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Sources and transport of black carbon at the California–Mexico border

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A B S T R A C T

At international border areas that suffer from poor air quality, assessment of pollutant sources and transport across the border is important for designing effective air quality management strategies. As part of the Cal-Mex 2010 field campaign at the US–Mexico border in San Diego and Tijuana, we measured black carbon (BC) concentrations at three locations in Mexico and one in the United States. The measurements were intended to support the following objectives: to characterize the spatial and temporal variability in BC, to estimate the BC emission inventory, to identify potential source areas of BC emissions, and to assess the cross-border transport of BC. Concentrations at Parque Morelos, the campaign's supersite, averaged 2.2 μg m^{-3} and reached a maximum value of 55.9 μg m^{-3} (1-min average). Sharp, regularly occurring peaks around midnight were suggestive of clandestine industrial activity. BC concentrations were more than two times higher, on average, in Tijuana compared to San Diego. BC and carbon monoxide (CO) were strongly correlated at the three sites in Mexico. The ΔBC/ΔCO ratio of 5.6 ± 0.5 μg m^{-3} ppm^{-1} in Tijuana, or 4.7 ± 0.5 μg m^{-3} ppm^{-1} when adjusted for seasonal temperature effects to represent an annual average, was comparable to that in other urban areas. Tijuana's emissions of BC were estimated to be 230–890 metric tons per year, 6–23% of those estimated for San Diego. Large uncertainties in this estimate stem mainly from uncertainties in the CO emission inventory, and the lower end of the estimate is more likely to be accurate. Patterns in concentrations and winds suggest that BC in Tijuana was usually of local origin. Under typical summertime conditions such as those observed during the study, transport from Tijuana into the US was common, crossing the border in a northeasterly direction, sometimes as far east as Imperial County at the eastern edge of California.

1. Introduction

Growing population and industrial activity along the US–Mexico border have led to environmental stresses in both countries (Chow et al., 2000). The border region comprises 14 pairs of inter-dependent "sister-cities" containing 90% of the 14 million border area residents. Since the passage of the North American Free Trade Agreement in 1993, the border region has experienced a rapid increase in manufacturing plants (maquiladoras), transportation activity, and number of older vehicles on the road (Shi et al., 2009). In 1996, 95% of vehicles in Tijuana were at least five years old (Gobierno del Estado de Baja California et al., 2000a). Continued growth in the population and industrial development in this region is expected to strain environmental resources, including air quality. Between 2001 and 2005, the sister-city pair of San Diego–Tijuana exceeded the 8-h air quality standard for ozone of 80 ppb on average 15 days per year and the 24-h standard for coarse particulate matter (PM_{10}) of 150 μg m^{-3} on average 7 days per year (US Environmental Protection Agency (EPA) and Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT), 2006).

Although less information is available about BC compared to the criteria pollutants, which have national standards, it is of increasing concern because of its impacts on both climate and health. Its radiative forcing is estimated to be +0.9 W m^{-2} (with a range of +0.4 to +1.2 W m^{-2}), second only to carbon dioxide (Ramanathan and Carmichael, 2008), and exposure to it has been linked to respiratory and cardiovascular health effects (Gauderman et al., 2004; Gold et al., 2005; Kim et al., 2004; Peters et al., 2000; Power et al., 2011; Suglia et al., 2008). Because of these dual effects and because of its shorter lifetime in the atmosphere compared to carbon dioxide, it is an excellent target for emissions reductions (Jacobson, 2010). Given the status of ozone and PM_{10} in the US–Mexico border cities, it is likely that BC is also problematic in the region.

Air quality and pollutant emissions have been found to differ in the short distance across the US–Mexico border. Two studies of BC in the sister-city pair of Calexico–Mexicali found that BC was ~1.5

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times greater in Mexicali, which is on the Mexican side of the border, and that Mexicali exceeded the PM_{10} standard 23 times during the study, while Calexico only exceeded the standard three times (Chow et al., 2000; Kelly et al., 2006). Kelly et al. (2006) also measured BC in the sister-city pair of El Paso–Ciudad Juarez and found that it was ∼3.8 times higher in Ciudad Juarez, which is on the Mexican side of the border. Measurements of motor vehicle emissions in Mexicali showed that its fleet is significantly more polluting than that of Mexico City, Austin, and other cities in the US, probably due to the older average age of the vehicles (Zavala et al., 2009). Only a few studies have been conducted on the cross-border transport of pollutants, and none have considered BC. The previous work does suggest, however, that cross-border transport is likely to have significant impacts on air quality (Malm et al., 1990; Park et al., 2006).

Reducing BC emissions and improving air quality in the border region require an improved understanding of BC's spatial patterns, sources, and transport. The overall objective of this research is to assess emissions of BC and its transport in the California–Mexico border region. The assessment is based on measurements of BC and carbon monoxide (CO) at four sites during the Cal-Mex 2010 field campaign, and on trajectory modeling. The specific objectives of the research are to characterize the spatial and temporal variability in BC concentrations and emissions in the border region, to estimate the BC emission inventory, to identify potential source areas of BC emissions, and to characterize the cross-border transport of BC.

2. Methods

2.1. Field campaign

Measurements were conducted as part of the Cal-Mex 2010 field campaign, a multi-institutional collaborative effort between scientists and agencies in the US and Mexico, whose main objective was to improve the understanding of emissions and air quality along the California–Mexico border. The campaign was designed to complement the large CalNex 2010 study of air quality and climate change in California. The campaign ran for six weeks in June and July 2010 and focused on the sister-city pair of San Diego–Tijuana. San Diego County and the Tijuana metropolitan area have populations of 3.1 million and 1.7 million, respectively, and land development is nearly continuous between the two.

Fig. 1 shows a map of San Diego–Tijuana and the locations of the four measurement sites relative to borders and major roads. Measurements were conducted at Otay Mesa, California, next to a border crossing; Parque Morelos, a municipal park in central Tijuana that also served as the campaign's supersite; Universidad de Technológica de Tijuana (UTT) in southeast Tijuana; and El Trompo, a museum in central Tijuana ∼600 m southeast of Parque Morelos. At Otay Mesa, there were two different vehicle crossings, separated in the east-west direction along the border. The crossing for passenger vehicles was ∼400 m to the west of the one for commercial vehicles, mostly trucks. The measurement site was located between the two crossings but much closer to the one for passenger vehicles. Otay Mesa handles the second highest volume of all US–Mexico border crossings. In June 2010, 2200 trucks and 11,100 passenger vehicles per day crossed in the northbound direction, according to the US Board of Transportation Statistics. On the northern side of the border, land use is dedicated to commercial and industrial activity over an area of ∼3 km^2, and development beyond this area is sparse. On the southern side of the border, development is urban and dense. Table 1 contains additional details about the sites and dates of measurements, approximately one week per site.

2.2. BC and CO measurements

A mobile laboratory designed to conduct eddy covariance measurements was deployed during the Cal-Mex 2010 research campaign. It was equipped with a sonic anemometer and a comprehensive suite of fast-response instruments for gases and particles, including a handheld aethalometer (AE-51, Magee Scientific, Berkeley, CA) that measures BC. The aethalometer was advertised to employ a flow rate of 1 l min^{-1} in order to support a 1-s response time, but in our experience, the actual flow rate was closer to 0.4 l min^{-1} and the response time thus slower.

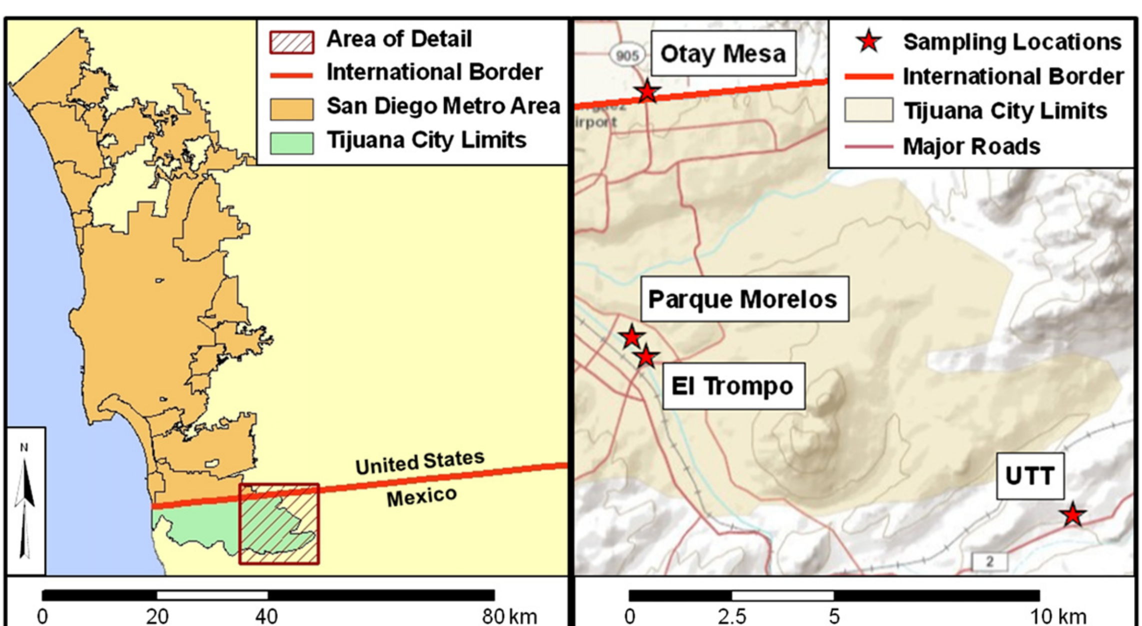

Fig. 1. Maps showing San Diego–Tijuana borders and measurement sites.