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*Supplement of*

## **Adverse effects of increasing drought on air quality via natural processes**

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## Supplementary materials

**Table S1: Technical details for four ACCMIP models**

	GISS-E2-R	GFDL-AM3	NCAR-CAM3.5	MIROC-CHEM
Available model output for historical runs	1981-2005	1981-1990, 2001-2010	1982-1989, 2002-2009	1980-1984, 2000-2010
Emissions	Anthropogenic	Prescribed		
	Biomass	Prescribed by decadal means		
	Biogenic	Interactive	Prescribed	
Detrend & deseasonalize method	7-yr moving average	Subtract time slice average by month	Subtract time slice average by month	Subtract time slice average by month

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**Table S2: Changes in meteorological variables at surface sites under drought conditions from the CRU observations, ISCCP satellite observations and ACCMIP models.**

	West	Great Plains	Southeast	Northeast	West	Great Plains	Southeast	Northeast
Diff * (drought minus normal)	Precipitation (mm/mth)				Temperature (□)			
	CRU	-15.51 (-52%)	-28.07 (-61%)	-58.32 (-53%)	-43.64 (-49%)	1.48	1.55	1.12
GFDL	-30.65 (-60%)	-46.19 (-56%)	-52.52 (-56%)	-50.70 (-51%)	2.48	2.51	1.64	2.17
GISS	-39.56 (-58%)	-43.01 (-58%)	-63.39 (-51%)	-58.17 (-52%)	2.52	2.28	1.21	1.33
NCAR	-26.82 (-68%)	-49.68 (-56%)	-48.15 (-50%)	-47.09 (-47%)	2.07	1.85	0.79	0.93
MIROC	-31.49 (-64%)	-33.99 (-55%)	-41.50 (-62%)	-45.93 (-49%)	1.71	1.80	1.60	1.87
	Total cloud fraction				Boundary-layer cloud fraction			
ISCCP	-5.99 (-17%)	-8.73 (-24%)	-8.20 (-16%)	-5.10 (-9%)	-0.49 (-13%)	-0.21 (-6%)	-1.70 (-10%)	-1.40 (-11%)
GFDL	-10.22 (-46%)	-15.40 (-47%)	-9.20 (-45%)	-12.47 (-41%)	-3.73 (-47%)	-5.55 (-47%)	-6.74 (-46%)	-9.58 (-42%)
GISS	-15.93 (-38%)	-15.62 (-37%)	-10.92 (-40%)	-9.98 (-32%)	-4.76 (-41%)	-7.87 (-42%)	-4.15 (-30%)	-6.28 (-33%)

\* All calculation are restricted to surface sites with more than 5 years observational records and drought frequency (SPEI<-1.3) greater than 10%.

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**Table S3: Fire occurrence frequency (%) and fire emissions of OC, BC, SO<sub>2</sub> and PM<sub>2.5</sub> under drought and normal conditions. Data are from the GFED inventory.**

GFED (g/m <sup>2</sup> month <sup>-1</sup> )	West			Great Plains			Southeast			Northeast		
	Dry	Nor <sup>b</sup>	Diff <sup>c</sup>	Dry	Nor	Diff	Dry	Nor	Diff	Dry	Nor	Diff
Fire freq <sup>a</sup> (%)	41.20	33.00	1.25	43.40	35.10	1.24	86.30	83.90	1.03	28.20	23.30	1.21
OC	102.03	42.03	2.43	31.83	9.41	3.38	220.87	125.07	1.77	60.40	76.89	0.79
BC	9.55	3.68	2.59	3.94	1.07	3.68	14.09	9.49	1.48	3.69	4.56	0.81
SO <sub>2</sub>	14.98	5.99	2.50	5.58	1.53	3.65	26.49	15.86	1.67	7.12	8.98	0.79
PM <sub>25</sub>	201.55	79.12	2.55	81.99	21.64	3.79	321.65	199.88	1.61	85.51	106.99	0.80

<sup>a</sup> Fire frequency is calculated by weighting the months impacted by fire emissions with the total months.

<sup>b</sup> Nor refer to normal conditions.

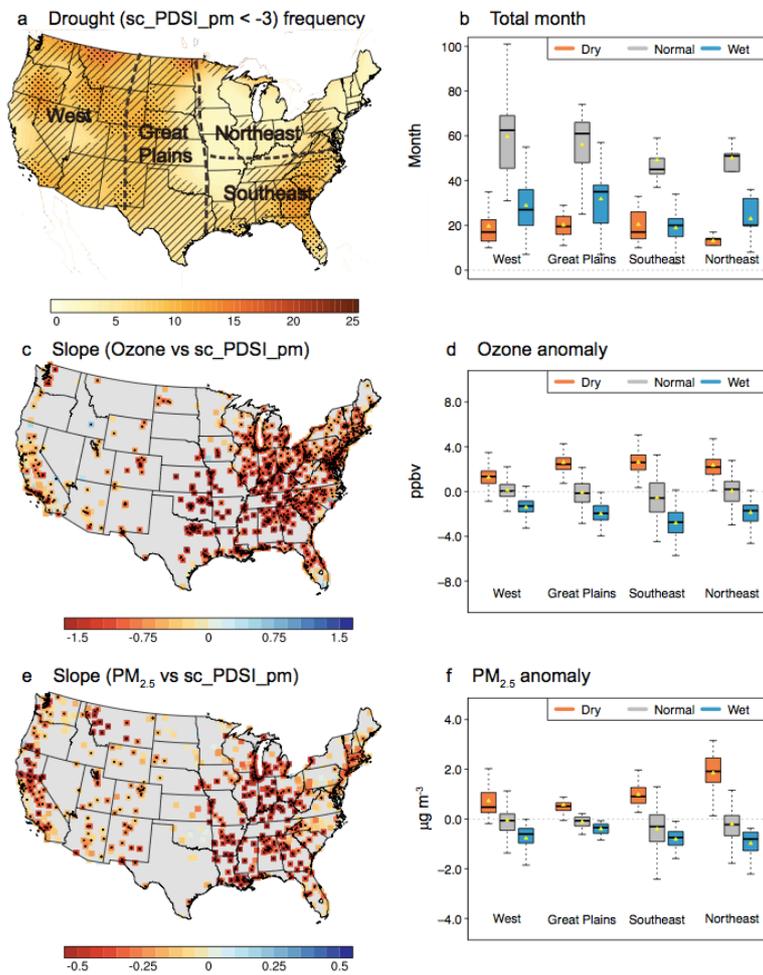
<sup>c</sup> Difference is in times.

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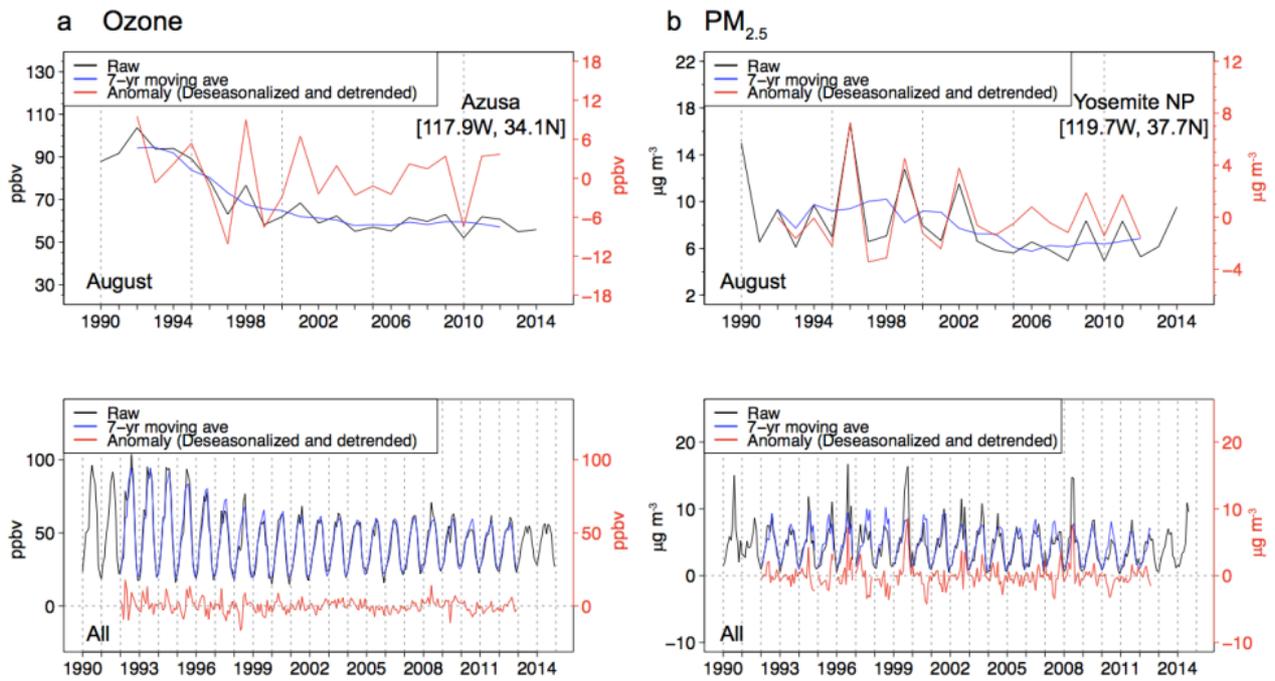
**Table S4: BC and OA concentrations (μg m<sup>-3</sup>) with and without fire impacts under drought and normal conditions.**

	West		Great Plains		Southeast		Northeast	
	BC	OA	BC	OA	BC	OA	BC	OA
Normal (all conditions)	0.19	1.72	0.13	1.25	0.50	3.69	0.41	2.30
Drought (all conditions)	0.26	2.66	0.15	1.70	0.54	4.52	0.45	2.53
Diff (%)	37.64	54.04	19.64	36.37	8.79	22.58	12.19	10.24
Normal (w/ fire)	0.29	2.68	0.14	1.42	0.49	3.72	0.72	3.53
Drought (w/ fire)	0.36	3.91	0.17	1.98	0.54	4.59	0.75	3.55
Diff (%)	25.27	45.50	16.62	39.46	9.78	23.37	4.30	0.37
Normal (w/o fire)	0.14	1.25	0.12	1.15	0.51	3.53	0.31	1.92
Drought (w/o fire)	0.19	1.78	0.14	1.49	0.52	4.10	0.34	2.13
Diff (%)	35.47	42.33	18.18	28.86	3.13	16.13	10.87	10.98

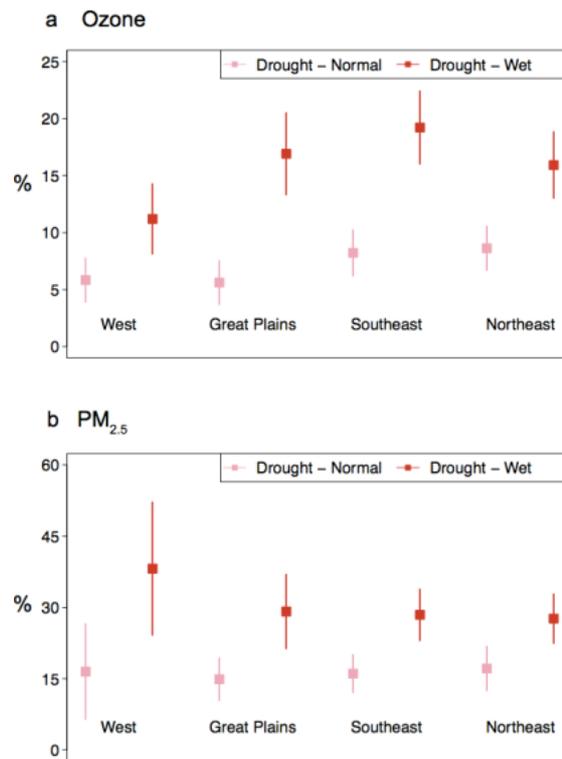
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**Figure S1:** Percentage occurrence of severe drought months ( $sc\_PDSI\_pm < -3$ ) over the continental US (a) during 1990-2014 (black dots indicate drought frequency greater than 10%, italic lines indicate drought frequency greater than 5%, and dashed lines show the division of four geographical regions).  
 5 Linear regression slope of  $sc\_PDSI\_pm$  with O<sub>3</sub> (c) and PM<sub>2.5</sub> (e) anomalies at surface sites; black dots indicate regression significance at 95% level. Boxplot comparisons of the number of months (b), ozone (d) and PM<sub>2.5</sub> (f) at drought ( $sc\_PDSI\_pm < -3$ ), normal ( $-1 < sc\_PDSI\_pm < 1$ ) and wet conditions ( $sc\_PDSI\_pm > 3$ ) by region. The triangles in the boxplot indicate mean value. All the surface data shown are restricted to sites with data records longer than 5 years and more than 5% occurrence of  
 10 drought.

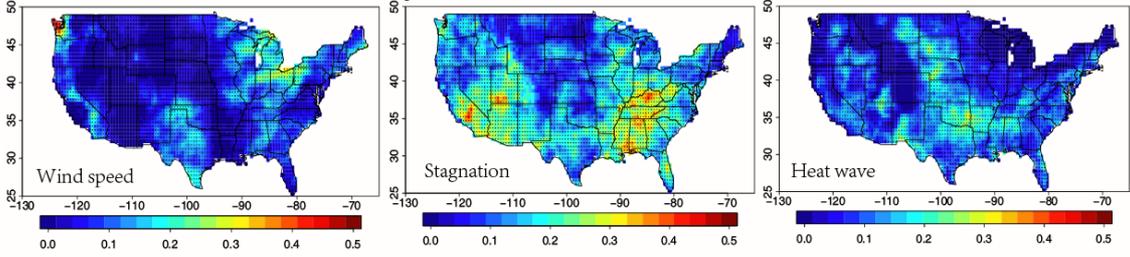


**Figure S2:** Comparison of the monthly raw data and anomalies of ozone time series at Azusa (a) and PM<sub>2.5</sub> time series at Yosemite NP (b). The upper panels show the data for the month of August and the lower panels for all the months during the time period of 1990-2014. The anomalies are derived by subtracting a 7-year moving average from the raw data at each month.

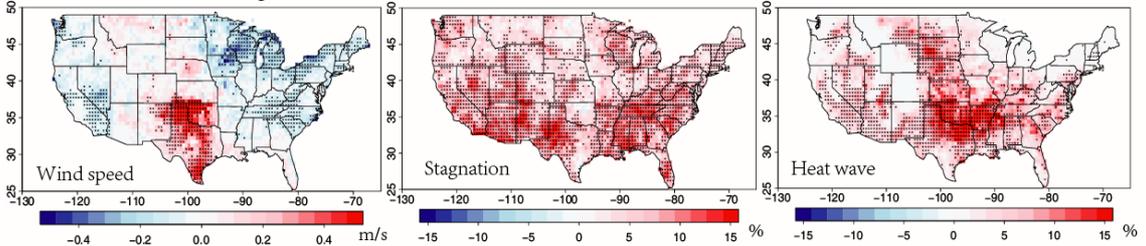


**Figure S3:** Percentage differences of ozone (a) and PM<sub>2.5</sub> (b) under drought (SPEI < -1.3) as compared to normal (-0.5 < SPEI < 0.5) and wet conditions (SPEI > 1.3) over the Western, Great Plains, Southeastern and Northeastern US. The error bar indicate 1/2 standard deviation. All surface sites are restricted with data records longer than 5 years and more than 10% occurrence of drought.

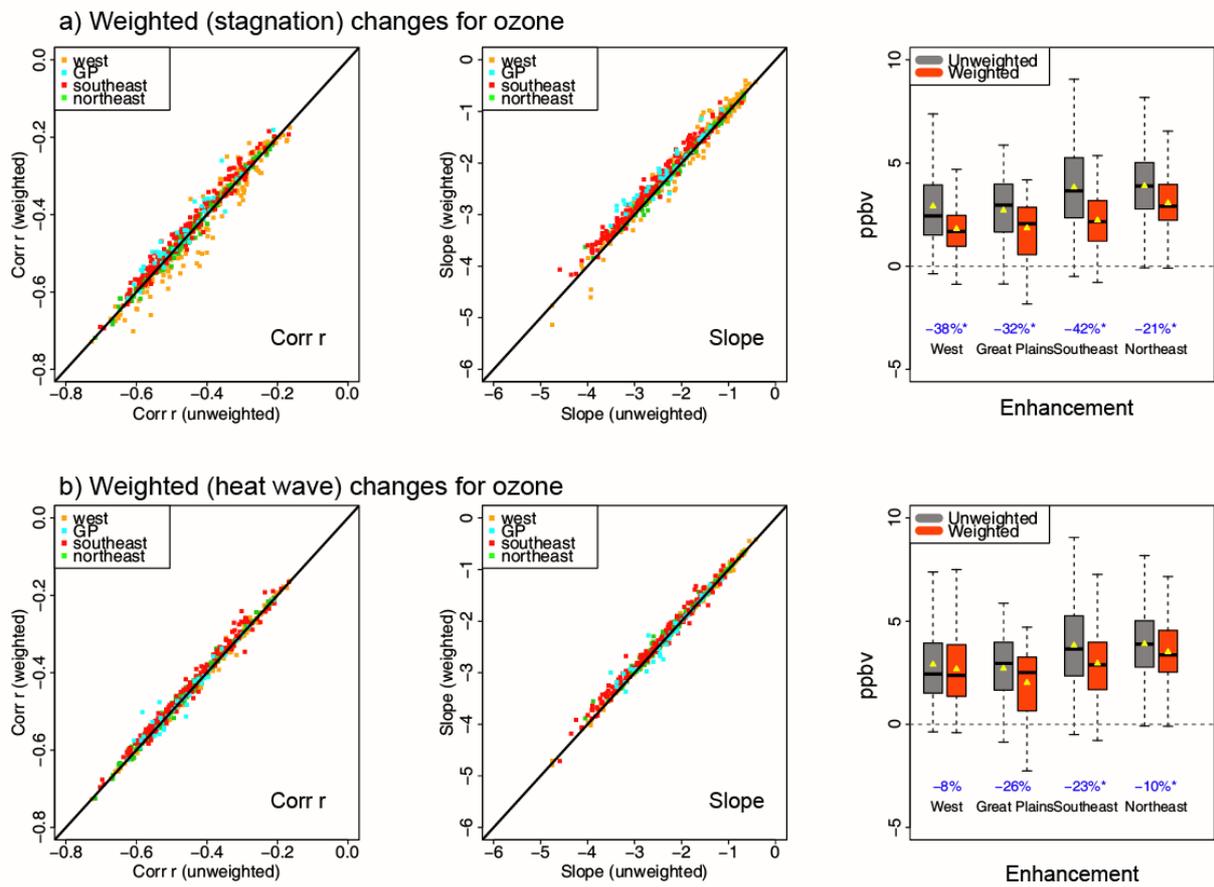
a) Correlation  $R^2$  between SPEI and meteorological variables



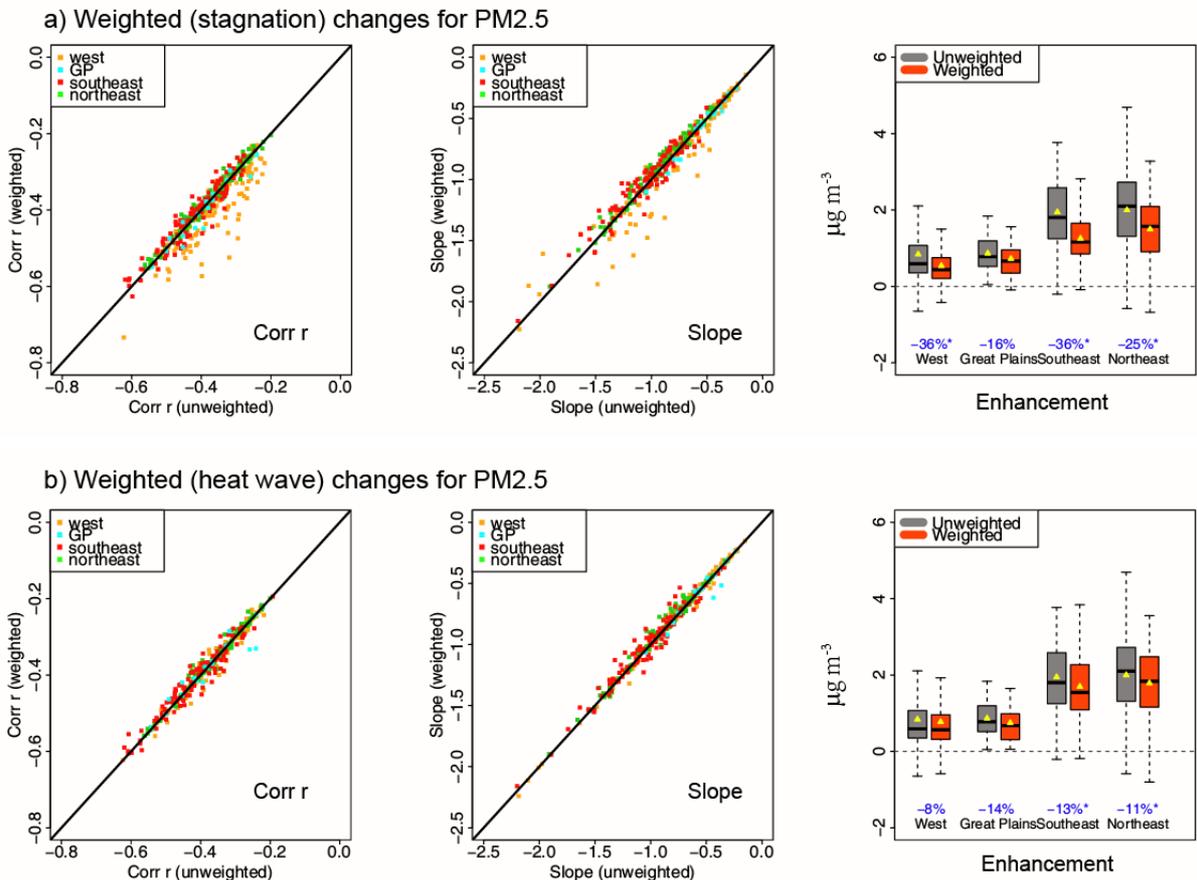
b) Differences between drought and normal conditions



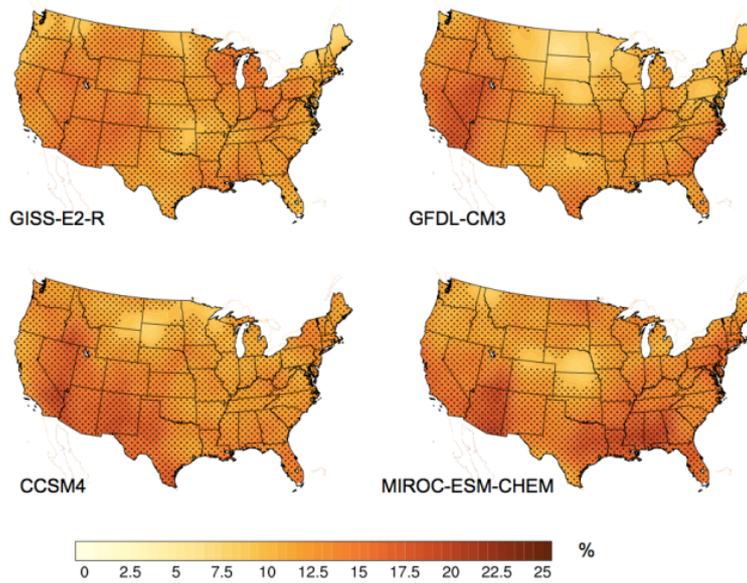
**Figure S4.** Correlation  $R^2$  between SPEI and wind speed, stagnation, and heat wave (a), and the corresponding differences between drought and normal conditions (b).



**Figure S5.** Comparison between the weighted (by frequency of stagnation) and un-weighted SPEI-pollutants relationship (correlation  $r$ , left panel; correlation slope, right panel) and pollutants enhancements (right panel). The upper panel is for ozone and the lower panel for PM<sub>2.5</sub>. Left and middle panels: the black lines are the 1:1 lines and different colors represent different regions. Right panel: the numbers below each box indicate the difference relative to the un-weighted enhancements.

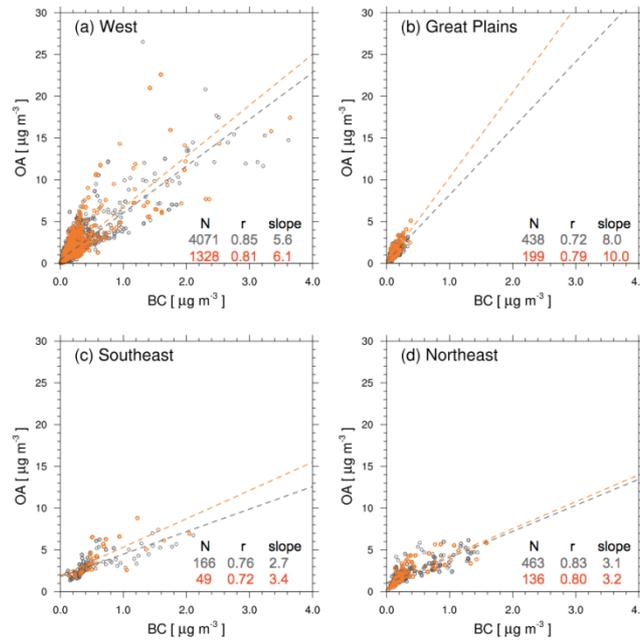


**Figure S6.** Same as Figure S5, but for weighted by heat wave frequency.



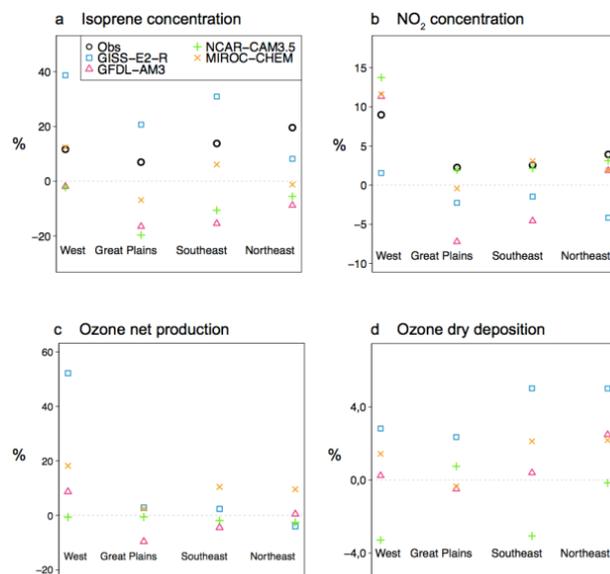
**Figure S7:** Simulated drought (SPEI < -1.3) frequency (%) by the four CMIP5 models during 1990-2014 periods (data for 1990-2005 are from historical runs and data for 2006-2014 are from RCP2.6 runs). Black dots indicate drought frequency greater than 10%.

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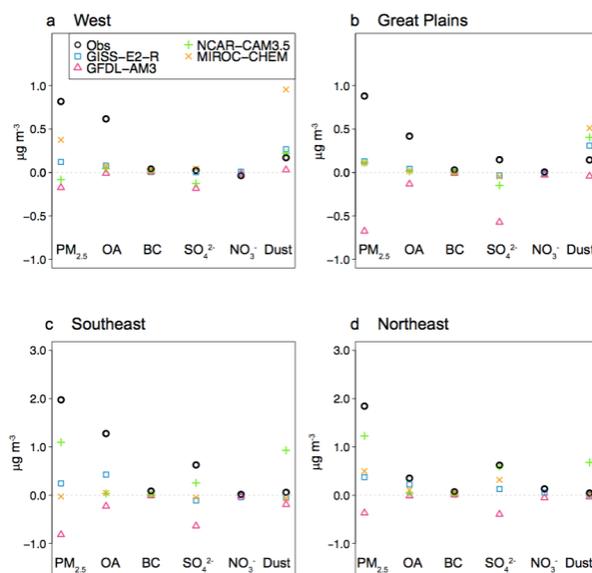


**Figure S8:** Comparison of BC and OA correlation between drought (SPEI < -1.3, color in orange) and normal (-0.5 < SPEI < 0.5, color in gray) condition without impacts from fire emissions over the Western (a), the Great Plains (b), Southeastern (c) and Northeastern (d) US. Shown in insert are the total number of data (N), correlation coefficient (r) and slope from linear regressions.

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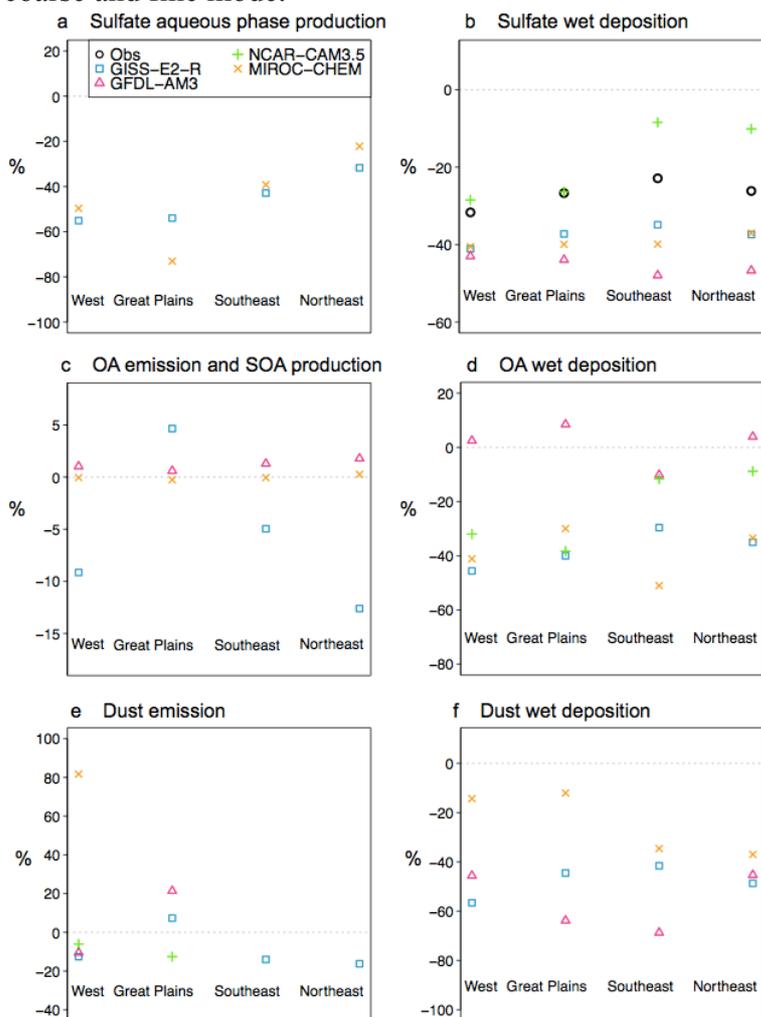


**Figure S9:** Percentage changes of surface concentrations of (a) isoprene, and (b) NO<sub>2</sub>, (c) ozone net production, and (d) ozone dry deposition between drought (SPEI < -1.3) and normal (-0.5 < SPEI < 0.5) conditions over the Western, the Great Plains, the Southeastern and Northeastern US from surface observations (black circle; when applicable) and ACCMIP models (colored symbols).



**Figure S10:** Changes of PM<sub>2.5</sub> speciation between drought (SPEI < -1.3) and normal (-0.5 < SPEI < 0.5) conditions over the Western, the Great Plains, the Southeastern and Northeastern US from surface

observations (black circle) and ACCMIP models (colored symbols, when available). Note the changes in dust includes both coarse and fine mode.



**Figure S11:** Percentage changes of sulfate production and wet deposition, OA emissions and wet deposition, and dust emission and wet deposition between drought (SPEI < -1.3) and normal (-0.5 < SPEI < 0.5) conditions over the Western, the Great Plains, the Southeastern and Northeastern US from surface observations (black circle, when available) and ACCMIP models (colored symbols, when available).