Development and evaluation of new Van Genuchten soil-properties ancillary files for JULES and the Unified Model

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Introduction

Soil physical properties affect the flow and drainage of heat and water between the surface and the entire soil column. The soil state, in turn, influences weather/climate, through controls on evapotranspiration and the Bowen ratio, affecting cloud formation and the hydrological and energy cycles. Downstream effects also impact our estimates of floods/droughts, forestry/agriculture, and the water supply.

The usage of Van Genuchten (1976) model parameters instead of Brooks & Corey (1964) model parameters may more accurately reflect the actual soil hydraulics. With this end, we are exploring the usage of Van Genuchten model parameters in the JULES (offline) land-surface model, with the hopes that it could eventually be used in the (coupled) Unified Model.

We have code working now for comparing different Pedotransfer Functions (PTFs) used to estimate the Van Genuchten soil-hydraulics parameters. We are currently exploring the use of the PTFs defined by Toth *et al.* (2014).

Brooks & Corey model and Van Genuchten model

Brooks and Corey:

Soil Water Retention Relationship

It has been shown that the Brooks and Corey equation (1964) provides a reasonably accurate representation of the water retention-matric potential relationship for tensions greater than 50 cm (Brakensiek et al., 1981). This equation is written as

$$S_e = (\psi_b/\psi)^\lambda \quad [1]$$

where

S_e (effective saturation) $= \theta - \theta_r/\theta - \theta_r$
θ = Soil water content, cm^3/cm^3
θ_r = Residual soil water content, cm^3/cm^3
ϕ = Total porosity, cm^3/cm^3
ψ_b = Bubbling pressure, cm of water
ψ = Capillary pressure, cm of water = Matric Potential
λ = Pore size distribution index

From: Rawls, Brakensiek, & Saxton (USDA), 1982, *Trans. Amer. Soc. Agric. Engineers*

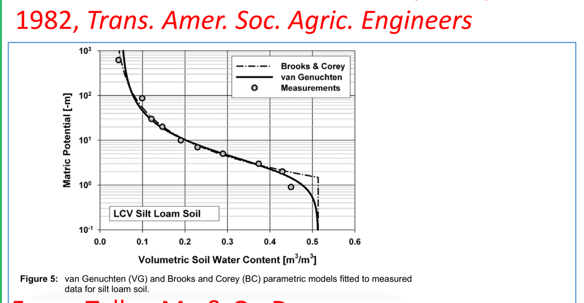

Figure 5: van Genuchten (VG) and Brooks and Corey (BC) parametric models fitted to measured data for silt loam soil.

From: Tuller, M., & Or, D. 2004, *Encyclopedia of Soils in the Environment*.

van Genuchten:

The *van Genuchten* [1976] model is widely used for predicting soil water content as a function of pressure head. This model is generally expressed as

$$\Theta = \Theta_r + \frac{(\Theta_s - \Theta_r)}{[1 + (\alpha h)^N]^M} \quad (1)$$

where

Θ water content;
Θ_r residual water content;
Θ_s total saturated water content;
α empirical constant, cm^{-1};
N empirical constant;
M empirical constant;
h capillary head, cm.

Also, where M is related to N as follows:

$$M = 1 - 1/N$$

Hydraulic conductivity can be represented by

$$\frac{K(\Theta)}{K_S} = \left\{\frac{\Theta - \Theta_r}{\Theta_s - \Theta_r}\right\}^{1/2}\left\{1 - \left[1 - \left(\frac{\Theta - \Theta_r}{\Theta_s - \Theta_r}\right)^{1/M}\right]^M\right\}^2 \quad (2)$$

where $K(\Theta)$ is the hydraulic conductivity for a given water content (centimeters per hour) and K_S is the saturated hydraulic conductivity (centimeters per hour). Equation (1) contains four independent parameters (Θ_s, Θ_r, α, N) that have to be estimated (h is assumed to be positive). Equation (2)

From: Carsel & Parrish (US EPA), 1988, *Water Resources Research*

At high values of $h \equiv \psi$, the models are equivalent if $b \equiv 1/\lambda$ is set $= 1/(N-1)$

This approximation breaks down at low values of $h \equiv \psi$

Rawls & Brakensiek (1985) PTF for Brooks and Corey water-retention curves

Term	ln (KS)	θr	ln (α⁻¹)	ln (N−1)
(Constant)	−8.96847	−0.0182482	5.3396738	−0.7842831
S	–	0.0087269	–	0.0177544
C	−0.028212	0.00513488	0.1845038	–
θ_s	19.52348	0.02939286	−2.48394546	−1.062498
S^2	0.00018107	–	–	−0.00005304
C^2	−0.0094125	−0.0015395	−0.00213853	−0.00273493
θ_s^2	−8.395215	–	–	1.11134946
SC	–	–	–	–
$S\theta_s$	0.077718	−0.0010827	−0.0435649	−0.03088295
$C\theta_s$	–	–	−0.61745089	–
S^2C	0.0000173	–	−0.00001282	−0.00000235
$C^2\theta_s$	0.02733	0.0030703	0.00895359	0.00798746
$S^2\theta_s$	0.001434	–	−0.0072472	–
SC_2	−0.0000035	–	0.0000054	–
$C\theta_s^2$	–	−0.0023584	0.50028060	−0.00674491
$S^2\theta_s^2$	−0.00298	–	0.00143598	0.00026587
$C^2\theta_s^2$	−0.019492	−0.0018233	−0.00855375	−0.00610522

Fig. 1. Multiple regression model and coefficients developed by *Rawls and Brakensiek* [1985] to estimate selected soil water retention characteristics.

S = percent sand (5<S<70)
C = percent clay (5<C<60)
θ_s = total saturated water content, $cm^3 cm^{-3}$
KS = saturated hydraulic conductivity, $cm\ hr^{-1}$
θ_r = residual water content, $cm^3 cm^{-3}$
α = empirical constant, cm^{-1}
N = empirical constant

General regression model:

$$f(S,C,\theta_s) = [b_0 + b_1 S + b_2 C + b_3\theta_s + b_{11}S^2 + b_{22}C^2 + b_{33}\theta_s^2 + b_{12}SC + b_{13}S\theta_s + b_{23}C\theta_s + b_{112}S^2C + b_{223}C^2\theta_s + b_{113}S^2\theta_s + b_{122}SC^2 + b_{233}C\theta_s^2 + b_{1133}S^2\theta_s^2 + b_{2233}C^2\theta_s^2]$$

This is a function-based 'continuous' PTF.

From: Carsel & Parrish (US EPA), 1988, *Water Resources Research*

Toth et al. (2014) continuous PTF's #20 and #21

MRC (θ_r / $cm^3\ cm^{-3}$, θ_s / $cm^3\ cm^{-3}$, $\log_{10}(\alpha$ / $\log_{10}(cm^{-1})$, $\log_{10}(n-1)$ / - parameters of VG model)

Rule 1
IF Sa >= 2.00
$\theta_r = 0.041$

Rule 2
IF Sa < 2.00
$\theta_r = 0.179$

Sa = % Sand
Si = % Silt
Cl = % Clay

BD = Bulk Density g/cm^3
OC = % Organic Carbon
CEC = Cation Exchange Capacity (meq $100g^{-1}$)
n = N (Van Genuchten) exponent

RT (for θ_r) and LR (for θ_s, $\log_{10}(\alpha)$ and $\log_{10}(\alpha)$)

PTF#20:

θ_s = 0.5056 - 0.1437 * (1/(OC+1)) + 0.0004152 * Si

$\log_{10}(\alpha)$ = -1.3050 - 0.0006123 * Si - 0.009810 * Cl + 0.07611 * (1/(OC+1)) - 0.0004508 * Si * Cl + 0.03472 * Cl * (1/(OC+1)) - 0.01226 * Si * (1/(OC+1))

$\log_{10}(n-1)$ = 0.01516 - 0.005775 * (1/(OC+1)) - 0.24885 * $\log_{10}$(CEC) - 0.01918 * Cl - 0.0005052 * Si - 0.007544 * pH^2 - 0.02159 * Cl * (1/(OC+1)) + 0.01556 * Cl * $\log_{10}$(CEC) + 0.01477 * (1/(OC+1)) * pH^2 + 0.0001121 * Si * Cl - 0.33198 * (1/(OC+1)) * $\log_{10}$(CEC)

PTF#21:

θ_s = 0.83080 - 0.28217 * BD + 0.0002728 * Cl + 0.000187 * Si

$\log_{10}(\alpha)$ = -0.43348 - 0.41729 * BD - 0.04762 * OC + 0.21810 * T/S - 0.01581 * Cl - 0.01207 * Si

$\log_{10}(n-1)$ = 0.22236 - 0.30189 * BD -0.05558 * T/S - 0.005306 * Cl - 0.003084 * Si - 0.01072 * OC

Toth PTF21 consists of model-regression fits against variables that include Organic Carbon (OC) instead of Cation Exchange Capacity (CEC) and pH, as in TothPTF20

Methods

- Python code was used to compute the Van Genuchten parameters from each of the Pedotransfer Functions (PTFs) published by Toth *et al.* (2014).
- This Python code uses the ANTS libraries (**An**cillary **T**ools and **S**uites) developed at the Met Office.
- The Toth PTFs use soil measurements from the European Hydropedological Data Inventory (EU-HYDI, Weynants *et al.* 2013) for the regressions.
- We used the SoilGrids database (Hengl *et al.* 2014) at 5km resolution for the input data to the Toth PTFs.
- We are currently computing soil-property Van Genuchten soil-properties ancillary files for JULES for the WFDEI grid at 0.5-degree resolution.
- The results shown on the right are for the depth range of 0.6-1.0 m.
- The Van Genuchten parameters with the Toth PTFs are compared to the Brooks & Corey parameters with the Rawls & Brakensiek PTF.
- The Brooks & Corey parameters were computed with the ROSETTA version 2 software, with the selected PTF being the Rawls & Brakensiek PTF.
- The Rawls & Brakensiek PTF (1985) uses USDA soil data (measured for soils from across the USA) for the regressions.

Preliminary Conclusions

- There is still work to do. These results are preliminary.
- With a set of three different PTFs developed by the same authors (Toth *et al.* 2014) with the same data set, the results do give different geographical distributions for each of the three PTFs presented here.
- The Toth PTF21 gives very low values for the 1/(N-1) Van Genuchten exponent, with a range from 2-4. This is confirmed by other authors who did the same procedure with the same SoilGrids data and the same Toth PTF21 (F. De Boer, 2016).
- The Toth PTF21 also give very high values for the Soil Suction at saturation, predominantly with values of >0.65 m.
- Some of the geographical differences between the Van Genuchten parameters with the Toth PTF occur even when restricted to Europe (where Toth et al. did their regressions to the soil measurements).
- Some of the geographical differences (i.e. in the deserts) may reflect the lack of desert-data in the EU-HYDI database used in the regressions by Toth *et al.*
- Using the Toth Continuous PTF20 may be better than Toth Continuous PTF21 or the Toth Discrete-Textures PTF19 for the Van Genuchten parameters since the ranges are more similar to the Brooks & Corey parameters given by the Rawls & Brakensiek PTF, but more study is needed.

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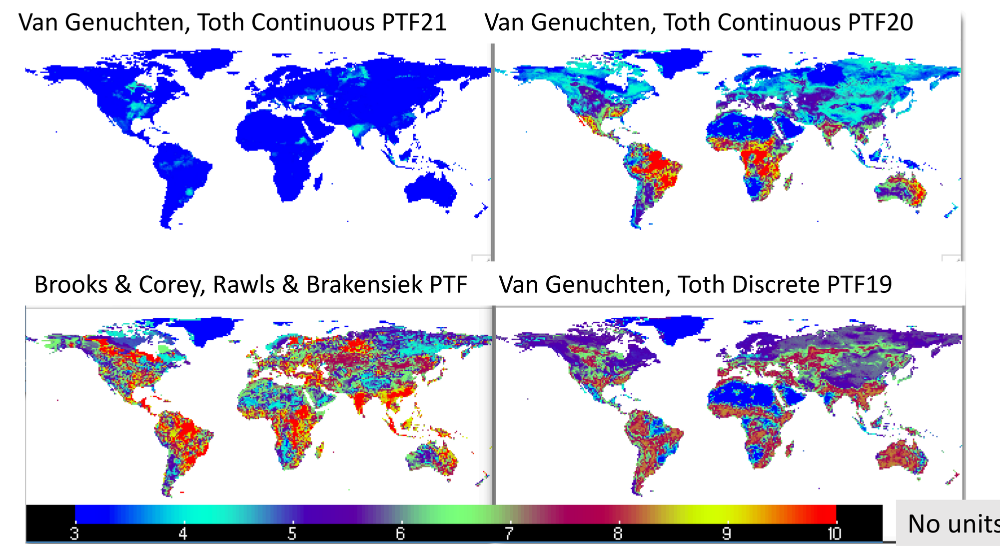
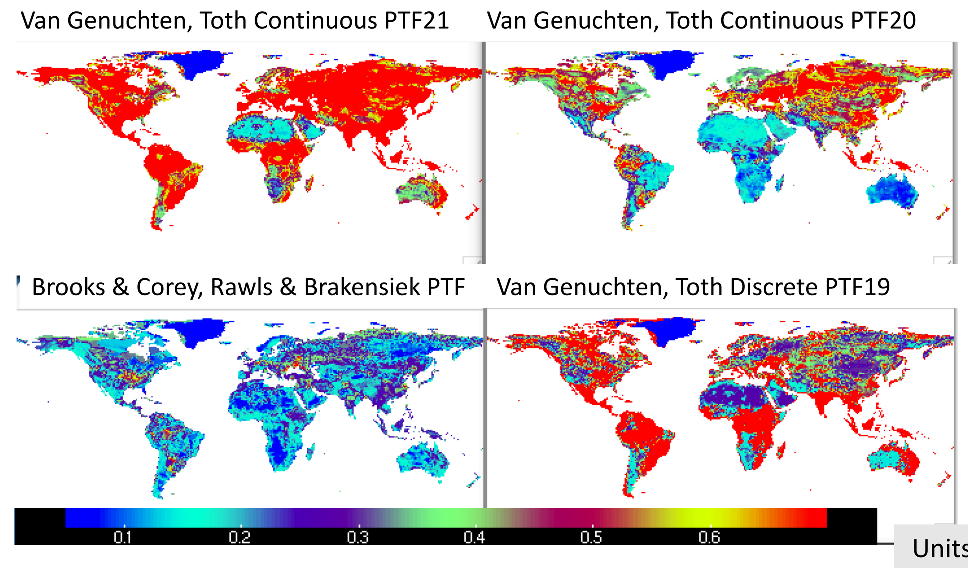
Preliminary results

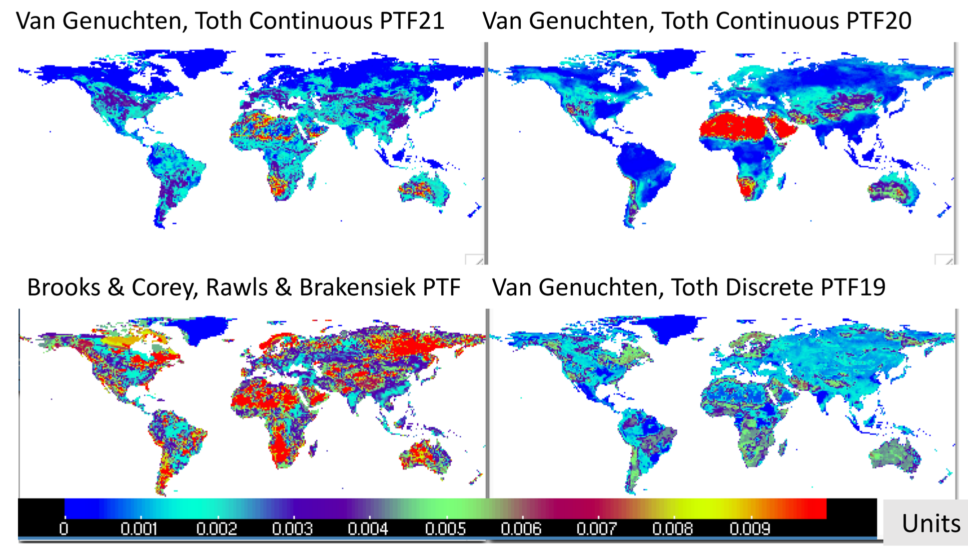
Exponent: b (Brooks & Corey) or $\frac{1}{N-1}$ (Van Genuchten)



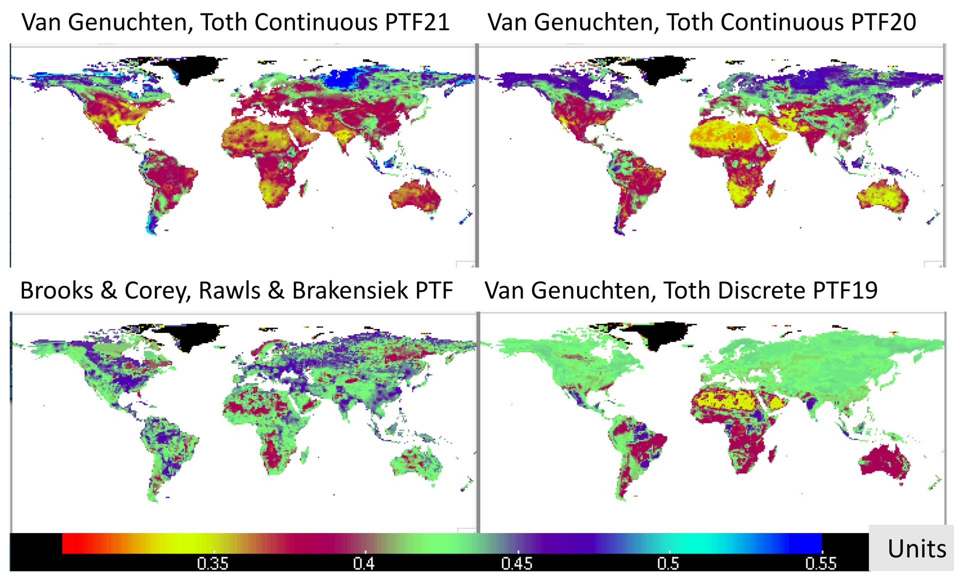
Soil Suction at saturation: ψ_b (B & C) or $\frac{1}{\alpha}$ (VG)



Hydraulic Conductivity at saturation (K_{sat})



Soil Moisture at saturation – Residual Soil Moisture



Soil Moisture at wilting point – Residual Soil Moisture