Improvement of Vegetation Soil Moisture Stress Simulation in JULES

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INTRODUCTION

- There are 2 configurations available in JULES Rose/Cylc suite u-al752 for calculation of plant soil water stress:

Index	Param. Sym.	Param. name	Param. unit	JULES model name	Variable symbol	Variable name	Variable unit	Lower value	Corresponding soil conditions	Upper value	Corresponding soil conditions
1	θ	Volumetric soil water content	$\frac{m^3}{m^3}$	Standard	β	Soil water availability to plants	(-)	0	dry	1	wet
2	$\psi_{s,c}$	Soil water potential when stomata close	MPa	Sinclair	RT	Relative transpiration	(-)	0.033	dry	2.5	wet

$$\beta = 0 \le \frac{\Theta - \Theta_{PWP}}{\Theta_{FC} - \Theta_{PWP}} \le 1$$

θ_{pwp} : soil water content at permanent wilting point (m^3 / m^3)

θ_{FC} : soil water content at field capacity (m^3 / m^3)

$$RT = 1 - \frac{\Psi_s}{\Psi_e}$$

Ψ_s : soil water potential (Mpa)

Ψ_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 Ψ_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 (θ) (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;
  - Presentation by Verhoef.A , Gregorio Egea.G , Vidale.PL and Sarojini.B, 2017, Representation of soil water stress in Land Surface Models)

Questions

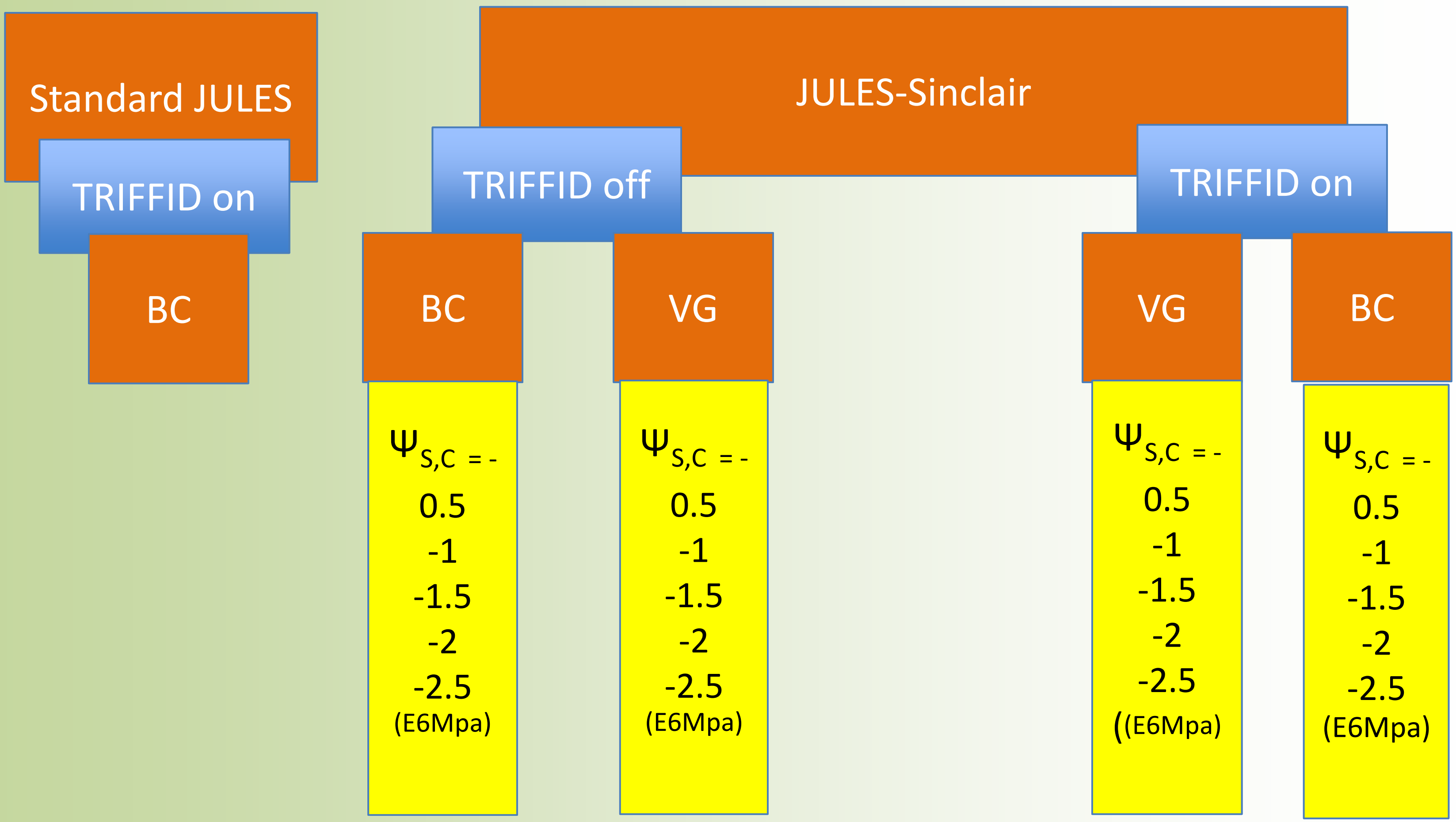
- In what cases the use of Standard JULES or Sinclair is advised to simulate plant soil water stress?
- What difference do TRIFFID on/off, BC and VG configurations make in the simulation of plant soil water stress?

Methodology

Change of JULES configurations to adopt Sinclair

Code name	JULES Sinclair	Standard JULES	comment
l_use_pft_psi	true	false	use/not use of soil water potential
fsmc_shape	1	0	Shape of the β depends on soil water potential (if not, it should depend on the volumetric soil moisture content)
psi_open_io=	0	9*-0.033E6	*Maximum value of Ψs, o (soil water potential when stomata are open, the wet end)*

Setting up JULES runs



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)

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

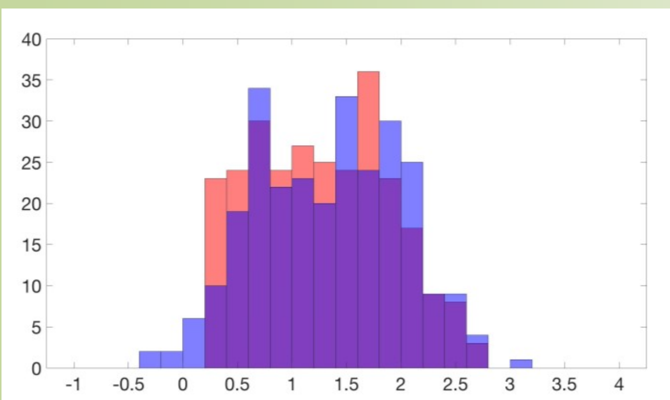
- distribution overlap

Efficiency metric: Distribution overlap

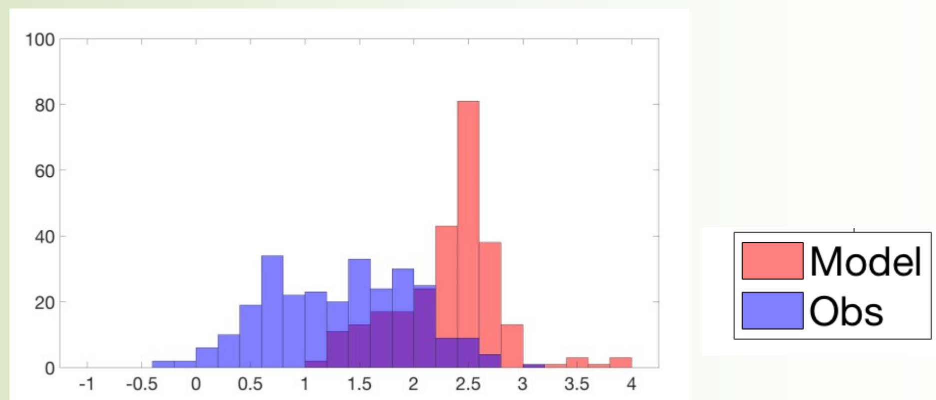
- distribution overlap efficiency, is the normalized shared area between two distributions (Weitzman, 1970).

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

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



$\Psi_{S,C}$ = -0.5 E6MPa



$\Psi_{S,C}$ = -2.5 E6Map

efficiency improvement

- Efficiency improvement (*E_i*) calculation for GPP and latent heat

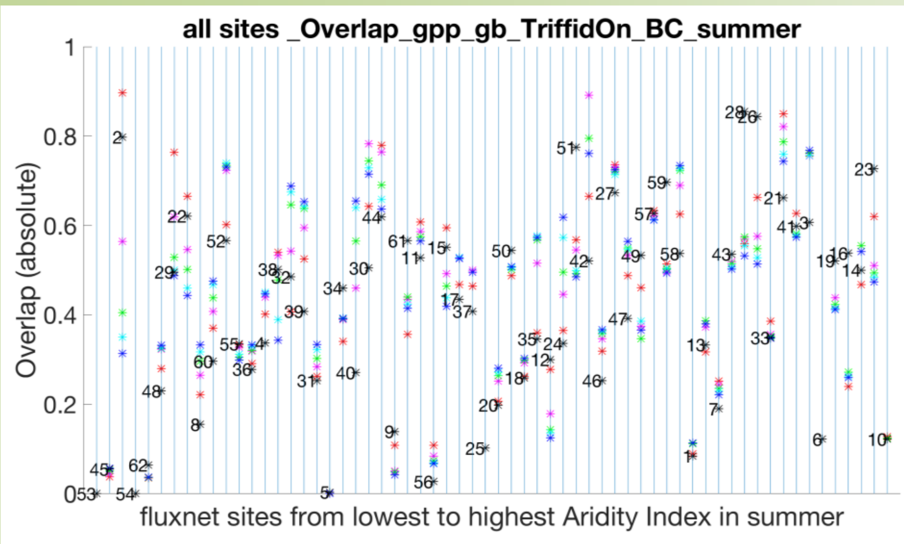
$$E_i = E_{\psi_n} - E_{std}$$

$E_{\psi n}$ is the efficiency metric when *Ψs,c = -0.5, -1, -1.5, -2, -2.5 E6Mpa.*

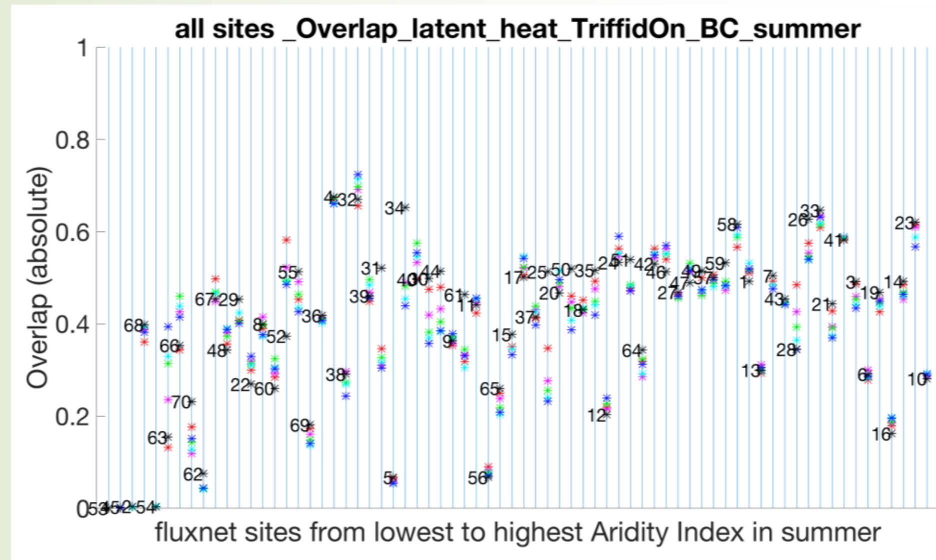
RESULTS

Comparison of GPP and latent heat sensitivity to $\Psi_{S,C}$ values

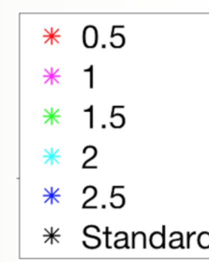
the overlap of modelled and observed **GPP and LE** distributions for the range of $\Psi_{S,C}$ and standard JULES values:



GPP



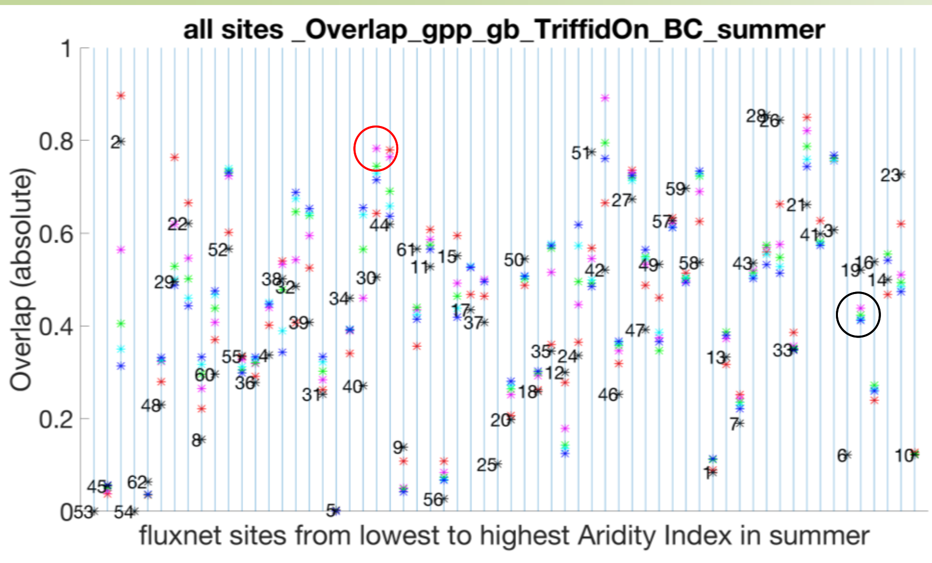
LE



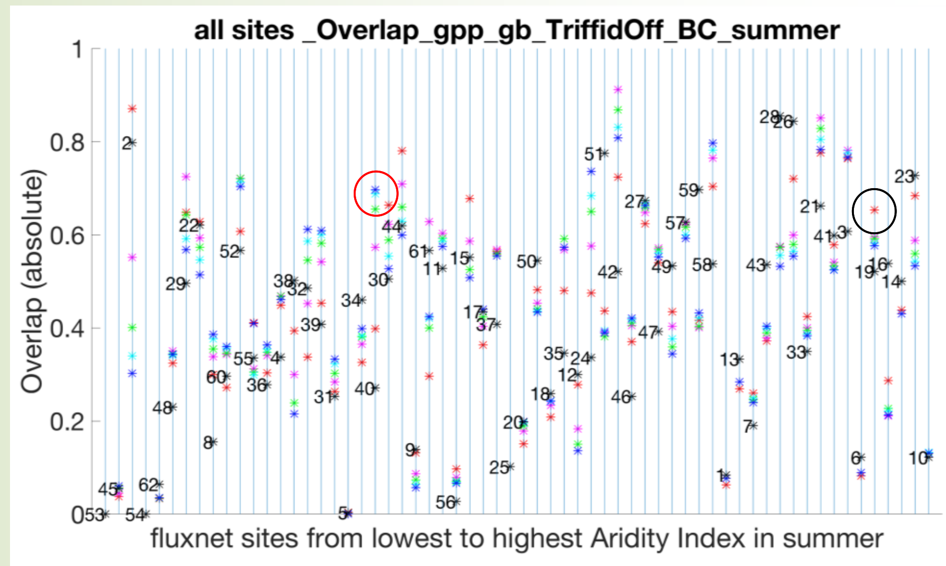
GPP shows higher overlap values and more variability compared to LE.

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:



TRIFFID on

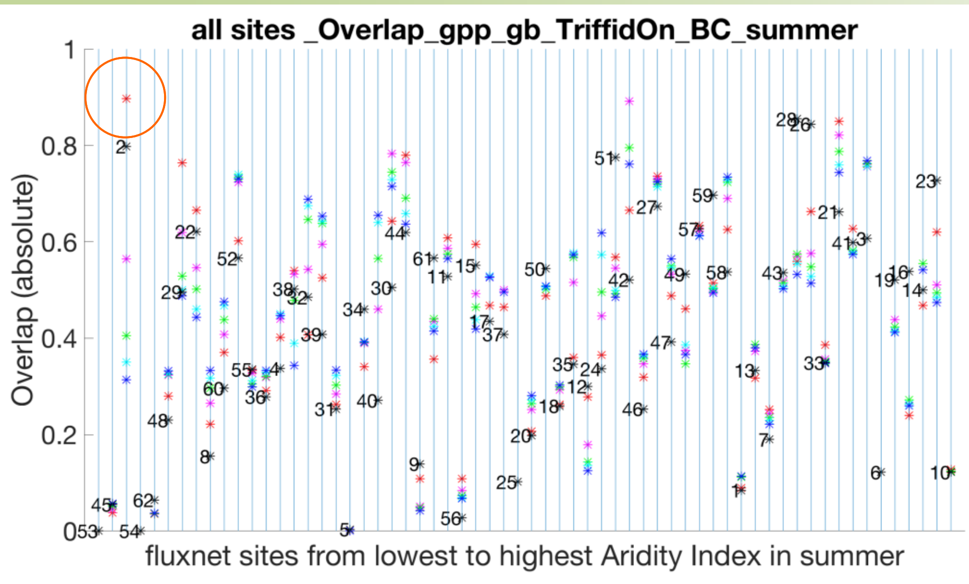


TRIFFID off

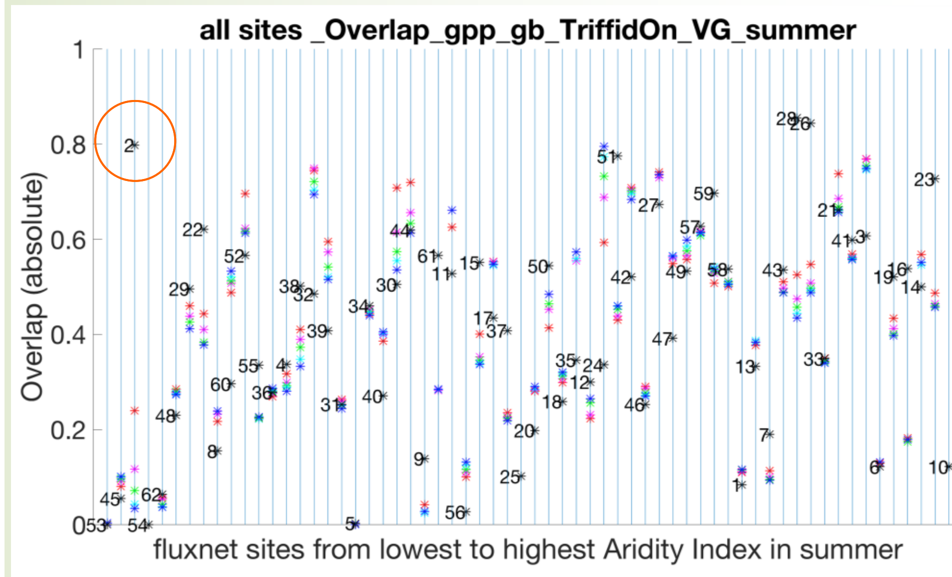
- There are very slight differences between TRIFFID on and off configurations regarding the model improvement (site 19 DE-Sfn, or site 30 IT-Col, where using TRIFFID is better).

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.

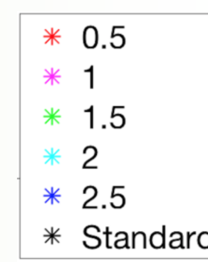


BC



VG

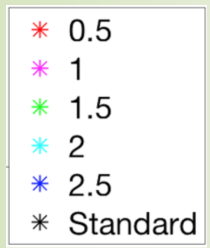
- The differences between hydraulic configurations in model performance is more noticeable than the TRIFFID.
- Generally BC shows higher overlap compared to VG (e.g. site 2 AU-Fog).

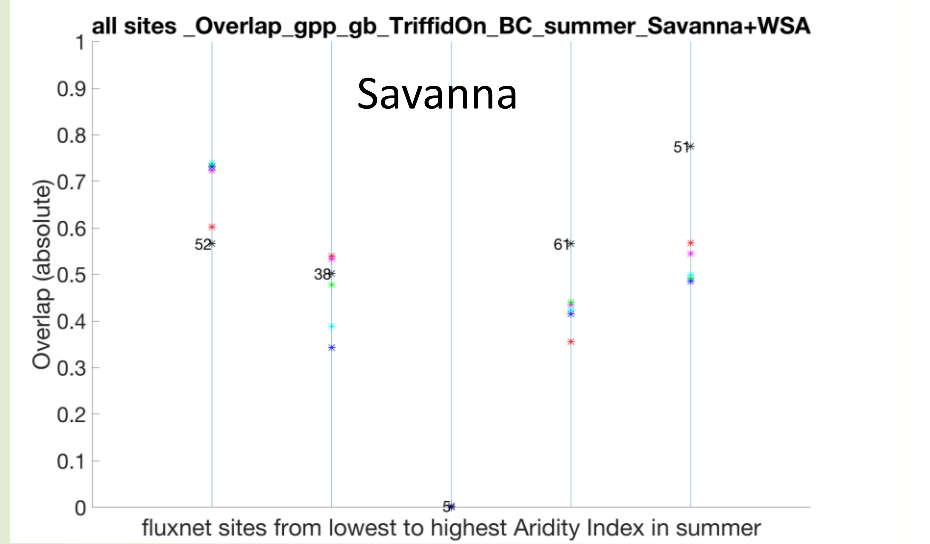


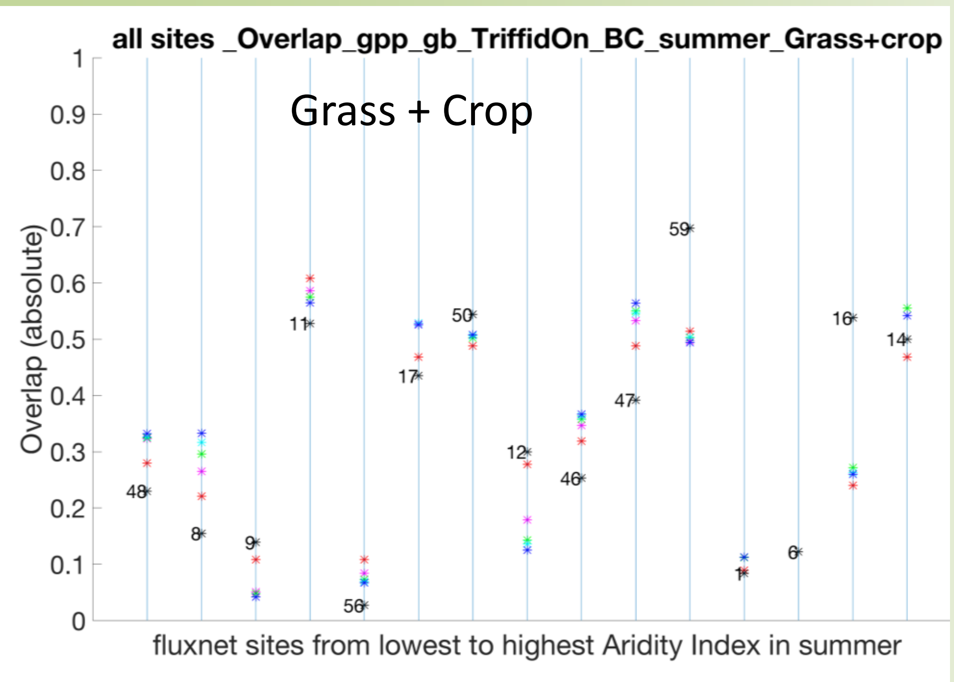
vegetation cover classification

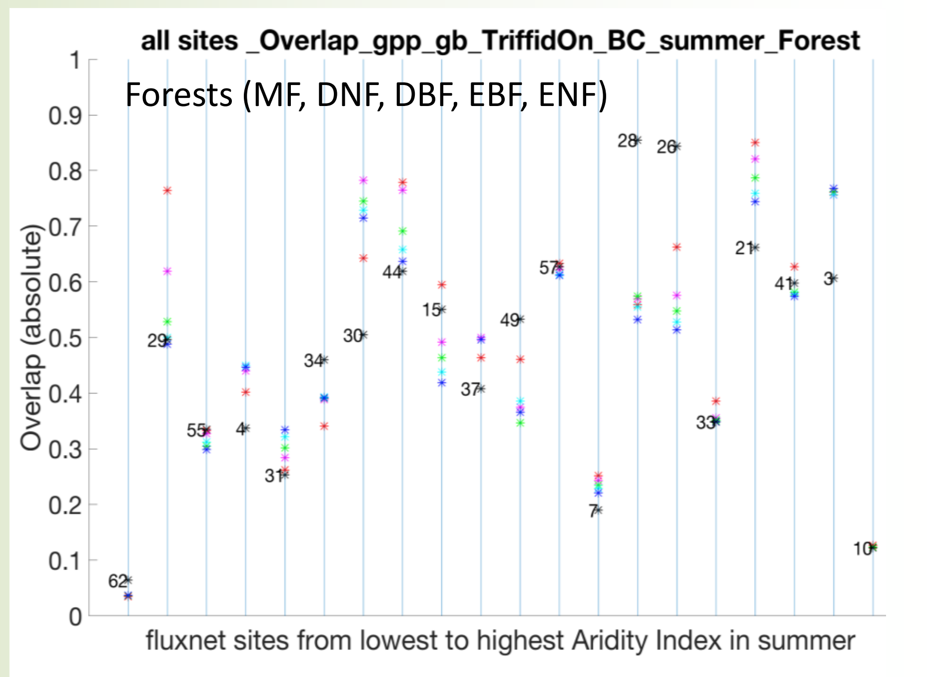
Generally, $\Psi_{0.5}$ and standard JULES seem to have the highest overlap values in Grass, Crop, Forests, and Savannas, with some exceptions.

Savanna

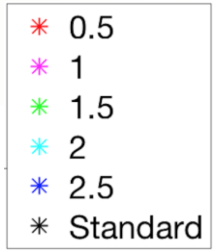


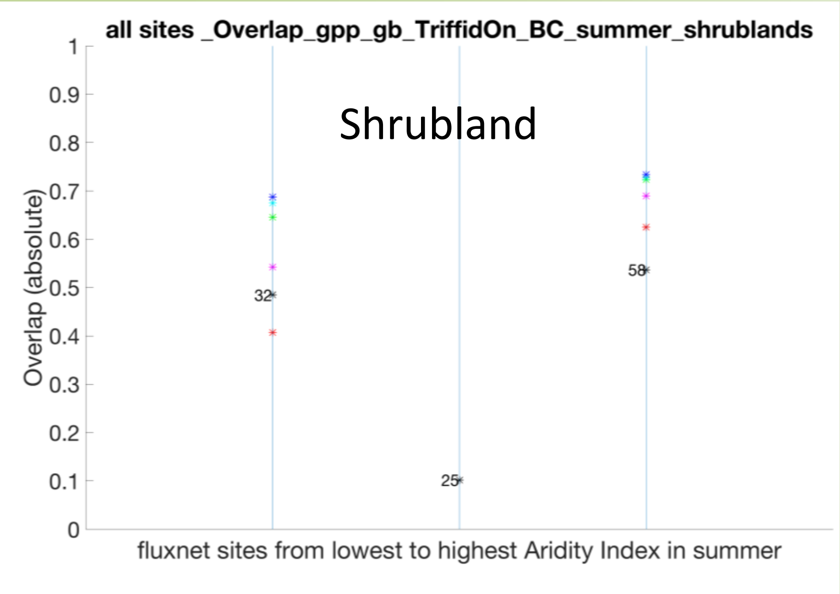


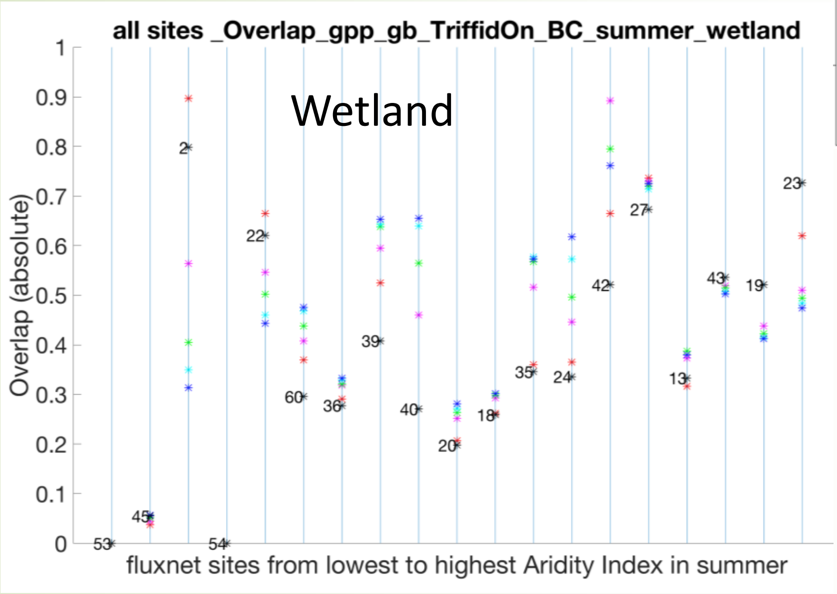




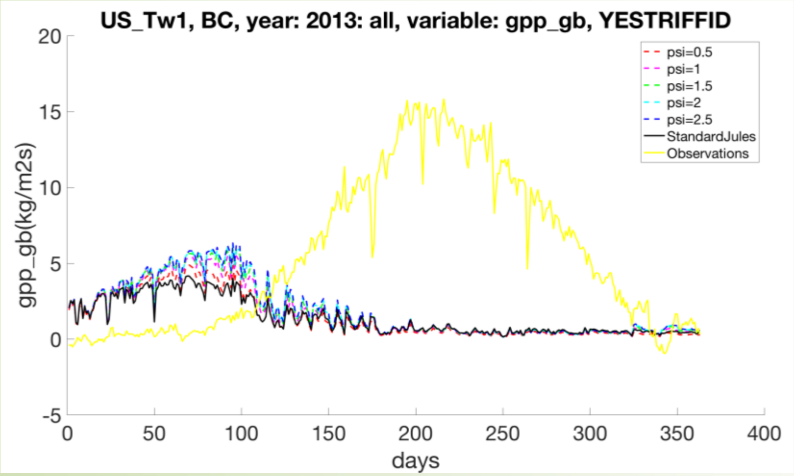
In Shrublands and wetlands, $\Psi_{2.5}$ becomes important too.



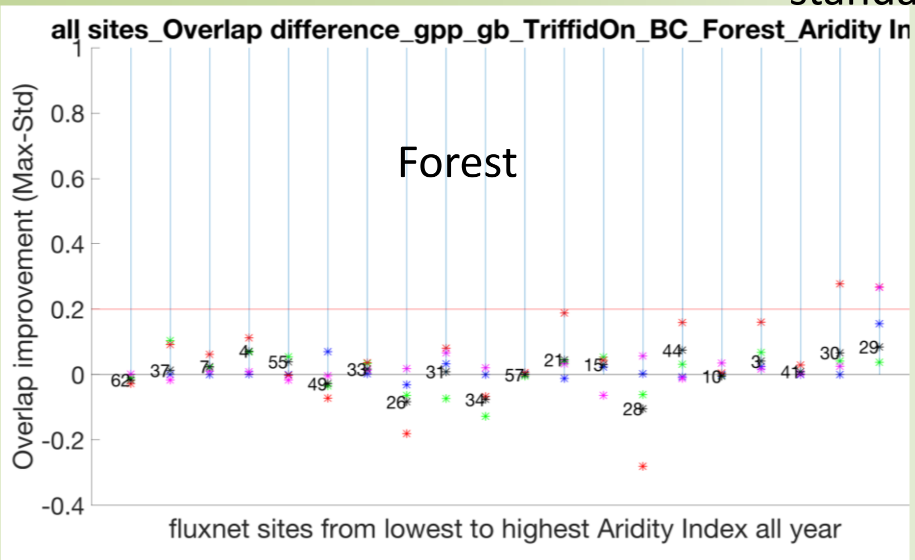


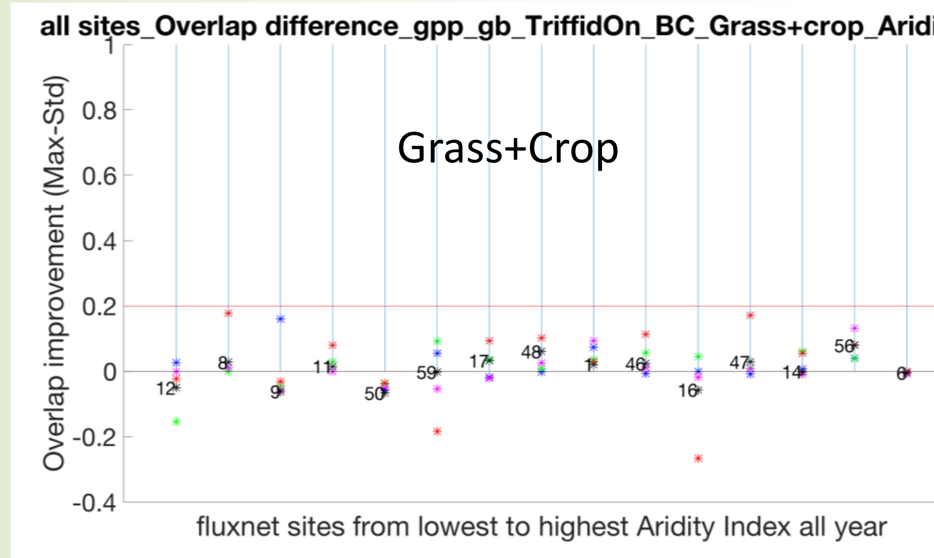


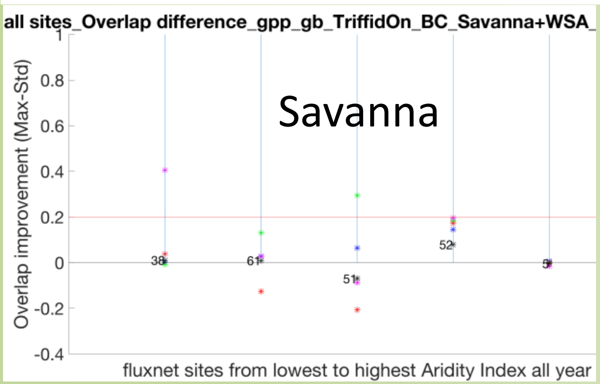
In some sites, use of Sinclair does not make any improvements to the overlap efficiency metric (e.g. site 53 US-Tw1). The reason is that the model output and observations are too far from each other for the variation in $\Psi_{s,c}$ to make a difference.



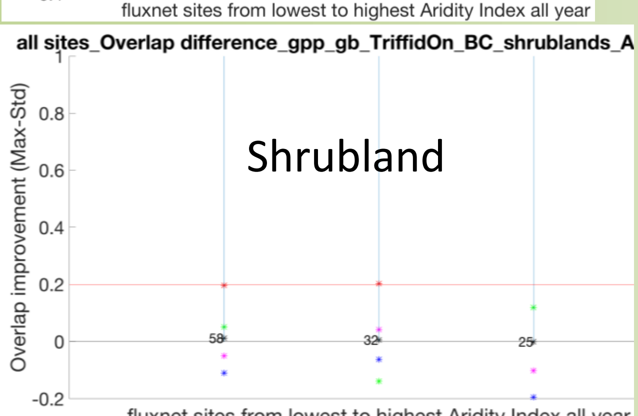
seasons impact on overlap improvement in GPP using JULES- Sinclair instead of standard JULES

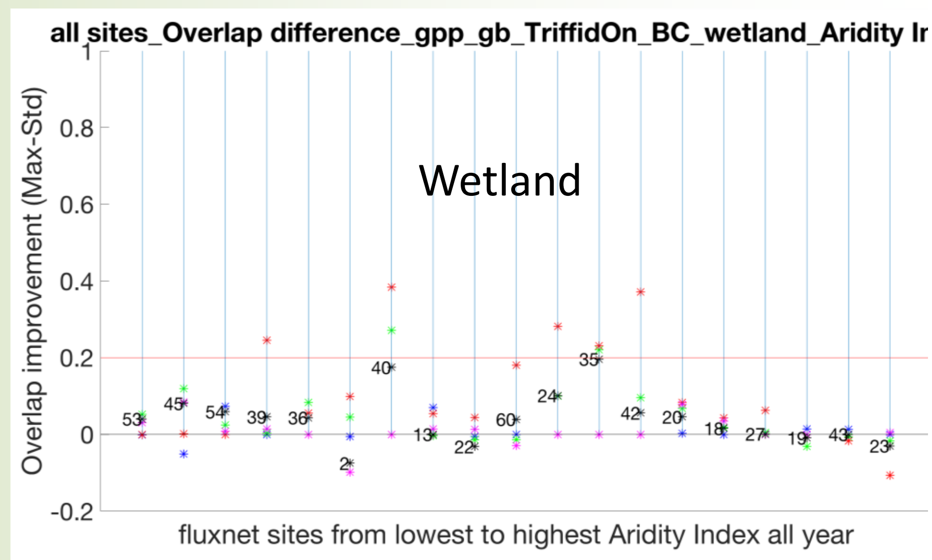




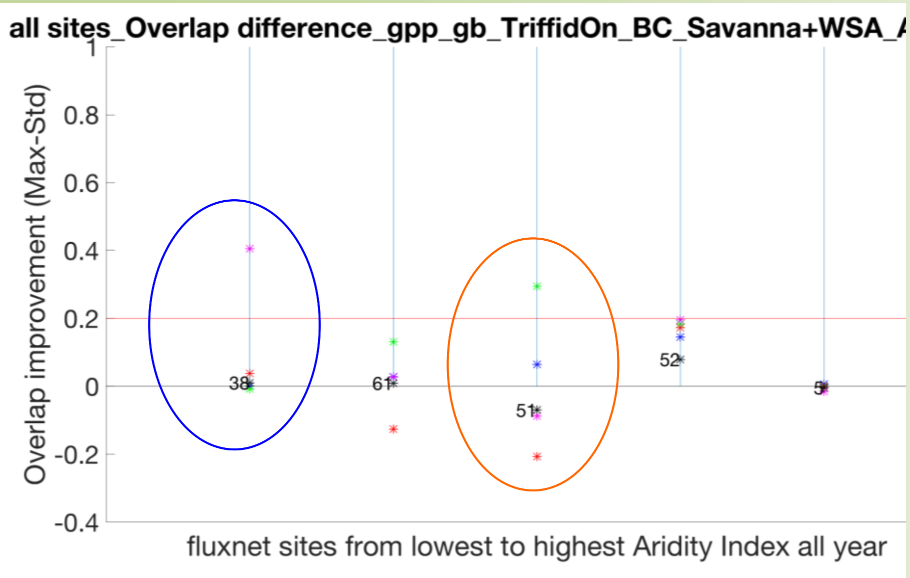


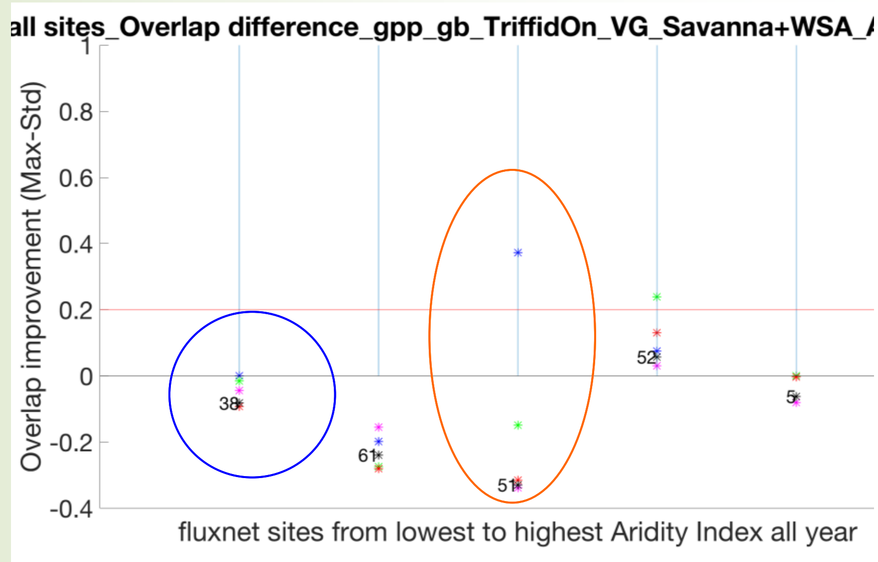
summer is mostly the season that improvement happens





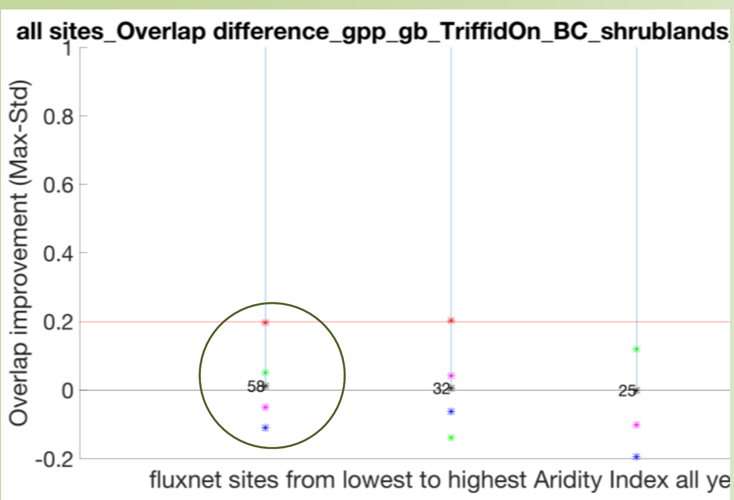
Hydraulic configuration affects seasonal improvement

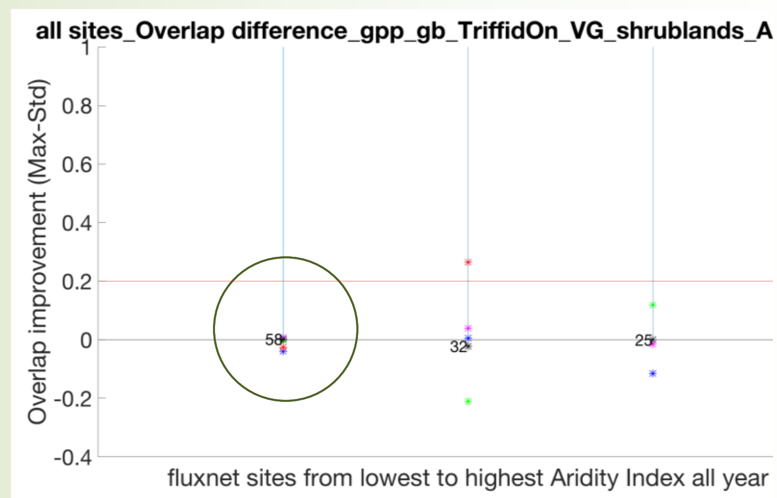




Savanna: BC

VG



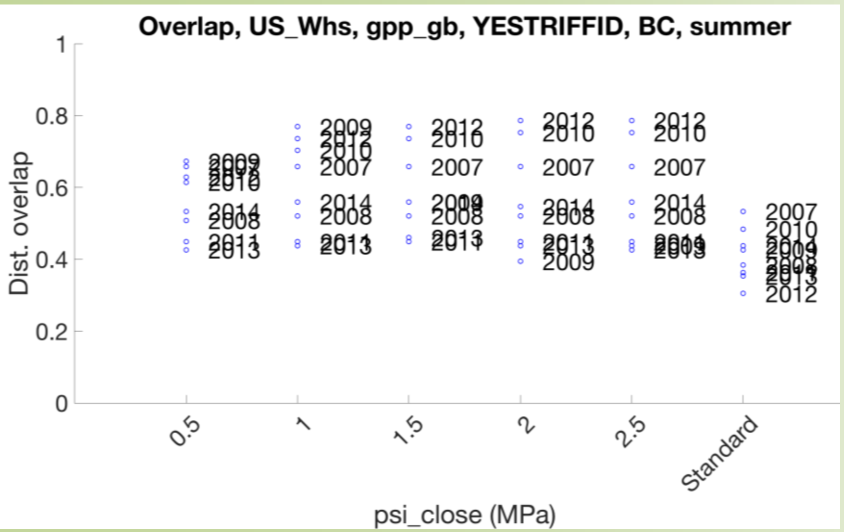


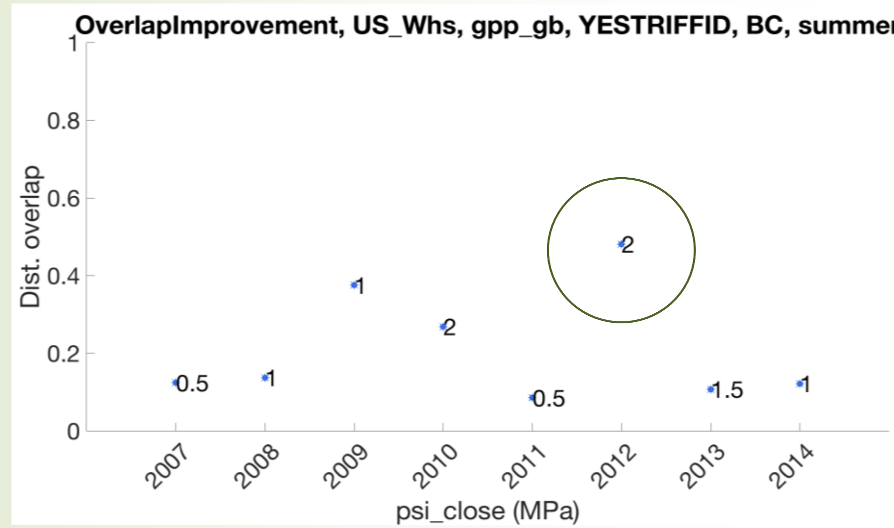
Shrubland: BC

VG

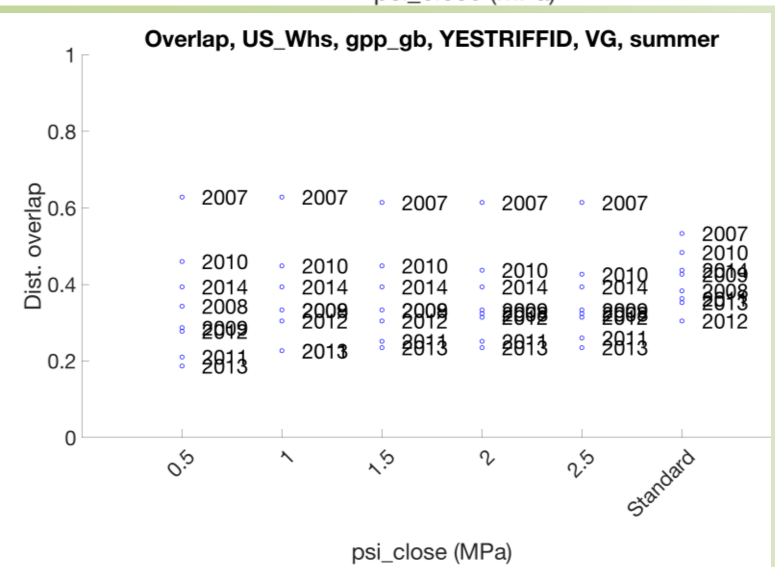
Improvement in $\Psi_{s,c}$ changes year by year

- E.g. at site 58 (US-Whs), most improvement happened in summer 2012 by using BC with Ψ_2 .

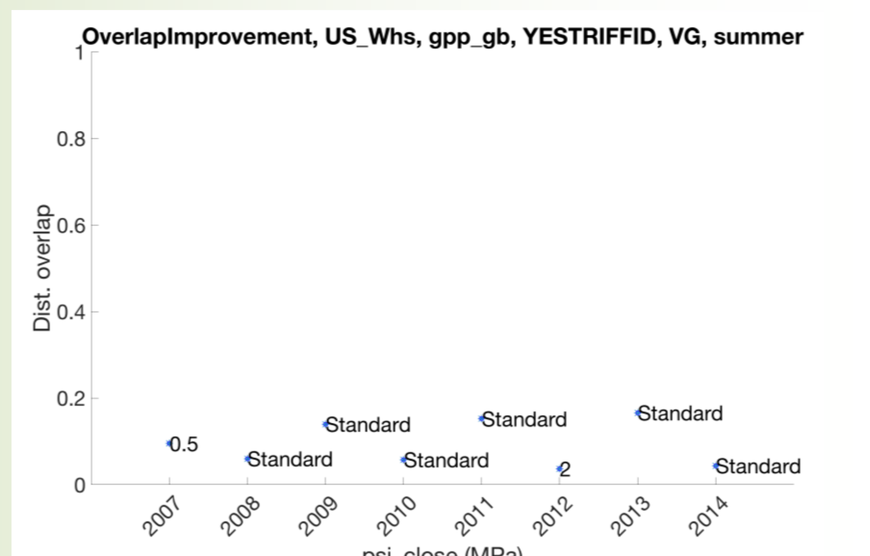




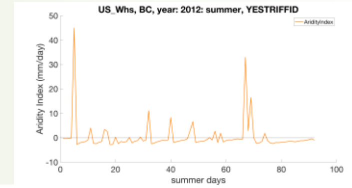
BC

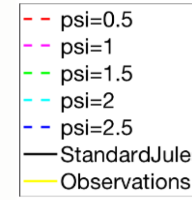


VG

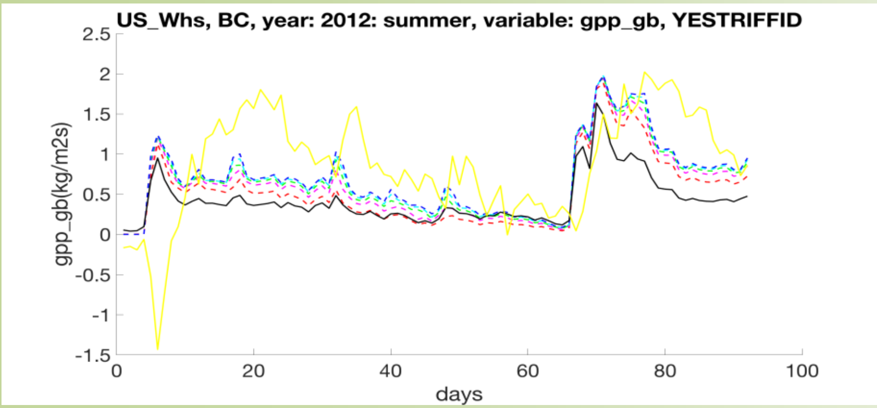


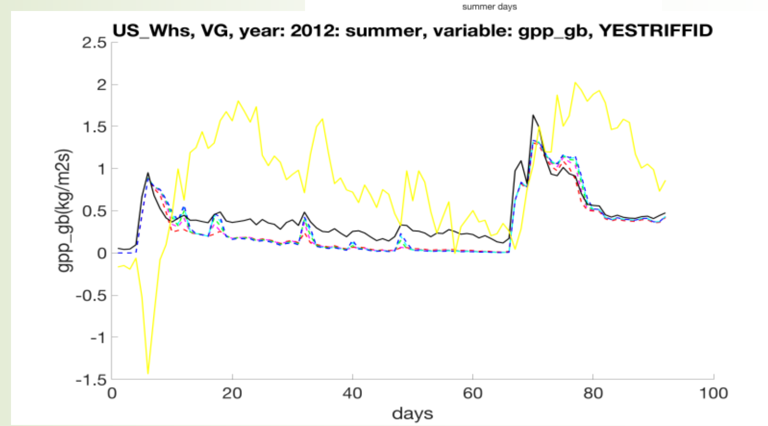
An example of model underestimation



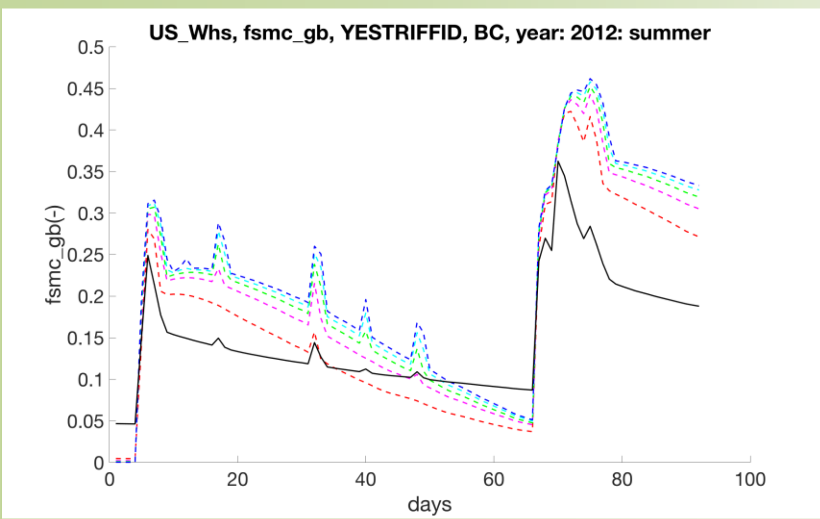


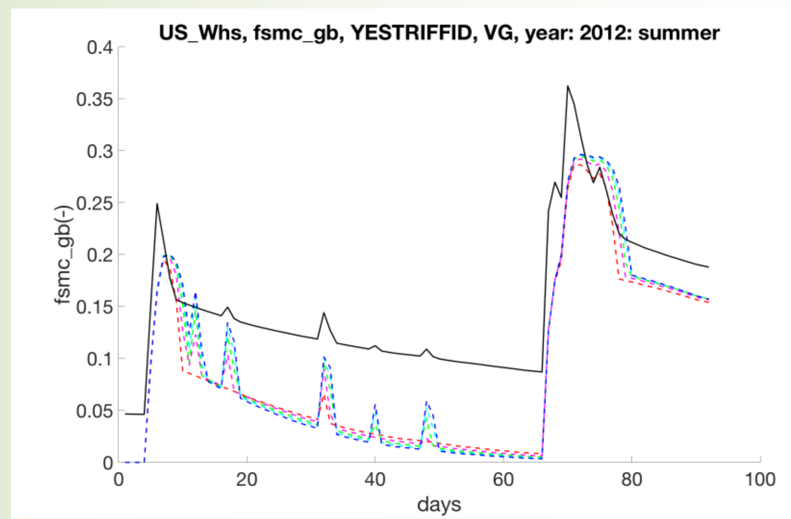
- We know that in US-Whs, in summer 2012, using BC resulted in more improvement than VG. The GPP and β plots show:





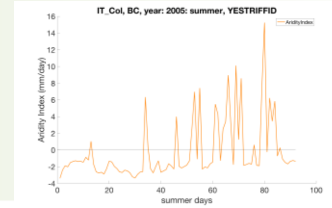
GPP: BC VG

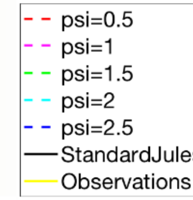


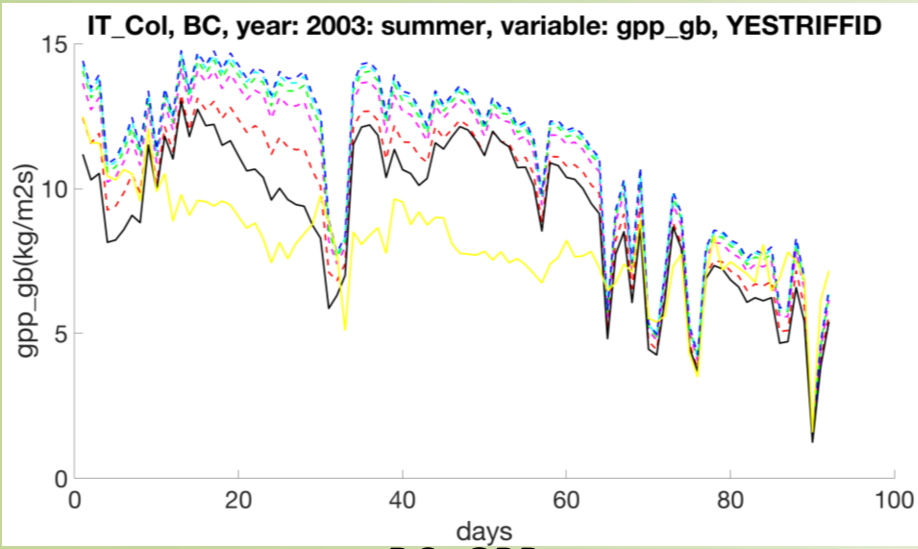


β: BC VG

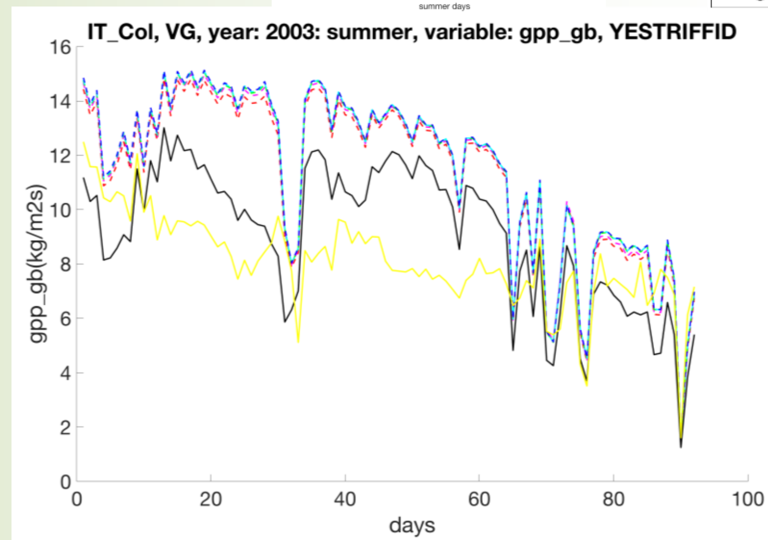
An example of model overestimation



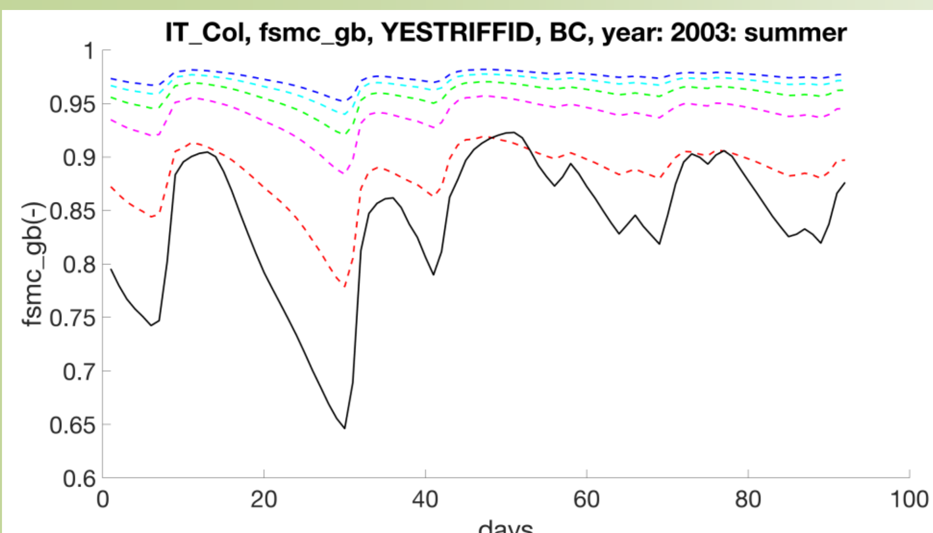




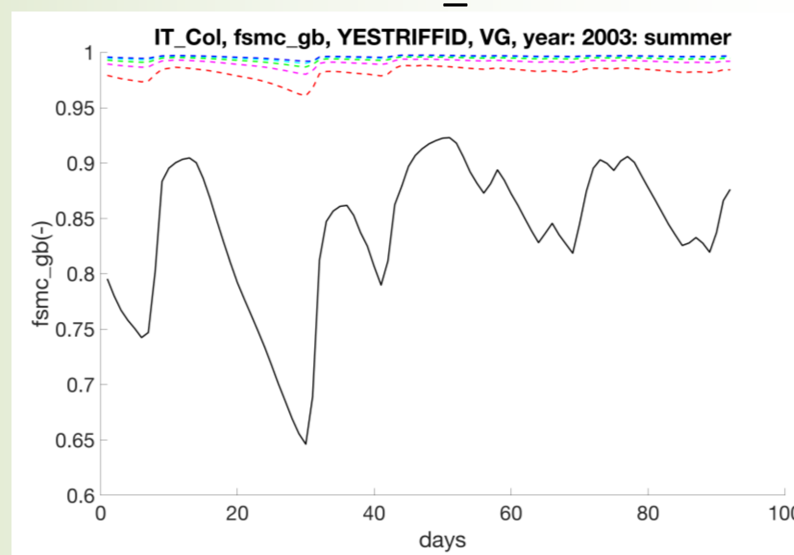
BC_GPP



VG_GPP

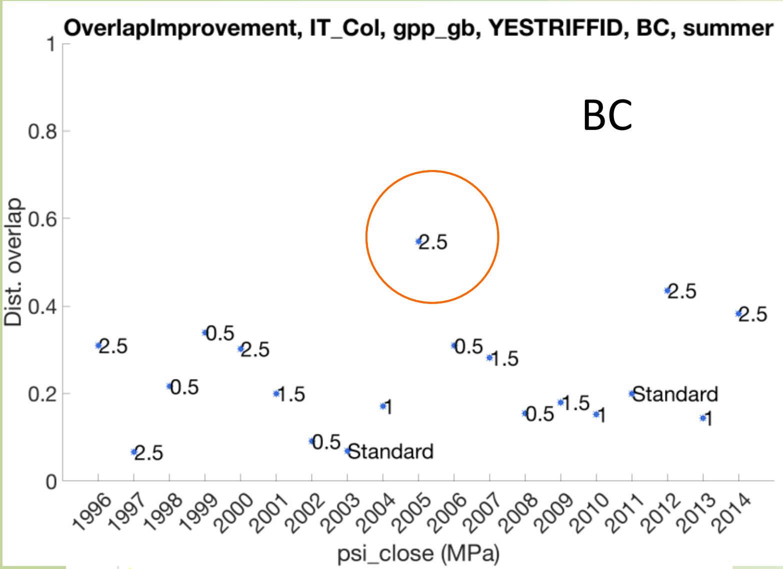


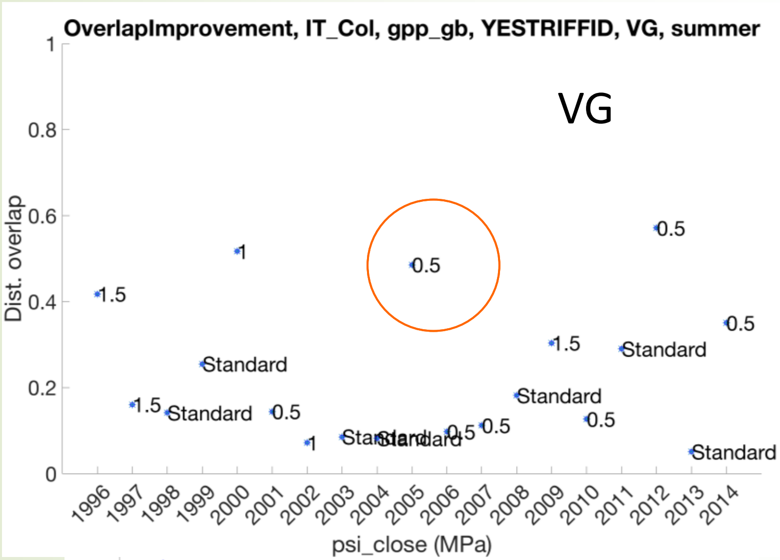
BC_Beta

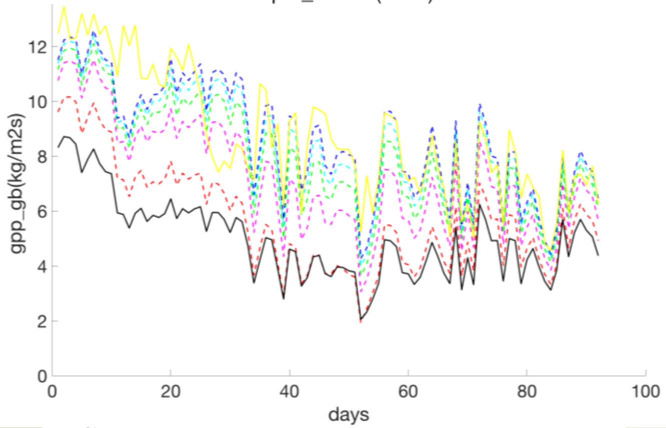


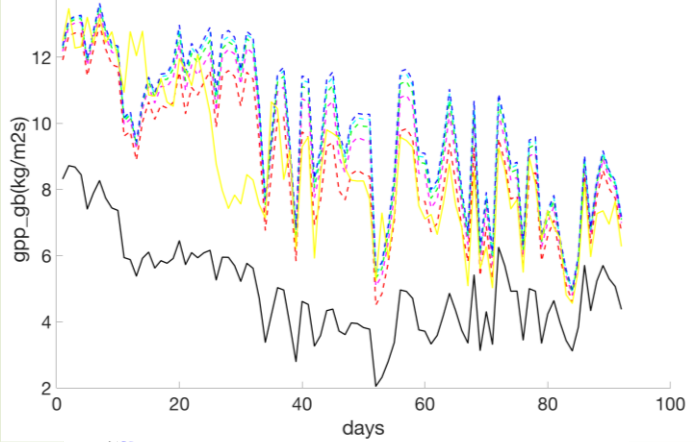
VG_Beta

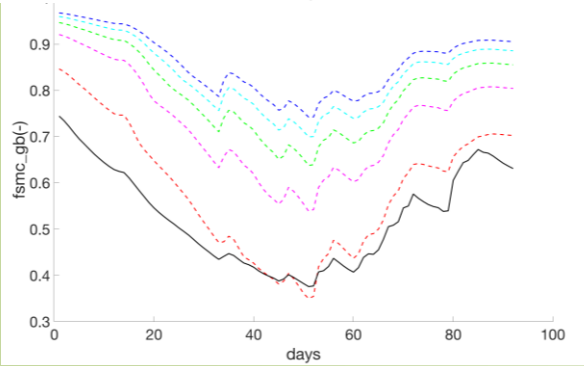
BC and VG do not always agree on the best $\Psi_{S,C}$

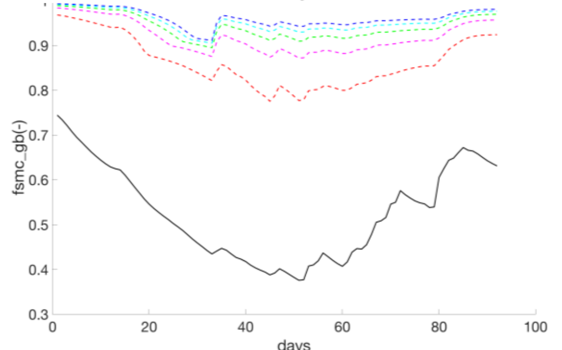












CONCLUSION

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
  - Vcmax and Jmax.

  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

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