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*Supplement of*

## **Magnitude, trends, and impacts of ambient long-term ozone exposure in the United States from 2000 to 2015**

**Karl M. Seltzer et al.**

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| Performance Metric                                     | Year | MDA1               | MDA8        | M12               | AOT40            |
|--|------|--------------------|-------------|-------------------|------------------|
|  |      | April – Sept. Avg. | Annual Avg. | July – Sept. Avg. | July – Sept. Sum |
| Mean Bias<br>ppb: MDA1,<br>MDA8, M12<br>ppmh:<br>AOT40 | 2000 | 0.11               | 0.47        | 0.57              | -0.18            |
|  | 2001 | -0.60              | -0.13       | 0.52              | 0.52             |
|  | 2002 | -0.60              | -0.23       | -0.89             | -0.30            |
|  | 2003 | -1.26              | -0.29       | -0.69             | -0.17            |
|  | 2004 | 0.67               | 0.29        | 0.38              | 0.31             |
|  | 2005 | -0.61              | -0.22       | 0.51              | 0.37             |
|  | 2006 | -1.09              | -0.66       | -0.50             | 0.02             |
|  | 2007 | -1.09              | -0.43       | -0.07             | 0.01             |
|  | 2008 | -0.98              | -0.18       | 0.74              | 0.38             |
|  | 2009 | 0.19               | 0.42        | 0.97              | 0.87             |
|  | 2010 | 0.03               | -0.36       | 0.86              | 0.73             |
|  | 2011 | -0.42              | -0.11       | 0.17              | 0.64             |
|  | 2012 | -1.16              | -0.31       | -0.64             | -0.16            |
|  | 2013 | -0.12              | -0.04       | 0.29              | 0.39             |
|  | 2014 | -0.02              | 0.30        | 0.70              | 0.12             |
|  | 2015 | -0.43              | 0.24        | -0.07             | 0.24             |
| RMSE<br>ppb: MDA1,<br>MDA8, M12<br>ppmh:<br>AOT40      | 2000 | 4.27               | 3.87        | 4.36              | 2.84             |
|  | 2001 | 4.04               | 3.70        | 4.07              | 2.80             |
|  | 2002 | 4.38               | 3.87        | 4.45              | 3.24             |
|  | 2003 | 4.36               | 3.51        | 4.48              | 2.94             |
|  | 2004 | 3.96               | 3.39        | 4.08              | 2.68             |
|  | 2005 | 3.84               | 3.08        | 4.02              | 2.83             |
|  | 2006 | 3.97               | 3.36        | 4.01              | 2.72             |
|  | 2007 | 3.93               | 3.04        | 3.84              | 2.76             |
|  | 2008 | 3.79               | 3.05        | 3.84              | 2.46             |
|  | 2009 | 3.44               | 2.99        | 3.70              | 2.32             |
|  | 2010 | 3.41               | 2.78        | 3.82              | 2.48             |
|  | 2011 | 3.38               | 2.75        | 3.58              | 2.50             |
|  | 2012 | 3.59               | 2.83        | 3.73              | 2.42             |
|  | 2013 | 3.17               | 2.74        | 3.36              | 2.11             |
|  | 2014 | 3.15               | 2.64        | 3.30              | 1.83             |
|  | 2015 | 3.07               | 2.31        | 3.06              | 1.92             |
| $r^2$<br>[unitless]                                    | 2000 | 0.80               | 0.77        | 0.81              | 0.81             |
|  | 2001 | 0.81               | 0.74        | 0.80              | 0.78             |
|  | 2002 | 0.80               | 0.75        | 0.79              | 0.79             |
|  | 2003 | 0.77               | 0.75        | 0.75              | 0.78             |
|  | 2004 | 0.77               | 0.76        | 0.76              | 0.76             |
|  | 2005 | 0.79               | 0.77        | 0.77              | 0.77             |
|  | 2006 | 0.79               | 0.76        | 0.76              | 0.76             |
|  | 2007 | 0.81               | 0.79        | 0.81              | 0.77             |
|  | 2008 | 0.83               | 0.80        | 0.81              | 0.81             |
|  | 2009 | 0.81               | 0.78        | 0.82              | 0.84             |
|  | 2010 | 0.82               | 0.80        | 0.81              | 0.80             |
|  | 2011 | 0.84               | 0.82        | 0.83              | 0.83             |
|  | 2012 | 0.83               | 0.80        | 0.83              | 0.83             |
|  | 2013 | 0.82               | 0.76        | 0.81              | 0.81             |
|  | 2014 | 0.80               | 0.76        | 0.79              | 0.80             |
|  | 2015 | 0.81               | 0.79        | 0.77              | 0.77             |

Table S1: Evaluation of the ANN predictions using the original TOAR observations. Note: RMSE = Root-mean squared error.

| Year | MDA1<br>[ppb]      | MDA8<br>[ppb] |          |          |          |          |
|------|--------------------|---------------|----------|----------|----------|----------|
|      | April – Sept. Avg. | Annual Avg.   | DJF Avg. | MAM Avg. | JJA Avg. | SON Avg. |
| 2000 | 53.67              | 39.88         | 27.69    | 45.21    | 49.97    | 36.64    |
| 2001 | 54.65              | 40.10         | 27.10    | 44.58    | 51.54    | 37.20    |
| 2002 | 55.88              | 40.31         | 27.90    | 44.29    | 52.72    | 36.33    |
| 2003 | 52.34              | 39.12         | 28.09    | 43.34    | 48.35    | 36.70    |
| 2004 | 52.16              | 39.16         | 28.54    | 45.22    | 47.04    | 35.85    |
| 2005 | 54.73              | 40.43         | 27.79    | 45.05    | 50.37    | 38.51    |
| 2006 | 52.93              | 40.09         | 29.13    | 45.76    | 49.84    | 35.63    |
| 2007 | 53.03              | 40.41         | 29.57    | 46.15    | 48.18    | 37.73    |
| 2008 | 51.11              | 39.81         | 30.23    | 44.92    | 47.39    | 36.72    |
| 2009 | 48.84              | 38.68         | 30.76    | 44.68    | 44.73    | 34.53    |
| 2010 | 51.17              | 40.15         | 30.63    | 45.38    | 46.70    | 37.91    |
| 2011 | 51.21              | 40.46         | 31.11    | 44.65    | 48.50    | 37.59    |
| 2012 | 51.79              | 40.67         | 31.34    | 45.50    | 48.98    | 36.86    |
| 2013 | 48.39              | 39.10         | 31.29    | 44.47    | 43.95    | 36.70    |
| 2014 | 48.19              | 39.21         | 31.73    | 44.74    | 43.60    | 36.75    |
| 2015 | 48.34              | 39.14         | 31.59    | 43.68    | 43.90    | 37.36    |

**Table S2: Population-weighted exposure concentrations from 2000-2015. Note: DJF = December-February (all months within same calendar year); MAM = March-May; JJA = July-August; SON = September-November.**

| Year | M12<br>[ppb]   |                  | AOT40<br>[ppmh] |                  |                |                |
|------|----------------|------------------|-----------------|------------------|----------------|----------------|
|      | Maize<br>(JAS) | Soybean<br>(JAS) | Maize<br>(JAS)  | Soybean<br>(JAS) | Wheat<br>(MAM) | Wheat<br>(MJJ) |
| 2000 | 43.20          | 44.20            | 9.61            | 10.48            | 7.40           | 10.84          |
| 2001 | 42.23          | 42.40            | 9.60            | 9.68             | 6.97           | 11.69          |
| 2002 | 44.17          | 44.26            | 11.19           | 11.46            | 6.98           | 12.05          |
| 2003 | 42.36          | 42.04            | 9.63            | 9.46             | 7.05           | 10.51          |
| 2004 | 40.16          | 39.89            | 7.25            | 6.91             | 7.23           | 9.26           |
| 2005 | 43.79          | 44.20            | 9.87            | 10.22            | 7.37           | 10.74          |
| 2006 | 40.88          | 41.03            | 8.02            | 8.20             | 7.71           | 12.07          |
| 2007 | 41.42          | 41.89            | 7.86            | 8.33             | 6.90           | 8.52           |
| 2008 | 39.17          | 38.89            | 6.16            | 6.00             | 6.66           | 8.84           |
| 2009 | 37.26          | 36.67            | 4.94            | 4.54             | 6.48           | 8.40           |
| 2010 | 39.47          | 39.66            | 6.24            | 6.40             | 6.78           | 7.48           |
| 2011 | 40.27          | 40.61            | 7.79            | 8.00             | 6.48           | 11.20          |
| 2012 | 43.25          | 43.02            | 9.87            | 9.70             | 7.17           | 11.83          |
| 2013 | 38.87          | 38.76            | 5.77            | 5.51             | 5.93           | 7.47           |
| 2014 | 36.83          | 36.51            | 3.84            | 3.50             | 6.95           | 6.62           |
| 2015 | 37.58          | 37.24            | 4.39            | 4.20             | 5.73           | 5.45           |

**Table S3: Agriculture-weighted exposure concentrations from 2000-2015. Note: JAS = July-September; MAM = March-May; MJJ = May-July.**

| Trend Type    | MDA1<br>[ppb/yr]        |                         |                         | MDA8<br>[ppb/yr]     |                         |                        |
|---------------|-------------------------|-------------------------|-------------------------|----------------------|-------------------------|------------------------|
|               | West                    | East                    | Total                   | West                 | East                    | Total                  |
| Met. Adjusted | -0.32<br>[-0.25, -0.39] | -0.46<br>[-0.39, -0.52] | -0.41<br>[-0.35, -0.47] | 0.04<br>[0.07, 0.00] | -0.04<br>[-0.01, -0.07] | -0.02<br>[0.01, -0.04] |
| Non-Adjusted  | -0.31<br>[-0.21, -0.41] | -0.49<br>[-0.28, -0.69] | -0.43<br>[-0.28, -0.57] | 0.06<br>[0.11, 0.01] | -0.08<br>[0.02, -0.17]  | -0.03<br>[0.04, -0.10] |

| Trend Type    | MDA8-JJA<br>[ppb/yr]    |                         |                         | MDA8-DJF<br>[ppb/yr] |                      |                      |
|---------------|-------------------------|-------------------------|-------------------------|----------------------|----------------------|----------------------|
|               | West                    | East                    | Total                   | West                 | East                 | Total                |
| Met. Adjusted | -0.29<br>[-0.23, -0.35] | -0.46<br>[-0.4, -0.53]  | -0.40<br>[-0.35, -0.45] | 0.33<br>[0.35, 0.30] | 0.33<br>[0.35, 0.31] | 0.33<br>[0.35, 0.31] |
| Non-Adjusted  | -0.29<br>[-0.17, -0.41] | -0.54<br>[-0.28, -0.80] | -0.45<br>[-0.27, -0.64] | 0.35<br>[0.42, 0.29] | 0.31<br>[0.37, 0.26] | 0.33<br>[0.37, 0.28] |

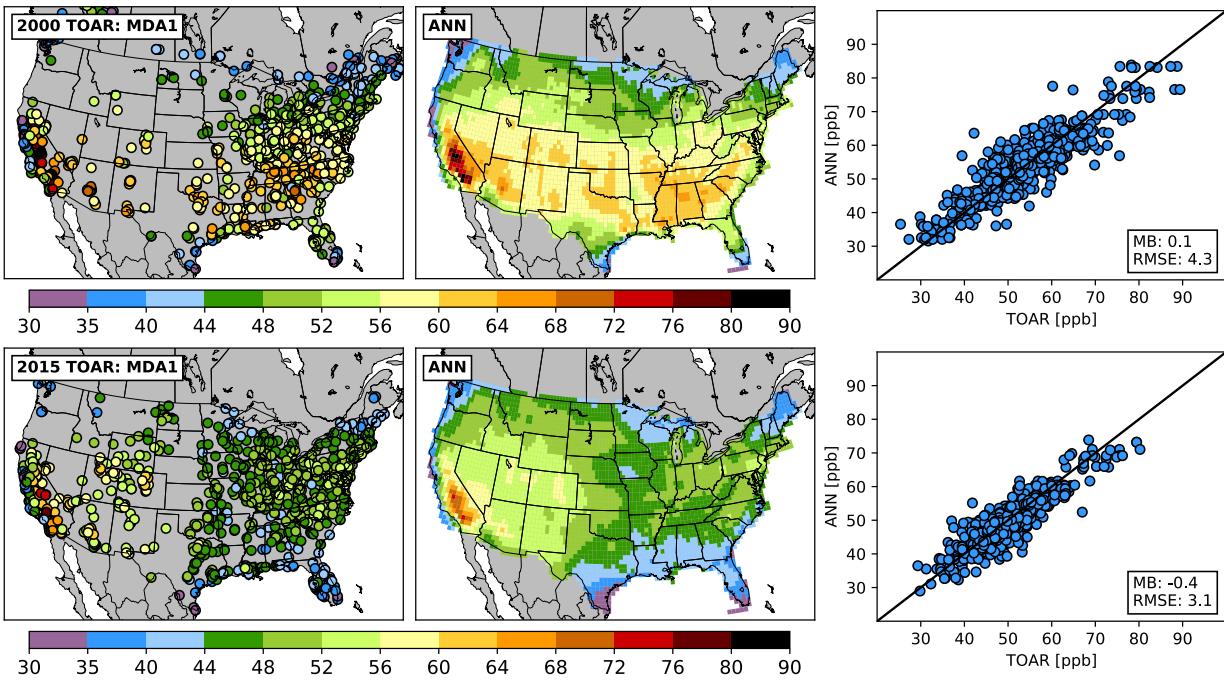
| Trend Type    | MDA8-MAM<br>[ppb/yr] |                        |                        | MDA8-SON<br>[ppb/yr] |                        |                        |
|---------------|----------------------|------------------------|------------------------|----------------------|------------------------|------------------------|
|               | West                 | East                   | Total                  | West                 | East                   | Total                  |
| Met. Adjusted | 0.06<br>[0.11, 0.02] | -0.01<br>[0.04, -0.05] | 0.02<br>[0.05, -0.02]  | 0.04<br>[0.07, 0.02] | -0.03<br>[0.01, -0.07] | -0.01<br>[0.02, -0.04] |
| Non-Adjusted  | 0.07<br>[0.13, 0.02] | -0.05<br>[0.07, -0.17] | -0.01<br>[0.07, -0.09] | 0.10<br>[0.19, 0.02] | -0.03<br>[0.12, -0.17] | 0.02<br>[0.13, -0.08]  |

| Trend Type    | M12 Maize<br>[ppb/yr]   | M12 Soybean<br>[ppb/yr] | AOT40<br>Maize<br>[ppmh/yr] | AOT40<br>Soybean<br>[ppmh/yr] | AOT40<br>Wheat MAM<br>[ppmh/yr] | AOT40<br>Wheat MJJ<br>[ppmh/yr] |
|---------------|-------------------------|-------------------------|-----------------------------|-------------------------------|---------------------------------|---------------------------------|
| Met. Adjusted | -0.22<br>[-0.19, -0.26] | -0.26<br>[-0.22, -0.30] | -0.27<br>[-0.22, -0.32]     | -0.30<br>[-0.25, -0.36]       | -0.04<br>[-0.02, -0.07]         | -0.24<br>[-0.2, -0.28]          |
| Non-Adjusted  | -0.35<br>[-0.17, -0.54] | -0.39<br>[-0.19, -0.59] | -0.35<br>[-0.18, -0.51]     | -0.39<br>[-0.21, -0.56]       | -0.07<br>[-0.03, -0.11]         | -0.29<br>[-0.12, -0.47]         |

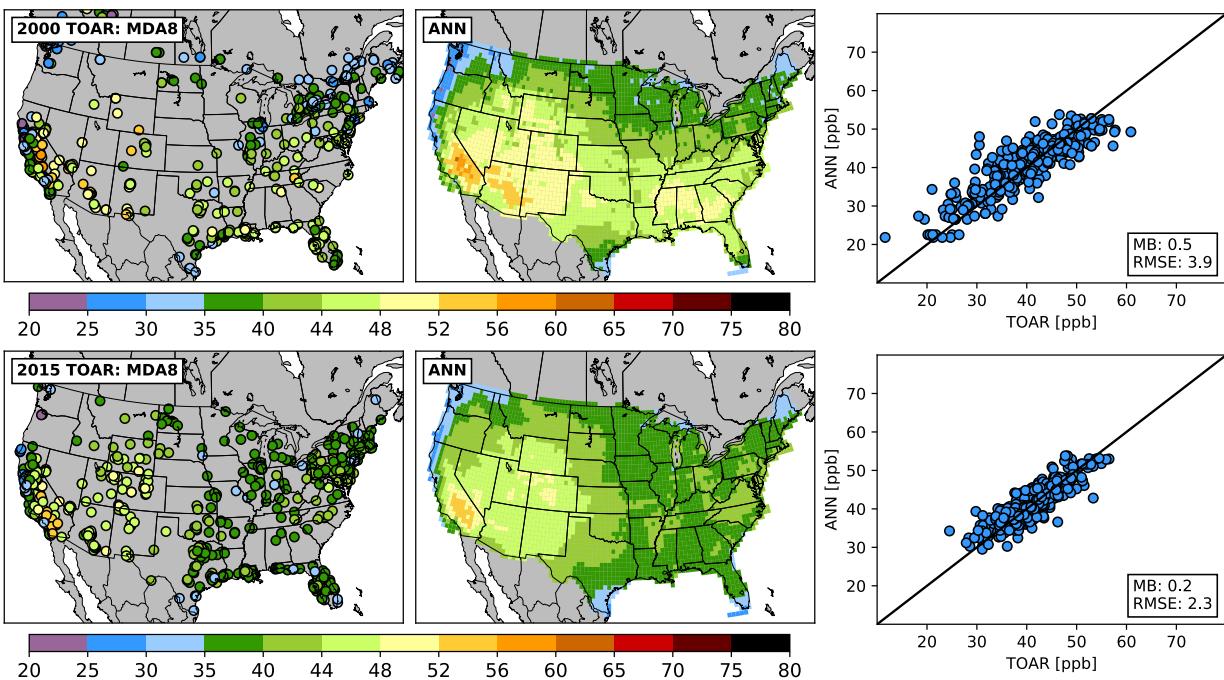
**Table S4: Meteorological adjusted and non-adjusted trends of all metrics (population-weighted and agriculture-weighted, respectively) from 2000-2015. Note: DJF = December-February (all months within same calendar year); MAM = March-May; JJA = July-August; SON = September-November.**

| Year | Estimated Human-Health Impacts<br>[# mortalities / 100,000 ppl / year] |                        | Estimated Agriculture Impacts<br>[% Relative Yield Lost] |                |                 |                   |                |
|------|--|------------------------|--|----------------|-----------------|-------------------|----------------|
|      | J2009<br>[95% CI]  | T2016<br>[95% CI]      | M12<br>Maize   | AOT40<br>Maize | M12<br>Soybeans | AOT40<br>Soybeans | AOT40<br>Wheat |
| 2000 | 6.02<br>[2.04, 9.66]   | 10.81<br>[7.55, 13.79] | 4.58   | 3.42           | 16.28           | 11.85             | 12.09          |
| 2001 | 6.34<br>[2.16, 10.18]  | 11.08<br>[7.74, 14.14] | 4.26   | 3.42           | 14.94           | 10.95             | 11.39          |
| 2002 | 6.75<br>[2.30, 10.80]  | 11.33<br>[7.91, 14.46] | 4.85   | 3.99           | 16.31           | 12.97             | 11.41          |
| 2003 | 5.73<br>[1.94, 9.22]   | 10.41<br>[7.25, 13.31] | 4.28   | 3.43           | 14.66           | 10.70             | 11.53          |
| 2004 | 5.58<br>[1.89, 8.98]   | 10.27<br>[7.15, 13.13] | 3.60   | 2.58           | 13.09           | 7.82              | 11.82          |
| 2005 | 6.40<br>[2.17, 10.27]  | 11.42<br>[7.96, 14.58] | 4.70   | 3.51           | 16.26           | 11.57             | 12.05          |
| 2006 | 5.88<br>[1.99, 9.46]   | 11.11<br>[7.75, 14.18] | 3.80   | 2.86           | 13.92           | 9.28              | 12.60          |
| 2007 | 5.90<br>[2.00, 9.49]   | 11.38<br>[7.94, 14.52] | 4.02   | 2.80           | 14.57           | 9.42              | 11.28          |
| 2008 | 5.43<br>[1.84, 8.75]   | 11.08<br>[7.72, 14.15] | 3.35   | 2.19           | 12.38           | 6.79              | 10.89          |
| 2009 | 4.77<br>[1.61, 7.70]   | 10.19<br>[7.09, 13.05] | 2.84   | 1.76           | 10.78           | 5.13              | 10.60          |
| 2010 | 5.42<br>[1.84, 8.74]   | 11.32<br>[7.89, 14.46] | 3.46   | 2.22           | 12.95           | 7.24              | 11.09          |
| 2011 | 5.58<br>[1.89, 8.99]   | 11.83<br>[8.26, 15.10] | 3.68   | 2.78           | 13.63           | 9.06              | 10.59          |
| 2012 | 5.80<br>[1.96, 9.33]   | 12.11<br>[8.45, 15.46] | 4.55   | 3.52           | 15.39           | 10.98             | 11.72          |
| 2013 | 4.84<br>[1.63, 7.82]   | 11.01<br>[7.66, 14.08] | 3.24   | 2.05           | 12.28           | 6.23              | 9.71           |
| 2014 | 4.83<br>[1.63, 7.81]   | 11.22<br>[7.81, 14.35] | 2.72   | 1.37           | 10.67           | 3.95              | 11.36          |
| 2015 | 4.95<br>[1.67, 8.00]   | 11.32<br>[7.88, 14.49] | 2.87   | 1.57           | 11.18           | 4.76              | 9.38           |

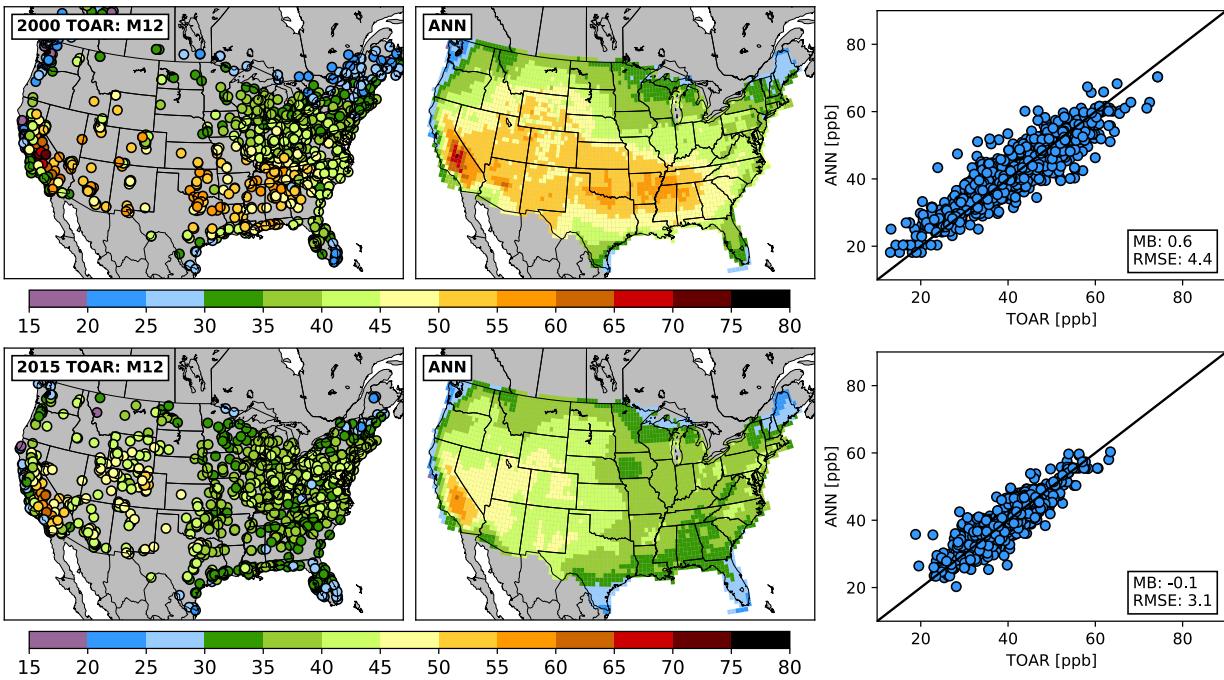
Table S5: Estimated human-health and crop-loss impacts attributable to long-term O<sub>3</sub> exposure from 2000-2015. Note: CI = Confidence Interval.



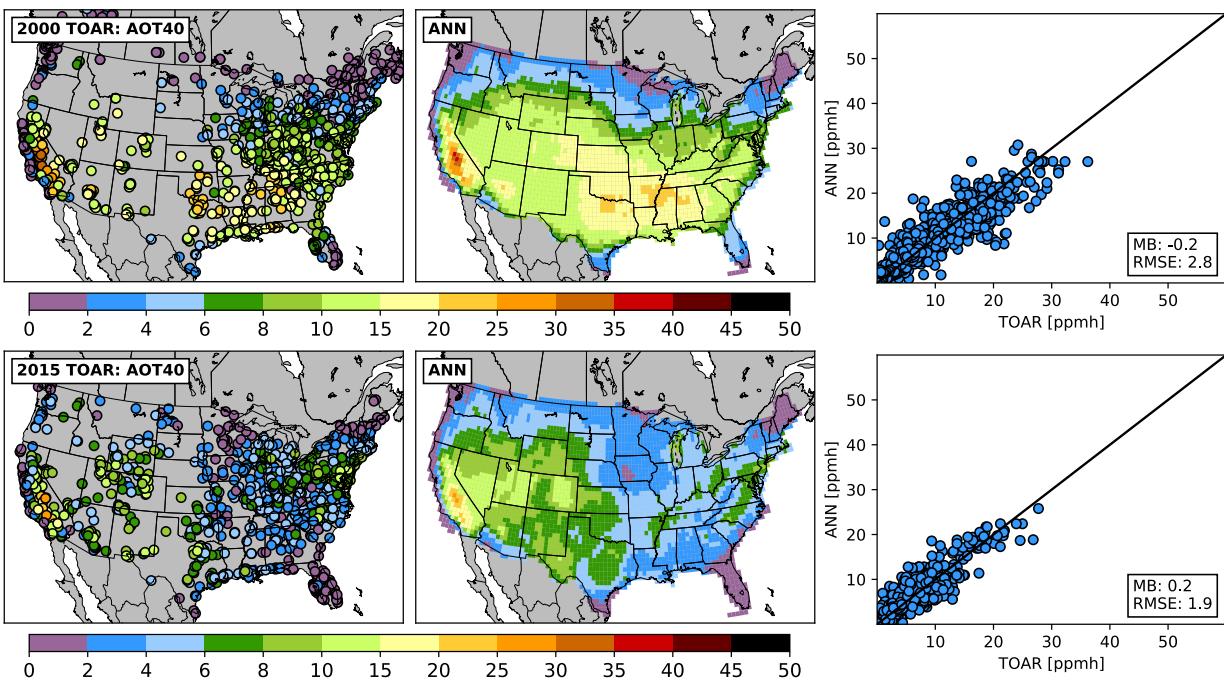
**Figure S1:** TOAR observations (left) of the April-September average of the daily 1-hour maximum concentration (Jerrett et al. 2009 averaging metric) and predictions using the ANN (center). Concentrations are reported in ppb. Note: color bar has non-uniform intervals. Right: Scatter plot comparing TOAR observations (left) and ANN predictions (center), with each dot representing a monitoring location. The mean bias (ppb) and root mean square error (ppb) are included in the scatter plot panel.



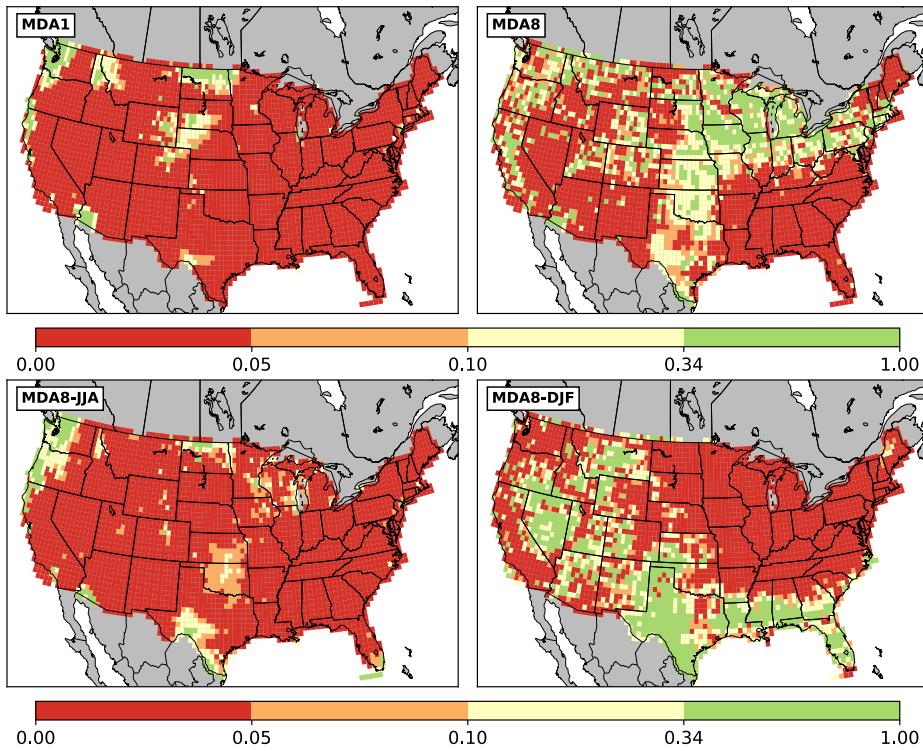
**Figure S2:** TOAR observations (left) of the annual average of the maximum daily 8-hour concentration (Turner et al. 2016 averaging metric) and predictions using the ANN (center). Concentrations are reported in ppb. Note: color bar has non-uniform intervals. Right: Scatter plot comparing TOAR observations (left) and ANN predictions (center), with each dot representing a monitoring location. The mean bias (ppb) and root mean square error (ppb) are included in the scatter plot panel.



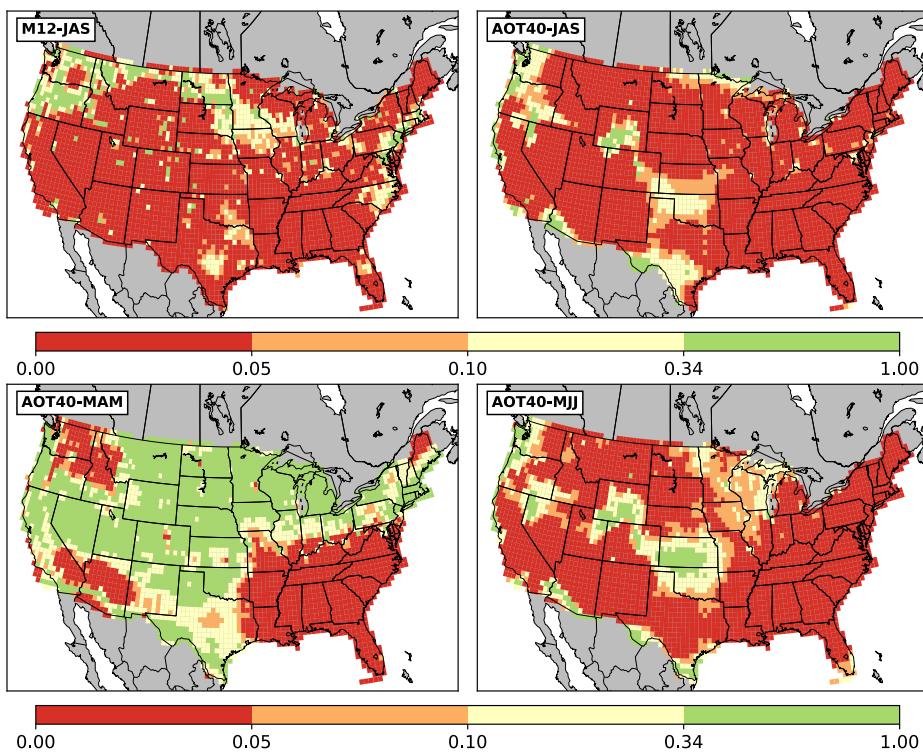
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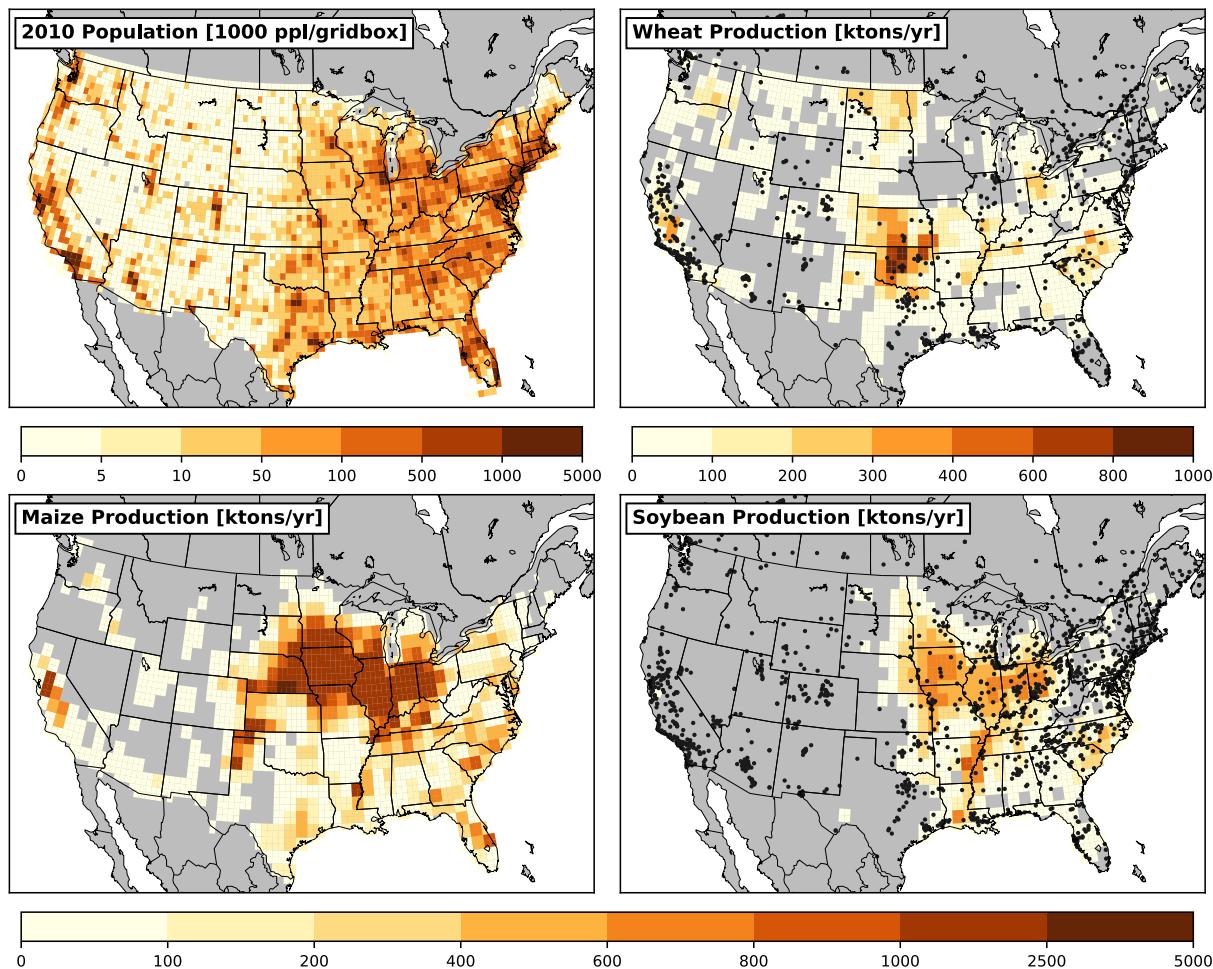
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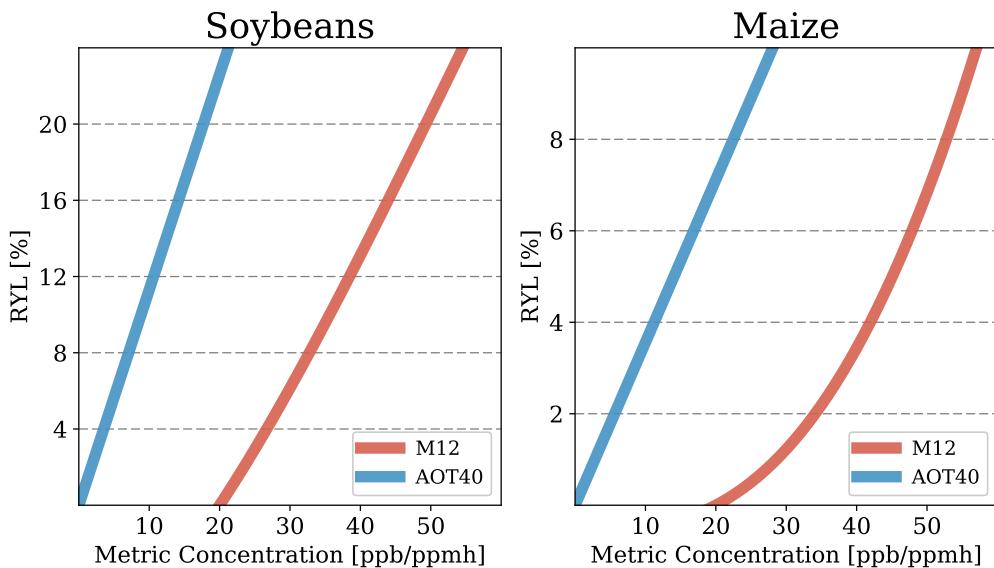
**Figure S5:** The p-values for the trends presented in Fig. 2 from the main text.



**Figure S6:** The p-values for the trends presented in Fig. 4 from the main text.



**Figure S7:** 2010 USA population (top left) and wheat (top right), maize (bottom left), and soybean (bottom right) production maps. Dots in top right panel represent monitoring locations with available data on January 1, 2010 and dots in bottom right panel represent monitoring locations with available data on July 1, 2010.



**Figure S8:** Comparison of the M12 and AOT40 concentration-response curves for soybeans and maize. To note: the concentrations are different for the M12 (ppb) and AOT40 (ppmh) metrics.