Mortality Effects of Reduced Sulfur Oxide Air Pollution Due to a Copper Smelting Strike in 1967-1968

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Pollution from Geneva Steel–Utah Valley

Epidemiological evidence
(Pope et al. 1989-1996)

- Increased pediatric respiratory hospital admissions
- Increased respiratory symptoms
- Reduced lung function
- Increased school absences
- Increased respiratory and cardiovascular deaths

Experimental evidence of biological effects of PM extracted from filters
(Ghio, Kennedy, Frampton, Costa, Dye, Devlin et al. 1998-2004)

- Acute airway injury and inflammation in rats and humans
- *In vitro* oxidative stress and release of proinflammatory mediators by cultured respiratory epithelial cells
- Differential toxicities of PM when the mill was operating versus when it was not (metals content and mixtures?)

Table 2. Comparison of percentage increase (and 95% CI) in relative risk of mortality associated with long-term particulate exposure.

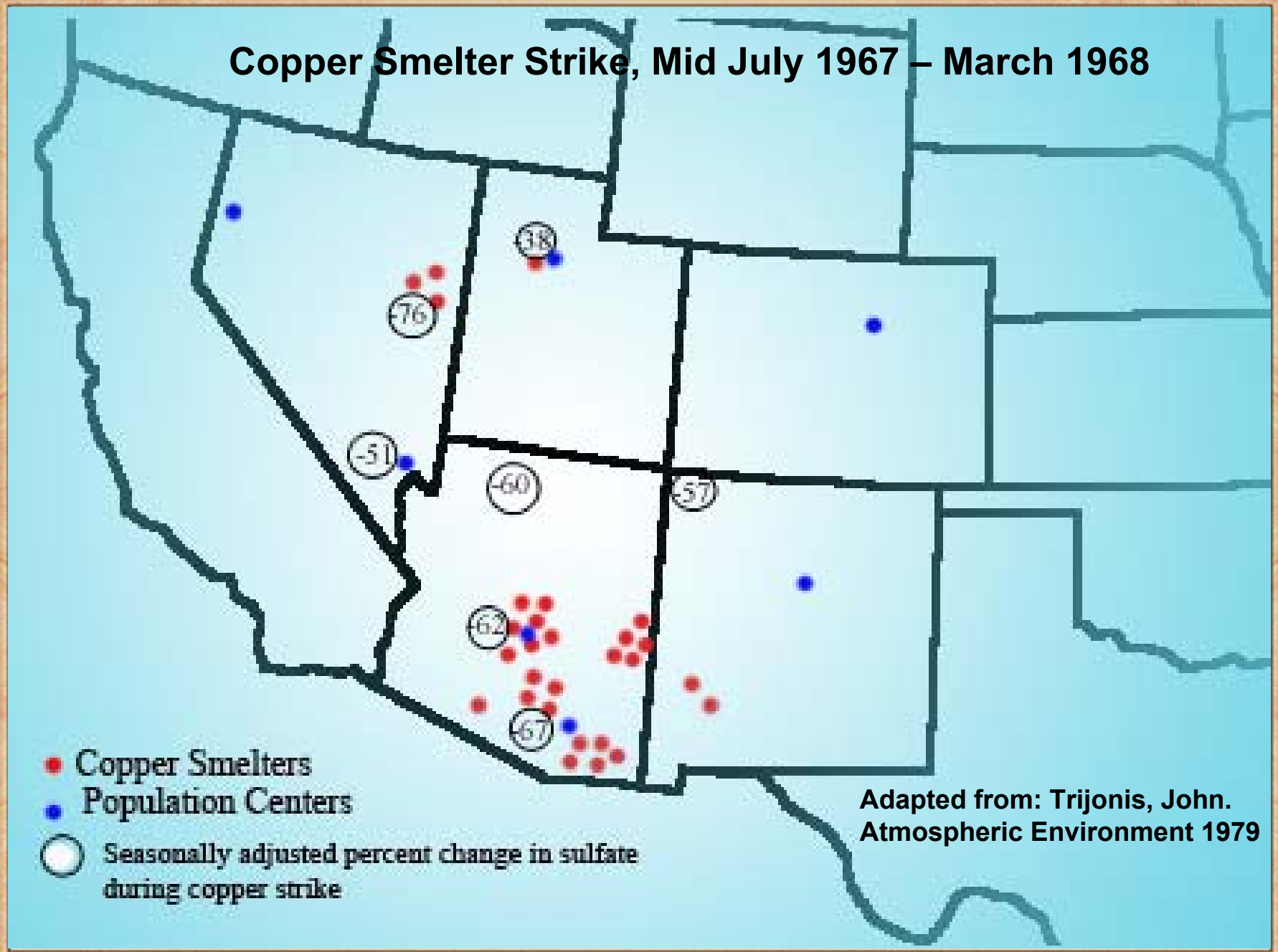
Study	Primary Sources	Exposure Increment	Percent Increases in Relative Risk of Mortality (95% CI)		
			All Cause	Cardiopulmonary	Lung Cancer
Harvard Six Cities, original	Dockery et al. 1993[26]	10 $\mu g/m^3$ $PM_{2.5}$	13 (4.2, 23)	18 (6.0, 32)	18 (−11, 57)
Harvard Six Cities, HEI reanalysis	Krewski et al. 2000[177]	10 $\mu g/m^3$ $PM_{2.5}$	14 (5.4, 23)	19 (6.5, 33)	21 (−8.4, 60)
Harvard Six Cities, extended analysis	Laden et al. 2006[184]	10 $\mu g/m^3$ $PM_{2.5}$	16 (7, 26)	28 (13, 44)[a]	27 (−4, 69)
ACS, original	Pope et al. 1995[27]	10 $\mu g/m^3$ $PM_{2.5}$	6.6 (3.5, 9.8)	12 (6.7,17)	1.2 (−8.7, 12)
ACS, HEI reanalysis	Krewski et al. 2000[177]	10 $\mu g/m^3$ $PM_{2.5}$	7.0 (3.9, 10)	12 (7.4, 17)	0.8 (−8.7, 11)
ACS, extended analysis	Pope et al. 2002[179]	10 $\mu g/m^3$ $PM_{2.5}$	6.2 (1.6, 11)	9.3 (3.3, 16)	13.5 (4.4, 23)
	Pope et al. 2004[180]			12 (8, 15)[a]	
ACS adjusted using various education weighting schemes	Dockery et al. 1993[26]	10 $\mu g/m^3$ $PM_{2.5}$	8–11	12–14	3–24
	Pope et al. 2002[179]				
	Krewski et al. 2000[177]				
ACS intrametro Los Angeles	Jerrett et al. 2005[181]	10 $\mu g/m^3$ $PM_{2.5}$	17 (5, 30)	12 (−3, 30)	44 (−2, 211)
Postneonatal infant mortality, U.S.	Woodruff et al. 1997[185]	20 $\mu g/m^3$ PM_{10}	8.0 (4, 14)	–	–
Postneonatal infant mortality, CA	Woodruff et al. 2006[186]	10 $\mu g/m^3$ $PM_{2.5}$	7.0 (−7, 24)	113 (12, 305)[c]	–
AHSMOG[b]	Abbey et al. 1999[187]	20 $\mu g/m^3$ PM_{10}	2.1 (−4.5, 9.2)	0.6 (−7.8, 10)	81 (14, 186)
AHSMOG, males only	McDonnell et al. 2000[188]	10 $\mu g/m^3$ $PM_{2.5}$	8.5 (−2.3, 21)	23 (−3, 55)	39 (−21, 150)
AHSMOG, females only	Chen et al. 2005[189]	10 $\mu g/m^3$ $PM_{2.5}$	–	42 (6, 90)[a]	–
Women's Health Initiative	Miller et al. 2004[190]	10 $\mu g/m^3$ $PM_{2.5}$	–	32 (1, 73)[a]	
VA, preliminary	Lipfert et al. 2000, 2003[190,192]	10 $\mu g/m^3$ $PM_{2.5}$	0.3 (NS)[d]	–	–
VA, extended	Lipfert et al. 2006[193]	10 $\mu g/m^3$ $PM_{2.5}$	15 (5, 26)[a]	–	–
11 CA counties, elderly	Enstrom 2005[194]	10 $\mu g/m^3$ $PM_{2.5}$	1 (−0.6, 2.6)	–	–
Netherlands	Hoek et al. 2002[195]	10 $\mu g/m^3$ BS	17 (−24, 78)	34 (−32, 164)	–
Netherlands	Hoek et al. 2002[195]	Near major road	41 (−6, 112)	95 (9, 251)	–
Hamilton, Ontario, Canada	Finkelstein et al. 2004[197]	Near major road	18 (2, 38)	–	–
French PAARC	Filleul et al. 2005[198]	10 $\mu g/m^3$ BS	7 (3, 10)[f]	5 (−2,12)[f]	3 (−8,15)[f]
Cystic fibrosis	Goss et al. 2004[200]	10 $\mu g/m^3$ $PM_{2.5}$	32 (−9, 93)	–	–

10 $\mu g/m^3$ $PM_{2.5}$ → approximately 6% to 17% increase in relative risk of mortality, with some outliers.

Generally bigger effects on cardiopulmonary/cardiovascular disease mortality.

Interesting paper by: John Trijonis. Visibility in the Southwest—An Exploration of the Historical Data Base. *Atmospheric Environment*. 1979

- During the late 1960's copper smelters were the source of more than 90% of SO_x emissions in the Southwest.
- Between mid July 1967 – March 1968 a copper smelter strike shut down copper smelters in the Southwest.
- During the strike, average regional sulfate concentrations were reduced by about 1-3 $\mu g/m^3$.
- Substantial improvements in visibility were also observed.


Copper Smelter Strike, Mid July 1967 – March 1968
-38
-76
-51
-60
-57
-62
-67
Copper Smelters
Population Centers
Seasonally adjusted percent change in sulfate during copper strike
Adapted from: Trijonis, John. Atmospheric Environment 1979

Research question:

Given that the strike resulted in measurable reductions in regional sulfate concentrations and improvements in visibility, were there also measurable reductions in mortality?

Mortality data collected for 1960-1975:

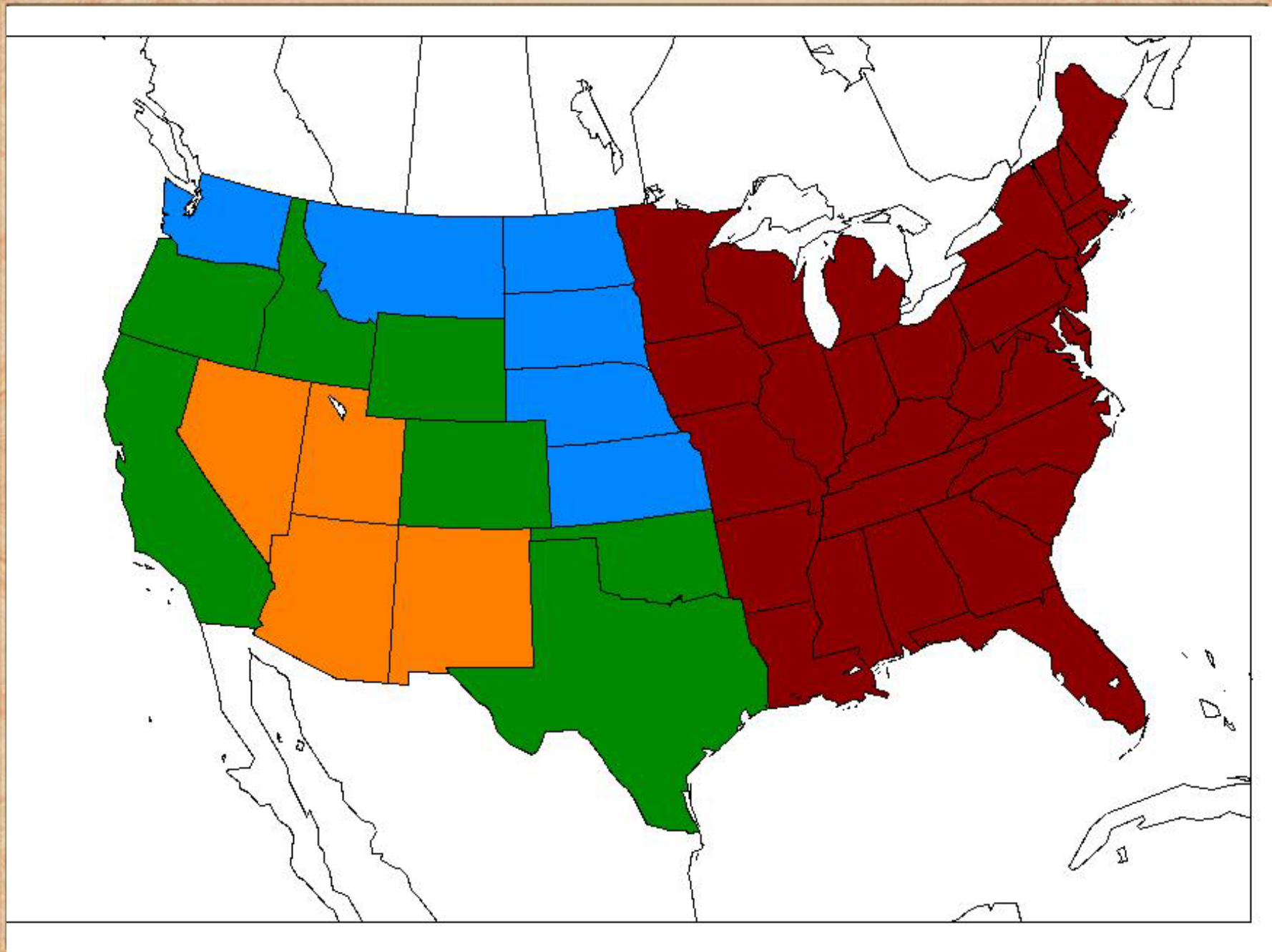
1. Total monthly mortality counts for U.S., each state, and different regions.

2. Monthly counts for different causes of death (Influenza/Pneumonia, CVD, other respiratory) for U.S.

Source of mortality data: U.S. Dept. of Health Services, National Center for Health Statistics. Vital Statistics of the United States.

Complications:

- Monthly mortality counts by cause of death available for U.S. but not by state.
- Change in ICD coding (ICD7-ICD8) on Jan. 1968 (right in the middle of the strike).
- Influenza pandemic during year following strike.



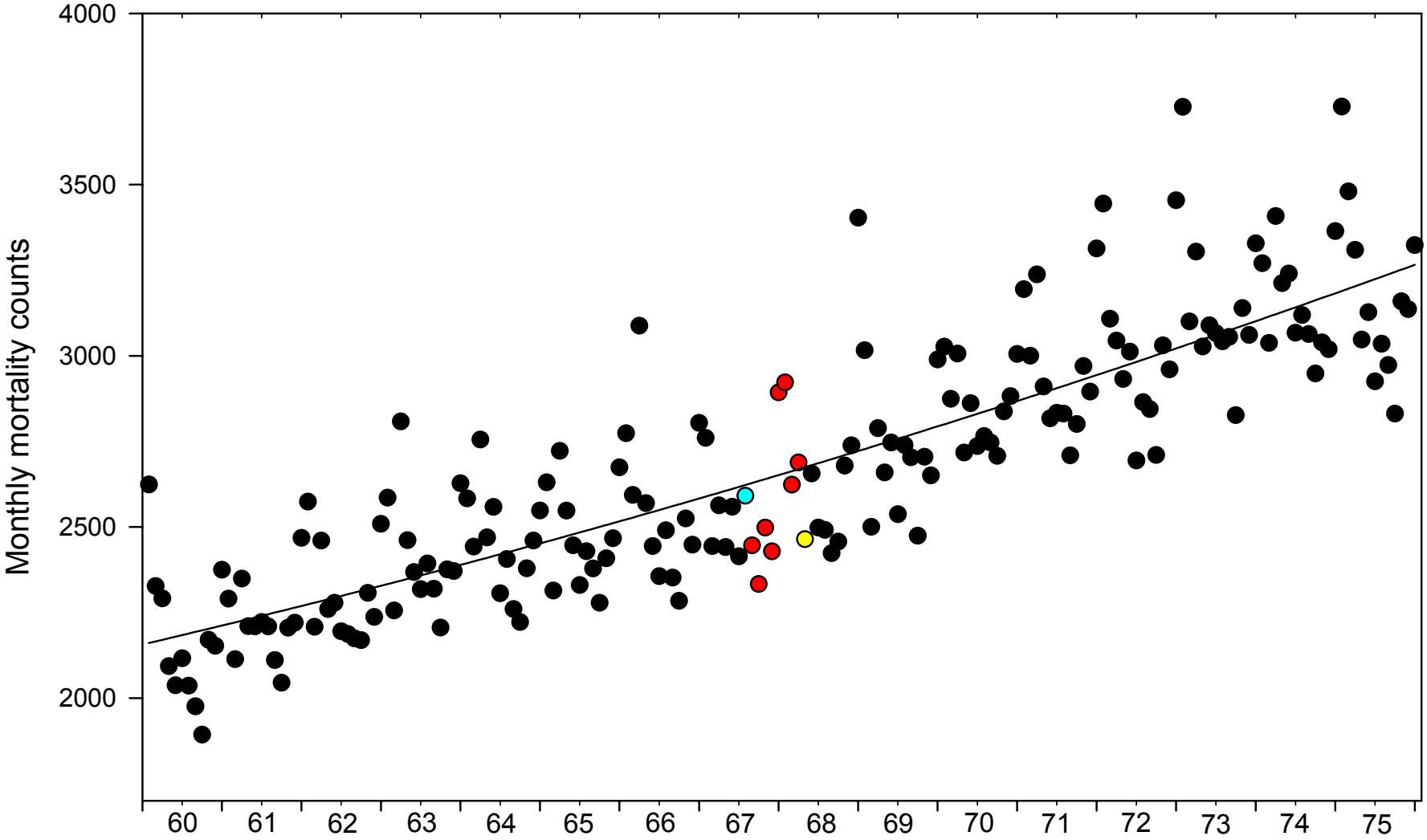


Figure 1. Monthly mortality counts for the 4 Southwest states plotted over time. The blue dot indicates the month when strike began mid month (July 1967). Red dots indicate full strike months (Aug. 1967-March 1968). Yellow dot indicates first end-of-strike month (April 1968).

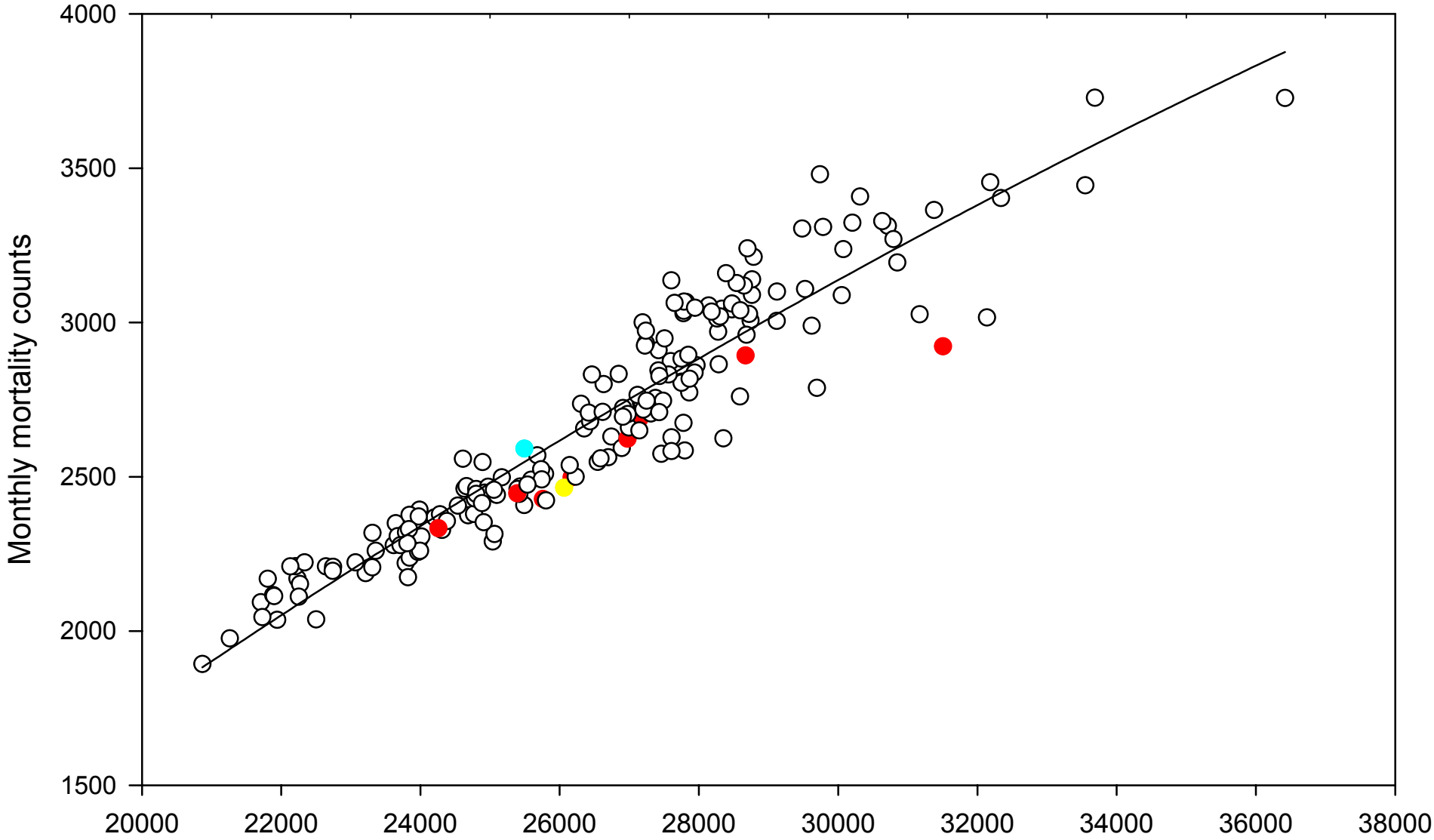


Figure 2. Monthly mortality counts for the 4 Southwest states plotted over monthly mortality counts for bordering states. The blue dot indicates the month when strike began mid month (July 1967). Red dots indicate full strike months (Aug. 1967-March 1968). Yellow dot indicates first end-of-strike month (April 1968).

Model	Control for Time	Mortality Count	Causes of Mortality
1	3 df spline smoother	Rest of US	---
2	3 df spline smoother	Eastern US	---
3	3 df spline smoother	Neighboring States	---
4	3 df spline smoother	Bordering States	---
5	3 df spline smoother	Rest of US	Influenza/Pneumonia†
6	3 df spline smoother	Eastern US	Influenza/Pneumonia
7	3 df spline smoother	Neighboring States	Influenza/Pneumonia
8	3 df spline smoother	Bordering States	Influenza/Pneumonia
9	3 df spline smoother	Rest of US	Influenza/Pneumonia, CVD‡, other respiratory
10	3 df spline smoother	Eastern US	Influenza/Pneumonia, CVD, other respiratory
11	3 df spline smoother	Neighboring States	Influenza/Pneumonia, CVD, other respiratory
12	3 df spline smoother	Bordering States	Influenza/Pneumonia, CVD, other respiratory

† Due to a change in ICD codes from the 7th to the 8th revision in January of 1968, two separate variables were created for influenza/pneumonia, CVD, and other respiratory to account for the change.

‡ CVD – Cardiovascular Disease

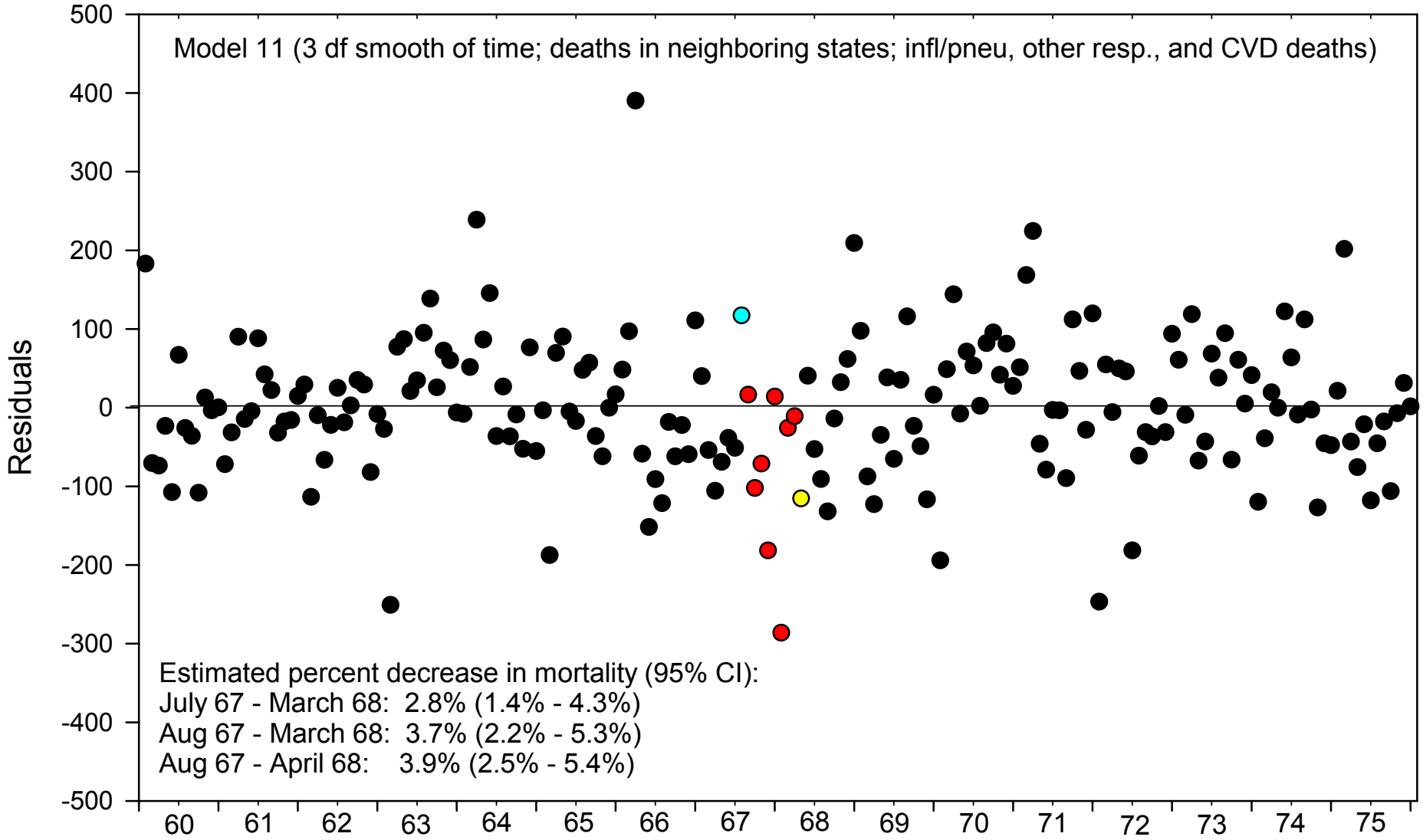


Figure 3a. Residual plot of model 11. The blue dot indicates the month when strike began mid month (July 1967). Red dots indicate full strike months (Aug. 1967-March 1968). Yellow dot indicates first end-of-strike month (April 1968).

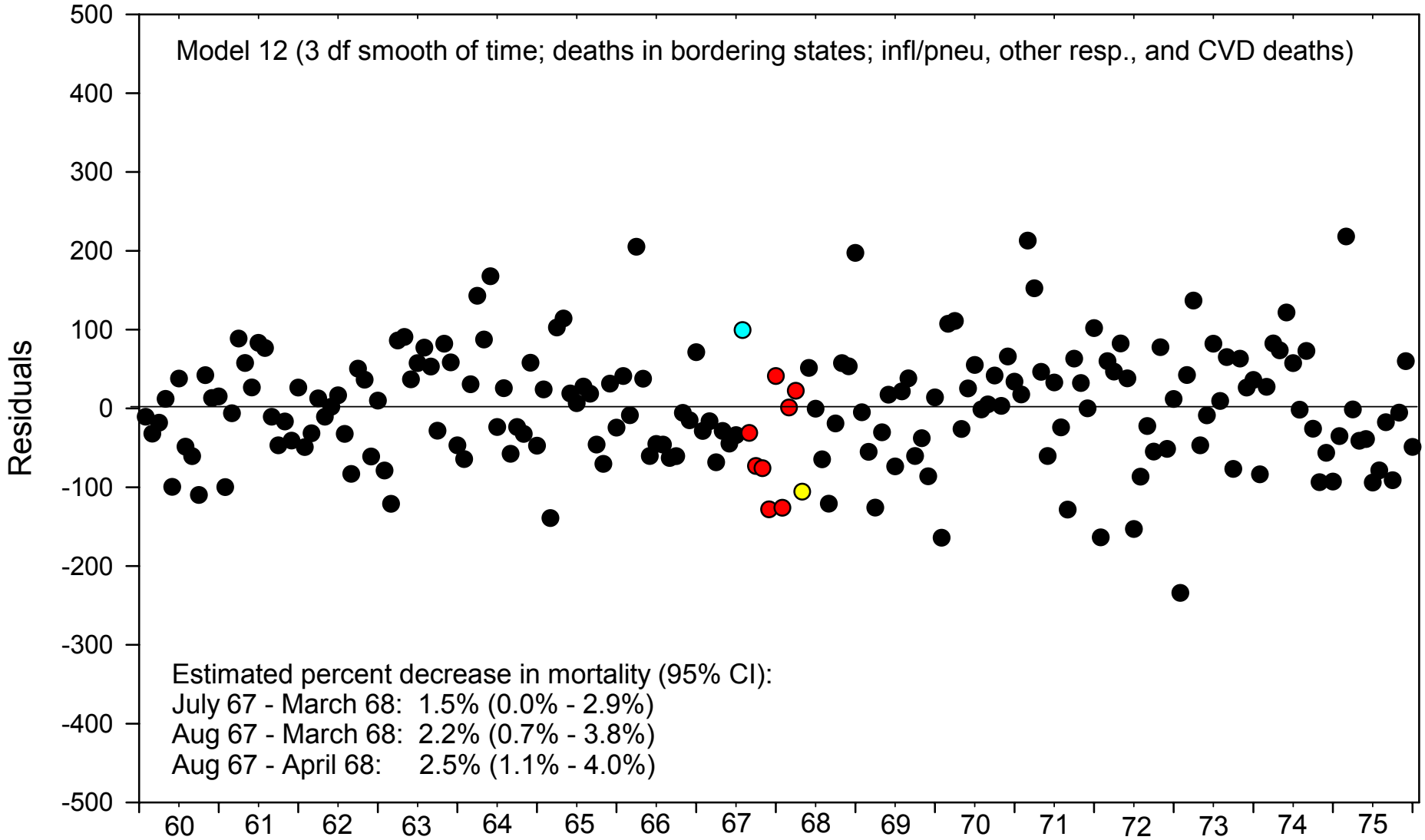


Figure 3b. Residual plots of model 12. The blue dot indicates the month when strike began mid month (July 1967). Red dots indicate full strike months (Aug. 1967-March 1968). Yellow dot indicates first end-of-strike month (April 1968).

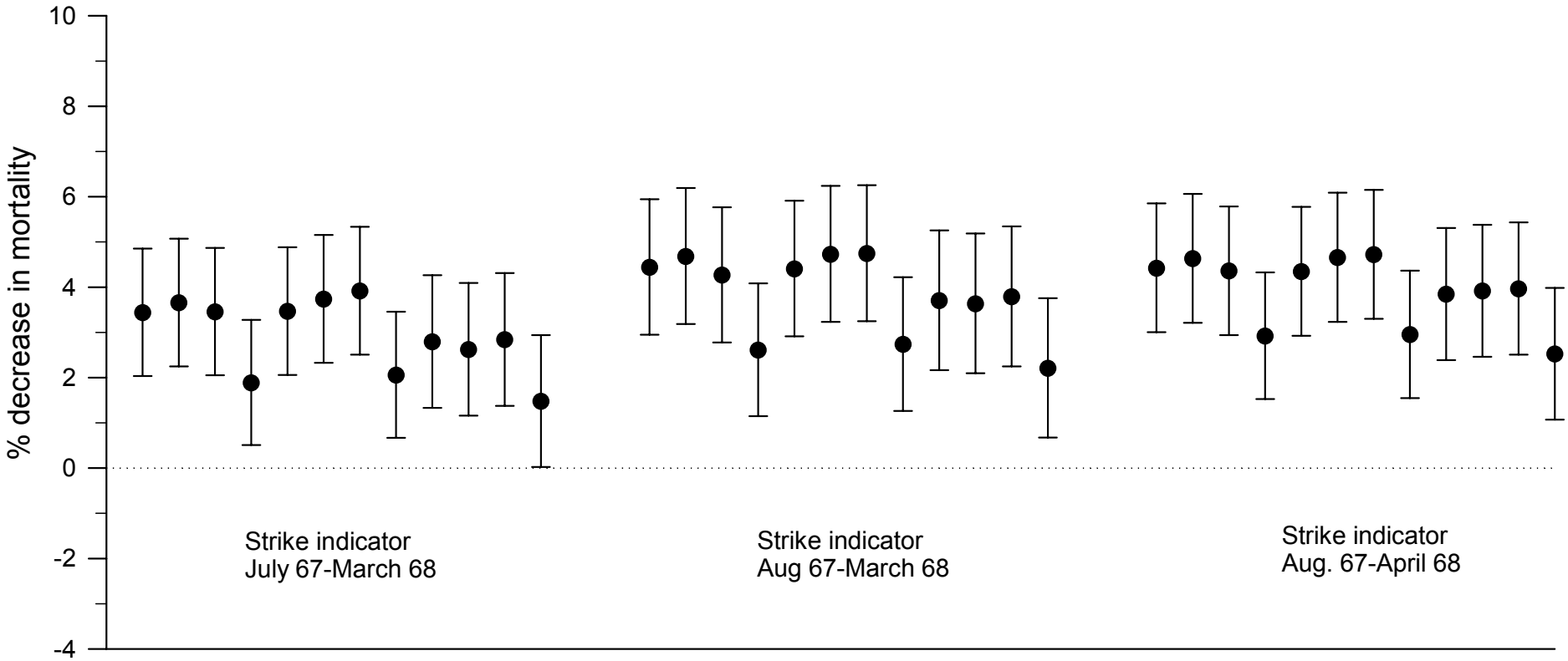


Figure 4. Estimated percent decrease in mortality (and 95% CIs) associated with different strike indicator periods for the 12 different models for all four Southwest states.

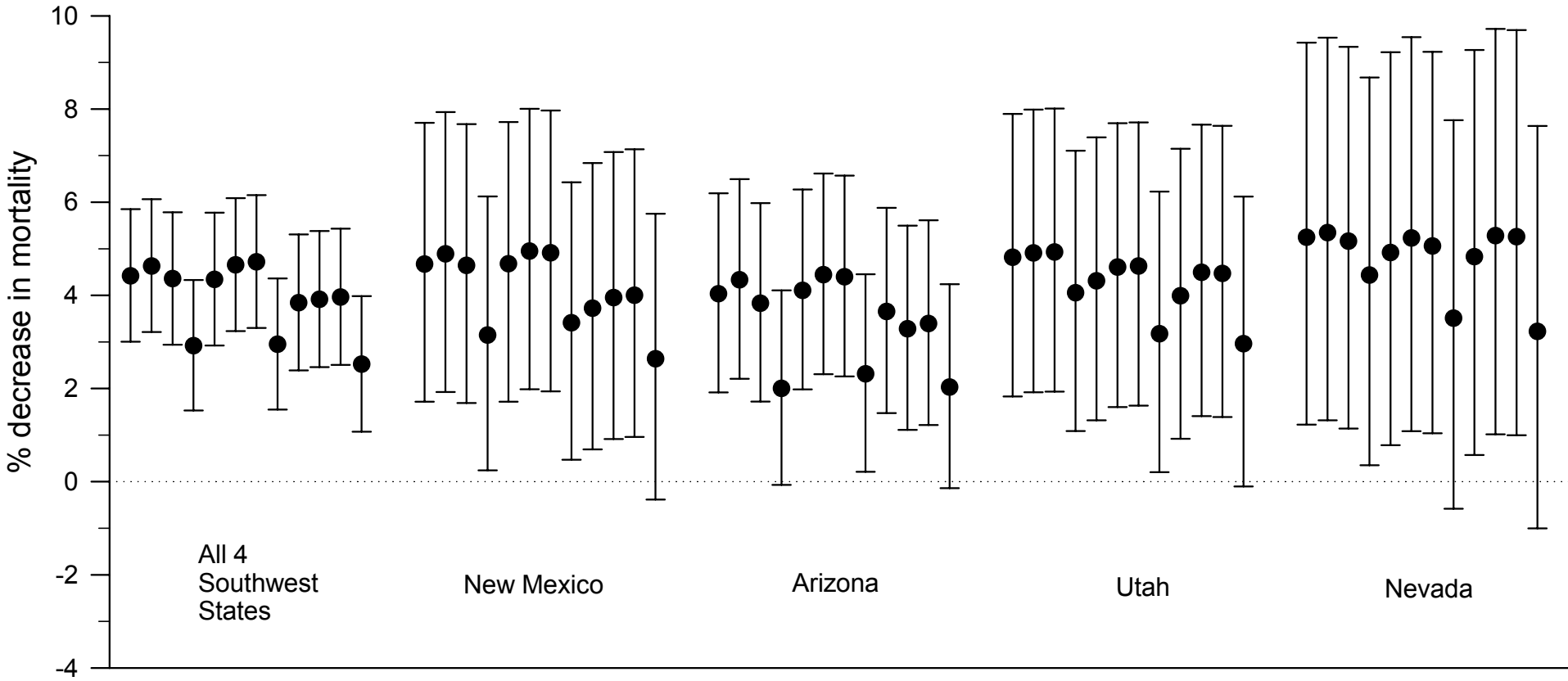


Figure 5. Estimated percent decrease in mortality (and 95% CIs) associated with strike indicator period (August 1967-April 1968) for the 12 different models, for all four Southwest states, and for each state of the four states individually.

Conclusion

These analyses suggest that the approximately 60% reduction in regional sulfate concentrations (1-2 $\mu g/m^3$) associated with the copper smelter strike, resulted in a small but measurable reduction in mortality (1.5% to 4.0%).

Other factors that may have influenced mortality during this strike period cannot be ruled out with certainty.