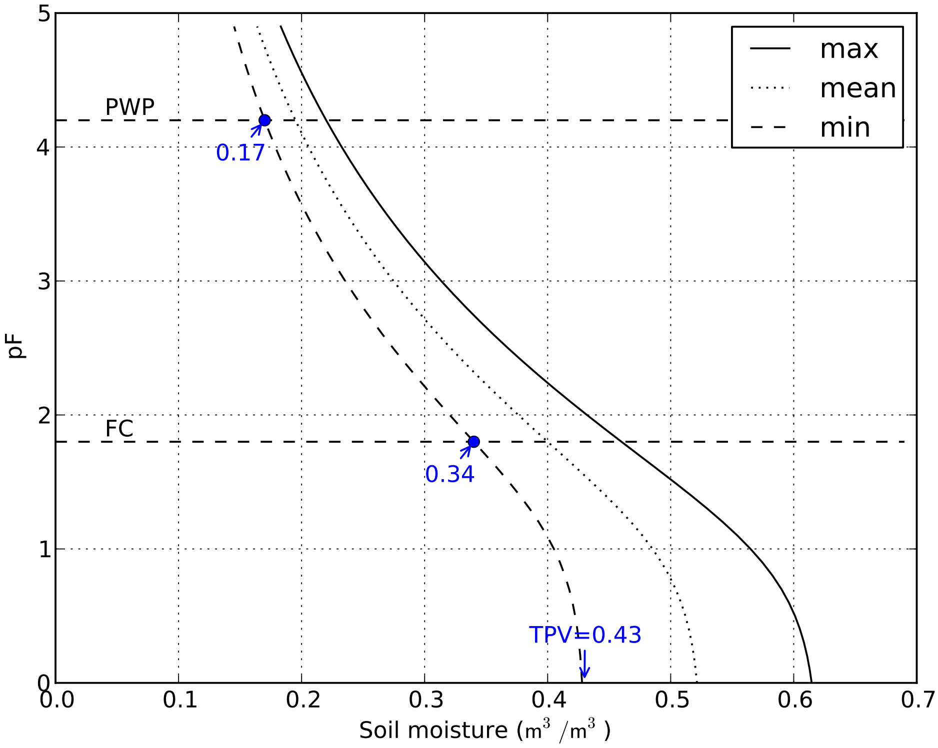

Figure 3: Soil moisture retention curves for station 15 with PWP, FK and TPV values indicated for the min. curve.

Station nr.	Curve	α	n	θ_s	θ_r
6	max	0.0713	1.221	0.530	0.099
	mean	0.0655	1.221	0.440	0.096
	min	0.0564	1.224	0.350	0.094
15	max	0.0823	1.216	0.620	0.112
	mean	0.0722	1.213	0.525	0.100
	min	0.0578	1.212	0.430	0.090
19	max	0.0649	1.216	0.630	0.102
	mean	0.0530	1.195	0.540	0.095
	min	0.0330	1.179	0.450	0.093
27	max	0.0823	1.216	0.620	0.112
	mean	0.0722	1.213	0.525	0.100
	min	0.0578	1.212	0.430	0.090
34	max	0.0823	1.216	0.620	0.112
	mean	0.0722	1.213	0.525	0.100
	min	0.0578	1.212	0.430	0.090
50	max	0.0823	1.216	0.620	0.112
	mean	0.0722	1.213	0.525	0.100
	min	0.0578	1.212	0.430	0.090
54	max	0.0823	1.216	0.620	0.112
	mean	0.0722	1.213	0.525	0.100
	min	0.0578	1.212	0.430	0.090
77	max	0.0823	1.216	0.620	0.112
	mean	0.0700	1.223	0.510	0.112
	min	0.0521	1.241	0.400	0.113
78	max	0.0823	1.216	0.620	0.112
	mean	0.0700	1.223	0.510	0.112
	min	0.0521	1.241	0.400	0.113
84	max	0.0713	1.221	0.530	0.099
	mean	0.0655	1.221	0.440	0.096
	min	0.0564	1.224	0.350	0.094
85	max	0.0823	1.216	0.620	0.112
	mean	0.0722	1.213	0.525	0.100
	min	0.0578	1.212	0.430	0.090
99	max	0.1060	1.164	0.680	0.069
	mean	0.0872	1.171	0.590	0.082
	min	0.0643	1.185	0.500	0.099

Table 5: Mualem-Van Genuchten parameters for all 12 stations.

6 Examples

Figures 4 to 6 show examples for precipitation, soil moisture and pF-value at station 15 as displayed on the WegenerNet webportal (www.wegenernet.org). The precipitation results, with a delay of about 3.5 h, in a rise of about 20 % in soil moisture within 2.5 h. The uncertainty of soil parameters is reflected in a difference between maximum and minimum soil moisture of about 9 % for the dry state and about 17 % for the wet state, respectively.

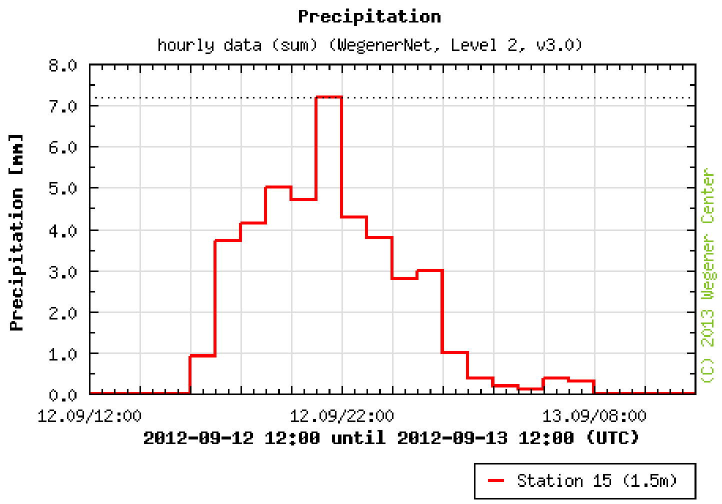

Figure 4: Precipitation at station 15 from 2012-09-12 12:00 to 2012-09-13 12:00.

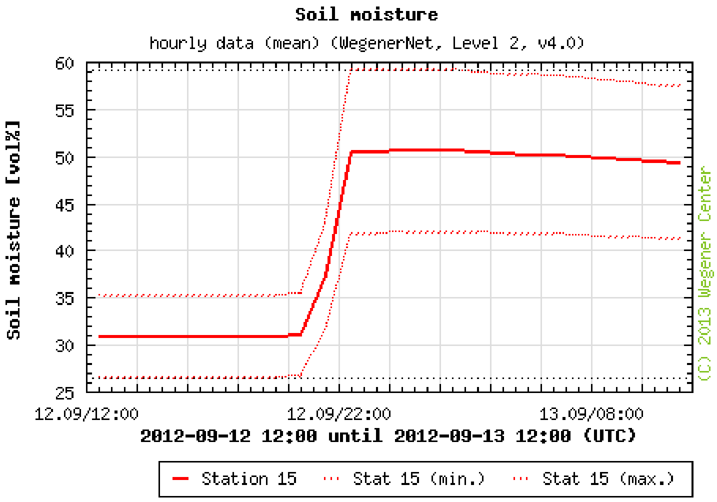

Figure 5: Soil moisture at station 15 from 2012-09-12 12:00 to 2012-09-13 12:00.

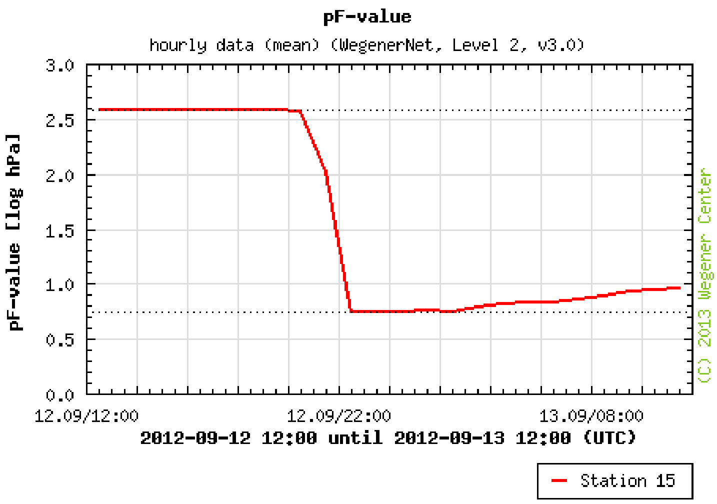

Figure 6: pF-value at station 15 from 2012-09-12 12:00 to 2012-09-13 12:00.

7 Outlook

To further reduce uncertainty in future soil moisture estimations from the measured pF-values, we plan to take additional soil samples at all stations. These samples will be examined in a laboratory to obtain the moisture retention curves directly, with significantly smaller uncertainty range.

Furthermore we are in the process of complementing or replacing some pF-meters by Hydra Probe soil sensors [Stevens 2013], which measure soil moisture directly. We are planning to perform parallel measurements of pF-value and soil moisture at least at stations 27 and 77.

For better accessibility and visibility of these soil moisture data, now available as records since the year 2007, we also are in the process of joining the International Soil Moisture Network ISMN [Dorigo et al. 2011] with these WegenerNet data records.

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