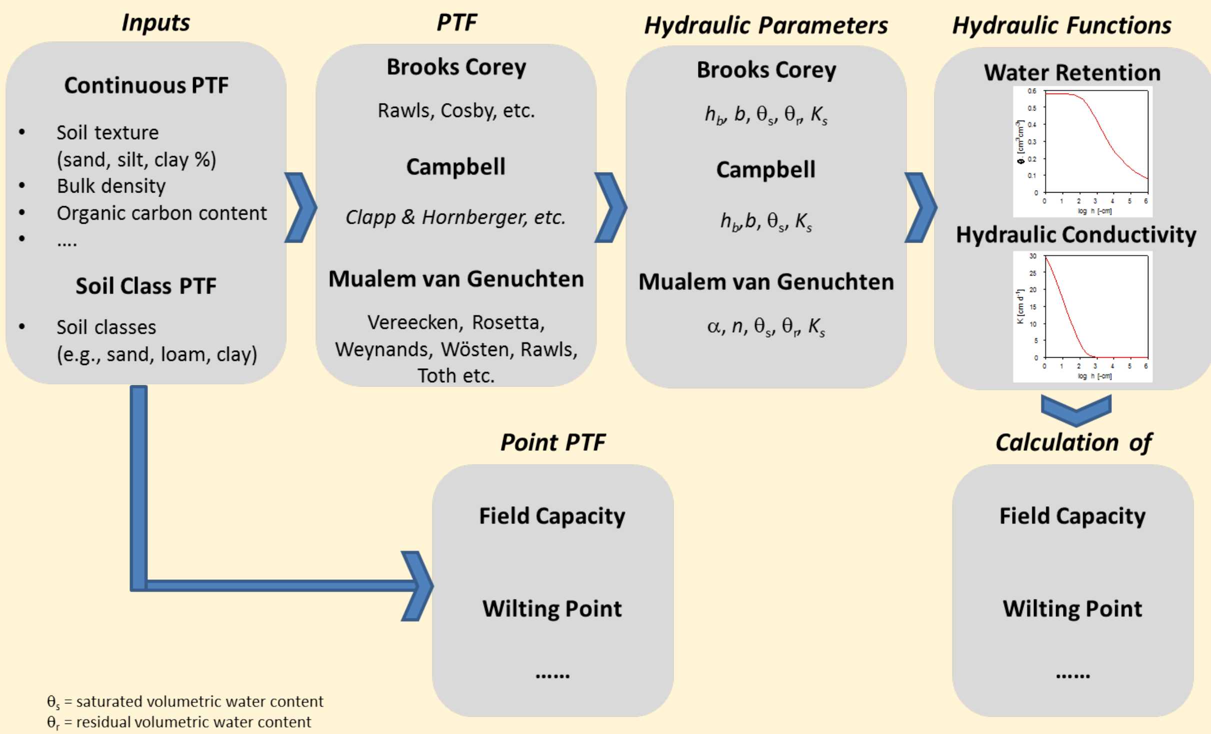
ISMC-GEWEX-SoilWat initiative on comparing soil hydraulic & thermal properties description and pedotransfer functions in LSMs

Anne Verhoef, Harry Vereecken, Lutz Weihermuller, Carsten Montzka, Michael Herbst, Kris van Looy



θ_s = saturated volumetric water content
θ_r = residual volumetric water content
K_s = saturated hydraulic conductivity
b = Brooks Corey or Campbell shape parameter
h_b = air entrancy value for Brooks Corey and Campbell (often also ψ_s)
α = reciprocal of the air entrance value for Mualem van Genuchten
n = shape parameter for Mualem van Genuchten

JÜLICH FORSCHUNGSZENTRUM

GLASS meeting, 15 May 2017

University of Reading

Mission

The mission of the International Soil Modeling Consortium (ISMC) is to integrate and advance soil systems modeling, data gathering and observational capabilities. It aims for a definitive quantification of soil ecosystem services, impacts of climate change, land use and agricultural intensification on soils and terrestrial systems at scales ranging from local to global.

The specific objectives of the ISMC are:

- To develop the first generation of integrated soil system models and establish a platform for **model development and validation**
- To perform **soil model intercomparison studies at local to global scales**
- To consolidate and develop soil and other data platforms for dissemination of soil information and for modeling
- To **promote integration of soil modelling expertise** in neighboring disciplines (climate, land surface, ecological, crop, and other models)
- To integrate societal and environmental considerations into soil and ecosystem functioning

Described in White paper:
Vereecken et al. 2016, *Vadose Zone Journal*

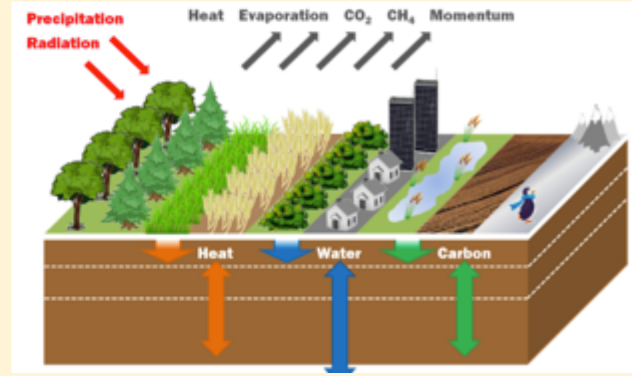
OVERVIEW

Overview

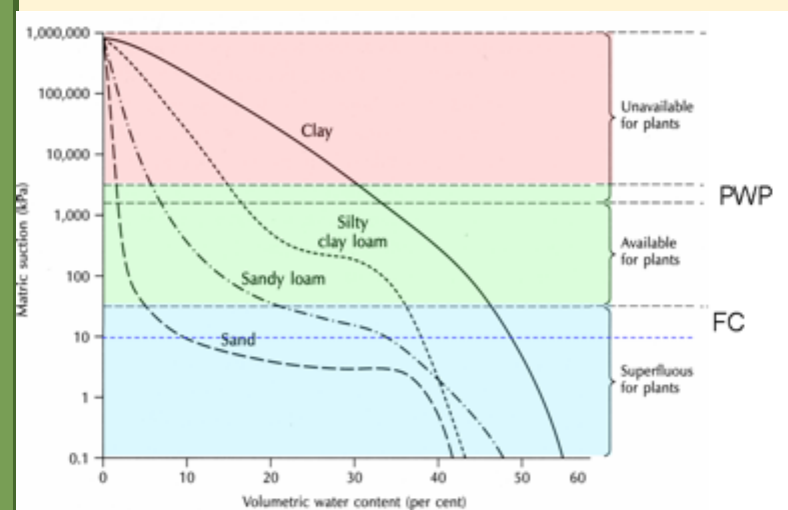
- GEWEX and the soil and critical zone communities: improve interactions and integration of soil and subsurface processes in present climate models

- Planning workshop aimed at designing and prioritizing interactions took place in June 28-30, 2016 in Leipzig

- Various initatives: (1) Evaluation of pedotransfer functions and related functional descriptions for calculation of hydraulic and thermal soil properties in global climate and hydrological models. A joint GEWEX-SoilWAT-ISMC project, led by Harry Vereecken and Anne Verhoef



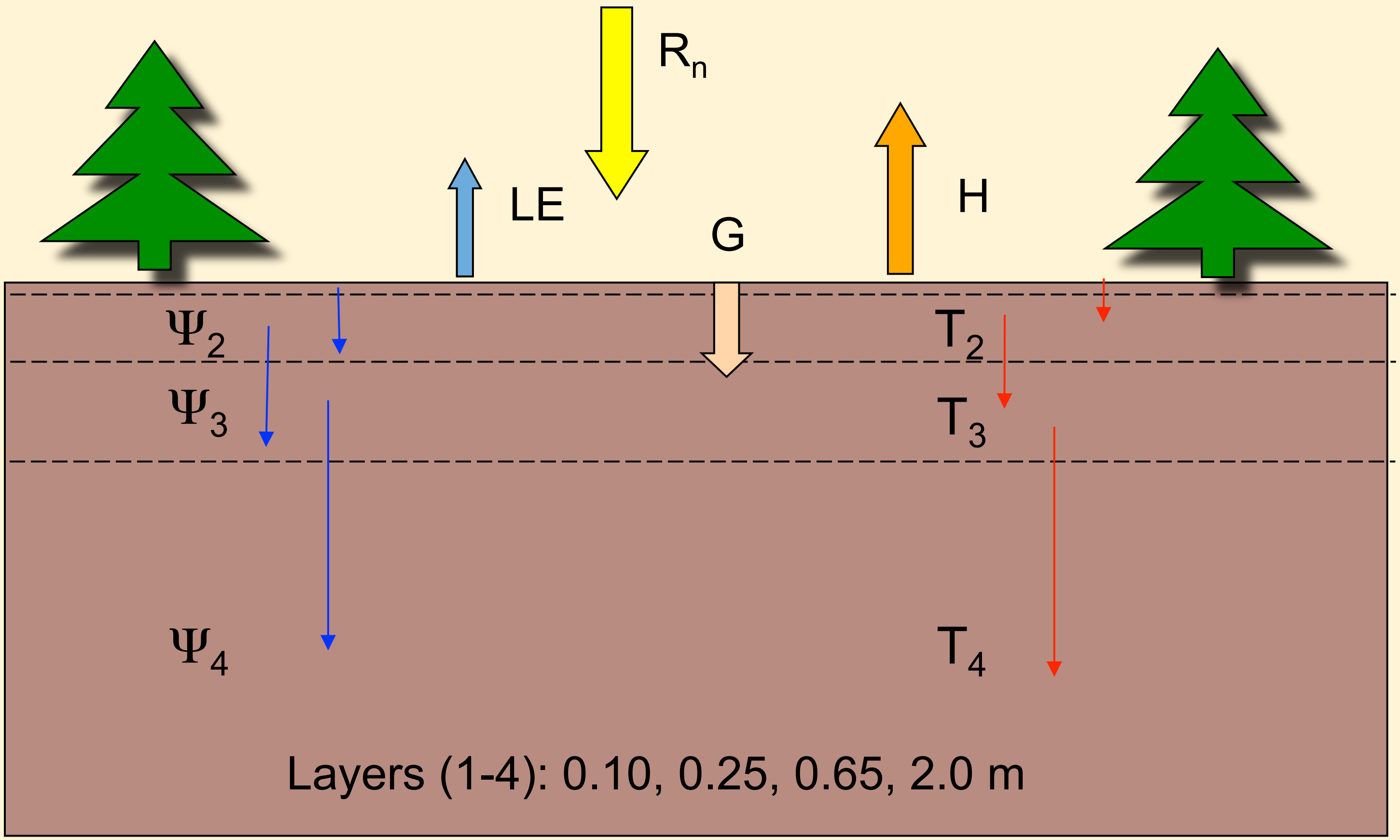
JULES land surface model



LSM SOIL WATER- AND HEAT TRANSFER

WITHIN-SOIL TRANSFER

- Water flow: Darcy's law combined with Richard's equation
- Heat flow: Fourier equation and heat conservation equation



$$W = K\left\{\frac{\Delta\psi}{\Delta z} + 1\right\}$$

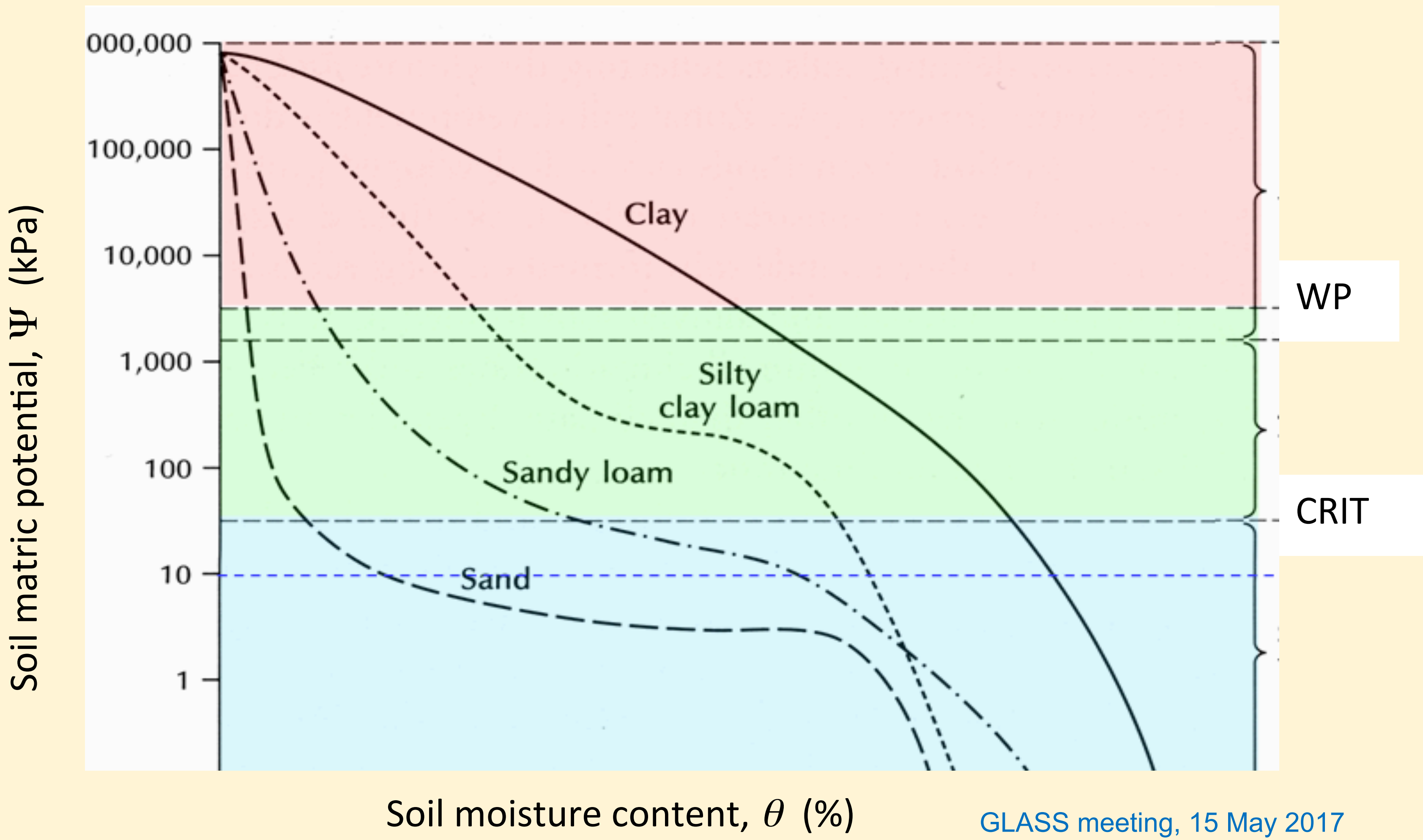
$$G = \lambda \frac{\Delta T}{\Delta z}$$

Plus advective heat transfer

HYDRAULIC PROPERTIES

WATER RETENTION CURVE (WRC) & HYDRAULIC CONDUCTIVITY CURVE

- Relationship between soil matric potential/HCC and soil moisture content
- Different functional description are available (Brooks & Corey; Van Genuchten-Mualem

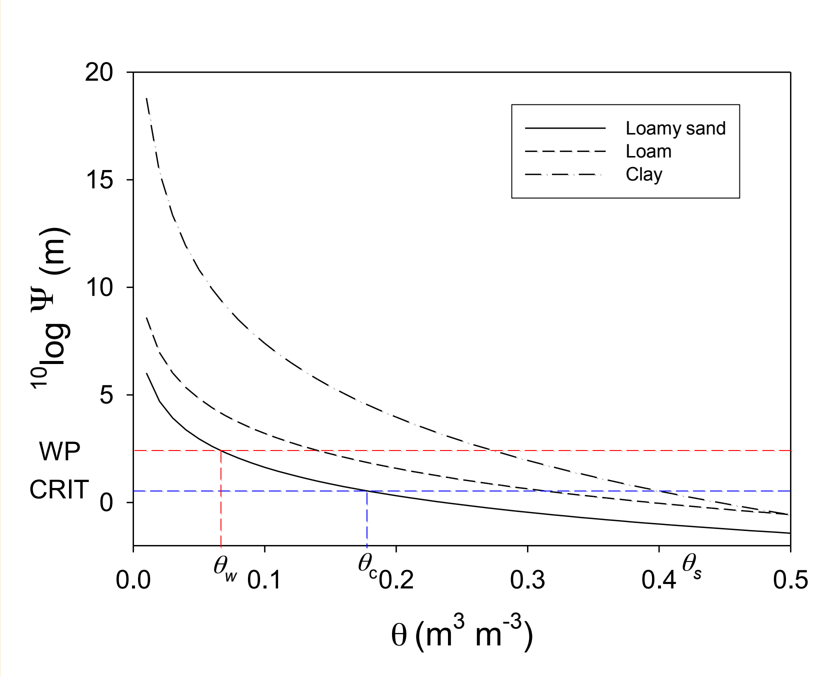


Clapp and Hornberger

Hydraulic functions

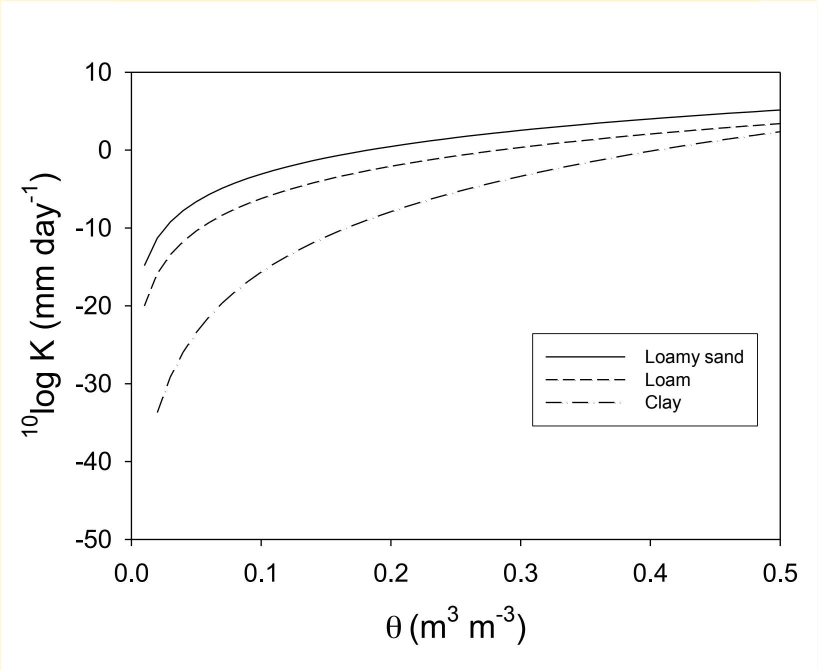
WRC

$$\psi = \psi_s \left(\theta / \theta_s \right)^{-b}$$



HCC

$$K = K_s \left(\theta / \theta_s \right)^{2b+3}$$



Soil texture	f_{sand} (%)	f_{silt} (%)	f_{clay} (%)
Loamy sand	82	12	6
Loam	43	39	18
Clay	22	20	58

HYDRAULIC FUNCTIONS

VAN GENUCHTEN

WRC

$$\psi = \frac{\left(\Theta^{-1/m} - 1\right)^{1/n}}{\alpha}$$

HCC

$$K = K_s \frac{\left[1 - (\alpha\psi)^{n-1}\left\{1 + (\alpha\psi)^n\right\}^{-m}\right]^2}{\left[1 + (\alpha\psi)^n\right]^{m/2}}$$

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

$$m = 1 - \frac{1}{n}$$

Clapp and Hornberger parameters table for Brooks & Corey equations

Parameters; soil classes

Soil texture	b (-)	θ_s (m^3 m^{-3})	ψ_s (m)	QC (-)	K_s (cm/min)
Sand	4.05	0.395	-0.121	0.92	1.056
Loamy sand	4.38	0.410	-0.090	0.82	0.938
Sandy loam	4.90	0.435	-0.218	0.60	0.208
Silt loam	5.30	0.485	-0.786	0.25	0.0432
Loam	5.39	0.451	-0.478	0.40	0.0417
Sandy clay loam	7.12	0.420	-0.299	0.60	0.0378
Silty clay loam	7.75	0.477	-0.356	0.10	0.0102
Clay loam	8.52	0.476	-0.630	0.35	0.0147
Sandy clay	10.40	0.426	-0.153	0.52	0.013
Silty clay	10.40	0.492	-0.490	0.52	0.013
Clay	11.40	0.482	-0.405	0.25	0.0062

BROOKS AND COREY HYDRAULIC FUNCTIONS; COSBY ET AL. PTFS

- based on MLRA (multiple linear regression analysis)
- dependent on percentages of sand, silt and clay

$$b = 3.1 + 0.157 f_{clay} - 0.003 f_{sand}$$

$$\theta_s = \left(50.5 - 0.142 f_{sand} - 0.037 f_{clay}\right)/100$$

$$\psi_s = 0.01 \times 10^{1.54 - 0.0095 f_{sand} + 0.0063 f_{silt}}$$

$$K_s = a \times 10^{-0.6 - 0.0064 f_{clay} + 0.0126 f_{sand}}$$

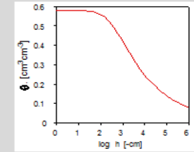
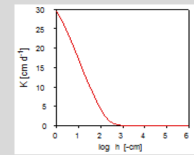
ISMC-GEWEX-SoilWat initiative on comparing soil hydraulic & thermal properties description and pedotransfer functions in LSMs

OBJECTIVES

OBJECTIVES

- To summarize the functional descriptions used to estimate hydraulic and thermal properties (WRC and HCC) in LSMs and hydrological models, as well as equations that make use of secondary data derived from these curves (e.g. field capacity/wilting point).
- To provide an overview of PTFs (and their fitting parameters) used for calculation of hydraulic and thermal properties for simulation of water and energy related processes in global climate and hydrological models. We will compare these approaches with state of the art PTFs used in soil science.
- To quantify uncertainty in water and energy fluxes and states generated by PTF and/or type of hydraulic/thermal function, and aggregration or upscaling.
- To perform 1D simulations using state of the art soil models, such as Hydrus, to assess the impact of the type of hydraulic/thermal function, PTFs, and the inherent uncertainties embedded in these equations on key soil processes.

MODEL COMPARISON

Inputs	*PTF*	*Hydraulic Parameters*	*Hydraulic Functions*
Continuous PTF	**Brooks Corey**	**Brooks Corey**	**Water Retention**
• Soil texture (sand, silt, clay %) • Bulk density • Organic carbon content •	Rawls, Cosby, etc.	h_b, b, θ_s, θ_r, K_s	
Soil Class PTF	**Campbell**	**Campbell**	**Hydraulic Conductivity**
• Soil classes (e.g., sand, loam, clay)	*Clapp & Hornberger, etc.*	h_b, b, θ_s, K_s	
	Mualem van Genuchten	**Mualem van Genuchten**	
	Vereecken, Rosetta, Weynands, Wösten, Rawls, Toth etc.	α, n, θ_s, θ_r, K_s	

Point PTF

Field Capacity

Wilting Point

......

Calculation of

Field Capacity

Wilting Point

......

θ_s = saturated volumetric water content
θ_r = residual volumetric water content
K_s = saturated hydraulic conductivity
b = Brooks Corey or Campbell shape parameter
h_b = air entrancy value for Brooks Corey and Campbell (often also ψ_s)
α = reciprocal of the air entrance value for Mualem van Genuchten
n = shape parameter for Mualem van Genuchten

Model					...oint PTF
JSBACH version 3.0					...o Kleidon (2004) ...agemann (2002) ...and Willmott (1996)
Community Land Model CLM 4.5					...rted
ORCHIDEE rev3959					...ted from WRC
Catchment land surface NASA_CATCHMENT_LSM					...ted from WRC
SURFEXv8.0 version 8.0					...d from WRC or by PTF ...erger (1978) database
MPI-HM					...d from additional data ...ng depth dataset)
JULES version 4.6					...ted from WRC
NOAH-MP version 3.0					...ted from WRC
LEAF / OLAM version 4	McCumber and Pielke (1981), Walko et al. (2000)	diffusivity form of Richards equation	Campbell (1974) or van Genuchten (1980)	classes for van Genuchten (1980) (source of parameters not provided)	PWP & FC calculated from WRC
SSiB Simplified Simple Biosphere model Version 3.5	Xue et al. (1991), Zhan et al. (2003), Sun and Xue (2001)	bucket model	extended Campbell (1974) for partially frozen soils	Clapp and Hornberger (1978) for WR and modified Clapp and Hornberger (1974) according to Jame and Norum (1980) for HC	PWP according to Xue et al. (1991)
CABLE Community Atmosphere Biosphere Land Exchange model	Kowalczyk (2006), Wang et al. (2011)	diffusivity form of Richards equation	Campbell (1974)	Clapp and Hornberger (1978)	PWP & FC calculated from WRC

[*] revised version used for SMAP L4_SM used van Genuchten parameters according to Wösten et al. (2001)
[†] hereby van Genuchten function was coupled to Brooks-Corey parameters
[§] reformulated to match metric units

Review paper on Pedotransfer functions, led by Kris van Looy

Pedotransfer functions in Earth system science: challenges and perspectives

Van Looy, Vereecken, Bouma, Schaap, Zhang, Nemes, Koestel, Weihermüller, Verhoef, Montzka, Minasny, Pachepsky, Padarian, Herbst, Vanderborght, Mishra, Tóth, Zacharias

Outline

1. Introduction and brief history of PTFs (Vereecken, Bouma, Van Looy)
    1. Preface and outline
    2. A brief history of PTFs
    3. PTFs of soil hydraulic properties and beyond
2. Methods to derive and evaluate pedotransfer functions (Schaap)
    1. Derivation with regression techniques, neural networks, support vector machines, nearest neighbor methods, …
    2. Methods for evaluating the quality of PTFs with statistical indicators, functional evaluation, ensemble simulations, …
3. Methodological challenges for PTFs in Earth system models (Minasny & Padarian)
    1. Extrapolation
    2. Scaling
    3. Integration
4. PTFs in Earth system models
    1. PTFs of water flow (Vereecken, Vanderborght, Montzka)
        1) Soil hydraulic processes
        2) Root zone hydraulic processes
        3) Hydraulic parameterization
    2. PTFs of solute flow (Koestel)
        1) Solute transport processes

GLOBAL HYDRAULIC PARAMETER MAP PLUS DATA SET; MONTZKA ET AL.

Earth Syst. Sci. Data Discuss., doi:10.5194/essd-2017-13, 2017
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 23 February 2017

Open Access Earth System Science Data Discussions

A global data set of soil hydraulic properties and sub-grid variability of soil water retention and hydraulic conductivity curves

Carsten Montzka[1], Michael Herbst[1], Lutz Weihermüller[1], Anne Verhoef[2], Harry Vereecken[1]

[1]Forschungszentrum Jülich GmbH, Institute of Bio- and Geosciences: Agrosphere (IBG-3), Jülich, Germany
[2]University of Reading, Department of Geography and Environmental Science, Reading, UK

Correspondence to: Carsten Montzka (c.montzka@fz-juelich.de)

Abstract. Agroecosytem models, regional and global climate models, as well as numerical weather prediction models require adequate parameterization of soil hydraulic properties. These properties are fundamental for describing and predicting water and energy exchange processes at the transition zone between solid Earth and Atmosphere, and regulate evapotranspiration, infiltration, and runoff generation. Hydraulic parameters describing the soil water retention (WRC) and hydraulic conductivity (HCC) curves are typically derived from soil texture via pedotransfer functions (PTFs). Resampling

GLOBAL HYDRAULIC PARAMETER MAP PLUS DATA SET; MONTZKA ET AL.

Not logged in

PANGAEA.

Data Publisher for Earth & Environmental Science

SEARCH SUBMIT ABOUT CONTACT

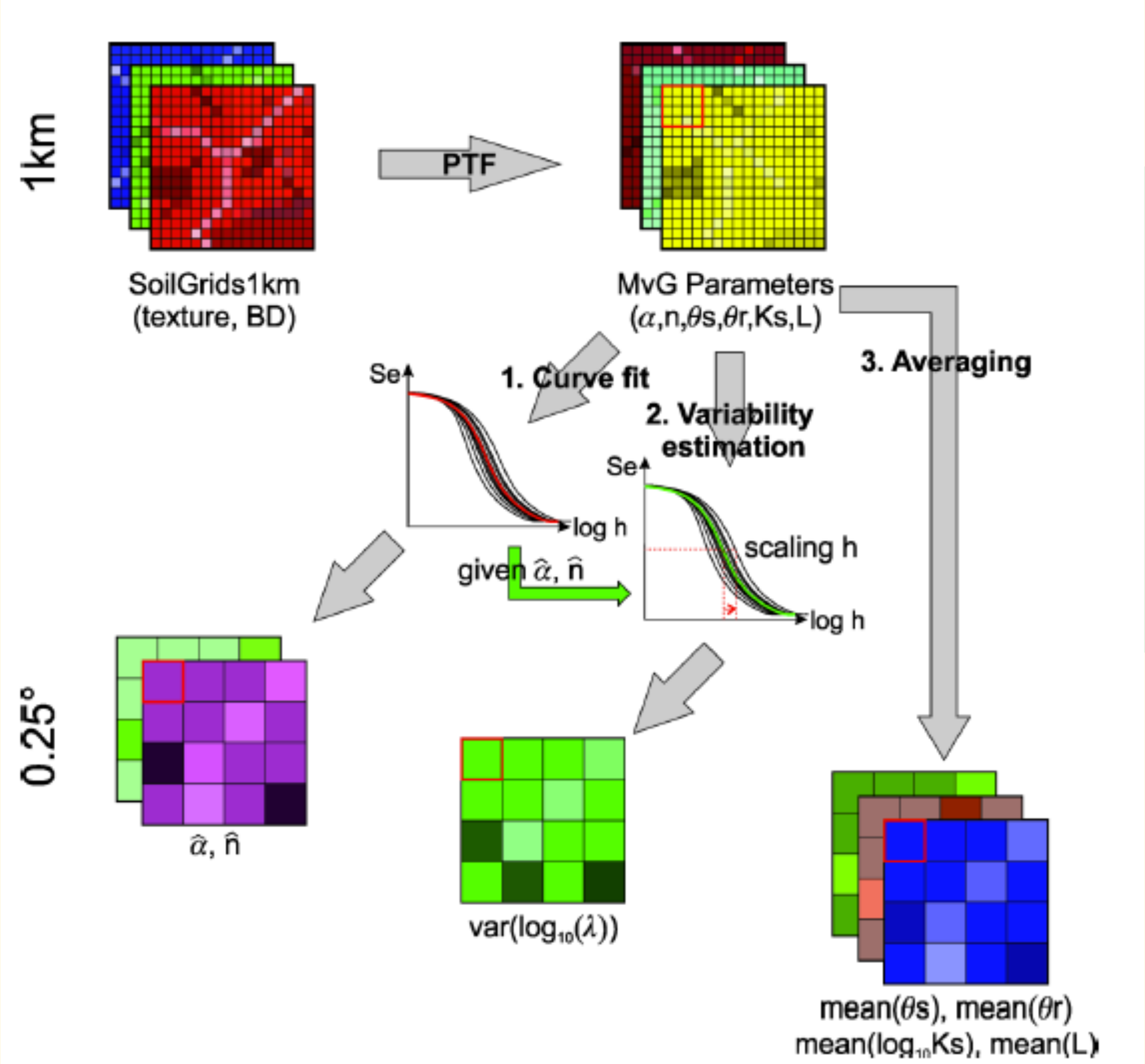
Montzka, Carsten; Herbst, Michael; Weihermüller, Lutz; Verhoef, Anne; Vereecken, Harry (2017): A global data set of soil hydraulic properties and sub-grid variability of soil water retention and hydraulic conductivity curves, link to model result files in NetCDF format. doi:10.1594/PANGAEA.870605,

Supplement to: Montzka, C et al. (in prep.): A global data set of soil hydraulic properties and sub-grid variability of soil water retention and hydraulic conductivity curves. *Earth System Science Data Discussions*

Always quote above citation when using data! You can download the citation in several formats below.

RIS Citation | BibTeX Citation | Text Citation | Facebook | Twitter | Google+

GLOBAL HYDRAULIC PARAMETER MAP PLUS DATA SET; MONTZKA ET AL.



Proposed method to aggregate soil hydraulic properties and sub-grid variability of soil water retention and hydraulic conductivity curves.

NOVEL HIGH-RES HYDRAULIC PARAMETER MAPS

GLOBAL HYDRAULIC PARAMETER MAP PLUS DATA SET; MONTZKA ET AL.

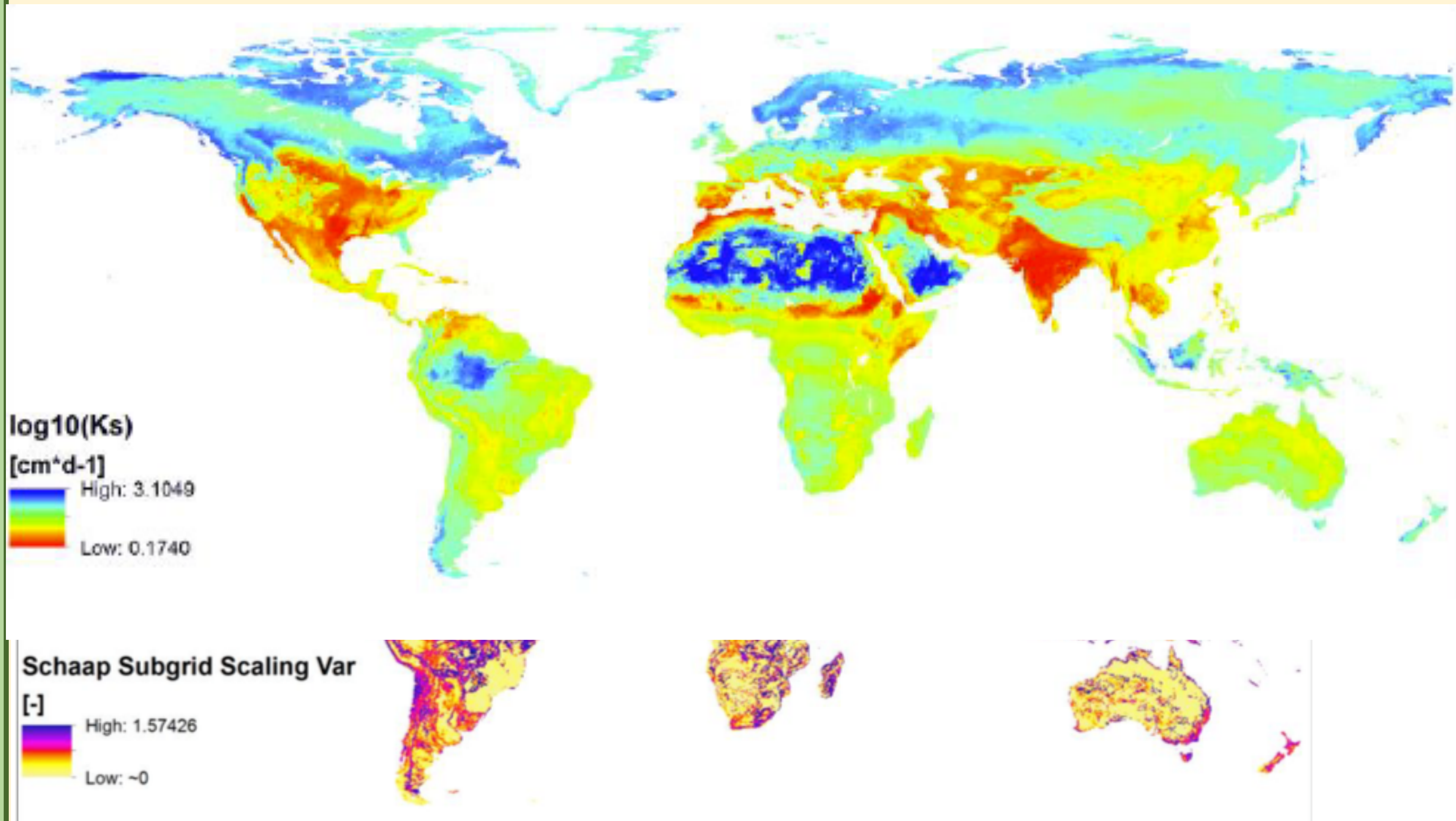
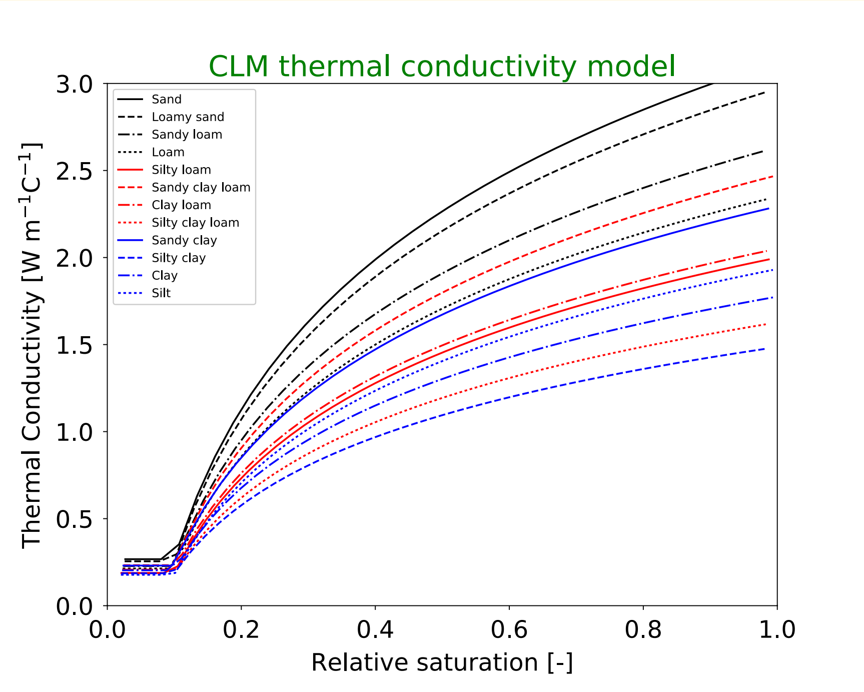


Figure 6: Global map of $\mathrm{var}(\log_{10}\hat{\lambda}_i)$ calculated from SoilGrids1km data set and the Rosetta PTF (Schaap et al., 2001) for 0.25° resolution.

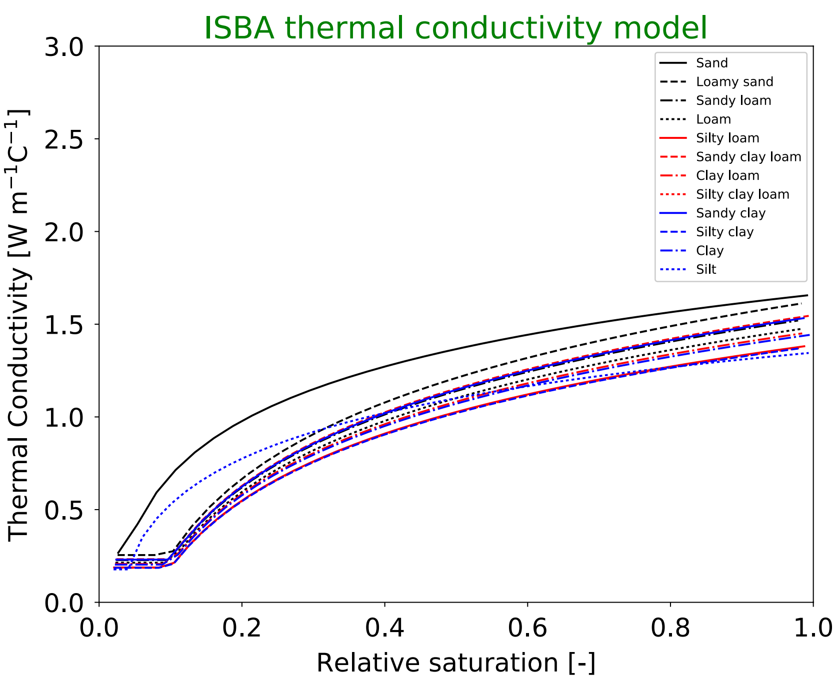
RESULTS: THERMAL CONDUCTIVITY



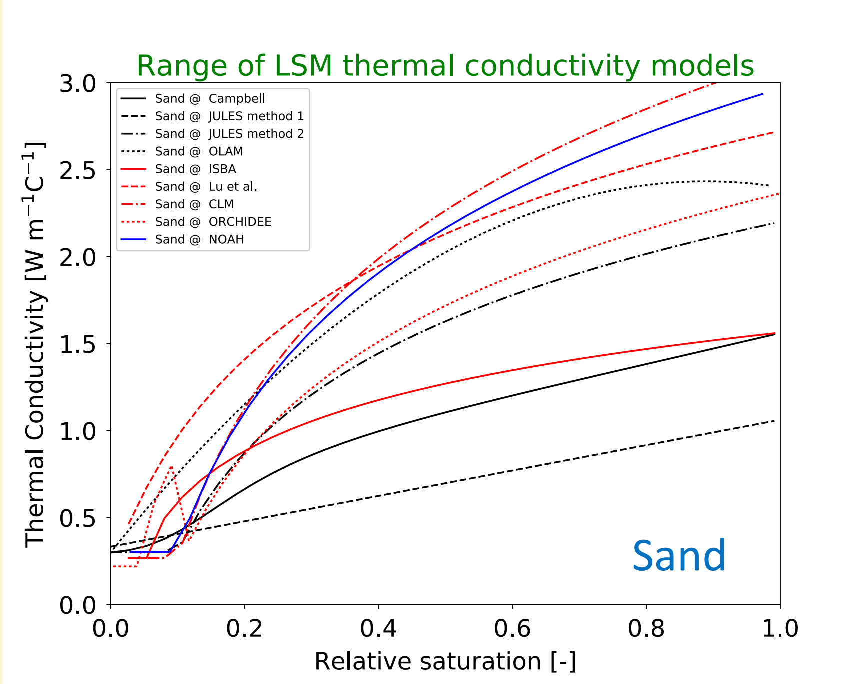
WORK IN PROGRESS THERMAL PROPERTIES; VERHOEF ET AL.

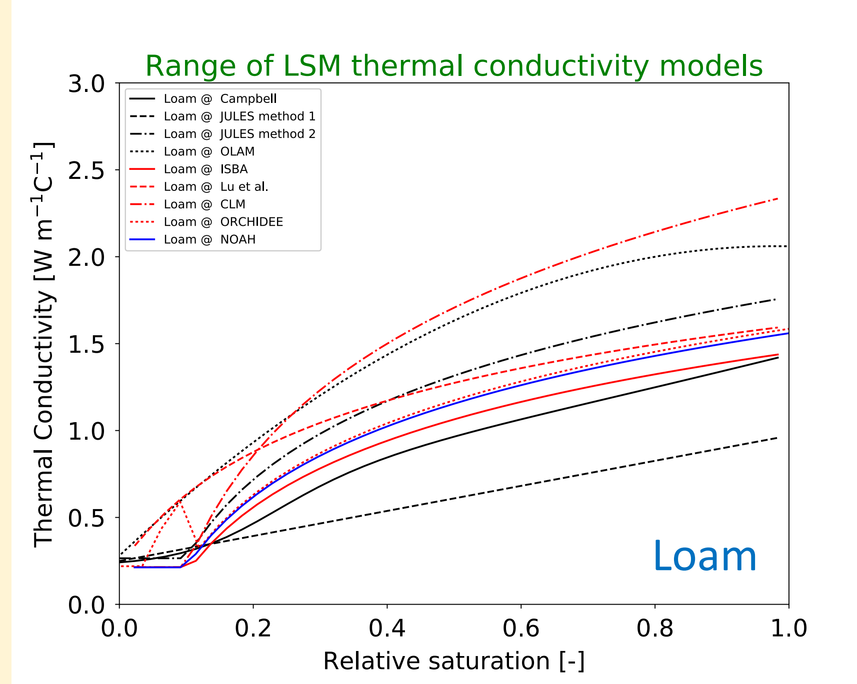
RESULTS, thermal conductivity

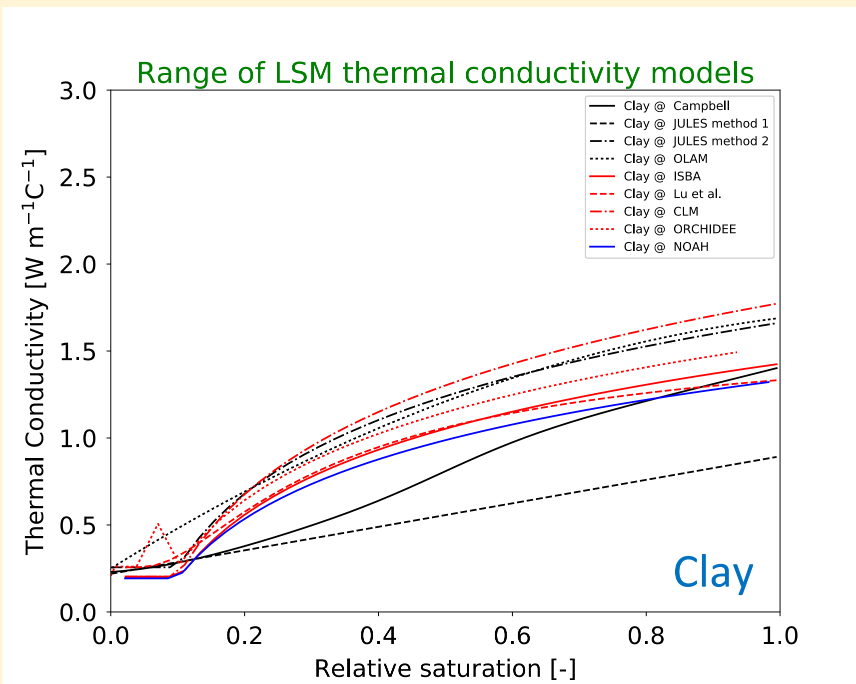
- Some models use look up tables for parameters in thermal conductivity, others use continuous functions
- Some models show a large degree of separation between soils, others don't



Results: Thermal Conductivity







Results, thermal conductivity

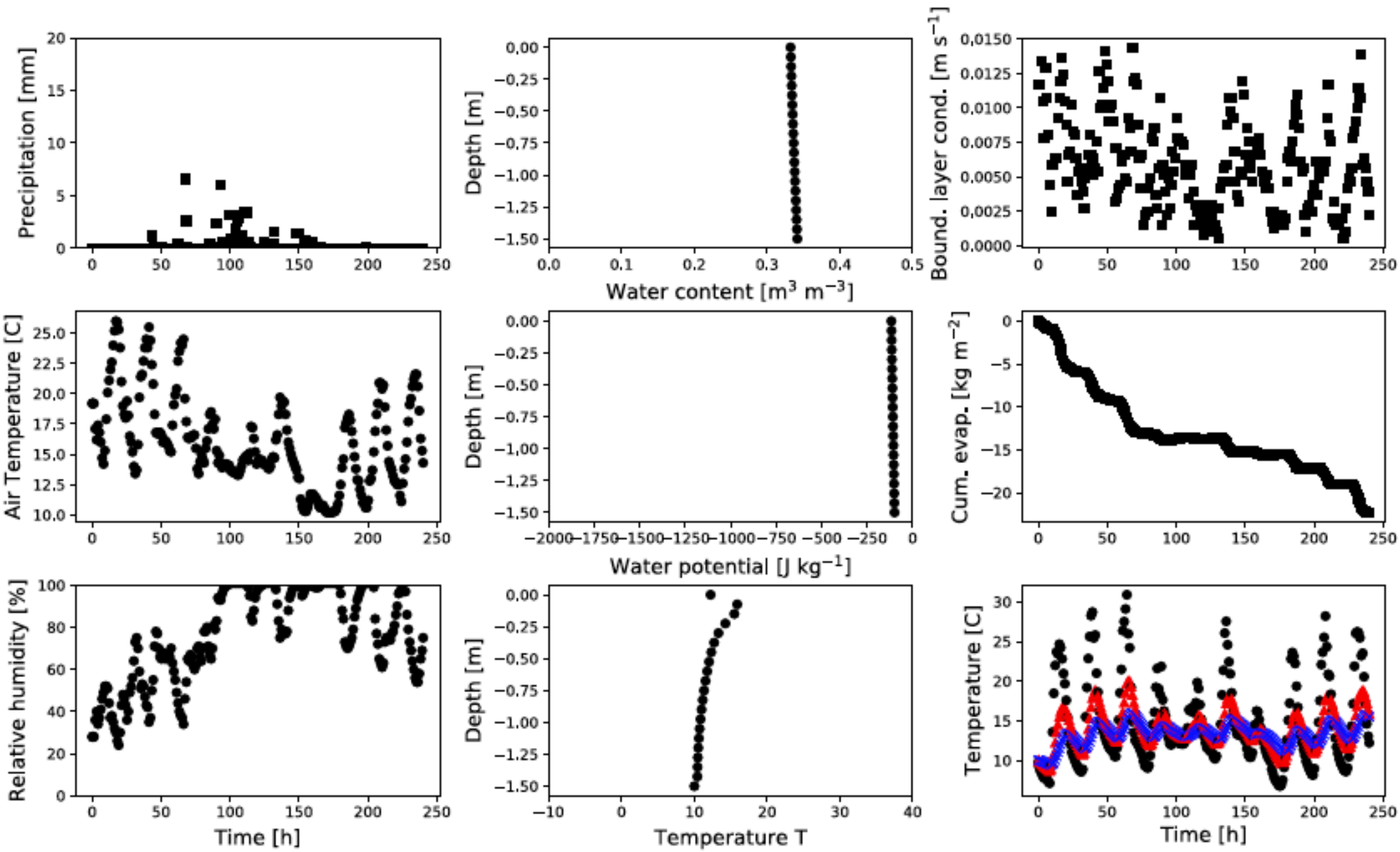
- Per soil type, large difference between models
- Considerably different functional shapes between models

1-D Model Runs

TEMPORAL VARIABILITY OF SOIL VARIABLE PROFILES AND FLUXES

Driving variables

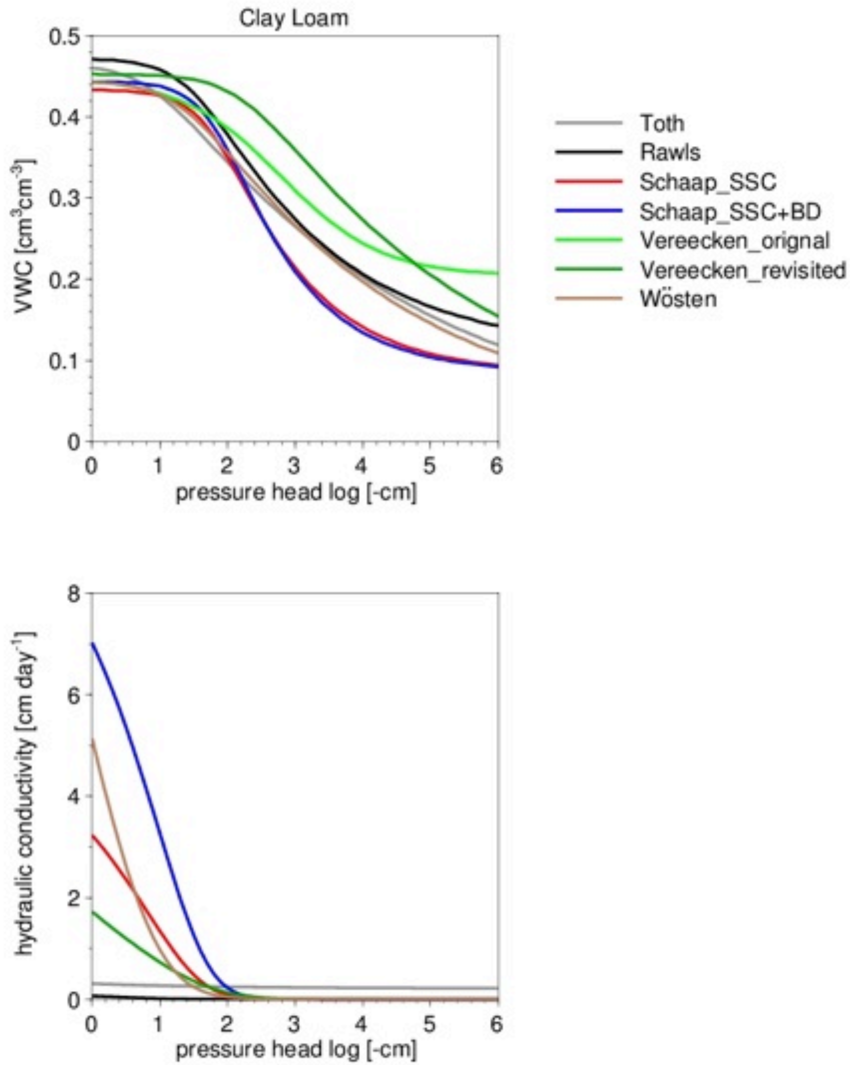
Final soil profile



- Brooks & Corey equation + Cosby parameters (sandy soil)
- JULES thermal conductivity method 1

COMPARISON HYDRAULIC PTFS

WORK IN PROGRESS HYDRAULIC PROPERTIES; WEIHERMULLER ET AL.



RESULTS, hydraulic properties

- Per soil type, large difference between models
- Considerably different functional shapes between models

COLLABORATORS

LSM proformas filled out by

CABLE: Mark Decker
Catchment land surface model: Randy Koster, Gabriëlle De Lannoy (& Joe Santanello)
CLM: David Lawrence
JSBACH: Stefan Hagemann, inputs from Christian Beer
JULES: Anne Verhoef (inputs from Imtiaz Dharssi, Toby Marthews, Pier Luigi Vidale, Heather Ashton & John Edwards
MPI-HM: Tobias Stacke
NOAH-(MP): Yihua Wu and Michel Ek
OLAM: Robert Walko
ORCHIDEE: Agnès Ducharne and Fuxing Wang
SSiB: Yongkang Xue, Qian Li
SURFEX-ISBA: Aaron Boone and Sebastien Garrigues