Predicting the probability of severe droughts and changes in potential GPP under changing climate

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Soil water model is part of a more complicated combination of process-based models...

Poster 188: Mäkipää et al.
Differences in forest carbon stock and timber supply between management options under changing climate
Models for soil water capacity and Gross Primary Production:
Soil water model

- Soil water model(*) is a simple "open bucket"-type model,
- Soil water holding capacity is the (metric) difference between wilting point and field capacity
- The difference translates to the maximum water layer thickness that the soil can hold
- Soil water holding capacity depends on soil thickness, soil type, texture etc.
- for modeling purposes volume of retained water is sufficient!

(*) based loosely on Duursma, R. A. et al. 2006. Predicting the decline in daily maximum transpiration rate of two pine stands during drought based on constant minimum leaf water potential and plant hydraulic conductance, Tree Physiology 28, 265–276.
**Soil water -model**

- Precipitation comes from meteorological data.
- Evapotranspiration calculated as:

\[
Et = \left( E_0 \cdot f(PAR) \cdot f(T) \cdot f(VPD) + a_1 \cdot PAR + a_2 \right) \cdot f(\theta)
\]

- where
- \( E_0 = 1.74 \cdot 10^{-2} \)
- \( a_1 = 0.0007 \)
- \( a_2 = 0.0836 \)
- \( f(PAR) = PAR \)
- \( f(T) = \) delayed average with \( \tau = 14 \) days
- \( f(D) = e^{\kappa \cdot VPD}, \kappa = -2.63 \cdot 10^{-4} \)
- \( f(\theta) = \) drought modifier

(*) Model by Mäkelä & Linkosalo (unpublished)
Soil water -model

- $f(\theta) = \text{drought modifier; reduces evapotranspiration when soil water level below 15\%, and totally shuts it off when soil water level below 10\% (based on Duursma et al. 2006, Tree Physiology)}$
**Soil water -model**

- Model fitted to Eddy-covariance data from SMEAR II station in central Finland
- takes into account both stand and understorey

![Graph showing soil moisture and evapotranspiration](image)

- Precipitation, snow melt
- Evapotranspiration
- Runoff, drainage

![Graph showing soil moisture and evapotranspiration](image)
Gross Primary Production -model

Potential GPP calculated with equations somewhat similar to evapotranspiration:(*)

\[ P_0 = \left( \beta \cdot f(PAR) \cdot f(T) \cdot f(VPD) \right) \cdot f(\theta) \], where
\[ \beta = 0.541 \text{ (maximum potential photosynthetic rate)} \]

\[ f(PAR) = \frac{PAR}{\gamma \cdot PAR + 1} \], \[ \gamma = 0.0223 \]

\[ f(T) = \text{delayed average with } \tau = 17 \text{ days} \]
\[ f(D) = e^{\kappa \cdot VPD} \], \[ \kappa = -4.03 \cdot 10^{-2} \]
\[ f(\theta) = \text{drought modifier} \]

**Gross Primary Production -model**

- GPP summed over the whole year, and averaged over years
- $f(\theta)$ as in evapotranspiration model:
  - at $\theta$ below 15% GPP production scaled down,
  - at $\theta$ below 10% GPP accumulation set to zero
Climate change simulation:
Weather data and climate change simulation

- Interpolated weather data for 1961 to 2007 (*)
- Data in 10*10km grid (Finnish Uniform Grid)
- Data for: temperature, PAR, precipitation, water vapour partial pressure (-> VPD)
- All models calculated for each cell in the grid

Weather data and climate change simulation

- For climate change simulation, a crude modification along A2-scenario:
  - Temperature increased by 3ºC (mean increase for summer months)
  - Precipitation increased by 10% (i.e. frequency of rain not changed, but intensity increased)
  - Also tested increase of 5ºC, change of precipitation of ±0% and -10%
Weather data and climate change simulation

- No detailed soil data available in the 10*10km grid

- Thus two values of soil water retention capacity were used, 200mm and 100mm

- The soil at SMEAR II station, is a normal to thin mineral soil on solid bedrock and on top of a hill. It has a measured water retention capacity of 200mm; this was considered a slightly dryer than average value for Finnish soils.

- Thus 100mm is a quite arid place in Finnish perspective
Results:
# Results

1. Number of drought days (soil water below 10% of capacity)

<table>
<thead>
<tr>
<th>Soil 200mm</th>
<th>Current weather</th>
<th>T+3C Prec +10%</th>
<th>T+3C Prec 0%</th>
<th>T+3C Prec -10%</th>
<th>T+5C Prec 0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil 100mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions on drought days

- Under current conditions drought days are quite rare, except on:
  - most arid growing sites
  - coastal areas and Åland archipelago

- With climatic warming drought days will be more frequent, but the increase is not dramatic.
Results  

2. potential GPP [kg(C)/ha/a]  
(assuming 100% light capture, limited by water, T, PAR and VPD)
Conclusions on potential GPP

- Currently soil water limits potential GPP up to 10% for most arid places.

- Climate change will increase potential GPP on all sites.

- As GPP will increase also on arid places, and the increase of drought days does not restrict increase of GPP, the latter is mostly due to increase in temperature.
What about phenology?

- So far calculations have assumed, that GPP accumulates throughout the year (as for conifers).

- What if the growing season is limited?

- This most likely in spring, when conditions may be feasible (plenty of light, warm enough, lots of soil moisture), but leaves have not yet unfolded.

- *maybe the result that GPP increases with climatic warming is due to GPP change during these spring days, that broadleaf species cannot utilize?*
What about phenology?

- To study this, we used a simple *thermal time* -model (temperature sum starts adding up in 8th April, sums up at temperatures above 1.5ºC, predicts bud burst when temperature sum reaches 167 degree-days);

- Climatic warming will also advance the bud burst timing, hence *increasing* potential GPP!

- For the phenology simulation, temperature sum was only accumulated after the predicted bud burst:
Results

2. potential GPP [kg(C)/ha/a] **with phenology**
(assuming 100% light capture, limited by water, T, PAR and VPD)
<table>
<thead>
<tr>
<th>potential GPP [kg(C)/ha/a]</th>
<th>Soil water retention capacity (mm)</th>
<th>Current climate</th>
<th>Temperature +3°C, precipitation +10%</th>
<th>Temperature +3°C, precipitation ±0%</th>
<th>Temperature +3°C, precipitation -10%</th>
<th>Temperature +5°C, precipitation ±0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No phenology</td>
<td>200</td>
<td>981</td>
<td>1250</td>
<td>1239</td>
<td>1220</td>
<td>1393</td>
</tr>
<tr>
<td>With phenology</td>
<td>757</td>
<td>955</td>
<td>944</td>
<td>924</td>
<td>1040</td>
<td></td>
</tr>
<tr>
<td>No phenology</td>
<td>100</td>
<td>931</td>
<td>1184</td>
<td>1159</td>
<td>1123</td>
<td>1298</td>
</tr>
<tr>
<td>With phenology</td>
<td>712</td>
<td>889</td>
<td>863</td>
<td>828</td>
<td>946</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GPP potential increase (%)</th>
<th>No phenology</th>
<th>200</th>
<th>0.0</th>
<th>27.4</th>
<th>26.3</th>
<th>24.3</th>
<th>41.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>With phenology</td>
<td>0.0</td>
<td>26.2</td>
<td>24.7</td>
<td>22.1</td>
<td>37.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No phenology</td>
<td>100</td>
<td>0.0</td>
<td>27.2</td>
<td>24.4</td>
<td>20.6</td>
<td>39.4</td>
<td></td>
</tr>
<tr>
<td>With phenology</td>
<td>0.0</td>
<td>24.8</td>
<td>21.2</td>
<td>16.3</td>
<td>32.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions on phenology

- Taking phenology into account will reduce the overall GPP, but the climate change will still increase the potential GPP, and the magnitude of change is similar.

- Conservative phenology model, with a more extreme one inclusion may even increase the effect of global change.

- Probably no change in the competition status between conifers and broadleaves.
Restrictions of current results:

- No information on how the water vapour pressure deficit will change, therefore assumed that relative humidity will not change. If it decreases, it may reduce GPP.

- The effect of other soil features next to water holding capacity (texture, structure, water retention, soil types etc.)

- Will the rain frequency/patterns change?
future work:

- Find out how air humidity/VPD will change
- Get more realistic estimates for changes in rain frequencies / intervals.
- Use actual soil data to get distributions for different counties.
- Use actual stand data to get Net Primary Production (NPP) values (note: different stand LAI and understorey will effect the ET model!)
- Try different climate change scenarios.
Related projects

- **CC-tame**
  - "The CC-TAME project concentrates on assessing the impacts of agricultural, climate, energy, forestry and other associated land-use policies considering the resulting feed-backs on the climate system in the European Union."

- **Isto**
  - A national mitigation programme of the ministry of agriculture and forestry

- **SusEn**
  - Sustainable energy production, programme of the Academy of Finland
- That’s all folks!