

Combining continuous near-road monitoring and inverse modeling to isolate the effect of highway expansion on a school in Las Vegas

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Abstract

The impact of a highway expansion on a school adjacent to the highway is investigated with a novel method called the Sustained Wind Incidence Method (SWIM). The highway was expanded from a 6-lane highway to a 12-lane highway. SWIM falls under the broad group of environmental forensics methods where measured concentration data are used to identify possible contributors such as a point, line or a sectional source. SWIM helps identify potential sources by highlighting spatial domains associated with the markers unique to potential contributors. In this study, SWIM is used to identify sources of traffic related emissions. The marker used to measure the impact of the traffic due to expansion is black carbon (BC), a key traffic related emission mostly associated with large vehicles (> 40 ft. in length), collected both before and after the road expansion. Using this method, multiple source domains may be simultaneously identified. For this study, the data collection site was situated at the school about 20 meters from the sound wall (7 meters high) separating the school and the highway. SWIM results show that the road expansions may have impacted the traffic patterns of the nearby non-highway feeder road and on-ramp (adjacent to the sound wall) traffic to the highway. This sector showed a surprisingly larger change than the highway in the observed increase in their relative contribution to the receptor site. Some domains (apportioned sector) show a dramatic increase ranging roughly from 10% to 50% in relative contributions. Using the output from SWIM and knowledge of local contributors, a local source landscape is painted.

Key words: Near-road, Sustained Wind Incidence Method; Sector Apportionment, Inverse Model

Introduction

U.S. 95 was one of Nevada's most congested stretches of highway, with nearly 12,000 vehicles traveling less than half the speed allowed during peak commuting hours. An expansion from 6 lanes to 12 lanes was envisaged to reduce peak hour traffic jams by accommodating up to 34% increase (up to 303,000 vehicles per day) in the daily traffic volume. Citing a link between exhaust emissions and increased incidence of cancers, a public interest law suit was filed to halt the expansion. An out-of-court settlement resulted in many changes including an agreement to study the possible health impacts of the expansion on the immediate vicinity of the highway. The primary motivation is to develop a reliable method to measure the impact of the road expansion on Las Vegas school adjacent to the highway US-95. Exposure of vulnerable populations, young children at school, to near-road sources is the central issue that is addressed by this and other manuscripts associated with this study.

One of the main reasons for selecting the stretch of US 95 in Las Vegas, Nevada between Torrey Pines Road and Valley Forge Blvd. for data collection and analysis is because three schools: Fyfe Elementary, Western High, and Adcock Elementary situated on the roads adjacent to US 95 with only a 7 meter high sound wall separating the school playground and other facilities from exposure to US 95 traffic emissions. Also, multiple locations within the schools were chosen. Measurements were made near the playground, air intake systems and in some cases, inside the classrooms. Multiple pollutants, both organic and inorganic, were measured at varying time resolutions. The fourth school was situated one mile from US 95 and was used as background site. The sound wall bordering the highway was not modified during the expansion. With the expanded lanes, both traffic volume and average speeds were expected to increase and also reduce congestion. Traffic volume was projected to reach 450,000 vehicles day by the year 2020 with more expansion slated for the future. But, due to economic downturn that started in 2007 and felt acutely in the state of Nevada, this projected figure is likely to be reduced greatly.

Concerns about possible health effects from exposure to emissions from motor vehicles were the primary reason for undertaking the near-road study in Las Vegas. A number of studies have demonstrated the significant health impacts from air pollution, including increased asthma rates, detrimental fetal development during pregnancy, and decreased lung capacity (Brunekreef et al., 1997; McDonald et al., 2004; Dockery et al., 1993; Dockery and Stone, 2007; Schwarz et al., 1996; Wilson and Suh 1997). This has been further confirmed in subjects exposed to ambient air near major roadways (Edwards et al., 1994; Nitta et al., 1993). BC, carbon monoxide (CO), Nitrogen Oxides (NO_x), Particulate Matter (PM) mass and ultrafine particles (UFP) have been the focus in many near-road studies (Zhu et al., 2002; Zhang et al., 2004; Phuleria et al., 2007; Ntziachristos et al., 2007; Fruin et al., 2008; Hagler et al., 2009).

It has been shown that local traffic diesel based traffic contributed significant amounts of BC to the air shed (Pakkenen et. al., 2000, Ban-Weiss et al., 2009). Combustion of fossil fuels by catalytic converter equipped vehicles has been shown to be significant emitters of atmospheric BC (Cachier, 1995; Penner et al. 1993; Cooke and Wilson, 1996).

Data Collection

A two-channel (370nm and 880 nm) Magee Scientific Aethalometer™ was used to measure BC in 5-minute intervals by collecting aerosol on a quartz fiber tape, after passing through a Harvard impactor with a size-cut of 2.5 microns. Raw data were screened with the Washington University Air Quality Lab (WUAQLAethDataMasher Version 5.0a (AethDataMasher 2006), to format date time stamps and perform data validation. Records were screened for “lamp on” voltages that indicate tape advancement and/or hardware performance problems, and for >25% deviations from the mean flow rate. Records with values less than $-10 \mu\text{g}/\text{m}^3$ were also removed. For the data used in the model, 6.25% of the data were either missing or eliminated using the above mentioned criteria. Due to the high temporal resolution of data and their high quality during the peak periods, the lost data are not likely to meaningfully affect the results. The wind data were collected using an AQ 5305-L™ wind monitor manufactured by RM Young Company.

Data Used in the Model

BC data were collected between May 2007 and September 2008 at Fyfe Elementary School situated on US 95 effectively covering both the period before and after the expanded lanes of US 95 were open to traffic as shown in the graphic. Since the ambient values measured at the receptor site were influenced by both the traffic and meteorology, data for analysis were chosen from the same season to mitigate potential meteorological influence. Hence, to study only the effects of the lane expansions using ambient data with minimal meteorological changes, the summers of 2007 (“before”) and 2008 (“after”) were chosen for analysis.

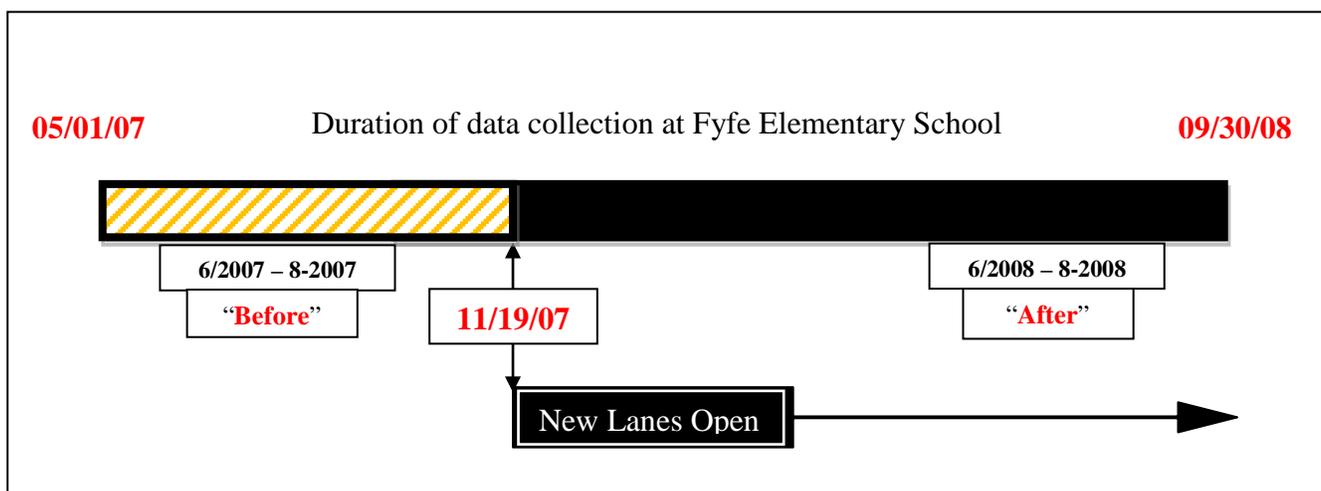


Figure 1: Dates of data collection and use

Also, with only 15 continuous months of data, the summers were the only available season for which the data were available for the pre- and post-expansion periods. After analyzing the traffic volume numbers provided by the Nevada Department of Transportation (NDOT), it was observed that large vehicles (> 40 ft. in length) traffic did not have the classic bi-modal morning and evening rush hour traffic peaks. Instead, large vehicle traffic remains high through out the day. Also, on Sundays, the traffic volume is predictably low all day and did not add to the quality of the data. Hence it was not included in the analysis. In summary, the present analysis focused only on data collected during the hours of 5 AM through 6 PM during the weekdays and Saturdays. Also, data for which observed wind speed did not exceed 0.5 m/s were excluded from the analysis due to uncertainty associated with wind directions at such low speeds. Thus, BC data collected from the Fyfe Elementary School from June-August 2007 and June-August 2008 were chosen to capture the effects of expansion. Both sets of data were examined in detail.

Methodology

The data collection intensive was started early enough (May 2007) so that the effects of the expansion (completed in November 2007) could be evaluated by comparing the traffic emissions before and after the expanded lanes were open to traffic. This analysis focused on high time resolution (5-min interval) BC and meteorological data including wind speed, wind direction, and sigma-theta (the standard deviation in the wind direction) that were collected during the study. BC was chosen as a surrogate for large vehicle exhaust to study the effects of the freeway expansion and the resulting change in traffic patterns. This study focuses on BC measurements obtained at Fyfe Elementary school [36°10'35.41"N 115°11'42.85"W], because this school was the closest in proximity (20 meters) to US-95 and therefore suspected to have the largest impact from roadway expansion.

The method used to analyze the data is called the Sustained Wind Incidence Method (SWIM). SWIM is an improvement on Non-parametric Wind Regression (NWR) (Henry et. al, 2009) method. While NWR relies on wind speed and wind direction alone, SWIM incorporates the wind direction standard deviation in the model to compute the results. The incorporation of wind direction standard deviation in the model results in the reduction of the effect of data collected during highly unstable meteorological periods with large wind directional changes. In other words, the SWIM identifies the effects of steady (low wind direction standard deviation) meteorological periods. Just like NWR, SWIM utilizes the smoothing techniques to derive an estimate of the distribution of the mean ambient concentration as a function of wind speed and wind direction. Then, using this distribution, the fraction of the mean concentration associated with a certain angular sector, which will hitherto referred as sector apportionment, and their associated uncertainties are derived.

However, it must be noted that the use of wind direction standard deviation does not introduce any methodological bias. The software code for SWIM was written using MATLAB[®] developed by The Mathworks Inc. to take advantage of the high time resolution air pollution measurements and meteorology.

In many cases, simple analysis of a cause (expansion) and effect (environmental impact) could have been done using a metric such as mean value to measure change. But, in this case, such point-wise comparison of data from two summers is inappropriate since wind speed and wind direction are not deterministic by nature. However, it is justifiable to compare the *distribution* of two consecutive summers since meteorology, in the sense of distribution, was expectedly invariant between two successive years. The overall features such as the wind event distribution are remarkably similar (Figure 2) between the two years. In the figure, each segment of the pollution rose associated with BC is further sub-divided into bins where bin length

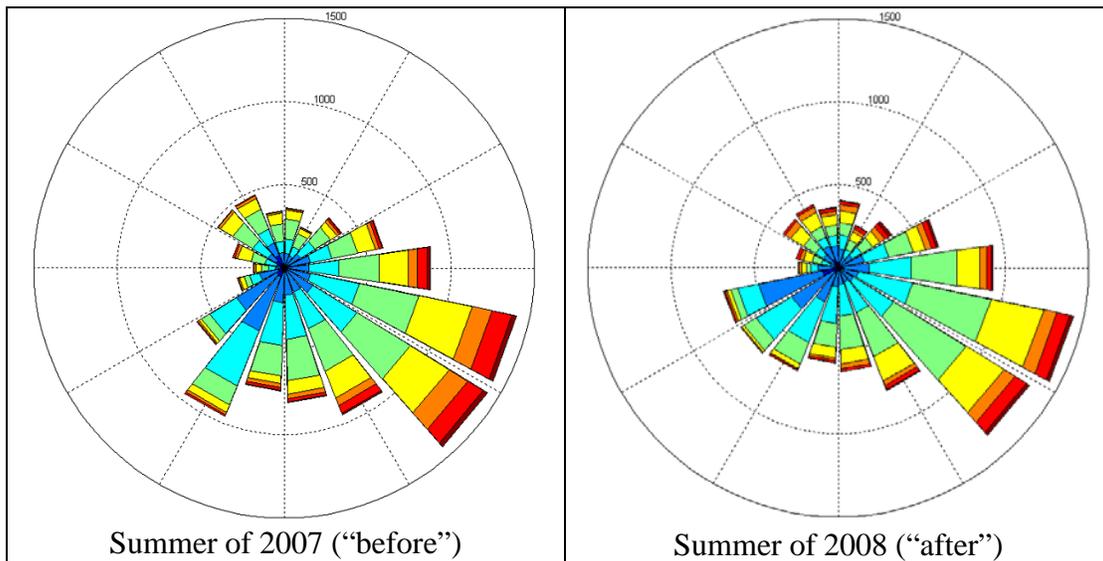


Figure 2: Pollution roses binned by concentration values for Fyfe Elementary School

represents the fraction of BC values in the percentile intervals. The bin interval break points and the associated BC values are shown in Figure 2. Even though overall meteorology remained relatively unchanged, important elements in the study like the average BC concentration and traffic volumes changed dramatically. The average ambient BC concentration dropped from $1.97 \mu\text{g}/\text{m}^3$ in summer of 2007 to $1.15 \mu\text{g}/\text{m}^3$ in the summer of 2008, a drop of 42%. This drop was widespread and was observed even at a background location. Data collected at a background site (Hancock Elementary School) about a 1 mile away from US 95 showed similar decrease between summer of 2007 (average of $0.78 \mu\text{g}/\text{m}^3$) and summer of 2008 (average of $0.63 \mu\text{g}/\text{m}^3$), a drop of about 20%.

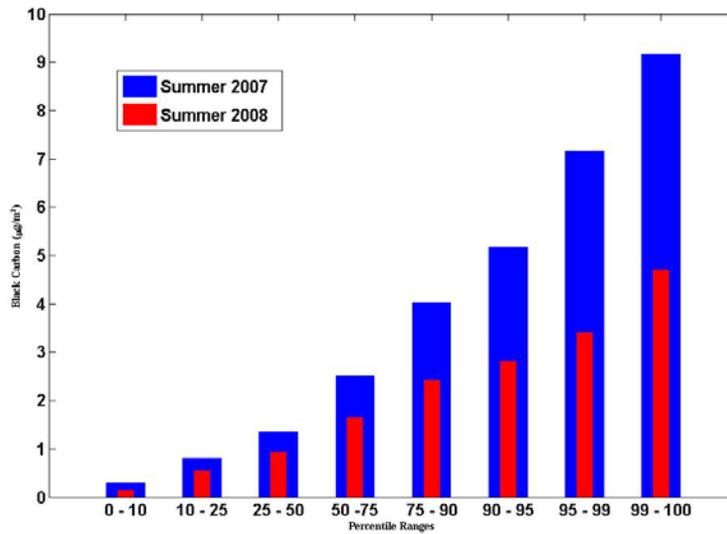


Figure 3: Percentile Bin Ranges for BC ($\mu\text{g}/\text{m}^3$) for 2007 (Blue) and 2008 (Red)

This is likely due to the fact that large vehicle traffic (> 40 ft. in length), the largest contributor of BC, dropped by 18% after the expansion. The large vehicles classification does not include vehicles used during road construction as they are typically short of 40 ft. in length. The drop in large vehicles like delivery trucks is most likely due to the deep economic woes experienced by Las Vegas starting from the middle of 2007. With steep drops in large vehicle traffic volume resulting in the drop in the measured BC values, a straightforward claim on the impact of the lane expansions on the nearby school can not be made without a more detailed analysis method.

To handle the asymmetric change (expanded highway vs. reduced traffic), a straightforward comparison of the data may not be useful. Therefore, the data are analyzed to observe any changes in emission rates between the two years. But, in this case, even this type of analysis is inadequate since the values in the summer of 2007 are much higher than the values in the summer of 2008. To extract meaningful conclusions from the data, the individual results from each year are normalized to a maximum of 1. We refer to this as the normalized values. Other forms of normalizations may be performed as well. But, since the ordinal values are invariant to the normalization scheme, qualitative results from the analysis of the data will remain unchanged. The Sustained Wind Influence Method (SWIM) uses ambient concentration and its associated meteorological data to construct an estimate of the underlying distribution function of the means concentration using kernel smoothing methods (Wand and Jones, 1995). By comparing the

normalized values from the same sectors between the two summers, it is possible to construct a picture of change between the two summers. This can be interpreted as the relative changes in contributions from the pre-defined sectors. SWIM is suitable for identifying local source types since it uses local area meteorology data only. We will discuss SWIM in more detail in the following section.

Sustained Wind Incidence Method

First, we introduce the kernel density estimate $\hat{f}(\theta, u)$ that approximates the unknown concentration density function $f(\theta, u)$ as a function of wind direction (θ) and wind speed (u). The kernel density estimate used by SWIM has the same functional representation as NWR but with one crucial change. It is given by

$$\hat{f}(\theta, u) = \frac{1}{N} \sum_{i=1}^N \frac{1}{\hat{\sigma}_i} K_1\left(\frac{(\theta - W_i)}{\hat{\sigma}_i}\right) * \frac{1}{\hat{h}_i} K_2\left(\frac{(u - U_i)}{\hat{h}_i}\right). \quad (1)$$

where kernel functions are used for wind direction K_1 and wind speed K_2 .

Here, U_i and W_i are the observed wind speed and direction associated with C_i the i^{th} observation ($1 \leq i \leq N$) in a time period starting at time t_i . Also, $\hat{\sigma}_i$ is the wind direction standard deviation \bar{h}_i

is the wind speed standard deviation and N is the number of samples. The definition for $\hat{f}(\theta, u)$ differs from the one used by NWR in using the wind direction standard deviation $\hat{\sigma}_i$ associated with the wind event instead a fixed and arbitrary smoothing parameter σ (and similarly for h). This change is both necessary and advantageous as will be shown and is driven by one of the basic requirements in kernel density estimation theory that as $N \rightarrow \infty$, the estimated density will converge to the actual density function. The mathematical statement that summarizes this requirement is $\hat{\sigma}_i \rightarrow 0$ and $N\hat{\sigma}_i \rightarrow \infty$ as $N \rightarrow \infty$. Similar assumptions are also made for h_i . This allows the approximations to be computed in the absence of an exact result in a closed form. Without these assumptions, the expressions for means and variances of the various quantities are not bounded as $N \rightarrow \infty$ and their approximations will not be accurate.

For the sake of brevity, the following derivations will be presented with $\hat{f} = \hat{f}(\theta)$, that is, as a function of a single variable. Then, the average value of $\hat{f}(\theta)$ is given by

$$E \hat{f}(\theta) = \int \frac{1}{N} \sum_{i=1}^N \frac{1}{\hat{\sigma}_i} K\left(\frac{(\theta - W_i)}{\hat{\sigma}_i}\right) f(\theta) d\theta$$

where $f(\theta)$ is the unknown density. By a change of variables and using the Taylor series expansion, we obtain

$$E \hat{f}(\theta) = f(\theta) + \frac{1}{2} \sum_{i=1}^N \mu_i^2 f''(\theta) + \sum_{j=1}^{\infty} \sum_{i=1}^N o(\hat{\sigma}_i^{2j}) \quad (2)$$

where we have used the standard assumptions for the kernels, $\int K(z) dz = 1$,

$\int z^{2j+1} K(z) dz = 0$, $j=0,1,\dots$ and $\int z^2 K(z) dz = \mu^2 < \infty$. By defining $\hat{\sigma}_i = \frac{\sigma_i}{N^\alpha}$ with $0 < \alpha < 1$, we not only satisfy the assumptions made earlier about σ_i , but also approximate

$$E \hat{f}(\theta) \approx f(\theta) + \frac{1}{2} \sum_{i=1}^N \mu_i^2 f''(\theta), \quad (3)$$

for large enough values of N . This implies that $\text{var}(\hat{f}(\theta)) \approx \sum_{i=1}^N \frac{1}{N \hat{\sigma}_i} \mu_i^2 f(\theta)$.

In addition, σ_i can be viewed as a uncertainty associated with quality of the i^{th} observation. Larger values of σ_i imply large variation in the wind direction over the period in which the values were averaged which implies a comparably higher inconsistency. By using a kernel such the Gaussian kernel, the contribution from such observations will be proportionally adjusted due to the effect of σ_i on the kernel associated with the wind direction..

The uncertainty estimate $\text{var}(S(\Theta, U))$ is given by

$$\text{var}(S(\Theta, U)) = \sum_{\theta_k, \theta_m \in \Theta} \sum_{u_k, u_n \in U} s(\theta_k, u_j) s(\theta_m, u_n) \exp\left(-\frac{1}{2} \left(\frac{\theta_k - \theta_m}{\bar{\sigma}}\right)^2\right) \quad (4)$$

where $\bar{\sigma}$ is the overall average of the wind direction standard deviation. More details of the derivation and other details may be found both in (Henry et al. 2009) and the supplementary material provided.

Results

Fyfe Elementary is bordered by the freeway US-95 on the south, Valley View Boulevard on the east and West Bonanza Road on the north. Also, there are likely high traffic intersections to the north-east and north-west of the receptor site at varying distances. Sector apportionment plots generated using SWIM are shown in Figure 4. The output plots have been placed on site using Google Earth[®] with the center (red circle) of the plots positioned exactly at the location of the data collection site at Fyfe Elementary School. The left panel of Figure 4 shows the aerial image of the vicinity of the site captured in June of 2007. It shows the expansion project underway. The right panel shows the completed expansion project and the image is dated February, 2008 (expansion project completion: November 19, 2007).

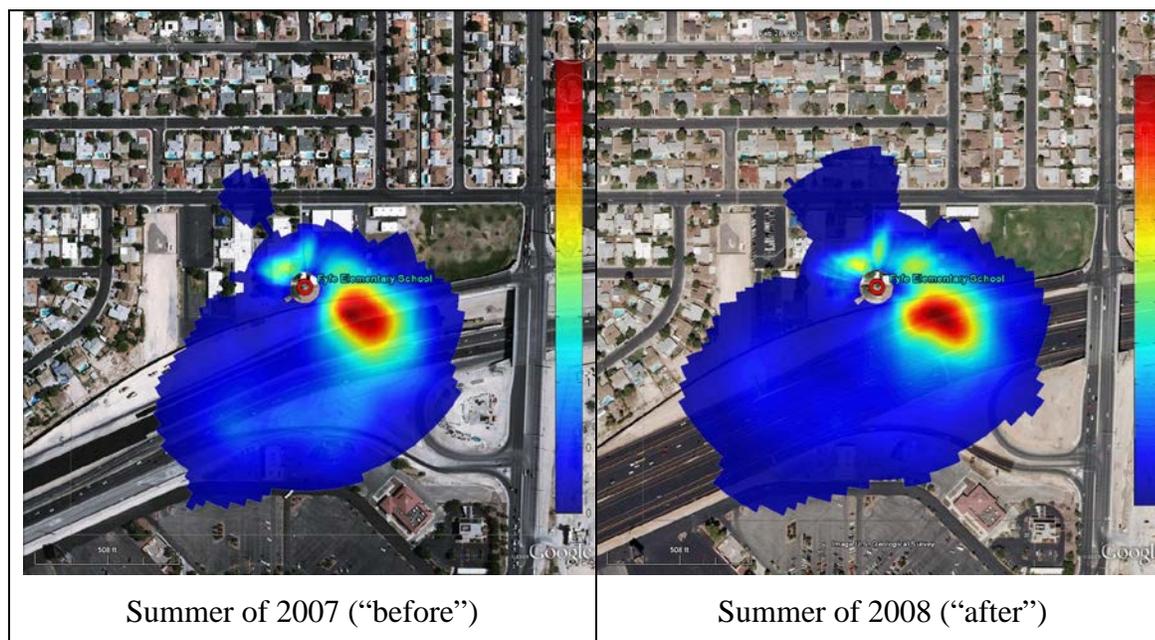


Figure 4: SWIM Sector Apportionment Results from Summer of 2007 and Summer of 2008

As a function of wind speed (radial) and wind direction (angular), the plot represents the distribution of BC over the speed-direction domain. The dark red areas of the plot imply the highest attribution domain and dark blue, the lowest. The colors in the middle of the range imply in-between attribution. The actual scale associated with the plots range from 0 to $0.0035 \mu\text{g}/\text{m}^3$ for the summer of 2007 (left panel) and 0 to $0.0022 \mu\text{g}/\text{m}^3$ for summer of 2008 (panel 2) in Figure 4.

It is important to note that, in Figure 4, the output from SWIM, plotted in the direction (angular) and speed (radial) units has been overlaid on a geographical map with direction (angular) and distance (radial) units. This poses a question of interpretation of the figure. We view the term domain (angle-speed) to be more general and different from the term region (angle-distance). The meteorological inputs to SWIM are wind speed and direction related quantities. Therefore, the model can suggest only directional and speed domain as its output. In Figure 4, the hotspot in the 80° - 120° domain can imply sources as close as the on-ramp, or another BC source within a few miles but contained in the directional cone of the hotspot. Frequently, the implication of a source region due to placement of the output on a map can be purely coincidental. But, hotspots in the low wind speed range are much likely a very local region than otherwise. In this case, with the wind speed domain of the hotspot in both figures (80° - 120°) ranging from 1 m/s to 7 m/s, the biggest contributor to the hotspot is much more likely the on-ramp close (20 m) to the receptor than any other BC source in the directional cone of the hotspot. Similarly, the highlighted spot northeast of the site is likely pointing to the intersection on Valley View Boulevard and Bonanza Road (240 m).

The plot shows values only when the signal (apportioned mean) is at least twice as large as the noise (associated calculated uncertainty). As such, the colors in the plots only help identify sectors of high impact. Both plots in Figure 4 suggest high impacts (reds) from the south-west region from events with wind speeds up to 7 m/s, medium level impacts from the north-west to the north-east and low level impact elsewhere (blue). The proximity of on-ramp has a dominant impact on the receptor site in both years.

To quantify the results, we present the apportionment quantities associated with user-selected sectors in the following table (Table 1). The table shows the apportionment percent and its associated uncertainty in each of the sectors defined in terms of the average BC value. The sector breakdown was motivated by grouping possible source regions.

Sector	Summer 2007	Summer 2008
220° - 30°	22% ± 4%	26% ± 3%
30° - 80°	9% ± 7%	12% ± 7%
80° - 220°	69% ± 2%	62% ± 2%

Table 1: SWIM sector apportionment results from Fyfe Elementary School

Discussion

The dominance of the 80° - 220° masks the other dramatic changes in the 30° - 80° sector. To extract that effect, both plots were normalized by their maximum value and low values were screened out to reduce false effects. Then, the corresponding values from 2007 were subtracted from 2008 values. The net effect of this exercise is to reveal relative contribution changes between the summers of 2007 and 2008.

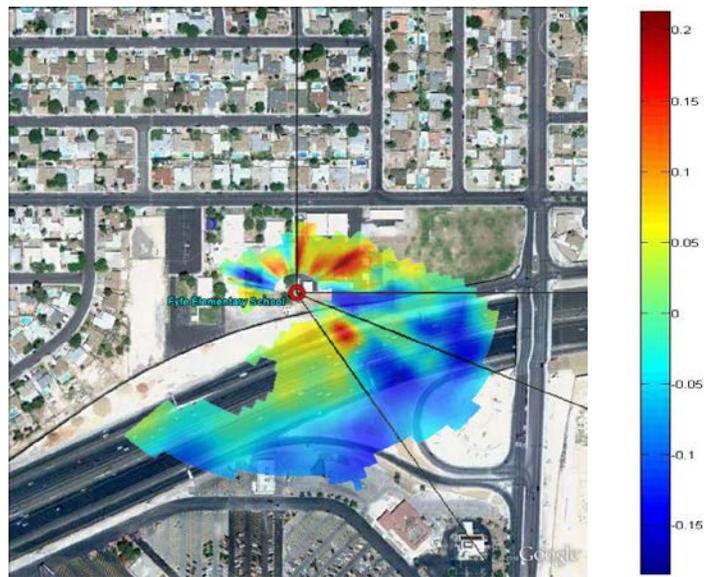


Figure 5: Normalized Difference between 2008 and 2007

The relative contributions from the northeast sector increased dramatically (Figure 5), as shown by the difference plot (marked in reddish colors). The range shows the percent of increase in the direction-speed domain. For instance, the darkest red color shows an increase of about 22% while the teal color shows 0% increase and the darkest blue shows a decrease of about 18%. If relative contributions from the entire domain did not change substantially from summer of 2007 to summer of 2008, the plot range would be quite small. That is not the case here with the

net change ranging from -18% to about +22% (a range of roughly 40 %.). This implies substantial changes in the relative contribution map between the two summers and not a small scale swap between domains.

To further quantify these changes, the values in Figure 5 were added along radial lines. That is, each direction was assigned a value summing the net change along the direction. We will refer to this as the radial sum. The radial sum values in the 30°- 80° sector alone increased by an average of almost 50% between 2007 and 2008 putting the spotlight on the traffic light on Valley View Boulevard Boulevard and all other roads in that sector. This increase is well supported by the data provided by Nevada Department of Transportation (NDOT). The Annual Average Daily Traffic (AADT) count at that intersection increased from 11400 vehicles in 2007 to 13100 vehicles in 2008, a 16% increase. It also shows an increase in traffic volume on both the on-ramp and off-ramp associated with US-95 near Valley View Boulevard. Secondly, even more remarkably, the increase in the 40°- 60° sub-sector is fueled by fewer wind events in 2008 (389) compared to 2007 (420) and these wind events carry an increased proportion of high concentration values. In this sub-sector, 83 (21%) wind events exceeded the 90th percentile value in 2008, whereas only 35 (8%) wind events in the same sector exceeded the 90th percentile value in 2007. Wind direction standard deviations remained comparable between both summers for this sector. Thus, the change in the 30°- 80° sector from 2007 to 2008 can be wholly attributable to a sizable increase in high-concentration events in 2008 than in 2007 likely due to increased use in the feeder roads. These observations strengthen the plausibility of the increase in the 30°- 80° sector from 2007 and 2008.

The other hotspot in Figure 5 falls in the 120° - 150° sub-sector of the 80°-220° pointing to the on-ramp due to vehicles accelerating prior to getting on US-95. The hotspot appears to be purely driven by a larger proportion of high BC values (99th-100th percentiles) in 2008 compared to 2007 and may be due to increased use of the ramp. This is also the sector where largest numbers of wind events occur (Figure 2). Diurnal patterns in Las Vegas suggest that these events likely happened during the afternoon hours when the winds are predominantly from the southeast. But, the average radial sum in that sector dropped by almost 49%. In fact, the radial sum is negative for the entire 80°-220° sector. The relative drop in contribution appears inline with the

substantial drop in the large vehicle traffic (-18%). Also, for both years, the high value events in this sector had typically higher wind direction standard deviation ($\sim 20^\circ$) compared to other sectors. Due to this, SWIM apportioned only a muted effect from high values to this sub-sector.

Finally, the 220° - 30° sector west of the receptor site was not subject to many wind episodes during the summer in both years (Figure 2). But, even in that sector, high value events resulted in an increase of about 10% from 2007 to 2008. This is likely to be due to increased use of Decatur Boulevard, a busy thoroughfare west of Fyfe Elementary.

The aforementioned arguments show that SWIM is an effective model that helps capture not just the main features but also the nuanced features of sector apportionment in addition to providing the uncertainty associated with those apportionments.

Conclusion

The use of local meteorology precludes the use of models such as NWR and SWIM from locating non-local and regional sources. Both NWR and SWIM calculate the cumulative effect of individual wind events. But, depending on the data set, these methods can highlight different sectors with varying intensities. Using the mathematical construct of the models, certain general observations can be made. For instance, due to the fact that NWR does not use standard deviations of the observations, all observations contribute equally. But, the downside of equal weights is that NWR can be disproportionately influenced by high frequency sectors. Also, when wind direction changes abruptly, accumulation may occur and thus an elevated sample concentration may be recorded. Such wind events have the potential to disproportionately influence the results generated by NWR method, and highlight a less likely source region or, at the very least, associate elevated importance to the sector in which the anomalous wind event was recorded. But, these anomalous wind events will have a reduced impact when using SWIM due to the fact that the associated wind direction standard deviation is likely to be large in such cases. Agreement between NWR and SWIM are observed if there are very few wind events with large standard deviations.

Using SWIM, the near-road effects of expansion of a busy arterial road in Las Vegas on Fyfe Elementary School adjacent to the road has been studied. SWIM shows that, even with unhelpful turn of events like drop in traffic volume, conclusions be drawn on effects of road expansion from increased on-ramp usage. The second and a more intriguing conclusion on the increased use of surface roads like Valley View Boulevard suggests that environmental impact studies should include such feeder roads and the cascading effects of lane expansions.

Nevertheless, it is clear that the new method highlights a possible effect caused by increased traffic from feeder/secondary roads due to expansion. In the case of Fyfe Elementary School receptor site, the secondary roads such as Valley View Blvd. and Decatur Road appear as possible new sources of traffic related emissions more so than the expected source (US-95).

Data requirements such as wind speed and wind direction standard deviation are not an impediment since most meteorological measurement devices are already capable of collecting a multitude of data that help to understand the local wind patterns. In this approach, point source and/or source regions are identifiable or confirmed only if the meteorology cooperates. These models must be part of a larger group of methods such as constructive and statistical methods leading to the weight of evidence collectively pointing out to a credible conclusion.

Nevertheless, the approach is quite helpful in providing an insight into receptor modeling dynamics under minimal input data requirements.

Disclaimer

This manuscript is now being subject to external peer-review and has not been cleared for publication by the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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