From Pedo to Pedon: Towards the next generation of transfer functions to estimate saturated hydraulic conductivity

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Why you should stay in this presentation?

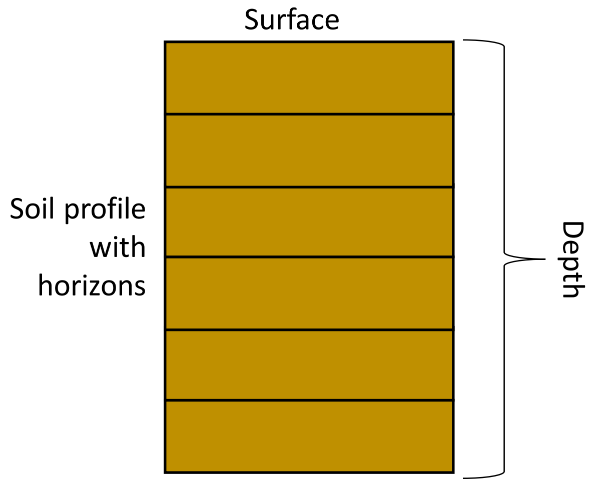
Here we present a new framework to predict K_{sat} using transfer functions

From Pedotransfer Function (PTF) → **To Pedontransfer Function (PnTF)**

Common PTFs (usually used)

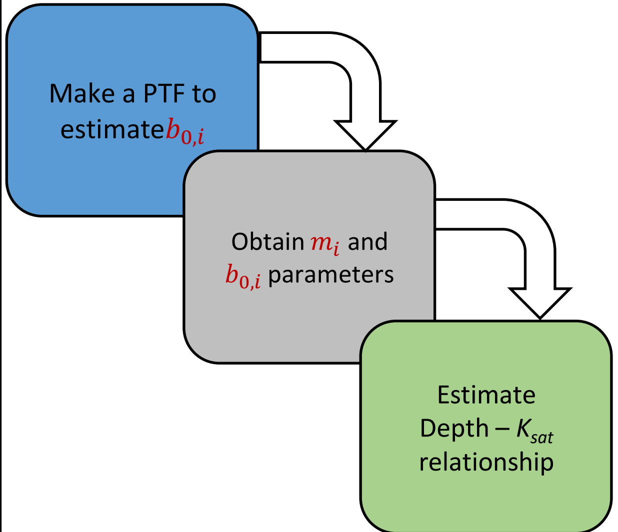
- Soil material arising from different soil horizons are treated as independent samples.
- Highly dependent of soil textural information

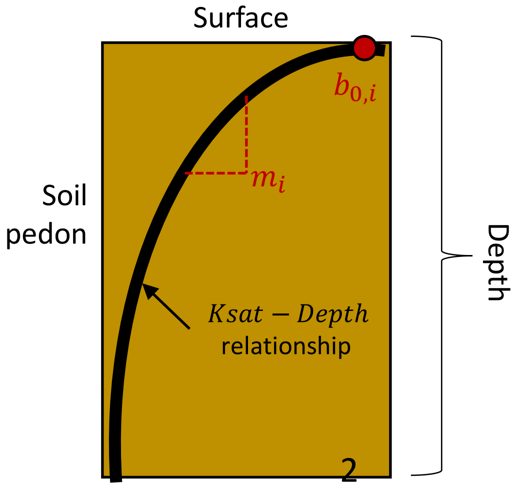
$$K_{sat} = f(clay) + f(sand) + f(bulk\ density)$$



This work (what we propose)

- We present a framework to predict K_{sat} that incorporates its depth dependency.
- We show that we can predict K_{sat} at an arbitrary depth from surface information.
- Our best predictors incorporates time-varying information (i.e., meteorological data).

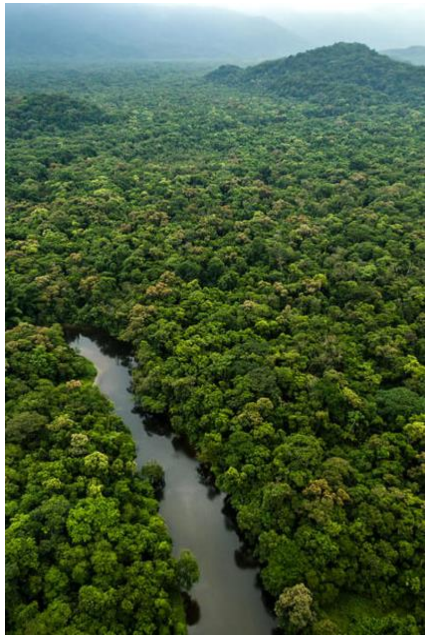




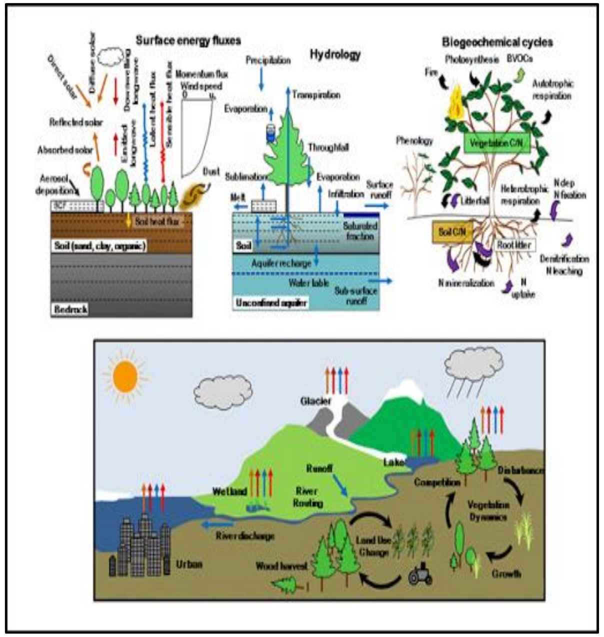
Different models need PTFs at different spatial scales

Single-point scale

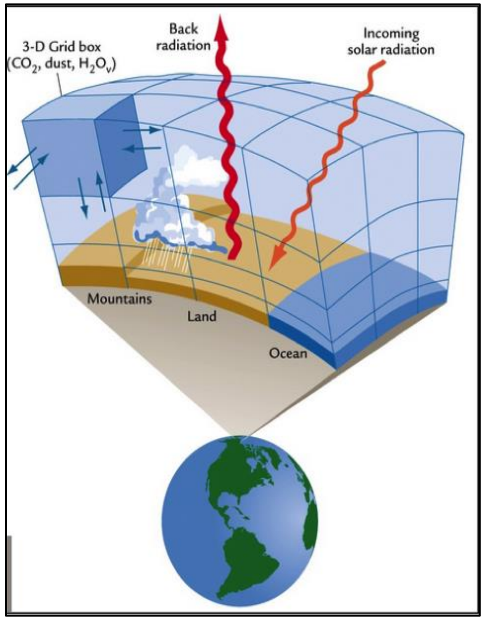
Field scale



Landscape scale



Land Surface Model



Global Climate Model

Small scale

Large scale

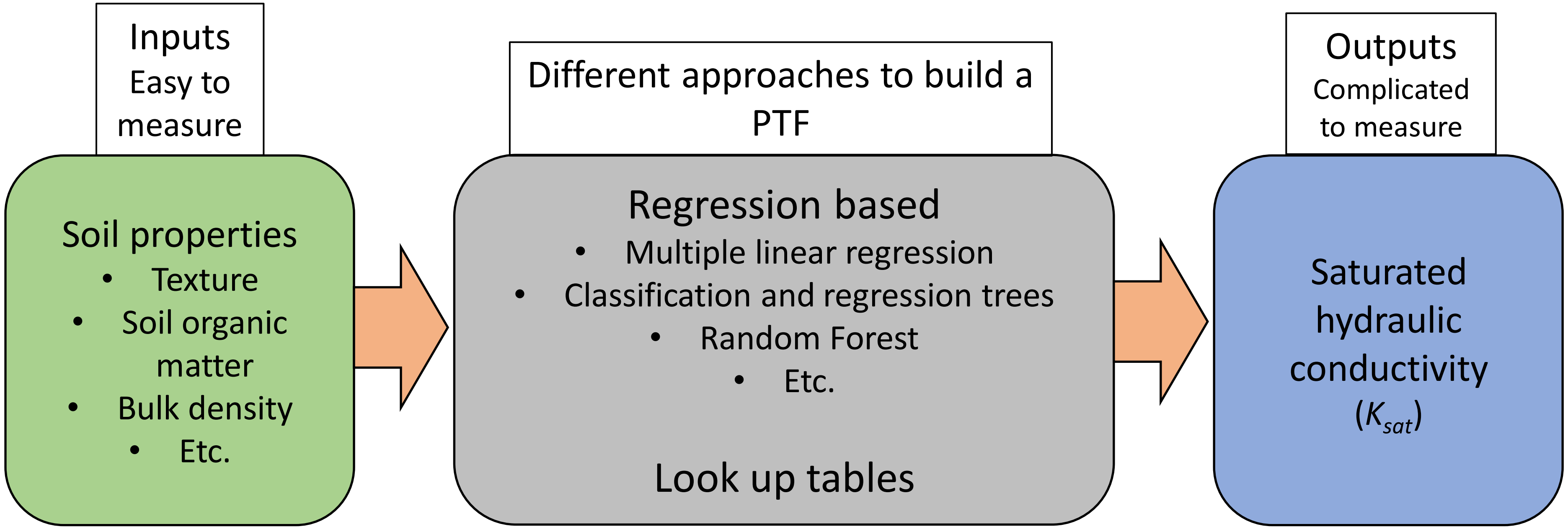
Agriculture, water, solute transport

Energy and mass balance

Climate change

Figures from: van Looy et al. (2017); Lawrence et al. (2019); Ruddiman (2000)

Common PTFs are simple to implement



Soil material arising from different soil horizons are treated as independent samples despite the depth dependency that exists for horizons within individual profiles.

Limitations

PTFs remain highly dependent of soil textural information rather than incorporating time varying biotic or climatological variables.

Common PTFs are simple to implement

Examples from Zhang & Schaap (2019)

(2) Two independent variables to estimate K_s in Cosby et al. (1984)

$$K_s = 60.96 \times 10^{0.0126 \times sand - 0.0064 \times clay - 0.6} \quad \text{(B3)}$$

(3) Wösten et al. (1999)

$$K_s = \exp[7.755 + 0.0352 \times silt + 0.93 \times topsoil - 0.967 \times BD^2 - 0.000484 \times clay^2 - 0.000322 \times silt^2 + 0.001/silt - 0.0748/OM - 0.643 \times \ln(silt) - 0.01398 \times BD \times clay - 0.1673 \times BD \times OM + 0.02986 \times topsoil \times clay - 0.03305 \times topsoil \times silt] \quad \text{(B4)}$$

where topsoil and subsoil are qualitative variables having the value of 1 or 0, respectively.

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From <u>Pedo</u> to <u>Pedon</u>

Is there a depth-dependency of K_{sat} and can we incorporate the depth-dependency of K_{sat} in PTFs?

- Need to incorporate time-varying variables to predict K_{sat}

Time varying variables usually are available/influence soil surface
(Precipitation, VPD, LAI, NDVI)

Motivation:

- Could K_{sat} at an arbitrary depth be predicted from the surface?

What data did we used?

Pedogenic and Environmental DataSet (PEDS)

Includes climatological and field-based pedon information from >300,000 soil horizons across the globe. We used USA data only.

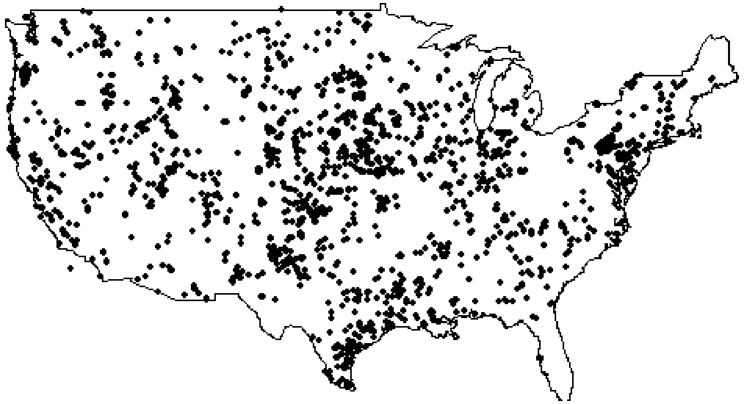
K_{sat} was estimated using a Kozeny-Carman equation:

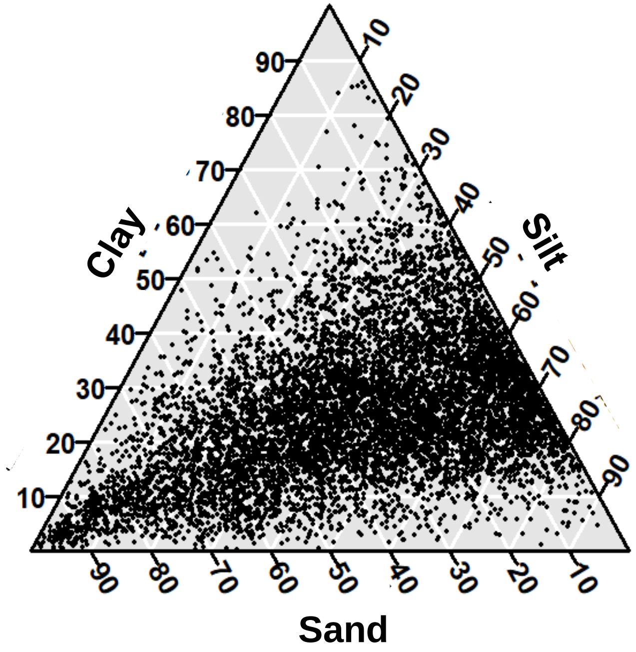
$$K_{sat} = 1930EP^{3-D}$$

where:

D = Slope of the water retention curve

EP = Effective porosity





Further information about PEDS

Mohammed A.K., Hirmas D.R., Nemes A., Giménez D. (2020) Exogenous and endogenous controls on the development of soil structure. Geoderma, 357(11395)

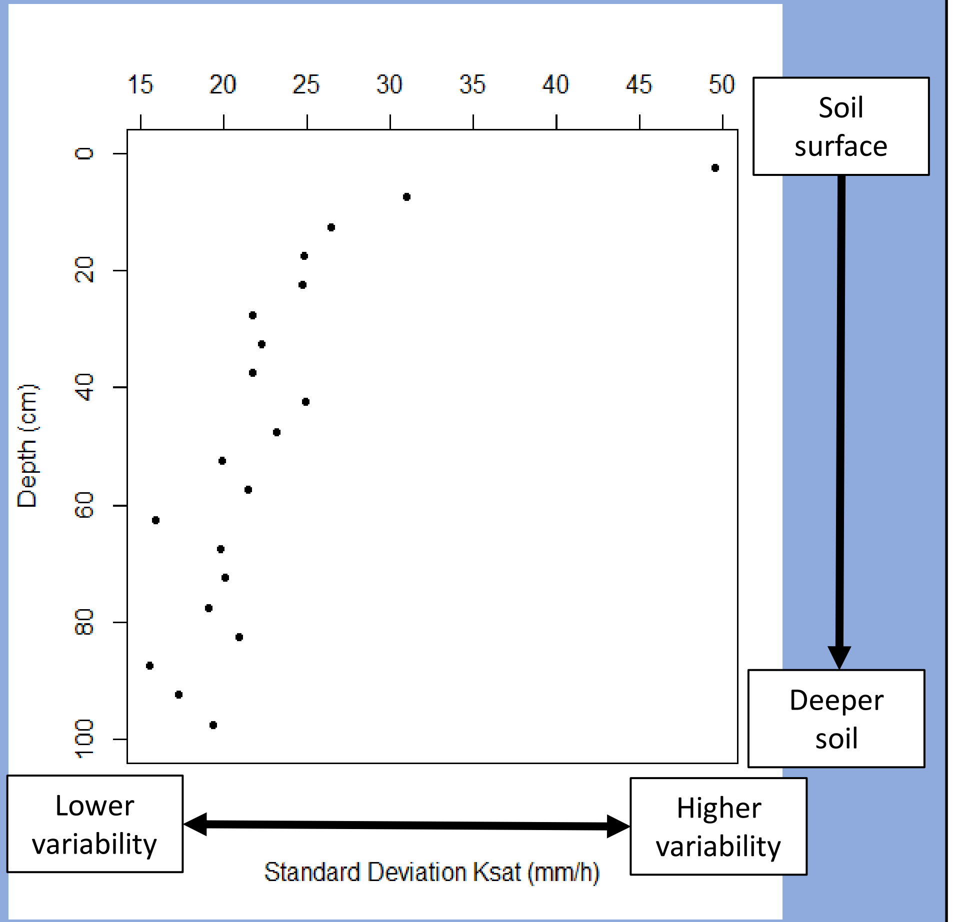
Is there a depth-dependency of K_{sat}?

Variability of K_{sat} decreases at depth

- Higher variability of K_{sat} at surface, lower variability of K_{sat} at depth
- The magnitude of Ksat decreases with depth

Potential reasons:

- Macroporosity constrained by overburden pressure
- Lessivage of soil fine particles



Is there a depth-dependency of K_{sat}?

Could K_{sat} at an arbitrary depth be predicted from the surface?

$$K_{sat} = b_{0,i}(Z)^{m_i}$$ Left panel

$$\ln K_{sat} = \ln b_{0,i} + m_i \ln Z$$ Right panel

where:

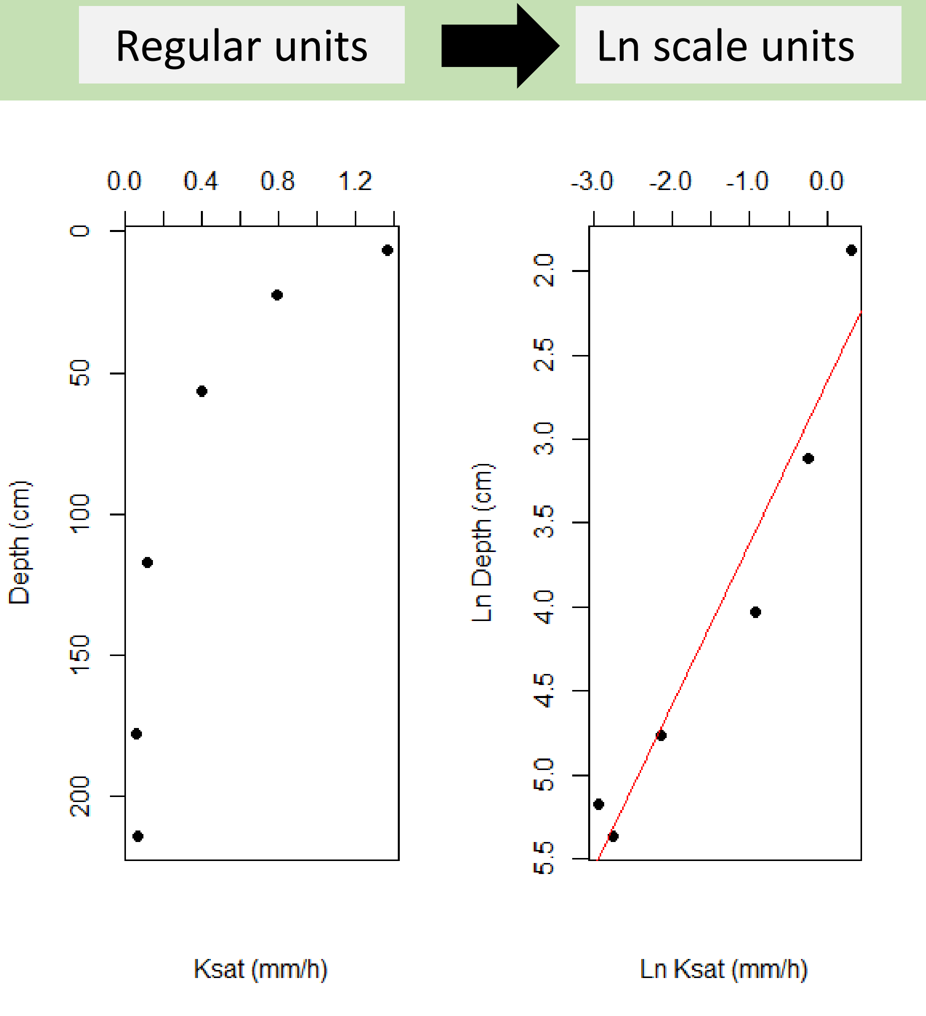
K_{sat} = Saturated hydraulic conductivity

Z = Soil depth

$b_{0,i}$= Intercept or K_{sat} at 1 cm below land surface in the *i*th soil profile

m_i= Slope of the linearized K_{sat}-Z function for the ith soil profile

We estimated the $b_{0,i}$ and m_i parameters for each soil profile



Is there a depth-dependency of K_{sat}?

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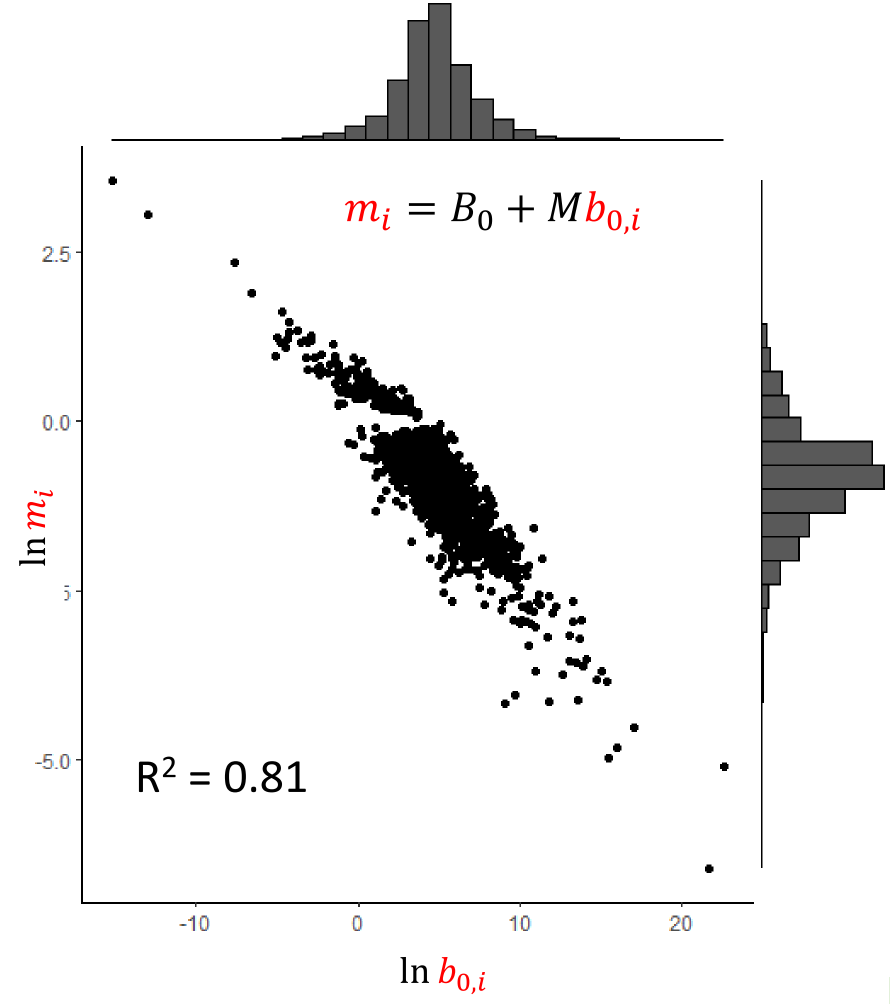
We estimated the $b_{0,i}$ and m_i parameters for each soil profile

We found a negative linear relationship that exists between the intercept and the slope of the regressions

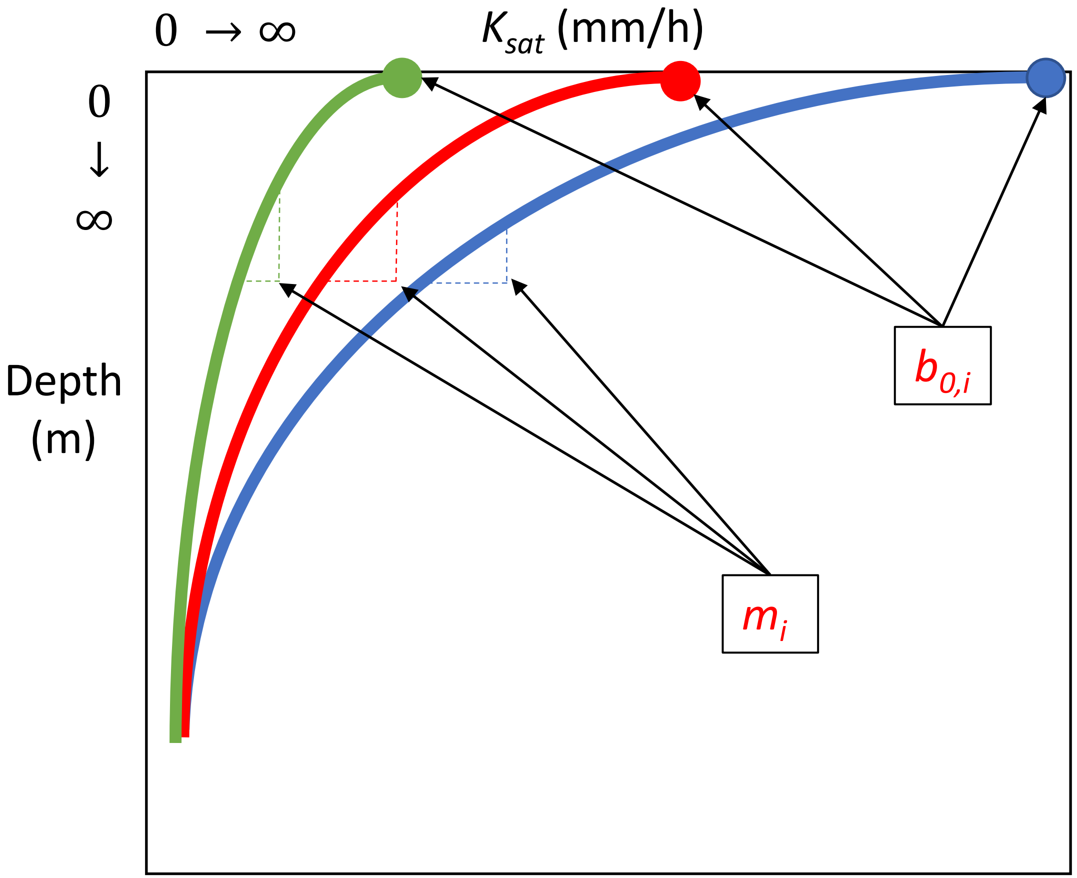


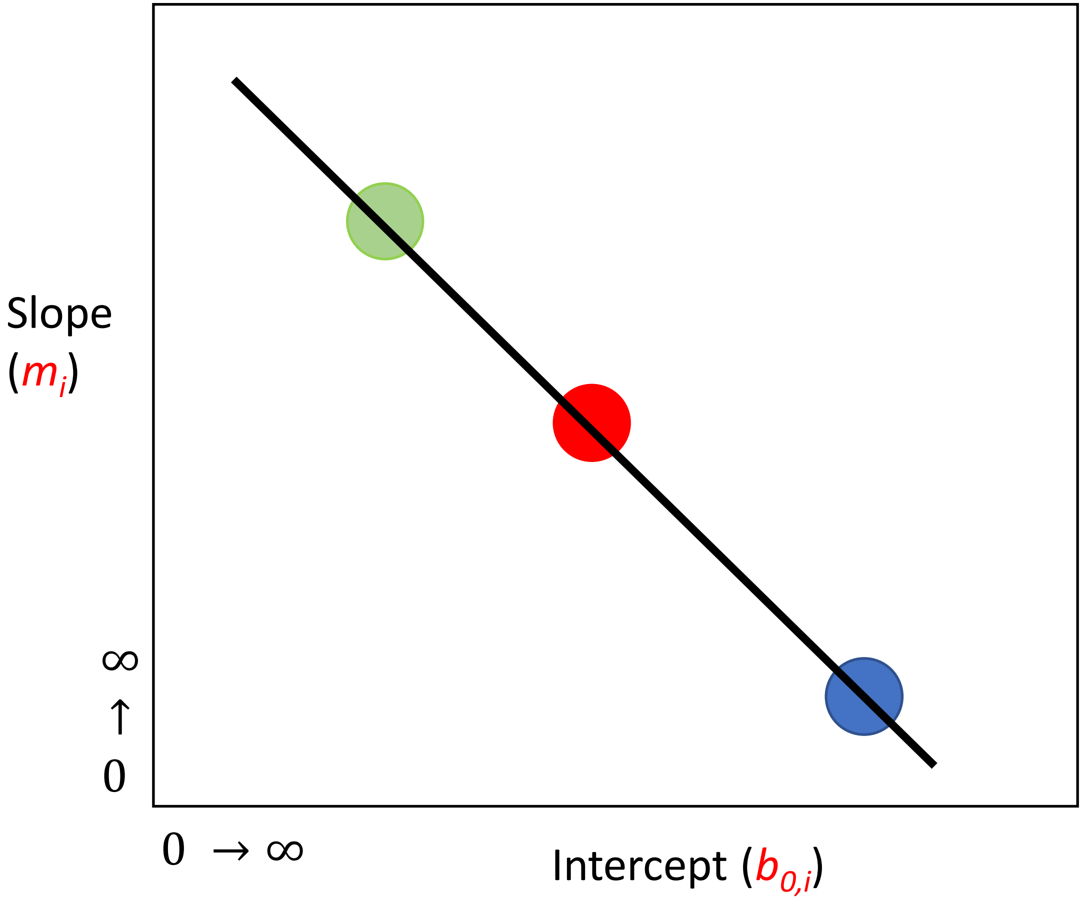
This suggest that we can use K_{sat} at surface ($b_{0,i}$) to predict its rate of change in relation to depth

B_0 = Intercept from a population of profile-derived parameters

M = Corresponding slope

Example for the negative linear relationship between the intercept and the slope of the regressions





$b_{0,i}$= Intercept or K_{sat} at 1 cm below land surface in the *i*th soil profile

m_i= Slope of the linearized K_{sat}-*Z* function for the *i*th soil profile

The higher the intercept, the higher the rate of decrease

Can we predict K_{sat} at surface ($b_{0,i}$)?

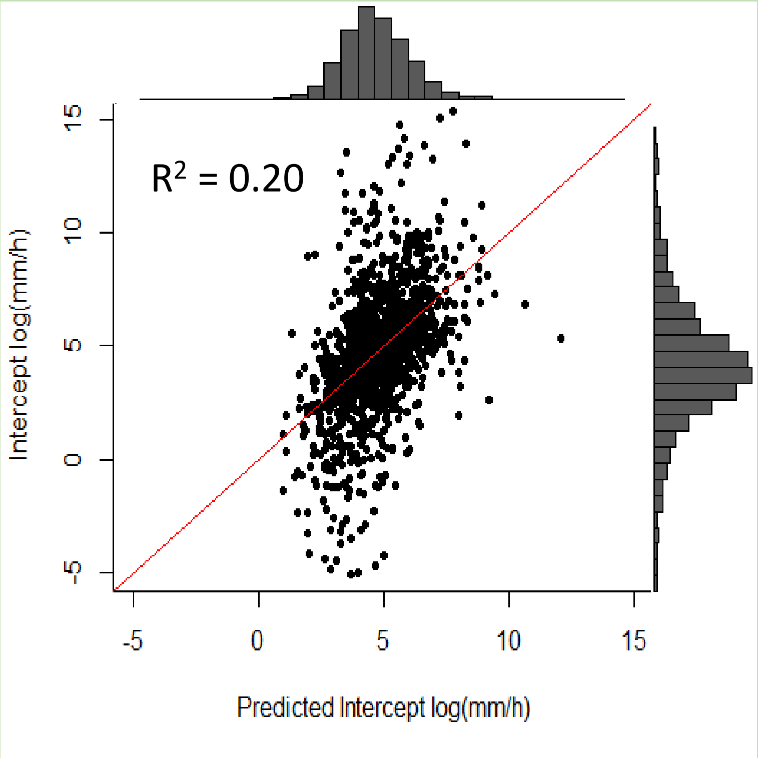
- We build a common PTF to predict $b_{0,i}$
- We used a stepwise multiple linear regression (MLR) to predict $b_{0,i}$

- Initial predictor variables:
  - *Bulk density (BD)*
  - *Sand*
  - *Clay*
  - *pH*
  - *Coefficient of linear extensibility (COLE)*
  - *Mean annual precipitation (MAP)*
  - *Mean annual temperature (MAT)*
  - *Vapor pressure deficit (VPD)*

***Soil data is for the upper horizon**

$b_{0,i}$= Intercept or K_{sat} at 1 cm below land surface in the *i*th soil profile

m_i= Slope of the linearized K_{sat}-Z function for the *i*th soil profile



Final predictor variables:

- *Bulk density*
- *Sand*
- *Coefficient of Linear Extensibility (COLE)*
- *Mean annual temperature (MAT)*
- *Vapor pressure deficit (VPD)*

$$b_{0,i} = 12.62 - (5.8 \times BD) + (0.038 \times Sand) - (24.75 \times COLE) + (0.157 \times MAT) - (0.175 \times VPD)$$

***Soil data is for the upper horizon**

Workflow - <u>**Pedon**</u>transfer Function (PnTF)

Make a PTF to estimate $b_{0,i}$

Obtain m_i and $b_{0,i}$ parameters

Estimate Depth – K_{sat} relationship

$$b_{0,i} = 12.62 - (5.8 \times BD) + (0.038 \times Sand) - (24.75 \times COLE) + (0.157 \times MAT) - (0.175 \times VPD)$$

***Soil data from the upper horizon**

$$m_i = 0.377 - 0.266 b_{0,i}$$

$$\ln K_{sat} = \ln b_{0,i} + m_i \ln Z$$

$b_{0,i}$= Intercept or K_{sat} at 1 cm below land surface in the *i*th soil profile

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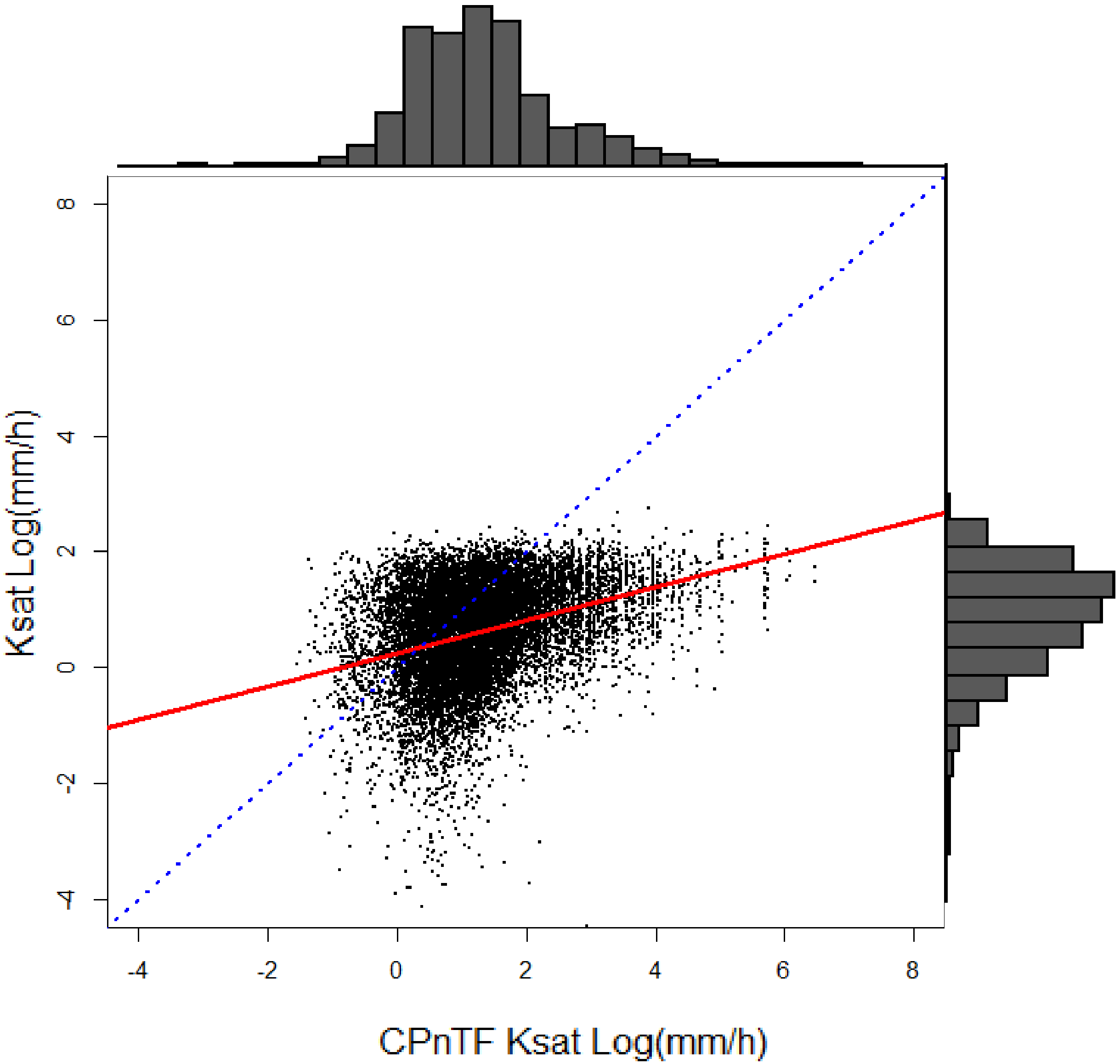
Pedontransfer Function (PnTF)



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m_i= Slope of the linearized K_{sat}-Z function for the *i*th soil profile

Summary and conclusions

Limitations

- There are overestimations at high and low extremes of K_{sat}
- There is a low explained variability of the 1:1 relationship of the predicted VS observed K_{sat}

Future work

- Improve the prediction of $b_{0,i}$
  - Classification and regression trees
  - Random forests
  - Artificial Neural Networks
- Explore new predictors for $b_{0,i}$
- Use taxonomic information to find where the performance of PnTF is good/bad

$b_{0,i}$= Intercept or K_{sat} at 1 cm below land surface in the *i*th soil profile

m_i= Slope of the linearized K_{sat}-Z function for the *i*th soil profile

Summary and conclusions

- We presented a framework to predict K_{sat} that incorporates its depth dependency.
- We have shown that, at a modest level, we can predict K_{sat} at an arbitrary depth from surface information.
- Our best predictors incorporates time-varying information (i.e., meteorological data).

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Questions?

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