Improvement of Vegetation Soil Moisture Stress Simulation in JULES

Azin Wright¹, Anne Verhoef¹, Karina Williams², Anna Harper³, Patrick C. McGuire¹, Pier Luigi Vidale¹

¹ University of Reading
² Met Office, Exeter
³ University of Exeter
INTRODUCTION
There are 2 configurations available in JULES Rose/Cylc suite u-al752 for calculation of plant soil water stress:

<table>
<thead>
<tr>
<th>Index</th>
<th>Param. Sym.</th>
<th>Param. name</th>
<th>Param. unit</th>
<th>JULES model name</th>
<th>Variable symbol</th>
<th>Variable name</th>
<th>Variable unit</th>
<th>Lower value</th>
<th>Corresponding soil conditions</th>
<th>Upper value</th>
<th>Corresponding soil conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>θ</td>
<td>Volumetric soil water content</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Standard</td>
<td>β</td>
<td>Soil water availability to plants</td>
<td>(-)</td>
<td>0</td>
<td>dry</td>
<td>1</td>
<td>wet</td>
</tr>
<tr>
<td>2</td>
<td>ψ&lt;sub&gt;s,c&lt;/sub&gt;</td>
<td>Soil water potential when stomata close</td>
<td>MPa</td>
<td>Sinclair</td>
<td>RT</td>
<td>Relative transpiration</td>
<td>(-)</td>
<td>0.033</td>
<td>dry</td>
<td>2.5</td>
<td>wet</td>
</tr>
</tbody>
</table>

\[ \beta = 0 \leq \frac{\theta - \theta_{PWP}}{\theta_{FC} - \theta_{PWP}} \leq 1 \]

\[ RT = 1 - \frac{\Psi_s}{\Psi_e} \]

\( \theta_{PWP} \): soil water content at permanent wilting point (m<sup>3</sup>/m<sup>3</sup>)

\( \theta_{FC} \): soil water content at field capacity (m<sup>3</sup>/m<sup>3</sup>)

\( \Psi_s \): soil water potential (Mpa)

\( \Psi_e \): water potential of the bulk leaf epidermis

Equation by Sinclair (2005)

Assumption by Verhoef and Egea (2014), if soil water potential (\( \Psi_{s,c} \)) is equal to \( \Psi_e \):

\[ \beta \sim RT \]
Motivation

- theory: Plant’s response to soil moisture stress (which is closing the stomata) is more dependent on ‘soil water potential ($\Psi_{S,C}$)’ rather than volumetric soil moisture content ($\theta$) (Marshall et al., 1996; Mullins, 2001; Gregory and Nortcliff, 2013; Verhoef and Egea, 2014).

- there has been work on optimisation of $\Psi_{S,C}$ previously, but none of the works found the Sinclair method to have a significant effect on the output:
  - personal correspondence from Williams.K regarding implementation of Sinclair for online runs, which was used by Best.M;
Questions

• In what cases the use of Standard JULES or Sinclair is advised to simulate plant soil water stress?
• What difference do TRIFFID on/off, BC and VG configurations make in the simulation of plant soil water stress?
Methodology
Change of JULES configurations to adopt Sinclair

<table>
<thead>
<tr>
<th>Code name</th>
<th>JULES Sinclair</th>
<th>Standard JULES</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>l_use_pft_psi</td>
<td>true</td>
<td>false</td>
<td>use/not use of soil water potential</td>
</tr>
<tr>
<td>fsmc_shape</td>
<td>1</td>
<td>0</td>
<td>Shape of the $\beta$ depends on soil water potential (if not, it should depend on the volumetric soil moisture content)</td>
</tr>
<tr>
<td>psi_open_io=</td>
<td>0</td>
<td>9*-0.033E6</td>
<td>Maximum value of $\Psi_s$, o (soil water potential when stomata are open, the wet end)</td>
</tr>
</tbody>
</table>
Setting up JULES runs

Standard JULES

TRIFFID on

BC

JULES-Sinclair

TRIFFID off

BC

VG

Ψ_{S,C} = -0.5
-1
-1.5
-2
-2.5
(E6Mpa)

Ψ_{S,C} = -0.5
-1
-1.5
-2
-2.5
(E6Mpa)

Ψ_{S,C} = -0.5
-1
-1.5
-2
-2.5
(E6Mpa)

TRIFFID on

VG

BC
Choice of sites and their categorization

- All FLUXNET sites available in u-al752 were used except for LBA sites and sites with no more than one year data (62 sites).
- Sites were categorized on:
  - vegetation cover
  - climate
  - soil type
  - and aridity index:
    - Precipitation – Evapotranspiration (mm/day), low values: dry; high values: wet.
performance metrics

- variability
- bias
- RMSE
- Kling-Gupta Efficiency (KGE) metric (Gupta et al, 2009)

\[
KGE = 1 - \sqrt{(r_{\text{Pearson}} - 1)^2 + \left(\frac{\sigma_{\text{model}}}{\sigma_{\text{obs}}} - 1\right)^2 + \left(\frac{\mu_{\text{model}}}{\mu_{\text{obs}}} - 1\right)^2}
\]

- distribution overlap
Efficiency metric: Distribution overlap

- distribution overlap efficiency, is the normalized shared area between two distributions (Weitzman, 1970).

\[
OVL = \int_{R_n} \min[f_1(\bar{x}), f_2(\bar{x})] \, d\bar{x}.
\]

E.g. GPP for Au_Fog, TRIFFID on, BC hydraulic scheme, Day 180 to 270 in 2006 to 2008

\[\Psi_{S,C} = -0.5 \text{ E6MPa}\]

\[\Psi_{S,C} = -2.5 \text{ E6Map}\]
efficiency improvement

• Efficiency improvement \((E_i)\) calculation for GPP and latent heat

\[ E_i = E_{\psi_n} - E_{std} \]

\(E_{\psi_n}\) is the efficiency metric when \(\psi_{s,c} = -0.5, -1, -1.5, -2, -2.5\ E6\text{Mpa}\).
RESULTS
Comparison of GPP and latent heat sensitivity to $\Psi_{S,C}$ values

The overlap of modelled and observed GPP and LE distributions for the range of $\Psi_{S,C}$ and standard JULES values:

GPP shows higher overlap values and more variability compared to LE.
comparison of TRIFFID respond to choice of Standard or Sinclair

- the overlap distributions of modelled and observed data with TRIFFID on and TRIFFID off configuration for the range of $\Psi_{S,C}$ and standard JULES values:

- There are very slight differences between TRIFFID on and off configurations regarding the model improvement (site 19 DE-Sfn, or site 30 IT-Col, where using TRIFFID is better).
comparison of hydraulic configuration respond to choice of Standard or Sinclair

- the overlap of modelled and observed distributions with BC and VG for the range of $\Psi_{S,C}$ and standard JULES values.

The differences between hydraulic configurations in model performance is more noticeable than the TRIFFID.

- Generally BC shows higher overlap compared to VG (e.g. site 2 AU-Fog).
Generally, $\Psi_{0.5}$ and standard JULES seem to have the highest overlap values in Grass, Crop, Forests, and Savannas, with some exceptions.
In Shrublands and wetlands, $\Psi_{2.5}$ becomes important too.

In some sites, use of Sinclair does not make any improvements to the overlap efficiency metric (e.g. site 53 US-Tw1). The reason is that the model output and observations are too far from each other for the variation in $\Psi_{s,c}$ to make a difference.
seasons impact on overlap improvement in GPP using JULES-Sinclair instead of standard JULES

summer is mostly the season that improvement happens
Hydraulic configuration affects seasonal improvement

Savanna:

Shrubland:
Improvement in $\Psi_{S,C}$ changes year by year

- E.g. at site 58 (US-Whs), most improvement happened in summer 2012 by using BC with $\Psi_2$. 

[Graphs showing overlap and improvement over years for different conditions BC and VG]
An example of model underestimation

- We know that in US-Whs, in summer 2012, using BC resulted in more improvement than VG. The GPP and β plots show:
An example of model overestimation
BC and VG do not always agree on the best $\Psi_{S,C}$
CONCLUSION
Conclusion

- overall, BC in summer tends to results in improvement.
- in case of overestimation of GPP (or LE), $\Psi_{0.5}$ can be used.
- in case of underestimation of GPP (or LE), $\Psi_{2.5}$ or JULES standard can be used.
- TRIFFID does not make much difference in model improvement.
- The improvement in model efficiency differs based on:
  - selected hydraulic scheme: Brooks and Corey or van Genuchten
  - selected model variable: Latent heat/GPP.
  - selected year, season (which implicitly depends on climate)
  - vegetation type and soil type?
Future work

• The identified best stress parameters can be applied to:
  – stomatal conductance
  – mesophyll conductance
  – $V_{\text{cmax}}$ and $J_{\text{max}}$.

  to find the best application method.

• It might be an idea to use machine learning to find the best stress parameter across non-fluxnet sites, after it was found when and why the model overestimates/underestimates.
Acknowledgement

• This research was funded by IMPETUS (Improving Predictions of Drought for user Decision-making).
References