Modeling water availability for trees in tropical forests

Fabien Wagner\textsuperscript{1}, Bruno Herault\textsuperscript{1}, Clement Stahl\textsuperscript{2}, Damien Bonal\textsuperscript{3} Vivien Rossi\textsuperscript{4}

\textsuperscript{1}Université Antilles-Guyane, UMR 'Ecologie des Forêts de Guyane', French Guiana; \textsuperscript{2}INRA, UMR 'Ecologie des Forêts de Guyane', French Guiana \textsuperscript{3}INRA, UMR INRA-UHP 1137 'Ecologie et Ecophysiologie Forestière', France; \textsuperscript{4}CIRAD, UMR 'Ecologie des Forêts de Guyane', French Guiana
outline

1 background

2 the model

3 results

4 summary/future works
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 developing soil water availability model for tropical forests
soil water cycle model

Relative Extractable Water: \[ REW = \frac{EW}{EW_{\text{MAX}}} , \in [0, 1] \]
soil water balance model

\[ \Delta EW = P - In - Tr - Eu - Dr \]
water infiltration

- soil layers
  - soil = succession of 1cm layers
  - each layer has a $\theta_{PWP}$ a $\theta_{FC}$ and a % of roots
  - estimates of $\theta_{PWP}$ and $\theta_{FC}$ in the calibration

- water dynamics
  - water > field capacity in a layer $\implies$ water fills the next layers
  - water remains after the last layer $\implies$ lost by deep drainage

- REW
  - $REW_d = \sum_{l=1}^{N_{layer}} \left( \frac{\hat{EW}_{l,d} - \theta_{PWP,l}}{(\theta_{FC,l} - \theta_{PWP,l})} \right) \times \frac{Rfd_l}{\sum_{l=1}^{N_{layer}} Rfd_l}$
    
    REW$_{layer}$
    layer roots %
tree transpiration

▶ computation

\[
\rho = \frac{Tr}{PET}
\]

▶ tree transpiration extraction

- fine root density (Rfd) \( \implies \) exponential function
  \[
  Rfd(depth) = \lambda_{Rfd} \times \exp(-\lambda_{Rfd} \times depth)
  \]
- \( Rfd_l = \int_{depth_{l-1}}^{depth_l} Rfd(depth) \, ddepth \)
- \( Tr_{l,d} = \rho_l \times PET \times (1 - \exp(-\lambda_{Rfd} \times N_{layer})) \times Rfd_l \)
calibration data

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

- soil moisture measurement: 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

Forest  Paracou
Soil  Alt  SLD  DhS  UhS
Tube  tube 1  tube 2  tube 4  tube 13  tube 5  tube 9  tube 18  tube 7  tube 19  tube 16
Parameters
\[ \rho, \lambda, \theta_{PWP}, \theta_{FC} \]
\[ \rho_1, \lambda_1, \theta_{PWP,1}, \theta_{FC,1} \]
\[ \rho_2, \lambda_2, \theta_{PWP,2}, \theta_{FC,2} \]
\[ \rho_4, \lambda_4, \theta_{PWP,4}, \theta_{FC,4} \]
\[ \rho_{13}, \lambda_{13}, \theta_{PWP,13}, \theta_{FC,13} \]
\[ \rho_5, \lambda_5, \theta_{PWP,5}, \theta_{FC,5} \]
\[ \rho_9, \lambda_9, \theta_{PWP,9}, \theta_{FC,9} \]
\[ \rho_{18}, \lambda_{18}, \theta_{PWP,18}, \theta_{FC,18} \]
\[ \rho_7, \lambda_7, \theta_{PWP,7}, \theta_{FC,7} \]
\[ \rho_{19}, \lambda_{19}, \theta_{PWP,19}, \theta_{FC,19} \]
\[ \rho_{16}, \lambda_{16}, \theta_{PWP,16}, \theta_{FC,16} \]

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soil water model for tropical forests
model parameters and inference

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

\[
\mathcal{L}(Data|\Theta_m) = \prod_{p=1}^{N_{\text{tube}}} \mathcal{L}(Data_p|\Theta_m) = \prod_{p=1}^{N_{\text{tube}}} \prod_{d=1}^{N_{\text{day}}} \prod_{l=1}^{N_{\text{layer}}} \exp \left[ - \frac{(\hat{EW}_{l,d}^p - EW_{l,d}^p)^2}{2(0.2 \times EW_{l,d}^p)^2} \right] \sqrt{\frac{2\pi}{0.2 \times EW_{l,d}^p}}
\]

- \(\hat{EW}_{l,d}^p\) are the predicted extractable water values
Metropolis-Hastings within a Gibbs algorithm

generation of a candidate $\theta_k^*$ and the new vector of parameters $\Theta^*$:

$\theta_*^k \sim \pi_{\theta}^{\text{prop}}(\theta_{k}^{n-1})$

$\Theta^* = \{ \theta_1^{n-1}, \ldots, \theta_{k-1}^{n-1}, \theta_*^k, \theta_{k+1}^{n-1}, \ldots, \theta_{N\text{par}}^{n-1} \}$

acceptation or rejection of the new candidate $\theta_*^k$ by computing the ratio of the likelihood:

$$\gamma = \frac{\mathcal{L}(\text{Data}|\Theta^*)}{\mathcal{L}(\text{Data}|\Theta_{n-1}^{*})} \times \frac{\pi_{0}(\theta_*^k)}{\pi_{0}(\theta_{k}^{n-1})} \times \frac{\pi_{\theta}^{\text{prop}}(\theta_{k}^{n-1}|\theta_*^k)}{\pi_{\theta}^{\text{prop}}(\theta_*^k|\theta_{k}^{n-1})} \land 1$$

the candidate $\theta_*^k$ is accepted or rejected as follows:

$$u^t \sim \mathcal{U}[0,1], \quad \theta_k^n \begin{cases} \theta_*^k & \text{if } \gamma \geq u^t \\ \theta_{k-1}^{n-1} & \text{if } \gamma < u^t \end{cases}$$
model predictions: soil water content

Soil Water Content (%) vs Time (days) for different depths:
- 0.2 m
- 0.8 m
- 1.8 m
- 2.4 m

Data points and model predictions for the years 2007 to 2010 are shown.
model predictions: REW, relative extractable water
REW and tree growth

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soil water model for tropical forests
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 functioning 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