Ozone and Carbon Dioxide in Oakland: Assessing the Exposure within Census Tracts

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ABSTRACT

Various findings have established the relationship between socio-economic status and air pollution. However, some studies have brought up the need to collect more data because sparse data can lead to an unreliable use of spatial techniques and thus unreliable results. This study addresses this issue by using Project BEACON, a monitoring network designed to collect data on greenhouse gas emissions through the use of a denser distribution of monitors. Project BEACON has deployed 14 monitors throughout Oakland, California, and is set to establish more in the near future. Given the density in the monitoring sites' distance to each other, I expected that Project BEACON would provide more reliable results than using the Environmental Protection Agency's Air Quality System (AQS). In this study, I set out to supplement the existing air pollution dataset, by using spatial interpolation to create a spatial map of the distribution of carbon dioxide concentrations given Project BEACON. Moreover, I conducted a preliminary exposure assessment, and determined which areas in Oakland experienced the highest concentrations in carbon dioxide and ozone. I found that ozone distribution within Oakland was not high enough to be classified as detrimental to human health. I also found that carbon dioxide concentration was highest near freeway corridors, like the I-580 and I-880. Furthermore, I found that carbon dioxide concentrations were highest in six census tracts that reported 34.23%, 34.99%, 5.25%, 12.85%, 61.41%, and 45.47% of households living under the U.S. poverty line.

KEYWORDS

ArcMap, socio-economic status, spatial analysis, environmental justice

INTRODUCTION

Environmental justice is an expanding field that addresses inequities in exposure to environmental hazards (Livernash 1995). By cooperating with government agencies, environmental justice proponents ensure that communities are protected from environmental hazards (Livernash 1995). In the presence of environmental hazards, like water and air problems, environmental justice proponents attempt to ameliorate any disproportionate effects that any community might experience (Livernash 1995). For instance, environmental justice enforcers ensure that regions comply with regulations set forth by legislation, such as the Clean Air Act and Clean Water Act (Gruber 2000, Johnson and Graham 2005, and Smail et al. 2012). Although some environmental justice enforcers have been successful in ensuring community safety, as seen in the vast improvement of Los Angeles's water quality (Smail et al. 2012), environmental injustices still exist (Havard et al. 2009 and Young et al. 2012).

Along with water pollution, air pollution is also another focus of environmental justice studies because communities are still disproportionately affected along ethnic and social gradients (Havard et al. 2009, Su et al. 2010, and Young et al. 2012). For example, in Los Angeles, urban parks and surrounding communities are exposed to different levels of air pollution based on socioeconomic and racial-ethnic gradients (Su et al. 2010). Further studies have also found that long-term exposure to various air pollutants is linked to long-term health complications, like decreased lung function (Thurston and Ito 1999). Air pollutants, like ozone, are also associated with increased mortality rates (Bell et al. 2005 and Samoli et al. 2008). Air pollution, thus, is a topic that environmental justice studies have began to focus on so that there is a better understanding of the distribution of air pollutants within communities comprised of different socio-economic an ethnic groups (Hackbarth et al. 2011).

Previously, environmental justice studies have assessed the relationships between air pollution and community characteristics, like socioeconomic status and ethnicity, by relying on datasets that are available through agencies, such as the Environmental Protection Agency (EPA) (Morello-Frosch et al. 2010 and Schweitzer and Zhou 2010). However, some researchers have pointed out that EPA air pollution data often relies on few monitoring sites in a limited number of districts (Schweitzer and Zhou 2010). When extensive air monitoring networks are absent, using spatial interpolation methods in environmental justice studies must be used flexibly because inappropriate use may lead to questionable methodology (Buzzeli and Jerrett 2011). Therefore, in order to better understand the disproportionate health outcomes that result in different communities, more exposure data needs to be collected (Livernash 1995).

Project BEACON in Oakland, California has addressed the need to collect more data by building a denser grid network of air monitors (Cohen 2011). Through this grid system, researchers managing Project BEACON aim to understand the sources and sinks of greenhouse gases like carbon dioxide (Cohen 2011). My study will address the issue of air pollution data collection in Oakland by supplementing the EPA's Oakland air pollution dataset with an ArcMap database created Project BEACON's Data. I will create a map with the spatial distributions of ozone and carbon dioxide. I will also use the Kriging interpolation along with spatial analysis to conduct a preliminary exposure assessment.

METHODS

Data collection

Study site

I downloaded boundary data provided by the TIGER Database (http://www.census.gov/geo/maps-data/data/tiger.html) . TIGER data was available to download as a shapefile, and was readily loaded on to ArcMap 10.1. TIGER's data also contained boundary information for all cities within California, so I extracted Oakland boundaries using ArcMap's "select by attributes" and "extract data" function. I also downloaded census tract boundary information from the TIGER database. This information included all census tracts within California, so I used a "clip" function to extract all census tracts within Oakland.

Socio-economic status

I used income as an indicator for socio-economic status, and collected this information from the U.S Census Bureau's American FactFinder. American FactFinder provides different demographic information, and also provides data from the American Cultures Survey's (ACS) estimates for three income metrics. These metrics include, mean income, median income, and poverty to income ratio. For this study, I collected data on poverty to income ratios from the 2011 American Cultures Survey 5-year estimate. This metric gives an estimate of the number of households within a given census tract living below the United States poverty line. In total, I collected information for poverty to income ratio for all 140 Oakland census tracts. I also used Excel to calculate the percentage of households living under the poverty line in each census tract.

Project BEACON

Project BEACON is an air-monitoring network unique to Oakland, and its managers have set out to deploy about 40 monitors. Project BEACON currently consists of 14 monitoring sites (See Appendix A), but each site began collecting data at different times, leading to incongruous monitoring data. Thus, I selected five monitoring sites because of their similar data collection timelines. These five sites included: Chabot Space and Science Center, Laurel Elementary, Skyline High School, International Community School, and St. Elizabeth High School. Data collection at these five sites coincided over a five-month time frame from June 1 2012 to October 31 2012.

EPA AQS

To assess ozone distribution within Oakland, I also collected information from the EPA's Air Quality Systems (AQS). The AQS is the EPA's database for air quality information and consists of approximately10000 monitors, 5000, of which, are currently active. Because the AQS collects information for the entire United States, I extracted information from two AQS monitors located in Oakland and two AQS monitors outside of Oakland. The data I collected from the AQS's Oakland sites consisted of monitors, 06-001-0009 and 06-001-0011. I also collected data from monitors 06-001-007 and 06-002-2001, located in Livermore and Hayward, respectively. Moreover, the AQS reported ozone measurements in parts per billion (ppb) for an hour time scale, so I converted these measurements to parts per million (ppm), to maintain a consistent unit of measurement.

In order to attribute for the daily variation in ozone concentrations, I collected measurements for 8AM, 1PM, and 6PM for my four selected monitoring sites. However, this data was only available from June to August. Ozone measurements from September to October were given as daily averages. Thus, my final ozone dataset consisted of three hourly averages from June through August and daily averages from September through October.

Data analysis

Project BEACON

I used two programs for my data analysis, Excel and ArcMap. I used Excel to calculate a monthly average for the five monitoring sites' carbon dioxide measurements. I also used Excel to match and organize my calculated monthly average concentrations to their respective coordinates. I input this information into ArcMap, and loaded the five BEACON monitoring points along with their respective monthly averages. With this information loaded on ArcMap, I used a Kriging interpolation method to map the distribution of carbon dioxide within the five BEACON sites.

I analyzed the carbon dioxide distributions on ArcMap after I used a Kriging interpolation method. Using the "Identify" tool, I picked out the census tracts that experienced the highest levels in carbon dioxide distribution. I also used the "Identify" tool to take note of the percentage of households living below the poverty line in those census tracts.

EPA AQS

I used Excel to calculate the monthly average concentration of ozone for 8AM, 1PM, and 6PM. I also used Excel to organize and match the calculated monthly average concentrations with their respective coordinates. Once this information was calculated, I used ArcMap to load the monitoring sites' coordinates and average ozone concentration. With my loaded monitoring points and associated average ozone concentration, I used a Kriging Interpolation method to map the distribution of ozone within the four AQS sites.

After mapping the distribution of ozone with a Kriging Interpolation method, I analyzed my kriged layers to assess which census tracts were exposed to the highest levels of ozone concentrations. I used ArcMap's "Identify" tool to pick out the census tracts that experienced the highest levels in ozone concentration. With the "Identify" tool I also took note of the census tract's income to poverty ratio information.

RESULTS

BEACON Project

Excel analysis

I found that monthly average carbon dioxide concentrations at the five BEACON monitoring sites decreased between June and July, and increased again from September onwards (Fig. 1). When I compared these measurements to NASA's Global Monthly Average, I found that three monitoring sites recorded at least one monthly average higher than NASA's Global Monthly Average (Fig. 2). I also found that all sites nearest to a major freeway corridor recorded monthly averages higher than NASA's.

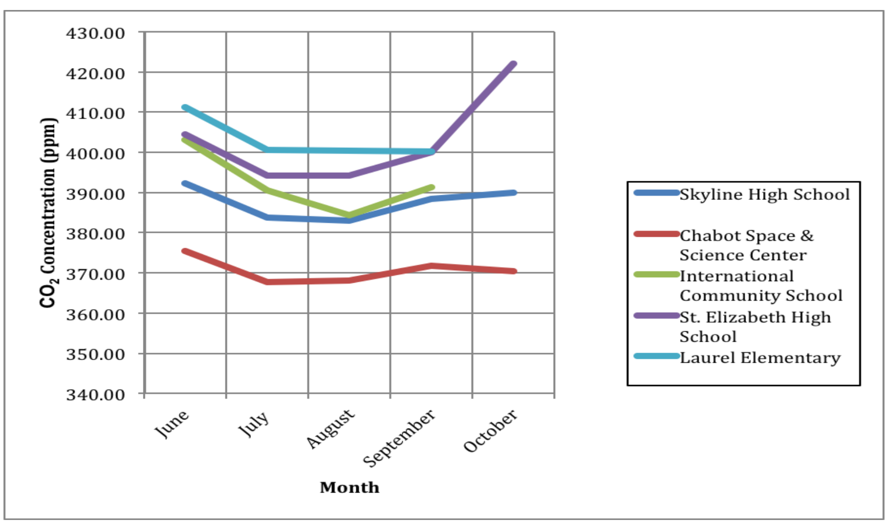


Fig. 1. Temporal variation in average monthly CO_2 concentrations. Average monthly CO_2 concentrations throughout June and October for all five BEACON monitoring sites.

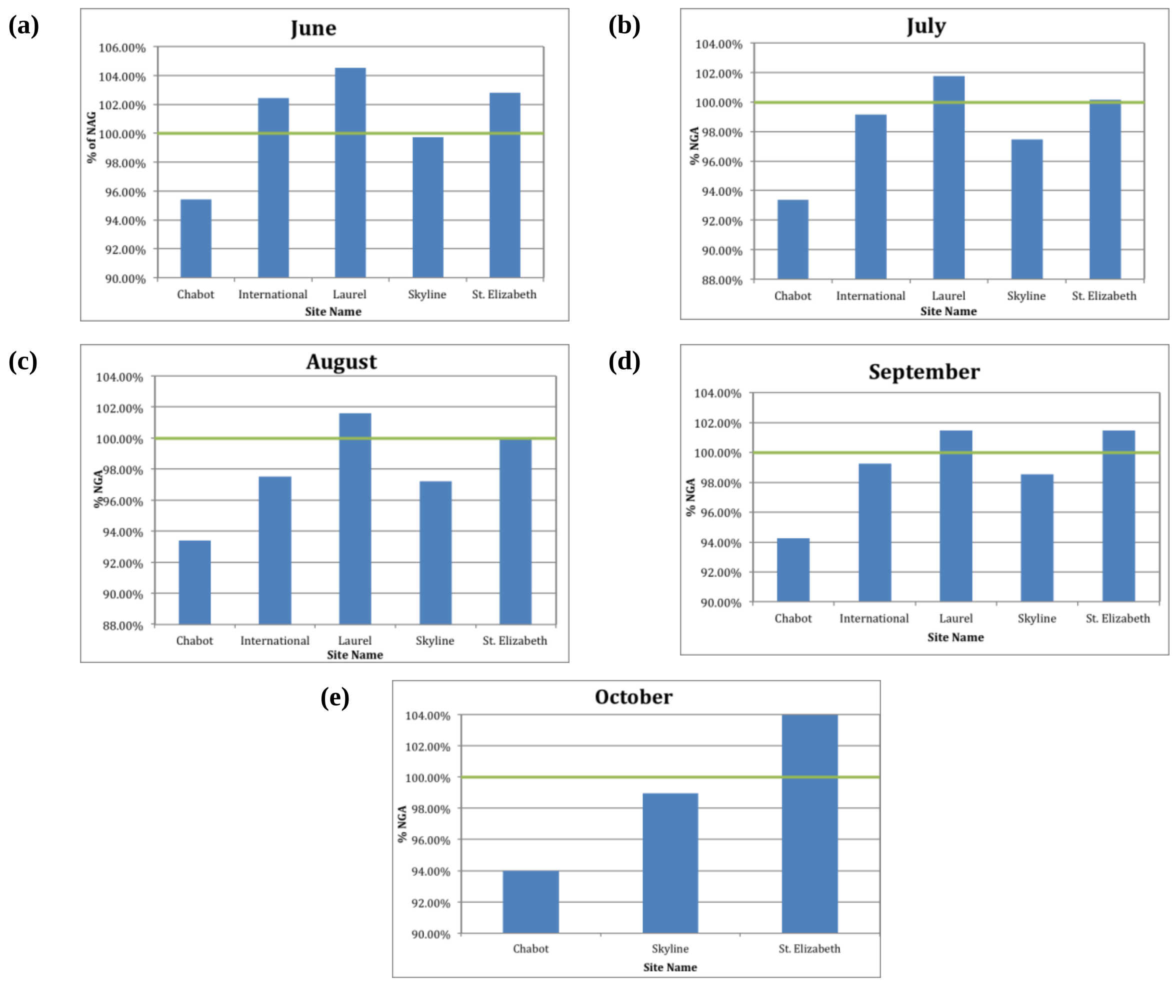


Fig. 2. Percentage of NASA's global monthly average. (a) June (b) July (c) August (d) September (e) October. Some BEACON monitoring sites recorded CO_2 concentrations above NASA's global monthly average (green line). In diagram (e), two of the five monitoring sites had incomplete data.

Kriging interpolation and spatial analysis

After using a Kriging interpolation method, I found that my results did not encompass all 140 Oakland census tracts. Instead, my kriged layer contained 18 census tracts (Fig. 3). I also found that my kriged layers for all 5 months resulted in different distributions of carbon dioxide (Fig. 4). Moreover, within these kriged layers, I found that throughout my study time frame, census tracts 4068, 4069, 4070 consistently experienced the highest carbon dioxide concentrations from June through September (Fig. 4). On October, however, census tracts 4065, 4071.01, and 4071.02 experienced the highest levels of carbon dioxide.

After using ArcMap's "Identify" tool, I found that the ACS 5-year estimate reported 5.25% of total households living under the poverty line within census tract 4068. The ACS also reported that census tracts 4069 and 4070 had 34.23%, and 34.99% of households living under the United States poverty line, respectively (Table 1). In census tracts 4065, 4071.01, and 4071.02 the ACS 5-year estimate reported 12.85%, 61.41%, and 45.74% of households living under the poverty, respectively.

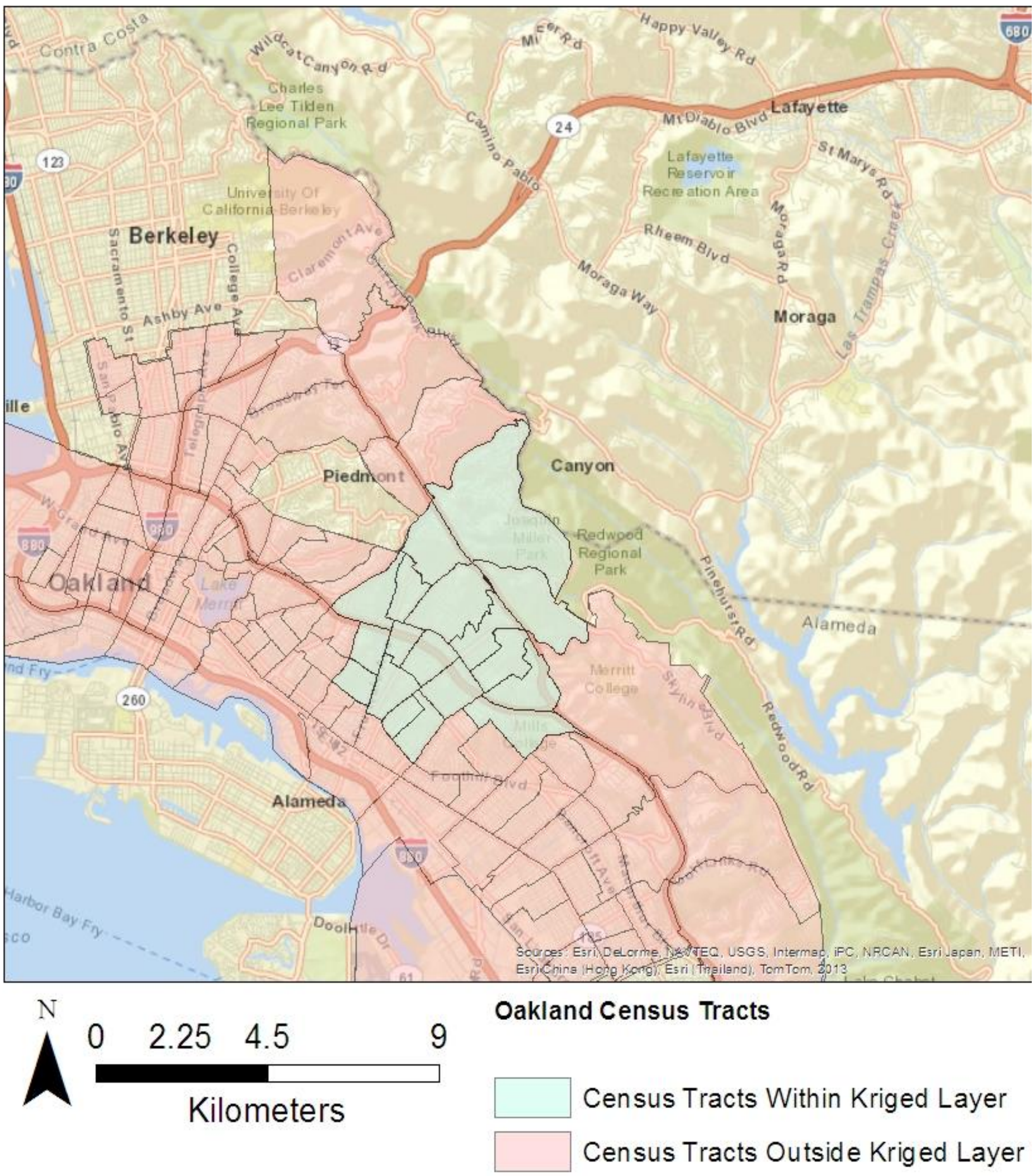
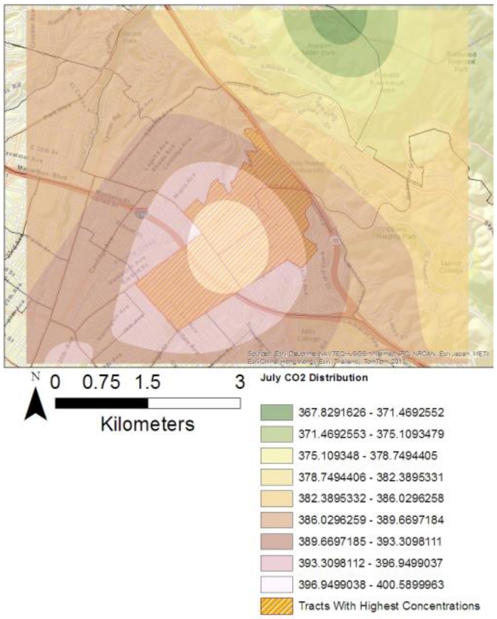
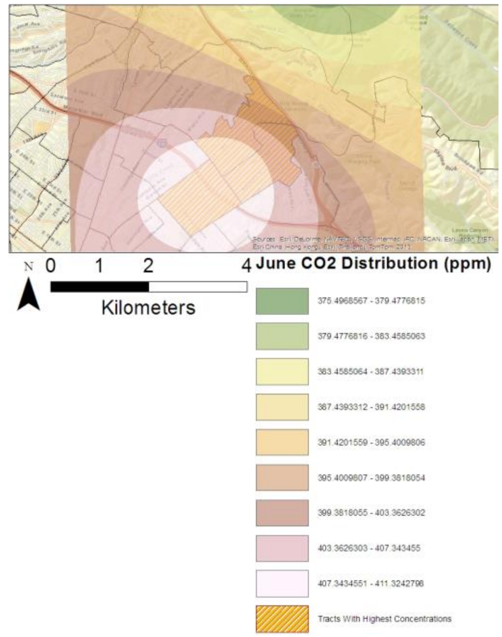


Fig. 3. Census tracts within kriged layer. After using a Kriging interpolation method, only18 census tracts were within the kriged layer.

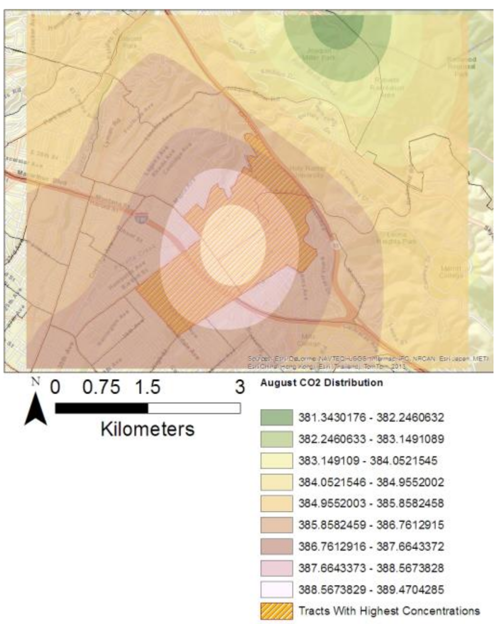
(a)


0 0.75 1.5 3
Kilometers
N
July CO2 Distribution
367.8291626 - 371.4692552
371.4692553 - 375.1093479
375.109348 - 378.7494405
378.7494406 - 382.3895331
382.3895332 - 386.0296258
386.0296259 - 389.6697184
389.6697185 - 393.3098111
393.3098112 - 396.9499037
396.9499038 - 400.5899963
Tracts With Highest Concentrations

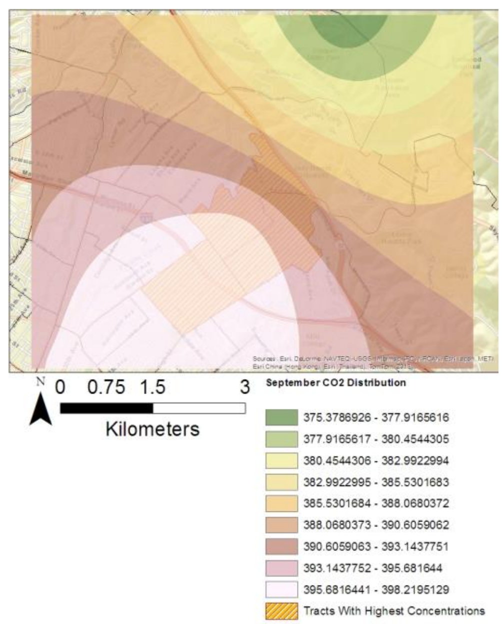
(b)


0 1 2 4
Kilometers
N
June CO2 Distribution (ppm)
375.4968567 - 379.4776815
379.4776816 - 383.4585063
383.4585064 - 387.4393311
387.4393312 - 391.4201558
391.4201559 - 395.4009806
395.4009807 - 399.3818054
399.3818055 - 403.3626302
403.3626303 - 407.343455
407.3434551 - 411.3242798
Tracts With Highest Concentrations

(c)


0 0.75 1.5 3
Kilometers
N
August CO2 Distribution
381.3430176 - 382.2460632
382.2460633 - 383.1491089
383.149109 - 384.0521545
384.0521546 - 384.9552002
384.9552003 - 385.8582458
385.8582459 - 386.7612915
386.7612916 - 387.6643372
387.6643373 - 388.5673828
388.5673829 - 389.4704285
Tracts With Highest Concentrations

(d)


0 0.75 1.5 3
Kilometers
N
September CO2 Distribution
375.3786926 - 377.9165616
377.9165617 - 380.4544305
380.4544306 - 382.9922994
382.9922995 - 385.5301683
385.5301684 - 388.0680372
388.0680373 - 390.6059062
390.6059063 - 393.1437751
393.1437752 - 395.681644
395.6816441 - 398.2195129
Tracts With Highest Concentrations

(e)

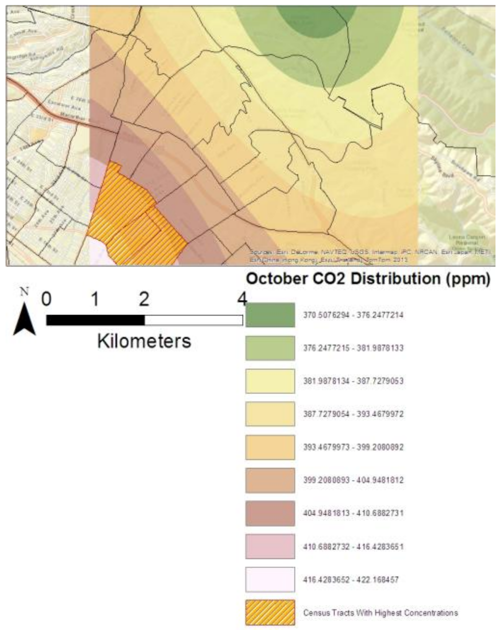


Fig. 4. Spatial distribution of CO_2 from June through October. After Kriging interpolation, CO_2 distribution within the five BEACON monitoring sites changed. Throughout: (a) June (b) July (c) August (d) September, census tracts 4068, 4069, and 4070 experienced the highest CO_2 concentrations. In the month of (e) October, census tracts 4065, 4071.01, and 4071.02 experienced the highest CO_2 concentrations.

Table 1. Percentage of total households living under the U.S. poverty line. The ACS 2011 5-year estimate reported the following number of households living under the U.S. poverty line in census tracts 4068, 4069, and 4070.

Census Tract ID	Under 1.00	1.00 and 1.99	2.0 and Over	Total Households	Percent Households Under1.00
4065	160	1085	0	1245	12.85%
4068	35	181	451	667	5.25%
4069	279	48	488	815	34.23%
4070	505	435	503	1443	34.99%
4071.01	697	303	135	1135	61.41%
4071.02	483	70	503	1056	45.74%

EPA AQS

Excel analysis

After calculating the monthly average ozone concentrations from June through August, I found that ozone concentrations followed a similar trend throughout the day. Ozone increased from a lower concentration to a higher concentration, reaching peak concentrations around 1PM. After reaching peak concentrations, ozone concentrations decreased, but were still above 8AM concentrations (Fig. 5). Ozone concentrations at all AQS monitoring sites also did not exceed the 2008 National Ambient Air Quality Standard (NAAQS), which has set .075 ppm ozone as the maximum limit. My calculated average concentrations also meant that there were no associated health risks throughout my study time frame (Fig. 6).

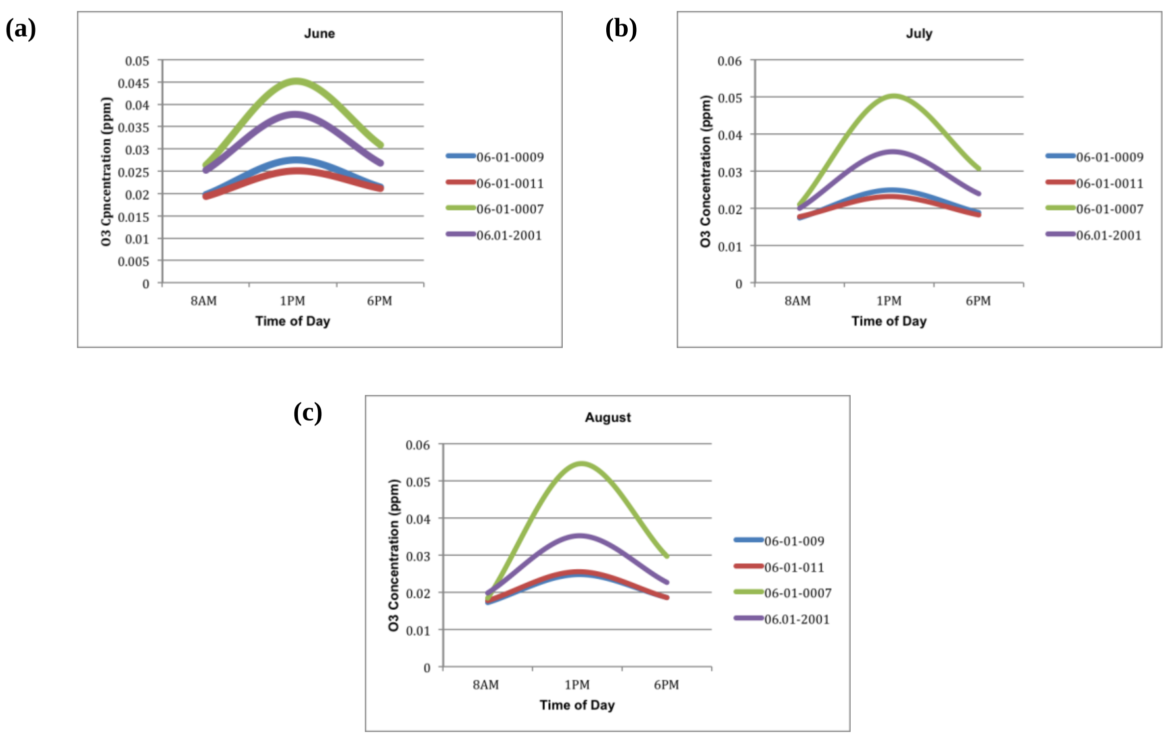


Fig.5. Daily variation in O_3 concentrations from June through August. Months between June and August had data on hourly averages of O_3 concentrations. Concentrations at all four AQS monitors for these months increased throughout the day, and reached their peak at 1PM.

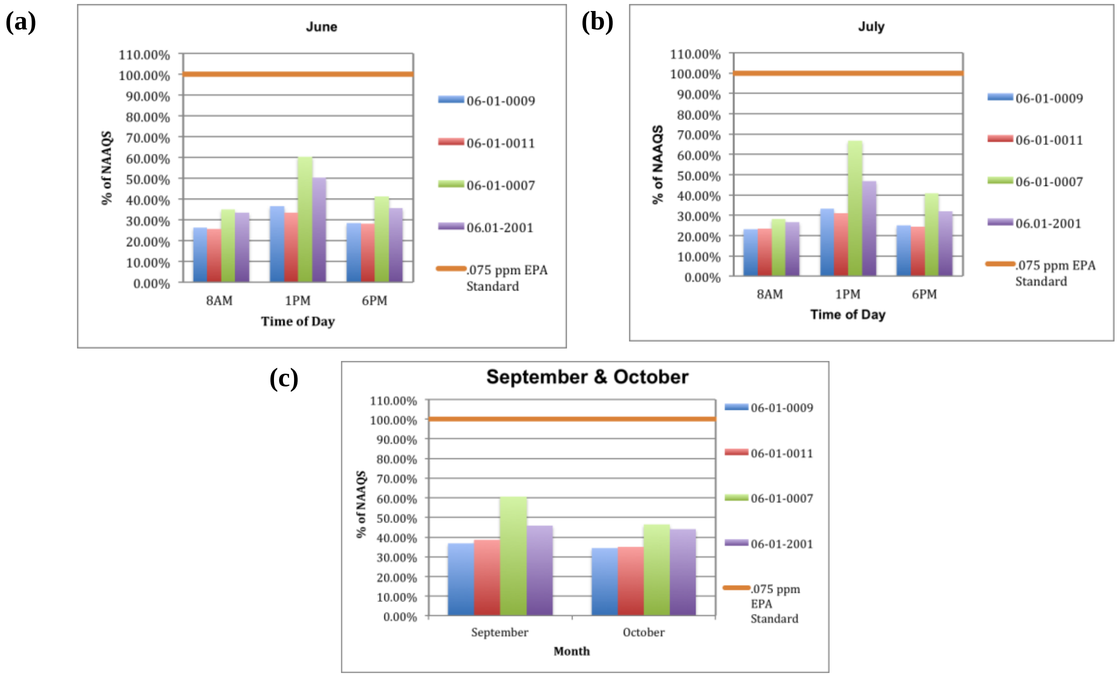


Fig. 6. Percent of 2008 NAAQS. Between the months of June and December, monthly average O_3 concentrations did not exceed the 2008 National Ambient Air Quality Standard. Moreover, at these levels, there are no associated health risks from O_3 exposure.

Kriging interpolation and spatial analysis

Using Kriging interpolation on the AQS data, I found that ozone distribution throughout my study timeline looked similar each month. The highest concentrations of ozone were located outside of my study site and closest to monitors 06-01-0007 and 06-01-2001. Within my study site, ozone concentrations did not exceed .030 ppm, which poses no associated health risks. Moreover, unlike the BEACON Project results, my ozone kriged layer covered most of the Oakland census tracts, with the exception of a few census tracts. (See Appendix B). I also found that across all Oakland census tracts inside my kriged layer ozone concentrations were the same (See Appendix B).

DISCUSSION

In this study I assessed the spatial distribution of both carbon dioxide and ozone using data from Project BEACON and EPA AQS. Along with the poverty to income ratio data I collected from Census Factfinder, I also determined which census tracts in Oakland, California were exposed to the highest concentrations of ozone and carbon dioxide between June and October. My study objectives were to construct a spatial distribution database for carbon dioxide and ozone in Oakland. I also set out to conduct a preliminary exposure assessment in order to assess the relationship between socio-economic status and air pollution.

Carbon dioxide

I observed the highest carbon dioxide concentrations near Oakland's two major freeway corridors, I-580 and I-880, suggesting that vehicular emissions are a major source of carbon dioxide production. One third of the United States' carbon dioxide emissions is attributed to transportation, and in an urban setting, traffic congestion plays a big role in carbon dioxide emissions (Barth and Boriboonsomsin 2008, Zhang et al. 2011). Thus, my findings can be expected given the high volume of traffic that both freeway corridors experience on a daily basis. My findings are also consistent with Amirjamshidi et al.'s (2013) study conducted in the Toronto Waterfront Area that observed highest carbon dioxide concentrations near high capacity roadways.

Ozone

Ozone concentrations at all four AQS sites varied throughout the day, with peak concentrations occurring at1 P.M. This trend might suggest that commuting plays a role in ozone production. Oxides of nitrogen (NO_x) resulting from fuel combustion in vehicles have been linked to the increased formation of ozone (Yerramsetti et al. 2013). Moreover, increased NO_x emissions occur during rush hour congestion and higher density roadways (Barth and Boriboonsomsin 2008, Zhang et al. 2011).

Exposure assessment

In this study I used ArcMap's identify tool to pick out the census tracts that were located in the areas with highest carbon dioxide and ozone concentrations. I found that within my carbon dioxide kriged layer three census tracts were consistently exposed to the highest concentrations for four months. On the fifth month of my study another three census tracts were exposed to the highest carbon dioxide concentrations. Of these six census tracts, four census tracts were reported to have above 30% of families living under the United States poverty line.

By using a Kriging Interpolation on the EPA AQS ozone data, I found that the highest levels of ozone were located outside of Oakland, and the lowest levels were spread out evenly throughout all Oakland census tracts. These findings are not consistent with previous studies linking socio-economic status and various air pollutants (Maantay et al. 2009, Young et al. 2012). This may be due to the greater distance between each AQS monitor, which could have led to an unreliable use of Kriging Interpolation (Buzzelli and Jerrett 2003).

Limitations and future directions

Limitations of my study include the time frame I used. Using data for the last half of the 2012 year is not representative of the entire year. Moreover, my study used 5 monitoring sites whose data coincided with each other, but Project BEACON is comprised of 14 monitoring sites to date. If my study had used all 14 BEACON monitoring sites, I expect that the number of census tracts I could have looked at would be much bigger, and my observations on the number of census tracts being exposed to the highest levels of carbon dioxide would have been more extensive. Furthermore, although using Kriging interpolation produces optimal estimates in areas that are unmonitored (Lee et al. 2012), it cannot account for individual exposures that are produced through advanced exposure models, like Stochastic Human Exposure and Dose Simulation Models (SHEDS) (Watkins et al. 2012). Therefore, further studies may take into consideration how individual exposure may vary across Oakland. Future exposure assessments will also benefit from a larger Project BEACON data set, especially because Project BEACON's managers expect to install more monitors across Oakland, and update them to collect data on ozone and other hazardous air pollutants.

Prior studies have addressed the fact that there is paucity of monitoring data, and sparse data requires intricate spatial metrics (Buzzelli and Jerrett 2003). Other studies have also focused on cross-validation methods for a single dataset to determine which interpolation methods are more accurate (Thepanondh and Toruksa 2011). Thus, Project BEACON's expected updates may benefit future ozone exposure assessments in Oakland because there is less distance between each BEACON monitor than there is between each AQS monitor. As mentioned, the fact that I did not observe any difference in ozone exposure across all census tracts in Oakland may be due to sparse AQS monitors.

Climate Action

The differences in average carbon dioxide measurements across Oakland may have been influenced by geographical location. I observed higher average monthly carbon dioxide nearer major freeway corridors, like the Interstate 880 and Interstate 580, which might have been due to increased traffic. Increased tree cover may have influenced the lower monthly carbon dioxide measurements I observed near Chabot Space and Science Center and Skyline High School. Similarly, the variation in ozone concentrations throughout a 24-hour day may also be indicative of the impact that increased traffic may have on ozone production.

With the introduction of Oakland's Climate Action Plan on December 4, 2012, officials expect to reduce greenhouse gas levels to 25% of 2006 levels (ECAP 2012). These results might provide more insight into which aspects of pollution should be addressed. To reduce a larger influx in cars during the morning and afternoon, officials might look into offering alternative transportation for commuters. Furthermore, officials may benefit from focusing on the areas with highest carbon dioxide concentrations.

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REFERENCES

Amirjamshidi, G., T. S. Mostafa, A. Misra, and M. J. Roorda. 2013. Integrated model for microsimulating vehicle emissions, pollutant dispersion and population exposure. Transportation Research Part D-Transport and Environment **18**:16–24.

Barth, M., and K. Boriboonsomsin. 2008. Real-World Carbon Dioxide Impacts of Traffic Congestion. Transportation Research Record: Journal of the Transportation Research Board **2058**:163–171.

Bell, M.L., F. Dominici, and J.M. Samet. 2005. A meta-analysis of time-series studies of ozone and mortality with comparison to the national morbidity, mortality, and air pollution study. Epidemiology **16**:436-445

Buzzelli, M., and M. Jerrett. 2003. Comparing Proximity Measures of Exposure to Geostatistical Estimates in Environmental Justice Research. Global Environmental Change Part B: Environmental Hazards **5**:13–21.

Gruber D. 2000. The U.S. Clean Water Act and the application of microbiotests to demonstrate compliance. Environmental toxicology **15**:417-420.

Hackbarth A. D., J. A. Romley, and D. P. Goldman. 2011. Racial and ethnic disparities in hospital care resulting from air pollution in excess of federal standards. Social science & medicine **73**:1163-1168.

Havard S., S. Deguen, D. Zmirou-Navier, C. Schillinger, and D. Bard. 2009. Traffic-related air pollution and socioeconomic status a spatial autocorrelation study to assess environmental equity on a small-area scale. Epidemiology **20**:223-230.

Johnson P. R. S., and J. J. Graham. 2005. Fine particulate matter National Ambient Air Quality standards: Public health impact on populations in the northeastern United States. Environmental health perspectives **113**:1140-1147.

Lee, S.J., M. L. Serre, A. van Donkelaar, R. V. Martin, R. T. Burnett, and M. Jerrett. 2012. Comparison of geostatistical interpolation and remote sensing techniques for estimating long-term exposure to ambient PM2.5 concentrations across the continental United States. Environmental health perspectives **120**:1727–1732.

Livernash, R.1995.Environmental quality. Pages 109-127. Environmental quality in R. Livernash, editor. The Council on Environmental Quality. Washington D.C.,USA

Maantay, J. A., J. Tu, and A. R. Maroko. 2009. Loose-coupling an air dispersion model and a geographic information system (GIS) for studying air pollution and asthma in the Bronx, New York City. International Journal of Environmental Health Research **19**:59–79.

Morello-Frosch R., B. M. Jesdale, J. L. Sadd, and M. Pastor. 2010. Ambient air pollution exposure and full-term birth weight in California. Environmental Health **9**:44.

Samoli, E., R. Peng, T. Ramsay, M. Pipikou, G. Touloumi, F. Dominici, R. Burnett, A. Cohen, D. Krewski, J. Samet, and K. Katsouyanni. 2008. Acute effect of ambient particulate matter on mortality in Europe and North America: Results from the APHENA study. Environmental Health Perspectives **116**: 1480-1486

Schweitzer L., J. Zhou. 2010. Neighborhood air Quality, respiratory health, and vulnerable populations in compact and sprawled regions. Journal of the American Planning Association **76**:363-371.

Smail E. A., E. A. Webb, R. P. Franks, K. W. Bruland, and S. A. Sanudo-Wilhelmy. 2012. Status of metal contamination in surface waters of the coastal ocean off Los Angeles, California since the implementation of the Clean Water Act. Environmental Science & Technology **46**:4304-4311.

Su J. G., M. Jerrett, A. de Nazelle, and J. Wolch. 2011. Does exposure to air pollution in urban parks have socioeconomic, racial or ethnic gradients? Environmental Research **111**:319-328.

Thepanondh, S., and W. Toruksa. 2011. Proximity analysis of air pollution exposure and its potential risk. JEM Journal of Environmental Monitoring **13**:1264–1270.

Thurston, G.D., and K. Kazuhiko. 1999. Epidemiological studies of ozone exposure effects. Air Pollution and Health **1**:485-509

Watkins, T., L. Baxter, H. Özkaynak, V. Isakov, and D. Mobley. 2012. Novel Approaches for Estimating Human Exposure to Air Pollutants. Pages 741–745 *in* D. G. Steyn and S. T. Castelli, editors. Air Pollution Modeling and its Application XXI. . Springer Netherlands.

Yerramsetti, V. S., N. G. Navlur, V. Rapolu, N. S. K. C. Dhulipala, P. R. Sinha, S. Srinavasan, and G. R. Anupoju. 2013. Role of Nitrogen Oxides, Black Carbon, and Meteorological Parameters on the Variation of Surface Ozone Levels at a Tropical Urban Site - Hyderabad, India. Clean-Soil Air Water **41**:215–225.

Young G. S., M. A. Fox, M. Trush, N. Kanarek, T. A. Glass, and F. C. Curriero. 2012. Differential exposure to hazardous air pollution in the United States: a multilevel analysis of urbanization and neighborhood socioeconomic deprivation. International Journal of Environmental Research and Public Health **9**:2204-2225.

Zhang, K., S. Batterman, and F. Dion. 2011. Vehicle emissions in congestion: Comparison of work zone, rush hour and free-flow conditions. Atmospheric Environment **45**:1929–1939.

APPENDIX A: BEACON Monitoring Sites

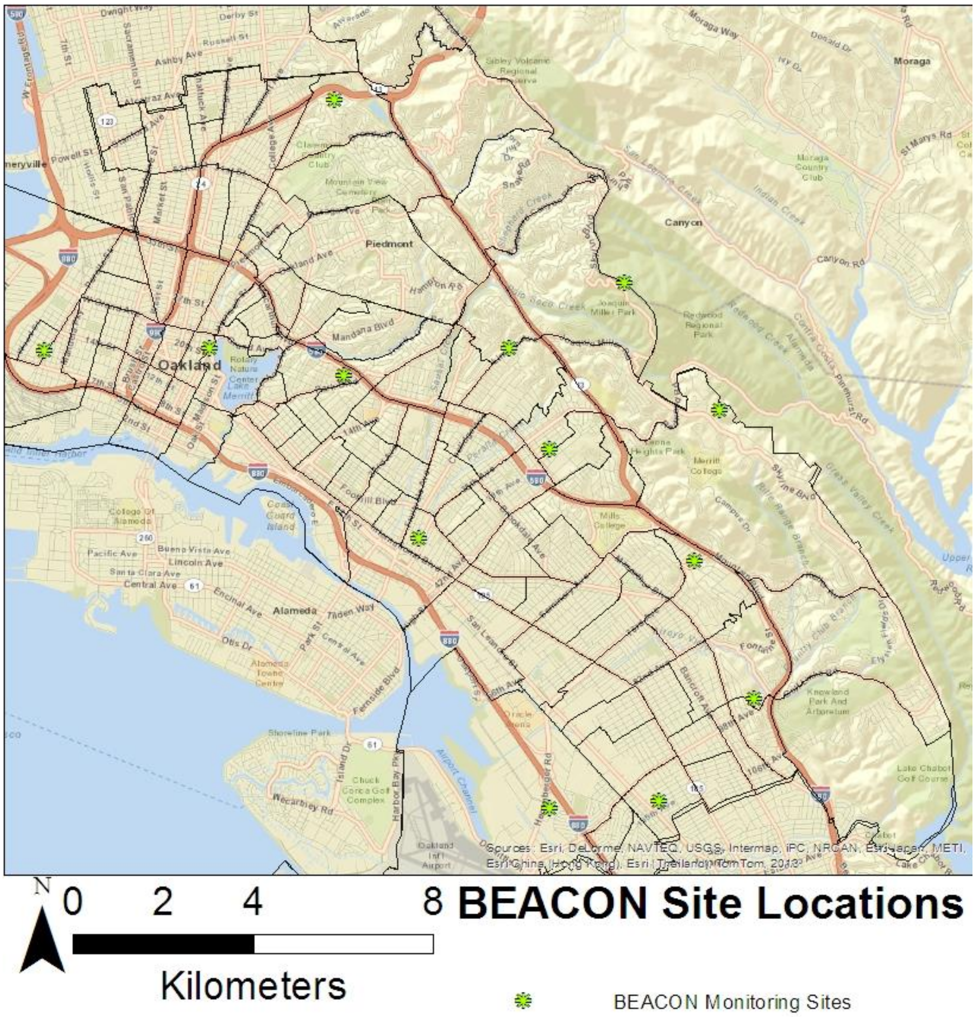
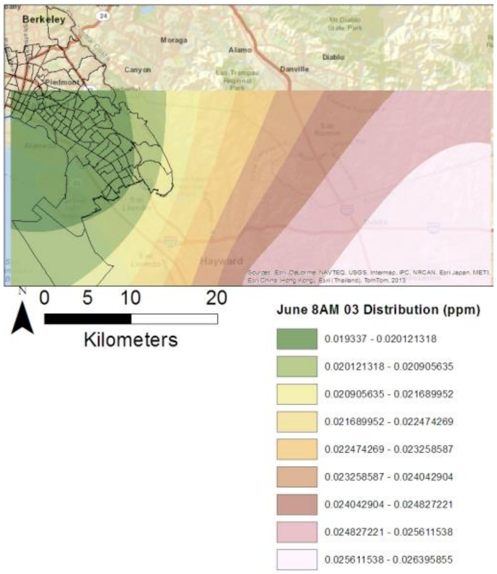


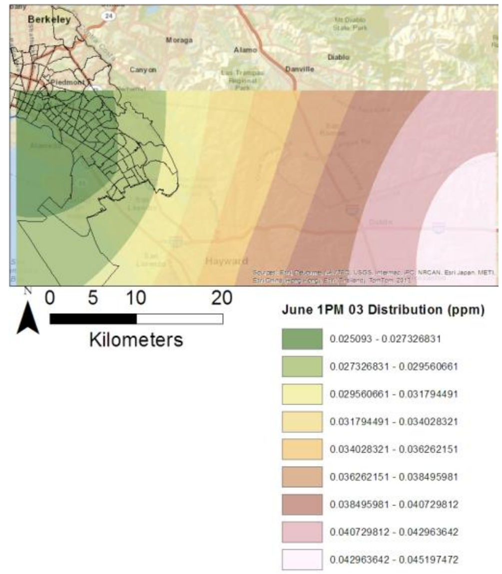
Fig.A1. BEACON monitoring sites locations. Project BEACON currently manages 14 monitoring sites that are spread throughout Oakland.

Appendix B: Ozone distribution from June to October

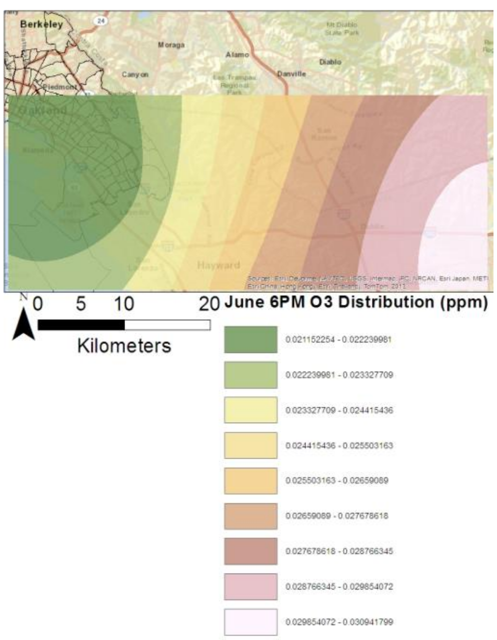
(a)



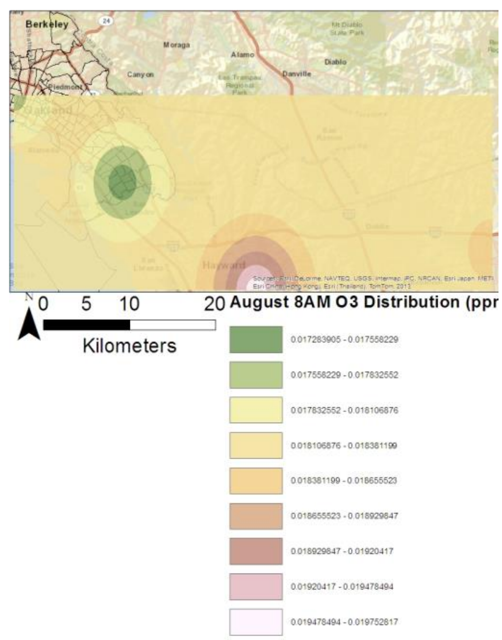
(b)



(c)



(d)



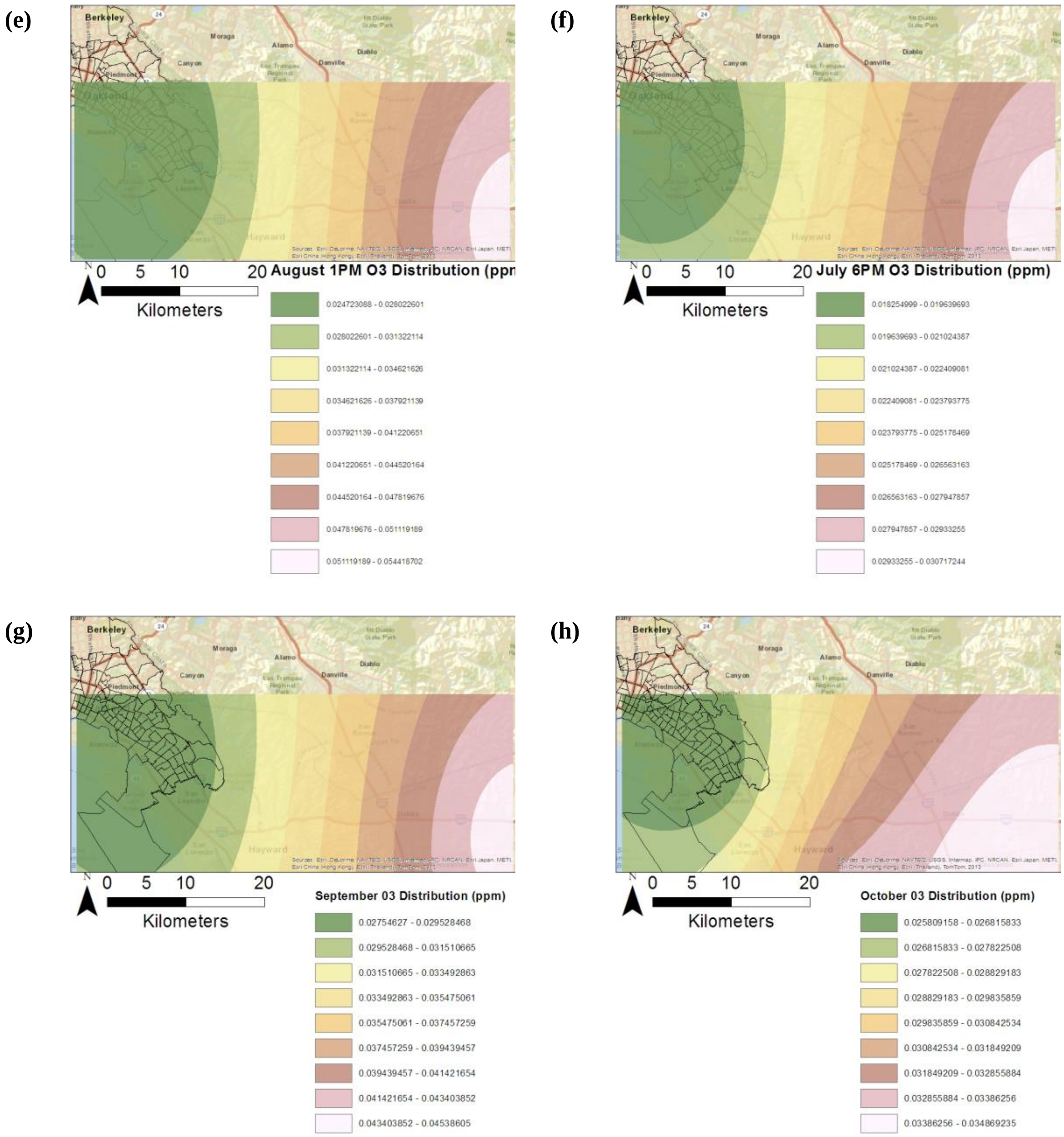


Fig.B1. Spatial distribution of ozone from June through October. (a) June 8AM distribution (b) June 1PM distribution (c) June 6PM distribution (d) July 8AM distribution (e) July 1PM distribution (f) July 6PM distribution (g) September distribution (h) October distribution. Between June and October, ozone distribution remained relatively the same, with the exception of August 8AM's distribution. Within Oakland, ozone concentrations were the levels that are not indicative of any health risks.