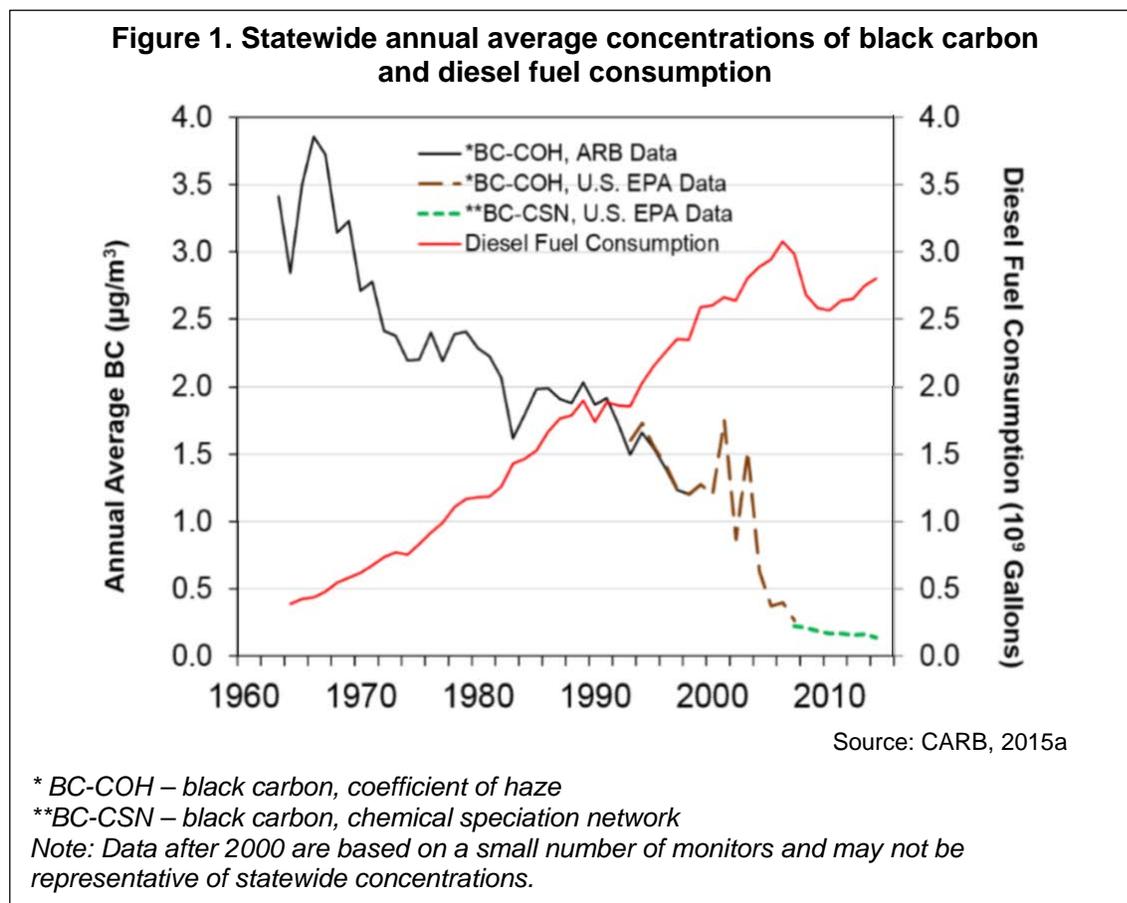


## ATMOSPHERIC BLACK CARBON CONCENTRATIONS

Atmospheric levels of black carbon, a major short-lived climate pollutant, have decreased dramatically in California since the 1960s.



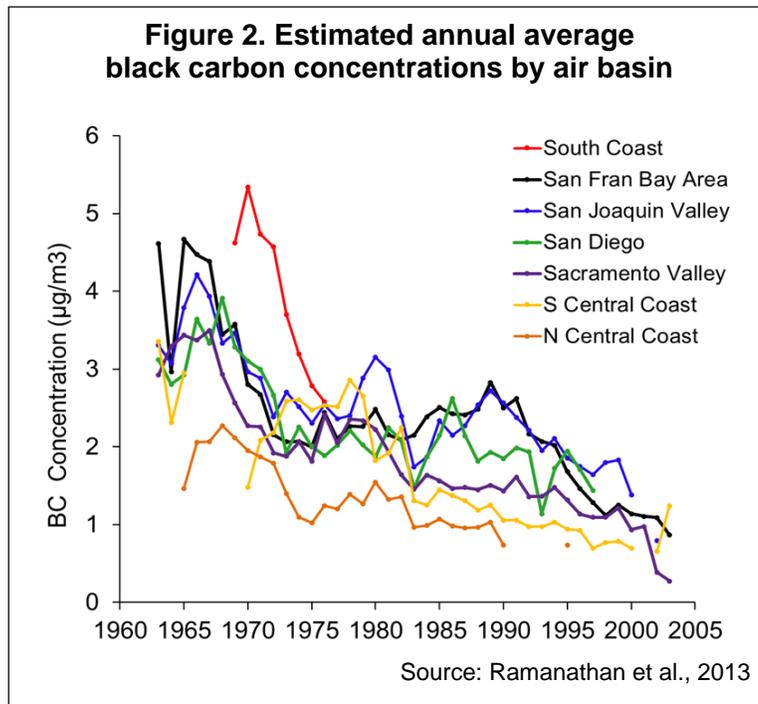
### What does the indicator show?

Long-term data show that ambient black carbon (BC) concentrations in California have declined steadily (Figure 1). Annual average BC concentrations have dropped by more than 90 percent over the past 50 years, from an average of 3.4 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) in the 1960s to  $0.14 \mu\text{g}/\text{m}^3$  since 2010. This dramatic decline in BC concentrations in the last five decades occurred despite a seven-fold increase in statewide diesel fuel consumption — the largest anthropogenic source of BC emissions in California. New emission standards and restrictions on diesel engines and biomass burning have significantly reduced atmospheric BC concentrations across the state (Kirchstetter et al., 2017).

Archived records of coefficient of haze (COH) were used to reconstruct historical BC concentrations. COH was one of the first measures of particulate matter (PM) pollution used by regulatory agencies and was determined to be a strong proxy for BC. (Please see *Technical Considerations* for a discussion of the data presented).



Although there is considerable variation, BC concentrations by air basin generally followed the decreasing statewide average trend. As shown in Figure 2, downward trends occur across all of the State's major air basins from the mid-1960s to the early 2000s. BC concentrations were considerably higher in the South Coast Air Basin than in the rest of California, at least until the mid-1970s; the lowest BC concentrations were in the North Central Coast Air Basin.



**Why is this indicator important?**

Black carbon is a light-absorbing particle in the air, commonly known as soot. Scientists recently determined that BC may be the second most important contributor to global warming after carbon dioxide (CO<sub>2</sub>) (Bond et al., 2013). However, it behaves very differently than long-lived greenhouse gases such as CO<sub>2</sub> do. While greenhouse gases trap heat from the Earth's surface, BC contributes to climate warming by absorbing sunlight directly and releasing heat energy in the atmosphere. CO<sub>2</sub> remains in the atmosphere for hundreds of years, while BC particles are removed from the atmosphere by rain and by deposition after a few days or weeks. However, although BC has a shorter lifespan, it is a much more powerful warming agent than CO<sub>2</sub>. For example, one ton of BC has a warming effect equal to 900 tons of CO<sub>2</sub> over a 100-year period. Over 20 years, one ton of BC has the warming impact of 3,200 tons of CO<sub>2</sub> (Bond et al., 2013). Hence, it is considered a critical short-lived climate pollutant.

Black carbon influences the climate in several complex ways. In addition to its direct warming effects, BC particles can deposit on snow, glaciers, and sea ice. This darkens these light, frozen surfaces and reduces their reflectivity. Darker surfaces absorb more solar energy, causing snow and ice to melt more quickly (Hadley et al., 2010; Hadley and Kirchstetter, 2012). This early melting could significantly affect California's summer water supplies, which rely heavily on snowmelt runoff from the Sierra Nevada. Less snowmelt runoff during the spring months, combined with warmer temperatures over already dry areas, increases wildfire risks — which can in turn release more BC particles.

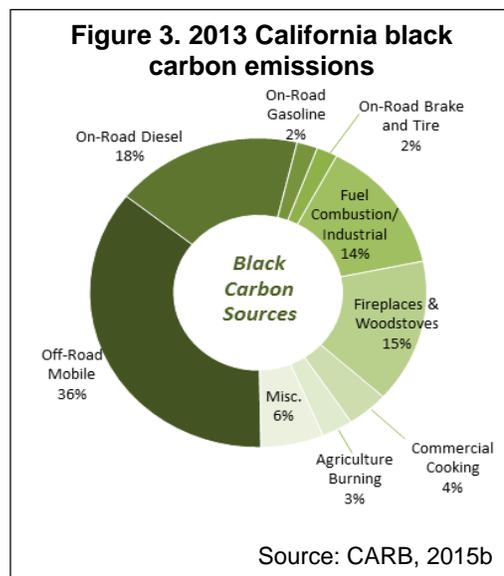
Black carbon can also change the reflectivity, stability, and duration of clouds. Its effects are different depending on how much of it is in the air and where it occurs in the atmosphere. Black carbon particles in a cloud layer can absorb solar radiation, heating the air in it, and leading to cloud evaporation and reduction. However, quantification of this indirect impact on the climate system is imprecise (Koch and Del Genio, 2010).



Reducing emissions of BC presents an opportunity to slow the rate of global warming in the near term. Black carbon is also a component of PM<sub>2.5</sub> air pollution (fine particulate matter that is 2.5 microns or less in diameter). PM<sub>2.5</sub> has been linked to respiratory and cardiovascular disease (US EPA, 2009). Hence, reduced BC emissions also provide public health benefits. Control measures are projected to lead to substantial reductions in BC emissions from mobile sources, preventing an estimated 5,000 premature deaths in the State each year (CARB, 2016). These reductions are especially beneficial to disadvantaged communities. For example, diesel particulate matter concentrations are highest along freight corridors and near ports and rail yards where disadvantaged communities are often located. Regardless of net climate forcing or other climatic effects, all BC mitigation options bring health benefits through reduced particulate matter exposure. A worldwide program along the lines of what is being done in California would avoid hundreds of thousands of premature deaths annually (Anenberg et al., 2011).

**What factors influence this indicator?**

In California, the major anthropogenic sources of BC in 2013 include a diesel-fueled mobile sources, fuel combustion and industrial processes, and residential fireplaces and woodstoves. Off-road mobile emissions account for over a third of statewide BC emissions. On-road mobile sources account for nearly a quarter of emissions, primarily from on-road diesel combustion, which contributes approximately 18 percent to California’s BC emissions. On-road gasoline, as well as brake wear and tire wear emissions of BC are relatively small. Residential fireplaces and woodstoves currently account for approximately 15 percent of BC emissions, with another 14 percent attributable to fuel combustion and industrial processes.



Other anthropogenic sources include dust, waste disposal, residential natural gas combustion, and unplanned structure and car fires. These sources and the ambient concentrations of BC vary geographically and temporally. Emissions standards and restrictions implemented on diesel engines and biomass burning activities have had a significant effect on decreasing ambient air BC concentrations across the State. In 2013, total anthropogenic BC emissions were about 38 million metric tons of carbon dioxide equivalent (MMTCO<sub>2e</sub>), using the 20-year Global Warming Potential (GWP) value of 3,200 from the IPCC Fifth Assessment Report (IPCC, 2013).

Anthropogenic BC emissions do not include forest-related sources (i.e., wildfires and prescribed burning). Wildfire is the largest source of BC emissions in California, contributing an estimated 87 MMTCO<sub>2e</sub> annually (calculated as a ten-year annual



average); prescribed fires, an important tool for forest managers, emit an estimated 4 MMTCO<sub>2e</sub>. (To provide a more representative view of emissions without large year-to-year variability driven by natural forces, forestry emissions are calculated as a ten-year average) (CARB, 2017).

As shown in Figure 1, the largest decline in BC concentrations occurred in the years before 1975, coinciding with the adoption of state and federal air quality regulations. These include tailpipe emission limits established by California in the mid-1960s, federal emission standards for stationary sources and motor vehicles adopted in the mid-1960s, and diesel emission controls introduced nationally in 1970. Between 1975 and 1990, BC levels declined more gradually, likely due to the replacement of older, more polluting diesel vehicles as a result of on-road heavy-duty diesel particulate matter emission standards adopted in 1973 by California. BC concentrations decreased more rapidly after 1990, despite intermittent increases in the early 2000s (Kirchstetter et al., 2008). Retrofitting of urban transit buses with oxidation catalysts, limits on sulfur content in diesel fuel, changes in diesel engine technology, and restrictions on agricultural burning and residential wood combustion, among other measures, contributed to the reductions.

Existing regulatory programs, including ongoing efforts to reduce tailpipe emissions from trucks and buses, will continue to reduce BC emissions. For example, further reductions are expected from stricter diesel engine emission standards implemented by the state in 2007 and the complementary low-sulfur fuel introduced nationally in 2006. To comply with federal air quality standards, control measures that reduce PM<sub>2.5</sub> pollution (including BC and other constituents) are projected to decrease BC emissions from mobile sources in California by 75 percent between 2000 and 2020 (CARB, 2016). Senate Bill 1383 (Chapter 395, Statutes of 2016) sets a target to reduce BC emissions by 50 percent below 2013 levels by 2030, with a focus on disadvantaged communities.

### ***Technical Considerations***

#### **Data Characteristics**

Because of their short residence time in the atmosphere and their strong dependence on local sources, particles exhibit high spatial and temporal variation, requiring frequent measurements at numerous sites to reliably track trends. However, few extensive records of particle concentrations are available. One of the first measures of PM pollution used by regulatory agencies, the coefficient of haze (COH), was determined to be a strong proxy for BC, based on co-located field measurements of BC and COH. Archived records of COH, a now-retired measure of light-absorbing PM, were used to reconstruct historical BC concentrations. BC concentrations were inferred from COH data based on a relationship determined from statistical analyses (see Chapter 2.0 of Ramanathan et al., 2013). Statewide average BC concentrations were computed separately using data from CARB (1963 to 2000), and US EPA (1993 to 2007).

Where the US EPA and CARB datasets overlap, agreement is very good. The location and number of COH monitors operating in California has varied over time. From the mid-1970s to 2000, 30 or more COH monitors were in operation for the majority of the year, but these dropped to 15 by mid-2000 (mainly in the US EPA dataset). Hence, the



data after 2000 are based on a smaller number of monitors, and may not be as representative of statewide concentrations.

Data from 2007 to 2017 are from the US EPA's Chemical Speciation Network (CSN). Since early 2000, about 17 CSN sites have been providing information on PM<sub>2.5</sub> concentrations in California's ambient air. Samplers operate on a 24-hour schedule from midnight to midnight, generally sampling every third day or every sixth day. CSN must meet all federal and state requirements for monitoring methodology and quality assurance. CSN is designed to track the progress of PM<sub>2.5</sub> emission reduction strategies through the characterization of trends of individual PM<sub>2.5</sub> species, including BC. Although the CSN network has been collecting BC data since 2000, the collection and analysis methods were different during the first few years of the program (Chow et al., 2007). The differences were significant enough to affect the trends, therefore data from the CSN network prior to 2007 are not presented in Figure 1.

#### Strengths and Limitations of the Data

For the purposes of climate change study, BC is defined as the carbon component of PM that absorbs light. A significant advantage of monitoring BC by an optical method is that it delivers results in real time with a high time resolution (in minutes). However, BC as a component of PM is difficult to measure. Methods that measure light absorption in PM assume that BC is the only light-absorbing component present. However, some components of organic carbon can also be light-absorbing. The impact of BC on climate forcing is well established, but the magnitude and wavelength dependence of absorption by organic carbon (often called brown carbon, a by-product of the biomass burning) is poorly constrained. Existing methods, such as using an enhanced thermal/optical carbon analyzer with multi-wavelength capabilities, can add value to current PM monitoring programs by providing a complete identification and quantitation of the carbonaceous component of ambient aerosols in near-real time.

Emissions inventories for climate change studies have focused primarily on greenhouse gases. Most of the important sources of greenhouse gases are also important sources of health-related pollutants. Likewise, BC is emitted primarily from combustion sources which are also important sources of health-related pollutants. California's BC inventory relies on PM inventories coupled with speciation profiles that define the fraction of PM that is BC. However, it is a challenge to estimate statewide BC emissions, and to define speciation profiles for all sources. Hence, improved emissions inventory methodologies and tools developed for health-related pollutants can also provide opportunities for improving climate change emission inventories (and vice versa).



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