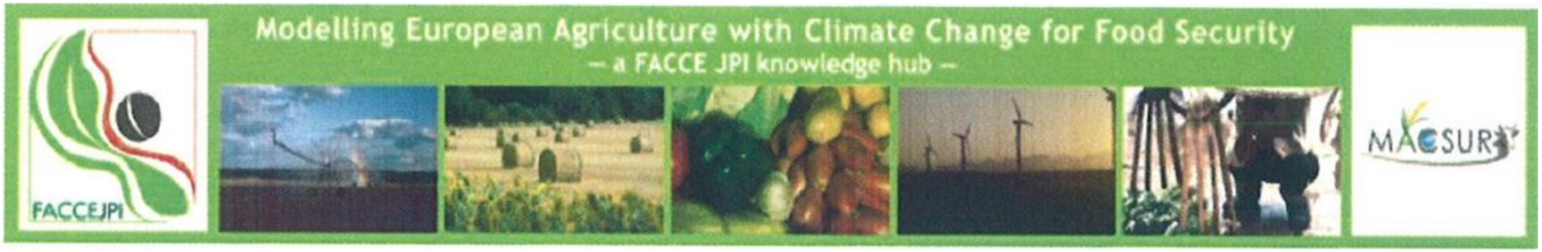

Assessing modelling approaches for simulating the effect of high temperature stress on yield

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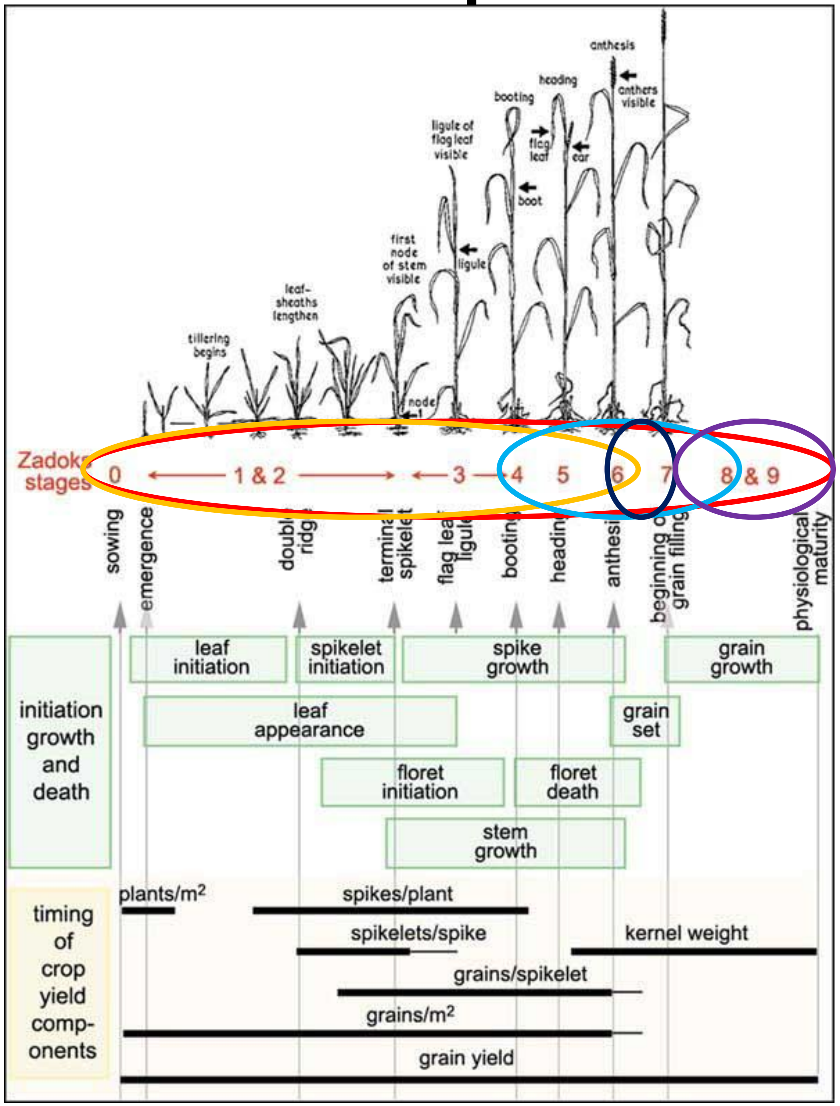
Introduction

- Heat stress has been shown to have strongly affected crop yields historically e.g. for maize in Africa (Lobell et al. 2011); and wheat in China (Liu et al. 2013) and France (Hawkins et al. 2012)
- With an increase of extreme events in the future (IPCC 2012) the impact of heat stress on crop yield are expected to become larger
- Several models are now beginning to include heat stress functions (e.g. APSIM, AQUACROP, CERES, ECOSYS, GLAM, GAEZ, MCLWA, PEGASUS, REGCROP)
- Simulation studies have shown large projected decreases in simulated yield due to an increase in the occurrence of high temperature events (Gobin 2010; Sanai et al. 2010; Semenov and Shewry 2011; Teixeira et al. 2013; Deryng et al. 2014)
- **Here we test three modeling approaches by implementing these into LPJ-GUESS**

Heat stress during different phenological stages



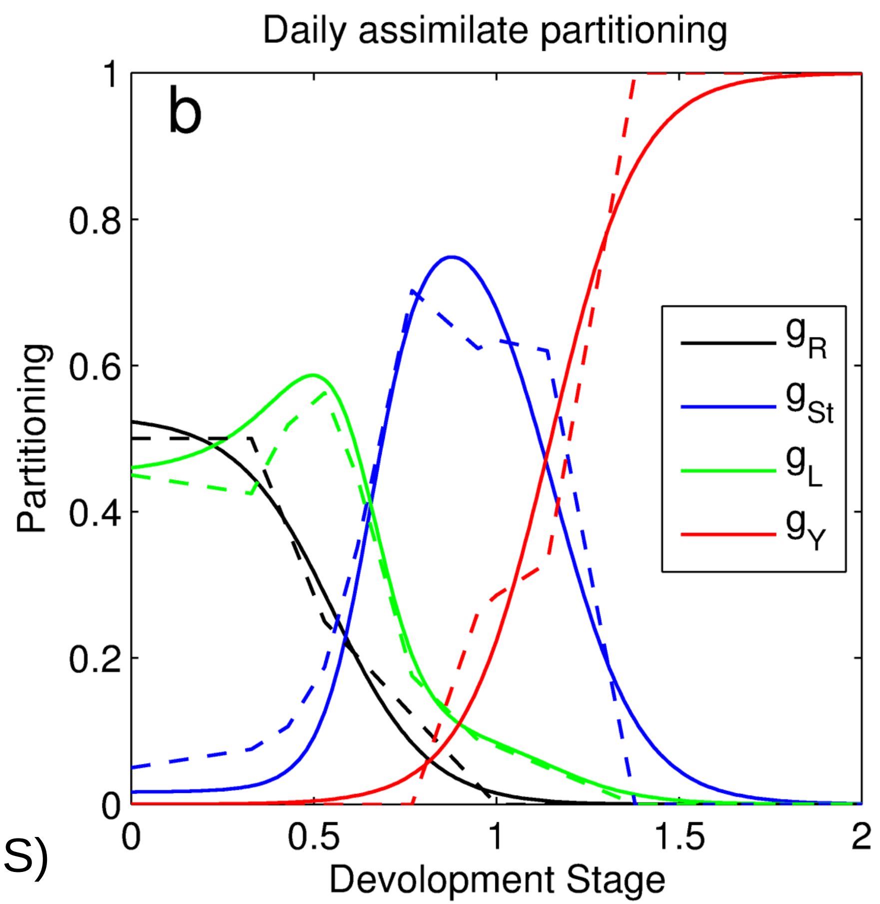
- Onset of phenological stages
- Photosynthesis
- Autotrophic respiration
- Lethal temperatures
- Senescence
- Grain set (near anthesis)
- Grain growth (grain filling)

LPJ-GUESS

- LPJ-GUESS (Smith et al.2001; 2014) is a Dynamical Vegetation Model optimized for regional to global application.
- Recent development include managed land (Lindeskog et al 2013; Olin et al. 2015).
- Plants and crops are represented by Plant Functional Types (PFTs) and Crop Functional Types (CFTs) (Bondeau et al. 2007)
- The model uses climate (temperature, precipitation, solar radiation), CO2, soil information and N fertilization as input
- Photosynthesis, stomatal conductance and respiration are simulated at a daily time step

Phenology and C-allocation

- Crop development is based on Wang and Engel (1998) 0.0<DS<2.0
- DS=1.0 -> Flowering
- DS=2.0 ->Maturity
- Carbon allocation is based on Penning deVries (1989)



Heat stress equations:
C_grain = allocation(ns) * HS
C_loss due to HS = allocation(ns) * (1.0 - HS)
HS=hs(f)*HS(gf)

GAEZ (Challinor et al. 2004; Teixeira et al. 2013)

Heat stress during flowering

If (tday < 27.0)

hs(f,d) = 1.0

if (tday > 40.0)

hs(f,d) = 0.0

if (tday >= 27.0 && tday <= 40.0)

hs(f,d) = 1.0 - (tday-27.0) / (40.0 -27.0)

Where hs(f) is the mean of hs(f,d) during flowering

Heat stress during grain filling

hs(gf)=1.0

CERES (Moreno-Sotomayor & Weiss, 2004):

Heat stress during flowering

if (tmean > 25.0)

hs_f = (-0.0626 *tmean) +2.57)

where *tmean* is the mean temperature during flowering

Heat stress during grain filling

if (dtemp > 20.0 & DS<1.5)

0.0058 * $dtemp^2$ + 0.2377 * $dtemp^2$ -1.4342);

if (dtemp > 20.0 & DS>=1.5)

hs(gf)=(-0.0213 * dtemp +1.4275);

if (climate.temp <= 20.0

hs(gf) = 1.0;

APSIM (Asseng et al. 2011):

Heat stress during flowering
if (tmax > 34.0) (32^oC used for effect)
Senesc(h) = 4.0 - (1.0 - (tmax) - 34.0) / 2.0);

Multiply senescence with this factor. Treat N from heat stress senescence differently from normal senescence. (N and C to dead leaves instead of labile pools)

Heat stress during grain filling
hs(gf) = 1.0

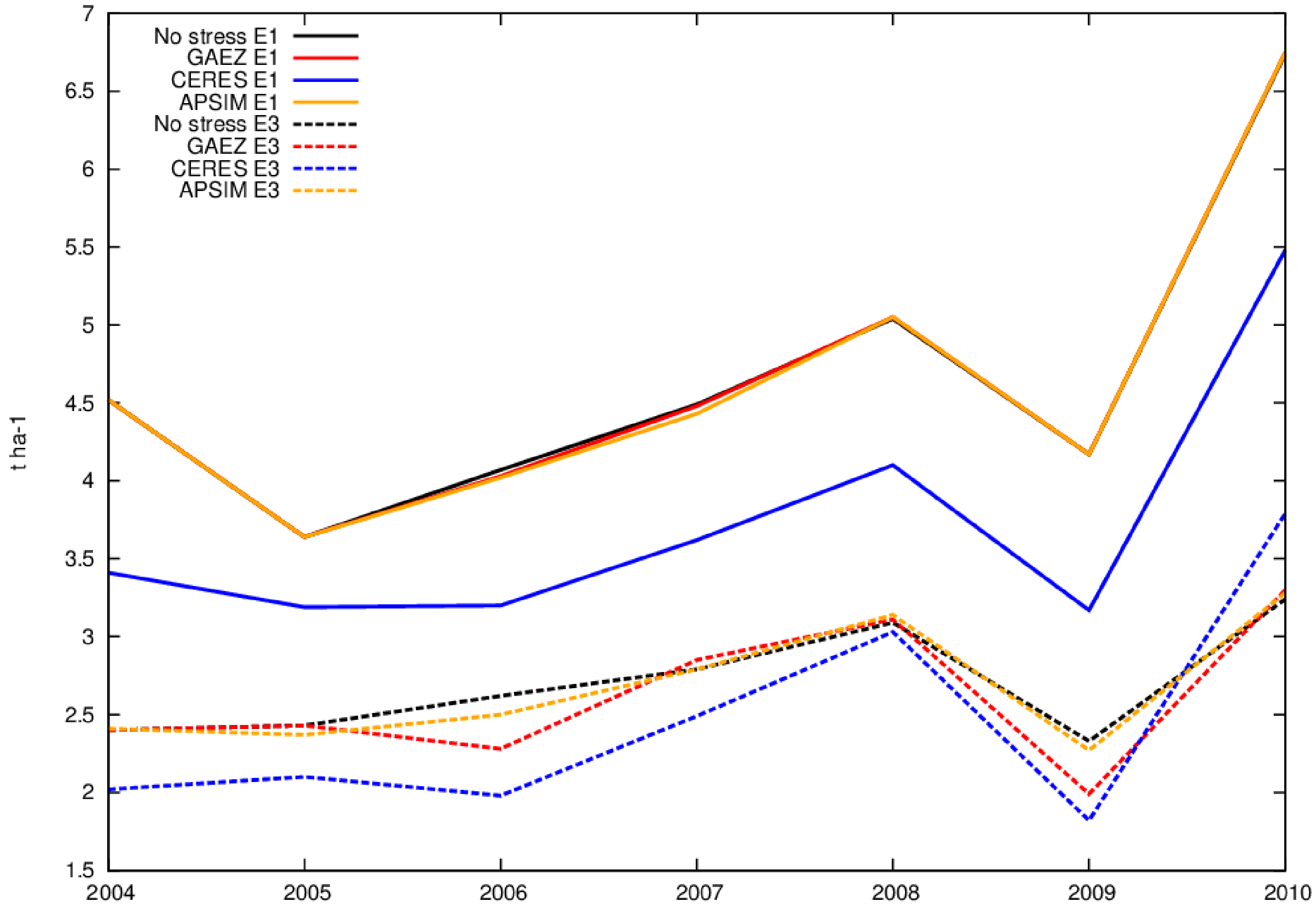
Model test

- 3 heat stress models
- 1 site (Lleida in Spain; using data from the MACSUR IRS study; Cartelle et al. (2006); Abeledo et al. (2008))
- 6 experiments (next slide)
- Parameterized regarding phenology
- Climate sensitivity (-2,-1,..,+4^{o}C)
- <u>Work in progress</u> (no parameterization of yield or heat stress models)

Experiments

	Sowing date	Irrigation	N-appl
Experiment 1	351	Yes	130
Experiment 2	15	Yes	130
Experiment 3	46	Yes	130
Experiment 4	74	Yes	130
Experiment 5	325	Yes	100
Experiment 6	325	No	100

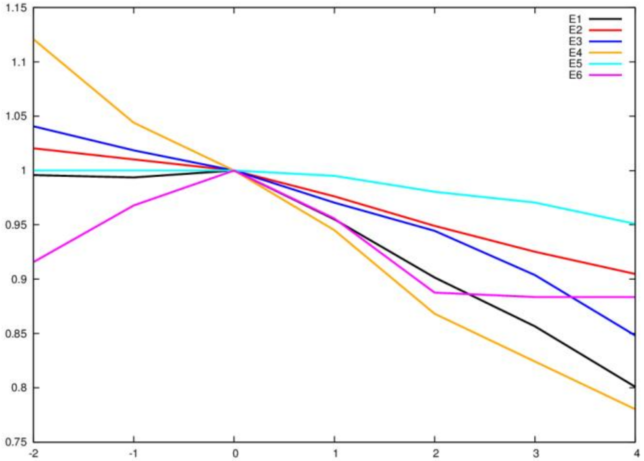
Results I



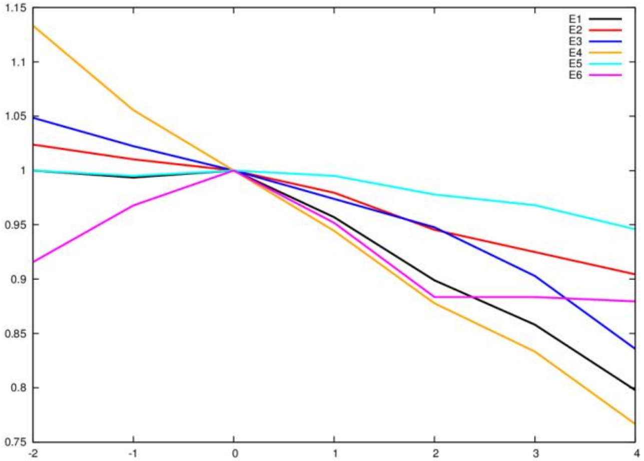
No stress E1
GAEZ E1
CERES E1
APSIM E1
No stress E3
GAEZ E3
CERES E3
APSIM E3
t ha-1
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
2004
2005
2006
2007
2008
2009
2010

Results II

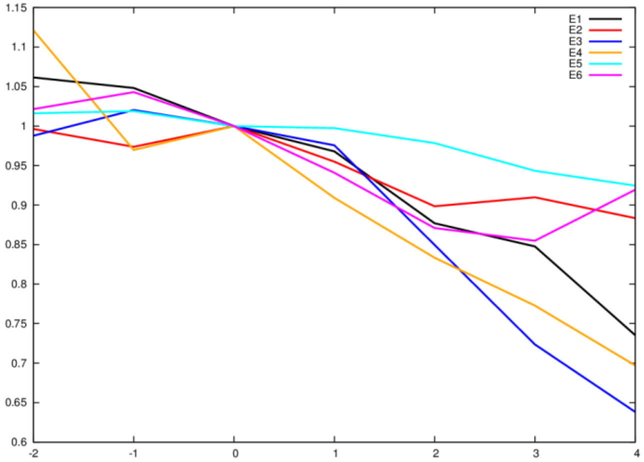
No stress



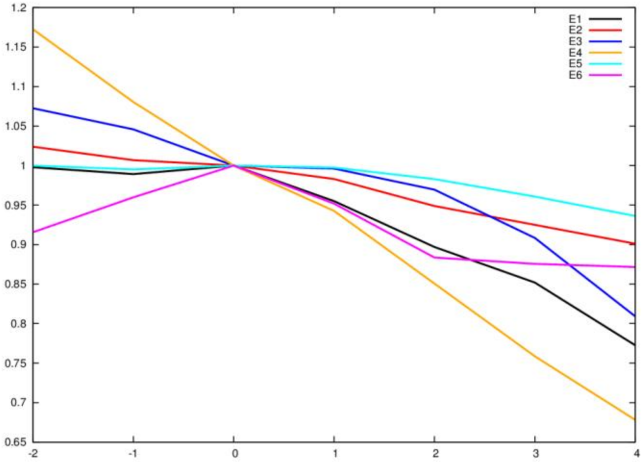
APSIM



CERES



GAEZ



Conclusions

- Work in progress…
- Relatively similar temporal dynamics between models
- CERES gives a reduced yield compared to NS for most years
- Dynamics are sensitive to sowing dates
- Temperature response of APSIM and GAEZ are relatively similar to NS
- Temperature response of CERES is non linear (due to different effects during flowering and grain filling)
- Parameterization of yield and heat stress model parameters needed
- Missing effects (canopy/leaf temperature instead of air temperature; transpirational cooling).