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Supplemental Material

Updated global estimates of respiratory mortality in adults ≥30 years of age attributable to long-term ozone exposure

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References

Table S1: Comparison of the characteristics of the Jerrett et al. (2009) and Turner et al. (2016) analyses of the American Cancer Society Cancer Prevention Study-II cohort population.

Characteristic	**Jerret et al. (2009)**	**Turner et al. (2016)**
Total population size	448,850	669,046
Follow-up period	1982-2000	1982-2004
Total deaths during follow-up	118,777	237,201
Geographic region	96 U.S. metropolitan statistical areas	Contiguous United States
Ozone metric[a]	Six month summer average daily maximum 1h concentration (average between April-June and July-September values) (6mDM1h)	Annual average daily maximum 8h concentration (ADM8h)
Ozone data source	Ozone monitoring data: average of all monitors in each metropolitan area	US EPA hierarchical Bayesian space-time model: Combination of ambient monitoring data with gridded (36 x 36 km) photochemical model output
Ozone exposure spatial variation	33.3-104.0 ppb (6mDM1h)	26.7-59.3 ppb (ADM8h)
Ozone exposure period[b]	1977-2000	2002-2004[c]
Pollutants controlled for in multi-pollutant models	$PM_{2.5}$ (Annual average 1999-2000)	$PM_{2.5}$ decomposed into near-source and regional components (Annual average 1999-2004) NO_2 (Annual average 2006)
Correlation between ozone and $PM_{2.5}$ exposure estimates	$r = 0.64$	'near-source' $PM_{2.5}$ $r = -0.13$ 'regional' $PM_{2.5}$ $r = 0.23$

[a] Correlation between the metrics used in Turner et al. (2016) and Jerrett et al. (2009) was 'moderately strong ($r = 0.70$)' (Turner et al. 2016).

[b] The time periods used to characterise long-term exposure to the pollutants are more similar in Turner et al. (2016) compared to Jerrett et al. (2009). The latter assessed O_3 exposure over 23 years, but $PM_{2.5}$ concentrations during 2 years at the end of the follow-up period. Hence changes in O_3 concentrations over the 23 years were accounted for in Jerrett et al. (2009), but changes that occurred in $PM_{2.5}$ concentrations were not.

[c] While estimation of long-term O_3 exposure at the end of the follow-up allowed for inclusion of a larger population, it did not capture changes in exposure occurring over the follow-up period which coincided with large reductions in O_3 precursor emissions in the US (Simon et al. 2015). Jerrett et al. (2009) assessed the magnitude of the relationship between mortality and long-term O_3 exposure at the start, end, and throughout the follow-up period, and estimated no significant change in the magnitude of the effect. Ozone concentrations in each of these periods in Jerrett et al. (2009) were also correlated (the correlation between O_3 concentrations in 1978-1980 and 1998-2000 was 0.58, and in 1988-1990 and 1998-2000 was 0.80).

Table S2. Global and regional estimates of long-term O_3 attributable respiratory deaths for adults ≥30 years of age only. Estimates were calculated using relationships between long-term O_3 exposure and respiratory mortality derived in Turner et al. (2016) using a multi-pollutant model (adjusting for near-source $PM_{2.5}$, regional $PM_{2.5}$, and NO_2 concentrations), and a single-pollutant model (no adjustment for other pollutants). Values in brackets are 95% confidence intervals.

Region	Low Concentration Cut-off[a]	Attributable respiratory deaths T2016: 3 pollutant model (thousands)[b]	Attributable respiratory deaths T2016: single pollutant model (thousands)[c]
Asia	26.7 ppb	970 (686-1,253)	1,092 (817-1,367)
	31.1 ppb	844 (593-1,095)	953 (709-1,198)
China	26.7 ppb	316 (230-403)	357 (275-439)
	31.1 ppb	274 (198-351)	311 (238-383)
India	26.7 ppb	450 (329-572)	506 (391-621)
	31.1 ppb	402 (291-513)	453 (347-559)
Europe	26.7 ppb	78.9 (54.2-104)	90.0 (65.5-114)
	31.1 ppb	55.9 (38.1-73.8)	64.0 (46.2-81.7)
Africa	26.7 ppb	80.6 (37.1-124)	91.8 (44.5-139)
	31.1 ppb	59.6 (27.5-91.6)	68.0 (33.1-103)
Latin America and the Caribbean	26.7 ppb	39.9 (27.4-52.4)	45.4 (33.1-57.8)
	31.1 ppb	27.2 (18.6-35.7)	31.0 (22.6-39.5)
North America	26.7 ppb	63.8 (46.3-81.3)	72.3 (55.7-88.9)
	31.1 ppb	53.5 (38.4-68.5)	60.7 (46.4-75.1)
Oceania	26.7 ppb	1.0 (0.7-1.3)	1.2 (0.8-1.5)
	31.1 ppb	0.4 (0.3-0.6)	0.5 (0.3-0.6)
Global	26.7 ppb	1,234 (851-1,616)	1,393 (1,016-1,769)
	31.1 ppb	1,040 (716-1,365)	1,178 (858-1,497)

[a] Lower value is the minimum ozone concentration (annual daily maximum 8h concentration), and the upper value is the 5th percentile of the ozone concentration, for the population used to derive the T2016 relative risk estimates.

[b] T2016 estimates use HR = 1.12 (95% CI: 1.08, 1.16) as the relative risk estimate derived from a multi-pollutant model that did adjust for near-source and regional $PM_{2.5}$ exposure, and NO_2 exposure, and the annual daily 8h maximum ozone concentration as the exposure metric (Turner et al. 2016).

[c] T2016 estimates use HR = 1.14 (95% CI: 1.10, 1.18) as the relative risk estimate derived from a single pollutant model that did not adjust for $PM_{2.5}$ and NO_2 exposure, and the annual daily 8h maximum ozone concentration as the exposure metric (Turner et al. 2016).

Table S3. Summary of global estimates of long-term O_3 attributable respiratory deaths calculated using the J2009 relative risk estimates. Estimates from previous studies (from the Global Burden of Disease (GBD) project and other studies), and those derived in this study using comparable metrics, low concentration cut-offs and Hazard Ratios are shown. Values in brackets are 95% confidence intervals.

Health impact study	Year of estimate	Ozone model	Model grid resolution	Low concentration cut-off (ppb)	Hazard Ratio (10 ppb change in O_3)	Metric	Disease Category	Attributable deaths (thousands)
Lim et al. (2012) (GBD 2010)	2010	TM5	1º × 1º	33.3-41.9 (uniform distribution)	1.029 (1.010-1.048)[a]	Max 3-m daily max 1h[b]	COPD	152 (52-267)
Forouzanfar et al. (2015) (GBD 2013)	2013	TM5-FASST	1º × 1º	33.3-41.9 (uniform distribution)	1.029 (1.010-1.048)[a]	Max 3-m daily max 1h[b]	COPD	217 (161-272)
Forouzanfar et al. (2016) (GBD 2015)	2015	TM5-FASST	1º × 1º	33.3-41.9 (uniform distribution)	1.029 (1.010-1.048) [a]	Max 3-m daily max 1h[b]	COPD	254 (97-422)
Anenberg et al. (2010)	2000	MOZART-2	2.8º × 2.8º	33.3	1.040 (1.013-1.067)	Max 6-m daily max 1h	Resp.	470 ± 288 (Mean ± 1 S.D.)
Fang et al. (2013)	2000	GFDL-AM3	Cubed sphere grid (163 km at corners and 231 km at centre)	Preindustrial	1.040 (1.013-1.067)	Max 6-m daily max 1h	Resp.	375 (129-592)
Silva et al. (2013)	2000	ACCMIP ensemble	Model's native resolution ranged between 1.9º × 1.2º and 5º × 5º	Preindustrial	1.040 (1.013-1.067)	Max 6-m daily max 1h	Resp.	470 (140-900)
Silva et al. (2016)	2005	MOZART-4	0.67º × 0.5º	Preindustrial	1.040 (1.013-1.067)	Max 6-m daily max 1h	Resp.	493 (122-989)
This study	2010	GEOS-Chem	2º × 2.5º	33.3	1.029 (1.010-1.048)[a]	Max 3-m daily max 1h[b]	COPD	294 (120-468)
This study	2010	GEOS-Chem	2º × 2.5º	41.9	1.029 (1.010-1.048)[a]	Max 3-m daily max 1h[b]	COPD	230 (92.4-368)
This study	2010	GEOS-Chem	2º × 2.5º	33.3	1.040 (1.013-1.067)	Max 6-m daily max 1h	Resp.	547 (198-897)
This study	2010	GEOS-Chem	2º × 2.5º	41.9	1.040 (1.013-1.067)	Max 6-m daily max 1h	Resp.	398 (142-654)

[a] Relative risk estimates derived from single-pollutant model in Jerrett et al. (2009) for the association between O_3 exposure and total respiratory mortality. The Global Burden of Disease (GBD) studies have applied this relative risk estimate to long-term O_3-attributable COPD deaths specifically. We provide estimates of long-term O_3-attributable COPD deaths using this relative risk estimate for comparison with these previous estimates (Forouzanfar et al. 2015, 2016; Lim et al. 2012).

[b] Jerrett et al. (2009) estimated O_3 exposure among the ACS CPS-II cohort as the 6-month average daily maximum 1h O_3 concentration (average of Apr-Jun and Jul-Sep values), but GBD studies have applied the J2009 relative risk estimates with maximum 3-month daily maximum 1h O_3 concentrations. We provide estimates of long-term O_3-attributable COPD deaths using this O_3 exposure metric for comparison with these previous estimates.

Table S4. Global and regional estimates of long-term O_3-attributable annual COPD deaths for adults ≥30 years of age only derived using relative risk estimates from Turner et al. (2016). Estimates are also expressed as a proportion of all COPD deaths for the population equal to or over 30 years old in each region. Values in brackets are 95% confidence intervals.

Region	Low Concentration Cut-off[a]	Attributable COPD deaths T2016[b] (thousands)	Proportion of total COPD deaths (T2016 estimates, %)
Asia	26.7 ppb	726 (458-994)	32.5 (20.1-43.9)
	31.1 ppb	637 (396-877)	28.5 (17.6-39.7)
China	26.7 ppb	290 (186-394)	31.5 (19.7-42.8)
	31.1 ppb	252 (159-345)	27.4 (17.8-37.7)
India	26.7 ppb	335 (218-452)	36.1 (23.6-50.0)
	31.1 ppb	300 (192-407)	32.4 (20.5-44.9)
Europe	26.7 ppb	46.8 (27.9-65.7)	17.5 (10.3-24.3)
	31.1 ppb	33.7 (19.8-47.6)	12.6 (7.1-17.8)
Africa	26.7 ppb	21.3 (9.1-33.5)	19.7 (8.6-31.5)
	31.1 ppb	16.3 (7.0-25.6)	15.1 (6.5-23.8)
Latin America and the Caribbean	26.7 ppb	20.1 (12.2-28.1)	14.3 (8.8-19.9)
	31.1 ppb	14.0 (8.5-19.6)	10.0 (6.0-13.7)
North America	26.7 ppb	41.0 (25.9-56.2)	27.1 (16.7-37.6)
	31.1 ppb	34.5 (21.4-47.6)	22.8 (14.6-31.4)
Oceania	26.7 ppb	0.7 (0.4-1.0)	4.7 (2.7-7.1)
	31.1 ppb	0.3 (0.2-0.4)	1.9 (1.1-2.9)
Global	26.7 ppb	856 (534-1,178)	29.3 (18.2-40.5)
	31.1 ppb	736 (453-1,018)	25.2 (16.2-34.6)

[a] Lower value is the minimum ozone concentration (annual daily maximum 8h concentration), and the upper value is the 5th percentile of the ozone concentration, for the population used to derive the T2016 relative risk estimates.
[b] T2016 estimates use HR = 1.14 (95% CI: 1.08, 1.21) as the relative risk estimate and the annual daily 8h maximum ozone concentration as the exposure metric (Turner et al. 2016).

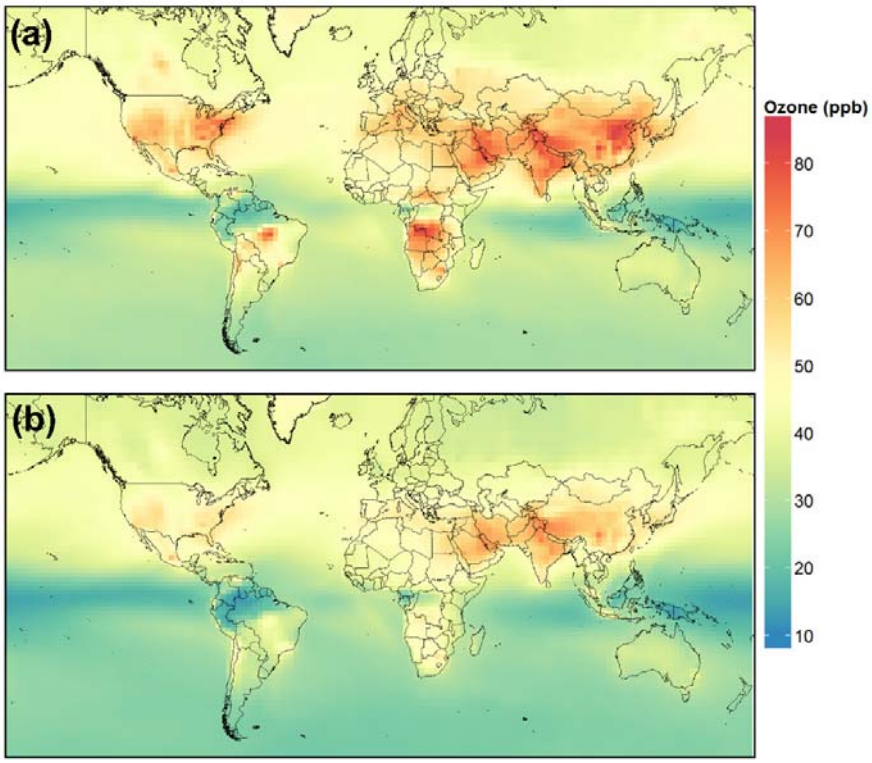
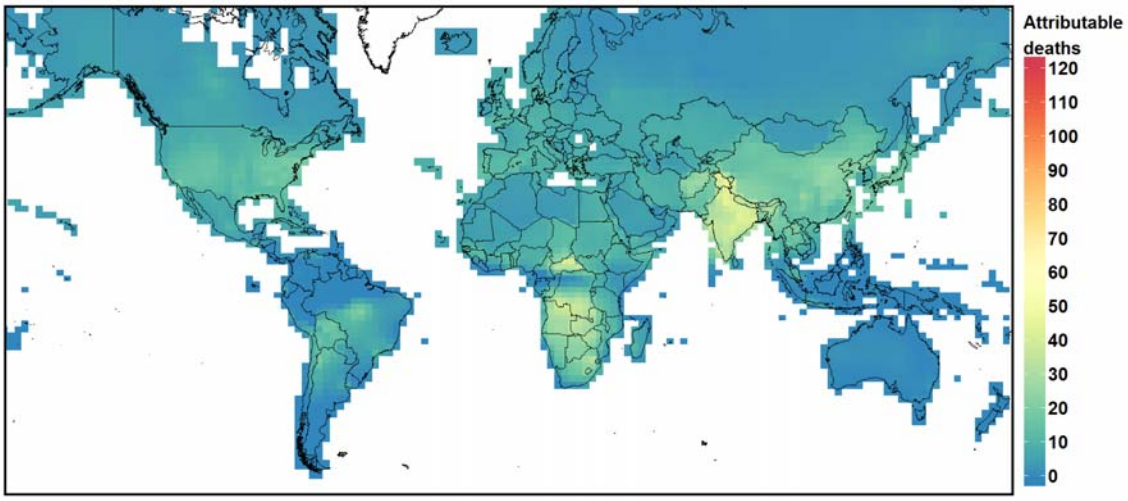


Figure S1. GEOS-Chem-derived global gridded long term O_3 exposure estimates. Long-term O_3 exposures are calculated as a) maximum 6-month average daily max 1h concentration (6mDMA1, relevant for J2009 relative risk estimates), b) annual average daily max 8h concentrations (ADMA8, relevant for T2016 relative risk estimates) (Map Data: © EuroGeographics for the administrative boundaries).



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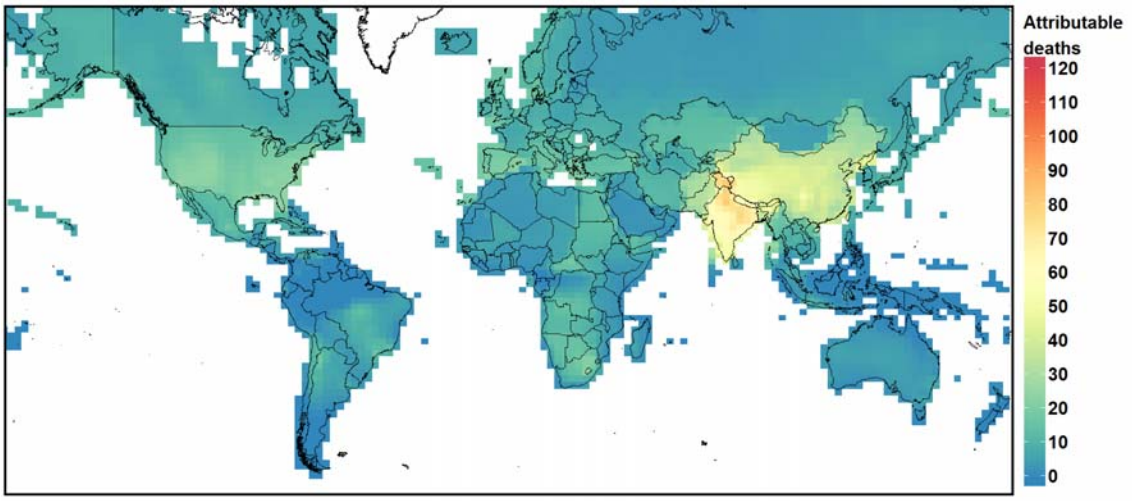

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