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Crop modelling with JULES using productivity optimisation arguments

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July 23rd, 2019

Motivation

Humans and their choices are a vital part of Earth system models.

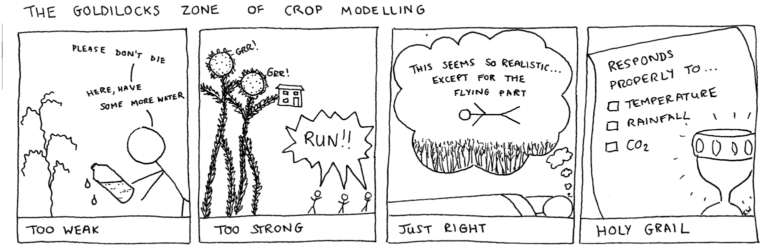
For example, crops are important factor in

- modelling surface properties
- food and water resource modelling

Motivation

Impacts parameterisations need to interact with the rest of the Earth system model in a physically meaningful way.

For example, crops need the correct response to climate.



Motivation

- JULES-crop (Osborne et al 2015, KW et al 2017) is a crop parameterisation in the JULES land-surface model.
- JULES-crop is only available in 'offline' JULES runs i.e. it can not yet be coupled to an atmospheric model.
- In the UK Earth System Model 1 (UKESM1), crops are modelled by JULES as natural vegetation, with reserved space and a proportion of plant carbon added to soil and atmosphere at each timestep.

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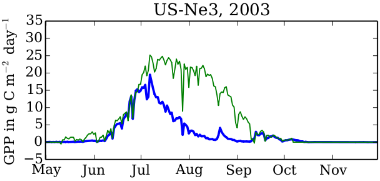
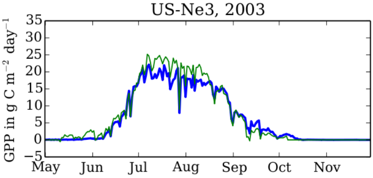
Motivation

(a) JULES-crop can overexaggerate water stress.

E.g. Rainfed maize at FLUXNET site US-Ne3, blue is model, green is observations.



Water stress switched on

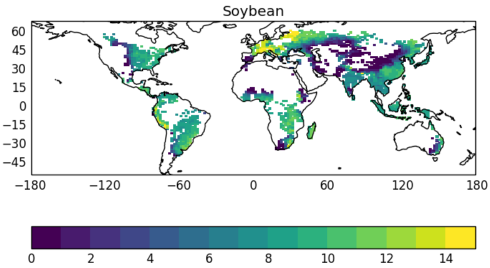


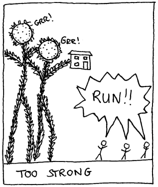
Water stress switched off

Motivation

(b) JULES-crop can grow unrealistically large plants

E.g. Maximum soybean leaf area index (LAI) in the Osborne et al 2015 global run.



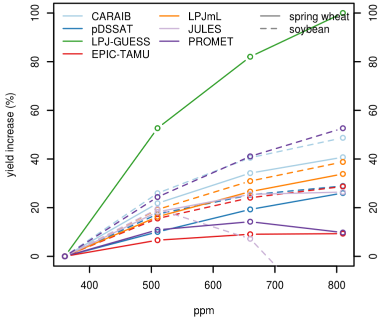


Crop is forcibly killed at LAI=15.

Leads to misleading results.

Motivation

Global yield increase for irrigated spring wheat and soybean under different CO_2 levels for AGMIP GGCMI phase 2 model runs (plot from Christoph Müller).



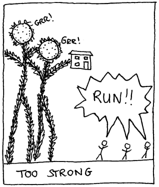
Nose-dive in JULES-crop soybean yield is **not** realistic. It's a result of the crop being killed when LAI = 15.

(a) JULES-crop can overexaggerate water stress.

Solution: Get experts from across the JULES community (and related areas) involved in finding improvements

→ the 1st JULES Process Evaluation Group (Anna's talk),
→ AGMIP maize ET study (round 1: Kimball et al 2019, round 2 coming soon).

(b) JULES-crop can grow unrealistically large plants.



Solution: Simplify the model and then impose 'common sense' e.g. by optimisation arguments.

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JULES-opticrop

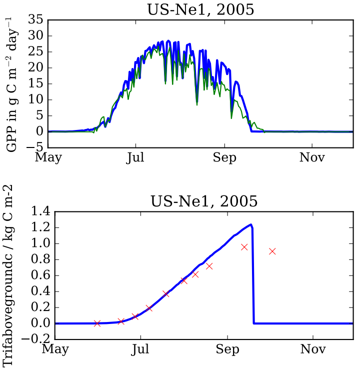
- A simplified crop parameterisation in JULES (sits between UKESM1 crops and JULES-crop).
- Aim: start with ‘sensible’ values. Then add optimisation arguments (not got to this bit yet).
- But even with the ‘sensible’ values, already have a much more stable model - can start using it for practical applications.

JULES-crop vs JULES-opticrop

	JULES-crop	JULES-opticrop
Parameters	28 new parameters per crop tile (in JULES_CROPPARM namelist).	JULES-opticrop has no new parameters outside those already used by JULES natural vegetation and TRIFFID
Ancils	Sowing date, thermal time between emergence and flowering, thermal time between flowering and harvest.	Emergence date, date senescence starts, maturity date.
Prognostics	Root carbon, harvest carbon, reserve pool carbon, DVI	Harvest carbon.
Plant development	Crop development (DVI) calculated from thermal time. Partitioning of NPP to carbon pools (leaf, root, stem, stem reserve, harvest) and specific leaf area depend on DVI.	Crop is initialised on emergence day and gets grown by TRIFFID. Excess carbon as maximum LAI is aproached is put in the harvest carbon pool, rather than used for spreading.
Senescence	Daily reduction of leaf carbon parameterised by DVI.	Extension to JULES phenology scheme, uses new ancils. Difference between actual LAI and balanced LAI is put in harvest pool.
Harvest	A number of harvest triggers (DVI=2, LAI=15 etc). Harvest carbon converted to crop yield.	On maturity day, harvest carbon goes to TRIFFID CO_2, rest to litter.

JULES-opticrop with sensible parameters

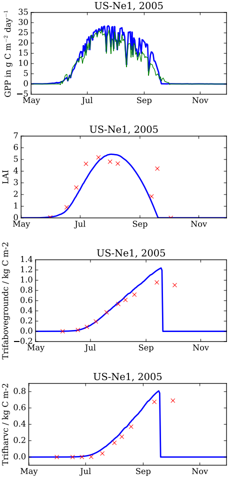
One example year of irrigated maize (Mead, Nebraska - golden site):



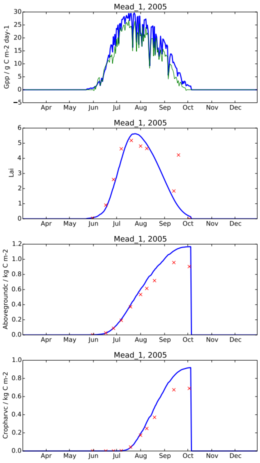
Blue: model. Green/red: observations.

JULES-opticrop compared to JULES-crop

JULES-opticrop



JULES-crop (from KW et al 2017)



Gross Primary Productivity

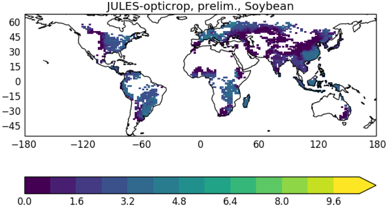
Leaf Area Index

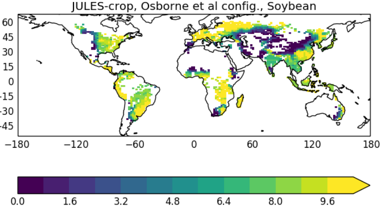
Above-ground carbon

Harvest carbon

JULES-opticrop compared to JULES-crop

Maximum Leaf Area Index





In this JULES-opticrop run, LAI_{max} is set to 5.

$\rightarrow$ in the future, want to set this (and other parameters) from optimisation arguments.

JULES-opticrop

This simpler crop parameterisation also allows a much more transparent investigation of model behaviour.

- We are using JULES-opticrop to explore the effect of different adaptation strategies e.g. moving to crop varieties with different thermal time parameters (which govern the season length) or leaf assimilation properties.

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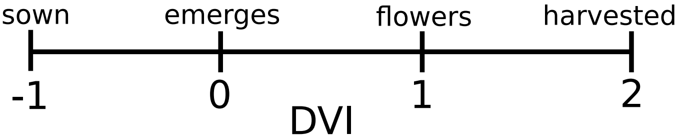
Summary

- An important application of JULES (offline and online) is to model food resources, vegetation, water availability, and land-surface feedbacks.
- These components need to interact in a meaningful way.
- JULES-opticrop will allow us to explore how optimisation arguments can make the interactions more realistic. This will give increased confidence in the resulting projections, and enable them to be used to explore adaptation options.
- This simple model will also allow us to pick apart and evaluate the various different processes involved in simulating a crop in JULES $\rightarrow$ will feed in to JULES-crop model development.

Additional slides

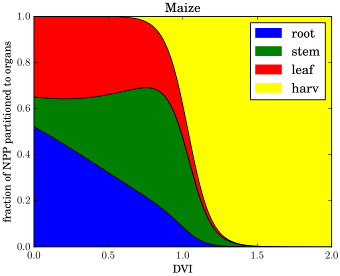
JULES-crop

- JULES-crop is a generic parameterisation of crops, which has been in JULES since version 4.0 (Osborne et al 2015).
- Each crop is treated as a separate surface tile.
- Rate of crop development is determined by temperature and parametrised by the crop development index (DVI).



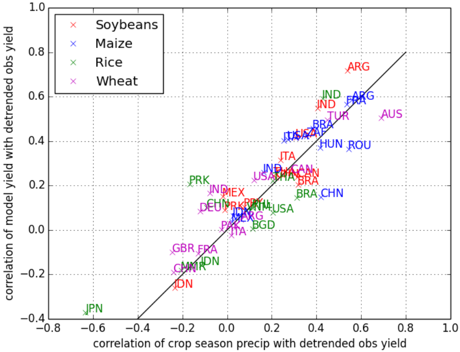
JULES-crop carbon pools

- NPP is distributed to leaf, root, stem, harvest and reserve carbon pools according to DVI.
- Carbon is moved between carbon pools to simulate the remobilisation of stem reserves and leaf senescence.
- LAI is calculated from leaf carbon, canopy height is calculated from stem carbon



JULES-crop results

Correlations with FAO yield observations

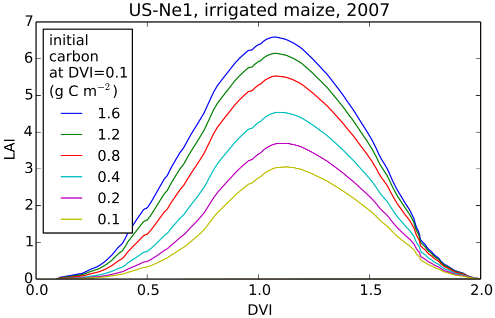


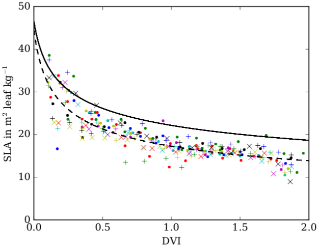
JULES-crop does roughly as well as crop season precipitation.
Is this for the right reasons? We've already seen that JULES may be too sensitive to water availability

→ consider whether using crop season precipitation is more transparent for your application.

JULES-crop

Feedback between leaf area and productivity means that crop is oversensitive to early conditions, which affects interannual variability (Williams et al 2017).





Points: maize observations (US-Ne1/2/3)
Solid line: Osborne et al 2015 parameters
Dashed line: Williams et al 2017 parameters.

Prescribing LAI

For some applications, it can be more suitable to turn the crop model off and prescribe LAI instead. PFT parameters can still be tuned to that crop (e.g. Williams et al 2017).

Advantage: More stable at the moment.

Disadvantage: Missing the features of the crop model e.g. explicit carbon pool modelling. Have to get LAI from somewhere.

Prescribed LAI runs can also be useful for tuning crop model runs.

preliminary JULES-opticrop yield