Web-based Supplementary Materials for *A Bayesian model for quantifying the change in mortality associated with future ozone exposures under climate change*

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Web Appendix A

Proof of exact integral solutions in Section 3.2

Lemma 1.

Suppose β is a scalar random variable and $\boldsymbol{X}$ is a random vector of length $N \times T$. Let β be Normally distributed, $\beta \sim N(\mu, \sigma^2)$, and assume $\boldsymbol{X}$ has some arbitrary multivariate distribution $F_{\boldsymbol{X}}$. Also assume that β and $\boldsymbol{X}$ are independent. Let $c_1, \ldots, c_N$ be constants.

Then define a new scalar random variable D such that $D = \sum_{i=1}^{N} \sum_{t=1}^{T} c_i \exp(\beta x_{it})$. It follows that

(i) the expectation of D is

$$E(D) = \int \sum_{t=1}^{T} \sum_{i=1}^{N} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x},$$

and

(ii) the variance of D is

$$\begin{aligned} Var(D) = & \int \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{t=1}^{T} \sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it} + x_{js}) + \sigma^2 (x_{it} + x_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x} \\ & - \left[\int \sum_{i=1}^{N} \sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x}\right]^2 \end{aligned}$$

Proof of Lemma 1.

Proof of (i).
Starting with the definition of expectation, we combine the exponential terms in D and in the probability distribution function for β. Then by completing the square and rearranging terms again, we isolate an integral of another Normal distribution wrt β with a different mean and variance. Integrating over the density of the pdf is 1, yielding our result.

$$
\begin{aligned}
&E(D) \\
&= \int\int D f_{\beta}(\beta) f_{\mathbf{X}}(\mathbf{x}) d\beta d\mathbf{x} \\
&= \int\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left(\beta x_{it}\right) \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta-\mu)^2/(2\sigma^2)\right\} f_{\mathbf{X}}(\mathbf{x}) d\beta d\mathbf{x} \\
&= \int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \int \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta^2 - 2\beta\mu + \mu^2 - 2\sigma^2\beta x_{it})/(2\sigma^2)\right\} d\beta f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x} \\
&= \int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \int \frac{1}{\sqrt{2\pi\sigma^2}} \exp\Big\{ -(\beta^2 - 2\beta[\mu+\sigma^2 x_{it}] + \mu^2 + 2\sigma^2 x_{it}\mu + [\sigma^2 x_{it}]^2 - 2\sigma^2 x_{it}\mu \\
&\qquad\qquad - [\sigma^2 x_{it}]^2)/(2\sigma^2)\Big\} d\beta f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x} \\
&= \int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \int \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta - [\mu+\sigma^2 x_{it}])^2/(2\sigma^2)\right\} \exp\left\{-(-2\sigma^2 x_{it}\mu - [\sigma^2 x_{it}]^2)/(2\sigma^2)\right\} d\beta f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x} \\
&= \int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} \int \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta - [\mu+\sigma^2 x_{it}])^2/(2\sigma^2)\right\} d\beta f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x} \\
&= \int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x}
\end{aligned}
$$

Proof of (ii).
First,

$$Var\left(D\right) = E\left(D^2\right) - E\left(D\right)^2$$

We have already derived an expression for $E\left[D\right]$ in part (i). Next, we derive an expression for $E\left[D^2\right]$. By repeatedly applying the identity $(\sum_i a_i)^2 = \sum_{i,j} a_i a_j$ for a sequence a_i, and following the steps in the proof of part (i) by completing the square and isolating an integral of another Normal distribution wrt β, we obtain,

$$\begin{aligned}
&E\left(D^2\right)\\
&= \int\int D^2 f_\beta(\beta) f_{\mathbf{X}}(\mathbf{x}) d\beta d\mathbf{x}\\
&= \int\int \left\{\sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left(\beta x_{it}\right)\right\}^2 \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta-\mu)^2/(2\sigma^2)\right\} f_{\mathbf{X}}(\mathbf{x}) d\beta d\mathbf{x}\\
&= \int\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i \exp\left(\beta x_{it}\right) c_j \exp\left(\beta x_{js}\right) \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta-\mu)^2/(2\sigma^2)\right\} f_{\mathbf{X}}(\mathbf{x}) d\beta d\mathbf{x}\\
&= \int\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\{\beta^2 - 2\beta(\mu + \sigma^2 x_{it} + \sigma^2 x_{js}) + \mu^2\}/(2\sigma^2)\right] f_{\mathbf{X}}(\mathbf{x}) d\beta d\mathbf{x}\\
&= \int\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \frac{1}{\sqrt{2\pi\sigma^2}} \exp\Big[-\{\beta^2 - 2\beta(\mu + \sigma^2 x_{it} + \sigma^2 x_{js}) + (\mu + \sigma^2 x_{it} + \sigma^2 x_{js})^2\\
&\qquad - (\mu + \sigma^2 x_{it} + \sigma^2 x_{js})^2 + \mu^2\}/(2\sigma^2)\Big] f_{\mathbf{X}}(\mathbf{x}) d\beta d\mathbf{x}\\
&= \int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \left\{\int \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\{\beta - (\mu + \sigma^2 x_{it} + \sigma^2 x_{js})\}^2/(2\sigma^2)\right] d\beta\right\}\\
&\qquad \cdot \exp\Big[\mu(x_{it} + x_{js}) + \sigma^2(x_{it} + x_{js})^2/2\Big] f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x}\\
&= \int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it} + x_{js}) + \sigma^2(x_{it} + x_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x}
\end{aligned}$$

Hence,

$$\begin{aligned}
Var\left(D\right) &= \int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it} + x_{js}) + \sigma^2(x_{it} + x_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x}\\
&\quad - \left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x}\right]^2
\end{aligned}$$

Corollary 1.

Suppose β is a scalar random variable and $\boldsymbol{X}$ is a random vector of length $N \times T$. Let β be Normally distributed, $\beta \sim N(\mu, \sigma^2)$, and assume $\boldsymbol{X}$ and $\boldsymbol{W}$ each has some arbitrary multivariate distribution $F_{\boldsymbol{X}}$ and $F_{\boldsymbol{W}}$ respectively. Also assume that β, $\boldsymbol{X}$, $\boldsymbol{W}$ are mutually independent. Let $c_1, \ldots, c_N$ be constants.

Then define a new scalar random variables D, A such that $D = \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp(\beta X_{it})$ and $A = \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp(\beta W_{it})$. It follows that

(i) the expectation of $D - A$ is

$$E(D-A) = \int \sum_{t=1}^{T}\sum_{i=1}^{N} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x})d\mathbf{x} - \int \sum_{t=1}^{T}\sum_{i=1}^{N} c_i \exp\left\{w_{it}\mu + \sigma^2 w_{it}^2/2\right\} f_{\mathbf{W}}(\mathbf{w})d\mathbf{w},$$

and

(ii) the variance of $D - A$ is

$$\begin{aligned}
Var\,(D-A) = &\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it}+x_{js}) + \sigma^2(x_{it}+x_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x})d\mathbf{x} \\
&- \left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x})d\mathbf{x}\right]^2 \\
&+ \int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(w_{it}+w_{js}) + \sigma^2(w_{it}+w_{js})^2/2\right] f_{\mathbf{W}}(\mathbf{w})d\mathbf{w} \\
&- \left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{w_{it}\mu + \sigma^2 w_{it}^2/2\right\} f_{\mathbf{W}}(\mathbf{w})d\mathbf{w}\right]^2 \\
&- 2\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it}+w_{js}) + \sigma^2(x_{it}+w_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\mathbf{x}d\mathbf{w} \\
&+ 2\left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x})d\mathbf{x}\right]\left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{w_{it}\mu + \sigma^2 w_{it}^2/2\right\} f_{\mathbf{W}}(\mathbf{w})d\mathbf{w}\right]
\end{aligned}$$

Proof of Corollary 1.

Proof of (i).
By linearity of expectation and Lemma 1, we have our result.

$$\begin{aligned}
&E(D-A) \\
&= E(D) - E(A) \\
&= \int \sum_{t=1}^{T}\sum_{i=1}^{N} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x})d\mathbf{x} - \int \sum_{t=1}^{T}\sum_{i=1}^{N} c_i \exp\left\{w_{it}\mu + \sigma^2 w_{it}^2/2\right\} f_{\mathbf{W}}(\mathbf{w})d\mathbf{w}
\end{aligned}$$

Proof of (ii).
First,

$$Var\,(D-A) = Var\,(D) + Var\,(A) - 2Cov(D,A)$$

From Lemma 1, we have expressions for $Var(D)$ and $Var(A)$. Next, we derive an expression for $E\,[DA]$ by following the same steps as the proof of Lemma 1 (ii).

$$
\begin{aligned}
&E\,(DA) \\
&= \int\int\int DAf_{\beta}(\beta)f_{\mathbf{X}}(\mathbf{x})d\beta d\mathbf{x}d\mathbf{w} \\
&= \int\int \left\{\sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left(\beta x_{it}\right)\right\}\left\{\sum_{j=1}^{N}\sum_{s=1}^{T} c_j \exp\left(\beta w_{js}\right)\right\} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta-\mu)^2/(2\sigma^2)\right\} f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\beta d\mathbf{x}d\mathbf{w} \\
&= \int\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i \exp\left(\beta x_{it}\right) c_j \exp\left(\beta w_{js}\right) \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-(\beta-\mu)^2/(2\sigma^2)\right\} f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\beta d\mathbf{x}d\mathbf{w} \\
&= \int\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\{\beta^2 - 2\mu\beta + \mu^2 - 2\sigma^2\beta(x_{it}+w_{js})\}/(2\sigma^2)\right] f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\beta d\mathbf{x}d\mathbf{w} \\
&= \int\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \frac{1}{\sqrt{2\pi\sigma^2}} \exp\Big[-\{\beta^2 - 2\beta(\mu+\sigma^2 x_{it}+\sigma^2 w_{js}) + (\mu+\sigma^2 x_{it}+\sigma^2 w_{js})^2 \\
&\qquad\qquad - (\mu+\sigma^2 x_{it}+\sigma^2 w_{js})^2 + \mu^2\}/(2\sigma^2)\Big] f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\beta d\mathbf{x}d\mathbf{w} \\
&= \int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \left\{\int \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\{\beta-(\mu+\sigma^2 x_{it}+\sigma^2 w_{js})\}^2/(2\sigma^2)\right] d\beta\right\} \\
&\qquad\qquad \cdot \exp\left[\mu(x_{it}+w_{js}) + \sigma^2(x_{it}+w_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\mathbf{x}d\mathbf{w} \\
&= \int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it}+w_{js}) + \sigma^2(x_{it}+w_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\mathbf{x}d\mathbf{w}
\end{aligned}
$$

Hence,

$$
\begin{aligned}
Var\,(D-A) = &\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it}+x_{js}) + \sigma^2(x_{it}+x_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x})d\mathbf{x} \\
&- \left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x})d\mathbf{x}\right]^2 \\
&+ \int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(w_{it}+w_{js}) + \sigma^2(w_{it}+w_{js})^2/2\right] f_{\mathbf{W}}(\mathbf{w})d\mathbf{w} \\
&- \left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{w_{it}\mu + \sigma^2 w_{it}^2/2\right\} f_{\mathbf{W}}(\mathbf{w})d\mathbf{w}\right]^2 \\
&- 2\int \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T}\sum_{s=1}^{T} c_i c_j \exp\left[\mu(x_{it}+w_{js}) + \sigma^2(x_{it}+w_{js})^2/2\right] f_{\mathbf{X}}(\mathbf{x})f_{\mathbf{W}}(\mathbf{w})d\mathbf{x}d\mathbf{w} \\
&+ 2\left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{x_{it}\mu + \sigma^2 x_{it}^2/2\right\} f_{\mathbf{X}}(\mathbf{x})d\mathbf{x}\right]\left[\int \sum_{i=1}^{N}\sum_{t=1}^{T} c_i \exp\left\{w_{it}\mu + \sigma^2 w_{it}^2/2\right\} f_{\mathbf{W}}(\mathbf{w})d\mathbf{w}\right]
\end{aligned}
$$

Monte Carlo Procedure and Simplifications

Monte Carlo for percent change in total summertime mortality

The integrals derived in Section 3.2 can be approximated by Monte Carlo as follows. First, simulate M realizations of summertime ozone in the present, $\boldsymbol{X}^{P,1}, \ldots, \boldsymbol{X}^{P,M}$ and M' realizations of summertime ozone in the future, $\boldsymbol{X}^{F,1}, \ldots, \boldsymbol{X}^{F,M'}$. Also simulate K realizations of β from the posterior distribution for the health effect, $\beta^1, \ldots, \beta^K$. Then, Equation (3) can be approximated as

$$\frac{1}{M'}\frac{1}{M}\frac{1}{K}\sum_{m'=1}^{M'}\sum_{k=1}^{K}\sum_{m=1}^{M}\left\{\frac{\eta(\beta^k, \boldsymbol{X}^{F,m'}) - \eta(\beta^k, \boldsymbol{X}^{P,m})}{\eta(\beta^k, \boldsymbol{X}^{P,m})}\right\}.$$

And Equation (4) can be approximated as

$$\frac{1}{M}\frac{1}{M'}\frac{1}{K}\sum_{m=1}^{M}\sum_{m'=1}^{M'}\sum_{k=1}^{K} I\left[\left\{\frac{\eta(\beta^k, \boldsymbol{X}^{F,m'}) - \eta(\beta^k, \boldsymbol{X}^{P,m})}{\eta(\beta^k \boldsymbol{X}^{P,m})}\right\} \leq a\right].$$

Monte Carlo for change in total summertime mortality

The integrals derived in Section 3.3 can be approximated by Monte Carlo as follows. Given M realizations of summertime ozone in the present, $\boldsymbol{X}^{P,1}, \ldots, \boldsymbol{X}^{P,M}$, and M' realizations of summertime ozone in the future, $\boldsymbol{X}^{F,1}, \ldots, \boldsymbol{X}^{F,M'}$, and K realizations of β from the posterior distribution for the health effect, $\beta^1, \ldots, \beta^K$, Equation (6), can be approximated as

$$\frac{1}{M'}\frac{1}{K}\sum_{m'=1}^{M'}\sum_{k=1}^{K}\eta(\beta^k, \boldsymbol{X}^{F,m'}) - \frac{1}{M}\frac{1}{K}\sum_{m=1}^{M}\sum_{k=1}^{K}\eta(\beta^k, \boldsymbol{X}^{P,m}).$$

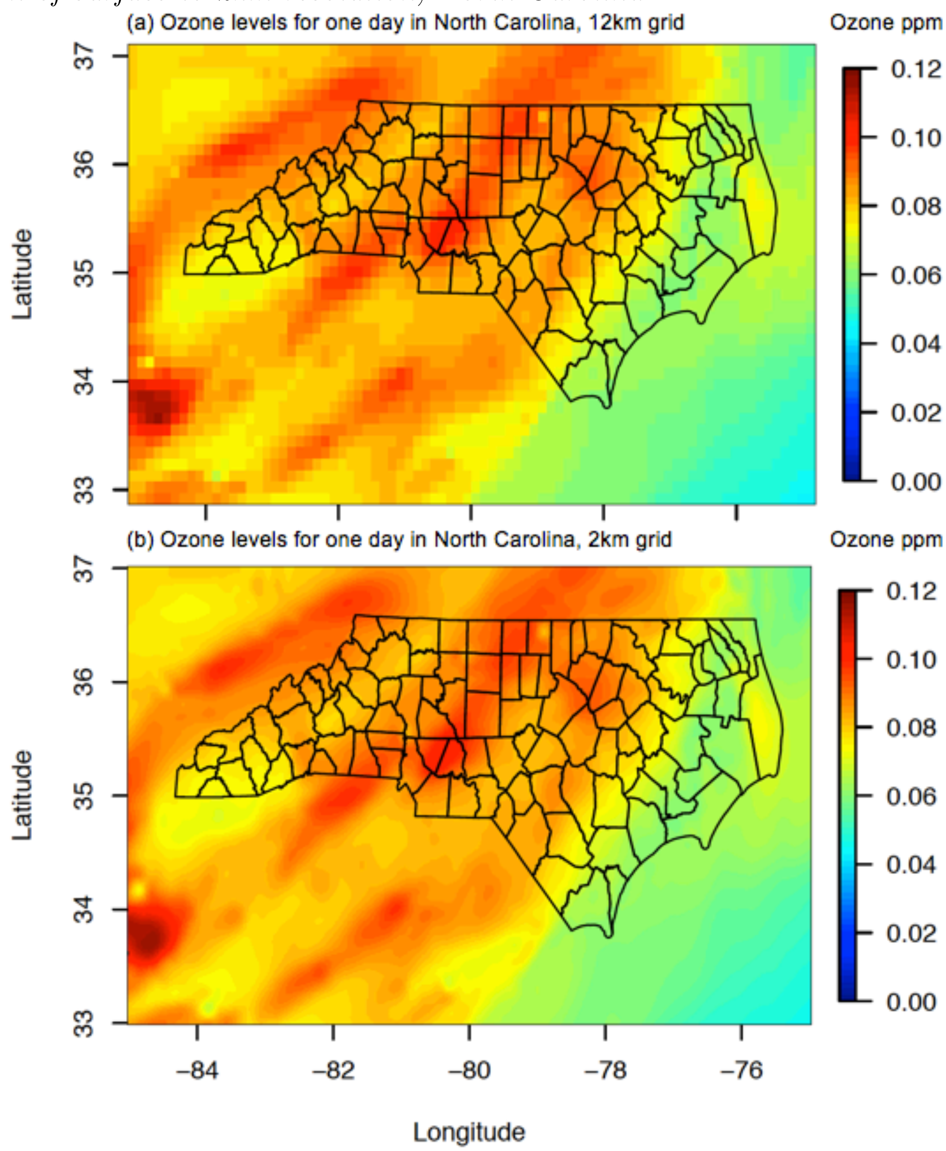
This approximates the posterior mean of the difference in expected summertime mortality between the future and the present. Equation (7) can be approximated as

$$\frac{1}{M}\frac{1}{M'}\frac{1}{K}\sum_{m=1}^{M}\sum_{m'=1}^{M'}\sum_{k=1}^{K} I\left[\eta(\beta^k, \boldsymbol{X}^{F,m'}) - \eta(\beta^k, \boldsymbol{X}^{P,m}) \leq a\right].$$

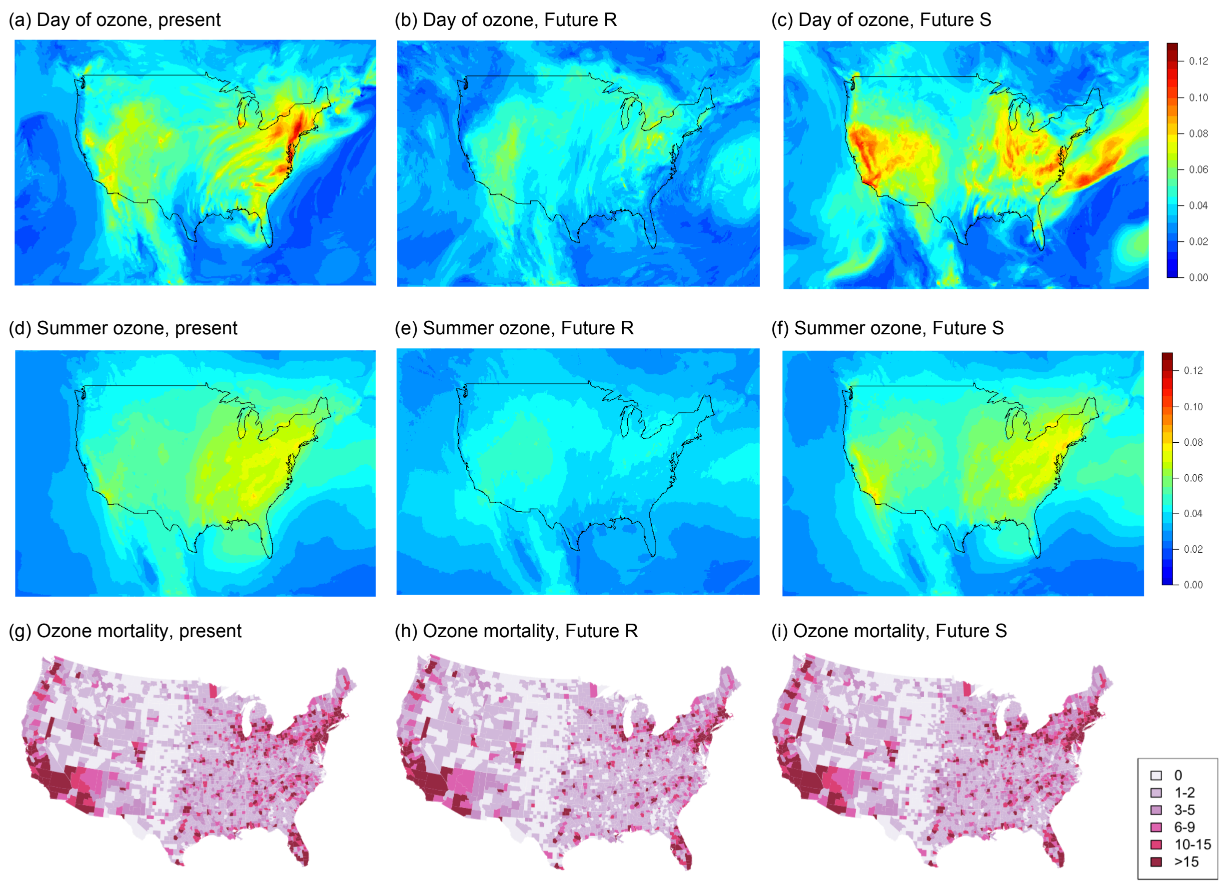
This approximates the c.d.f. of the posterior of the difference in expected summertime mortality between the future and the present for any a. To obtain the bounds for the central 95% credible interval, we approximate the inverse of the c.d.f by computing the 0.025 and 0.975 quantiles over all the Monte Carlo samples.

Web Appendix B

Web Figure 1: *Ozone concentration projections at 12km resolution and thin plate spline interpolation of surface to 2km resolution, North Carolina.*



Web Figure 2: *Ozone 24-hour average concentrations from atmospheric chemistry simulations at a 12km resolution over the U.S., for one day in the present, Future S, and Future R (a-c), for one summer in the present, Future S, and Future R (d-f), with the corresponding estimate of ozone-related mortality for that summer using the mean estimated heath association parameter (g-i).*



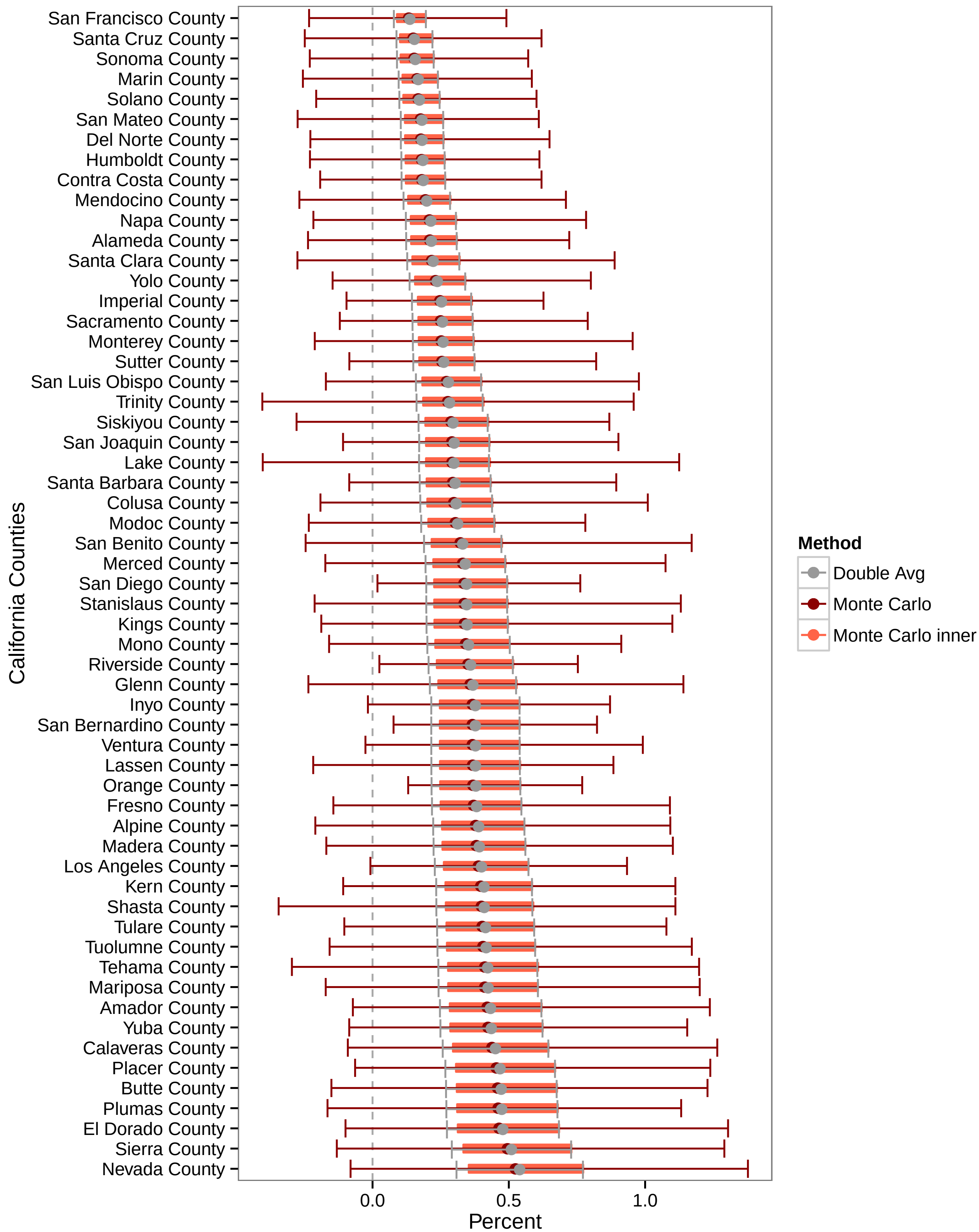
Web Table 1: *Estimated change in ozone-related deaths in summertime and estimated percent change in total summertime mortality attributable to ozone in each state for Future S compared to the present.*

	Difference			Percent Change		
StateName	Mean	2.5%	97.5%	Mean	2.5%	97.5%
DELAWARE	2	-7	14	0.16	-0.45	0.90
DISTRICT OF COLUMBIA	3	-6	13	0.21	-0.35	0.83
ALABAMA	27	-45	98	0.27	-0.44	0.96
FLORIDA	37	-151	232	0.10	-0.41	0.63
GEORGIA	36	-69	143	0.26	-0.48	1.01
IDAHO	6	-1	13	0.30	-0.04	0.61
ILLINOIS	53	-98	198	0.23	-0.42	0.85
INDIANA	43	-29	126	0.35	-0.23	1.00
IOWA	21	-16	65	0.33	-0.26	1.02
KANSAS	16	-17	52	0.31	-0.32	0.97
KENTUCKY	27	-27	83	0.31	-0.31	0.95
LOUISIANA	17	-49	75	0.19	-0.53	0.80
MAINE	4	-8	17	0.14	-0.29	0.62
MARYLAND	19	-37	84	0.20	-0.37	0.84
MASSACHUSETTS	18	-58	104	0.14	-0.44	0.79
MICHIGAN	46	-74	169	0.24	-0.38	0.87
MINNESOTA	22	-10	68	0.26	-0.11	0.81
MISSISSIPPI	15	-30	56	0.24	-0.49	0.91
MISSOURI	36	-34	109	0.29	-0.27	0.87
MONTANA	4	-0	10	0.20	-0.02	0.54
NEBRASKA	11	-4	31	0.32	-0.13	0.93
NEVADA	11	3	23	0.33	0.08	0.65
NEW HAMPSHIRE	5	-5	18	0.21	-0.25	0.82
NEW JERSEY	21	-84	142	0.13	-0.50	0.85
NEW MEXICO	6	-4	19	0.20	-0.14	0.66
NEW YORK	33	-144	229	0.09	-0.40	0.65
NORTH CAROLINA	24	-75	135	0.15	-0.47	0.85
NORTH DAKOTA	3	-2	10	0.21	-0.13	0.73
OHIO	74	-71	249	0.31	-0.29	1.02
OKLAHOMA	23	-28	67	0.30	-0.36	0.87
OREGON	17	-9	46	0.25	-0.14	0.68
PENNSYLVANIA	72	-92	258	0.24	-0.31	0.86
ARIZONA	15	-13	42	0.17	-0.15	0.48
RHODE ISLAND	2	-15	21	0.09	-0.64	0.90
SOUTH CAROLINA	11	-50	73	0.14	-0.61	0.91
SOUTH DAKOTA	5	-1	12	0.29	-0.05	0.77
TENNESSEE	37	-41	116	0.29	-0.31	0.89
TEXAS	73	-152	266	0.22	-0.45	0.79
UTAH	9	2	17	0.33	0.09	0.62
VERMONT	3	-2	10	0.22	-0.20	0.84
VIRGINIA	26	-41	103	0.20	-0.33	0.82
WASHINGTON	26	-10	69	0.27	-0.10	0.69
ARKANSAS	16	-29	57	0.26	-0.47	0.91
WEST VIRGINIA	13	-16	44	0.27	-0.33	0.94
WISCONSIN	23	-35	85	0.22	-0.34	0.83
WYOMING	3	1	6	0.34	0.09	0.70
CALIFORNIA	166	12	404	0.32	0.02	0.78
COLORADO	23	8	46	0.36	0.13	0.73
CONNECTICUT	7	-37	56	0.10	-0.54	0.82

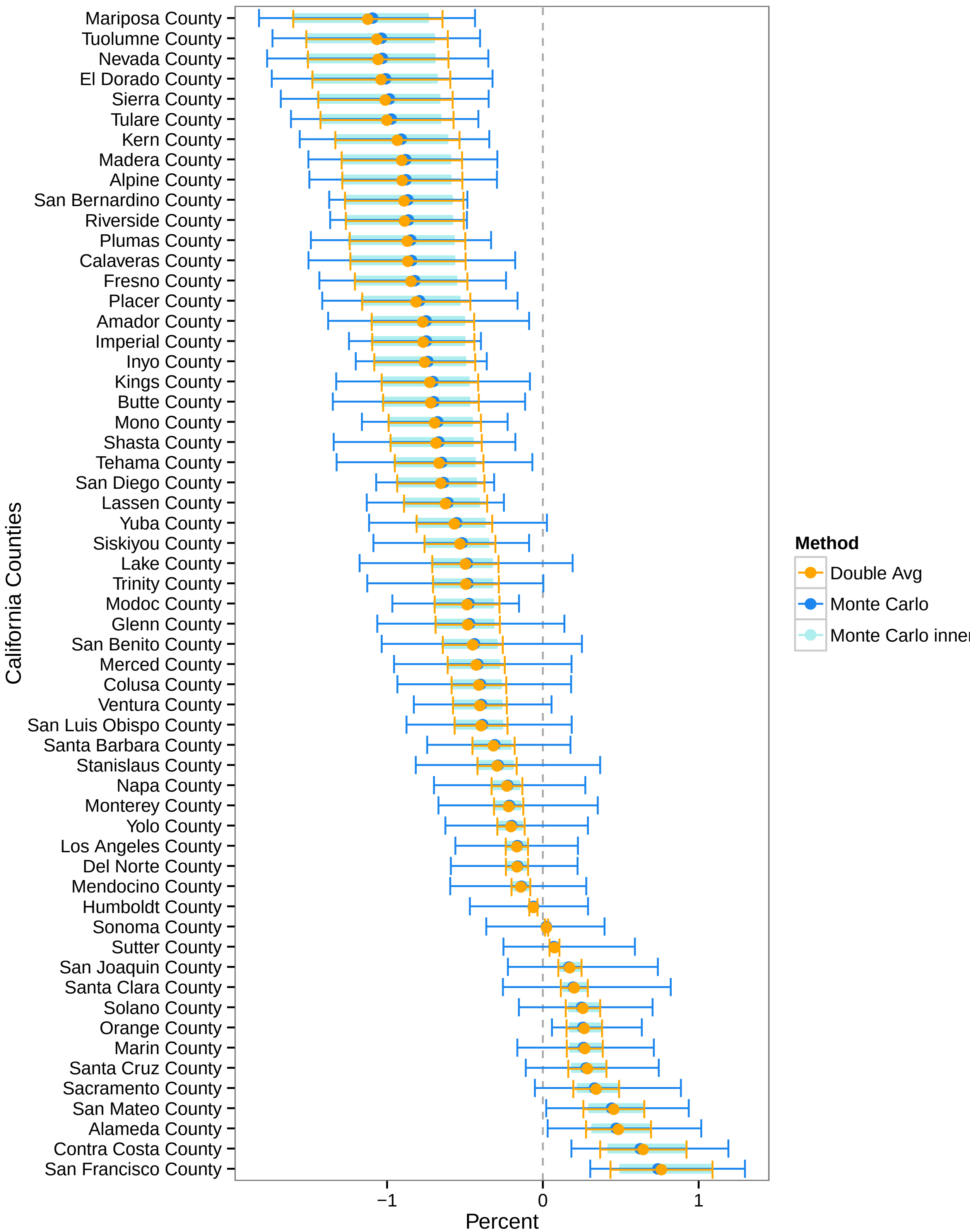
Web Table 2: *Estimated change in ozone-related deaths in summertime and estimated percent change in total summertime mortality attributable to ozone in each state for Future R compared to the present.*

	Difference			Percent Change		
StateName	Mean	2.5%	97.5%	Mean	2.5%	97.5%
DELAWARE	-16	-29	-6	-1.07	-1.91	-0.38
DISTRICT OF COLUMBIA	-5	-14	2	-0.30	-0.88	0.15
ALABAMA	-99	-188	-44	-0.98	-1.84	-0.44
FLORIDA	-24	-186	133	-0.06	-0.50	0.36
GEORGIA	-128	-240	-46	-0.90	-1.67	-0.32
IDAHO	-5	-11	-1	-0.24	-0.50	-0.05
ILLINOIS	-48	-198	55	-0.21	-0.84	0.24
INDIANA	-82	-161	-25	-0.65	-1.26	-0.20
IOWA	-41	-81	-10	-0.64	-1.27	-0.15
KANSAS	-31	-68	-4	-0.58	-1.27	-0.07
KENTUCKY	-75	-136	-35	-0.86	-1.54	-0.40
LOUISIANA	-50	-117	-17	-0.54	-1.25	-0.18
MAINE	-22	-37	-10	-0.78	-1.32	-0.35
MARYLAND	-81	-156	-27	-0.81	-1.54	-0.28
MASSACHUSETTS	-75	-154	-18	-0.57	-1.15	-0.14
MICHIGAN	-67	-185	2	-0.35	-0.94	0.01
MINNESOTA	-15	-45	9	-0.18	-0.53	0.11
MISSISSIPPI	-56	-107	-22	-0.91	-1.74	-0.36
MISSOURI	-84	-165	-24	-0.67	-1.30	-0.20
MONTANA	-4	-8	0	-0.20	-0.43	0.01
NEBRASKA	-11	-27	2	-0.33	-0.82	0.07
NEVADA	-20	-33	-11	-0.59	-0.94	-0.31
NEW HAMPSHIRE	-21	-35	-9	-0.98	-1.61	-0.43
NEW JERSEY	-78	-185	9	-0.46	-1.09	0.05
NEW MEXICO	-4	-15	4	-0.16	-0.53	0.14
NEW YORK	-27	-187	136	-0.08	-0.52	0.38
NORTH CAROLINA	-159	-280	-67	-1.00	-1.75	-0.43
NORTH DAKOTA	-3	-8	2	-0.22	-0.57	0.12
OHIO	-147	-304	-48	-0.60	-1.24	-0.20
OKLAHOMA	-56	-114	-17	-0.73	-1.46	-0.23
OREGON	-7	-31	14	-0.11	-0.46	0.22
PENNSYLVANIA	-219	-424	-77	-0.73	-1.40	-0.26
ARIZONA	-32	-69	-10	-0.38	-0.79	-0.12
RHODE ISLAND	-17	-34	-4	-0.75	-1.45	-0.16
SOUTH CAROLINA	-75	-141	-25	-0.92	-1.72	-0.32
SOUTH DAKOTA	-4	-10	0	-0.28	-0.61	0.03
TENNESSEE	-121	-223	-56	-0.93	-1.69	-0.44
TEXAS	-64	-277	69	-0.19	-0.82	0.21
UTAH	-1	-7	5	-0.04	-0.25	0.17
VERMONT	-14	-24	-6	-1.20	-1.98	-0.56
VIRGINIA	-133	-229	-59	-1.05	-1.79	-0.47
WASHINGTON	-10	-44	17	-0.10	-0.44	0.17
ARKANSAS	-60	-113	-27	-0.95	-1.78	-0.43
WEST VIRGINIA	-58	-97	-32	-1.23	-2.02	-0.68
WISCONSIN	-54	-118	-12	-0.52	-1.14	-0.12
WYOMING	-2	-4	-0	-0.22	-0.46	-0.01
CALIFORNIA	-94	-263	88	-0.18	-0.51	0.17
COLORADO	-2	-13	14	-0.03	-0.21	0.22
CONNECTICUT	-43	-87	-6	-0.63	-1.27	-0.09

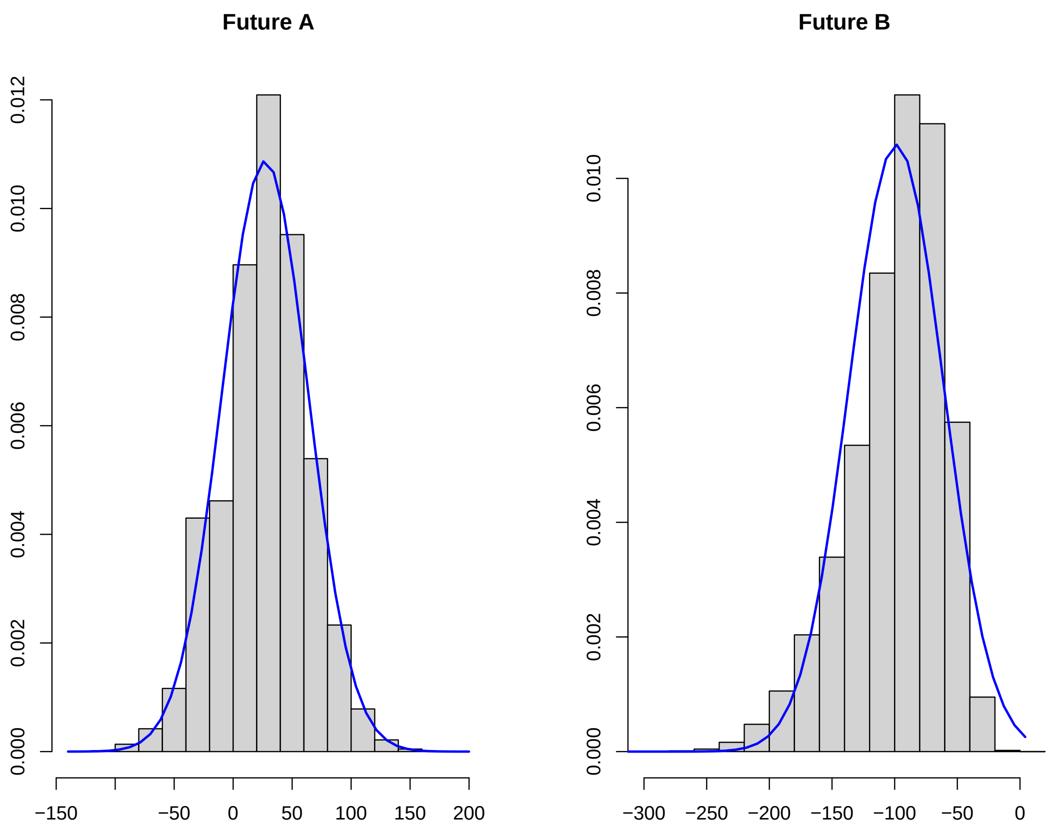
Web Figure 3: *Percent change in expected total summertime mortality attributable to ozone under Future S for each county in California, comparing our Bayesian model with Monte Carlo estimation method to the double averaging method.*



Web Figure 4: *Percent change in expected total summertime mortality attributable to ozone under Future R for each county in California, comparing our Bayesian model with Monte Carlo estimation method to the double averaging method.*



Web Figure 5: *Histogram of the Monte Carlo samples of ozone mortality over* β *and ozone, versus the Normal distribution using the mean and variance solution using the exact integral with respect to* β*.*



Web Appendix C

```
# Part I: Build my Ozone database
# for County average ozone
# with kriging interpolation step for change of support

# Stacey Alexeeff

# -------------------------------------------------------------- #
# Program Notes:
#    Creates a database in netcdf file "O3data_state##_county_YYYY_v04.nc"
#    Year read in from UNIX by echo command as variable "year1"
#    Read in my data from all "O3data_YYYY.nc"
#    For interpolation, uses fields package

# -------------------------------------------------------------- #
# Run Job Notes:
#    Run on geyser (one job, one node)
#    "Run_MyO3Data_county_netcdf_allyears_v04.lsf"
# -------------------------------------------------------------- #

library( ncdf4)
library( fields, lib.loc="~/work/Rpackages")

# -------------------------------------------------------------- #
# READ in data

  # Read in O3 for year1 from "O3data_YYYY.nc"
  file.year1 <- paste("~/O3data/O3data_",year1,".nc",sep="")
  NETCDF.year1 <- nc_open(file.year1)
     # daily O3 avgs for 92 days of summer
     O3_day_max1hr_array <- ncvar_get(NETCDF.year1, "O3_max1hr")
     O3_day_max8hr_array <- ncvar_get(NETCDF.year1, "O3_max8hr")
     O3_day_avg24hr_array <- ncvar_get(NETCDF.year1, "O3_avg24hr")
     # Lat, Long matrices
      Latitude <- ncvar_get(NETCDF.year1, "Latitude")
     Longitude <- ncvar_get(NETCDF.year1, "Longitude")
     # Date
     Date.char <- ncvar_get(NETCDF.year1, "Date")
  nc_close(NETCDF.year1)

   # Read in County labels
   # Labels assign each gridbox to a county - 2km
   County.2km.lab <- read.csv("~/Censusdata/County_2km_labels.csv", row.names="X")
   # Create State column
   County.2km.lab$State <- ifelse( nchar(as.character(County.2km.lab$CountyID))==4,
            substr(County.2km.lab$CountyID, 1,1 ), substr(County.2km.lab$CountyID, 1,2 ) )
   StateCountyList <- na.omit(  unique( subset(County.2km.lab, select=c(CountyID, State ))))
   StateNCountyList <- data.frame( table( StateCountyList$State))
   names(StateNCountyList) <- c("State","N_county")

  mystates = c( 1,4,5,6,8,9,10,11,12,13,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,
          34,35,36,37,38,39,40,41,42,44,45,46,47,48,49,50,51,53,54,55,56 )  # FIPS number
  N_days=92
```

```
# ---------------------------------------------------------------- #
# OUTPUT - create netcdf file "O3data_state##_county_YYYY_v04.nc"


# function to generate netcdf files for each state
create.netcdf.state <- function( state1, N_county ){

 # Define dimensions for variables for my new netcdf file
 N_days = 92; N_years = 13
county_index <- ncdim_def( "county_index", units="index county", vals=1:N_county )
   day_index <- ncdim_def( "day_index", units="index days of summer", vals=1:N_days)
  year_index <- ncdim_def( "year_index", units="index year of simulation", vals=1)
    dimnchar <- ncdim_def("nchar", "", 1:10, create_dimvar=FALSE )
    dim3char <- ncdim_def("char3", "", 1:3, create_dimvar=FALSE )

 # Define variables for my new netcdf file
 O3_max1hr <- ncvar_def( name="O3_max1hr", units="ppmv",
               dim=list(county_index,day_index,year_index),
               missval=NA,
               longname="1hr max O3 concentration at surface",
               prec="single")
 O3_max8hr <- ncvar_def( name="O3_max8hr", units="ppmv",
              dim=list(county_index,day_index,year_index),
               missval=NA,
               longname="8hr max O3 concentration at surface",
               prec="single")
 O3_avg24hr <- ncvar_def( name="O3_avg24hr", units="ppmv",
              dim=list(county_index,day_index,year_index),
               missval=NA,
               longname="24hr avg O3 concentration at surface",
               prec="single")
 CountyID  <- ncvar_def( name="CountyID", units="",
              dim=list(dim3char,county_index),
               longname="County FIPS ID from Census",
               prec="char")
 Date <- ncvar_def( name="Date", units="",
               dim=list(dimnchar,day_index,year_index),
               longname="Date as character string",
               prec="char")

 # Create a new netcdf file for all my O3 data
 mynetcdf.filename <- paste("O3data_state",state1,"_county_",year1,"_v04.nc",sep="")
 nc_create( mynetcdf.filename,
             vars=list(Date, O3_max1hr, O3_max8hr, O3_avg24hr, CountyID ),
             verbose=FALSE )

}

 # apply this function to list of states to create netcdfs for each state
 mapply(create.netcdf.state, StateNCountyList[,1],StateNCountyList[,2])
```

```
# -------------------------------------------------------------- #
# FOR LOOP over days in summer
#   O3 data: interpolate, then average over county

# loop over days
for(day in 1:N_days){

   # O3 for day
   O3_day_max1hr_USA_xyz <- list( x=Longitude[,1], y=Latitude[1,], z=O3_day_max1hr_array[,,day])
   O3_day_max8hr_USA_xyz <- list( x=Longitude[,1], y=Latitude[1,], z=O3_day_max8hr_array[,,day])
   O3_day_avg24hr_USA_xyz<- list( x=Longitude[,1], y=Latitude[1,], z=O3_day_avg24hr_array[,,day])


   # -------------------------------------------------------------- #
   # INTERPOLATE daily O3 data from 12km to 2km

   if( day==1 ){    # fit interpolation and make grids only once
     # Fit thin plate spline with theta=0.25
     xg <- make.surface.grid( list( x=O3_day_max1hr_USA_xyz$x, y=O3_day_max1hr_USA_xyz$y))
     # interpolation, no smoothing
     TpsObject <- fastTps(xg, c( O3_day_max1hr_USA_xyz$z), theta = 0.25, lambda=0)
     # INTERPOLATE to 2km grid
     gridList<- list( x= seq( min(O3_day_avg24hr_USA_xyz$x), max(O3_day_avg24hr_USA_xyz$x),
                             length=length(O3_day_avg24hr_USA_xyz$x)*6),
                     y= seq( min(O3_day_avg24hr_USA_xyz$y), max(O3_day_avg24hr_USA_xyz$y),
                             length=length(O3_day_avg24hr_USA_xyz$y)*6)   )
     # use version in fields 6.8.1
     Tps.max1hr.out <- predictSurfaceFastTps(TpsObject, gridList )
    }else{     # otherwise use existing grid and update interpolation
     Tps.max8hr.out <- predictSurfaceFastTps(TpsObject, gridList, ynew=c(O3_day_max1hr_USA_xyz$z))
    }

   # Update to 2km grid by changing O3 only, really fast
   Tps.max8hr.out  <- predictSurfaceFastTps(TpsObject, gridList, ynew=c(O3_day_max8hr_USA_xyz$z))
   Tps.avg24hr.out <- predictSurfaceFastTps(TpsObject, gridList, ynew=c(O3_day_avg24hr_USA_xyz$z))

   # -------------------------------------------------------------- #
   # AVERAGE OVER COUNTY
   # Average ozone over gridboxes within each NC county - 2km
   O3_county_day_max1hr <- tapply( as.vector(Tps.max1hr.out$z), County.2km.lab$CountyID, mean)
   O3_county_day_max8hr <- tapply( as.vector(Tps.max8hr.out$z), County.2km.lab$CountyID, mean)
   O3_county_day_avg24hr<- tapply( as.vector(Tps.avg24hr.out$z),County.2km.lab$CountyID, mean)

   # -------------------------------------------------------------- #
   # OUTPUT - netcdf file "O3data_state##_county_YYYY_v04.nc"

   # Split data into a list by state
    state.factor <-  ifelse( nchar(names(O3_county_day_max1hr))==4,
           substr(names(O3_county_day_max1hr),1,1), substr(names(O3_county_day_max1hr),1,2))
    O3_county_day_max1hr_statelist <- split(O3_county_day_max1hr, state.factor)
    O3_county_day_max8hr_statelist <- split(O3_county_day_max8hr, state.factor)
    O3_county_day_avg24hr_statelist <- split(O3_county_day_avg24hr, state.factor)
```

```
 for( i.state in 1:49){
   state1=names(table(state.factor))[i.state]
   # Write each county avg vector of O3 data to my netcdf file
   mynetcdf.filename <- paste("O3data_state",state1,"_county_",year1,"_v04.nc",sep="")
   NETCDF.new <- nc_open( mynetcdf.filename, write=TRUE )
   ncvar_put( NETCDF.new, varid="O3_max1hr", vals=O3_county_day_max1hr_statelist[[i.state]],
      start=c(1,day,1), count=c(-1,1,1) )
   ncvar_put( NETCDF.new, varid="O3_max8hr", vals=O3_county_day_max8hr_statelist[[i.state]],
      start=c(1,day,1), count=c(-1,1,1) )
   ncvar_put( NETCDF.new, varid="O3_avg24hr", vals=O3_county_day_avg24hr_statelist[[i.state]],
      start=c(1,day,1), count=c(-1,1,1) )
   ncvar_put( NETCDF.new, varid="Date", vals=Date.char, start=c(1,day,1), count=c(-1,1,1) )
   CountyID_statei <- ifelse( nchar(names( O3_county_day_avg24hr_statelist[[i.state]] ))==4,
      substr(names( O3_county_day_avg24hr_statelist[[i.state]] ),2,4),
      substr(names( O3_county_day_avg24hr_statelist[[i.state]] ), 3,5 ) )
   ncvar_put( NETCDF.new, varid="CountyID", vals=CountyID_statei, start=c(1,1), count=c(-1,-1))
   nc_close(NETCDF.new)
  }

}

# END OF FOR LOOP
# -------------------------------------------------------------- #
```

```
# Part II: Monte Carlo Sampling
# Ozone and Mortality - US
# Stacey Alexeeff

# -------------------------------------------------------------- #
# Datasets used:
# Ozone simulations:
#    ~/O3data/O3data_state##_county_YYYY_v04.nc
#    for YYYY 1996-2008, 2046-2058, 2046a-2058a
#    for ## state codes (FIPS)
# Population (US Census 2000):
#    ~/Censusdata/USCensus2000_PopulationData_state##_County.csv
#    for ## state codes (FIPS)
#
# Program Notes:
#     "state1" variable read in from UNIX by echo command as part of batch job

# -------------------------------------------------------------- #
library( ncdf4)
library( fields)
library( maps)

# -------------------------------------------------------------- #
# settings
 K=100
 M=13

# -------------------------------------------------------------- #
# Beta distribution from meta-analysis
# Bell et al. 2005, US only resuls
# 10-ppb increase in daily 24hr avg ozone associated with
# Pooled Log-relative rate, total mortality: 0.84%

# parameters for 1-ppb increase:
  mu_beta = 0.00084          # US only results
  sigma_beta = 0.000183      # US only results

# -------------------------------------------------------------- #
# Census Data

# Population
  Census <- read.csv(paste("USCensus2000_PopulationData_state",state1,"_County.csv",sep=""))

# Number of counties
  Ncounty = nrow(Census)

# -------------------------------------------------------------- #
# CDC Data
# Daily Mortality Rate for state

source(paste("~/CDCdata/MortalityRate_state",state1,".r",sep=""))
```

```
# -------------------------------------------------------------- #
# Sampling - Future S vs. Present, Future vs. Present

deaths.summer.diff.F <- matrix(nrow=M*M*K,ncol=Ncounty)
deaths.summer.diff.FS <- matrix(nrow=M*M*K,ncol=Ncounty)
deaths.summer.pres <- matrix(nrow=M*M*K,ncol=Ncounty)
fun1 <- function(x,b){ sum( exp(b*x) ) }

# Present ozone data, loop over years
for(m1 in 1:M){
  year.m1 = (1996:2008)[m1]
  file.O3data.m1 <- paste("~/O3data/O3data_state",state1,"_county_",year.m1,"_v04.nc",sep="")
  NETCDF.O3data.m1 <- nc_open(file.O3data.m1)
  # present summer ozone, ppm, all counties
  O3_avg24hr_county.m1 <- array(NA, dim=c(Ncounty,92) )
  O3_avg24hr_county.m1[,] <- 1000*ncvar_get(NETCDF.O3data.m1, "O3_avg24hr")
  nc_close(NETCDF.O3data.m1)

  # Future, Future S ozone data, loop over years
  for(m2 in 1:M){
    year.m2 = (2046:2058)[m2]

    # Future S
    file.O3data.m2.FS <- paste("~/O3data/O3data_state",state1,"_county_",year.m2,"a_v04.nc",sep="")
    NETCDF.O3data.m2.FS <- nc_open(file.O3data.m2.FS)
    # future summer ozone, ppm, all counties
    O3_avg24hr_county.m2.FS <- array(NA, dim=c(Ncounty,92) )
    O3_avg24hr_county.m2.FS[,] <- 1000*ncvar_get(NETCDF.O3data.m2.FS, "O3_avg24hr")
    nc_close(NETCDF.O3data.m2.FS)

    # Future
    file.O3data.m2.F <- paste("~/O3data/O3data_state",state1,"_county_",year.m2,"_v04.nc",sep="")
    NETCDF.O3data.m2.F <- nc_open(file.O3data.m2.F)
    # future summer ozone, ppm, all counties
    O3_avg24hr_county.m2.F <- array(NA, dim=c(Ncounty,92) )
    O3_avg24hr_county.m2.F[,] <- 1000*ncvar_get(NETCDF.O3data.m2.F, "O3_avg24hr")
    nc_close(NETCDF.O3data.m2.F)

    # loop over samples of beta
    for(k in 1:K){
      beta.k = rnorm(1, mean=mu_beta, sd=sigma_beta)

      mmk = M*M*(k-1) + M*(m1-1)+m2        # Index
      # Compute deaths for each county
      # Differences
      deaths.summer.diff.FS[mmk,] <- MR*Census$POP100*(apply(O3_avg24hr_county.m2.FS,1,fun1,beta.k)
                                     -  apply(O3_avg24hr_county.m1,1,fun1,beta.k ) )
      deaths.summer.diff.F[mmk,] <- MR*Census$POP100*(apply(O3_avg24hr_county.m2.F,1,fun1,beta.k)
                                     -  apply(O3_avg24hr_county.m1,1,fun1,beta.k ) )
     # Present total
     deaths.summer.pres[mmk,] <- MR*Census$POP100*(apply(O3_avg24hr_county.m1,1,fun1,beta.k) )
   }
   }
}
```

```
# ------------------------------------------------------------- #
# Save samples
write.csv(deaths.summer.diff.FS,
   paste("Results_Ozone_Mortality_Diff_FutureS_state",state1,"_County.csv",sep="") )
write.csv(deaths.summer.diff.F,
   paste("Results_Ozone_Mortality_Diff_Future_state",state1,"_County.csv",sep="") )
write.csv(deaths.summer.pres,
   paste("Results_Ozone_Mortality_Present_state",state1,"_County.csv",sep="") )
```