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

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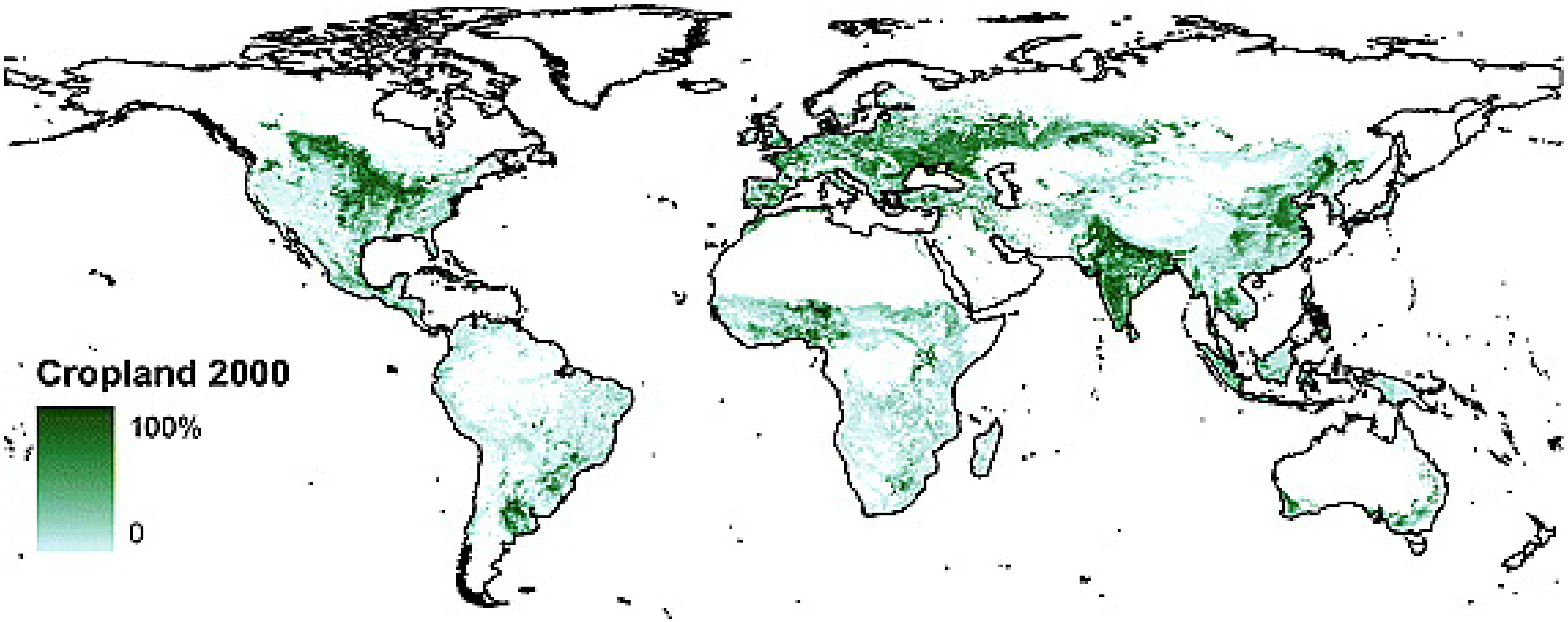
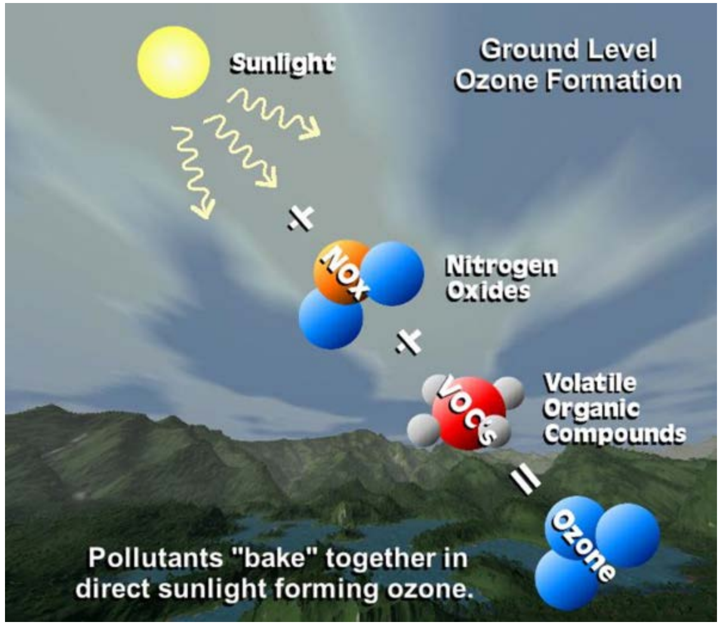
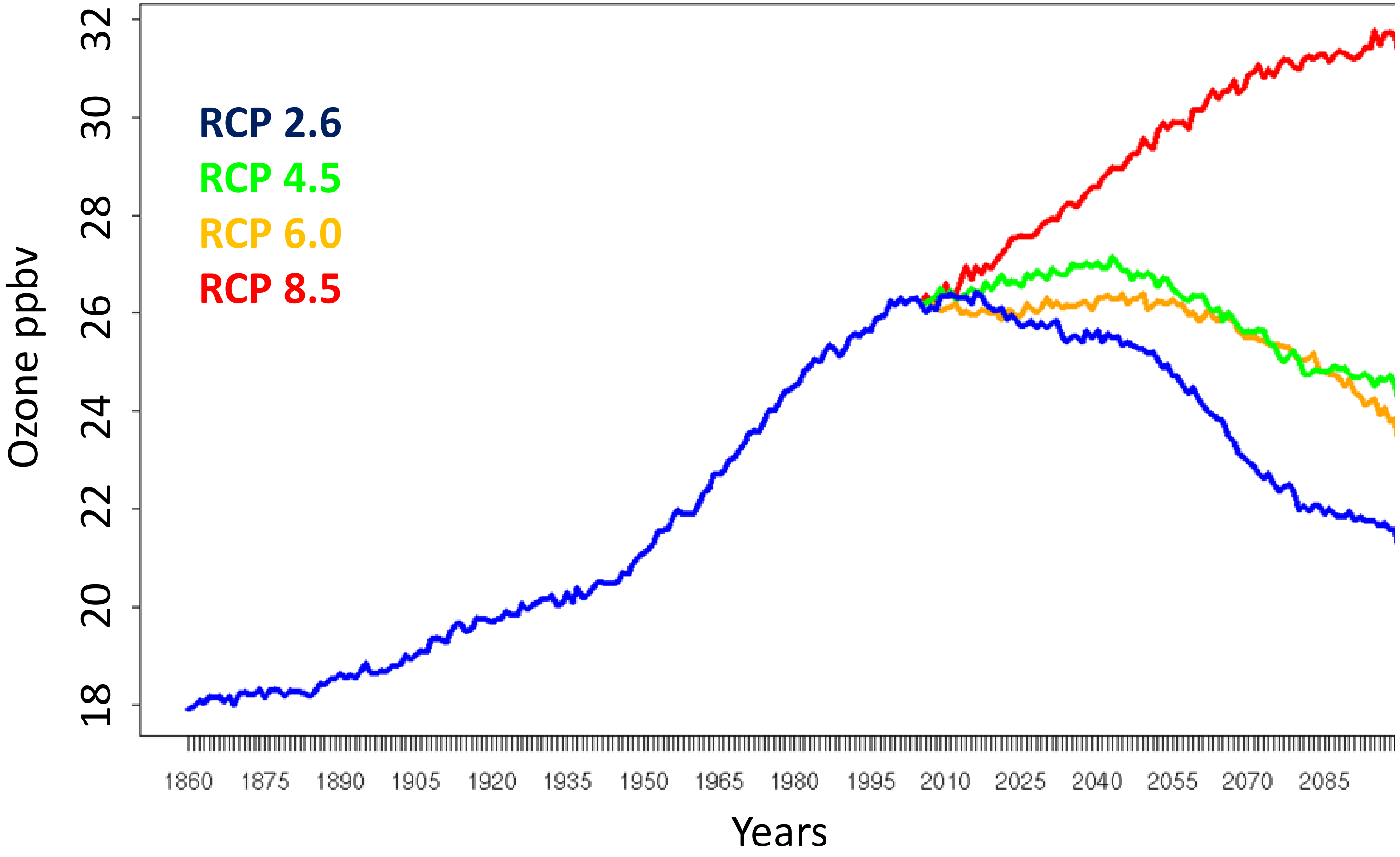


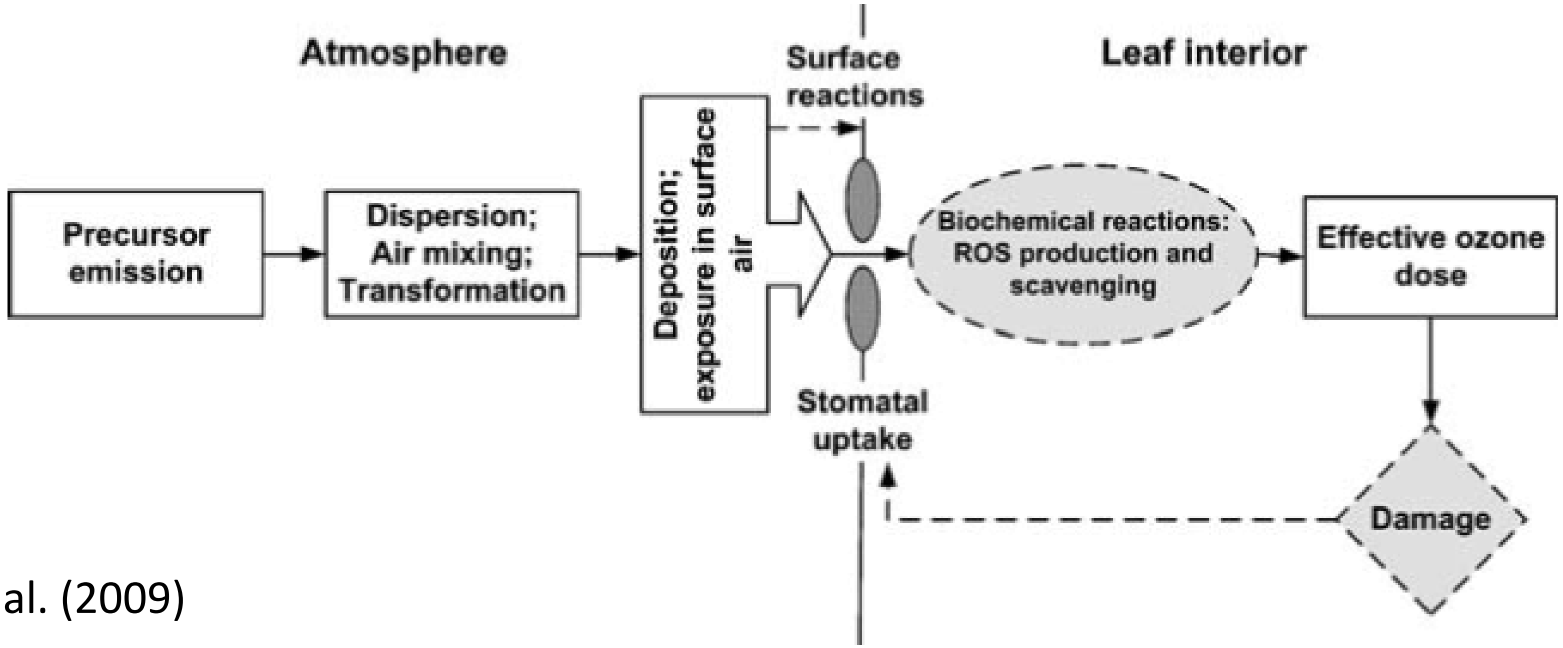
Ozone production and trend



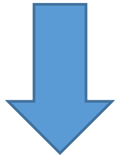
Representative Concentration Pathway (RCPs) of tropospheric ozone trajectories



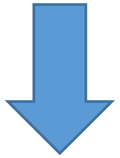
Biochemical effect of ozone on plant



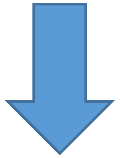
Castagna et al. (2009)



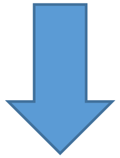
Maximum RuBP saturated rate of carboxylation (Vc max)



Gross Primary Productivity

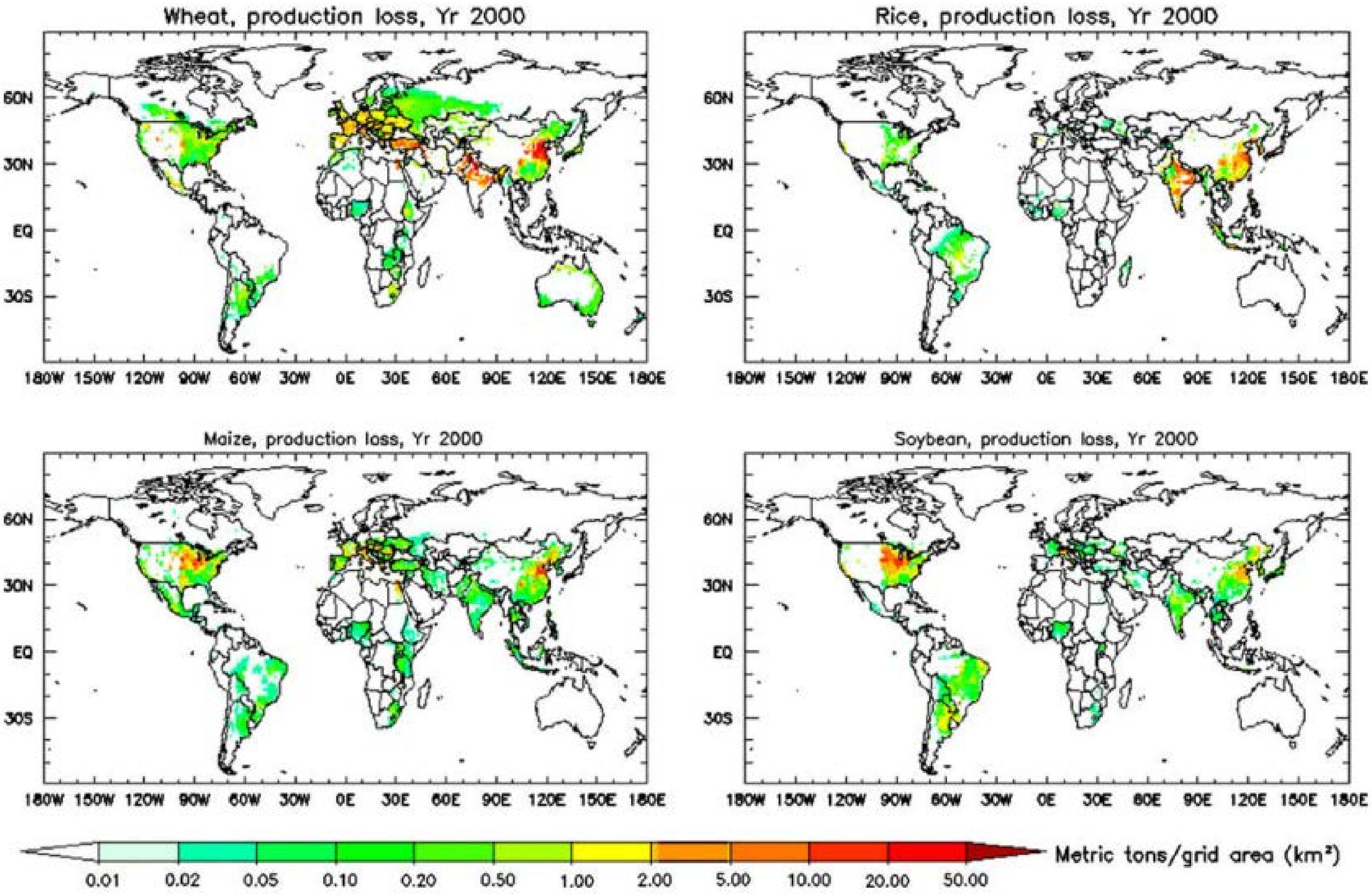


Leaf Area Index



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.

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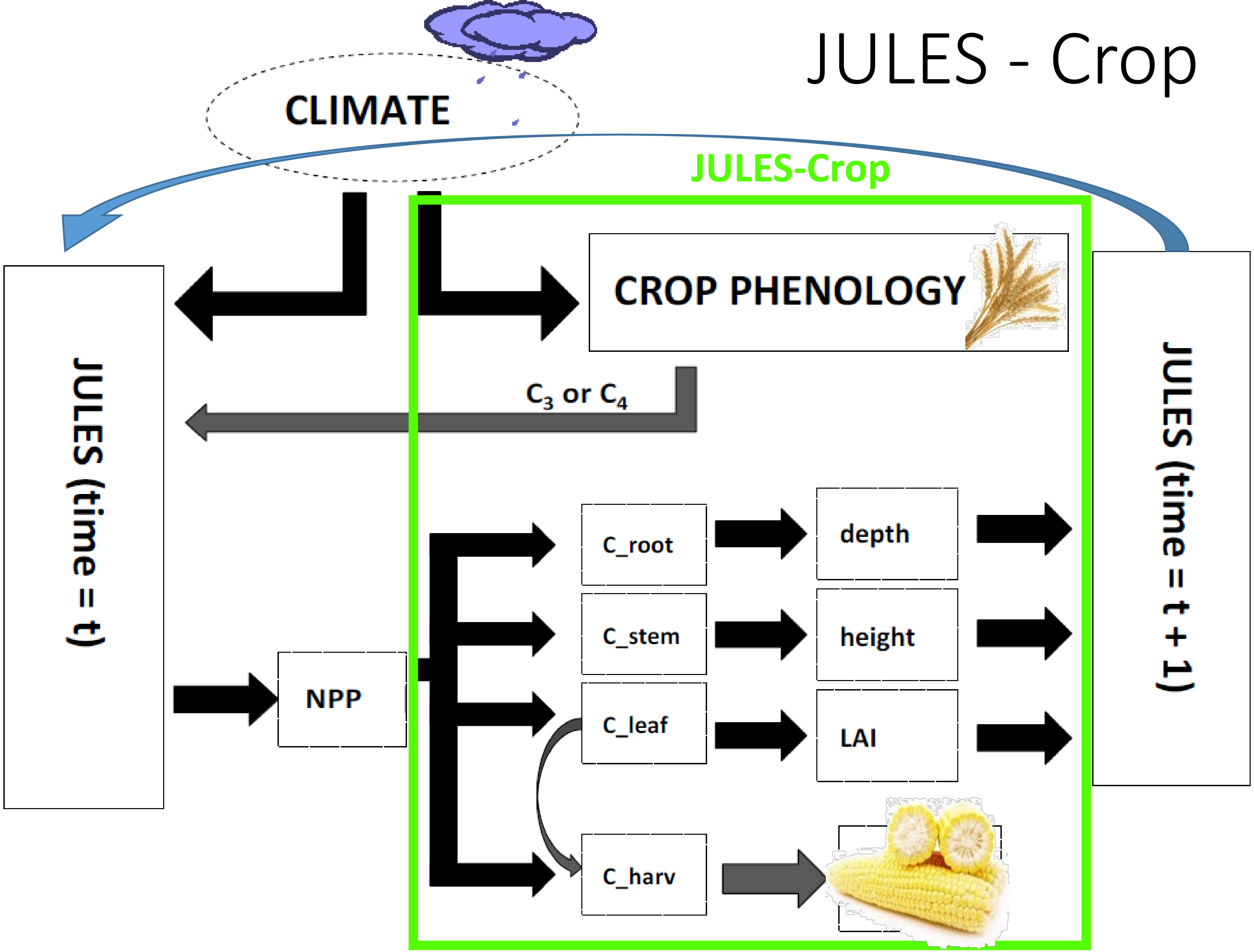
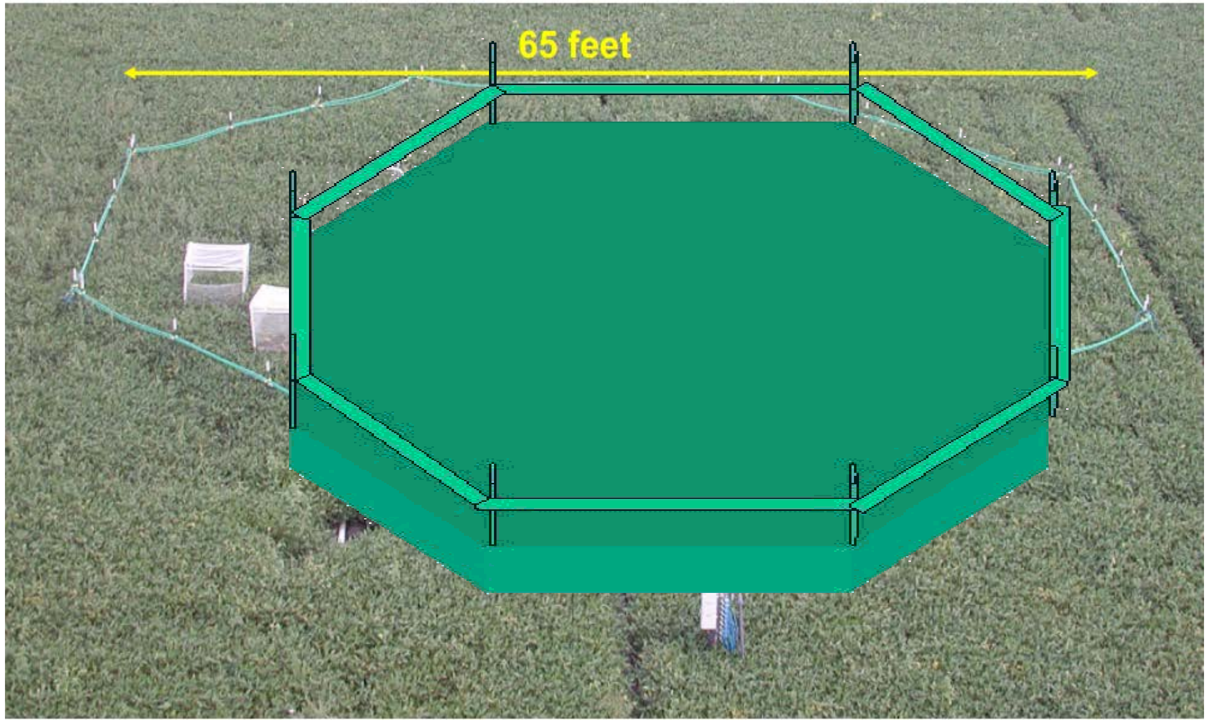
JULES - Crop


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

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



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

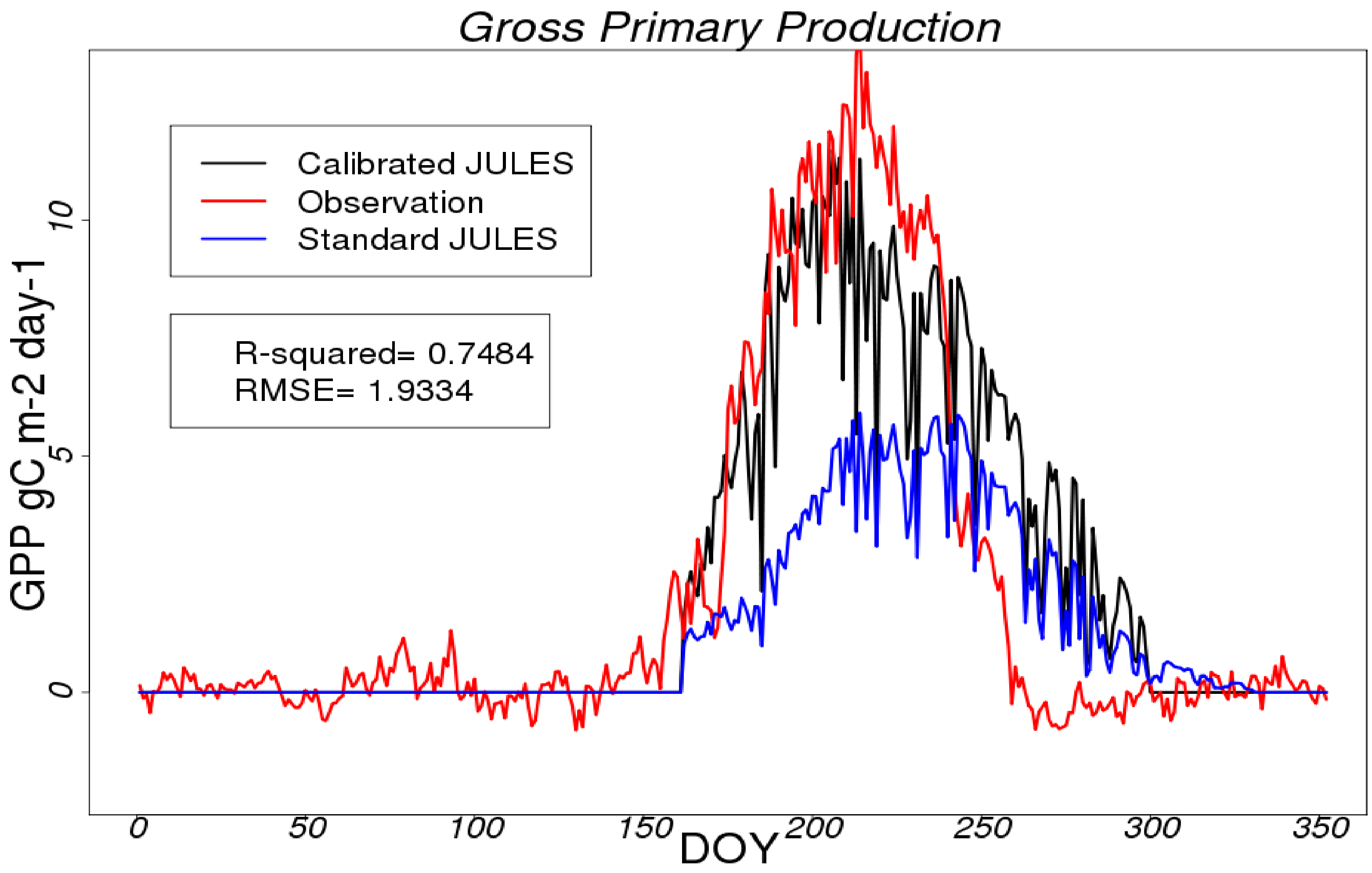
Vc max calibration

Sources	Description	Vc max	Unit
Kattge et al. (TRY database , accessed on 12/05/2015)	Average of all literatures with soybean Vc max	121.89	μ mol m^{-2} s^{-1}
Betzelberger et al.	SoyFACE measurement	120	μ mol m^{-2} s^{-1}
JULES C3 grass	Used as soybean default	58.4	μ mol m^{-2} s^{-1}

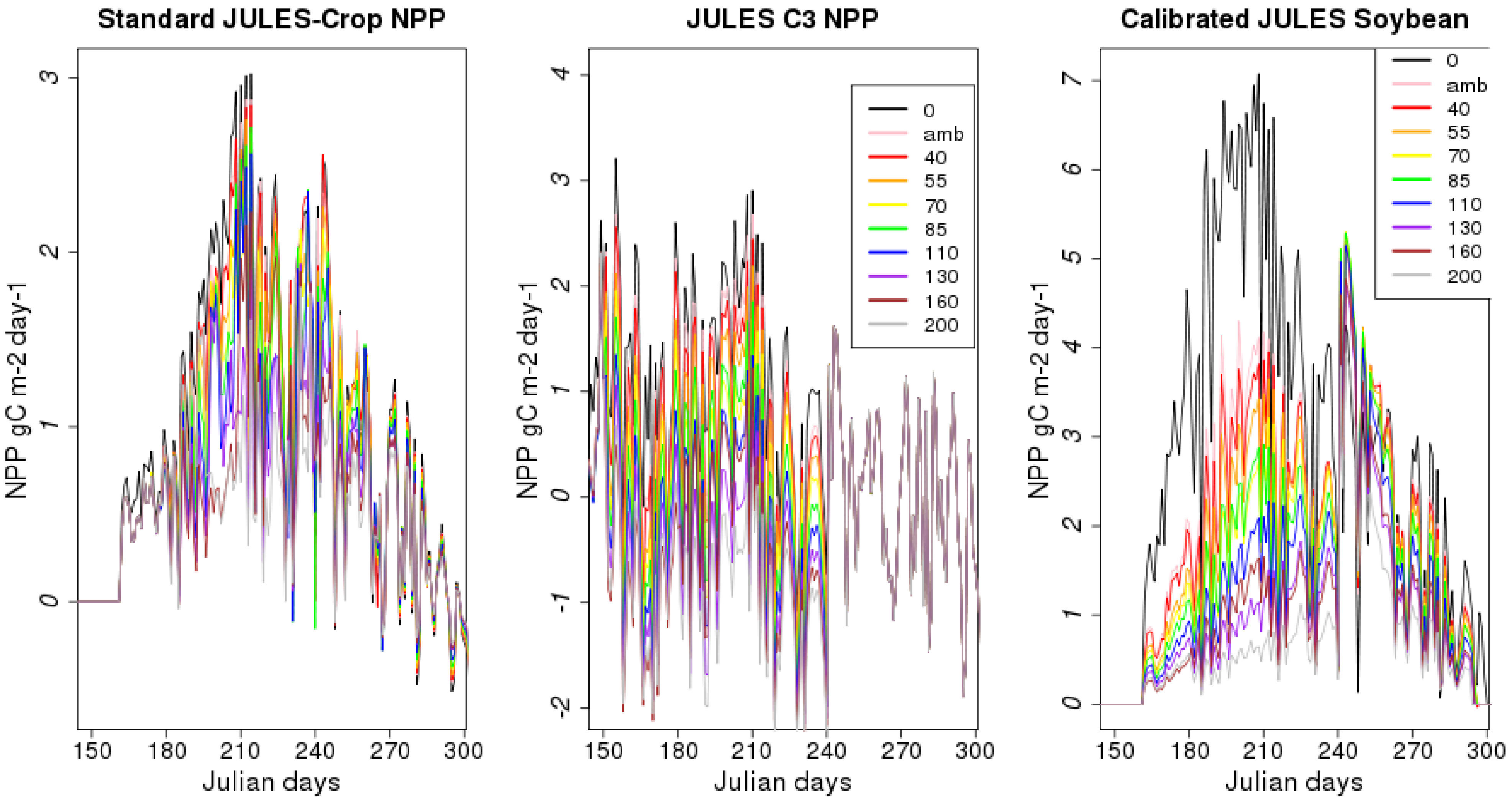
Soybean parameters calibration

JULES Parameters	Default	Tuned
Top leaf nitrogen concentration (kg N/kg C)	0.073	0.13
Scale factor of top leaf nitrogen to Vc_{max}	0.0008	0.001
Ratio of root N to leaf N	1.0	0.1
Ratio of stem N to leaf N	1.0	0.1
Fractional reduction of photosynthesis by O_3 (sensitivity) (mmol m^{-2})	1.40	0.825
Threshold of ozone flux (mmol m^{-2} s^{-1})	5.0	4.0

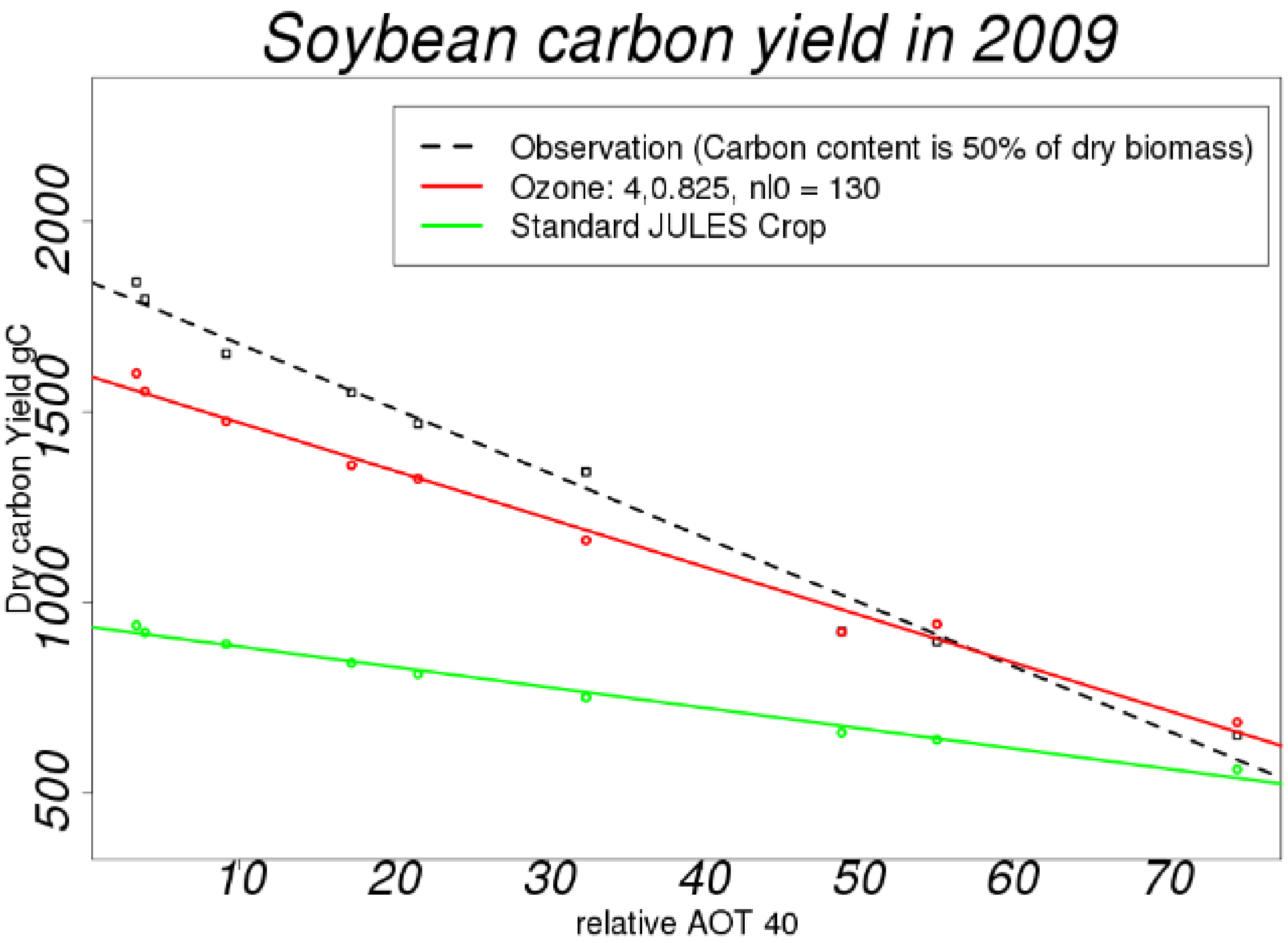
Calibration with SoyFACE site (Bondville Fluxnet)



Comparison of calibrated and standard JULES



Calibration of ozone damage on soybean



Net photosynthesis =

*photosynthesis * O_3 reduction factor*

$$A_l = A_l^* F$$

$F_{O3\ crit}$ =Threshold ozone flux

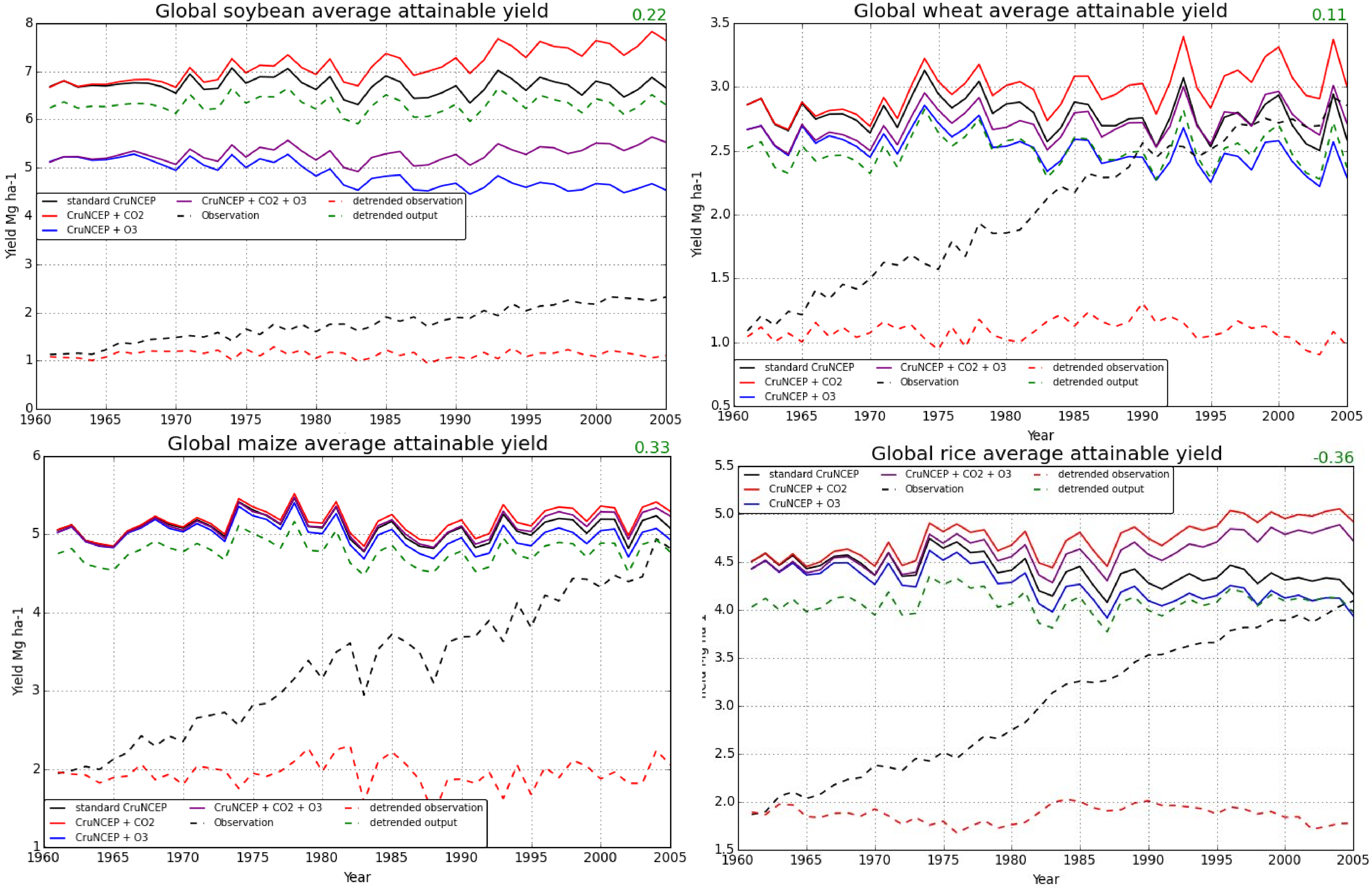
a = sensitivity of ozone

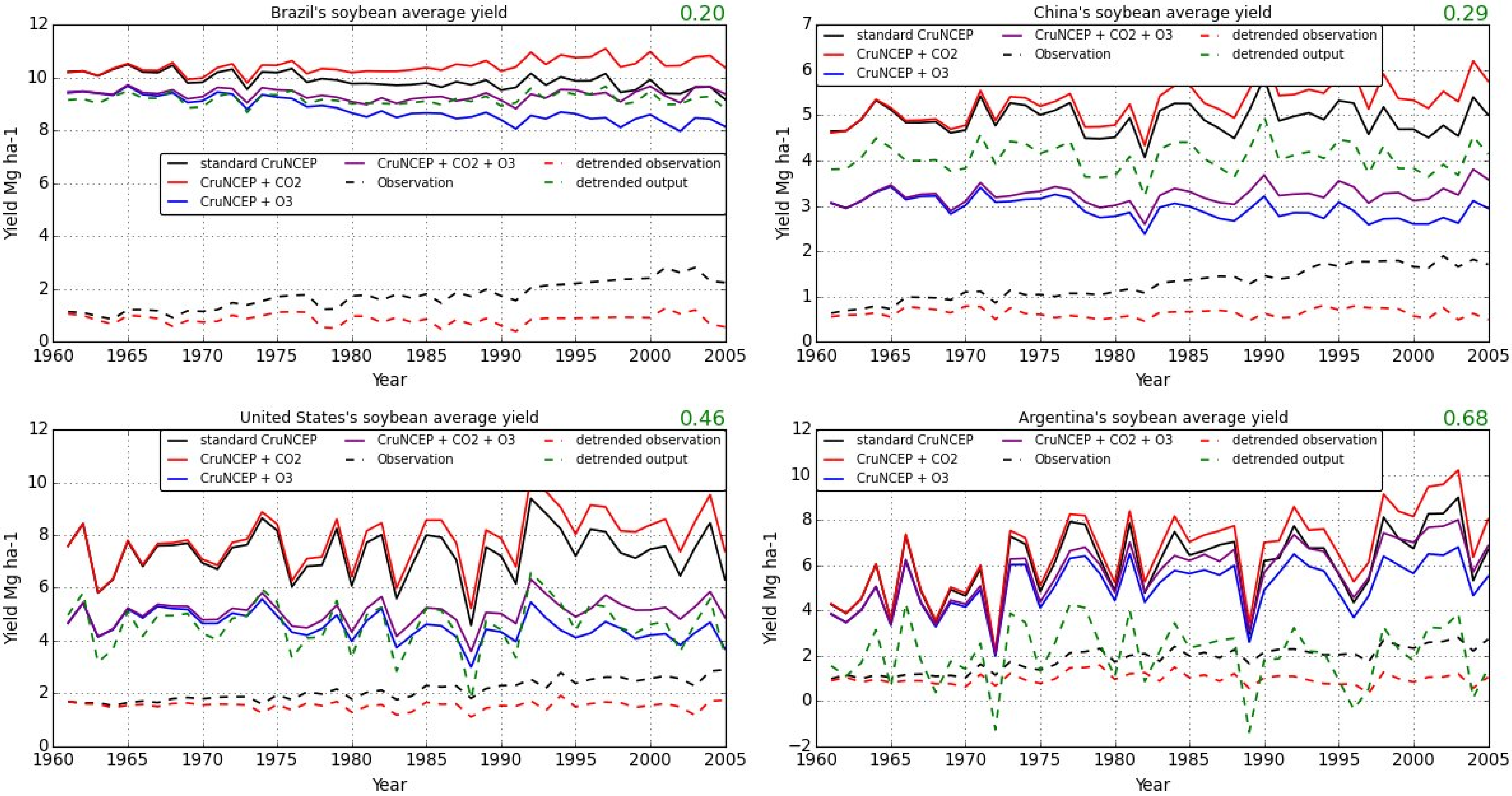
$$F = 1 - a \cdot \max\left[F_{O_3} - F_{O_3\,crit}, 0\right]$$

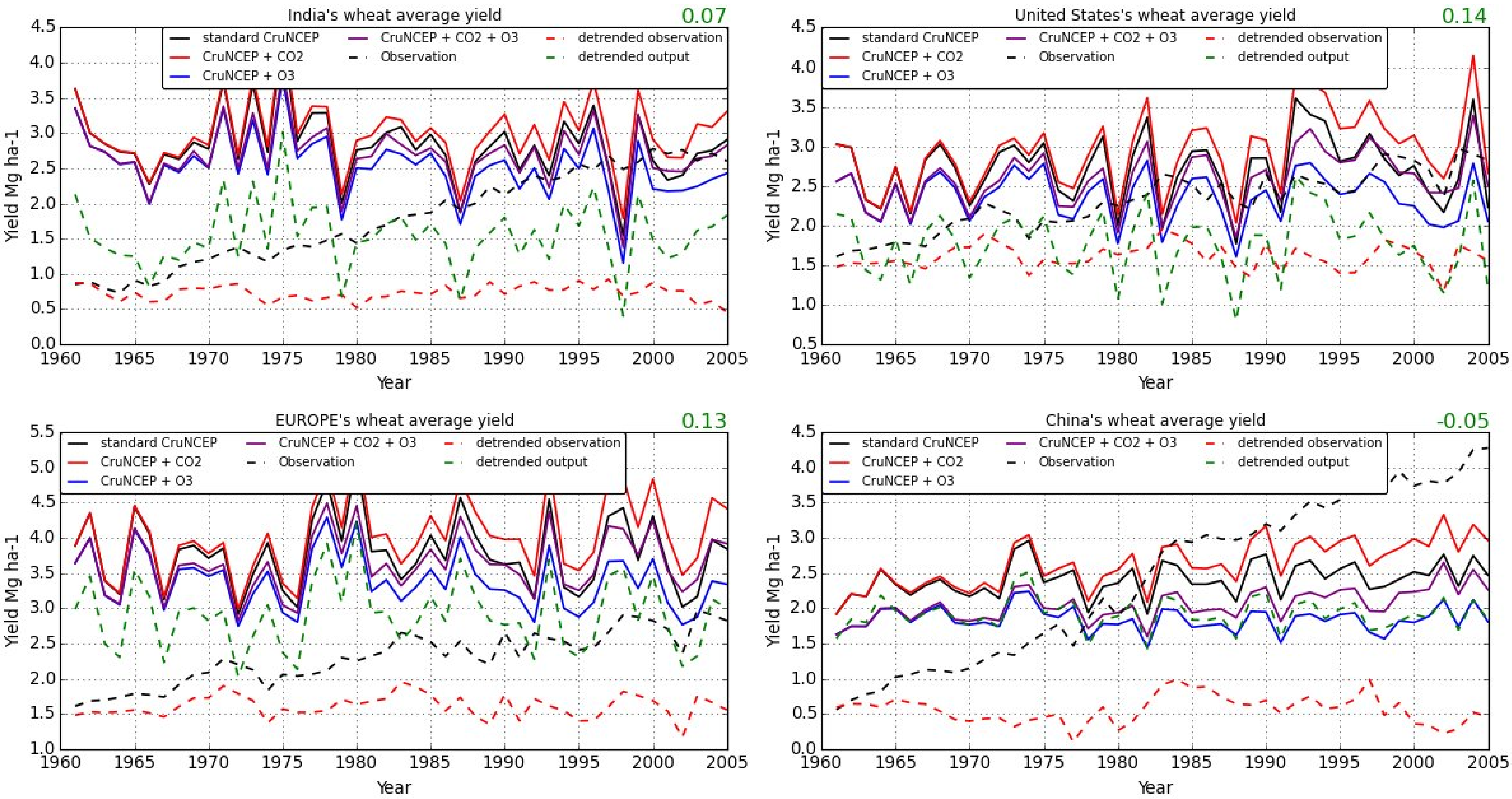
Historical simulation

- **Black**: climate change
- **Green**: detrended climate change
- **Red**: CO_2 and climate
- **Black dashed** : FAO observation
- **Blue**: O_3 and climate
- **Red dashed**: detrended FAO observation
- **Purple**: CO_2, O_3 and climate change
- Climatology: CRU-NCEPv4 , CO_2: CRUNCEP, O_3: HadGEM2-ES
- Time: 1961-2005
- can_rad_mod = 5

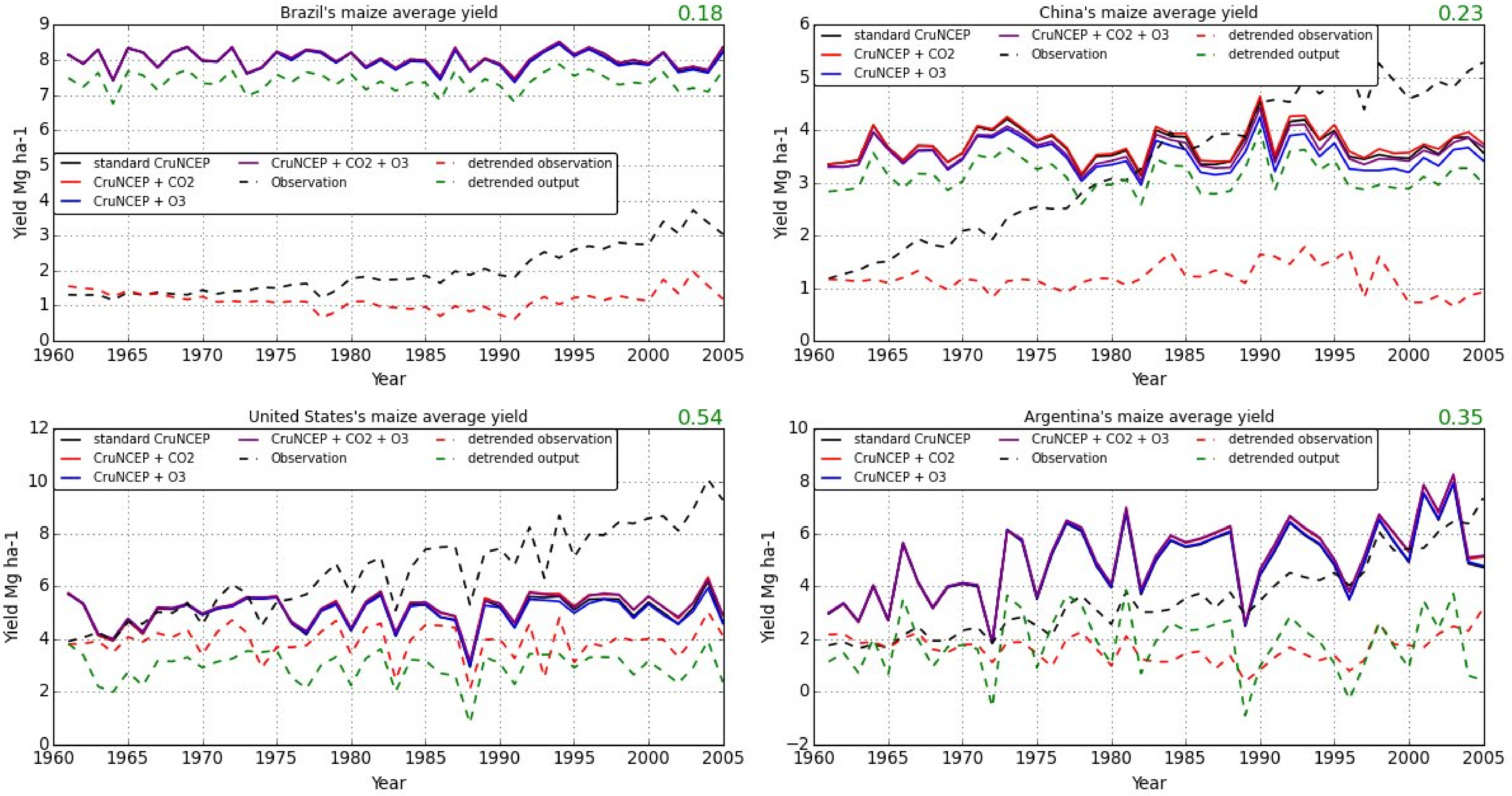
Crop	Percentage of storage organ of harvested crop
Wheat	0.85
Soybean	0.6
Maize	0.7
Rice	0.8


Global soybean average attainable yield
0.22
Yield Mg ha-1
standard CruNCEP
CruNCEP + CO2
CruNCEP + O3
CruNCEP + CO2 + O3
Observation
detrended observation
detrended output
Global wheat average attainable yield
0.11
Yield Mg ha-1
Year
standard CruNCEP
CruNCEP + CO2
CruNCEP + O3
CruNCEP + CO2 + O3
Observation
detrended observation
detrended output
Global maize average attainable yield
0.33
Yield Mg ha-1
Year
standard CruNCEP
CruNCEP + CO2
CruNCEP + O3
CruNCEP + CO2 + O3
Observation
detrended observation
detrended output
Global rice average attainable yield
-0.36
Year
standard CruNCEP
CruNCEP + CO2
CruNCEP + O3
CruNCEP + CO2 + O3
Observation
detrended observation
detrended output


Brazil's soybean average yield
0.20
China's soybean average yield
0.29
United States's soybean average yield
0.46
Argentina's soybean average yield
0.68
standard CruNCEP
CruNCEP + CO2
CruNCEP + O3
CruNCEP + CO2 + O3
Observation
detrended observation
detrended output
Yield Mg ha-1
Year

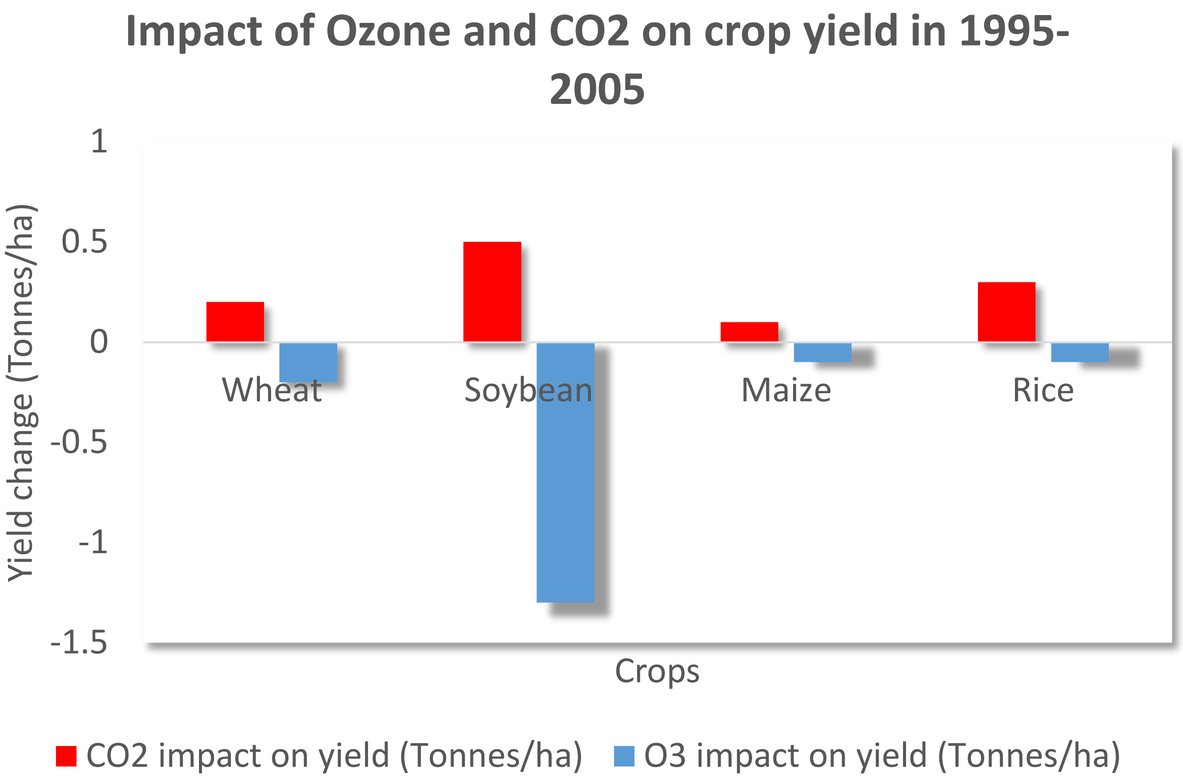


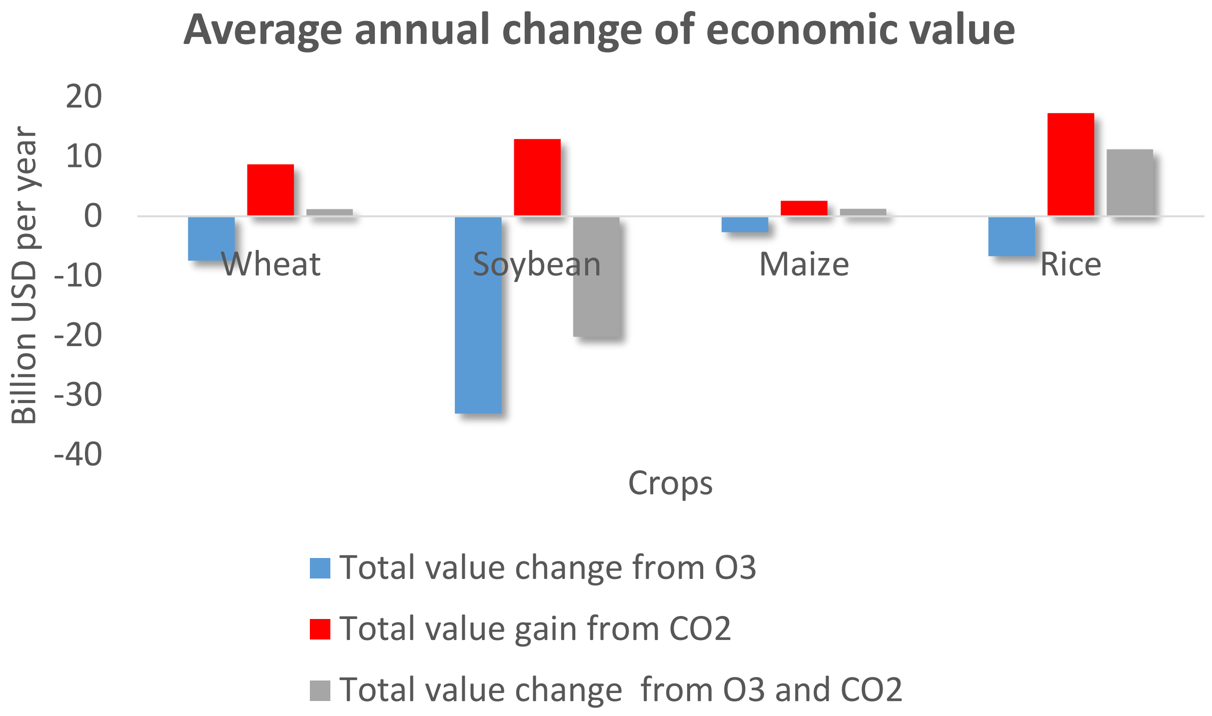
India's wheat average yield
0.07
United States's wheat average yield
0.14
EUROPE's wheat average yield
0.13
China's wheat average yield
-0.05
standard CruNCEP
CruNCEP + CO2
CruNCEP + O3
CruNCEP + CO2 + O3
Observation
detrended observation
detrended output
Yield Mg ha-1
Year



Brazil's maize average yield
0.18
China's maize average yield
0.23
United States's maize average yield
0.54
Argentina's maize average yield
0.35
standard CruNCEP
CruNCEP + CO2
CruNCEP + O3
CruNCEP + CO2 + O3
Observation
detrended observation
detrended output
Yield Mg ha-1
Year

Global economic impact of O_3 and CO_2



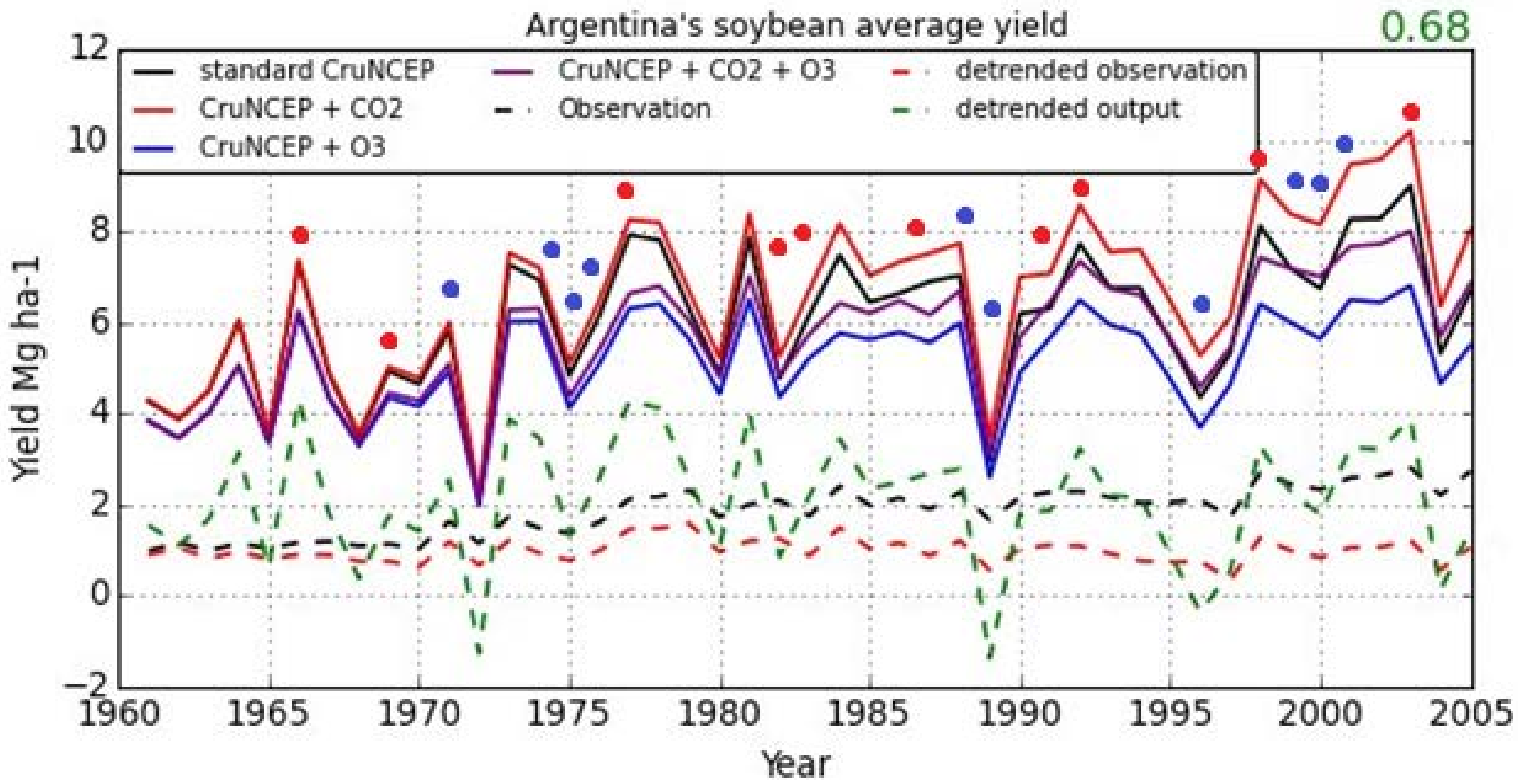


Economic value of crop is taken from FAO statistic using data from 1991-2005. Harvested area from FAO was multiplied with the model yield output

Summary for historical yield

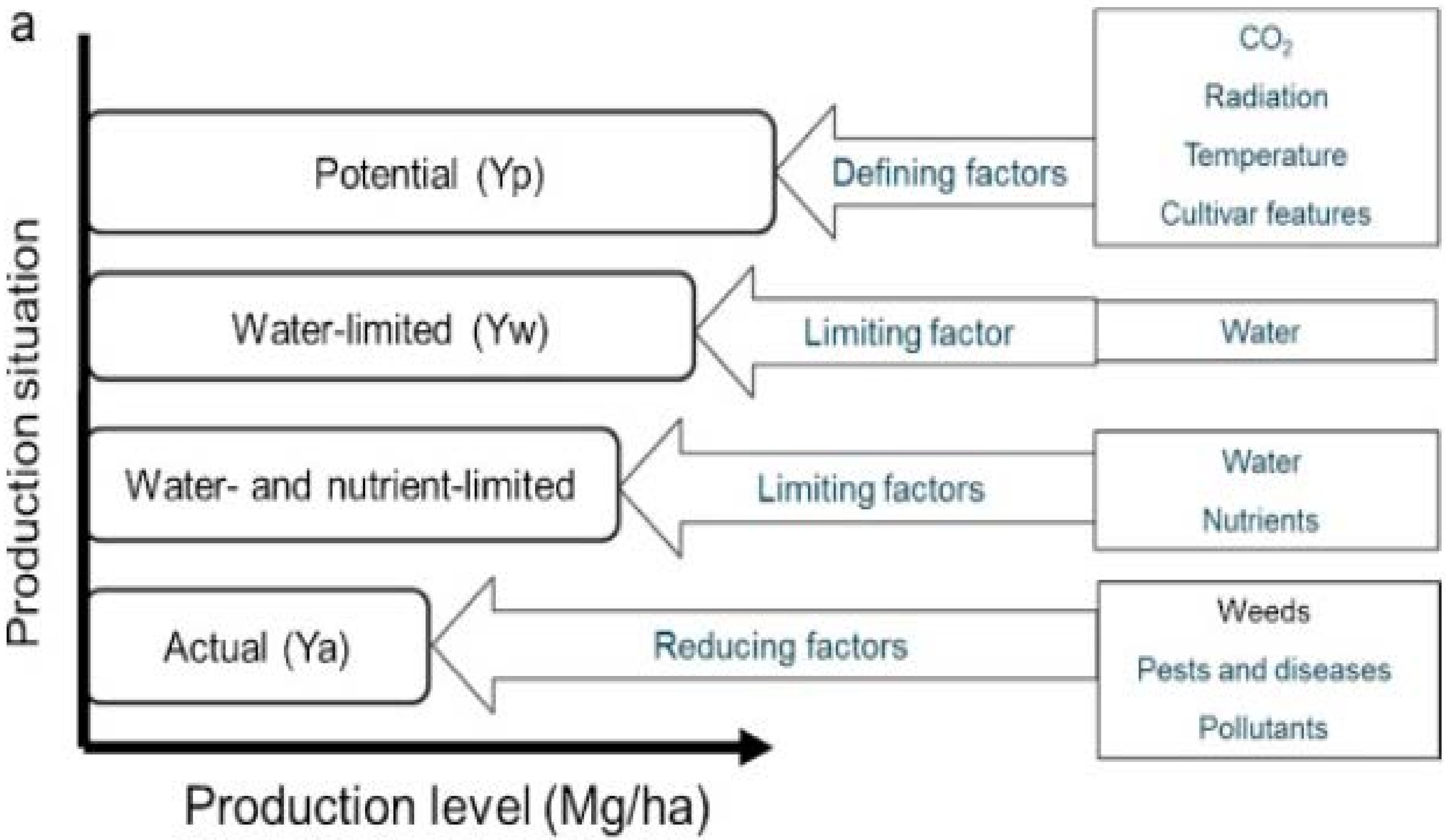
- Simulated yields shows a larger magnitude of variability than the observed yields
- JULES is more sensitive to climate variation due to lack of human management in the model
- Very sensitive to precipitation and rainfall at water limited region, has high impact on crop yield (Williams & Falloon, 2015)
- The economic loss from ozone is highest for soybean
- Yield gap in developed countries such as USA, Europe and Argentina are smaller than developing countries e.g. China and India.
- JULES-crop tends to overestimate yields in tropical regions.

ENSO impact on crop yield in Argentina



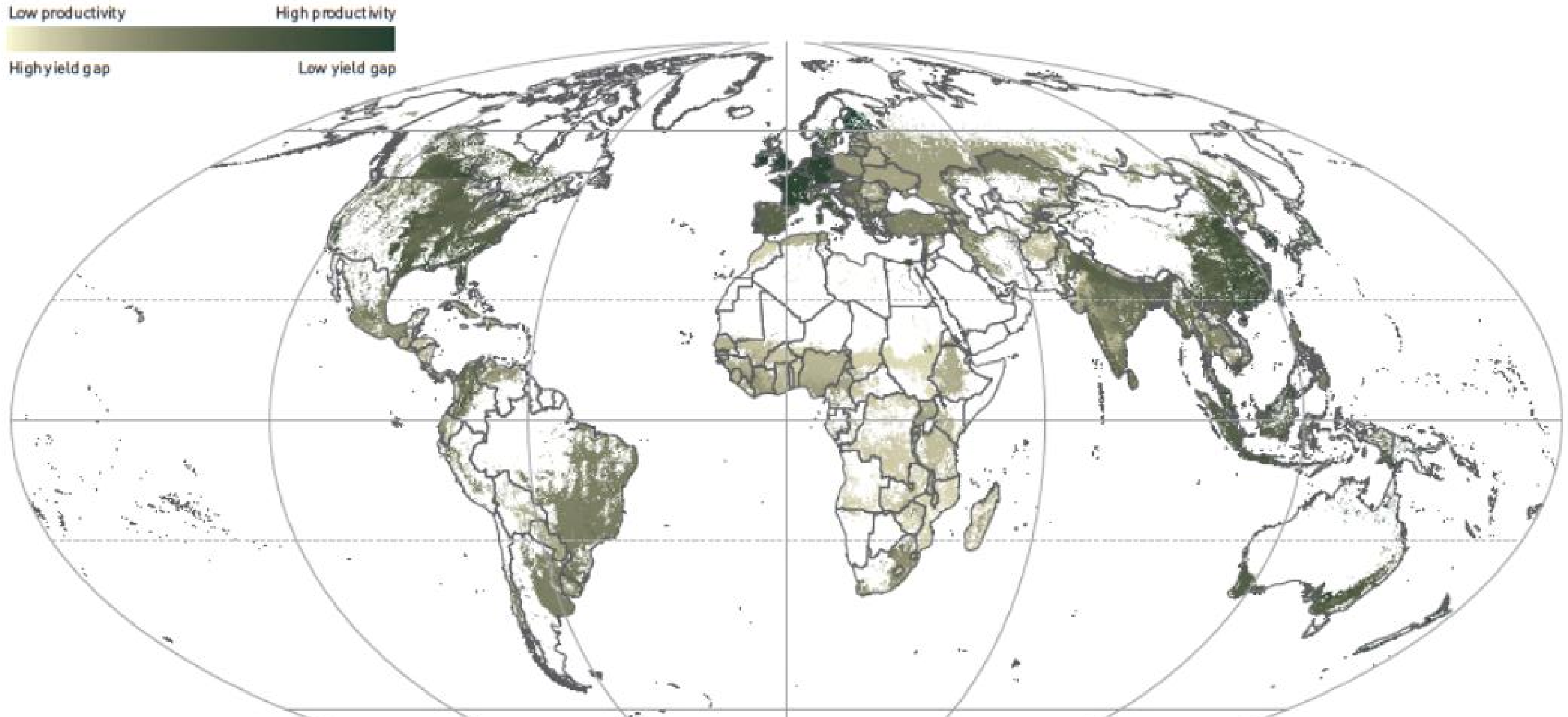
Red dots above the line represent “El Niño” wet year and the blue dots are “La Niña” dry year

Yield gap

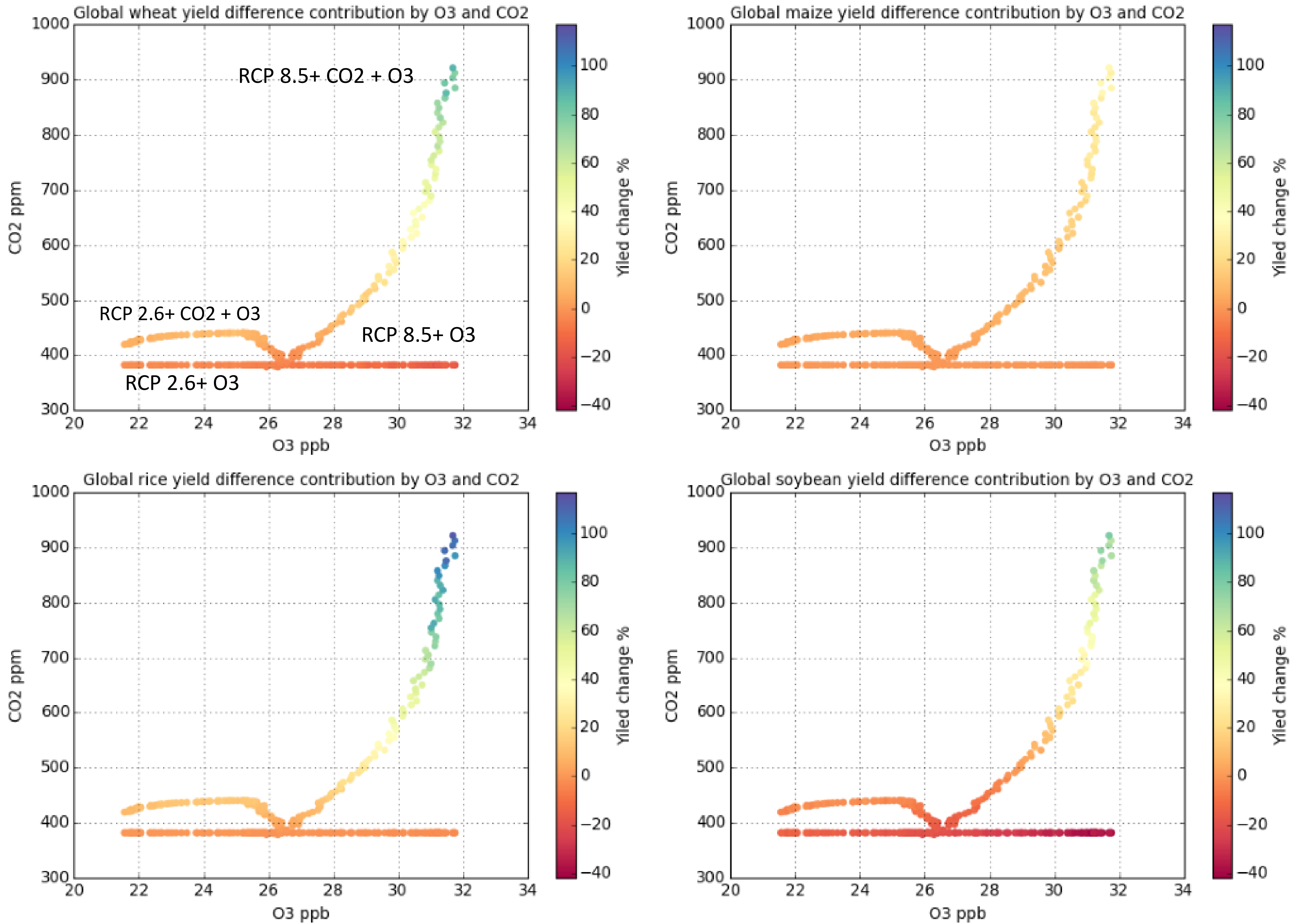

a
Production situation
Potential (Yp)
Water-limited (Yw)
Water- and nutrient-limited
Actual (Ya)
Production level (Mg/ha)
Defining factors
Limiting factor
Limiting factors
Reducing factors
CO_2
Radiation
Temperature
Cultivar features
Water
Water
Nutrients
Weeds
Pests and diseases
Pollutants

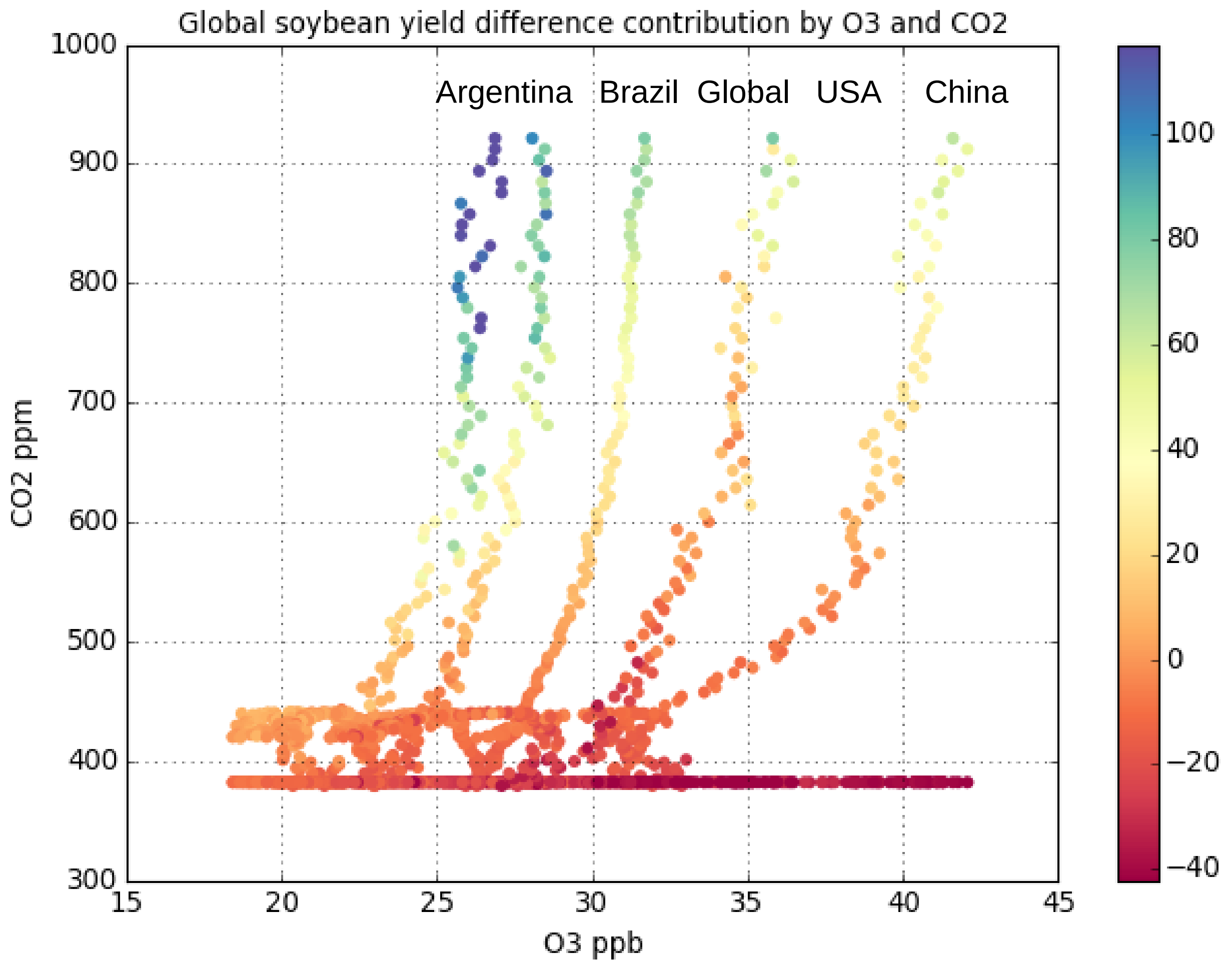
Calculate yield gap

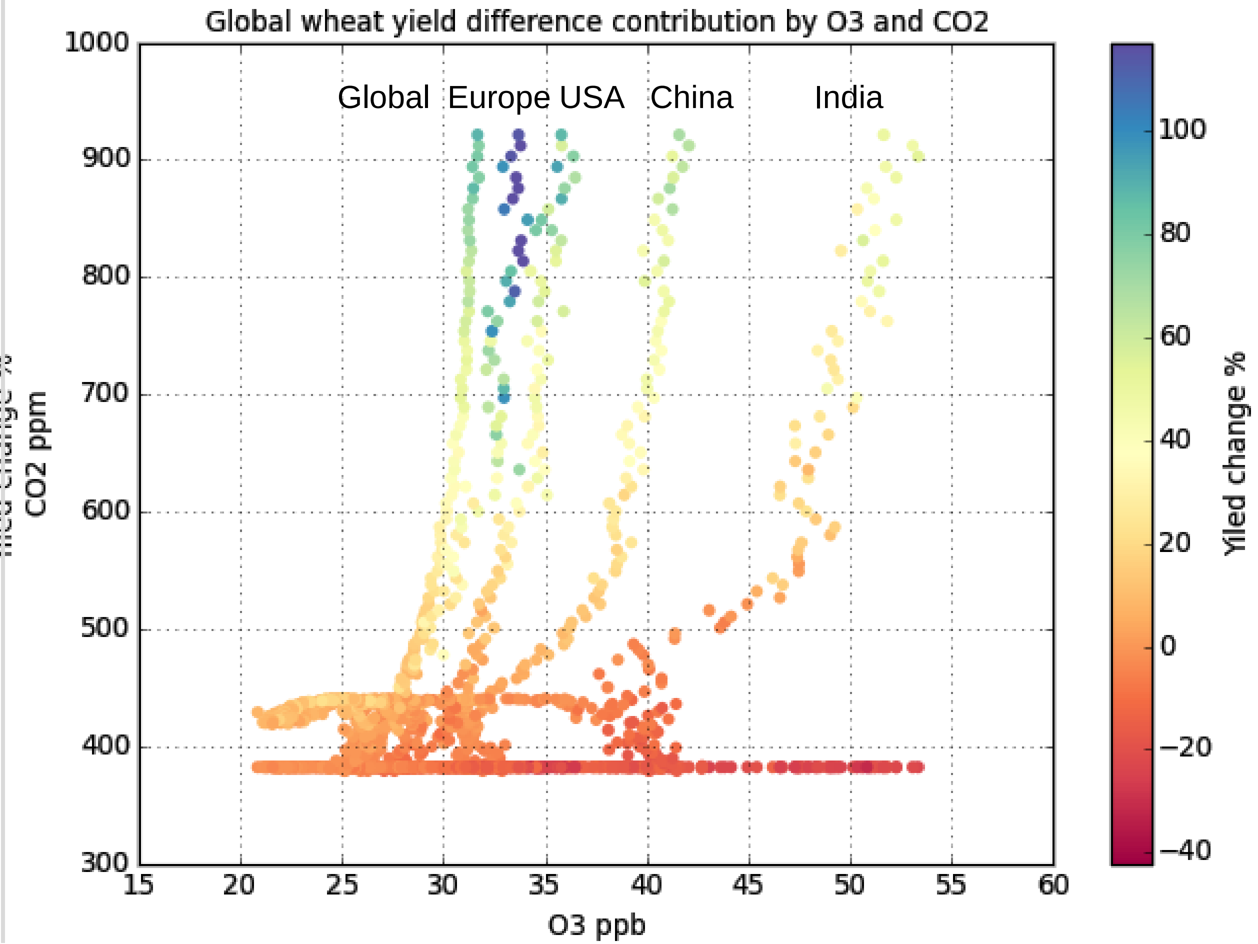
- the crop area is categorised into 100 equal-area “bins” of similar climate (growing degree-day and annual precipitation) for each crops
- The maximum observed yield for the crop of the same climate bin is considered as the “attainable yield" and the yield difference from the attainable yield is the yield gap.

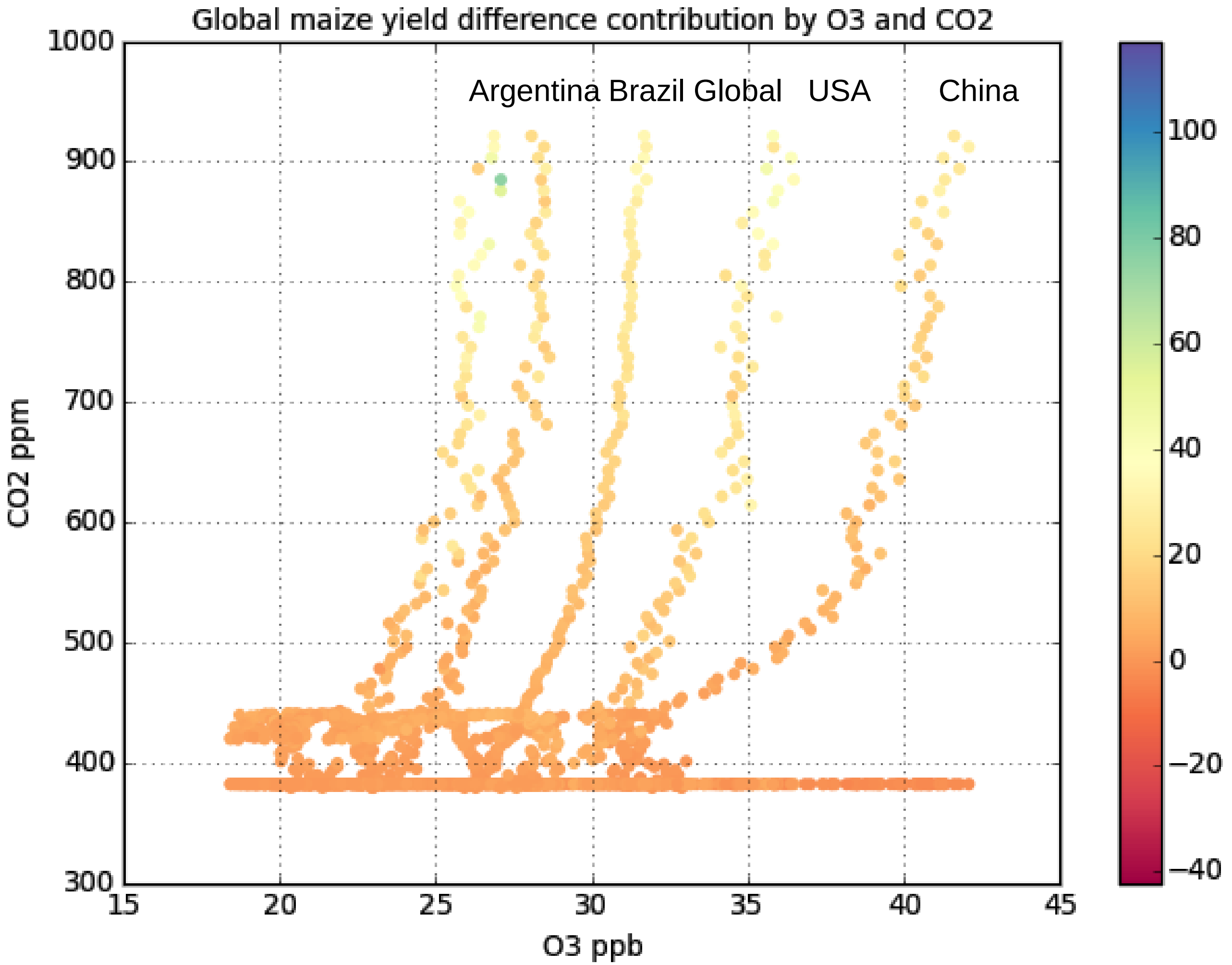


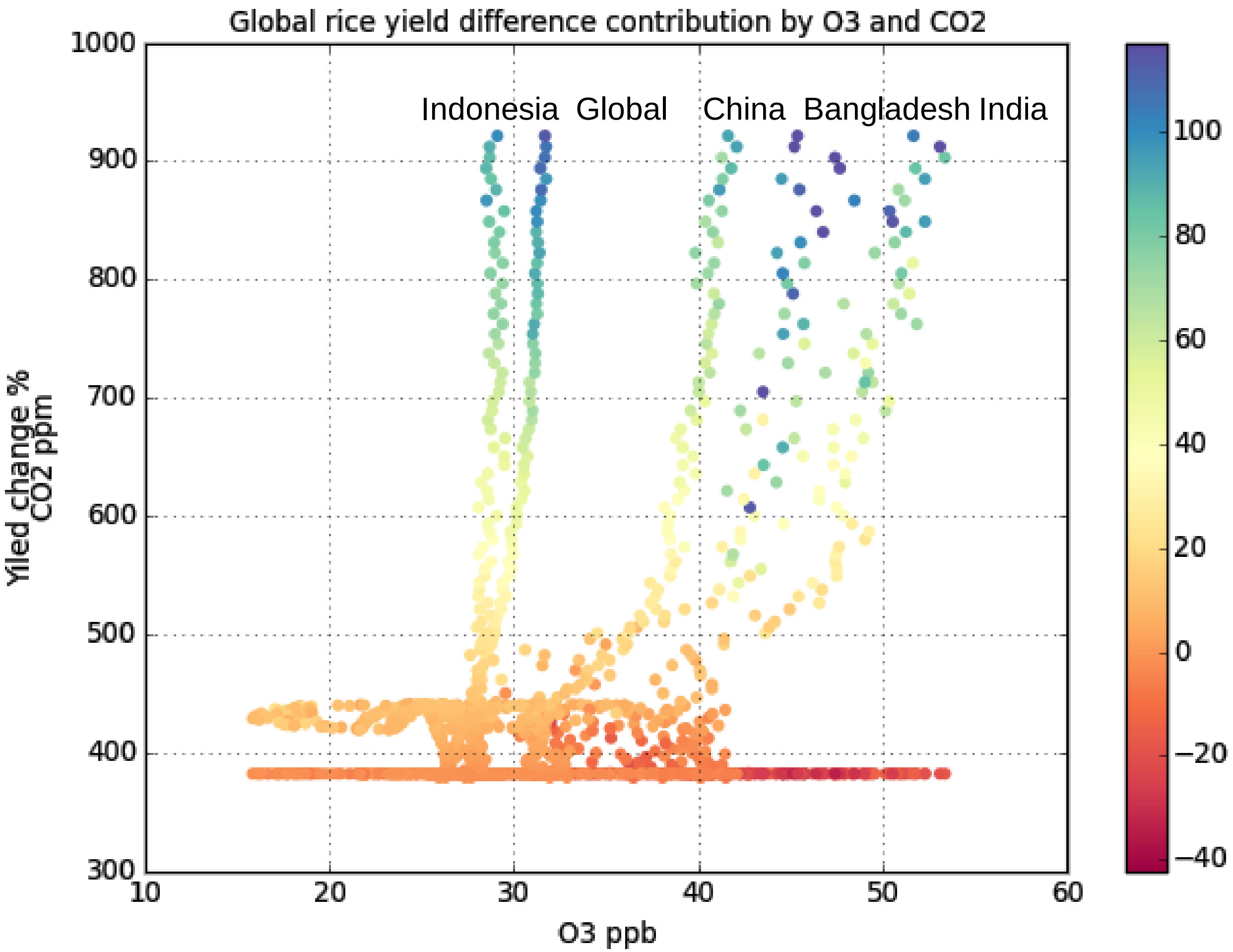
Relative impact of O_3 and CO_2 on yield

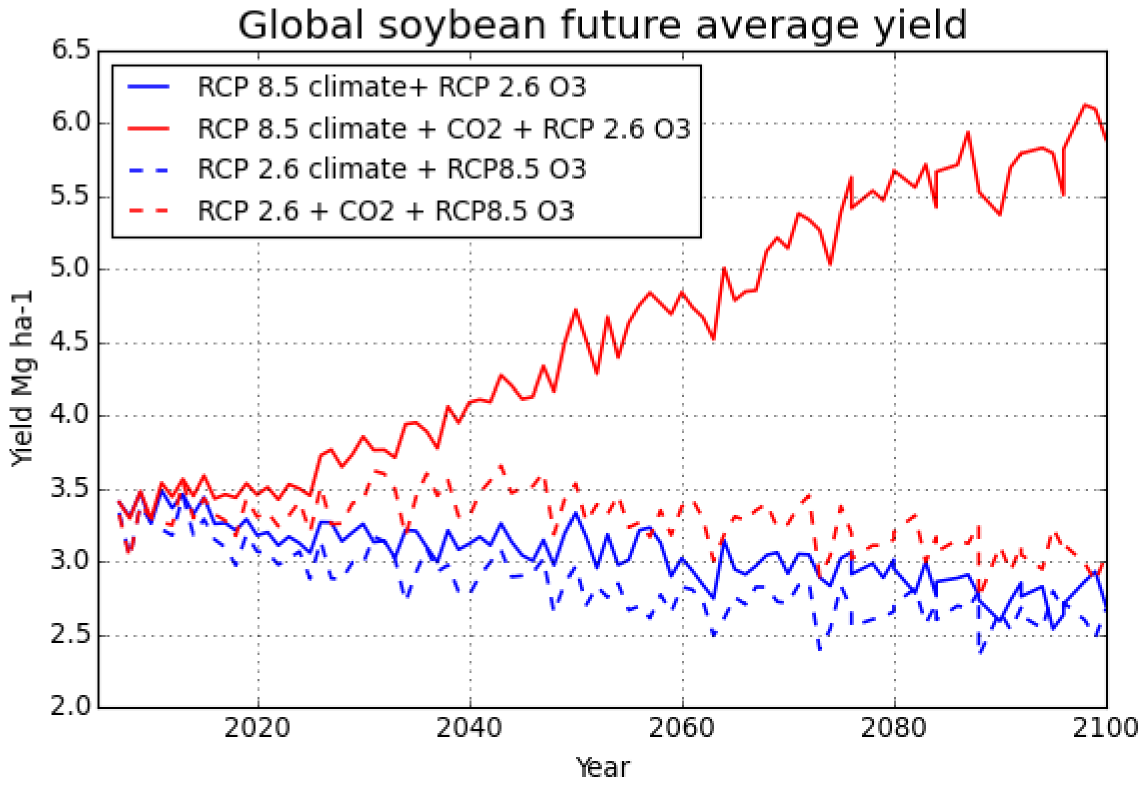


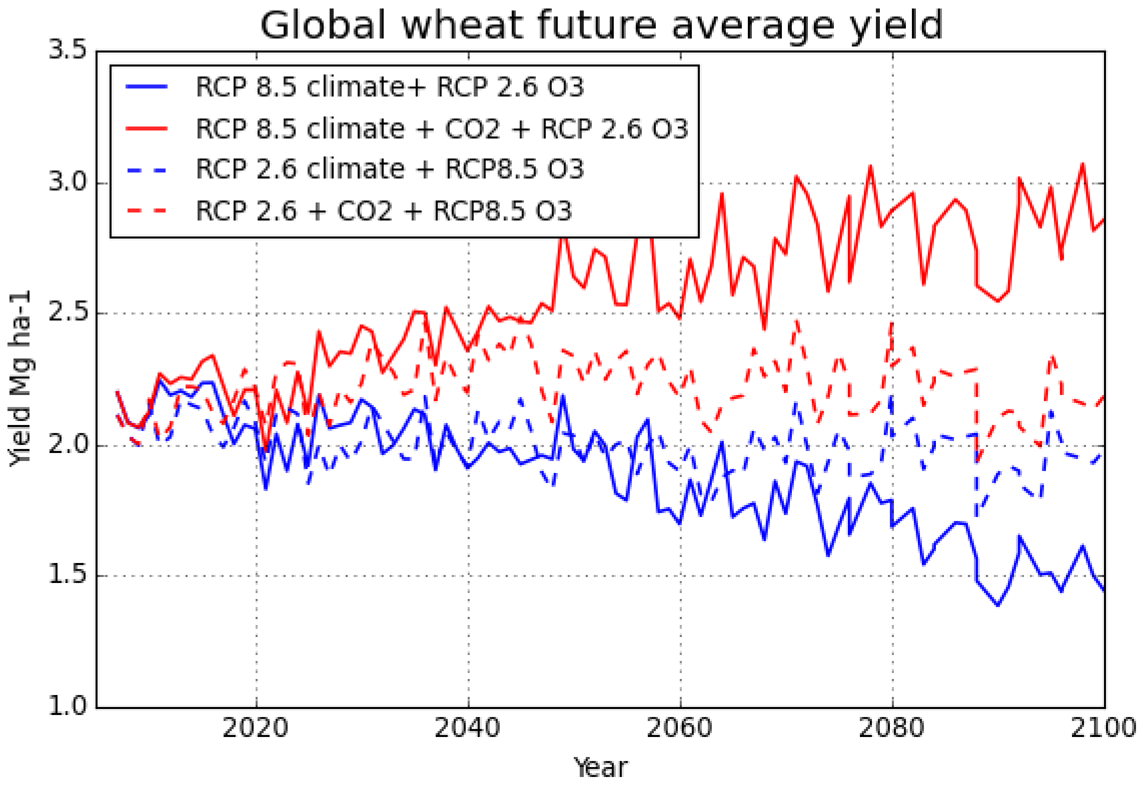

Global soybean yield difference contribution by O3 and CO2
Argentina
Brazil
Global
USA
China
CO2 ppm
O3 ppb
Yiled change %


Global wheat yield difference contribution by O3 and CO2
Global
Europe
USA
China
India
CO2 ppm
O3 ppb
Yiled change %


Global maize yield difference contribution by O3 and CO2
Argentina Brazil Global USA China
CO2 ppm
O3 ppb
Yiled change %
1000
900
800
700
600
500
400
300
15
20
25
30
35
40
45
100
80
60
40
20
0
−20
−40


Global rice yield difference contribution by O3 and CO2
Indonesia Global China Bangladesh India
CO2 ppm
O3 ppb
1000
900
800
700
600
500
400
300
10
20
30
40
50
60
100
80
60
40
20
0
−20
−40


Global soybean future average yield
RCP 8.5 climate+ RCP 2.6 O3
RCP 8.5 climate + CO2 + RCP 2.6 O3
RCP 2.6 climate + RCP8.5 O3
RCP 2.6 + CO2 + RCP8.5 O3
Yield Mg ha-1
Year
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
2020
2040
2060
2080
2100


Global wheat future average yield
RCP 8.5 climate+ RCP 2.6 O3
RCP 8.5 climate + CO2 + RCP 2.6 O3
RCP 2.6 climate + RCP8.5 O3
RCP 2.6 + CO2 + RCP8.5 O3
Yield Mg ha-1
Year
3.5
3.0
2.5
2.0
1.5
1.0
2020
2040
2060
2080
2100

Future works

- In RCP 2.6 the ozone concentration decrease is not mainly due to clean air policy but climate change mitigation policy which also reduce ozone precursors
- This suggests climate change mitigation is more important than clean air policy
- Combination of RCP 8.5 climatology, RCP 8.5 CO_2 and RCP 2.6 O_3 gives the highest yield
- Solar Radiation Management with clean air policy can reduce global warming and improve yield