

# Modeling Exposure to Air Pollution from the WTC Disaster Based on Reports of Perceived Air Pollution

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We examined the utility of a newly developed perceived air pollution (PAP) scale and of a modeled air pollution (MAP) scale derived from it for predicting previously observed birth outcomes of pregnant women enrolled following September 11, 2001. Women reported their home and work locations in the four weeks after September 11, 2001 and the PAP at each site on a four-point scale designed for this purpose. Locations were geocoded and their distance from the World Trade Center (WTC) site determined. PAP values were used to develop a model of air pollution for a 20-mile radius from the WTC site. MAP values were assigned to each geocoded location. We examined the relationship of PAP and MAP values to maternal characteristics and to distance of home and work sites from the WTC site. Both PAP and MAP values were highly correlated with distance from the WTC. Maternal characteristics that were associated with PAP values reported for home or work sites (race, demoralization, material hardship, first trimester on September 11) were not associated with modeled MAP values. Relationships of several birth outcomes to proximity to the WTC, which we previously reported using this data set, were also seen when MAP values were used as the measure of exposure, instead of proximity. MAP developed from reports of PAP may be useful to identify high-risk areas and predict health outcomes when there are multiple sources of pollution and a “distance from source” analysis is impossible.

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**KEY WORDS:** Air pollution; birth length; birth weight; gestational duration; GIS; mathematical models; pregnancy; WTC

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## 1. INTRODUCTION

At the time of the attack on the World Trade Center (WTC) in September 2001, few air monitors

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were operating in areas of NYC exposed to the resulting pollution. Placement of additional air monitors close to or within the rescue and recovery site began within a few weeks of September 11. By October 24, portable equipment and 19 fixed air monitors were being used to sample the air in and around the WTC site, with different monitors measuring heavy metals, various organic compounds, asbestos, or particulate matter (<http://www.epa.gov/wtc/summaries/epa-osh102401.htm>). For weeks after September 11, 2001, foul odors and smoke were readily detected over a fairly large area, including lower Manhattan and parts of Brooklyn and New Jersey. Odors persisted, with less visible smoke, for a longer period

close to the WTC site. Nevertheless, it is not possible to estimate individual exposure after September 11 from data available at the time because of the limitations in the timing, distribution, and scope of air monitoring following September 11, and the variations in pollution determined by local wind patterns.

Several studies have used people's perception of air pollution as a way of characterizing pollution distribution or exposure to harmful airborne pollutants.<sup>(1-5)</sup> The relation of psychological factors to perception of environmental exposures has also been studied, with recognition that perceptions may be influenced by social and cultural factors, such as race,<sup>(6,7)</sup> ethnicity,<sup>(6,8,9)</sup> income,<sup>(10,11)</sup> and the presence of respiratory symptoms.<sup>(5)</sup> In one study, a "neighborhood halo effect" has been described in which individuals attributed lower levels of (chronic) air pollution to their home area in comparison to other areas with similar pollution.<sup>(12)</sup> Other work suggests that visible materials such as dust, soot, smoke, and fumes may be important determinants of pollution perception.<sup>(12)</sup>

To examine the possibility of estimating exposure from individual perception of air pollution, we used a specially designed perceived air pollution (PAP) scale, with associated geocoded data for the locations of this perception measure, to develop a mathematically derived index of pollution, the modeled air pollution (MAP) measure. We then studied whether the modeled values were useable as a measure of individual exposure to air pollution resulting from the WTC tragedy in the month after September 11, 2001, by comparing them to another measure of exposure (distance from the WTC site) and by examining their relation to birth outcomes previously studied. When pollution comes from a single source, such as the WTC site, distance from that source can be used as a measure of exposure. We previously reported less favorable birth outcomes of women living or working within 2 miles of the WTC site in analyses that compared them to women living and working further away.<sup>(13)</sup> Here, we compare those findings to the results obtained using the MAP values at the women's home and work sites as the measure of exposure. With this approach we confirm the validity of using proximity to a single source, the WTC site, as a measure of exposure; we also provide data on whether MAP derived from PAP could be useful in situations not involving a known single source, but multiple sources, where a "distance from source" approach would likely be unsuitable.

## 2. MATERIALS AND METHODS

### 2.1. Enrollment

This work was part of a study of the effects of exposure to the WTC event on pregnancy outcome and child development.<sup>(13)</sup> Briefly, the study enrolled 329 pregnant women having a single infant as they appeared for delivery of their baby at one of three downtown Manhattan hospitals: Beth Israel, St. Vincent's, and New York University Downtown. Women were screened for eligibility and recruited, enrolled, and consented before delivery. Enrolled women were 18 to 39 years old, delivering within 41 weeks of September 11, 2001, had not smoked during pregnancy (<1 cigarette/day at any time), reported no diabetes, hypertension, HIV infection/AIDS, or use of illegal drugs in the last year, and provided a sample of their own blood and/or the infant's cord blood. Women were enrolled between December 2001 and June 2002. As a result, most had been in their first or second trimester on September 11, 2001.

### 2.2. Interview

A 30- to 45-minute interview was administered at the hospital after delivery in the woman's preferred or native language (English, Spanish, or Chinese). The interview questions covered demographics, reproductive history, and background environmental exposures; it included the PERI Demoralization Scale,<sup>(14)</sup> which measures nonspecific psychological distress. This scale has been used with community samples as a measure of the total burden of stress<sup>(15-17)</sup> and in relation to adverse environmental exposures,<sup>(18,19)</sup> demonstrating high internal consistency/reliability in white, African-American, and Hispanic urban populations.<sup>(20)</sup> The Material Hardship Scale of Mayer and Jencks (1988)<sup>(21)</sup> also was used, with material hardship defined as going without or having inadequate food, clothing, or housing at some time in the past year. A question on satisfaction with living conditions used a five-point scale ranging from very satisfied to very dissatisfied. Information about the pregnancy, type of delivery, and birth outcomes was abstracted from the hospital's medical records of the mother and newborn and obtained during the maternal interview.

### 2.3. Geographical Data

We developed a set of questions for the maternal interview that had each woman report, for each of the four weeks following September 11, 2001, her

home and work site locations, (where they actually were working and living each week, even if it was not their usual location). These addresses were geocoded at the Center for International Earth Science Information Network (CIESIN) of Columbia University's Earth Institute, using geographic information system (GIS) software from the Environmental Systems Research Institute, including ArcGIS 8.3, the Street Map 2003 extension, and the New York City Department of Environmental Protection NYC Map. Using the geocoded data, the linear distance from the WTC site was computed for each residence and work location. The estimated level of horizontal accuracy of the geocoded location is  $\pm 25$  feet.

**2.4. Perceived Air Pollution (PAP)**

Each woman also reported, for each of the four weeks following September 11, 2001, the hours/day spent at each home and work site location, and her perception of air pollution at both places, using a four-point PAP scale. The question, for example, for the woman's main residential location in the first week after September 11, 2001 was:

How would you describe the condition of the air outside the place where you were living most during the first week, Sept 11th to 17th? Would you say it was . . .

- Not visibly hazy or smoky, and with only occasional or no bad smell . . . . . = 1
- Rarely visibly hazy or smoky, with a bad smell during some of the time . . . . . = 2
- Very hazy or smoky only some of the time, but with a bad smell during most of that time . . . . . = 3
- Dense with visible haze or smoke and with a bad smell during a lot of that time . . . . . = 4.

These responses provided a PAP value for each week at each geocoded home and work location. We developed this scale in expectation that such pollution reports, if gathered from a large number of persons, might be used to characterize the spread of air pollution locally and over time. This approach was examined because of its possible value for other pollution studies, not only those where toxic materials were emanating from a single source at a fixed distance, as in the case of the WTC event, but, even more importantly, in the case of multiple sources at varying distances from exposure locations at home and work. However, based on literature indicating that air pollution perception might be influenced by personal factors, we examined several of the women's personal

characteristics as potential determinants of their reported PAP values.

We gave the set of questions in the PAP scale to researchers from Mt. Sinai and they have used them in their published work,<sup>(22)</sup> demonstrating a strong association between our PAP measure and an Exposure Index they developed. The index was based in part on women's reports (five or more months later) of their hour-by-hour locations in the weeks after September 11, 2001, and in part on a model of dust distribution from the WTC plume, which used a variety of assumptions related to the rate of emissions from the fires, the indoor/outdoor pollutant ratio, the difference between resuspended dust levels at the ground compared to the plume, etc.

**2.5. Modeled Air Pollution (MAP)**

Air pollution can be mathematically modeled based on monitoring instruments that detect particulate matter, CO, NO<sub>2</sub>, etc., averaging over space the measured values from multiple monitors collecting data concurrently. Similarly, to minimize misclassification based on individual reports, we used the kriging method of interpolation of the PAP integer values (from home and work sites within a 20-mile radius of the WTC) with their geocoded locations to mathematically model the weekly distribution of the pollution that women were detecting in each of the four weeks after September 11. This process was done with ESRI's ArcGIS 9.1 Spatial Analyst extension. A spherical semivariogram model with a variable radius encompassing 12 points was used. This modeling smoothes out occasional extreme values that might reflect insensitivity or hypersensitivity of individual women to local pollution. PAP values from 310 home and 133 work locations in the greater New York area were used for the first week; additional values were available in later weeks, as participants who had left the area returned home and work sites that had closed after September 11 reopened. The resulting model was used to assign each geocoded home and work location its calculated MAP value for each week. MAP values reflected the averaging across space of the reported PAP values in the area.

The MAP values obtained at each site for the first week following September 11, 2001 were divided into deciles and these were used to create 10 color-coded isopleths for creating colored maps of air pollution distribution, with each color delineating geographic areas in the NY metropolitan area within the same decile of MAP values. These Week-1 decile categories

were used with the modeled data from subsequent weeks to create isopleth maps for each of the four weeks after September 11, 2001.

## 2.6. Statistical Methods

Correlation coefficients assessed the relationship between MAP and PAP by week. To understand the factors influencing MAP and PAP, maternal age, income, education, race/ethnicity, receipt of Medicaid, trimester of pregnancy on September 11, material hardship, demoralization, and satisfaction with living conditions were assessed separately in bivariate analysis. Variables significantly associated with PAP at home or work sites in bivariate analyses were used in multivariable linear regression analyses with PAP or MAP as the independent variable, with distance included as a continuous variable (excluding locations more than 20 miles from the WTC site). This approach enabled us to determine whether psychosocial and demographic factors that affected PAP had less of an effect on MAP.

Multiple linear regression of full-term deliveries (258 days or 36 6/7 completed weeks or more of gestation) in women who were pregnant on September 11, 2001, based on the gestational age of the baby at birth and the date of delivery (criteria resulting in exclusion of 29 women), explored the relation of MAP to birth outcomes. Factors with  $p < 0.1$  in bivariate analyses were included as covariates along with other known factors associated with outcome. Maternal smoking was not included in the analyses because only women who reported being nonsmokers during their entire pregnancy were enrolled. We had previously used similar variables in analyses that demonstrated significant reductions in birth weight and birth length of newborns of women living within 2 miles of the WTC site in the four weeks after September 11, 2001, compared to women working within 2 miles or women living and working further away.<sup>(13)</sup> To determine whether MAP was similarly associated with birth outcomes, we allocated women to three analogous groups for regression analyses with birth outcomes as the dependent variables. The residential group was defined by whether the home was in the highest 25th percentile of MAP values when MAP values at home for all four weeks were combined. The employed group was then defined as those remaining women who were in the highest 25th percentile of work site MAP values with values from all four weeks combined. Those not in the high MAP value groups at home or work were in the reference group.

The results were compared to results from the prior distance analyses.<sup>(13)</sup> Analysis used SPSS 11.5 (SPSS, Inc., Chicago, IL).

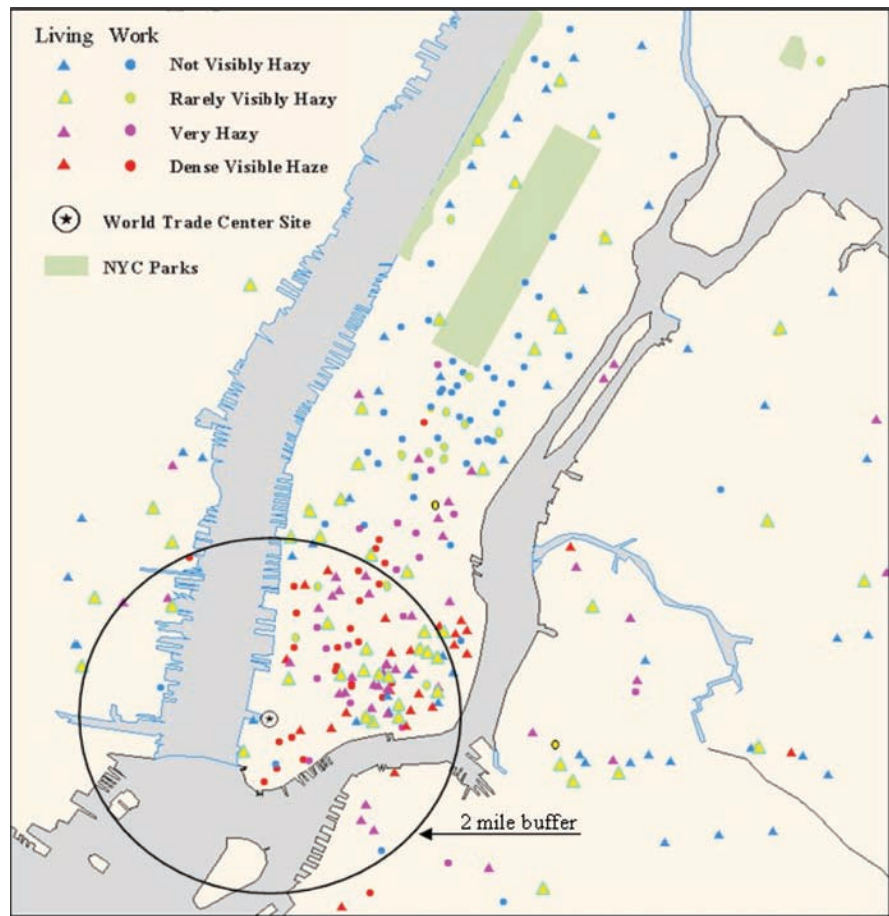
## 3. RESULTS

### 3.1. PAP

The map in Fig. 1 shows the distribution of participating women's home and work sites and the color- and shape-coded PAP values reported for these locations in the first week after September 11, on the four-point scale described above. The figure demonstrates that some areas of New York City were generally perceived as having poorer air quality than other areas. However, even in areas close to the WTC site, a few women reported no notable haze or odor in the first week after September 11, 2001. Similarly, some women reported marked haze/odor, although they were located several miles from the WTC site. As expected, PAP values declined across the four weeks studied (data not shown), but even in the final week some downtown areas were reported as having poor air quality. PAP values were reported in the hospital interviews three to nine months after September 11, 2001. In regressions with PAP as the outcome, elapsed time between September 11, 2001 and the time of the PAP report was not significantly associated with PAP, suggesting that the passage of time did not influence reported perception (data not shown).

### 3.2. MAP

PAP values for each week were used to model air pollution across the city for that week, with geocoded locations then assigned a MAP value based on the model. Fig. 2A shows the results of using equal interval deciles of the resulting MAP values (for both the home and work sites for the first week after September 11, 2001) to develop 10 isopleths of modeled pollution, each indicated by a different color. Maps shown in Figs. 2B–2D were created using the decile values of MAP from Week 1 to define the isopleths for Weeks 2 to 4 after September 11, 2001. These maps illustrate that, in the first week after September 11, 2001, areas of Brooklyn as well as lower Manhattan were significantly affected by WTC dust and odor, with the area of strong odor/haze gradually shrinking during the four weeks. Although satellite images indicate that the plume traveled far beyond the local area, the visible plume was noted to have risen high above ground level very quickly, due to convection induced



**Fig. 1.** PAP at work and home sites in first week after September 11, 2001.

by the ongoing fires.<sup>(23,24)</sup> In contrast to satellite images, our results refer to PAP (or MAP) values at or near ground level.

As expected, PAP values were significantly correlated with the MAP values derived from them (Spearman’s correlation coefficients for the model = 0.65, 0.64, 0.54, 0.56 for home sites for Weeks 1 to 4, respectively, and 0.74, 0.76, 0.76, 0.74 for work sites for the four weeks, all  $p < 0.01$ ). The higher correlations of MAP with PAP at work sites suggest that work site pollution perception was less affected than was home site pollution perception by occasional extreme values that would be averaged with less extreme values during the modeling process.

We examined the correlations of PAP and MAP values with distance from the WTC site to determine if the distance and perception measures of exposure were capturing similar information (Table I). Sites more than 20 miles from the WTC were excluded, since odor and haze fell off rapidly with distance. PAP values were highly inversely correlated with distance

in all four weeks (correlations ranged from  $-0.49$  to  $-0.59$  at home sites,  $-0.67$  to  $-0.71$  at work sites), but the correlations of MAP with distance were much greater (correlations from  $-0.79$  to  $-0.90$  at home sites,  $-0.89$  to  $-0.90$  at work sites; Table I), probably reflecting the reduced effect on MAP than on PAP of a few extreme reports within a given area.

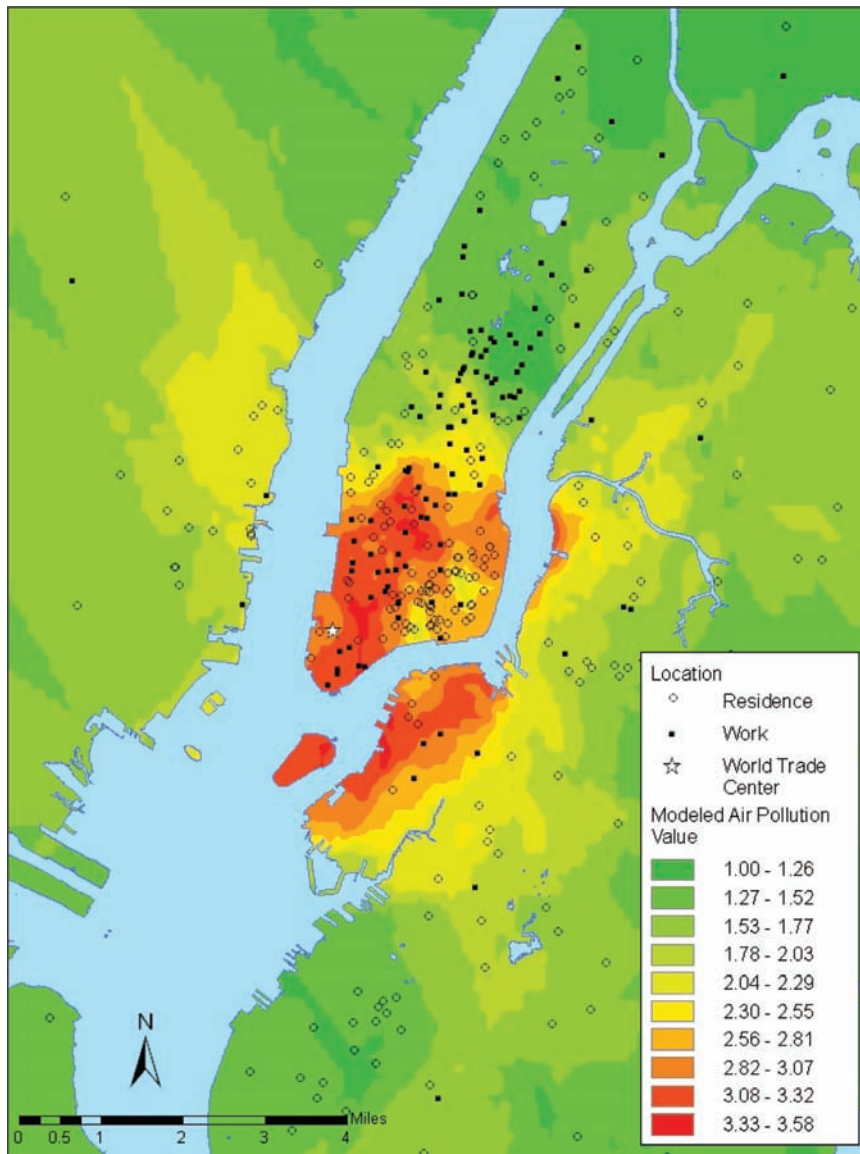
### 3.3. Factors Affecting PAP and MAP Values

The higher correlations with distance from the WTC site of PAP values at work sites compared to home sites (Table I) indicate that high PAP values were reported for a larger area at home locations than at work locations. Work site locations with high PAP values were closer to the WTC than were home sites with similarly high values.

Prior literature suggests that perception of risk from air pollution can be related to characteristics of the individuals studied, such as race, sex, age,

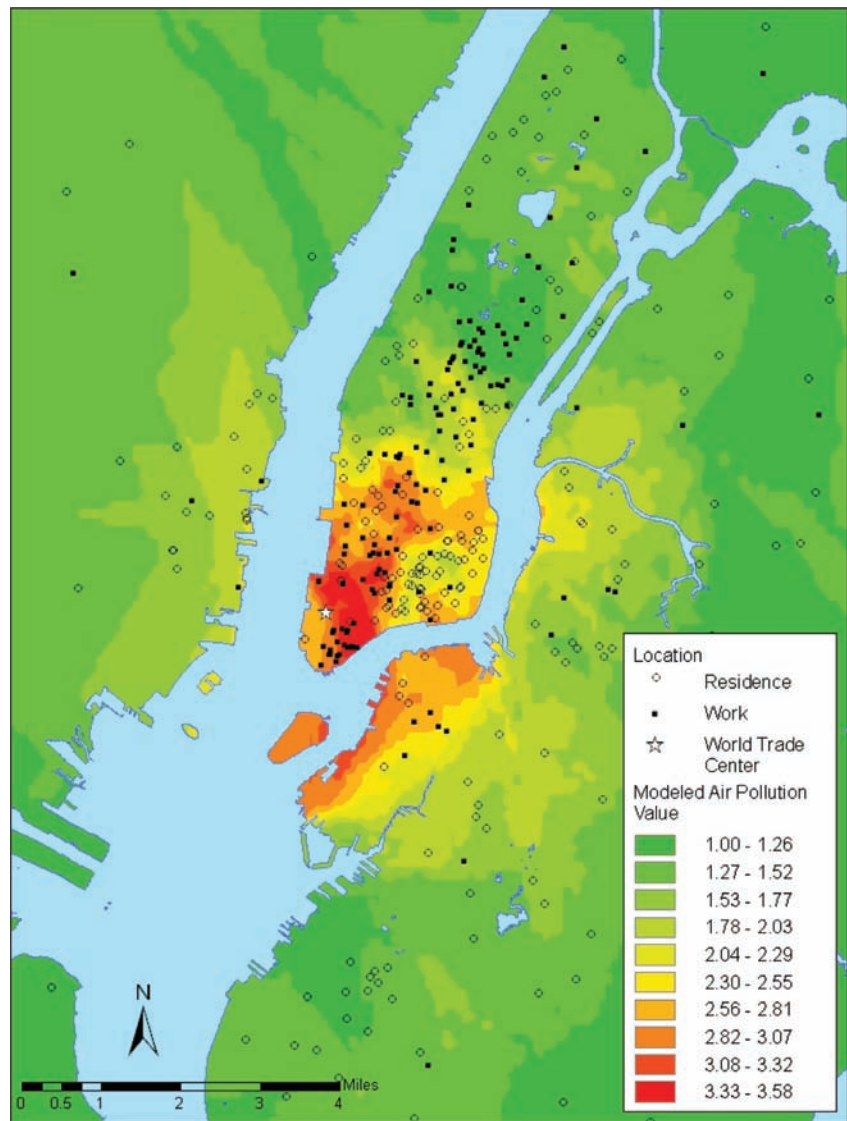
education,<sup>(1)</sup> pet or home ownership, or respiratory symptoms.<sup>(4)</sup> We examined the bivariate associations of demographic and lifestyle variables with PAP at home and work sites (Table II). PAP values at home sites were significantly lower (in three of four weeks) for Asian women. In all four weeks, PAP values at home increased with increased maternal demoralization or material hardship (classified as any vs. none). At work sites, only material hardship was associated with increased PAP values in all four weeks. Being in the first trimester on September 11, 2001 raised PAP values at work sites in Weeks 3 and 4 only. Of all the variables considered, material hardship had the largest effect (*b*-value) on PAP values.

To explore the unadjusted effects, shown in Table II, of maternal psychosocial characteristics on the relation of PAP at work or home to distance from the WTC site, we performed separate regressions for each of the four weeks after September 11. Distance from the WTC site (>20 miles excluded) and demoralization and material hardship, the psychosocial variables that we found to be associated with PAP values, were included as independent variables (Table III). At work locations, PAP values were not significantly associated with demoralization or material hardship with distance controlled, although material hardship *p*-values were at the margins of significance (between 0.05 and 0.1). Demoralization and



**Fig. 2.** (A) MAP in first week after September 11, 2001. (B) MAP in second week after September 11, 2001. (C) MAP in third week after September 11, 2001. (D) MAP in fourth week after September 11, 2001.

Fig. 2. (Continued).



material hardship were separately significantly associated with an increase in PAP at home locations with distance controlled in all four weeks studied and in three of four weeks when both were included in the same equation (Table III). In contrast, demoralization and material hardship were not significantly associated with MAP at either work or home sites in any week with distance controlled (Table III), indicating that psychosocial characteristics that influenced PAP values at home were not determinants of modeled values.

Finally, multivariable regression analyses that included as covariates all factors seen to be associated with PAP ( $p < 0.1$ ) in bivariate analyses (Table II) showed that only distance from the WTC site was sig-

nificantly (inversely) associated with MAP values at home and work sites in all four weeks ( $p < 0.001$ ); the first trimester variable remained significantly associated with MAP at work locations in Weeks 3 and 4 only,  $p < 0.03$  (data not shown). Clearly, personal characteristics that influenced PAP values were largely unrelated to MAP values.

### 3.4. Birth Outcomes

To determine if MAP values were associated with adverse birth outcomes, we examined the relationship of exposure, defined by MAP values at home and work, to birth weight, length, and head circumference, and gestational duration, excluding 29 women

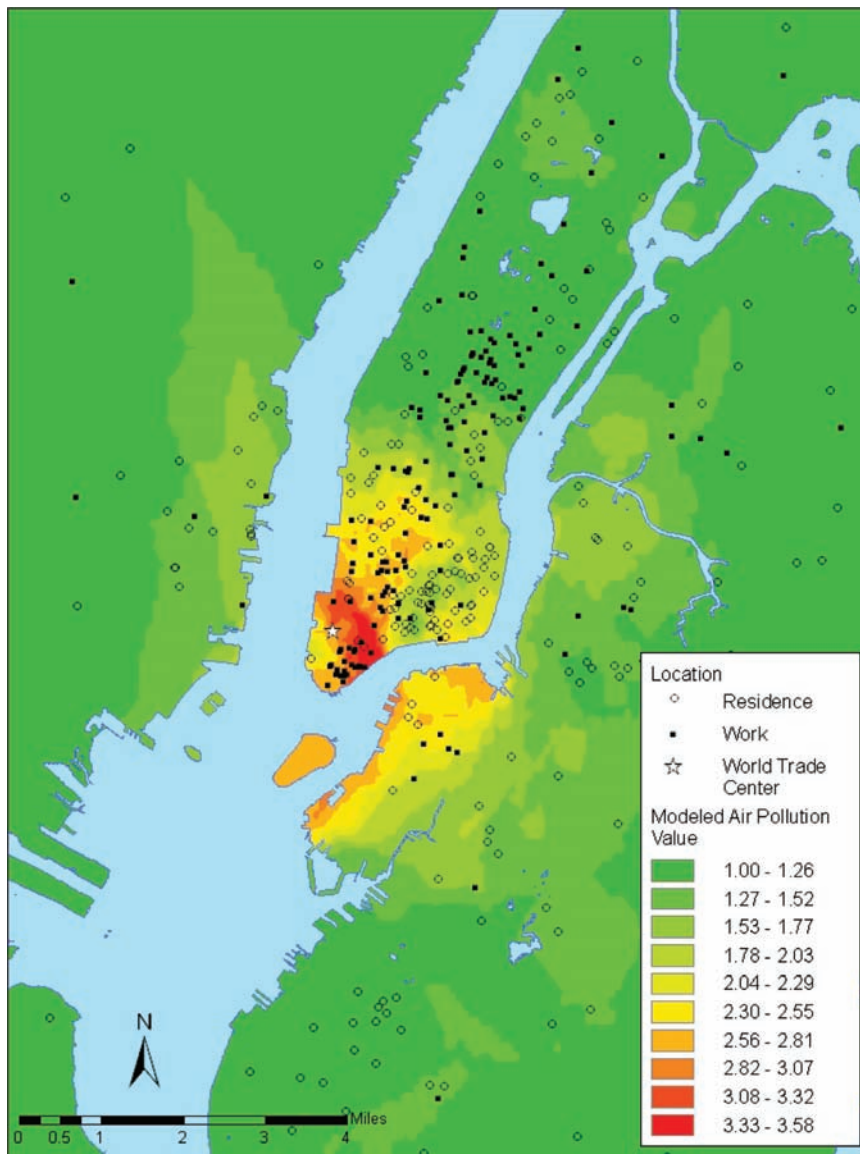
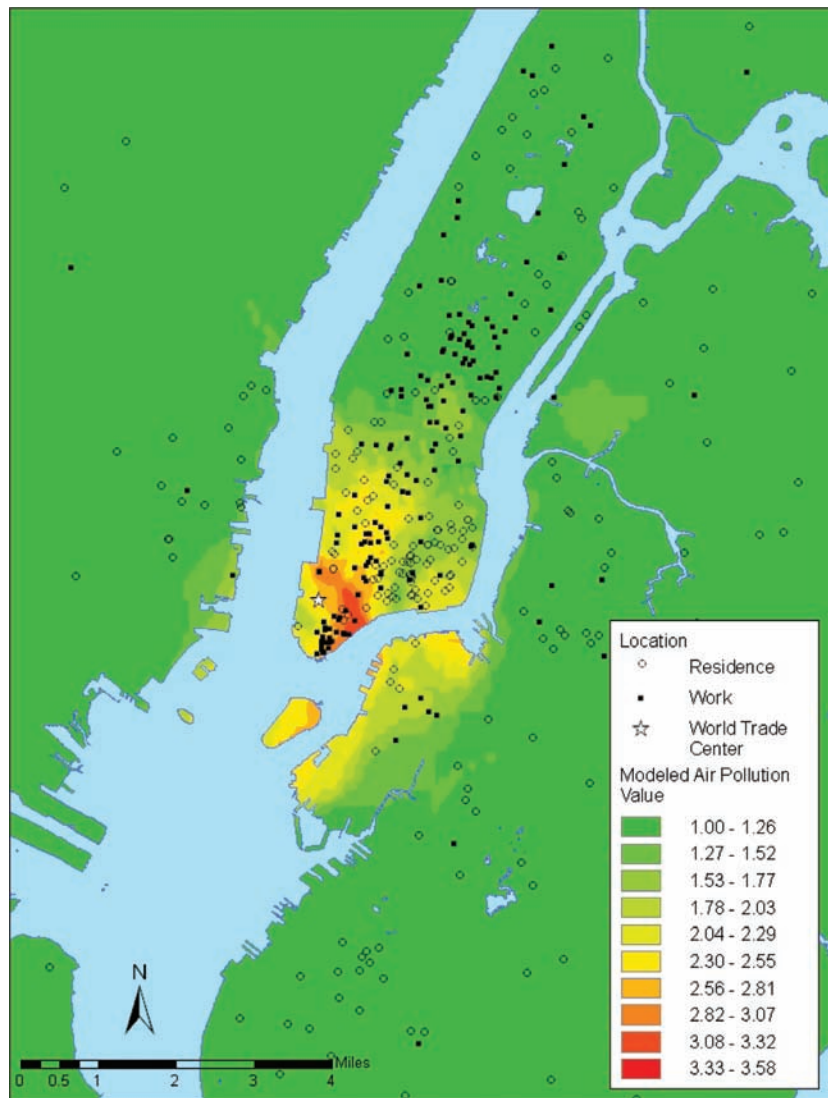


Fig. 2. (Continued).

who delivered before 258 days, gestation or who were not pregnant yet on September 11, 2001 (Table IV). In these analyses, the top 25% of MAP values at women's home sites in the four weeks after September 11, 2001 were used to define a "top 25% MAP area, home, any week" group. This was intended to be analogous to our previous report examining factors associated with birth outcomes,<sup>(13)</sup> where women residing within 2 miles of the WTC site in any of the four weeks after September 11 were combined into one group, which included 26.7% of the enrolled women. A similar process was followed for the MAP values at work sites for women who did not live in a high MAP area by selecting for a "top 25% MAP area,

work, any week" group those remaining women with the top 25% of MAP values for work sites for the four weeks after September 11, 2001 (analogous to the 17.0% of the women in our prior distance analyses who worked within 2 miles of the WTC during that period). Women not in either of these groups were in the reference group for the birth outcomes analyses, just as women not living or working within 2 miles of the WTC site were in the reference group in our prior analyses. It should be noted that women who lived or worked close to the WTC in the four weeks after September 11, 2001, who also reported higher PAP during that period, were likely to have exposure that continued beyond the four weeks we evaluated.

Fig. 2. (Continued).



Dust particles in carpets, furniture upholstery, drapes, air-conditioning systems, and other places within the household could be resuspended over time, continuing exposure. Some dust particles might also be carried from the workplace back to the residence.

The results from the prior distance analyses are shown in the first three columns of Table IV. This work showed that infants of women who resided within 2 miles of the WTC site were born with lower birth weight and length than infants of women residing and working further away. Significant decrements in gestational duration and head circumference and marginally significant additional decrements in birth weight ( $-104\text{ g}$ ,  $p = 0.057$ ) were observed in newborns of women who were in the first trimester on September 11, 2001. The remaining columns of

Table IV show present results using the top 25% of MAP values at home or work sites, instead of distance from the WTC site, to identify women exposed at these locations. With high exposure defined as the top 25% of MAP values (at home or work) in any of the four weeks after September 11, the four birth outcomes generally show a similar exposure effect as seen in analyses when high exposure was defined as being within 2 miles of the WTC at home or work.

In analyses without gestation duration controlled, the previously reported significant reduction of birth weight ( $-149\text{ g}$ ) associated with residential proximity to the WTC site was reduced (to  $-97\text{ g}$ ,  $p = 0.10$ ) when high MAP values were used to define the exposed groups. The 0.8 cm significant reduction in length of

**Table I.** Correlation with Distance<sup>†</sup> from the WTC Site of Perceived Air Pollution (PAP) and Modeled Air Pollution (MAP) at Home and Work Sites in the Four Weeks After September 11, 2001

	PAP Week 1	PAP Week 2	PAP Week 3	PAP Week 4	MAP Week 1	MAP Week 2	MAP Week 3	MAP Week 4
HOME, distance from WTC								
wk1.....	-0.592**				-0.893**			
wk2.....		-0.587**				-0.896**		
wk3.....			-0.489**				-0.848**	
wk4.....				-0.492**				-0.789**
WORK, distance from WTC								
wk1.....	-0.670**				-0.887**			
wk2.....		-0.684**				-0.902**		
wk3.....			-0.704**				-0.901**	
wk4.....				-0.710**				-0.889**

<sup>†</sup>Excluding locations more than 20 miles from the WTC site.

\*\*Correlation is significant at  $p < 0.01$ .

**Table II.** Bivariate Associations,  $b$ -Value and  $p$ -Value, of Potential Covariates with Perceived Air Pollution (PAP) at Home and at Work Sites by Week After September 11, 2001 ( $N = 329$ )

	Perceived Air Pollution							
	Week 1		Week 2		Week 3		Week 4	
	B	$p$	B	$p$	B	$p$	B	$p$
Home site								
Maternal age	0.002	(0.823)	4.26E-5	(0.996)	0.005	(0.525)	0.007	(0.292)
Is Asian	-0.342	<b>(0.003)</b>	-0.318	<b>(0.002)</b>	-0.190	<b>(0.025)</b>	-0.109	(0.154)
Is African American	-0.293	(0.053)	-0.214	(0.115)	-0.150	(0.200)	-0.196	(0.055)
College degree (yes/no)	0.070	(0.526)	0.027	(0.784)	-0.043	(0.609)	-0.080	(0.279)
Medicaid receipt	-0.192	(0.082)	-0.146	(0.137)	-0.101	(0.230)	-0.055	(0.459)
Household income <sup>a</sup> deciles	6.247E-6	(0.061)	3.10E-6	(0.305)	2.46E-6	(0.345)	1.56E-6	(0.492)
ETS exposure at home	0.192	(0.176)	0.111	(0.387)	0.144	(0.184)	0.148	(0.120)
1st trimester on September 11	0.053	(0.649)	0.058	(0.576)	0.022	(0.808)	0.097	(0.212)
Demoralization	0.475	<b>(&lt;0.001)</b>	0.457	<b>(&lt;0.001)</b>	0.314	<b>(&lt;0.001)</b>	0.335	<b>(&lt;0.001)</b>
Material hardship	0.674	<b>(&lt;0.001)</b>	0.723	<b>(&lt;0.001)</b>	0.589	<b>(&lt;0.001)</b>	0.523	<b>(&lt;0.001)</b>
Life satisfaction	0.020	(0.734)	0.009	(0.873)	-0.021	(0.639)	0.009	(0.824)
Work site								
Maternal age	-0.026	(0.166)	-0.006	(0.740)	0.003	(0.871)	0.015	(0.278)
College degree (yes/no)	-0.131	(0.510)	-0.162	(0.371)	-0.090	(0.572)	-0.109	(0.459)
Is Asian	-0.312	(0.181)	-0.181	(0.404)	-0.208	(0.271)	-0.069	(0.690)
Is African American	0.083	(0.735)	-0.083	(0.705)	0.086	(0.659)	0.045	(0.804)
Medicaid receipt	-0.046	(0.839)	-0.204	(0.330)	-0.280	(0.122)	-0.230	(0.168)
Household income deciles	1.28E-6	(0.826)	8.02E-7	(0.884)	3.06E-6	(0.525)	5.26E-6	(0.239)
ETS exposure at home	0.055	(0.833)	0.187	(0.429)	-0.123	(0.553)	-0.007	(0.972)
1st trimester on September 11	0.128	(0.547)	0.184	(0.345)	0.335	<b>(0.048)</b>	0.323	<b>(0.041)</b>
Demoralization	0.264	(0.247)	0.303	(0.144)	0.199	(0.260)	0.180	(0.266)
Material hardship	0.752	<b>(0.024)</b>	0.685	<b>(0.033)</b>	0.800	<b>(0.004)</b>	0.778	<b>(0.004)</b>
Life satisfaction	0.002	(0.983)	-0.073	(0.458)	-0.036	(0.669)	-0.030	(0.705)

<sup>a</sup>Household income per household member, calculated from the medians of 10 categories divided by number of household members. Based on individual bivariate linear regression models. Significant ones are highlighted.

**Table III.** Regression Models for Relationships of Psychosocial Variables to Perceived Air Pollution (PAP) or Modeled Air Pollution (MAP) with Distance Controlled, Excluding > 20 miles (N = 300)

	PAP		PAP		PAP		PAP		PAP		PAP		PAP	
	Home, wk 1		Home, wk 2		Home, wk 3		Home, wk 4		Work, wk 1		Work, wk 2		Work, wk 3	
	B	p	B	p	B	p	B	p	B	p	B	p	B	p
Distance from WTC, miles	-0.134	<0.001	-0.117	<0.001	-0.084	<0.001	-0.069	<0.001	-0.202	<0.001	-0.242	<0.001	-0.219	<0.001
Demoralization	0.362	0.001	0.379	<0.001	0.263	0.003	0.293	<0.001	0.087	0.702	0.058	0.758	-0.021	0.897
Distance from WTC, miles	-0.136	<0.001	-0.118	<0.001	-0.083	<0.001	-0.069	<0.001	-0.195	<0.001	-0.235	<0.001	-0.211	<0.001
Material hardship	0.439	0.007	0.531	0.001	0.463	0.001	0.416	0.001	0.556	0.082	0.500	0.082	0.480	0.055
Distance from WTC, miles	-0.132	<0.001	-0.114	<0.001	-0.081	<0.001	-0.066	<0.001	-0.195	<0.001	-0.239	<0.001	-0.214	<0.001
Demoralization	0.304	0.006	0.312	0.002	0.200	0.028	0.241	0.003	-0.038	0.871	-0.038	0.846	-0.107	0.521
Material hardship	0.292	0.086	0.395	0.013	0.374	0.010	0.312	0.014	0.560	0.100	0.494	0.102	0.508	0.051

	MAP		MAP		MAP		MAP		MAP		MAP		MAP	
	Home, wk 1		Home, wk 2		Home, wk 3		Home, wk 4		Work, wk 1		Work, wk 2		Work, wk 3	
	B	p	B	p	B	p	B	p	B	p	B	p	B	p
Distance from WTC, miles	-0.139	<0.001	-0.125	<0.001	-0.096	<0.001	-0.079	<0.001	-0.170	<0.001	-0.209	<0.001	-0.187	<0.001
Demoralization	0.047	0.387	0.034	0.520	0.036	0.448	0.009	0.846	-0.077	0.553	-0.119	0.263	0.003	0.972
Distance from WTC, miles	-0.140	<0.001	-0.127	<0.001	-0.097	<0.001	-0.079	<0.001	-0.166	<0.001	-0.208	<0.001	-0.186	<0.001
Material hardship	0.061	0.465	0.021	0.794	0.020	0.785	0.031	0.679	0.292	0.114	0.076	0.653	0.118	0.428
Distance from WTC, miles	-0.138	<0.001	-0.125	<0.001	-0.096	<0.001	-0.078	<0.001	-0.165	<0.001	-0.208	<0.001	-0.186	<0.001
Demoralization	0.037	0.514	0.032	0.562	0.035	0.481	0.004	0.937	-0.156	0.251	-0.142	0.199	-0.017	0.863
Material hardship	0.048	0.580	0.011	0.895	0.006	0.937	0.030	0.700	0.355	0.068	0.135	0.443	0.124	0.421

p < 0.05 are highlighted.

**Table IV** Effects on Birth Outcomes of Exposure Defined by Top 25% of MAP Values at Home or Work, Compared to Exposure Defined as Within 2 Miles of the WTC Site at Home or Work, in the Four Weeks After September 11, 2001

	Gestational Duration Not Controlled <sup>a</sup>		Gestational Duration Controlled <sup>a,f</sup>		Gestational Duration Not Controlled		Gestational Duration Controlled <sup>d</sup>	
	B	(p)	B	(p)	B	(p)	B	(p)
<b>Birth weight, g</b>								
Lived within 2 miles of WTC, any week <sup>b</sup>	-149	<b>(0.012)</b>	-122	<b>(0.024)</b>	-97.4	<b>(0.10)</b>	-85.5	<b>(0.12)</b>
Worked within 2 miles of WTC, any week <sup>e</sup>	1.44	(0.984)	53.7	(0.419)	-51.6	(0.48)	27.3	(0.69)
1st trimester on September 11, 2001 <sup>e</sup>	-104	<b>(0.057)</b>	-27.0	(0.595)	-97.8	<b>(0.073)</b>	-19.4	(0.70)
<b>Birth length, cm</b>								
Lived within 2 miles of WTC, any week	-0.819	<b>(0.026)</b>	-0.737	<b>(0.039)</b>	-0.715	<b>(0.052)</b>	-0.676	<b>(0.059)</b>
Worked within 2 miles of WTC, any week	0.853	<b>(0.063)</b>	1.01	<b>(0.024)</b>	0.631	(0.17)	0.888	<b>(0.049)</b>
1st trimester on September 11, 2001	-0.204	(0.545)	0.075	(0.823)	-0.127	(0.71)	0.161	(0.63)
<b>Head circumference, cm</b>								
Lived within 2 miles of WTC, any week	-0.288	(0.151)	-0.231	(0.231)	-0.035	(0.86)	-0.009	(0.96)
Worked within 2 miles of WTC, any week	-0.156	(0.527)	-0.037	(0.876)	-0.185	(0.45)	-0.012	(0.96)
1st trimester on September 11, 2001	-0.477	<b>(0.010)</b>	-0.300	<b>(0.096)</b>	-0.483	<b>(0.008)</b>	-0.302	<b>(0.092)</b>
<b>Gestational duration, days</b>								
Lived within 2 miles of WTC, any week	-1.22	(0.279)			-0.408	(0.71)		
Worked within 2 miles of WTC, any week	-2.59	<b>(0.055)</b>			-3.70	<b>(0.008)</b>		
1st trimester on September 11, 2001	-3.55	<b>(0.001)</b>			-3.62	<b>(&lt;0.001)</b>		

<sup>a</sup>Data in this column are from Lederman *et al.*, (2005). Includes 300 births, excluding deliveries before 258 days' gestation or those not yet pregnant on September 11, 2001. Each column shows the regression's adjusted, unstandardized *b*-values and *p*-values, *p* < 0.1 are highlighted.

<sup>b</sup>“Any week” means any of the four weeks after September 11, 2001.

<sup>c</sup>Top 25% MAP area, home, identifies women with the top 25% of MAP values for home sites with all four weeks combined.

<sup>d</sup>Top 25% MAP area, work, identifies women with the top 25% of MAP values for work sites with all four weeks combined, after excluding women in the “Top 25% MAP area, home” group.

<sup>e</sup>This variable indicates whether the participant was in the first trimester ( $\leq 91$  days gestation) on September 11, 2001.

<sup>f</sup>Birth length, weight, head circumference, and gestational duration are adjusted for baby's sex, maternal age, parity, Medicaid status, race/ethnicity (Asian or black vs. others), and medical complications (hypertension, diabetes, preeclampsia). Head circumference also adjusted for c-section delivery.

infants of mothers residing within 2 miles was attenuated and marginally significant ( $-0.7$  cm,  $p = 0.052$ ) when MAP values were used to define the groups. Prior work showed a reduction in gestational duration of women who worked within 2 miles of the WTC ( $-2.6$  days,  $p = 0.055$ ); this report shows a somewhat larger, significant effect on gestational duration ( $-3.7$  days,  $p = 0.008$ ) among women working in high MAP areas. The previously reported significant reductions seen (without control for gestation length) in newborn head circumference, gestational duration, and in birth weight ( $p = 0.057$ ) for women who were in the first trimester on September 11, 2001, were also demonstrated in women in the first trimester when high MAP values were used to define the groups (Table IV). With gestational duration controlled (Table IV), most of the results that were significant or marginally significant in the analyses based on proximity to the WTC were also significant or marginally significant in analyses based on high MAP values.

Had the pollution perceived by our study subjects been from multiple sources rather than a single source (precluding analyses controlling for distance), the results using MAP to define the exposure groups would have identified most of the changes in birth outcomes identified in prior analyses that were based on proximity to the WTC site. Specifically demonstrated were decrements in gestational duration in women in high MAP areas at work and declines in head circumference, gestational duration, and possibly birth weight associated with being in the first trimester on September 11, irrespective of location of work or home. We also replicated other findings from the prior distance analyses. Women residing in high MAP areas showed reductions in birth weight ( $p = 0.10$ ) and length ( $p = 0.052$ ) that were attenuated by controlling for gestational duration, similar to findings for women residing within 2 miles of the WTC. Whether classified as working in high MAP areas or working within 2 miles of the WTC, women bore infants that were slightly (not significantly) longer than those of the corresponding residential or reference groups; this effect was increased and significant in both the proximity and MAP analyses when gestational duration was controlled.

#### 4. DISCUSSION

We have shown that PAP determined from a four-point scale was related to distance from the source of pollution. The MAP measure developed from the PAP values was even more highly correlated with dis-

tance from the source than was PAP. Our results indicate that, with distance controlled, the perception of air pollution at home but not at work locations was increased by maternal demoralization or material hardship. Our observation that MAP values at home were not associated with these psychosocial measures suggests that reverse causation, where high pollution levels increase demoralization or hardship, was not a factor. We did not observe lower PAP at the home sites as previously reported for chronic air pollution.<sup>(12)</sup> Pollution observed at home sites may be more disturbing than at work sites when an acute (terrorist) event is the cause, but be less noticed when chronic air pollution is evaluated. To some extent, higher PAP levels at home may be a consequence of the greater number of hours spent at home than at work. Those women residing within 2 miles of the WTC averaged 16.2 to 17.1 hours/day at home for the four weeks after September 11, whereas those only working in that radius spent an average of 5.9 hours daily in the first week to 8.0 hours in the fourth week.<sup>(13)</sup> Unlike those only working close to the WTC site, residents were also exposed at night, when air inversions sometimes brought the plume closer to ground level. The additional exposure duration of residents compared to women who only worked in the area may also explain the greater effects on birth outcomes in the residential group.

We had previously identified significant differences in head circumference ( $b = -0.477$ ,  $p = 0.01$ ), gestational duration ( $b = -3.55$ ,  $p = 0.001$ ), and birth weight ( $b = -104$ ,  $p = 0.057$ ) due to exposure in the first trimester of pregnancy. These differences had been observed even when the distances of work or home sites from the WTC were controlled. Similar effects on birth outcomes of exposure in the first trimester were identified when women were classified by high MAP values, supporting the utility of this measure for identifying factors affecting birth outcome.

A measure of pollution perception on a four-point scale suffers from several limitations. First, a measure of perception of odor and dust may not capture differences in concentration of air pollutants that determine health effects. Second, individual perceptions at the same location differ due to biological variation in sensitivity to odor and smoke ("detector" sensitivity). Further, variations in air quality during a week might not be "averaged" in the same way by different people, resulting in different reported values at the same location. Some of the women may have been reporting on odors due to very local air pollution, unrelated to the WTC event. Our modeling would not capture these local effects.

Recall of air pollution several months after September 11 might be expected to be very poor and this is a major limitation of this work. Recall also might differ among women as the time of the report became more distant from the time of the event, increasing the variability of the reports. Although we found no differences in PAP values related to the three- to nine-month interval between the time of the reports and September 11, 2001, changes in remembered pollution might occur mostly in the first weeks after the event, a period we did not study. It is also likely that effects of the passage of time on the accuracy of reported PAP values would introduce additional variation that would bias our findings toward that null. These factors would operate to cause us to underestimate the strength of the relationships we studied.

Prior work, which is reassuring, has used our PAP scale in women who were interviewed five or more months after September 11.<sup>(22)</sup> The authors developed an Exposure Index by combining data from the women's reports of (weekly) perceptions of air pollution and their hour-by-hour locations for each day in the month after September 11 with data obtained by modeling ground-level air pollution, using simulations of the distribution of particulate matter in the WTC plume with several assumptions relating these to ground-level pollution. Despite the long delay in collecting these women's reports, their PAP values were strongly associated with the Exposure Index.

Personal circumstances might affect perception of odor and smoke ("detector" bias), as demoralization and material hardship seemed to do. It is revealing that, while demoralization seemed to raise perceptions of air pollution at home but not at work, material hardship, which was more strongly related to home PAP values, was marginally significantly related to values at work as well. This may indicate that demoralization is closely related to, and perhaps determined by, the characteristics of personal life, whereas material hardship is also often somewhat related to employment factors. Our data do not provide information that would allow greater insights into these differences.

Also worth considering, our reports were from women who were pregnant during the period whose pollution they assessed. Men or nonpregnant women might have reported differently from the pregnant women in our study. In a prior study, women reported greater annoyance than men from air pollution.<sup>(5)</sup> Furthermore, the difference between the MAP and PAP values at the home location (an indicator of PAP

values that were different from the modeled values for that location) was significantly correlated to the difference between MAP and PAP values at the work location, suggesting that some individuals consistently reported air pollution differently from others. These personal characteristics could result in exposure misclassification using perceived pollution measures only. The development of a MAP scale appeared to have eliminated the influence of such individual effects.

Our model used weekly reports from more than 400 home and work locations. A much larger number of reports could easily be obtained in serious air polluting events, including those due to terrorism, forest fires, or industrial accidents or emissions, using web-based reporting. If such an event were to occur, systems could be established to have many more people use such a scale to periodically enter online PAP values for their home and/or work locations, along with the dates, times, and locations involved. Such work could also avoid the delay we had, of several months, between the time of the observation of the pollution level and the time of the report, potentially greatly improving the accuracy of reporting. People reporting on PAP for the purposes of modeling air pollution need not be the same people whose health outcomes are used to determine their relation to pollution. With a large database of pollution reports, areal models of air pollution would be improved, and they could be used to allocate resources, target public health interventions, or identify the location of major sources of pollution. A prior study,<sup>(5)</sup> based on interviews of nearly 10,000 participants who assessed annoyance from chronic air pollution on an 11-point scale, demonstrated that mean areal reported annoyance was significantly correlated with PM<sub>10</sub> and NO<sub>2</sub> levels measured at local monitoring sites.

In summary, despite the limitations of the data we were able to collect, the MAP values we derived from PAP reports for home and work locations appear to have captured differences in exposure determined by distance of these home and work sites from the WTC. The results support our prior findings of adverse effects of September 11 on birth outcomes, as MAP values also were associated with differences in birth outcomes previously related to distance from the WTC site. Future work should determine whether models derived from PAP (preferably reported at the time of the ongoing event by a large number of people, including many with significant degrees of exposure) can be used to relate exposure to health effects other than birth outcomes.

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