Modeling water availability for trees in tropical forests

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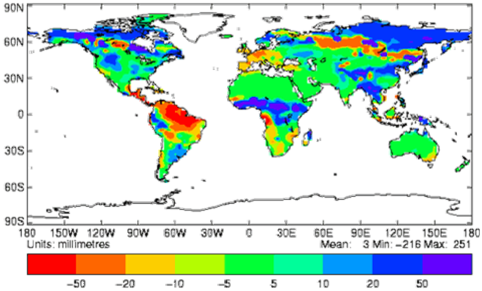
outline

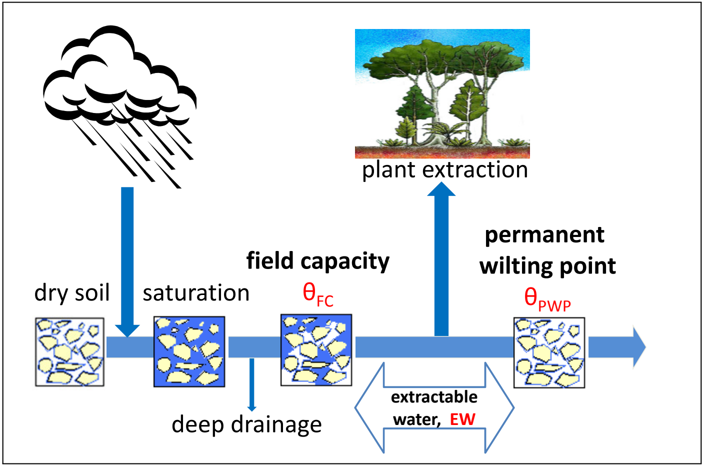
why modelling water availability in tropical forest ?

- tropical forests are subject to a dry season, incl. Amazon Basin
- climate modeling scenarios, Hadley center, change in annual soil water content for the late XXIth



- need for developping soil water availability model for tropical forests

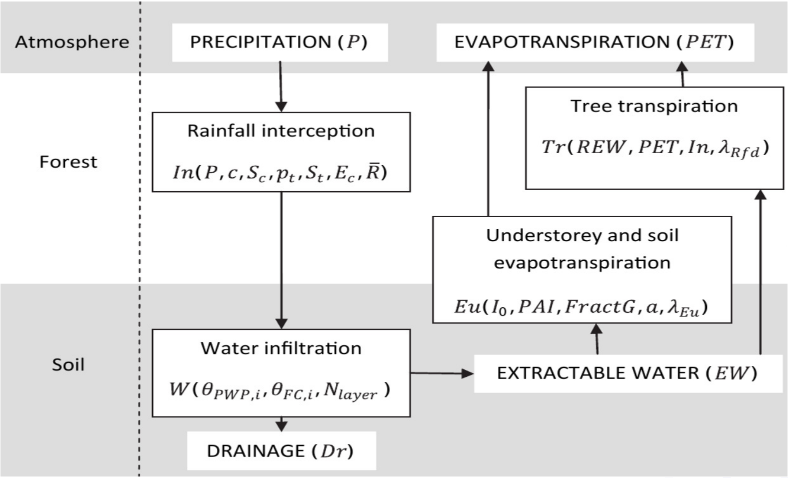
soil water cycle model



- Relative Extractable Water: $REW = \frac{EW}{EW_{MAX}}, \in [0, 1]$

soil water balance model

- $\Delta EW = P - In - Tr - Eu - Dr$

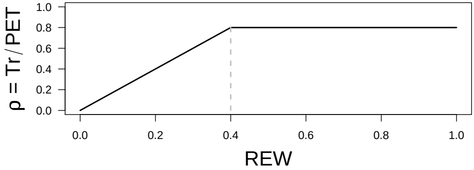


water infiltration

- soil layers
  - soil = succession of 1cm layers
  - each layer has a θ_{PWP} a θ_{FC} and a % of roots
  - estimates of θ_{PWP} and θ_{FC} in the calibration
- water dynamics
  - water > field capacity in a layer $\Longrightarrow$ water fills the next layers
  - water remains after the last layer $\Longrightarrow$ lost by deep drainage
- REW
  - $REW_d = \sum_{l=1}^{N_{layer}} \underbrace{\left(\frac{(\widehat{EW}_{l,d} - \theta_{PWP,l})}{(\theta_{FC,l} - \theta_{PWP,l})}\right)}_{REW_{layer}} \times \underbrace{Rfd_l / \sum_{l=1}^{N_{layer}} Rfd_l}_{layer\ roots\ \%}$

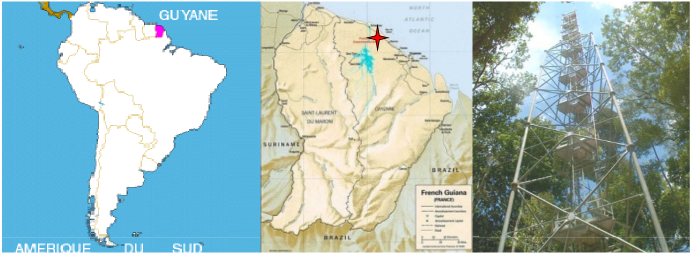
tree transpiration

- computation



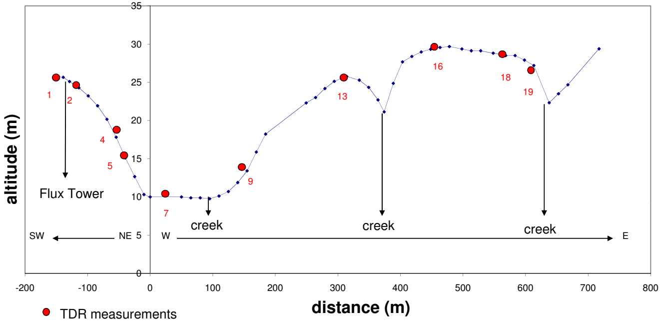
- tree transpiration extraction
  - fine root density (Rfd) $\Longrightarrow$ exponential function
  - $Rfd(depth) = \lambda_{Rfd} \times exp(-\lambda_{Rfd} \times depth)$
  - $Rfd_l = \int_{depth_{l-1}}^{depth_l} Rfd(depth)\mathrm{d}depth$
  - $Tr_{l,d} = \rho_l \times PET \times (1 - exp(-\lambda_{Rfd} \times N_{layer})) \times Rfd_l$

calibration data



- site : Paracou experimental site, French Guiana
- meteorological data : Guyaflux, flux tower, since 2003

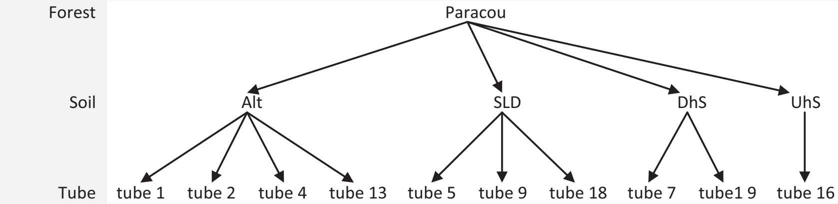
calibration data



- soil moisture measurment : 10 tubes on 4 soil types, TDR probe measurements from 20 to 260 cm by 20, since 2004
- automatic stem growth measurements: 6 dominant trees

model parameters and inference

- nested structure of the model



Parameters										
ρ	ρ_1	ρ_2	ρ_4	ρ_{13}	ρ_5	ρ_9	ρ_{18}	ρ_7	ρ_{19}	ρ_{16}
λ	λ_1	λ_2	λ_4	λ_{13}	λ_5	λ_9	λ_{18}	λ_7	λ_{19}	λ_{16}
θ_{PWP}	$\theta_{PWP,1}$	$\theta_{PWP,2}$	$\theta_{PWP,4}$	$\theta_{PWP,13}$	$\theta_{PWP,5}$	$\theta_{PWP,9}$	$\theta_{PWP,18}$	$\theta_{PWP,7}$	$\theta_{PWP,19}$	$\theta_{PWP,16}$
θ_{FC}	$\theta_{FC,1}$	$\theta_{FC,2}$	$\theta_{FC,4}$	$\theta_{FC,13}$	$\theta_{FC,5}$	$\theta_{FC,9}$	$\theta_{FC,18}$	$\theta_{FC,7}$	$\theta_{FC,19}$	$\theta_{FC,16}$

model parameters and inference

- stochasticity of the model : normal error of the probe
- likelihood of the model

$$\mathcal{L}(Data|\Theta_m) = \prod_{p=1}^{N_{tube}} \mathcal{L}(Data_p|\Theta_m)$$

$$= \prod_{p=1}^{N_{tube}} \prod_{d=1}^{N_{day}} \prod_{l=1}^{N_{layer}} \frac{\exp\left[-\frac{(\widehat{EW}^p_{l,d} - EW^p_{l,d})^2}{2(0.2 \times EW^p_{l,d})^2}\right]}{\sqrt{2\pi(0.2 \times EW^p_{l,d})}}$$

- $\widehat{EW}^p_{l,d}$ are the predicted extractable water values

Metropolis-Hastings within a Gibbs algorithm

generation of a candidate θ_k^* and the new vector of parameters Θ^*:¡

$$
\begin{aligned}
\theta_k^* &\sim \pi_\theta^{prop}(\theta_k^{n-1}) \\
\Theta^* &= \left\{\theta_1^{n-1}, ..., \theta_{k-1}^{n-1}, \theta_k^*, \theta_{k+1}^{n-1}, ..., \theta_{Npar}^{n-1}\right\}
\end{aligned}
$$

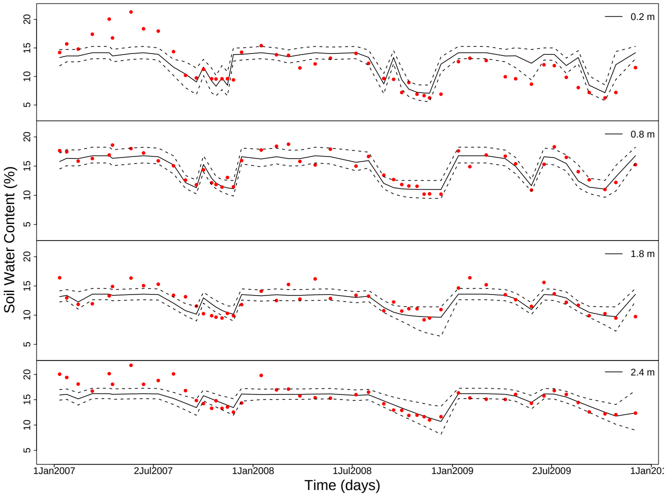
acceptation or rejection of the new candidate θ_k^* by computing the ratio of the likelihood :

$$
\gamma = \underbrace{\frac{\mathcal{L}(Data|\Theta^*)}{\mathcal{L}(Data|\Theta^{n-1})}}_{likelihood} \times \underbrace{\frac{\pi_0(\theta_k^*)}{\pi_0(\theta_k^{n-1})}}_{prior} \times \underbrace{\frac{\pi_\theta^{prop}(\theta_k^{n-1}|\theta_k^*)}{\pi_\theta^{prop}(\theta_k^*|\theta_k^{n-1})}}_{proposal} \wedge 1
$$

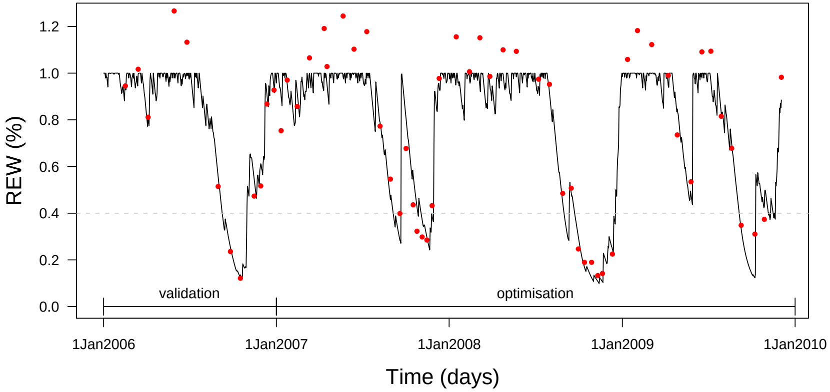
the candidate θ_k^* is accepted or rejected as follows :

$$
u^t \sim \mathcal{U}_{[0,1]}, \quad \theta_k^n \begin{cases} \theta_k^* & if \quad \gamma \geq u^t \\ \theta_k^{n-1} & if \quad \gamma < u^t \end{cases}
$$

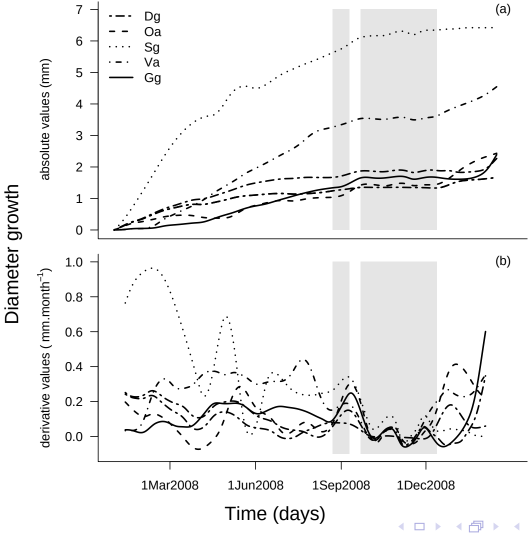
model predictions: soil water content



model predictions: REW, relative extractable water



REW and tree growth



- summary
  1. the method achieve to reproduce the daily extractable water
  2. new method to estimate field capacity and permanent wilting point
  3. new method to model roots functionning in soil water balance model

- perspectives
  1. history of the soil water availability
  2. linking REW to long-term follow up of tropical forest dynamics
  3. REW 0.4 threshold for tropical forest species