HETEROFOR: A model to predict climate change impacts on tree growth in heterogeneous stands

Phenology and water cycle

Louis de Wergifosse, Frédéric André, Hugues Goosse, Mathieu Jonard
Model features

• Mechanistic
• Individual based
• Spatially-explicit

→ Versatile model that can be theoretically used in any environmental conditions and for any stand configuration
HETEROFOR overview

Atmospheric deposition

Mineralization

Potential uptake

SUPPLY vs DEMAND

Actual uptake

Mineralization

hor. 1
hor. 2
hor. 3

Litter

Foliage
Trunk
Branches
Roots
Fines roots

Nutritional status

PAR
APAR
GPP
NPP
HETEROFOR overview

Atmospheric deposition

Phenology

minerals = solution = exchange complex

hor. 1
hor. 2
hor. 3

Mineralization

PAR
APAR
GPP
NPP

SUPPLY vs DEMAND

Actual uptake

Potential uptake

Foliage
Trunk
Branches
Roots
Fines roots

Nutritional status
HETEROFOR overview: Phenology

Phenology

Vegetation period

LAD proportion

start

end

yellowing
start
end

budburst

start
end

Leaffall

start
end

DOY

0 1

0 115 130 265 305 325 365

dates depending on climate variables (air T°, wind, photoperiod, frost events)
HETEROFOR overview: Water cycle
Sites of model evaluation

- Lauzelle: Beech stand with a few oaks
- Chimay: Oak stand with hornbeam understory
- Baileux (three plots): Pure oak, pure beech and mixed stands
- Virton: Beech stand with various deciduous species
Phenology evaluation: budburst

Unichill: Chilling and forcing periods (Chuine, 2000)

Uniforc: Single-phase forcing period (Chuine, 2000)

Sequential: Chilling and forcing periods (Kramer, 1994)
Phenology evaluation: LAD and leaf yellowing

Yearly evaluation of the green and total leaf proportion in an oak stand (Chimay)
Water cycle evaluation: Throughfall and deep drainage
Water cycle evaluation: Relative extractable water

\[ REW = \frac{EW}{EW_{ref}} \]

with

\[ EW = \sum_{hr=1}^{n}(\theta_{hr} - \theta_{wp_{hr}}) \cdot th_{hr} \cdot (1 - v_{hr}) \]

\[ EW_{ref} = \sum_{hr=1}^{n}(\theta_{fc_{hr}} - \theta_{wp_{hr}}) \cdot th_{hr} \cdot (1 - v_{hr}) \]

Baileux - oak

RMSE = 0.17
bias = 5.0%
Pearson's r = 0.942
Water cycle evaluation: Relative extractable water

- **Baileux - oak**
  - RMSE = 0.17
  - Bias = 5.0%
  - Pearson's r = 0.942

- **Baileux - beech**
  - RMSE = 0.31
  - Bias = 2.4%
  - Pearson's r = 0.934

- **Baileux - mixed**
  - RMSE = 0.19
  - Bias = -1.5%
  - Pearson's r = 0.917

- **LLN**
  - RMSE = 0.38
  - Bias = 27.3%
  - Pearson's r = 0.948

- **Chimay**
  - RMSE = 0.34
  - Bias = 16.8%
  - Pearson's r = 0.921

- **Virton**
  - RMSE = 0.41
  - Bias = 25.2%
  - Pearson's r = 0.855
Simulation description

• 6 sites in Wallonia (Southern Belgium)

• 3 downscaled climate scenarios (RCP2.6-4.5-8.5) for the 2011-2100 period

• 1 downscaled reference climate period between 1976-2005

• Succession of 1-year model run with same initial conditions

• Repetition of simulations with constant and variable CO₂ concentrations
Simulation results: NPP evolution
Simulation results: Increase of vegetation period
Simulation results: Increase of drought stress
Simulation results: Factors of NPP variability

Drought index explains 32% of NPP variability

The influence of the vegetation period length is significant but often hidden because of its lower variability.

A major part of NPP variability (38%) depends on the site (stand, soil and climate).

<table>
<thead>
<tr>
<th>Fixed effects</th>
<th>Estimate</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>545.42</td>
<td>/</td>
</tr>
<tr>
<td>Drought index</td>
<td>-5.48</td>
<td>0.322</td>
</tr>
<tr>
<td>Vegetation period</td>
<td>2.07</td>
<td>0.066</td>
</tr>
<tr>
<td>Random effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site</td>
<td>0</td>
<td>0.384</td>
</tr>
<tr>
<td>Residuals</td>
<td>0</td>
<td>0.230</td>
</tr>
<tr>
<td>Total</td>
<td>/</td>
<td>0.770</td>
</tr>
</tbody>
</table>
Disentangling the stand, soil and climate influence

Simulations with 6 stands x 6 soils x 4 climate (reference period) = 144 combinations

NPP variability
- Climate: 1.7%
- Soil: 11.2% → Drought index
- Stand: 49.6% → Species
- Residuals: 33% → Interannual variability (DI, vegetation period)
Perspectives: Improvement of the model ability to predict climate change impacts

- Adaptation of HETEROFOR to coniferous species (Norway spruce, Scots pine, Douglas fir, Silver fir)

- Model evaluation and simulations at the European scale using level II plots of ICP forests (RENECOFOR)

- Estimation of prediction uncertainty originating from climate projections and model parameters
  - Improvement and comparison of climate downscaling methods
  - Characterization of model parameter distribution with a Bayesian calibration procedure