

Quantifying Soybean Yield Loss from Satellite-Constrained Ozone Exposure Assessment

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OZONE'S IMPACT ON PLANT GROWTH

- O_3 enters plant leaves through the stomata.
- In plant tissue, O_3 reacts to form toxic byproducts which:
 - Reduces photosynthesis
 - Produces detoxification systems
- Visible symptoms include flecking, stippling, bronzing, and reddening.

Open-Top Chamber used to study ozone impact on plants

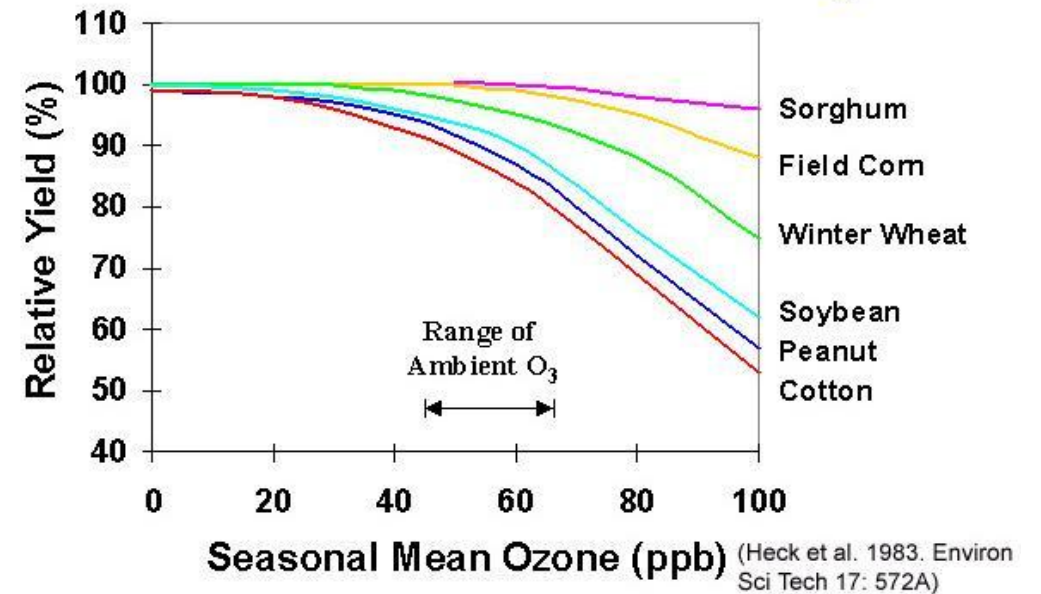
IMPORTANCE OF SOYBEANS & CROP EXPOSURE EFFECTS

U.S. is the world's leading soybean producer and second-leading exporter

Soybeans makeup 90% of U.S. oilseed production

Soybeans are among the most sensitive crops to O₃ exposures

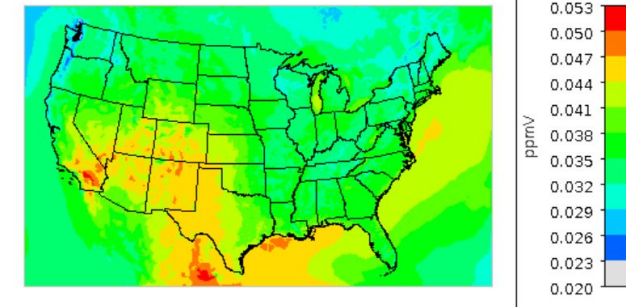
Effect of O₃ on Yield of Crops



EMISSION CHANGES CAUSED BY COVID-19

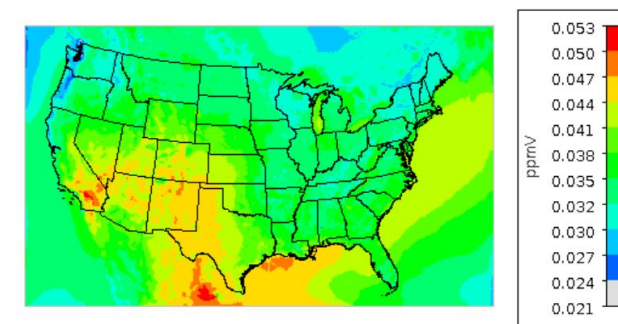
- O_3 changes derived from the differences between two scenarios: the business-as-usual (BAU) case and the COVID-19 (C19) case.
- **BAU Scenario:**
 - Emission data from National Emission Inventory 2014 version 2 (NEIv2) projected onto “would-be” 2020 level.
- **C19 Scenario:**
 - Fused observed NO_2 trends using OMI NO_2 and EPA monitors from 2014 to 2020 represent the actual emission level under pandemic conditions (Tong et al., 2016)
- Emission data after adjustment are used to drive the CMAQ air quality model to calculate the ground-level O_3 levels under each scenario (Campbell et al., 2021)

BAU Scenario



May-June 2020
Min = 0.020, Max = 0.053

C19 Scenario



May-June 2020
Min = 0.021, Max = 0.053

EXAMINATION OF SOYBEAN CROP EXPOSURE TO OZONE

$$AOT40(ppmV\ hr^{-1}) = \sum_{i=1}^n [C_{O_3} - 0.04]_i \text{ for } C_{O_3} \geq 0.04ppm$$

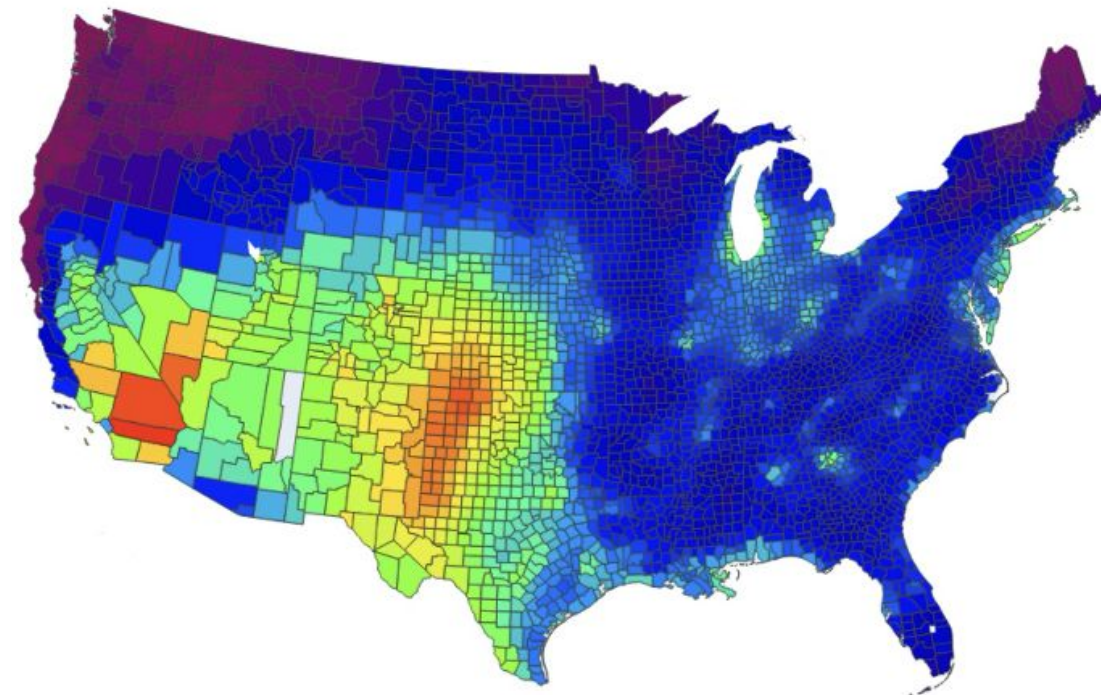
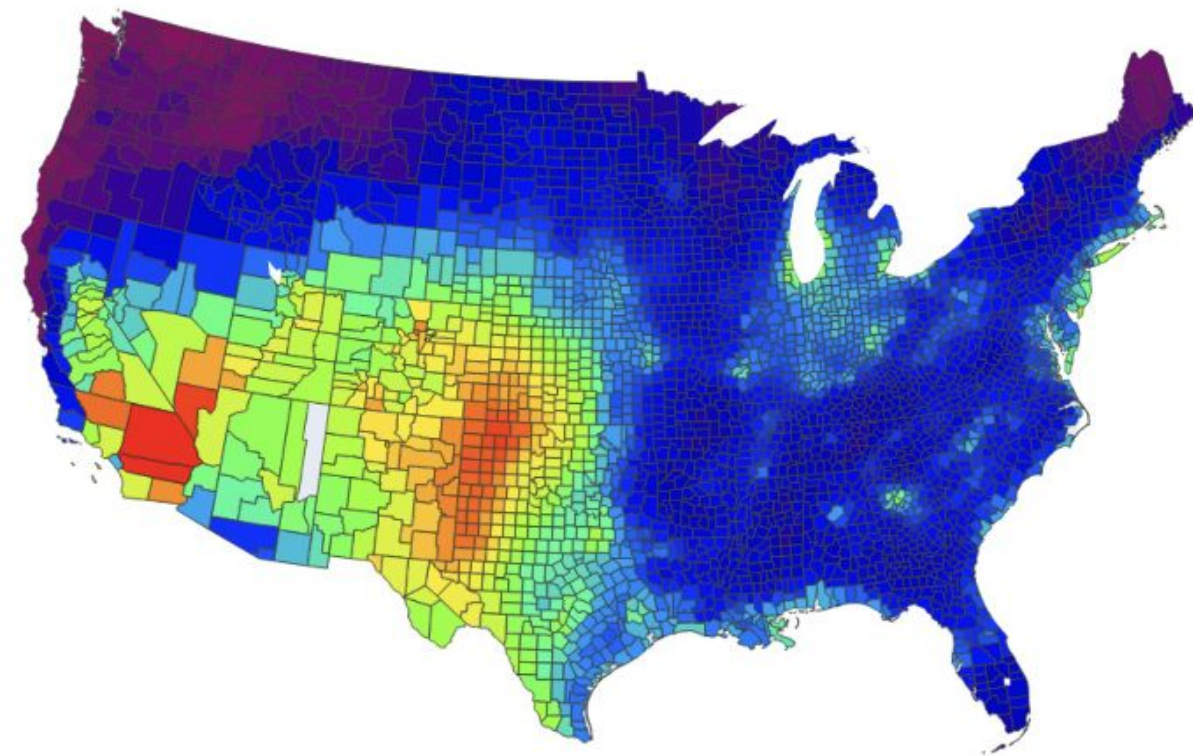
- Calculated using **cumulative** exposure index AOT40 ([Tong et al., 2007](#)):
 - Utilize previously derived hourly O_3 concentrations
 - Accumulated over three-month period (May-July 2020)
 - Grid-based indices are converted into county-level averages

COUNTY-LEVEL OZONE EXPOSURES

BAU Scenario

C19 Scenario

AOT_{40}
(ppmV hr^{-1})

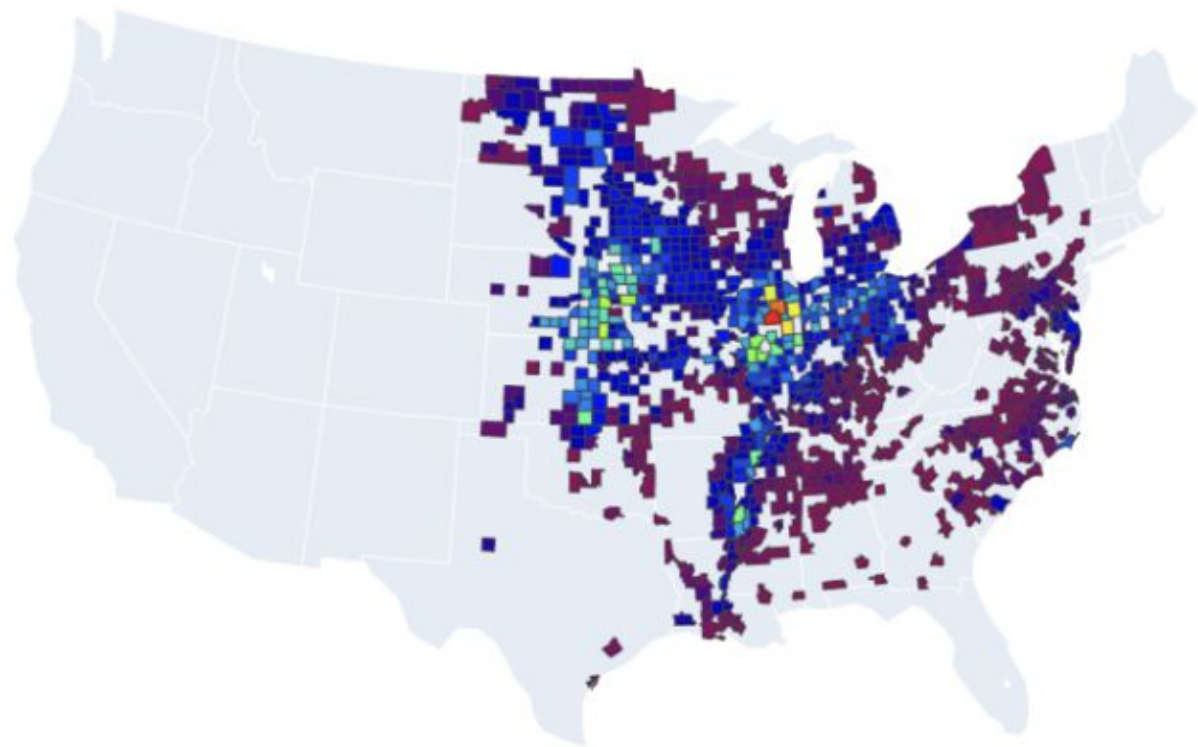


ACTUAL YIELD LOSS

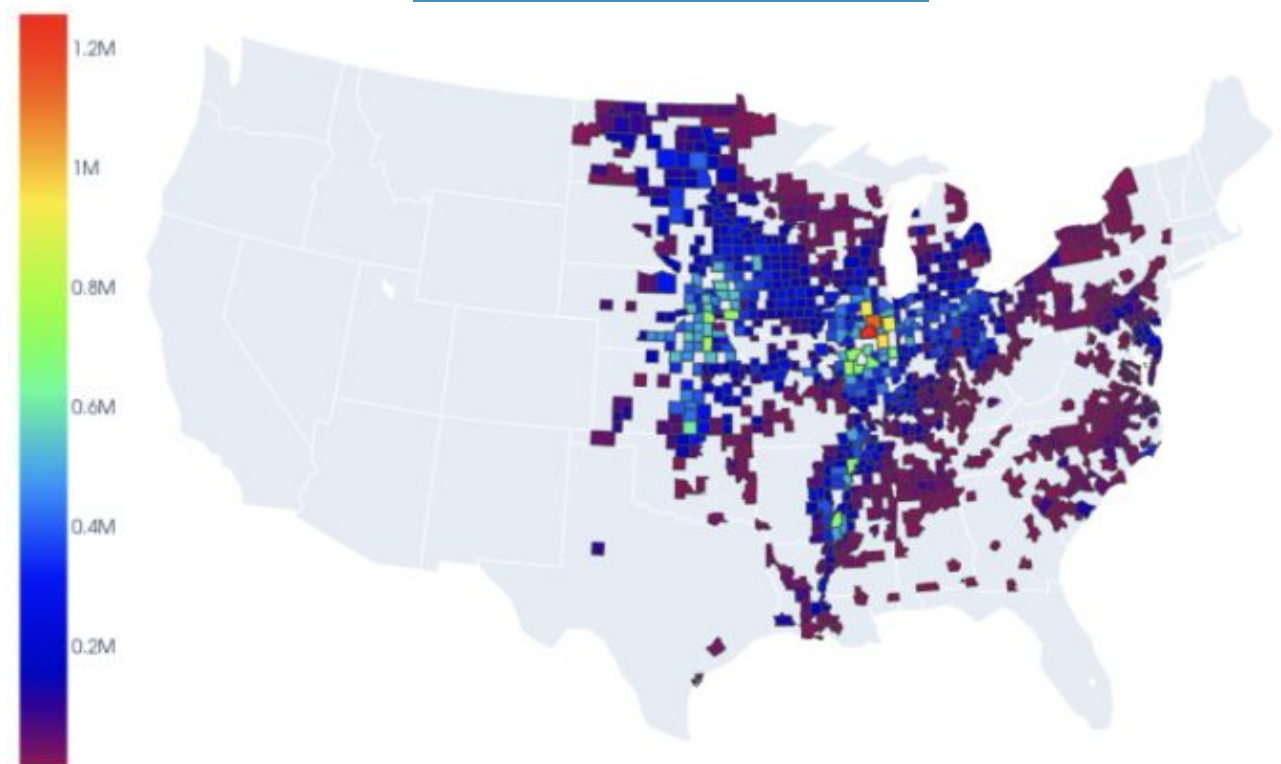
Relative yield loss (RYL) due to O_3 exposure: $RYL \text{ (ppmvhr}^{-1}\text{)} = a \times AOT40$

Constant $a = 0.0113$ is determined from Dingenen et al. (2009)

BAU Scenario



CI9 Scenario



SUMMARY OF YIELD LOSS CHANGES & PRODUCTION EFFECTS

Yield Loss Changes

	BAU	C19
Total Yield Loss (Bushels)	164.5 Million	165.1 Million
U.S. Soybean Yield Loss (%)	5.87	5.89
Difference in Losses (%)	-	0.02

Production Effects

U.S. Soybean Price Per Bushel (as of August 21 st , 2020)	\$9.01
BAU Production Loss	\$1,482.2M
C19 Production Loss	\$1,486.9M
Production loss from COVID-19	\$4.7M

(Christopoulos et al., 2023)



CONCLUSIONS

Satellite constrained air quality forecasts to assess crop yield loss

Crop Exposure Changes during COVID-19

- Highest exposures in Southwest U.S.
- Increases in exposures under COVID-19 in Mississippi River Valley and southeast U.S.; Decreases in Midwest

Yield Loss and Production Effects:

- US soybean yield losses from O₃ exposure: \$1.5B USD/yr
- Minimal yield loss from COVID-19: ~ \$4 million USD

Reference

- Tong, D., et al., (2007). *Atmospheric Environment*, 41(38), 8772-8784.
- Tong, D. et al., (2016). *Geophysical Research Letters*, 43(17), 9280-9288
- Campbell et al., (2021). *Atmospheric Environment* 264, 118713.
- Christopoulos, Julianna, et al. (2023): *Scientific Reports* 13.1: 12574.