Quantifying the impacts of tropospheric ozone on crop production at regional scale using JULES-Crop

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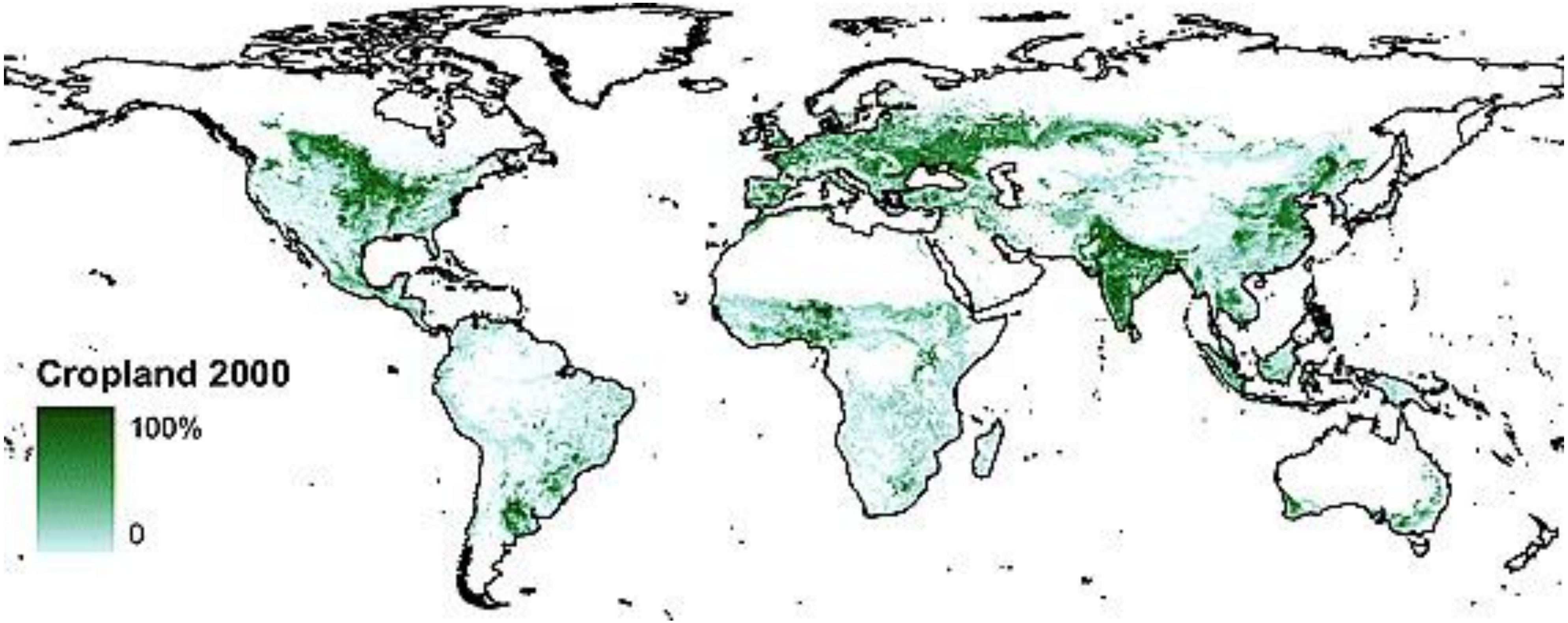
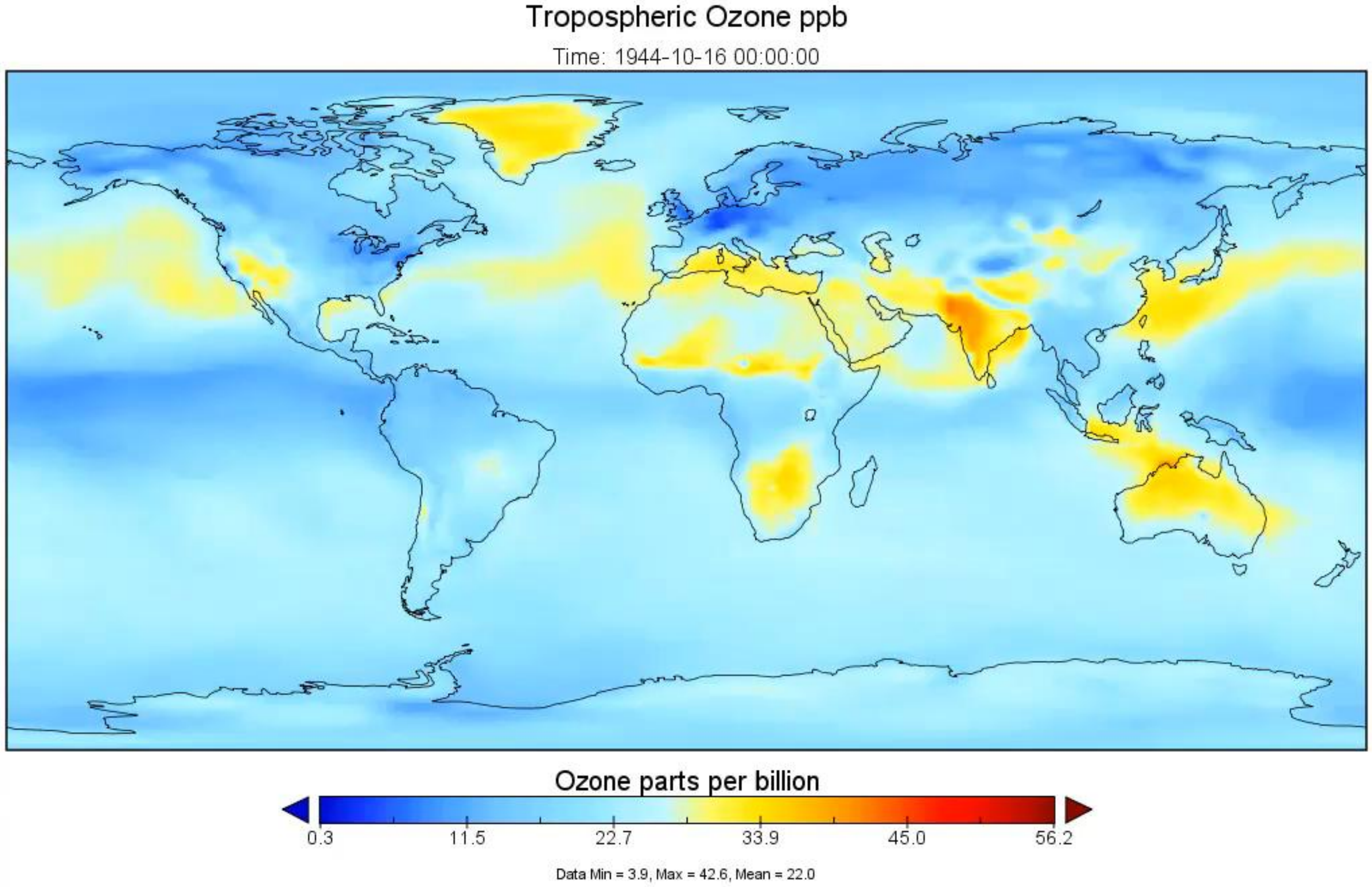


Monfreda et al. (2008) **Global Biogeochemical Cycles**
Volume 22, Issue 1, GB1003, 17 JAN 2008 DOI: 10.1029/2007GB002952

Spatial and temporal scale of tropospheric ozone

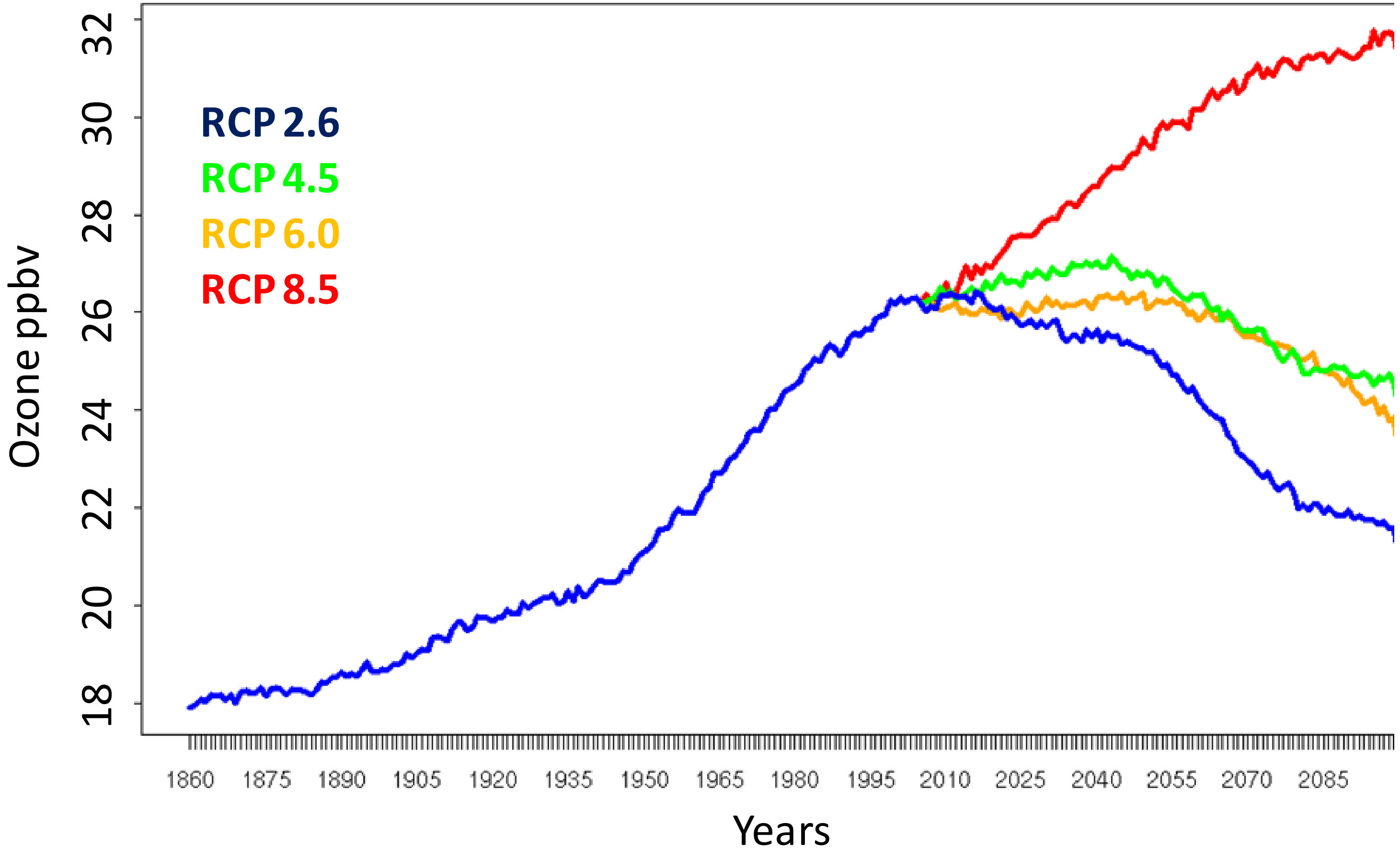
Hadley Centre Global Environmental Model 2- Earth System

1950-2005 Historical ozone distribution

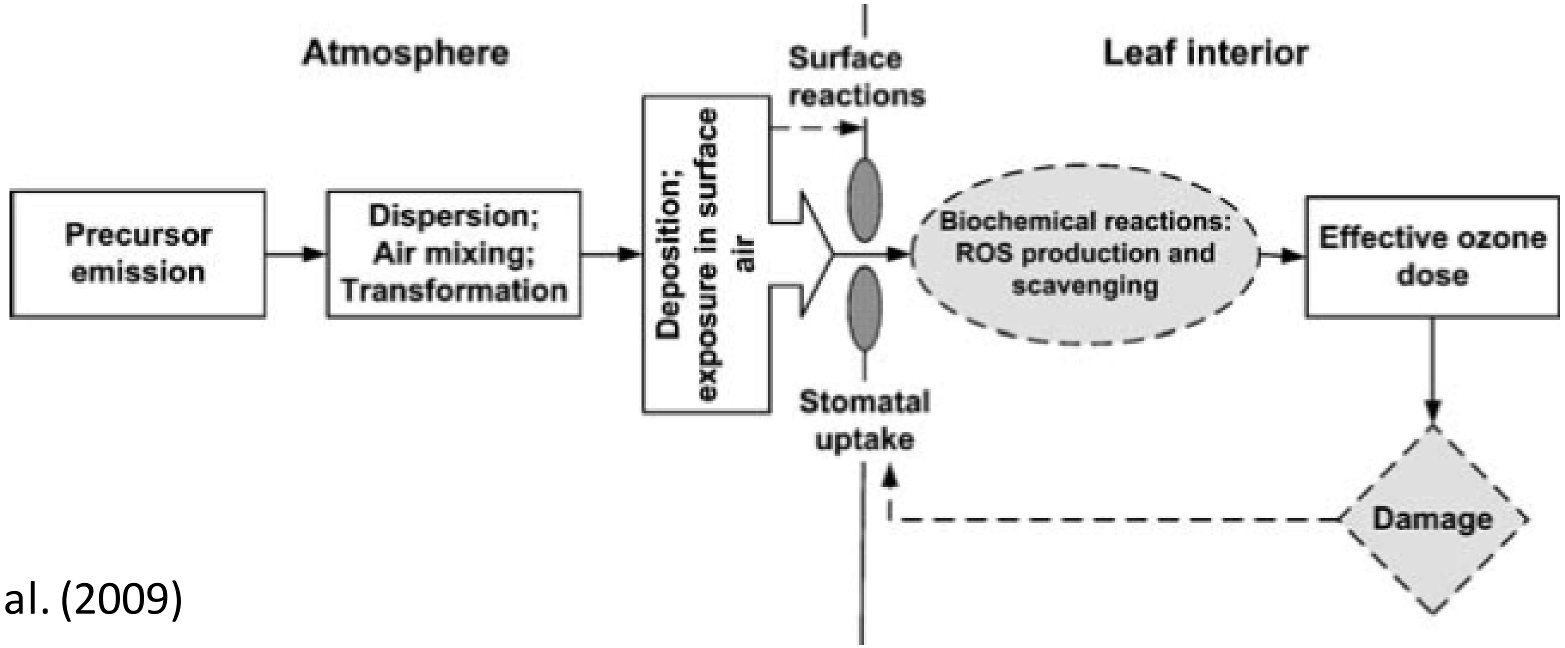


Projection of tropospheric ozone

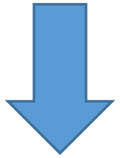
Representative Concentration Pathway (RCPs) of tropospheric ozone trajectories



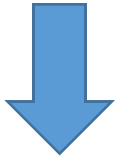
Biochemical effect of ozone on plant



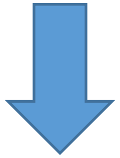
Castagna et al. (2009)



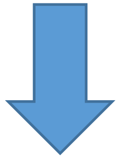
Maximum RuBP saturated rate of carboxylation (Vc max)



Gross Primary Productivity

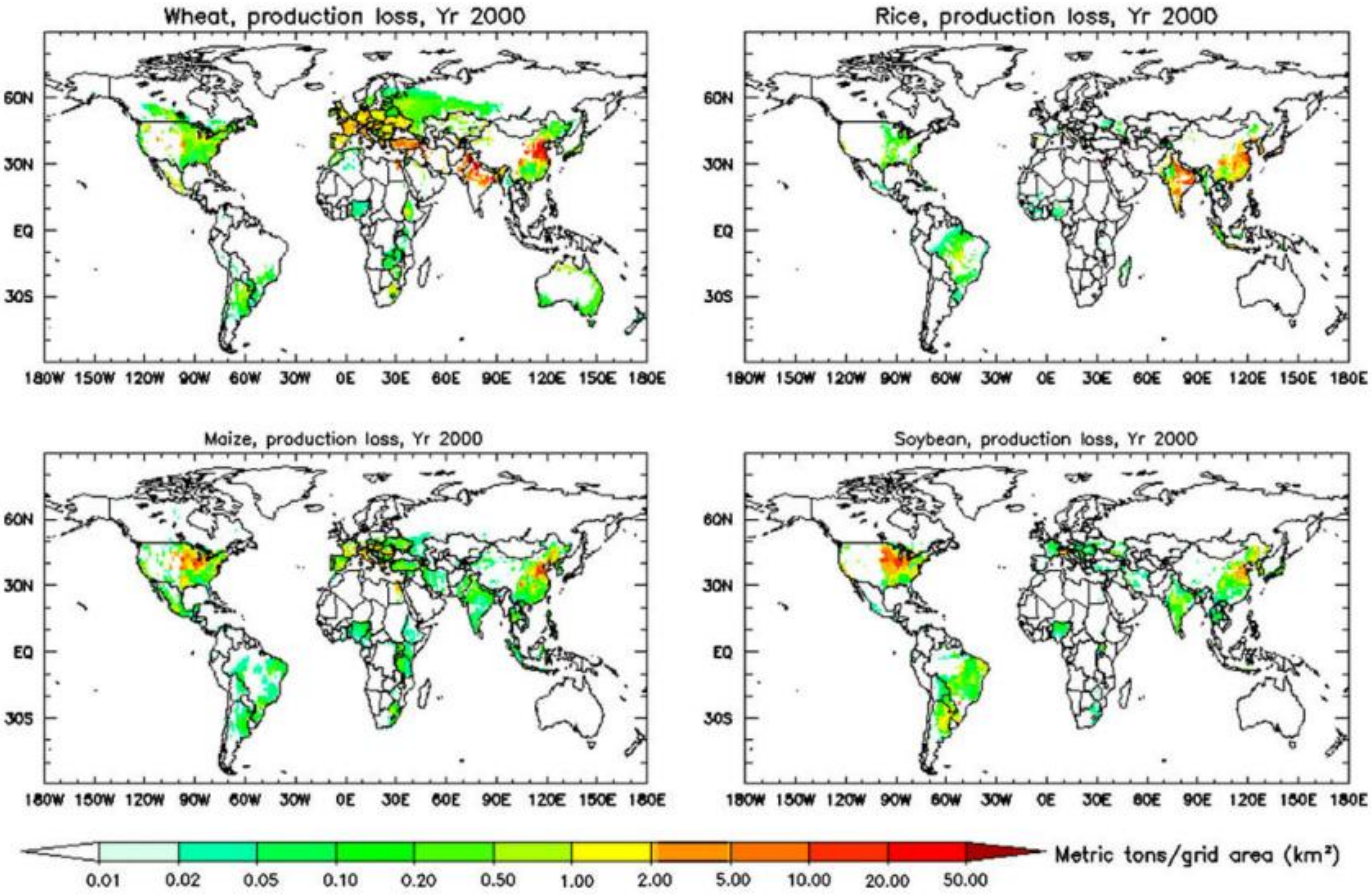


Leaf Area Index



Stomata conductance

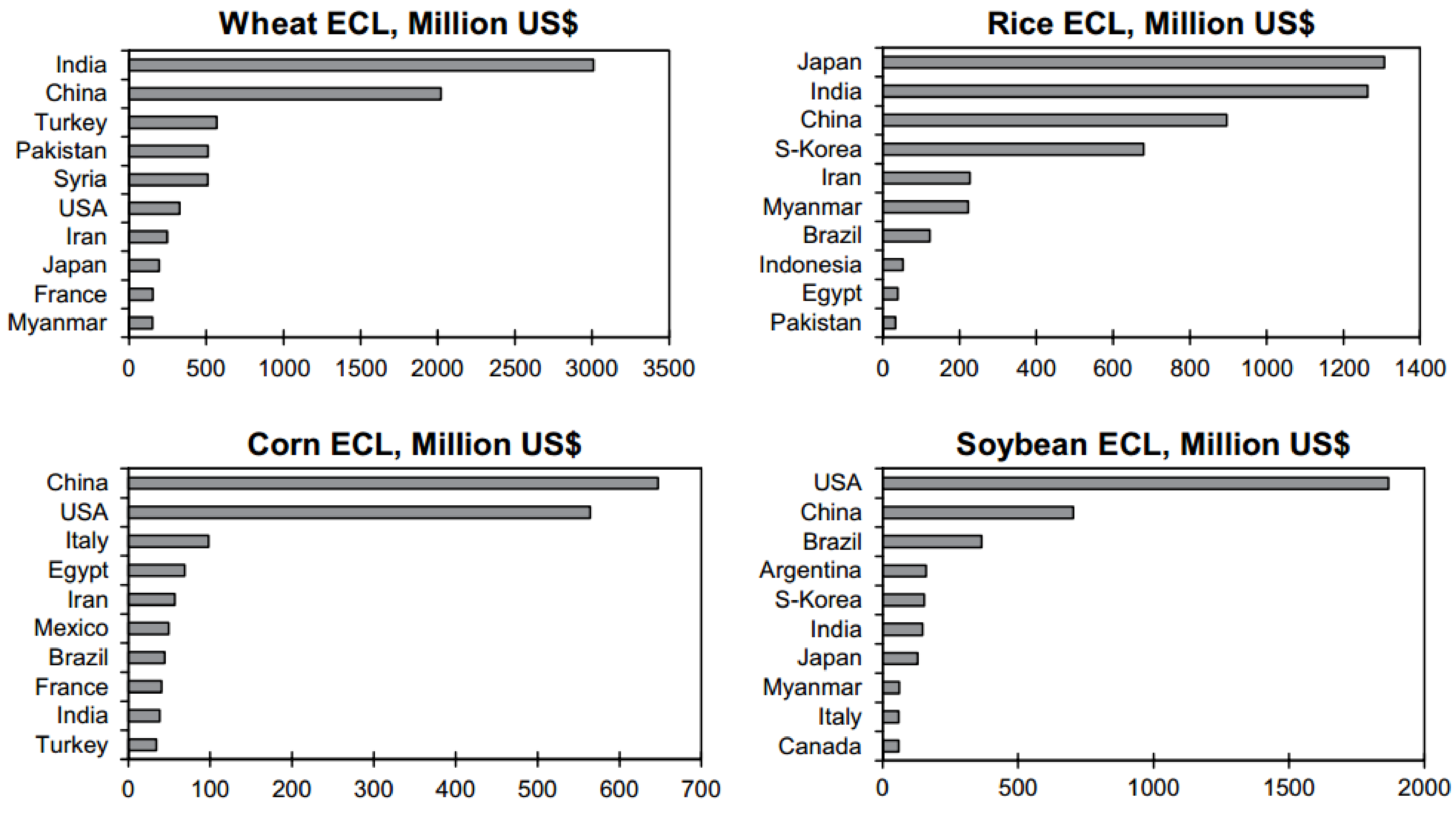
Crop production loss due to ozone



Average crop production loss from 2 metrics for the 4 crops, year 2000. The production loss numbers are normalized to the grid cell area.

Atmospheric Environment 43 (2009) 604-618

Economic loss due to ozone damage

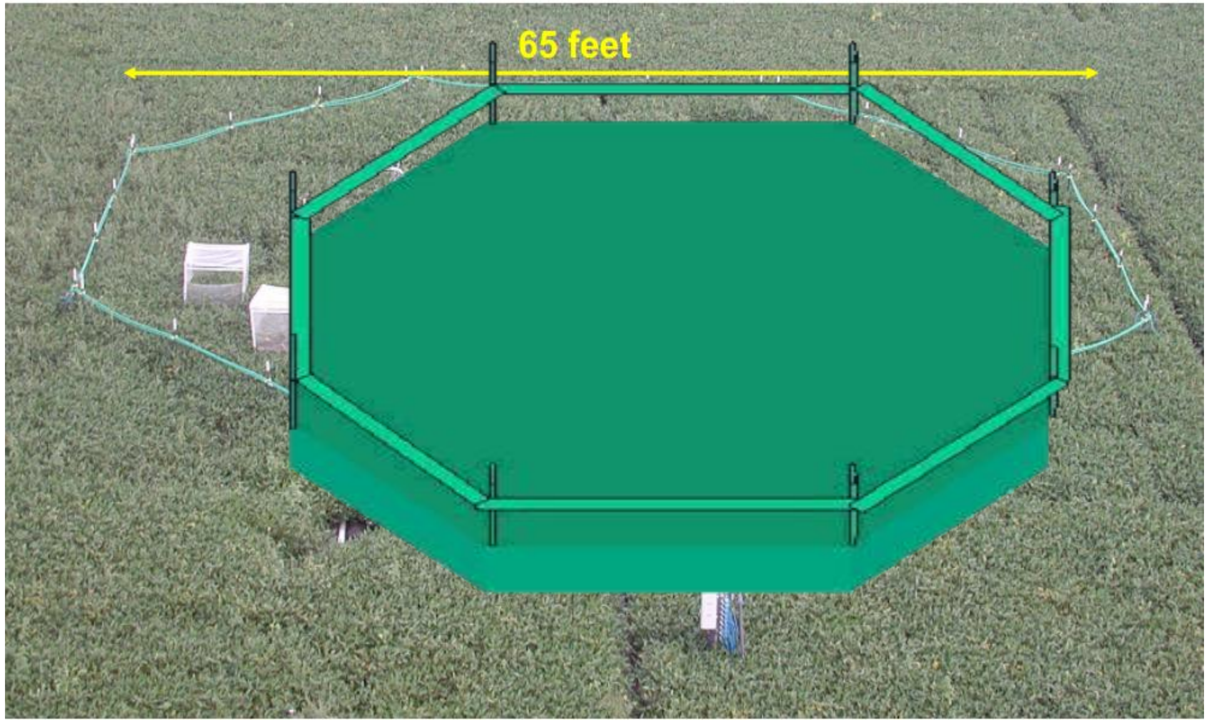


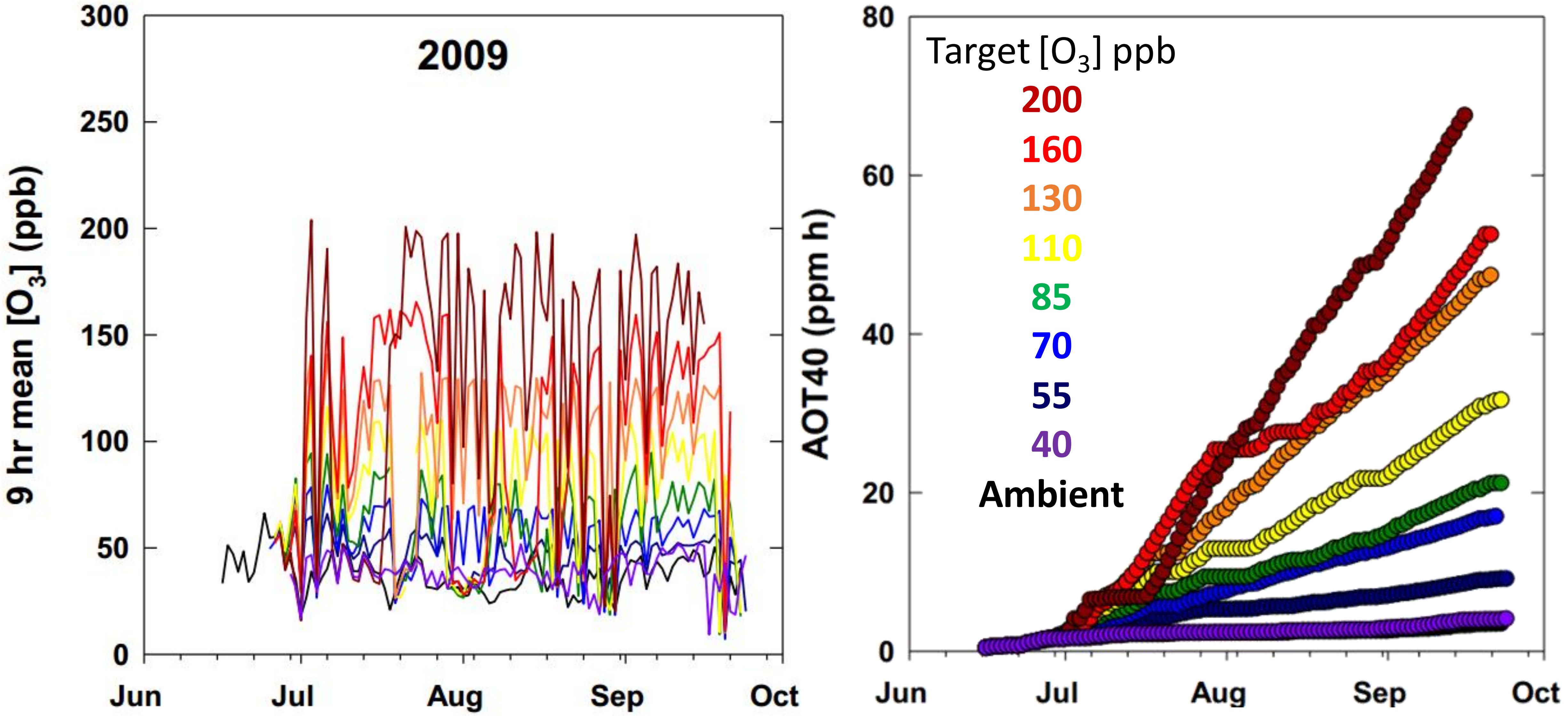
Estimated economic losses of 10 highest ranked countries for the year 2000.

Atmospheric Environment 43 (2009) 604-618

SoyFACE project

- O_3 Free Air CO_2 Enrichment (FACE-O_3) on soybean at Illinois, USA
- Chamber environment modifies plant response and underestimate the yield losses.
- SoyFACE allows controlled CO_2 and O_3 enrichment to simulate different RCPs in 2100.
- 20m diameter
- Fumigate 9 hours per day
- Stop fumigation if the leaves are wet





Betzelberger et al., 2012 SoyFACE ozone concentration

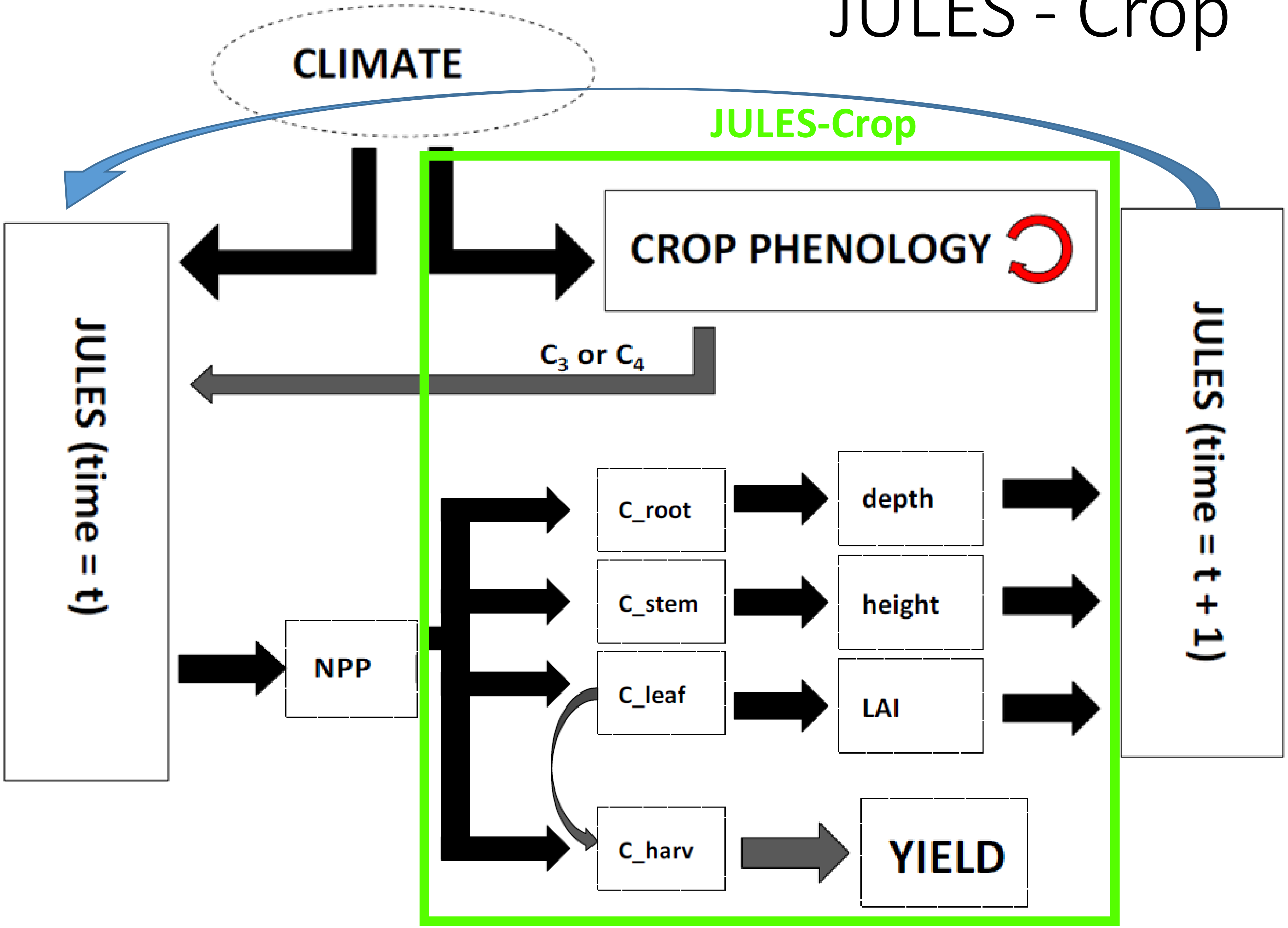
Knowledge gaps

- The sensitivity of different crop species to O_3
- The combined effect of O_3 on crops with other stress (e.g. drought, climate change, excessive nitrogen deposition, pest)
- Regional implications of to O_3, CO_2 and drought interaction
- Coupled Ozone-climate interactions
- Impact of O_3 damage on different plant tissue
- The implication of ozone damage to food security

Joint UK Land Environment Simulator (JULES)-Crop

- Cropland and pasture represent 12% and 26% of land surface
- 5 normal plant functional types
- C3 and C4 crops
- Different day sensitivity and growth rate.
- Simulate farm-level productivity
- 4 Crop functional types
- Variables associated with climate change e.g. drought, flood, rising temperature

JULES - Crop



CLIMATE
JULES-Crop
CROP PHENOLOGY
C_3 or C_4
JULES (time = t)
NPP
C_root
C_stem
C_leaf
C_harv
depth
height
LAI
YIELD
JULES (time = t + 1)

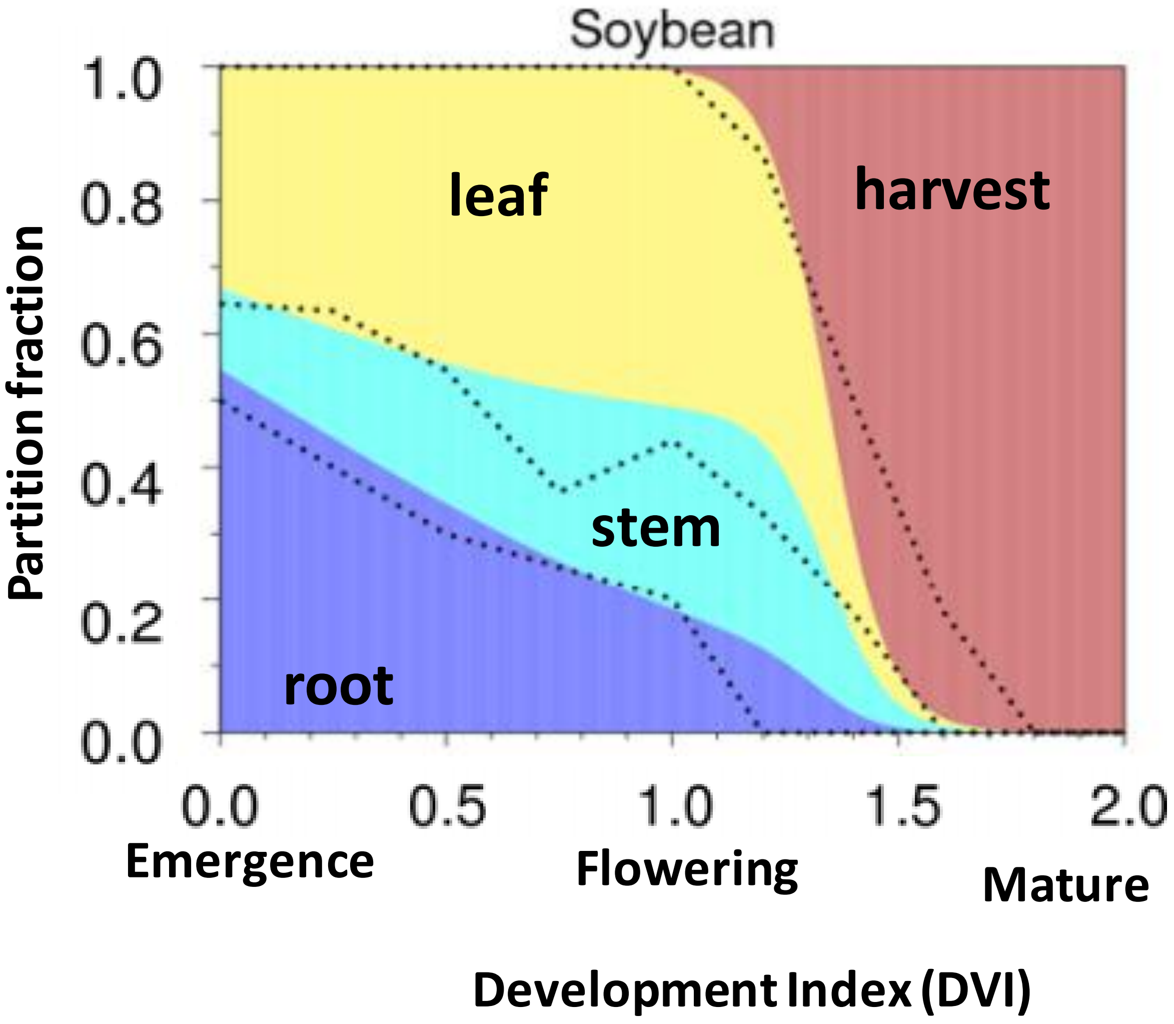
Crop Development Index

$$p_{root} = \frac{e^{\alpha_{root}+(\beta_{root}\mathrm{DVI})}}{e^{\alpha_{root}+(\beta_{root}\mathrm{DVI})} + e^{\alpha_{stem}+(\beta_{stem}\mathrm{DVI})} + e^{\alpha_{leaf}+(\beta_{leaf}\mathrm{DVI})} + 1}$$

$$p_{stem} = \frac{e^{\alpha_{stem}+(\beta_{stem}\mathrm{DVI})}}{e^{\alpha_{root}+(\beta_{root}\mathrm{DVI})} + e^{\alpha_{stem}+(\beta_{stem}\mathrm{DVI})} + e^{\alpha_{leaf}+(\beta_{leaf}\mathrm{DVI})} + 1}$$

$$p_{leaf} = \frac{e^{\alpha_{leaf}+(\beta_{leaf}\mathrm{DVI})}}{e^{\alpha_{root}+(\beta_{root}\mathrm{DVI})} + e^{\alpha_{stem}+(\beta_{stem}\mathrm{DVI})} + e^{\alpha_{leaf}+(\beta_{leaf}\mathrm{DVI})} + 1}$$

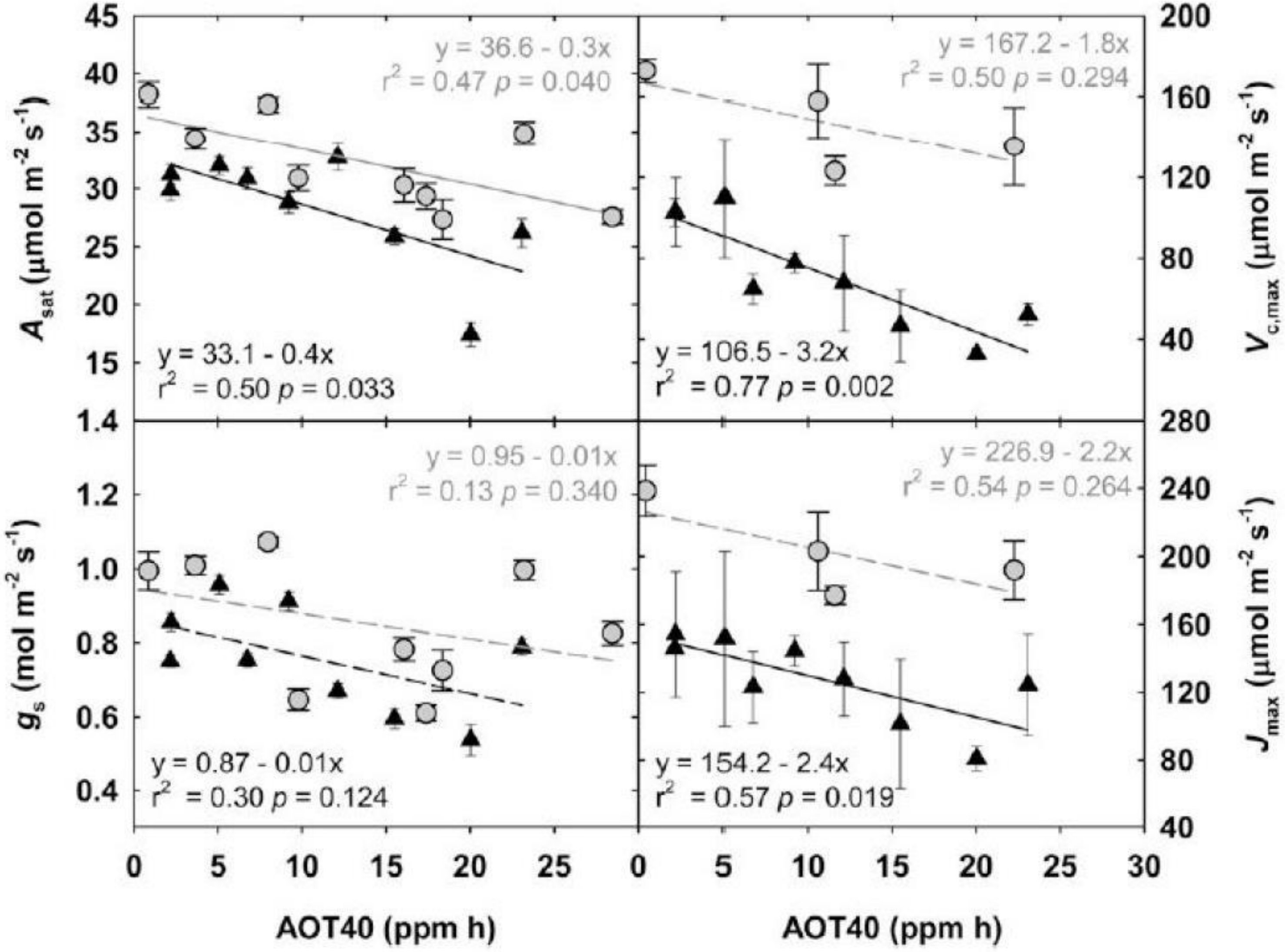
$$p_{harv} = \frac{1}{e^{\alpha_{root}+(\beta_{root}\mathrm{DVI})} + e^{\alpha_{stem}+(\beta_{stem}\mathrm{DVI})} + e^{\alpha_{leaf}+(\beta_{leaf}\mathrm{DVI})} + 1}$$



SoyFACE observation

Light saturated photosynthetic activity

Stomatal conductance



The maximum rate of Rubisco saturated carboxylase activity

the maximum rate of photosynthetic electron transport

Betzelberger et al., 2012 Vc max of soybean decrease as AOT40 increase

Tuning soybean parameters from literature

$$Max\ rate\ of\ carboxylation = quantum\ efficiency\ * top\ leaf\ [N]$$
$$Vc_{max} = \text{neff} * \text{nl0}$$

$$Rate\ of\ dark\ respiration = dark\ respiration\ factor\ * Vc_{max}$$
$$R_d = fd_{io} * Vc_{max}$$

$$Growth\ respiration = growth\ resp\ coeff\ \{NPP - maintenance\ resp\}$$
$$R_{pg} = r_g\{G - R_{pm}\}$$

Parameters for ozone effect

		Broadleaf tree	Needleleaf tree	C_3 grass	C_4 grass	Shrub
$F_{O_3\,crit}$ ($nmol\,m^{-2}\,s^{-1}$)	Threshold ozone flux	1.6	1.6	5.0	5.0	1.6
a ($mmol^{-1}\,m^{-2}$)	Ozone factor	0.04	0.02	0.25	0.13	0.03

$$A_l = A_l^* F$$

Net Photosynthesis = Photosynthesis * O_3 reduction factor

$$F = 1 - a \cdot \max\left[F_{O_3} - F_{O_3\,crit}, 0\right]$$

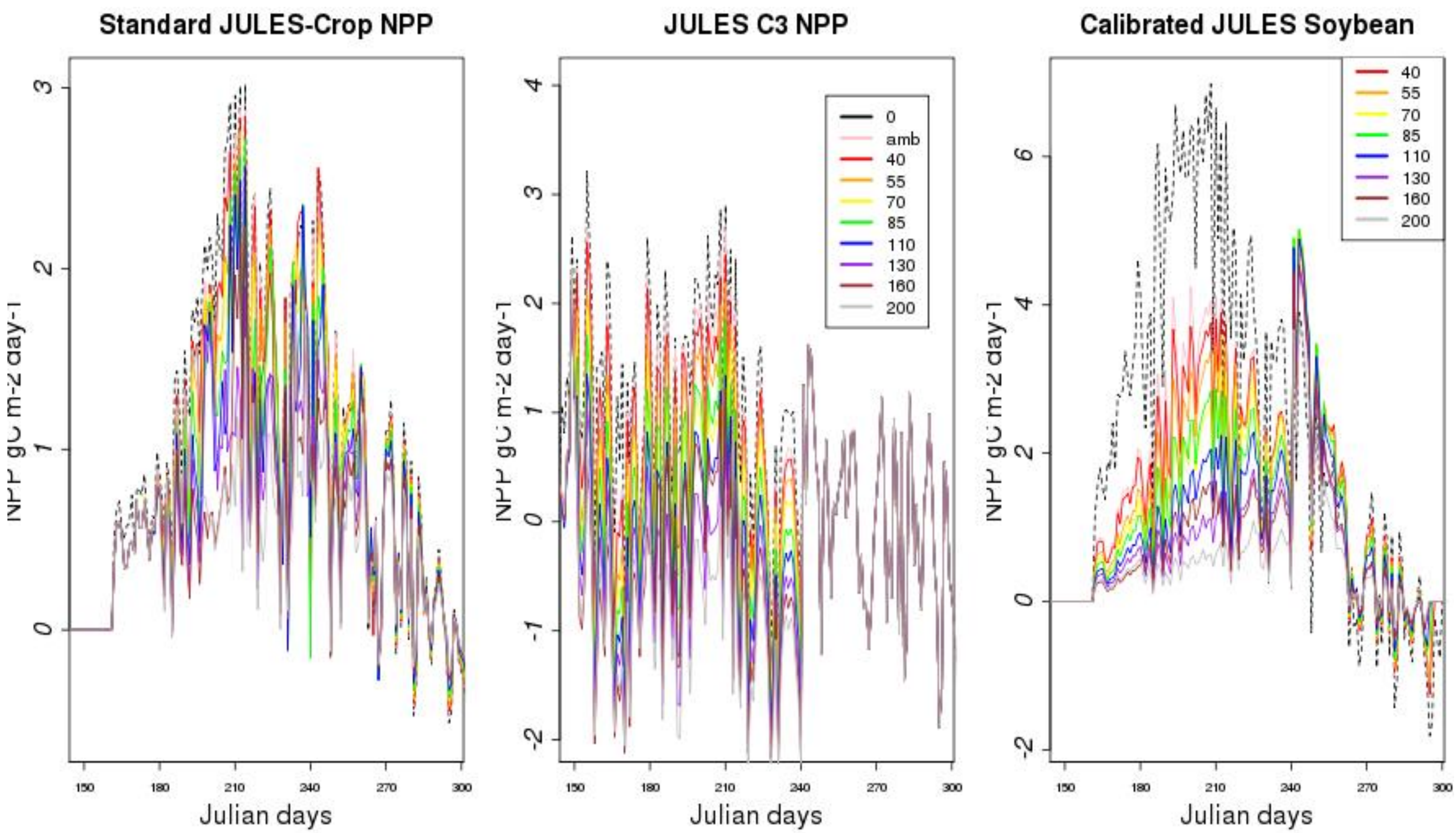
FO_3 :Pleijel et al. (2004)
a: Sitch et al. (2007)

$$F_{O_3} = \frac{[O_3]}{r_a + \kappa_{O_3}/g_l}$$

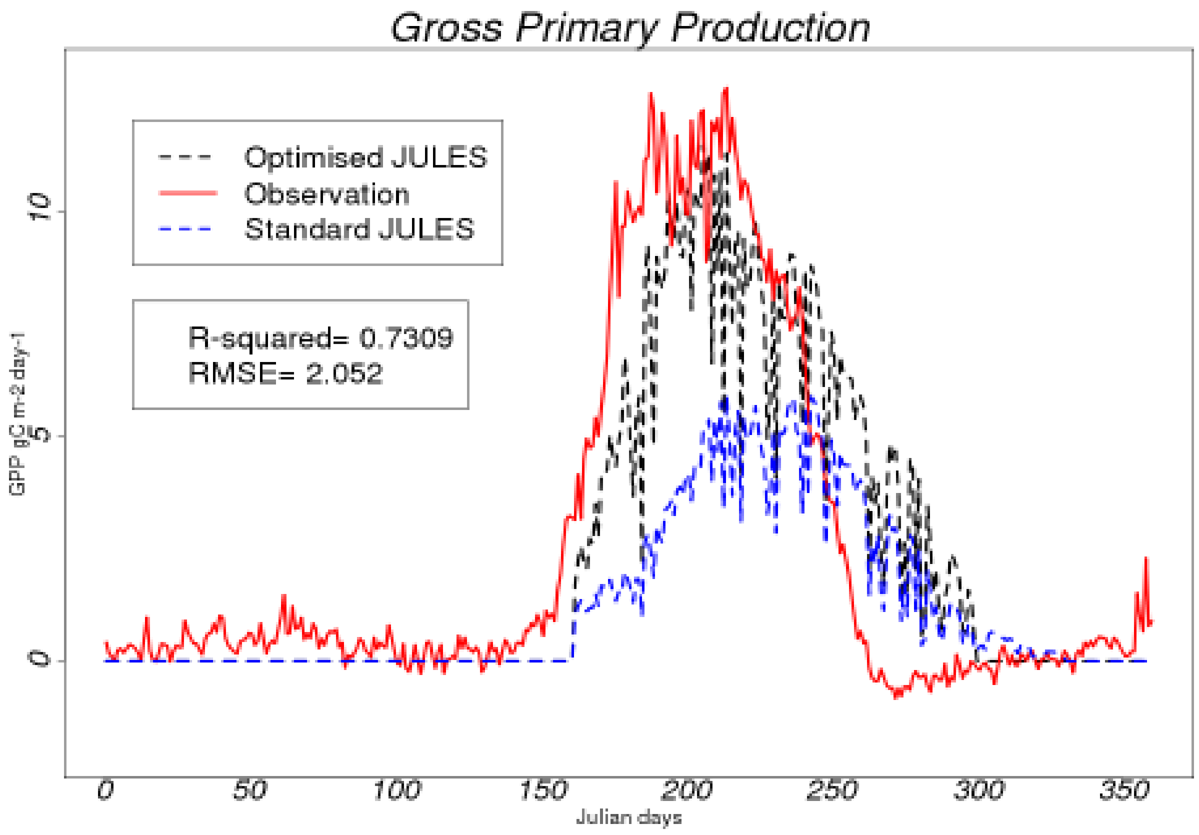
Flux of O_3, r_a is the aerodynamic and boundary layer resistance
g1 is the leaf conductance for H_2O
KO_3 = 1.67 is the ratio of leaf resistance for O_3 to water vapour

Calibration of soybean parameters

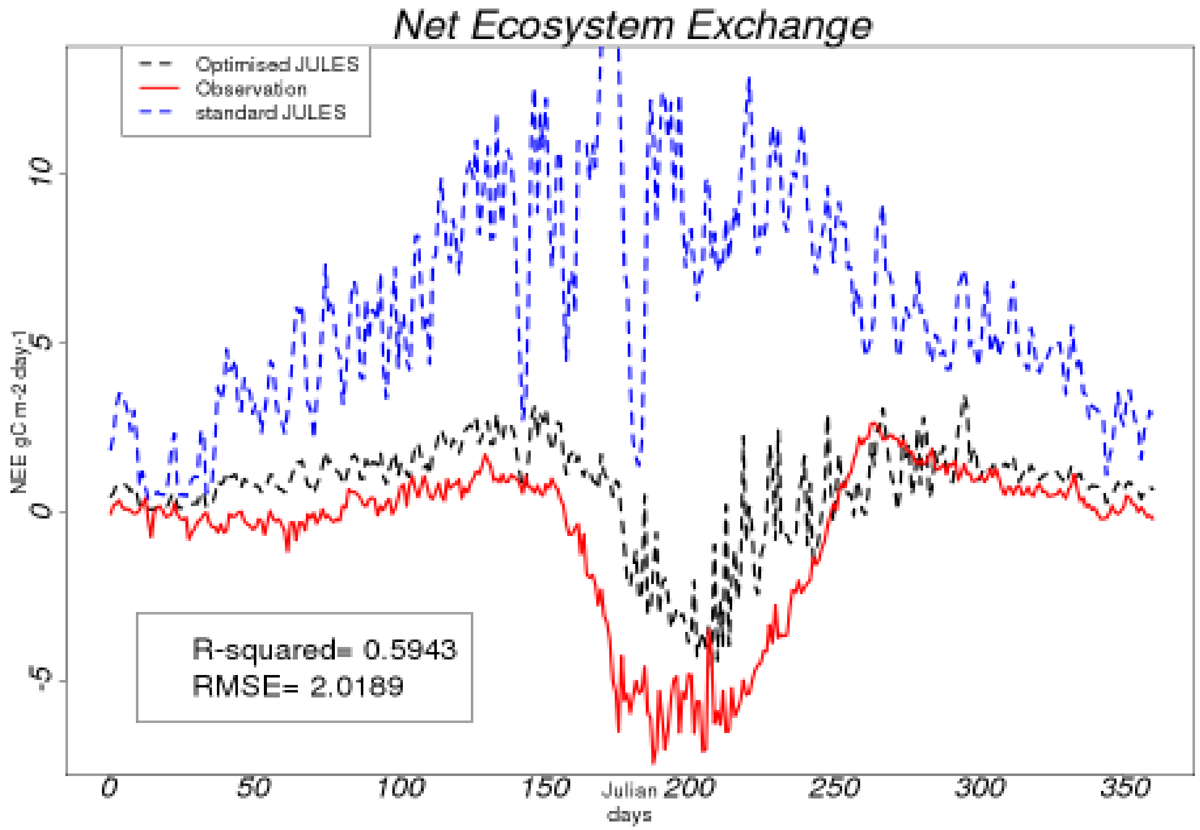
Parameters in JULES	Description	Standard default	Calibrated
fd_io	Dark respiration coefficient	0.015	0.006
nl0_io	Top leaf nitrogen concentration	0.073	0.13
neff_io	Scale factor of top leaf nitrogen to Vc_{max} (quantum efficiency)	0.0008	0.001
nr_nl_io	Ratio of root N to leaf N	1.0	0.1
ns_nl_io	Ratio of stem N to leaf N	1.0	0.1
dfp_dcuo_io	Fractional reduction of photosynthesis by O_3 (sensitivity)	1.40	0.25 (Low)
fl_o3_ct_io	Critical flux of Ozone to vegetation (threshold)	5.0	4.0



Standard JULES-Crop NPP
JULES C3 NPP
Calibrated JULES Soybean
NPP gC m-2 day-1
Julian days
0
amb
40
55
70
85
110
130
160
200

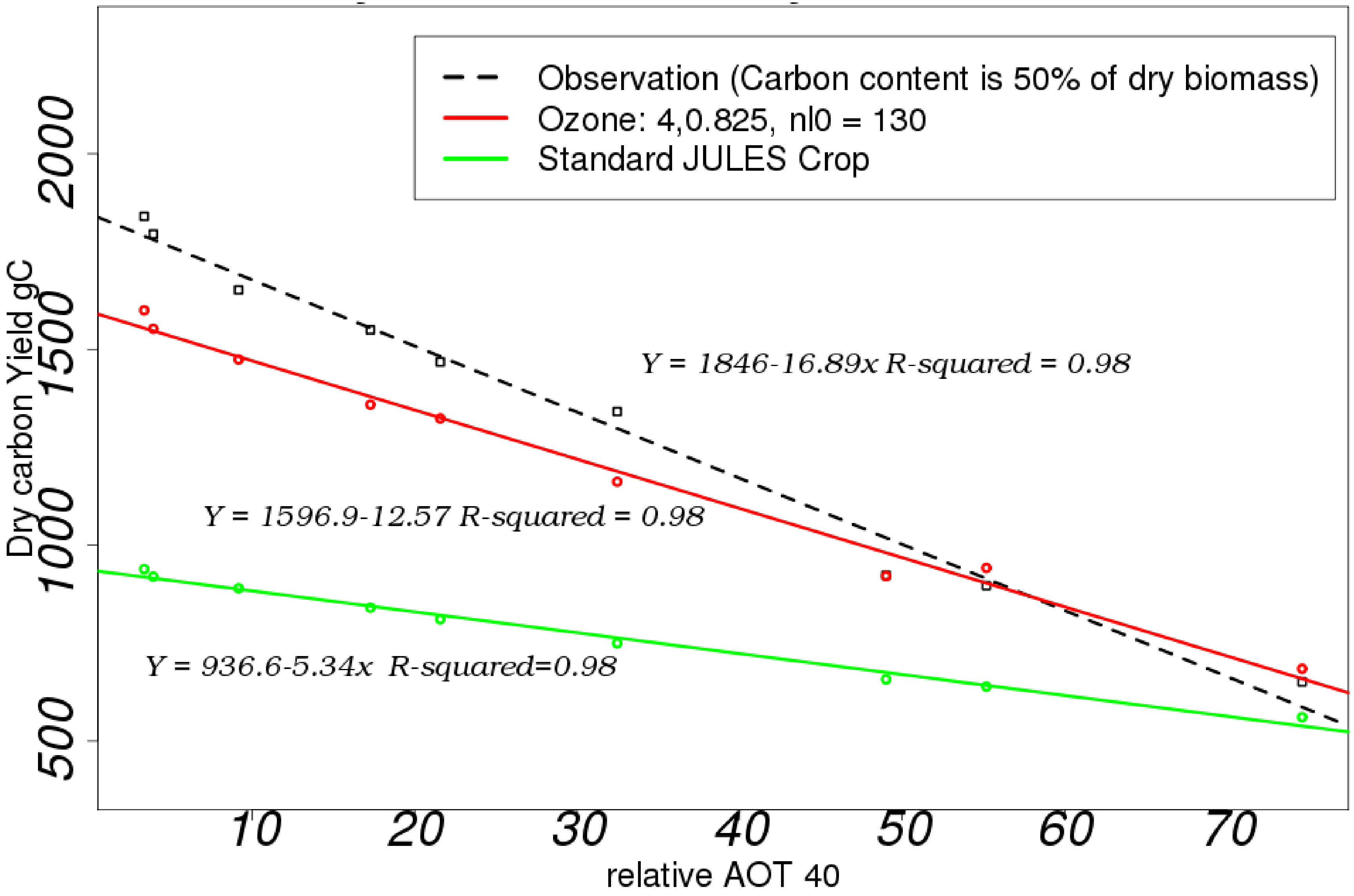


Gross Primary Production
Optimised JULES
Observation
Standard JULES
R-squared= 0.7309
RMSE= 2.052
GPP gC m-2 day-1
Julian days

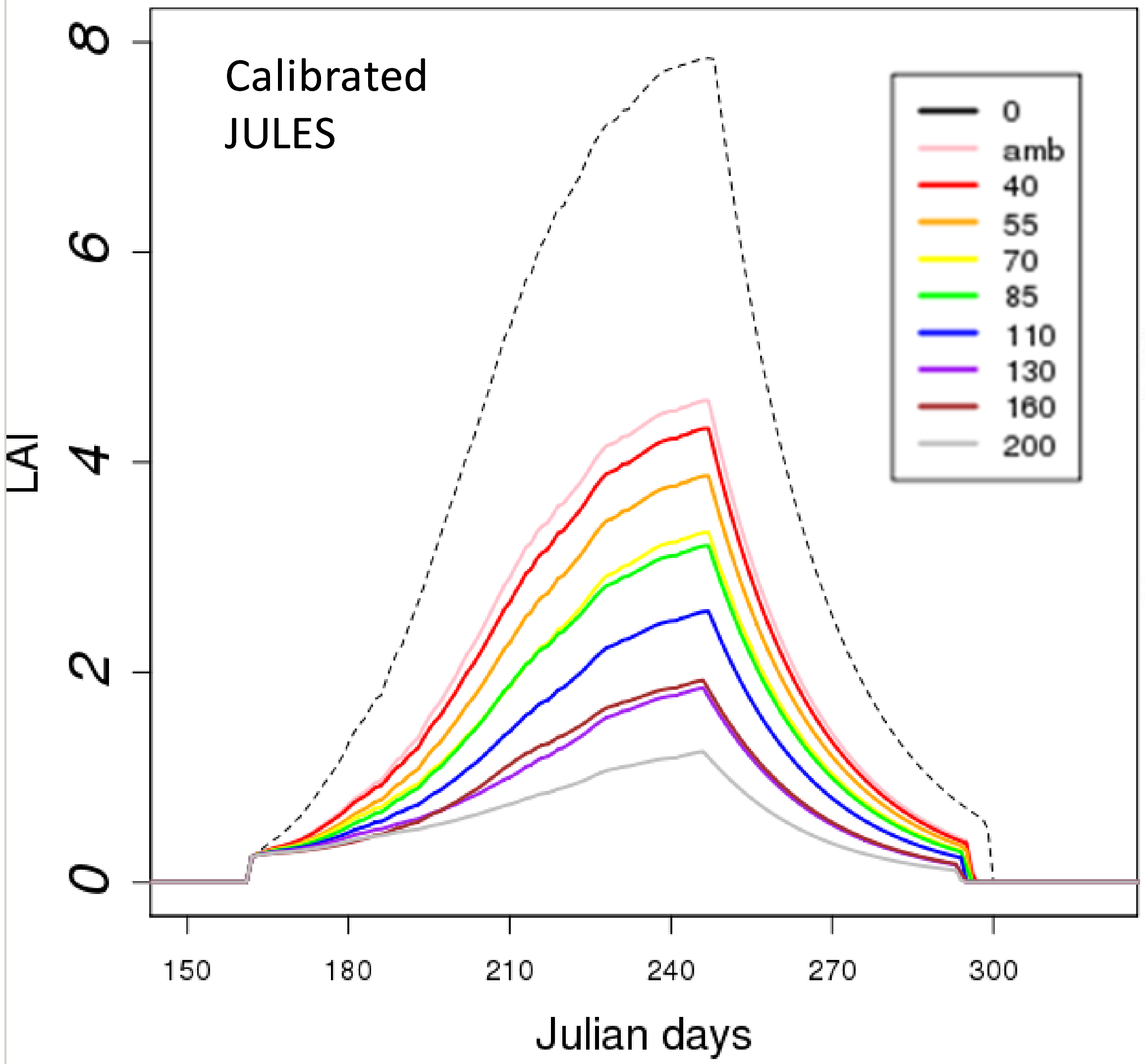


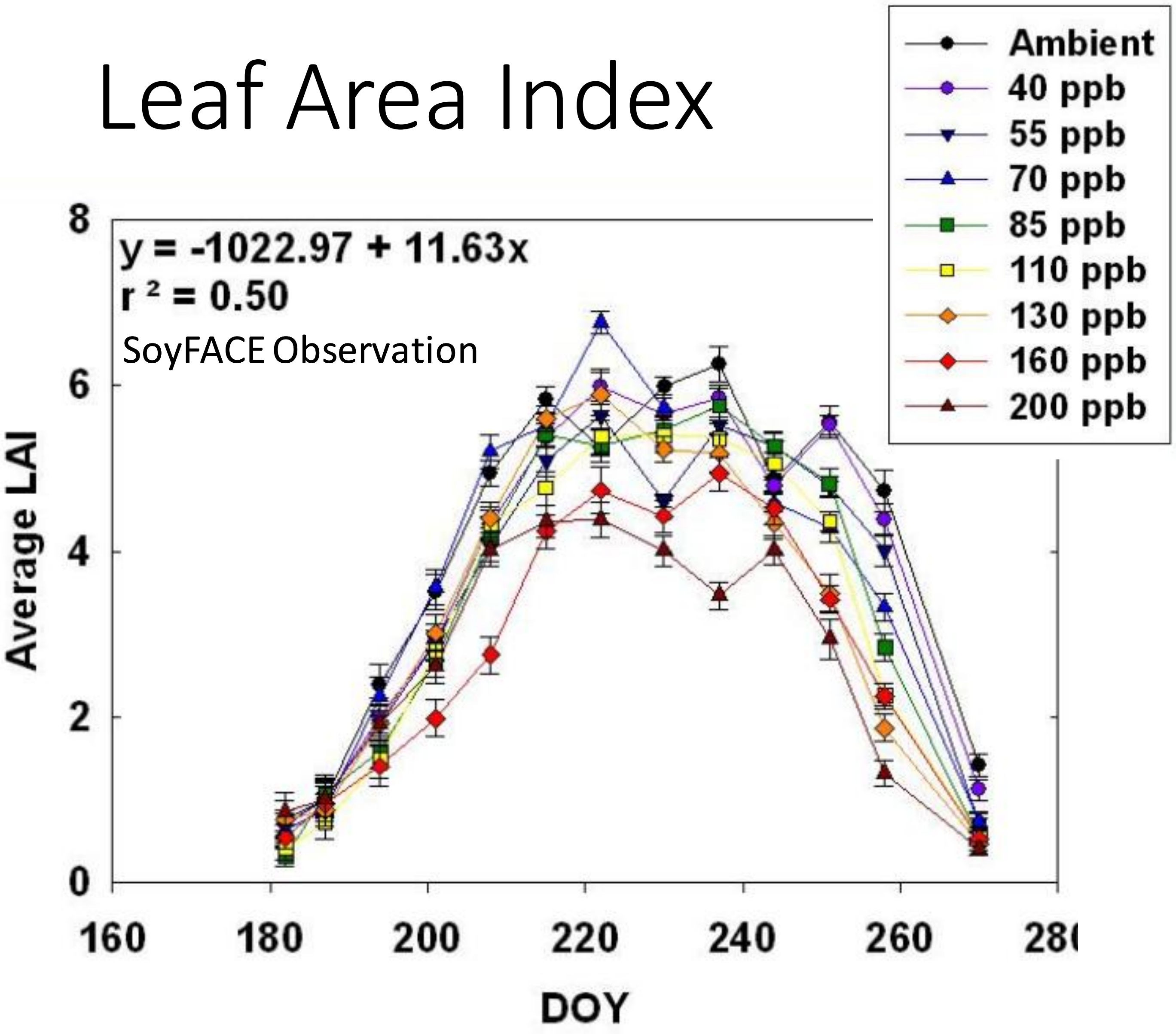
Net Ecosystem Exchange
Optimised JULES
Observation
standard JULES
R-squared= 0.5943
RMSE= 2.0189
NEE gC m-2 day-1
Julian days

O_3 impact (AOT40) on soybean yield

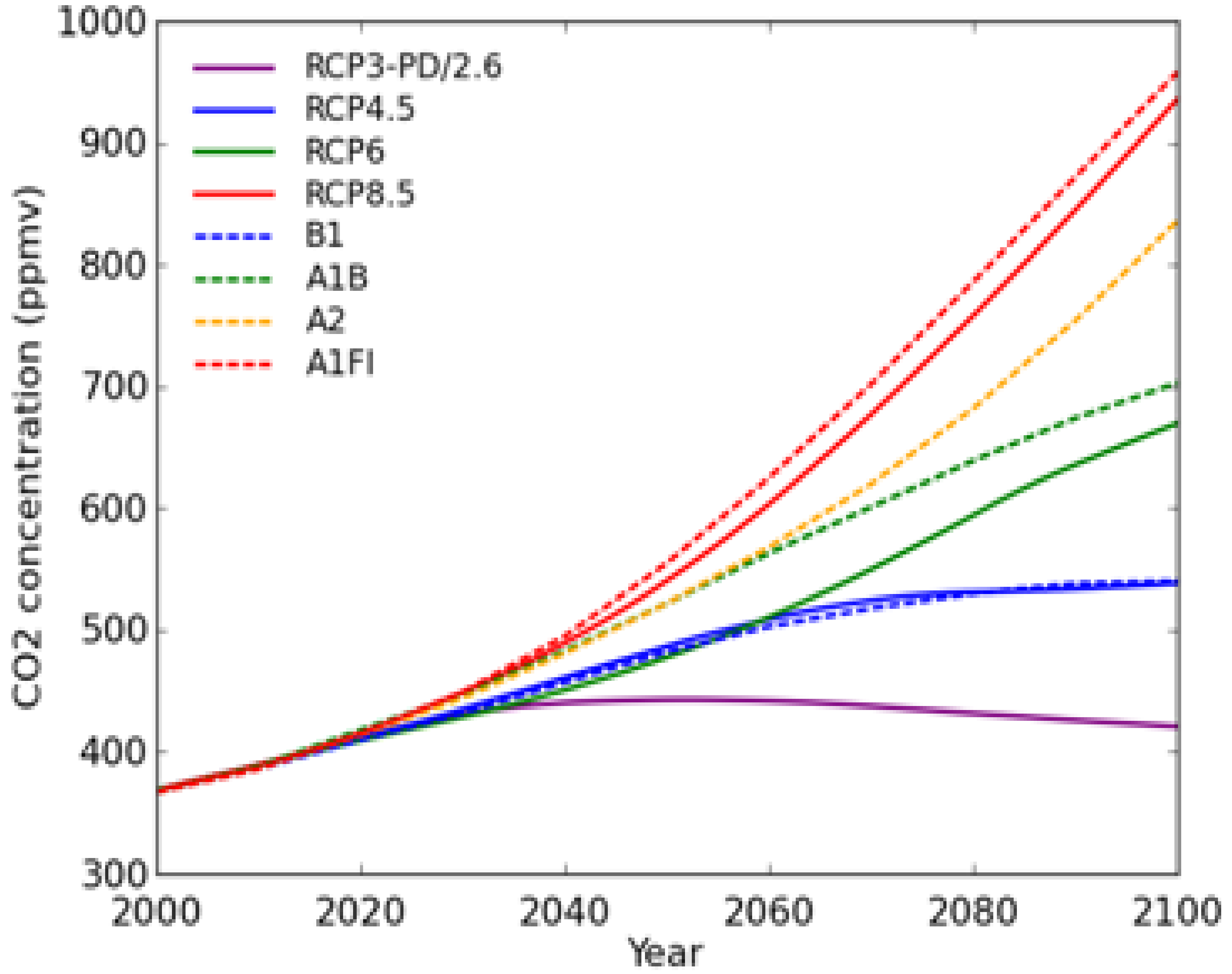


Leaf Area Index



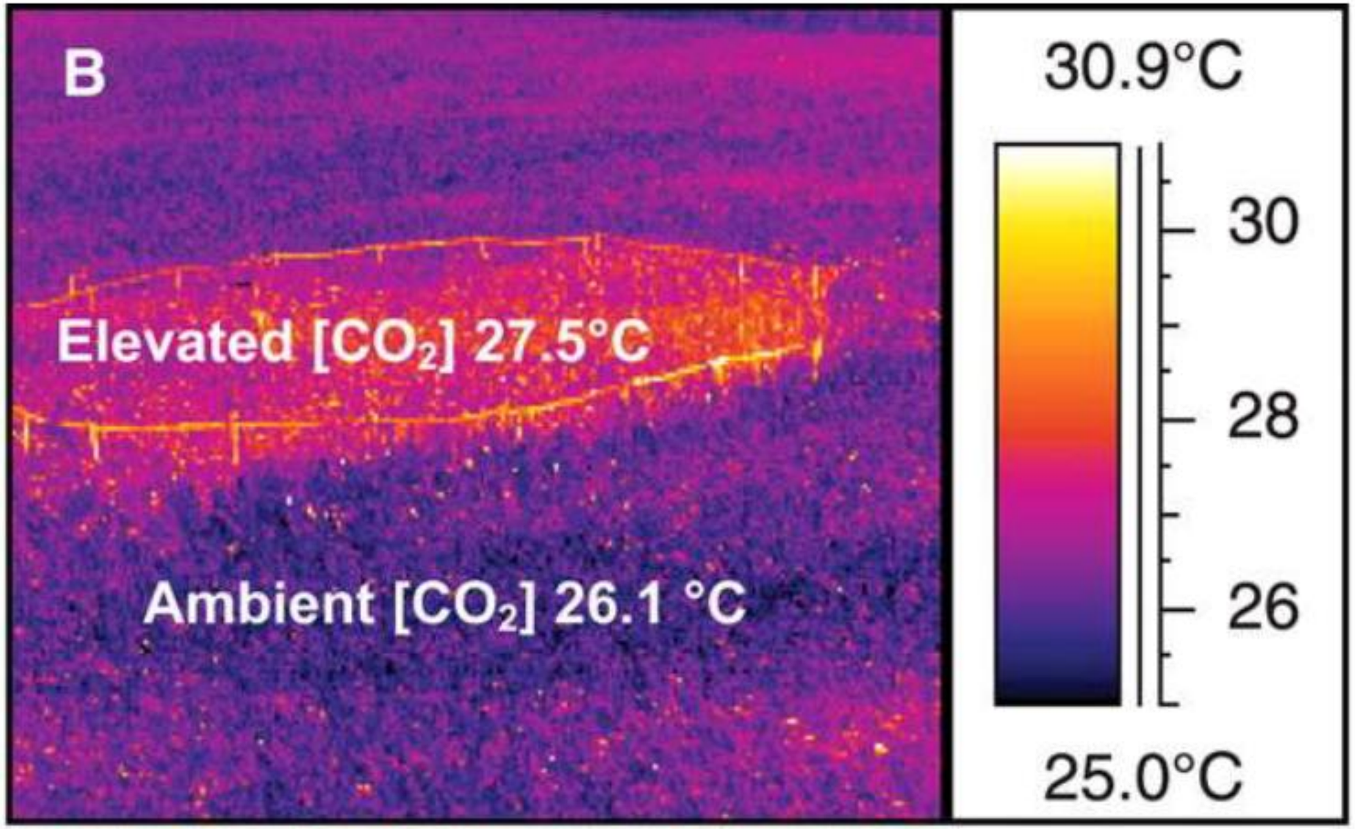


CO_2 concentrations in SRES and RCP scenarios

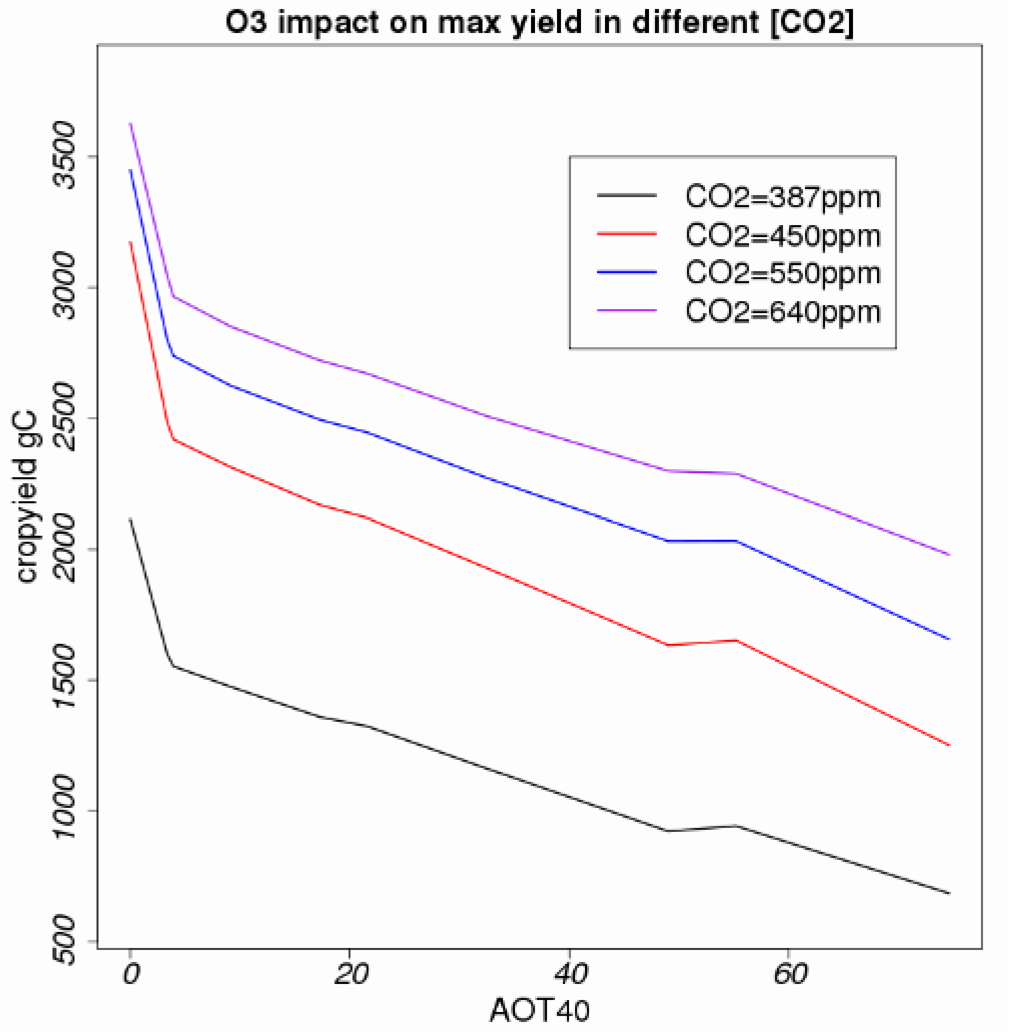


RCP scenarios	CO_2 ppm	Year
	387	2010
2.6	450	2070
6.0	550	2070
8.5	640	2070

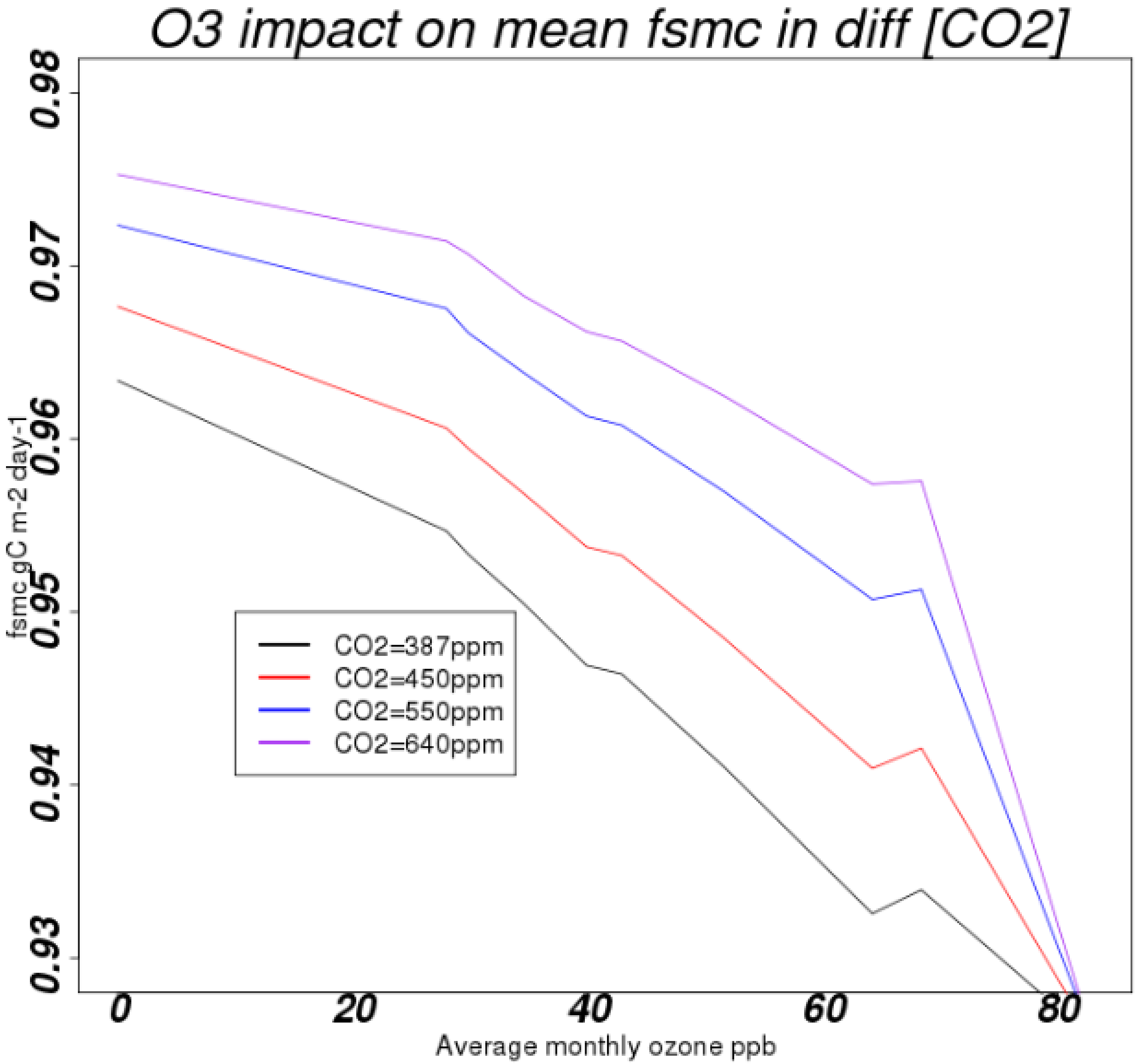
Factorial experiment with elevated O_3 and CO_2

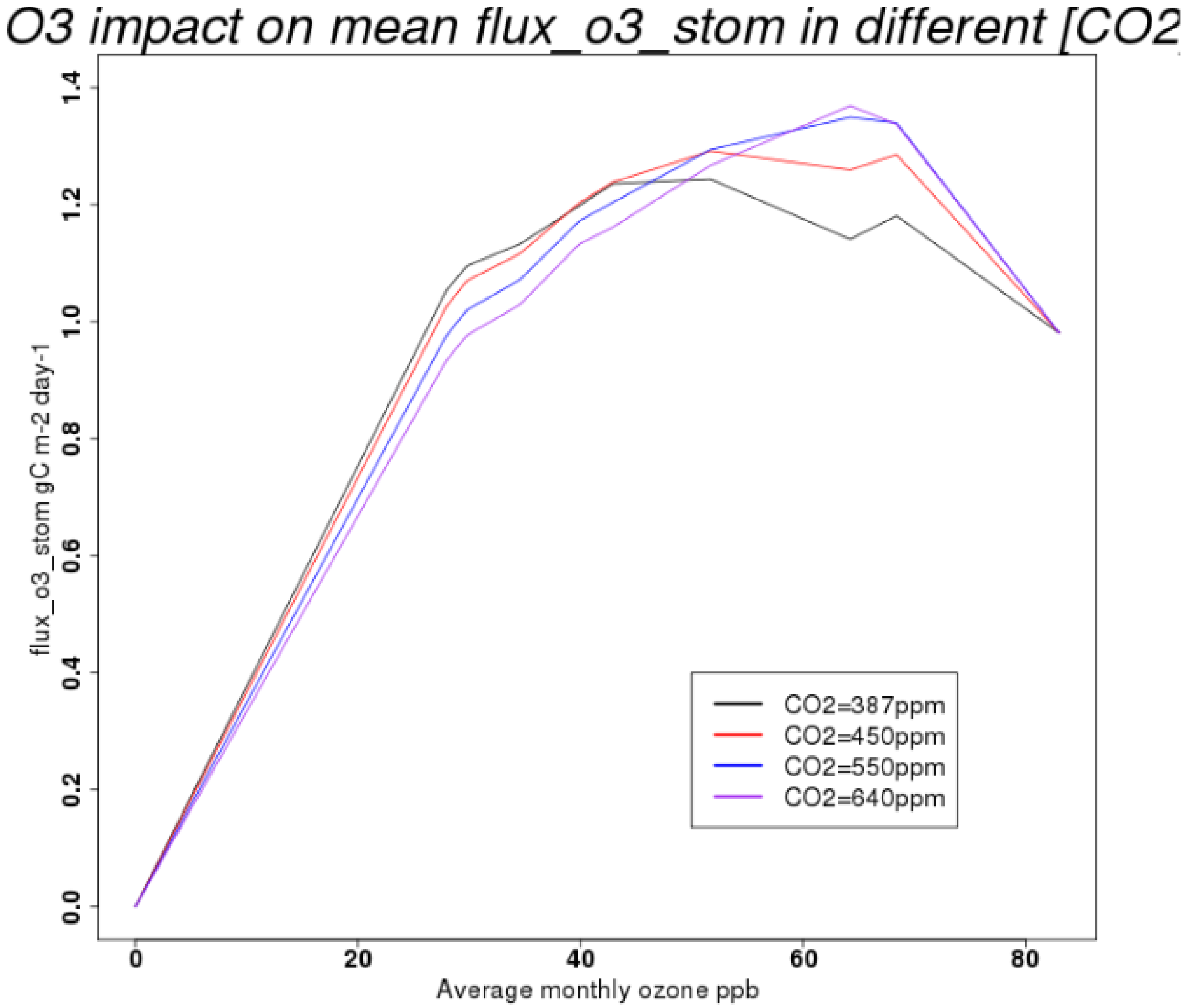


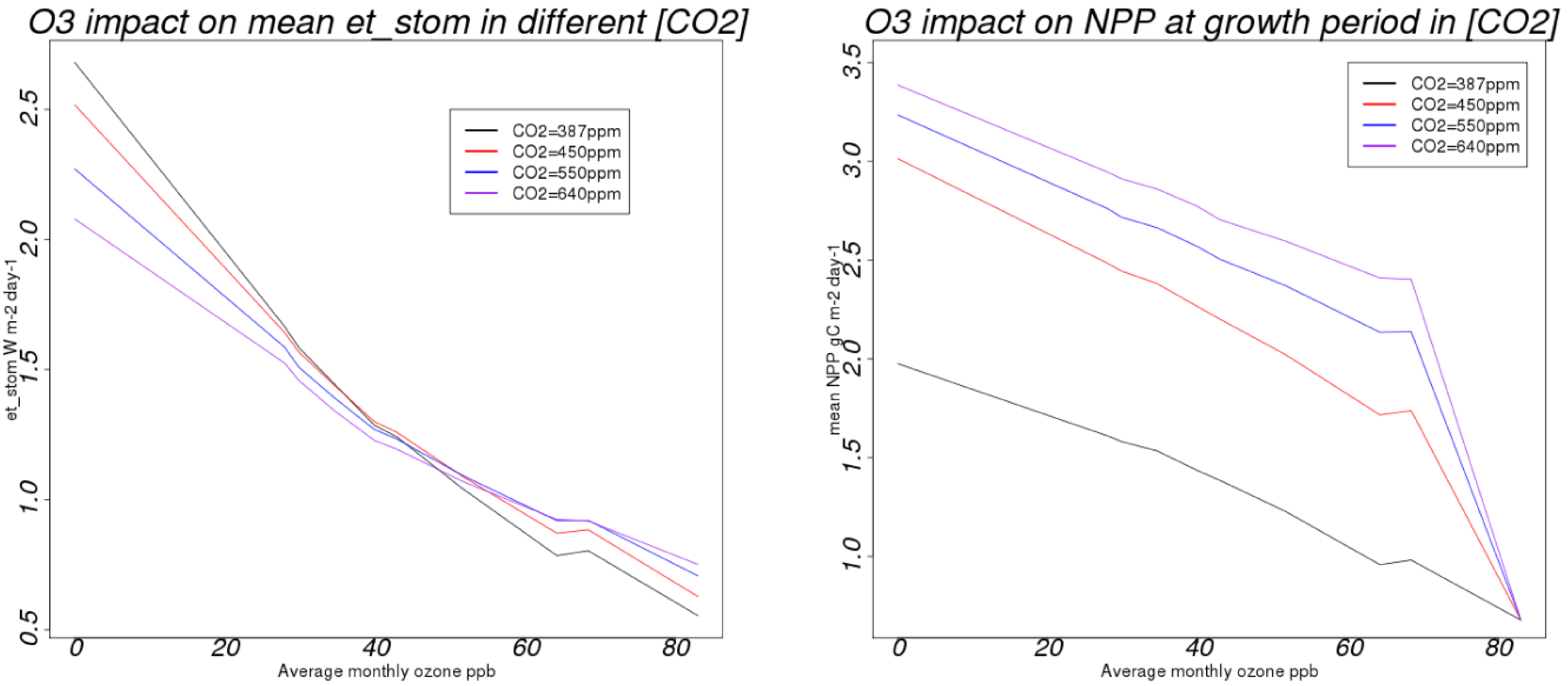
Long et al., 2006



CO_2 and O_3 interaction on moisture availability and flux of ozone to stomata







O3 impact on mean et_stom in different [CO2]
et_stom W m-2 day-1
Average monthly ozone ppb
CO2=387ppm
CO2=450ppm
CO2=550ppm
CO2=640ppm
0.5
1.0
1.5
2.0
2.5
0
20
40
60
80
O3 impact on NPP at growth period in [CO2]
mean NPP gC m-2 day-1
Average monthly ozone ppb
CO2=387ppm
CO2=450ppm
CO2=550ppm
CO2=640ppm
1.0
1.5
2.0
2.5
3.0
3.5
0
20
40
60
80

Future Plan

- Calibrate elevated O_3 and CO_2 impact with other crops (Rice, maize, wheat)
- Run global model with calibrated parameters
- Prescribe JULES with RCP scenarios emissions, temperature, agricultural land use change e.g. biofuel and estimate future O_3 impact to crops productivity
- Investigate the impact of O_3 on global carbon sink using TRENDY run

Interactive experiments

Run	Climatology	CO_2	O_3
1	RCP 2.6		
2	RCP 2.6	RCP 2.6	RCP 2.6
3	RCP 2.6	RCP 8.5	RCP 2.6
4	RCP 2.6	RCP 2.6	RCP 8.5
5	RCP 8.5		
6	RCP 8.5	RCP 8.5	RCP 8.5
7	RCP 8.5	RCP 2.6	RCP 8.5
8	RCP 8.5	RCP 8.5	RCP 2.6

Run	Climatology	CO_2	O_3
1	CruNCEP		
2	CruNCEP	✓	
3	CruNCEP		✓
4	CruNCEP	✓	✓
5	HadGEM		
6	HadGEM	✓	
7	HadGEM		✓
8	HadGEM	✓	✓