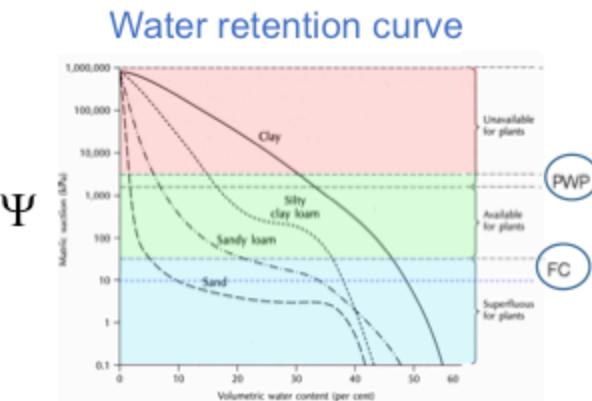
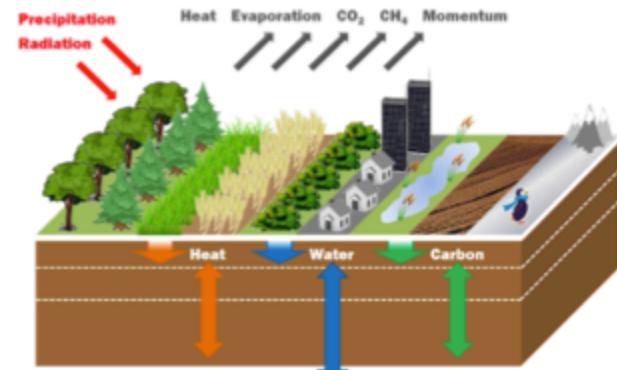


SoilWat PTF & SP-MIP: Testing and improving soil hydraulic and thermal properties in LSMs

Anne Verhoef, Lutz Weihermuller, Jirka Simunek, Harry Vereecken, Lukas Gudmundsson, Matthias Cuntz, Dani Or, Pier Luigi Vidale, Imtiaz Dharssi plus many LSM collaborators

- Large uncertainty in LSM outputs
- Soil properties play an important role
- Focus on soil hydraulic and thermal properties, that affect water flow, heat flow, thaw, plant water uptake etc.



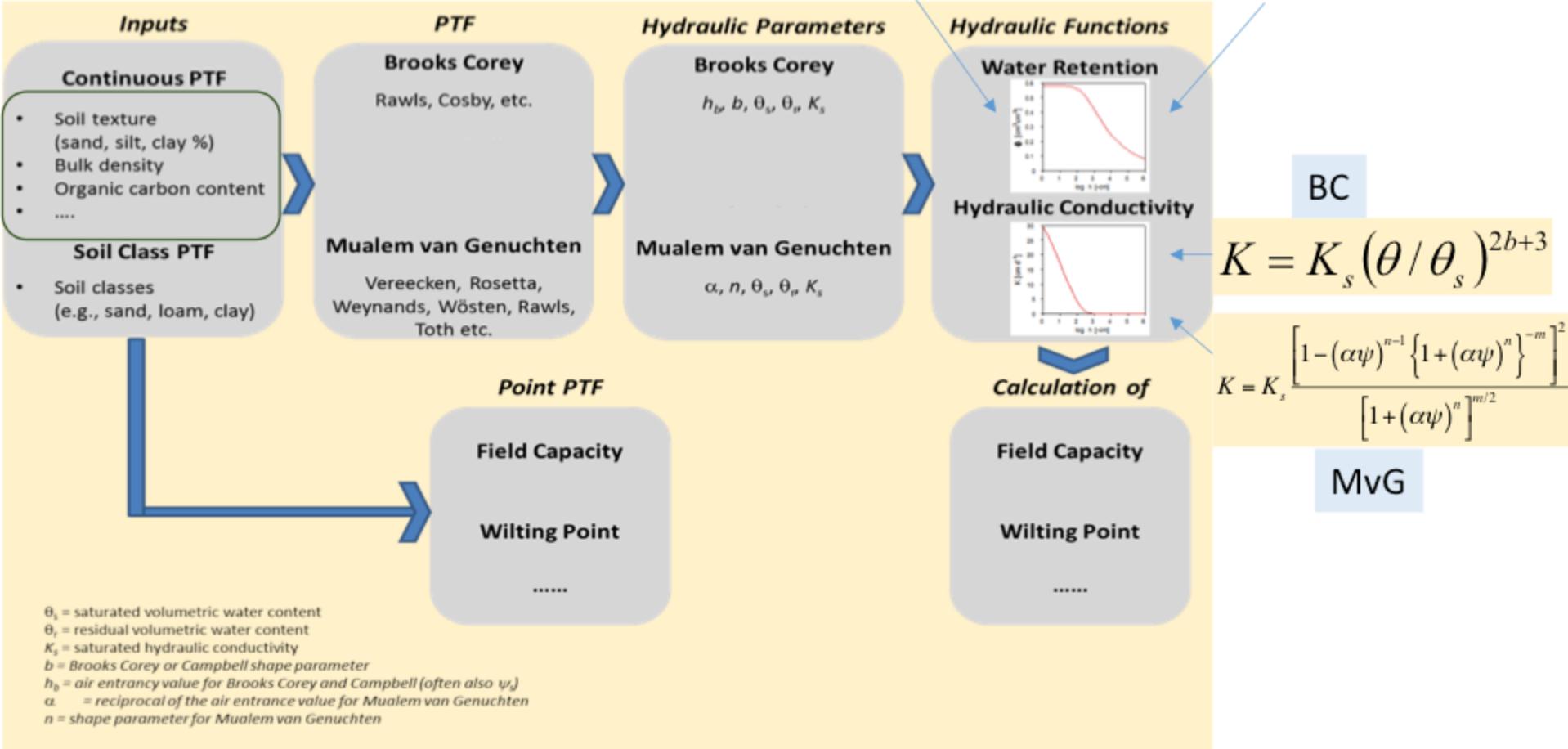
Background: hydraulic properties

Mualem v. Genuchten: MvG

Brooks & Corey: BC

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

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



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

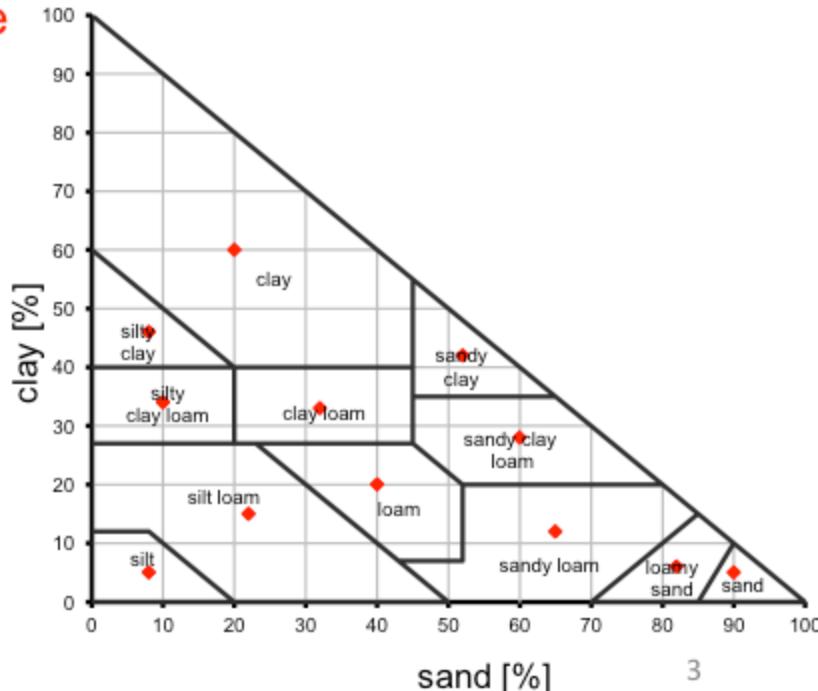
n = shape parameter for Mualem van Genuchten

SoilWat-PTF: Methods hydraulic parameters

- Use of different PTFs and hydraulic models (Mualem-van Genuchten vs Brooks-Corey)
- 12 USDA soil classes
- Water flow simulation using HYDRUS-1D
- 30 years climate data from Germany (daily values: 1982- 2011)
- 200 cm deep, homogeneous bare soil profile

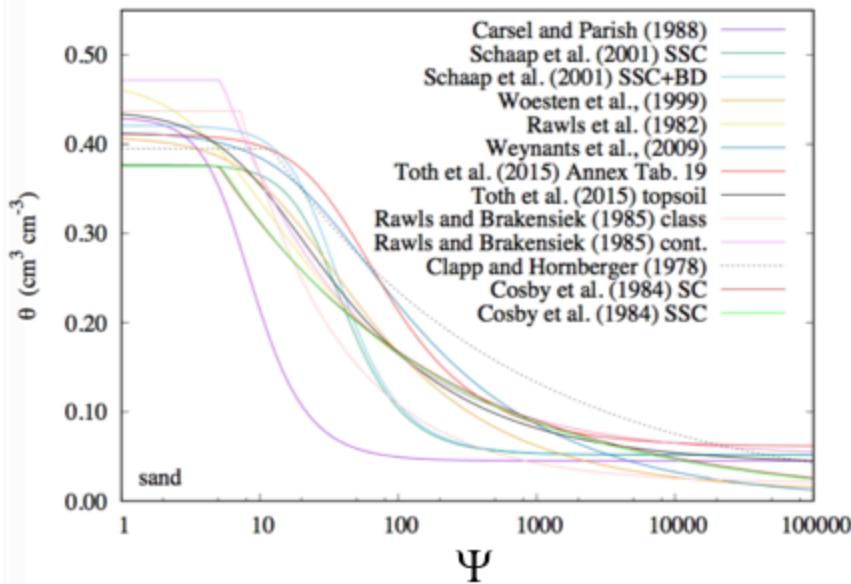
Pedotransfer functions

- 13 PTFs (5 BC & 8 MvG)
- 4 class transfer functions (2x MvG, 2x BC)

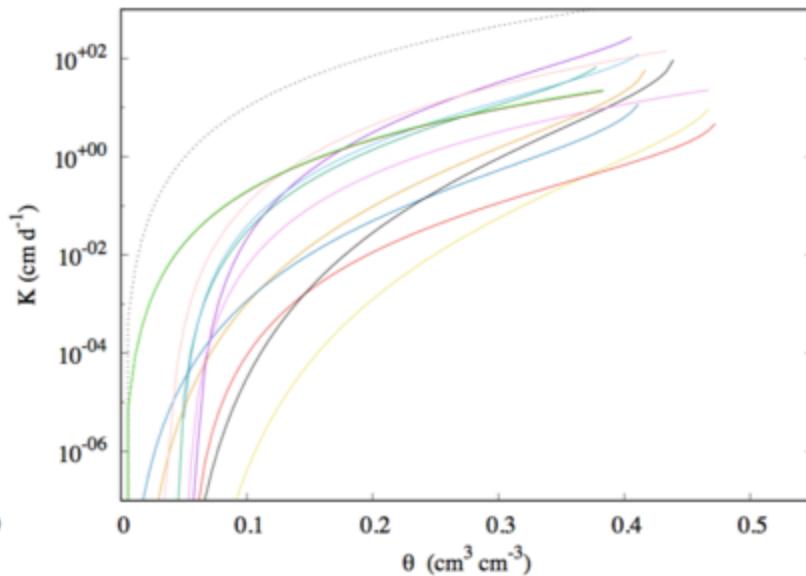
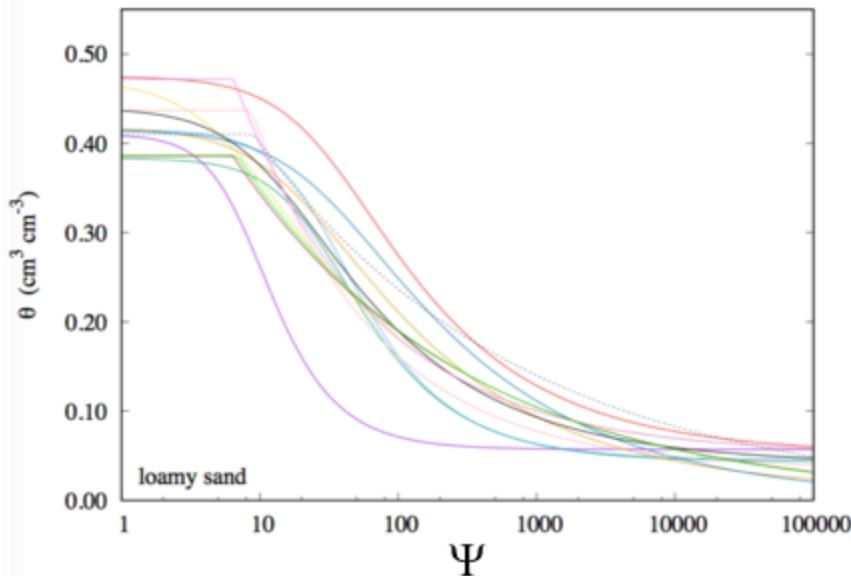
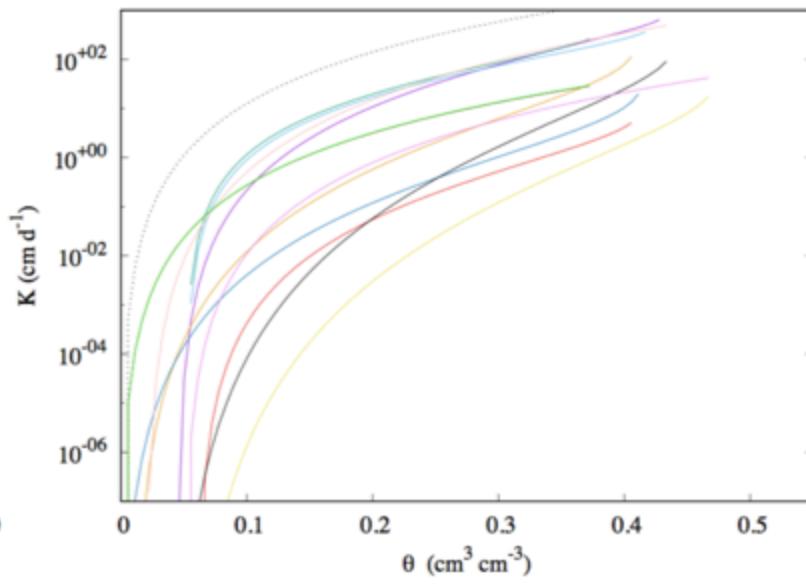


Water retention & hydraulic conductivity curves

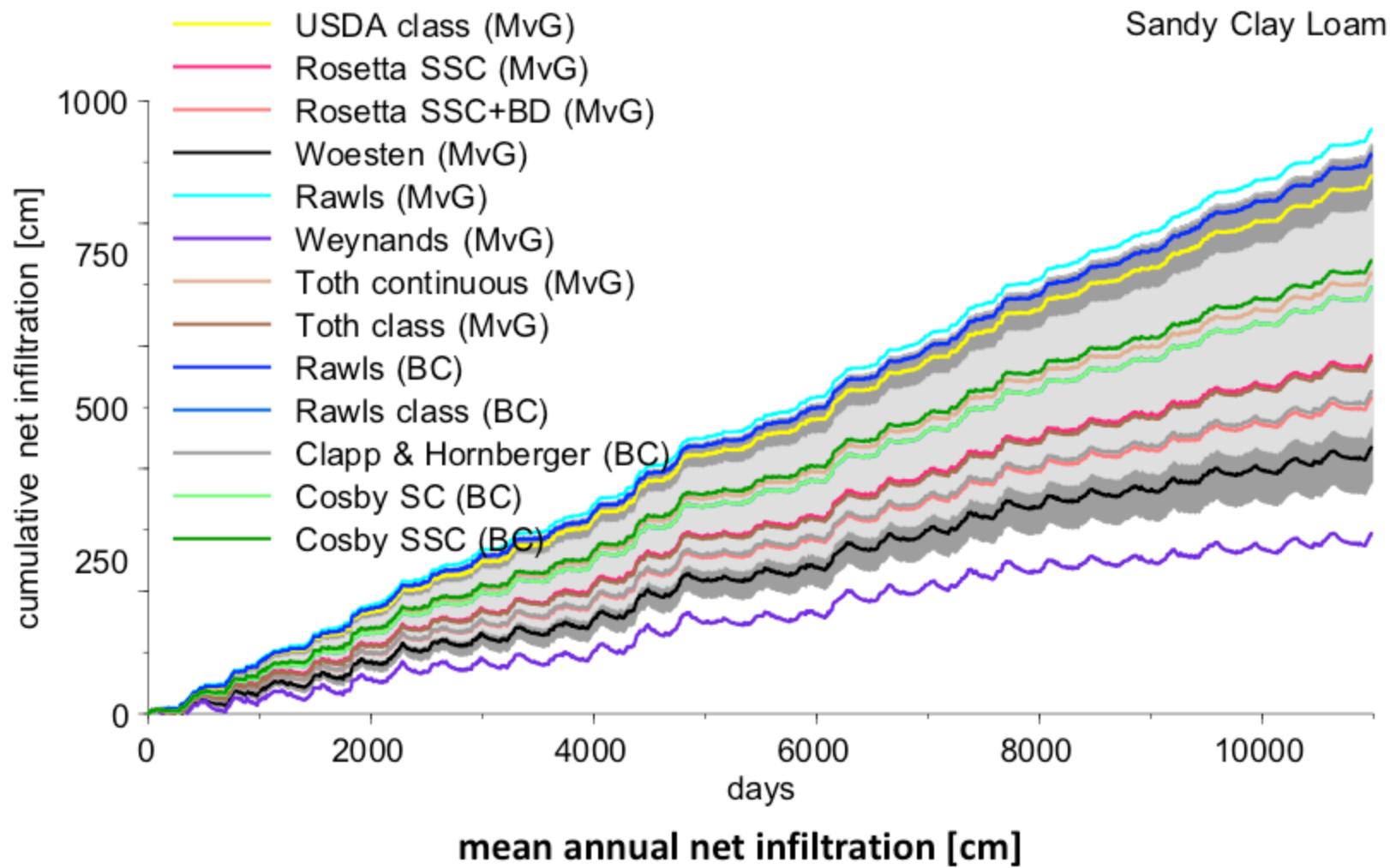
Water retention curve



K-curve



Net infiltration sandy clay loam



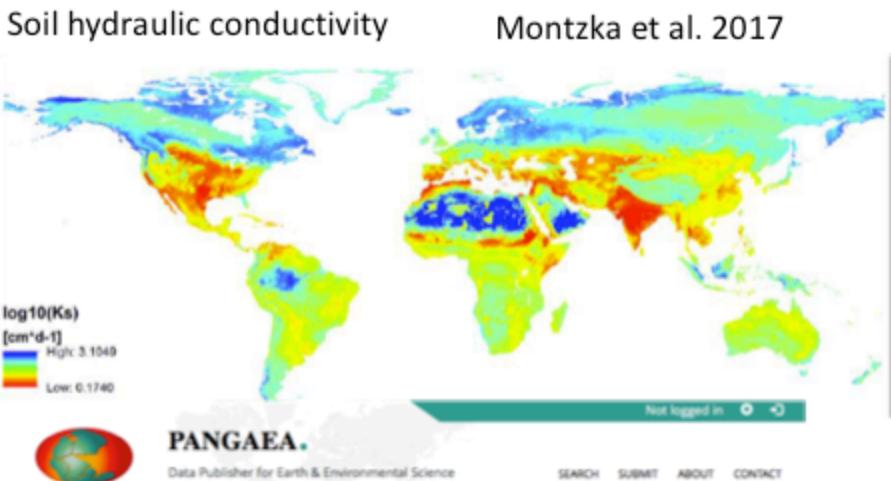
USDA class	Rosetta SSC	Rosetta SSC+BD	Wösten	Rawls MvG	Rawls BC	Rawls BC Class	Weynands	Toth_cont	Toth_class	Clapp& Horn.	Cosby SC	Cosby SSC
29,2	19,5	17,2	14,5	31,8	30,4	23,2	9,8	24,0	19,3	17,5	23,2	24,6

mean annual precipitation = 82.8 cm

5

SP-MIP: Soil Parameter Model Intercomparison

- Following LS3MIP protocol (van den Hurk et al. 2016)
- 30 years (1980-2010) of atmospheric forcing: GSWP3 (Kim et al. 20XX, in prep.)
- Soil data: SoilGrids.org
- Coverage: 0.5-degree spatial resolution



Ex1: Identical soil parameter maps

- Global soil hydraulic parameter maps provided by SP-MIP

Ex2: Identical soil texture maps

- Global soil texture maps provided by SP-MIP
- Hydraulic parameters are derived by the modelling groups individually

Ex3: Default soil parameter maps

- Each model is run with its default soil parameter maps

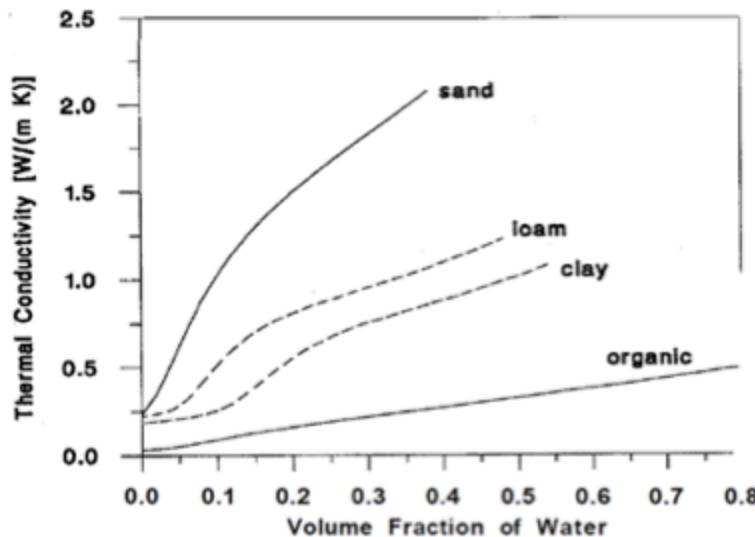
Ex4: Spatially uniform soil parameters

- Four model runs with spatially uniform soil parameters
- Considered soil types: loamy sand, loam, clay, and silt

Current state

- 1 Simulation submitted (JSBACH)
- 3 Simulations ongoing(ORCHIDEE, NOAH-MP, CABLE)
 - Contact us if you want to be involved
 - Data-analysis will start after at least 5 models are available.

Thermal equations and PTFs



SOIL HEAT CAPACITY, C_h

THERMAL CONDUCTIVITY, λ

$$C_h = \phi_{min} C_{min} + \phi_{org} C_{org} + \phi_{liq} C_{liq} + \phi_{ice} C_{ice} + \phi_{air} C_{air}$$

$$\lambda = (1 - F_\theta) \lambda_{dry} + F_\theta \lambda_{sat}$$

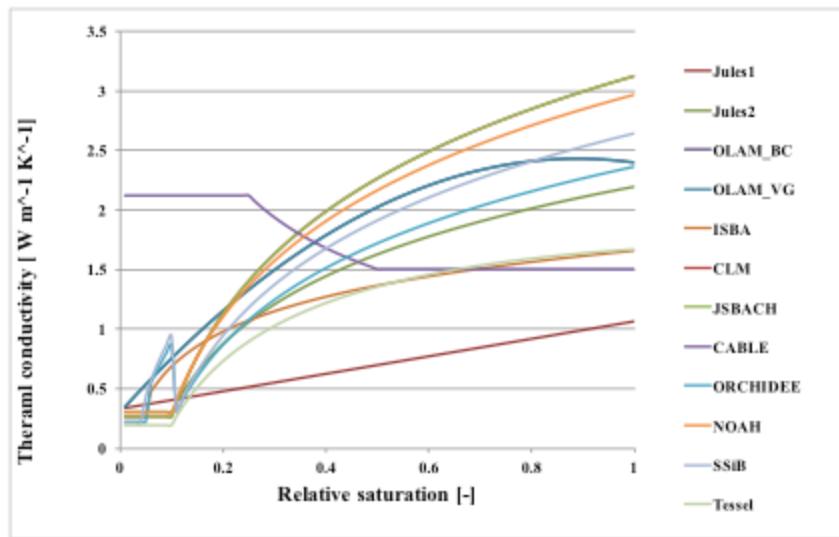
depends on dry and saturated conductivity
in combination with a soil moisture
dependent weighting function, F_θ

depends on the **volumetric heat capacities**
of the **solid soil material**, water, ice, and air,
and their **volume fractions** (ϕ_i).

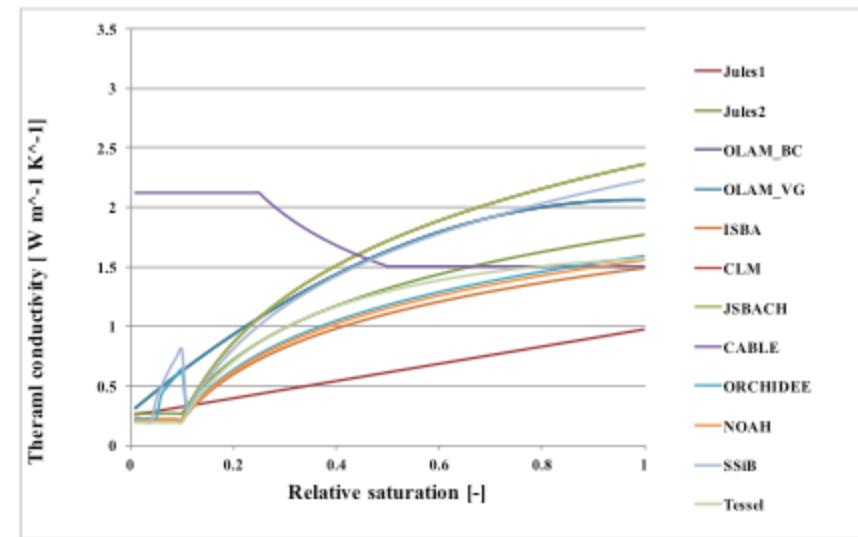
- PTFs are required to estimate parameters that determine λ_{dry} , λ_{sat} , F_θ ,
and C_{min} and ϕ_{min}

Comparison LSM thermal properties: Thermal conductivity, λ

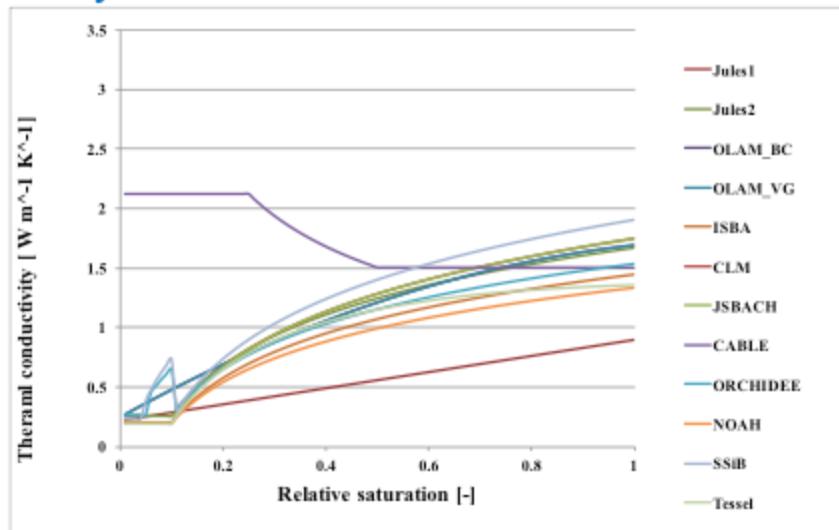
Sand



Loam

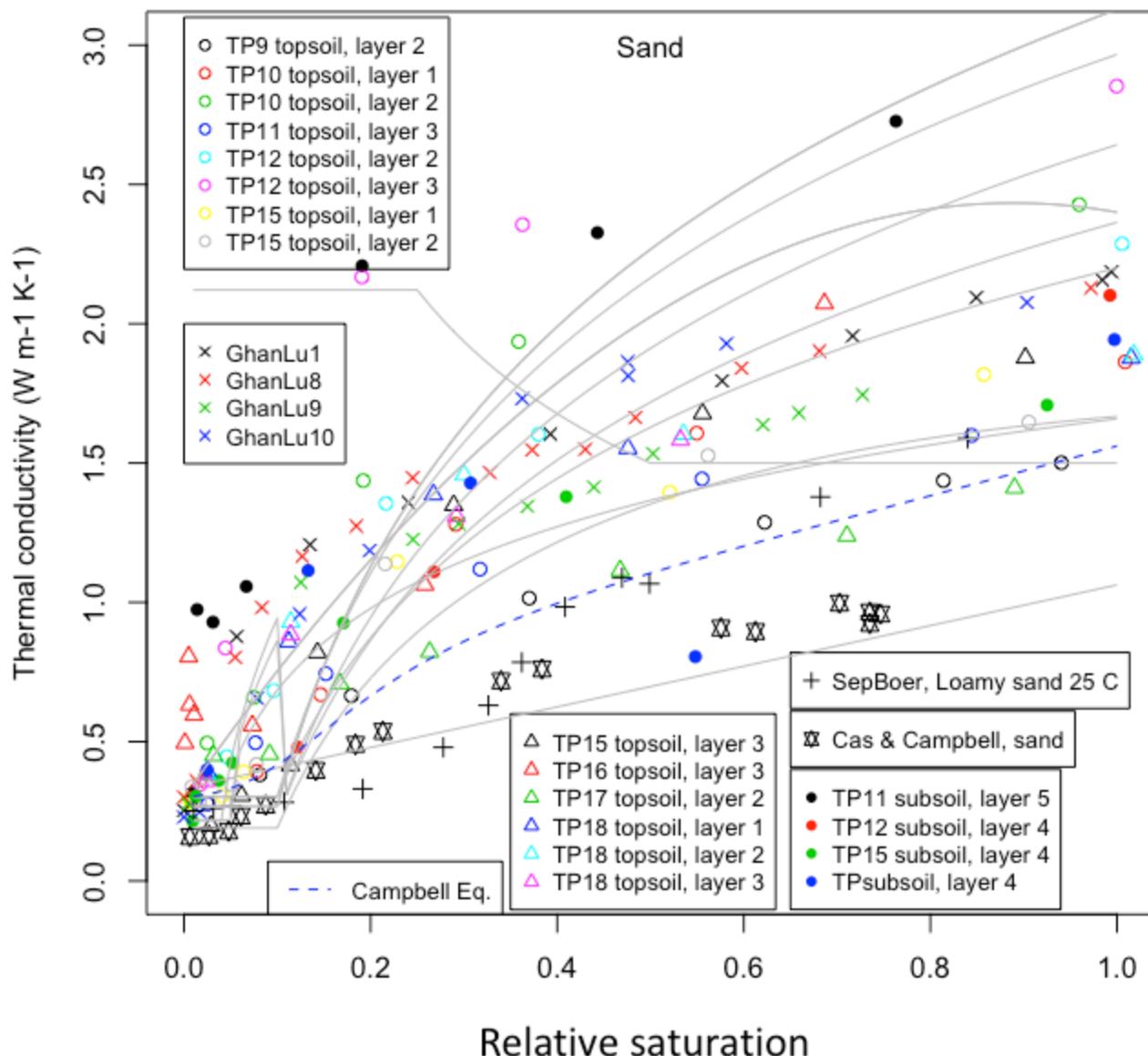


Clay



- Per soil type: large difference in λ between models
- Considerably different functional shapes between models

Comparison of model thermal cond. with measurements



Issues at low θ , and effects of

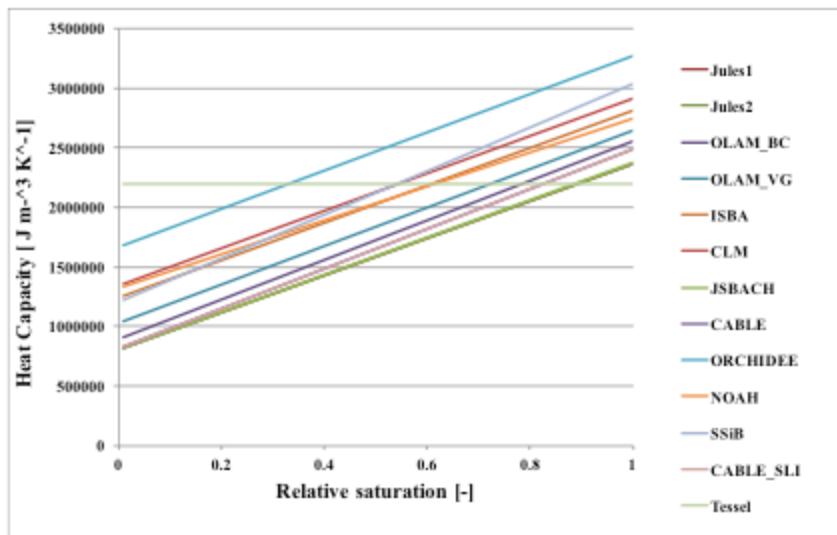
- Soil depth
- Different minerals
- Organic matter

Data sources:

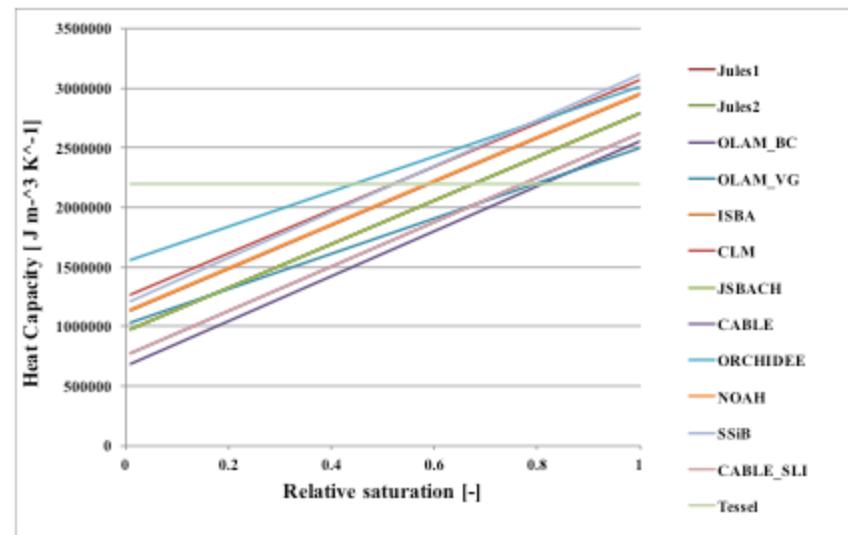
- Lu et al. (2014)
- Ghanbarian and Baigle (2015)
- Zhao et al. (2018)

Comparison LSM thermal properties: Heat capacity, C_h

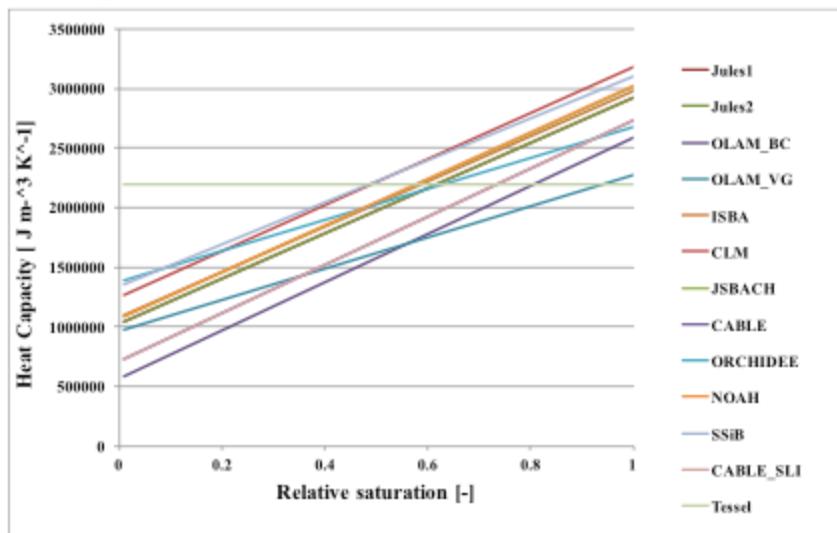
Sand



Loam



Clay

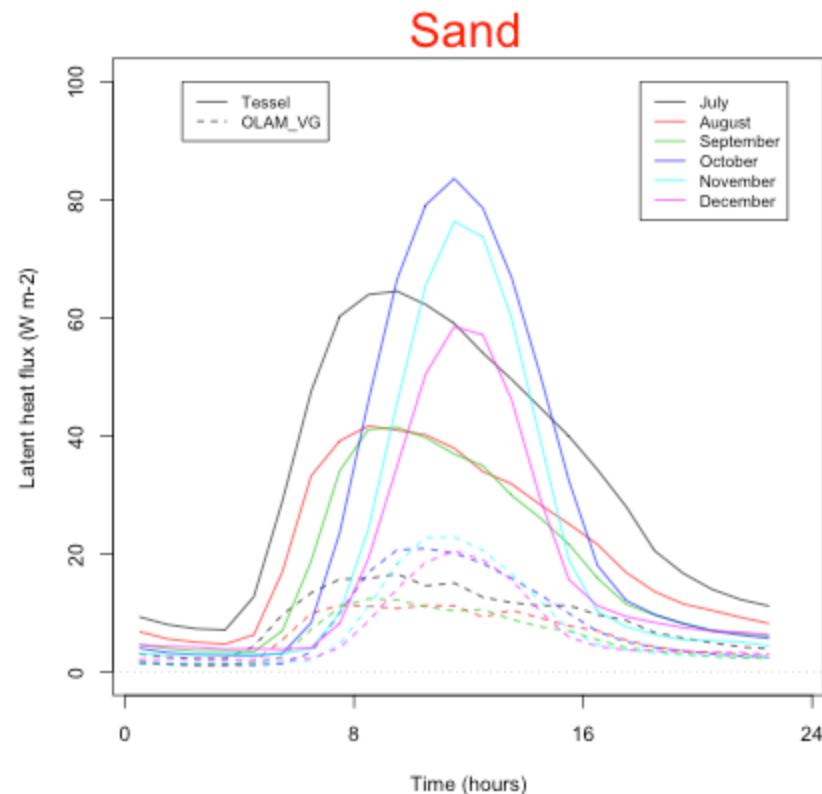


- Per soil type: considerable difference in C_h between models
- In some cases, different slopes between models

Hydrus-1D model runs, using model-specific thermal and hydraulic properties

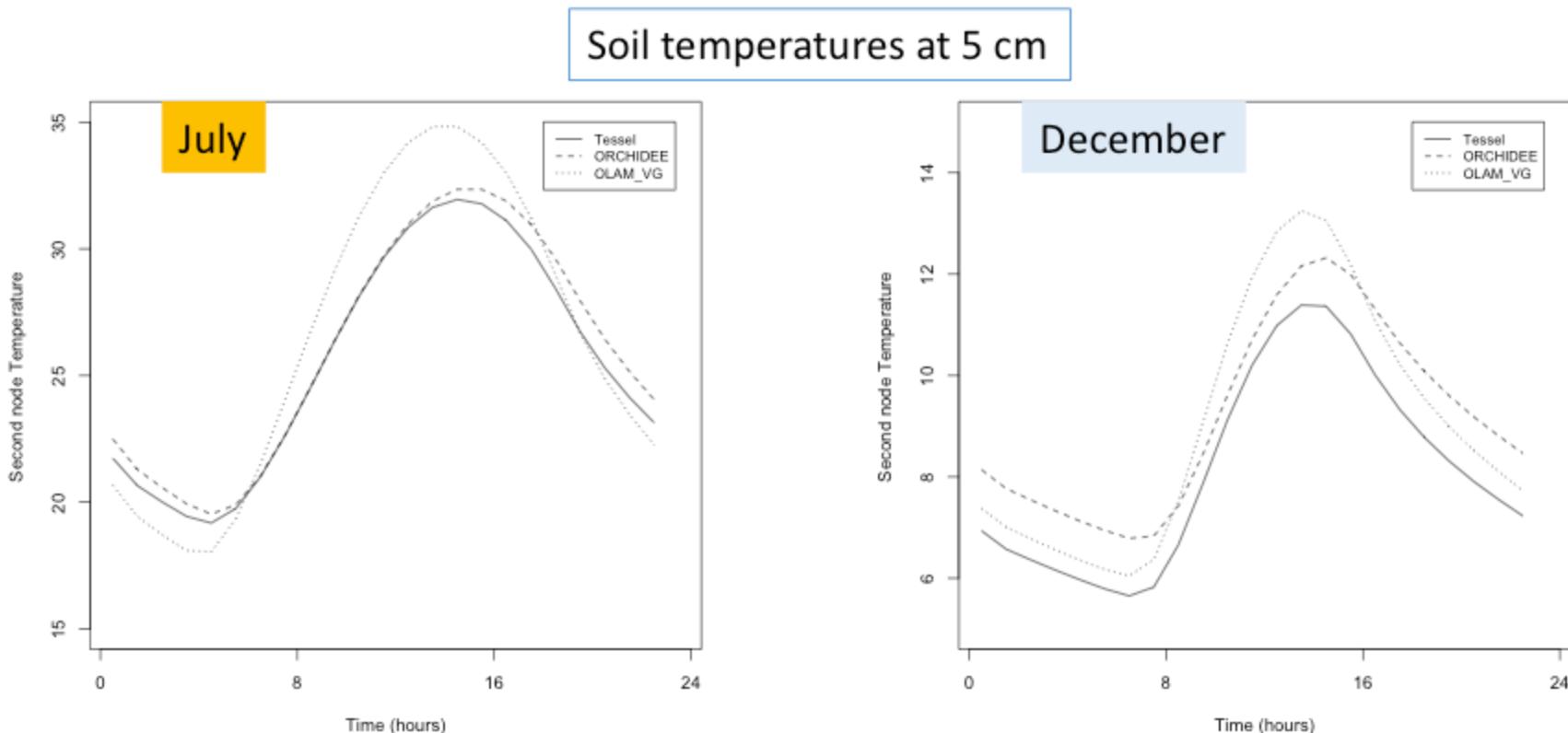
- LSM thermal/hydraulic equations implemented into Hydrus-1D
- Runs with Hydrus 1-D for 14 years (2001-2014) of half-hourly data from Avignon, France
- Bare soil profile of 300 cm, free drainage
- Effects on energy- and water balance
- Analyses of diurnal and seasonal cycles and extremes

Multi-year monthly averaged diurnal evaporation



Hydrus-1D model runs, using model-specific thermal properties

- Below: exact same hydraulic functions, but different thermal functions
- Considerable effect on deeper soil temperatures
- Causes differences in values, amplitudes and phase-shifts: implications for soil freezing/thaw and soil CO₂ flux

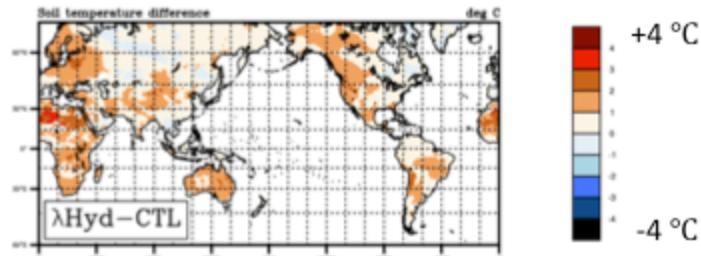


Previous work: HadGAM1 coupled AGCM runs

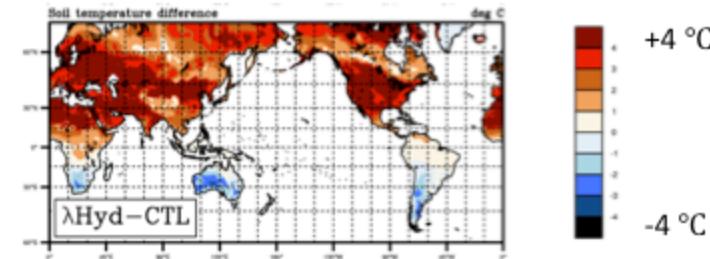
- Improved PTFs (BC) and new model of thermal conductivity: λ_{Hyd} ; compared to original (CTL)

Average JJA Soil temperature difference ($^{\circ}\text{C}$)

Layer 1 (0-0.10 m)

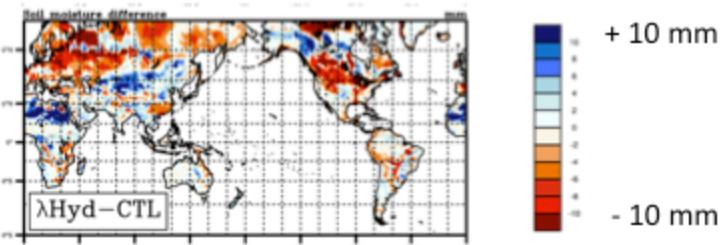


Layer 4 (2.0-3.0 m)

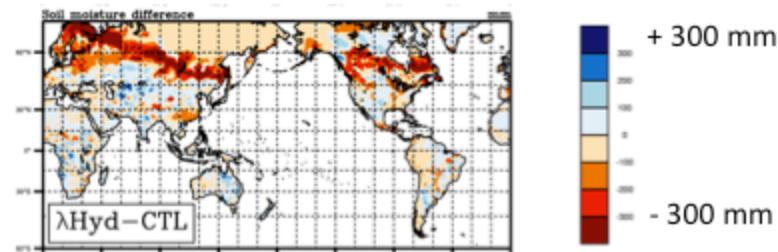


Average JJA Soil moisture difference (mm)

Layer 1 (0-0.10 m)



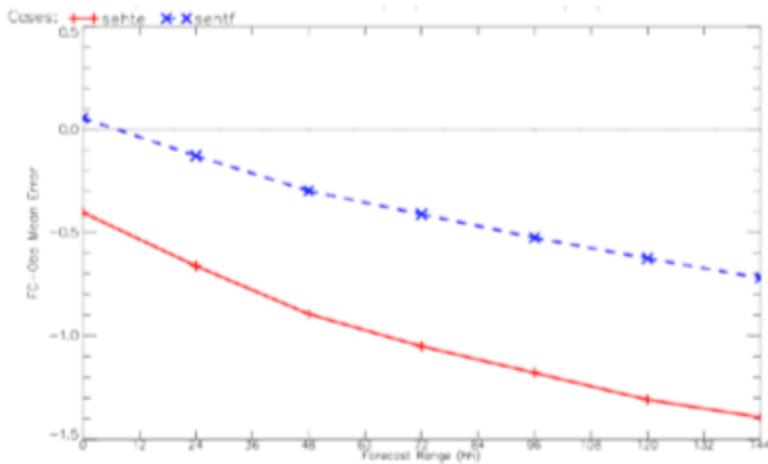
Layer 4 (2.0-3.0 m)



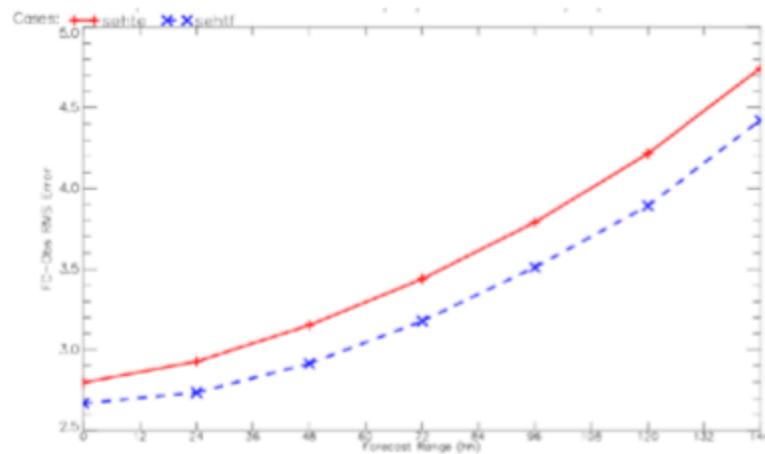
Improvement of Unified Model weather forecasts

- Improved hydraulic PTFs and new model of thermal conductivity (blue) compared to original model (red)

Reduction of UM 2m Temp **cold bias**



Reduction of UM winter 2m Temp **RMSE**

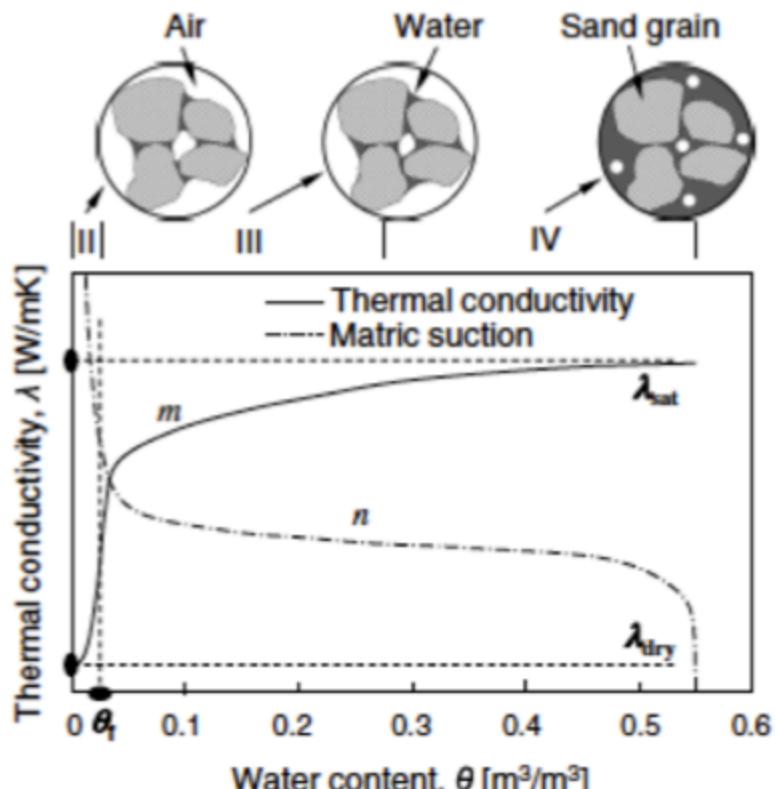


UKMO R&D Technical report 528, 2009. New soil physical properties implemented in the Unified Model at PS18 by Dharssi et al.

Conclusions

- LSM models exhibit **very different shapes** for hydraulic and thermal property curves
- PTFs vary considerably between models.
- The **combined effect** of thermal and hydraulic equations on the energy and water balance is large
- When only the **thermal properties** differ, the main effect is on deeper soil temperatures
- This has implications for modelling of **freeze/thaw** and **carbon cycle**
- Effects on the **water balance** and **LSA-feedbacks**

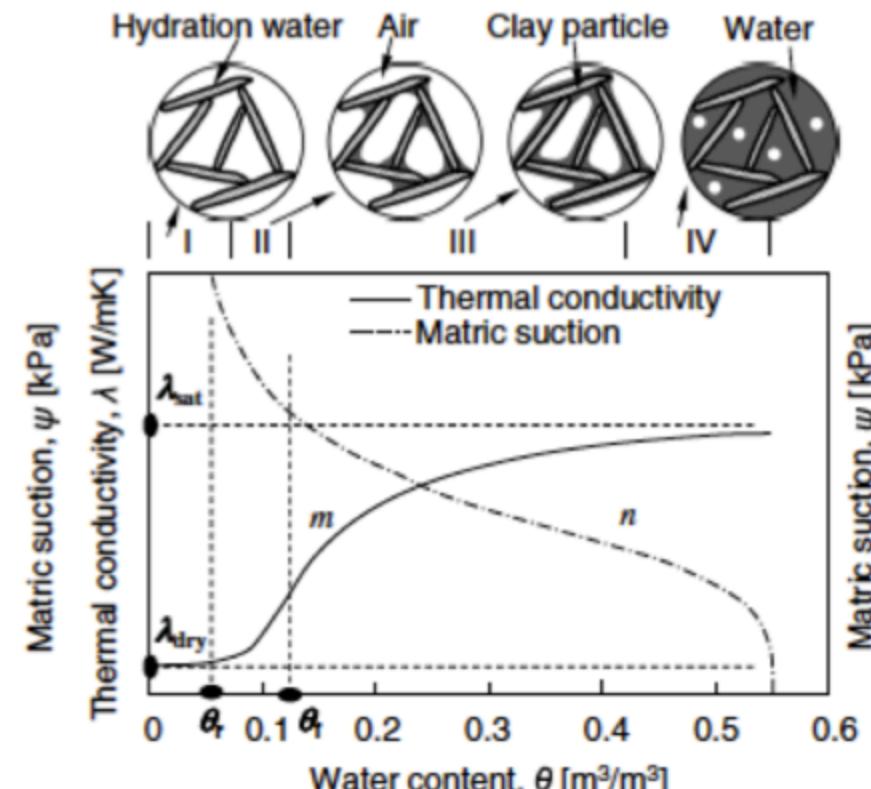
Outlook



(a)

I: hydration

II: pendular



(b)

III: funicular

IV: capillary

Lu & Dong (2015): Conceptual model for **thermal conductivity** as a function of **water retention regimes**

Collaborators and contacts

LSM collaborators

CABLE: Mark Decker

CLM: David Lawrence

JSBACH: Philip de Vrese, inputs from Christian Beer and Stefan Hagemann

JULES: inputs from Imtiaz Dharssi, Toby Marthews, Pier Luigi Vidale, Heather Ashton & John Edwards)

NOAH-(MP): Yihua Wu and Michael Ek

OLAM: Robert Walko

ORCHIDEE: Agnès Ducharne and Fuxing Wang

SSiB: Yongkang Xue, Qian Li

SURFEX-ISBA: Aaron Boone and Sébastien Garrigues

Thermal properties: Hong Zhao, Yijian Zeng, Shaoning Lv, Bob Su, Bing Tong

Contacts SoilWat

SoilWat-PTF: Anne Verhoef (a.verhoef@reading.ac.uk)

SP-MIP: Matthias Cuntz (Matthias.Cuntz@inra.fr) &
Lukas Gudmundsson (lukas.gudmundsson@env.ethz.ch)

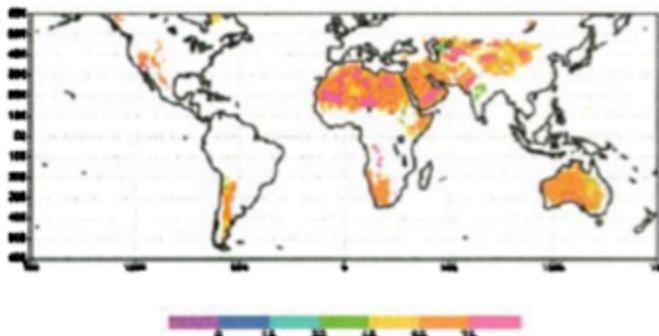
International Soil Modelling Consortium (ISMC): <https://soil-modeling.org>

TABLE 1. Thermal conductivities of common minerals in sedimentary rocks. Determined from needle probe measurements carried out at room temperature (Horai, 1971).

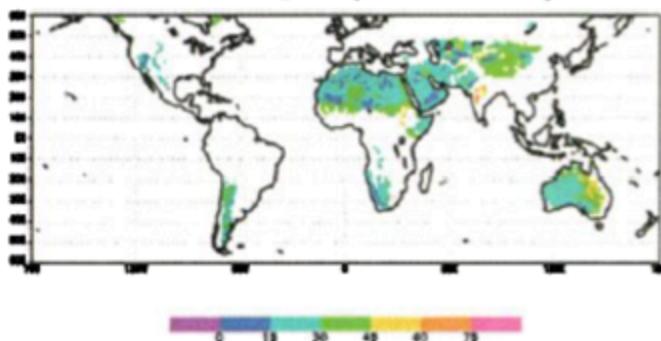
Mineral	Thermal conductivity W/mK
Quartz	7.8
Calcite	3.4
Dolomite	5.1
Anhydrite	6.4
Pyrite	19.2
Siderite	3.0
Orthoclase	2.3
Albite	2.3
Halite	6.5
Mica	2.3
Chlorite*	5.1
Kaolinite	2.8
Smectite (BMT)	1.8
Illite	1.8
Mixed-layer I-S	1.9
Air	0.03
Water	0.60

*Chlorite: 3.3 W/mK: Brigaud & Vasseur (1989).

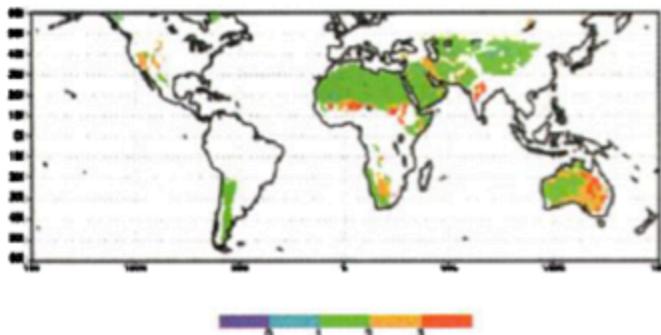
b - Quartz (silt fraction)



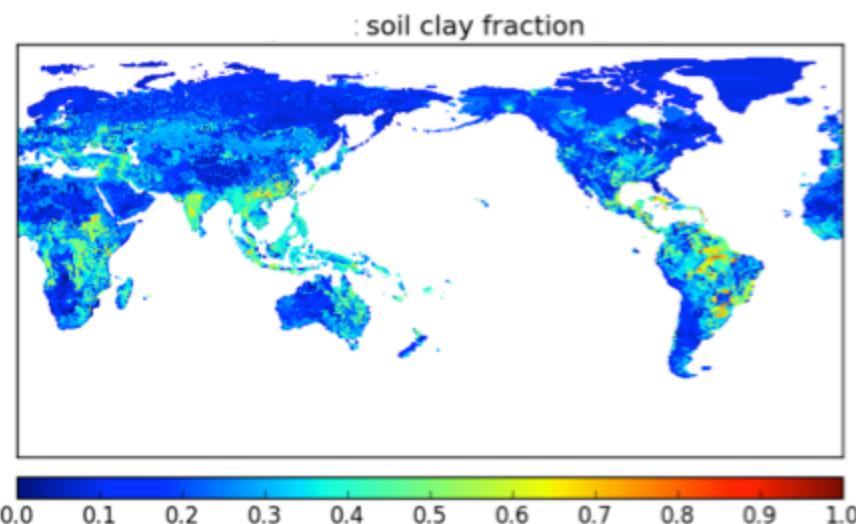
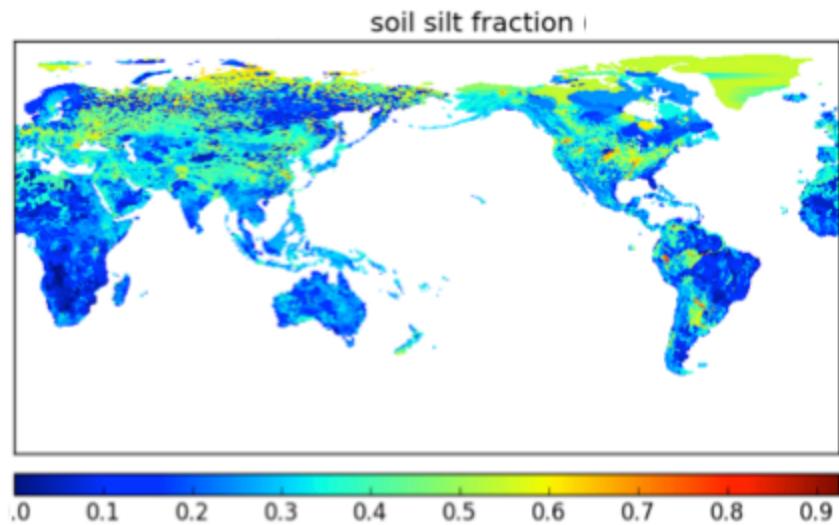
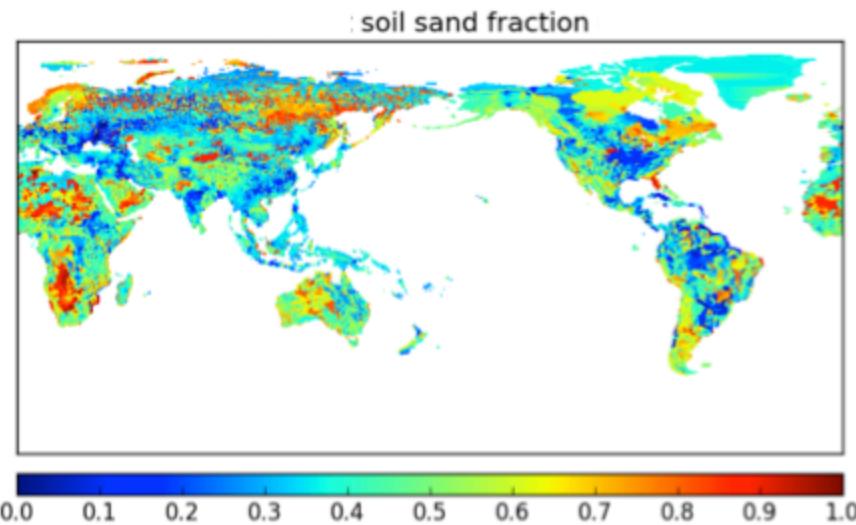
d - Feldspar (silt fraction)



f - Hematite (silt fraction)



Soil texture data JULES/UM model → soil parameters



↗ Cosby PTF → hydraulic parameters

