Vegetation O_3 damage:
Impacts on plants & ecosystems

Danica Lombardozzi
National Center for Atmospheric Research

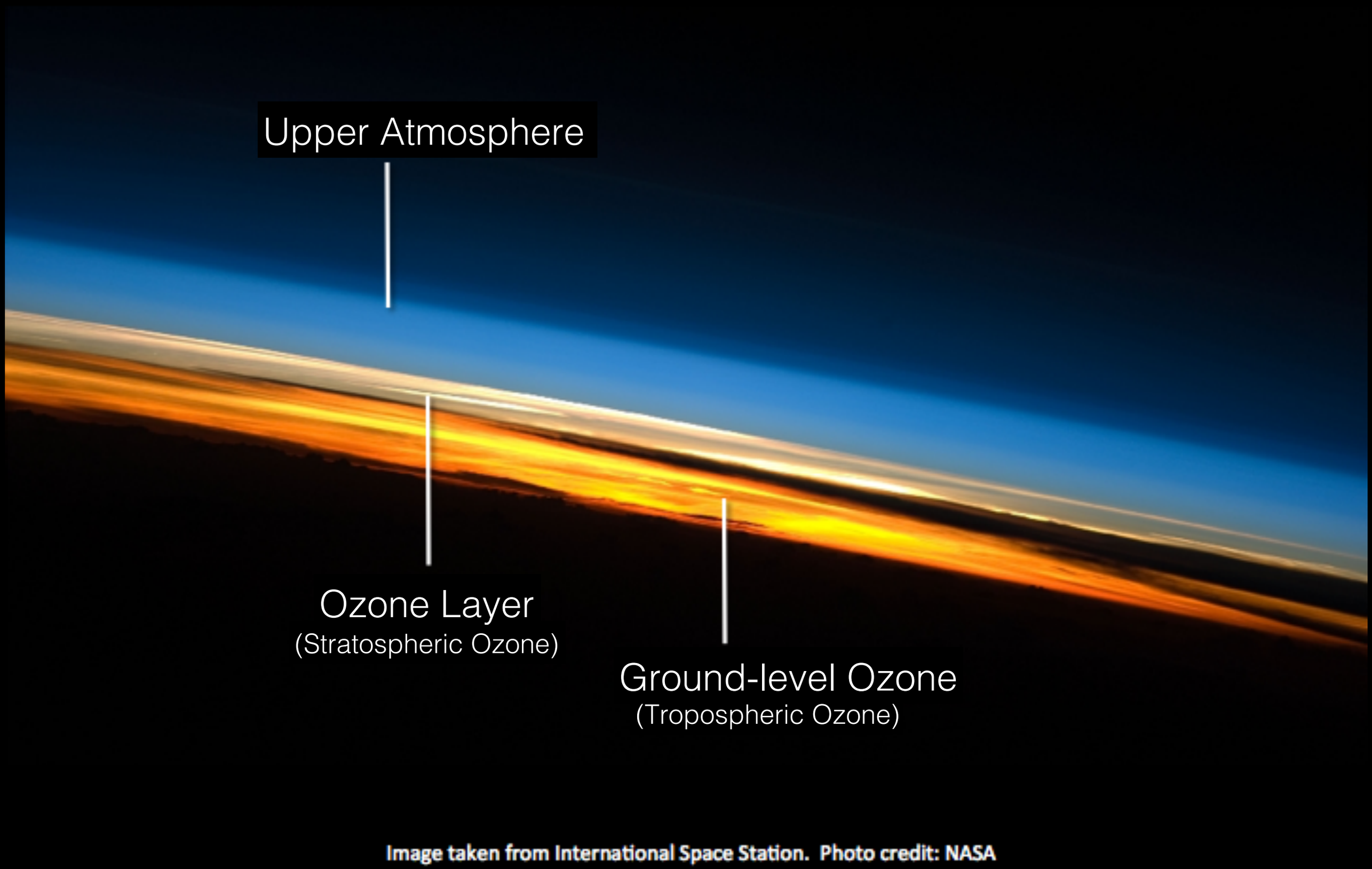


Image taken from International Space Station. Photo credit: NASA

Smog

Ozone (O_3) Formation:

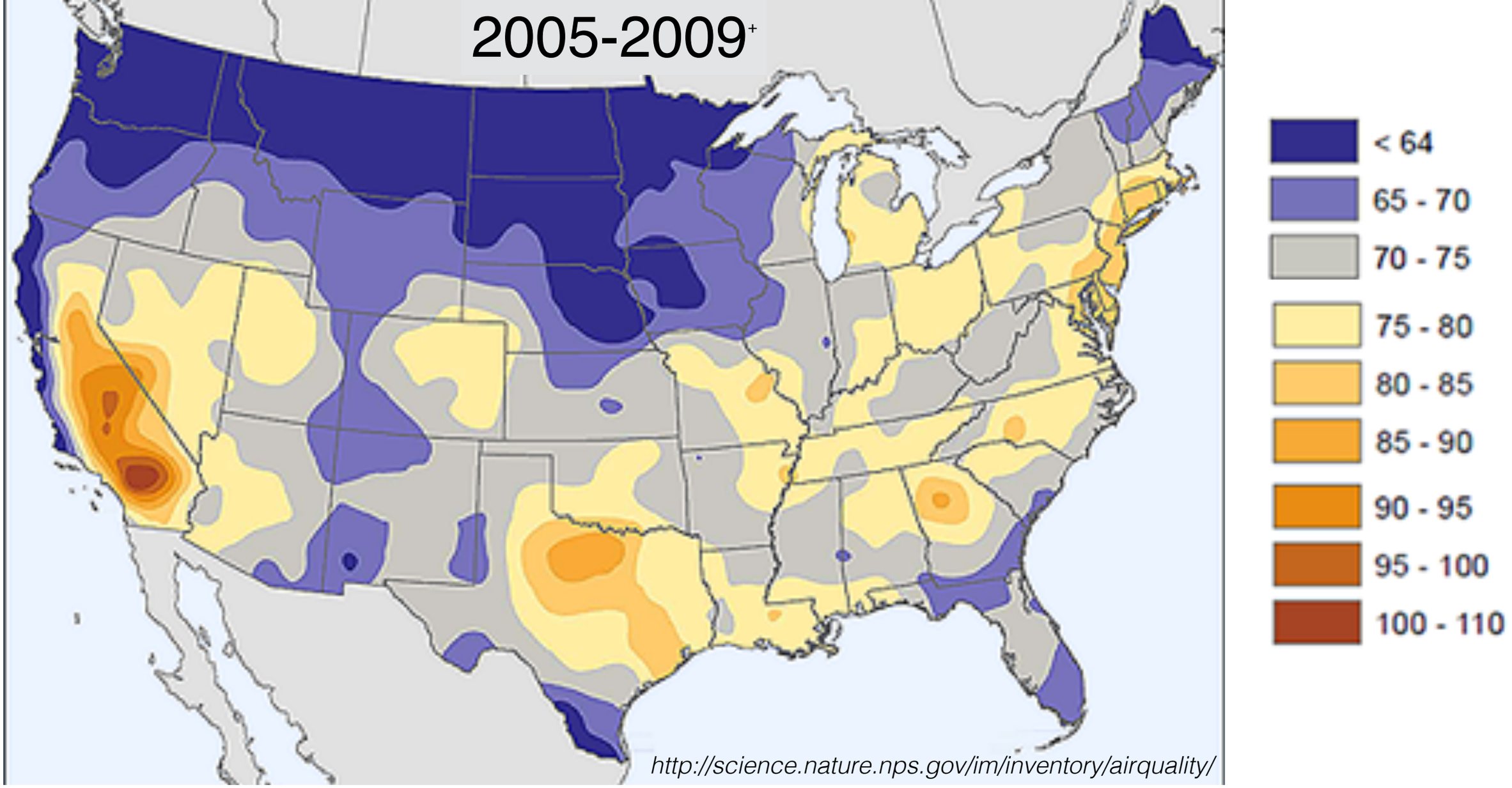
Nitrogen Oxides (NO_x)

Volatile Organic Compounds (VOCs)

\+ Sunlight

Ground-level Ozone (O_3)

↕ Smog



+The 4th highest annual value of the maximum daily 8-hour ozone concentration in parts per billion

EPA limit: 70 ppb over 8 hours

Human Sensitivity*: ~60 ppb
Plant Sensitivity*: ~40 ppb

** There is a lot of variation in human and plant sensitivities. Some humans and plants are sensitive below these concentrations, while others are not affected until concentrations are much higher.*

August 4

Potato, var. LaChipper

August 4

Potato, var. LaChipper

August 28

Potato, var. LaChipper

August 4

August 28

September 9

Questions for today:

How does ozone pollution change:

1. Leaf processes?

Questions for today:

How does ozone pollution change:

1. Leaf processes?

2. Global terrestrial processes?

Questions for today:

How does ozone pollution change:

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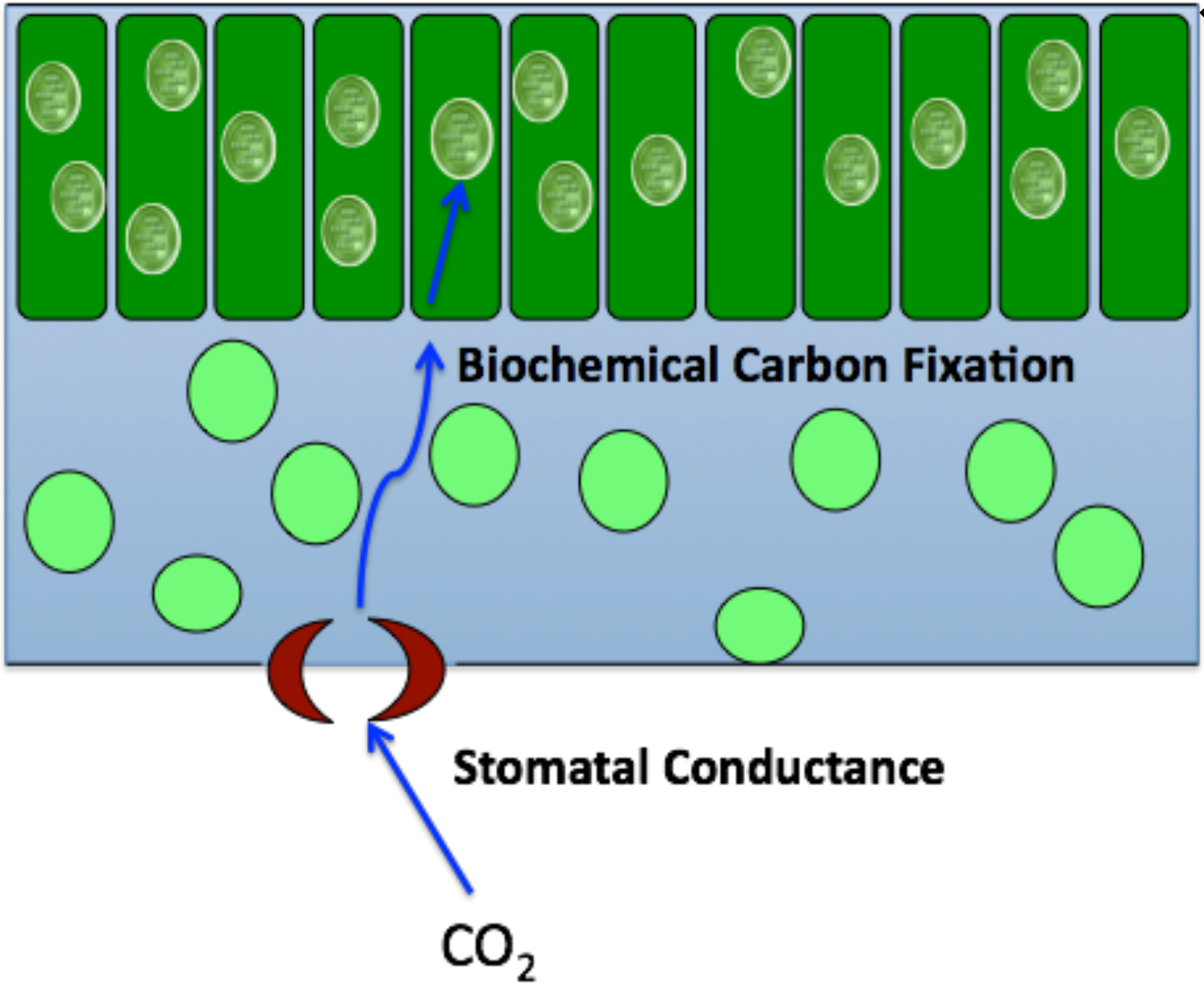
3. Crop yields?

Questions for today:

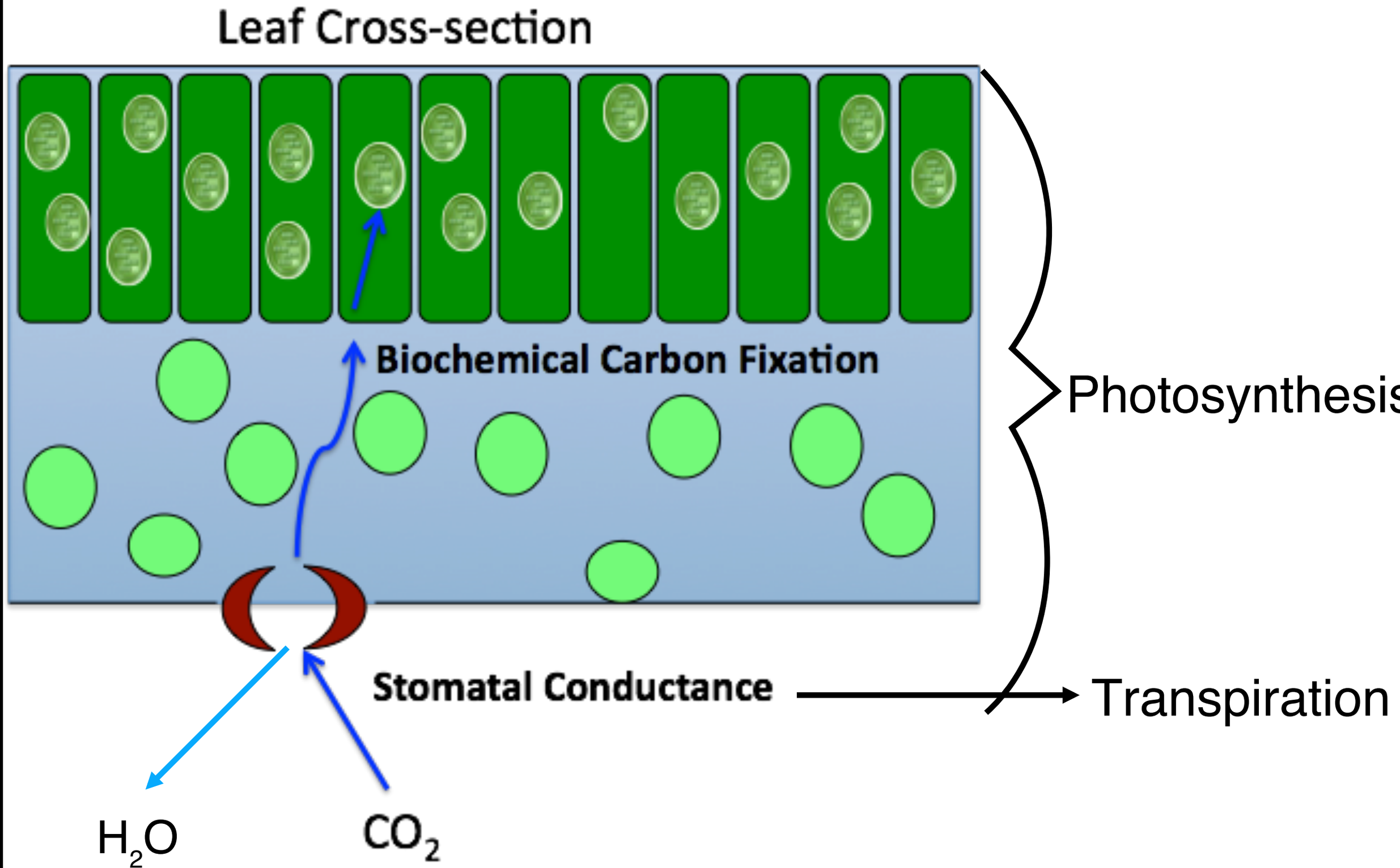
How does ozone pollution change:

1. Leaf processes?

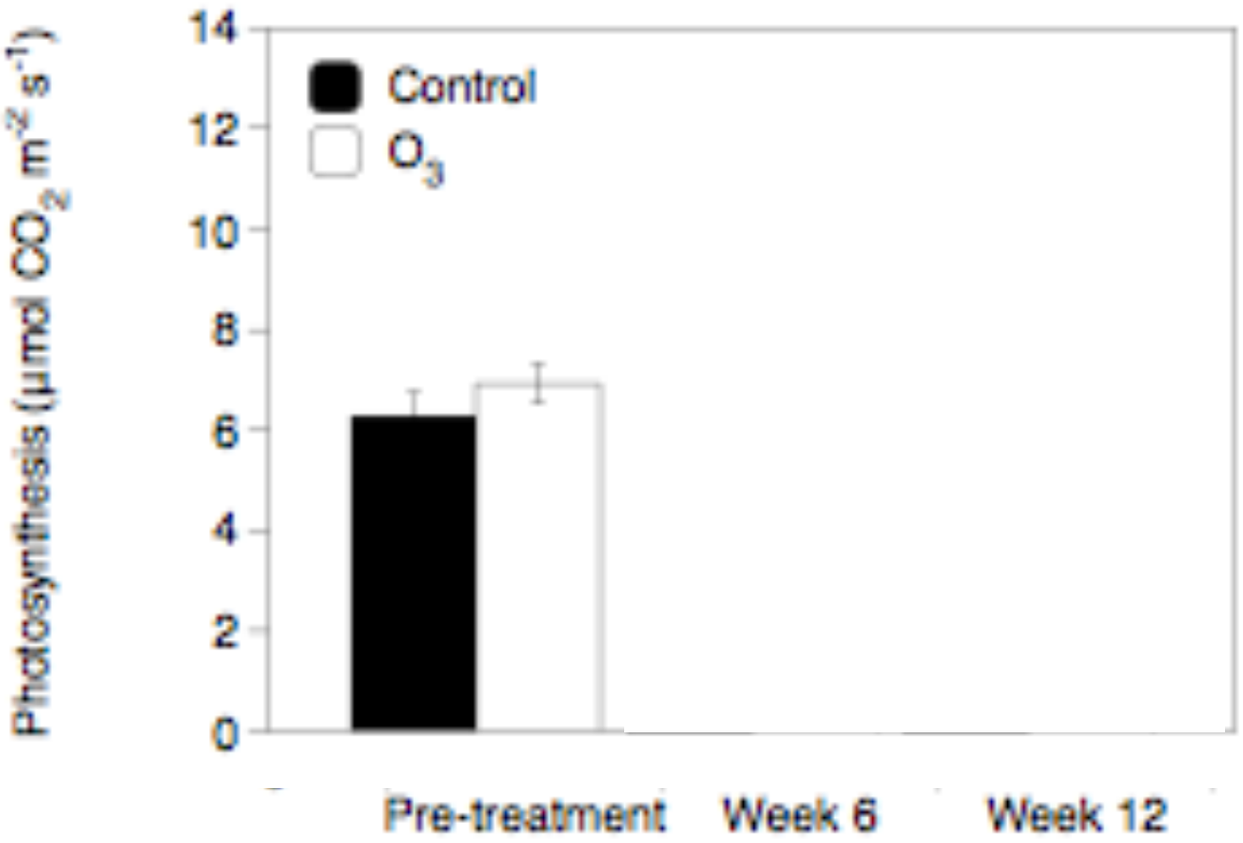
Leaf Cross-section



Photosynthesis


Leaf Cross-section
Biochemical Carbon Fixation
Photosynthesis
Stomatal Conductance
Transpiration
H_2O
CO_2

Tulip poplar seedlings: O_3 = ~100 ppb



Lombardozzi et al., 2012 *Oecologia*

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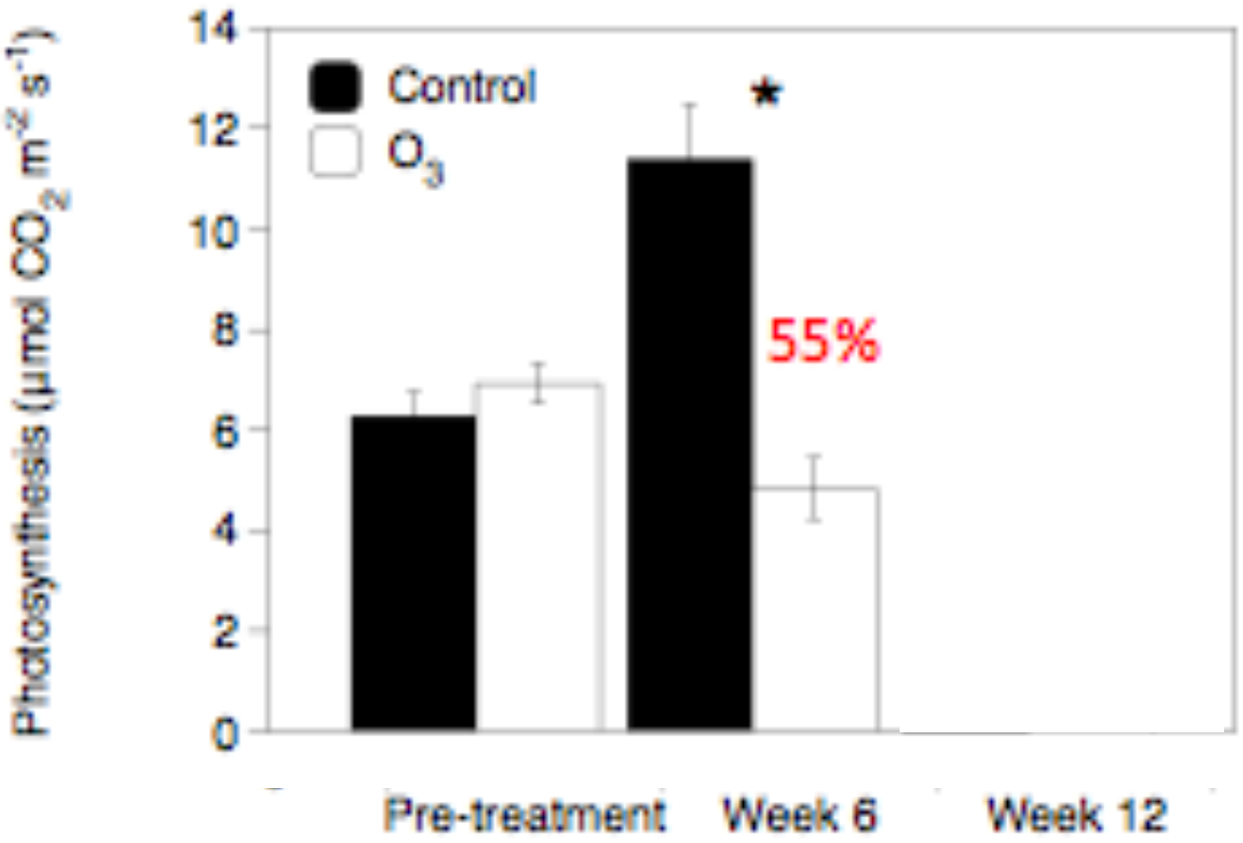

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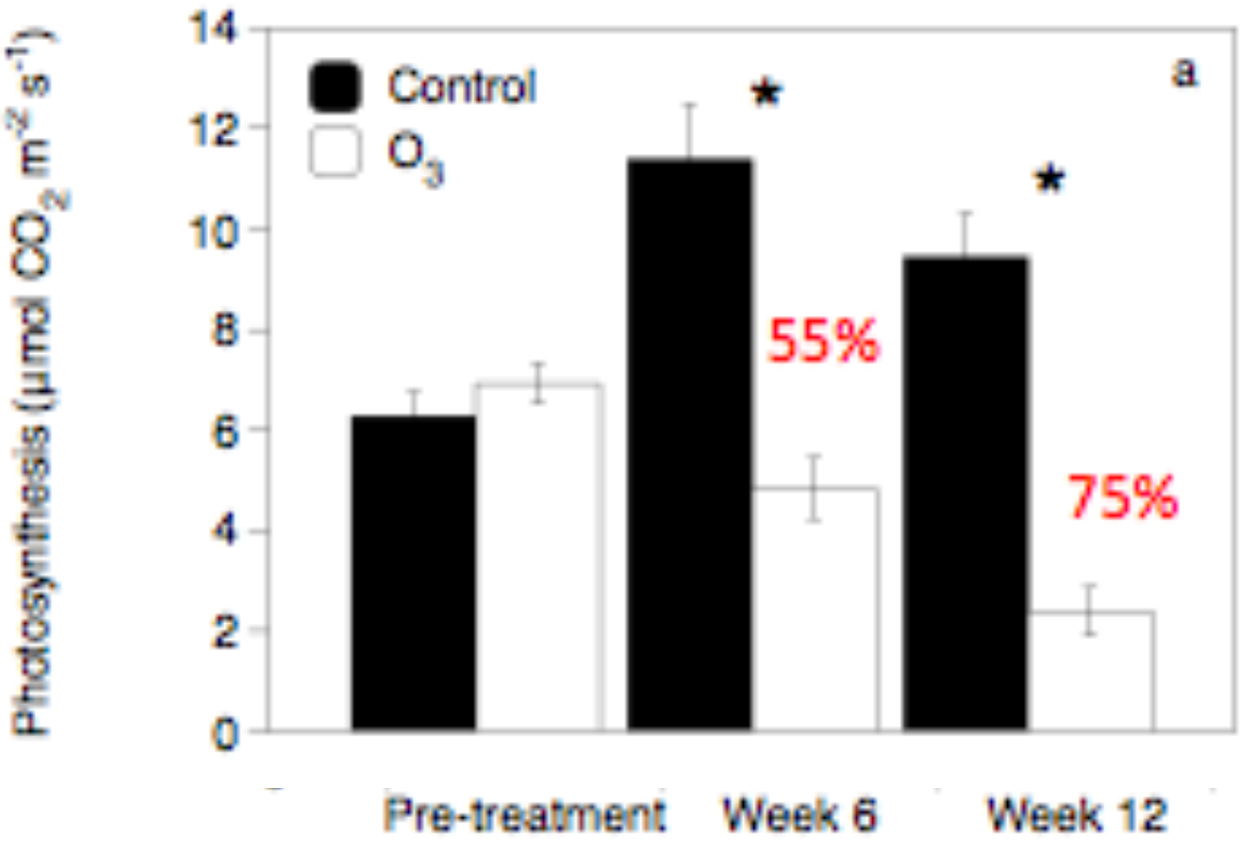

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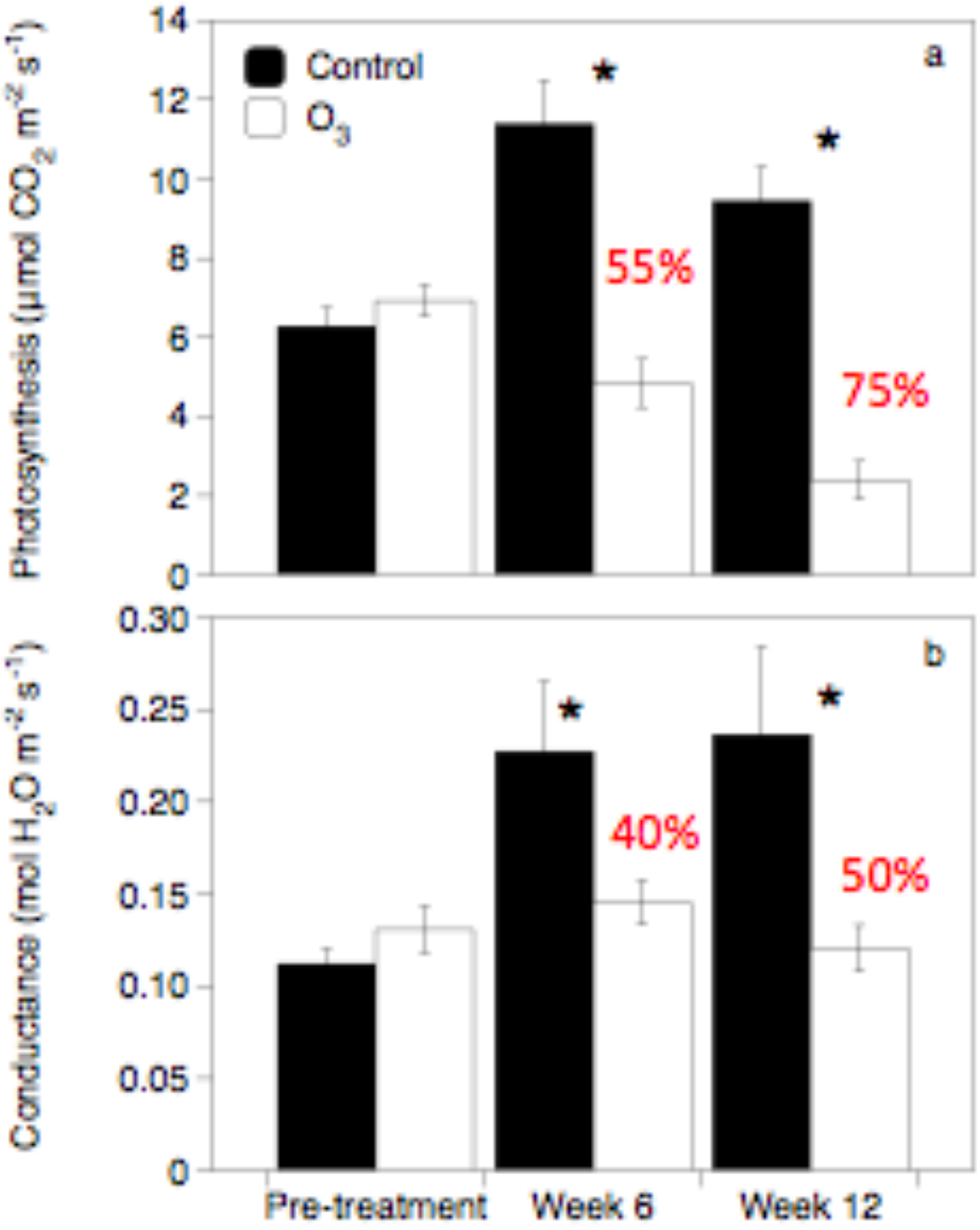
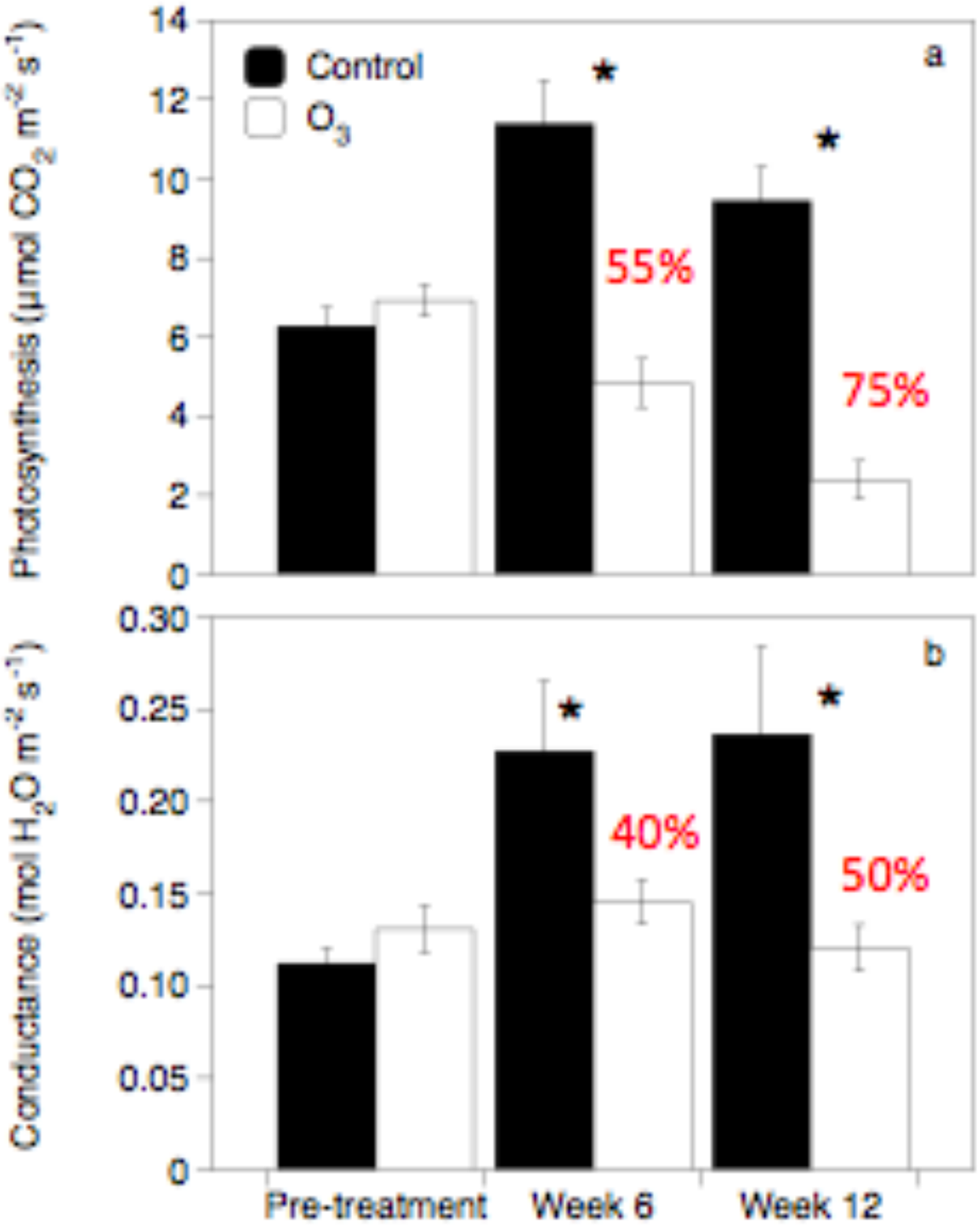


Lombardozzi et al., 2012 *Oecologia*

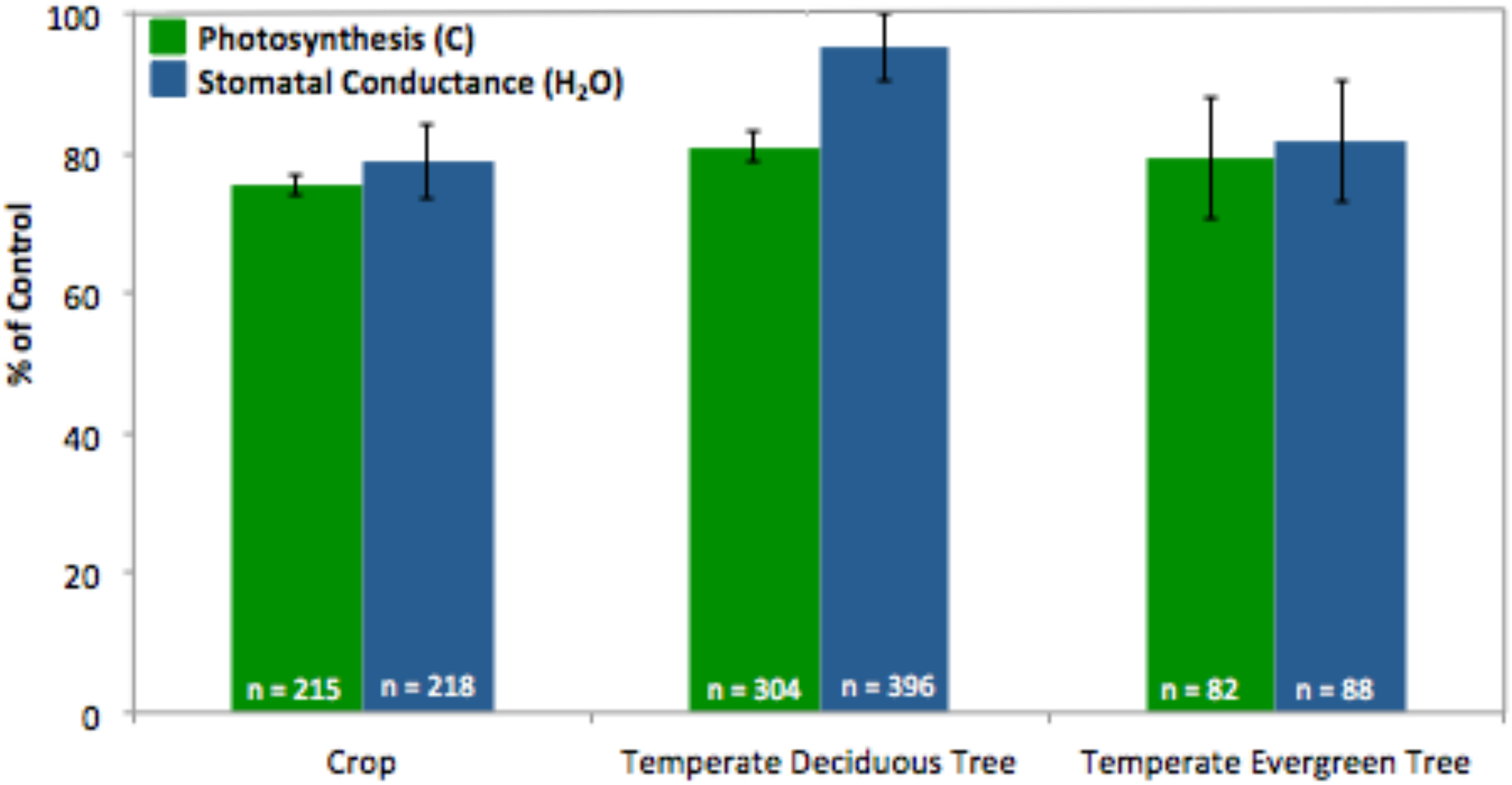
Is this pattern similar for all plant types?



Lombardozzi et al., 2012 *Oecologia*

Mean photosynthetic change = -21% *

Mean conductance change = -11%



127 studies sampled, only 15 contain data for other plant types.

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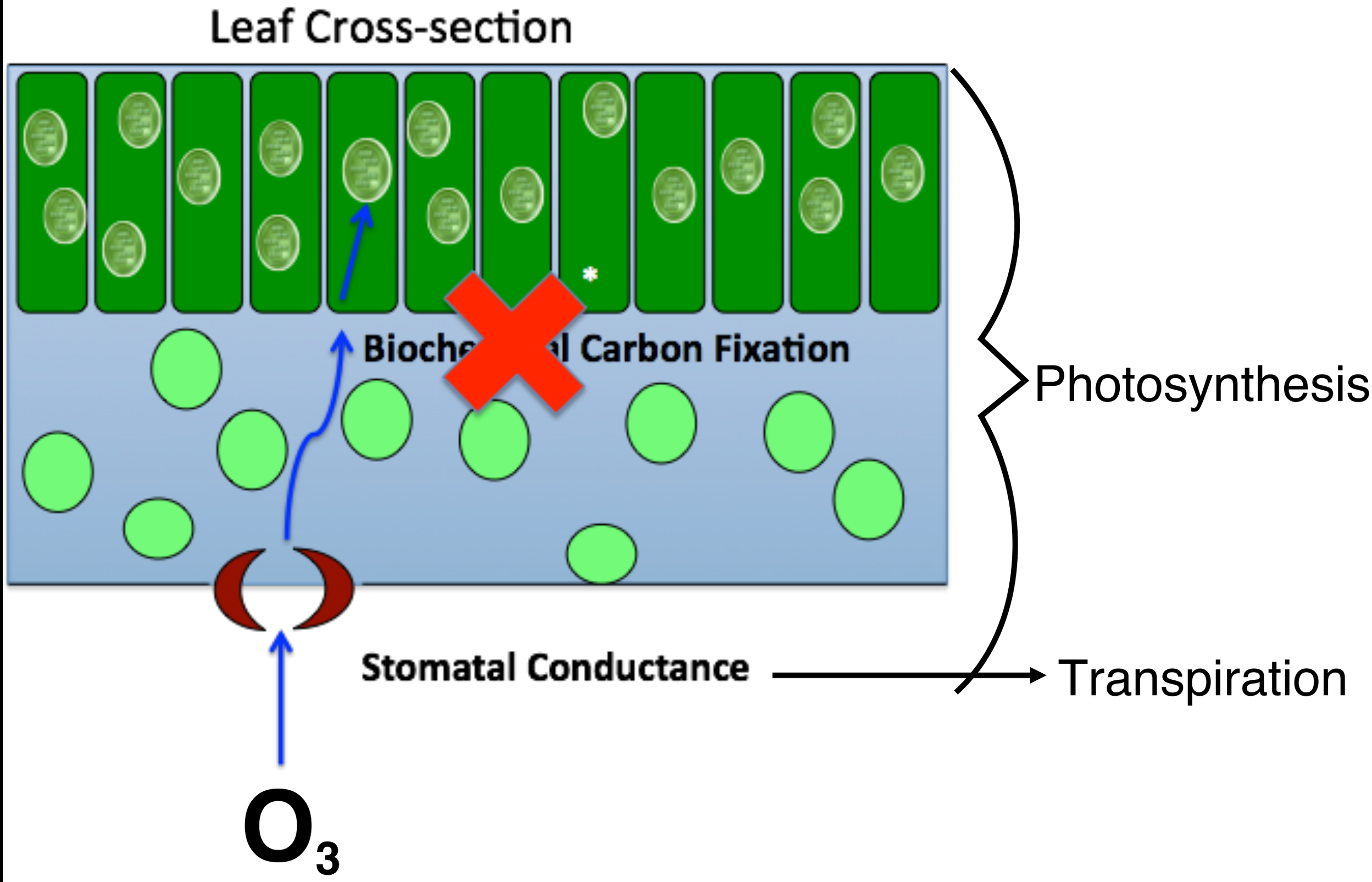

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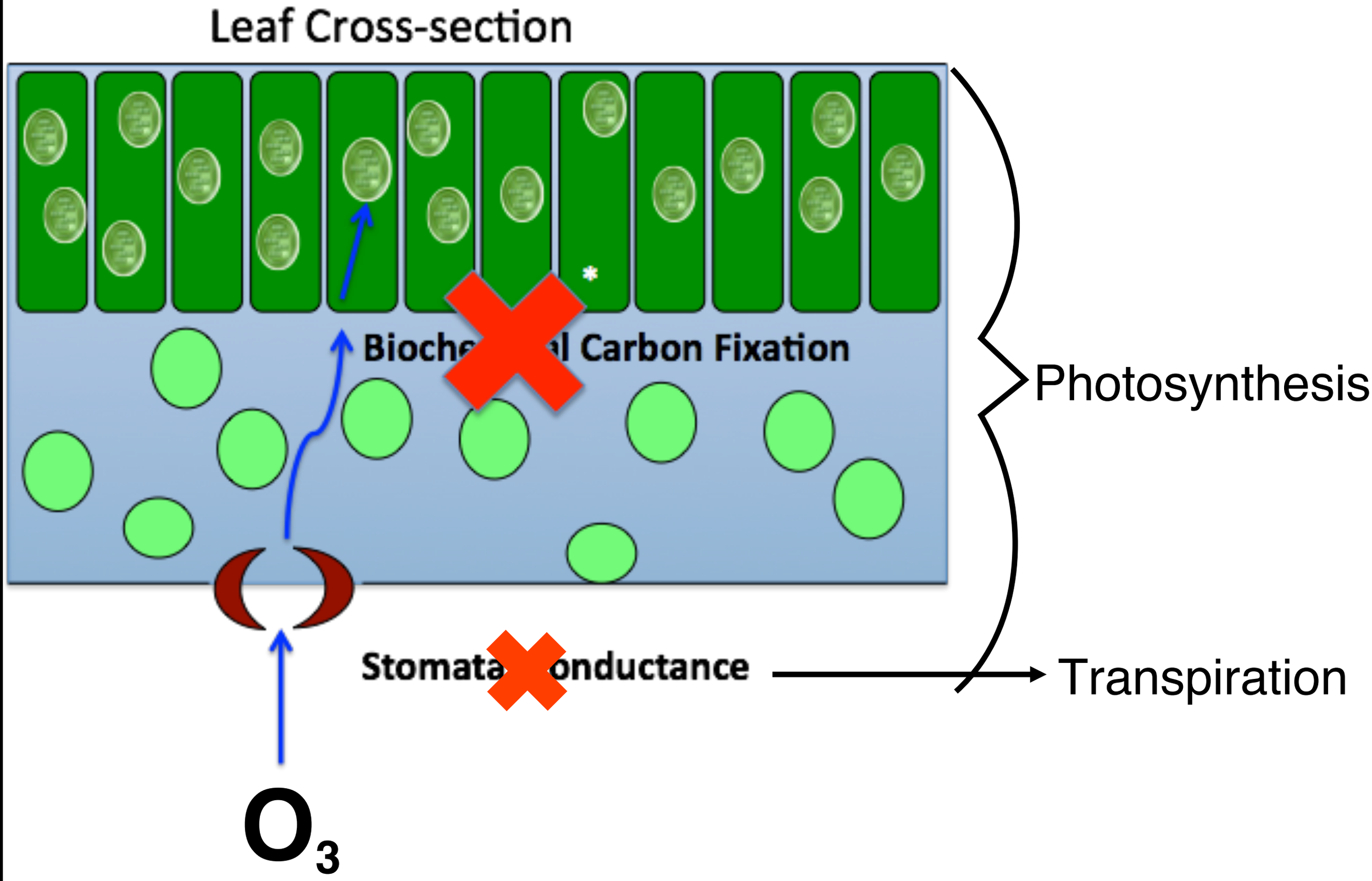

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Ball-Berry Stomatal Conductance (g_s)

$$g_s = m\left[\frac{\text{Photosynthesis}}{[CO_2] \text{ @ leaf surface}}\,RH\right] + b$$

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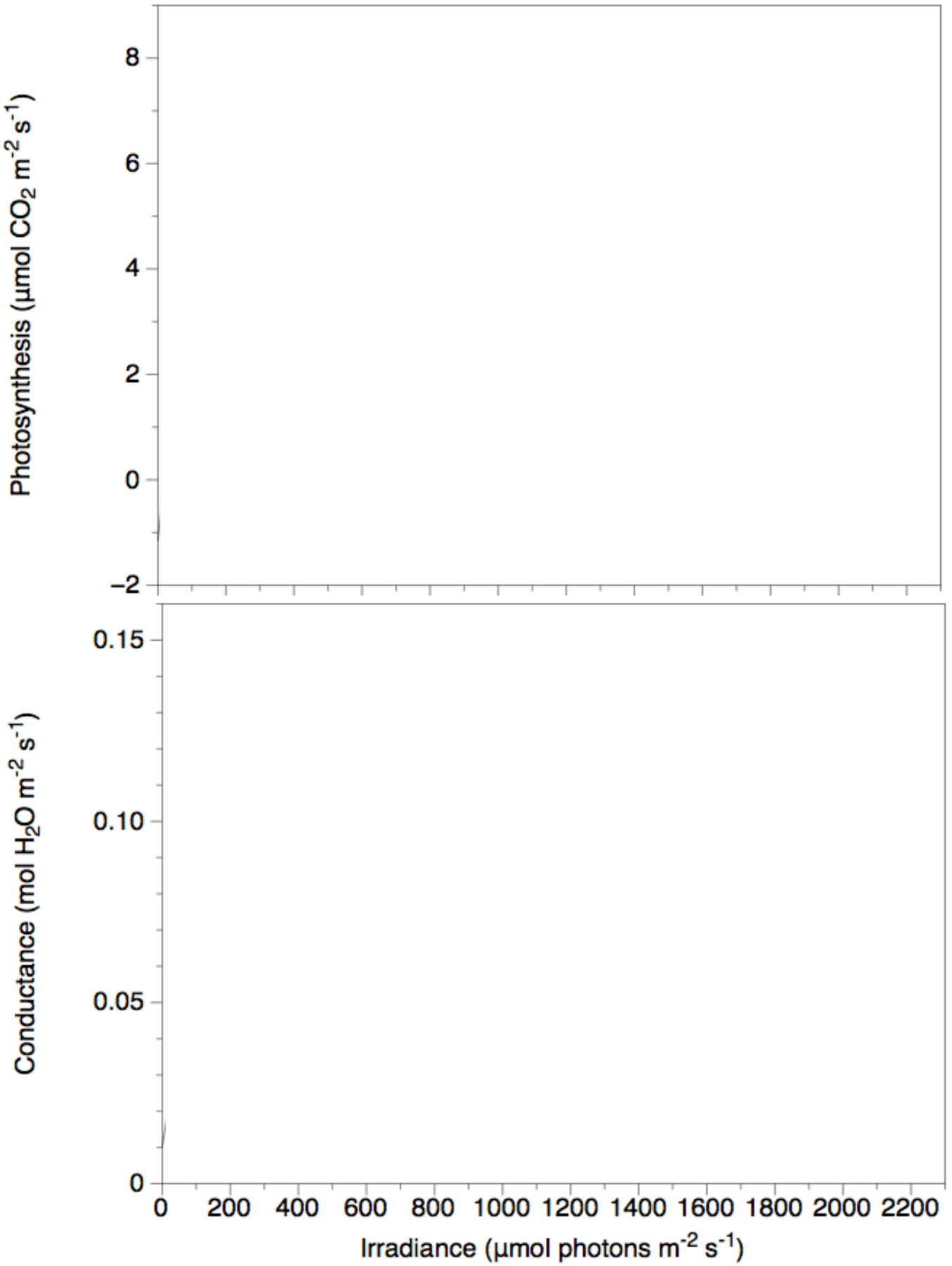

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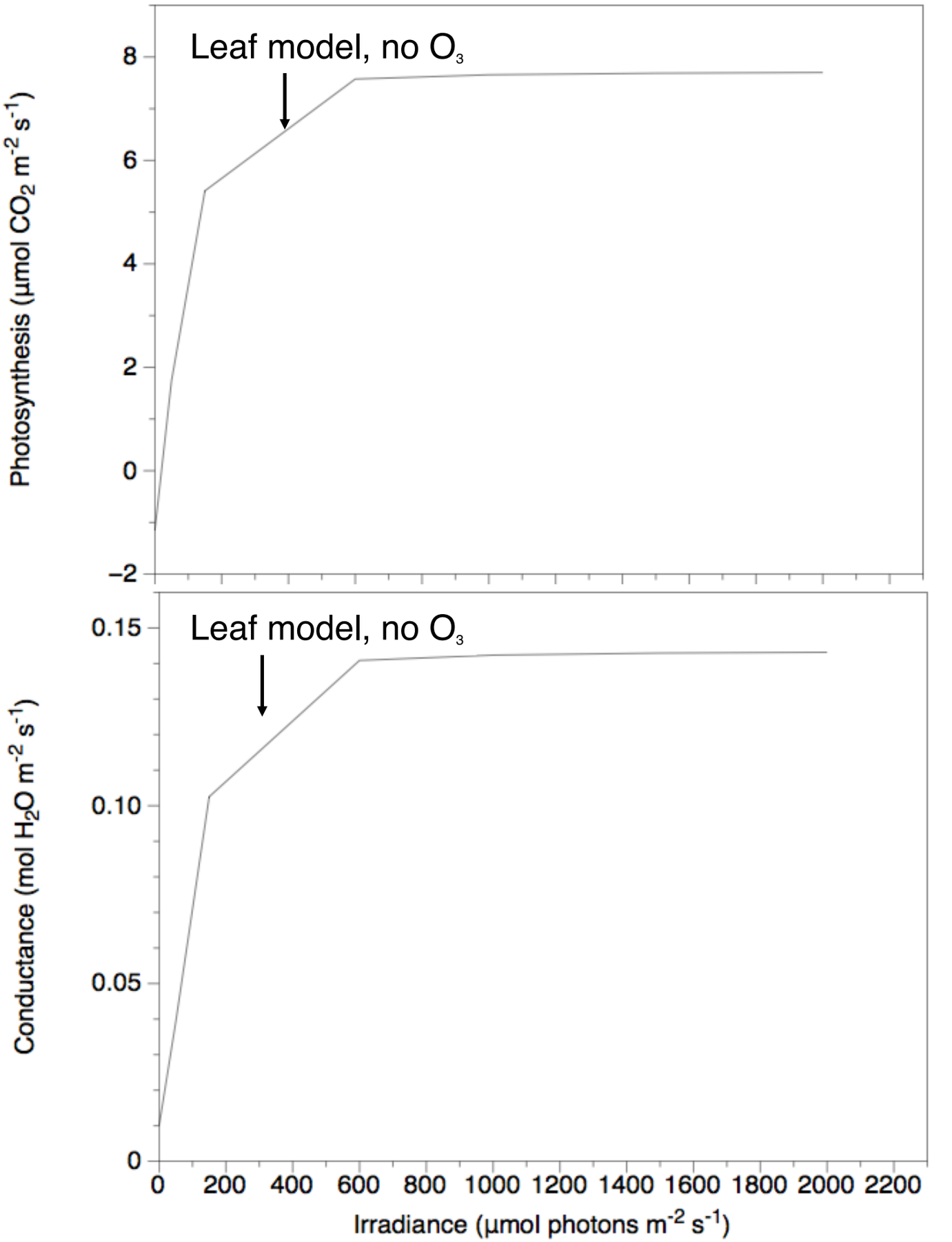

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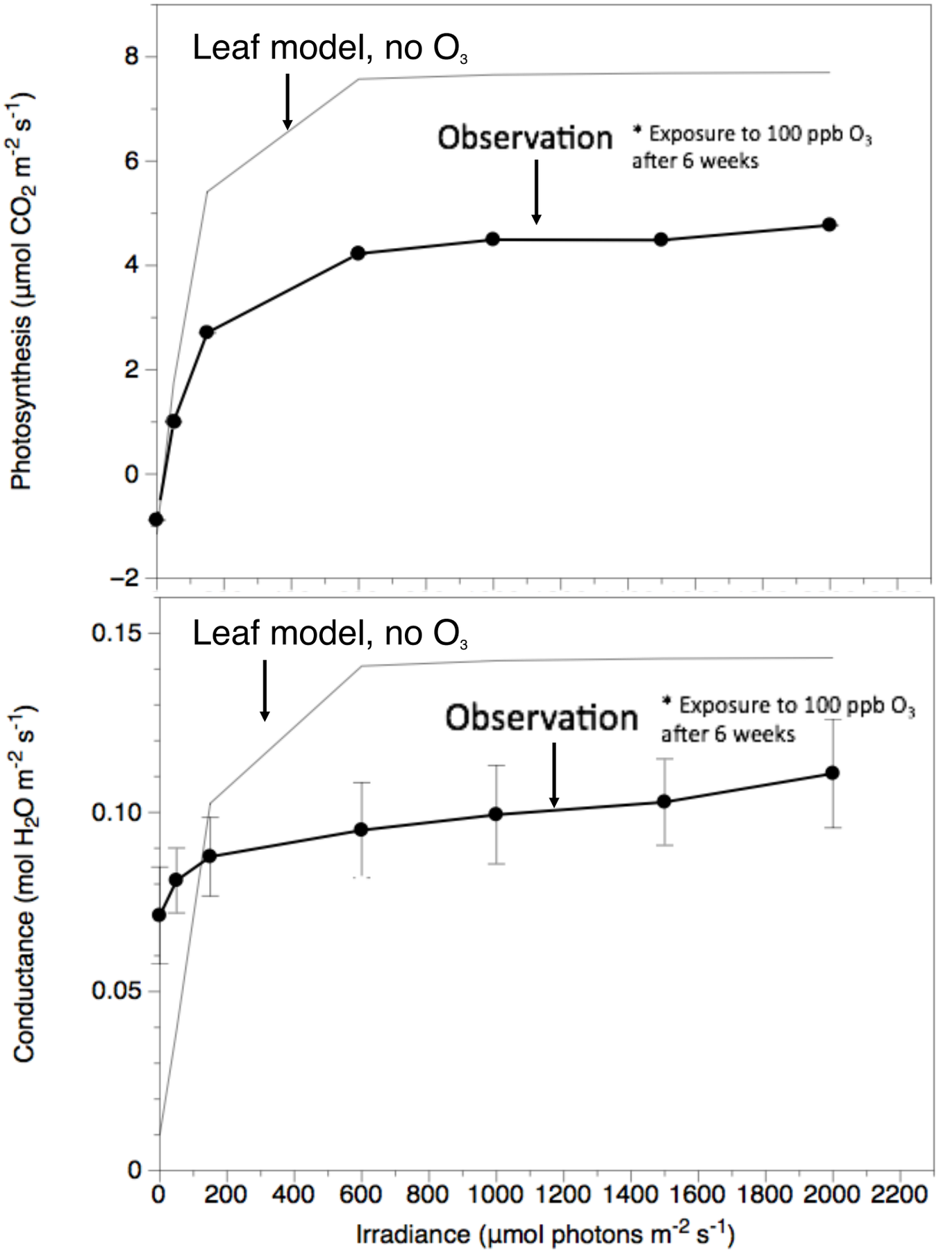

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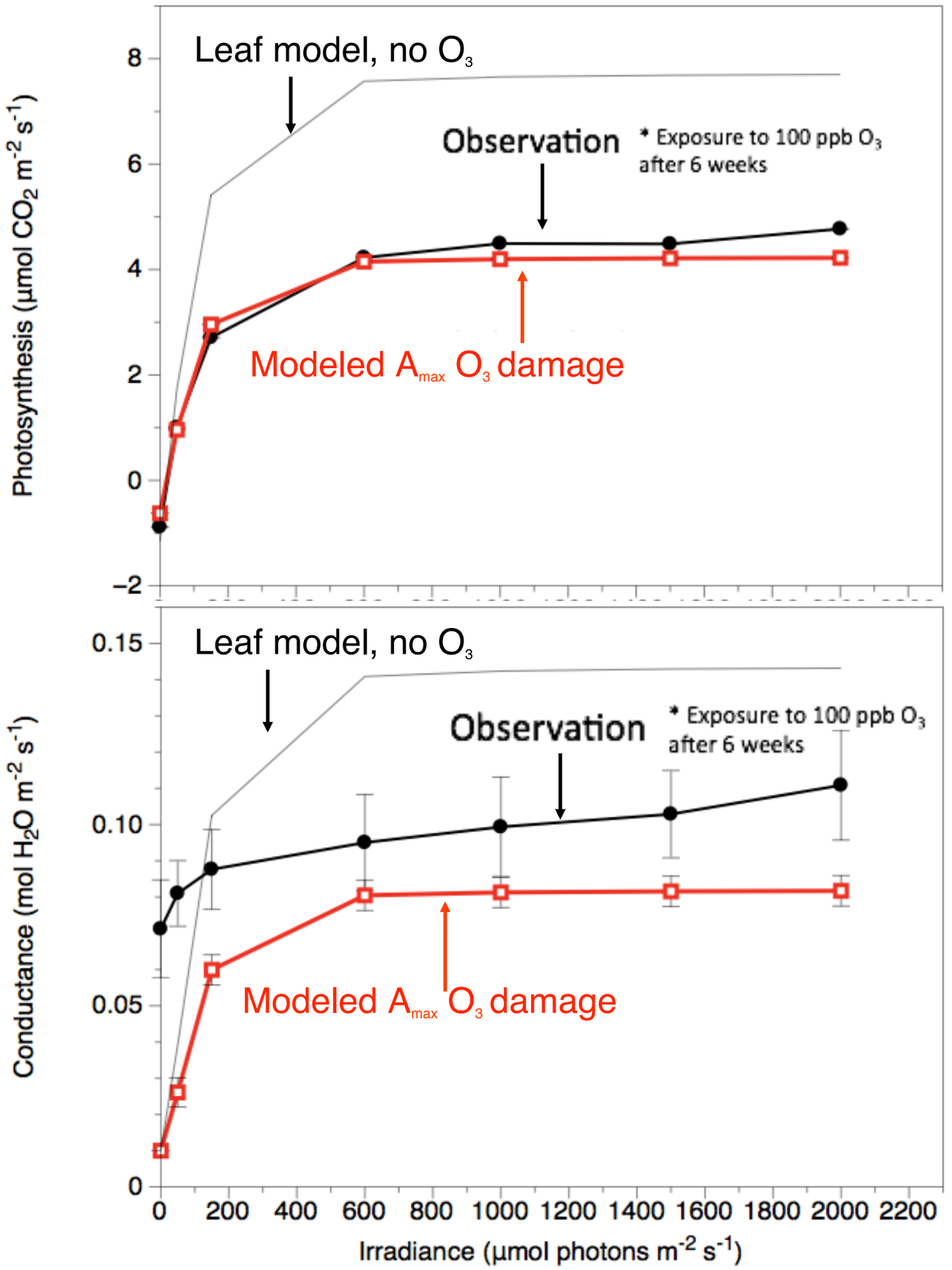

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Ball-Berry Stomatal Conductance (g_s)

Undamaged

#1) $$g_s = m\left[\frac{\text{Photosynthesis}}{[CO_2] \text{ @ leaf surface}} RH\right] + b$$

Ball-Berry Stomatal Conductance (g_s)

Undamaged

#2)

#1) $g_s = m \left[\frac{\text{Photosynthesis}}{[CO_2] \text{ @ leaf surface}} RH \right] + b$

Photosynthesis* = Photosynthesis x O_3 damage

Ball-Berry Stomatal Conductance (g_s)

Undamaged

#2)

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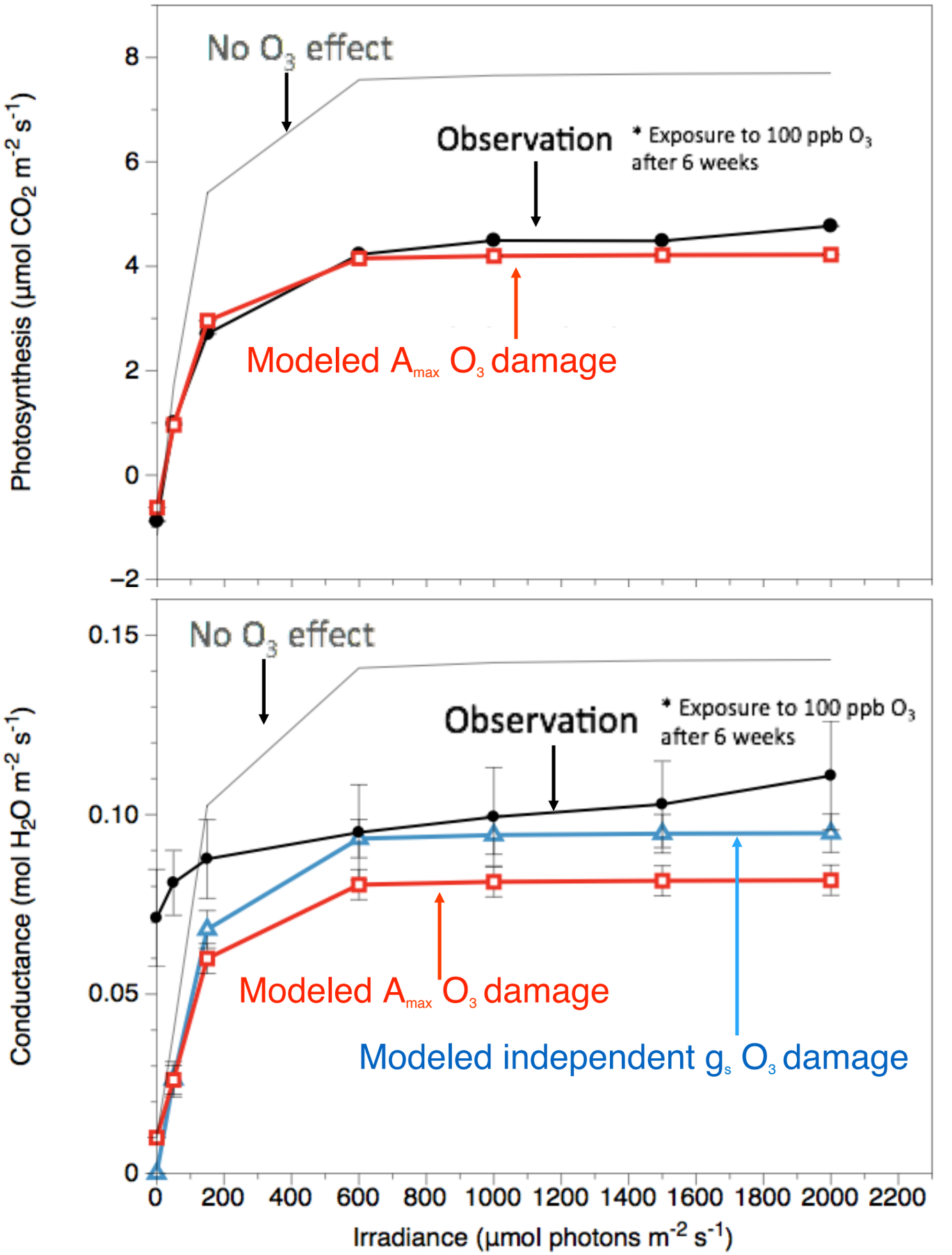
$\text{Photosynthesis}^* = \text{Photosynthesis} \times O_3 \text{ damage}$

$g_s^* = g_s \times O_3 \text{ damage}$

#3)



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Questions for today:

How does ozone pollution change:

1. Leaf processes?

- Photosynthesis decreases more than conductance
- Models must be adjusted properly to account for the differences in photosynthetic and stomatal responses

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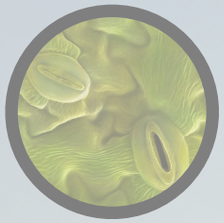
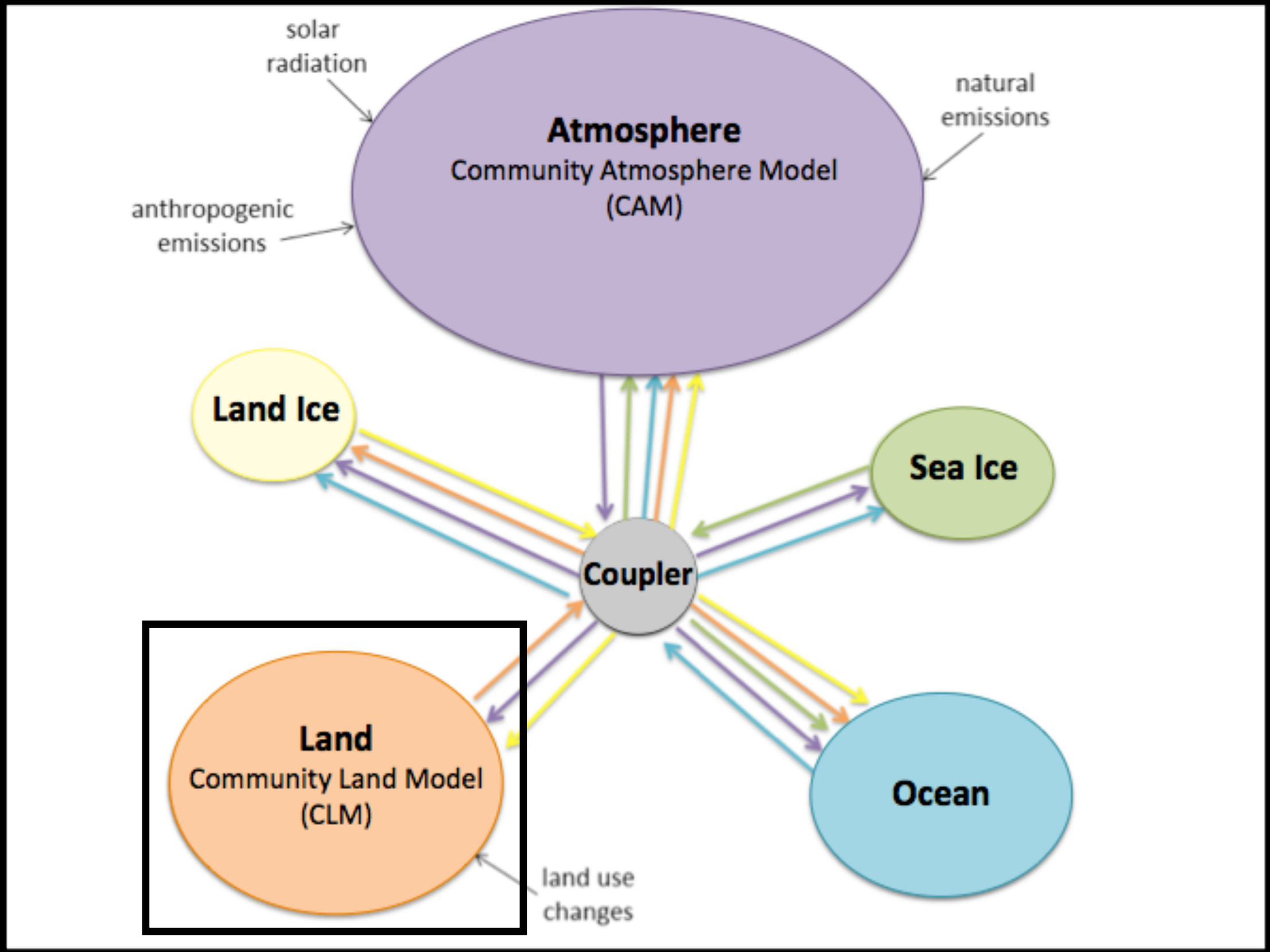


1. Leaf processes?

2. Global terrestrial processes?

Community Earth System Model



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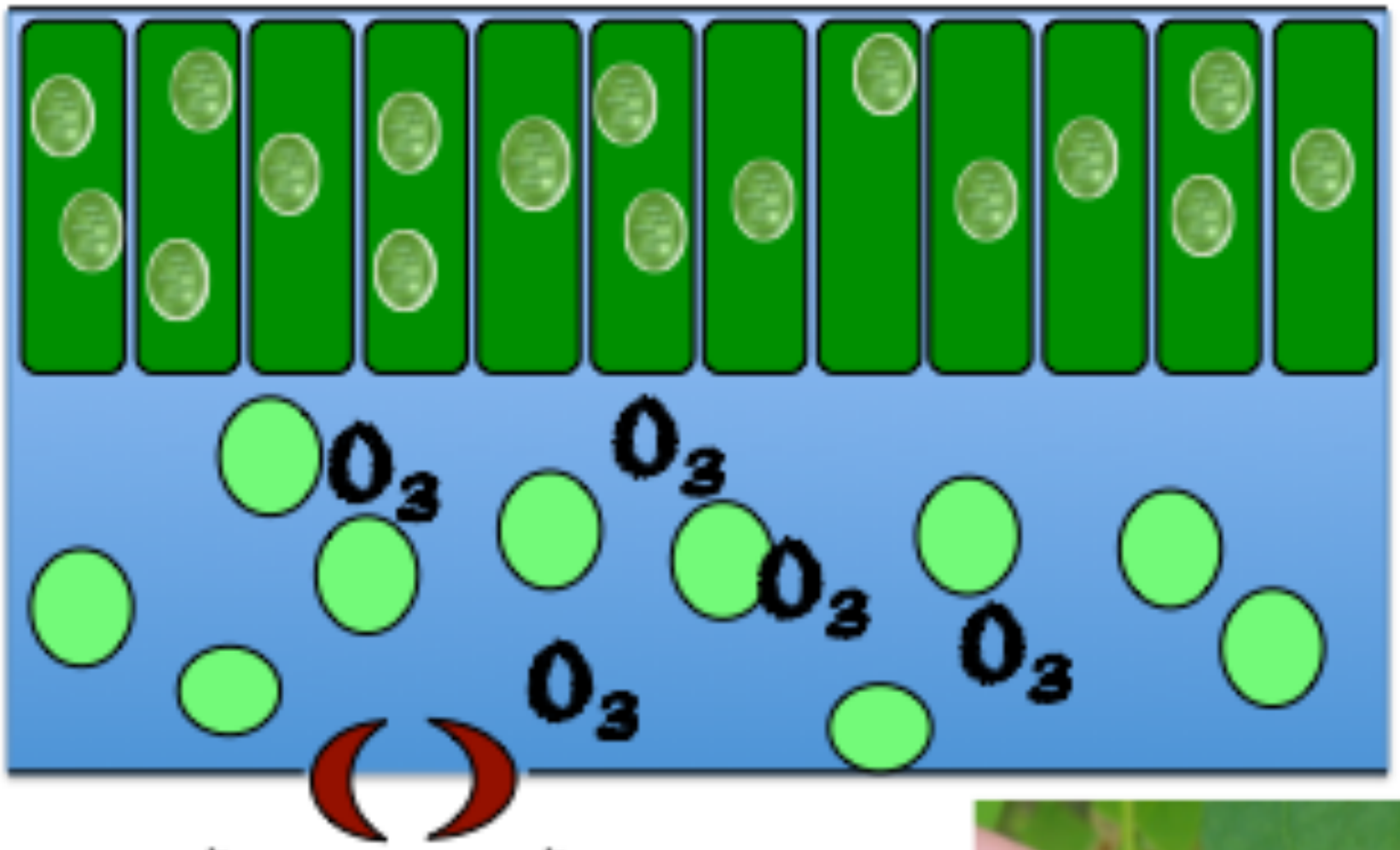

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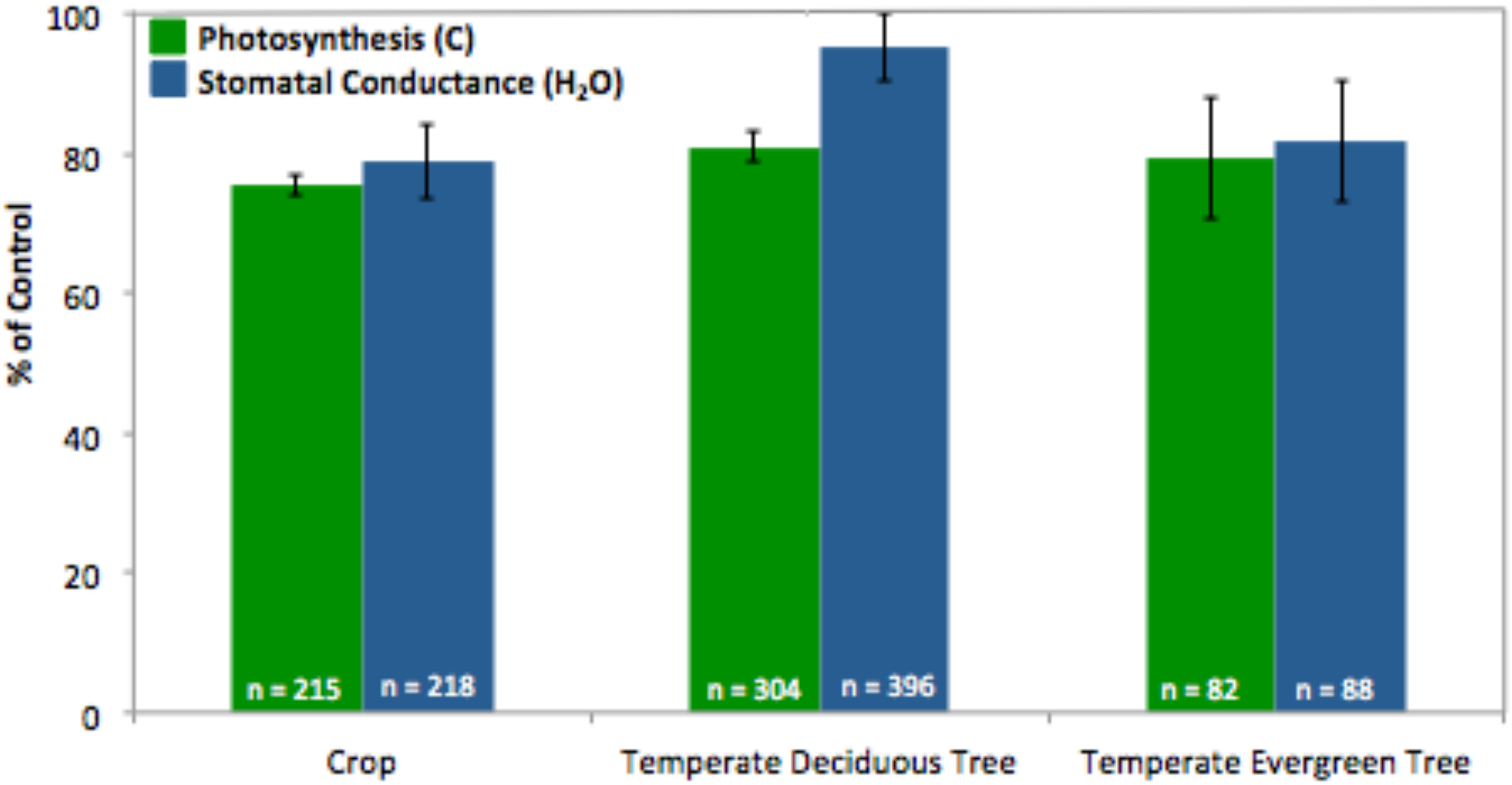

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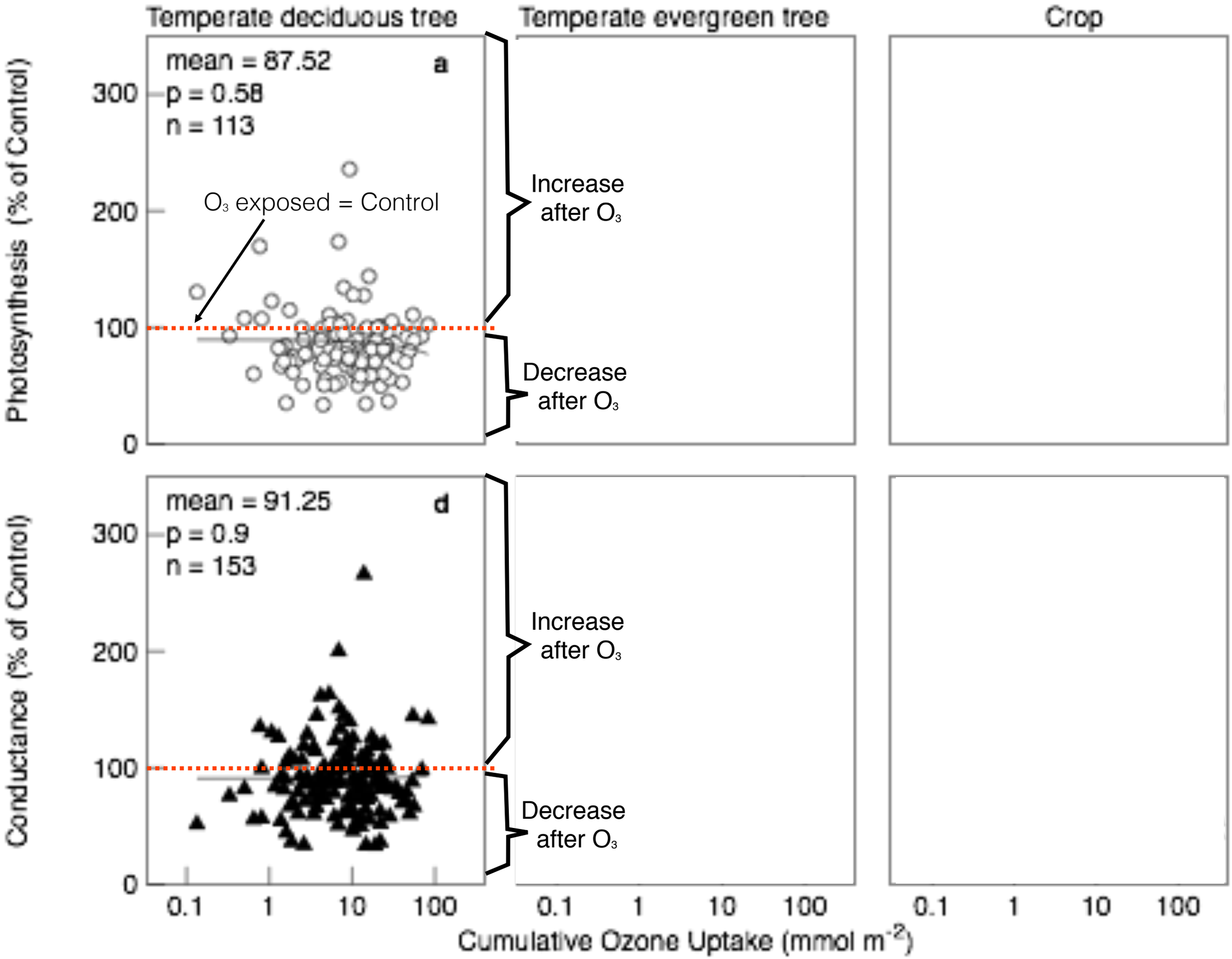
in CLM: *All deciduous trees* *All evergreen trees* *All grasses and crops*



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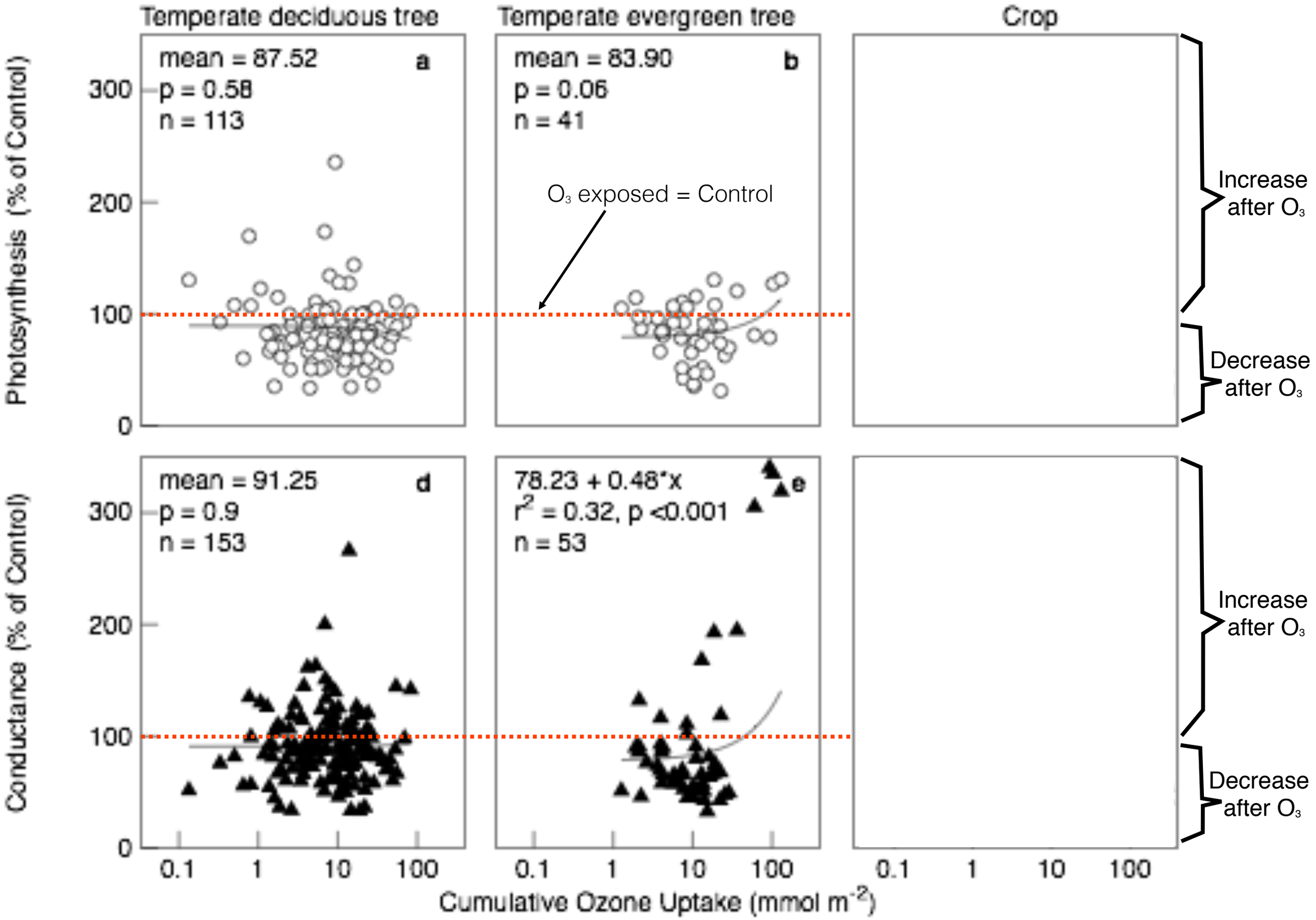

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in CLM: *All deciduous trees* *All evergreen trees* *All grasses and crops*

Temperate deciduous tree

mean = 87.52
p = 0.58
n = 113
a

Temperate evergreen tree

mean = 83.90
p = 0.06
n = 41
b

O_3 exposed = Control

Crop

80.21 - 0.09*x
r2 = 0.08, p < 0.001
n = 134
c

Photosynthesis (% of Control)

300
200
100
0

Increase after O_3

Decrease after O_3

mean = 91.25
p = 0.9
n = 153
d

78.23 + 0.48*x
r^2 = 0.32, p <0.001
n = 53
e

mean =75.11
p = 0.43
n = 136
f

Conductance (% of Control)

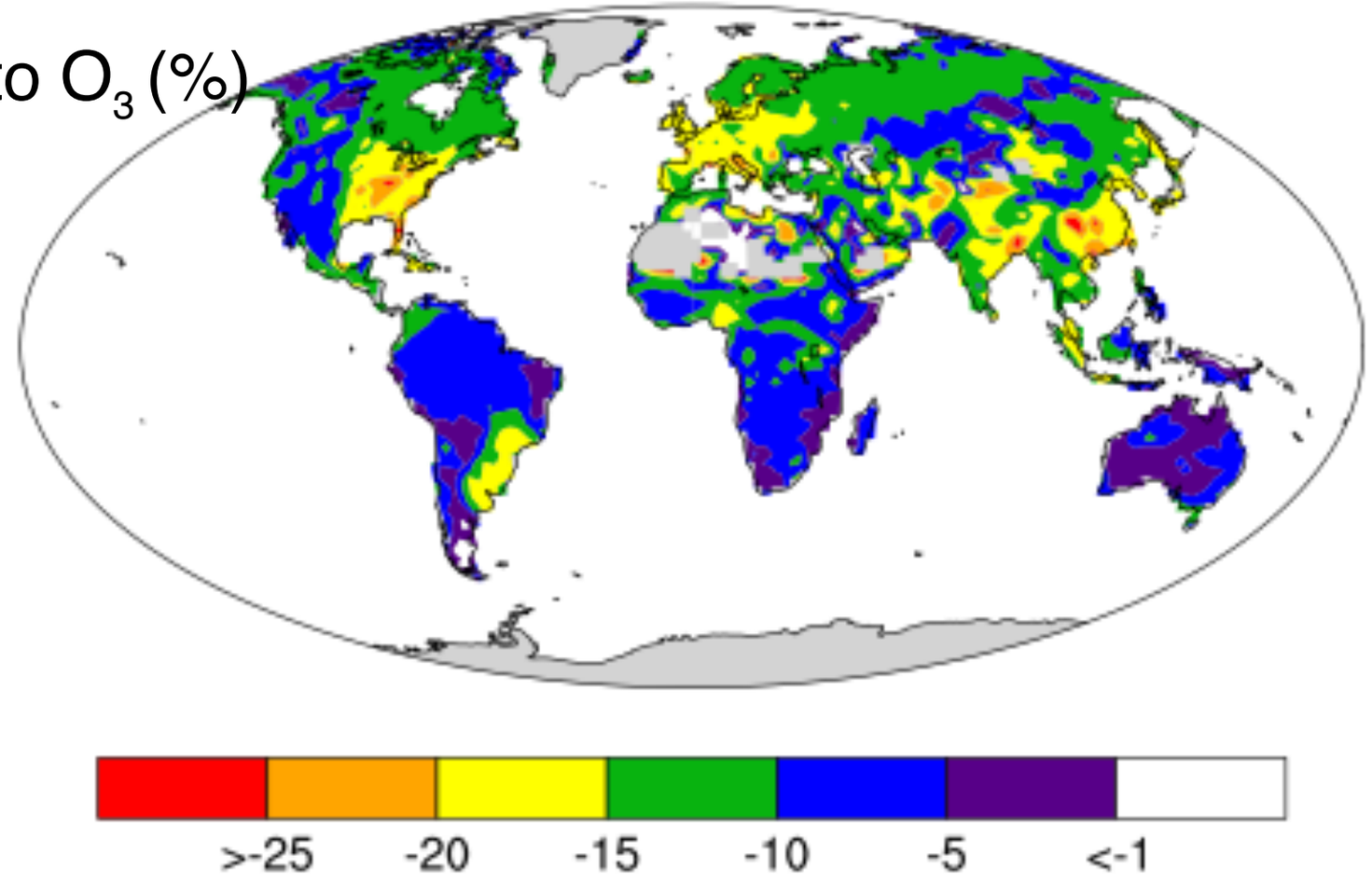
300
200
100
0

0.1 1 10 100

Cumulative Ozone Uptake (mmol m^{-2})

Lombardozzi et al. 2013 BGS

Change in **Photosynthesis** due to O_3 (%)
(change in C gain)



Lombardozzi et al. 2015 *J. Climate*

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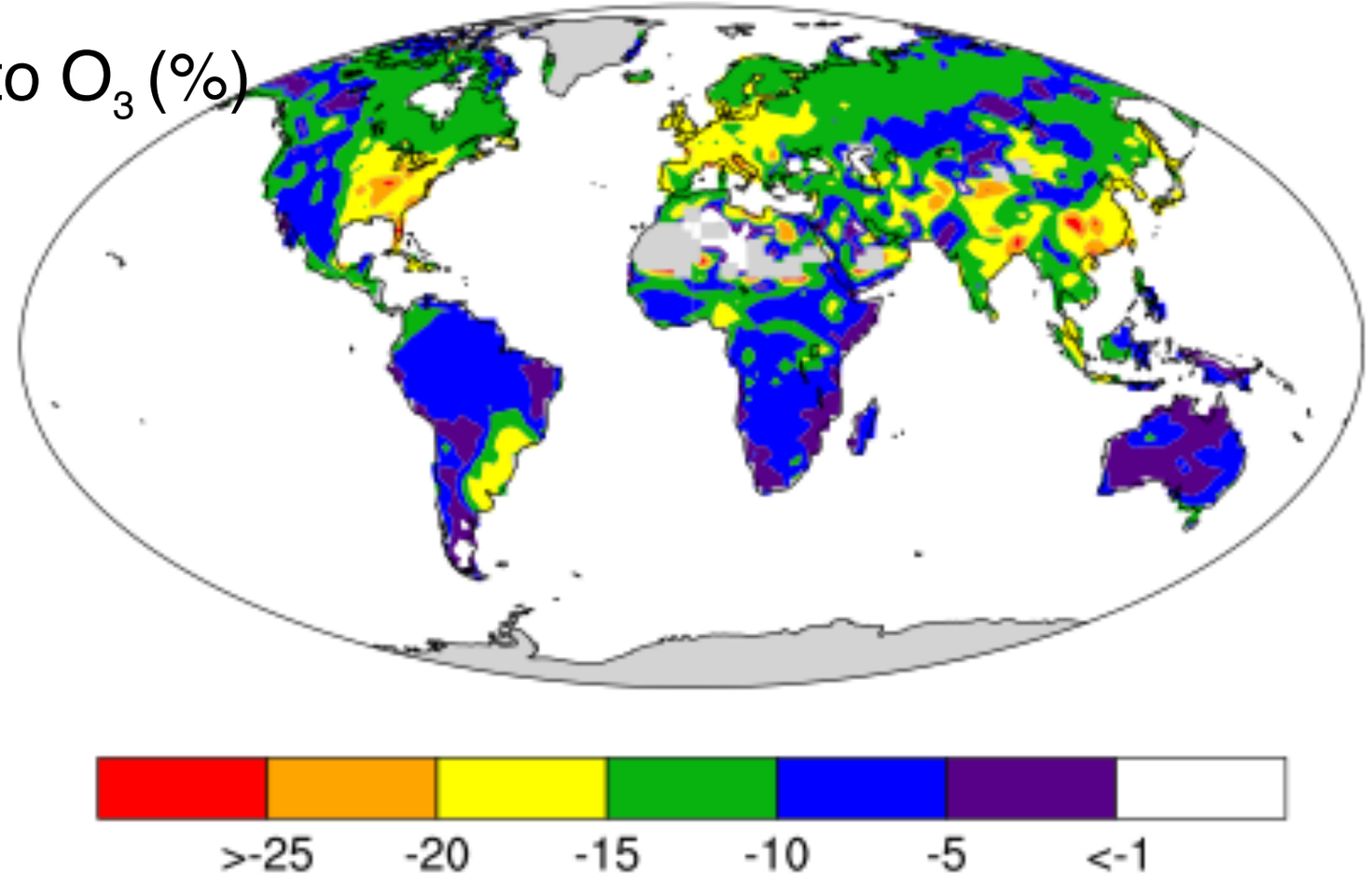
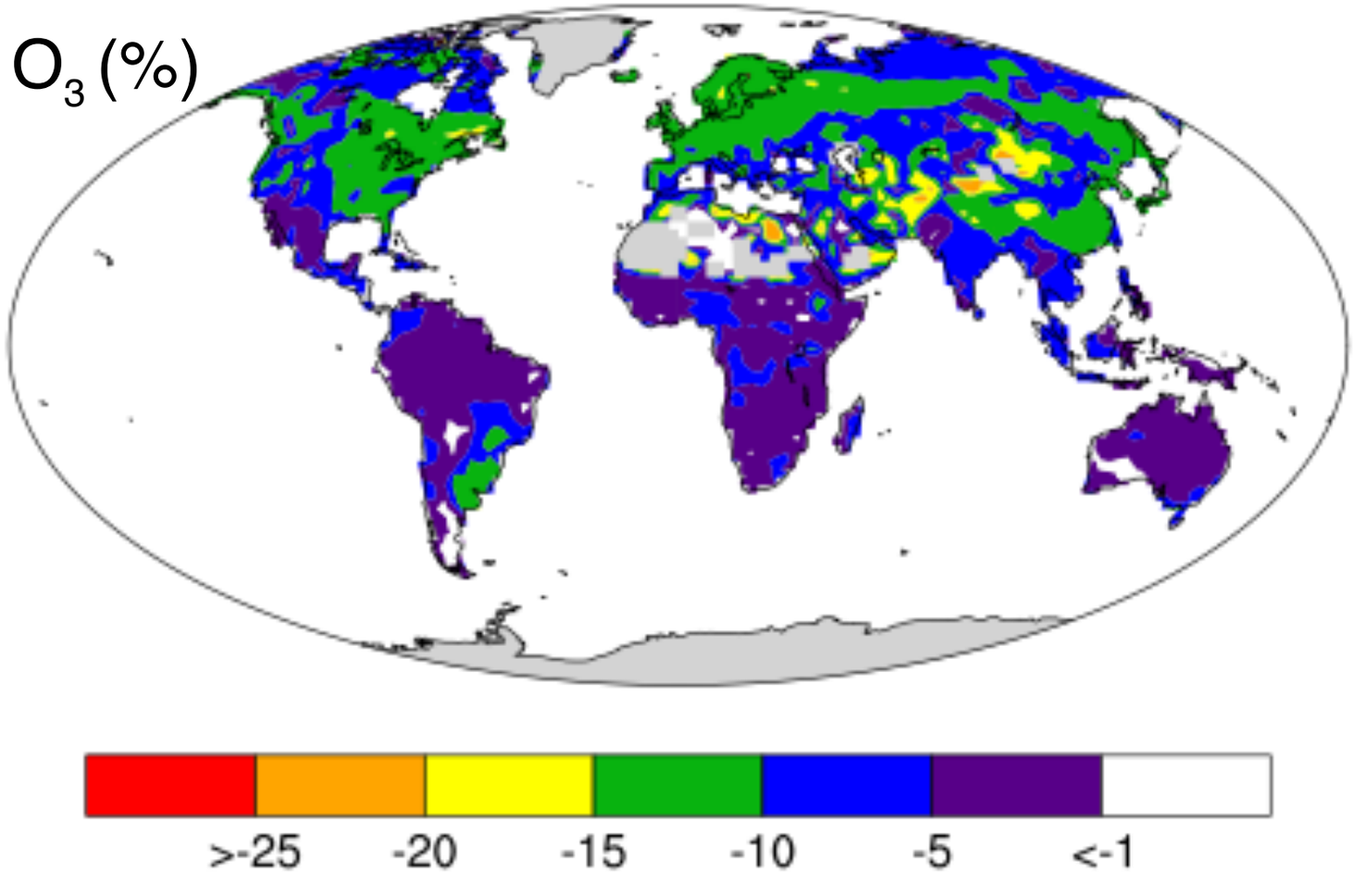


Change in **Transpiration** due to O_3 (%)
(change in H_2O loss)



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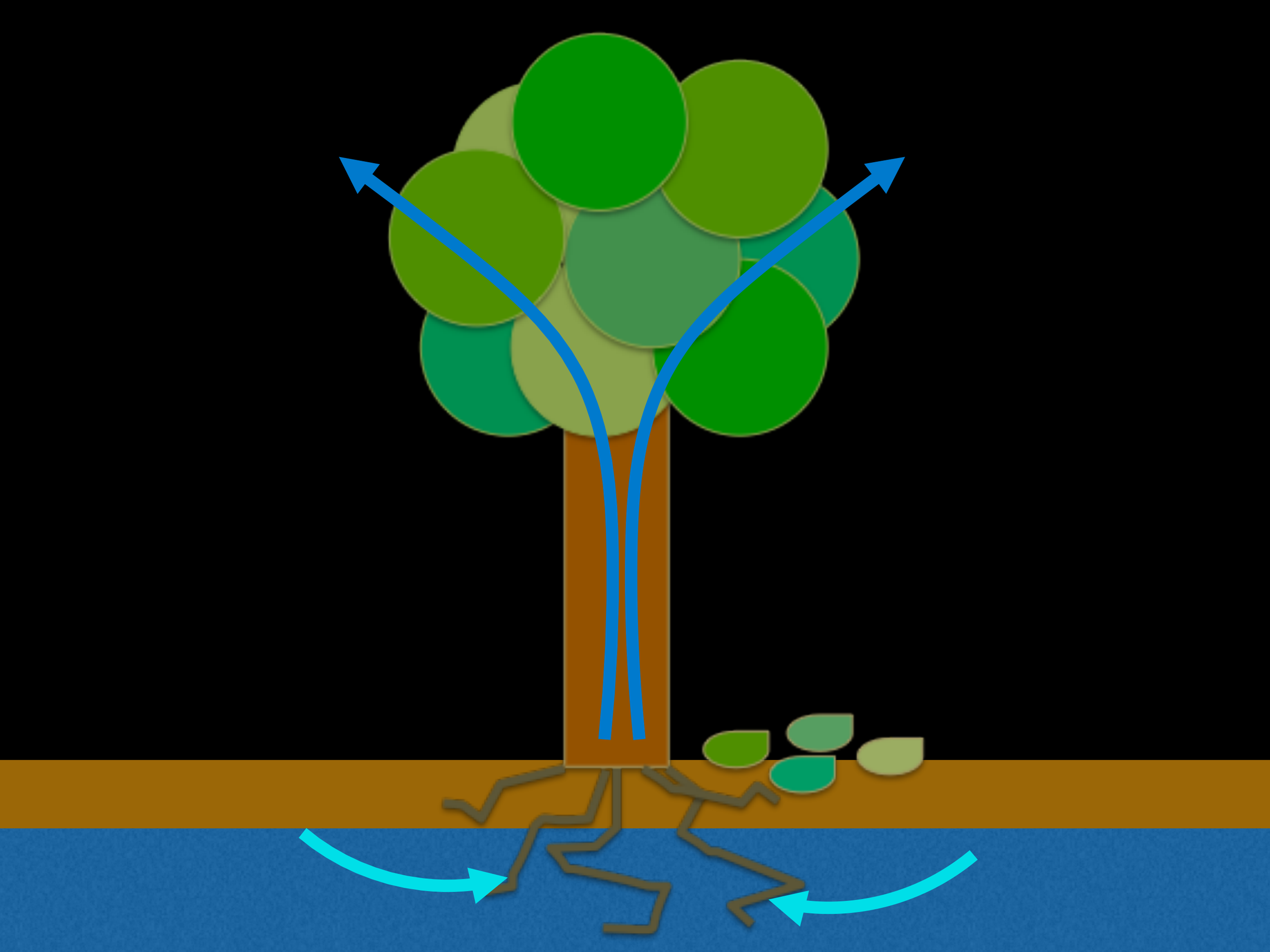

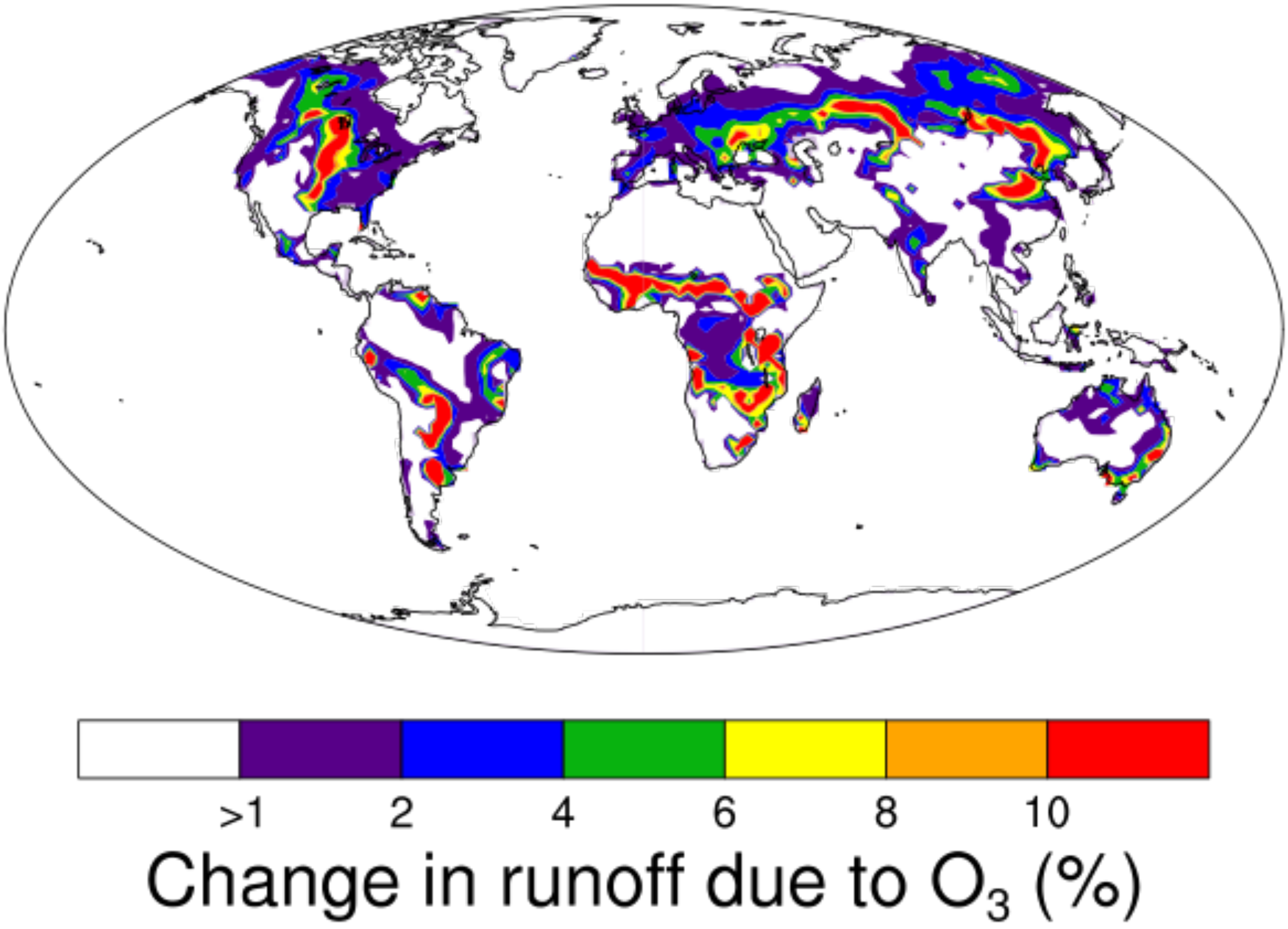

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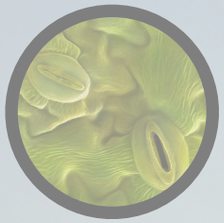

1. Leaf processes?

2. Global terrestrial processes?

   - Global C gain decreases more than H_2O lost
   - Hydrological impacts, including increasing surface runoff

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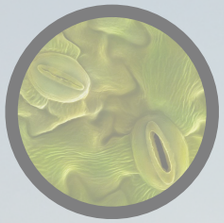

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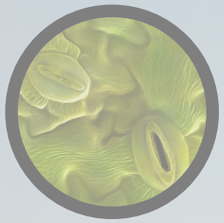

1. Leaf processes?

2. Global terrestrial processes?

3. Crop yields?

Estimated 65% increased demand

CLM-Crop

Corn*

Wheat

Sugarcane

Soy*

Cotton

Rice

** Temperate and tropical varieties*

Plant

Fertilize (N only)

Harvest

Irrigate

Experimental Design

Simulation Name	**Physical Climate**	**CO_2**	**O_3**
Constant Forcings			
Climate Change			
CO_2 Fertilization			
O_3 Change			

Experimental Design

Simulation Name	**Physical Climate**	**CO_2**	**O_3**
Constant Forcings	2006	2006	None
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Transient = RCP 8.5

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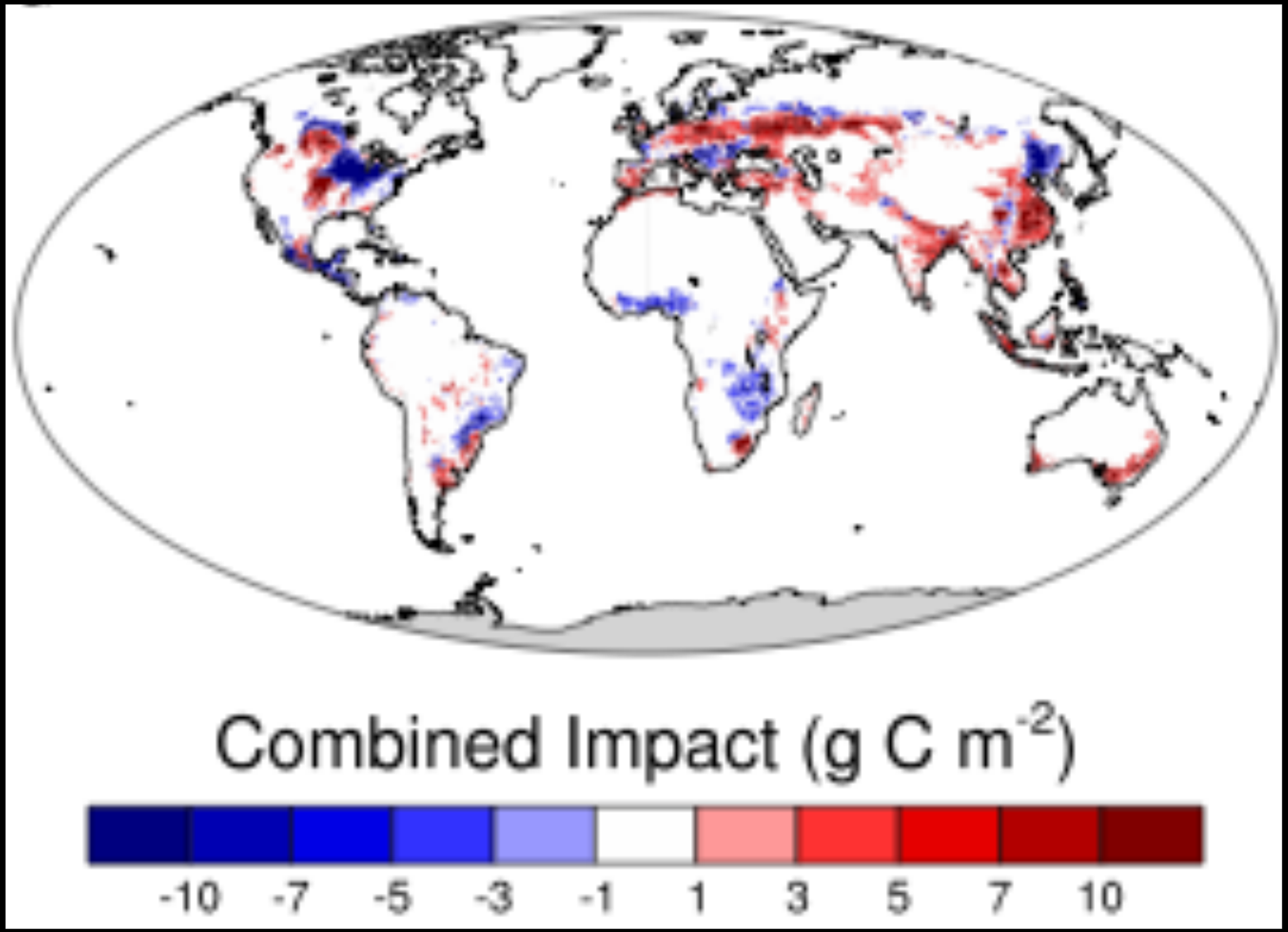
△2100 Average Crop Yield



Lombardozzi et al. In Prep

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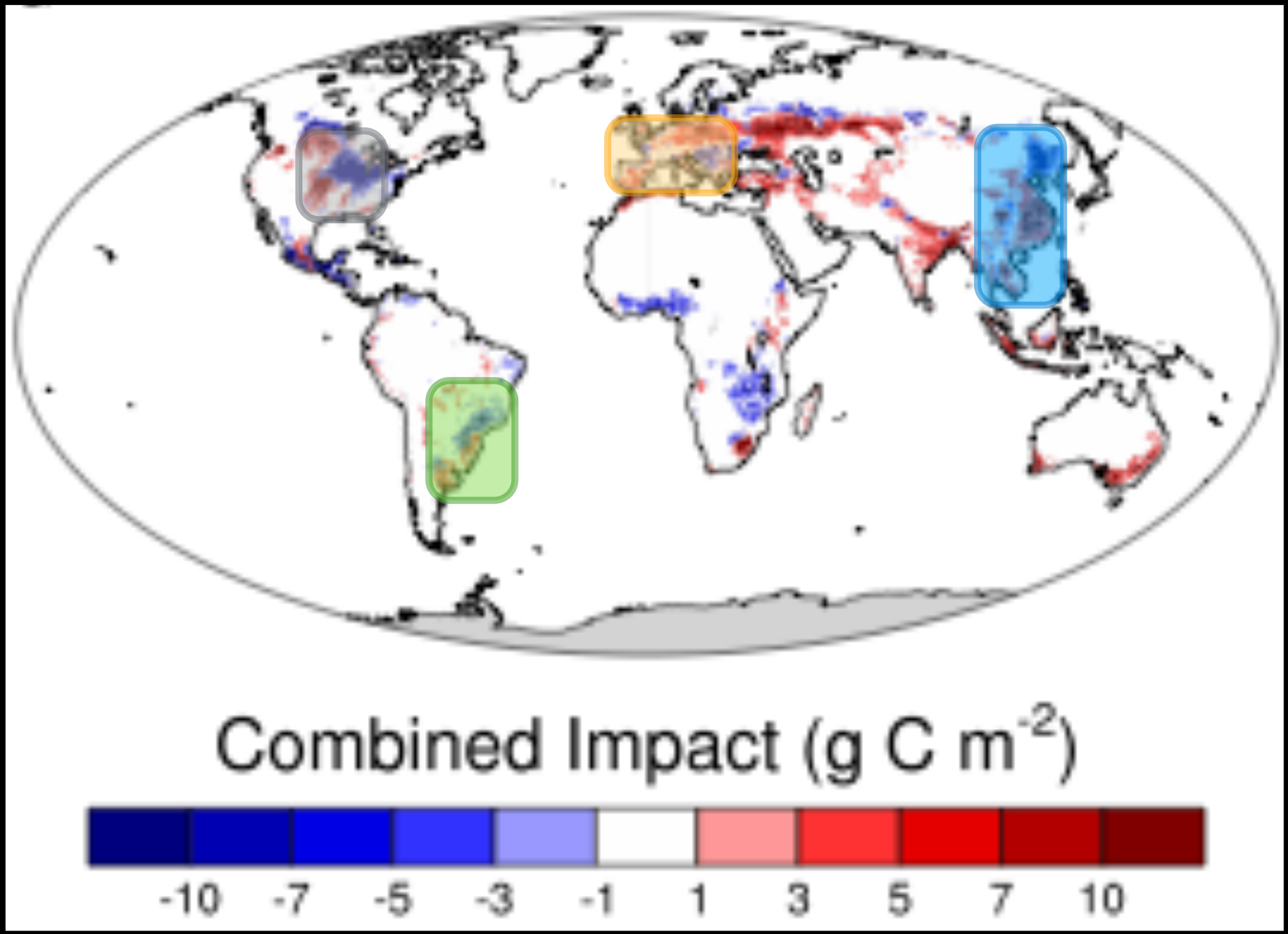

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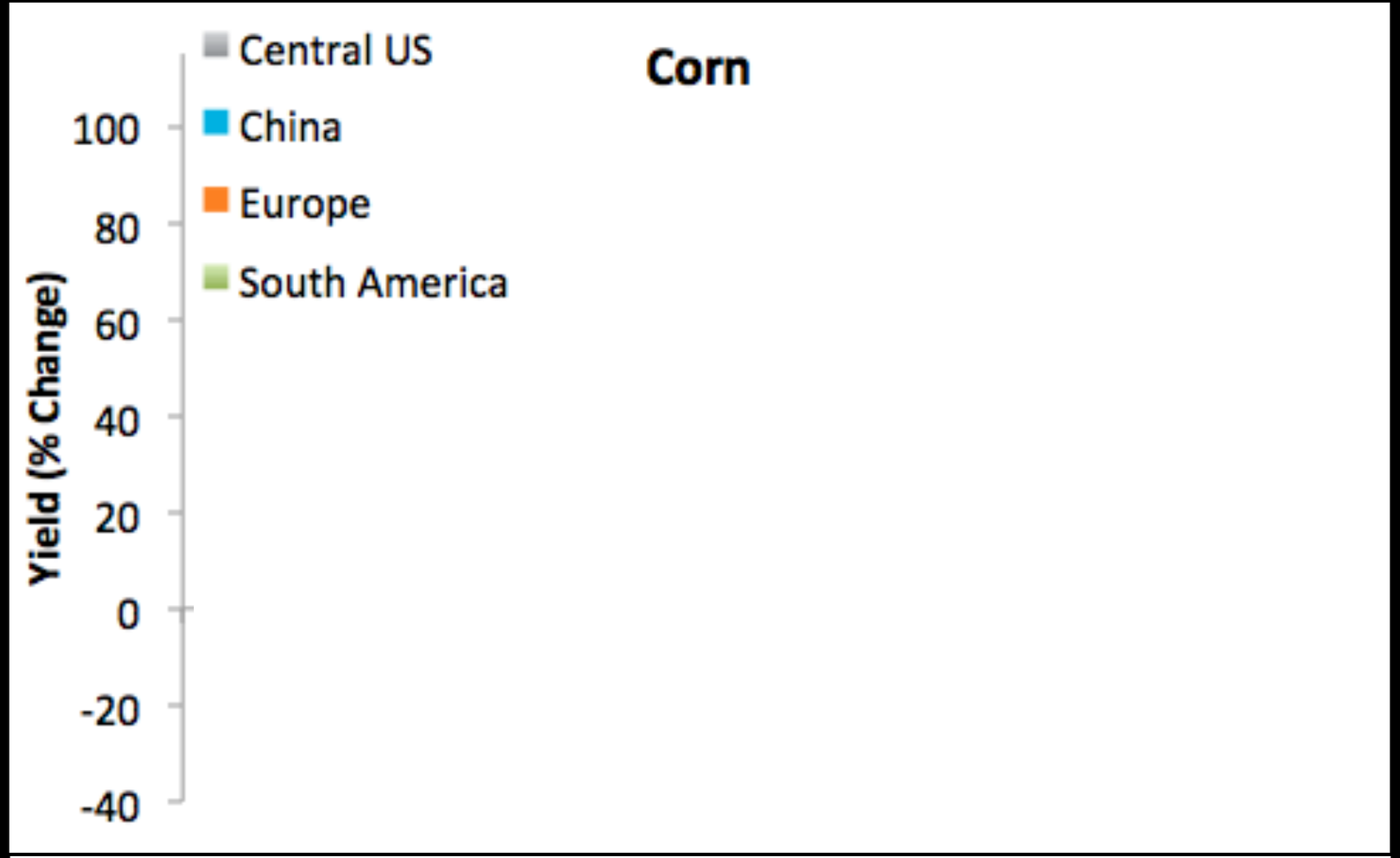

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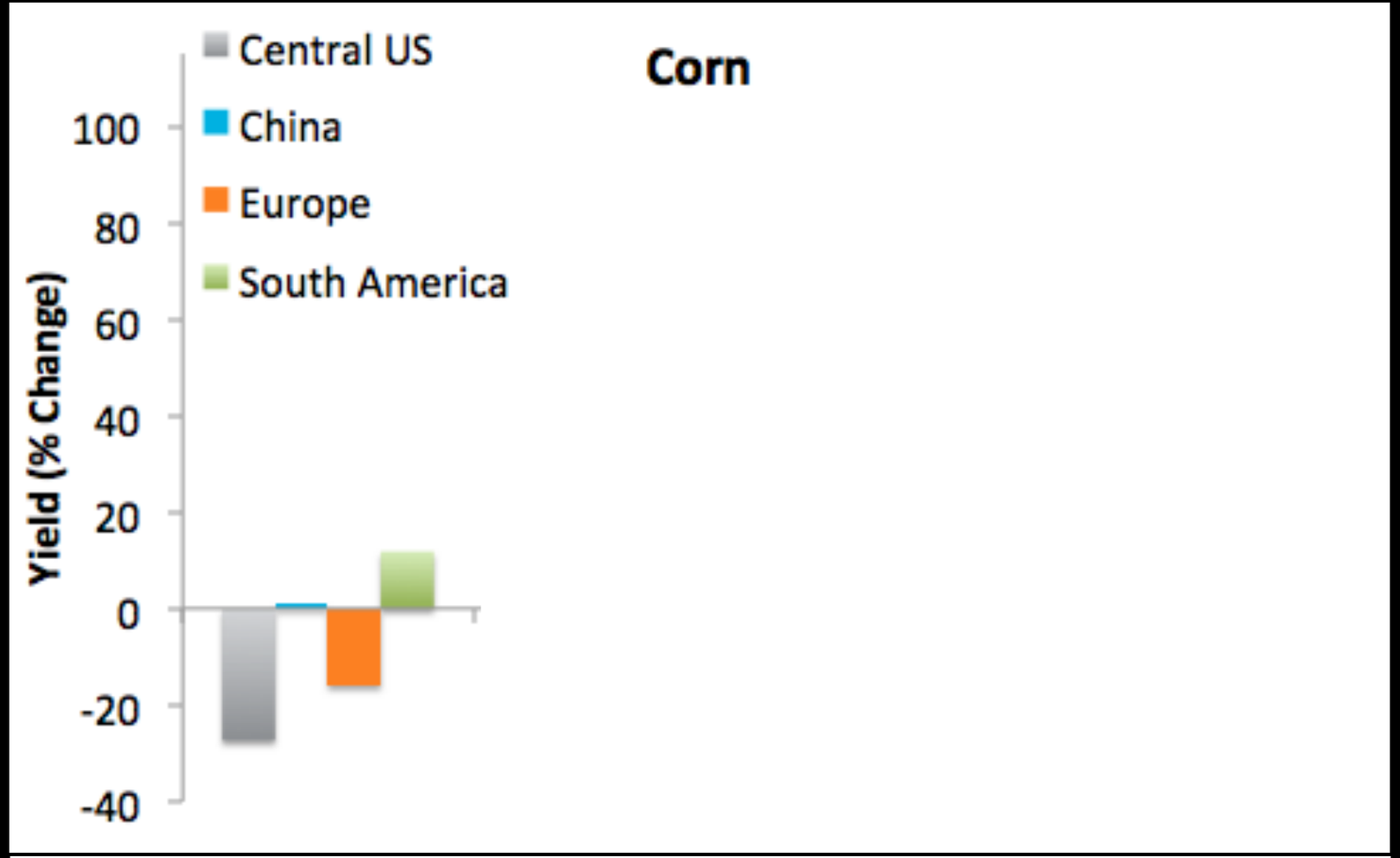

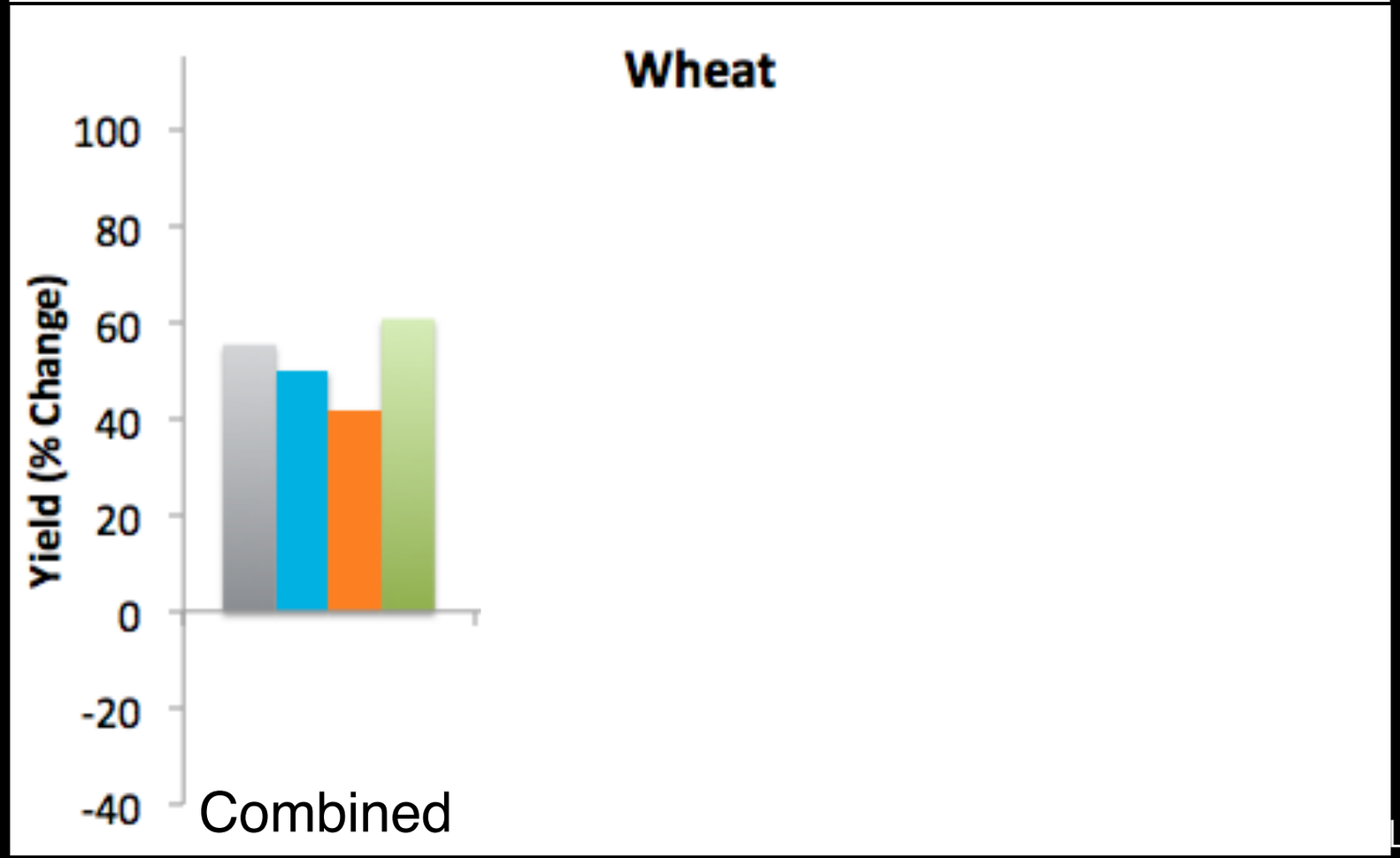

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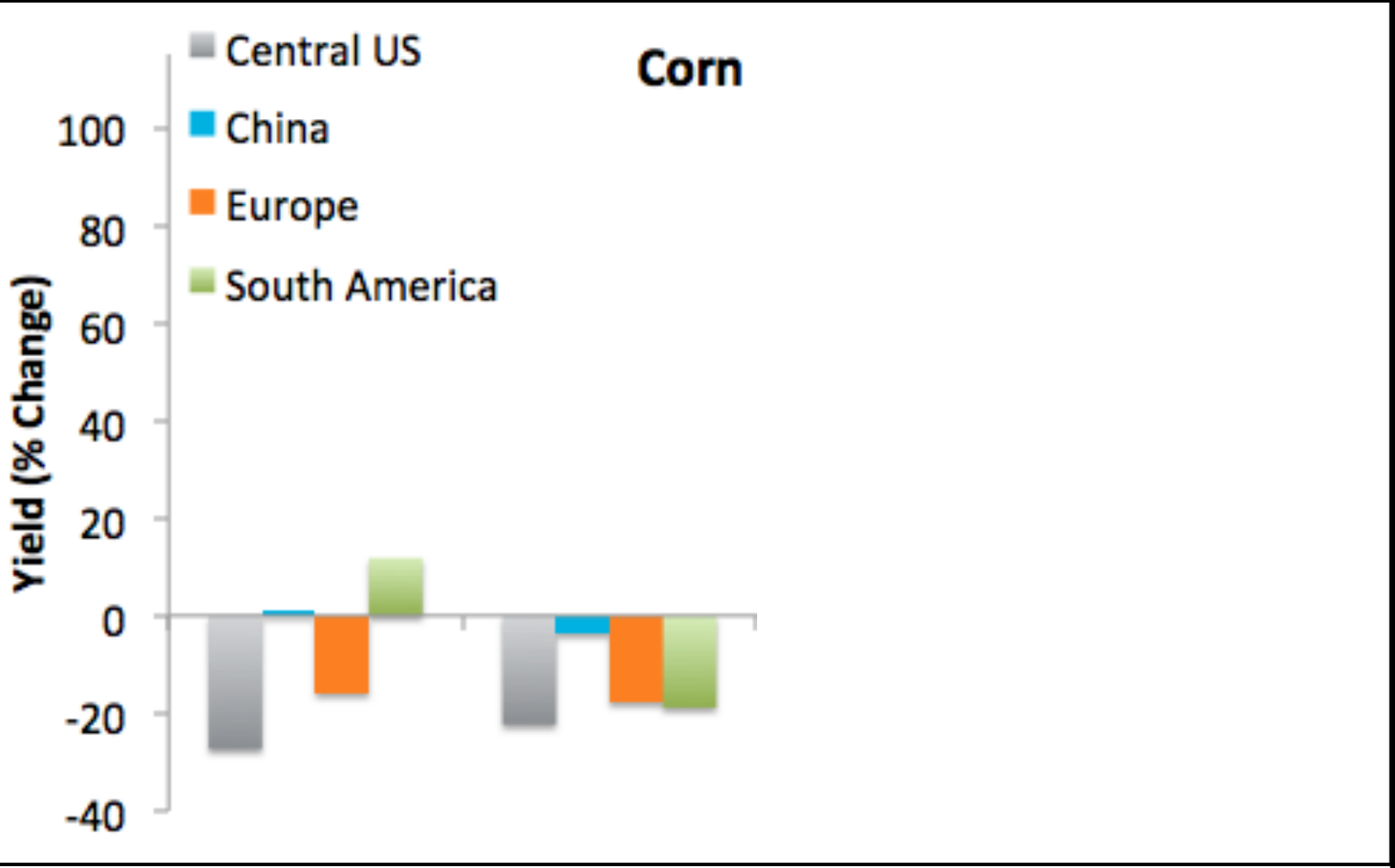

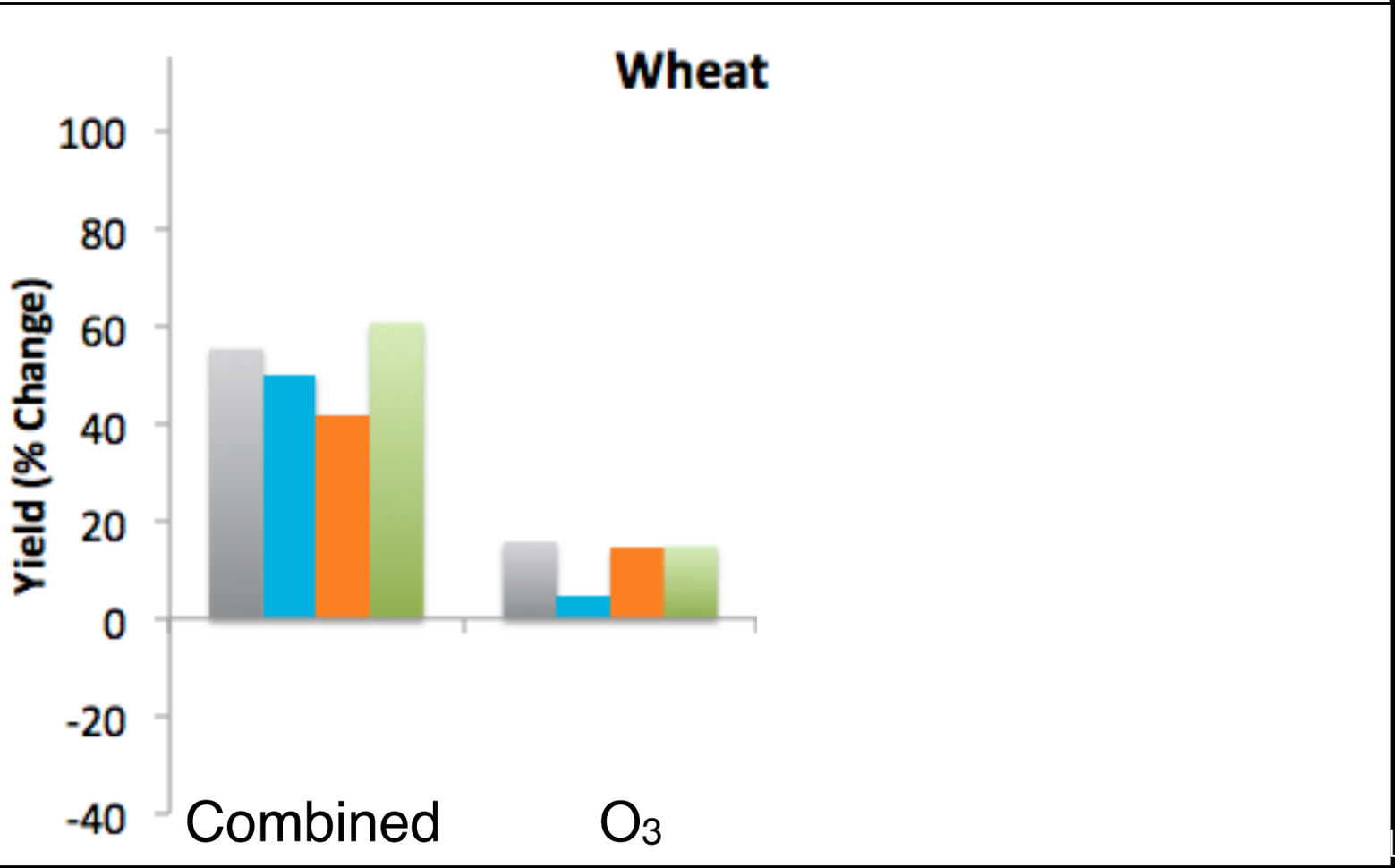

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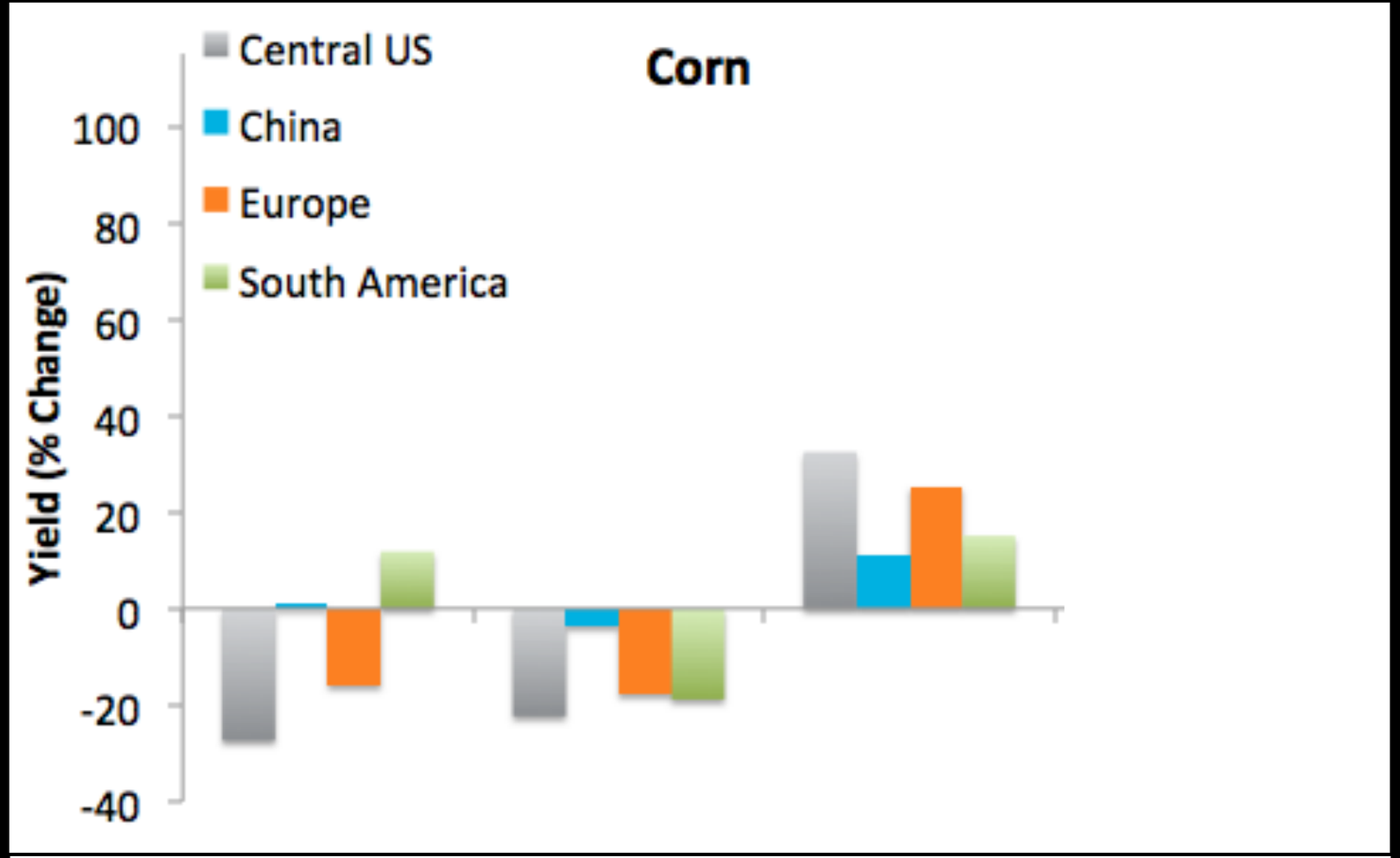

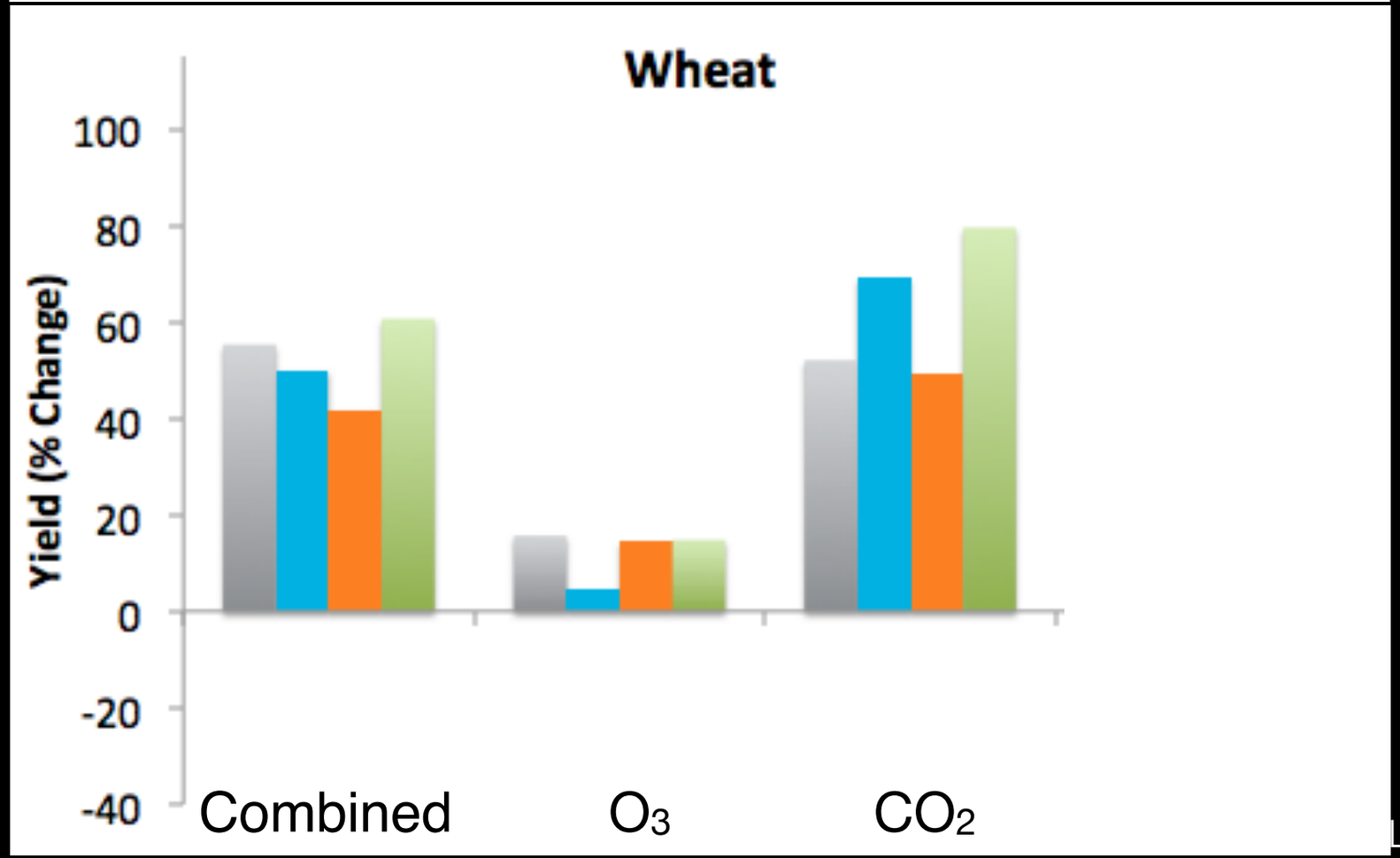

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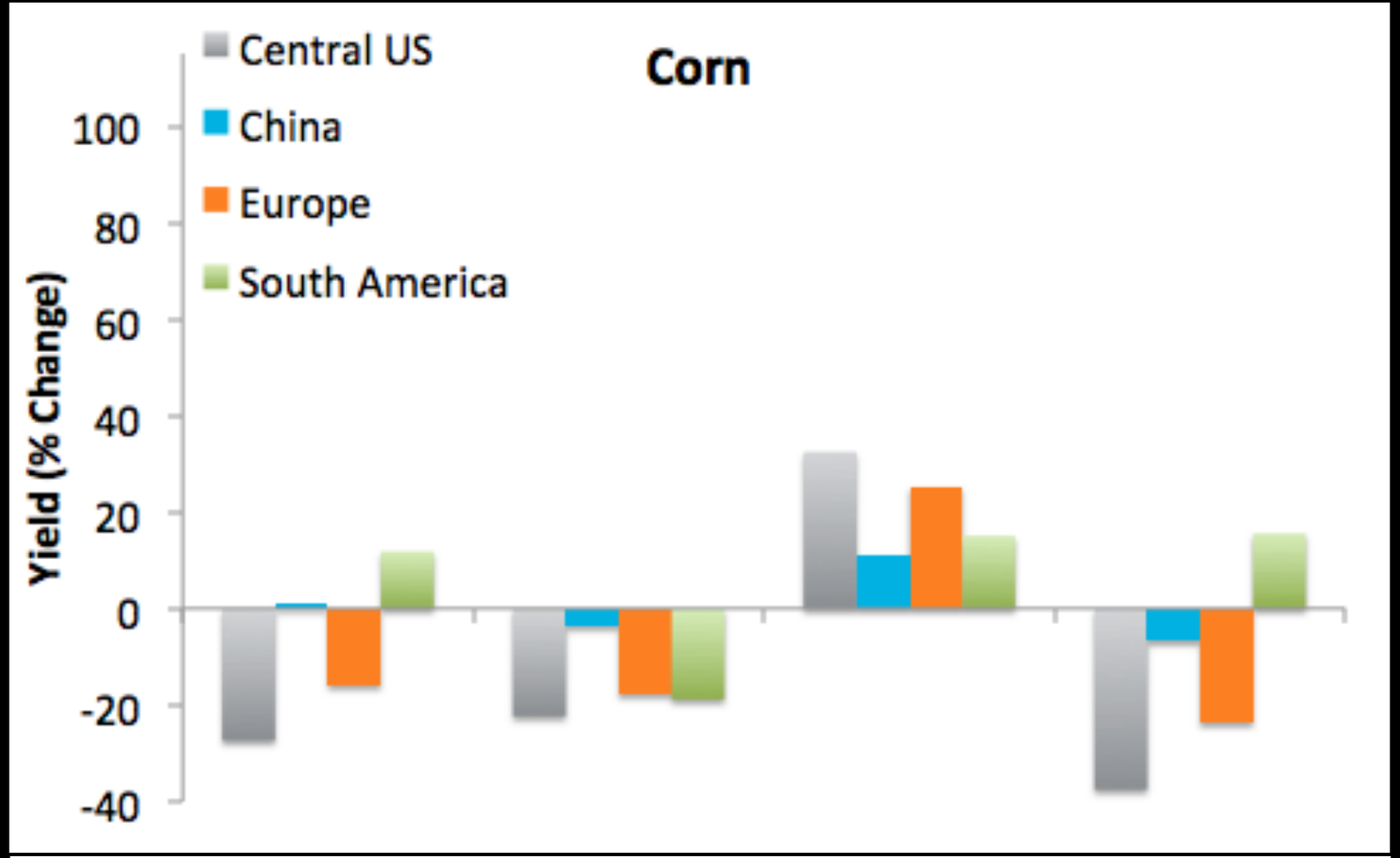
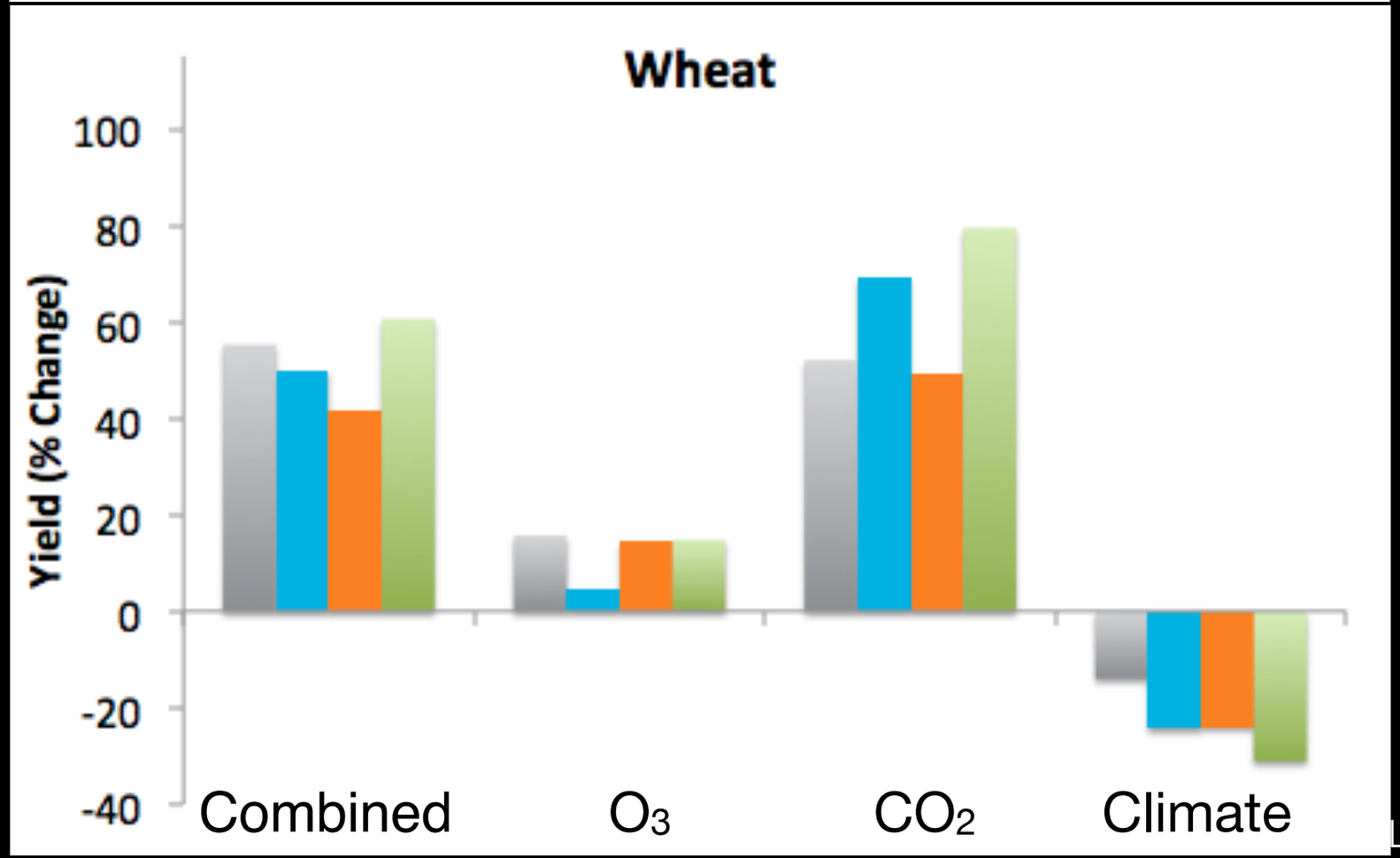
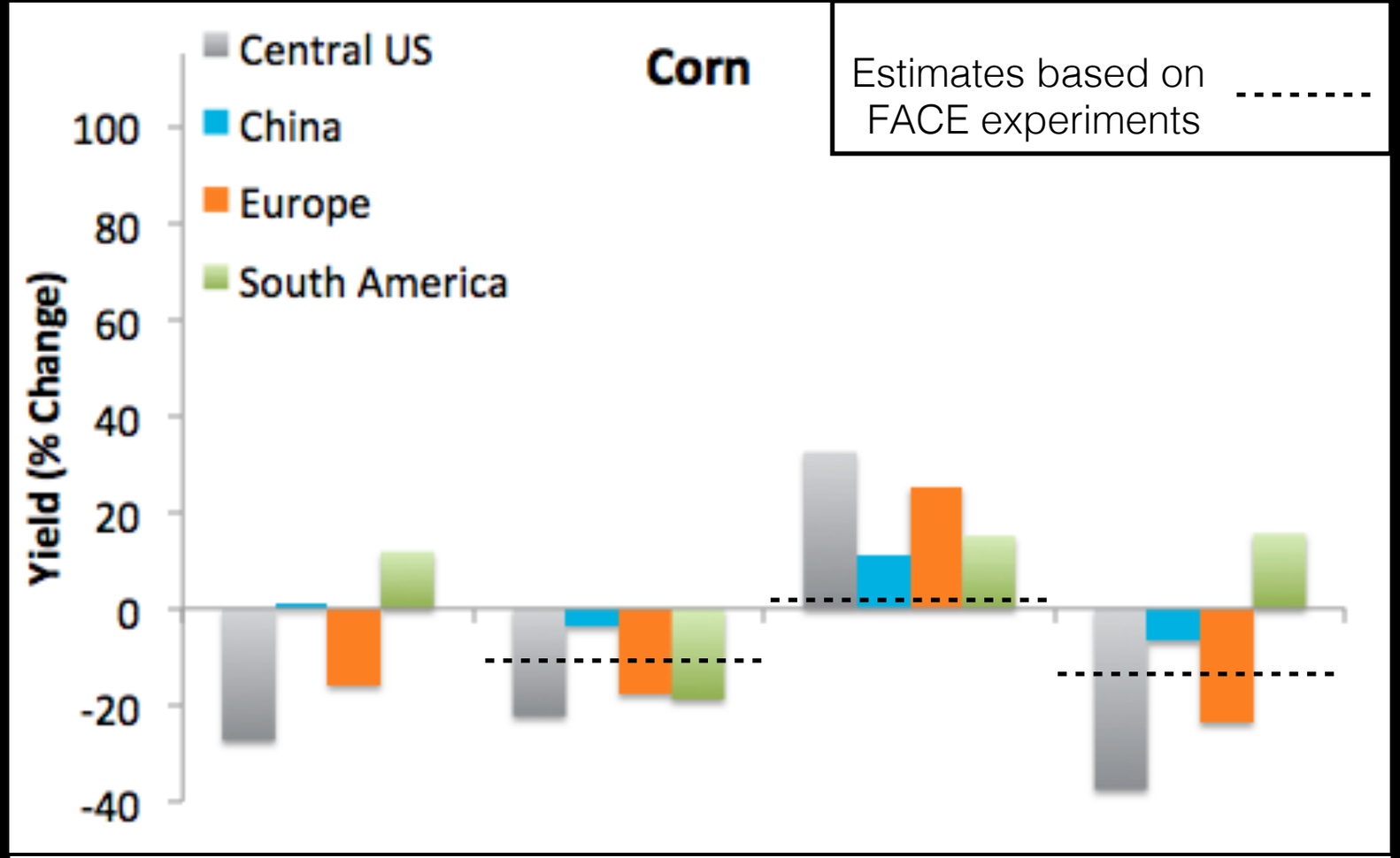
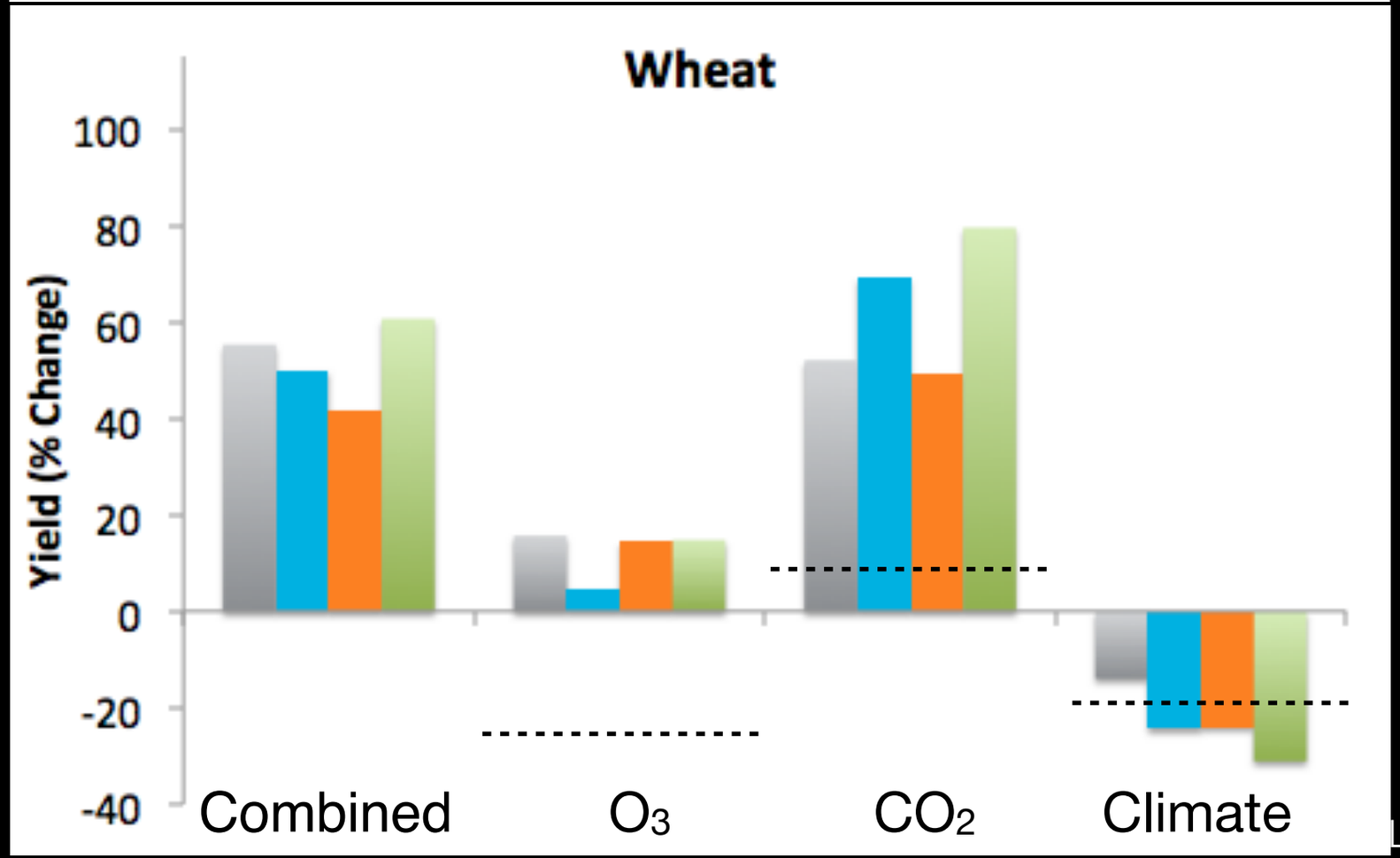




Lombardozzi et al. In Prep

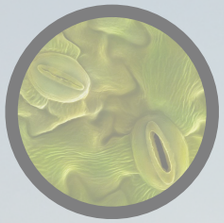




Lombardozzi et al. In Prep

Questions for today:

How does ozone pollution change:



1. Leaf processes?

2. Global terrestrial processes?

3. Crop yields?

- Yield depends on region and crop type
- O_3 and climate: decrease future yields
- CO_2: increases future yields, and its effect is overestimated

Questions for today:

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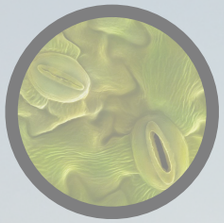

1. Leaf processes?

2. Global terrestrial processes?

3. Crop yields?

- Yield depends on region and crop type
- O_3 and climate: decrease future yields
- CO_2: increases future yields, and its effect is overestimated

Future crop yields likely won't meet the estimated 65% increased demand.

Vegetation O_3 damage:

Vegetation O_3 damage:

- Damages photosynthesis more than conductance

Vegetation O_3 damage:

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- Changes global-scale water and carbon exchange

Vegetation O_3 damage:

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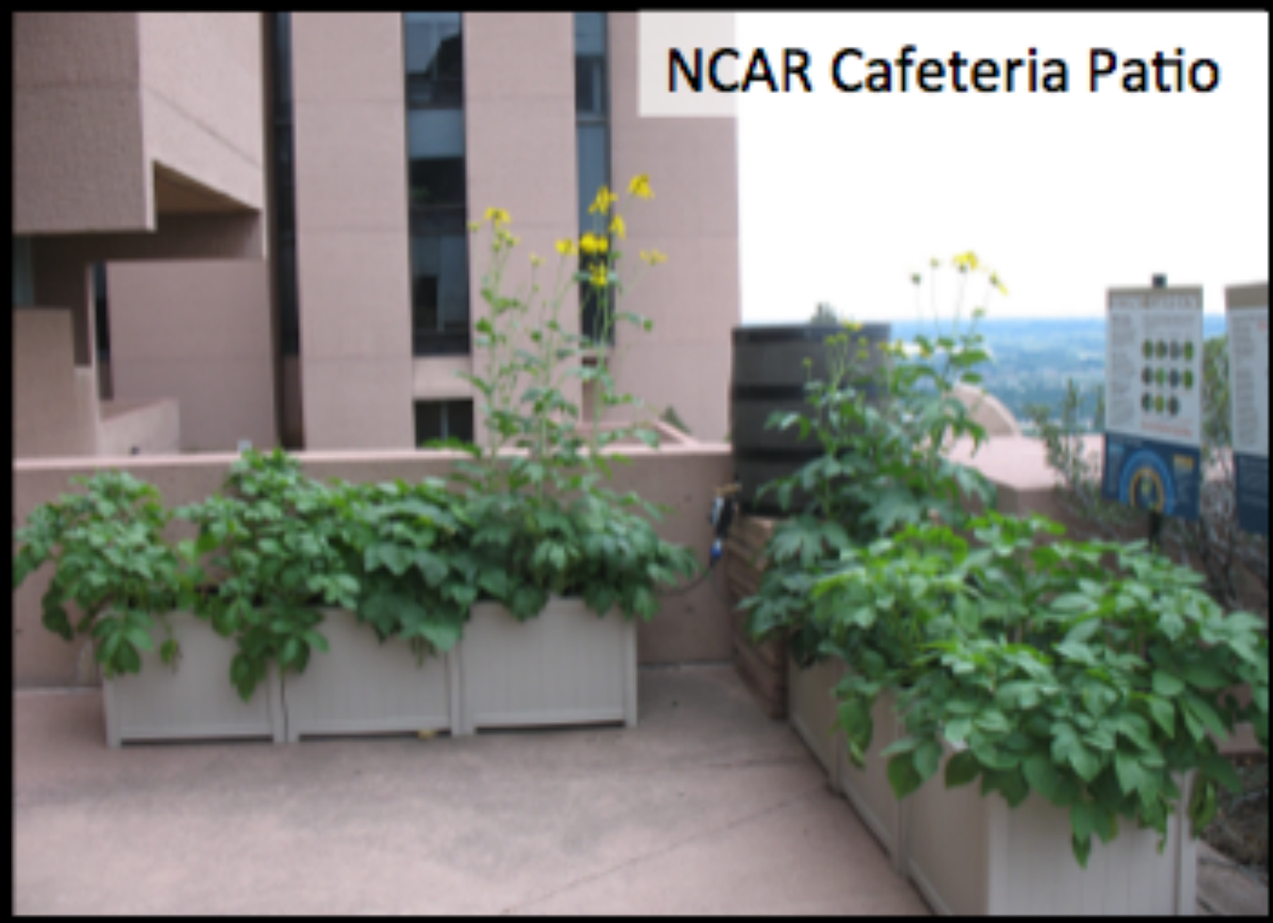
- Changes global-scale water and carbon exchange
- Decreases crop yields


NCAR Front Entrance


CU Mountain Research Station


CU Museum of Natural History


NCAR Cafeteria Patio

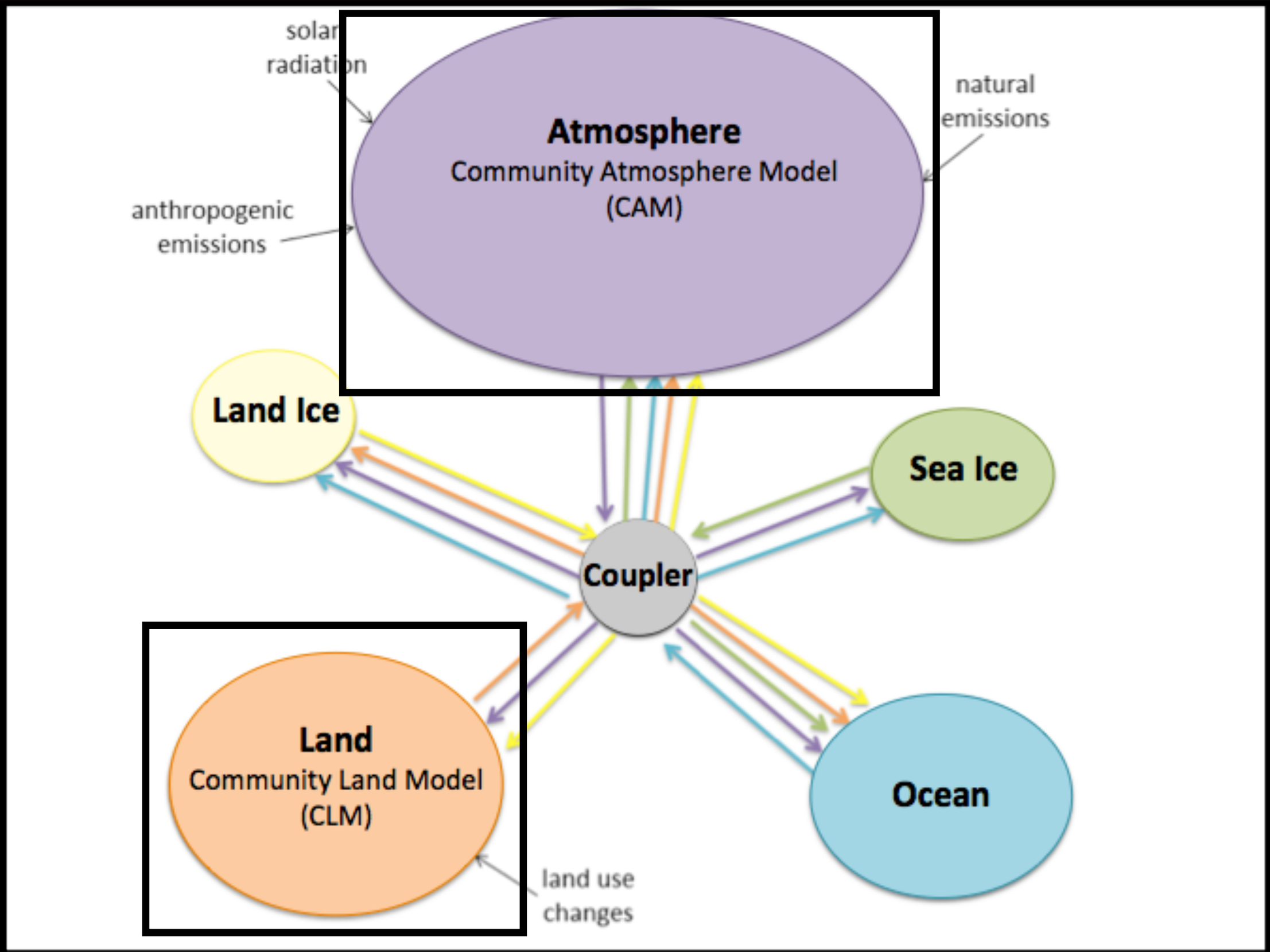
Danica Lombardozzi
dll@ucar.edu

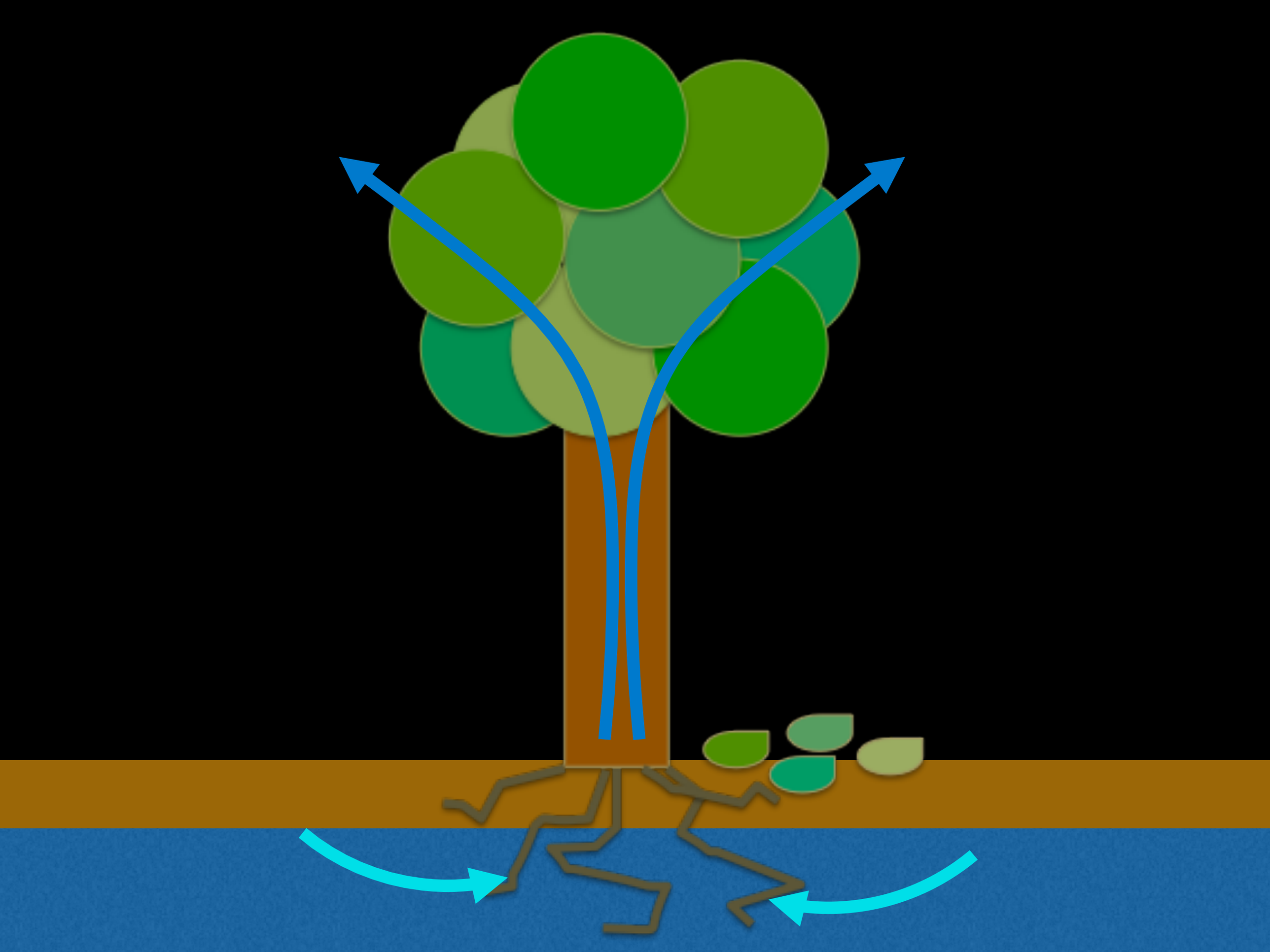
Questions for today:

How does ozone pollution change:

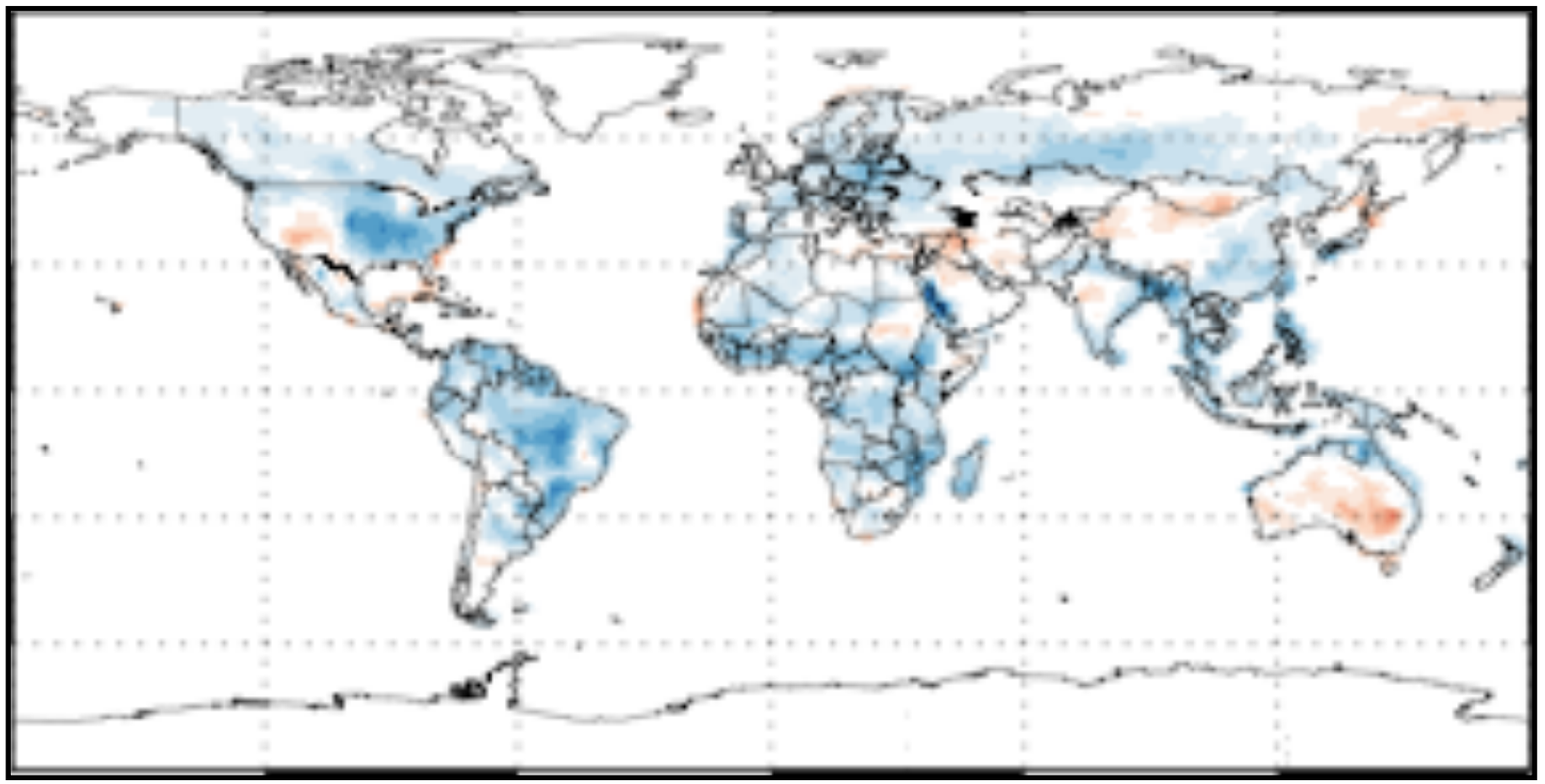
Climate & chemistry feedbacks?

Community Earth System Model





Change in **Latent Heat Flux** due to O_3 ($W\ m^{-2}$)



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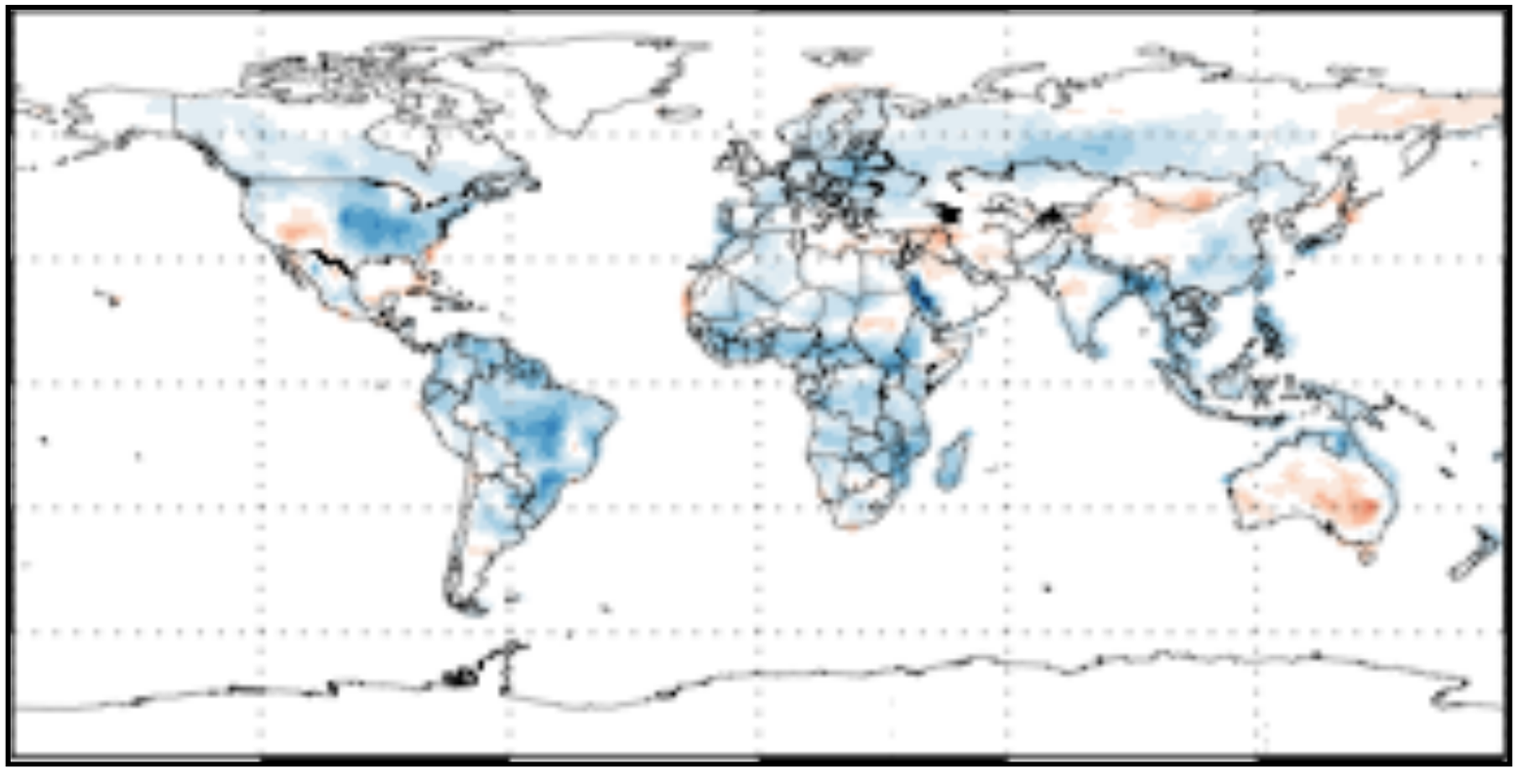
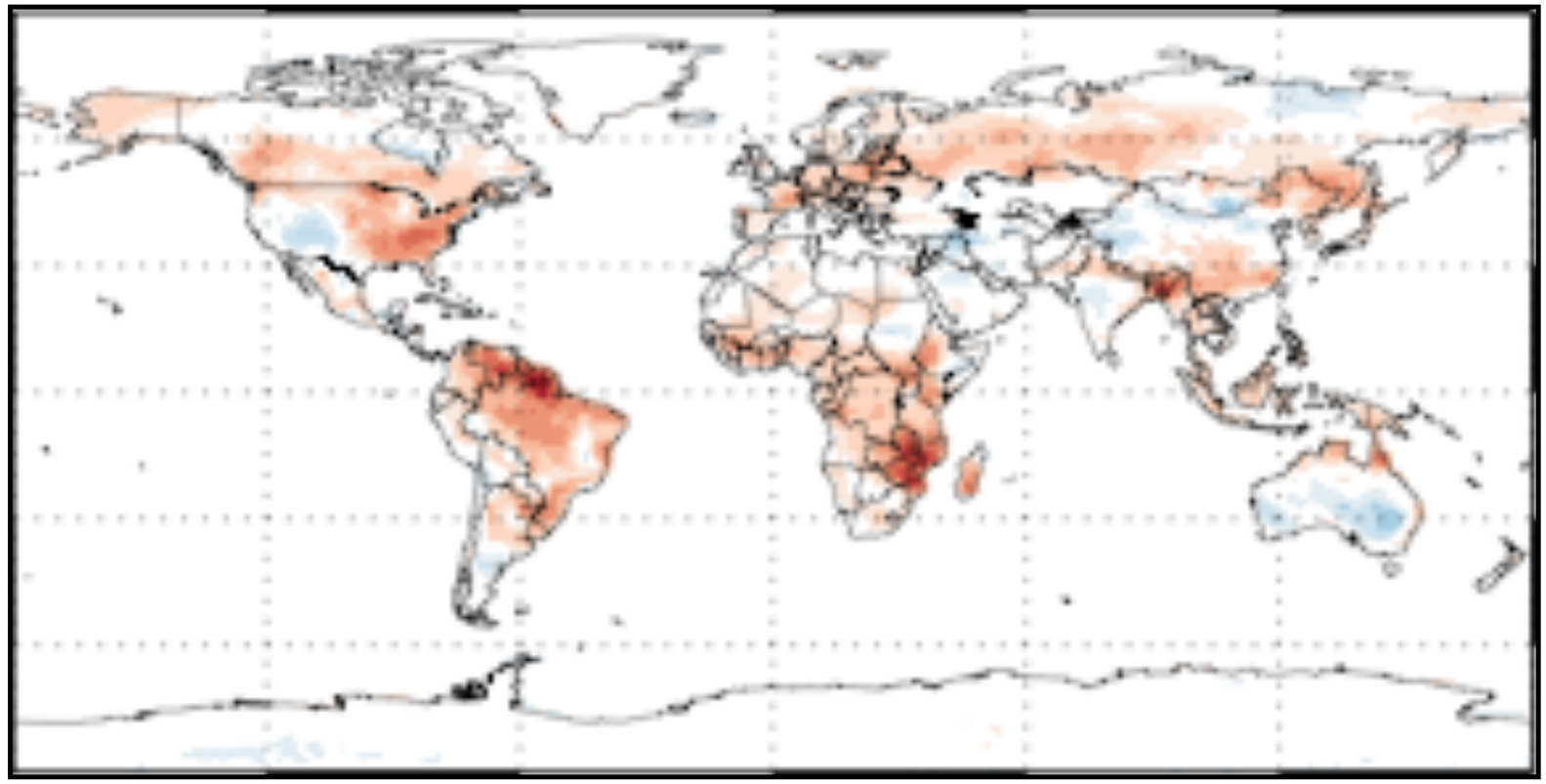
Change in **Latent Heat Flux** due to O_3 ($W\ m^{-2}$)



Change in **Sensible Heat Flux** due to O_3 ($W\ m^{-2}$)



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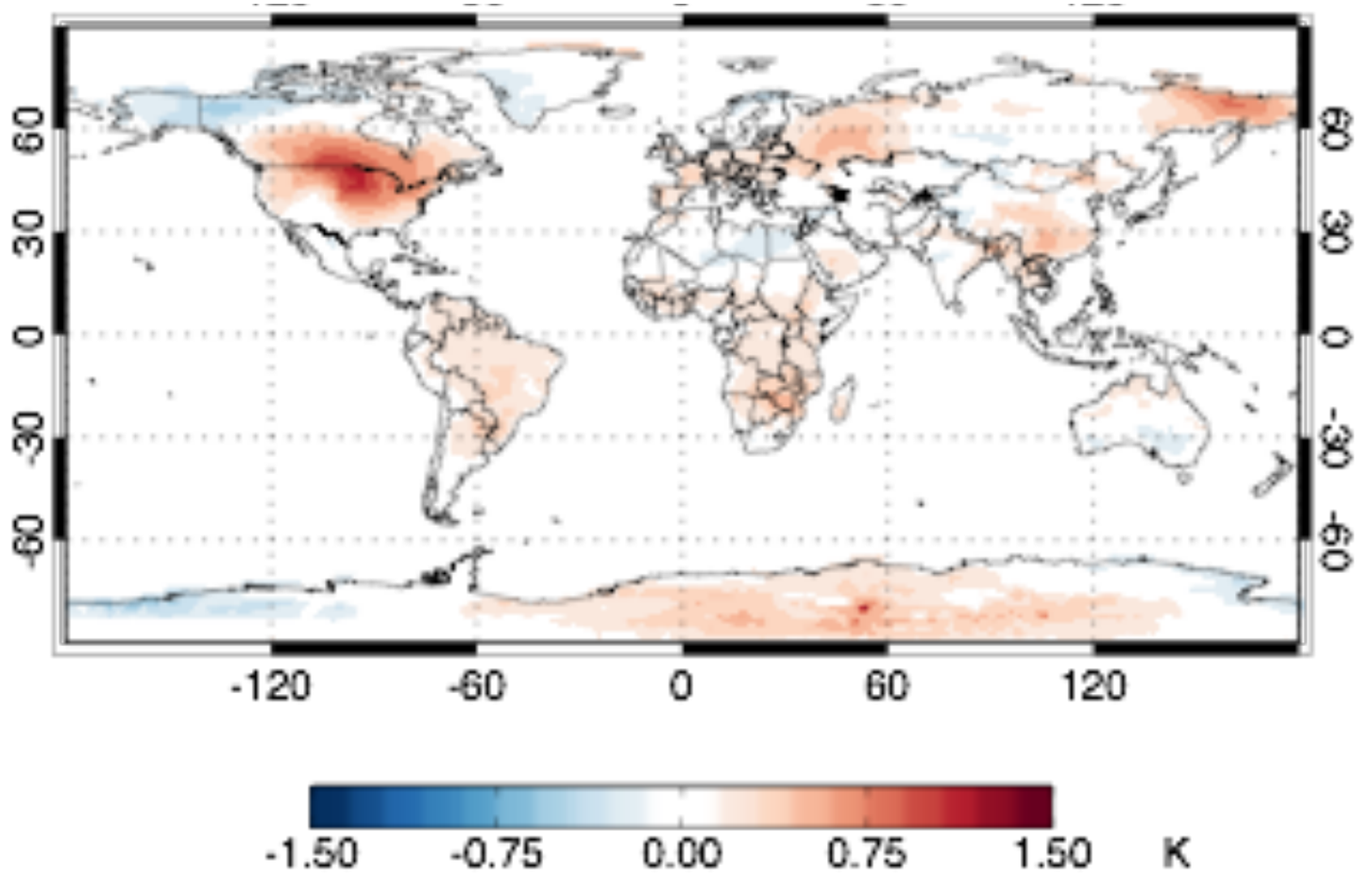
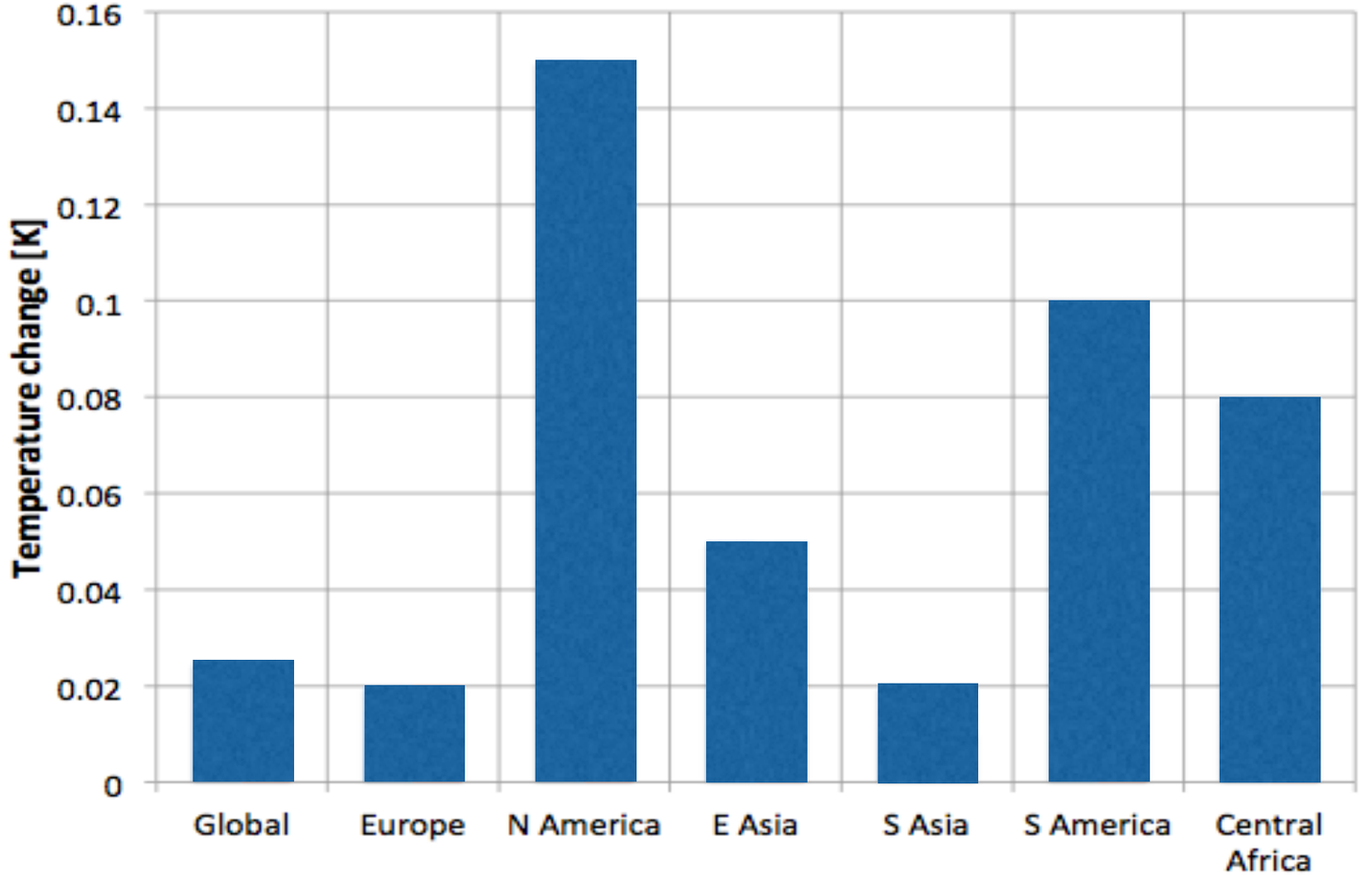
Change in **Surface Temperature** due to O_3 (K)



Regional **Temperature** change due to O_3 (K)



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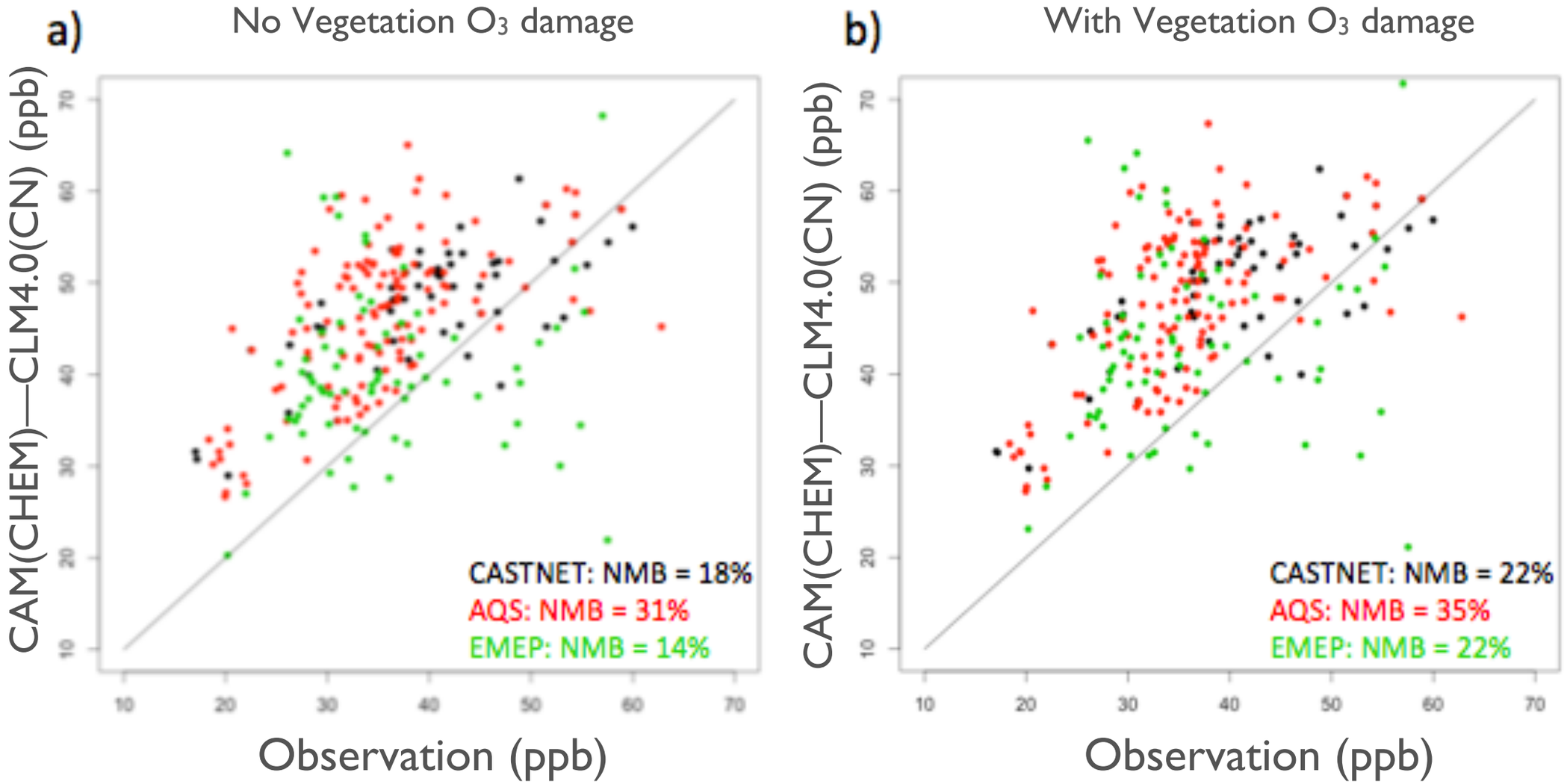
6% [O_3] increase in Northern Hemisphere



Sadiq et al., *ACPD*

Questions for today:

How does ozone pollution change:

Climate & chemistry feedbacks?

- Increased surface & air temperatures
- Increased [O_3] in the northern hemisphere

Vegetation O_3 damage:

- Damages photosynthesis more than conductance
- Changes global-scale water and carbon exchange
- Increases surface temperature through changing heat fluxes
- Increases ozone concentrations
- Decreases crop yields

Engaging Communities in Citizen Science

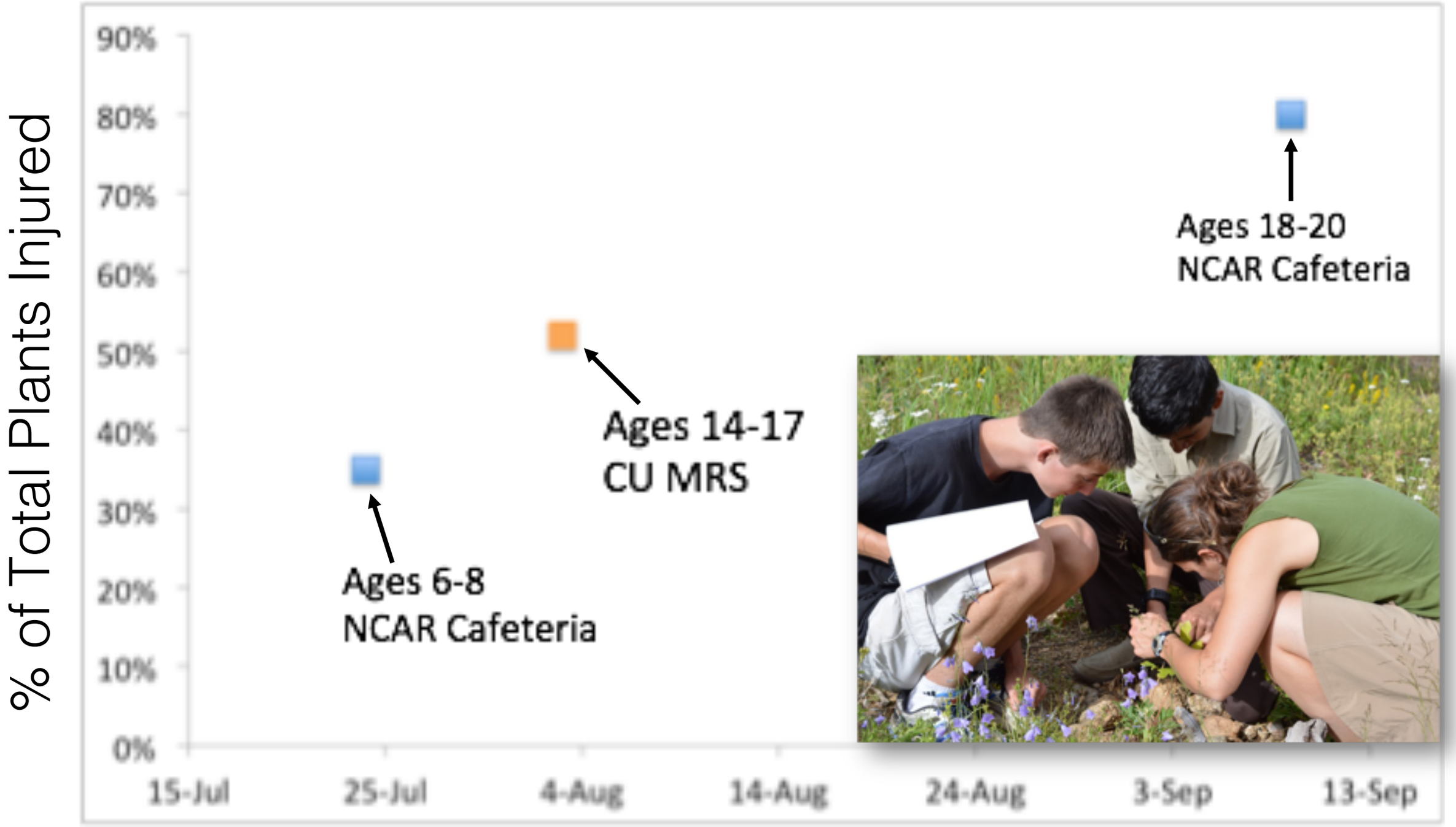
COLORADO MATTERS

How Plants Show The Strains Of Ozone Pollution

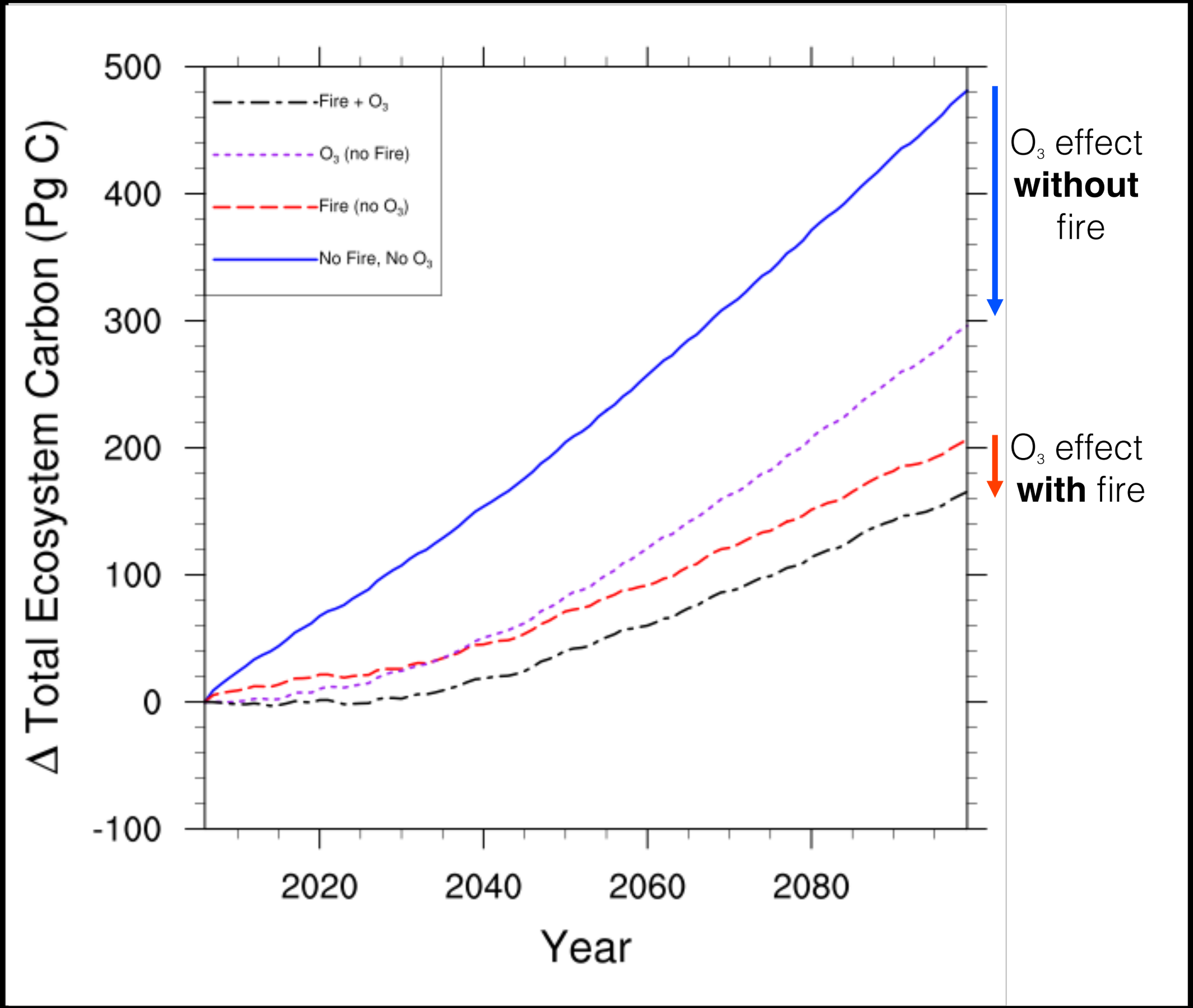
BY MICHAEL DE YOANNA
JUL 29, 2014

LISTEN Audio: NCAR Researcher Danica Lombardozzi Speaks With Ryan Warner

Jumbo screens along Front Range highways have warned drivers a dozen times so far this year about high levels of ozone. But there's another way to tell if the invisible gas, also known as smog, is in the air: Check your garden.


% of Total Plants Injured
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
15-Jul
25-Jul
4-Aug
14-Aug
24-Aug
3-Sep
13-Sep
Ages 18-20
NCAR Cafeteria
Ages 14-17
CU MRS
Ages 6-8
NCAR Cafeteria

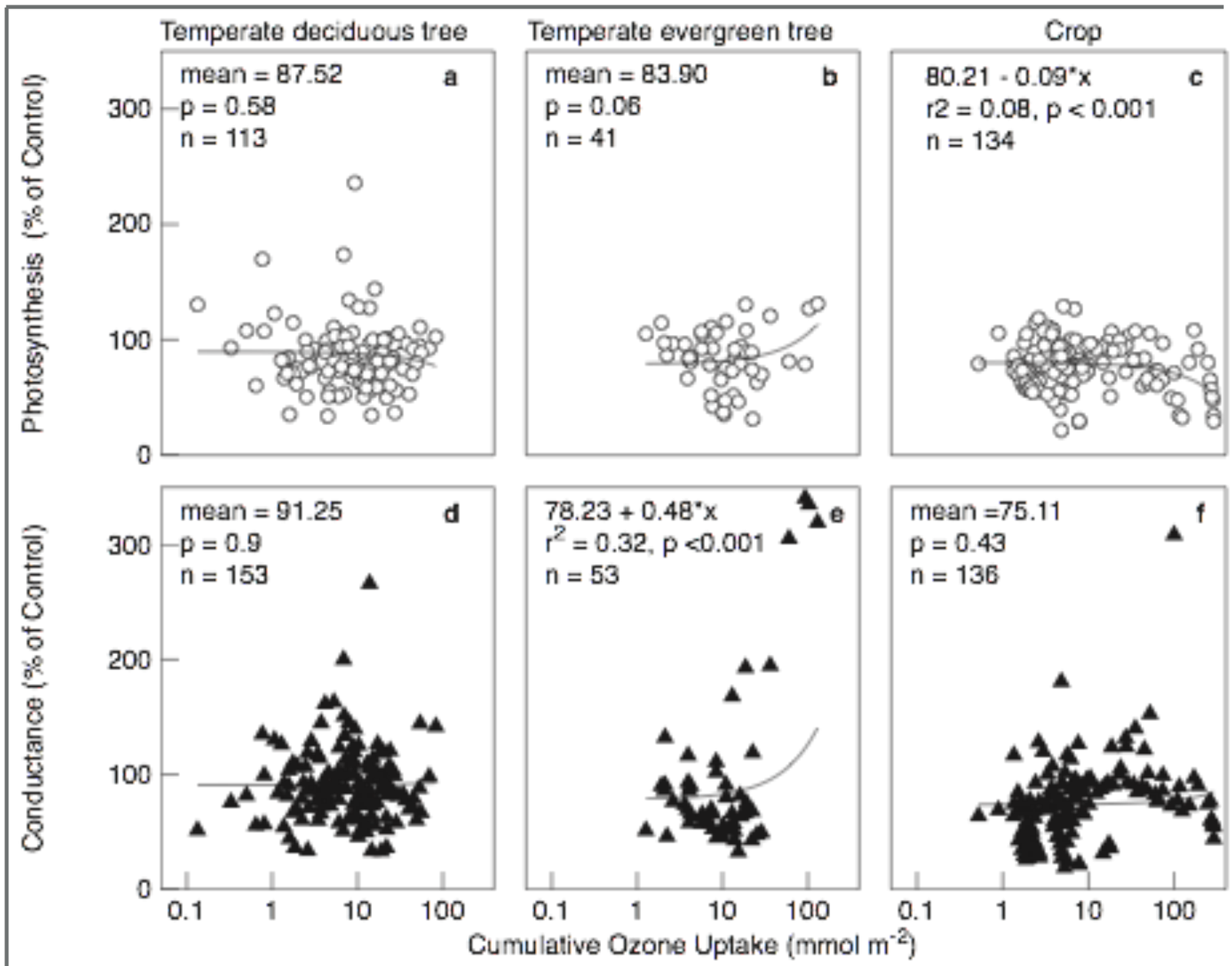
O_3-Fire Interactions



PROBLEMS & CONSIDERATIONS

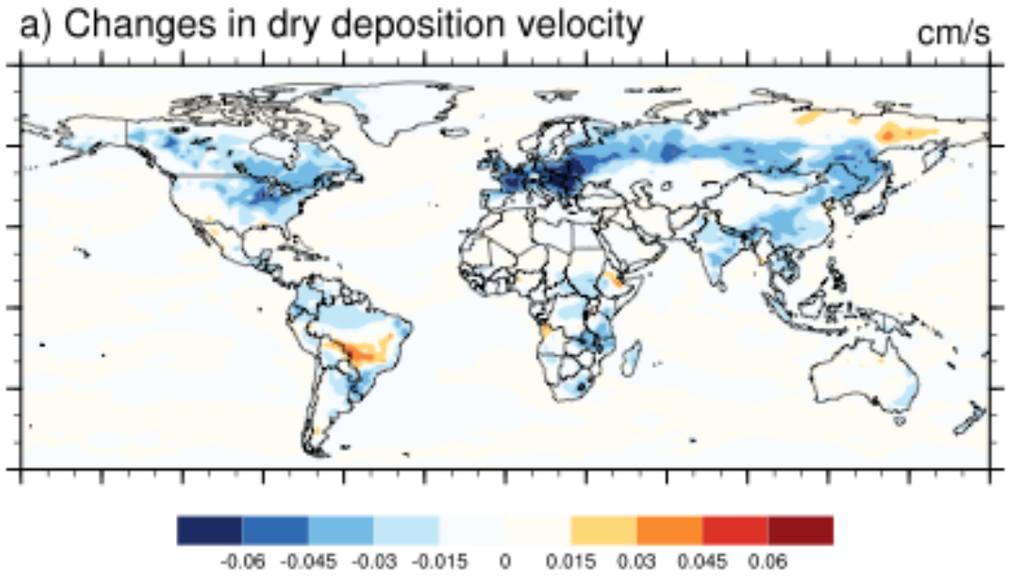
Uncertainty in parameterization

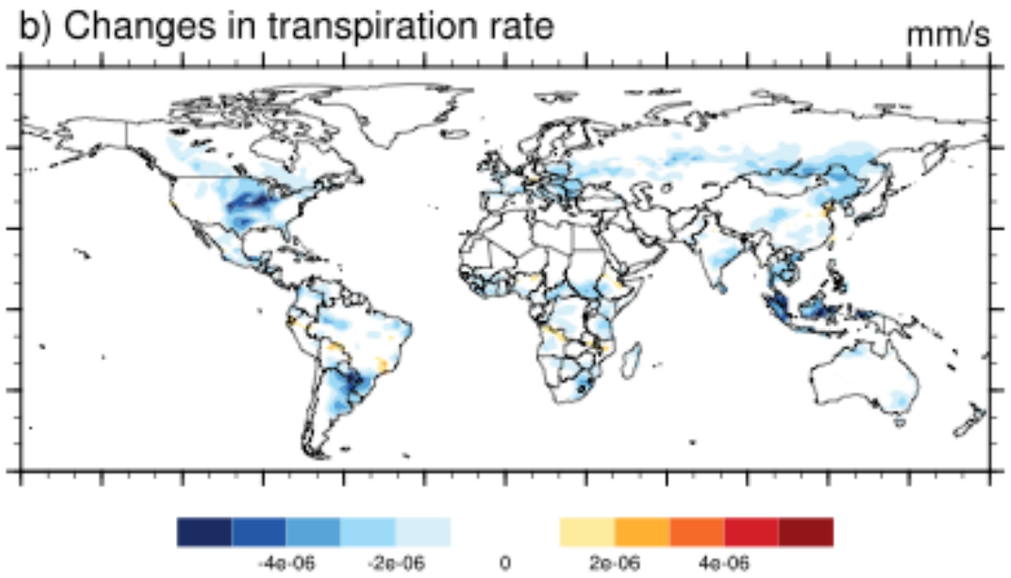
- 95% available data is for temperate plants
- No strong correlations between O_3 dose & physiological damage
- High sensitivity to O_3 dose threshold

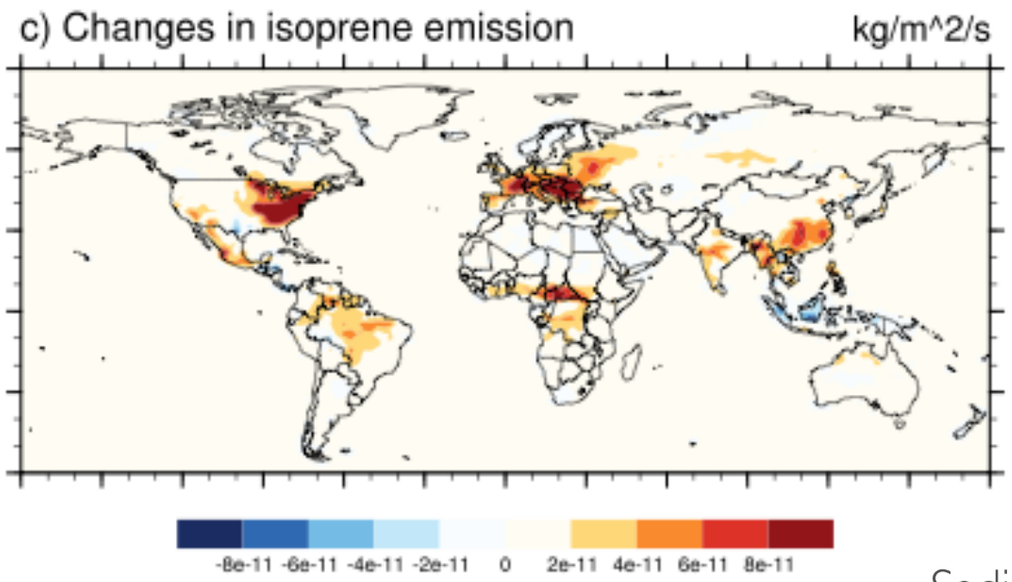


Correlations used in CLM-O_3 parameterization

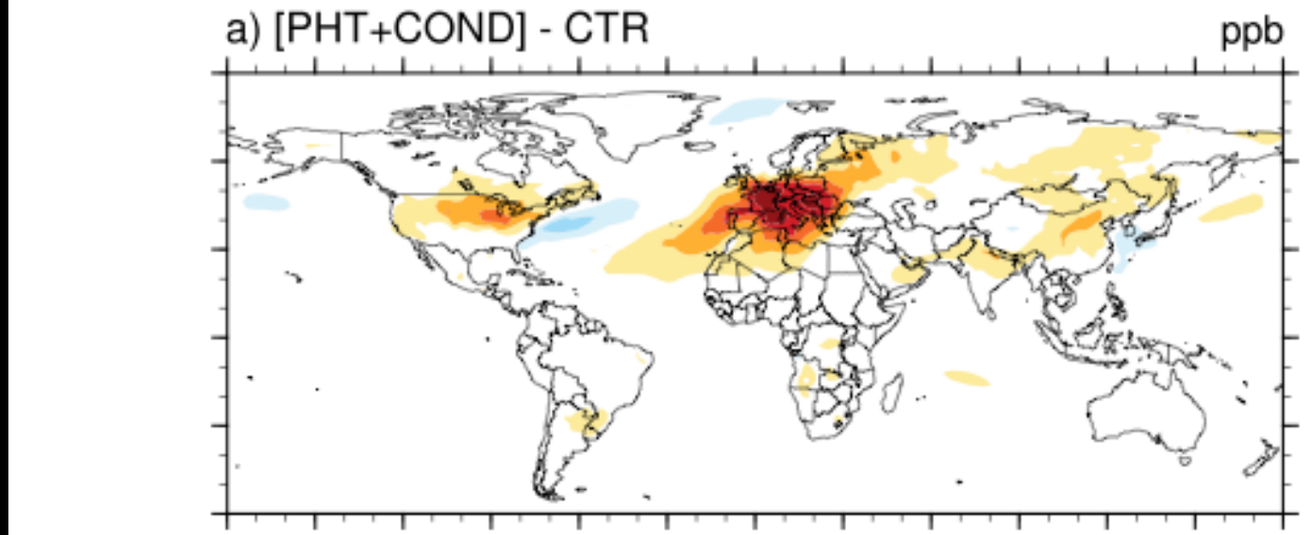
Lombardozzi et al. 2014

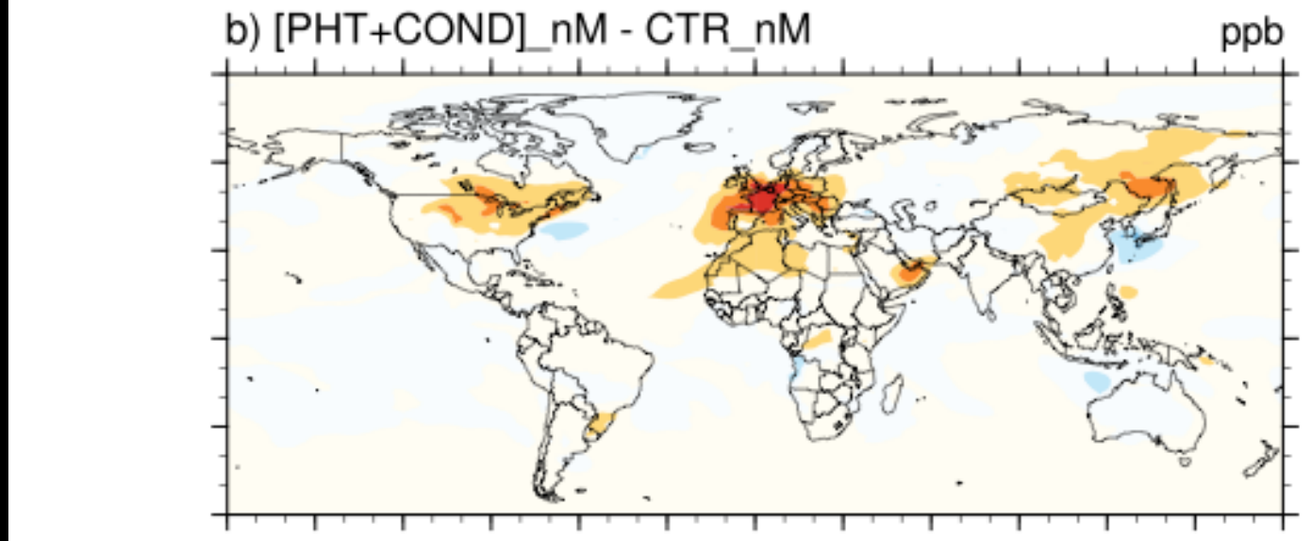


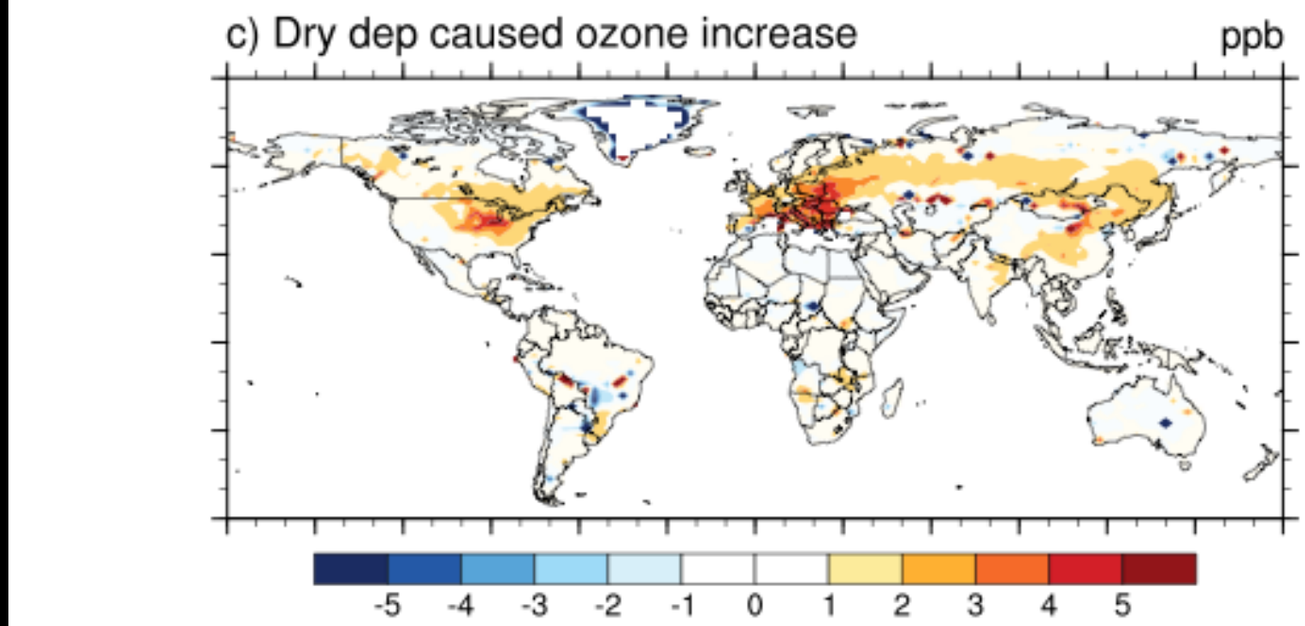




Sadiq et al. *ACPD*







Sadiq et al. *ACPD*

Collaborators

Gordon Bonan

Jed Sparks

Dave Lawrence

Peter Hess

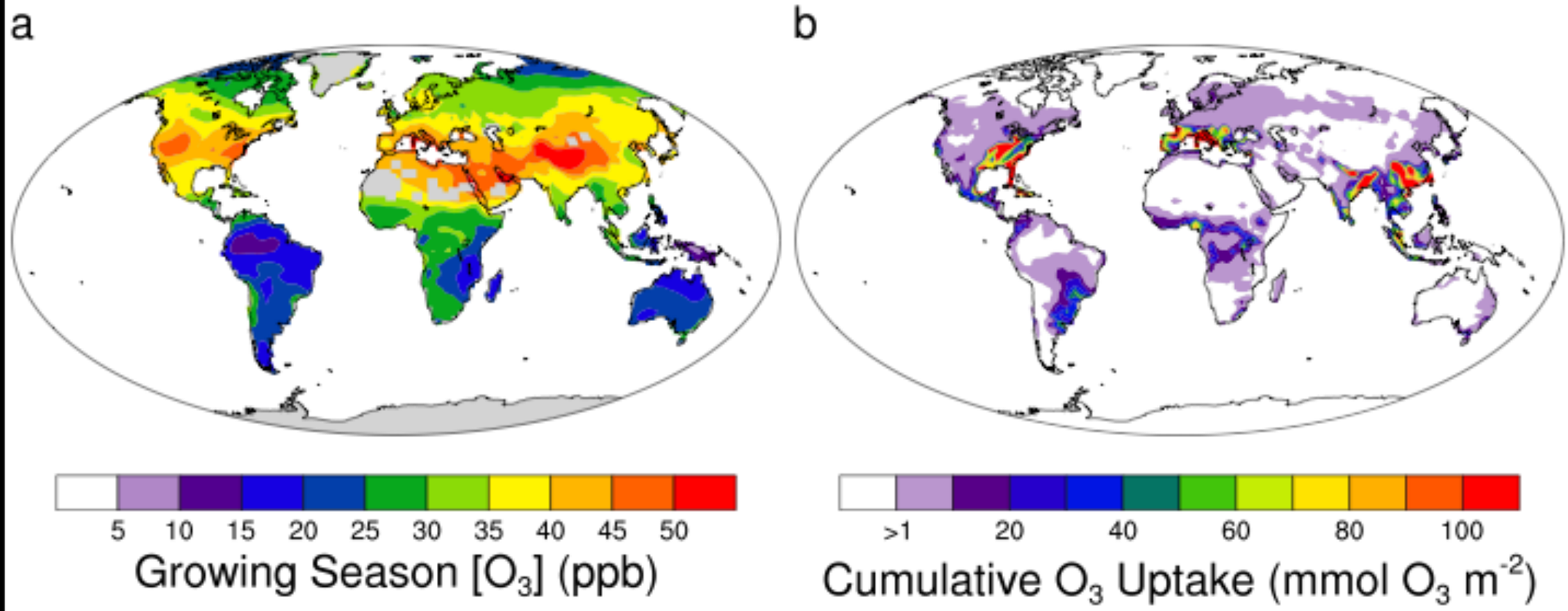
Sam Levis

Amos Tai

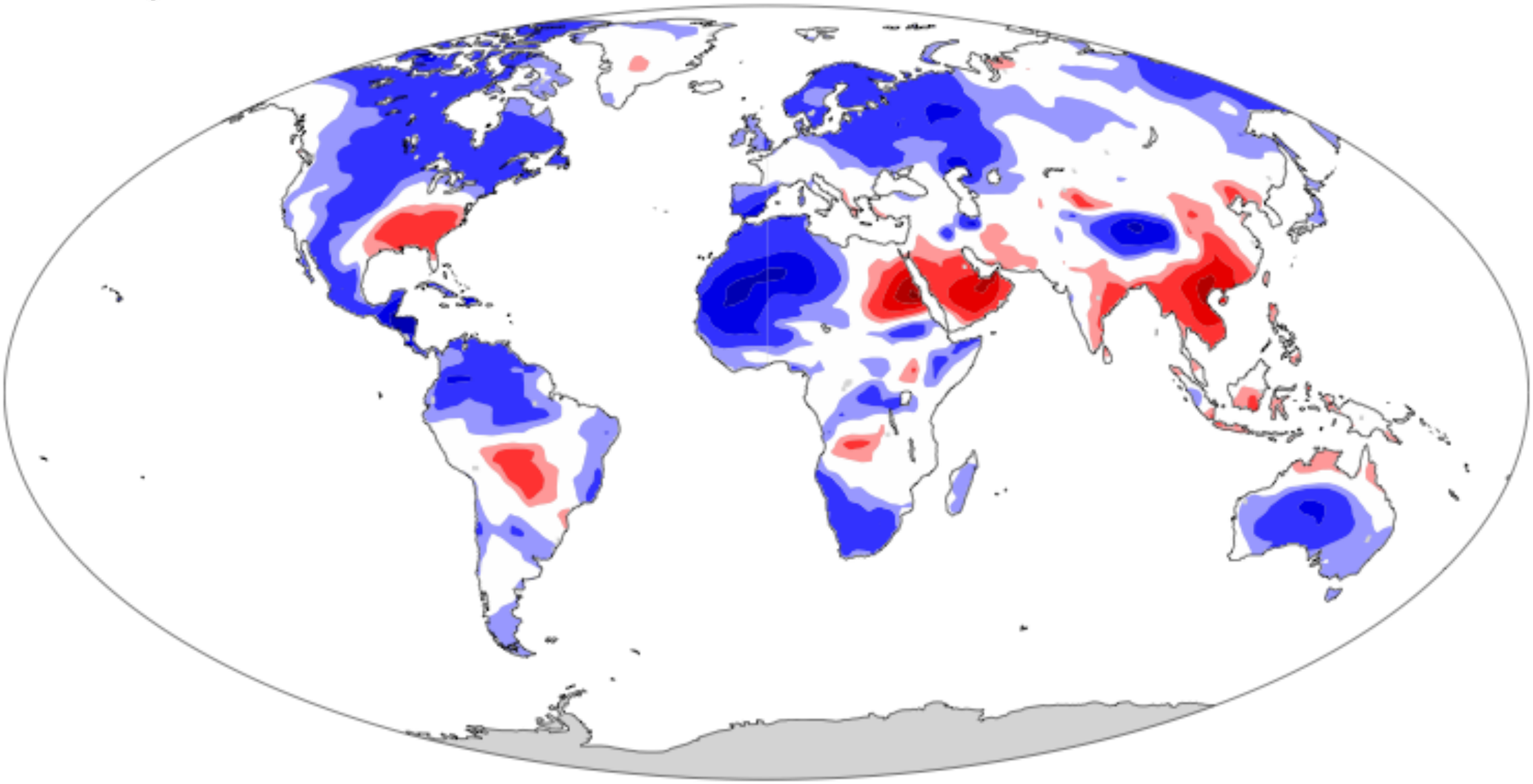
Steve Arnold

Mehliyar Sadiq

Climatological Present Day Ozone

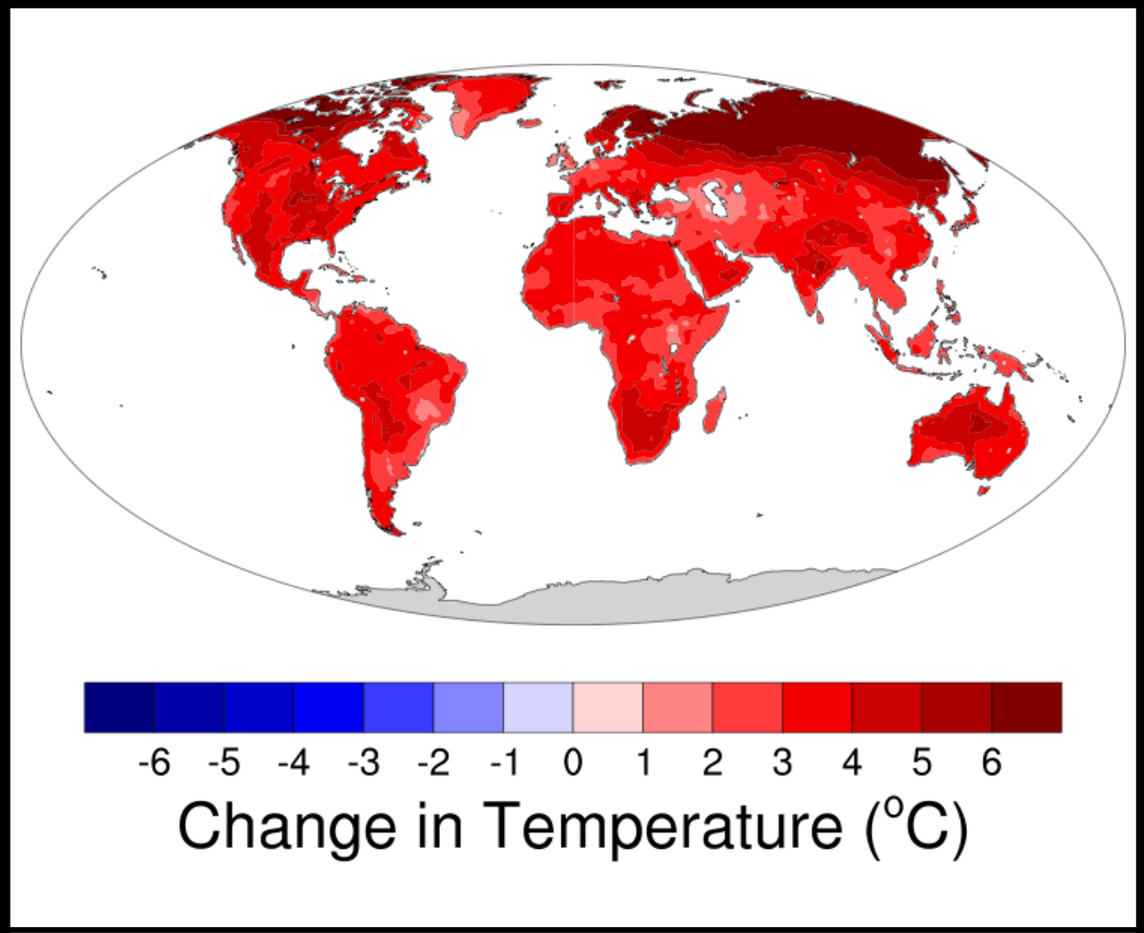


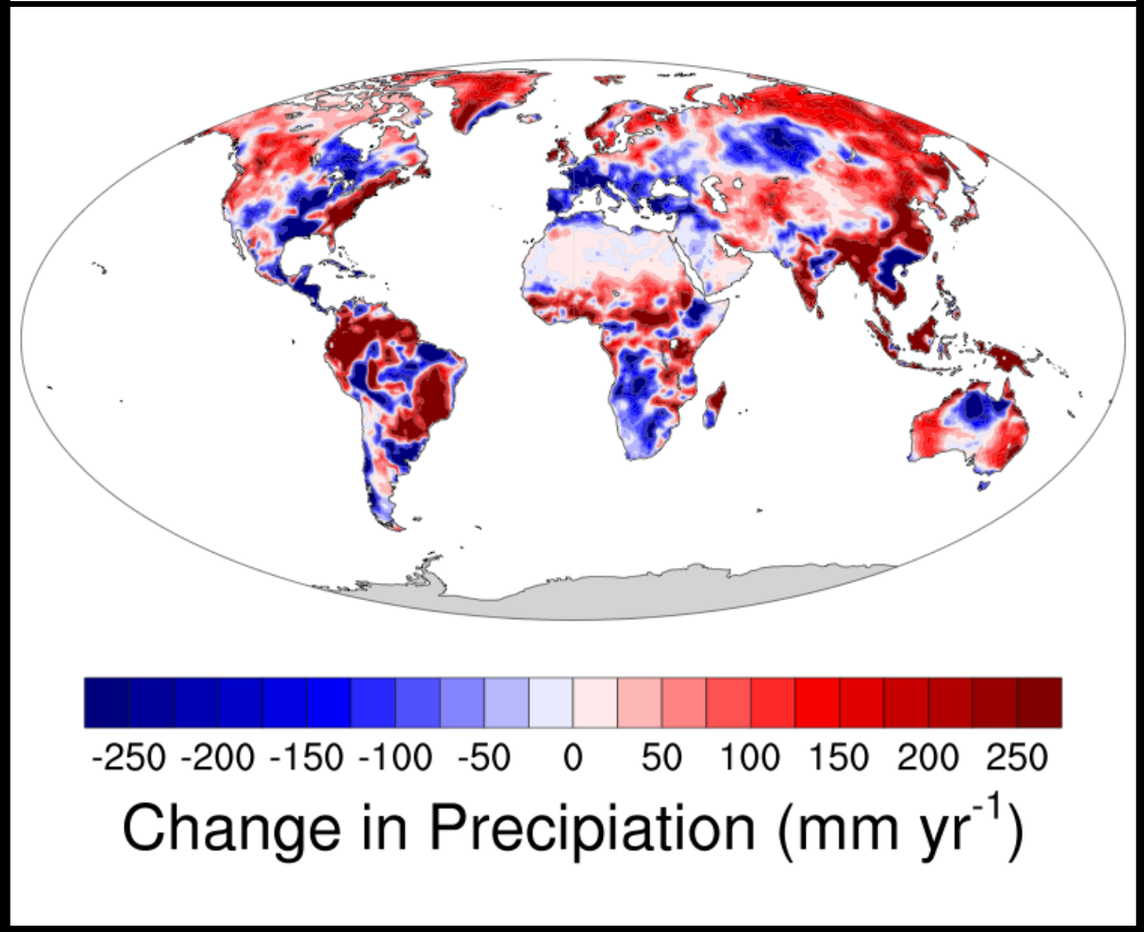
Change in Ozone Concentrations between 2100 and 2006



Change in $[O_3]$ (ppb)

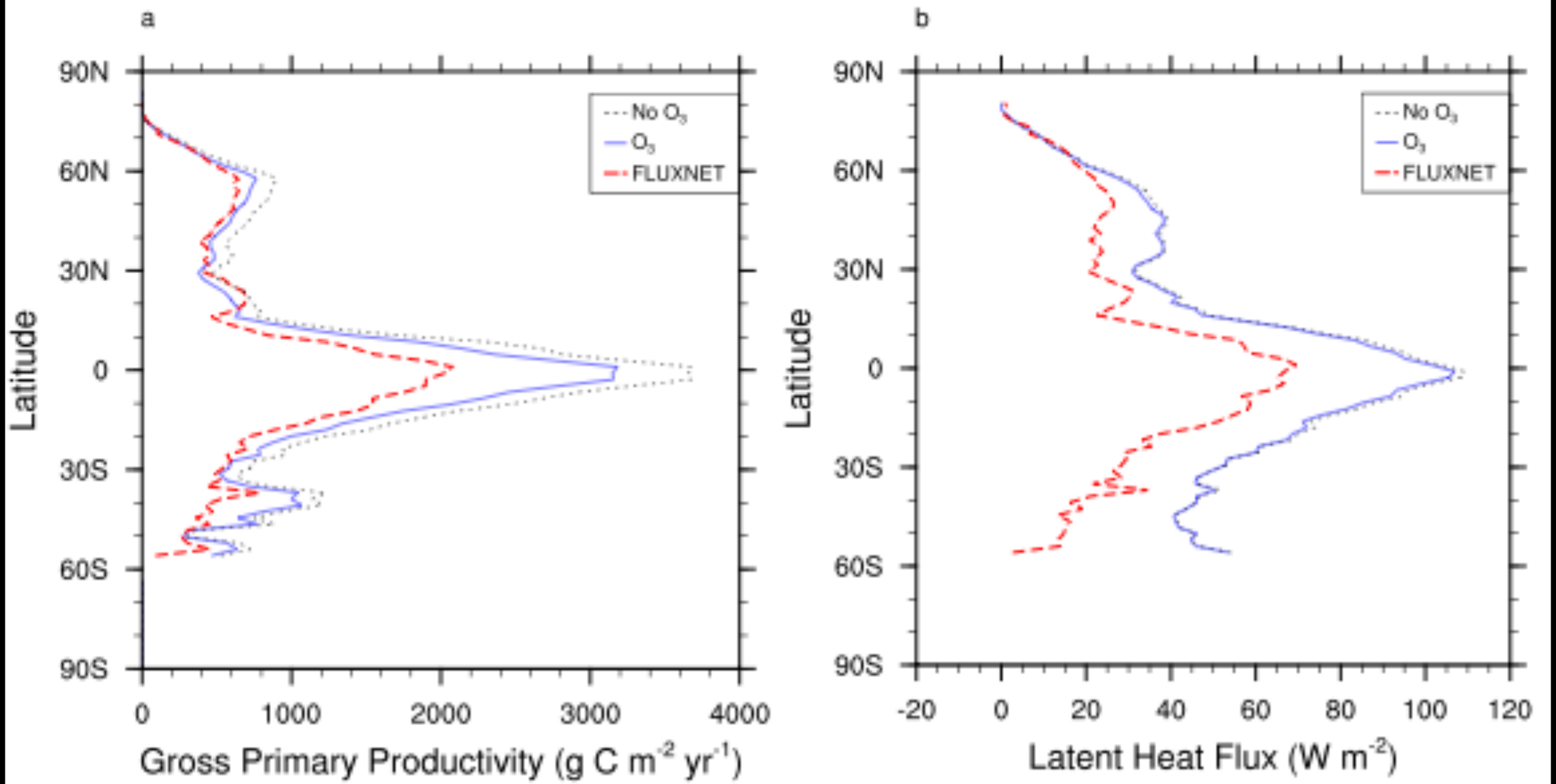
Change = 2100 - 2006 (RCP8.5)





Forcing Impact Calculations	
Climate Change Impact	Constant Forcings - ΔClimate Change
CO_2 Fertilization Impact	ΔCO_2 Fertilization - ΔClimate Change
O_3 Impact	ΔO_3 Change - ΔCO_2 Fertilization
Combined Impact	ΔO_3 Change - Constant Forcings

Comparison of observed vs modeled GPP and LH Flux



Arnold, Lombardozzi et al. *In Prep*

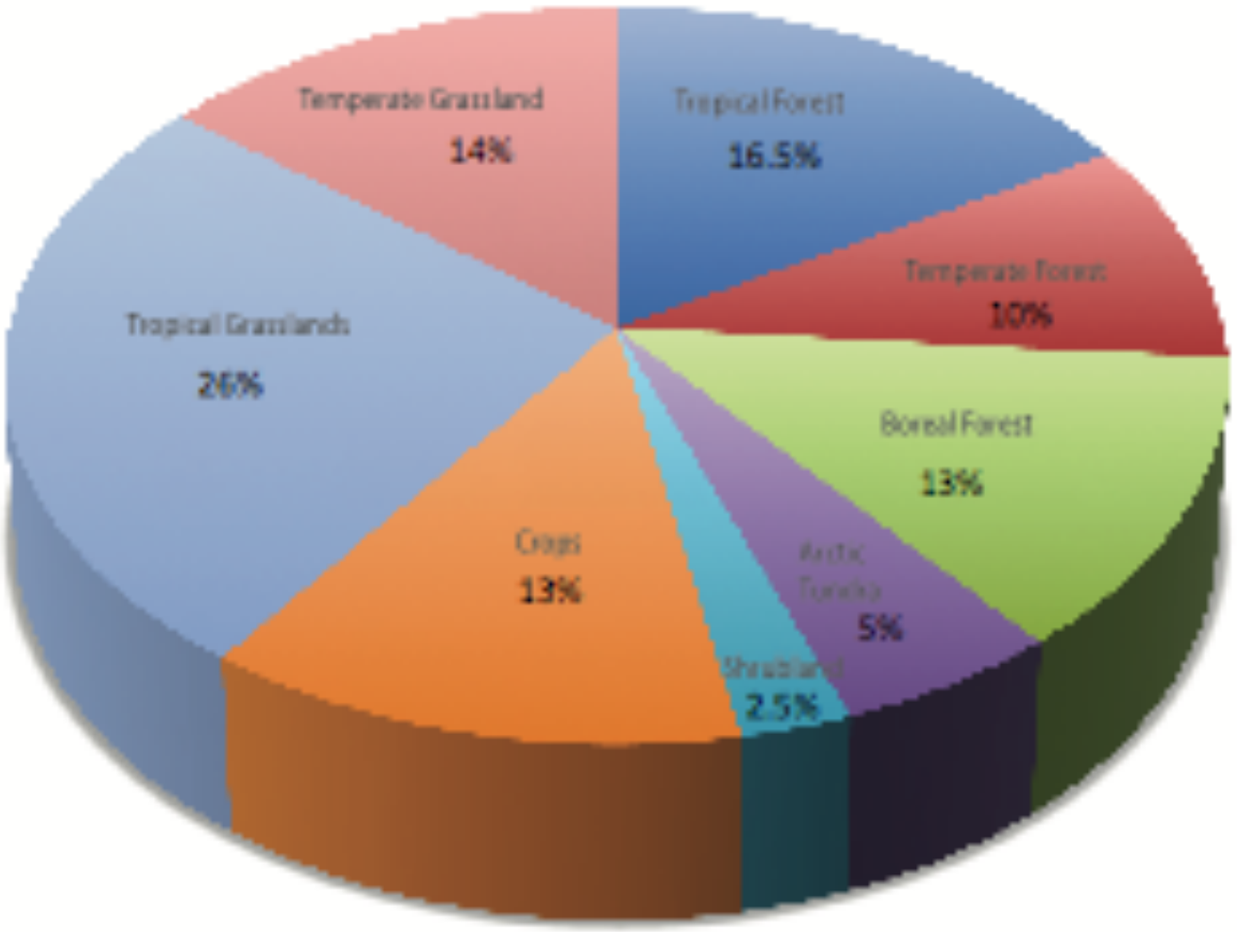
Diana Rypkema, Cornell University (now at Stanford)

Is the response the same for all types of plants?

Browsed >500 manuscripts returned by Web of Science keyword search

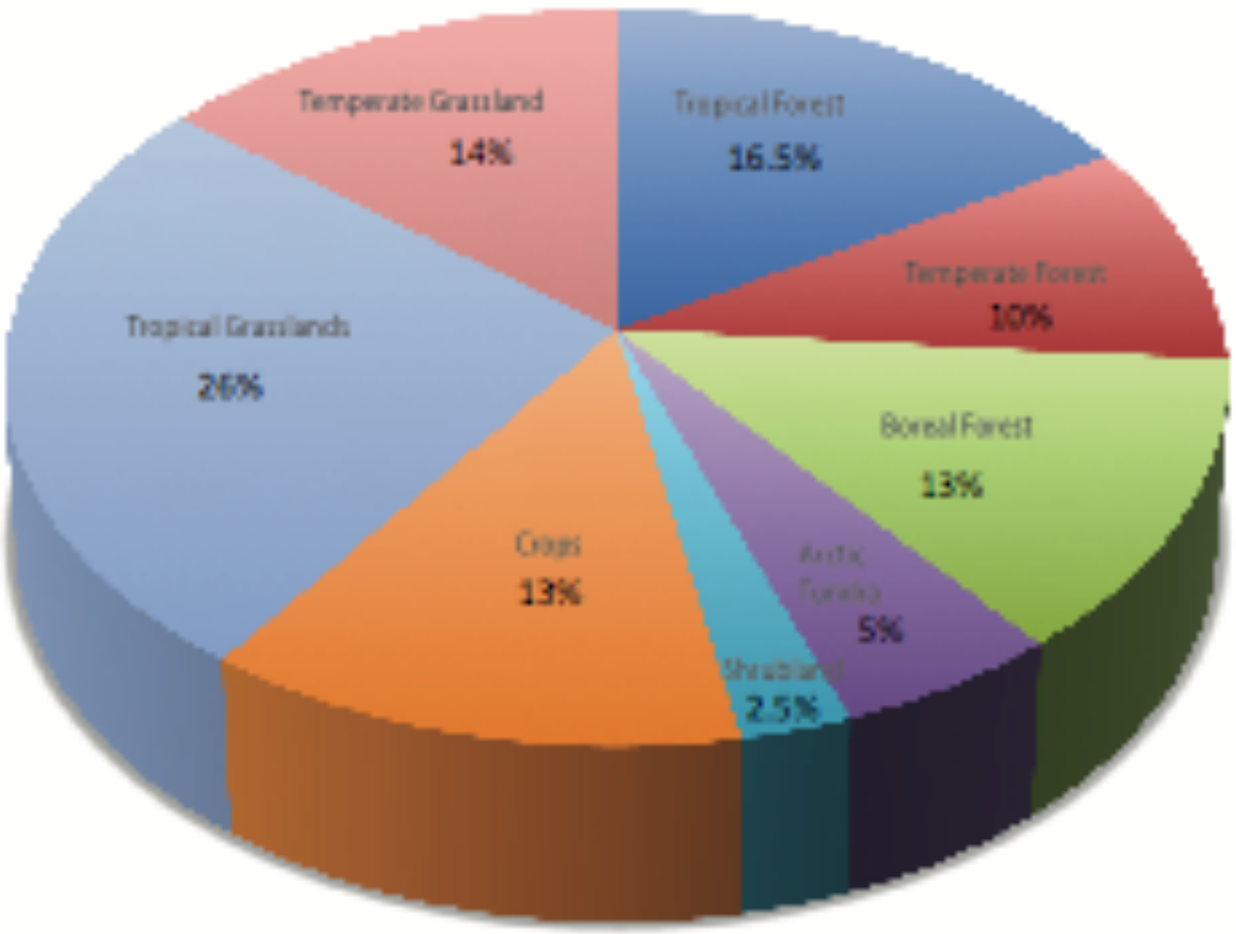
Screened all studies for photosynthesis and stomatal conductance responses

Proportion of Land Area



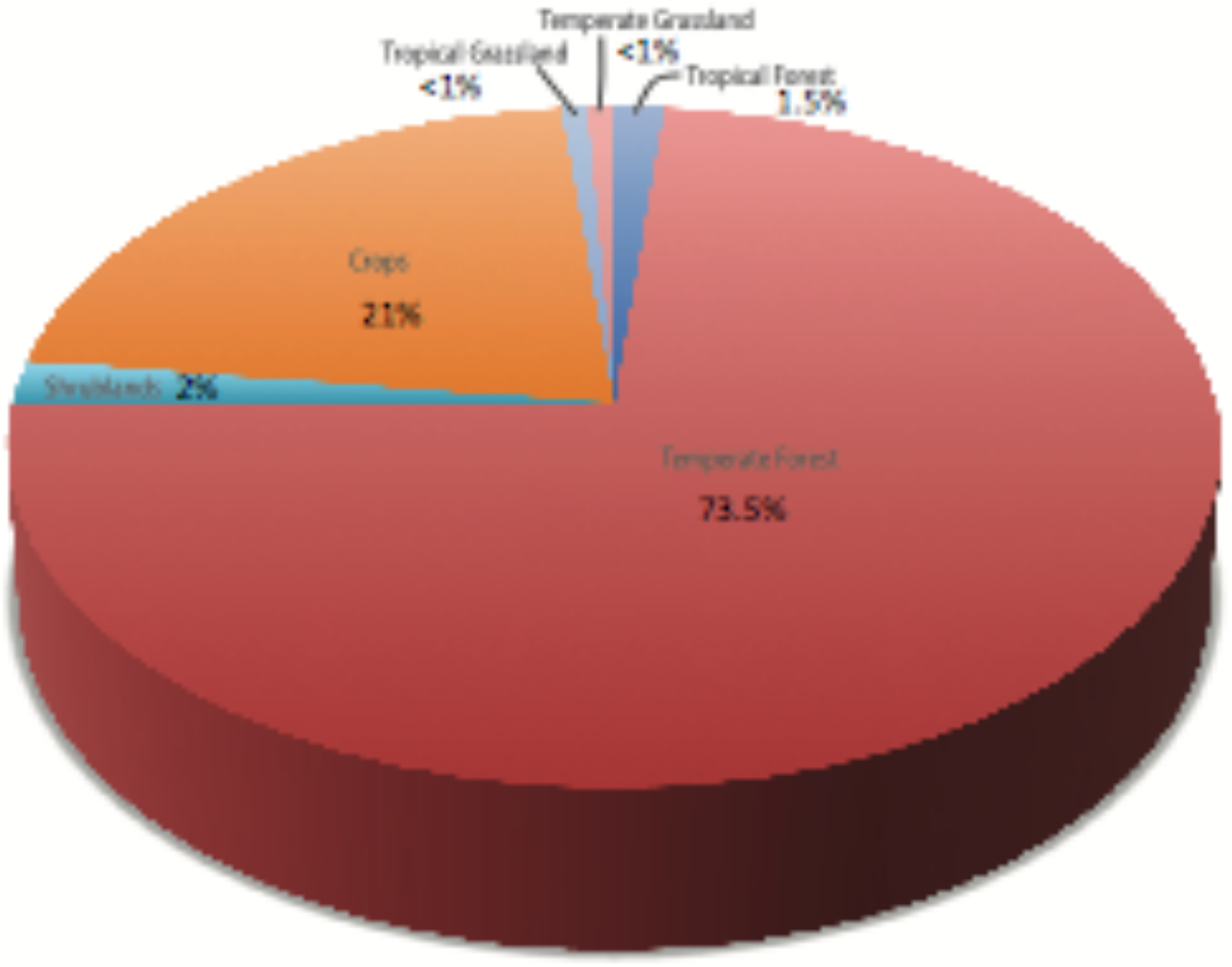
Data from Grace, J. (2004). *Journal of Ecology, 92(2), 189–202.*

Proportion of Land Area



Data from Grace, J. (2004). *Journal of Ecology, 92(2), 189–202.*

Proportion of Available O_3 Response Data

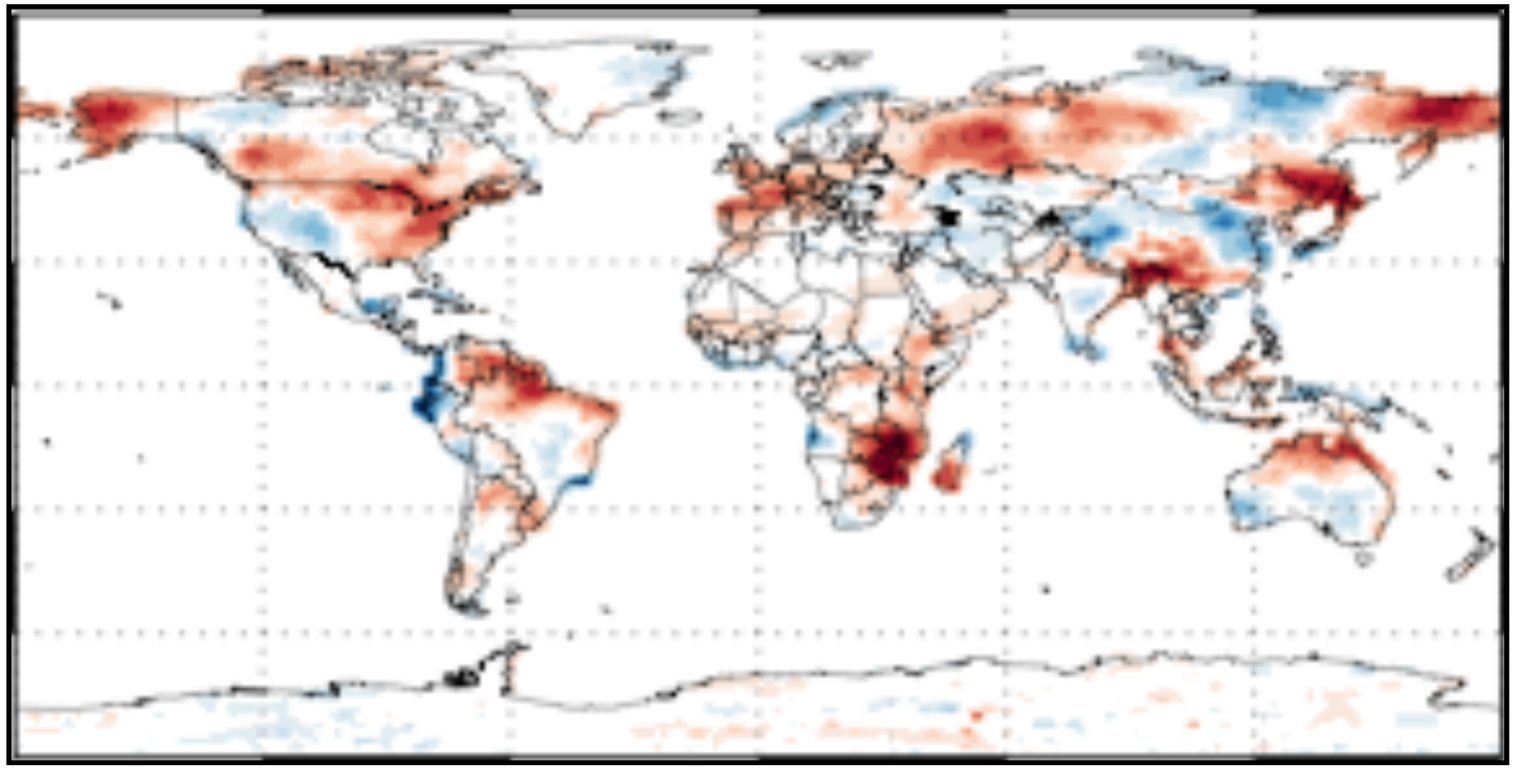


Data from Lombardozzi et al. (2012). *BGS*

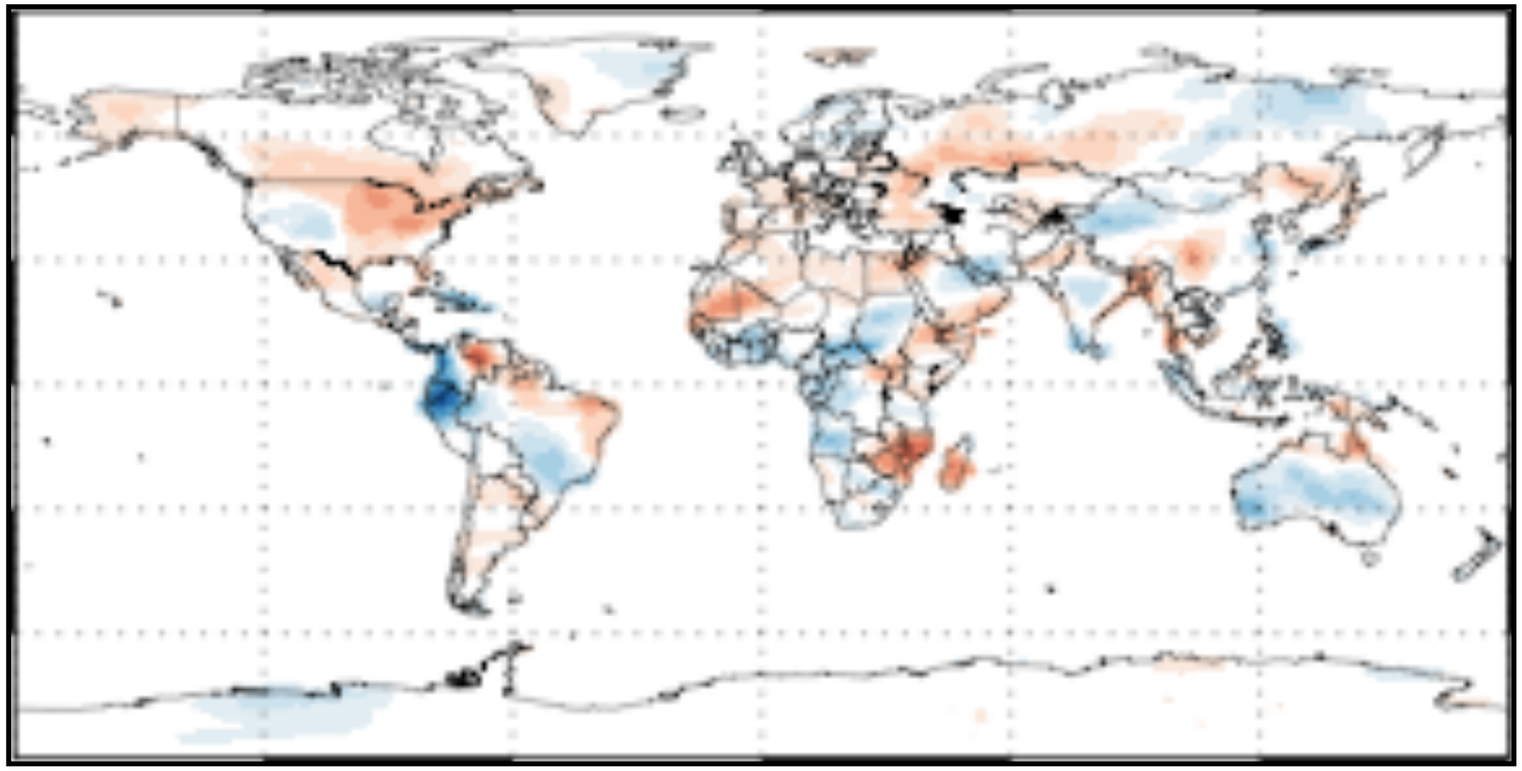
>-10 -8 -6 -4 -2 <-1

Change in WUE due to O_3 (%)

Change in Top of Atmosphere **Shortwave Radiation** due to O_3 ($W\ m^{-2}$)



Change in Top of Atmosphere **Longwave Radiation** due to O_3 ($W\ m^{-2}$)



Arnold, Lombardozzi et al. *In Prep*