Cracking the AQ Code

ADEQ Arizona Department of Environmental Quality
Air Quality Forecast Team

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Outdoor Carbon Monoxide: the Pollutant of Yesteryear

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Have you ever held your breath while walking behind a running vehicle? Or perhaps when a bus or truck passed you by while you were strolling along the sidewalk? Was it to avoid that wonderful smell of the exhaust, or were you trying to protect your health? Or both? Unfortunately, in a developed urban area, vehicle emissions are pretty much ubiquitous. It ultimately comes down to the fact that engines are not perfectly efficient and their resultant waste has to go somewhere (see Figure 1).

Figure 1. Exhaust from a running car. CO is a small component of vehicle exhaust, which also includes harmless gases such as nitrogen, water vapor, and carbon dioxide and other harmful gases including hydrocarbons and nitrogen oxides (howstuffworks).

Photo credit: CC Image courtesy of eutrophication&hypoxia on Flickr

About "Cracking the AQ Code"

In an effort to further ADEQ's mission of protecting and enhancing the public health and environment, the Forecast Team has decided to produce periodic, in-depth articles about various topics related to weather and air quality.

Our hope is that these articles provide you with a better understanding of Arizona's air quality and environment. Together we can strive for a healthier future.

We hope you find them useful!

Upcoming Topics…

- Tools of the Air Quality Forecasting Trade Part 3: Satellite Imagery
- You Ask, We Answer
- Stratospheric Intrusions: Ozone Transport from Above

Nevertheless, within exhaust, we find an odorless, colorless, tasteless, invisible gas: carbon monoxide (CO) (See Figure 2). This subtle chemical compound is the topic of this issue of the ADEQ Forecast Team's *Cracking the AQ Code*. As the title implies, outdoor CO's heyday is a thing of the past. By the end of this article, you'll be better informed on outdoor CO's history in the U.S. and how it was once a significant issue in Arizona.

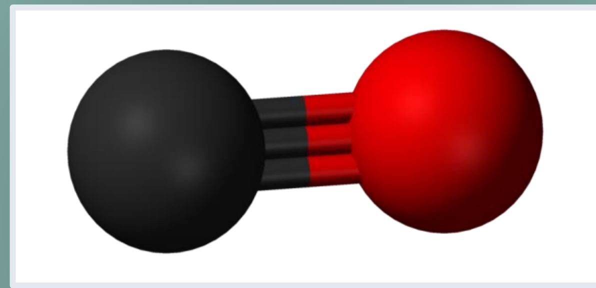

Figure 2: A diagram of the carbon monoxide compound. In chemistry, a chemical compound consists of as least two different elements. The symbol for carbon monoxide, CO, shows that carbon monoxide consists of one carbon (C) atom (black) and one oxygen (O) atom (red). *Public Domain*

Carbon Monoxide as a "Criteria Pollutant"

In 1970, Congress established the Clean Air Act (CAA) to regulate air pollution in the United States in order to protect public health and the environment. As a result, this tasked the U.S. Environmental Protection Agency (EPA) with creating National Ambient Air Quality Standards (NAAQS) for common pollutants found in the U.S. that are harmful to both public health and the environment. Six common pollutants, referred to as "criteria pollutants", have national health standards associated with them: ground-level ozone, particulate matter, *carbon monoxide*, lead, sulfur dioxide, and nitrogen dioxide. The standard for outdoor CO is that concentrations are not to exceed either an hourly average of 35 ppm (parts per million) or an 8-hour average of 9 ppm more than once in a year. As we will see, Phoenix has easily met this standard over at least the past 15 years (see Figure 3).

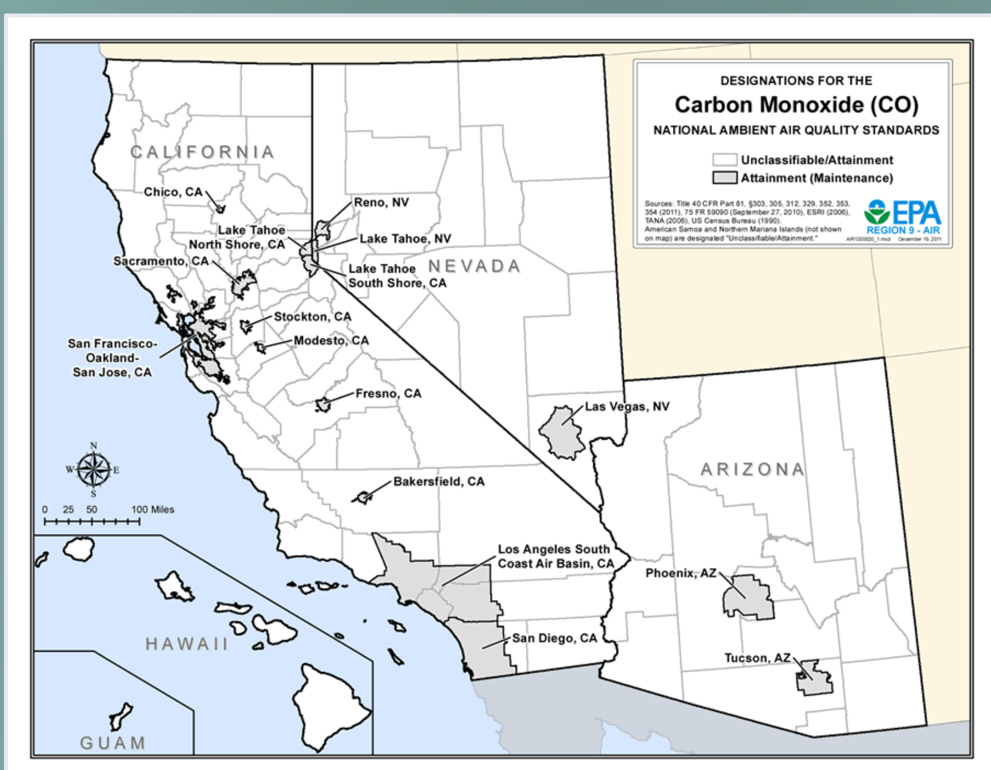

Figure 3. A map of the carbon monoxide (CO) Attainment (Maintenance) areas in EPA's Region 9, which consists of Arizona, California, Hawaii, Nevada, Pacific islands, and 148 tribes. All of the gray areas represent metropolitan areas that have met the national health standard for outdoor CO and are maintaining that standard.

Source: EPA

Health Effects of Carbon Monoxide

Carbon monoxide (CO) is a serious threat to human health and even life when inhaled at high concentrations. The problem with CO is that it prevents oxygen from being absorbed by red blood cells (see this illustrative video). Thus, too much CO will hinder the transport of oxygen from the lungs to vital organs such as the heart and brain, which need it to function (EPA). For this reason, being exposed to high levels of CO leads to what is called "carbon monoxide poisoning". Common symptoms of carbon monoxide poisoning include: "dizziness, weakness, nausea, vomiting, chest pain, and altered mental status" (CDC). Symptoms of carbon monoxide poisoning can be similar to that of the flu, but without the fever. Prolonged exposure to high CO levels can be fatal (see Figure 4). Due to its lack of odor, color, and irritation, CO is sometimes called the "silent killer" (NYDOH). However, very high levels of CO are typically limited to enclosed or indoor spaces. For more information on indoor CO impacts, click here.

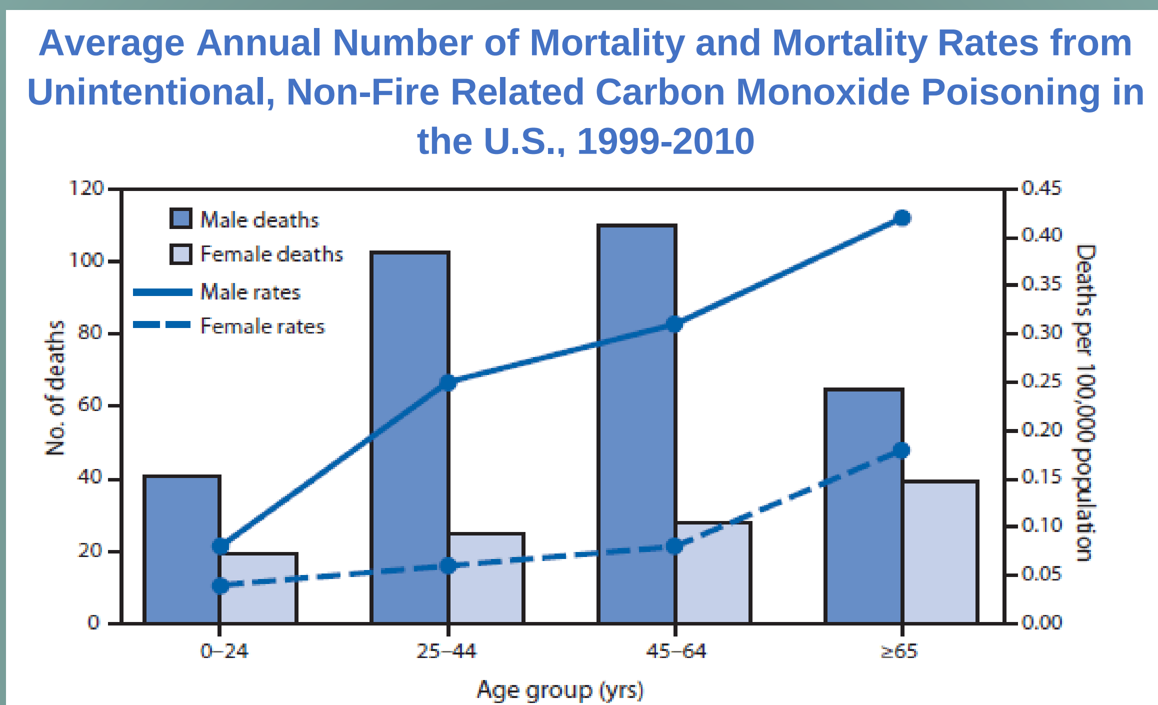

Figure 4: A graph showing the average annual number of mortalities (left axis) and mortality rates (right axis) from unintentional, non-fire related carbon monoxide (CO) poisoning in the U.S., during 1999-2010. Male statistics are represented by the dark blue bars, female statistics by the light blue bars. Each pair represents a different age group. A total of 5,149 deaths from unintentional CO poisoning were recorded for this time period.

Source: CDC Morbidity and Mortality Weekly Report

The good news is that CO does not usually reach very high levels *outdoors*. This means that outdoor CO is not typically a significant concern for the general population. CO is of interest to air quality regulators and forecasters however, because sensitive populations including children, the elderly, and people with heart diseases or respiratory problems can be vulnerable to it. Sensitive people may already have a reduced capacity for their blood to be oxygenated; exposure to elevated CO levels outdoors would exacerbate their condition, especially if they are exerting themselves (EPA).

Outdoor Carbon Monoxide Sources

So, where does CO come from? In general, CO is the result of the incomplete burning of fuels that contain carbon (Thompson). In other words, anything that burns releases some amount of CO. Examples of fuels that can be burned include: "…wood, oil, natural gas, propane, kerosene, coal, and gasoline" (NYDOH). When it comes to outdoor CO in the United States, vehicles are the largest source. This includes cars, trucks, or any kind of vehicle or machinery that burns fossil fuels (see Figure 5). Other sources could be fixed sources such as industrial plants (EPA). *From here on out, all references to CO imply outdoor CO.*

Figure 5. A picture of pistons inside an internal combustion engine (ICE). Most vehicles are powered by ICEs. When a piston moves upward, it compresses a mixture of fuel and air, which is then ignited by a spark plug above. The ensuing "explosion" burns the fuel and powers the vehicle. Since a fuel is burned, carbon monoxide and other pollutants are generated; they eventually exit the car as exhaust.

Source: © Mj-bird/Wikimedia Commons/CC-BY-SA 3.0

Reducing Carbon Monoxide

Fortunately, with technology advancements over the years, coupled with stricter national air quality standards, we have made great strides in reducing the CO output from vehicles, power plants, etc. Here are a few things that played a role in reducing CO from these sources:

Catalytic Converters

CO emissions took a hit with the advent of the catalytic converter in the mid-70s. A catalytic converter (see Figure 6) is a device installed underneath a vehicle which reduces the amount of harmful gases emitted from the engine. It works by "converting" the harmful gases within the exhaust (such as CO) into harmless gases by way of a chemical reaction between the harmful gases and the metal within the converter. For example, harmful nitrogen oxide gases are broken down into oxygen and nitrogen; carbon monoxide is oxidized and carbon dioxide forms in its place; hydrocarbons are oxidized and carbon dioxide and water vapor form (explainthatstuff).

You Ask, We Answer

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Email us your question at: ForecastTeam@azdeq.gov

Figure 6. A picture of a catalytic converter on an automobile. Before exiting the tailpipe, the exhaust from the engine passes through the catalytic converter, which changes the molecular structure of the harmful gases and creates harmless gases instead (explainthatstuff).

Photo credit: CC Image courtesy of VANAGON BLOG on Flickr

Engine Control Technology

Advancements in automobile technology have also put a large dent in CO emissions. Throughout the years, automobiles have become more sophisticated and "smart" in order to meet stricter emissions standards set by the U.S. Environmental Protection Agency (EPA). For example, in 1981, the EPA established new emission certification standards for manufactured passenger vehicles, requiring manufacturers to stay within a precise CO emissions limit (NAP). To accomplish this, computers have been built into vehicles to manage the engine's fuel economy (see Figure 7). These computers are able to perform countless calculations to make the engine's performance as efficient as possible. This helps to reduce CO emissions through more complete fuel burning and ensures the catalytic converter is as effective as possible in reducing harmful gases like CO (howstuffworks). Ultimately, the emission certification standards proved to be successful as they cut vehicle-related CO emissions by about 36% from 1980-1999 (NAP).

Figure 7. An engine control unit (an automobile's computer) from the late 90s. *Public Domain*

Reformulated Gasoline

Lastly, reformulated gasoline has also joined the fight against CO. In 1990, amendments were made to the Clean Air Act to require reformulated gasoline in U.S. cities with high smog levels. Reformulated gasoline burns cleaner and thus, reduces the amount of pollutants in exhaust from vehicles (EPA). Arizona eventually established its own program for implementing reformulated gasoline, called the Cleaner Burning Gasoline program (see Figure 8) (EPA). As a result of this plan, Maricopa County and small portions of Pinal and Yavapai Counties use different fuel blends between the summer and winter seasons to reduce pollutant emissions. The summer blend reduces the emissions of ozone ingredients and PM-10 (coarse particulate matter) while the winter blend reduces the emissions of CO and PM-10 (ADEQ).

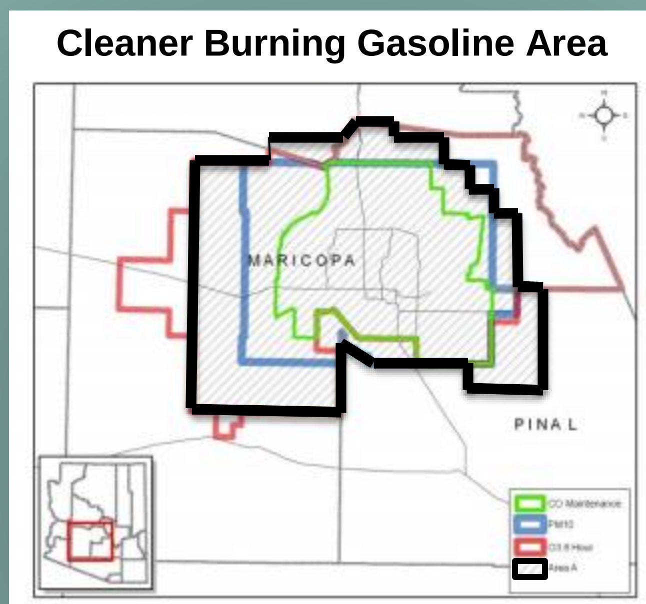

Figure 8. A map showing the area where the Cleaner Burning Gasoline (CBG) program applies (black boundary), along with the maintenance (meets national health standard) boundary for carbon monoxide (green) and the non-attainment (does not meet national health standard) boundaries for PM-10 (blue) and ozone (red). Gasoline sold within the CBG boundary must comply with Arizona's standards for gasoline, which help to reduce pollution from vehicles.

Source: ADEQ

National Carbon Monoxide Historical Trends

In the history of air quality in the United States, the reduction of CO could be considered a great success story. Take a look at the graph in Figure 9, which shows national CO trends from 1980 through 2015. The orange line represents the national health standard for CO. CO is not to exceed an 8-hour average of 9 parts per million (ppm) more than once at a given CO monitor in a year. Over the past few decades, CO levels in U.S. metropolitan areas have almost unwaveringly followed on a downward trajectory. This has been largely due to decreased CO emissions from vehicles. Fortunately, CO levels over the past decade have, by and large, remained well below the health standard.

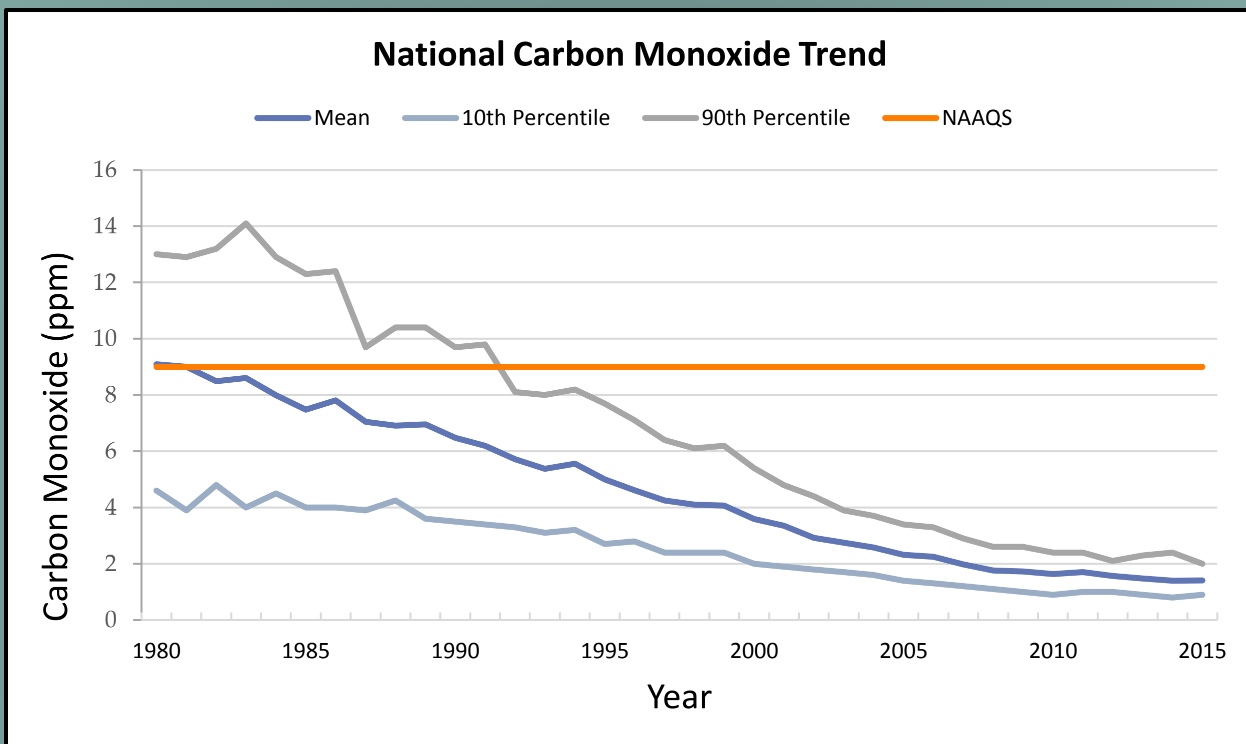

Figure 9. Historical trends of carbon monoxide in the U.S. from 1980 to 2015. This graph takes into account carbon monoxide data from 82 monitors in 63 counties around the country. It should be noted that monitors are located in metropolitan areas where they are exposed to high traffic. So, they may not be representative of areas outside of metro areas. Graph tip: The 90th percentile trend line represents the value below which 90% percent of the CO data are found for a given year. It could also be said that 10% of all the CO data for a given year are found above the 90th percentile.

Source: [EPA]

Southwest Carbon Monoxide Historical Trends

A similar storyline can be said of the Southwest U.S. The following graph in Figure 10 shows CO trends for cities in Arizona, California, and Nevada from 1970 to 2012. Through the 1970s and 1980s, CO was a significant issue for the region. It wasn't until the early 90s when most Southwest cities began to meet the national health standard. Three cities that stick out as having high CO levels for longer periods of time are Los Angeles, California, Phoenix, Arizona, and Las Vegas, Nevada. Focusing on Phoenix, Phoenix was originally designated as a non-attainment area for CO in 1990 by amendments to the Clean Air Act. Phoenix eventually met the standard, with its last exceedance of the CO health standard occurring in 1996 ([Maricopa]()).

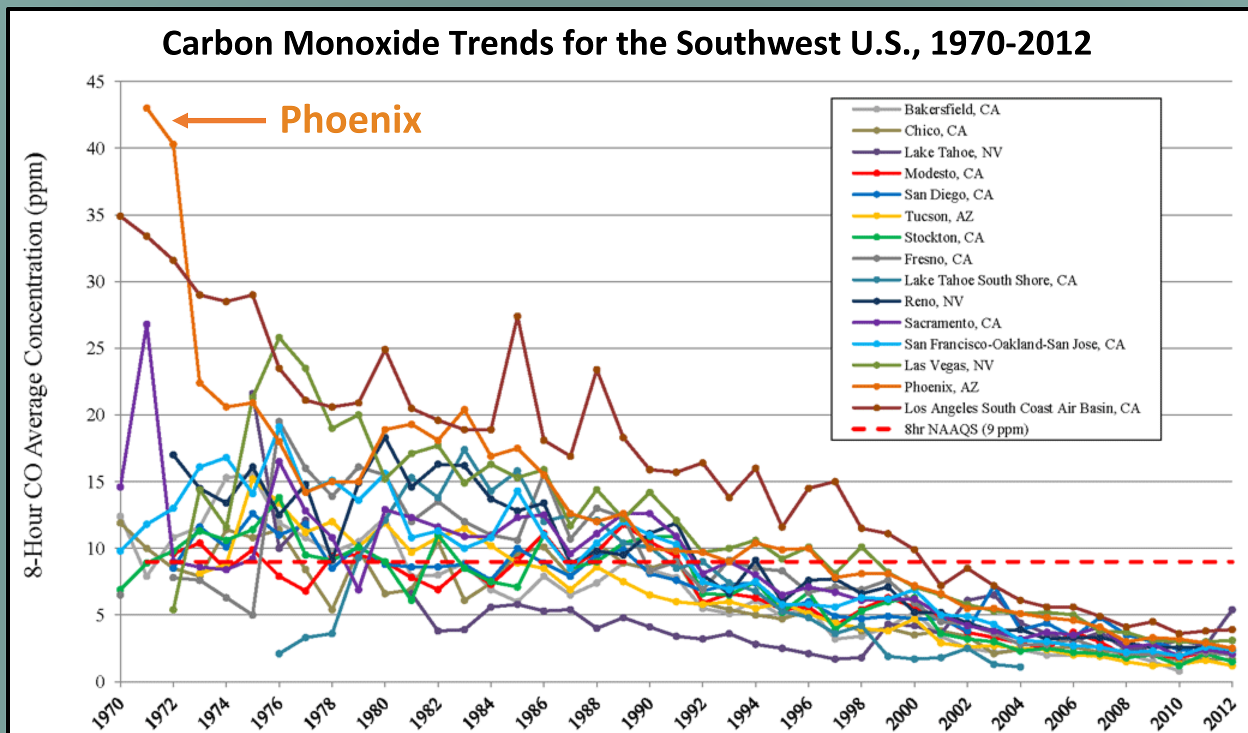

Figure 10. A graph showing carbon monoxide trends for cities in the Southwest U.S. for the period of 1970-2012. Each point represents the second highest 8-hour average CO concentration for a given year. Phoenix is represented by the orange trend line (denoted by arrow), Tucson by the yellow trend line.

Source: [EPA]()

Carbon Monoxide Forecasting

Prediction and Prevention

In response to Phoenix's designation as a non-attainment area for CO, a forecasting program for CO was established at ADEQ in the early 1990s. The core purpose of this program was to predict when CO would approach or exceed the national health standard in Maricopa County, particularly the 1-hour standard of 35 ppm. If air quality meteorologists expected CO to have the potential to approach or exceed the standard on a given day, the County would issue a CO pollution alert. This then required appropriate actions to be taken to reduce CO concentrations and perhaps prevent them from exceeding the national health standard. Since the two main sources of CO were vehicle emissions (see Figure 11) and residential wood-burning (note that the season for high outdoor CO is the winter), people were encouraged to carpool and all wood-burning activities were banned (unless they were essential for heat or cooking) during a CO pollution alert. Unfortunately, in the 1990s, the only way for pollution alerts to reach the public was through media or the press. Therefore, the extent of air quality messaging was a lot more limited than it is today.

Carbon Monoxide Forecasts

CO forecasts were issued on a daily basis at 9:00 AM and were valid for the evening of that day and the following morning. In this way, both the evening commute and the morning commute of the next day could be covered by the forecast.

Figure 11: Backed up traffic--an all too familiar sight on the highways here in the Valley—can result in a local build-up of CO concentrations.

Source: ADOT Twitter

Limited Tools

Compared to the resources and technology available to air quality meteorologists today, those available in the 90s could be considered "primitive". For one, there was limited internet. So, for weather data such as weather maps and satellite photos, air quality meteorologists relied on the National Weather Service to send them that data; online providers of weather data didn't show up until the mid-90s. Also, since weather information was limited, air quality meteorologists had to be creative in finding ways to estimate important meteorological variables that affect CO (see the *Meteorological Variables* section below). As if matters couldn't be more inefficient, CO concentration data was not available in real-time due to slow dataloggers. Because of this time delay, air quality meteorologists would often stay in the office late at night to verify CO trends. Fortunately, meteorologists did have at their disposal a statistical model that could help them predict what the highest hourly CO concentration might be for the day, based on past CO and weather data.

Weather Patterns

Despite the limited tools available to air quality meteorologists, they were able to learn, through observation, the weather patterns and conditions associated with high CO levels. Much like particulates, CO is prone to accumulate when atmospheric conditions are stagnant and cold. The main weather pattern favorable for stagnation is high pressure situated over the Desert Southwest (see Figure 12). Also, this pattern pushes the jet stream to the north, forcing winter storm systems to track more north of the region. Less frequent storms passing through Arizona means less opportunities for Phoenix's air pollution to be cleared out.

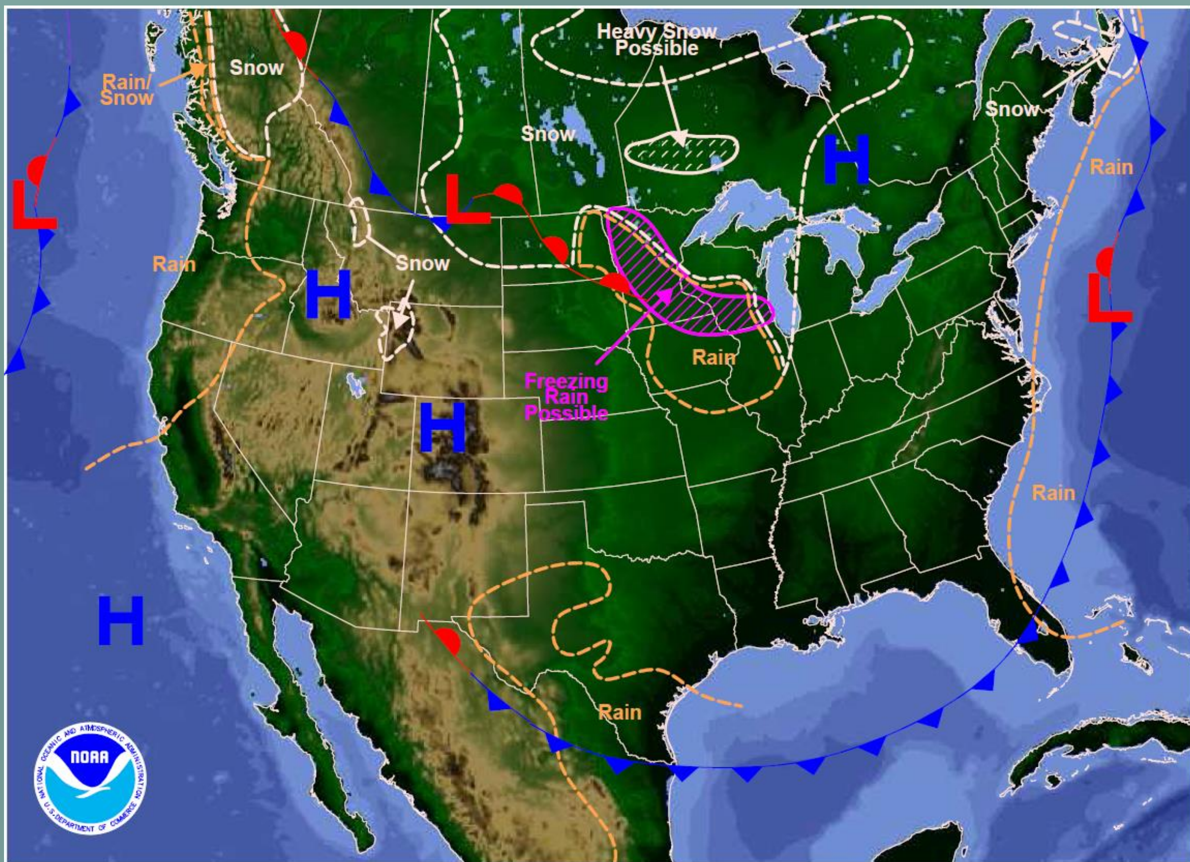

Figure 12. A weather forecast map of the U.S. issued in the morning of Sunday, December 7, 2014. High pressure is the dominant weather feature over the West and Southwest. Weekend fireplace usage in combination with stagnant conditions resulted in PM-2.5 exceeding the national health standard on this day. Needless to say, carbon monoxide easily remained in the Good Air Quality Index (AQI) category on this day. However, its levels reached their highest of the month on this day (the AQI was 31, corresponding to a maximum 8-hour average of 2.7 ppm). If these exact circumstances had occurred sometime in the 90s, a CO pollution alert might have been necessary.

Source: NOAA, WPC Archive of the National Forecast Chart

Meteorological Variables

Several other meteorological factors air quality meteorologists would consider include inversion strength, moisture, and visibility. You may be familiar with the term "inversion". The inversion is simply a layer of warm air above colder air near the surface. In effect, the inversion acts as a lid and holds pollutants underneath. The greater the temperature difference between the inversion and the ground, the stronger the inversion. On cold days when the inversion was strong, stagnation was greater and would result in more build-up of CO from vehicles and fireplaces. Dry air was also an indicator of potentially high CO. Drier air leads to colder temperatures at night, resulting in a stronger inversion. CO is also able to accumulate better in drier air than in moister air. Lastly, deterioration in visibility could be used as an indicator of high CO. Often, under calm conditions, a "fog bank" could be seen over the Valley due to wood burning. This would, in turn, coincide with high CO levels.

Conclusion

In this issue of *Cracking the AQ Code*, we shined some light on the invisible, colorless gas of carbon monoxide, focusing on carbon monoxide found outside. We now know where it comes from, how it has been controlled and reduced over the recent decades, and how it was once a significant pollutant in Phoenix's air quality. It's almost hard to believe that carbon monoxide (CO) was once a problem pollutant, as we've become accustomed to low CO levels. In all, Arizona fits right in with the rest of the nation regarding declining CO over the years. CO is truly the pollutant of yesteryear.

We hope you enjoyed learning about outdoor carbon monoxide's history in the U.S. and Arizona!

Sincerely,
The ADEQ Forecast Team
ForecastTeam@azdeq.gov

If you haven't already, click HERE to start receiving your Daily Air Quality Forecasts (Phoenix, Yuma, Nogales)

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In case you missed the previous Issues…

Here's a look at what we'll be discussing in the near future…

-Tools of the Air Quality Forecasting Trade Part 3: Satellite Imagery
-You Ask, We Answer!
-Stratospheric Intrusions: Ozone Transport from Above

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