Effects of ozone on crop production in Asia

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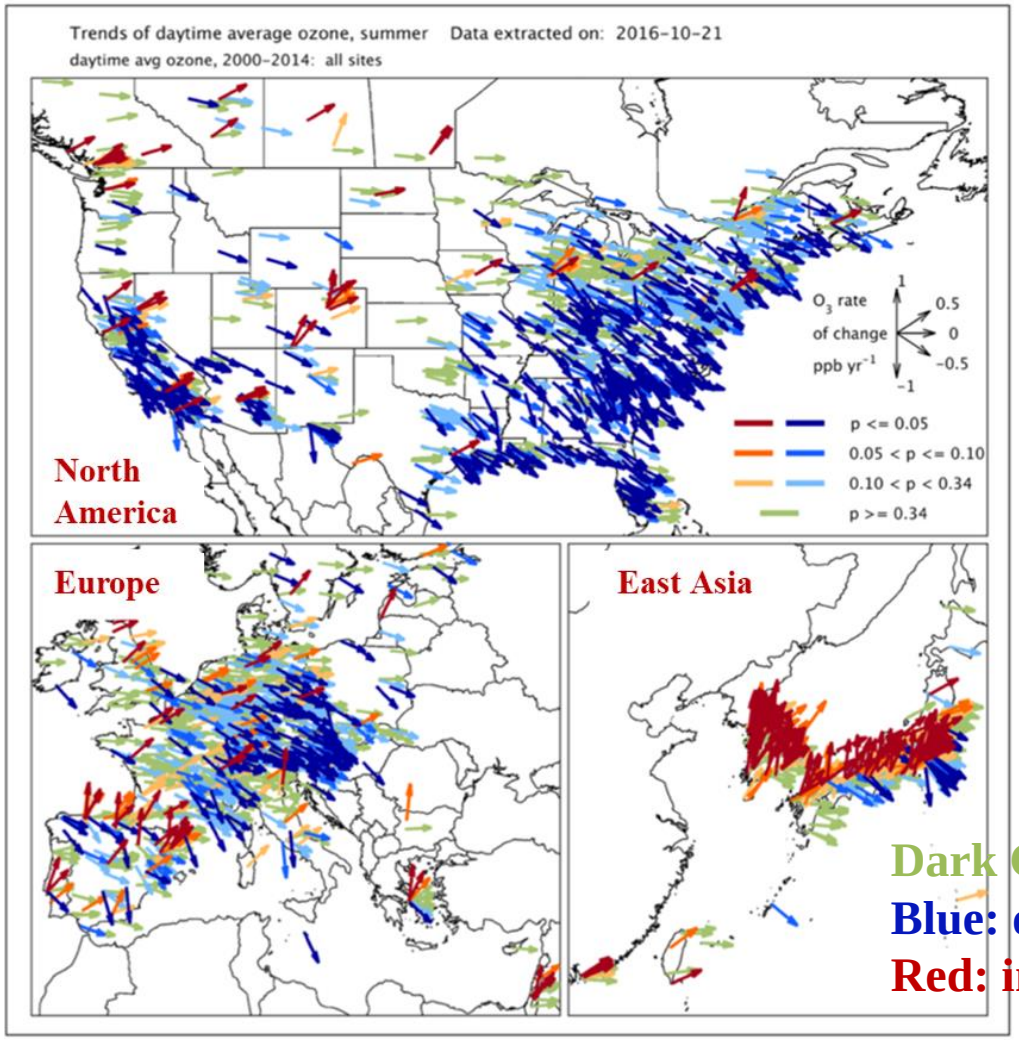
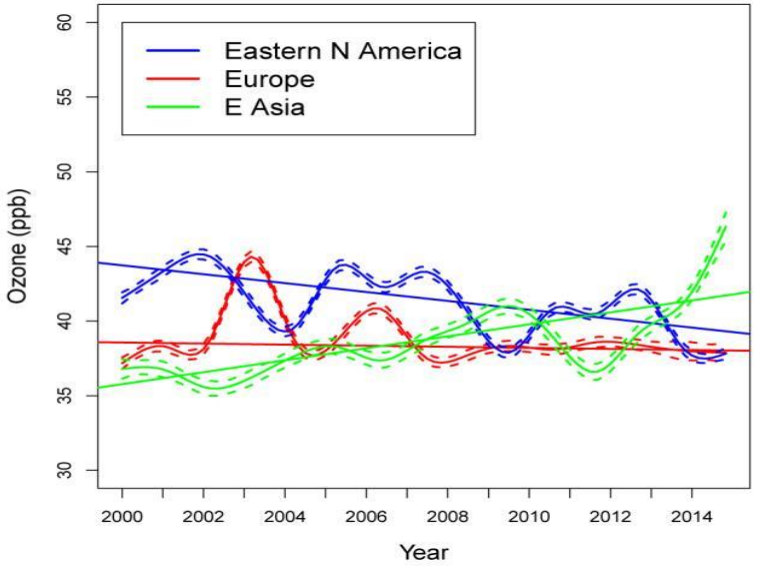
31 October 2022

The trend of surface O_3 concentrations at global scale

Database: TOAR (April-Sep.) during 2000-2014



East Asia increase significantly



Dark Green: no change

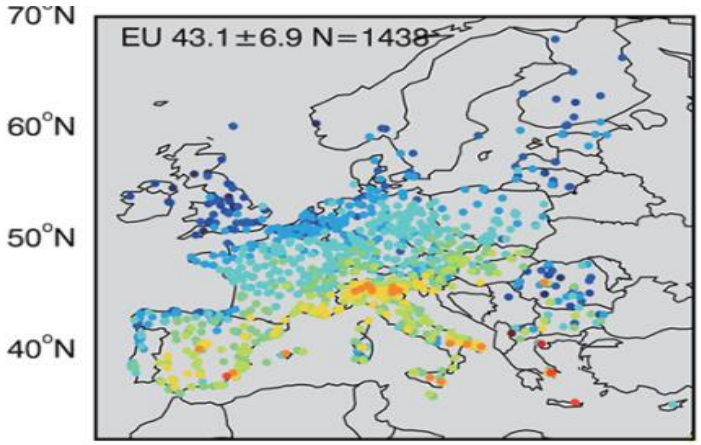
Blue: decrease

Red: increase

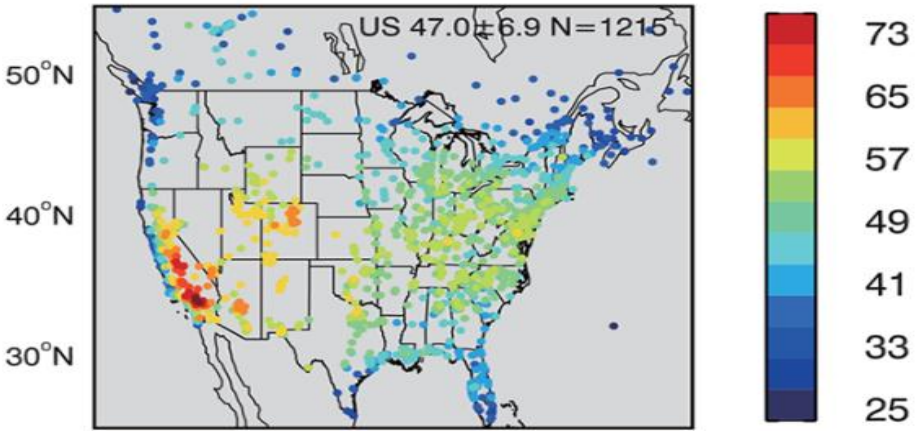
Chang et al., 2017, Elem Sci Anth

Comparison of AVGMDA8 between East Asia and other regions

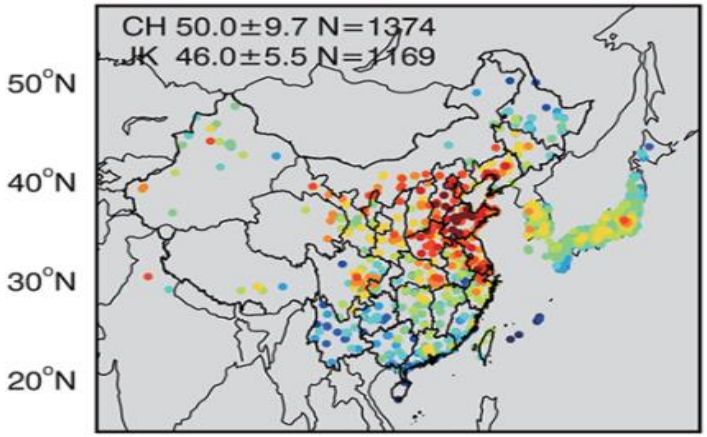
Europe



the United States



East Asia



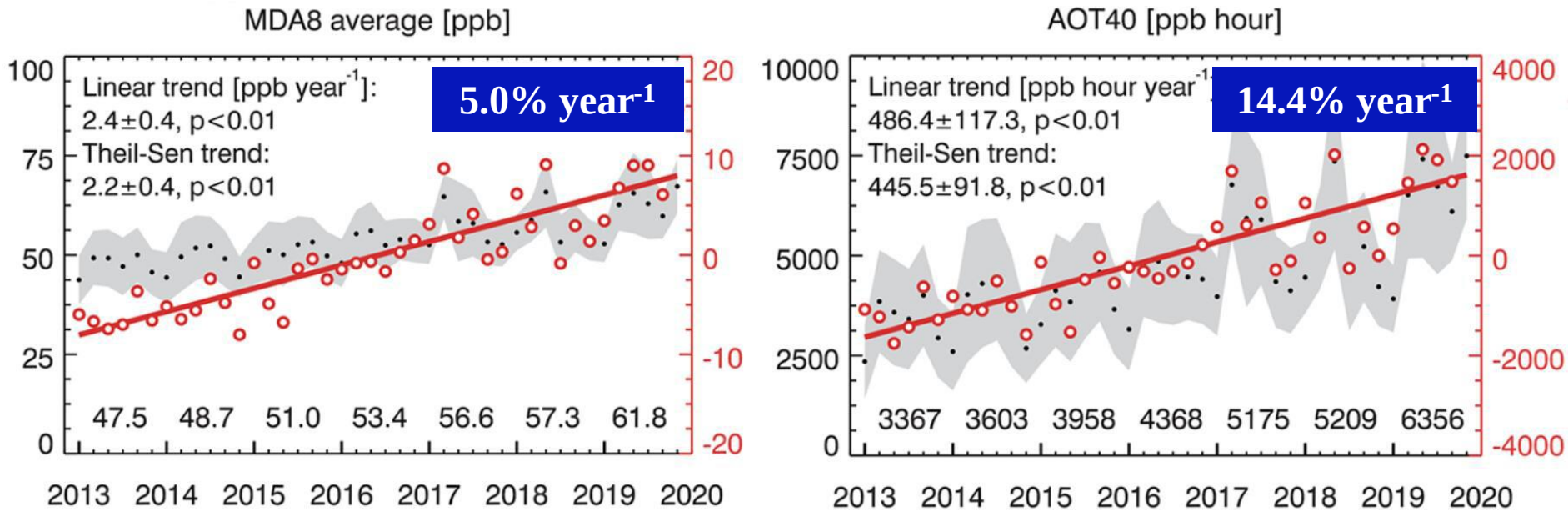
AVGMDA8 (the mean of the daily maximum 8 h average from Apr.-Sep.)

USA: 47.0 ppb Europe: 43.1 ppb
Japan: 46.0 ppb China: 50.0 ppb

Lu et al., 2020

The trend of surface O_3 concentrations in China

Time series of the average of MDA8 (left) and AOT40 (right) from April−September 2013−2019 at 243 Chinese ozone monitoring sites

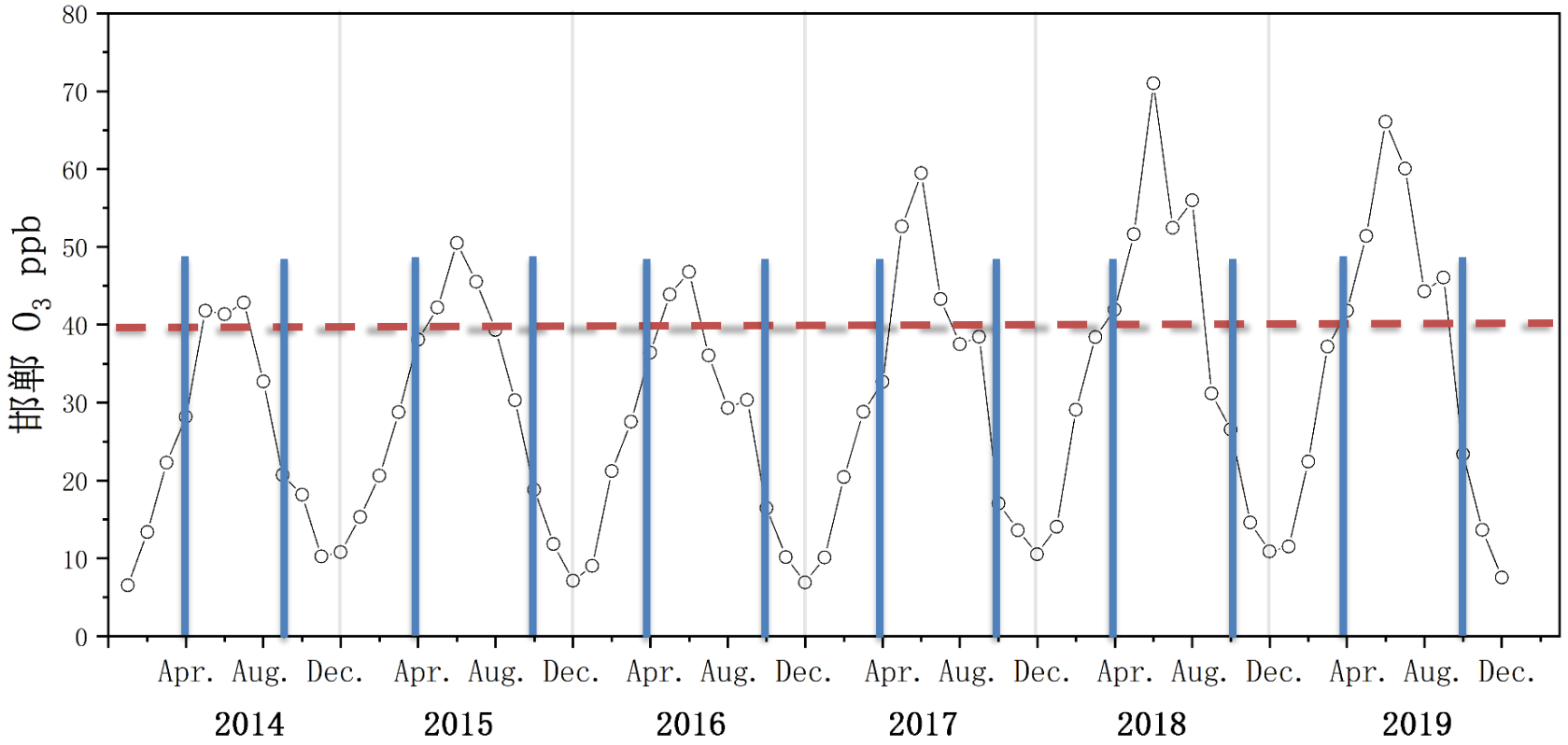


- The April−September mean MDA8 increase by 2.4 ppb $year^{-1}$ (5.0%), with more than 90% of the sites showing positive trends.
- AOT40 values have been increasing at rates of 14.4 $year^{-1}$ from 2013−2019.

Lu et al., 2020

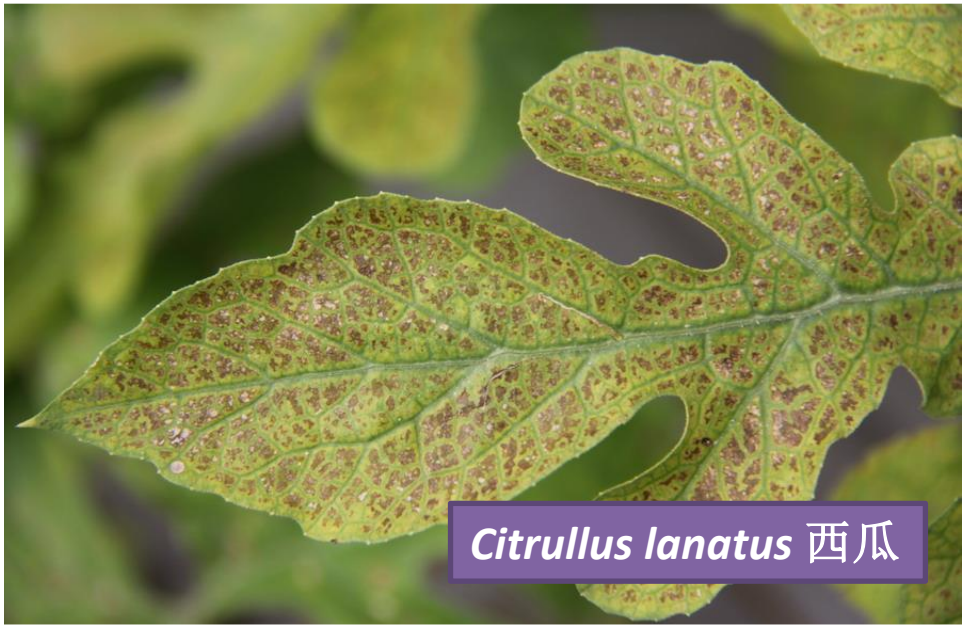
Seasonal variation of surface O_3 concentrations

Handan, Hebei, China



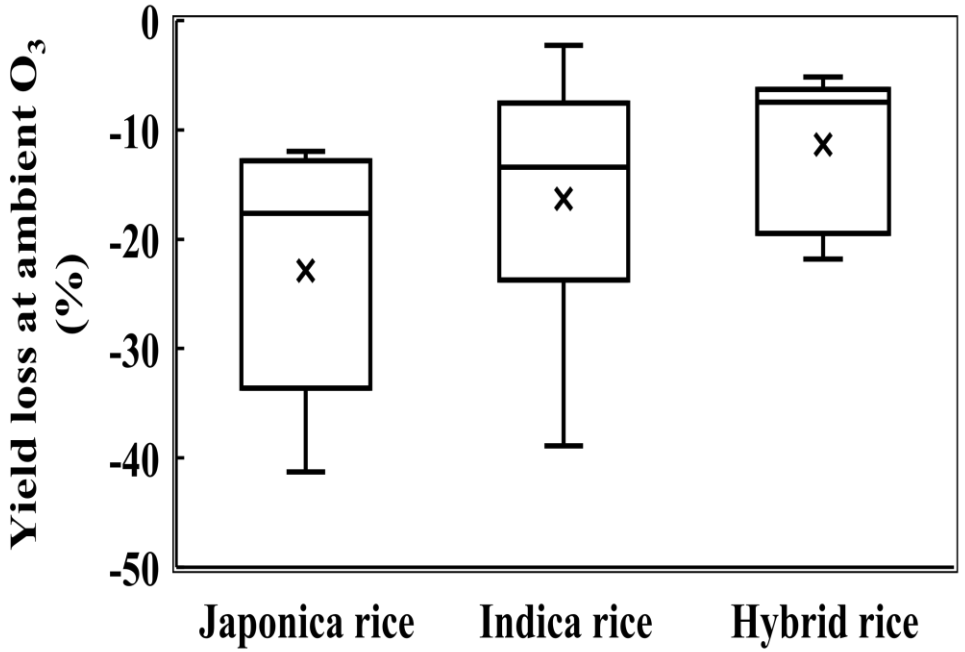
- **Strong seasonal fluctuation in monthly-mean daytime ozone concentrations is observed.**
- **High [O_3] occurs mainly in Apr.-Sep, which coincides with the main crop growth season.**

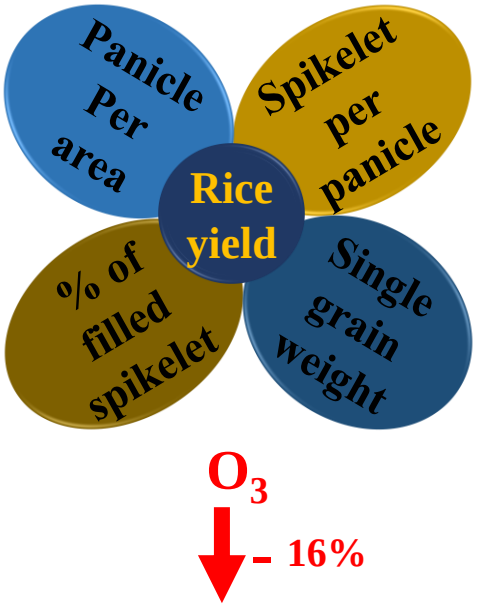
Ozone symptoms in horticultural plants



Leaf senescence of wheat

Effects of ambient ozone on hybrid cultivars of rice in YRD



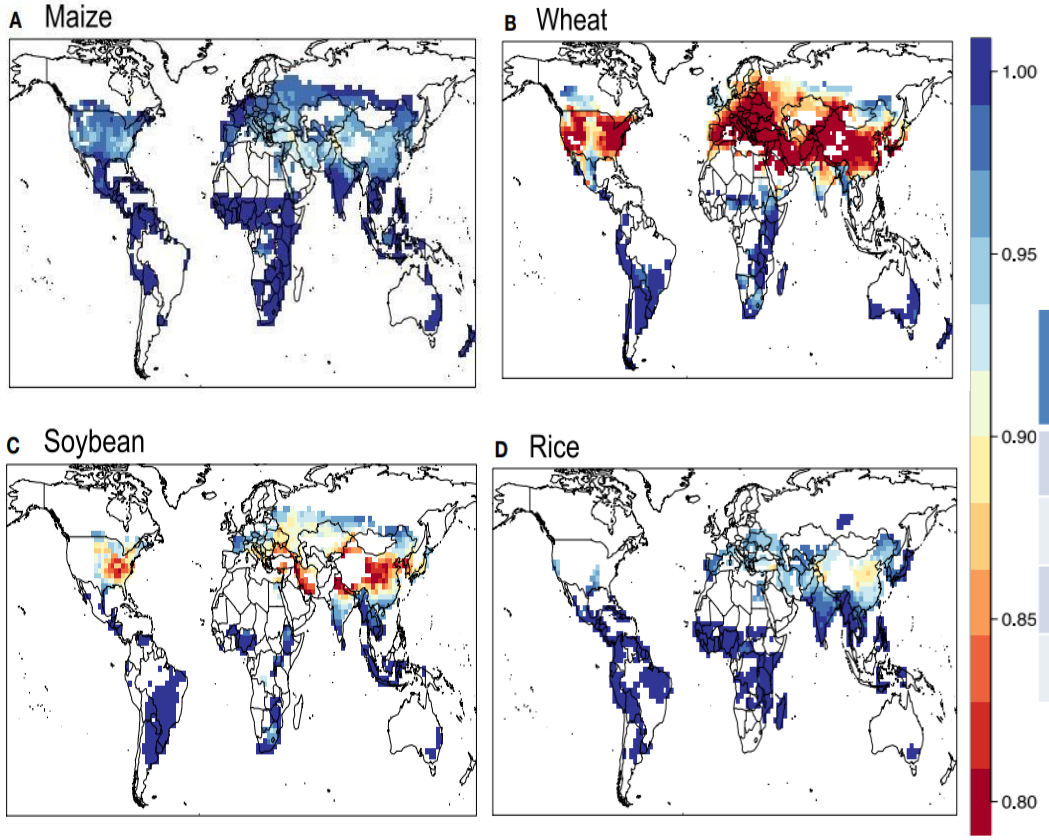


The experiment was conducted in YRD, and the daytime 12-h mean O_3 concentration was 45.9ppb

- The yield of rice was significantly increased by EDU (450 ppm), with the average 19% increase.

Zhanget al., ESPR, 2021

Yield loss by O_3 pollution



Relative yield based on the AOT40 metric for (A) maize, (B) wheat, (C) soybean, and (D) rice.

O_3 pollution significantly decreased crop yields

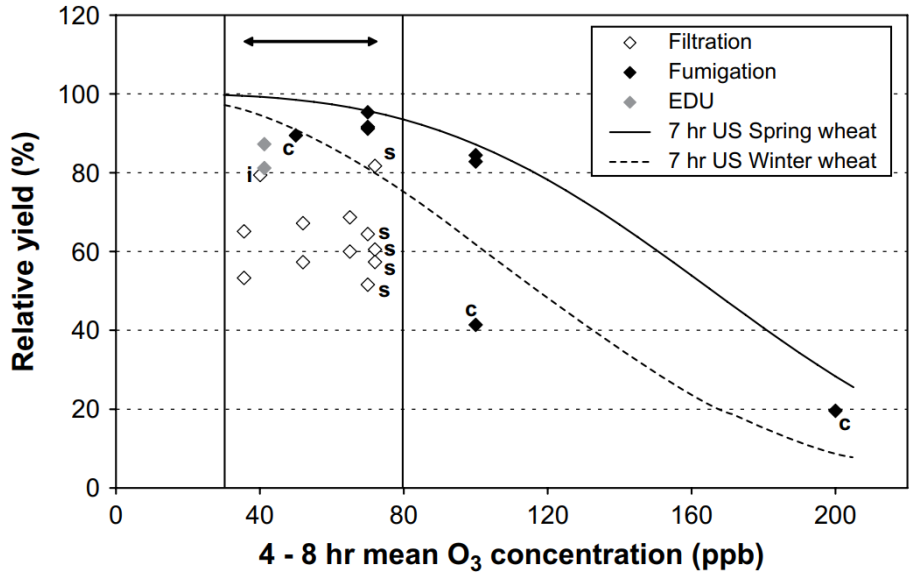
Crop variety	the global average	the national average (China)
Maize	3.6±1.1%	1.8~6.4%
Rice	2.6±0.8%	5.2~18.4%
Soybean	6.7±4.1%	5.3~18.9%
Wheat	7.2±7.3%	10.5~37.3%

Simulated [O_3]

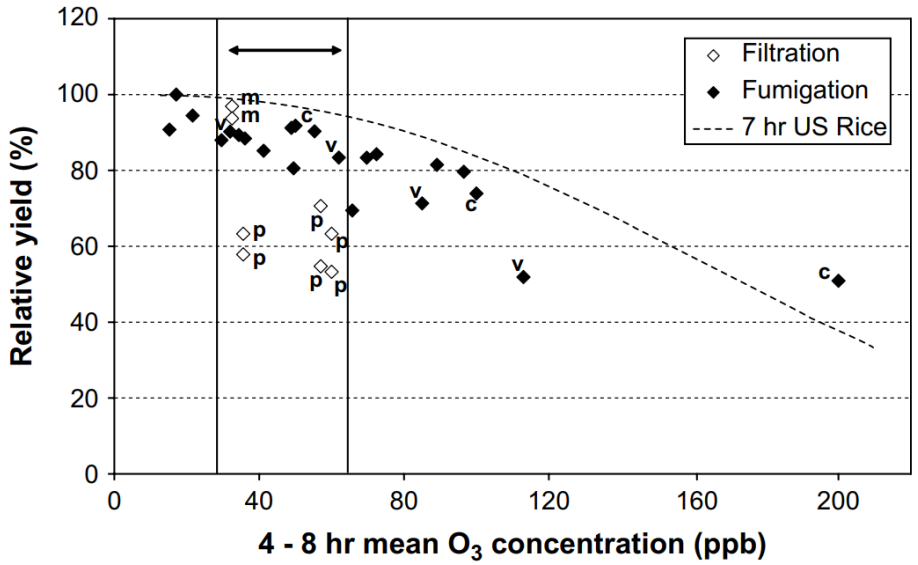
Difference in Assessment model, approach, Ozone data source

Feng et al., Atmos. Environ, 2019; Feng et al., Environ Int, 2019; Tai et al., 2021; Feng et al., Sci Total Environ, 2020; Hu et al., Environ Pollut, 2020

Asian wheat and rice are more sensitive to O_3 than US



Wheat



Rice

Emberson et al., Atmos. Environ, 2009

Hypotheses and objectives

Hypotheses：

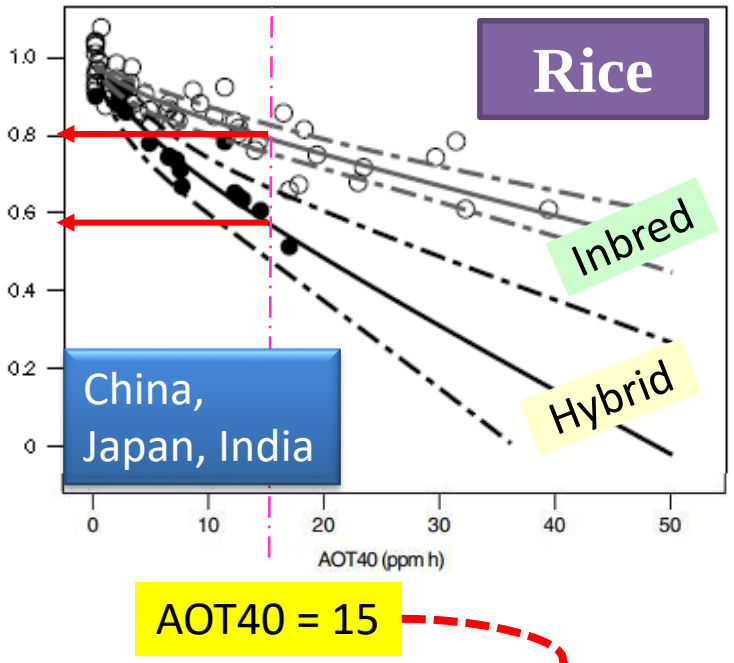
- ✓ **The existing O_3 risk assessments have underestimated the crop yield loss in Asia.**
- ✓ **The crop yield loss is better estimated by using ozone monitoring data than the model outputs.**

Objectives:

- **To buildup the O_3-dose response relationships based on field experiments in Asia**
- **To reassess the ozone-induced yield loss and economic loss**
- **To assess the yield benefits of halving the O_3 dose**

O_3 dose-yield response relationship for rice conducted in Asia

This study



AOT40 = 15

Other studies

Source	Relationship between RY and $AOT40_{dd}$ or M7	R^2	Yield loss at 15 ppm h AOT40 relative to that at zero AOT40
Olszyk et al. (1988)	$RY=\exp(-M7/2016)^{2.474}/\exp(-25/2016)^{2.474}$	-	3%
Mills et al. (2007)	$RY=0.94(1-0.0041*AOT40_{90})$	0.20	6%
Mills et al. (2018)	$RY=0.99(1-0.002*M7)$	0.35	6%
Sinha et al. (2015)	$RY=0.95(1-0.105*AOT40_{90})$	0.89	16%

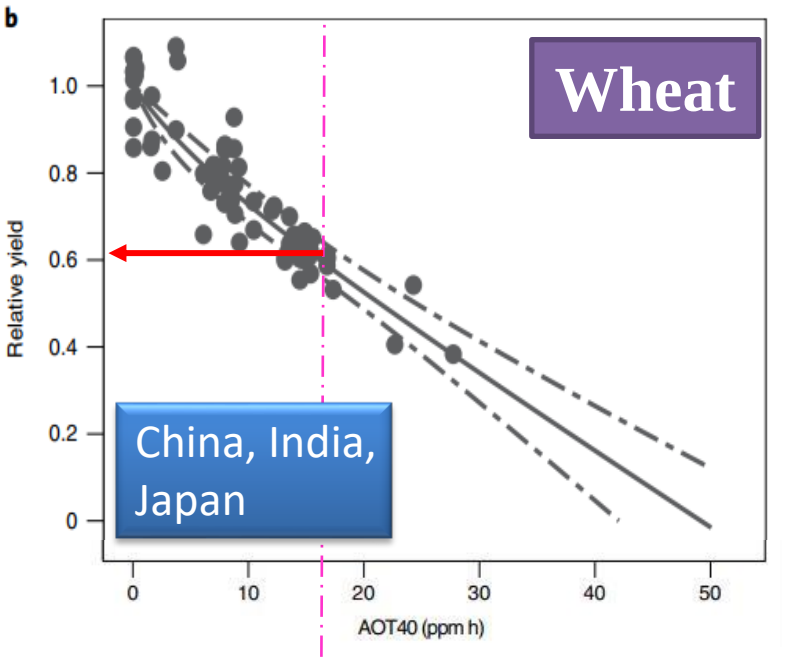
This study: 19% for inbred rice, 42% for hybrid rice

$$RY= \{1 - S [AOT40_{90} + (40 - x) * 1.08 - (20.22 - 0.01264x^2)/ (1 + 0.207\ AOT40_{90} - 0.0001293x^2\ AOT40_{90}]\} / [1- S (22.98 - 1.08\ x + 0.01264\ x^2)]$$

S= 0.0071 [0.0055, 0.0094] for inbred cultivars,
S= 0.0145 [0.0096, 0.0234] for hybrid cultivars,
x= 19.4 [4.6, 34.8] for both inbreds and hybrids.

O_3 dose-yield response relationship for wheat conducted in Asia

This study



AOT40 = 15

Other studies

Source	Relationship between RY and $AOT40_{dd}$ or M7	R^2	Yield loss at 15 ppm h AOT40 relative to that at zero AOT40
Lesser et al. (1988)	$RY=exp(-M7/136)^{2.56}/exp(-25/136)^{2.56}$	-	7%
Mills et al. (2007)	$RY=0.99(1-0.0163*AOT40_{90})$	0.89	24%
Mills et al. (2018)	$RY=0.96(1-0.005*M7)$	0.62	16%
Pleijel et al. (2019)	$RY=0.93(1-0.020*AOT40_{45})$ $RY=0.98(1-0.024*AOT40_{45})$ $RY=1.01(1-0.014*AOT40_{45})$	0.52 0.77 0.51	18% 22% 13%
Pleijel et al. (2021)	$RY=0.98(1-0.039*AOT40_{45})$	0.76	35%
Sinha et al. (2015)	$RY=1.01(1-0.026*AOT40_{90})$	0.68	39%

This study: 38%

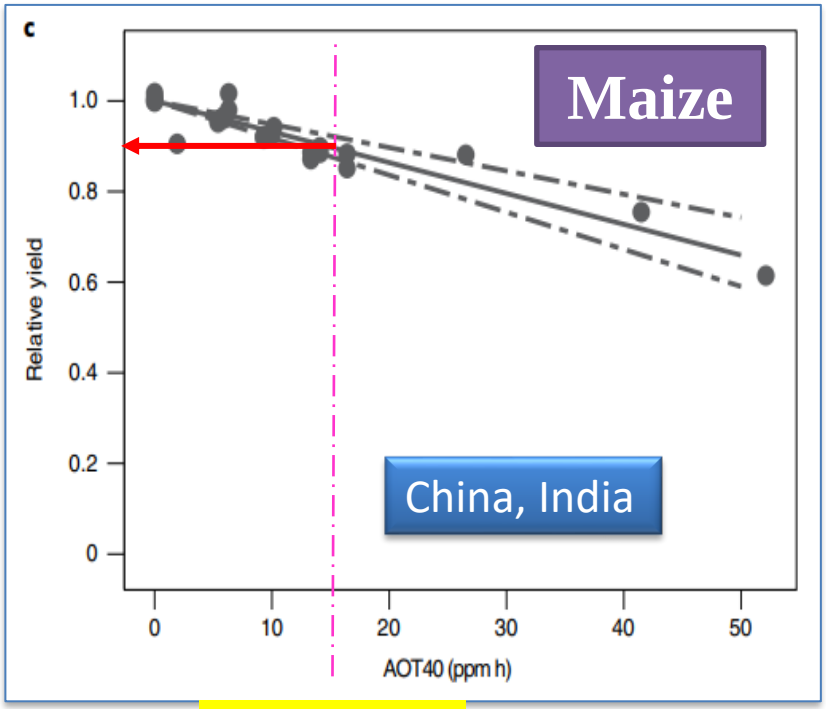
$$RY = \{1 - S\,[A040_{90} + (40 - x) * 1.08 - (20.22 - 0.01264\,x2) / (1 + 0.207\,AOT40_{90} - 0.0001293\,x2\,AOT40_{90})]\} / [1 - S\,(22.98 - 1.08\,x + 0.01264\,x2)],$$

$$S = 0.0161\ [0.0130, 0.0236];$$

$$x = 26.5\ [18.6, 39.9]$$

O_3 dose-yield response relationship for maize conducted in Asia

This study



AOT40 = 15

Other studies

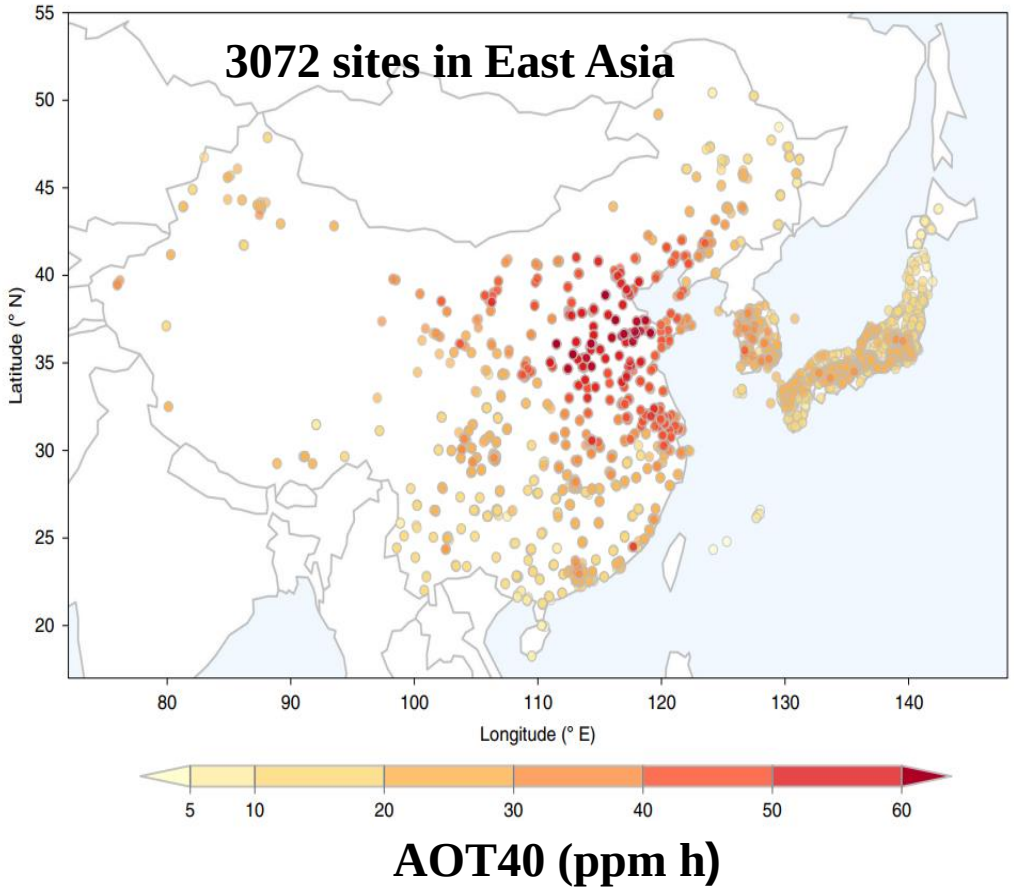
Source	Relationship between RY and $AOT40_{dd}$ or M7	R^2	Yield loss at 15 ppm h AOT40 relative to that at zero AOT40
Lesser et al. (1990)	$RY=exp(-M7/124)^{2.83}/exp(-25/124)^{2.83}$	-	7%
Mills et al. (2007)	$RY=1.02(1-0.0035*AOT40_{90})$	0.35	5%
Mills et al. (2018)	$RY=1.03(1-0.003*M7)$	0.62	9%

This study: 10%

$$RY= \{1 - S [AOT40_{90} + (40 - x) * 1.08 - (20.22 - 0.01264\ x2)/ (1 + 0.207\ AOT40_{90} - 0.0001293\ x2\ AOT40_{90})]\} / [1- S (22.98 - 1.08\ x + 0.01264\ x2)]$$

$$S= 0.0068\ [0.0052, 0.0082] \text{ and } x= 40.0\ [40.0, 40.0]$$

O_3 levels across East Asia (1 April to 30 Sep.)



Number of O_3 monitoring sites in Asian countries included in this study.

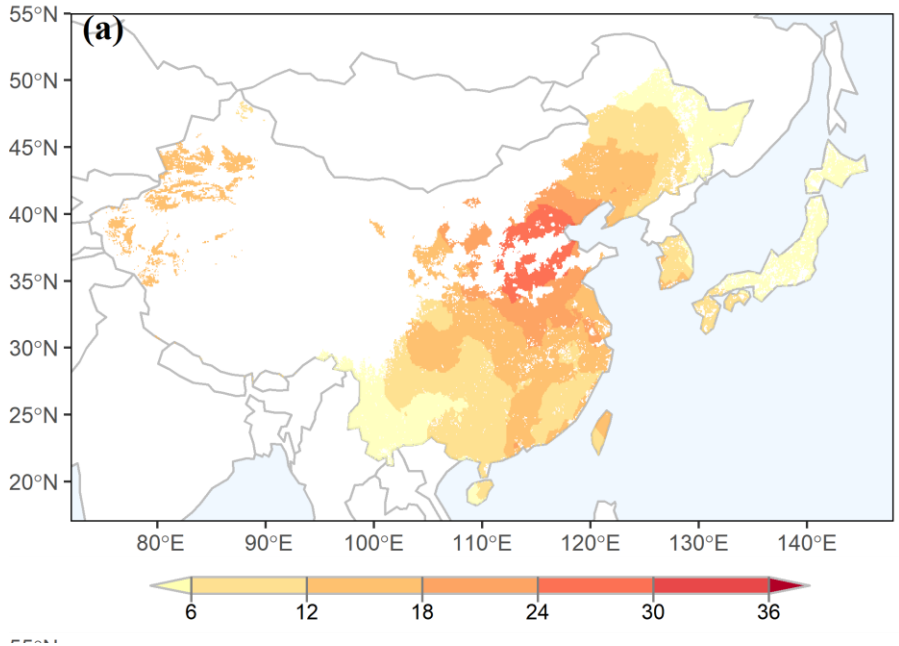
	2015	2016	2017	2018	2019
China			1430	1470	1451
Japan	830	871	1166		
S Korea		312	308	312	

China: 30.9 ppm h
Japan: 17.5 ppm h
S Korea: 21.2 ppm h

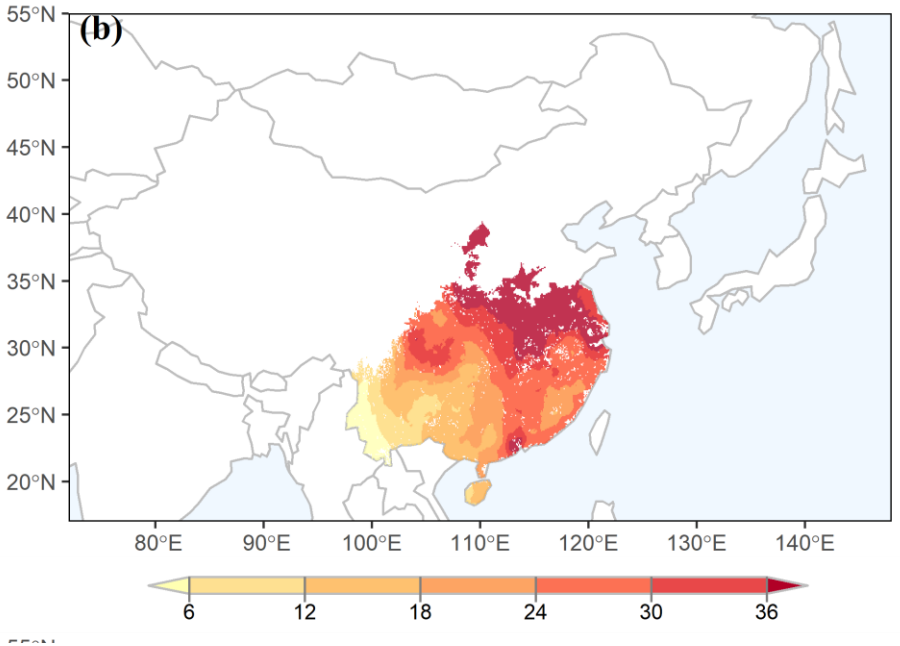
- ✓ **The fraction >5 ppm h (AOT40) was highest in China (99.4%), with a high AOT40 >50 ppm h located in North China Plain.**
- ✓ **China, South Korea and Japan had much higher values than did the United States (15.7ppm h) and Europe (11.1ppm h)**

RYLs distribution for Rice in China, Japan and S Korea

Inbred rice



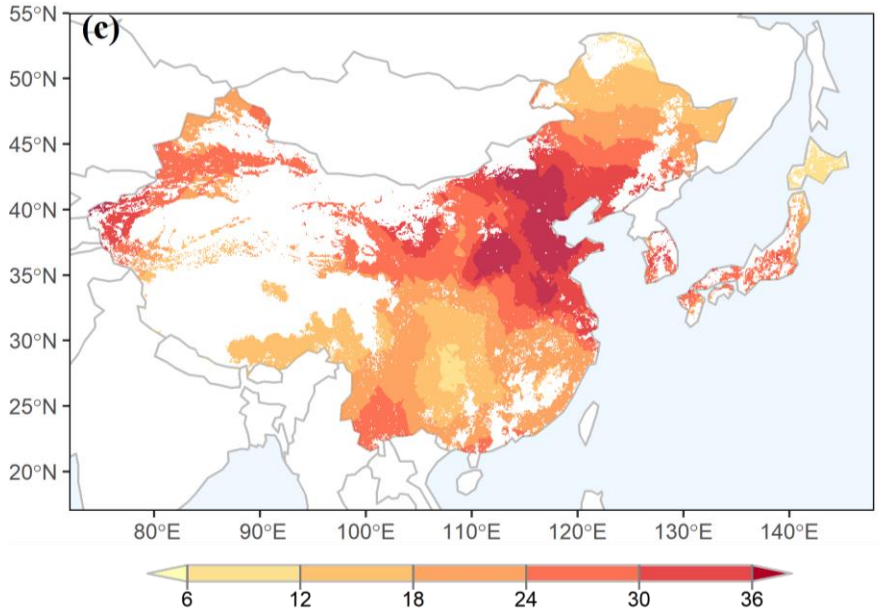
Hybrid rice



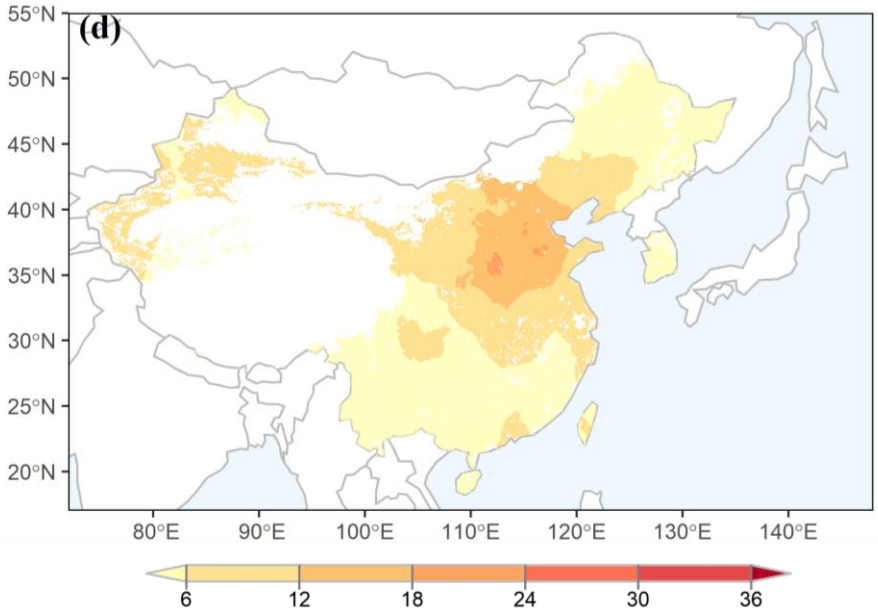
- ✓ **For inbred rice, maximum RYL is in the North China Plain, and tends to decline toward northeast and southwest of China.**
- ✓ **For hybrid rice, the RYL exceeds 35% in the northernmost part of its planting areas in the middle to the south of China .**
- ✓ **RYL ranges between 25 and 30% when early and late-double crops are combined for those double rice cropping.**

RYL distribution for wheat & maize in China, Japan and S Korea

Wheat

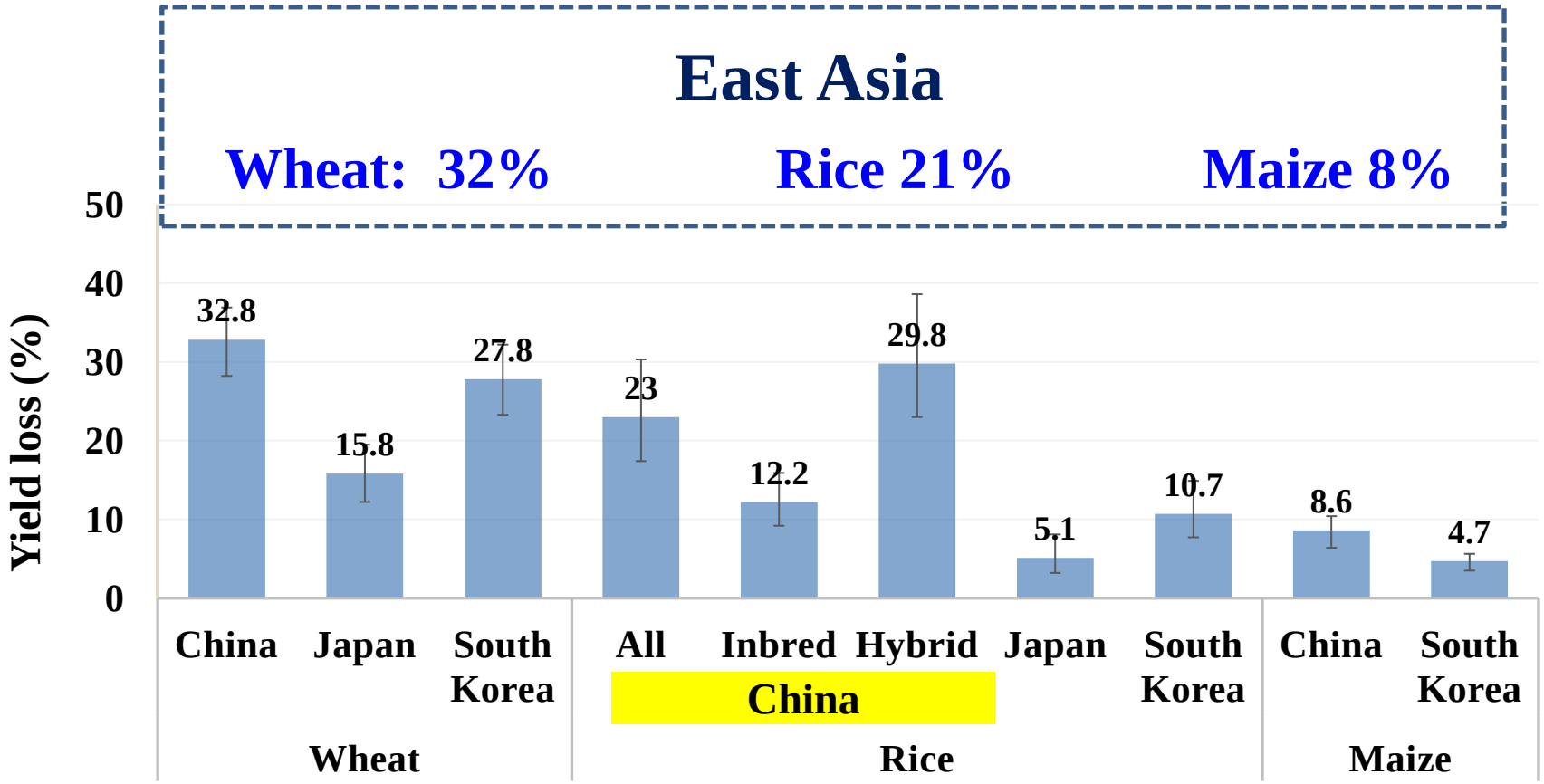


Maize



- ✓ **For wheat, the RYL is much larger than any other crops, and it exceeds 35% across the North China Plain, where the AOT40 reaches 15 ppm h;**
- ✓ **For maize, the distribution pattern of RYL is similar to that of wheat with a peak in the North China Plain and declines toward northeast and southwest, while the level of RYL is much lower.**

Relative yield loss of each crop in China, Japan and South Korea



✓ **The relative yield loss in the figure was weight-averaged across each country by the production amount in each province (China and South Korea) or prefecture (Japan).**

Production loss and economic loss due to ozone in China, Japan and S Korea.

Crop	Country	Production loss (tonnes)		Economic loss (USD)	
		Mean	95% confidence	Mean	95% confidence
Wheat	China	**6.17×10^{7}**	$4.97\text{-}7.39\times10^{7}$	**2.18×10^{10}**	$1.76\text{-}2.61\times10^{10}$
	Japan	**1.54×10^{5}**	$1.14\text{-}1.98\times10^{5}$	**4.65×10^{7}**	$3.45\text{-}6.00\times10^{7}$
	South Korea	**1.31×10^{4}**	$1.03\text{-}1.61\times10^{4}$	**1.16×10^{7}**	$0.91\text{-}1.43\times10^{7}$
	Total	**62 Mt**		**22 B**	
Rice	China	**6.15×10^{7}**	$4.36\text{-}8.95\times10^{7}$	**3.08×10^{10}**	$2.18\text{-}4.48\times10^{10}$
	Japan	**5.82×10^{5}**	$3.55\text{-}9.49\times10^{5}$	**1.18×10^{9}**	$0.72\text{-}1.92\times10^{9}$
	South Korea	**6.45×10^{5}**	$4.46\text{-}9.37\times10^{5}$	**1.08×10^{9}**	$0.74\text{-}1.56\times10^{9}$
	Total	63 Mt		33 B	
Maize	China	**2.27×10^{7}**	$1.66\text{-}2.80\times10^{7}$	**7.81×10^{9}**	$5.73\text{-}9.66\times10^{9}$
	South Korea	**3.65×10^{3}**	$2.73\text{-}4.44\times10^{3}$	**2.40×10^{6}**	$1.79\text{-}2.92\times10^{6}$
	Total	23Mt		7.8 B	

The production value in each country was averaged across three years (2016, 2017 and 2018) from FAO statistics

Estimated increase of crop production by halving AOT40

Crop	Country	Estimated production loss (tonne) [a]		Estimated production increase by halving AOT40		
		Current AO40	Halved AOT40	Amount (tonne)	Fraction of production	Fraction of supply
Wheat	China	6.17×10^7	3.54×10^7	2.63×10^7	20%	21%
	Japan	1.54×10^5	8.56×10^4	6.84×10^4	8%	1%
	South Korea	1.31×10^4	7.45×10^3	5.65×10^3	17%	0.1%
Rice	China	6.15×10^7	4.12×10^7	2.03×10^7	9%	10%
	Japan	5.82×10^5	3.25×10^5	2.57×10^5	3%	2%
	South Korea	6.45×10^5	3.83×10^5	2.62×10^5	5%	4%
Maize	China	2.27×10^7	1.13×10^7	1.14×10^7	4%	4%
	South Korea	3.65×10^3	1.83×10^3	1.82×10^3	2%	0.02%

- ✓ **For wheat, the production gain is substantial, ranging between 20% in China and 8% in Japan. The production gain amounts to 21% of the domestic supply in China.**
- ✓ **For rice, the production gain relative to the supply is 10% in China, 2% in Japan and 4% in South Korea.**

Conclusions

- **The Asia crop-O_3 dose response relationship was built up based on Asian field experiments.**
- **The hybrid rice is more sensitive to O_3 than inbred rice, being close to that for wheat**
- **China shows the highest relative yield loss than Japan and Korea.**
- **Total O_3-induced annual loss of crop production is estimated at US$63 billion.**
- **Crop production can be increase by the maximum by 20% for wheat if the AOT40 is reduced to a half.**
- **We have to take mitigation action for O_3 emission control and adaptive agronomic measures against the rising surface O_3 levels across East Asia.**

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ARTICLES

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Ozone pollution threatens the production of major staple crops in East Asia

Zhaozhong Feng[1,10] ✉, Yansen Xu[1,10], Kazuhiko Kobayashi[2,10] ✉, Lulu Dai[1,3], Tianyi Zhang[4],

Feng et al. Ozone pollution threatens the production of major staple crops in East Asia. **Nature Food**, 2022, 3: 47-56.

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